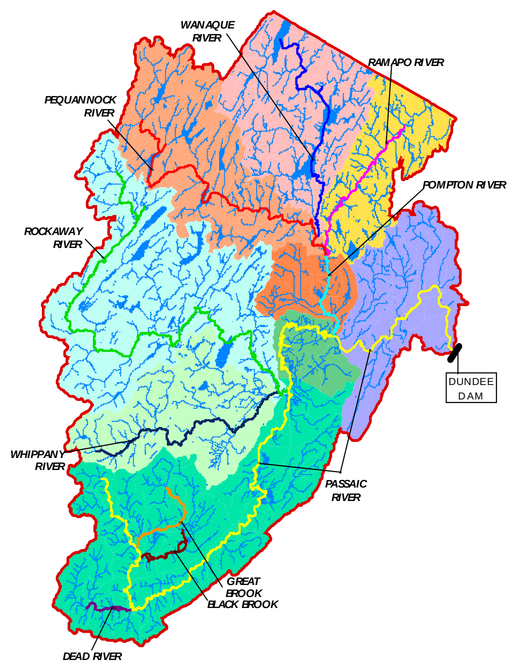
Omni Environmental

FINAL REPORT

The Non-Tidal Passaic River Basin Nutrient TMDL Study
Phase II Watershed Model and TMDL Calculations



Prepared for:

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and
New Jersey Department of Environmental Protection
Division of Watershed Management

February 23, 2007

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I. INTRODUCTION

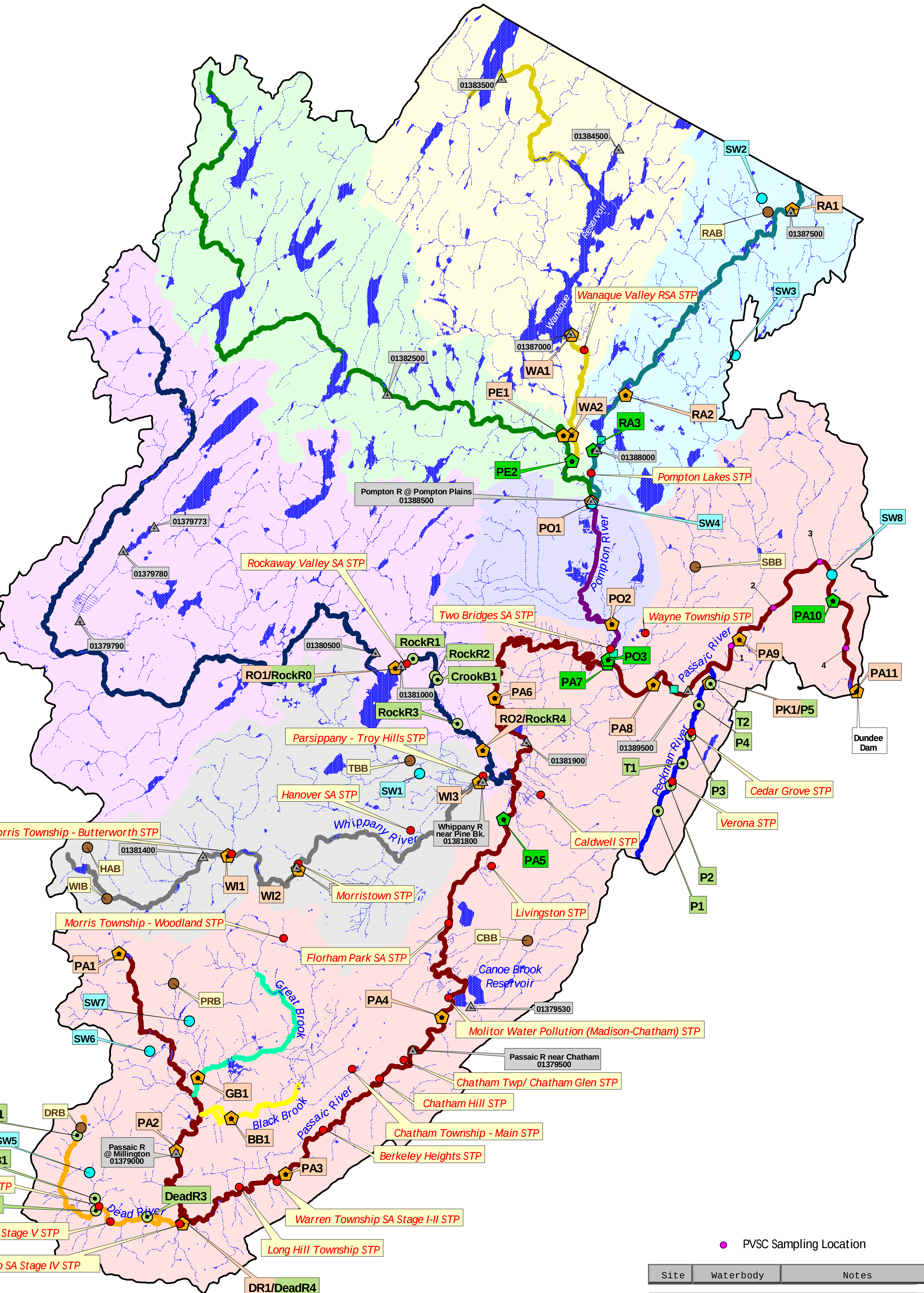
This project was completed in order to provide a scientifically defensible approach to establishing a nutrient Total Maximum Daily Load (TMDL) for the Non-Tidal Passaic River Basin (hereafter referred to as Passaic River Basin or simply Basin). A TMDL specifies the maximum amount of a pollutant that a waterbody can receive while still being in compliance with the applicable water quality standards and is required for all impaired waters by the Clean Water Act (Section 303d). The emphasis of this project was to develop a tool to answer many of the questions that have arisen during the last fifteen years regarding nutrient management in the Passaic River Basin, and ultimately to establish nutrient load reductions that will translate into environmental benefits. Extensive sampling, data analysis, and stream assessment were performed during Phase I of this project (TRC Omni, 2004). Figure 1 is provided to illustrate the monitoring station locations (stream, STP, and stormwater). The results of Phase II, including model development, TMDL definition, and load allocations, are provided in this report.

Omni Environmental[1] (Omni) worked closely with the New Jersey Department of Environmental Protection (NJDEP, also referred to as "the Department") Division of Watershed Management to perform this work under a contract with the Rutgers University New Jersey EcoComplex (NJEC). Funding and project oversight was provided by NJDEP, while academic technical review and contract management were provided by NJEC. Project presentations provided to NJDEP and NJEC on October 7, 2005 and April 28, 2006 are provided in Appendix A, along with the public presentation to Passaic River Basin stakeholders on May 19, 2006.

I.A. Integrated List of Waterbodies

Section 305(b) of the Federal Clean Water Act (CWA) requires the State of New Jersey to prepare and submit to the United States Environmental Protection Agency (USEPA) a Water Quality Inventory Report that summarizes the overall water quality of the State's waters. The State is also required under Section 303(d) of the CWA to prepare and submit to USEPA a List of Impaired Waterbodies that identifies waters that do not meet or are not expected to meet Surface Water Quality Standards (SWQS) after implementation of technology-based effluent limitations or other required controls. The waterbodies designated as impaired require TMDL evaluations.

[1] Formerly TRC Omni Environmental



Site	Waterbody	Notes
1	Passaic River	Totowa Ave.
2	Passaic River	Alfano Furniture
3	Passaic River	Granada Rest.
4	Passaic River	Market St.

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FIGURE 1: Monitoring Locations

Phase II Non-Tidal
Passaic River Basin
Nutrient TMDL Study

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Non Tidal Passaic Watershed Boundary

Sub-Basins
- Passaic River
- Pequannock River
- Pompton River
- Ramapo River
- Rockaway River
- Wanaque River
- Whippany River

DATA SOURCE: NJDEP GIS Resource Data CD-Rom; Stations globally positioned by Omni Environmental, May 2003.

Non Tidal Rivers
- Black Brook
- Dead River
- Great Brook
- Passaic River
- Peckman River
- Pequannock River
- Pompton River
- Ramapo River
- Rockaway River
- Wanaque River
- Whippany River

Non Tidal Streams

Monitoring Locations
- Intensive Hi Flow/Lo Flow Station
- Weekly Station
- Supplemental Station
- Stormwater Station
- Baseflow/Reference Station
- Monitored STP
- USGS Station
- Major Drinking Water Intake

3 0 3
Miles

In 2002, NJDEP began integrating the Water Quality Inventory Report (305(b) Report) and the List of Impaired Waterbodies (303(d) List) into one report entitled the Integrated Water Quality Monitoring and Assessment Report, commonly called the Integrated List of Waterbodies. This integrated report assigns waterbodies to one of five Sublists according to the degree of designated use impairments. Sublist 5 constitutes the traditional List of Impaired Waterbodies for which one or more TMDL evaluations are needed. Most of the major tributaries within the Passaic River Basin are designated as impaired by NJDEP because total phosphorus concentrations exceed 0.1 mg/l in at least 10% of samples analyzed. Tributaries designated as impaired for phosphorus in 2004 (NJDEP, 2004) include: Black Brook, Dead River, Passaic River mainstem, Pompton River, Ramapo River, Rockaway River, Wanaque River, and Whippany River (Figure 2). The latest assessment report released on February 16, 2007 (NJDEP, 2006) added the Lincoln Park tributaries of the Pompton River to the list of waters impaired by phosphorus.

I.B. Total Maximum Daily Load (TMDL)

A TMDL represents the assimilative or carrying capacity of a waterbody, taking into consideration point and nonpoint source of pollutants of concern, natural background and surface water withdrawals. The amount of a pollutant a water body can assimilate without violating water quality standards is quantified, and that load capacity is allocated among known point sources in the form of wasteload allocations (WLAs), nonpoint sources in the form of load allocations (LAs), and a margin of safety. A TMDL is developed as a mechanism for identifying all the contributors to surface water quality impacts and establishing load reductions as necessary to meet SWQS.

I.C. Non-Tidal Passaic River Basin TMDL Process

While there were certainly earlier watershed planning efforts in the Passaic River Basin, including 208 Plans and a steady-state Passaic River model (NJDEP, 1987), the current TMDL planning effort is an extension of the pilot watershed planning initiative in the Whippany River watershed. The Whippany River is a major tributary (through the Rockaway River) to the upper Passaic River. The Whippany River Watershed Project was a pilot effort initiated in October 1993 to aid the Department in developing a comprehensive watershed management process that could be replicated throughout the state. This project involved an extensive technical effort to provide an understanding of the cause and effect relationships associated with all significant pollution sources, both point and nonpoint. There was significant public involvement in the Whippany River Watershed Project, formalized through the creation of the Whippany Watershed Partnership in 1994.

The Whippany River Watershed pilot program completed years of extensive technical work to develop a TMDL for total phosphorus (TP), and then established an Interim Total Phosphorus Reduction Plan instead (NJDEP, 1999). The Department determined that phosphorus was neither limiting primary production nor causing impairment of designated uses in the Whippany River, and therefore the numerical TP criterion of 0.1 mg/l does not apply to the Whippany River. In other words, the Whippany River itself was determined to be in compliance with the Surface Water Quality Standards with respect to phosphorus, despite having concentrations in excess of 0.1 mg/l total phosphorus. However, it was anticipated that phosphorus controls might be required in the Whippany River and other tributaries to the Passaic River, as well as within the mainstem, in order to satisfy the TMDL for the Passaic River. The Department implemented interim phosphorus restrictions on municipal dischargers within the Whippany River Watershed in order to minimize phosphorus discharges to the Passaic River while the TMDL was being developed.

After the Whippany TMDL Report was published, NJDEP initiated watershed management planning on a statewide level. Twenty Watershed Management Areas (WMAs) were established, with Public Advisory Groups and Technical Advisory Groups formed in each. Since the Non-Tidal Passaic River Basin includes all of WMAs 3 and 6, as well as part of WMA 4, a technical advisory group was formed for the TMDL with representation from all three WMAs, called the Passaic River TMDL Work Group (TMDL-WG). The Department memorialized the progress of the TMDL-WG in a Technical Approaches document (NJDEP, 2002), which recommended the development of the Wanaque Reservoir TMDL Study (Najarian, 2005), the Pompton Lake TMDL

Study (QEA, 2005) and a flow simulation model for the non-tidal Passaic River and its major tributaries (USGS, 2006 in press).

The Department issued a Request for Proposals for the studies relating to the Non-Tidal Passaic River Basin TMDL, but received no direct response to the request for a watershed model to link the other TMDL study components (i.e., flow model, reservoir model, and Pompton Lake characterization/model) together. The Passaic River Basin Alliance (PRBA), an association of wastewater treatment plant dischargers in the Passaic River Basin, provided the funding to develop a technical approach and work plan for the Non-Tidal Passaic River Basin Nutrient TMDL Study (TRC Omni, 2003). As part of an earlier settlement agreement with NJDEP finalized on January 20, 2000, these dischargers had agreed to provide up to $10,000 to fund the development of a scope of work for the TMDL. Upon revision through the EcoComplex peer review process, the Scope of Work was deemed by the Department to fulfill the watershed model study component and the discharger parties' obligation to pay for the scope of work. All parties viewed this approach as beneficial since it would allow an opportunity for the development of scientifically-based effluent limitations, rather than the imposition of less than fully defensible phosphorus limitations requiring significant treatment plant upgrades without a clear understanding as to the associated environmental benefit. In the interim, the dischargers agreed to meet "existing effluent quality" (EEQ) phosphorus effluent limitations.

I.D. Pollutant of Concern

The primary pollutant of concern for these TMDLs is total phosphorus. The mechanism by which phosphorus can cause use impairment is via excessive primary productivity. Phosphorus is an essential nutrient for plants and algae, but is considered a pollutant because it can stimulate excessive growth (primary production) leading to accelerated eutrophication. Symptoms of eutrophication (primary impacts) include oxygen supersaturation during the day and oxygen depletion during night, both driven by excessive growth of algae and aquatic plants. For this reason, this research primarily emphasized the impacts of phosphorus on dissolved oxygen and algae growth.

Dissolved oxygen was identified as a critical parameter of concern because it is a direct cause of aquatic life use impairment. The SWQS define dissolved oxygen criteria in terms of minimum thresholds that vary according to stream classification. Generally, one or both of the following factors can cause low dissolved oxygen conditions:

- excessive oxygen-demanding substances exposed to the water column, usually expressed as carbonaceous oxygen demand, nitrogenous oxygen demand, and/or sediment oxygen demand; and/or
- excessive plant and algal growth, leading to oxygen deficits in the pre-dawn hours when respiration and decomposition are not overshadowed by photosynthesis.

Secondary treatment of municipal wastewater has greatly reduced the occurrence of oxygen depletion caused by excessive oxygen-demanding substances in the water column. As a result, neither biological oxygen demand nor nitrogenous oxygen demand is significant in the non-tidal Passaic River basin in terms of their effect on dissolved oxygen. As mentioned previously, understanding the impacts of excessive plant and algal growth on dissolved oxygen was among the primary goals of this research. These impacts, which are focused on the most downstream branch of the Passaic River, are explored thoroughly in the ensuing report.

One of the important findings of the Non-Tidal Passaic River Basin TMDL Study is the fact that low dissolved oxygen conditions are naturally occurring throughout many portions of the non-tidal Passaic River Basin. While only the Whippany River near its confluence with the Rockaway River is designated by NJDEP as impaired by dissolved oxygen (NJDEP, 2006), there are many similar areas that exhibit low dissolved oxygen concentrations. These areas include: the Black Brook and the Great Brook within the Great Swamp, the Dead River near Millington, the Whippany and Rockaway Rivers near their confluence, the Passaic River mainstem all the way from the Great Swamp to Little Falls, and the Pompton River near its confluence with the Passaic River. All of these areas are significantly affected by natural wetland complexes, namely the Great Swamp, Troy Brook meadows, Pine Brook meadows, and the Great Piece meadows. These areas exhibit high sediment oxygen demand as well as very low dissolved oxygen during summer rainfall periods, as water stored in wetlands gets pushed into the streams. There is no apparent relationship between areas of higher productivity and areas with higher sediment oxygen demand. The most pristine areas, such as within the Great Swamp, exhibit the lowest dissolved oxygen, usually below the SWQS minimum criterion of 4 mg/l. These areas generally exhibit low diurnal dissolved oxygen variability and, while productivity is generally low due to naturally black and turbid water, the overall oxygen condition improves during periods of higher productivity. Areas immediately downstream of treatment plant discharges also exhibit improved dissolved oxygen conditions due to the higher dissolved oxygen in the effluent diluting the naturally low dissolved oxygen in the streams. The low dissolved oxygen conditions at these locations (Black Brook, Great Brook, Dead River, Whippany and Rockaway Rivers, upper and mid-Passaic River, and lower Pompton River) are not caused by excessive productivity; in fact, they represent the natural condition for the upper and mid-Passaic River watershed and its immediate tributaries.

Nitrate was identified as a pollutant of concern (NJDEP, 2002) since its concentration was nearing the 10 mg/l criterion for freshwater streams. The criterion for nitrate is based on its toxicity in drinking water, not its potential to contribute to eutrophication. The Dead River was previously designated by NJDEP as impaired due to nitrate (NJDEP, 2004). However, NJDEP's most recent assessment report delisted the Dead River for nitrate, and in fact does not list any waters in the Passaic River basin as impaired due to nitrate (NJDEP, 2006). The Passaic River at Little Falls is the critical location for nitrate in the Passaic River Basin, being the only place where river water is directly withdrawn into a water treatment plant. The overall concern about nitrate in the Passaic River Basin has lessened in recent years because voluntary operational changes (on/off aeration) performed at a few large treatment plants (e.g., RVRSA and Wayne STP) have noticeably reduced the nitrate concentrations in the mainstem Passaic River, especially under low stream flow conditions. Data and model results for the Non-Tidal Passaic River Basin TMDL Study indicate that elevated nitrate concentrations occur only immediately downstream of substantial STP discharges (relative to the size of the receiving stream). Furthermore, NJDEP has begun to implement water quality based effluent limitations (WQBELs) for nitrate upon renewal of NJPDES permits based on compliance with the 10 mg/l nitrate criterion under low design flow conditions (7Q10). Since elevated nitrate concentrations in this system are caused directly by STPs discharging during low-flow stream conditions, these WQBELs will ensure continued compliance with the nitrate criterion throughout the basin.

Finally, total nitrogen was identified as a pollutant of concern because the TMDL to address oxygen depletion in the NY/NJ Harbor will likely result in a load allocation of total nitrogen to the Passaic River at Dundee. The model developed for the Non-Tidal Passaic River Basin Nutrient TMDL Study (see Section II) is calibrated for ammonia, nitrate, and organic nitrogen, and can therefore be used to translate a load allocation for the Passaic River at Dundee into wasteload and load allocations throughout the system.

I.E. Area of Interest

The non-tidal Passaic River Basin is defined as the 810 square mile watershed area that drains to the Passaic River and its tributaries upstream of the Dundee Dam on the Clifton/Garfield boundary. The Basin includes all of WMA 3 (Pequannock River, Wanaque River, Ramapo River, and Pompton River), a portion of WMA 4 (Lower Passaic River and tributaries), and all of WMA 6 (Whippany River, Rockaway River, Dead River and Upper Passaic River). The Wanaque River and Ramapo River watersheds extend well into New York State. Figure 2 is provided as a basin overview map.

The TMDL study area (see Figure 3) is defined more narrowly for a variety of reasons. The study area extends upstream in the Rockaway River to the outlet of Boonton Dam, just upstream of Rockaway Valley Regional Sewerage Authority discharge. Similarly, the study area extends a relatively short distance upstream in the Pequannock River to Riverdale. The waters upstream of these points are relatively pristine and include multiple drinking water reservoirs. None of the streams in these headwaters is listed as impaired for phosphorus (as shown on Figure 2); furthermore, the phosphorus concentrations at these boundaries are very low.

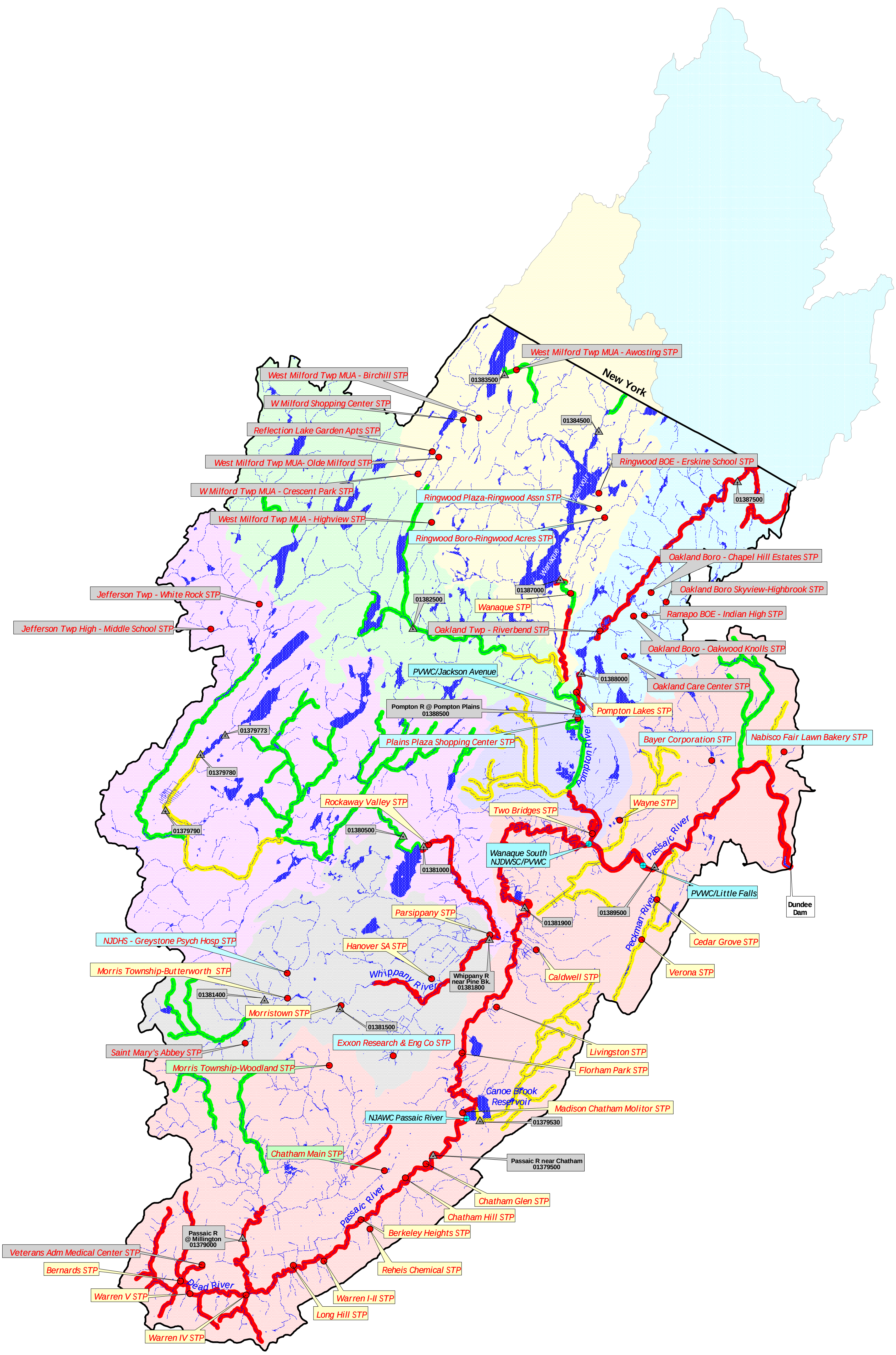

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FIGURE 2:
Basin Overview

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Non Tidal Passaic Watershed Boundary

Sub-Basins
- Passaic River
- Pequannock River
- Pompton River
- Ramapo River
- Rockaway River
- Wanaque River
- Whippany River

DATA SOURCE: NJDEP GIS Resource Data CD-Rom; Stations globally positioned by Omni Environmental, May 2003.

STP
- Simulated in Flow & Water Quality Model
- Simulated as Load in NPS Model
- Simulated in Great Swamp Watershed Analysis
- Not Simulated

USGS Station
Diversion

Phosphorus Impairment Designation (NJDEP 2004)
- Full Attainment
- Non Attainment
- Insufficient Data

3 0 3
Miles

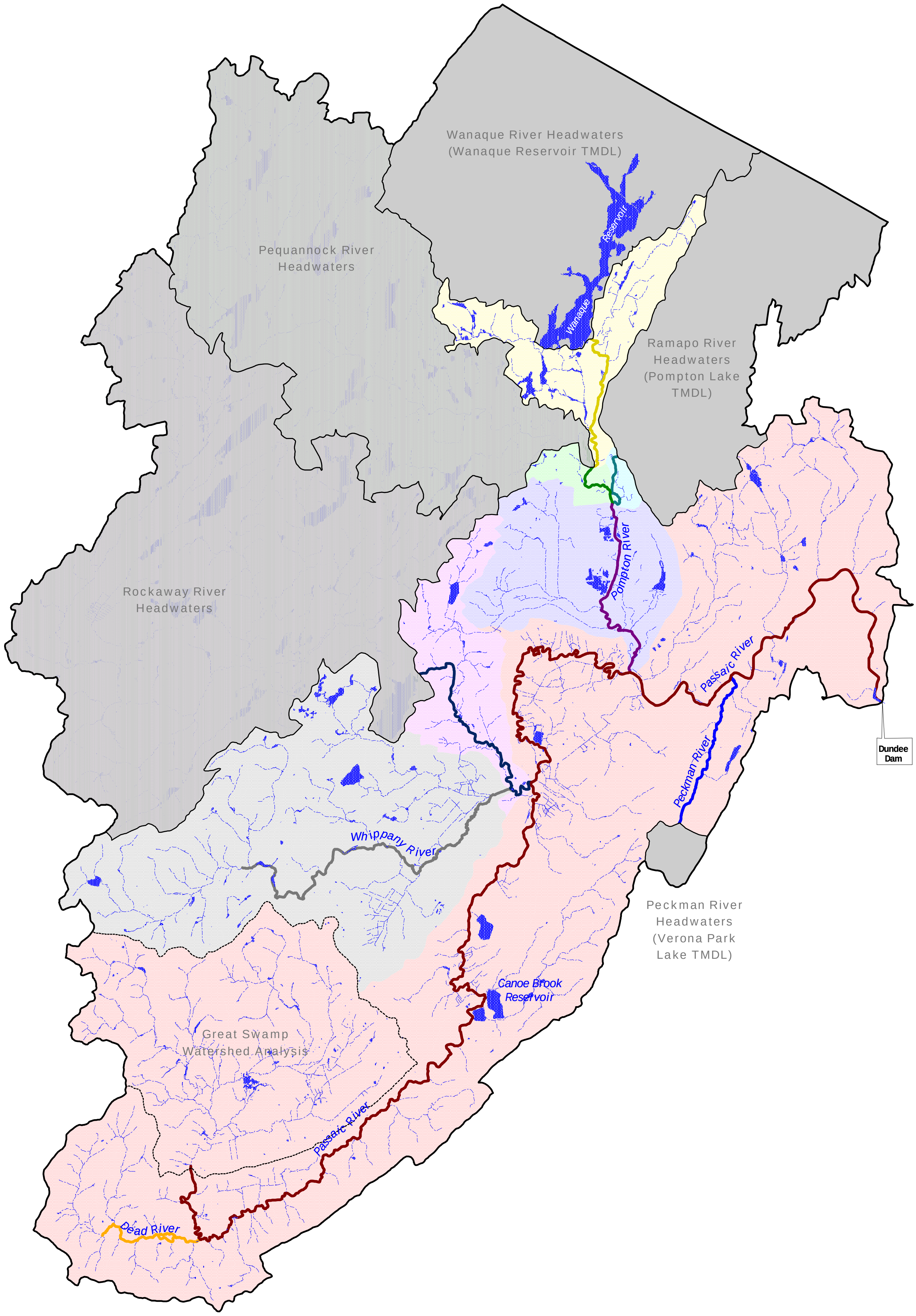

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FIGURE 3:
Study Area

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Passaic River Basin
Nutrient TMDL Study

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Modeled Segment
- Dead River
- Passaic River
- Pequannock River
- Peckman River
- Pompton River
- Ramapo River
- Rockaway River
- Wanaque River
- Whippany River

Headwater Sub-Basin Outside Study Area
Non Tidal Streams

2 0 2
Miles

Other boundaries to the study area are defined by the study areas of three other TMDL studies performed in certain headwater areas. This study was designed to complement these other TMDL studies. In the Wanaque River, the study area is bounded upstream by the outlet of the Wanaque Reservoir, which was the subject of a phosphorus TMDL study (Najarian, 2005). The major connection between the Wanaque Reservoir TMDL and the Non-Tidal Passaic River Basin TMDL Study is the Wanaque South pumping station in the Pompton River at Two Bridges. Wanaque South is a major diversion from the Pompton and Passaic Rivers, and therefore a major source of phosphorus to the Wanaque Reservoir (see Chapter IV.B.1). In the Ramapo River, the study area is bounded upstream by Pompton Lake, which was also the subject of a phosphorus TMDL study (QEA, 2005). In addition, the Wanaque Reservoir TMDL study included a modeling study of the watershed that drains to the intake at Pompton Lake. Finally, the study area extends upstream in the Peckman River to Verona Park Lake, which was the subject of a previous TMDL established by NJDEP (NJDEP, 2003a). Other than the headwater areas described above, the area of interest for the Non-Tidal Passaic River Basin TMDL Study extends from the headwaters of the Passaic River to the tidal boundary at Dundee Dam, as shown in Figure 3.

There are numerous municipal and industrial wastewater treatment plant discharges (i.e., point sources) within the study area, as shown in Figure 2. In addition, there are four potable water intake locations within the study area that provide water to reservoirs or directly to water treatment plants. Tables 1 and 2 list the water supply intakes and sewage treatment plants (STPs) that lie within the study area, respectively. Note that Table 2 provides the manner in which the treatment plants were simulated. Further discussion of the simulation techniques utilized in the modeling effort are provided in Section II of this report.

TABLE 1: Water Supply Intakes in the Non-Tidal Passaic River Basin Study Area

Intake	Water Purveyor	Source Water	Destination
NJAWC Passaic	New Jersey American Water Company	Passaic River	Canoe Brook Reservoir
Jackson Avenue	Passaic Valley Water Commission	Pompton River	Point View Reservoir and Little Falls WTP
Wanaque South	North Jersey District Water Supply Commission	Pompton and Passaic Rivers	Wanaque Reservoir*
	Passaic Valley Water Commission		Little Falls WTP
Little Falls	Passaic Valley Water Commission	Passaic River	Little Falls WTP

*Note: Water can also be diverted from Pompton and Passaic Rivers to Oradell Reservoir in Hackensack River Basin.

TABLE 2: STP Discharges in the Non-Tidal Passaic River Basin Study Area

NJPDES ID	Facility Name	Receiving Water	Permitted Flow (mgd)	Simulation Method
NJ0104451	Bayer Corporation	Molly Ann Brook via Storm Sewer	0.216	NPS Load
NJ0027961	Berkeley Heights WPCP	Passaic River	3.10	F & WQ
NJ0022845	Bernards SA – Harrison Brook STP	Dead River	2.50	F & WQ
NJ0020427	Caldwell Boro STP	Passaic River via unnamed tributary	4.50	F & WQ
NJ0025330	Cedar Grove Twp STP	Peckman River	2.00	F & WQ
NJ0020281	Chatham Hill STP	Passaic River	0.03	F & WQ
NJ0052256	Chatham Twp – Chatham Glen STP	Passaic River	0.155	F & WQ
NJ0020290	Chatham Twp – Main STP	Black Brook via unnamed tributary	1.00	Great Swamp
NJ0003476	Exxon Research & Eng Co	Black Brook (tributary to Whippany R.)	0.29	NPS Load
NJ0025518	Florham Park SA	Passaic River	1.40	F & WQ
NJ0024902	Hanover SA	Whippany River via ditch	4.61	F & WQ
NJ0024511	Livingston Twp STP	Passaic River	4.60	F & WQ
NJ0024465	Long Hill Twp – Stirling Hills STP	Passaic River	0.90	F & WQ
NJ0024937	Madison Chatham Joint Mtg – Molitor	Passaic River	3.50	F & WQ
NJ0024911	Morris Twp – Butterworth STP	Whippany River	3.30	F & WQ
NJ0024929	Morris Twp – Woodland STP	Loantaka Brook	2.00	Great Swamp
NJ0025496	Morristown Town STP	Whippany River	6.30	F & WQ
NJ0002577	Nabisco Fair Lawn Bakery	Henderson Brook	0.3202	NPS Load

TABLE 2: STP Discharges in the Non-Tidal Passaic River Basin Study Area (continued)

NJPDES ID	Facility Name	Receiving Water	Permitted Flow (mgd)	Simulation Method
NJ0026689	NJDHS - Greystone Psychiatric Hospital	Jaqui Pond (Whippany River)	0.40	NPS Load
NJ0024970	Parsippany-Troy Hills SA	Whippany River	16.00	F & WQ
NJ0026514	Plains Plaza Shopping Center	Pompton River	0.02	NPS Load
NJ0023698	Pompton Lakes Borough MUA	Ramapo River	1.20	F & WQ
NJ0002551	Reheis Chemical	Passaic River via unnamed tributary	DMR	F & WQ
NJ0027006	Ringwood Boro – Ringwood Acres STP	High Mountain Brook	0.036	NPS Load
NJ0032395	Ringwood Plaza STP – Ringwood Assn	Meadow Brook	0.0117	NPS Load
NJ0022349	Rockaway Valley Regional SA	Rockaway River	12.00	F & WQ
NJ0029386	Two Bridges SA	Pompton River	10.00	F & WQ
NJ0021083	Veterans Affairs Medical Center	Harrison Brook via unnamed tributary	0.40	Included in Dead River Headwater
NJ0024490	Verona Twp STP	Peckman River	3.00	F & WQ
NJ0053759	Wanaque Valley Regional SA	Wanaque River	1.25	F & WQ
NJ0022489	Warren Twp Stage I&II STP	Passaic River	0.47	F & WQ
NJ0022497	Warren Stage IV STP	Dead River	0.80	F & WQ
NJ0050369	Warren Stage V STP	Dead River	0.38	F & WQ
NJ0028002	Wayne Twp – Mountain View STP	Singac Brook	13.50	F & WQ

Note: "F&WQ" designates STP simulated explicitly in Flow and Water Quality Model
"NPS Load" designates STP simulated as load in NPS model
"Great Swamp" designates STP simulated within Great Swamp Watershed Analysis

I.F. Applicable Surface Water Quality Standards

In order to prevent excessive primary productivity and consequent impairment of recreational, water supply and aquatic life designated uses, the New Jersey Surface Water Quality Standards (N.J.A.C. 7:9B) require that:

- total phosphorus in all freshwater streams not exceed 0.1 mg/l, unless it can be demonstrated that total phosphorus is not a limiting nutrient and will not otherwise render the waters unsuitable for the designated uses;
- total phosphorus not exceed 0.05 mg/l in any lake, pond or reservoir, or in a tributary at the point where it enters such bodies of water;
- except as due to natural conditions, nutrients shall not be allowed in concentrations that cause objectionable algal densities, nuisance aquatic vegetation, abnormal diurnal fluctuations in dissolved oxygen or pH, changes to the composition of aquatic ecosystems, or otherwise render the waters unsuitable for the designated uses.

Nutrient Policy #3 further states: "The Department may establish watershed site-specific water quality criteria for nutrients in lakes, ponds, reservoirs or stream, in addition to or in place of the criteria in N.J.A.C. 7:9B-1.14, when necessary to protect existing or designated uses. Such criteria shall become part of these SWQS." This study provides a direct and quantitative linkage between phosphorus sources and productivity impacts, and was therefore used to establish a watershed-specific criterion for phosphorus. The basis for the watershed-specific criterion is provided in Section IV. TMDL calculations in this study are based on compliance with the watershed-specific criteria developed in Section IV.

II. WATERSHED MODEL DEVELOPMENT

II.A. Watershed Model Purpose and Objectives

The purpose of the Passaic River Basin model is to relate point and nonpoint sources of phosphorus to water quality impacts at critical locations under a variety of conditions, including critical conditions. Dissolved oxygen was identified as a primary water quality indicator, as well as phytoplankton (measured as water column chlorophyll-a), especially in the most downstream areas of the system. In addition, phosphorus concentrations and loads are important, especially for water supply diversions. Therefore, the model must be able to relate phosphorus sources to instream phosphorus concentration and dissolved oxygen throughout the system, as well as phytoplankton in downstream areas prone to substantial phytoplankton growth.

II.B. Watershed Model Overview

The Non-Tidal Passaic River Basin TMDL Study is divided into two major modeling tasks: stream flow and water quality. The stream flow modeling effort was initiated by the United States Geological Survey (USGS), and the water quality model and TMDL analyses were prepared by Omni. The spatial extent of the Non-Tidal Passaic TMDL water quality and flow models includes the Passaic River, the Pompton River and their major tributaries.

In order to simulate the dynamics of nutrient cycling and its effects on water quality variables in the Passaic River Basin, a modeling approach using the Water Quality Analysis Program 7.0 (WASP7) was adopted. The WASP7 model is an enhancement of the original WASP model (Di Toro et al., 1983, Connolly and Winfield, 1984, Ambrose, R.B. et al., 1988). WASP7 is a dynamic compartment-modeling program for aquatic systems, which includes time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange. WASP7 uses as inputs time series of flow, pollutant loads, and several water quality parameters (Wool, et al., 2003).

The flow model used for the Non-Tidal Passaic River Basin TMDL Study was DAFLOW. DAFLOW is a digital model developed by USGS for routing stream flow using diffusion analogy in conjunction with a Lagrangian solution scheme (Jobson, H. E., 1989). The flow model routes water downstream using the following time series as inputs: flows from stream flow gauges; flows from discharges and diversions; and incremental flows from tributaries and sub-basins along the mainstems.

The flow model provides important information for the water quality modeling stream system. Water quality variables such as dissolved oxygen and algae concentrations are directly affected by stream flow and nutrient availability. Stream flow affects important physical parameters that impact the nutrient cycles in the stream, such as velocity, depth, turbulence and reaeration. These physical parameters indirectly affect the assimilation of nutrients by algae and consequently the concentration of dissolved oxygen and other water quality variables. The water quality model prepared for the Passaic River Basin uses the flow model as a basis for establishing a model network, and also to obtain mass transport information and cross-sectional geometric characteristics throughout the system.

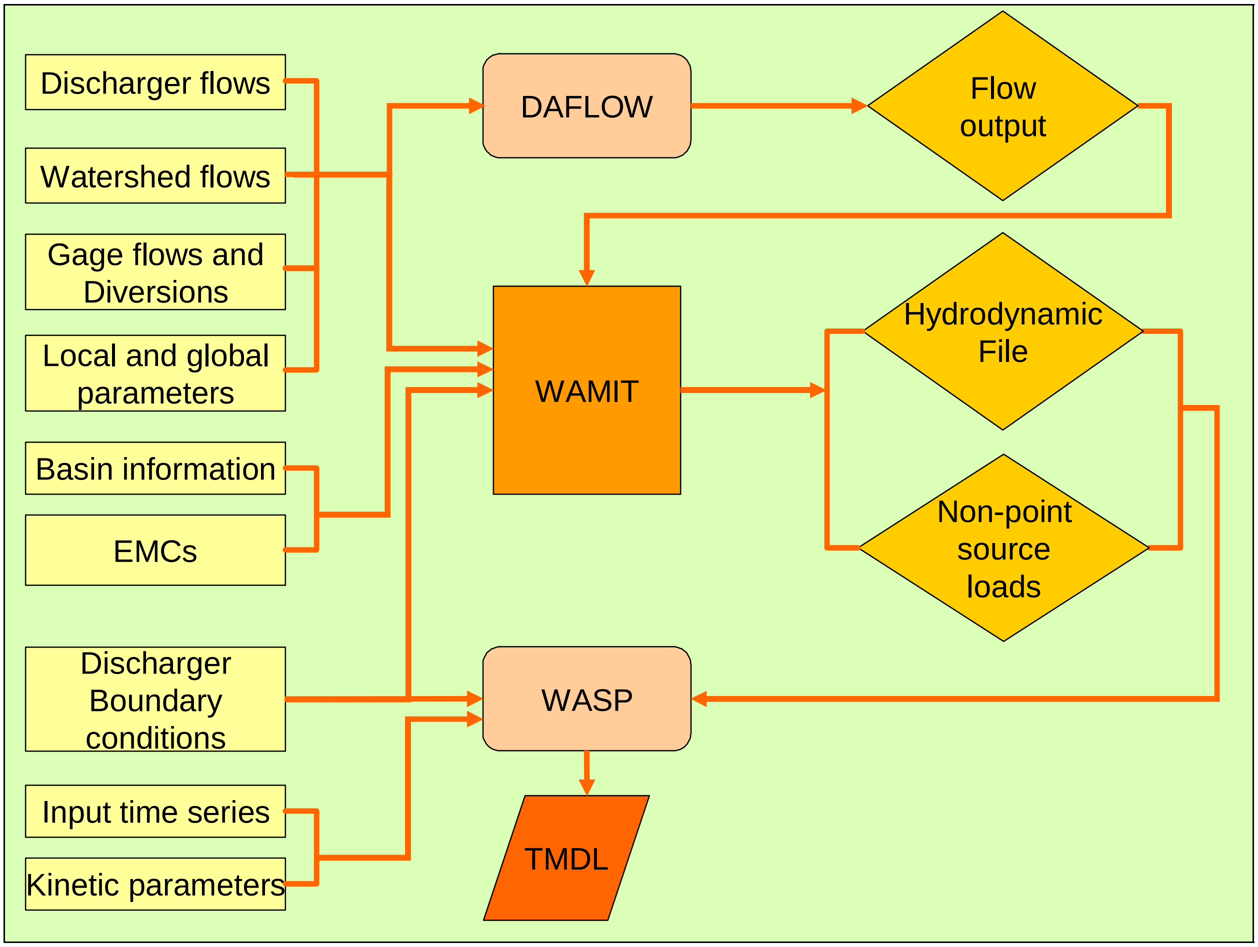
Because the modeling study includes two different models that need to share information, a graphical watershed model integration tool (WAMIT) was developed for data sharing, data visualization, model input calculation, and decision support. WAMIT is primarily a graphical user interface for DAFLOW with Geographic Information Systems (GIS) capabilities. WAMIT also contains four main data processing algorithms. The first algorithm translates DAFLOW outputs from a Lagrangian structure into a finite difference structure necessary for WASP and creates a hydrodynamic input file. The other three algorithms are used to calculate non-point source loads in the system as a function of tributary baseflow and surface flows given by a hydrograph separation routine, sub-basin characteristics, and flow-weighted runoff concentrations for different land use types. The stream flow simulations from DAFLOW are shared with WASP through a hydrodynamic file, and the non-point source inputs are given through a nonpoint source (NPS) file containing daily loads for several water quality constituents.

An extensive amount of input data was necessary for the Passaic River Basin TMDL Study. Discharger flows and quality, water supply diversions, flow at gauges, time series data for solar radiation and stream water temperature, and several water quality kinetic parameters had to be obtained from a variety of sources. Spatial databases were used to derive watershed boundaries and spatial parameters for the models. Calibration and validation data were collected throughout the basin by Omni (TRC Omni, 2004), and combined with existing water quality databases.

The flow and water quality models were calibrated during 2003 and validated over a four year period at selected locations throughout the system. The simulations were prepared for a four year period and were subdivided into four water years for modeling purposes.

The chart presented in Figure 4 shows all components used for the Non-Tidal Passaic TMDL model. In the center of the flow chart are the computational applications; the elements on the left are inputs to the models; the elements on the right are outputs and processed inputs. WAMIT is responsible for managing the input data for the models, and for deriving hydrodynamic and NPS input files for WASP. Data inputs to WAMIT are flow time series, NPS data, and point source data. Flow boundary conditions are inputs for DAFLOW, which provides flow along the stream network as output. The flow outputs from DAFLOW are used to create hydrodynamic inputs for WASP. NPS data consists of event mean concentrations and basin local parameters. Point source data consists of discharger water quality data. Input parameters for WASP are added directly in WASP user's interface, which can be accessed through WAMIT. Finally, water quality simulations from WASP provide the basis for the Passaic River Basin TMDL. All aspects of the Passaic TMDL Model mentioned above are presented and discussed in subsequent sections of this report.

FIGURE 4: Passaic River Basin TMDL Model System



II.C. <u>Spatial and Temporal Extent</u>

The model extent for the Non-Tidal Passaic River Basin model (as previously shown in Figure 3) was determined based on the location of continuous stream flow gauges that drive the flow model, the inclusion of STP discharges that represent substantial phosphorus sources, and the inclusion of streams designated by NJDEP as impaired by phosphorus.

For modeling purposes, the Passaic River was subdivided into three main parts: Upper Passaic, Mid Passaic and Lower Passaic[2].

- The Upper Passaic River starts at Millington Gorge just downstream of Great

[2] In other contexts, the Lower Passaic River refers to the tidal portion downstream of Dundee Dam. This operational definition of Upper, Mid, and Lower Passaic refers only to non-tidal portions of the Passaic River Basin.

Swamp and two miles upstream of the confluence with the Dead River, and ends at the confluence with the Rockaway River.

- The Mid Passaic River starts at the confluence with the Rockaway River near Pine Brook and ends at the confluence with the Pompton River at Two Bridges.
- The Lower Passaic River starts downstream of the confluence with the Pompton River and ends at Dundee Dam.

The Upper Passaic River tributaries that are modeled include:

- the Dead River starting at the Harrison Brook confluence;
- the Whippany River downstream of the USGS stream flow gauge at Morristown (01381400); and
- the Rockaway River downstream of the Boonton Reservoir.

Modeled tributaries of the Lower Passaic River include:

- Singac Brook from Wayne STP discharge to its mouth; and
- the Peckman River from Verona Park Lake to its mouth.

The Pompton River, a tributary of the Mid Passaic River, starts at the confluence with the Pequannock River and the Ramapo River, and ends at the confluence with the Mid Passaic River. In addition to the Pompton River mainstem, tributaries to the Pompton River that are being modeled include:

- the Wanaque River downstream of the Wanaque Reservoir;
- a small stretch of the Pequannock River starting in Riverdale approximately two miles upstream of the confluence with the Wanaque River; and
- a small stretch of the Ramapo River beginning at the USGS stream flow gauge (01388000) downstream of Pompton Lake.

The spatial extent of the Non-Tidal Passaic River Basin model is shown in Figure 3 (previously provided) by color coding each of the modeled segments.

A multiple year simulation was necessary for the Non-Tidal Passaic TMDL in order to capture the impact of different flow conditions on water quality. Independent models were setup for four simulation periods, which are referred to as water years. The entire period of simulation starts on October 1, 1999 and ends on November 30, 2003. This period was subdivided into four water years in order to accommodate input and processing limitations of the flow and water quality models. The first water year (WY2000) covers the period from October 1, 1999 to September 30, 2000. The second water year (WY2001) covers the period from October 1, 2000 to September 30, 2001. The third water year (WY2002) covers the period from October 1, 2001 to September 30, 2002. Finally, the fourth water year (WY2003) covers the period from October 1, 2002 to November 30, 2003. Except for WY2003, these water years coincide with USGS water year definitions. WY2003 was extended to include November 2003, when winter calibration data were collected. These simulation years represent typical, dry, extreme drought, and wet years, respectively.

II.D. Flow Model

One of the most important aspects of a watershed model is the transport of water and its constituents throughout the system. DAFLOW was the model chosen by USGS to route incremental flow inputs through the Passaic River and its tributaries. DAFLOW is a one-dimensional diffusive wave flow model that uses a Lagrangian solution method to calculate stream flows at each time step and location (Jobson, 1989).

Flow model inputs include: stream network elements, which consist of junctions, branches, and nodes; geometric characteristics for each node; time series of flow for the upstream boundaries; flows from the dischargers and diversions; and incremental flows from tributaries and sub-basins along modeled streams. Flow inputs and geometric characteristics are assigned to nodes along a branch. DAFLOW provides as outputs: the discharge at each node, the calculated cross-sectional area, the calculated top width, and tributary inflow that was input.

As a diffusive wave flow model, the original code of DAFLOW could not accurately represent backwater effects that are known to occur at the confluence of the Passaic and Pompton Rivers. The large water supply diversion at Wanaque South, located at the Pompton River approximately 1,000 feet upstream from the confluence with the Passaic River, can reverse the flow in the Pompton River between the confluence and the withdrawal under some critical conditions. This made it necessary to modify the model in order to account for the occasional reversal of flow. For a complete description of the DAFLOW simulation, the reader is referred to the USGS documentation (USGS, 2006 in press).

Outputs from DAFLOW are used by WASP to simulate water quality. In order to make DAFLOW simulations available for WASP, the flow model network and the results originally provided on a Lagrangian solution scheme had to be translated into an Eulerian solution scheme used by WASP. Besides translating the model data, some modifications had to be made on DAFLOW's original code to obtain stable flow files that could be used in WASP. The stream network set up, DAFLOW network and output translation, and the modifications needed to perform stable WASP simulations are discussed below.

II.D.1. Stream Network Setup

The stream network is a conceptual model of the system's characteristics and connectivity. It represents the water bodies and the path of water using a sequence of interconnected elements. The stream network for the Passaic River Basin was defined by observing important aspects of both the flow and water quality models. Aspects of interest include the definition of upstream boundaries at locations where flows are gauged, the location of incremental flows from contributing watersheds, sampling stations, diversions, and variability of cross-sectional characteristics.

In the case of the Non-Tidal Passaic River Basin, 17 branches were defined with a variable number of nodes per branch as shown in Figure 5 Stream Model Network. Nodes were located to represent major dischargers, diversions, headwater boundaries, incremental watershed flows, and special locations such as water quality sampling stations and flow gauges. The relevant point source dischargers considered in the analysis were those classified as Major Municipal Dischargers (MMJ) and selected Minor Municipal Dischargers (MMI). Next, water diversions, major tributaries, USGS stream flow gauges, and locations near

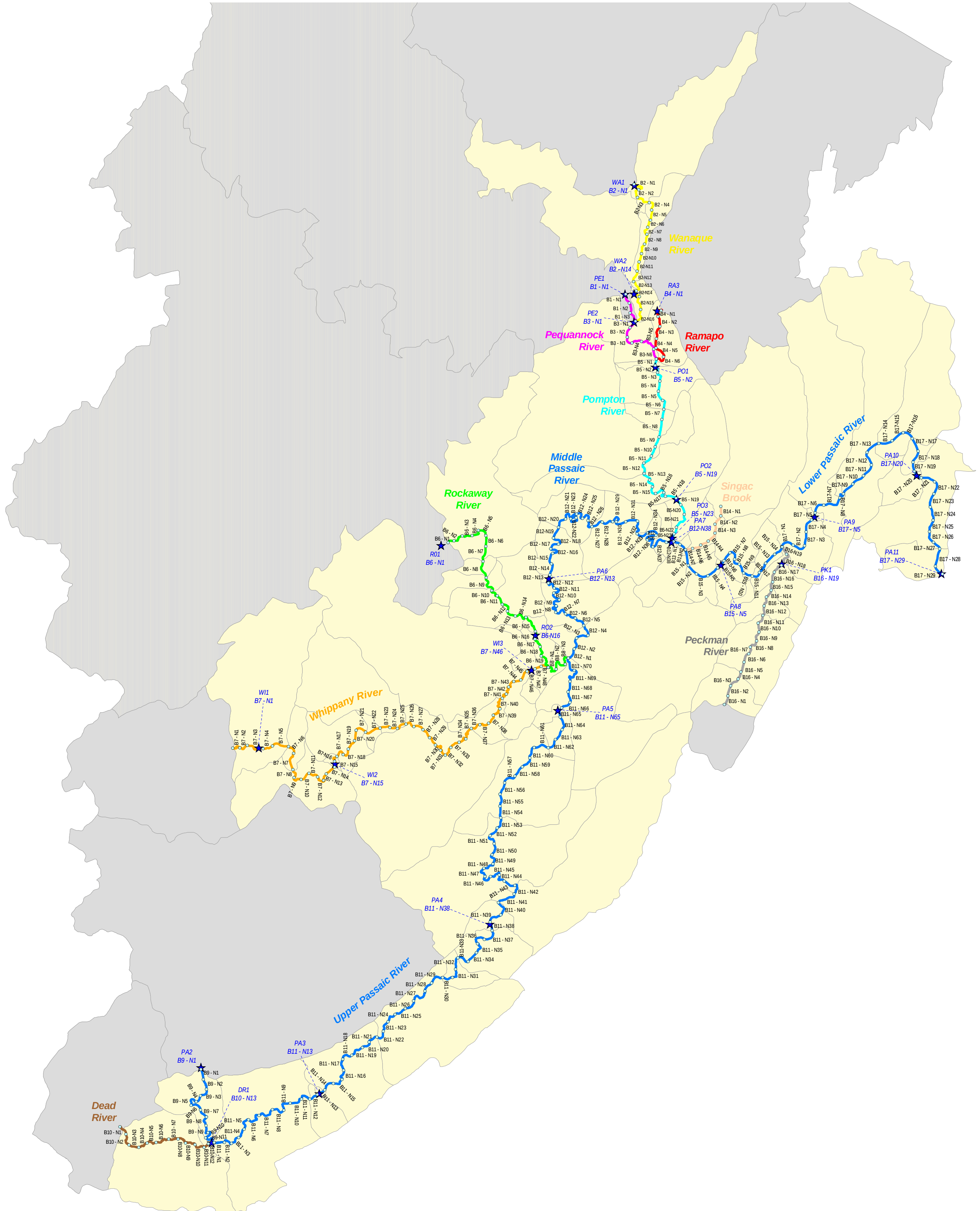


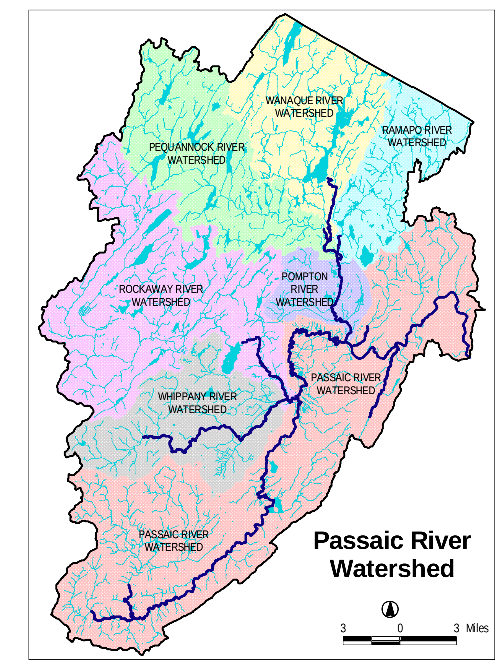
FIGURE 5: Stream Model Network

Phase II Non-Tidal
Passaic River Basin
Nutrient TMDL Study

B = Branch; N = Node
DAFLOW Model Node
Omni Stream Sampling Station

River Segment
- Dead River
- Passaic River
- Peckman River
- Pequannock River
- Pompton River
- Ramapo River
- Rockaway River
- Singac Brook
- Wanaque River
- Whippany River

Passaic River Watershed Sub-Basin
Headwater Sub-Basin Not Within Model Domain



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sampling stations were identified. Major water supply diversions in the Non-Tidal Passaic River Basin include: Passaic Valley Water Commission (PVWC), North Jersey District Water Supply Commission (NJDWSC), and New Jersey American Water Company (NJAWC). Examples of tributaries that are not explicitly modeled but have their flows taken into account in the model are: Packanack Brook on the Pompton River, Canoe Brook on the Upper Passaic River, and Goffle Brook on the Lower Passaic River. USGS stream flow gauges along the branches were identified for flow model calibration and validation purposes. Upstream and downstream nodes from sampling stations were established to provide a more discrete representation of flows at these locations for water quality model calibration and validation. The tasks of defining the extent of branches and model nodes locations were performed using GIS tools and layers.

