ABSTRACT

HYDRODYNAMIC AND WATER QUALITY MODELING OF THE WHIPPANY RIVER

by
John E. Krohn

The Whippany River is located in northern New Jersey and is a major tributary to the Passaic River System. This waterway accepts a wide variety of wastes from the diverse communities within its watershed. These wastes contribute to a rather complex network of biological, chemical and physical interactions.

The purpose of this study is to develop a water quality model using QUAL2E. This model will be used as a tool to simulate the complex interactions that take place within the river system. The river must be considered from physical, biological and chemical perspectives. A successful model can determine current water quality conditions or predict a future waste load's impact on water quality.

The major systems that have an effect on DO and will be considered here include aquatic plants, biochemical oxygen demand, the nitrogen cycle, sediment oxygen demand, and atmospheric reaeration on the dissolved oxygen levels in the water.

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by
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This thesis is dedicated to
Mom and Dad

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CHAPTER 1

INTRODUCTION

The Whippany River is a waterway located in northeastern New Jersey which accepts a wide variety of wastes from the diverse communities within its watershed. The addition of wastes to the Whippany River system contributes to a rather complex network of biological, chemical and physical interactions. For a number of years, these wastes loads have exceeded the river's ability to digest them. "This waste is mostly in the form of reduced organic and nitrogen compounds which are utilized by the stream's biota as energy and nutrient sources" (New Jersey Department of Environmental Protection 1985, 1). These reduced compounds are oxidized under aerobic conditions with the free oxygen which is dissolved in the water, acting as the final electron acceptor. If the oxygen uptake rate due to the various oxygen depleting mechanisms within the ecosystem exceeds the rate in which oxygen can be supplied, then an oxygen stressed system could result.

Water quality models are developed as a tool to simulate the complex interactions that take place within the river's ecosystem. The river must be considered from physical, biological and chemical perspectives. With this in mind a water quality model can determine current water quality conditions or predict a future waste load's impact on water quality. The model is a tool to predict changes in the concentration of a water quality constituent with respect to time and distance. The results of the model can then be compared to state mandated water quality criteria to determine if any sections of the river are not in compliance.

This work, in addition to efforts by the New Jersey Department of Environmental Protection (NJDEP), are being completed in order to evaluate the present quality of the water in the Whippany River. The results obtained can be used to determine and justify waste load allocations within the river's drainage basin.

CHAPTER 2

OBJECTIVE

The Whippany River is located in northern New Jersey and is a major tributary to the Passaic River System. This waterway accepts a wide variety of wastes from the diverse communities within its watershed. These wastes contribute to a rather complex network of biological, chemical and physical interactions. For a number of years, these inputs have exceeded the rivers ability to digest them.

The objective of this study is to develop a model using QUAL2E. This model will be used as a tool to simulate the complex interactions that take place within the river system. The river must be considered from physical, biological and chemical perspectives to determine its ability to oxidize and assimilate waste without a significant reduction in the dissolved oxygen (DO) concentration . A successful model can determine current water quality conditions or predict a future waste load's impact on the quality of the water.

The effect of aquatic plants, biochemical oxygen demand, the nitrogen cycle, sediment oxygen demand, and atmospheric reaeration on the DO levels in the water will be considered in this model.

CHAPTER 3

WHIPPANY RIVER SYSTEM DESCRIPTION

The Whippany River is a major tributary to the Passaic River System. Located in northeast New Jersey, and entirely within Morris County, the Whippany River basin encompasses an area of approximately 72 square miles. This area receives approximately 1.2 meters of rainfall per year of which 0.51 - 0.64 meters are lost to evapotranspiration (NJDEP 1985, 3).

Figure 3.1 shows a map of the Whippany River Basin. Its confluence with the Rockaway River is designated as kilometer 0.0. The portion of the river modeled includes most of the mainstem. The western terminus is located at kilometer 15.2 just upstream of the Morristown Sewage Treatment Plant (STP) outfall, with the river flowing easterly. The downstream terminus is located just upstream of the confluence of the Rockaway at kilometer 0.2.

Within the studied reach there is a large impoundment just upstream of the Eden Lane Dam and a smaller one above the Whippany Road Dam . Three major tributaries enter the reach: Stoney Brook (also called Malapardis Brook) from the north, Black Brook from the south, and Troy Brook from the north. In addition, the Morristown STP and the Hanover STP both discharge into the studied reach. The locations of dams, tributaries, and STP's along the river are illustrated in Figure 3.1.

The Whippany River Basin is diverse with respect to its land use and ranges from rural to suburban. The headwaters are located in an area of sparse development but downstream from that area the river is infiltrated with a broad range of wastes generated by a densely populated and complex community consisting of residential, industrial, and commercial areas, while the last few miles of the river are a low lying natural swamp.

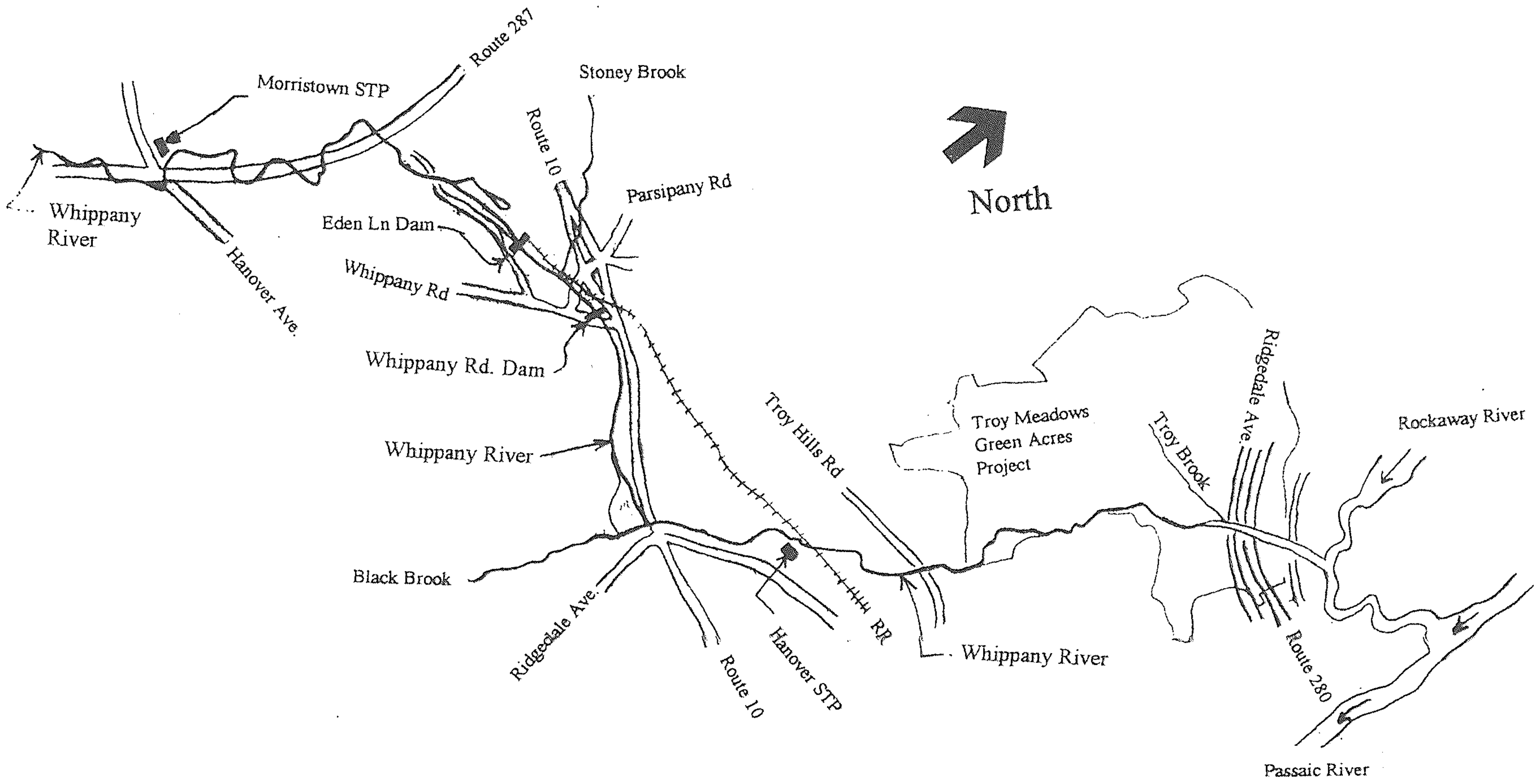


Figure 3.1 Geographical location of the Whippany River and localized detail of dams, tributaries, STP's, and surrounding landmarks for the stretch being studied (Hagstrom 1989, Morris County Map).

CHAPTER 4

OVERVIEW OF THE QUAL2E MODELING SYSTEM

4.1 Conceptual Representation

Figure 4.1 shows a stream divided into reaches and computational elements.

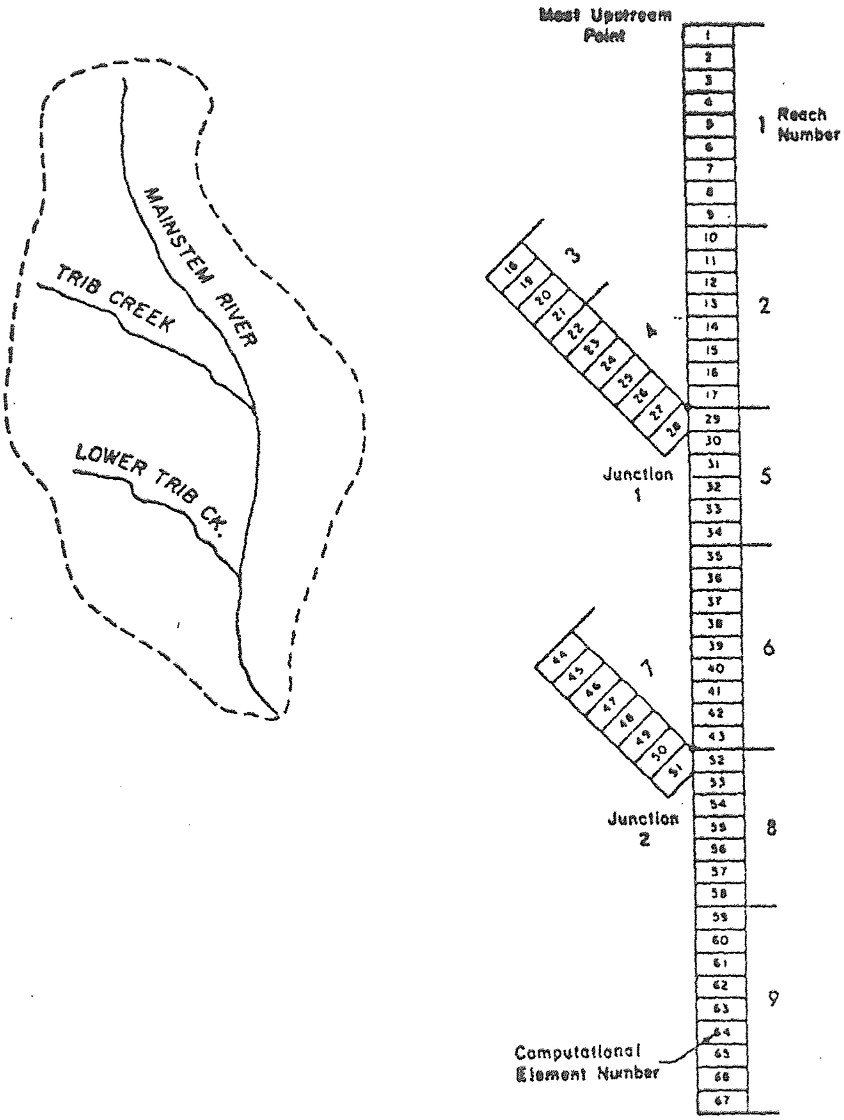


Figure 4.1 Stream network of reaches and computational elements (Brown and Barnwell 1987, 13).

These reaches are determined by dividing the stream system into lengths which have uniform hydraulic characteristics. These reaches are then divided into computational elements of length Δx. In order to obtain a more accurate simulation, the length of the computational elements in all reaches should be equal.

4.2 Mathematical Representation

4.2.1 Flow Balance Equation

A flow balance is applied to an elemental control volume, as shown in Figure 4.2, in order to maintain flow continuity. QUAL2E assumes that the stream's hydraulic regime is steady state; i.e., $\partial Q/\partial t = 0$.

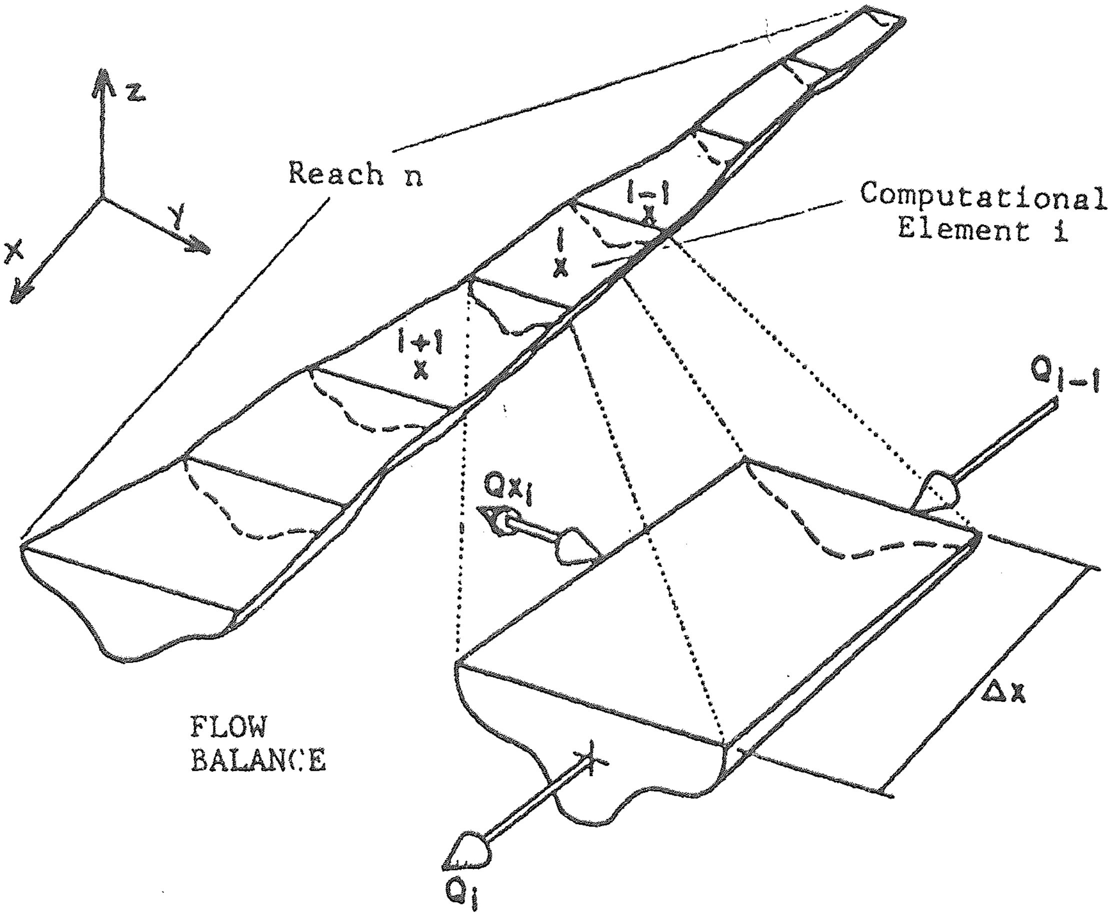


Figure 4.2 Flow balance as applied to a computational element (Brown and Barnwell 1987, 12).

The flow balance includes a term for groundwater seepage ($+Qx_i$) or groundwater recharge ($-Qx_i$) which allows for incremental flow change along the length of the river . The flow balance equation written in terms of flows into the upstream face of the element, groundwater sources or withdrawals, and outflow through the downstream face of the element becomes

$$Q_i = Q_{i-1} \pm Qx_i \quad (4.1)$$

where

Q_{i-1} = flow into upstream face of computational element, ft^3/s

$\pm Qx_i$ = flow supplied to (+) or taken from (-) computational element by groundwater, ft^3/s

Q_i = flow out of downstream face of computational element, ft^3/s

4.2.2 Mass Balance Equation

The basic principle of the water quality model is the conservation of mass. The water volume and water quality constituent masses being simulated are tracked and accounted for over time and space using a series of mass balancing equations. QUAL2E does this by conserving mass in both space and time from a point of spatial and temporal input of a constituent to a final point of export.

A mass balance equation for dissolved constituents in a body of water must account for all material entering and exiting a computational element through direct and diffuse loading, advective and dispersive transport, and physical, chemical, and biological transformation. Figure 4.3 conceptually represents an elemental control volume and the nomenclature used for the mass balance. QUAL2E assumes vertical and lateral homogeneity, therefore the derivation of the finite-difference form of the mass balance equation will be for a one dimensional reach; i.e., no change in concentration with respect to the y or z directions.

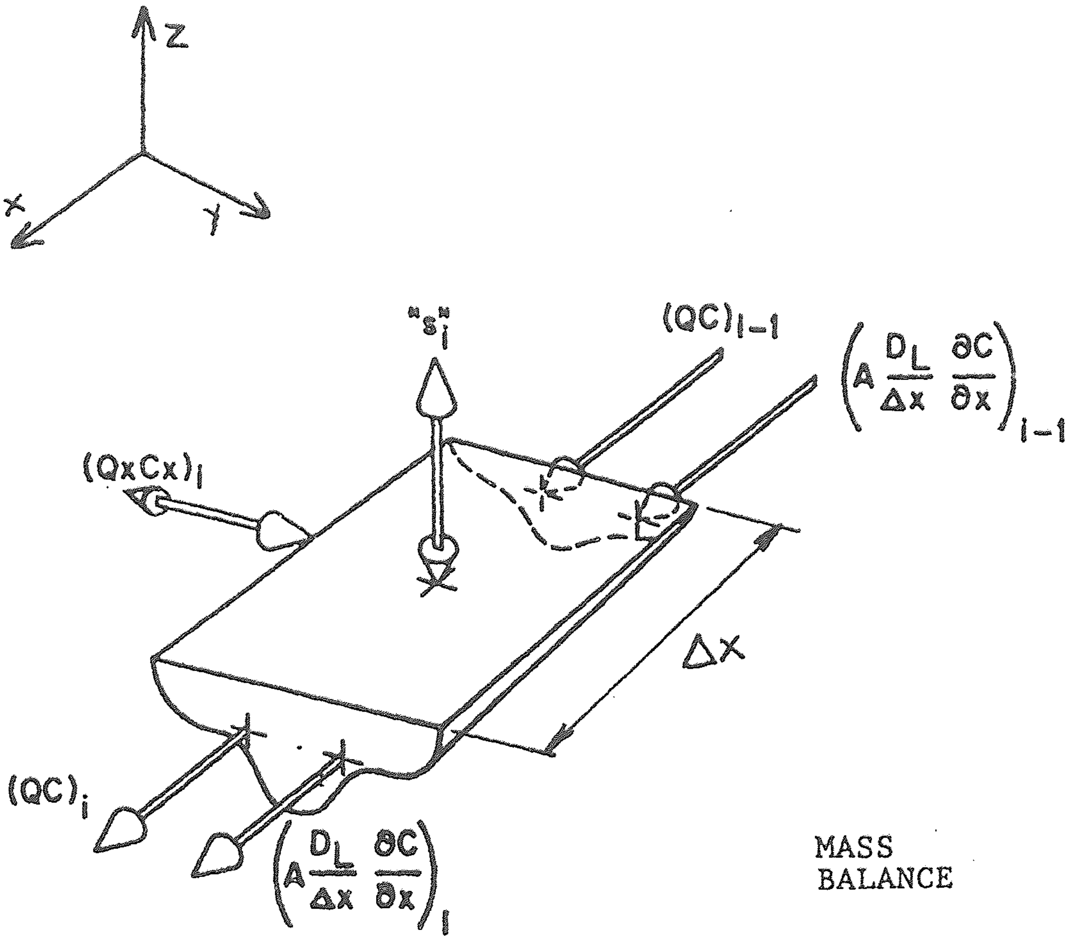


Figure 4.3 Mass balance as applied to a computational element (Brown and Barnwell 1987, 12).

The mass balance around an element consists of

$$\text{change in mass} = \text{mass in} - \text{mass out} \pm \text{transformation} \quad (4.2)$$

Assuming that there is no change in flow within the element with respect to time; i.e., $\partial Q/\partial t = 0$, the mathematical expressions for each term are

A. Change in mass

1. $(\partial c/\partial t)A\Delta x\Delta t$ - net change in mass of a water quality constituent in a computational element.

B. Mass in

1. $(Qc)\Delta t$ - mass transported into an element from an upstream element through advective flow.
2. $-[(EA)\partial c/\partial x]\Delta t$ - mass transported into an element from an upstream element through dispersive flow.
3. S_o - mass transported into an element from a source in the benthos.

C. Mass out

1. $Q[c + (\partial c/\partial x)\Delta x]\Delta t$ - mass transported out of an element to a downstream element through advective flow.
2. $\{-EA[\partial c/\partial x + \partial/\partial x \partial c/\partial x)\Delta x]\}\Delta t$ - mass transported out of an element to a downstream element through dispersive flow.
3. S_i - mass transported out of an element from a sink in the benthos.

D. Transformation

1. $(\partial c/\partial t)\Delta x\Delta t$ - change in mass due to physical, chemical, and/or biological transformation. Examples would include reaeration, biodegradation, respiration, photosynthesis, and chemical reactions.

Before writing the expression, we will take a look at the transformation term first. Manipulating this term first is done for clarity. We first assume that each elemental control volume is a completely mixed chamber. This means that the concentration of the water quality constituent is homogeneous throughout the computational element. Since there will be no change in concentration in the x, y or z direction; i.e., $dx/dt = dy/dt = dz/dt = 0$, the partial derivative can become a normal derivative with respect to time and can be written as

$$(dc/dt)\Delta x\Delta t \quad (4.3)$$

> Note: This term, which is concerned with constituent changes due to growth and decay, should not be confused with the term for "change in mass" which depicts the local concentration gradient. The latter term is concerned with change that occurs along the entire reach and therefor does change with respect to time and distance downstream (Brown and Barnwell 1987, 14).

Since the water quality constituents that we are concerned with will almost always be first order reactions, we will only consider such reactions. In such a reaction, the rate of decomposition is directly proportional to the amount of undecayed material remaining. This is written mathematically as

$$dc/dt = -kc \quad (4.4)$$

where k is the reaction rate constant and has units of 1/time. A negative rate constant indicates decay and a positive value indicates growth. Substituting Equation 4.4 into Equation 4.3 gives the expression which will be used for change in mass as a result of physical, chemical, or biological transformation as

$$\text{change in mass due to reaction} = (-kc)\Delta x\Delta t \quad (4.5)$$

We turn our attention back to the mass balance equation now that we have our term for "change in mass due to reaction". By putting the mathematical terms for each expression into Equation 4.2 we get

$$(\partial c/\partial t)A\Delta x\Delta t = (Qc)\Delta t + \{-[(EA)\partial c/\partial x]\Delta t\} - Q[c + (\partial c/\partial x)\Delta x]\Delta t - \{-EA[\partial c/\partial x + (\partial/\partial x)(\partial c/\partial x)\Delta x]\}\Delta t - (-kc)\Delta x\Delta t + S_o - S_i \quad (4.6)$$

which by algebraic manipulation reduces to

$$\partial c/\partial t = -Q/A\partial c/\partial x + E\partial^2 c/\partial x^2 + kc + S_o - S_i \quad (4.7)$$

which represent the simplified form of the mass balance equation.

