MPCA Technical Note

Water Quality Parameter and Calibration Guidance for HSPF

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For RESPEC, Mr. Tony Donigian was the Work Assignment Manager, and Mr. John Imhoff served as the Project Engineer. Both contributed to conceptualization, design, performance and review of the project, and both took on selective writing assignments and review responsibilities. Portions of the written text were also generated by Mr. Brian Bicknell and Mr. Seth Kenner. Dr. Anurag Mishra had responsibility for organizing the very large body of parameter values and performing the analyses that resulted in the parameter value ranges that are presented in this document. All the above-mentioned staff contributed to the production of the final document.

The water quality calibration and parameter guidance contained in this document was derived from numerous proficient HSPF modelers who provided source data and documents. While many of the foundational materials used to develop this document were those the Project Team had developed or acquired in-house over the last 30 years, we are also indebted to significant contributions that were provided for the current project by three individuals: Dr. Chuck Regan at the Minnesota Pollution Control Agency, Dr. Jon Butcher at Tetra Tech, Inc. and Mr. Gary Shenk at the USEPA Chesapeake Bay Program Office.

The material contained in this document should be viewed as ***general*** guidance which will continue to evolve and change as the water quality modeling technology and data bases expand and improve with time.

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1.0 Introduction

This Technical Note (Note) provides users with guidance on how to estimate the water quality input parameters in the PQUAL, IQUAL, and RCHRES (free-flowing reach or mixed reservoir) modules of the Hydrological Simulation Program-Fortran (HSPF) watershed model. The primary purpose of this Technical Note (Note) is to provide guidance for the calibration of the parameters involved in waterbody loadings, and stream and lake biochemical transformations. The emphasis of parameter discussions and calibration guidance pertain to the PQUAL/IQUAL loadings modules, water temperature (HTRCH), dissolved oxygen (OXRX), nutrient (NUTRX) and plankton (PLANK) module sections of the RCHRES block. Recognizing that successful instream water quality calibration cannot be achieved without appropriate consideration and representation of constituent fluxes (i.e., loadings) into water bodies, the Note provides guidance for modeling point and nonpoint sources of temperature, dissolved oxygen and nutrients. Nonpoint sources that are addressed include land surface washoff and subsurface contributions, and wet and dry atmospheric deposition.

This Technical Note provides similar guidance (using a similar format) for HSPF water quality simulation to that which has been previously developed for HSPF hydrology and sediment simulation by means of two BASINS Technical Notes:

- EPA BASINS Technical Note 6: Estimating Hydrology and Hydraulic Parameters for HSPF (USEPA, 2000)
- EPA BASINS Technical Note 8: Sediment Parameter and Calibration Guidance for HSPF (USEPA, 2006)

As was the case with the two previous Technical Notes, this Note addresses relevant sections of both the pervious (PERLND) and impervious (IMPLND) land surface modeling components, and the instream (RCHRES) component.

For each relevant input parameter, this guidance includes a parameter definition, the units used in HSPF, and how the input value may be determined (e.g. initialize with reported values, estimate, measure, and/or calibrate). Where possible, we discuss how to estimate initial values using the data and tools included with BASINS. Also discussed, where appropriate, is the physical basis of each parameter and the corresponding algorithms as described in the HSPF User's Manual (Bicknell, et al, 2006) and other literature sources. In addition to the guidance provided herein, model users are directed to other sources, including the HSPF Application Guide (Donigian et al., 1984) and an early summary of HSPF calibration experience by Donigian (2002). As noted above, a greater level of detail is dedicated to outlining suggested procedures for instream water quality calibration, using a variety of graphical and statistical measures.

Summary tables are attached (in Section 10) that provide general guidance (i.e. 'expected') ranges for the parameters discussed below, based on both the parameter guidance and experience with HSPF over the past four decades on watersheds across the U.S. and abroad (Donigian, 2002). It should be noted that the ranges for the nonpoint source parameters are based on the full range of values from the literature, since these also vary by constituent and land use; whereas the instream water quality parameters are derived from a statistical analysis of all the applications

reviewed to determine both the **25%-75% range**, and the **5% - 95% range** of parameter values to provide some assessment of the most likely and possible ranges, respectively.

The overarching principal in parameter estimation should be that the estimated values must be realistic, i.e. make 'physical' sense, and must reflect conditions on the watershed. If the values estimated by the model user and/or derived from the guidance herein, do not agree with the value ranges in the summary table, the user should question and re-examine the estimation procedures. The estimated values may still be appropriate, but the user needs to confirm that the parameter values reflect unusual conditions on the watershed. In cases where the modeler chooses to use parameter values that are outside the value ranges in the summary tables, explanation of why this was done should be a component of the documentation for the model application.

Another source of instream parameter information is the HSPF Parameter Database (HSPFParm) (US EPA, 1999) http://www.epa.gov/ost/basins/support.htm. HSPFParm consists of parameter values from previous applications of HSPF across North America assimilated into a single database, and with a customized graphical user interface for viewing and exporting the data. The pilot HSPFParm Database contains parameter values for model applications in over 40 watersheds in 14 states. MPCA funded an update to HSPFParm in 2012. Under contract to the MPCA, AQUA TERRA Consultants ported the original stand-alone HSPFParm software to this BASINS plug-in. As part of that project, many recent and completed Minnesota HSPF applications were added to the HSPFParm database to provide a MN-specific set of parameters for future applications. Currently, the HSPFParm software resides as a plugin within the release of BASINS 4.5.

The parameter values, contained in the database, characterize a broad variety of physical settings, land use practices, and water quality constituents. The database has been provided with a simplified interactive interface that enables modelers to access and explore the HSPF parameter values developed and calibrated in various watersheds across the United States, and to assess the relevance of the parameters to their own watershed setting.

2.0 Methodology

To develop this Technical Note we extended a request to targeted members of the HSPF user community for both parameter values (in the form of User Control Inputs or an alternative reach- or land segment-specific format) and written elements of land segment or instream water quality calibration guidance.

2.1 Approach to Parameter Evaluation

Baseline condition parameter values for nearly 20,000 land segments (pervious and impervious) and 9000 reaches were collected and evaluated. For the collected land segment parameter values we have tabulated minimum and maximum values. Because instream/lake parameter values are highly variable (i.e. the minimum-maximum ranges are often very large), we have provided additional insight into the distribution of reach baseline values by computing the 5th, 25th, 75th, and 95th percentile values for each parameter, and then displaying both the **25%-75% range** and the **5% - 95% range** in the summary tables. Accordingly, as a final step we reviewed the results that were obtained using the statistical metrics (noted above) and made adjustments in the ranges for certain parameters based on professional judgment.

Our purpose in providing this information is to offer application developers a better idea of the values that more commonly characterize reach attributes and processes. The less frequently used values that are nearer the minima and maxima should not be considered less valid than the mid-range values that are more frequently used. However, we believe that it is good modeling practice to document and describe the rationale for assigning extreme parameter values.

As stated above, the ranges and limits displayed do not imply that HSPF modelers should not use values beyond these ranges; just that, if such values are used, the modelers should describe the rationale and justification for those ‘outlier’ values as part of the study report.

The results of this evaluation are provided in tables in Sections 11 and 12, that are identical in format to those that were presented in EPA’s previous Technical Notes for Hydrology/ Hydraulics and Sediment.

2.2 Approach to Developing Calibration Guidance

As noted above, Technical Note is intended to provide nonpoint and instream water quality parameter calibration guidance that parallels the antecedent technical notes for HSPF hydrology/hydraulics and sediment. Our approach to developing and providing calibration guidance (Sections 3.0 and 4.0) has been to merge procedures that are practiced by various accomplished HSPF water quality modelers into a single body of guidance that sequentially addresses four topics: (1) Waterbody loadings as input to stream reaches; (2) initial HTRCH and RQUAL calibration guidelines; (3) an overview of parameter adjustments for HTRCH and RQUAL calibration; and (4) graphical aids for calibration.

3.0 Constituent Contributions to Waterbodies

Potential constituent loadings to a stream or lake modeled using RCHRES can originate as washoff from a pervious land surface and subsurface, washoff from an impervious land surface, dry or wet deposition from the atmosphere (including loadings associated with direct precipitation on the RCHRES surface), and/or point sources introduced directly into the RCHRES. The potential impacts of each of these loading types are discussed below.

3.1 Land Surface Contributions

Since direct observations of loading rates are often limited, and rarely available for most modeled watersheds, “target” ranges are developed from all available local, and possibly regional information on nonpoint source (NPS) contributions. Based on a literature review of available data within MN and elsewhere in the US, reviews of selected watershed models in MN, discussions with MPCA staff, and professional judgment, Target Loading Rates for MN were developed, as shown in Table 3.1(Donigian and Mishra, 2015). An earlier version of the table was developed to help guide the NPS and water quality calibration for the Illinois River Watershed (IRW) in Arkansas and Oklahoma. In addition, these ranges were also supported by earlier modeling studies in Arkansas (Donigian et al., 2005; Donigian et al., 2009), Minnesota (Mishra et al., 2014), Iowa (Donigian et al., 1995a) and Maryland (Donigian et al., 1995b)."

In making use of this table and the value ranges, the following should be noted:

a. The target NPS ranges are general guidelines to help modelers calibrate the NPS contributions within the watershed model.
b. Values for Biochemical Oxygen Demand (BOD)/Organics are likely to be more uncertain than most of the others due to the paucity of BOD data in most current studies.
c. The low end of the range of values is also likely to be more uncertain than the upper end due to difficulties in measuring extremely low concentrations.
d. The Sediment/Total Suspended Solids (TSS) loading rates in Table 3.1, especially for pasture and cropland, are derived from MN-specific studies and tend to be lower than comparable rates in the general literature for these land categories in other parts of the US. This may be due to the generally flat terrain, numerous lakes, and extensive wetlands common to MN, behaving as trapping mechanisms reducing sediment loading rates throughout the State.
e. If a site-specific watershed model requires significant deviation from the target ranges, the modeler should justify and document the reasons for the deviations in the modeling report.
f. All future modeling efforts in MN. and elsewhere, should include tabulations like Table 3.1, so that the experience gained from each model application can provide additional information to improve these loading rate estimates.

It should be noted that this section focuses on nonpoint loadings modeled with the PQUAL/IQUAL modules of HSPF; it does not include guidance for use of the more detailed and process-focused AGCHEM module which is much more data intensive for both setup and calibration. Model users who wish to employ AGCHEM should refer to the original HSPF Application Guide (Donigian, et al., 1984) and a recent application to the Illinois River Watershed in Arkansas and Oklahoma (Michael Baker Jr. et al., 2015).

Table 3.1. Recommended Target Nonpoint Source Loading Ranges for Minnesota

Constituent	Forest		Pasture*		Developed		Cropland		Impervious	
	Low	High	Low	High	Low	High	Low	High	Low	High
Sediment/TSS (tons/ac/yr)	0.05	0.15	0.2	1.0	0.15	0.5	0.1	1.5	0.05	0.5
BOD/Organics (lbs/ac/yr)	2	10	5	70	5	15	5	50	3	20
NO_3-N (lbs/ac/yr)	1	5	1	15	3	10	10	30	2	5
NH_4-N (lbs/ac/yr)**	0.1	1.0	0.2	1.5	0.2	2.0	0.5	2.0	0.5	1.5
TN (lbs/ac/yr)	2	8	2	25	5	15	10	50	3	10
PO_4-P (lbs/ac/yr)	0.02	0.10	0.2	2.0	0.1	1.0	0.3	2.0	0.2	0.7
TP (lbs/ac/yr)	0.05	0.50	0.5	2.5	0.2	1.5	0.5	3.0	0.3	1.0

* excludes pasture receiving manure/litter applications
** In this document, NH4 will be used to designate all forms and species of ammonia and ammonium.

3.2 PERLND Calibration Overview and Guidelines

PERLND and IMPLND calibration is also hierarchical, with the flow (including snow) and sediment calibration performed first prior to calibration of loadings provided by the land areas. Water temperature is the next step prior to attempting nutrient loading calibrations. In situations where nonpoint loadings contribute a significant volume of water to the reach system, the water temperature values simulated in PSTEMP (Soil Temperature Section of PERLND module) and PWTGAS (Water Temperature and Dissolved Gases section of PERLND module) may become dominant factors in water temperature simulation. The parameterization of the PSTEMP section should be checked for reasonableness prior to beginning the process of instream water temperature calibration. Similarly, the pollutant loadings to the RCHRES network should be checked for reasonableness before beginning the Dissolved Oxygen (DO), nutrient and plankton calibrations.

For PWTGAS/IWTGAS simulation and calibration the following procedure should be used:

- Estimate All Dissolved Gas Parameters

PWTGAS - ELEV, IDOXP, ICO2P, ADOXP, ACO2P
IWTGAS - ELEV, AWTF, BWTF

ELEV - Model Segment Elevation
IDOXP & ICO2P - Interflow Concentrations
ADOXP & ACO2P - Baseflow Concentrations
AWTF & BWTF - Regression Parameters for Impervious Surface Runoff Temperature

- Adjust Temperatures (Simulated or Input) to Modify Gas Saturation Concentrations in Overland Flow
- For PWTGAS, Adjust Interflow and Groundwater Gas Concentrations, if necessary

The initial iteration should adjust the nutrient loadings to match the monthly and flow-based concentrations using the monthly accumulation and washoff, interflow concentrations, and groundwater concentrations. The groundwater concentrations will have the most impact at low flows and interflow has the most impact at high flows. The accumulation rate of nutrients (ACCUM), asymptotic limit of accumulation (SQOLIM), and washoff (WSQOP) parameters will mostly impact the simulated loading rates and concentrations at extreme flows as compared

to observed data available at those flows. Decreasing SQOLIM or increasing ACCUM/SQOLIM will generally increase the loading rates.

For PQUAL/IQUAL simulation and calibration, the following procedure should be used:

- For sediment-associated pollutants, calibration entails adjusting relevant Potency Factors (POTFW, POTFS)
- For overland pollutants,
  - Reduce SQOLIM if too much washoff occurs for all storms, and vice versa
  - Increase WSQOP if too much washoff occurs for small storms only, and vice versa
  - Reduce ACQOP if too much washoff occurs for closely-spaced storms only, and vice versa
- For interflow and groundwater pollutants, adjust IOQC and AOQC, respectively, for appropriate time periods.

3.3 Atmospheric Contributions

Atmospheric nitrogen and phosphorous from natural and human sources can fall onto land and waters through both wet weather deposition in rainfall and snow, or through dry weather deposition when particles and vapor are deposited without precipitation.

Based on the Community Multiscale Air Quality-modeled results provided by the EPA, wet plus dry atmospheric **inorganic nitrogen** (N) deposition contributes between 4 and 14 pounds annually per acre to Minnesota soil and water, averaging 8.4 pounds/acre/year across the state. Atmospheric deposition is highest in the south and southeast parts of the state and lowest in the north and northeast where fewer urban and agricultural sources exist. The annual wet and dry deposition amounts are nearly equal, on average, across the state. The inorganic N in wet plus dry deposition is about 62% unoxidized (NHx – mostly ammonia and ammonium) and 38% oxidized (N0x - nitrite, nitrate, other). Approximately 82.5% of total statewide inorganic N deposition falls onto land, and 17.5% falls directly into lakes, marshes, wetlands, and flowing waters. Of the N falling directly into waters, 97.5% falls into lakes and marshes, and about 2.5% falls directly into rivers, streams, and creeks (MPCA, 2013).

Statewide in Minnesota, the **phosphorous** loading from atmospheric deposition (total; wet+dry) is approximately 19% of total phosphorus loading using the 2007 estimate of atmospheric P deposition. The relative contributions of atmospheric P are larger for forest-dominated areas and smaller for agriculturally dominated areas. Accordingly, basin estimates range form approximately 4% for the Cedar and Lower Mississippi basins to 54% for the Rainy River Basin. These estimates are based on using uniform dry deposition estimates for all agricultural (0.241 lb/ac/yr), forest (0.102 lb/ac/yr) and urban (0.277 lb/ac/yr) areas in Minnesota (Barr Engineering Company, 2007)

Atmospheric inputs of nutrients to watersheds are highly dependent upon precipitation amounts. For nitrogen, precipitation typically accounts for a majority (50-80%) of total atmospheric inputs, while dry deposition typically accounts for the balance of total inputs (Pratt et al., 1996). It is currently assumed that precipitation inputs of phosphorus are important, but the limited data for phosphorus does not yet provide a clear picture of the actual relationship between precipitation inputs versus dry deposition inputs (Barr Engineering Company, 2007).

In HSPF PERLND and IMPLND unit area fluxes associated with atmospheric deposition are added to surface or upper zone
Dry Flux: ADDR = ADFX
Wet Flux: ADWT = PREC * ADCN
where ADFX is the areal flux rate – ADFX expressed as lb/ac or kg/ha per interval
ADCN is the concentration in rainfall expressed as mg/l and converted internally to lb/ac.in or kg/ha.in

In RCHRES total fluxes are added to dissolved storage
Dry Flux: ADDR = ADFX * SAREA
Wet Flux: ADWT = PREC * ADCN * SAREA

3.3.1 Dry Deposition Overview and Guidelines

Dry atmospheric deposition data can be downloaded from the EPA's Clean Air Status and Trends Network (CASTNet). Since dry deposition does not depend on precipitation, nitrate and ammonia dry deposition data (originally in kilogram/hectare) can be applied in an HSPF model application by using a pound-per-acre approach.

Original dry deposition data are supplied at a weekly time-step as kg/ha. To transform the data into daily time series, the data should be divided by the number of days in the sampling period. Dry atmospheric deposition of phosphorus also contributes to the total phosphorus load in the Lake of the Woods/Rainy River Basin [Barr Engineering, 2007]. Because of the lack of temporal data, atmospheric phosphorus deposition was represented by using monthly values of daily dry fluxes using the MONTH-DATA block in HSPF. A value of 0.12 kilogram/hectare per year (kg/ha/yr) (0.00029 pound per acre per day [lbs/ac/day]) was provided by Barr Engineering and was distributed throughout the months with higher values in the summer and lower values in the winter.

3.3.2 Wet Deposition Calibration Overview and Guidelines

Wet atmospheric deposition data can be downloaded from the National Atmospheric Deposition Program (NADP). Wet deposition of nitrate and ammonia can be used to account for nutrient inputs (as concentrations) during precipitation events. Thus, the nitrate and ammonia wet deposition concentrations time series can be paired with the precipitation input time series to characterize those loads.

The wet deposition data are obtained at a weekly time-step, plus or minus multiple days. Because wet deposition is expressed in units of concentration, the data do not need to be divided by the number of days in the sampling period. Instead, a concentration can be assigned to each day of the sampling period. Once transformed to daily time-series data, missing deposition data can be patched by using interpolation between the previous and later dates (when fewer than 7 days occurred between values [rare with this dataset], and by using monthly mean values (when more than 7 days occurred between values [a more likely scenario]).

3.3.3 Dissolved Oxygen Contribution in Direct Precipitation on the Waterbody Surface

A version of the HSPF code has been modified such that the DO in precipitation can be accounted for in the simulation. This enhancement is backwards compatible. The new version of HSPF with this enhancement is numbered as HSPF12.6b and is currently only available to MPCA (Duda and Mishra, 2018).

3.4 Point Source Contributions

In situations where point loadings contribute a significant volume of water to the reach system, the water temperature values assigned to the point loading may become a dominant factor in the water temperature simulation. Input data for point loads should be checked for reasonableness of water temperature values, as well as all chemical constituents.

In point source processing for HSPF instream model applications we typically do not have complete monitoring for N (usually only total ammonia, or TAM is reported); in addition, we may not have speciation of total phosphorus (TP). Common practice has been to use default tables of nutrient concentrations and/or distributions by treatment plant type. For instance, Class C (municipal small mechanical plant and pond mix) is reported to have typical values of 10 mg/L total nitrogen (TN), 7 mg/L nitrate as nitrogen (NO_3-N), 3 mg/L total Kjeldahl nitrogen (TKN), and 1 mg/L TAM. One approach is to use measured values for TAM, then assume that the other N components have the default values.

This characterization is unlikely to be absolutely correct in all situations, as speciation varies with plant performance, but it is the TN amount that is most likely to be conserved and is most important. We often see TAM values in monitoring in excess of 5 mg/L. If we combine this with 7 mg/L NO_3-N and 2 mg/L organic N, then we are raising the implied TN concentration from 10 to 14. In addition, we must recognize that in the HSPF setup the labile organic nutrients are "hidden" as a fraction of Carbonaceous Biochemical Oxygen Demand (CBOD).

Recommended standardized procedures are provided below. Use of these procedures will help eliminate instances in which we are over-estimating WWTP contributions to nutrients in streams.

N Components When Only TAM Is Reported
The recommended way to interpret the N components when only TAM is reported is as described in Table 3.2, below.

Below are default "typical" concentrations (mg/L) for selected treatment types:

Table 3.2. Default "Typical" Concentrations (mg/L) for Selected Treatment Types

	Class C (small mech/pond mix)	Class B (medium mechanical)
TN	10	17
NO_3-N	7	10
OrgN	1	3

With these N concentrations, and using factors CVON and CVOP, which express the labile organic fraction of CBOD (for N and P respectively, see below), one can calculate the following wastewater concentrations relative to measured TAM:

REFORGN = max {OrgN – CVON x CBOD, 0}
NO_3-N = max {TN – TAM – OrgN, 0}
where REFORGN = Refractory Org N

P Components When Only Total Phosphorus (TP) Is Reported
MPCA's default assumption is that TP is 72.3% orthophosphate as phosphorus (PO_4-P), but the total must still be corrected for labile P "hidden" in CBOD. One can perform this calculation as follows:
PO_4-P = 0.723 x TP
REFORGP = max {0.277 TP – CVOP x CBOD, 0}
where REFORGP = Refractory Org P

CBOD
In some Daily Monitoring Reports (DMR), CBOD is reported, while others report total BOD. Both are implicitly 5-day values. Working with 5-day CBOD is usually sufficient for river models, but we must correct for the nitrogenous component. Short term nitrogenous BOD is dominated by oxidation of ammonia, and can be estimated as:
CBOD = BOD – TAM x (1 – exp (-KTAM20 x *t*)),
where, BOD = Biochemical Oxygen Demand (5-day)
TAM = Total ammonia
KTAM20 = ammonia oxidation rate coefficient at 20ºC
t = time in hours (120 hrs)

Typical values of KTAM20 are in the range of 0.02 to 0.03/hr (use the same value as is specified in the NUT-NITDENIT block of an application's UCI), and since the evaluation extends for 5 days, *t* = 120 hours. For example, if KTAM20 is 0.02 then CBOD = BOD – TAM x (1 – 0.0907).

Labile Organic Fractions of CBOD
When CBOD decays, HSPF creates a proportional amount of inorganic N and P. The fractions of these hidden labile organic nutrient components are expressed by variables CVON (stoichiometric conversion from oxygen to labile N) and CVOP (same for P) that are calculated within subroutine NUTRX from the input variables contained in the CONV-VAL1 block of the UCI file. CVON = CVBN/CVBO, where CVBN = 14 x CVBPN x CVBP/31. We usually keep the CONV-VAL1 values at defaults, as in this example:

```
CONV-VAL1
*** RCHRES     CVBO    CVBPC    CVBPN   BPCNTC
*** x -  x     mg/mg   mols/mol mols/mol
100  999         1.63      106.       16.      49.
END CONV-VAL1
```

Using these values, CVON = 0.052938.
Similarly, CVOP is calculated as CVBP/CVBO and CVBP = (31 x BPCNTC)/(1200 x CVBPC). Using the example values, this yields CVOP = 0.007326.
See Section 8.0 CONV-VAL1 table for a more complete description of these parameters.

3.4 Constituent Transfers Between the Waterbody and the Waterbody Bed

Sediment diagenesis involves the degradation of organic material within the bed sediments of a stream or lake. This process requires significant oxygen consumption and uses oxygen from the water column as its primary source. HSPF represents the water column oxygen depletion from this process with one constant parameter, BENOD (Benthal Oxygen Demand at 20ºC with unlimited DO concentration). BENOD represents oxygen demand from the benthos or bed sediment. In the current RQUAL module, this parameter is not responsive to changes in incoming or outgoing organic material that settles in or is scoured from the stream bed. As a result, the BENOD parameter is manually increased or decreased to represent higher or lower incoming sources to the stream respectively. This methodology is also applied to the BRBOD parameter which is the release of BOD from the stream bed sediments. Note that the value designated for BENOD is a maximum value that is only achieved when the DO and water temperature conditions of the water column allow it. The effects of temperature and dissolved oxygen concentration on realized benthal demand are determined by the following equation:

BENOX = BENOD*(TCBEN**TW20)*(1.0 - Exp(-EXPOD*DOX)) (3)

where:

BENOX = amount of oxygen demand exerted by benthal muds (mg/m^2/interval)
BENOD = reach dependent benthal oxygen demand at 20 degrees C (mg/m^2/interval)
TCBEN = temperature correction factor for benthal oxygen demand
TW20 = water temperature – 20.0 (deg C)
EXPOD = exponential factor to benthal oxygen demand function (default value = 1.22)
DOX = dissolved oxygen concentration (mg/l)

4.0 Instream (RCHRES) Water Quality Calibration Overview

4.1 Introduction

Dissolved Oxygen (DO) concentrations in a stream reach are primarily affected by the following environmental factors and processes:

- Temperature – more DO can dissolve in cooler water and less in warmer water
- Reaeration – transfer of DO across the air-water interface in response to a DO deficit or surplus with respect to saturation conditions in the water – affected by turbulence and wind
- Addition of DO in the water from upstream, surface runoff, point sources, and groundwater
- Bacterial decay of CBOD (i.e., organic matter)
- Bacterial oxidation of ammonia (NH_3) to nitrite (NO_2) and nitrate (NO_3) (nitrification)
- Uptake of DO by decay of organic material in the sediment bed (SOD)
- Photosynthetic activity (phytoplankton and benthic algae/periphyton growth) which produces DO
- Phytoplankton/periphyton respiration, which consumes DO

In the MPCA models, the above processes are represented in each reach, and the model simulates DO in response to various driving forces (temperature, wind, and light) and inputs of water, DO, nutrients, and CBOD. The model's process representation considers the key input parameters, forces and chemicals that determine the DO concentration. Figure 4.1 provides an illustration of these processes. Table 4.1 provides a summary of the processes with their principal parameters. Complete descriptions of the parameters are included in the parameter guidance sections 6, 7, 8, and 9, and in the parameter tables in Section 12.

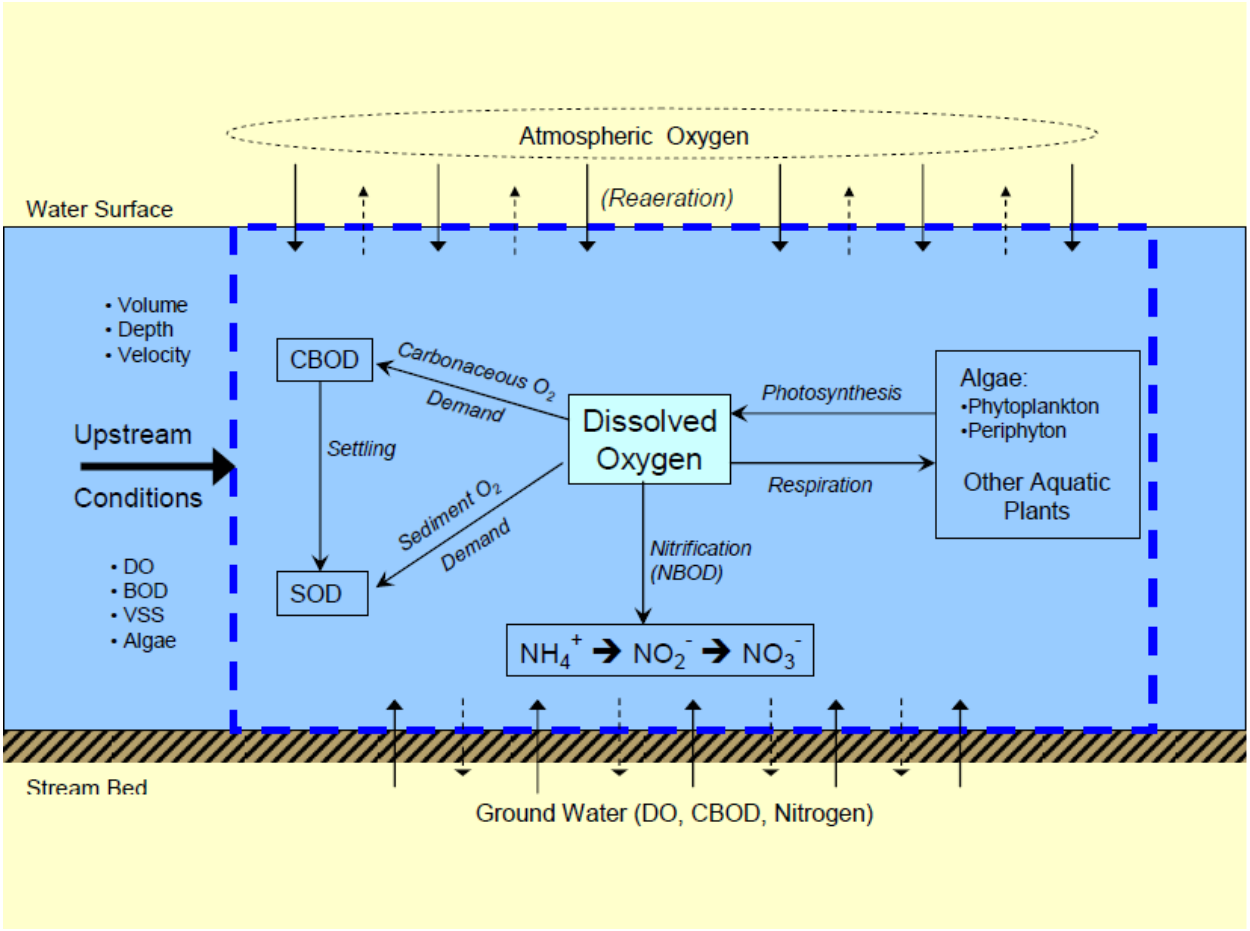

Figure 4.1. Stream Dissolved Oxygen Balance (MPCA, 2008).

