Benthic TMDL Development for the Jackson River, Virginia

Submitted to

Virginia Department of Environmental Quality

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Executive Summary

Background

This report presents the development of the Jackson River benthic TMDL. The Jackson River originates in Highland County in southwestern Virginia, and extends to the confluence of the Jackson River with the Cowpasture River in Botetourt County, where the two rivers join to form the James River. The Jackson River flows through sections of Alleghany, Bath, Craig, and Highland Counties, as well as the Cities of Covington and Clifton Forge. The Gathright Dam regulates the stream flow in the Jackson River.

The impaired segment on the Jackson River is 24.21 total miles. It is listed for dissolved oxygen and General Standard benthic impairments (DEQ, 2004). The upstream limit of the impaired segment is below the Covington City Water Treatment Plant intake, and its downstream limit is at the confluence of the Jackson and Cowpasture Rivers. The impairments include the following:

- Dissolved oxygen impairment, extending from river mile 24.21 downstream to river mile 13.00 (11.21 miles of the impairment segment).

- General standard benthic impairment, extending from river mile 24.21 to river mile zero, which is the confluence of the Jackson River with the Cowpasture River (24.21 miles of the impairment segment).

Stressor Identification

The stressor identification for the biologically impaired segment of the Jackson River was performed using the available biological and water quality monitoring data. In addition, Discharge Monitoring Reports (DMR) and Nutrient Monitoring Reports (NMR); Toxicity Testing, Whole Effluent Toxicity (WET) data; and special studies were also used in the identification of the stressors on the Jackson River. The stressor identification follows guidelines outlined in the EPA Stressor Identification Guidance (EPA 2000).

The identification of the most probable cause of biological impairment in the Jackson River was based on evaluations of candidate stressors that can potentially impact the river. The 2004 Water Quality Assessment 305(b)/303(d) Integrated Report Fact Sheet identified "nutrient and organic enrichment" as possible sources of biological impairment. Therefore, these pollutants were considered in the evaluation of candidate stressors along with other probable stressors such as pH, temperature, dissolved oxygen, sediment, ammonia, flow modification, and toxic compounds. Each candidate stressor was evaluated based on available monitoring data, field observations, and consideration of potential sources in the watershed. Furthermore, potential stressors were classified as a non-stressor, possible stressor, or most probable stressor.

Non-Stressors:

The stressors with data indicating normal conditions and without water quality standard violations, or without any apparent impact, were considered as non-stressors. Based on the data analyzed, temperature, pH, metals, organics and sediment, as well as non-point sources loading under wet-weather flow were eliminated as stressors in the impaired segment of the Jackson River.

Possible Stressors:

The stressors with data indicating possible links, but inconclusive data, are considered as possible stressors. The results indicate that Total Dissolved Solids (TDS) with the associated toxicity, low-dissolved oxygen, and flow modification are possible stressors to the benthic community in the Jackson River.

Most Probable Stressors:

The stressors with the most complete data linking them to the poorer benthic community are considered as most probable stressors. The results indicate that excessive nutrient loading leading to excessive periphyton growth are adversely impacting the biological communities in the impaired segment of the Jackson River.

Stressor Identification Summary

In summary, the data analysis shows that the common "end-point stressor" is the excessive periphyton growth and accumulation in the Jackson River causing the benthic impairment. This excessive periphyton growth is caused by the excessive nutrients in the river.

Consequently, the periphyton issue in the Jackson River should be addressed through a reduction in nutrient (particularly phosphorus) loadings.

TMDL Endpoint Development

As stated above, Virginia does not currently have established numeric criteria for nutrients. Therefore, it was necessary to use a relationship that would represent stream conditions that replenish and maintain the benthic macroinvertebrate community in Jackson River.

Development of Predictive Empirical Model

Because of the extensive monitoring data available in the Jackson River, a regression model between the periphyton and the water-column nutrients specific to the Jackson River was developed. Extensive ambient monitoring was performed between 2000 and 2002 as part of the implementation of a water quality model in the Jackson River (MeadWestvaco 2003). In addition, VADEQ has an extensive monitoring program at different stations in the Jackson River. These data include nutrient (N,P) and periphyton observations at several stations along mainstem the Jackson River was developed.

The objective is to develop regression equations between benthic chlorophyll and in-stream nutrient concentrations; in other words we attempt to identify any strong relationships between water-column nutrients and periphyton biomass in the Jackson River. First, the complete data was screened to identify observations containing simultaneous TN, TP, and benthic chlorophyll (only data collected during the same day are included in the analysis). A total of 158 observations of benthic chlorophyll and nutrient species were used to develop the regressions. These water quality observations

were measured during the months of June trough October. The observations from all the stations in the Jackson River were combined in one data set (including stations upstream and downstream of MeadWestvaco). The statistical package Minitab® (Version 14) was used to develop these regressions in order to attempt to explain any eventual relationship between nutrient and benthic algae.

The nutrient data, recorded simultaneously with benthic chlorophyll, consist of NH3-N, NO2-N, NO3-N, PO4-P, and total dissolved nitrogen (TDN). First, a single regression analysis was developed between benthic chlorophyll and each of the nutrient species. Then, using a multiple regression analysis, a relationship was developed between chlorophyll, TDN, and PO4-P. The objective of this analysis was to identify any meaningful relationship between the variables in the dataset. **Table E-1** shows the result of this analysis.

Table E-1: Regression Models for Benthic Chlorophyll as a Function of Nutrients in the Jackson River

Dependent Variable (Response)	Independent Variable 1	Independent Variable 2	Intercept	R-square	Adjusted R-square
Log Chla	0.400*Log(NH4)	-	2.63	0.093	0.087
Log Chla	-0.544*Log(NO3)	-	1.57	0.023	0.017
Log Chla	2.43*Log(TDN)	-	2.90	0.293	0.289
Log Chla	0.543*Log(TDP)	-	2.62	0.602	0.599
Log Chla	0.524*Log(TDP)	0.178*Log(TDN)	2.66	0.603	0.598
Log Chla	0.423*Log(PO4)	-	2.60	0.597	0.594
Log Chla	0.395*Log(PO4)	0.359*Log(TDN)	2.69	0.600	0.595

The results from this data analysis clearly show that PO4-P or total dissolved phosphorus explain approximately 60% of the variation in benthic biomass in the Jackson River. A weak relationship was derived from the nitrogen species (NH4, NO3, and TDN). In addition, the regression results show that using TDN and PO4 as independent variables do not produce any statistical improvement. In other words, the regression using only PO4 as independent variable produces an R-square of 0.594 and when adding TDN to PO4 as an independent variable results to a similar R-square of 0.595.

Table E-2 depicts the proposed TMDL PO4-P endpoint, the periphyton concentration of 100 mg/m2 and the corresponding TN:TP ratio (total nitrogen versus total phosphorus) for each endpoint. Total nitrogen and total phosphorus was obtained from relationships, using available data from DEQ, between observed TN and TDN (NO2-N + NO3-N + NH3-N + DON) and observed TP and PO4-P. From these relationships, conversion factors were determined (1.14 for TN/TDN and 1.27 for TP/PO4-P) and applied to the average concentration of TDN in the Jackson River downstream of MeadWestvaco (0.49 mg/L) and to the endpoint for PO4-P (0.038 mg/L), respectively. This resulted to instream total nitrogen of 0.56 mg/L and total phosphorus of 0.048 (at 100 Chlamg/m2) and therefore to a N/P ratio of 11.7.

Table E-2: Proposed Nutrient TMDL Endpoints and Resulting N:P ratios

PO_4-P TMDL endpoint (mg/L)	Periphyton-Chla (mg/m^2)	N:P ratio
0.038	100	11.7

The TMDL endpoint of 0.038 gm/L for PO4-P at a periphyton chlorophyll concentration of 100 mg/m2 corresponds to a phosphorus-limited system and ensures that the periphyton biomass will be reduced in the Jackson River.

Models Development and Implementation

The overall strategy in support of the TMDL development for the Jackson River consists of applying the EPA Water Quality Simulation Program (WASP7.2) to the impaired segment of Jackson River. Specifically, the WASP7.2 eutrophication module was implemented and includes nitrogen and phosphorus cycling, dissolved oxygen-organic matter interactions, as well as phytoplankton and periphyton kinetics. Point source loads were put into WASP7.2, which was implemented during the time period from June to October. Specifically, years 2000 and 2001 were used to calibrate and validate the model, where extensive data is available. Besides the considerable amount of monitoring data available, the Jackson River experienced the most deteriorated water quality conditions (excessive periphyton growth) during this time span.

The TMDL must also address nonpoint source loads (NPS). Consequently, the Hydrological Simulation FORTRAN Program (HSPF) was implemented to generate the NPS loads. The NPS loads output from the HSPF model was formatted and linked to WASP7.2. The following sections provide a description of the two models (WASP7.2 and HSPF) and outline the key steps used in the implementation of the modeling strategy for the Jackson River TMDL.

WASP7 Model Implementation

The Water Quality Simulation Analysis, version 7.2 (EPA, 2006), was used for the development of the Jackson River TMDL. It consists of the standard WASP eutrophication module and the advanced WASP7 module. The standard WASP eutrophication module includes nitrogen and phosphorus cycling dissolved oxygen-organic matter interactions, and phytoplankton kinetics. The advanced WASP7 module (July 20006), named "periphyton," includes the standard WASP eutrophication algorithms and incorporates bottom algae with three additional state variables: bottom algal biomass, bottom algal cell nitrogen, and bottom algal cell phosphorus.

In WASP7.2, bottom algae concentrations are simulated based on sources and sinks. The impact of advective and dispersive transport is not considered. As a consequence, elevated velocities, hence greater sheer stress, will not affect the bottom algae in WASP7.2. Sources and sinks include nutrient uptake, growth, nutrient excretion, death, and respiration. Nutrient uptake rates are driven by concentrations of inorganic nitrogen and phosphorus in the water column and within algal cells, and are controlled by cell minimum and half-saturation parameters. Biomass growth is computed from a maximum zero or first-order rate constant that is adjusted internally by water temperature, bottom light intensity, internal nutrient concentrations, and maximum carrying capacity. Nutrient excretion, death, and respiration are represented by first-order, temperature dependent rates. Growth, respiration, and death rates affect other model state variables, including dissolved oxygen and nutrients. The algorithms for predicting bottom algal biomass and nutrient concentrations in WASP7.2 are based upon the periphyton routines included in the QUAL2K model (Chapra and Pelletier, 2003).

The WASP7.2 model was applied over five months between June 1st and October 31st for 2000, 2001, and 2006, respectively. The model simulation run for 2001 is the calibration run, since 2001 had the most complete set of measured data for WASP7.2 model input. The model simulation run for 2000 is the validation run, in which the model input values are the same as in 2001 due to the lack of measurements taken during this period. The model simulation run for 2006 simulates existing conditions of the Jackson River.

WASP 7 Model Segmentation

The segmentation was based on the location of drainage catchments (for later inclusion of NPS loads), location of major point sources and water quality monitoring stations, and location of tributaries (Dunlap and Potts). The model segmentation used for the TMDL development is presented in **Table E-3** depicting the volume, length, width, slope, and bottom roughness for each segment. **Figure E-1** shows the location of the model-segments in the Jackson River. The segmentation consists of 24 model segments (18 main-stem segments and 6 tributary-segments).

Table E-3: WASP7 Model Segments and Characteristics

Model Segment	Volume m3	Length m	Width m	Depth m	Slope	Bottom Roughness
S1 - Headwater (RM -1.8) to RM -1.5	12710	500	41	0.62	0.0115	0.071
S2 - RM -1.5 to Filtration Plant (RM -1.2)	13650	500	42	0.65	0.0002	0.070
S3 - Filtration Plant (RM -1.2) to RM -0.9	23628	807	43.7	0.67	0.0007	0.070
S4 - RM -0.9 to Mill Bridge (MeadWestvaco)	40138	1403	42.7	0.67	0.0009	0.070
S5 - Mill Bridge to before Dunlap Creek	10304	535	42.8	0.45	0.0090	0.069
S6 Dunlap - (RM 1.2) to RM 0.9	3800	500	20	0.38	0.0001	0.071
S7 Dunlap - RM 0.9 to RM 0.6	5000	500	25	0.4	0.0050	0.071
S8 Dunlap - RM 0.6 to RM 0.0	14080	1000	32	0.44	0.0009	0.071
S9 - After Dunlap Creek to before Fudges Bridge	74682	2379	43.6	0.72	0.0050	0.069
S10 - before Fudges Creek to Industrial Park (RM 3.0)	51578	1805	38.1	0.75	0.0074	0.068
S11 - Industrial Park to Hercules Bridge	67404	1715	39.7	0.99	0.0049	0.067
S12 - Hercules Bridge to before Potts Creek	67109	1541	40.7	1.07	0.0009	0.067
S13 Potts - (RM 1.2) to RM 0.9	3800	500	20	0.38	0.0021	0.071
S14 Potts - RM 0.9 to RM 0.6	5000	500	25	0.4	0.0033	0.071
S15 Potts - RM 0.6 to RM 0.0	14080	1000	32	0.45	0.0038	0.071
S16 - Potts Creek to Idlewidle Bridge (Covington STP)	43681	1325	40.7	0.81	0.0006	0.066
S17 - Idelwidle Bridge to Mallow Mall	222343	4756	42.5	1.1	0.0003	0.065
S18 - Mallow Mall	233996	4727	46.7	1.06	0.0005	0.063
S19 - RM 11.7 to before Valley Bridge	111881	2239	46.7	1.07	0.0004	0.062
S20 - before Valley Bridge to RM 15.8	228673	4372	46.7	1.12	0.0003	0.061
S21 - RM 15.8 to RM 17.3	121032	2445	46.7	1.06	0.0003	0.060
S22 - RM 17.3 to RM 19.6 (Berger's Mile)	180688	3616	46.7	1.07	0.0007	0.059
S23 - RM 19.6 to RM 21.6 (Clifton Forge STP)	174277	3332	46.7	1.12	0.0003	0.058
S24 - RM 21.6 to RM 24.1	208641	3989	46.7	1.12	0.0004	0.056

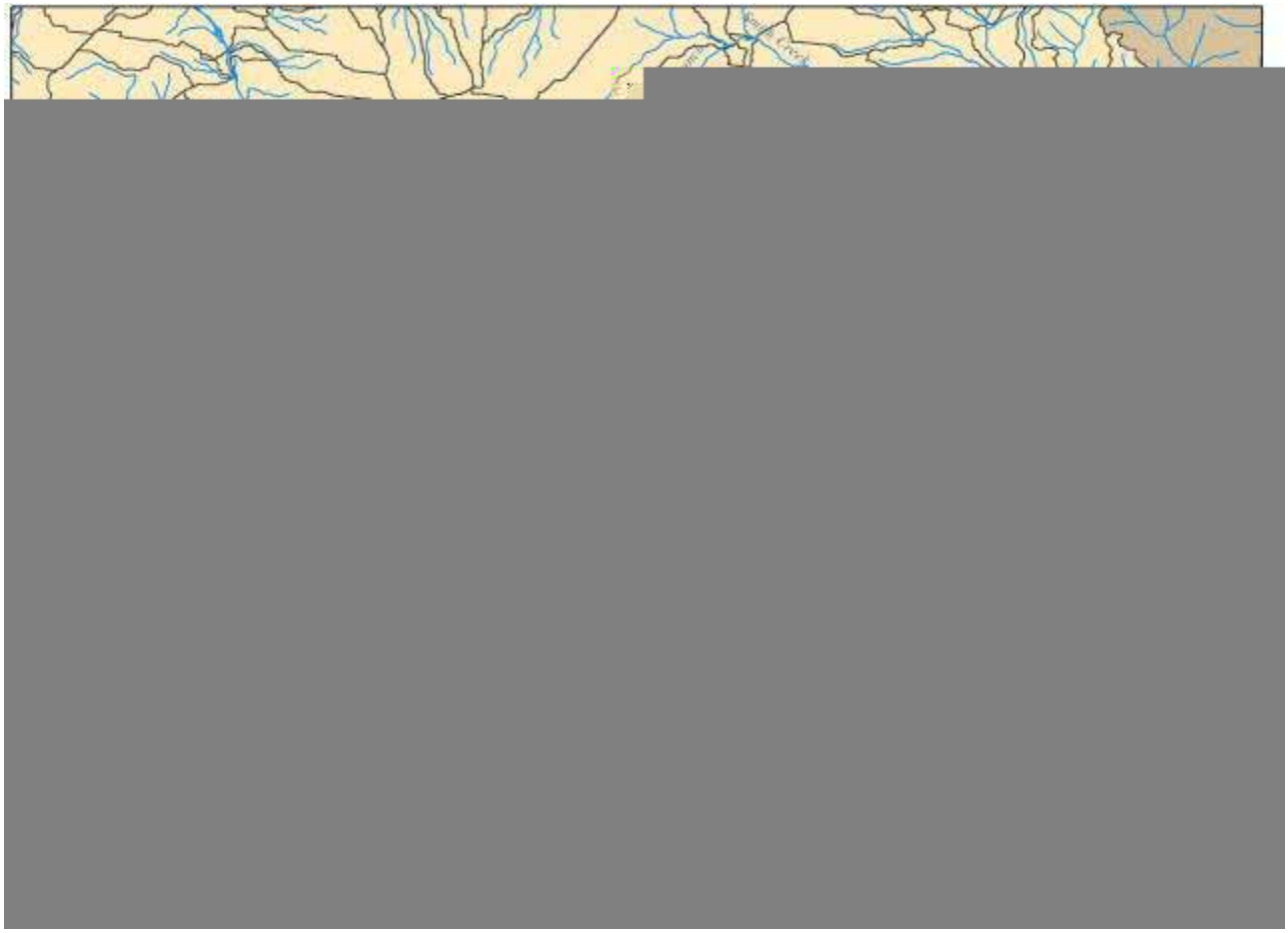


Figure E-1: Jackson River Model Segments

HSPF Model Description

The Hydrologic Simulation Program-Fortran (HSPF) was used to estimate the nutrient nonpoint source loads to the Jackson River. HSPF is a continuous, physically based, lumped-parameter model which simulates hydrology, sediment, and chemical pollutants in the soil and in streams. Nutrient simulation modules are detailed and flexible, and thus can be used to simulate a variety of land use types. The HSPF model is normally calibrated to observed flow and water quality data measured at the outlet of a watershed.

The Chesapeake Bay Program in Annapolis calibrated the HSPF Model over the entire Chesapeake Bay watershed. The model divides the 64,000 square mile Chesapeake Bay drainage basin into model segments. Each segment contains information generated by a

hydrologic sub-model, a nonpoint source sub-model and a river sub-model. The hydrologic sub-model uses rainfall, evaporation and meteorological data to calculate runoff and subsurface flow for all the basin land uses including forest, agricultural and urban lands. The surface and subsurface flows ultimately drive the nonpoint source sub-model, which simulates soil erosion and the pollutant loads from the land to the rivers. The river sub-model routes flow and associated pollutant loads from the land through lakes, rivers and reservoirs to the Bay. In the most recent version of the Chesapeake Bay model, Phase 5, flow and water quality data from 1985 to 2003 were used for the calibration of the model.

HSPF Model Implementation

The Jackson River is part of the James River Basin which drains to the Chesapeake Bay watershed. Consequently, the Louis Berger Group acquired the calibrated HSPF model files for the entire James River Basin, and implemented the model. The model was calibrated from 1985 to 1999 and validated during the period spanning 2000 to 2003. The validation files are used to generate nutrient loads for the Jackson River TMDL, since they coincide with our instream model (WASP7) calibration and validation periods.

HSPF model input files and data specific to the James River were processed and the model was implemented for the specific model-segments comprising the Jackson River watershed.

Modeling Scenarios

The models were calibrated and validated during the growing periods (June to October) 2000 and 2001. The results of the calibration and validation are shown in **Chapter 6**. The WASP7.2 calibration results include a graphical comparison between observed and predicted results. A graphical comparison between observed and simulated instream concentrations provides the first check of the accuracy of the predicted values. However, it is meant to be the first check, since its accuracy strongly depends on the scale of the presented results. In addition, the graphical comparison is a qualitative measure, which often fails to quantify the accuracy of the model simulations. For testing the model

results, statistical techniques are used to quantify the accuracy of the models results (Power, 1993; Mayer and Butler, 1993).

The WASP7.2 model performance evaluation also focuses on comparing observed and simulated values using cumulative distribution functions (CDFs). The CDF allows one to capture the magnitude and frequency of concentrations. In addition, the statistical distribution of observed and simulated values is more important than fitting precise timing given uncertainty of exact loading of nutrient inputs form point sources (Thomann and Barnwell, 1980, EPA Chesapeake Bay Office 2004).

The CDFs were computed using paired observed and simulated values. Paired values consist of simulated and observed values generated by the model or collected at the same time. For instance, when there are 30 observed values for the period of interest (June to October) the corresponding 30 simulated values will be used to generate the median relative error (consisting of 30 paired values). Overall, the calibration results reproduce the observed data quite well.

Following the calibration and validation of the models, a 2006 Existing Conditions Scenario was implemented. The objective of the Existing Conditions Scenario is to utilize the calibrated model to assess the periphyton level during the 2006 growing season in the mainstem of the Jackson River. In addition, water quality data collected by the ANS, MeadWestvaco, and VADEQ in the spring of 2006 as part of the flow-pulse studies will be used to further validate the calibrated water quality model. The 2006 average periphyton level in the main stem model segments is approximately 165 mg/m^2

Jackson River TMDL Allocations

The development of the allocations for the Jackson River TMDL is based on the Chesapeake Bay Modeling Scenario. Based on their findings, nitrogen and phosphorus discharges have been shown to impact the water quality in the Bay and its tidal rivers. As a result, the Virginia State Water Control Board (SWCB) proposed guidelines controlling

the discharge of total nitrogen and total phosphorus within the Virginia portion of the Chesapeake Bay watershed. The Chesapeake Bay Scenario uses the calibrated WASP7 model implemented for the 2006 growing season with adjustments to the point source dischargers loads to reflect the EPA Chesapeake Bay future discharge guidelines depicted in **Table E-4**. Clifton Forge STP (VA0022772) will be phased-out and replaced by the Lower Jackson River WWTP (VA0090671).

Table E-4: Chesapeake Bay Recommended Nutrient Load Discharges

Facility Name	VPDES Permit	Discharge Flow (MGD)	TP Load (lbs/yr)	TP Conc. (mg/L)	TN Load (lbs/yr)	TN Conc. (mg/L)
MeadWestvaco	VA0003646	35.0	159,815	1.5	394,211	3.7
Covington STP	VA0025542	3.0	4,566	0.5	54,794	6.0
Low Moor WWTP	VA0027979	0.3	1,050	1.15	5,479	6.0
Lower Jackson River WWTP	VA0090671	2.6	3,957	0.5	47,488	6.0

The resulting periphyton levels resulting from the implementation of the Chesapeake Bay Scenario in each modeling segment of the Jackson River are depicted in **Figure E-2**. The average periphyton level in the 15 mainstem model-segments is approximately 137 mg/m^2. This level is lower than the 165 mg/m^2 periphyton biomass resulting from the implementation of the 2006 Existing Conditions Scenario.

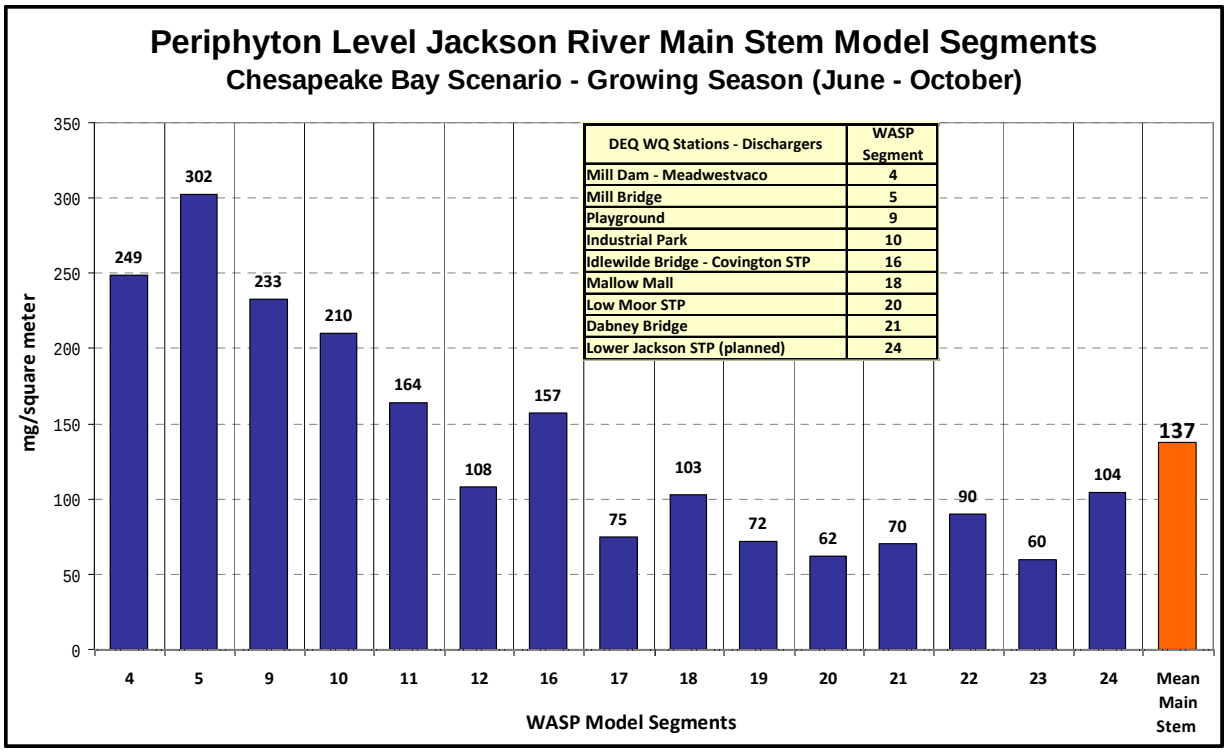


Figure E-2: Chesapeake Bay Modeling Scenario – Periphyton Levels Main Stem Jackson River

Flow Augmentation and Periphyton Scouring

The results of the Chesapeake Modeling Scenario indicate that the PO4-P endpoint of 38 ug/L and the corresponding periphyton target of 100 mg/m^2 cannot be reached in the Jackson River. This is due to the fact that the Jackson River is not a free flowing river and also to the fact that MeadWestvaco, the main nutrient contributor to the Jackson River, has reached its limits of technology in term of phosphorus reductions. The remaining option that will help the Jackson River achieve a healthy and balanced biologic community is to mimic the natural hydrology and flows that have existed before the operation of the Gathright Dam. Since it is unlikely to fully reestablish the pre-Gathright Dam hydrologic regime, VADEQ proposed that flow will be released from the dam to provide periphyton scouring and help reach the assigned endpoints. Consequently, VADEQ in cooperation with MeadWestvaco, the Philadelphia Academy of Sciences and the US Army Corps of Engineers (USACE), implemented and developed in October 2007 a flow release study where the primary objective was to assess the level of periphyton biomass scouring resulting from flow augmentation test-pulses under a flow

augmentation study. The other objective was to identify the number and level of the flow pulses that can be technically feasible. The flow pulse study indicated that the flow releases from the Gathright Dam will help the Jackson River meet the assigned endpoints. In addition, six flow pulses of 3,000 cfs each were recommended during the growing season.

Implementation of the Chesapeake Bay Scenario with Flow Augmentation Pulses

In order to demonstrate that the flow releases will help restore the benthic community in the Jackson River, a modeling scenario was developed incorporating the Chesapeake Bay conditions with the recommended flow augmentation pulses. A velocity-periphyton relationship developed by the Philadelphia Academy of Natural Sciences (ANS) in artificial streamside channels was used to relate the effect of stream velocity changes on the periphyton scouring. The dimensionless relationship was applied to the periphyton and stream velocity time-series output from the Chesapeake Bay Scenario for each of the 15 mainstem model-segments to develop the periphyton time series resulting from the flow-augmentation pulses. The resulting periphyton levels are shown in **Figure E-3** indicates that an average periphyton level of 101 mg/m^2 can be reached in the main stem of the Jackson River. This level of periphyton biomass is comparable to the periphyton endpoint of 100 mg/m^2 that will allow the Jackson River meet its aquatic life endpoint.

Allocation

The Jackson River the TMDL endpoint will be achieved using a combination of load allocations and a flow augmentation in the main stem. In fact, the various modeling scenarios indicated that in order to restore the Jackson River benthic community it is necessary to:

- Assign to the WWTPs the recommended Chesapeake Bay discharge levels, and assign the 2006 levels in term of PO4-P discharge for the MeadWestvaco plant.
- Implement the 6 flow pulses recommended under the 216 study.

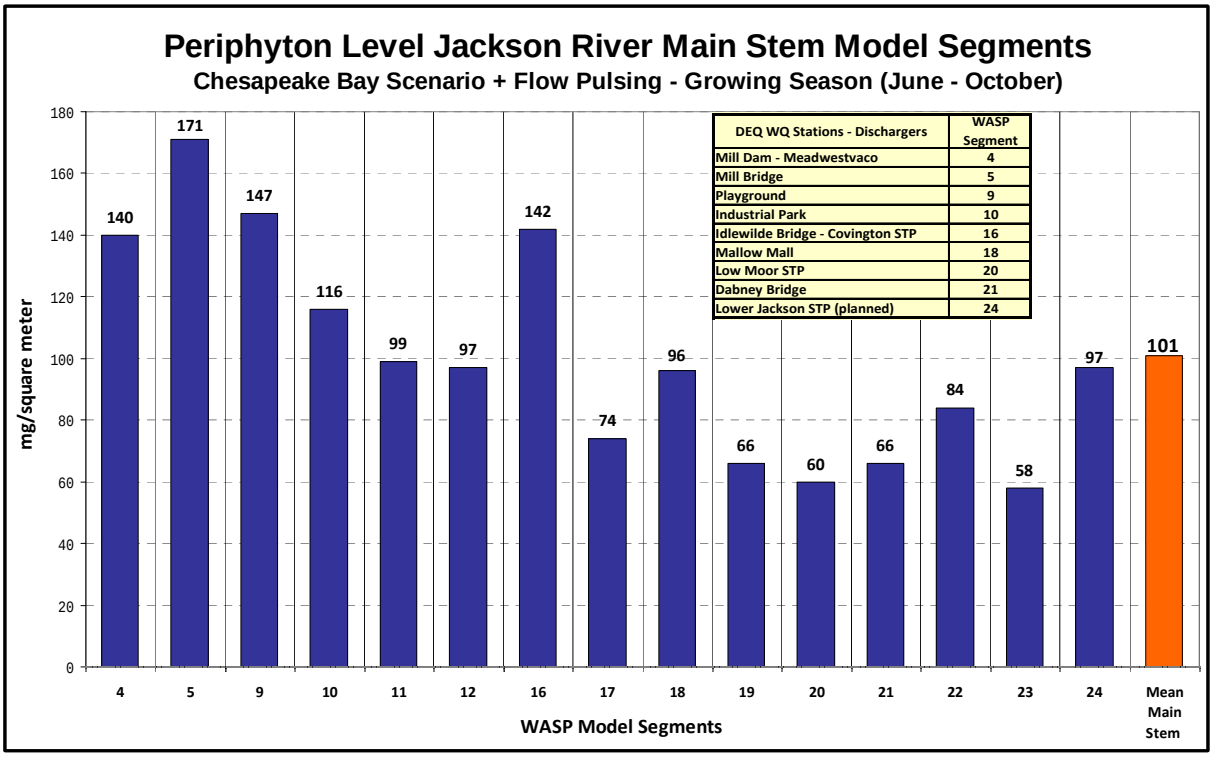


Figure E-1: Periphyton level - Chesapeake Bay Scenario and Flow Pulses

The load allocations were developed using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

Where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (non-point source allocation); and

MOS = margin of safety.

Incorporation of Margin of Safety

The margin of safety (MOS) is a required component of the TMDL to account for any lack of knowledge concerning the relationship between effluent limitations and water quality. According to EPA guidance (*Guidance for Water Quality-Based Decisions: The TMDL Process, 1991*), the MOS can be incorporated into the TMDL using two methods:

- Implicitly incorporating the MOS using conservative model assumptions to develop allocations; or
- Explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations.

The MOS will be implicitly incorporated into this TMDL using conservative modeling assumptions.

Jackson River TMDL Allocations

A summary of the TMDL allocation plan loads the Jackson River are presented in **Table E-5 and Table E-6** for total phosphorus and total nitrogen respectively.

Table E-5: Jackson River Total Phosphorus TMDL (Lbs/Growing Season)

WLA (Point Sources)	LA (Non-point sources)	MOS (Margin of Safety)	TMDL
71,004	2,880	Implicit	73,884

Table E-6: Jackson River Total Nitrogen TMDL (Lbs/Growing Season)

WLA (Point Sources)	LA (Non-point sources)	MOS (Margin of Safety)	TMDL
213,478	24,160	Implicit	237,638

Reasonable Assurance

The upper Jackson River and its current flow have been mitigated and compromised by a low flow augmentation scheduled that was established by the USACE in 1981. The existing low flow regime was implemented to address high BOD and low DO conditions of the stream at Covington. Over the past 30 years, there have been significant reductions in the amount of BOD discharged and DO conditions have improved. Today, excessive nutrients / periphyton have replaced BOD as the pollutant of concern in this section of the river.

The Jackson River TMDL is recommending the existing flow augmentation schedule be modified to restore natural stream flow variability. The proposed flow release modification is to remediate current water quality problems. This change will simulate or mimic natural storm events, particularly during the critical growing period of the periphyton. The TMDL modeling and monitoring studies have demonstrated pulses during critical periods can and do scour and flush excess periphyton downstream. This action results in improved biological communities in the river below Covington.

Therefore, this TMDL is unique since the implementation consists of increasing the flow in the main stem of the Jackson River. The flow augmentation study, insuring that the Virginia aquatic life standards will be met, is being implemented and finalized through a 216 study authorized by Section 216 of the River and Harbor and Flood Control Act of 1970 (Public Law 91-611), dated 31 December 1970, which states:

> "The Secretary of the Army, acting through the Chief of Engineers, is authorized to review the operation of projects the construction of which has been completed and which were constructed by the Corps of Engineers in the interest of navigation, flood control, water supply, and related purposes, when found advisable due to significantly changed physical or economic conditions, and to report thereon to Congress with recommendations on the advisability of modifying the structures or their operation, and for improving the quality of the environment in the overall public interest."

The overall purpose of the flow augmentation feasibility \study is to ensure the timely and economical completion of a quality Feasibility Report that will review the existing conditions of the Gathright Dam and Lake Moomaw Federal project to determine if any changes to release procedures would significantly enhance habitat and benefit water quality downstream of the project on the Jackson River to the confluence with the head of the James River. The primary focus of the study will be directed to fine tuning the water release procedures during low flow conditions by incorporating new techniques, such as pulsing, to better mimic natural stream conditions that occurred before the project existed. These release modifications shall be developed to protect the in-lake fishery and

downstream fisheries. Habitat enhancement shall address benthic organisms, siltation, and water quality. The Feasibility Study shall be fully consistent with and in support of the goals, mandates, and direction of the Chesapeake Bay Agreement and other pertinent state and Federal statutes and initiatives. EPA uses the term "*reasonable assurance*" to emphasize that implementation of a TMDL is critical to the ultimate attainment of standards in the impaired waterbody. Reasonable assurance is defined as "a *demonstration that the TMDL will be implemented through regulatory or voluntary actions, by Federal, State or local governments, authorized tribes or individuals*" (EPA, 2000). There is a reasonable assurance that the 216 study will be implemented through a flow augmentation in the main stem of the Jackson River leading to the attainment of the identified endpoint. In fact, the US Army Corps of Engineers and the VADEQ entered and signed an official agreement funding the 216 study and insuring that the flow augmentation study will be implemented and completed in the next 3 years. In fact and as shown in **Table E-7,** a Feasibility Cost Sharing Agreement (FCSA) between the USACE Norfolk District and the Commonwealth of Virginia, the study's local sponsor, was executed in December 21st 2009. A Project Management Plan (PMP) was also approved outlining all the steps necessary for the conduct of the 216 study. In addition, memorandums of understanding (MOAs) were executed between VADEQ, MeadWestvaco and the Virginia Department of Game and Inland Fisheries (DGIF) for the development of a monitoring Quality Assurance Project Plan (QAPP) and the coordination of the monitoring plan itself.

Table E-7: Agreements and Planned Phases of the 216 Flow Augmentation Study

FCSA Execution	December 21, 2009	December 21, 2009
PMP Execution	February 5, 2010	February 1, 2010
State Funds/Work In Kind Received	February 5, 2010	February 1, 2010
Initial Coordination Meeting	March 24, 2010	-
Peer Review Plan Approved	April 2, 2010	-
AFB Briefing	October 24, 2011	-
DRAFT 216 Study Report	May 15, 2012	-

1.0 Introduction

Total Maximum Daily Load (TMDL) development for biological impairment requires a methodology to identify impairment causes and to determine pollutant reductions that will allow streams to attain their designated uses. The identification of the pollutant(s), or *stressor(s)*, responsible for the impaired biological communities is an important first step in developing a TMDL that accurately specifies the pollutant load reductions necessary for the river to comply with Virginia's water quality standards. This report details the steps used to identify and characterize the stressor(s) responsible for biological impairments on the Jackson River. The first section of this report presents the regulatory guidance and defines the applicable water quality criteria for biological impairment. In the subsequent sections of this report, watershed and environmental monitoring data collected on the Jackson River are presented and discussed. Stressors, which may be impacting the river, are then analyzed in the stressor identification section. Based on this analysis, candidate stressors impacting benthic invertebrate communities in the river are identified. A TMDL will be developed for the stressor identified as the most probable cause of biological impairment in the Jackson River as outlined in the EPA Stressor Identification Guidance (EPA 2000).

1.1 Regulatory Guidance

Section 303(d) of the Clean Water Act and the Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are exceeding water quality standards. TMDLs represent the total pollutant loading that a waterbody can receive without violating water quality standards. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and instream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and non-point sources to restore and maintain the quality of their water resources (EPA, 2001).

The state regulatory agency for Virginia is the Department of Environmental Quality (DEQ). DEQ works in coordination with the Virginia Department of Conservation and Recreation (DCR), the Department of Mines, Minerals, and Energy (DMME), and the Virginia Department of Health (VDH) to develop and regulate a more effective TMDL process. DEQ is the lead agency for the development of TMDLs statewide and focuses its efforts on all aspects of reduction and prevention of pollution to state waters. DEQ ensures compliance with the Federal Clean Water Act and the Water Quality Planning Regulations, as well as with the Virginia Water Quality Monitoring, Information, and Restoration Act (WQMIRA, passed by the Virginia General Assembly in 1997), and coordinates public participation throughout the TMDL development process. The role of DCR is to initiate non-point source pollution control programs statewide with federal grant money. DMME focuses its efforts on issuing surface mining permits and National Pollution Discharge Elimination System (NPDES) permits for industrial and mining operations. Lastly, VDH monitors waters for fecal coliform, classifies waters for shellfish growth and harvesting, and conducts surveys to determine sources of bacterial contamination (DEQ, 2001).

As required by the Clean Water Act and WQMIRA, DEQ develops and maintains a listing of all impaired waters in the state that details the pollutant(s) causing each impairment and the potential source(s) of each pollutant. This list is referred to as the Section 303(d) List of Impaired Waters. In addition to Section 303(d) List development, WQMIRA directs DEQ to develop and implement TMDLs for listed waters (DEQ, 2001a). Once TMDLs have been developed, they are distributed for public comment and then submitted to the EPA for approval.

1.2 Jackson River Description and Impairment Listing

The Jackson River flows through a narrow valley, with mountain peak elevations of approximately 2,500 feet above mean sea level. The headwaters of the Jackson River originate in Highland County in southwestern Virginia, and extend to the confluence of the Jackson River with the Cowpasture River in Botetourt County, where the two rivers join to form the James River. The Jackson River flows through sections of Alleghany,

Bath, Craig, and Highland Counties, as well as the Cities of Covington and Clifton Forge. The Gathright Dam regulates the stream flow in the Jackson River.

The Jackson River was initially listed on Virginia's 1996 Section 303(d) Total Maximum Daily Load Priority List and Report (DEQ, 1996), and was subsequently included on Virginia's 1998 and 2002 Section 303(d) Lists of Impaired Waters (DEQ, 2002) and in the 2004 Water Quality Assessment 305(b)/303(d) Integrated Report (DEQ, 2004).

The impaired segment of the Jackson River, included in the 2004 305(b)/303(d) Integrated Report, is 25.24 miles long, from its upstream limit immediately below the Covington City Water Treatment Plant intake to its downstream limit at the confluence of the Jackson and Cowpasture Rivers. The impairments include the following:

- Dissolved oxygen impairment, extending from river mile 24.21 downstream to river mile 13.00 (11.21 miles of the impairment segment).

- General standard benthic impairment, extending from river mile 24.21 to river mile zero, which is the confluence of the Jackson River with the Cowpasture River (24.21 miles of the impairment segment).

- Bacteria impairment and failure to attain the primary contact recreation and aquatic life uses, extending from river mile 25.24 to river mile 21.86 (3.38 miles of the impairment segment). However, the recent data supplied by the DEQ indicates that the fecal coliform bacteria concentrations are false positive results due to *Klebsiella pneumoniae*. Consequently, EPA concurred that a bacteria TMDL is not required for the Jackson River (Memorandum from Jon Capacasa, Director Water Protection Division EPA Region 3, to Ellen Gilinsky VADEQ, 2005).

Consequently, this report addresses the impaired segment, with a total mileage of 24.21 miles, for General Standard benthic impairments. Figure 1-1 depicts this impaired segment.

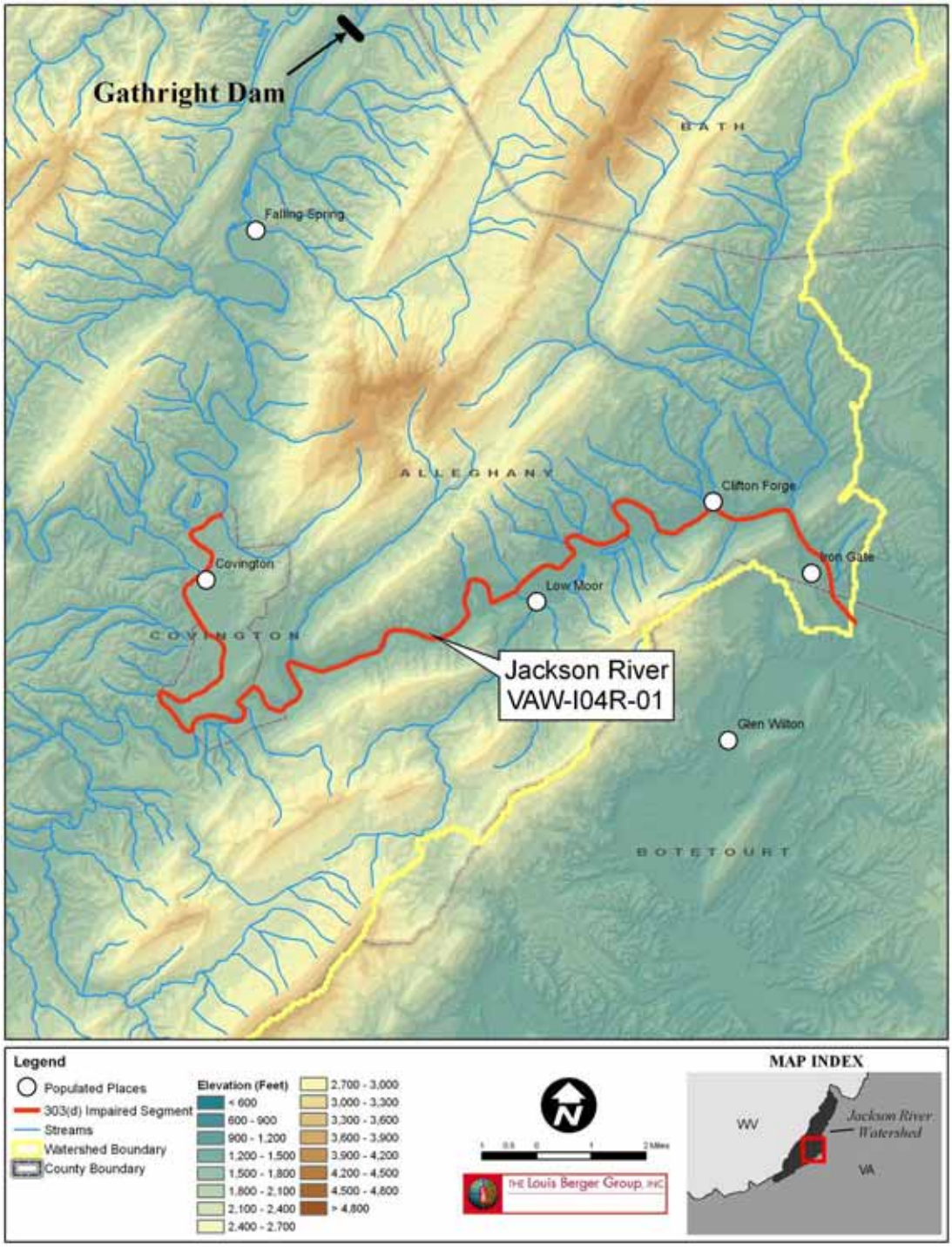


Figure 1-1: Jackson River Location and Benthic Impairment Segment

1.3 Applicable Water Quality Standard

Water quality standards consist of designated uses for a waterbody and water quality criteria necessary to support those designated uses. According to Virginia Water Quality Standards (9 VAC 25-260-5), the term *water quality standards* means "provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect public health or welfare, enhance the quality of water, and serve the purposes of the State Water Control Law (§62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 et seq.)."

1.3.1 Designated Uses

According to Virginia Water Quality Standards (9 VAC 25-260-10):

> *"all state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)."*

The listed segment defined in Section 1.2 does not support the propagation and growth of aquatic life in the Jackson River, based on the biological assessment surveys conducted on the river.

1.3.2 Water Quality Criteria

The General Standard defined in Virginia Water Quality Standards (9 VAC 25-260-20) provides general, narrative criteria for the protection of designated uses from substances that may interfere with attainment of such uses. The General Standard states:

> *"All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life."*

The biological assessments conducted on the Jackson River indicate that some pollutant(s) are interfering with attainment of the General Standard, as impaired invertebrate communities have been observed in the listed segment of the river. Although biological assessments are indicative of the impacts of pollution, the specific pollutant(s) and source(s) are not necessarily known based on biological assessments alone.

2.0 Watershed Characterization

The physical conditions of the Jackson River watershed were characterized using a geographic information system (GIS) developed for the watershed. The purpose of the watershed characterization was to provide an overview of the conditions in the watershed related to the benthic impairment present in the river. Information contained in the watershed GIS was used in the stressor identification analysis, as well as for the subsequent TMDL development. In particular, watershed physical features such as topography, soils types, and land use conditions were characterized. In addition, the number and location of permitted discharge facilities and DEQ monitoring stations in the watershed were summarized.

2.1 Physical Characteristics

Important physical characteristics of the Jackson River watershed that may be contributing to the benthic impairment were analyzed using GIS coverages developed for the area. GIS coverages for the watershed boundary, stream network, topography, soils, land use, and ecoregion of the watershed were compiled and analyzed.

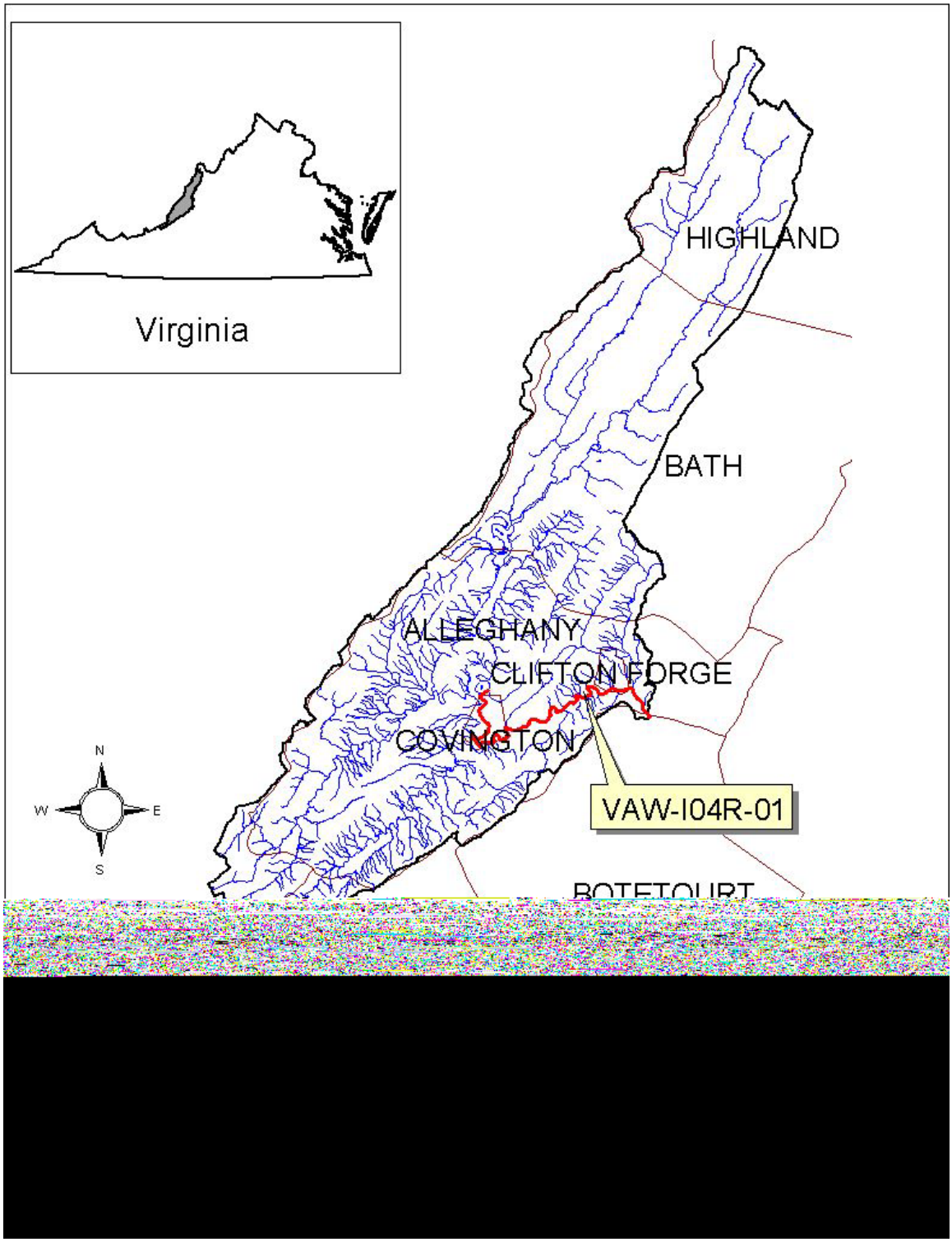
2.1.1 Watershed Location and Boundary

The Jackson River watershed flows through sections of Allegheny, Bath, Craig, and Highland Counties, as well as the Cities of Covington and Clifton Forge (Figure 2-1). Small sections of the watershed are located in West Virginia. The watershed is approximately 584,686 acres or 916 square miles. Gathright Dam controls 345 square miles of the drainage area, which is 38 percent of the Jackson River watershed. Gathright Dam also controls 56 percent of the drainage area above the USGS stream gage station at the city park in Covington and controls 75 percent of the drainage area in the Jackson River watershed above the mouth of Dunlap Creek.

2.1.2 Stream Network

The stream network for the Jackson River watershed was obtained from the USGS National Hydrography Dataset (NHD). The stream network and benthic impairment segments are presented in **Figure 2-1**.

Figure 2-1: Stream Network for the Jackson River Watershed



2.1.3 Topography

A digital elevation model (DEM) was used to characterize topography in the watershed. DEM data obtained from BASINS show that elevation in the watershed ranges from 912 to 4,116 feet above mean sea level, with an average elevation of 2,223 feet.

2.1.4 Soils

The Jackson River watershed soil characterization was based on the NRCS State Soil Geographic (STATSGO) Database for Virginia and West Virginia. There are fifteen general soil associations present in the Jackson River watershed (**Table 2-1**). The majority of soils in the watershed are comprised of the Wallen-Dekalb-Drypond, Berks-Weikert-Laidig, Shottower-Laidig-Weikert, and Wallen-Dekalb-Drypond soils associations. Combined, these four soil associations account for almost 85 percent of the soils in the watershed.

Table 2-1: Soil Types in the Jackson River Watershed

Map Unit ID	Soil Association	Percent	Hydrologic Soil Group
VA001	Berks-Weikert-Laidig	17.0	B/D
VA003	Frederick-Carbo-Timberville	3.3	B/D
VA004	Moomaw-Jefferson-Alonzville	3.4	C
VA005	Wallen-Dekalb-Drypond	54.2	C
VA016	Shottower-Laidig-Weikert	8.2	C
VA072	Opequon-Berks-Blackthorn	4.0	C
VA073	Mandy-Trussel-Gauley	0.1	C
VA075	Calvin-Dekalb-Hazleton	0.9	A/B/C
WV002	Frederick-Carbo-Timberville	1.4	B/C
WV003	Cateache-Berks-Shouns	0.2	B/C
WV022	Weikert-Berks-Dekalb	0.1	B/C/D
WV048	Mandy-Trussel-Gauley	0.03	C
WV119	Wallen-Dekalb-Drypond	5.1	B/C/D
WV120	Shottower-Laidig-Weikert	1.3	B/C
WV121	Moomaw-Jefferson-Alonzville	0.8	B/C

Source: State Soil Geographic (STATSGO) Database for Virginia and West Virginia

The hydrologic soil groups of each of the soil associations are also presented in Table 2-1. The hydrologic soil groups represent the different levels of soil infiltration capacity. Hydrologic soil group "A" designates soils that are well to excessively well drained, whereas hydrologic soil group "D" designates soils that are poorly drained. This means that soils in hydrologic group "A" allow a larger portion of the rainfall to infiltrate and become part of the ground water system. On the other hand, compared to the soils in hydrologic group "A", soils in hydrologic group "D" allow a smaller portion of the rainfall to infiltrate and become part of the ground water, resulting in more rainfall delivered to surface waters in the form of runoff. Descriptions of the hydrologic soil groups are presented in Table 2-2.

Table 2-2: Descriptions of Hydrologic Soil Groups

Hydrologic Soil Group	Description
A	High infiltration rates. Soils are deep, well drained to excessively drained sand and gravels.
B	Moderate infiltration rates. Deep and moderately deep, moderately well and well-drained soils with moderately coarse textures.
C	Moderate to slow infiltration rates. Soils with layers impeding downward movement of water or soils with moderately fine or fine textures.
D	Very slow infiltration rates. Soils are clayey, have high water table, or shallow to an impervious cover.

2.1.5 Land Use

The land use characterization was based on USGS National Land Cover Data (NLCD). The distribution of land uses in the Jackson River watershed, by land area and percentage, is presented in Table 2-3. Forested lands (89.3%) and agricultural lands (8.5%) represent the dominant land uses in the watershed. Brief descriptions of land use classifications are presented in Table 2-4. Figure 2-2 displays a map of the land uses within the watershed. Forested lands are ubiquitous throughout the watershed. Agricultural lands are most concentrated in the northern headwaters of the basin. Small percentages of urban and industrial areas are associated with the Cities of Covington and Clifton Forge.

Table 2-3: Jackson River Watershed Land Use Distribution

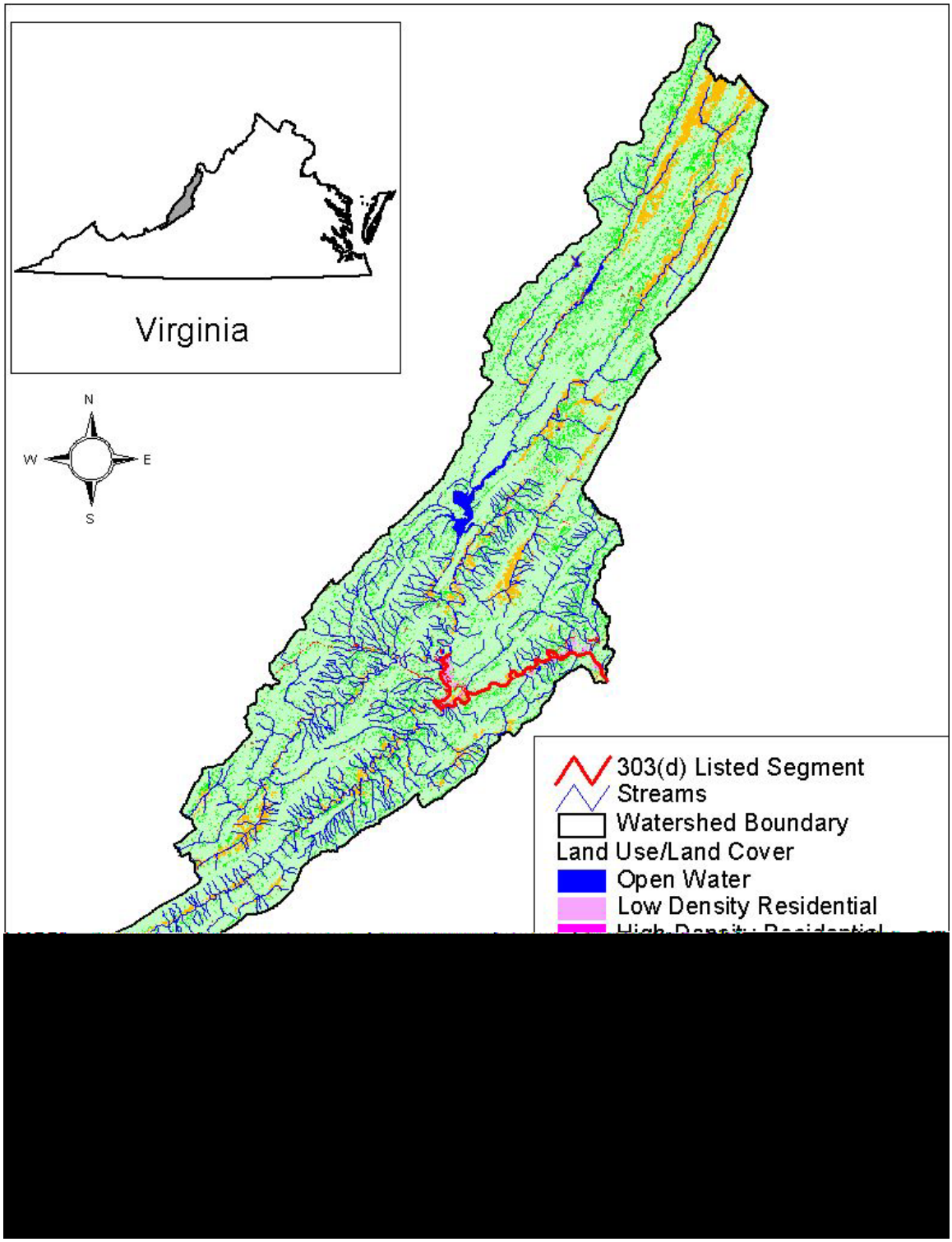
General Land Use Category	NLCD Land Use Type	Acres	Percent of Watershed	Total Percent
Water/ Wetlands	Open Water	4536.0	0.78	**0.8**
	Woody Wetlands	215.7	0.04	
	Emergent Herbaceous Wetlands	178.3	0.03	
Developed	Low Intensity Residential	3253.7	0.56	**0.9**
	High Intensity Residential	22.5	0.004	
	Commercial/Industrial/Transportation	1889.6	0.32	
Agriculture	Pasture/Hay	43541.7	7.45	**8.5**
	Row Crop	6233.7	1.07	
Forest	Deciduous Forest	435637.1	74.57	**89.3**
	Evergreen Forest	20336.1	3.48	
	Mixed Forest	65758.8	11.26	
Other	Transitional	2496.2	0.43	**0.4**
	Urban/Recreational Grasses	131.9	0.02	
Total		**584,686**	**100**	**100**

Table 2-4: Descriptions of NLCD Land Use Types

Land Use Type	Description
Open Water	Areas of open water, generally with less than 25 percent or greater cover of water
Woody Wetlands	Areas where forest or shrubland vegetation accounts for 25-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.
Emergent Herbaceous Wetlands	Areas where perennial herbaceous vegetation accounts for 75-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.
Low Intensity Residential	Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.
High Intensity Residential	Includes heavily built up urban centers where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80-100 percent of the cover.
Commercial/ Industrial/ Transportation	Includes infrastructure (e.g. roads, railroads, etc.) and all highways and all developed areas not classified as High Intensity Residential.
Pasture/Hay	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.
Row Crop	Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.
Deciduous Forest	Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen Forest	Areas characterized by trees where 75 percent or more of the tree species maintain their leaves all year. Canopy is never without green foliage.
Mixed Forest	Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.
Transitional	Areas of sparse vegetative cover (less than 25 percent that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clearcuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.)
Urban/ Recreational Grasses	Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.

Source: National Land Cover Data (NLCD)

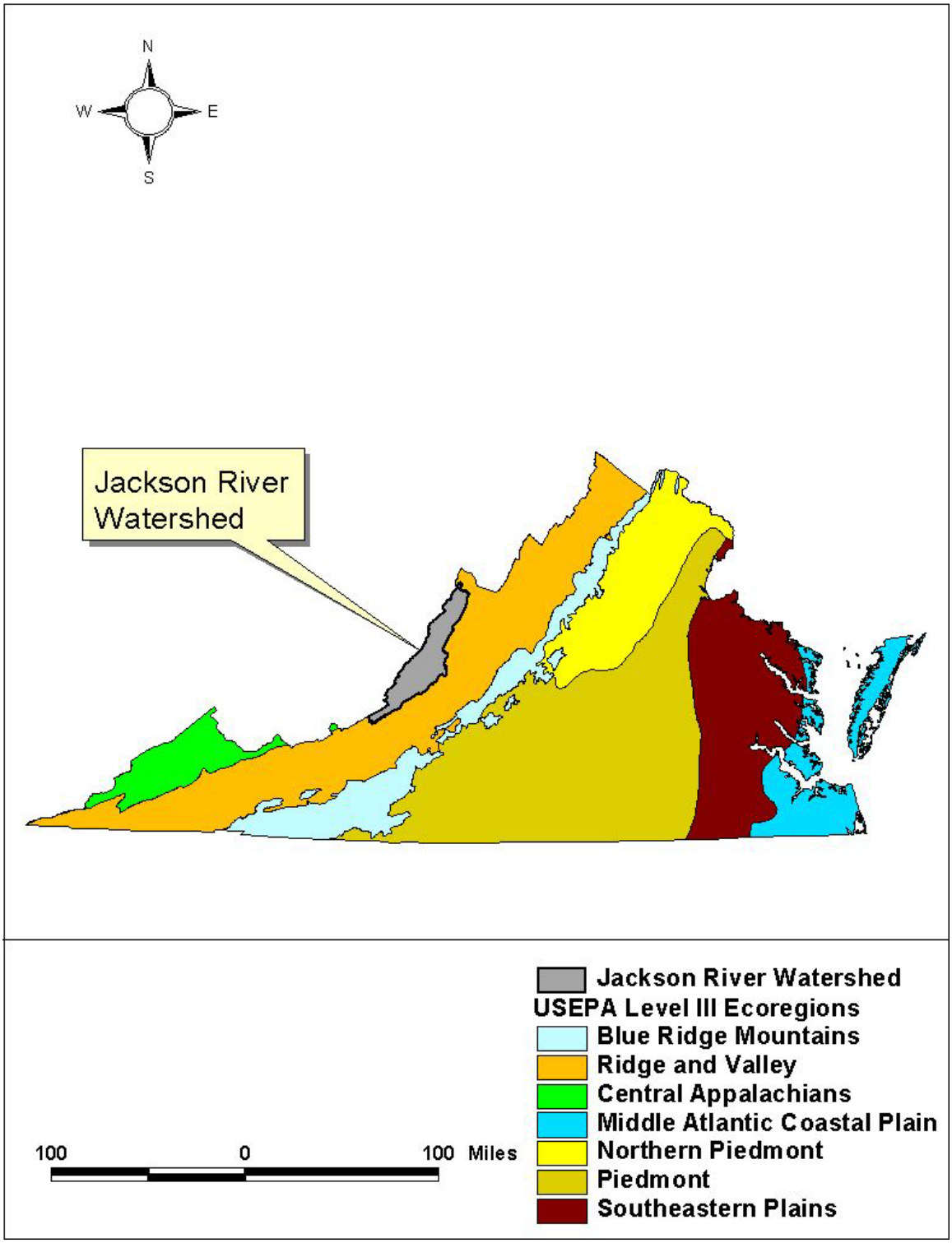
Figure 2-2: Land Use in the Jackson River Watershed



2.1.6 Ecoregion Classification

The Jackson River watershed is located in the Central Appalachian Ridge and Valley ecoregion, USEPA Level III classification number 67 (Woods et al., 1999). The location of the Jackson River watershed within this ecoregion is presented in Figure 2-3. The Ridge and Valley ecoregion extends from Wayne County, Pennsylvania, through Virginia in a southwesterly direction, and is characterized by alternating forested ridges and agricultural valleys; approximately 50 percent of the region is forested. The Ridge and Valley ecoregion is situated between higher elevation mountainous regions with greater forest cover. The region's roughly parallel ridges and valleys are comprised of a variety of geologic materials, including limestone, dolomite, shale, siltstone, sandstone, chert, mudstone, and marble. Elevation in the region ranges from about 500 to 4,300 feet above mean sea level.

Figure 2-3: Virginia Level III Ecoregions



2.2 Permitted Discharge Facilities

There are 15 facilities holding active individual discharge permits in the Jackson River watershed. The permit number, type, permitted flow, receiving waterbody, and status of each of the facilities holding individual permits are presented in Table 2-5, and their locations are presented in Figure 2-4. There are also a total of 18 general permits in the Jackson River watershed; 11 stormwater permits issued to industrial sites, 3 permits issued to domestic sewage facilities, 2 permits issued to mines, 1 stormwater permit issued to a construction site, and 1 permit issued to a concrete facility. Additional information regarding the general permits is presented in Table 2-6.

Table 2-5: Facilities Holding Individual Permits in the Jackson River Watershed

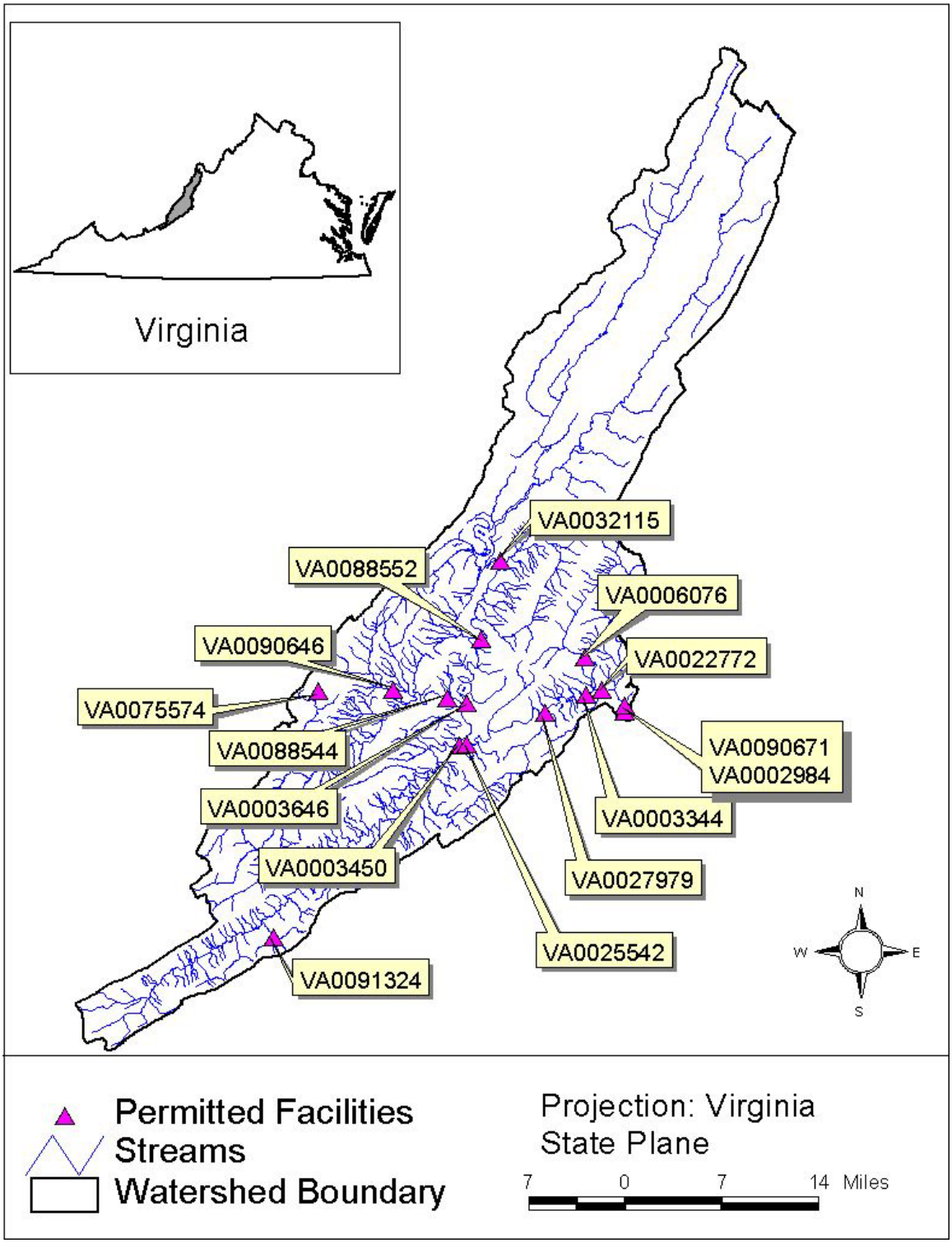
Permit Number	Facility Name	Facility Type	Design Flow (gpd)[1]	Receiving Waterbody	Status
VA0027979	Alleghany County - Low Moor STP	Municipal	500,000	Jackson River	Active
VA0003450	Applied Extrusion Technologies	Industrial	1,000,000	Jackson River	Active
VA0088544	Boys Home Inc STP	Municipal	24,000	Dunlap Creek	Active
VA0022772	Clifton Forge City STP	Municipal	2,000,000	Jackson River	Active
VA0006076	Clifton Forge Water Treatment Plant	Industrial	50,000	Smith Creek	Active
VA0025542	Covington City STP	Municipal	3,000,000	Jackson River	Active
VA0003344	CSX Transportation Inc - Clifton Forge	Industrial	25,000	Jackson River	Active
VA0091324	DGIF Paint Bank Fish Cultural Station	Industrial	2,900,000	Paint Bank Branch	Active
VA0003646	MeadWestvaco Packaging Resource Group	Industrial	32,890,000	Jackson River	Active
VA0032115	Morris Hill STP	Municipal	15,000	Jackson River	Active
VA0002984	Parker Hannifin Powertrain Division	Industrial	208,000	Jackson River	Active
VA0088552	Sponaugle Subdivision	Municipal	16,000	Jackson River	Active
VA0090646	Tanglewood Manor Home for Adults	Municipal	18,000	Ogle Creek	Active
VA0075574	VDOT I64 Rest Area - Alleghany County	Municipal	15,000	Jerry's Run	Active
VA0090671	Alleghany Co - Lower Jackson River WWTP	Municipal	2,000,000	Jackson River	Inactive

1: Gallons per Day

Table 2-6: Facilities Holding Active General Permits in the Jackson River Watershed

Permit Number	Facility Name	Permit Type	Receiving Waterbody	Status
VAR102964	Kim Stan Landfill Superfund Site Remedial Action	Stormwater Construction	Jackson River	Active
VAR050759	Alleghany Asphalt Plt – Lowmoor	Stormwater Industrial	Jackson River, UT	Active
VAR050765	Bennett Logging & Lumber Inc	Stormwater Industrial	Jackson River, UT	Active
VAR050713	Bradley Saw Mill Inc	Stormwater Industrial	Ogles Creek	Active
VAR051383	Clifton Forge Water Treatment Plant	Stormwater Industrial	Hazel Hollow	Active
VAR051361	Covington Wastewater Treatment Plant	Stormwater Industrial	Jackson River	Active
VAR050182	General Chemical LLC	Stormwater Industrial	Jackson River	Active
VAR050408	Kestersons Used Parts	Stormwater Industrial	Ogle Creek	Active
VAR050415	Lear Corp - Covington	Stormwater Industrial	Harmon Run	Active
VAR050440	Martin Co Coal Corp - Coal Handling Facility Inc	Stormwater Industrial	Jackson River	Active
VAR051392	Peters Mountain Landfill	Stormwater Industrial	Harmon Run	Active
VAR050393	Westvaco - Low Moor Converting Plant	Stormwater Industrial	Jackson River, UT	Active
VAG402026	Rothe, Martin Residence	Domestic Sewage	East Branch of Dry Creek	Active
VAG402094	Shirley Residence	Domestic Sewage	Anderson Hollow, UT	Active
VAG402098	Rogers Residence James O and Iris L	Domestic Sewage	Bens Run	Active
VAG840047	Boxley Materials Company - Alleghany Plant	Mines	Karnes Creek	Active
VAG842020	Boxley Materials Company - Alleghany Plant	Mines	Karnes Creek	Active
VAG110170	Cliftondale Redi Mix	Stormwater Concrete	Wilson Creek, UT	Active

Figure 2-4: Facilities with Individual Permits in the Jackson River Watershed



2.3 DEQ Monitoring Stations

DEQ has several active monitoring stations on the Jackson River, which are used for biological and ambient water quality monitoring.

DEQ's biological monitoring program uses several methods and metrics to assess the ecological health of freshwater streams and rivers. These methods and metrics are based on the assessment of the benthic macroinvertebrate community. They consist of a modified version of the EPA Rapid Bioassessment Protocols II (RBPII), the Virginia Stream Condition Index (SCI), and the inspection of several habitat variables to derive Habitat Assessment Scores. The result and analysis of the biomonitoring data is presented in Section 3.1.

DEQ's ambient water quality monitoring collects water samples on a routine schedule at several locations in the Jackson River Watershed. The samples are tested for levels of nutrients, solids, bacteria associated with human and animal wastes, toxic metals, pesticides and harmful organic compounds. DEQ also perform on-the-spot field tests for dissolved oxygen, pH, temperature, salinity, and additional indications of water quality. The analysis of the water quality data in the Jackson River's impairment is presented in Section 3.2.

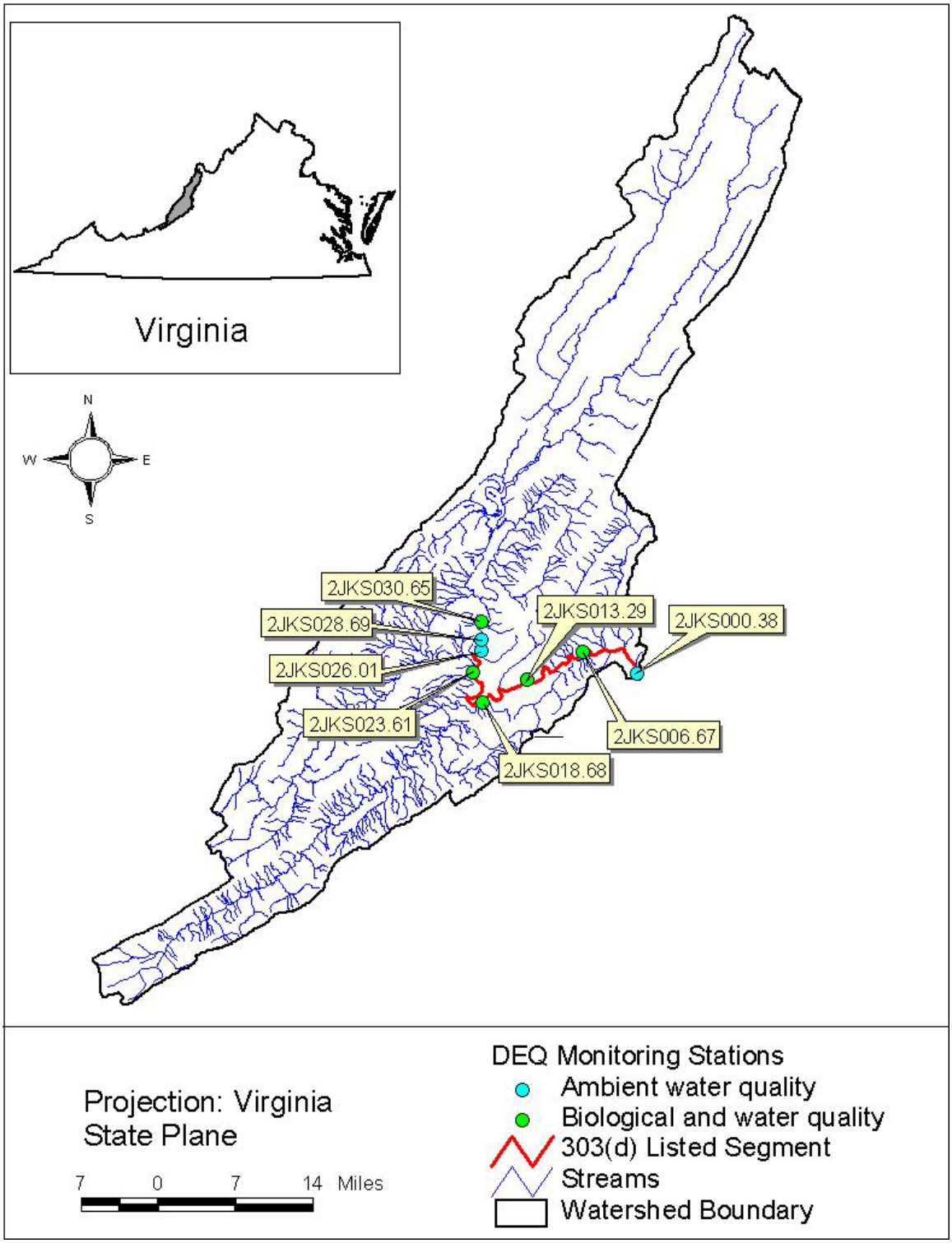
A summary list of the DEQ monitoring stations located on the Jackson River is presented in Table 2-7, and the locations of these stations are presented in Figure 2-5. It should be noted that additional water quality monitoring data were collected at tributary stations located within the Jackson River watershed. These data were evaluated as part of the benthic stressor analysis; however, because the biological impairment is located on the mainstem Jackson River, discussion of water quality data in this report is limited to those data collected at mainstem Jackson River stations on or above the impaired biological segment. Station identification numbers include the abbreviated creek name and the river mile on that creek where the station is located. For instance, station name 2JKS013.29 comprises of the abbreviated name *2JKS* and is at river mile *013.29*. The river mile number represents the distance from the mouth of the creek.

Table 2-7: Summary of Monitoring Stations on the Jackson River

Station ID	Station Location	Latitude[1]	Longitude[1]	Station Type	Period Of Record
2JKS000.38	At Rt. 727 Iron Gate	37.788	-79.781	Ambient water quality	1974-2005
2JKS006.67	At Low Water bridge near Dabney Lancaster, Alleghany Co.	37.811	-79.854	Ambient and biological	1988-2003
2JKS013.29	At Rt. 696 near Low Moor Cave, Alleghany Co.	37.781	-79.928	Ambient and biological	1989-2003
2JKS018.68	At Rt. 18 Bridge in Covington, Alleghany Co.	37.756	-79.987	Ambient and biological	1974-2001
2JKS023.61	At City Park in Covington, Alleghany Co.	37.789	-80.001	Ambient and biological	1979-2005
2JKS026.01	At Covington Water Filtration Plant	37.811	-78.011	Ambient water quality	2003-2005
2JKS028.69	North of Intervale	37.823	-78.011	Ambient water quality	2004
2JKS030.65	At Rt. 687 Bridge, Alleghany Co.	37.842	-79.989	Ambient and biological	1988-2005

[1] In Decimal Degrees

Figure 2-5: DEQ Monitoring Stations in the Jackson River Watershed

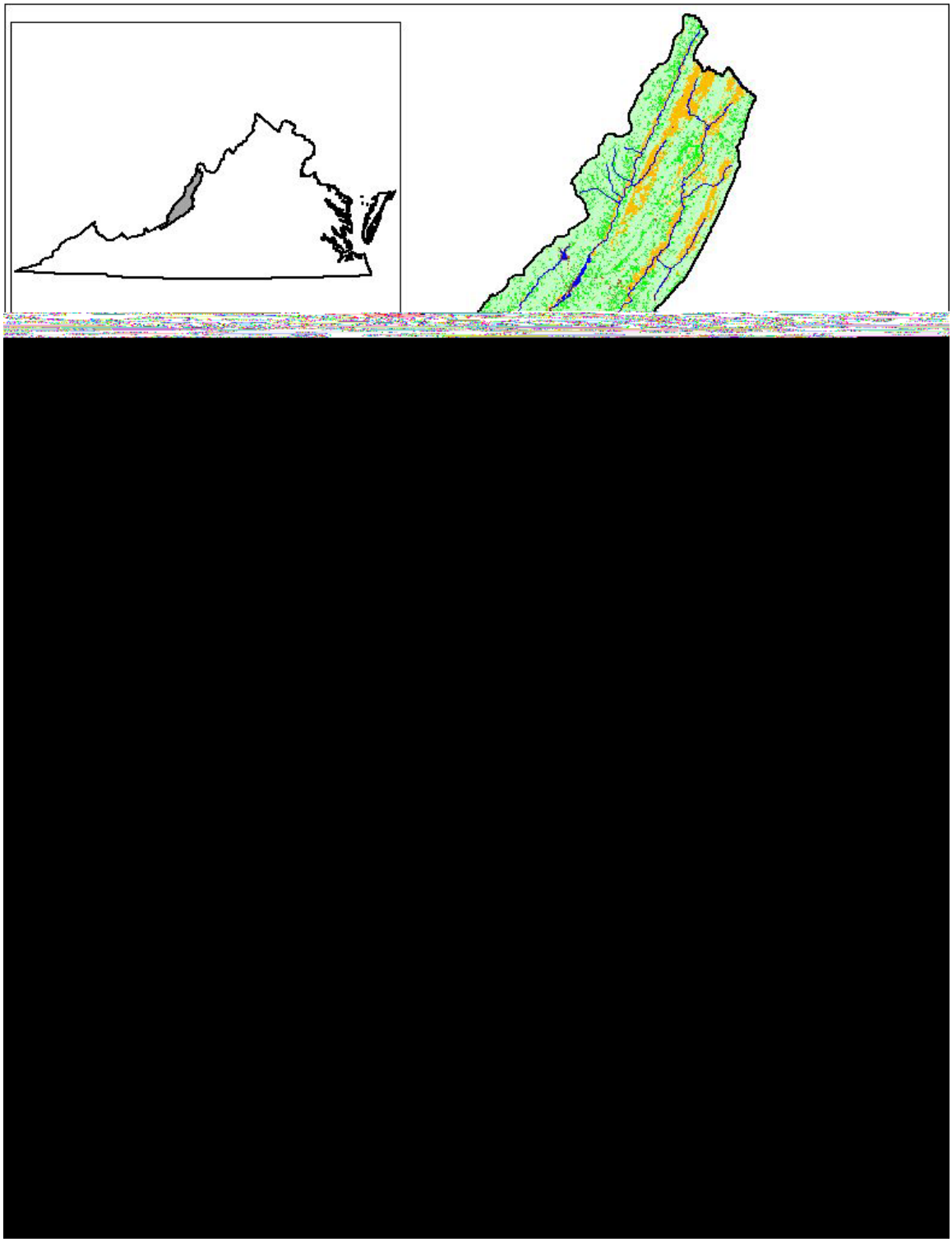


The benthic invertebrate communities at stations 2JKS006.67, 2JKS013.29, 2JKS018.68, and 2JKS023.61 are classified as impaired based on DEQ bioassessments. Station 2JKS030.65 is the biological monitoring station that was used as a reference station for bioassessments. Additional water quality data were collected at stations 2JKS000.38, 2JKS026.01, and 2JKS028.69 on the Jackson River mainstem. A detailed discussion of environmental monitoring data is presented in Section 3.0.

2.4 Overview of the Jackson River Watershed

Forested lands (89.3%) and agricultural lands (8.5%) represent the dominant land uses in the Jackson River watershed. There are 15 facilities holding individual discharge permits in the watershed, and 18 facilities holding active general permits. Biological monitoring has been conducted by DEQ at five mainstem Jackson River stations on or upstream of the impairment biological segment, and DEQ has collected ambient water quality data at eight mainstem stations in the watershed. The land use and the locations of the facilities and monitoring stations in the watershed are shown in the summary map presented in Figure 2-6.

Figure 2-6: Overview of the Jackson River Watershed



3.0 Environmental Monitoring

The first step in benthic TMDL development is the identification of the pollutant stressor(s) affecting the benthic community. Environmental monitoring data are vital to this initial step. The following sections summarize and present the available monitoring data used to determine the primary stressor affecting the biologically impaired segment of the Jackson River. Analyzed data sources included available biological and water quality monitoring data, Discharge Monitoring Reports (DMR) from the permitted facilities, and special studies conducted on the Jackson River. The collection period, content, and monitored sites for these data sources are summarized in Table 3-1. The locations of permitted discharge facilities and monitoring stations were presented previously in Figures 2-4 and 2-5.

Table 3-1: Inventory of Environmental Monitoring Data for the Jackson River

Data Type	Source	Period	DEQ Monitoring Stations								Permitted Facilities
			2JKS000.38	2JKS006.67	2JKS013.29	2JKS018.68	2JKS023.61	2JKS026.01	2JKS028.69	2JKS030.65	
Biological Monitoring	DEQ	1994-2004		X	X	X	X		X	X	
Ambient Water Quality Monitoring	DEQ	1989-2005	X	X	X	X	X	X	X	X	
Field Water Quality Monitoring	DEQ	1994-2004		X	X	X	X			X	
Ambient Water Quality Monitoring	MeadWestvaco	1998-2001									X
Biological Monitoring	MeadWestvaco	1998-1999									X
Discharge Monitoring Reports (DMR)	DEQ	1999-2005									X
Nutrient Monitoring Reports	DEQ	2004-2005									X
Special Studies	MeadWestvaco	1997-2001									X

3.1 Biological Monitoring Data

Based on biomonitoring data conducted from 1994 to 2004, the 2004 Virginia Section 303(d) list indicates that the benthic community in the Jackson River is impaired for 24.21 miles, beginning at river mile 24.21 and extending to the confluence of the Jackson River and the Cowpasture River. In addition, the Jackson River is listed as impaired, due to low dissolved oxygen for 11.21 miles of the biologically impaired segment extending from river mile 24.21 to river mile 13.00.

The biological conditions of the Jackson River were evaluated using a modified version of the EPA Rapid Bioassessments Protocols II (RBPII) to assess the river's benthic invertebrate communities; the Virginia Stream Condition Index (SCI); and the Habitat Assessment Scores.

3.1.1 EPA Rapid Bioassessment Protocols (RBPII)

VADEQ's RBPII follows a paired reference approach using upstream stations located in the same watershed. The protocol uses eight standard metrics to compare monitored and reference sites. These metrics include taxa richness, composition, and tolerance/intolerance measures. Candidate RBPII metrics, as specified in EPA's Rapid Bioassessment Protocols for Use in Streams and Wadable Rivers, Second Edition (Barbour et al., 1999), are presented in Table 3-2. The RBPII Scores calculated for the Jackson River biological monitoring stations and used to specify the Section 303(d) listings are presented in Table 3-3. DEQ field data sheets and bioassessment forms completed for each biological assessment conducted on the mainstem Jackson River contained the following information:

- Assessment ratings for each station for each survey event
- The numbers and types of macroinvertebrates present at each station
- Habitat assessment scores taken during each survey
- Field water quality data collected as part of each survey

Table 3-2: Candidate RBPII Metrics Specified in Barbour et al. (2002)

Category	Metric	Definition	Expected Response to Disturbance
Richness Measures	Total No. Taxa	Measures overall variety of invertebrate assemblage	Decrease
	No. EPT Taxa	Number of Ephemeroptera, Plecoptera, and Trichoptera taxa	Decrease
	No. Ephemeroptera Taxa	Number of mayfly taxa	Decrease
	No. Plecoptera Taxa	Number of stonefly taxa	Decrease
	No. Trichoptera Taxa	Number of caddisfly taxa	Decrease
Composition Measures	% EPT	Percent of the composite of mayfly, stonefly, and caddisfly larvae	Decrease
	% Ephemeroptera	Percent of mayfly nymphs	Decrease
Tolerance/ Intolerance Measures	No. Intolerant Taxa	Taxa richness of organisms considered to be sensitive to perturbation	Decrease
	% Tolerant Organisms	Percent of the macrobenthos considered to be tolerant of various types of perturbation	Increase
	% Dominant Taxon	Measures dominance of the most abundant taxon. Can be calculated as dominant 2, 3, 4, or 5 taxa	Increase
Feeding Measures	% Filterers	Percent of the macrobenthos that filter FPOM from water column or sediment	Variable
	% Grazers and Scrapers	Percent of macrobenthos that scrape or graze upon periphyton	Decrease
Other Measures	Hilsenhoff Biotic Index	Uses tolerance values to weight abundance in an estimate of overall pollution	Increase

Table 3-3: RBPII Scores at Jackson River Monitoring Stations

Station	Year	Season	RBPII Score	Assessment
2JKS006.67	1998	Spring	47.83	Moderately Impaired
		Fall	33.33	Severely Impaired (BPJ)[1]
	1999	Spring	34.78	Severely Impaired (BPJ)
		Fall	39.13	Severely Impaired (BPJ)
	2000	Spring	21.47	Severely Impaired (BPJ)
		Fall	37.50	Moderately Impaired
	2001	Spring	29.17	Moderately Impaired
		Fall	N/A	Not Sampled
2JKS013.29	1998	Spring	30.43	Moderately Impaired
		Fall	12.50	Severely Impaired
	1999	Spring	26.09	Severely Impaired (BPJ)
		Fall	43.48	Severely Impaired (BPJ)
	2000	Spring	13.04	Severely Impaired
		Fall	16.67	Severely Impaired
2JKS018.68	1998	Spring	68.75	Moderately Impaired
		Fall	41.67	Moderately Impaired
	1999	Spring	30.43	Severely Impaired (BPJ)
		Fall	39.13	Severely Impaired (BPJ)
	2000	Spring	21.74	Severely Impaired (BPJ)
		Fall	16.67	Severely Impaired
2JKS023.61	1998	Spring	13.04	Severely Impaired
		Fall	12.50	Severely Impaired
	1999	Spring	30.43	Severely Impaired (BPJ)
		Fall	26.09	Severely Impaired (BPJ)
	2000	Spring	13.04	Severely Impaired
		Fall	8.33	Severely Impaired
	2001	Spring	12.50	Severely Impaired
		Fall	21.74	Severely Impaired (BPJ)
	2002	Spring	22.73	Severely Impaired (BPJ)
		Fall	N/A	Not Sampled
2JKS030.65	1998	Spring	100.00	Non-impaired
		Fall	100.00	Non-impaired
	1999	Spring	100.00	Non-impaired
		Fall	100.00	Non-impaired
	2000	Spring	100.00	Non-impaired
		Fall	100.00	Non-impaired
	2001	Spring	100.00	Non-impaired
		Fall	100.00	Non-impaired
	2002	Spring	100.00	Non-impaired
		Fall	N/A	Not Sampled

1: Most assessments where RBPII scores resulted in Moderately Impaired designations, the scores were skewed higher by trophic (functional feeding group) level metrics. Using best professional judgment (BPJ) and looking at metrics that are better indicators of pollution tolerance/intolerance, several assessments were changed to severely impaired.

3.1.2 Virginia Stream Condition Index (SCI) Scores

Biological assessment scores derived from biomonitoring data collected on the impaired segment were also calculated using the Virginia Stream Condition Index (SCI) currently being developed by DEQ. The SCI is an eco-regionally-calibrated index comprised of eight metrics that are listed in Table 3-4. SCI scores are considered draft and are used as an additional assessment tool. The reference condition of the SCI Index is based on an aggregate of reference sites within the region, rather than a single paired reference site. Therefore, SCI scores provide a measure of stream biological integrity on a regional basis. An impairment cutoff score of 60 has been proposed for assessing results obtained with the SCI. Streams that score greater than 60 are considered non-impaired, whereas streams that score less than 60 are considered impaired.

Table 3-4: Metrics Used to Calculate the Virginia Stream Condition Index (SCI)

Candidate Metrics (by categories)	Expected Response to Disturbance	Definition of Metric
Taxonomic Richness		
Total Taxa	Decrease	Total number of taxa observed
EPT Taxa	Decrease	Total number of pollution sensitive Ephemoroptera, Plecoptera, and Trichoptera taxa observed
Taxonomic Composition		
% EPT Less Hydropsychidae	Decrease	% EPT taxa in samples, subtracting pollution-tolerant Hydropsychidae
% Ephemoroptera	Decrease	% Ephemoroptera taxa present in sample
% Chironomidae	Increase	% pollution-tolerant Chironomidae present
Balance/Diversity		
% Top 2 Dominant	Increase	% dominance of the 2 most abundant taxa
Tolerance		
HBI (Family level)	Increase	Hilsenhoff Biotic Index
Trophic		
% Scrapers	Decrease	% of scraper functional feeding group

Calculated SCI scores for the biomonitoring stations located on or above the biologically impaired segment, are presented in Table 3-5. SCI scores calculated for stations 2JKS013.29, 2JKS018.68, and 2JKS023.61 were consistently below the proposed impairment cutoff score of 60. Therefore, these stations are considered impaired, and

were used to define the biologically impaired segment of the Jackson River. Station 2JKS030.65 served as the reference station for the biological RBPII assessments; biological assessments conducted at this station were consistently above the proposed impairment cutoff score.

Table 3-5: Virginia SCI Scores for the Jackson River

Collection Period	SCI Score						
	2JKS006.67	2JKS013.29	2JKS018.68	2JKS023.61	2JKS028.69	[1]2JKS030.65	2JKS020.41
Fall 1994	44	33	37	30		80	
Spring 1995	40	46	48	24		84	
Fall 1995	-	-	40	24		79	
Spring 1996	-	-	46	33		87	
Fall 1996	28	35	43	16		73	
Spring 1997	44	54	61	29		78	
Summer 1997	-	-	43	28		74	
Fall 1997	39	37	50	18		73	
Spring 1998	50	44	62	25		71	
Fall 1998	38	34	53	29		79	
Spring 1999	40	33	37	33		74	
Fall 1999	42	42	48	32		74	
Spring 2000	37	28	29	38		82	
Fall 2000	42	30	33	28		80	
Spring 2001	40	-	-	31		78	
Fall 2001	-	-	-	34		79	
Spring 2002	-	-	-	38		75	
Spring 2003	-	-	-	-		77	
Fall 2003	56	50	-	39		73	
Spring 2004					80		
Fall 2004					77		
Fall 2006		61	51	34			
Spring 2007	64	37	57	33			55
Fall 2007	67	59	46	38			41
Fall 2008	66		50	38			
Average	**46.1**	**41.6**	**46.3**	**30.6**	**78.5**	**77.4**	**48.1**

[1]Monitoring Station 2-JKS030.65 was used as the reference station for bioassessments

3.1.3 Habitat Assessment Scores

A suite of habitat variables were visually inspected at the bio-monitoring stations as part of every biological assessment conducted on the Jackson River. These habitat variables are derived using the EPA Rapid Habitat Assessment Guidance for High Gradient Streams (EPA/841/B99/002). Habitat parameters that examined include channel alteration, sedimentation, substrate embeddedness, riffle frequency, channel flow and velocity, stream bank stability and vegetation, and riparian zone vegetation. Each parameter was assigned a score from zero to 20, with 20 indicating optimal conditions, and 0 indicating very poor conditions. Box plots depicting the minimum, maximum, 25th percentile, 50th percentile, and 75th percentile of selected habitat parameters scored at each of the monitoring stations are presented in Figures 3-1 to 3-3. Box plots of all scored habitat parameters are presented in Appendix A.

Habitat conditions at the biological monitoring stations declined as sampling moved from upstream to downstream (Figures 3-1 and 3-2, Appendix A). Conditions decreased after stations 2JKS030.65 (the biological reference station) and 2-JKS028.69 then gradually increased at the most downstream stations. This decrease corresponds to the presence of the Cities of Covington and Clifton Forge, and several large point sources, which are present in the area (Figure 2-4). Total habitat scores, defined as the sum of all habitat parameter scores, showed a similar trend, decreasing after stations 2JKS030.65 and 2-JKS028.69 then gradually increasing as sampling moved from upstream to downstream (Figure 3-3).

Figure 3-1: Substrate Embeddedness Scores for Jackson River Monitoring Stations

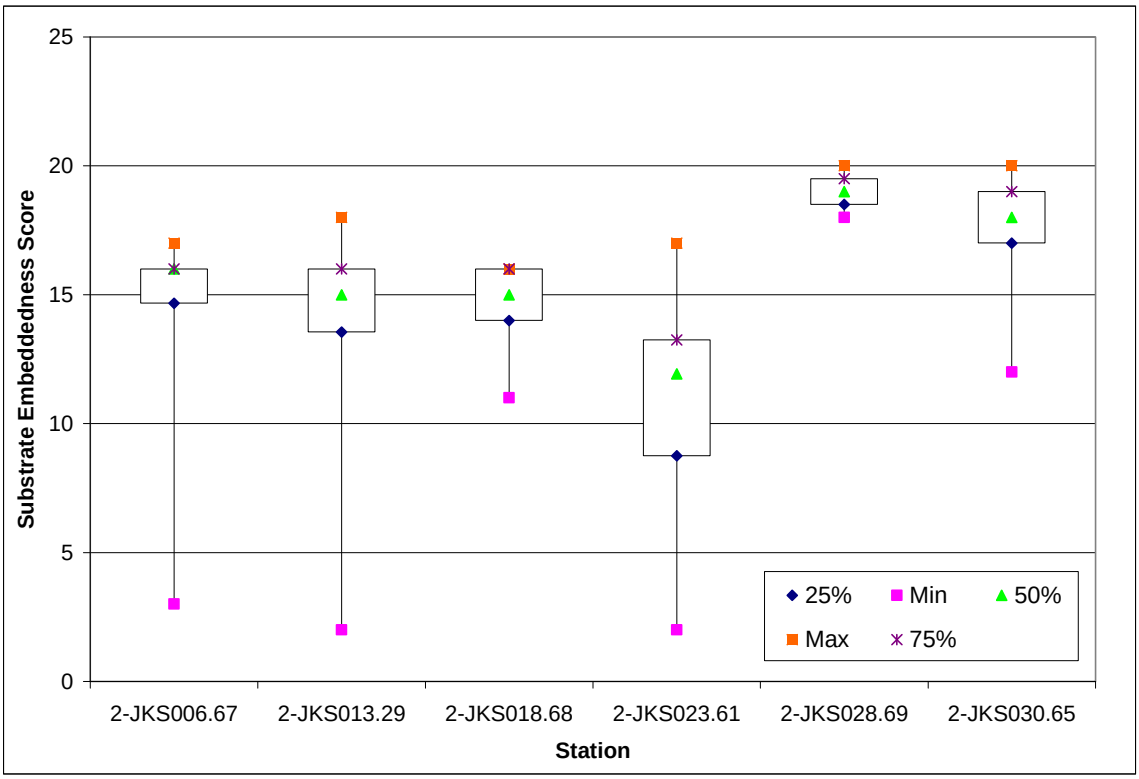


Figure 3-2: Riparian Vegetation Scores for Jackson River Monitoring Stations

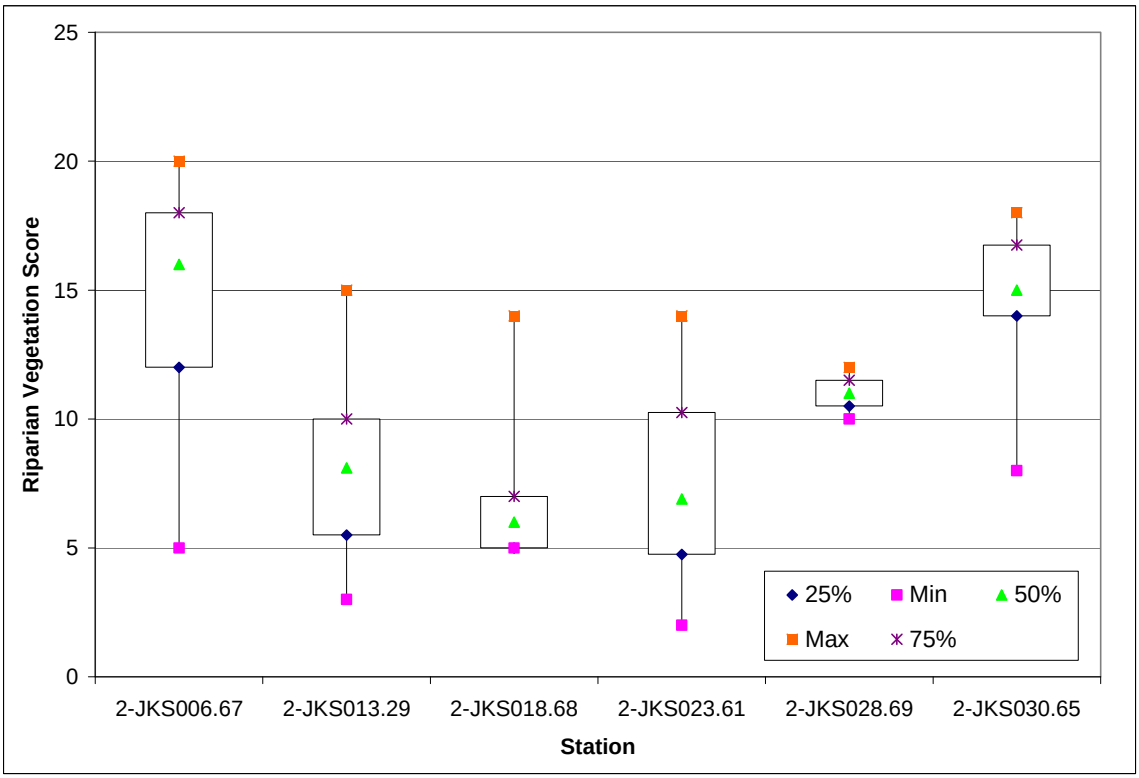
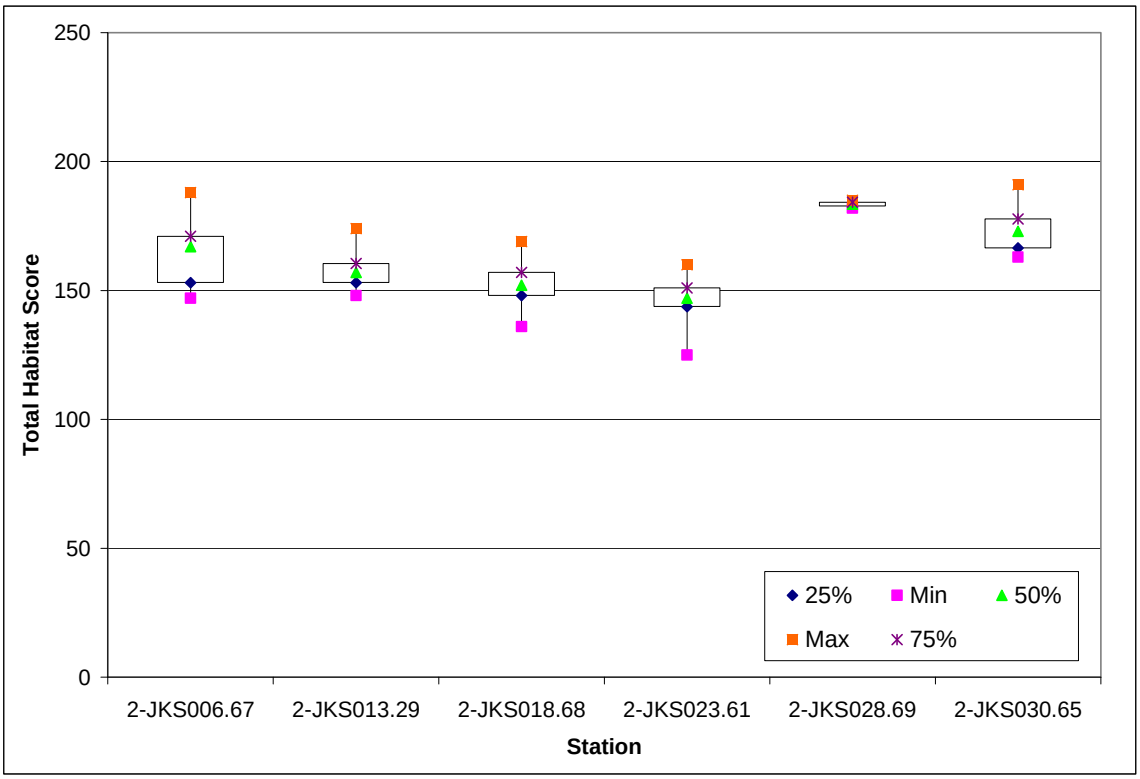


Figure 3-3: Total Habitat Scores for Jackson River Monitoring Stations



3.2 Water Quality Monitoring

There are eight DEQ ambient water quality monitoring stations located on the mainstem Jackson River on or above the biologically impaired segment. Table 3-6 presents the information for each DEQ ambient monitoring. Monitoring stations 2JKS000.38, 2JKS006.67, 2JKS018.68, 2JKS023.61, and 2JK030.65 represent the largest sources of water quality data available for the study area.