4.2.3 Mass Transport Equation

Since

$$M = cV \quad (4.8)$$

where

M = mass of a water quality constituent, mg

c = concentration of a water quality constituent, mg/L

V = volume of the computational element, L

the change in mass of a water quality constituent with respect to time can be written as

$$\partial M/\partial t = \partial(cV)/\partial t = V(\partial c/\partial t) + c(\partial V/\partial t) \quad (4.9)$$

However, since we assume flow does not change with respect to time, volume will remain constant with respect to time as well; i.e., $\partial V/\partial t = 0$. Therefore Equation 4.9 becomes

$$\partial M/\partial t = V(\partial c/\partial t) \quad (4.10)$$

or

$$\partial c/\partial t = (1/V)(\partial M/\partial t) \quad (4.11)$$

Substitution of Equation 4.11 into Equation 4.7 yields

$$(1/V)(\partial M/\partial t) = -Q/A(\partial c/\partial x) + E(\partial^2 c/\partial x^2) + kc + S_o - S_i \quad (4.12)$$

Equation 4.12 can then be written as

$$\partial M/\partial t = -(V)Q/A(\partial c/\partial x) + EV(\partial^2 c/\partial x^2) + Vkc + S_oV - S_iV \quad (4.13)$$

For an elemental control volume the volume can be expressed as

$$V = A \times dx \quad (4.14)$$

Substitution of Equation 4.14 into Equation 4.13 gives the following expression

$$\partial M/\partial t = -Q(\partial c/\partial x)dx + EA(\partial^2 c/\partial x^2)dx + (Akc)dx + (S_oA)dx - (S_iA)dx \quad (4.15)$$

where

∂M = change in mass of a water quality constituent, (M)

∂t = program simulation time step, (T)

Q = flow, (L^3/T)

∂c = change in concentration of a water quality constituent, (M/L^3)

$\partial x, dx$ = length of computational element, (L)

E = Dispersion coefficient, (L^2/T)

A = cross-sectional area of computational element, (L^2)

k = reaction rate constant, $(1/T)$

S_o = external source, (M/T)

S_i = external sink, (M/T)

which is the one dimensional mass transport equation used by QUAL2E. The terms on the right hand side of the equation account for the changes in mass of a water quality constituent within an elemental control volume with respect to time and space due to advection, dispersion, transformation (growth or decay), sources, and sinks, respectively.

4.3 Hydraulic Characteristics

4.3.1 Hydraulic Geometry Relationships

It is desirable to use mathematical expressions that describe the relationships between the flow, velocity, and depth so that hydraulic characteristics can essentially be specified in terms of a single variable. Leopold and Maddock (1953) have examined various rivers and developed empirical relationships between flow, velocity, and depth. These expressions take the form of power functions with flow as the independent variable.

$$U = aQ^b \quad (4.16)$$

$$d = cQ^d \quad (4.17)$$

where

Q = flow, (L^3/T)

U = mean velocity, (L/T)

d = stream depth, (L)

a,b,c,d = empirical constants, (dimensionless)

Values for the empirical constants can be obtained by plotting field data for a particular river on Log-Log paper. These constants will vary from river to river although the range in which they will fall is fairly stable (Thomann and Mueller 1987, 44). Table 4.1 shows some typical values obtained from investigations of various rivers.

Table 4.1 Average values of exponents in hydraulic geometry relationships (Thomann and Mueller 1987, 44).

River or river basin	b	d
Great Plains and Southwest	0.34	0.40
Tennessee Valley	0.46	0.48
Scioto River, Susquehanna Basin, PA	0.70	0.30
Willamette River, Eugene to Oregon City, OR	--	0.61
Potomac River	0.47	0.40
Black River, NY	0.70	0.10
Watertown	0.40	0.40
Delaware River, below Easton, PA	0.40	0.50

4.3.2 Longitudinal Dispersion Coefficient

As water flows down a river, mixing occurs along the length of the river mainly due to horizontal and vertical velocity gradients. Changes in river's morphometry can also further increase this mixing. This phenomenon is called longitudinal dispersion. Figure 4.4 illustrates the dispersive properties of a river by measuring the concentration of a conservative substance, such as a dye or chlorine, at three different locations along a river following an upstream pulse input.

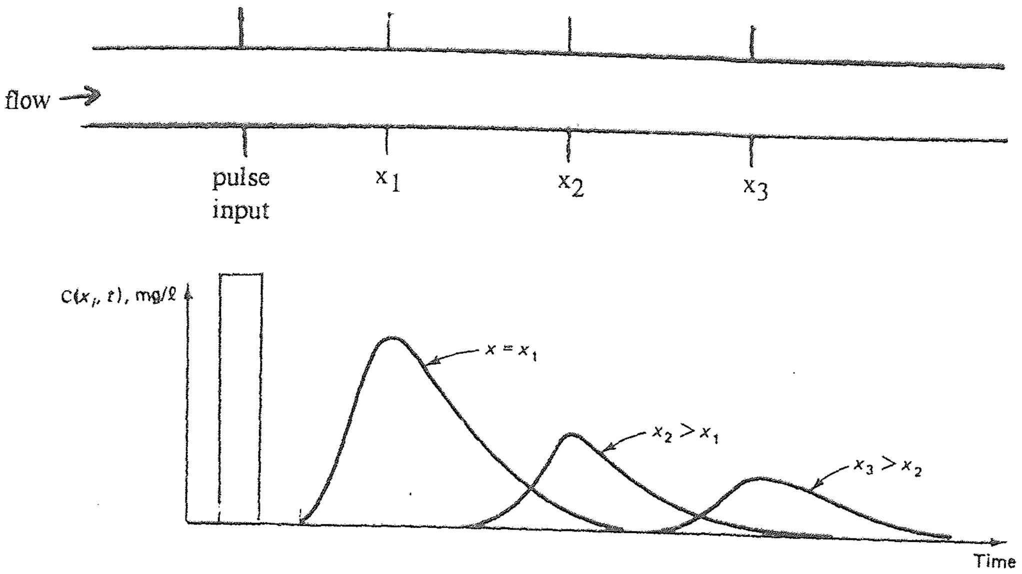


Figure 4.4 Dispersive stream quality response to a pulse input over time and distance (Thomann and Mueller 1987, 72).

QUAL2E uses the following expression developed by Elder (1959), which assumed that only the vertical velocity gradient was important in streamflow.

$$E = Kdu^* \quad (4.18)$$

where

E = dispersion coefficient, m^2/s
K = dispersion constant, (dimensionless)
d = mean stream depth, m
u^* = average shear velocity, m/s

Typical values of K for various rivers can be found in Table B.2 of Appendix B. The average shear velocity for steady-state open channel flow can be expressed as

$$u^* = C\sqrt{R_h S_e} \quad (4.19)$$

where

u^* = average shear velocity, m/s

C = Chezy's coefficient, (dimensionless)

R_h = hydraulic radius, m

S_e = slope of the energy grade line, m/m

Chezy's coefficient can be found by the following equation

$$C = (R_h)^{1/6} / n \quad (4.20)$$

where

R_h = hydraulic radius, m

n = Manning's roughness coefficient, (dimensionless)

Typical values of n for various surfaces can be found in Table B.3 of Appendix B.

The slope of the energy line, $S_{e,}$ is found by using Manning's equation.

$$S_e = [\,(U \times n) / (R_h)^{2/3}\,]^2 \quad (4.21)$$

where

S_e = slope of the energy grade line, m/m

U = mean velocity, m/s

n = Manning's roughness coefficient, (dimensionless)

R_h = hydraulic radius, m

CHAPTER 5

MATHEMATICAL METHODS USED FOR SYSTEM MODELING

5.1 Dissolved Oxygen

5.1.1 Principal Components of DO Analysis

All living organisms depend on oxygen in one form or another to maintain the metabolic processes that produce energy for growth and reproduction. Within a water body, aerobic processes are of the greatest interest because of there need of free oxygen; i.e., O_2. Appropriate DO levels in surface waters is a large factor in determining the general health of an aquatic ecosystem. Low DO concentrations or anaerobic conditions can result in an unbalanced ecosystem, fish mortality, odors and other aesthetic nuisances.

Atmospheric gases are all soluble in water to some degree. Oxygen and nitrogen are considered poorly soluble, and since they don't react with water chemically, their solubility is directly proportional to their partial pressures (Sawyer and McCarty 1978, 405). The solubility of oxygen varies a great deal within the temperature range of interest to a modeler. Since oxygen is a poorly soluble gas, its solubility also varies directly with atmospheric pressure at a given temperature. This may become a factor if a particular water body is located at a high altitude. The saturation value of a polluted river is also less than that of a clean river. Solubility curves for oxygen and nitrogen in distilled or low-solids-content water in equilibrium with air at standard atmospheric pressure (760 mm Hg) are shown in Figure 5.1.

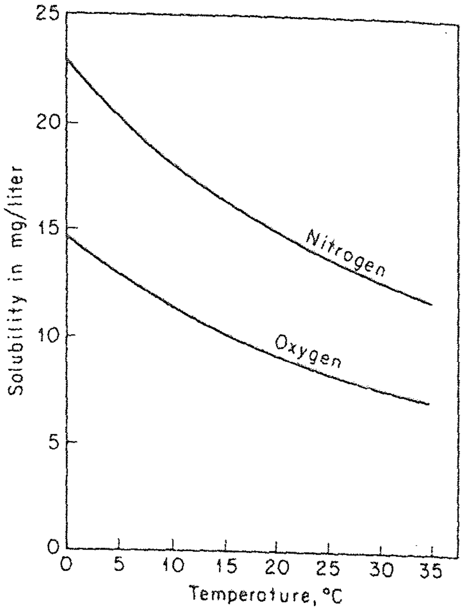


Figure 5.1 Solubility of oxygen and nitrogen in distilled or low-solids-content water saturated with air at standard atmospheric pressure (760 mm Hg) (Sawyer and McCarty 1978, 406).

Within a body of water there are a number of possible ways in which oxygen is supplied to the water and these are referred to as sources. There are also a number of interactions that exert an oxygen demand on the water called sinks. The major possible sources of DO to surface waters are:

1. Atmospheric reaeration.
2. Photosynthetic production of free oxygen.
3. DO supplied by tributaries or effluents.

The major possible sinks of oxygen are:

1. Oxygen used during respiration by aquatic plants.
2. Oxidation of nitrogenous compounds.
3. Oxidation of carbonaceous compounds.

4. Oxygen used by the sediments in a river bed.

The interaction between the sources and sinks and DO as well as the nomenclature used to represent them are represented schematically in Figure 5.2. The nomenclature used in this diagram will not be defined here since they will be referred to in subsequent sections where each constituent is described in more detail. A description of terms can be found in Table A.1 of Appendix A.

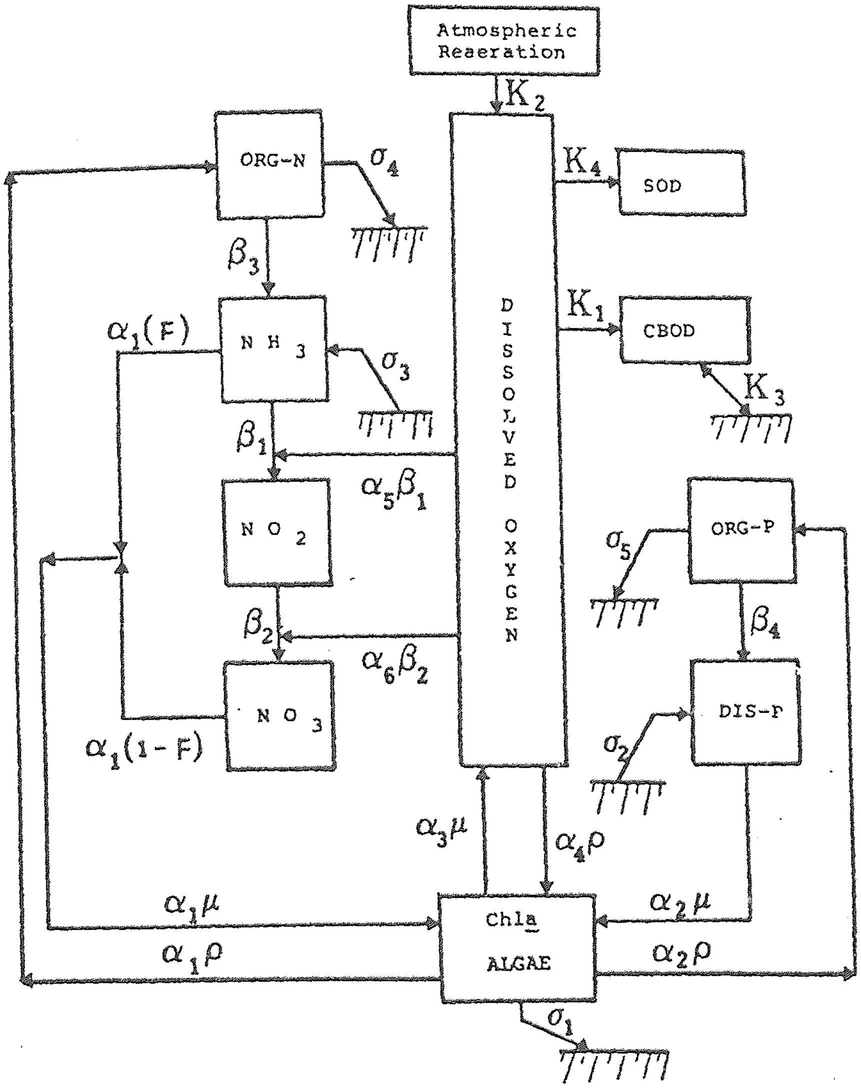


Figure 5.2 Relationship between major constituents in a water body and DO levels (Brown and Barnwell 1987, 23).

5.1.2 Mathematical Representation

The oxygen balance in a surface water is a function of the advective and diffusive properties of the water body, as described in Section 4.3, and the internal sources and sinks of oxygen discussed in the preceding section. The differential equation that QUAL2E uses to describe the rate of change of DO levels is shown below.

$$dO/dt = K_2(O^* - O) + (\alpha_3\mu - \alpha_4\rho)A_m - K_1L - K_4/d - \alpha_5\beta_1N_1 - \alpha_6\beta_2N_2 \quad (5.1)$$

where

O = the concentration of DO, mg/L

O^* = the saturation concentration of DO at the local temperature and pressure, mg/L

α_3 = the rate of oxygen production per unit of algal photosynthesis, mg-O/mg-A_m

α_4 = the rate of oxygen uptake per unit of algae respired, mg-O/mg-A_m

α_5 = the rate of oxygen uptake per unit of ammonia nitrogen oxidation, mg-O/mg-A_m

α_6 = the rate of oxygen uptake per unit of nitrite nitrogen oxidation, mg-O/mg-A_m

μ = the algal growth rate, 1/day

ρ = the algal respiration rate, 1/day

A_m = algal biomass concentration, mg-A_m/L

L = concentration of the ultimate carbonaceous BOD, mg/L

d = mean stream depth, ft

K_1 = carbonaceous BOD deoxygenation rate, 1/day

K_2 = atmospheric reaeration rate, 1/day

K_4 = sediment oxygen demand rate, 1/day

β_1 = ammonia oxidation rate coefficient, 1/day

β_2 = nitrite oxidation rate coefficient, 1/day

N_1 = concentration of ammonia nitrogen, mg-N/L

N_2 = concentration of nitrite nitrogen, mg-N/L

5.1.2.1 DO Saturation Concentration

As discussed above, the saturation concentration of DO depends upon temperature, pressure, and the amount of pollution or dissolved solids in a surface water. QUAL2E uses the following equation to determine the appropriate value for the saturation concentration of DO at a specific temperature

$$\ln O^* = -139.3441 + (1.575701 \times 10^5/T) - (6.642308 \times 10^7/T^2) + (1.2438 \times 10^{10}/T^3) - (8.621949 \times 10^{11}/T^4) \quad (5.2)$$

where

O^* = the saturation concentration of DO at the local temperature, mg/L

T = temperature, °K

This equation is suitable for temperature ranges of 0 to 40°C (32 to 104°F).

The Whippany River model will assume standard atmospheric pressure and that the amount of dissolved solids in the water is negligible throughout the studied reach. Therefore, the saturation concentration will only be adjusted for changes in temperature during the simulation.

5.1.2.2 Atmospheric Reaeration Coefficient Estimation

Oxygen transfer from the atmosphere to water as a function of internal mixing and turbulence has been studied and evaluated in great detail by a number of people. Several mathematical expressions based on both theoretical and empirical investigations have been developed to describe this transfer and are usually expressed as a function of stream depth and velocity. Among the most noteworthy are O'Connor and Dobbins (1958), Churchill et al. (1962), Owens et al. (1964), and Tsivoglou et al. (1968). QUAL2E allows you the option of choosing between the expressions developed in the aforementioned studies in addition to some other options. It is not the purpose of this paper to discuss each of these studies in detail. The reader is directed to the particular reports by each author as listed in the reference section, Brown and Barnwell (1987) or Thomann and Mueller (1987) for further discussion on reaeration rates.

Option 3, which uses the equations developed by O'Connor and Dobbins (1958), will be used for the Whippany River model. For this option, the reaeration coefficient is represented by

$$K_2 = [(D_m\, U)1/2]/d^{1.25} \quad (5.4)$$

where

K_2 = reaeration coefficient, 1/day
D_m = molecular diffusion coefficient, m^2/day
U = mean velocity, m/day
d = mean stream depth, m

This option was developed for streams with low velocities and is generally applicable for most cases (Brown and Barnwell 1987, 44-45).

5.2 Algae

5.2.1 General Considerations

The presence of aquatic plants can have a dynamic effect on the DO concentration in a water body. (It should be noted that the terms "aquatic plant" and "algae" will both be used and they should be considered interchangeable) These aquatic plants use light as a source of energy and carbon dioxide as their sole source of carbon. Carbon dioxide must first be reduced to a carbohydrate in order for it to be useful for metabolism. The process by which plants convert carbon dioxide to a carbohydrate is called photosynthesis. This overall reaction can be written as

$$6CO_2 + 6H_2O \xrightarrow{\text{photosynthesis}} C_6H_{12}O_6 + 6O_2 \quad (5.5)$$

Oxygen is produced by the removal of hydrogen atoms from water which forms a peroxide that is eventually broken down to oxygen and water. "The water is now subject to an 'atmosphere' of pure oxygen as compared to the water surface where reaeration comes from an atmosphere containing only about 21 % oxygen. Since all saturation values of DO are referred to the standard atmosphere, photosynthesis can result in supersaturated values. DO levels as high as 150-200% of the air saturation are not uncommon" (Thomann and Mueller 1987, 284). In addition to this process, aquatic plants require oxygen for respiration. Aerobic respiration is an energy yielding process in which electrons from an oxidizable substrate are transferred through an electron transport chain to oxygen which acts as the terminal electron acceptor. This electron transport chain is called the respiratory chain.

Aquatic plants require a variety of nutrients to grow. Among the most important are carbon, nitrogen and phosphorus. The average molar ratios (Redfield ratios) of carbon to nitrogen to phosphorus in algal protoplasm are approximately C:N:P = 105:15:1 (Metcalf and Eddy, Inc. 1991, 1204). If one of these nutrients exist in a smaller proportion to the other than that is the limiting nutrient. Addition of this nutrient will result in a higher biomass production while addition of another nutrient will not have an effect.

When low to moderate nutrient enrichment levels exist, photosynthesis and respiration tend to counterbalance each other and therefore will have little effect on overall DO levels. In situations where there is a high level of nutrient enrichment in correct proportions , such as waste from a sewage treatment plant, high productivity will result. This situation is called eutrophication and it can have profound effects on the DO concentration. Diurnal fluctuations can develop with supersaturated DO levels during daylight hours due to photosynthesis and very low DO levels at night due to respiration with the absence of photosynthesis. In this way, algae and weeds constitute an oxygen source during daylight hours due to photosynthesis and a continuous sink due to respiration. The resulting low concentrations of DO at night can create a potential for fish kill (Thomann & Mueller 1987, 284). Figure 5.3 shows typical diurnal variations of DO due to photosynthesis and respiration by aquatic plants.

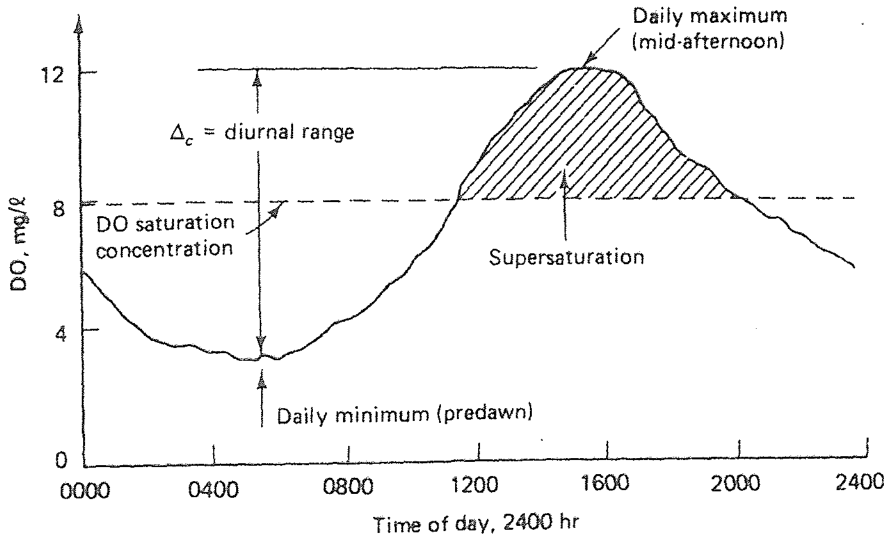


Figure 5.3 Typical diurnal variations of DO due to photosynthesis and respiration by aquatic plants (Thomann and Mueller 1987, 284).

Longer term fluctuations in DO levels can also develop due to biomass growth and decay periods. Among other things, growth and decay fluctuations can result from variations in nutrient loading, temperature changes, changes in light intensity (including self shading), and pH. We will not be considering these effects since it would require extensive data which would be labor intensive and cost prohibitive. Steady state conditions will be assumed.

The modeler is then faced with determining two major components of the interaction between aquatic plants and DO levels. "The degree to which the net effect of photosynthesis and respiration contributes to the average DO resources of the water body and the expected diurnal variability in DO as a result of the presence of aquatic plants" (Thomann and Mueller 19 87, 284).

5.2.2 Mathematical Representation

"There are five chlorophylls: a, b, c, d, and e. Chlorophyll a is present in all algae, as it is in all photosynthetic organisms other than an oxygenic photosynthetic bacteria" (Pelczar et al. 1986, 72). The concentration of phytoplanktonic algal biomass is considered to be directly proportional to the amount of chlorophyll a present. QUAL2E converts Chlorophyll a to algal biomass using the following relationship

$$\mathrm{Chl}\underline{a} = \alpha_0 A_m \quad (5.6)$$

where

$\mathrm{Chl}\underline{a}$ = chlorophyll a concentration, μg-Chl$\underline{a}$/L

A_m = algal biomass concentration, mg-A_m/L

α_0 = conversion factor, μg-Chl$\underline{a}$/mg-A_m

The differential equation that QUAL2E uses to determine the growth and production of algae (chlorophyll a) is

$$dA_m/dt = \mu A_m - \rho A_m - (\sigma_1/d)A_m \quad (5.7)$$

where

A_m = algal biomass concentration, mg-A_m/L

t = time, day

μ = the local specific growth rate of algae, 1/day

ρ = the local respiration rate of algae, 1/day

$\sigma 1$ = the local settling rate for algae, 1/day

d = average depth, m

5.2.2.1 Algal Respiration Rate QUAL2E uses the algal respiration rate, ρ, to describe the rate of three different processes: 1) the endogenous respiration of algae, 2) the conversion of algal nitrogen to organic nitrogen, and 3) the conversion of algal phosphorus to organic phosphorus. There is no distinction between the three within the model. This is done in the State of Vermont's revised Meta Systems version of QUAL-II discussed in the studies conducted by JRB Associates (1983), and Walker (1981).

5.2.2.2 Algal Specific Growth Rate Growth can be regarded as the result of two enzymatic activities: the "transporting processes", by which nutrient units are transferred to the places where they are needed, and the "building-in processes", by which units are added to active algal structures (DeGroot 1983, 100). These enzymatic activities can only take place if the required nutrients and a source of energy are present. If there is a deficiency of one of these requirements then the rate of growth will decrease. For aquatic plants, the nutrients that tend to limit growth are nitrogen and phosphorus since these are not as readily available as other nutrient requirements. Energy is supplied in the form of light which can also be a limiting factor. Length of day in a particular region, shading, and the amount of suspended material in the water (including aquatic plants), are all things that effect the amount of light that is available.

There are three options available to the modeler for determining growth rate. The first option is termed the multiplicative option. The kinetic factors that are used to represent the effects of nitrogen, phosphorus and light are multiplied along with the maximum specific algal growth rate. The equation is written

$$\mu = \mu_{max} \times (FL) \times (FN) \times (FP) \quad (5.8a)$$

where

μ_{max} = maximum specific algal growth rate, 1/day
FL = algal growth limitation factor for light
FN = algal growth limitation factor for nitrogen
FP = algal growth limitation factor for phosphorus

This equation is based on the multiplicative effects of enzymatic processes involved in photosynthesis. However, Bloomfield et al. (1973) point out that this construct becomes extremely limiting for even slightly non-optimum conditions due to the reduction effect of multiplying fractions. This severe limitation is probably not found in natural streams so this option will not be used.