The extent of the branches was defined according to model objectives, areas of interest, and availability of flow gauges. The NJDEP county stream shapefile was used as a basis to define the model branches. This layer was later edited to eliminate double lines, dangle nodes, and to adjust the stream paths to the NJDEP aerial photography.

The node location along a branch was defined based on spatial layers with discharger, gauge, and sub-basin delineation. Two main classes of nodes can be divided in DAFLOW: active and inactive nodes. Active nodes are those where a flow boundary is defined. They can represent a discharger, diversion or incremental watershed inflow. Inactive nodes do not represent a flow source to the model. They are important to obtain outputs from the model between active nodes, and to provide finer stream network segmentation for WASP. The GIS layers used to assign active node locations were: NJPDES surface water dischargers, USGS flow gauges, Omni sampling stations, and Passaic River watershed sub-basins.

GIS layers such as discharge locations and USGS gauges were retrieved from the NJDEP GIS repository (http://www.state.nj.us/dep/gis/lists.html).

However, Omni sampling stations and watershed sub-basins had to be created. Omni sampling stations are identified as a node shapefile representing the geographic location of the water quality sampling stations sampled during Phase I of the study. The watershed sub-basins are based on a refined watershed delineation, which was created as a function of existing HUC14 level watershed delineations and watershed delineation algorithms as described below.

II.D.2. Sub-Basin Delineation

The methodology used to delineate sub-basins for DAFLOW's nodes consists of combining an existing NJDEP sub-basin layer with automatically delineated sub-basins using GIS methods. The existing coverage is defined by the HUC14 coverage prepared by the USGS and distributed by the NJDEP. This 1994 coverage provides higher resolution delineation than the NJDEP-HUC14 shapefiles from 2004.

Sub-basin drainage areas for each node in the DAFLOW model were delineated based on GIS routines and a Digital Elevation Model (DEM) as shown in Figure 5. The methodology for sub-basin delineation can be divided into three main steps: automatic sub-basin delineation, integration of automatically generated sub-basins with existing NJDEP delineation, and aggregation of sub-basins.

Automatic sub-basin delineation was performed using the ArcView extension AVSWAT2000 (http://www.brc.tamus.edu/swat/avswat/) and a 10-meter resolution DEM. AVSWAT2000 allows digitized streams to be defined as preferential flow paths, leading to more accurate watershed delineation. DAFLOW's branch layer was used to define preferential drainage paths, and sub-basins were automatically delineated for all DAFLOW nodes. The 10-meter resolution DEM was obtained from the NJDEP Bureau of Geographic Information System. DEMs from WMAs 3, 6, and 4 were merged to form a single DEM, which comprises the spatial extent of the entire Non-Tidal Passaic River Basin.

The second step consisted of integrating the automatically delineated watershed boundaries for individual nodes with the existing watershed boundaries. In order to keep the watershed delineation for DAFLOW nodes compatible with existing watershed databases, the drainage areas delineated using AVSWAT2000 were overlaid to the existing HUC14 coverage. As expected, there was a good match between the HUC14 sub-basins and those obtained through automatic delineation. However, since the automatic delineation is based on a grid, the boundaries are not as smooth as those in the HUC14 coverage. Thus, in order to obtain a final product that is compatible with existing watershed boundaries, the HUC14 coverage was manually edited in order to incorporate the new sub-basins delineated for DAFLOW nodes. This process increased the resolution of the HUC14 coverage by adding new watershed boundaries.

The final step consisted of aggregating multiple sub-basins that drain to a single DAFLOW node, assigning a unique identifier to the sub-basins, and calculating its area. The aggregation process was performed using the county stream layers as a basis for sub-basin connectivity. Sub-basins are defined only for headwater and incremental flow nodes. Discharger and diverter nodes are not assumed to have a watershed contributing flow. The choice of assigning point and non-point source flows to distinct nodes was made to facilitate the process of assigning water quality concentrations to their respective sources.

The longitudinal distance between nodes, which is an input parameter for DAFLOW, was calculated using GIS methods. The layer with node locations was initially snapped to a linear type layer representing the model branches. After the snapping procedure, the linear layer was split at each node locations and the length of each segment was automatically calculated.

II.D.3. Model Inputs

Data inputs for DAFLOW are broken into three datasets: general information, branch information, and boundary conditions. The general information dataset consists of parameters that control the simulation, such as the time step size, the number of time steps, and the system of units. The general information dataset also specifies network schematization parameters, such as number of branches and interior junctions. The branch information dataset contains information about the number of nodes, the number of downstream and upstream junctions, the node distance from upstream junction, the initial flow, and the hydraulic geometry parameters. Finally, the boundary conditions' datasets are average flows during the time step for each node. The boundary conditions represent incremental, time series of flow, which can be positive in the case of discharger and tributary inflows, or negative in the case of a diversion. All input datasets for DAFLOW are contained in a file called FLOW.IN, which is a formatted text file that is accessed by DAFLOW's code at run time. A more complete description of all input parameters can be found in Jobson, H. E., 1989.

General information datasets are set by the modeler for proper model control and performance. Information, such as the number of internal junctions and branches in the system are a function of the model network. The number of time steps is a function of time step size and the total period of planned simulation. Perhaps, one of the most important parameters within the general information dataset is the time step size, which must be optimized to insure stable and accurate simulations. Smaller time steps are desirable from a water quality perspective; however, due to DAFLOW diffusion analogy, more stable flow simulations would be obtained with larger time steps. Also, given the model complexity and duration of simulation, run times are a major issue as well. Based on sensitivity analyses, a time step of three hours was chosen to simulate flow in the Non-Tidal Passaic River Basin.

Branch parameters are a function of the stream network defined by the modeler and the physical properties of the system. The number of nodes within a branch, the beginning and end junctions, and the distance of a particular node from the branch's upstream junction can be obtained from the model network and with the help of GIS. Other parameters, such as hydraulic geometry and cross-sectional characteristics, which are essential to accurately simulate flow, depend on physical properties of the system. Hydraulic geometry parameters are used in mathematical equations that provide cross-sectional area and tributary width as a function of flow. They can also be constant values representing storage or ineffective flow areas. In DAFLOW, the calculated cross-sectional area is given by the parameter A_1 times the flow (Q) to the power of the parameter A_2 plus the dead storage area, parameter A_0. The top width is given by the parameter W_1 multiplied by the flow (Q) to the power of parameter W_2. Equations 1 and 2 show the relationship used by DAFLOW to calculate cross-sectional area and top width, respectively.

$$A = A_1 * Q^{A_2} + A_0 \quad (1)$$

$$W = W_1 * Q^{W_2} \quad (2)$$

These are standard equations used to estimate cross-sectional characteristics. The parameters A_1, A_2, A_0, W_1 and W_2 are most commonly derived using regression analysis. A detailed discussion about how this set of hydraulic geometry parameters was estimated is present in the flow model report prepared by the USGS (USGS, 2006 in press). General dataset parameters and branch parameters used in the model are also presented in the flow model report.

The last set of parameters necessary to perform DAFLOW simulations are flow boundary conditions. This dataset consists of all water inputs and outputs from the system for the entire period of simulation. Flow boundary conditions are a time series of incremental flows in each node. They represent the average input or output from flow at a given node within the model time step.

Boundary flows can be classified as external or internal. External boundary flows are defined for upstream boundary nodes. In most cases, the flow for external boundaries is derived directly from USGS gauge data. Whenever possible, upstream boundaries in the model are located in the proximity of flow gauges. These selected gauges provide 15 minute data records of flow that are averaged within the model time step. Internal boundary flow inputs are defined for all internal nodes. Internal nodes are positioned to represent major dischargers, diversions, stormwater and groundwater discharge.

Time series data for flow and for all upstream boundary gauges and major dischargers present in the model had to be collected. Gauge flows were obtained and averaged for a 3-hour time step by USGS. All participating dischargers were contacted by Omni and requested to provide their flow records for the period of simulation. The format in which the data was provided and the frequency of measurements of the selected water quality parameters varied significantly by discharger. In order to fill in the missing records in the discharger data and to verify the datasets provided, Omni requested Discharge Monitoring Reports (DMRs), which contains reported monthly averages of flow for the period of simulation for all participant dischargers. The DMR and discharger datasets were compiled in one database, and the DMR information was used to fill in missing records whenever possible. The smallest resolution for discharger flows available was average daily flow. These data had to be broken up into smaller time intervals that were equivalent to the model time step in order to be used. Table 3 lists all dischargers included in the flow model.

The other type of flow inputs besides upstream boundary conditions and discharger flows are the nonpoint source flows such as tributaries, stormwater flows and baseflow. Unlike the point source flows and gauged streams, there are no flow records available for nonpoint source flows from ungauged tributaries and watersheds. The contribution of non-point source flows depends on several factors, such as precipitation, land use, land cover, soil drainage, geomorphology and geology.

Nonpoint source flows vary according to the characteristics of its contributing area, which is the watershed. Watersheds were delineated for nodes where nonpoint source flows were needed for the model. All nonpoint source flow generated by a given drainage area was assumed to enter the system at its respective node. As discussed in the model network section, distances between contributing watershed nodes were kept to a maximum of 1.5 miles, in order to minimize the effect of lumping non-point source flows at nodes for water quality simulations.

TABLE 3: Point Sources Explicitly Included in the Flow Model

NJPDES ID	Facility Name
NJ0027961	Berkeley Heights WPCP
NJ0022845	Bernards SA – Harrison Brook STP
NJ0020427	Caldwell Boro STP
NJ0025330	Cedar Grove Twp STP
NJ0020281	Chatham Hill STP
NJ0052256	Chatham Twp – Chatham Glen STP
NJ0025518	Florham Park SA
NJ0024902	Hanover SA
NJ0024511	Livingston Twp STP
NJ0024465	Long Hill Twp – Stirling Hills STP
NJ0024937	Madison Chatham Joint Mtg – Molitor
NJ0024911	Morris Twp – Butterworth STP
NJ0025496	Morristown Town STP
NJ0024970	Parsippany-Troy Hills SA
NJ0023698	Pompton Lakes Borough MUA
NJ0002551	Reheis Chemical
NJ0022349	Rockaway Valley Regional SA
NJ0029386	Two Bridges SA
NJ0024490	Verona Twp STP
NJ0053759	Wanaque Valley Regional SA
NJ0022489	Warren Twp Stage I&II STP
NJ0022497	Warren Stage IV STP
NJ0050369	Warren Stage V STP
NJ0028002	Wayne Twp – Mountain View STP

The watershed defines the physical drainage area and the properties influencing groundwater and runoff. Several methods can be utilized to estimate flow based on watershed characteristics in order to generate the necessary watershed flow inputs for DAFLOW. A drainage area ratio approach was utilized to obtain watersheds flow estimates. The drainage area ratio method consists of calculating total flows from watersheds based on flows from comparable gauged tributaries. This method provides an adequate estimate of watershed flows with relatively few inputs.

II.D.4. Model Outputs

Outputs from DAFLOW are used by WASP to drive water quality simulations. Thus, outputs for each node in the stream network for all time steps are necessary. The output variables include: the discharge at each node at the end of each time step, the average cross-sectional area during the time step, the average tributary width during the time step, the average tributary input over the time step, and the volume at the end of the time step (Jobson, H.E., 1989).

In order to make DAFLOW simulations available for WASP, the flow model network and results had to be translated into the solution scheme used by WASP. This data translation process consisted of: creating WASP segments from DAFLOW nodes; assigning network connectivity, model boundaries, and unit conversions; interpolating flow outputs to a time step used in WASP; and writing a WASP hydrodynamic file. The algorithm responsible for the data translation can be accessed in WAMIT and is described elsewhere in this report.

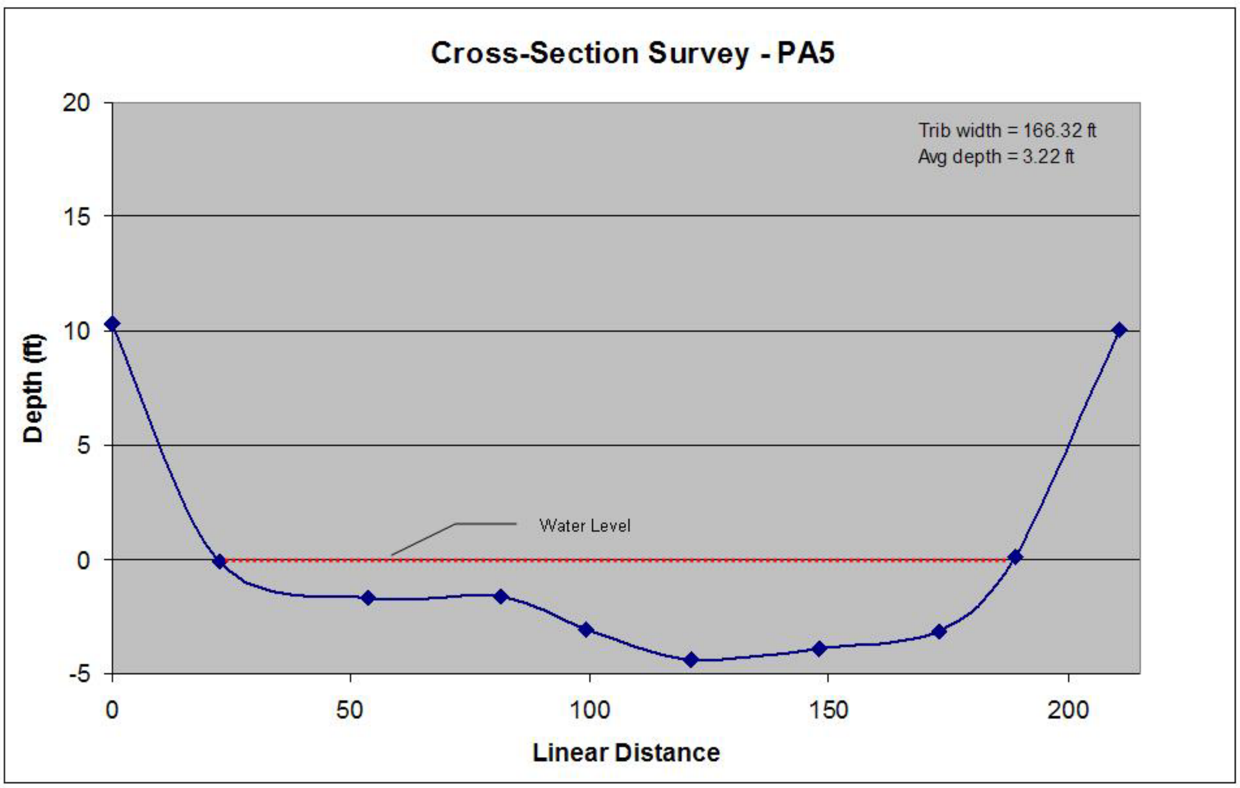
II.D.5. Cross-sectional Parameter Calibration

The hydraulic geometry parameters used in the mathematical equations that provide cross-sectional area and tributary width needed to be derived in order to provide a realistic representation of the stream geometry. Cross-sectional areas are of great importance for the transport of water constituents and to determine wave celerity and velocity in the water bodies. For a good representation of the width, it is important to capture the average depth, which is given by dividing the cross-sectional area by the top width. The average depth influences many processes of the water quality simulation, such as reaeration and light availability in the water column, which in turn influence algae and periphyton growth. DAFLOW cross-sectional parameters were obtained by comparing simulated flow versus cross-sectional area, and depth versus width, against measured values obtained from three major sources: cross-section surveys performed at Omni's water quality stations, USGS gauge data, and dye studies performed at various segments along the Passaic River and some of its tributaries.

Omni's surveys are an important source of cross-sectional information. A total of 24 stations were surveyed in the Passaic River and its tributaries. The surveys were used to obtain depth versus width relationships, and an approximation of the flow versus cross-sectional area, which are used to derive DAFLOW cross-sectional parameters. The method consists of using known cross-section geometry, flow, and water surface elevation to estimate the depth versus width and the flow versus cross-sectional area relationships, using a steady state water surface elevation model.

Each of Omni's water quality sampling stations within the model domain were surveyed. The surveys consisted of elevation measurements along a section of the river, and the respective water surface elevations. The water surface elevation is a function of the flow. Although flow was not measured during the surveys, gauge data available throughout the basin was used to estimate the flow on the day of the survey. Figure 6 represents a typical cross-section survey.

FIGURE 6: Cross-Section Plot of PA5 in the Upper Passaic River



The cross-section geometry, water surface elevation and the flows were entered into the Hydrologic Engineering Center River Analysis System (HEC-RAS), which was developed by the United States Army Corps of Engineers, and can perform steady state simulations of water surface elevation (Brunner, 2002). HEC-RAS was used to calculate cross-sectional area and top width for a uniform reach for a steady state flow. The average depth was calculated by dividing the cross-sectional area by the top width. For the purpose of this analysis, each cross-section was represented by an individual reach. The reaches were not interconnected, and they were assumed to be uniform and 1,000 feet in length. Different flow profiles were defined to provide flow versus cross-sectional area and depth versus width relationships, which were later compared with simulated DAFLOW geometry for a given location.

Besides cross-section geometry, boundary conditions that relate flow and water surface elevation were needed to provide an approximation of the flow versus cross-sectional area. In order to capture the flow versus cross-sectional area, a flow rating curve was used as the boundary condition for each reach. The water surface elevation for a cross-section and the respective flow were used to establish rating curves in HEC-RAS. The known water surface elevation and flow on the day of the survey is one of the points of the rating curve. This value of flow and water surface elevation represents, in general, low or average flow conditions. Because there is only one known value of flow and water surface elevation for Omni's stations, an upper boundary was estimated using high flow values obtained from gauge observations, and the elevation of the edge of the stream bank.

Flow profiles varying from low flows to high flows, and for the estimated flow value on the day of the survey, were defined for each reach. Simulations were performed, and tabular output containing top width and cross-sectional area for different flows was obtained. These values were placed in a spreadsheet, where average depths are calculated. Table 4 contains a sample of the output from HEC-RAS.

TABLE 4: Sample output from HEC-RAS

Flow (cfs)	Flow Area (ft^2)	Top Width (ft)	Depth (ft)
50	107	86	1.3
121	480	168	2.9
400	682	173	3.9
700	906	179	5.1
1000	1136	184	6.2
2500	2393	211	11.4

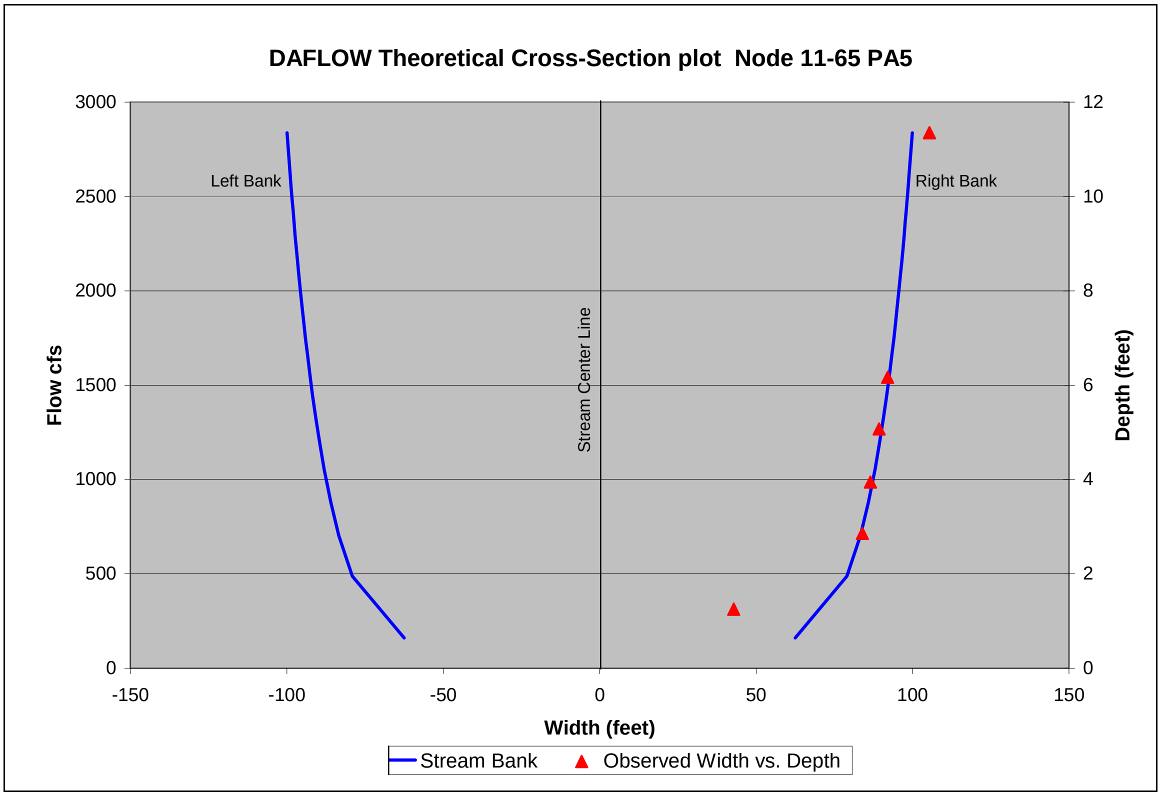
Once the cross-sectional area, top width, and average depth were obtained for a range of flows, they were used to calibrate DAFLOW cross-sectional parameters. DAFLOW equations provide geometry of the channel as a function of the flow. The equations and the respective cross-sectional parameters for area and width are shown in Equations 1 and 2 on Page 28.

This set of equations is a theoretical approximation of the stream geometry. Therefore, not all the data obtained using the cross-section survey can be captured by the model. However, a good approximation can be obtained in most cases. Cross-sectional area, top width and average depth were derived using DAFLOW equations for varying flow levels. The calibration process consists of finding values for A1, A2, A0, W1 and W2 that fit the depths versus width and the flow versus cross-sectional area relationships obtained from HEC-RAS. DAFLOW equations form a system with more unknown variables than system equations, making calibration challenging.

Trying to match DAFLOW curves with depth versus width and flow versus cross-sectional area from steady state water surface simulations proved an effective way to capture the general properties of the cross-section. The calibration began by fitting DAFLOW simulated cross-sectional area for various flows to the ones obtained using HEC-RAS. Because the flow vs. cross-sectional area pair, which is represented in the survey, is the actual observed value, more weight was given to this pair during the calibration. Once the cross-sections areas were calibrated, the width vs. depth was adjusted. Because the average depth is calculated as a function of the area and top width, it is important that the area be well represented first. Sometimes, either the area or the width needed to be rearranged to improve the depth representation.

DAFLOW parameters were calibrated in order to yield an acceptable fit of the equations against the flow versus cross-sectional area and depth versus width from the steady state water surface model, and to avoid unrealistic representations of the physical system. Figure 7 shows a calibrated cross-section.

FIGURE 7: Example Calibrated Cross-Section



In Figure 7 above, the blue lines represent the stream banks, while the red marks are depth versus width obtained from the cross-section survey and the water surface elevation model. Note that it is not necessary or desirable to calibrate the cross-sectional parameters to fit unrealistically shallow depths that might be generated by the water surface elevation model.

Omni's surveys provide information only at water quality sampling stations, which are crucial locations for the calibration and validation of the water quality model. However, they are not enough to represent the cross-sectional variation along the system. Using only one source of information could lead to a cross-sectional geometry that does not represent the average conditions of the reach. Therefore, USGS stations in the basin were also used to derive cross-sectional parameters.

A similar approach for the calibration of DAFLOW's cross-sectional parameters using Omni's surveys was adopted for the USGS stations. One important distinction is that the use of a water surface elevation model was not required. USGS data consists of field measurements of cross-sectional area and width for several flow conditions. Thus, there was no need to generate cross-sectional area and width for a range of flows using a water surface elevation model. The available data, quality, time frame and representation of different flow conditions vary considerably among the USGS stations. Given the field measurements of flow versus cross-section area and depth versus width, the calibration process was analogous to the one described previously using Omni's cross-section survey data.

A third and final element for obtaining cross-sectional parameters for DAFLOW was dye studies performed previously in the Passaic River and its tributaries. These studies do not cover the entire basin, but they provide an average cross-sectional area for a given flow condition at a few locations. The area from the dye study is used to validate the cross-sectional parameters calibrated using Omni's surveys and USGS station data. The cross-sectional areas obtained from dye studies were compared against the length-averaged cross-sectional areas that were calculated using DAFLOW equations and calibrated cross-sectional parameters. A length-averaged cross-sectional area is important to better represent the average cross-section of long branches with variable cross-section parameters and variable distances between nodes, such as branches 11 and 17.

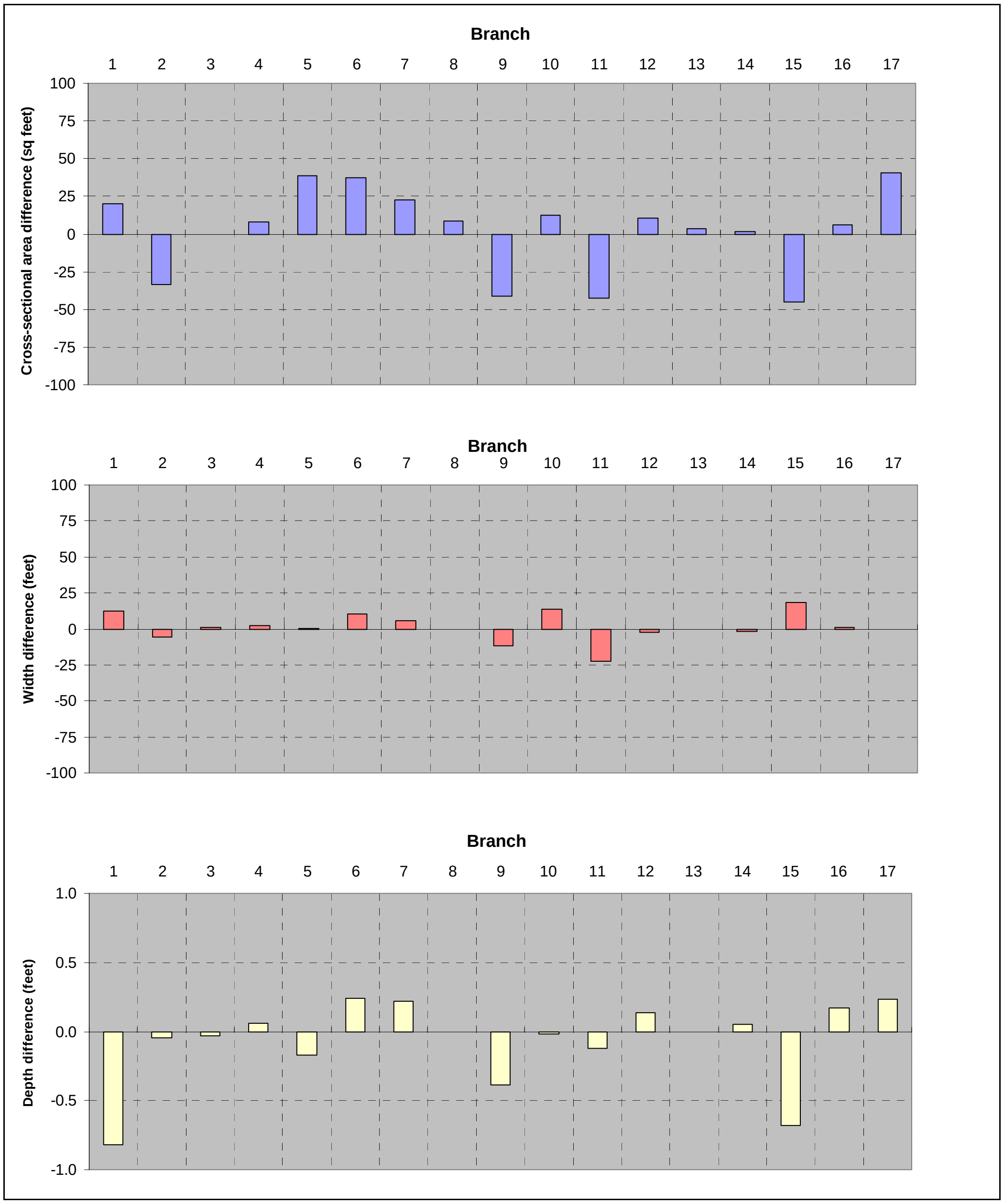
Table 5 shows the locations with available data used to derive the cross-sectional parameters.

TABLE 5: Locations Used for Calibration of Cross-sectional Parameters

	Waterbody	Location ID	Segment	Branch/Node
1	Pequannock River	PE1	1	1-1
2	Wanaque River	1387000	4	2-1
3	Wanaque River	WA1	4	2-1
4	Wanaque River	WA2	17	2-14
5	Pequannock River	PE2	20	3-1
6	Ramapo River	RA3	26	4-1
7	Ramapo River	1388100	29	4-4
8	Pompton River	PO1	33	5-2
9	Pompton River	1388500	33	5-2
10	Pompton River	PO2	50	5-19
11	Pompton River	PO3	54	5-23
12	Rockaway River	RO1	55	6-1
13	Rockaway River	RO2	70	6-16
14	Whippany River	WI1	74	7-1
15	Whippany River	WI2	88	7-15
16	Whippany River	WI3	119	7-46
17	Passaic River	PA2	125	9-1
18	Passaic River	1379000	125	9-1
19	Dead River	DR1	148	10-13
20	Passaic River	1379300	156	11-8
21	Passaic River	PA3	161	11-13
22	Passaic River	1379500	181	11-33
23	Passaic River	PA4	186	11-38
24	Passaic River	1379570	206	11-58
25	Passaic River	PA5	213	11-65
26	Passaic River	1381900	223	12-5
27	Passaic River	PA6	231	12-13
28	Passaic River	PA7	256	12-38
29	Passaic River	1389005	257	13-1
30	Singac Brook	1389100	265	14-7
31	Passaic River	PA8	270	15-5
32	Passaic River	1389500	277	15-12
33	Peckman River	1389534	284	16-5
34	Peckman River	PK1	298	16-19
35	Passaic River	PA9	303	17-5
36	Passaic River	1389802	306	17-8
37	Passaic River	1389870	318	17-20
38	Passaic River	PA10	318	17-20
39	Passaic River	PA11	327	17-28

In addition, the observed values of the cross-sectional area, width, and depth from Omni's surveys, USGS stations, and the dye studies were compared with simulated values using DAFLOW equations and calibrated parameters. A general measure of fitness is provided by calculating the difference between branch-averaged cross-sectional area, depth, and width for observed and simulated values. Figure 8 shows the differences between simulated and observed values.

FIGURE 8: USGS Flow Model Simulated Versus Observed Cross-sectional Values



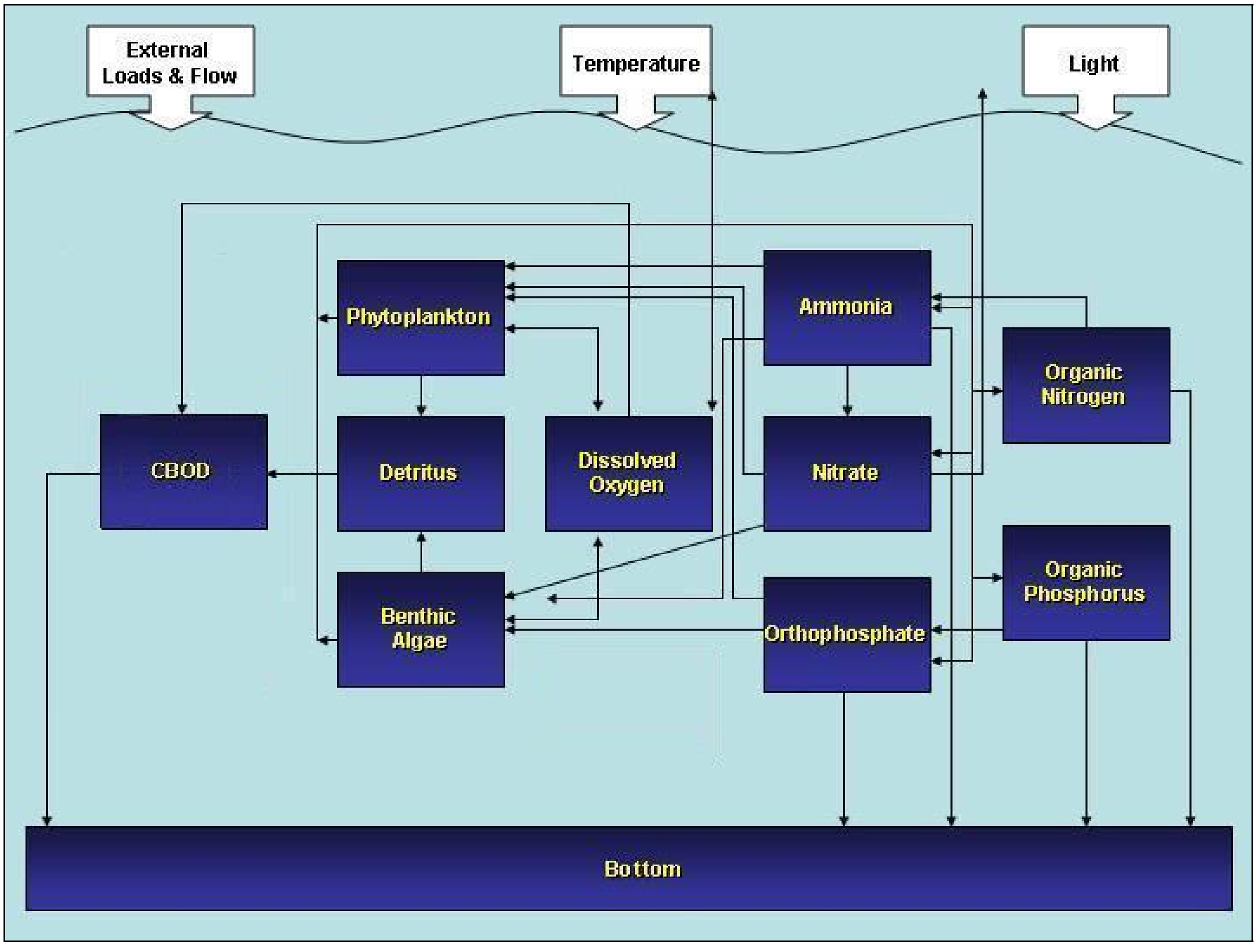
II.E. <u>Water Quality Model</u>

In order to simulate the dynamics of nutrient cycling and its effects on water quality variables in the Passaic River Basin, a modeling approach using the Water Quality Analysis Program 7.0 (WASP7) was adopted. WASP7 includes routines for simulating the fate and transport of conventional water constituents, which are required for the TMDL analyses. WASP7 is supplied with two kinetic sub-models, EUTRO and TOXI. EUTRO simulates conventional pollutant dynamics involving dissolved oxygen, BOD, nutrients and eutrophication, while TOXI simulates toxic pollutants (Ambrose, R.B. et al., 1993). The EUTRO sub-model was used for the Non-Tidal Passaic River Basin model to simulate dissolved oxygen and associated variables.

Several physical-chemical processes can affect the transport and interaction among nutrients, phytoplankton, benthic algae (and/or macrophytes), carbonaceous material, and dissolved oxygen in the aquatic environment (Wool et al., 2003). Figure 9 presents the main kinetic interactions for the nutrient cycle and dissolved oxygen as modeled within EUTRO. The blue dark boxes represent systems simulated in WASP7, and the arrows represent the relationships among them.

Five EUTRO state variables can participate directly in the dissolved oxygen balance: phytoplankton, benthic algae, ammonia, CBOD and dissolved oxygen. Note that the state variable for benthic algae represents macrophytes and periphyton in most segments of the Passaic River Basin. The reduction of dissolved oxygen is a consequence of the aerobic respiratory processes in the water column and the anaerobic process in the underlying sediments. Dissolved oxygen increases due to plant photosynthesis and decreases due to CBOD oxidation, nitrification, and plant respiration. Depending on water saturation, dissolved oxygen can be lost or gained via reaeration. Besides DO, the systems simulated in EUTRO are CBOD, phytoplankton, benthic algae, ammonia, nitrate, organic nitrogen, organic phosphorus, orthophosphate, and detritus. The formulae and description of these processes can be found in the WASP Manual (Wool et al., 2003).

FIGURE 9: WASP7 EUTRO Model Diagram



Modified from USEPA (2004) to represent the processes used for the Non-Tidal Passaic River Basin model.

II.E.1. Stream Network Setup

The WASP stream network is formed by a sequence of segments, which are control volumes that represent the physical configuration of the water body. The WASP model network can have up to three dimensions, which allows the water body to be subdivided laterally, vertically and longitudinally. Because DAFLOW is a one-dimensional model, WASP setup was also limited to only one dimension. State variables, such as concentrations of water quality constituents, are calculated within each segment. Transport rates of water constituents, such as flow, are calculated or assigned across the interface of adjoining segments (Wool, et al., 2003).

The WASP segments were defined as a function of the stream network for the flow model, which itself (as described previously) was defined according to WASP's model network needs. Nodes were positioned to provide segment sizes that minimize the effects of numerical dispersion and numerical instabilities. The WASP stream network, segment volumes, depths, flows, and velocities were all created within WAMIT.

The WASP stream network contains 327 interconnected segments distributed over approximately 107 river miles. In addition to segments, there are 451 interfacial flows defined for the network. Interfacial flows are defined between two consecutive segments and between a segment and its boundary. Segments with boundaries are those where there are flow inputs, such as wastewater treatment plant discharges, incremental watershed flows, and headwaters. A total of 117 boundary segments are defined for the Passaic River Basin network. A schematic of the model segmentation was previously shown in Figure 5.

II.E.2. Model Inputs

II.E.2.a. Flow

Flow inputs for the water quality model are entered via hydrodynamic linkage. Hydrodynamic linkage is accomplished through an external hydrodynamic file containing hydrodynamic simulation results of the system. The hydrodynamic file contains segment volumes at the beginning of each time step and average segment interfacial flows during each time step. WASP uses the interfacial flows to calculate mass transport and the volumes to calculate constituent concentrations. Segment depths and velocities are also contained in the hydrodynamic file for use in calculating respiration and other rates (Wool et al., 2003).

In the case of the Passaic River Basin model, the hydrodynamic file was created using outputs from DAFLOW. In order to be able to use DAFLOW simulations, a methodology was developed to generate compatible model networks and to convert DAFLOW results to the structure required by WASP. This methodology is presented in detail in Section II.F of this report.

II.E.2.b. Water Quality

The water quality constituents simulated in WASP for the Passaic River Basin model include: ammonia, nitrate, organic nitrogen, orthophosphate, organic phosphorus, dissolved oxygen, chlorophyll-a, ultimate biochemical oxygen demand, and benthic algae (or macrophytes). The constituents above are state variables in the water quality model. State variables represent the state (concentration) of water quality constituents for a given time of the simulation. The value of state variables is that they change with time according to the processes and inputs defined in the model.

Inputs of the water quality constituents in WASP can be added through initial water quality concentrations, water quality boundary conditions, and loads. Initial water quality concentrations are assigned to all segments of the system, and only impact very early stages of the simulations. The water quality boundary conditions for WASP consist of concentrations of water quality constituents associated with a boundary flow. Water quality boundary conditions are entered for all segments representing point source inputs in the system. Loads are the total mass of a given constituent entering the system during a day of simulation. Loads in WASP are not a function of flow, and they can be assigned to any segment with or without boundary flows. The constituents reaching water bodies via non-point sources are entered as loads to the system.

II.E.2.b.(1) Initial Conditions

Initial concentrations must be specified for each segment in WASP. For long-term dynamic simulations, initial water quality concentrations only impact the very early stages of the simulations. Since a multi-year simulation approach was adopted, initial concentrations do not impact model results materially. In order to maintain the continuity between consecutive simulation years, the initial concentration for each segment in a given year was assumed to be the same as the last time step for the prior simulation year. For the first water year, average values were used to define the initial conditions for each segment.

II.E.2.b.(2) Boundary Conditions

Water quality boundary conditions in WASP are a function of flow boundary conditions. Therefore, when flow boundaries are defined, so are water quality boundaries. The boundary conditions specify the water constituent's concentrations for point source flows and upstream boundaries of the system.

WASP's boundary conditions can be subdivided into internal and external boundaries. Internal water quality boundary conditions are defined for dischargers, while external boundary conditions are defined for headwater boundaries. Water quality parameters that need to be entered as boundary conditions include: ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), organic nitrogen (OrgN), dissolved orthophosphate (OrthoP), organic phosphorus (OrgP), dissolved oxygen (DO), ultimate carbonaceous biochemical oxygen demand ($CBOD_u$) and chlorophyll-a (Chl-a).

Obtaining water quality boundary conditions for the non-tidal Passaic River was a major undertaking for the model development. This task included gathering point source discharge data and in-stream water quality from several sources, manually entering written records provided by some dischargers, formatting existing digital records, assembling all the information into a digital database, deriving relationships among water quality constituents, and formulating assumptions to estimate water quality variables for periods and locations where measurements were not available.

The data used to derive water quality boundary conditions consist of Omni's 2003 instream sampling, Omni's 2003 STP effluent sampling, discharger STP effluent sampling from October 1999 through November

2003, and reported DMR data available from October 1999 through November 2003. The availability of data for water quality boundary conditions varies considerably by location, the period of time, the discharger, and the variable of interest. Thus, methods and assumptions for obtaining the water quality boundaries vary in order to best represent the water quality inputs for the model. Furthermore, water quality simulations require continuous boundary inputs; discrete data records therefore need to be processed to provide a continuous series of inputs to the model. Data resolution varies considerably, and linear interpolation was used to estimate continuous values between two discrete values.

All boundary conditions are provided electronically in Appendix M.

II.E.2.b.(2)(a) Headwater Boundaries

Instream water quality measurements provide the basis for assigning water quality concentrations to headwater boundaries. Locations defining most headwater boundaries in the model were sampled by Omni during May to November of 2003. Depending on the location, 12 to 20 samples were taken (TRC Omni, 2003 QASP). Additional data collected during 2004 was used to developed boundary conditions for the Dead and Peckman Rivers.

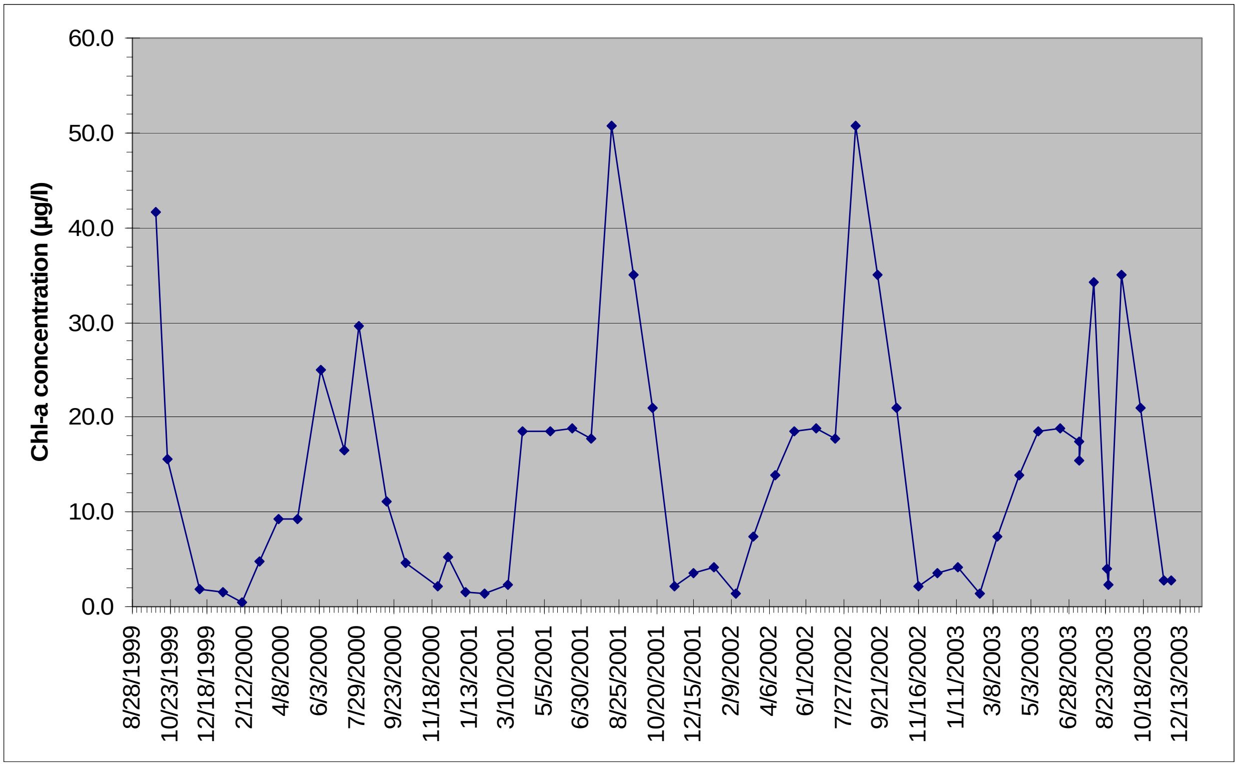
Generally, the continuous headwater concentrations for all parameters except DO were obtained using the actual discrete measurements. Actual values were used on the dates samples were taken. On the days between available samples, concentrations were linearly interpolated. During long periods without available data (i.e., > 2 months), an average of all available concentrations at that location was utilized. This approach for obtaining continuous concentrations series provided a good estimate for most parameters.

In order to account for seasonal DO variations due to temperature, the oxygen saturation level corrected by a site-specific average percent of saturation was adopted. The site-specific percent of DO saturation was calculated based on observed percent saturations. Theoretical equations for DO saturation based on temperature (Chapra, 1997) were used to calculate DO based on temperature, and an average percent saturation was obtained for each headwater location. Daily values of DO were then obtained for each headwater boundary by using the DO saturation equations, daily values of stream water temperatures for each site, and the average percent DO saturation. As with all other parameters, actual DO was used in place of calculated DO on days when it was measured.

Because in-stream water quality data used to derive headwater boundaries is limited to water year 2003, the same values were used to represent headwater boundaries for the remaining simulation years. As in 2003, DO boundaries were calculated based on stream water temperature. Since upstream areas are mostly natural, covered mostly by wetlands and forest, using the same continuous concentration series for most parameters for the previous simulation years is a reasonable assumption. The nutrient concentrations for headwater boundaries are mostly within the lower range found in water bodies. This demonstrates the relative pristine conditions of their watersheds, and supports the assumption of using the same concentrations series for other water years.

One important boundary that is not pristine is the Ramapo River boundary at Pompton Lake. This is the only boundary with significant contributions of chlorophyll-a. Furthermore, chlorophyll-a varies tremendously year-to-year, seasonally, and with flow. Fortunately, historical chlorophyll-a data from Pompton Lake were available to develop a reasonable boundary condition at this location. These data were collected by NJDWSC and published in the TMDL study for Pompton Lake (QEA, 2005). Data were not available for a portion of 2002; data from the same time period in 2001 were used for this time period, since both summers were dry. This methodology produced a reasonable boundary condition for chlorophyll-a at this location (see Figure 10 below).

FIGURE 10: Existing Chl-a Boundary Condition in Ramapo River at Pompton Lake



Another important boundary is the headwater model boundary in the Passaic River at Millington Gorge (USGS gauge 01379000, Omni Station PA2), which is just downstream of the Great Swamp and exhibits relatively high phosphorus concentrations. The average phosphorus concentration based on the sampling performed in 2003 by Omni was 0.13 mg/l total phosphorus, which is consistent with earlier data collected by NJDEP in the 1990s when that station was included in the Ambient Surface Water Monitoring Network (ASMN). Indeed, water quality sampling performed by Omni within the Great Swamp upstream of the influence of any STP discharges reveal total phosphorus concentrations as high as 2.4 mg/l (Township of Chatham, 2005). Water quality data obtained in January 2006 from Great

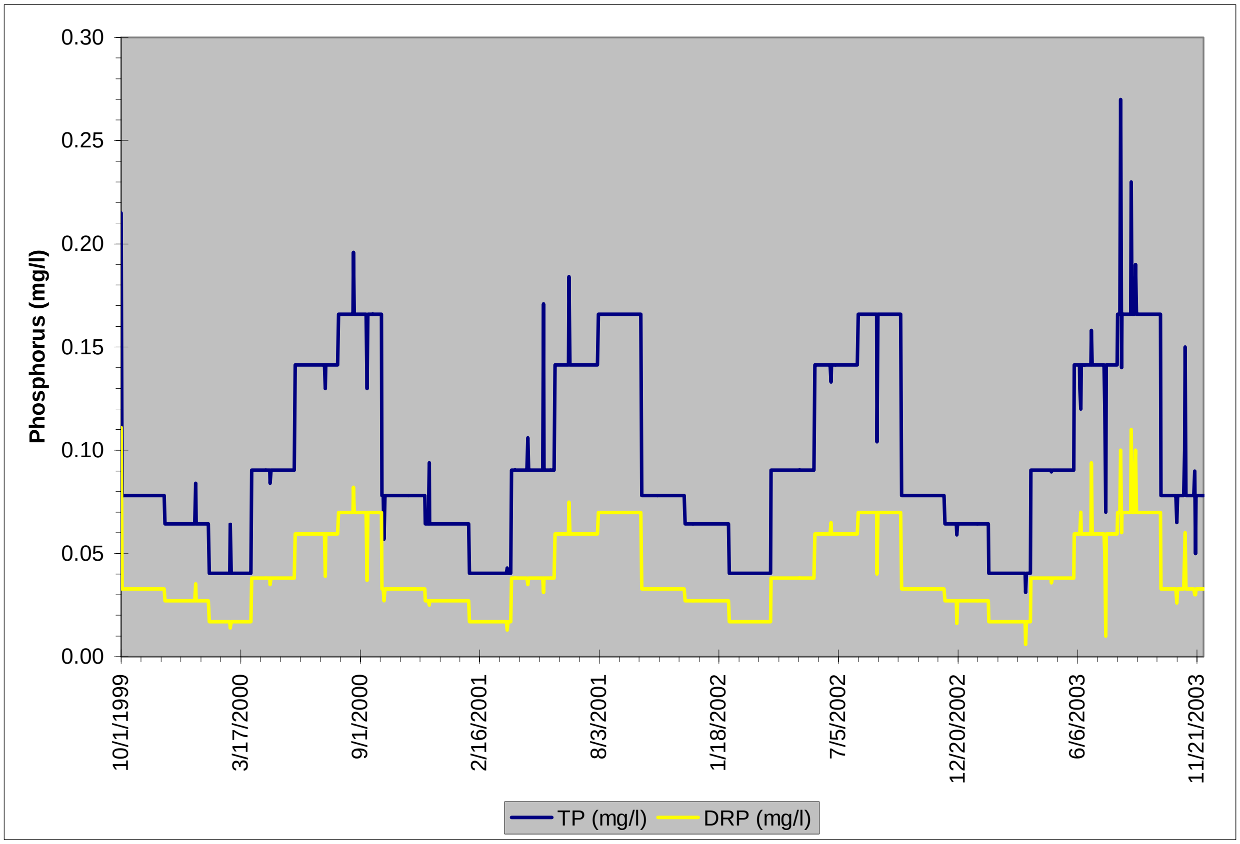
Swamp Watershed Association (GWSA, 2006) provided a high quality historical dataset of water quality data from the Passaic River at the model boundary. These data, collected approximately quarterly since 1999, reveal no relationship with flow, but instead show a strong seasonal trend. Bi-monthly average total phosphorus concentrations at the outlet of the Great Swamp in the Passaic River at Millington Gorge are provided in Table 6 below. Bimonthly average concentrations for total phosphorus were used along with actual measured concentrations to develop a seasonally-varying boundary condition for total phosphorus at the Passaic River headwater boundary. The average percent dissolved reactive phosphorus was used along with actual measured concentrations to develop the boundary condition for orthophosphorus. The resultant boundary conditions for total phosphorus and orthophosphorus are shown in Figure 11.

TABLE 6: Phosphorus Concentrations at Passaic River Headwater (Great Swamp Outlet)

Bi-Month	Total Phosphorus Average (mg/l)
Dec-Jan	0.064
Feb-March	0.040
April-May	0.090
June-July	0.141
Aug-Sept	0.166
Oct-Nov	0.078

In order to better characterize phosphorus conditions at the Passaic River headwater boundary, Omni performed a study to evaluate the relationship between tributary and point source phosphorus imports to Great Swamp versus export to the Passaic River. A thorough analysis of the export of phosphorus from the Great Swamp to the Passaic River is provided in Appendix D.

FIGURE 11: Passaic River Boundary Condition for Phosphorus



II.E.2.b.(2)(b) Internal Boundaries

Internal boundaries are concentration series for point source dischargers. These concentrations vary in time according to discharger and the parameter. The data used to derive internal concentration boundaries consist of periodic discharger water quality measurements, Omni 2003 STP effluent sampling, and DMR data.

The water quality data obtained from the different sources mentioned above were compiled within a single database and used to derive boundary conditions for the model. The frequency of discharger measurements and the parameters measured vary considerably. Also, DMR data for all parameters are not available for the entire simulation period for all dischargers. Therefore, methods to determine discharger boundary conditions vary according to water quality parameter and discharger. Table 7 below contains a summary of data sources used to derive internal boundary conditions for each discharger.

Daily water quality measurements were used as boundary concentrations for the respective day the samples were taken. The finest water quality sampling resolution is daily, which was obtained from some dischargers. Discrete sample values were interpolated to provide a continuous series of measurements. WASP automatically uses linear interpolation between consecutive discrete values to create a continuous series of concentration data.

When water quality samples were not available on a daily frequency, some assumptions were needed to form a continuous series of concentrations. In general, if data were not available at the beginning or end of a simulation year, the value was linearly interpolated between the last measured value in the previous year and the first measured value in the next year. When a value was not available on the previous year of simulation, the first measured record of the next year was used. In addition, if a value was not available for the last day of simulation, the last measured record was used. A detailed description of the methods for each water quality parameter is presented below.

Weekly or daily records of ammonia were available for most dischargers. Exceptions were: Cedar Grove, Verona, Warren Township Stages I-II, IV, and V, which all provided monthly data; Chatham Hill and New Providence, where only DMR data was available; and Reheis, where no data were available. Reheis is an industrial discharge; it was included in the flow model due to its flow contribution. It was assumed that no ammonia is discharged from Reheis.