Table 4.1. Primary Fluxes of DO in HSPF Models – Includes Key Parameters and Factors

Reaeration (+ or -)
• Reaeration (REAK, EXPRED, EXPREV, SUPSAT, CFOREA) • Flow velocity and/or depth • Temperature (determines DO saturation)
BOD Decay (-)
• Decay rate (KBOD20) • Loading rate from point & nonpoint sources (and internal loading from algal death) • Settling rate (KODSET) (settling affects amount of BOD available, not DO directly) • Benthal release (BRBOD1 & BRBOD2)
SOD/Benthic Demand (-)
• Benthic oxygen demand (BENOD)
Nitrification of NH_3 & NO_2 to NO_3 (-)
• Nitrification rate(s) (KTAM20, KNO220) • NH_4-N loading (includes NH_3 from BOD decay process)
Algal Growth/Respiration (+ & -)
• Availability of nutrients NH_3, PO_4, NO_3 (many factors affect this) • Availability of light – solar radiation, water depth, self-shading, sediment (EXTB, CFSAEX) • Temperature – (TALGRL, TALGRM, TALGRH) • Growth, respiration, & death rates – (MALGR, ALR20, ALDL, ALDH, OXALD) • Additional growth rate parameters – (CMMLT, CMMN, CMMNP, CMMP) • Misc. – (RATCLP, NONREF, ALNPR, SEED, MXSTAY, OREF, CLALDH, PHYSET)

In HSPF, SOD is represented using a very simple temperature-corrected rate that is also an exponential function of the concentration of DO in the water. At high DO levels, the full amount of the oxygen demand specified by the input demand (BENOD) is removed from the water, while at low concentrations, less of the demand is removed. At a DO concentration of 2 mg/L, only about 70% of the demand is removed, subject to temperature impacts. The BENOD parameter is a key input for calibrating DO, particularly in impacted stream reaches; and also for making adjustments when modeling scenarios that are expected to result in future changes in SOD. Measurements of SOD, which can be used to guide calibration of this process are relatively rare.

The CBOD simulation is dependent on the inputs of CBOD material, primarily from land areas and point sources, the decay process, and settling of the CBOD material to the bottom. Calibration adjustments of CBOD concentrations (if measurements are available) and calibration of DO concentrations are generally made by three types of adjustments. First, loading of CBOD from land areas is generally calibrated to typical annual and/or monthly loading rates for the various land categories. Second, the CBOD first order decay rate at 20ºC (KBOD20) is adjusted, typically within fairly narrow bounds. Third, the settling rate of CBOD material (KODSET) can be adjusted. The material that settles to the bottom is effectively removed from the system.

A related process that supplements the loading of CBOD is release of CBOD from the bottom sediments. This process is typically used in the MPCA models and is occasionally used to increase the nutrients (ammonia and orthophosphate) available for algal growth or to calibrate the nutrients to measured data. The two principal parameters (BRBOD1 and BRBOD2) are the benthal release rates of BOD under aerobic and anaerobic (incremental amount) conditions, respectively.

An important aspect of CBOD decay in HSPF is that the process results in the production of NH_4 and PO_4 according to the stoichiometry of the biomass. This is different than many other models in common use, and can be a significant source of the two nutrients if the model is parameterized or calibrated incorrectly. In effect, the CBOD decay process consumes DO, which results in production of NH_4, which in turn is oxidized to NO_3 with further consumption of DO.

The effect of temperature is very significant, since the saturation DO level is a strong function of temperature; furthermore, there is no other parameter which directly affects saturation. DO saturation ranges from 7.6 mg/L at 30ºC to 14.6 mg/L at 0ºC. In HSPF, the DO concentration will generally attempt to return to the saturation level in response to processes that change the concentration from saturation. For example, CBOD decay, nitrification, or algal respiration can remove oxygen, while algal growth increases oxygen. Reaeration is the process that allows the model to return to saturation DO levels. Reaeration in HSPF is generally a function of turbulence caused by flow velocity or wind (for lakes), and there are several optional methods for computing the key determinant of reaeration, the reaeration coefficient (KOREA). In MPCA models, the free-flowing stream method depends on user-defined parameters that are combined with the varying flow velocities and depths to compute KOREA. In lakes, the input wind speed is combined with a user-specified correction factor in the lake aeration equation (CFOREA) and the varying depths to compute KOREA. Typically, these reaeration-associated parameters are not adjusted much during calibration.

Nitrification is the microbial oxidation of NH_3 in a two-step process first to NO_2 and then to NO_3 that consumes DO. In streams with significant concentrations of NH_3, this process is a significant DO sink. The process is parameterized by the ammonia oxidation rate at 20ºC (KTAM20) and NO_2 oxidation rate coefficient at 20ºC (KNO220). While the model does not include default rates, the MPCA models generally use values in a narrow range and this process is typically not used as a calibration mechanism for DO; in some cases, the rates are adjusted to improve NH_4-N concentrations.

Phytoplankton and benthic algae growth and respiration processes are usually modeled in the MPCA models, and these processes are important determinants of the diurnal DO variation. The processes are modeled using standard formulations of algal growth and respiration that respond to available nutrient, light, and temperature inputs. Typically, the processes are not used to calibrate DO unless the default parameters result in consistent over-simulation of observed low DO values, and many of the input parameters are often not adjusted at all; most experienced HSPF modelers use a similar set of "standard" parameter values for most of the growth, respiration, and death processes. However, there are several parameters that are adjusted to improve the seasonal timing and magnitude of algal growth in addition to occasional use for nutrient calibration. These include the primary algal growth rate (MALGR), the phytoplankton settling rate (PHYSET), the base light extinction parameter (EXTB), and the three temperature correction factors (TALGRH, TALGRL, TALGRM). One problematic area of phytoplankton parameterization has been the neglect of advection related parameters, i.e., SEED, MXSTAY, and OREF.

In summary, DO is affected by many instream processes in the MPCA models. Many of the processes have a significant impact but are not usually used to improve the calibration of DO. Include among these are the nitrification of NH3 and algal growth/respiration, since their values remain relatively uniform for different streams and lakes. The key processes that are generally used to calibrate DO, once the temperature has been well calibrated and checked, are the CBOD loading and decay rates, plus the benthic uptake of DO (SOD). Additional DO calibration parameters that are typically used are the adjustment factor for lake reaeration CFOREA and the supersaturation fraction SUPSAT. Occasionally, the algal growth parameters and benthic release of CBOD are also used for calibration, if needed.

Biochemical transformations involve numerous water quality constituents that include dissolved oxygen (DO), biochemical oxygen demand (BOD), nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), organic nitrogen (ORN), orthophosphate (PO_4), organic phosphorus (ORP) and algae. All three primary modules in HSPF (PERLND, IMPLND, RCHRES) play a significant role in the main biochemical transformations that impact the water quality constituents. The guidance that follows is specific to the HTRCH (water temperature) and RQUAL (biochemical reactions) module sections within RCHRES. The focus of the guidance with respect to RQUAL is on the following:

1. Primary DO and BOD Balances (OXRX)
2. Primary Inorganic Nitrogen and Phosphorus Balances (NUTRX)
3. Plankton Populations and Associated Reactions (PLANK)

Since the process of calibration entails establishing the best fit between observed and simulated values for like constituents, it is useful to remain mindful of the nature and limitations of the observed values that are used in calibration. Much of the observed water quality data commonly

used during calibration are grab samples at one specific location along the stream and one typical depth. HSPF, however, simulates an entire stream reach as one completely mixed system. In a natural system, water quality concentrations can vary significantly along the stream length, depth, and width. As a result, engineering judgement must be employed during calibration to interpret the observed data, which may contain extremes, as it is compared to simulated results that represent the average conditions along the stream's length, width, and depth. For deeper lakes, calibration typically focusses on the observed data collected near the surface because those measurements best capture the water quality of flows that are released at the lake outlet.

The calibration of DO, nutrients and algae should begin after the hydrologic (see BASINS Technical Note 6), water temperature, and sediment (see BASINS Technical Note 8) calibrations have taken place. The water temperature calibration can be performed as an independent exercise before the calibration effort for OXRX, NUTRX and PLANK is undertaken. As will be elaborated below, the complex interdependencies between DO, nutrients and algae necessitate that the calibration effort for these constituents be performed as a coupled and iterative process that is comprised of multiple parameter adjustments in the OXRX/NUTRX/PLANK sections and evaluation of impacts on constituent concentrations and fluxes generated by all three module sections.

The calibration guidance that is provided in this section sequentially addresses three topics: (1) initial HTRCH and RQUAL calibration guidelines; (2) an overview of parameter adjustments for HTRCH and RQUAL calibration; and (3) graphical aids for calibration.

Water Temperature (HTRCH)

Given the strong influence that water temperature has on biological and chemical reaction rates, it is important to obtain the most reasonable values possible for the simulated water temperature in comparison to the observed data. If available meteorological data and observed instream temperature data are adequate to perform temperature simulation and calibration, the modeler should use adjustments primarily to five parameters: CFSAEX, KATRAD, KCOND, KEVAP, and KMUD as a basis for calibration. Note that each of these HTRCH parameters are discussed in detail in Section 5, along with estimation guidelines.

For water temperature calibration, the following steps and guidance are recommended:

1. CFSAEX is the ratio of shortwave radiation incident to a reach to radiation incident at the recording station. If heavy vegetation or irregular topography shades a reach for all or part of the day, the value of this parameter can be lowered accordingly. Since shortwave radiation is the largest source of heat to the reach, adjustment of the value for CFSAEX is the most effective of all five water temperature calibration parameters.
2. The values for KATRAD, KCOND and KEVAP parameters are empirically based, and the default values for all three should be used for the first calibration run.
3. Simulated water temperature will tend to increase with a higher value assigned to the atmospheric longwave radiation heat transfer coefficient (KATRAD), and decrease with a lower value.
4. An increase in the value of the conductive convective heat transfer coefficient (KCOND) will increase heat transfer between water and the atmosphere. Consequently, simulated water temperature may either increase or decrease depending on the relative temperatures of water and air.

5. Simulated water temperature will tend to decrease with a higher value assigned to the evaporation coefficient (KEVAP), and increase with a lower value.
6. KMUD is the heat conduction coefficient between water and the mud/ground beneath the water in the optional bed conduction process. Higher values of KMUD will tend to decrease the diurnal swing in water temperature, since heat can be transferred between the bottom mud and the water in response to a temperature difference between the ground and the water. This process also depends on the value of MUDDEP and careful specification of the ground temperature TGRND (or TGRNDM, i.e., monthly values of TGRND). This process is generally more important and useful for smaller, i.e., shallower rivers and streams where the ratio of water surface to streambed area is typically lower than in deeper rivers during a large portion of the year. In such settings if the value for TGRND is incorrectly specified, this process could cause water temperature to be consistently over- or under-simulated.

In situations where point or nonpoint loadings contribute a significant volume of water to the reach system, the water temperature values assigned to the point loading, or the temperatures simulated in PSTEMP and PWTGAS for the nonpoint heat loadings, may become the dominant factor in water temperature simulation. If reasonable adjustments to the calibration parameters cannot produce an acceptable calibration, input data for point loads or the parameterization of the PSTEMP (soil temperature) section should be re-visited. Alternatively, one or more of the meteorological input data time series may not properly represent the study reaches and should be re-examined.

Biochemical Reactions (RQUAL)

The hydrology, climate, and physical characteristics of a watershed have significant impacts on the hourly, seasonal, and annual processes involved in the simulated biochemical transformations. Because of this, it is often difficult to accurately represent them in watershed and stream models. The water quality response of a stream or lake is collectively determined by loadings from a watershed's surface, interflow, groundwater, and point sources contributions; sources and sinks within the water body; and all the interdependent biochemical transformations themselves.

The calibration of RQUAL can be quite complicated and time-consuming, depending on the number of constituents and processes that are simulated. In fact, adjustment of RQUAL simulation results to more closely duplicate observed values is not always achieved solely by calibration. In some cases, simulation of additional constituents and/or processes may allow improvements to simulation results which cannot be obtained solely by adjustment of parameter values. For example, simulation of plankton may be necessary in order to duplicate observed seasonal fluctuations in nutrient concentrations. Thus, while the user is allowed to model nutrients without consideration of plankton, it may not be possible to obtain a good fit between simulated and observed nutrient values in cases where biological factors are important, but are not modeled. Module sections GQUAL and RQUAL contain many user options for simulating or not simulating various constituents and processes. Simulation results are equally dependent on the simulation of all important constituents/processes and on development of realistic parameter values.

Calibration of RQUAL is also further complicated by two additional factors. First, the interrelationships of the various constituents result in changes in simulated concentrations for numerous constituents by adjustment of a parameter value specific to only one constituent. For

example, if one increases the value for the algal respiration rate parameter in order to reduce simulated plankton populations, the modification will also result in increased values for nutrients and inorganic carbon and a decreased value for dissolved oxygen. Thus, the final calibration of any one constituent in RQUAL cannot be completed until all adjustments have been made to associated constituents. The calibration of RQUAL is complete when the best overall fit to data is achieved for all constituents which are simulated, with the additional caveat that the various process fluxes are all reasonable for the water quality conditions of each modeled reach. Attaining 'best overall fit' is of necessity a matter of professional judgment.

The second factor which complicates the calibration of RQUAL is the wide range of values which have been reported for the model parameters. The variability of literature values for many parameters results from the complexity of the physical, chemical, and biological factors which influence the ultimate biochemistry of each individual stream or lake. Quite often it is difficult for the model user to know whether or not the values assigned to calibration parameters are reasonable for the study area, even if the values do result in a good simulation.

Given the potential complexity of RQUAL simulation, as well as the flexibility allowed in the choice of constituents/processes simulated, it is not possible to provide a detailed step-by-step calibration procedure. However, it is possible to provide overall guidance, offer general recommendations and point out important considerations. The following guidelines are helpful for understanding the processes that affect the various constituents and the HSPF parameters that affect these processes.

4.2 Initial RQUAL Calibration Guidelines

The initial step is to determine the processes and constituents that are appropriate for inclusion in the model based on the monitoring data available, the requirements of the ultimate model users, and the type of questions that are to be answered by the model. For example, should the model include nutrients, but not the processes that generally affect nutrients such as algal growth? Or should the model consider the effects of sediment association on PO_4 and/or NH_3 simulation? Should the model include the effects of denitrification on NO_3 concentrations? Should benthic algae be modeled using the simple representation based on multipliers to the phytoplankton process rates, or should it be modeled using the detailed methods that also allow multiple species? The answers to these questions are often data dependent.

The initial step should also include determination of which constituents have sufficient monitoring data to support calibration. If there are no data for some constituents (e.g., CBOD), the simulated values should still be reviewed along with the constituents that have monitoring data, so that the modeler can ascertain that reasonable levels are maintained.

Once the basic process/constituent choices have been made, an initial estimate of all parameters should be completed by using all available knowledge of the watershed, the modeler's experience, and parameters from nearby watersheds where HSPF has been applied. Alternatively, this step can also start by acquiring the necessary "minimum and/or possible" parameter values that are included in the tables in Section 10.

An important element of the RQUAL calibration is to try to ensure that all reaches that are being calibrated to monitoring data maintain sufficient flow during most of the time period so that the

biochemical processes can be simulated. **In HSPF, this minimum flow threshold is defined by the average depth (AVDEP) being greater than 2 inches. When the depth is below the threshold, the processes are not operable, and all constituents are subject only to advection.** In this low-flow regime, nutrients and dissolved oxygen concentrations will generally reflect the baseflow, i.e., the active groundwater concentrations that are defined in the PQUAL section of the PERLND land segments, and once the constituents are in the reach, they will only be affected by advection, direct rainfall inputs, and evaporation of the water until the depth rises above the 2-inch threshold.

In some projects, the lack of algae (Chlorophyll *a*) monitoring data or a perceived absence of an algal problem in the water bodies will result in a decision to not model phytoplankton and/or benthic algae. In these cases, users should be aware that in any natural waters where DO levels are depressed and/or nutrient levels are moderate, algal growth is likely occurring if there is sufficient light available, and the resulting growth/respiration cycle during the day is affecting the DO concentrations. The concentrations will increase during the day and decrease at night. In addition to missing the diurnal DO behavior, the lack of algal growth processes will result in simulating higher concentrations of inorganic nutrients (NO_3, NH_4, and PO_4), since they won't be taken up by the algae. In general, it is recommended to simulate algal dynamics (e.g., at least phytoplankton) even if there are no chlorophyll data available. The phytoplankton chlorophyll a can be calibrated to low values during the spring-summer-autumn part of the year. This will provide more realistic simulation of the nutrient and DO dynamics.

For a model application that includes algal simulation, the recommended approach to calibration is to consider all constituents concurrently, since most constituents and processes are dependent on each other. The concentrations that should be reviewed include the DO, CBOD, NH_3, NO_3, PO_4, phytoplankton, and benthic algae. In addition to graphical output of the concentrations and statistical comparisons (if sufficient monitoring data are available), the other primary output that is useful is a summary of the various fluxes for each reach. Ideally, these summaries should include the following quantities:

- inflows from upstream reaches
- inflow from local land areas and any point sources and/or diversions
- inputs from atmospheric deposition
- outflows
- various process fluxes relevant to the constituent

For example, for DO the main process fluxes consist of:

- losses due to CBOD decay
- losses due to nitrification
- losses due to algal respiration
- gains (and losses) from reaeration
- gains due to algal growth/photosynthesis

Reviewing these fluxes for appropriateness provides valuable information for adjusting process parameters to increase or decrease the concentrations in subsequent calibration runs. The user should be aware that the time increment of the above flux summary might mask some of the important behavior. If the summary pertains to the entire time period of the run, important seasonal and diurnal variations might be hidden in the annual/total amounts. Currently, the program HSPEXP+ (Mishra et al., 2017) includes the capability to generate tables of the overall

(i.e., annual) inflows, outflows, and the process fluxes for DO, BOD, TN, and TP for each reach in a model; the component nutrients NO_3, NH_3, and PO_4 are included in the TN and TP summaries. The individual inflows, i.e., nonpoint, upstream, and point source quantities are combined into a total inflow. Table 4.2 shows an example of the reach-specific summary for BOD; current plans are to extend this capability for DO and nutrient species. Note, the HSPEXP+ summaries also include summaries of the land area loads for all pervious and impervious segments in the model.

Table 4.2. Example BOD Flux Summary Report for a Selected Reach (Expressed as Lbs)

	Mean	2003	2004	2005	2006	2007
BOD Inflow	229,700	279,980	166,820	296,500	161,490	200,220
BOD Decay	-4,055.40	-5,350.80	-4,100.10	-5,014.30	-2,674	-3,178.40
BOD Settle	-10,104	-9,898.10	-11,007	-11,566	-7,862.40	-9,365.90
BOD Benthic Release	5,847	5,501.90	6,107.40	6,737.50	4,682.50	5,436.70
BOD Phytoplankton	19.384	34.823	13.947	29.245	11.695	3.427
BOD Zooplankton	0	0	0	0	0	0
BOD Benthic Algae	5,158.10	5,770.40	6,626.90	6,053	2,846.60	4,636.10
BOD Outflow	226,570	276,040	164,450	292,730	158,510	197,750

In addition to summaries of the fluxes, a graphical summary of nutrients and algae concentrations on the same graph is provides valuable information on the seasonal behavior of how nutrients are impacting (and reacting to) the algal growth and death cycles. Figure 4.2 shows an example of this type of graph. Currently, the program HSPEXP+ generates one of these graphs for each reach in a model. This feature is available as “Regan Plots” under the “Graph” heading in HSPEXP+; note that the concentrations in these graphs are the “end of interval values; the intervals are specified in the BINARY-INFO table of HSPEXP+.

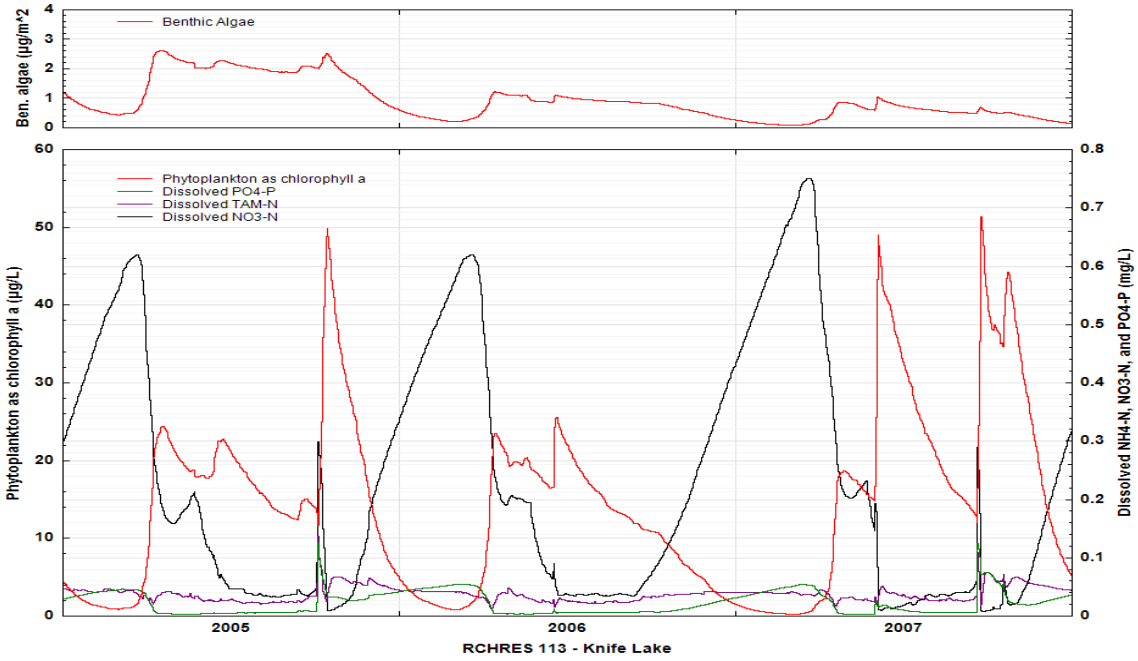

Figure 4.2. Regan Plots Demonstrating the Interactions among Algae and Nutrient Concentrations in a Reach.

4.3 Overview of Parameter Adjustments for RQUAL Calibration

The following sections describe the iterative procedures that are used to adjust the primary water quality characteristics that are important to ensure the biochemical system is being accurately represented. Initial iterations of the following procedures should be done with significant parameter changes to quickly get concentrations well within range of the targets. Later iterations can focus more on smaller adjustments to converge on more specific and subtle patterns in observed water quality data.

In this section separate discussions are provided for the key chemical constituents that are simulated with OXRX, NUTRX and PLANK. Each discussion begins by identifying key parameters that are associated with the process simulation. Next the direct, immediate impact of increasing or decreasing the value for each key parameter is indicated. (In most cases there will also be secondary and tertiary impacts to water quality because of the interactive nature of the biochemical transformations simulated in HSPF, as shown in Figure 4.1.) Finally, guidance for performing and sequencing calibration steps is suggested.

OXRX (Key constituents: DO and CBOD)

DO

There are several important processes that affect DO, and an important part of calibrating DO is ensuring that the relative magnitudes of the processes that are having the largest effects are reasonable for a given water body and reach. Modelers should make use of process flux summaries such as those described above for this constituent. The effects and conditions that are generally important are the saturation concentration, reaeration, CBOD decay, nitrification of NH_3, SOD, and algal growth/photosynthesis and respiration. Saturation concentration and reaeration gains (or losses) that the model computes to approach saturation are usually the most dominant processes. The saturation concentration is a direct function of water temperature, so if the simulated temperatures are not representative, DO concentrations that are simulated are not likely to be appropriate.

The reaeration rate controls the dominant process for changing DO in the streams. Reaeration in the Minnesota HSPF models is calculated as a power function of hydraulic depth and velocity. The primary parameters are the coefficient (REAK), which reflects a direct factor to the rate, and two exponents in the reaeration equation. The exponents (EXPREV and EXPRED) are applied to the average stream velocity and the average stream depth. The standard values used in most of the models are 0.969 for EXPREV and -1.673 for EXPRED. Increasing EXPREV will increase the reaeration rate, and increasing (i.e., larger negative values) EXPRED will reduce the reaeration rate over most of the depth range. Typically, calibration is performed using the factor REAK instead of the exponent parameters. The rate is also a function of temperature.

The CBOD decay, NH_3 nitrification, and SOD processes are usually important loss mechanisms for DO, depending on the levels of CBOD and NH_3 in the water body and the expected influence of SOD as indicated by knowledge of poor water quality conditions and a sediment bed with significant organic material content. The CBOD decay process can be adjusted by the decay rate KBOD20 and/or the CBOD settling rate KODSET. CBOD decay can also be adjusted by changing the amount of CBOD available for decay, either from loading or the benthic release rate parameter BRBOD. Nitrification can be adjusted with the nitrification rate constants

KTAM20 and KNO220 or adjustments to the amounts of NH_3 available for nitrification. In addition to ammonia loading from nonpoint and point sources, many models include benthic release of NH_3, BRTAM(1) and BRTAM(2).

Finally, if the flux of DO associated with algal growth is a significant fraction of the DO budget, then the phytoplankton and/or the benthic algae rates can be adjusted to increase or decrease DO concentrations. These adjustments are generally complex, since the effects will be widespread, i.e., all nutrients will be impacted and will likely show some differences. If algal growth is being simulated reasonably, these adjustments to DO should be the last resort. A final note: the DO process flux evaluation should also include examination of the diurnal variation; doing so requires specifying and evaluating a more detailed output than is typically generated.

CBOD

The primary CBOD-related processes, in addition to loading from land areas and point sources, are CBOD decay, benthic release of CBOD (optional process), settling of CBOD to the bottom sediments, and algal death. If observed CBOD concentration data are available, the loading rates will be the primary calibration adjustment, with the adjustment of process parameter values as a secondary means of calibration. Also, the model/simulated values are considered the *ultimate* CBOD, so observed data, which are often 5-day CBOD should be adjusted by a factor to approximate the *ultimate* CBOD (Refer to standard wastewater textbooks for appropriate conversion factors). If total organic carbon (TOC) measured data are available instead of CBOD, these same parameter adjustments are recommended; however, simulated TOC concentration (from the PLANK section) should be compared to the measured TOC data instead of CBOD.

Once again, it should be emphasized that adjustment of CBOD processes will affect a number of other constituents. The CBOD decay and settling process parameters are KBOD20 and KODSET, respectively. Increasing the values for these parameters will remove CBOD. The benthic release process parameters are BRBOD(1) and BRBOD(2). The first one is the base release rate under conditions that are both non-scouring and aerobic, while the second one is an increment to the base release that comes into play under scouring and/or aerobic conditions that disrupt bed sediment armoring. The final process that generally provides significant CBOD is death of algae (i.e., phytoplankton and benthic algae). If these constituents are not well represented in a current simulation, adjustments to the relevant parameters to increase or decrease CBOD may be advisable. Additional guidance for the algal processes is provided below under the phytoplankton and benthic algae headings. As noted, algal processes affect all other RQUAL constituents, so these adjustments should be a last resort if the algal simulation is acceptable.

In summary, if available instream DO data are adequate to perform DO simulation and calibration, the modeler should consider adjustments to seven parameters: KBOD20, KODSET, SUPSAT, REAK, CFOREA, BENOD, and BRBOD as a primary basis for calibration:

1. KBOD20 is the decay rate of BOD in the stream and has a larger impact at low flows. Increasing KBOD20 will generally reduce the BOD, increase the inorganic nutrients, and decrease DO.
2. KODSET is the settling rate of BOD in the stream and has a larger impact at low flows. Increasing KODSET will generally reduce BOD and inorganic nutrients, and increase DO. The impact of adjustments to KODSET is sensitive to the depth of water in a reach.

3. SUPSAT is the factor used to set the maximum allowable DO concentration as a factor of the DO saturation concentration. Increasing SUPSAT allows for DO concentrations above the DO saturation concentration to potentially increase.
4. REAK is the factor for reaeration in stream reaches. Both physical and biological processes play a role in determining reaeration phenomena. For stream conditions where the dissolved oxygen concentration is below saturation, increasing REAK will increase the dissolved oxygen concentrations. For stream conditions where the dissolved oxygen concentration exceed saturation, increasing REAK will decrease the dissolved oxygen concentrations. Supersaturated stream DO concentrations are most often attributable to excessive algal photosynthesis. Under these circumstances the impact of changing the value of REAK must be considered on a diurnal basis: an increase in REAK will result in decreasing DO values during the period of day during which photosynthesis occurs, but increasing DO values during the period of day during which photosynthesis ceases, but algal respiration continues.
5. CFOREA is a factor for lake reaeration used to account for good or poor circulation characteristics. Increasing CFOREA will increase lake DO concentrations.
6. BENOD is a factor for representing oxygen demand from bed sediments (SOD) and has a higher impact on the dissolved oxygen concentration at lower flows. Increasing BENOD will decrease DO concentrations.
7. BRBOD is the release of BOD from bed sediments. Increasing BRBOD increases nitrogen, phosphorus, and BOD concentrations and decreases DO concentrations.

Suggested steps in calibration of DO and BOD are as follows:

After the initial parameter values have been set, the overall simulated DO concentrations should be adjusted to be in a reasonable close range to the observed values using mostly independent reaeration coefficients REAK and CFOREA. Both seasonal and diurnal variations come into play in calibrating these parameters. Seasonal calibration should be considered first. This effort focuses on the net seasonal impacts of algal growth dynamics and their resulting diurnal fluctuations in photosynthesis/respiration (and the seasonal absence or minimization of these processes). Decreasing reaeration will decrease DO concentrations overall but will differentially impact the seasonal fluxes. In the northern hemisphere, to the extent that algal growth is suppressed by temperature and sunlight during the winter, decreasing REAK slows down the rate at which waterbody DO concentrations deviate from saturation. During the summer decreasing REAK has been observed to differentially decrease the lower simulated DO concentrations. A ‘reality check’ on the reasonableness of the diurnal fluctuations of DO concentrations in reaches with algal densities should also be performed.

For future iterations, when the incoming sources of nutrients are understood, the bed sediment oxygen parameter BENOD can also be adjusted. BENOD should be higher downstream of higher incoming sources of nutrients and BOD (such as downstream of effluent discharges) where more oxygen demanding nutrients have settled into the bed sediment. BENOD has a larger impact on lower flows but has some impact on all flows.

DO concentrations in subsurface flows (i.e., interflow and baseflow) can be used in later iterations to adjust the seasonal and flow-based DO concentrations after the nutrients, BOD, and chlorophyll *a* concentrations are generally well represented. These concentrations can be adjusted monthly and separately for interflow and groundwater. The groundwater concentrations have the most sensitivity especially at low flows. Interflow concentrations typically have

minimal impact on the higher flows when the DO balance is quickly dominated by reaeration when it enters the stream.

CBOD calibration is achieved by demonstrating a credible match of simulation results to the observed monthly BOD concentrations and flow patterns. In subsequent iterations, the instream loadings and losses should be considered for effectively representing the nutrient loadings from upstream to downstream. To effectively represent the spatial distribution, water quality data is needed at strategic locations to identify areas where higher nutrient loadings are apparent. Consecutive reaches that flow through areas with fairly similar nutrient loadings are also valuable for determining the balance between incoming sources and instream losses.