The second option, which is termed the limiting nutrient option, uses the multiplicative effect as well, however its basis is that algal growth rate is limited by light and either nitrogen or phosphorus. In other words, the light-nutrient effect is multiplicative but the nutrient-nutrient effects are alternate (Brown and Barnwell 1987, 25). The equation is written

$$\mu = \mu_{max} \times (FL) \times \text{Minimum}\,(FN, FP) \quad (5.8b)$$

"This relationship, which mimics Liebig's law of the minimum, can be expected to produce reasonable results when dealing with pure cultures. When natural assemblages are considered, however, the adaptability of the assemblage precludes the use of this option." (Steele 1962, 144)

Option 3 is a compromise between options 1 and 2 and is called the harmonic mean option. This option offers a compromise between the first two options. "It is reasonable to assume that adaptation and species replacement in a natural assemblage will moderate the limiting effect of any particular nutrient or combination of nutrients. Therefore, this construct, which is mathematically analogous to resistors in series, may better represent the actual limitation process at the ecosystem level" (Scavia and Park 1975, 39). The equation is given as

$$\mu = \mu_{max} \times (FL) \times [\, 2/(1/FN + 1/FP)] \quad (5.8c)$$

This equation represents a multiplicative effect between light and nutrients while the relationship between the nutrients is given as the harmonic mean (Brown and Barnwell 1987, 25). This option should not be used when one nutrient is in excess and one is extremely limiting. For example, in a situation where FN approaches a value of 1 and FP approaches 0, the harmonic mean approaches 2×FP when it should be FP. In this situation, option 2 would be more accurate.

The Whippany River has a well balanced supply of nutrients as well as a diverse supply of microorganisms. With this in mind, option 3 will be used for this model since it will most accurately represent the river's algal specific growth rate .

5.2.2.3 Algal Light Relationships The effect of light on the productivity of aquatic plants is of great importance to models which try to simulate water quality conditions since photosynthesis plays a major role in determining the level of DO. Numerous studies have been conducted to develop quantitative expressions which give the rate of reflection of incident light at a water surface as well as absorption and scattering of light by organic and inorganic particles in the water. The most notable of these are Jassby and Platt (1976), Field and Effler (1982), and Bannister (1974). It is not the intention of this paper to discuss all the possible mathematical options which are available to describe the relationship between light and algal productivity. Therefore, only the options chosen will be discussed.

5.2.2.3.1 Light Function "Photosynthetic light curves have well known properties. Over a low illumination range, the rate of photosynthesis rises almost linearly with illumination. At higher illuminations, the rate rises more slowly and eventually reaches a maximum rate at light saturation. At yet higher illuminations, the rate generally declines due to photoinhibition" (Bannister 1974, 3). There are three options available in QUAL2E to describe aquatic plant productivity as a function of light: Option 1 is the half saturation method, option 2 uses Smith's Function Smith (1936), and option 3 uses Steele's equation Steele (1962). These three options are compared in Figure 5.4.

Option 1 will be used for the Whippany River model. This option uses a Monod expression to define the algal growth limitation factor for light and is represented by

$$FL_Z = I_Z/(K_L + I_Z) \quad (5.9)$$

where

FL_Z = algal growth attenuation factor for light at intensity I_Z

I_Z = light intensity at a given depth (z), Btu/ft^2-hr

K_L = Michaelis-Menton half saturation coefficient for light, Btu/ft^2-hr

d = depth, ft

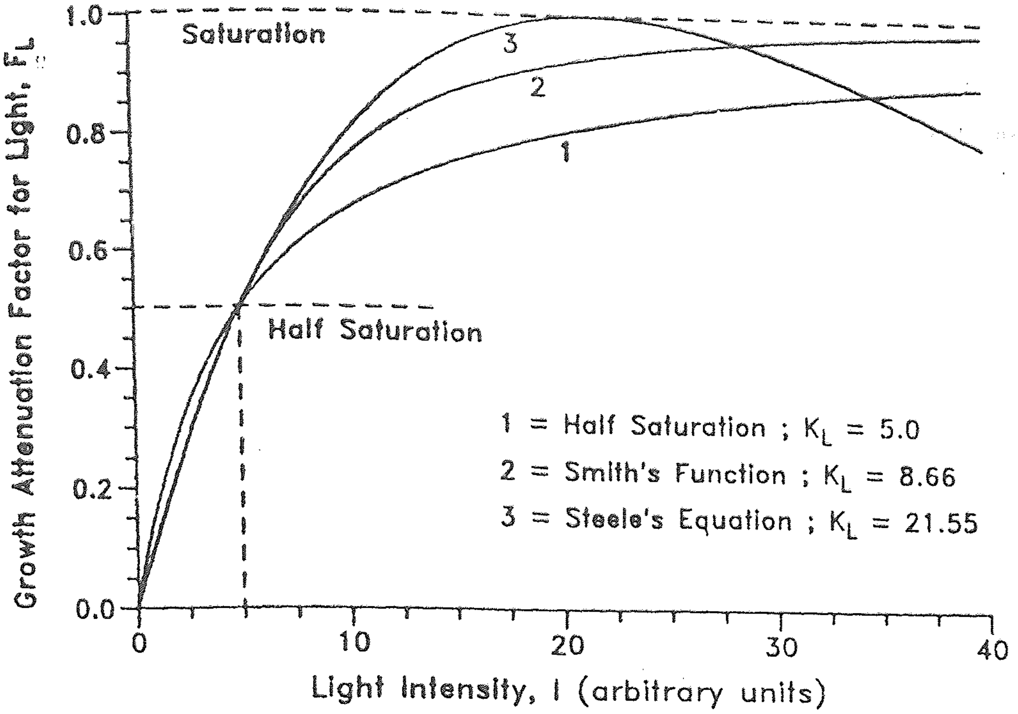


Figure 5.4 Graphical representation of available options to describe algal productivity as a function of light (Brown and Barnwell 1987, 29).

Light curves always refer to photosynthesis in an optically thin layer — thin enough so that the incident illumination is essentially unattenuated by the layer and all algae are uniformly illuminated (Bannister 1974, 3). An expression is therefore needed to describe light intensity as a function of depth. For this we use Beer's law which determines I_Z at a given depth as

$$I_Z = I \times \exp(-\lambda d) \quad (5.10)$$

I_Z = light intensity at a given depth (z), Btu/ft^2-hr
I = surface light intensity, Btu/ft^2-hr
λ = light extinction coefficient, 1/ft

d = depth, ft

When Equation 5.10 is substituted into Equation 5.9 and integrated over the depth of flow, the following equation...

$$FL = (1/\lambda d) \times \ln[(K_L + I)/(K_L + I \times e^{-\lambda d})] \quad (5.11)$$

where

FL = depth averaged algal growth attenuation factor for light

K_L = Michaelis-Menton half saturation coefficient for light, Btu/ft^2-hr

λ = light extinction coefficient, 1/ft

d = depth of flow, ft

I = surface light intensity, Btu/ft^2-hr

...describes the depth averaged attenuation factor for light.

*5.2.2.3.2 **Light Averaging*** Option 2 will be used for light averaging calculations. This option allows the user to directly input the value of the total photosynthetically active solar radiation and the hours of sunlight per day. The averaging is then accomplished by the following equation

$$I_{alg} = I_{tot}/N_{dh} \quad (5.12)$$

where

I_{alg} = daylight average, photosynthetically active, light intensity, Btu/ft^2

I_{tot} = total daily photosynthetically active solar radiation, Btu/ft^2

N_{dh} = number of daylight hours per day, hr

5.2.2.3.3 Algal Self Shading The light extinction coefficient, λ, is coupled to the algal density using the nonlinear equation

$$\lambda = \lambda_0 + \lambda_1 \alpha_0 A_m + \lambda_2 \times (\alpha_0 A_m)^{2/3} \quad (5.13)$$

where

λ = light extinction coefficient, 1/ft

λ_0 = non-algal portion of the light extinction coefficient, 1/ft

λ_1 = linear algal self shading coefficient, $1/[\text{ft} \times (\mu\text{g-Chl}\underline{\text{a}}/\text{L})]$

λ_2 = nonlinear algal self shading coefficient, $1/[\text{ft} \times (\mu\text{g-Chl}\underline{\text{a}}/\text{L})^{2/3}]$

α_0 = conversion factor, $\mu\text{g-Chl}\underline{\text{a}}/\text{mg-}A_m$

A_m = algal biomass concentration, $\text{mg-}A_m/\text{L}$

The type of algal self shading is determined by the selected values of λ_1 and λ_2 as shown below

A. No algal self shading

$\lambda_1 = \lambda_2 = 0$

B. Linear algal self shading, JRB Associates (1983)

$\lambda_1 \neq 0 , \lambda_2 = 0$

C. Nonlinear algal self shading, Bowie et al. (1985)

$\lambda_1 = 0.00268 \ 1/[\text{ft} \times (\mu\text{g-Chl}\underline{\text{a}}/\text{L})]$

$\lambda_2 = 0.0165 \ 1/[\text{ft} \times (\mu\text{g-Chl}\underline{\text{a}}/\text{L})^{2/3}]$

or

$\lambda_1 = 0.0088 \ 1/[\text{ft} \times (\mu\text{g-Chl}\underline{\text{a}}/\text{L})]$

$\lambda_2 = 0.054 \ 1/[\text{ft} \times (\mu\text{g-Chl}\underline{\text{a}}/\text{L})^{2/3}]$

5.2.2.4 Algal Nutrient Relationships

5.2.2.4.1 Nitrogen The algal growth limitation factor (FN) is calculated from the Monod expression

$$FN = N_e/(N_e + K_N) \quad (5.14)$$

where

N_e = the effective local concentration of available inorganic nitrogen, mg-N/L

K_N = Michaelis-Menton half-saturation constant for nitrogen, mg-N/L

Since algae can use either ammonia and/or nitrate as a source of inorganic nitrogen, the effective concentration of available nitrogen, N_e is given by

$$N_e = N_1 + N_3 \quad (5.15)$$

where

N_1 = concentration of ammonia nitrogen, mg-N/L

N_2 = concentration of nitrate nitrogen, mg-N/L

5.2.2.4.2 Phosphorus The algal growth limitation factor (FP) is calculated from the Monod expression

$$FP = P_2/(P_2 + K_p) \quad (5.16)$$

where

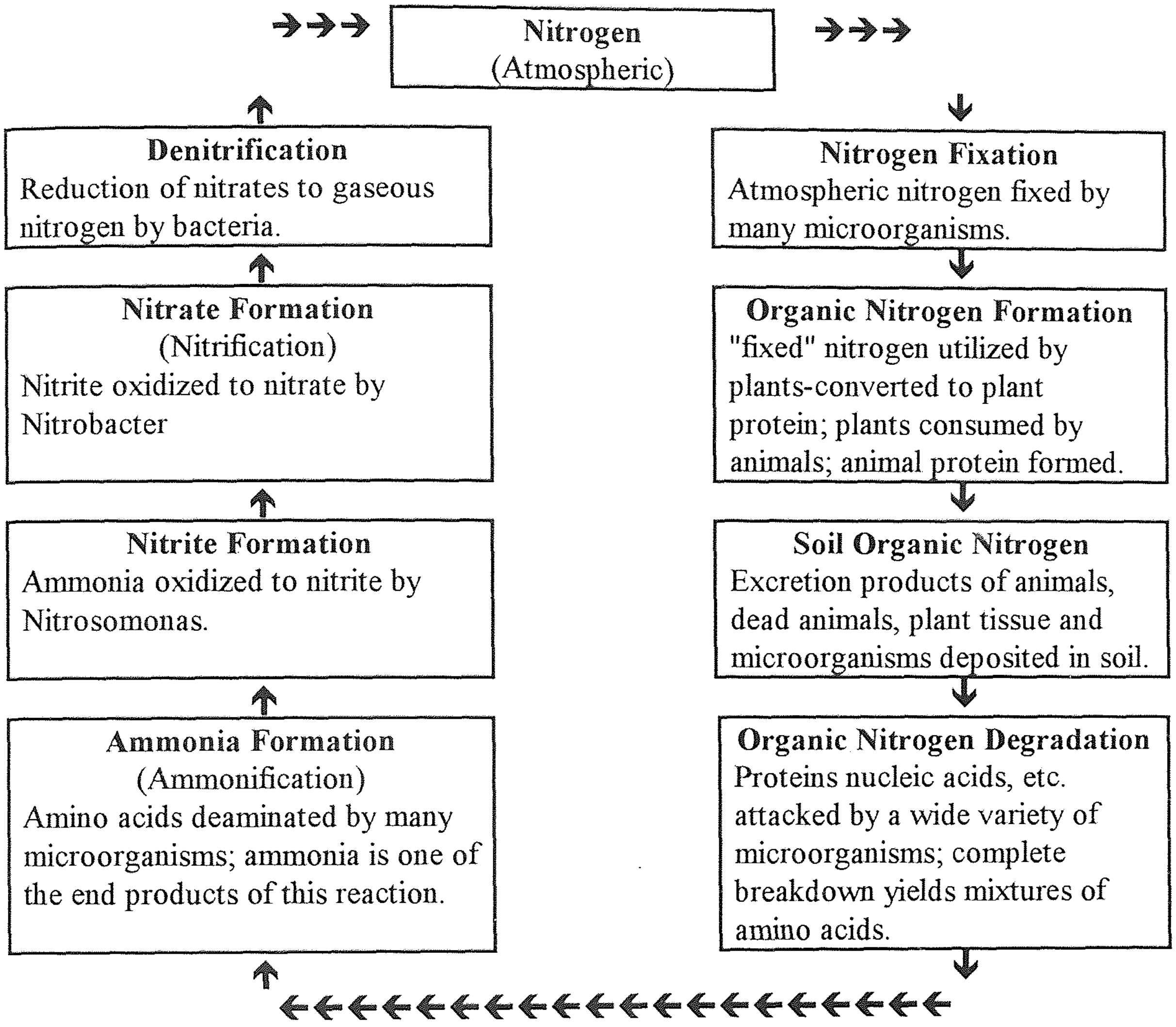
P_2 = the local concentration of dissolved phosphorus, mg-N/L

K_P = the Michaelis-Menton half-saturation constant for phosphorus, mg-P/L

5.3 Nitrogen

5.3.1 Nitrogen Cycle

The biochemical events that take place during the nitrogen cycle are of importance to a water quality model because of there effect on the DO levels. The sequence of changes from free atmospheric nitrogen to fixed inorganic nitrogen, to simple organic compounds, to complex organic compounds in the tissue of plants, animals, and microorganisms and the eventual release of this nitrogen back to the atmosphere is shown in Figure 5.5.



Nitrogen
(Atmospheric)

Nitrogen Fixation
Atmospheric nitrogen fixed by many microorganisms.

Organic Nitrogen Formation
"fixed" nitrogen utilized by plants-converted to plant protein; plants consumed by animals; animal protein formed.

Soil Organic Nitrogen
Excretion products of animals, dead animals, plant tissue and microorganisms deposited in soil.

Organic Nitrogen Degradation
Proteins nucleic acids, etc. attacked by a wide variety of microorganisms; complete breakdown yields mixtures of amino acids.

Ammonia Formation
(Ammonification)
Amino acids deaminated by many microorganisms; ammonia is one of the end products of this reaction.

Nitrite Formation
Ammonia oxidized to nitrite by Nitrosomonas.

Nitrate Formation
(Nitrification)
Nitrite oxidized to nitrate by Nitrobacter

Denitrification
Reduction of nitrates to gaseous nitrogen by bacteria.

Figure 5.5 Schematic diagram of the nitrogen cycle as it occurs in nature (Pelczar et al. 1986, 554).

The Nitrogenous matter (organic nitrogen) contained in waste loads on a water body can consist of proteins, urea, ammonia, and sometimes nitrate. The proteins, which are present in a variety of forms, are broken down by enzymatic hydrolysis into amino acids. Ammonia is then released through the deamination process. Ammonia can also be formed from the decomposition of different types of organic matter naturally present in the water; i.e., animal excretion, plant tissue, animal tissue and microorganisms. Thus, the amount of ammonia present in natural waters can be a result of direct loading of waste into the water or the decomposition of organic matter already present in the water.

The ammonia is then oxidized under aerobic conditions to nitrite according to the following reaction

$$NH_4 + 1.5O_2 \xrightarrow[\text{bacteria}]{\text{Nitrosomonas}} 2H^+ + H_2O + NO_2^- \qquad (5.17)$$

The weight of nitrogen and oxygen in this reaction is calculated as follows

atomic weight (N) = 14 g/mol.
molecular weight (O_2) = 2 × (16 g/mol.)
= 32 g/mol.

grams of (N) = 1.0 mol. × (14 g/mol.) = 14 g
grams of (O_2) = 1.5 mol. × (32 g/mol.) = 48 g

For this reaction, the theoretical amount of oxygen required for every gram of nitrogen would be

$$48\ \text{g}\ O_2\ /14\ \text{g N} = 3.43\ \text{g}\ O_2/\text{g N}$$

The nitrite formed in Equation 5.17 is then further oxidized to nitrate as follows

$$NO_2^- + 0.5O_2 \xrightarrow[\text{bacteria}]{\text{Nitrobacter}} NO_3^- \quad (5.18)$$

The weight of nitrogen and oxygen in this reaction is calculated using the atomic and molecular weights shown above.

$$\text{grams of (N)} = 1.0\ \text{mol.} \times (14\ \text{g/mol.}) = 14\ \text{g}$$
$$\text{grams of} (O_2) = 0.5\ \text{mol.} \times (32\ \text{g/mol.}) = 16\ \text{g}$$

For this reaction, the theoretical amount of oxygen required for every gram of nitrogen would be

$$16\ \text{g}\ O_2\ /14\ \text{g N} = 1.14\ \text{g}\ O_2\ /\text{g N}$$

The total weight of oxygen utilized per g of ammonia nitrogen oxidized to nitrate is

$$3.43\ \text{g}\ O_2\ /\text{g N} + 1.14\ \text{g}\ O_2\ /\text{g N} = 4.57\ \text{g}\ O_2\ /\text{g N}$$

5.3.2 Mathematical Representation

QUAL2E uses 4 differential equations to describe the transformation of organic nitrogen to ammonia nitrogen to nitrite nitrogen and finally to nitrate nitrogen. They are as follows:

Organic Nitrogen

$$dN_4/dt = \alpha_1 \rho A_m - \beta_3 N_4 - \sigma_4 N_4 \quad (5.19)$$

where

N_4 = concentration of organic nitrogen, mg-N/L

$\alpha 1$ = fraction of algal biomass that is nitrogen, mg-N/mg-Am

ρ = algal respiration rate, 1/day

A_m = algal biomass concentration, mg-A_m/L

$\beta 3$ = rate constant for hydrolysis of organic nitrogen to ammonia nitrogen, temperature dependent, 1/day

σ_4 = rate coefficient for organic nitrogen settling, temperature dependent, 1/day

Ammonia Nitrogen

$$dN_1/dt = \beta_3 N_4 - \beta_1 N_1 + \sigma_3 d - F_1 \alpha_1 \rho \mu A_m \quad (5.20)$$

where

F_1 = $P_N N_1/(P_N N_1 + (1 - P_N)N_3)$

N_1 = concentration of ammonia nitrogen, mg-N/L

N_3 = concentration of nitrate nitrogen, mg-N/L

N_4 = concentration of organic nitrogen, mg-N/L

β_1 = rate constant for biological oxidation of ammonia nitrogen, temperature dependent, 1/day

β_3 = rate constant for hydrolysis of organic nitrogen to ammonia nitrogen, temperature dependent, 1/day

α_1 = fraction of algal biomass that is nitrogen, mg-N/mg-A_m

σ_3 = the benthos source rate for ammonia nitrogen, mg-N/ft^2-day

d = mean depth of flow, m

F_1 = fraction of algal nitrogen uptake from ammonia pool

μ = local specific growth rate of algae, 1/day

A_m = algal biomass concentration, mg-A_m/L

P_N = preference factor for ammonia nitrogen, range = (0.0 - 1.0)

Nitrite Nitrogen

$$dN_1/dt = \beta_3 N_4 - \beta_1 N_1 \quad (5.21)$$

where

N_1 = concentration of ammonia nitrogen, mg-N/L

N2 = concentration of nitrite nitrogen, mg-N/L

N_4 = concentration of organic nitrogen, mg-N/L

β_1 = rate constant for the biological oxidation of ammonia nitrogen, temperature dependent, 1/day

β_2 = rate constant for the biological oxidation of nitrite nitrogen, temperature dependent, 1/day

Nitrate Nitrogen

$$dN_3/dt = \beta_2 N_2 - (1 - F)\alpha_1 \mu A_m \quad (5.22)$$

where

N_3 = concentration of nitrate nitrogen, mg-N/L

N_2 = concentration of nitrite nitrogen, mg-N/L

β_2 = rate constant for the biological oxidation of nitrite nitrogen, temperature dependent, 1/day

μ = local specific growth rate of algae, 1/day

F_1 = fraction of algal nitrogen taken from ammonia pool range = (0.0 - 1.0)

5.4 Carbonaceous Biochemical Oxygen Demand

5.4.1 Principal Components of BOD Analysis

"Studies of the kinetics of biochemical oxygen demand (BOD) reactions have established that they are for most practical purposes 'first order' in character, or the rate of the reaction is proportional to the amount of oxidizable organic matter remaining at any time, as modified by the population of active organisms. Once the population of organisms has reached a level at which only minor variations occur, the reaction rate is controlled by the amount of food available to the organisms" (Sawyer and McCarty 1978, 418). This may be expressed mathematically as follows

$$-dL/dt \propto kL \quad (5.23)$$

or

$$-dL/dt = kL \quad (5.24)$$

where

L = the concentration of oxidizable organic matter at time, t, mg/L

k = rate constant for the reaction, 1/day

This equation is represented graphically in Figure 5.6

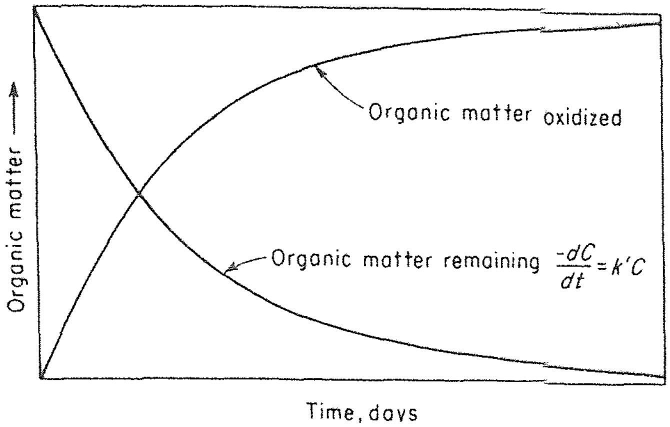


Figure 5.6 Changes in organic matter during biological oxidation under aerobic conditions (Sawyer and McCarty 1978, 419).

5.4.2 Mathematical Representation

The BOD function as expressed in the model also takes into account additional BOD removal due to sedimentation, scour and flocculation, which do not exert an oxygen demand (Thomas 1948, 410).

$$dL/dt = -K_1L - K_3L \quad (5.25)$$

where

L = the concentration of oxidizable organic matter at time, t, mg/L

K_1 = deoxygenation rate constant for the reaction, 1/day

K_3 = the rate of loss of BOD due to settling, 1/day

CHAPTER 6

WHIPPANY RIVER MODEL

6.1 Physical Representation of the Whippany River

The downstream boundary of the Whippany River model is 0.2 kilometers upstream from the confluence with the Rockaway River. This confluence is designated as kilometer 0.0 and the downstream boundary is designated as kilometer 0.2. The upstream boundary is located approximately 15.2 kilometers upstream from the confluence with the Rockaway River. Figure 3.1 shows the geographical location of the Whippany River and localized detail of its tributaries and surrounding landmarks for the area being studied. Figure 6.1 shows elevation changes in the river bed with respect to distance downstream.