TABLE 7: Summary of Data Sources for Discharger Boundary Conditions

DAFLOW Node	WASP Segment	Reach	Discharger	Data Sources
11-20	168	Passaic	Berkeley Heights WPCP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling, DMR data
10-2	137	Dead river	Bernards SA – Harrison Brook STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling
11-70	218	Passaic	Caldwell Boro STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling, DMR data for NO3
16-12	291	Peckman	Cedar Grove Twp STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling, DMR data
11-28	176	Passaic	Chatham Hill STP	DMR data
11-30	178	Passaic	Chatham Twp – Chatham Glen STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling, DMR data
11-54	202	Passaic	Florham Park SA	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling
7-36	109	Whippany	Hanover SA	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling
11-62	210	Passaic	Livingston Twp STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling
11-8	156	Passaic	Long Hill Twp – Stirling Hills STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling
11-41	189	Passaic	Madison Chatham Joint Mtg – Molitor	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling
7-4	77	Whippany	Morris Twp – Butterworth STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling
7-17	90	Whippany	Morristown Town STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling
7-48	121	Whippany	Parsippany-Troy Hills SA	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling, DMR data for NO3
4-4	29	Ramapo	Pompton Lakes Borough MUA	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling, DMR data for NO3
11-22	170	Passaic	Reheis Chemical	DMR data and Omni sample on 7/6/05
6-2	56	Rockaway	Rockaway Valley Regional SA	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling, DMR data for NO3
5-22	53	Pompton	Two Bridges SA	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling
16-5	284	Peckman	Verona Twp STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling, DMR data for NO3
2-4	7	Wanaque	Wanaque Valley Regional SA	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling
11-12	160	Passaic	Warren Twp Stage I&II STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling, DMR data for DO
10-4	139	Dead	Warren Stage IV STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling, DMR data for DO
10-12	147	Dead	Warren Stage V STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling, DMR data for DO
14-2	260	Singac	Wayne Twp – Mountain View STP	Discharger data from 10/01/1999 to 11/30/2003, Omni 2003 sampling

Nitrate was not measured by most dischargers with enough frequency for model input. The sampling frequency varies from daily to no samples at all over the simulation period. When data were not available for extended periods, DMR data were used. Since DMR data represent monthly averages, a step interpolation method was used to fill in the missing data for those respective months. If neither discharger data nor DMR data were available for a discharger, then a straight average of Omni's 2003 sampling results was used.

Organic nitrogen (OrgN) is not sampled by dischargers. In order to derive OrgN boundary conditions, OrgN was calculated from Omni's sampling results by subtracting NH_3-N from TKN. An average of the data was used for headwater boundaries and for discharger boundaries on days when values measured by Omni were not available.

Orthophosphate (OrthoP) is also not directly measured by dischargers, which are required to sample only total phosphorus (TP). Omni's 2003 STP effluent sampling results contain data for both TP and dissolved orthophosphate. An average ratio between TP and OrthoP values from Omni 2003 STP effluent sampling was calculated for each discharger and used to derive discrete OrthoP values based on discharger samples of TP. Organic phosphorus (OrgP) is also not measured by dischargers; OrthoP values for each discharger were subtracted from the sampled TP values to calculate the OrgP values used in the model.

Dissolved Oxygen is a common measurement required by NJ permits, and generally weekly or daily records are available. Exceptions are: Chatham Hill, where only DMR data were available; Verona and Warren Township Stages I-II, IV, and V, where only monthly data were provided; and New Providence and Reheis, where no data were available. When DO data were not available, average values from dischargers with similar flow were used.

Ultimate CBOD values were calculated based on CBOD5 data, using a multiplying factor of 1.6 (Table 6.5 page 273. Robert V. Thomann and John A. Mueller's, 1987). CBOD data were available from discharger and Omni effluent sampling data.

Appendix M contains an electronic copy of the boundary conditions used in the water quality model for each water year. The boundary conditions show the data available for each discharger and the calculation methods used to derive parameters that were not available in the database.

II.E.2.c. Loads

Loads are the mass of a given substance that is added to a WASP control volume during a given period of time. In contrast to water quality boundary conditions, loads do not necessarily have a flow boundary associated with them. In the case of the Passaic River Basin model, loads are used to represent inputs of constituents originating from nonpoint sources, minor discharges, CSOs, and to account for reaeration due to major waterfalls. Loads are entered in the system in a three hour time step (flow resolution) through a nonpoint source file. Loads of NH_3-N, NO_3-N, OrgN, OrthoP, OrgP, DO and CBODu are estimated using WAMIT and the NPS file is then created and imported into the WASP project.

II.E.2.c.(1) Nonpoint Source Loads

In the Passaic River Model conceptualization, nonpoint source loads include the constituent mass associated with the incremental watershed flows within the model extent. It does not include nonpoint sources in the headwaters, since headwater flows and constituent concentrations are assigned as boundary conditions to the model. Incremental watershed flows are separated (as described in Section II.F.2.a of this report) into runoff and tributary baseflow. The loads associated with each flow component are discussed below.

II.E.2.c.(1)(a) Runoff

Nonpoint source pollution can be a considerable fraction of the pollutant load to rivers. This becomes critical during storm events, when large volumes of surface runoff reach the water bodies. Nonpoint source loads vary considerable according to the source area. Factors that influence the concentration of water quality constituents for surface runoff are land use, soil type, the existence of best management practices, and the duration and the intensity of storm events.

Runoff NPS loads to the system were derived using average event mean concentrations (EMCs) of water quality constituents for each land type. Stormwater sampling conducted specifically for this project in 2003, stormwater sampling collected in the mid-1990s for the Whippany River project, and more recent stormwater sampling conducted in the Raritan River Basin by Omni, were used to derive EMCs. More details about the storm water data collected in 2003 are available in the Non-Tidal Passaic River Basin Nutrient TMDL Phase 1 Report (TRC Omni, 2003).

EMCs were calculated by averaging concentrations first within each storm at each station, then among storms at each station, then among stations for each land use category. Averages within storms were flow-weighted. In some cases, where a direct estimate of flow was not available, precipitation was used as a surrogate for flow to weight the results. Flow-weighting had only a minor impact on the results. This study benefited from the considerable amount of local stormwater data available. The use of EMCs is preferred because the scale of analysis attenuates any “first flush” impact; also, the stormwater data support the premise of constant runoff concentrations irrespective of timing within the storm. In other words, samples taken near the beginning of storms do not necessarily contain the highest pollutant concentrations. Furthermore, concentration variability among sites is much greater than variability within sites, lending further credence to the approach of tying constant runoff concentrations to land uses.

The EMCs provide the fundamental basis for estimating loads to the system. In addition to the EMCs, a methodology was developed to account for spatially variable EMCs, best management practices, the effects of storms with different intensities, and the volume of flow generated during the storm event. This methodology is explained in detail in the WAMIT section of this report.

The required parameters for each sub-basin include: the area of each land type in the sub-basin, the area-weighted curve number (CN), and the EMCs for NH_3-N, NO_3-N, OrgN, OrthoP, OrgP, DO and CBODu for each land type. Land use types are subdivided into residential, commercial, agricultural, forest, wetlands and barren. These land use types were used based on the Anderson type I land use classification, with the original urban land type subdivided into residential and commercial (all urban land use except residential). Since EMCs for barren land were not available for the storm water sampling events, they were assumed to be the same as forest EMCs. Barren land and agriculture represent very small land uses in the Passaic River Basin.

Table 8 shows which stormwater sites were used to characterize each land use category. An additional wetland stormwater site from the Whippany River study was not used because, based on technical concerns raised during the Whippany River pilot study, it appeared that some of the samples were affected by flooding from the Whippany River itself. In addition, one of the stormwater

TABLE 8: Stormwater Sites Used to Characterize Each Land Use Category

Study Year	Basin	Watershed	Station	Station Type	Land Use Category
2003	Passaic	Dead	SW5	Residential (Construction)	Residential
2003	Passaic	Upper Passaic	SW7	Rural Residential	Residential
1996-1998	Passaic	Whippany	LS-3	Mixed Use	Residential
1996-1998	Passaic	Whippany	LS-4	Residential	Residential
2003	Passaic	Ramapo	SW3	Highway	Commercial
2003	Passaic	Pompton	SW4	Industrial/Commercial	Commercial
2003	Passaic	Upper Passaic	SW6	Corporate Center	Commercial
2003	Passaic	Lower Passaic	SW8	Old Urban	Commercial
1996-1998	Passaic	Whippany	LS-2	Mixed Urban	Commercial
2004	Raritan	Neshanic	AgCrop	Agricultural Cropland	Agriculture
2004	Raritan	SB Raritan	AgPast	Agricultural Pasture	Agriculture
2001-2002	Raritan	Beden / Pike	A	Agricultural	Agriculture
2003	Passaic	Ramapo	SW2	Forest	Forest
1996-1998	Passaic	Whippany	LS-1	Forest	Forest
2003	Passaic	Whippany	SW1	Wetlands	Wetlands

samples taken during the Phase I sampling at site SW1 (10/14/2003 at 17:43) was excluded from the characterization of wetland runoff quality because it was unusually high in phosphorus concentration and would have skewed the EMC for wetland runoff. Whereas all of the other stormwater samples from site SW1 contained total phosphorus concentrations within a narrow range around the average, the excluded sample contained ten times the maximum concentration from all the other stormwater samples at that location.

EMCs calculated for each land use are provided in Table 9. Recall that organic nitrogen and organic phosphorus are both calculated as TKN minus NH_3 and TP minus OrthoP, respectively. Dissolved oxygen is not frequently measured in stormwater, and in any case the DO delivered to a stream from runoff might be very different than DO measured in runoff at a particular location. For these reasons, EMCs for DO were adjusted during calibration and varied from 5 to 8 based on land use type and sub-basin.

TABLE 9: Runoff EMCs for Each Land Use Category

Constituent	Residential	Commercial	Agriculture	Wetlands	Forest
NH_3-N	0.16	0.21	0.10	0.12	0.04
NO_3-N	0.94	0.65	1.42	0.76	0.26
Org-N	1.27	0.90	1.09	1.58	0.54
OrthoP	0.103	0.076	0.261	0.170	0.023
Org-P	0.217	0.149	0.183	0.186	0.064
$CBOD_5$	2.7	4.2	3.8	5.9	1.3

The area of each land use type and the area-weighted CN were obtained using GIS tools and digital layers. The NJDEP land use shapefile with 1995 land use data, the State Soil Geographic (STASGO), and SCS tables with CN values for each combination of soil type and land use were used to derive the area-weighted CNs. It is important to note that curve numbers were NOT used to calculate any flows for the model. Flows were provided by DAFLOW and separated, as described in Section II.F.2.a of this report, into tributary baseflow and runoff. Curve numbers were used only to estimate the proportion of runoff flow that is generated by each land type in order to properly weight the EMCs for each sub-basin.

The process of obtaining the area-weighted CN starts with the union of the land use and STASGO layers to define polygons with unique combinations of soil type and land use. After these polygons were defined, their area was calculated and CN values were assigned to each individual polygon, according to its respective land use and hydrologic soil group. The area-weighted CN was obtained by grouping areas with the same land use type, and calculating the weighted average CN based on the area of each polygon. Appendix C contains the CN values used for each land use type and hydrologic soil group (SCS, 1986), as well as the composite CNs used for each land use in each contributing subwatershed.

The feature of being able to vary CNs and EMCs allows the effects of BMPs to be considered in the analysis. In some watersheds, the effect of BMPs and the connectivity between pervious and impervious areas, and the land use distribution over the watershed, can make a big difference in NPS loads. EMCs and CNs can be adjusted to reflect the impact of these BMPs. For example, watersheds with a high percentage of forested land along the water bodies are likely to have reduced NPS loads due to pollution trapping in the riparian buffers. Likewise, areas with a high number of detention basins and wetlands that receive storm water runoff, can present a dramatic reduction in NPS loads. The nonpoint source model allows these considerations to be included in simulation of future scenarios. A few sub-basins in the Passaic basin were subject to reductions in the EMCs to accommodate the effect of existing BMPs. These areas are identified in the calibration section of this report.

II.E.2.c.(1)(b) Tributary Baseflow

Tributary baseflow concentrations were not assumed to vary by land use type, although phosphorus concentrations were varied by sub-basin within WAMIT as described below. Tributary baseflow in this context is not primarily the direct discharge of groundwater to modeled streams. Tributary baseflow also reflects dry-weather discharge of tributaries within each contributing sub-basin. Omni conducted sampling of small watersheds in pristine areas and in areas affected only by nonpoint sources during low flow periods to estimate tributary baseflow concentrations in the Passaic River Basin (TRC Omni, 2004). Total phosphorus concentrations in baseflow ranged from 0.02 to 0.09 mg/l in pristine locations, and from 0.02 to 0.13 in areas affected only by nonpoint sources. The percent forest and percent wetland within the watersheds contributing to the baseflow sampling locations appeared to exert the most influence on the phosphorus concentrations measured, although baseflow data from specific land uses were not available such that land use type could be used to estimate tributary baseflow concentrations.

The results from the sampling station in Troy Brook (TBB) were used to characterize tributary baseflow for all parameters except phosphorus, since TBB most closely resembles the contributing watersheds to the model in terms of forest and wetland composition. Dissolved oxygen concentration for tributary baseflow was set to 3 mg/l, reflective of the substantial baseflow inputs of low DO waters from wetlands in the contributing watersheds. Chlorophyll concentrations in tributary baseflow were assumed to be zero. Tributary baseflow concentrations (other than phosphorus) used for the Passaic River Basin are provided in Table 10. The tributary baseflow concentrations were applied uniformly as a first approximation; model calibration and validation determined the need for a few sub-basin specific concentrations, as discussed in ensuing calibration sections.

TABLE 10: Tributary Baseflow Concentrations for Contributing Watersheds

NH_3-N (mg/l)	NO_3-N (mg/l)	Org-N (mg/l)	$CBOD_5$ (mg/l)	DO (mg/l)
0.09	0.56	0.09	2.0	3.0

In consultation with NJEC and NJDEP, a broader set of baseflow sampling locations were selected to characterize phosphorus in tributary baseflow. Stations were selected that bear strong similarity, in terms of forest and wetland composition, to the contributing watersheds of specific branches where tributary baseflow originates in the model. Based on baseflow sampling in 2003 and 2004, tributary baseflow phosphorus concentrations were set according to stream branch groupings to the values in Table 11.

TABLE 11: Tributary Baseflow Phosphorus Concentrations for Contributing Watersheds

Model Branch Groupings	Basis (Stations)	TP (mg/l)	Ortho P (mg/l)
Forest Dominated (Wanaque - 2)	RAB, HAB, PRB, PA1	0.045	0.021
Major Tribs (3, 4, 5, 6, 7, 13)	WIB, TBB, CrookB1, WI1	0.054	0.023
Upper Passaic / Minor Tribs (8, 9, 10, 11, 12, 14)	DRB, WIB, SBB, TBB	0.063	0.022
Lower Passaic (15, 16, 17)	SBB, P2	0.060	0.031

II.E.2.c.(2) Minor Dischargers

Minor dischargers within the model extent (Table 1) that were not included in the flow model due to their insignificant flow were added directly to the model as additional loads using WAMIT. Minor discharges can represent any pollution source discharging directly into a modeled waterbody or to tributaries that are not explicitly being simulated, but are within the model extent. Pollution sources that are located upstream of the headwater boundaries of the model were not added as minor discharges, since headwater boundary conditions were derived based on actual stream sampling; adding a load upstream of the headwater would double-count the minor discharger load.

Minor discharger datasets generally consist of average concentrations and flows. Although minor dischargers do not represent a flow source to the model, their flows were used to estimate loads. Data needed to calculate minor dischargers' loads in WAMIT are average effluent flows and concentrations for the parameters of interest. In addition, minor dischargers were assigned to a model node, which represents the location where the loads are input into the system. In order to calculate minor dischargers' loads, monthly average effluent flows and modeled constituent concentrations were assembled from DMR data for each facility. WAMIT calculates the daily loads and includes them in the correct position in the NPS file used by WASP.

II.E.2.c.(3) Combined Sewer Overflows (CSOs)

The existence of combined sewer overflows (CSOs) in the City of Paterson, NJ created the need to assess the impact of their respective loads to the Passaic River between Great Falls and Dundee Dam. A model to estimate the CSO loads for the entire simulation period using SWMM was developed by Hydroqual (Hydroqual, 2004). The model outputs are daily loads of NH_3-N, NO_3-N, OrgN, OrthoP, OrgP, DO and CBODu for each outfall location.

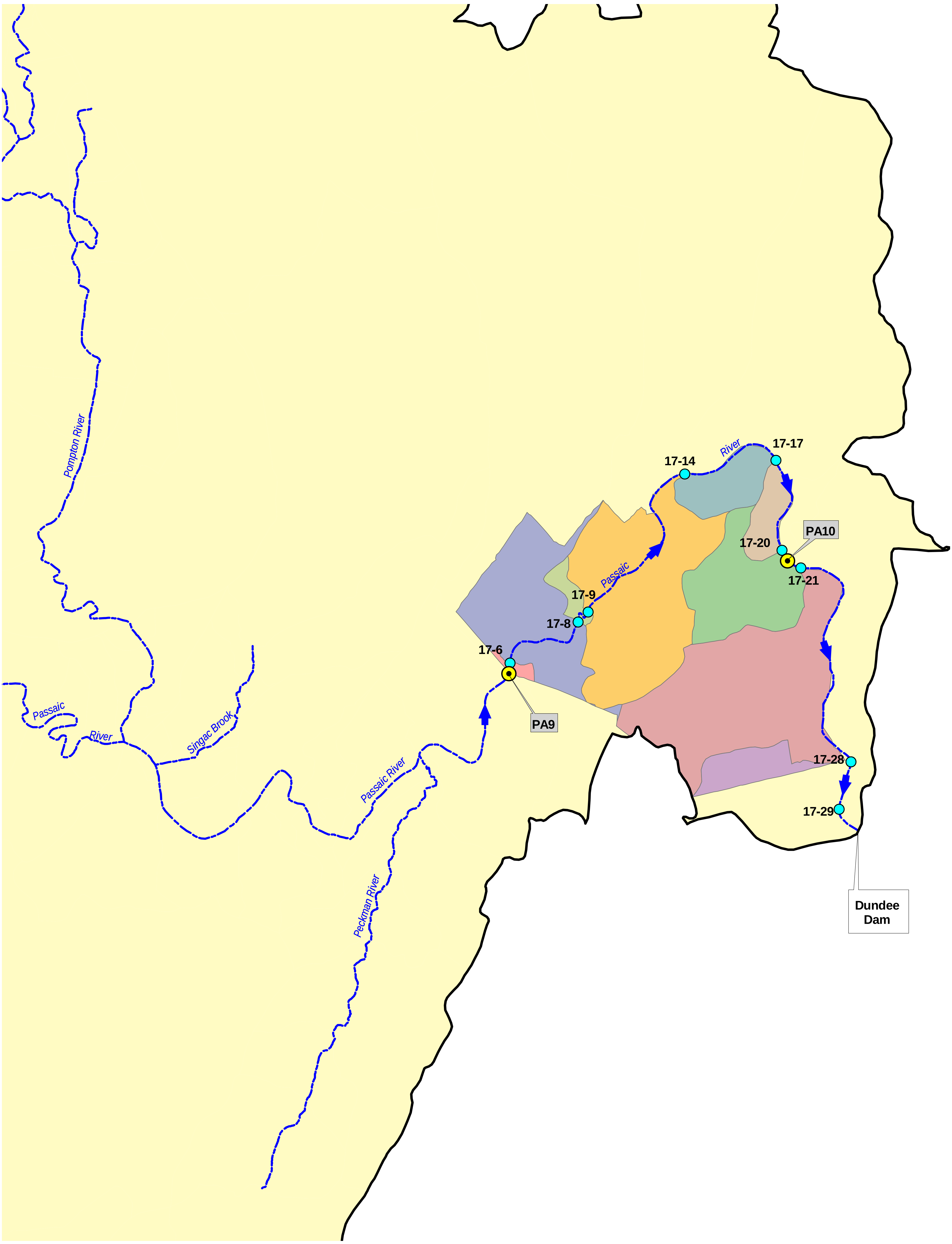
A structure was developed in WAMIT to include the CSO loads provided by Hydroqual. CSO drainage areas (sewersheds) were separated from the originally delineated sub-basins to provide NPS inputs to the model, and to add the CSO loads directly into the respective nodes where they are located. CSO loads are imported by WAMIT and incorporated into the NPS file in the correct locations. CSO loads are given by sewersheds instead of sub-watersheds. A sewershed can be located within one or more sub-watersheds, and the ridges defining sewersheds and sub-watersheds are not necessarily the same. The original sub-basins delineated for the Passaic River Basin model had to be edited in order to avoid double-counting of pollutant loads. The area of the sewersheds were subtracted from the original sub-basins and the land use distributions were recalculated. In addition, the flows originating in the CSO sewersheds were subtracted from the total sub-watershed flows used to estimate the NPS loads.

Because storm water flows from SWMM and WAMIT are calculated using different assumptions, the flows provided by SWMM were not used directly. Instead, the flow from the original sub-basins containing CSOs were assumed to be uniformly distributed over the watershed, and the portion attributed to the CSO sewershed was subtracted from the original flow. This option of adjusting the flows based on a percentage of effective contributing area was preferred to avoid inconsistencies due to different methodologies used to derive stormwater flows. The CSO loads were therefore entered as daily concentrations of water quality constituents. Figure 12 shows the CSO sewersheds, model sub-basins, and nodes to which CSOs are assigned.

II.E.2.c.(4) <u>Waterfall Reaeration Loads</u>

Waterfalls can have a great impact on oxygen transfer in streams. There are two major waterfalls in the non-tidal Passaic River: Little Falls and Great Falls. These falls are located in the lower Passaic River in the Paterson area. Little Falls has a water head of 35 feet and Great Falls 65 feet (NJDEP, 1987). Waterfall reaeration in the Passaic River has been studied previously (e.g. Uchrin et al., 1985). An approach suggested by Butts and Evans (1983) was adopted to account for the oxygen transfers due to waterfalls. The authors developed an empirical equation that correlates water head elevation (H), temperature (T), dam type coefficient (a), and water quality coefficient (b), to derive a ratio of DO deficit above and below the waterfall or dam (r) given by Equation 3.

$$r = 1 + 0.38abH(1 - 0.11H)(1 + 0.046T) \qquad (3)$$



February 23, 2007

FIGURE 12:
CSO Sewersheds

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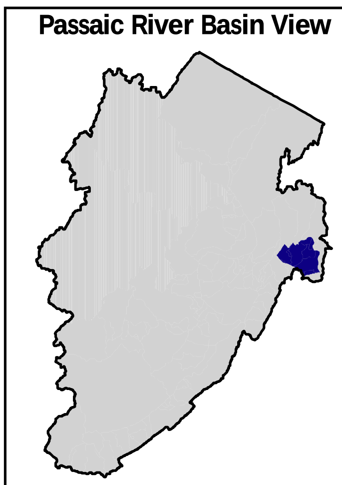
Stream
Omni Stream Sampling Location
Model Node ID
Passaic River Basin

Sewershed (Node ID)

17-6	17-20
17-8	17-21
17-9	17-28
17-14	17-29
17-17	

Passaic River Basin View



4000 0 4000
Feet

Although WASP documentation mentions that Dam/Waterfall reaeration can be simulated by the model, this function was not functional using externally specified flows. Therefore, an equivalent load of oxygen was calculated externally using the Butts and Evans relationship.

Values of r are calculated every three hours (every time step in the flow model) using Equation 3 and then used to estimate the equivalent DO concentration downstream of each waterfall, based on flow and DO concentrations above each waterfall. This is somewhat iterative, since simulated concentrations above the dam are needed to calculate the equivalent concentration downstream. After the downstream concentrations are calculated, oxygen loads are added to the system at the appropriate model nodes. Little Falls and Great Falls loads were added to nodes 15-11 and 17-9, respectively, and they can be visualized using WAMIT.

The equation adopted to calculate reaeration due to waterfall is most sensitive to the waterfall height and temperature. The dam type coefficient and water quality coefficient do not impact DO concentrations downstream of either falls significantly. The waterfall height was obtained from studies previously made for the Passaic River (NJDEP, 1987). The dam type coefficients and water quality coefficients were obtained from Chapra, 1997.

II.E.2.d. Model Parameters and Time Series

In addition to water quality inputs through boundary conditions and direct loads, kinetic transformation coefficients, as well as descriptive data that represent properties of stream segments, are needed for the model. Kinetic parameters are coefficients that specify the rate at which water quality constituents are reacting given the existing environmental conditions. Kinetic parameters are global, meaning they affect all compartments of the system and do not change in time. Although their value is fixed in time, they are often assigned temperature correction coefficients. Descriptive parameters include stream water temperature, solar radiation, sediment oxygen demand, light extinction, and other data that describe environmental properties of a given compartment of the model. These data are not simulated, but they impact chemical-physical transformations in the water column. Descriptive data can vary according to model segment and some of them vary in time as well.

II.E.2.d.(1) Kinetic Parameters

The kinetic parameters used in WASP are a function of the systems that are simulated. In the case of the Passaic River Basin model, systems that are being simulated include ammonia, nitrate, organic nitrogen, orthophosphate, organic phosphorus, chlorophyll-a, dissolved oxygen, CBOD, benthic algae and detritus. Most of these parameters were obtained from the literature; however some were calculated and others required extensive calibration.

The non-tidal Passaic River Basin includes water bodies with very distinct characteristics. Because kinetic parameters are global, choosing representative parameters for all model segments is a very challenging exercise. Section 2.H of this report describes the calibration process and presents all global kinetic parameters, their calibrated values, and literature range, when applicable.

The stoichiometric composition of organic mater, which is used as kinetic parameters, was calculated using compositions idealized by Redfield et al. (1963), and Stumm and Morgan (1981). The dry-weight composition can be idealized as the following detailed representation of the photosynthesis/respiration process:

$$106CO_2 + 16NH_4{}^+ + HPO_4{}^{2-} + 108H_2O \Leftrightarrow \underbrace{C_{106}H_{263}O_{110}N_{16}P_1}_{Algae} + 107O_2 + 14H^+$$

The stoichiometric parameters are obtained using the atomic weight of the substances:

$$\text{mgN/mgC}: \frac{16*14}{106*12} = 0.176$$

mgP/mgC: $\frac{1*30}{106*12} = 0.0235$

mgO/mgC: $\frac{107*32}{106*12} = 2.69$

II.E.2.d.(2) Descriptive Parameters

Descriptive parameters in WASP are assigned for each model segment. Some are time variable, while others are fixed in time. Some descriptive parameters consist of measured environmental data, such as stream water temperature and solar radiation. Other parameters, such as SOD and the fraction of segment bottom covered with benthic algae (or macrophytes), were assumed as calibration parameters. The descriptive parameters used for the Passaic River Basin model, and how they were implemented in the model are discussed below.

II.E.2.d.(2)(a) Time Functions

Descriptive data that can be entered as time functions in WASP are stream water temperature, solar radiation, light extinction, benthic fluxes of ammonia and phosphate, air temperature, ice cover, zooplankton population, reaeration, and velocity. For the Non-Tidal Passaic River Basin model, stream water temperature, solar radiation and ammonia benthic flux are used as descriptive time functions.

WASP can accept up to four different stream temperature time functions with a maximum of 4,000 records. Continuous stream temperature in the Passaic River watershed was available at two locations. The first is USGS station 01389005 just downstream of the confluence between the Passaic and Pompton Rivers. Station 01389005 measures and records temperatures at three locations: one at the center of the river, one at the right bank and one at the left bank. The second location is USGS station 1388000 in the Ramapo River at Pompton Lakes. Temperature measurements at these stations are available at one-hour intervals. Because WASP can accept up to 4,000 records per time function, the one-hour interval data was averaged to a 3-hour interval. The impact of this change in stream temperature data resolution was evaluated and no significant changes occurred in the simulations.

Three stream water temperature time functions were used in the model: USGS 01389005 Right[2], USGS 01389005 Left[2] and USGS 1388000. The time functions were assigned to given model branches according to their correlation to diurnal temperature measurements taken during the 2003 summer sampling. Table 12 shows the stream water time series assigned to individual branches. These time series were scaled up or down in individual branches as described in Section II.E.2.d.(2)(b).

The stream temperature data obtained from the USGS is available for most times between 10/01/1999 to 11/30/2003. However, some periods are missing, most of them in the winter. When stream temperature was not available, it was interpolated using conditions before and after the period without data, or they were calculated based on correlations derived from existing temperature data for other stations with available data.

Solar radiation records were available during portions of 2003 as measured by Omni within the watershed. Additional data during other times were obtained from a station maintained by Rutgers University and located at Cook Campus in New Brunswick, New Jersey. Hourly solar radiation records are available for most of the modeling time frame. The hourly solar radiation data had to be averaged for a 3-hour time step in order to be used as a time-series in WASP. Solar radiation records are available for almost the entire simulations period. When records were not available, average values from the same period during other years were used.

TABLE 12: Temperature Gauge Assignments

Branch	River	Temperature Time Series
1	Pequannock	USGS01389005LEFT
2	Wanaque	USGS01389005LEFT
3	Pequannock	USGS01389005LEFT
4	Ramapo	USGS1388000
5	Pompton	USGS01389005LEFT
6	Rockaway	USGS01389005RIGHT
7	Whippany	USGS01389005RIGHT
7	Whippany downstream Speedwell Lake	USGS01389005RIGHT
8	Rockaway downstream Whippany	USGS01389005RIGHT
9	Upper Passaic upstream Dead River	USGS01389005RIGHT
10	Dead River	USGS01389005RIGHT
11	Upper Passaic downstream Dead River	USGS01389005RIGHT
12	Mid Passaic	USGS01389005RIGHT
13	Lower Passaic upstream Singac Brook	USGS01389005RIGHT
14	Singac Brook	USGS01389005RIGHT
15	Lower Passaic downstream Singac Brook	USGS01389005RIGHT
16	Peckman	USGS01389005RIGHT
17	Lower Passaic downstream Peckman	USGS01389005RIGHT

Benthic ammonia flux was added in some sections of the Passaic River where the sediment bed and wetlands are driving transformations in the water column during some periods. Benthic ammonia was added each simulation year from June 1st through August 30th to account for additional decomposition of organic matter on the sediment bed and from macrophytes. During this time period, a constant value of 200 mg/m^2/day was added to segments of the Lower Passaic River and Mid Passaic River. This value was obtained through calibration.

II.E.2.d.(2)(b) Descriptive Data Coefficients

Descriptive data coefficients are assigned to stream segments. They include: multipliers of a temperature time function, light extinction coefficient of a segment, particulate fraction, SOD temperature correction factor, and fraction of bottom segment covered by benthic algae (or macrophytes). Because of their local character, parameters such as SOD and fraction of bottom segment covered by benthic algae were extensively used for calibration. Other descriptive data coefficients, like temperature multipliers and light extinction, were calculated.

The light extinction coefficient assumes an important role in the Passaic River Basin model. Because diurnal DO variations occur mostly because of the presence of macrophytes attached to substrate at the stream bottom, the effects of light extinction influence the diurnal DO variations by impacting directly the amount of light reaching the stream bottom. Light extinction coefficients were derived based on light extinction measurements performed at Omni sampling stations during the summer of 2003, and on the Beer-Lambert law, which models light extinction as an exponential decay. The Beer-Lambert law is presented below.

$$I(z) = I_0 e^{-K_e Z}$$

Where:
$I(z)$ = light energy (ly hr^{-1})
I_0 = Surface light energy (ly hr^{-1})
K_e = an extinction coefficient (m^{-1})
Z = depth

The measurements conducted by Omni provide light energy at the surface and at several depths for each sampling station. The surface light energy and the light energy at the deepest measurement were used to derive the value of K. Generally, two sets of measurements were available for almost all stations. A few stations had two measurements taken during the same event, as shown in Table 13 below. Measurements that resulted in unrealistic K1 values were not utilized, and are indicated in Table 13 as “out of range.” The K value was calculated for each event and the average K was used for the simulations. Table 13 presents the K values (m^{-1}) calculated for each sampling station. The light extinction coefficients were assigned to the model segments according to the reach and proximity to a given sampling station.

TABLE 13: Light Extinction Coefficients

Station	July Event K1 (m^{-1})	August Event K1 (m^{-1})	K average
DR1	4.6	2.8	3.7
PA1	7.4	2.7	5.1
PA10	2.7	2.7	2.7
PA11	4.9	6.4	5.6
PA2	5.2 / 5.5	6.1	5.6
PA3	6.8	8.8	7.8
PA4	Out of range	6.2	6.2
PA5	6.9	7.4	7.1
PA6	4.1	4.0	4.1
PA7	3.5	4.8	4.2
PA8	2.9	3.0/2.6	2.9
PE2	2.7	2.2	2.5
PK 1	1.7	1.8	1.7
PO1	2.1	1.5	1.8
PO2	2.5	2.5	2.5
PO3	2.7	2.3	2.5
RA1	2.4	2.6	2.5
RA3	2.7	2.5	2.6
RO2	2.0	2.3	2.2
WA2	1.7	3.3	2.5
WI1	1.6	1.8	1.7
WI2	6.1 / 3.0	2.9	4.0
WI3	7.3	2.7	5.0

Stream temperature multipliers were developed to account for differences of temperature between the USGS stations and the model segments to which they were assigned. These multipliers were derived by calculating the average ratio between observed temperatures at

Omni stations and the temperatures recorded at USGS stations during the same period of time. The stream temperature multipliers were assigned to each segment and used to scale the temperature time function at every time step. Table 14 presents the water temperature multipliers assigned to the branches of the model and the respective time function.

TABLE 14: Stream Temperature Correction Factors

Branch	River	Temperature Time Series	Temperature Correction Factor
1	Pequannock	USGS01389005LEFT	0.97
2	Wanaque	USGS01389005LEFT	0.95
3	Pequannock	USGS01389005LEFT	0.91
4	Ramapo	USGS1388000	1.00
5	Pompton	USGS01389005LEFT	0.97
6	Rockaway	USGS01389005RIGHT	1.01
7	Whippany	USGS01389005RIGHT	0.91
7	Whippany downstream Speedwell Lake	USGS01389005RIGHT	0.90
8	Rockaway downstream Whippany	USGS01389005RIGHT	0.90
9	Upper Passaic upstream Dead River	USGS01389005RIGHT	0.92
10	Dead River	USGS01389005RIGHT	0.93
11	Upper Passaic downstream Dead River	USGS01389005RIGHT	0.94
12	Mid Passaic	USGS01389005RIGHT	1.00
13	Lower Passaic upstream Singac Brook	USGS01389005RIGHT	1.00
14	Singac Brook	USGS01389005RIGHT	1.01
15	Lower Passaic downstream Singac Brook	USGS01389005RIGHT	1.01
16	Peckman	USGS01389005RIGHT	1.06
17	Lower Passaic downstream Peckman	USGS01389005RIGHT	1.02

Sediment oxygen demand and fraction of bottom segment covered by benthic algae were both used as calibration parameters for the Passaic River Basin model. SOD measurements were made at several locations for order of magnitude comparisons. Maps are provided in Figures 13 and 14 showing the final SOD values and fraction of bottom segment covered by benthic algae per segment. Recall that for the Passaic River Basin model, benthic algae is used in most places to represent macrophytes.

The last set of descriptive data coefficients includes settling rates and the dissolved fraction of water constituents in the water column. Settling rates represent the net effect of settling and resuspension. Settling rates were assumed as constant for the entire simulation period. Settling rates and dissolved fraction were also considered calibration parameters. Different settling rates were specified for each stream branch and vary from 0.001 to 0.6 cm/s. Phosphorus settling rate parameters were also calibrated to account for adsorption of orthophosphate to the sediment bed and extra phosphorus uptake by macrophytes in certain areas of the Passaic River due to influence of wetland meadows. This subject is explored in more detail in the calibration section of this report.

II.E.3. Model Outputs

The main outputs provided by the Passaic Basin Water Quality Model are time series of the simulated state variables at stream segments throughout the model extent. These variables are orthophosphate, total phosphorus (actually the sum of orthophosphate and organic phosphorus), ammonia, nitrate, organic nitrogen, chlorophyll-a, CBOD5 and dissolved oxygen. Other parameters, which are not state variables, such as flow, velocity, and depth, can also be output through the WASP model for the Passaic River Basin.

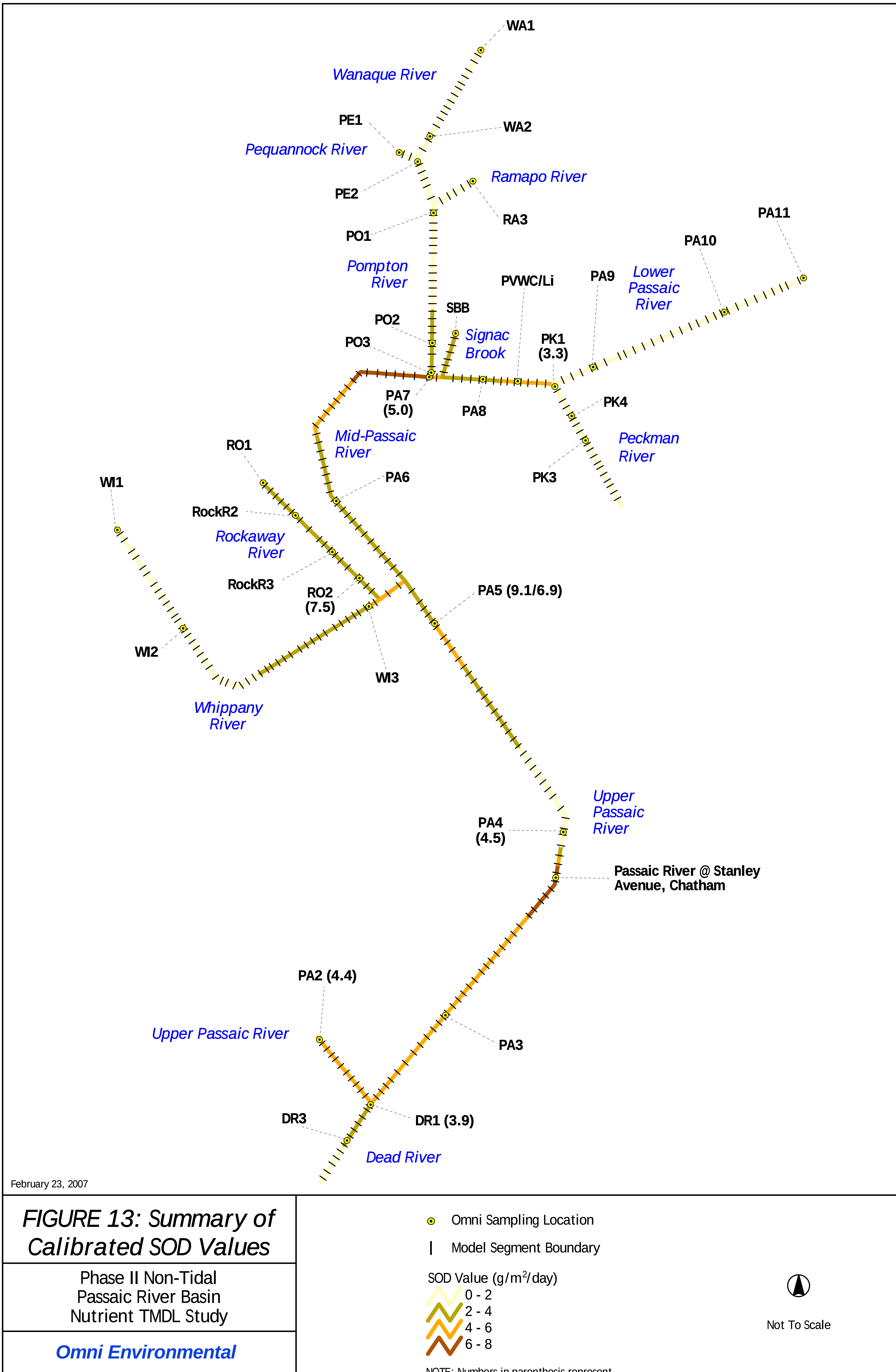


FIGURE 13: Summary of Calibrated SOD Values

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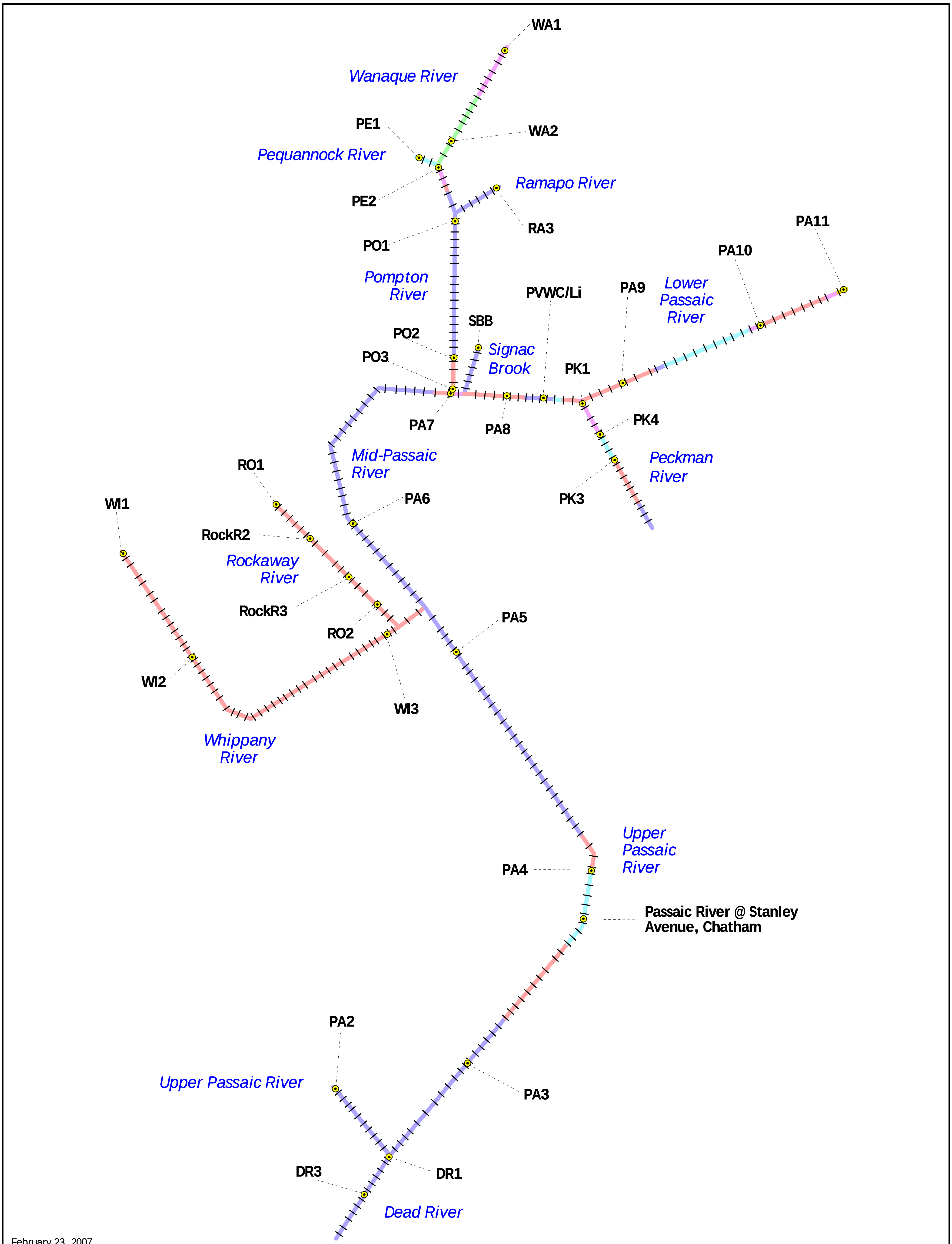

FIGURE 14: Fraction of Bottom Sediment Covered with Algae or Plants

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II.F. Model Integration

As explained previously, two models were used for the Non-Tidal Passaic River Basin model. The flow component of the study is provided by DAFLOW (Jobson, H. E., 1989), which applies diffusion analogy in conjunction with a Lagrangian solution scheme. The water quality component is simulated with WASP7 (Wool, et al., 2003), which applies an Eulerian solution scheme. WASP requires as inputs, flows, velocities, segment volumes, and depths calculated by DAFLOW. Therefore, a structure to integrate these models, which use distinct solution schemes, was developed. This chapter focuses exclusively on the integration between the models. The integration between DAFLOW and WASP includes translating data from distinct simulation schemes, creating a relationship between different stream segmentation frameworks, unit conversions, results interpolation, and writing a WASP HYD file.

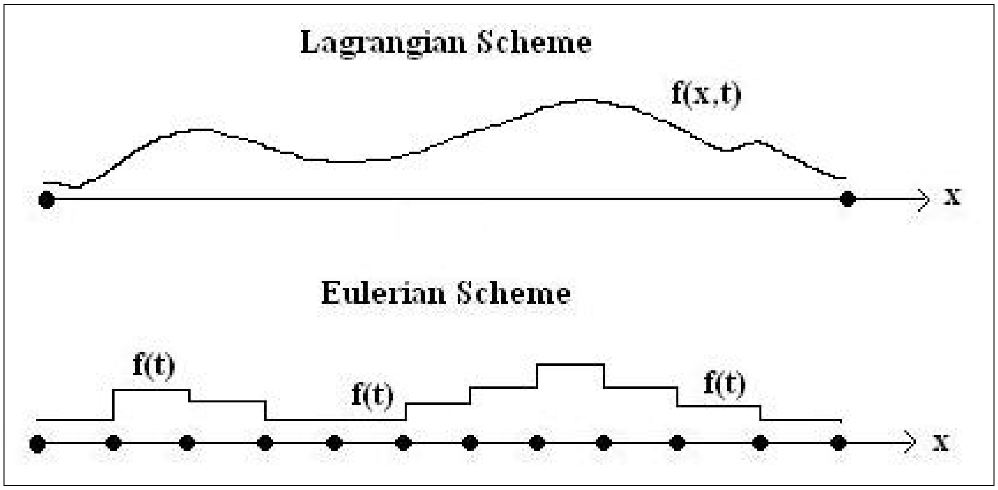
II.F.1. Critical Issues

II.F.1.a. Model Solution Scheme

WASP and DAFLOW use different modeling schemes. DAFLOW uses a Lagrangian solution scheme to route flow. The Langrangian approach simulates the dynamics of a system from the perspective of the center-of-mass of particles along the main axis. According to the Lagrangian framework, the decision variable is a function of space and time within a given segment. In contrast with the flow model, WASP simulates water quality variables using an Eulerian solution scheme, which tracks the particles along the axis from a fixed point of view. According to the Eulerian approach, the decision variables within a segment do not vary in space, only in time. Because the decision variable is constant within a simulation element, an Eulerian approach generally includes a fine system segmentation, with several simulation elements. The difference between the Lagrangian and Eulerian schemes can also be seen as analogous to the difference between continuous and discrete functions. Figure 15 shows a sample schematic of Lagrangian and Eulerian modeling frameworks.

The difference between modeling approaches creates the need to define some assumptions for data interpretation and consistency in order to use flow simulations from DAFLOW as a basis for WASP water quality simulations. The first assumption regards the spatial segmentation, and consists of having both models using the same segmentation framework.

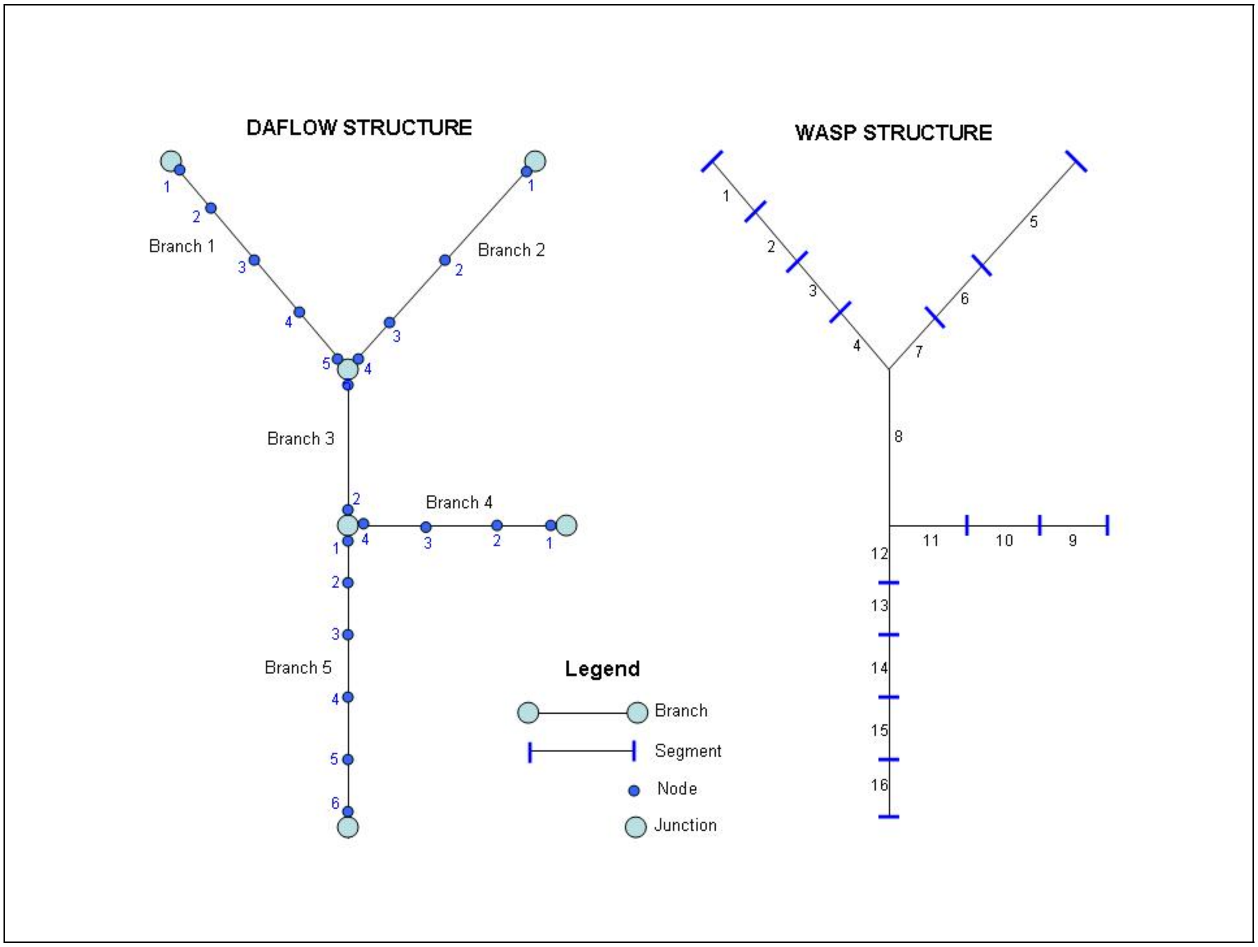
FIGURE 15: Lagrangian and Eulerian Modeling Frameworks



The conceptualization of a stream network according to DAFLOW consists of branches, junctions, grid points (nodes), and sub-reaches (segments). Branches are one-dimensional river segments. Each branch must start and end at a junction. A junction defines the beginning, end, and the connection between two or more branches. Nodes are positions along a branch. Each branch must contain at least two nodes, and every two nodes define a segment. The stream characteristics are defined for each node and are applicable for its downstream segment. Nodes are not necessarily equally spaced. Internal nodes may have tributary inputs, such as tributary streams, point source discharges, and diversions (tributary inputs are not defined for the first and last node of a segment). The input from a tributary is applicable immediately upstream of its respective node. Nodes within a branch have to be numbered sequentially starting from one at the most upstream node (Jobson, H.E., 1989). Segments are not originally defined as a modeling element for DAFLOW, thus no numbers are assigned to segments.

WASP's conceptual stream network framework is simpler than DAFLOW's. For a one-dimensional model setup, WASP segmentation consists only of stream segments. There are no particular rules for numbering the segments. The network connectivity is defined by assigning interfacial flow pair segments. Differently from DAFLOW's framework, nodes are not defined for the WASP stream network. Figure 16 shows examples of segmentation according to DAFLOW and WASP.

FIGURE 16: DAFLOW and WASP Segmentation



In order to make these two approaches compatible, WASP segments are defined as being the same as DAFLOW segments between two nodes, where the properties of a segment are given by the upstream node in DAFLOW. For example, the segment between nodes one and two of branch 1 corresponds to segment one in WASP stream network, which is assigned with node 1-1 properties. The segment between nodes 3 and 4 of branch 5 corresponds to segment 14 in WASP, which has the same properties as node 5-3.

According to WASP's segmentation scheme, nodes are not defined as an element. However, interfacial flow pairs between segments need to be defined. These pairs consist of flow interfaces between adjacent segments or between a segment and its boundary. Therefore, interfacial flow pairs correspond to nodes in the DAFLOW segmentation framework. For example, DAFLOW's node 2-2 corresponds to the interfacial flow pair from segment 5 to segment 6 in WASP's framework.

Another assumption to overcome is the difference in modeling schemes between the two models consists of making instantaneous results for a given DAFLOW node constant for its entire downstream portion until the beginning of the next node. This last assumption essentially converts a Lagrangian approach to an Eulerian approach by assuming the decision variables for a given segment in the longitudinal axis are constant for a given time step. This is a very reasonable assumption, since outputs from DAFLOW are already provided with some spatial or temporal averaging. The outputs of interest from DAFLOW are discharge, tributary discharge, cross-section area, and top width. The first two outputs, discharge at the node and tributary discharge at the node, are averaged for the time step. This value represents the flow at the interface of two segments within a time step, which corresponds to the interfacial flow values in WASP. Therefore, the values of interfacial flows are equivalent to the discharge output and the tributary boundary inflows at the node for a given time step. For example, the flow rate at DAFLOW's node 1-3 corresponds to the interfacial flow from WASP's segment 2 to segment 3. Therefore, since flows in WASP are defined for segment interfaces, not for segments, the flow rate outputs from DAFLOW do not require spatial averaging.

Differently from discharges, cross-section area and top-width outputs are averaged in space not in time by DAFLOW. The outputs from cross-section area and top-width represent instantaneous values at the end of the time step averaged over the segment. These values, associated with flows and segment length, are used to calculate segment volume, depth and velocities, which according to the Eulerian scheme should be constant within a segment for a given time step. Therefore, the segments outputs from DAFLOW at the end of a time step are used to calculate WASP's segments properties at the end of the time step, which is consistent with WASP's Eulerian scheme, and the mass balance within each segment.