As noted above, nutrient loading rates should first be calibrated relative to the expected loading rates by land use and region. Next, if the concentrations at downstream gages are being simulated in proximity to observed data and upstream concentrations are generally high, then the instream loading representation should be increased as one moves downstream. The settling rates should then be increased or the nutrient loadings should be decreased watershed-wide to get the downstream concentrations to achieve the closest possible match to observed concentrations.

NUTRX (Key constituents: NO_3, NH_3, ORN and ORP, PO_4)

Nitrate (NO_3)

The NO_3 processes that should be adjusted first are gains due to nitrification of NH_3, and decay of CBOD, and losses due to algal growth and denitrification. Depending on the required direction of change and the existing magnitudes of the fluxes, nitrification can be adjusted by the nitrification rate constants KTAM20 and KNO220 or adjustments to the amounts of ammonia available for nitrification. In addition to NH_3 loading from nonpoint and point sources, many models include benthic release of ammonia BRTAM(1) and BRTAM(2). Since CBOD decay can contribute to the nitrate (and ammonia) pools, adjustments can be made using the CBOD decay rate KBOD20 or the amount of CBOD available for decay from loading and/or the CBOD benthic release parameters BRBOD(1) and BRBOD(2). The settling of CBOD to the bottom of the stream (KODSET parameter) also is a loss mechanism of CBOD that would affect NO_3 slightly. Denitrification of NO_3 can be adjusted using the rate constant KNO320 and the DO threshold for denitrification DENOXT. Finally, if NO_3 is providing a significant fraction of the N used for algal growth and algal growth is a significant fraction of the nitrate losses, then the phytoplankton and/or the benthic algae rates can be adjusted to increase or decrease the nitrate concentration. These adjustments are generally complex, since the effects will be widespread, i.e., all other nutrients and DO will likely show some differences to varying degrees. If algal growth is being simulated reasonably, these adjustments should be the last resort.

Denitrification is generally assumed to occur only in anoxic bottom sediments, where some bacteria utilize NO_3 for respiration because there is no oxygen available. Since HSPF does not include a separate benthic compartment where this process can be explicitly modeled, the usual alternative is to model denitrification in the water column to remove NO_3. This process is necessary for reaches that experience very low DO levels in the sediments. However, it is generally used for all reaches as an additional mechanism for reducing NO_3.

Ammonia (NH_3)

As is evident from the previous discussion of NO_3, the NH_3 processes are very much related to NO_3, and the procedures above provide guidance on NH_3. The primary processes are the gains due to benthic release (in many models) and decay of CBOD, and losses due to nitrification and algal growth. Depending on the magnitudes of the relevant process fluxes and loadings, the same parameters listed for NO_3 adjustments can be used for NH_3 adjustments. These include the 1) nitrification rates KTAM20 and KNO220, 2) the benthic release rates BRTAM(1) and BRTAM(2), and 3) the CBOD decay rate KBOD20. If necessary (and if NH_3 is providing significant N requirements for algae), the algal parameters can be adjusted to increase or decrease the NH_3 that is taken up by algal growth.

Organic N (ORN) and Organic P (ORP)

ORN and ORP concentrations should be adjusted to match observations or, lacking the observed data, they should be adjusted to reasonable levels. Modelers should note that the total ORN and ORP state variables consist of the N (or P) contained in phytoplankton, CBOD, and the refractory organic material (N or P). The primary processes that affect these organics, in addition to loading from point and nonpoint sources are algal growth, respiration and death and CBOD decay.

Orthophosphorus (PO_4)

This constituent is similar to NH_3 in some key ways. The processes that are most important are gains due to benthic release (in many models) and decay of CBOD, and losses due to algal growth. Depending on the magnitudes of the relevant process fluxes and loadings, the parameter adjustments include the benthic release rates BRPO4(1) and BRPO4(2), and the CBOD decay rate KBOD20. If necessary, the algal parameters can be adjusted to increase or decrease the PO_4 that is taken up during algal growth.

Generally, PO_4 is represented as a sum of dissolved inorganic P and reactive particulate P constituents. In HSPF, the total PO_4 variable can be modeled as completely dissolved, or more typically it is modeled as "sediment-associated" to include the particulate component. The relationship between the dissolved and particulate components is a function of the simulated sediment material (sand, silt, and clay), and it is determined by equilibrium adsorption parameters for each sediment size fraction. These adsorption coefficients are ADPOPM(1), ADPOPM(2), and ADPOPM(3), for PO_4 adsorbed to sand, silt, and clay, respectively. While representation of both the dissolved and particulate fractions is generally considered preferable, it should be noted that the equilibrium adsorption process is susceptible to some inaccuracy under conditions of variable/low suspended sediment concentrations.

If available instream nutrient data are adequate to perform nutrient simulation and calibration, the modeler should consider adjustments to six parameters: BRTAM, BRPO4, KTAM20, KNO220, KNO320 and DENOXT as a basis for calibration, as follows:

1. BRTAM is the release of ammonia from bed sediments. Increasing BRTAM will increase the ammonia concentrations.
2. BRPO4 is the release of phosphate from bed sediments. Increasing BRPO4 will increase the phosphate concentrations.
3. KTAM20 is the nitrification rate of ammonia. Increasing KTAM will decrease the ammonia concentrations but may or may not increase NO_2 and NO_3 concentrations depending on the denitrification and algal growth rates.

4. KNO220 is the nitrification rate of NO_2. Increasing KNO220 will increase the NO_3 to NO_2 concentration ratio. The value of this parameter is usually maintained at a level much higher than that of KNNO3 (below). Note that an option exists to not model nitrite at all.
5. KNO320 is the denitrification rate of NO_3. Increasing KNO320 will decrease the NO_3 concentrations.
6. DENOXT is the DO concentration threshold where denitrification occurs when the DO concentration is lower than DENOXT. Increasing DENOXT will decrease NO3 concentrations. The significance of the decrease will depend on how often DO conditions fall below the new threshold that the value of DENOXT establishes.

Suggested steps in calibration of nutrients are as follows:

Analogous to the CBOD calibration (discussed above), nutrient calibration is achieved by demonstrating a credible match of simulation results to the observed species, as evidenced in monthly and flow patterns in the concentrations for the main nutrient constituents NO_X (NO_2+NO_3), TAM, PO_4, and BOD/Organics.

Nutrient constituents should be adjusted after BOD calibration (if BOD data is available). Otherwise simulation results should be matched to organic nutrient data followed by TAM, PO_4, and NO_X, respectively. It may help to adjust TAM and PO_4 simultaneously because of their interdependent relationship with algal growth. Model users should consider modeling CBOD even if no observed data is available as the modeling of CBOD (often represented as combined BOD/Organics) is a primary means of allowing for organics loadings to the stream, which are known to occur.

In subsequent iterations, the instream loadings and losses should be considered in order to effectively represent the nutrient loadings from upstream to downstream. As noted earlier, to effectively represent the spatial distribution, water quality data is needed at strategic locations to identify areas where higher nutrient loadings are apparent. Consecutive reaches that flow through areas with fairly similar nutrient loadings are also valuable for determining the balance between incoming sources and instream losses.

Nutrient and BOD/Organic loading rates should first be calibrated relative to the expected loading rates by land use and region. Next, if the concentrations at downstream gages are being simulated in proximity to observed data and upstream concentrations are generally high, then the instream loading representation should be increased as one moves downstream. The settling rates should then be increased or the landscape loadings should be decreased watershed-wide to get the downstream concentrations to achieve the closest possible match to observed concentrations.

The primary parameters that impact nitrogen species distribution are the upland loading distribution, nitrification and denitrification rates, and algae nitrogen preference. Representing the balance between the inorganic forms of nitrogen is best achieved if observed water quality data is available for the species one is trying to represent; otherwise the default parameters should be used.

Initial iterations should use the loading distribution of TAM and NO_X to adjust the seasonal and flow distribution of their respective concentrations. Again, accumulation and interflow will impact higher flows, whereas groundwater will impact lower flows. The algae growth preference

for NO_3 (ALNPR) can also be adjusted to balance TAM and NO_X but should be adjusted considering locations with both low and high algae growth to get a better understanding of the nature of adjustments that are warranted. If watershed loading rates are well represented and low algae growth locations are reasonable but high algae growth locations show higher NO_3, then ALNPR should be increased. Experience in MN suggests that ALNPR should be at least 0.5, if not higher (C. Regan, personal communication, May 15, 2018).

Subsequent iterations should adjust the instream loading, transformations, and losses while considering the spatial difference in the nitrogen species distribution. After the loading rates have been calibrated adequately relative to the expected loading rates by land use and region, the instream processes can be used to reflect the difference in distribution from upstream to downstream. The general migration is from TAM to NO_3 so if the downstream distribution is more shifted toward NO_3 than observed data show, then the instream nitrification rates should be decreased and nonpoint loadings be readjusted watershed wide.

PLANK (Key constituents: Phytoplankton, Benthic Algae)

Phytoplankton

The biological activity of an ecosystem often depends upon the rate of primary production by photosynthetic organisms. Through the process of photosynthesis, phytoplankton consume carbon dioxide (CO_2) and release oxygen (O_2) into the water. At the same time, algal respiration consumes O_2 and releases CO_2. Phytoplankton reduce the concentration of nutrients in the water by consuming inorganic PO_4, NO_3, and NH_3. Through assimilation, these nutrients are transformed into organic materials which serve as a food source for higher trophic levels. A portion of the organic matter that is not used for food decomposes, which further affects the O_2 and nutrient levels in the water. In water bodies where phytoplankton have grown excessively, much of the available O_2 supply of the water may be depleted by decomposition of dead algae and respiration.

In some projects, the lack of algae (Chlorophyll a) monitoring data or a perceived absence of an algal problem in the water bodies may result in a decision to not model phytoplankton and/or benthic algae. In these cases, users should be aware that in any natural waters where DO levels are depressed and/or nutrient levels are moderate, algal growth is likely occurring if there is sufficient light available, and the resulting growth/respiration cycle during the day is likely affecting the DO concentrations. The concentrations will increase during the day and decrease at night. In addition to missing the diurnal DO behavior, the lack of algal growth processes will result in simulating higher concentrations of inorganic nutrients (NO3, NH4, and Ortho-P), since they won't be taken up by the algae. In general, it is preferable and recommended to simulate algal dynamics (e.g., at least phytoplankton) even if there are no chlorophyll data available. The phytoplankton chlorophyll a can be calibrated to low values during the spring-summer-autumn part of the year. This will provide more realistic simulation of the nutrient and DO dynamics.

Phytoplankton undergo three principal processes, **growth**, **respiration**, and **death**. The growth rate is affected by temperature conditions and the availability of light and nutrients. The growth process is modeled using a relatively complex set of equations, requiring solar radiation and temperature data, nutrient concentrations, and multiple parameters. On the other hand, the respiration and death processes are determined primarily by simple user-specified rates, subject to temperature effects and nutrient availability. In addition to the processes discussed above,

phytoplankton are subject to a modified form of **advection**, and they also can **settle** to the bottom of the reach, where they are considered lost from the system. These processes are described below with guidance on adjusting various parameters during calibration.

HSPF assumes that the entire phytoplankton population consists of one species. Furthermore, the model assumes that biomass of all living and dead biota (i.e., phytoplankton, zooplankton, benthic algae, dead organic materials) has a consistent chemical composition. The user specifies the biomass composition by indicating the carbon : nitrogen : phosphorus ratio and the percent-by-weight of carbon. This definition is done in the CONV-VAL1 table, which is part of the inorganic nutrient section NUTRX.

Additionally, the set-up of the phytoplankton model includes several options that must be selected in the PLNK-FLAGS table. In the standard approach described here, zooplankton are not simulated (i.e., the zooplankton flag ZOOFG = 0), and the effects of grazing are generally assumed to be included as a component of the algal death rate and/or the settling rate. Suspended sediment is generally assumed to contribute to light extinction, so it is recommended to set the flag SDLTFG to 1. Most models assume that ammonia makes up an important part of the nitrogen supply, so the flag NSFG should be set to 1, and this implies that ammonia does not retard nitrogen-limited growth; therefore, AMRFG should be set to 0. Finally, since most models do not include the increased complication of modeling pH, the CO_2 limitation on phytoplankton growth can be turned off by setting DECFG to 1, i.e., the phytoplankton – CO_2 linkage is decoupled.

Growth of phytoplankton is ultimately determined by a growth rate that is affected by the environmental conditions listed above. The program computes a unit growth rate for each of the factors PO_4, N, and light, and then it uses the smallest rate, i.e., the limiting rate to compute the actual growth rate. Each of these unit growth rates utilizes a temperature-adjusted maximum growth rate based on three user-specified temperature parameters and the user-specified maximum growth rate. The growth rates are computed using Michaelis-Menten (or Monod) kinetic equations that require individual constants for each of the limiting factors. Finally, the program compares the growth and respiration rates and determines whether their net effect results in growth or respiration occurring in the current time interval.

Measurements of phytoplankton, which are typically expressed as µg/l of Chlorophyll *a* (Chl-*a*), are generally infrequent. The standard practice is to reproduce the timing and approximate levels of Chl-*a* that are typically found in the water body. The best way to accomplish this is to compare simulated and monitored concentrations using time series plots and frequency plots. Figure 4.3 shows examples of these plots.

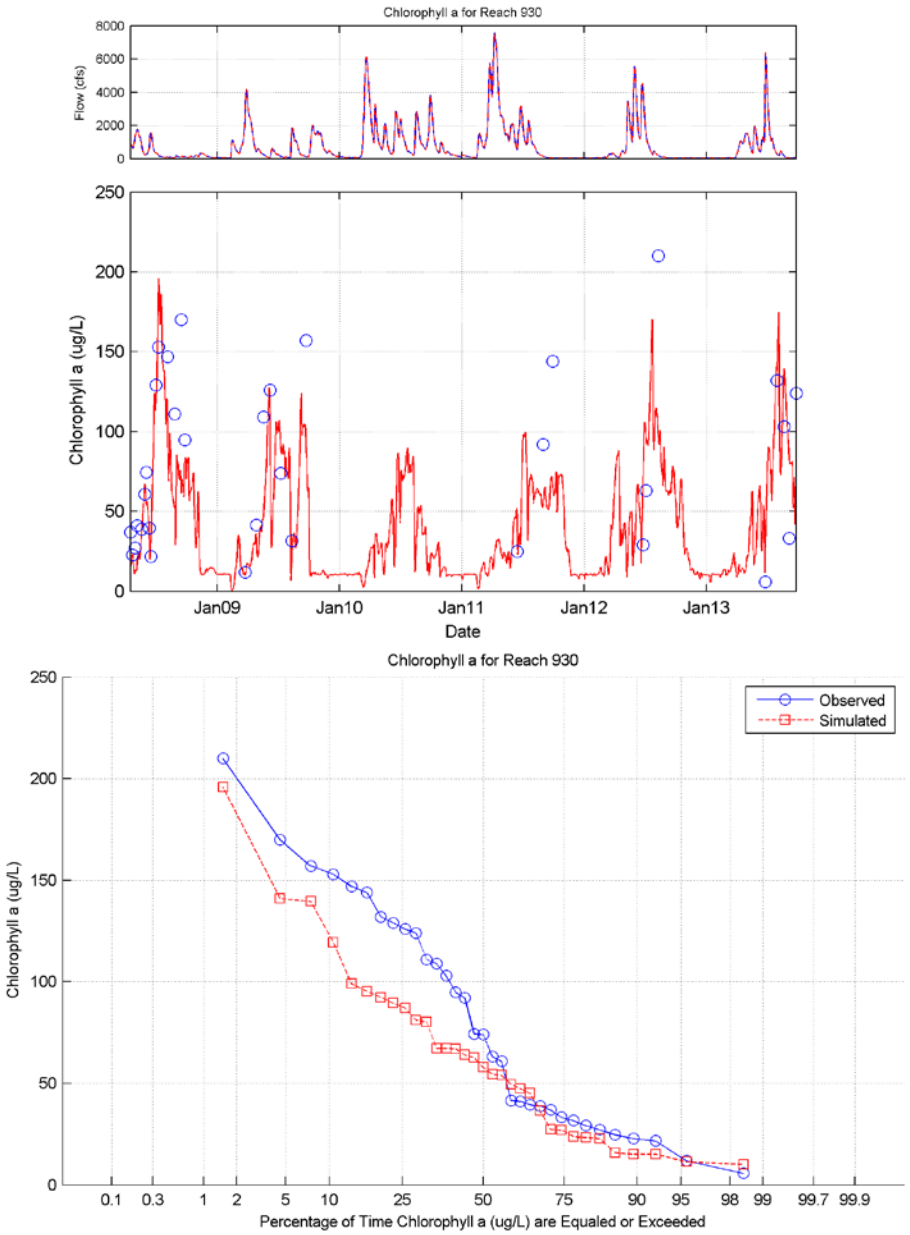

Figure 4.3. Time Series and Frequency Graphs of Phytoplankton (as Chlorophyll *a*).

Because of the large number of parameters in the phytoplankton model, the recommended approach is to start with a set of parameters that have been found from research and past (hopefully nearby) applications of HSPF to be appropriate in many situations, and then adjust a limited subset of parameters to achieve a stable and reasonable phytoplankton concentration regime. See Section 12 for suggested typical and possible parameter values. As noted, the recommended approach is to keep most of the parameter values constant, and only adjust several key parameters initially. It should be noted that since the phytoplankton growth rate relies greatly on the availability of nutrients, the user should ensure that the inorganic N (NO_3 and NH_3) and PO_4 concentrations are already at reasonable levels prior to beginning the phytoplankton calibration. After the initial parameter adjustments have been made, additional parameters can be adjusted to improve the calibration if sufficient monitoring data are available.

The initial parameters that should be adjusted to obtain a stable and seasonally-appropriate population are those that primarily affect the temperature limitations, the overall growth rate, the amount of available light, and (if needed) the settling rate. The temperature-control parameters consist of three temperature limits that define the temperature region that allows algal growth and modifies the growth rate within that region. TALGRL and TALGRH define the lower and upper temperatures, respectively, of the range in which algal growth can occur. The TALGRM parameter is the temperature above which growth rates are optimum, up to TALGRH; below TALGRM, the growth rate is reduced linearly with temperature until it reaches zero at TALGRL. Reductions of TALGRL will increase the algal growth "season", and TALGRM can be reduced to increase the season/period when growth rates are high.

The amount of light that is available for phytoplankton growth is determined by several factors and parameters. It depends on the input time series of solar radiation, so it is important that radiation data used for simulation of a particular watershed appropriately characterize factors such as cloud cover, latitude, and seasonality; and the data also needs to correctly characterize diurnal variation. In other words, the time resolution should be no more than one hour. The parameters that affect light are primarily the reach-specific shading parameter CFSAEX, which is defined in the water temperature section of HSPF, and anything that reduces light in the water, i.e., extinction. If algal growth simulations suggest that additional light is needed, CFSAEX can be adjusted upward; however, this will possibly affect water temperature in the reach. The light extinction is a combination of the base extinction coefficient (EXTB) and contributions due to sediment and phytoplankton. The sediment-related extinction is adjustable by the parameter LITSED. Typically, small adjustments can be made to the nominal value of EXTB to change the amount of light available; EXTB (and LITSED) increases result in less light in the water column.

The primary parameter for directly adjusting the phytoplankton growth rate, assuming that other conditions (temperature, light, nutrients) will allow growth to occur, is the maximum unit growth rate MALGR. If the user has watershed-specific knowledge of the dominant phytoplankton species and conditions, or significant experience with algal growth modeling, then the Michaelis-Menten (or half-saturation) constants can be adjusted. These include CMMP, CMMNP, CMMN, and CMMLT. The user is referred to the reference manual (EPA, 1985) for a comprehensive discussion of phytoplankton dynamics and a compilation from literature of these constants for various types of phytoplankton.

The settling rate parameter, PHYSET, is generally considered to be a calibration parameter because of the wide range of possible values, given the different shapes, sizes, and densities of phytoplankton cells. It can be set to its nominal value for free-flowing channels and then adjusted within a narrow range. It is more effective for calibration in lakes where settling is an important process for moving algae out of the photic zone and for the annual cycling of organic matter to the bottom where it decays. Increasing the settling rate has the effect of reducing phytoplankton concentration.

The advection of phytoplankton is modified from the standard advection procedures to ensure that free-flowing reaches can maintain a population of phytoplankton even under relatively high flow conditions. The model includes three parameters for this process. SEED is the concentration of phytoplankton that is never subject to advection at the highest flows, while MXSTAY is the maximum possible concentration that is not subject to advection at low flow. At any time, the actual concentration not subject to advection is between these two values, and is computed from

SEED and MXSTAY, plus the OREF parameter, which is the flow rate at which the protected concentration is at the midpoint between SEED and MXSTAY. Very high values of OREF provide more protection from advection, i.e., values of the computed quantity STAY are close to MXSTAY over most of the flow regime, while very low values of OREF provide the minimum protection from advection (SEED) over much of the flow regime. See the graphic in Section 9 (under the PHYTO-PARM table) to visualize the relationships among these parameters.

The final set of parameters that are available for calibration are the phytoplankton respiration and death rates; they are specified in the table PLNK-PARM3. These parameters are generally not recommended as major calibration parameters, but can be adjusted slightly. They include the unit respiration rate (ALR20), the high phytoplankton death rate (ALDH) and the low phytoplankton death rate (ALDL). ALDH is used when conditions are poor, and ALDL is used when conditions are good for algal growth, i.e., nutrients are plentiful and phytoplankton populations are not excessive. The OXALD parameter is an increment to the death rate under anaerobic conditions, and the NALDH and PALDH parameters are threshold N and P concentrations that define when conditions are good or poor (whether ALDL or ALDH is used for the death rate).

Benthic Algae

In free-flowing streams, large diurnal fluctuations of oxygen can be attributed to benthic algae. Benthic algae influence the nutrient balance of the RCHRES by their extraction of nutrients for growth. The processes that benthic algae undergo are primarily the same as those for phytoplankton, i.e., growth, respiration, and death. It should be noted that benthic algae measurements are exceedingly rare, so calibration typically consists of ensuring that a reasonable concentration (density), and seasonal pattern of benthic algae are maintained in streams during the phytoplankton growing season. Benthic algae simulation in lakes is less important, and generally represents growth of macroalgae.

If benthic algae are being modeled, the initial task is to decide whether to utilize the original benthic algae model of a single species or a more detailed model that allows multiple species. The original model assumes a single species of algae that is simulated using most of the same process formulations and parameter values as the phytoplankton, with some necessary differences and multiplication factors to the phytoplankton growth and respiration rates. This is the model that is currently utilized for the Minnesota watersheds.

The detailed model allows definition of up to four separate species. In this model, the benthic algae are assumed to grow only in portions of the stream that can be described as riffles. Algal growth is a function of the available nutrients, light, temperature, and the total density of benthic algae. Nitrogen-fixing (blue-green) algae can be represented, and algae are generally not permitted to reduce nutrients below a user-defined floor. Respiration is dependent on temperature. Algae are lost or die (i.e., removed) through grazing/disturbance by benthic invertebrates and through scouring or sloughing processes.

Calibration of the single-species benthic algae model is conceptually simple, but is complicated by the fact that the growth, respiration, and death parameter values for phytoplankton are used to determine the corresponding parameters for benthic algae in the same reach. There are just three parameters that are specific to benthic algae; however, all of the phytoplankton parameters except those that relate to advection and settling are also effective in modeling the benthic algae. First, the maximum density of benthic algae (MBAL) is defined. This provides an upper limit to

algae growth in the reach. In addition to the phytoplankton parameters, there are two factors (CFBALG and CFBALR); these are multiplication factors that are applied to the computed phytoplankton growth and respiration rates. They can be adjusted to maintain a reasonable population during the growing season.

The detailed, multiple-species benthic algae model represents the processes growth, respiration, and removal by scouring and invertebrate grazing. This method limits algal growth to a user-defined fraction of the reach where there are riffles. Some of the processes (i.e., scouring and light limitation on growth) are dependent on depth and velocity of the flow in the riffle area; therefore, there are several parameters that adjust the standard computed depth and velocity to approximate the corresponding values applicable in the riffle area.

The key parameters for growth *for each species* are the maximum growth rate (MBALGR), the half-saturation constants for N, P, and density-limited growth (CMMNB, CMMPB, CMMD1, CMMD2), and the saturation light level for growth (CSLIT). Respiration is determined by the temperature-corrected rate for each species BALR20(x). The final processes that affect the amount of benthic algae are grazing by benthic invertebrates and scouring, which are summed as removal or death. The parameters that affect grazing are the removal rate (CREMVL), the half-saturation constant for grazing (CMMBI), and the density of benthic invertebrates (BINV), which can be specified as a constant, monthly, or as a time series. The total amount of grazing is apportioned among the species. Scouring is a species-specific process, and the main parameters are the rate coefficient (CSLOF1) and exponent (CSLOF2) in the scouring regression equation.

Calibration of the detailed benthic algae will likely be performed with the objectives of (1) establishing a stable population of algae, and (2) achieving impacts to DO, nutrient levels, and organics (refractory and labile) that demonstrate an appropriate pattern during periods of net positive and negative growth and removal. It should be noted that a difference between the multi-species method and the simpler single species method is that a fraction (FRAVL) of the removal amount is immediately decomposed to inorganic nutrients and organic carbon. An additional difference is that benthic algae can optionally be modeled as a nitrogen-fixing species, so that instead of taking up N, the species adds N to the system.

If available instream algal data are adequate to perform phytoplankton and/or benthic algae simulation and calibration, the modeler should consider adjustments to 13 parameters: ALNPR, EXTB, MALGR, ALR20, SEED, MXSTAY, OREF, CLALDH, PHYSET, REFSET, MBAL, CFBALR, and CFBALG, as a basis for calibration, as discussed below:

1. ALNPR is the fraction of total nitrogen required for phytoplankton growth that is satisfied by nitrate. Increasing ALNPR decreases the NO_3 concentration and increases the NH_3 concentration and vice-versa.
2. EXTB is the base extinction rate of phytoplankton. Increasing EXTB will reduce Chl-*a* concentrations.
3. MALGR is the maximum algal growth rate for phytoplankton. Increasing MALGR will increase Chl-*a* and DO concentrations when sufficient nutrient are available but may reduce nutrient concentrations by using up the nutrients more quickly so less are subsequently available.
4. ALR20 is the algal respiration rate for phytoplankton at 20ºC. Increasing ALR20 will reduce Chl-*a* concentrations and decrease the daily minimum DO concentrations.

5. SEED is the minimum Chl-*a* concentration that is not subject to advection. Increasing SEED will increase Chl-*a* concentrations and has more impact at higher flows.
6. MXSTAY is the maximum Chl-*a* concentration that is not subject to advection. Increasing MXSTAY will increase Chl-*a* and DO concentrations and has more impact at flows less than OREF. Increasing MXSTAY may increase or decrease nutrients depending on the phytoplankton settling rate.
7. OREF is a flow rate in cubic feet per second (cfs) that is used to set the curve to determine the actual Chl-*a* concentration not subject to advection. The Chl-*a* not subject to advection is halfway between SEED and MXSTAY when the flow is equal to OREF. Increasing OREF will increase Chl-*a*, increase DO, and may increase or decrease nutrients depending on the phytoplankton settling rate.
8. CLALDH is the Chl-*a* concentration above which high algae death occurs. Increasing CLALDH will increase concentrations of Chl-*a*, increase in organic concentrations, and an increase in dissolved oxygen diurnal fluctuation (increase maxima and decrease minima). The net impact of increasing the diurnal fluctuation of DO varies with numerous environmental factors, and it is difficult to make generalized statements concerning the net impact on DO of making a parameter adjustment that results in increased Chl-*a* concentrations.
9. PHYSET is the settling rate of phytoplankton. Increasing PHYSET will decrease Chl-*a* and organic concentrations and has a larger impact at lower flows. Decreasing PHYSET will also decrease dissolved oxygen diurnal fluctuation (decrease maxima and increase minima). The net impact of decreasing the diurnal fluctuation of DO varies with numerous environmental factors, and it is difficult to make generalized statements concerning the net impact on DO that will result from making a parameter adjustment that produces increased Chl-a concentrations.
10. REFSET is the settling rate of dead refractory organics. Increasing REFSET will decrease organic concentrations with no impact to inorganic or DO concentrations.
11. MBAL is the maximum benthic algae density. Increasing MBAL will decrease Chl-*a*, increase daily average DO, decrease daily minimum DO, increase organic nutrients, and decrease inorganic nutrients. As the depth of lakes increases, the impacts that MBAL has on Chl-*a*, DO and nutrients reduces.
12. CFBALR is the ratio of the benthic algae to phytoplankton respiration rate. Impacts of changing CFBALR are dependent on many other factors but if nutrients are readily available, then increasing CFBALR will generally decrease DO, and increase Chl-*a*.
13. CFBALG is the ratio of the benthic algae to phytoplankton growth rate. Impacts of changing CFBALG are dependent on many other factors but if nutrients are readily available then increasing CFBALG will generally increase DO, decrease Chl-*a*.

Suggested steps in calibration of algae are as follows:

Calibration procedures for phytoplankton and benthic algae are the most difficult to navigate because most of the parameter changes will have significant impacts on numerous other parameters and constituents with secondary and tertiary impacts. At the same time parameter value changes could have little impact because of limiting factors such as available nutrients and DO levels. It is beneficial to have observed Chl-*a*, inorganic nutrients and organic or total nutrient data, as well as DO concentrations to provide perspective. BOD and Chl-*a* data are helpful for this procedure but their availability can be limited; consequently the observed inorganic, organic, and DO data become more important. The BOD calibration effort that has already been described is essentially the first step to the calibration of living and dead organics.

Adjusting the algal processes is a primary focus because of the impacts algae have on DO concentrations as well as those that they exert on inorganic and organic nutrient distribution for nitrogen and phosphorus. If Chl-*a* data is available, the instream phytoplankton parameters should be adjusted to achieve an acceptable match. Increasing OREF and MXSTAY and decreasing PHYSET, CLALDH, and EXTB will increase chlorophyll *a* primarily at lower flows. Increasing MALGR and SEED will increase chlorophyll *a* primarily at higher flows. Increasing algae at higher flows may decrease them at low flows because it may use up more of the nutrients available.

If more algal growth is needed to match observed data for DO and the inorganic to organic nutrient distribution but the chlorophyll *a* is reasonable or high, one can increase benthic algae using the MBAL parameter. The benthic algae have a larger impact on low flows and little to no impact in lakes. Hourly DO is also sensitive to MBAL along with the phytoplankton parameters MALGR and ALR20. If daily DO is reasonable but the diurnal (hourly) flux is low, then one should increase MALGR and ALR20 and increase MBAL.

If Chl-*a* and BOD data are not available, then one can use the inorganic and organic nutrient distributions of phosphorus and nitrogen along with DO concentrations to adjust the algae and BOD. If the inorganic to organic nutrient distribution is reasonable but the DO is low, then one can decrease the ratio of NPS organic load to total load, and increase algae growth.