Table 3-6: DEQ Ambient Water Quality Monitoring Stations on the Jackson River

Station Id	Station Location	Period of Record	No. Sampling Events
2JKS000.38	Route 727 Iron Gate	1989-2005	4703
2JKS006.67	Low Water Bridge Near Dabney Lancaster	1989-2004	4299
2JKS013.29	Off Route 696, Above Low Moore- Alleghany	1989-2005	404
2JKS018.68	Route 18 Bridge- City of Covington	1989-2003	4049
2JKS023.61	Covington Gage City Park	1989-2005	4775
2JKS026.01	Route 687 Bridge, Clearwater Park Alleghany	2003-2005	70
2JKS028.69	North of Intervale	2004	209
2JKS030.65	Route 687 Bridge Clearwater Park Alleghany	1989-2005	2990

Additionally, the MeadWestvaco Packaging Resource Group, the largest facility discharging into the Jackson River, has collected substantial ambient water quality data on the river. Section 3.2.5 presents the review and analysis of these data.

3.2.1 DEQ Instream Water Quality Data

This Section presents the instream water quality data collected on the Jackson River by DEQ. When the same parameter is recorded at more than three stations, statistics are presented through box plots depicting the minimum, maximum, 25th percentile, 50th percentile, and 75th percentile of the water quality parameter observed at each of the monitoring stations.

3.2.1.1 Compliance with Water Quality Standards (Temperature, pH, and DO)

The Jackson River is classified as a Class IV water body, as defined in the Virginia Water Quality Standards (9 VAC 25-260-50). This stream section encompasses the biologically impaired segment of the Jackson River; thus, water quality parameters in the biologically impaired segment must meet the Class IV standards presented in Table 3-7.

Table 3-7: Water Quality Standards for the Impaired Segment of the Jackson River

Class	Description of Waters	Dissolved Oxygen (mg/L)		pH	Maximum Temperature (Deg. C)
		Minimum	Daily Ave.		
IV	Mountainous Zone Waters	4.0	5.0	6-9	31

As shown in Figure 3-4, temperature field values are in compliance with the numeric criteria for Class IV waters at all monitoring stations in both the impaired segment and upstream of the biological impairment. The field pH values are presented in Figure 3-5. The data indicates that the pH values are generally in compliance with class IV criteria for the majority of the time, except for a brief period between January and May 2001. However, this pH drop could not be clearly explained based on the available data and information. Figure 3-6 shows that the field dissolved oxygen concentrations are generally in compliance with established standards; although one violation of the daily average dissolved oxygen standard occurred at station 2JKS018.68.

Figure 3-4: Field Temperature at Jackson River Monitoring Stations

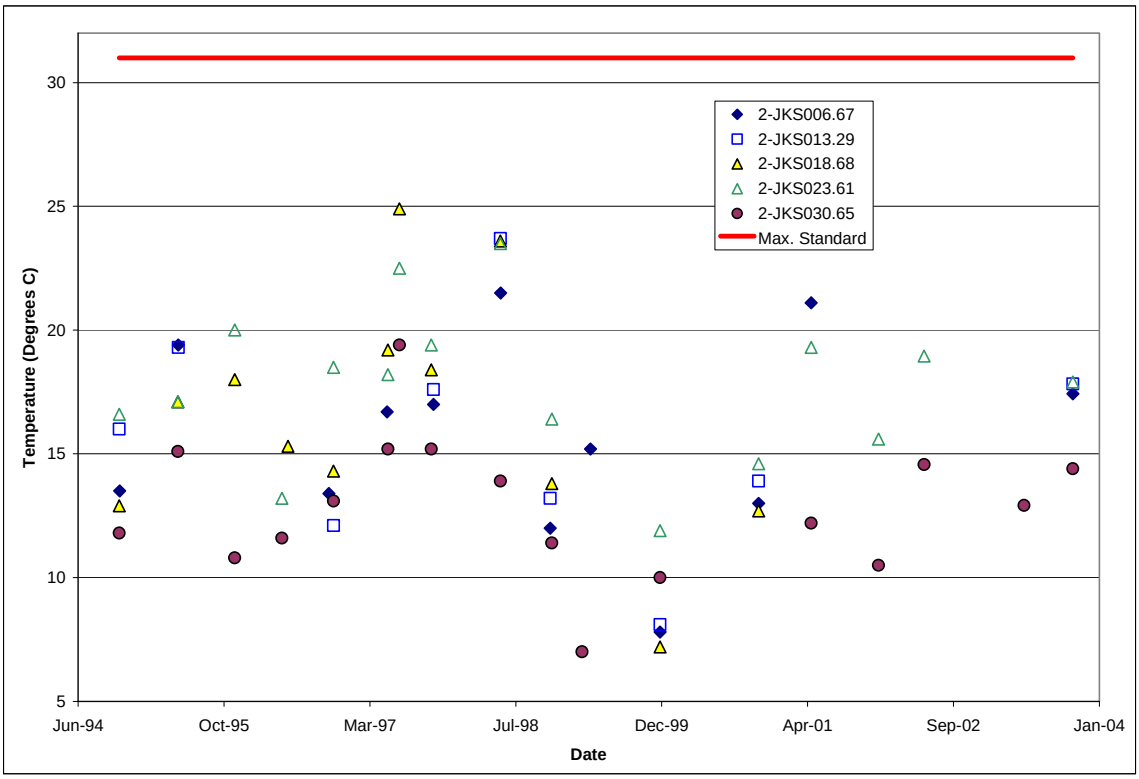


Figure 3-5: Field pH Values at Jackson River Monitoring Stations

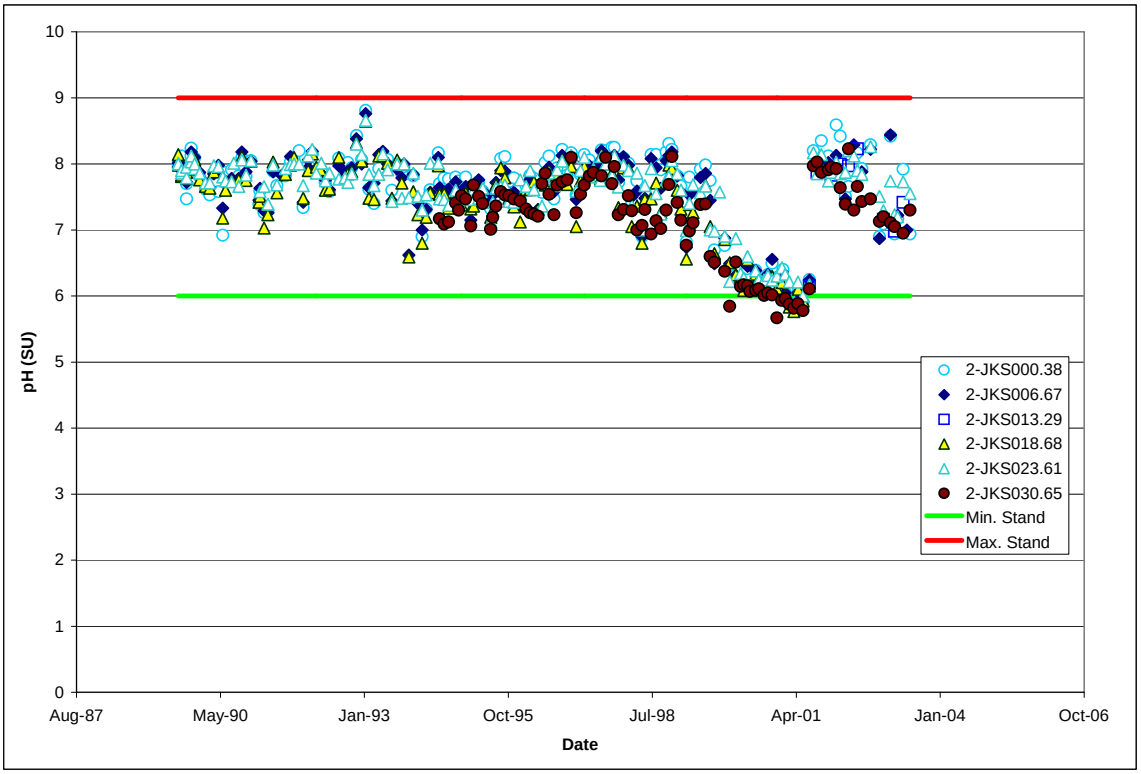
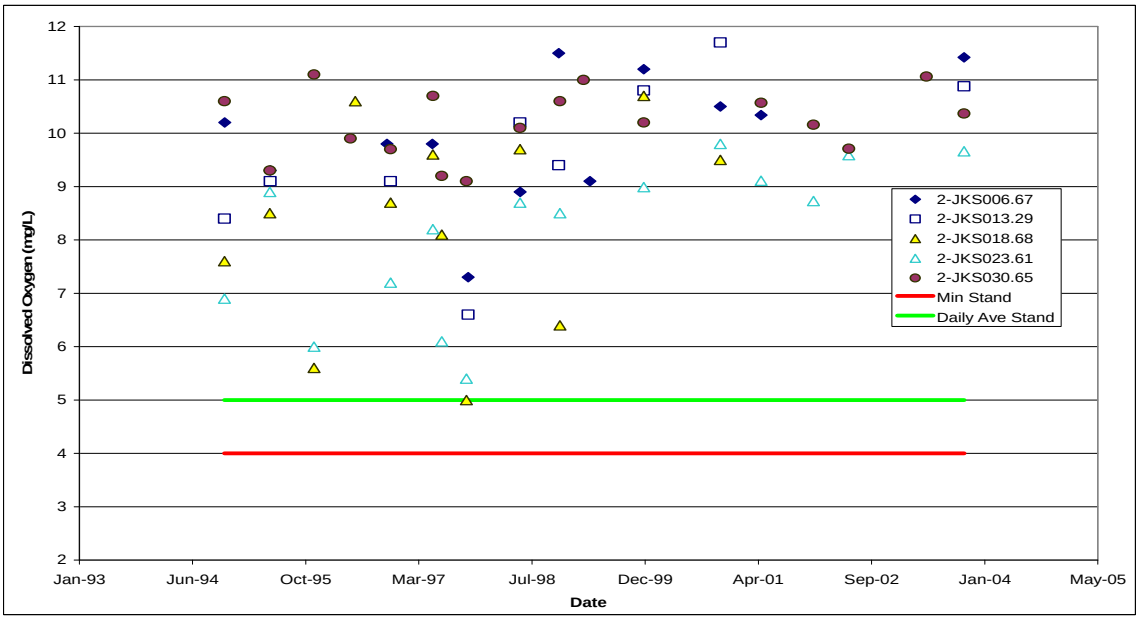


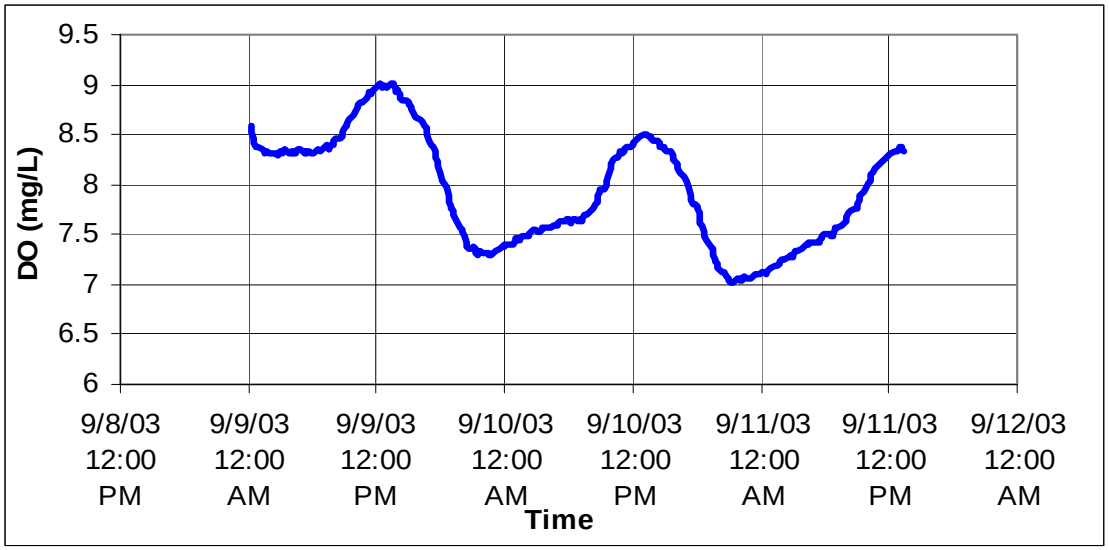
Figure 3-6: Field Dissolved Oxygen Concentrations



In addition to the field DO data shown in Figure 3-6, the VADEQ performed diurnal continuous DO monitoring during the fall season at locations on the Jackson River. The objective of the continuous DO monitoring was to assess and identify any DO violations

during the evening and night periods and compare the DO diurnal variations on the Jackson to the natural variations on a reference stream outside the Jackson River impaired segment. The reference station selected is located in Tom's Creek, a tributary within the Jackson River ecoregion. Figure 3-7 depicts the 15-minute diurnal dissolved oxygen in Tom's Creek recorded between September 9, 2003 and September 11, 2003.

Figure 3-7: Tom's Creek Diurnal DO Levels - Sept. 9 to Sept.11 2003

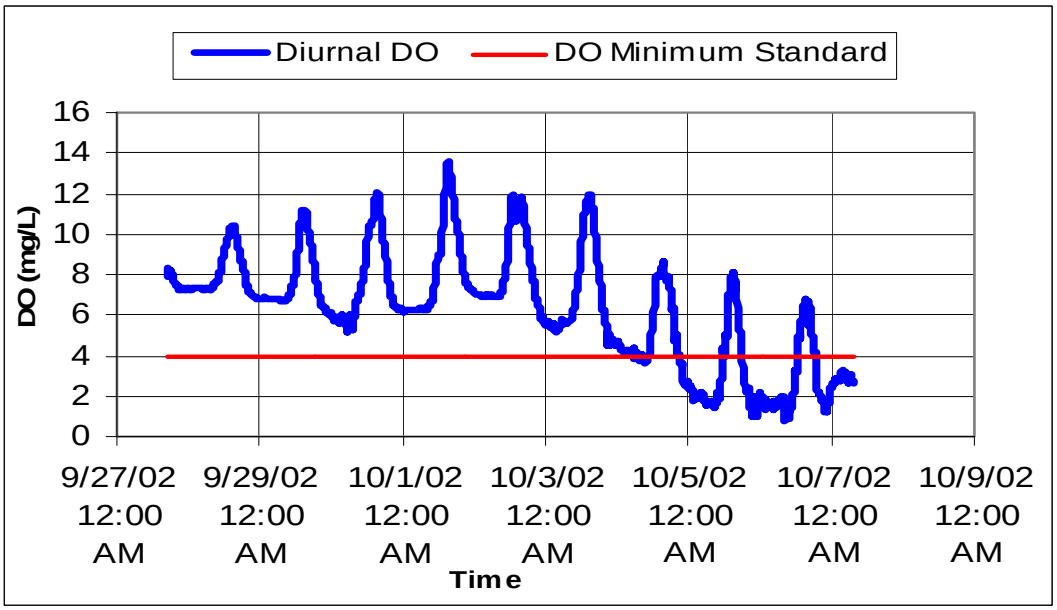


The continuous dissolved oxygen data within Tom's Creek show a moderate diurnal variation of 2 mg/l with a minimum DO of 7 mg/L, depicting the oxygen levels within a natural and unaffected stream system. The diurnal dissolved oxygen swings within Tom's Creek are included in this report as a depiction of the oxygen levels within a natural stream system and are not used to define or derive an endpoint to develop the TMDL for the Jackson River.

These natural DO variations are compared to the diurnal data recorded on the impaired segment of the Jackson River. In fact, 15-minute diurnal dissolved oxygen data were collected on the Jackson River between September 27 and October 7 2002, October 29 and November 1 2004, and between October 3 and October 5 2005. These sampling periods were selected in order to quantify oxygen conditions in the Jackson River under low flow, effluent dominated conditions.

Dissolved oxygen measurements collected during the period of September 27 to October 7 2002, shown in Figure 3-8, violated the minimum dissolved oxygen standard on numerous occasions, especially throughout the 7-day period spanning between October 1 and October 7 2002. The lowest recorded diurnal dissolved oxygen concentration during this period was 0.74 mg/L on October 6, 2002 at 8:30am. In addition, the data show dissolved oxygen fluctuations of over 7 mg/L in a 24-hour time period, indicating the possibility that eutrophic conditions were present in the river.

Figure 3-8: Jackson River Diurnal Dissolved Oxygen – September 27 - October 7, 2002



The diurnal DO data recorded during the period of October 29 to November 1 2004 do not violate in stream dissolved oxygen standards. Figure 3-9, shows that the DO levels are above the minimum DO standard of 4 mg/L and never fell below 4 mg/L.

Figure 3-9: Jackson River Diurnal Dissolved Oxygen – October 29 – November 1, 2004

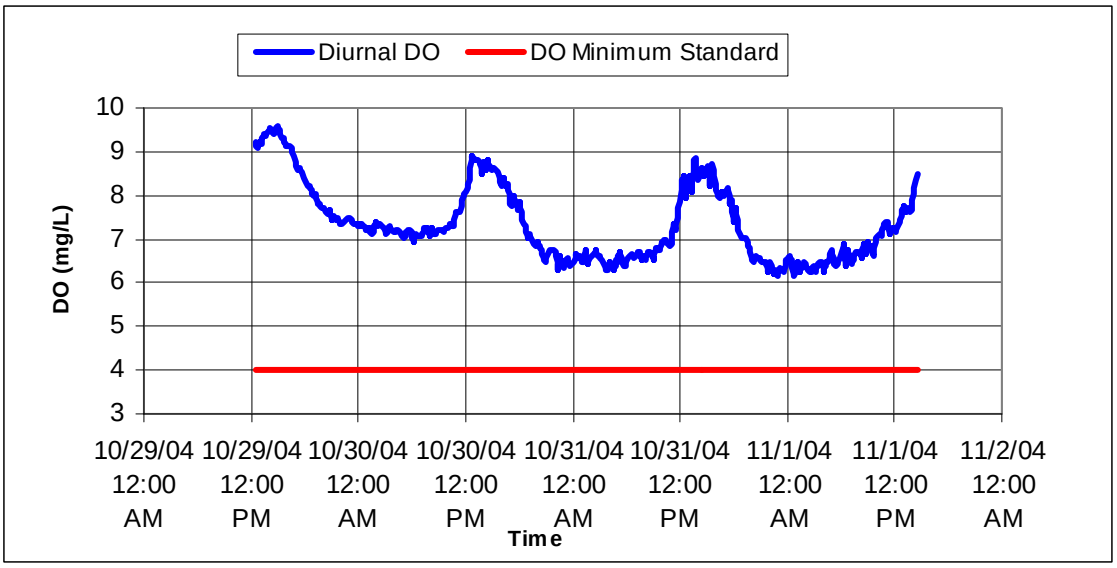
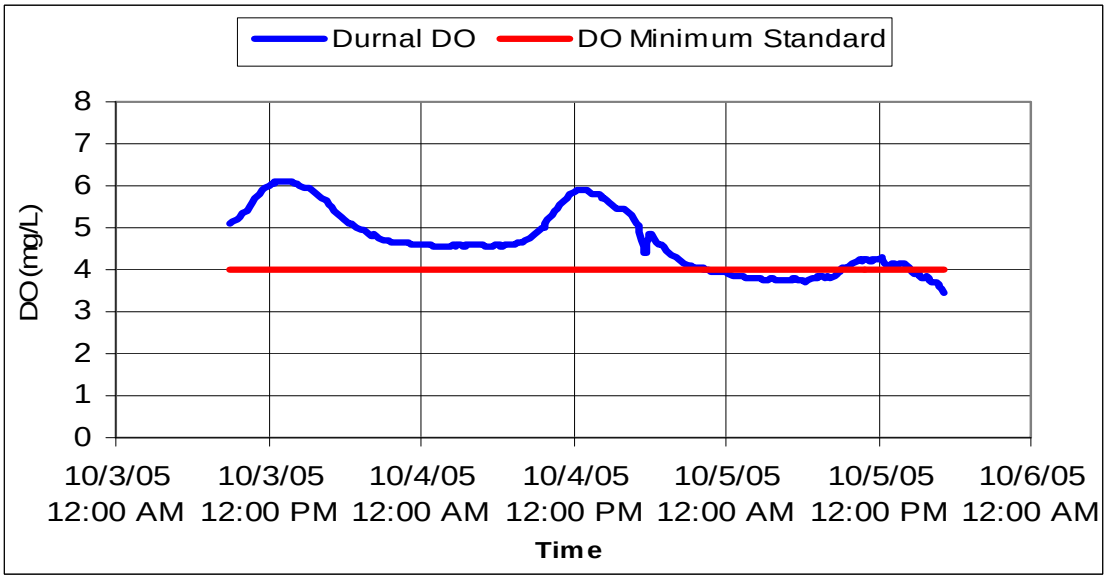


Figure 3-10 shows the results of the diurnal DO monitoring for the period spanning October 3 to October 5 2005. It indicates that the DO levels fell below the minimum DO standards on October 5, 2005.

Figure 3-10: Jackson River Diurnal Dissolved Oxygen - October 3 – October 5, 2005

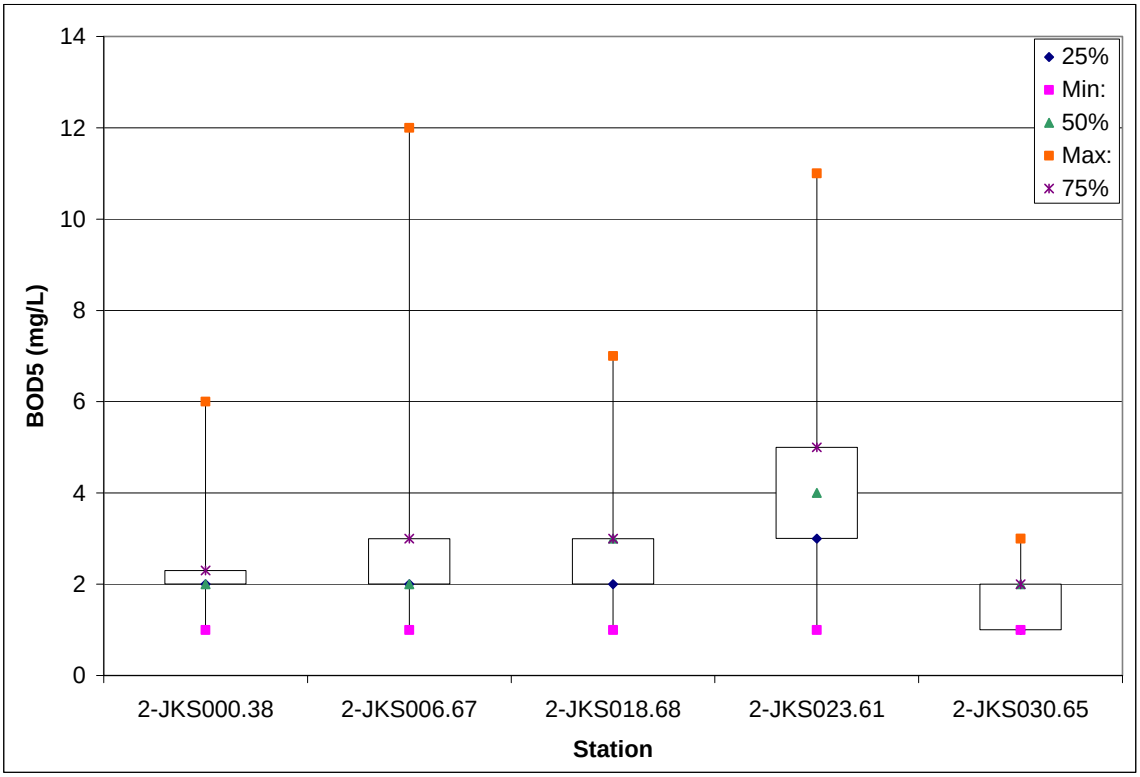


In summary, the analysis of the temperature and pH data indicates adequate levels in the Jackson River. However, the diurnal dissolved oxygen data shows numerous violations of the minimum DO standard of 4 mg/L indicating that eutrophic conditions might be present in the river. The diurnal DO monitoring data was mainly performed during low-flow conditions. Consequently, a detailed a analysis of the diurnal DO data and the low-flow conditions is presented in Section 3-4.

3.2.1.2 Analysis of Other Water Quality Parameters

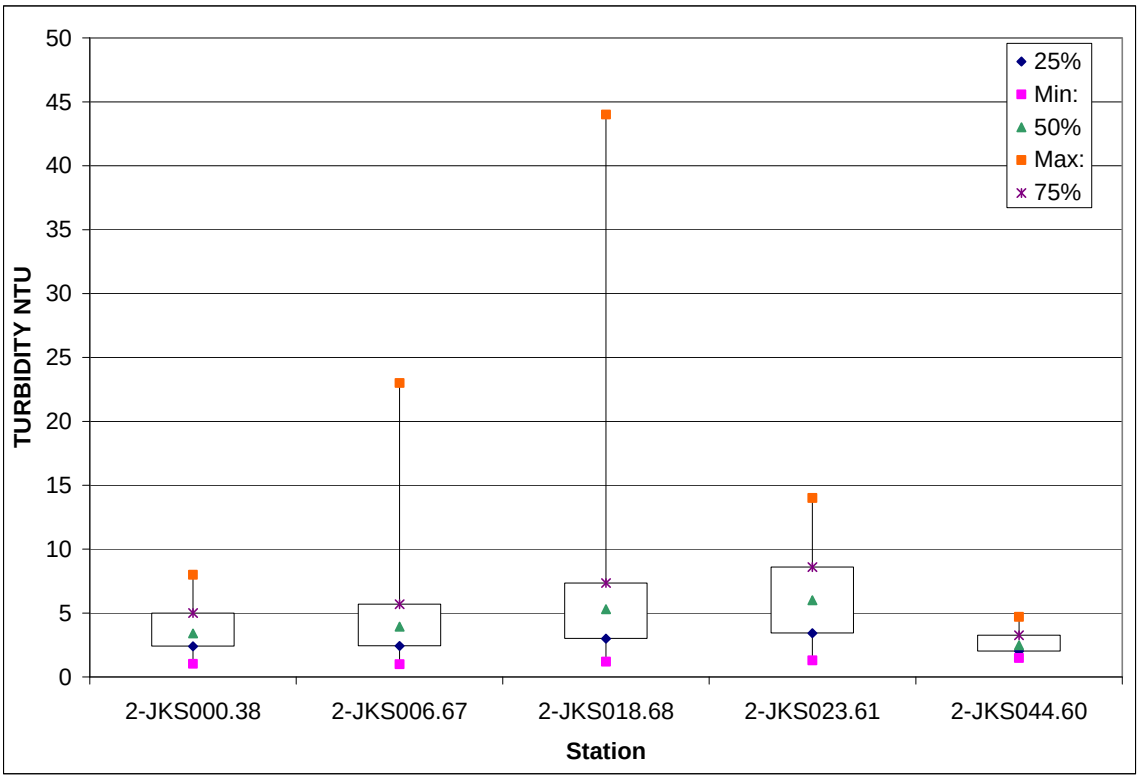
This section presents the analysis of other relevant instream water-quality parameters consisting of Biochemical Oxygen Demand (BOD), Turbidity, Nutrients, Chlorophyll a, and Fecal Coliform. Figure 3-11 indicates that instream Biochemical Oxygen Demand (BOD) concentrations were relatively low across all the stations in the Jackson River. It should be reminded that Station identification numbers include the abbreviated creek name and the river mile on that creek where the station is located. For instance Station name 2JKS018.68 comprises of the abbreviated name *2JKS* and is at river mile *018.68*. Consequently, the most upstream is the reference station 2JKS030.65 and the down-stream stations are presented from right to left on the X-axis, with decreasing river mile.

Figure 3-11: Biochemical Oxygen Demand at Jackson River Monitoring Stations



BOD data summary indicates that BOD concentrations range from 1 to 2 mg/L at the reference station, with BOD levels increasing slightly at station 2JKS023.61 (3 to 5 mg/L) and leveling off between 2 and 3 mg/L at all the other downstream stations. Figure 3-12 shows the turbidity values at various monitoring stations in the Jackson River. These values are generally low across all sites, but elevated concentrations were recorded on some occasions.

Figure 3-12: Turbidity at Jackson River Monitoring Stations



Electrical conductivity is often used as a surrogate measure of the concentration of total dissolved solids in water. High levels of conductivity were observed at several monitoring stations in the Jackson River. Figure 3-13 indicates that the conductivity levels at station 2JKS023.61 were 5 to 10 times higher than the conductivity level at the reference station (2-JKS030.65).

Figure 3-14 indicates that nitrogen concentrations increased slightly from the upstream to downstream stations. Ammonia concentrations shown in Figure 3-15 indicate that the level of ammonia in the Jackson River is low and the median values do not vary between the stations. On the other hand, phosphorous concentrations increased substantially after station 2JKS026.01 and remained elevated at the downstream stations (Figure 3-16).

Figure 3-13: Conductivity at Jackson River Monitoring Stations

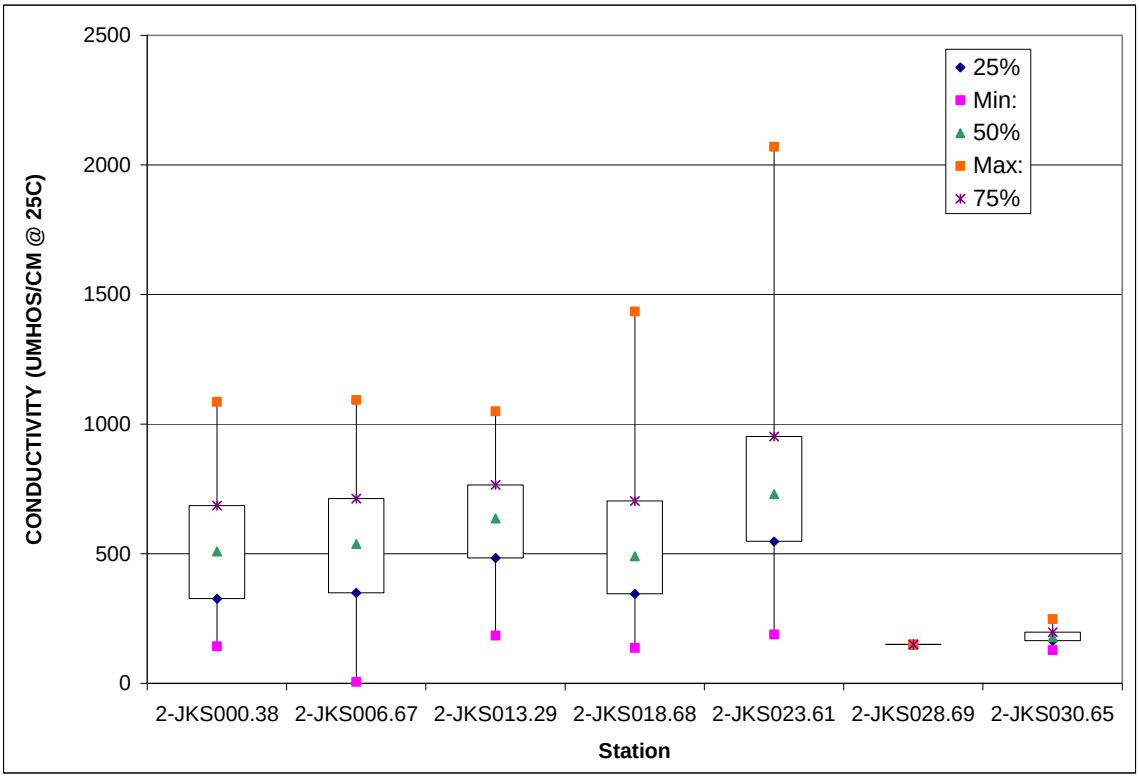


Figure 3-14: Total Nitrogen Concentrations at Jackson River Monitoring Stations

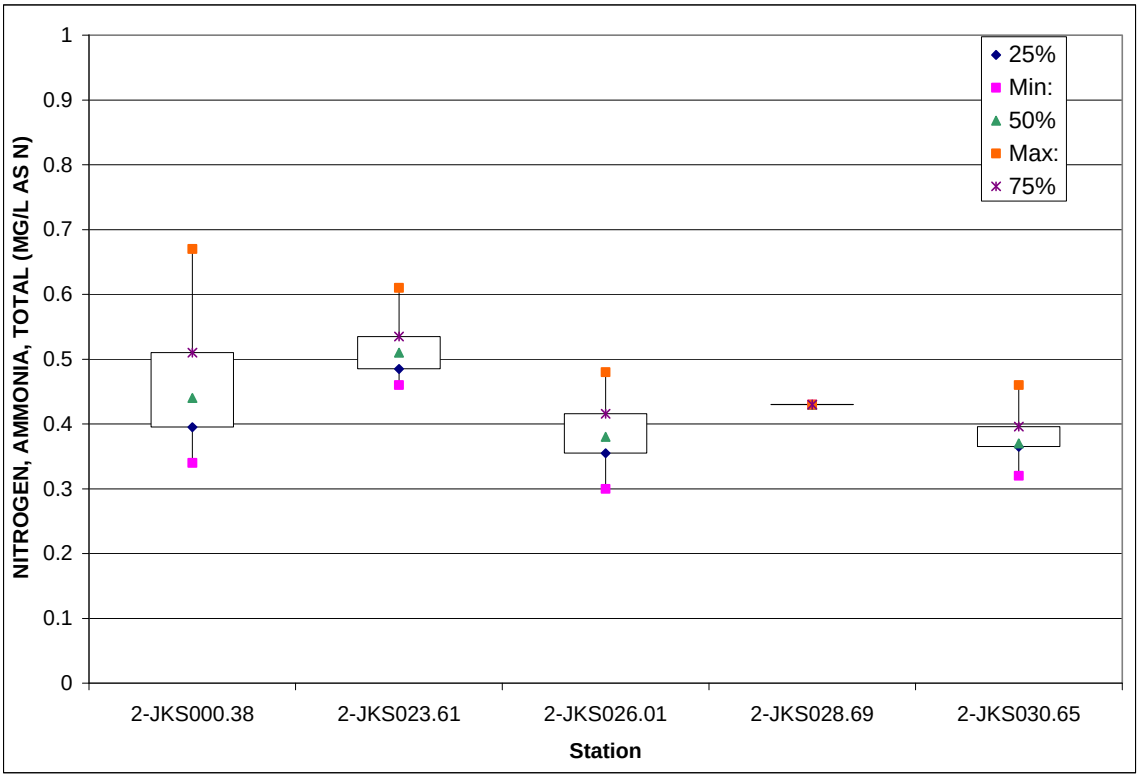


Figure 3-15: Ammonia Concentrations at Jackson River Monitoring Stations

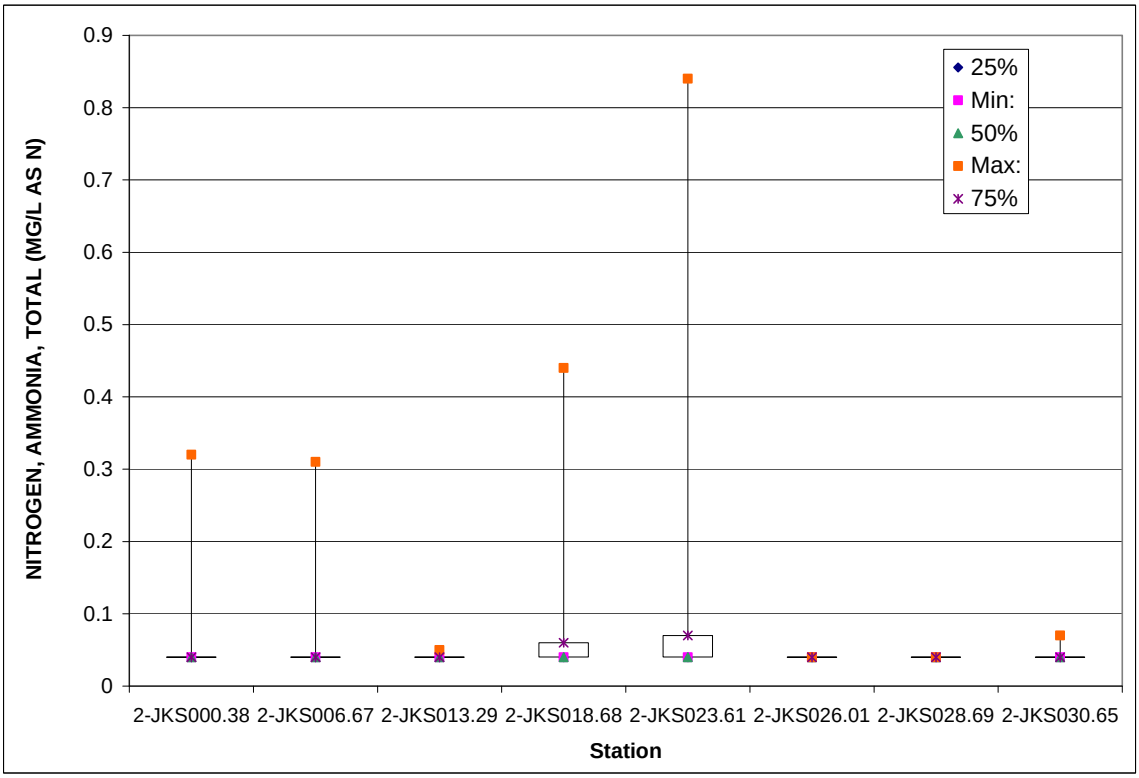
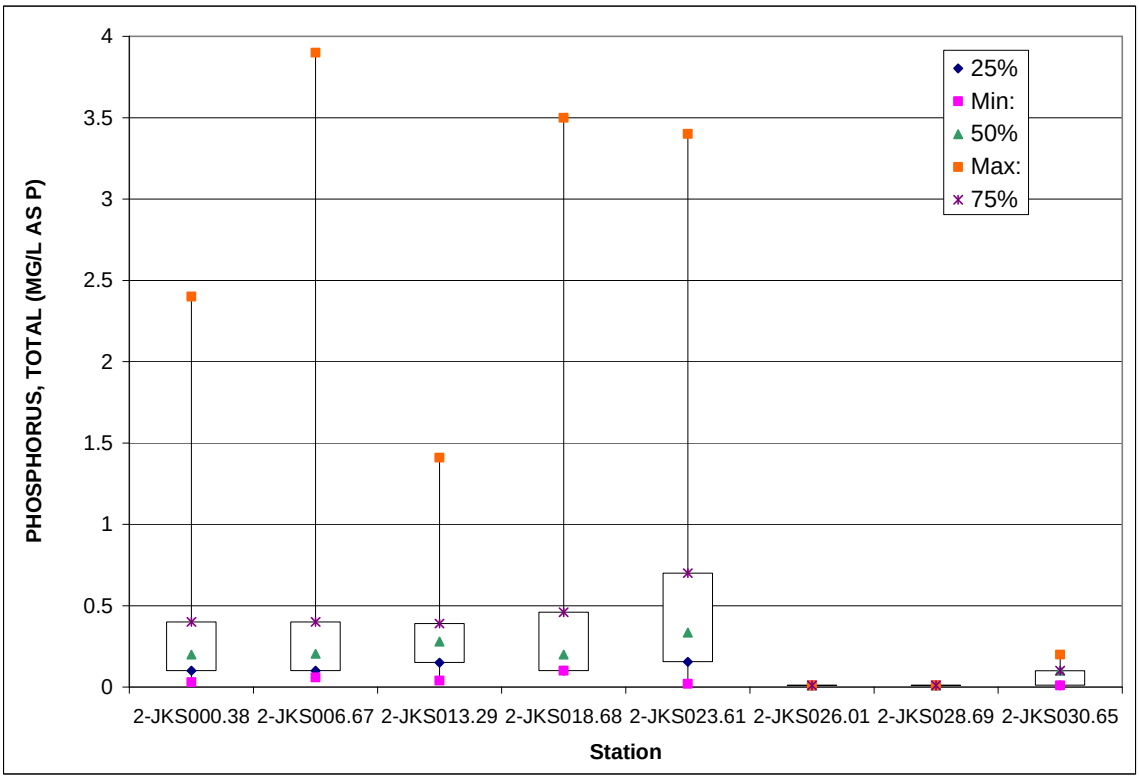


Figure 3-16: Total Phosphorus Concentrations at Jackson River Monitoring Stations



Observed chlorophyll a concentrations were elevated at stations downstream of reference station 2JKS030.65 (Figure 3-17). Fecal coliform concentrations were highest at station 2-JKS023.61 and were generally low at all other stations (Figure 3-18).

Figure 3-17: Phytoplankton Chlorophyll a Concentrations at Jackson River Monitoring Stations

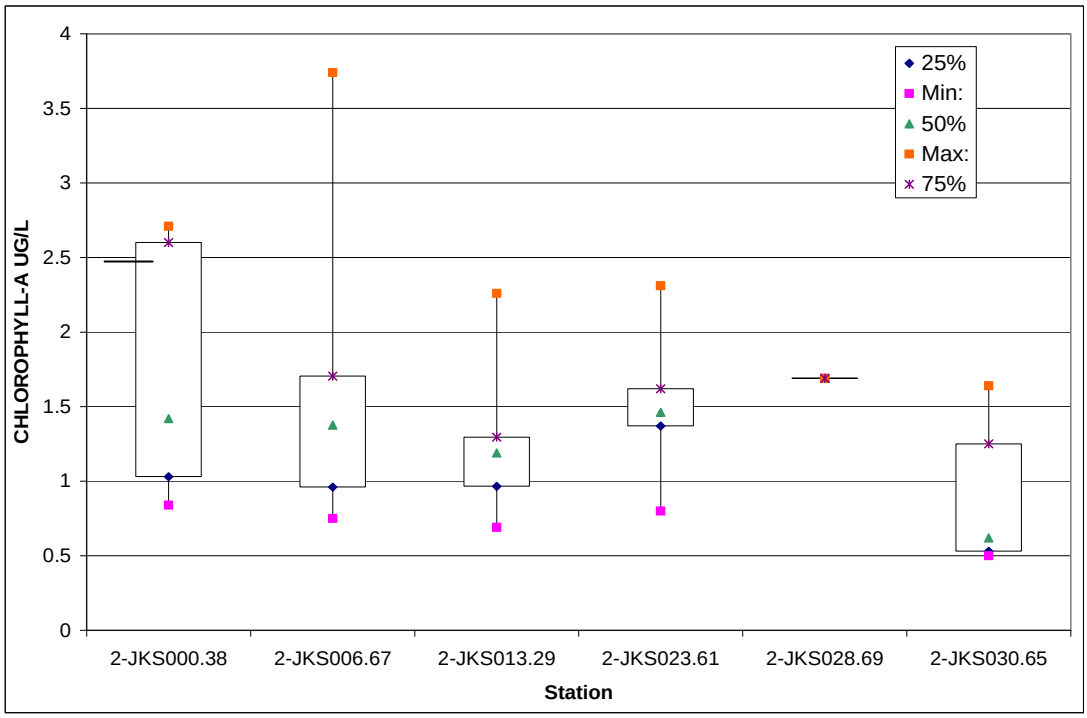
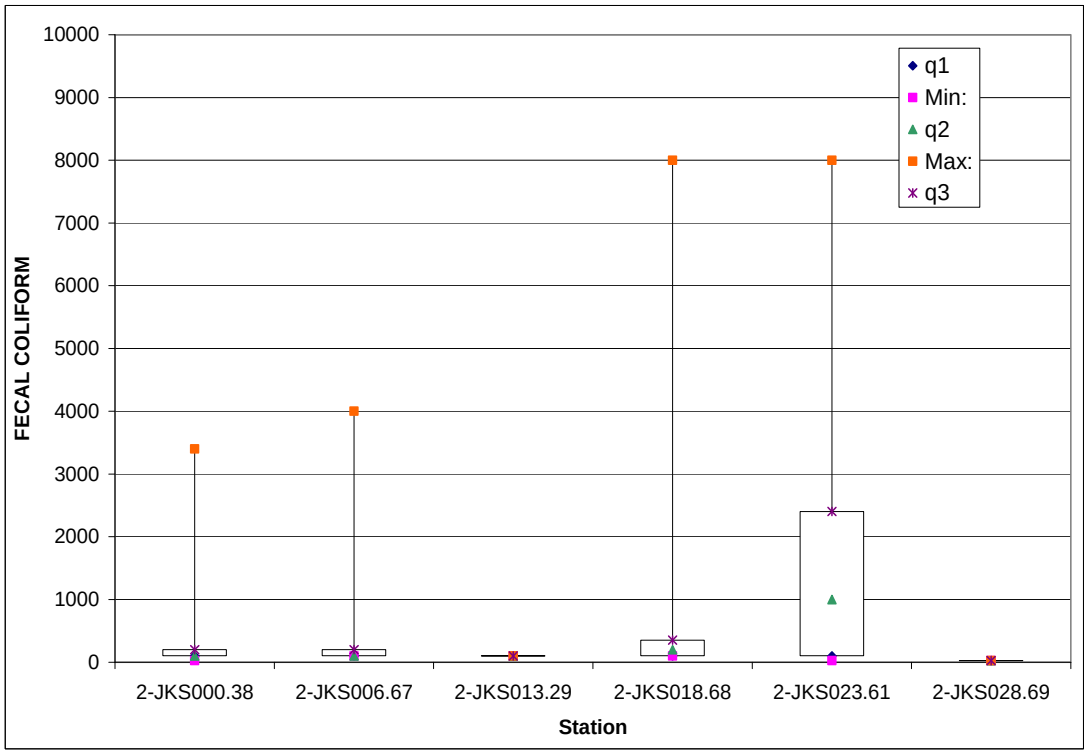


Figure 3-18: Fecal Coliform Concentrations at Jackson River Monitoring Stations



3.2.2 DEQ Metals Data

Both dissolved and sediment metals data were collected on the mainstem Jackson River. Dissolved metals data (Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Selenium, and Zinc) were collected at four stations on the impaired segment, stations 2JKS000.38, 2JKS006.67, 2JKS0018.86, and 2JKS0023.61 (Table 3-8). Sampling was conducted once in March 1990, and again in June 1992. As noted in Table 3-8, the criteria for many metals parameters are expressed as a function of total hardness as calcium carbonate and the Water Effect Ratio (WER), a measure of biological availability. In these instances, criteria were calculated using the average observed hardness of 137 mg/L as $CaCO_3$ and a WER of one. As indicated in Table 3-8, no dissolved metals parameters violated either the Virginia acute or chronic freshwater aquatic life criteria for dissolved metals.

Sediment metals data (Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Selenium, Silver, and Zinc) were collected at stations 2JKS00.0038, 2JKS006.67, 2JKS0018.86, 2JKS0023.61, 2JKS0028.65, 2JKS0030.61 (Table 3-9). Sediment metals data were collected between 35 and 42 occasions at each monitoring station from 1995 to 2004. There are currently no water quality standards established in Virginia for sediment metals; however, the 2004 DEQ assessment guidance memorandum (DEQ, 2004) establishes consensus based sediment screening values for use in determining aquatic life use support (Table 3-9). Sediment nickel values exceeded the 48,600 µg/kg screening value on several occasions at stations 2JKS000.38 and 2JKS006.67. In these instances, DEQ guidance states that “one or more exceedances of the sediment screening value results in a fully supporting but having observed effects status for aquatic life use support” (DEQ, 2004). All other observed sediment metals values were below the consensus based sediment screening values.

Table 3-8: Summary of Dissolved Metals Data Collected on Jackson River

Metals Parameter	River Mile	Date Collected	Total Number of Samples	Dissolved Freshwater Aquatic Life Criteria		Violation
				Acute (µg/L)	Chronic (µg/L)	
Arsenic	0.38, 6.67, 18.86, 23.61	1990,1992	9	340	150	No
Cadmium	0.38, 6.67, 18.86, 23.61	1990,1992	9	5.59[a]	1.42[a]	No
Chromium	0.38, 6.67, 18.86, 23.61	1990,1992	9	737.29[a]	95.89[a]	No
Copper	0.38, 6.67, 18.86, 23.61	1990,1992	9	18.06[a]	11.69[a]	No
Lead	0.38, 6.67, 18.86, 23.61	1990,1992	9	177.5[a]	20.08[a]	No
Mercury	0.38, 6.67, 18.86, 23.61	1990,1992	9	1.4	0.77	No
Nickel	0.38, 6.67, 18.86, 23.61	1990, 1992	9	237.94[a]	26.44[a]	No
Selenium	0.38, 6.67, 18.86, 23.61	1990, 1992	9	20	5	No
Zinc	0.38, 6.67, 18.86, 23.61	1990, 1992	9	152.90[a]	153.83[a]	No

a: Dissolved Criteria calculated based on an average observed hardness of 137 mg/L as CaCO3 and Water Effect Ratio of 1

Table 3-9: Summary of Sediment Metals Data Collected on Jackson River

Metals Parameter	Collection Period	Total Number of Samples	River Mile	Freshwater Aquatic Life Support	
				Sediment Screening Value[a] (µg/kg)	Violation
Arsenic	1995-2004	43	0.38, 6.67, 18.86, 23.61, 28.65, 30.61	33,000	No
Cadmium	1995-2004	43	0.38, 6.67, 18.86, 23.61, 28.65, 30.61	4,980	No
Chromium	1995-2004	43	0.38, 6.67, 18.86, 23.61, 28.65, 30.61	111,000	No
Copper	1995-2004	43	0.38, 6.67, 18.86, 23.61, 28.65, 30.61	149,000	No
Lead	1995-2004	43	0.38, 6.67, 18.86, 23.61, 28.65, 30.611	128,000	No
Mercury	1995-2004	43	0.38, 6.67, 18.86, 23.61, 28.65, 30.61	1,060	No
Nickel	1995-2004	43	0.38, 6.67, 18.86, 23.61, 28.65, 30.61	48,600	Yes
Selenium	1995-2004	39	0.38, 6.67, 18.86, 23.61, 28.65, 30.61	NA	NA
Silver	1995-2004	35	0.38, 6.67, 18.86, 23.61, 28.65, 30.61	NA	NA
Zinc	1995-2004	40	0.38, 6.67, 18.86, 23.61, 28.65, 30.61	459,000	No

a: Screening values specified in DEQ 2004 assessment guidance memorandum
NA: No value specified

3.2.3 DEQ Organics Monitoring

All available organics (Chlordane, DDD, DDE,, Endrin, Endosulfan, Heptachlor Epoxide, and total PCBs) data collected on the Jackson River by DEQ were analyzed to determine whether the examined parameters complied with Virginia's established water quality standards and sediment screening values. Table 3-10 summarizes the monitored organics compounds. The majority of the available sediment organics data were below detection limits. Along the impaired segment of the Jackson River, no monitored dissolved organics parameters violated acute or chronic dissolved freshwater criteria specified in Virginia's water quality standards. Additionally, no exceedances of the sediment screening values specified in the DEQ 2004 assessment guidance memorandum were observed.

Table 3-10: Summary of Organics Data Collected at Jackson River Monitoring Stations

Organics Parameter	Collection Period	River Mile	Number Dissolved Samples	Number Sediment Samples	Freshwater Aquatic Life Support			Number Acute/ Chronic Violations	Number Screening Value Violations
					Acute Dissolved Criteria (µg/L)	Chronic Dissolved Criteria (µg/L)	Sediment Screening Value[a] (µg/kg)		
Chlordane	1992-2000	0.38, 6.67, 18.86, 23.61, 30.65	None	42	2.4	0.0043	17.6	NA	0
DDD	1992-2000	0.38, 6.67, 18.86, 23.61, 30.65	None	42	NA	NA	28	NA	0
DDE	1992-2000	0.38, 6.67, 18.86, 23.61, 30.65	None	42	NA	NA	31.3	NA	0
Endrin	1992-2000	0.38, 6.67, 18.86, 23.61, 30.65	1	42	0.086	0.036	207	0	0
Endosulfan	2004	28.69	None	1	0.22	0.056	NA	0	NA
Heptachlor Epoxide	1992-2000	0.38, 6.67, 18.86, 23.61, 30.65	1	42	0.52	0.0038	16	0	0
PCBs, total	1995-2000	0.38, 6.67, 18.86, 23.61, 30.65	None	42	NA	NA	676	NA	0

a: Screening values specified in DEQ 2004 assessment guidance memorandum
NA: No criteria or value specified

3.2.4 DEQ Toxicity Testing

Toxicity testing was performed on water samples collected from the Jackson River by DEQ on May 2, 4, and 6, 2005 at stations 2JKS006.67 and 2JKS023.61. The EPA Region 3 laboratory in Wheeling, West Virginia performed acute and chronic toxicity testing on samples using fathead minnows (Pimephales promelas) and water fleas (Ceriodaphnia dubia) as test organisms.

Test results indicated that Ceriodaphnia mortality and reproduction in the Jackson River water samples were not statistically different than mortality and reproduction in the control samples, thus indicating that there were no toxic water column effects to Ceriodaphnia in the Jackson River samples. Fathead minnow growth in the Jackson River water samples was statistically different from growth in the control samples. Fathead minnow survival in samples collected at both station 2JKS006.67 and station 2JKS023.61 did significantly vary from minnow survival in the control samples. The ranges of minnow survival in samples collected at station 2JKS006.67 were between 10% to 80% and were statistically different from the laboratory control. Ranges of fathead minnow survival in samples collected at station 2JKS023.61 was between 30% to 60%, which was statistically different from the laboratory control. However, this result is inconsistent with previous toxicity tests showing that Ceriodaphnia are more sensitive than the fathead minnow. The EPA Region 3 laboratory in Wheeling indicated that in their professional judgment, these results "were probably biologically significant", and that it was necessary to compare the observed toxicity testing results with other water quality data collected at these sites to determine the presence of toxicity.

Levels of ammonia, toxic to aquatic organisms in high concentrations, were low across all monitoring stations (Figure 3-14), suggesting that ammonia is not adversely impacting benthic invertebrates in the biologically impaired segment of the Jackson River

3.2.5 MeadWestvaco Water Quality Data

The MeadWestvaco Packaging Resource Group is the largest permitted discharger on the mainstem Jackson River. As part of the effort to improve water quality conditions in the river, MeadWestvaco has expended significant resources to support the collection of environmental monitoring data on the Jackson River. These data are presented below and

divided into the following categories: benthic invertebrate monitoring data; instream water-quality data; effluent metals data; and periphyton data.

3.2.5.1 Benthic Invertebrate Monitoring Data

MeadWestvaco has sponsored or conducted over 24 biological studies of the Jackson River, beginning in 1951. The most recent study was conducted in 1998, and published in February 1999. Field work was conducted in the early summer, fall and early winter of 1998 at two reference sites and eight sites downstream of the MeadWestvaco facility (Environmental and Analytical Services, 1999). Biological monitoring stations 1-2 are the two reference sites located above the MeadWestvaco plant; stations 3-7 are located downstream of the facility (Table 3-11). These stations correspond roughly to the DEQ biological monitoring stations. The total area assessed in the biological monitoring survey encompassed over 50 miles of the Jackson River. Collection of benthic macroinvertebrates was conducted using natural and artificial substrate invertebrate sampling methods. Data analysis was conducted using the USEPA Level III Biological Condition Index (BCI) Score. Biological monitoring sampling results for natural and artificial substrates are summarized in Tables 3-12 and 3-13, respectively. Note that artificial substrate sampling was conducted only at stations 1, 2, 3, 4, and 6 on the Jackson River.

Table 3-11: Location of MeadWestvaco Biological Monitoring Stations

Biological Monitoring Station	River Mile	Site Description
1 (Reference Site)	29.4	Clearwater Park
2 (Reference Site)	25.3	Rivermont
3	23.6	Playground
4	20.8	Upstream of AET Facility
5	12.9	ValRidRd Cave
6	6.6	BLC College
7	0.5	Iron Gate

Table 3-12: Summary of MeadWestvaco Biological Monitoring Results (Natural Substrate)

Collection Period	Reference Score (Sites 1 and 2)	Station Number									
		3		4		5		6		7	
		BCI Score	Assessment	BCI Score	Assessment	BCI Score	Assessment	BCI Score	Assessment	BCI Score	Assessment
Early Summer	40	30	MOD	70	SLT	60	SLT	75	SLT	75	SLT
Fall	38	42	MOD	63	SLT	68	SLT	47	MOD	79	SLT

Figure 3-20 shows that the lowest monthly-average flows occur during the months of July, August, September, and October. The lowest monthly-average flow was recorded in October (1985-2004).

Critical periods in water quality often occur during short periods of one to two weeks. Consequently, weekly low-flow analysis was performed on the streamflow data at the City Playground Station. This analysis consists of identifying the lowest weekly-average flow in the Jackson River for each year spanning the period of 1984 to 2005 and during the 4-month period of July, August, September and October. Table 3-21 shows the results of the analysis and indicates that most of the time, the lowest weekly-average flow occurs the month of October.

Table 3-22: Lowest Weekly Average Flow Occurring[1] each Year (1984 -2005)

Year	Week	City Playground USGS 02013100 (cfs)	Gathright Dam USGS 02011800 (cfs)	Dunlap Creek USGS 02013000 (cfs)	% of Stream Flow from Gathright Release[2]
1984	Oct 7 - Oct 13	241	179	36	74
1985	Oct 3 - Oct 10	204	149	19	73
1986	Oct 18 - Oct 24	202	178	21	88
1987	Sept 30 - Oct 6	222	179	29	81
1988	Oct 14 - Oct 20	192	172	17	90
1989	Oct 10 -Oct 16	393	224	87	57
1990	Oct 1 - Oct 7	214	186	16	87
1991	Oct 16 - Oct 22	244	198	19	81
1992	Oct 24 - Oct 30	238	191	33	80
1993	Oct 15 - Oct 21	217	199	22	92
1994	Oct 7 - Oct 13	213	189	22	89
1995	Oct 25- Oct 30	247	199	35	81
1996	Oct 3 - Oct 9	257	181	40	70
1997	Oct 5 - Oct 11	250	192	16	77
1998	Oct 25 - Oct 31	232	199	17	86
1999	Oct 25 - Oct 31	191	156	34	82
2000	Oct 3 - Oct 9	258	191	36	74
2001	Oct 3 - Oct 9	231	191	14	83
2002	Oct 4 - Oct 10	189	149	22	79
2003	Oct 7 - Oct 14	271	187	42	69
2004	Sept 1 – Sept 7	286	191	71	61
2005[3]	Sept 30 - Oct 6	250	212	19	85

[1] during the critical months of July, August, September, and October
[2] percent of flow from the Gathright Dam release at the City Playground station
[3] provisional USGS flow data – subject to revision

The lowest weekly-average flow recorded is in October 2002 (189 cfs, October 4 to October 10). The highest weekly-average flow recorded is in October 1989 (393 cfs, October 10 to October 16). Table 3-21 also shows that during these critical periods the Gathright Dam release consists of approximately 70 to 90 percent of the total flow at the City Playground Station. It should be noted that the Gathright Dam operations manual specifies a minimum flow release of 188 cfs above Dunlap Creek, however, during the week of October 4 through October 10, 2002 the Gathright Dam's release averaged 149 cfs (Table 3-21). It should be noted that in 1999 and 2002 the releases from Gathright Dam were modified at the request of the Commonwealth of Virginia to respond to on-going drought conditions. Additionally, aeration was accomplished by Mead-Westvaco during these periods of reduced Gathright Dam flow releases.

3.4.2 Continuous DO Monitoring

The results of the low-flow analysis were combined with the continuous diurnal dissolved oxygen observations recorded in the fall of 2002, 2004, and 2005. This information is presented in Figure 3-8 through 3-10, and reproduced below in Figures 3-21 through 3-23 with the addition of the stream flows recorded during the same period. Streamflow data presented in Figures 3-21 through 3-23 consist of data from the City Playground, Dunlap Creek, and Gathright Dam.

The key observation of this analysis that the lowest weekly average flow on record (October 4 to October 10, 2002) coincides with the lowest observed diurnal dissolved oxygen concentration of 0.74 mg/L recorded on October 6, 2002 (Figure 3-21). In addition, the lowest critical weekly flow also coincides with the highest diurnal DO fluctuations of over 7 mg/L. It should be noted that these low-DO observations coincide with critical weekly flow with has an average return period of 21 years. In other words, this low diurnal DO, which corresponds to an extreme low-flow condition, is considered as an extreme event. Figure 3-21 also shows that the low-DO observations also coincide with above-normal seasonal ambient temperature.

Other information deducted from Figure 3-21 is that the critical weekly low-flow period of October 4 to October 10, 2002 was preceded by a major wet-weather event. As depicted in Figure 3-21, the flow at the City Playground station increased to 724 cfs on October 27,

2002 following a rainfall event of 1.90 inches recorded on October 26 at the Gathright Dam precipitation station.

The wet weather event suggests that the diurnal low DO might not be solely caused by the critical low flow experienced in the Jackson River. However, the dissolved oxygen critical drop occurred almost a week after the wet-weather event making it unlikely to have contributed or caused directly this low oxygen level in the Jackson River.

On the other hand, the diurnal DO data recorded between October 29 and November 1 2004 do not violate instream dissolved oxygen standards (Figure 3-22). The weekly average flow during this period is 322 cfs at the city playground, well above the 2004 critical weekly flow of 286 cfs recorded during the week of September 1 to September 7 2004 (Table 3-21).

Diurnal dissolved oxygen data collected in the fall of 2005 violate the DO standard. As shown in Figure 3-23, DO levels dropped below the minimum standard during the night of October 4 to October 5 2005. However, the DO violation in the fall of 2005 cannot be solely attributed to flow conditions. The flow at this period was the lowest weekly average flow recorded in 2005 (July, August, September, and October 2005), however, the flow rate of 250 cfs is well above the critical low-flow conditions shown in Table 3-21. It should be noted that the flow for this period was retrieved from the USGS real-time flow web site, and all the data from this site is provisional. The final analysis and conclusion on the diurnal DO data for the fall 2005 will be adjusted when final flow data is available from USGS.

Figure 3-21: Jackson River Dissolved Oxygen and Flow - Fall 2002

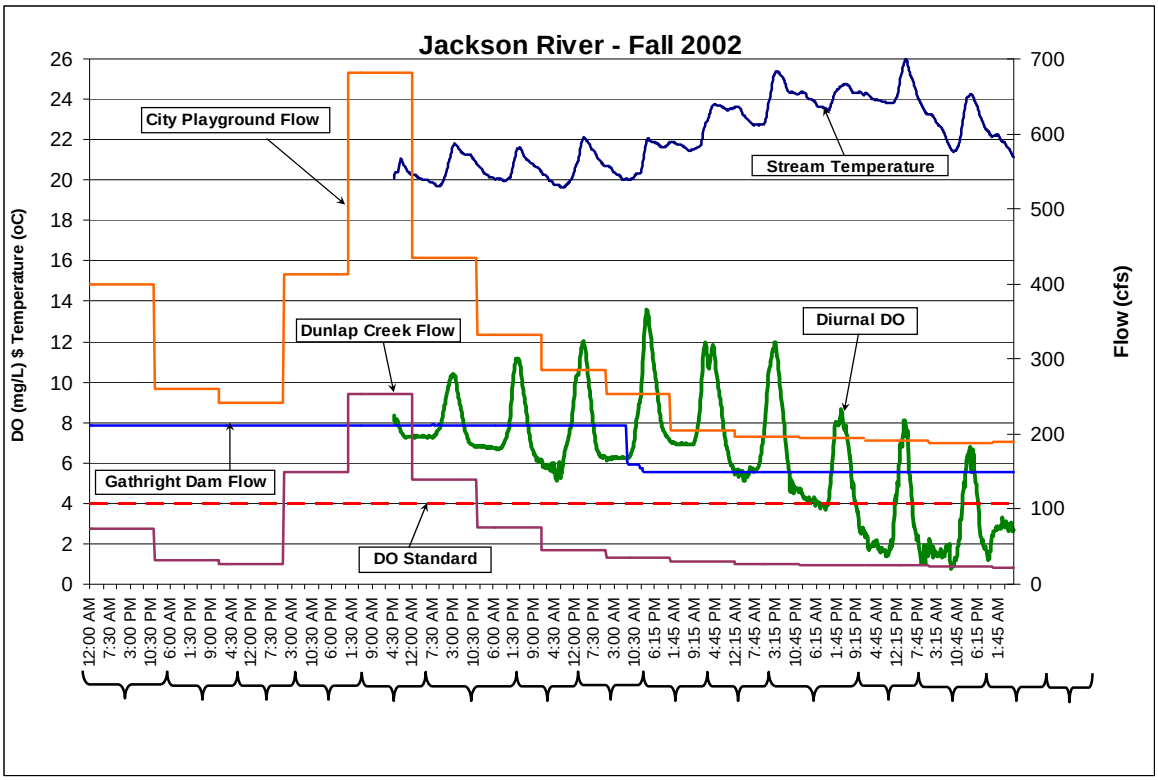


Figure 3-22: Jackson River Dissolved Oxygen and Flow – Fall 2004

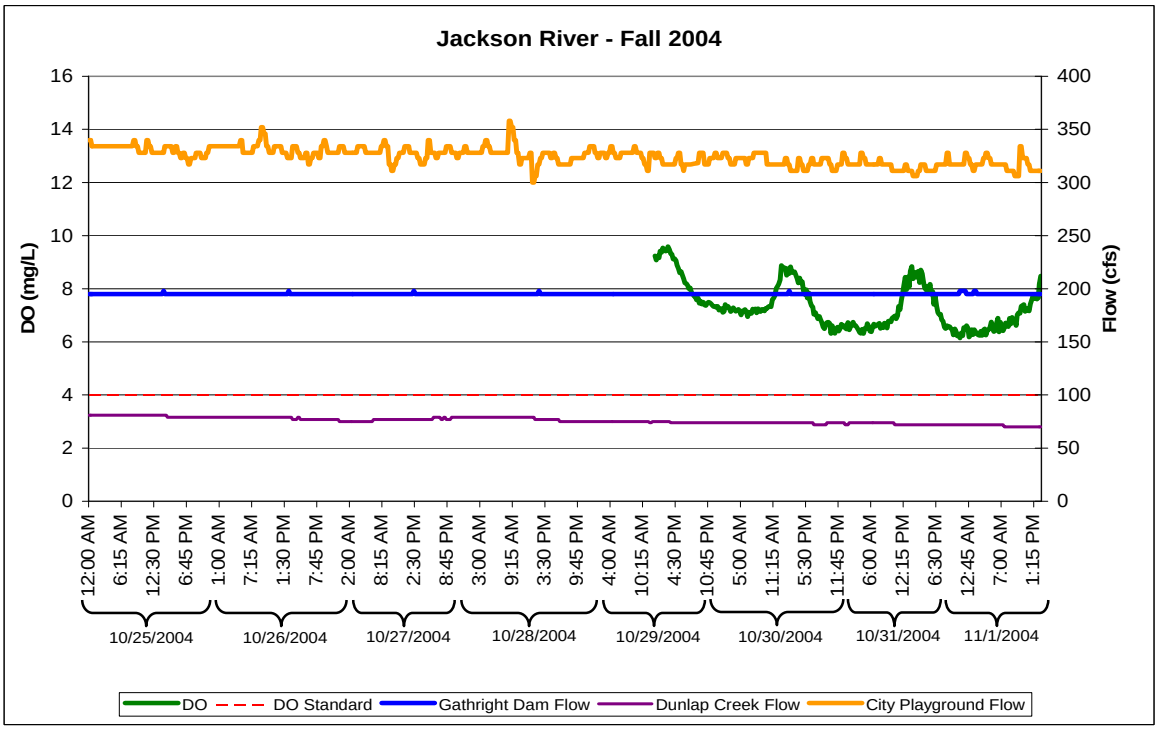
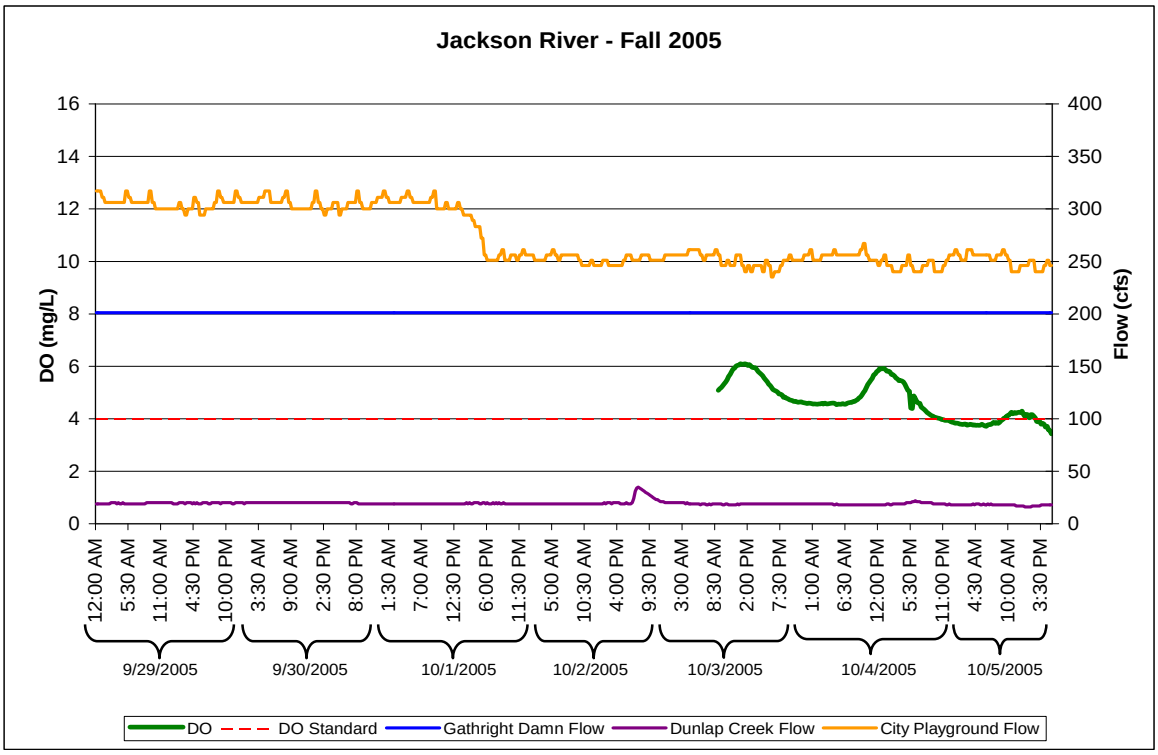


Figure 3-23: Jackson River Dissolved Oxygen and Flow – Fall 2005



4.0 Stressor Identification Analysis

TMDL development for benthic impairment requires identification of pollutant stressor(s) affecting the benthic macroinvertebrate community. Stressor identification for the biologically impaired segment of the Jackson River was performed using the available environmental monitoring and watershed characterization data discussed in previous sections. The stressor identification follows guidelines outlined in the EPA Stressor Identification Guidance (EPA 2000).

The identification of the most probable cause of biological impairment in the Jackson River was based on evaluations of candidate stressors that can potentially impact the river. The 2004 Water Quality Assessment 305(b)/303(d) Integrated Report Fact Sheet identified "nutrient and organic enrichment" as possible sources of biological impairment. Therefore, these pollutants were considered in the evaluation of candidate stressors along with other probable stressors such as pH, temperature, dissolved oxygen, sediment, ammonia, flow modification, and toxic compounds. Each candidate stressor was evaluated based on available monitoring data, field observations, and consideration of potential sources in the watershed. Furthermore, potential stressors were classified as a *non-stressor*, *possible stressor*, or *most probable stressor*. Table 4.1 summarizes the results of the analysis.

Table 4.1: Summary of Stressor Identification in the Jackson River

Parameter	Location in Document
Non-Stressors	
Temperature and pH	Section 4.1.1
Metals and Organics	Section 4.1.2
Sediments	Section 4.1.3
Wet Weather	Section 4.1.4
Possible Stressors	
TDS-Toxicity	Section 4.2.1
Low Dissolved Oxygen	Section 4.2.2
Flow Modification	Section 4.2.3
Most Probable Stressors	
Nutrients/Periphyton	Section 4.3.1

4.1 Non-Stressors

4.1.1. Temperature and pH

Benthic invertebrates require a suitable range of temperature and pH conditions. Although these ranges may vary by invertebrate phylogeny, high instream temperature values and either very high or very low pH values may result in a depauperate invertebrate assemblage comprised predominantly of tolerant organisms. The Virginia Class IV water quality standards identify the acceptable pH and temperature ranges for the Jackson River. Field measurements indicated adequate temperature and pH values on and upstream of the biologically impaired segment (Figures 3-4 and 3-5). There have been no observed violations of Class IV water quality standards for pH and temperature. Therefore, pH and temperature do not appear to be adversely impacting benthic communities in the Jackson River.

4.1.2. Metals and Organics

Analysis of the available DEQ water quality data indicated no dissolved metals parameters exceeded Virginia's established water quality standards (Table 3-6), and only nickel values exceeded the sediment screening values at River mile 6 and 0.38 which are downstream of the impaired segment (Table 3-7). Observed dissolved metals concentrations in the effluent of the MeadWestvaco facility, the largest discharger on the Jackson River, were also low across all parameters (Table 3-14), indicating that MeadWestvaco is not a significant contributor of metals loading to the river. Metals and organics data collected by DEQ do not suggest the presence of toxicity in the Jackson River. Therefore, metals and organics do not appear to be a primary stressor impacting the benthic macroinvertebrates in the Jackson River.

4.1.3. Sediments

Excessive sediment loading can negatively impact benthic invertebrate communities by silting over invertebrate habitat, choking invertebrates with suspended sediment particles,

and bringing invertebrates into contact with other pollutants that enter surface water via adhesion to sediment particles.

Habitat metrics collected during biological monitoring surveys did show a trend of habitat conditions declining as sampling moved from upstream to downstream (Figures 3-1 to 3-3; Appendix A), substrate embeddedness scores and other indicators of sediment loading did not substantially vary from the overall trend. The Jackson River is a point source dominated stream along the length of the impaired segment, and the observed decline in habitat conditions is likely a result of the point sources discharges. Average effluent suspended solids concentrations were generally low for most of the major dischargers (i.e., facilities with design flows greater than 1 MGD) in the watershed (Figure 3-20). Additionally, total suspended solids concentrations collected downstream of the MeadWestvaco plant, the largest discharger present on the river, were consistently low across monitoring stations (Table 3-12). Because the Jackson River watershed is largely forested (Table 2-3), excessive non-point source sediment loading to the river is also unlikely. For the reasons stated above, sediment is considered as a non-stressor in the Jackson River.

4.1.4. Wet-Weather Flow – Non-Point Sources

A wet weather event preceding the low diurnal DO conditions observed in October 2002 suggests that non-point sources loads might have contributed to the low-DO conditions (Figure 3-17). However, the storm preceding the DO incursion below 4 mg/L is an average high-flow event and the low observed DO occurred almost one week after this wet weather. Consequently, this wet-weather event is unlikely to have directly caused or contributed to the DO drop. Therefore, non-point sources loading under wet-weather flow is considered as a non-stressor in the Jackson River.

4.2 Possible Stressors

4-2.1 TDS and Toxicity

The toxicity data analysis presented in Sections 3.1.2 (WET toxicity) and 3.2.3 (Instream Toxicity Testing), indicates that there is some degree of toxicity in the Jackson River. The overall conclusion is that the toxicity results are probably biologically significant. Toxicity in the Jackson River is not attributed to the levels of ammonia, metals, and organics since they were low across all monitoring stations. However, toxicity is often caused by relatively high Total Dissolved Solids (TDS) concentrations. Aquatic organisms are highly sensitive to elevated TDS concentrations, which can reduce water quality and significantly impact fish and wildlife (Chapman et al. 2000).

In fact, conductivity data collected at different stations in the Jackson River exhibit extremely high concentrations as compared to a reference station (Figure 3-9). Conductivity is an appropriate surrogate for TDS since the degree of conductivity is directly proportional to the concentration of total dissolved solids in water. For the reasons stated above, TDS and toxicity are considered as possible stressors affecting the benthic macroinvertebrate community in the Jackson River.

4.2.2 Low Dissolved Oxygen

Adequate dissolved oxygen levels are necessary for invertebrates and other aquatic organisms to survive in the benthic sediments of rivers or streams. Decreases in instream oxygen levels can result in oxygen depletion or anoxic sediments, which adversely impact the river's benthic community. As discussed in the preceding section, diurnal dissolved oxygen studies showed large diurnal fluctuations in instream oxygen concentrations (Figures 3-16) and violated dissolved oxygen standards for Class IV waters (Figure 3-16 and Figure 3-18).

However, the severe violations observed in the fall of 2002 coincide with an extreme low-flow event and are episodic in nature. In addition the low-flow events associated with the low-DO were combined with above-normal seasonal ambient temperature

(Figure 3-21). In other words, the low dissolved oxygen might contribute occasionally to the benthic impairment; however, it cannot be classified as the primary stressor causing the benthic impairment in the Jackson River. Consequently, dissolved oxygen is classified as a possible stressor affecting the benthic macroinvertebrate community in the Jackson River.

4.2.3 Flow Modification

Section 3-4 addressed any potential contribution of the flow release at Gathright Dam on the overall dissolved levels during critical low flow events. One indication is that the worst DO levels recorded in the Jackson River (October 2002) coincide with an extreme weekly low-flow event. However, this observation is not confirmed with the diurnal DO measurements taken in October 2005. In fact, dissolved oxygen levels in 2005 fall below the minimum DO standard of 4 mg/L; however, they do not coincide with an extreme low-flow event. In addition the biological data collected along the Jackson River strongly suggest that the flow modification is not the direct cause of the benthic impairment. In fact, key habitat scores such as Substrate Embeddedness, Riparian Vegetation as well as the Total Habitat score indicate a healthy benthic community upstream of the major dischargers in the Jackson River (Section 3.1.3). Therefore, the flow modification is classified as a possible stressor affecting the benthic macroinvertebrate community in the Jackson River.

4.3 Most Probable Stressors

4.3.1 Nutrients

High nitrogen and phosphorus concentrations can stimulate algal growth, which may result in eutrophic conditions, high organic loading, and decreased dissolved oxygen. High nutrient concentrations were observed in the Jackson River, and do appear to be resulting in significant periphyton growth which may impact the benthic macroinvertebrates present in the river. DEQ ambient instream monitoring indicated that total phosphorus concentrations increase significantly in the Jackson River at station 2JKS023.61, below the MeadWestvaco facility and at the upstream end of the

biologically impaired segment (Figure 3-12). Monitoring data collected by MeadWestvaco confirmed this trend, and indicate that instream phosphorus concentrations were elevated below the MeadWestvaco plant as compared to stations upstream of the facility (Table 3-13). Instream nitrogen concentrations also increase significantly as the Jackson River flows downstream (Figure 3-9; Table 3-13).

Because the Jackson River is effluent-dominated under low flow conditions (when excessive periphyton growth and algal blooms are prone to occur), point sources appear to be the predominant source of the excessive nutrient loading present in the river. Only two major dischargers (i.e., facilities with design flows greater than 1 MGD) monitored their effluent for total nitrogen and total phosphorus. Phosphorus concentrations in the effluent of both of these facilities, MeadWestvaco and the Clifton Forge City STP, were generally elevated (Figure 3-25). Effluent nitrogen concentrations were also fairly high at the Clifton Forge STP, and on some occasions at the MeadWestvaco plant (Figure 3-24). Additionally, instream monitoring conducted immediately downstream of other facilities (e.g., the Covington City STP) also indicates that some facilities which do not currently monitor their effluent for nutrients may nonetheless be contributing large nutrient loads to the Jackson River, as evidenced by the spike in nitrogen and phosphorus concentrations observed at these monitoring stations (Figures 3-9, 3-11; Table 3-13).

Periphyton data collected in the Jackson River correspond to the patterns of nutrient loading observed. Periphyton are attached algae that grow on the bottom of stream beds, and represent the dominant type of algal biomass in lotic ecosystems. In addition to contributing to high organic loading, excessive periphyton can also impair benthic macroinvertebrate assemblages by covering the interstitial spaces between rocks and cobble that comprise much of the habitat for many types of invertebrates. Observed periphyton chlorophyll A values increased at the Mill Dam and Mill Bridge stations, located in the immediate vicinity of the MeadWestvaco facility, and showed another spike near the Playground, Skate Park, and Industrial Park monitoring stations, located downstream of several additional point sources (Table 3-15).

Further evidence of excessive nutrient loading was indicated by diurnal dissolved oxygen studies, which demonstrated that large diurnal swings in dissolved oxygen occur in the Jackson River under low flow, effluent-dominated conditions (Figures 3-14 to 3-16). These large diurnal oxygen swings are often indicative of eutrophic conditions, and result from increased algal biomass contributing to organic enrichment of the river. During the daylight hours, the algae photosynthesize and increase the dissolved oxygen present in the river. However, in the evening the algae are not able to photosynthesize, but microbial respiration continues to occur as decomposition of the excessive organic matter persists. This results in large diurnal oxygen swings, such as those observed in the Jackson River, in which dissolved oxygen concentrations peak in the daylight hours, and fall to very low levels in the evening. The fact that this pattern was observed repeatedly in the Jackson River strongly suggests that nutrient loading leading to excessive periphyton growth is adversely impacting the biological communities in the river.

Benthic macroinvertebrate assemblages are generally sensitive to organically enriched conditions. Excess nutrients entering the river system over-stimulate algal growth which can alter macroinvertebrates communities by providing an increase in food supply for opportunistic invertebrates that use algae as a food source. These opportunistic invertebrates are often generalists and can easily outcompete more sensitive species and dominate a community (EPA, 2000). At the same time, the benthic macroinvertebrate community is also affected by a change in instream habitat since the abundance of periphyton will cover the majority of instream habitat areas. These affects on the species composition alters the natural balance in the benthic community and creates a shift toward pollution tolerant organisms that feed on algae (scrapers) and suspended detritus (collector-filterers) (Voshell, 2002). Overall, an increase in nutrients will lower the macroinvertebrate species diversity and reduce the variety of food available for fish and other vertebrates present within the ecosystem.

For the reasons stated above, excessive nutrient loading leading to eutrophic conditions is considered to be a most probable stressor impacting benthic invertebrates in the Jackson River. Stoichiometric nutrient ratios indicate that the Jackson River is primarily a phosphorus-limited stream (Figures 3-9, 3-11; Table 3-13). Therefore, nutrients

(primarily phosphorus) are considered to be a most probable stressor affecting the benthic macroinvertebrate community in the Jackson River.

4.4 Stressor Identification Summary

The data and analysis presented in this report indicate that temperature, pH, and sediments in the biologically impaired segment of the river are adequate to support a healthy invertebrate community, and are not stressors contributing to the benthic impairment. Concentrations of metals and organics were generally low or below analytical detection limits and are also classified as non-stressors. In addition, non-point sources loading under wet-weather flow is also considered as a non-stressor in the Jackson River since the existing data indicate that the wet-weather event in Figure (3-21) occurred one week prior to the low observed DO and therefore is unlikely to have directly caused the decrease in dissolved oxygen levels.

The data analysis also shows that high TDS in the stream and TDS related toxicity, low-dissolved oxygen episodically associated with low-flow conditions also can contribute to the benthic impairment in the Jackson River. In addition the flow modification/regulation caused by the Gathright Dam is also classified as possible stressor to the benthic community in the Jackson River. Consequently, low-dissolved oxygen, flow modification as well as high TDS concentrations and toxicity are classified as possible stressors.

Excessive periphyton growth caused by an excess of nutrient (in particular phosphorus) has been identified as the most probable stressors impacting benthic invertebrates in the biologically impaired segment of the Jackson River.

Elevated nutrient concentrations were observed downstream of major point sources discharging to the river. Excessive periphyton growth and large diurnal dissolved oxygen swings also indicate the presence of eutrophic conditions in the Jackson River. Because stoichiometric nutrient ratios indicate that the Jackson River is primarily a phosphorus-limited stream, phosphorus is considered a most probable stressor affecting the benthic macroinvertebrate community.

In summary, the data analysis shows that the common “end-point stressor” is the excessive periphyton growth and accumulation in the Jackson River causing the benthic impairment. This excessive periphyton growth is mainly caused by the excessive nutrients in the river.

Consequently, the periphyton issue in the Jackson River would be addressed a reduction in nutrient loadings.

5.0 End Point Determination

5.1 Methodology

TMDL development requires the determination of endpoints, or water quality goals/targets, for the impaired waterbody. TMDL endpoints represent the stream conditions at which a given stream would meet water quality standards. Endpoints are normally expressed as the numeric water quality criteria for the pollutant causing the impairment. Compliance with numeric water quality criteria, such as a maximum allowable pollutant concentration, is expected to achieve full use support for the waterbody. However, not all pollutants have established numeric water quality criteria. In these cases, alternative approaches may be used to define the TMDL endpoint.

Stream segments in the Jackson River watershed were listed on Virginia's 2005 303(d) List of Impaired Waters as benthic impaired. As described in Chapter 4, that the most probable stressor in the Jackson River is the excessive periphyton growth in the stream. The excessive periphyton grown impairs benthic macroinvertebrates assemblages by covering the interstitial spaces between rocks and cobble that comprise much of the habitat for many types of invertebrates. This excessive periphyton growth is caused by excessive nutrient loading. Consequently, reductions in nutrients are necessary to replenish and maintain the benthic macroinvertebrate community in the Jackson River. Virginia currently has not established numeric criteria for nutrients. Therefore, an alternate approach for determining the nutrient endpoint was utilized.

The development of the TMDL endpoint for the Jackson River consisted of the following steps:

- The first step was to identify the benthic chlorophyll[1] levels that are acceptable and amenable in restoring the Jackson River benthic community. Based on previous work, benthic chlorophyll levels in streams that range from 100-150 mg/m2 are considered excessive and at nuisance level (Welch et al. 1988,

[1] Chlorophyll *a* is referred simply as chlorophyll throughout the document.

Virginia Tech, 2006). Chlorophyll *a* is a photosynthetic pigment in algae and is used as an indicator of algal biomass (Barbour et al., 1999). Consequently, benthic chlorophyll level at or below 100 mg/m2 is the periphyton TMDL endpoint in the Jackson River.

- The second step was to establish a link between the benthic chlorophyll threshold of 100 mg/m2 and the instream nutrient concentrations (total dissolved nitrogen and PO4-P). These nutrient concentrations, corresponding to benthic level of 100 mg/m2, are the nutrient TMDL endpoints in the Jackson River.

- The third step was to utilize the link between the benthic chlorophyll threshold of 100 mg/m2 and the instream nutrient concentrations for PO4-P to establish a TMDL endpoint for PO4-P. The PO4-P endpoint will be used by VA DEQ to establish a PO4-P permit limit for the discharger MeadWestvaco.

5.2 Endpoint Development

As stated above, Virginia does not currently have established numeric criteria for nutrients. Therefore, it was necessary to use a relationship that would represent stream conditions that replenish and maintain the benthic macroinvertebrate community in Jackson River.

5.2.1 Development of Predictive Empirical Model

Predictive empirical models are commonly used in water quality modeling and assessment. Empirical models, which are often based on statistical relationships, attempt to establish correlations between key variables. In this case, the extensive water quality monitoring data in the Jackson River was used to determine how water column nutrients are linked to periphyton and try to identify if there are strong relationships between stream benthic algae and nutrients in the Jackson River.

Empirical regression models that link algal biomass (phytoplankton) and water column nutrients have been used successfully in the eutrophication management of freshwater lakes and reservoirs (Smith 1998, 1999), (Cooke et al. 1998). Similarly, empirical

regression models have been recently developed by Dodds et al. (2002) using multiple regression analysis between periphyton and water-column nutrients from rivers located in USA and New Zealand. The results of this analysis showed that the mean benthic biomass in these streams was explained by about 40% (R-square = 0.4) by concentrations of Total N and Total P. The disadvantage of such a general relationship, developed by Dodds (2002), is that does not apply to a specific region or stream.

Because of the extensive monitoring data available in the Jackson River, a regression model between the periphyton and the water-column nutrients specific to the Jackson River was developed.

Extensive ambient monitoring was performed between 2000 and 2002 as part of the implementation of a water quality model in the Jackson River (MeadWestvaco 2003). In addition, VADEQ has an extensive monitoring program at different stations in the Jackson River. These data include nutrient (N,P) and periphyton observations at several stations along mainstem the Jackson River was developed.

The objective is to develop regression equations between benthic chlorophyll and in-stream nutrient concentrations; in other words we attempt to identify any strong relationships between water-column nutrients and periphyton biomass in the Jackson River.

First, the complete data was screened to identify observations containing simultaneous TN, TP, and benthic chlorophyll (only data collected during the same day are included in the analysis). A total of 158 observations of benthic chlorophyll and nutrient species were used to develop the regressions. These water quality observations were measured during the months of June trough October. The observations from all the stations in the Jackson River were combined in one data set (including stations upstream and downstream of MeadWestvaco). The statistical package Minitab® (Version 14) was used to develop these regressions in order to attempt to explain any eventual relationship between nutrient and benthic algae.

5.2.2 Summary of Results

The nutrient data, recorded simultaneously with benthic chlorophyll, consist of NH3-N, NO2-N, NO3-N, PO4-P, and total dissolved nitrogen (TDN). First, a single regression analysis was developed between benthic chlorophyll and each of the nutrient species. Then, using a multiple regression analysis, a relationship was developed between chlorophyll, TDN, and PO4-P. The objective of this analysis was to identify any meaningful relationship between the variables in the dataset. **Table 5-1** shows the result of this analysis.

Table 5-1: Regression Models for Benthic Chlorophyll as a Function of Nutrients in the Jackson River

Dependent Variable (Response)	Independent Variable 1	Independent Variable 2	Intercept	R-square	Adjusted R-square
Log Chla	0.400*Log(NH4)	-	2.63	0.093	0.087
Log Chla	-0.544*Log(NO3)	-	1.57	0.023	0.017
Log Chla	2.43*Log(TDN)	-	2.90	0.293	0.289
Log Chla	0.543*Log(TDP)	-	2.62	0.602	0.599
Log Chla	0.524*Log(TDP)	0.178*Log(TDN)	2.66	0.603	0.598
Log Chla	0.423*Log(PO4)	-	2.60	0.597	0.594
Log Chla	0.395*Log(PO4)	0.359*Log(TDN)	2.69	0.600	0.595

The results from this data analysis clearly show that PO4-P or total dissolved phosphorus explain approximately 60% of the variation in benthic biomass in the Jackson River. A weak relationship was derived from the nitrogen species (NH4, NO3, and TDN). In addition, the regression results show that using TDN and PO4 as independent variables do not produce any statistical improvement. In other words, the regression using only PO4 as independent variable produces an R-square of 0.594 and when adding TDN to PO4 as an independent variable results to a similar R-square of 0.595.

Consequently, the multiple regression analysis (TDN and PO4-P) confirms that phosphorus explains approximately 60% of the benthic biomass variations in the Jackson River. Therefore, only PO4 will be used to develop the TMDL endpoint for the Jackson River. **Appendix D** displays all the data used in the development of the statistical regressions.

Prior to developing the nutrient TMDL endpoint, it is necessary to summarize and present the periphyton and nutrient data at several stations in the Jackson River. **Figures 5-1** through **5-3** depict the data summary.

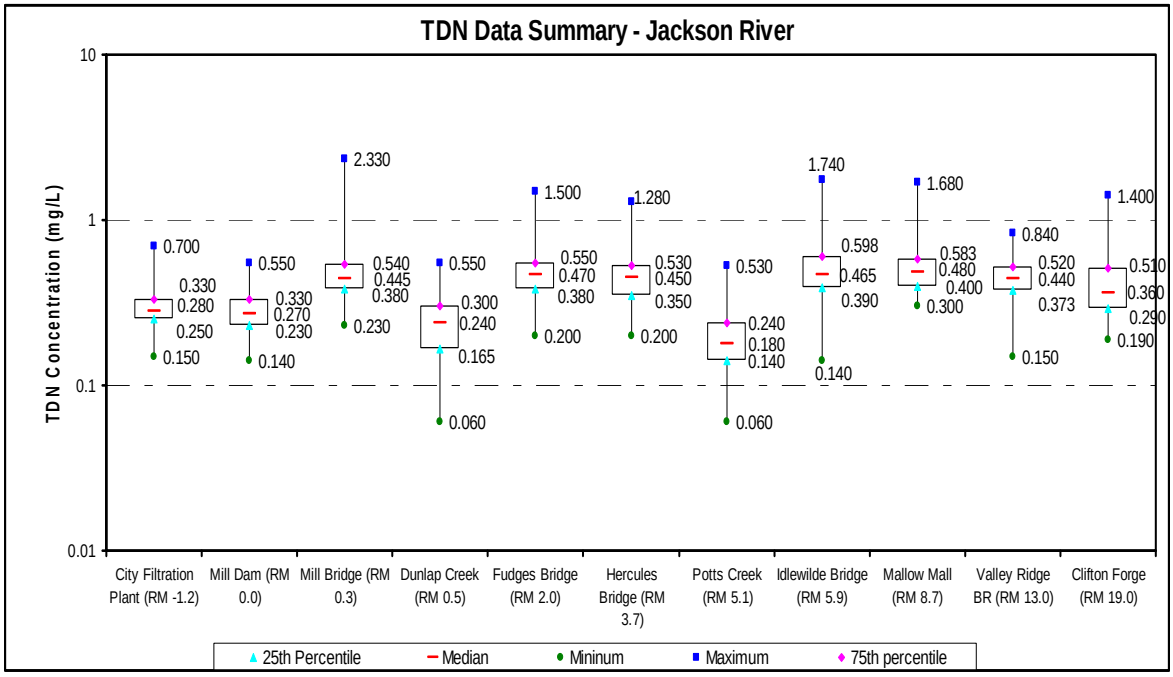


Figure 5-1: TDN Data Summary

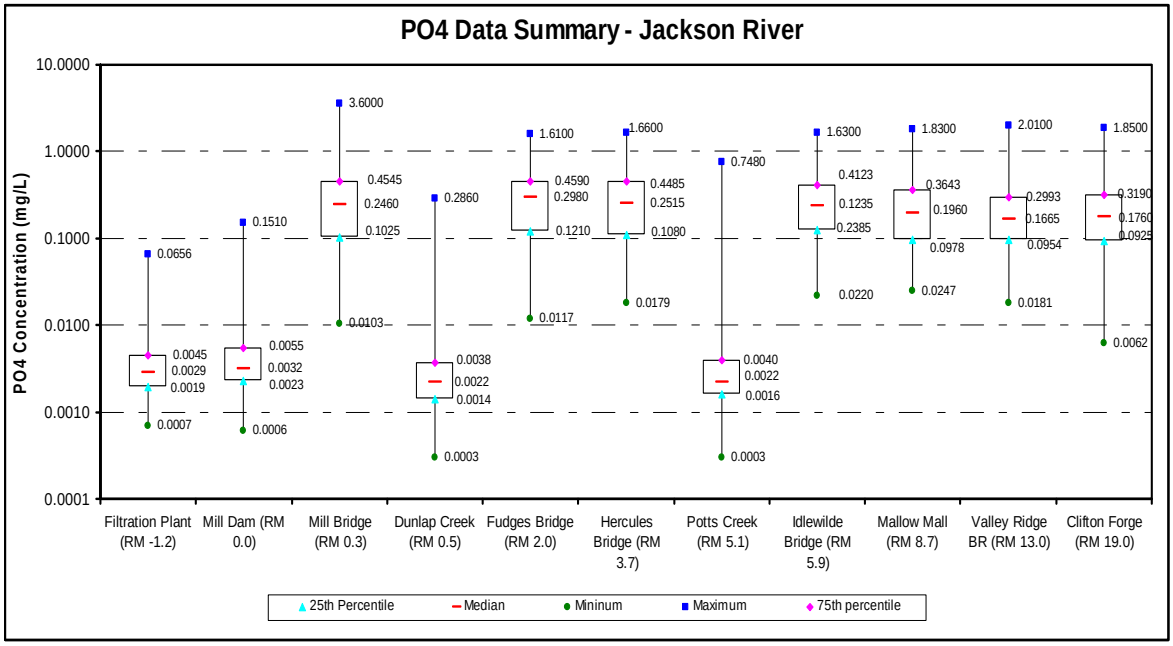


Figure 5-2: PO4-P Data Summary

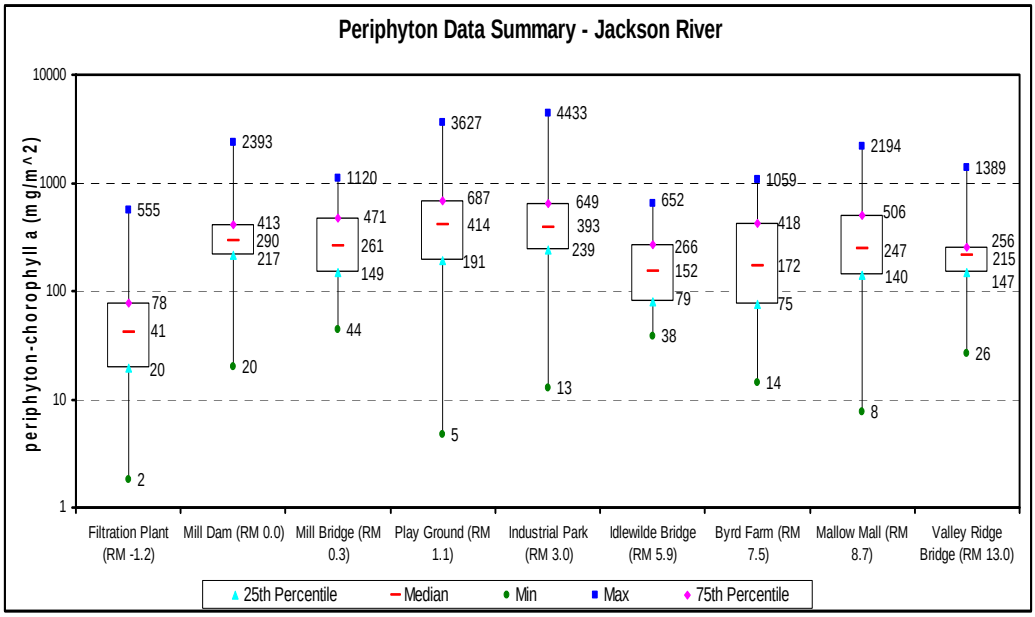


Figure 5-3: Periphyton Data Summary

The TDN data shown in **Figure 5-1** indicate that TDN observations are relatively similar upstream of the MeadWestvaco discharge and in the two tributaries; Dunlap Creek and Potts Creek (median values of 0.24 mg/L). Below the MeadWestvaco discharge, TDN increases to 0.45 mg/l and remains at this level along the Jackson River.

