HEC-RAS Water Quality User's Manual

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Exported on 10/18/2023

Table of Contents

1 Introduction

The Water Quality model simulates the fate and transport of heat, nutrients, and other constituents. It is a generalized, configurable model that allows the user to select not only a nutrient kinetics library, and multiple temperature modeling options, but also supports configuration of unique constituents that are not part of supplied libraries. For example, a simulation of nitrogen, phosphorus, and dissolved oxygen could support multiple forms of nitrogen, phosphorus and carbon. A simplified form of this model that simulates only oxygen and BOD (the Streeter-Phelps model) could also be configured using this same library. Interaction with the bed could be enabled or disabled, a sediment diagenesis component could also be added. A TDG (total dissolved gas) option is also available. Heat and temperature may be simulated using a full energy budget model, an equilibrium model, or temperature may be set constant. A simple conservative constituent (tracer) simulation may be easily and quickly configured.

Individual Water Quality Libraries are made available as "plug-in" dynamic link libraries (DLLs). Future tools will allow users to define configurations, parameters and interactions. All DLLs share the requirement of constituent and parameter data: boundary and initial conditions, rate constants, and specific fitting parameters.

Simulation options associated with the advection-dispersion engine, including activation of the limiter (designed to eliminate over-and under-shoots), selection of the maximum time step, dispersion coefficient, and cell lengths are chosen independent of the DLL. The advection-dispersion simulation is then run, and constituents as configured within the chosen DLL are transported, kinetics are applied, and resulting concentrations computed. Output tools are available for viewing (and exporting) resulting constituent concentrations.

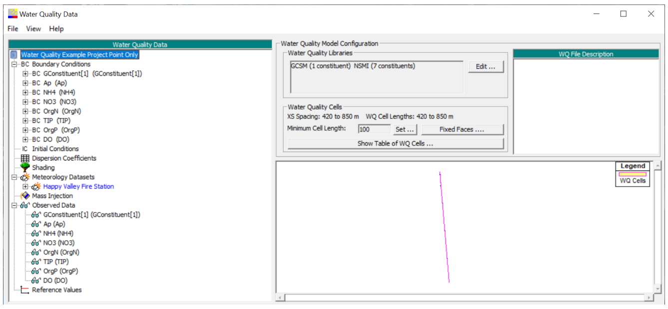
To help with estimation of parameters, a zero-dimension water quality model is available as a separate module. This simple model, a single continuously stirred tank reactor (CSTR) with no transport component, allows setting and adjusting of parameters without running the advection-dispersion engine. The CSTR allows the user to experiment with DLL parameters and other variables in an experimental single-cell before running the full advection-dispersion engine. The CSTR does not require a geometry file, a hydraulics, or a hydrodynamics file to run. Running the CSTR and experimenting with DLL parameter is a help first step but it is not required. The advection-dispersion engine may be run independently.

2 Menu System

The **Water Quality Data Entry** window is accessed from the main HEC-RAS window either through the menu bar by selecting **Edit… Water Quality Data** or by selecting the **Water Quality Data Icon.**

The **Water Quality Data Entry** window handles all input data, and allows the user to select and configure the desired water quality library (DLL). Because of the many constituents available, and their associated parameters, this window is complex and layered. In addition to time series data, limited geometric information particular to the water quality model, including the definition and grouping of water quality cells, is handled here. All water quality data time series including concentrations at system boundaries, time series of meteorological data, concentrations of initial conditions, fitting parameters associated with energy budget fluxes and nutrient kinetics, and methods for re-aeration and other processes are found in the **Water Quality Model Configuration** window.

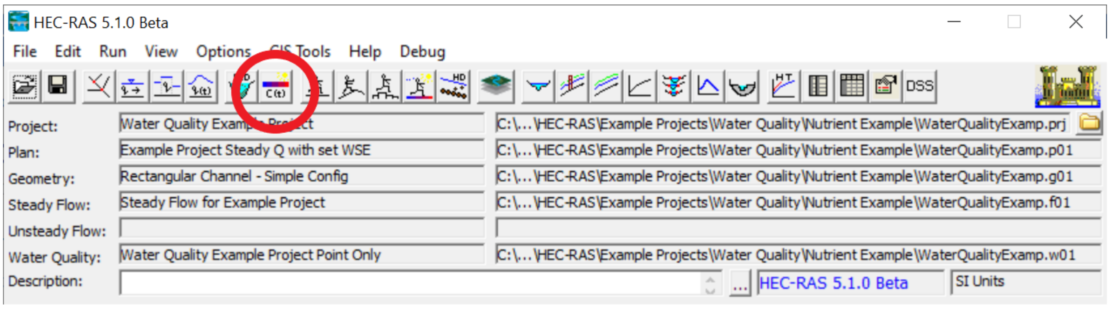
Due to the complexity of the water quality model, an effort has been made to allow the user to turn on and off detailed output. Commonly used derived variables such as Total Kjeldahl Nitrogen, or Total Nitrogen are available. For temperature modeling, latent heat flux density, and sensible heat flux density as well as evaporation are available. In addition, detailed information such as individual pathways (fluxes to and from individual constituents) may be turned on and off. These pathways include but aren't limited to: algal growth, death, and respiration, constituent settling, and all nutrient fluxes.



GCSM (1 constituent) NSMI (7 constituents)

XS Spacing: 420 to 850 m WQ Cell Lengths: 420 to 850 m

Minimum Cell Length: 100



Project: Water Quality Example Project C:\...\HEC-RAS\Example Projects\Water Quality\Nutrient Example\WaterQualityExamp.prj

Plan: Example Project Steady Q with set WSE C:\...\HEC-RAS\Example Projects\Water Quality\Nutrient Example\WaterQualityExamp.p01

Geometry: Rectangular Channel - Simple Config C:\...\HEC-RAS\Example Projects\Water Quality\Nutrient Example\WaterQualityExamp.g01

Steady Flow: Steady Flow for Example Project C:\...\HEC-RAS\Example Projects\Water Quality\Nutrient Example\WaterQualityExamp.f01

Unsteady Flow:

Water Quality: Water Quality Example Project Point Only C:\...\HEC-RAS\Example Projects\Water Quality\Nutrient Example\WaterQualityExamp.w01

Description: HEC-RAS 5.1.0 Beta SI Units

3 Setting and Adjusting Physical Properties

Physical properties defined and edited here are independent of water quality and water temperature parameters. These include setting water quality cell lengths, assigning dispersion coefficients, and defining meteorological and water quality regions.

3.1 Water Quality Cells

When a new water quality dataset it created, water quality cells are initially created between each cross section in the river system. In simple models, this is a reasonable approximation and no adjustment is necessary. However, there are a handful of situations that require adjustment and management of water quality cells on an individual or system wide basis. For example, cross sections may have been spaced closely around hydraulic structures, or the entire system may have interpolated cross sections at a small spacing in order to stabilize the hydrodynamic model. In these and other cases, it may be necessary to create water quality cells that encompass multiple cross sections. Always keep in mind that while a larger water quality cell spacing does lead to a faster run time, water quality kinetics must also considered.

Finally, multiple meteorological datasets and multiple sets water quality parameters may be created. Each water quality cell is assigned a particular meteorological dataset and a particular parameter set for each DLL.

Instructions for creating, editing and managing water quality cells, and for assigning datasets to them are found on the page: Working With Water Quality Cells (see page 20).

3.2 Dispersion Coefficients

3.3 Meteorological Regions

Meteorological data sometimes vary dramatically within a river system. Each water quality cell is assigned to a particular meteorological region to facilitate the use of multiple meteorological datasets within the same model.

3.4 Water Quality Regions

Non-uniformity in model geometry, topographic features, or hydrodynamics may create a need for assigning parameters that vary in space (but not time). Water Quality Regions allow the user to specify multiple sets of parameters.

Not Yet Implemented

Setting, editing and managing Water Quality Regions are features that have not yet been implemented.

4 Stability, Courant and Peclet Considerations

5 Working With WQ Libraries (DLLs)

5.1 Temperature Modeling

5.1.1 Temperature Dependence

5.1.2 Temperature Modeling Using the Energy Budget Approach (TEMP DLL)

Water temperature is an important physical characteristic of aquatic systems. It also influences all biological and chemical reactions in water quality models. The Energy Budget Temperature Model () uses a full energy budget to account for heat inputs and outputs from forcing functions and heat exchange at the air-water and sediment-water interfaces. Inputs required for this model include: measured or simulated solar (short-wave) radiation, air temperature, relative humidity, wind speed and atmospheric pressure.

5.1.3 Temperature Modeling Using the Equilibrium Temperature Approach (TEQ DLL)

The Equilibrium Temperature Model () uses a simplified energy balance computed based on an approximate heat balance derived from relative humidity, solar (short-wave) radiation, and wind speed.

5.2 Generalized Constituent Modeling

5.2.1 The Generalized Constituent Simulation Library (GCSM DLL)

The Generalized Constituent Simulation Library (GCSM) is a DLL that the f and transport of user specified conservative and non-conservative tracers. Parameters include growth/decay rate, and a temperature correction coefficient. All constituents in this library are independent. That is the growth/decay of one is not linked to another.

5.3 Nutrient Modeling

5.3.1 The Nutrient Simulation Library (NSMII)

The Nutrient Simulation Library (NSM) is a DLL that has been designed to conduct an advanced water quality simulation. There are twenty four water quality state variables including multiple algal groups, organic nitrogen and phosphorous split into dissolved and particulate species, a carbon cycle, pH and benthic sediment diagenesis. Organic carbon particulate organic carbon, nitrogen, and phosphorus are split into labile and refractory fractions. The algorithms and formulations in the NSM were adopted in part from four surface water quality models: QUAL2K, WASP, CE-QUAL-W2, and CE-QUAL-ICM.

5.4 Modeling Suspended Solids

5.4.1 The Solids Simulation Library (SOLIDS)

6 Entering Water Quality Data

6.1 Working with Time Series Data

6.2 Entering and Manipulation Boundary and Initial Condition Data

6.3 Working with Weather Data

6.3.1 Air Temperature

6.3.2 Atmospheric Pressure

6.3.3 Cloudiness

6.3.4 Humidity

6.3.5 Solar Radiation

6.4 Setting WQ Parameters

6.4.1 Zero-Dimension Modeling

A zero-dimension model, or a continuously stirred tank reactor (CSTR), has been provided to assist in setting and experimenting with parameter values. Zero-dimension models predict the concentration of a contaminant as a singular function of time. System hydraulics or hydrodynamics are not considered or included. A single element, no transport is specified. The CSTR may be interpreted as a coarse fully mixed lake with no inflow or outflow.

7 Performing a Simulation

7.1 Setting Parameters

7.2 Running the Simulation

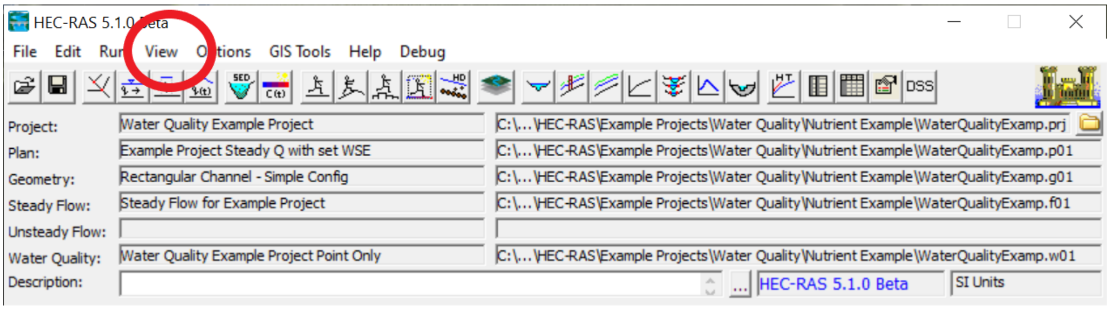
This window allows the editor to create, edit, and invoke a water quality simulation.

The Water Quality Analysis window pairs a hydrodynamics plan with a Water Quality Input file. The simulation time window is also set here, and simulation options are chosen, including the output interval, controls on QUICKEST-ULTIMATE such as time step, continuity and oscillation control.

All water quality data simulations are performed by first opening the **Water Quality Analysis Window**, accessed from the main HEC-RAS window either through the menu bar by selecting **Run… Water Quality Analysis** or by selecting the **Water Quality Analysis Icon.**

7.3 Viewing Simulation Results

Water Quality results are available in either spatial or time series format. Plots and tables are accessed only from the main HEC-RAS window by selecting **View… Water Quality Spatial Plot** or **View… Water Quality Time Series Plot**.



Project: Water Quality Example Project — C:\...\HEC-RAS\Example Projects\Water Quality\Nutrient Example\WaterQualityExamp.prj

Plan: Example Project Steady Q with set WSE — C:\...\HEC-RAS\Example Projects\Water Quality\Nutrient Example\WaterQualityExamp.p01

Geometry: Rectangular Channel - Simple Config — C:\...\HEC-RAS\Example Projects\Water Quality\Nutrient Example\WaterQualityExamp.g01

Steady Flow: Steady Flow for Example Project — C:\...\HEC-RAS\Example Projects\Water Quality\Nutrient Example\WaterQualityExamp.f01

Unsteady Flow:

Water Quality: Water Quality Example Project Point Only — C:\...\HEC-RAS\Example Projects\Water Quality\Nutrient Example\WaterQualityExamp.w01

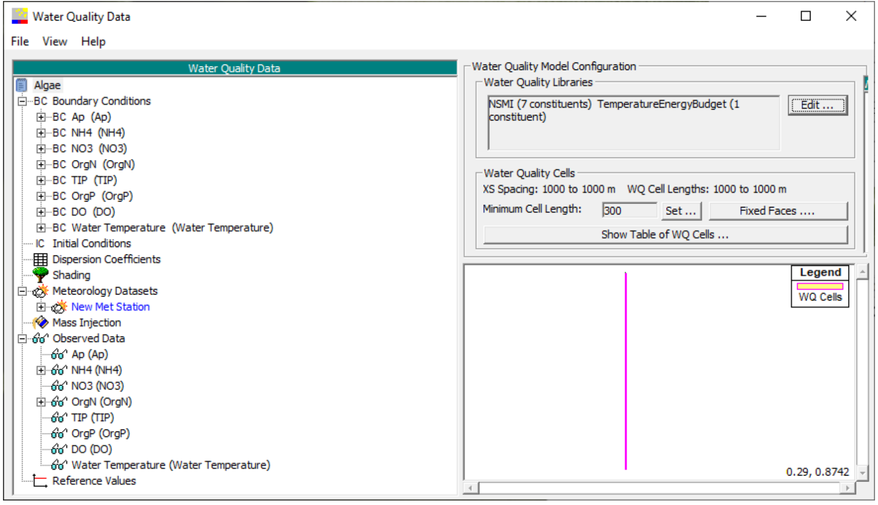
Description: … HEC-RAS 5.1.0 Beta — SI Units

8 The Water Quality Data Editor

Accessed from the main HEC-RAS window either through the menu bar by selecting **Edit… Water Quality Data** or by selecting the **Water Quality Data Icon**, the **Water Quality Data Entry** window allows the user to select and configure the desired water quality library (DLL), enter and edit boundary and initial conditions, and set all parameters required to run the model. .

8.1 **Overview of Water Quality Data Window**

The **Water Quality Data** window is divided into three sections: water quality datasets (mostly time series), configuration of water quality libraries, or DLLs, and configuration of water quality cells.



NSMI (7 constituents) TemperatureEnergyBudget (1 constituent)

XS Spacing: 1000 to 1000 m WQ Cell Lengths: 1000 to 1000 m

Minimum Cell Length: 300

*The main **Water Quality Data Window**: Entering and Editing **Water Quality Datasets** (left), Choosing and **Configuring Water Quality Libraries**(right top), and **Configuring Water Quality Cells** (right bottom).*

8.1.1 Entering and Editing Water Quality Datasets (left pane)

Most data in this window are time series. Initial conditions, boundary conditions, weather data, and observed data are accessed here. Dispersion coefficients are also configured through this window.

8.2 Managing Water Quality Data Files

To save, delete, or rename the current water quality file, highlight the file name at the top of the navigation bar. Once highlighted, select **File...** in the menu bar, as shown in Figure 19-2.

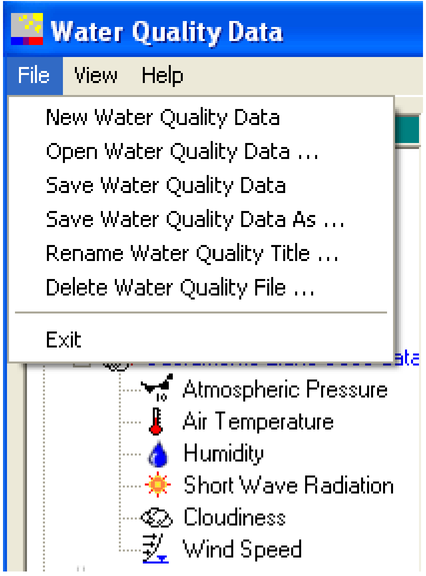
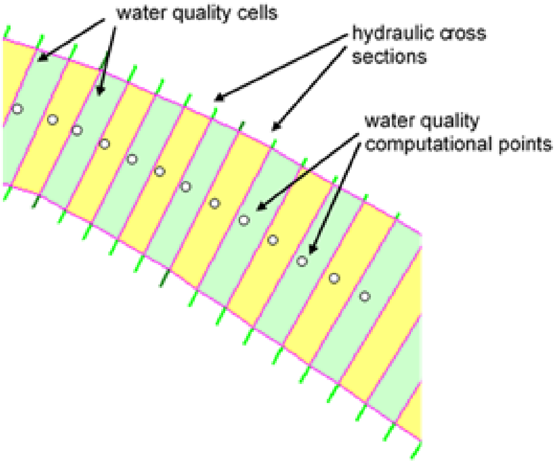


Figure 19-2. Managing water quality data files.

8.3 Working With Water Quality Cells

8.3.1 Default Configuration

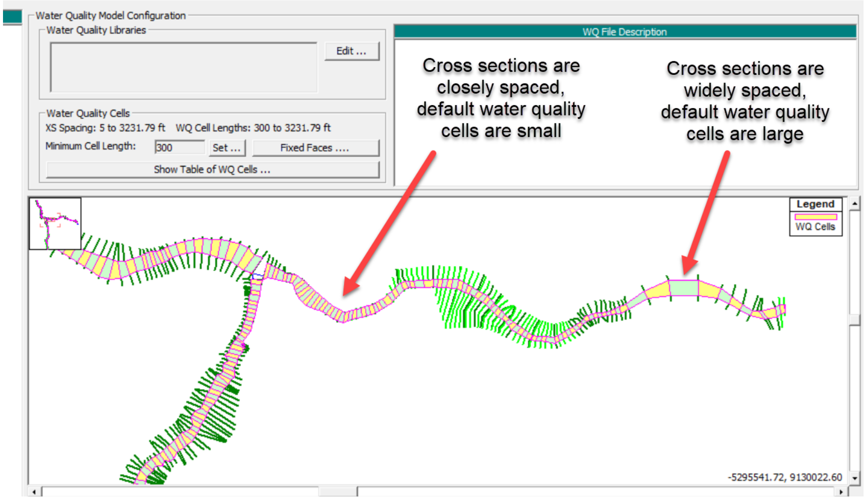
When a new water quality file is created, water quality cells are created, with the default that one water quality cell is created between each set of adjacent cross sections. This is illustrated below, green lines represent the edges of hydraulic cross sections, water quality cells are drawn in pink, and are filled with alternating green and yellow color (to help distinguish them from their neighbors).



In simple systems, the water quality model will run quickly and without problems using this default configuration; however, if very small water quality cells are included in the model, they may lead to long run times or instability. In situations where hydraulic cross sections have been placed very close together (such as around bridges or other hydraulic structures), default water quality cells will be small. A very small water quality cell surrounded by larger cells is a challenging computational problem that may lead to instability. A single small water quality cell will also force the model to run with a correspondingly small time step, in order to satisfy both the Courant and Peclet conditions. (discussed later in this chapter in the **Water Quality Analysis** window under **Water Quality Simulation Options**). Small water quality cells lead to shorter time steps, longer simulation times, and in some cases model instability.

8.3.1.1 Combining Water Quality Cells

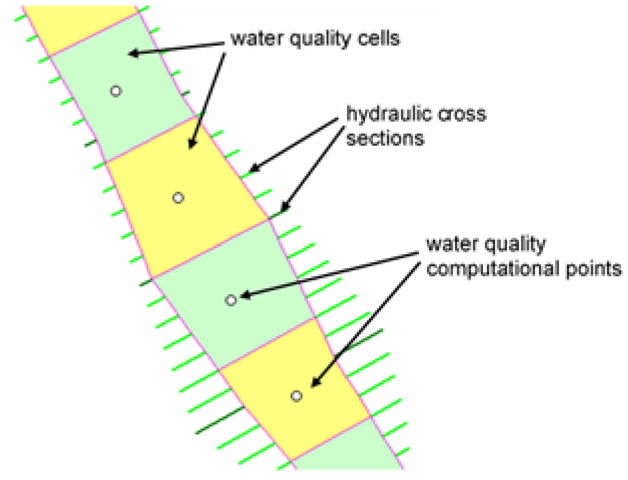
Water quality cells may be grouped together into larger ones by setting the **Minimum Cell Length**.


Water Quality Cells
XS Spacing: 5 to 3231.79 ft   WQ Cell Lengths: 300 to 3231.79 ft
Minimum Cell Length: 300

Cross sections are closely spaced, default water quality cells are small

Cross sections are widely spaced, default water quality cells are large

-5295541.72, 9130022.60

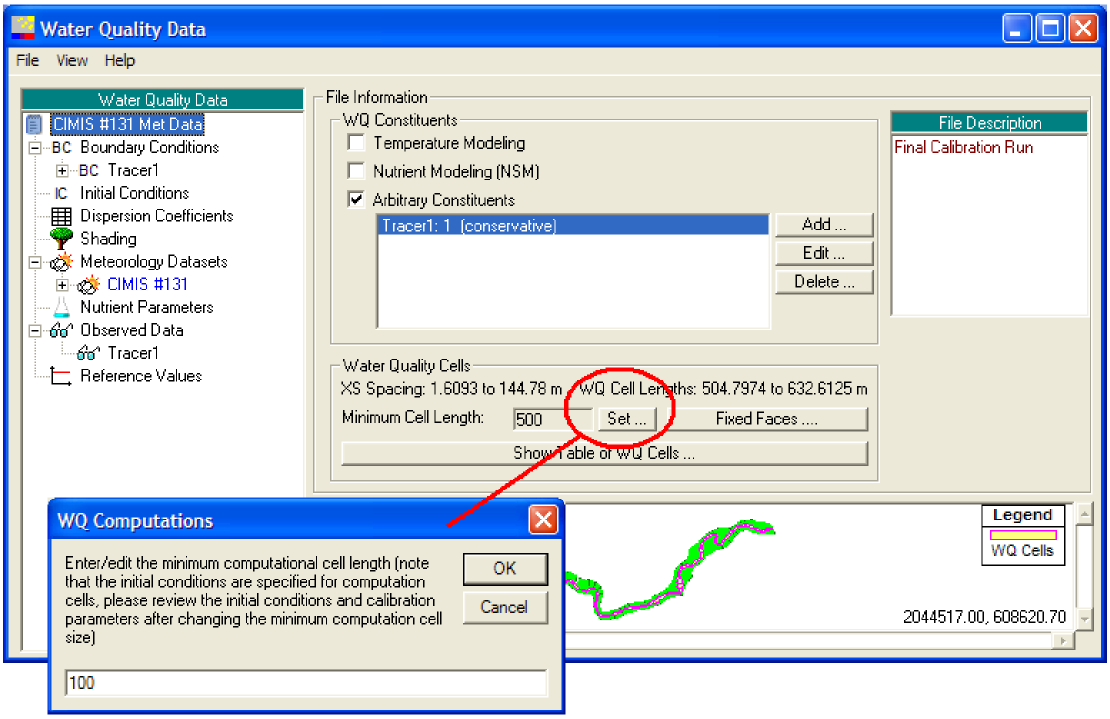


An example of the result of grouping water quality cells together into larger cells is shown in Figure 19-4. Note that regardless of grouping, water quality cells faces are always coincidental with hydraulic cross sections. When cells are combined, internal cross sections are sometimes incorporated into larger water quality cells. Once cells are combined, every water quality cell face will still be coincidental with a hydraulic cross section; however, not all cross sections must be associated with a water quality cell face. Computational points are always located at the center of a water quality cell. When cells are combined, the computational point is located at the center of the (new) combined cell.

Figure 19-4 Combined water quality cell configuration: five water quality cells combined into a single (larger) water quality cell.

Grouping smaller cells into larger ones results in a reduction in the number of total cells in the system, increasing the length of the time step and reducing overall computation time.

Water quality cells are combined by changing the **minimum cell length. Minimum cell length** is accessed in the **Water Quality Data** window as shown in Figure 19-5. Setting the minimum water quality cell length directs the software to combine water quality cells to ensure that the all cells are at least as long as this user specified minimum. The **Set…** button displays a subwindow allowing the user to input a minimum cell length as shown.



File Description: Final Calibration Run

XS Spacing: 1.6093 to 144.78 m

WQ Cell Lengths: 504.7974 to 632.6125 m

Minimum Cell Length: 500

Enter/edit the minimum computational cell length (note that the initial conditions are specified for computation cells, please review the initial conditions and calibration parameters after changing the minimum computation cell size)

100

The absolute minimum cell length that will be accepted is the smallest hydraulic reach length (this length is the default upon opening the program). To return to this default setting, decrease the **Minimum Water Quality Cell Length** to 1. The minimum cell length will then correspond with the minimum reach length in the system geometry.

To assist in configuring water quality cell lengths, maximum and minimum cross section spacing and water quality cell lengths are printed to the window subpane. Cross section spacing is the maximum and minimum distance between cross sections. Water quality cell lengths indicate the longest and shortest water quality cells in the system.

Changing the water quality cell length has no effect on hydraulic computations. It is not necessary to re-run the unsteady (or steady) flow simulation after adjusting water quality cell lengths.

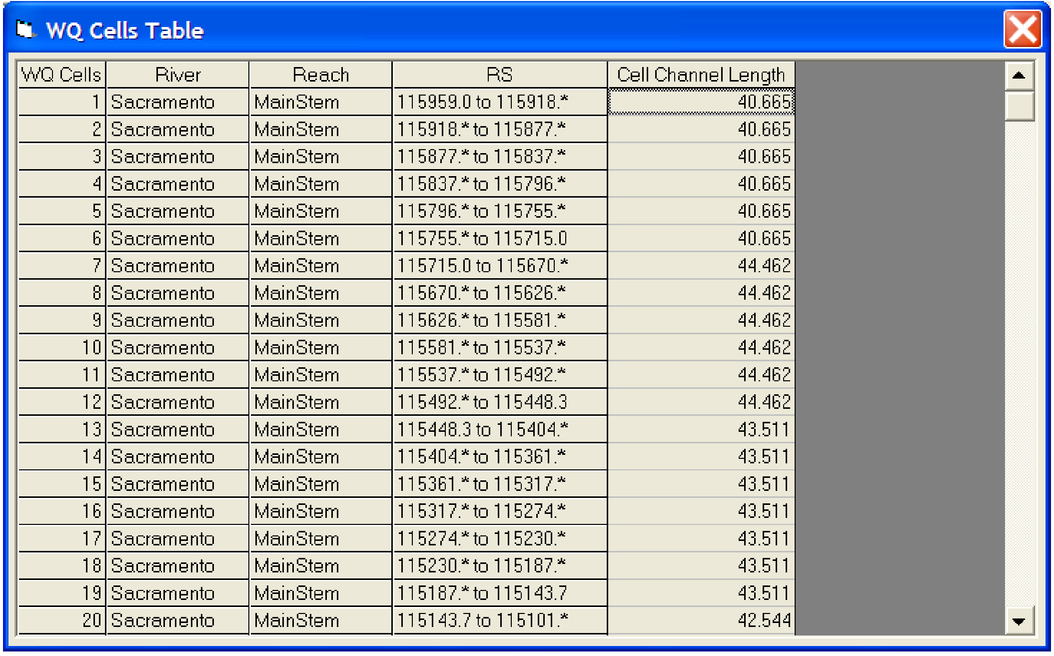
Fixed Faces… allows the user to establish particular cross sections as fixed faces. Such fixed faces will always be located at the boundary of water quality cells.

8.3.2 Viewing Water Quality Cell Configuration

Once water quality cell lengths have been adjusted it is sometimes useful to review a table showing cross sections bounding each water quality cell and associated water quality cell lengths.

Show Table of WQ Cells… displays the results of the current configuration. In this table, cells are listed along with River Stations that bound them and their lengths. An example is shown below in Figure 19-6. For example, WQ Cell 10 is bounded by the interpolated cross-sections 115581* and 115537* and it is 44.462

meters in length.



WQ Cells	River	Reach	RS	Cell Channel Length
1	Sacramento	MainStem	115959.0 to 115918.*	40.665
2	Sacramento	MainStem	115918.* to 115877.*	40.665
3	Sacramento	MainStem	115877.* to 115837.*	40.665
4	Sacramento	MainStem	115837.* to 115796.*	40.665
5	Sacramento	MainStem	115796.* to 115755.*	40.665
6	Sacramento	MainStem	115755.* to 115715.0	40.665
7	Sacramento	MainStem	115715.0 to 115670.*	44.462
8	Sacramento	MainStem	115670.* to 115626.*	44.462
9	Sacramento	MainStem	115626.* to 115581.*	44.462
10	Sacramento	MainStem	115581.* to 115537.*	44.462
11	Sacramento	MainStem	115537.* to 115492.*	44.462
12	Sacramento	MainStem	115492.* to 115448.3	44.462
13	Sacramento	MainStem	115448.3 to 115404.*	43.511
14	Sacramento	MainStem	115404.* to 115361.*	43.511
15	Sacramento	MainStem	115361.* to 115317.*	43.511
16	Sacramento	MainStem	115317.* to 115274.*	43.511
17	Sacramento	MainStem	115274.* to 115230.*	43.511
18	Sacramento	MainStem	115230.* to 115187.*	43.511
19	Sacramento	MainStem	115187.* to 115143.7	43.511
20	Sacramento	MainStem	115143.7 to 115101.*	42.544

8.3.3 Assigning Meteorological Datasets to Water Quality Cells

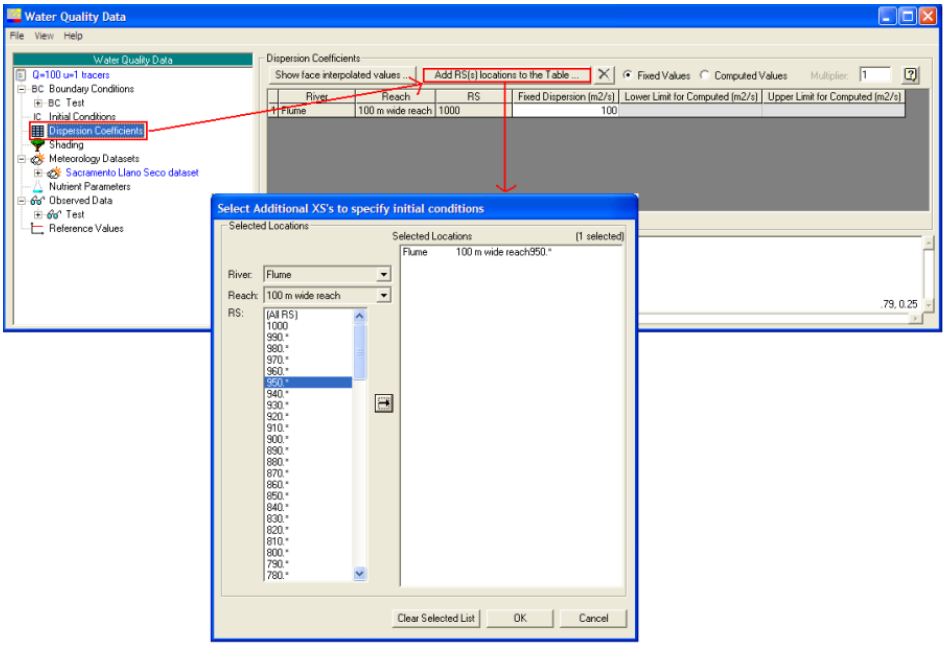
8.3.4 Assigning Water Quality Datasets to Water Quality Cells

This feature not yet implemented.

This version of HEC-RAS does not support assignment of Water Quality Parameters to individual water quality cells. Water quality parameters are currently applied systemwide.

8.4 COPY Entering Dispersion Coefficients

Dispersion coefficients may be assigned to as few as one or as many as all cross sections. Selecting **Dispersion Coefficients** in the navigation bar brings up a list of locations where dispersion coefficients have already been entered, as shown in the Figure 19-21.



● Fixed Values ○ Computed Values Multiplier: 1

	River	Reach	RS	Fixed Dispersion (m2/s)	Lower Limit for Computed (m2/s)	Upper Limit for Computed (m2/s)
1	Flume	100 m wide reach	1000	100		

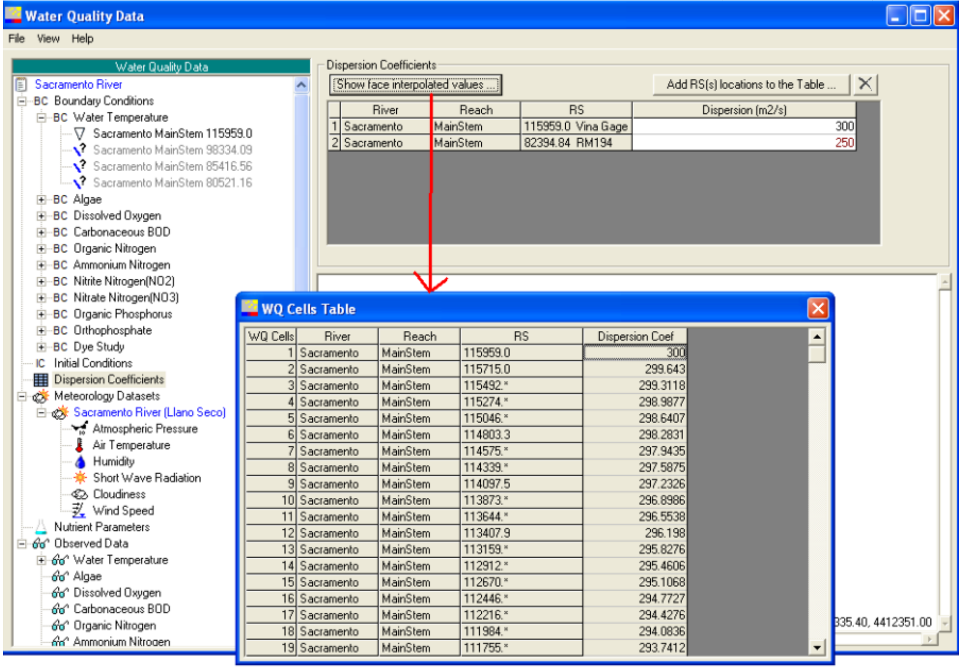
River: Flume
Reach: 100 m wide reach
RS: (All RS) 1000, 990.*, 980.*, 970.*, 960.*, 950.*, 940.*, 930.*, 920.*, 910.*, 900.*, 890.*, 880.*, 870.*, 860.*, 850.*, 840.*, 830.*, 820.*, 810.*, 800.*, 790.*, 780.*

Selected Locations (1 selected)
Flume 100 m wide reach950.*

Figure 19-21. Entering and editing dispersion coefficients.