Equation 4 shows the water mass balance for a time step t for any given segment. Vt is the volume at the end of time step t, Vt-1 is the volume at the end of the previous time step time, and Qt-1 is the net average incremental flow in the previous time step. Note that Qt-1 is the net flow variation, which includes contributing flows from adjacent segments plus or minus tributary inflows our outflows.

$$V_t = V_{t-1} + \Delta Q_{t-1} * t \qquad (4)$$

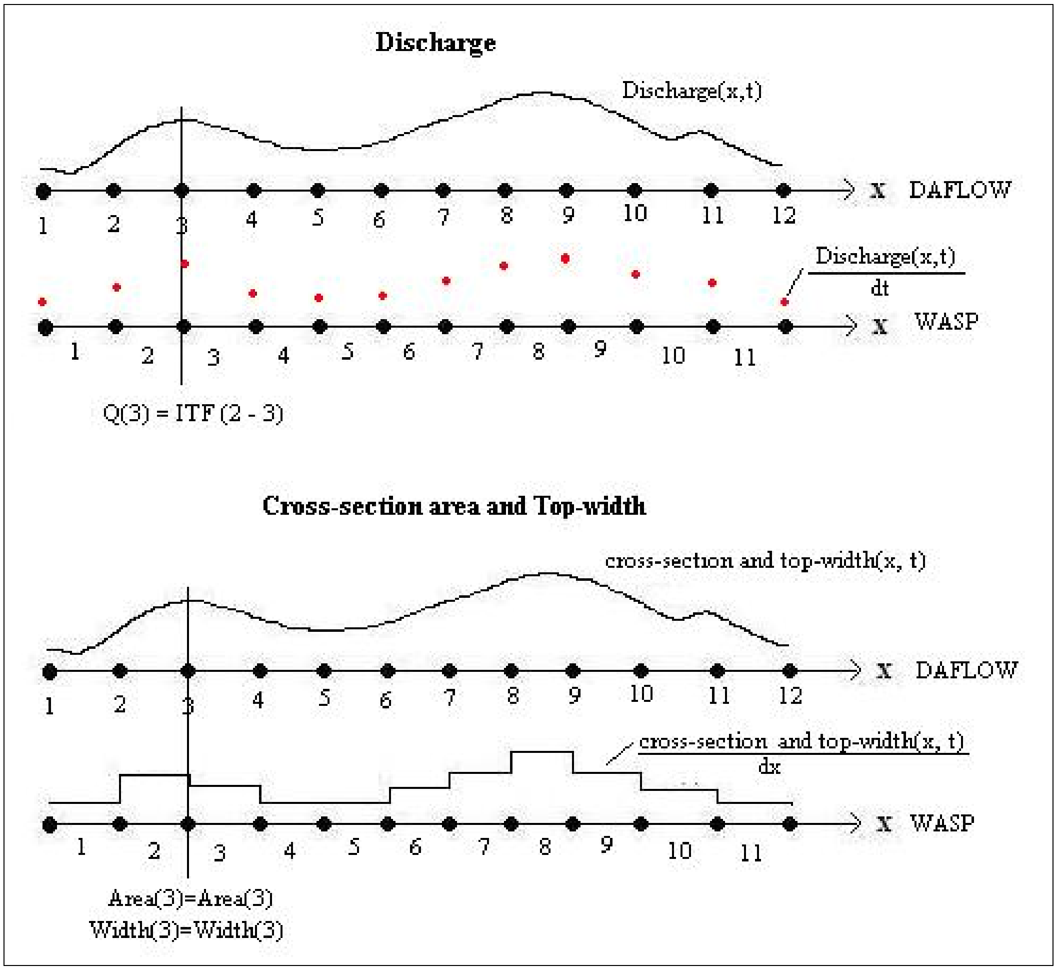
The Q term in Equation 4 consists of net interfacial flows from adjacent segments, and also tributary or boundary condition flows. The assumptions for data interpretation are also show in Figure 17.

Interfacial flow pairs for boundary segments also have to be defined. According to WASP's segmentation framework, each segment can have only one boundary. The interfacial flow pairs corresponding to the segment boundaries are listed first, followed by the interfacial flow pairs for the tributary flows.

The stream network in WASP and DAFLOW can be made compatible using the assumptions discussed previously. No additional flow spatial averaging is needed, since the segment properties for each time step provided by DAFLOW are already averaged for the segment that has its characteristics assigned by its upstream beginning node, and discharges for WASP are defined for segments interfaces.

After the conceptual stream networks of DAFLOW and WASP were made compatible using the assumptions of uniform segmentation and flow averaging for the segments, flow outputs from DAFLOW were assigned as flow inputs for WASP. The data sharing between DAFLOW and WASP is made through the HYD file.

FIGURE 17: Translation from Lagrangian to Eulerian Reference Scheme



II.F.1.b. Model Consistency

An important aspect of integrating DAFLOW and WASP is the consistency between time steps and spatial elements. Because DAFLOW uses a Lagrangian reference solution scheme, its time steps tend to be larger, and the size of segments can vary considerably and it is not a function of time step. In WASP, there is a trade off between time step and the size of the spatial elements. Because the Eulerian reference scheme considers that a segment's properties are constant over the length of the segment, the time scale of the flow and velocity have to be within the spatial scale of the element. For example, if the velocity is 1m/s and time step is 60 seconds, the length of the segment has to be greater than 60 meters. Thus, small segments in DAFLOW may require a very small time step in WASP to avoid model instability, which will result in very time consuming simulations.

To avoid WASP instability problems, WASP's time step was chosen by observing the range of velocities for the segments. A good time step approximation is given by dividing the length of the smallest segment by its maximum velocity over the period of simulation. The fact that WASP requires smaller time steps than DAFLOW does not affect the integration between the models significantly. Routines for interpolating results between DAFLOW time steps are part of the WAMIT computer application. These routines linearly interpolate values of discharge, velocity and depth for any DAFLOW and WASP time step combination.

II.F.2. Watershed Model Integration Tool

The WAMIT interface is a GIS tool developed by Omni that allows the user to set up a flow simulation using DAFLOW, export the results to WASP, calculate NPS inputs to the system as a function of EMCs, and to visualize DAFLOW outputs. WAMIT can manage the large number of time series of flows and parameters necessary for creating NPS inputs. The input is given through five main sheets: DAFLOW global parameters, flow, point and nonpoint source, sub-basin, and minor dischargers. Local inputs can be accessed through the GIS display or through a tree view display.

The GIS display adds functionality for accessing and managing the datasets. Time series and watershed parameters can be accessed by clicking on shapefiles previously prepared for the model. Two types of data can be imported into the GIS display: shapefiles and geo-referenced JPG images. Basic GIS visualization functions such as zoom, pam, add theme, delete theme, select and info are available. Attributes from shapefiles can also be accessed using the GIS display.

The input parameters on WAMIT are located on tabsheets above the GIS display, so that nodes and branches can be selected from the GIS display for visualization purposes. The first tabsheet contains DAFLOW global parameters that are necessary for DAFLOW simulations. Global parameters include number of internal junctions and branches in the system, the number of time steps, the time step size and the total period of planned simulation.

II.F.2.a. WAMIT Algorithms

II.F.2.a.(1) Flow-Weighted EMC Method

The storm water EMC flow-weighting algorithm is used to account for differences in surface flow contributions for different land use types. The methodology applied by USGS to estimate watershed flows does not explicitly account for source areas with distinct land uses. The surface runoff and base flow are given by sub-basin (see Hydrograph Separation section), which lumps source areas with various degrees of perviousness. EMCs alone represent average concentrations of stormwater constituents for a given area based on land use. Since different areas generate different proportions of runoff volume, simply calculating the area-weighted EMC could substantially misrepresent the total load from a sub-basin. Therefore, in order to better represent the relative contribution of areas with distinct land use and soil type, the source area EMCs are flow-weighted based on an approach that uses the Curve Number Method. Note that the curve number method is not used to calculate any flows in the model. Flows are provided by DAFLOW and separated, as described in Section II.F.2.a of this report, into baseflow and runoff. Curve numbers were used only to estimate the proportion of runoff flow that is generated by each land type in order to properly weight the EMCs for each sub-basin, as described below.

The flow-weighting method requires land type EMCs, basin parameters and a value for the representative storm as inputs. Land type EMCs were discussed previously in Section II.E.2.c.1.(a) of this report. Basin parameters consist of areas for each land use type within a sub-basin and their respective composite curve number. The assignment of basin parameters was performed by defining source areas with unique combinations of land use and soil type and assigning a curve number to each. An area-weighted composite curve number was then calculated for each land use type, as discussed previously (Section II.E.2.c.(1)(a)). These steps were performed using standard Geoprocessing tools available in ArcView. The representative storm is necessary to calculate a percent contribution of flow from areas with different land use types. A value of 1.5 inches was chosen as the representative storm based on rainfall records available for New Jersey. About 94% of the storms in New Jersey are 1.5 inches or smaller, and about 76% of the annual rainfall is delivered in storms of 1.5 inches or smaller.

The flow-weighted EMC for each land use type and for each sub-basin were calculated using Equations 5 and 6 below. Equation 5 provides the representative surface runoff (f_i) from each land use type (i) (in inches) as a function of the representative storm (P) and the area-weighted average moisture curve number for the respective land use type (CN_i). The flow-weighted EMC ($fEMC_j$) for each parameter (j) was calculated using Equation 6, by dividing the sum of the representative loads from each land use type by the sum of the representative volumes.

$$f_i = \frac{\left[P - 0.2 * \left(\frac{1000}{CN_i} - 10\right)\right]^2}{\left[P + 0.8 * \left(\frac{1000}{CN_i} - 10\right)\right]} \qquad (5)$$

$$fEMC_j = \frac{\sum f_i * A_i * EMC_{ij}}{\sum f_i * A_i} \qquad (6)$$

II.F.2.a.(2) NPS File Generator

The NPS file generator is the simplest algorithm embedded in WAMIT. It generates a text file with loads of NH_3-N, NO_3-N, OrgN, OrthoP, OrgP, DO, and $CBOD_u$ for each sub-basin and assigns the loads to the sub-basin's respective segment in WASP. The loads are calculated based on the flow-weighted EMCs for each parameter and sub-basin, tributary baseflow concentrations for baseflows, and the surface flows and baseflows calculated with the hydrograph separation algorithm. The total volume of water from baseflow and surface flow reaching the streams during a flow model time step (3 hours) are multiplied by the tributary baseflow concentrations and fEMCs, respectively. This multiplication yields the nonpoint source load for each water quality parameter.

II.F.2.a.(3) Hydrograph Separation Algorithm

The hydrograph separation algorithm is necessary to provide an estimate of the individual contribution of surface flow and tributary baseflow from each sub-basin. Contributing watershed flows in DAFLOW lump surface flows and baseflow in one single time series of flow. This approach is appropriate from a flow routing perspective. However, concentrations of water constituents in tributary baseflow and surface flow differ considerably, and so does the proportion of these flows according to sub-basin characteristics. These differences in concentrations and degree of perviousness of a sub-basin directly affect nonpoint source loads. The hydrograph separation algorithm separates the original watershed flows from DAFLOW into surface flow and tributary baseflow. This separation of watershed flows allows nonpoint source pollution to be directly addressed in the model.

The hydrograph separation algorithm is based upon a recursive digital filter method (Nathan R.J. and T.A. McMahon, 1990). The digital filter method has been widely used for hydrograph separation programs such as USGS's HYSEP (Sloto and Crouse, 1996) and it can be used with one or two filtering parameters. For the one-parameter method, the filter is represented by Equation 7 as shown by Nathan R.J. and T.A. McMahon, 1990.

$$f_k = \alpha f_{k-1} + \frac{(1+\alpha)}{2}(Q_k - Q_{k-1}) \quad (7)$$

Where: f_k = filtered direct runoff at the t time step

f_{k-1} = filtered direct runoff at the t-1 time step

α = filter parameter

Q_k = total stream flow at the t time step

Q_{k-1} = total stream flow at the t-1 time step

The filter parameter represents the recession coefficient of a drainage area. The digital filter for the two-parameter method is given by Equation 8 Eckhardt (2005). This method, in addition to the recession coefficient, also uses the BFImax index, which represents the maximum value of long-term ratio of baseflow to total stream flow.

$$bt = \frac{(1-BFI_{\max})\times\alpha\times b_{t-1} + (1-\alpha)\times BFI_{\max}\times Q_t}{1-\alpha\times BFI_{\max}} \quad (8)$$

Where: b_t = filtered baseflow at the t time step

b_{t-1} = filtered baseflow at the t-1 time step

BFI_{max} = maximum value of long-term ratio of baseflow to total stream flow

α = filter parameter

Q_t = total stream flow at the t time step

The two-parameter method was used to separate surface flows and tributary baseflows for the Passaic River Basin model. Default parameters suggested by the literature were initially used for α and BFI_{max} and were later calibrated based on annual ground water recharge estimated using the GSR-32 method and sub-basin characteristics. Values for α vary from 0.95 to 0.98 and values for BFI_{max} vary from 0.75 to 0.95.

II.F.2.a.(4) Hydrodynamic File Generator

The hydrodynamic file generator converts DAFLOW outputs from a Lagrangian solution scheme to a finite difference structure as required by WASP. The difference between modeling approaches requires the definition of assumptions for data interpretation and consistency, as described previously.

After the conceptual stream networks of DAFLOW and WASP were made compatible using the assumptions of uniform segmentation and flow averaging for the segments, flow outputs from DAFLOW were assigned as flow inputs for WASP. The data sharing between DAFLOW and WASP is made through the HYD file. The HYD file is a formatted text file or binary file that contains global information, network connectivity, segment properties for each segment, and flows for each interfacial flow segment for each time step. Global information consists of the calculation time step, the start and end times of the simulation. Network connectivity consists of defining interfacial flow pairs for adjacent segments and boundaries according to the flow path. Segments' properties consist of the volume, depth, and velocity for each time step. The segment interfacial flows consist of flow transfers between two adjacent segments or the segment and its boundary for each time step.

The hydrodynamic file generator automatically converts DAFLOW outputs to a WASP HYD file by executing the following:

- assigning new segment numbering to DAFLOW's conceptual stream network according to WASP's framework;
- defining the interfacial flows segments based on the new numbering system;
- reading the FLOW.in file and the BLTM.flw output file from DAFLOW and assigning its values to variables;

- interpolating flows and segment properties between DAFLOW's time steps to match a more refined WASP time step; and
- writing the HYD file that will be used by WASP to perform water quality simulations.

The application requires as inputs the BLTW.flw file, the FLOW.in file and the path and name to the new HYD file to be created. Besides file names and paths, global temporal and spatial variables are also needed for both models. The global variables required are DAFLOW's time step, DAFLOW duration, DAFLOW number of branches and maximum number of nodes within a branch. WASP's global variables are time step and duration. The duration (total simulation time) and time step may differ for both models. The interface linearly interpolating results between time steps. The only condition is that the WASP time step must be a multiple of DAFLOW's time step and WASP duration.

II.G. Model Sensitivity Tests

Model tests and sensitivity analysis are important aspects of the modeling effort. Model tests were performed to detect possible simulation errors and numerical instabilities. Sensitivity analyses were performed to assess the effects of different input parameters on model results. The model was tested for time step stability, numerical dispersion, and conservation of mass transport. Sensitivity analyses were performed for the input time series resolution. Additional sensitivity analyses were performed after future scenarios were simulated; these are described elsewhere in the report.

II.G.1. Time Step

Dynamic compartment models like WASP are very sensitive to instabilities due to time step. The time step should be within the time scale of the flow and size of the simulation compartments. A series of HYD files were created with varying time steps to assess model performance. A bigger time step is desirable from a computational standpoint. Very small time steps can lead to a very long processing time, which can delay other aspects of the modeling effort such as calibration.

The test for time step was made in WASP by assuming a constant boundary input of a conservative substance with concentrations equal to 1 for all flow boundaries. According to this set up, the concentration at all segments should converge to one, without fluctuations, if the model is stable.

HYD files with seven different time steps were prepared. WASP simulations with constant boundary conditions of 1 mg/l were set up, and the results were compared for segments throughout the system. Particular importance was given to segments in the most downstream branch, which would reflect instabilities of upstream segments, in case they occur. Time steps of 540, 360, 180, 144, 108, 72 and 36 seconds were used. The ideal time step is the one that results in simulations that converge to 1 mg/l, with no fluctuations. However, a trade off between instability and simulation time should also be taken into account when selecting the model time step.

Simulations using a time step of 540 seconds do not progress for more than a few days of simulation. Big fluctuations in concentrations due to numerical instability cause WASP to terminate the simulation before the pre-determined completion time for WY 2003. Simulations with 360 seconds progress through a few months, but it is also prematurely terminated by the model because of numerical instabilities.

Time steps less than 180 seconds (0.05 hour) result in complete simulations. A 180-second time step results in a few fluctuations, which are associated with strong flow gradients. The fluctuations are not considered as limiting to model results since they are observed for a very short periods of time, and their magnitude is in the order of 0.001mg/l. This is considered an acceptable level of instability, which does not compromise the quality of the simulations.

Simulations with time steps shorter than 180 seconds were also tested. The number of fluctuations in concentration decrease as time step decreases, but the magnitude of the fluctuations is approximately the same. Only with a 36-

second (0.01 hour) time step was it possible to achieve an instability free simulation. However, the binary HYD file necessary to complete this simulation would be on the order of 15 Gbytes, and the text file from which the binary HYD is derived would be around 100-150 Gbytes. In addition, a full year simulation time would take around 24 hours to be completed. For the Non-Tidal Passaic River Basin model, a 180-second time step was selected.

II.G.2. Dispersion and Transport Time Scale

Two main processes influence the transport of pollutant in water bodies: advection and dispersion. Advection is the main component of pollutant transport in rivers and it is influenced by flow. The effect of dispersion in rivers is generally overshadowed by the advective time scale. It is not unusual to disregard the effect of dispersion in river system models where loads are fairly constant and simulations cover long periods of time, such as the Passaic River Basin model.

The water quality model with compartmented solution schemes such as WASP can potentially overestimate the effect of longitudinal dispersion; this effect is known as numerical dispersion. In order to decrease the effect of numerical dispersion in compartmented water quality models, the segments have to be smaller, and compatible with the dispersion time scale. The use of large segments could substantially increase the effect of dispersion, which could imply a faster moving plume, with broad edges and peaks with lower concentration. The effects of model segmentation on dispersive time scale and the advective time scale was evaluated using dye studies performed in the Passaic River in the 1960's. The results of the analysis are interpreted taking into account the limitations of the study and information available.

Horwitz and Anderson (1966) published results of a dye study performed at several sections of the Passaic River from Chatham to Little Falls. The parameters measured include: discharge, leading edge of the dye, peak of dye concentration passage time of dye, and velocity. Two sets of measurements were performed: one at low-average flows (probability of 67% of being exceeded in 1964) and another at extremely low flows (probability of 99.4% of being exceeded 1964). The first measurements were used for the analysis. Average flow conditions tend to provide more reliable information, and will reflect average transport conditions.

The area of study presented in Horwitz and Anderson (1966) was divided into six sub-reaches of various lengths: Chatham to Florham Park, Florham Park to Hanover, Hanover to Pine Brook, Pine Brook to Clinton, Clinton to Two Bridges, and Two Bridges to Little Falls. The precise location of the stations, which defines the starting and ending points of a sub-reach, were not available in the paper, so they were approximated, based on the distances between stations. This lack of precision regarding the location of stations was considered in the interpretation of results.

In order to compare the observed plume of dye to the one predicted by the model, a steady state flow model set up was prepared exclusively for this analysis. The steady flows of each sub-reach were set to values shown by Horwitz and Anderson (1966), for the low-average flow conditions. The analysis was performed individually for each sub-reach. A constant load of a conservative substance was added at the start station of the sub-reach for a 15-minute period. The travel time of the peak and the leading edge of the dye were then compared to the observed data presented by Horwitz and Anderson (1966) at the end of the respective sub-reach. Table 15 shows the data used for setting up the analysis and the results from the model.

The results presented below must be interpreted carefully. No information was available about the total mass, or the time interval the dye was introduced. This could affect the time that the leading edge of the plume gets to the downstream station. In addition, the accuracy of the equipment used during the dye study could be questionable given how long ago the study was performed.

TABLE 15: Information from Travel Time Studies

Sub-reach	Length (Miles)	Discharge (cfs)	Dye Peak Travel Time (hours)			Leading Edge of Dye (hours)		
			Measured	Predicted	Difference	Measured	Predicted	Difference
Chatham to Florham Park	4.0	59.5	9.8	10	-0.2	6.3	5	1.3
Florham Park to Hanover	4.9	55.4	19.5	15	4.5	16	11	5
Hanover to Pine Brook	5.7	136	18.6	22	-3.4	15.3	8	7.3
Pine Brook to Clinton	3.2	136	9.5	10	-0.5	6.7	3	3.7
Clinton to Two Bridges	8.6	192	43.1	25	18.1	36.6	18	18.6
Two Bridges to Little falls	3.4	320	19	19	0	12.5	11	1.5

As expected, the leading edge of the dye seems to move faster than the observed data. The only way to reduce the effect of numerical dispersion would be by decreasing the size of the segments. This would imply in a far bigger model, smaller time steps, and more time-consuming simulations and data analysis. In the case of the Passaic River Basin model, the effects of the dispersion do not interfere with the results of the water quality simulation. The advective time scale is of much more importance in this system than dispersion. Dispersion would be critical if the effects of instantaneous pollutant spills or acute substances were of interest. In the case of the Passaic River Basin model, the long term effect of pollutants are of interest; thus, continuous loads from discharges and the long term simulations will decrease the effects of potential excessive dispersion. Therefore, giving the uncertainties of the dye data and the goals of the model, the segment configuration is considered appropriate for the analysis.

The advective time scale, which is of more importance for the model, presents a better agreement between observed and predicted data. The travel time of the peak gives the time scale of advection. Given the uncertainties surrounding the dye study and the lack of information, the results are acceptable. The only segment that stands out with a considerable difference is between Clinton and Two Bridges. In order to address this issue, the cross-sectional parameters of DAFLOW, which influence velocity in that section were checked. However, model calibration and the cross-section configuration did not show the model would be overpredicting velocities in that reach.

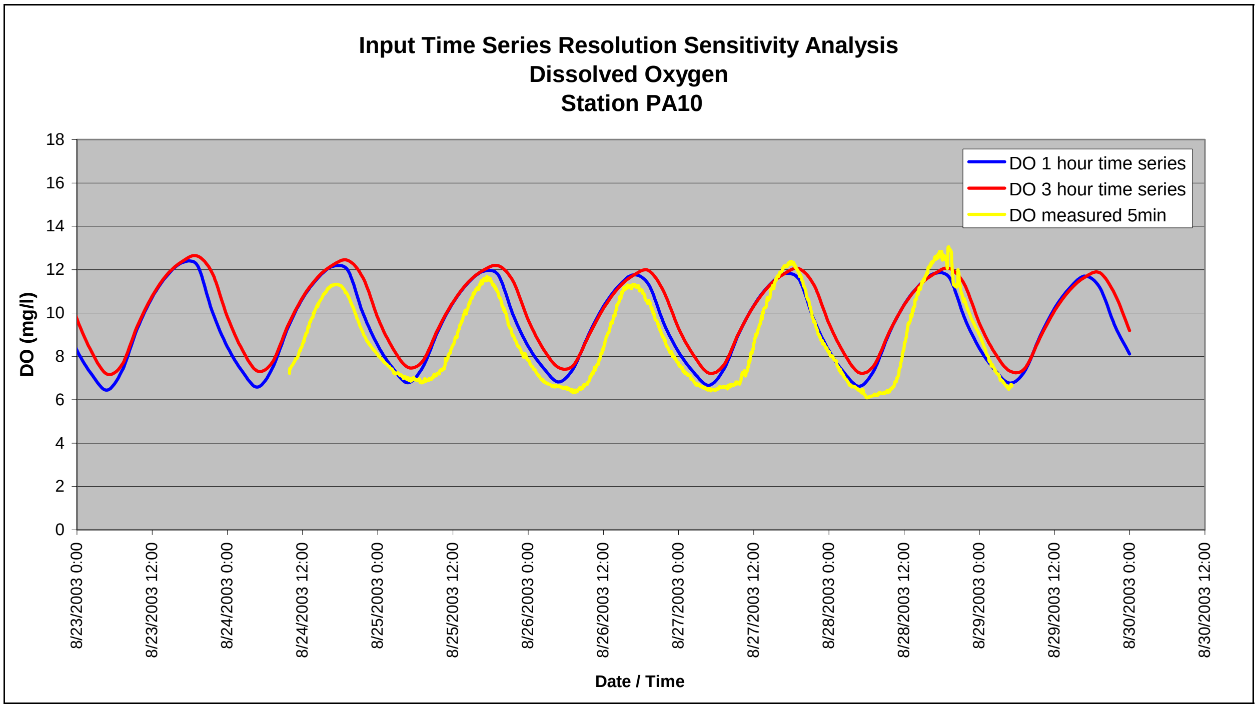
II.G.3. Input Time Series Resolution

Time series containing stream water temperature and solar radiations are important inputs for the model. The variation of temperature and solar radiation in time has a big impact on the simulation of some water quality parameters. Because the diurnal variation of dissolved oxygen is an important aspect of this study and because there is a limited number of records that could be used to represent these time series, a sensitivity analysis of the impact of time series resolution was performed.

Stream water temperature and solar radiation are provided with a one-hour resolution. WASP time series have a limit of 4,000 records. One-year simulations would require at least 8,640 records if a one-hour resolution were used.

Steady state simulations, covering a one-week period during August 2003, when extensive diurnal data were available, were prepared specifically for this analysis. The results for the same model setup using distinct time series resolution, with one and three-hour resolutions, were compared. The Omni sampling station PA10, which showed a substantial diurnal DO swing, was chosen as a basis for the analysis. The comparison of DO simulations with one and three-hour time series resolution is shown in Figure 18. Based on these results, a 3-hour resolution was selected for temperature and solar radiation inputs.

FIGURE 18: Comparison Between One and Three-Hour Resolution of Input Time Series



II.G.4. Mass Transport – Simulation of Total Dissolved Solids (TDS)

Mass transport in the model is a key element for water quality simulations. Pollutants entering the system from point and nonpoint sources are transported with flow and subject to transformations within the stream. Therefore, the concentration of a water quality parameter in a given location and time could be understood as being a function of two main processes: flow processes and kinetic processes. Flow processes include the physical movement of pollutants through advection and diffusion, which will depend on the flow rate and cross-sectional characteristics, such as volume. Kinetic transformations consist of chemical transformations and interactions among substances present in the water body, such as pollutant decay rates and plant uptake.

In order to test flow processes, mass inputs, and the mass balance of the Passaic River Basin model, a conservative substance was simulated. A conservative substance is subject to very little or no effect of chemical transformations, making it desirable to test the model's mass budget and flow processes. Total Dissolved Solids (TDS) was chosen as the conservative parameter for this simulation. TDS samples were collected from sampling stations and STP effluents by Omni in 2003. In addition, measurements of TDS taken by the dischargers were also used to define boundary conditions for the model, similar to other constituents as discussed earlier.

Nonpoint source loads of TDS were calculated using the NPS load component of WAMIT. Surface flow concentrations of TDS from surface runoff were assumed to vary according to land use. TDS tributary baseflow concentration was assumed constant throughout the watershed for the purpose of this analysis. Averages for land use and tributary baseflow concentrations were calculated based on stormwater and baseflow sampling performed by Omni (TRC Omni, 2004). Table 16 summarizes the surface runoff concentrations of TDS by land use and the concentration used for tributary baseflow.

TABLE 16: TDS Inputs

Landuse	TDS (mg/l)
Residential	161
Commercial	139
Agricultural	153
Forest	99
Wetland	158
Barren	153
Baseflow	250

The model was set up for the year 2003 and verified using the observed data for 19 sampling locations collected from June to November 2003. The simulated data presents a high level of agreement with observed data. Table 17 shows a summary of model fit statistics with coefficients of correlation means and standard deviations for each station. Values of the square coefficient of correlation (r^2) average 0.83. These results show a high correlation between predicted and observed TDS for all stations. The results of the TDS simulation for year 2003 indicate that TDS loads to the system and the mass budget is being simulated with desired accuracy.

TABLE 17: TDS Model Calibration Statistics

Station	R^2	Mean		Standard Deviation	
		Observed	Predicted	Observed	Predicted
DR1	0.83	261.67	253.34	70.69	24.86
PA3	0.93	192.50	200.87	43.61	36.72
PA4	0.83	201.67	211.03	47.76	39.57
PA5	0.80	214.03	231.41	59.74	45.70
PA6	0.93	250.83	247.98	85.38	60.97
PA7	0.69	244.23	245.28	69.78	47.65
PA8	0.92	237.50	233.89	67.22	53.81
PA9	0.94	233.33	233.07	66.87	52.47
PA10	0.90	241.92	233.67	64.21	44.57
PA11	0.79	238.33	233.04	75.70	50.77
WA2	0.72	181.67	190.16	36.24	25.85
PE2	0.73	167.30	179.91	46.45	29.92
PO1	0.90	211.67	209.66	54.89	50.71
PO2	0.64	229.17	210.51	70.88	49.63
PO3	0.76	219.61	215.69	50.19	45.54
RO2	0.98	235.00	234.23	75.44	81.24
WI2	0.72	250.00	234.23	52.91	43.85
WI3	0.94	276.67	237.83	89.00	54.63

II.H. Model Calibration and Validation

Model calibration and validation are critical parts of a modeling effort. Model calibration consists of adjusting some pre-determined parameters, both local and global, in order to obtain meaningful simulations under different conditions. The parameter adjustment procedure occurs by comparing simulated and observed data at various locations and times. Model validation consists of comparing the calibrated result with an independent set of observations, which was not used for calibration purposes, and covers different conditions.

A number of locations, which include Omni sampling stations, USGS stations, Passaic Valley Water Commission (PVWC) and Passaic Valley Sewerage Commission (PVSC) stations with available water quality data, were used for model calibration and validation. Instream water quality data available for stations within the model extent in the Passaic River Basin from all sources for the period of simulation (October 1999 through November 2003) were assembled into a digital database.

Generally, one third of the Omni data from 2003 was used for model calibration, while the other two thirds as well as data from the other sources over the entire simulation period were used for model validation. There were two exceptions: NJDEP diurnal DO data from 2002 and PVSC chlorophyll-a data from 2001 and 2002 were also used for model calibration. The diurnal DO was taken at a critical locations in the Passaic River Basin for which diurnal data were not collected in 2003. The chlorophyll-a data from the drier years of 2001 and 2002 was important to calibrate the growth rate for chlorophyll-a in the system. The other data, collected mostly by USGS, PVWC and PVSC, were used for model validation. It is important to note that the validation data was not all subject to the same level of quality assurance. All the available data for the simulation period were compared with model output, but not all the data were given the same level of importance when evaluating the results. In particular, many inconsistencies in the chemical data provided by PVWC were noted (e.g., dissolved phosphorus often reported as greater value than total phosphorus).

Each Omni sampling station contains at least six events with two observations each collected in 2003. In general, there are three low flow events and three high flow events (TRC Omni, 2003 and 2004). One set of low and high flow events were performed in November to capture winter conditions. In order to capture critical conditions in the system, the August low flow and high flow events were chosen for most of the calibration. All other events were used mostly for validation. Additional data collected by Omni in the Rockaway River, Dead River and Peckman River were also used for calibration and validation (Appendix B). The additional data collected in 2004 cover a larger spatial extent of the Rockaway River, Dead River and Peckman River. The 2004 data were used in the WY 2003 calibration during a time period when the flow, temperature and light conditions were similar to the conditions in 2004 under which the samples were collected.

Model calibration and validation were performed by focusing on six parameters: DO, NH_3-N, NO_3-N, TP, OrthoP and Chla. The calibration process was manual and iterative. Each parameter was calibrated individually by station, starting from the most upstream stations. Generally, DO and Chla were calibrated first, followed by NH_3-N, NO_3-N, TP and OrthoP. A total of 31 stations were used for model calibration and validation: 26 Omni sampling stations; 3 USGS sites with diurnal data: one at Chatham, one at Little Falls and one at Pompton Plains; and 2 PVSC sites in the lower Passaic River with chlorophyll-a measurements over several years. In addition, continuous DO data recorded by USGS at three locations across the Passaic River at Two Bridges just downstream of the Pompton River were compared with model output in the Passaic and Pompton Rivers at Two Bridges. Other stations throughout the basin maintained by PVSC, PVWC and USGS were used exclusively for independent validation. A list of all calibration and validation stations is provided in Table 18 for grab chemistry and diurnal monitoring, respectively.

The calibration procedure consisted of plotting the discrete observed data and the continuous simulated data together, and comparing them. The first cut of calibration was obtained by visual inspection of the plot. The observed concentrations obtained during August 2003 were compared against the continuous simulations in 2003. When results were converging, the mean error was calculated to provide a quantitative measure of calibration fitness. In addition, several statistics were derived to demonstrate model fitness as appropriate. Giving the data limitations, a general measure of fitness of the Omni sampling stations was calculated using all observed data. This was necessary in order to represent the overall fitness of the data. The general measure of fitness is provided only for Omni stations because of the relatively few observations at other stations. Independent validation was performed using the sampling from USGS, PVWC and PVSC; however, statistics were only derived when enough observed data were available. Although limited statistics were considered at the stations to provide some guidance during calibration, a formal numerical optimization procedure was not conducted for calibration due to the limited data and the high number of stations.

TABLE 18: Calibration and Validation Station Summary

Segment	Branch-node	Location Description	Calibration/Validation	Omni 2003	Omni 2004	USGS	Other
17	2-14	Wanaque River at Hamburg Turnpike, Pompton Lakes	Calibration/Validation	WA2			PVWC510
20	3-1	Pequannock River at Riverdale Road, Pompton Lakes	Calibration/Validation	PE2			
33	5-2	Pompton River at Jackson Avenue (CR680), Pompton Plains	Calibration/Validation	PO1		01388500	PVWC650
50	5-19	Pompton River at Route 202, Mountainview	Calibration/Validation	PO2			
54	5-23	Pompton River at Two Bridges Road, Two Bridges	Calibration/Validation	PO3		[01389005LB]	PVWC610, PVWC612
61	6-7	Rockaway River at Knoll Rd. in Parsippany - Troy Hills / Montville	Calibration		RockR2		
66	6-12	Rockaway River at Vail Rd. in Parsippany - Troy Hills / Montville	Calibration		RockR3		
70	6-16	Rockaway River at Old Bloomfield Ave. in Parsippany - Troy Hills / Montville	Calibration/Validation	RO2	RockR4	01381200	PVWC310
79	7-6	Whippany River at Speedwell Avenue Bridge, Morristown	Validation				PVWC290
88	7-15	Whippany River at East Hanover Avenue, Morristown	Calibration/Validation	WI2		[01381500]	PVWC280
120	7-47	Whippany River at Edwards Road, Parsippany - Troy Hills	Calibration/Validation	[WI3]		01381800	PVWC210
142	10-7	Dead River at Dead River Road on Bernards/Warren Twp boundary	Calibration		DeadR3		
146	10-11	Dead River upstream Warren IV STP	Validation	DR1troll			
148	10-13	Dead River at Mouth near Millington (King George / Stonehouse Rd)	Calibration/Validation	DR1	DeadR4	01379200	PVWC805
161	11-13	Passaic River at Mountain Avenue, Gillette	Calibration/Validation	PA3			
181	11-33	Passaic River at Stanley Avenue, Chatham	Calibration/Validation			01379500	PVWC165
186	11-38	Passaic River at Main Street, Chatham	Calibration/Validation	PA4			
205	11-57	Passaic River at Route 10 Bridge	Validation				PVWC140
213	11-65	Passaic River at Eagle Rock Ave., East Hanover	Calibration/Validation	PA5			PVWC130
223	12-5	Passaic River at Pine Brook	Validation			01381900	PVWC120
231	12-13	Passaic River at Horseneck Road, Montville	Calibration/Validation	PA6			
256	12-38	Passaic River at Passaic Avenue, Two Bridges	Calibration/Validation	PA7		01382000, [01389005RB]	PVWC110
265	14-7	Singac Brook at Passaic River confluence, Wayne	Calibration/Validation				PVWC106B, Singac
267	15-2	Passaic River at Deepavaal Brook confluence	Validation				
270	15-5	Passaic River at Route 23, Little Falls	Calibration/Validation	PA8			
275	15-10	Passaic River at PVWC Intake, Little Falls	Validation				PVWC101
277	15-12	Passaic River at Little Falls	Calibration/Validation			01389500	
298	16-19	Peckman River at McBride Avenue in West Paterson	Calibration/Validation	PK1	P5	01389600	
303	17-5	Passaic River at Glover Ave., West Paterson	Calibration/Validation	PA9			[PVSC1]
308	17-10	Passaic River at Alfano Furniture	Validation				PVSC2
314	17-16	Passaic River at Grenada Rest.	Validation				PVSC3
318	17-20	Passaic River at Morlott Ave., Paterson	Calibration/Validation	PA10			
323	17-25	Passaic River at Market Street	Calibration/Validation				PVSC4
327	17-29	Passaic River above Dundee Dam	Calibration/Validation	PA11			

Note: [ ] indicates actual sampling station location in adjacent segment. Comparison is provided in order to minimize output locations

The statistics used for model calibration and validation are described below. The relevant formulae and detailed descriptions about the several statistics can be found in Reckhow and Chapra, 1983 and Stow C.A. et al., 2003.

- AE: "average error" measures the size and discrepancy between predicted and observed values.
- AP: "average predicted" measures the average of predicted values.
- STDP: "standard deviation predicted" measures the standard deviation of predicted values.
- AObs: "average observed" measures the average of observed values.
- STDObs: "standard deviation observed" measures the standard deviation of observed values.
- R^2: "squared correlation coefficient" of model predictions and observations measures the tendency of the predicted and observed values to vary together linearly. An R^2 of 1 indicates that the data are perfectly predicted by the model. R^2 values are not provided for ammonia, dissolved oxygen, and chlorophyll-a because the diurnal variation and (in the case of chlorophyll-a) the sampling variability of these parameters often renders the r^2 statistic meaningless.

Global parameters that were adjusted during calibration are listed below:

- Nitrification rate;
- Phytoplankton maximum growth rate;
- Phytoplankton death rate;
- Phytoplankton respiration rate;
- Benthic algae maximum growth rate;
- Benthic algae respiration rate;
- Benthic algae death rate;

- Benthic algae ammonia preference;
- Light constant for growth; and
- Detritus dissolution rate.

Local parameters adjusted during the calibration process are listed below:

- Percent of bottle segment covered by benthic algae;
- SOD;
- Benthic ammonia flux;
- Fraction dissolved; and
- Settling rates for particulate phosphorus.

Global parameters can be difficult to calibrate because they affect the entire system. Local parameters only influence their particular segment and segments in the downstream vicinity. However, they have to be estimated for every segment in the stream network. The calibration of local and global parameters needs to occur simultaneously because they are interdependent. Therefore, a systematic approach for calibrating a large and diverse system such as the Passaic River Basin was developed.

The approach used for calibration consisted of adjusting the parameters at the tributary stations first and then adjusting parameters from stations in the mainstems. After an acceptable calibration was obtained at the mainstem stations, the tributary stations were revisited. The calibration in the tributaries and the mainstems was made according to the flow direction; the stations near the headwaters were calibrated first followed by the ones downstream.

The calibration at a given station can change considerably as global parameters are modified. A good example is nitrification rate. Nitrification rates can be very different in small rivers like the Pequannock and the Wanaque, when compared to large water bodies such as the Passaic River. It may be the case, for instance, that a good calibration for ammonia in a small tributary station needs to be sacrificed in order to prevent a bad ammonia calibration at stations in the Passaic River. In summary, the best fit for a particular station does not always represent the best fit for model calibration as a whole. The best parameter value is the one that results in meaningful simulations for the larger number of stations.

Finding parameters that result in a good overall fit can be difficult to obtain due to the number of calibration stations. In addition, the interdependency between parameters further complicates calibration. In heavily parameterized models like WASP, it is possible to calibrate the model by focusing on the wrong processes or parameters, which will later prove incorrect during the validation process. The diurnal variation of DO is a good example. Both phytoplankton and benthic algae can influence diurnal variation of DO; therefore, it is important to first calibrate the parameters that influence variables that have more reliable calibration data, and that have a global impact. Table 19 provides a list of each of the global kinetic parameters within the WASP model, along with the final values utilized in the model and the available literature range.

Calibration and validation graphs are provided in Appendix E (grab data) and Appendix F (diurnal data). The calibration procedures adopted for parameters affecting each individual water quality variables are discussed below.

II.H.1. Phosphorus

Phosphorus is an important component of the Non-Tidal Passaic River Basin TMDL Study, and special attention was given to its calibration. The simulation of phosphorus in WASP can explicitly account for the phosphorus uptake by plants and algae, the settling of particulate phosphorus, and the decomposition of organic matter. The sorption of OrthoP to the bottom sediment, which is believed to be a process of relevant importance in the cycle of phosphorus in the Passaic River Basin, and the removal of OrthoP by rooted plants from the bottom sediment, are not explicitly modeled in WASP7. These processes were therefore incorporated into the settling rates of phosphate, as described below.

There are two global parameters available to account for the phosphorus transformations. The first parameter is the mineralization rate of organic phosphorus. This parameter defines how fast dissolved organic phosphorus that resulted from organic compound decomposition is transformed into OrthoP. The

TABLE 19: Global Kinetic Parameters for Non-Tidal Passaic River Basin Model

Parameter Type	Parameter	Units	Value Used in Model	Literature Min	Literature Max
General	Nitrification Rate @20ºC	/d	0.25	0	10
	Nitrification Temperature Coefficient	-	1.07	1	1.08
	Half Saturation: Nitrification Oxygen Limit	mg/L	1	0	2
	Denitrification Rate@20ºC	/d	0.04	0	0.09
	Dissolved Organic Nitrogen Mineralization Rate @20ºC	/d	0.02	0	1.08
	Dissolved Organic Nitrogen Mineralization Temperature Coefficient	-	1.02	1	1.08
	Fraction of Phytoplankton Death Recycled to Organic Nitrogen	-	0.5	0	1
	Mineralization Rate of Dissolved Organic Phosphorus @20ºC	/d	0.2	0	0.22
	Dissolved Organic Phosphorus Mineralization Temperature Coefficient	-	1.08	0	1.08
	Fraction of Phytoplankton Death Recycled to Organic Phosphorus	-	0.5	0	1
	Theta -- Reaeration Temperature Correction	-	1.018	1	1.03
	Oxygen:Carbon Stoichiometeric Ratio	-	2.69	0	2.69
	BOD Decay Rate @20ºC	/d	0.5	0	5.6
	BOD Decay Rate Temperature Correction	-	1.04	0	1.07
	BOD Half Saturation Oxygen Limit	mg/L	0.5	0	0.5
Detritus	Detritus Dissolution Rate	/d	0.00001	0	1
	Temp Correction for detritus dissolution	-	1.08	1	1.08
Phytoplankton	Maximum Growth Rate @20ºC	/d	1.25	0	3
	Growth Temperature Coefficient	-	1.068	1	1.07
	Light Formulation Switch (1=Steele, 2=Smith)	-	1		
	Maximum Quantum Yield Constant	mgC/mole photon	720	0	720
	Carbon: Chlorophyll Ratio	-	20	0	200
	Optimal Light Saturation	langleys/d	320	0	350
	Half-Saturation Constant for Nitrogen	mgN/L	0.025	0	0.05
	Half-Saturation Constant for Phosphorus	mgP/L	0.0025	0	0.05
	Endogenous Respiration Rate @20ºC	/d	0.15	0	0.5
	Respiration Temperature Coefficient	-	1.068	1	1.08
	Death Rate Non-Zooplankton Predation	/d	0.1	0	0.25
	Nutrient Limitation Option	-	1		
	Phosphorus::Carbon Ratio	-	0.024	0	0.24
	Nitrogen::Carbon Ratio	-	0.176	0	0.43
	Half-Sat. for Recycle of Nitrogen and Phosphorus	mg/L	0.5	0	1
Benthic Algae	Max Growth Rate	gD/m^2/d	60	10	100
	Temp Coefficient for Benthic Algal Growth	-	1.08	1	1.08
	Respiration Rate	/d	0.01	0.05	0.2
	Temperature Coefficient for Benthic Algal Respiration	-	1.08	1	1.08
	Death Rate	/d	0.005	0.01	0.5
	Temperature Coefficient for Benthic Algal Death	-	1.07	1	1.08
	Nitrogen Half Sat Constant for growth	mgN/L	0.025	0.015	0.1
	Phosphorus Half Sat Constant for growth	mgP/L	0.0025	0.0025	0.08
	Light Option, 1=Half saturation, 2=Smith, 3= Steele	-	2		
	Light Constant for growth	langleys/d	350	0	350
	Benthic algae ammonia preference	mgN/L	0.1	0	0.5
	mg N/mg C	-	0.176		
	mg Dry Weight/mg C	-	2.99		
	mg P/mg C	-	0.0235		
	mg O2/mg C	-	2.69		

second parameter is the "fraction of phytoplankton death recycled to organic phosphorus," which affects only the fraction of floating algae that is converted to phosphorus. Neither of the parameters above was found to be important for phosphorus simulations in this case.

Phosphorus concentrations were most sensitive to boundary conditions loads (i.e., point sources), plant productivity, stoichiometry, and settling. Boundary conditions were defined according to data availability and are described in the previous section of this report. Plant productivity was calibrated to capture diurnal DO concentrations. Stoichiometry was considered fixed and was obtained using detailed equations for photosynthesis and respiration by algae as suggested by Redfield et al. (1963), and Stumm and Morgan (1981). Therefore, settling was used to adjust phosphorus at some locations in the Passaic Basin.

According to Wetzel (2001), the exchange of phosphorus between sediments and the water column is a major component of the phosphorus cycle in natural waters, and the adsorption and precipitation of phosphorus with inorganic compounds is one of the components of this exchange process. In general, the calibration of phosphorus consisted of decreasing phosphorus concentrations during low flow periods by settling it to the bottom sediments. This is consistent with the processes modeled in WASP. The phosphorus uptake by plants does not reduce concentrations enough to match observed levels. In addition, the fact that benthic algae and macrophytes are being simulated as one variable might not completely capture the actual uptake of phosphorus by plants. The adsorption of OrthoP to bottom sediment and extra plant uptake by macrophytes, which are not explicitly simulated by WASP, were incorporated into the settling rates of phosphate. Settling rates were used to represent the physical settling of organic and inorganic particulate phosphorus, adsorption of orthophosphate to the sediment bed and extra phosphorus uptake by macrophytes in certain areas of the Passaic River and its tributaries due to influence of wetland meadows.

In order to incorporate adsorption and additional phosphorus uptake from macrophytes into settling rates, a percentage of OrthoP subject to settling, adsorption to the bottom sediment, and uptake were defined. Next, the settling rates that represent the velocity of the physical settling and the speed of the sorption process and uptake were defined. Spatially variable settling rates were defined according to the reach and they are assumed to be fixed in time. The actual settling varies according to the stream velocity and depth at a given time step.

This approach was not necessary in every location. Stations located in the Pompton, Pequannock, Wanaque, Ramapo, and Dead River did not show strong influences of the sediment bed in the fate of phosphorus. Stations located in the Rockaway, Whippany, Peckman, Mid-Passaic and Lower Passaic seemed to be subject to a strong influence of the bottom sediment in the phosphorus cycle. For these stations, 60% of the OrthoP was made available for settling. Spatially variable settling rates were then defined according to the reach, in order to obtain the desirable levels of phosphorus. Settling rates can range from 0.001 cm/s to 0.6 cm/s. High settling rates such as 0.6 cm/s would be unrealistic if used only to represent the physical settling. However, these higher values were necessary in order to incorporate processes that are not explicitly simulated in WASP7.0, such as the complex wetland kinetics and sediment bed interactions with the water column.

Non-point source loads of phosphorus also needed to be adjusted in one location in order to avoid excessive concentrations during high flow events. The watersheds contributing to the Wanaque River are mostly forested. When EMCs are used to calculate nonpoint source loads, the effects of the vegetation buffers, which can trap on average 70% of pollutants, are not taken into account. During the calibration process, unrealistically high phosphorus concentrations were being simulated in the Wanaque only during high flow events, which clearly show a correlation with nonpoint source runoff loads. Therefore, in order to have meaningful phosphorus simulations in the Wanaque, the effect of the vegetation buffers on the trapping of pollutants was taken into account by assuming that the EMCs of forested land use were representative for the entire watershed.

An example calibration graph for phosphorus, showing both TP and OrthoP, is provided in Figure 19. Tables 20 and 21 show the model calibration statistics for OrthoP and TP, respectively, at Omni stations. Graphs showing the correlation between model predictions and measured values of TP are provided for each sampling station in Appendix G. The representation of phosphorus was satisfactory in all stations. It is important to note that the stations with lower r^2 correlations (e.g., PE2 and WA2) are those at which phosphorus concentrations are dominated by upstream treatment plant discharges. Since instream phosphorus concentrations will greatly vary as a result of changes in STP concentrations and flows, and we do not have actual data on the STP flow and concentration variation, it is not surprising that the statistics are poorer at these locations. Some stations presented a high degree of diurnal variations of phosphorus. This pattern occurs in streams strongly influenced by discharger loads, which were set up in the flow model to vary diurnally. The same pattern can also be observed for ammonia and nitrate at some locations. Additional phosphorus oscillation is due to the growth and respiration processes of plants.

FIGURE 19: Example Phosphorus Calibration Graph

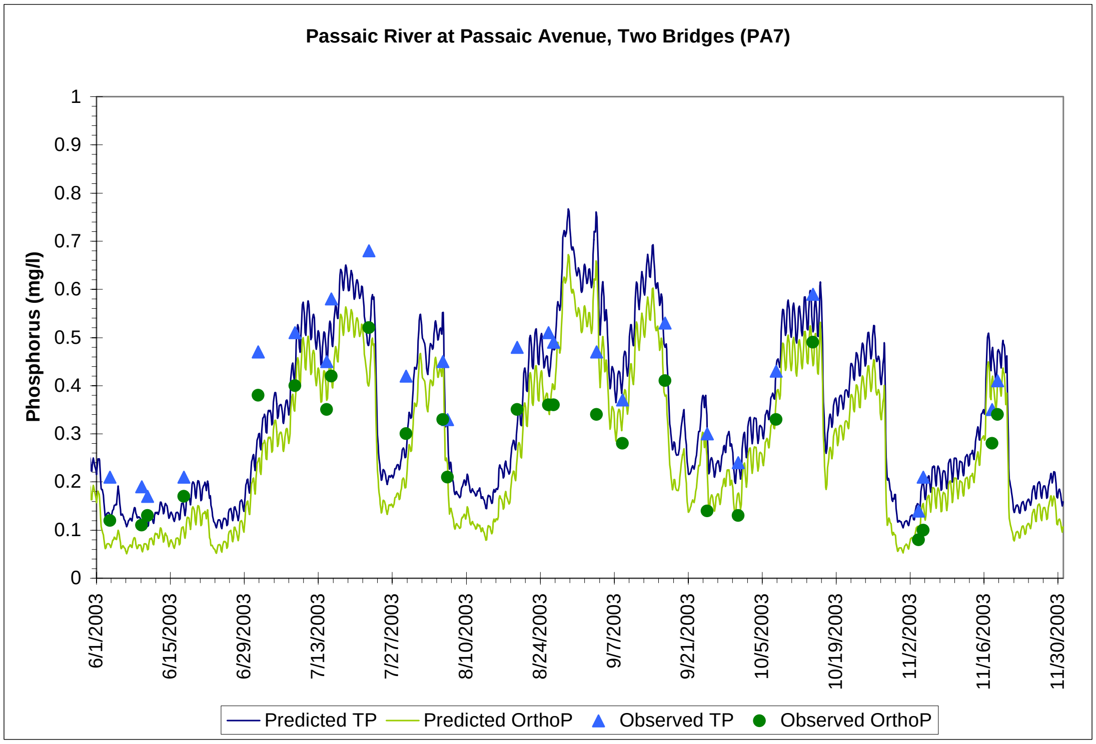


TABLE 20: OrthoP Model Calibration Statistics

Station	Mean Error	Predicted Mean	Observed Mean	Predicted Standard Deviation	Observed Standard Deviation	R^2 Correlation
DR1	-0.05	0.27	0.32	0.21	0.22	0.97
PA10	-0.01	0.20	0.21	0.10	0.08	0.76
PA11	0.03	0.20	0.17	0.10	0.07	0.80
PA3	0.02	0.15	0.13	0.09	0.06	0.85
PA4	0.00	0.14	0.14	0.08	0.05	0.74
PA5	0.02	0.26	0.24	0.13	0.09	0.47
PA6	0.04	0.34	0.30	0.22	0.16	0.98
PA7	0.01	0.29	0.29	0.15	0.12	0.60
PA8	0.01	0.22	0.21	0.12	0.10	0.96
PA9	0.01	0.21	0.20	0.11	0.10	0.95
PE2	-0.01	0.00	0.01	0.00	0.00	0.09
PK1	-0.20	0.69	0.89	0.34	0.27	0.52
PO1	0.00	0.02	0.02	0.01	0.01	0.71
PO2	0.01	0.02	0.01	0.01	0.01	0.40
PO3	0.00	0.07	0.07	0.03	0.04	0.60
RO2	0.04	0.29	0.25	0.29	0.28	0.94
WA2	0.00	0.01	0.01	0.01	0.00	0.31
WI2	0.03	0.07	0.04	0.04	0.02	0.82
WI3	0.03	0.14	0.12	0.08	0.05	0.70

TABLE 21: TP Model Calibration Statistics

Station	Mean Error	Predicted Mean	Observed Mean	Predicted Standard Deviation	Observed Standard Deviation	R^2 Correlation
DR1	-0.07	0.32	0.40	0.21	0.24	0.92
PA10	-0.03	0.27	0.30	0.11	0.09	0.66
PA11	0.00	0.26	0.26	0.11	0.08	0.74
PA3	0.00	0.22	0.22	0.09	0.09	0.59
PA4	-0.03	0.21	0.24	0.09	0.07	0.54
PA5	0.00	0.36	0.36	0.15	0.13	0.45
PA6	-0.01	0.41	0.42	0.23	0.23	0.96
PA7	-0.03	0.36	0.39	0.16	0.14	0.62
PA8	0.00	0.28	0.29	0.13	0.12	0.93
PA9	-0.01	0.27	0.29	0.12	0.11	0.94
PE2	0.00	0.03	0.04	0.01	0.02	0.23
PK1	-0.26	0.75	1.01	0.35	0.32	0.37
PO1	-0.01	0.07	0.08	0.02	0.03	0.70
PO2	0.00	0.07	0.07	0.03	0.03	0.72
PO3	-0.01	0.13	0.14	0.04	0.05	0.55
RO2	0.05	0.36	0.31	0.35	0.31	0.94
WA2	0.00	0.04	0.04	0.01	0.02	0.31
WI2	0.02	0.12	0.10	0.06	0.04	0.53
WI3	0.00	0.20	0.20	0.09	0.06	0.56

II.H.2. Ammonia

The fate of ammonia is associated with other processes such as algae respiration, photosynthesis, and detritus dissolution. The main parameters affecting ammonia are nitrification rate and ammonia preference, which are both global parameters. The nitrification rate determines how fast ammonia decays to nitrite-nitrate. Nitrification is caused by autotrophic bacteria, which assimilate ammonia and create nitrite and nitrate. A value of 0.25/day was chosen to represent the entire system. This value is within the range found in the literature. Nitrification rates can vary considerably. The characteristics of the water body, such as depth, temperature and substrate influences the presence of the nitrifying bacteria. The value of the nitrification parameter was calibrated to provide an acceptable fit for the entire system.