A number of secondary impacts that occur as the concentrations of key water quality constituents change in response to the processes and parameter changes described above are also noteworthy:

1. Changes in dissolved oxygen (DO) can have impacts on bed release of nutrients and denitrification. Decreases in DO have the potential to increase nutrients released from the bed sediments and decrease nitrogen from increased denitrification.
2. Increasing NH_3 can cause decreases in DO and increases in NO_X because of nitrification. Increases in DO could also occur because of increases in algal growth if nitrogen is a limiting factor. Increasing TAM will also cause increases in TN and TKN.
3. Increasing and decreasing nitrate and nitrite (NO_X) generally has the least sensitive impacts to other constituents. Increasing NO_X can increase DO when denitrification is occurring and increase algal growth if nitrogen is a limiting factor. Increasing NO_X will also cause increases in total nitrogen.
4. Increasing PO_4 will cause an increase in algal growth and DO when PO_4 is the limiting factor. Increasing PO_4 will also cause an increase in TP.
5. Increases in organic material can be from external sources or from internal processes. Increases in nonrefractory organics (BOD) from external sources will cause increases in most nutrients and decreases in DO. Increases in organics (algae) from internal processes generally have their origin in algal growth which will likely simultaneously decrease nutrients because inorganics are converted to organics which have the potential to settle out. The algal growth will also cause increases in Chl-*a* and an increase in dissolved oxygen diurnal fluctuation (increase maxima and decrease minima). The net impact of increasing the diurnal fluctuation of DO varies with numerous environmental factors, and it is difficult to make generalized statements concerning the net impact on DO of increased Chl-a concentrations.

It should be noted that there is a moderate amount of experience in simulating and calibrating phytoplankton processes, somewhat lesser experience in simulating benthic algae, and very limited experience with the multi-species benthic algae capability. In fact, we are only aware of a single application of the benthic algae multi-species formulation (as of 2018) and that was part of its original development effort on the Truckee River in Nevada (Limno-Tech, Inc., 2003). Consequently, model users will see limited information for the multi-species benthic algae parameters and their estimation in Section 10, and therefore consider the guidance provided as preliminary at this time.

4.4 Special Calibration Issues

There are a number of processes that occur in a natural surface water system that are not explicitly represented in HSPF. As a result, some parametrization methods have been developed to try to mimic, as closely as possible, the impact that these processes have on biochemical transformations. The following sections list and discuss each of these processes.

1. **Sediment Diagenesis**. Sediment diagenesis involves the degradation of organic material within the bed sediments of a stream. This process causes significant oxygen depletion, so it demands oxygen from the water column. HSPF represents the oxygen depletion from this process with one constant parameter, BENOD, which represents oxygen demand from the benthos or bed sediment. This parameter is not responsive to changes in incoming or outgoing organic material that settles in or is scoured from the stream bed. As a result, the BENOD parameter is manually increased or decreased to represent higher or lower incoming sources to the stream respectively. This methodology is also applied to the BRBOD parameter which is the release of BOD from the stream bed sediments. It should also be noted that HSPF represents the waterbody bed as an infinite source and sink of nutrient and dissolved oxygen exchange.
2. **Phytoplankton Species**. HSPF treats the phytoplankton population as one species, but in a natural system, there are often many species that each behave differently during different times of the year. The benthic algae simulation can represent up to 4 different types of algae, but this is only recommended if sufficient observed data is available, and this is especially rare for benthic algae. The phytoplankton and benthic algae simulations are typically used to represent the more dominant algae trends within the system. In MN, most DO impairments are caused by blue-green algae, and mostly in the months of August and September (C. Regan, personal communication, May 15, 2018).
3. **Nitrogen Fixation of Surface Algae.** Nitrogen fixation is primarily associated with blue-green algae and is the process in which the algae on the water surface can convert atmospheric nitrogen to ammonia for growth. This process is more prominent in hyper-eutrophic lakes when nitrogen is the limiting factor for algal growth. HSPF does not represent this process but has parameters that limit algal growth based on low nitrogen levels in the water (CMMN, NALDH) and a parameter that introduces ammonia directly to the stream (BRNH3). These parameters have been used in tandem to sustain algae growth when nitrogen becomes the limiting factor.
4. **Dissolved Oxygen in Precipitation Directly on a RCHRES**. The precipitation that falls directly on a RCHRES stream or lake comes in with zero DO concentration which can cause issues during low flows or extreme precipitation events. An approach used by some modelers that mitigates this issue to some extent is to

represent open water as a PERLND or IMPLND where precipitation results in surface runoff that has DO at the saturation concentration. In this approach, DO in precipitation is not simulated directly on the reach. Note that MPCA has issued a task order to add a capability within HSPF to allow DO in precipitation to be included; this enhancement has been implemented in HSPF version 12.6b currently available to MPCA.

5. **Lake Stratification Layers and Turnover**. Lakes in temperate climates can experience thermal stratification where the lake separates into three distinct thermal layers; the epilimnion, metalimnion or thermocline, and hypolimnion. Each layer presents different water quality characteristics because of the differences in temperature and light availability. This process occurs more often in larger, deeper lakes. During the fall, the epilimnion cools and sinks causing a mixing event. Understandably this process is difficult to represent using a completely mixed representation of a water body. One approach that has been attempted to simulate this process is to use separate RCHRES segment to represent each of the three layers. Most commonly, lake parameterization and calibration efforts focus on representing the epilimnion layer (i.e., the surface layer) because that is the layer that typically determines the water quality that outflows downstream.
6. **Large Headwater Lakes**. Lake water quality calibrations are often difficult in HSPF because the model simulates a completely mixed system (homogeneous water body with no vertical stratification). Large, deep headwater lakes with little inflow/outflow can produce an overestimation/accumulation of nitrogen or phosphorus and low chlorophyll *a* concentrations. The inherent variability in depth, surface area, volume, and residence time between lakes in a model application causes each lake to behave differently, which makes developing a standard approach or solution difficult.

   The most common issue is an accumulation of phosphorus. This occurs when inorganic nitrogen (NO_{2-3} and NH_4) becomes the limiting nutrient. Once inorganic nitrogen is depleted, algae growth stops and inorganic phosphorus (PO_4) begins to accumulate. The only pathway for PO_4, outside of advection and sediment adsorption, is uptake by phytoplankton and benthic algae. The algal uptake converts the PO_4 to biomass and is then subject to settling.

   An important phosphorus removal mechanism that is not represented in HSPF is the precipitation of phosphorus by iron. Ferrous iron oxidizes to insoluble ferric iron, and then settles out thereby removing phosphorus from the water column. Anaerobic respiration occurs in the sediment and releases ferrous iron back into the water column. The anaerobic respiration also releases phosphorus, but typically at a lower rate. This cycle acts to keep phosphorus levels reduced and stable in a natural system.

   The general approach to solve this problem and achieve a dynamic, steady-state system is to increase inorganic nitrogen and decrease BOD. This can be done by adjusting loading from the land, in-stream parameters, or a combination of the two. What seems to work best is increasing the benthic release of ammonia using the BRTAM parameter. This may not be an accurate representation of the natural system but serves as a proxy for algal fixation (using the nitrogen in the atmosphere to grow), which is not a direct option in HSPF. Other parameter changes that help stabilize N and P concentrations are to lower BRBOD to reduce phosphorus inflow and increase

DENOXT to stabilize nitrogen. It is also critical to maintain the phytoplankton concentration which is done with lower MALGR and PHYSET rates and higher values of OREF, MXSTAY, and CLALDH.

7. **Algae Growth Shutoff**. HSPF has a fixed water depth threshold of 2 inches built into the simulation so that when the water depth in a reach is below the threshold, the algal processes shut off. This is because the equations used to simulate the algae processes have significant limitations for shallow water conditions. However, algal processes tend to increase at lower flows because of increased temperatures and light availability. This limitation can cause inorganic nutrient concentrations to become unstable and increase to extreme levels. To minimize this limitation, dead storage is added to the FTABLES by adding depth, volume, and a small amount of surface area to the FTABLE with no outflow to try to maintain a minimum depth greater than 2 inches.

4.5 Graphical Aids for Calibration

Various times in the discussion above the implicit utility of having readily available information regarding the magnitude of external DO and nutrient loadings and internal DO, nutrient and algal process fluxes has been conveyed. However, even for the most knowledgeable HSPF modelers procedures for effectively interpreting and using information on loadings and fluxes to direct specific calibration actions remains in the early stages of a learning curve. To varying extents HSPF water quality modelers have used existing HSPF output capabilities to explore and understand loadings and fluxes. A current tool development thrust is the enhancement of software tools (such as HSPEXP+) that are used to post-process HSPF simulation results so that they are able to provide loading and flux information that is presented with scope and format options that make the information more directly useful in supporting calibration efforts. We expect that assessing fluxes as a component of the calibration process for HSPF water quality models will become more common and more valuable in the future.

Figure 4.2 above introduced one graphic option that offers particular benefit in support of the calibration process. Generally speaking, when calibrating it is suggested that simulated results be compared to observed data in four different ways (depending on the availability of adequate observed data to generate each graphic type): time-series plots, monthly box plots, flow vs. concentration plots, and concentration exceedance curves. Figures 4.4 through 4.8 below show an example of each of the plots mentioned. Plots of water quality loads can be used but can cause a bias towards the high flows whereas concentrations help to evenly weight high and low flows. In the case of temperature and dissolved oxygen it is recommended that box plots by hour of the day be evaluated. This ensures simulated diurnal, seasonal, and flow fluctuations as well as overall and monthly highs, medians, and lows approximate the in-stream observations.

Numerous software options are available for generating the necessary graphics including HSPEXP+ (Mishra et al., 2017) as well as commercial products such as Microsoft Excel and MATLAB.

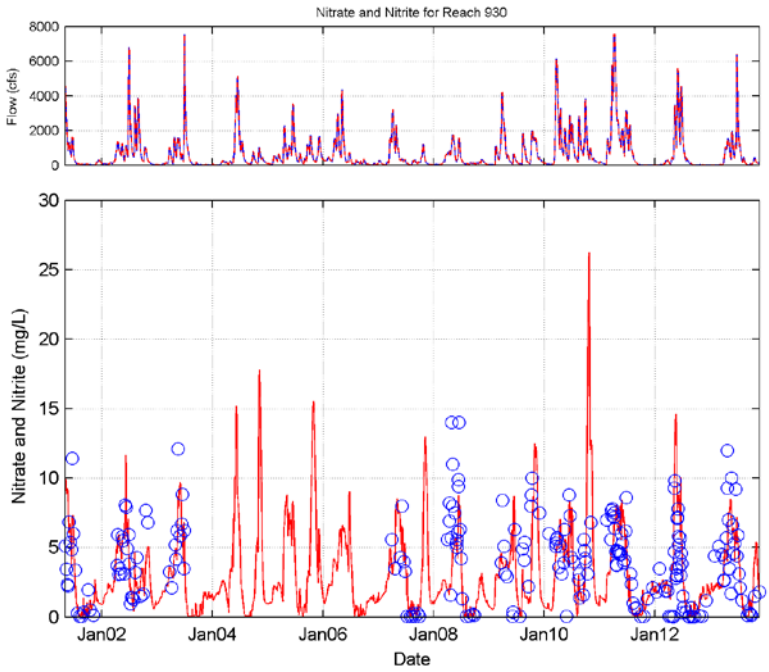

Figure 4.4. Timeseries of NO_x Concentrations.

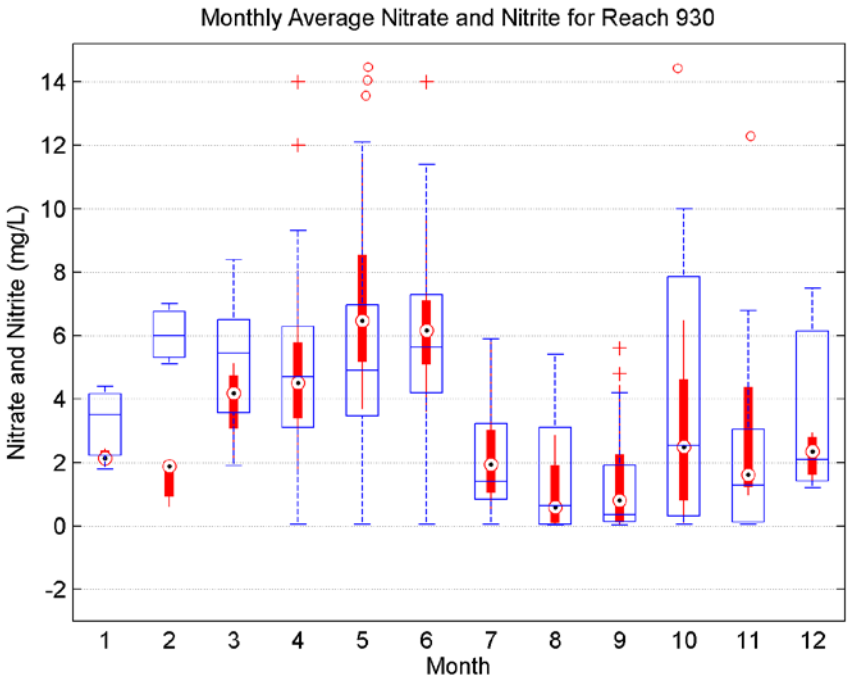

Figure 4.5. Box-Whisker Plot Monthly Nitrite and Nitrate Concentrations.

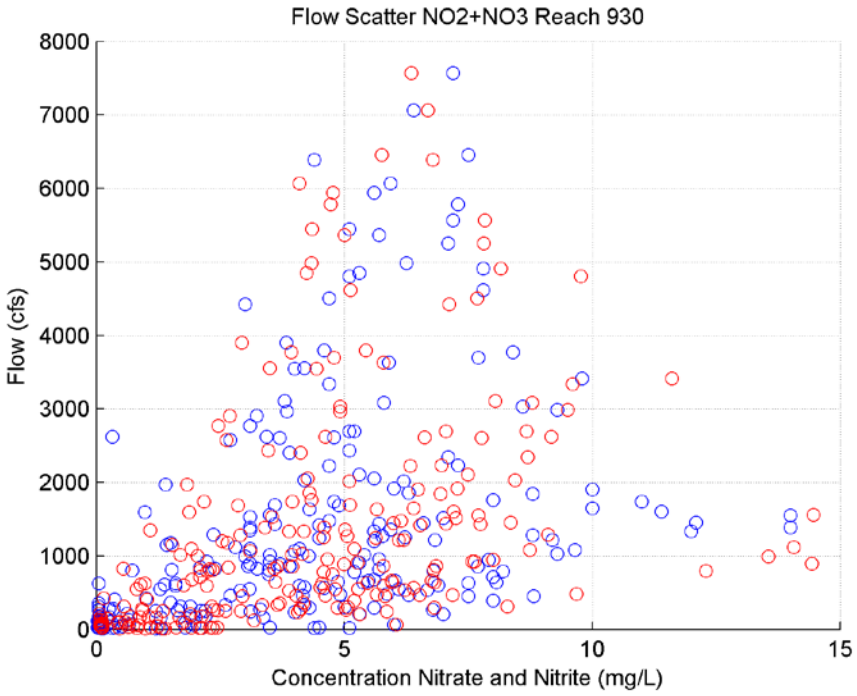

Figure 4.6. Plot of NO_3 and NO_2 Concentration Versus Flow.

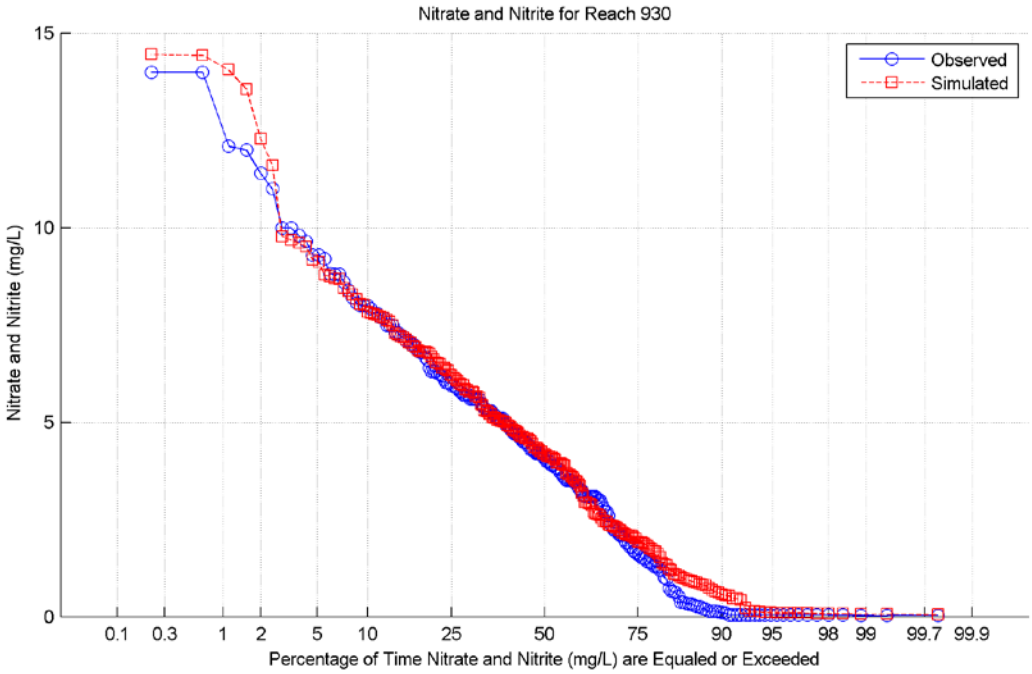

Figure 4.7. Frequency Plot of NO_3 and NO_2 Concentrations.

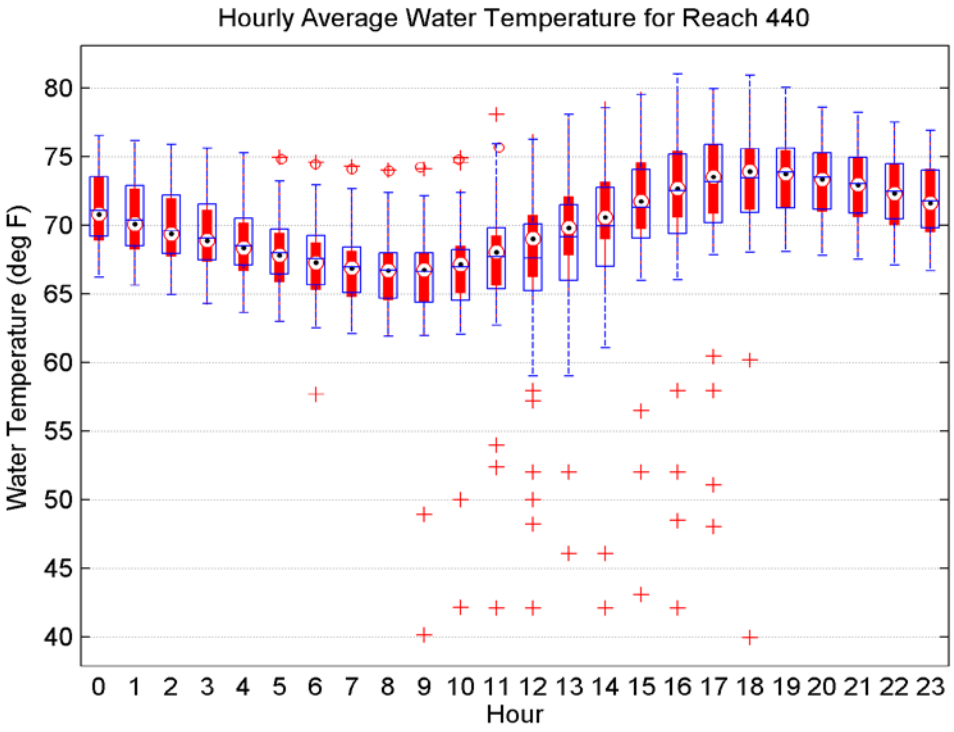

Figure 4.8. Diurnal Box-Whisker Plots of Water Temperature.

4.6 Alternative Calibration Techniques

The EPA Chesapeake Bay Program Office developed an automated method of water quality calibration for the Phase 5.3 HSPF Watershed Model (USEPA, 2010). Parameters are paired with calibration metrics such that each parameter can be optimized to a unique set of metrics. An automated approach to water quality calibration was advantageous in the case of the Chesapeake Bay Watershed Model because of the overall size of the watershed (64,000 square miles) and the level of segmentation (737 reaches). The approach is likely not advantageous to calibrating most HSPF applications, and consequently we have opted to include its description as an appendix (Appendix A) as opposed to including it in the more generally applicable guidance that we provide in the main body of this Technical Note.

Parameter Guidance Section

The parameter guidance that follows is listed in the order of the parameter tables required by the PERLND, IMPLND and RCHRES modules responsible for simulating pollutant loadings, heat, dissolved oxygen, nutrients, phytoplankton (RCHRES only), and benthic algae (RCHRES only). The parameters are grouped as required in each User Control Input (UCI) table.

5.0 PERLND and IMPLND Parameter Guidance for Water Temperature (PSTEMP), Dissolved Oxygen (PWTGAS, IWTGAS) and Nutrients (PQUAL, IQUAL)
6.0 Heat Exchange and Water Temperature (HTRCH) Parameter Guidance
7.0 Dissolved Oxygen (OXRX) Parameter Guidance
8.0 Nutrient (NUTRX) Parameter Guidance
9.0 Plankton (PLANK) Parameter Guidance

5.0 PERLND and IMPLND Parameter Guidance for Water Temperature (PSTEMP), Dissolved Oxygen (PWTGAS, IWTGAS) and Nutrients (PQUAL, IQUAL)

5.1 PSTEMP (PERLND)

PSTEMP simulates soil temperatures for the surface, upper, and lower/groundwater layers of a land segment for use in module section PWTGAS.

PSTEMP-PARM1 Table:

The parameters in this table select the method for estimating subsurface soil temperatures and select whether the values of the parameters must be constant or vary monthly. Monthly varying parameters allow finer control of water temperature on the surface and sub surface. Although additional parameters allow more degrees of freedom, they also need additional calibration effort. Modeler must select these options based on available resources for model calibration.

SLTVFG Flag to select if the surface layer temperature can vary throughout the year.
0. The surface layer temperature stays constant.
1. The surface layer temperature varies through the year and the table types MON-ASLT and MON-BWTF are provided.

ULTVFG Flag to select if the upper layer temperature can vary throughout the year.
0. The upper layer temperature stays constant.
1. The upper layer temperature varies through the year and the table types MON-ULTP1 and MON-ULTP2 are provided.

LGTVFG Flag to select if the lower layer temperature can vary throughout the year.
0. The lower layer temperature stays constant.
1. The lower layer temperature varies through the year and the table types MON-LGTP1 and MON-LGTP2 are provided.

TSOPFG Flag to select the method used to estimate subsurface soil temperatures.
0. The subsurface soil temperatures are computed using mean departure from air temperature, together with smoothing factors.
1. The upper layer soil temperature is estimated by regression on air temperature (like surface temperature). The lower layer and groundwater temperature is supplied by the user.
2. The lower and groundwater layer temperature is calculated from the upper layer soil temperature.

PSTEMP-PARM2 Table:

ASLT Surface layer temperature when the air temperature is 32ºF (0ºC). It is the intercept of the surface layer temperature regression equation. If SLTVFG = 1, then MON-ASLT table is provided with the monthly varying values of ASLT.

BSLT Slope of the surface layer temperature regression equation. If SLTVFG = 1, then MON-BSLT table is provided with the monthly varying values of BSLT.

ULTP1 If TSOPFG = 0 or 2, then ULTP1 is the smoothing factor in upper layer temperature calculation. If TSOPFG = 1, ULPT1 is the intercept in the upper layer soil temperature regression equation. If ULTVFG = 1, then table MON-ULTP1 is provided with monthly varying values of ULTP1.

ULTP2 If TSOPFG = 0 or 2, then ULTP2 is the mean difference between upper layer soil temperature and air temperature. If TSOPFG = 1, ULPT2 is the slope in the upper layer soil temperature regression equation. If ULTVFG = 1, then table MON-ULTP2 is provided with monthly varying values of ULTP1.

LGTP1 If TSOPFG = 0 or 2, then LGTP1 is the smoothing factor in lower layer/groundwater temperature calculation. If TSOPFG = 1, LGTP1 is the lower layer/groundwater temperature. If LGTVFG = 1, then table MON-LGTP1 is provided with monthly varying values of LGTP1.

LGTP2 If TSOPFG = 0, then LGTP2 is the mean departure from the air temperature. If TSOPFG = 1, LGTP2 is not used. If TSOPFG =2, LGTP2 is the mean departure from the upper later soil temperature. If LGTVFG = 1, then table MON-LGTP2 is provided with monthly varying values of LGTP2.

PSTEMP-TEMPS Table:

AIRTC Initial air temperature.

SLTMP Initial surface layer soil temperature.

ULTMP Initial upper layer soil temperature.

LGTMP Initial lower layer/groundwater layer soil temperature.

5.2 PWTGAS (PERLND)

PWTGAS estimates water temperature and concentrations of dissolved oxygen in surface, interflow, and groundwater outflows from a land segment.

PWT-PARM1 Table:

This table provides flags for section PWTGAS and specifies whether the concentration of dissolved oxygen (DO) and carbon-di-oxide (CO_2) may vary monthly. Monthly varying tables provide greater flexibility in DO and CO_2 simulation. CO_2 simulation is not required unless pH is being simulated.

IDVFG Flag for specifying if DO in interflow varies throughout the year.
0. The DO concentration in interflow remains constant throughout the year.
1. The DO concentration in interflow varies monthly and the table MON-IFWDOX is provided.

ICVFG Flag for specifying if CO_2in interflow varies throughout the year.

0. The CO_2 concentration in interflow remains constant throughout the year.
1. The CO_2 concentration in interflow varies monthly and the table MON-IFWCO2 is provided.

GDVFG Flag for specifying if DO in groundwater varies throughout the year.
0. The DO concentration in groundwater flow remains constant throughout the year.
1. The DO concentration in groundwater varies monthly and the table MON-GRNDDOX is provided.

GCVFG Flag for specifying if CO_2 in interflow varies throughout the year.
0. The CO_2 concentration in groundwater flow remains constant throughout the year.
1. The CO_2 concentration in groundwater flow varies monthly and the table MON-GRNDCO2 is provided.

PWT-PARM2 Table:
Second round of PWTGAS parameters.

ELEV Elevation of PLS above mean sea level. It must be estimated using GIS analysis of elevation data.

IDOXP Concentration of DO in interflow. If IDVFG = 1, then table MON-IFWDOX is provided with monthly varying values.

ICO2P Concentration of CO_2 in interflow. If ICVFG = 1, then table MON-IFWCO2 is provided with monthly varying values.

ADOXP Concentration of DO in groundwater flow. If GDVFG = 1, then table MON-GRNDDOX is provided with monthly varying values.

ACO2P Concentration of CO_2 in groundwater flow. If GCVFG = 1, then table MON-GRNDCO2 is provided with monthly varying values.

5.3 PQUAL (PERLND)

The PQUAL module section simulates water quality constituents or pollutants in the outflows from a pervious land segment using simple relationships with water and/or sediment yield. Any constituent can be simulated by this module section. The user supplies the name, units and parameter values appropriate to each of the constituents that are needed in the simulation.

The quality constituent guidance in this document is focused on four specific pollutants; ammonia and ammonium as nitrogen, nitrate as nitrogen, orthophosphate as phosphorus, and biological oxygen demand that includes organic materials.

PQL-AD-FLAGS Table:
This table specifies if the constituent get input through atmospheric deposition. The atmospheric deposition can be input as a time series or as a monthly table. The selection of either option

depends upon the data availability. Generally, the atmospheric deposition data for N is available, however, in some cases atmospheric deposition data of P is also available.

QUAL Flag for each quality constituent (QUAL1, QUAL2…etc.) in the order of their listing in the subsequent tables in the UCI file, there are two flags, "F", and "C".

F This flag is for dry or total deposition flux. The value of the flags defines the source of atmospheric deposition input.
0 No deposition of this type is simulated.
-1 Deposition of this type is input as a time series PQADFX.
>0 Deposition of this type is input in the MONTH-DATA table with the corresponding table ID number.

C This flag is for wet deposition concentration. The value of the flags defines the source of atmospheric deposition input.
0 No deposition of this type is simulated.
-1 Deposition of this type is input as a time series PQADCN.
>0 Deposition of this type is input in the MONTH-DATA table with the corresponding table ID number.

QUAL-PROPS Table:

This table defines the properties of the table including name, units, adsorbed and/or dissolved etc. Selecting standard names and units for the constituents makes the HSPF model easier to compare with similar models.

QUALID Name of the quality constituent. In this document, following name conventions have been used.
NH3+NH4 – Ammonium and ammonia as nitrogen
NO3 – Nitrate and nitrite as nitrogen
ORTHO P – Orthophosphate as phosphorus
BOD – Biological Oxygen Demand as organics

QTYID Units of the quality constituent. In this document, the units of all constituents are pounds (lbs).

QSDFG Flag to specify if the constituent is sediment associated. In general, ORTHO P is considered sediment associated. In some models, NH3+NH4 and BOD is also considered sediment associated. NO3 is always considered to be associated with overland flow only.

VPFWFG Flag to specify how the washoff potency factor of constituent varies. Providing monthly varying potency factors provides more control during model calibration.
0. The washoff potency factor does not vary monthly.
1. The washoff potency factor varies monthly and the table MON-POTFW is provided. The daily factors are computed by interpolation between monthly values.

2. The washoff potency factor varies monthly and the table MON-POTFW is provided. The daily factors are not computed by interpolation between monthly values.

VPFSFG This flag is similar to the VPFWFG for quality constituent associated with scoured sediment.

QSOFG Flag to specify if the constituent is directly associated with overland flow. It is possible to have a constituent can be associated with overland flow and sediment at the same time. However, this option is rarely used.

VQOFG Flag to specify if the accumulation and removal of quality constituents vary monthly.

0. The accumulation and removal of quality constituent does not vary monthly.
1. The accumulation and removal occur daily, independent of atmospheric deposition. Tables MON-ACCUM and MON-SQOLIM are provided.
2. The accumulation and removal occur every interval, and the removal rate is applied to atmospheric deposition and lateral inflows, as well as accumulation. Tables MON-ACCUM and MON-SQOLIM are provided.

QIFWFG Flag to specify if the quality constituent is associated with interflow.

0. The constituent is not associated with interflow.
1. The constituent is associated with interflow.

VIQCFG Flag to specify if the concentration of constituent in interflow may vary throughout the year.