Use **Add RS location(s) to the table…** to add cross section locations and use the icon to delete them if necessary.

If more than one dispersion coefficient is entered, values will be interpolated across all river stations. To view the result of the interpolation, select **Show cell Interpolated values…** Dispersion is a face property, so results of this interpolation are reported at individual cross sections (Figure 19-22).



	River	Reach	RS	Dispersion (m2/s)
1	Sacramento	MainStem	115959.0 Vina Gage	300
2	Sacramento	MainStem	82394.84 RM194	250

WQ Cells	River	Reach	RS	Dispersion Coef
1	Sacramento	MainStem	115959.0	300
2	Sacramento	MainStem	115715.0	299.643
3	Sacramento	MainStem	115492.*	299.3118
4	Sacramento	MainStem	115274.*	298.9877
5	Sacramento	MainStem	115046.*	298.6407
6	Sacramento	MainStem	114803.3	298.2831
7	Sacramento	MainStem	114575.*	297.9435
8	Sacramento	MainStem	114339.*	297.5875
9	Sacramento	MainStem	114097.5	297.2326
10	Sacramento	MainStem	113873.*	296.8986
11	Sacramento	MainStem	113644.*	296.5538
12	Sacramento	MainStem	113407.9	296.198
13	Sacramento	MainStem	113159.*	295.8276
14	Sacramento	MainStem	112912.*	295.4606
15	Sacramento	MainStem	112670.*	295.1068
16	Sacramento	MainStem	112446.*	294.7727
17	Sacramento	MainStem	112216.*	294.4276
18	Sacramento	MainStem	111984.*	294.0836
19	Sacramento	MainStem	111755.*	293.7412

Figure 19-22. Viewing interpolated dispersion coefficient values.

8.5 COPY Preparing WQ Input (empty)

8.5.1 COPY Preparing the Water Quality Input

8.5.1.1 Requirements for All Water Quality Models

- Standard output files for a calibrated steady flow model

or

- Computation level output file for a calibrated unsteady flow model

8.5.1.2 Requirements for Water Temperature Modeling

- Water temperature time series at all hydraulic boundaries
- At least one initial condition value in each reach or a restart file
- Meteorological Time Series
    - Solar radiation (or site latitude and longitude)
    - Air Temperature
    - Relative Humidity (or vapor pressure, dew point, wet bulb)
    - Wind speed
    - Cloudiness
    - Atmospheric Pressure (or estimation of site elevation)

8.5.1.3 Requirements for Nutrient Modeling

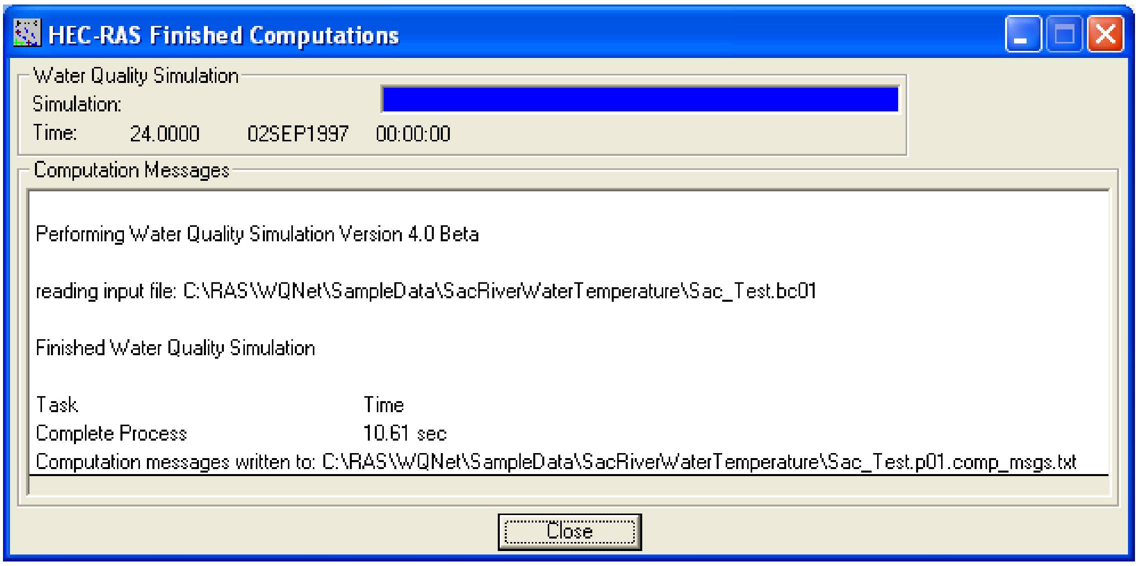
- A complete set of water temperature model input as outlined above
- Time series of constituent concentrations at all hydraulic boundaries
- At least one initial condition value for all constituents in each reach or a restart file

8.5.1.4 Requirements for Arbitrary Constituent Modeling

- Time series of constituent concentration at all hydraulic boundaries
- At least one initial condition value for the constituents in each reach or a restart file
- Estimated rate constant(s) for the constituent(s) to be modeled

8.5.2 COPY Running the Water Quality Model

Selecting **Compute** brings up a status window. An example is shown in Figure 19-42. If the water quality model runs without error, a message is displayed along with the total computation time.



Simulation:
Time: 24.0000 02SEP1997 00:00:00

```
Performing Water Quality Simulation Version 4.0 Beta

reading input file: C:\RAS\WQNet\SampleData\SacRiverWaterTemperature\Sac_Test.bc01

Finished Water Quality Simulation

Task                                  Time
Complete Process                      10.61 sec
Computation messages written to: C:\RAS\WQNet\SampleData\SacRiverWaterTemperature\Sac_Test.p01.comp_msgs.txt
```

Figure 19-42. Successful completion of a water quality simulation.

8.5.3 COPY Entering Boundary Condition Data *

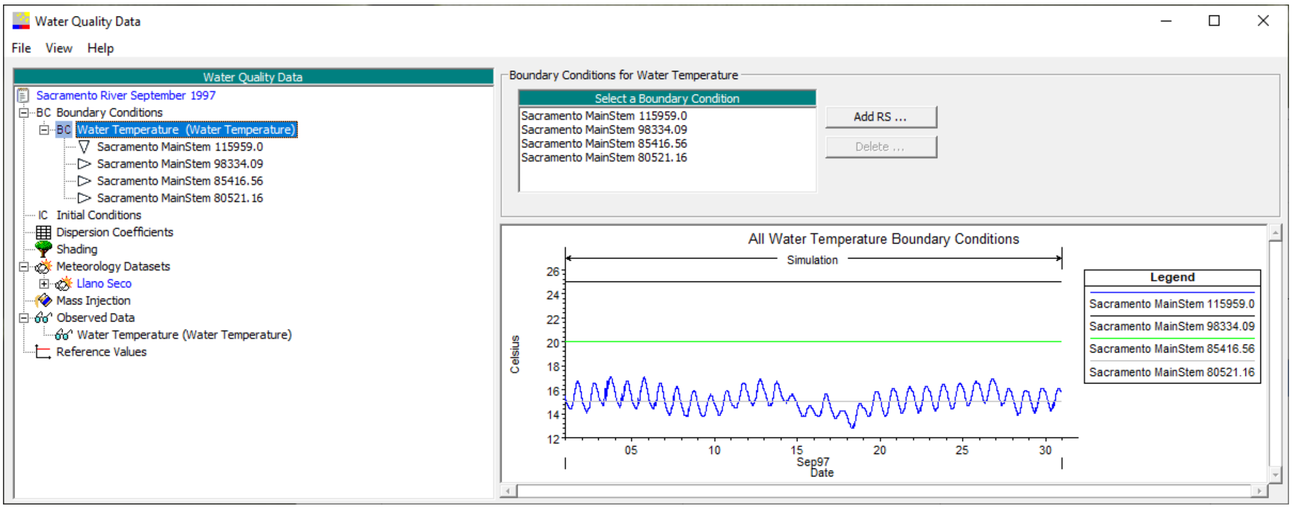
A time series (boundary condition) must be specified for each modeled constituent at any location where flow enters the system, including upstream boundaries of the main channel, boundaries of tributaries and any lateral inflows. If the modeled reach is tidal, a boundary condition must also be included at the tidal boundary.

8.5.3.1 Viewing Required Boundary Condition Data Sets

Locations of required boundary conditions are determined by hydraulic model output. Expanding the **Boundary Conditions** entry in the navigation bar lists locations of required boundary conditions with icons specific to type:

▽ Upstream boundary (positive flow across boundary)
▷ Lateral inflow (flow into water quality cell not at boundary)
△ Downstream boundary (negative flow across boundary)

In the figure below, data sets at four boundaries are required: the upstream boundary around RS 115959, and tributaries (or lateral inflows) around RS 98334, RS 85416 and RS 80521. A time series has been entered for RS 115959 (blue). A constant value of 25˚C has been entered for and RS 98334 (black), a constant value of 15˚C has been entered for RS 80521 (grey) and a constant value of 20˚C has been entered for RS 85416 (green).



Combined plot of all entered boundary conditions.

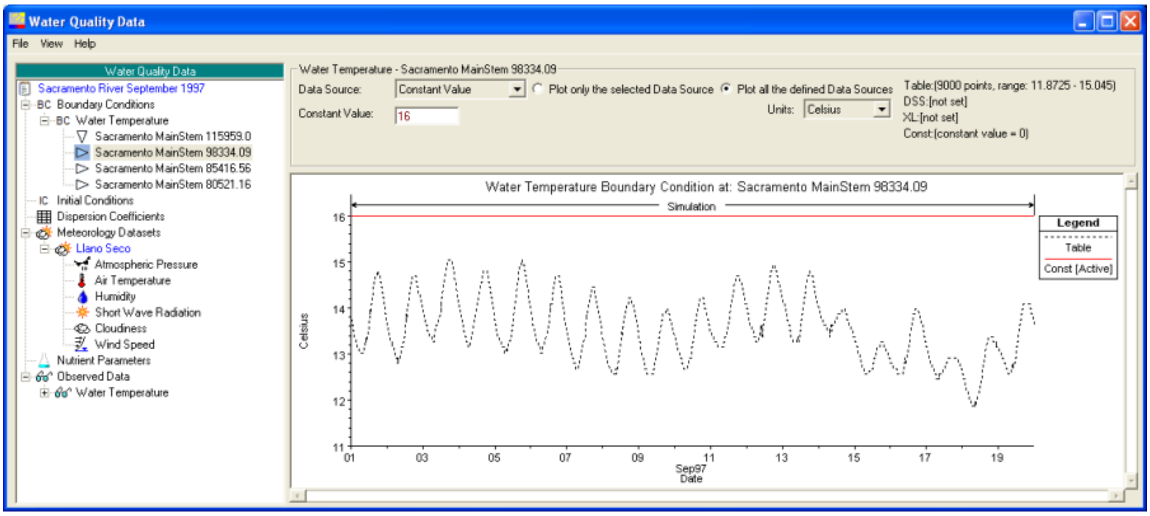
8.5.3.1.1 Unattached Boundary Condition Data Sets

A water quality boundary time series (or constant value) is required at every location where there is also a flow boundary (e.g., upstream and downstream boundaries, tributaries, lateral inflows). If after entering this water quality boundary data, a flow boundary is subsequently removed from the hydraulics model, the associated water quality boundary data has no associated hydraulics boundary and becomes "unattached". For this special case (when no flow information is available at an existing water quality boundary location) an icon with a question mark appears at the location.

The question mark indicates that water quality boundary data is present and will be saved in the water quality data file. However, because there is no associated hydrodynamics data at the boundary, the water quality boundary data will not be used in the simulation.

8.5.3.2 Entering Water Quality Boundary Conditions

To enter boundary condition information, select the desired location in the navigation bar. The **Boundary Condition Data Entry Window** will appear (at the right) and all data available for the location will be plotted, as shown in the figure below.



Water Temperature - Sacramento MainStem 98334.09

Data Source: Constant Value

○ Plot only the selected Data Source ● Plot all the defined Data Sources

Constant Value: 16

Units: Celsius

Table:(9000 points, range: 11.8725 - 15.045)
DSS:[not set]
XL:[not set]
Const:(constant value = 0)

Entering water quality boundary condition information.

The data entry window allows the user to enter data from up to four sources. In Figure 19-8, data has been entered from two sources: a constant value of 16 ˚C has been entered, and a time series has also been entered directly into HEC-RAS. All data sources will be shown on the plot. Time series and constant values are entered directly into HEC-RAS and will reside with the project. Data may also reside in an excel spreadsheet or in a DSS file and be referenced by the water quality model.
The data source currently chosen in the **Data Source** pulldown will be the data applied during the simulation.

8.5.3.2.1 Boundary Condition Controls

8.5.3.2.1.1 Data Units

Although the water quality model uses SI units internally, water quality and meteorological data sets are often supplied in a variety of (non-SI) units. For example, an air or water temperature time series may be entered in degrees Fahrenheit or Celsius; if Fahrenheit is selected, the program converts the time series to Celsius when the data is read into the water quality model. Units are indicated by the pulldown menu. Input data is always plotted in its original units.

8.5.3.2.1.2 Data Plotting

The plot window shows all data entered at the currently selected location for the simulation period. Choosing **Plot only the selected Data Source** plots only the data indicated on the data source pulldown. This is the data source that will be used the next time a water quality simulation is run. Choosing **Plot all the defined Data Sources** shows all data sources currently entered or referenced for this location.

8.5.3.2.1.3 Data Source Selection

Data may be read into the model from one or all of the following sources:

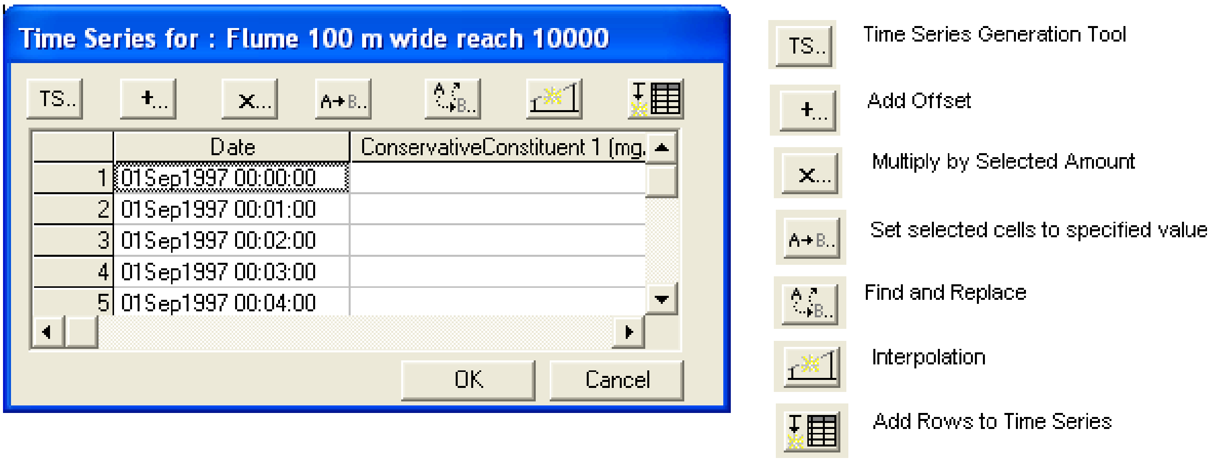
1. **Table Data** – Data is entered directly into HEC-RAS and is stored with project model files.

2. **DSS** – Reference to DSS file is entered. Data is stored in DSS file.
3. **Excel Worksheet** – Reference to Excel Worksheet is entered. Data is stored in Excel file.
4. **Constant value** – Single value is entered into HEC-RAS. Value is stored with project model files.

Note that the data entry window changes in response to the data source selection.

Entering and Editing Table Data

Choosing Table Data from the Data Source selection field opens the Enter/Edit Table… subwindow.
This time series editor includes tools to create a times series (and to manipulate the values of a time series once it has been created).
The time series editor and its tools are summarized below.



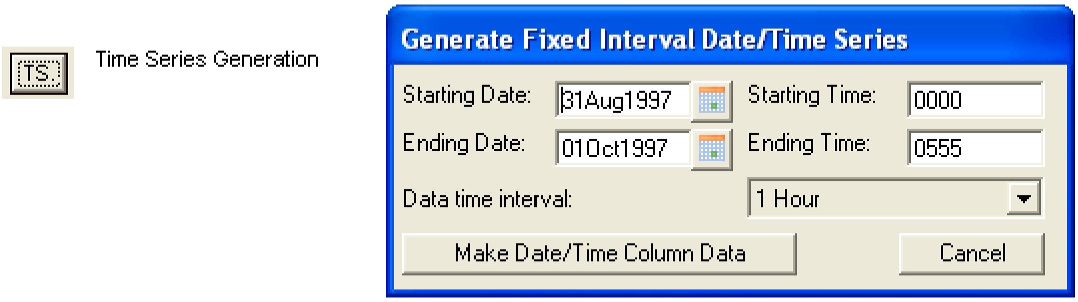
Time Series for : Flume 100 m wide reach 10000

	Date	ConservativeConstituent 1 (mg.
1	01Sep1997 00:00:00	
2	01Sep1997 00:01:00	
3	01Sep1997 00:02:00	
4	01Sep1997 00:03:00	
5	01Sep1997 00:04:00	

Time series editor and tools.

Time Series Generation Tool

The time series generation button sets the beginning and ending time of the time series as well as the data time interval. **Make Date/Time Column Data** creates an empty time series with a data and time column but with no data. Once this time series has been created, data can be typed into the table, or pasted into the table from the clipboard.



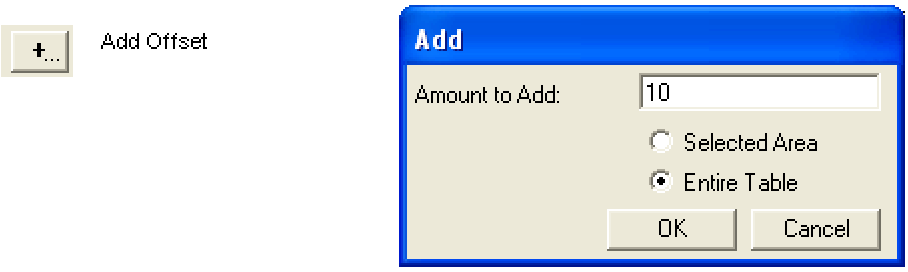
Generate Fixed Interval Date/Time Series

Starting Date: 31Aug1997
Starting Time: 0000
Ending Date: 01Oct1997
Ending Time: 0555
Data time interval: 1 Hour

Using the time series generation tool.

Add Offset

This tool adds the amount entered in the text box to the currently selected (highlighted) area range in the table or to the entire table. Note that if the the data column is selected, this number will also be added to the date. For dates the offset is in days (i.e. adding ten adds ten days).

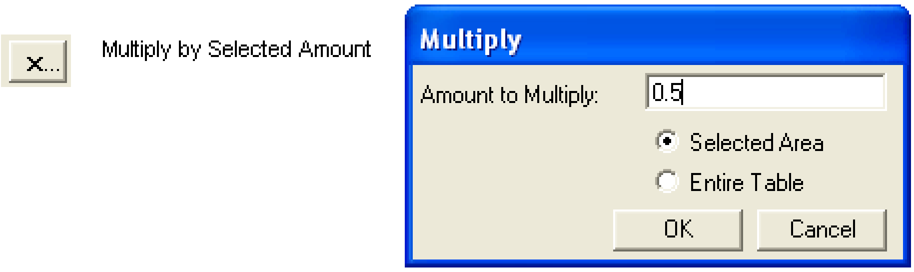


Amount to Add: 10
○ Selected Area
● Entire Table

Using the add offset tool.

Multiply by Selected Amount

This tool multiplies the amount entered in the text box with the currently selected (highlighted) area range in the table or to the entire table. Note that unlike the offset tool, dates are not affected by this command.

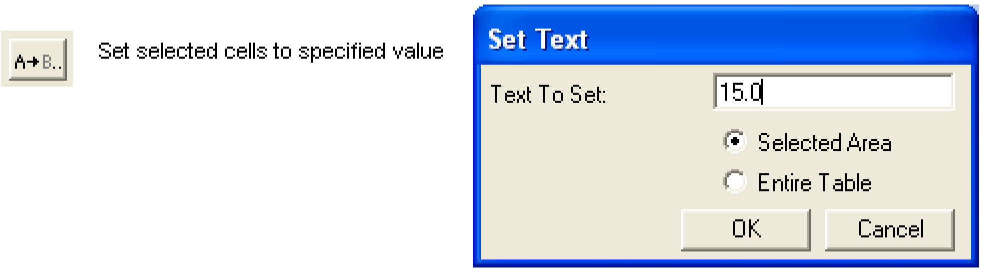


Amount to Multiply: 0.5
● Selected Area
○ Entire Table

Using the multiply by selected amount tool.

Set to Specified Value

This tool sets the selected cells or the entire table to the value entered in the text box. In this example, the selected cells will be set to the value 15.0.



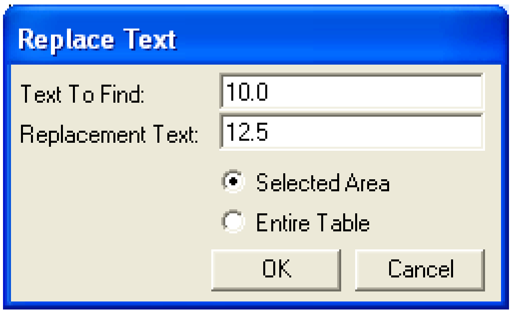
Text To Set: 15.0
● Selected Area
○ Entire Table

Using the set selected cells to specified value tool.

Find and Replace

Standard find and replace with the user entered value.

Find and Replace



Text To Find: 10.0
Replacement Text: 12.5
● Selected Area
○ Entire Table

Using the find and replace tool.

Time Series Interpolation Tool

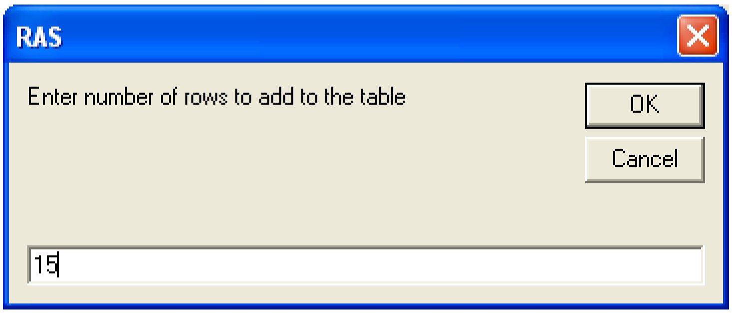
This time series tool uses linear interpolation to fill in missing values. Blank cells will be interpolated; the selection must include both the cell(s) with missing values, the cell before, and the cell after the blank cells. Cells must be highlighted before applying the interpolation tool.

No submenu appears. Missing cells are simply filled in.

Add Rows to Time Series

This tool adds the entered amount of blank rows to the current time series Facilitates cut and paste from the clipboard into a time series.
Note that it is not necessary for the time series to be evenly spaced.

Add Rows to Time Series

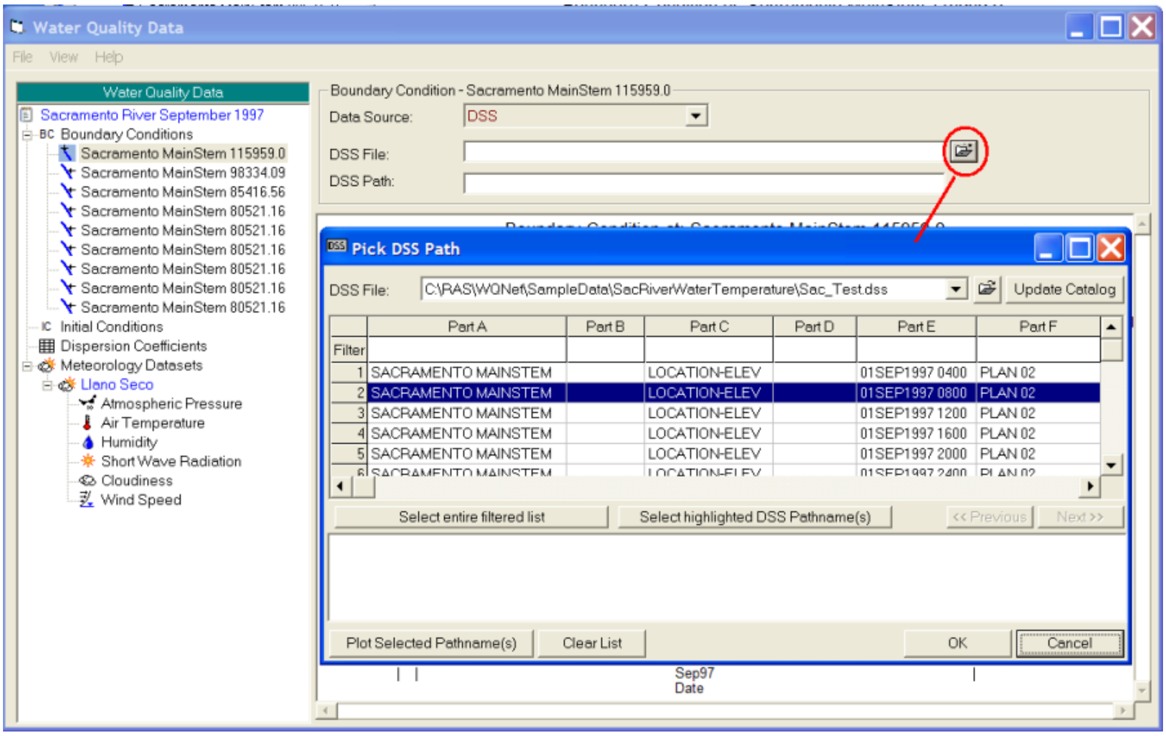


Enter number of rows to add to the table

15

Using the add rows to time series tool.

Referencing DSS Data



Boundary Condition - Sacramento MainStem 115959.0

Data Source: DSS

DSS File:

DSS Path:

DSS File: C:\RAS\WQNet\SampleData\SacRiverWaterTemperature\Sac_Test.dss

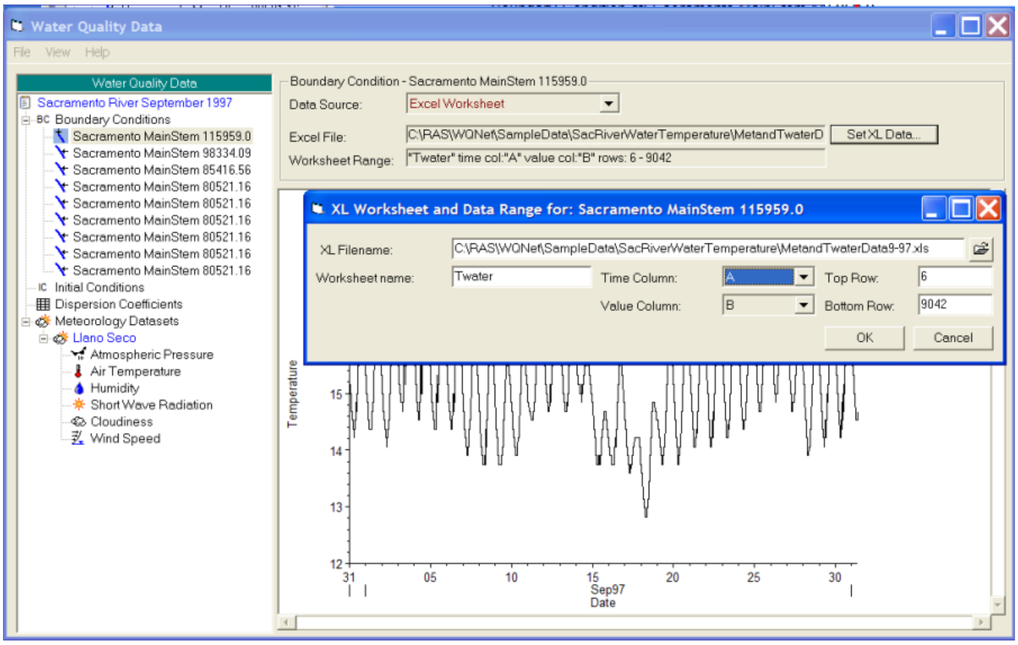
	Part A	Part B	Part C	Part D	Part E	Part F
Filter						
1	SACRAMENTO MAINSTEM		LOCATION-ELEV		01SEP1997 0400	PLAN 02
2	SACRAMENTO MAINSTEM		LOCATION-ELEV		01SEP1997 0800	PLAN 02
3	SACRAMENTO MAINSTEM		LOCATION-ELEV		01SEP1997 1200	PLAN 02
4	SACRAMENTO MAINSTEM		LOCATION-ELEV		01SEP1997 1600	PLAN 02
5	SACRAMENTO MAINSTEM		LOCATION-ELEV		01SEP1997 2000	PLAN 02
6	SACRAMENTO MAINSTEM		LOCATION-ELEV		01SEP1997 2400	PLAN 02

Referencing data in a DSS file.

The Data Source selection DSS allows the user to select the DSS file and path (Figure 19-16). Once the path is selected and the DSS path sub window is closed, both the DSS file and path will be filled. DSS referenced data will continue to reside in the DSS file.

Referencing Excel Worksheet Data

From the **Data Source** filed, select **Excel Worksheet** (Figure 19-17). The **Worksheet name** must be entered directly. The time series time column and value column do not have to be located side by side. However, the top and bottom row of the time and value columns must be the same. As is the case with the worksheet name, the **Time Column**, **Value Column**, **Top Row** and **Bottom Row** must all be entered directly. Data will continue to reside in the (referenced) excel worksheet.



Boundary Condition - Sacramento MainStem 115959.0

Data Source: Excel Worksheet

Excel File: C:\RAS\WQNet\SampleData\SacRiverWaterTemperature\MetandTwaterD

Worksheet Range: "Twater" time col:"A" value col:"B" rows: 6 - 9042

XL Worksheet and Data Range for: Sacramento MainStem 115959.0

XL Filename: C:\RAS\WQNet\SampleData\SacRiverWaterTemperature\MetandTwaterData9-97.xls

Worksheet name: Twater

Time Column: A

Value Column: B

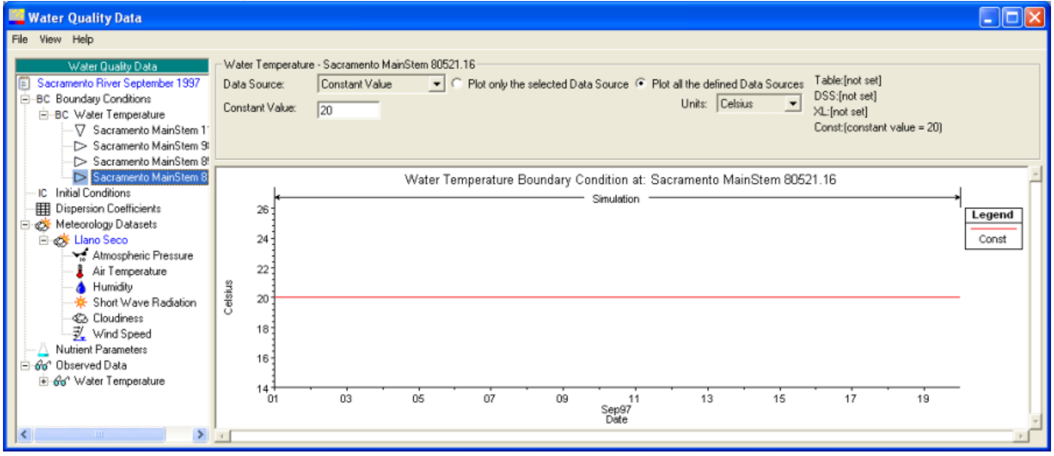
Top Row: 6

Bottom Row: 9042

Referencing data in an excel worksheet.

Setting a Constant Value

A constant value may also be entered. One value is entered into the sub-window as shown below.



Water Temperature - Sacramento MainStem 80521.16

Data Source: Constant Value

○ Plot only the selected Data Source ● Plot all the defined Data Sources

Constant Value: 20

Units: Celsius

Table:[not set]
DSS:[not set]
XL:[not set]
Const:[constant value = 20]

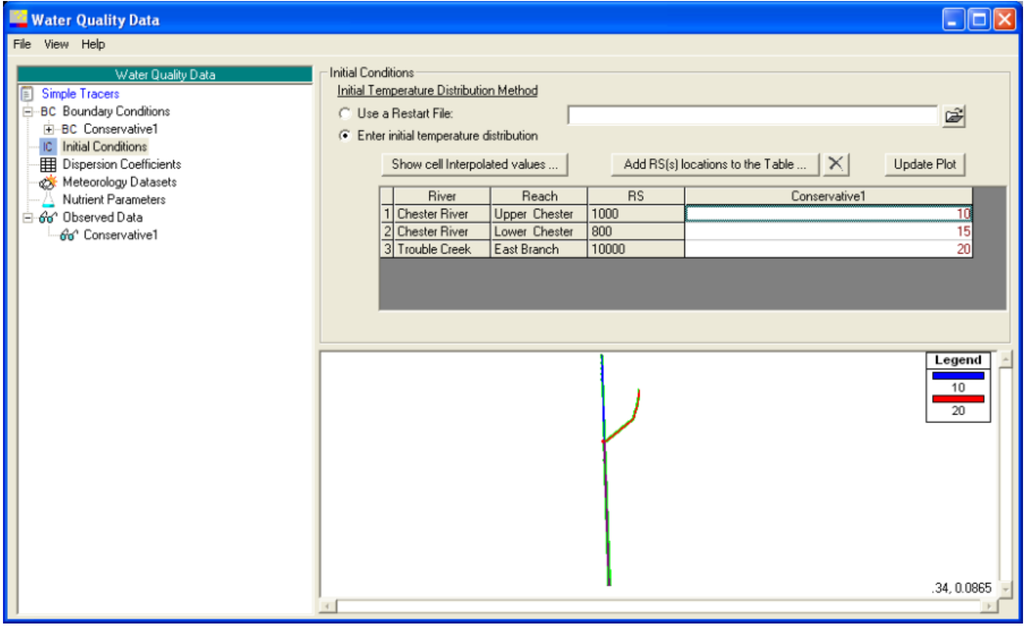
Entering a constant value.