Ammonia preference is associated with algae and plant growth. This parameter determines the proportion of ammonia that is used in the photosynthesis and respiration processes compared to nitrate. As phytoplankton and macrophytes grow, dissolved inorganic nitrogen is taken up and incorporated into biomass. Both ammonia and nitrate are available for uptake. The value of the ammonia preference was set to 0.1 mgN/l. There were no measurements of ammonia preference made. Literature rates for ammonia preference range from 0.1 to 0.5 mgN/l (Chapra, 1997).

Ammonia is a sub-product of organic matter decomposition. External sources of organic matter include STP discharges and to a lesser extent non-point source loads. External sources are accounted by boundary condition inputs. However, there are also sources of organic matter which are not explicitly simulated by the model. The river bed can contain a considerable amount of organic matter, which is a result of years of continuous accumulation, and wetland complexes can serve as active sources of ammonia during certain flow conditions. Therefore, in certain areas and under certain conditions, some of the ammonia load is not automatically taken into account by the model. In order to consider the ammonia generated in the stream bottom and by wetlands functioning as active ammonia sources, benthic ammonia fluxes were added where appropriate. The loads are local, and happen only at the specified segments. Observed data for ammonia showed that during the summer of 2003, the ammonia levels are higher for stations at the mid-Passaic River and at end of the Upper Passaic River (PA5, PA6 and PA7). However, the same phenomenon is not observed in WY 2000, 2001 and 2002. After nitrification and the ammonia preference were calibrated, a benthic ammonia flux was defined for model segments from PA5 to PA7 for WY 2003. The benthic ammonia load was obtained through calibration. A value of 300 mg/m^2/day was used for segments 208 through 239. Because of the particular flow conditions in 2003 and the possibility of wetlands acting as continuous sources of ammonia loads to the system, the benthic ammonia flux was only used in WY 2003.

An example calibration graph for nitrogen, showing both ammonia and nitrate, is provided in Figure 20. The calibration statistics for ammonia for Omni sampling stations are shown on Table 22. Nitrate calibration is discussed in the ensuing section.

FIGURE 20: Example Nitrogen Calibration Graph

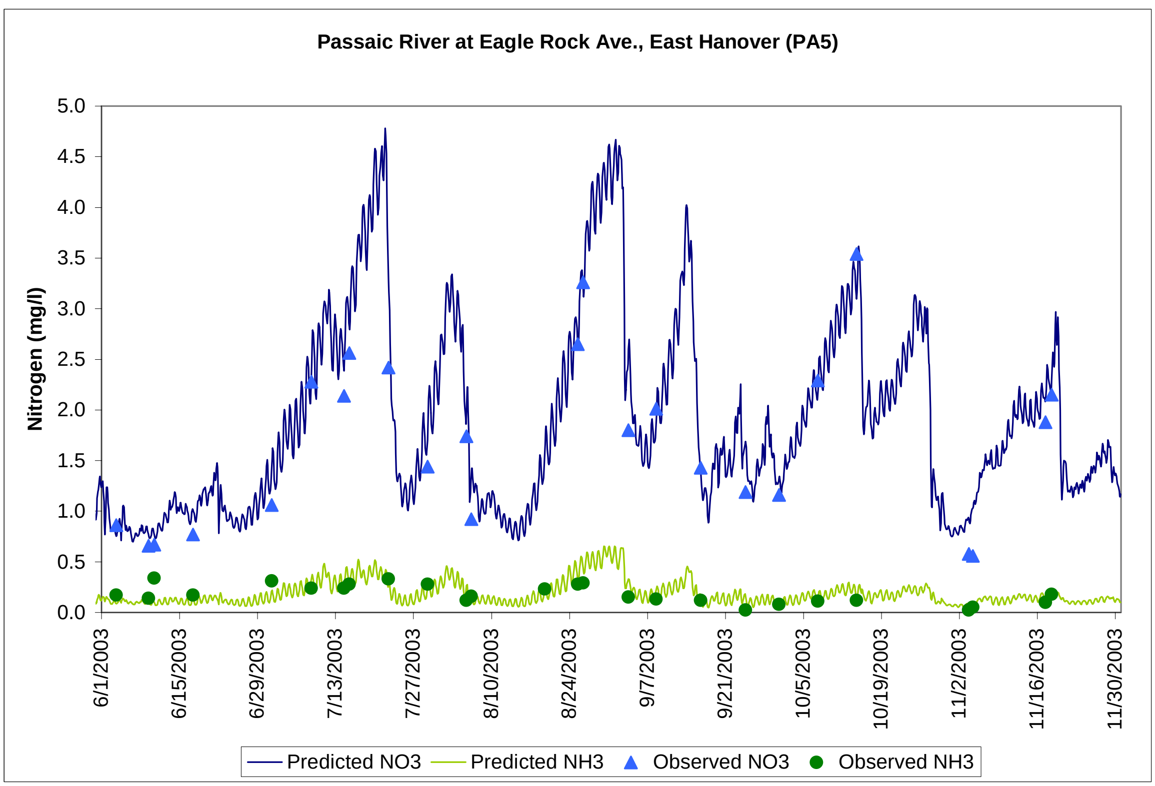


TABLE 22: Ammonia Model Calibration Statistics

Station	Mean Error	Predicted Mean	Observed Mean	Predicted Standard Deviation	Observed Standard Deviation
DR1	-0.02	0.09	0.11	0.03	0.06
PA10	0.02	0.13	0.11	0.05	0.06
PA11	0.01	0.13	0.12	0.04	0.09
PA3	-0.04	0.10	0.14	0.02	0.06
PA4	0.05	0.16	0.11	0.11	0.08
PA5	0.03	0.21	0.18	0.09	0.09
PA6	0.02	0.22	0.21	0.13	0.10
PA7	0.04	0.22	0.18	0.11	0.08
PA8	0.02	0.17	0.15	0.07	0.06
PA9	0.02	0.13	0.11	0.03	0.05
PE2	0.03	0.11	0.08	0.04	0.06
PK1	-0.05	0.11	0.16	0.06	0.12
PO1	0.04	0.13	0.10	0.06	0.05
PO2	0.01	0.10	0.09	0.03	0.03
PO3	-0.01	0.09	0.10	0.03	0.05
RO2	-0.05	0.12	0.17	0.08	0.10
WA2	0.03	0.15	0.12	0.05	0.06
WI2	0.04	0.14	0.09	0.05	0.05
WI3	-0.09	0.14	0.23	0.04	0.22

II.H.3. Nitrate

Nitrate is a variable highly influenced by boundary conditions. Ammonia nitrification, which results in nitrate as a sub-product, is not significant in this system, where point source loads of ammonia are relatively low and nitrate loads dominate. Nitrate can also be used by plants and algae. However, these plants tend to prefer ammonia over nitrate as a source of nutrient, and the amount of nitrate consumed is small compared to the nitrate available in the water column.

The only parameter available for direct nitrate calibration is denitrification rate. However, denitrification only occurs under anoxic conditions and depends on the presence of denitrifying bacteria. Because denitrification is not believed to impact nitrate in the Passaic River Basin, this function was not activated in the model.

Nitrate did not require any calibration. The representation of nitrate is good at the great majority of stations. Table 23 show the general fit of nitrate at Omni stations.

TABLE 23: Nitrate Model Calibration Statistics

Station	Mean Error	Predicted Mean	Observed Mean	Predicted Standard Deviation	Observed Standard Deviation	R^2 Correlation
DR1	-0.35	1.45	1.80	0.63	0.73	0.58
PA10	0.20	1.77	1.57	0.74	0.68	0.89
PA11	0.37	1.77	1.40	0.78	0.61	0.85
PA3	0.10	1.01	0.91	0.40	0.32	0.63
PA4	0.06	1.24	1.17	0.57	0.50	0.87
PA5	0.21	1.87	1.66	0.76	0.82	0.88
PA6	0.31	2.24	1.93	1.30	1.23	0.99
PA7	0.44	2.18	1.74	0.98	0.92	0.84
PA8	0.30	1.91	1.62	0.95	0.87	0.96
PA9	0.30	1.88	1.58	0.89	0.79	0.96
PE2	-0.07	0.69	0.76	0.15	0.24	0.68
PK1	-1.14	3.33	4.47	1.67	1.46	0.33
PO1	-0.01	0.82	0.83	0.15	0.17	0.95
PO2	0.01	0.80	0.80	0.14	0.16	0.90
PO3	-0.03	1.14	1.16	0.33	0.42	0.64
RO2	-0.16	1.29	1.45	0.88	1.17	0.96
WA2	0.12	0.80	0.68	0.27	0.15	0.25
WI2	-0.04	1.26	1.29	0.22	0.20	0.52
WI3	0.19	1.66	1.47	0.66	0.84	0.86

II.H.4. Dissolved Oxygen

The simulation of DO is very complex. The main processes affecting DO concentrations in the water column include: phytoplankton growth, attached algae and plant growth, nitrification, CBOD, SOD, and transport related parameters such as velocities and stream geometry that affect reaeration. Besides the processes mentioned above, environmental factors, such as water temperature, solar radiation, and light extinction, can influence DO concentrations directly or indirectly.

Phytoplankton and benthic algae or macrophytes affect the diurnal concentration of DO. Photosynthesis increases DO concentrations during the day, when the net productivity of oxygen is higher than the demand of oxygen by respiration. At night, when photosynthetic processes are inactive, DO consumption is higher than production and DO levels drop.

The decomposition of carbonaceous material also affects oxygen concentrations in the water column. The decomposition process results in a biochemical oxygen demand caused by decomposing bacteria. The process is not significant in terms of oxygen budget for the non-tidal Passaic River Basin. Measured CBOD levels are very low throughout the basin, usually below detection limit. Therefore, CBOD was not relevant for DO calibration.

Nitrogen compounds also have an impact on a river's oxygen resources. The nitrogenous biological oxygen demand (NBOD) is a result of the nitrification of ammonia. The nitrification rate could cause a noticeable impact in the DO concentrations at some stations, generally at lower order streams. However, once ammonia was calibrated, the nitrification rate was not altered significantly to correct DO.

Reaeration is one of the major processes affecting DO. Reaeration is calculated by the model using the Covar method (Covar, 1976). This method calculates reaeration as a function of velocity and depth by one of three formulas: Owens, Churchill, or O'Connor-Dobbins. These formulae use as inputs the average segment depth and average water velocity within the segment. The method consists of selecting the optimal equation according to considerations of depth and velocity. The Covar method relies exclusively on model hydrodynamic simulations of depth, velocity and parameters obtained empirically. Only temperature correction parameters, which have only a minor influence in the Passaic River Basin model, could be used to make minor adjustments.

Because reaeration is a function of hydrodynamic variables, it was not an important aspect of the DO calibration. However, there are two main processes that have a great impact on DO and were extensively used for calibration: SOD and the growth of rooted algae and macrophytes.

SOD is a natural process in lakes and rivers due to oxidation of organic matter in the bottom sediments. These benthic deposits are a result of the accumulation of particulates, such as leaf litter and eroded soils. Independent of the source, oxidation of the accumulated organic matter will result in a sediment oxygen demand. SOD varies considerably spatially and is difficult to measure and consequently to simulate. SOD is introduced in the model as a fixed local parameter expressing the SOD value in g/m^2/day at 20^{o}C. Each segment can assume a different SOD value, which is obtained through calibration. Calibration was performed only at stations where DO observations were made. Thus, SOD values for segments in between sampling stations were estimated according to its proximity to a calibrated station.

Although the SOD assigned for each segment is fixed, the value used by the model varies according to water temperature. The effect of SOD is linear, so it is used to lower or increase the average DO concentration of a given segment. In order to perform a reality check on SOD values obtained through calibration, Omni conducted SOD measurements at sampling stations in the Passaic River. SOD analysis was also conducted by Hydroqual at some Omni stations. The comparison between the SOD obtained through calibration and the observed values are shown in Table 24. The calibrated results are of the same magnitude as the measurements made by Omni.

TABLE 24: Comparison between Observed and Calibrated SOD Values

Omni Station	Observed Omni (2004)		Observed Hydroqual (2003)		Calibrated
	SOD (g/m^2/day)	SOD (g/m^2/day)	SOD (g/m^2/day)	SOD (g/m^2/day)	SOD (g/m^2/day)
DR1	3.9		0.4	1.4	3.0
PA2	4.4				5.0
PA4	4.5				2.0
PA5	9.1	6.9	0.4	0.3	5.0
PA7	5.0				8.0
PK1	3.3				2.0
RO2	7.5				3.0
PO2			0.8	0.5	3.0
PA11			1.4	0.4	0.1
WI1			0.3	0.4	0.1

SOD influences the average DO and causes only minor impact on the DO diurnal variation. The diurnal DO swing is caused by the presence of algae and aquatic plants in the system. Photosynthetic and respiration processes from phytoplankton, benthic algae, and macrophytes are the major causes of diurnal DO variations.

Phytoplankton has a global implication in the model. Once the phytoplankton growth, respiration, and death rates are calibrated, they are effective for the entire system. The concentration of phytoplankton can only be affected locally by the presence of enough nutrients to support growth, or hydraulic properties. Chlorophyll-a measurements in the basin do not show concentrations that would cause a significant impact of diurnal DO in most of the system except in summer 2001 and 2002 during extreme low flows in the lower Passaic River. Once the growth rate of phytoplankton was calibrated using observed chlorophyll-a data, respiration rates were adjusted to impact DO concentrations.

However, phytoplankton alone was not able to produce the strong diurnal swings observed in the Passaic River and its tributaries. Phytoplankton is not the only photosynthetic organism that impacts the DO budget. Macrophytes, which are known to exist in abundance in the Passaic River Basin, were a very important aspect of DO simulation. WASP can simulate the effects of attached algae on water quality parameters. The model was initially developed to account for the effect of periphyton on water quality parameters. Periphyton is obviously different from macrophytes; however, both macrophytes and periphyton are photosynthetic organisms attached to the bottom. This commonality supports the assumption that periphyton and macrophytes can be simulated together as a single state variable.

The local parameter in WASP7 used to account for the presence of benthic algae and macrophytes is the "percent of bottom segment covered by benthic algae." This is a local parameter that varies from 0 to 1. The values of the "percent of bottom segment covered by benthic algae" were obtained through calibration. Although this is an important local parameter, growth, respiration and death rates, which are global parameters, were also calibrated.

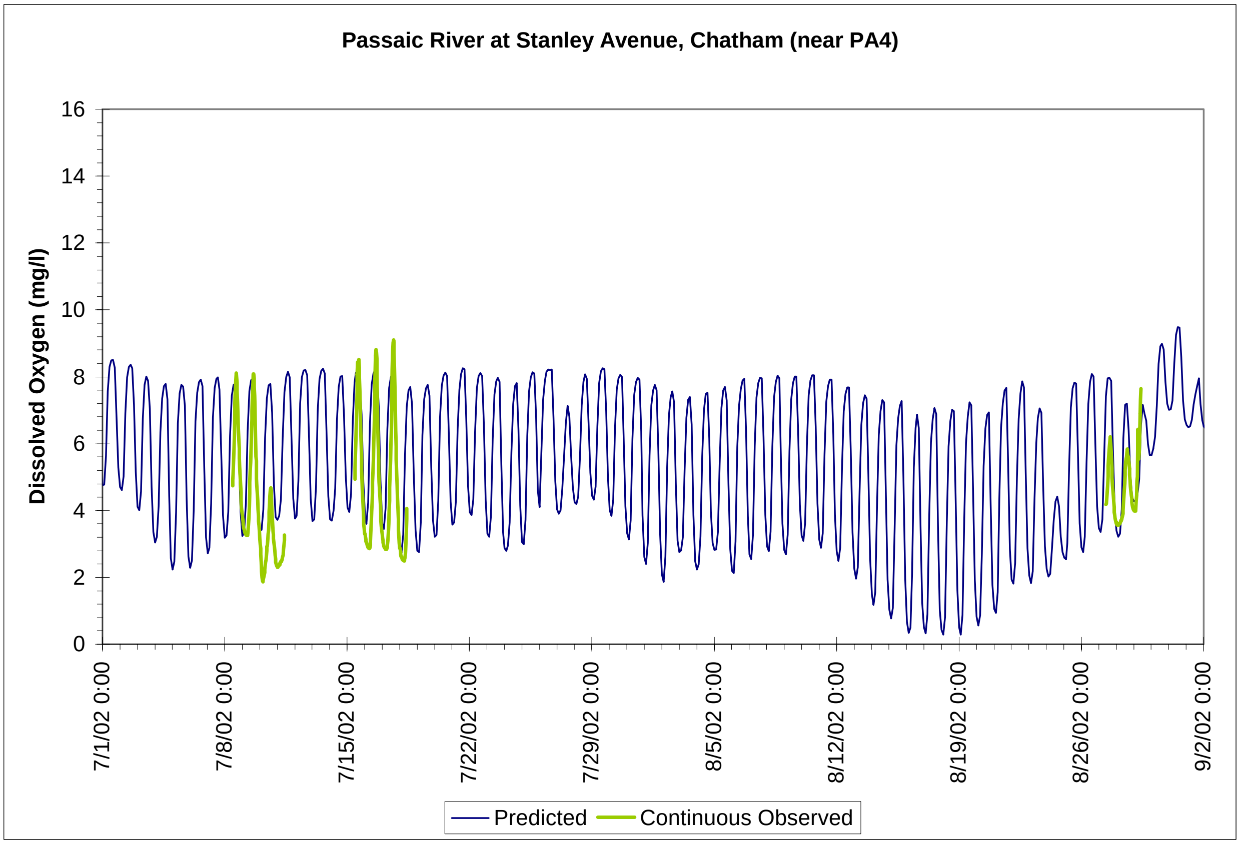
Calibration involving global and local parameters was performed iteratively. First, the values of global parameters were assumed based on the literature. The simulation was performed using average values of "percent of bottom segment covered by benthic algae," which demonstrated the direction the global parameters needed to be changed. Different growth rates, respiration, and death rates were tested. After the first round of global parameters calibration, the local parameters are adjusted. Another round of global parameter calibration was performed until meaningful simulations for the entire basin were obtained. The calibrated value of the maximum growth rate of benthic algae and macrophytes was 60 g/m^2/day. The calibrated values for respiration and death rates were 0.01 and 0.005/day, respectively. The growth rate and respiration rates were within the range suggested by the WASP course materials. Death rates were lower than the range of 0.01-0.5 suggested by the WASP course material. However, lower death rates make sense in this case, because macrophytes would be expected to have lower death rates than periphyton. The calibration process presented here was time consuming given the number of stations involved.

Values of the intermediate segments were assumed to vary proportionally according to the values of consecutive sampling stations. Values were assumed constant for a given stretch to provide better representation of the DO variation along the stream or river. The occurrence of benthic algae and macrophytes was highly variable and difficult to measure. Omni conducted measurements of periphyton for selected stations. However, because periphyton and macrophytes were simulated as a single state variable, the observed periphyton data and the simulated values are not directly comparable.

The model representation of diurnal DO varied according to the location. DO calibration was performed using the continuous DO and grab values from the August 2003 low flow event, as well as diurnal data collected by NJDEP during 2002 from the Passaic River near Chatham. The remaining events and locations were used for validation. The match was close for most stations. Some stations, like the ones at the Rockaway, presented some unusual DO patterns, which were not able to be captured by the model. Another example of this is the Passaic

River at Two Bridges, which occasionally exhibits unusually high DO that cannot be explained, much less simulated. Greater importance was given to the continuous data during calibration. However, when the continuous data and the grab DO values were contradictory, the preference was given to grab values for calibration. It is possible that the continuous recording device in those instances was installed too close to the sediments and may not be representative of the water column itself, as the grab samples would be. The DO calibration for Passaic River at Chatham using 2002 diurnal data from NJDEP is shown in Figure 21 below.

FIGURE 21: Example Diurnal DO Calibration Graph



High flow events were also evaluated for calibration. The model tends to overestimate DO concentrations at the stations at the Lower and Mid-Passaic River during high flow periods. This can be explained partially due to the existence of large wetland complexes in that area that discharge low DO water.

Another possible reason for the overestimation of DO is the configuration of channel geometric characteristics during extreme high flows. Overbank flows, which occur during high flow events, can significantly impact reaeration rates, since they are a function of velocities and depths. Overbank flows cannot be captured by the flow model, and consequently by the water quality model.

In order to better capture the DO variation at the confluence of the Passaic and Pompton Rivers, continuous DO data measured by USGS just downstream of the confluence was utilized. Since continuous data were available for 2002, representative periods of summer 2002 were chosen for calibration, and 2003 was used as a validation year. Three sets of measurements are available immediately downstream of the confluence between the Passaic and Pompton Rivers: one at the right bank of the Passaic, one in the middle and one in the left bank, looking downstream. The left bank data was used to calibrate DO at the last segment of the Pompton River (5-23); the right bank data was used to calibrate the last segment of the Passaic River before the confluence (12-38).

Statistics demonstrating general DO fit were derived using the grab DO data for all Omni Stations, and are shown in Table 25. These statistics do not adequately reflect the quality of the DO calibration, since diurnal events were also used extensively for calibration. Diurnal DO calibration and validation graphs are provided in Appendix F.

TABLE 25: DO Model Calibration Statistics

Station	Mean Error	Predicted Mean	Observed Mean	Predicted Standard Deviation	Observed Standard Deviation
DR1	0.87	8.53	7.66	1.10	1.89
PA10	0.47	9.99	9.52	1.18	1.64
PA11	0.38	10.31	9.93	1.50	1.74
PA3	0.71	6.68	5.97	1.65	1.84
PA4	0.88	9.08	8.20	1.18	1.75
PA5	0.90	6.71	5.80	1.71	1.74
PA6	0.50	6.76	6.25	1.62	1.52
PA7	1.31	7.46	6.16	1.30	1.55
PA8	0.08	7.01	6.93	2.03	1.59
PA9	0.37	9.38	9.01	1.05	1.41
PE2	0.19	9.33	9.14	0.76	0.98
PK1	0.39	10.31	9.92	1.31	1.63
PO1	-0.17	8.60	8.77	1.53	1.31
PO2	0.34	8.37	8.03	1.24	1.32
PO3	-0.06	8.38	8.44	1.31	1.54
RO2	0.00	7.90	7.90	2.14	1.63
WA2	-0.33	8.42	8.76	0.74	0.83
WI2	-0.59	8.89	9.48	0.85	1.34
WI3	-0.33	6.32	6.65	0.66	2.31

II.H.5. Chlorophyll-a

Chlorophyll-a provides a measure of the amount of phytoplankton in the water column. Chlorophyll-a was one of the first variables to be calibrated. In systems like the Passaic River Basin, where nutrients are not limiting in most areas, phytoplankton growth is influenced by only a few global kinetic parameters that require calibration. The other factors influencing phytoplankton growth are stream water temperatures and solar radiation, which are time-functions not subject to calibration, and transport-related inputs, which are defined by the flow model and were previously calibrated.

Phytoplankton maximum growth rate, phytoplankton death rate, and phytoplankton respiration rate are the parameters adjusted for chlorophyll-a calibration. Chlorophyll-a is most sensitive to phytoplankton growth. A value of 1.25/day was chosen as the final calibrated parameter. This value is within the range suggested by the literature for phytoplankton growth (Chapra, 1997).

Besides growth rate, phytoplankton growth is very sensitive to the transport-related parameters such as flows, velocities and detention times, water temperature and solar radiation. The influence of these inputs was considered during the calibration.

The chlorophyll-a data used for calibration was limited. Two PVSC stations with a significant number of chlorophyll-a data throughout the years were chosen for calibration. The stations used for chlorophyll-a calibration were: PVSC1- Passaic at Totowa Avenue, and PVSC4- Passaic at Market St. The WY2002 was chosen as the base year for chlorophyll-a calibration since extreme low flow conditions considerably influenced algae growth. Omni chlorophyll-a data, which consisted of three low flow events sampled in 2003, were used for validation purposes. Sampling stations at tributaries showed very low chlorophyll-a concentrations. Boundary conditions were found to be very important in the Pompton River, due to the influence of Pompton Lake.

An example calibration graph for chlorophyll-a is shown below in Figure 22. A good fit of chlorophyll-a was obtained for the entire basin. The general fitness of chlorophyll-a predictions, using the calibration data from PVSC as well as the validation data from Omni, is provided in Table 26.

FIGURE 22: Example Chlorophyll-a Calibration Graph

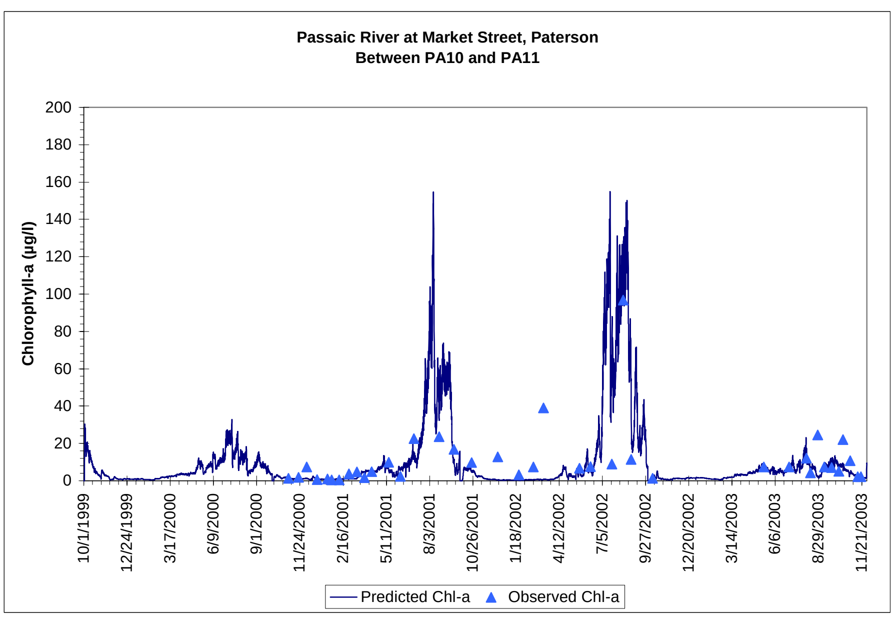


TABLE 26: Chlorophyll-a Model Calibration Statistics

Station	Mean Error	Predicted Mean	Observed Mean	Predicted Standard Deviation	Observed Standard Deviation
2002 Calibration (PVSC)					
PVSC1	-3.26	10.30	13.56	16.99	18.65
PVSC4	4.66	25.05	20.40	36.89	27.18
2003 Validation (Omni)					
DR1	-0.92	1.38	2.30	0.34	1.53
PA10	-3.95	2.95	6.90	1.36	3.32
PA11	-8.20	3.49	11.68	1.72	6.78
PA3	0.00	1.37	1.37	0.30	0.94
PA5	-0.37	1.13	1.50	0.13	0.91
PA6	-0.11	1.14	1.25	0.33	0.75
PA7	-0.96	1.24	2.20	0.24	1.12
PA8	-1.99	2.46	4.45	1.07	2.46
PA9	-3.95	3.61	7.57	0.99	0.84
PE2	-0.47	1.04	1.52	0.33	0.68
PO1	0.25	5.05	4.80	3.93	3.69
PO2	-0.10	4.45	4.55	3.31	3.90
PO3	-0.18	4.66	4.83	3.59	4.35
RO2	0.58	1.86	1.28	0.99	0.88
WA2	-0.48	1.01	1.48	0.42	0.96
WI2	-1.30	1.13	2.43	0.45	1.00
WI3	-1.20	0.49	1.68	0.19	1.96

III. WATERSHED MODELING ANALYSES

The Non-Tidal Passaic River Basin model, as described above, represents a system-wide water quality model that is calibrated and validated for nutrients, dissolved oxygen, and water column chlorophyll-a. Watershed modeling analyses were performed to assess the impact of point and nonpoint source reductions on dissolved oxygen, phosphorus concentrations, and chlorophyll-a in streams throughout the system.

III.A. Seasonal Variation and Critical Conditions

The TMDL analysis must account for seasonal variations and demonstrate compliance with water quality standards under critical conditions. These objectives were accomplished through continuous simulation over more than four water years, from October 1999 through November 2003. These four water years include a range of hydrologic conditions, both seasonal and year-to-year. The impact of typical spring rains, summer thunderstorms, summer dry periods, and low flows are all represented during continuous simulation over several seasons. Critical conditions are ensured through the inclusion water years with both typical and extreme hydrologic conditions. WY2000 represents a typical year with near-average precipitation distributed mostly in smaller storm events. WY2001 represents a year with an unusually hot, dry summer with low flows. WY2002 represents a severe drought condition during a water supply emergency. Finally, WY2003 represents an unusually wet summer period.

III.B. Model Scenarios

Three scenarios were simulated in order to bound the impacts of increases and decreases in phosphorus loads on water quality parameters, namely phosphorus concentration, dissolved oxygen, and phytoplankton (water column chlorophyll-a). These scenarios are described below.

III.B.1. Existing Condition

The Passaic River Basin model was run over the entire simulation period in order to define the Existing Condition. The calibrated and validated model essentially defines the Existing Condition for the Passaic River Basin. Headwater loads coming into the model domain represent the best estimate of actual loads that occurred during the simulation period. Similarly, point sources loads were based on the actual effluent flows and concentrations discharged during the simulation period, estimated based on actual records. Nonpoint sources, including runoff and tributary baseflow, were estimated based on actual conditions. The definition of Existing Condition over such diverse hydrologic conditions throughout the Passaic River Basin represents a major achievement of this study.

III.B.2. Baseline Future Condition

The Baseline Future Condition simulation was developed primarily in order to determine how water quality would change in the Passaic River Basin if point sources were discharging their maximum permitted flows at their maximum permitted concentrations. For several reasons, this scenario represents an upper boundary in terms of the impact of phosphorus sources on water quality in the Passaic River Basin. First, the assumption that point sources are discharging their permitted flows at their permitted concentrations is not realistic, since capacity assurance requirements, mandatory penalties, and operational treatment variability all ensure that regulated point sources discharge less than their permitted flows and concentrations on a regular basis. Furthermore, nonpoint sources (which are assumed to remain the same as the Existing Condition) are minor compared to point sources, and are not expected to increase substantially above current levels due to enhanced stormwater controls that may actually result in decreased runoff loads. For all these reasons, the Baseline Future Condition represents an upper bound on phosphorus sources to the Passaic River Basin.

The point source flows and concentrations assumed for the Baseline Future Condition are provided in Table 27.

TABLE 27: Permitted Flows and Concentrations for Baseline Future Condition

NJPDES ID	Facility	Reach	Permitted Flow (mgd)	TP Permitted Summer Concentration (mg/l) (Baseline Future)	TP Permitted Winter Concentration (mg/l) (Baseline Future)
NJ0104451	Bayer Corporation	Passaic	0.2160	1.0 Assumed	1.0 Assumed
NJ0027961	Berkeley Heights WPCP	Passaic	3.1	1.0	1.0
NJ0022845	Bernards SA – Harrison Brook STP	Dead	2.5	5.2	5.0
NJ0020427	Caldwell Boro STP	Passaic	4.5	4.2	4.0
NJ0025330	Cedar Grove Twp STP	Peckman	2.0	4.0	3.5
NJ0020281	Chatham Hill STP	Passaic	0.03	4.16*	4.16*
NJ0052256	Chatham Twp – Chatham Glen STP	Passaic	0.155	4.16*	4.16*
NJ0003476	Exxon Research & Eng Co	Whippany	0.2900	1.0 Assumed	1.0 Assumed
NJ0025518	Florham Park SA	Passaic	1.4	2.45*	2.45*
NJ0024902	Hanover SA	Whippany	4.61	5.0	4.5
NJ0024511	Livingston Twp STP	Passaic	4.6	4.3	3.9
NJ0024465	Long Hill Twp – Stirling Hills STP	Passaic	0.9	4.4	3.7
NJ0024937	Madison Chatham Joint Mtg – Molitor	Passaic	3.5	4.4	4.0
NJ0024911	Morris Twp – Butterworth STP	Whippany	3.3	3.04	2.24
NJ0025496	Morristown Town STP	Whippany	6.3	1.0	1.0
NJ0002577	Nabisco Fair Lawn Bakery / Kraft	Passaic	0.3202	1.0 Assumed	1.0 Assumed
NJ0026689	NJDHS - Greystone Psychiatric Hospital	Passaic	0.4000	1.0 Assumed	1.0 Assumed

TABLE 27: Permitted Flows and Concentrations for Baseline Future Condition (cont'd)

NJPDES ID	Facility	Reach	Permitted Flow (mgd)	TP Permitted Summer Concentration (mg/l) (Baseline Future)	TP Permitted Winter Concentration (mg/l) (Baseline Future)
NJ0024970	Parsippany-Troy Hills SA	Whippany	16.0	4.9	5.0
NJ0026514	Plains Plaza Shopping Center	Pompton	0.0200	1.0 Assumed	1.0 Assumed
NJ0023698	Pompton Lakes Borough MUA	Ramapo	1.2	1.0	1.0
NJ0002551	Reheis Chemical	Passaic	DMR	0.05	0.05
NJ0027006	Ringwood Boro – Ringwood Acres STP	Wanaque	0.0360	1.0 Assumed	1.0 Assumed
NJ0032395	Ringwood Plaza STP – Ringwood Assn	Wanaque	0.0117	1.0 Assumed	1.0 Assumed
NJ0022349	Rockaway Valley Regional SA	Rockaway	12.0	3.4	3.2
NJ0029386	Two Bridges SA	Pompton	10.0	1.0	1.0
NJ0024490	Verona Twp STP	Peckman	3.0	5.4	3.7
NJ0053759	Wanaque Valley Regional SA	Wanaque	1.25	1.0	1.0
NJ0022489	Warren Twp Stage I&II STP	Passaic	0.47	4.2	3.6
NJ0022497	Warren Stage IV STP	Dead	0.80	7.1	5.2
NJ0050369	Warren Stage V STP	Dead	0.38	7.1	5.1
NJ0028002	Wayne Twp – Mountain View STP	Singac	13.5	3.4	3.1

*Note: No phosphorus effluent limit provided by NJDEP at the time boundary condition was developed; concentration based on the 90th percentile of data obtained from discharger and DMRs

Several other modifications were made to the Baseline Future Condition scenario in order to coordinate the analysis with other TMDL studies and to accommodate Reserve Capacity for the Wanaque Reservoir. The first change made to the Baseline Future Condition was to replace the actual time series for the Wanaque South flow diversion with a future diversion scenario that incorporates a reserve capacity for NJDWSC. The new diversion time series was developed by North Jersey District Water Supply Commission (NJDWSC) for the Wanaque Reservoir TMDL Study (Najarian, 2005) in order to reflect the amount of pumping that would have been required if NJDWSC were operating the Wanaque Reservoir at its full safe yield of 173 mgd. The new diversion time series was only developed for simulation through 2002; since very little pumping occurred in 2003, the existing diversion was used for WY2003 simulations. Note that PVWC also diverts from the Wanaque South intake, and that portion of the diversion was kept the same for the Baseline Future Scenario. The total diversion time series used for the Baseline Future Condition scenario is provided electronically in Appendix M.

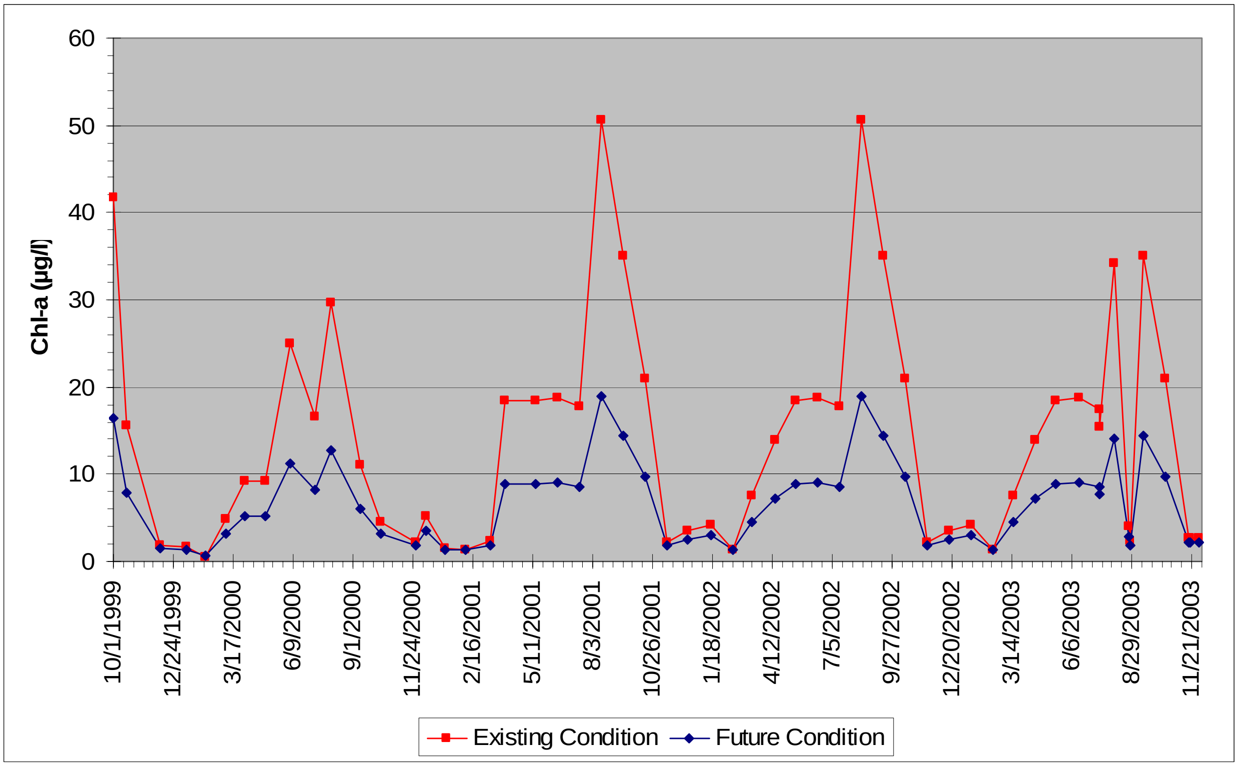
The other changes were made to headwater boundary conditions of the Peckman and Ramapo Rivers to reflect the successful implementation of TMDLs established for Verona Park Lake and Pompton Lake, respectively. The upstream model boundary in the Peckman River is the outlet of Verona Park Lake, which was the subject of a TMDL established in 2003 (NJDEP, 2003). The boundary condition for phosphorus in the Peckman River was set to a constant of 0.05 mg/l total phosphorus, the lake criterion for phosphorus around which the Verona Park Lake TMDL was based. OrthoP was also held constant at 0.02 mg/l based on the average proportion of OrthoP to TP (40%) observed immediately downstream of Verona Park Lake (P1).

Similarly, the upstream model boundary in the Ramapo River is the outlet of Pompton Lake, which was also the subject of a previous TMDL proposed in 2005 (NJDEP, 2005). Pompton Lake is also affected by the Wanaque Reservoir TMDL, which is being established concurrently (Najarian, 2005), because there is a reservoir intake in Pompton Lake that diverts water to the Wanaque Reservoir. The Ramapo River boundary condition at Pompton Lake was changed for both phosphorus and chlorophyll-a in order to better reflect the TMDL condition established for Pompton Lake and the Wanaque Reservoir.

The TMDLs for the Wanaque Reservoir and Pompton Lake will require that reductions in New York State bring the Ramapo River to 0.1 mg/l total phosphorus. For this reason, the Wanaque Reservoir TMDL Study (Najarian, 2005) developed a model of the Ramapo River in order to predict phosphorus concentrations at the reservoir intake in Pompton Lake. Pompton Lake is also the Ramapo River boundary for the Passaic River Basin model; therefore, the phosphorus concentrations predicted by the Najarian Study for the Pompton Lake were used to define the Ramapo River boundary condition for the Baseline Future Condition. Simulation for 2003 used the average phosphorus concentrations predicted by the Najarian Study, since simulations for that study extended only through 2002. Average phosphorus concentrations predicted by the Najarian Study for the outlet of Pompton Lake were 0.02 and 0.014 mg/l TP and OrthoP, respectively.

Recall that historical chlorophyll-a data from Pompton Lake were used to develop the Ramapo River headwater boundary for chlorophyll-a for the Existing Condition. Since the boundary condition for chlorophyll-a at this location proved to be an important driver for the Pompton River (see Sensitivity Analyses section), a modified boundary condition was developed for the Baseline Future Condition. Reduction of phosphorus concentration in Pompton Lake to 0.02 mg/l would result in a dramatic decrease in phytoplankton production in the lake. A new Ramapo River boundary condition for chlorophyll-a was developed using a power function by multiplying the Existing Condition boundary by the power of 0.75. The resultant boundary condition (shown in Figure 23 along with the original boundary condition) does not exceed 20 µg/l chlorophyll-a, which represents a reasonable scenario for a lake with an average total phosphorus concentration of 0.02 mg/l.

FIGURE 23: Chl-a Boundary Conditions in Ramapo River at Pompton Lake



III.B.3. Most Extreme Reduced Phosphorus Condition

Whereas the Baseline Future Condition represents an upper bound of the load of phosphorus that could ever be expected to occur in the Passaic River Basin, a Most Extreme Reduced Phosphorus[3] (MERP) Condition was developed to represent a lower bound to the load of phosphorus that could ever be expected to occur in the Passaic River Basin. The MERP Condition was developed by making the following changes to the Baseline Future Condition:

- All point sources were set to 0.05 mg/l effluent TP concentrations;
- Phosphorus runoff loads from urban and agricultural land uses were reduced by 80%;

The purpose of the MERP Condition was to define the water quality condition that would exist if all point sources were discharging at 0.05 mg/l total phosphorus, and all nonpoint runoff sources were reduced by at least as much as

[3] The designation "Most Extreme Reduced Phosphorus" is used to distinguish this scenario from earlier versions named "Reduced Phosphorus" and "Extreme Reduced Phosphorus."

possible throughout the basin. The value of 0.05 mg/l for point source effluent concentration was selected because a long-term average concentration of 0.05 mg/l coincides with monthly effluent limitations near the phosphorus stream criterion (0.1 mg/l) and is generally considered the most stringent effluent limitation for phosphorus. It is important to note that 0.05 mg/l total phosphorus is lower than the tributary baseflow concentrations in the contributing watersheds of the Passaic River Basin study area, particularly in the Upper Passaic River Basin. It is also important to note that meeting a long-term average effluent concentration of 0.05 mg/l total phosphorus likely would not be consistently achievable for all point sources, even with state-of-the-art upgrades.

Similarly, nonpoint runoff sources of phosphorus from urban and agricultural land uses were reduced by 80%. Omni does not believe that 80% reduction of nonpoint sources from stormwater is achievable throughout the Passaic River Basin; however, the 80% reduction was selected at the direction of NJDEP to coincide with the nonpoint source reductions contemplated in the proposed Wanaque Reservoir TMDL (NJDEP, 2005b). The 80% reduction of nonpoint source runoff load was achieved by reducing the phosphorus EMCs for urban and agricultural land uses, and then recalculating the flow-weighted runoff EMCs for each sub-basin using WAMIT.

III.C. Phosphorus Source Assessment

In order to characterize phosphorus loadings in the Non-Tidal Passaic River Basin, source assessments were performed using the Passaic River Basin model described previously. Source assessment identifies the types of sources and their relative contributions to phosphorus loadings. Four categories of phosphorus sources were evaluated: STP discharges, NPS runoff, headwaters, and NPS background.

For the purpose of TMDL development, point sources include domestic and industrial wastewater treatment plants that discharge to surface water, as well as surface water discharges of stormwater subject to regulation under the National Pollutant Discharge Elimination System (NPDES). STP discharges are explicitly modeled and easily summarized within the Passaic River Basin model. The STP discharges within the area of interest for the Non-Tidal Passaic River Basin study that are explicitly modeled by the flow and water quality model are listed below in Table 28; actual (annual average) flows and phosphorus concentrations, as well as permitted flows and phosphorus concentrations, are provided for each discharge.

TABLE 28: Flows and Phosphorus Concentrations from STP Discharges in the Passaic River Basin

NJPDES ID	Facility	Receiving Water	Actual		Permitted		
			Flow (mgd)	TP Concentration (mg/l)	Flow (mgd)	Summer TP Concentration (mg/l)	Winter TP Concentration (mg/l)
NJ0027961	Berkeley Heights WPCP	Passaic River	1.78	2.59***	3.10	1	1
NJ0022845	Bernards SA – Harrison Brook STP	Dead River	1.89	3.25	2.50	5.2	5
NJ0020427	Caldwell Boro STP	Passaic River via unnamed trib	3.75	2.38	4.50	4.2	4
NJ0025330	Cedar Grove Twp STP	Peckman River	1.21	1.90	2.00	4	3.5
NJ0020281	Chatham Hill STP	Passaic River	0.01	No Data**	0.03	4.16*	4.16*
NJ0052256	Chatham Twp – Chatham Glen STP	Passaic River	0.12	3.50	0.16	4.16*	4.16*
NJ0025518	Florham Park SA	Passaic River	0.93	1.70	1.40	3.3****	2.9****
NJ0024902	Hanover SA	Whippany River via ditch	1.99	3.60	4.61	5	4.5
NJ0024511	Livingston Twp STP	Passaic River	3.10	2.75	4.60	4.3	3.9
NJ0024465	Long Hill Twp – Stirling Hills STP	Passaic River	0.97	2.59	0.90	4.4	3.7
NJ0024937	Madison Chatham Joint Mtg – Molitor	Passaic River	2.61	3.42	3.50	4.4	4
NJ0024911	Morris Twp – Butterworth STP	Whippany River	1.83	1.29	3.30	3.04	2.24
NJ0025496	Morristown Town STP	Whippany River	2.94	0.55	6.30	1	1
NJ0024970	Parsippany-Troy Hills SA	Whippany River	12.45	3.56	16.00	4.9	5
NJ0023698	Pompton Lakes Borough MUA	Ramapo River	0.82	0.22	1.20	1	1
NJ0002551	Reheis Chemical	Passaic River via unnamed trib	0.91	0.05	DMR	0.05	0.05
NJ0022349	Rockaway Valley Regional SA	Rockaway River	9.82	1.50	12.00	3.4	3.2
NJ0029386	Two Bridges SA	Pompton River	5.17	3.08	10.00	1	1
NJ0024490	Verona Twp STP	Peckman River	2.15	3.17	3.00	5.4	3.7
NJ0053759	Wanaque Valley Regional SA	Wanaque River	0.98	0.34	1.25	1	1
NJ0022489	Warren Twp Stage I&II STP	Passaic River	0.38	2.32	0.47	4.2	3.6
NJ0022497	Warren Stage IV STP	Dead River	0.38	3.63	0.80	7.1	5.2
NJ0050369	Warren Stage V STP	Dead River	0.15	3.20	0.38	7.1	5.1
NJ0028002	Wayne Twp – Mountain View STP	Singac Brook	6.79	2.29	13.50	3.4	3.1

Note: * No phosphorus effluent limit; concentration based on the 90th percentile of data obtained from discharger and DMRS
**Assumed average of Chatham Glen's data for simulation purposes
***Phosphorus treatment began in July 2002
****Phosphorus limits set 8/1/05. Baseline simulation completed at 90th percentile of data (2.45mg/l) since these new limits were established after simulations completed

Stormwater point sources are modeled as NPS runoff in the Passaic River Basin model; stormwater point sources are the portion of NPS runoff that originated from residential and commercial land use areas. The methodology applied to simulate NPS runoff resulted in an average runoff yield of 0.56 lbs/acre/yr total phosphorus. Like nonpoint sources, stormwater point sources derive their pollutant load from runoff from land surfaces and load reduction is accomplished through Best Management Practices (BMPs). The distinction is that stormwater point sources are regulated under the Clean Water Act. Load reductions from stormwater point sources will be addressed through the management practices required through the discharge permits, and load reductions will be expressed as a percent reduction for the corresponding land use. Table 29 shows the areal NPS loads (i.e., runoff yield) for total phosphorus and total nitrogen, as well as the total (area-weighted) yield for all land use areas. All values are averaged over the four simulation years.

TABLE 29: Average NPS Runoff Yield (lbs/acre/yr) for Existing Condition

lbs/acre/yr	Residential	Commercial	Agricultural	Forest	Wetland	Barren	Composite
TP	0.48	1.20	1.18	0.05	0.75	0.06	0.56
TN	3.6	9.2	7.1	0.5	5.2	0.6	4.2

Headwater loads originate upstream of the Passaic River Basin model extent. Headwaters loads that would be expected to change as a result of the implementation of upstream TMDLs were set accordingly for all future conditons. These headwaters, including the Ramapo River at Pompton Lake and Peckman River at Verona Park Lake, are considered outside the area of interest for this study. Headwater loads that are within the area of interest for the Non-Tidal Passaic River study, but upstream of the model extent, include the Passaic River, Dead River, Whippany River, Rockaway River, Wanaque River, Pequannock River, and Singac Brook headwaters. Water quality at the model boundary of these headwaters is generally pristine or nearly pristine. The water quality model assumes these conditions remain unchanged for future scenarios. Finally, NPS background loads represent the load associated with the tributary baseflow from contributing watersheds within the model extent. These loads are considered naturally occurring and are not expected to change substantially.

Annual phosphorus loads to the Passaic River Basin were compared using the Existing Condition simulation, first by simulation year (Figure 24) and then by basin (Figure 25). Several observations stand out from these load comparisons. First, STP Discharges comprise the largest source of phosphorus to the system, which was expected. Second, the smallest load occurred in 2002, when the most severe water quality impacts were observed. Also, the largest loads occurred in 2003, when minimal productivity impacts were observed. This illustrates the importance of the timing of when loads are delivered to the system.

FIGURE 24: Non-Tidal Passaic River Basin Annual Phosphorus Loads

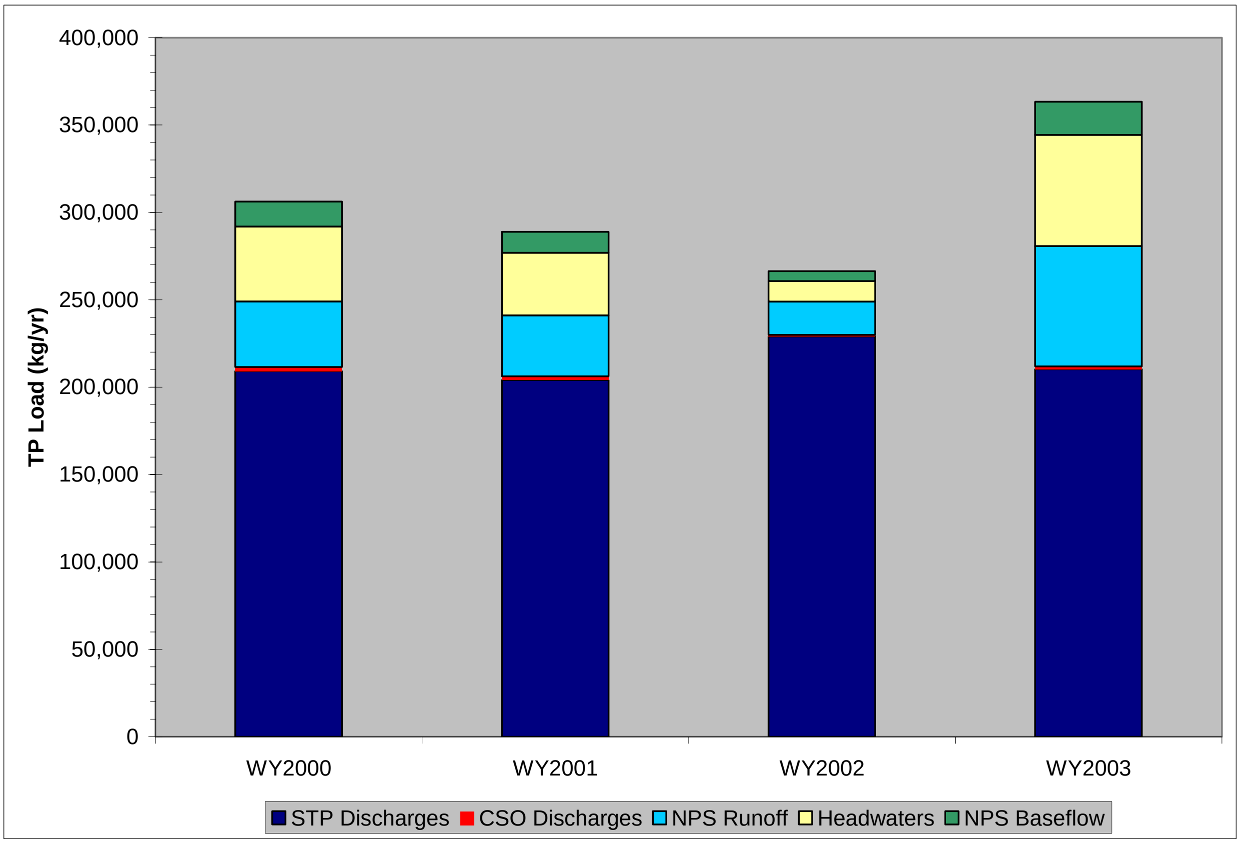
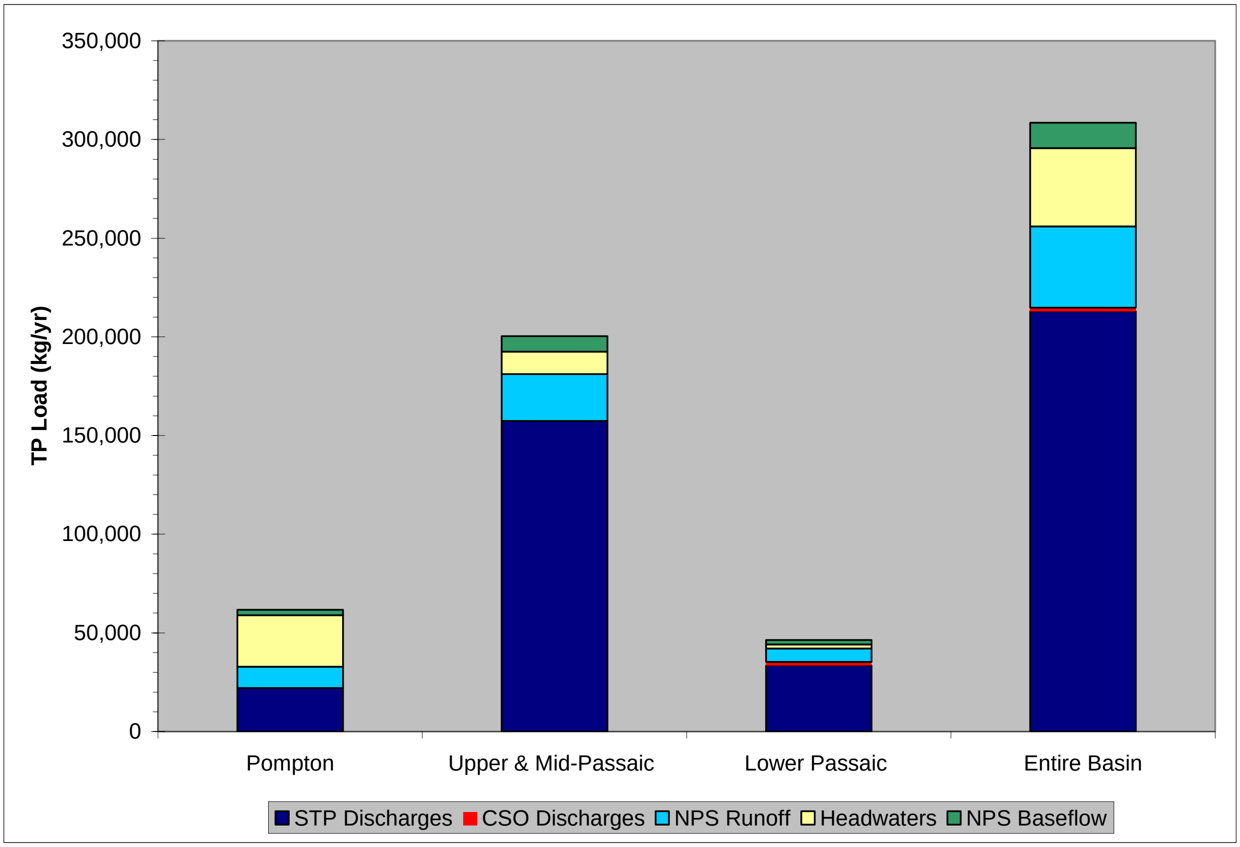


FIGURE 25: Average Annual Phosphorus Loads by Basin



III.D. Impact of Permitted Phosphorus Loads

In order to evaluate the impact of increasing phosphorus loads to the Passaic River Basin on water quality, the Existing Condition simulation was compared with the Baseline Future Condition simulation. Recall that the Baseline Future Condition simulation assumed STP point sources were discharging their permitted flows at their permitted concentrations. Generally, this simulation represents an upper bound to the phosphorus loads in the system, although upstream TMDLs were assumed to be effectively implemented.