0. The concentration of constituent in interflow does not vary monthly.
1. The concentration of this constituent in interflow may vary throughout the year and the table MON-IFLW-CONC is provided.
2. The daily values are directly obtained from the monthly values provided in MON-IFLW-CONC table and no interpolation between monthly values is performed.
3. The values of monthly interflow are obtained by interpolation of the monthly values provided in the MON-IFLW-CONC table, and the units of interflow are in mg/l. This option requires that the QTYID be pounds (English system) or kilograms (Metric system).
4. The values of monthly interflow are directly obtained by the monthly values provided in the MON-IFLW-CONC table, and the units of interflow are in mg/l. This option requires that the QTYID be pounds (English system) or kilograms (Metric system)

QAGWFG Flag to specify if the quality constituent is associated with groundwater flow.

0. The constituent is not associated with groundwater flow.
1. The constituent is associated with groundwater flow.

VAQCFG Flag to specify if the concentration of constituent in groundwater flow may vary throughout the year.

0. The concentration of constituent in groundwater flow does not vary monthly.

1. The concentration of this constituent in groundwater flow may vary throughout the year and the table MON-GRND-CONC is provided.
2. The daily values are directly obtained from the monthly values provided in the MON-GRND-CONC table, no interpolation between monthly values is performed.
3. The values of monthly groundwater flow are obtained by interpolation from the values provided in the MON-GRND-CONC table, and the units of groundwater flow are in mg/l. This option requires that the QTYID be pounds (English system) or kilograms (Metric system).
4. The values of monthly groundwater flow are directly obtained by the monthly values provided in the MON-GRND-CONC table, and the units of groundwater flow are in mg/l. This option requires that the QTYID be pounds (English system) or kilograms (Metric system)

QUAL-INPUT Table:

This table provides the values of nonseasonal PQUAL parameters. If the flags for monthly varying values are set to 0, then the values in this table are used.

SQO Initial storage of quality constituent on the pervious land segment, if the constituent is associated with overland flow.

POTFW Washoff potency factor for constituent associated with sediment. If VPFWFG is greater than 1, then MON-POTFW table is expected and this value is ignored.

POTFS Scour potency factor for constituent associated with sediment detached by scour. If VPFSFG is greater than 0, then MON-POTFS table is expected and this value is ignored.

ACQOP Accumulation rate of quality constituent associated with overland flow. If VQOQFG is greater than 1, then the table MON-ACCUM is expected, and this value is ignored.

SQOLIM Maximum storage of quality constituent associated with overland flow. If VQOQFG is greater than 1, then table MON-SQOLIM is expected, and this value is ignored.

WSQOP Rate of surface runoff which will remove 90 percent of stored overland flow associated quality constituent per hour.

IOQC Concentration of quality constituent in interflow. If VIQCFG is greater than 1, then table MON-IFLW-CONC is expected and this value is ignored.

AOQC Concentration of quality constituent in groundwater flow. If VAQCFG is greater than 1, then table MON-GRND-CONC is expected and this value is ignored.

5.3 IWTGAS (IMPLND)

The IWTGAS section estimates the water temperature and concentrations of dissolved oxygen and carbon dioxide in the outflow from the impervious land segment.

IWT-PARM1 Table:

The parameters in these table select whether water temperature parameters on impervious land operations may vary monthly and the snow effect flag. Unless there are significant impervious areas flowing to the reaches, modeler should select constant value of these parameters. Snow effect should be considered when snow is being simulated on impervious area.

WTVFG Flag to select whether water temperature regression parameter can vary throughout the year.

0. The parameters AWTF and BWTF stay constant throughout the year.
1. The parameters AWTF and BWTF vary monthly according to the values provided in the tables MON-AWTF and MON-BWTF.

CSNOFG Flag to select the effects of snow accumulation and melt.

0. Effect of snow accumulation and melt are not considered.
1. Effect of snow accumulation and melt are considered.

IWT-PARM2 Table:

Second group of IWTGAS parameters.

ELEV Elevation of the impervious land segment above the mean sea level. This value must be calculated using GIS analysis of elevation data.

AWTF Surface water temperature when air temperature is 32ºF (0ºC). If WTVFG =1, then MON-AWTF is provided with monthly varying values of AWTF.

BWTF Slope of surface water temperature regression equation. If WTVFG =1, then MON-BWTF is provided with monthly varying values of BWTF.

5.5 IQUAL (IMPLND)

The IQUAL module section simulates water quality constituents or pollutants in the outflows from an impervious land segment using simple relationships with water yield and/or solids. Any constituent can be simulated by this module section. The user supplies the name, units and parameter values appropriate to each of the constituents that are needed in the simulation.

As noted for the pervious land segment simulation, the quality constituent guidance in this document is focused on four specific pollutants; ammonia and ammonium as nitrogen, nitrate as nitrogen, orthophosphate as phosphorus, and biological oxygen demand that include organic materials. The parameters for impervious land segment simulation are similar to the parameters for the pervious land operations, except the processes scour, interflow, and groundwater are not considered for impervious areas and there are no comparable parameters for impervious areas.

Often, many water quality constituents that are considered only associated with sediment for pervious areas are considered associated with overland flow for impervious areas.

6.0 Heat Exchange and Water Temperature (HTRCH) Parameter Guidance

The HTRCH section simulates the processes which determine the water temperature in a reach or mixed reservoir.

HT-BED-FLAGS Table:

BEDFLG Flag to select the method to use for heat conduction through the bed.

0. Bed conduction is not simulated.
1. Single interface (water-mud) heat transfer method
2. Two-interface (water-mud, and mud-ground) heat transfer method
3. Jobson method

TGFLG Flag to select the source of ground temperature for bed conduction (if BEDFLG = 1 or 2)

1. time-series
2. single value
3. monthly values

TSTOP Number of time steps (prior to the current time step) that impact the heat flux at the current time; used when the Jobson method is in effect.

HEAT-PARM Table:

ELEV Mean RCHRES elevation. RCHRES elevation can be computed from the Digital Elevation Model (DEM) used to develop the model. When a model is prepared from BASINS, the mean RCHRES elevation is computed from the DEM data. The elevation is used to adjust the conductive-convective heat transport for the effects of atmospheric pressure changes with elevation.

ELDAT Difference in elevation between the RCHRES and the air temperature gage (positive if the RCHRES is higher than the gage). ELDAT can be calculated using DEM data and the elevation of the air temperature gage. The input air temperature is adjusted for elevation. The program uses different lapse rates depending on whether it is raining or not. Higher elevations (and higher values of ELDAT) result in lower temperatures.

CFSAEX Correction factor for solar radiation; it is the fraction of the RCHRES surface exposed to radiation. CFSAEX quantifies the surface exposure due to shading by vegetation, hillsides, and streambanks. This is often used as a calibration parameter, and therefore values greater than 1 are allowed (the maximum is 2). Wide rivers or lakes will have higher CFSAEX values, while narrow streams with significant riparian vegetation will have lower values. Higher values indicating greater exposure to solar radiation will result in higher daytime temperatures.

KATRAD Longwave radiation coefficient. The default value of 9.4 is the value of the coefficient in an empirical equation for longwave radiation energy fluxes into

water bodies from the atmosphere. Higher values result in higher water temperatures, primarily under cloudy conditions. KATRAD does not affect the longwave radiation emitted from the water as a result of its temperature. This parameter is generally used for calibration, and values from 1 to 20 are reasonable.

KCOND Conduction-convection heat transport coefficient. The default value of 6.1 is the value of the coefficient in an empirical equation for conduction-convection heat transport between the air and water bodies. Higher values result in faster equilibration between air and water temperatures, in other words, the water temperature will react more quickly to changes in air temperature. This parameter is generally used for calibration, and values from 1 to 20 are reasonable.

KEVAP Evaporation coefficient. The default value of 2.24 is the value of the coefficient in an empirical equation for evaporative heat losses from water bodies. Higher values result in lower water temperatures. This parameter is generally used for calibration, and values from 1 to 10 are reasonable.

HT-BED-PARM Table:

MUDDEP Depth of mud layer in the two-interface model (BEDFLG = 2). Mud depth tends to be greater in slow moving, higher order streams and in lakes. This parameter affects the transfer of heat between the ground (i.e., stream bed) and the overlying water column, and lower values increase the rate of transfer, and therefore increase the rate that water temperatures approach the ground temperature TGRND. MUDDEP can be used as a minor calibration parameter, but the heat transfer coefficients KMUD and KGRND are more effective. The limited number of applications of the two-interface model suggest depths of 1-2 feet are appropriate.

TGRND TGRND is the constant (TGFLG = 2) ground/bed temperature; it is used in the one and two-interface models (BEDFLG = 1 or 2). Optionally, the ground temperature can be input in the form of twelve monthly values or a time series. This is the temperature of the ground that drives the transfer of heat across the water-sediment interface. When the ground temperature is higher than the water temperature, heat moves into the water and vice versa. A good starting estimate for this input can be obtained from the mean annual air temperature of the region or measured shallow groundwater temperatures. It is useful as a calibration parameter, but adjustments should be relatively small, and the final value should generally be between the typical diurnal water temperature extremes. This suggests that it is preferable to specify TGRND using the monthly option or a timeseries so that it is appropriate for varying conditions over the entire year.

KMUD Heat conduction coefficient between water and the ground if BEDFLG =1 or the heat conduction coefficient between water and mud layer if BEDFLG =2. This parameter is a measure of the rate of heat transfer between the ground and water, and is useful as a calibration parameter to maintain reasonable diurnal temperature fluctuations. If KMUD is too high, the water temperature will change

too quickly and be unduly influenced by the bed heat transfer process. Likewise, if it is too low, heat transfers with the bed will be small, and diurnal temperature extremes will tend to be excessive in streams where the bed should have an effect. There is relatively little experience with these process algorithms in HSPF; however, previous studies suggest values of KMUD in the range 20-100 are appropriate when using the two-interface model (BEDFLG=2).

KGRND Heat conduction coefficient between ground and mud in the two-interface model (BEDFLG = 2). KGRND is like KMUD except that it applies to the transfer of heat from the ground to the mud layer; therefore, the impact of its adjustment on water temperature will be similar. Higher values will lead to water temperatures that tend to approach the value of TGRND more quickly and vice versa, so it can impact temperatures differently in different seasons. Experience with this process is limited, and the few studies that reported values suggest a range of 0.1-10. Since KMUD and KGRND work together to transfer heat between the ground and water, adjustments of both are recommended in order to determine their relationship in a specific stream.

MON-HT-TGRND Table:

TGRND (1-12) Temperature of ground/bed layer at the start of the month. Refer to the information for TGRND in table HT-BED-PARM.

Input for RQUAL Sections

BENTH-FLAGS Table:

BENRFG Value of 1 means that benthal influences are considered in the various RQUAL sections. These include benthal oxygen demand and benthal release of BOD in the OXRX section, benthal release of NH_3 and PO_4 in the NUTRX section, and benthal release of CO_2 in the PHCARB section. Most model applications will benefit from one or more of these processes, especially benthal releases of BOD, NH_3 and PO_4, and benthal oxygen demand.

SCOUR-PARMS Table:

SCRVEL Threshold velocity above which the effect of scouring on benthal release rates is considered. This parameter determines when “scour” conditions are in effect for the benthal release rates of BOD, NH_3, and PO_4. If the average velocity in the reach is greater than SCRVEL, the release rates are multiplied by SCRMUL. This parameter can be used during calibration; however, it is not generally considered a major parameter, since water quality monitoring is typically not frequent during storms. Most models omit this table, which results in the default value of 10 ft/sec for SCRVEL. However, the recommended practice is to include the table so that the value is shown in the UCI file for documentation purposes.

SCRMUL Multiplier by which benthal releases are increased during scouring. The multiplier can be adjusted during calibration to increase or decrease the benthal release rates

of BOD, NH_3, and PO_4 under high flow conditions. As described above for SCRVEL, this parameter is typically not used for calibration. The default value of 2.0 is used in most models.

7.0 Dissolved Oxygen (OXRX) Parameter and Guidance

OXRX simulates the primary processes which determine the dissolved oxygen concentration in a reach or mixed reservoir.

OX-FLAGS Table:

REAMFG REAMFG indicates the method used to calculate the reaeration coefficient for free-flowing streams

1. Tsivoglu method
2. Owens/Churchill/O'Connor-Dobbins method that depends upon the velocity and depth of the water
3. Coefficient is calculated as a power function of velocity and/or depth; user inputs exponents for velocity and depth and an empirical constant (REAK).

OX-GENPARM Table:

KBOD20 Unit BOD decay rate at 20ºC. This is the first-order decay rate of water column carbonaceous BOD (i.e., CBOD), and is based on the assumption that the material is the ultimate CBOD, as opposed to the 5-day CBOD. Since temperature effects, settling, and benthal releases are modeled explicitly, the primary determinant of this decay rate is the nature of the specific waste, and is therefore site-specific. Turbulence is also considered to affect the decay rate; however, this process might be confused with the effects of benthal scouring. If laboratory measurements of KBOD20 are available for the watershed, they should be used as a starting point; otherwise start with a value of 0.01 /hour. Since adjustments of KBOD20 will impact simulated BOD and DO concentrations, it can be calibrated to improve agreement with monitoring data for these constituents. Calibrated values in various modeling studies range from 0.01 to 2.0 /day (0.0004 – 0.08 /hour).

TCBOD Temperature correction coefficient for BOD decay. Values greater than 1 will result in higher BOD decay rate with increasing temperature. Literature values range from 1.02 – 1.15. Since temperature dependence has a relatively minor effect, it is recommended to use a standard value (e.g., 1.047) without calibration.

KODSET Rate of BOD settling. Sedimentation or settling of BOD removes it from the water column, and therefore in HSPF, it is a BOD loss mechanism that does not involve DO depletion. In nature, the settled material is assumed to become part of the benthal processing, i.e., sediment oxygen demand and benthal release of BOD. This parameter affects both BOD concentration and DO concentration, and is generally considered a calibration parameter. Increasing KODSET will decrease BOD and result in higher DO concentration. It is more effective in lakes, due to the longer residence time. It is also dependent on the particulate/dissolved nature of the BOD material. If the material is particulate, it is recommended to use a value consistent with typical particulate settling velocities in water. Otherwise use lower values to avoid confusing the removal mechanism with decay.

SUPSAT Maximum allowable dissolved oxygen supersaturation (expressed as a multiple of the dissolved oxygen saturation concentration). This parameter allows algal growth to temporarily increase the DO concentration above the temperature-dependent saturation limit. If midday DO concentrations are under-simulated during the algal growth season (and phytoplankton and benthic algae levels are reasonable), SUPSAT can be increased to improve the agreement. However, if the model reaeration rate is high, this adjustment might not be effective, due to rapid "negative" reaeration. Typical values are usually in the range of 1.0 to 1.5.

OX-BENPARM Table:

BENOD Benthal oxygen demand at 20ºC. This is commonly known as sediment oxygen demand (SOD), and accounts for oxygen removed from the water column by complex decay processes in the bottom sediments. SOD is higher in streams and lakes where organic matter from natural and manmade sources have settled to the bottom. Local measurements of SOD should be used whenever they are available, and will be different for streams and lakes. The values, which are expressed in units of mg-O_2/hour/m^2 and are converted to mg-O_2/L using the average depth, range between 1 and 400 in the literature. It is typically used in calibrating DO concentration. Reductions in BENOD are sometimes used in future scenario simulations to represent the effect of improvements in wastewater treatment, either upstream of, or discharging to, a reach.

TCBEN Temperature correction coefficient for benthal oxygen demand. Similar to the temperature correction for BOD decay, values greater than 1 will result in higher benthal oxygen demand with increasing temperature. Typical values range from 1.02 – 1.1. Since temperature dependence has a relatively minor effect, it is recommended to use a standard value (e.g., 1.047), and not adjust it during calibration.

EXPOD Exponential factor in the dissolved oxygen term for the benthal oxygen demand equation. The effect of the exponential factor on the benthal oxygen demand equation is to reduce the demand at low oxygen concentrations. However, its effect is very small at values of EXPOD greater than 0.5. Unless local conditions suggest that SOD is strongly dependent on DO, it is recommended to set EXPOD at the default value (1.2) and not adjust it for calibration.

BRBOD(1) Benthal release rate of BOD under aerobic conditions. Benthal release of BOD represents an internal (autochthonous) source of BOD from past deposition of organic material, including dead plankton to the bottom. The process is related to SOD, since it results in reduction of DO; however, because BOD decay also results in release of inorganic nutrients, this process is sometimes used to stabilize the availability of nutrients for algal growth, especially in lakes. Similar to other benthal processes, the rate is expressed in units of mg-BOD/hour/m^2 and is converted to mg-BOD/L using the average depth. It is used as a calibration parameter. Values from previous HSPF model applications (no literature data are available) range from 0.1 to 6.0. Note that this release rate is increased under scouring conditions (refer to table SCOUR-PARMS).

BRBOD(2) Increment to the BOD benthal release rate under anaerobic conditions. Refer to the description of BRBOD(1) above. This parameter is an additional BOD release rate that occurs when the DO concentration is low. Typical values are in the range of 1.0 to 100.The DO dependence of this release rate is determined by the parameter EXPREL.

EXPREL Exponent in the DO-dependent term of the BOD benthal release equation. Refer to the description of BRBOD(2) above. This parameter determines the DO concentration levels under which the anaerobic BOD release rate is significant. If EXPREL is near the default value of 2.88, the anaerobic increment will be very small until the DO is less than 1 mg/L. If EXPREL is 0.3 significant releases of the anaerobic increment of BOD will occur at DO concentrations below 6 mg/L.

OX-CFOREA Table:

CFOREA Correction factor in the lake reaeration equation; it accounts for good or poor circulation characteristics. The reaeration coefficient in lakes is a function of wind speed and surface area. In lakes with poor circulation, reaeration may be reduced because of low turbulence. Alternatively, some lakes may experience greater reaeration than predicted by the wind speed algorithm. Therefore, if monitoring data in a lake indicates that reaeration is poorly simulated, this parameter should be used to improve the agreement. CFOREA can range from 0.01 to 2.

OX-TSIVOGLOU Table:
This table is required if REAMFG in Table-Type OX-FLAGS is 1.

REAKT Empirical constant in Tsivoglou's equation for reaeration. If this energy dissipation method is being used to compute reaeration, REAKT is the user-specified coefficient in the equation. The developer suggests that values of this calibration parameter should range from 0.054 to 0.110.

TCGINV Temperature correction coefficient for reaeration in the Tsivoglou energy dissipation method. Similar to the temperature correction for other processes in RQUAL, values greater than 1 will result in higher reaeration with increasing temperature. Typical values range from 1.02 – 1.1. Since temperature dependence has a relatively minor effect, it is recommended to use a standard value (e.g., 1.047), and not adjust it during calibration.

OX-REAPARM Table:
This table is required if REAMFG in OX-FLAGS table is 3.

TCGINV Temperature correction coefficient for reaeration. Refer to Table OX-TSIVOGLOU.

REAK Empirical constant in the equation used to calculate the reaeration coefficient. This method of computing reaeration uses a power function equation with user-specified parameters, and contains factors with average velocity and average

depth. REAK is the constant coefficient in the equation, and typical values derived from the original developers of the methods indicate a range from 0.4 to 1.0. Increases in this calibration parameter will result in increased reaeration under all conditions, and vice versa. If modelers want to make selective adjustments based on either depth or velocity, the other two parameters in this equation (EXPRED and EXPREV) should be adjusted. It should be noted that if REAMFG is set to 2 (instead of 3), this same method is used to compute reaeration, but the three parameters are not adjustable by the modeler; three sets of the parameters are automatically selected depending on the simulated values of velocity and depth in the reach.

EXPRED Exponent to depth in the reaeration rate coefficient equation. Refer to the parameter REAK above for details about the method. Typical values of EXPRED range from -1.5 to -1.85. In this range, the reaeration rate decreases with increasing depth assuming other factors (velocity and temperature) remain constant. Also, in this range increases in EXPRED (e.g., changing from -1.5 to -1.85) result in increasing the effect of depth on reaeration and vice versa.

EXPREV Exponent to velocity in the reaeration rate coefficient equation. Refer to the parameter REAK above. Typical values of EXPREV range from 0.5 to 1.0. In this range, the reaeration rate increases with increasing velocity assuming other factors (depth and temperature) remain constant. Also, in this range increases in EXPREV result in increasing the effect of velocity on reaeration and vice versa.

8.0 Nutrient (NUTRX) Parameter Guidance

NUTRX simulates the primary processes which determine the balance of inorganic nitrogen and phosphorus in natural waters.

NUT-FLAGS Table:
The default value for each of the first seven flags is 0. In this situation, only nitrate would be simulated in this section, and its only process would be generation when BOD decays. Most models will include simulation of phytoplankton and/or benthic algae, which requires simulation of orthophosphorus.

TAMFG Value of 1 means total ammonia is simulated. If ammonia loadings from land or other sources are being modeled, this flag should be set to 1 and other ammonia parameters should be specified, including nitrification and denitrification rate(s) in table NUT-NITDENIT.

NO2FG Value of 1 means nitrite is simulated. The nitrification of ammonia to nitrate can be modeled as either a one-step or two-step process, and the second step (nitrite to nitrate) is chemically faster. Therefore, nitrite is usually a small fraction of the total nitrate and nitrite. Very few models include nonpoint nitrite loads, but some point source data include separate nitrate and nitrite levels. If local requirements specify simulation of nitrite, this flag should be set to 1, and individual nitrification rates for ammonia and nitrite should be specified in table NUT-NITDENIT.

PO4FG Value of 1 means ortho-phosphorus is simulated. If phosphorus loadings from land or other sources are being modeled and phytoplankton is being simulated in the PLANK section, this flag should be set to 1.

AMVFG Value of 1 means ammonia volatilization is enabled. Under conditions of high pH, un-ionized ammonia could be significant and could be subject to volatilization from the water. Recommendation: set AMVFG to 0.

DENFG Value of 1 means denitrification is enabled. Denitrification is reduction of nitrate to (primarily) nitrogen gas under anaerobic conditions, usually in the bed sediment. If this process is likely to be a significant loss mechanism for nitrate, set DENFG to 1.

ADNHFG Value of 1 means ammonia adsorption is simulated. Since a small fraction of the ammonia in natural waters is considered particulate, adsorption of ammonia to sediment is an optional process in HSPF. If this flag is set to 1, enter ammonia adsorption parameters in tables NUT-ADSPARM, NUT-BEDCONC, and NUT-ADSINIT.

ADPOFG Value of 1 means orthophosphorus adsorption is simulated. Since a fraction of the orthophosphorus in natural waters is particulate, adsorption to sediments is an optional process in HSPF. In most models, set this flag to 1 and enter ortho-

phosphorus adsorption parameters in tables NUT-ADSPARM, NUT-BEDCONC, and NUT-ADSINIT.

PHFLAG Source of pH data (1 = input time series of values, 2 = constant value, 3 = 12 monthly values). pH data are only required if ammonia volatilization is being modeled. In most models, set this flag to 2, and enter a constant pH value in table NUT-DINIT.

CONV-VAL1 Table:
HSPF assumes that biomass of all types (phytoplankton, benthic algae, zooplankton, and dead organic materials) have the same chemical (C, N, P, O) composition. That composition is defined in this table. In most models, the values in this table are not calibrated.

CVBO Conversion from milligrams biomass to milligrams oxygen. The units are mg-oxygen/mg-biomass. This parameter is the conversion factor that is used to determine the amount of oxygen that is produced during algal growth. It is also used to determine the nutrient content of BOD (BOD is expressed in terms of oxygen). The value 1.63 is recommended.

CVBPC Conversion from biomass expressed as phosphorus to carbon. The units are moles-C/moles-P. The default values for CVBPC and CVBPN correspond to the originally-estimated Redfield ratio of C:N:P = 106:16:1. These values are used in most models. If local data indicates the predominant cell composition is different, those values should be used. Otherwise, the default value 106 is recommended.

CVBPN Conversion from biomass expressed as phosphorus to nitrogen. The units are moles-N/moles-P. See above for CVBPC. The default value 16 is recommended.

BPCNTC Percentage of biomass which is carbon (by weight). Depending on the specific species of phytoplankton or benthic algae (or assemblage) that the model is attempting to represent most closely, this parameter can range between 10 and 70%. If specific species data are not available, the default 49% is recommended.

NUT-BENPARM Table:
This table is used if BENRFG = 1 in Table-type BENTH-FLAG (see RQUAL section).

BRNIT(1) Benthal release rates of ammonia under aerobic conditions. Modelers should be aware that total loadings of ammonia from internal sources (i.e., not those from nonpoint and point sources) can occur directly from this benthal release rate and from scour of sediment when ammonia is modeled as a particulate material. It can also occur indirectly from benthal release of BOD, since BOD decay generates ammonia. Modelers are cautioned to avoid multiple sources of ammonia from the bed that might result in over-simulating these internal sources. Many models set this release rate to 0 in reaches that are not overly impacted. However, if these benthal releases are used as the primary internal source of ammonia, the parameter can be used to help calibrate ammonia, and to provide a small stable source of ammonia in headwater reaches to support algal growth. Modelers

should ensure that the relative loadings of ammonia from point/nonpoint sources and benthal releases are reasonable.

BRNIT(2) Benthal release rates of ammonia under anaerobic conditions. If aerobic releases are modeled, this anaerobic release rate should be set to a lower value. A layer of oxidized materials tends to form on the benthal surface during aerobic periods, and this layer retards the release rate of additional benthal materials.

BRPO4(1) Benthal release rates of ortho-phosphorus under aerobic conditions. See BRBNIT(1) above.

BRPO4(2) Benthal release rates of ortho-phosphorus under anaerobic conditions. See BRBNIT(2) above.

ANAER Concentration of dissolved oxygen in the water column below which anaerobic conditions are assumed to exist in the bed sediment. When the dissolved oxygen concentration falls below this value, the anaerobic release rates of ammonia and ortho-phosphorus described above are used instead of the aerobic rates. Since this concentration is the water column value, it is not likely to approach zero. Simulated water column dissolved oxygen concentrations rarely go lower than 2 mg/L unless extremely high BOD loading or high benthal oxygen demand occurs. Therefore, if these benthal releases are considered important, it is recommended to adjust this parameter to achieve the expected frequency of bed sediment anaerobic conditions. This parameter affects the death rates of phytoplankton, benthic algae, and zooplankton.

NUT-NITDENIT Table:

KTAM20 Nitrification rate of ammonia at 20ºC. Nitrification is a two-step bacterial oxidation of ammonia to nitrite and then to nitrate; both steps consume oxygen. If nitrite is not simulated, it is treated as a one step oxidation of ammonia to nitrate. KTAM20 is the first order (in ammonia) rate for either the one step process or the first step in the two-step process. Both temperature and dissolved oxygen affect nitrification rates, and these effects are included in HSPF explicitly. The temperature effect is determined by the parameter TCNIT, and nitrification only occurs when dissolved oxygen is greater than 2 mg/L. The nitrification rates from previous studies vary over a wide range of 0.002 – 0.65 /hour, and the value is often used to calibrate levels of both ammonia and nitrate. Higher rates reduce ammonia and increase nitrate. A recommended starting range is 0.02 – 0.04 /hour.

KNO220 Nitrification rate of nitrite at 20ºC. This is the rate constant for the second step in the two-step ammonia oxidation process. Refer to the discussion above for details. Most studies that use separate rates report a higher rate for this second step of nitrite to nitrate. Since this step is faster, there is relatively less nitrite present in most natural waters. Therefore, it is recommended to use a slightly higher rate for KNO220 than KTAM20.

KNO320 Nitrate denitrification rate at 20ºC. Denitrification is reduction of nitrate to nitrogen gas under anaerobic conditions, and is assume to occur primarily in the bed sediment. In HSPF, anaerobic conditions for this process are defined by the parameter DENOXT. Refer to that discussion below. Few studies have reported measured or calibrated values of KNO320. It is recommended to use a starting value of 0.002 /hour and calibrate to adjust nitrate concentrations.

TCNIT Temperature correction coefficient for nitrification. This value applies to both the one-step nitrification process and to both steps of the two-step process. Similar to the temperature correction for other processes in RQUAL, values greater than 1 will result in higher nitrification with increasing temperature. Typical values for the ammonia nitrification range from 1.05 – 1.10 for the ammonia to nitrite step and 1.04 – 1.07 for the nitrite to nitrate step. Since temperature dependence has a relatively minor effect, it is recommended to use a midrange value (e.g., 1.06), and not adjust it during calibration. However, nitrification is retarded by extremely high temperatures such as those above 30 deg. C, so if high water temperatures are prevalent in a reach, it might be advisable to set TCNIT to 1.0.

TCDEN Temperature correction coefficient for denitrification. Similar to the temperature correction for other processes in RQUAL, values greater than 1 will result in higher denitrification with increasing temperature. Typical values for this factor range from 1.02 – 1.09. Since temperature dependence has a relatively minor effect, it is recommended to use a value of 1.045, and not adjust it during calibration.

DENOXT Dissolved oxygen concentration threshold for denitrification. Concentration of dissolved oxygen in the water column below which denitrification is occurring (which generally occurs under anaerobic conditions in the bed sediment). Since this concentration is the water column value, it is not likely to approach zero. Simulated water column DO concentrations rarely go lower than 2 mg/L unless extremely high BOD loading or high benthal oxygen demand occurs. Therefore, if denitrification of nitrate is considered important, it is recommended to adjust DENOXT to achieve the expected frequency of bed sediment anaerobic conditions which will allow denitrification to occur. (Note: the nitrate that denitrifies is in the water column.) Reasonable values of DENOXT can range between 1 and 10; however, at the higher values, it is possible that the simulated denitrification losses are actually caused by some other process, or the nitrate loading is too high.

NUT-NH3VOLAT Table: *This table is required if AMVFG is set to 1 in the NUT-FLAGS table. This activates the volatilization of unionized ammonia (NH_3). Modelers should be cautious in activating this process to make sure it doesn't lead to excessive ammonia loss. We generally recommend setting the flag to 0, and not attempting to simulate this volatilization process, at the current time.*

EXPNVG Exponent in the gas layer mass transfer coefficient equation for ammonia volatilization. The ammonia volatilization first-order rate is computed from a two-layer (gas and liquid) mass transfer model. The overall mass transfer coefficient

has a term for each of the layers, and EXPNVG is the exponential factor in the gas layer term. Higher values increase the volatilization rate, and the full range of possible values result in a maximum factor of 1.5 change in this term. The gas layer rate term is also a function of wind speed, water temperature, and pH. If ammonia volatilization is being modeled, the recommended value for this parameter is the default value, 0.5.

EXPNVL Exponent in the liquid layer mass transfer coefficient for NH3 volatilization. Refer to the discussion for EXPNVG above. EXPNVL is the exponential factor in the liquid layer term. Higher values increase the volatilization rate, and the full range of possible values result in a maximum factor of 2 change in this term. The liquid layer rate term is also a function of the oxygen reaeration rate KOREA. If ammonia volatilization is being modeled, the recommended value for this parameter is the default value, 0.667.