8.5.4 COPY Entering Initial Conditions

The **Initial Conditions Editor** is selected by choosing the **Initial Conditions** heading in the Navigation Bar. At least one initial condition value is required for each modeled constituent in each reach. Initial conditions may be read from a restart file or they may be entered by hand (as an initial temperature distribution). The initial conditions subwindow contains radio buttons to choose between a restart file and an initial condition distribution. The restart file (if one has been chosen) and the initial condition distribution entry table remain in the subwindow regardless of the active choice. The model schematic is color coded with the active choice and is supplied as a graphic in the lower pane.

8.5.4.1 Entering an Initial Distribution

An initial distribution requires at minimum one value for each constituent for each reach. Once initial conditions have been entered, they are interpolated to generate a table of initial conditions at all water quality computational points. An example is shown in the Figure 19-19.



Initial Conditions

Initial Temperature Distribution Method

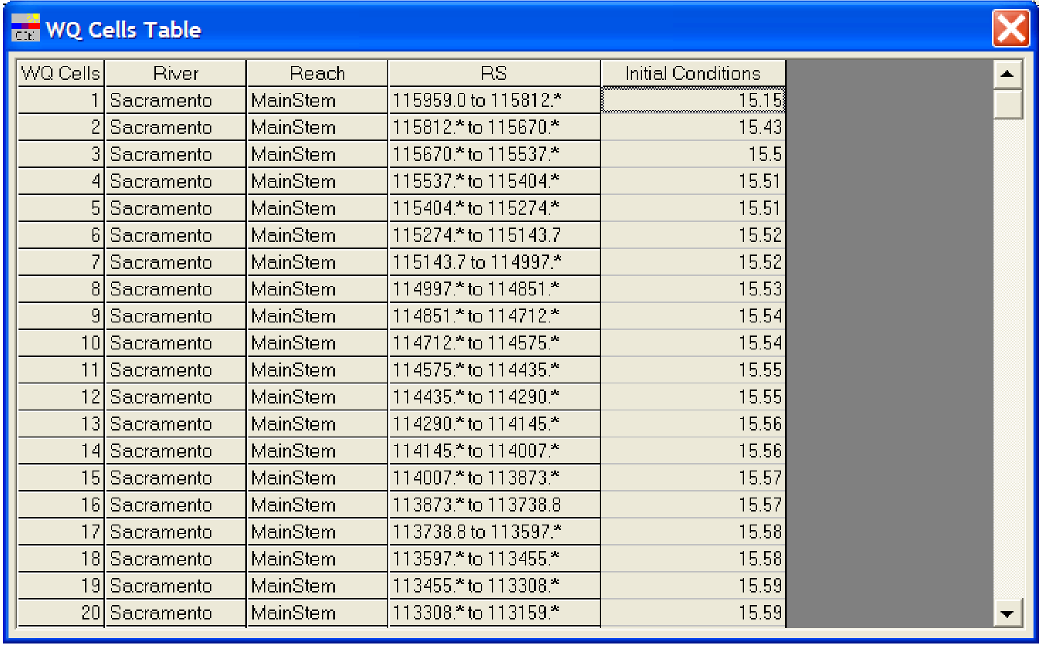
○ Use a Restart File:

● Enter initial temperature distribution

	River	Reach	RS	Conservative1
1	Chester River	Upper Chester	1000	10
2	Chester River	Lower Chester	800	15
3	Trouble Creek	East Branch	10000	20

Figure 19-19. Entering initial conditions in the water quality data window.

Use **Add RS location(s) to the table…** to add cross section locations and use the ✕ icon to delete them if necessary. In order to view the result of the interpolation, select **Show cell Interpolated values…** . A second window will appear, displaying values at the center of each water quality cell. Each water quality cell is identified by the two cross sections that bound it as shown in the Figure 19-20.



WQ Cells	River	Reach	RS	Initial Conditions
1	Sacramento	MainStem	115959.0 to 115812.*	15.15
2	Sacramento	MainStem	115812.* to 115670.*	15.43
3	Sacramento	MainStem	115670.* to 115537.*	15.5
4	Sacramento	MainStem	115537.* to 115404.*	15.51
5	Sacramento	MainStem	115404.* to 115274.*	15.51
6	Sacramento	MainStem	115274.* to 115143.7	15.52
7	Sacramento	MainStem	115143.7 to 114997.*	15.52
8	Sacramento	MainStem	114997.* to 114851.*	15.53
9	Sacramento	MainStem	114851.* to 114712.*	15.54
10	Sacramento	MainStem	114712.* to 114575.*	15.54
11	Sacramento	MainStem	114575.* to 114435.*	15.55
12	Sacramento	MainStem	114435.* to 114290.*	15.55
13	Sacramento	MainStem	114290.* to 114145.*	15.56
14	Sacramento	MainStem	114145.* to 114007.*	15.56
15	Sacramento	MainStem	114007.* to 113873.*	15.57
16	Sacramento	MainStem	113873.* to 113738.8	15.57
17	Sacramento	MainStem	113738.8 to 113597.*	15.58
18	Sacramento	MainStem	113597.* to 113455.*	15.58
19	Sacramento	MainStem	113455.* to 113308.*	15.59
20	Sacramento	MainStem	113308.* to 113159.*	15.59

Figure 19-20. Viewing table of initial conditions after interpolation across all water quality cells.

Note that because initial conditions are assigned to particular cross sections, it is not necessary to re-enter initial conditions if water quality cell lengths are changed.

8.5.4.2 Using Water Quality Restart Files

Water Quality restart files allow the user to save results of a (previous) water quality simulation and to use those results as initial conditions in subsequent simulations.

To specify a restart file, navigate to it using the file open icon. Water quality restart files are identified by the suffix ".wqrst".

Restart files are not automatically generated. Restart file options are accessed though the **Water Quality Computation Options** subwindow. See the Water Quality Analysis section later in this chapter for details on how to create a restart file.

8.5.5 COPY Entering Observed Data

Time series of observed data may be entered into HEC–RAS to enable comparison with model results. Each observed data time series is associated with a particular cross-section.

To enter an observed data time series, click on the **Observed Data** icon in the navigation bar as shown in Figure 19-37. Observed data time series may be moved, copied, deleted or created using the tools in the top pane of the data window.

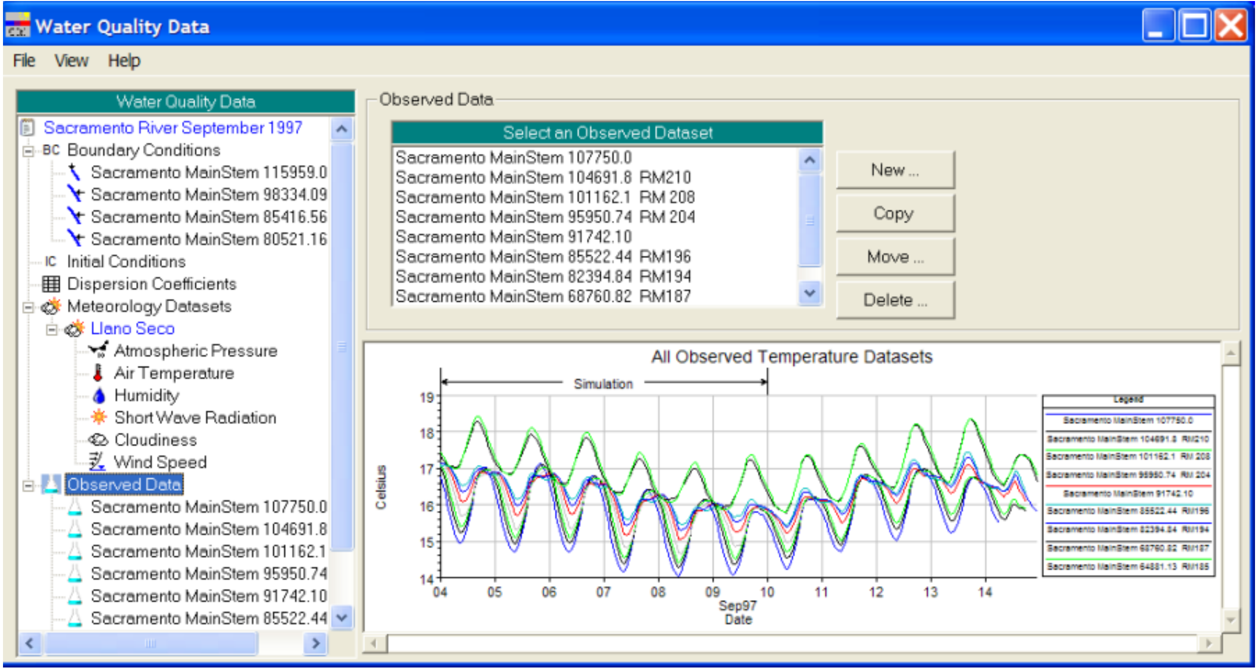
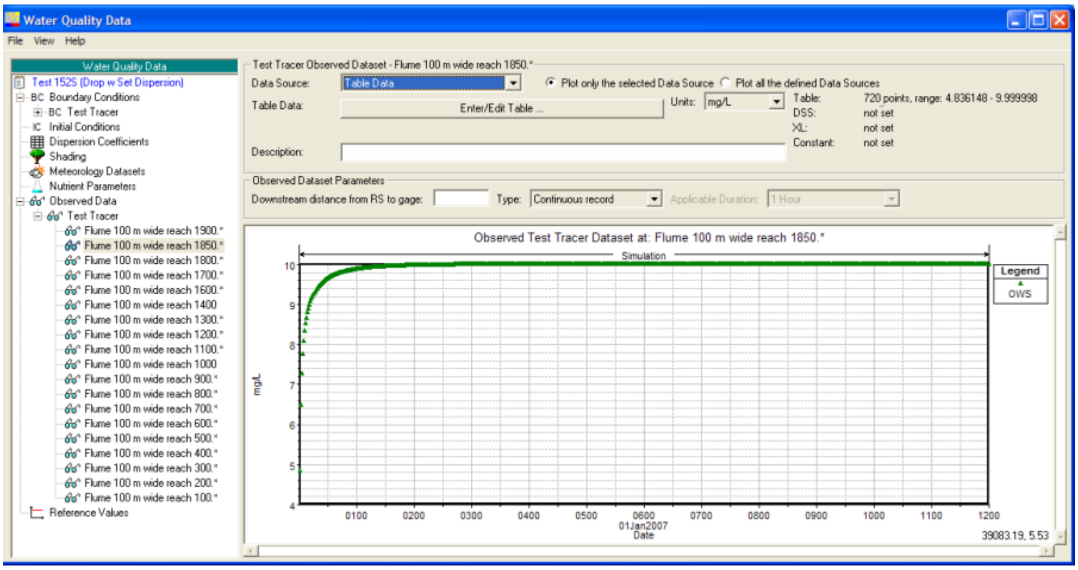


Figure 19-37. Entering and adjusting observed data.

Choosing **New…** brings up a submenu that allows the user to select the cross section to which the new data will be assigned. A time series of observed data may be entered for any state variable at any location. These data will be available for plotting with model output.

Once a new dataset has been created at a particular location, clicking on the new observed data location in the navigation bar brings up a submenu that allows a time series or constant value to be entered. Time series may be entered directly as Table Data, from a DSS file, or from an Excel spreadsheet.

The **Downstream distance form RS to gage** option allows the user to enter a distance downstream of the associated river station to spatially locate the observed data time series on the WQ spatial data plot. Note that this adjustment is associated with spatial placement only. The observed time series will not be adjusted for the travel time associated with this downstream distance.



Test Tracer Observed Dataset - Flume 100 m wide reach 1850.*

Data Source: Table Data ● Plot only the selected Data Source ○ Plot all the defined Data Sources

Table Data: Units: mg/L

Table: 720 points, range: 4.836148 - 9.999998
DSS: not set
XL: not set
Constant: not set

Description:

Observed Dataset Parameters

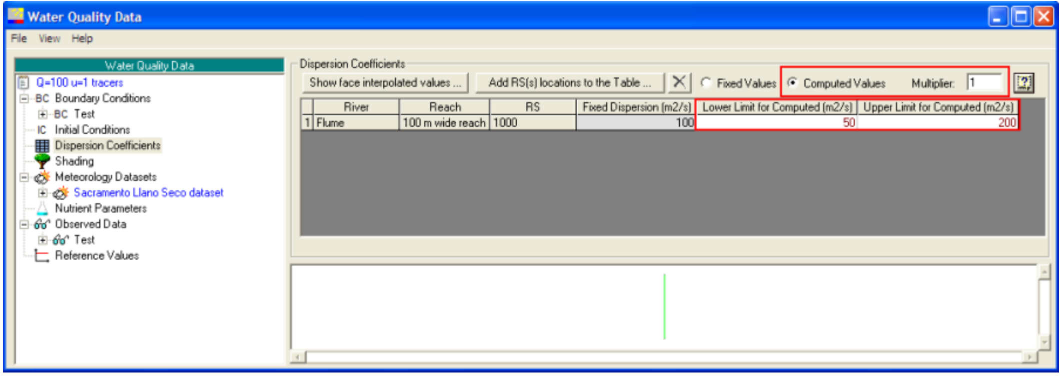
Downstream distance from RS to gage: Type: Continuous record Applicable Duration: 1 Hour

Figure 19-38. The water quality observed data entry window.

The observed dataset **Type** pulldown allows the user to choose between a continuous record and grab sample data. These options affect how data is displayed in the WQ spatial data plot. The **continuous record** option is preferred for regularly spaced time series data. The **grab sample** option is a convenient option for data that has been sampled infrequently. The applicable duration pulldown allows the user to choose the duration over which each of the entered points will be displayed on the WQ spatial data plot.

8.6 COPY Using Computed Values for Dispersion Coefficients

An alternative to user assigned dispersion coefficients is to have the water quality model compute dispersion coefficients based on hydraulic variables at each face. This method avoids potential model instability that may occur when a cross section with a large face area and large dispersion coefficient is immediately followed by a cross section with a small face area and small dispersion coefficient. Selecting **Computed Values** in the navigation bar, turns this option on, as shown in the Figure 19-23.



Dispersion Coefficients

○ Fixed Values ● Computed Values Multiplier: 1

	River	Reach	RS	Fixed Dispersion (m2/s)	Lower Limit for Computed (m2/s)	Upper Limit for Computed (m2/s)
1	Flume	100 m wide reach	1000	100	50	200

Figure 19-23. Choosing the Computed Values option for Dispersion Coefficients.

The equation for model computed dispersion coefficients is:

$$D = m\ 0.011\frac{u^2w^2}{yu^*}$$ (19-1)

m=user assigned multiplier (unitless)
u =face velocity (m/s)
w=average channel width (m)
y=average channel depth (m)
u*=shear velocity (m/s)

and shear velocity is computed as: (19-2)

$$u^* = \sqrt{gdS}$$

g=gravitational constant (9.81 m/s^2)
d=average channel depth (m)
S=friction slope (unitless)

Note that the user assigned multiplier (m) is the **Multiplier** shown in the toolbar in Figure 19-23.

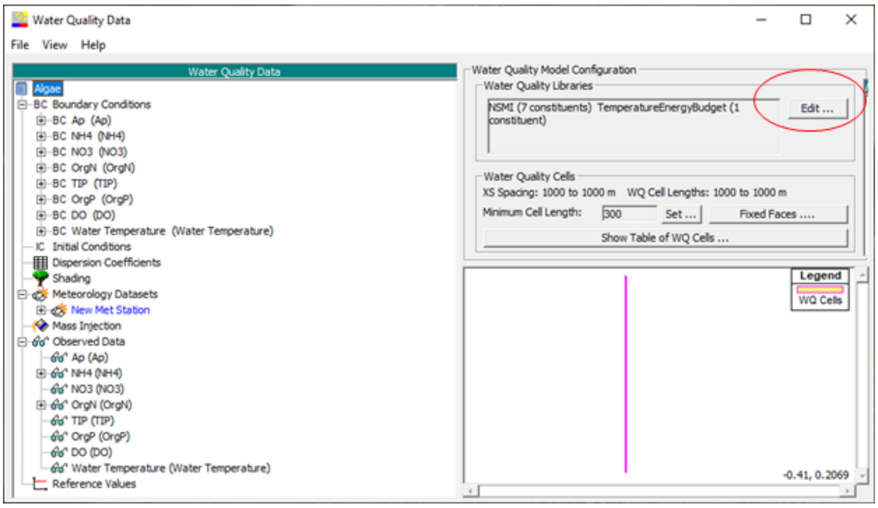
Finally, **Lower Limited for Computed** and **Upper Limit for Computed** are user defined values that constrain the computed dispersion values.

The equation for computed dispersion is based on the equation given by Fischer (1979). Fischer's equation, which did not include the multiplier, is an estimate of shear flow dispersion based on hydraulic and geometric quantities (velocity, channel width, depth, and slope). Fischer's comparisons of field observations and equation 19-2 suggest that this equation is a good estimation within a factor of four or so. Enter 1.0 to obtain Fischer's original form. Enter 0.0 to obtain a diffusion coefficient of 0.0. No limits have been placed on the multiplier, aside from that it must be positive.

8.7 COPY Water Quality Libraries (DLLs)

Water Quality Libraries (DLLs) are organized in three major groups: **General Constituents, Nutrient Simulation, Solids Simulation,** and **Water Temperature.** There are one General Constituent Library, one Nutrient Simulation Library, one Solid Simulation Library, and three Water Temperature Libraries available to the user.

To activate one or more water quality libraries, choose the **Edit...** button in the **Water Quality Data Window**.

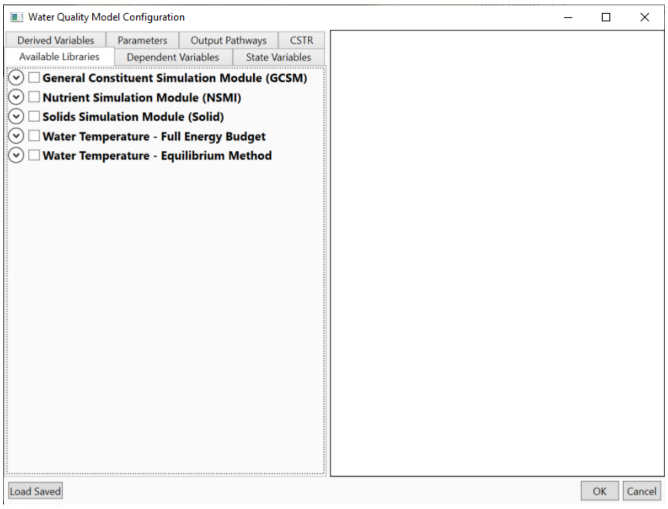


NSMI (7 constituents) TemperatureEnergyBudget (1 constituent)

XS Spacing: 1000 to 1000 m WQ Cell Lengths: 1000 to 1000 m

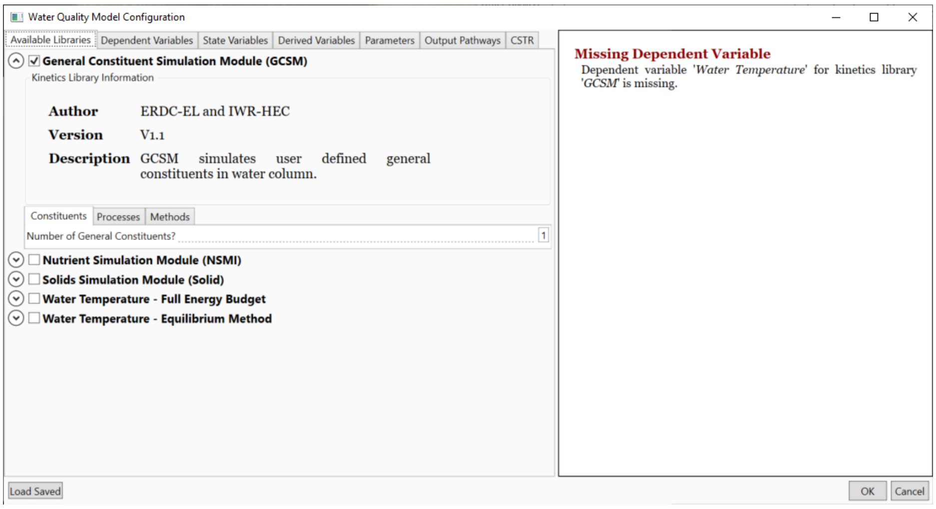
Minimum Cell Length: 300

The **Edit..** button brings up a configuration window that allows the user to activate one or more water quality libraries.



8.7.1 General Constituent Simulation Model (GCSM)

The GCSM simulates simple kinetics for up to ___ user-defined state variables.   The number of constituents to be modeled is entered in the Water Quality Model Configuration Window as shown below. Once the number of constituents are entered,



Author ERDC-EL and IWR-HEC

Version V1.1

Description GCSM simulates user defined general constituents in water column.

Number of General Constituents? 1

Missing Dependent Variable

Dependent variable '*Water Temperature*' for kinetics library '*GCSM*' is missing.

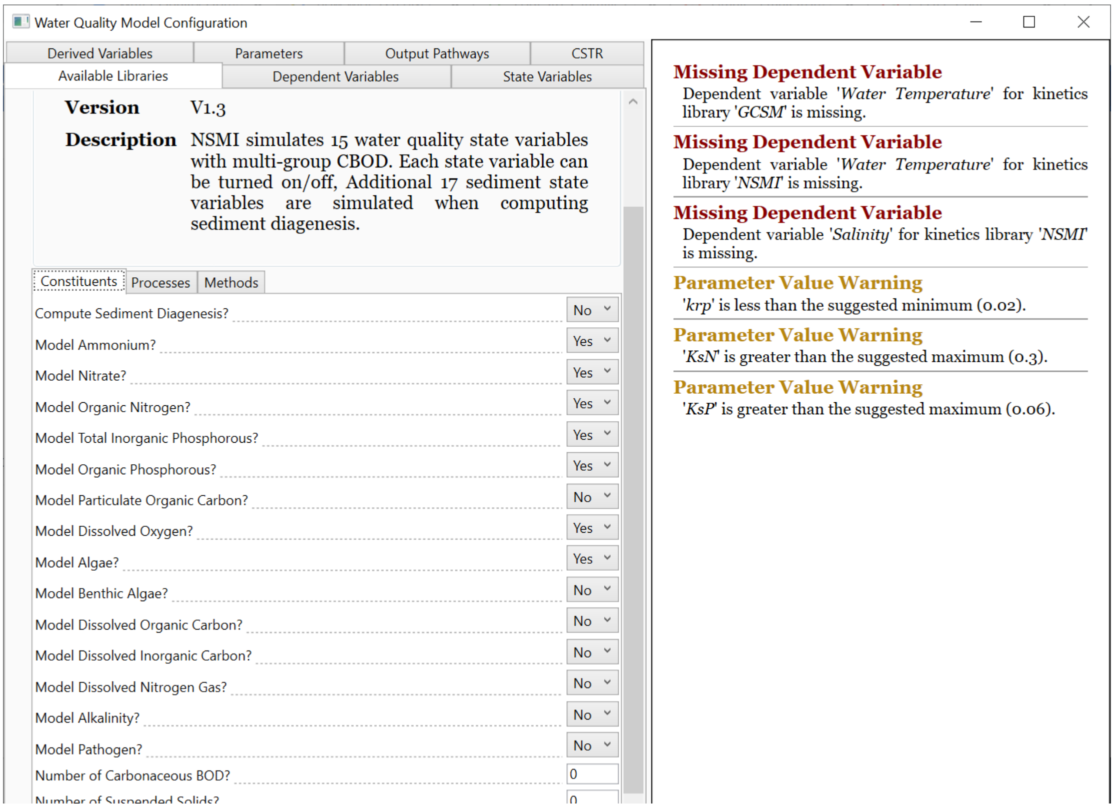
Each general constituent may be simulated as zero-order growth or decay, or subjected to first-order growth order decay or as a loss to or gain from sediment.

(Note sign: first and second order reactions are always losses, model currently works as indicated)

$$\frac{dC}{dt} = \frac{r_{gci}(T)}{h} - | k_{0i}(T) | - | k_{1i}(T) | C_i - v_{si}\frac{C_i}{h}$$

8.7.2 Nutrient Simulation Module I (NSMI)

The Nutrient Simulation Model (NSMI) models up to 16 state variables and allows the user to enable each using the"Yes/No" pull down on the right side of variable list. When enabled (set to "Yes") NSMI computes all internal source and sink terms associated with the enabled variable for every time step.



Version V1.3

Description NSMI simulates 15 water quality state variables with multi-group CBOD. Each state variable can be turned on/off, Additional 17 sediment state variables are simulated when computing sediment diagenesis.

Compute Sediment Diagenesis? No
Model Ammonium? Yes
Model Nitrate? Yes
Model Organic Nitrogen? Yes
Model Total Inorganic Phosphorous? Yes
Model Organic Phosphorous? Yes
Model Particulate Organic Carbon? No
Model Dissolved Oxygen? Yes
Model Algae? Yes
Model Benthic Algae? No
Model Dissolved Organic Carbon? No
Model Dissolved Inorganic Carbon? No
Model Dissolved Nitrogen Gas? No
Model Alkalinity? No
Model Pathogen? No
Number of Carbonaceous BOD? 0
Number of Suspended Solids? 0

Missing Dependent Variable
Dependent variable '*Water Temperature*' for kinetics library '*GCSM*' is missing.

Missing Dependent Variable
Dependent variable '*Water Temperature*' for kinetics library '*NSMI*' is missing.

Missing Dependent Variable
Dependent variable '*Salinity*' for kinetics library '*NSMI*' is missing.

Parameter Value Warning
'*krp*' is less than the suggested minimum (0.02).

Parameter Value Warning
'*KsN*' is greater than the suggested maximum (0.3).

Parameter Value Warning
'*KsP*' is greater than the suggested maximum (0.06).

8.7.3 Water Temperature - Full Energy Budget

8.7.4 Solid Simulation Model (SOLIDS)

9 Running a Water Quality Simulation

9.1 Quick Reference (put on own page)

Water Quality Data	Description	Always Required?	Location in Interface
Meteorological Information	Weather data - may vary by region. Air temperature, relative humidity, wind speed, atmospheric pressure, solar radiation	No	Water Quality Data Editor
Boundary Conditions	Data for all state variables is required at all boundaries	Yes	Water Quality Data Editor
Observed data	Time series or single observation of a state variable at any location within the model at any time interval. Note that observed data is necessary for calibration but it is not required to run the model.	No	Water Quality Data Editor
Model Parameters	Non-time varying parameters such as rate constants, reaeration coefficients	Defaults provided	Parameters Tab
Hydraulic Information	Information from associated HEC-RAS hydraulic simulation Included when a project plan is specified	Must specify plan	Water Quality Analysis Window
Water Quality Cell Configuration	Water quality cells are created between cross-sections by default but may be reconfigured.	Defaults provided	Water Quality Data Window

Water Quality Data	Description	Always Required?	Location in Interface
Simulation Options	Computational time step Time (or timestep) interval for model output Resolution of Hydrodynamic Continuity Error LIMITER Control Specification of Restart File		Water Quality Simulation Window Options tab
Output Options Water Quality	Enables output of Water Quality Pathways Water Quality Derived Variables		Water Quality Model Configuration Window Output Pathways and Derived Variables Tabs
Output Options Hydrodynamics	Enables output of Upstream face flow, velocity area, dispersion Upstream face local Courant, local Peclet		DISABLED
Output Options Constituent Variables	Enables output of QUICKEST face flux and derivative QUICKET face A/D mass Cell Mass		DISABLED
Output Options WQ Cell	Enables output of WQ Cell Volume, surface area WQ Continuity error, cumulative continuity error		DISABLED
Generate Detailed Log Output			

9.2 Hydraulics Plan and Time Window

Output from a calibrated steady or unsteady flow analysis is a required input for a water quality analysis. The water quality analysis window allows the user to add a water quality file to an existing hydraulics plan file.

If the hydraulics plan is from a steady flow analysis, a profile must also be specified.

If the hydraulics plan is from an unsteady flow analysis, the simulation times for the unsteady flow analysis and the water quality analysis do not need to be the same. However, the simulation time window for the water quality simulation must not start before or extend beyond the start and end times of the unsteady flow analysis.

9.3 Water Quality Simulation Options

The simulation options subwindow is opened by selecting **Simulation Options…** under **Options** in the Water Quality Analysis menu bar as shown.

Figure 19-40. Opening the simulation options window.

9.3.1 Resolution of Hydrodynamic Continuity Error

Because the hydraulics model and the water quality model do not solve continuity in exactly the same way, a small continuity error (in water volume) is sometimes encountered in the water quality model.

The **preserve concentration** option adds or subtracts this small difference in volume, resolving the hydrodynamic continuity error. The constituent concentration associated with this (water) volume is assumed to be the concentration of the cell at the previous time step. Thus adding (water) volume to satisfy continuity adds both water and constituent mass to the system, and removing volume removes constituent mass. This method resolves any hydrodynamic continuity errors; however, it does so at the cost of conservation of constituent mass.

The **conserve mass** option does nothing to correct for a (water) volume continuity error. That is, if continuity of water volume is not met, no water volume is added or subtracted (and no associated constituent mass is added or removed). This method conserves total system constituent mass; however because losses or gains in (water) volume associated with hydrodynamic continuity errors are not resolved, this option will result in a corresponding increase or decrease in constituent concentration. This method may result in irregular concentrations in some systems.

9.3.2 ULTIMATE Limiter

Advection problems sometimes present challenges that can result in non-physical oscillations. The universal limiter (ULTIMATE) developed by Leonard (1991) for the QUICKEST scheme has been included in the code.

When ULTIMATE is on, computed cell concentrations are first tested for non-physical oscillation and monotonicity. If the solution reveals that either of these two conditions are not met, the computed solution is not reported, and the concentration of the cell face is used instead. Even when ULTIMATE is on, it is selective and it is active only when the cell face solution is found to be non-monotonic.

9.3.3 Upper Limit on Computational Time Step

Unlike the hydraulic model, which allows the user to set and adjust the time step, the time step used by the water quality computation engine is re-calculated dynamically at each computation interval. This ensures model stability by determining a time step that satisfies the local Courant and Peclet constraint and minimizes run time by selecting the largest time step that satisfies these constraints. In order to enhance model stability, the water quality model constantly adjusts the model time step to ensure a Courant condition less than 0.9, and a Peclet number less than 0.4. The Courant number is a face property and is a function of the (previously computed) velocity, the time step, and the water quality cell length. The Peclet number is also a face property and is a function of the (user entered) dispersion coefficient and the water quality cell length.

The time step is chosen to satisfy both the Courant (C) and Peclet (α) constraints:

9.3.3.1 The Courant Constraint

The local Courant number is computed as:

$$C_{us} = u_{us} \frac{\Delta t}{\Delta x} \leq 0.9$$

where

C_{us}	=	Local Courant number computed at upstream face of cell	dimensionless
u_{us}	=	Velocity at upstream face of cell	ms^{-1}
Δx	=	Length of water quality cell	m
Δt	=	Time step	s

9.3.3.2 The Peclet Constraint

The local Peclet number is computed as:

$$\alpha_{us} = \Gamma_{us} \frac{\Delta t}{\Delta x^2} \leq 0.4$$

where

α_{us}	=	Local Peclet number computed at upstream face of cell	dimensionless
Γ_{us}	=	Dispersion coefficient at upstream face of cell	$\mathrm{m^2 s^{-1}}$
Δx	=	Length of water quality cell	m
Δt	=	Time step	s

To compute the optimal time step, the model code selects the smallest of three values: the maximum time step that satisfies the Courant constraint; the maximum time step that satisfies the Peclet constraint; and the user entered **Maximum Allowable Time Step**. The latter is selected in the **Water Quality Computation Options** sub-menu. This menu is obtained by selecting **Run… Water Quality Analysis** in the menu bar of the main RAS window (or by selecting the ☐ icon) followed by selecting **Options… Simulation Options** in the **Water Quality Analysis** window.

In some cases, when computed in this manner, the water quality computational time step may be longer than desired. For example, the computational time step computed based on the Peclet and Courant constraints may be longer than an hour.

If, for example, an hourly time step is desirable because the simulation is for water temperature simulation. Setting the **Maximum Allowable Time Step** to one hour would ensure that the time step will never exceed one hour, even in the case of very slow velocities or long cell lengths.

Note that if water quality cells are small, these Courant and Peclet constraints can force a very short time step. Small time steps lead to long computation time and large output files. If short cell lengths force a short time step, small water quality cells can be combined using the **Water Quality Cell** tool in the **Data Entry Window**.

Both the local Courant number and the local Peclet numbers are available as model output.

9.3.4 Post Processing

Daily maximum, minimum and average values are available as post processed information, and if selected they appear in an additional special output file. In order to create this special file, the **Write max, min, mean and daily range to output file** selection must be checked for the file to be created.

9.3.5 Output Options and Additional Output Variables

In addition to state variable concentrations which are always available as model output, water quality sources and sinks and other incremental computations are also available as optional model output. These additional output variables must be selected in the **Additional Output Variables** section of the **Water Quality Output Computation** window, obtained by selecting **Simulation Options…** under the Options tab in the **Water Quality Analysis** window.

Most of these additional output variables are component parts of the difference equation for advection diffusion. The equation is:

$$V^{n+1}\phi^{n+1} = V^{n}\phi^{n} + \Delta t\left(Q_{up}\phi^{*}_{up} - Q_{dn}\phi^{*}_{dn} + \Gamma_{dn}A_{dn}\frac{\partial\phi^{*}}{\partial x_{dn}} - \Gamma_{up}A_{up}\frac{\partial\phi^{*}}{\partial x_{up}}\right) + \Delta t\frac{\partial\phi}{\partial t}$$

where

ϕ^{n+1}	=	Concentration at present time step	$\mathrm{kg\ m^{-3}}$
ϕ^{n}	=	Concentration at previous time step	$\mathrm{kg\ m^{-3}}$
ϕ^{*}_{up}	=	QUICKEST concentration at upstream face	$\mathrm{kg\ m^{-3}}$
ϕ^{*}_{dn}	=	QUICKEST concentration at downstream face	$\mathrm{kg\ m^{-3}}$
$\frac{\partial\phi^{*}}{\partial x_{up}}$	=	QUICKEST derivative at upstream face	$\mathrm{kg\ m^{-4}}$
$\frac{\partial\phi^{*}}{\partial x_{dn}}$	=	QUICKEST derivative at downstream face	$\mathrm{kg\ m^{-4}}$
Γ_{up}	=	Dispersion coefficient at upstream face of cell	$\mathrm{m^{2}\ s^{-1}}$
V^{n+1}	=	Volume of water quality cell at next time step	$\mathrm{m^{3}}$
V^{n}	=	Volume of water quality cell at current time step	$\mathrm{m^{3}}$
Q_{up}	=	Flow at upstream face	$\mathrm{m^{3}\ s^{-1}}$
A_{up}	=	Area of upstream face	$\mathrm{m^{2}}$
Δx	=	Length of water quality cell	m
Δt	=	Time step	s
$\frac{\partial\phi}{\partial t}$	=	Cell source or sink	$\mathrm{kg\ m^{-3}\ s^{-1}}$

Note that the subscript *dn* indicates the downstream face of the water quality cell, and because faces are shared (the downstream face of an upstream cell is the upstream face of the adjacent downstream cell) only upstream faces are available for output.