The PO4-P data shown in **Figure 5-2** indicate that PO4-P observations are low upstream of the MeadWestvaco discharge (median values of 0.0029 mg/L and 0.0032 mg/L at City Filtration and Mill Dam, respectively) and in the two tributaries (median value of 0.0022mg/L for Dunlap Creek and Potts Creek). Below the MeadWestvaco discharge, PO4-P increases substantially to approximately 0.25 mg/L (median value).

The periphyton data shown in **Figure 5-3** indicate that almost all the observations are above the 100 mg/m2 threshold discussed previously. Only one station, above the MeadWestvaco discharge (Filtration Plant), has an acceptable level of algal biomass. Above the MeadWestvaco discharge the average N:P (TDN:PO4-P) ratio is approximately 84, suggesting that the stream at this location is phosphorus limited. However, below the MeadWestvaco discharge the N:P ratio shifts drastically to a value of 1.8. This N:P ratio shift is due to the excessive phosphorus loading to the Jackson River.

5.2.3 Discussion of the Regression Models and Development of the TMDL Endpoint

Prior to developing the phosphorus endpoint, the multiple-regression between chlorophyll, TDN and PO4 [Log (Chla) = 0.395*Log (PO4) + 0.359*Log (TDN) + 2.69 (r2 = 0.600)] is presented graphically and discussed. Similarly, the regression between chlorophyll and PO4 is also presented graphically and used to develop the final phosphorus endpoint [Log (Chla) = 0.423*Log (PO4) +2.60 (r2 = 0.597)].

5.2.3.1. Multiple Regression between Periphyton-Chlorophyll, PO4-P, and TDN

In order to visualize this three-dimensional equation, a two-dimensional plot was developed with TDN and PO4-P as x and y axes with the corresponding iso-periphyton-concentrations. The results of this analysis are displayed in **Figure 5-4**.

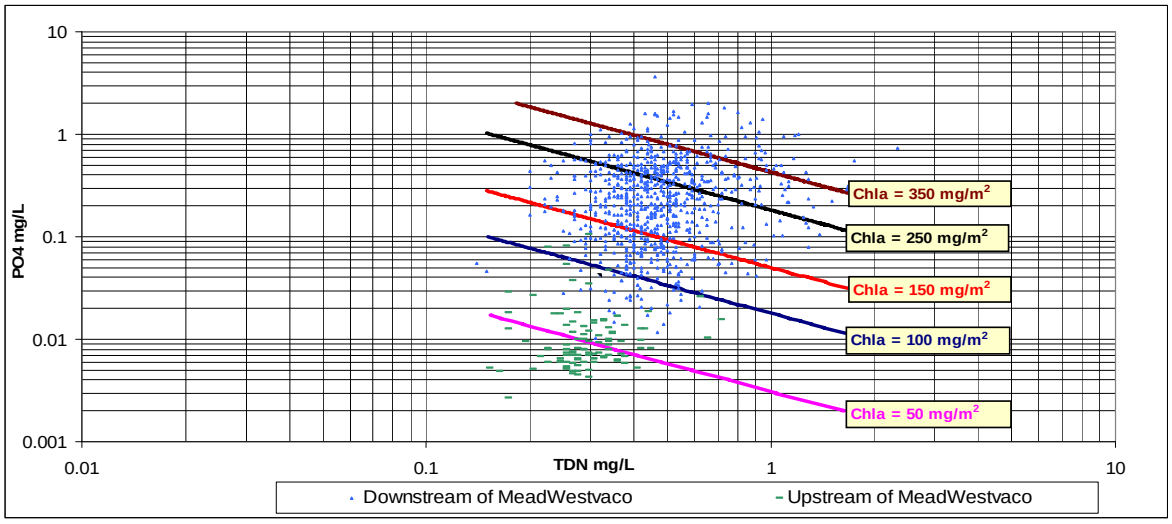


Figure 5-4: Periphyton and Nutrient Relationship in the Jackson River

A computer program was developed to identify the combinations of PO4-P and TDN concentrations resulting in specific periphyton concentrations (50, 100, 150, 250, and 350 mg/m2 of chlorophyll). Each solid line in **Figure 5-4** represents a specific periphyton concentration. For instance, the line labeled "Chla =100 mg/m2" represents the combinations of TDN and PO4-P concentrations which result in a periphyton concentration of 100 mg/m2, using the regression equation Log (Chla) = 0.395*Log (PO4) + 0.359*Log (TDN) + 2.69.

In addition, **Figure 5-4** also displays all the TDN and PO4-P concentrations recorded in the Jackson River (combination of N&P recorded the same day). In fact, two time series of TDN and PO4-P observations are displayed in **Figure 5-4;** one for the observations downstream of MeadWestvaco, and one for the observations upstream of MeadWestvaco. It should be noted that the data used for the derivation of the regression equations is a subset of the one presented in **Figure 5-4** (TDN, Chlorophyll, and PO4-P concentrations).

Figure 5-4 indicates that the regression accurately reproduces the observed periphyton concentrations in the Jackson River. In fact, upstream of the MeadWestvaco discharge at the Filtration Plant Station, the mean chlorophyll concentration is approximately 58 mg/m2 and is well reproduced by the line representing the 50 mg/m2 shown in **Figure 5-4**. In addition, **Figure 5-4** also shows that most of the observations below the MeadWestvaco discharge fall between 200 and 350 mg/m2, which accurately reproduce the observed periphyton data shown in **Figure 5-3**.

The multi-regression equation between Chla, PO4-P, and TDN is used to derive the PO4-P endpoint. [Log (Chla) = 0.395*Log (PO4-P) + 0.359*Log (TDN) + 2.69]. Assuming that the nitrogen level remains unchanged in the Jackson River and at 0.49 mg/L (mean of all the means at all the stations except Filtration Plant, Dunlap, and Potts), PO4-P levels of 0.034 mg/L are needed to achieve a periphyton concentration of 100 mg/m2.

5.2.3.2. Regression between Periphyton-Chlorophyll and Ortho Phosphorus

For the development of the phosphorus endpoint in the Jackson River, the following relationship was used between PO4-P and periphyton-chlorophyll: [Log (Chla) = 0.423*Log (PO4) +2.60 (r2 = 0.602)]. **Figure 5-5** presents the results of the regression analysis with all the data points used and **Figure 5-6** displays this regression along with the corresponding PO4-P concentration for a periphyton concentration of 100 mg/m2. As shown in Figure 6, this relationship results in an average PO4-P concentration of 0.038 mg/L corresponding to an average periphyton concentration of 100 mg/m2. It should be noted that this endpoint is similar to the one derived using the multiple relationship between Chla, PO4-P, and TDN.

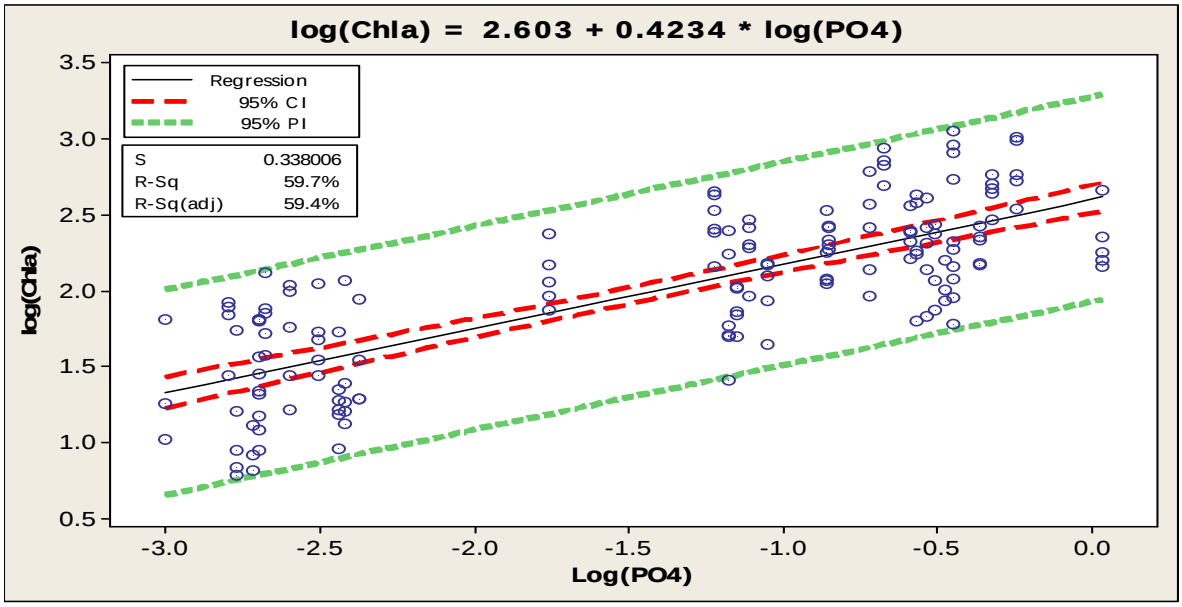


Figure 5-5: Periphyton and PO4-P Regression in the Jackson River

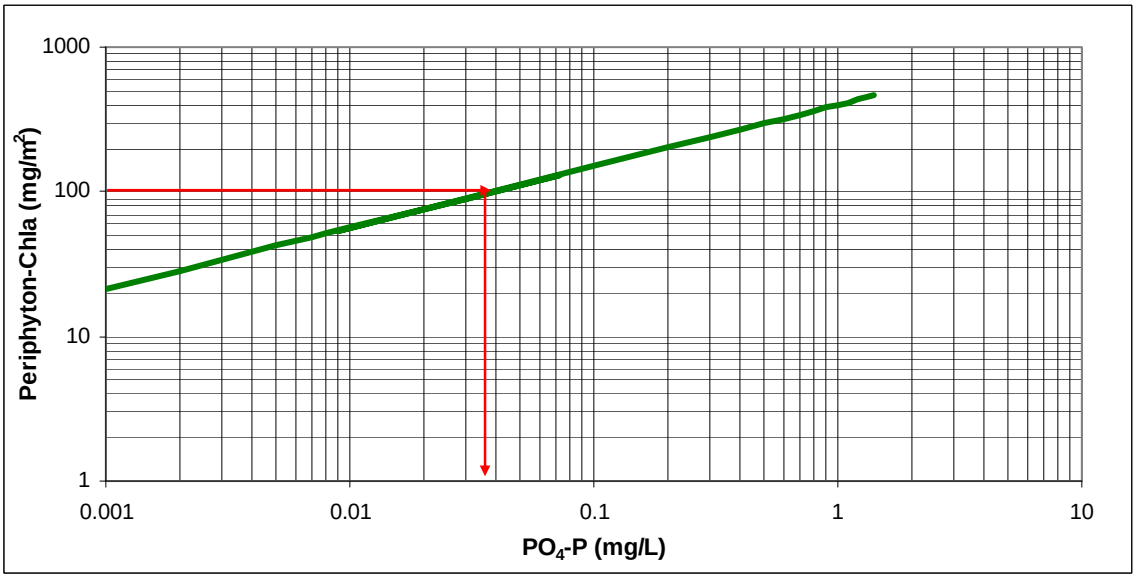


Figure 5-6: Periphyton-PO4-P Regression and TMDL Endpoint in the Jackson River

Table 5-2 depicts the proposed TMDL PO4-P endpoint, the periphyton concentration of 100 mg/m2 and the corresponding TN:TP ratio (total nitrogen versus total phosphorus) for each endpoint. Total nitrogen and total phosphorus was obtained from relationships, using available data from DEQ, between observed TN and TDN (NO2-N + NO3-N +

NH3-N + DON) and observed TP and PO4-P. From these relationships, conversion factors were determined (1.14 for TN/TDN and 1.27 for TP/PO4-P) and applied to the average concentration of TDN in the Jackson River downstream of MeadWestvaco (0.49 mg/L) and to the endpoint for PO4-P (0.038 mg/L), respectively. This resulted to instream total nitrogen of 0.56 mg/L and total phosphorus of 0.048 (at 100 Chlamg/m2) and therefore to a N/P ratio of 11.7.

Table 5-2: Proposed Nutrient TMDL Endpoints and Resulting N:P ratios

PO_4-P TMDL endpoint (mg/L)	Periphyton-Chla (mg/m^2)	N:P ratio
0.038	100	11.7

The TMDL endpoint of 0.038 gm/L for PO4-P at a periphyton chlorophyll concentration of 100 mg/m2 corresponds to a phosphorus-limited system and ensures that the periphyton biomass will be reduced in the Jackson River. Consequently, the initial endpoint for PO4-P is 0.038 mg/L for the Jackson River TMDL will be applied on a monthly basis, consistent with VADEQ permitting practices. The final TMDL endpoint for PO4-P will be evaluated based on multiple flow scenarios using the output from the water quality model WASP7.

6.0 Models Development and Implementation

The overall strategy in support of the TMDL development for the Jackson River consists of applying the EPA Water Quality Simulation Program (WASP7.2) to the impaired segment of Jackson River. Specifically, the WASP7.2 eutrophication module was implemented and includes nitrogen and phosphorus cycling, dissolved oxygen-organic matter interactions, as well as phytoplankton and periphyton kinetics. Point source loads were put into WASP7.2, which was implemented during the time period from June to October. Specifically, years 2000 and 2001 were used to calibrate and validate the model, where extensive data are available. Besides the considerable amount of monitoring data available, the Jackson River experienced the most deteriorated water quality conditions (excessive periphyton growth) during the period of June to October 2000 and 2001.

In order to address nonpoint source loads (NPS), the Hydrological Simulation FORTRAN Program (HSPF) was employed to characterize these loads. The NPS loads output from the HSPF model were formatted and linked to WASP7.2. The following sections provide a description of the two models (WASP7.2 and HSPF) and outline the key steps used in the implementation of the modeling strategy for the Jackson River TMDL.

6.1 WASP7 Model Implementation

The advanced WASP7 module (July 20006), named "periphyton," includes the standard WASP eutrophication algorithms and incorporates bottom algae with three additional state variables: bottom algal biomass, bottom algal cell nitrogen, and bottom algal cell phosphorus.

In WASP7.2, bottom algae concentrations are simulated based on sources and sinks. The impacts of advective and dispersive transport are not considered. As a consequence, elevated velocities, hence greater sheer stress, will not affect the bottom algae in WASP7.2. Sources and sinks include nutrient uptake, growth, nutrient excretion, death, and respiration. Nutrient uptake rates are driven by concentrations of inorganic nitrogen

and phosphorus in the water column and within algal cells, and are controlled by cell minimum and half-saturation parameters. Biomass growth is computed from a maximum zero or first-order rate constant that is adjusted internally by water temperature, bottom light intensity, internal nutrient concentrations, and maximum carrying capacity. Nutrient excretion, death, and respiration are represented by first-order, temperature dependent rates. Growth, respiration, and death rates affect other model state variables, including dissolved oxygen and nutrients. The algorithms for predicting bottom algal biomass and nutrient concentrations in WASP7.2 are based upon the periphyton routines included in the QUAL2K model (Chapra and Pelletier, 2003).

The WASP7.2 model was applied over five months between June 1st and October 31st for 2000, 2001, and 2006, respectively. The model simulation run for 2001 is the calibration run, since 2001 had the most complete set of measured data for model input. The model simulation run for 2000 is the validation run, in which the model input values are the same as in 2001 due to the lack of measurements taken during this period. The model simulation run for 2006 simulates existing conditions of the Jackson River.

6.1.1 WASP 7 Model Segmentation

The model segmentation was based on the location of drainage catchments (for later inclusion of NPS loads), location of major point sources and water quality monitoring stations, and location of tributaries (Dunlap Creek and Potts Creek). The segmentation consists of 24 model segments (18 main-stem segments and 6 tributary-segments) as shown in **Table 6-1**. The initial model segmentation includes volume, length, width, slope, and bottom roughness for each segment. **Figure 6-1** shows the location of the model-segments in the Jackson River.

Table 6-1: WASP7 Model Segments and Characteristics						
Model Segment	**Volume m3**	**Length m**	**Width m**	**Depth m**	**Slope**	**Bottom Roughness**
S1 - Headwater (RM -1.8) to RM -1.5	12710	500	41	0.62	0.0115	0.071
S2 - RM -1.5 to Filtration Plant (RM -1.2)	13650	500	42	0.65	0.0002	0.070
S3 - Filtration Plant (RM -1.2) to RM -0.9	23628	807	43.7	0.67	0.0007	0.070
S4 - RM -0.9 to Mill Bridge (MeadWestvaco)	40138	1403	42.7	0.67	0.0009	0.070
S5 - Mill Bridge to before Dunlap Creek	10304	535	42.8	0.45	0.0090	0.069
S6 Dunlap - (RM 1.2) to RM 0.9	3800	500	20	0.38	0.0001	0.071
S7 Dunlap - RM 0.9 to RM 0.6	5000	500	25	0.4	0.0050	0.071
S8 Dunlap - RM 0.6 to RM 0.0	14080	1000	32	0.44	0.0009	0.071
S9 - After Dunlap Creek to before Fudges Bridge	74682	2379	43.6	0.72	0.0050	0.069
S10 - before Fudges Creek to Industrial Park (RM 3.0)	51578	1805	38.1	0.75	0.0074	0.068
S11 - Industrial Park to Hercules Bridge	67404	1715	39.7	0.99	0.0049	0.067
S12 - Hercules Bridge to before Potts Creek	67109	1541	40.7	1.07	0.0009	0.067
S13 Potts - (RM 1.2) to RM 0.9	3800	500	20	0.38	0.0021	0.071
S14 Potts - RM 0.9 to RM 0.6	5000	500	25	0.4	0.0033	0.071
S15 Potts - RM 0.6 to RM 0.0	14080	1000	32	0.45	0.0038	0.071
S16 - Potts Creek to Idlewidle Bridge (Covington STP)	43681	1325	40.7	0.81	0.0006	0.066
S17 - Idlewilde Bridge to Mallow Mall	222343	4756	42.5	1.1	0.0003	0.065
S18 - Mallow Mall	233996	4727	46.7	1.06	0.0005	0.063
S19 - RM 11.7 to before Valley Bridge	111881	2239	46.7	1.07	0.0004	0.062
S20 - before Valley Bridge to RM 15.8	228673	4372	46.7	1.12	0.0003	0.061
S21 - RM 15.8 to RM 17.3	121032	2445	46.7	1.06	0.0003	0.060
S22 - RM 17.3 to RM 19.6 (Berger's Mile)	180688	3616	46.7	1.07	0.0007	0.059
S23 - RM 19.6 to RM 21.6 (Clifton Forge STP)	174277	3332	46.7	1.12	0.0003	0.058
S24 - RM 21.6 to RM 24.1	208641	3989	46.7	1.12	0.0004	0.056

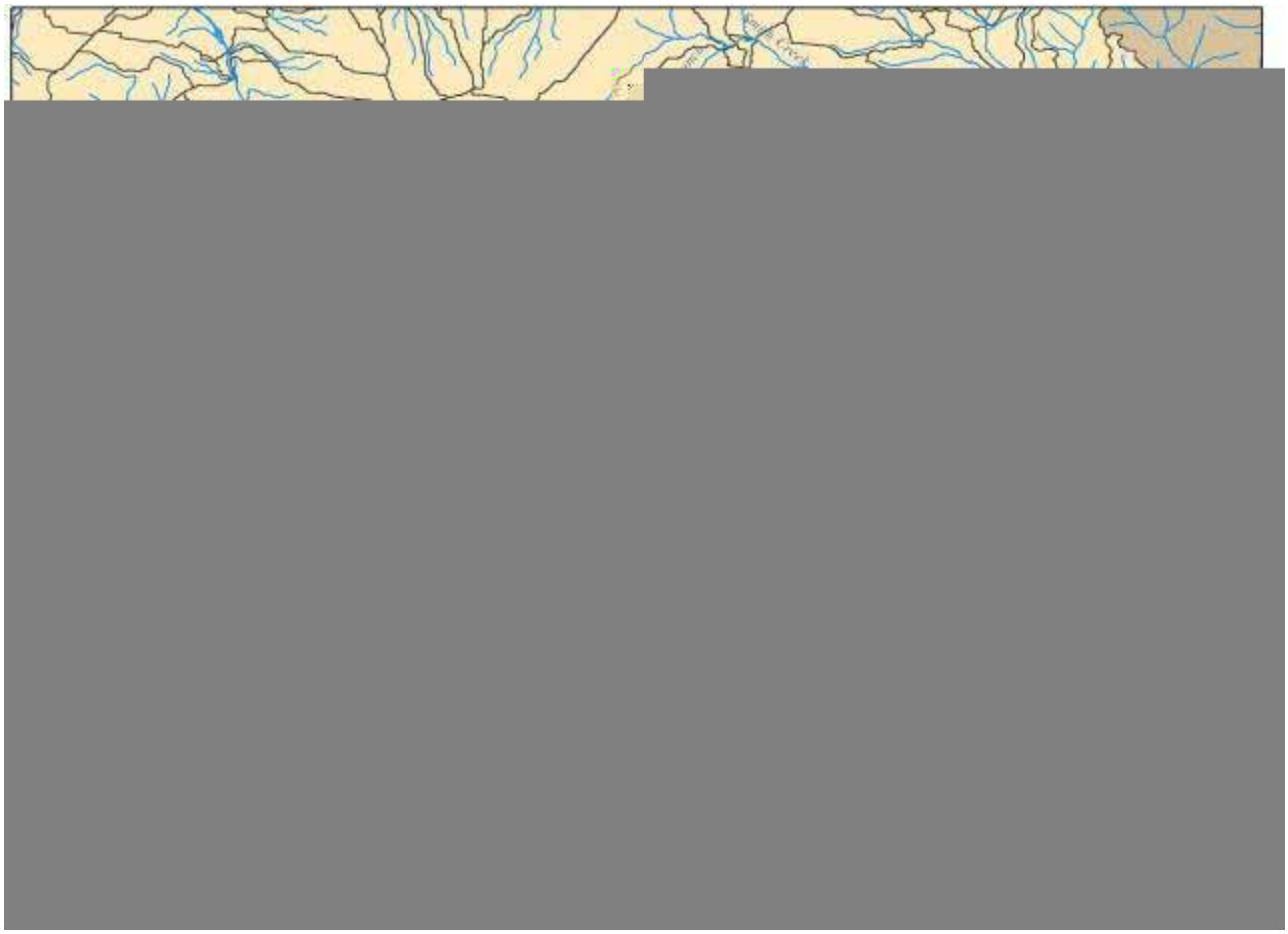


Figure 6-1: Jackson River Model Segments

6.1.2 WASP7 Model Boundaries

Five boundaries were defined within the model framework. The first boundary is the headwater for the model located at the Filtration Plant. The remaining four boundaries are major dischargers in Jackson River (Clifton Forge City STP, MeadWestvaco, Covington City STP, and Alleghany County WWTP).

6.1.3 WASP7 Model Hydraulics

The Jackson River Modeling application (WASP7.2) uses the Kinematic Wave Equation option to compute flow wave propagation resulting in variable flows, volumes, depths, and velocities throughout the modeled network. The input data required for the Kinematic Wave Equation consists of:

- Time-variable upstream and tributary inflows (Filtration plant, Dunlap Creek, and Potts Creek)
- Continuity flow paths for main stem and each tributary
- Channel properties:
  - length (m), width (m), initial depth (m)
  - bottom slope (m/m)
  - Manning's roughness coefficient

6.1.4 WASP7 Model Input

The model requires instream water quality input variables at boundary stations (headwaters and point sources) and time functions for light extinction coefficient, temperature, and solar radiation. The input variables for all three simulation runs (calibration, validation, and existing condition) are summarized in **Table 6-2**.

Table 6-2: Source of WASP7 Input Data for Simulation Runs in 2001. 2000. and 2006

						Time Functions		
WASP 7.2 Simulation Runs	**Year**	**Input for Headwaters[1]**		**Point Sources**		**Temperature**	**ke[2]**	**Solar Radiation**
		Flow	**Conc.**	**Flow**	**Conc.**			
Calibration	2001	Gathright Dam and USGS flow of 2001	observed instream data by Mead Westvaco	Average flow of 2001	HydroQual Report: time series	MeadWestvaco/HydroQual Model	MeadWestvaco/HydroQual Model	MeadWestvaco/HydroQual Model
Validation	2000	Gathright Dam and USGS flow of 2000	same data as in calibration run 2001	Average flow of 2000	HydroQual Report: constant value	same data as in calibration run 2001	2001 values adjusted for calibration	MeadWestvaco/HydroQual Model
Existing Condition	2006	Gathright Dam and USGS of 2006	VADEQ	Average flow of 2006	MeadWestvaco	estimated	computed internally in WASP7.2	Computed[3]

[1] headwaters: upstream of Filtration Plant, Dunlap Creek, and Potts Creek

[2] Light extinction coefficient

[3] SolarCalc (Version 1.0) by United States Department of Agriculture

The calibration run (2001) incorporates the most complete set of observed data measured between May and October 2001 when compared to simulation runs in 2000 and 2006. The model input for headwaters (upstream of Filtration Plant, Dunlap Creek, and Potts

Creek) were based on measured values by MeadWestvaco. The model input for the point sources (MeadWestvaco, Covington City STP, and Clifton Forge City STP) were retrieved from the report "*Development and Calibration of the Jackson River Periphyton Model*" (HydroQual 2003). The three time functions (temperature, light extinction coefficient, and hourly solar radiation) were also obtained from the Jackson River Periphyton Model developed by MeadWestvaco/HydroQual (Hydroqual 2003).

Input data for the validation run (2000) uses observed data from 2000 and 2001 as well as computed data, since instream and effluent measurements was very limited for 2000. For instance, the nutrient concentrations for the headwaters, the temperature time function, and the solar radiation were based on 2001 measured data. Observed effluent was also limited availability and consisted of one constant value over the simulation period.

Input data for the existing condition run (2006) uses light extinction coefficient computed internally. The hourly solar radiation between June 1st and October 31st was computed based on the simulation program SolarCalc (Version 1.0) developed by the United States Department of Agriculture. Instream temperature data was estimated using temperature time function for 2001 and air temperature for 2001 and 2006 respectively.

6.2 HSPF Model Description

The Hydrologic Simulation Program-Fortran (HSPF) is a continuous, physically based, lumped-parameter model which simulates hydrology, sediment, and chemical pollutants in the soil and in streams. Nutrient simulation modules are detailed and flexible, and thus can be used to simulate a variety of land use types. This model is normally calibrated to observed flow and water quality data measured at the outlet of a watershed.

The Chesapeake Bay Program in Annapolis calibrated the HSPF Model over the entire Chesapeake Bay watershed. The model divides the 64,000 square mile Chesapeake Bay drainage basin into model segments. Each segment contains information generated by a hydrologic sub-model, a nonpoint source sub-model and a river sub-model. The hydrologic sub-model uses rainfall, evaporation and meteorological data to calculate

runoff and subsurface flow for all the basin land uses including forest, agricultural and urban lands. The surface and subsurface flows ultimately drive the nonpoint source sub-model, which simulates soil erosion and the pollutant loads from the land to the rivers. The river sub-model routes flow and associated pollutant loads from the land through lakes, rivers and reservoirs to the Bay. In the most recent version of the Chesapeake Bay model, Phase 5, flow and water quality data from 1985 to 2003 were used for the calibration of the model.

6.2.1 HSPF Model Implementation

The Jackson River is part of the James River Basin which drains to the Chesapeake Bay watershed. Consequently, the Louis Berger Group acquired the calibrated HSPF model files for the entire James River Basin, and implemented the model. The model was calibrated from 1985 to 1999 and validated during the period spanning 2000 to 2003. The validation files are used to generate nutrient loads for the Jackson River TMDL, since they coincide with our instream model (WASP7) calibration and validation periods.

HSPF model input files and data specific to the James River were processed and the model was implemented for the specific model-segments comprising the Jackson River watershed. **Figure 6-2** shows the Chesapeake Bay HSPF model-segments included in the estimation of the NPS loads in the Jackson River. The first step of the HSPF model implementation for the Jackson River TMDL consists of generating the runoff and nutrient NPS loads from each HSPF model-segment in the Jackson River. As shown in **Figure 6-2**, each of the HSPF model segment include several WASP7.2 model segments. The next step consists of distributing the HSPF-model output to each specific WASP7 model-segment using its specific drainage area for each WASP model-segment.

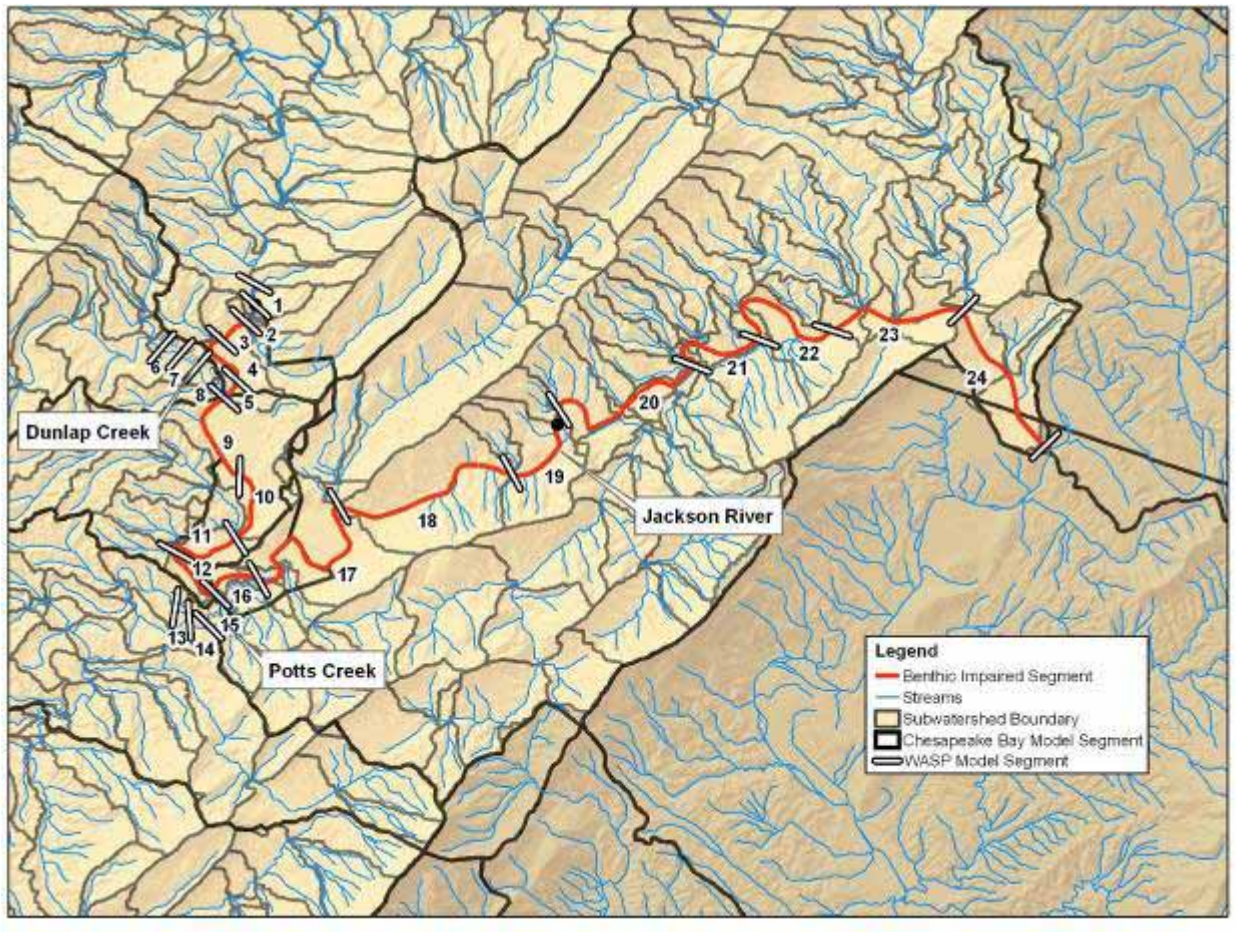


Figure 6-2: HSPF Model Segments

6.3 Modeling Results

This section presents the simulation output resulting from the implementation of the WASP7.2 and HSPF models. It includes the flow and water quality simulation output from the WASP7.2 model.

6.3.1 Stream Flow Modeling Results

As mentioned in Section 6.1.3, the WASP7.2 model uses the Kinematic Wave Equation to compute flow and velocities throughout the modeled Jackson River stream network. Output to the Jackson River WASP segments include tributary flows from Dunlap Creek and Potts Creek, upstream flow at the filtration plant which consists of Gathright Dam release, and runoff flows into each WASP model-segment generated from the HSPF

model. **Figure 6-3** compares the simulated and observed flows for year 2001 at the City Park USGS station (USGS 02013100) and shows agreement with observed and simulated values. Similarly, **Figure 6-4** depicts the simulated and observed flows at the City Park USGS station for the year 2000.

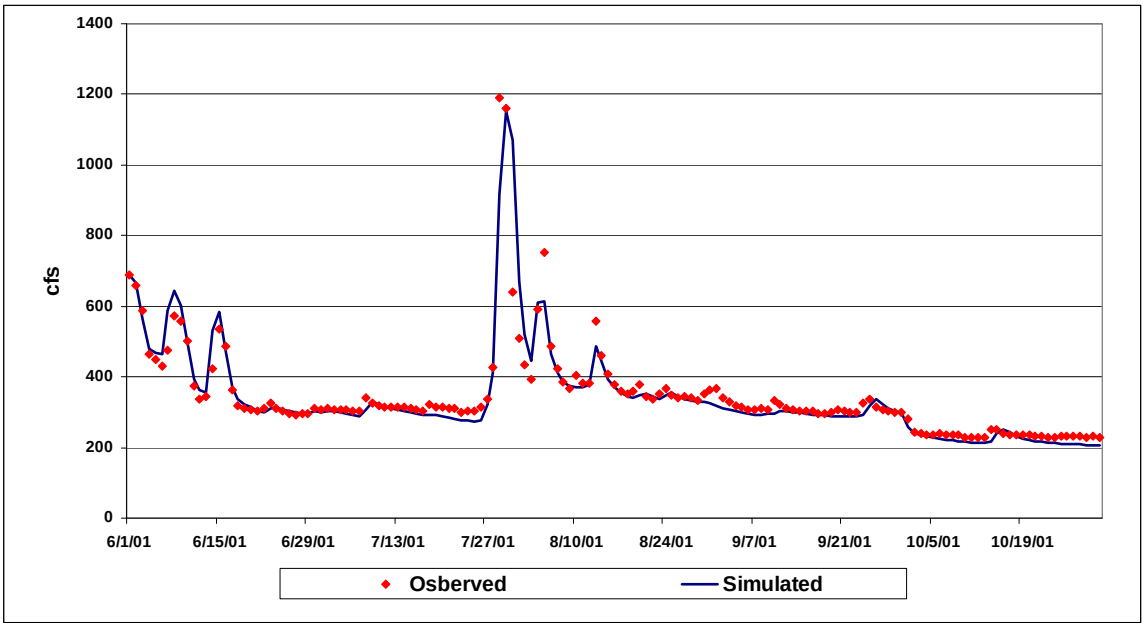


Figure 6-3: 2001 Flow Simulation at City Park (USGS 020131000)

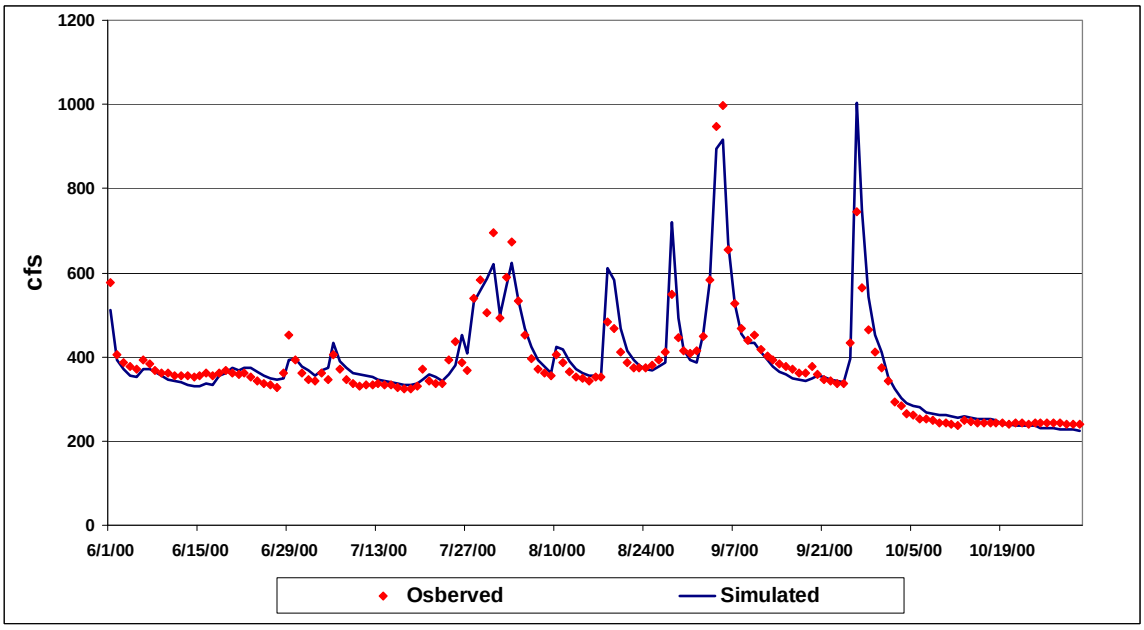


Figure 6-4: 2000 Flow Simulation at City Park (USGS 020131000)

6.3.2 Water Quality Calibration

This section presents the results of the water quality calibration for the Jackson River. In addition, it provides information on the periphyton parameterization used for the calibration.

The WASP7.2 model requires instream water quality input variables at boundary stations (headwaters and point sources) and time functions for light extinction coefficient, temperature, and solar radiation. The water quality input variables for headwaters are based on data measured by MeadWestvaco between June and October 2001. The water quality input for point sources were obtained from HydroQual (2003). Four time functions for the light extinction coefficient and temperature, respectively, were retrieved from the Jackson River Periphyton Model by MeadWestvaco/HydroQual and applied to the WASP7.2 calibration model. The solar radiation function was also retrieved from the Jackson River Periphyton Model by MeadWestvaco/HydroQual.

An important component of the water calibration is the model parameterization, especially for the benthic algae constants and parameters, where the model coefficients and variables are derived using several studies and reports (Bowie *et al.*, 1985, Brown and Barnwell, 1987, Bott, 1998 and 1999, Academy, 2001, HydroQual, 2003, Chapra, 2006). Model parameters 1 through 5; shown in **Table 6-3**, were established based on measurements conducted in June and August 2000 (Academy, 2001) and parameters 6, 7, and 10 based on measurements conducted in October 1998 (Bott, 1999). The remaining parameters were obtained from other studies and reports and were used in the calibration of the model (Bowie *et al.*, 1985, Brown and Barnwell, 1987, Bott, 1998, HydroQual, 2003, Chapra, 2006). **Table 6-3** shows the parameterization of the WASP7.2 periphyton component used in all three simulation runs (calibration, validation, and existing conditions).

Table 6-3: WASP7.2 Periphyton Model Parameterization	
Model Parameter	**Value**
Benthic Algae D:C Ratio (mg Dry Weight/mg C)	9.47
Benthic Algae N:C Ratio (mg N/mg C)	0.132
Benthic Algae P:C Ratio (mg P/mg C)	0.021
Benthic Algae Chl a:C Ratio (mg Chlorophyll a / mg C)	0.025
Benthic Algae O2:C Production (mg O2/mg C)	2.7
Growth Model, 0 = Zero Order; 1 = First Order	1
Max Growth Rate (gD/m2/d for 0-order growth, 1/d for 1-order growth)	0.88
Temp Coefficient for Benthic Algal Growth	1.068
Carrying Capacity for First Order Model (gD/m2)	500
Respiration Rate Constant (1/day)	0.1
Temperature Coefficient for Benthic Algal Respiration	1.1
Internal Nutrient Excretion Rate Constant for Benthic Algae (1/day)	0.06
Temperature Coefficient for Benthic Algal Nutrient Excretion	1.06
Death Rate Constant (1/day)	0.1
Temperature Coefficient for Benthic Algal Death	1.07
Half Saturation Uptake Constant for Extracellular Nitrogen (mg N/L)	0.15
Half Saturation Uptake Constant for Extracellular Phosphorus (mg P/L)	0.2
Inorganic Carbon Half-Saturation Constant (not implemented) (moles/L)	0.005
LIGHT OPTION, 1=Half saturation, 2=SMITH, 3= STEELE	2
Light Constant for growth (langleys/day)	135
Benthic Algae ammonia preference (mg N/L)	0.03
Minimum Cell Quota of Internal Nitrogen for Growth (mgN/gDW)	4
Minimum Cell Quota of Internal Phosphorus for Growth (mgP/gDW)	0.6
Maximum Nitrogen Uptake Rate for Benthic Algae (mgN/gDW-day)	52.798
Maximum Phosphorus Uptake Rate for Benthic Algae (mgP/gDW-day)	19.007
Half Saturation Uptake Constant for Intracellular Nitrogen (mgN/gDW)	7.603
Half Saturation Uptake Constant for Intracellular Phosphorus (mgP/gDW)	0.422

6.3.3 Calibration Results

This section presents the WASP7.2 calibration results for the period of June through October 2001. The calibration results include a graphical comparison between observed and predicted results. A graphical comparison between observed and simulated instream concentrations provides the first check of the accuracy of the predicted values. In addition and to further test the model, statistical techniques are used to quantify the accuracy of the models results (Power, 1993; Mayer and Butler, 1993) focusing on comparing observed and simulated values through cumulative distribution functions (CDFs). The CDF allows one to capture the magnitude and frequency of concentrations.

In addition, the statistical distribution of observed and simulated values is more important than fitting precise timing given uncertainty of exact loading of nutrient inputs form point sources (Thomann and Barnwell, 1980, EPA Chesapeake Bay Office 2004).

The CDFs were computed using paired observed and simulated values. Paired values consist of simulated and observed values generated. For instance, when there are 30 observed values for the period of interest (June to October) the corresponding 30 simulated values will be used to generate the median relative error (consisting of 30 paired values).

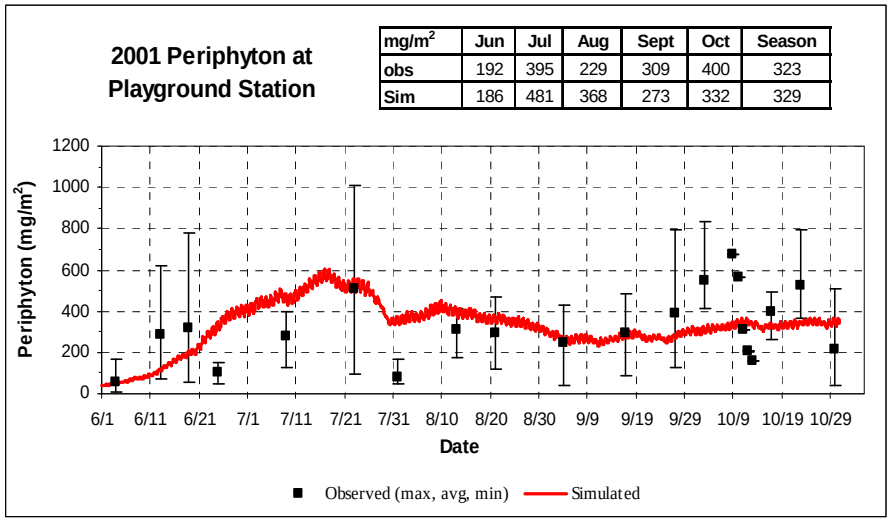
In addition to the CDF for each simulated and observed variable, the mean observed and simulated value for each month and the growing season (June through October) are shown in each figure.

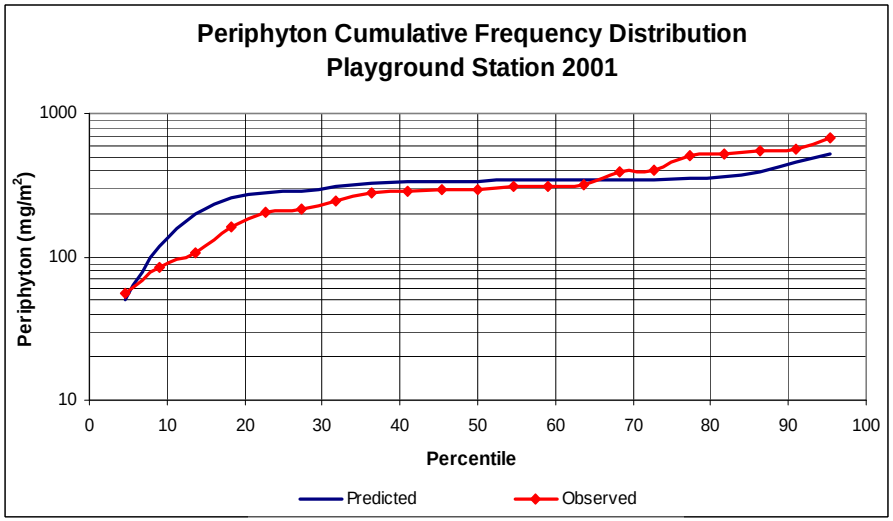
Overall, the calibration results reproduce the observed data quite well. **Figures 6-5** and **6-6** depict simulated and observed periphyton and CDFs at Playground, Industrial Park, Dabney Bridge, and Mallow Mall respectively.

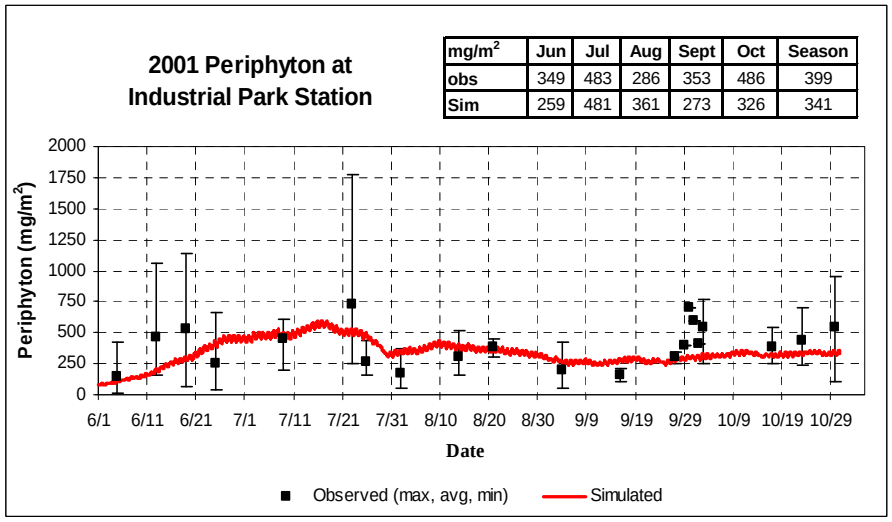
Figures 6-7 through **6-12** depict simulated and observed nutrients (ammonia, nitrate, and ortho-phosphorus) at Mallow Mall, Pedestrian Bridge, and Hercules Bridge respectively.

Figure 6-13 depicts the simulated values of dissolved oxygen at Mill Bridge, Playground, Industrial Park, and Mallow Mall, respectively.

Figure 6-14 depicts the spatial comparison of observed and simulated values along the Jackson River for ammonia, nitrate, ortho-phosphorus, and periphyton.







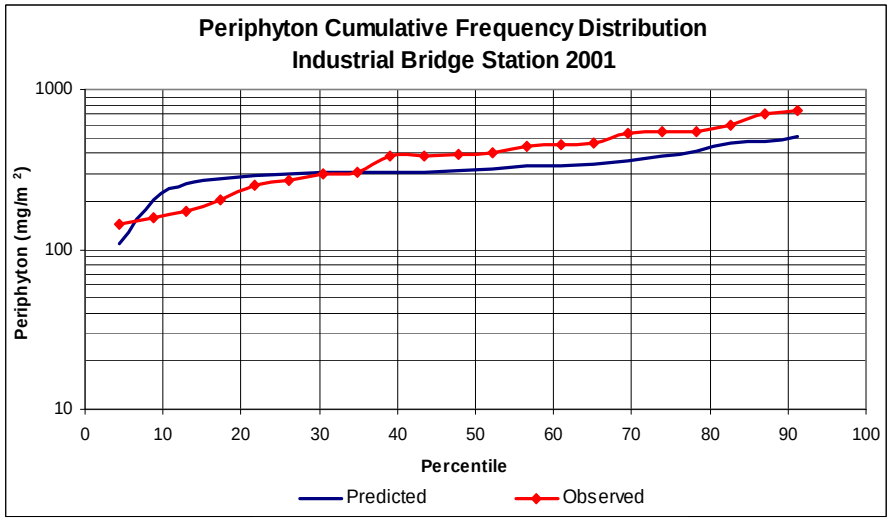
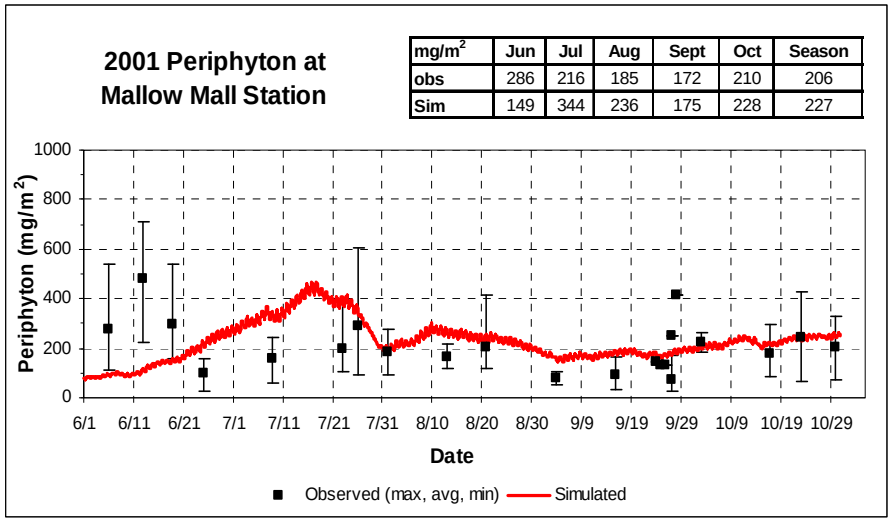
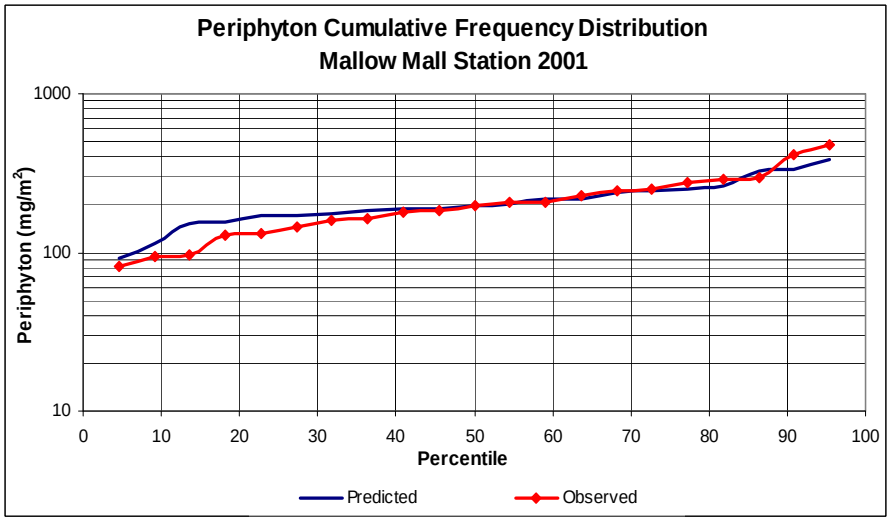
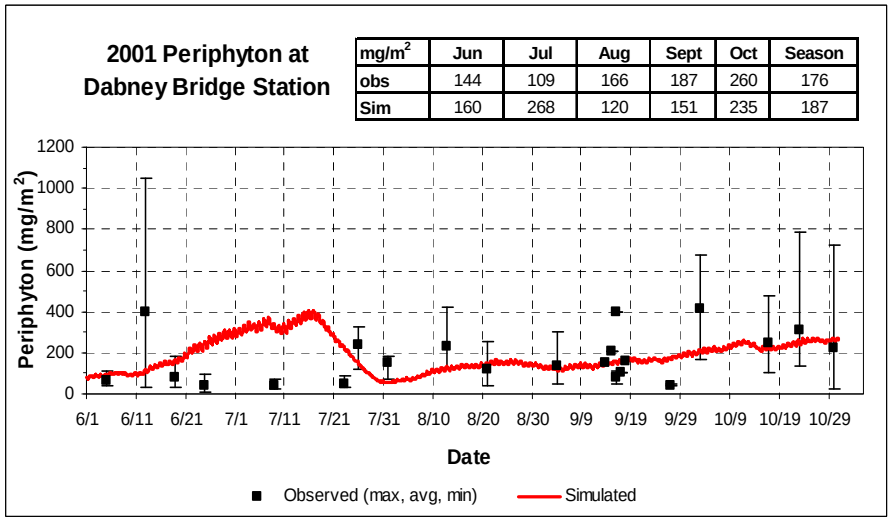


Figure 6-5: 2001 Periphyton at Playground and Industrial Park







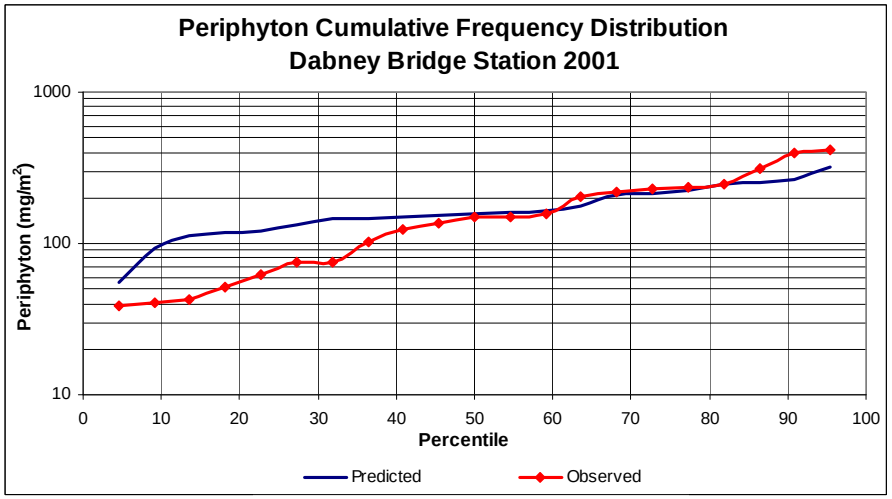
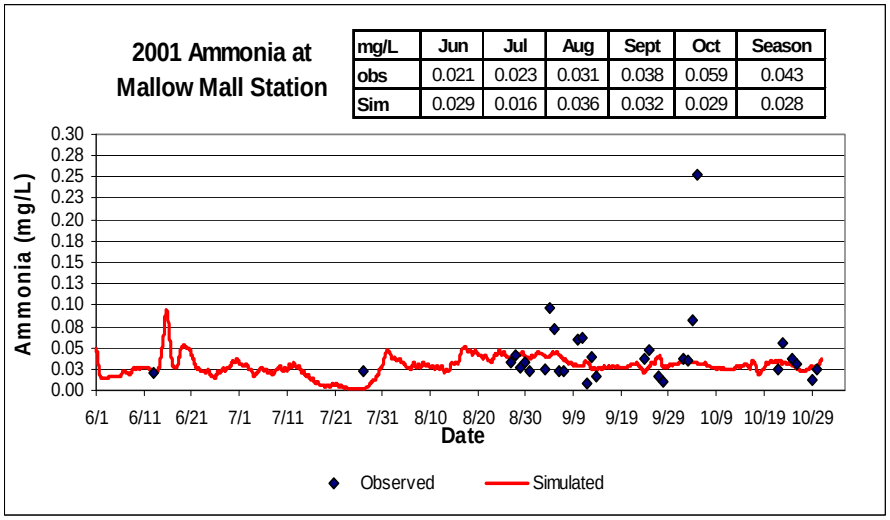
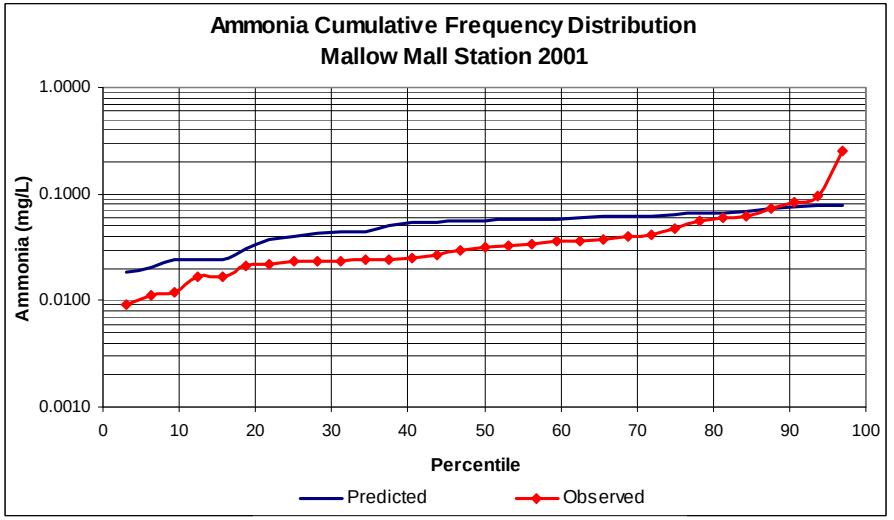
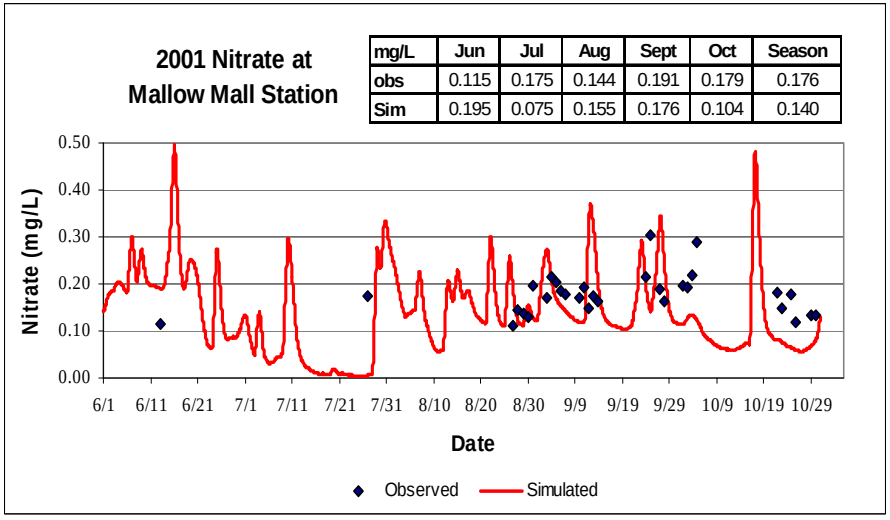


Figure 6-6: 2001 Periphyton at Mallow Mall and Dabney Bridge







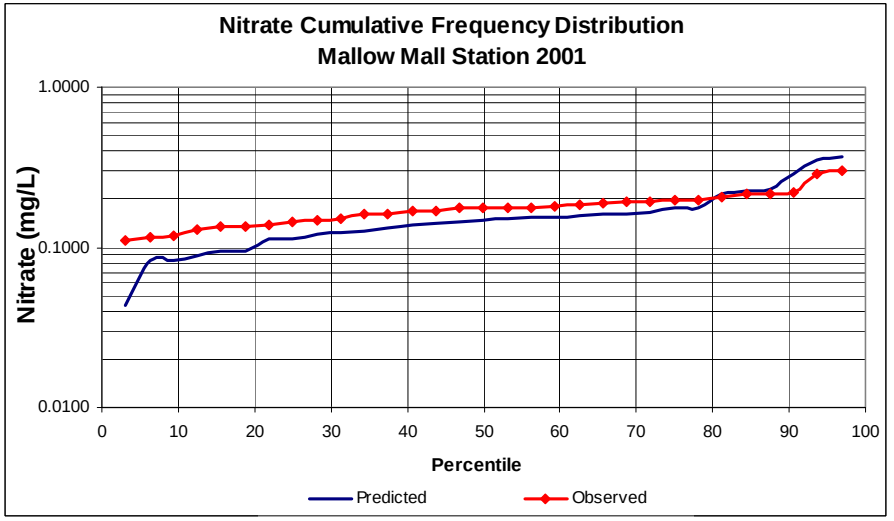
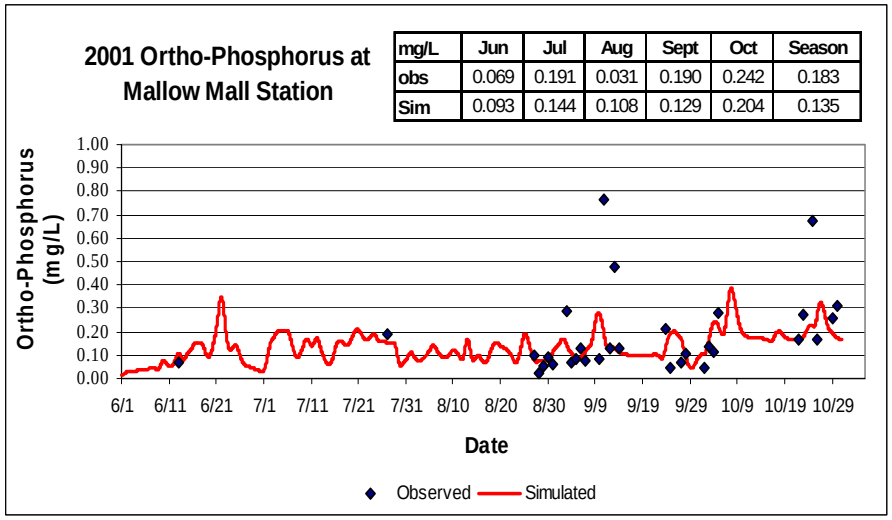


Figure 6-7: 2001 Ammonia and Nitrate at Mallow Mall



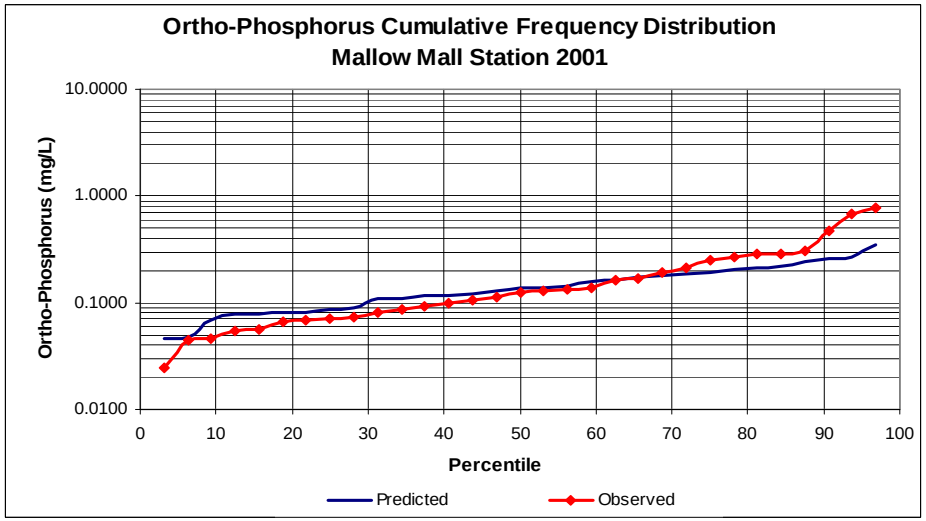
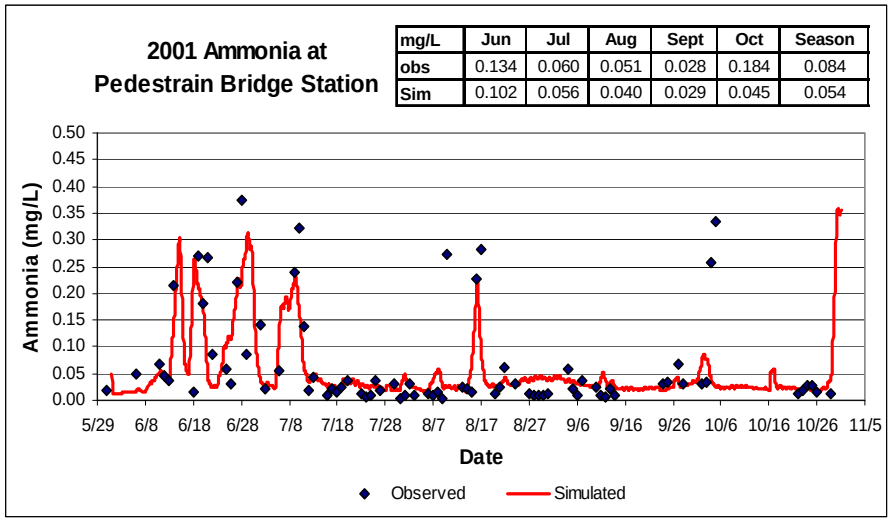
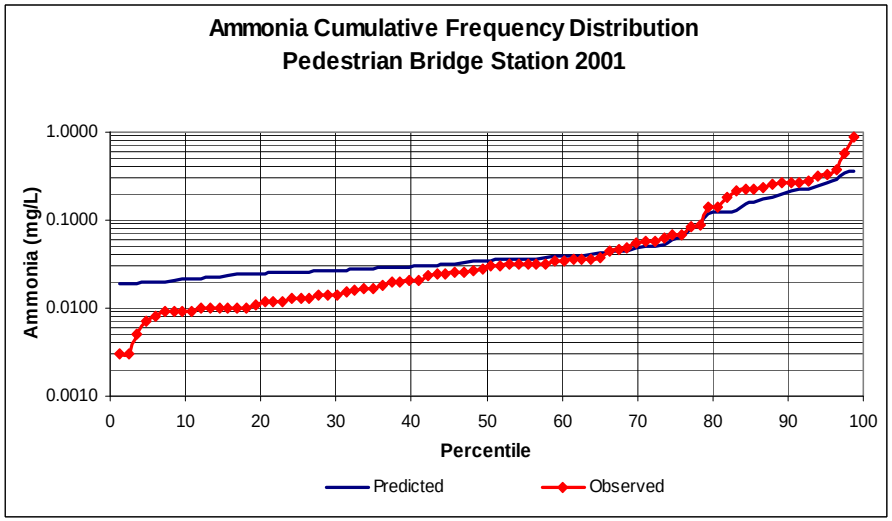
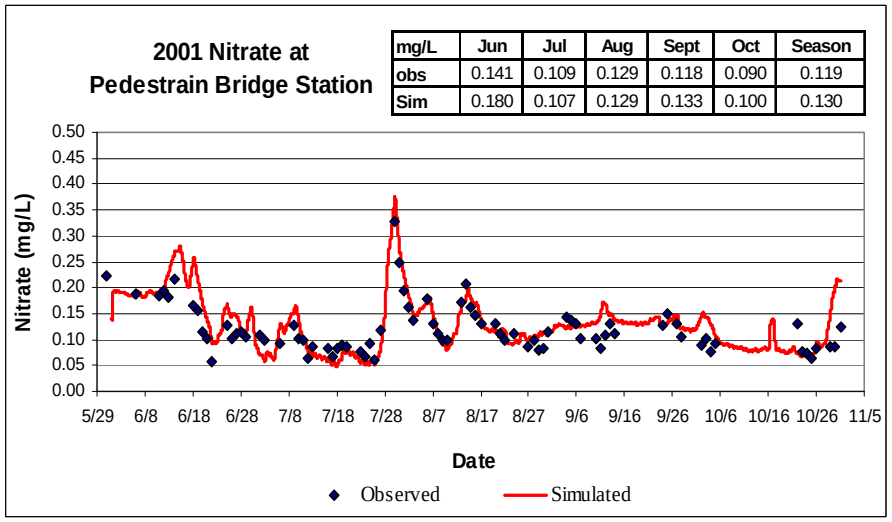


Figure 6-8: 2001 Ortho-Phosphorus at Mallow Mall







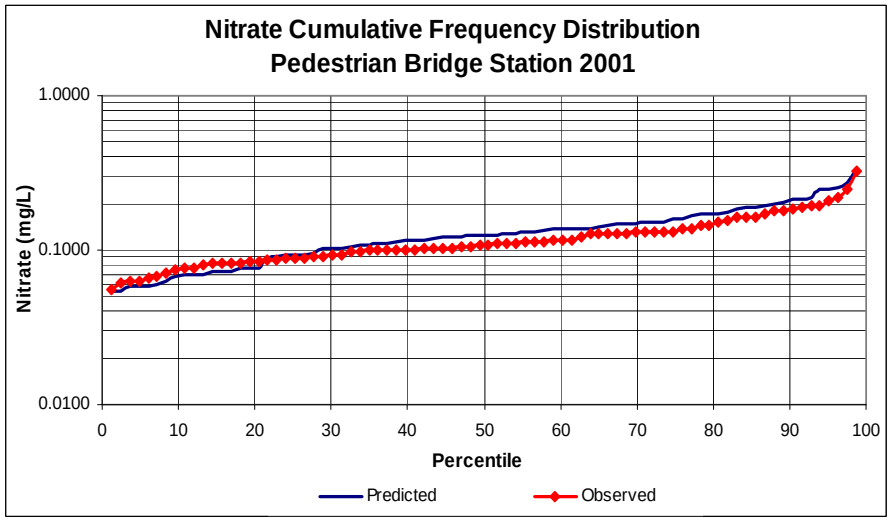
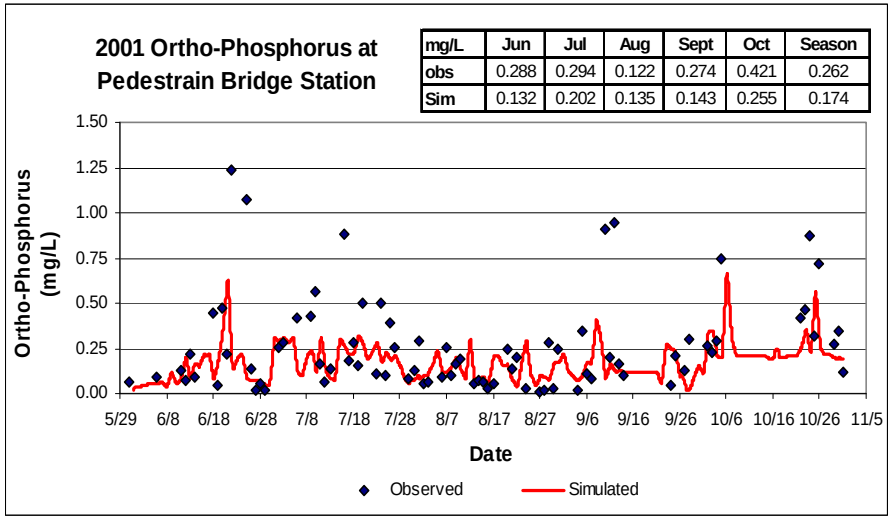


Figure 6-9: 2001 Ammonia and Nitrate at Pedestrian Bridge



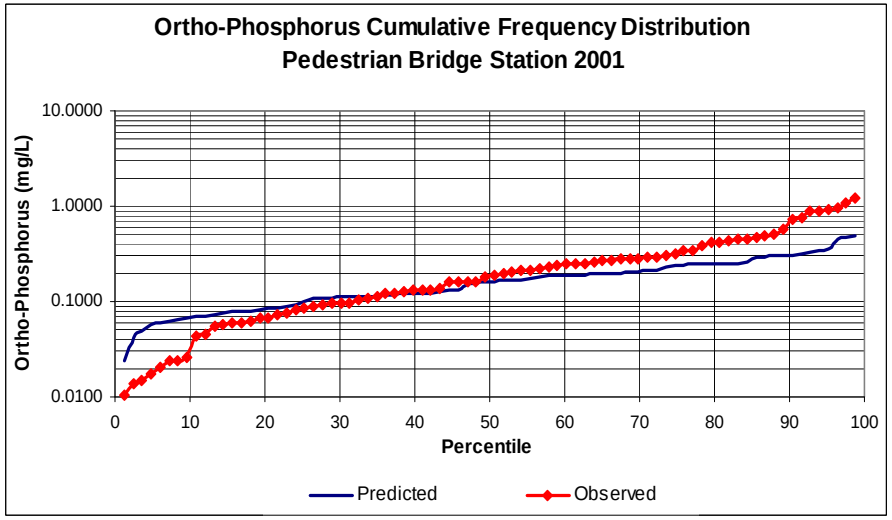
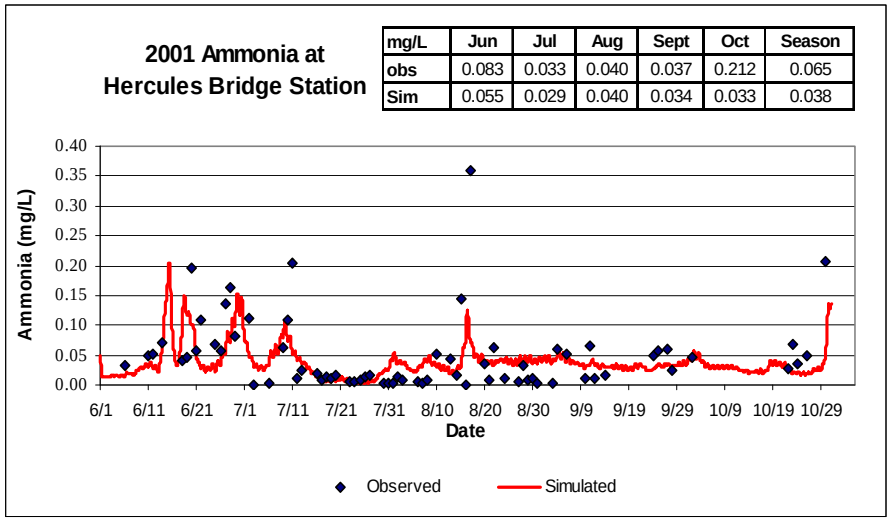
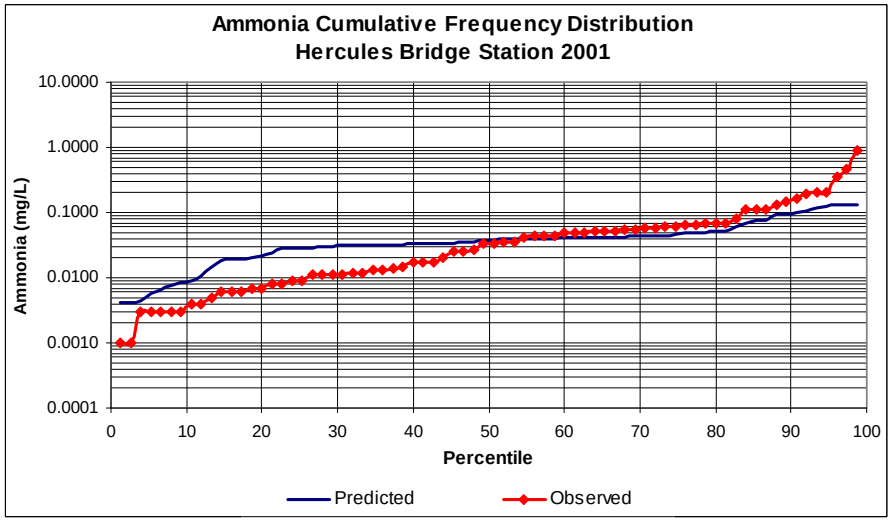
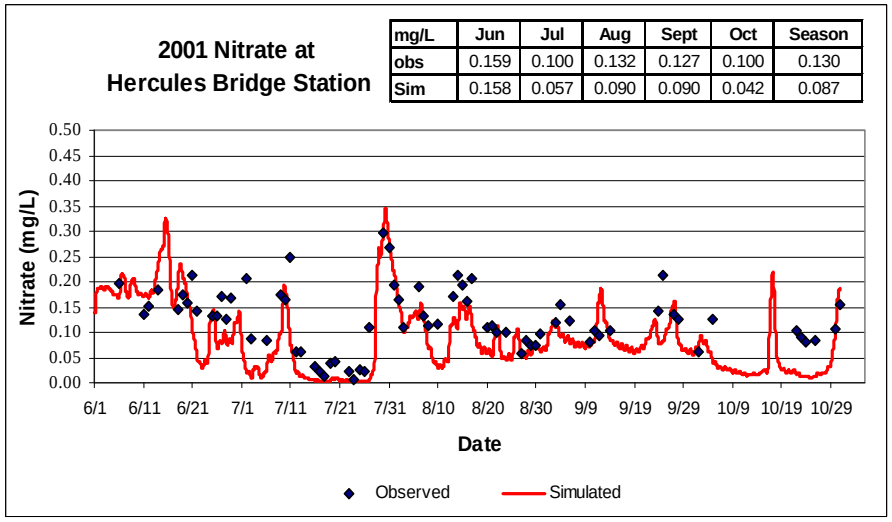


Figure 6-10: 2001 Ortho-Phosphorus at Pedestrian Bridge







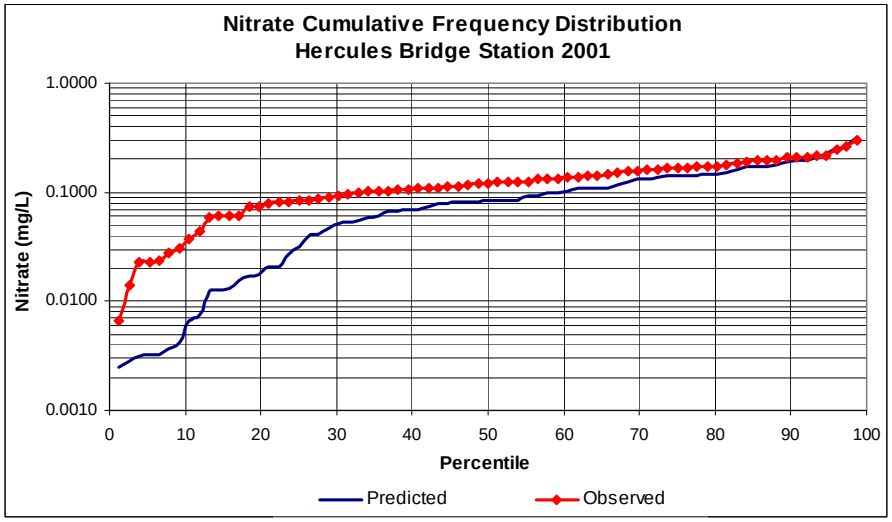
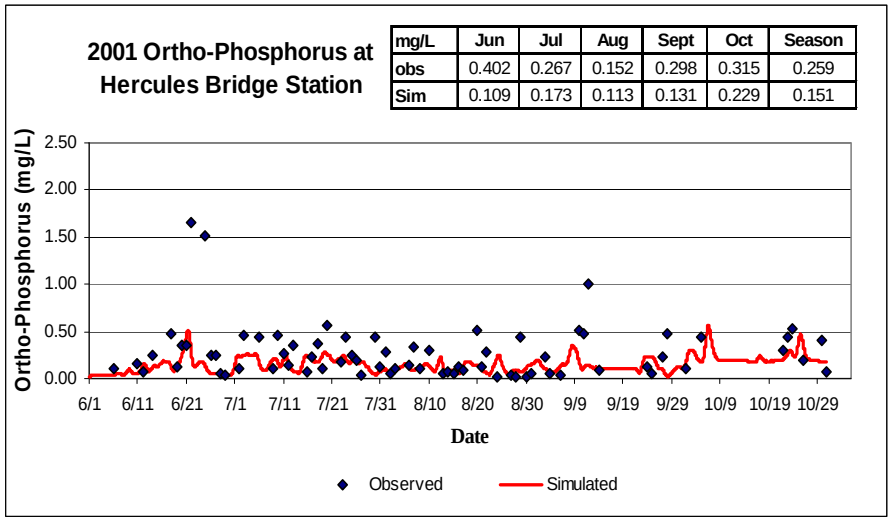


Figure 6-11: 2001 Ammonia and Nitrate at Hercules Bridge



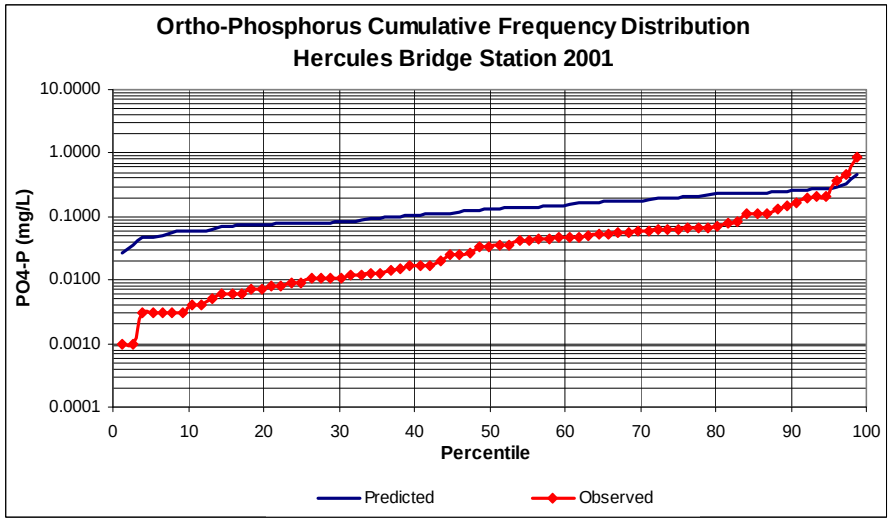
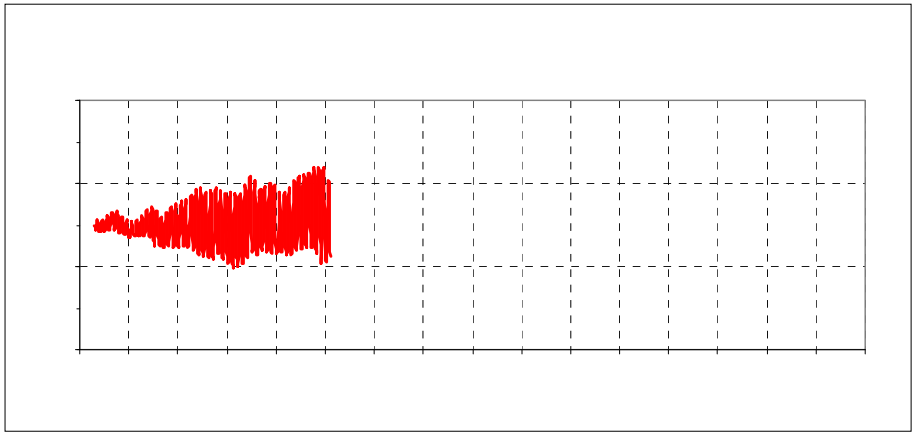


Figure 6-12: 2001 Ortho-Phosphorus at Hercules Bridge



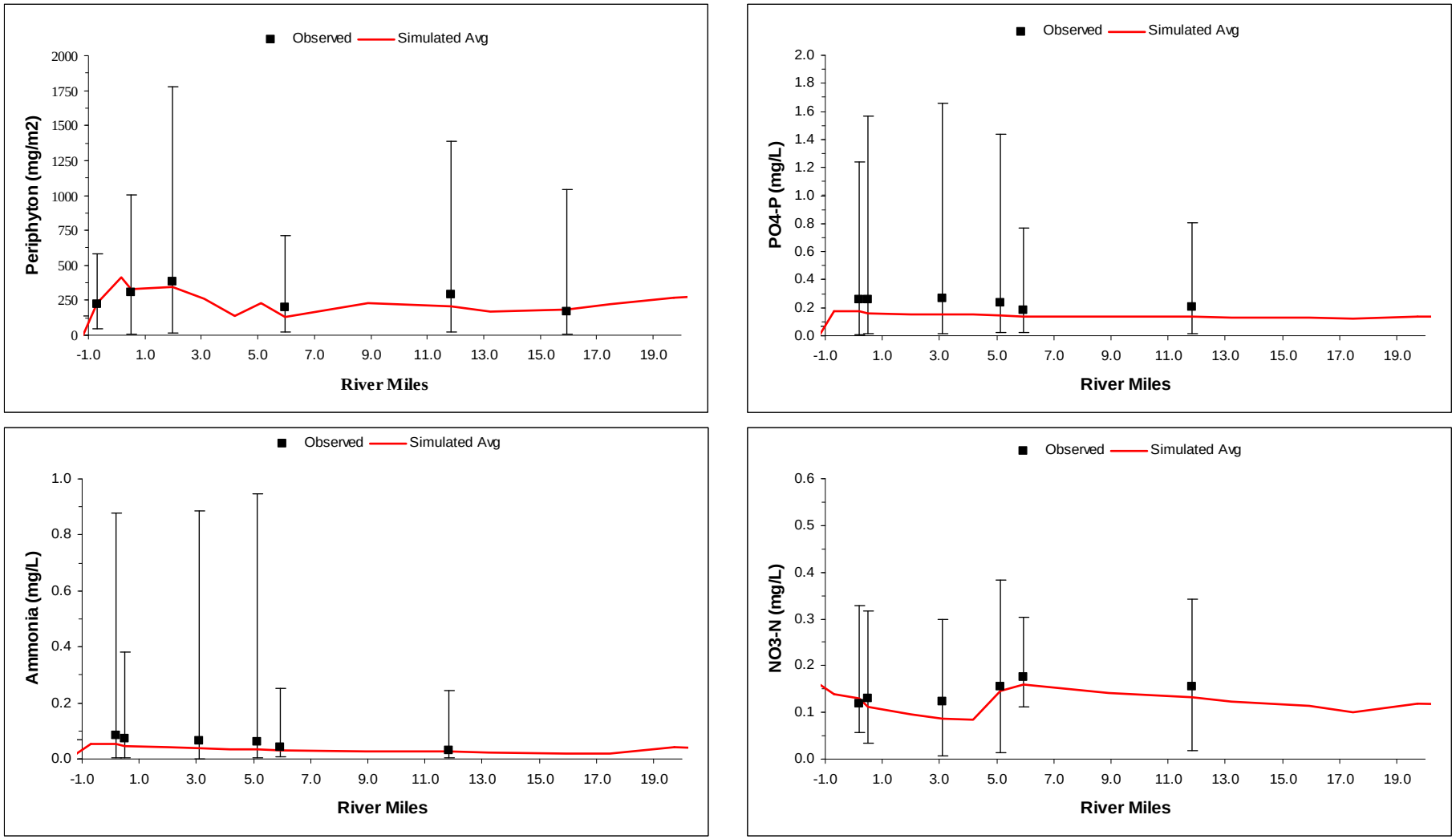


Figure 6-14: 2001 Spatial Comparison of Periphyton, Ammonia, Nitrate, Ortho-Phosphorus, and Periphyton

6.3.4 Validation Results

This section presents the WASP7.2 validation results for the growing season of June through October 2000. It also presents cumulative frequency distributions (CDF) for observed and simulated periphyton. CDFs were not developed for nutrients because of the limited amount of observed data available. In addition to presenting the CDF for periphyton, the mean observed and simulated value for each month and the growing season are shown in each figure.

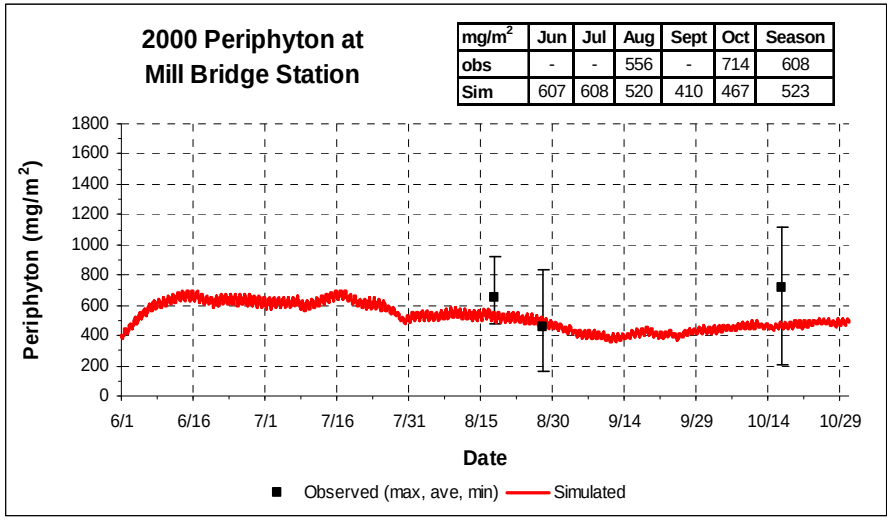
Overall, the validation run reproduced the observed data significantly less accurately than the calibration run. This can be attributed to the limited data available for the validation run. For instance, the variability over time could not be simulated well in the model since the nutrient input values for effluent were based on a constant load.

Figures 6-15 through **6-17** depict simulated and observed periphyton, and the cumulative frequency distributions for periphyton at Mill Bridge and Playground, Industrial Park, Mallow Mall, and Dabney Bridge.

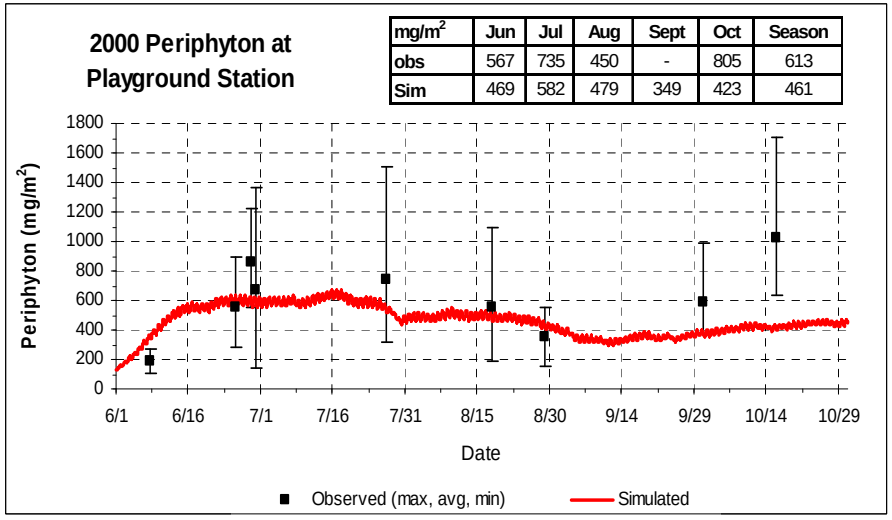
Figures 6-18 through **6-20** depict simulated and observed nutrients (ammonia, nitrate, and ortho-phosphorus) at Mill Bridge, Fudges Bridge, and Idlewilde Bridge, respectively. Cumulative frequency distributions were not developed for nutrients due to the small number of nutrient measurements conducted during 2000.

Figure 6-21 depict simulated dissolved oxygen at Mill Bridge, Playground, Industrial Park, and Mallow Mall, respectively. Observed dissolved oxygen measurements were not available for 2000.

Figure 6-22 depicts the spatial comparison of observed and simulated values along the Jackson River for periphyton, ammonia, nitrate, and ortho-phosphorus.