Water quality between Existing Condition and Baseline Future Condition was evaluated by comparing TP, DO, and, where important, chlorophyll-a at selected locations in each major tributary. Predictably, TP increased in the Baseline Future Condition because STP point sources were set to their permitted flows and concentrations. The only exception was the Pompton River just below Two Bridges:

phosphorus concentrations at that location were similar in magnitude in both scenarios. The reason for this is the concentration at that location is often driven by the Two Bridges Sewerage Authority STP discharge just upstream. The permitted phosphorus concentration for that discharge is actually lower than its current discharge concentration, because the permit has a lower phosphorus limit once their flow increases to 10 mgd.

Productivity, as evaluated in terms of DO swing and chlorophyll-a peaks, generally stayed the same or decreased slightly in the Baseline Future Condition. Only the Wanaque River showed a slight increase in productivity in the Baseline Future Condition; minimum diurnal DO stayed the same, but the maximum diurnal DO increased by about 0.5 mg/l (Figure 26). Productivity in the Whippany River, for example, stayed nearly identical (Figure 27). Most areas showed a slight decrease in productivity in the Baseline Future Condition. Depending on whether productivity was causing oxygen conditions to improve or worsen, sites showing slightly less productivity showed slightly better or worse DO conditions. For instance, productivity in the Passaic River at Chatham exacerbates the low DO condition at that location; since the Baseline Future Condition reduced productivity slightly, the DO condition at that location improved (Figure 28). On the other hand, productivity in most of the Upper and Mid-Passaic River, such as Passaic River at Pine Brook, improves the normally low DO condition by increasing the average DO; since the Baseline Future Condition reduced productivity slightly, the DO condition at those locations worsened slightly (Figure 29). Finally, locations in the lower Passaic River that exhibit high phytoplankton concentrations during the summer showed an improvement in the Baseline Future Condition due to the decreased productivity (Figure 30).

FIGURE 26: Baseline Future Condition – Productivity Increases Slightly

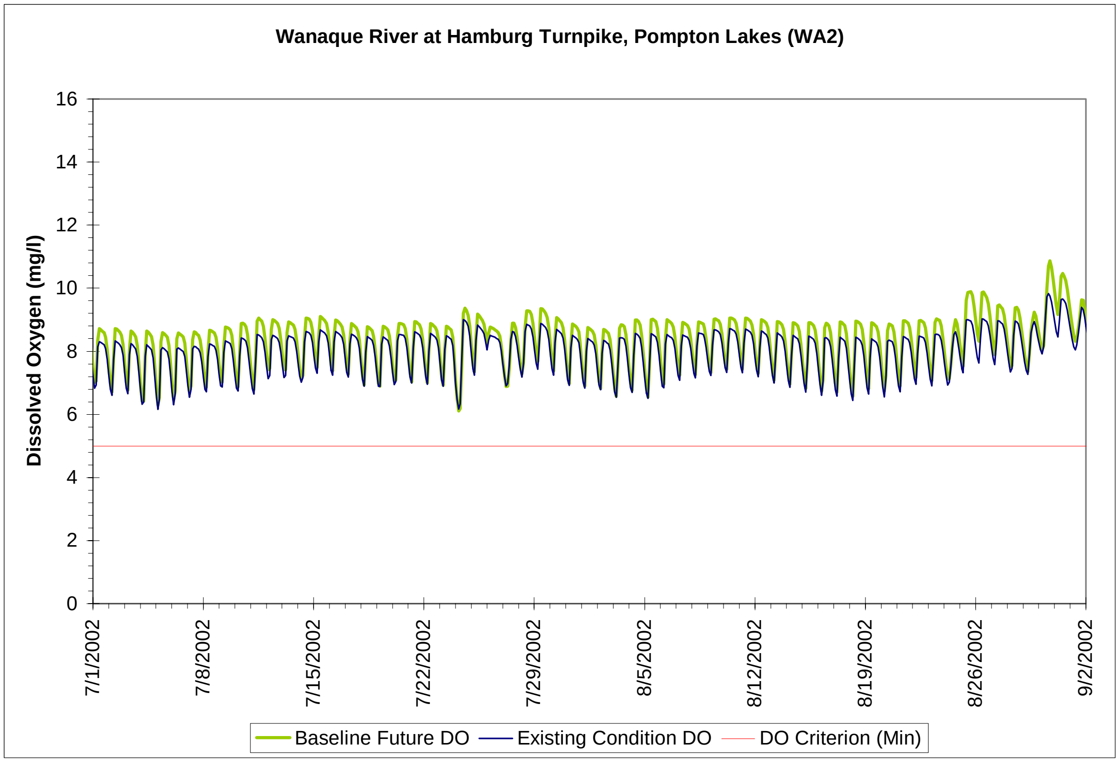


FIGURE 27: Baseline Future Condition – Productivity Remains the Same

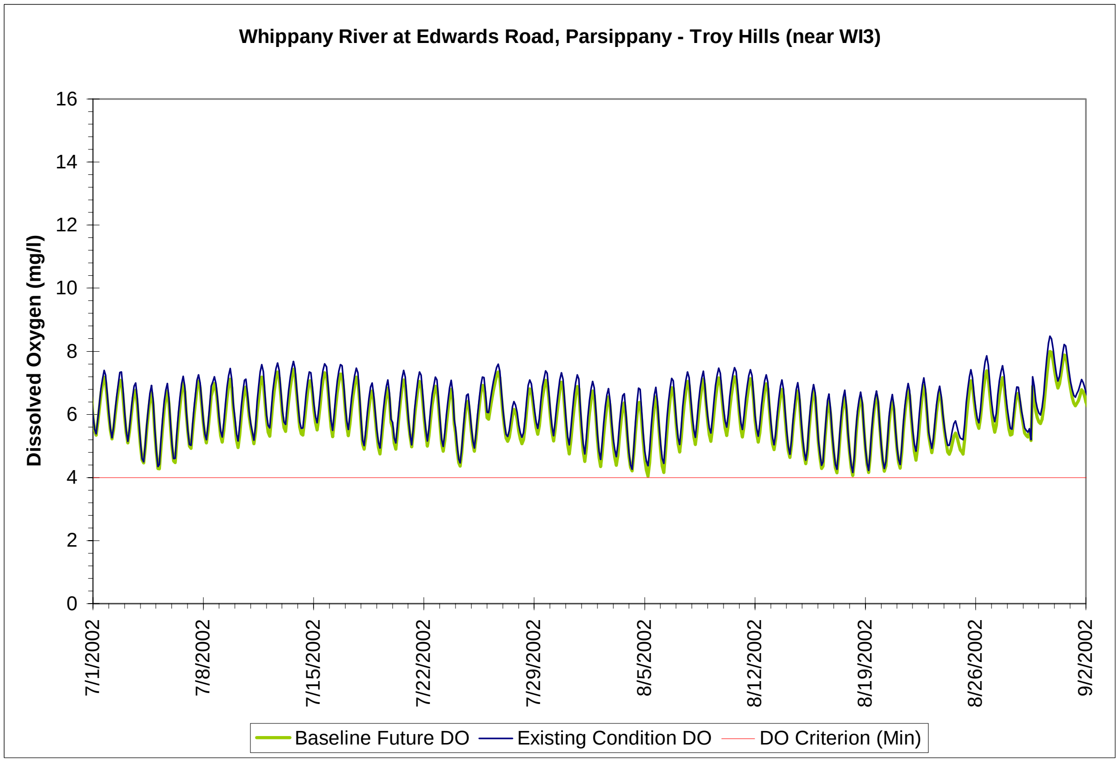


FIGURE 28: Baseline Future Condition – Productivity Decreases and DO Improves

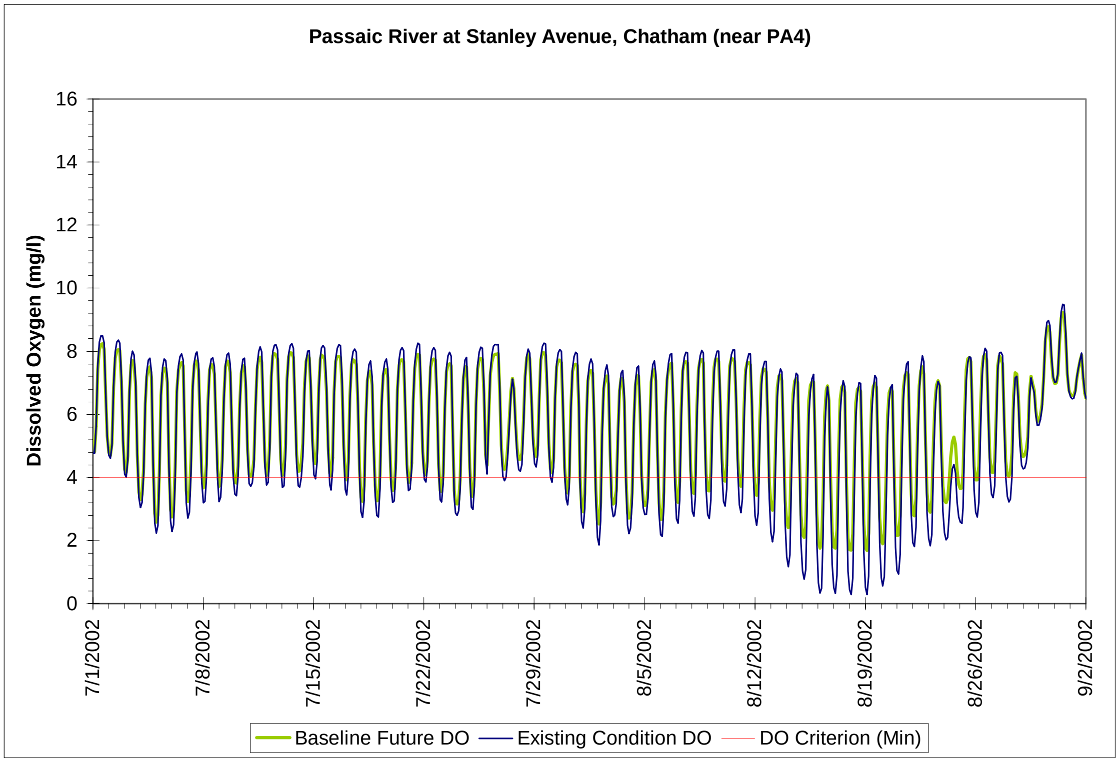


FIGURE 29: Baseline Future Condition – Productivity Decreases and DO Worsens

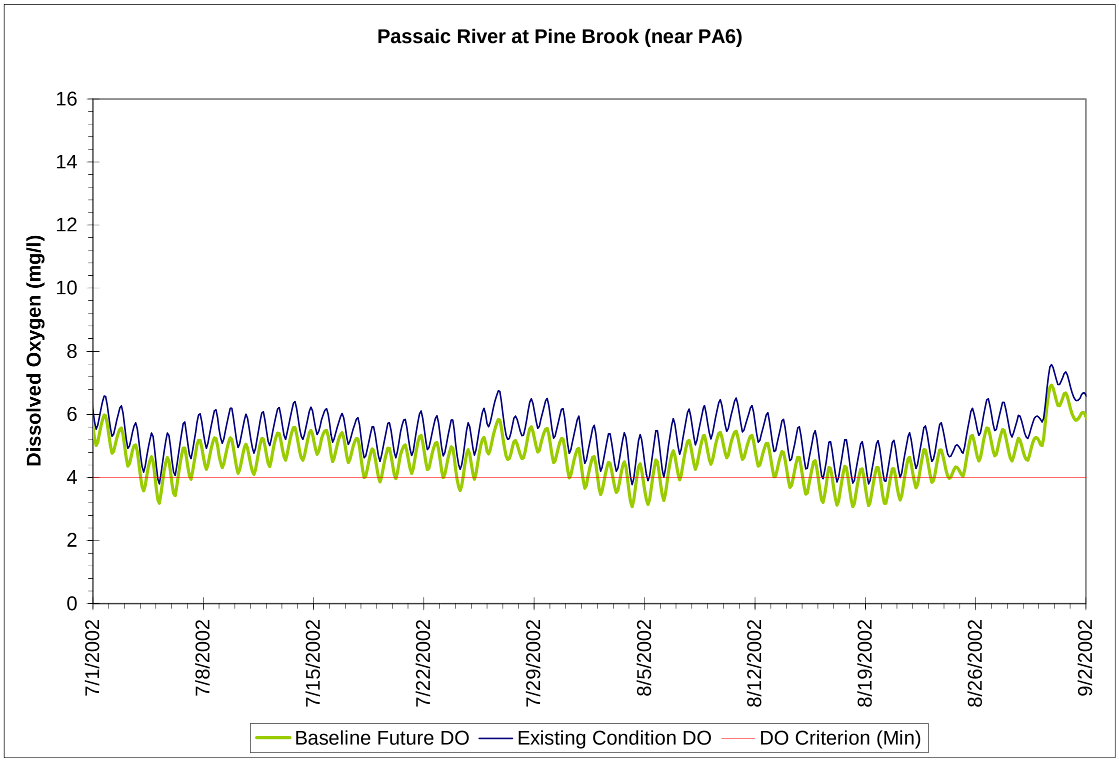
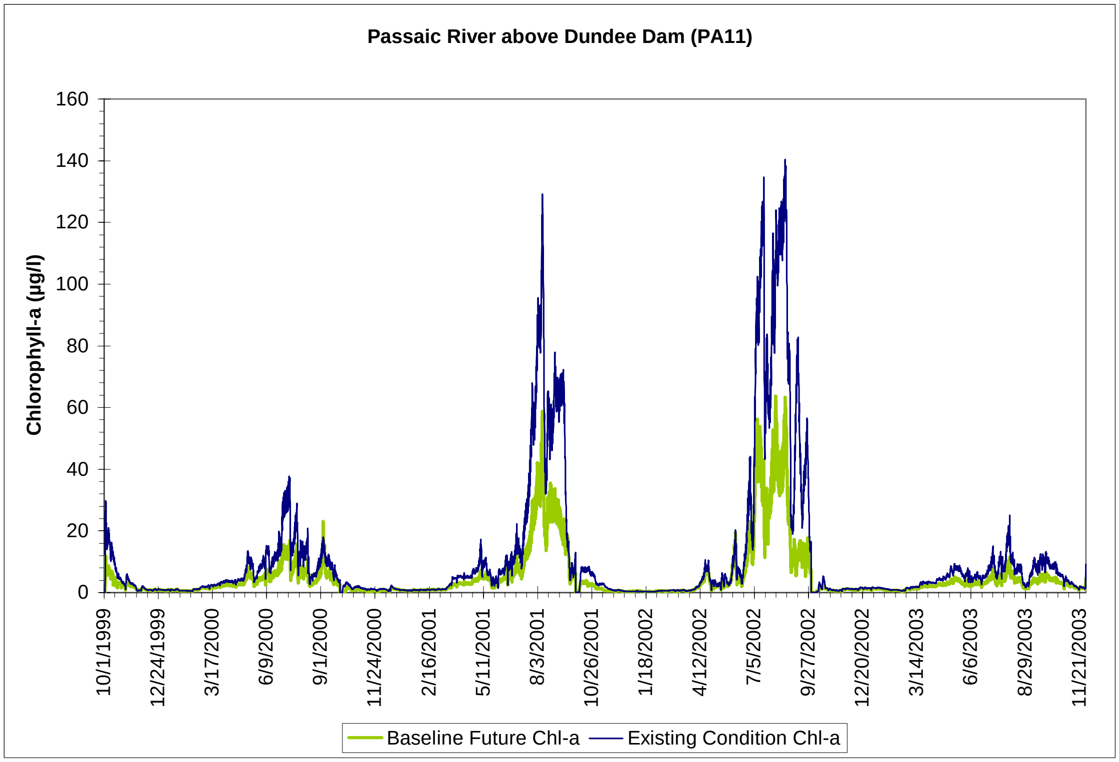


FIGURE 30: Baseline Future Condition – Productivity Decreases and Chl-a Improves



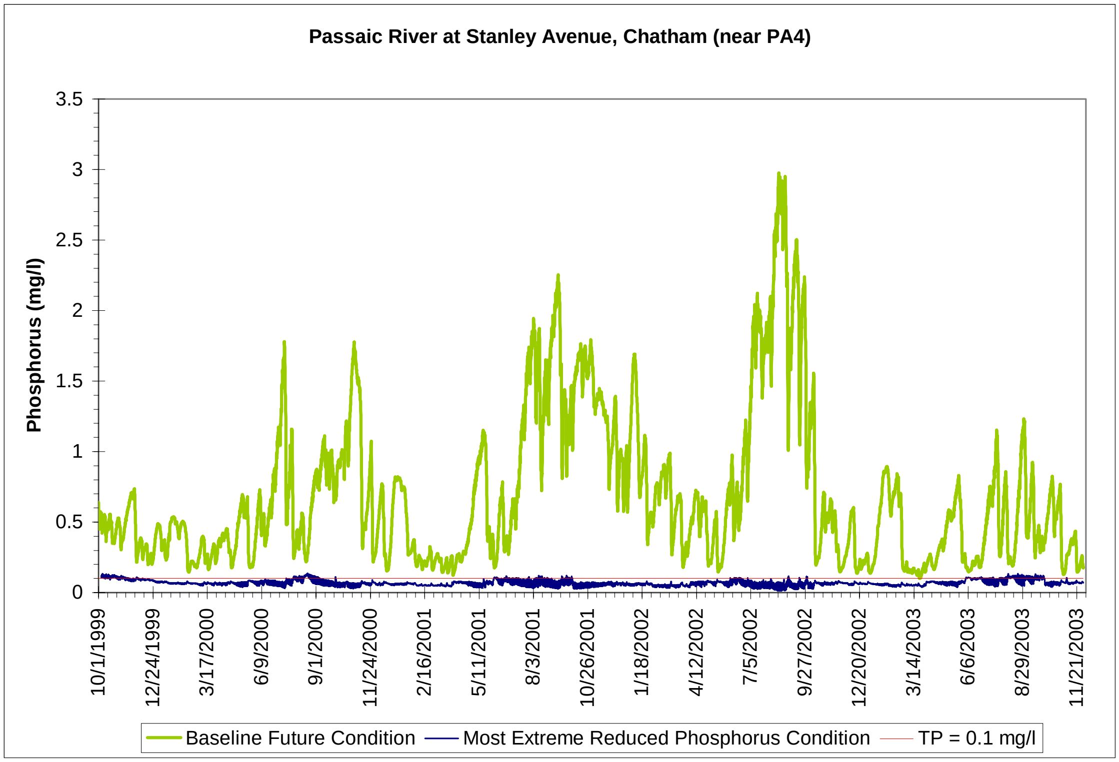
The results demonstrate that the impact of increasing phosphorus loads to the Passaic River Basin would be generally minimal. This is expected, since there is already more phosphorus than necessary to support the maximum amount of productivity in most parts of the system. The unexpected result from this comparison was that productivity was generally reduced in the Baseline Future simulation. This is due to the fact that increased effluent flows increase the overall stream flows under critical low flow periods when noticeable productivity occurs. It should be noted that the flow simulation for the Baseline Future did not account for any decreased baseflow that might be associated with the water supply increase that would be necessary to generated permitted effluent flows. The fact that the simulations predict a decrease in productivity is not overly important, except that it demonstrates that stream flow during low flow summer months is an important driver for productivity in the Passaic River Basin.

III.E. <u>Impact of Extreme Phosphorus Reductions</u>

In order to evaluate the impact of decreasing phosphorus loads to the Passaic River Basin on water quality, the Baseline Future Condition simulation was compared with the MERP Condition simulation. Recall that the MERP Condition simulation assumed STP point sources were discharging their permitted flows at 0.05 mg/l total phosphorus concentration, and that phosphorus NPS runoff loads from urban and agricultural land areas decreased by 80%. This simulation represents a lower bound to the phosphorus loads in the system.

Water quality between Baseline Future Condition and MERP Condition was evaluated by comparing TP, DO, and chlorophyll-a at all sampling locations in each major tributary. Predictably, TP decreased dramatically in the MERP Condition throughout the Passaic River Basin because of the decreased point and nonpoint sources in that simulation. It is important to note that even in the MERP Condition, many of the streams in the Passaic River Basin would still exceed concentrations of 0.1 mg/l total phosphorus, albeit less frequently. This is especially true in the Upper and Mid-Passaic River, as shown in Figure 31. The impact on productivity, as evaluated in terms of DO swing and chlorophyll-a peaks, is discussed for each of the major tributaries of the Passaic River Basin in the ensuing sections. Additional graphs showing comparisons between MERP and Baseline Future Condition simulations are provided in Appendix J.

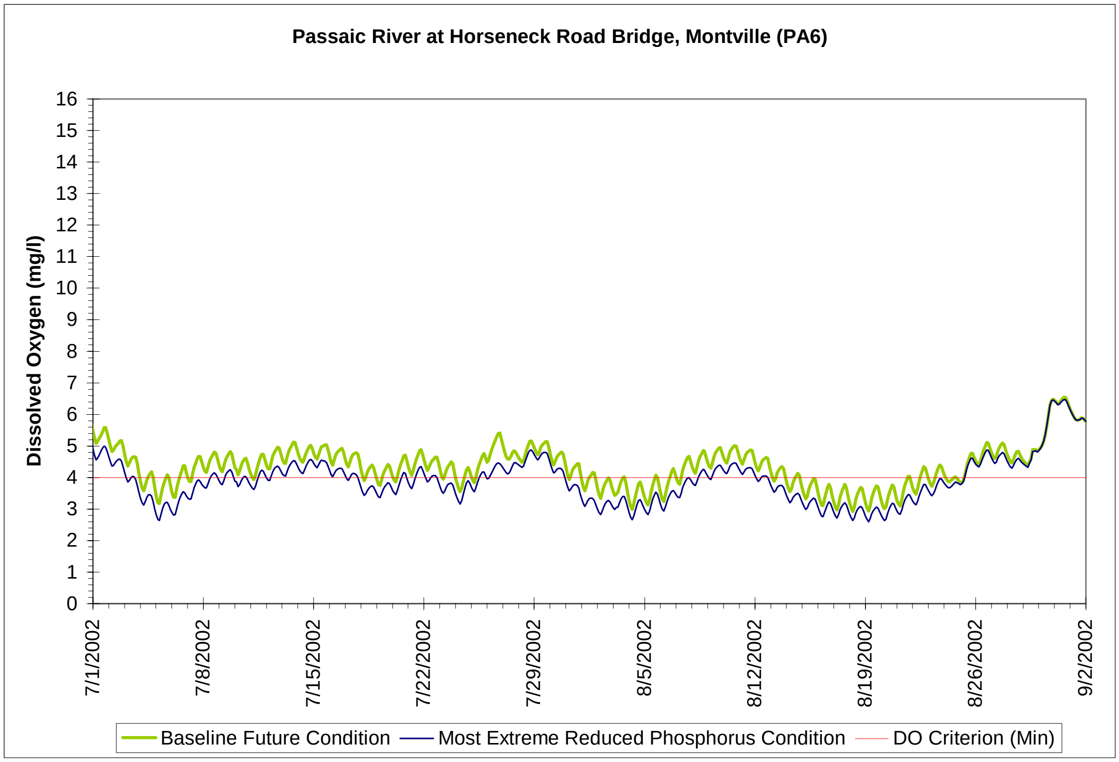
FIGURE 31: MERP Condition – Phosphorus Remains over 0.1 mg/l



III.E.1. Upper and Mid-Passaic River Mainstem

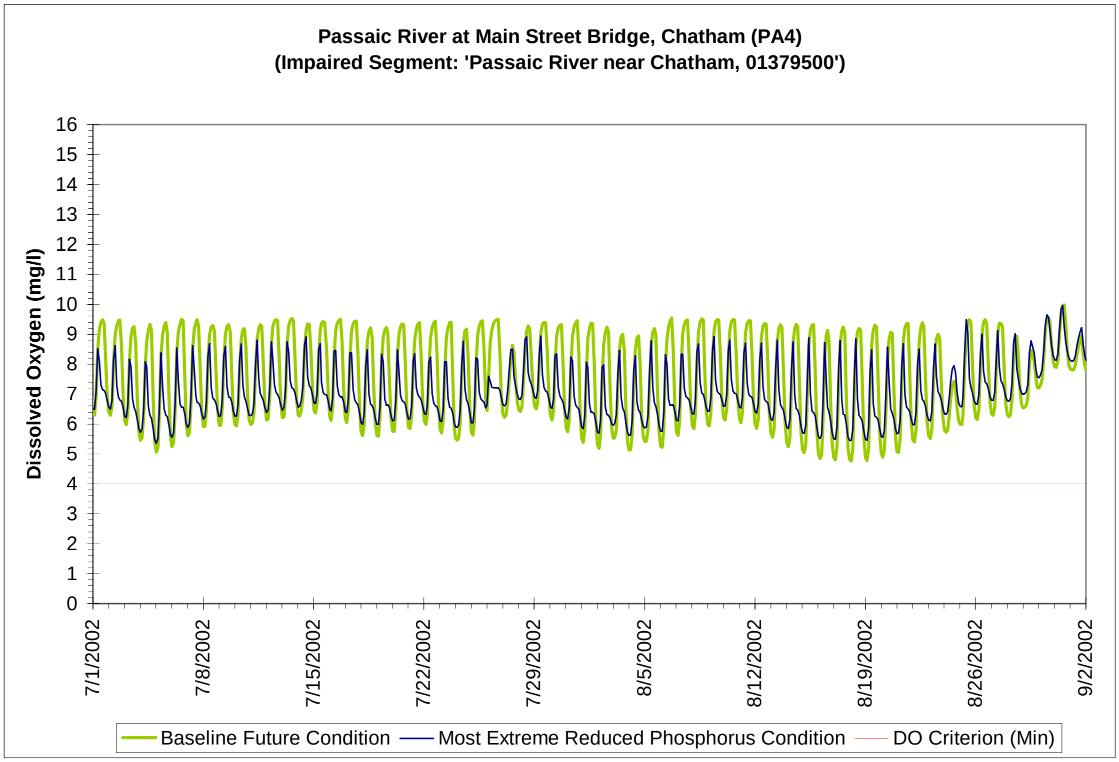
The Upper and Mid-Passaic River from the headwaters to the confluence with the Pompton is generally low in DO, and exhibits only minor diurnal variation. More productivity tends to improve the overall oxygen condition by increasing the average oxygen levels in the stream. However, since the existing level of productivity is low, the MERP Condition did not change the oxygen levels appreciably. The Passaic River at Pine Brook is representative of this section of the stream; a comparison of DO simulation results for July and August, 2002 is shown in Figure 32.

FIGURE 32: MERP Condition in Upper & Mid-Passaic River – DO Remains the Same



The Passaic River at Chatham is one area of the Upper and Mid-Passaic River that is known to exhibit more productivity in terms of diurnal DO variations driven by macrophytes. Furthermore, this productivity appears to exacerbate the normally low DO condition characteristic of the Upper and Mid-Passaic River. The MERP Condition did reduce the productivity somewhat and therefore improve the DO condition slightly. However, the MERP Condition did not change the oxygen levels enough to change the degree of use impairment. A comparison between DO simulation results of the Passaic River at Chatham for July and August, 2002 is shown in Figure 33.

FIGURE 33: MERP Condition in Upper & Mid-Passaic River – DO Improves Slightly



In summary, the Upper and Mid-Passaic River is not very sensitive to decreases in phosphorus loads. Productivity is generally not very high, and dissolved oxygen is naturally very low. In locations that exhibit greater diurnal DO swings, reducing phosphorus produced a noticeable reduction in the swing, but not enough to produce a substantial change in terms of use impairment.

III.E.2. Lower Passaic River Mainstem

The Lower Passaic River is defined for this study as the Passaic River from the Pompton River confluence to the study area boundary at Dundee Dam. This portion of the Passaic River is more productive than upstream areas, as reflected in diurnal dissolved oxygen variations. Also, this portion of the Passaic River grows high concentrations of phytoplankton during critical summer periods, in addition to macrophytes.

Upstream of Little Falls, DO levels are still strongly influenced by SOD; as a result, the decrease in productivity associated with the MERP Condition lowered the DO slightly in the MERP simulation. The simulation demonstrates that the DO condition is driven much more by SOD and stream depth than by productivity. Given the generalized hydraulic representation of the flow model upstream of Little Falls and the static representation of SOD, it is doubtful whether a decrease in productivity would actually lower the DO condition at this location to the degree that the model simulates. The decrease in productivity associated with the MERP Condition can also be seen by comparing chlorophyll-a simulation results for the Passaic River upstream of Little Falls, as shown in Figure 34. The slight worsening of DO associated with the MERP Condition can be seen by comparing DO simulation results during July and August of 2002 for the Passaic River upstream of Little Falls, as shown in Figure 35.

FIGURE 34: MERP Condition in Passaic River Upstream Little Falls – Chl-a is Reduced

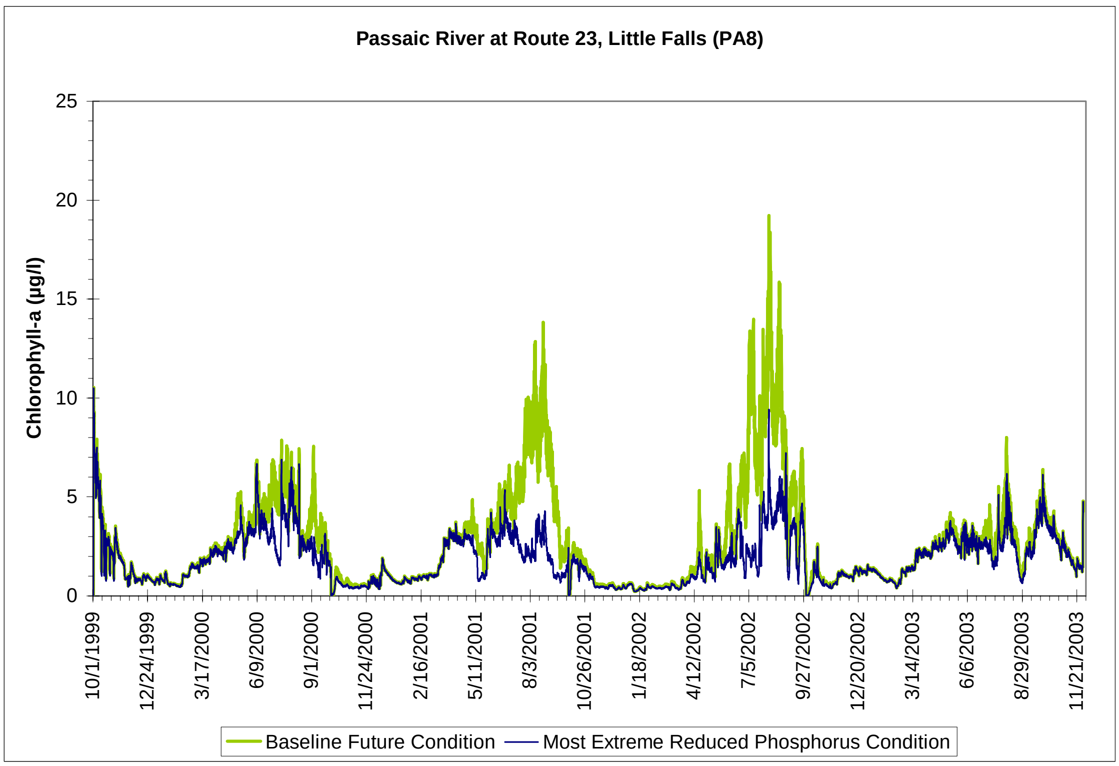
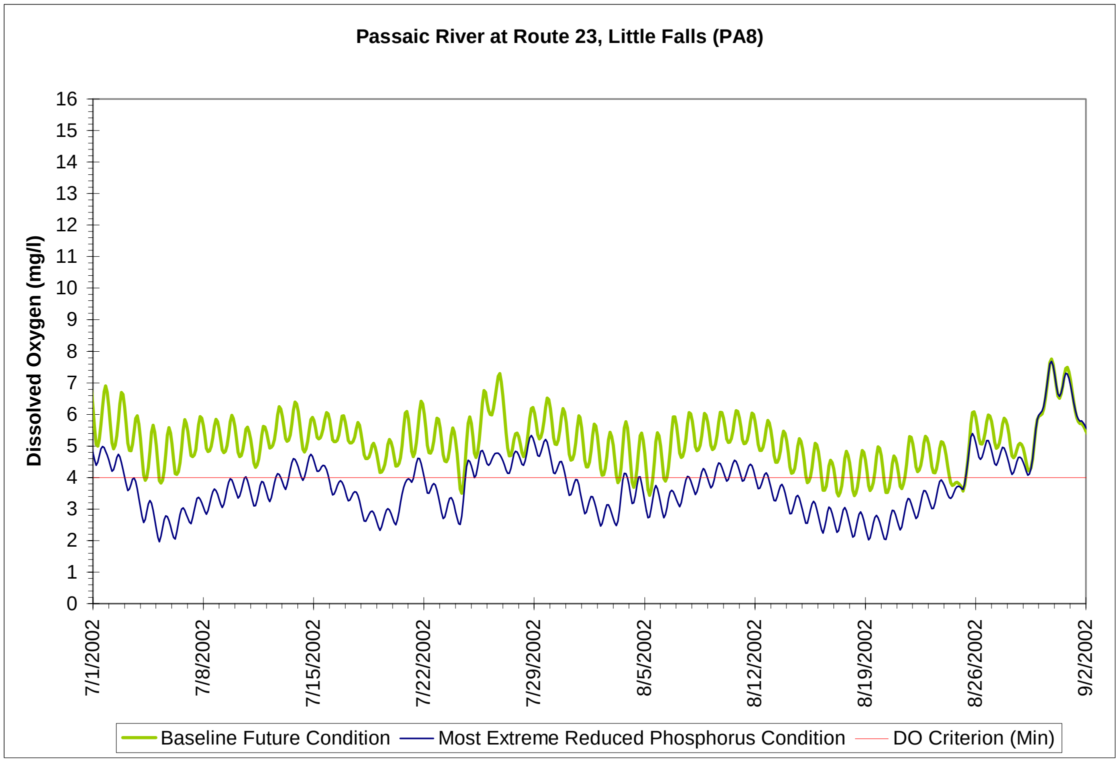


FIGURE 35: MERP Condition in Passaic R. Upstream Little Falls – DO Worsens Slightly



Downstream of Little Falls to Dundee Dam, DO levels in the Passaic River are driven by macrophyte and phytoplankton productivity. As a result, the decrease in productivity associated with the MERP Condition reduced phytoplankton peaks and reduced the DO swings substantially. The decrease in productivity associated with the MERP Condition is most pronounced in the Passaic River upstream of Dundee Dam: a comparison of chlorophyll-a simulation results is shown in Figure 36, while a comparison of DO simulation results during July and August of 2002 is shown in Figure 37.

FIGURE 36: MERP Condition in Passaic R. at Dundee Dam – Chl-a Reduced Dramatically

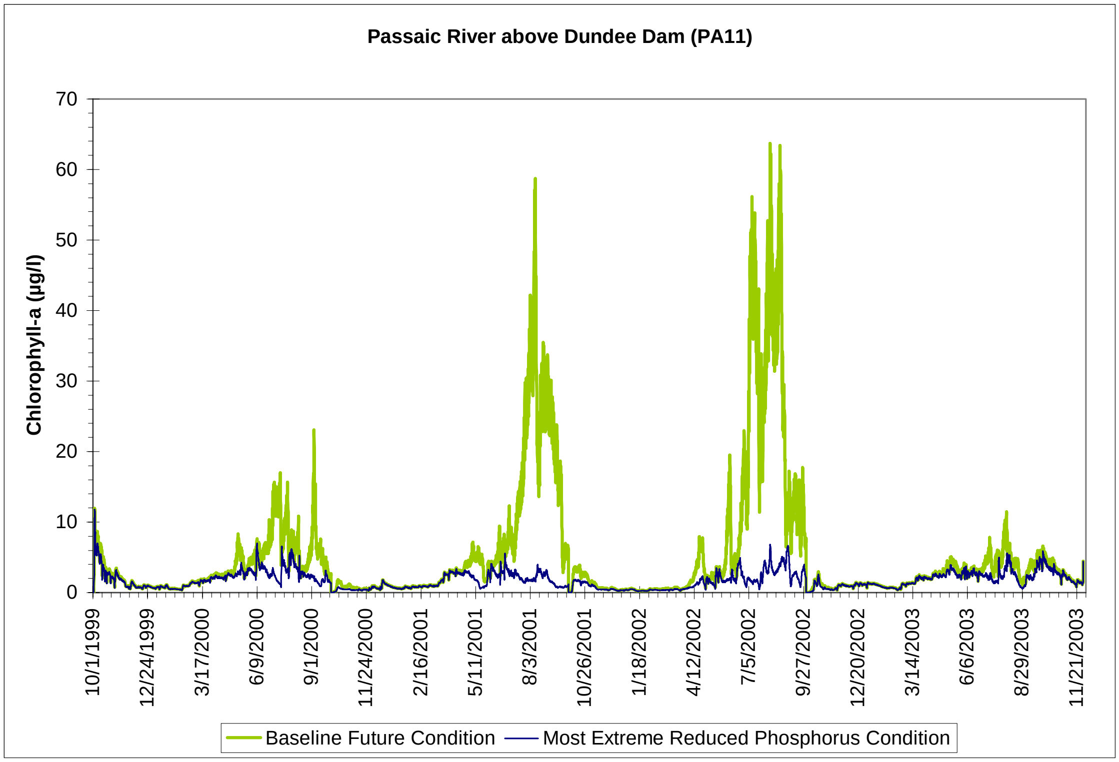
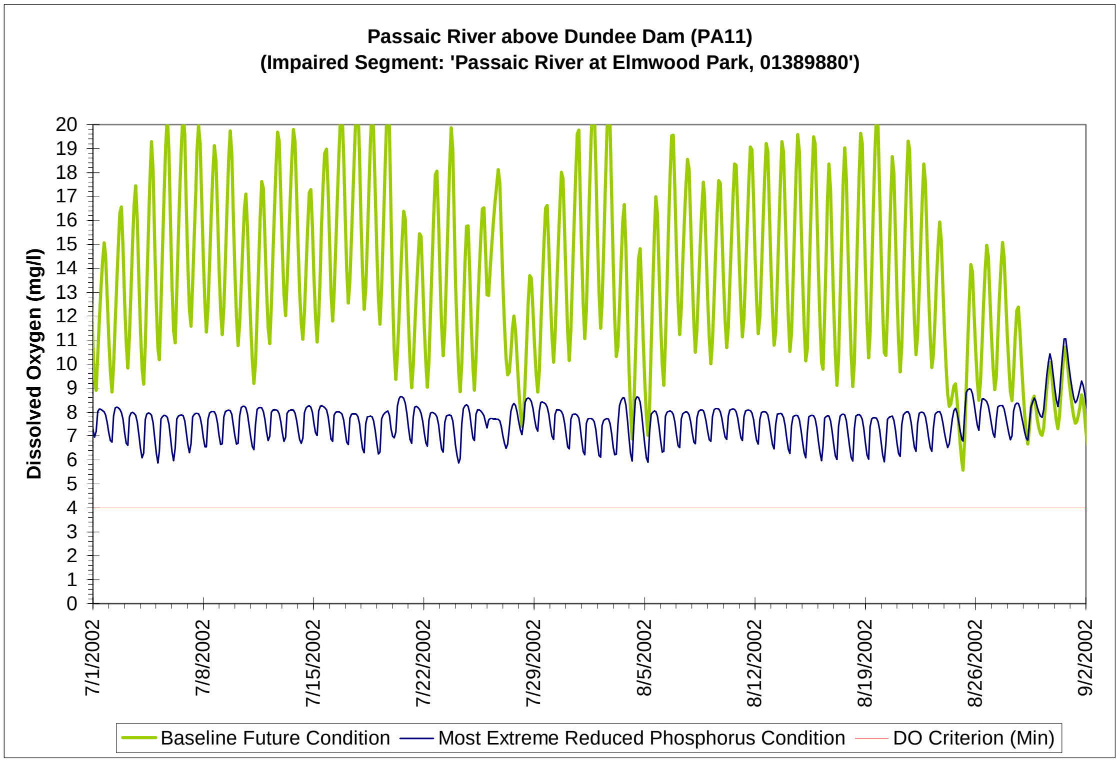


FIGURE 37: MERP Condition in Passaic R. at Dundee Dam – DO Swing Reduced Dramatically

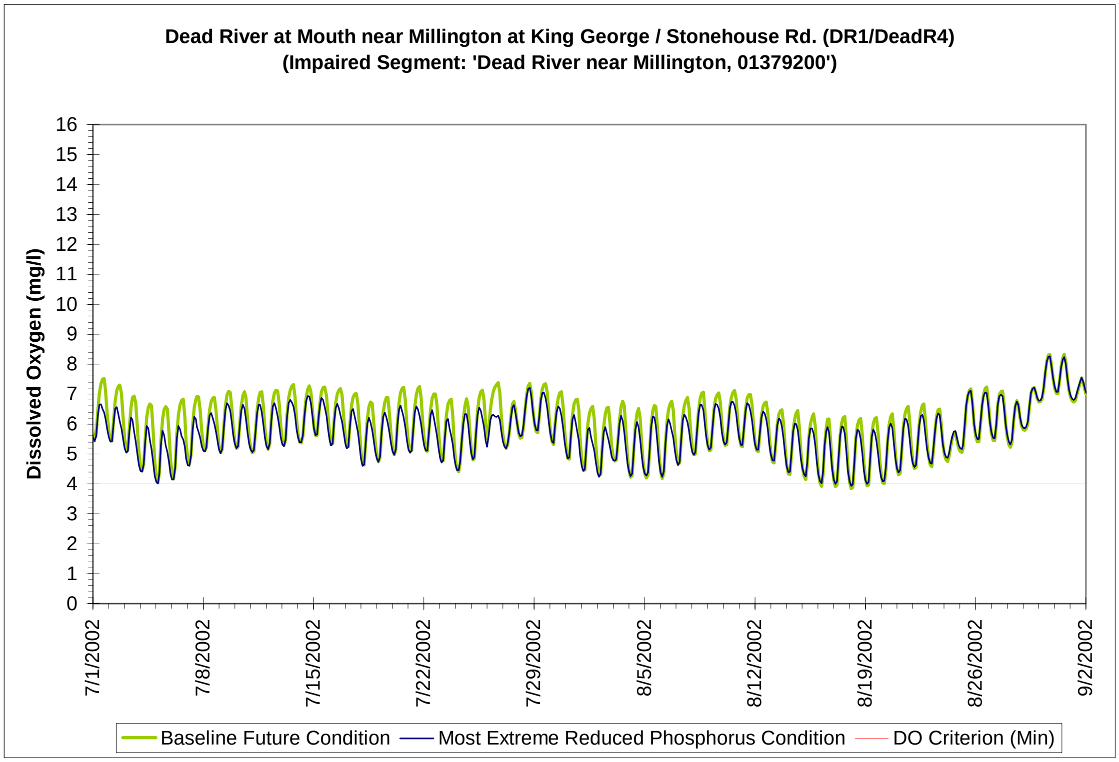


In summary, the Lower Passaic River is much more sensitive to decreases in phosphorus loads. Upstream of Little Falls, the decrease in productivity somewhat affected chlorophyll-a peaks and DO. This segment does not appear to be currently impaired by excessive productivity, so the reduction in productivity did not represent a substantial change. Furthermore, the existing level of productivity appears to be improving the DO condition in the Passaic River upstream of Little Falls. However, the Passaic River from Little Falls to Dundee exhibits very high chlorophyll-a peaks and DO swings, both of which were reduced dramatically in the MERP Condition.

III.E.3. Dead River, Singac Brook, Peckman River

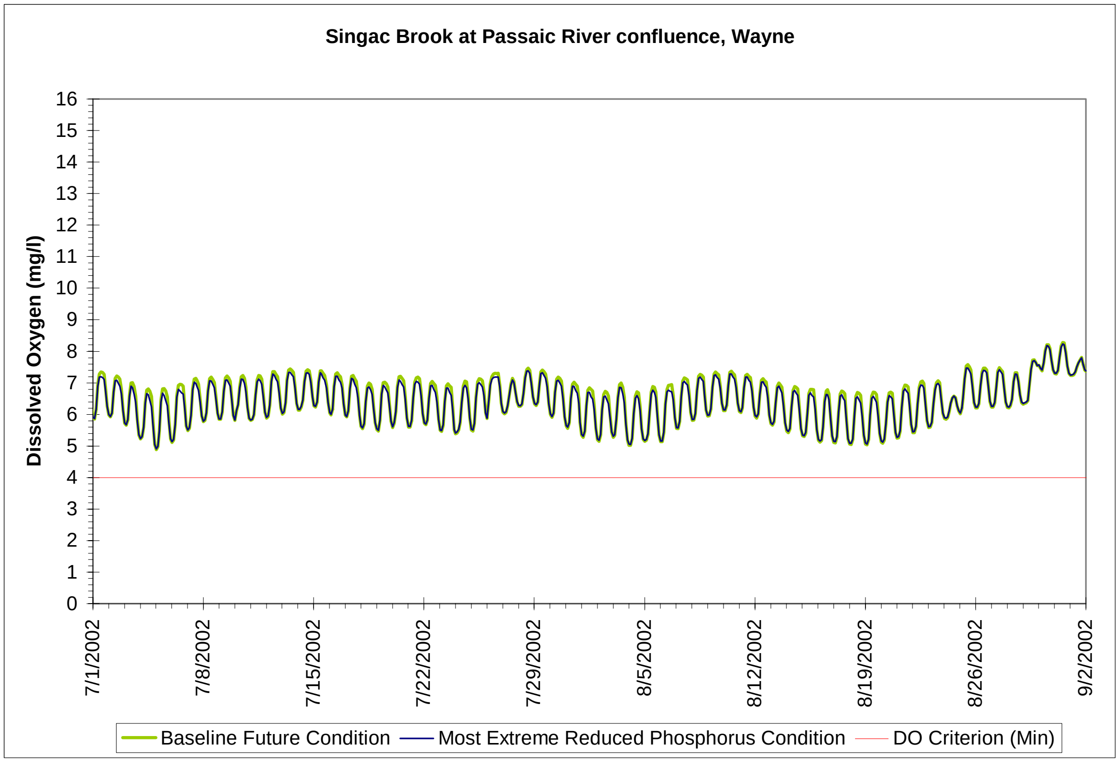
Similar to the Upper and Mid-Passaic River, the Dead River is generally low in DO; however, it exhibits moderate diurnal DO swings. The MERP Condition did not change the oxygen levels appreciably; apparently, phosphorus levels were still sufficient to drive the current level of productivity. A comparison of DO simulation results of the Dead River for July and August of 2002 is shown in Figure 38.

FIGURE 38: MERP Condition in Dead River – DO Remains the Same



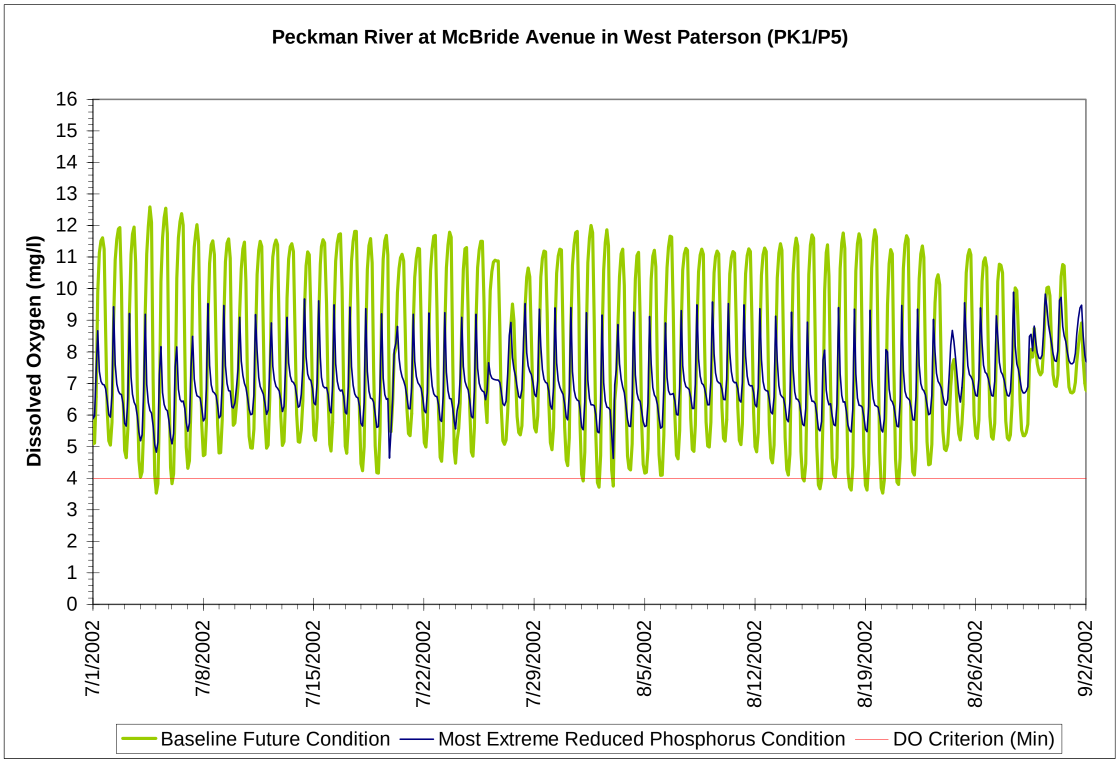
Singac Brook is very high in phosphorus concentration, but appears to exhibit only minor diurnal DO swings and remains well above the minimum DO criterion. DO in Singac Brook is likely moderated substantially by the Wayne STP discharge, which strongly influences the conditions in Singac Brook. The MERP Condition did not change the oxygen levels at all. A comparison of DO simulation results of the Singac Brook for July and August of 2002 is shown in Figure 39.

FIGURE 39: MERP Condition in Singac Brook – DO Remains the Same



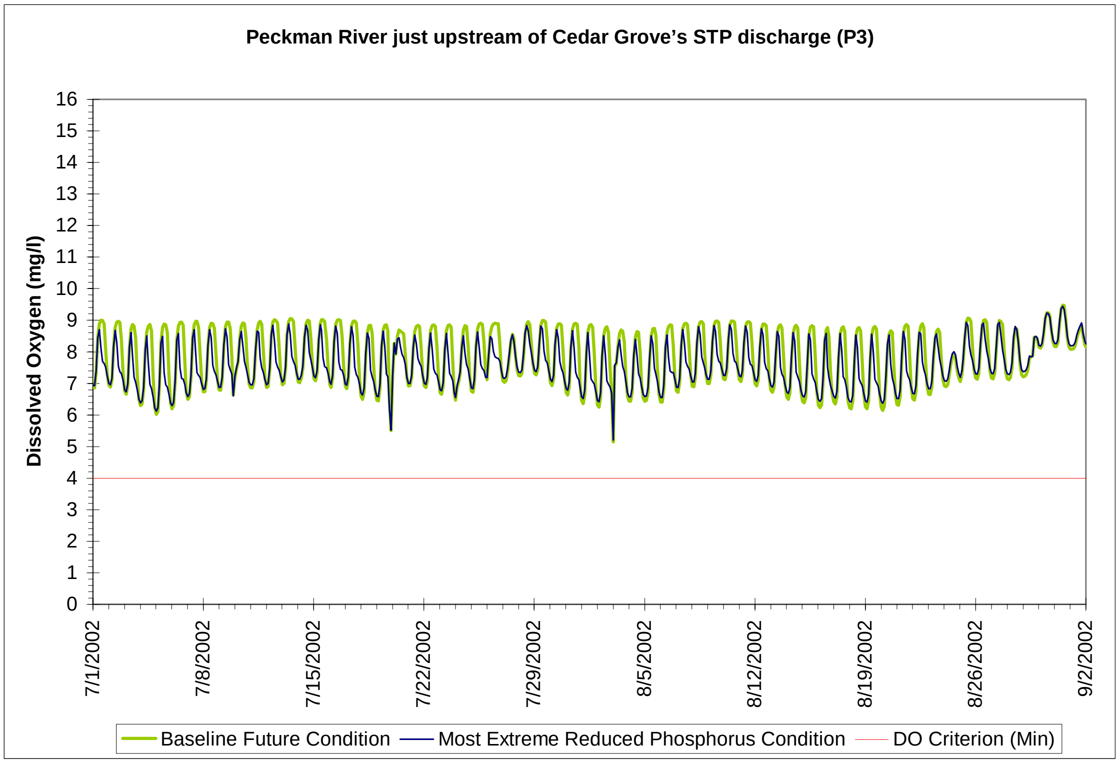
The Peckman River near its mouth exhibits very high diurnal DO variations that apparently cause DO to drop below the minimum DO criterion of 4 mg/l during critical summer periods. Phytoplankton is very low in the Peckman River; productivity appears to be driven by macrophytes near its mouth. The decrease in productivity associated with the MERP Condition reduced the DO swing substantially and increased the minimum DO above the minimum DO criterion. A comparison of DO simulation results for the Peckman River near its mouth during July and August of 2002 is shown in Figure 40.