Water quality model output is available at two time intervals. **Output on an even time interval**, or **Output on a selected number of time steps**.

Output on Even Time Interval

The first option, **Output on an even time interval** allows the user to select an even time increment (e.g. 1 hour, 15 minute) for model output. Select the time interval using the pull-down menu. Because the water quality model time step is not evenly spaced, this option requires interpolation of model results. Water quality state variables are linearly interpolated between their values at the two bounding computational time steps. Some other output variables, such as energy budget terms and cell nutrient terms, are output in a stepwise manner. In this (stepwise) case, the value from the last (water quality) computational time step is reported for all output times until the next computational time step is reached. Table 19-6 summarizes these special output variables and indicates the manner in which they have been interpolated.

Output on a Selected Number of Time Steps

This option writes output at a computational time step. No interpolation is necessary.

Cell Energy Budget or Cell Nutrient Terms

Multiple variables are output when **Cell nutrient terms** or **Cell energy budget terms** are selected. These variables include individual sources and sinks and limitation factors. All are available as special output when selected. See Table 19-7 for details.

Table 19-6. Output variables and interpolation method for output on even time intervals.

Output Variable	**Symbol**	**Description of variable and source**	**Reporting Method for WQ Output at User Defined Intervals**	**Units**
Upstream face flow	Q_{us}	Flow at upstream face Hydraulic model output at (hydraulic) computational time step. Interpolated linearly to obtain value for A/D difference equation at (WQ) computational time step.	Stepwise	$m^3 s^{-1}$
Upstream face area	A_{us}	Cross sectional flow area at upstream face Computed from channel average depth	Stepwise	m^2
Upstream face velocity	u_{us}	Computed at each (WQ) computational time step from Q and A $u_{us} = Q_{us} / A_{us}$	Stepwise	$m s^{-1}$

Upstream face dispersion	Γ_{us}	Geometric property of water quality cells	Not time varying	$m^2 s^{-1}$
Cell volume	V	$V = 0.5 * (V^{n+1} + V^n)$	Stepwise	m^3
Cell surface area	A_s	Computed from hydraulic output average width and WQ cell length A_s = average width * cell length	Stepwise	m^2
Cell continuity error	q_e	$q_e = V^{n+1} - V^n + \Delta t (Q_{up} - Q_{dn})$	Running total	m^3
Upstream face avg conc	Φ^*	QUICKEST computed time-average concentration at upstream cell face	Linear Interpolation	$kg\ m^{-3}$
Upstream face avg d(conc)/dx	$d\Phi/dx$ *	QUICKEST computed spatial derivative of time-average concentration at upstream cell face	Linear Interpolation	$kg\ m^{-4}$
Upstream face advection mass	M_{adv}	$M_{adv} = \Phi^* \Delta t\ Q_{us}$	Linear Interpolation	kg
Upstream face dispersion mass	M_{disp}	$M_{disp} = d\Phi/dx * \Delta t\ \Gamma_{us} A_{us}$	Linear Interpolation	kg
Cell mass	$V \Phi$	Cell concentration (Φ) is the computed result of the A/D difference equation	Linear Interpolation	kg
Local Courant	C_{us}	$C_{us} = u_{us}$ * (Δt / cell length)	Stepwise	unitless
Local Peclet	α_{us}	$\alpha_{us} = \Gamma_{us}$ * (Δt / cell $length^2$)	Stepwise	unitless
Cell energy budget terms		$q_{net}, q_{sw}, q_{atm}, q_b, q_h, q_l$ See water temperature source sink section for details.	Stepwise	$W\ m^{-2}$

Cell nutrient terms		Nitrogen, phosphorus, algae, DO, and BOD sources and sinks. See table 19-7	Stepwise	kg m^{-3} s^{-1}

9.3.6 Restart Files

A restart file saves a snapshot of model output at all model locations. Once created, a restart file can be used to specify initial conditions for subsequent model runs.

Restart files are written at a user specified time. This time may be specified as either a number of hours from the start of the simulation or at a particular date and time (Figure 19-41).

To generate a restart file, the **Write Water Quality Initial Condition File** option must be selected in the **Water Quality Computation Options** window prior to performing a water quality simulation.

The water quality initial condition file is named by default as the current plan appended with ".wqrst".

Figure 19-41. Writing a water quality initial conditions file.

9.3.7 Detailed Log Output

Checking **Detailed Log Output** writes a system summary to the water quality computations log file, identified with the extension ".wqo".

9.3.8 Temperature Override

Checking **Override computed temperatures** replaces the computed output temperature with the value entered in the text box to the right. Energy budget computations still proceed; however, the output temperature is overwritten. Note that even with this option checked, solar radiation time series values are passed through to the NSM model. This allows algal growth and respiration to respond to day and night conditions. This option is not recommended except for testing purposes.

10 COPY Viewing and Interpreting Results (empty)

10.1 COPY Water Quality Output Files (file types, brief)

Model output is made available in two output files. The default water quality output file (**.wqxx) is always written and contains output at all water quality cells at the time interval specified in the Water Quality Computation window. The secondary output file** (.daily.wqxx) contains computed daily maximum, mean, and minimum temperatures. The default water quality file is always written; the secondary output file is written only when the appropriate check box in the Water Quality Computation Options Window has been selected.

10.2 COPY Water Quality Spatial Plots (original)

Water quality spatial plots are available from the main HEC-RAS menu under the **View** menu heading as shown in Figure 19-43.

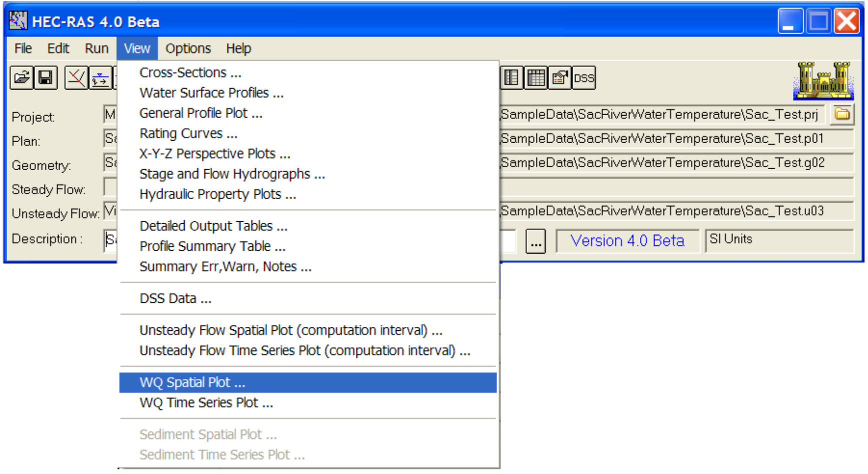


Figure 19-43. Opening a water quality spatial plot from the main HEC-RAS window.

Individual profiles may be selected using the **Profiles…** button which allows the user to select one or multiple times for which profiles are drawn. The animation tools at the right of the menu bar allow animation of a complete time series.

A profile plot of water temperature is shown in Figure 19-44. Observed data, if available, is displayed on the profile plot if the **Plot Observed Data** check box is selected.

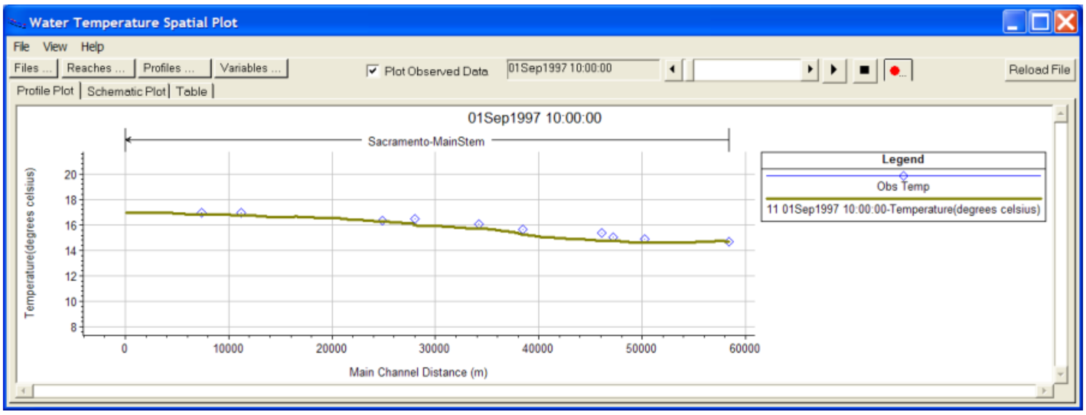


Figure 19-44. Water temperature profile plot showing model simulation and observed data.

Line weights and colors can be changed by the user by right clicking on the legend and choosing **Lines and Symbols…**.

If additional output variables have been specified, they may also be viewed in a spatial format. For example, a profile plot of the radiation terms is shown in Figure 19-45. This plot was generated by selecting solar radiation, upwelling long wave radiation and downwelling long wave radiation from the **Variables…** button.

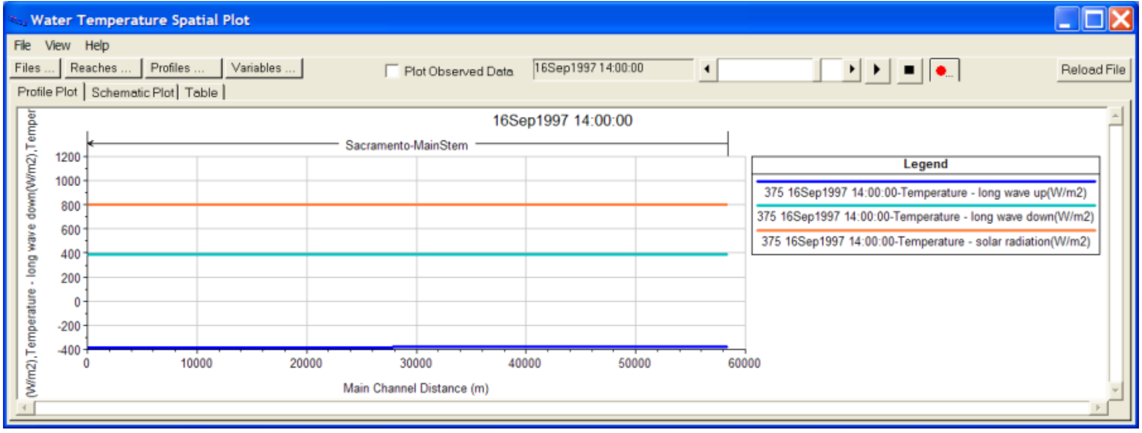


Figure 19-45. Heat flux profile plot.

In addition to profile plots for particular simulation times, profile plots of daily mean, maximum, and minimum are also available by selecting the **.daily.wqxx file from the file menu. Note that this file is only available if the *Write max, min, mean and daily range to output file** check box in the Water Quality Computation Window has been selected.

If observed data is available, daily maximum, minimum and mean will be computed from the observed data and it will be available for plotting along with model output. Figure 19-46 is a profile plot of the daily mean, maximum, and minimum for September 7. Vertical lines indicate the daily range computed from observed. Diamonds located on each vertical line indicate observed daily mean values.

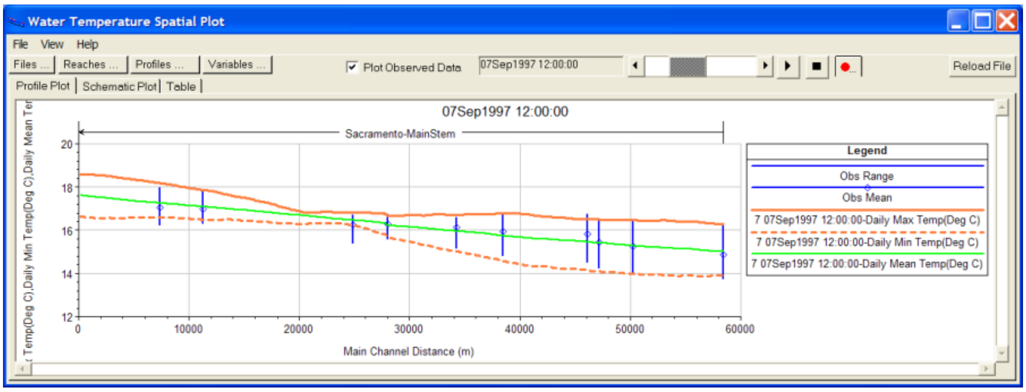
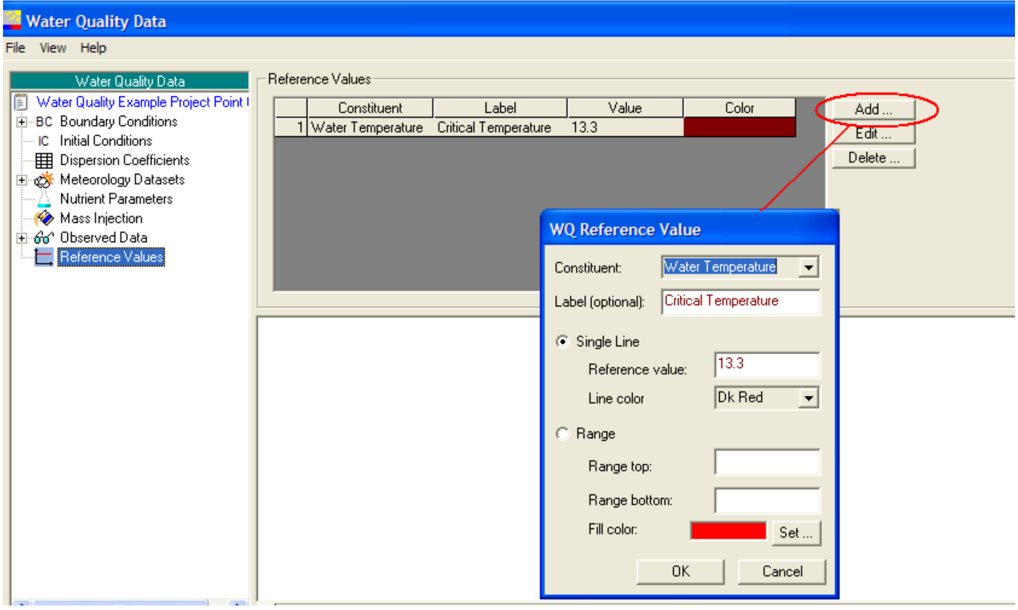


Figure 1946. Daily maximum, minimum, and mean water temperature profile with observed data.

10.2.1 Adding Reference Values

Reference values are useful when model output is to be compared to a target or critical value. Reference values may be added for one or all constituents and will appear on both spatial and time series plots. A single value or a maximum minimum pair (range) may be entered. Choose **Reference Values** in the navigation bar of the water quality data submenu to activate this feature as shown in Figure 19-47.



Reference Values

	Constituent	Label	Value	Color
1	Water Temperature	Critical Temperature	13.3	🟥

Constituent: Water Temperature

Label (optional): Critical Temperature

● Single Line

Reference value: 13.3

Line color: Dk Red

○ Range

Range top:

Range bottom:

Fill color: 🟥

Figure 1947. Adding Reference Values.

Schematic Plots

Schematic plots display results in the form of a color-coded map. Water temperature is plotted in the example shown in Figure 19-48.

Color may be set by the user with the legend to the far right.

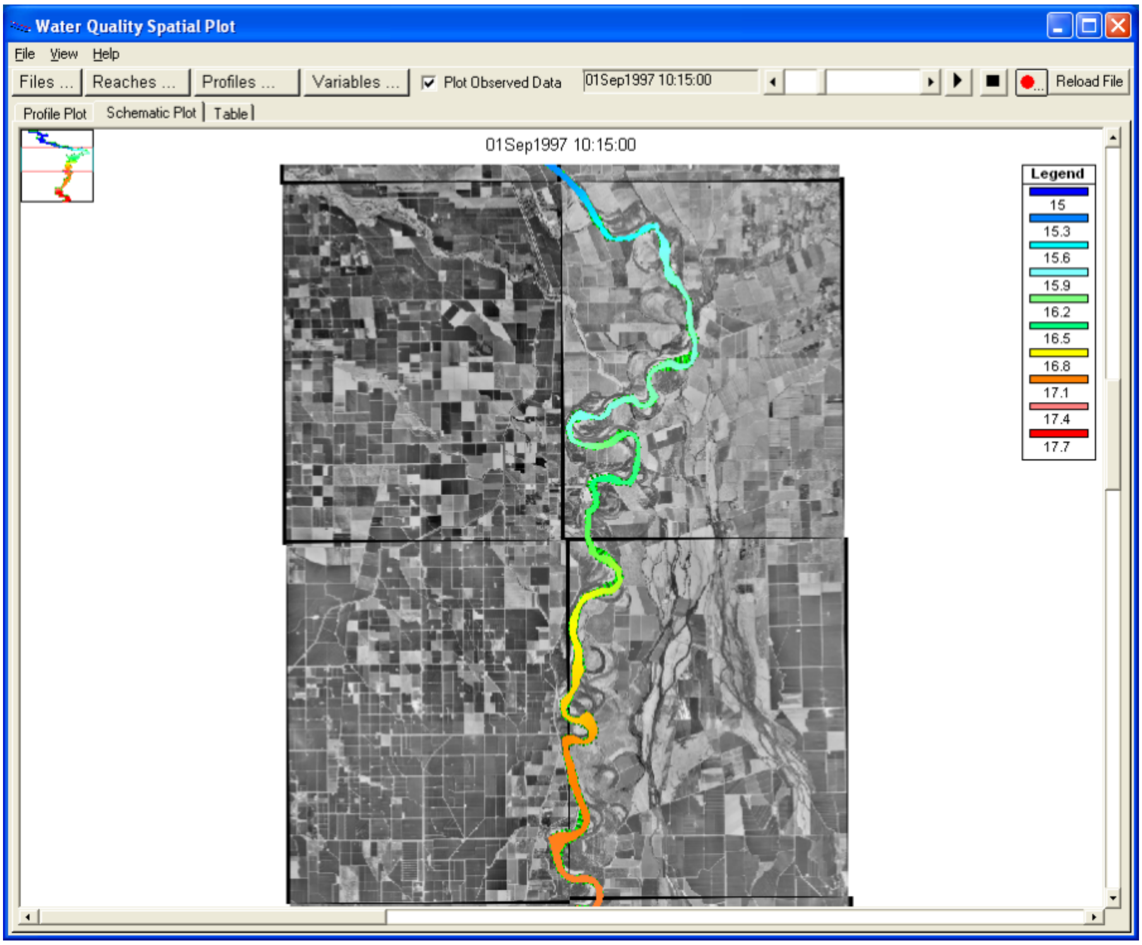
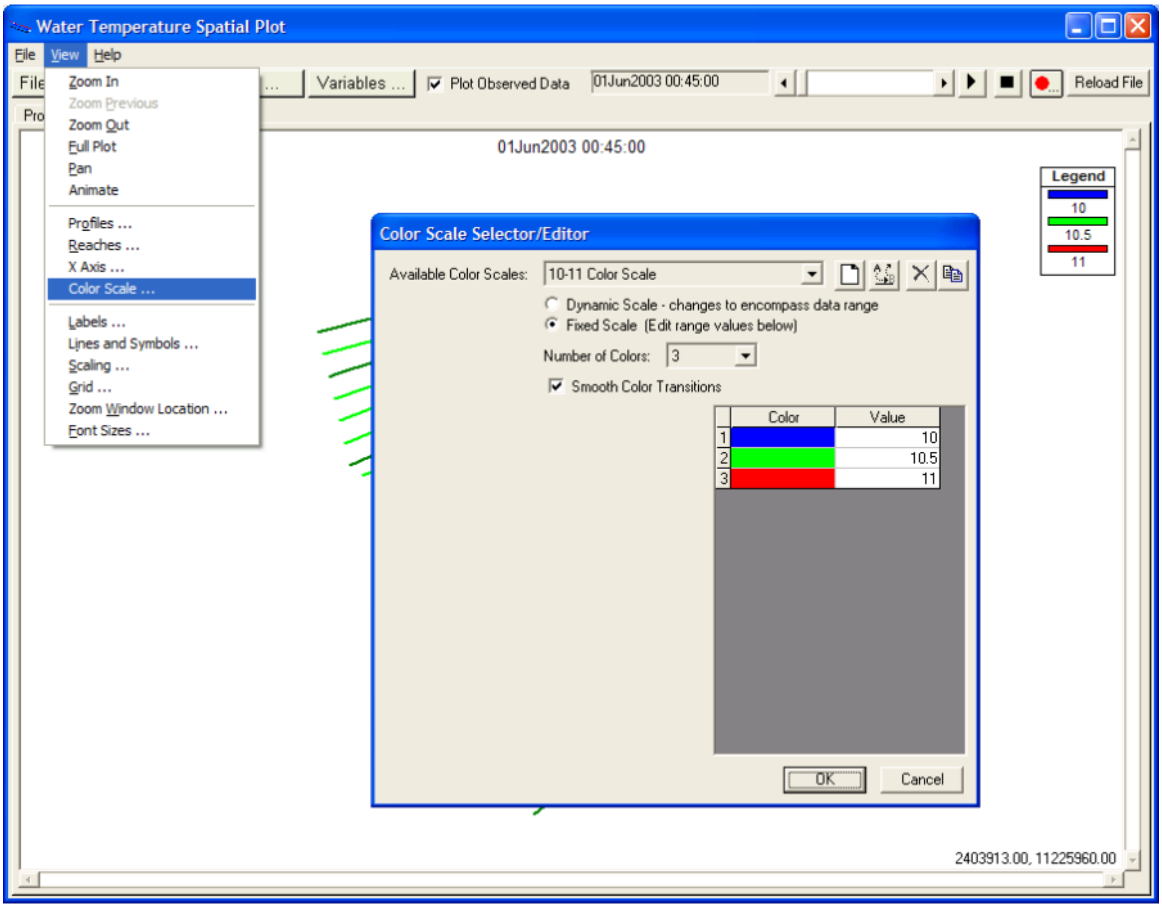


Figure 19-48. Schematic plot of water temperature.

There are several default color scales available to choose from in the **Color Scale Selector/Editor** where users can also create their own scales. The default color scales use the "Dynamic Scale." This option adjusts the values associated with the colors to cover the range at that particular time step. Fixed Scales set the values so that the meaning of the color does not change from time step to time step. The schematic spatial plot uses a custom color scale with the Fixed Scale option with smooth color transitions. With smooth color transitions, the cells with temperatures between the set values are interpolated.

To open the **Color Scale Selector/Editor**, right click on the Legend and choose **Color Scale...** or choose the option from the View menu as shown in Figure 19-49.



☑ Plot Observed Data 01Jun2003 00:45:00

Available Color Scales: 10-11 Color Scale

○ Dynamic Scale - changes to encompass data range
● Fixed Scale (Edit range values below)

Number of Colors: 3

☑ Smooth Color Transitions

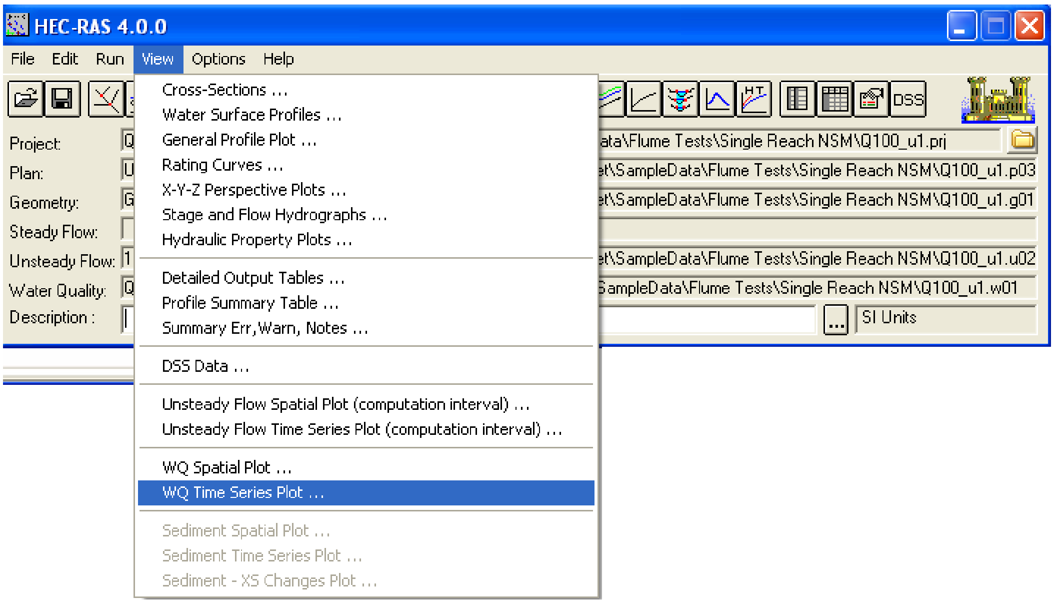
	Color	Value
1	🟦	10
2	🟩	10.5
3	🟥	11

Figure 19-49. Using the color scale tool with a schematic plot.

Finally, all profile information is available in table form for copying and pasting into spreadsheets by choosing the **Table** tab.

10.3 COPY Water Quality Time Series Plots (original)

Time series plots display model results and observed data at particular locations. Water quality time series plots are available from the main HEC-RAS menu under the **View** menu heading as shown in Figure 19-50.



Project: ata\Flume Tests\Single Reach NSM\Q100_u1.prj
Plan: t\SampleData\Flume Tests\Single Reach NSM\Q100_u1.p03
Geometry: t\SampleData\Flume Tests\Single Reach NSM\Q100_u1.g01
Steady Flow:
Unsteady Flow: t\SampleData\Flume Tests\Single Reach NSM\Q100_u1.u02
Water Quality: SampleData\Flume Tests\Single Reach NSM\Q100_u1.w01
Description :

Figure 19-50. Opening a water quality time series plot from the main HEC-RAS window.

Simulated results may be viewed at any of the water quality cells by selecting the desired cell in the **River Station** menu bar at the left of the screen (Figure 19-51). This pulldown menu also provides a facility for displaying observed data. These observed data are indicated with a special icon. If the observed data check box is selected, observed data will be displayed when available.

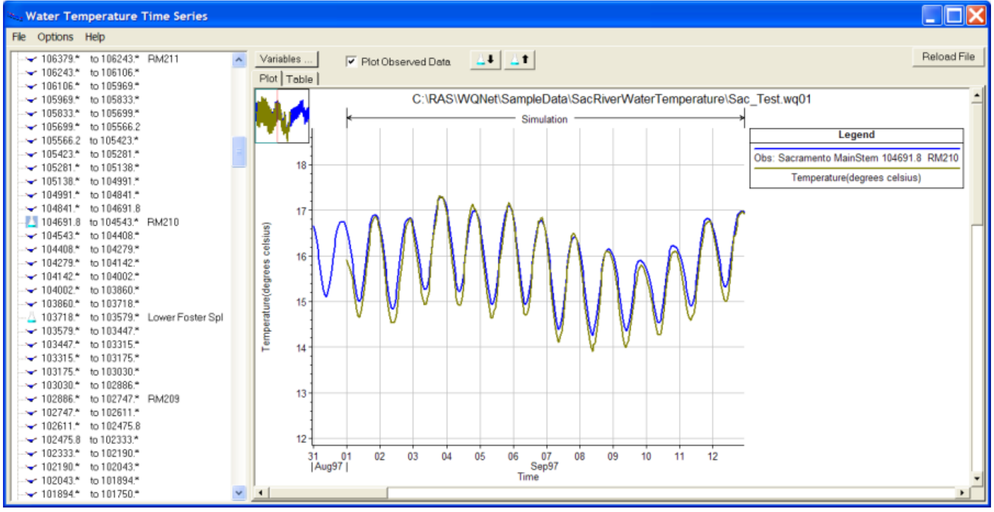


Figure 19-51. Water Quality Time Series Plot.

Selecting the **Table** tab presents time series data in table format enabling copying and pasting into Excel or other programs.

In addition to water temperature data, energy budget components are also available for plotting. In the example shown in Figure 19-52, net heat flux and solar radiation have been plotted together.

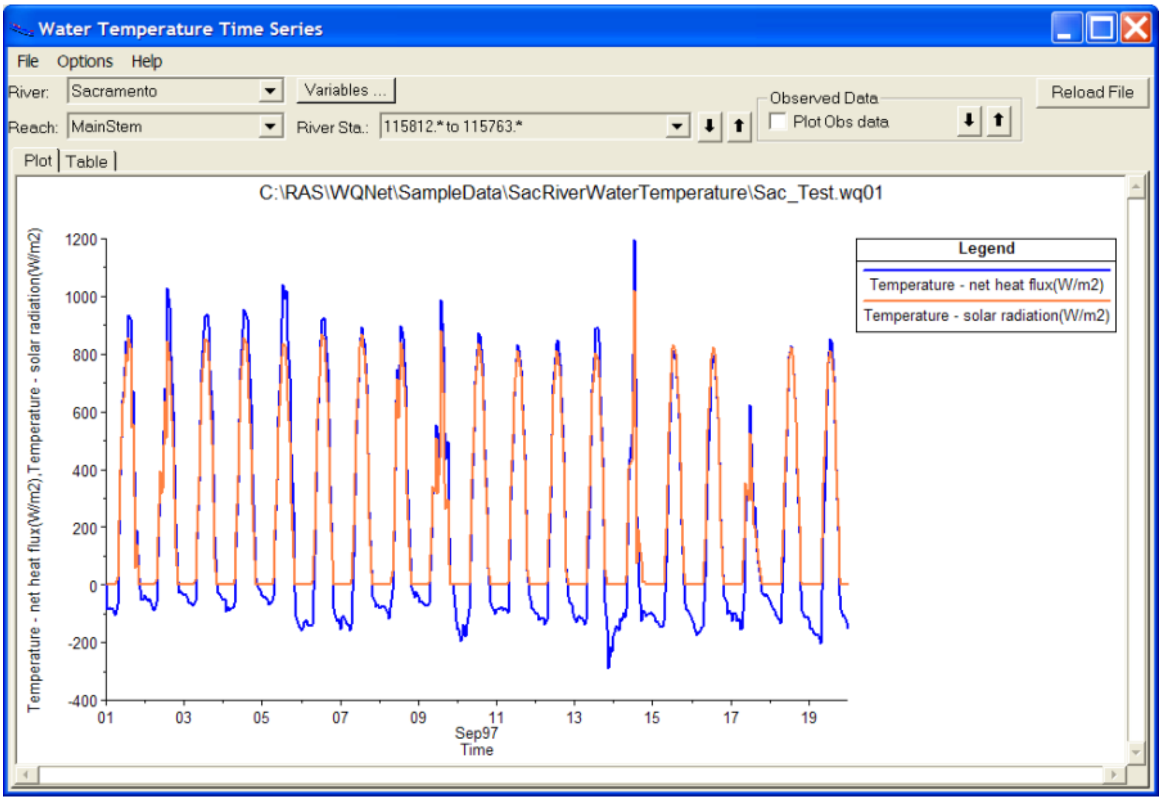


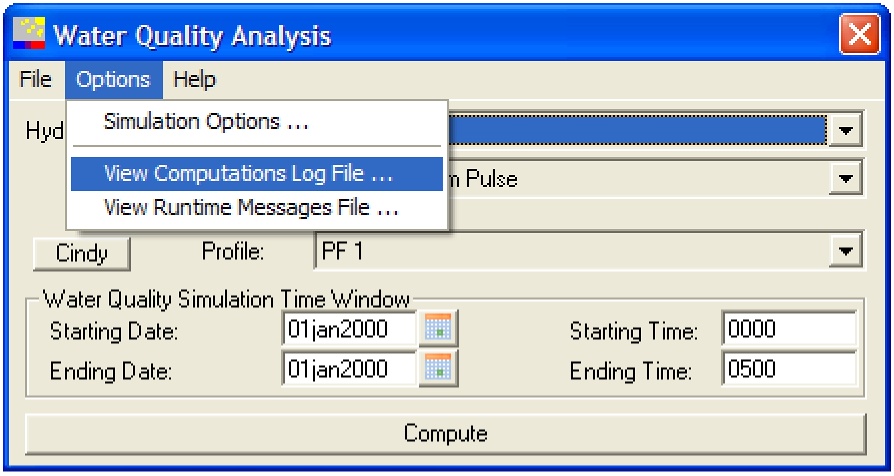
Figure 19-52. Time series plot of energy budget components.

Detailed Log Output File

The **Computations Log File** is available through the Options pull down in the water quality analysis window as shown in Figure 19-53.

This file records the simulation options settings as well as detailed continuity error information for water volume and conservative arbitrary constituents. Continuity error information is not available for non-conservative arbitrary constituents, nutrient sub-model constituents or water temperature.

Each time step is listed along with the volume of both water and constituent mass at the start of each time step. In addition to system volume, total system inflow and outflow at external reaches and lateral inflows are reported along with the associated continuity error. This information is provided for troubleshooting purposes and allows the user to locate periods in the simulation when there are instabilities in the hydrodynamics field.



Profile: PF 1

Water Quality Simulation Time Window

Starting Date: 01jan2000

Ending Date: 01jan2000

Starting Time: 0000

Ending Time: 0500

Figure 19-53. Opening the Computations Log File.

11 COPY Meteorological Datasets*

11.1 Overview

Each meteorologic data set contains multiple time series of weather information including: atmospheric pressure; air temperature; humidity (vapor pressure, relative humidity, wet bulb or dew point); solar radiation; wind speed; and cloudiness.   This weather data may come from a variety of sources, such as local airports, schools, fire stations or research facilities, or from remote sensing. This data may be entered into the water quality data model residing with the project, or it may reside in a DSS or Excel file. At its most bare bones, for trouble shooting or testing purposes, a meteorologic dataset may simply be a collection of constant vales.