NO SUFFICIENT OBSERVED DATA (3 DATA POINTS) TO DEVELOP THE CDF



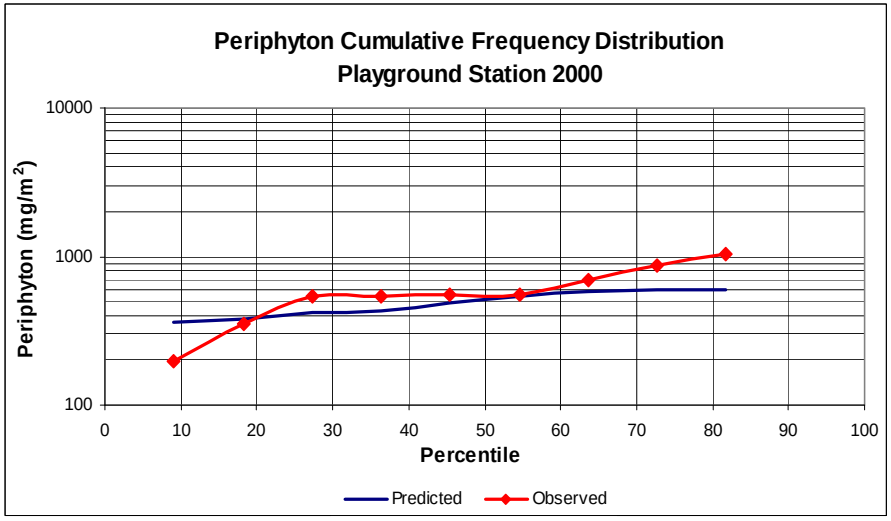
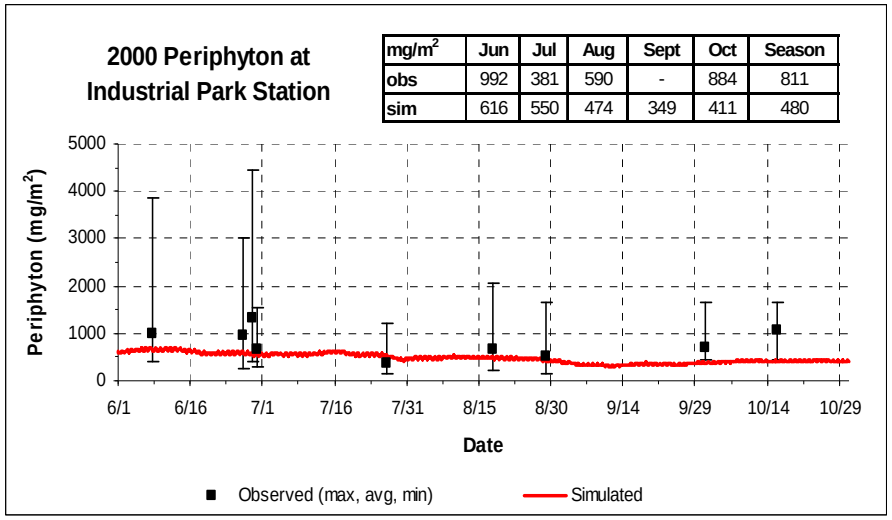
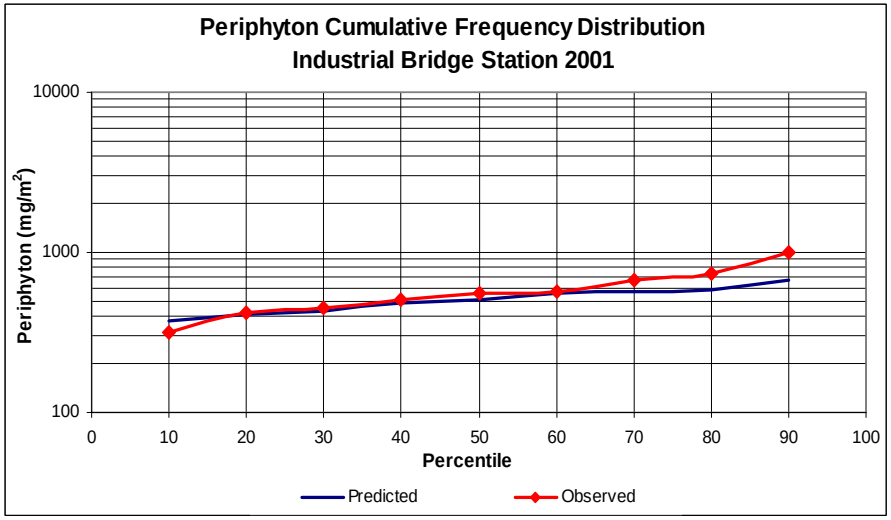
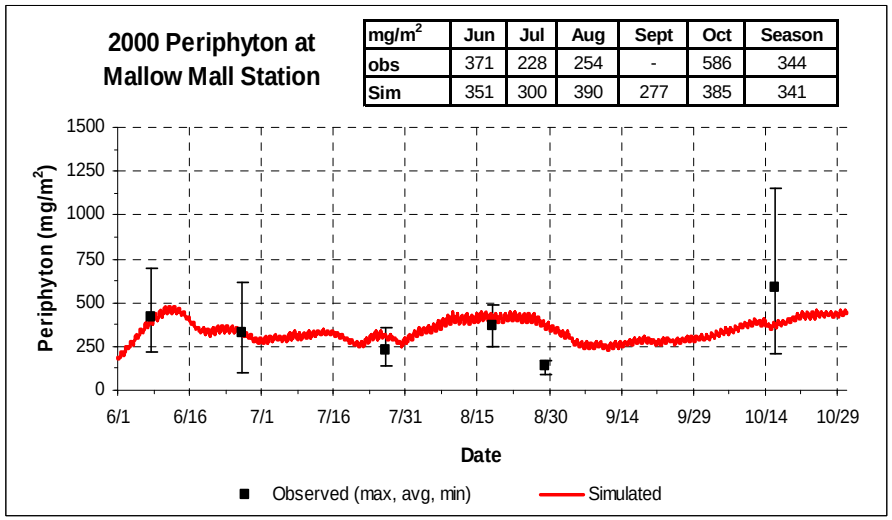


Figure 6-15: 2000 Periphyton Chlorophyll *a* and Cumulative Frequency Distribution at Mill Bridge and Playground







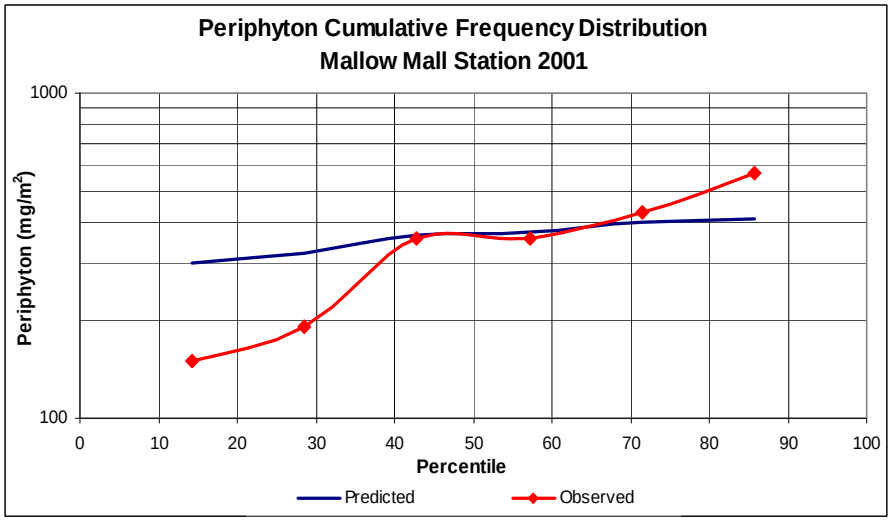
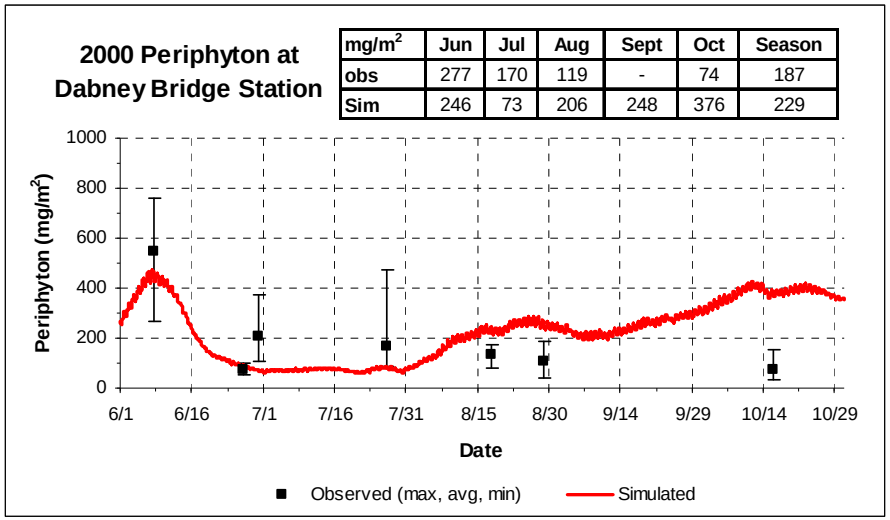


Figure 6-16: 2000 Periphyton Chlorophyll *a* and Cumulative Frequency Distribution at Industrial Park and Mallow Mall



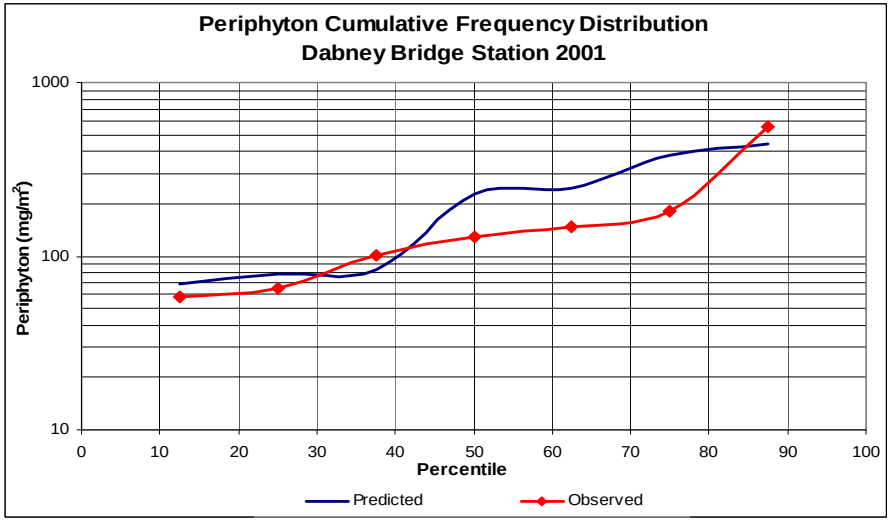
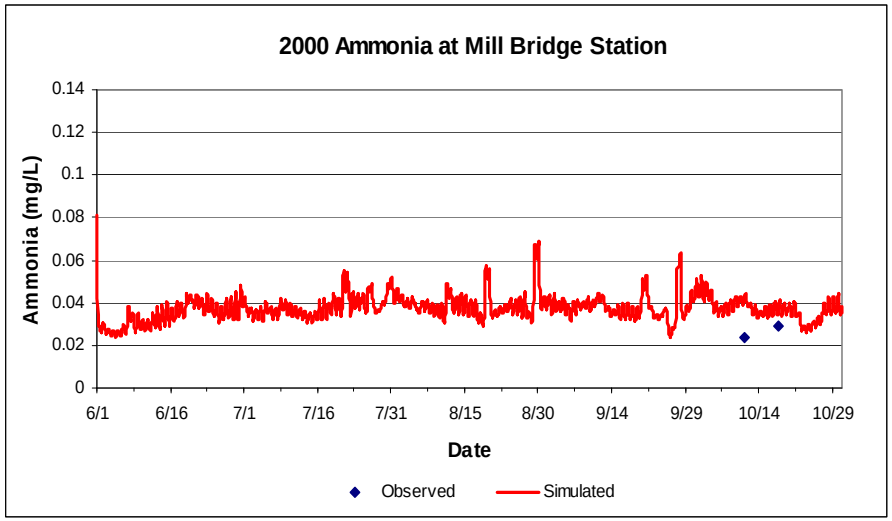
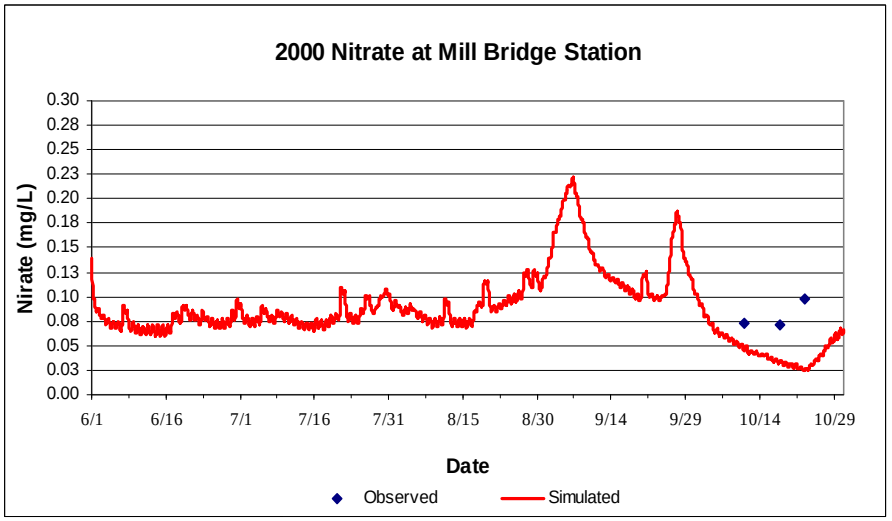


Figure 6-17: 2000 Periphyton Chlorophyll *a* and Cumulative Frequency Distribution at Dabney Bridge





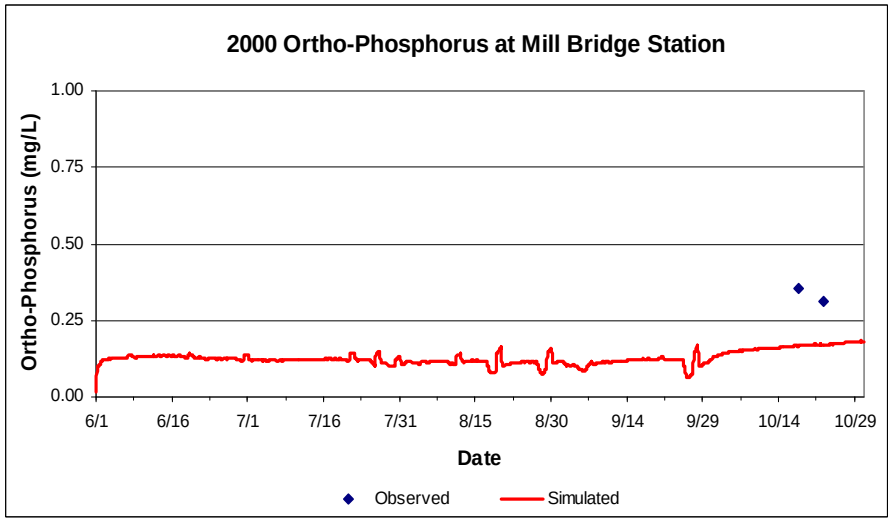
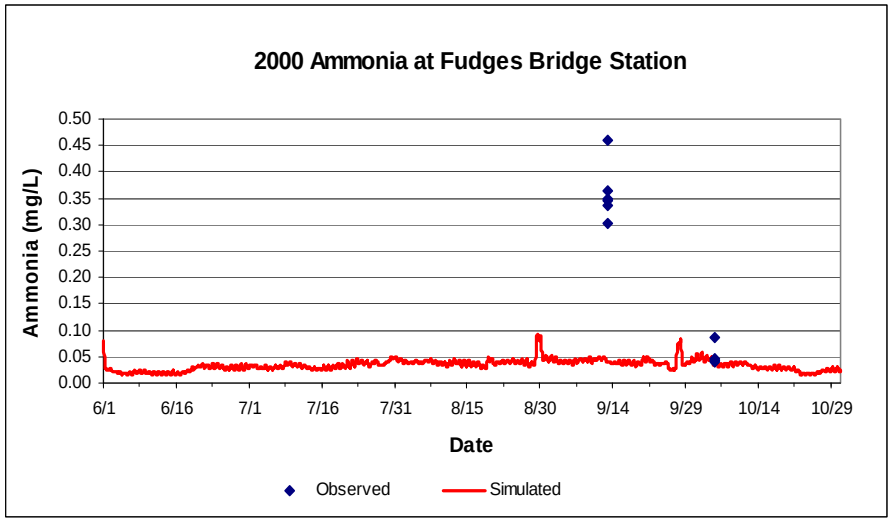
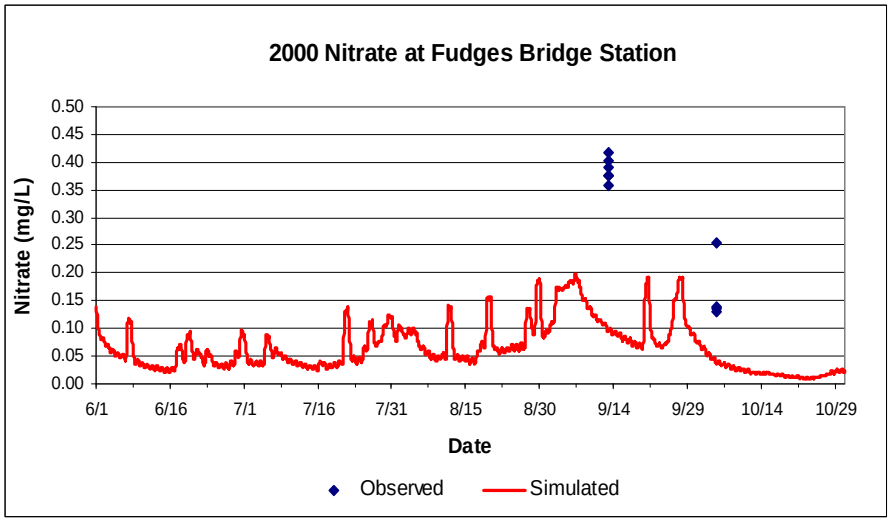


Figure 6-18: 2000 Ammonia, Nitrate, and Ortho-Phosphorus at Mill Bridge





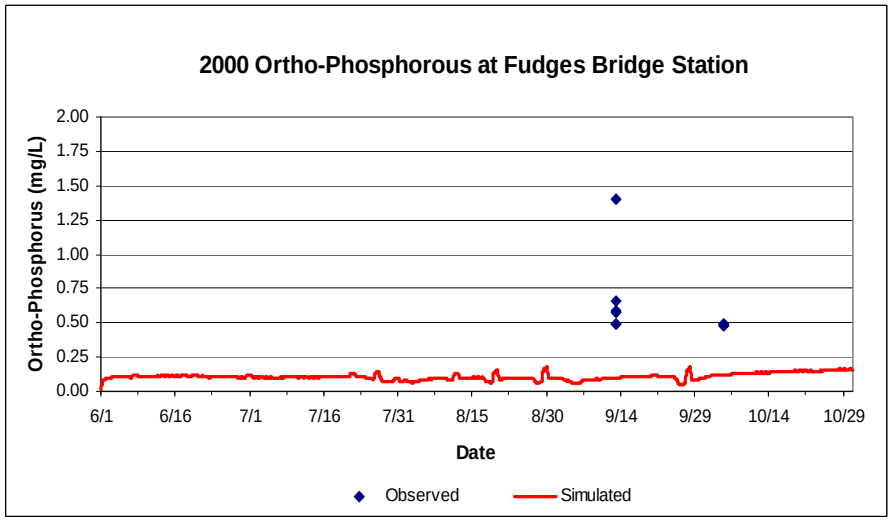
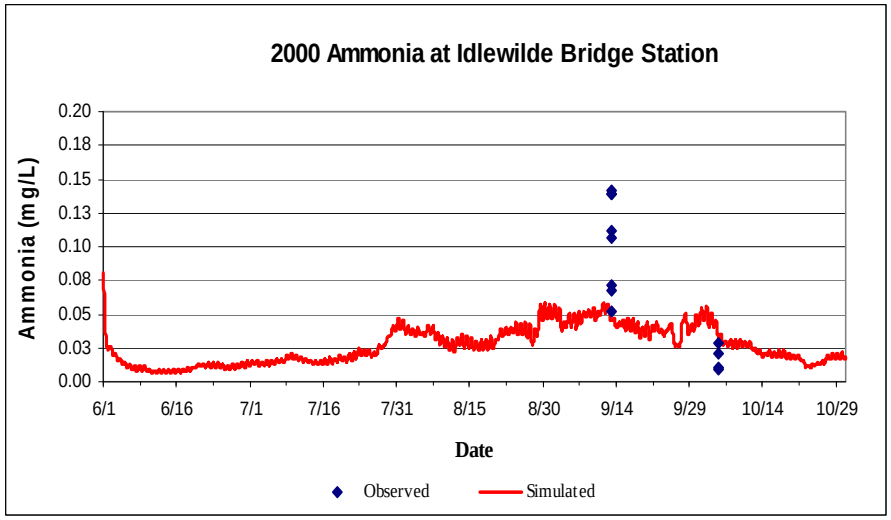
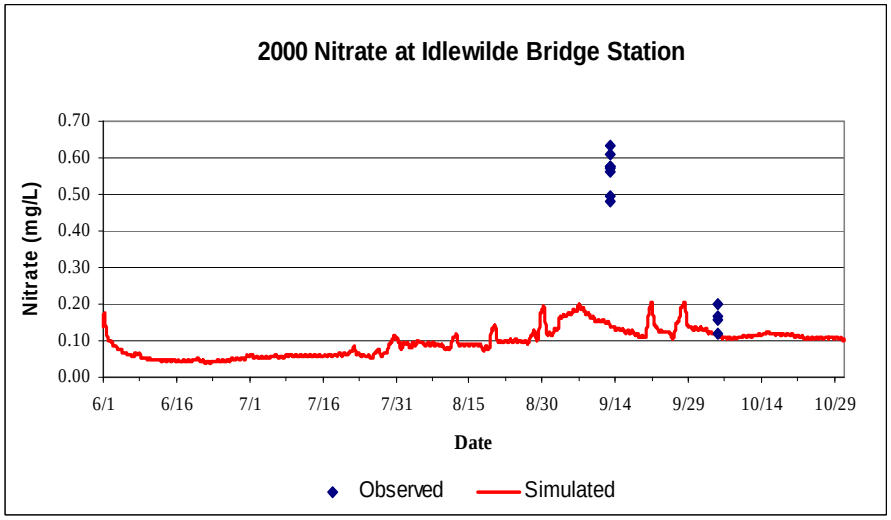


Figure 6-19: 2000 Ammonia, Nitrate, and Ortho-Phosphorus at Fudges Bridge





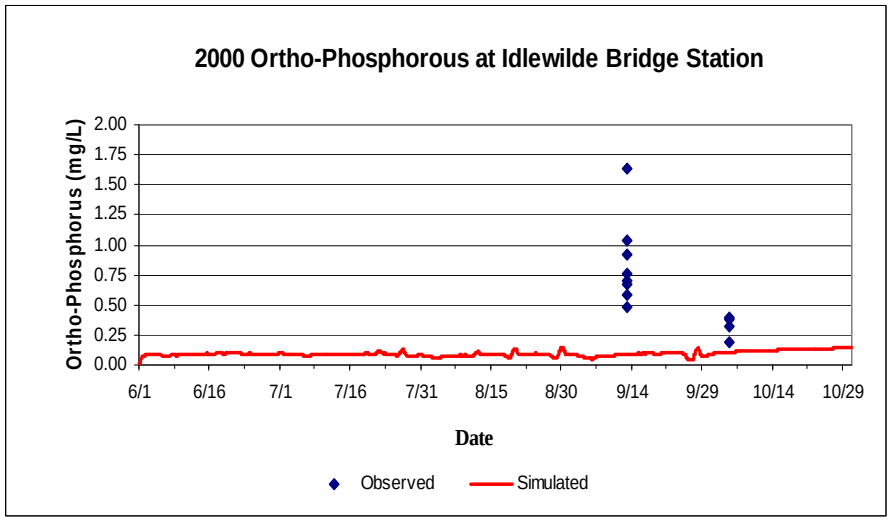


Figure 6-20: 2000 Ammonia, Nitrate, and Ortho-Phosphorus at Idlewilde Bridge

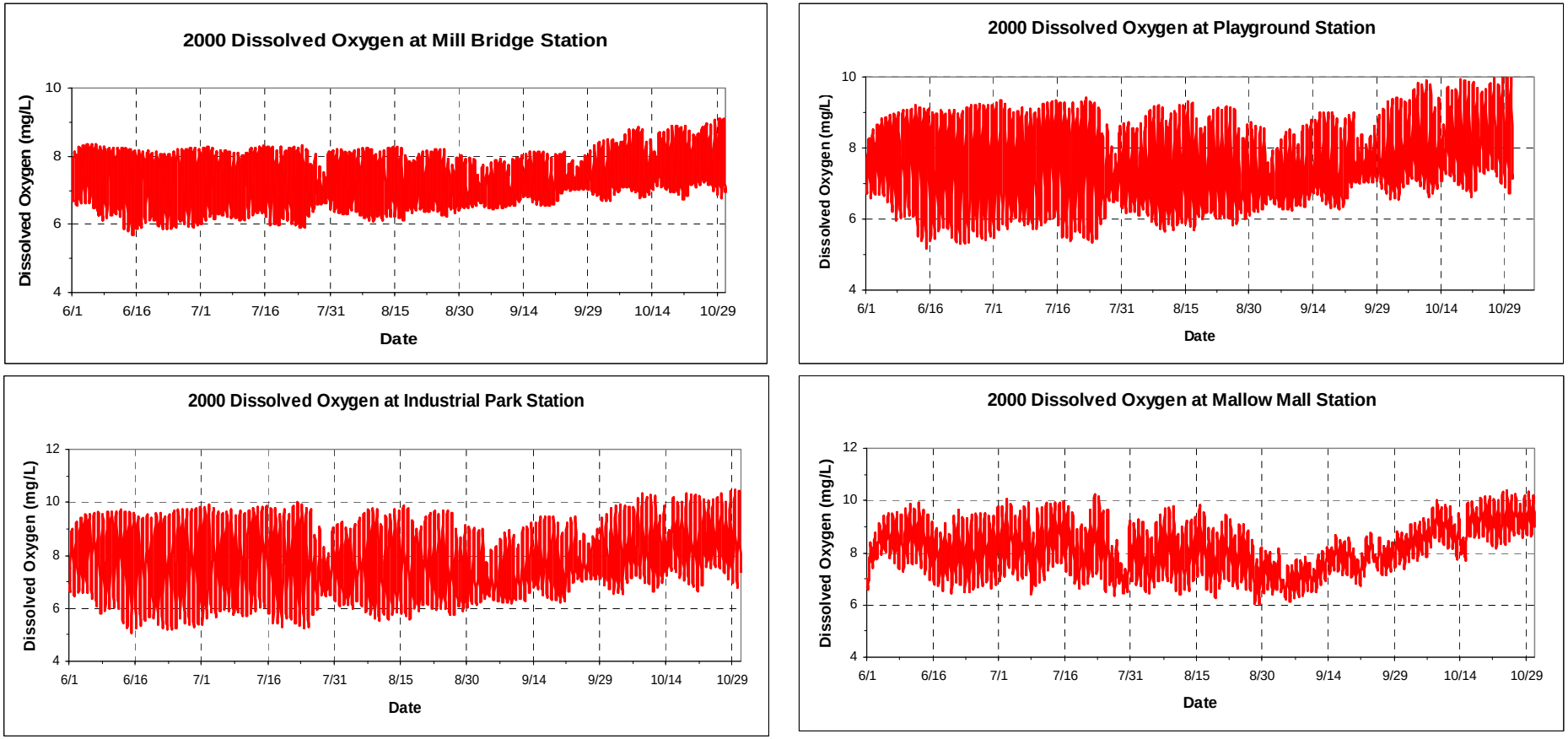


Figure 6-21: 2000 Simulated Dissolved Oxygen at Mill Bridge, Playground, Industrial Park, and Mallow Mall

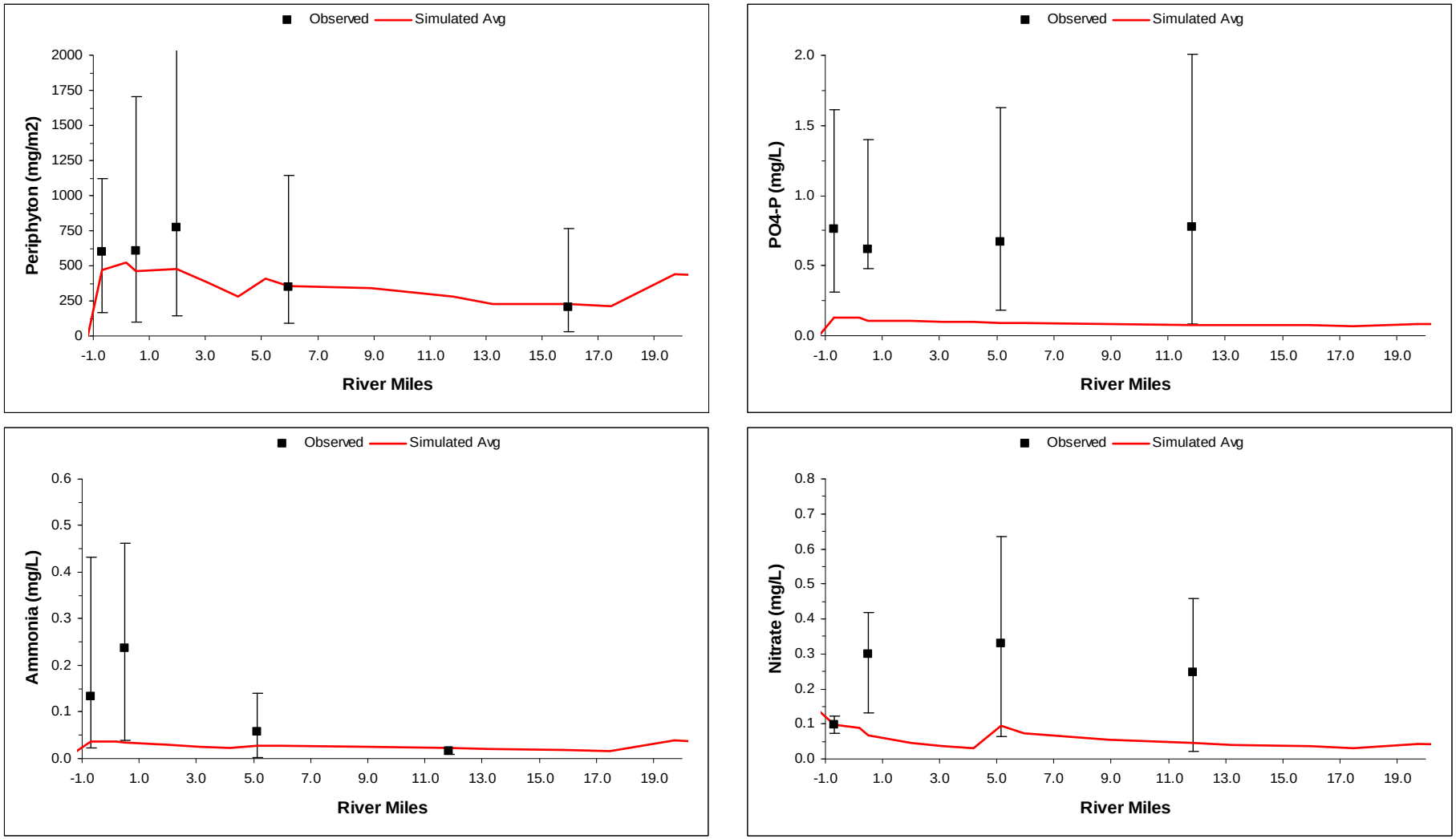


Figure 6-22: 2000 Spatial Profiles for Periphyton, Ammonia, Nitrate, and Ortho-Phosphorus, and Periphyton

6.4 Existing Conditions Scenario (2006 Growing Season)

Calibration and validation of the WASP7 model focused on reproducing periphyton and nutrient observations during the 2000 and 2001 growing season. The objective of the Existing Conditions Scenario is to utilize the calibrated model to assess the periphyton level during the 2006 growing season in the mainstem of the Jackson River. In addition, water quality data collected by the ANS, MeadWestvaco, and VADEQ in the spring of 2006 as part of the flow-pulse studies will be used to further validate the calibrated water quality model. This scenario uses recent (2006) DMR data as input for the point sources and the estimated NPS loads using the HSPF model as depicted in **Table 6-4.**

Table 6-4: 2006 Scenario PO4-P Point and Nonpoint Source Loads - June to October 2006

Discharger	WASP Model Segment	Flow (MGD)	Average Discharge PO4-P (mg/L)	PO4-P (lbs/day)	PO4-P (lbs/2006 Growing Season)
MeadWestvaco	4	32.2	0.21	56.4	8,628
Covington STP	16	1.79	1.15	17.2	2,627
Clifton Forge STP	20	1.39	3.3	38.3	5,853
Low Moor STP	23	0.16	1.15	1.5	235
NPS Load	-	-	-	12.6	1,930
Total Point and Nonpoint Sources Load				**113.4**	**19,273**

Overall, the calibrated model reflects the 2006 growing-season observed data reasonably well. The following figures present the simulation results for the 2006 Existing Conditions Scenario:

Figure 6-23 and 6-24 shows the distribution of periphyton at Playground, Mill Bridge, Industrial Park, Mallow Mall, and Dabney Bridge.

Figure 6-25 shows the simulated and observed ammonia levels at the Playground, Mill Bridge, Industrial Park, and Mallow Mall.

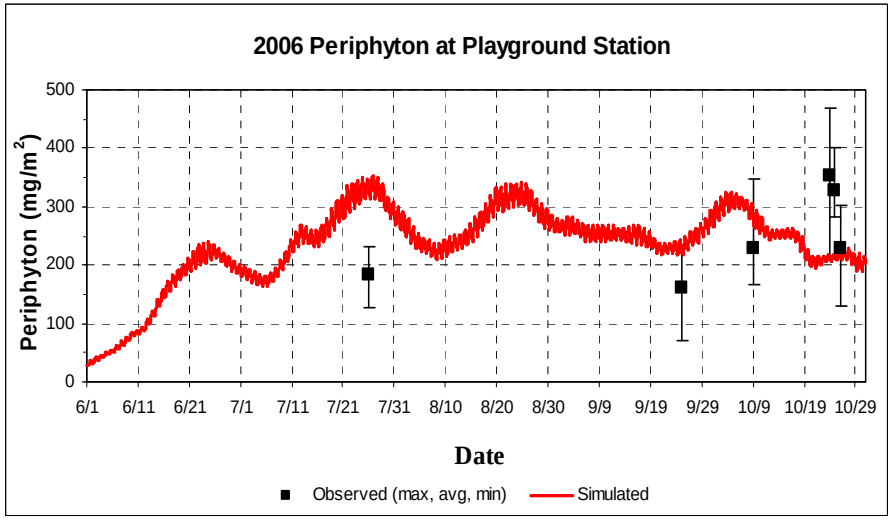
Figure 6-26 shows the simulated and observed nitrate levels at the Playground, Mill Bridge, Industrial Park, and Mallow Mall.

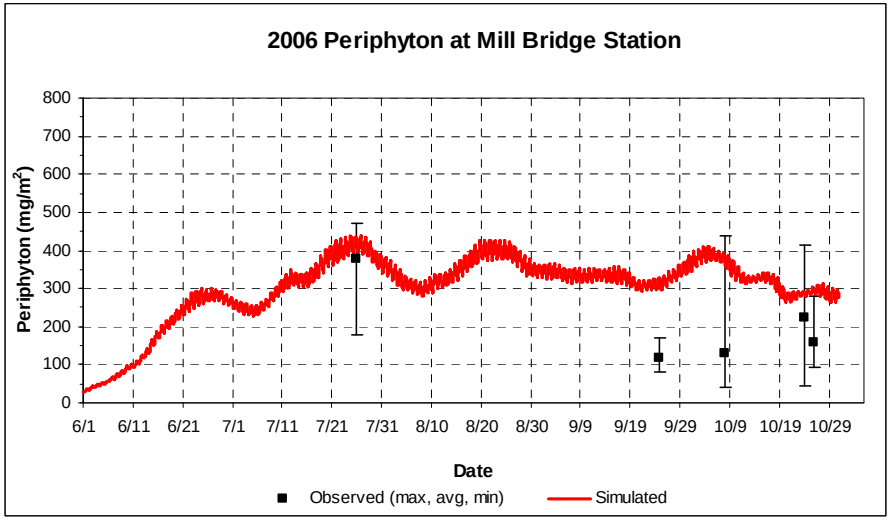
Figure 6-27 shows the simulated and observed ortho-phosphorus levels at the Playground, Mill Bridge, Industrial Park, and Mallow Mall.

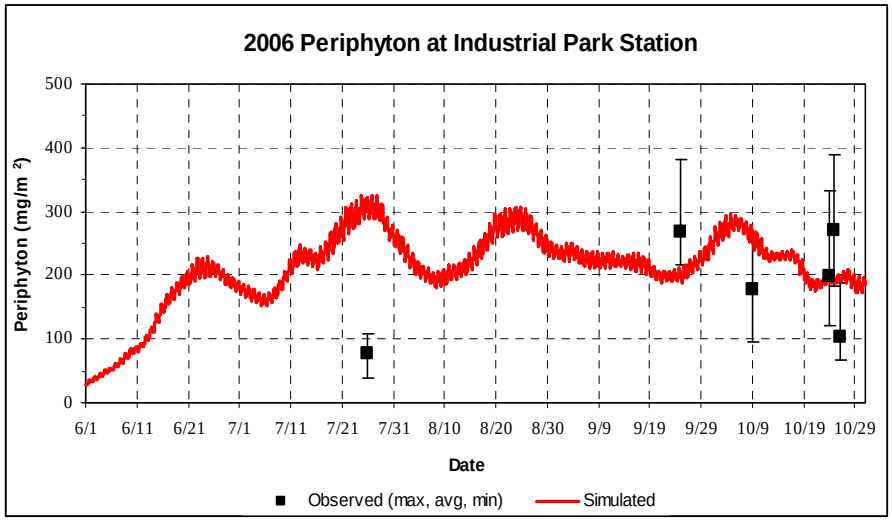
Figure 6-28 shows the simulated dissolved oxygen levels at the Playground, Mill Bridge, Industrial Park, and Mallow Mall.

Figure 6-29 shows the spatial profiles for periphyton, ammonia, nitrate, and ortho-phosphorus along the Jackson River.

Figure 6-30 shows that the 2006 average periphyton level in the main stem model segments is approximately 165 mg/m^2







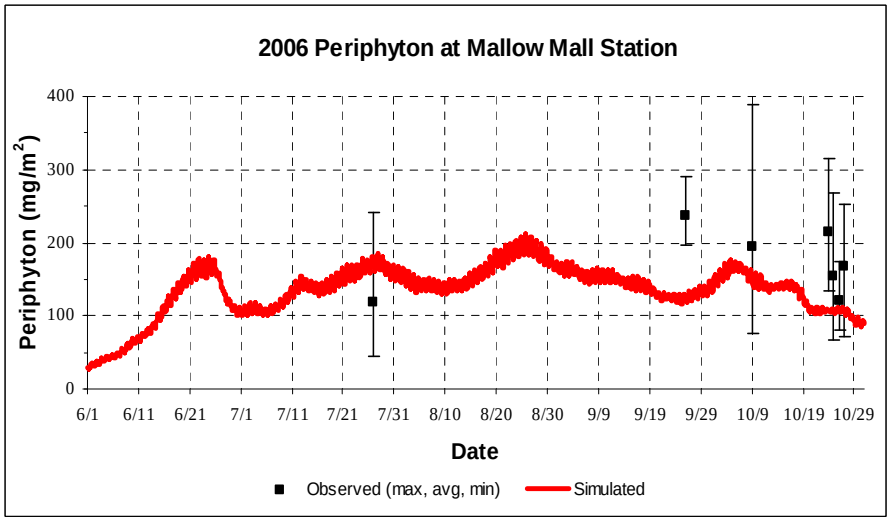


Figure 6-23: 2006 Periphyton at Playground, Mill Bridge, Industrial Park, and Mallow Mall

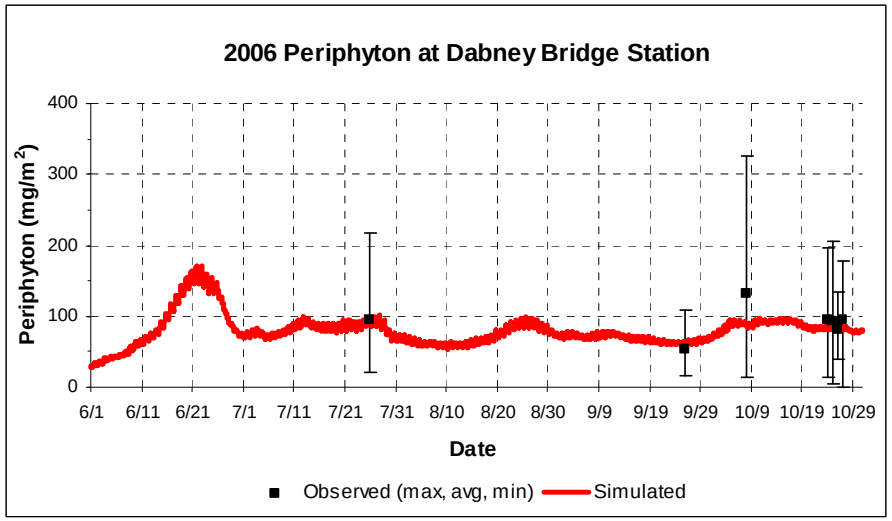


Figure 6-24: 2006 Periphyton at Dabney Bridge

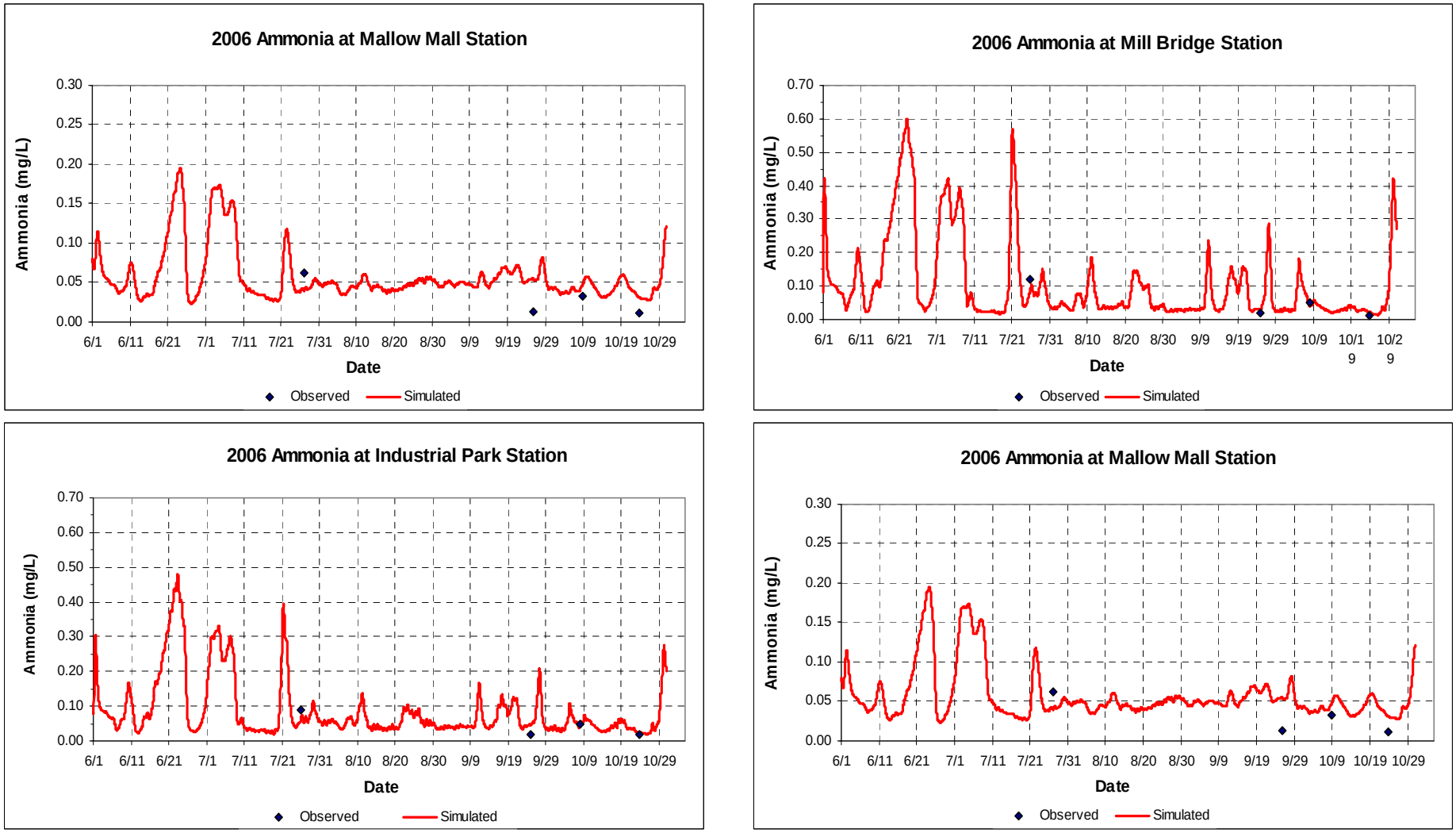
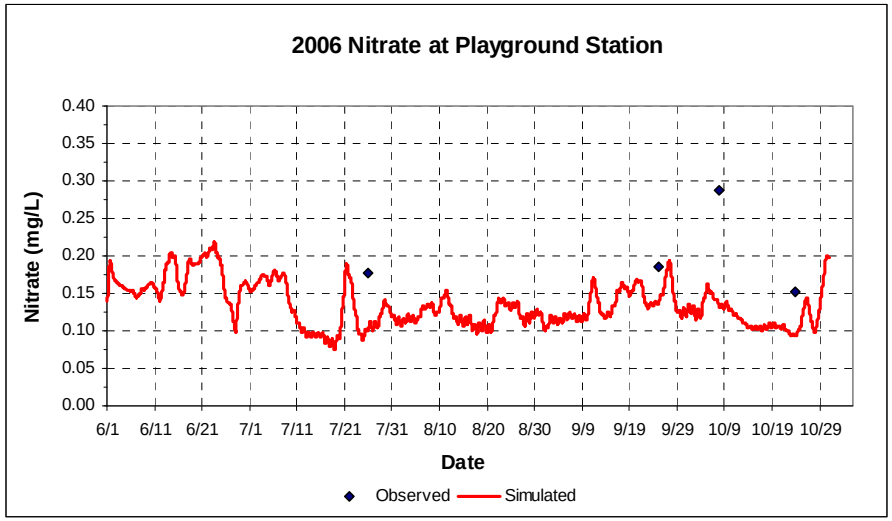
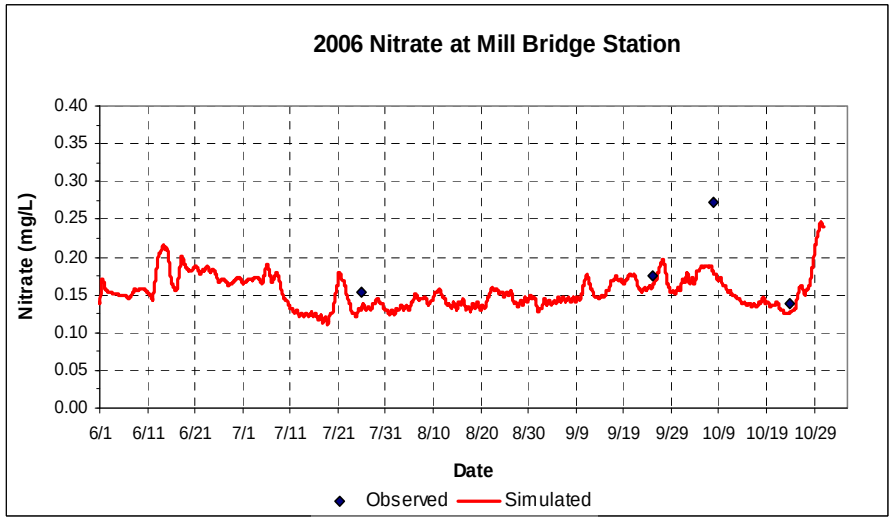
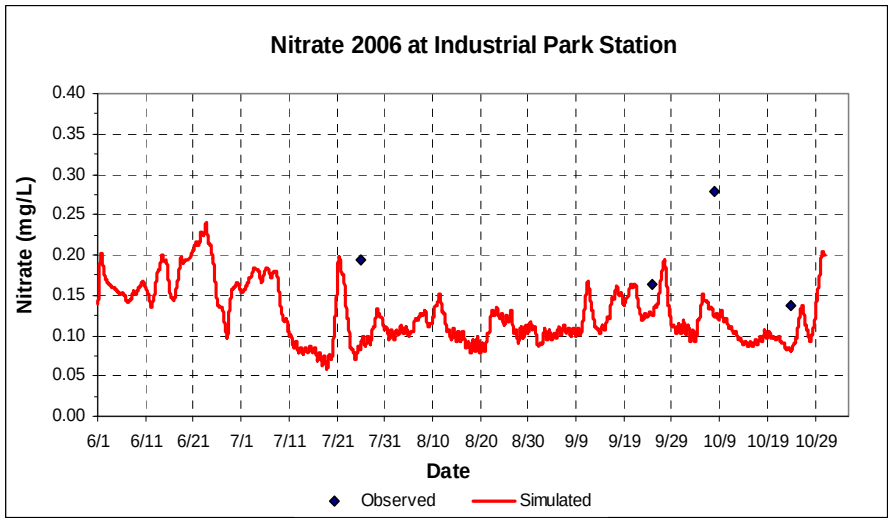


Figure 6-25: 2006 Ammonia at Playground, Mill Bridge, Industrial Park, and Mallow Mall







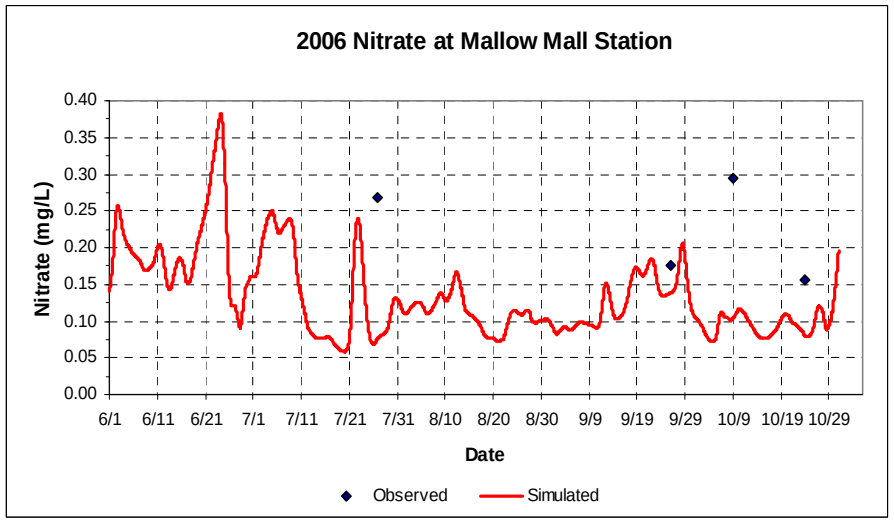
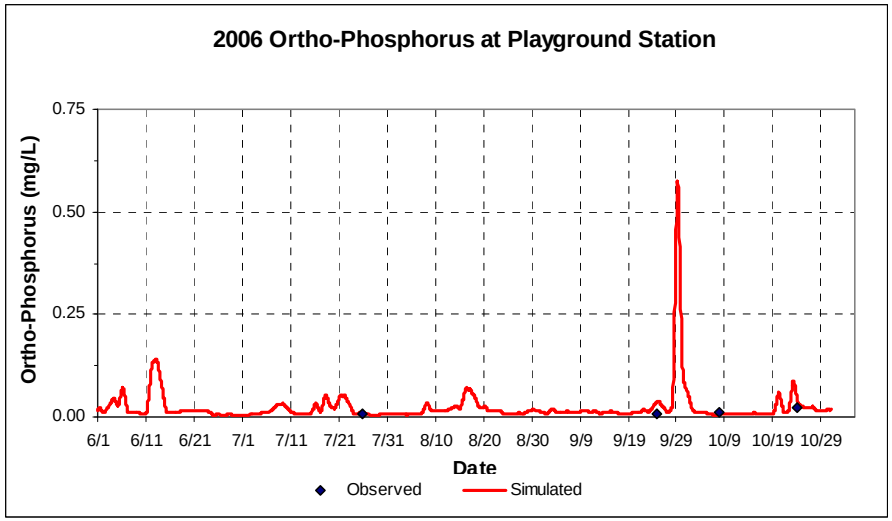
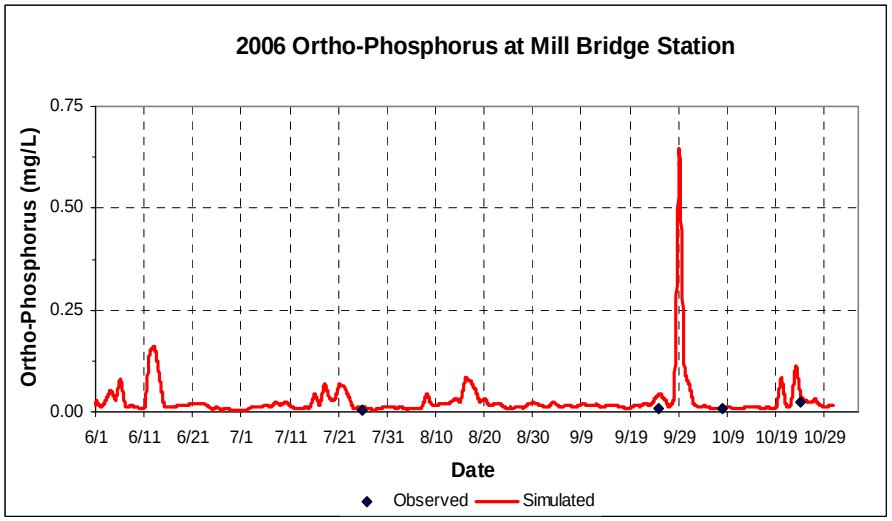
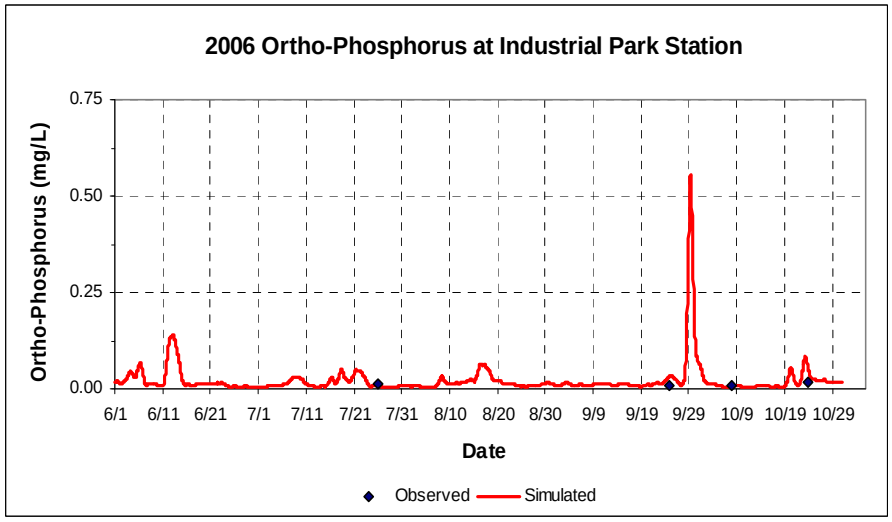


Figure 6-26: 2006 Nitrate at Playground, Mill Bridge, Industrial Park, and Mallow Mall







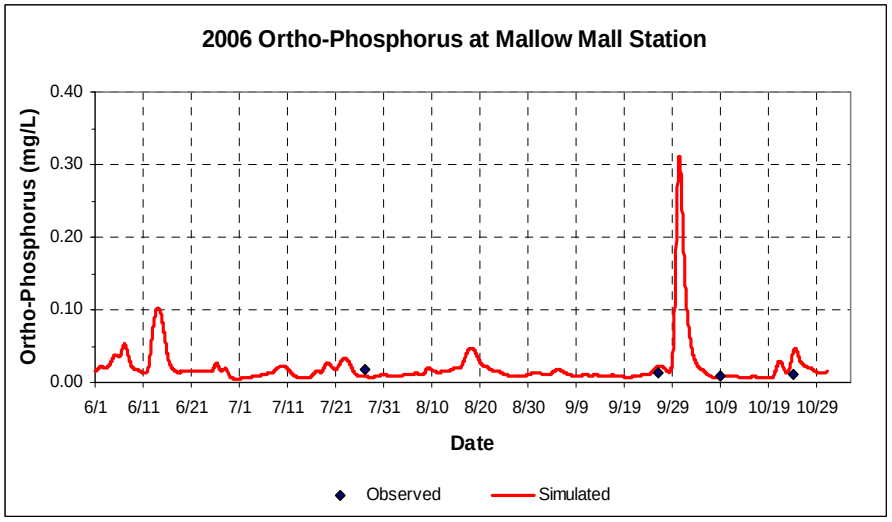


Figure 6-27: 2006 Ortho-Phosphorous at Playground, Mill Bridge, Industrial Park, and Mallow Mall

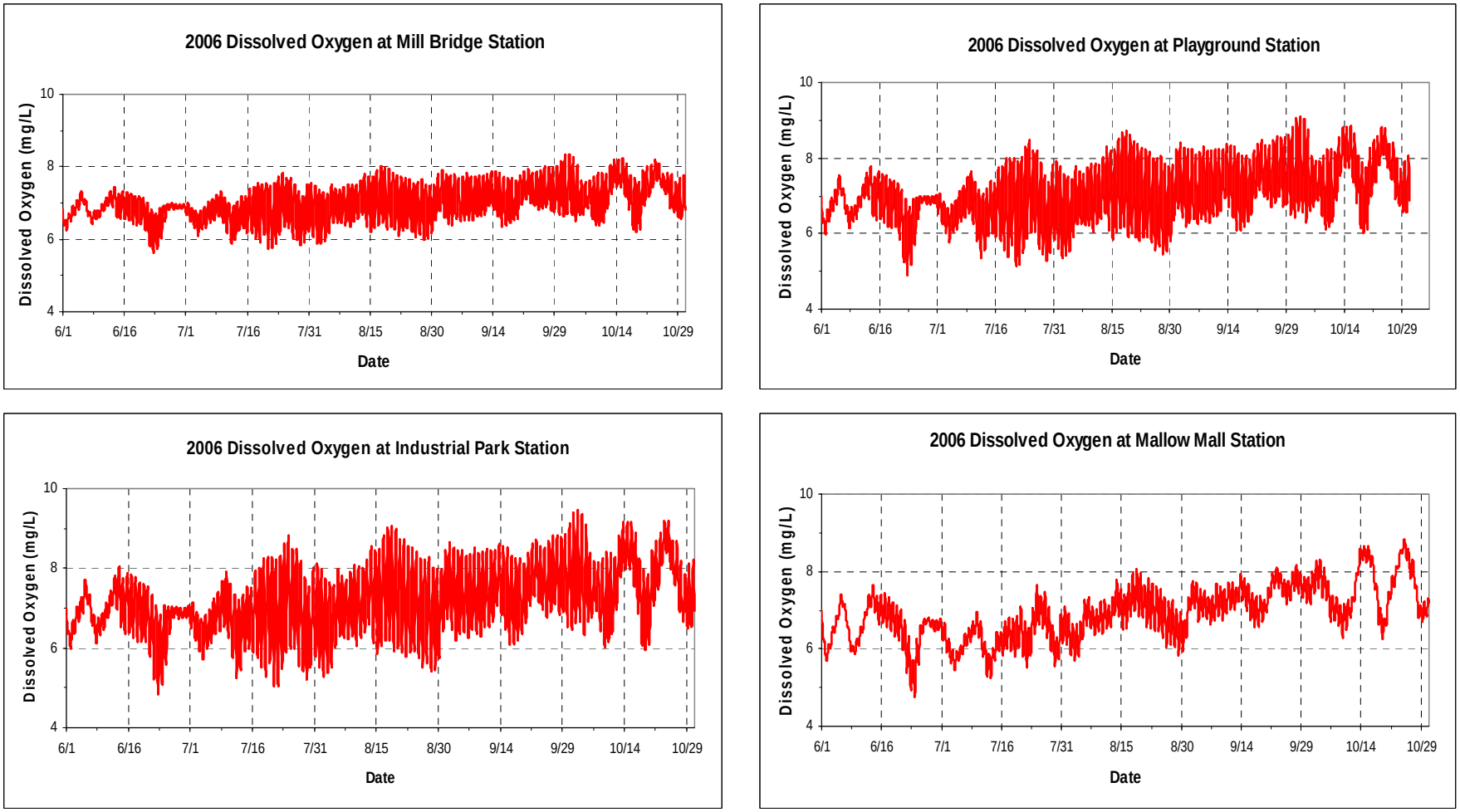


Figure 6-28: 2006 Simulated Dissolved Oxygen at Mill Bridge, Playground, Industrial Park, and Mallow Mall

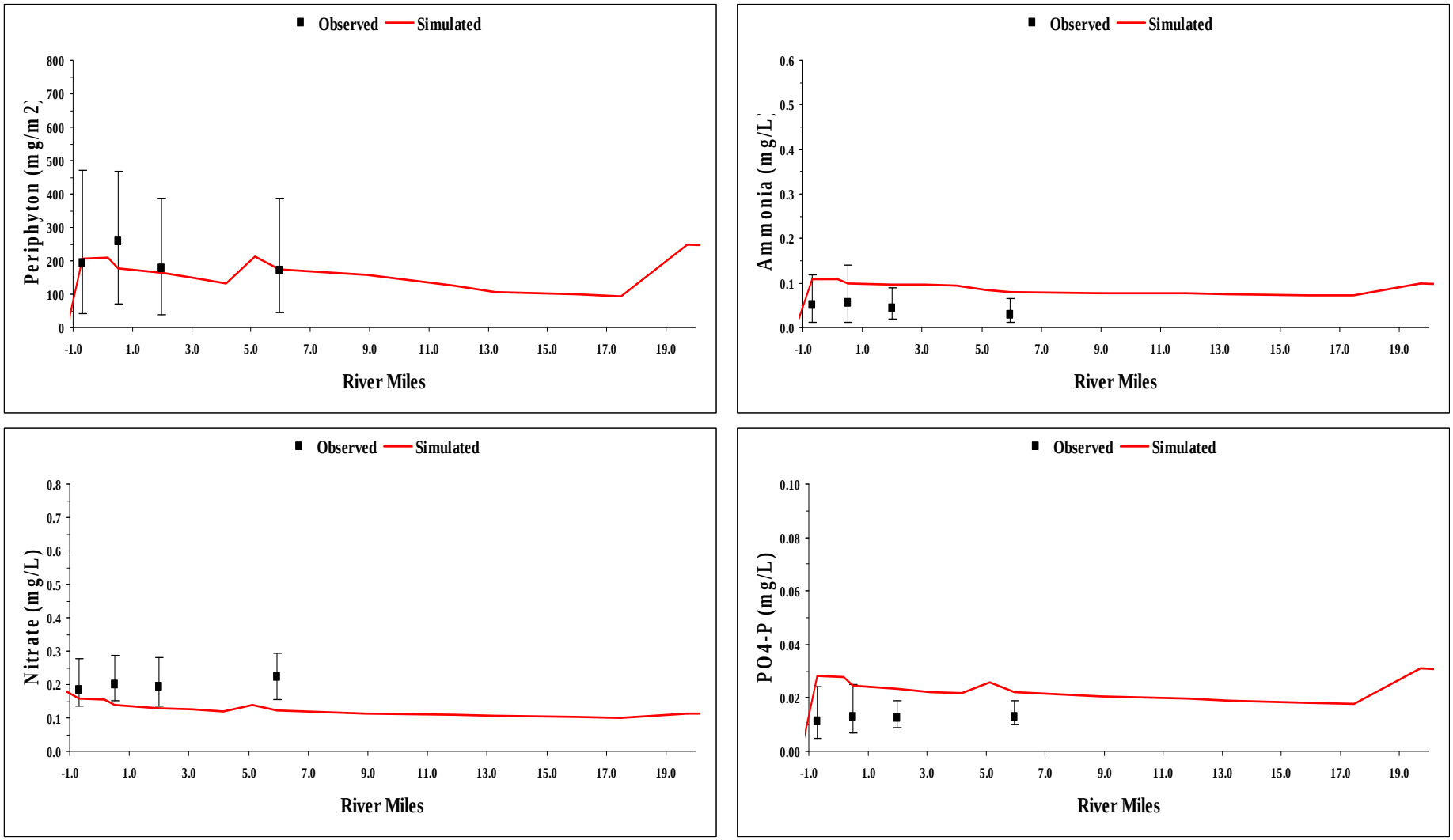


Figure 6-29: 2006 Spatial Profiles for Periphyton, Ammonia, Nitrate, and Ortho-Phosphorus

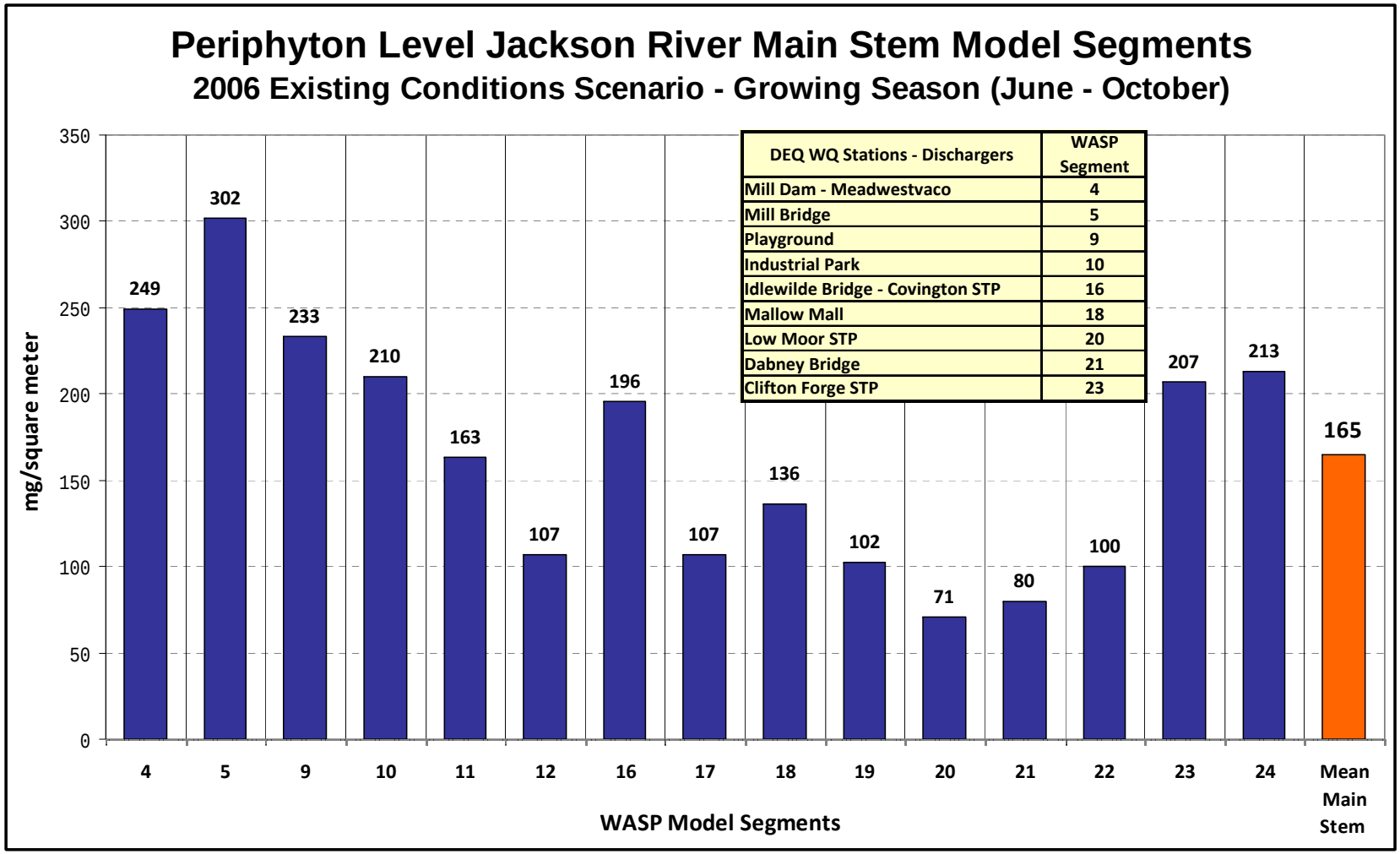


Figure 6-30: 2006 Existing Conditions Scenario Periphyton Level in the Jackson River

7.0 Jackson River TMDL Allocations

The development of the allocations for the Jackson River TMDL is based on the Chesapeake Bay Modeling Scenario. This scenario stems from the fact that the Jackson River is part of the Chesapeake Bay Watershed as characterized in **Section 6.2**. Based on their findings, nitrogen and phosphorus discharges have been shown to impact the water quality in the Bay and its tidal rivers. As a result, the Virginia State Water Control Board (SWCB) proposed guidelines controlling the discharge of total nitrogen and total phosphorus within the Virginia portion of the Chesapeake Bay watershed. The Chesapeake Bay Scenario uses the calibrated WASP7 model implemented for the 2006 growing season (**Chapter 6**) with adjustments to the point source dischargers loads to reflect the EPA Chesapeake Bay future discharge guidelines depicted in **Table 7-1**. It should be noted that Clifton Forge STP (VA0022772) will be phased-out and replaced by the Lower Jackson River WWTP (VA0090671).

Table 7-1: Chesapeake Bay Recommended Nutrient Load Discharges

Facility Name	VPDES Permit	Discharge Flow (MGD)	TP Load (lbs/yr)	TP Conc. (mg/L)	TN Load (lbs/yr)	TN Conc. (mg/L)
MeadWestvaco	VA0003646	35.0	159,815	1.5	394,211	3.7
Covington STP	VA0025542	3.0	4,566	0.5	54,794	6.0
Low Moor WWTP	VA0027979	0.3	1,050	1.15	5,479	6.0
Lower Jackson River WWTP	VA0090671	2.6	3,957	0.5	47,488	6.0

The current discharge levels from the MeadWestvaco plant are much lower that the Chesapeake Bay recommended discharge levels shown above. In fact and based on recent DMR data, MeadWestvaco has reduced considerably its phosphorus discharge to the Jackson River. As shown in **Figure 7-1** the PO4-P discharge levels from the MeadWestvaco Plant were considerably reduced during the period of 2003 to 2006 reaching a recorded and consistent discharge load of 8,550 lbs during the growing season from June to October 2006. This corresponds to an average PO4-P discharge concentration of 0.21 mg/L. These discharge levels also indicate that this facility has

reached the limits of technology in terms of phosphorus reductions. Therefore, the 2006 nutrient loadings from the MeadWestvaco were used in the implementation the Chesapeake Bay Modeling scenario.

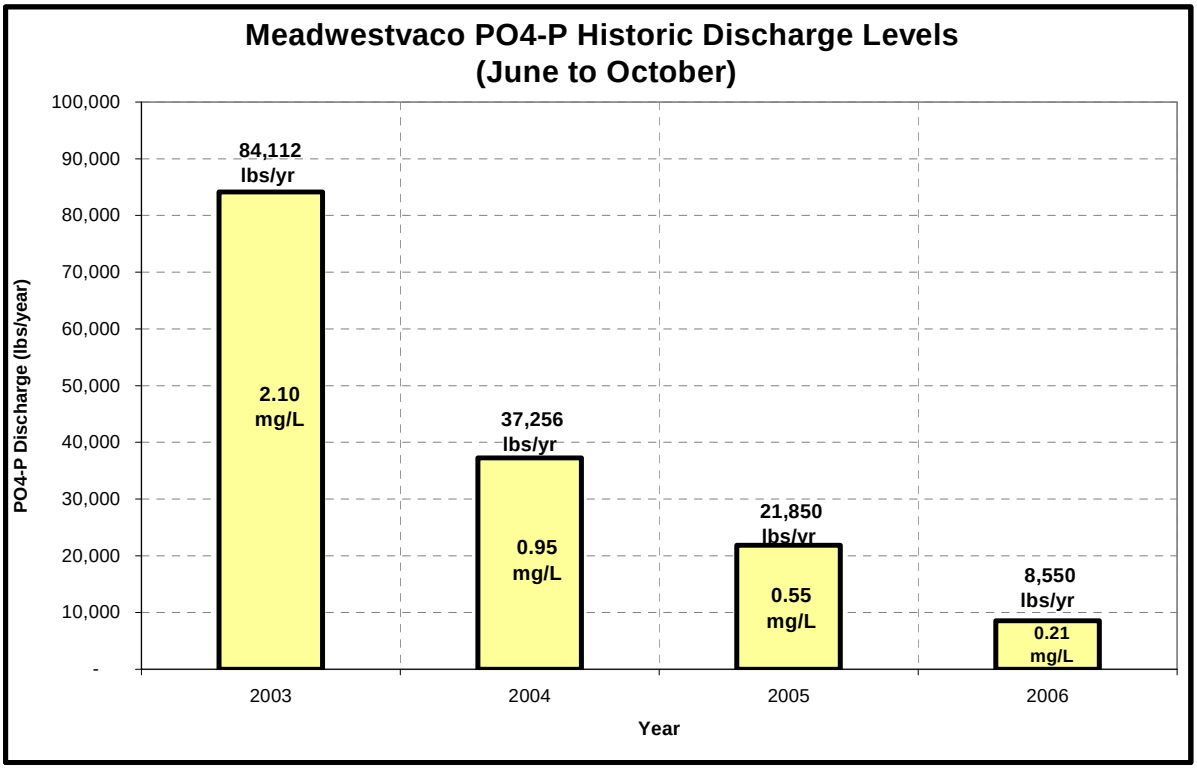


Figure 7- 1: MeadWestvaco Growing Season Historic PO4-P Discharge levels

Nutrient species distribution for the WWTPs were developed using the EPA Chesapeake Bay Program guidelines[1]. These guidelines recommend the use of a "*67/33*" distribution between PO_4-P and total organic phosphorus; in other words 67% of the TP is assumed to be in the form of ortho-phosphorus (PO_4-P).

Similarly a "*7/80/13*" nitrogen species distribution, also recommended by the EPA Chesapeake Bay Program, is applied to the nitrogen species (NH_3/NO_3/ORGN) for the WWTPs. However, nitrogen discharge input data for the MeadWestvaco plant were developed using actual DMR data resulting to the following discharge concentrations: NH_3: 0.83 mg/l; NO_3: 0.06mg/L; and Organic Nitrogen: 2.2 mg/L.

[1] *Chesapeake Bay Phase 5 Community Watershed Model Documentation, Section 7. Point Sources, Water Withdrawal, and On-Site Waste Disposal Systems. EPA Chesapeake Bay Program 2008*

The resulting periphyton levels resulting from the implementation of the Chesapeake Bay Scenario in each modeling segment of the Jackson River are depicted in **Figure 7-2**. The average periphyton level in the 15 mainstem model-segments is approximately 137 mg/m^2. This level is lower than the 165 mg/m^2 periphyton biomass resulting from the implementation of the 2006 Existing Conditions Scenario (**Chapter 6**). The main difference between these two scenarios (2006 Existing Conditions and Chesapeake Bay Scenarios) is the lower periphyton level under the Chesapeake Bay Modeling scenario below the Covington STP (Model Segment 16) caused by a decrease in nutrient discharge from the WWTPs under the Chesapeake Bay Scenario.

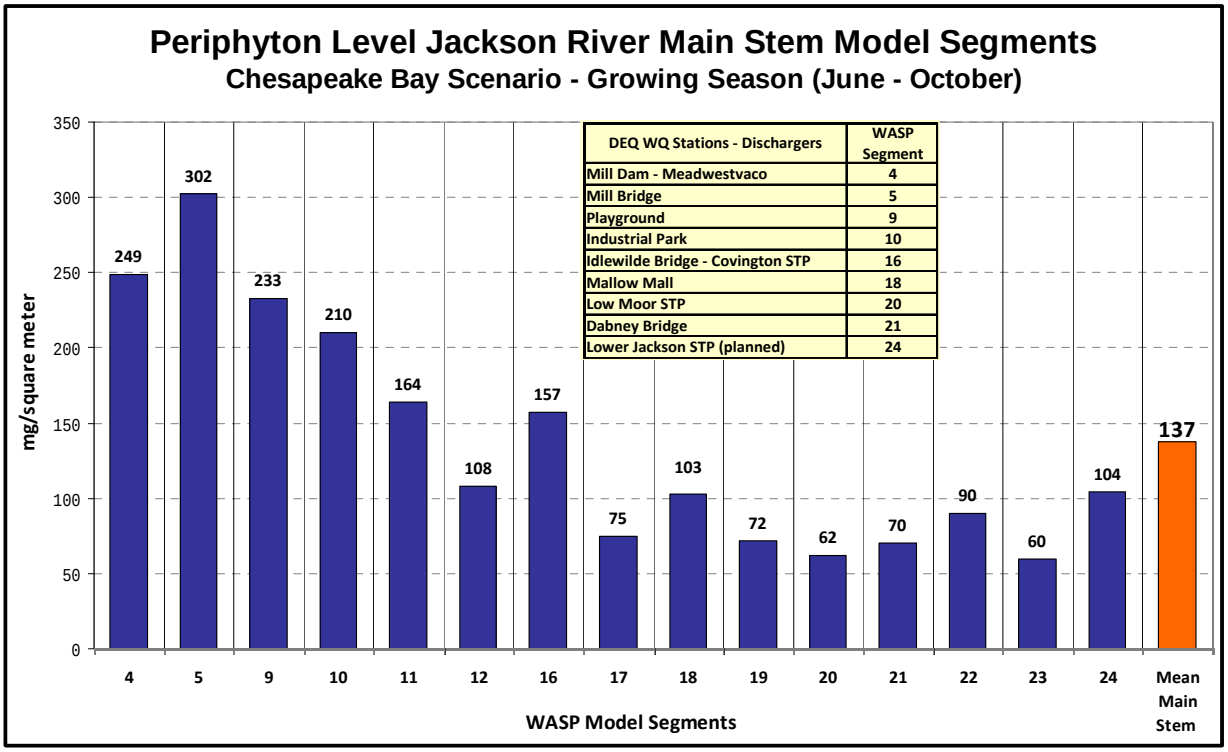


Figure 7- 2: Chesapeake Bay Modeling Scenario – Periphyton Levels Main Stem Jackson River

7.1 Flow Augmentation and Periphyton Scouring

The results of the Chesapeake Modeling Scenario indicate that the PO4-P endpoint of 38 ug/L and the corresponding periphyton target of 100 mg/m^2 cannot be reached in the Jackson River. This is due to the fact that the Jackson River is not a free flowing river and also to the fact that MeadWestvaco, the main nutrient contributor to the Jackson River, has reached its limits of technology in term of phosphorus reductions. The remaining option

that will help the Jackson River achieve a healthy and balanced biologic community is to mimic the natural hydrology and flows that have existed before the operation of the Gathright Dam. Since it is unlikely to fully reestablish the pre-Gathright Dam hydrologic regime, VADEQ proposed that flow will be released from the dam to provide periphyton scouring and help reach the assigned endpoints. Consequently, VADEQ in cooperation with MeadWestvaco, the Philadelphia Academy of Sciences and the US Army Corps of Engineers (USACE), implemented and developed in October 2007 a flow release study where the primary objective was to assess the level of periphyton biomass scouring resulting from flow augmentation test-pulses under a flow augmentation study. The other objective was to identify the number and level of the flow pulses that can be technically feasible. The flow pulse study indicated that the flow releases from the Gathright Dam will help the Jackson River meet the assigned endpoints. In addition, six flow pulses of 3,000 cfs each were recommended during the growing season. **Table 7-2** depicts the pattern of one flow pulse recommended for the Jackson River flow augmentation study. The 2007 flow-pulse study led to a development of a working group consisting of VADEQ, MeadWestvaco, and USACE to study the feasibility of flow release from Gathright Dam under a USACE 216 study.

Table 7-2: Flow Augmentation Pulse Pattern

Time	Release (cfs)	Downstream Gage	Flow Augmentation
	270	9.20	
0:00	417	9.55	147
0:30	597	9.90	327
1:00	811	10.25	541
1:30	1,061	10.60	791
2:00	1,350	10.95	1,080
2:30	1,685	11.30	1,415
3:00	2,082	11.65	1,812
3:30	2,532	12.00	2,262
4:00	3,012	12.32	2,742
4:30	3,012	12.32	2,742
5:00	3,012	12.32	2,742
5:30	3,012	12.32	2,742
6:00	2,268	11.80	1,998
6:30	1,685	11.30	1,415
7:00	1,222	10.80	952
7:30	845	10.30	575
8:00	542	9.80	272
8:30	270	9.20	

7.2 Implementation of the Chesapeake Bay Scenario with Flow Augmentation Pulses

The 216 Study will assess the feasibility and evaluate the environmental impact of flow augmentation during the growing season. Specifically, during the 216 Study there will be three release alternatives examined with varying reduced monthly minimum flows and six summer/fall pulses. In order to demonstrate that the flow releases will help restore the benthic community in the Jackson River, a modeling scenario was developed incorporating the Chesapeake Bay conditions with the recommended flow augmentation pulses. A velocity-periphyton relationship developed by the Philadelphia Academy of Natural Sciences (ANS) in artificial streamside channels was used to relate the effect of stream velocity changes on the periphyton scouring. This relationship shown in **Figure 7-3** indicates that there is a good correlation between stream velocity and periphyton biomass levels. This relationship also indicates that there is "breakpoint" velocity of 40 cm/s where periphyton starts to be scoured at higher velocity. Using this breakpoint velocity the ANS relationship shown in **Figure 7-3** was modified to develop a dimensionless relationship relating the changes in stream velocity and periphyton biomass levels (**Figure 7-4**).

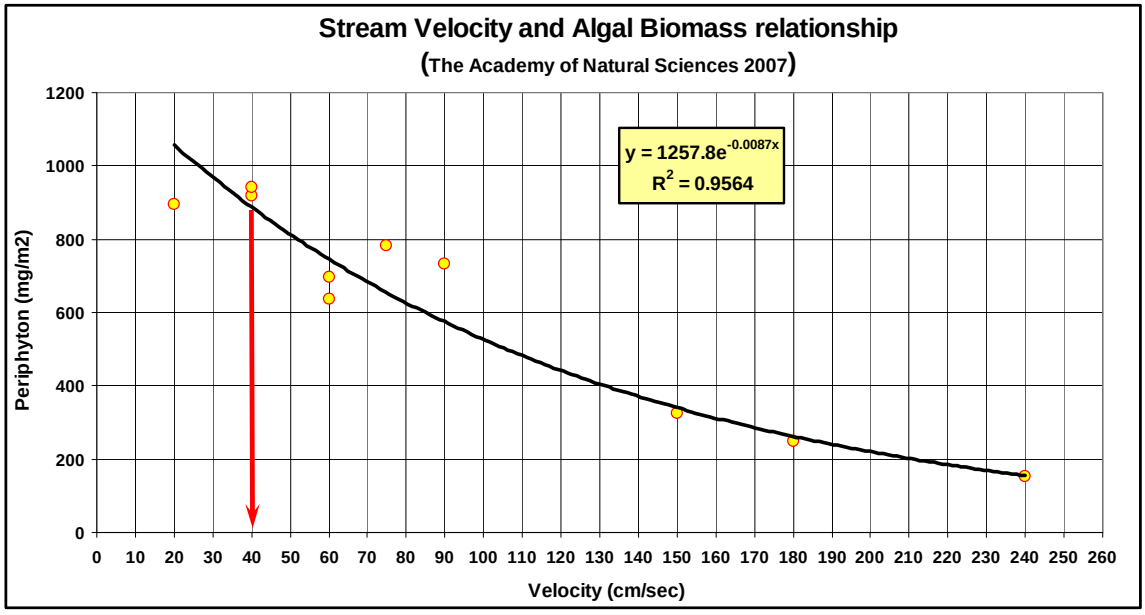


Figure 7-3: Stream Velocity and Algal Biomass Relationship

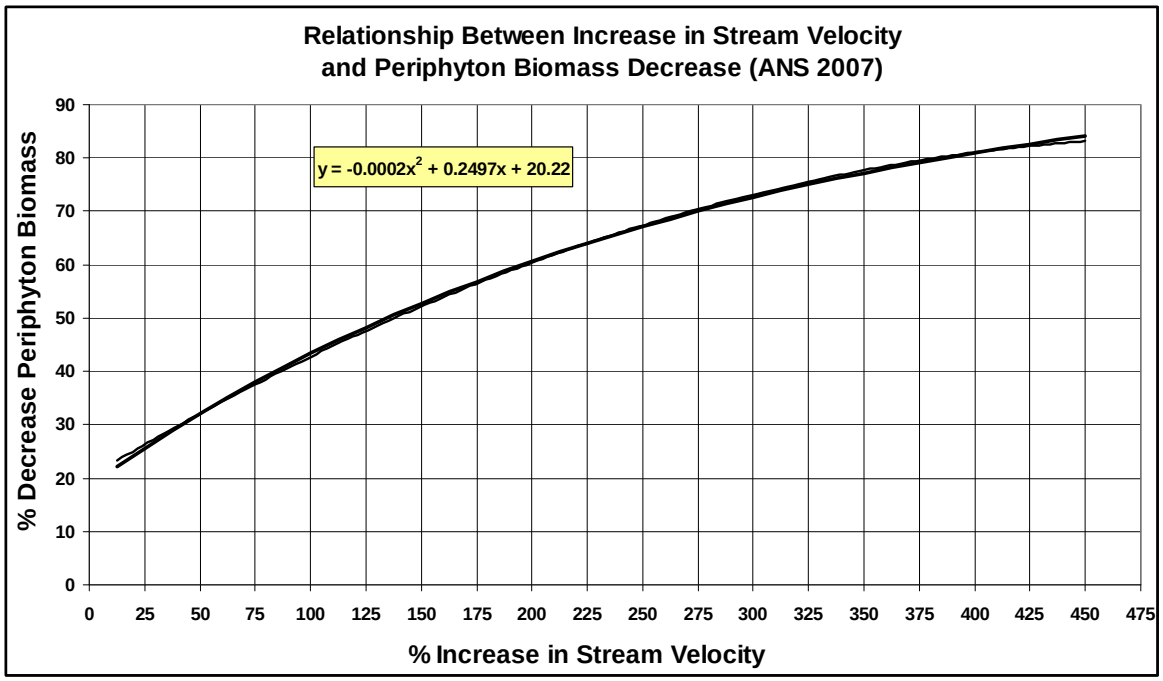


Figure 7-4: Percent Increase in Stream Velocity vs. Percent Decrease in Periphyton Biomass

The dimensionless relationship shown in **Figure 7-4** was applied to the periphyton and stream velocity time-series output from the Chesapeake Bay Scenario for each of the 15 mainstem model-segments to develop the periphyton time series resulting from the flow-augmentation pulses. The resulting periphyton levels are shown in **Figure 7-5** indicating that an average periphyton level of 101 mg/m^2 can be reached in the main stem of the Jackson River (**Figure 7-5**). This level of periphyton biomass is comparable to the periphyton endpoint of 100 mg/m^2 and will allow the Jackson River meet its aquatic life endpoint.

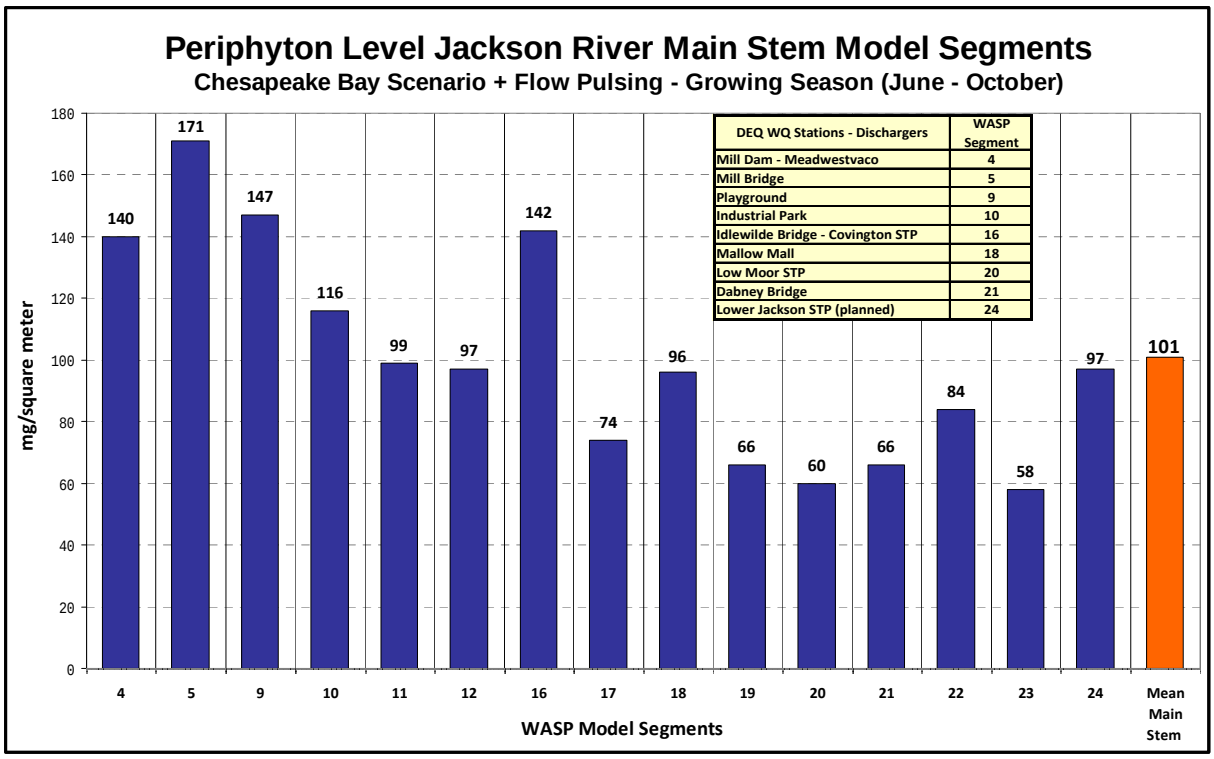


Figure 7- 5: Periphyton Levels - Chesapeake Bay Scenario with Flow Pulses

7.3 Allocation

Typically a TMDL represents the maximum amount of pollutant that a water body can receive without exceeding the water quality standard. For the Jackson River the TMDL endpoint will be achieved using a combination of load allocations and a flow augmentation in the main stem. In fact, the various modeling scenarios indicated that in order to restore the Jackson River benthic community it is necessary to:

- Assign to the WWTPs the recommended Chesapeake Bay discharge levels, and assign the 2006 levels in term of PO4-P discharge for the MeadWestvaco plant.
- Implement the 6 flow pulses recommended under the 216 study.

The load allocations were developed using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

Where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (non-point source allocation); and

MOS = margin of safety.

7.3.1 Incorporation of Margin of Safety

The margin of safety (MOS) is a required component of the TMDL to account for any lack of knowledge concerning the relationship between effluent limitations and water quality. According to EPA guidance (*Guidance for Water Quality-Based Decisions: The TMDL Process, 1991*), the MOS can be incorporated into the TMDL using two methods:

- Implicitly incorporating the MOS using conservative model assumptions to develop allocations; or
- Explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations.

The MOS will be implicitly incorporated into this TMDL using conservative modeling assumptions.

7.3.2 Jackson River Waste Load Allocation

The wasteload allocation for the permitted facilities requires maintaining the MeadWestvaco PO4-P discharge at the 2006 level and the WWTPs discharges at the levels recommended by the EPA Chesapeake Bay Program. **Table 7-3** presents the Total Phosphorus WLA during the growing season (June to October). **Table 7-4** provides the total phosphorus allocation breakdown depicting the allocations for PO4-P and organic phosphorus.

Similarly, **Table 7-5** presents the Total Nitrogen WLA during the growing season (June to October). **Table 7-6** provides the total nitrogen allocation breakdown depicting the allocations for ammonia (NH_3), nitrates (NO_3), and organic nitrogen.

Table 7-3: Jackson River Total Phosphorus Waste Load Allocations				
Facility Name	**VPDES Permit**	**Discharge Flow (MGD)**	**TP Conc. (mg/L)**	**TP Load Allocation (lbs/Growing Season)**
MeadWestvaco	VA0003646	35	1.5	66,991
Covington STP	VA0025542	3	0.5	1,914
Low Moor WWTP	VA0027979	0.3	1.15	440
Lower Jackson River WWTP	VA0090671	2.6	0.5	1,659
			Total	**71,004**

Table 7-4: Jackson River PO4-P and Organic P Waste Load Allocations					
Facility Name	**VPDES Permit**	**PO4-P Conc. (mg/L)**	**PO4-P Load Allocation (lbs/Growing Season)**	**Org P Conc. (mg/L)**	**Organic P Load Allocation (lbs/Growing Season)**
MeadWestvaco	VA0003646	0.21	9,379	1.290	57,612
Covington STP	VA0025542	0.335	1,282	0.165	632
Low Moor WWTP	VA0027979	0.7705	295	0.380	145
Lower Jackson River WWTP	VA0090671	0.335	1,111	0.165	547
		Total	**12,068**	**-**	**58,936**

Table 7-5: Jackson River Total Nitrogen Waste Load Allocations				
Facility Name	**VPDES Permit**	**Discharge Flow (MGD)**	**TN Conc. (mg/L)**	**TP Load Allocation (lbs/Growing Season)**
MeadWestvaco	VA0003646	35	3.7	165,245
Covington STP	VA0025542	3	6	22,968
Low Moor WWTP	VA0027979	0.3	14	5,359
Lower Jackson River WWTP	VA0090671	2.6	6	19,906
			Total	**213,478**

Table 7-6: Jackson River NH3, NO3, and Organic N Waste Load Allocations						
Facility Name	**NH3-N Conc. (mg/L)**	**NH3-N Load Allocation (lbs/Growing Season)**	**NO3-N Conc. (mg/L)**	**NO3-N Load Allocation (lbs/Growing Season)**	**Organic-N Conc. (mg/L))**	**Organic-N Load Allocation (lbs/ Growing Season**
MeadWestvaco	0.83	37,068	0.1	4,466	2.8	123,710
Covington STP	0.42	1,608	4.8	18,375	0.8	2,986
Low Moor WWTP	0.98	375	11.2	4,287	1.8	697
Lower Jackson River WWTP	0.42	1,393	4.8	15,925	0.8	2,588
		40,445		**43,053**		**129,981**

7.3.3 Jackson River Load Allocation

The nonpoint sources modeling presented in **Chapter 6** resulted in an average PO4-P load during the growing season of 1,930 lbs. This corresponds to a TP load of 2,880 lbs during the growing season. Similarly the modeling resulted in a total nitrogen load of 24,160 lbs during the growing season. No reductions are applied to the nonpoint source loads.

7.3.4 Jackson River TMDL

A summary of the TMDL allocation plan loads the Jackson River are presented in **Table 7-7 and Table 7-8** for total phosphorus and total nitrogen respectively. Section 7-3-5 provides that the reasonable assurance that the Jackson River TMDL will be implemented through regulatory actions by Federal and State Agencies.

Table 7-7: Jackson River Total Phosphorus TMDL (Lbs/Growing Season)			
WLA (Point Sources)	**LA (Non-point sources)**	**MOS (Margin of Safety)**	**TMDL**
71,004	**2,880**	**Implicit**	**73,884**

Table 7-8: Jackson River Total Nitrogen TMDL (Lbs/Growing Season)			
WLA (Point Sources)	**LA (Non-point sources)**	**MOS (Margin of Safety)**	**TMDL**
213,478	**24,160**	**Implicit**	**237,638**

7.3.5 Reasonable Assurance

The upper Jackson River and its current flow have been mitigated and compromised by a low flow augmentation scheduled that was established by the USACE in 1981. The existing low flow regime was implemented to address high BOD and low DO conditions of the stream at Covington. Over the past 30 years, there have been significant reductions in the amount of BOD discharged and DO conditions have improved. Today, excessive nutrients / periphyton have replaced BOD as the pollutant of concern in this section of the river.

The Jackson River TMDL is recommending the existing flow augmentation schedule be modified to restore natural stream flow variability. The proposed flow release modification is to remediate current water quality problems. This change will simulate or mimic natural storm events, particularly during the critical growing period of the periphyton. The TMDL modeling and monitoring studies have demonstrated pulses during critical periods can and do scour and flush excess periphyton downstream. This action results in improved biological communities in the river below Covington.

Therefore, this TMDL is unique since the implementation consists of increasing the flow in the main stem of the Jackson River. The flow augmentation study, insuring that the Virginia aquatic life standards will be met, is being implemented and finalized through a 216 study authorized by Section 216 of the River and Harbor and Flood Control Act of 1970 (Public Law 91-611), dated 31 December 1970, which states:

> "The Secretary of the Army, acting through the Chief of Engineers, is authorized to review the operation of projects the construction of which has been completed and which were constructed by the Corps of Engineers in the interest of navigation, flood control, water supply, and related purposes, when found advisable due to significantly changed physical or economic conditions, and to report thereon to Congress with recommendations on the advisability of modifying the structures or their operation, and for improving the quality of the environment in the overall public interest."

The overall purpose of the flow augmentation feasibility \study is to ensure the timely and economical completion of a quality Feasibility Report that will review the existing conditions of the Gathright Dam and Lake Moomaw Federal project to determine if any changes to release procedures would significantly enhance habitat and benefit water quality downstream of the project on the Jackson River to the confluence with the head of the James River. The primary focus of the study will be directed to fine tuning the water release procedures during low flow conditions by incorporating new techniques, such as pulsing, to better mimic natural stream conditions that occurred before the project existed. These release modifications shall be developed to protect the in-lake fishery and downstream fisheries. Habitat enhancement shall address benthic organisms, siltation, and water quality. The Feasibility Study shall be fully consistent with and in support of the goals, mandates, and direction of the Chesapeake Bay Agreement and other pertinent state and Federal statutes and initiatives.