The Morristown STP discharges into the Whippany River at kilometer 15.0 and the Hanover STP discharges at kilometer 5.8. There are two dams located along the studied reach; Eden Lane Dam at kilometer 11.9, and Whippany Road Dam at kilometer 10.0. There are three major tributaries located along the reach; Stoney Brook at kilometer 10.3, Black Brook at kilometer 7.6, and Troy Brook at kilometer 1.0.

6.2 Physical Representation of the Whippany River Model

Careful consideration must be given to segmentation of a river for modeling. Two important criteria for developing an accurate model with QUAL2E are: 1) hydraulic characteristics within a reach should be similar, and 2) computational elements along the entire stretch being studied should be equal. The modeled river should be divided into reaches with similar hydraulic characteristics because input variables describing water flow are entered once for each reach. The length of each computational element should be equal since the value used for Δx is defined once and used throughout the simulation for all computations.

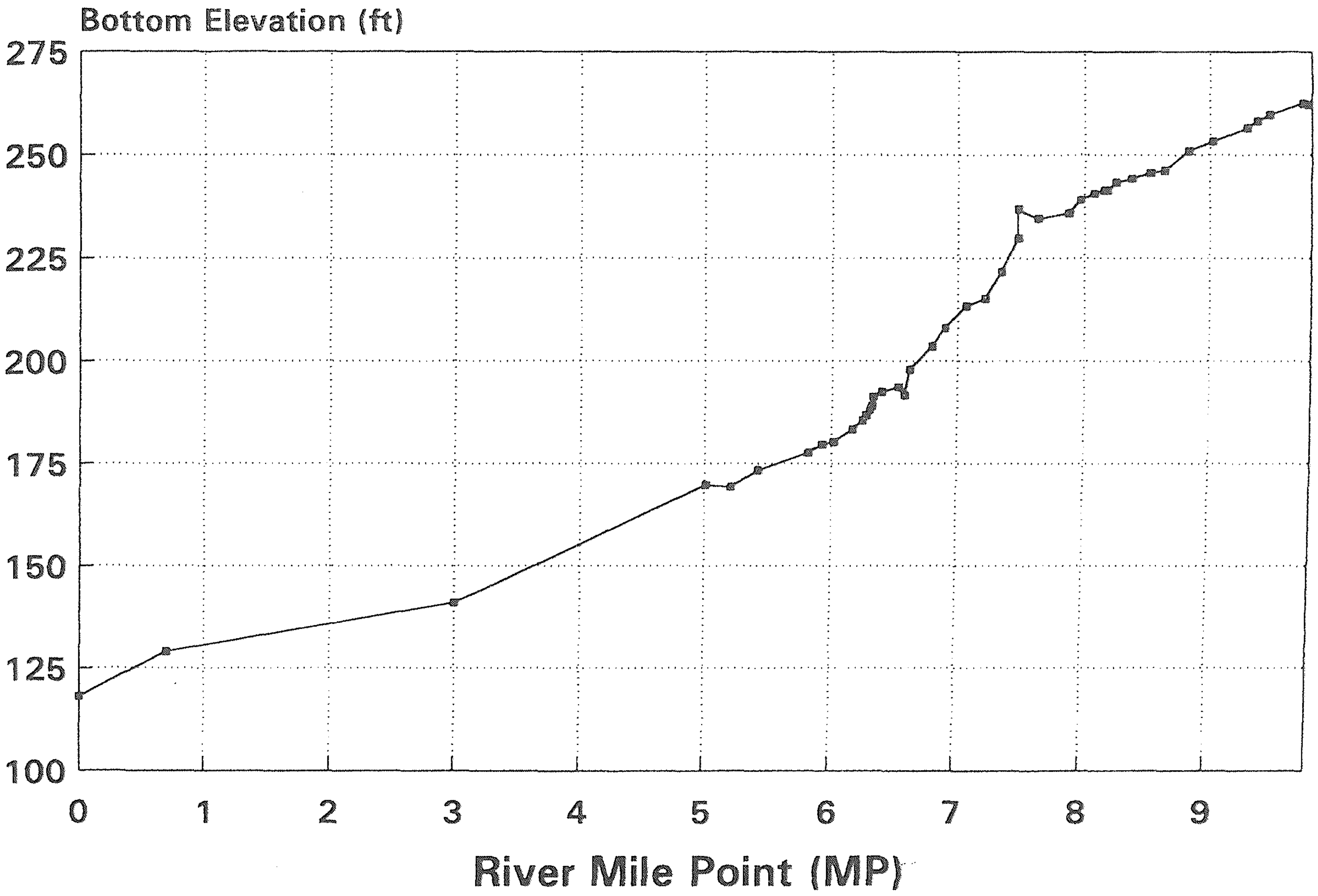


Figure 6.1 Elevation changes in the river bed with respect to distance upstream.
Note: River bed elevations from MP 0.0 - MP 5.01 are estimated values from USGS topographical maps. River bed elevations from MP 5.01 - MP 9.77 were obtained from USGS.

The segmentation of the Whippany River is described in Table 6.1. The length of each computational element (Δx) was set at 0.2 kilometers.

Table 6.1 Reach segmentation for Whippany River model.

Reach number	Reach beginning point (kilometers)	Reach ending point (kilometers)	Length of reach (kilometers)	Number of computational elements in reach
1	15.2	12.6	2.6	13
2	12.6	12.0	0.6	3
3	12.0	10.4	1.6	8
4	10.4	10.0	0.4	2
5	10.0	7.6	2.4	12
6	7.6	5.8	1.8	9
7	5.8	4.6	1.2	6
8	4.6	1.0	3.6	18
9	1.0	0.2	1.0	4

A schematic diagram of the Whippany River showing inputs from STP's and tributaries, designated reach assignments, and computational element numbers is illustrated in Figure 6.2. Table B.3 of Appendix B lists the relevant hydraulic characteristics and was designed to show the rational used in assigning reach numbers. Figures B.1.a, b, and c of Appendix B shows the slope of the river bed for the entire model. Figure B.1.a illustrates the method used for calculating slopes along the studied reach.

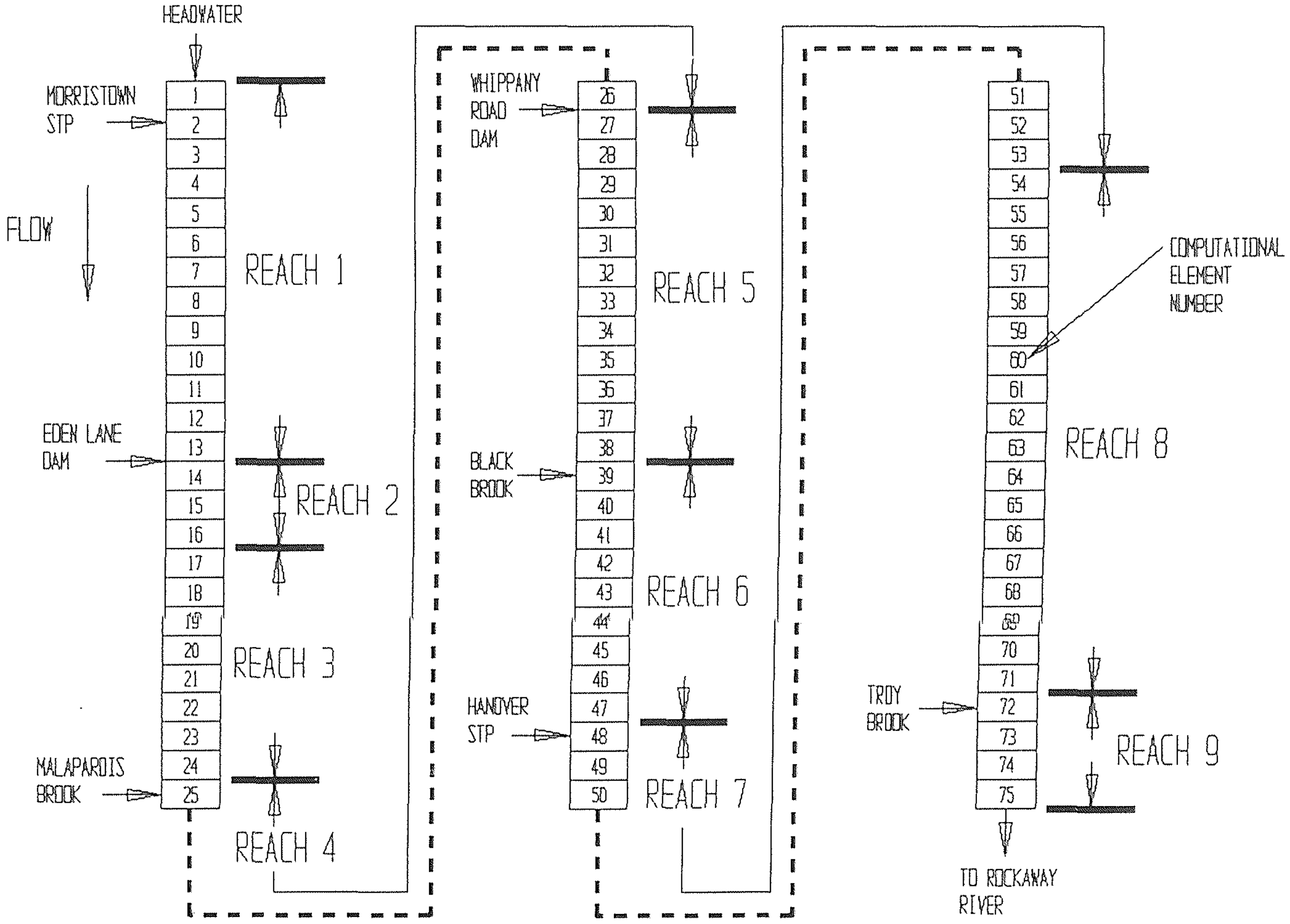


Figure 6.2 Schematic diagram of the Whippany River showing inputs from STP's and tributaries, designated reach assignments, and computational element numbers.

6.3 Discussion of Parameters Chosen for the Preliminary Whippany River Model

6.3.1 General Considerations

The Whippany River model will be ran using steady state conditions; i.e., no change in flow or input characteristics with respect to time. There are 5 point sources as discussed in the preceding section; 3 tributaries, and 2 STP's. The tributaries were treated as point source loads (see Figure 6.2) rather than modeling a segment of the tributary above the confluence and joining it to the river as shown in Figure 4.1. This was due to the limited amount of data available on the tributaries. Modeling the tributaries would involve substantial guesswork and therefore would jeopardize the accuracy of the model. A single headwater will be used since there is only one chain of computational elements. Upstream conditions will be used to obtain input parameters describing the headwater. The length of each computational element throughout the entire model will be set at 0.2 kilometers as discussed above.

This section is presented to illustrate the parameters chosen for the preliminary model. This is considered a preliminary model because subsequent calibration to a second set of data is required in order to increase the accuracy of the model. This calibration will alter the input parameters and the model will be referred to as the calibrated model.

6.3.2 Global Constants

Global constants are used during the course of the simulation and do not change with respect to time. For brevity, Table 6.2 was created for those global constants where sufficient data was not available to determine a constant which specifically applied to the Whippany River. For some constants, QUAL2E provides a range of values, and sometimes a typical value which are also shown in Table 6.2.

Table 6.2 Global constants chosen for the Whippany River model and values suggested by the QUAL2E manual.

Global constant	Whippany River model	QUAL2E typical value[1]	QUAL2E range of values[1]
O_2 production by algae (mg O_2/mg-A)	1.6	1.6	1.4 - 1.8
O_2 uptake by algae (mg O_2/mg A)	2.00	2.0	1.6 - 2.3
N content of algae (mg N/mg A)	0.085	*	0.08 - 0.09
P content of algae (mg P/mg A)	0.013	*	0.012 - 0.015
Algae maximum specific growth rate (1/DAY)	2.0	*	1.0 - 3.0
Algae respiration rate (1/DAY)	0.1	*	0.05[2] - 0.2[3]
N half saturation constant (mg/L)	0.16	*	0.01 - 0.3
P half saturation constant (mg/L)	0.03	*	0.001 - 0.05
Linear algae self-shading light Extinction coefficient (1/FT)/(μg-Chla/L)	0.0088	0.0088	0 OR 0.0088[4]
Nonlinear algae self-shading light extinction coefficient $(1/FT)/(\mu g\text{-}Chla/L)^{2/3}$	0.054	0.054	0 OR 0.054[4]
Light averaging factor	0.95	*	0.85 - 1.0
Algal preference for NH_3-N	0.8	0.5	0.0 - 1.0[5]
Algae/temperature solar radiation factor	0.45	0.45	0.0 - 1.0
Nitrification inhibition coefficient	5.0	*	0.0 - 10.0

* No value given

1. Source: QUAL2E Manual.
2. For clean streams
3. When NE and P2 concentrations are greater than twice the half saturation constants.
4. If both set equal to 0 than no self-shading occurs, if the linear coefficient does not equal 0 and the nonlinear coefficient does than there is linear self shading, if both are not equal to 0 than there will be nonlinear self-shading.
5. Value of 0 indicates algae will only use nitrate for growth.
   Value of 0.5 indicates algae will have equal preference for nitrate and ammonia.
   Value of 0 indicates algae will only use ammonia for growth.

It should be noted that for algal respiration rate, QUAL2E recommends a value of 0.05 for clean streams and a value of 0.2 when the concentrations of N_E and P_2 are larger than twice the half saturation constants. Since observed values of N_E and P_2 are slightly lower than the half saturation constants we will initially use a value of 0.1. Further scrutiny of this value will be addressed during model calibration if necessary.

Many of the chemical and biological reactions modeled by QUAL2E are temperature dependent. Correction factors are used to account for the changes in a reaction due to a change in temperature. The default values which were used in the Whippany River model are shown in Table 6.3.

Table 6.3 Default values for temperature correction factors which were used in the Whippany River model.

Reaction rate	Default value for temperature correction factor
BOD settling rate	1.024
NH_3 Decay rate	1.083
Oxygen transfer rate	1.024
Organic settling rate	1.024

The number of daylight hours, which affects the amount of photosynthesis, was set at 15 hours out of 24 hours.

5 day BOD values will be used to describe initial conditions. Therefore, these values will be converted to ultimate BOD values within the program according to the following equation

$$BOD_5 = BOD_u \times (1.0 - e^{5KBOD}) \quad (6.1)$$

where

BOD_5 = 5 day BOD, mg/l

BOD_u = ultimate BOD, mg/l

KBOD = BOD conversion rate coefficient, 1/day

5 day BOD represents about 80 % of the ultimate BOD for most carbonaceous organic waste. It is a function of the rate of the biodegradation of the material. The value of KBOD was set at 0.2 to agree with the characteristics of the majority of wastes. Possible adjustment to this number may be needed during calibration.

The oxygen uptake by NH_3 oxidizing to NO_2 and NO_2 oxidizing to $N0_3$ was set at 3.43 mg O_2/mg N and 1.14 mg O_2/mg N, respectively. The rational for these numbers is discussed in section 5.3.1.

Table 6.4 lists 3 options used by the Whippany River model to describe the effects of aquatic plants. The section of text where the advantages and drawbacks of each option is discussed as they apply to the Whippany River is also listed for the reader's reference.

Table 6.4 Options used to describe the effects of algae on the Whippany River and sections numbers where they are discussed in more detail.

Option description	Option number	Section number
Light function	1	5.2.2.3.1
Daily light averaging function	2	5.2.2.3.2
Algal specific growth rate option	3	5.2.2.2

6.3.3. Hydraulic Relationships

The hydraulic characteristics used for the Whippany River are shown in Table 6.5. The dispersion coefficient was found by looking at Table A.2 in Appendix A and finding a river that was similar in terms of depth of flow, channel width, and velocity. The dispersion constant found for the Copper Creek was used for this model. Further scrutiny of this value may be needed during calibration. All other values, unless otherwise noted were obtained from United States Geological Survey (USGS) and are listed in Table B.3 of Appendix B.

Table 6.5 Hydraulic characteristics used in the Whippany River model.

Reach	Dispersion constant	Hydraulic relationships $V = aQ^b$ depth $= cQ^d$				Manning's coefficient
#	K	a	b	c	d	n
1	245	0.469	0.432	0.163	0.367	0.03
2	245	0.164	0.602	0.464	0.331	0.03
3	245	0.164	0.602	0.464	0.331	0.03
4	245	0.164	0.602	0.464	0.331	0.03
5	245	0.480	0.320	0.209	0.628	0.03
6	245	0.121	0.422	0.666	0.510	0.04
7	245	0.121	0.422	0.666	0.510	0.03
8	245	0.119	0.380	0.727	0.525	0.03
9	245	0.119	0.380	0.727	0.525	0.03

Option 3 will be used to estimate the atmospheric reaeration rate and is discussed in section 5.1.2.2.

Careful investigation of flow data showed that there is no significant amount of loss or gain in flow along the studied reach. Therefore no incremental flows will be used in the model of the Whippany River.

6.3.4 Reach Dependent Coefficients

Due to the lack of historical data, coefficients which are shown in Tables 6.6, 6.7, and 6.8 were estimated from research done on each individual reaction. Rates were estimated on the basis of average values normally discovered in similar environments. These values will initially be used to describe reactions for each reach defined in the model. They will be adjusted during calibration if necessary.

Table 6.6 BOD and Sediment Oxygen Demand (SOD) coefficients used for the Whippany River model.

Coefficient	Value
BOD decay rate (1/day)	0.40
BOD settling rate (1/day)	0.40
SOD (mg O_2/m^2-day)	1.5

Table 6.7 Nitrogen and phosphorus coefficients used for the Whippany River model.

Coefficient	Value
Rate of hydrolysis of organic N to NH_3 (1/day)	0.10
Organic nitrogen settling rate (1/day)	0.01
Rate of biological oxidation of NH_3 to NO_2 (1/day)	0.30
Benthos source rate for NH_3-N (mg O_2/m^2-day)	0.2
Rate of biological oxidation of NO_2 to NO_3 (1/day)	0.30
Rate of decay of organic P to dissolved P (1/day)	0.20
Organic P settling rate (1/day)	0.01
Benthos source rate for dissolved P (mg O_2/m^2-day)	0.2

Table 6.8 Algae coefficients used for the Whippany River model.

Coefficient	Value
Ratio of chlorophyll a to algae (μg Chl<u>a</u>/mg algae)	50
Algal settling (m/day)	0.15
Non-algal light extinction (1/m)	0.01

6.3.5 Initial Conditions

Historical data collected by NJDEP in their intensive survey during the summer of 1980 was used for determining the initial conditions in each reach. Table 6.9 shows the initial conditions used for temperature, DO, and BOD_5. Raw data collected by NJDEP is shown in Table C.2 of Appendix C. The correlation between NJDEP sampling stations and assigned reaches for this model is illustrated in Table C.1.

Table 6.9 Initial conditions used for temperature, DO, and BOD_5 (NJDEP 1980, 12-21).

Reach #	Temperature (°C)	DO (mg/L)	BOD_5 (mg/L)
1	23.0	6.5	7.1
2	24	5.9	5.8
3	24.8	5.8	5.1
4	24.6	5.3	4.5
5	24.3	4.4	3.5
6	24.0	3.7	3.6
7	24.3[1]	4.0[1]	4.0[1]
8	24.5	4.2	4.6
9	25.0	5.2	4.3

1. No data existed in this reach therefore these are estimated values.

Using the data shown in Table C.2 initial conditions were determined for organic nitrogen (ON), ammonia nitrogen ($NH_3 + NH_4^+$-N), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), organic phosphorus (Ortho P), and dissolved phosphorus (total P). $NH_3 + NH_4^+$-N, NO_2-N, and Ortho P are read directly from the data. ON, NO_3-N, and total P are calculated as follows

$$\text{ON} = \text{total Kjeldahl nitrogen(TKN)} - (NH_3 + NH_4^+\text{-N}) \quad (6.2)$$

$$NO_3\text{-N} = (NO_2 + NO_3\text{-N}) - NO_2 \quad (6.3)$$

$$\text{OP} = (\text{total P}) - (\text{Ortho P}) \quad (6.4)$$

Table 6.10 shows the initial conditions used for nitrogen and phosphorus concentrations in each reach.

Table 6.10 Initial conditions for nitrogen and phosphorus concentrations in each reach.

Reach #	ON (mg/L)	$NH_3 + NH_4^+$-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	Ortho P (mg/L)	total P (mg/L)
1	3.55	3.17	0.071	0.999	0.17	1.06
2	1.71	1.43	0.143	0.557	0.12	0.67
3	1.84	1.76	0.309	0.551	0.12	0.82
4	2.00	1.50	0.350	0.600	0.12	0.75
5	2.69	1.20	0.370	0.850	0.12	0.71
6	1.55	0.87	0.401	0.930	0.11	0.61
7	1.50[1]	1.00[1]	0.400[1]	1.000[1]	0.12[1]	0.70[1]
8	1.40	1.60	0.396	1.044	0.15	0.78
9	1.39	1.12	0.331	1.089	0.16	0.74

1. No data existed in this reach therefore these are estimated values.

No historical data was available for chlorophyll-a concentrations therefore this value was estimated at 0.1 µg Chla/L for the entire studied area. This may need to be adjusted during calibration of the model.

6.3.6 Characterization of Input Loads

Input loading sources on the Whippany River need to be characterized so that their effects can be accounted for. These inputs sources along the Whippany River include: the headwater (upstream conditions), two STP's, and three tributaries. Tables 6.11 and 6.12 show the levels of water quality constituents used to describe the inputs from these sources. Historical data collected by NJDEP in their intensive survey during the summer of 1980 was used for determining these levels. These values are listed in Table C.2 of

Appendix C. Methods used to calculate nitrogen and phosphorus input levels are identical to those stated in the previous section.

Table 6.11 Input loading concentrations for flow, temperature, DO, and BOD_5 (NJDEP 1980, 12-21).

Input	Flow (m^3/s)	Temperature (°C)	DO (mg/L)	BOD_5 (mg/L)
Headwater	0.518	23.3	7.3	1.6
Morristown STP	0.144	23.0	3.2	4.3
Hanover STP	0.076	23.6	5.0	3.2
Stoney Brook	0.991	23.0	8.5	1.8
Black Brook	0.113	22.1	3.5	2.4
Troy Brook	0.091	25.0	7.8	1.7

Table 6.12 Input loading concentrations for nitrogen and phosphorus constituents (NJDEP 1980, 12-21).

Input	ON (mg/L)	$NH_3 + NH_4^+$-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	Ortho P (mg/L)	Total P (mg/L)
Headwater	0.69	0.22	0.11	1.49	0.06	0.70
Morristown STP	11.7	10.9	.027	.083	0.11	3.10
Hanover STP	6.6	13.7	.47	1.17	0.64	5.00
Stoney Brook	0.43	0.15	0.064	0.466	0.01	0.03
Black Brook	0.64	0.62	.104	1.026	0.07	0.33
Troy Brook	0.18	0.52	0.017	0.403	0.05	0.18

No historical data was available for chlorophyll-a concentrations therefore this value was estimated at 0.1 µg Chl<u>a</u>/L for each input load. This may need to be adjusted during calibration of the model.

6.3.7 Preliminary Model Input Dataset

A copy of the input dataset for the preliminary model of the Whippany River is shown in full in Appendix D. This preliminary model reflects the topics discussed and values presented in this chapter.

6.3.8 Preliminary Model Output

Figure 6.3 shows DO levels along the length of the studied river. This data is presented here for illustration only. The preliminary model will not be used for calibration until temperature, flow, and input adjustments are made to correspond to conditions that existed during the collection of the calibration data. This is discussed in the following chapter.