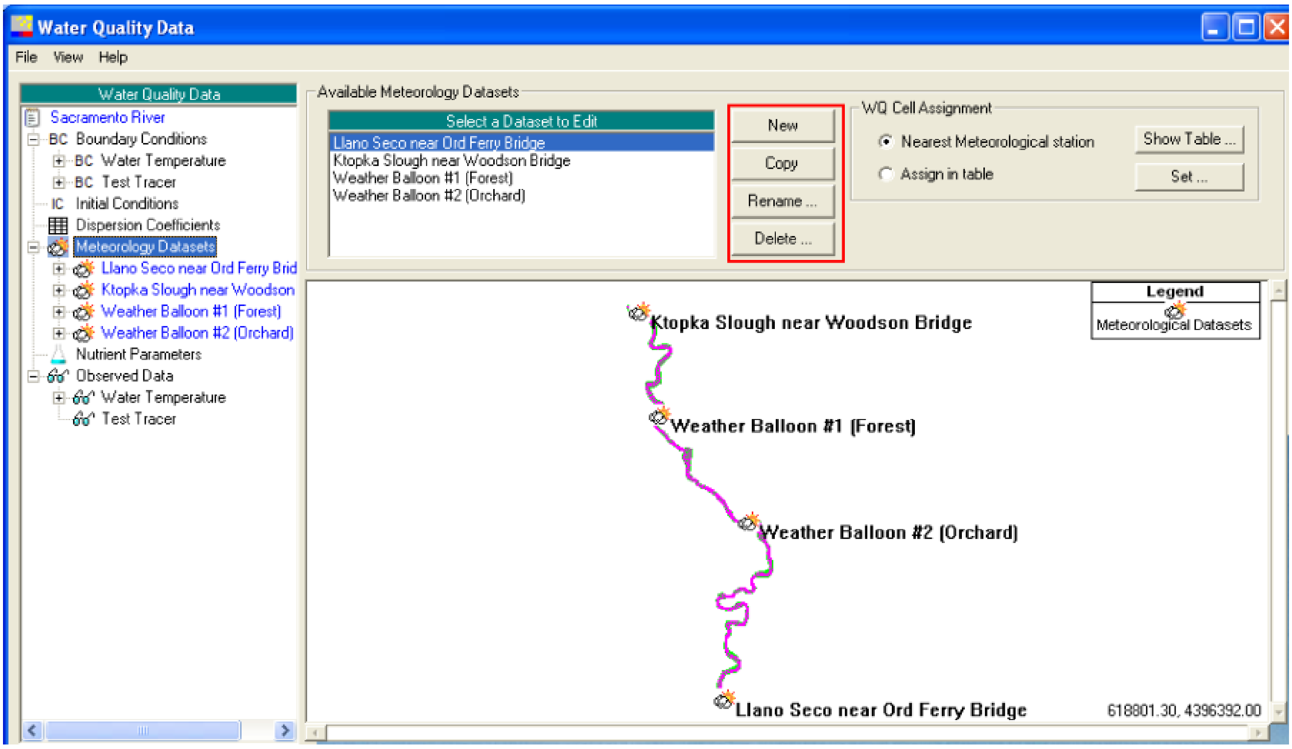
Not all water quality DLLs require a meteorological dataset; however, many do. For example, at least one full meteorological data set is required to model temperature, and a solar radiation dataset is required in order to model algal dynamics.

A sampling frequency of at least once per three hours is recommended for simulation of diurnal water temperature variation.

Finally, multiple meteorologic datasets are supported. Each water quality cell is associated with one meteorological data set for the entire simulation.

11.2 Physical Properties Associated with Meteorologic Datasets

For many projects, a single meteorologic dataset is sufficient. In the case of a single dataset, only one dataset will appear in the Navigation Bar (left pane) under the heading **Meteorologic Datasets**. However, if local meteorology varies significantly within the model geography, it may be useful to use multiple meteorological data sets.
In the figure below, as an example, time series information from four weather stations has been entered into the model. Use the New, Copy, Rename, and Delete buttons to create and edit your list of weather stations.



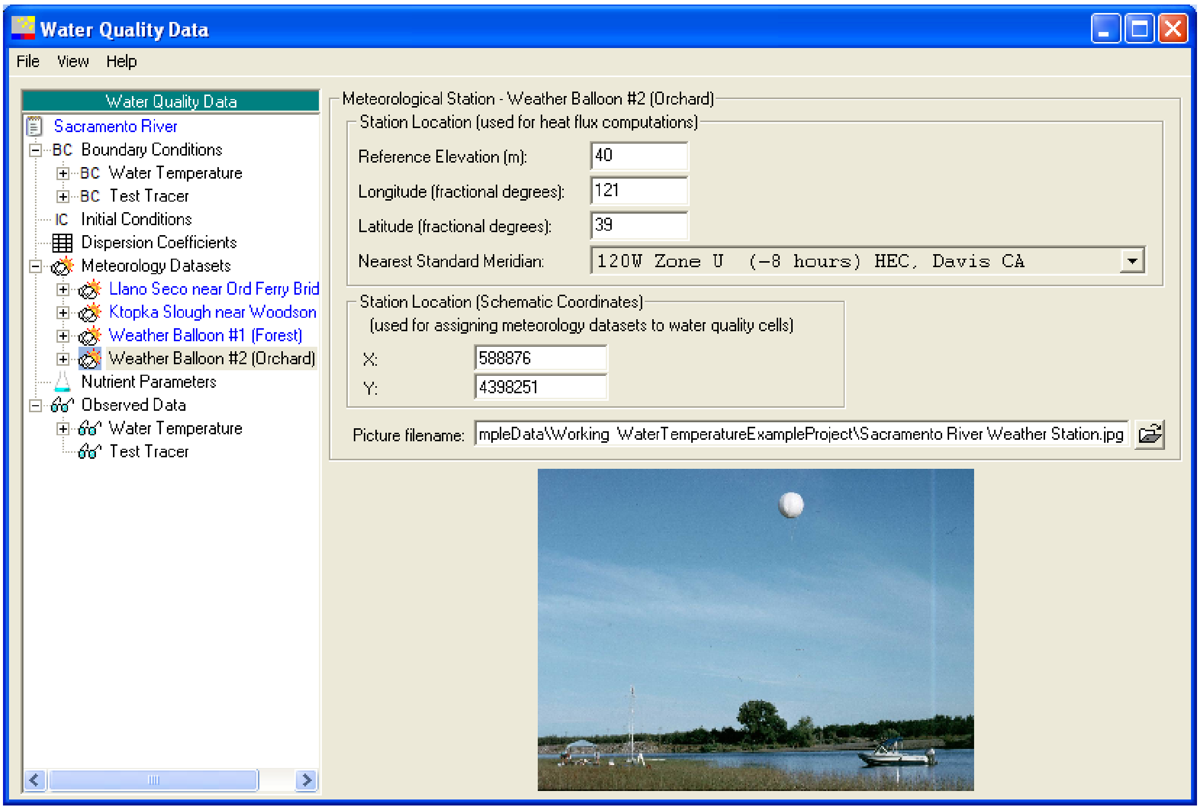
Select a Dataset to Edit:
Llano Seco near Ord Ferry Bridge
Ktopka Slough near Woodson Bridge
Weather Balloon #1 (Forest)
Weather Balloon #2 (Orchard)

WQ Cell Assignment: ● Nearest Meteorological station ○ Assign in table

Figure () Organizing meteorological data sets.

11.2.1 Physical Location of the Weather Station

A handful of physical properties are required for each meteorological dataset. These are accessed by clicking on an individual meteorological station in the navigation bar (left pane). An example is shown in the figure below.



Meteorological Station - Weather Balloon #2 (Orchard)

Station Location (used for heat flux computations)

Reference Elevation (m): 40

Longitude (fractional degrees): 121

Latitude (fractional degrees): 39

Nearest Standard Meridian: 120W Zone U (-8 hours) HEC, Davis CA

Station Location (Schematic Coordinates)
(used for assigning meteorology datasets to water quality cells)

X: 588876

Y: 4398251

Picture filename: mpleData\Working WaterTemperatureExampleProject\Sacramento River Weather Station.jpg

Figure ()Entering physical location information for a meteorological data set.

11.2.1.1 Reference Elevation

Although a time series of measured atmospheric pressure is preferred, if none is available, local atmospheric pressure may be estimated from elevation. If a time series of atmospheric elevation is not available, a user specified **Reference Elevation** is entered in this subwindow. This reference elevation should correspond to an average land surface elevation.

11.2.1.2 Latitude, Longitude

Although a time series of measured solar radiation is preferred, if none is available, a synthetic solar radiation time series may be estimated based on location, time of day, cloudiness and fitting parameters (e.g., atmospheric dust). If a weather station will be used to collect other meteorological data but this station does not provide solar radiation, the longitude and latitude entered should be the location of the weather station. If there is no nearby weather station and time series for air temperature and relative humidity are only available from a weather station not near the river, it is best to choose a central longitude and latitude that is representative of the average location of the river.

11.2.1.3 **Nearest Standard Meridian**

The **Nearest Standard Meridian** references the local time zone. It is important that this time be the time zone in which all other time series (including air temperature, relative humidity, water quality boundary conditions as well as all hydrodynamic data) have been entered.

11.2.1.4 Station Location

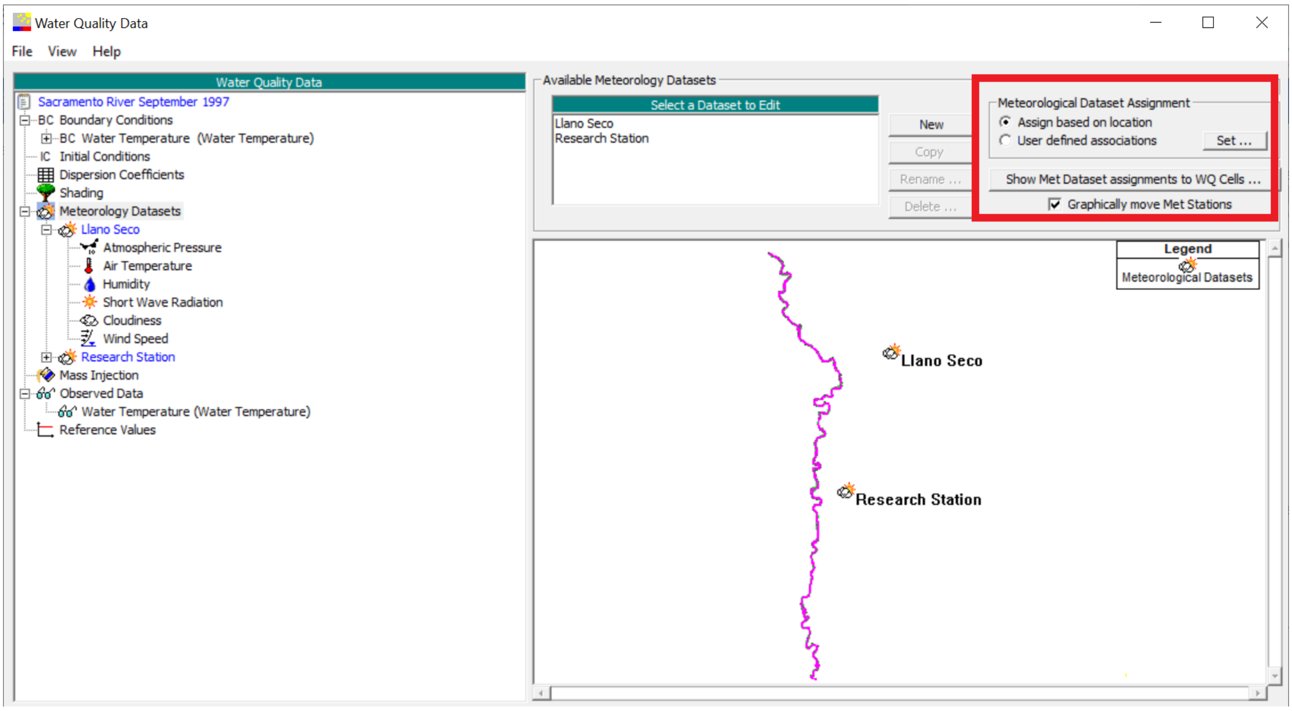
The **Station Location** orients the meteorological station with the x-y coordinates of the river schematic. These are not geo-referenced coordinates. Their use is only to determine the nearest meteorological station if **Nearest Meteorological Station** is chosen in the water quality cell assignment window. The easiest way to determine the coordinates of the meteorological station is to orient your mouse over the map provided in the lower window to the approximate location of the meteorological station. As you move the mouse, its location will be shown in the lower right hand corner. Write down the x- and y- coordinates that best approximate the location of the weather station. Enter these local x- and y-coordinates into the station location text box. Keep in mind that these coordinates have a singular purpose and will only be used if **Nearest Meteorological Station** is selected under **WQ Cell Assignment**.

11.2.1.5 Picture Filename

This filename references the location of a drawing or photograph to be shown in this window only. This picture only appears in this window.

11.2.2 Associating Water Quality Cells with Meteorologic Datasets

If multiple datasets are entered, each water quality cell must be assigned to a particular meteorologic dataset. This association may be made using the sub-window **Meteorologic Dataset Assignments**. Choose either **Assign based on location** (assigns each water quality cell to the closest meteorological station), or **User defined associations** (allows specific water quality cells to be assigned to meteorological datasets via a user accessible table).



Llano Seco
Research Station

● Assign based on location
○ User defined associations
☑ Graphically move Met Stations

11.3

Entering and Editing a Meteorologic Time Series

Six time series of meteorologic data are required: Atmospheric Pressure, Air Temperature, Humidity, Short Wave Radiation, Cloudiness, and Wind Speed. Each may be entered in one of four ways: set to a constant value; referenced to a time series in an Excel spreadsheet; referenced to a time series in DSS; entered directly into the project. All time series do not need to reference the same source. For example, atmospheric pressure might be set to a constant value, solar radiation might be computed using latitude and longitude, air temperature might reference an external DSS file, humidity and cloudiness might be entered directly into the project. Any combination of sources is supported; however, data must be available from the chosen source for the entire simulation period.

11.4 COPY Entering a Cloudiness Time Series

Cloudiness is a required parameter for both calculated solar radiation and downwelling longwave radiation, and describes the fraction of sky covered with clouds, and varies from 0 to 0.9.

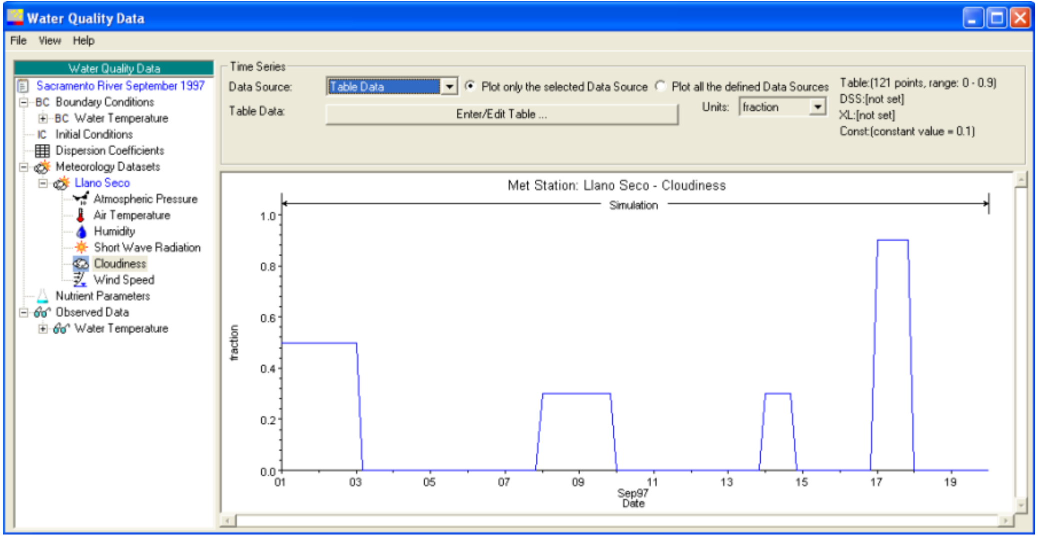
As cloudiness increases, computed solar radiation decreases and computed downwelling longwave radiation increases.

Table () Guideline for Cloudiness Values

Rough Cloudiness Guideline	
Description	**Cloudiness (Cl)**
Overcast Skies	0.9
Broken Skies	0.5 - 0.9
Clear Skies	0.1

Cloudiness values may be entered into the project as Table Data, may reference an external DSS or Excel file, or may be computed using observed short wave radiation.

An example time series is shown in Figure 19-30.



Data Source: Table Data

● Plot only the selected Data Source ○ Plot all the defined Data Sources

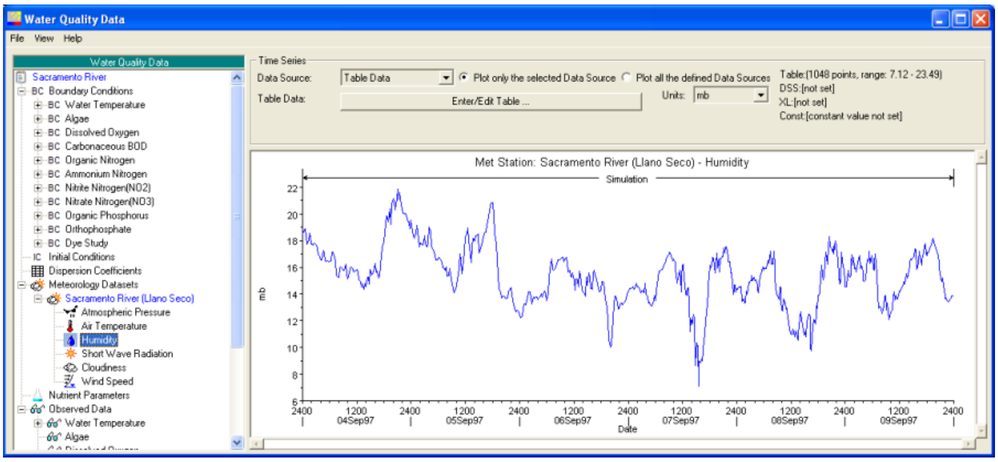
Units: fraction

Table:(121 points, range: 0 - 0.9)
DSS:[not set]
XL:[not set]
Const:(constant value = 0.1)

Figure 19-30. Entering cloudiness time series information.

11.5 COPY Entering a Humidity Time Series

A time series of humidity is required input for the water temperature model. Humidity may be expressed as relative humidity (%), wet-bulb temperature (°C or °F), dew-point temperature (°C or °F), or vapor pressure (mmHg, inHg, or mb). Although a constant value is an available option, it is stressed that a time series of humidity is necessary if diurnal variations in water temperature are to be simulated. An example of a humidity time series displayed as vapor pressure in mb is shown in Figure 19-28.



Data Source: Table Data

Table Data:

Units: mb

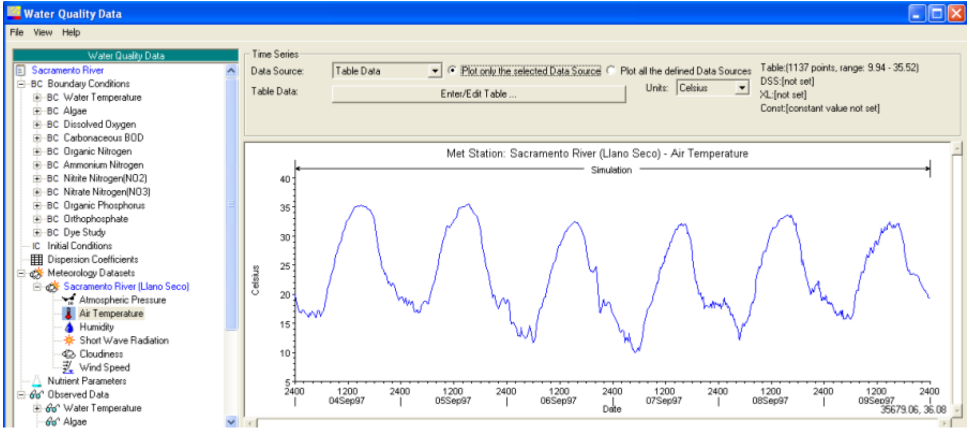
Table:(1048 points, range: 7.12 - 23.49)
DSS:[not set]
XL:[not set]
Const:[constant value not set]

Figure 19-28. Viewing and organizing humidity data.

11.6 COPY Entering an Air Temperature Time Series

A time series of air temperature is required input for the water temperature model. Air temperature may be entered in units of Celsius or Fahrenheit.

Although a constant value is an available option, it is stressed that a time series is necessary if diurnal variations in water temperature are to be simulated. The constant value option is included for testing purposes. An example of the air temperature data entry window and an air temperature time series is shown in the Figure 19-27.



Data Source: Table Data

Table Data:

Units: Celsius

Table:(1137 points, range: 9.94 - 35.52)
DSS:[not set]
XL:[not set]
Const:[constant value not set]

Figure 19-27. Viewing and organizing air temperature data.

11.7 COPY Entering an Atmospheric Pressure Time Series

Atmospheric or barometric pressure is the pressure exerted by all gases in moist air. Atmospheric pressure is a strong function of elevation and varies with local meteorology. It generally decreases with increasing altitude. At sea level, observed values are on order of 1000mb.

Atmospheric pressure may be entered into the water quality model in units of millibars (mb), millimeters of mercury (mmHg), inches of mercury (inHg) or atmospheres (atm). The data will be converted to mb at simulation time.

In a manner analogous to the way boundary condition information is managed and stored, weather time series may be referenced and or stored from a handful of sources. A time series may be entered directly into a table to be stored with the water quality model; a reference may be made to data residing in a DSS file; a reference may be made to data in an Excel Worksheet; a constant may be entered; or for the case of atmospheric pressure, an approximation may be made from the physical elevation of the site.

An example is shown in Figure 19-26. In the figure, a constant value (1 atm) was entered, and since an elevation was entered for the site, the atmospheric pressure has also been estimated (at around 1000 mb). Because **Plot all the defined Data Sources** has been selected, both are plotted on the same graph. Note that they are both plotted in their original units.

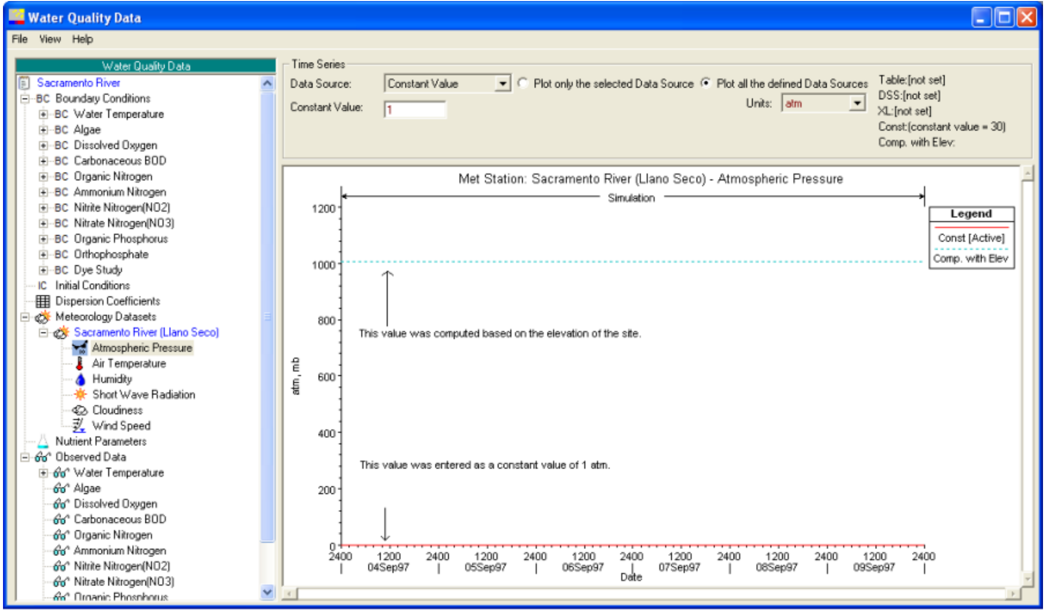

Data Source: Constant Value
Constant Value: 1
○ Plot only the selected Data Source ● Plot all the defined Data Sources
Units: atm
Table:[not set]
DSS:[not set]
XL:[not set]
Const:(constant value = 30)
Comp. with Elev:

Figure 19-26. Viewing and organizing atmospheric pressure data.

The data source selected in the pull down is the value that will be applied at the time of simulation. In this case, the value applied would be converted from 1 atm. Although it is preferable to obtain a time series of atmospheric pressure, this data is difficult to obtain and a constant (either entered or estimated) is often used instead. The model is much less sensitive to diurnal variation in atmospheric pressure than it is to diurnal variation in air temperature, humidity, wind speed, and solar radiation.

11.8 COPY Entering a Solar Radiation Time Series

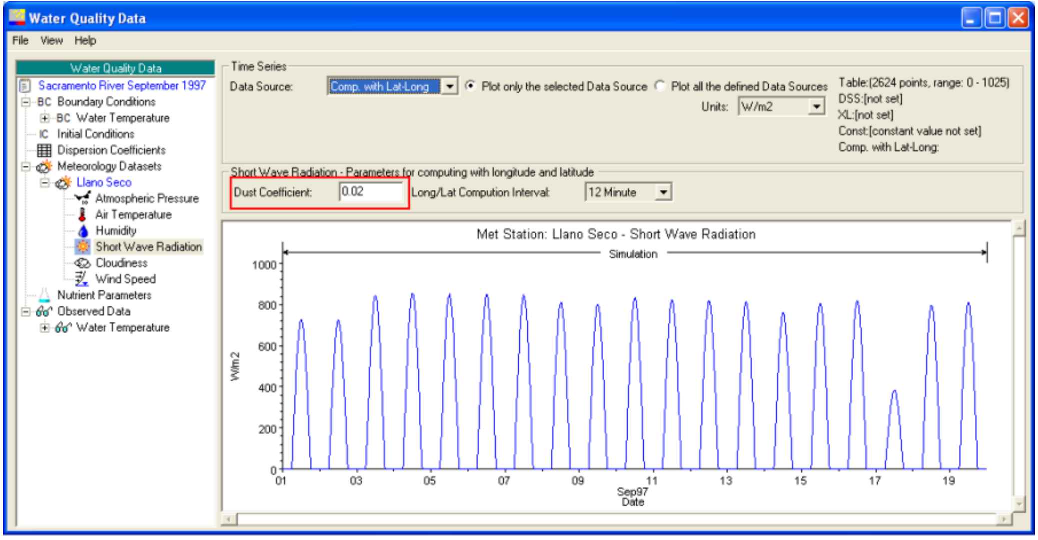
Measured solar radiation is often available from a local weather station. Satellite data is also available. The most common units for solar radiation are W/m2, cal/cm2/day and MJ/m2/day. Data can be entered in any of these units, internal calculations are performed in W/m2.

If direct measurement cannot be obtained, solar radiation may be computed from the longitude and latitude of the site, the time of day, cloudiness, and a user supplied dust coefficient which represents local atmospheric attenuation and is often used as a calibration parameter. Solar radiation is the primary driver for the water temperature model.

11.8.1 Dust Coefficient

The **Dust Coefficient** is entered in the shortwave radiation time series window (indicated by the red box in the figure below). The dust coefficient estimates attenuation of solar radiation by dust (due to scattering and absorption).

The range of the dust coefficient is between 0 and 0.2 (the larger the dust coefficient, the greater the attenuation). Generally speaking, coefficients for urban areas tend toward 0.2; coefficients for rural areas toward 0. The dust coefficient is often treated as a calibration parameter. An example of a solar radiation time series generated from latitude, longitude, cloudiness, time of day, day of the year, and the dust coefficient is shown in the Figure 19-29.



Data Source: Comp. with Lat-Long
● Plot only the selected Data Source ○ Plot all the defined Data Sources
Units: W/m2
Table:(2624 points, range: 0 - 1025)
DSS:[not set]
XL:[not set]
Const:[constant value not set]
Comp. with Lat-Long:

Short Wave Radiation - Parameters for computing with longitude and latitude
Dust Coefficient: 0.02
Long/Lat Compution Interval: 12 Minute

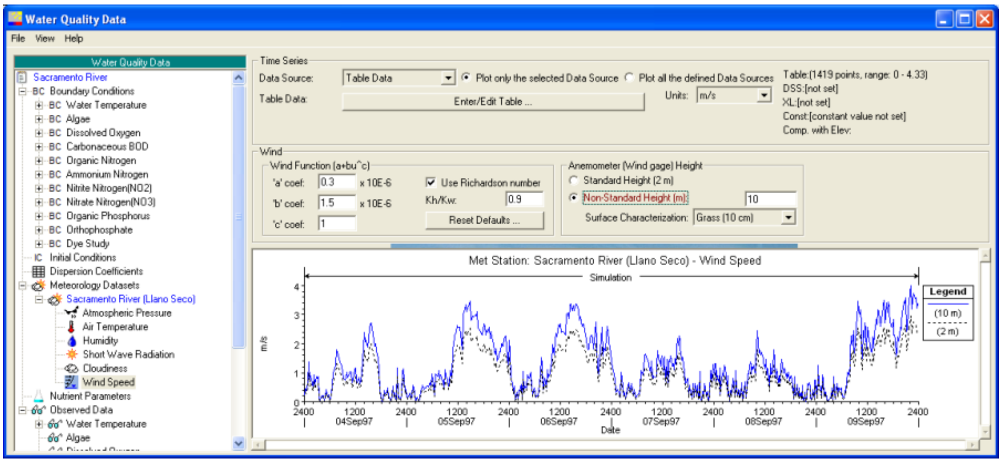
Figure 19-29. Computing solar radiation from latitude, longitude, cloudiness, time of day, day of the year, and the user entered dust coefficient.

11.9 COPY Entering a Wind Speed Time Series

Wind is a necessary parameter for surface flux (latent and sensible heat) estimation. Common units for wind speed are meters per second, miles per hour, and feet per second. Data can be entered in any of these units; internal calculations are performed in meters per second.

11.9.1 Anemometer Height

The standard height of a wind gage (anemometer) is two meters, and the surface flux formulations used in this model have been developed for wind measured at this standard height. However, anemometers are not always positioned at this height, particularly in urban areas. If the recording anemometer has been mounted at a non-standard height, select the **Non-Standard Height** option (Figure 19-31), enter the elevation at which the anemometer is located and select the option for surface characterization that best describes the surrounding area. Enter the raw data recorded by the anemometer into the table data editor. It will be corrected for height and surface roughness.
The plot window will show both the original and corrected data. The Figure 19-31 shows a time series of wind speed recorded by an instrument located at ten meters above the ground and the corrected wind speed at the standard height of two meters above the ground.



Time Series

Data Source: Table Data ● Plot only the selected Data Source ○ Plot all the defined Data Sources

Units: m/s

Table:(1419 points, range: 0 - 4.33)
DSS:[not set]
XL:[not set]
Const:[constant value not set]
Comp. with Elev:

Wind

Wind Function (a+bu^c)

'a' coef: 0.3 x 10E-6
'b' coef: 1.5 x 10E-6
'c' coef: 1

☑ Use Richardson number

Kh/Kw: 0.9

Anemometer (Wind gage) Height

○ Standard Height (2 m)
● Non-Standard Height (m): 10

Surface Characterization: Grass (10 cm)

Figure 19-31. Entering wind speed time series information.

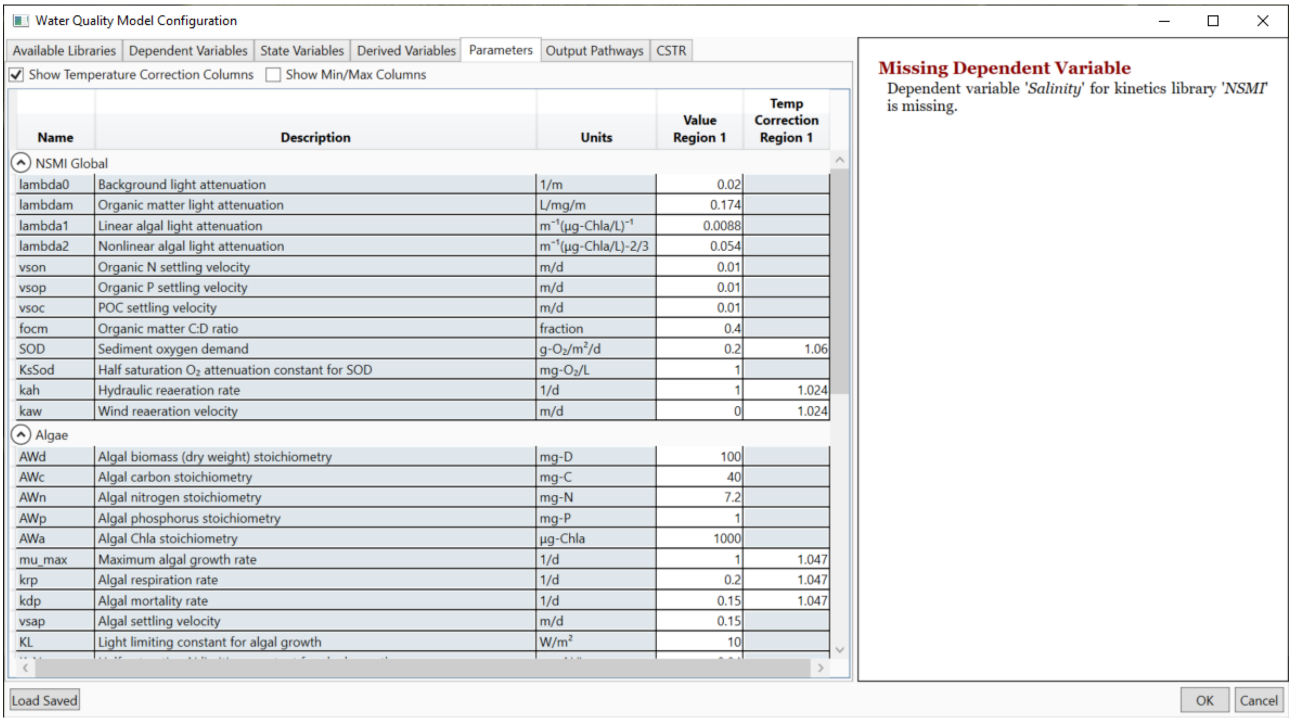
11.9.2 Wind Function Parameters

The primary calibration parameters for the surface fluxes are the wind function parameters '**a**', '**b**', and '**c**', and a flux partitioning coefficient (**Kh/Kw**). A Richardson's number type stability adjustment is also provided and can be turned on or off using the **Use Richardson number** check box. See the Water Temperature Parameters section later in this chapter for a more detailed discussion of these parameters.

12 Temperature Dependent Coefficients

12.1 Entering the Temperature Correction Coefficient

Values for kinetic **Temperature Correction Coefficients (θ)** are entered in the far right column of the **Water Quality Model Configuration** window under the **Parameters** tab. Be sure to check **Show Temperature Correction Columns** to see and enter these values.



☑ Show Temperature Correction Columns ☐ Show Min/Max Columns

Name	Description	Units	Value Region 1	Temp Correction Region 1
NSMI Global				
lambda0	Background light attenuation	1/m	0.02	
lambdam	Organic matter light attenuation	L/mg/m	0.174	
lambda1	Linear algal light attenuation	m^{-1}(µg-Chla/L)$^{-1}$	0.0088	
lambda2	Nonlinear algal light attenuation	m^{-1}(µg-Chla/L)-2/3	0.054	
vson	Organic N settling velocity	m/d	0.01	
vsop	Organic P settling velocity	m/d	0.01	
vsoc	POC settling velocity	m/d	0.01	
focm	Organic matter C:D ratio	fraction	0.4	
SOD	Sediment oxygen demand	g-O_2/m^2/d	0.2	1.06
KsSod	Half saturation O_2 attenuation constant for SOD	mg-O_2/L	1	
kah	Hydraulic reaeration rate	1/d	1	1.024
kaw	Wind reaeration velocity	m/d	0	1.024
Algae				
AWd	Algal biomass (dry weight) stoichiometry	mg-D	100	
AWc	Algal carbon stoichiometry	mg-C	40	
AWn	Algal nitrogen stoichiometry	mg-N	7.2	
AWp	Algal phosphorus stoichiometry	mg-P	1	
AWa	Algal Chla stoichiometry	µg-Chla	1000	
mu_max	Maximum algal growth rate	1/d	1	1.047
krp	Algal respiration rate	1/d	0.2	1.047
kdp	Algal mortality rate	1/d	0.15	1.047
vsap	Algal settling velocity	m/d	0.15	
KL	Light limiting constant for algal growth	W/m^2	10	

Missing Dependent Variable

Dependent variable '*Salinity*' for kinetics library '*NSMI*' is missing.