EPA uses the term "*reasonable assurance*" to emphasize that implementation of a TMDL is critical to the ultimate attainment of standards in the impaired waterbody. Reasonable assurance is defined as "a *demonstration that the TMDL will be implemented through regulatory or voluntary actions, by Federal, State or local governments, authorized tribes or individuals*" (EPA, 2000). There is a reasonable assurance that the 216 study will be implemented through a flow augmentation in the main stem of the Jackson River leading to the attainment of the identified endpoint. In fact, the US Army Corps of Engineers and the VADEQ entered and signed an official agreement funding the 216 study and insuring that the flow augmentation study will be implemented and completed in the next 3 years. In fact and as shown in **Table 7-9,** a Feasibility Cost Sharing

Facility Name	Permit No.	Major/Minor	Municipal/ Industrial	Design Flow	Outfall No.	Parameter Description	Quantity Average	Quantity Maximum	Concentration Avg.	Concentration Max.
						TSS	NL	NL	NL	NL
Applied Extrusion Technologies - Covington	VA0003450	Minor	Industrial	1	102	BOD5	NL	12.3	NL	NL
						Flow	NL	NL	*********	*********
						Oil & Grease	NL	13.72	NL	NL
						pH	*********	*********	*********	9
						TSS	NL	8.98	NL	NL
Applied Extrusion Technologies - Covington	VA0003450	Minor	Industrial	1	103	BOD5	1.9	5.08	NL	NL
						Flow	NL	NL	*********	*********
						pH	*********	*********	*********	9
						TSS	*********	*********	*********	9
Boys Home Inc - Sewage Treatment Plant	VA0088544	Minor	Municipal	0.024	1	BOD5	2.5	3.8	30	45
						CL2, Inst Res Max	*********	*********	2	2.4
						CL2, Inst Tech Min Limit	*********	*********	*********	*********
						CL2, total contact	*********	*********	*********	*********
						Flow	0.024	NL		
						Oil and Grease	*********	*********	NL	NL
						pH	*********	*********	*********	9
						TSS	2.5	3.8	30	45
Clifton Forge City - Sewage Treatment Plant	VA0022772	Major	Municipal	2	1	BOD5	227	340	30	45
						CL2, Inst Tech Min Limit	*********	*********	*********	*********
						CL2, Total	********	********	106	128
						CL2, Total Contact	*********	*********	*********	*********
						Flow	2	NL	*********	*********
						Nitrite +Nitrate -N,Total	NL	*********	NL	*********
						Nitrate, Total as N	NL	*********	NL	*********
						Nitrogen, Total as N (KG/MO)	********	NL	*********	*********

Facility Name	Permit No.	Major/Minor	Municipal/ Industrial	Design Flow	Outfall No.	Parameter Description	Quantity Average	Quantity Maximum	Concentration Avg.	Concentration Max.
						Nitrogen, Total as N (KG/YR)	********	NL	*********	*********
						Orthophosphate (as P)	NL	*********	NL	*********
						pH	*********	*********	*********	9
						Phosphate, total (as P)	NL	********	NL	*********
						Phosphate, total (as P) (KG/MO)	********	NL	*********	*********
						Phosphorus, total (as P) (KG/YR)	********	NL	*********	*********
						TKN (N-KJEL)	NL	*********	NL	*********
						TSS	227	340	30	45
						TUa - Acute 48 HR Stat Pimephales Promelas	********	********	*********	NL
						TUc – Chronic 7 Day Statre Primephales Promelas	********	********	*********	NL
Clifton Forge Water Treatment Plant	VA0006076	Minor	Industrial	-	1	CL2, inst res max	*********	*********	0.016	0.016
						Flow	NL	NL	*********	*********
						pH	*********	*********	*********	9
						TSS	*********	*********	30	60
Covington City - Sewage Treatment Plant	VA0025542	Major	Municipal	3	1	BOD5	340	510	30	45
						Fecal Coliform	*********	*********	200	*********
						Flow	3	NL	*********	*********
						Nitrogen, Total AS N	NL	NL	NL	NL
						pH	*********	*********	*********	9
						Total Phosphorous	NL	NL	NL	NL
						TSS	340	510	30	45
CSX Transportation Inc - Clifton Forge	VA0003344	Minor	Industrial	0.025	1	Total Organic Carbon	*********	*********	*********	110
						Flow	NL	NL	*********	*********
						Total Nitrogen	*********	*********	*********	NL
						Total Recoverable Petroleum Hydrocarbons	*********	*********	10	15
						pH	*********	*********	*********	9
						Total Phosphorous	*********	*********	*********	NL
						Final Acute Toxicity	*********	*********	*********	1

Facility Name	Permit No.	Major/Minor	Municipal/ Industrial	Design Flow	Outfall No.	Parameter Description	Quantity Average	Quantity Maximum	Concentration Avg.	Concentration Max.
						TSS	*********	*********	30	60
DGIF Paint Bank Fish Cultural Station	VA0091324	Minor	Industrial	2.9	1, 2, 3, 4, 5, 6, 7, 8, 9	Ammonia as N	********	********	*********	NL
						Flow	NL	NL	*********	*********
						Settable Solids	********	********	0.1	0.5
						TSS	********	********	10	15
Douthat Road Mobile Home Park STP	VA0089001	Minor	Municipal	0.011	1	BOD5	1.2	1.8	30	45
						CL2 Inst, Res Max	*********	*********	0.08	0.1
						CL2, Inst Teach Limit	*********	*********	*********	*********
						CL2, Total Contact	*********	*********	*********	*********
						Flow	0.011	NL	*********	*********
						pH	*********	*********	*********	9
						TSS	1.2	1.8	30	45
MeadWestvaco Packaging Resource Group	VA0003646	Major	Industrial	32.89	3	Flow	NL	NL	*********	*********
						pH	*********	*********	*********	9
						BOD5	4195	8390	NL	NL
						TSS	17000	33200	NL	NL
						COD	********	********	*********	NL
						Total Phosphorous	********	********	*********	NL
						Total Nitrogen	********	********	NL	NL
						Water Temperatrue (Deg. C)	********	********	*********	43
						Color, PCU	*********	*********	800	NL
						2,3,7,8-TCDD	*********	0.00165	*********	14
						AOX (Adsorbable Organic Halides)	2370	3618	NL	NL
MeadWestvaco Packaging Resource Group	VA0003646	Major	Industrial	-	4	BOD5	********	*********	*********	NL
						COD	********	********	*********	NL
						Flow, Precipitation Event	********	NL	*********	*********
						Total Recoverable Iron	********	********	*********	NL
						TKN (N-KJEL)	********	********	*********	NL

Facility Name	Permit No.	Major/Minor	Municipal/ Industrial	Design Flow	Outfall No.	Parameter Description	Quantity Average	Quantity Maximum	Concentration Avg.	Concentration Max.
						TSS	********	********	*********	NL
MeadWestvaco Packaging Resource Group	VA0003646	Major	Industrial	-	5	BOD5	********	*********	*********	NL
						COD	********	********	*********	NL
						Flow, Precipitation Event	********	NL	*********	*********
						Nitrite and Nirtrate, N Total	********	********	*********	NL
						TKN (N-KJEL)	********	********	*********	NL
						TSS	********	********	*********	NL
MeadWestvaco Packaging Resource Group	VA0003646	Major	Industrial	-	5	BOD5	********	*********	*********	NL
						COD	********	********	*********	NL
						Flow, Precipitation Event	********	NL	*********	*********
						Total Recoverable Iron	********	********	*********	NL
						Total Phosphorous	********	********	*********	NL
						TKN (N-KJEL)	********	********	*********	NL
						TSS	********	********	*********	NL
MeadWestvaco Packaging Resource Group	VA0003646	Major	Industrial	-	7	BOD5	********	*********	*********	NL
						COD	********	********	*********	NL
						Flow, Precipitation Event	********	NL	*********	*********
						Total Recoverable Iron	********	********	*********	NL
						Total Phosphorous	********	********	*********	NL
						TKN (N-KJEL)	********	********	*********	NL
						TSS	********	********	*********	NL
MeadWestvaco Packaging Resource Group	VA0003646	Major	Industrial	-	8	BOD5	********	*********	*********	NL
						COD	********	********	*********	NL
						Flow, Precipitation Event	********	NL	*********	*********
						Total Recoverable Iron	********	********	*********	NL
						Total Phosphorous	********	********	*********	NL
						TKN (N-KJEL)	********	********	*********	NL
						TSS	********	********	*********	NL

Facility Name	Permit No.	Major/Minor	Municipal/ Industrial	Design Flow	Outfall No.	Parameter Description	Quantity Average	Quantity Maximum	Concentration Avg.	Concentration Max.
MeadWestvaco Packaging Resource Group	VA0003646	Major	Industrial	-	9	BOD5	********	*********	*********	NL
						COD	********	********	*********	NL
						Flow, Precipitation Event	********	NL	*********	*********
						Total Recoverable Iron	********	********	*********	NL
						Total Phosphorous	********	********	*********	NL
						TKN (N-KJEL)	********	********	*********	NL
						TSS	********	********	*********	NL
MeadWestvaco Packaging Resource Group	VA0003646	Major	Industrial	-	10	AMMONIA, AS N	********	********	*********	NL
						BOD5	********	*********	*********	NL
						COD	********	********	*********	NL
						Flow, Precipitation Event	********	NL	*********	*********
						Total Recoverable Iron	********	********	*********	NL
						Nitrite and Nitrate, Total	********	********	*********	NL
						TKN (N-KJEL)	********	********	*********	NL
						TSS	********	********	*********	NL
MeadWestvaco Packaging Resource Group	VA0003646	Major	Industrial	-	12	BOD5	********	*********	*********	NL
						Flow, Precipitation Event	********	NL	*********	*********
						TKN (N-KJEL)	********	********	*********	NL
MeadWestvaco Packaging Resource Group	VA0003646	Major	Industrial	-	13	BOD5	********	*********	*********	NL
						Color, PCU	********	********	*********	NL
						Flow, Precipitation Event	********	NL	*********	*********
						PH	********	********	*********	NL
						Total Phosphorous	********	********	*********	NL
						TKN (N-KJEL)	********	********	*********	NL
MeadWestvaco Packaging Resource Group	VA0003646	Major	Industrial	-	15	BOD5	********	*********	*********	NL
						Flow, Precipitation Event	********	NL	*********	*********
						TSS	********	********	*********	NL
MeadWestvaco	VA00036	Major	Industrial	-	301	2,3,4,6-TETRACHLOROPHENOL	********	********	NL	2.5

Facility Name	Permit No.	Major/Minor	Municipal/ Industrial	Design Flow	Outfall No.	Parameter Description	Quantity Average	Quantity Maximum	Concentration Avg.	Concentration Max.
Packaging Resource Group	46					2,3,7,8-TCDD	********	********	NL	10
						2,3,7,8-TETRACHLORODIBENZOFURAN (PPQ)	********	********	NL	31.9
						2,4,5-TRICHLOROPHENOL	********	********	NL	2.5
						2,4,6-TRICHLOROPHENOL	********	********	NL	2.5
						3,4,5-TRICHLOROCATECHOL	********	********	NL	5
						3,4,5-TRICHLOROGUAIACOL	********	********	NL	2.5
						3,4,6-TRICHLOROCATECHOL	********	********	NL	5
						3,4,6-TRICHLOROGUAIACOL	********	********	NL	2.5
						4,5,6-TRICHLOROGUAIACOL	********	********	NL	2.5
						CHLOROFORM (AS CHCL3)	4956	8285	NL	NL
						PENTACHLOROPHENOL	********	********	NL	5
						TETRACHLOROCATECHOL	********	********	NL	5
						TETRACHLOROGUAIACOL	********	********	NL	5
						TRICHLOROSYRINGOL	********	********	NL	2.5
MeadWestvaco Packaging Resource Group	VA00036 46	Major	Industrial	-	302	2,3,4,6-TETRACHLOROPHENOL	********	********	NL	2.5
						2,3,7,8-TCDD	********	********	NL	10
						2,3,7,8-TETRACHLORODIBENZOFURAN (PPQ)	********	********	NL	31.9
						2,4,5-TRICHLOROPHENOL	********	********	NL	2.5
						2,4,6-TRICHLOROPHENOL	********	********	NL	2.5
						3,4,5-TRICHLOROCATECHOL	********	********	NL	5
						3,4,5-TRICHLOROGUAIACOL	********	********	NL	2.5
						3,4,6-TRICHLOROCATECHOL	********	********	NL	5
						3,4,6-TRICHLOROGUAIACOL	********	********	NL	2.5
						4,5,6-TRICHLOROGUAIACOL	********	********	NL	2.5
						CHLOROFORM (AS CHCL3)	5839	9760	NL	NL
						PENTACHLOROPHENOL	********	********	NL	5
						TETRACHLOROCATECHOL	********	********	NL	5

Facility Name	Permit No.	Major/Minor	Municipal/ Industrial	Design Flow	Outfall No.	Parameter Description	Quantity Average	Quantity Maximum	Concentration Avg.	Concentration Max.
						TETRACHLOROGUAIACOL	********	********	NL	5
						TRICHLOROSYRINGOL	********	********	NL	2.5
MeadWestvaco Packaging Resource Group	VA0003646	Major	Industrial	-	303	2,3,4,6-TETRACHLOROPHENOL	********	********	NL	2.5
						2,3,7,8-TCDD	********	********	NL	10
						2,3,7,8-TETRACHLORODIBENZOFURAN (PPQ)	********	********	NL	31.9
						2,4,5-TRICHLOROPHENOL	********	********	NL	2.5
						2,4,6-TRICHLOROPHENOL	********	********	NL	2.5
						3,4,5-TRICHLOROCATECHOL	********	********	NL	5
						3,4,5-TRICHLOROGUAIACOL	********	********	NL	2.5
						3,4,6-TRICHLOROCATECHOL	********	********	NL	5
						3,4,6-TRICHLOROGUAIACOL	********	********	NL	2.5
						4,5,6-TRICHLOROGUAIACOL	********	********	NL	2.5
						CHLOROFORM (AS CHCL3)	4956	8285	NL	NL
						PENTACHLOROPHENOL	********	********	NL	5
						TETRACHLOROCATECHOL	********	********	NL	5
						TETRACHLOROGUAIACOL	********	********	NL	5
						TRICHLOROSYRINGOL	********	********	NL	2.5
Morris Hill Sewage Treatment Plant	VA0032115	Minor	Municipal	0.015	1	BOD5	1.7	2.5	30	45
						CL2, Inst Res Max	*********	*********	2	2.4
						CL2, Inst Tech Limit	*********	*********	*********	*********
						CL2, Total Contact	*********	*********	*********	*********
						DO	*********	*********	*********	*********
						Flow	0.015	NL	*********	*********
						pH	*********	*********	*********	9
						TSS	1.7	2.5	30	45
						BOD5	*********	*********	NL	NL
						Flow	NL	NL	*********	*********
						Water Temperature (DEG. C)	*********	*********	*********	31

Facility Name	Permit No.	Major/Minor	Municipal/ Industrial	Design Flow	Outfall No.	Parameter Description	Quantity Average	Quantity Maximum	Concentration Avg.	Concentration Max.
Parker Hannifin Powertrain Division	VA0002984	Minor	Industrial	0.208	1	BOD5	*********	*********	NL	NL
						Flow	NL	NL	*********	*********
						pH	*********	*********	*********	9
						Water Temperature (DEG. C)	*********	*********	*********	31
Parker Hannifin Powertrain Division	VA0002984	Minor	Industrial	-	2	BOD5	*********	*********	NL	NL
						Flow	NL	NL	*********	*********
						pH	*********	*********	*********	9
						Water Temperature (DEG. C)	*********	*********	*********	31
Parker Hannifin Powertrain Division	VA0002984	Minor	Industrial	-	3	Flow, Precipitation Event	********	NL	*********	*********
						pH	********	********	*********	NL
						Zinc, Total Recoverable	********	********	*********	NL
Parker Hannifin Powertrain Division	VA0002984	Minor	Industrial	-	5	Flow, Precipitation Event	********	NL	*********	*********
						pH	********	********	*********	NL
						Zinc, Total Recoverable	********	********	*********	NL
Parker Hannifin Powertrain Division	VA0002984	Minor	Industrial	-	901	Flow, Precipitation Event	********	NL	*********	*********
						pH	********	********	*********	9
						Water Temperature (DEG. C)	********	********	*********	31
						Zinc, Total Recoverable	********	********	*********	NL
Parker Hannifin Powertrain Division	VA0002984	Minor	Industrial	-	902	Flow, Precipitation Event	********	NL	*********	*********
						pH	********	********	*********	9
						Water Temperature (DEG. C)	********	********	*********	31
						Zinc, Total Recoverable	********	********	*********	NL
Parker Hannifin Powertrain Division	VA0002984	Minor	Industrial	-	999	BOD5	6	9	*********	*********
Sponaugle Subdivision	VA0088552	Minor	Municipal	0.016	1	BOD5	1.82	2.72	30	45
						CL2, Inst Res Max	********	********	2	2.4
						CL2, Inst Teach Limit	********	********	*********	*********

Facility Name	Permit No.	Major/Minor	Municipal/ Industrial	Design Flow	Outfall No.	Parameter Description	Quantity Average	Quantity Maximum	Concentration Avg.	Concentration Max.
						CL2, Total Contact	********	********	*********	*********
						Flow	0.016	NL	*********	*********
						pH	*********	*********	*********	9
						TSS	1.82	2.72	30	45
Tanglewood Manor Home for Adults Inc	VA0090646	Minor	Municipal	0.018	1	Ammonia, as N Jan-May	********	********	2.1	2.1
						Ammonia, as N Jun-Dec	********	********	1.6	1.6
						CBOD5, Jan-May	1.6	2.4	24	36
						CBOD5, Jun-Dec	1	1.5	15	22.5
						CL2, Inst Res Max	*********	*********	0.007	0.009
						CL2, Inst Tech Min Limit	*********	*********	*********	*********
						CL2, Total Contact	*********	*********	*********	*********
						Fecal Coliform			20	
						DO, Jan- May	********	********	*********	*********
						DO, Jun-Dec	********	********	*********	*********
						Flow	0.018	NL	*********	*********
						pH	*********	*********	*********	8.1
						TKN, Jan- May	********	********	9	13.5
						TKN, Jun-Dec	*********	********	5.1	7.6
						TSS	2	3	30	45
VDOT I64 Rest Area - Alleghany Co	VA0075574	Minor	Municipal	0.015	1	Ammonia, as N Jan-May	*********	*********	4	4
						Ammonia, as N Jun-Dec	*********	*********	3.1	3.1
						BOD5, Jan-May	1.7	2.5	30	45
						CBOD5, Jun-Dec	0.56	0.85	10	15
						Dissolved Copper (UG/L as CU)	********	********	23.1	23.1
						DO	*********	*********	*********	*********
						E.COLI	********	********	126	*********
						Flow	NL	NL	*********	*********
						pH	*********	*********	*********	9

Facility Name	Permit No.	Major/Minor	Municipal/ Industrial	Design Flow	Outfall No.	Parameter Description	Quantity Average	Quantity Maximum	Concentration Avg.	Concentration Max.
						TKN, Jun-Dec	0.23	0.34	4.1	6.1
						TSS	1.7	2.5	30	45
						Dissolved Zinc (UG/L as ZN)	********	*********	148.6	148.6

APPENDIX C

Discharge Monitoring Reports (DMR) from Individual Permitted Facilities within the Jackson River Watershed

Figure C-1: Alleghany Moore STP Effluent Flow Values

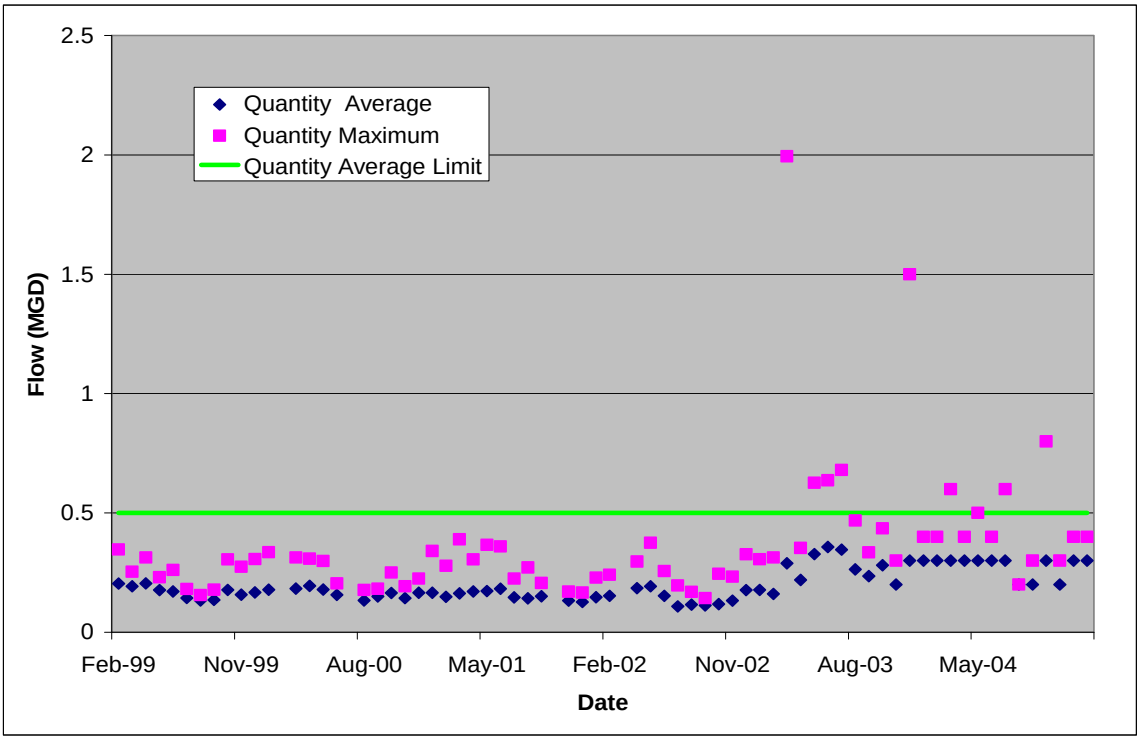


Figure C-2: Alleghany Moore STP Effluent BOD5 Quantities

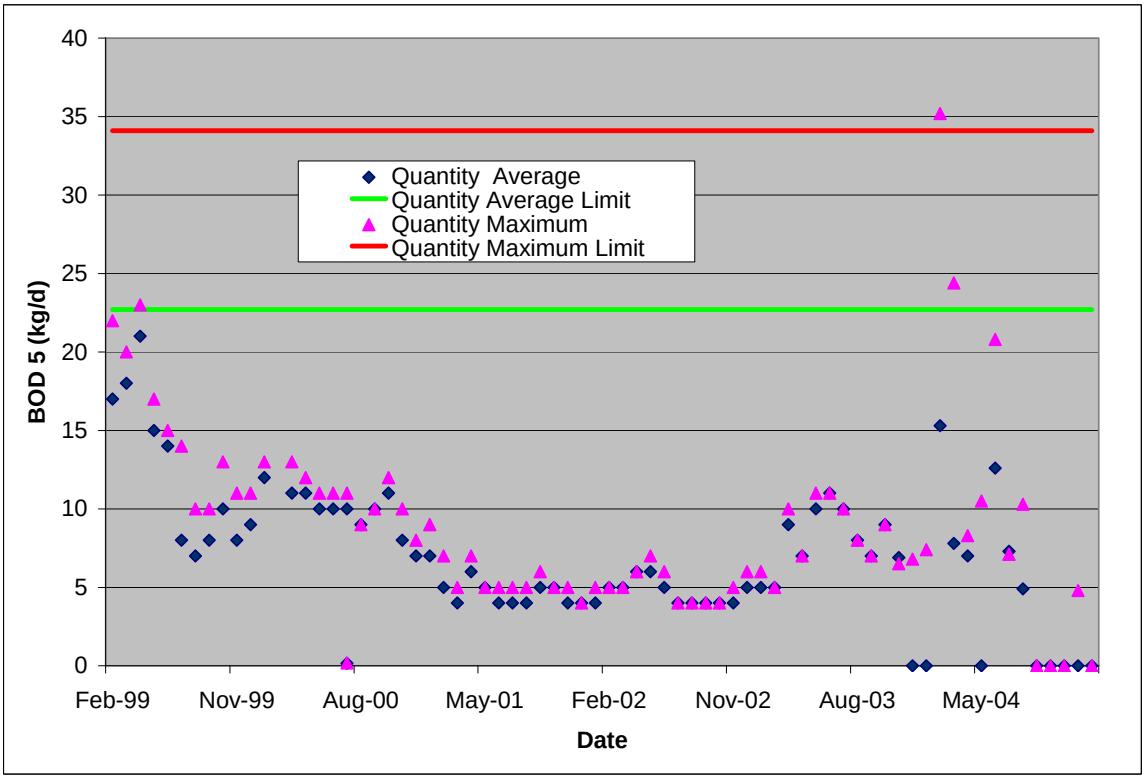


Figure C-3: Alleghany Moore STP Effluent BOD5 Concentrations

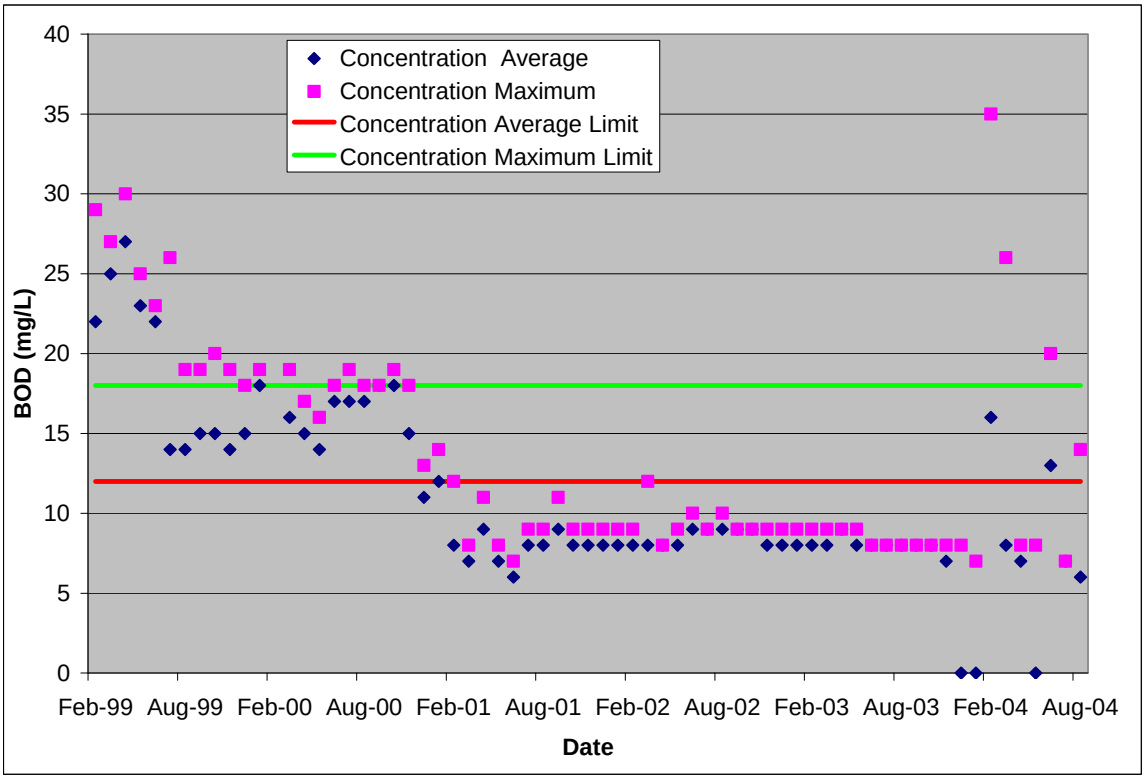


Figure C-4: Alleghany Moore STP Effluent Cl2 Concentrations

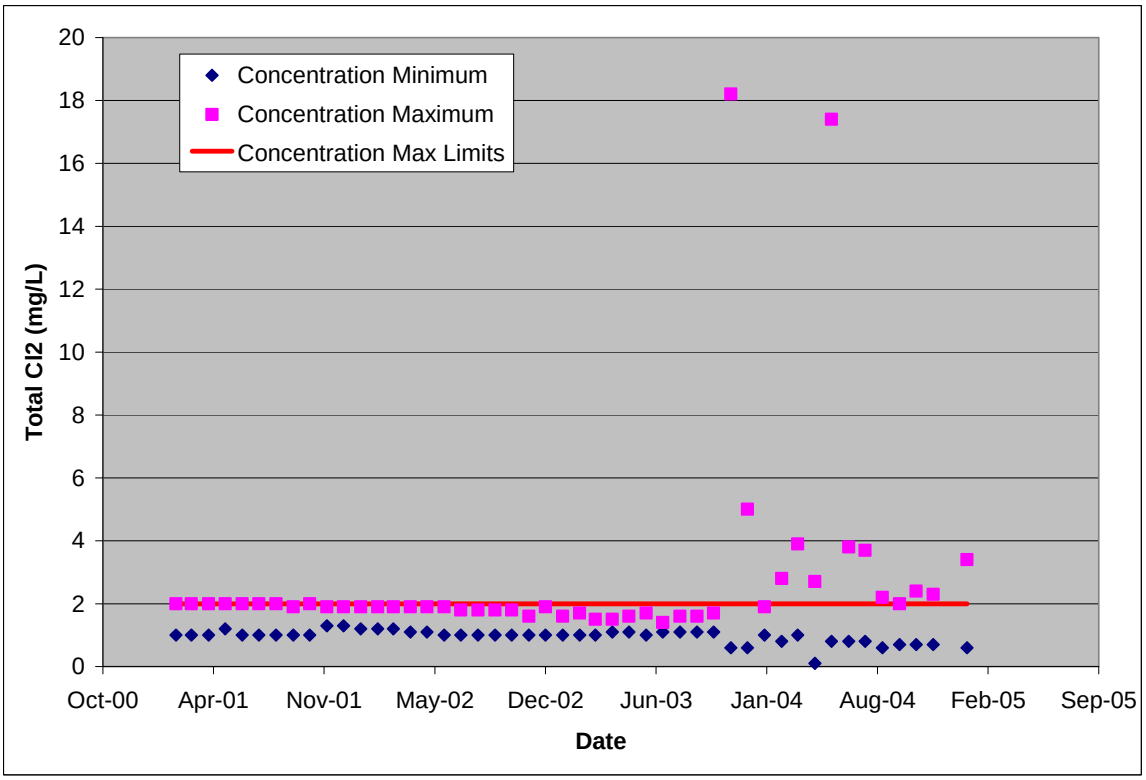


Figure C-5: Alleghany Moore STP Effluent Dissolved Oxygen Concentrations

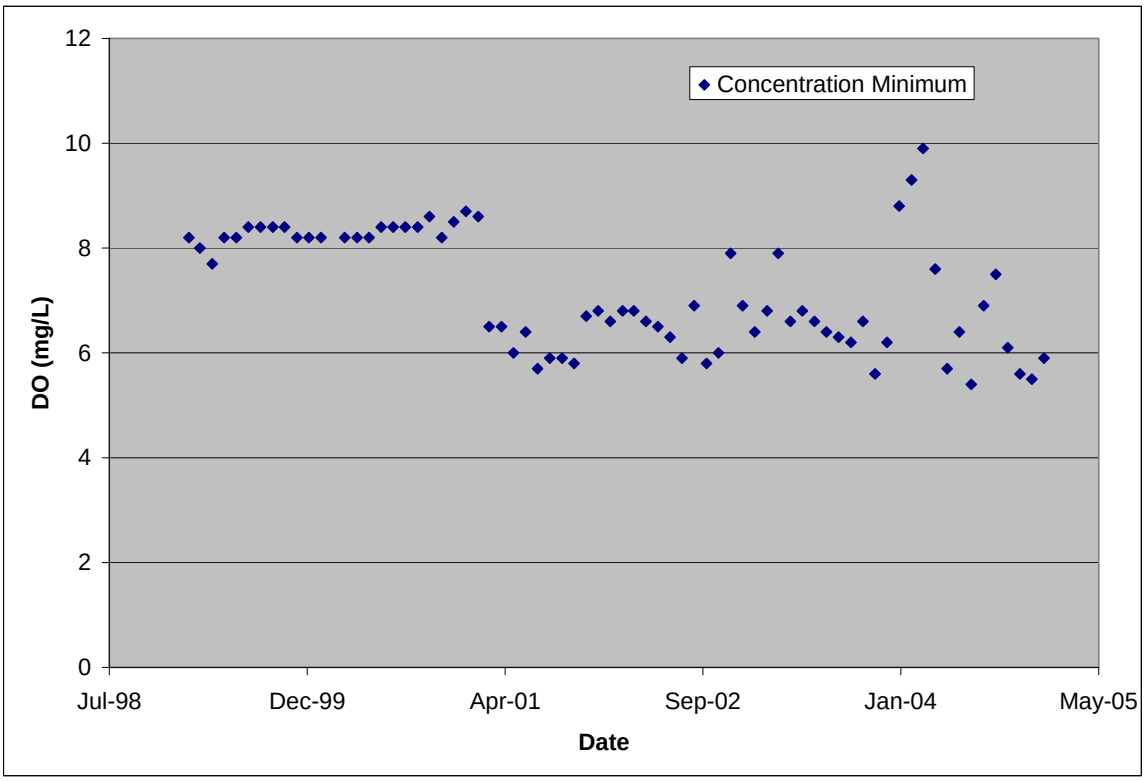


Figure C-6: Alleghany Moore STP Effluent TSS Quantities

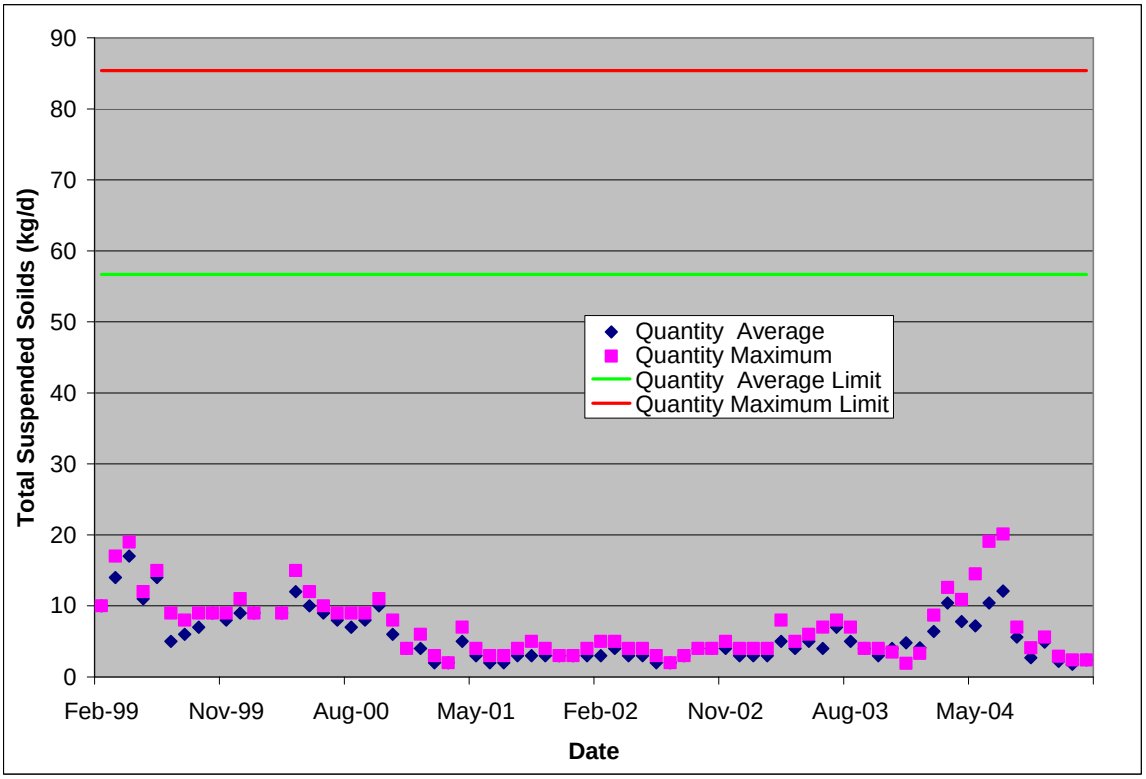


Figure C-7: Alleghany Moore STP Effluent TSS Concentrations

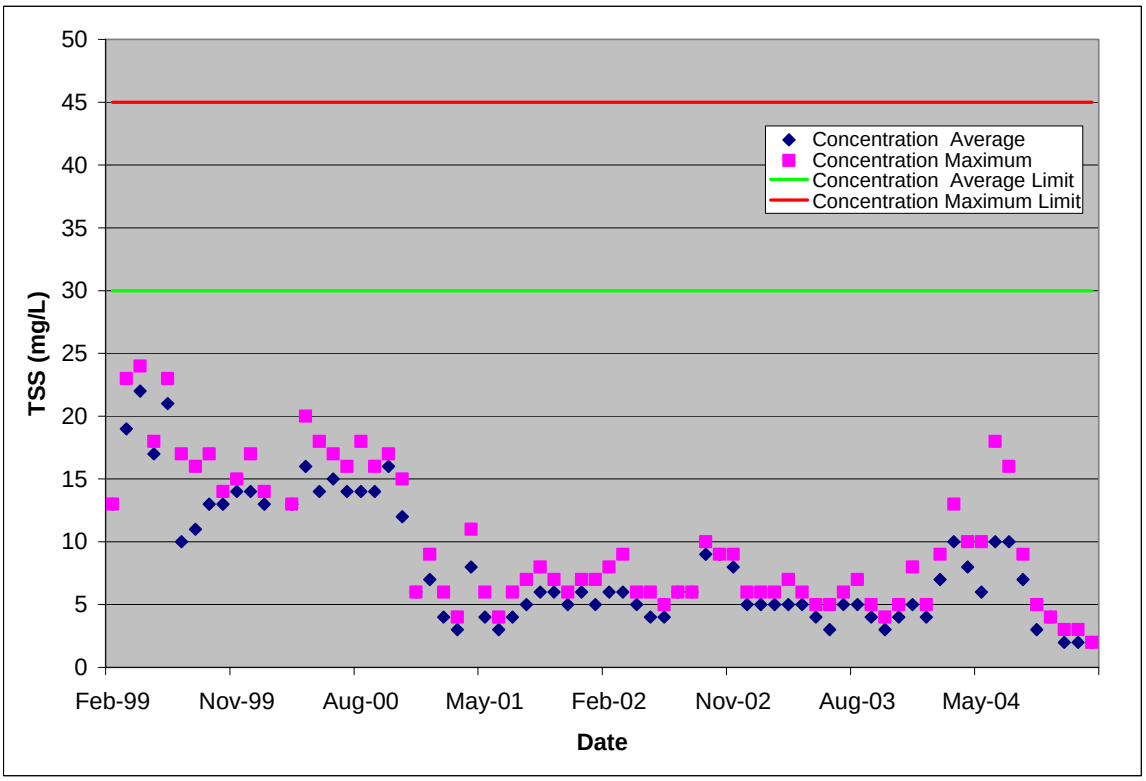


Figure C-8: Applied Extrusion Technologies Effluent Flow Data from Outfall 1

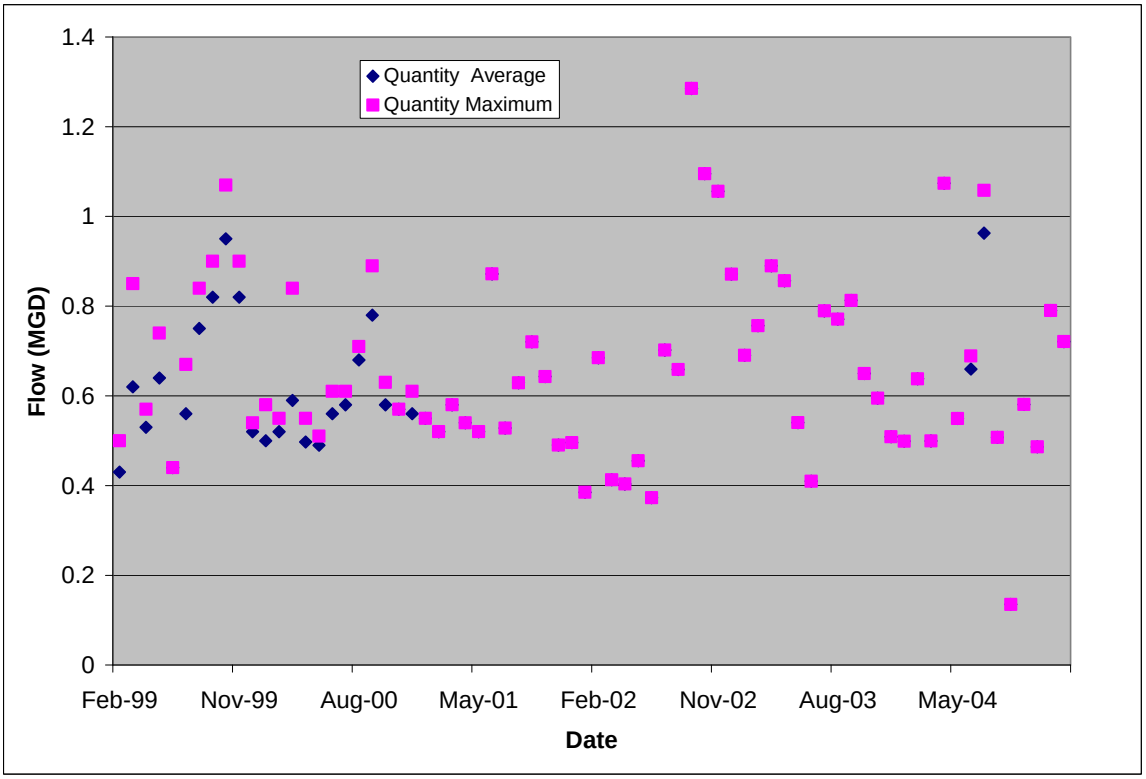


Figure C-9: Applied Extrusion Technologies Effluent TSS Concentrations from Outfall 1

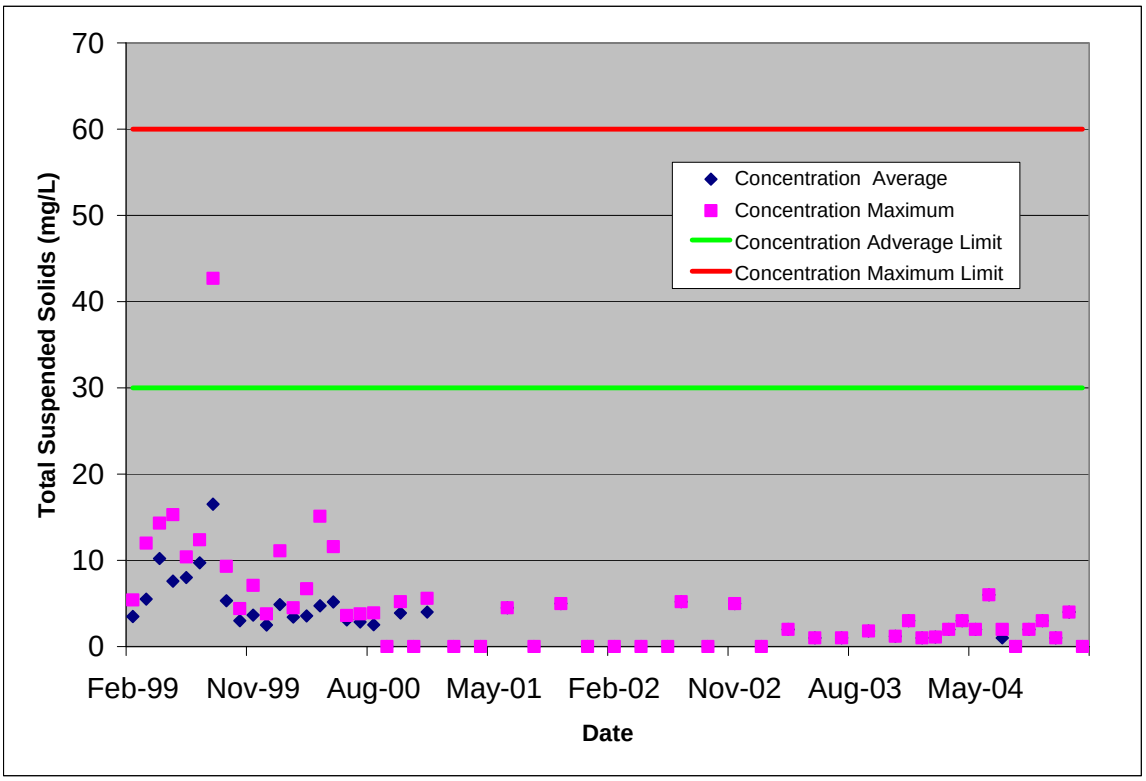


Figure C-10: Applied Extrusion Technologies Effluent Temperature Values from Outfall 1

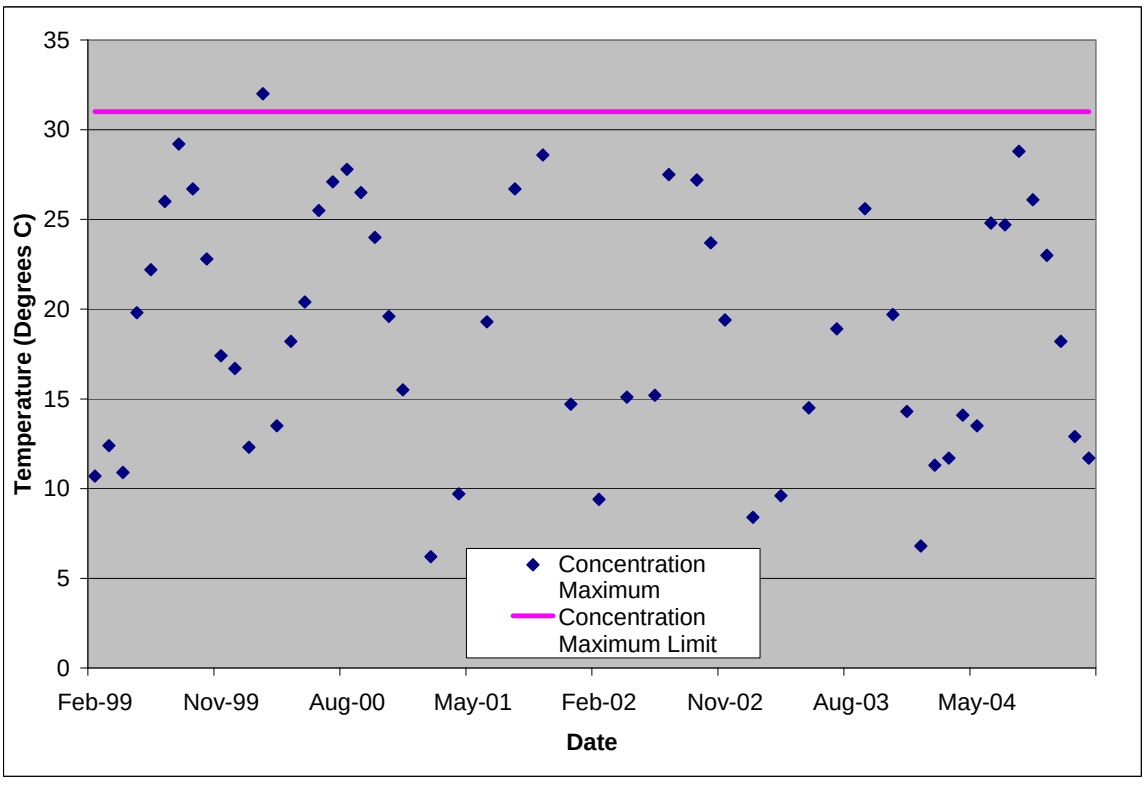


Figure C-11 Applied Extrusion Technologies Effluent pH Values from Outfall 1

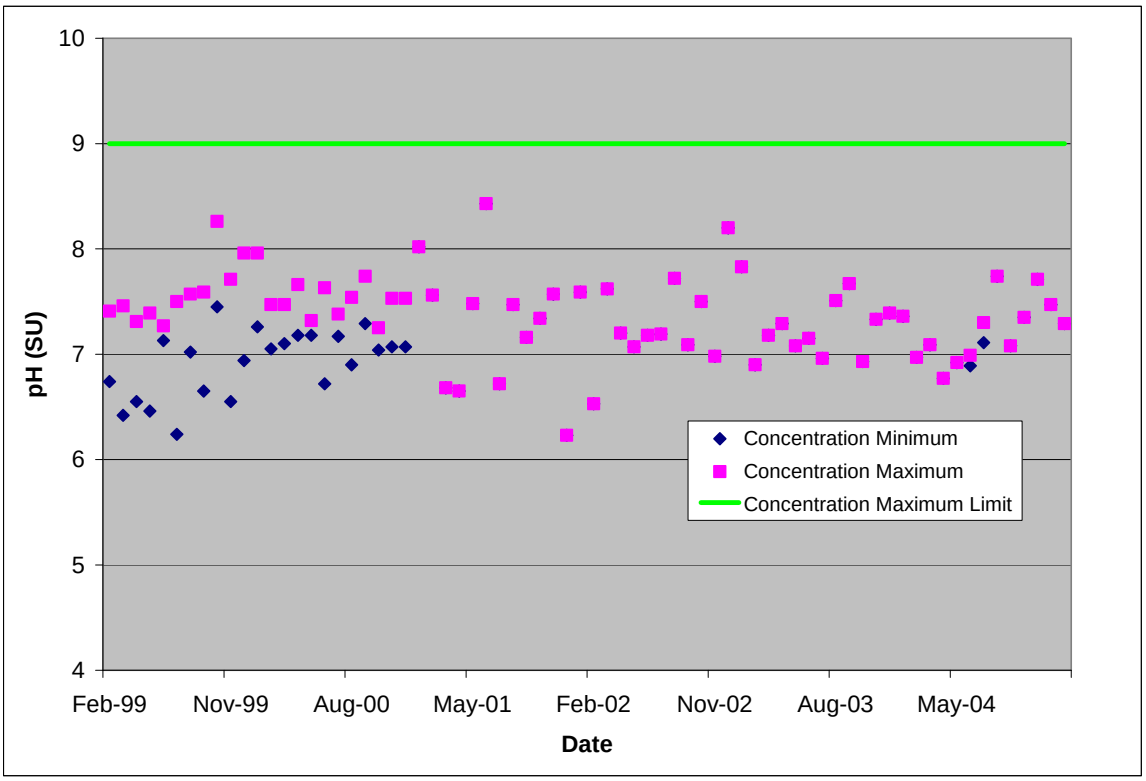


Figure C-12: Applied Extrusion Technologies Effluent BOD5 Quantities from Outfall 1

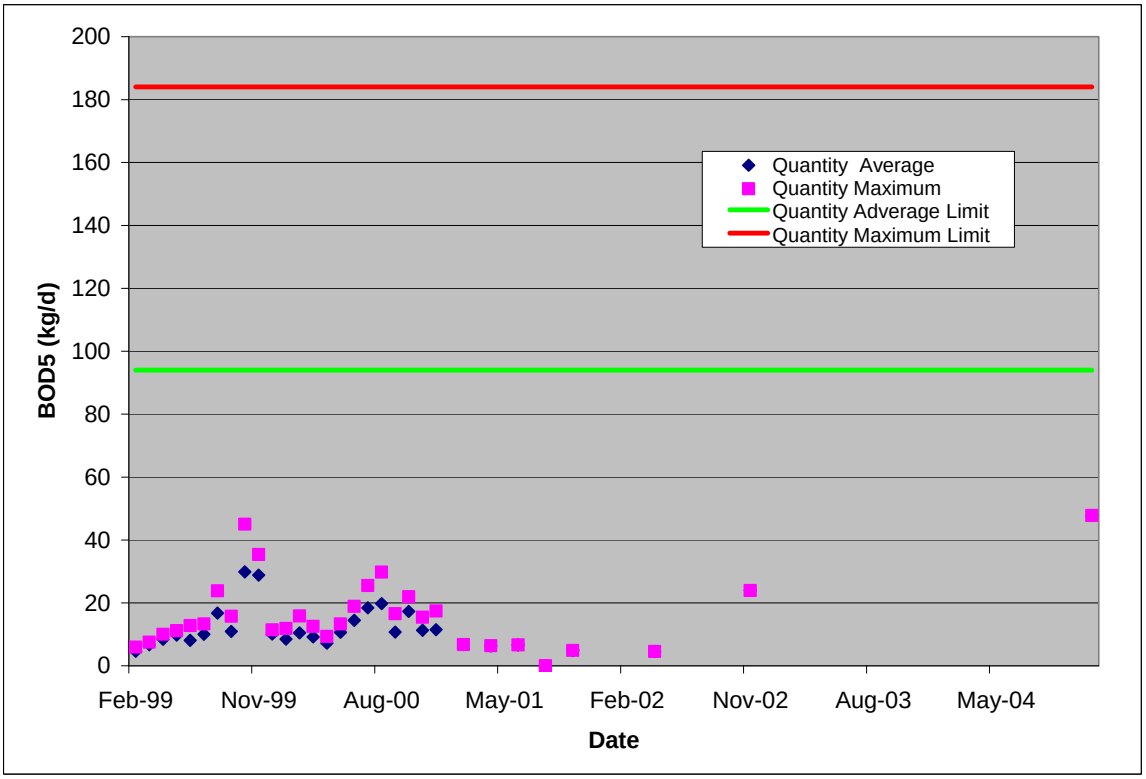


Figure C-13: Applied Extrusion Technologies Effluent Flow Values from Outfall 2

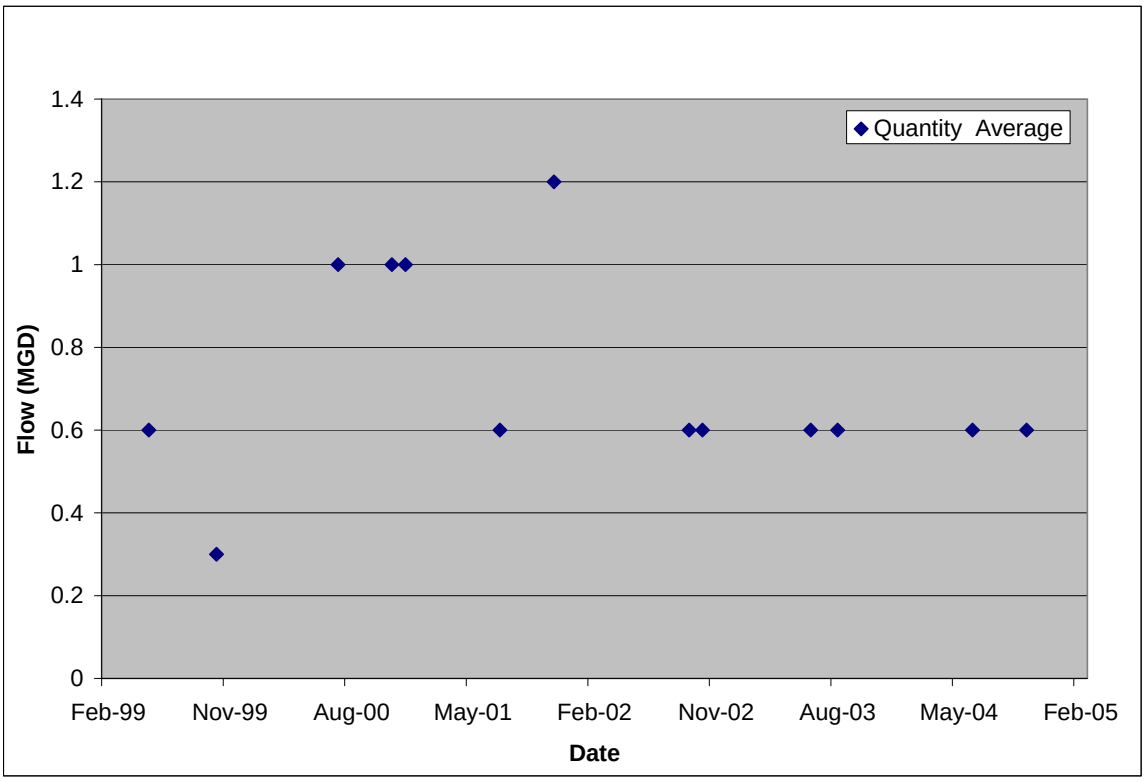


Figure C-14: Applied Extrusion Technologies Effluent TSS Concentrations from Outfall 2

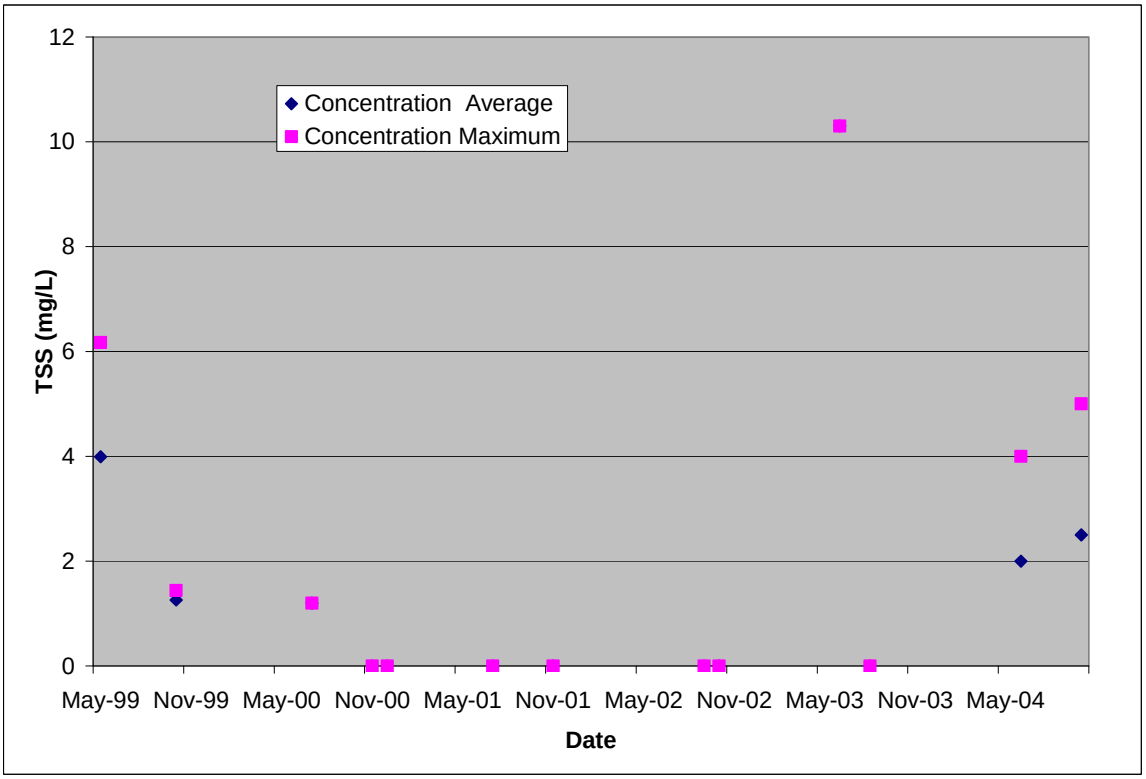


Figure C-15: Applied Extrusion Technologies Effluent Flow Values from Outfall 103

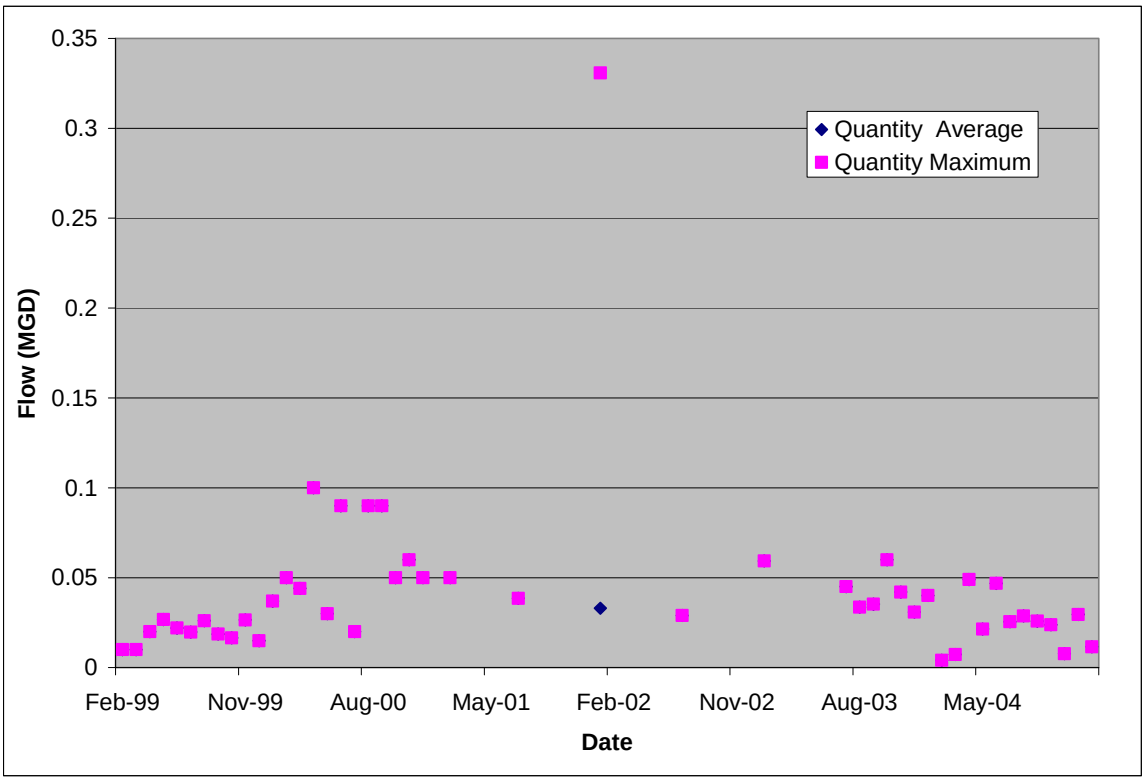


Figure C-16: Applied Extrusion Technologies Effluent TSS Quantities from Outfall 103