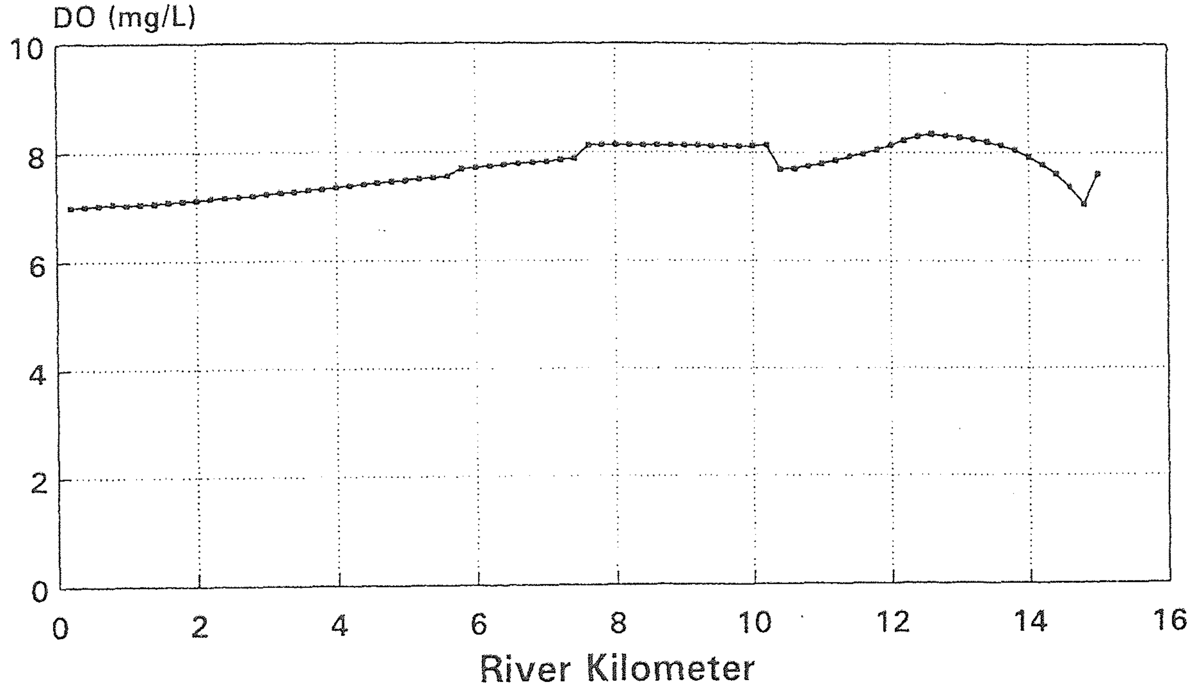


Figure 6.3 DO levels along the length of the river prior to preliminary model adjustment.

CHAPTER 7

CALIBRATION OF THE WHIPPANY RIVER MODEL

7.1 General Considerations

Before calibration can begin, input parameters should reflect the environmental conditions that existed during data collection, namely flow, temperature, and input loading conditions. The temperatures used in the preliminary model ranged from 23-25 °C while the calibration data was collected at around 13°C. The proper temperature for each reach and input was found by correlating site numbers of the calibration data to reach numbers and inputs. This correlation can be found in Table F.1 of Appendix F. Calibration data can also be found in Appendix F.

The flow, temperature, and concentrations of water quality constituents which are being loaded to the Whippany River by tributaries and headwaters were also adjusted to reflect the values in the calibration data. These values are shown in Tables 7.1 and 7.2. It should be noted that there was no data available on the Morristown STP nor the Hanover STP in the calibration data. It should also be noted that data for chlorophyll a is available for calibration and is listed in Table 7.1.

Table 7.1 Input loading concentrations for flow, temperature, DO, BOD_5, and Chl<u>a</u> (NJDEP 1995, 10-20).

Input	Flow (m^3/s)	Temperature (°C)	DO (mg/L)	BOD_5 (mg/L)	Chl<u>a</u> μg chl<u>a</u>/L
Headwater	0.467	11.3	9.9	1.0	0.0038
Stoney Brook	0.991	12.0	11.4	1.0	0.0025
Black Brook	0.113	10.5	8.8	1.5	0.0060
Troy Brook	0.091	11.4	8.9	1.0	0.0110

The calibration data was collected under low flow conditions. Actual flow values were not included in the report, therefore values at the low end of the range as shown in Table C.2 of Appendix C were used for flowrates in the calibration model.

Table 7.2 Input loading concentrations for nitrogen and phosphorus constituents (NJDEP 1995, 10-20).

Input	ON (mg/L)	$NH_3 + NH_4^+$-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	Ortho P (mg/L)	Total P (mg/L)
Headwater	2.83	0.012	0.023	2.17	0.031	0.073
Stoney Brook	0.646	0.007	0.011	0.44	0.00	0.013
Black Brook	1.32	0.007	0.028	0.907	0.005	0.052
Troy Brook	0.592	0.092	0.010	0.311	0.00	0.104

7.2 Comparison of Preliminary Model Results to Calibration Data

The preliminary model was ran once the proper adjustments were made to the input file. The results obtained are tabulated in Appendix E. The output data was then used to compare between DO values obtained by the preliminary model's simulation and those measured in the field. This was done for the entire length of the studied river and is illustrated in Figure 7.1.

DO levels are slightly lower for the preliminary model than the calibration data reflects. This may be due to an overestimation of the SOD and the reaeration coefficient. The SOD values were adjusted to the values shown in Table 7.3. BOD values were slightly lower in the model than actual field measurements. The BOD decay rate was decreased to increase the levels of BOD along the length of the river. The BOD settling rate was also decreased for the same reason. The changes in these values are also shown in Table 7.3.

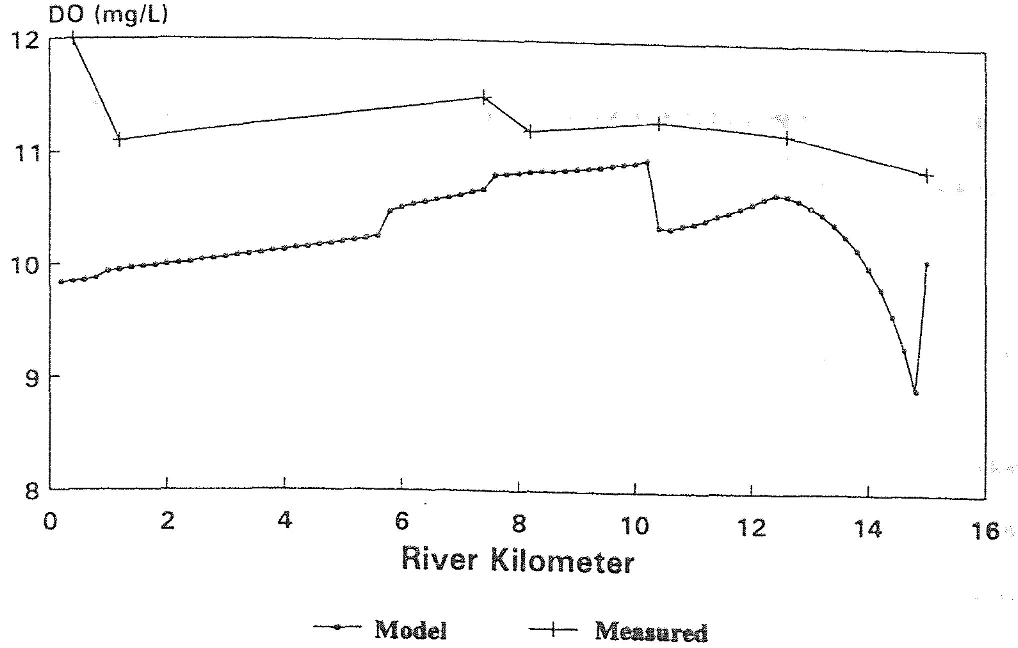


Figure 7.1 Comparison between DO values obtained by the preliminary model and those measured in the field for the entire length of the studied river.

Table 7.3 Adjustments made to BOD decay rate, BOD settling rate, and SOD for calibration of the Whippany River model.

Coefficient	Value used for preliminary model	Value used for calibration model
BOD decay rate (1/day)	0.4	0.3
BOD settling rate (1/day)	0.4	0.36
SOD (mg O_2/m^2-day)	1.5	0.5

With the exception of organic nitrogen, observed values of nitrogen containing compounds and phosphorus containing compounds were generally higher in the model compared to the data collected for calibration. This may be due to an overestimation of the benthos as a source for these compounds as well as low reaction rate values for the various reactions that take place involving theses compounds. The appropriate adjustments which were made to the input dataset in order to account for these deficiencies and are listed in Table 7.4.

The values listed in Tables 7.3 and 7.4 were entered into the calibrated model input dataset. The program was ran and the output showing the DO level vs distance downstream is illustrated in Figure 7.2

Table 7.4 Adjustments made to nitrogen and phosphorus coefficients used for the calibration of the Whippany River model.

Coefficient	Value used for preliminary model	Value used for calibration model
Rate of hydrolysis of organic N to NH_3 (1/day)	0.10	0.2
Organic nitrogen settling rate (1/day)	0.01	0.005
Rate of biological oxidation of NH_3 to NO_2 (1/day)	0.30	0.015
Benthos source rate for NH_3-N (mg O_2/m^2-day)	0.2	0.0
Rate of biological oxidation of NO_2 to NO_3 (1/day)	0.30	0.45
Rate of decay of organic P to dissolved P (1/day)	0.20	0.25
Organic P settling rate (1/day)	0.01	0.20
Benthos source rate for dissolved P (mg O_2/m^2-day)	0.2	0.0

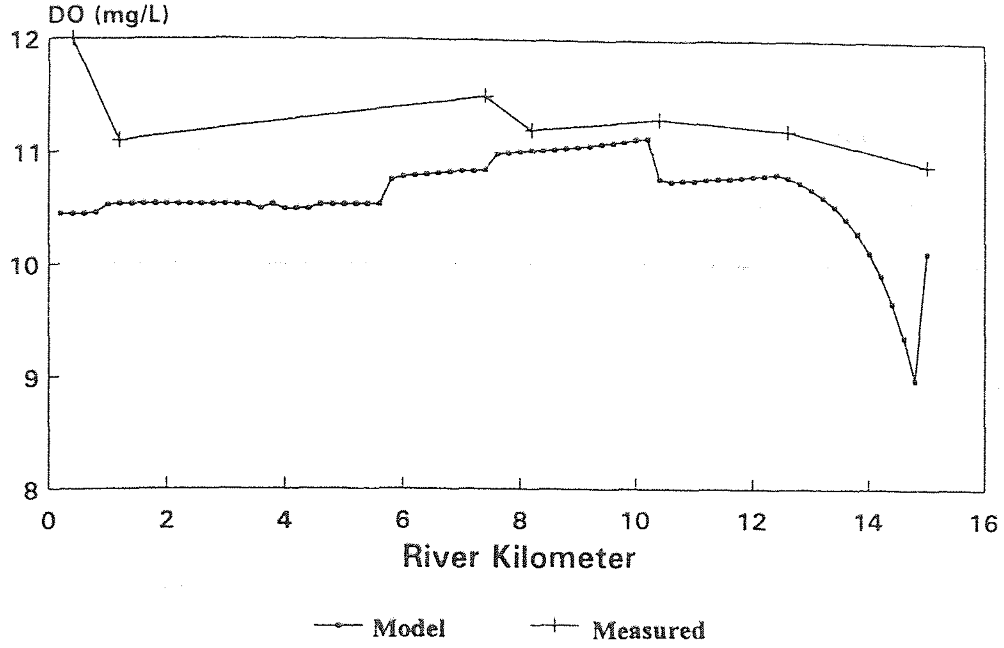


Figure 7.2 Comparison between DO values calculated by the calibrated model and those measured in the field for the entire length of the studied river.

As shown in Figure 7.2, the values of DO obtained by the calibrated model are much closer to the observed values than those illustrated in Figure 7.1. The output from the calibrated model is tabulated in Table H.1 of the Appendix. The raw data used for calibration is located in Appendix F. Comparison of the other water quality constituents levels from the calibrated model to those values measured in the calibration data reveals that they are more closely in line actual values in the river than for the preliminary model.

A copy of the input dataset for the calibrated model of the Whippany River is shown in full in Appendix G. This calibrated model reflects the topics discussed and values presented in this chapter.

CHAPTER 8

CONCLUSION

The model developed and outlined here for the Whippany River produced favorable results. More accurate models can be obtained by the collection of additional data. The relative high cost associated with sample collection and sample analysis often renders it cost prohibitive. This can often lead to large gaps in required information which need to be bridged by "seat of the pants judgment" by the modeler. This judgment is quite often the difference between a successful model and an inaccurate model.

The results obtained by the calibrated model discussed in the preceding chapter, were considerably closer to the measured values in the data used for calibration. However, caution must be used when evaluating a model at this stage. Although the model may appear to be an accurate description of the water quality constituents within a water body, it must be kept in mind that the data was adjusted towards the values represented by the calibration data. This adjustment can often be incorrectly executed even by an experienced modeler. The product of this sometimes unconscious "curve fitting" is an inaccurate model.

The technique used to identify an inaccurate model is called "model verification". This requires a third set of data on the same water body. The input parameters are adjusted according to the conditions that existed during the collection of the verification data. The model is then ran and resulting levels of water quality constituents are compared to the measured values in the river. If concentrations are within an acceptable tolerance then the model is verified to be accurate.

This third set of data, which is needed for verification, is unavailable for the studied reach. Therefore it is the author's recommendation that this data be collected and used to verify this model before it is used to predict future changes in the concentration of a water quality constituent or determine a waste load's impact on water quality.

APPENDIX A

NOMENCLATURE

Table A.1 Nomenclature (Brown and Barnwell 1987, 54 - 56).

Variable	Description	Units
α_0	Ratio of chlorophyll-a to algal biomass	μg-Chla/mg-A
α_1	Fraction of an algal biomass that is nitrogen	mg-N/mg-A
α_2	Fraction of algal biomass that is phosphorus	mg-P/mg-A
α_3	O_2 production per unit of algal growth	mg-O_2/mg-A
α_4	O_2 uptake per unit of algal respired	mg-O_2/mg-A
α_5	O_2uptake per unit of NH_3 oxidation	mg-O_2/mg-N
α_6	O_2uptake per unit of NO_2 oxidation	mg-O_2/mg-N
β_1	Rate constant for the biological oxidation of NH_3 to NO_2	1/day
β_2	Rate constant for the biological oxidation of NO_2 to NO_3	1/day
β_3	Rate constant for the hydrolysis of organic-N to ammonia	1/day
β_4	Rate constant for the decay of organic-P to dissolved-P	1/day
λ_0	Non-algal light extinction coefficient	1/ft
λ_1	Linear algal self-shading coefficient	(1/ft)/(μg-Chla/L)
λ_2	Non-linear algal self-shading coefficient	$(1/ft)/(\mu g\text{-}Chla/L)^{2/3}$
μ_{max}	Maximum algal growth rate	1/day
μ	Algal growth rate	1/day
ρ	Algal respiration rate	1/day

"**Table A.1** (continued)"

Variable	Description	Units
σ_1	Algal setting rate	ft/day
σ_2	Benthos source rate for dissolved phosphorus	mg-P/ft^2-day
σ_3	Benthos source rate foe ammonia nitrogen	mg-O_2/ft^2-day
σ_4	Organic nitrogen settling rate	1/day
σ_5	Organic phosphorus settling rate	1/day
σ_6	Arbitrary non-conservative settling rate	1/day
A	Cross sectional area of a computational element	m^2
A_m	Algal biomass concentration	mg-A/L
a, b, c, d	Empirical constants	dimensionless
C	C hezy's coefficient	dimensionless
Chla	concentration of chlorophyll a	µg-Chla/L
c	Concentration of water quality constituent	mg/L
d	Mean stream depth	m
D_m	Molecular diffusion coefficient	dimensionless
E	Dispersion coefficient	m^2/day
F_1	Fraction of algal nitrogen uptake from ammonia pool	range=(0.0-1.0)
FL	Depth averaged algal growth attenuation factor for light	range=(0.0-1.0)
FN	Algal growth limitation factor for nitrogen	range=(0.0-1.0)
FP	Algal growth limitation factor for Phosphorus	range=(0.0-1.0)
I	Surface light intensity	Btu/ft^2-hr

"**Table A.1** (continued)"

Variable	Description	Units
I_{alg}	Daylight average, photosynthetically active light	Btu-ft^2
I_{tot}	Total daily photosynthetically active solar radiation	Btu/ft^2
I_z	Light intensity at a given depth	Btu/ft^2-hr
k	Reaction rate constant	1/day
K	Dispersion constant	dimensionless
K_1	Carbonaceous deoxygenation rate constant	1/day
K_2	Reaeration rate constant	1/day
K_3	Rate of loss of BOD due to settling	1/day
K_4	Benthic oxygen uptake	mg-O_2/ft^2-day
K_5	Coliform die-off rate	1/day
K_6	Arbitrary non-conservative decay coefficient	1/day
K_L	Michaelis-Menton half-saturation constant for light	Btu/ft^2-min
K_N	Michaelis-Menton half-saturation constant for nitrogen	mg-N/L
K_P	Michaelis-Menton half-saturation constant for phosphorus	mg-P/L
L	Concentration of the ultimate carbonaceous BOD	mg/L
M	Mass of a given water quality constituent	mg
n	Mannings roughness coefficient	dimensionless
N_1	Concentration of ammonia nitrogen	mg-N/L

"**Table A.1** (continued)"

Variable	Description	Units
N_2	Concentration of nitrite nitrogen	mg-N/L
N_3	Concentration of nitrate nitrogen	mg-N/L
N_4	Concentration of organic nitrogen	mg-N/L
N_{dh}	Number of daylight hours per day	hr
N_e	Effective local concentrate of available inorganic nitrogen	mg-N/L
P_N	Algal preference factor for ammonia	range=(0.0-1.0)
O^*	Saturation concentration of DO at the local temperature and pressure	mg/L
P_2	Local concentration of dissolved phosphorus	mg-P/L
Q	Flow	m^3/s
R_h	Hydraulic radius	m
S_e	Slope of the energy grade line	m/m
S_i	External sink of DO	M/T
S_o	External source of DO	M/T
t	time	day or hr
T	Temperature	K or C
U	Mean velocity	m/s
u^*	Average sheer velocity	m/s
μ_{max}	Maximum specific algal growth rate	1/day

APPENDIX B

HYDRODYNAMIC DATA

Table B.1 Values of Manning's roughness coefficient, n (Henderson 1966, 99).

Surface Material	Manning's n
Glass, plastic, machined metal	0.010
Dressed timber, joints flush	0.011
Sawn timber, joints uneven	0.014
Cement plaster	0.011
Concrete, steel troweled	0.012
Concrete, timber forms, unfinished	0.014
Untreated gunite	0.015 - 0.017
Brickwork or dressed masonry	0.014
Rubble set in cement	0.017
Earth, smooth, no weeds	0.020
Earth, some stones and weeds	0.025
Natural river channels	
Clean and straight	0.025 - 0.030
Winding, with pools and shoals	0.033 - 0.040
Very weedy, winding and overgrown	0.075 - 0.150
Clean straight alluvial channels	$0.031d^{1/6}$

d = D-75 size in ft.

Table B.2 Experimental measurements of longitudinal dispersion in open channels (Brown and Barnwell 1987, 54 - 56).

River channel	d (ft)	W (ft)	v (ft/s)	u* (ft/s)	K
Chicago ship channel	26.5	160	0.89	0.063	20
Sacramento River	13.1	*	1.74	0.17	74
River Derwent	0.82	*	1.25	0.46	131
South Platte River	1.5	*	2.17	0.23	510
Yuma Mesa	11.3	*	2.23	1.13	8.6
Green-Duwamish River	3.61	66	*	0.16	120-160
Missouri River	8.86	660	5.09	0.24	7500
Copper Creek (below gage)	1.61	52	0.85	0.26	245
Clinch River	6.89	197	3.08	.034	245
Copper Creek (above gage)	1.31	62	0.52	0.38	220
Powell River	2.79	112	0.49	0.18	200
Clinch River	26.5	160	0.89	0.063	20
Coachella River	13.1	44	1.74	0.17	74
Bayon Anacoco	0.82	88	1.25	0.46	131
Nooksack River	1.5	65	2.17	0.23	510
Wind/Bighorn Rivers	11.3	23	2.23	1.13	8.6
John Day River	3.61	66		0.16	120-160
Comite River	8.86	660	5.09	0.24	7500
Sabine River	1.61	52	0.85	0.26	245
Yadkin River	6.89	197	3.08	.034	245

where:

d = depth of channel
W = width of channel
v = mean velocity
u* = shear velocity
K = dispersion constant

Table B.3 Hydraulic characteristics of the Whippany River (USGS)

REACH NUMBER	RIVER POINT (Km)	RIVER MILE (mi)	BED SLOPE (ft/ft)	Hydraulic Characteristics* a	b	c	d	Manning's Coefficient n	COMMENTS
REACH 1	15.2	9.45	0.00256	0.469	0.432	0.432	0.163	0.367	USGS Station
	15	9.32	0.00256	0.469	0.432	0.163	0.367	** 0.03	<-- Morristown STP input
	14.8	9.20	0.00256	0.469	0.432	0.163	0.367	** 0.03	
	14.6	9.07	0.00256	0.469	0.432	0.163	0.367	** 0.03	
	14.4	8.95	0.00256	0.469	0.432	0.163	0.367	** 0.03	
	14.2	8.82	0.00256	0.469	0.432	0.163	0.367	** 0.03	
	14	8.70	0.00256	0.469	0.432	0.163	0.367	** 0.03	
	13.8	8.58	0.00256	0.469	0.432	0.163	0.367	** 0.03	
	13.6	8.45	0.00256	0.469	0.432	0.163	0.367	** 0.03	
	13.4	8.33	0.00256	0.469	0.432	0.163	0.367	** 0.03	
	13.2	8.20	0.00256	0.469	0.432	0.163	0.367	** 0.03	
	13	8.08	0.00256	0.469	0.432	0.163	0.367	** 0.03	
	12.8	7.95	0.00256	0.469	0.432	0.163	0.367	** 0.03	
	12.6	7.83	0.00256	0.469	0.432	0.163	0.367	** 0.03	
REACH 2	12.4	7.71	0.0002	0.164	0.602	0.602	0.331	** 0.03	
	12.2	7.58	0.0002	0.164	0.602	0.602	0.331	** 0.03	
	12	7.46	0.0002	0.164	0.602	0.602	0.331	** 0.03	Eden Lane Dam
REACH 3	11.8	7.33	0.0064	0.164	0.602	0.602	0.331	** 0.03	
	11.6	7.21	0.0064	0.164	0.602	0.602	0.331	** 0.03	
	11.4	7.08	0.0064	0.164	0.602	0.602	0.331	** 0.03	
	11.2	6.96	0.0064	0.164	0.602	0.602	0.331	** 0.03	
	11	6.84	0.0064	0.164	0.602	0.602	0.331	** 0.03	
	10.8	6.71	0.0064	0.164	0.602	0.602	0.331	0.03	
	10.6	6.59	0.0064	0.164	0.602	0.602	0.331	0.03	
	10.4	6.46	0.0064	0.164	0.602	0.602	0.331	0.03	
REACH 4	10.2	6.34	0.0064	0.164	0.602	0.602	0.331	0.03	<-- Stoney Brook
	10	6.21	0.0032	0.164	0.602	0.602	0.331	0.03	Whippany Road Dam

Notes at the end of the table

"**Table B.3** (continued)"

REACH NUMBER	RIVER POINT (Km)	RIVER MILE (mi)	BED SLOPE (ft/ft)	Hydraulic Characteristics*				Manning's Coefficient	COMMENTS
				a	b	c	d	n	
REACH 5	9.8	6.09	0.0032	0.48	0.32	0.209	0.628	0.03	
	9.6	5.97	0.0032	0.48	0.32	0.209	0.628	0.03	
	9.4	5.84	0.0032	0.48	0.32	0.209	0.628	0.03	
	9.2	5.72	0.0032	0.48	0.32	0.209	0.628	0.03	
	9	5.59	0.0032	0.48	0.32	0.209	0.628	0.03	
	8.8	5.47	0.0032	0.48	0.32	0.209	0.628	0.03	
	8.6	5.34	0.0032	0.48	0.32	0.209	0.628	0.03	
	8.4	5.22	0.0032	0.48	0.32	0.209	0.628	0.03	
	8.2	5.10	0.0032	0.48	0.32	0.209	0.628	0.03	
	8	4.97	** 0.003	0.48	0.32	0.209	0.628	0.03	
	7.8	4.85	** 0.003	0.48	0.32	0.209	0.628	0.03	
	7.6	4.72	** 0.003	0.48	0.32	0.209	0.628	0.03	
REACH 6	7.4	4.60	** 0.003	0.48	0.32	0.209	0.628	0.03	<-- Black Brook
	7.2	4.47	** 0.003	0.121	0.422	0.666	0.514	0.03	
	7	4.35	** 0.003	0.121	0.422	0.666	0.514	0.03	
	6.8	4.23	** 0.003	0.121	0.422	0.666	0.514	0.03	
	6.6	4.10	** 0.003	0.121	0.422	0.666	0.514	0.045	
	6.4	3.98	** 0.003	0.121	0.422	0.666	0.514	0.045	
	6.2	3.85	** 0.003	0.121	0.422	0.666	0.514	0.045	
	6	3.73	** 0.003	0.121	0.422	0.666	0.514	0.04	
	5.8	3.60	** 0.003	0.121	0.422	0.666	0.514	0.04	
REACH 7	5.6	3.48	** 0.003	0.121	0.422	0.666	0.514	0.04	<-- Hanover STP input
	5.4	3.36	** 0.003	0.121	0.422	0.666	0.514	0.04	
	5.2	3.23	** 0.003	0.121	0.422	0.666	0.514	0.04	
	5	3.11	** 0.003	0.121	0.422	0.666	0.514	0.04	
	4.8	2.98	** 0.001	0.121	0.422	0.666	0.514	0.03	
	4.6	2.86	** 0.001	0.121	0.422	0.666	0.514	0.03	

Notes at the end of the table

"**Table B.3** (continued)"

REACH NUMBER	RIVER POINT (Km)	RIVER MILE (mi)	BED SLOPE (ft/ft)	Hydraulic Characteristics*				Manning's Coefficient	COMMENTS
				a	b	c	d	n	
REACH 8	4.4	2.73	** 0.001	No Data Available				0.03	
	4.2	2.61	** 0.001	No Data Available				0.03	
	4	2.49	** 0.001	No Data Available				0.03	
	3.8	2.36	** 0.001	0.119	0.38	0.727	0.525	0.03	
	3.6	2.24	** 0.001	0.119	0.38	0.727	0.525	0.03	
	3.4	2.11	** 0.001	0.119	0.38	0.727	0.525	0.03	
	3.2	1.99	** 0.001	0.119	0.38	0.727	0.525	0.03	
	3	1.86	** 0.001	0.119	0.38	0.727	0.525	0.03	
	2.8	1.74	** 0.001	0.119	0.38	0.727	0.525	0.03	
	2.6	1.62	** 0.001	0.119	0.38	0.727	0.525	0.03	
	2.4	1.49	** 0.001	0.119	0.38	0.727	0.525	0.03	
	2.2	1.37	** 0.001	0.119	0.38	0.727	0.525	0.03	
	2	1.24	** 0.001	0.119	0.38	0.727	0.525	0.03	
	1.8	1.12	** 0.001	0.119	0.38	0.727	0.525	0.03	
	1.6	0.99	** 0.001	0.119	0.38	0.727	0.525	0.03	
	1.4	0.87	** 0.001	0.119	0.38	0.727	0.525	0.03	
	1.2	0.75	** 0.001	0.119	0.38	0.727	0.525	0.03	
	1	0.62	** 0.001	0.119	0.38	0.727	0.525	0.03	
	0.8	0.50	** 0.001	0.119	0.38	0.727	0.525	0.03	<-- Troy Brook
REACH 9	0.6	0.37	** 0.003	0.119	0.38	0.727	0.525	0.03	
	0.4	0.25	** 0.003	0.119	0.38	0.727	0.525	0.03	USGS Station
	0.2	0.12	** 0.003	0.119	0.38	0.727	0.525	0.03	

* Values for a, b, c, and d where converted from english system values obtained from USGS
where V (m/s) = aQ^b and d (m) = cQ^d and Q is in m^3/s.