12.2 Modified Arrhenius Equation for Temperature Correction

The specified reaction rate is a user defined parameter. These user defined reaction rates are then corrected for temperature using the modified Arrhenius Equation,

$$k(T) = k_{20}\theta^{[T-20]}$$

Symbol	Definition	Units
$k(T)$	Kinetic rate coefficient after correction for local water temperature	$1/\text{day}$
k_{20}	Kinetic rate coefficient as entered by user (assumed to be kinetic rate at 20 C)	$1/\text{day}$
θ	Temperature correction coefficient as entered by user	$unitless$

12.3 Suggested Values for Temperature Correction Coefficients

The temperature correction coefficient (θ) generally ranges between 1.01 and 1.10. It is typically set to 1.024 for physical reactions and 1.047 for chemical reactions.

A summary of default values for kinetic rates for GCSM and NSMI kinetics are shown in the table below.

Library	Kinetic Rate	Description	Units	Local Temperature	Default Temperature Correction Coefficient
GCSM	k_0	Zero-Order growth/ decay rate	$mg/L/day$	water	1.047
GCSM	k_1	First-Order growth/ decay rate	$1/day$	water	1.047
GCSM	r_{gc}	Sediment release rate	$g/m^2/day$	water	1.047
NSMI	k_{ah}	Hydraulic re-aeration rate	$1/day$	water	1.024
NSMI	k_{aw}	Wind re-aeration rate	$1/day$	water	1.024
NSMI	μ_{max}	Maximum algal growth rate	$1/day$	water	1.047
NSMI	k_{rp}	Algal respiration rate	$1/day$	water	1.047
NSMI	k_{dp}	Algal mortality rate	$1/day$	water	1.047

Library	Kinetic Rate	Description	Units	Local Temperature	Default Temperature Correction Coefficient
NSMI	μ_{bmax}	Maximum benthic algal growth rate	$1/day$	water	1.047
NSMI	k_{rb}	Benthic algae respiration rate	$1/day$	water	1.06
NSMI	k_{db}	Benthic algae mortality rate	$1/day$	water	1.047
NSMI	k_{on}	Organic N hydrolysis rate	$1/day$	water	1.047
NSMI	k_{nit}	Nitrification rate	$1/day$	water	1.083
NSMI	k_{dnit}	Denitrification rate	$1/day$	water	1.045
NSMI	k_{op}	Organic P hydrolysis rate	$1/day$	water	1.047
NSMI	k_{poc}	Particulate Organic C hydrolysis rate	$1/day$	water	1.047
NSMI	k_{doc}	Dissolved Organic C hydrolysis rate	$1/day$	water	1.047
NSMI	k_{dx}	Pathogen death rate	$1/day$	water	1.07
NSMI	D_d	Pore-water diffusion coefficient between layer 1 and 2	m^2/day	sediment	1.08
NSMI	D_p	Particle mixing coefficient between layer 1 and 2	m^2/day	sediment	1.117
NSMI	$K_{PON,G1}$	Sediment PON (Labile) diagenesis rate	$1/day$	sediment	1.1

Library	Kinetic Rate	Description	Units	Local Temperature	Default Temperature Correction Coefficient
NSMI	$K_{PON,G2}$	Sediment PON (Refractory) diagenesis rate	$1/day$	sediment	1.15
NSMI	$K_{POP,G1}$	Sediment POP (Labile) diagenesis rate	$1/day$	sediment	1.1
NSMI	$K_{POP,G1}$	Sediment POP (Refractory) diagenesis rate	$1/day$	sediment	1.15
NSMI	$K_{POC,G1}$	Sediment POC (Labile) diagenesis rate	$1/day$	sediment	1.1
NSMI	$K_{POC,G2}$	Sediment POC (Refractory) diagenesis rate	$1/day$	sediment	1.15

12.4 Modified Arrhenius Equation for Sediment Transfer Velocity Temperature Corrections

Most of the sediment diagenesis reaction rates are corrected according to the Modified Arrhenius Equation above. However the oxidation transfer velocities are corrected with a different equation, also based on the Arrhenius Equation,

$$v(T) = v_{20}\ \theta^{[\frac{T_{sed} - 20}{2}]}$$

12.5 Suggested Values for Sediment Transfer Velocity Temperature Corrections

A summary of suggested values for sediment transfer velocity temperature corrections are show in the table below

Library	Kinetic Rate	Description	Units	Local Temperature	Default Sediment Transfer Velocity
NSMI	$\upsilon_{nh_4,1}$	Sediment Layer 1 nitrification transfer velocity	m/day	sediment	1.123
NSMI	$\upsilon_{no_3,1}$	Sediment Layer 1 denitrification transfer velocity	m/day	sediment	1.08
NSMI	$\upsilon_{ch_4,1}$	Sediment Layer 1 CH_4 oxidation transfer velocity	m/day	sediment	1.079
NSMI	$\upsilon_{h_2s,d}$	Sediment Layer 1 dissolved H_2S oxidation transfer velocity	m/day	sediment	1.079
NSMI	$\upsilon_{h_2s,p}$	Sediment Layer 1 particulate H_2S oxidation transfer velocity	m/day	sediment	1.079
NSMI	$\upsilon_{no_3,2}$	Sediment Layer 2 denitrification transfer velocity	m/day	sediment	1.08

13 COPY Water Quality Modules (DLLs)

13.1 General Constituent Simulation Module (GCSM)

The general constituent simulation module allows the modeling of many arbitrary constituents.

For each user-defined general constituent, four processes may be simulated: 0^{th} order decay (temperature dependent), 1^{st} order decay (temperature dependent), sediment release (temperature dependent) and net settling loss. The kinetic equation for any constituent in the water column is,

$$\frac{\partial C_i}{\partial t} = \frac{r_{gci}(T_w)}{h} - k_{0i}(T_w) - k_{1i}(T_w)C_i - v_{si}\frac{C_i}{h}$$

Symbol	**Description**	**Units**
C_i	Concentration of constituent *i*	$\mathrm{mg\,L^{-1}}$
v_{si}	Settling velocity of constituent *i*	$\mathrm{m\,day^{-1}}$
$r_{gci}(T_w)$	Sediment release rate of constituent *i*	$\mathrm{g\,m^{-2}\,day^{-1}}$
h	Average depth of water quality cell	m
$k_{0i}(T_w)$	0^{th} order decay rate of constituent *i*	$\mathrm{day^{-1}}$
$k_{1i}(T_w)$	1^{st} order decay rate of constituent *i*	$\mathrm{day^{-1}}$

13.2 Nutrient Simulation Module (NSMI)

NSMI has been designed to conduct an aquatic eutrophication simulation with simplified processes and minimum state variables. The algorithms that are incorporated into NSMI were derived, in part, from QUAL2e (Brown and Barnwell, 1987), QUAL2K (Chapra et al. 2008), WASP (Wool et al. 2006) and CE-QUAL-RIV1(EL 1995a).

The nitrogen cycle is composed of three state variables: organic nitrogen, ammonium, and nitrate. The phosphorus cycle consists of organic phosphorus and inorganic phosphorus. The carbon cycle consists of particulate and dissolved organic carbon and dissolved inorganic carbon. CBOD, pathogens, alkalinity, suspended solids and dissolved nitrogen gas are also modeled in NSMI.

The NSMI includes a sediment diagenesis option. This module focuses on four components of organic matter: carbon, nitrogen, phosphorous, and silica, resulting in 27 sediment diagenesis state variables.

13.3 Solids Simulation Module (Solid)

13.4 Water Temperature Module - Full Energy Budget

The Full Energy Budget temperature module computes the net heat flux density based on computed or observed short-wave (solar) radiation, computed downwelling long-wave (atmospheric) radiation, computed upwelling long-wave (water surface) radiation, latent heat flux density (evaporation and condensation), sensible heat flux density (conduction), and bed conduction. The net heat flux density of the sum of these terms is computed as q_{net}. The change in water temperature due to a change in heat flux is then computed as,

$$\frac{\partial T_w}{\partial t} = \frac{A_s}{V}\frac{q_{net}}{\rho_w C_{pw}}$$

Symbol	Description	Units
T_w	Water temperature in fully mixed water quality cell	C
t	Time	s
ρ_w	Density of water	$\mathrm{kg\,m^{-3}}$
C_{pw}	Specific heat capacity of water	$\mathrm{J\,kg\,m^{-1}\,C^{-1}}$
V	Volume of water quality cell	$\mathrm{m^3}$
A_s	Surface area of water quality cell	$\mathrm{m^2}$
q_{net}	Net heat flux at air-water and sediment-water interfaces	$\mathrm{W\,m^{-2}}$

13.5 Water Temperature Module - Equilibrium Method

The Equilibrium Method computes a simplified energy balance, simplifying the mathematical relations of the complete energy budget and requiring less input data. This method assumes an equilibrium temperature, T_{eq} , that would be reached under steady-state meteorological conditions. The net heat flux density, $K_T\left(T_{eq}-T_w\right)$, is assumed to be proportional to the difference of the actual water temperature, T_w and the equilibrium water temperature, T_{eq} . The change in water temperature due to a change in heat flux using this equilibrium approach is computed as,

$$\frac{\partial T_w}{\partial t} = \frac{A_s}{V}\frac{K(T_{eq}-T_w)}{\rho_w C_{pw}}$$

Symbol	Description	Units
T_w	Water temperature in fully mixed water quality cell	C
T_{eq}	Equilibrium temperature	C
$\mathrm{K_T}$	Overall heat exchange coefficient	$\mathrm{W\,m^{-2}\,C^{-1}}$

13.6 COPY General Constituent Simulation Module (GCSM)

13.6.1 Overview

The **General Constituent Simulation Module (GCSM)** is selected by checking it in the list under the **Available Libraries** tab in the **Water Quality Model Configuration Window**.

The kinetics for the GSSM are as follows,

$$\frac{\partial C_i}{\partial t} = \frac{r_{gci}(T_w)}{h} - k_{0i}(T_w) - k_{1i}(T_w)C_i - v_{si}\frac{C_i}{h}$$

13.6.2 Dependencies

13.6.2.1 Hydrodynamic Dependencies

Sediment release is a source for general constituents and is inversely proportional to average channel depth.

Sediment settling to bed is a sink for general constituents and is also inversely proportional to average channel depth.

GCSM Computation	Requires	Variable	Units
Sediment release	Average channel depth	h	m
Settling to bed	Average channel depth	h	m

13.6.2.2 Temperature Dependencies

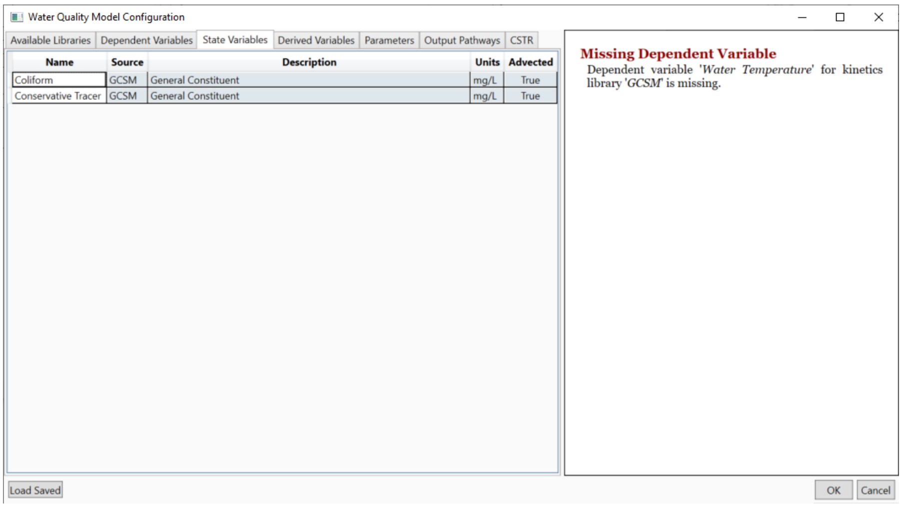
The sediment release rate r_{gci} , zero-order decay k_{0i} , and first-order decay k_{1i} , are all temperature dependent.

All are corrected

$$k(T_w) = k\theta^{T_w - 20}$$

13.6.3 State Variables

The State Variables tab allows the user to change the name of the general constituents.



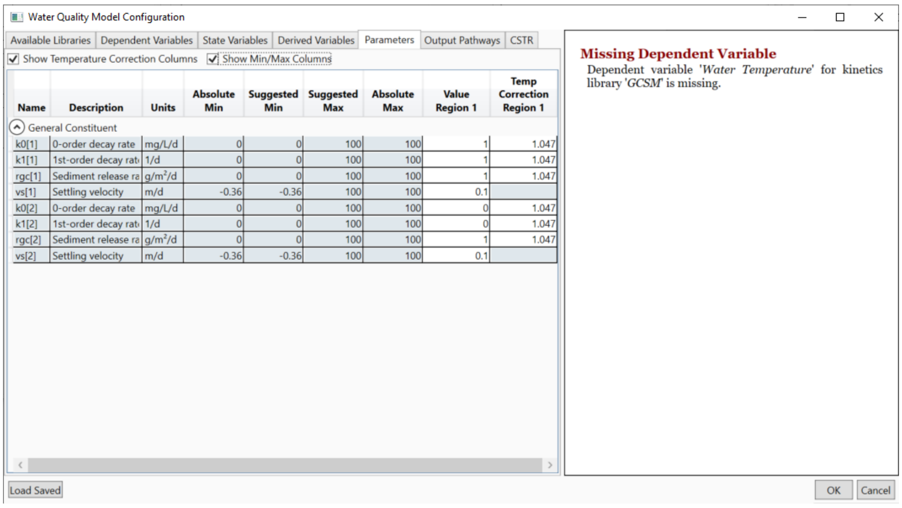
Name	Source	Description	Units	Advected
Coliform	GCSM	General Constituent	mg/L	True
Conservative Tracer	GCSM	General Constituent	mg/L	True

Missing Dependent Variable

Dependent variable '*Water Temperature*' for kinetics library '*GCSM*' is missing.

13.6.4 Parameters

Parameters are edited here. Note that it is not possible for the user to change the values above the absolute max or below the absolute minimum. Note that there have been two general constituents chosen and there is one region in this model.



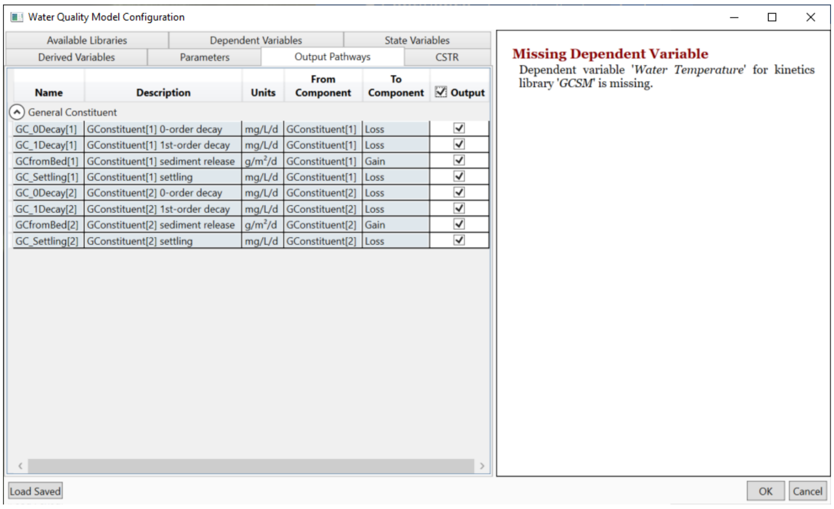
☑ Show Temperature Correction Columns ☑ Show Min/Max Columns

General Constituent

Name	Description	Units	Absolute Min	Suggested Min	Suggested Max	Absolute Max	Value Region 1	Temp Correction Region 1
k0[1]	0-order decay rate	mg/L/d	0	0	100	100	1	1.047
k1[1]	1st-order decay rat	1/d	0	0	100	100	1	1.047
rgc[1]	Sediment release ra	$g/m^2/d$	0	0	100	100	1	1.047
vs[1]	Settling velocity	m/d	-0.36	-0.36	100	100	0.1	
k0[2]	0-order decay rate	mg/L/d	0	0	100	100	0	1.047
k1[2]	1st-order decay rat	1/d	0	0	100	100	0	1.047
rgc[2]	Sediment release ra	$g/m^2/d$	0	0	100	100	1	1.047
vs[2]	Settling velocity	m/d	-0.36	-0.36	100	100	0.1	

Missing Dependent Variable
Dependent variable '*Water Temperature*' for kinetics library '*GCSM*' is missing.

13.6.5 Output Pathways



General Constituent

Name	Description	Units	From Component	To Component	☑ Output
GC_0Decay[1]	GConstituent[1] 0-order decay	mg/L/d	GConstituent[1]	Loss	☑
GC_1Decay[1]	GConstituent[1] 1st-order decay	mg/L/d	GConstituent[1]	Loss	☑
GCfromBed[1]	GConstituent[1] sediment release	$g/m^2/d$	GConstituent[1]	Gain	☑
GC_Settling[1]	GConstituent[1] settling	mg/L/d	GConstituent[1]	Loss	☑
GC_0Decay[2]	GConstituent[2] 0-order decay	mg/L/d	GConstituent[2]	Loss	☑
GC_1Decay[2]	GConstituent[2] 1st-order decay	mg/L/d	GConstituent[2]	Loss	☑
GCfromBed[2]	GConstituent[2] sediment release	$g/m^2/d$	GConstituent[2]	Gain	☑
GC_Settling[2]	GConstituent[2] settling	mg/L/d	GConstituent[2]	Loss	☑

Missing Dependent Variable
Dependent variable '*Water Temperature*' for kinetics library '*GCSM*' is missing.

13.6.5.1 Zero-Order Decay

$$\frac{\partial C_i}{\partial t} = -k_{0i}(T)$$

Symbol	Description	Units
C_i	Concentration of Constituent	mgL^{-1}
k_{0i}	0th order growth/decay rate	$mgL^{-1}d^{-1}$

13.6.5.2 First-Order Decay

$$\frac{\partial C_i}{\partial t} = -k_{1i}(T)C_i$$

Symbol	Description	Units
k_{1i}	1st order growth/decay rate	d^{-1}

13.6.5.3 Sediment Release

$$\frac{\partial C_i}{\partial t} = +\frac{r_{gci}(T)}{h}$$

13.6.5.4 Settling

$$\frac{\partial C_i}{\partial t} = -v_{si}\frac{C_i(T)}{h}$$

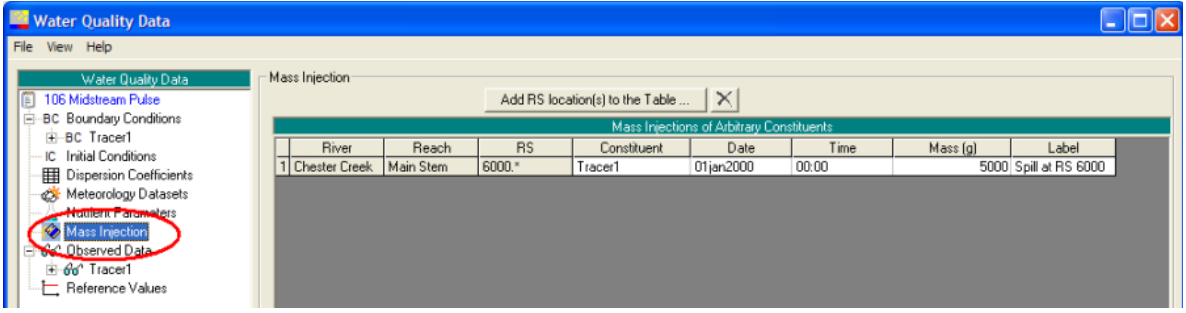
13.6.6 COPY Mass Injection

HEC-RAS provides a method to introduce a quantity of mass rather than concentration into the model. This feature is useful for simulation of spills and for dye studies, when the problem requires the introduction of mass rather than concentration of a particular constituent.

If you have not done so already, create an arbitrary constituent using the method described in the previous section. To introduce into the system, choose Mass Injection in the navigation bar of the Water Quality Data Entry Window as shown in Figure 19-35.

Mass will be instantaneously introduced into the water quality cell just downstream of the river station selected using the **Add RS location(s) to the Table…** button.

Use the **Constituent** pulldown to assign the mass injection to the selected constituent. Mass will be added during the water quality time step bounding the specified injection time. Multiple mass injections may be specified. If a time series is desired at a particular location it must be entered as a collection of instantaneous injections.



	River	Reach	RS	Constituent	Date	Time	Mass (g)	Label
1	Chester Creek	Main Stem	6000.*	Tracer1	01jan2000	00:00	5000	Spill at RS 6000

Figure 19-35. Creating an instantaneous mass injection point.

13.6.7 COPY Arbitrary Constituent - Tech Ref

The Arbitrary Constituent Module (ACM) simulates simple kinetics for up to ___ user-defined state variables in the water column.

Conservative or non-conservative tracers, coliform bacteria and reactive particles are examples of arbitrary constituents that can be simulated.

13.6.7.1 Kinetic Equation

For each user-defined arbitrary constituent, four processes may be simulated: zero-order growth or decay, first-order growth or decay, sediment release, and net settling loss. The arbitrary constituent module does not simulate any interactions among constituents in this module or with other modules. The kinetic source and sink equation for any arbitrary constituent is written as

$$\frac{dC_i}{dt} = \frac{r_{gci}(T)}{h} - k_{0i}(T) - k_{1i}(T)C_i - v_{si}\frac{C_i}{h}$$

where

C_i	=	concentration of constituent i	$(\mathrm{mg\,L^{-1}})$
v_{si}	=	settling velocity of constituent i	$(\mathrm{m\,s^{-1}})$
r_{gci}	=	sediment release rate of constituent i	$(\mathrm{gm\,m^{-2}d^{-1}})$
h	=	channel depth	(m)
k_{0i}	=	0^{th} order growth/decay rate of constituent i	$(\mathrm{mg\,L^{-1}d^{-1}})$

k_{1i}	=	1^{st} order growth/decay rate of constituent i	(d^{-1})

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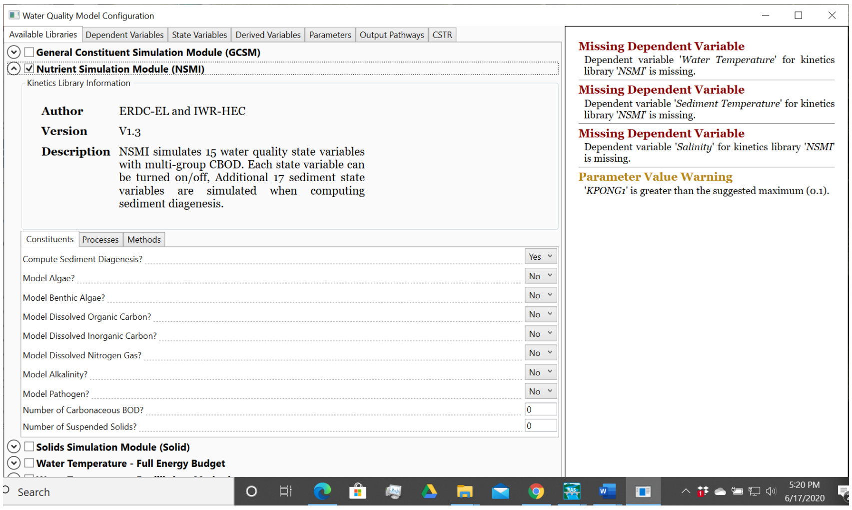
13.7 COPY NSMII Nutrient Simulation Module



☐ **General Constituent Simulation Module (GCSM)**

☑ **Nutrient Simulation Module (NSMI)**

Author ERDC-EL and IWR-HEC

Version V1.3

Description NSMI simulates 15 water quality state variables with multi-group CBOD. Each state variable can be turned on/off, Additional 17 sediment state variables are simulated when computing sediment diagenesis.

Compute Sediment Diagenesis?	Yes
Model Algae?	No
Model Benthic Algae?	No
Model Dissolved Organic Carbon?	No
Model Dissolved Inorganic Carbon?	No
Model Dissolved Nitrogen Gas?	No
Model Alkalinity?	No
Model Pathogen?	No
Number of Carbonaceous BOD?	0
Number of Suspended Solids?	0

☐ **Solids Simulation Module (Solid)**

☐ **Water Temperature - Full Energy Budget**

Missing Dependent Variable
Dependent variable '*Water Temperature*' for kinetics library '*NSMI*' is missing.

Missing Dependent Variable
Dependent variable '*Sediment Temperature*' for kinetics library '*NSMI*' is missing.

Missing Dependent Variable
Dependent variable '*Salinity*' for kinetics library '*NSMI*' is missing.

Parameter Value Warning
'*KPONG1*' is greater than the suggested maximum (0.1).

Water quality state variables modeling in NSMI include:

Variable	Description	Units
NH_4	Ammonium	$mgN\ L^{-1}$
NO_3	Nitrate	$mgN\ L^{-1}$
$OrgN$	Organic nitrogen	$mgN\ L^{-1}$
TIP	Total inorganic phosphorus	$mgP\ L^{-1}$
$OrgP$	Organic phosphorus	$mgP\ L^{-1}$
POC	Particulate organic carbon	$mgC\ L^{-1}$

Variable	**Description**	**Units**
DO	Dissolved oxygen	$mgO\ L^{-1}$
A_p	Algae	$\mu g - Chla\ L^{-1}$
A_b	Benthic algae	gDm^{-2}
DOC	Dissolved organic carbon	$mgC\ L^{-1}$
DIC	Dissolved inorganic carbon	$mgC\ L^{-1}$
$N_2\ gas$	Dissolved nitrogen gas	$mgN\ L^{-1}$
Alk	Alkalinity	$mgCaCO_3\ L^{-1}$
PX	Pathogen	$cfu\ (100\ mL)^{-1}$
$CBOD_i$	Carbonaceous BOD	$mg\ O_2\ L^{-1}$
SS_i	Suspended solids	$mg\ L^{-1}$

Nutrient parameters include rate constants for physical and chemical reactions between algae, nitrogen, phosphorous, dissolved oxygen, CBOD, and sediment. These rate constants control the rates of the source / sink term (S) in the advection dispersion equation:

$$\frac{\partial}{\partial t}(V\Phi) = -\frac{\partial}{\partial x}(Q\Phi)\Delta x + \frac{\partial}{\partial x}\left(\Gamma A\frac{\partial \Phi}{\partial x}\right)\Delta x + S \qquad (19\text{-}1)$$

V=volume of the water quality cell (m^3)
Φ=water temperature (C) or concentration ($kg\ m^{-3}$)
Q=flow ($m^3\ s^{-1}$)
Γ=user-defined dispersion coefficient ($m^2\ s^{-1}$)
A=cross sectional area (m^2)

S=sources and sinks (kg s^{-1})
Source/Sink terms for each of the state variables as well as their user adjustable rate constants are discussed in this section of the manual.

13.7.1 COPY Temperature Dependence of Rate Reactions

Some water quality reactions are strongly influenced by temperature. Rate constants are specified at a reference temperature of 20^0C and are corrected to the local water temperature. The relationship between reaction rate and temperature is modeled with the *Arrenius* rate law (EPA 1985):

$$k_T = k_{20}\theta^{(T-20)} \quad (19\text{-}2)$$

k_T=rate constant at temperature T

k_{20} =rate constant at 20^0C

θ=temperature correction coefficient
Many of the rate constants used in the nutrient submodel are temperature dependant. The rate constant that is specified in the table is the rate at 20^0C. This rate constant is specified along with the empirical temperature correction coefficient (θ). The temperature correction coefficient for these water quality reactions is generally set to 1.024 for physical reactions and to 1.047 for chemical reactions with some exceptions. In the source sink equations that follow, an asterisk ★ after a rate constant indicates temperature dependence.

13.7.2 COPY Algae

The water quality model supports only phytoplankton algae which are free-floating and consume nutrients from the water column. Algal growth and respiration affects algal concentration (A), nutrient concentrations (NH4, NO3, PO4, OrgN and OrgP), and dissolved oxygen (DOX). During the day, algal photosynthesis produces dissolved oxygen and during the night respiration utilizes oxygen. Algae utilize phosphorus and nitrogen in their dissolved inorganic forms (NH4, NO3, and PO4). Algae are a source of the organic forms of nitrogen (OrgN) and phosphorus (OrgP). Sources and sinks as well as parameters that control their rates are described in detail in this section.
User adjustable parameters for algae, default values and suggested ranges are summarized in Table 19-1, at the end of this section.

13.7.2.1 Chlorophyll-a (CHL)

Chlorophyll-a is a commonly monitored water quality parameter; however it is not a modeled state variable. Chlorophyll-a concentrations (ug/L) are measures of the gross level of phytoplankton. Chlorophyll-a does not provide information on species levels, nor does it group algae into classes.
Chlorophyll-a is a parameter in the non-linear formulation for algal growth light limitation (discussed later in the section). The linear relationship between chlorophyll-a and algal biomass is:

$$CHL = \alpha_0 A \quad (19\text{-}3)$$

CHL=chlorophyll-a concentration (μg Chl-a L^{-1})
α_0 =ratio of chlorophyll-a to algal biomass (μg Chl-a / mg A)
The chlorophyll-a: algal biomass ratio is user set. It is not temperature dependent. See Table 19-1.

13.7.2.2 Algal Biomass Concentration (A)

The single internal source of algal biomass (A) is algal growth. Two sinks are simulated: algal respiration and settling. Sources and sinks of algae are computed as:

A $_{\text{source/sink}}$ = $A\square^{*}$ algal growth (19-4)

- $A\square^{*}$ algal respiration
- $\frac{\square_{1}^{*}}{d}A$ algal settling

□ *=algal local respiration rate (day^{-1})

The algal respiration rate combines the process of endogenous respiration of algae, conversion of algal phosphorus to organic phosphorus and conversion of algal nitrogen to organic nitrogen. The three processes are lumped and the range is user set. Temperature dependent. See Table 19-1.

σ1*=algal settling rate (m day $^{-1}$)

The algal settling rate is user set. See Table 19-1. Temperature dependent.

d=average channel depth (m)

Water column depth is passed to the water quality model from the hydraulic model.

μ=local growth rate for algae (day^{-1})

The local algal growth rate is a function of the user specified maximum algal growth rate and algal growth rate limitation functions.

$\square \; \square \; \square_{\max}^{*} GL$ (19-5)

μ $_{\max}$*=local maximum growth rate for algae.

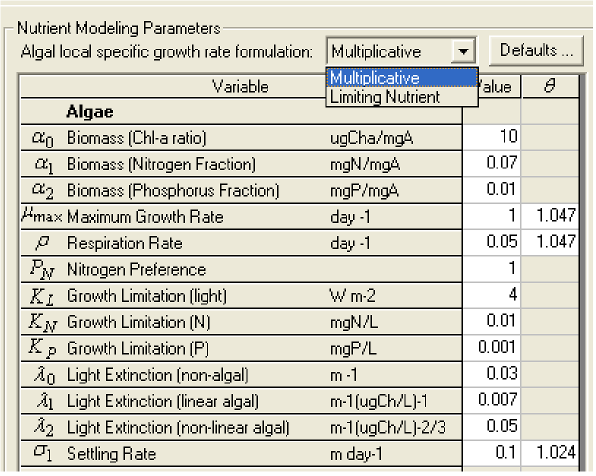
Local maximum growth rate is a user defined parameter set in the nutrient parameter table. It is temperature dependent. See Table 19-1.

GL=algal specific growth rate limitation

Algal growth limitation is a function of available nitrogen, phosphorus, and light. It is described in detail below.

Algal Specific Growth Rate Formulation

The maximum algal growth rate is computed as a function of one of two growth rate limitation functions: Leiberg's **Limiting Nutrient** formulation or the **Multiplicative** formulation. The limitation function is selected in the Nutrient Parameter window from the pulldown at the top of the parameter table as shown in the Figure 19-33.



Nutrient Modeling Parameters

Algal local specific growth rate formulation: Multiplicative

	Variable		Value	θ
	Algae			
α_0	Biomass (Chl-a ratio)	ugCha/mgA	10	
α_1	Biomass (Nitrogen Fraction)	mgN/mgA	0.07	
α_2	Biomass (Phosphorus Fraction)	mgP/mgA	0.01	
μ_{max}	Maximum Growth Rate	day -1	1	1.047
ρ	Respiration Rate	day -1	0.05	1.047
P_N	Nitrogen Preference		1	
K_L	Growth Limitation (light)	W m-2	4	
K_N	Growth Limitation (N)	mgN/L	0.01	
K_P	Growth Limitation (P)	mgP/L	0.001	
λ_0	Light Extinction (non-algal)	m -1	0.03	
λ_1	Light Extinction (linear algal)	m-1(ugCh/L)-1	0.007	
λ_2	Light Extinction (non-linear algal)	m-1(ugCh/L)-2/3	0.05	
σ_1	Settling Rate	m day-1	0.1	1.024

Figure 19-33. Choosing the algal local specific growth rate formulation.

Leiberg's law of the minimum limiting nutrient formulation limits growth due to light availability and the nutrient that is least available. When this formulation is chosen, the nutrient in excess does not affect the growth rate.

$$GL = FL \min(FP, FN) \quad (19\text{-}6)$$

The **multiplicative formulation** limits growth due to light availability and the availability of both nutrients.

$$GL = FL\ FP\ FN \quad (19\text{-}7)$$

<u>Nutrient Limitation for Nitrogen (FN)</u>

The nutrient limitation for nitrogen (FN) is a function of user entered **Michaelis-Menton nitrogen half-saturation constant (KN),** and concentrations of the state variables ammonium (NH4), and nitrate (NO3).

The Michaelis-Menton half-saturation constants determine the efficiency with which phytoplankton uptake nitrogen (and phosphorous) at low concentrations.

The limitation factor for nitrogen is the unitless expression:

$$FN = \frac{Ne}{Ne + KN} \quad (19\text{-}8)$$

Ne is the effective local concentration of available inorganic nitrogen

$$Ne = (NH4) + (NO3) \quad (19\text{-}9)$$

KN=half-saturation constant for nitrogen (mg N/L)

KN is a user adjustable parameter. It is not temperature dependent. See Table 19-1.

<u>Nutrient Limitation for Phosphorous (FP)</u>

The nutrient limitation for phosphorus (FP) is a function of the user entered **Michaelis-Menton phosphorus half-saturation constant (KP),** and concentration of inorganic phosphorus.