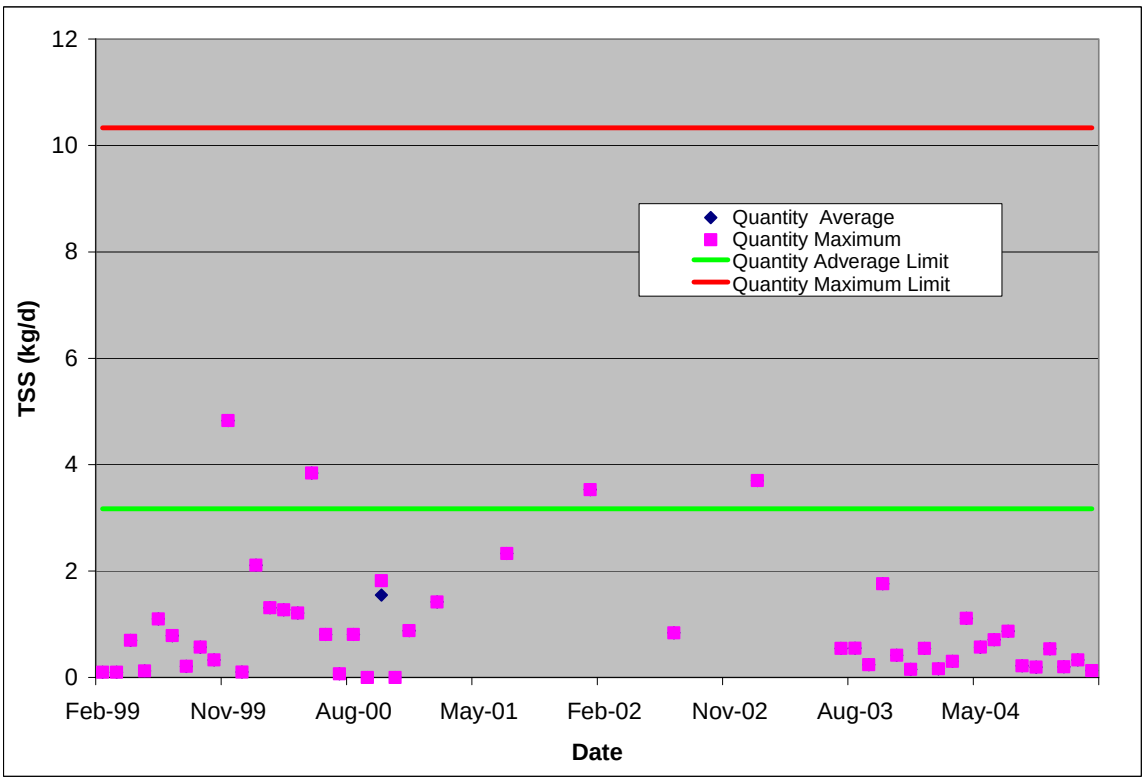


Figure C-17: Applied Extrusion Technologies Effluent BOD5 Quantities Outfall 103

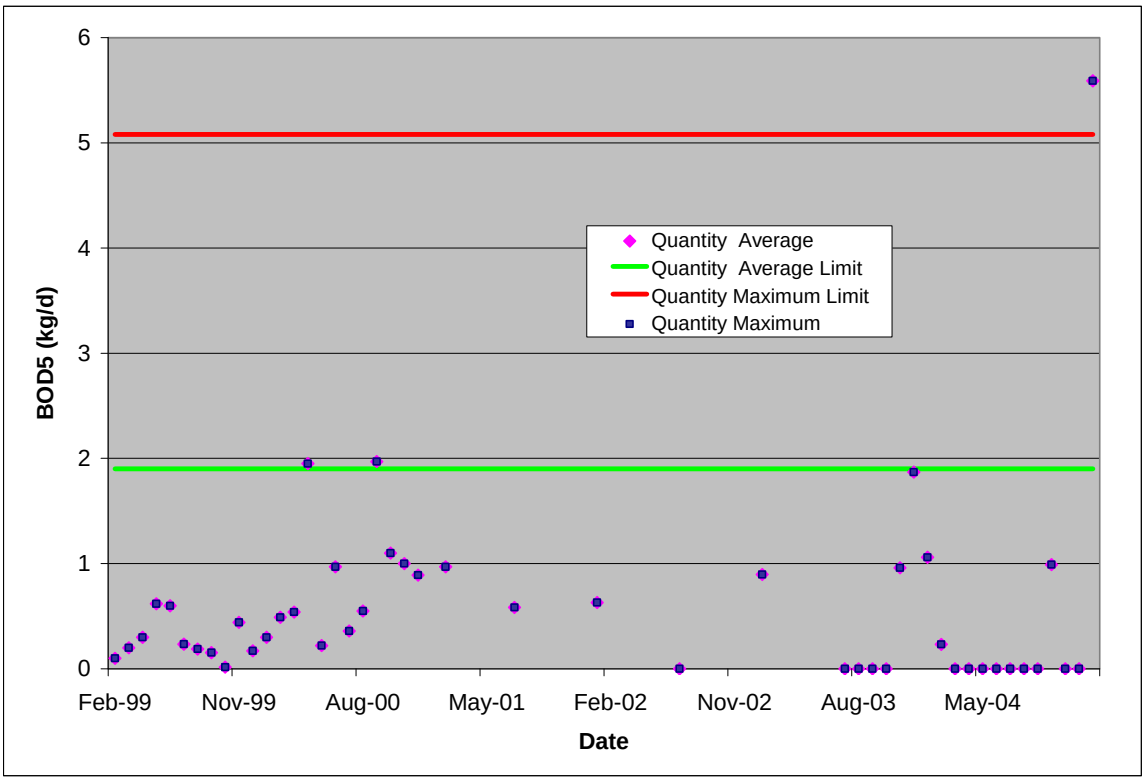


Figure C-18: Boys Home STP Effluent Flow Values

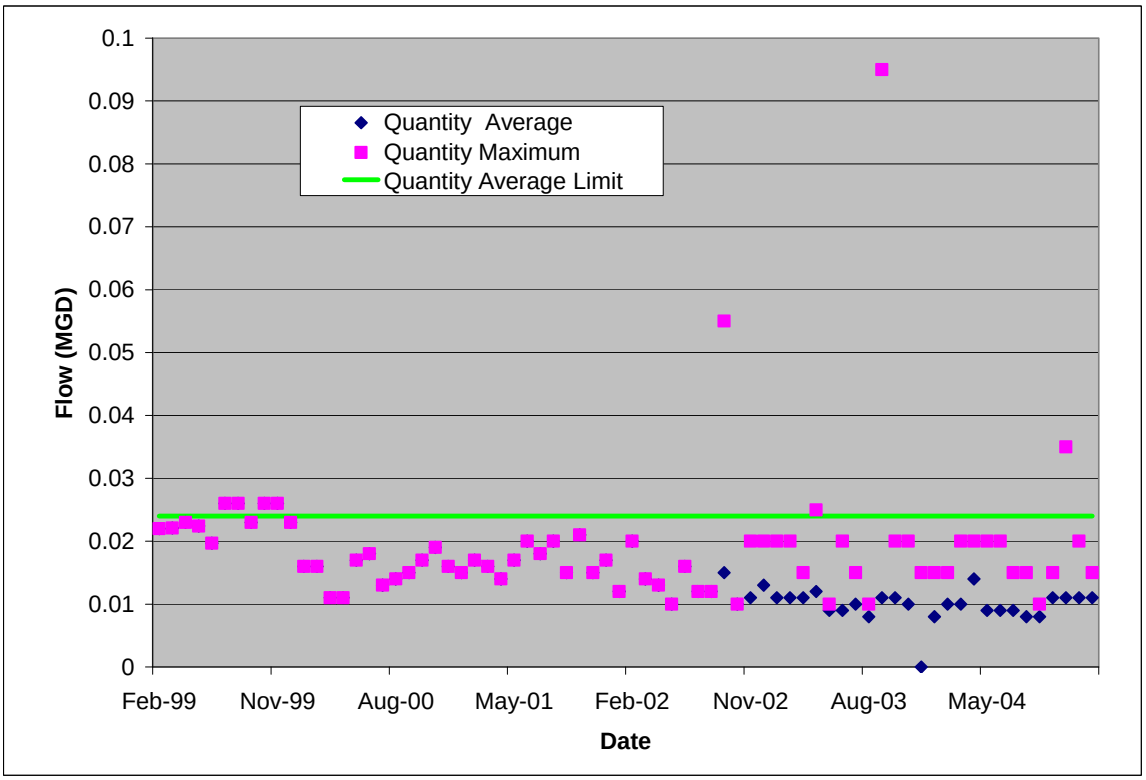


Figure C-19: Boys Home STP Effluent pH Values

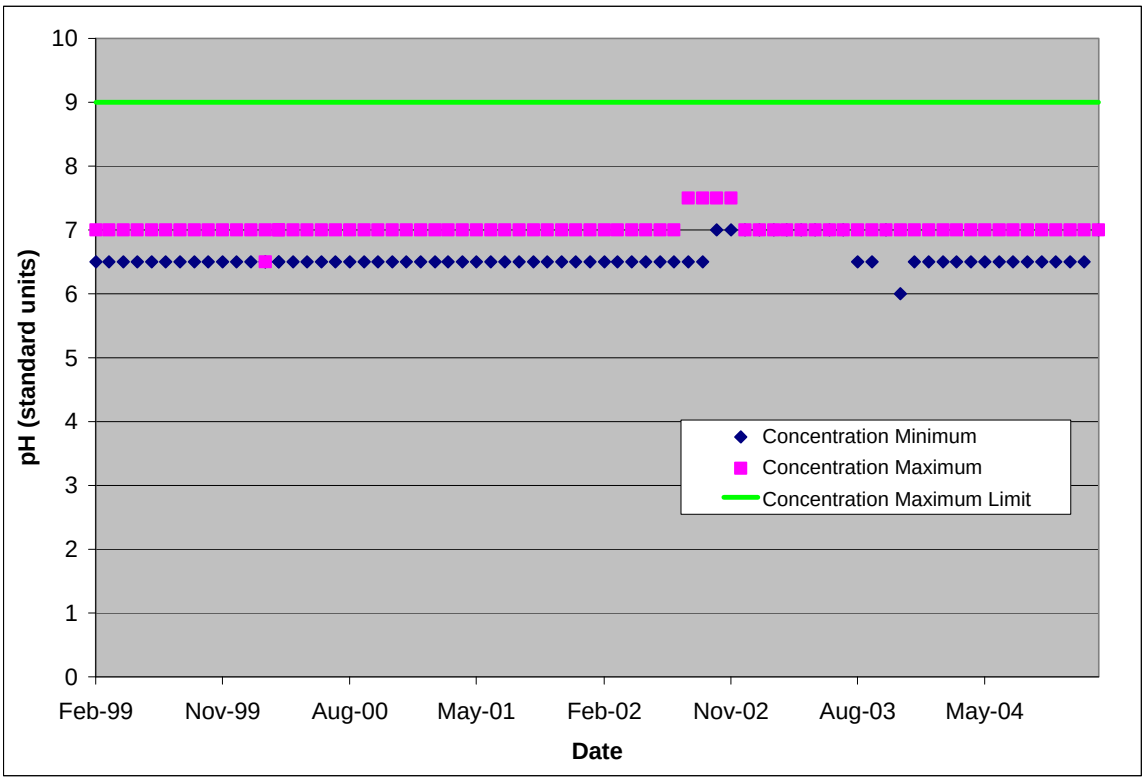


Figure C-20: Boys Home STP Effluent TSS Quantities

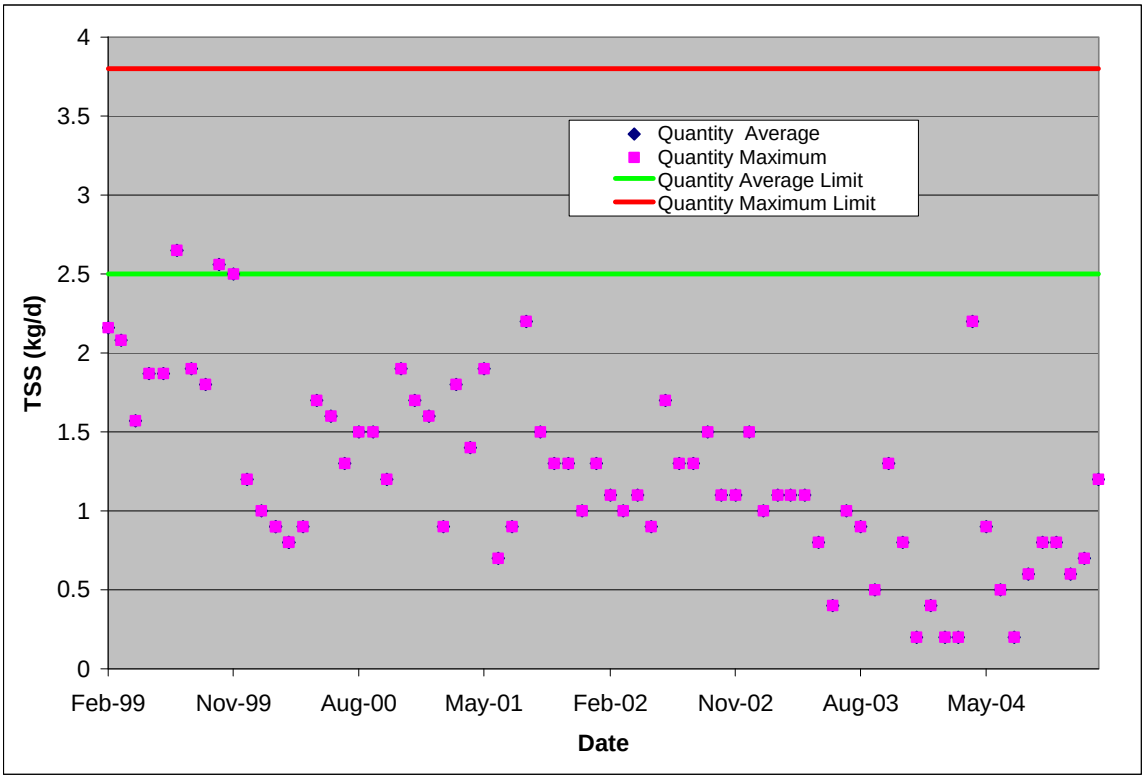


Figure C-21: Boys Home STP Effluent TSS Concentrations

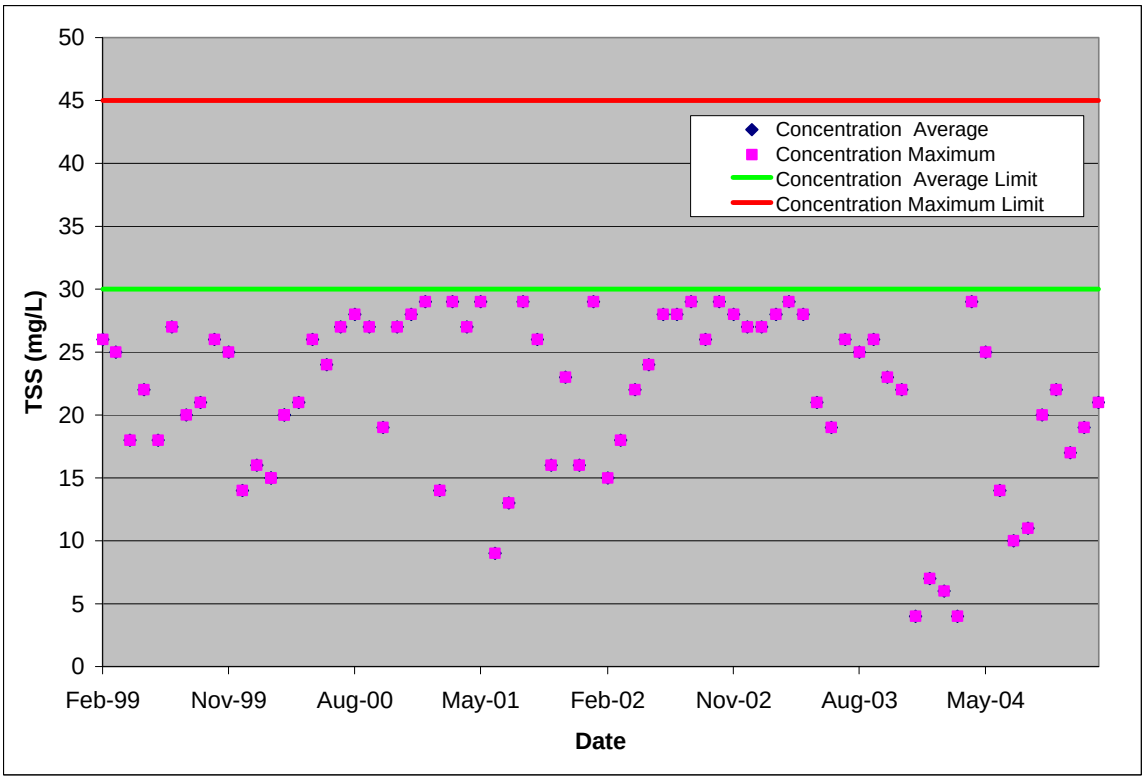


Figure C-22: Boys Home STP Effluent Oil and Grease Concentrations

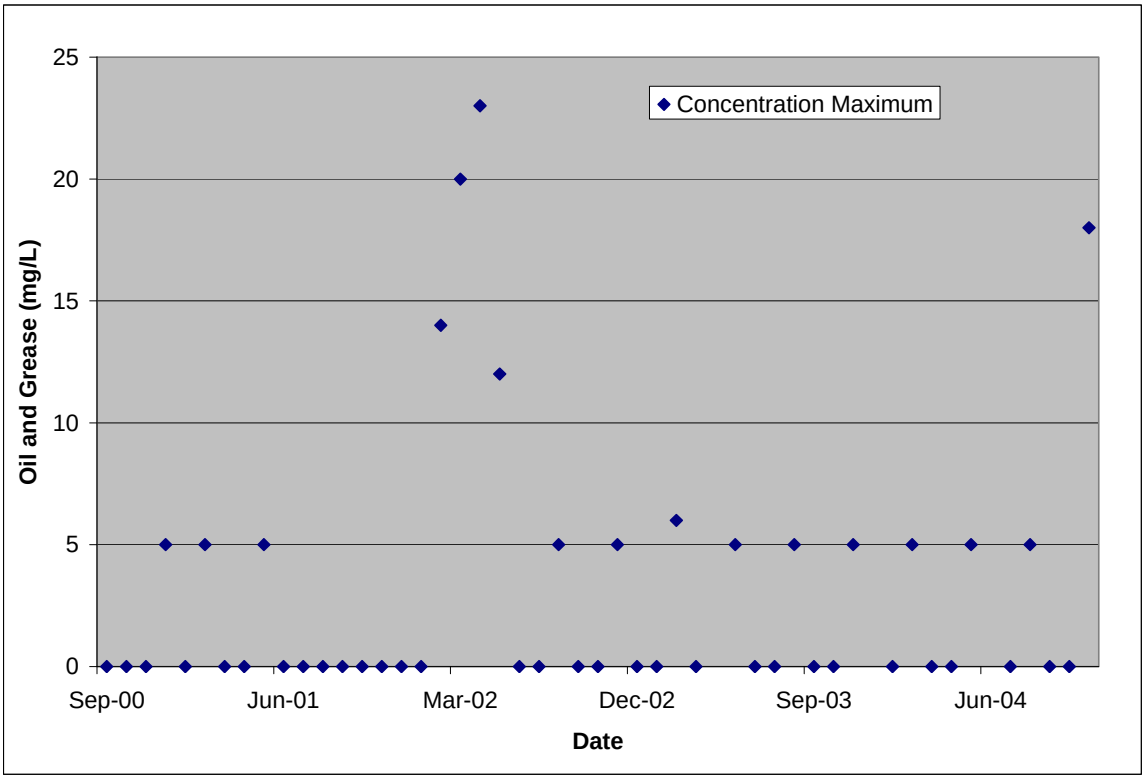


Figure C-23: Boys Home STP Effluent CL2 Concentrations

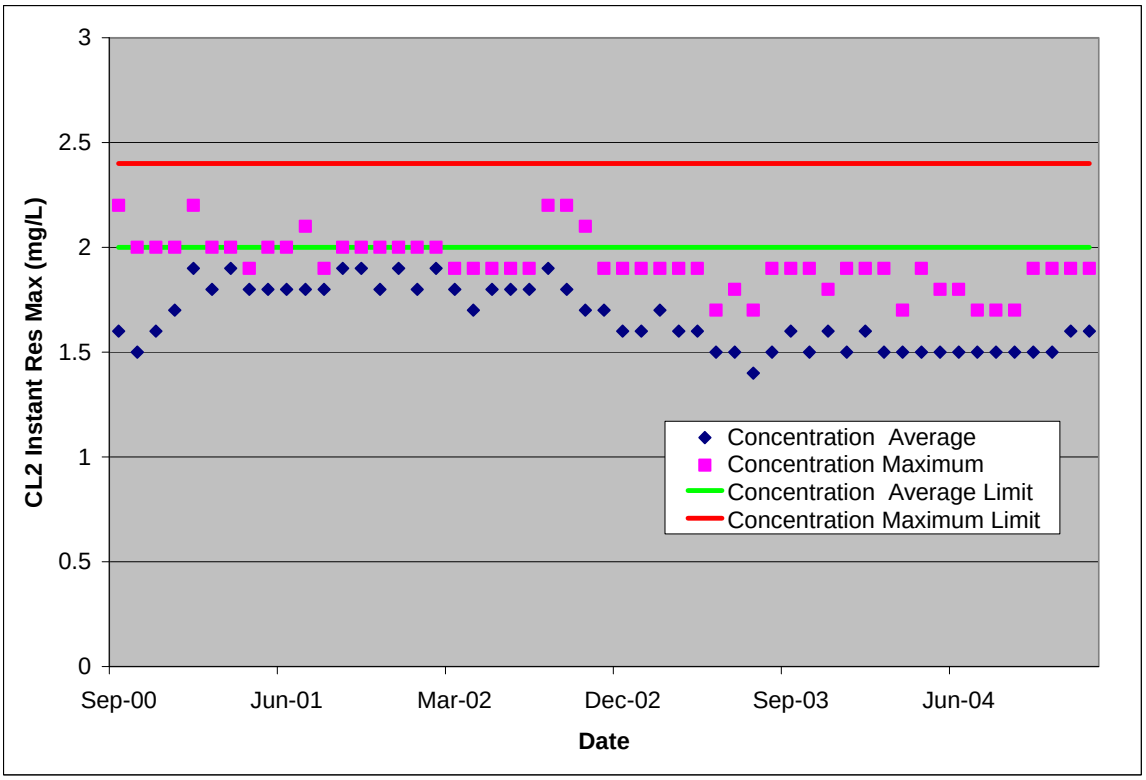


Figure C-24: Boys Home STP Effluent BOD5 Quantities

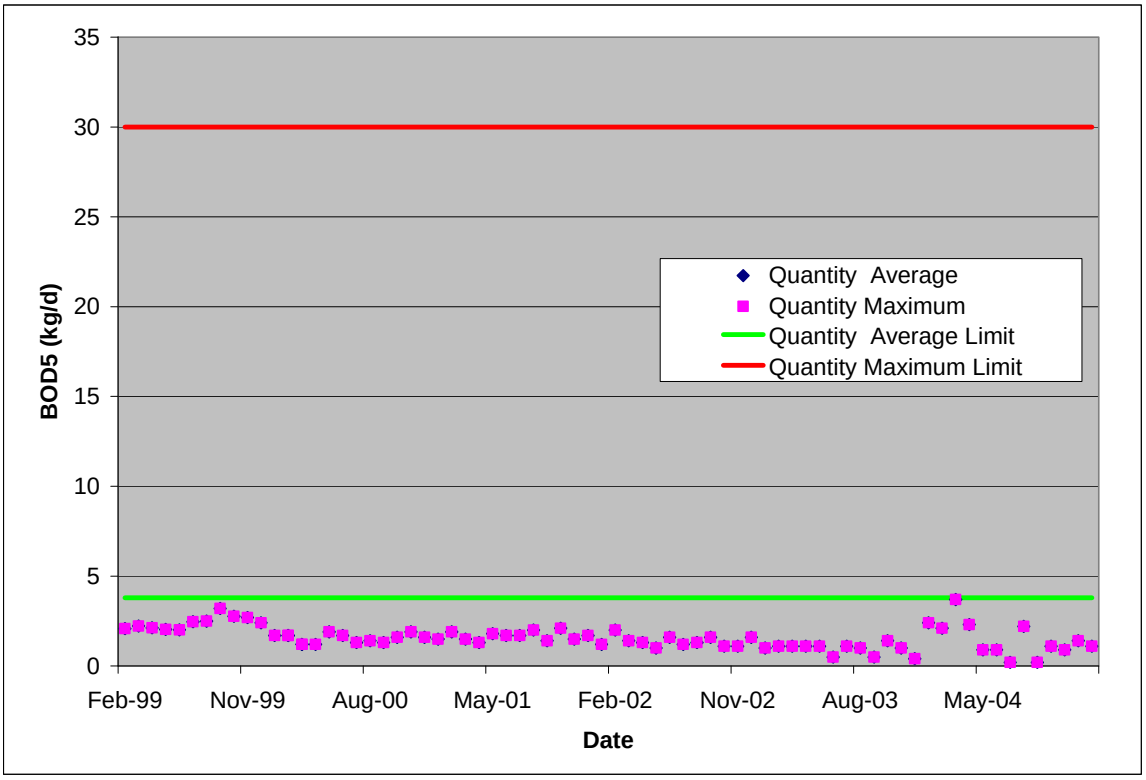


Figure C-25: Clifton Forge STP Effluent Flow Values

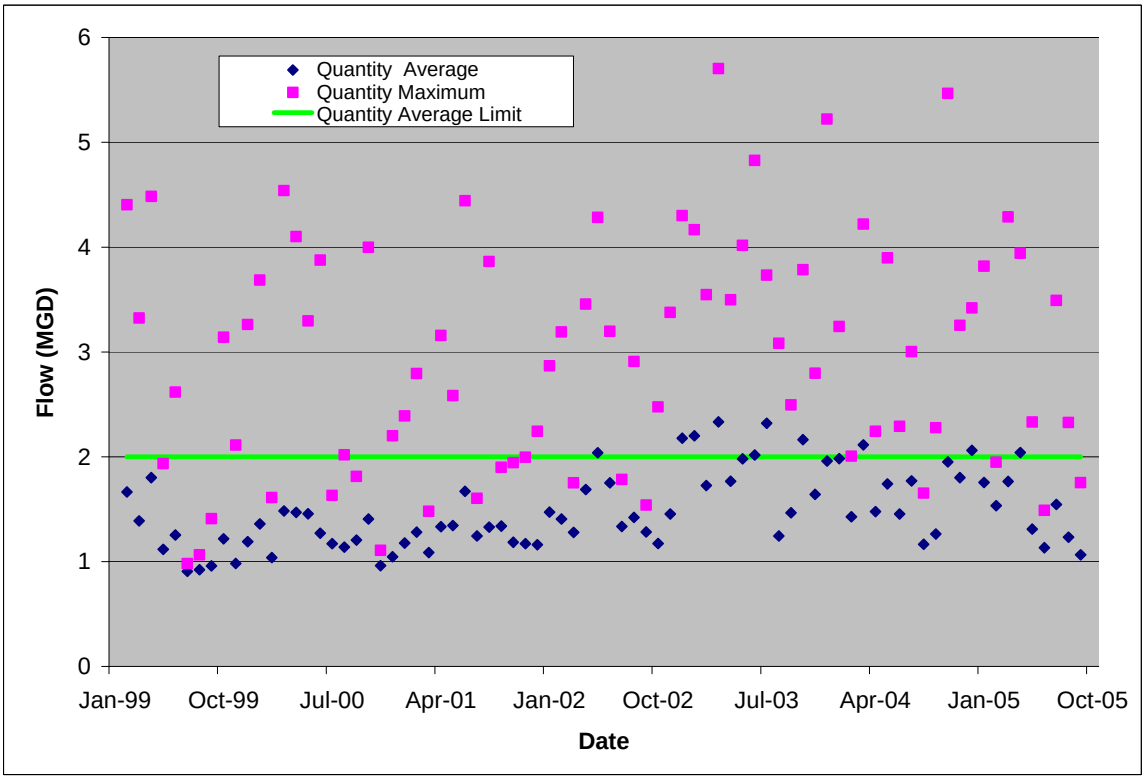


Figure C-26: Clifton Forge STP Effluent BOD5 Concentrations

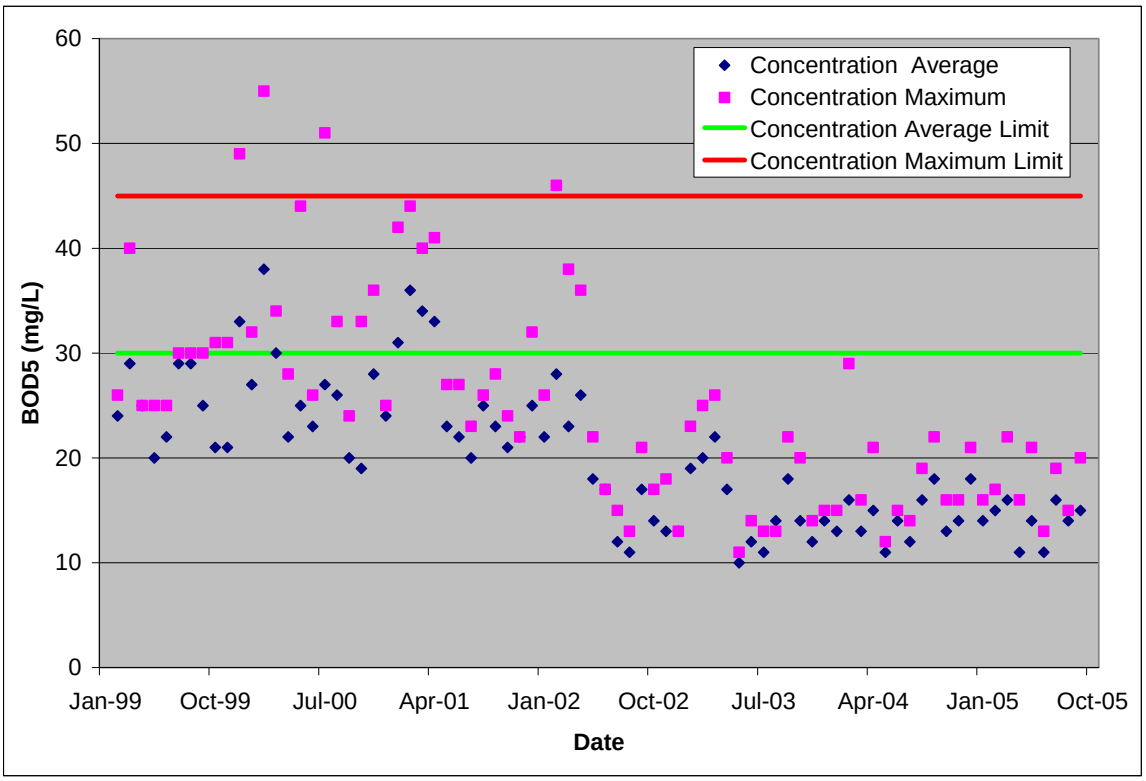


Figure C-27: Clifton Forge STP Effluent BOD5 Quantities

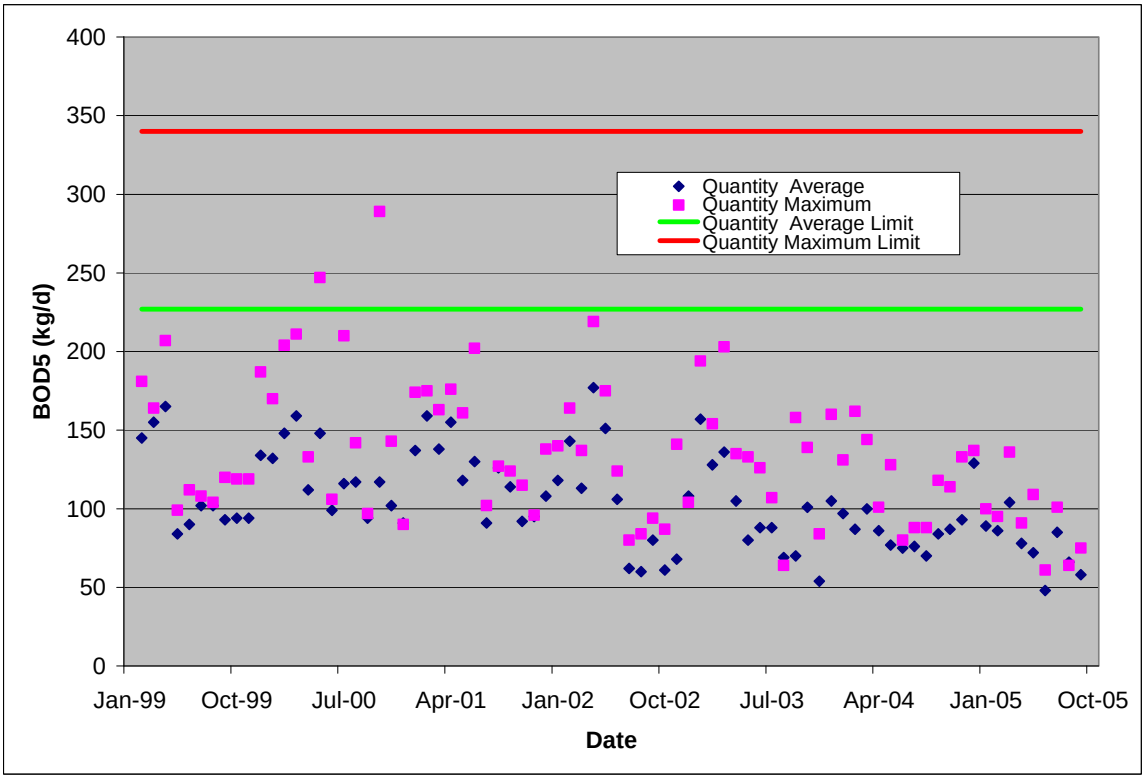


Figure C-28: Clifton Forge City STP Effluent CL2 Concentrations

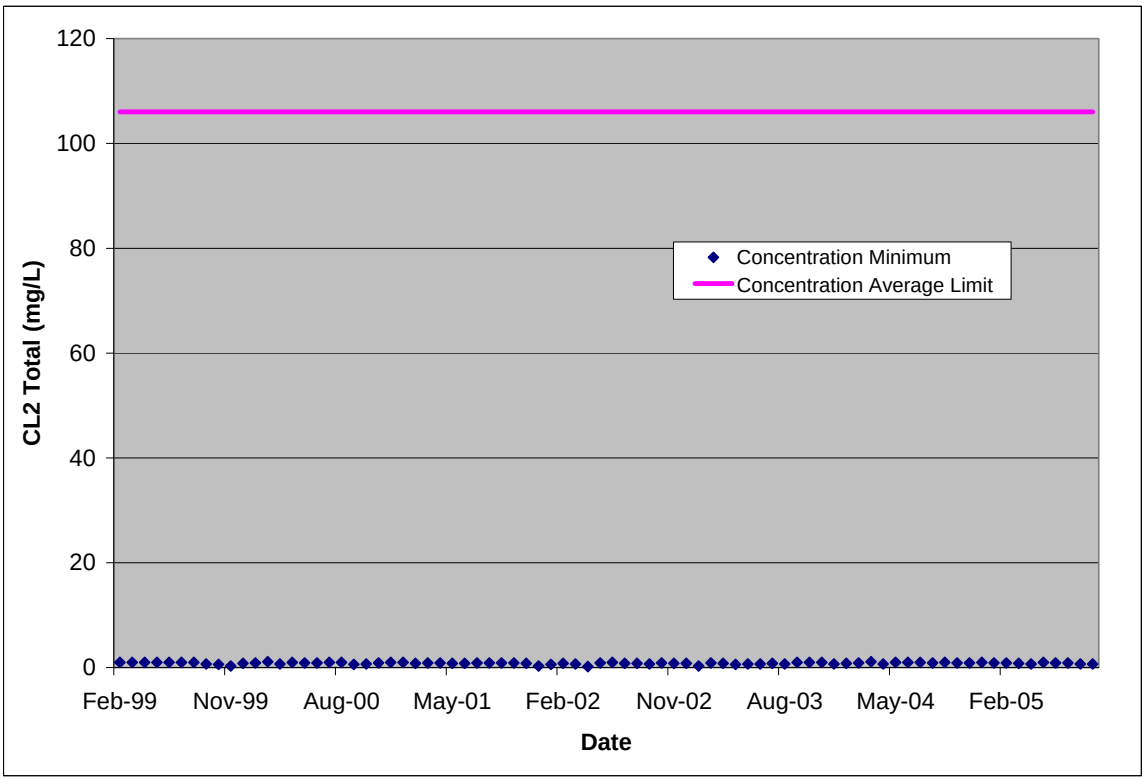


Figure C-29: Clifton Forge STP Effluent TSS Concentrations

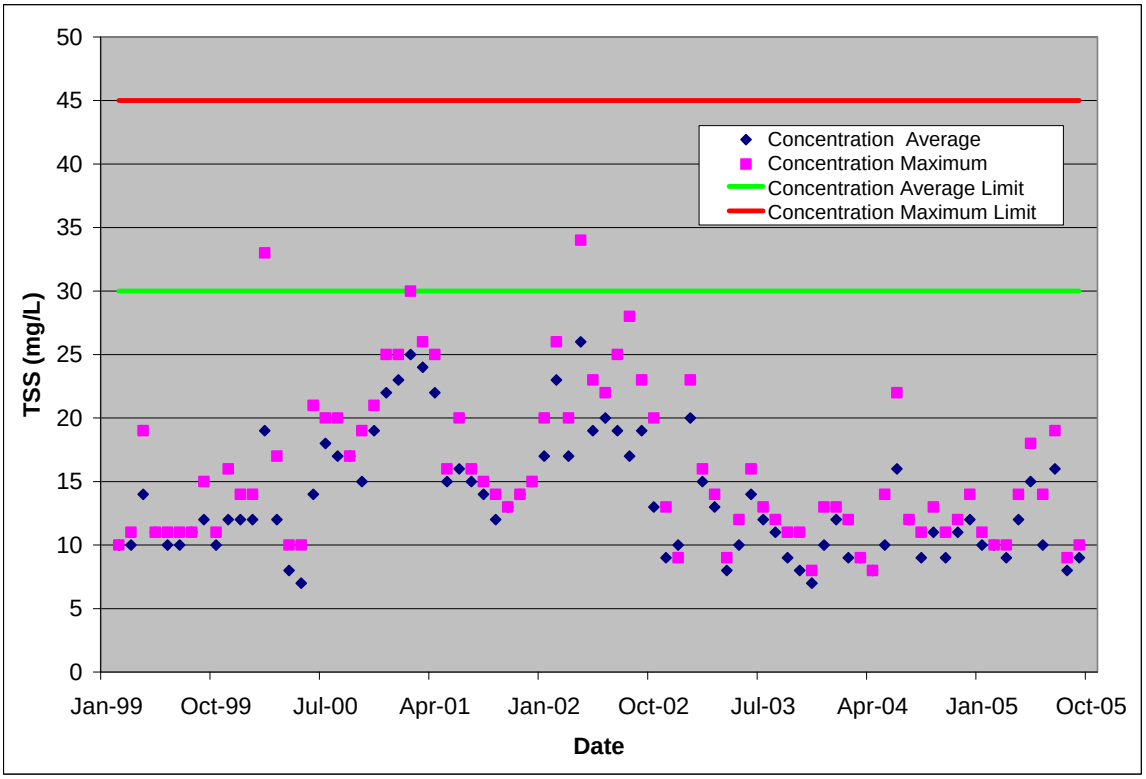


Figure C-30: Clifton Forge City STP Effluent TSS Quantities

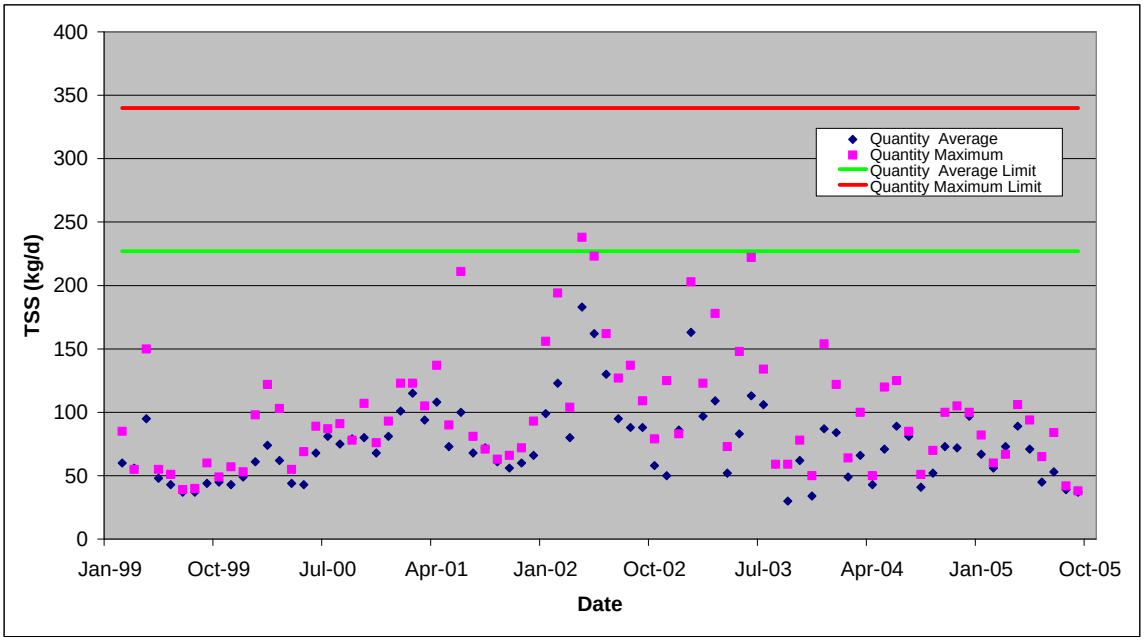


Figure C-31: Clifton Forge WTP Effluent Total Nitrogen as N Concentrations

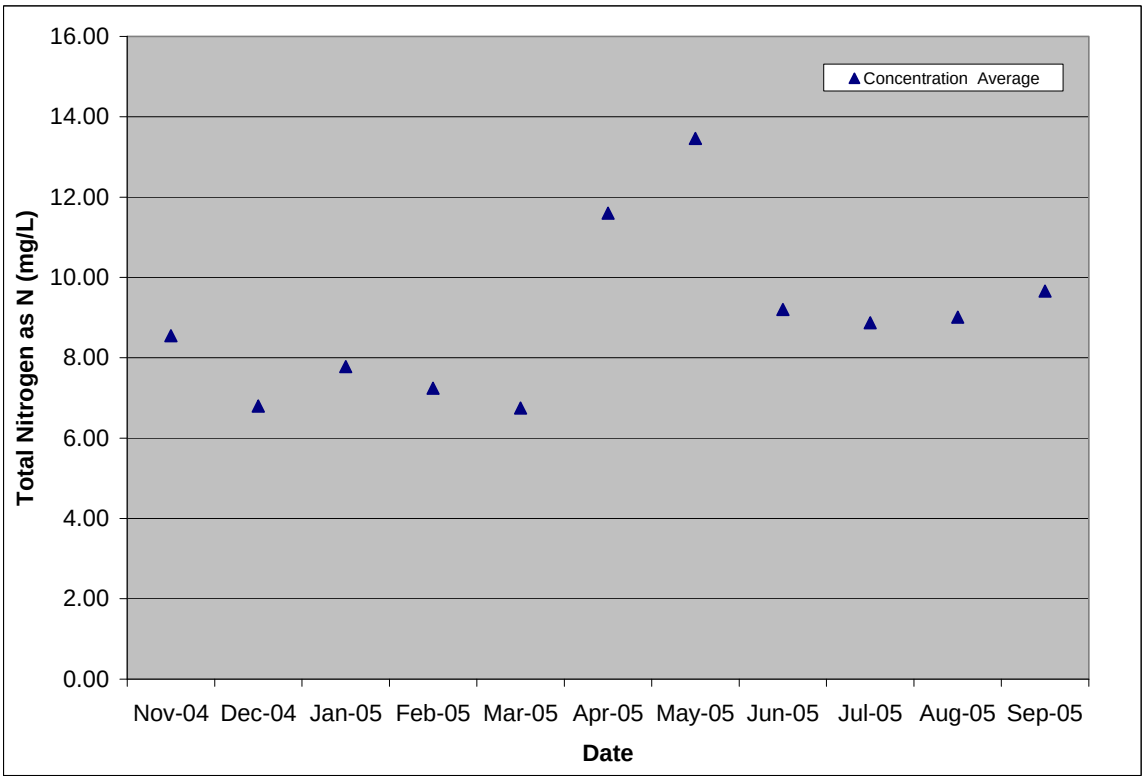


Figure C-32: Clifton Forge City STP Effluent Total Nitrogen as N Quantities

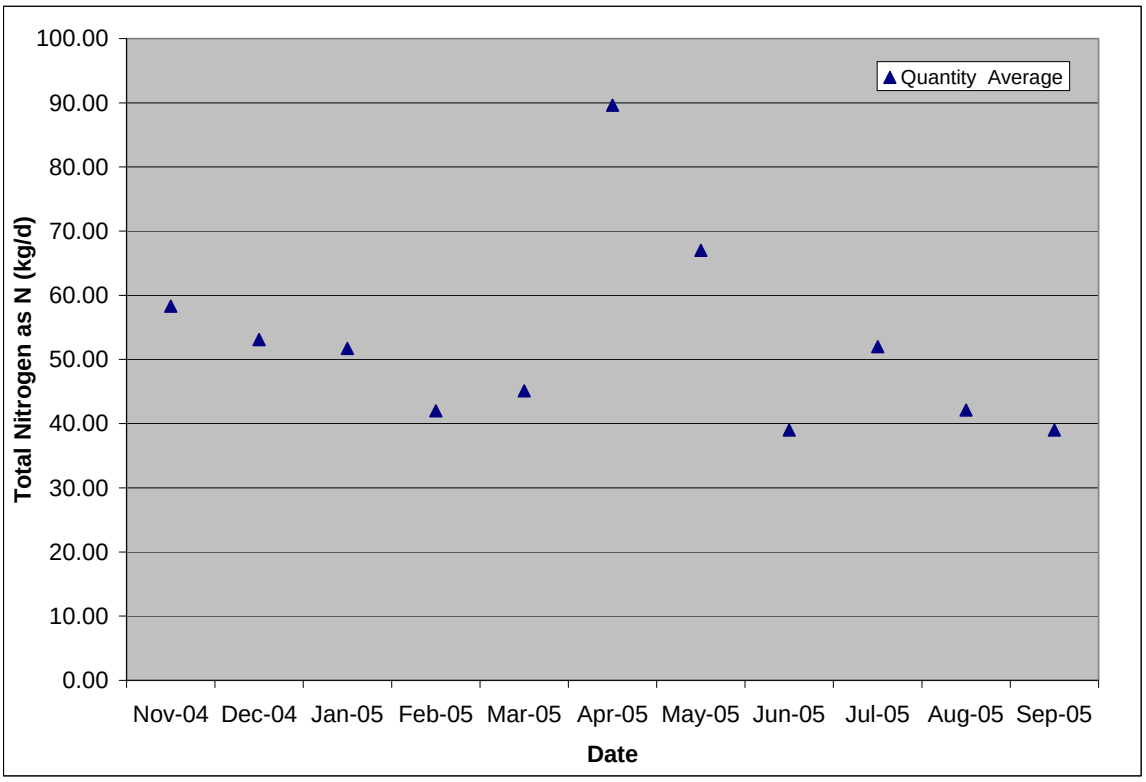


Figure C-33: Clifton Forge WTP Effluent Total Phosphorus as P Concentrations

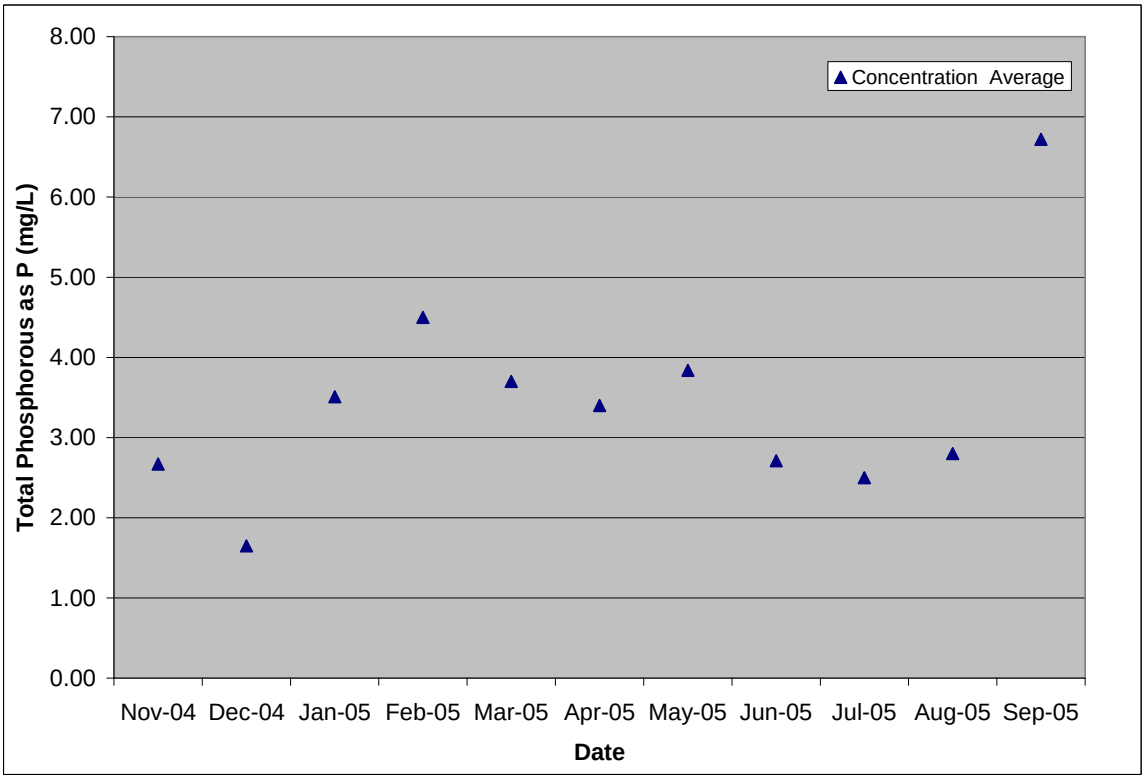


Figure C-34: Clifton Forge City STP Effluent Total Phosphorus as P Quantities

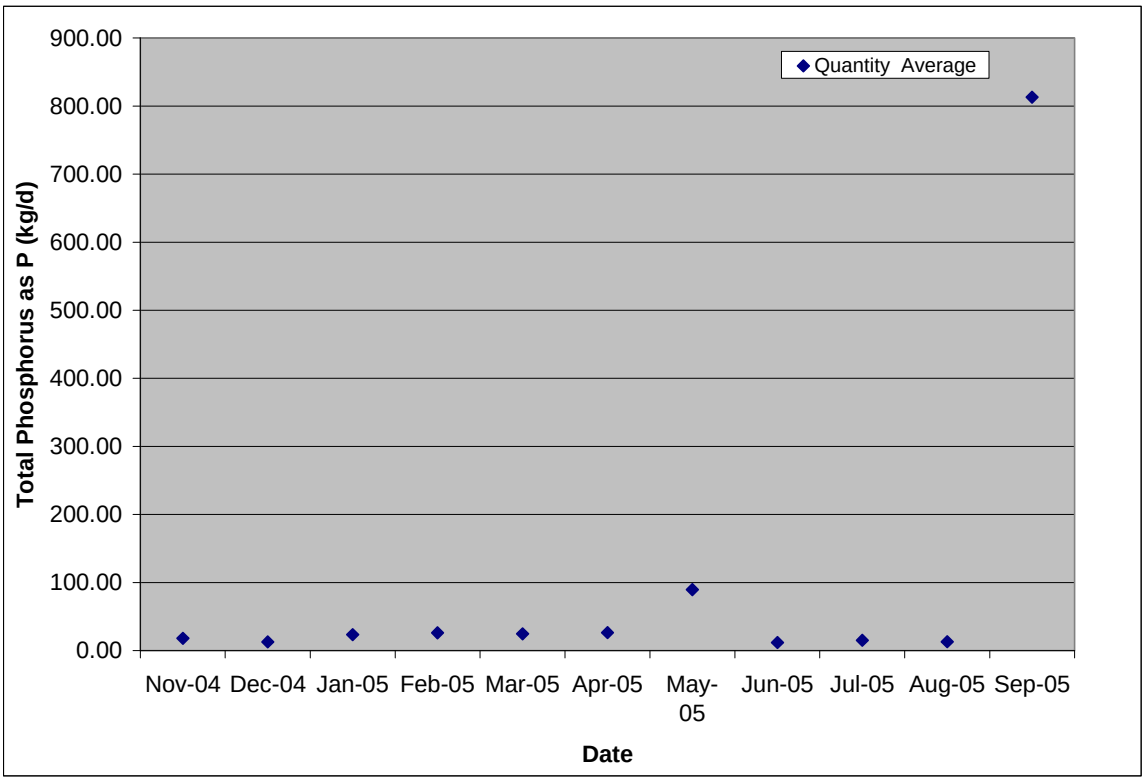


Figure C-35: Clifton Forge WTP Effluent pH Values

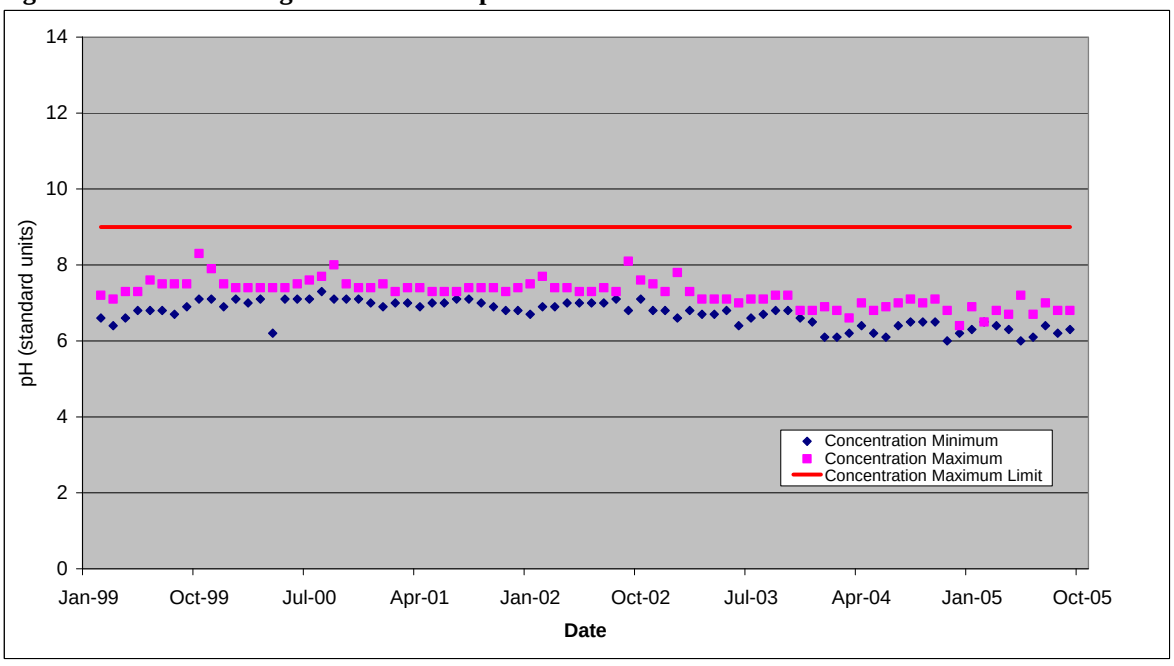


Figure C-36: Covington City STP Effluent Flow Values

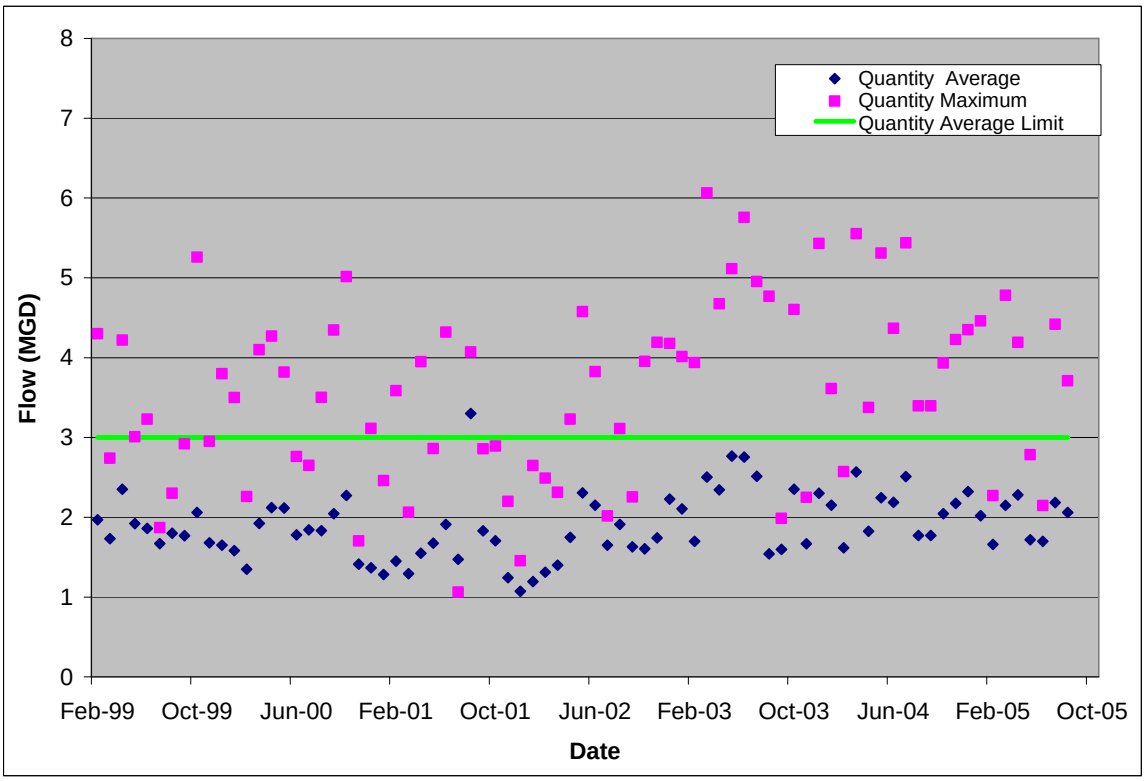


Figure C-37: Covington City STP Effluent pH Values

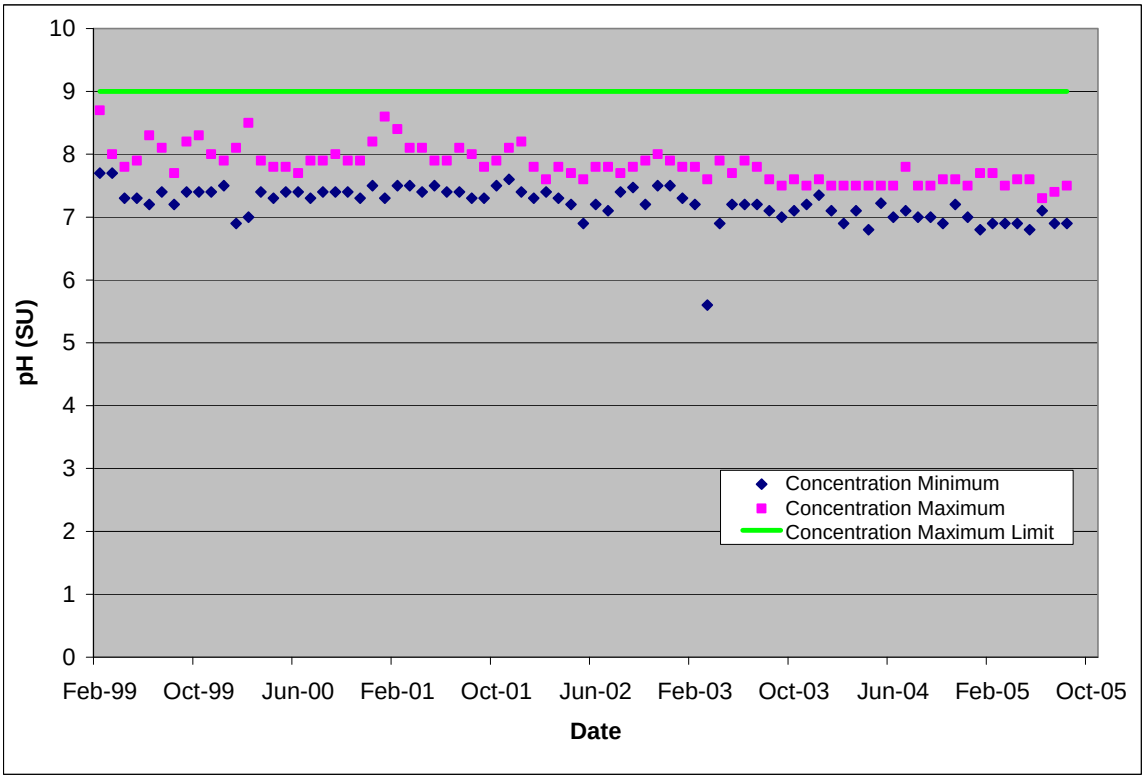


Figure C-38: Covington City STP Effluent TSS Concentrations

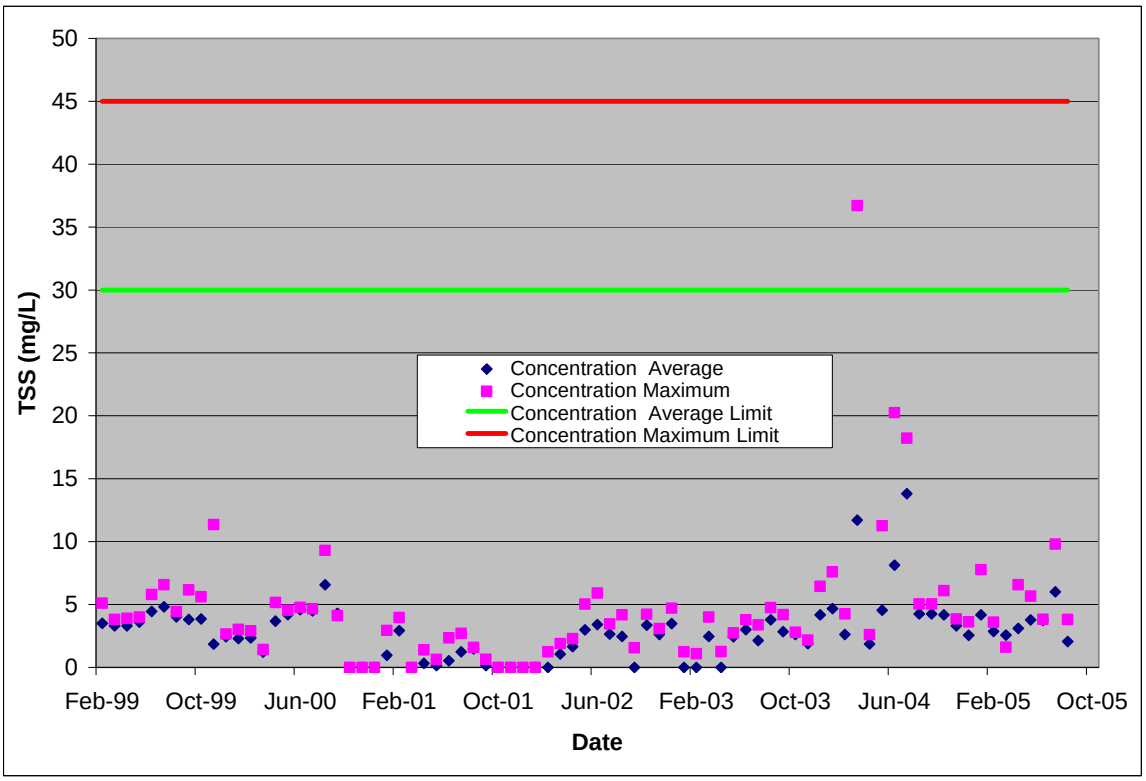


Figure C-39: Covington City STP Effluent TSS Quantities

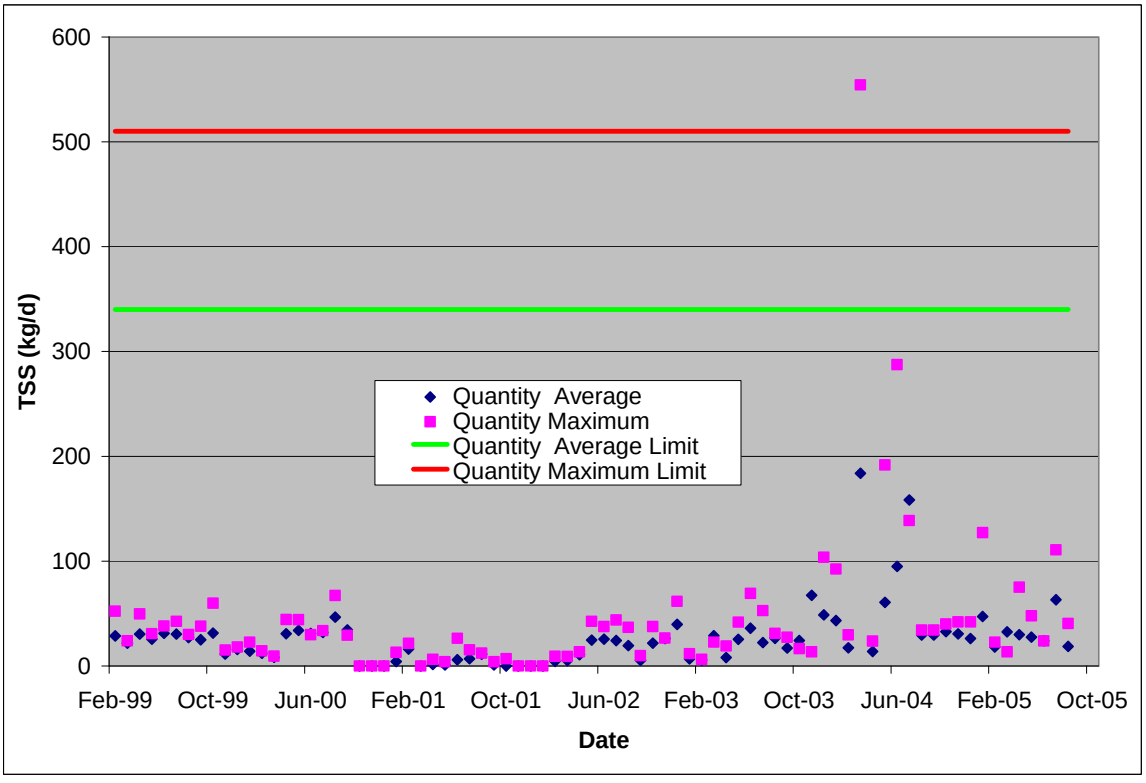


Figure C-40: Covington City STP Fecal Coliform Concentrations

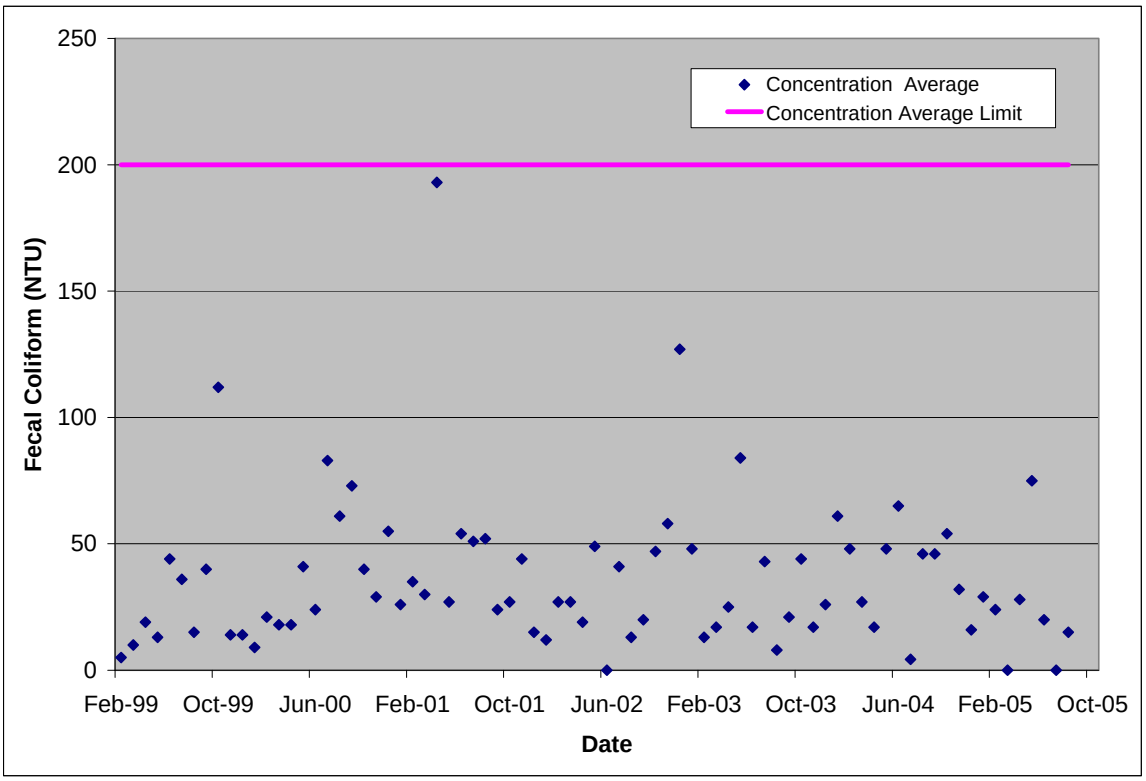


Figure C-41: Covington City STP Effluent BOD5 Concentrations

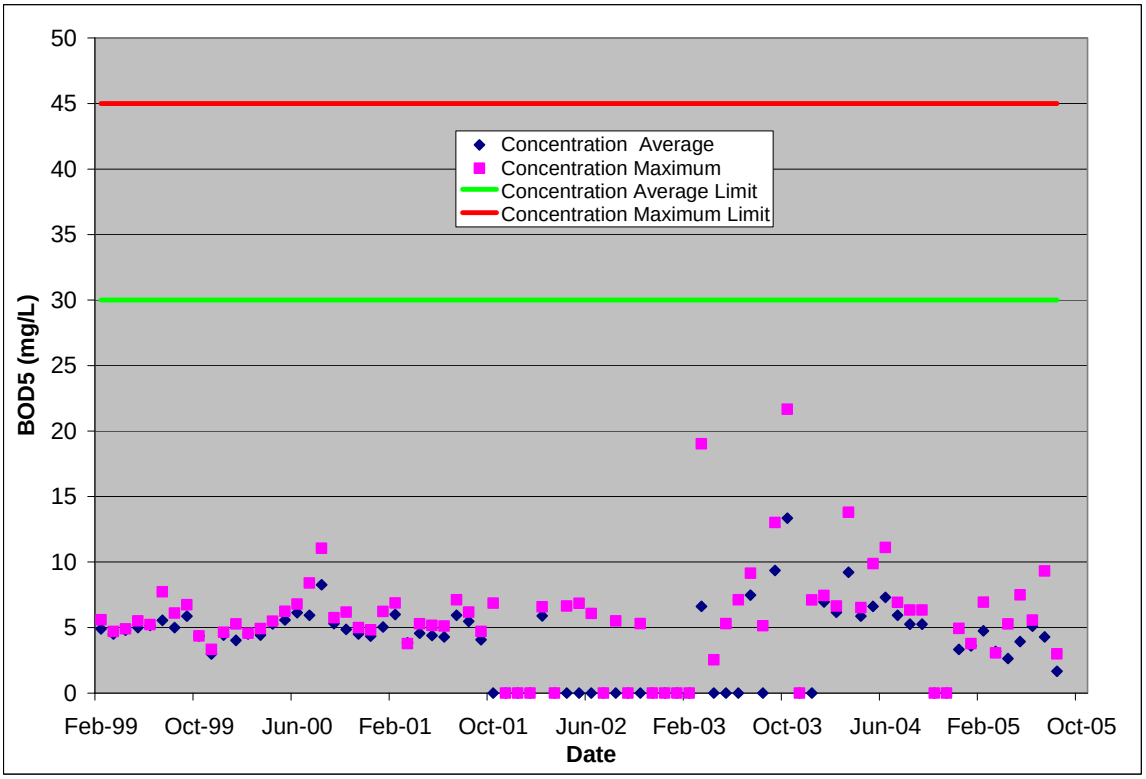


Figure C-42: Covington City STP Effluent BOD5 Quantities

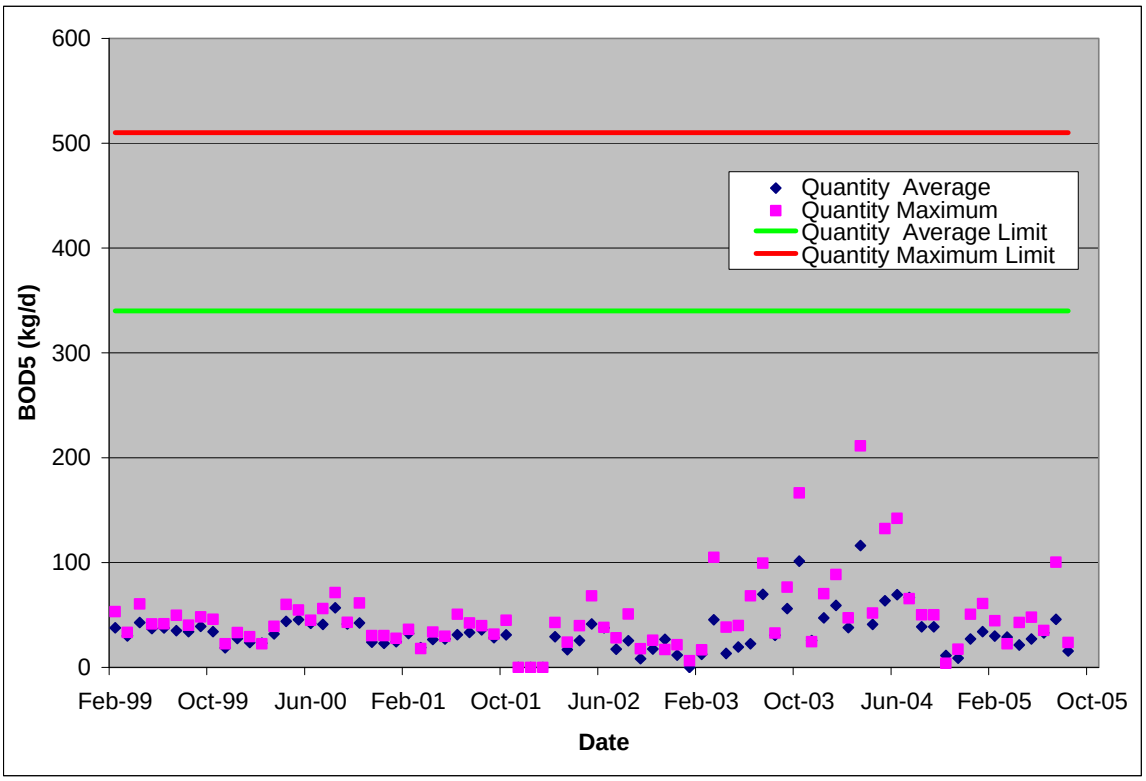


Figure C-43: Covington City STP Effluent Total Nitrogen as N Concentrations

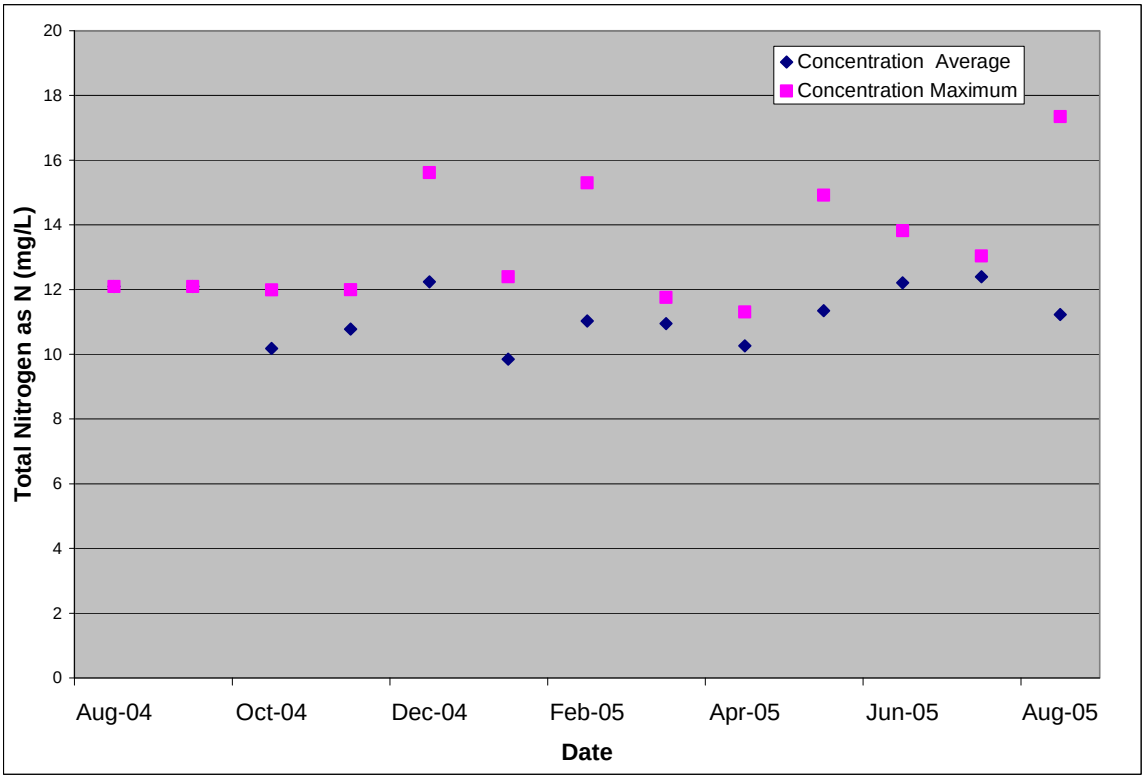


Figure C-44: Covington City STP Effluent Total Nitrogen as N Quantities

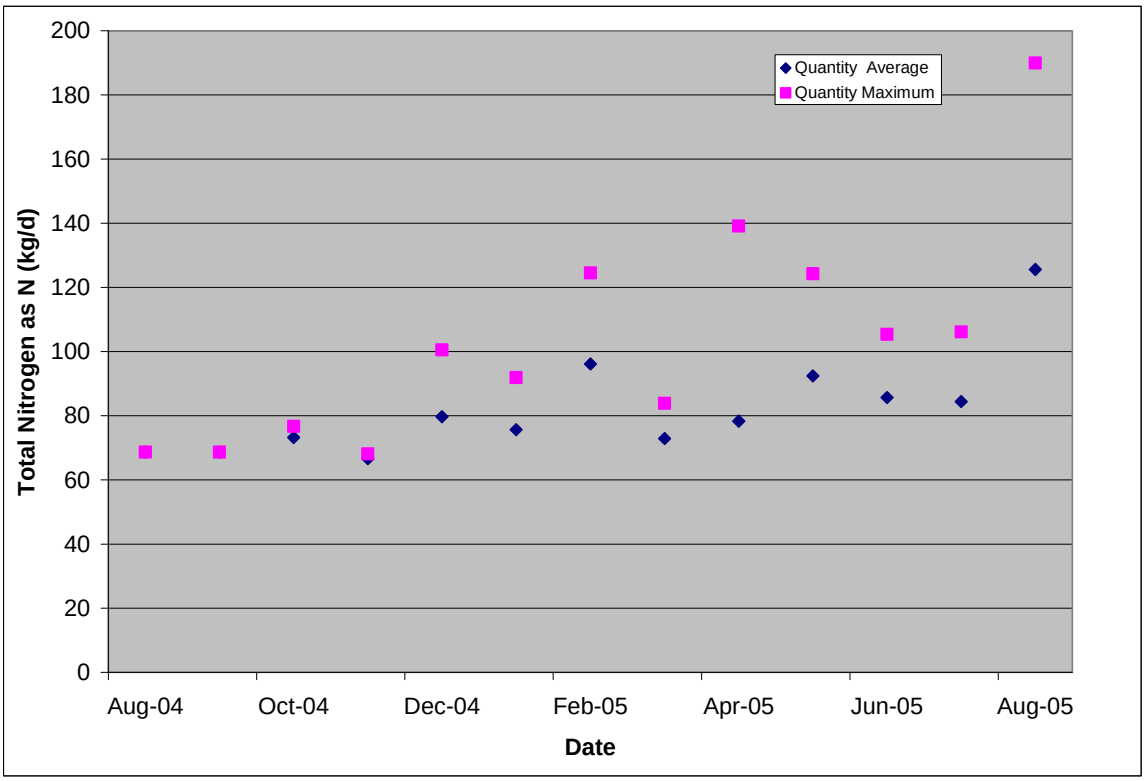


Figure C-45: Covington City STP Effluent Total Phosphorous as P Concentrations

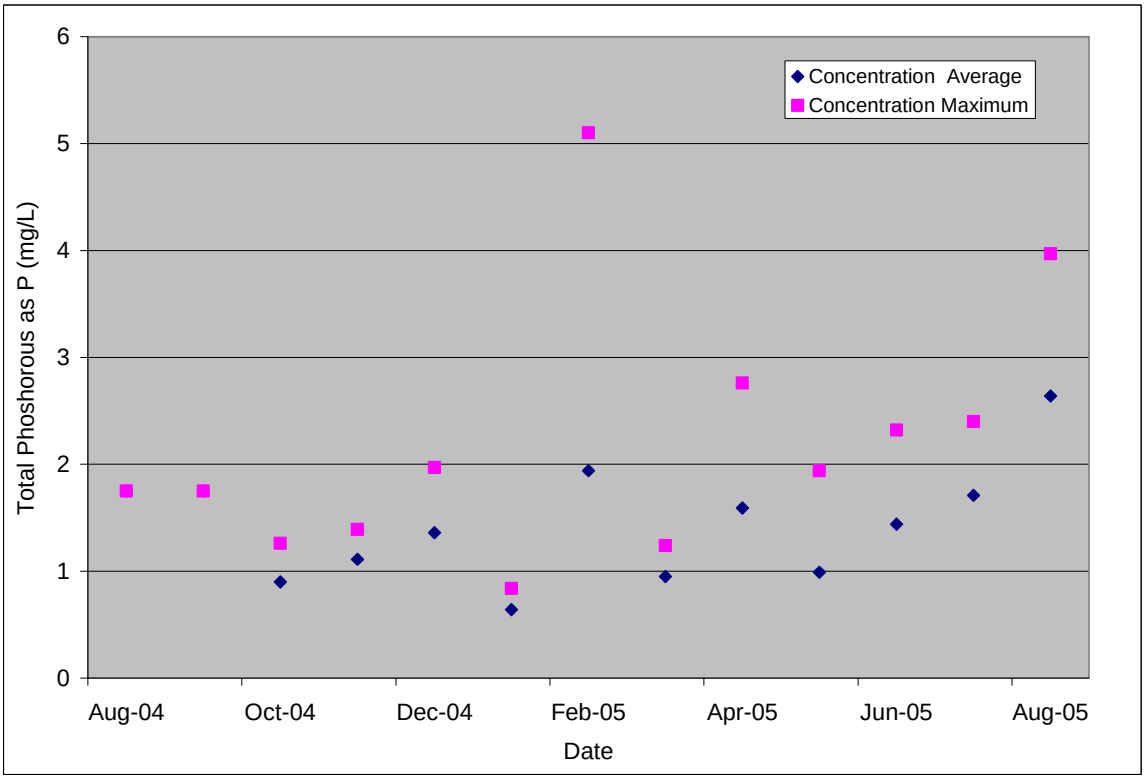


Figure C-46: Covington City STP Effluent Total Phosphorous as P Quantities

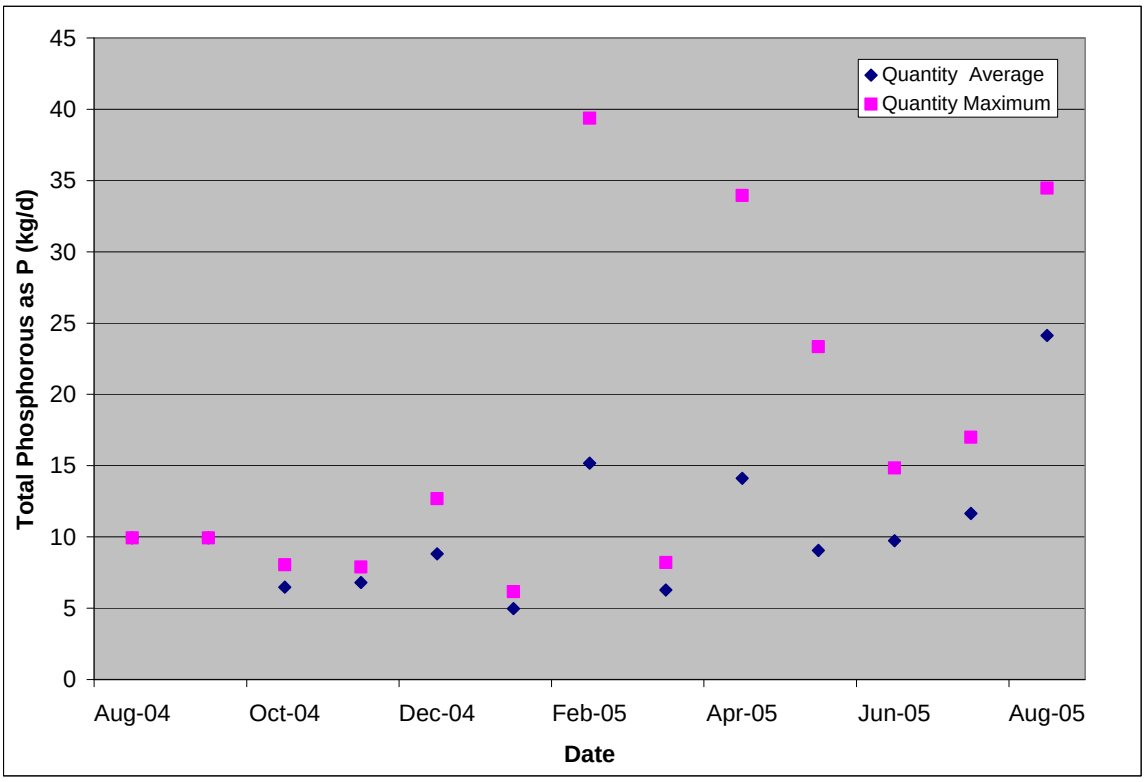


Figure C-47: CSX Transportation Effluent Flow Values

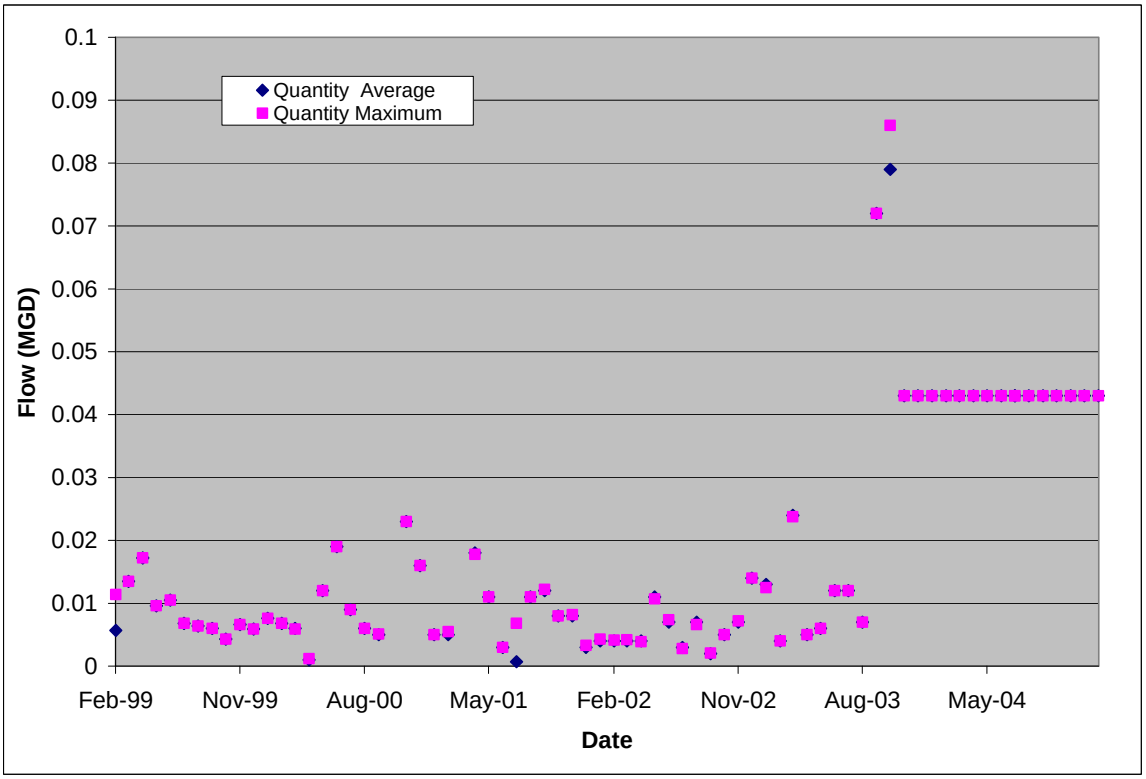


Figure C-48: CSX Transportation Effluent pH Values

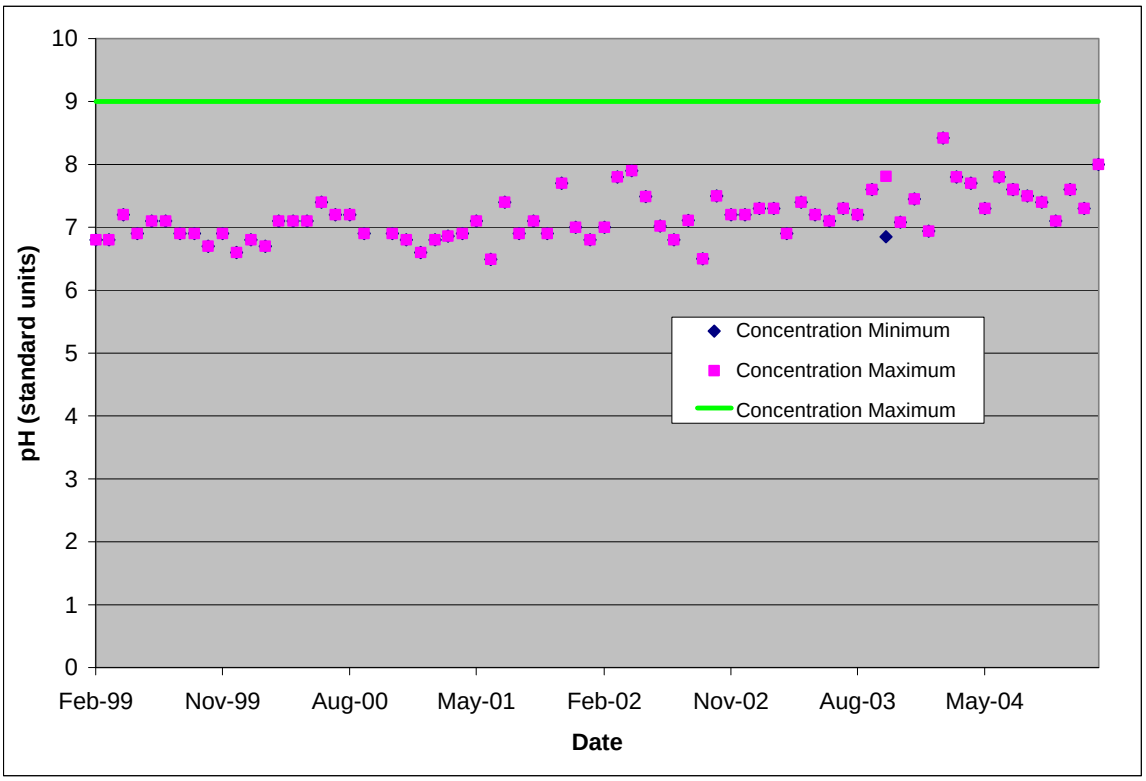


Figure C-49: CSX Transportation Effluent TSS Concentrations

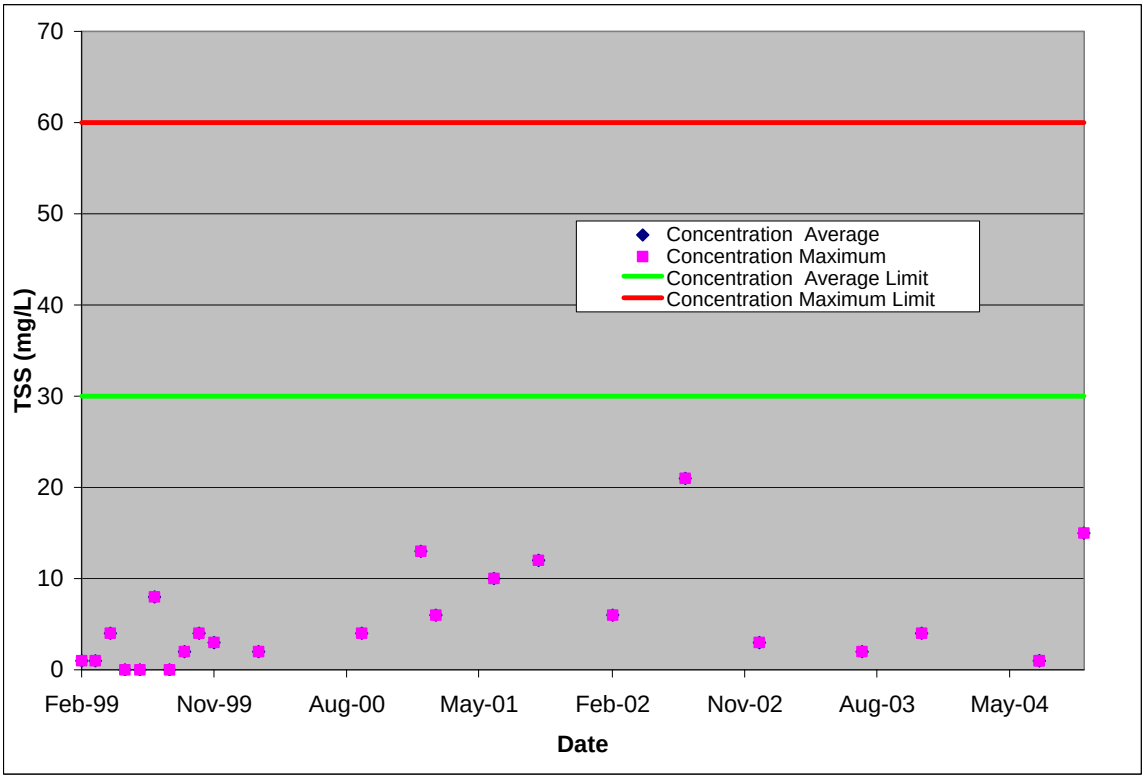


Figure C-50: CSX Transportation Effluent Acute Toxicity Values

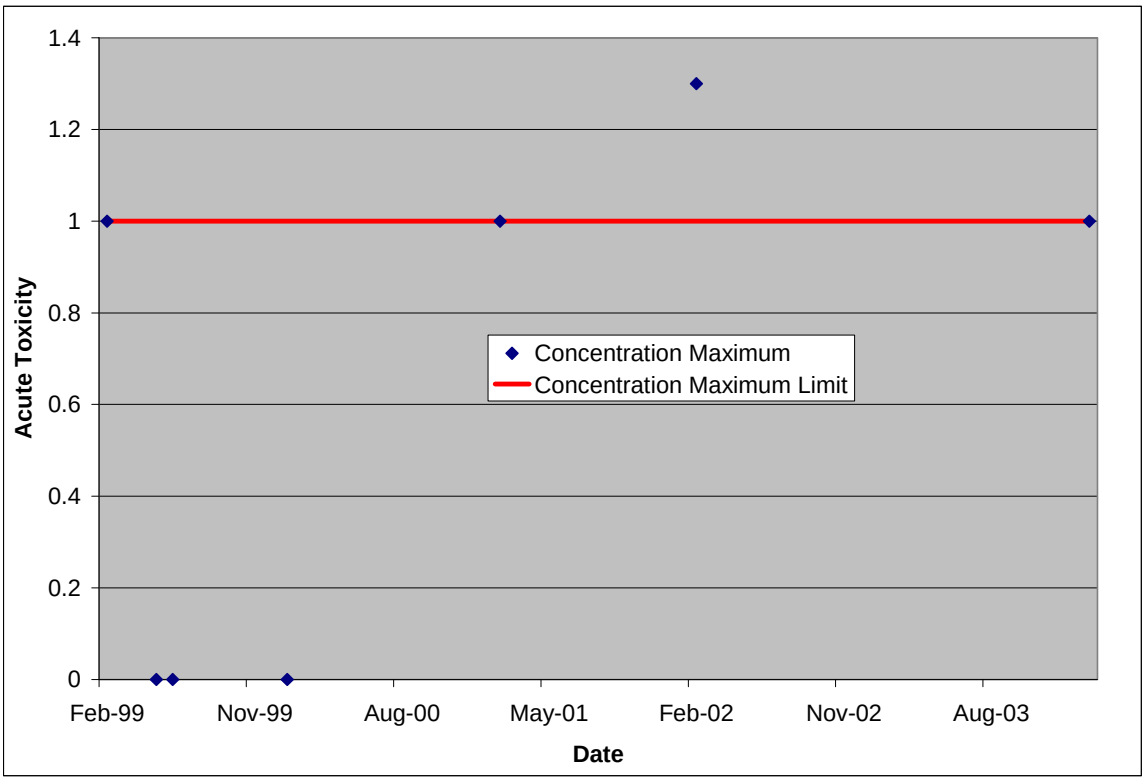


Figure C-51: CSX Transportation Effluent Petroleum Hydrocarbon Concentrations

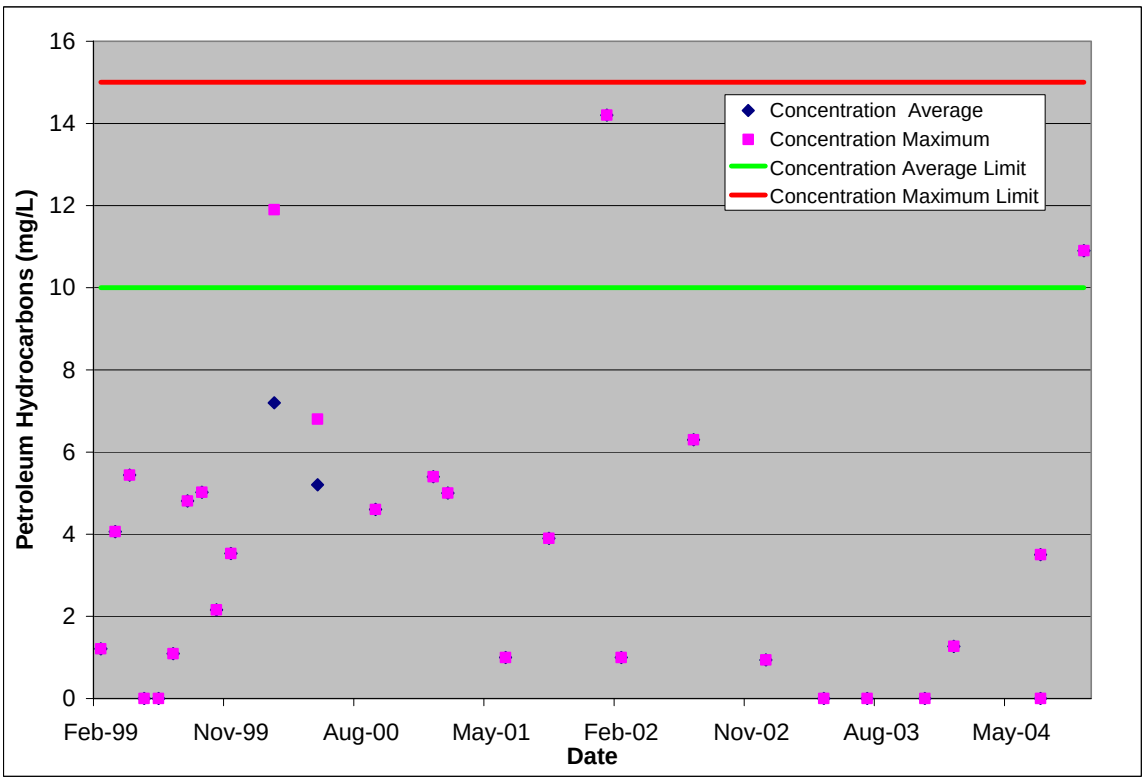


Figure C-52: CSX Transportation Effluent Oil and Grease Concentrations

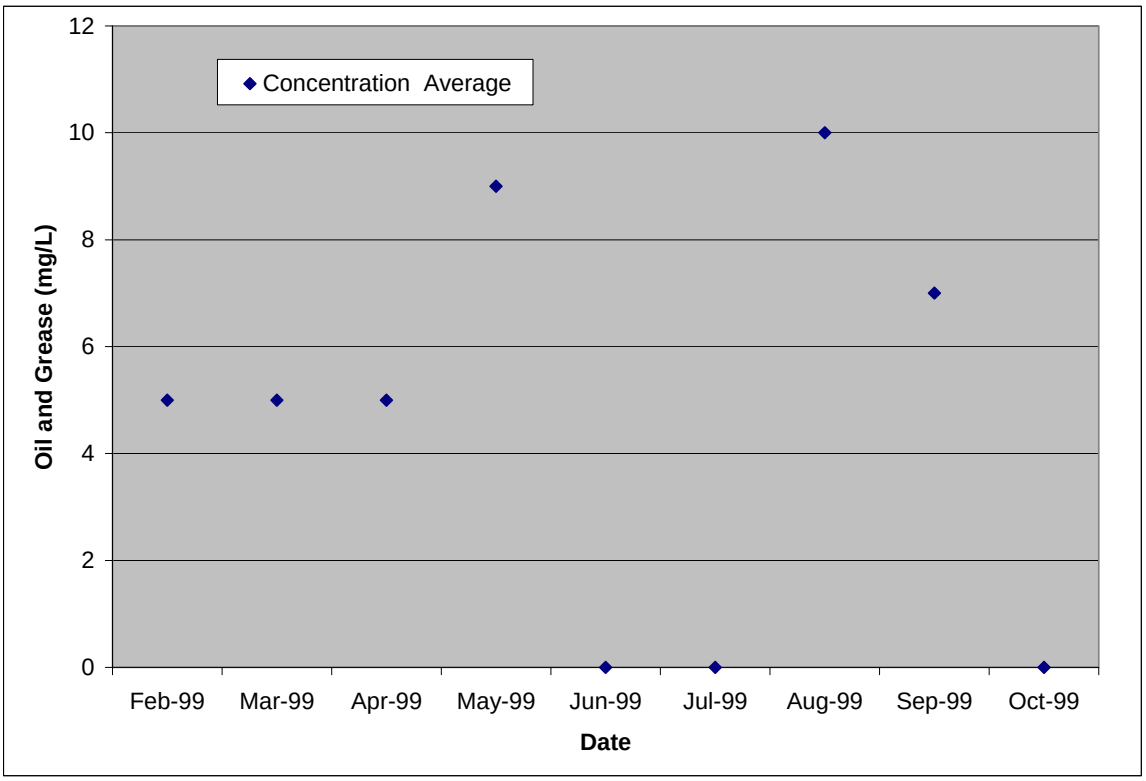


Figure C-53: DGIF Paint Bank Fish Cultural Station Effluent Flow Values from Outfall 1

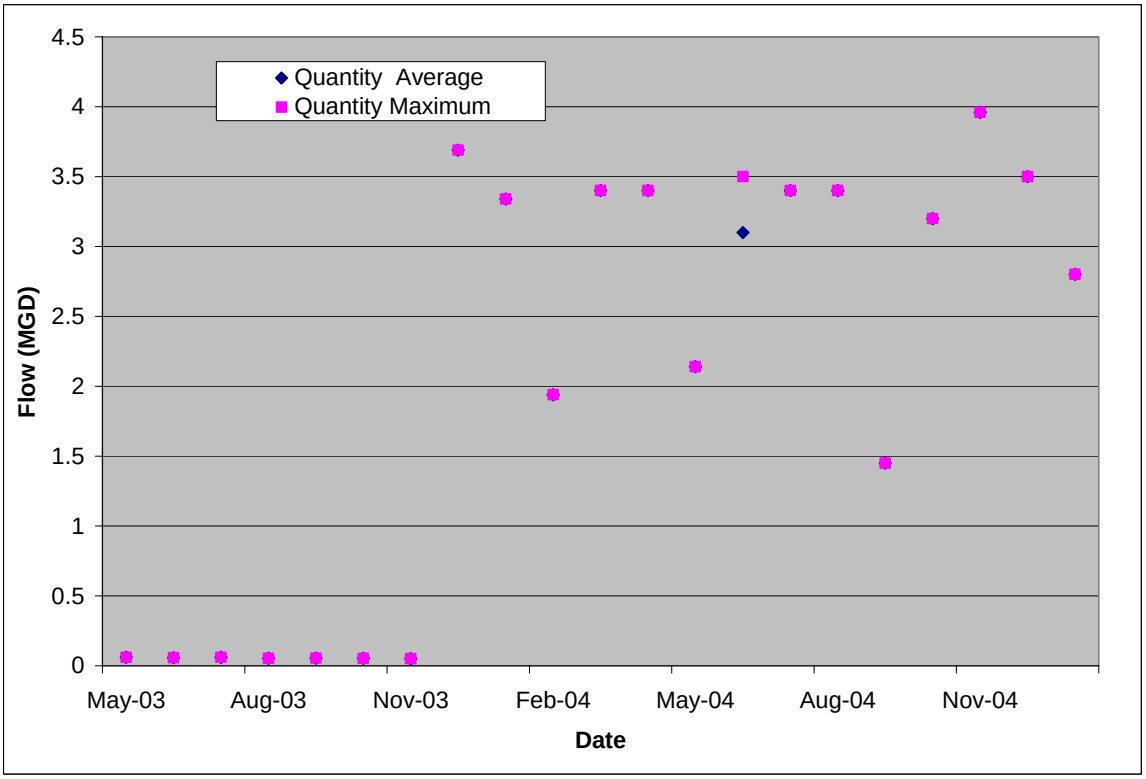


Figure C-54: DGIF Paint Bank Fish Cultural Station Effluent TSS Concentrations from Outfall 1

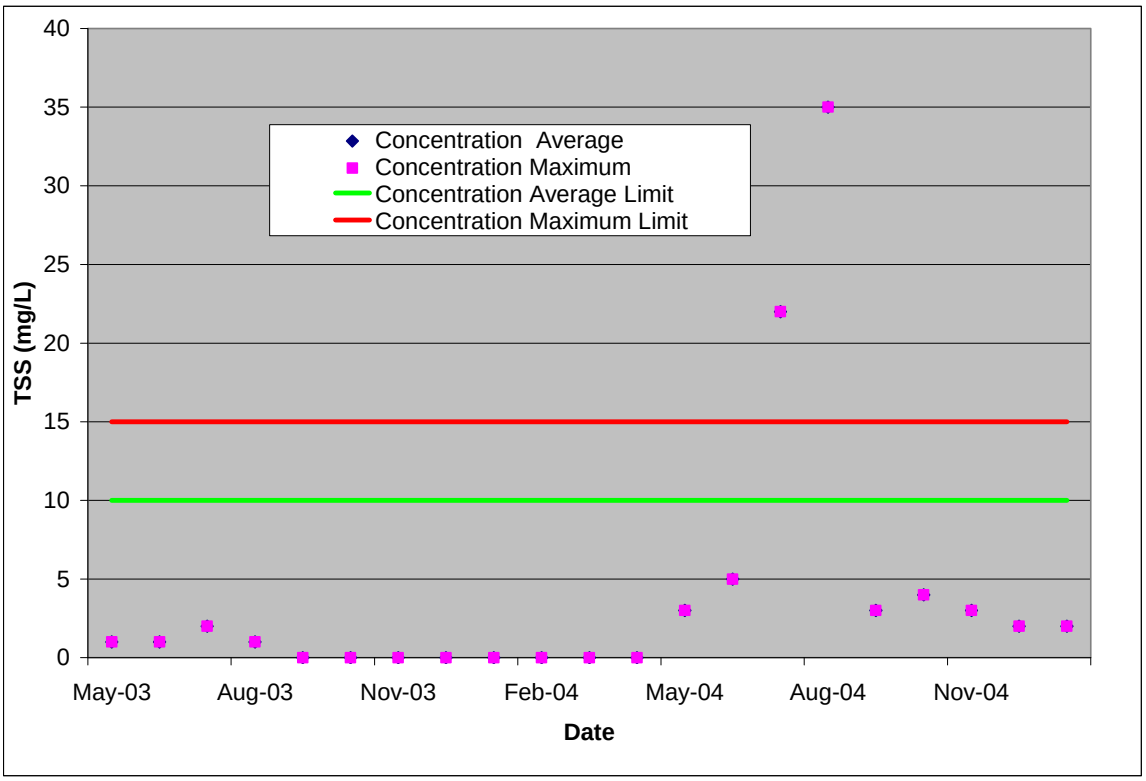


Figure C-55: DGIF Paint Bank Fish Cultural Station Effluent Settable Solids Concentrations from Outfall 1

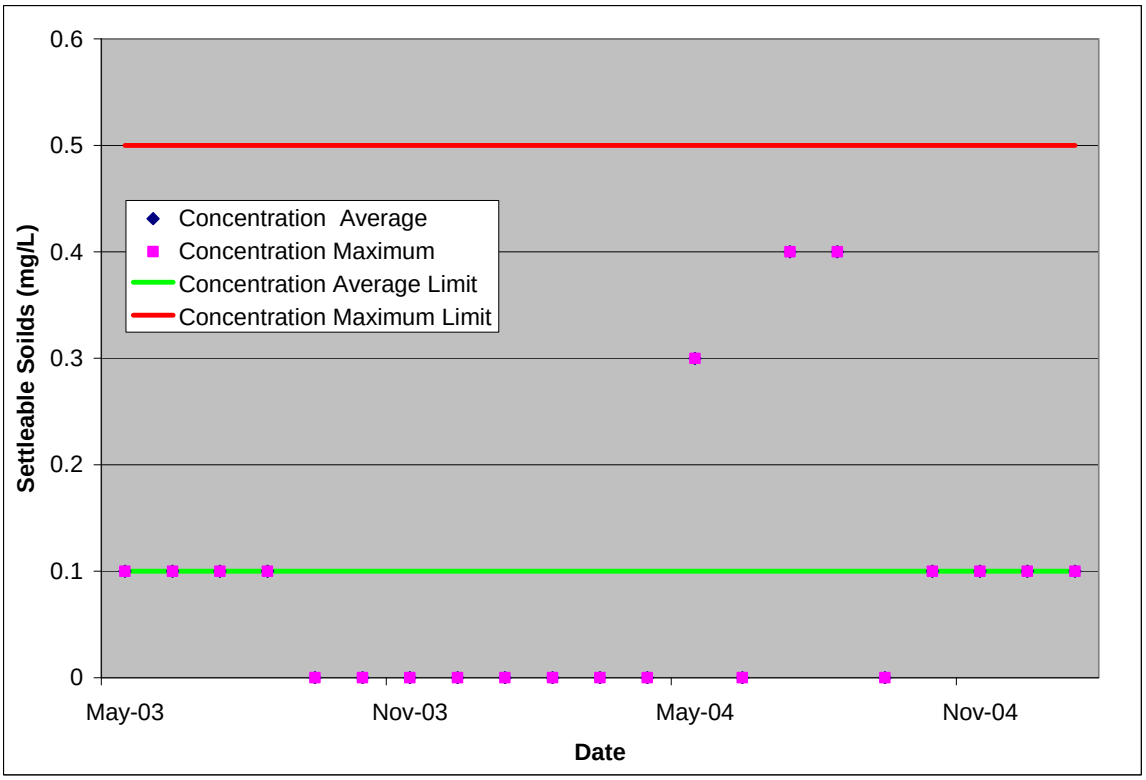


Figure C-56: DGIF Paint Bank Fish Cultural Station Effluent Flow Values from Outfall 3

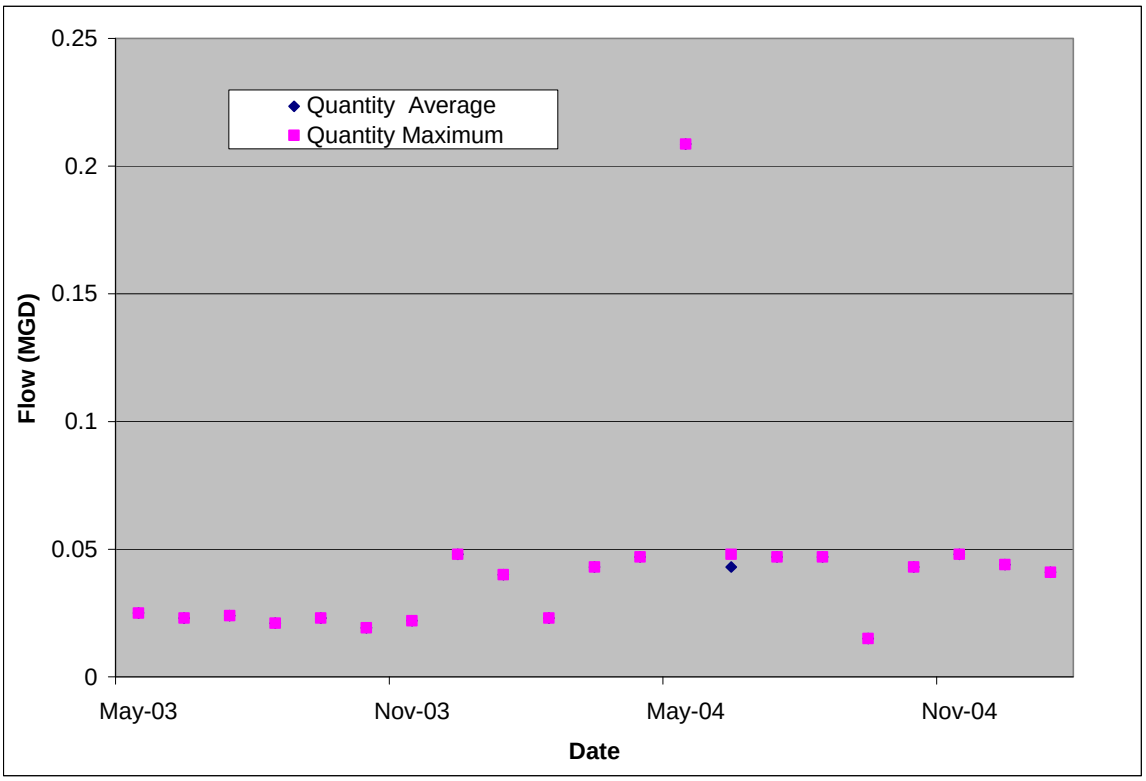


Figure C-57: DGIF Paint Bank Fish Cultural Station Effluent TSS Concentrations from Outfall 3

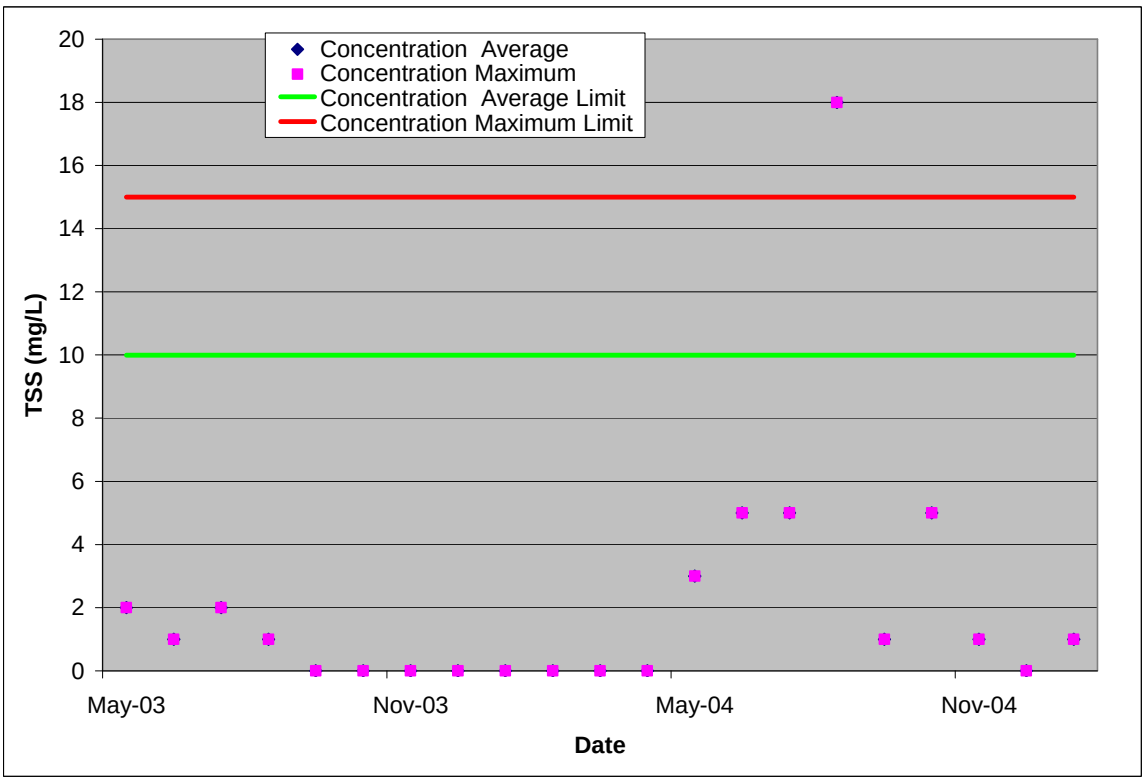


Figure C-58: DGIF Paint Bank Fish Cultural Station Settleable Solids Concentrations from Outfall 3

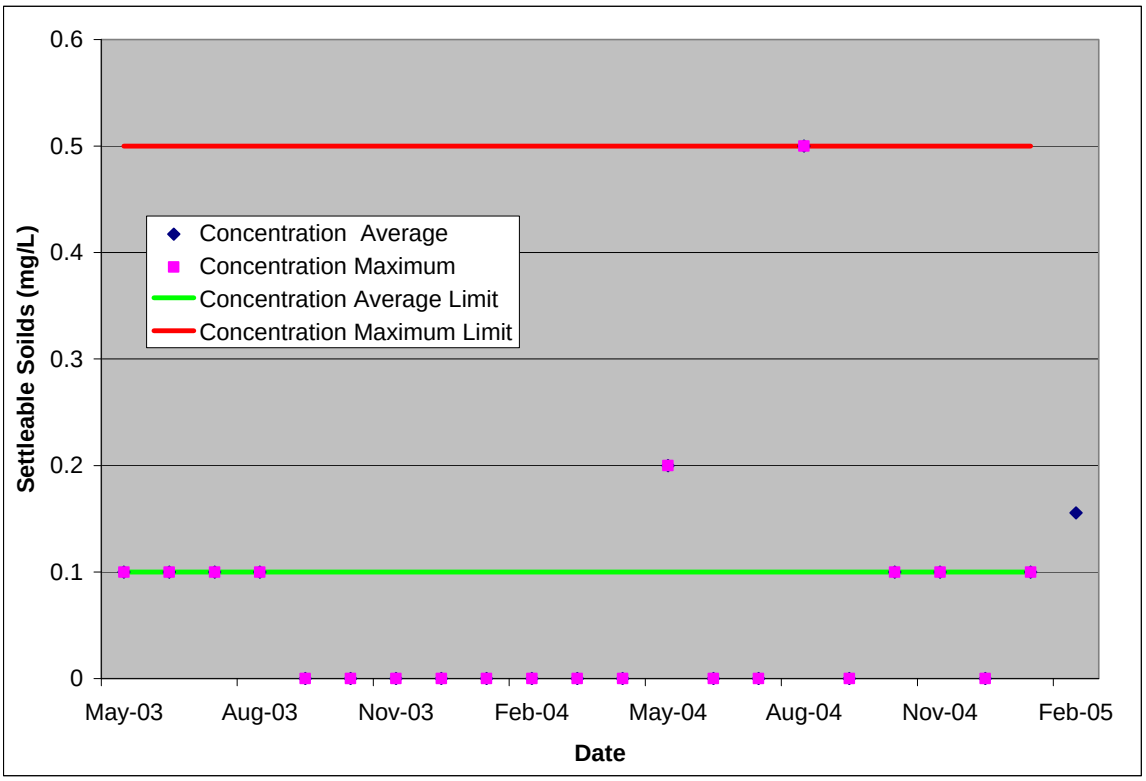


Figure C-59: DGIF Paint Bank Fish Cultural Station Flow Values from Outfall 4

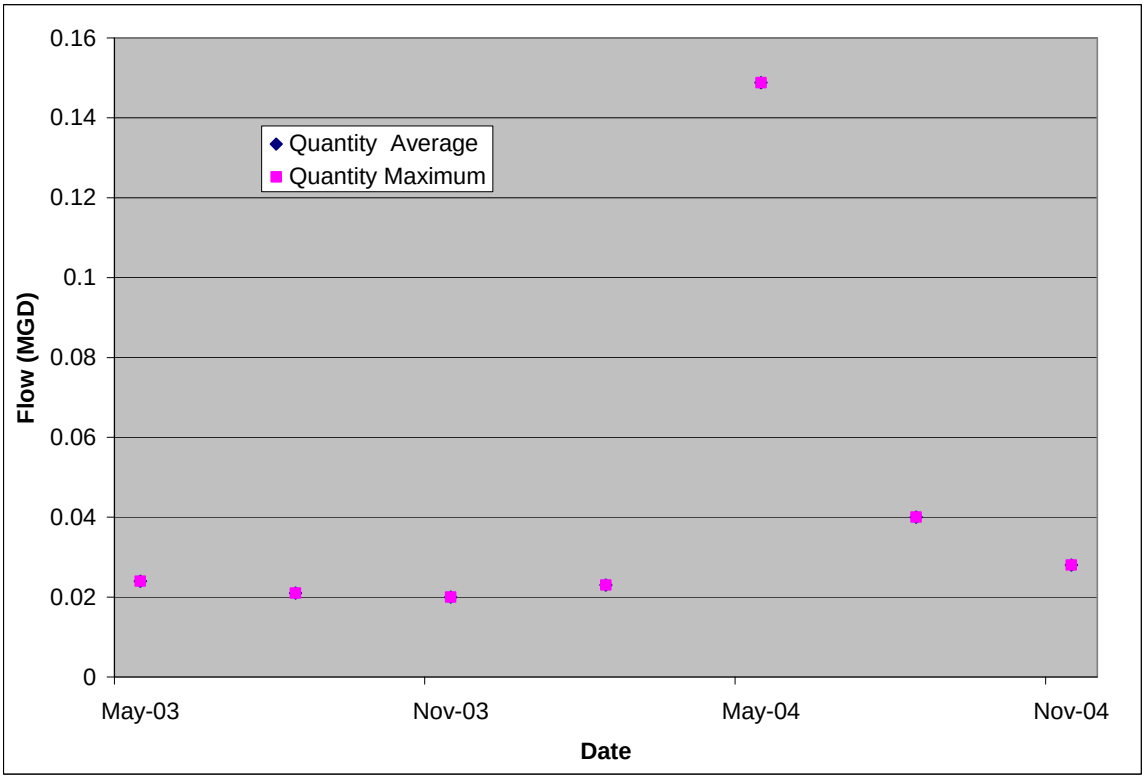


Figure C-60: DGIF Paint Bank Fish Cultural Station Effluent Settable Solids Concentrations from Outfall 4

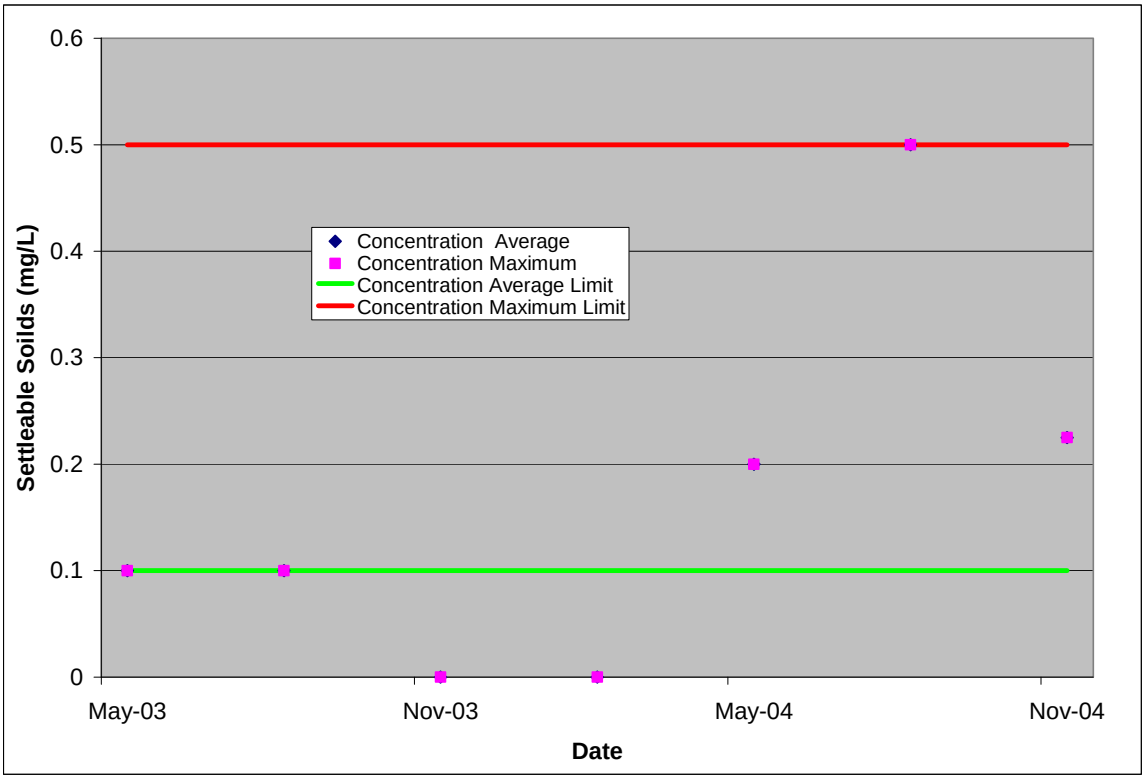


Figure C-61: DGIF Paint Bank Fish Cultural Station Effluent TSS Concentrations from Outfall 4

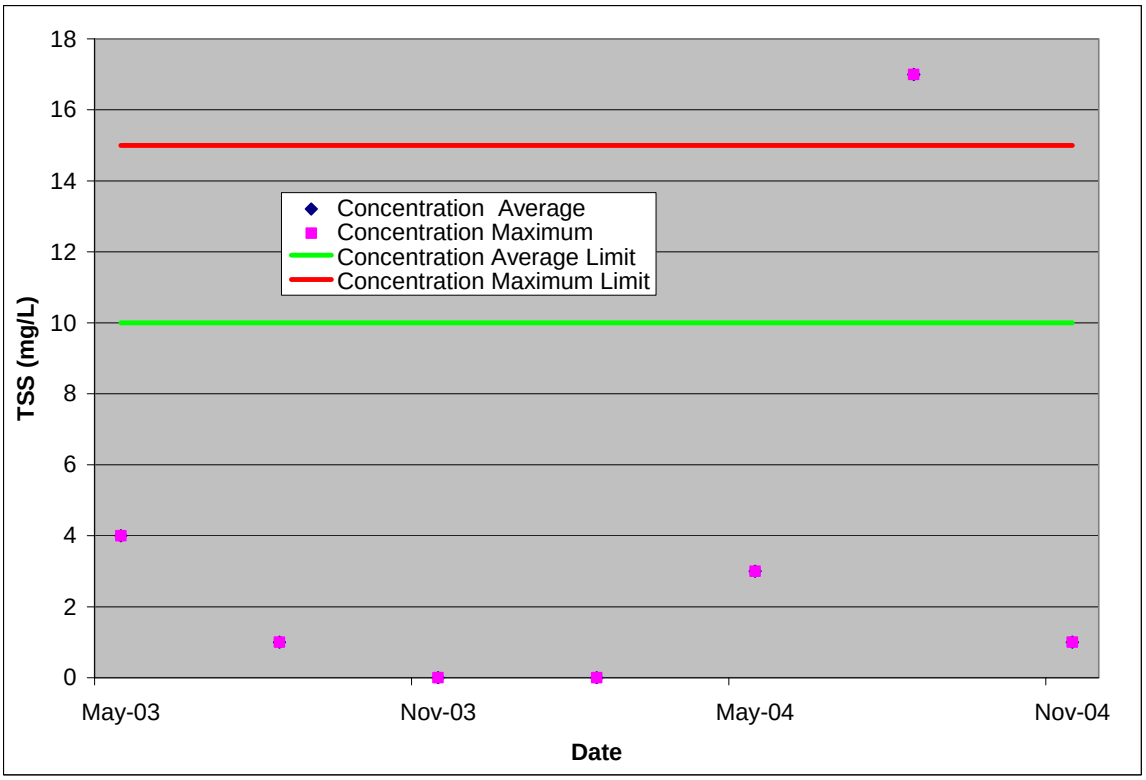


Figure C-62: DGIF Paint Bank Fish Cultural Station Flow Values from Outfall 5

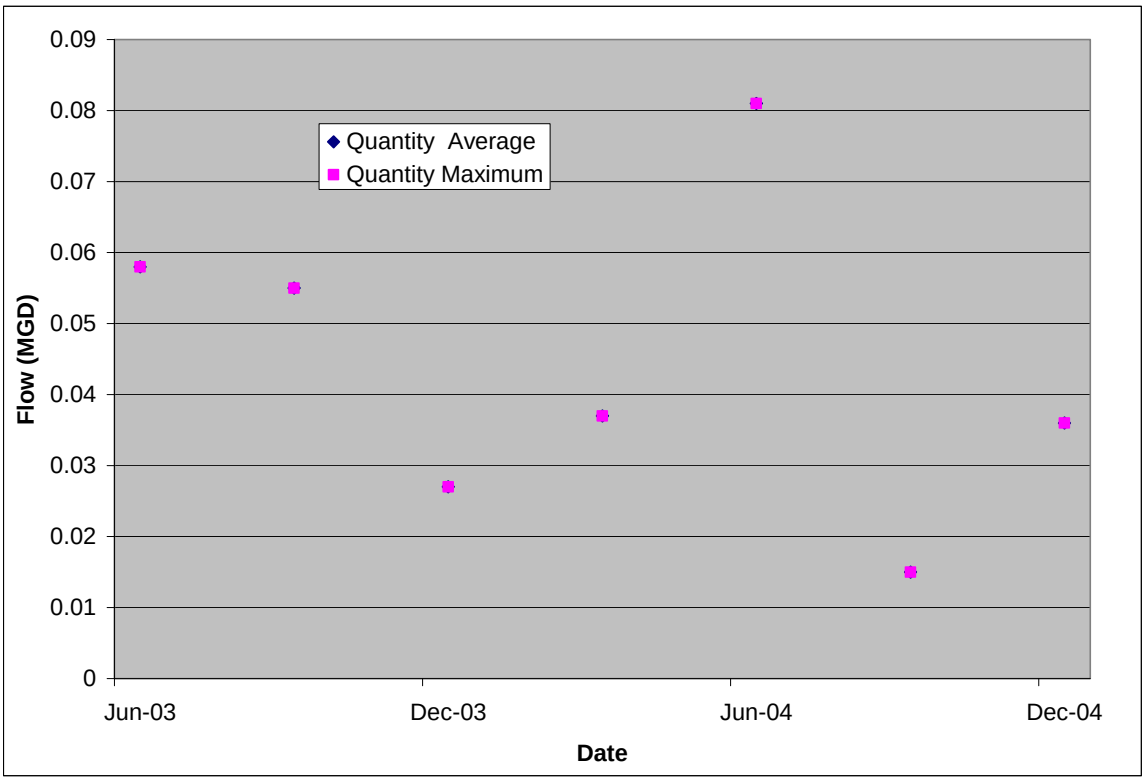


Figure C-63: DGIF Paint Bank Fish Cultural Station Effluent TSS Concentrations from Outfall 5

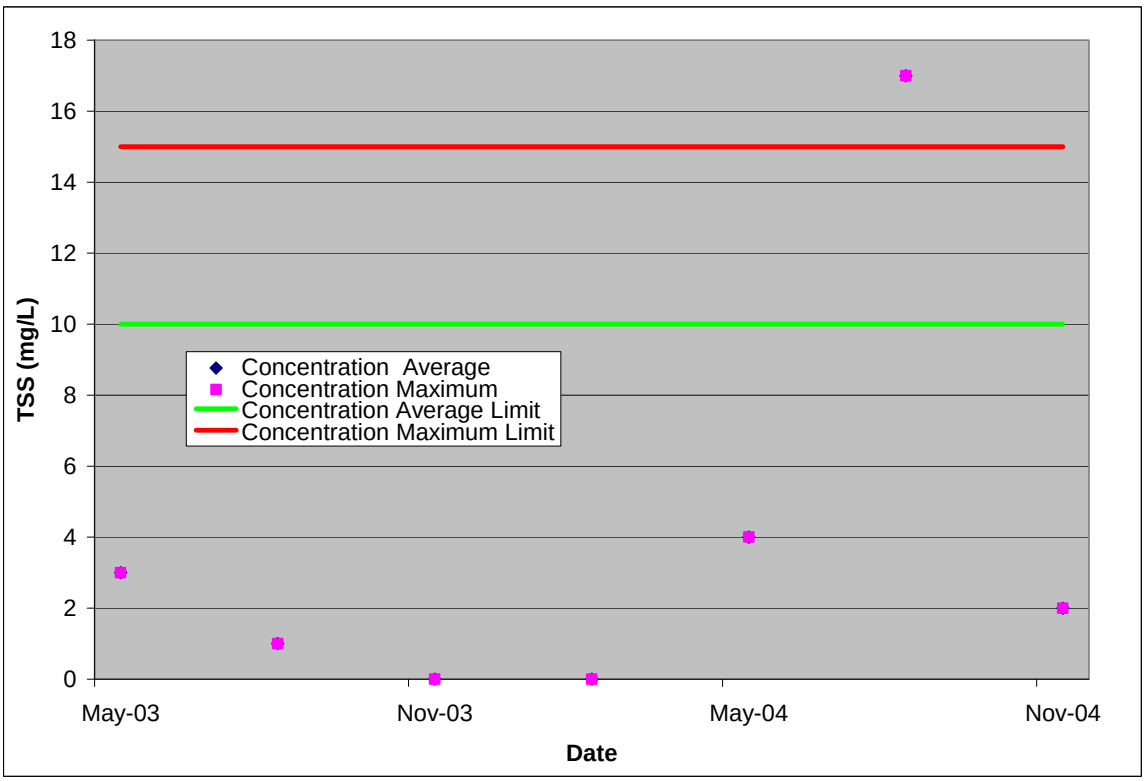


Figure C-64: DGIF Paint Bank Fish Cultural Station Effluent Settable Solids Concentrations from Outfall 5

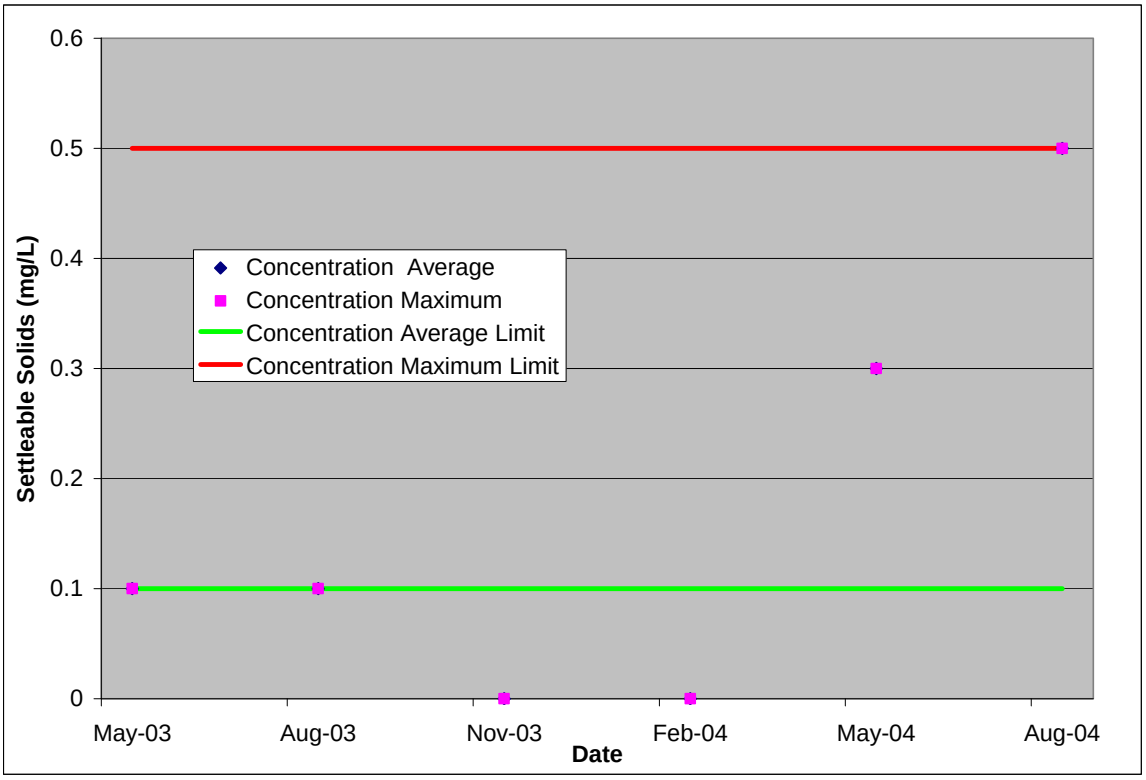


Figure C-65: DGIF Paint Bank Fish Cultural Station Effluent Flow Values from Outfall 6

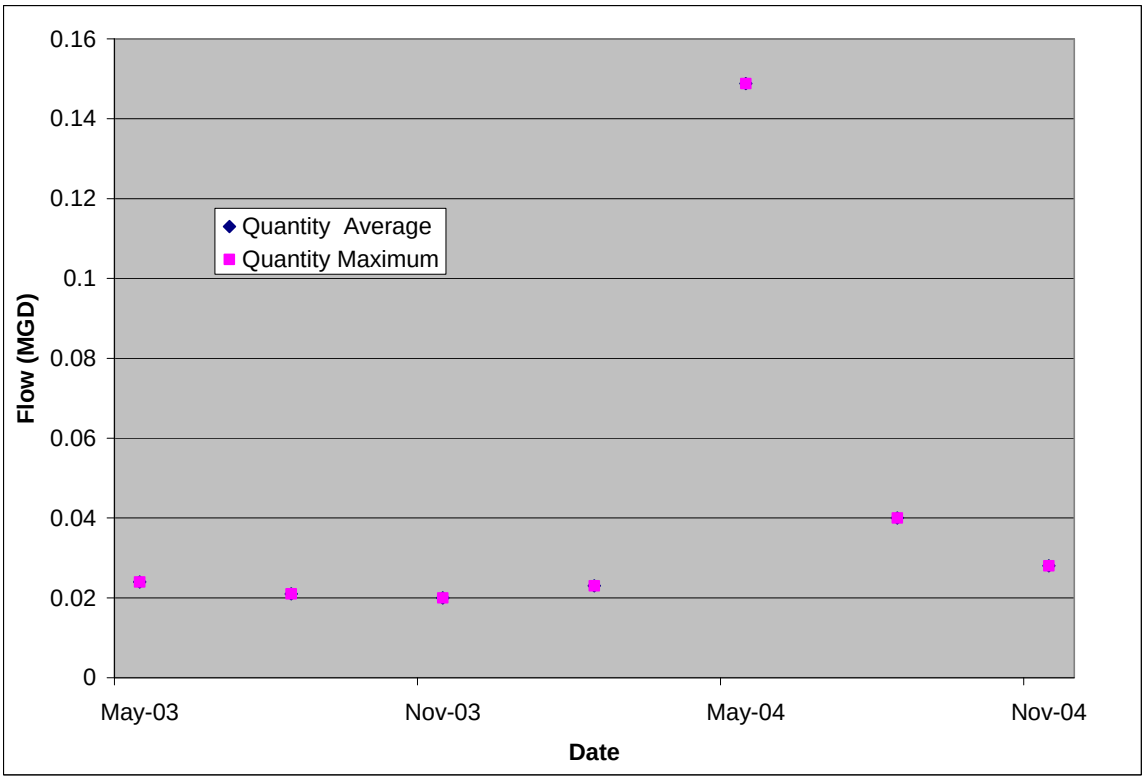


Figure C-66: DGIF Paint Bank Fish Cultural Station Effluent TSS Concentrations from Outfall 6

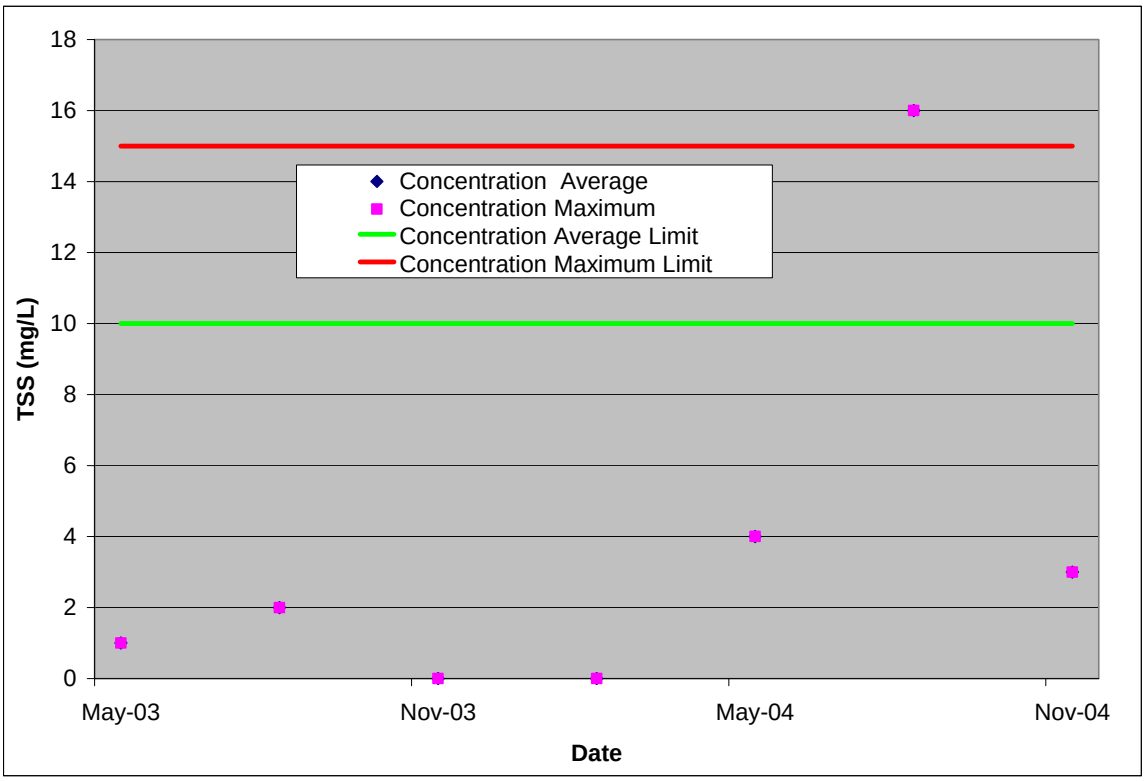


Figure C-67: DGIF Paint Bank Fish Cultural Station Effluent Settable Solids Concentrations from Outfall 6

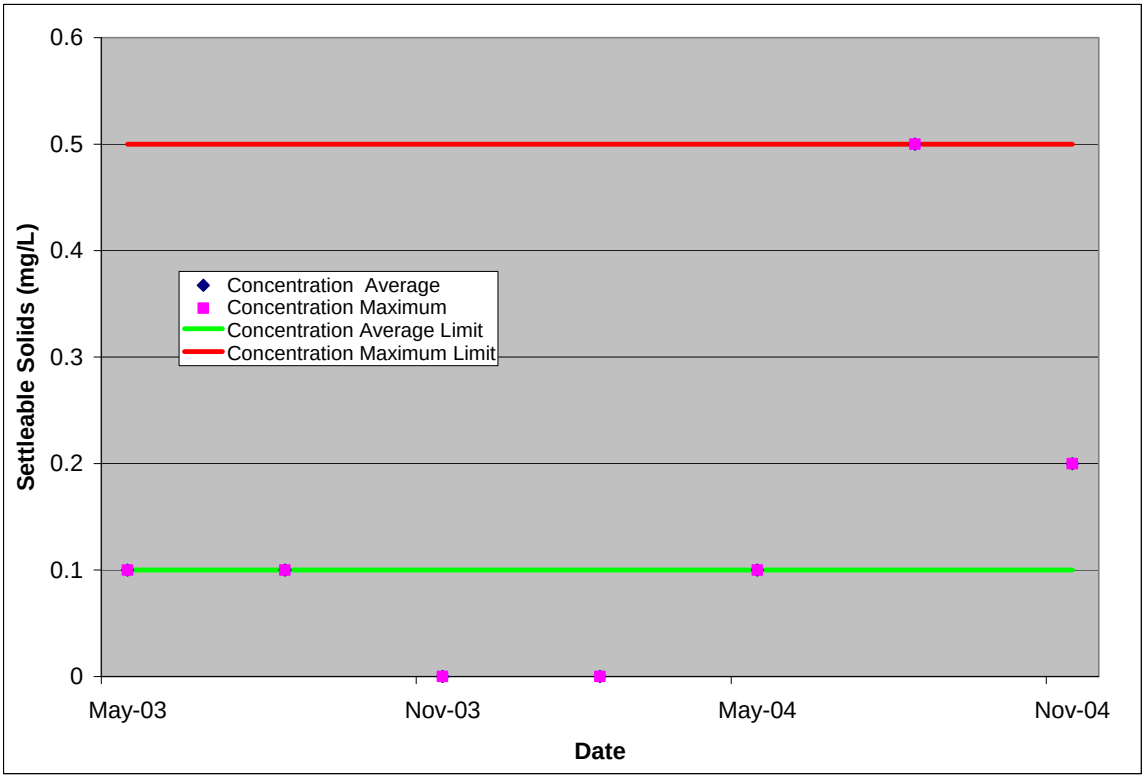


Figure C-68: DGIF Paint Bank Fish Cultural Station Effluent Flow Values from Outfall 8

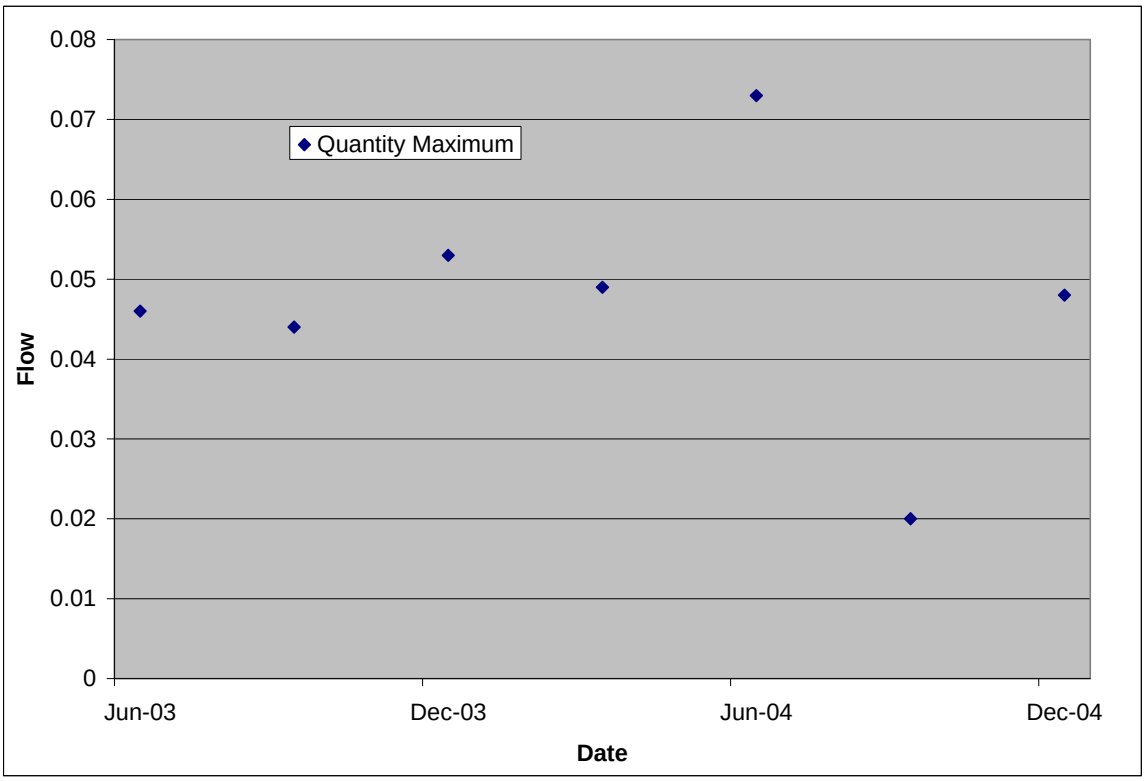


Figure C-69: DGIF Paint Bank Fish Cultural Station Effluent Total Suspended Solids Concentrations from Outfall 8

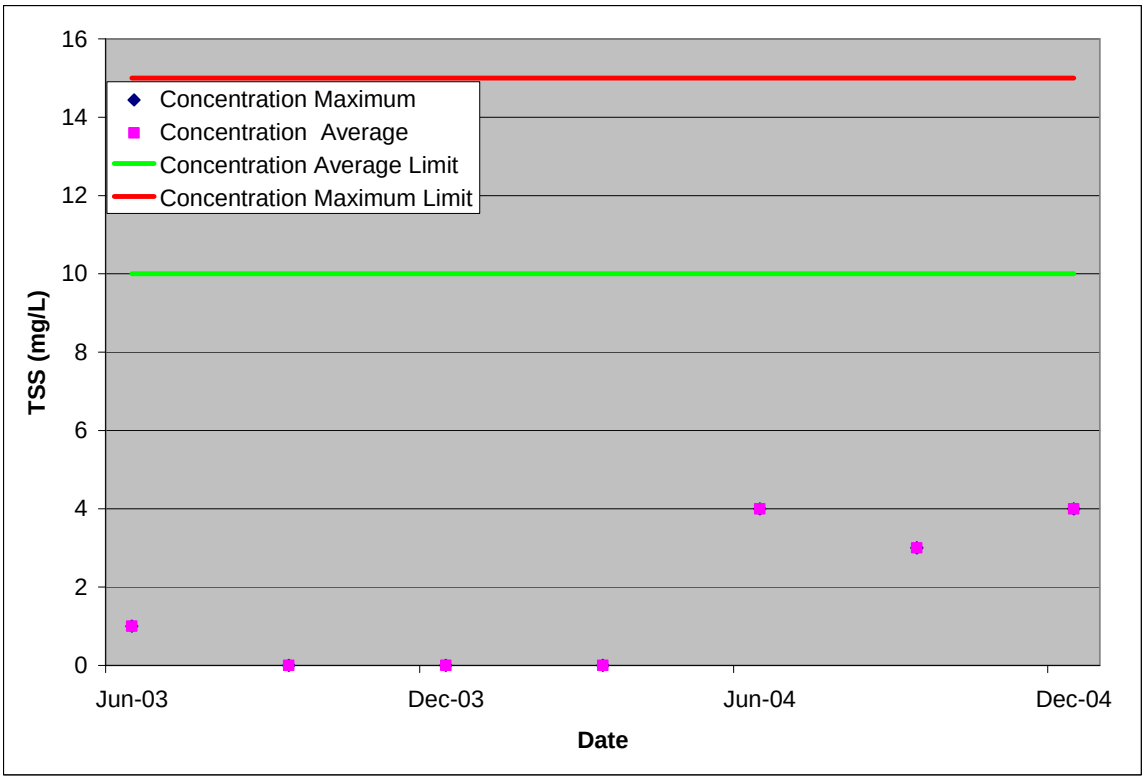


Figure C-70: DGIF Paint Bank Fish Cultural Station Effluent Ammonia Concentrations from Outfall 8