FIGURE 40: MERP Condition in Peckman River near mouth – DO Swing is Reduced and Minimum DO is Increased



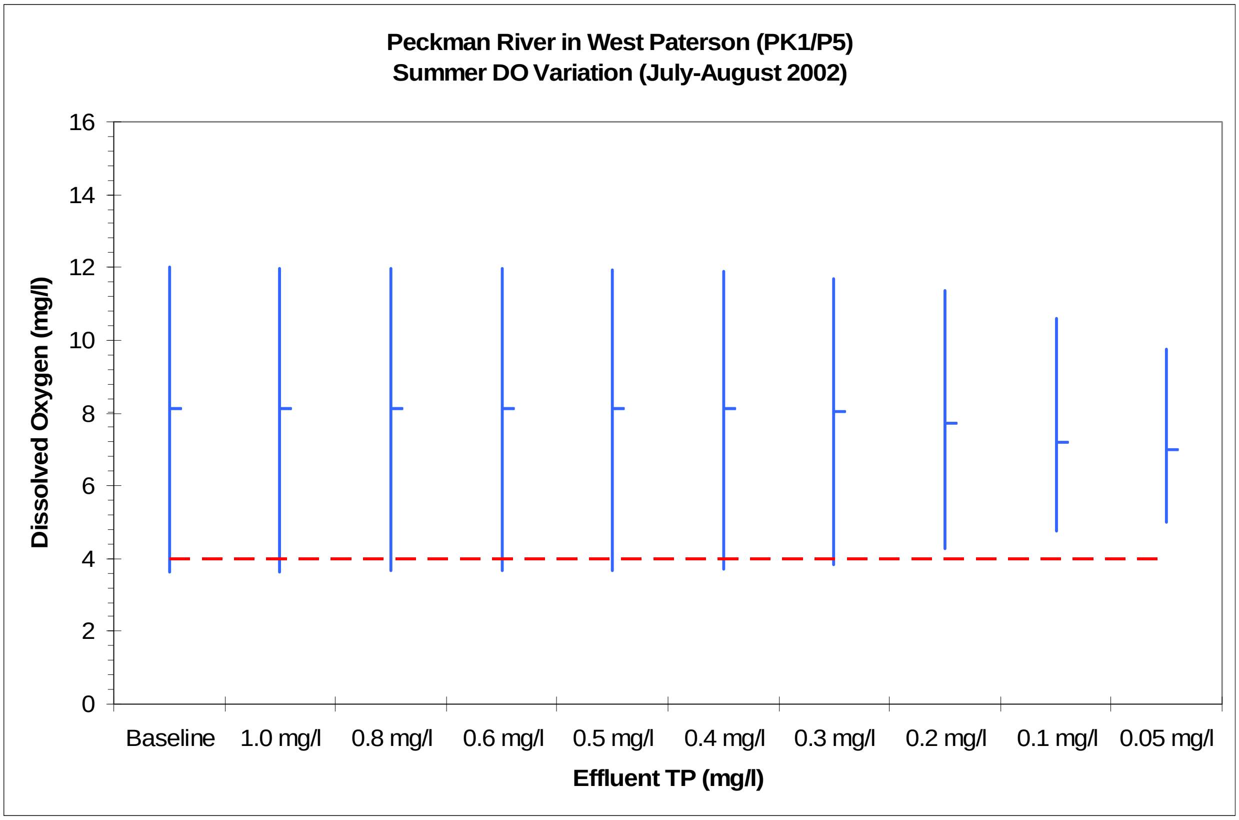
While the Peckman River near its mouth exhibits substantial diurnal DO swings during critical summer conditions, this is not typical of the Peckman River generally. Data collected at five locations in the Peckman River during critical conditions during the summer of 2004 indicate that only the most downstream sampling location exhibits unhealthy DO conditions. Figure 41 shows a comparison of DO simulation results at a more typical location in the Peckman River. It shows healthy DO levels that are not affected noticeably by phosphorus reductions.

FIGURE 41: MERP Condition in Peckman River (typical) – DO Swing is Minor and Stays the Same



It is the most downstream half-mile of the Peckman River that exhibits substantial diurnal DO swings that would theoretically improve with extreme phosphorus reductions. However, model results do not show any DO improvement in the Peckman River except with extremely low phosphorus simulations. Figure 42 shows the DO variation in July and August of 2002 associated with various effluent phosphorus concentration simulations. These simulations assume that the upstream boundary at Verona Park Lake is achieving the lake criterion of 0.05 mg/l total phosphorus; currently, Verona Park Lake discharges phosphorus concentrations over 0.1 mg/l to the Peckman River.

FIGURE 42: Sensitivity of DO in Peckman River to Effluent Concentration



The sensitivity of DO at the mouth of the Peckman River to phosphorus reduction is very low; it is not until effluent phosphorus concentrations decrease below 0.2 mg/l that noticeable DO improvements are simulated. In fact, the sensitivity of DO at this location to phosphorus reduction is very low compared to the model accuracy. In other words, changes in effluent phosphorus concentration between 0.2, 0.1, and 0.05 mg/l result in extremely small changes in stream phosphorus concentration. These minor differences in stream phosphorus concentrations are causing the model to simulate DO improvements, but the improvements are based on differences in phosphorus concentrations that are smaller than the model can accurately predict. As a result, it is not possible to reliably determine the effluent concentration, if any, that would trigger the DO improvement. Even if effluent concentrations were reduced to 0.05 mg/l, it is very possible that DO conditions would not improve in this small segment of the Peckman River.

While DO in the Peckman River is not very sensitive to phosphorus reductions, it is very sensitive to changes in velocity and light. Restoration measures that either increase stream velocity under low-flow conditions or increase shading at the mouth of the Peckman would have a much bigger impact than reducing phosphorus. It is possible that stream velocity could be increased by reducing backwater effects near the mouth – for instance, removing sediment deposited near the mouth that may be exacerbating backwater effects. Shading could be increased by increasing the canopy cover. The feasibility of remedial restoration measures would have to be investigated carefully before implementation.

III.E.4. Whippany and Rockaway Rivers

Similar to the Dead River, the Whippany and Rockaway Rivers are generally low in DO and exhibit moderate diurnal DO swings. Moreover, productivity in both these rivers helps offset the depletion of DO due to SOD. The MERP Condition reduced the diurnal DO peaks, but did not change the oxygen levels appreciably. Comparisons of DO simulation results from the Whippany and Rockaway Rivers for July and August of 2002 are shown in Figures 43 and 44.

FIGURE 43: MERP Condition in Whippany River – Diurnal DO Peaks Slightly Reduced

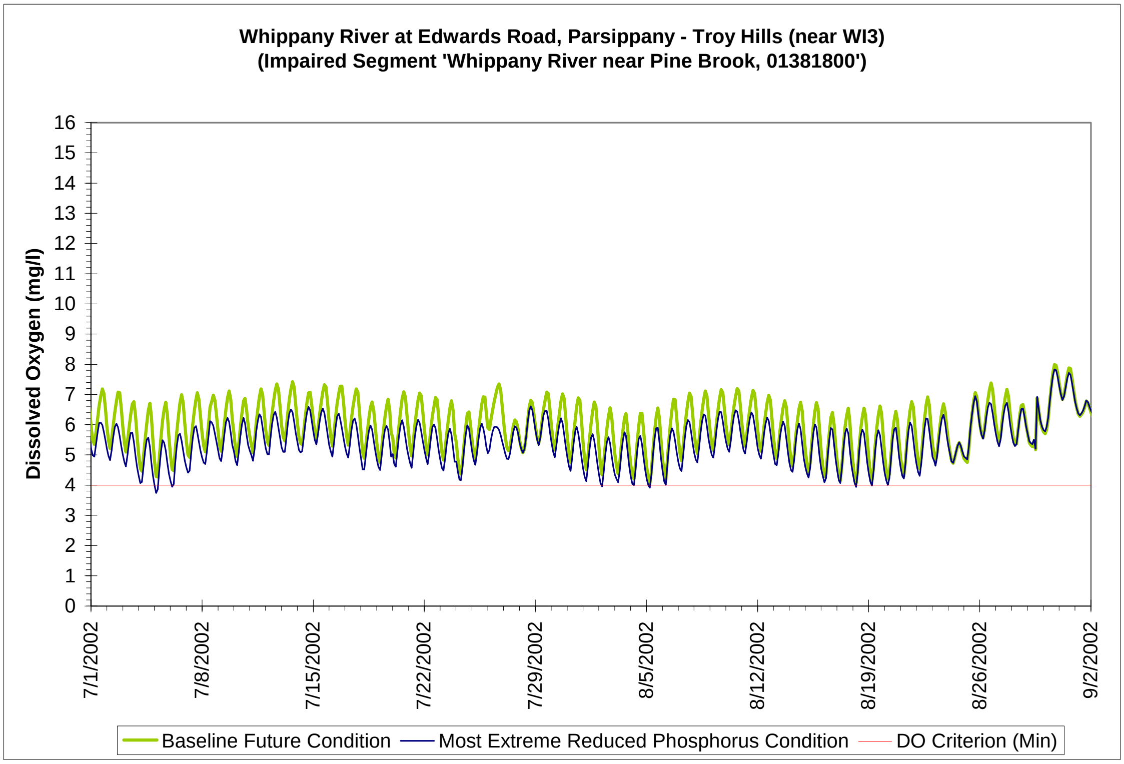
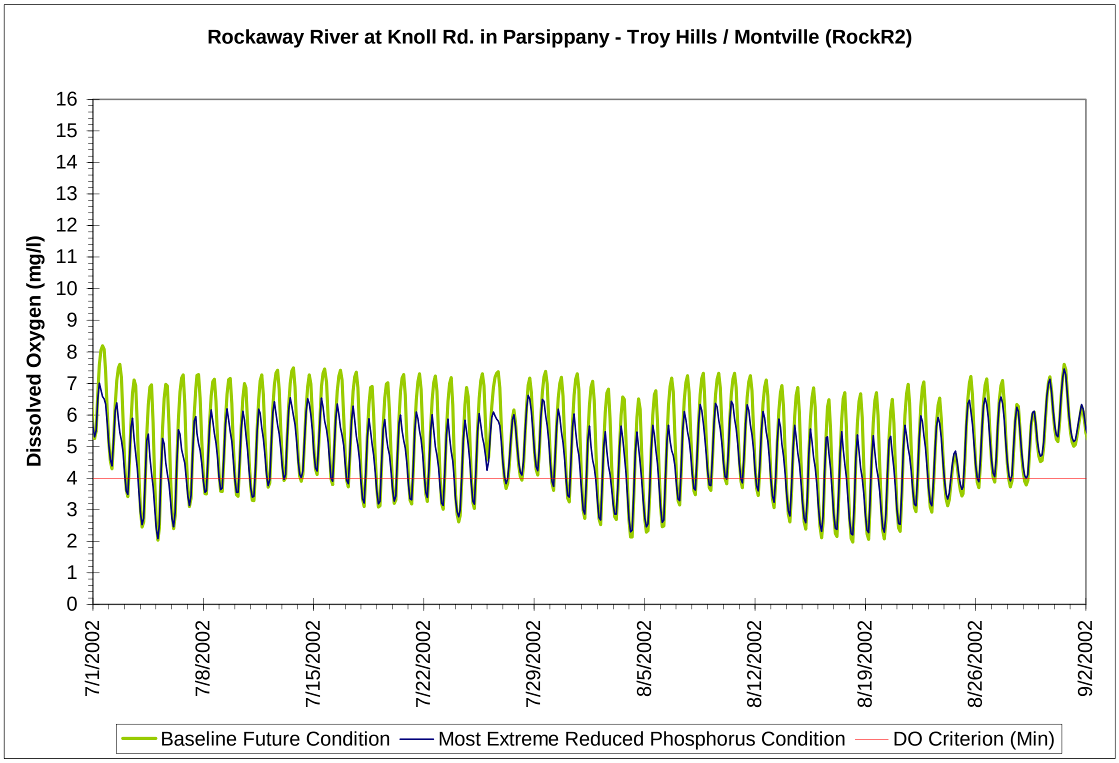


FIGURE 44: MERP Condition in Rockaway River – Diurnal DO Peaks Slightly Reduced



III.E.5. Wanaque, Pequannock, and Pompton Rivers

The Wanaque and Pequannock Rivers are nearly pristine waters. They are low in phosphorus and exhibit healthy DO patterns consisting of small diurnal DO swings well above the minimum DO criterion. The MERP Condition reduced the diurnal DO peaks; however, since the diurnal DO variations in the Existing Condition were minor, reducing phosphorus did not change the overall oxygen levels appreciably. Comparisons of DO simulation results from the Wanaque and Pequannock Rivers for July and August of 2002 are shown in Figures 45 and 46.

FIGURE 45: MERP Condition in Wanaque River – Diurnal DO Peaks Reduced

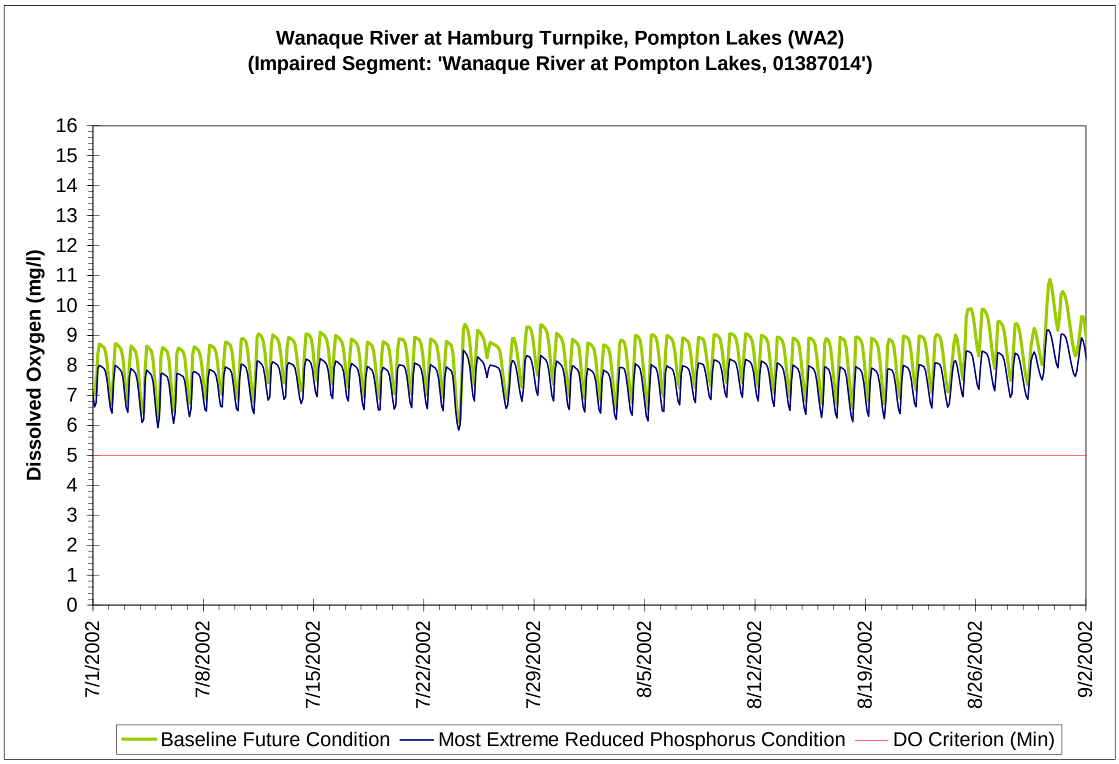
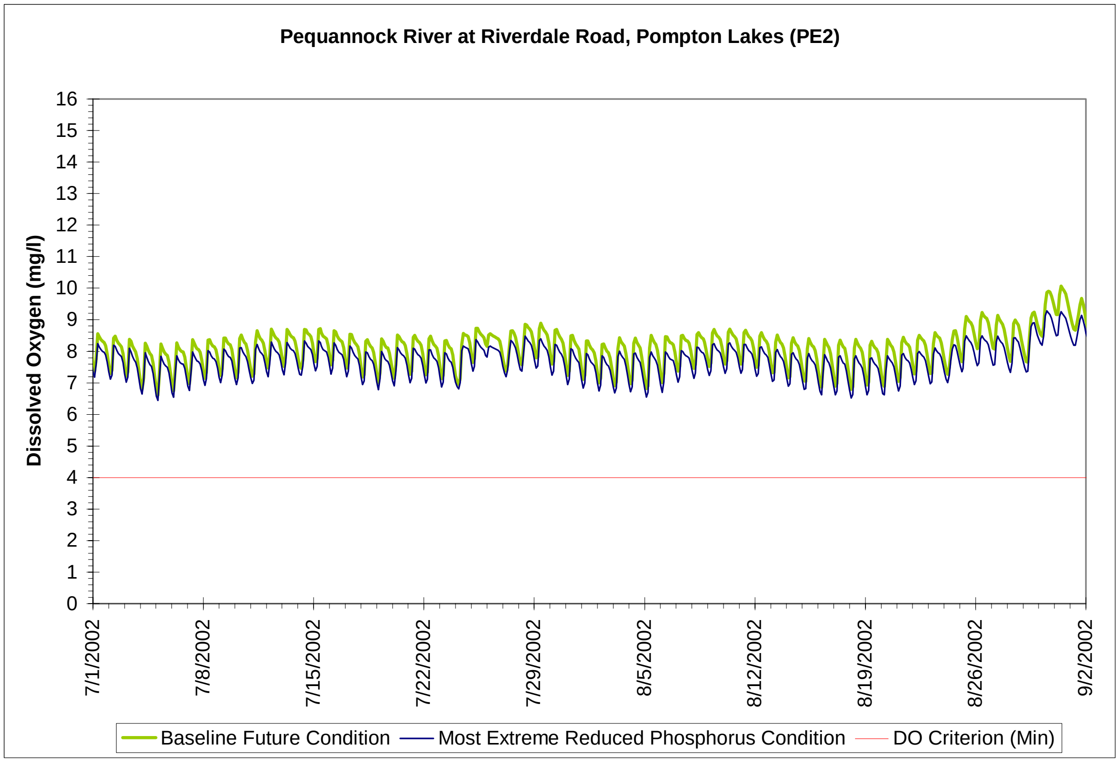
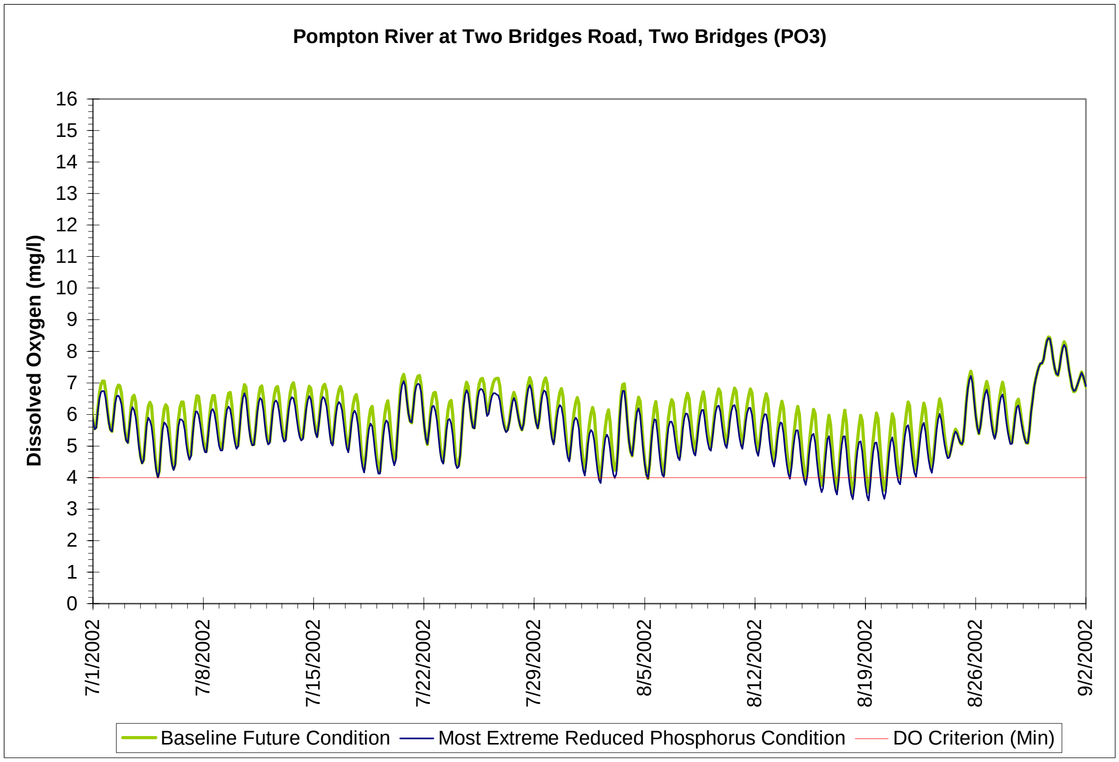


FIGURE 46: MERP Condition in Pequannock River – Diurnal DO Peaks Reduced



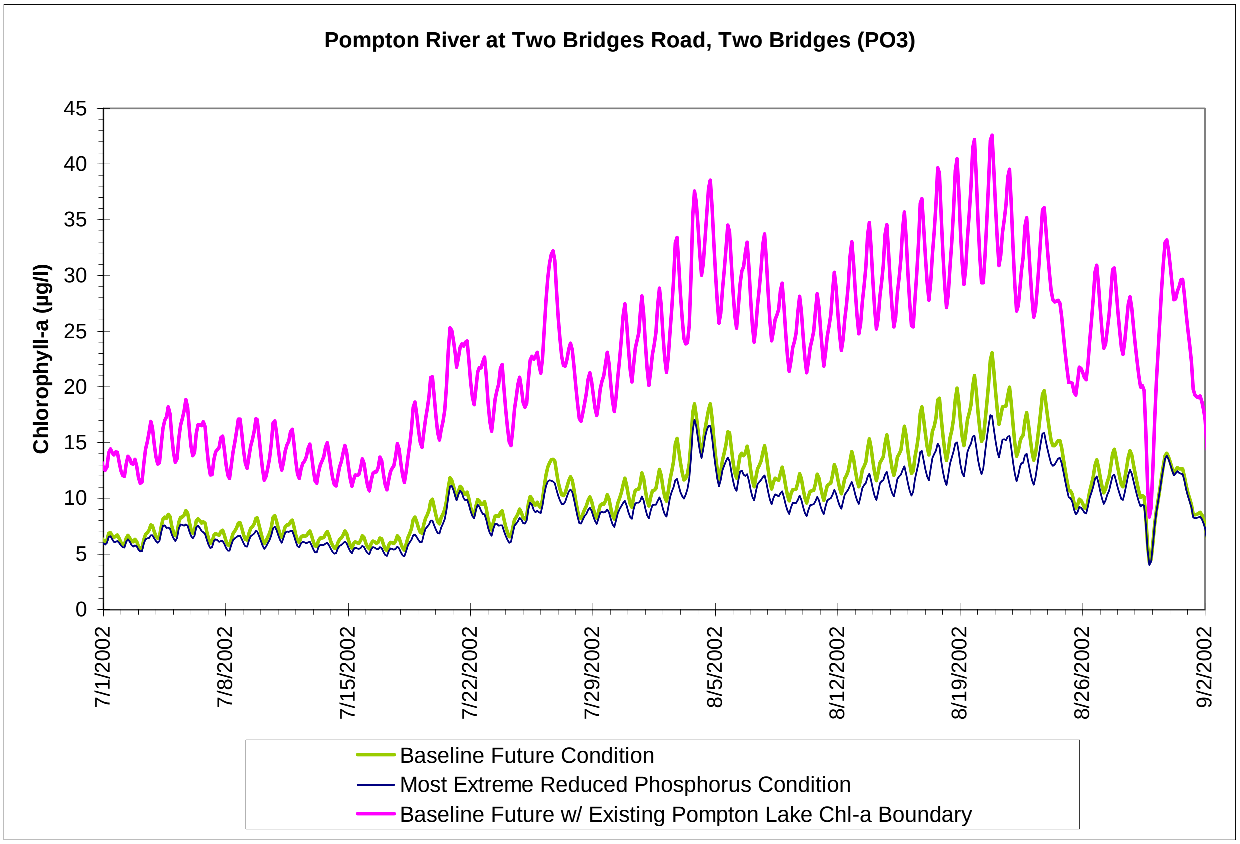
The Pompton River is generally low in DO and exhibits moderate diurnal DO swings. It is also known to occasionally exhibit substantial algal blooms. The MERP Condition reduced the diurnal DO peaks, but did not change the oxygen levels appreciably. The comparison of DO simulation results from the Pompton River for July and August of 2002 is shown in Figure 47.

FIGURE 47: MERP Condition in Pompton River – Diurnal DO Peaks Reduced



The MERP Condition also reduced the phytoplankton peaks slightly in the Pompton River, but the phytoplankton peaks in the Pompton River are more sensitive to the chlorophyll-a boundary condition for the Ramapo River at Pompton Lake. Recall that both the Baseline Future and MERP Conditions used a modified boundary condition to reflect the implementation of the Pompton Lake TMDL, which would be expected to result in less phytoplankton production in Pompton Lake. A comparison of chlorophyll-a simulations of the Pompton River is shown in Figure 48. In addition to the Baseline Future Condition and the MERP Condition, a third series is included; the third series is the same as the Baseline Future Condition, but the chlorophyll-a boundary condition for the Ramapo River at Pompton Lake was NOT reduced to account for the Pompton Lake TMDL. This graph shows that chlorophyll-a production in the Pompton River is driven much more by the algae produced in Pompton Lake than the phosphorus condition in the Pompton River.

FIGURE 48: MERP Condition in Pompton River – Diurnal DO Peaks Reduced



III.F. <u>Sensitivity Analyses</u>

A number of sensitivity analyses were performed on various scenarios in order to determine how robust the results were, and to determine the main factors driving those results. Sensitivity simulations are electronically catalogued within the output viewer described in Appendix H and provided on the CD in Appendix M. Sensitivity analyses were performed before the scenarios were finalized, so the exact results cannot be compared directly with any of the final scenarios (e.g., Existing Condition, Baseline Future, MERP). A few of the more important sensitivity analyses are described below.

III.F.1. No Kinetics

In order to assess the importance of instream kinetics on nutrient balances in the Passaic River Basin, a No Kinetics simulation was prepared based on the Existing Condition and run for WY2001. All kinetic processes were turned off for this simulation, leaving simply a dilution model. Phosphorus and nitrogen results were evaluated in Passaic River at Two Bridges and compared with the results for the Existing Condition simulation. As shown in Figures 49 and 50, kinetics affect phosphorus and ammonia by a factor of two, while they are not as important for nitrate.

FIGURE 49: Sensitivity of Phosphorus to Instream Kinetics

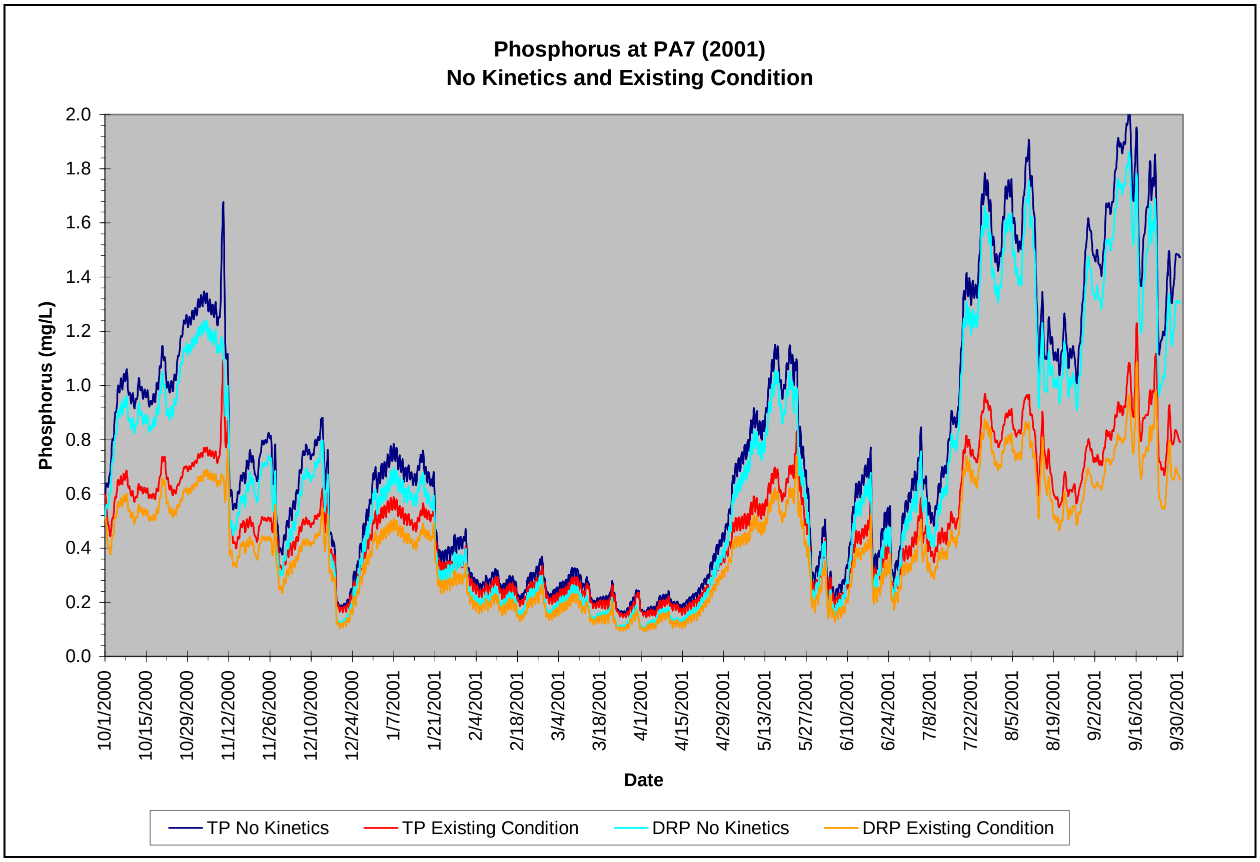
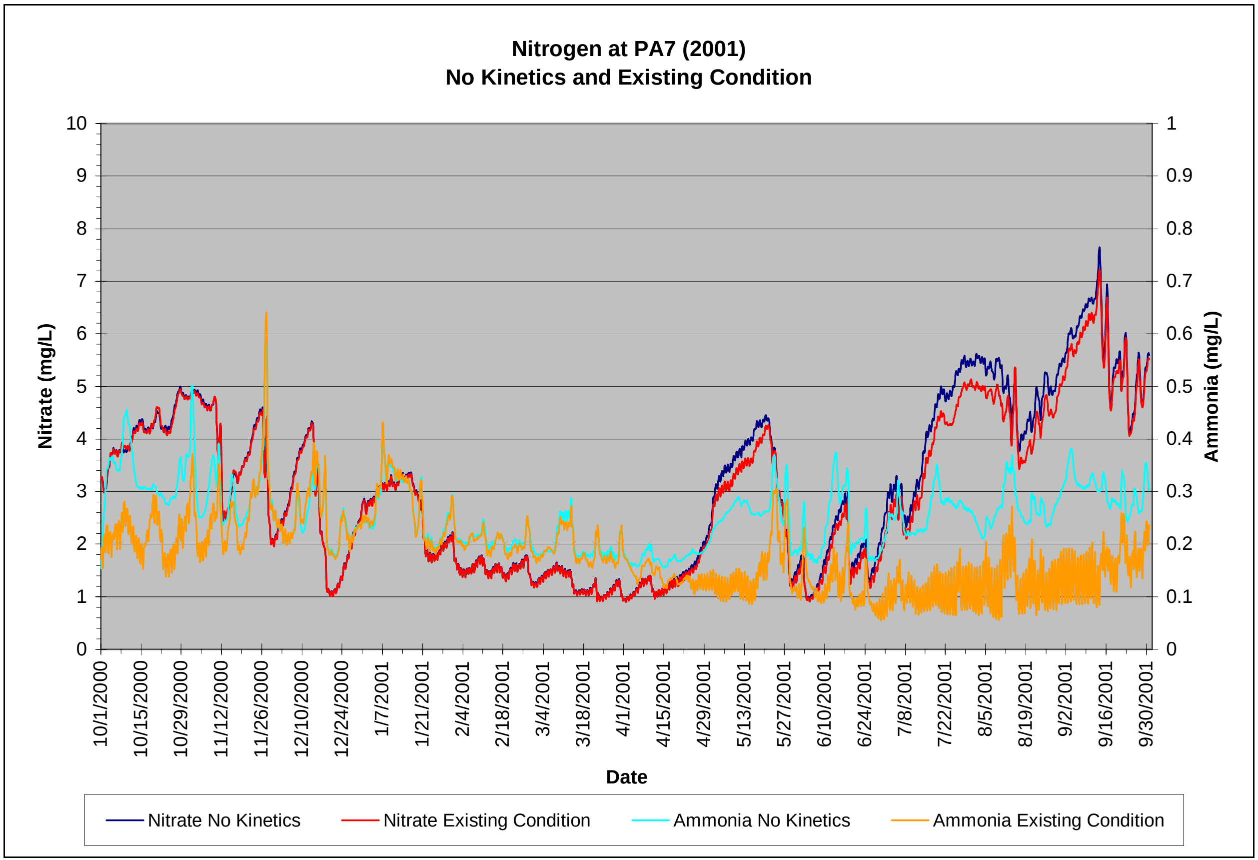


FIGURE 50: Sensitivity of Nitrogen to Instream Kinetics



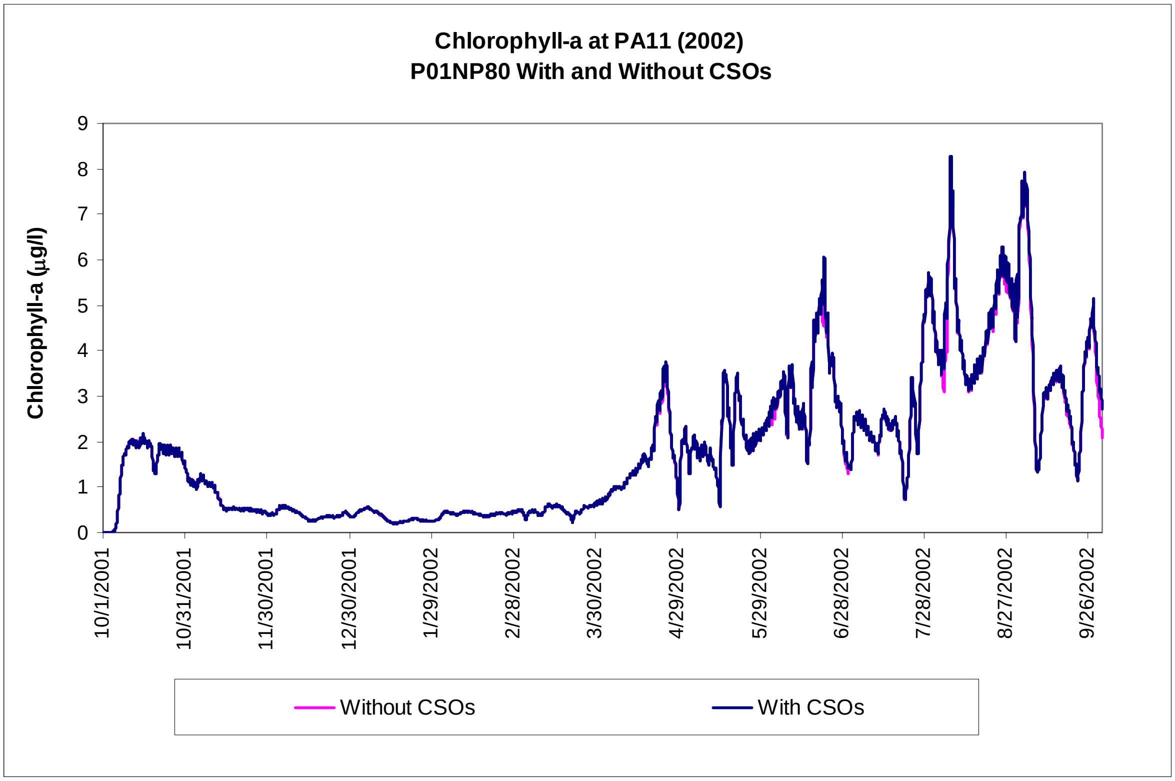
III.F.2. No CSOs

Phosphorus loads from CSOs were not reduced in the MERP Condition scenario. Sensitivity analyses were prepared to evaluate the sensitivity of the Existing Condition and P01NP80 Condition[4] to CSO loads. Phosphorus loads from CSOs were set to zero in the Existing Condition for simulations performed in WY2001 (a dry year) and WY2003 (a wet year). In addition, phosphorus loads from CSOs were set to zero in the P01NP80 for a simulation performed in WY2002. Phosphorus, chlorophyll-a, and dissolved oxygen were compared in the Passaic River at Dundee, downstream of the CSO discharge locations in Paterson, between the NO CSO scenarios and the original scenarios. CSOs do not substantially affect phosphorus, chlorophyll-a, or dissolved oxygen in either the Existing Condition or the P01NP80 Condition. Figure 51 shows chlorophyll-a in

[4] P01NP80 Condition is similar to the MERP Condition except that point sources phosphorus concentrations were set to 0.1 mg/l instead of 0.05 mg/l.

the Passaic River at Dundee Dam for the P01NP80 Condition, with and without phosphorus loads from CSOs, for the WY2002 simulation.

FIGURE 51: Sensitivity to CSO Loads



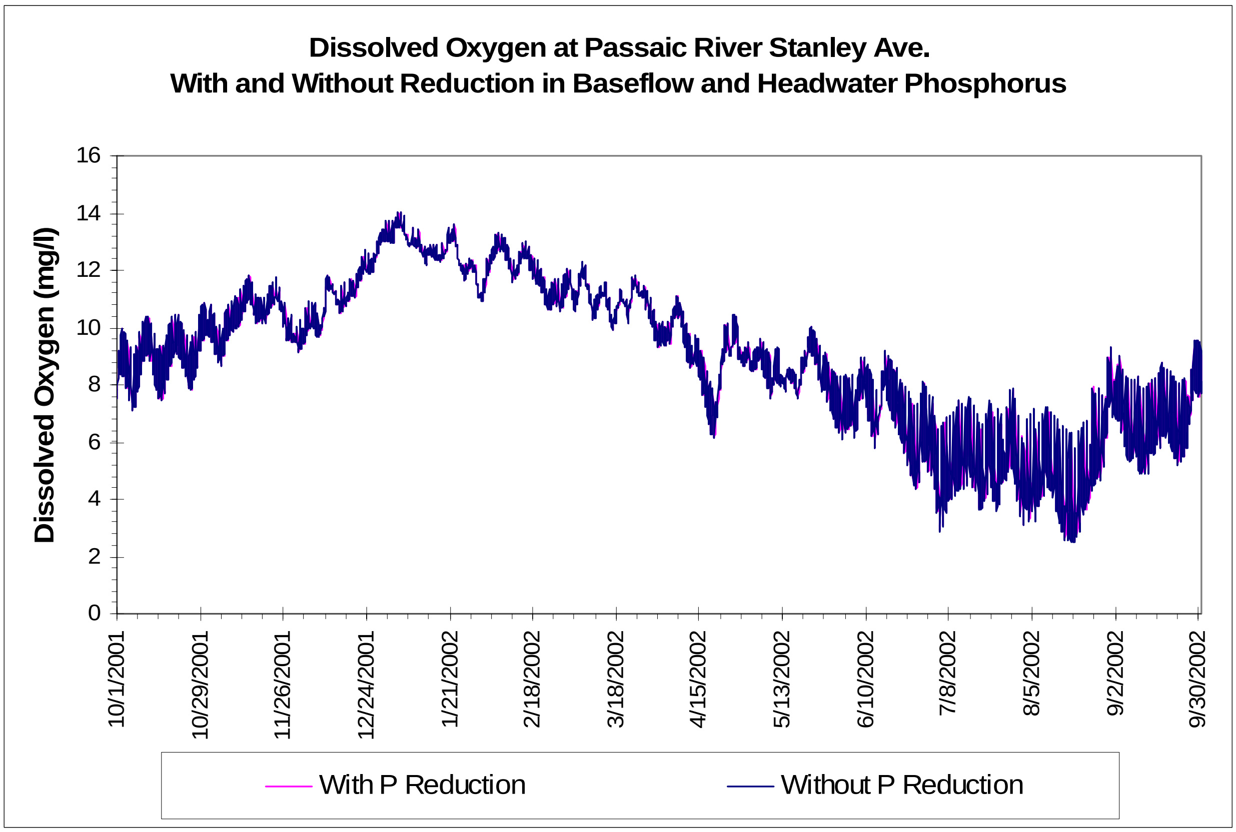
III.F.3. Tributary Baseflow and Passaic River Headwater Phosphorus Concentrations

Sensitivity analyses were prepared to explore the impact of reducing phosphorus concentrations in tributary baseflow and Passaic River headwater on the P01NP80 condition. Three simulations were prepared for WY2002:

- Tributary baseflow TP concentration was reduced from 0.08 mg/l to 0.04 mg/l;
- Passaic River headwater boundary for total phosphorus changed from 0.13 mg/l to 0.1 mg/l; and
- Tributary baseflow TP concentration and Passaic River headwater were both changed together.

DO and chl-a were evaluated at critical locations in all branches of the model. None of the changes produced a noticeable effect on either productivity indicator. The Passaic River at Stanley Avenue (Chatham) would be the location most likely to be impacted by a change in Passaic River headwater concentration and tributary baseflow concentration. Figure 52 shows the Passaic River at Chatham with both Passaic River headwater phosphorus concentration and tributary baseflow phosphorus concentration reduced.

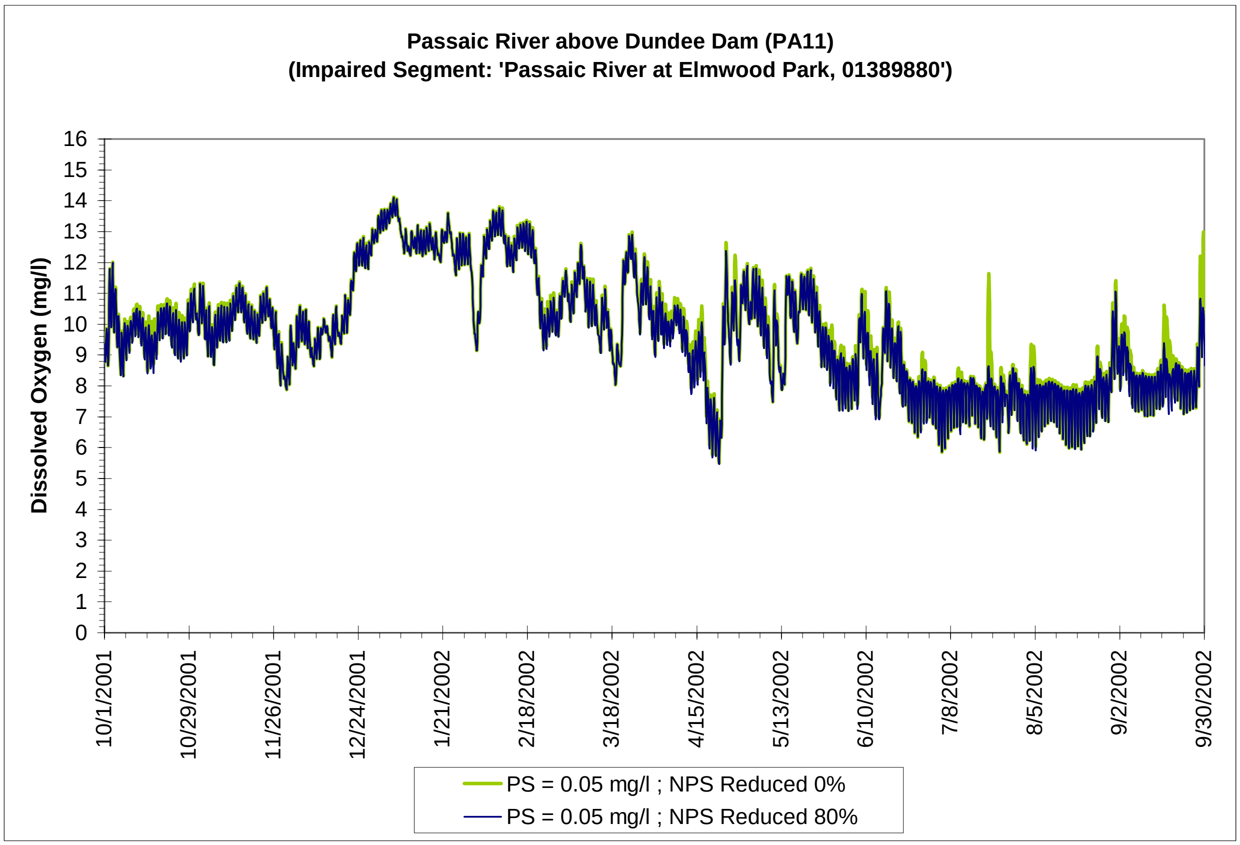
FIGURE 52: Sensitivity to Passaic River Headwater and Baseflow TP Concentrations



III.F.4. Nonpoint Source Reductions

Sensitivity analyses were prepared to demonstrate the impact of nonpoint source reductions on productivity indicators in the Passaic River Basin. The MERP Condition was compared with the 0.05 mg/l effluent sensitivity simulation for WY2002. Both simulations set phosphorus effluent concentrations to 0.05 mg/l from all point sources, thereby maximizing the potential impact of NPS runoff reductions. However, the MERP Conditions also reduced the phosphorus in runoff from urban and agricultural land areas by 80%. DO and chl-a were evaluated at critical locations in all branches of the Passaic River Basin. Results indicate that even an extreme reduction of phosphorus in NPS runoff by 80% produces no difference in productivity in the most downstream branch of the Passaic River. A comparison of DO simulations in the Passaic River at Dundee Dam for July and August 2002 showing the sensitivity to nonpoint source reductions is provided in Figure 53 below.

FIGURE 53: Sensitivity of DO in Passaic River to Nonpoint Source Reductions



III.G. <u>Summary</u>

There is one location within the Passaic River Basin study area where it can be shown that phosphorus reductions can substantially improve water quality. Reduction of phosphorus to the Passaic River from upstream Great Falls to Dundee Dam can attenuate the extreme DO swings and reduce the phytoplankton peaks experienced during critical summer conditions.

Nonpoint runoff sources do not appear to have a substantial impact on instream productivity indicators in the Passaic River Basin. The primary reason appears to be that productivity impacts occur during low-flow summer periods; only sources delivered during low-flow summer periods can substantially affect productivity in the Passaic River Basin.

There are many sources of uncertainty that must be considered when evaluating the results of the watershed modeling analyses performed through this study. One is the role of sediments as a phosphorus source under severely reduced phosphorus scenarios. While the impact of SOD on water column oxygen was fully considered in the Passaic River Basin model, the sediments were not modeled dynamically, nor were the sediments considered a source of phosphorus. Under current conditions, phosphorus concentrations in the water column can be explained without including sediments as a source of phosphorus. Indeed, with current water column concentrations of phosphorus so high throughout much of the Passaic River Basin, phosphorus in the sediments would not be expected to diffuse into the water column, and there appears to be a net settling of phosphorus in some areas. However, if phosphorus concentrations were reduced substantially, the role of the sediments may change in ways that cannot be predicted. In particular, the sediments may provide a source of phosphorus that the model does not simulate; as a result, the model may exaggerate somewhat the benefits of reducing phosphorus in the Passaic River Basin. We would not expect this to become a major issue unless phosphorus concentrations were reduced to very low levels, which is not achievable in this system anyway.

Another broad source of uncertainty is localized conditions throughout the Passaic River Basin that are not captured by the model. The Passaic River Basin model is a large system-scale model that cannot be expected to simulate localized dynamics, especially when data are not available to calibrate such locations. We believe the model adequately captures the salient features of the Passaic River Basin as a unified system.

IV. WATERSHED-SPECIFIC CRITERIA

The instream phosphorus criterion [N.J.A.C. 7:9B-1.14(c)5ii] reads:

> "Except […] where watershed or site-specific criteria are developed pursuant to N.J.A.C 7:9B-1.5(g)3, phosphorus as total P shall not exceed 0.1 in any stream, unless it can be demonstrated that total P is not a limiting nutrient and will not otherwise render the waters unsuitable for the designated uses."

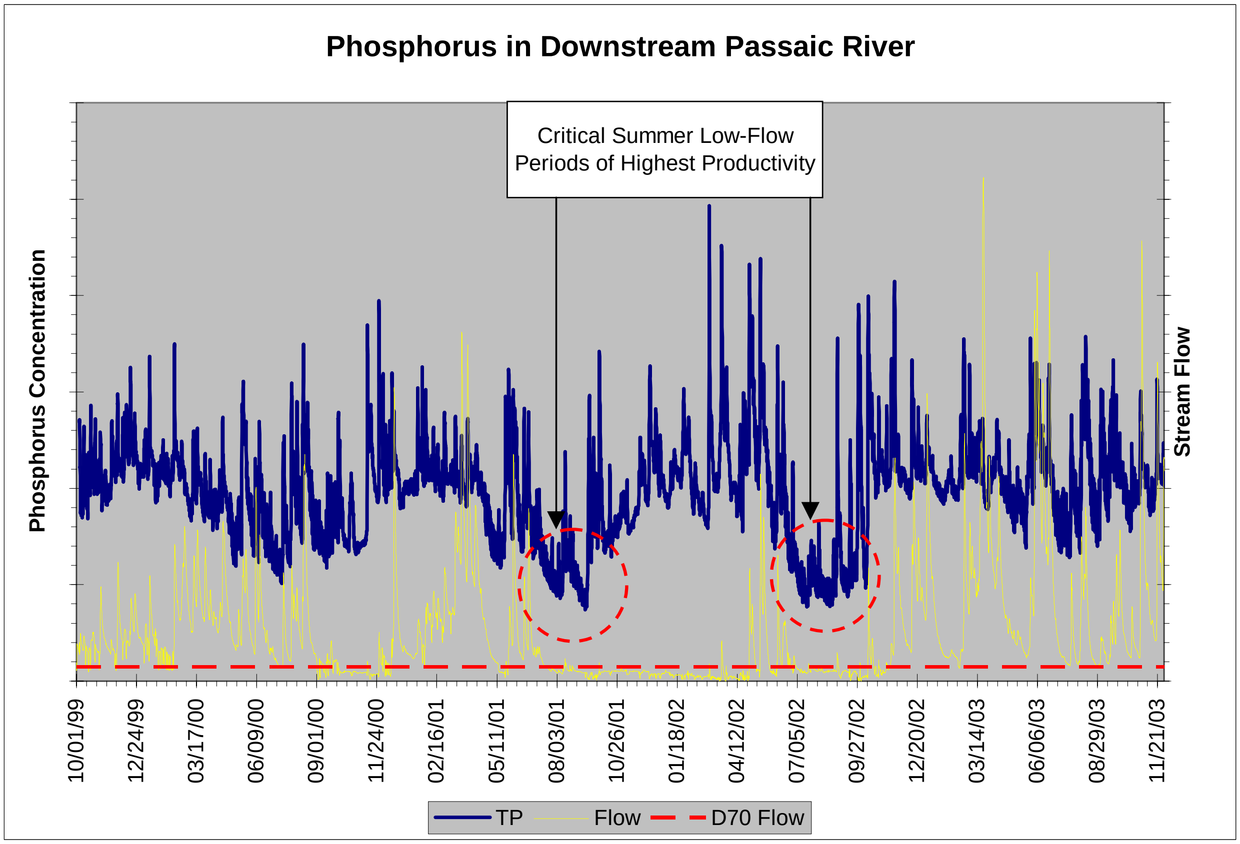
Nutrient Policy #3 [N.J.A.C 7:9B-1.5(g)3] further states: "The Department may establish watershed site-specific water quality criteria for nutrients in lakes, ponds, reservoirs or stream, in addition to or in place of the criteria in N.J.A.C. 7:9B-1.14, when necessary to protect existing or designated uses. Such criteria shall become part of these SWQS."

There are several disadvantages to applying the 0.1 mg/l instream phosphorus criterion directly in the Non-Tidal Passaic River Basin without considering both the conditions under which the criterion does not apply and watershed-specific criteria to protect uses. First, expensive point and nonpoint source reductions would be implemented beyond those necessary to achieve water quality benefits. Furthermore, most streams would remain designated as impaired even after successful implementation of phosphorus reductions, since 0.1 mg/l is not consistently achievable in many streams in the Passaic River Basin.

On the other hand, there are several compelling advantages to developing a watershed-specific criterion for the Passaic River Basin. The regulatory mechanism of a watershed-specific criterion is found not only in the narrative Nutrient Policies, but also within the phosphorus criterion itself. This study provides a direct and quantitative linkage between phosphorus sources and productivity impacts, and can therefore be used to establish a watershed-specific criterion for phosphorus. Indeed, it is hard to imagine a stronger basis. Furthermore, by focusing on critical locations where phosphorus reductions can result in water quality improvement, a watershed-specific criterion will allow for point source trading to optimize reductions.

Figure 54 shows what a reduced phosphorus condition will look like in terms of phosphorus concentrations in the downstream areas of the Passaic River. Concentration units would depend on the exact point source concentrations and would also vary according to location. However, the phosphorus concentration profile would look similar for any reduced phosphorus condition. Stream flow is also provided as a frame of reference. Phosphorus concentration is lowest during the most critical conditions in July and August of 2001 and 2002. The reason is that, unlike the current condition, a reduced phosphorus condition will exhibit the highest phosphorus concentrations during higher flows due to natural nonpoint sources. As a result, any not-to-exceed phosphorus concentration (including 0.1 mg/l) will be either not be protective during critical summer low-flow conditions, or it will be protective during critical conditions but exceeded during most other conditions. Only watershed-specific criteria that relate phosphorus reductions to actual use impairment will provide the basis for a meaningful TMDL. Watershed-specific criteria were defined by NJDEP for the Non-Tidal Passaic River Basin to satisfy the water quality end points for the Passaic River upstream of Dundee Dam ("Dundee Lake") and the Wanaque Reservoir, as described below.

FIGURE 54: Reduced Phosphorus Condition in Downstream Passaic River



IV.A. Critical Locations

The impact of extreme phosphorus reductions at locations throughout the Passaic River Basin is shown in the graphs in Appendix J. These graphs provide a comparison between an unrealistically high phosphorus condition and an unrealistically low phosphorus condition in order to show the maximum change that might be expected from phosphorus source reductions. Furthermore, the sensitivity of productivity indicators at selected locations to effluent phosphorus concentration is provided in the graphs in Appendix K. Critical locations in the Passaic River Basin were identified as those locations exhibiting use impairment that can be restored through reduction of phosphorus sources. Based on the assessment of stream response provided in section III above and the Wanaque Reservoir TMDL, two critical stream locations have been identified in the Passaic River Basin:

- Pompton River at the Passaic River Confluence – the Wanaque South intake, which draws water from both the Passaic and Pompton Rivers under certain flow conditions, is a critical location because it represents a major source of phosphorus to the Wanaque Reservoir.
- Passaic River upstream Dundee Dam – reduction of phosphorus can attenuate the extreme DO swings and reduce the phytoplankton peaks experienced during critical summer conditions in the downstream portion of the Passaic River from upstream Great Falls to Dundee Dam.