The limitation factor for phosphorus is the unitless expression:

$$FP = \frac{PO_4}{PO_4 + KP} \quad (19\text{-}10)$$

FP=limitation for phosphorous (unitless)

KP=half-saturation constant for phosphorus (mg P/L)

KP is a user adjustable parameter. It is not temperature dependent. See Table 19-1.

<u>Limitation for Light (FL)</u>

The limitation for light (FL) is a vertically averaged formulation that has been integrated over depth.

$$FL = \frac{1}{\lambda d}\ln\left(\frac{KL + I_o}{KL + I_o e^{-\lambda d}}\right) \quad (19\text{-}11)$$

I_o=surface light intensity (W m-2)

d=average channel depth (m)

λ=light extinction coefficient (m-1)

The **light saturation coefficient (KL)** is the half saturation constant defining the light level at which algal growth is one-half the maximum rate.

Because almost all radiation outside of the visible range is absorbed within the first meter below the surface (Orlob, 1977 as cited in Bowie, 1985), surface light intensity (I_o) applied to lake models (and to this river model) is often estimated to be a fraction of the solar radiation flux density used in heat budget computations. The magnitude of the visible range is roughly half the computed (or observed) short-wave (solar) radiation (q_{sw}).

In the HEC-RAS code, an attenuation coefficient is used to adjust the computed (or observed) short-wave radiation (q_{sw}) used in energy budget computations for use as surface light intensity in the light saturation coefficient computation:

$$I_o = a_{sw} q_{sw} \quad (19\text{-}12)$$

q_{sw}=short-wave (solar) radiation(W m^{-2})

a_{sw}=short-wave radiation attenuation coefficient (unitless)

The **short-wave radiation attenuation coefficient (a_{sw})** has been set to 0.50 for this release of the HEC-RAS water quality code. The light extinction coefficient (λ) is coupled to the limitation for light (FL) using the equation:

$$\lambda = \lambda_0 + \lambda_1 \alpha_0 A + \lambda_2 \left(\alpha_0 A\right)^{2/3} \quad (19\text{-}13)$$

λ_0=non-algal portion of light extinction coefficient (m^{-1})

λ_1=linear algal self shading coefficient (ugChla)($m^{-1}L^{-1}$)

λ_2 =non-linear algal self shading coefficient $(ugChla/L)^{-2/3}(m^{-1})$

All three of the above coefficients are user set.

For no algal self-shading set $\lambda_1=0$ $\lambda_2=0$

For linear algal self shading set $\lambda_1 \neq 0$ $\lambda_2=0$

For nonlinear self shading set λ_1 and λ_2 to appropriate values.

13.7.2.3 Table of Rate Constants and Parameters for Algae

Suggested values and ranges for algae parameters are provided in the Table 19-1. Defaults shown in the table match those set in model code. For most coefficients, defaults are set to the lowest value in the range.

Table 19-1. Suggested range and default values for algae rate constants and parameters.

Symbol	**Variable**	**Description**	**Units**	**QUAL2E[1] Suggested Range**	**Default Value**	**Temperature Correction Coefficient (Θ)**
α_0	alpha0	Conversion algae → chlorophyll-a	μg Chla mgA^{-1}	10 - 100	10	no correction
μ_{max}*	mu_max	Maximum algal growth rate	day^{-1}	1.0 – 3.0	1.0	1.047
	rho	Algal respiration rate	day^{-1}	0.05 – 0.5	0.05	1.047
K_L	KL	Michaelis-Menton half saturation constant (light)	$W\ m^{-}sec^{-1}$	4 - 20	4	no correction
K_N	KN	Michaelis-Menton half saturation constant (nitrogen)	mg N/ liter	0.01 – 0.30	0.01	no correction
K_P	KP	Michaelis-Menton half saturation constant (phosphorus)	mg P/ liter	0.001 – 0.05	0.001	no correction
λ_0	lambda0	Light extinction coefficient (non-algal)	m^{-1}	≥ 0.03	0.03	no correction
λ_1	lambda1	Algal self shading coefficient (linear)	m^{-1} / μg Chla/L	0.007 – 0.07	0.007	no correction
λ_2	lambda2	Algal self shading coefficient (non-linear)	m^{-1} / $(\mu g\ Chla/L)^{2/3}$	variable	0.05	no correction

σ_1*	sigma1	Settling rate (algae)	m day $^{-1}$	0.1 – 2.0	0.1	1.024

[1] Brown and Barnwell (1987)

13.7.3 COPY Nitrogen Parameters

Nitrogen species most commonly found in river water are dissolved organic nitrogen (OrgN); dissolved ammonium nitrogen (NH4); dissolved nitrite nitrogen (NO2); dissolved nitrate nitrogen (NO3); and particulate organic nitrogen. The first four (dissolved) forms are HEC-RAS state variables. Particulate organic nitrogen is not included in this version of the water quality model. Within natural aerobic waters there is a constant transformation of organic nitrogen (OrgN) to ammonium (NH4), to nitrite (NO2), and finally to nitrate (NO3). Dissolved ammonium is assumed to be the form NH4. Although ammonia (NH3) and ammonium (NH4) may be present in surface water, the pH at which the transformation of ammonia to ammonium ion is half complete is 9.24, above the pH of most rivers (Hem, 1985).

Measurements for nitrate and nitrite in river water are common largely because elevated concentrations are of concern for human and livestock health. Nitrite (NO2) is rarely abundant in rivers (Meybeck, 1982 and Hem, 1985). Nitrate (NO3) is more stable and commonly found in natural waters.

Because organic nitrogen (OrgN) and nitrite (NO2) are generally unstable in aerated water, elevated concentrations of organic nitrogen and nitrite are potential indicators of a waste discharge nearby. Nitrate (NO3) and ammonium (NH4) are also indicators of waste discharge, but because these forms are more stable, elevated concentration of nitrate and ammonium suggest a waste source further upstream (Hem, 1985). Elevated concentrations of ammonium (NH4) are more commonly associated with urban waste, elevated concentrations of nitrate (NO3) are more commonly associated with agricultural runoff (Meybek, 1982).

A constant stepwise process transforms organic nitrogen (OrgN) to ammonium nitrogen (NH4) then to nitrite (NO2) and nitrate (NO3). In addition to these (internal) sources and sinks, algal growth and decay also consumes and produces nitrogen. Finally the bed acts as a potential source and sink of nitrogen. Sources and sinks as well as parameters that control their rates are described in detail in this section.

User adjustable parameters for the nitrogen cycle, default values and suggested ranges are summarized in Table 19-2, at the end of this section.

13.7.3.1 Sources and Sinks of Dissolved Organic Nitrogen (OrgN)

The only internal source of organic nitrogen (OrgN) in the model is algal respiration. Organic nitrogen sinks include settling to the bed and hydrolysis to form ammonium nitrogen (NH4). Sources and sinks for the organic nitrogen (OrgN) pool are:

OrgN$_{source/sinks}$ = + !worddav784720da1d9ed6de77c65b8b986b3757.png|height=32,width=40!Algal Respiration (19-14)

- !worddav6d8a7400d2c59b7d1cd05842a2a23acb.png|height=32,width=64!Hydrolysis (OrgN → NH4)
- !worddav450c33b2d0b59d66df2f3291014e62e3.png|height=32,width=64!Settling

α_1= fraction of algal biomass that is nitrogen (mgN mgA^{-1})

User set parameter that describes the fraction of algae that is contributed to the nitrogen pool. See Table 19-2.

ρ*=algal local respiration rate (day^{-1})

See algae section, and Table 19-1.
β_3*=rate constant: hydrolysis of OrgN to ammonium (day^{-1})
User set parameter. Temperature dependent. See Table 19-2.
σ_4*=rate constant: organic N settling rate (day^{-1})
User set parameter. Temperature dependent. See Table 19-2.

13.7.3.2 Sources and Sinks of Ammonium Nitrogen (NH4)

Internal sources of ammonium (NH4) include hydrolysis of organic nitrogen (OrgN), and uptake (diffusion) from the benthos. Internal sinks include oxidation of ammonium to form nitrite (NO2) and algal uptake. Sources and sinks for the ammonium nitrogen (NH4) pool are:

$NH4_{source/sinks}$ = $\beta_3^* OrgN$ Hydrolysis (OrgN → NH4) (19-15)

\+ $\frac{\sigma_3^*}{d}$ Diffusion from benthos

\- $\beta_1^*(1-\exp^{-KNR \cdot DOX})\,NH4$ Oxidation (NH4 → NO2)

$-F_1 \alpha_1 \mu A$ Algal uptake

β_3*=rate constant: hydrolysis of OrgN to ammonium (day^{-1})
See organic nitrogen section and Table 19-2.
β_1*=rate constant: oxidation of ammonium to nitrite (day^{-1})
The NH4 oxidation rate is user set. Temperature dependent. See Table 19-2.
σ_3*=benthos source rate: ammonium ($mgN\ m^{-2}\ day^{-1}$)
The NH4 benthos source rate is user set. See Table 19-2.
d=average channel depth (m)
Water column depth is passed to the water quality model from the hydraulic model.
μ=local growth rate for algae (day^{-1})
See algae section.
α_1= fraction of algal biomass that is nitrogen ($mgN\ mgA^{-1}$)
See organic nitrogen section and Table 19-2.
KNR=first order nitrification inhibition coefficient (mgO^{-1} L)
User set parameter, generally set to 0.6. See Table 19-2.
GL=growth limitation for algae (unitless)
Computed value. See algae section for discussion.
F1=fraction of algal uptake from ammonium pool (unitless)
The **fraction algal uptake from the ammonia pool (F1)** is a computed value. It is a function of the user entered **nitrogen preference factor (PN)** and the state variables ammonium (NH4) and nitrate (NO3):

$$F_1 = \frac{P_N\ NH4}{P_N\ NH4 + (1 - P_N)\,NO3} \qquad (19\text{-}16)$$

The **preference factor for ammonia (PN)** varies between zero and one. Setting the value to 1 indicates algal preference for ammonium (NH4). Setting the value to 0 indicates algal preference for nitrate (NO3). The default for this parameter is 1.0 (exclusive preference for ammonium). See Table 19-2.

13.7.3.3 Sources and Sinks of Nitrite Nitrogen (NO2)

The internal source of nitrite (NO2) is oxidation of ammonium (NH4) to nitrite (NO2). The only modeled sink is oxidation of nitrite (NO2) to nitrate (NO3). Sources and sinks for the nitrite pool are:
$NO2_{Sources/Sinks}$ =

$\beta_1 * (1 - \exp^{-KNR \cdot DOX}) NH4$ Oxidation (NH4 → NO2) (19-17)

- $-\beta_2 * (1 - \exp^{-KNR \cdot DOX}) NO2$ Oxidation (NO2 → NO3)

β_1*=rate constant: oxidation of ammonium to nitrite (day^{-1})
See ammonium section and Table 19-2.
β_2*=rate constant: oxidation of nitrite to nitrate (day^{-1})
Progresses rapidly. Temperature dependent. See Table 19-2.
KNR=first order nitrification inhibition coefficient (mgO^{-1} L)
See Table 19-2.

13.7.3.4 Sources and Sinks of Nitrate Nitrogen (NO3)

The only internal source of nitrate nitrogen is oxidation of nitrite (NO2) to nitrate (NO3). The only modeled sink is algal uptake. Sources and sinks for the nitrate pool are:
$NO3_{Sources/Sinks}$=

$\beta_2 * (1 - \exp^{-KNR \cdot DOX}) NO2$ Oxidation (NO2 → NO3) (19-18)

- $-(1 - F_1)\alpha_1 \mu A$ Algal uptake

β_2*=rate constant: oxidation of nitrite to nitrate (day^{-1})
See nitrite nitrogen section and Table 19-2.
KNR=first order nitrification inhibition coefficient (mgO^{-1} L)
See ammonium nitrogen section and Table 19-2.
α_1= fraction of algal biomass that is nitrogen ($mgN\ mgA^{-1}$)
See organic nitrogen section and Table 19-2.
μ=local growth rate for algae (day^{-1})
See algae section.
F1=fraction of algal uptake from ammonium pool (unitless)
See Table 19-2.

13.7.3.5 Table of Rate Constants and Parameters for Nitrogen

Suggested values and ranges for nitrogen parameters are provided in Table 19-2. Defaults shown in the table match those set in model code. For most coefficients, defaults are set to the lowest value in the range.

Table 19-2. Parameters for nitrogen sources and sinks.

Symbol	Variable	Description	Units	QUAL2E Suggested Range	Default Value	Temperature Correction Coefficient (Θ)
β_3 *	beta3	Rate constant: OrgN → NH4	day^{-1}	0.02 – 0.4	0.02	1.047
β_1*	beta1	Rate constant: NH4 → NO2	day^{-1}	0.10 – 1.0	0.1	1.083
β_2*	beta2	Rate constant: N02 → NO3	day^{-1}	0.20 – 2.0	0.2	1.047
σ_4*	sigma4	Settling rate (Organic N)	day^{-1}	0.001 – 0.1	0.001	1.024
σ_3*	sigma3	Benthos source rate (dissolved N)	$mg\ N\ m^{-2}\ day^{-1}$	Variable	0.0	1.074
KNR	KNR	Nitrification inhibition coefficient	unitless	0.6 - 0.7	0.6	no correction
P_N	PN	Algal preference factor for ammonia	unitless	1 = NH4 0 = NO3	1	no correction
α_1	alpha1	Fraction algal biomass that is nitrogen	$mg\ N\ mgA^{-1}$	0.07 – 0.09	0.07	no correction

13.7.4 COPY Phosphorus

Two phosphorus species are modeled: dissolved organic phosphorus (OrgP), and dissolved inorganic orthophosphate (PO4).
In the natural environment, phosphorus is obtained from dissolution of rocks and minerals with low solubility. Soil erosion in agricultural areas is a significant source of (particulate) phosphorus. Although phosphorus enters rivers primarily as particulate matter, particulate organic phosphorus is not included in

this version of the water quality model. It is planned for future versions.
Animal metabolic waste is another source of phosphorus. Phosphorus is present in sewage in the dissolved inorganic form (PO4) (Brown and Barnwell 1987). Sources and sinks as well as parameters that control their rates are described in detail in this section.
User adjustable parameters for the phosphorus cycle, default values and suggested ranges are summarized in Table 19-3, at the end of this section.

13.7.4.1 Sources and Sinks of Organic Phosphorus (OrgP)

The only internal source of organic phosphorus (OrgP) is algal respiration. Internal sinks for OrgP are decay of organic phosphorus (OrgP) to form orthophosphate (PO4), and settling to the bed. Sources and sinks for the organic phosphorus pool are:
OrgP $_{\text{Sources/Sinks}}$ = $\square_2\square^* A$ Algal respiration (19-19)
!worddav5dbb8298d921bb93156859f8c7dd55f9.png|height=32,width=88!Decay (OrgP → PO4)
!worddav68291d7ff31e13476a0e981a58aaab95.png|height=32,width=88!Org P settling

β_4*=rate constant: oxidation of OrgP to PO4 (day^{-1})
User set. Temperature dependent. See Table 19-3.
σ_5*=settling rate: organic phosphorus (OrgP) (day^{-1})
User set. Temperature dependent. See Table 19-3.
ρ*=algal local respiration rate (day^{-1})
See algae section, and Table 19-1.
α_2=fraction of algal biomass that is phosphorus (mgP mgA^{-1})
User set parameter that describes the fraction of algae that is contributed to the phosphorus pool. See Table 19-3.

13.7.4.2 Sources and Sinks of Orthophosphate (PO4)

There are two internal sources of dissolved orthophosphate (PO4): decay of organic phosphorus (OrgP); and diffusion from benthos. The only internal sink of orthophosphate (PO4) is algal uptake. The differential equation that governs the orthophosphate pool is:
PO4 $_{\text{Sources/Sinks}}$ = $\square_4 OrgP$ Decay (OrgP → PO4) (19-20)
+ $\frac{\square_2^*}{d}$ Diffusion from benthos

- !worddav4809ffb9fded894e9621fc6f3ff413a9.png|height=16,width=40!Algal uptake
  σ_2*=benthos source rate: orthophosphate (PO4) (mgP m^{-2} day^{-1})
  Set by the user. QUAL2e does not provide a suggested range. Temperature dependent. See Table 19-3.
  α_2=fraction of algal biomass that is phosphorus (mgP mgA^{-1})
  See Table 19-3.
  μ=local growth rate for algae (day^{-1})
  See algae section.
  d=average channel depth (m)
  Water column depth is passed to the water quality model from the hydraulic model.

13.7.4.3 Table of Rate Constants and Parameters for Phosphorus

Suggested values and ranges for phosphorus parameters are provided in Table 19-3. Defaults shown in the table match those set in model code. For most coefficients, defaults are set to the lowest value in the range.

Table 19-3. Parameters for phosphorus sources and sinks.

Symbol	**Variable**	**Description**	**Units**	**QUAL2E Suggested Range**	**Default Value**	**Temperature Correction Coefficient (Θ)**
β_4^*	beta4	Rate constant OrgP → PO4	day $^{-1}$	0.01 – 0.7	0.01	1.047
σ_5^*	sigma5	Settling rate (Organic P)	day $^{-1}$	0.001 – 0.1	0.001	1.024
σ_2^*	sigma2	Benthos source rate (dissolved P)	mg P m^{-2} day $^{-1}$	Variable	0.0	1.074
α_2	alpha2	Fraction algal biomass that is phosphorus	mg P mgA^{-1}	0.01 – 0.02	0.01	no correction

13.7.5 COPY Carbonaceous Biological Oxygen Demand (CBOD)

Carbonaceous biological oxygen demand (CBOD) is a state variable. A first order reaction describes oxidation of CBOD. The carbon cycle is not modeled in this version of the model. Losses of CBOD include settling and decay via oxidation:

CBOD $_{Sources/Sinks}$ = $\square K_1 CBOD$ (oxidation) (19-21)

$\square K_3 CBOD$ (settling)

K_1^*=deoxygenation rate coefficient (day^{-1})

User set parameter. Temperature dependent. See Table 19-4.

K_3^*=rate of loss of carbonaceous BOD from settling (day^{-1})

User set parameter. Temperature dependent. See Table 19-4.

13.7.5.1 Table of Rate Constants and Parameters for CBOD

Suggested values and ranges for CBOD parameters are provided in Table 19-4. Defaults shown in the table match those set in model code. For most coefficients, defaults are set to the lowest value in the range.
Table 19-4. Parameters for CBOD sources and sinks.

Symbol	**Description**	**Units**	**QUAL2E Suggested Range**	**Default Value**	**Temperature Correction Coefficient (Θ)**
K_1 *	Deoxygenation rate (CBOD)	day $^{-1}$	0.02 – 3.4	0.02	1.047
K_3 *	Settling rate (CBOD)	day $^{-1}$	-0.36 – 0.36	0	1.024

13.7.6 COPY Dissolved Oxygen (DOX)

Dissolved oxygen sources are atmospheric reaeration and algal photosynthesis. Generally speaking, dissolved oxygen concentrations are less than saturation; however, photosynthesis can result in dissolved oxygen concentrations exceeding saturation.
Losses include algal respiration, sediment oxygen demand, carbonaceous biological demand (CBOD), and oxidation of ammonium and nitrite. Sources and sinks of dissolved oxygen are:
DOX $_{Source/Sink}$= !worddavb5d0fe8226d7b3578eee1513b477444f.png|height=32,width=104!reaeration (19-22)
A□$_3$□ □□$_4$□[photosynthesis and respiration

- $K_1 CBOD$ CBOD demand
- $\frac{K_4}{d}$ sediment demand
- !worddav6b41ff729120511b800b93a2de147a4a.png|height=16,width=64!ammonium oxidation
- !worddav60ff4ee1097b4c6a0923831936541406.png|height=16,width=64!nitrite oxidation

Osat= dissolved oxygen concentration at saturation (mgO L $^{-1}$)
Computed value. Function of water temperature.
α_3 = O2 production per unit algal growth (mgO mgA $^{-1}$)
User entered value. See Table 19-5.
α_4 = O2 uptake per unit algae respired (mgO mgA $^{-1}$)
User entered value. See Table 19-5.
α_5 = O2 uptake per unit NH4 oxidized (mgO mgN $^{-1}$)
User entered value. See Table 19-5.
α_6 = O2 uptake per unit NO2 oxidized (mgO mgN $^{-1}$)

User entered value. See Table 19-5.

K1*= carbonaceous BOD deoxygenation rate (day $^{-1}$)

See CBOD section, and Table 19-4.

K2*= reaeration transfer rate (day $^{-1}$)

Reaeration is the process of oxygen exchange between the water and the atmosphere across the air-water interface. In this model, reaeration is simulated as a flux gradient process, the product of a reaeration rate constant (K2) and the difference between the actual and saturated dissolved oxygen concentration. This parameter is user set and temperature dependent. See Table 19-5.

K4*= sediment oxygen demand rate (mg m2 day $^{-1}$)

This parameter is user set and temperature dependent. See Table 19-5.

β_1* =rate of ammonia oxidation (day $^{-1}$)

See ammonium nitrogen section and Table 19-2.

β_2* =rate of nitrite oxidation (day $^{-1}$)

See nitrite nitrogen section and Table 19-2.

d=average channel depth (m)

13.7.6.1 Table of Rate Constants and Parameters for DOX

Suggested values and ranges for dissolved oxygen parameters are provided in Table 19-5. Defaults shown in the table match those set in model code. For most coefficients, defaults are set to the lowest value in the range.

Table 19-5. Parameters for dissolved oxygen sources and sinks.

Symbol	**Variable**	**Description**	**Units**	**QUAL2E Suggested Range**	**Default Value**	**Temperature Correction Coefficient (Θ)**
α_3	alpha3	O_2 production per unit algal growth	mg O mgA^{-1}	1.4 – 1.8	1.4	no correction
α_4	alpha4	O_2 uptake per unit algae respired	mg O mgA^{-1}	1.6 – 2.3	1.6	no correction
α_5	alpha5	O_2 uptake per unit NH4 oxidized	mg O mgN^{-1}	3.0 – 4.0	3.0	no correction

α_6	alpha6	O_2 uptake per unit of NO_2 oxidized	mg O mgN^{-1}	1.0 – 1.14	1.0	no correction
K_2^*	K2	Reaeration rate	day $^{-1}$	0 – 100	0	1.024
K_4^*	K4	SOD oxygen uptake	mgO m^{-2} day^{-1}	variable	0	1.060

13.8 COPY Overview of Solar Radiation Modules

There are three modules for computation of Solar Radiation: the EPA module, is similar to CE-QUAL-W2; the KLEIN module is similar to QUAL2E and CE-QUAL-RIV1; and the MBH (Meeus, Bird, and Hulstrom) module is similar to formulations used by QUAL2kw.

A summary of the differences between the three modules is shown in the table below. The EPA module is the most simple approach and provides the user with no parameter adjustments. It is used in the current version of CE-QUAL-W2. The Klein module is based on Klein (1948) with many updates. It provides the user with three calibration parameters and is similar to the approach used in QUAL2E and CE-QUAL-RIV1. The MBH is a complicated formulation similar to the model QUAL2kw and should be used only if the user has calibration data available.

See Annear and Wells (2007) for a complete comparison of these methods.

Solar Radiation Module (DLL)	**Description**	**Adjustable parameters**	**Water quality models using this formulation**
EPA	Update of the EPA (1971) model. Clear sky radiation calculated using a least squares fit polynomial regression on Solar Altitude.	None	CE-QUAL-W2 (Cole and Wells, 2000)

Solar Radiation Module (DLL)	Description	Adjustable parameters	Water quality models using this formulation
KLEIN	Update of the Klein (1948) model. Uses precipitable water content, relative optical air mass, atmospheric transmission coefficients and dust to calculate the total clear sky radiation.	Precipitable Water Content Dust Coefficient Cloud Cover	QUAL2E (Brown and Barnwell, 1987) CE-QUAL-RIV1 (Environmental Laboratory, 1995)
MBH	Update of the Meeus (1999) and Bird and Hulstrom(1981) models. Uses transmittance of aerosol absorptance and scattering, transmittance of uniformly mixed gasses, transmittance of ozone content, transmittance of Rayleigh scattering, and solar altitude to calculate the total clear sky radiation. Uses a solar altitude correction for atmospheric refraction.	Ratio of Forward-Scattered Irradiance to the Total Scattered Aerosol Absorptance Coefficient Atmospheric Turbidity Ozone Parameters	QUAL2kw (Pelletier and Chapra (2004)

13.8.1 References

Annear, R.L., and S.A. Wells (2007),A comparison of five models for estimating clear-sky solar radiation, *Water Resour. Res., 43,* W10415, doi:10.1029/2006WR005055.

Brown, L., and T. Barnwell (1987), The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual, *EPA/600/3-87/007*, Envir. Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Cole, T., and S. A. Wells (2000), CE-QUAL-W2: A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.0, *Instruction Report EL-00-1*, Waterways Experimentation Station, U.S. Army Corps of Eng., Vicksburg, MS.

Environmental Laboratory (1995), CE-QUAL-RIV1: A Dynamic, One-Dimensional (Longitudinal) Water Quality Model for Streams: User's Manual, Instruction Report *EL-95-2*, 290 pp., Waterways Experiments Station, U.S. Army Corps of Eng., Vicksburg, MS.

Pelletier, G., and S. Chapra (2004), QUAL2Kw, Documentation and User Manual for a Modeling Framework to Simulate River and Stream Water Quality, Publication Number *03-03-041*, 177 pp., Washington State Dept. of Ecology, Olympia, WA.

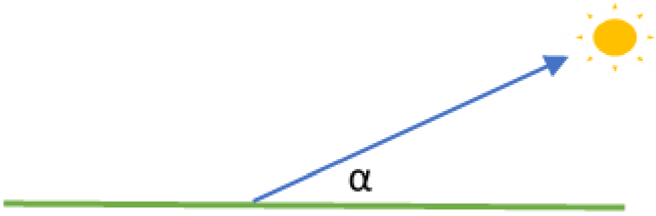
13.8.2 COPY Solar Altitude and Zenith (-> tech ref)

The sun's altitude and zenith angles are needed for computation of solar radiation and also for shading. These calculations are required by all Solar Radiation Modules (DLLs).

13.8.2.1 Computing the Solar Altitude

13.8.2.1.1 Solar Altitude

The solar altitude is the angle between the sun and the horizon (radians).



It is a function of the latitude, the declination and the time of day.

The equation for the solar altitude (α), in radians is,

$$sin\alpha = sin\phi \; sin\delta \; + \; cos\phi \; cos\delta \; cosh$$

Where:

Symbol	Description	Units
ϕ	Latitude	radians
δ	Declination	radians
h	Hour angle	radians

13.8.2.1.2 Solar Declination

Because the earth's axis is not perpendicular to its orbit around the sun, the declination (the angle between the sun and the plan the earth's equator) changes throughout the year. In the Northern Hemisphere, the longest day (the summer solstice) occurs around June 21st. The shortest day (the winter solstice) occurs around December 22nd. At these times, the declination is at its maximum and minimum value.

The maximum value of the declination, positive or negative, is approximately 23.45°.

The equation for declination (δ) in radians is,

$$\delta = 23.45 \left(\frac{2\pi}{360} \right) \; cos \left[\frac{2\pi}{365} (172 - D) \right]$$

Where:

Symbol	Description	Units
D	Day of year (1 on January 1st)	unitless

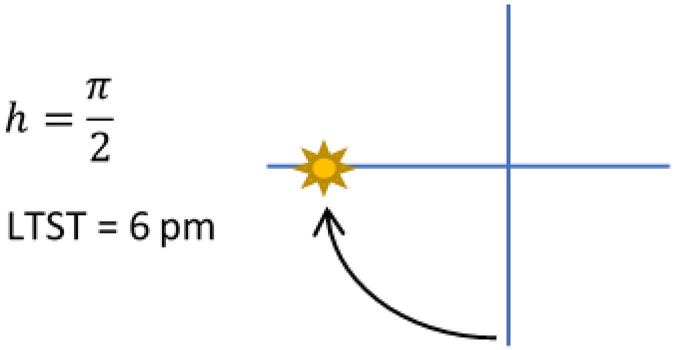
13.8.2.1.3 Hour Angle

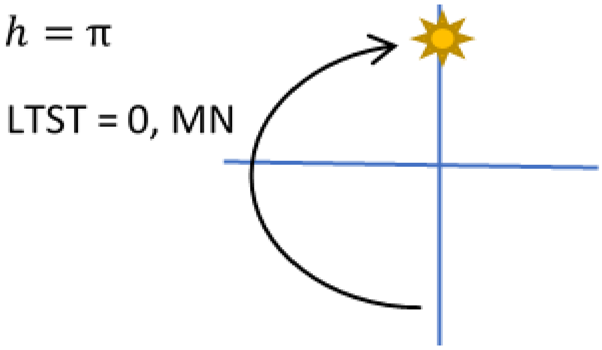
The local hour angle (or hour angle) is a function of time of day and location. It is an angular expression of the position of the sun in the sky as it relates to the hour of the day. All clocks that are in the same time zone read the same time. Because this time is an average representation over an entire time zone it does not represent the precise location of the sun. This section on Hour Angle describes the calculations required to correct the time of day as read on a clock (Civil) to the precise time that represents the suns location at a particular location (Local True Solar Time). Local True Solar Time is then converted to the angular expression of time (Hour Angle).

13.8.2.1.3.1 Local True Solar Time (LTST)

Local true solar time (LTST) reads noon when the sun is directly over the local meridian, and is expressed as hours since midnight, on a 24-hour clock.

The hour angle is the angle between the local meridian and the sun as measured clockwise from noon, as shown below.





Local True Solar Time (hours)	Hour Angle (radians)
0 hours (Midnight)	π
6 hours (6 AM)	$\frac{3\pi}{2}$
12 hours (noon)	$0, 2\pi$
18 hours (6PM)	$\frac{\pi}{2}$

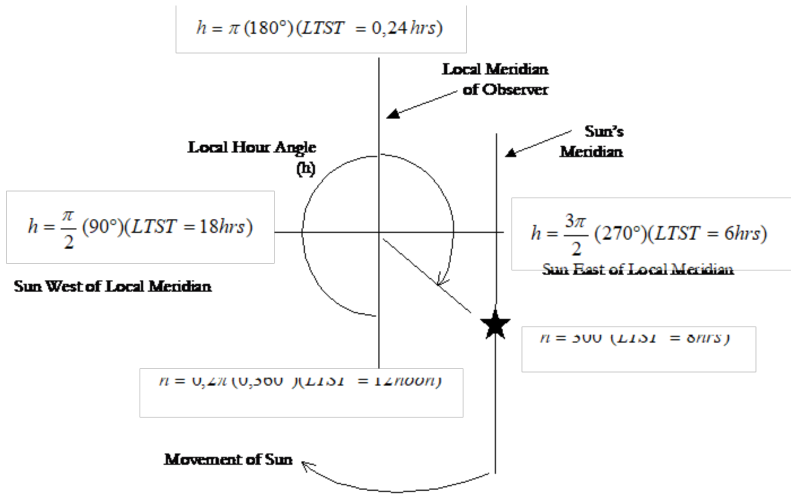
For sun east of the local meridian, the relationship between local hour angle (h) and LTST is,

For sun east of the local meridian, the relationship between local hour angle (h) and LTST is,

$$h = \frac{\pi}{12}(LTST + 12\ hours)$$

For sun west of the local meridian, the relationship is,

$$h = \frac{\pi}{12}(LTST - 12\ hours)$$



Standard Time (ST)

For convenience, time zones have been established for particular geographic regions within which all clocks read Standard Time (also called Local Clock Time or Civil Time). Standard Time (ST) is averaged for geographic regions, that are arbitrarily defined by local standard meridians, which are generally spaced 15° apart in the United States. Thus, clocks within the same time zone read the same time, and differ from cocks in the adjacent time zones by one hour. in most U.S. locations, Local Mean Standard Time is related to Standard Time by the equation,

$$LMST = ST - \frac{\xi}{15}(LSM - LLM)$$

Where:

Symbol	Description	Units
$LMST$	Local mean solar time	hours
ST	Standard time	hours
ξ	$\xi = -1$ west longitude $\xi = +1$ for east longitude	unitless

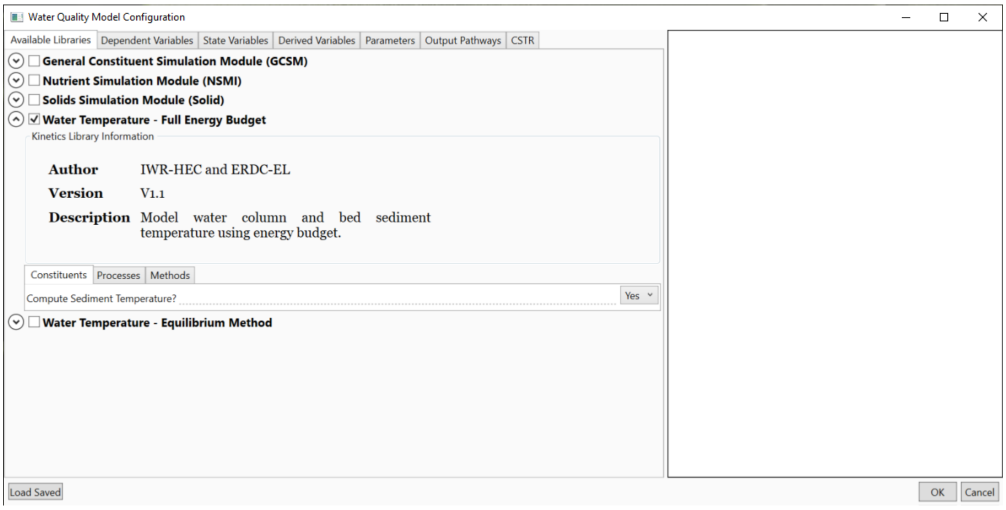
Universal Time Coordinate (UTC) or Greenwich Mean Time (GMT)

Time of day is often provided with reference to the Universal Time Coordinate (or Greenwich Mean Time). UTC or GMT is the Standard Time at the Prime Meridian (i.e. at zero degrees longitude or at Greenwich, England).

13.9 COPY TEMP Full Energy Budget Temperature Module

13.9.1 TEMP Source Sink Terms

The Full Energy Budget Temperature Module (TEMP) is selected by checking it in the list of **Available Libraries** tab in the **Water Quality Model Configuration Window**. Water temperature is always enabled, the user has the choice to **Compute Sediment Temperature** using the pull down as shown



☐ General Constituent Simulation Module (GCSM)
☐ Nutrient Simulation Module (NSMI)
☐ Solids Simulation Module (Solid)
☑ Water Temperature - Full Energy Budget

Author IWR-HEC and ERDC-EL
Version V1.1
Description Model water column and bed sediment temperature using energy budget.

Compute Sediment Temperature? Yes

☐ Water Temperature - Equilibrium Method

Heat is the transported constituent, and is related to temperature by specific heat and density of water.