** No data is available therefore these are estimated values.

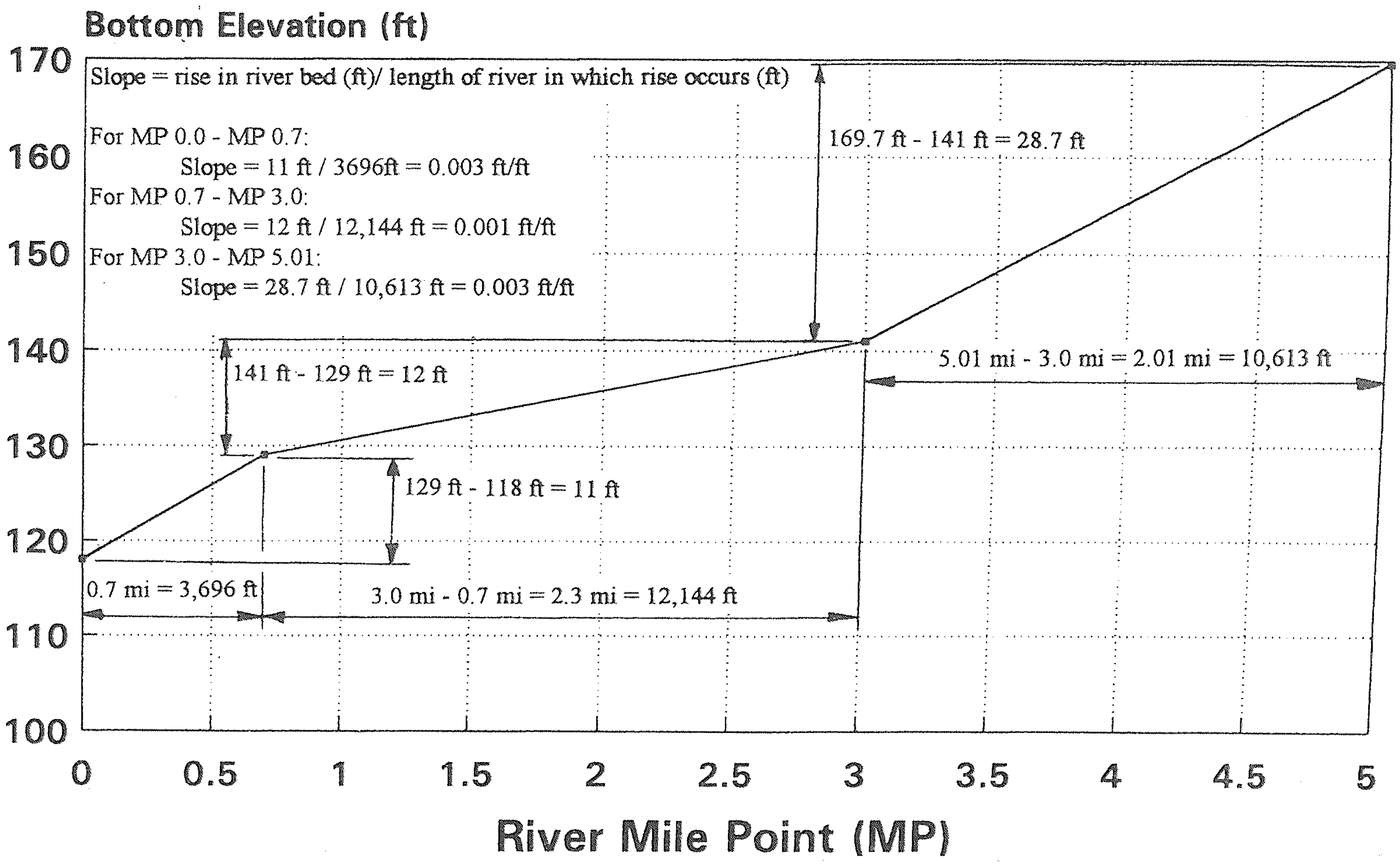


Figure B.1a Graphical representation of Whippany River bed slope from Mile Point 0.0 (MP 0.0) to MP 5.01. Data points for MP 0.0, MP 0.7, and MP 3.0 were estimated from a USGS topographical map.

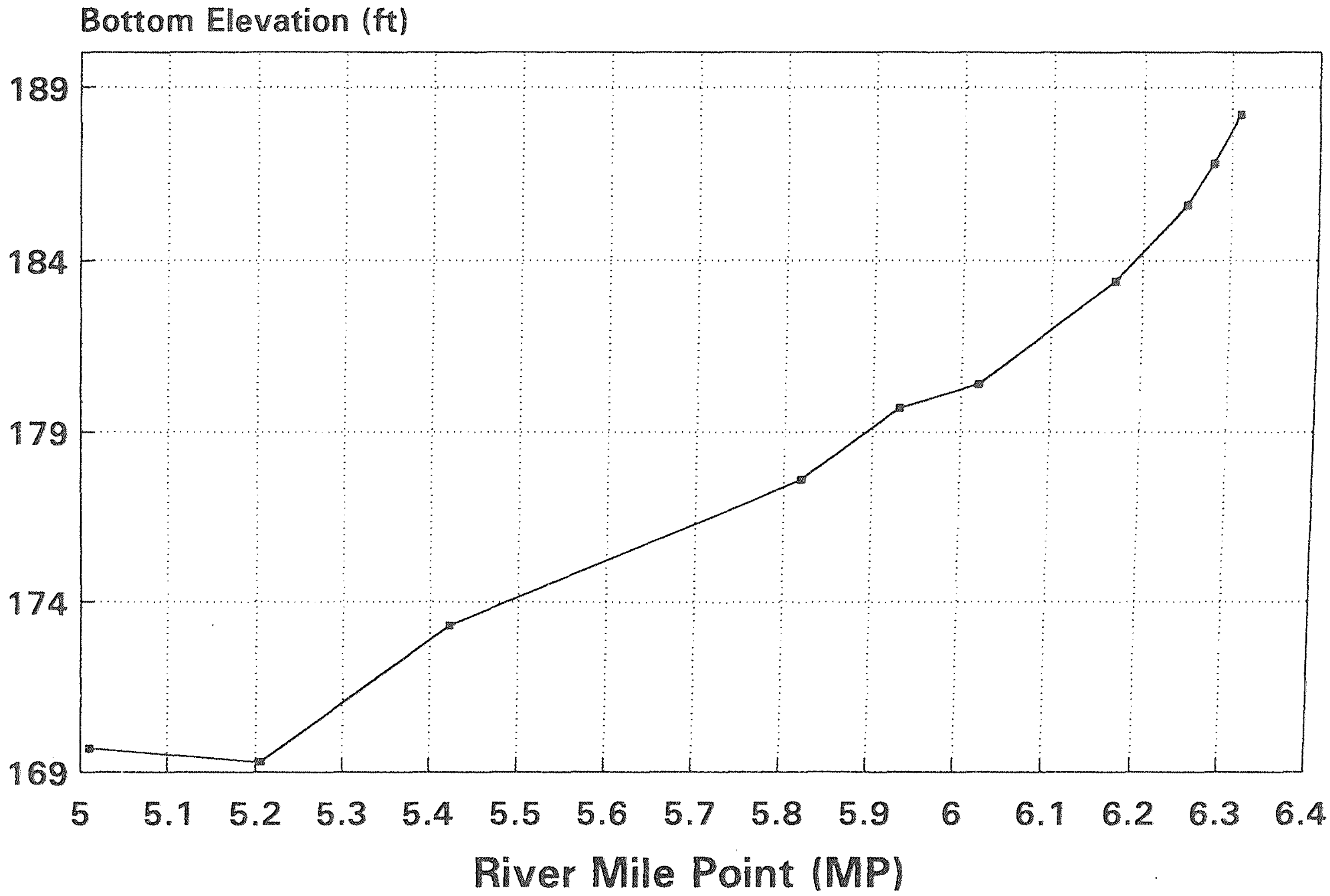


Figure B.1b Graphical representation of Whippany River bed slope from MP 5.01 to MP 6.31. Elevation data courtesy of USGS.

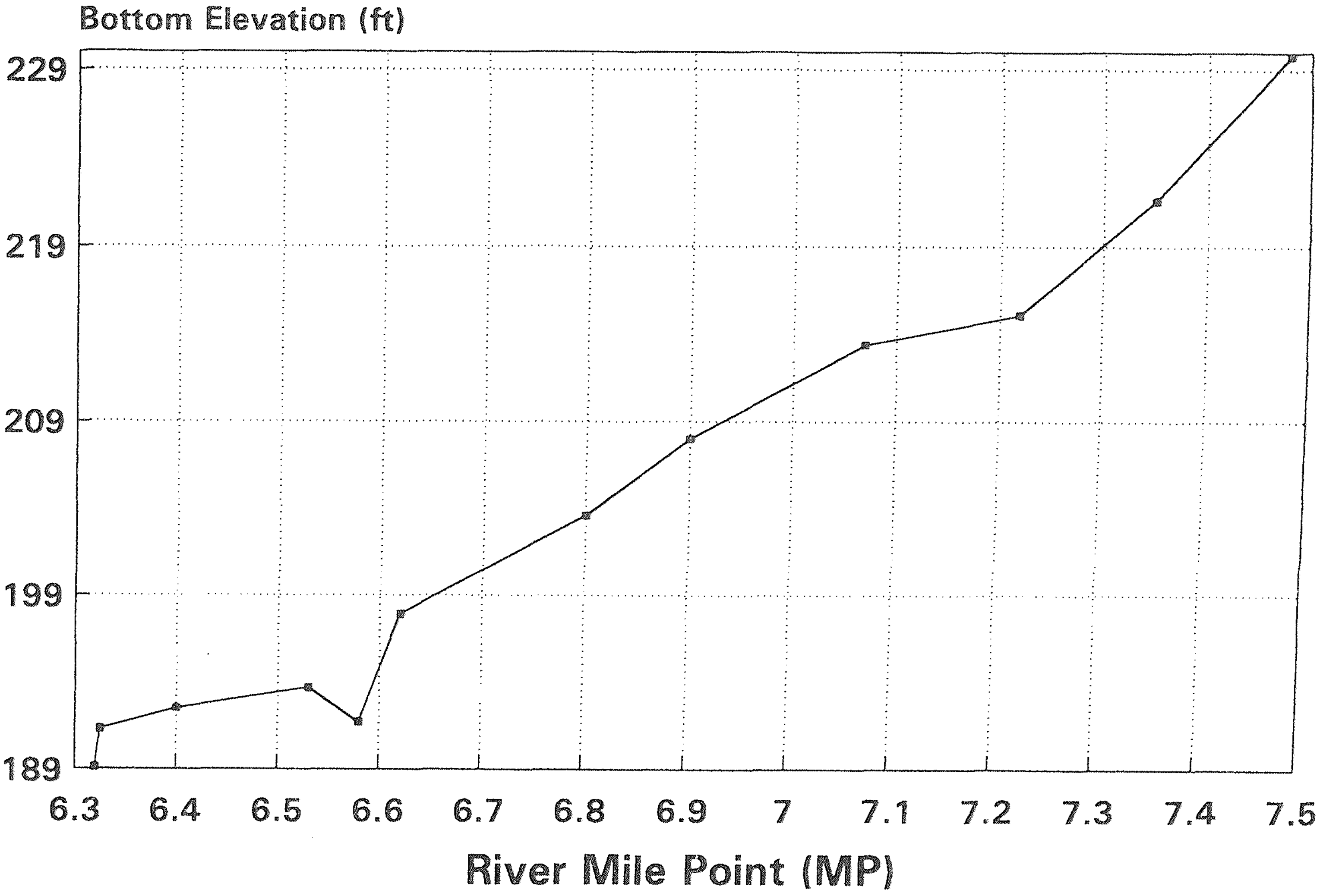


Figure B.1c Graphical representation of Whippany River bed slope from MP 6.31 to MP 7.48. Elevation data courtesy of USGS.

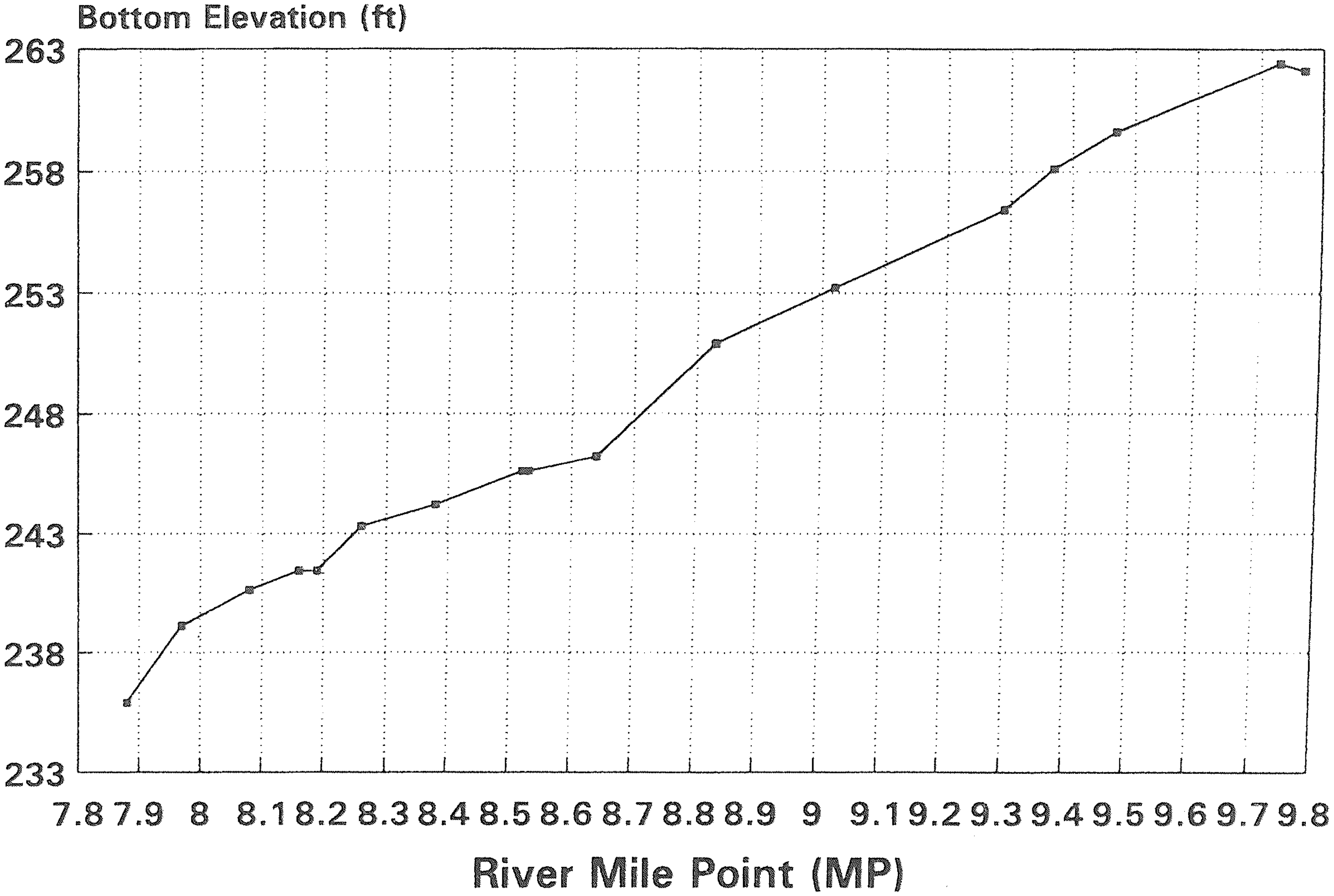


Figure B.1d Graphical representation of Whippany River bed slope from MP 7.88 to MP 9.77. Elevation data courtesy of USGS.

APPENDIX C

RAW DATA

Table C.1 Correlation between sampling station number and reach number or sampling station number and input source for data used in the preliminary model.

Station #[1]	Location upstream from confluence (Km)	Used as initial conditions for
2	15.4	Headwater
4	14.8	Reach 1
5	12.6	Reach 2
9	10.5	Reach 3
10	Data from Stoney Brook[2]	Stoney Brook[2]
11	10.3	Reach 4
12	7.7	Reach 5
13	Data from Black Brook	Black Brook
14	6.4	Reach 6
16	4.3	Reach 8
18	Data from Troy Brook	Troy Brook
19	0.8	Reach 9

1. Station numbers correspond to station numbers listed in Table C.2.

2. Stoney Brook is also called Malapardis Brook.

Note: Iinitial conditions for reach 7 were estimated.

Table C.2 Whippany River water quality parameters (NJDEP 1980, 12-21).

Station #	Flow m^3/s mean (range)	Water Temp. (C)	DO (mg/L)	BOD5 (mg/L)	Ortho P (mg/L)	Total P (mg/L)
2	*	23.3	7.3	1.6	0.06	0.70
4	0.592 (0.462-0.787)	23.0	6.5	7.1	0.17	1.06
5	0.699 (0.444-1.11)	24.0	5.9	5.8	0.12	0.67
9	2.92 (1.23-3.54)	24.8	5.8	5.1	0.12	0.82
10	0.991 (0.487-1.47)	23.0	8.5	1.8	0.01	0.03
11	1.13 (0.447-2.198)	24.6	5.3	4.5	0.12	0.75
12	0.685 (19.8-32.2)	24.3	4.4	3.5	0.12	0.71
13	0.113 (0.085-0.147)	22.1	3.5	2.4	0.07	0.33
14	0.663 (0.450-0.878)	24.0	3.7	3.6	0.11	0.61
16	0.801 (0.450-1.27)	24.5	4.2	4.6	0.15	0.78
18	0.091 (0.017-0.173)	25.0	7.18	1.7	0.05	0.18
19	* (6.57-1.13)	25.0	5.2	4.3	0.16	0.74
STP 1[1]	*	23.0	3.2	4.3	0.11	3.10
STP 2[2]	*	23.6	5.0	3.2	0.64	5.00

1. STP 1 = Morristown STP
2. STP 2 = Hanover STP

* No data available

"**Table C.2** (continued)"

Station #	TKN (mg/L)	NH_3 (mg/L)	NH_3+NH_4-N (mg/L)	NO_2-N (mg/L)	NO_2+NO_3-N (mg/L)
2	0.91	0.002	0.22	0.11	1.60
4	6.72	0.050	3.17	0.071	1.07
5	3.14	0.060	1.43	0.143	0.07
9	3.60	0.040	1.76	0.309	0.86
10	0.58	0.005	0.15	0.064	0.53
11	3.89	0.030	1.50	0.350	1.22
12	2.38	0.020	1.20	0.370	1.32
13	1.26	0.010	0.62	0.104	1.13
14	2.48	0.010	0.87	0.401	1.43
16	3.00	0.030	1.60	0.396	1.44
18	0.70	0.110	0.52	0.017	0.42
19	2.51	0.040	1.12	0.331	1.42
STP 1[1]	22.6	*	10.9	.027	0.110
STP 2[2]	20.3	0.25	13.7	0.47	1.64

1. STP 1 = Morristown STP

2. STP 2 = Hanover STP

* No data available

APPENDIX D

INPUT FILE FOR THE PRELIMINARY MODEL OF THE WHIPPANY RIVER

```
TITLE01          QUAL-2E; INPUT DATA FILE FOR PRELIMINARY MODEL
TITLE02          WHIPPANY RIVER BASIN-MORRISTOWN STP TO ROCKAWAY
TITLE03   NO     CONSERVATIVE MINERAL  I
TITLE04   NO     CONSERVATIVE MINERAL  II
TITLE05   NO     CONSERVATIVE MINERAL III
TITLE06   NO     TEMPERATURE
TITLE07  YES     BIOCHEMICAL OXYGEN DEMAND IN MG/L
TITLE08  YES     ALGAE AS CHL-A IN UG/L
TITLE09   NO     PHOSPHORUS CYCLE AS P IN MG/L
TITLE10          (ORGANIC-P; DISSOLVED-P)
TITLE11  YES     NITROGEN CYCLE AS N IN MG/L
TITLE12          (ORGANIC-N; AMMONIA-N; NITRITE-N; NITRATE-N)
TITLE13  YES     DISSOLVED OXYGEN IN MG/L
TITLE14   NO     FECAL COLIFORMS IN NO./100 ML
TITLE15   NO     ARBITRARY NON-CONSERVATIVE  BOD    MG/L
ENDTITLE
LIST DATA INPUT
WRITE OPTIONAL SUMMARY
NO FLOW AUGMENTATION
STEADY STATE
NO TRAPEZOIDAL X-SECTIONS
PRINT LCD/SOLAR DATA
PLOT DO AND BOD
FIXED DNSTM CONC (YES=1) =       0.0        5D-ULT BOD CONV RATE COEF        0.20
INPUT METRIC (YES=1) =           1          OUTPUT METRIC (YES=1) =          1
NUMBER OF REACHES =              9          NUMBER OF JUNCTIONS =            0
NUM OF HEADWATERS =              1          NUMBER OF POINT LOADS =          5
TIME STEP (HOURS) =              0.0        LNTH  COMP  ELEMENT (DX) =       0.2
MAXIMUM ITERATIONS (HRS)=        30.0       TIME INC. FOR RPT2 (HRS) =       0.0
LATITUDE OF BASIN (DEG) =        40.8       LONGITUDE OF BASIN (DEG) =       74.5
STANDARD MERIDIAN (DEG) =        75.0       DAY OF YEAR START TIME =         240.0
EVAP. COEFF. (AE) = .            0000062    EVAP. COEF. (BE) =               0000055
ELEV  OF BASIN (meter) =         79.2       DUST ATTENUATION COEF.  =        0.13
ENDATA1
O UPTAKE BY NH3 OXID(MG O/MG N)=        3.43    O UPTAKE BY NO2 OXID(MG O/MG N)=         1.14
O PROD  BY ALGAE (MG O/MG A) =          1.6     O UPTAKE BY ALGAE (MG O/MG A) =          2.00
N CONTENT OF ALGAE (MG N/MG A) =        085     P CONTENT OF ALGAE (MG P/MG A) =         0.013
ALG MAX SPEC GROWTH RATE(1/DAY)=        2.0     ALGAE RESPIRATION RATE (1/DAY) =         0.1
N HALF SATURATION CONST  (MG/L)=        .16     P HALF SATURATION CONST  (MG/L) =        0.03
LIN ALG EXCO (1/FT)/(UG-CHLA/L)=        .0088   NLINCO(1/FT)/(UG-CHLA/L)**(2/3) =        .054
LIGHT FUNCTION OPTION (LFNOPT) =        1       LIGHT SATURATION COEF(LNGY/MIN) =        5.0
DAILY AVERAGING OPTION (LAVOPT)=        2       LIGHT AVERAGING FACTOR (AFACT) =         .95
NUMBER OF DAYLIGHT HOURS (DLH) =        15      TOTAL DAILY SOLAR RADTN (LNGYS) =        200
ALGY GROWTH CALC OPTION(LGROPT)=        3       ALGAL PREF FOR NH3-N (PREFN) =           0.8
ALG/TEMP SOLR RAD FACTOR(TFACT)=        .45     NITRIFICATION INHIBITION COEF =          5.0
ENDATA1A
```