NUT-BEDCONC Table:

BNH4(1-3) Constant bed concentrations of ammonia-N adsorbed to sand, silt, and clay. The bed sediment may contain ammonia (and orthophosphorus) if the reach has historically received flows containing high amounts of ammonia and orthophosphorus. If any sediment scour occurs, this results in adsorbed ammonia and orthophosphorus addition to the water column based on these concentrations and the bed sediment scout amounts. The units are mg-N/kg-sediment, and typical values range from 10 to 1000. It should be noted that this process is separate from the benthal release of ammonia and orthophosphorus that is specified in table NUT-BENPARM. That process is also subject to increases during scour conditions, based on the parameters in table SCOUR-PARMS. Users should be aware of the possibility of excessive internal sources of these nutrients. These nutrients are also generated by decay of BOD that is released during benthal release of BOD. It is recommended that modelers compare the nutrients generated from these internal sources with nonpoint and point sources to ensure they are reasonable and valid for their watershed.

BPO4(1-3) Constant bed concentrations of orthophosphorus-P adsorbed to sand, silt, and clay. Refer to discussion above for BNH4.

NUT-ADSPARM Table:

ADNHPM(1-3) Equlibrium adsorption coefficients (Kd) for ammonia-N adsorbed to sand, silt, and clay. If ammonia is expected to have a significant particulate nature, this process is used to model it. Higher values of the parameter result in more adsorption. Some of the effects of more adsorption are reduced nitrification, reduced algal uptake, and greater ammonia loss by sedimentation. Typical values range from 10 to 200, with the lower values applied to sand, and higher values for silt and clay.

ADPOPM(1-3) Equlibrium adsorption coefficients (Kd) for ortho-phosphorus-P adsorbed to sand, silt, and clay. Typically, a fraction of the orthophosphorus is expected to

exhibit a particulate nature, and this process is used to model that fraction. Higher values of the parameter result in more adsorption. Some of the effects of more adsorption are reduced reduced algal uptake, and greater orthophosphorus loss by sedimentation. Typical values range from 400 to 1000, with the lower values applied to sand, and higher values for silt and clay.

9.0 Plankton (PLANK) Parameter Guidance

PLNK-FLAGS Table:

PHYFG Value of 1 means phytoplankton are simulated.

ZOOFG Value of 1 means, zooplankton are simulated.

BALFG Value of 1 means a single species of benthic algae is simulated, with growth and respiration rates proportional to phytoplankton (PHYFG must be 1). If BALFG is 2, multiple benthic algae species (between one and four) are simulated using a different benthic algae method; in this option, PHYFG can be 1 or 0. If BALFG is 0, no benthic algae are simulated.

SDLTFG Value of 1 means the influence of suspended sediment on light extinction is simulated based on the computed (or input) sediment concentration. Value of 2 means light extinction is based on a linear regression with the flow rate (requires input of Table-type BENAL-LIGHT). Value of 0 means light extinction dependence on suspended sediment is not considered explicitly.

AMRFG Value of 1 means ammonia retardation of nitrogen-limited growth is enabled. There is some evidence that high ammonia concentration retards algal growth. Unless this process is known to be important in your watershed, it is recommended to set this flag to 0.

DECFG Value of 1 means linkage between carbon-dioxide and phytoplankton growth is decoupled, i.e., CO2 is not considered a limiting nutrient. DECFG is only effective if pH is being simulated, in which case it is recommended to set DECFG to 0.

NSFG Value of 1 means that ammonia is included as part of available nitrogen supply in N-limited growth calculations. There is disagreement over whether algae generally prefer to utilize ammonia or nitrate for growth. Most models include ammonia as a source of nitrogen, along with nitrate. If ammonia is known to not be utilized by the predominant algae in a watershed, set NSFG to 0; otherwise, it should be set to 1. If both ammonia and nitrate are considered nitrogen sources, the uptake proportions are determined by ALNPR, the fraction of uptake that is satisfied by nitrate.

ZFOOD Indicates the quality of zooplankton food; 1= high quality, 2 = medium, 3 = low. This flag determines the efficiency with which zooplankton assimilates the food (phytoplankton) that it ingests.

BENPFG Value of 0 indicates benthic algae use ALNPR in Table-type PLNK-PARM1 to determine preference between ammonia and nitrate. Value of 1 means nitrogen preference is computed with an alternative method, which is based on CAMPR in Table-type BENAL-PARM.

BENAL-FLAGS Table:
This table is only read if BALFG=2 in the Table-type PLNK-FLAGS.

NUMBAL Number of benthic algae species that are being simulated using the modified approach, i.e., Method 2. This input is not effective if benthic algae are being modeled with the original approach, which is directly dependent on the simulated phytoplankton growth and respiration.

BINVFG Specifies the source of benthic macroinvertebrates for the computation of grazing in the modified benthic algae model. 1 means a timeseries is being input as BINV in the EXTNL group of timeseries; 2 means a constant value of BINV is specified in Table-type BENAL-GRAZE; and 3 means that monthly values are input in Table-type MON-BINV.

BFIXFG(4) Flags that indicate whether a species of benthic algae fixes nitrogen, so that growth is not nitrogen-limited. A value of 1 means that the species fixes nitrogen. There is one flag for each species.

PLNK-PARM1 Table:

RATCLP Ratio of chlorophyll *a* content of biomass to phosphorus content. This parameter facilitates conversion of simulated phytoplankton and benthic algae amounts to the chlorophyll *a* units that are typically used for algal measurements and water quality standards. Research suggests this parameter should range from 1 to 2; however, most HSPF models have relied on values closer to the default 0.6; and many models have used 0.68. Higher values will result in higher chlorophyll *a* predictions for the same amount of phytoplankton or benthic algae. In some existing models, more algal growth and consequent nutrient uptake are simulated than would have occurred because the computed chlorophyll *a* values are artificially low, leading modelers to increase growth to match observed chlorophyll *a* data.

NONREF Non-refractory fraction of algae and zooplankton biomass. HSPF assumes that a portion of the biomass (phytoplankton, benthic algae, and zooplankton) cannot be degraded upon algal death. This material is released as the refractory (unreactive) organic nutrients (N, P, C). The non-refractory portion is assumed to be released as BOD, which can degrade to generate inorganic nutrients. The main effect of higher values of NONREF is to increase inorganic nutrient and BOD concentrations and decrease refractory organic nutrients. This parameter is unique to HSPF, since most models assume that 100% of algal biomass that dies is available for decomposition. Most HSPF models use a value of 0.5 (50%). It is recommended to use values at least 0.5 or higher.

LITSED Multiplication factor to total sediment concentration to determine sediment contribution to light extinction. It is only used if SDLTFG = 1 (in Table-type PLNK-FLAGS). The units of LITSED are L/mg/ft. Higher vlues of LITSED will result in greater light attenuation (and lower algal growth) during periods of high suspended sediment concentration. LITSED should be in the range of 0.01 – 0.03.

Values used in some HSPF models are an order of magnitude lower, which reduces the effect of suspended sediment on light attenuation.

ALNPR Fraction of the nitrogen required for phytoplankton growth that is satisfied by nitrate. It is also used for benthic algae if BALFG > 0 and BNPFG = 1 in Table-type PLNK-FLAGS. In other fixed-stoichiometry algal models, the preference for ammonia vs. nitrate is referred to as an "ammonia preference factor", and is equal to 1 – ALNPR. In these models, this preference factor can be specified as a constant or is sometimes allowed to vary according to the relative concentrations of the two nutrients. The effect of higher values of ALNPR is to increase nitrate uptake relative to ammonia uptake. The recommended range is 0.1 – 0.7.

EXTB Base extinction coefficient for light in units of /ft. The value for pure water is approximately 0.01. Values of EXTB are generally higher, in order to account for the effect of materials entrained in the water column that prevent light from penetrating to deeper depths. The total extinction factor is a sum of the base extinction plus contributions from sediment and phytoplankton. The sediment contribution can be included using the LITSED parameter (above), and self shading by phytoplankton is automatically included. EXTB is sometimes adjusted in the calibration of algal (phytoplankton and benthic algae) growth. This can result in values that are lower than 0.01. A recommended starting (and minimum) value is 0.015.

MALGR Maximum unit algal growth rate for phytoplankton in units of /hour. This is the growth rate that is applicable under ideal conditions of nutrient and light availability. Values of MALGR are generally defined at a reference temperature, such as 20 degrees C. The computed growth rate at any time will be reduced by effects of nutrient and/or light limitation and by sub-optimum temperatures. Literature values generally range from 0.05 to 0.20 depending on the type of algae, and this parameter is often used to calibrate algal growth.

PARADF Fraction of solar radiation that is photosynthetically active. The light used by algae corresponds to only the visible range of frequencies, which is approximately half of the total surface radiation. That suggests that PARADF should be no larger than 0.5. Most HSPF models use the default value of 1.0. Light limitation is affected by several processes, including extinction by water, sediment, and phytoplankton; and effective shading as defined by the CFSAEX and PARADF parameters. The recommended value for PARADF is 0.5, and it can be used to calibrate algal growth. Modelers should be aware that increases in algal growth due to light availability can be obtained by adjusting three parameters: PARADF, CFSAEX, and EXTB. Note: CFSAEX adjustments will also affect water temperature.

PLNK-PARM2 Table:

CMMLT Michaelis-Menten constant for light limited growth for phytoplankton in units of Langleys/minute. Light limitation is modeled with a simple Michaelis-Menten formulation. This parameter is the half-saturation constant in that equation (refer

to discussion under CMMN). Increases in CMMLT result in decreased unit growth rate based on light limitation. Values for CMMLT should be in the range 0.010 – 0.36 for phytoplankton. Smaller values (> 0.0003) are possible for diatoms. The default value (0.033) is recommended if specific information for the watershed is not available. CMMLT is generally not used for calibration.

CMMN Michaelis-Menten constant for nitrogen limited growth for phytoplankton in units of mg nitrogen/L. This is the half-saturation constant in the nitrogen limited growth equation. It is the concentration of the nutrient (in this case nitrate or nitrate plus ammonia) at which the growth rate is one half of its maximum growth. The general Michelis-Menten model results in a growth curve that starts out linear with concentration at low nutrient concentration, and levels off at a maximum growth rate at high nutrient concentration. CMMN values are typically in the range 0.001 – 1.0, and it is not generally used for calibration. The recommended value is the default: 0.045.

CMMNP Nitrate Michaelis-Menten constant for phosphorus limited growth for phytoplankton in units of mg nitrate-N/L. Refer to discussion of CMMN above. In HSPF, the phosphorus limited growth equation includes a dependence on nitrate concentration as well as orthophosphorus concentration. If this condition is likely, then the recommended value for CMMNP is the default 0.028. However, most models assume that phosphorus limited growth is not dependent on nitrate, and the recommended value of CMMNP in this case is 0.0001, which effectively removes the nitrate dependence.

CMMP Michaelis-Menten constant for phosphorus limited growth for phytoplankton in units of mg orthophosphorus-P/L. Refer to discussion of CMMN above. In most freshwater systems, phosphorus is most often (seasonally) the limiting nutrient. Values of CMMP are in the range 0.0005 – 0.2, with values for phytoplankton typically in the middle of that range. If local information is not available, the recommended value is the default 0.015.

TALGRH Temperature above which phytoplankton growth ceases. The effect of temperature on the maximum growth rate in HSPF is a relatively simple curve. Growth is optimum (and constant) within the temperature range of TALGRM to TALGRH. Within the range TALGRL up to TALGRM, the rate increases linearly with temperature from 0 to the optimum rate at TALGRM. Below TALGRL and above TALGRH, the growth rate is zero. Most algae will experience growth rate reductions and zero growth between 30 and 40 degrees C. The recommended value for TALGRH is in the range 33 – 35 degrees C (91 - 95 degrees F).

TALGRL Temperature below which phytoplankton growth ceases. See discussion for TALGRH. Algae growth is likely to stop in the range of 2 - 3 degrees C; however, some modelers use lower values of TALGRL in order to impose a flatter temperature response between TALGRL and TALGRM. The recommended value of TALGRL is 5 degrees C (41 degrees F).

TALGRM Temperature below which phytoplankton growth is retarded. See discussion for TALGRH. This is the temperature above which algal growth becomes maximum or optimum. The most appropriate values of TALGRM are in the range 22 – 27 degrees C, but calibration of this parameter within the range 18 – 30 degrees C is reasonable. The recommended value is 25 degrees C (77 degrees F).

PLNK-PARM3 Table:

ALR20 Phytoplankton unit respiration rate at 20ºC in units of /hour. Respiration is a function of the species and current growth conditions, and it is primarily determined by temperature. In HSPF, the computed respiration, which is a direct function of temperature, is subtracted from the growth to compute net growth. When conditions for growth are poor, net growth will be negative. Typical values of ALR20 are in the range 0.0002 – 0.040, and the recommended value is 0.004 – 0.005.

ALDH High phytoplankton unit death rate in units of /hour. Algal death occurs at either the high rate (ALDH) or a lower rate (ALDL), depending on current conditions of nitrogen, phosphorus, and phytoplankton concentrations. The nitrogen and phosphorus thresholds for the high death rate are NALDH and PALDH, which are specified in this table. The threshold for phytoplankton is CLALDH, which is specified in table PHYTO-PARM. In addition, an increment to the death rate under anaerobic conditions is included when the dissolved oxygen concentration is below the value of the ANAER parameter in table NUT-BENPARM. Death accounts for non-predatory mortality, i.e., losses to other stresses besides assimilation by zooplankton, such as extreme heat or toxic substances. Literature values for these types of death rates range from 0.0001 – 0.010 /hour. If zooplankton are not modeled, then death rates could be higher to account for the predatory losses. The recommended value for ALDH is the default (0.01) or lower. In most applications, the death rate parameters are not used for calibration; if they are, it is recommended that the adjustments be small, and the resulting fluxes (losses) of algae be checked for reasonableness.

ALDL Low phytoplankton unit death rate in units of /hour. See discussion for ALDH above. The recommended value for ALDL is the default (0.001).

OXALD Increment to phytoplankton unit death rate due to anaerobic conditions in units of /hour. See discussion for ALDH above. The recommended value for OXALD is the default (0.03).

NALDH Inorganic nitrogen concentration below which high phytoplankton death rate occurs (as nitrogen) in units of mg-N/L. See discussion for ALDH above. The recommended value for NALDH is 0.01.

PALDH Inorganic phosphorus concentration below which high phytoplankton death rate occurs (as phosphorus) in units of mg-P/L. See discussion for ALDH above. See discussion for ALDH above. The recommended value for PALDH is 0.002.

PLNK-PARM4 Table:

NMINGR Minimum nitrate-N concentration for algal growth in units of mg N/L. If nitrate concentration is below NMINGR, no algae, including benthic algae will grow. In earlier versions of HSPF, this value was hard coded to 0.001, which is the default value. Most models do not include this table, which results in default values of all of the parameters. **Note that all of the parameters in this table have a default value of 0.001.** In most cases, none of these parameters are useful for calibration.

PMINGR Minimum orthophosphate-P concentration for algal growth in units of mg P/L. Refer to discussion of NMINGR above.

CMINGR Minimum CO2-C concentration for algal growth in units of mg C/L. Refer to discussion of NMINGR above.

LMINGR Minimum light intensity for algal growth in units of Langleys/minute. Refer to discussion of NMINGR above.

NMINC Minimum concentration for both inorganic N species (ammonia and nitrate) allowed to remain after algal uptake in units of mg N/L. If the concentration of either species goes below this level, it is set to zero. The discussion of NMINGR above applies to NMINC.

PHYTO-PARM Table:

SEED Minimum concentration of plankton not subject to advection (i.e., at high flow) in units of mg phytoplankton/L. The first three parameters in this table parameterize this reduced advection of phytoplankton. Since phytoplankton tend to be located close to channel edges, where flow is lower, they have a longer residence time than fully entrained or dissolved constituents. Also, since biological growth rates are lower than normal advection rates, many free-flowing reaches could not maintain a viable phytoplankton population without this method. The method of computing the amount of phytoplankton that is not subject to advection (STAY) is illustrated below in Figure 9.1. SEED is the small concentration that is never subject to advection, even during high flow conditions. It is recommended that a non-zero value be used. Typical values are close to 1 mg/L.

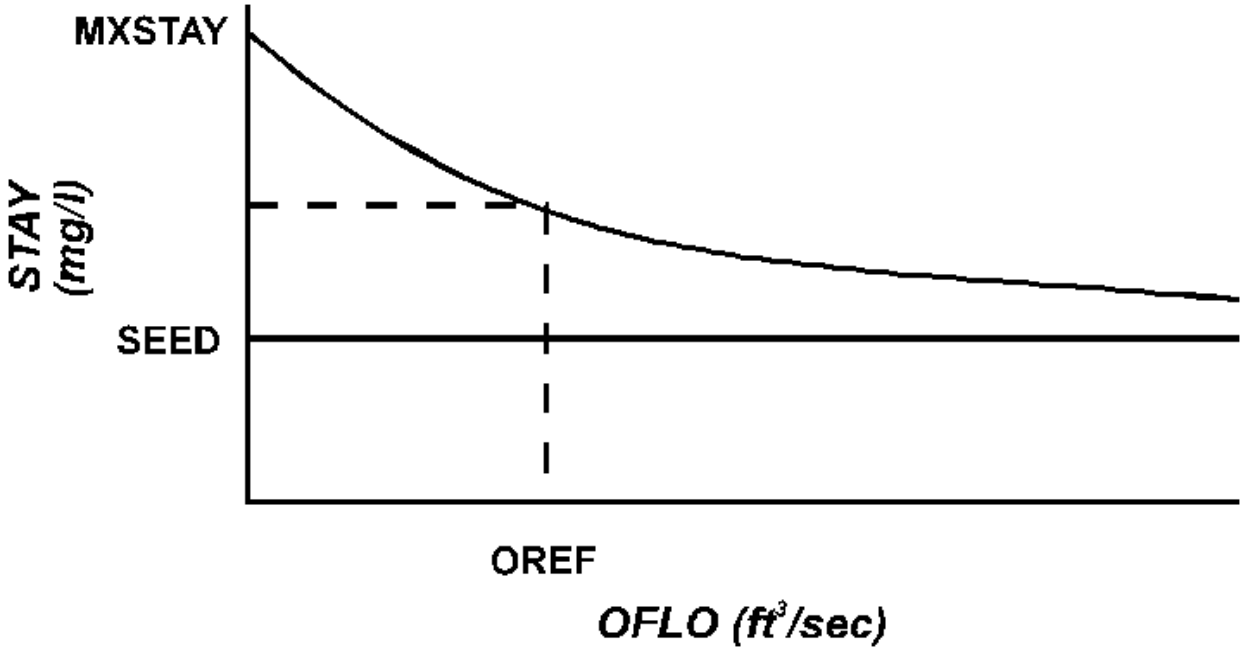

Figure 9.1. Relationship of Parameters for Advection of Plankton.

MXSTAY Maximum concentration of phytoplankton not subject to advection in units of mg phytoplankton/L; this occurs at very low flow. See the discussion above. MXSTAY is occasionally used for calibrating phytoplankton. Values range from 5 to 100 mg/L.

OREF The outflow (in units of ft^3/s) at which the concentration of plankton not subject to advection (STAY) is midway between SEED and MXSTAY. See the discussion above. OREF is occasionally used for calibrating phytoplankton along with MXSTAY. A reasonable starting value for OREF is the median value of the flow rate in the reach.

CLALDH The chlorophyll *a* concentration above which high algal death rate occurs in units of ug/l. Refer to the discussion for ALDH in table PLNK-PARM3. Phytoplankton are assumed to experience greater mortality when their total population becomes excessive. CLALDH is not typically used for calibration. The recommended range is 50 – 75 ug/l.

PHYSET Rate of phytoplankton settling in units of feet/hour. Phytoplankton settling depends on many factors, including cell shape and density, flow turbulence and velocity, and water density and viscosity. However, most models represent a lumped phytoplankton species, and don't readily allow for including these factors that affect settling. Therefore, the settling rate is typically used as a calibration parameter. Model values generally fall in the range 0.0005 – 1 ft/hr. Lower values are recommended for lakes.

REFSET Rate of settling for non-living, refractory organic species (N, P, C) in units of feet/hour. If these organic nutrients are known to exhibit particulate behavior, settling losses can be included by specifying REFSET. This parameter is

sometimes used to calibrate the refractory organics as part of the calibration of total N and P. Higher values will reduce the concentrations. Values range from 0.001 to 0.2. Note that if the default settling rate (0.0) is not desired, this table should be included in models where phytoplankton are not being simulated (i.e., PHYFG = 0 in Table-type PLNK-FLAGS).

ZOO-PARM1 Table:

MZOEAT Maximum zooplankton unit ingestion rate in units of mg phytoplankton per mg zooplankton per hour. The computed unit ingestion rate ZOEAT is a function of the temperature, the zooplankton filtering rate at 20 degrees C (ZFIL20), and the phytoplankton concentration. If ZOEAT is greater than MZOEAT, ZOEAT is set to MZOEAT. Related to ingestion, the assimilation of the food, i.e., its conversion to zooplankton biomass is assumed to be less efficient than 100 percent. Assimilation efficiency in HSPF is determined by the quality of the food, which is assigned by the parameter ZFOOD in table PLNK-FLAGS.

ZFIL20 Zooplankton filtering rate at 20ºC in units of L/mg zooplankton/hour. It is the rate of intake of water (containing phytoplankton) that results in ingestion and assimilation of the phytoplankton. This process results in reduction of phytoplankton concentration and growth of zooplankton. It is the first order (in phytoplankton) rate constant in the equation for the ingestion (ZOEAT) of phytoplankton (see discussion of MZOEAT). Typical values of ZFIL20 are 0.01 – 0.2, and this parameter is useful for calibration of the zooplankton population. It should be noted that the filtering efficiency in HSPF is assumed to be 1; if a lower efficiency is desired, the value of ZFIL20 can be reduced accordingly. Also, the ingestion process is adjusted for temperature.

ZRES20 Zooplankton unit respiration rate at 20ºC in units of /hour. Respiration is a process which results in a reduction in zooplankton mass and release of nutrients. It is a function of many factors, including temperature, zooplankton age, dissolved oxygen, and crowding. In some models, mortality (death) is lumped into respiration. In HSPF, death is modeled separately, and the temperature effect is modeled explicitly with a temperature correction factor. Typical values of ZRES20 range from 0.0001 to 0.50. A reasonable starting value is the default 0.0015, and it can be useful for calibration. Increases will result in zooplankton and dissolved oxygen reductions and increases in nutrient concentrations.

ZD Natural zooplankton unit death rate in units of /hour. In HSPF, zooplankton death is modeled separately from respiration. It is related to the same factors as respiration, and it includes predation by higher trophic levels (i.e., fish). Death results in reduction of dissolved oxygen and zooplankton, and release of inorganic and organic nutrients. Death rates in the literature range from 0.00005 to 0.005. The recommended value is the default 0.0001.

OXZD Increment to unit zooplankton death rate due to anaerobic conditions in units of /hour. If anaerobic conditions exist (i.e., the dissolved oxygen concentration is less than the parameter ANAER (table NUT-BENPARM), death is assumed to

increase by a large factor. OXZD is the additional/incremental death rate that is applied. The recommended value is the default 0.03.

ZOO-PARM2 Table:

TCZFIL Temperature correction coefficient for zooplankton filtering. Similar to the temperature correction for other processes in RQUAL, values greater than 1 will result in higher filtering with increasing temperature. Zooplankton filtering is likely to have a higher temperature dependence than other processes, so it is recommended to use a value of 1.10 – 1.17, and not adjust it during calibration.

TCZRES Temperature correction coefficient for zooplankton respiration. Similar to the temperature correction for other processes in RQUAL, values greater than 1 will result in higher respiration with increasing temperature. Since temperature dependence has a smaller effect on this process, it is recommended to use a value of 1.07, and not adjust it during calibration.

ZEXDEL Fraction of non-refractory zooplankton excretion which is immediately decomposed when the ingestion rate is greater than MZOEAT. At high ingestion rates, i.e. at the rate MZOEAT, some of the excretion is released as BOD material. At lower ingestion rates, all of the excreted material is assumed to be degraded and converted to inorganic nutrients. ZEXDEL is the fraction that is released as inorganic nutrients at high ingestion rates. Higher values of ZEXDEL will result in somewhat higher production of inorganic nitrogen and phosphorus; however, excretion of BOD will also increase these constituents as it decays. The recommended value is the default 0.7.

ZOMASS Average weight of a zooplankton organism in units of mg/organism. This is used to convert zooplankton concentration between units of organisms/L and mg-biomass/L. Typical values range from 0.00001 to 0.1 mg. In the absence of specific information on the zooplankton species, the default value of 0.0003 should be used.

BENAL-PARM Table:

MBAL Maximum benthic algae density (as biomass) in units of mg biomass/m^2. This parameter applies when BALFG = 1, in Table-type PLNK-FLAGS. In this method, when growth conditions are good (i.e., nutrients, light, temperature), benthic algae can grow to a maximum density on rocks and other substrates in the water body. Typical measured values of benthic algae density cover the wide range of 10 – 100,000 mg biomass/m^2, so while MBAL values in HSPF models are typically 100 – 2000, these values can obviously be much higher. MBAL is generally considered a calibration parameter. Note: any potential growth above MBAL is added to the benthic algae death in that model interval. It should also be noted that the model maintains a minimum benthic algae biomass of 0.0026 mg/m^2.

CFBALR Ratio of benthic algae to phytoplankton respiration rate. Since the Method 1 benthic algae approach utilizes the computed phytoplankton respiration rate, the CFBALR parameter provides a factor to adjust the respiration if there is evidence that the benthic algae population does not exhibit the same respiration rate as the phytoplankton population. This is a useful parameter for calibration, since it does not change the phytoplankton simulation, except for the secondary effect of competition for nutrients). The recommended starting value is the default value 1 (note, this is also the maximum value).

CFBALG Ratio of benthic algae to phytoplankton growth rate. Refer to the discussion of CFBALR above. The same comments apply to the benthic algae growth rate factor CFBALG.

MINBAL Minimum benthic algae (in units of mg biomass/m^2), if BALFG=2 in Table-type PLNK-FLAGS. This minimum is applied separately to each of the benthic algae types that are modeled using Method 2. This minimum density is maintained by adjusting the growth and death rates of the individual benthic algae types. The default value (0.0001) is equivalent to 0.80E-5 mg Chl-a/m^2; since typical measurements are greater than 0.1 mg Chl-a/m^2, the default value is not recommended.

CAMPR Coefficient in the alternative nitrogen preference equation for benthic algae, if BALFG = 2 and BNPFG = 1 in Table-type PLNK-FLAGS. The benthic algae Method 2 approach allows an optional nitrogen preference function. The optional method is a function of the ammonia and nitrate concentrations and CAMPR. At low values of CAMPR (< 5), nitrate is strongly preferred as the source for growth, and at values greater than 10, ammonia is preferred. Nitrate preference increases with higher nitrate concentrations, and vice versa. The default value (0.001) will cause essentially all uptake to be nitrate. A value between 1 and 5 is recommended unless specific information is available.

FRAVL Fraction of nonrefractory nutrients resulting from benthic algae death/removal that are assumed to immediately be available as inorganic nutrients and refractory organic carbon. Used if BALFG = 2 in Table-type PLNK-FLAGS. In the Method 2 approach, when benthic algae die or are removed by scouring, the cell material is converted and apportioned to refractory organic nutrients, i.e., N, P, C and non-refractory organic material (BOD) based on the REFR parameter; this is the same as phytoplankton and benthic algae Method 1. In method 2, a fraction of this BOD is immediately converted to inorganic nutrients plus refractory organic C based on FRAVL. The default value of FRAVL is 0. Nonzero values of FRAVL will make more inorganic nutrients available for uptake by algae.

NMAXFX Concentration of available inorganic nitrogen in the water column (ammonia + nitrite + nitrate in units of mg-N/L) above which nitrogen-fixation by benthic algae is suppressed. If this concentration is greater than NMAXFX, fixation does not occur. Used if BALFG = 2 in Table-type PLNK-FLAGS and BFIXFG = 1 in table BENAL-FLAGS (note: there is a separate BFIXFG flag for each benthic algae species).

BENAL-GROW Table:
This table is only used when BALFG = 2 in Table-type PLNK-FLAGS. The values given here apply to one of up to four benthic algae types or species. The table should appear once for each species, i.e., NUMBAL times. NUMBAL is defined in Table-type BENAL-FLAGS.

MBALGR Maximum or optimal benthic algae growth rate for a benthic algae species in units of /hour. In the Method 2 approach, benthic algae growth is a function of nutrients, light, temperature, and total benthic algae density. MBALGR is the optimal growth rate, and it is multiplied by the simple temperature correction function and the minimum of the nutrient, light, and density limitation functions. The half saturation constants for the nutrient (nitrogen and phosphorus) and density limitations are included in this table.

TCBALG Temperature correction coefficient for growth for a species. Values greater than 1 will result in higher growth with increasing temperature. Typical values range from 1.02 – 1.1. Since temperature dependence has a relatively minor effect, it is recommended to use the default value (e.g., 1.07), unless species-specific information is available.

CMMNB Half-saturation constant for nitrogen-limited growth for a species in units of mg nitrogen/L. If the value is zero, then growth is not limited (i.e., this species fixes nitrogen). It is the concentration of the nutrient (in this case nitrate or nitrate plus ammonia) at which the growth rate is one half of its maximum growth. The general Michelis-Menten model results in a growth curve that starts out linear with concentration at low nutrient concentration, and levels off at a maximum growth rate at high nutrient concentration. CMMNB values are typically in the range 0.001 – 1.0, and it is not generally used for calibration. The recommended value is the default: 0.045.

CMMPB Half-saturation constant for phosphorus-limited growth for a species in units of mg ortho-phosphorus-P/L. In freshwater systems, phosphorus is most often (seasonally) the limiting nutrient. Values of CMMPB are in the range 0.0005 – 0.2, with values for benthic algae typically in the middle of that range. If local information is not available, the recommended value is the default 0.015.

CMMD1 Coefficient for total benthic algae density in the density-limited growth equation for a species.

CMMD2 Half-saturation constant for density-limited growth for a species in units of mg biomass/m^2.

CSLIT Saturation light level for a species in units of Langleys/minute.

BENAL-RESSCR Table:
This table is only used when BALFG = 2 in Table-type PLNK-FLAGS. The values given here apply to one of up to four benthic algae species. The table should appear once for each species, i.e., NUMBAL times. NUMBAL is defined in Table-type BENAL-FLAGS.