The source/sink term for a change in water temperature is related to a change in net heat flux (q_{net}),

$$Heat_{source/sink} = \frac{q_{net}}{\rho_w C_{pw}} \frac{As}{V}$$

Symbol	Description	Units
q_{net}	net heat flux at the air-water interface	$\mathrm{W\,m^{-2}}$
ρ_w	density of water	$\mathrm{kg\,m^{-3}}$
C_{pw}	specific heat of water	$\mathrm{Jkg^{-1}C^{-1}}$
A_s	surface area of water quality cell	$\mathrm{m^2}$
V	volume of water quality cell	$\mathrm{m^3}$

Net heat flux (q_{net}) for a water quality cell is the sum of heat flux density at the air-water interface: radiation fluxes (short- and long-wave), and surface fluxes (latent and sensible heat) and heat flux, and heat flux at the sediment-water interface.

$$q_{net} = q_{sw} + q_{atm} - q_b + q_h - q_l + q_{sed}$$

Symbol	Description	Units
q_{net}	Net heat flux density at the air-water interface	$\mathrm{W/m^2}$
q_{sw}	Short-wave (solar) radiation flux density	$\mathrm{W/m^2}$
q_{atm}	Atmospheric (downwelling) long-wave radiation flux density	$\mathrm{W/m^2}$
q_b	Back (upwelling) long-wave radiation flux density	$\mathrm{W/m^2}$
q_h	Sensible heat flux density	$\mathrm{W/m^2}$
q_l	Latent heat flux density	$\mathrm{W/m^2}$
q_{sed}	Sediment-water heat flux density	$\mathrm{W/m^2}$

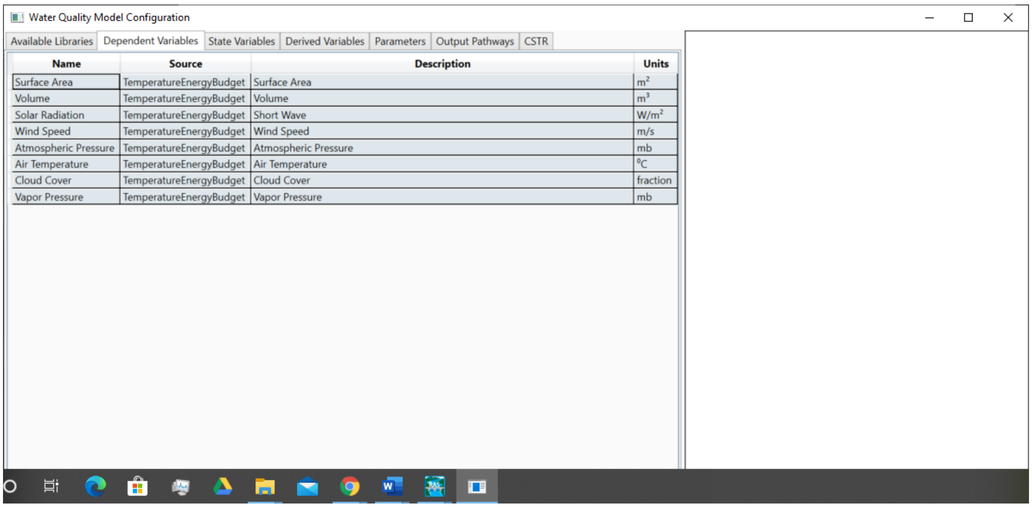
Short-wave (solar) radiation flux density may be measured directly, or computed based on latitude, longitude and measured cloudiness. All other heat fluxes are computed from time series of observations of air temperature, humidity (reported as relative humidity, vapor pressure or wet bulb temperature), wind speed, and cloudiness (if available). Calibration is performed by adjusting the surface fluxes (sensible and latent heat flux density) to match observed time series of water temperature.

**** See the technical reference manual for a detailed description of each of these heat flux terms.**

It is important to have a fully calibrated hydrodynamics model in place before beginning the process of water temperature modeling as errors in water quality cell volume, face velocity and water quality cell surface area create problems for the water temperature model. If calibration of the surface fluxes produces non-physical values, it is worth considering that the problem may be with hydrodynamics rather than the energy budget.

13.9.2 TEMP Dependencies

Dependencies are time series obtained from another model, or from observed data. These dependencies are shown under the **Dependent Variables** tab in the **Water Quality Model Configuration** window.



Name	Source	Description	Units
Surface Area	TemperatureEnergyBudget	Surface Area	m^2
Volume	TemperatureEnergyBudget	Volume	m^3
Solar Radiation	TemperatureEnergyBudget	Short Wave	W/m^2
Wind Speed	TemperatureEnergyBudget	Wind Speed	m/s
Atmospheric Pressure	TemperatureEnergyBudget	Atmospheric Pressure	mb
Air Temperature	TemperatureEnergyBudget	Air Temperature	^0C
Cloud Cover	TemperatureEnergyBudget	Cloud Cover	fraction
Vapor Pressure	TemperatureEnergyBudget	Vapor Pressure	mb

13.9.2.1 Hydrodynamic Dependencies

Hydrodynamic dependencies for computing the heat source/sink term are currently met using output from a HEC-RAS steady or unsteady-flow model.

Required by Energy Budget Computation	**Symbol**	**Units**	**Requires**	**Symbol**	**Units**
Heat source/sink	$Heat_{source/sink}$	K/s	Time series of surface area	A_s	m^2
Heat source/sink	$Heat_{source/sink}$	K/s	Time series of cell Volume	V	m^3

13.9.2.2 Meteorologic Dependencies

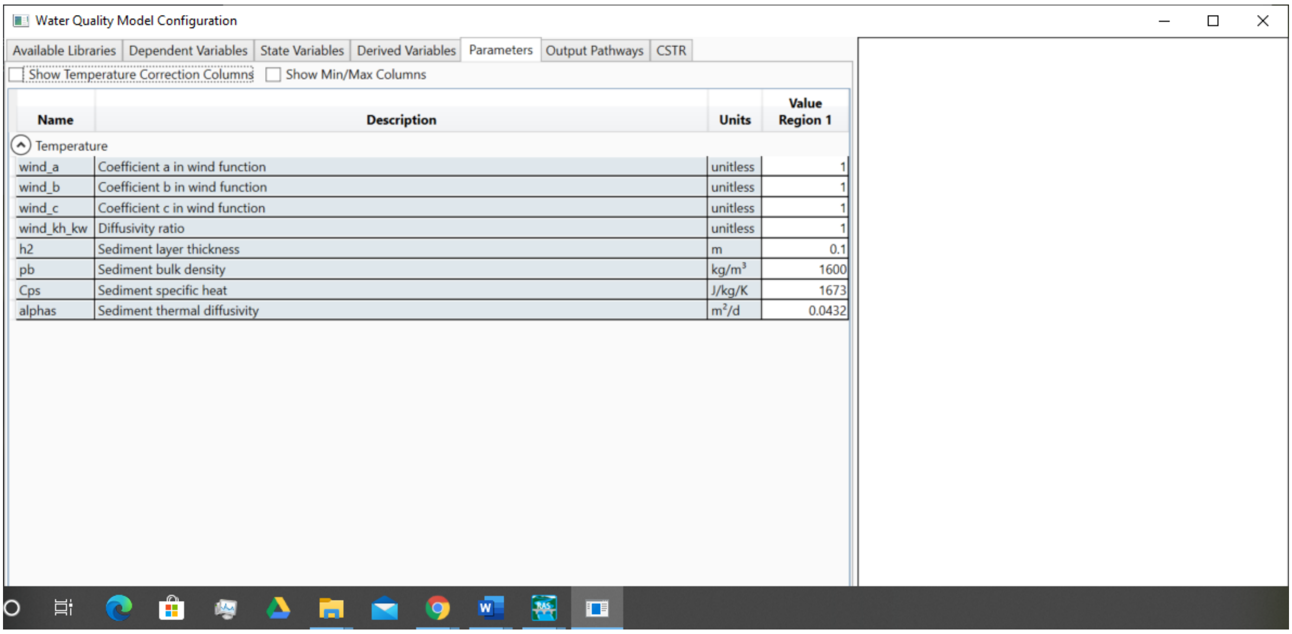
Time series data for solar radiation, air temperature, relative humidity, atmospheric pressure, and cloudiness are required elements for this water temperature model.

See the manual page on entering time series for details on how to input this meteorological information directly into your project, or by creating a link between the project and an excel or DSS file.

Energy Budget Computation	**Symbol**	**Units**	**Requires**	**Symbol**	**Units**
Short-wave solar radiation	q_{sw}	W/m^2	Observed time series of Solar Radiation (or estimate from site latitude and longitude)	q_{sw}	W/m^2

Energy Budget Computation	Symbol	Units	Requires	Symbol	Units
Long-wave (downwelling) radiation flux	q_{atm}	$\mathrm{W/m^2}$	Meteorological time series of Air Temperature	T_{air}	C
Sensible heat flux density	q_h	$\mathrm{W/m^2}$			
Long-wave (downwelling) radiation flux	q_{atm}	$\mathrm{W/m^2}$	Meteorological time series of Cloudiness	Cl	fraction
Short-wave solar radiation	q_{sw}	$\mathrm{W/m^2}$			
Latent heat flux density	q_l	$\mathrm{W/m^2}$	Meteorological time series of Vapor Pressure or RH	vp	mb
Latent heat flux density	q_l	$\mathrm{W/m^2}$	Meteorological time series of Wind Speed	U	$\mathrm{m/s}$
Sensible heat flux density	q_h	$\mathrm{W/m^2}$			
Latent heat flux density	q_l	$\mathrm{W/m^2}$	Meteorological time series of Atmospheric Pressure (or estimate from Site Elevation)	P_{atm}	atm

13.9.3 TEMP Parameters



☐ Show Temperature Correction Columns ☐ Show Min/Max Columns

Name	Description	Units	Value Region 1
Temperature			
wind_a	Coefficient a in wind function	unitless	1
wind_b	Coefficient b in wind function	unitless	1
wind_c	Coefficient c in wind function	unitless	1
wind_kh_kw	Diffusivity ratio	unitless	1
h2	Sediment layer thickness	m	0.1
pb	Sediment bulk density	kg/m^3	1600
Cps	Sediment specific heat	J/kg/K	1673
alphas	Sediment thermal diffusivity	m^2/d	0.0432

13.9.3.1 Surface Fluxes (Wind Coefficients a, b,and c)

13.9.3.2 Sediment

13.9.3.2.1 Sediment Layer Thickness

13.9.3.2.2 Sediment bulk density

13.9.3.2.3 Sediment Specific Heat

13.9.4 Output Pathways

13.9.5 COPY Net Heat Flux

Net heat flux is computed as the sum of individual heat budget components:

$$q_{net} \square q_{sw} \square q_{atm} \square q_b \square q_h \square q_{\square} \quad (19\text{-}25)$$

$q_{sw=}$ solar radiation (W m^{-2})
q_{atm} =atmospheric (downwelling) longwave radiation (W m^{-2})
q_b =back (upwelling) longwave radiation (W m^{-2})
q_h =sensible heat (W m^{-2})
q_l =latent heat (W m^{-2})
Note: the water quality module of HEC-RAS does not simulate ice formation and ice decay, and the energy associated with these physical processes is not included in this energy budget. Once heat loss has progressed to the extent that water temperature reaches freezing, temperatures will be reported at 0˚C. When surface heating increases, no energy is lost to ice decay.

13.9.6 COPY **Solar Radiation DLL - QUAL 2E and CE-QUAL-RIV1 Formulation

This model of solar radiation was used in the water quality model QUAL2E (Brown and Barnwell, 1987) and CE-QUAL-RIV1 (Environmental Laboratory, 1995). See Annear and Wells (2007) for further discussion of this and other DLLs.

13.9.6.1 Total Clear Sky Radiation (q_{sw})

The total clear sky radiation calculated using this method includes calculation of the precipitable water content, relative optical air mass, two atmospheric transmission coefficients and atmospheric dust is:

$$q_{sw\ clearsky} = q_{ext}\left[\frac{(a'' - d + 0.5(1 - a' + d))}{1 - 0.5\ R_g(1 - a' + d)}\right]$$

Where:

Symbol	Description	Units
$q_{sw\ clearsky}$	Total clear sky solar radiation	$\mathrm{W/m^2}$
q_{ext}	Extraterrestrial solar irradiance	$\mathrm{W/m^2}$
d	Atmospheric dust	dimensionless

Symbol	Description	Units
a'	Mean atmospheric transmission coefficient for a cloudless, dust-free moist air after scattering	dimensionless
a''	Mean atmospheric transmission coefficient for cloudless, dust-free moist air after scattering and absorption	dimensionless
R_g	Ground surface reflectivity	dimensionless

13.9.6.1.1 Extraterrestrial solar irradiance

The extraterrestrial solar irradiance is calculated as

$$q_{ext} = H_o E_o sin(A_o)$$

Where:

Symbol	Description	Units
H_o	Solar Constant (1367 W/m^2)	W/m^2
E_o	Eccentricity correction	unitless
A_o	Solar Altitude	radians

Solar (or short-wave) radiation is emitted by the sun, and is concentrated at high wavelengths, in the visible and near-infrared parts of the spectrum. In contrast, terrestrial (or long-wave) radiation is emitted by the earth’s surface and its atmosphere. Long-wave radiation is concentrated in the lower wavelengths of the infrared. This very distinct separation of wavelengths is due to the dramatic difference in temperature between the sun and the earth.

It is important to compute the two types of radiation separately partly because the physical manner in which radiation is absorbed and/or scattered varies according to wavelength. Important processes that affect solar radiation include absorption and scattering by clouds and absorption and scattering by gases (primarily ozone in the upper and water vapor in the lower atmosphere). Long-wave radiation is affected by absorption and scattering by gaseous constituents of the atmosphere such as carbon dioxide, water vapor, and ozone.

Time series information for both short-wave and long-wave radiation are required input for water temperature models. These time series may be computed from atmospheric variables (air temperature, relative humidity, cloudiness), or they may be measured directly using a pyranometer. Direct measurement of solar (short-wave) radiation using a pyranometer are common. Direct measurements of long-wave radiation are uncommon. This section provides an overview of methods for computing short-wave and long-wave radiation.

The magnitude of solar radiation reaching the top of the earth’s atmosphere is a straight forward calculation based on the solar altitude (varying with the day of year, time of day, and location of the observer on the earth’s surface), and a small adjustment do to irregularity of the earth’s orbit (equation of time). However, as the solar beam passes through the atmosphere, it is scattered and absorbed by clouds, atmospheric particles, and gasses. This reduces the magnitude of the direct solar beam and produces diffuse radiation. Some solar radiation is reflected by the water surface back to the atmosphere.

Solar radiation may be further attenuated (shaded) by physical objects in the path of the sun’s rays, such as tall banks, canyon walls, buildings and riparian vegetation.

These processes are summarized by the equation

$$q_{sw} = H_o\,(1 - R_s)\,a_t\,C_a(1 - S)$$

Where:

Symbol	Description	Units
H_o	Extraterrestrial radiation	$\mathrm{W/m^2}$
R_s	Albedo (Reflection coefficient)	unitless
a_t	Atmospheric Transmission	unitless
C_a	Cloudiness (Percentage not absorbed by clouds)	unitless
S	Shade factor (Percentage shaded)	unitless

13.9.6.1.2 Reflection Coefficient (Rs)

Albedo is the fraction of downwelling solar radiation that is reflected at the earth's surface. It is a strong function of color, ranging form 0.95 for fresh white snow, to 0.05 for dark wet soil, and in the case of water, a function of the smoothness of the water surface and the altitude angle of the sun. When the sun is directly overhead a smooth water surface, the albedo is approximately 0.05, increasing nearly to 1.0 as the sun approaches sunrise or sunset. The albedo of a water surface is also a function of wave state, a minimal consideration in all but very large rivers.

The reflictivity or albedo of a smooth water surface is estimated as,

$$R_s = AS^B$$

Where:

Symbol	Description	Units
R_s	Reflectivity of the water surface	$Unitless$

Symbol	Description	Units
S	Solar altitude	$Degrees$
A	Coefficient that depends on cloud cover	$1/Degrees$
B	Coefficient that depends on cloud cover	$Unitless$

Values for A and B are suggested as,

Description	Fraction Cloud Cover	A	B
Clear	$C_L \leq 1.0$	1.18	-0.77
Scattered	$1 < C_L \leq 0.5$	2.2	-0.97
Broken	$0.5 < C_L \leq 0.9$	0.95	-0.75
Overcast	$C_L \geq 0.9$	0.33	-0.45

13.9.6.1.3 Atmospheric Attenuation (a_t)

13.9.6.1.4 Extraterrestrial Radiation (H_o)

Extraterrestrial radiation is an expression of the short-wave radiation on a horizontal plane at the top of the atmosphere.

$$H_o = \frac{I_o}{r^2} sin\alpha$$

Where:

Symbol	Description	Units
H_o	Extraterrestrial radiation	$\mathrm{W/m^2}$
I_o	Solar irradiance	$\mathrm{W/m^2}$
r	Relative distance between earth and sun	

Symbol	Description	Units
α	Solar altitude	radians

13.9.6.1.4.1 Solar Irradiance (I_o)

Solar irradiance is is the intensity of solar radiation at the top of the earth's atmosphere, and is not user specified.

Solar irradiance has been set to:

$$I_o = 1367\ W/m^2$$

13.9.6.1.4.2 Relative Distance Between Earth and Sun (r)

The relative distance between the earth and sun is estimated as

$$r = 1.0\ +\ 0.017\ cos[\frac{2\pi}{365}(186 - D)]$$

Where:

Symbol	Description	Units
r	Relative distance between earth and sun	
D	Day of the year (1 on January 1st)	

Solar declination

Because the earth's axis is not perpendicular to its orbit around the sun, the declination (the angle between the sun and the plan the earth's equator) changes throughout the year. In the Northern Hemisphere, the longest day (the summer solstice) occurs around June 21st. The shortest day (the winter solstice) occurs around December 22nd. At these times, the declination is at its maximum and minimum value.

The maximum value of the declination, positive or negative, is approximately 23.45°.

The equation is computed as:

$$\delta = 23.45(\frac{2\pi}{360})\ cos[\frac{2\pi}{365}(172 - D)]$$

Where:

Symbol	Description	Units
δ	Declination	$radians$
D	Day of year (1 on January 1st)	unitless

Hour Angle

Local hour angle (or hour angle) is a complicated function of time of day and location. Computing it requires a number of computations that ultimately relate the time of day as read on a local clock, to the precise location of the sun in the sky.

Local True Solar Time (LTST)

LTST is expressed as hours since midnight, on a 24-hour clock. Local true solar time (LTST) reads noon when the sun is directly over the local meridian. At 6 pm the local hour angle is 90° and at midnight the sun is directly behind the earth at an hour angle of 180°.

For sun east of the local meridian, the relationship between local hour angle (h) and LTST is,

$$h = \frac{\pi}{12}(LTST + 12\ hours)$$

For sun west of the local meridian, the relationship is,

$$h = \frac{\pi}{12}(LTST - 12\ hours)$$

Where:

Symbol	Description	Units
h	Local hour angle	radians
$LTST$	Local true solar time	hours

Standard Time (ST)

For convenience, time zones have been established for particular geographic regions within which all clocks read Standard Time (also called Local Clock Time or Civil Time). Standard Time (ST) is averaged for geographic regions, that are arbitrarily defined by local standard meridians, which are generally spaced 15° apart in the United States. Thus, clocks within the same time zone read the same time, and differ from cocks in the adjacent time zones by one hour. in most U.S. locations, Local Mean Standard Time is related to Standard Time by the equation,

$$LMST = ST - \frac{\xi}{15}(LSM - LLM)$$

Where:

Symbol	Description	Units
$LMST$	Local mean solar time	hours
ST	Standard time	hours
ξ	$\xi = -1$ west longitude $\xi = +1$ for east longitude	unitless

Universal Time Coordinate (UTC) or Greenwich Mean Time (GMT)

Time of day is often provided with reference to the Universal Time Coordinate (or Greenwich Mean Time). UTC or GMT is the Standard Time at the Prime Meridian (i.e. at zero degrees longitude or at Greenwich, England).

Solar or shortwave radiation is emitted by the sun and is concentrated at high wavelengths in the visible and near-infrared parts of the spectrum. Long-wave radiation emitted by the earth's surface and its atmosphere is concentrated in the lower wavelengths of the infrared. This distinct separation of wavelengths is due to the dramatic difference in temperature between the sun and the earth.

The physical manner in which radiation is absorbed and scattered varies according to wavelength. Important processes that affect solar radiation include absorption and scattering by clouds and absorption and scattering by gases (primarily ozone in the upper and water vapor in the lower atmosphere). Terrestrial radiation is affected by absorption and scattering by gaseous constituents of the atmosphere such as carbon dioxide, water vapor, and ozone.

Time series information for both short-wave and long-wave radiation are required input for water temperature models. These time series may be computed from atmospheric variables (air temperature, relative humidity, cloudiness), or they may be measured directly using a pyranometer. A third source of estimated radiation is satellite information. This section provides an overview of methods for computing short-wave and long-wave radiation.

The magnitude of solar radiation reaching the top of the earth's atmosphere is a straight forward calculation based on the solar altitude (varying with the day of year, time of day, and location of the observer on the earth's surface), and a small adjustment do to irregularity of the earth's orbit (equation of time).

However, as the solar beam passes through the atmosphere, it is scattered and absorbed by clouds, atmospheric particles, and gasses. This reduces the magnitude of the direct solar beam and produces diffuse radiation.

Solar radiation is further attenuated (shaded) by physical objects in the path of the sun’s rays, such as tall banks, canyon walls, buildings and riparian vegetation. Some solar radiation is reflected by the water surface back to the atmosphere.

13.9.6.2 Solar Radiation (q_{SW})

In summary, four computational steps are necessary for computation of short-wave (solar) radiation. The magnitude of solar radiation at the top of the atmosphere is first computed. Next, this incoming radiation is reduced by atmospheric attenuation, shading, and reflection.

These processes are summarized by the equation

$$q_{sw} = H_o\,(1 - R_s)\,a_t\,C_a(1 - S)$$

Where:

Symbol	Description	Units
H_o	Extraterrestrial radiation	$\mathrm{W/m^2}$
R_s	Albedo (Reflection coefficient)	unitless
a_t	Atmospheric Transmission	unitless
C_a	Cloudiness (Percentage not absorbed by clouds)	unitless
S	Shade factor (Percentage shaded)	unitless

13.9.6.2.1 Reflection Coefficient (Rs)

Albedo is the fraction of downwelling solar radiation that is reflected at the earth's surface. It is a strong function of color, ranging form 0.95 for fresh white snow, to 0.05 for dark wet soil. When the sun is directly overhead a smooth water surface, the albedo is approximately 0.05, increasing nearly to 1.0 as the sun approaches sunrise or sunset. The albedo of a water surface is also a function of wave state, a minimal consideration in all but very large rivers.

The reflictivity or albedo of a smooth water surface is estimated as,

$$R_s = AS^B$$

Where:

Symbol	Description	Units
R_s	Reflectivity of the water surface	$Unitless$

Symbol	Description	Units
S	Solar altitude	$Degrees$
A	Coefficient that depends on cloud cover	$1/Degrees$
B	Coefficient that depends on cloud cover	$Unitless$

Description	Fraction Cloud Cover	A	B
Clear	$C_L \leq 1.0$	1.18	-0.77
Scattered	$1 < C_L \leq 0.5$	2.2	-0.97
Broken	$0.5 < C_L \leq 0.9$	0.95	-0.75
Overcast	$C_L \geq 0.9$	0.33	-0.45

13.9.6.2.2 Atmospheric Attenuation (a_t)

13.9.6.2.3 Extraterrestrial Radiation (H_o)

Extraterrestrial radiation is an expression of the short-wave radiation on a horizontal plane at the top of the atmosphere.

$$H_o = \frac{I_o}{r^2} \, sin\alpha$$

Where:

Symbol	Description	Units
H_o	Extraterrestrial radiation	$\mathrm{W/m^2}$
I_o	Solar irradiance	$\mathrm{W/m^2}$
r	Relative distance between earth and sun	

Symbol	Description	Units
α	Solar altitude	radians

13.9.6.2.3.1 Solar Irradiance (I_o)

Solar irradiance is is the intensity of solar radiation at the top of the earth's atmosphere, and is not user specified.

Solar irradiance has been set to:

$I_o = 1367\ W/m^2$

13.9.6.2.3.2 Relative Distance Between Earth and Sun (r)

The relative distance between the earth and sun is estimated as

$$r = 1.0 + 0.017\ cos[\frac{2\pi}{365}(186 - D)]$$

Where:

Symbol	Description	Units
r	Relative distance between earth and sun	
D	Day of the year (1 on January 1st)	

13.9.6.2.3.3 Solar Altitude

The solar altitude is the angle between the sun and the horizon (radians).

It is computed as:

$sin\alpha = sin\phi\ sin\delta + cos\phi\ cos\delta\ cosh$

Where:

Symbol	Description	Units
α	Solar altitude	radians
ϕ	Latitude	radians

Symbol	Description	Units
δ	Declination	radians
h	Hour angle	radians

Solar declination

Because the earth's axis is not perpendicular to its orbit around the sun, the declination (the angle between the sun and the plan the earth's equator) changes throughout the year. In the Northern Hemisphere, the longest day (the summer solstice) occurs around June 21st. The shortest day (the winter solstice) occurs around December 22nd. At these times, the declination is at its maximum and minimum value.

The maximum value of the declination, positive or negative, is approximately 23.45°.

The equation is computed as:

$$\delta = 23.45(\frac{2\pi}{360})\ cos[\frac{2\pi}{365}(172 - D)]$$

Where:

Symbol	Description	Units
δ	Declination	$radians$
D	Day of year (1 on January 1st)	unitless

Hour Angle

Local hour angle (or hour angle) is a complicated function of time of day and location. Computing it requires a number of computations that ultimately relate the time of day as read on a local clock, to the precise location of the sun in the sky.

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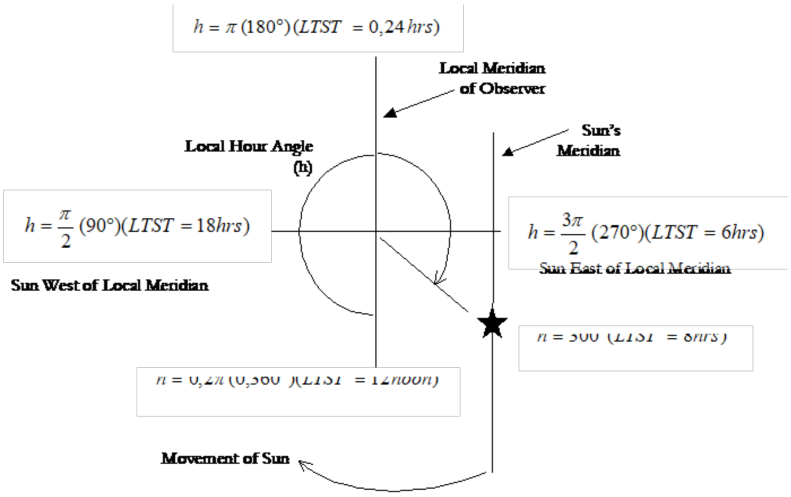

For sun east of the local meridian, the relationship between local hour angle (h) and LTST is,

$$h = \frac{\pi}{12}(LTST + 12\ hours)$$

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$$h = \frac{\pi}{12}(LTST - 12\ hours)$$

Where:

Symbol	Description	Units
h	Local hour angle	radians
$LTST$	Local true solar time	hours

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Where:

Symbol	Description	Units
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ξ	$\xi = -1$ west longitude $\xi = +1$ for east longitude	unitless

Universal Time Coordinate (UTC) or Greenwich Mean Time (GMT)

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13.9.7 COPY Atmospheric Longwave (Downwelling) Radiation

Upwelling (or back) longwave radiation is computed as:

$q_{atm} = \varepsilon_a \sigma T_{ak}^4$ (19-28)
ε_a=emissivity of air (unitless)
Computed value f(air temperature, cloudiness)
σ=Stefan Boltzman constant (W m^{-2} K^{-1})
Physical constant.
T_{ak}=air temperature (K)
Air temperature is a user entered time series value.

13.9.8 COPY Back Longwave (Upwelling) Radiation

Upwelling (or back) longwave radiation is computed as:

$q_b = \varepsilon_w \sigma T_{wK}^4$ (19-29)
ε_w=emissivity of water (unitless)
Assumed constant (set to 0.97)
Twk=water temperature (K)
Water temperature is a state variable. Computed value from previous time step is used.

13.9.9 COPY Surface Fluxes

The surface fluxes (latent and sensible heat) are closely related in their formulation. Both are flux gradient approximations. Both fluxes include an empirical wind function that is adjustable using the 'a', 'b' and 'c' coefficients.

13.9.9.1 Latent Heat

$$q_{l} = \frac{0.622}{P} L \rho_w (es - ea) f(U) \quad (19\text{-}30)$$

P = atmospheric pressure (mb)
User entered time series
L = latent heat of vaporization (J kg^{-1})
Computed as function of water temperature
ρw = density of water (kg m^{-3})
Computed as function of water temperature
es = saturated vapor pressure at water temperature (mb)
Computed as function of water temperature
ea = vapor pressure of overlying air (mb)
User entered time series
f(U) = the wind function (m s^{-1})
User entered time series adjusted with user entered parameters

13.9.9.2 Sensible Heat

$$q_h = \left(\frac{K_h}{K_w}\right) C_p \rho_w (Ta - Tw) f(U) \quad (19\text{-}31)$$

C_p = specific heat of air at constant pressure (J kg^{-1} C^{-1})
Constant
Ta = air temperature (C)
User entered time series
Tw = water surface temperature (C)
Water temperature is a state variable. Computed value from previous time step is used.
f(U) = wind function (m s^{-1})
Same as wind function in latent heat formulation
K_h/K_w = diffusivity ratio (unitless)
The diffusivity ratio **(K_h/K_w)** is a parameter that allows the user to partition flux between latent and sensible heat. It is generally set to unity but is allowed by the software to range between 0.5 and 1.5. A range of 0.9 to 1.1 is recommended.
The wind function is:

$$f(U) = R\left[a + bU^{c}\right] \quad (19\text{-}32)$$

a = user entered calibration coefficient on order of 10-6
b = user entered calibration coefficient on order of 10-6
c = user entered coefficient on order of one
R = a function of the Richardson number set by the software to one unless the **Use Richardson Number…** box has been checked. R is a function of air temperature, water temperature, and wind speed, varying from .03 under very stable conditions to 12.3 under unstable conditions.
The Richardson number is a measure of atmospheric stability. Without the Richardson number included in the wind function, the function tends to underestimate mixing processes under unstable atmospheric conditions, under predicting the surface fluxes. The converse is also true. Without the Richardson number, the function tends to over predict the surface fluxes under stable conditions.
The Richardson number is computed as:

$$Ri = -\frac{g(\rho_{air} - \rho_{sat})z}{\rho_{air}u^2} \qquad (19\text{-}33)$$

G = gravity (9.806 m s^{-2})

ρ_{air} = density of moist air (at air temperature) (kg m^{-3})

ρ_{sat} = density of saturated air (at water temperature) (kg m^{-3})

z = elevation of the recording station (m)

User entered physical description of the meteorological data set

u = wind speed (m s^{-1})

User entered time series

The Richardson number is positive for stable atmospheric conditions, negative for unstable, and near zero for neutral conditions.

The multiplier included in the wind function is set to unity unless the **Use Richardson number…** box is checked. If the box is checked, the multiplier is computed as a function of the Richardson number.

For an unstable atmosphere ($\rho_{air} > \rho_{sat}$):

$$R = 123 \text{ for } -1 > Ri$$

$$R = (1 - 22Ri)^{0.80} \text{ for } -0.01 \geq Ri > -1$$

For a neutral atmosphere:

$$R = 1 \text{ for } -0.01 < Ri < 0.01$$

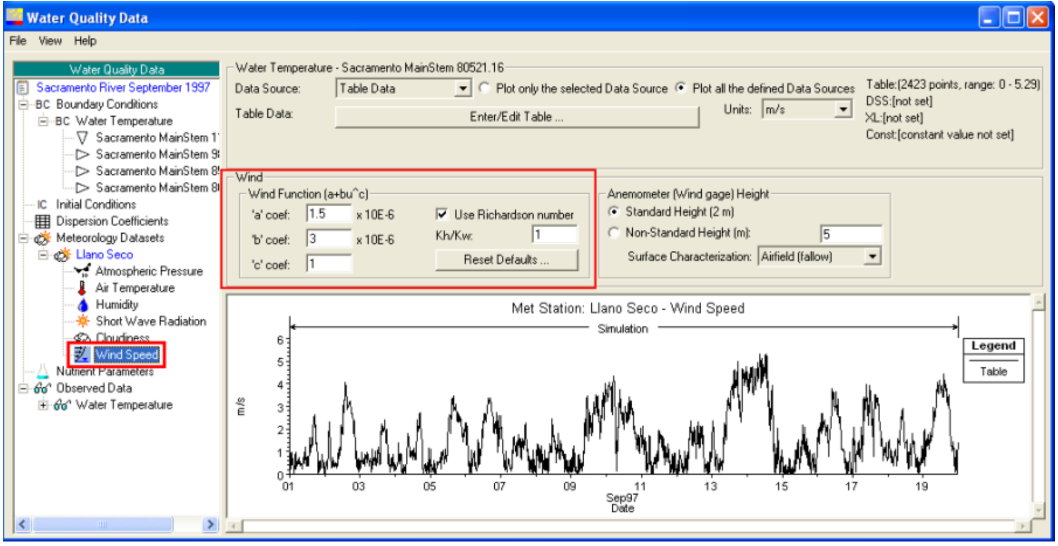
For a stable atmosphere ($\rho_{air} < \rho_{sat}$):

$$R = (1 + 34Ri)^{-0.80} \text{ for } 0.01 \leq Ri \leq 2$$

$$R = 0.03 \text{ for } 2 < Ri$$

Latent and sensible heat are difficult fluxes to estimate. The parameters provided are appropriate for many cases, but it important to keep in mind that some combinations can result in flux estimates that are not physically possible. The model will report individual energy budget terms in both time series format and spatial plots. Review of the magnitudes of latent and sensible heat fluxes is an important step in water temperature modeling that should not be overlooked.

The 'a', 'b' and 'c' coefficients and the diffusivity ratio are entered in the wind speed submenu in the Water Quality Data window (Figure 19-36). Checking the **Use Richardson number** box includes the Richardson number in the wind function. Leaving this box unchecked sets the Richardson number to one.



Water Temperature - Sacramento MainStem 80521.16

Data Source: Table Data ☐ Plot only the selected Data Source ● Plot all the defined Data Sources

Units: m/s

Table:[2423 points, range: 0 - 5.29]
DSS:[not set]
XL:[not set]
Const:[constant value not set]

Wind

Wind Function (a+bu^c)

'a' coef: 1.5 x 10E-6
'b' coef: 3 x 10E-6
'c' coef: 1

☑ Use Richardson number

Kh/Kw: 1

Anemometer (Wind gage) Height

● Standard Height (2 m)
○ Non-Standard Height (m): 5

Surface Characterization: Airfield (fallow)

Figure 19-36. Adjusting the wind function calibration parameters.