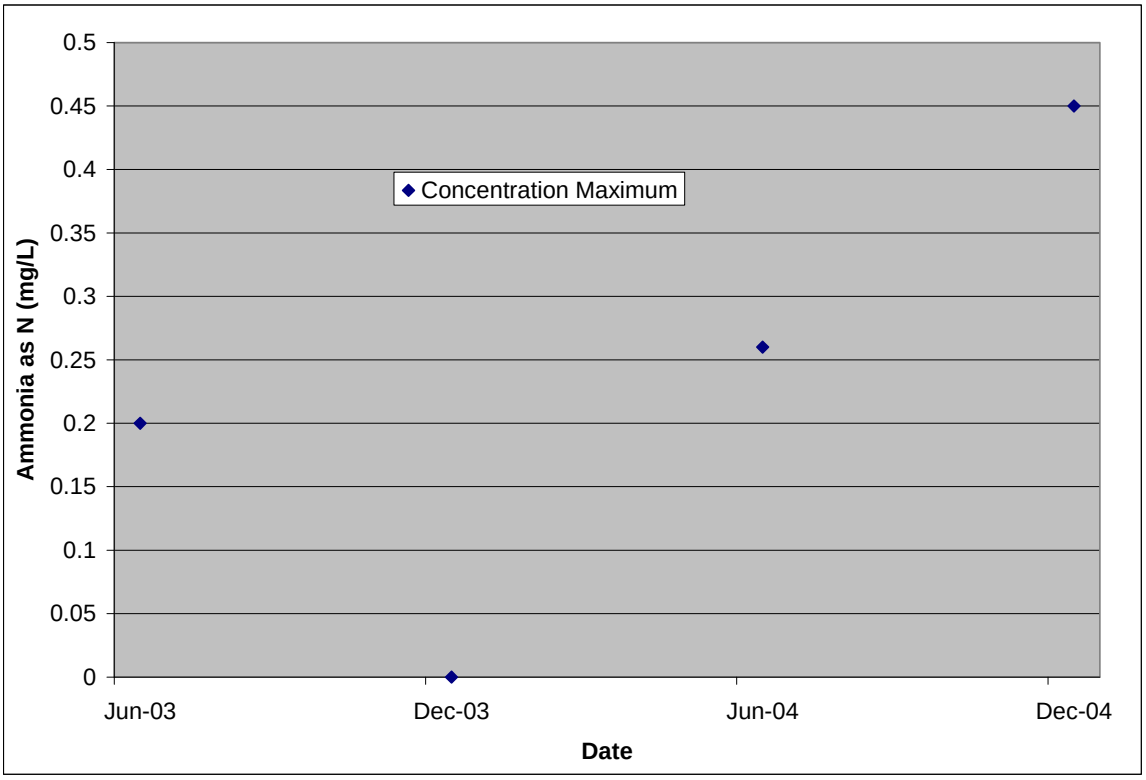


Figure C-71: DGIF Paint Bank Fish Cultural Station Effluent Flow Values from Outfall 9

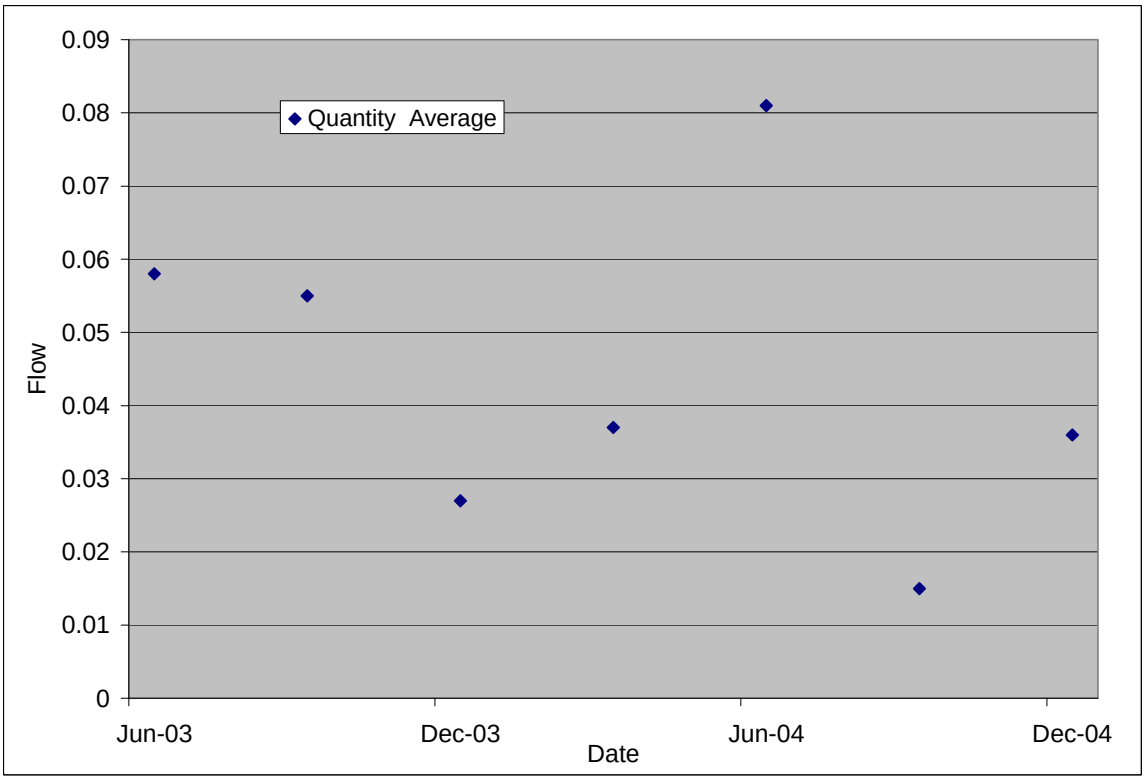


Figure C-72: DGIF Paint Bank Fish Cultural Station Effluent TSS Concentrations from Outfall 9

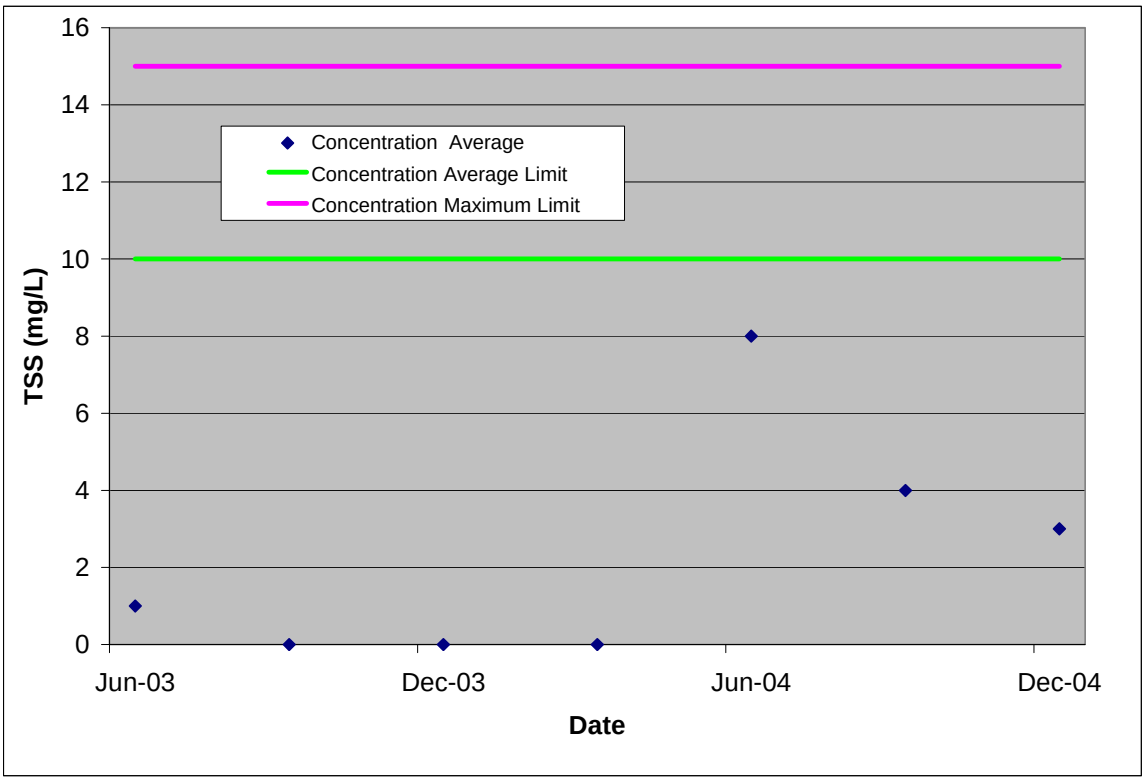


Figure C-73: DGIF Paint Bank Fish Cultural Station Settable Solids Concentrations from Outfall 9

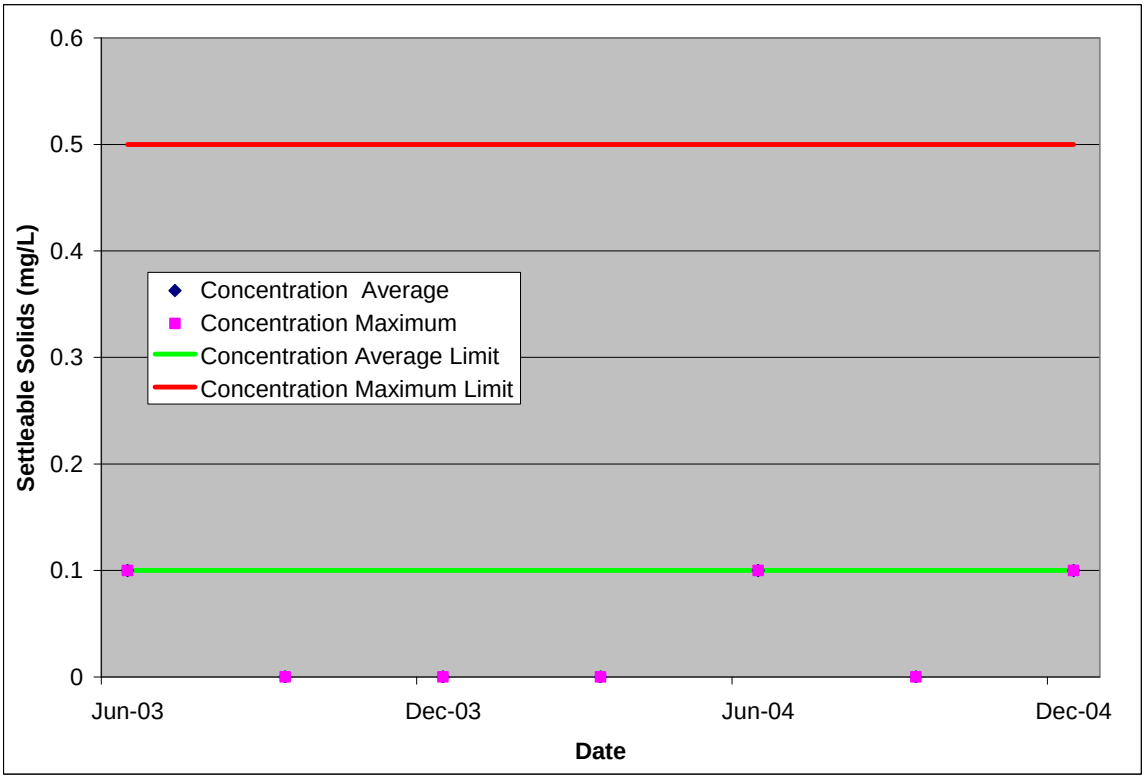


Figure C-74: Douthat Mobile Home Effluent Flow Values

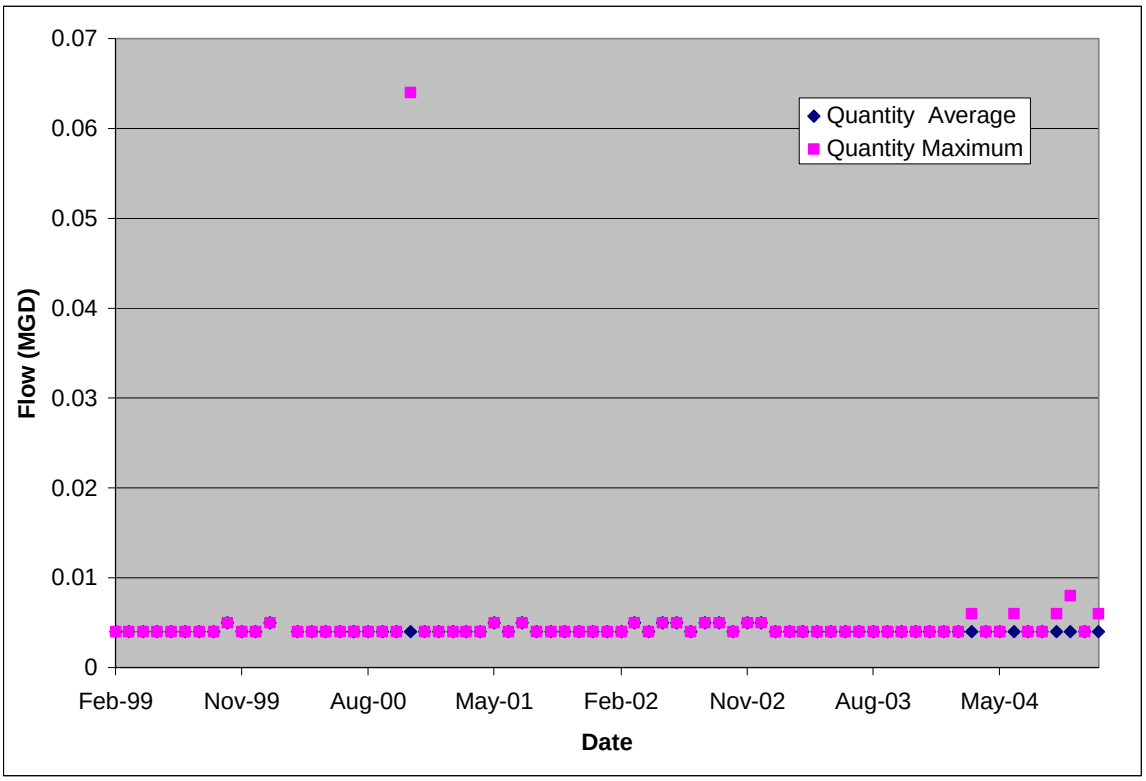


Figure C-75: Douthat Mobile Home Effluent pH Values

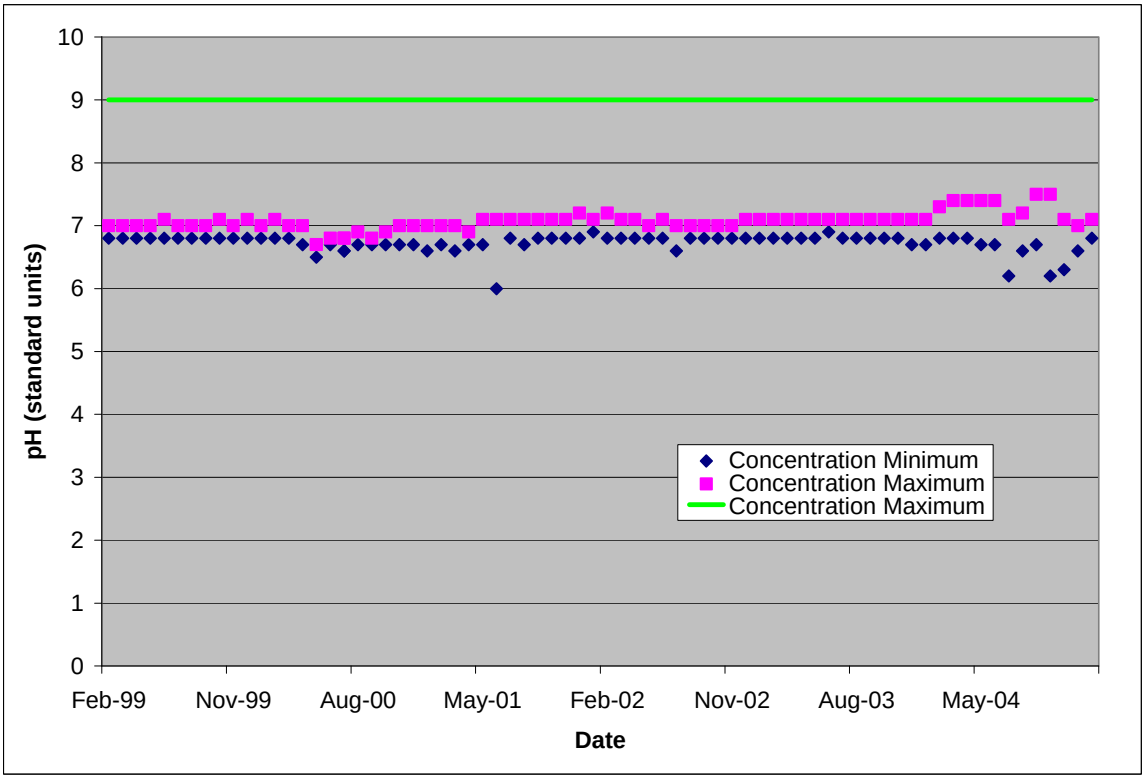


Figure C-76: Douthat Mobile Home Effluent TSS Concentrations

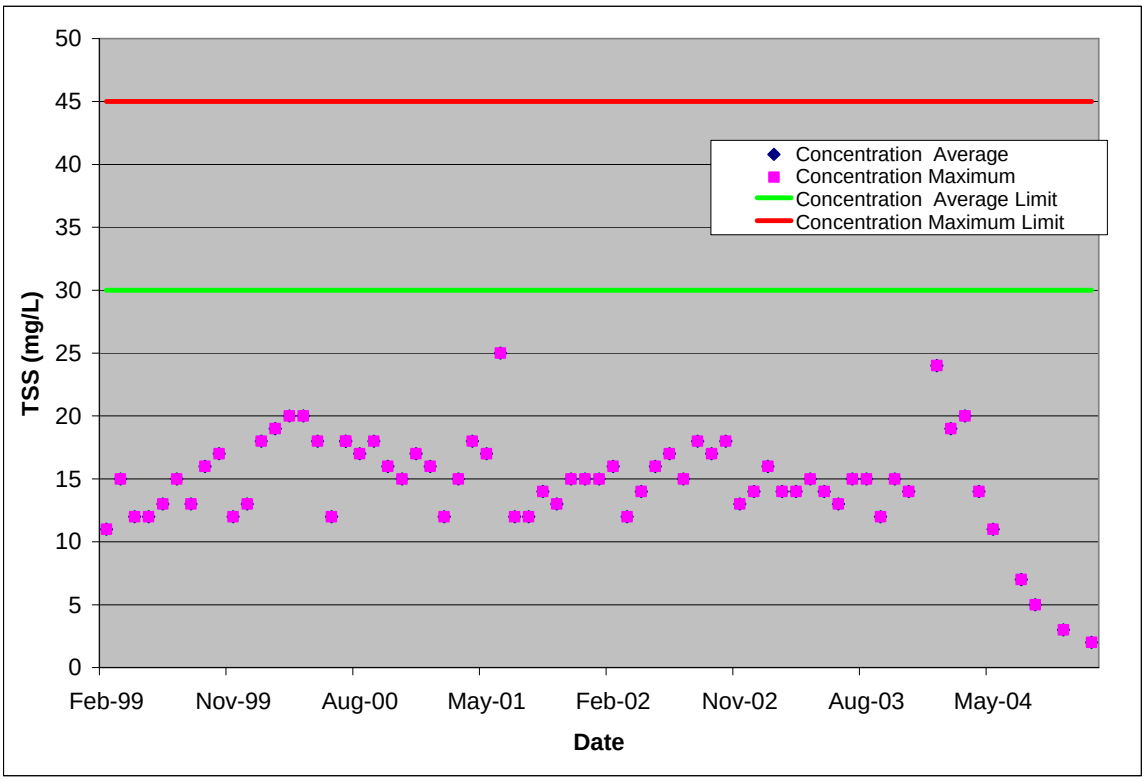


Figure C-77: Douthat Mobile Home Effluent TSS Quantities

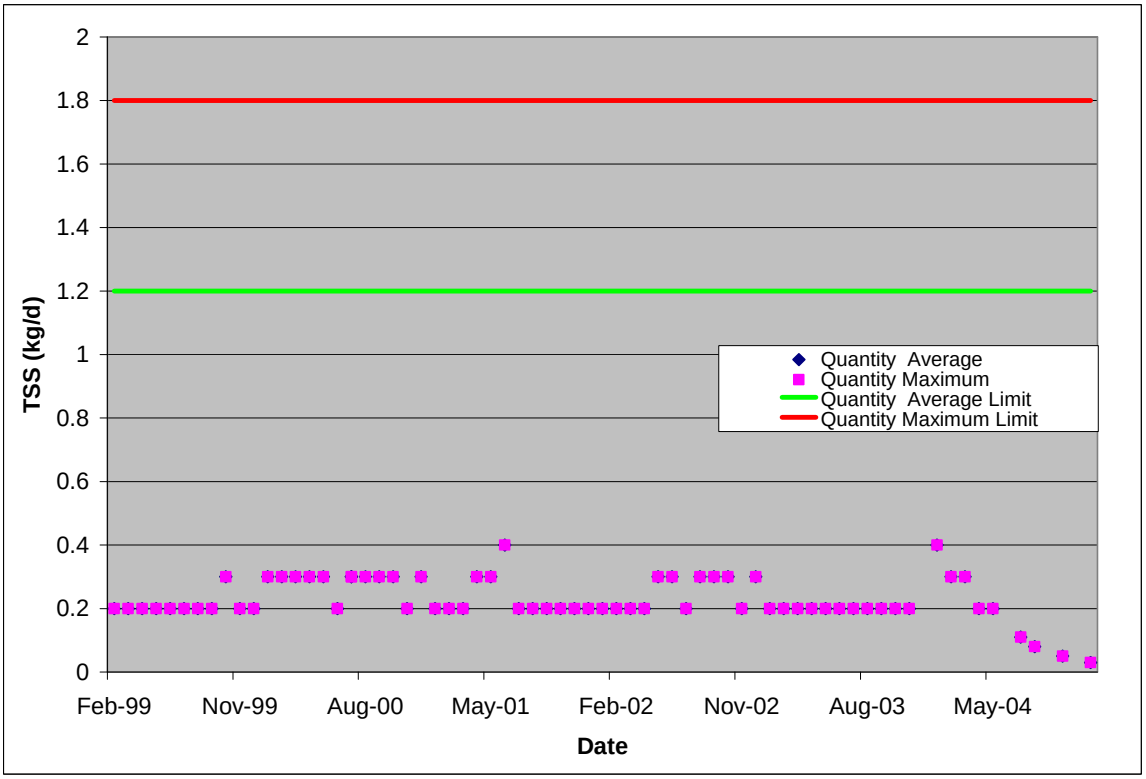


Figure C-78: Douthat Mobile Home Effluent Cl2 Concentrations

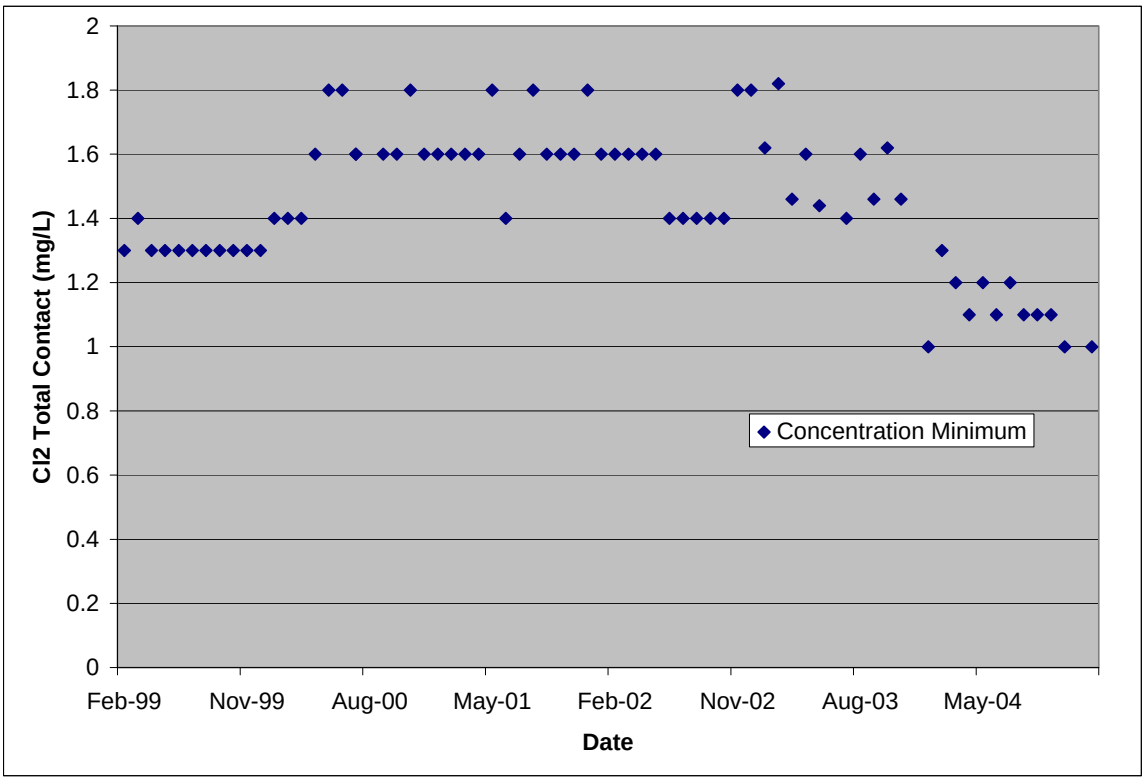


Figure C-79: Douthat Mobile Home Effluent BOD5 Concentrations

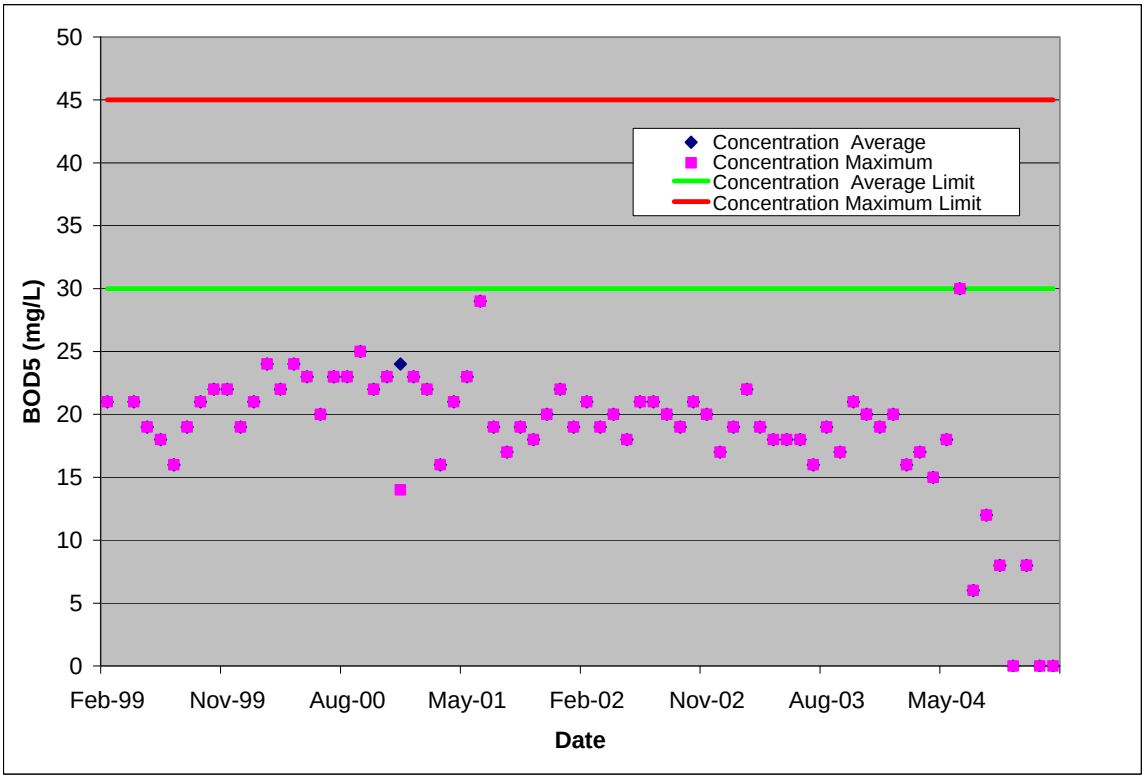


Figure C-80: Douthat Mobile Home Effluent BOD5 Quantities

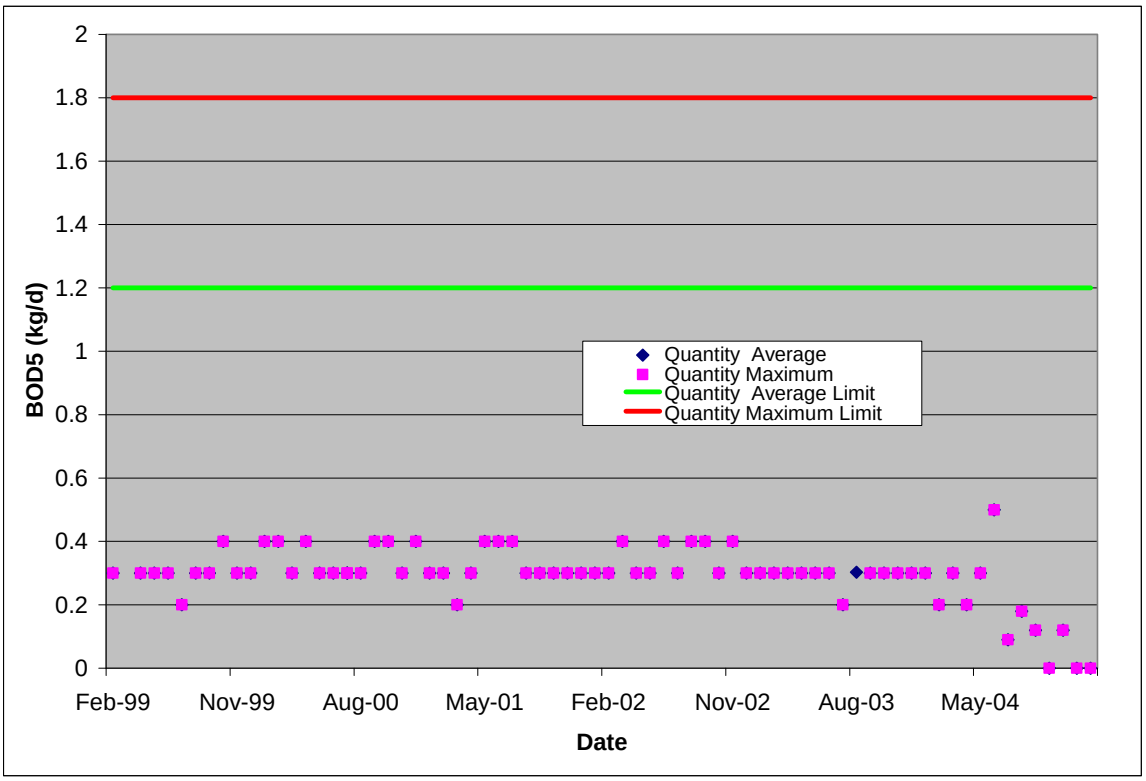


Figure C-81: Douthat Mobile Home Effluent Cl2 Inst Res Max Concentrations

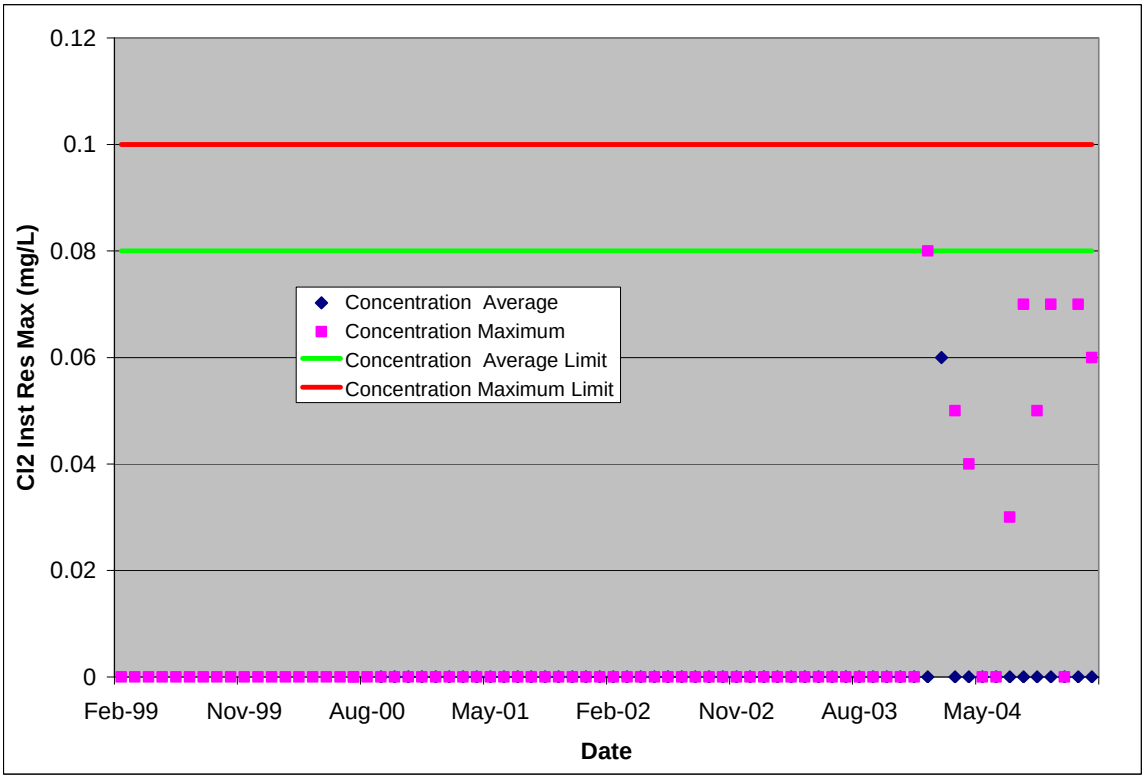


Figure C-82: MeadWestvaco Flow Values from Outfall 1

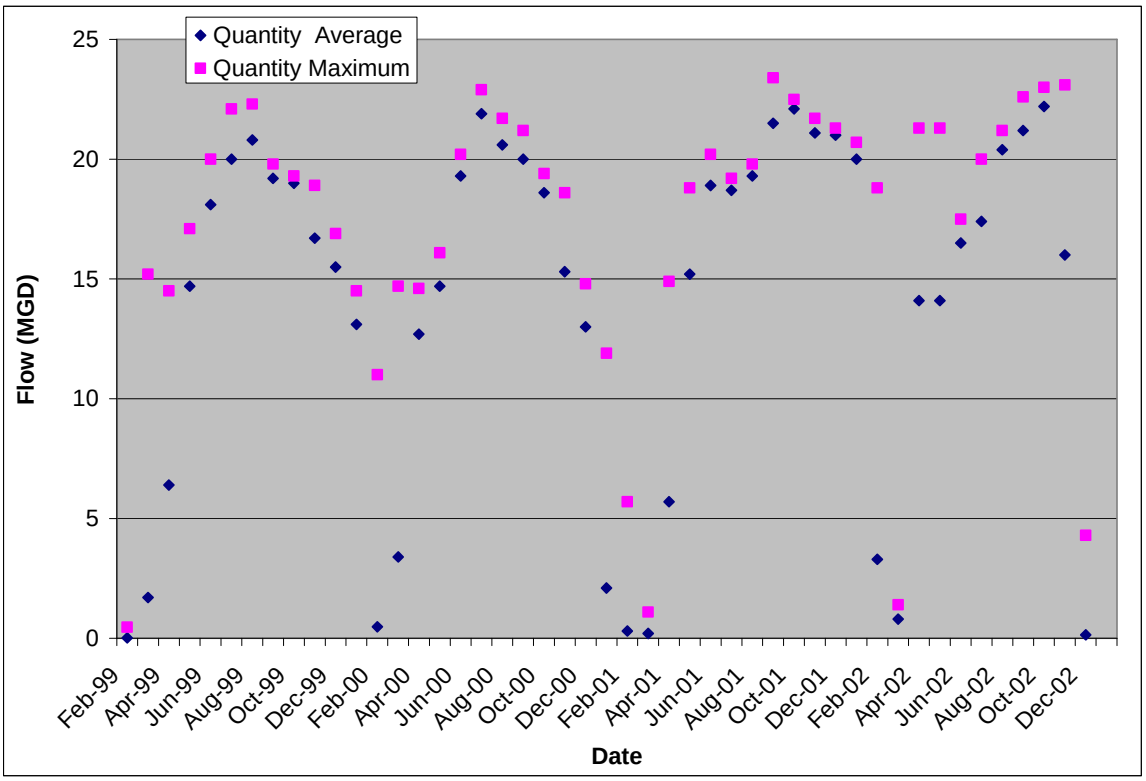


Figure C-83: MeadWestvaco Effluent pH Values from Outfall 1

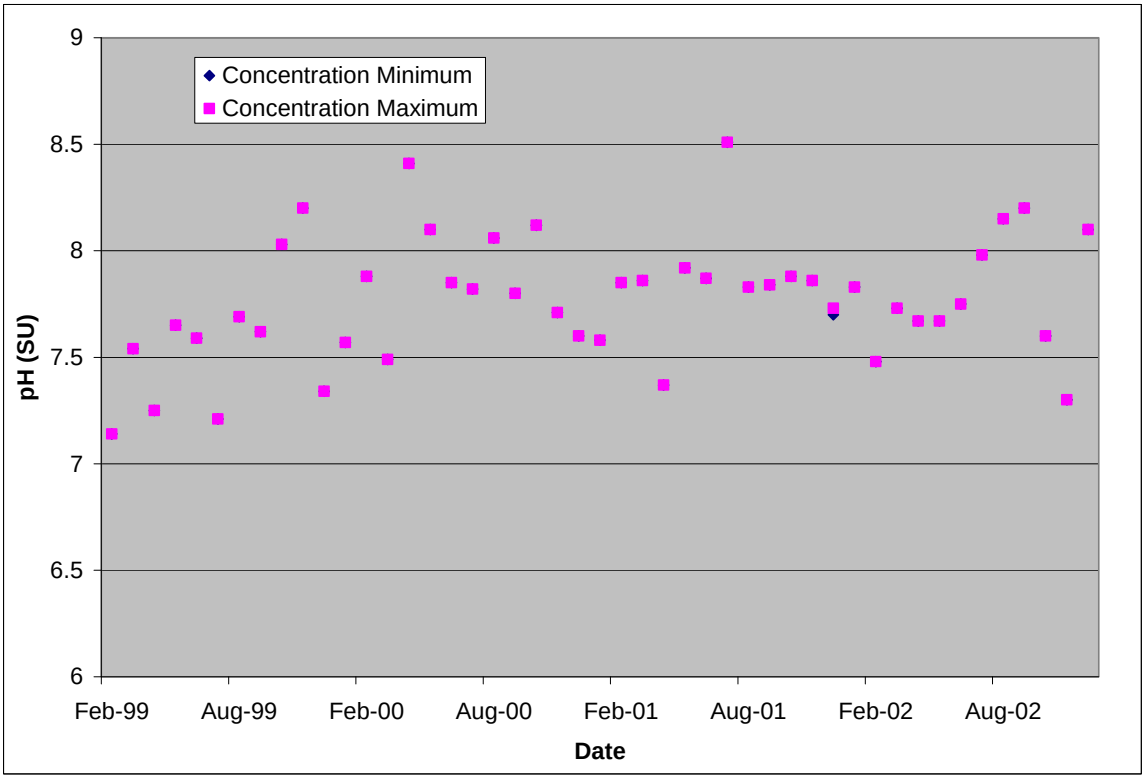


Figure C-84: Mead Westvaco Effluent Temperature Values from Outfall 1

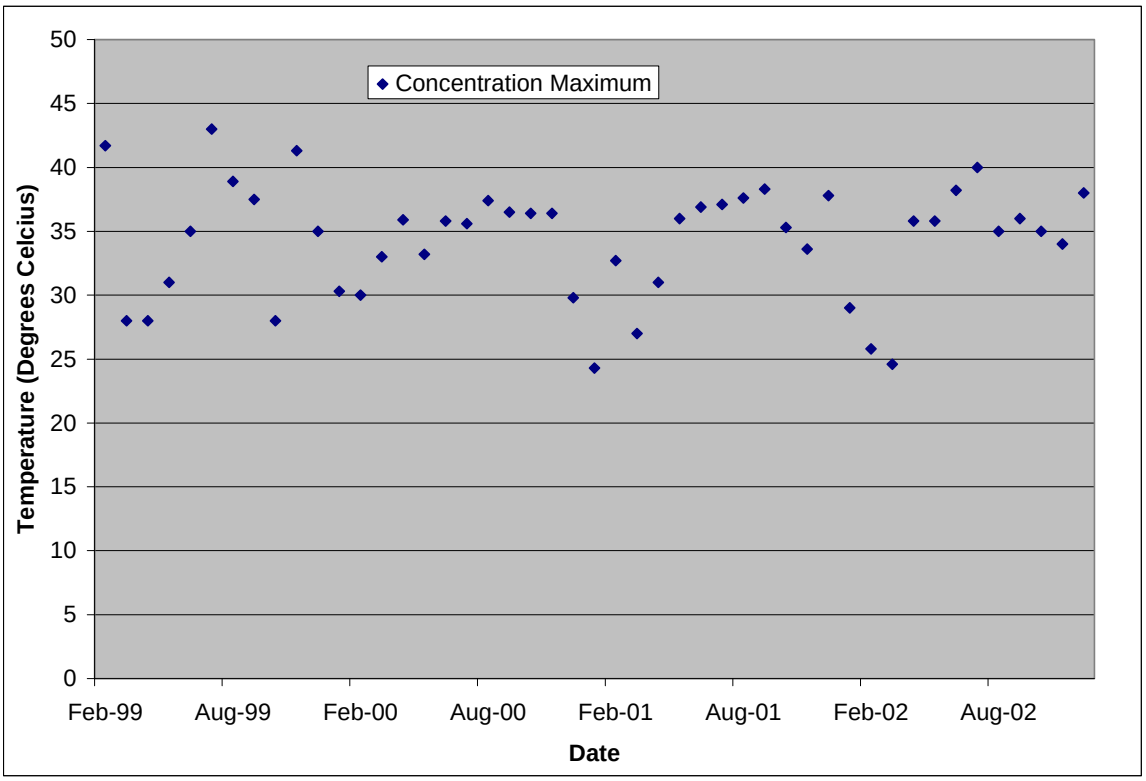


Figure C-85: MeadWestvaco Flow Values from Outfall 2

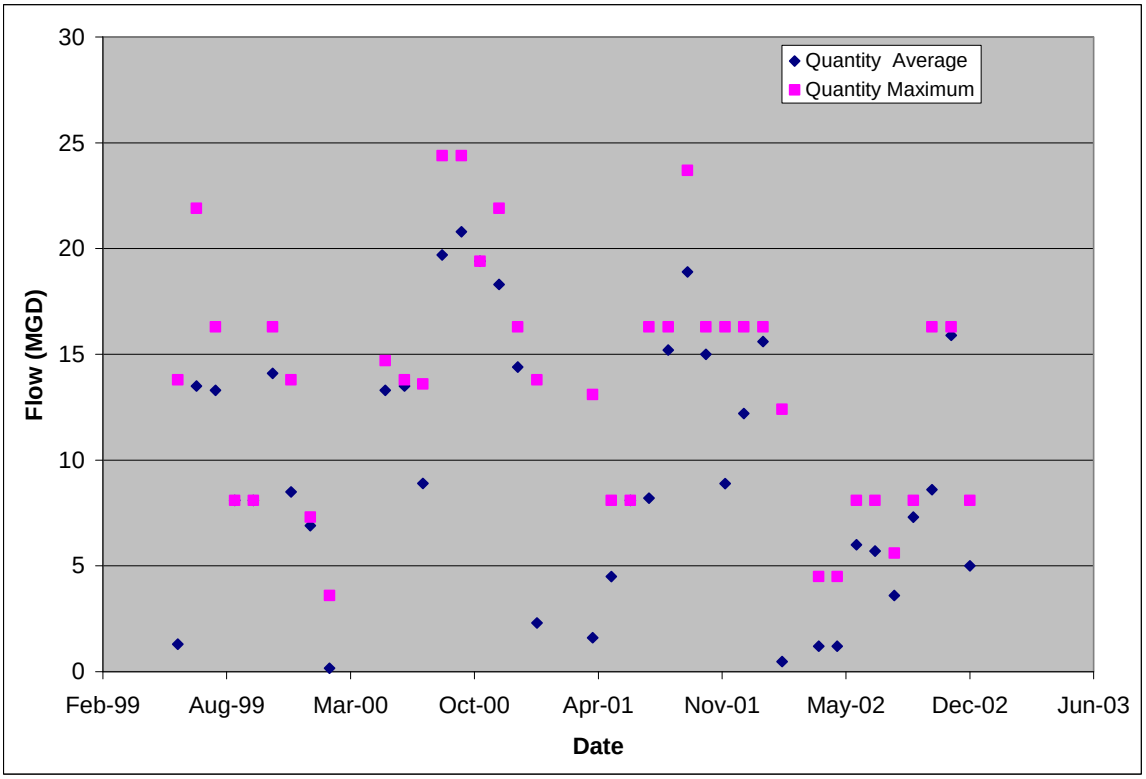


Figure C-86: MeadWestvaco Effluent pH Values from Outfall 2

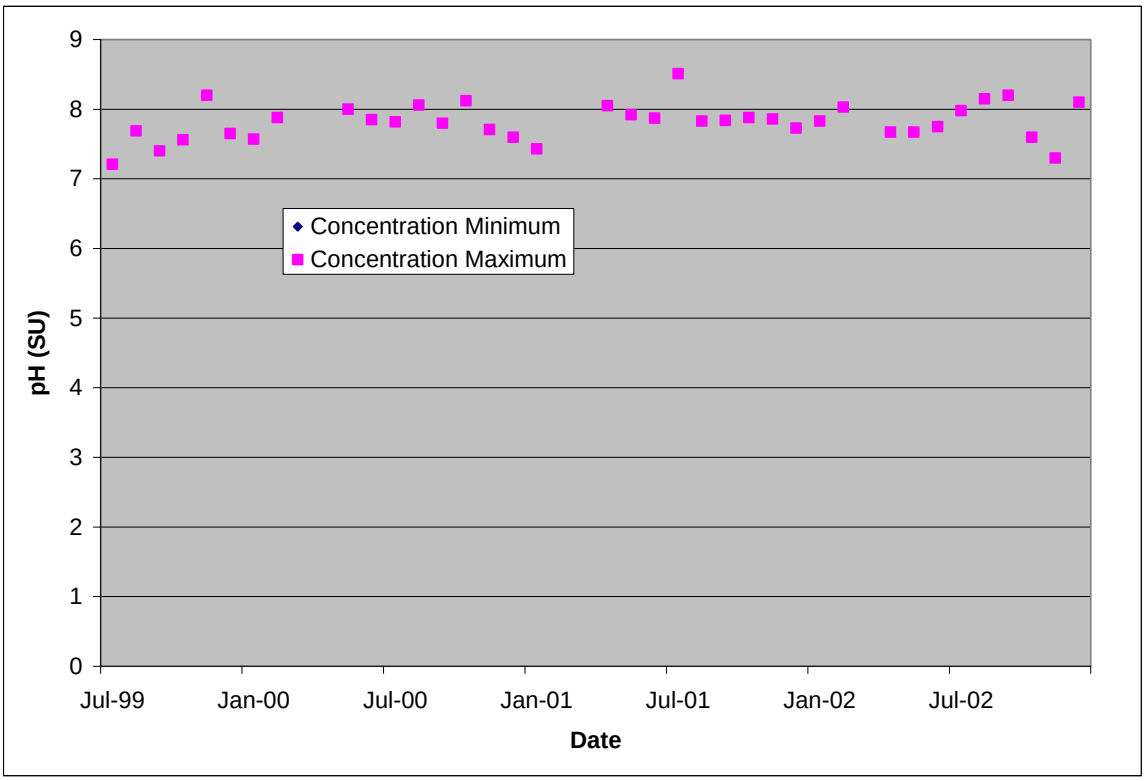


Figure C-87: MeadWestvaco Effluent Temperature Values from Outfall 2

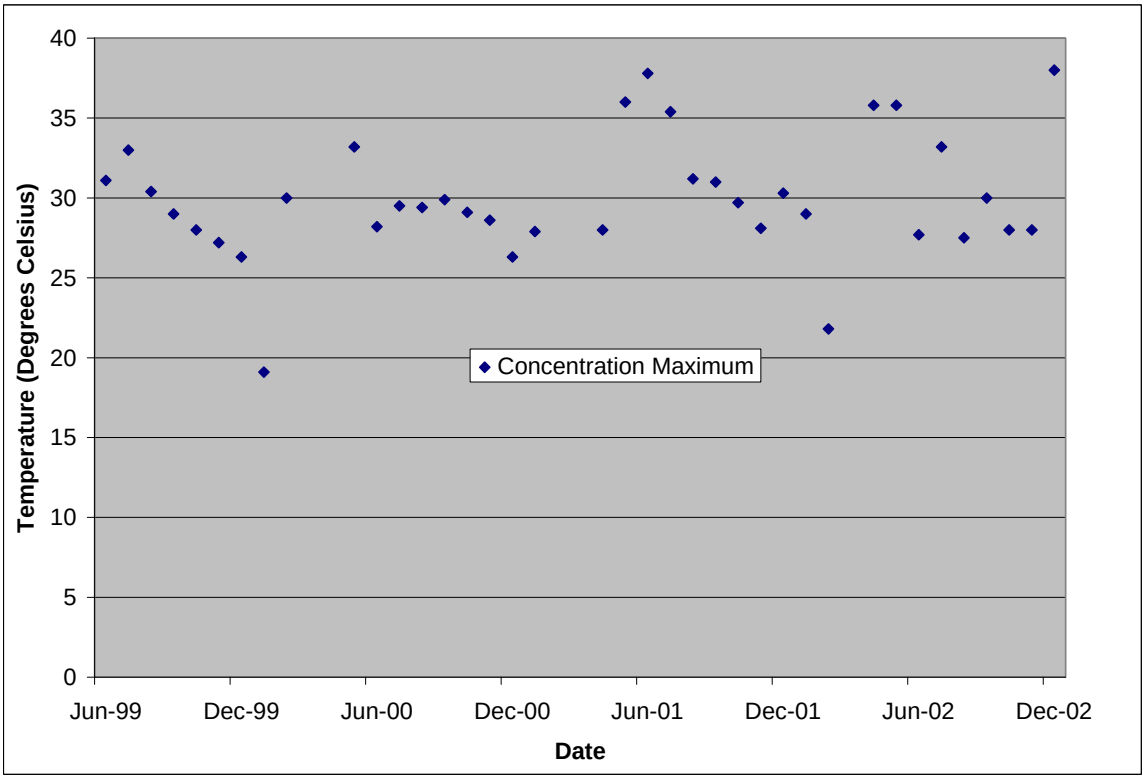


Figure C-88: MeadWestvaco Effluent Flow Values from Outfall 3

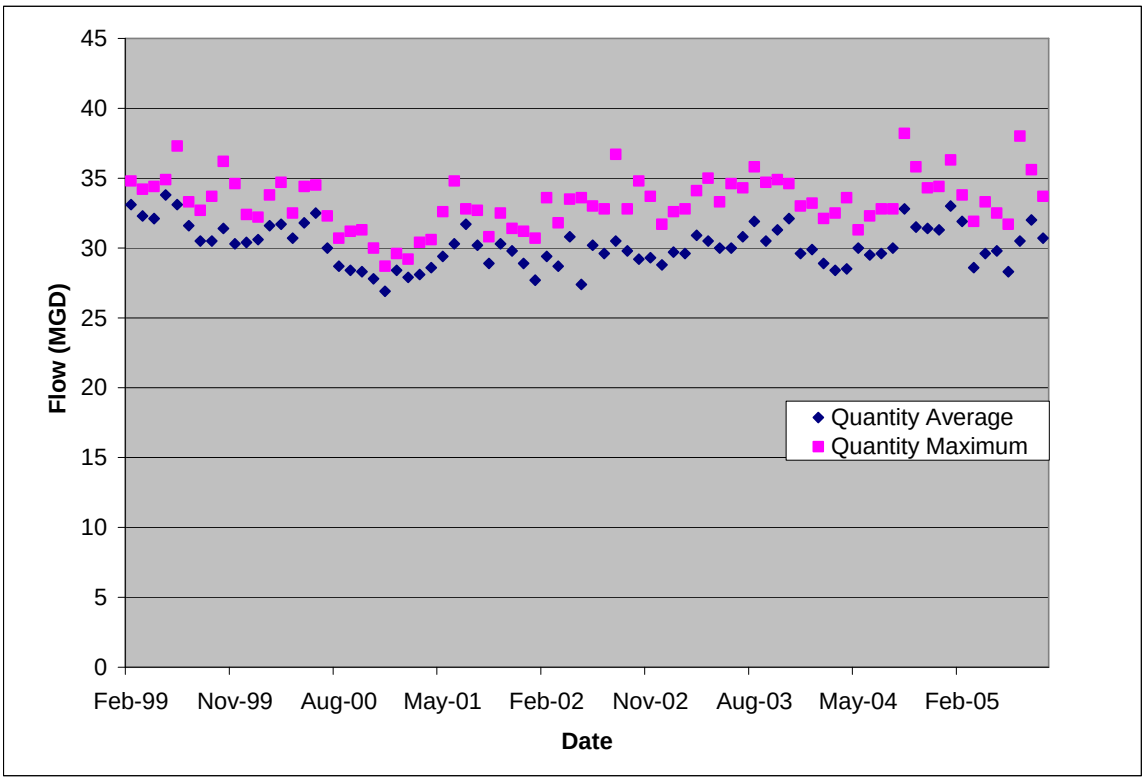


Figure C-89: MeadWestvaco Absorbable Organic Halides Effluent Concentrations from Outfall 3

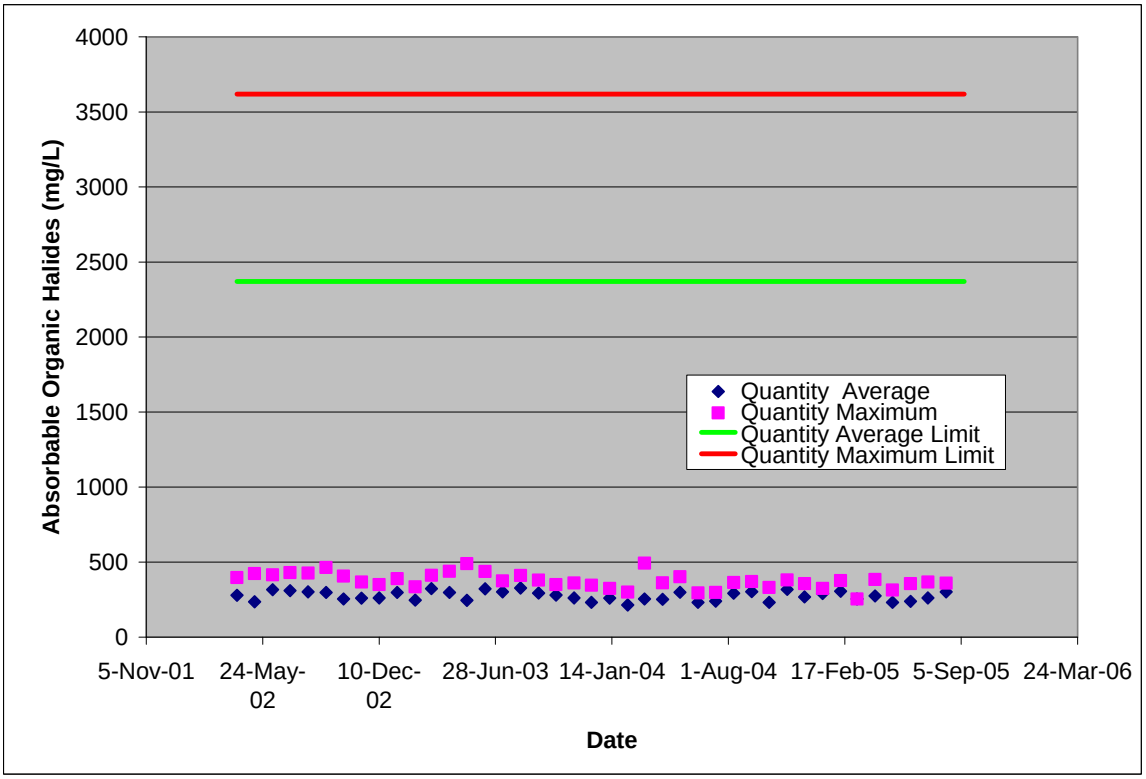


Figure C-90: MeadWestvaco Effluent BOD5 Concentrations from Outfall 3

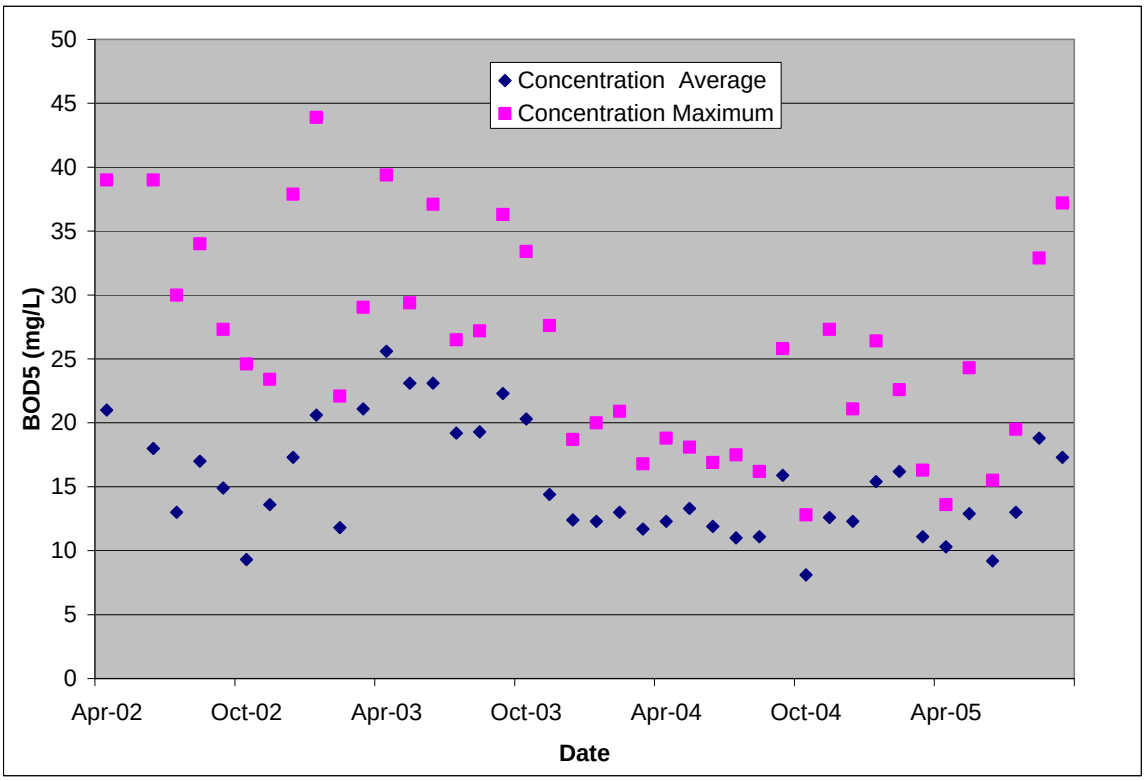


Figure C-91: MeadWestvaco Effluent COD Concentrations from Outfall 3

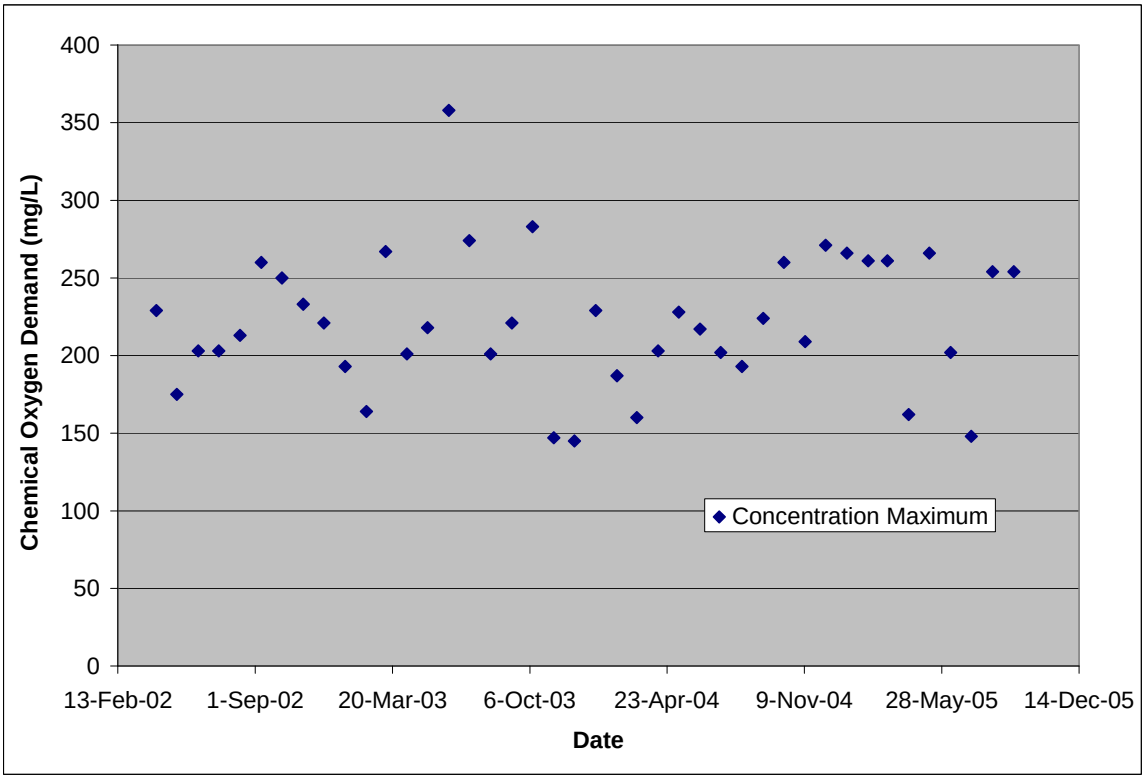


Figure C-92: MeadWestvaco Effluent Color Values from Outfall 3

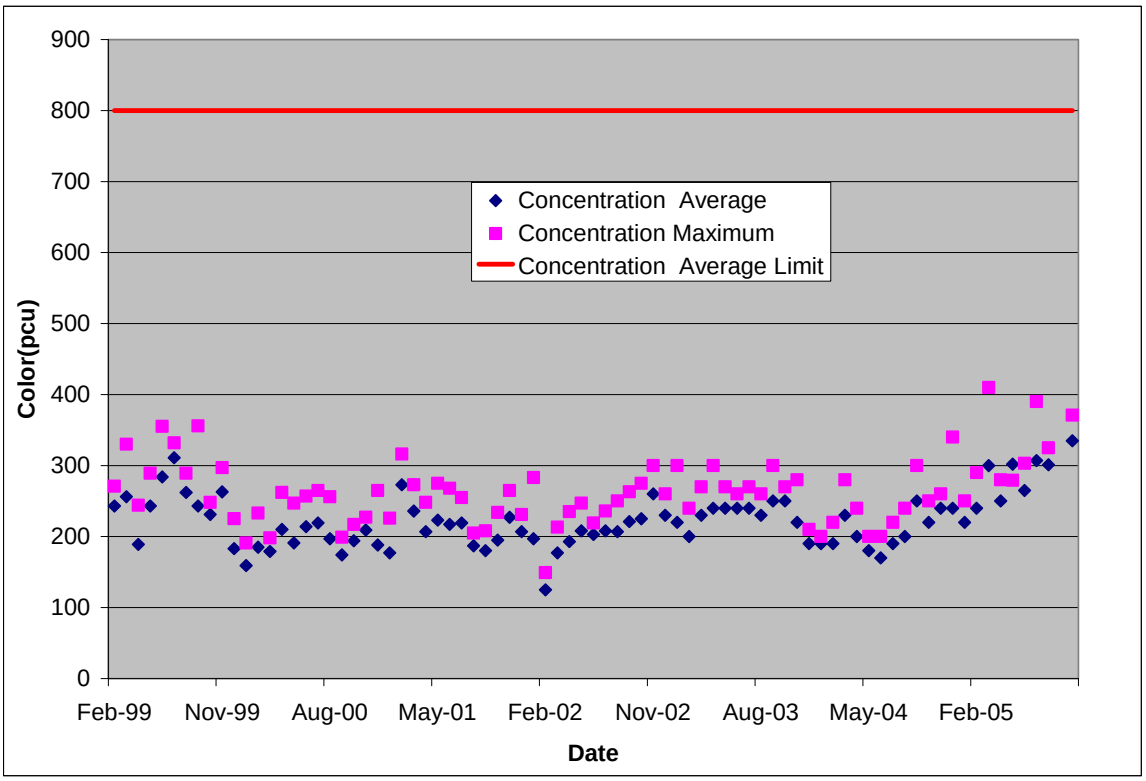


Figure C-93: MeadWestvaco Effluent Nitrogen Concentrations from Outfall 3

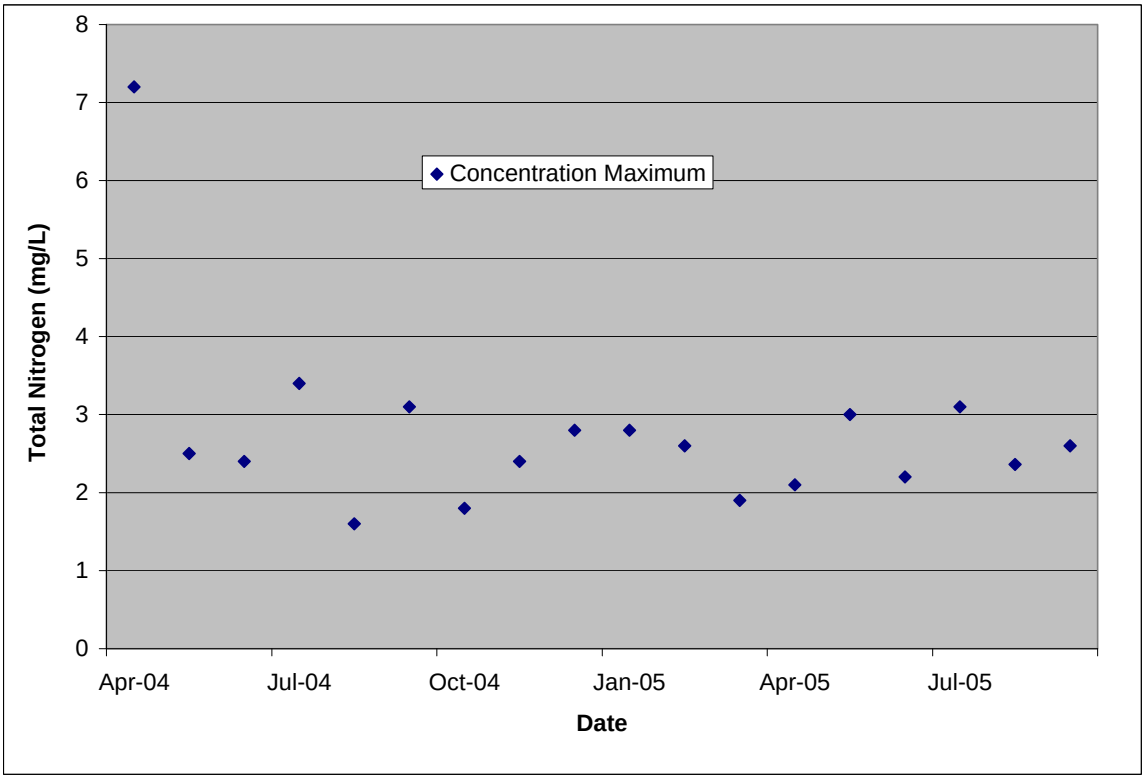


Figure C-94: MeadWestvaco Effluent Total Phosphorous Concentrations from Outfall 3

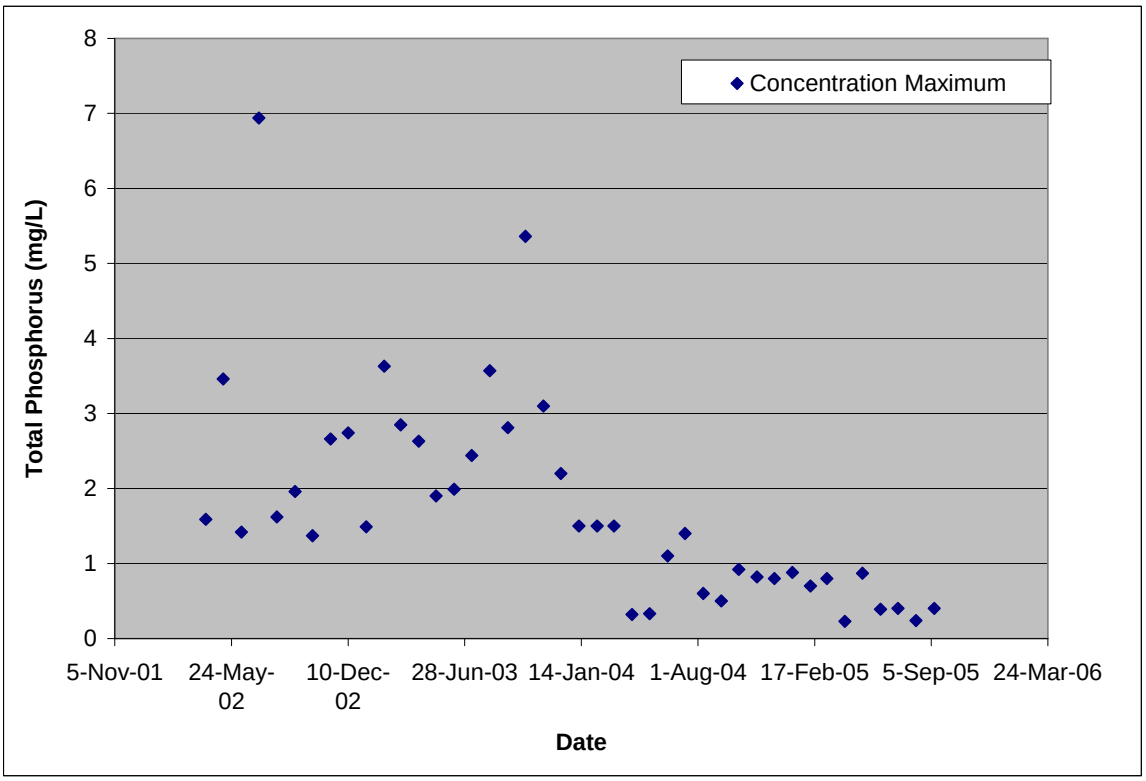


Figure C-95: MeadWestvaco Effluent pH Values from Outfall 3

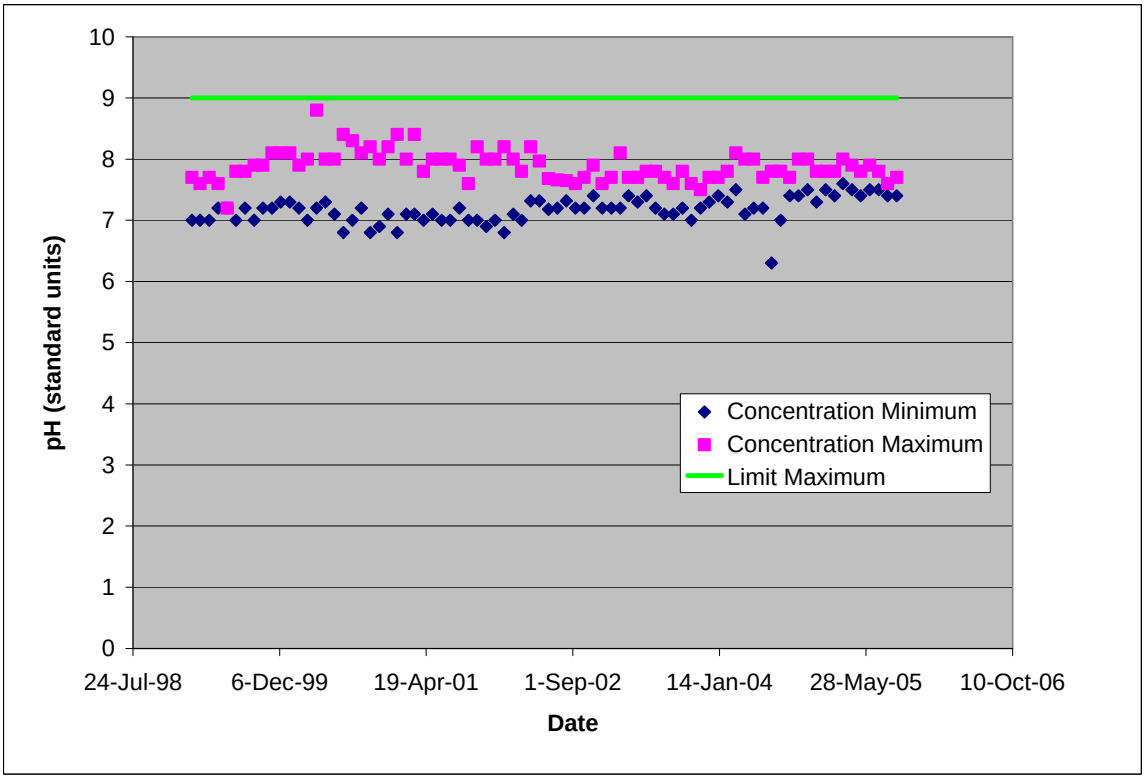


Figure C-96: MeadWestvaco Effluent Temperature Values from Outfall 3

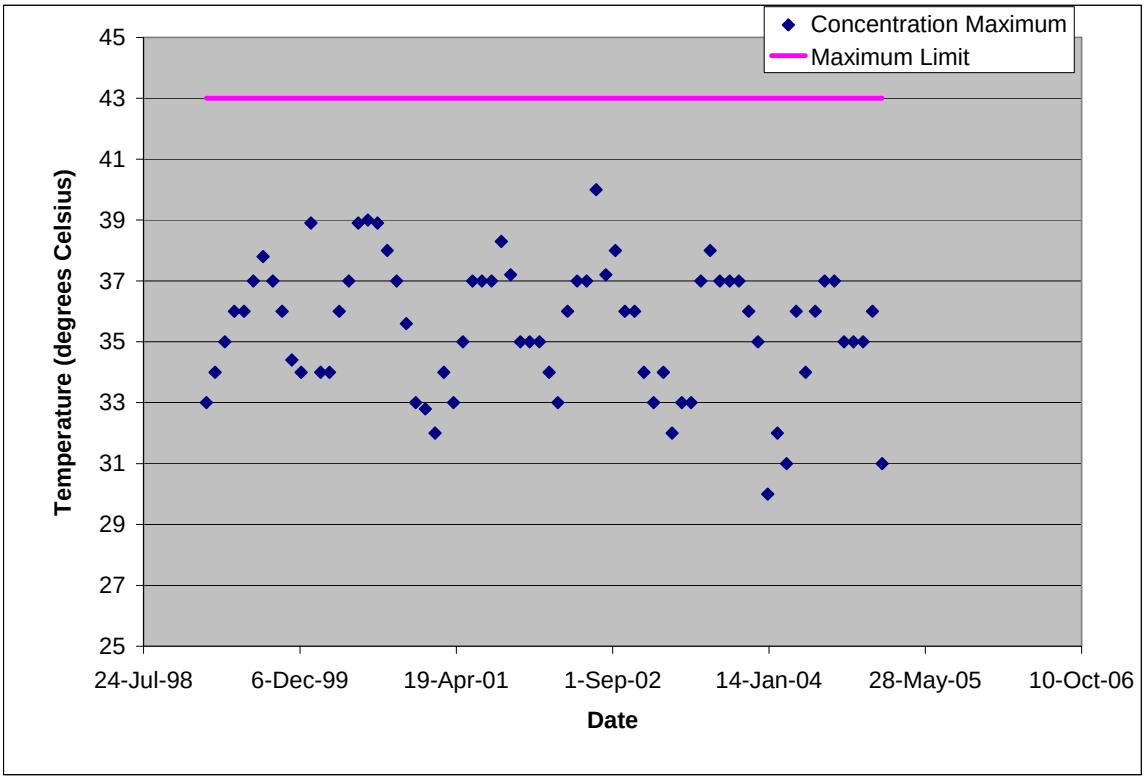


Figure C-97: MeadWestvaco Effluent TSS Quantities from Outfall 3

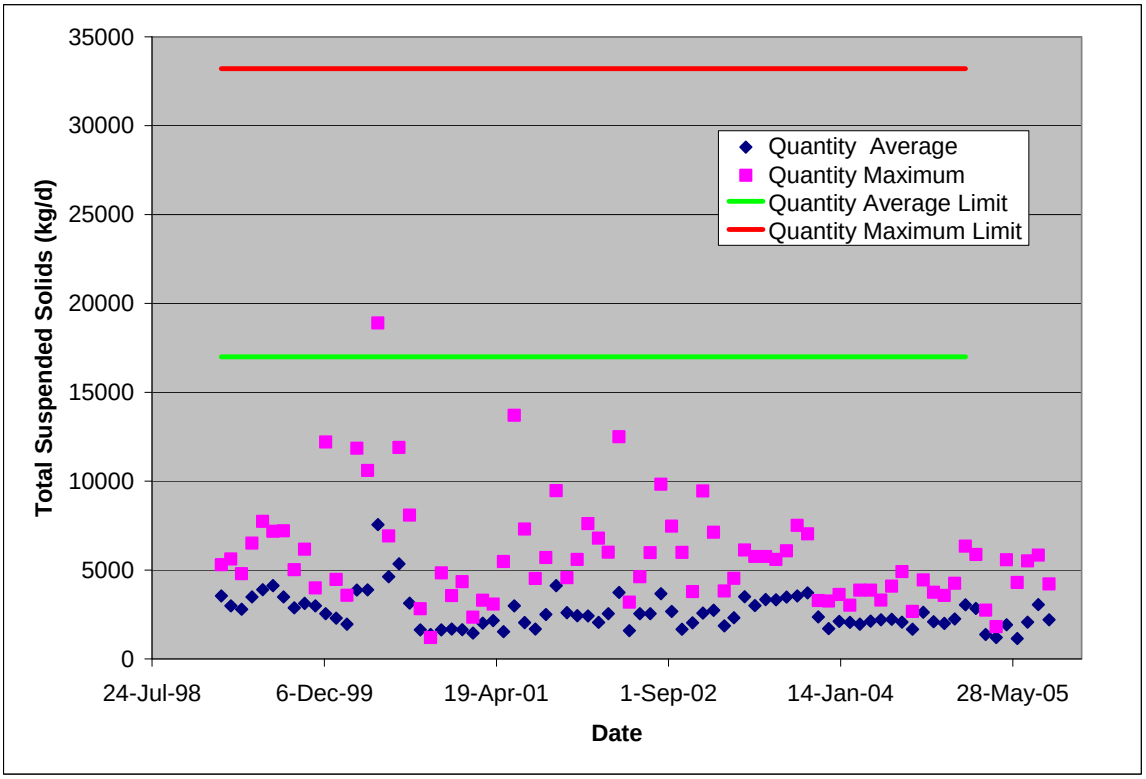


Figure C-98: MeadWestvaco Effluent Fecal Coliform Concentrations from Outfall 3

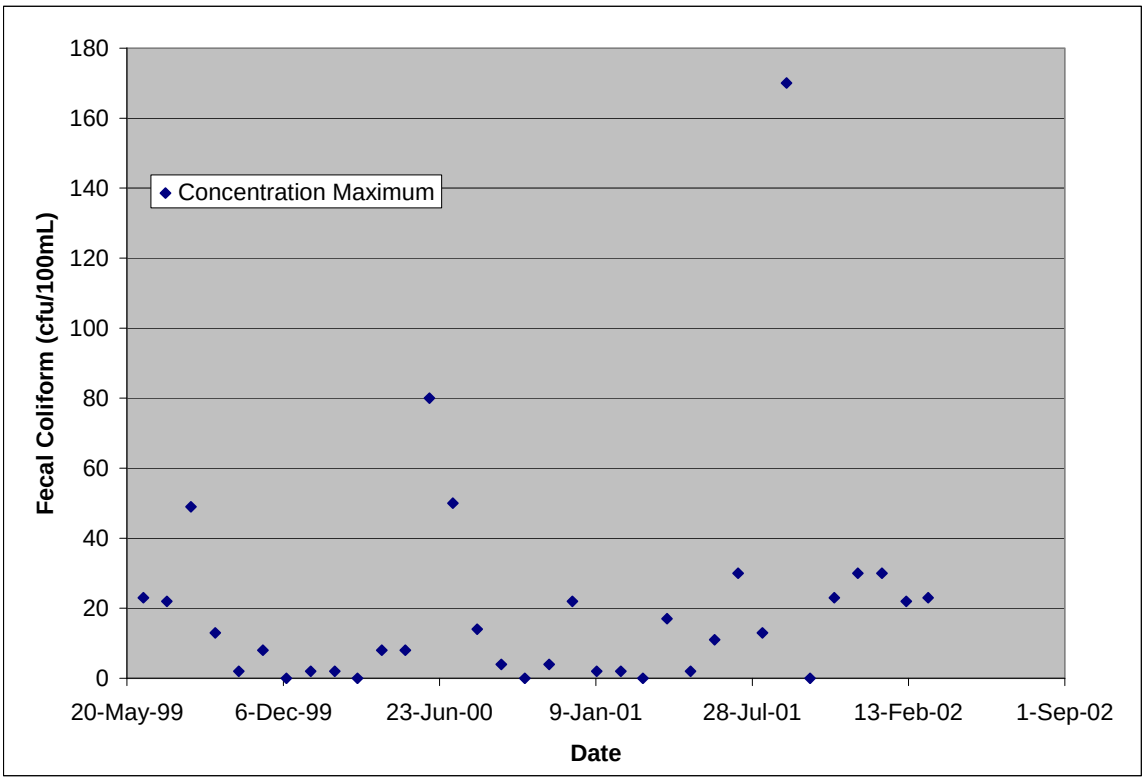


Figure C-99: MeadWestvaco Effluent Ammonia Concentrations from Outfall 3

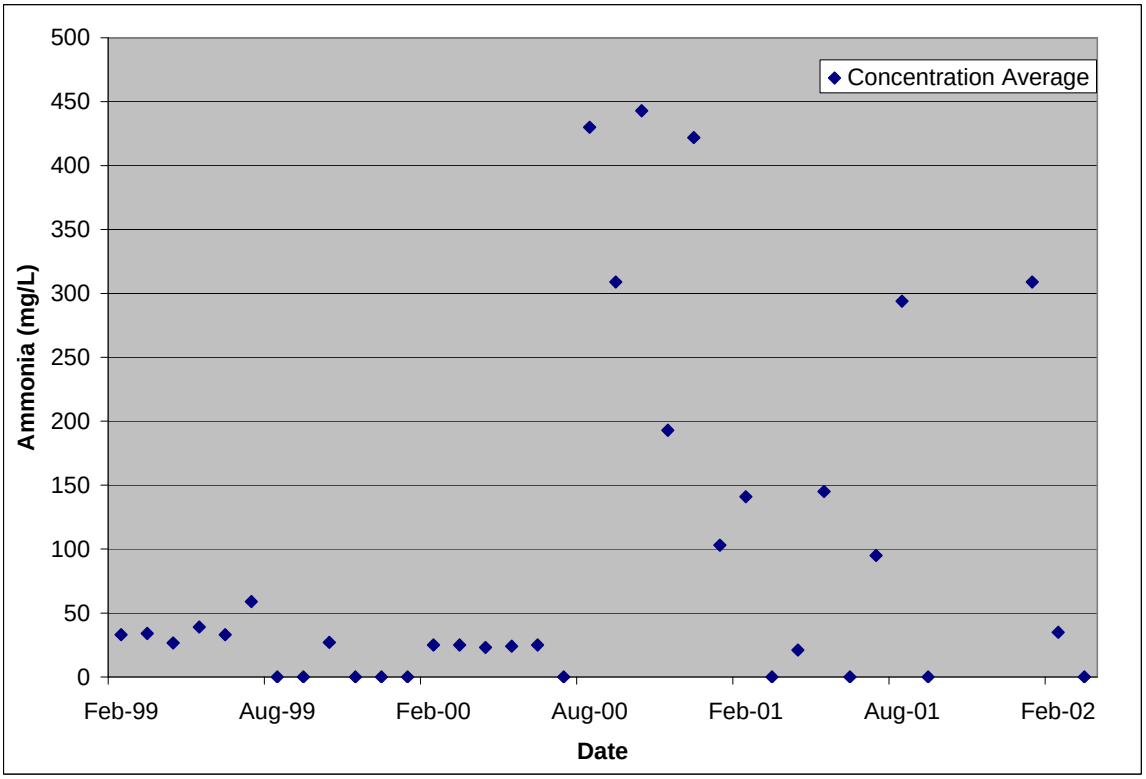


Figure C-100: MeadWestvaco Effluent Flow Values From Outfall 4

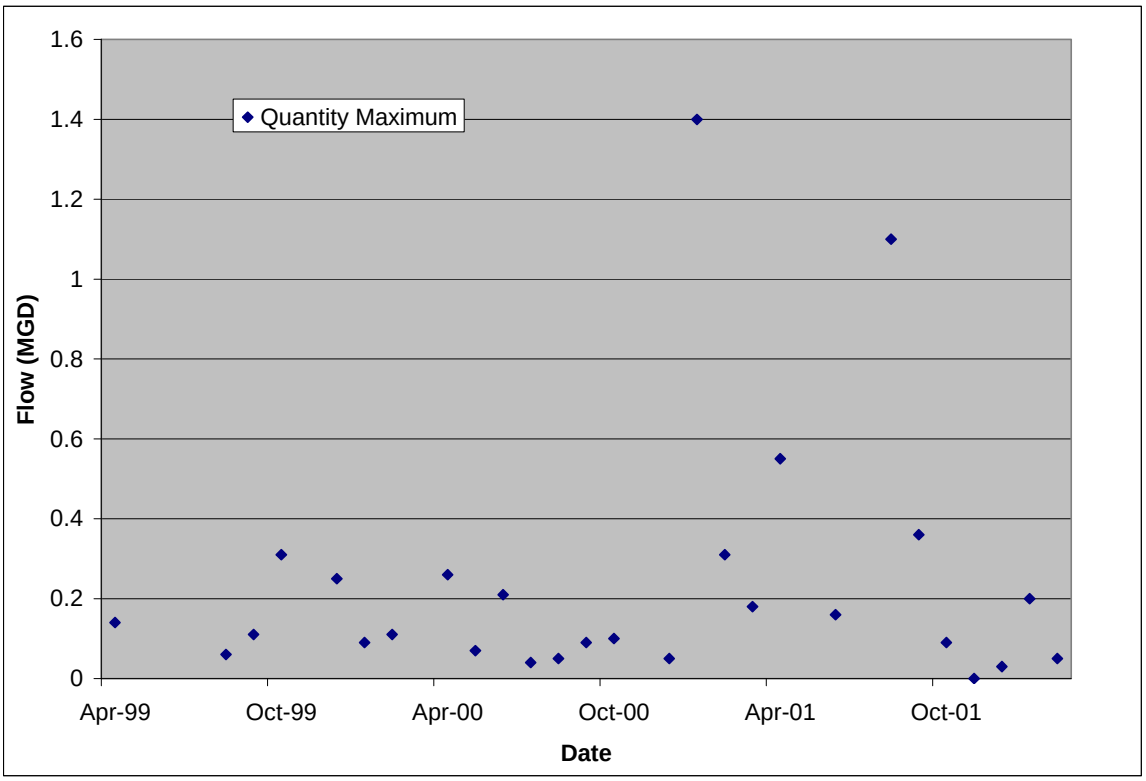


Figure C-101: Mead Westvaco Effluent Total Recoverable Iron from Outfall 4

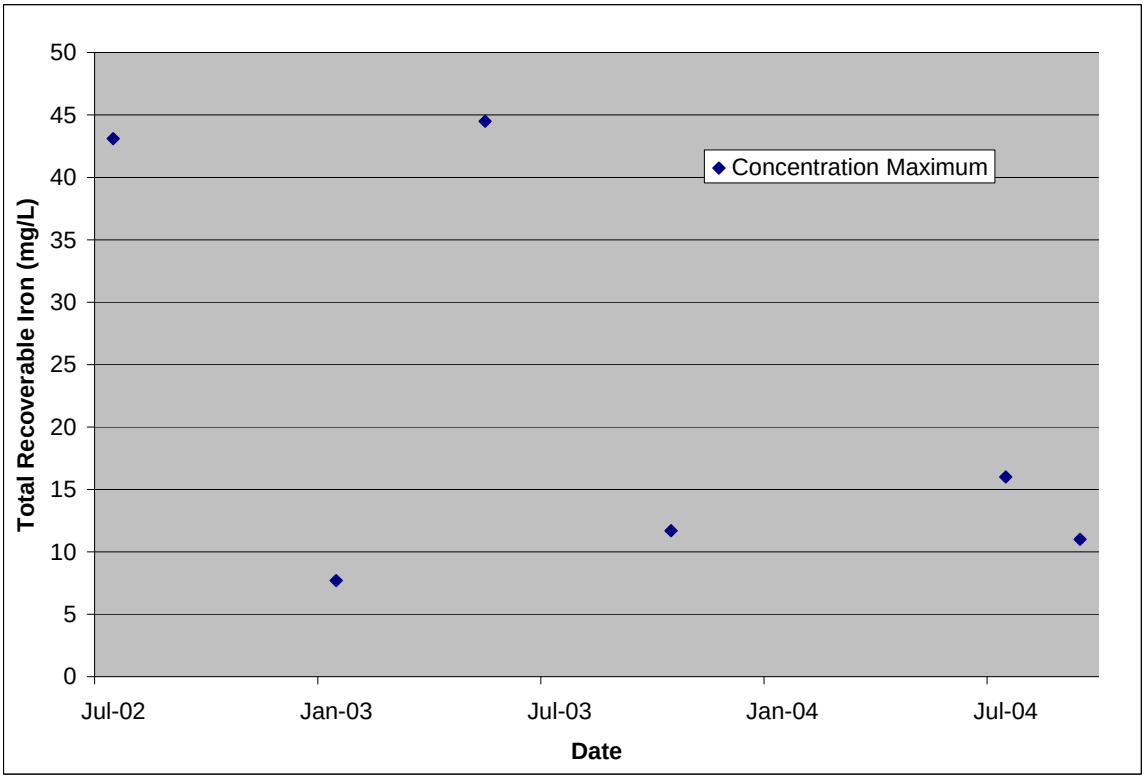


Figure C-102: MeadWestvaco Effluent BOD5 Values from Outfall 4

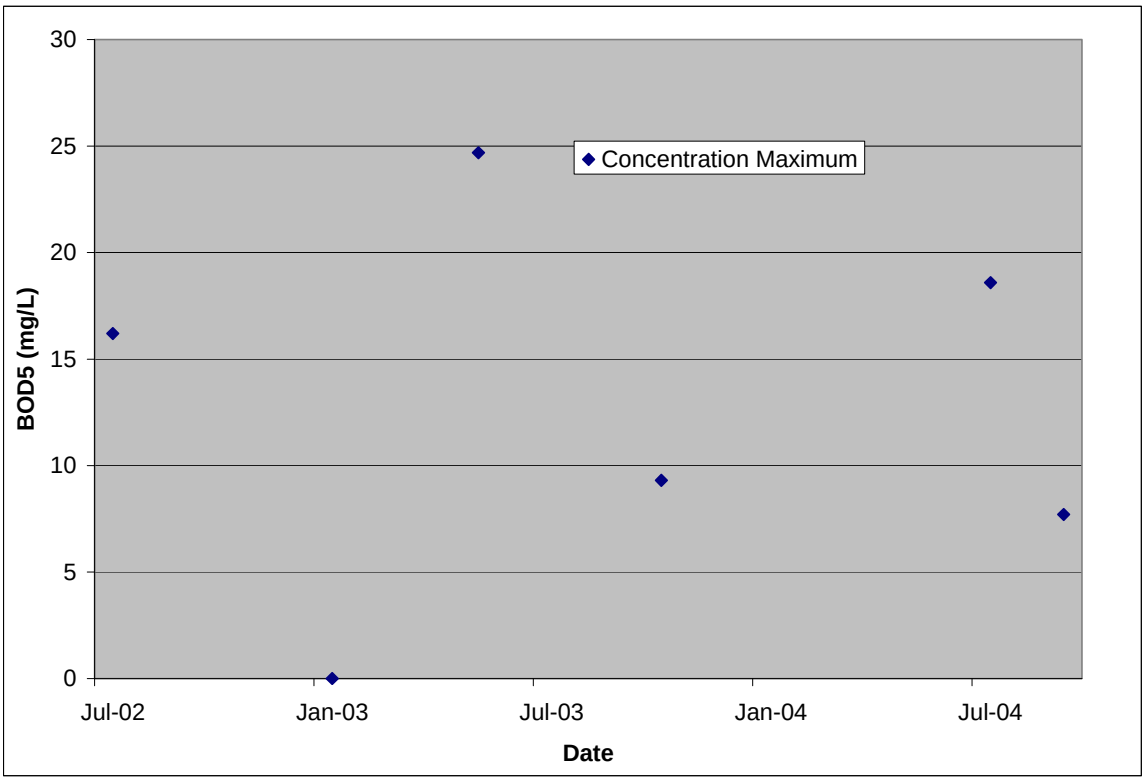


Figure C-103: MeadWestvaco Effluent COD Concentrations from Outfall 4

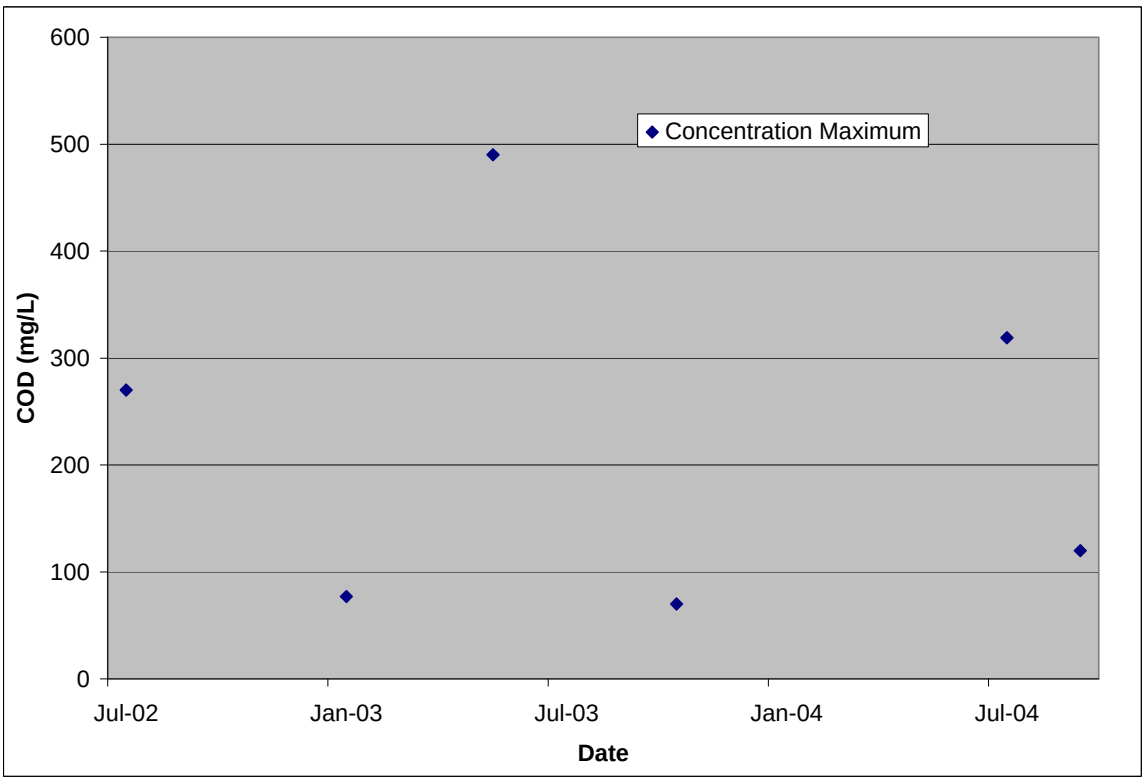


Figure C-104: MeadWestvaco Effluent Total Suspended Solid Concentrations from Outfall 4