"Input file for preliminary model of the Whippany River (continued)."

```
THETA    BOD SETT   1.024
THETA    NH3 DECA   1.083
THETA    OXY TRAN   1.024
THETA    ORGN SET   1.024
ENDATA1B
STREAM REACH    1.0RCH= MORRISTOWN STP               15.2   TO      12.6
STREAM REACH    2.0RCH= EDEN LANE                    12.6   TO      12.0
STREAM REACH    3.0RCH= PARSIPPANY RD                12.0   TO      10.4
STREAM REACH    4.0RCH= WHIPPANY RD                  10.4   TO      10.0
STREAM REACH    5.0RCH= ROUTE 10                     10.0   TO       7.6
STREAM REACH    6.0RCH= BELOW BLACK BK                7.6   TO       5.8
STREAM REACH    7.0RCH= HANOVER STP                   5.8   TO       4.6
STREAM REACH    8.0RCH= TROY ROAD                     4.6   TO       1.0
STREAM REACH    9.0RCH= BELOW TROY BROOK              1.0   TO       0.2
ENDATA2
ENDATA3
FLAG FIELD RCH=  1.0    13.0     1.6.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=  2.0     3.0     2.2.2.
FLAG FIELD RCH=  3.0     8.0     2.2.2.2.2.2.2.2.
FLAG FIELD RCH=  4.0     2.0     6.2.
FLAG FIELD RCH=  5.0    12.0     2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=  6.0     9.0     6.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=  7.0     6.0     6.2.2.2.2.2.
FLAG FIELD RCH=  8.0    18.0     2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=  9.0     4.0     6.2.2.5.
ENDATA4
HYDRAULICS RCH=  1.0    245.0    .469    .432    .163    .367    .030
HYDRAULICS RCH=  2.0    245.0    .164    .602    .464    .331    .030
HYDRAULICS RCH=  3.0    245.0    .164    .602    .464    .331    .030
HYDRAULICS RCH=  4.0    245.0    .164    .602    .464    .331    .030
HYDRAULICS RCH=  5.0    245.0    .480     .32    .209    .628    .030
HYDRAULICS RCH=  6.0    245.0    .121    .422    .666    .510    .040
HYDRAULICS RCH=  7.0    245.0    .121    .422    .666    .510    .030
HYDRAULICS RCH=  8.0    245.0    .119    .38     .727    .525    .030
HYDRAULICS RCH=  9.0    245.0    .119    .38     .727    .525    .030
ENDATA5
REACT COEF RCH=  1.0   0.40   0.40   1.5   3   0.0
REACT COEF RCH=  2.0   0.40   0.40   1.5   3   0.0
REACT COEF RCH=  3.0   0.40   0.40   1.5   3   0.0
REACT COEF RCH=  4.0   0.40   0.40   1.5   3   0.0
REACT COEF RCH=  5.0   0.40   0.40   1.5   3   0.0
REACT COEF RCH=  6.0   0.40   0.40   1.5   3   0.0
REACT COEF RCH=  7.0   0.40   0.40   1.5   3   0.0
REACT COEF RCH=  8.0   0.40   0.40   1.5   3   0.0
REACT COEF RCH=  9.0   0.40   0.40   1.5   3   0.0
ENDATA6
```

"**Input file for preliminary model of the Whippany River** (continued)."

```
N AND P COEF   RCH= 1.0  0.10  0.01  0.30  0.2  0.3  0.20  0.01  0.2
N AND P COEF   RCH= 2.0  0.10  0.01  0.30  0.2  0.3  0.20  0.01  0.2
N AND P COEF   RCH= 3.0  0.10  0.01  0.30  0.2  0.3  0.20  0.01  0.2
N AND P COEF   RCH= 4.0  0.10  0.01  0.30  0.2  0.3  0.20  0.01  0.2
N AND P COEF   RCH= 5.0  0.10  0.01  0.30  0.2  0.3  0.20  0.01  0.2
N AND P COEF   RCH= 6.0  0.10  0.01  0.30  0.2  0.3  0.20  0.01  0.2
N AND P COEF   RCH= 7.0  0.10  0.01  0.30  0.2  0.3  0.20  0.01  0.2
N AND P COEF   RCH= 8.0  0.10  0.01  0.30  0.2  0.3  0.20  0.01  0.2
N AND P COEF   RCH= 9.0  0.10  0.01  0.30  0.2  0.3  0.20  0.01  0.2
ENDATA6A
ALG/OTHER COEF RCH= 1.0  50.0  0.15  .01  0.0  0.0  0.0  0.0  0.0
ALG/OTHER COEF RCH= 2.0  50.0  0.15  .01  0.0  0.0  0.0  0.0  0.0
ALG/OTHER COEF RCH= 3.0  50.0  0.15  .01  0.0  0.0  0.0  0.0  0.0
ALG/OTHER COEF RCH= 4.0  50.0  0.15  .01  0.0  0.0  0.0  0.0  0.0
ALG/OTHER COEF RCH= 5.0  50.0  0.15  .01  0.0  0.0  0.0  0.0  0.0
ALG/OTHER COEF RCH= 6.0  50.0  0.15  .01  0.0  0.0  0.0  0.0  0.0
ALG/OTHER COEF RCH= 7.0  50.0  0.15  .01  0.0  0.0  0.0  0.0  0.0
ALG/OTHER COEF RCH= 8.0  50.0  0.15  .01  0.0  0.0  0.0  0.0  0.0
ALG/OTHER COEF RCH= 9.0  50.0  0.15  .01  0.0  0.0  0.0  0.0  0.0
ENDATA6B
INITIAL COND-1 RCH= 1.0  10.9  6.5  7.1  0.0  0.0  0.0  0.0  0.0
INITIAL COND-1 RCH= 2.0  11.2  5.9  5.8  0.0  0.0  0.0  0.0  0.0
INITIAL COND-1 RCH= 3.0  11.3  5.8  5.1  0.0  0.0  0.0  0.0  0.0
INITIAL COND-1 RCH= 4.0  11.3  5.3  4.5  0.0  0.0  0.0  0.0  0.0
INITIAL COND-1 RCH= 5.0  11.2  4.4  3.5  0.0  0.0  0.0  0.0  0.0
INITIAL COND-1 RCH= 6.0  11.5  3.7  3.6  0.0  0.0  0.0  0.0  0.0
INITIAL COND-1 RCH= 7.0  11.3  4.0  4.0  0.0  0.0  0.0  0.0  0.0
INITIAL COND-1 RCH= 8.0  11.1  4.2  4.6  0.0  0.0  0.0  0.0  0.0
INITIAL COND-1 RCH= 9.0  12.0  5.2  4.3  0.0  0.0  0.0  0.0  0.0
ENDATA7
INITIAL COND-2 RCH= 1.0  0.1  3.55  3.17  .071  .999  .17  1.06
INITIAL COND-2 RCH= 2.0  0.1  1.71  1.43  .143  .557  .12  .67
INITIAL COND-2 RCH= 3.0  0.1  1.84  1.76  .309  .551  .12  .82
INITIAL COND-2 RCH= 4.0  0.1  2.00  1.50  .350  .600  .12  .75
INITIAL COND-2 RCH= 5.0  0.1  2.69  1.20  .370  .850  .12  .71
INITIAL COND-2 RCH= 6.0  0.1  1.55  0.87  .401  .930  .11  .61
INITIAL COND-2 RCH= 7.0  0.1  1.50  1.00  .400 1.000  .12  .70
INITIAL COND-2 RCH= 8.0  0.1  1.40  1.60  .396 1.044  .15  .78
INITIAL COND-2 RCH= 9.0  0.1  1.39  1.12  .331 1.089  .16  .74
ENDATA7A
INCR INFLOW-1  RCH= 1.0   0   0   0   0   0   0   0
INCR INFLOW-1  RCH= 2.0   0   0   0   0   0   0   0
INCR INFLOW-1  RCH= 3.0   0   0   0   0   0   0   0
INCR INFLOW-1  RCH= 4.0   0   0   0   0   0   0   0
INCR INFLOW-1  RCH= 5.0   0   0   0   0   0   0   0
INCR INFLOW-1  RCH= 6.0   0   0   0   0   0   0   0
INCR INFLOW-1  RCH= 7.0   0   0   0   0   0   0   0
INCR INFLOW-1  RCH= 8.0   0   0   0   0   0   0   0
INCR INFLOW-1  RCH= 9.0   0   0   0   0   0   0   0
ENDATA8
```

"**Input file for preliminary model of the Whippany River** (continued)."

```
INCR INFLOW-2  RCH=  1.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  2.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  3.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  4.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  5.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  6.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  7.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  8.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  9.0    0    0    0    0    0    0
ENDATA8A
ENDATA9
HEADWTR-1 HDW=  1.0 MORRISTOWN GAGE   0.467  11.3   9.9  1.0
ENDATA10
HEADWTR-2 HDW=  1.00    0    0 .0038  2.83  .012  .023  2.17 0.031 0.073
ENDATA10A
POINTLD-1 PTL=  1.0MORRISTOWN               0.5   .144  12.0   3.2   4.3
POINTLD-1 PTL=  2.0STONEY BK                0.0   .991  12.0  11.4   1.0
POINTLD-1 PTL=  3.0BLACK BROOK              0.0   .113  10.5   8.8   1.5
POINTLD-1 PTL=  4.0HANOVER STP              0.5   .076  12.0   5.0   3.2
POINTLD-1 PTL=  5.0TROY BROOK               0.0   .091  11.4   8.9   1.0
ENDATA11
POINTLD-2 PTL=   1.0    0    0   .01  11.7  10.9  .027  .083  0.11  3.10
POINTLD-2 PTL=   2.0    0    0 .0025  .646  .007  .011  .440   .00  .013
POINTLD-2 PTL=   3.0    0    0 .0060  1.32  .007  .028  .907  .005  .052
POINTLD-2 PTL=   4.0    0    0   .01   6.6  13.7  .470  1.17  0.64  5.00
POINTLD-2 PTL=   5.0    0    0  .011  .592  .092  .010  .311   .00  .104
ENDATA11A
ENDATA12
ENDATA13
ENDATA13A
BEGIN  RCH    1
PLOT   RCH    1   2   3   4   5   6   7   8   9
```

APPENDIX E

OUTPUT DATA FOR THE PRELIMINARY MODEL OF THE WHIPPANY RIVER

Table E.1 Output data for the preliminary model of the Whippany River.

REACH #	ELE- MENT #	RIVER km	TEMP DEG-C	DO MG/L	BOD MG/L	ORGN MG/L	NH3N MG/L	NO2N MG/L	NO3N MG/L	SUM-N MG/L	ORGP MG/L	DIS-P MG/L	SUM-P MG/L
1	1	15	10.9	10.1	1	2.87	0.06	0.02	2.16	5.12	0.17	1.06	1.23
1	2	14.8	10.9	8.94	1.26	4.91	2.57	0.03	1.68	9.19	0.17	1.06	1.23
1	3	14.6	10.9	9.31	1.26	4.91	2.57	0.03	1.68	9.19	0.17	1.06	1.23
1	4	14.4	10.9	9.6	1.25	4.91	2.57	0.03	1.68	9.19	0.17	1.06	1.23
1	5	14.2	10.9	9.84	1.25	4.91	2.57	0.03	1.68	9.19	0.17	1.06	1.23
1	6	14	10.9	10.03	1.25	4.91	2.57	0.04	1.68	9.19	0.17	1.06	1.23
1	7	13.8	10.9	10.19	1.24	4.9	2.57	0.04	1.68	9.19	0.17	1.06	1.23
1	8	13.6	10.9	10.31	1.24	4.9	2.57	0.04	1.68	9.19	0.17	1.06	1.23
1	9	13.4	10.9	10.41	1.23	4.9	2.57	0.04	1.68	9.19	0.17	1.06	1.23
1	10	13.2	10.9	10.5	1.23	4.9	2.57	0.04	1.68	9.19	0.17	1.06	1.23
1	11	13	10.9	10.56	1.22	4.89	2.57	0.05	1.68	9.19	0.17	1.06	1.23
1	12	12.8	10.9	10.62	1.22	4.89	2.57	0.05	1.68	9.19	0.17	1.06	1.23
1	13	12.6	10.9	10.66	1.21	4.89	2.57	0.05	1.68	9.19	0.17	1.06	1.23
2	14	12.4	11.2	10.67	1.21	4.89	2.57	0.06	1.68	9.19	0.12	0.67	0.79
2	15	12.2	11.2	10.63	1.19	4.88	2.57	0.06	1.68	9.19	0.12	0.67	0.79
2	16	12	11.2	10.58	1.18	4.87	2.57	0.07	1.68	9.19	0.12	0.67	0.79
3	17	11.8	11.3	10.54	1.17	4.86	2.57	0.08	1.68	9.19	0.12	0.82	0.94
3	18	11.6	11.3	10.5	1.15	4.86	2.57	0.08	1.68	9.19	0.12	0.82	0.94
3	19	11.4	11.3	10.47	1.14	4.85	2.57	0.09	1.68	9.19	0.12	0.82	0.94
3	20	11.2	11.3	10.43	1.13	4.84	2.56	0.1	1.68	9.19	0.12	0.82	0.94
3	21	11	11.3	10.4	1.11	4.84	2.56	0.1	1.68	9.19	0.12	0.82	0.94
3	22	10.8	11.3	10.38	1.1	4.83	2.56	0.11	1.68	9.18	0.12	0.82	0.94
3	23	10.6	11.3	10.35	1.09	4.82	2.56	0.12	1.68	9.17	0.12	0.82	0.94
3	24	10.4	11.3	10.36	1.08	4.69	2.48	0.12	1.64	8.93	0.12	0.82	0.94
4	25	10.2	11.3	10.96	1.02	2.25	0.99	0.06	0.92	4.21	0.12	0.75	0.87

"Table E.1 (continued)"

REACH #	ELE- MENT #	RIVER km	TEMP DEG-C	DO MG/L	BOD MG/L	ORGN MG/L	NH3N MG/L	NO2N MG/L	NO3N MG/L	SUM-N MG/L	ORGP MG/L	DIS-P MG/L	SUM-P MG/L
4	26	10	11.3	10.93	1.02	2.24	0.99	0.06	0.92	4.21	0.12	0.75	0.87
5	27	9.8	11.2	10.92	1.01	2.24	0.99	0.06	0.92	4.21	0.12	0.71	0.83
5	28	9.6	11.2	10.91	1.01	2.24	0.99	0.06	0.92	4.21	0.12	0.71	0.83
5	29	9.4	11.2	10.89	1.01	2.24	0.99	0.06	0.92	4.21	0.12	0.71	0.83
5	30	9.2	11.2	10.88	1.01	2.24	0.99	0.06	0.92	4.21	0.12	0.71	0.83
5	31	9	11.2	10.87	1	2.24	0.99	0.06	0.92	4.21	0.12	0.71	0.83
5	32	8.8	11.2	10.86	1	2.24	0.99	0.06	0.92	4.21	0.12	0.71	0.83
5	33	8.6	11.2	10.85	1	2.24	0.99	0.06	0.92	4.21	0.12	0.71	0.83
5	34	8.4	11.2	10.85	1	2.24	0.99	0.06	0.92	4.21	0.12	0.71	0.83
5	35	8.2	11.2	10.84	0.99	2.24	0.99	0.06	0.92	4.21	0.12	0.71	0.83
5	36	8	11.2	10.83	0.99	2.24	0.99	0.06	0.92	4.21	0.12	0.71	0.83
5	37	7.8	11.2	10.82	0.99	2.24	0.99	0.06	0.92	4.21	0.12	0.71	0.83
5	38	7.6	11.2	10.81	0.99	2.23	0.99	0.06	0.92	4.2	0.12	0.71	0.83
6	39	7.4	11.5	10.68	1.01	2.18	0.93	0.06	0.92	4.08	0.11	0.61	0.72
6	40	7.2	11.5	10.66	1	2.17	0.93	0.07	0.92	4.08	0.11	0.61	0.72
6	41	7	11.5	10.63	0.99	2.17	0.93	0.07	0.92	4.08	0.11	0.61	0.72
6	42	6.8	11.5	10.61	0.99	2.17	0.93	0.07	0.92	4.08	0.11	0.61	0.72
6	43	6.6	11.5	10.59	0.98	2.17	0.93	0.07	0.92	4.08	0.11	0.61	0.72
6	44	6.4	11.5	10.57	0.97	2.16	0.93	0.07	0.92	4.08	0.11	0.61	0.72
6	45	6.2	11.5	10.55	0.96	2.16	0.93	0.07	0.92	4.08	0.11	0.61	0.72
6	46	6	11.5	10.52	0.95	2.16	0.93	0.08	0.92	4.09	0.11	0.61	0.72
6	47	5.8	11.5	10.48	0.95	2.18	0.99	0.08	0.92	4.17	0.11	0.61	0.72
7	48	5.6	11.3	10.26	0.96	2.34	1.47	0.1	0.93	4.84	0.12	0.7	0.82
7	49	5.4	11.3	10.24	0.95	2.34	1.47	0.1	0.93	4.84	0.12	0.7	0.82
7	50	5.2	11.3	10.22	0.94	2.34	1.47	0.1	0.93	4.84	0.12	0.7	0.82

"Table E.1 (continued)"

REACH #	ELE- MENT #	RIVER km	TEMP DEG-C	DO MG/L	BOD MG/L	ORGN MG/L	NH3N MG/L	NO2N MG/L	NO3N MG/L	SUM-N MG/L	ORGP MG/L	DIS-P MG/L	SUM-P MG/L
7	51	5	11.3	10.21	0.94	2.33	1.46	0.11	0.93	4.84	0.12	0.7	0.82
7	52	4.8	11.3	10.19	0.93	2.33	1.46	0.11	0.93	4.84	0.12	0.7	0.82
7	53	4.6	11.3	10.18	0.92	2.33	1.46	0.11	0.93	4.84	0.12	0.7	0.82
8	54	4.4	11.1	10.16	0.91	2.33	1.46	0.12	0.93	4.84	0.15	0.78	0.93
8	55	4.2	11.1	10.15	0.9	2.32	1.46	0.12	0.93	4.84	0.15	0.78	0.93
8	56	4	11.1	10.13	0.9	2.32	1.46	0.12	0.93	4.84	0.15	0.78	0.93
8	57	3.8	11.1	10.12	0.89	2.32	1.46	0.13	0.93	4.84	0.15	0.78	0.93
8	58	3.6	11.1	10.1	0.88	2.32	1.46	0.13	0.93	4.84	0.15	0.78	0.93
8	59	3.4	11.1	10.09	0.87	2.31	1.46	0.13	0.93	4.84	0.15	0.78	0.93
8	60	3.2	11.1	10.08	0.86	2.31	1.46	0.13	0.93	4.84	0.15	0.78	0.93
8	61	3	11.1	10.06	0.86	2.31	1.45	0.14	0.94	4.84	0.15	0.78	0.93
8	62	2.8	11.1	10.05	0.85	2.31	1.45	0.14	0.94	4.83	0.15	0.78	0.93
8	63	2.6	11.1	10.04	0.84	2.3	1.45	0.14	0.94	4.83	0.15	0.78	0.93
8	64	2.4	11.1	10.02	0.83	2.3	1.45	0.15	0.94	4.83	0.15	0.78	0.93
8	65	2.2	11.1	10.01	0.82	2.3	1.45	0.15	0.94	4.83	0.15	0.78	0.93
8	66	2	11.1	10	0.82	2.29	1.45	0.15	0.94	4.83	0.15	0.78	0.93
8	67	1.8	11.1	9.99	0.81	2.29	1.45	0.15	0.94	4.83	0.15	0.78	0.93
8	68	1.6	11.1	9.98	0.8	2.29	1.45	0.16	0.94	4.83	0.15	0.78	0.93
8	69	1.4	11.1	9.97	0.79	2.29	1.45	0.16	0.94	4.83	0.15	0.78	0.93
8	70	1.2	11.1	9.95	0.79	2.28	1.45	0.16	0.94	4.83	0.15	0.78	0.93
8	71	1	11.1	9.94	0.78	2.27	1.44	0.16	0.94	4.81	0.15	0.78	0.93
9	72	0.8	12	9.88	0.78	2.2	1.38	0.16	0.91	4.65	0.16	0.74	0.9
9	73	0.6	12	9.86	0.78	2.19	1.38	0.16	0.91	4.65	0.16	0.74	0.9
9	74	0.4	12	9.85	0.77	2.19	1.38	0.17	0.91	4.65	0.16	0.74	0.9
9	75	0.2	12	9.84	0.76	2.19	1.38	0.17	0.91	4.65	0.16	0.74	0.9

APPENDIX F

RAW DATA USED FOR CALIBRATION OF THE PRELIMINARY MODEL OF THE WHIPPANY RIVER

Table F.1 Correlation between site number and reach number or site number and input source for data used for calibration.

Site #[1]	Location upstream from confluence (Km)	Used to calibrate data for
7	16.0	Headwater
8	15.0	Reach 1
9	12.6	Reach 2
10	10.4	Reach 3
11	Data from Stoney Brook[2]	Stoney Brook[2]
12	8.2	Reach 5
13	Data from Black Brook	Black Brook
14	7.5	Reach 6
15	1.2	Reach 8
16	Data from Troy Brook	Troy Brook
17	0.5	Reach 9

1. Site numbers correspond to site numbers listed on the data sheet on the following page.
2. Stoney Brook is also called Malapardis Brook.

Note: Calibration data for reaches 4 and 7 were estimated.