BALR20 Benthic algae respiration rate at 20ºC for a species in units of /hour. In the method 2 approach, the rate of respiration of benthic algae is a sum of two terms. The first term is the temperature corrected rate given by BALR20 and TCBALR. The second term is an incremental respiration rate that is necessary to support the photosynthetic growth of the benthic algae. This term is given by the factor GRORES and the computed growth rate.

TCBALR Temperature correction coefficient for respiration for a species. Higher values will increase the respiration rate for a given temperature. Typical values are 1.0 – 1.1. A value of 1.07 (the default) or less is recommended.

CSLOF1 Rate coefficient in the benthic algae scour equation for a species in units of /hour. Benthic algae death/removal is a combination of 1) grazing and disturbance by benthic invertebrates and 2) scouring by the flow. The scouring component is computed from a rate coefficient CSLOF1 and an exponential factor based on the velocity and the factor CSLOF2 (see below). Higher values of CSLOF1 will result in higher scour losses.

CSLOF2 Multiplier of velocity in the exponential factor in the benthic algae scour equation for a species. See discussion of CSLOF1 above. Higher values of CSLOF2 will result in higher scour losses.

GRORES Fraction of photorespiration needed to support growth/photosynthesis for a species. See discussion for BALR20 above. This multiplier between 0 and 1 determines the second term in the benthic algae respiration.

BENAL-GRAZE Table:
This table is only used when BALFG = 2 in Table-type PLNK-FLAGS.

CREMVL Benthic algae grazing (removal) rate by invertebrates in units of mg biomass/mg invertebrates/year. This is the rate coefficient (at 20 degrees C) of the invertebrate-caused death/removal process for the Method 2 benthic algae approach. The process uses Michaelis-Menten kinetics, and is first-order in the density of grazing invertebrates (BINV) and the density of each benthic algae species. The process is also adjusted for temperature based on the TCGRAZ parameter. Note that removal also occurs by scouring (see table BENAL-RESSCR). There is no guidance available on values of the removal parameters CREMVL, CMMBI, and BINV. Using the default values of all the parameters in this table will result in zero removal by invertebrate grazing, because the default for BINV = 0.

CMMBI Half-saturation constant for grazing by invertebrates in units of mg biomass/m^2. Refer to the discussion above for CREMVL. Higher values of CMMBI will result in lower grazing removal.

BINV Biomass (density) of grazing invertebrates in the reach if BINVFG = 2 in Table-type BENAL-FLAGS. The units of BINV are mg invertebrates/m^2. Refer to the

discussion above for CREMVL. Note, seasonally-varying (monthly) values can be input for BINV in table MON-BINV; this seasonal option is selected by setting BINVFG = 3 in table BENAL-FLAGS. Higher values of BINV will cause higher removal by invertebrate grazing.

TCGRAZ Temperature correction coefficient for macroinvertebrate grazing. Refer to the discussion above for CREMVL. If grazing is known to increase with temperature, TCGRAZ should be set to a value greater than 1 (i.e., 1.05).

BENAL-LIGHT Table:
This table is only used when both BALFG = 2 and SEDLTFG = 2 in Table-type PLNK-FLAGS.

CTRBQ1 Coefficient in the turbidity estimation (based on flow rate) equation for the optional light extinction method when benthic algae are simulated with method 2. The units are NTU/ft^3/s. The turbidity computed from this equation is used to compute the total extinction coefficient and the extinction contribution from sediment. If SEDLTFG = 1, this equation is not used, and the sediment contribution to light extinction is computed using the LITSED parameter in table PLNK-PARM1. There is no guidance available on values of the turbidity-related parameters in this table. Also, note that the default values will result in zero shading by sediment, since the default values of the two coefficients are 0.

CTRBQ2 Exponent in the turbidity estimation equation. Refer to discussion for CTRBQ1 and CKTRB1. This exponent on the flow rate is defaulted to 1.

CKTRB1 Coefficient in the light extinction equation (based on turbidity computed by turbidity estimation equation above) for the optional light extinction method when benthic algae are simulated with method 2. The units are /ft.

CKTRB2 Exponent in the light extinction equation. Refer to discussion for CTRBQ1 and CKTRB1. This exponent on the turbidity is defaulted to 1.

BENAL-RIFF1 Table:
This table is only used when BALFG = 2 in Table-type PLNK-FLAGS.

FRRIF Fraction of the reach that is composed of riffles where benthic algae can grow in the benthic algae Method 2 approach.

CMMV Half-saturation constant for riffle velocity used to compute the nutrient availability for benthic algae in units of ft/s. The nutrient limitation function includes a factor (called the velocity limitation function) that is a computed from the streamflow velocity in the riffle areas. The velocity in riffle areas is computed by adjusting the standard velocity in HSPF based on three critical flow levels (see RIFCQ1-3 below) and the riffle velocity multipliers (RIFVEL1-4) specified in table BENAL-RIFF2. A similar procedure is used to adjust the average depth to make it representative of the riffle areas; this uses the same critical flow levels along with the riffle depth multipliers (RIFDEP1-4) specified in table BENAL-RIFF2.

RIFCQ1-3 Critical flow levels #1 - #3 for riffle velocity and average depth in units of ft^3/s. See discussion of CMMV above. If the current flow rate is below RIFCQ1, the velocity and depth factors for riffle areas are RIFVEL1 and RIFDEP1. If the flow rate is between RIFCQ1 and RIFCQ2, the velocity and depth factors for riffle areas are RIFVEL2 and RIFDEP2. If the flow rate is between RIFCQ2 and RIFCQ3, the velocity and depth factors for riffle areas are RIFVEL3 and RIFDEP3. And if the flow rate is higher than RIFCQ3, the velocity and depth factors for riffle areas are RIFVEL4 and RIFDEP4.

BENAL-RIFF2 Table:
This table is only used when BALFG = 2 in Table-type PLNK-FLAGS.

RIFVEL(4) Riffle velocity multipliers corresponding to the critical flow values (RIFCQ) in table BENAL-RIFF1. These factors adjust the computed average velocity to make it representative of the riffle areas in the reach. Refer to discussion for CMMV and RIFCQ1-3 in table BENAL-RIFF1.

RIFDEP(4) Riffle depth multipliers corresponding to the critical flow values (RIFCQ) in table BENAL-RIFF1. These factors adjust the computed average depth to make it representative of the riffle areas in the reach. Refer to discussion for CMMV and RIFCQ1-3 in table BENAL-RIFF1.

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11.0 PERLND and IMPLND Parameter and Value Range Summary Tables

Value Ranges for HSPF land segment Water Quality Parameters

Following tables include ranges of water quality parameters for PERLND and IMPLND. The parameter values have been regrouped by general land use categories used in the models from which these parameter values have been extracted, Monthly varying parameters are not presented in these tables, and the modeler must provide the monthly variation based on local watershed conditions.

Table 11.1. Temperature, Gas, and Quality Constituent Parameters for Pervious Land Segments

NAME	DEFINITION	UNITS	RANGE OF VALUES											
			Forest		Ag/Other		Grassland		Pasture		Urban		Wetland	
			MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
PSTEMP-PARM1	Flags for PSTEMP section													
SLTVFG	Flag to specify if parameters for estimating surface layer temperature vary throughout the year.		0	1	0	1	0	1	0	1	0	1	0	1
ULTVFG	Flag to specify if parameters for estimating upper layer temperature vary throughout the year.		0	1	0	1	0	1	0	1	0	1	0	1
LGTVFG	Flag to specify if parameters for estimating lower layer and active groundwater temperature vary throughout the year.		0	1	0	1	0	1	0	1	0	1	0	1
TSOPFG	Methods to estimate subsurface soil temperatures.		0	2	0	2	0	2	0	2	0	2	0	2
PSTEMP-PARM2	Second group of PSTEMP parameters													
ASLT	Surface layer temperature when the air temperature is 32°F	°C or °F	28	55	28	60	26	58	30	58	30	58	28	55
BSLT	slope of the surface layer temperature regression equation		0.34	0.68	0.45	0.8	0.4	0.75	0.35	0.75	0.333	0.75	0.34	0.6
ULTP1	If TSOP = 0 or 2, then ULTP1 is the smoothing factor in the upper layer temperature calculation. If TSOP = 1, ULTP1 is the intercept in the upper layer temperature regression equation (like ASLT).		36	48	34	54	34	50	34	54	35	54	36	49
ULTP2	If TSOP = 0 or 2, then ULTP2 is the mean difference between upper layer soil temperature and air temperature. If TSOP = 1, ULTP1 is the sloped in the upper layer temperature regression equation (like BSLT).	°C or °F	0.22	0.55	0.25	0.7	0.23	0.65	0.23	0.65	0.23	0.65	0.22	0.55
LGTP1	If TSOP = 0 or 2, LGTP1 is the smoothing factor from air temperature for calculating lower layer/groundwater soil temperature. If TSOP = 1, LGTP1 is the lower layer/groundwater layer soil temperature.	°C or °F	36.0	60.0	36.0	68.0	35.0	66.0	36.0	65.0	36.0	62.0	36.0	64.0
LGTP2	If TSOP = 0 or 2, LGTP2 is the mean departure from air temperature for calculating lower layer/groundwater soil temperature. If TSOP=1, LGTP2 is not used.		0	0.3	0.1	0.1			0	0.3	0	0.3	0.1	0.1
MON-ASLT	Monthly values for ASLT. Only required if SLVT = 1.	°C or °F												
MON-BSLT	Monthly values for BSLT. Only required if SLVT = 1.													
MON-ULTP1	Monthly values for ULTP1. Only required if ULTV = 1													
MON-ULTP2	Monthly values for ULTP2. Only required if ULTV = 1.	°C or °F												
MON-LGTP1	Monthly values for LGTP1. Only required if LGTV = 1.	°C or °F												

NAME	DEFINITION	UNITS	RANGE OF VALUES				Grassland		Pasture		Urban		Wetland	
			Forest		Ag/Other									
			MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
MON-LGTP2	Monthly values for LGTP2. Only required if LGTV = 1.													
PSTEMP-TEMPS	Initial temperatures													
AIRTC	Initial air temperature.		30	50	30	48	30	48	30	50	30	60	30	40
SLTMP	Initial surface layer soil temperature.		30	55	30	48	30	48	30	55	30	55	30	45
ULTMP	Initial upper layer temperature		32	60	32	48	32	48	32	60	32	60	32	48
LGTMP	Initial lower layer/groundwater layer soil temperature		40	60	40	49	40	49	40	60	40	60	40	49
PWT-PARM1	Flags for section PWTGAS													
IDVFG	Flag to specify if interflow dissolved oxygen concentration varies monthly		0	1	0	1	0	1	0	1	0	1	0	1
ICVFG	Flag to specify if interflow carbon-di-oxide concentration varies monthly.		0	1	0	1	0	1	0	1	0	1	0	1
GDVFG	Flag to specify if groundwater dissolved oxygen concentration varies monthly.		0	1	0	1	0	1	0	1	0	1	0	1
GCVFG	Flag to specify if groundwater carbon-di-oxide concentration varies monthly.		0	1	0	1	0	1	0	1	0	1	0	1
PWT-PARM2	Second group of PWTGAS parameters													
ELEV	ELEV is the elevation of the PLS above the sea level.	m or ft	282	1477	1009	1422	689	1548	265	1402	183	1436	500	1478
IDOXP	Concentration of dissolved oxygen in interflow outflow.	mg/l	6.2	14	6.2	12.7	6.2	12.7	6.2	12.94	6.2	13.88	5.5	12.7
ICO2P	Concentration of dissolved CO2 in interflow outflow.	mg C/l	0	0.53	0	0	0	0	0	0.55	0	0.6	0	0.06
ADOXP	Concentration of dissolved oxygen in active groundwater outflow.	mg/l	2	11.75	3	10	5	12	0.06	11.5	5	12	0.1	10
ACO2P	Concentration of dissolved CO2 in active groundwater outflow.	mg C/l	0	0.74	0	0	0	0	0	0.738	0	0.74	0	0.06
PWT-GASES	Initial concentration of dissolved gases in outflow													
SODOX	Initial DO concentration in surface outflow	mg/l	9	14.5	14.5	14.5	14.5	14.5	9	14.5	6	14.5	14.5	14.5
SOCO2	Initial CO2 concentration in surface outflow	mg C/l	0	0.275	0	0	0	0	0	0.5	0	0.5	0	0
IODOX	Initial DO concentration in interflow	mg/l	9	12.7	12.7	12.7	12.7	12.7	9	12.7	5	12.7	12.7	12.7
ICO2P	Initial CO2 concentration in interflow	mg C/l	0	0.53	0	0	0	0	0	0.55	0	0.6	0	0.06
AODOX	Initial DO concentration in groundwater flow	mg/l	9	10	10	10	10	10	9	10	5	10	10	10
AOCO2	Initial CO2 concentration in groundwater flow.	mg C/l	0	0.5	0	0	0	0	0	0.6	0	0.6	0	0
PQL-AD-FLAGS	Atmospheric deposition flags for PQUAL													
QUAL1	QUALID number is determined by the order in which the QUALS are input in the tables. Numbers of QUALS depend upon the number of Quality constituents													
F	Dry Deposition: 0, if no deposition of this type is simulated; -1, if deposition of this type is input as time series PQADFX or PQADCN; >0 if deposition of this type is input in the MONTH-DATA table with corresponding table ID number.		-1	None	-1	None	-1	None	-1	None	-1	None	-1	None
C	Wet Deposition: 0, if no deposition of this type is simulated; -1, if deposition of this type is input as time series PQADFX or PQADCN; >0 if deposition of this type is input in the MONTH-DATA table with corresponding table ID number.		-1	None	-1	None	-1	None	-1	None	-1	None	-1	None

NAME	DEFINITION	UNITS	RANGE OF VALUES				Grassland		Pasture		Urban		Wetland	
			Forest		Ag/Other									
			MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
PQUAL Parameters for Ammonia and Ammonium as Nitrogen														
QUAL-PROPS														
QUALID	10-character identifier (name) for the quality constituent		NH4-N											
QTYID	4-character identified for the units associated with the constituent (referred to as qty in subsequent tables).		lbs											
QSDFG	Flag to specify if the constituent is sediment-associated		0	1	0	1	0	1	0	1	0	1	0	1
VPFWFG	Flag to specify if the washoff potency factor varies monthly, and if daily factors are computed by interpolation.		0	2	0	2	0	2	0	2	0	2	0	2
VPFSFG	Flag to specify if scour potency factor may vary throughout the year.		0	1	0	1	0	1	0	1	0	1	0	1
QSOFG	Flag to specify if the constituent is associated with overland flow, and if accumulation and removal occur every day or interval.		0	2	0	2	0	2	0	2	0	2	0	2
VQOFG	Flag to specify if accumulation and limiting storage vary throughout the year.		0	1	0	1	0	1	0	1	0	1	0	1
QIFWFG	Flag to specify if the constituent is associated with interflow		0	1	0	1	0	1	0	1	0	1	0	1
VIQCFG	Flag to specify if the constituent in interflow may vary throughout the year. If VIQC is 2 or 4, the daily values are obtained directly from the monthly values; no interpolation between monthly values is performed. If VIQC is 3 or 4, the units of the input concentrations are mg/l; note: this option requires that the "qty" units be pounds (English system) or kilograms (Metric system).		0	4	0	4	0	4	0	4	0	4	0	4
QAGWFG	Flag to specify if the constituent is associated with groundwater flow.		0	1	0	1	0	1	0	1	0	1	0	1
VAQCFG	If VAQC is 1 or greater, the concentration of this constituent in groundwater outflow may vary throughout the year. If VAQCFG is 2 or 4, the daily values are obtained directly from the monthly values; no interpolation between monthly values is performed. If VAQCFG is 3 or 4, the units of the input concentrations are mg/l; note: this option requires that the "qty" units be pounds (English system) or kilograms (Metric system).		0	4	0	4	0	4	0	4	0	4	0	4
QUAL-INPUT														
SQO	Initial storage of QUALOF on the surface of PLS		0	0.033	0.02	0.365	0.01	0.05	0	0.365	0	0.37	0.007	0.07
POTFW	Washoff potency factor. Only applicable if constituent is QUALSD													
POTFS	Scour potency factor. Only applicable if constituent is QUALSD.													
ACQOP	Rate of accumulation of QUALOF. Only applicable if constituent is a QUALOF		0.0008	0.017	0.003	0.155	0.0008	0.023	0.0006	0.056	0.0002	0.07	0	0.023
SQOLIM	Maximum storage of QUALOF. Only applicable if constituent is a QUALOF		0.001	0.072	0.008	0.72	0.0014	0.07	0.002	0.263	0.001	0.332	0.001	0.08
WSQOP	Rate of surface runoff which will remove 90% of stored QUALOF per hour		0.48	1.9	0.6	2.7	0.38	2.25	0.38	2.7	0.5	2.2	0.2	3.4
IOQC	Concentration of the constituent in interflow outflow; it is meaningful only if this QUAL is a QUALIF.		0.002	0.58	0.1	3.7	0.03	0.75	0.0048	0.833	0.0005	0.96	0.0059	0.45
AOQC	Concentration of the constituent in groundwater outflow; it is meaningful only if this QUAL is a QUALIF.		0.006	0.55	0.048	2	0.013	0.564	0.014	0.59	0.005	0.73	0.0037	0.475

NAME	DEFINITION	UNITS	RANGE OF VALUES				Grassland		Pasture		Urban		Wetland	
			Forest		Ag/Other									
			MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
PQUAL Parameters for Nitrite and Nitrate as Nitrogen														
QUAL-INPUT														
SQO	Initial storage of QUALOF on the surface of PLS		0	1.25	0.2	5	0.02	1	0	2.62	0	0.45	0.027	1.25
POTFW	Washoff potency factor. Only applicable if constituent is QUALSD													
POTFS	Scour potency factor. Only applicable if constituents is QUALSD.													
ACQOP	Rate of accumulation of QUALOF. Only applicable if constituent is a QUALOF		0.0003	0.054	0.02	1.5	0.007	0.03	0.002	0.088	0.0002	0.088	0.0003	0.07
SQOLIM	Maximum storage of QUALOF. Only applicable if constituent is a QUALOF		0.0014	0.18	0.069	6	0.023	0.21	0.009	0.354	0.0024	0.45	0.0005	0.28
WSQOP	Rate of surface runoff which will remove 90% of stored QUALOF per hour		0.8	2.9	0.6	2.8	0.7	2.8	0.5	2.7	0.5	2.25	0.2	3.4
IOQC	Concentration of the constituent in interflow outflow; it is meaningful only if this QUAL is a QUALIF.		0.02	1.75	0.15	30	0.0315	3.71	0.064	8.1	0.13	6.678	0.0032	1.25
AOQC	Concentration of the constituent in groundwater outflow; it is meaningful only if this QUAL is a QUALIF.		0.01	0.72	0.1	9.5	0.02	1.5	0.044	6.555	0.06	3.5	0.0032	0.743
PQUAL Parameters for Orthophosphorus as Phosphorus														
QUAL-INPUT														
SQO	Initial storage of QUALOF on the surface of PLS		0	0.04	0	0.38	0	0.04	0	0.06	0	0.04	0	0.05
POTFW	Washoff potency factor. Only applicable if constituent is QUALSD		0.0009	0.35	0.01	0.01			0.0425	12.8	0.02	1.969	0	0
POTFS	Scour potency factor. Only applicable if constituent is QUALSD.		0	0.4	0	2	0	0.4	0	2	0	0.475	0	0.325
ACQOP	Rate of accumulation of QUALOF. Only applicable if constituent is a QUALOF		0.002	0.007	0.003	0.005			5E-05	5E-05	0.004	0.01	0.002	0.007
SQOLIM	Maximum storage of QUALOF. Only applicable if constituent is a QUALOF		0.004	0.01	0.005	0.012			0.002	0.002	0.008	0.02	0.004	0.01
WSQOP	Rate of surface runoff which will remove 90% of stored QUALOF per hour		0	1.9	0.5	1.7	0.5	1.7	0	1.64	0	1.64	0.425	1.9
IOQC	Concentration of the constituent in interflow outflow; it is meaningful only if this QUAL is a QUALIF.		0.001	0.225	0.027	2.26	0.01	0.338	0.002	0.556	0.002	0.32	0	0.264
AOQC	Concentration of the constituent in groundwater outflow; it is meaningful only if this QUAL is a QUALIF.		0.0002	0.07	0.01	0.87	0.006	0.2	8E-05	0.25	0.0002	0.15	0	0.132
PQUAL Parameters for Organics as Biochemical Oxygen Demand														
QUAL-INPUT														
SQO	Initial storage of QUALOF on the surface of PLS		0	1	0	14	1	1.75	0	7.88	0	3	0	2
POTFW	Washoff potency factor. Only applicable if constituent is QUALSD		3	46.55	3	141.8	3	55	3	55	3	55	3	133
POTFS	Scour potency factor. Only applicable if constituent is QUALSD.													
ACQOP	Rate of accumulation of QUALOF. Only applicable if constituent is a QUALOF		0.24	4	0	0.4	0	0	0.581	4	0.17	2.31	0	1.96
SQOLIM	Maximum storage of QUALOF. Only applicable if constituent is a QUALOF		1.6	48	0	7.2	0	0	6	96	2.97	25.35	0	3.2
WSQOP	Rate of surface runoff which will remove 90% of stored QUALOF per hour		0.7	1.9	0.5	1.7	0.5	1.6	0.5	1.64	0.5	1.5	0.2	1.9
IOQC	Concentration of the constituent in interflow outflow; it is meaningful only if this QUAL is a QUALIF.		1	36	6	115	2.35	40	3.5	50	1.587	39.6	1	29

NAME	DEFINITION	UNITS	RANGE OF VALUES											
			Forest		Ag/Other		Grassland		Pasture		Urban		Wetland	
			MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
AOQC	Concentration of the constituent in groundwater outflow; it is meaningful only if this QUAL is a QUALIF.		1	16	2.64	66.6	1.5	23	2	41.62	1.9	21.12	1	28.2

Table 11.2. Temperature, Gas, and Quality Constituent Parameters for the Impervious Land Segments

NAME	DEFINITION	UNITS	RANGE OF VALUES											
			Urban											
			MIN	MAX										
IWT-PARM1	Flags for section IWTGAS													
WTFVFG	If WTFVFG = 1, water temperature regression parameters (AWTF and BWTF) are allowed to vary throughout the year and tables MON-AWTF and MON-BWTF are provided. If WTFVFG=0, these values are not allowed to vary throughout the year.		1	1										
CSNOFG	Is CSNOFG = 1, the effects of snow accumulation and melt are considered; if it is zero, they are not.		0	1										
IWT-PARM2	Second group of IWTGAS parameters													
ELEV	Elevation of the impervious land segment above the mean sea level.	m or ft	287	1466										
AWTF	Surface water temperature where the air temperature is 32°F(0° C).	°F or °C	29	65										
BWTF	Slope of the surface water temperature regression equation		0.32	1.2										

NAME	DEFINITION	UNITS	RANGE OF VALUES							
			NH4		NO3		ORTHO P			
			MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
IQL-AD-FLAGS	Atmospheric deposition flags for IQUAL	1								
QUAL1	QUALID number is determined by the order in which the QUALS are input in the tables. Numbers of QUALS depend upon the number of Quality constituents	1								
F	Dry Deposition	1								
C	Wet Deposition	1								
QUAL-PROPS		1								
QUALID	10-character identifier (name) for the quality constituent	1	NH4		NO3		ORTHO P		BOD	
QTYID	4-character identifier for the units associated with the constituent (referred to as qty in subsequent tables).	1	lbs		lbs		lbs		lbs	
QSDFG	Flag to specify if the constituent is sediment-associated	1	0	0	0	0	0	1	0	0
VPFWFG	Flag to specify if the washoff potency factor varies monthly, and if daily factors are computed by interpolation.	1	0	0	0	0	0	0	0	0
QSOFG	Flag to specify if the constituent is associated with overland flow, and if accumulation and removal occur every day or interval.	1	1	2	1	2	1	2	1	2
VQOFG	Flag to specify if accumulation and limiting storage vary throughout the year.	1	0	0	0	0	0	0	0	0

QUAL-INPUT		1								
SQO	Initial storage of QUALOF on the surface of PLS	1	0.003	0.0297	0.005	0.4	0.001	0.05	0.5	1
POTFW	Washoff potency factor. Only applicable if constituent is QUALSD	1					0.05	0.65		
ACQOP	Rate of accumulation of QUALOF. Only applicable if constituents is a QUALOF	1	0.0008	0.04	0.001	0.121	0.001	0.01	0.07	0.196
SQOLIM	Maximum storage of QUALOF. Only applicable if constituents is a QUALOF	1	0.0051	0.121	0.012	0.362	0.008	0.12	0.5	2.45
WSQOP	Rate of surface runoff which will remove 90% of stored QUALOF per hour	1	0.5	0.75	0.5	0.75	0.5	0.8	0.5	0.5

12.0 RCHRES Parameter and Value Range Summary Tables

Table 12.1 contains the value ranges for HSPF instream water quality parameters. Note that the ranges were derived from an analysis of the entire model applications we analyzed; they do not imply that HSPF modelers should not use values beyond these ranges. However, if such values are used, the modelers should describe the rationale and justification for those 'outlier' values as part of the study report.

Table 12.1. Value Ranges for HSPF Instream Water Quality Parameters

NAME	DEFINITION	UNITS	RANGE OF VALUES (English Units)			
			25% to 75% range		5% to 95% range	
			MIN	MAX	MIN	MAX
HT-BED-FLAGS						
BEDFLG	Bed conduction flag: 0 = bed conduction not simulated, 1 = single interface (water-mud) heat transfer method, 2 = two-interface (mater-mud-ground) heat transfer method, 3 = Jobson method	none	1	2	0	2
TGFLG	Specifies source of ground temperature for bed conduction (BEDFLG = 1 or 2): 1 = time series; 2 = single value; 3 = monthly values	none	3	3	3	3
TSTOP	Number of time steps (prior to the current time step) that impact the heat flux at the current time step; used when the Jobson method is in effect.	none	55	55	1	55
HEAT-PARM						
ELEV	Mean RCHRES elevation	ft or m	80	400	60	700
ELDAT	Difference in elevation between the RCHRES and the air temperature gage (positive if the RCHRES is higher than the gage)	ft or m	-95	30	-368	252.2
CFSAEX	Correction factor for solar radiation; fraction of the RCHRES surface exposed to radiation	none	0.54	0.85	0.2	0.997
KATRAD	Longwave radiation coefficient	none	9	9.4	9	13.4
KCOND	Conduction-convection heat transport coefficient	none	6.12	6.12	6	15
KEVAP	Evaporation coefficient	none	2.24	2.5	1	2.5
HT-BED-PARM						
MUDDEP	Depth of the mud layer in the two-interface model (BEDFLG = 2)	ft or m	0.3	2	0.1	2
TGRND	Constant ground temperature (if TGFLG = 2); used in the one and two-interface models (BEDFLG = 1 or 2). Ground temperature can also be input in the form of twelve monthly values or a time series.	ºF or ºC	50	59	20	59
KMUD	Heat conduction coefficient between water and the mud/ground (BEDFLG = 1 or 2)	kcal/m2/C/hr	50	80	30	100
KGRND	Heat conduction coefficient between ground and mud in the two-interface model (BEDFLG = 2)	kcal/m2/C/hr	1.4	1.42	1.4	1.42
MON-HT-TGRND						
TGRND1	Ground Temperature on the start of month 1 of the year	ºF or ºC	40	46	36	48
TGRND2	Ground Temperature on the start of month 2 of the year	ºF or ºC	40	46	36	48
TGRND3	Ground Temperature on the start of month 3 of the year	ºF or ºC	40	49	38	53
TGRND4	Ground Temperature on the start of month 4 of the year	ºF or ºC	42	51	39	62
TGRND5	Ground Temperature on the start of month 5 of the year	ºF or ºC	50	60	50	70
TGRND6	Ground Temperature on the start of month 6 of the year	ºF or ºC	55	76	54	77
TGRND7	Ground Temperature on the start of month 7 of the year	ºF or ºC	57	76	55	79
TGRND8	Ground Temperature on the start of month 8 of the year	ºF or ºC	57	72	54	79
TGRND9	Ground Temperature on the start of month 9 of the year	ºF or ºC	56	68	52	73
TGRND10	Ground Temperature on the start of month 10 of the year	ºF or ºC	50	55	48	63
TGRND11	Ground Temperature on the start of month 11 of the year	ºF or ºC	45	50	40	53
TGRND12	Ground Temperature on the start of month 12 of the year	ºF or ºC	42	47	36	48

NAME	DEFINITION	UNITS	RANGE OF VALUES (English Units)			
			25% to 75% range		5% to 95% range	
			MIN	MAX	MIN	MAX
BENTH-FLAG						
BENRFG	Value of 1 means that the benthal influences are considered in the following sections.	none	1	1	0	1
SCOUR-PARMS						
SCRVEL	Threshold velocity above which the effect of scouring on benthal release rates is considered.	ft/sec or m/sec	10	10	3	10
SCRMUL	Multiplier by which benthal releases are increased during scouring.	none	2	2	2	650
OX-FLAGS						
REAMFG	REAMFG indicates the method used to calculate the reaeration coefficient for free-flowing streams. 1 = Tsivoglu, 2 = Owens/Churchill/O'Connor-Dobbins, 3 = same as 2 with user-specified exponents and coefficient	none	3	3	1	3
OX-GENPARM						
KBOD20	Unit BOD decay rate at 20 degrees C	/hr	0.004	0.006	0.0035	0.05
TCBOD	Temperature correction coefficient for BOD decay	none	1.047	1.047	1.047	1.075
KODSET	Rate of BOD settling	ft/hr or m/hr	0.014	0.027	0.005	0.127
SUPSAT	Maximum allowable DO supersaturation (multiple of the DO saturation concentration)	none	1.2	1.4	1.15	2.0
OX-BENPARM						
BENOD	Benthal oxygen demand at 20 degrees C	mg/m2/hr	60	75	1	400
TCBEN	Temperature correction coefficient for benthal oxygen demand	none	1.074	1.074	1.047	1.074
EXPOD	Exponential factor in the dissolved oxygen term of the benthal oxygen demand equation	none	1.22	1.22	1.22	1.22
BRBOD1	Benthal release rate of BOD under aerobic conditions	mg/m2/hr	0.1	6	0.001	10
BRBOD2	Increment to benthal release of BOD under anaerobic conditions	mg/m2/hr	1	100	0.001	100
EXPREL	Exponent in the DO term of the benthal BOD release equation	none	2.82	2.82	1	2.82
OX-CFOREA						
CFOREA	Correction factor in the lake reaeration equation; it accounts for good or poor circulation characteristics	none	2	1	1	3
OX-TSIVOGLOU						
REAKT	Empirical constant in Tsivoglou's equation for reaeration	/ft	0.06	0.06	0.0258	0.06
TCGINV	Temperature correction coefficient for surface gas invasion	none	1.07	1.07	1.047	1.07
OX-REAPARM						
TCGINV	Temperature correction coefficient for surface gas invasion	none	1.07	1.07	1.047	1.07
REAK	Empirical constant in the equation used to calculate the reaeration coefficient	/hr	0.190368	0.2	0.03	0.8
EXPRED	Exponent to depth in the reaeration coefficient equation	none	-1.673	-1.673	-1.673	-1.5
EXPREV	Exponent to velocity in the reaeration coefficient equation	none	0.969	0.969	0.5	0.969
NUT-FLAGS						
NH3FG	1 = ammonia is simulated	none	1	1	1	1
NO2FG	1 = nitrite is simulated	none	1	1	0	1
PO4FG	1 = orthophosphorus is simulated	none	1	1	1	1
AMVFG	1 = ammonia volatilization is simulated	none	0	0	0	1
DENFG	1 = denitrification is simulated	none	1	1	1	1
ADNHFG	1 = ammonia adsorption is simulated	none	1	1	0	1
ADPOFG	1 = orthophosphorus adsorption is simulated	none	1	1	1	1
PHFLAG	Source of pH data: 1=time series, 2=constant, 3=monthly values	none	1	2	1	2