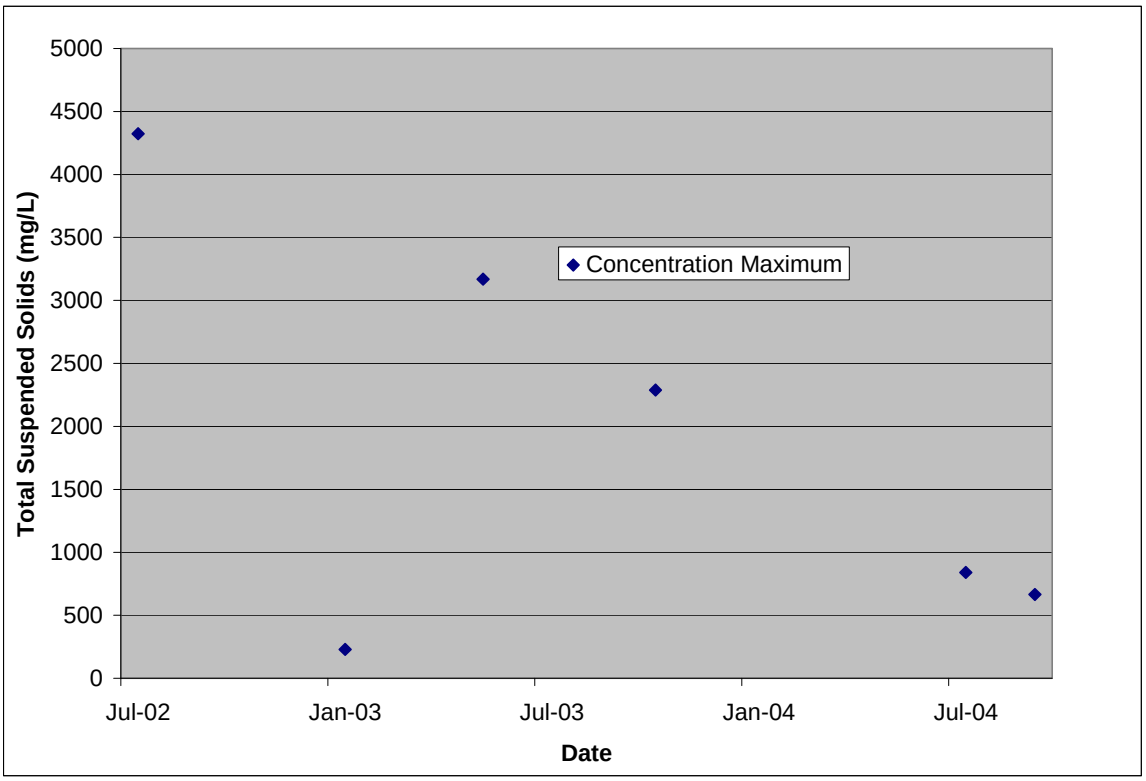


Figure C-105: MeadWestvaco Effluent Chloroform Quantities from Outfall 301

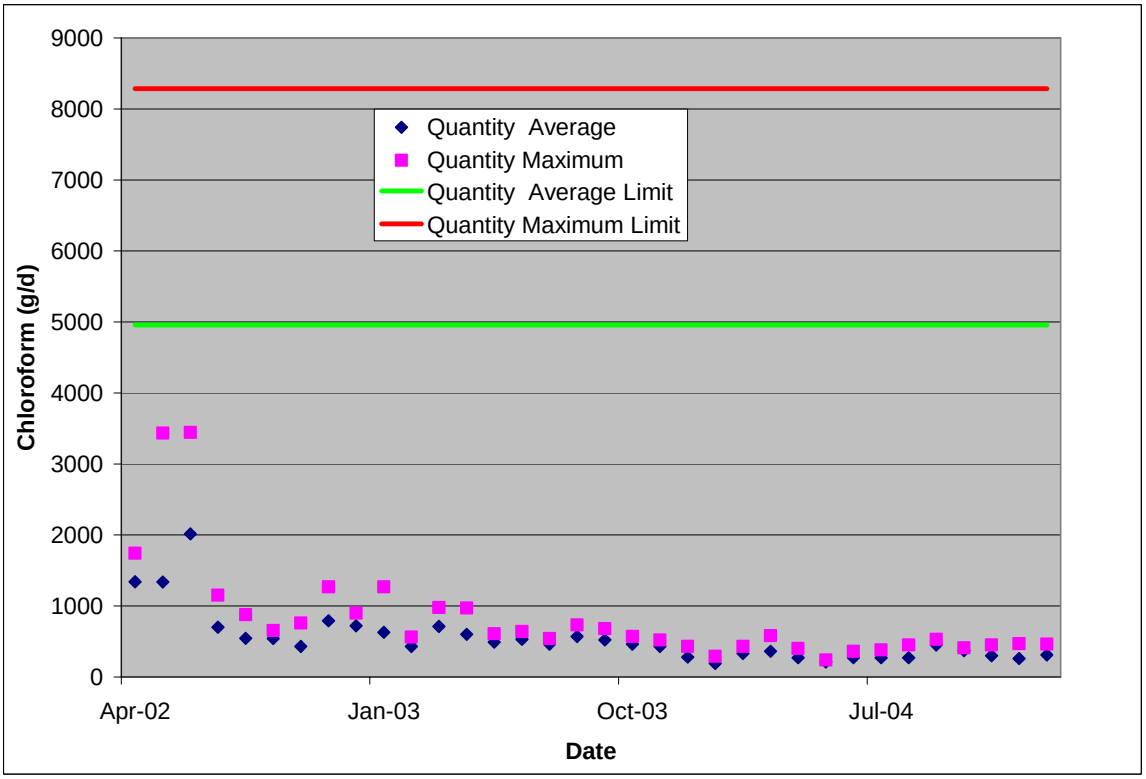


Figure C-106: MeadWestvaco Effluent Chloroform Quantities from Outfall 302

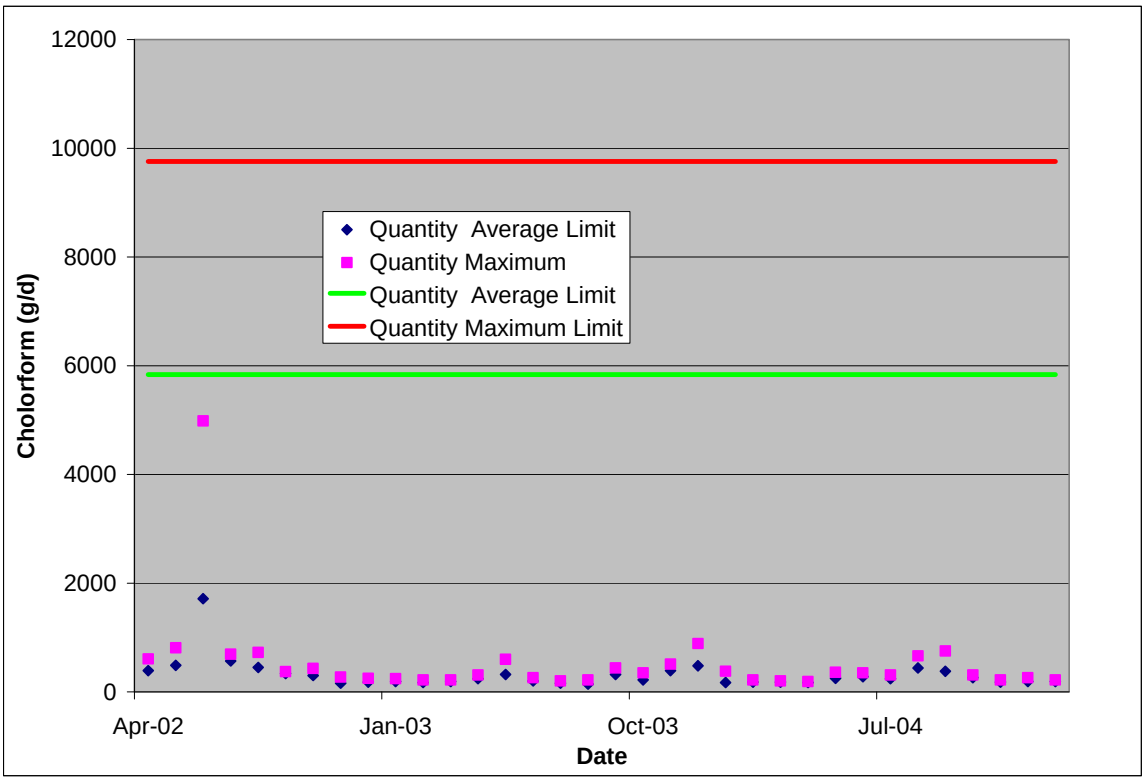


Figure C-107: MeadWestvaco Effluent Chloroform Quantities from Outfall 303

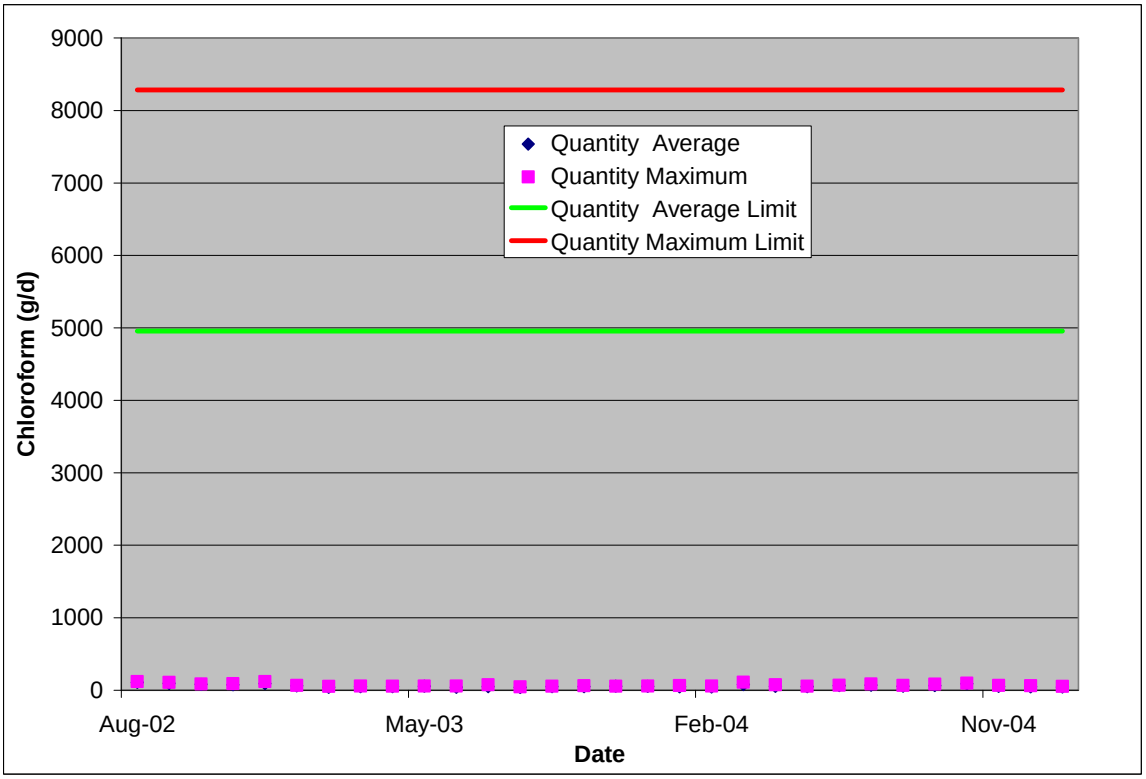


Figure C-108: MeadWestvaco Effluent Heat Values from Outfall 999

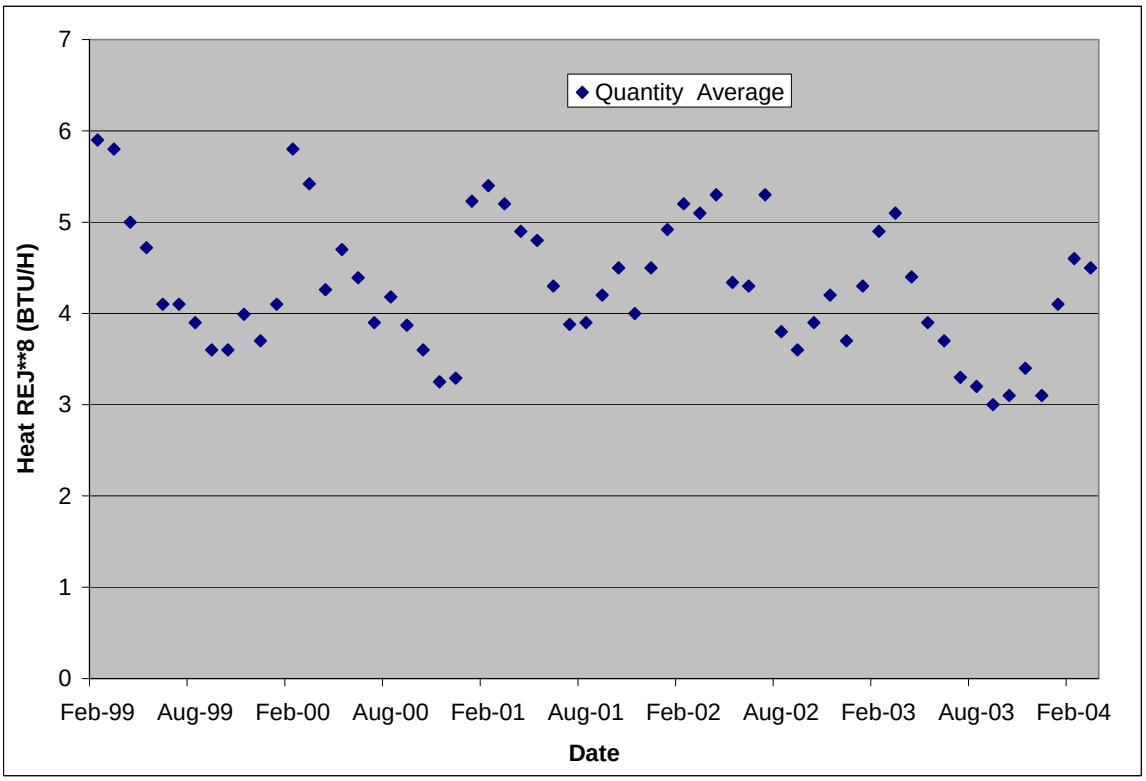


Figure C-109: Morris Hill STP Effluent Flow Values

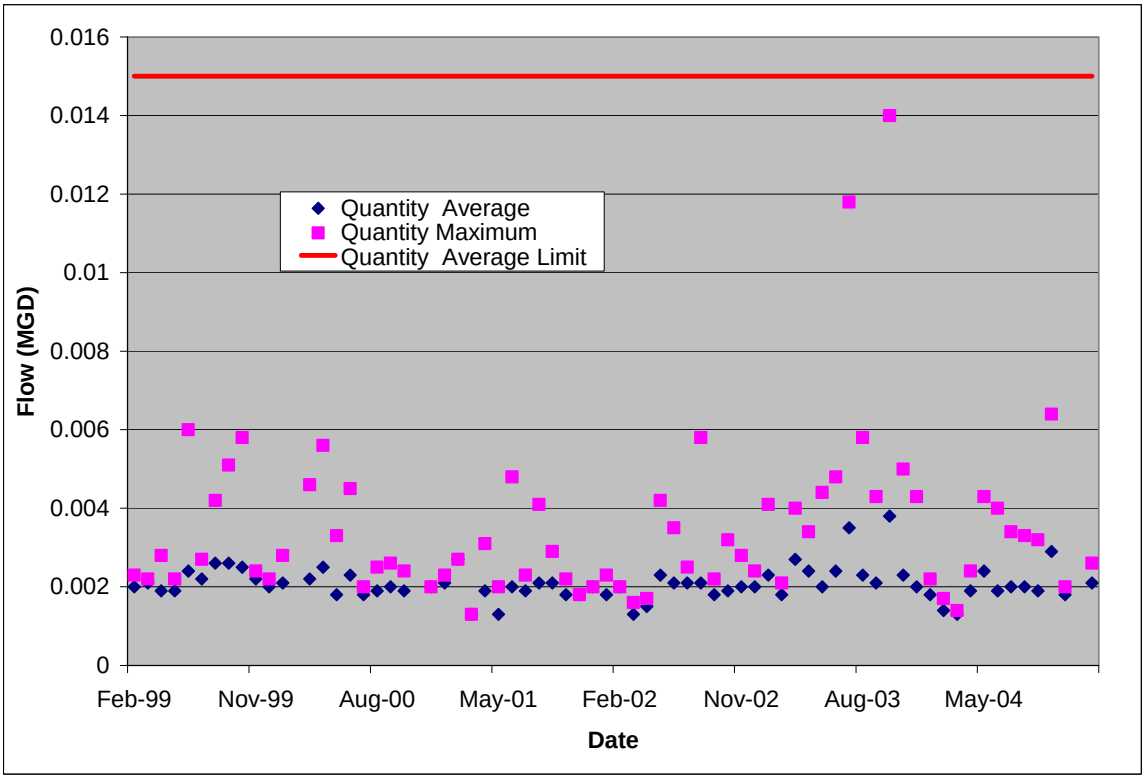


Figure C-110: Morris Hill STP Effluent Dissolved Oxygen Concentrations

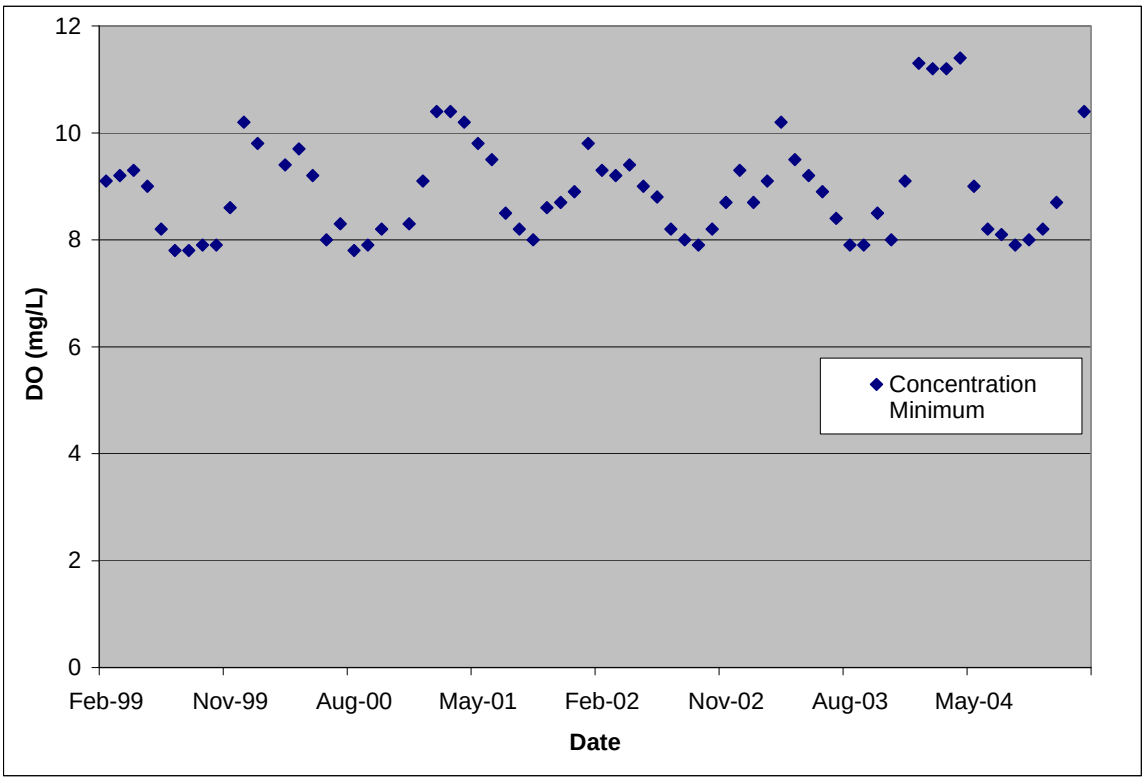


Figure C-111: Morris Hill STP Effluent Inst. Res. Max. CL2 Concentrations

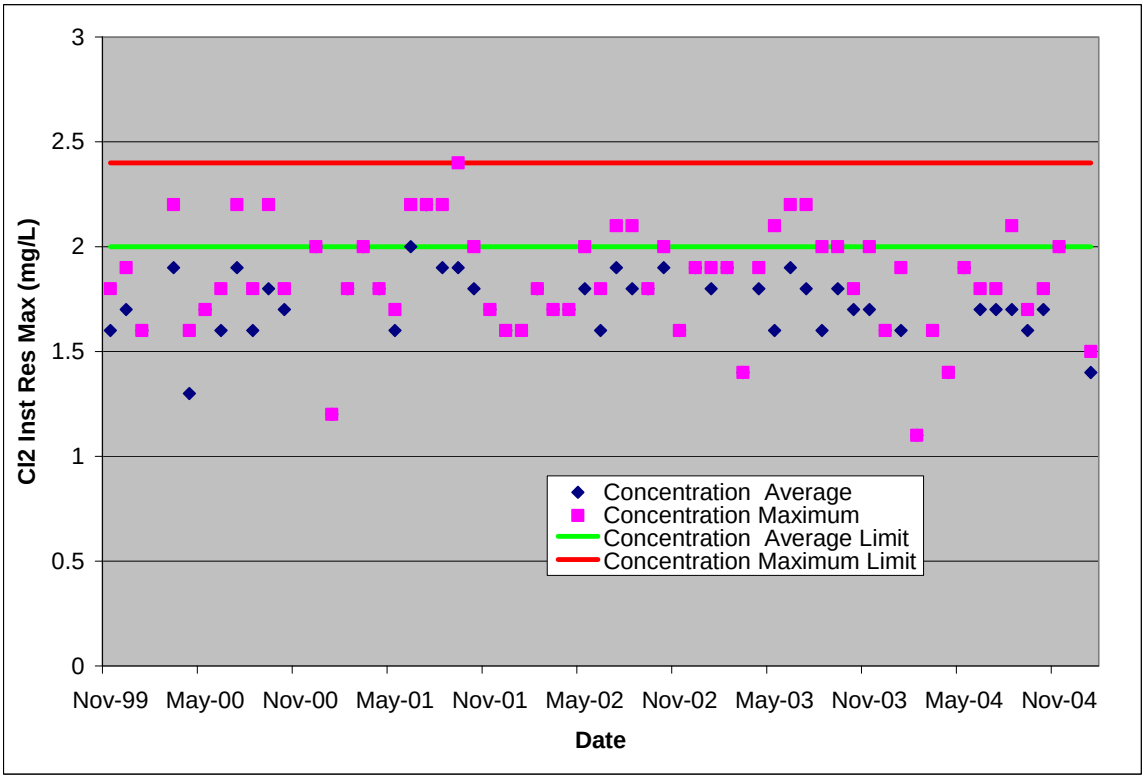


Figure C-112: Morris Hill STP Effluent TSS Concentrations

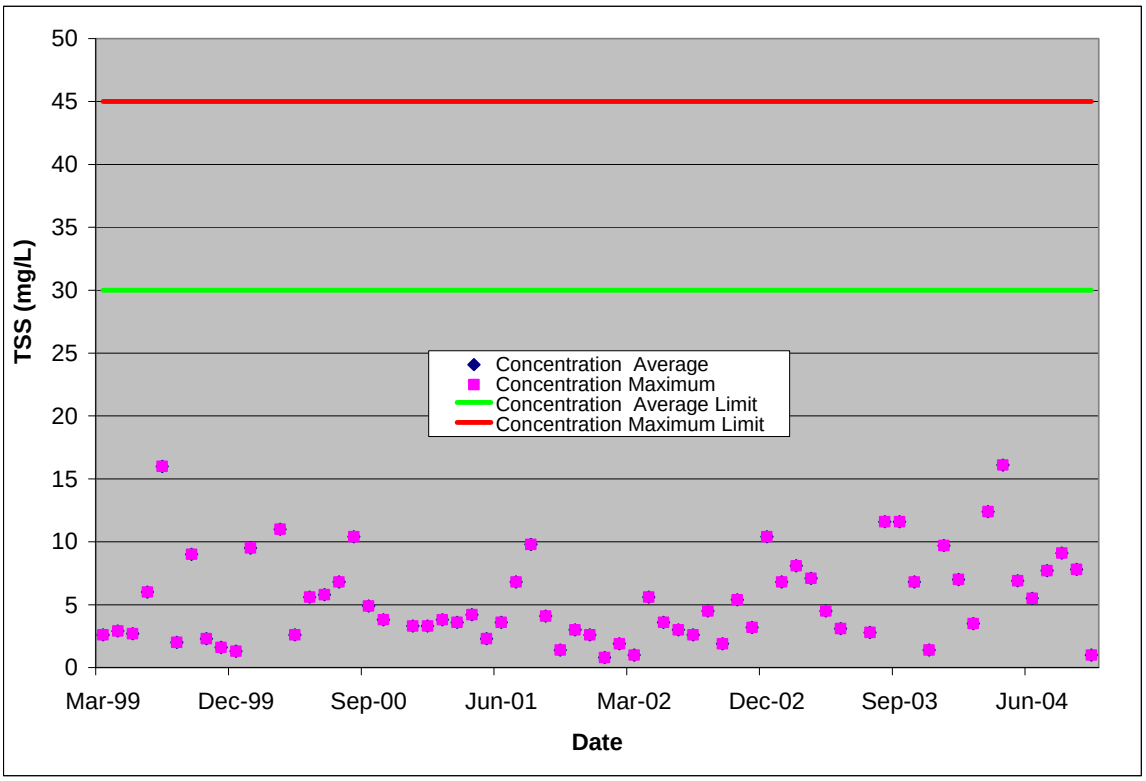


Figure C-113: Morris Hill STP Effluent pH Values

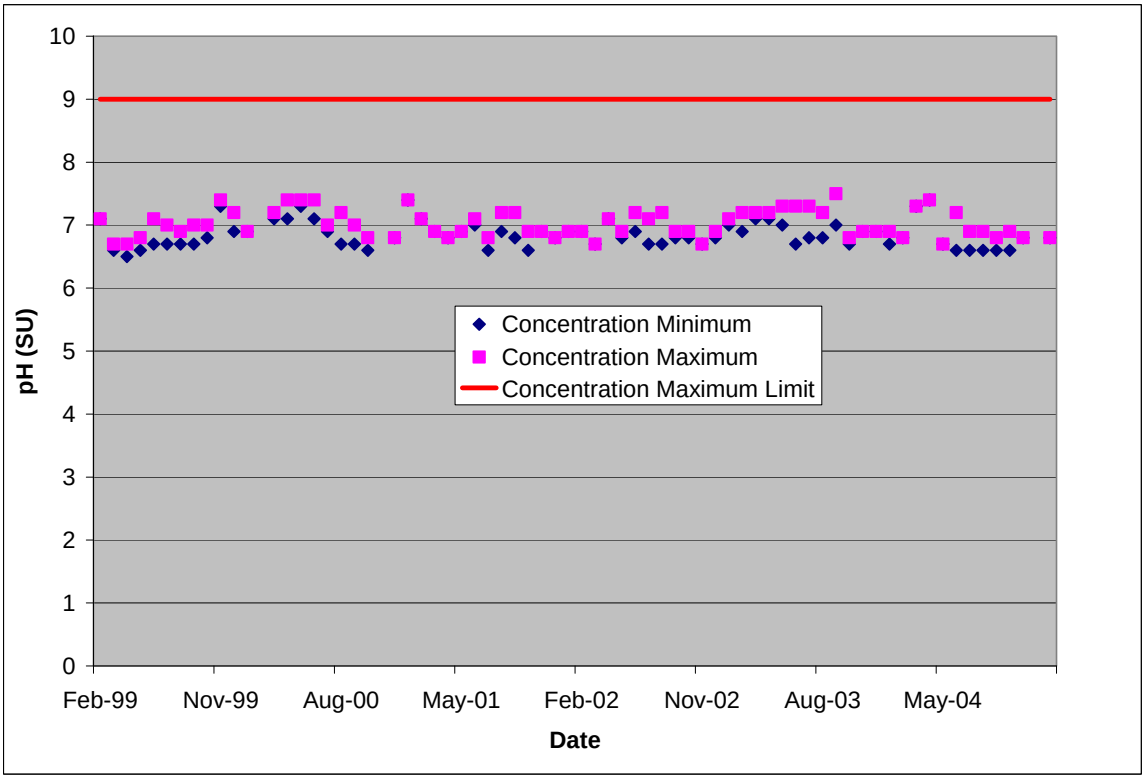


Figure C-114: Morris Hill STP Effluent BOD5 Quantities

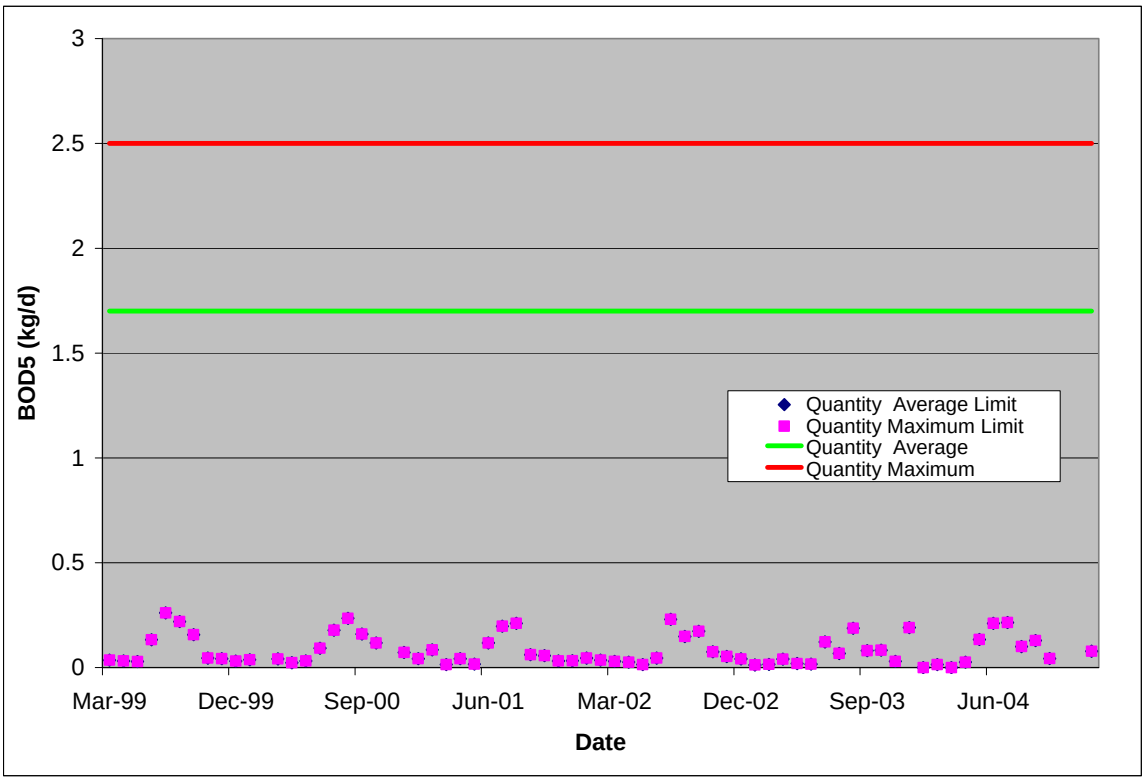


Figure C-115: Morris Hill STP Effluent BOD5 Concentrations

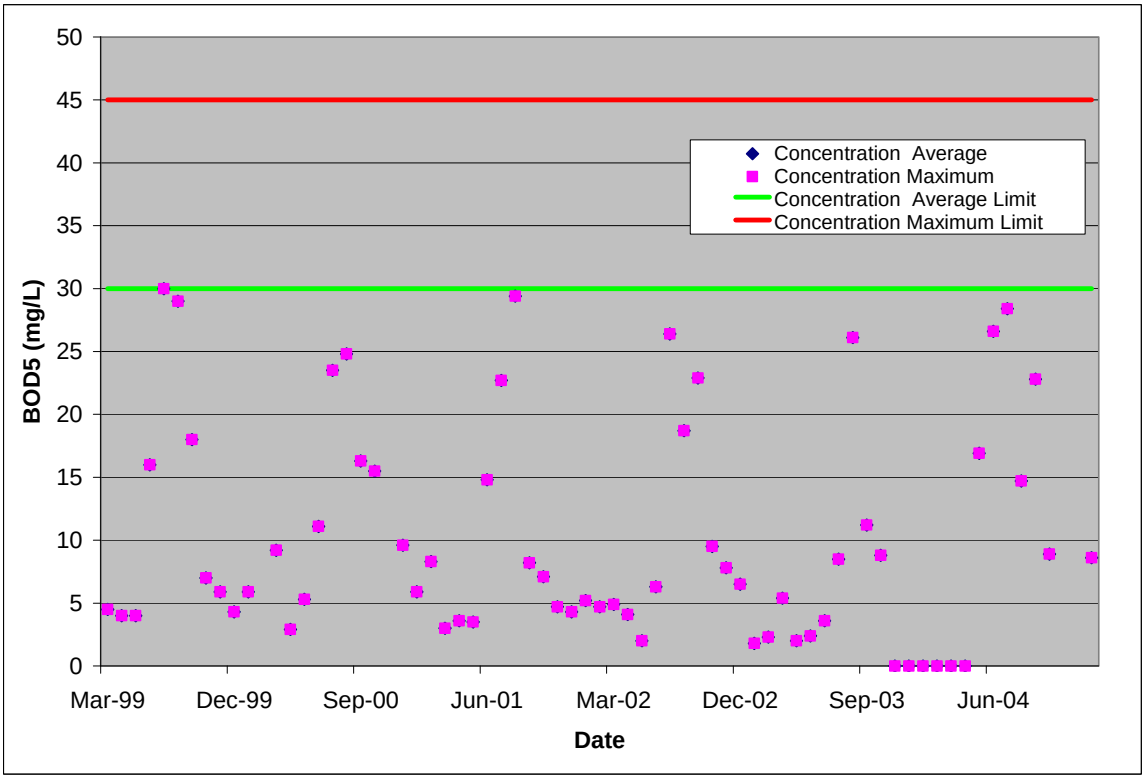


Figure C-116: Parker Hannifin Powertrain Division Effluent Flow Values from Outfall 1

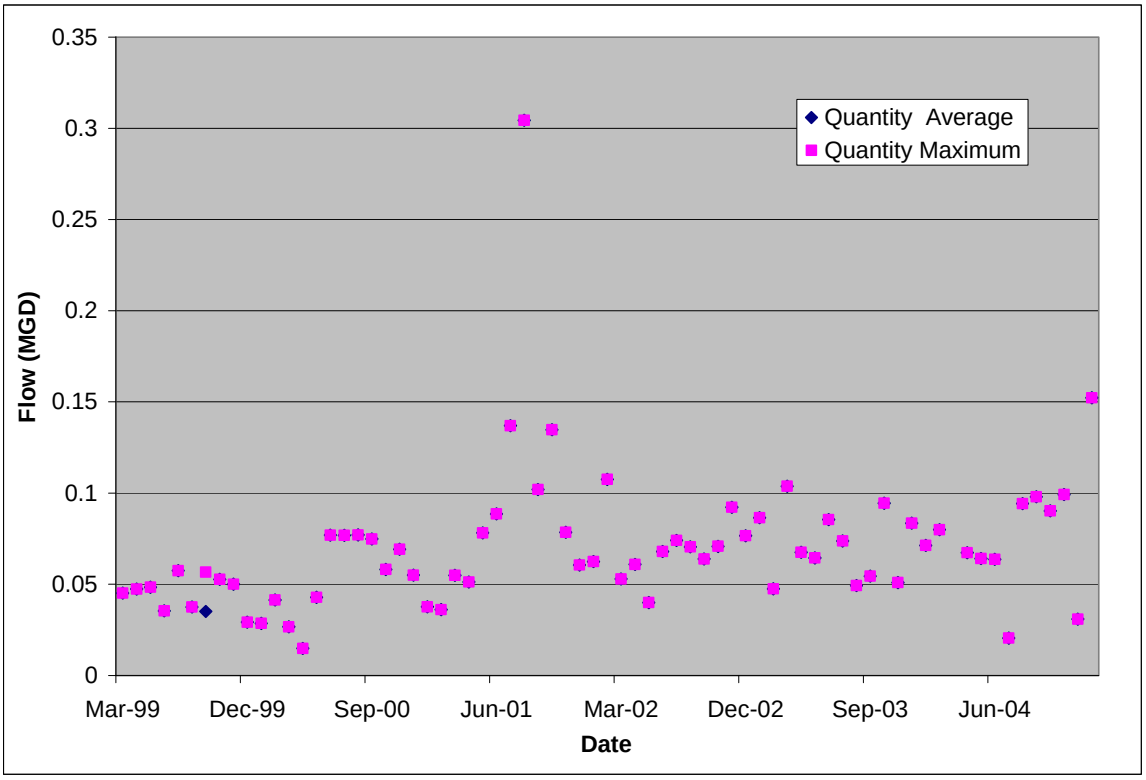


Figure C-117: Parker Hannifin Powertrain Division Effluent pH Values from Outfall 1

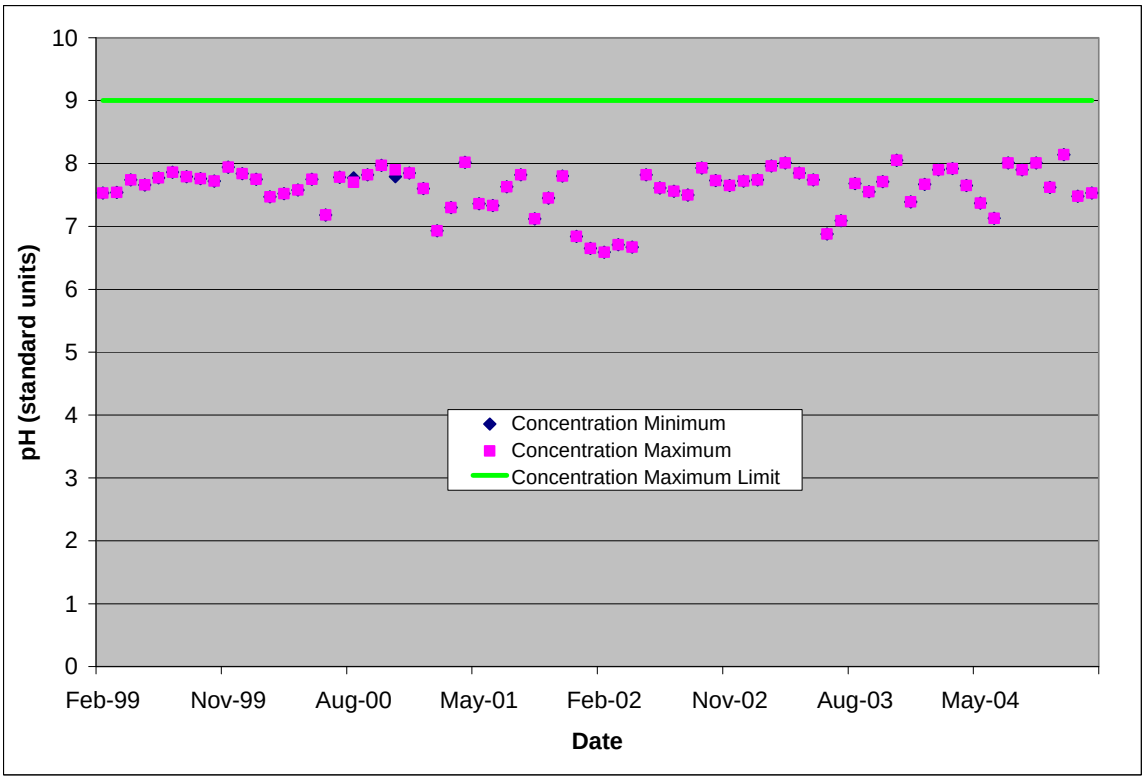


Figure C-118: Parker Hannifin Powertrain Division Effluent Temperature Values from Outfall 1

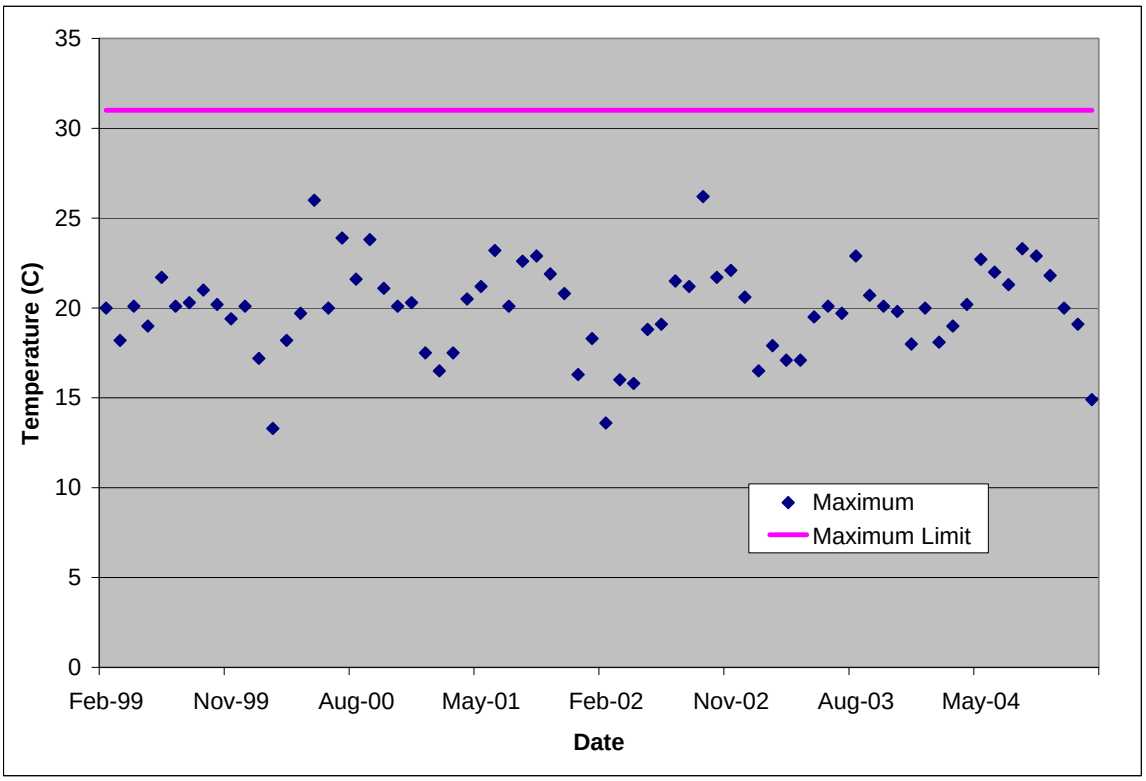


Figure C-119: Parker Hannifin Powertrain Division Effluent Flow Values from Outfall 2

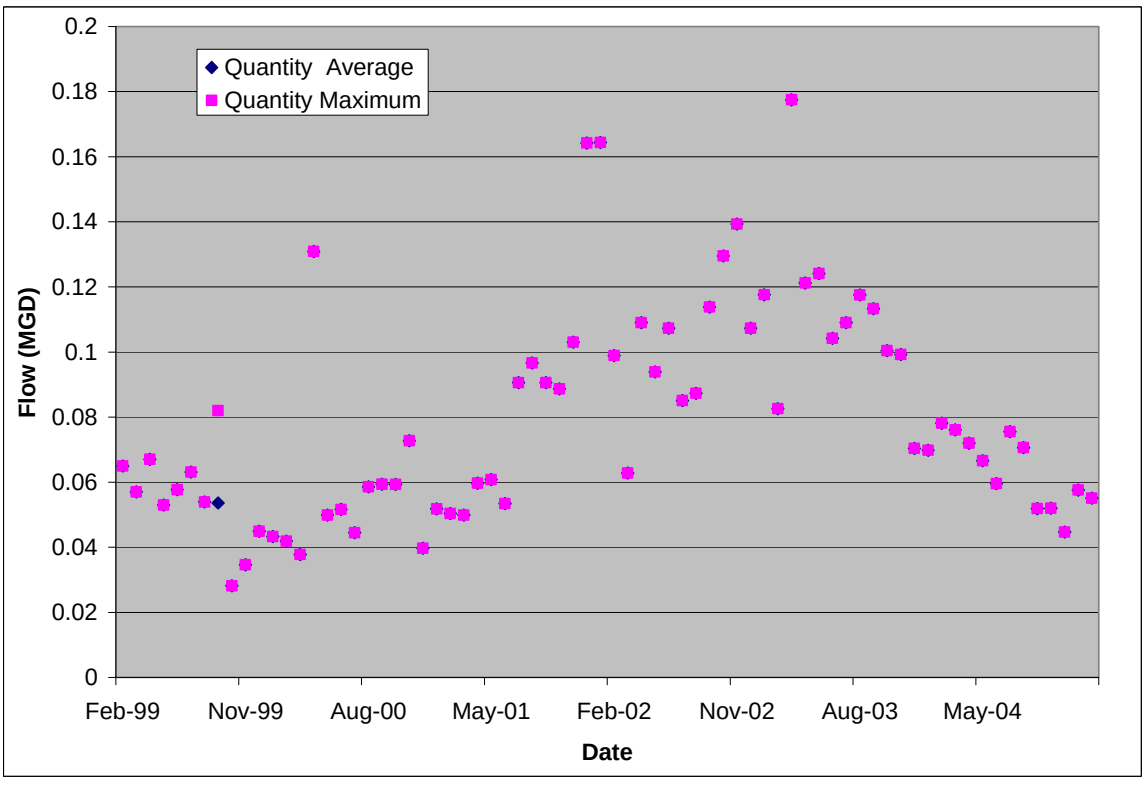


Figure C-120: Parker Hannifin Powertrain Division Effluent pH Values from Outfall 2

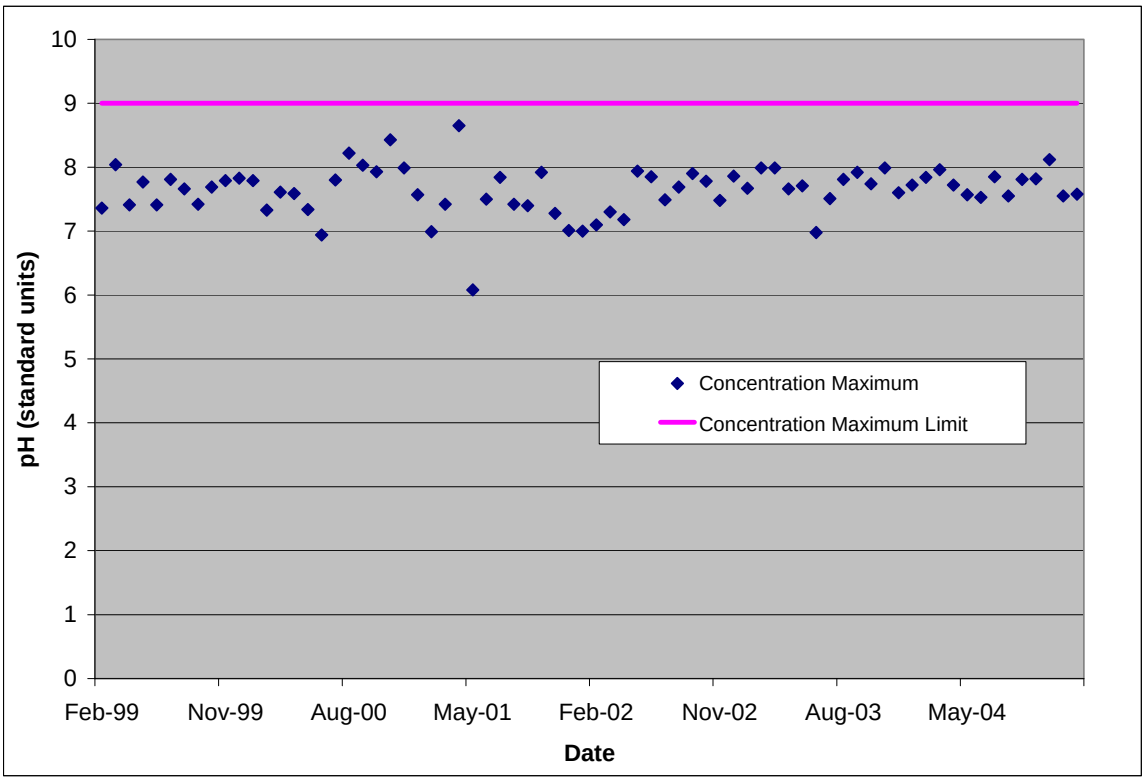


Figure C-121: Parker Hannifin Powertrain Division Effluent Temperature Values from Outfall 2

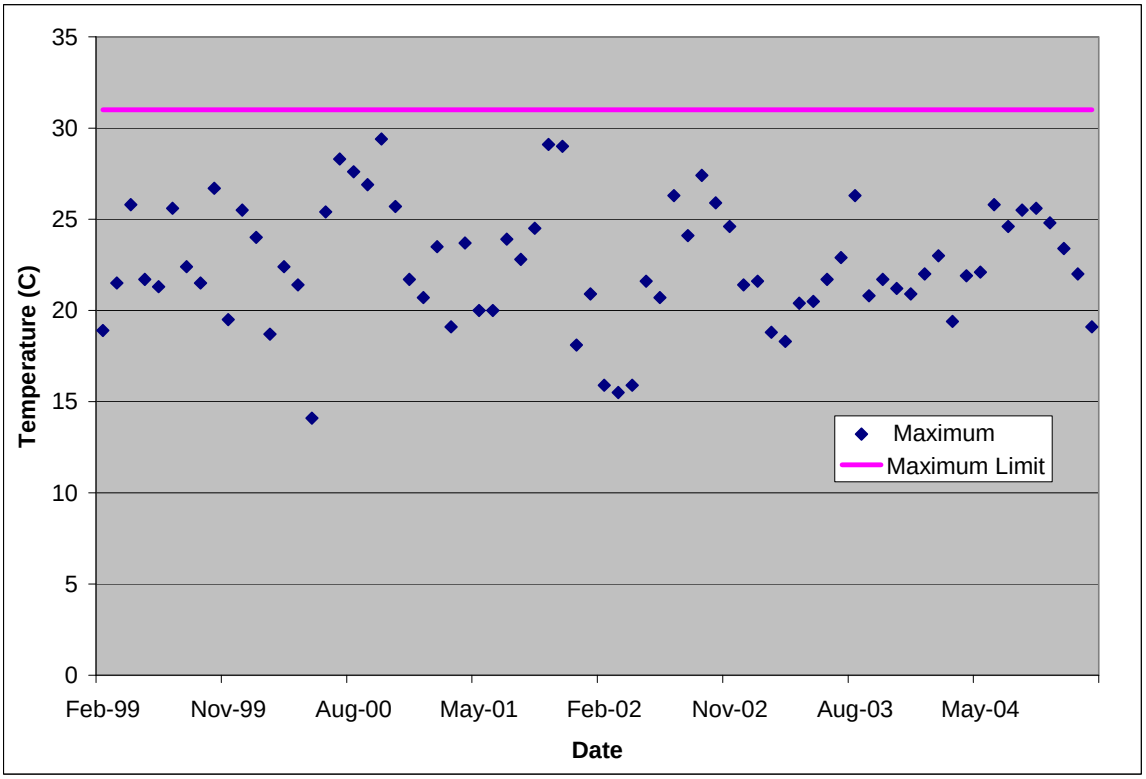


Figure C-122: Sponaugle Subdivision Effluent Flow Values

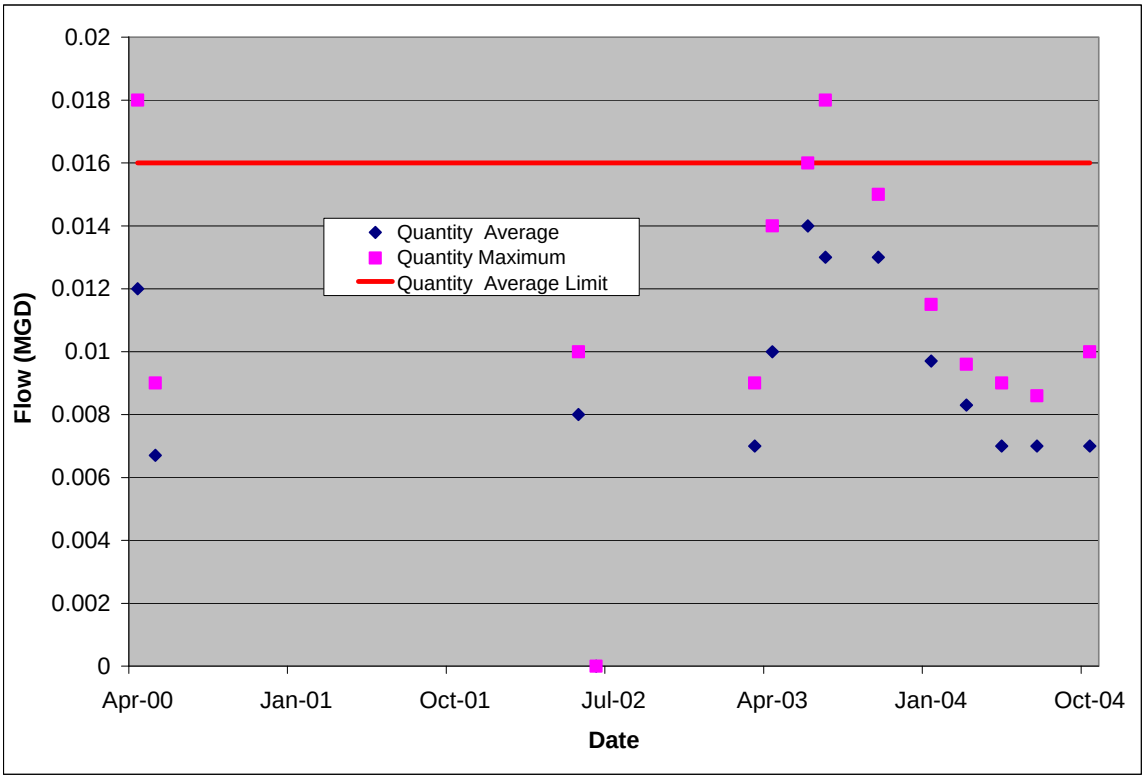


Figure C-123: Sponaugle Subdivision Effluent Cl2 Concentrations

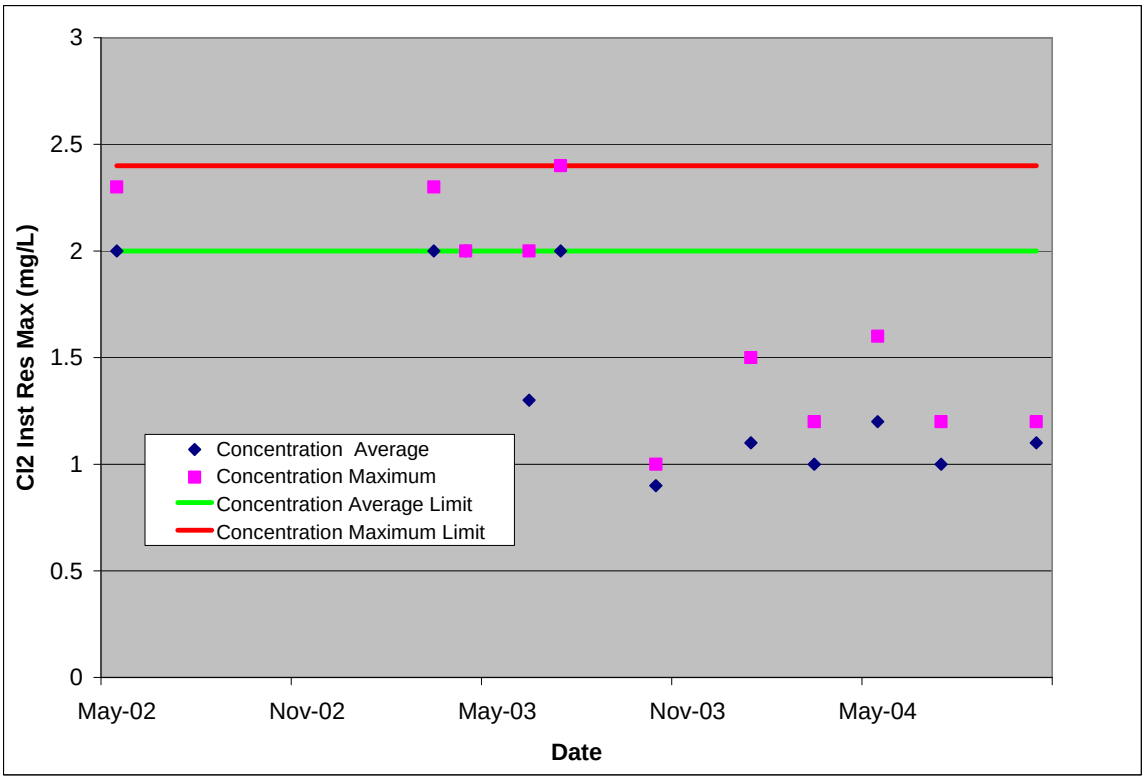


Figure C-124: Sponaugle Subdivision Effluent TSS Quantities

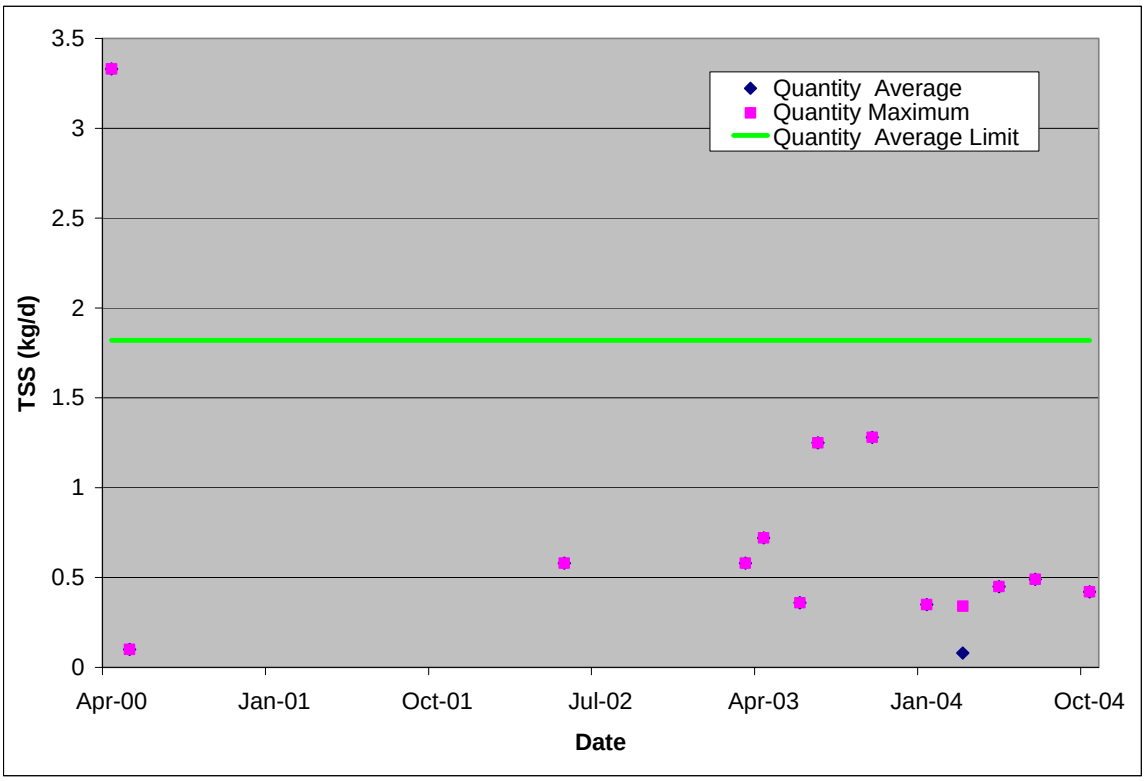


Figure C-125: Sponaugle Subdivision Effluent TSS Concentrations

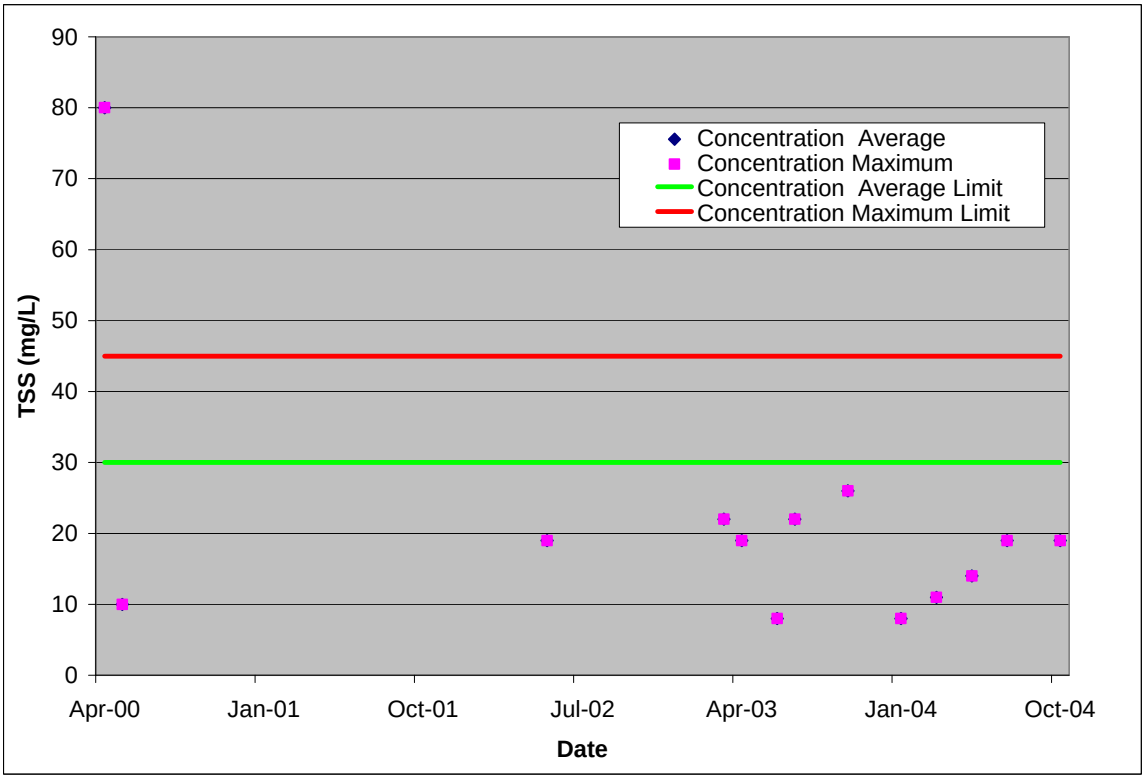


Figure C-126: Sponaugle Subdivision Effluent BOD5 Quantities

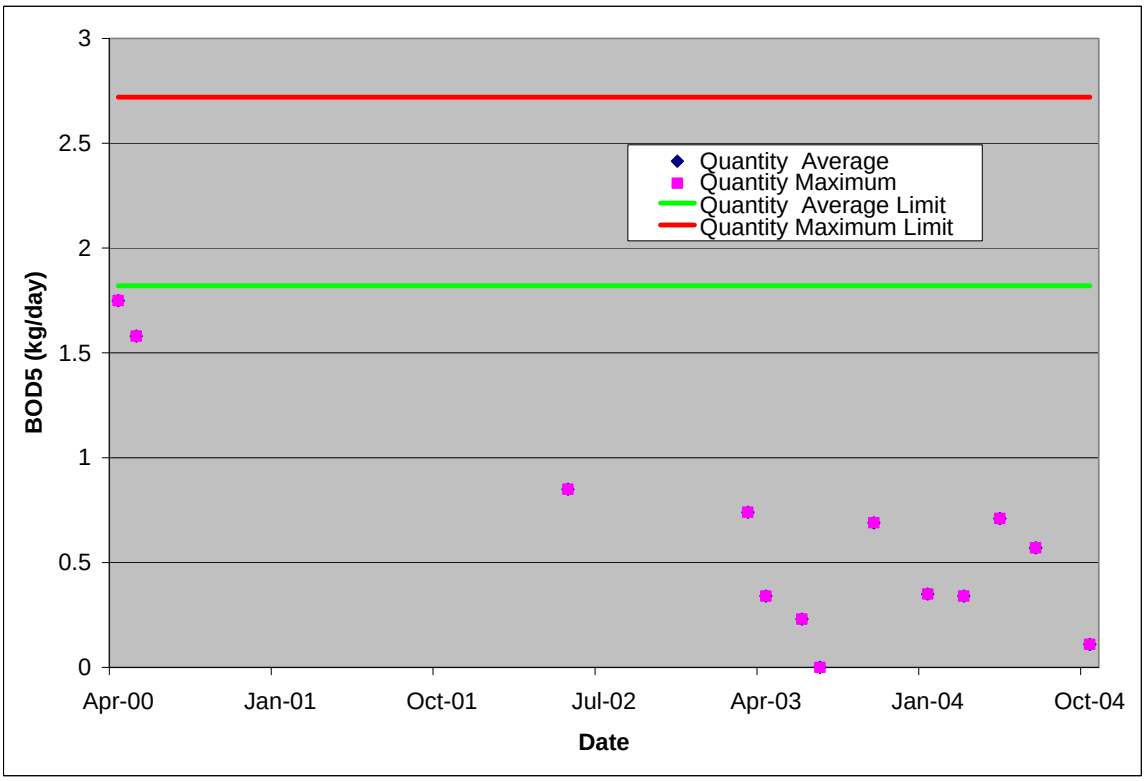


Figure C-127: Sponaugle Subdivision Effluent BOD5 Concentrations

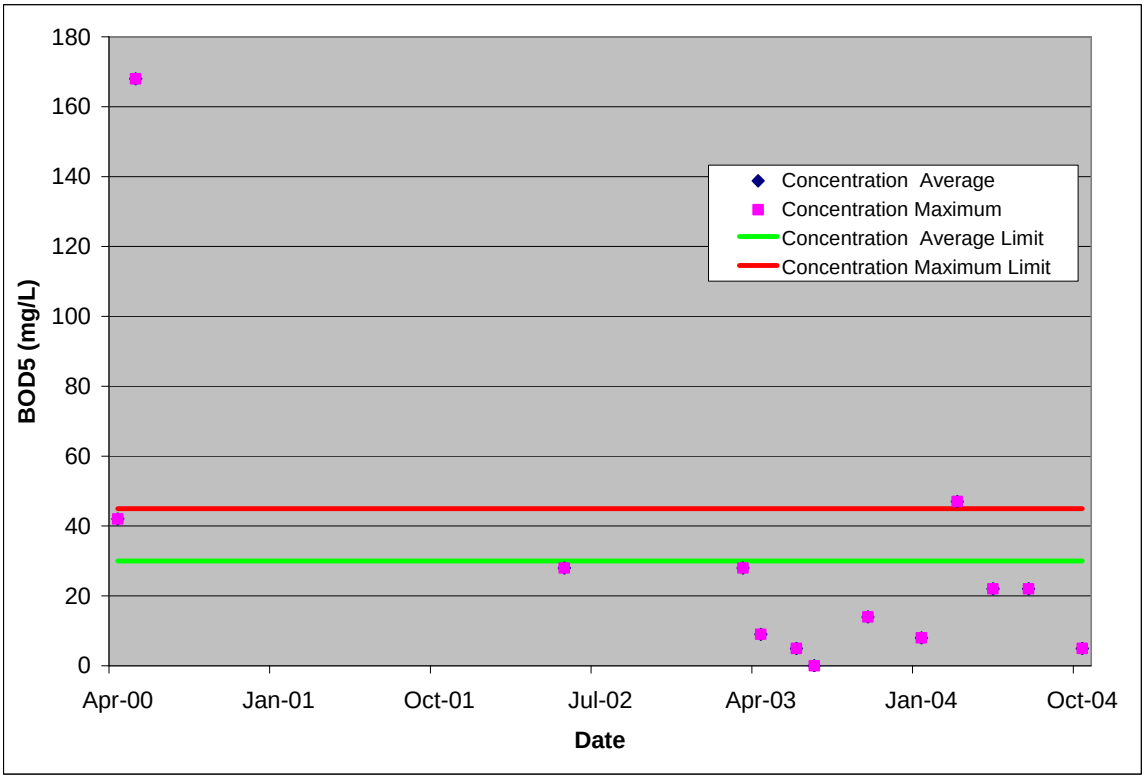


Figure C-128: VDOT I64 Rest Area - Alleghany Co. Effluent Flow Values

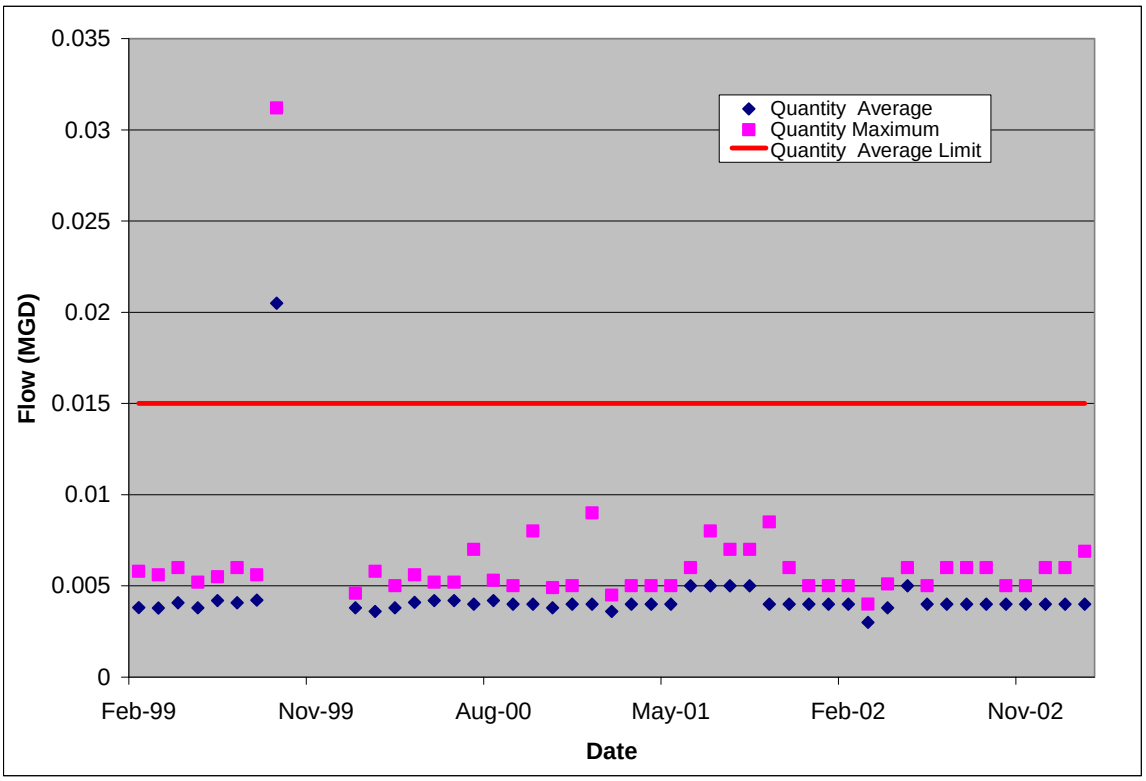


Figure C-129: VDOT I64 Rest Area - Alleghany Co. Effluent pH Values

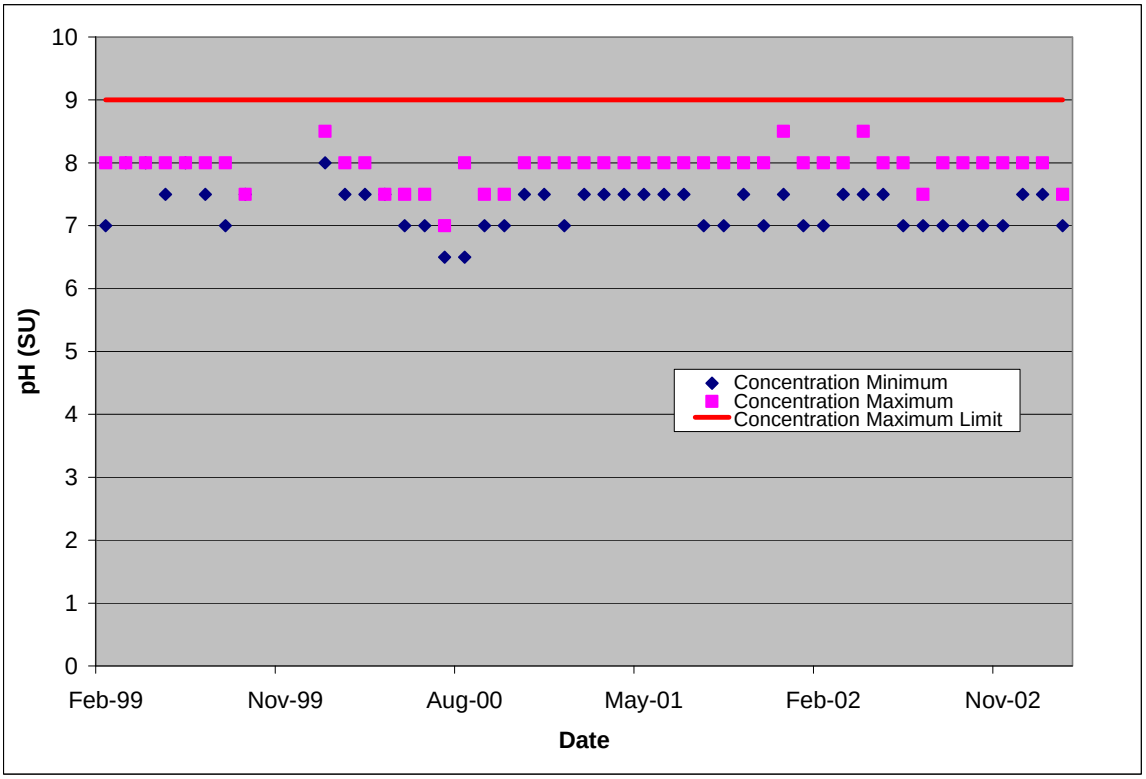


Figure C-130: VDOT I64 Rest Area - Alleghany Co. Effluent Dissolved Oxygen Concentrations

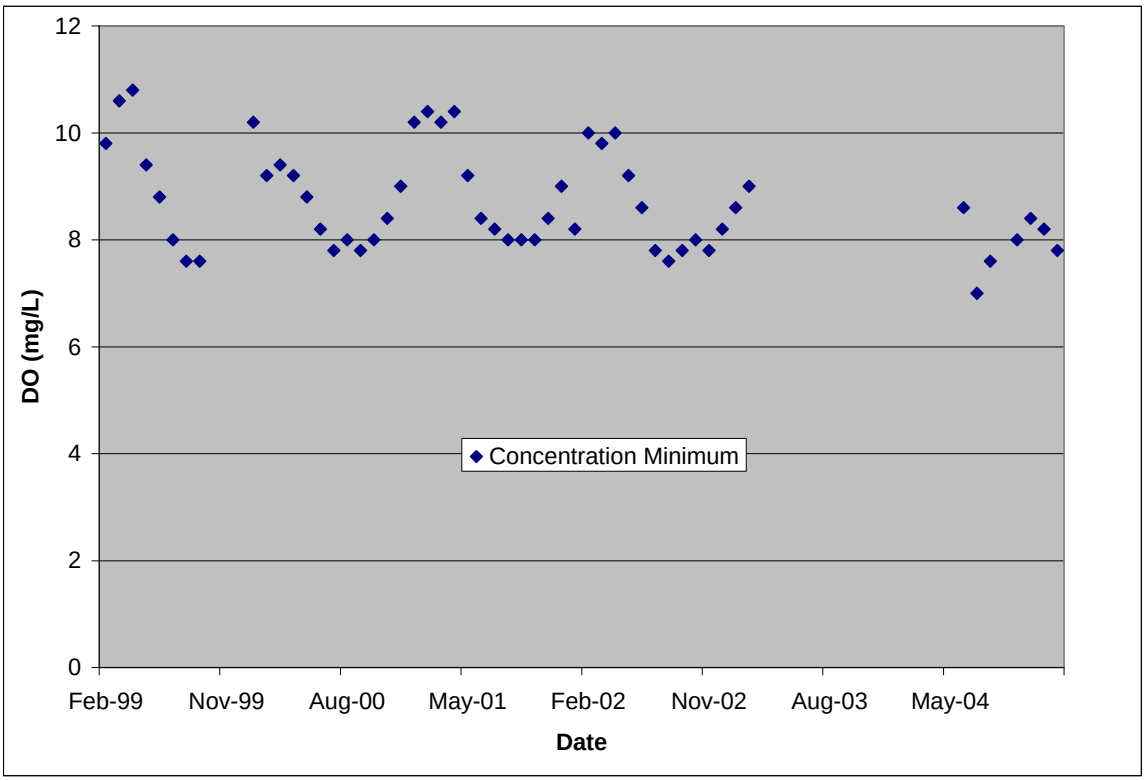


Figure C-131: VDOT I64 Rest Area - Alleghany Co. Effluent BOD Quantities

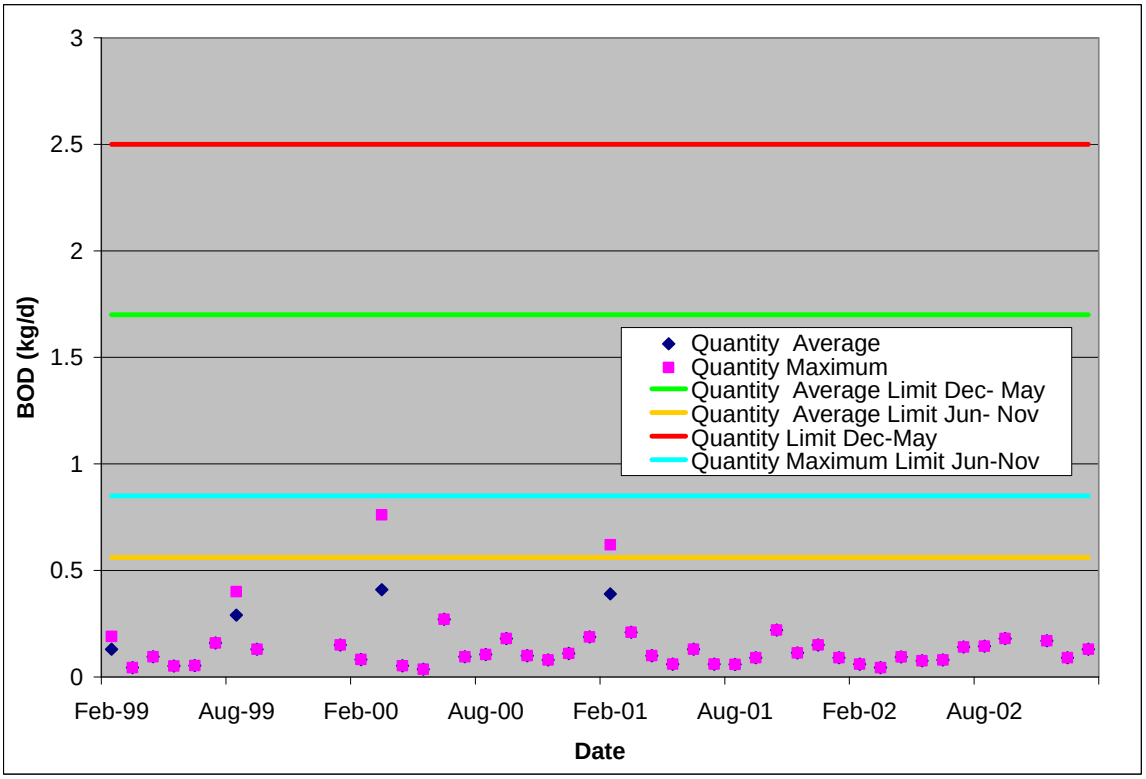


Figure C-132: VDOT I64 Rest Area - Alleghany Co. Effluent BOD Concentrations

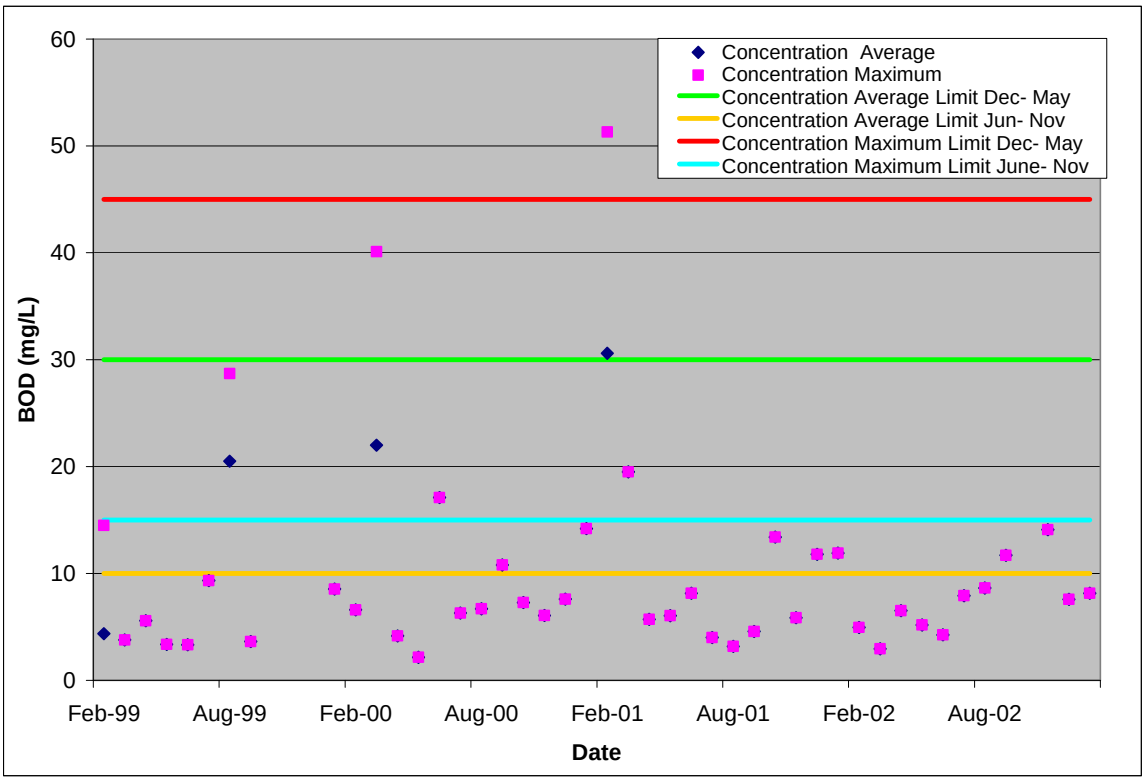


Figure C-133: VDOT I64 Rest Area - Alleghany Co Effluent TSS Concentrations

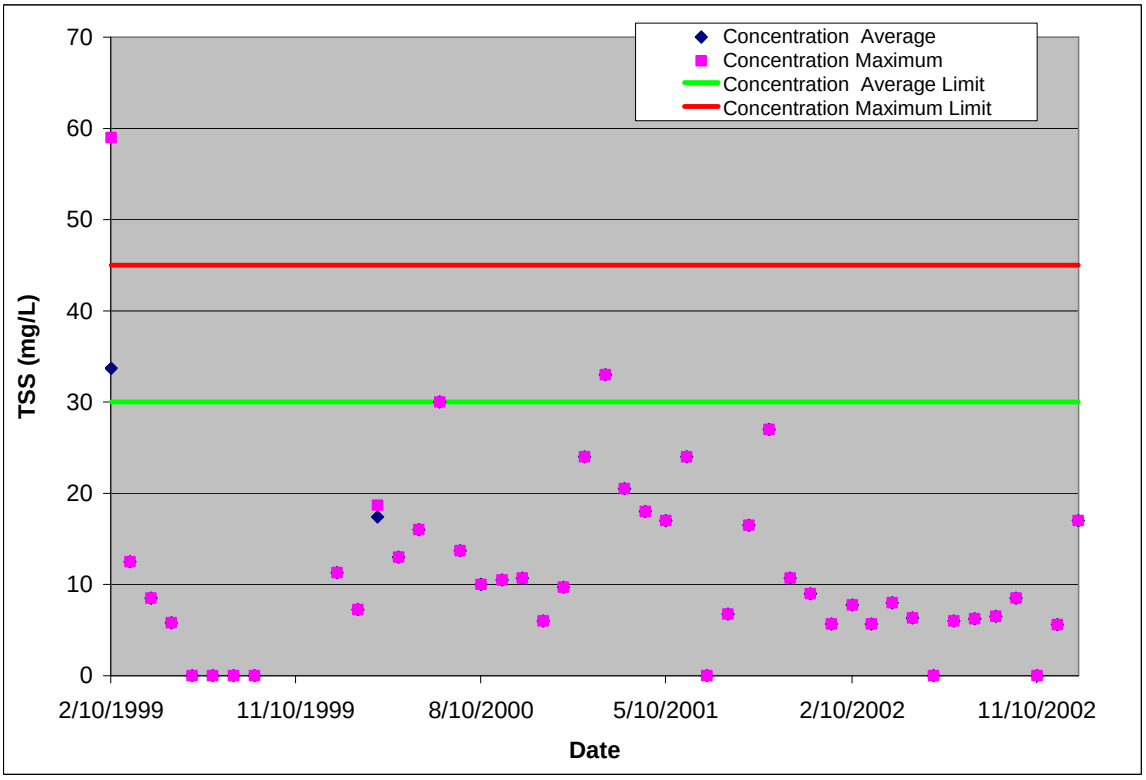
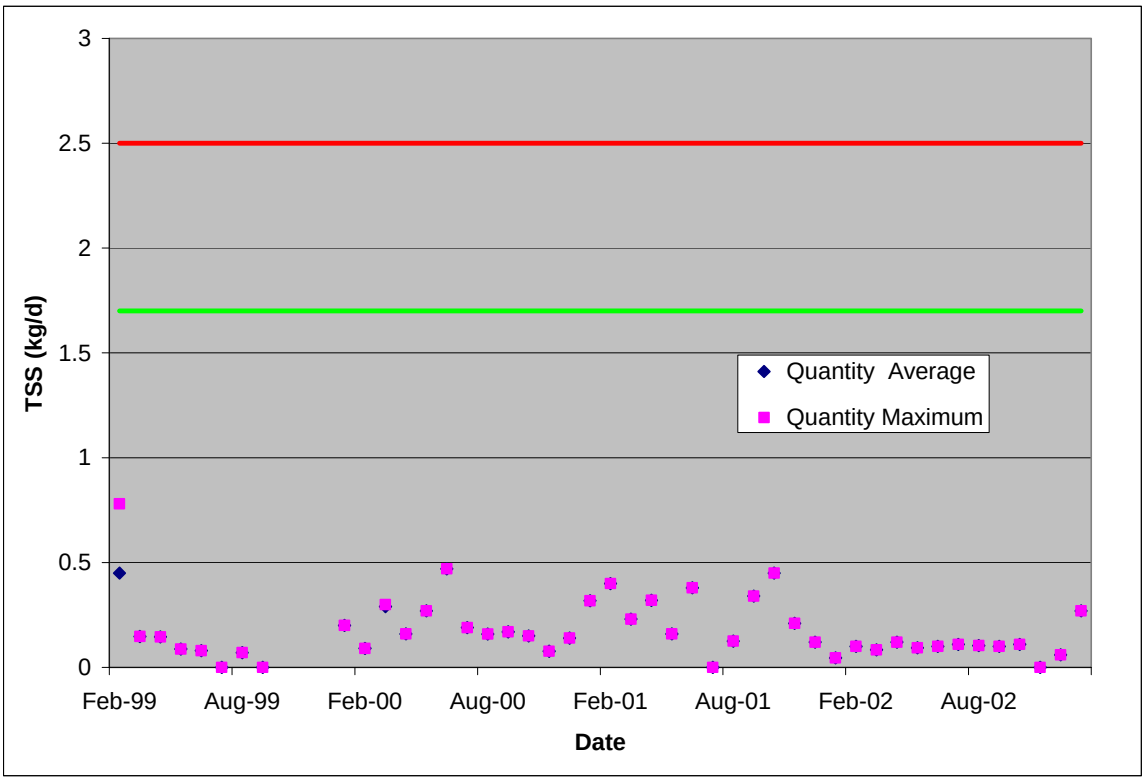


Figure C-134: VDOT I64 Rest Area - Alleghany Co Effluent TSS Quantities



Appendix D
TMDL Endpoint Development
Nutrient and Periphyton Data
Used to Develop the Regressions

Appendix D: Nutrient and Periphyton -Chlorophyll Data								
Station	**RM**	**Date**	**NH_4**	**NO_{23}**	**PO_4**	**TDP**	**TDN**	**Chla**
FILT	-1.2	8/11/2000	0.014	0.122	0.0016	0.0064	0.30	83.9
FILT	-1.2	8/11/2000	0.014	0.122	0.0016	0.0064	0.30	78.3
FILT	-1.2	8/11/2000	0.014	0.122	0.0016	0.0064	0.30	70.0
FILT	-1.2	8/11/2000	0.014	0.122	0.0016	0.0064	0.30	27.9
FILT	-1.2	8/27/2000	0.010	0.151	0.0021	0.0069	0.29	71.4
FILT	-1.2	8/27/2000	0.010	0.151	0.0021	0.0069	0.29	130.2
FILT	-1.2	8/27/2000	0.010	0.151	0.0021	0.0069	0.29	52.3
FILT	-1.2	8/27/2000	0.010	0.151	0.0021	0.0069	0.29	75.5
FILT	-1.2	8/27/2000	0.010	0.151	0.0021	0.0069	0.29	37.1
FILT	-1.2	6/6/2001	0.008	0.214	0.0019	0.0068	0.37	6.6
FILT	-1.2	6/6/2001	0.008	0.214	0.0019	0.0068	0.37	13.1
FILT	-1.2	6/6/2001	0.008	0.214	0.0019	0.0068	0.37	8.3
FILT	-1.2	6/13/2001	0.014	0.222	0.002	0.0062	0.35	28.5
FILT	-1.2	6/13/2001	0.014	0.222	0.002	0.0062	0.35	64.2
FILT	-1.2	6/13/2001	0.014	0.222	0.002	0.0062	0.35	14.9
FILT	-1.2	6/13/2001	0.014	0.222	0.002	0.0062	0.35	8.8
FILT	-1.2	6/13/2001	0.014	0.222	0.002	0.0062	0.35	21.8
FILT	-1.2	6/19/2001	0.037	0.197	0.002	0.0072	0.36	62.9
FILT	-1.2	6/19/2001	0.037	0.197	0.002	0.0072	0.36	36.4
FILT	-1.2	6/19/2001	0.037	0.197	0.002	0.0072	0.36	20.6
FILT	-1.2	6/19/2001	0.037	0.197	0.002	0.0072	0.36	12.2
FILT	-1.2	6/19/2001	0.037	0.197	0.002	0.0072	0.36	64.7
FILT	-1.2	6/25/2001	0.044	0.167	0.0017	0.0061	0.35	6.1
FILT	-1.2	6/25/2001	0.044	0.167	0.0017	0.0061	0.35	8.8
FILT	-1.2	6/25/2001	0.044	0.167	0.0017	0.0061	0.35	16.1
FILT	-1.2	6/25/2001	0.044	0.167	0.0017	0.0061	0.35	6.9
FILT	-1.2	6/25/2001	0.044	0.167	0.0017	0.0061	0.35	54.6
FILT	-1.2	7/9/2001	0.007	0.152	0.0031	0.0169	0.35	27.8
FILT	-1.2	7/9/2001	0.007	0.152	0.0031	0.0169	0.35	47.5
FILT	-1.2	7/9/2001	0.007	0.152	0.0031	0.0169	0.35	34.9
FILT	-1.2	7/9/2001	0.007	0.152	0.0031	0.0169	0.35	53.6
FILT	-1.2	7/9/2001	0.007	0.152	0.0031	0.0169	0.35	110.3
FILT	-1.2	8/1/2001	0.030	0.237	0.0025	0.0097	0.41	16.5
FILT	-1.2	8/1/2001	0.030	0.237	0.0025	0.0097	0.41	108.2
FILT	-1.2	8/1/2001	0.030	0.237	0.0025	0.0097	0.41	27.6
FILT	-1.2	8/1/2001	0.030	0.237	0.0025	0.0097	0.41	57.9
FILT	-1.2	8/1/2001	0.030	0.237	0.0025	0.0097	0.41	99.8
FILT	-1.2	8/13/2001	0.007	0.202	0.0042	0.007	0.33	19.6
FILT	-1.2	8/13/2001	0.007	0.202	0.0042	0.007	0.33	19.5
FILT	-1.2	8/13/2001	0.007	0.202	0.0042	0.007	0.33	34.8
FILT	-1.2	8/13/2001	0.007	0.202	0.0042	0.007	0.33	87.6
FILT	-1.2	10/2/2001	0.042	0.141	0.001	0.01	0.33	18.0

Appendix D: Nutrient and Periphyton -Chlorophyll Data								
Station	**RM**	**Date**	**NH_4**	**NO_{23}**	**PO_4**	**TDP**	**TDN**	**Chla**
FILT	-1.2	10/2/2001	0.042	0.141	0.001	0.01	0.33	10.5
FILT	-1.2	10/2/2001	0.042	0.141	0.001	0.01	0.33	65.3
FILT	-1.2	10/24/2001	0.014	0.098	0.0038	0.012	0.29	117.3
FILT	-1.2	10/24/2001	0.014	0.098	0.0038	0.012	0.29	24.5
FILT	-1.2	10/24/2001	0.014	0.098	0.0038	0.012	0.29	13.2
FILT	-1.2	10/24/2001	0.014	0.098	0.0038	0.012	0.29	16.1
FILT	-1.2	10/24/2001	0.014	0.098	0.0038	0.012	0.29	18.6
FILT	-1.2	10/31/2001	0.014	0.104	0.0036	0.0145	0.30	15.2
FILT	-1.2	10/31/2001	0.014	0.104	0.0036	0.0145	0.30	53.5
FILT	-1.2	10/31/2001	0.014	0.104	0.0036	0.0145	0.30	22.2
FILT	-1.2	10/31/2001	0.014	0.104	0.0036	0.0145	0.30	19.0
FILT	-1.2	10/31/2001	0.014	0.104	0.0036	0.0145	0.30	9.0
FILT	-1.2	10/31/2001	0.014	0.104	0.0036	0.0145	0.30	16.4
MILB	0.3	10/18/2000	0.029	0.072	0.3520	0.3917	0.42	1119.6
MILB	0.3	10/18/2000	0.029	0.072	0.3520	0.3917	0.42	536.7
MILB	0.3	10/18/2000	0.029	0.072	0.3520	0.3917	0.42	210.5
MILB	0.3	10/18/2000	0.029	0.072	0.3520	0.3917	0.42	803.0
MILB	0.3	10/18/2000	0.029	0.072	0.3520	0.3917	0.42	897.8
PEDE	0.3	6/6/2001	0.048	0.188	0.0882	0.1316	0.48	151.7
PEDE	0.3	6/6/2001	0.048	0.188	0.0882	0.1316	0.48	85.1
PEDE	0.3	6/6/2001	0.048	0.188	0.0882	0.1316	0.48	126.0
PEDE	0.3	6/6/2001	0.048	0.188	0.0882	0.1316	0.48	44.3
PEDE	0.3	6/6/2001	0.048	0.188	0.0882	0.1316	0.48	147.8
PEDE	0.3	6/20/2001	0.181	0.114	0.4760	0.5732	0.60	505.5
PEDE	0.3	6/20/2001	0.181	0.114	0.4760	0.5732	0.60	436.9
PEDE	0.3	6/20/2001	0.181	0.114	0.4760	0.5732	0.60	584.0
PEDE	0.3	6/20/2001	0.181	0.114	0.4760	0.5732	0.60	293.1
PEDE	0.3	6/20/2001	0.181	0.114	0.4760	0.5732	0.60	472.7
PEDE	0.3	6/25/2001	0.058	0.127	1.0700	1.2879	0.44	156.9
PEDE	0.3	6/25/2001	0.058	0.127	1.0700	1.2879	0.44	455.9
PEDE	0.3	6/25/2001	0.058	0.127	1.0700	1.2879	0.44	225.4
PEDE	0.3	6/25/2001	0.058	0.127	1.0700	1.2879	0.44	176.9
PEDE	0.3	6/25/2001	0.058	0.127	1.0700	1.2879	0.44	144.3
PEDE	0.3	7/9/2001	0.239	0.128	0.4300	0.5379	0.72	265.2
PEDE	0.3	7/9/2001	0.239	0.128	0.4300	0.5379	0.72	225.6
PEDE	0.3	7/9/2001	0.239	0.128	0.4300	0.5379	0.72	152.5
PEDE	0.3	7/9/2001	0.239	0.128	0.4300	0.5379	0.72	217.5
PEDE	0.3	7/9/2001	0.239	0.128	0.4300	0.5379	0.72	148.7
PEDE	0.3	8/1/2001	0.009	0.194	0.2920	0.3160	0.43	404.3
PEDE	0.3	8/1/2001	0.009	0.194	0.2920	0.3160	0.43	262.8
PEDE	0.3	8/1/2001	0.009	0.194	0.2920	0.3160	0.43	203.8
PEDE	0.3	8/1/2001	0.009	0.194	0.2920	0.3160	0.43	137.2
PEDE	0.3	8/1/2001	0.009	0.194	0.2920	0.3160	0.43	68.0
PEDE	0.3	8/14/2001	0.023	0.207	0.0770	0.0845	0.42	191.8
PEDE	0.3	8/14/2001	0.023	0.207	0.0770	0.0845	0.42	91.5
PEDE	0.3	8/14/2001	0.023	0.207	0.0770	0.0845	0.42	258.4
PEDE	0.3	8/14/2001	0.023	0.207	0.0770	0.0845	0.42	199.6
PEDE	0.3	8/14/2001	0.023	0.207	0.0770	0.0845	0.42	294.2
PEDE	0.3	8/21/2001	0.026	0.111	0.1370	0.1524	0.36	119.2
PEDE	0.3	8/21/2001	0.026	0.111	0.1370	0.1524	0.36	334.6
PEDE	0.3	8/21/2001	0.026	0.111	0.1370	0.1524	0.36	110.5

Appendix D: Nutrient and Periphyton -Chlorophyll Data								
Station	**RM**	**Date**	**NH_4**	**NO_{23}**	**PO_4**	**TDP**	**TDN**	**Chla**
PEDE	0.3	8/21/2001	0.026	0.111	0.1370	0.1524	0.36	179.2
PEDE	0.3	8/21/2001	0.026	0.111	0.1370	0.1524	0.36	117.9
PEDE	0.3	9/4/2001	0.058	0.144	0.0173	0.0272	0.44	236.2
PEDE	0.3	9/4/2001	0.058	0.144	0.0173	0.0272	0.44	147.1
PEDE	0.3	9/4/2001	0.058	0.144	0.0173	0.0272	0.44	92.8
PEDE	0.3	9/4/2001	0.058	0.144	0.0173	0.0272	0.44	114.5
PEDE	0.3	9/4/2001	0.058	0.144	0.0173	0.0272	0.44	74.1
MALL	8.7	11/8/2000	0.208	0.355	0.0600	0.1944	0.90	239.6
MALL	8.7	11/8/2000	0.208	0.355	0.0600	0.1944	0.90	430.5
MALL	8.7	11/8/2000	0.208	0.355	0.0600	0.1944	0.90	143.5
MALL	8.7	11/8/2000	0.208	0.355	0.0600	0.1944	0.90	452.4
MALL	8.7	11/8/2000	0.208	0.355	0.0600	0.1944	0.90	335.8
MALL	8.7	11/8/2000	0.208	0.355	0.0600	0.1944	0.90	253.9
MALL	8.7	12/13/2000	0.017	0.118	0.5650	0.6775	0.36	526.6
MALL	8.7	12/13/2000	0.017	0.118	0.5650	0.6775	0.36	580.4
MALL	8.7	12/13/2000	0.017	0.118	0.5650	0.6775	0.36	345.9
MALL	8.7	12/13/2000	0.017	0.118	0.5650	0.6775	0.36	1032.0
MALL	8.7	12/13/2000	0.017	0.118	0.5650	0.6775	0.36	969.2
MALL	8.7	7/27/2001	0.023	0.175	0.1910	0.2420	0.43	257.8
MALL	8.7	7/27/2001	0.023	0.175	0.1910	0.2420	0.43	136.5
MALL	8.7	7/27/2001	0.023	0.175	0.1910	0.2420	0.43	91.5
MALL	8.7	7/27/2001	0.023	0.175	0.1910	0.2420	0.43	606.3
MALL	8.7	7/27/2001	0.023	0.175	0.1910	0.2420	0.43	369.7
MALL	8.7	9/4/2001	0.096	0.216	0.0708	0.0784	0.53	49.6
MALL	8.7	9/4/2001	0.096	0.216	0.0708	0.0784	0.53	106.7
MALL	8.7	9/4/2001	0.096	0.216	0.0708	0.0784	0.53	104.8
MALL	8.7	9/4/2001	0.096	0.216	0.0708	0.0784	0.53	73.2
MALL	8.7	9/4/2001	0.096	0.216	0.0708	0.0784	0.53	70.0
MALL	8.7	9/27/2001	0.017	0.188	0.0669	0.0838	0.42	172.2
MALL	8.7	9/27/2001	0.017	0.188	0.0669	0.0838	0.42	50.3
MALL	8.7	9/27/2001	0.017	0.188	0.0669	0.0838	0.42	50.9
MALL	8.7	9/27/2001	0.017	0.188	0.0669	0.0838	0.42	58.9
MALL	8.7	9/27/2001	0.017	0.188	0.0669	0.0838	0.42	25.7
MALL	8.7	9/27/2001	0.017	0.188	0.0669	0.0838	0.42	250.9
MALL	8.7	10/3/2001	0.034	0.192	0.1400	0.2184	0.57	187.0
MALL	8.7	10/3/2001	0.034	0.192	0.1400	0.2184	0.57	265.6
MALL	8.7	10/3/2001	0.034	0.192	0.1400	0.2184	0.57	213.4
MALL	8.7	10/3/2001	0.034	0.192	0.1400	0.2184	0.57	201.1
MALL	8.7	10/3/2001	0.034	0.192	0.1400	0.2184	0.57	260.3
MALL	8.7	10/23/2001	0.055	0.150	0.2700	0.3367	0.62	377.6
MALL	8.7	10/23/2001	0.055	0.150	0.2700	0.3367	0.62	426.7
MALL	8.7	10/23/2001	0.055	0.150	0.2700	0.3367	0.62	172.2
MALL	8.7	10/23/2001	0.055	0.150	0.2700	0.3367	0.62	181.0
MALL	8.7	10/23/2001	0.055	0.150	0.2700	0.3367	0.62	63.0
MALL	8.7	10/30/2001	0.025	0.135	0.3080	0.4191	0.5	116.1
MALL	8.7	10/30/2001	0.025	0.135	0.3080	0.4191	0.5	75.3
MALL	8.7	10/30/2001	0.025	0.135	0.3080	0.4191	0.5	236.5
MALL	8.7	10/30/2001	0.025	0.135	0.3080	0.4191	0.5	274.8
IDLE	5.9	10/23/2001	0.068	0.072	0.3330	0.4416	0.49	158.2
IDLE	5.9	10/23/2001	0.068	0.072	0.3330	0.4416	0.49	100.7
IDLE	5.9	10/23/2001	0.068	0.072	0.3330	0.4416	0.49	86.2

Appendix D: Nutrient and Periphyton -Chlorophyll Data								
Station	**RM**	**Date**	**NH_4**	**NO_{23}**	**PO_4**	**TDP**	**TDN**	**Chla**
VALL	12.6	7/11/2001	0.036	0.229	0.3570	0.3966	0.51	89.6
VALL	12.6	7/11/2001	0.036	0.229	0.3570	0.3966	0.51	187.4
VALL	12.6	7/11/2001	0.036	0.229	0.3570	0.3966	0.51	60.0
VALL	12.6	7/11/2001	0.036	0.229	0.3570	0.3966	0.51	119.9
VALL	12.6	7/11/2001	0.036	0.229	0.3570	0.3966	0.51	142.5
VALL	12.6	10/23/2001	0.026	0.139	0.2570	0.2956	0.52	241.9
VALL	12.6	10/23/2001	0.026	0.139	0.2570	0.2956	0.52	362.2
VALL	12.6	10/23/2001	0.026	0.139	0.2570	0.2956	0.52	160.5
VALL	12.6	10/23/2001	0.026	0.139	0.2570	0.2956	0.52	209.5
VALL	12.6	10/23/2001	0.026	0.139	0.2570	0.2956	0.52	246.0
VALL	12.6	10/30/2001	0.010	0.141	0.2110	0.2891	0.52	670.3
VALL	12.6	10/30/2001	0.010	0.141	0.2110	0.2891	0.52	717.9
VALL	12.6	10/30/2001	0.010	0.141	0.2110	0.2891	0.52	488.1
VALL	12.6	10/30/2001	0.010	0.141	0.2110	0.2891	0.52	865.2