Table F.2 Whippany River calibration data

SITE #	RIVER KILOMETER	DO mg/L	BOD5 mg/L	TKN mg/L	NH3 mg/L	ON mg/L	NO2 mg/L	N03 mg/L	TOTAL P mg/L	ORTHO P mg/L	OP mg/L
8	15	10.1	1	2.69	0.00671	2.68329	0.016	2.13	0.08	0.061	0.019
9	12.6	11.6	1	3.7	0.01232	3.68768	0.0125	3.245	0.387	0.361	0.026
10	10.4	10.2	1	4.465	0.00671	4.45829	0.01634	4.289	0.721	0.628	0.093
12	8.2	9.9	1.1	3.551	0.04637	3.50463	0.01504	3.798	0.581	0.554	0.027
14	7.5	10	1	3.761	0.00671	3.75429	0.1245	3.492	0.544	0.51	0.034
15	1.2		9.2	4.83	0.00671	4.82329	0.01116	4.356	0.721	0.628	0.093
17	0.5	10.2	1.7	3.682	0.035	3.647	0.00986	3.371	0.511	0.51	0.001

APPENDIX G

INPUT FILE FOR THE CALIBRATED MODEL OF THE WHIPPANY RIVER

```
TITLE01          QUAL-2E; INPUT DATA WHIP3
TITLE02          WHIPPANY RIVER BASIN-MORRISTOWN STP TO ROCKAWAY
TITLE03   NO     CONSERVATIVE MINERAL  I
TITLE04   NO     CONSERVATIVE MINERAL  II
TITLE05   NO     CONSERVATIVE MINERAL III
TITLE06   NO     TEMPERATURE
TITLE07  YES     BIOCHEMICAL OXYGEN DEMAND IN MG/L
TITLE08  YES     ALGAE AS CHL-A IN UG/L
TITLE09   NO     PHOSPHORUS CYCLE AS P IN MG/L
TITLE10          (ORGANIC-P; DISSOLVED-P)
TITLE11  YES     NITROGEN CYCLE AS N IN MG/L
TITLE12          (ORGANIC-N; AMMONIA-N; NITRITE-N; NITRATE-N)
TITLE13  YES     DISSOLVED OXYGEN IN MG/L
TITLE14   NO     FECAL COLIFORMS IN NO./100 ML
TITLE15   NO     ARBITRARY NON-CONSERVATIVE  BOD    MG/L
ENDTITLE
LIST DATA INPUT
WRITE OPTIONAL SUMMARY
NO FLOW AUGMENTATION
STEADY STATE
NO TRAPEZOIDAL X-SECTIONS
PRINT LCD/SOLAR DATA
PLOT DO AND BOD
FIXED DNSTM CONC (YES=1) =          0.0           5D-ULT BOD CONV RATE COEF          0.20
INPUT METRIC (YES=1) =              1             OUTPUT METRIC (YES=1) =            1
NUMBER OF REACHES =                 9             NUMBER OF JUNCTIONS =              0
NUM OF HEADWATERS =                 1             NUMBER OF POINT LOADS =            5
TIME STEP (HOURS) =                 0.0           LNTH  COMP  ELEMENT (DX) =         0.2
MAXIMUM ITERATIONS (HRS)=           30.0          TIME INC. FOR RPT2 (HRS) =         0.0
LATITUDE OF BASIN (DEG) =           40.8          LONGITUDE OF BASIN (DEG) =         74.5
STANDARD MERIDIAN (DEG) =           75.0          DAY OF YEAR START TIME =           240.0
EVAP. COEFF. (AE) =  .              0000062       EVAP. COEF. (BE) =                 0000055
ELEV  OF BASIN (meter) =            79.2          DUST ATTENUATION COEF.  =          0.13
ENDATA1
O UPTAKE BY NH3 OXID(MG O/MG N)=          3.43    O UPTAKE BY NO2 OXID(MG O/MG N)=           1.14
O PROD  BY ALGAE (MG O/MG A) =            1.6     O UPTAKE BY ALGAE (MG O/MG A) =            2.00
N CONTENT OF ALGAE (MG N/MG A) =          085     P CONTENT OF ALGAE (MG P/MG A) =           0.013
ALG MAX SPEC GROWTH RATE(1/DAY)=          2.0     ALGAE RESPIRATION RATE (1/DAY) =           0.1
N HALF SATURATION CONST  (MG/L)=          .16     P HALF SATURATION CONST  (MG/L) =          0.03
LIN ALG EXCO (1/FT)/(UG-CHLA/L)=          .0088   NLINCO(1/FT)/(UG-CHLA/L)**(2/3) =          .054
LIGHT FUNCTION OPTION (LFNOPT) =          1       LIGHT SATURATION COEF(LNGY/MIN) =          5.0
DAILY AVERAGING OPTION (LAVOPT)=          2       LIGHT  AVERAGING FACTOR (AFACT) =          .95
NUMBER OF DAYLIGHT HOURS (DLH) =          15      TOTAL DAILY SOLAR RADTN (LNGYS) =          200
ALGY GROWTH CALC OPTION(LGROPT)=          3       ALGAL PREF FOR NH3-N (PREFN) =             0.8
ALG/TEMP SOLR RAD FACTOR(TFACT)=          .45     NITRIFICATION INHIBITION COEF =            5.0
ENDATA1A
```

"**Input file for the calibrated model of the Whippany River** (continued)."

```
THETA    BOD SETT      1.024
THETA    NH3 DECA      1.083
THETA    OXY TRAN      1.024
THETA    ORGN SET      1.024
ENDATA1B
STREAM REACH    1.0RCH= MORRISTOWN STP FROM          15.2   TO      12.6
STREAM REACH    2.0RCH= EDEN LANE  FROM              12.6   TO      12.0
STREAM REACH    3.0RCH= PARSIPPANY RD FROM            2.0   TO      10.4
STREAM REACH    4.0RCH= WHIPPANY RD FROM             10.4   TO      10.0
STREAM REACH    5.0RCH= ROUTE 10 FROM                10.0   TO       7.6
STREAM REACH    6.0RCH= BELOW BLACK BK FROM           7.6   TO       5.8
STREAM REACH    7.0RCH= HANOVER STP FROM              5.8   TO       4.6
STREAM REACH    8.0RCH= TROY ROAD FROM                4.6   TO       1.0
STREAM REACH    9.0RCH= BELOW TROY BRK. FROM          1.0   TO       0.2
ENDATA2
ENDATA3
FLAG FIELD RCH=  1.0     13.0      1.6.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=  2.0      3.0      2.2.2.
FLAG FIELD RCH=  3.0      8.0      2.2.2.2.2.2.2.2.
FLAG FIELD RCH=  4.0      2.0      6.2.
FLAG FIELD RCH=  5.0     12.0      2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=  6.0      9.0      6.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=  7.0      6.0      6.2.2.2.2.2.
FLAG FIELD RCH=  8.0     18.0      2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=  9.0      4.0      6.2.2.5.
ENDATA4
HYDRAULICS RCH=  1.0    245.0    .469    .432    .163    .367    .030
HYDRAULICS RCH=  2.0    245.0    .164    .602    .464    .331    .030
HYDRAULICS RCH=  3.0    245.0    .164    .602    .464    .331    .030
HYDRAULICS RCH=  4.0    245.0    .164    .602    .464    .331    .030
HYDRAULICS RCH=  5.0    245.0    .480    .320    .209    .628    .030
HYDRAULICS RCH=  6.0    245.0    .121    .422    .666    .510    .040
HYDRAULICS RCH=  7.0    245.0    .121    .422    .666    .510    .030
HYDRAULICS RCH=  8.0    245.0    .119    .380    .727    .525    .030
HYDRAULICS RCH=  9.0    245.0    .119    .380    .727    .525    .030
ENDATA5
REACT COEF RCH=  1.0   0.30   0.36   0.5   3  0.0
REACT COEF RCH=  2.0   0.30   0.36   0.5   3  0.0
REACT COEF RCH=  3.0   0.30   0.36   0.5   3  0.0
REACT COEF RCH=  4.0   0.30   0.36   0.5   3  0.0
REACT COEF RCH=  5.0   0.30   0.36   0.5   3  0.0
REACT COEF RCH=  6.0   0.30   0.36   0.5   3  0.0
REACT COEF RCH=  7.0   0.30   0.36   0.5   3  0.0
REACT COEF RCH=  8.0   0.30   0.36   0.5   3  0.0
REACT COEF RCH=  9.0   0.30   0.36   0.5   3  0.0
ENDATA6
```

"**Input file for the calibrated model of the Whippany River** (continued)."

```
N AND P COEF   RCH= 1.0  0.2  0.005  0.015  0.0   0.45  0.25  0.2   0.0
N AND P COEF   RCH= 2.0  0.2  0.005  0.015  0.0   0.45  0.25  0.2   0.0
N AND P COEF   RCH= 3.0  0.2  0.005  0.015  0.0   0.45  0.25  0.2   0.0
N AND P COEF   RCH= 4.0  0.2  0.005  0.015  0.0   0.45  0.25  0.2   0.0
N AND P COEF   RCH= 5.0  0.2  0.005  0.015  0.0   0.45  0.25  0.2   0.0
N AND P COEF   RCH= 6.0  0.2  0.005  0.015  0.0   0.45  0.25  0.2   0.0
N AND P COEF   RCH= 7.0  0.2  0.005  0.015  0.0   0.45  0.25  0.2   0.0
N AND P COEF   RCH= 8.0  0.2  0.005  0.015  0.0   0.45  0.25  0.2   0.0
N AND P COEF   RCH= 9.0  0.2  0.005  0.015  0.0   0.45  0.25  0.2   0.0
ENDATA6A
ALG/OTHER COEF RCH= 1.0  50.0  0.15   .01   0.0   0.0   0.0   0.0   0.0
ALG/OTHER COEF RCH= 2.0  50.0  0.15   .01   0.0   0.0   0.0   0.0   0.0
ALG/OTHER COEF RCH= 3.0  50.0  0.15   .01   0.0   0.0   0.0   0.0   0.0
ALG/OTHER COEF RCH= 4.0  50.0  0.15   .01   0.0   0.0   0.0   0.0   0.0
ALG/OTHER COEF RCH= 5.0  50.0  0.15   .01   0.0   0.0   0.0   0.0   0.0
ALG/OTHER COEF RCH= 6.0  50.0  0.15   .01   0.0   0.0   0.0   0.0   0.0
ALG/OTHER COEF RCH= 7.0  50.0  0.15   .01   0.0   0.0   0.0   0.0   0.0
ALG/OTHER COEF RCH= 8.0  50.0  0.15   .01   0.0   0.0   0.0   0.0   0.0
ALG/OTHER COEF RCH= 9.0  50.0  0.15   .01   0.0   0.0   0.0   0.0   0.0
ENDATA6B
INITIAL COND-1 RCH= 1.0  10.9   6.5   7.1   0.0   0.0   0.0   0.0   0.0
INITIAL COND-1 RCH= 2.0  11.2   5.9   5.8   0.0   0.0   0.0   0.0   0.0
INITIAL COND-1 RCH= 3.0  11.3   5.8   5.1   0.0   0.0   0.0   0.0   0.0
INITIAL COND-1 RCH= 4.0  11.3   5.3   4.5   0.0   0.0   0.0   0.0   0.0
INITIAL COND-1 RCH= 5.0  11.2   4.4   3.5   0.0   0.0   0.0   0.0   0.0
INITIAL COND-1 RCH= 6.0  11.5   3.7   3.6   0.0   0.0   0.0   0.0   0.0
INITIAL COND-1 RCH= 7.0  11.3   4.0   4.0   0.0   0.0   0.0   0.0   0.0
INITIAL COND-1 RCH= 8.0  11.1   4.2   4.6   0.0   0.0   0.0   0.0   0.0
INITIAL COND-1 RCH= 9.0  12.0   5.2   4.3   0.0   0.0   0.0   0.0   0.0
ENDATA7
INITIAL COND-2 RCH= 1.0   0.1  3.55  3.17  .071   .999  .17  1.06
INITIAL COND-2 RCH= 2.0   0.1  1.71  1.43  .143   .557  .12   .67
INITIAL COND-2 RCH= 3.0   0.1  1.84  1.76  .309   .551  .12   .82
INITIAL COND-2 RCH= 4.0   0.1  2.00  1.50  .350   .600  .12   .75
INITIAL COND-2 RCH= 5.0   0.1  2.69  1.20  .370   .850  .12   .71
INITIAL COND-2 RCH= 6.0   0.1  1.55  0.87  .401   .930  .11   .61
INITIAL COND-2 RCH= 7.0   0.1  1.50  1.00  .400  1.000  .12   .70
INITIAL COND-2 RCH= 8.0   0.1  1.40  1.60  .396  1.044  .15   .78
INITIAL COND-2 RCH= 9.0   0.1  1.39  1.12  .331  1.089  .16   .74
ENDATA7A
INCR INFLOW-1  RCH= 1.0    0    0    0    0    0    0    0
INCR INFLOW-1  RCH= 2.0    0    0    0    0    0    0    0
INCR INFLOW-1  RCH= 3.0    0    0    0    0    0    0    0
INCR INFLOW-1  RCH= 4.0    0    0    0    0    0    0    0
INCR INFLOW-1  RCH= 5.0    0    0    0    0    0    0    0
INCR INFLOW-1  RCH= 6.0    0    0    0    0    0    0    0
INCR INFLOW-1  RCH= 7.0    0    0    0    0    0    0    0
INCR INFLOW-1  RCH= 8.0    0    0    0    0    0    0    0
INCR INFLOW-1  RCH= 9.0    0    0    0    0    0    0    0
ENDATA8
```

"**Input file for the calibrated model of the Whippany River** (continued)."

```
INCR INFLOW-2  RCH=  1.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  2.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  3.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  4.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  5.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  6.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  7.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  8.0    0    0    0    0    0    0
INCR INFLOW-2  RCH=  9.0    0    0    0    0    0    0
ENDATA8A
ENDATA9
HEADWTR-1 HDW=  1.0 MORRISTOWN GAGE  0.467  11.3   9.9  1.0
ENDATA10
HEADWTR-2 HDW=  1.00     0     0 .0038  2.83  .012  .023  2.17 0.031 0.073
ENDATA10A

POINTLD-1 PTL=  1.0MORRISTOWN               0.5   .144  12.0  3.2   4.3
POINTLD-1 PTL=  2.0STONEY BK                0.0   .991  12.0  11.4  1.0
POINTLD-1 PTL=  3.0BLACK BROOK              0.0   .113  10.5  8.8   1.5
POINTLD-1 PTL=  4.0HANOVER STP              0.5   .076  12.0  5.0   3.2
POINTLD-1 PTL=  5.0TROY BROOK               0.0   .091  11.4  8.9   1.0
ENDATA11
POINTLD-2 PTL=   1.0    0     0   .01  11.7  10.9  .027  .083  0.11  3.10
POINTLD-2 PTL=   2.0    0     0 .0025  .646  .007  .011  .440   .00  .013
POINTLD-2 PTL=   3.0    0     0 .0060  1.32  .007  .028  .907  .005  .052
POINTLD-2 PTL=   4.0    0     0   .01   6.6  13.7  .470  1.17  0.64  5.00
POINTLD-2 PTL=   5.0    0     0  .011  .592  .092  .010  .311   .00  .104
ENDATA11A
ENDATA12
ENDATA13
ENDATA13A
BEGIN  RCH    1
PLOT   RCH    1   2   3   4   5   6   7   8   9
```

APPENDIX H

OUTPUT DATA FOR THE CALIBRATED MODEL OF THE WHIPPANY RIVER

Table H.1 Output data for the calibrated model of the Whippany River.

REACH #	ELE-MENT #	RIVER km	TEMP DEG-C	DO MG/L	BOD MG/L	ORGN MG/L	NH3N MG/L	NO2N MG/L	NO3N MG/L	SUM-N MG/L	ORGP MG/L	DIS-P MG/L	SUM-P MG/L
1	1	15	10.9	10.13	1	2.87	0.17	0.23	2.16	5.43	0.17	1.06	1.23
1	2	14.8	10.9	8.98	1.26	4.91	2.66	0.18	1.68	9.43	0.17	1.06	1.23
1	3	14.6	10.9	9.37	1.26	4.91	2.67	0.18	1.68	9.43	0.17	1.06	1.23
1	4	14.4	10.9	9.68	1.26	4.9	2.67	0.18	1.68	9.43	0.17	1.06	1.23
1	5	14.2	10.9	9.93	1.25	4.9	2.67	0.18	1.68	9.43	0.17	1.06	1.23
1	6	14	10.9	10.13	1.25	4.9	2.68	0.18	1.68	9.43	0.17	1.06	1.23
1	7	13.8	10.9	10.3	1.25	4.89	2.68	0.18	1.68	9.43	0.17	1.06	1.23
1	8	13.6	10.9	10.43	1.24	4.89	2.69	0.18	1.68	9.43	0.17	1.06	1.23
1	9	13.4	10.9	10.54	1.24	4.88	2.69	0.18	1.68	9.43	0.17	1.06	1.23
1	10	13.2	10.9	10.62	1.23	4.88	2.69	0.18	1.68	9.43	0.17	1.06	1.23
1	11	13	10.9	10.69	1.23	4.87	2.7	0.18	1.68	9.43	0.17	1.06	1.23
1	12	12.8	10.9	10.75	1.23	4.87	2.7	0.18	1.68	9.43	0.17	1.06	1.23
1	13	12.6	10.9	10.79	1.22	4.87	2.7	0.18	1.68	9.43	0.17	1.06	1.23
2	14	12.4	11.2	10.82	1.22	4.86	2.71	0.18	1.68	9.43	0.12	0.67	0.79
2	15	12.2	11.2	10.81	1.2	4.85	2.72	0.18	1.68	9.43	0.12	0.67	0.79
2	16	12	11.2	10.8	1.19	4.83	2.74	0.18	1.69	9.43	0.12	0.67	0.79
3	17	11.8	11.3	10.79	1.18	4.82	2.75	0.18	1.69	9.43	0.12	0.82	0.94
3	18	11.6	11.3	10.78	1.17	4.81	2.76	0.18	1.69	9.43	0.12	0.82	0.94
3	19	11.4	11.3	10.78	1.16	4.8	2.77	0.18	1.69	9.43	0.12	0.82	0.94
3	20	11.2	11.3	10.77	1.15	4.78	2.78	0.18	1.69	9.43	0.12	0.82	0.94
3	21	11	11.3	10.76	1.14	4.77	2.8	0.17	1.69	9.43	0.12	0.82	0.94
3	22	10.8	11.3	10.76	1.13	4.76	2.81	0.17	1.69	9.43	0.12	0.82	0.94
3	23	10.6	11.3	10.75	1.12	4.74	2.81	0.17	1.69	9.42	0.12	0.82	0.94
3	24	10.4	11.3	10.77	1.1	4.61	2.74	0.17	1.65	9.17	0.12	0.82	0.94
4	25	10.2	11.3	11.13	1.04	2.21	1.09	0.07	0.92	4.3	0.12	0.75	0.87

"Table H.1 (continued)"

REACH #	ELE-MENT #	RIVER km	TEMP DEG-C	DO MG/L	BOD MG/L	ORGN MG/L	NH3N MG/L	NO2N MG/L	NO3N MG/L	SUM-N MG/L	ORGP MG/L	DIS-P MG/L	SUM-P MG/L
4	26	10	11.3	11.12	1.03	2.21	1.1	0.07	0.92	4.3	0.12	0.75	0.87
5	27	9.8	11.2	11.1	1.03	2.21	1.1	0.07	0.92	4.3	0.12	0.71	0.83
5	28	9.6	11.2	11.09	1.03	2.21	1.1	0.07	0.92	4.3	0.12	0.71	0.83
5	29	9.4	11.2	11.08	1.02	2.21	1.1	0.07	0.92	4.3	0.12	0.71	0.83
5	30	9.2	11.2	11.06	1.02	2.2	1.1	0.07	0.92	4.3	0.12	0.71	0.83
5	31	9	11.2	11.05	1.02	2.2	1.1	0.07	0.92	4.3	0.12	0.71	0.83
5	32	8.8	11.2	11.04	1.02	2.2	1.1	0.07	0.92	4.3	0.12	0.71	0.83
5	33	8.6	11.2	11.03	1.02	2.2	1.11	0.07	0.92	4.3	0.12	0.71	0.83
5	34	8.4	11.2	11.02	1.01	2.2	1.11	0.07	0.92	4.3	0.12	0.71	0.83
5	35	8.2	11.2	11.02	1.01	2.2	1.11	0.07	0.92	4.3	0.12	0.71	0.83
5	36	8	11.2	11.01	1.01	2.2	1.11	0.07	0.92	4.3	0.12	0.71	0.83
5	37	7.8	11.2	11	1.01	2.2	1.11	0.07	0.92	4.3	0.12	0.71	0.83
5	38	7.6	11.2	10.99	1.01	2.19	1.11	0.07	0.92	4.3	0.12	0.71	0.83
6	39	7.4	11.5	10.85	1.03	2.14	1.05	0.07	0.92	4.17	0.11	0.61	0.72
6	40	7.2	11.5	10.84	1.02	2.13	1.05	0.07	0.92	4.17	0.11	0.61	0.72
6	41	7	11.5	10.84	1.02	2.13	1.05	0.07	0.92	4.17	0.11	0.61	0.72
6	42	6.8	11.5	10.83	1.01	2.12	1.06	0.07	0.92	4.17	0.11	0.61	0.72
6	43	6.6	11.5	10.82	1	2.12	1.06	0.07	0.92	4.17	0.11	0.61	0.72
6	44	6.4	11.5	10.81	0.99	2.11	1.07	0.07	0.92	4.17	0.11	0.61	0.72
6	45	6.2	11.5	10.8	0.99	2.11	1.07	0.07	0.92	4.17	0.11	0.61	0.72
6	46	6	11.5	10.79	0.98	2.11	1.08	0.07	0.92	4.18	0.11	0.61	0.72
6	47	5.8	11.5	10.76	0.97	2.12	1.14	0.07	0.93	4.26	0.11	0.61	0.72
7	48	5.6	11.3	10.54	0.99	2.29	1.62	0.08	0.94	4.93	0.12	0.7	0.82
7	49	5.4	11.3	10.54	0.98	2.28	1.62	0.08	0.94	4.93	0.12	0.7	0.82
7	50	5.2	11.3	10.54	0.98	2.28	1.63	0.08	0.94	4.93	0.12	0.7	0.82

"Table H.1 (continued)"

REACH #	ELE-MENT #	RIVER km	TEMP DEG-C	DO MG/L	BOD MG/L	ORGN MG/L	NH3N MG/L	NO2N MG/L	NO3N MG/L	SUM-N MG/L	ORGP MG/L	DIS-P MG/L	SUM-P MG/L
7	51	5	11.3	10.54	0.97	2.27	1.63	0.08	0.94	4.93	0.12	0.7	0.82
7	52	4.8	11.3	10.54	0.96	2.27	1.64	0.08	0.94	4.93	0.12	0.7	0.82
7	53	4.6	11.3	10.54	0.95	2.26	1.64	0.08	0.94	4.92	0.12	0.7	0.82
8	54	4.4	11.1	10.54	0.95	2.26	1.64	0.08	0.94	4.92	0.15	0.78	0.93
8	55	4.2	11.1	10.54	0.94	2.25	1.65	0.08	0.94	4.92	0.15	0.78	0.93
8	56	4	11.1	10.54	0.93	2.25	1.65	0.08	0.94	4.92	0.15	0.78	0.93
8	57	3.8	11.1	10.54	0.93	2.24	1.66	0.08	0.94	4.92	0.15	0.78	0.93
8	58	3.6	11.1	10.54	0.92	2.24	1.66	0.08	0.94	4.92	0.15	0.78	0.93
8	59	3.4	11.1	10.54	0.91	2.23	1.67	0.08	0.94	4.92	0.15	0.78	0.93
8	60	3.2	11.1	10.54	0.9	2.23	1.67	0.08	0.94	4.92	0.15	0.78	0.93
8	61	3	11.1	10.54	0.9	2.22	1.68	0.08	0.94	4.92	0.15	0.78	0.93
8	62	2.8	11.1	10.54	0.89	2.22	1.68	0.08	0.94	4.92	0.15	0.78	0.93
8	63	2.6	11.1	10.54	0.88	2.22	1.68	0.08	0.94	4.92	0.15	0.78	0.93
8	64	2.4	11.1	10.54	0.88	2.21	1.69	0.08	0.94	4.92	0.15	0.78	0.93
8	65	2.2	11.1	10.54	0.87	2.21	1.69	0.08	0.94	4.92	0.15	0.78	0.93
8	66	2	11.1	10.54	0.86	2.2	1.7	0.08	0.94	4.92	0.15	0.78	0.93
8	67	1.8	11.1	10.54	0.86	2.2	1.7	0.08	0.94	4.92	0.15	0.78	0.93
8	68	1.6	11.1	10.54	0.85	2.19	1.71	0.08	0.94	4.92	0.15	0.78	0.93
8	69	1.4	11.1	10.54	0.84	2.19	1.71	0.08	0.94	4.92	0.15	0.78	0.93
8	70	1.2	11.1	10.54	0.84	2.18	1.71	0.08	0.94	4.92	0.15	0.78	0.93
8	71	1	11.1	10.53	0.83	2.17	1.71	0.08	0.94	4.9	0.15	0.78	0.93
9	72	0.8	12	10.46	0.83	2.1	1.65	0.08	0.91	4.73	0.16	0.74	0.9
9	73	0.6	12	10.45	0.83	2.09	1.65	0.08	0.91	4.73	0.16	0.74	0.9
9	74	0.4	12	10.45	0.82	2.09	1.65	0.08	0.92	4.73	0.16	0.74	0.9
9	75	0.2	12	10.45	0.82	2.08	1.66	0.08	0.92	4.73	0.16	0.74	0.9

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