Several other areas of concern in the Passaic River Basin were identified that were not designated as critical locations around which watershed-specific criteria could be developed:

- Passaic River at Chatham – this portion of the stream is known to exhibit more productivity in terms of diurnal DO variations driven by macrophytes than is typical of the Upper Passaic River. While the productivity appears to exacerbate the normally low DO condition characteristic of the Upper and Mid-Passaic River, the MERP Condition did not change the oxygen levels enough to change the degree of use impairment. Consequently, the DO impairment is caused by factors other than productivity and appears to be a natural condition.

- Passaic River at Little Falls Intake – The Passaic Valley Water Commission withdraws water from the Passaic River at Little Falls to its water treatment facility, where it is used as a source of drinking water. Phosphorus competes with coagulants during several treatment processes, and therefore increases the amount of coagulant needed to treat drinking water. A study was performed (Appendix I) to better understand the costs associated with treating source water with high phosphorus concentrations at the PVWC WTP, and to ascertain whether there is a phosphorus concentration threshold above which treatment might be compromised, and that would therefore form the basis of a water quality target at that location. The study found a strong linear correlation between phosphorus concentration and treatment cost; however, within the range of phosphorus concentrations encountered in the Passaic River, there is no threshold phosphorus concentration that could be used as a water quality target. Treatment is effective at all phosphorus concentrations encountered. Costs associated with treating water from the Passaic River will decrease dramatically when phosphorus reductions are made to satisfy water quality targets in the Passaic River at Dundee Dam.

- Peckman River at mouth – unlike the Peckman River as a whole, the most downstream half-mile of the Peckman River exhibits substantial diurnal DO swings that would theoretically improve with extreme phosphorus reductions. However, model results show that the sensitivity of DO at this location to phosphorus reduction is very low compared to the model accuracy. As a result, it is not possible using this model to reliably determine the effluent concentration, if any, that would trigger a DO improvement. Furthermore, stream restoration measures to increase velocity and increase shading would certainly achieve much more than phosphorus reduction in terms of decreasing productivity.

The comparisons between an unrealistically high phosphorus condition (Baseline Future) and an unrealistically low phosphorus condition (MERP) in Appendix J show the maximum change that might be expected from phosphorus source reductions. Except for the two critical locations identified above, these comparisons demonstrate that phosphorus is not controlling productivity or otherwise rendering the waters unsuitable for the designated uses. Therefore, based on the narrative portion of the instream phosphorus criterion, the instream phosphorus criterion does not apply to streams throughout the Passaic River Basin other than the two critical locations identified above.

IV.B. End Points

Phytoplankton chlorophyll-a end points (water quality targets) were developed for both of the critical locations in the Passaic River Basin. Water column chlorophyll-a is an indicator of phytoplankton concentration, a response variable for phosphorus. In fact, it is the growth of phytoplankton blooms during critical summer periods that directly impairs uses at these locations. Because these chlorophyll-a end points relate directly to the impairment of uses at these locations, they form the basis for site-specific criteria in accordance with N.J.A.C 7:9B-1.5(g)3. As such, these end points supersede and replace the phosphorus criteria that would otherwise be applied to these waterbodies, and form the basis for watershed-specific criteria for the Non-Tidal Passaic River Basin.

Generally, phytoplankton targets are established in terms of mean growing season chlorophyll-a levels. For instance, North Carolina State University's watershed information database (http://www.water.ncsu.edu/watershedss/info/algae.html) suggests that a mean growing season limit of 15 μg/l chlorophyll-a is appropriate for drinking water reservoirs, and that a mean growing season limit of 25 μg/l is appropriate to protect all other uses, namely recreational, aesthetic, and aquatic life. However, more and less restrictive values can be found in the literature. The State of Vermont established a chlorophyll-a target of 3 μg/l for Lake Champlain, Vermont, a major recreational, aesthetic, and aquatic life resource. On the other hand, in North Carolina, for all water supply impoundments, chlorophyll-a levels may not exceed 40 μg/l at any time; for waters not serving as a water supply; chlorophyll-a may periodically exceed 40 μg/l during the growing season.

IV.B.1. Wanaque Reservoir

The Pompton River at its confluence with the Passaic River is a critical location because of the Wanaque South intake, which draws water from both the Passaic and Pompton Rivers under certain flow conditions and represents a major source of phosphorus to the Wanaque Reservoir. For this reason, a water quality target was developed for the Wanaque Reservoir itself.

In order to protect all uses in the Wanaque Reservoir, NJDEP established a watershed-specific criterion for the Wanaque Reservoir based on a water quality target of 10 µg/l chlorophyll-a as a summer average (June 15 to August 31). Given the narrow definition of growing season and the low target selected, this end point represents a very protective end point that will ensure near-pristine conditions in the Wanaque Reservoir. This reflects the importance of the Wanaque Reservoir as both a major water supply, aquatic life, and aesthetic resource in northern New Jersey. The watershed-specific criterion for the Wanaque Reservoir (10 µg/l summer average chlorophyll-a) supersedes and replaces the lake phosphorus criterion of 0.05 mg/l TP that would otherwise be applicable. The linkage between phosphorus sources and impacts to the Wanaque Reservoir is provided by the Wanaque Reservoir TMDL Study (Najarian, 2005 ; NJDEP, 2005b).

IV.B.2. Passaic River Upstream Dundee Dam ("Dundee Lake")

The downstream portion of the Passaic River from Great Falls to Dundee Dam is a critical location because reduction of phosphorus can attenuate the extreme DO swings and reduce the phytoplankton peaks experienced during critical summer conditions. The relationship between maximum dissolved oxygen swing and summer average chlorophyll-a at the Passaic River at Dundee Dam is provided in Figure 55. It shows a powerful logarithmic relationship with an r^2 (square of the correlation coefficient) near 0.99. Since the extreme DO swings are caused by the phytoplankton blooms (along with substantial macrophyte growth) and correlated with phytoplankton blooms, it is appropriate to establish the water quality target in terms of phytoplankton chlorophyll-a.

NJDEP established chlorophyll-a thresholds of 24 μg/l (seasonal average) and 32 μg/l (max 2-week mean) in order to determine nutrient impairment in streams (NJDEP, 2003b). However, the Passaic River upstream of Dundee Dam is referred to as Dundee Lake. The aerial photo in Figure 56 shows the portion of the Passaic River designated as Dundee Lake in the NJDEP lakes GIS coverage. A bridge forms the "lake" boundary; however, the Passaic River upstream of the bridge is just as wide as it is downstream, and the Passaic River is deeper for about a mile upstream of the Dundee Dam. The portion of the river that is designated as Dundee Lake includes slightly more than 0.8 miles of river above the dam. The detention time in that portion of the river averages about 1.7 days per mile of river length. The Passaic River upstream of Dundee Dam has characteristics of both an urban lake and a stream.

FIGURE 55: Relationship between DO Swing and Chlorophyll-a

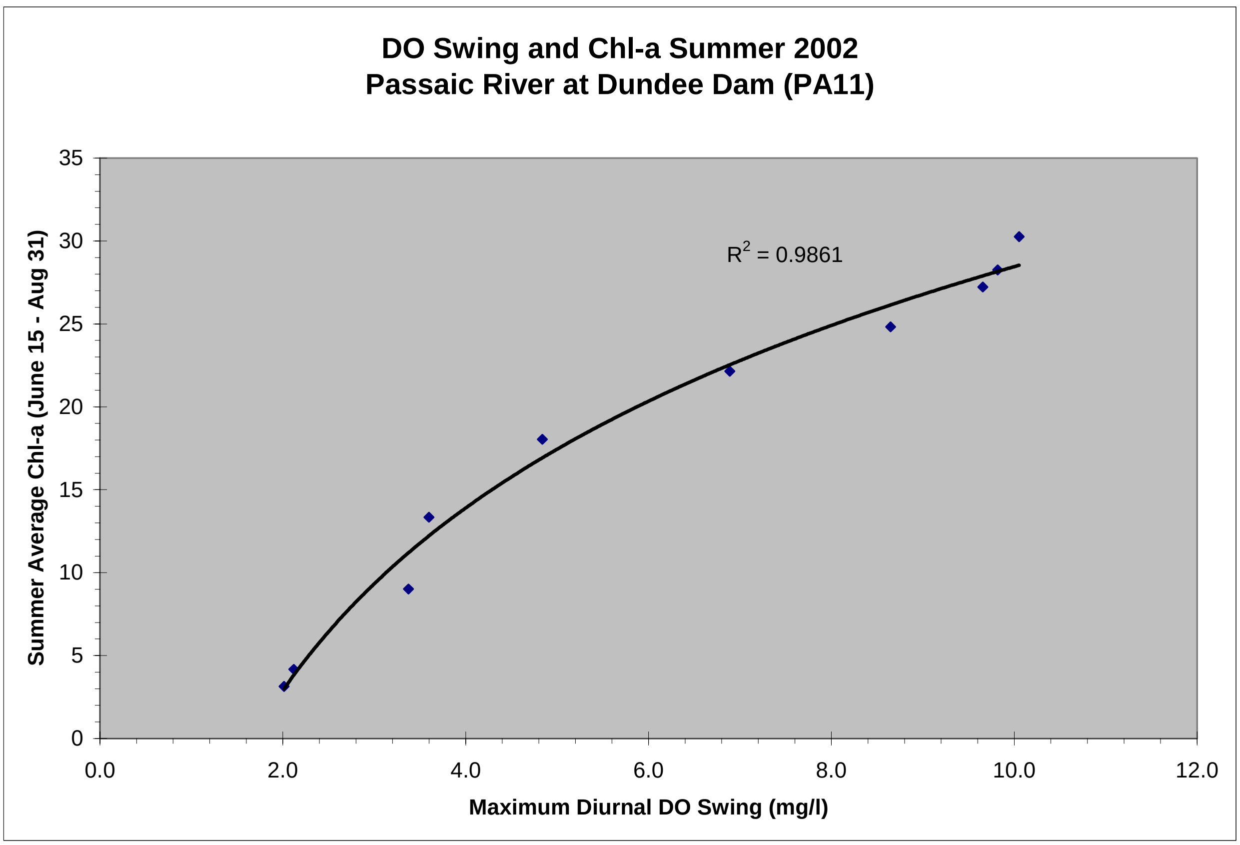


FIGURE 56: Aerial Photo of Dundee Lake

Similar to Dundee Lake, Dutch Fork Lake in Pennsylvania functions somewhere between a lake and a slowly moving stream. Pennsylvania uses a 14 day detention time to distinguish between lakes and flowing waters. Dutch Lake has a detention time of approximately 9 days, while Dundee Lake has an average detention time of 1.4 days. According to the Dutch Fork Lake TMDL (PADEP, 2003, p.5):

> "Hence, a 10 µg/l chlorophyll-a target, in addition to being infeasible and unachievable, is unnecessarily stringent in what is technically a flowing water. A 20 µg/l seasonal average chlorophyll-a target was used for the purpose of defining a total phosphorus TMDL for Dutch Fork Lake. This will result in a mildly eutrophic classification for Dutch Fork Lake. Given the natural progression of all lakes and the fact that Dutch Fork Lake is 45 years old, Pennsylvania believes this is consistent with water quality standards for the Lake."

The fact that the impoundment of the Passaic River upstream of Dundee Dam constitutes an urban feature with a low detention time argues for using values in the upper end of the literature range. If the Passaic River at Dundee Dam is to be regulated as a lake, a reasonable standard would be a seasonal average chlorophyll-a between 20 and 25 µg/l. For instance, the existing stream thresholds of 24 µg/l (seasonal average) and 32 µg/l (max 2-week mean) would be perfectly suitable for a run-of-the-river lake such as Dundee Lake.

In order to protect all uses in the Passaic River at Dundee (Dundee Lake), NJDEP established watershed-specific criterion for Dundee Lake based on a water quality target of 20 µg/l chlorophyll-a as a summer average (June 15 to August 31). Given the narrow definition of growing season and the relatively low target selected, this end point represents a very protective end point that will ensure aesthetically pleasing conditions in this urban lake feature. The watershed-specific criterion for Dundee Lake supersedes and replaces the instream and in-lake phosphorus criteria that would otherwise be applicable.

V. TMDL CALCULATIONS

NJDEP established the water quality end points for the Passaic River upstream of Dundee Dam ("Dundee Lake") and the Wanaque Reservoir, as described previously, as watershed-specific criteria for the Non-Tidal Passaic River Basin. Specifically, NJDEP established water quality targets of 10 µg/l and 20 µg/l chlorophyll-a as summer averages (June 15 to August 31) in order to protect all uses in the Wanaque Reservoir and Dundee Lake, respectively. Taken together, these end points form the basis for the watershed-specific criteria for the Non-Tidal Passaic River Basin, which supersede the instream phosphorus criterion throughout the Passaic River Basin [N.J.A.C 7:9B-1.5(g)3]. The TMDL calculations provided below define the phosphorus reductions required to satisfy the watershed-specific criteria for the Non-Tidal Passaic River Basin.

V.A. Reserve Capacity and Margin of Safety

Reserve Capacity (RC) is a means of reserving a portion of the loading capacity to allow for future growth. While RC is not a required component of a TMDL, NJDEP chose to incorporate it nonetheless in order to accommodate future growth in the basin. RC was incorporated implicitly through the design of the future scenarios for both wastewater flow and water supply diversions. Wastewater flows were set equal to their maximum permitted flows, thereby accommodating the future growth that would be necessary to generate those additional wastewater flows. Similarly, with regard to the volume of water diverted from the Pompton and Passaic River at the Wanaque South intake to the Wanaque Reservoir, a new diversion time series was developed (Najarian, 2005) in order to reflect the amount of pumping that would have been required if NJDWSC were operating the Wanaque Reservoir at its full safe yield of 173 mgd. This new diversion scenario was applied to all future scenarios in order to account for the future growth necessary to generate the increased water supply demand. In addition to these implicit sources of RC, the end points for both critical locations (Wanaque Reservoir and Dundee Lake) were both reduced in order to add explicit RC and Margin of Safety, as described below.

A Margin of Safety (MoS) is provided to account for "lack of knowledge concerning the relationship between effluent limitations and water quality" (40 CFR 130.7(c)). A MoS is required in order to account for uncertainty in the loading estimates, physical parameters and the model itself. The MoS can be either explicit, implicit (i.e., addressed through conservative assumptions used in establishing the TMDL), or both. For these TMDL calculations, an implicit as well as explicit MoS is provided. An implicit MoS is provided by using conservative critical conditions and a narrow definition of summer average for the calculation of end points. Critical conditions are ensured through the inclusion of water years with both typical and extreme hydrologic conditions. The inclusion of an extreme water supply drought (WY2002), and a period of time during which a statewide water supply emergency was declared, represents a major source of implicit MoS. The extreme drought conditions provides a MoS for the Wanaque Reservoir due to increased loads pumped to the reservoir from the Wanaque South intake, and it also provides MoS to Dundee Lake due to the extreme low flow conditions optimal for phytoplankton growth. Another important source of implicit MoS for both critical locations (Wanaque Reservoir and Dundee Lake) is the narrow definition of the summer average used to calculate their respective water quality targets. The watershed-specific criteria were based on water quality targets for both critical locations expressed in terms of maximum summer average phytoplankton concentration (as chlorophyll-a). The definition of summer average used to calculate both targets was June 15 to August 31. A broader definition of summer average, such as June through September, would have resulted in less restrictive load and wasteload allocations. The use of a narrow definition of summer average is technically justified and provides an important additional source of implicit MoS for both critical locations.

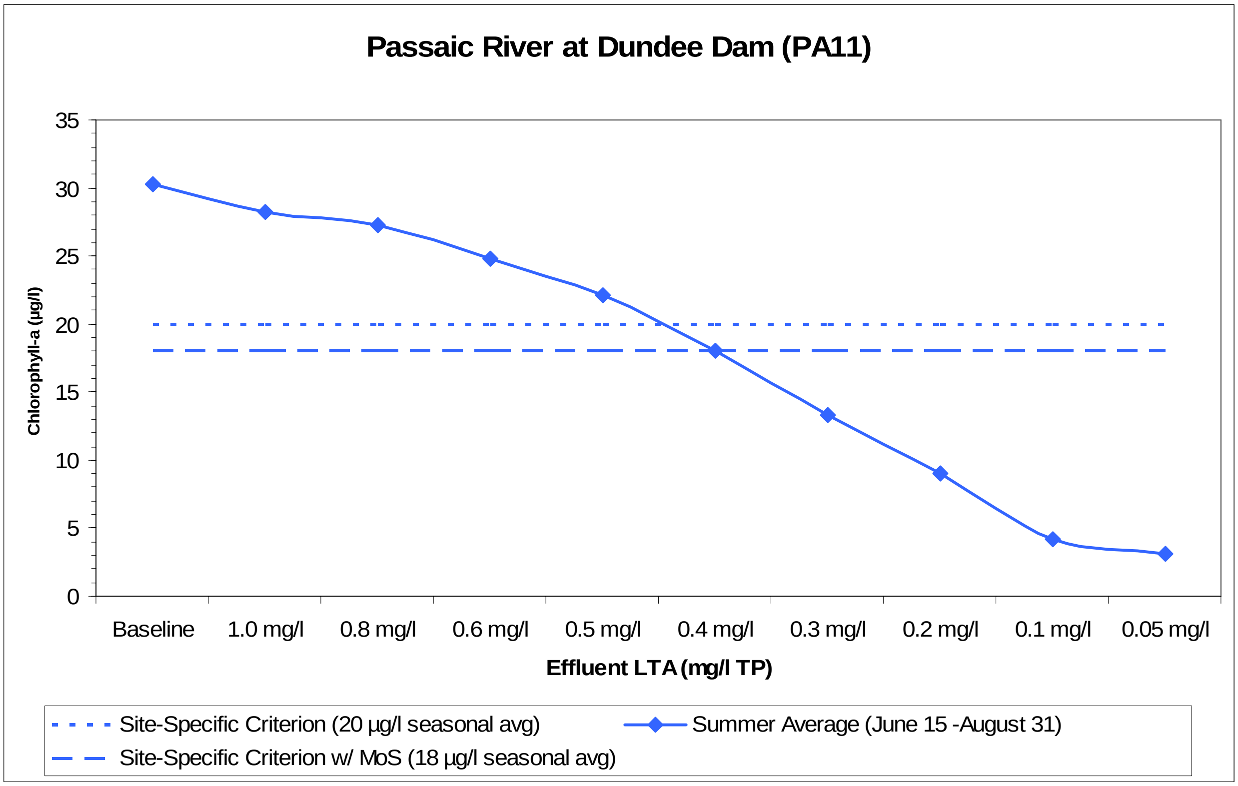
As discussed above, an implicit RC is provided based on the future diversion scenario and the use of permitted wastewater flows. An implicit MoS is also provided through conservative critical conditions and a conservative method (narrow seasonal definition) for calculating compliance with water quality targets. An additional explicit RC and MoS is incorporated into the water quality targets for both Dundee Lake and Wanaque Reservoir by reducing them from 20 to 18 and from 10 to 9 µg/l, respectively.

V.B. Target Condition

The target TMDL condition is defined as the phosphorus loading condition that satisfies the water quality end points for both the Wanaque Reservoir and Dundee Lake. As discussed previously, the water quality end point established for the Wanaque Reservoir is a maximum summer average phytoplankton concentration of 9 µg/l chlorophyll-a, which incorporates the explicit RC and MoS. In order to fully integrate the Non-Tidal Passaic River Basin TMDL Study with the Wanaque Reservoir TMDL Study, the Passaic River Basin model was used to simulate phosphorus concentration at the Wanaque South intake for various phosphorus reduction scenarios. Time series of phosphorus concentration predictions were provided to NJDEP and their technical consultant for the Wanaque Reservoir TMDL Study (Najarian and Associates) in order to predict the summer average phytoplankton in the Wanaque Reservoir associated with each phosphorus reduction scenario. Several combinations of point source effluent concentrations and nonpoint source phosphorus reductions were tested. Through an iterative process, it was determined that a point source long-term average (LTA) effluent concentration of 0.4 mg/l TP and a 60% reduction of phosphorus loads from runoff associated with urban and agricultural land uses will satisfy the water quality end point in the Wanaque Reservoir. The technical basis for the Wanaque Reservoir TMDL Study was published previously in draft (Najarian, 2005) and the final report is available from NJDEP.

As discussed above, the water quality end point established for Dundee Lake is a maximum summer average phytoplankton concentration of 18 µg/l chlorophyll-a, which incorporates the explicit RC and MoS. In order to determine the maximum effluent concentration that would satisfy the water quality target for Dundee Lake, a series of effluent concentration simulations were run for WY2002, ranging from the Baseline Future (permitted) all the way to an effluent concentration of 0.05 mg/l total phosphorus (LTA). Figure 57 shows the impact of various effluent concentration conditions on summer chlorophyll-a at Dundee Lake based on simulations for WY2002. An effluent phosphorus concentration of 0.4 mg/l as a long-term average results in compliance with the summer average (June 15 – August 31) chlorophyll-a end point of 18 µg/l, which incorporates the explicit RC and MoS.

FIGURE 57: Impact of Effluent TP Concentration on Phytoplankton at Dundee Lake



Based on the preceding analyses, the Target Condition that satisfies the water quality targets for both the Wanaque Reservoir and Dundee Lake is an effluent total phosphorus concentration of 0.4 mg/l as a long-term average and a 60% reduction of phosphorus runoff loads from urban and agricultural land uses. The Target Condition (i.e., TMDL Condition) incorporates critical conditions, implicit and explicit RC and MoS, and satisfies water quality targets established for both critical locations. Therefore, the TMDL Condition satisfies the watershed-specific criteria for the non-tidal Passaic River Basin, which supersede the 0.1 mg/l instream phosphorus criterion for this system.

Figures 58, 59, and 60 show the TMDL Condition at Dundee Lake (the Passaic River upstream of Dundee Dam) over the four-year simulation period in terms of DO, chlorophyll-a, and TP, respectively. Additional graphs showing comparisons of DO and chl-a (where important) results for July and August 2002 between TMDL Condition and Baseline Future Condition simulations for various locations throughout the system are provided in Appendix L.

FIGURE 58: TMDL Condition in Passaic River at Dundee Dam – DO

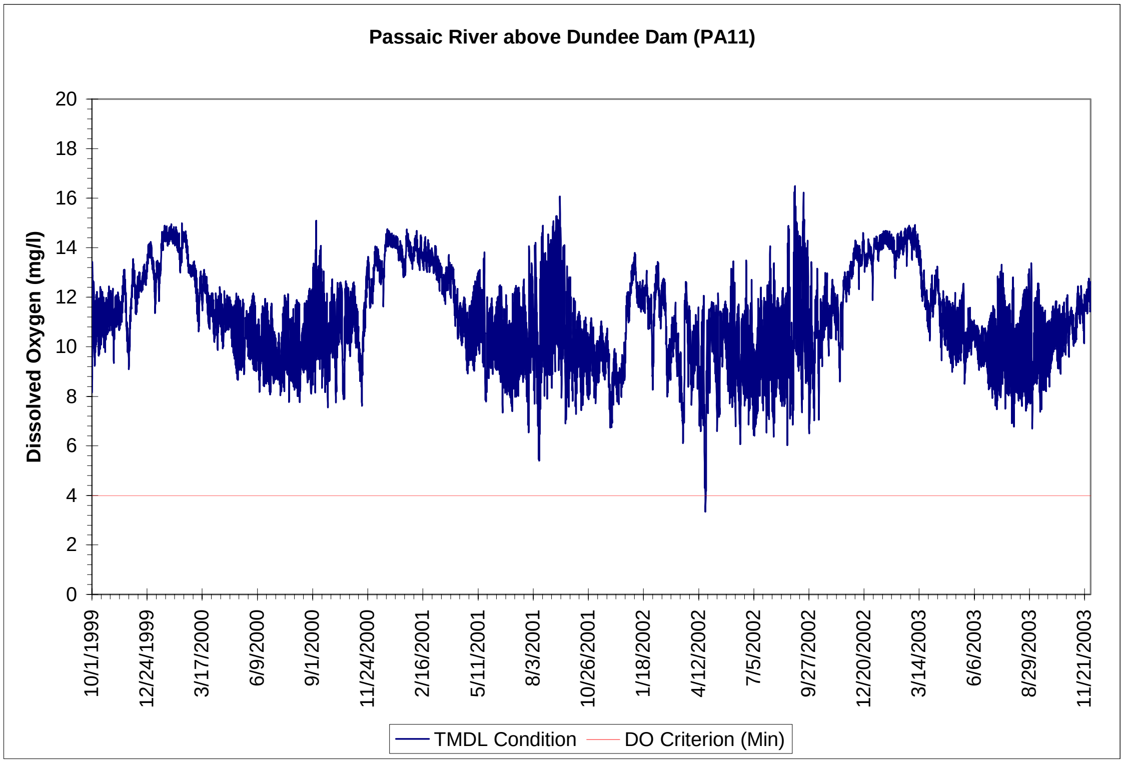


FIGURE 59: TMDL Condition in Passaic River at Dundee Dam – Chlorophyll-a

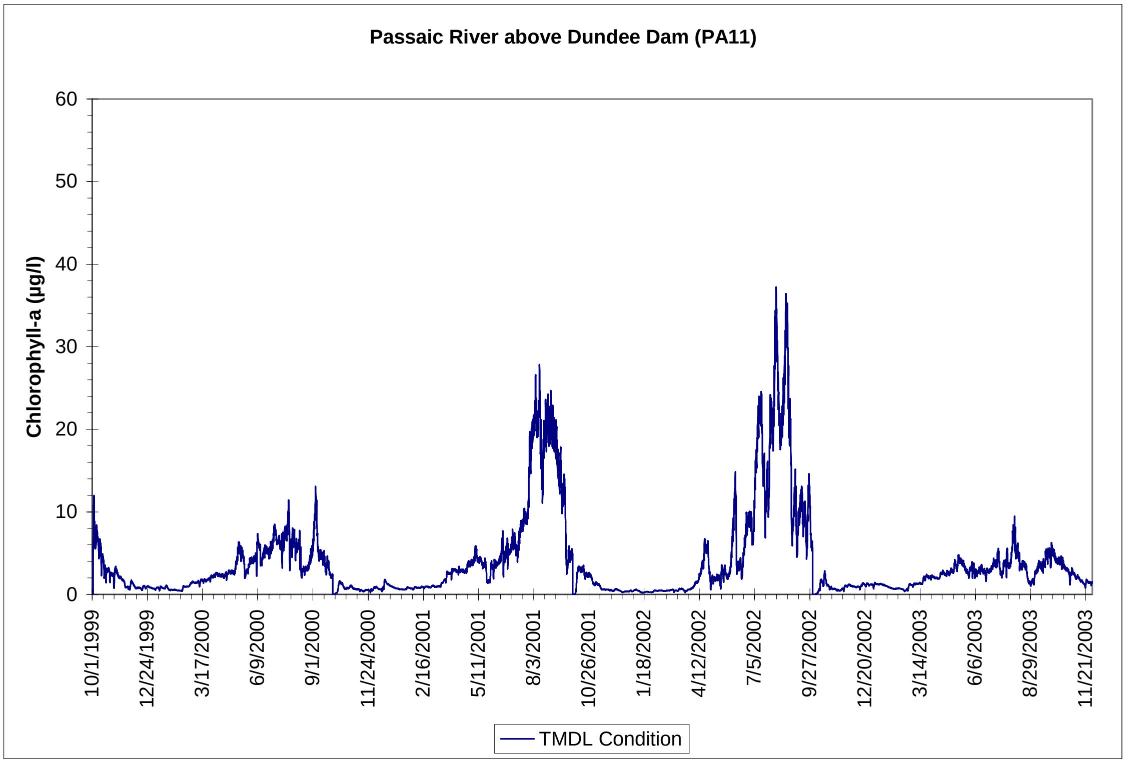
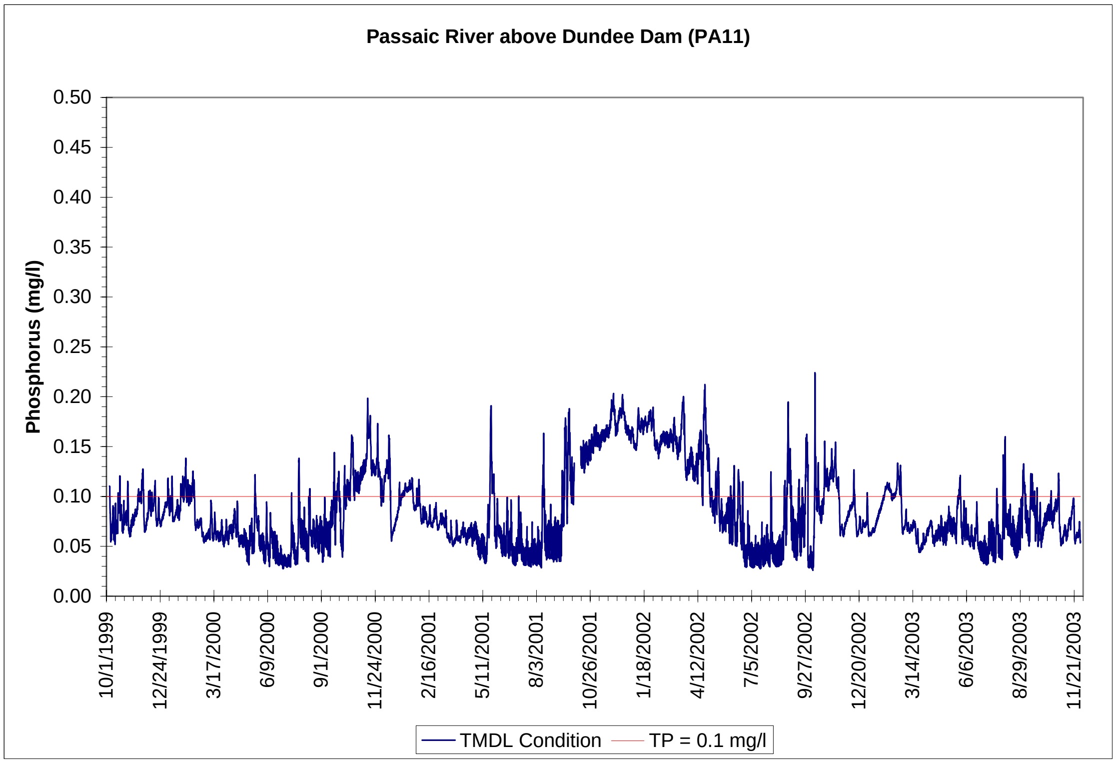


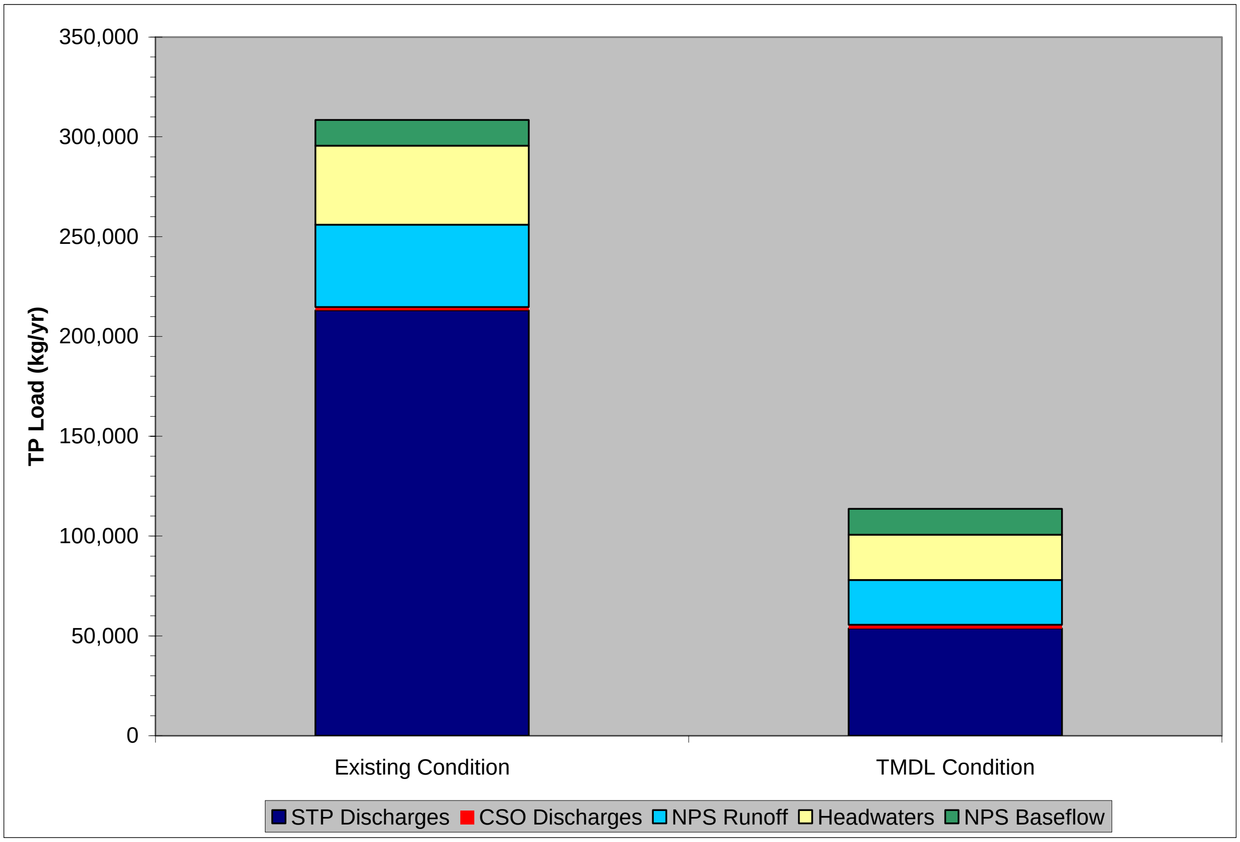
FIGURE 60: TMDL Condition in Passaic River at Dundee Dam – TP



V.C. <u>Loading Capacity</u>

The TMDL Condition represents a 63% decrease in phosphorus loads compared to the Existing Condition, as shown in Figure 61. STP point source loads decrease by 75% from the Existing Condition to the TMDL Condition, accounting for 82% of the total decrease in phosphorus load between the two scenarios. Stormwater runoff loads decrease by 45% (60% reduction of loads from urban and agricultural lands), accounting for 10% of the total decrease; headwater loads decrease by 43%, accounting for 9% of the total decrease in phosphorus load between the two scenarios. Virtually all of the decrease in headwater loads is due to the implementation of the Pompton Lake and Wanaque Reservoir TMDLs, resulting in a substantial decrease to the Ramapo River headwater phosphorus load at Pompton Lake.

FIGURE 61: Average Annual Phosphorus Loads: Existing vs. TMDL



A TMDL is defined by the simple equation:

$$TMDL = LC = \sum WLA + \sum LA + MoS + RC$$

Where: TMDL = Total Maximum Daily Load;
LC = Loading Capacity;
WLA = Wasteload Allocation for point sources;
LA = Load Allocation for nonpoint sources;
MoS = Margin of Safety; and
RC = Reserve Capacity.

A Modified Loading Capacity (LC′) can be defined as:

$$LC' = LC - MoS - RC = \sum WLA + \sum LA$$

Since the TMDL Condition incorporates both RC and MoS both implicitly and explicitly through reduced water quality targets, LC′ is equal to the total maximum daily phosphorus load allocated among all point and nonpoint sources. It is important to recognize that LC′ is based on long term average loads and calculated as an average over the four-year simulation period. The nature of the water quality targets demands that LC′ be expressed as a long term average: phytoplankton growth in both the Wanaque Reservoir and the Dundee Lake responds to the long-term nutrient concentration condition, not day-to-day peaks. Furthermore, a LC′ based on the maximum loads associated with high runoff periods would not be protective during dry weather periods; similarly, a LC′ based on acceptable loading conditions during a particular low flow period would be exceeded every time the flows increase. The only meaningful way to characterize LC′ is as a average daily load. Table 30 shows the average daily phosphorus loads associated with the Existing Condition and the TMDL Condition broken down by major basin.[5] The total average daily phosphorus load associated with the TMDL Condition represents the LC′: 312 kilograms per day (kg/d) as total phosphorus.

TABLE 30: Average Daily Total Phosphorus Loads: Existing vs. TMDL

TP Source	Existing Condition				TMDL Condition			
	Pompton	Upper/Mid Passaic	Lower Passaic	Total (kg/d)	Pompton	Upper/Mid Passaic	Lower Passaic	Total (kg/d)
Headwaters	72	31	5.7	108	26	31	4.9	62
NPS Runoff	29	65	18	113	19	35	7.9	62
NPS Baseflow	7.5	22	6.3	35	7.5	22	6.3	35
CSO Discharges	0	0	4.9	4.9	0	0	4.9	4.9
STP Discharges	61	431	92	584	19	100	29	148
TOTAL (kg/d)	**169**	**549**	**127**	**845**	**71**	**188**	**53**	**312**

V.D. Allocations

WLAs are established for all NJPDES-regulated point sources (including NJPDES-regulated stormwater sources) within each source category, while LAs are established for all nonpoint sources and stormwater sources that are not subject to

[5] The Upper/Mid Passaic Basin is the watershed that drains to the Passaic River upstream of the Pompton River confluence, while the Lower Passaic Basin is the watershed that drains to the Passaic River between the Pompton River confluence and Dundee Dam.

NJPDES regulation. Stormwater runoff sources were quantified according to land use type, as described previously. The land use runoff categories previously defined were used to determine whether runoff sources receive WLAs or LAs. Specifically, WLAs were calculated for runoff from urban land use types, namely residential and commercial. As described previously, commercial includes all non-residential urban land uses; for this reason, it is labeled "Other Urban" on the TMDL allocation tables. Table 31 provides the TMDL allocations for all phosphorus source categories broken down by major basin. In order to characterize the stormwater runoff allocations in more meaningful terms, Figure 62 shows the average total phosphorus runoff yields (lbs/acre/yr) for both the Existing and TMDL Conditions.

FIGURE 62: Stormwater Runoff Phosphorus Yield (lbs/acre/yr): Existing vs. TMDL

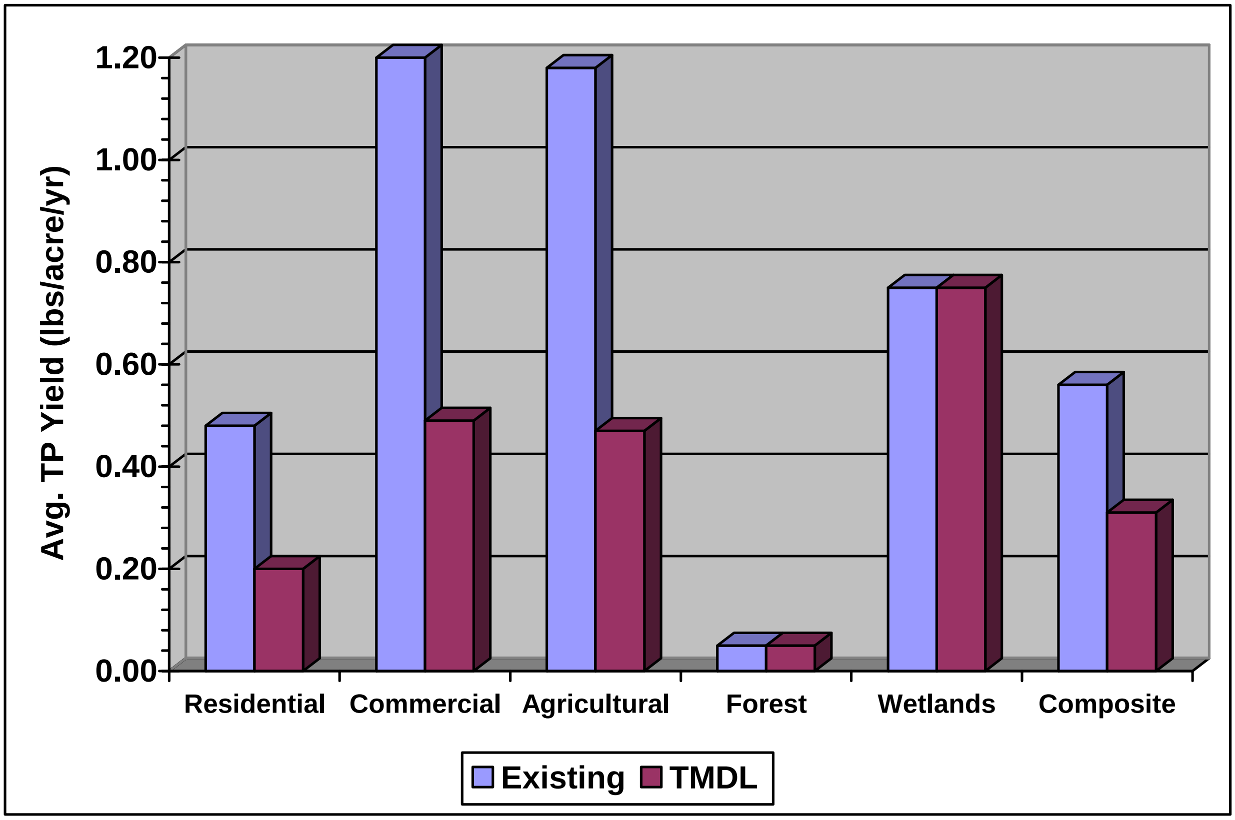


TABLE 31: TMDL Allocations for Phosphorus Source Categories by Basin

Long Term Average Daily (kg/d TP)	Pompton River Basin			Upper/Mid Passaic River Basin			Lower Passaic River Basin			Total		
	Existing Condition	TMDL Allocation	Percent Reduction	Existing Condition	TMDL Allocation	Percent Reduction	Existing Condition	TMDL Allocation	Percent Reduction	Existing Condition	TMDL Allocation	Percent Reduction
Wasteload Allocations (WLAs)												
Wastewater from STP Dischargers	61	19	69%	431	100	77%	92	29	69%	584	148	75%
Stormwater from Residential Land Use Areas	9.5	4.5	53%	24.1	9.6	60%	8.1	3.2	60%	42	17	60%
Stormwater from Other Urban Land Use Areas	9.5	4.4	54%	24.9	10.0	60%	9.5	3.8	60%	44	18	60%
CSO Discharges	0	0	N/A	0	0	N/A	4.9	4.9	0%	4.9	4.9	0%
Load Allocations (LAs)												
Headwater Boundaries	72	26	64%	31	31	0%	5.7	4.9	13%	108	62	43%
Tributary Baseflow	7.5	7.5	0%	21.6	21.6	0%	6.3	6.3	0%	35	35	0%
Stormwater from Agricultural Land Use Areas	0.5	0.2	60%	1.2	0.5	60%	0.0	0.0	60%	1.8	0.7	60%
Stormwater from Forest and Barren Land Use Areas	1.1	1.1	0%	0.8	0.8	0%	0.2	0.2	0%	2.1	2.1	0%
Stormwater from Wetlands Land Use Areas	8.5	8.5	0%	14.2	14.2	0%	0.7	0.7	0%	23	23	0%
Loading Capacity (LC′)	**169**	**71**	**58%**	**549**	**188**	**66%**	**127**	**53**	**58%**	**845**	**312**	**63%**

Table 32 provides specific TMDL allocations for individual STP dischargers by major basin. The TMDL allocation for each facility was obtained by multiplying the long-term average (LTA) effluent concentration associated with the TMDL Condition by the Permitted Flow, and is expressed as an average daily load (kg/d TP). The TMDL is based on LTA effluent concentrations; actual effluent concentrations vary under normal operational conditions, and can be expected to be higher or lower than the LTA at any given time. In order to achieve the LTA associated with the TMDL, the Average Monthly Limit (AML) for each facility will be established by NJDEP using USEPA's Technical Support Document (USEPA, 1991). For example, assuming a Coefficient of Variance (CV) of 0.6 and a sampling requirement of four samples per month, an LTA of 0.4 mg/l would result in an AML of 0.8 mg/l.

Because the TMDL is based on satisfying watershed-specific criteria at discrete locations, it presents a nearly ideal opportunity for point source trading to optimize reductions. New Jersey EcoComplex, in partnership with the Passaic River Basin Alliance and others, received a federal grant to develop a trading program for phosphorus in the non-tidal Passaic River basin. Trading may present an important funding mechanism for some treatment plants to upgrade to a higher level of phosphorus removal using money they receive from other treatment plants that could either not upgrade or upgrade to a lesser degree. Since kinetic losses are not evenly distributed throughout the basin, some treatment plants will exert a greater effect on the water quality end points than others. The Passaic TMDL Model can be applied directly to develop a trading currency among point sources to satisfy the watershed-specific criteria at both critical locations. A well-conceived trading program can serve to optimize phosphorus reductions to achieve the greatest environmental benefit at the most economical cost.

TABLE 32: TMDL Allocations for Individual STP Dischargers

NJPDES #	Facility Name	Permitted Flow (mgd)	TMDL Allocation	
			Long-Term Average Conc. (mg/l TP)	Long-Term Average Load (kg/d TP)
			Pompton River Basin STP Loading Capacity (LC′)	**19**
NJ0026514	Plains Plaza Shopping Center	0.02	0.4	0.03
NJ0023698	Pompton Lakes Borough MUA	1.2	0.4	1.8
NJ0027006	Ringwood Boro - Ringwood Acres STP	0.036	0.4	0.1
NJ0032395	Ringwood Plaza STP - Ringwood Assn.	0.0117	0.4	0.02
NJ0029386	Two Bridges SA	10	0.4	15.1
NJ0053759	Wanaque Valley Regional SA	1.25	0.4	1.9
			Upper/Mid Passaic River Basin STP Loading Capacity (LC′)	**100**
NJ0027961	Berkeley Heights WPCP	3.1	0.4	4.7
NJ0022845	Bernards SA - Harrison Brook STP	2.5	0.4	3.8
NJ0020427	Caldwell Boro STP	4.5	0.4	6.8
NJ0020281	Chatham Hill STP	0.03	0.4	0.05
NJ0052256	Chatham Twp - Chatham Glen STP	0.155	0.4	0.23
NJ0020290	Chatham Twp - Main STP*	1	0.4	1.51*
NJ0003476	Exxonmobil Research & Eng. Co.	0.29	0.4	0.4
NJ0025518	Florham Park SA	1.4	0.4	2.1
NJ0024902	Hanover SA	4.61	0.4	7.0
NJ0024511	Livingston Twp STP	4.6	0.4	7.0
NJ0024465	Long Hill Twp - Stirling Hills STP	0.9	0.4	1.4
NJ0024937	Madison Chatham Jt Mtg - Molitor	3.5	0.4	5.3
NJ0024911	Morris Twp - Butterworth STP	3.3	0.4	5.0
NJ0024929	Morris Twp - Woodland STP*	2	0.4	3.03*
NJ0025496	Morristown Town STP	6.3	0.4	9.5
NJ0026689	NJDHS - Greystone Psychiatric Hosp.	0.4	0.4	0.6
NJ0024970	Parsippany - Troy Hills SA	16	0.4	24.2
NJ0022349	Rockaway Valley Regional SA	12	0.4	18.2

TABLE 32: TMDL Allocations for Individual STP Dischargers (cont'd)

NJPDES #	Facility Name	Permitted Flow (mgd)	TMDL Allocation	
			Long-Term Average Conc. (mg/l TP)	Long-Term Average Load (kg/d TP)
NJ0021083	Veterans Affairs Medical Center	0.4	0.4	0.6
NJ0022489	Warren Twp Stage I-II STP	0.47	0.4	0.7
NJ0022497	Warren Twp Stage IV STP	0.8	0.4	1.2
NJ0050369	Warren Twp Stage V STP	0.38	0.4	0.6
Lower Passaic River Basin STP Loading Capacity (LC′)				**29**
NJ0104451	Bayer Corporation	0.216	0.4	0.3
NJ0025330	Cedar Grove Twp STP	2	0.4	3.0
NJ0002577	Nabisco Fair Lawn Bakery - DSN001A	0.379	0.4	0.6
NJ0002577	Nabisco Fair Lawn Bakery - DSN002A	0.0056	0.4	0.01
NJ0024490	Verona Twp STP	3	0.4	4.5
NJ0028002	Wayne Twp - Mountain View STP	13.5	0.4	20.4
Total STP Loading Capacity (LC′)				**148**

*These two facilities are located in the Great Swamp watershed and are included in the Passaic River headwater load allocation, which is assumed to remain the same. Based on the analysis provided in Appendix D, TMDL allocations are established for these facilities based on a LTA of 0.4 mg/l total phosphorus.

VI. CONCLUSIONS

This study provides a scientifically defensible approach to establishing a nutrient Total Maximum Daily Load (TMDL) for the Non-Tidal Passaic River Basin by relating point and nonpoint sources of phosphorus to water quality impacts at critical locations under a variety of conditions, including critical conditions.

The Non-Tidal Passaic River Basin model represents a system-wide water quality model that is calibrated and validated for nutrients, dissolved oxygen, and water column chlorophyll-a. Continuous simulations from October 1999 to November 2003 were used to account for seasonal variations and demonstrate compliance with water quality standards under critical conditions. These four water years include a range of hydrologic conditions, both seasonal and year-to-year. Watershed modeling analyses were performed to assess the impact of point and nonpoint source reductions on dissolved oxygen, phosphorus concentrations, and chlorophyll-a in streams throughout the system.

Three scenarios were simulated (Existing Condition, Baseline Future Condition, and MERP Condition) in order to bound the impacts of increases and decreases in phosphorus loads on key water quality parameters, namely phosphorus concentration, dissolved oxygen, and phytoplankton (water column chlorophyll-a). The Baseline Future Condition simulation assumed STP point sources were discharging their permitted flows at their permitted concentrations. The MERP Condition simulation assumed STP point sources were discharging their permitted flows at a 0.05 mg/l total phosphorus concentration, and that phosphorus NPS runoff loads from urban and agricultural land areas decreased by 80%.

In order to evaluate the impact of increasing phosphorus loads to the Passaic River Basin on water quality, the Existing Condition simulation was compared with the Baseline Future Condition simulation. Predictably, instream phosphorus increased in the Baseline Future Condition because STP point sources were set to their permitted flows and concentrations. Productivity, as evaluated in terms of DO swing and chlorophyll-a peaks, generally stayed the same or decreased slightly in the Baseline Future Condition. Depending on whether productivity was causing oxygen conditions to improve or worsen, sites showing slightly less productivity showed slightly better or worse DO conditions. The results demonstrate that the impact of increasing phosphorus loads to the Passaic River Basin would be generally minimal. This is expected, since there is already more phosphorus than necessary to support the maximum amount of productivity in most parts of the system.

In order to evaluate the impact of decreasing phosphorus loads to the Passaic River Basin on instream water quality, the Baseline Future Condition simulation was compared with the MERP Condition simulation. Predictably, instream phosphorus decreased dramatically in the MERP Condition throughout the Passaic River Basin because of the decreased point and nonpoint sources in that simulation. It is important to note that even in the MERP Condition, many of the streams in the Passaic River Basin would still exceed concentrations of 0.1 mg/l total phosphorus, albeit less frequently.

Most of the streams in the Passaic River Basin are not very sensitive to decreases in phosphorus loads. However, based on the assessment of stream response and the Wanaque Reservoir TMDL, two critical stream locations have been identified in the Passaic River Basin:

- Pompton River at the Passaic River Confluence – the Wanaque South intake draws water from both the Passaic and Pompton Rivers. This is a critical location because it represents a major source of phosphorus to the Wanaque Reservoir.
- Passaic River upstream Dundee Dam – reduction of phosphorus can attenuate the extreme DO swings and reduce the phytoplankton peaks experienced during critical summer conditions in the downstream portion of the Passaic River from upstream of Great Falls to Dundee Dam.

Except for the two critical locations identified above, phosphorus is not controlling productivity or otherwise rendering the waters unsuitable for the designated uses. Therefore, based on the narrative portion of the instream phosphorus criterion, the instream phosphorus criterion does not apply to streams throughout the Passaic River Basin other than the critical locations identified above. Watershed-specific criteria were developed for these two critical locations, which supersede and replace the instream and in-lake phosphorus criteria.

Phytoplankton chlorophyll-a end points (water quality targets) were developed for both of the critical locations in the Passaic River Basin:

- In order to protect all uses in the Wanaque Reservoir, NJDEP established a water quality target of 10 μg/l chlorophyll-a as a summer average (June 15 to August

31). Given the narrow definition of growing season and the low target selected, this end point represents a very protective end point that will ensure near-pristine conditions in the Wanaque Reservoir. This reflects the importance of the Wanaque Reservoir as both a major water supply, aquatic life, and aesthetic resource in northern New Jersey.

- In order to protect all uses upstream of Dundee Dam, NJDEP established a water quality target of 20 μg/l chlorophyll-a as a summer average (June 15 to August 31). Given the narrow definition of growing season and the relatively low target selected, this end point represents a very protective end point that will ensure aesthetically pleasing conditions in this urban lake feature.

Because these chlorophyll-a end points relate directly to the impairment of uses at these locations, they form the basis for site-specific criteria in accordance with N.J.A.C 7:9B-1.5(g)3. As such, these end points replace the phosphorus criteria that would otherwise be applied to these waterbodies. Taken together, the end points form the basis for watershed-specific criteria for the Non-Tidal Passaic River Basin, which in turn provide the basis for a meaningful TMDL.

The target TMDL condition is defined as the phosphorus loading condition that satisfies water quality end points for both Dundee Lake and the Wanaque Reservoir. The Passaic River Basin model was used to predict the water quality outcome associated with various phosphorus reduction scenarios, in particular the summer average phytoplankton concentration in the Passaic River at Dundee Lake. In order to fully integrate the Non-Tidal Passaic River Basin TMDL Study with the Wanaque Reservoir TMDL Study, the Passaic River Basin model was also used to simulate phosphorus concentration at the Wanaque South intake for various phosphorus reduction scenarios. Time series of phosphorus concentration predictions were provided to NJDEP and their technical consultant for the Wanaque Reservoir TMDL Study in order to predict the summer average phytoplankton in the Wanaque Reservoir associated with each phosphorus reduction scenario. Various combinations of effluent concentrations and runoff reductions were iteratively tested in terms of their impact on the end points at both critical locations.

The Target Condition that satisfies the water quality targets for both the Wanaque Reservoir and Dundee Lake is an effluent total phosphorus concentration of 0.4 mg/l as a long-term average and a 60% reduction of phosphorus runoff loads from urban and agricultural land uses. The TMDL Condition incorporates critical conditions, Reserve Capacity, and Margin of Safety, and satisfies water quality targets established for both critical locations. Therefore, the TMDL Condition satisfies the watershed-specific criteria for the non-tidal Passaic River Basin.

The Loading Capacity was calculated for the entire basin, and allocated among point sources (wasteload allocations) and nonpoint sources (load allocations) accordingly. Individual allocations were calculated for all STP dischargers within the study area. The TMDL will be implemented primarily through NJPDES regulation of wastewater and stormwater sources.

Because the TMDL is based on satisfying watershed-specific criteria at discrete locations, it presents a nearly ideal opportunity for point source trading to optimize reductions. The Passaic TMDL Model can be applied directly to develop a trading currency among point sources to satisfy the watershed-specific criteria at both critical locations. A well-conceived trading program can serve to optimize phosphorus reductions to achieve the greatest environmental benefit at the most economical cost.

This report and all appendices are provided electronically in Appendix M.

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