NAME	DEFINITION	UNITS	RANGE OF VALUES (English Units)			
			25% to 75% range		5% to 95% range	
			MIN	MAX	MIN	MAX
CONV-VAL1						
CVBO	Conversion from milligrams biomass to milligrams oxygen	mg/mg	1.63	1.63	1.63	1.98
CVBPC	Conversion from biomass expressed as phosphorus to carbon	mols/mol	106	106	106	106
CVBPN	Conversion from biomass expressed as phosphorus to nitrogen	mols/mol	16	16	16	16
BPCNTC	Percentage of biomass which is carbon (by weight)	none	49	49	49	49
NUT-BENPARM						
BRNIT1	Benthal release rate of ammonia under aerobic conditions	mg/m2/hr	0	0	0	0.6
BRNIT2	Benthal release rate of ammonia under anaerobic conditions	mg/m2/hr	0	0	0	0.2
BRPO41	Benthal release rate of ortho-phosphorus under aerobic conditions	mg/m2/hr	0	0	0	0.03
BRPO42	Benthal release rate of ortho-phosphorus under anaerobic conditions	mg/m2/hr	0	0	0	0.02
ANAER	Concentration of dissolved oxygen below which anaerobic conditions are assumed to exist	mg/l	1.0E-3	1.0E-3	1.0E-3	1
NUT-NITDENIT						
KTAM20	Nitrification rate of ammonia at 20 degrees C	/hr	0.01	0.03	0.002	0.3
KNO220	Nitrification rate of nitrite at 20 degrees C	/hr	0.01	0.012	0.002	0.012
TCNIT	Temperature correction coefficient for nitrification	none	1.07	1.07	1.07	1.07
KNO320	Nitrate denitrification rate at 20 degrees C	/hr	2.0E-3	3.0E-3	1.4E-3	2.0E-2
TCDEN	Temperature correction coefficient for denitrification	none	1.04	1.06	1.04	1.07
DENOXT	Dissolved oxygen concentration threshold for denitrification	mg/L	2	8	1	20
NUT-NH3VOLAT						
EXPNVG	Exponent in the gas layer mass transfer coefficient equation for NH3 volatilization	none	0.5	0.5	0.5	0.5
EXPNVL	Exponent in the liquid layer mass transfer coefficient equation for NH3 volatilization	none	0.667	0.667	0.6667	0.667
NUT-BEDCONC						
BNH4(1)	Constant bed concentrations of ammonia-N adsorbed to sand, silt, and clay	mg/kg	40	40	1.0E-4	40
BNH4(2)			80	100	2.0E-4	100
BNH4(3)			80	100	3.0E-4	100
BPO4(1)	Constant bed concentrations of ortho-phosphorus-P adsorbed to sand, silt, and clay	mg/kg	50	100	5.0E-5	600
BNH4(2)			80	100	2.0E-4	100
BNH4(2)			80	100	2.0E-4	100
NUT-ADSPARM						
ADNHPM(1)	Adsorption coefficients (Kd) for ammonia-N adsorbed to sand	cm3/g	10	10	0.0001	40
ADNHPM(2)	Adsorption coefficients (Kd) for ammonia-N adsorbed to silt		100	100	0.0001	100
ADNHPM(3)	Adsorption coefficients (Kd) for ammonia-N adsorbed to clay		100	100	0.0001	100
ADPOPM(1)	Adsorption coefficients (Kd) for orthophosphorus-P adsorbed to sand	cm3/g	10	600	6	600
ADPOPM(2)	Adsorption coefficients (Kd) for orthophosphorus-P adsorbed to silt		250	1000	10	1000
ADPOPM(3)	Adsorption coefficients (Kd) for orthophosphorus-P adsorbed to clay		250	1000	10	1000
PLNK-FLAGS						
PHYFG	1 = phytoplankton are simulated	none	1	1	1	1
ZOOFG	1 = zooplankton are simulated	none	0	0	0	0
BALFG	1 = a single species of benthic algae is simulated, with growth and respiration rates proportional to phytoplankton (PHYFG must be 1). 2 = multiple benthic algae species (between one and four) are	none	1	1	1	1

NAME	DEFINITION	UNITS	RANGE OF VALUES (English Units)			
			25% to 75% range		5% to 95% range	
			MIN	MAX	MIN	MAX
	simulated using different kinetics (PHYFG may be 1 or 0). 0 = no benthic algae are simulated					
SDLTFG	1 = the influence of sediment washload on light extinction is simulated based on computed or input sediment concentration. 2 = it is based on linear regression on flow (requires input of Table-type BENAL-LIGHT). 0 = it is not considered separately	none	0	1	0	1
AMRFG	1 = ammonia retardation of nitrogen-limited growth is enabled	none	0	0	0	0
DECFG	1 = linkage between carbon dioxide and phytoplankton growth is decoupled	none	1	1	1	1
NSFG	1 = ammonia is included as part of available nitrogen supply in N-limited growth calculations	none	1	1	0	1
ZFOOD	Indicates the quality of zooplankton food; 1=high quality, 2=medium, 3=low	none	2	2	0	2
BNPFG	0 = benthic algae use ALNPR in Table-type PLNK-PARM1 to determine preference between ammonia and nitrate. 1 = nitrogen preference is computed with an alternative method, which is based on CAMPR in Table-type BENAL-PARM	none	0	0	0	0
BENAL-FLAGS						
NUMBAL	Number of benthic algae species simulated	none				
BINVFG	Specifies the source of benthic macroinvertebrates for the computation of grazing. 1 = an input timeseries; 2 = a constant value in Table-type BENAL-GRAZE; 3 = monthly values in Table-type MON-BINV	none				
BFIXFG(1-4)	Flags that indicate whether a species of benthic algae fixes nitrogen, so that growth is not nitrogen-limited. 1 = the species fixes nitrogen	none				
PLNK-PARM1						
RATCLP	Ratio of chlorophyll A content of biomass to phosphorus content	none	0.68	0.68	0.6	0.68
NONREF	Non-refractory fraction of algae and zooplankton biomass	none	0.5	0.5	0.5	0.75
LITSED	Multiplication factor to total sediment concentration to determine sediment contribution to light extinction	L/mg/ft	0.0015	0.0015	0	0.1
ALNPR	Fraction of nitrogen requirements for phyto-plankton growth that is satisfied by nitrate	none	0.25	0.5	0.25	0.8
EXTB	Base extinction coefficient for light	/ft or /m	0.05	0.15	0.01	0.4
MALGR	Maximum unit algal growth rate for phytoplankton	/hr	0.065	0.085	0.03	0.17
PARADF	Fraction of solar radiation that is photosynthetically active	none	1	1	1	1
PLNK-PARM2						
CMMLT	Michaelis-Menten constant for light limited growth for phytoplankton	Langley/min	0.013	0.033	0.00001	0.033
CMMN	Nitrate Michaelis-Menten constant for nitrogen limited growth for phytoplankton	mg/L	0.045	0.045	0.025	0.045
CMMNP	Nitrate Michaelis-Menten constant for phosphorus limited growth for phytoplankton	mg/L	0.0001	0.001	0.0001	0.028
CMMP	Phosphate Michaelis-Menten constant for phosphorus limited growth for phytoplankton	mg/L	0.01	0.015	0.005	0.015
TALGRH	Temperature above which phytoplankton growth ceases	ºF or ºC	95	95	95	150
TALGRL	Temperature below which phytoplankton growth ceases	ºF or ºC	-10	20	-100	43
TALGRM	Temperature below which phytoplankton growth is retarded	ºF or ºC	72	77	68	86
PLNK-PARM3						
ALR20	Phytoplankton unit respiration rate at 20 C	/hr	0.004	0.005	0.003	0.005
ALDH	High phytoplankton unit death rate	/hr	0.01	0.02	0.001	0.02
ALDL	Low phytoplankton unit death rate	/hr	0.001	0.001	0.001	0.002
OXALD	Increment to phytoplankton unit death rate due to anaerobic conditions	/hr	0.03	0.03	0.01	0.03

NAME	DEFINITION	UNITS	RANGE OF VALUES (English Units)			
			25% to 75% range		5% to 95% range	
			MIN	MAX	MIN	MAX
NALDH	Inorganic nitrogen concentration (as N) below which high phytoplankton death rate occurs	mg/L	0.01	0.01	0.001	0.015
PALDH	Inorganic phosphorus concentration (as P) below which high phytoplankton death rate occurs	mg/L	0.002	0.002	0.0001	0.002
PLNK-PARM4						
NMINGR	Minimum nitrate-N concentration for algal growth	mg/L	1.0E-6	1.0E-6	1.0E-6	1.0E-6
PMINGR	Minimum orthophosphate-P concentration for algal growth	mg/L	0.001	0.001	0.001	0.001
CMINGR	Minimum CO2-C concentration for algal growth	mg/L	1.0E-6	1.0E-6	1.0E-6	1.0E-6
LMINGR	Minimum light intensity for algal growth	Langley/min	0.001	0.001	0.001	0.001
NMINC	Minimum concentration for inorganic N species (TAM, NO3) allowed to remain after algal uptake. Concentrations below this level are set to zero.	mg/L	1.0E-6	1.0E-6	1.0E-6	1.0E-6
PHYTO-PARM						
SEED	Minimum concentration of plankton not subject to advection (i.e., at high flow)	mg/L	1	3	0.2	6
MXSTAY	Concentration of plankton not subject to advection at very low flow	mg/L	2	6	0.2	24
OREF	Outflow rate at which the concentration of plankton not subject to advection is midway between SEED and MXSTAY	ft3/s or m3/s	0.001	1000	0.0001	1000
CLALDH	Chlorophyll A concentration above which high algal death rate occurs	µg/L	20	100	5	200
PHYSET	Rate of phytoplankton settling	ft/hr or m/hr	0.005	0.015	0.001	0.04
REFSET	Rate of settling for dead refractory organics (N, P, C)	ft/hr or m/hr	0.005	0.025	0.001	0.12
BENAL-PARM						
MBAL	Maximum benthic algae density (as biomass), if BALFG=1 in Table-type PLNK-FLAGS	mg/m2	1500	3500	50	10,000
CFBALR	Ratio of benthic algae to phytoplankton respiration, if BALFG=1	none	0.35	0.5	0.35	0.5
CFBALG	Ratio of benthic algae to phytoplankton growth rate, if BALFG=1	none	0.45	0.65	0.33	1
MINBAL	minimum benthic algae density (as biomass), if BALFG = 2. This minimum is applied separately to each of the benthic algal types.	mg/m2	0.0001	0.0001	0.0001	0.0001
CAMPR	the coefficient in the alternative nitrogen preference equation for benthic algae, if BALFG = 2 and BNPFG = 1 in Table-type PLNK-FLAGS.	none	0.001	0.001	0.001	0.001
FRAVL	the fraction of nonrefractory nutrients resulting from benthic algae death/removal that are assumed to be immediately available as inorganic nutrients, plus refractory organic carbon. Used if BALFG = 2.	none	0	0.5	0	0.8
NMAXFX	the concentration of available inorganic nitrogen in the water column (TAM + NO3 + NO2) above which nitrogen-fixation by benthic algae is suppressed. If the concentration is greater than NMAXFX, fixation does not occur. Used if BALFG = 2.	mg/l	10	10	10	20
ZOO-PARM1						
MZOEAT	Maximum zooplankton unit ingestion rate	mg-phyto/mg-zoo/hr	0.055	0.055	0.055	0.055
ZFIL20	Zooplankton filtering rate at 20 degrees C	L/mg-zoo/hr	0.01	0.2	0.01	0.2
ZRES20	Zooplankton unit respiration rate at 20 degrees C	/hr	0.00015	0.00015	0.00015	0.00015
ZD	Natural zooplankton unit death rate	/hr	0.0001	0.0001	0.0001	0.0001
OXZD	Increment to unit zooplankton death rate due to anaerobic conditions	/hr	0.03	0.3	0.03	0.3
ZOO-PARM2						
TCZFIL	Temperature correction coefficients for zooplankton filtering	none				
TCZRES	Temperature correction coefficients for zooplankton respiration	none	1.07	1.07	1.07	1.07

NAME	DEFINITION	UNITS	RANGE OF VALUES (English Units)			
			25% to 75% range		5% to 95% range	
			MIN	MAX	MIN	MAX
ZEXDEL	Fraction of non-refractory zooplankton excretion which is immediately decomposed when the ingestion rate is greater than MZOEAT	none	0.7	0.7	0.7	0.7
ZOMASS	Average weight of a zooplankton organism	mg/org	0.0003	0.0003	0.0003	0.0003
BENAL-GROW (repeats for NUMBAL species) – With limited experience with benthic algae, only a possible 'typical' range is shown for most parameters.						
MBALGR	maximum benthic algae base growth rate for each benthic algae species	/hr	0.15	0.19	0.00001	0.097?
TCBALG	Temperature correction coefficient for growth for each species	none	1.055	1.08	1.03	1.09
CMMNB	Half-saturation constant for nitrogen-limited growth for each species. If the value is zero, then growth is not limited (i.e., this species fixes nitrogen).	mg/L	0.005	0.025	?	?
CMMPB	Half-saturation constant for phosphorus-limited growth for each species	mg/L	0.0025	0.005	?	?
CMMD1	Coefficient for total benthic algae density in the density-limited growth equation for each species	none	0.10	0.10	?	?
CMMD2	Half-saturation constant for density-limited growth for each species	mg/m2	10000.	10000.	?	?
CSLIT	Saturation light level for each species	Langley/min	0.093	0.093	?	?
BENAL-RESSCR (repeats for NUMBAL species)						
BALR20	Benthic algae respiration rate at 20 C for each species	/hr	0.0052	0.0052	?	?
TCBALR	Temperature correction coeefficient for respiration for each species	none	1.08	1.08	?	?
CSLOF1	Rate coefficient in the benthic algae scour equation for each species	/hr	0.00003	0.00003	?	?
CSLOF2	Multiplier of velocity in the exponent in the benthic algae scour equation for each species	none	0.6	0.6	?	?
GRORES	Fraction of photorespiration needed to support growth/photosynthesis for each species	none	0.075	0.075	?	?
BENAL-GRAZE						
CREMVL	Annual benthic algae grazing (removal) rate by invertebrates	mg/mg/yr	34.7	34.7	?	?
CMMBI	Half-saturation constant for grazing by invertebrates	mg/m2	10000.	10000.	?	?
BINV	Biomass (density) of grazing invertebrates in the reach	mg/m2	2600	4140	?	?
TCGRAZ	Temperature correction coefficient for macroinvertebrate grazing	none	1.06	1.06	?	?
BENAL-LIGHT						
CTRBQ1	Coefficient in the turbidity estimation equation	NTU/cfs or NTU/cms	0.032	0.086	?	?
CTRBQ2	Exponent in the turbidity estimation equation	none	0.50	0.74	?	?
CKTRB1	Coefficient in the light extinction equation	/ft or /m	0.23	0.23	?	?
CKTRB2	Exponent in the light extinction equation	none	0.486	0.486	?	?
BENAL-RIFF1						
FRRIF	Fraction of the reach that is composed of riffles where benthic algae can grow	none	0.6	0.7	0.0	1.0
CMMV	Half-saturation constant for riffle velocity in the nutrient availability equation for benthic algae	ft/s or m/s	0.0001	0.0001	?	?

NAME	DEFINITION	UNITS	RANGE OF VALUES (English Units)			
			25% to 75% range		5% to 95% range	
			MIN	MAX	MIN	MAX
RIFCQ(1-3)	Critical flow levels for riffle velocity and average depth	ft3/s or m3/s	105.9	317.8	?	?
BENAL-RIFF2						
RIFVEL(1-4)	Riffle velocity multipliers corresponding to the critical flow values (RIFCQ) in table BENAL-RIFF1	none	1.0	1.8	?	?
RIFDEP(1-4)	Riffle depth multipliers corresponding to the critical flow values (RIFCQ) in table BENAL-RIFF1	none	0.55	0.85	?	?

Appendix A

Automated Water Quality Calibration Technique for USEPA Chesapeake Bay Watershed Model Version 5.3

The EPA Chesapeake Bay Program Office developed an automated method of water quality calibration for the Phase 5.3 HSPF Watershed Model (USEPA, 2010). Parameters are paired with calibration metrics such that each parameter can be optimized to a unique set of metrics.

Nested stations were considered by assigning a relative weight to each downstream station for each segment. The weight function was equal to the number of observations above the limit of detection and discounted by 90 percent when downstream of another water quality station. The weights were then scaled to add to 1.0 for each river-segment. For example, suppose a river- segment has two downstream water quality stations. The upper station has 50 observations, of which 20 are below the detection limit. The lower station has 400 observations, of which 200 are below the detection limit. The upper station is assigned a weight of 30. The lower station is assigned an initial weight of 200, but it is then discounted by 90 percent for a weight of 20. The stations are then scaled so the upper station has a weight of 60 percent while the lower station has a weight of 40 percent.

The calibration had significant challenges. There are fewer calibration stations than for hydrology calibration, and those stations that do exist have far fewer observations. A well-monitored station may have 20–30 samples per year, while many stations have fewer samples per year or are only monitored for a few years. This data paucity means that descriptive statistics cannot be calculated, which increases the difficulty of separating the effect of the various water quality simulation parameters. Nitrogen and phosphorus processes are linked, in that many processes affect both major constituents. This creates constraints that help to define the calibration method but also limit its flexibility.

For the Chesapeake Bay Watershed Model nitrogen, phosphorus, and sediment were all calibrated simultaneously. Relationships between simulation parameters and calibration metrics were defined and coded into software. The software automatically updated the parameters between runs similarly to the hydrology and land-based nutrient and sediment calibrations except that the sensitivities were calculated during each iteration. The sensitivities were based on the change in the calibration metric relative to the change in the parameter between the current and previous runs. The probability of interaction between variables and the likelihood of oscillation also needed to be considered. These were minimized by selecting specific calibration metrics that had minimal parameter interaction, by reducing the absolute value of the calculated sensitivity, and by constraining the calculated sensitivity to keep it within a specified range. Reasonable ranges of sensitivity were found through sensitivity tests over all segments. It was found through trial and error that the approach of calculating, reducing, and constraining the sensitivities resulted in better calibrations than specifying a universal sensitivity as was done in the hydrology and land-based sediment and nutrient calibrations.

An automated calibration routine was developed and run 30 times or until a convergence criterion was reached for each parameter. Figure A-1 shows the calibration progress in the Rappahannock for the Phase 5.3 Model calibration. Each nitrogen loss or gain process is plotted as a separate line versus iteration. The vertical axis is percent of total nitrogen inflow that is lost through each process. Settling and denitrification are the major simulated nitrogen loss mechanisms in the Rappahannock. This particular calibration is stable after approximately 10–15 iterations. Often, there is some oscillation in the earlier iterations, which is damped out as the process continues. Temperature was calibrated in a separate process.

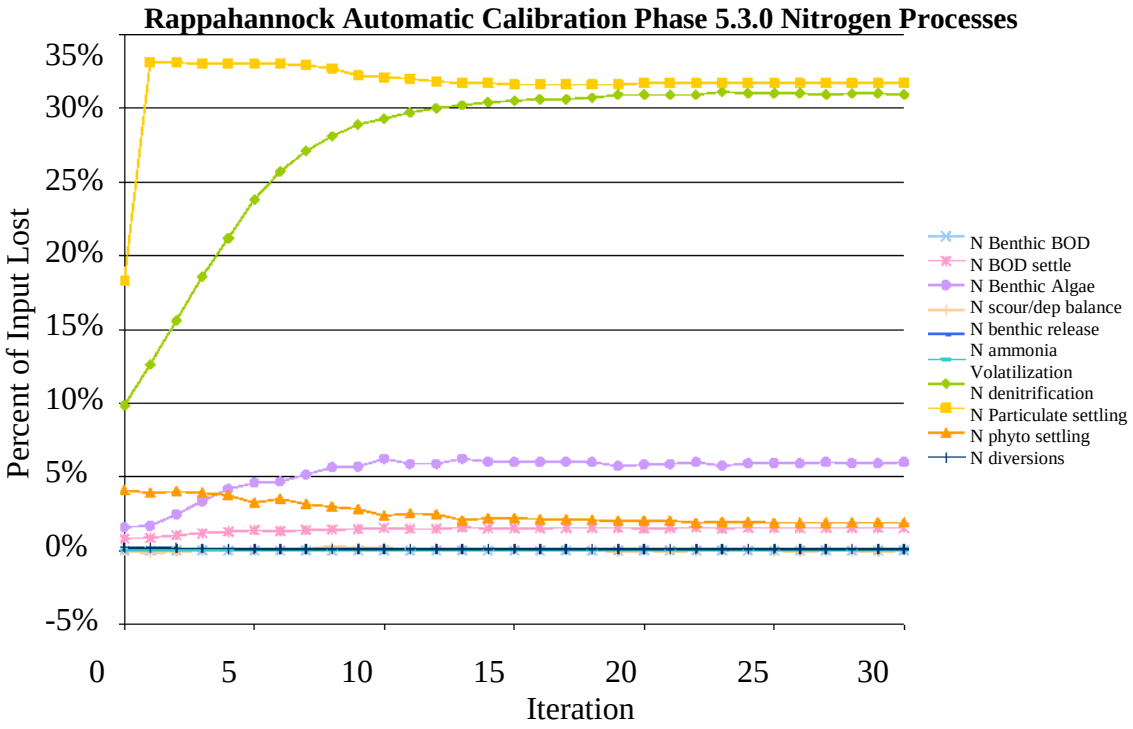

Figure A-1. Nitrogen Loss in the Rappahannock River Simulation as a Function of Calibration Iteration.

A.1. CBPO CALIBRATION METRICS

The most common calibration metric is the average value of each quintile of the paired observed and simulated cumulative frequency distribution in log scale. This is illustrated in Figure Y. First, simulated and observed data are paired, meaning that only days in which both existed are considered. A cumulative frequency distribution is created for both. The plot is divided into five probability zones, each representing 20 percent of the values. The relevant statistic is the agreement between the average simulated value within a probability zone and the average observed value within that zone. For example, in Figure A-2 the observed CFD variability in total nitrogen concentration is much greater than the simulated variability as represented by the vertical frequency distribution in the simulated total nitrogen CFD. Within the calibration routine, this is represented as needing to adjust parameterization such that the upper quintile of total nitrogen is increased and the lower quintiles of total nitrogen are decreased. In the actual calibration procedure, the values are in log scale.

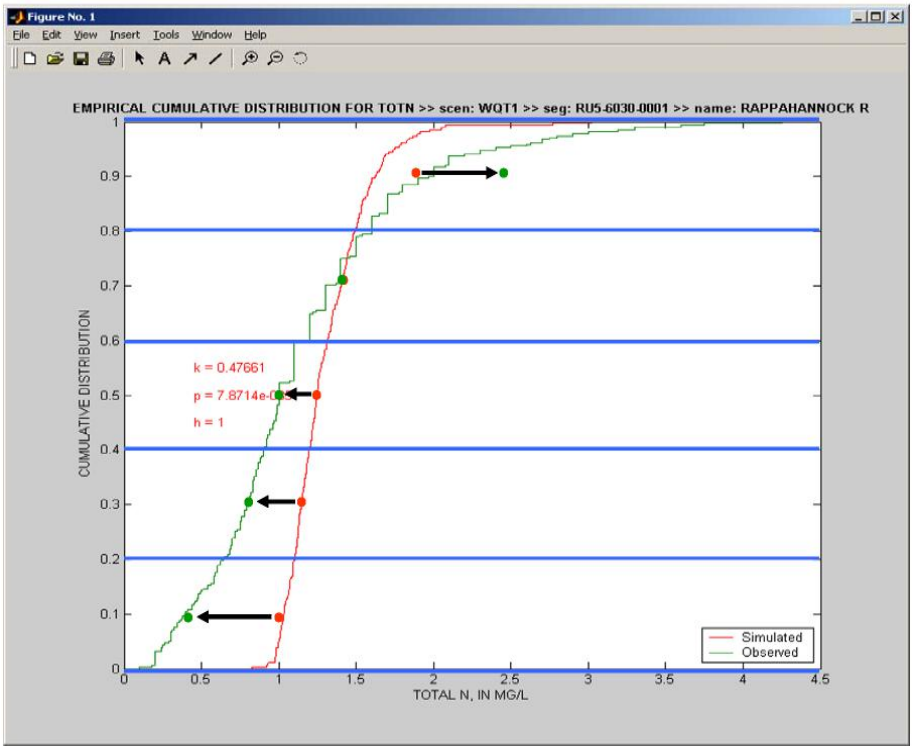

Figure A-2. Quintiles of the Paired Cumulative Frequency Distribution.

The difference between the simulated and observed average for any quintile is referred to here as the quintile bias, where a positive quintile bias indicates that the simulated has a higher value than the observed. The lowest quintile is referred to as quintile 1 and the highest quintile is quintile 5. In Figure Y, quintiles 1–3 have a positive bias and quintile 5 has a negative bias. The average of all five biases is referred to as the average bias, and it is an indicator of overall bias.

A.2. CBPO CALIBRATION RULES

Only a subset of available parameters was used in the calibration. The calibration parameters are detailed below. In some cases, such as for the parameters controlling chlorophyll *a*, the parameters are calibrated to keep a water quality constituent within a specified range.

Temperature

The temperature simulation in each river reach was calibrated against the next downstream gage. The simulated riverine heat balance processes include inflow, outflow, precipitation, evaporation, shortwave radiation, longwave radiation, and sensible heat transfer from the bed. The processes are mostly fully constrained, although there is a parameter associated with longwave radiation, KATRAD, which adjusts the transfer of heat from the atmosphere to the stream. The simulation of bed heat conduction is not temperature-related, so it is argued that this longwave radiation adjustment can be used to account for heat received by the stream from both longwave radiation and conduction.

Model efficiency was a concave function of KATRAD with a monotonic first derivative for all investigated river-segments. It was calibrated using a simple gradient-based optimization method.

Dissolved Oxygen
For overall mass balance, the average dissolved oxygen bias is related to the reaeration coefficient. For rivers, the reaeration coefficient is REAK; for reservoirs, it is CFOREA. To correct the shape of the distribution, the supersaturation coefficient SUPSAT is related to the fourth and fifth quintiles, while the benthic oxygen demand BENOD is related to the first and second quintiles.

Nutrients
Nitrogen and phosphorus are connected through processes that control both nutrients. Individual species of nutrients are also connected. For example, algal uptake converts inorganic nutrients to organic nutrients for both nitrogen and phosphorus.

Settling of Refractory Organics
The settling of refractory organics is one of the more important mechanisms for attenuating excess nitrogen and phosphorus in the river reach. Ideally, the settling factor REFSET would be related to organics. If there are sufficient data, then this is the case. If there are more than twice as many total nitrogen observations as organic nitrogen observations for a station, then total nitrogen is used instead. The same applies for total phosphorus. REFSET is related in the calibration to the average for nitrogen and phosphorus of the average bias statistic.

Inorganic Nitrogen
Denitrification is related to the average bias of the lower three quintiles of nitrate concentration. The denitrification parameter, KNO320, is increased if the bias is high, but only if the total nitrogen bias is positive. Conversely, KNO320 is decreased if the bias is low, but only if the total nitrogen bias is negative.

The benthic release parameter for ammonia has a low value for use under aerobic conditions, BRTAM1, and a high value for use under anaerobic conditions, BRTAM2. The sediments are assumed anaerobic when the water column reaches the dissolved oxygen level set by the parameter ANAER. ANAER is set to roughly the 20th percentile of dissolved oxygen (DO) by averaging the first and second quintiles of simulated DO. Ammonia is released from reservoir sediments relative to the average total nitrogen bias. These actions have the effect of releasing more ammonia from riverine sediments during warmer summer temperatures, but the amount of benthic ammonia release is guided of the calibration of the average total nitrogen bias.

Ammonium also enters the water column by attachment to sediment particles that are scoured. The concentration (mass/mass) is set by the parameters BEDNH4CLAY, BEDNH4SILT, and BEDNH4SAND. Since scoured ammonium represents a pulse of nutrients under high-flow conditions, the major effect is on the higher concentrations of nitrogen. These parameters are kept in a constant ratio to each other and are adjusted according to the fourth and fifth quintiles of total nitrogen.

The nitrification rate is used to adjust the simulated ratio of nitrate and ammonia relative to the observed ratio. The nitrification rate is increased to produce more nitrate and less ammonia, but the overall mass of inorganic nitrogen is unaffected.

Phosphate
Benthic release and scour of phosphate are handled similarly to these same processes for ammonia. A difference is that scour of phosphate is a much larger part of total phosphorus balance than the scour of ammonium is of the nitrogen balance, especially at higher concentrations. As with ammonium, scour of phosphate is related to the upper two quintiles of total phosphorus; however, benthic release in reservoirs is related to the lower four

quintiles rather than the entire range. An additional mechanism to adjust the balance between dissolved phosphate and total phosphorus is the adsorption coefficient, which is related to the upper two quintiles of dissolved phosphate.

Chlorophyll *a*

The phytoplankton settling rate, PHYSET, has the highest sensitivity to overall chlorophyll *a* mass and affects the lower concentrations by a greater amount than the higher concentrations. PHYSET is adjusted according to the average bias for the second, third, and fourth quintiles. The maximum algal growth rate, MALGR, is also important overall mass and especially affects higher concentrations. MALGR is related to the bias in the fifth quintile.

Observed chlorophyll *a* values are relatively rare; only 73 stations have observations. Of those 73 stations, only a little more than half have more than 40 observations spread over the entire 21-year calibration period. The river-segments with no chlorophyll *a* data for calibration were constrained to the interquartile range of the basin-wide observed data.