The Stream Temperature Model Component

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This document describes the Stream Temperature model component (STMComponent) that solves the one-dimensional advection dispersion equation using the explicit finite volume approximation for heat and solute transport over any type of stream/river network. The STMComponent was developed to be primarily used within the HydroCouple component-based modeling framework (Buahin and Horsburgh, 2016). However, it can be compiled and executed as a standalone executable.

1. Formulations

The 1D advection dispersion heat transport equation that is solved by the STMComponent model is shown in Equation 1.

$$\rho_w c_p \frac{\partial T}{\partial t} = -\rho_w c_p \frac{\partial (vT)}{\partial x} + \rho_w c_p \frac{\partial}{\partial x}\left(D \frac{\partial T}{\partial x}\right) + \sum \frac{\Phi}{\mathrm{Y}} + \sum S \tag{1}$$

where T is the water temperature $(\mathrm{°C})$, t is the time (s), v is the velocity of the water in the channel $\left(\frac{\mathrm{m}}{\mathrm{s}}\right)$, x is the distance along the channel (m), D longitudinal dispersion $\left(\frac{\mathrm{m}^2}{\mathrm{s}}\right)$, ρ_w is the water density $\left(\frac{\mathrm{kg}}{\mathrm{m}^3}\right)$, c_p is the specific heat capacity of water $\left(\frac{\mathrm{J}}{\mathrm{kg.°C}}\right)$, T is the temperature of the water (K), Φ are external radiant heat fluxes $\left(\frac{\mathrm{J}}{\mathrm{m}^2\mathrm{s}}\ or\ \frac{\mathrm{W}}{\mathrm{m}^2}\right)$ incident on the water surface, S are heat supplied by other external sources $\left(\frac{\mathrm{J}}{\mathrm{m}^3\mathrm{s}}\right)$, Y is the depth of water in the channel (m). Equation 1 is approximated numerically using the finite volume method as shown subsequently. The integral version of Equation 1 over a time step from t to Δt over the control volume i (i.e., CV_i in Figure 1) is shown in Equation 2.

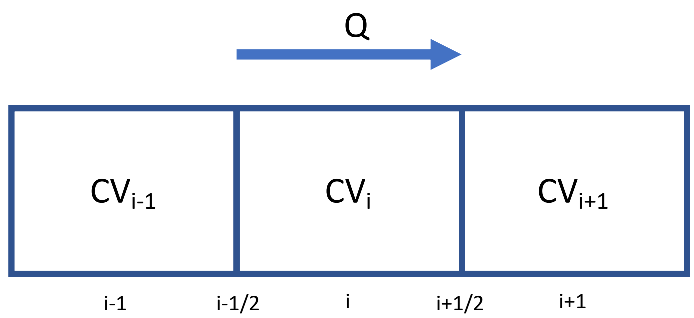

Figure 1. 1D control volume

$$\rho_w c_w \int_t^{t+\Delta t} \int_{CV} \frac{\partial T}{\partial t} dV dt = \rho_w c_w \int_t^{t+\Delta t} \int_{CV} \left(-\frac{\partial (vT)}{\partial x}\right) dV dt + \rho_w c_w \int_t^{t+\Delta t} \int_{CV} \frac{\partial}{\partial x}\left(D \frac{\partial T}{\partial x}\right) dV dt +$$

$$\int_t^{t+\Delta t} \int_{CV} \sum \frac{\Phi}{\mathrm{Y}} dV dt + \int_t^{t+\Delta t} \int_{CV} \sum S \, dV dt \tag{2}$$

where V is the volume of the CV (m^3), t represents the current time step (s), and $t + \Delta t$ represents the next time step where we seek a solution. Using Gauss's divergence theorem and expanding the terms for Equation 3 yields:

$$\int_t^{t+\Delta t} \rho_w c_w \frac{\partial T}{\partial t} V \, dt = \int_t^{t+\Delta t} \rho_w c_w \sum_{k=1}^{NB} (-vTA) \, dt + \int_t^{t+\Delta t} \rho_w c_w \sum_{k=1}^{NB} \left(D \frac{\partial T}{\partial x} A\right) dt +$$

$$\int_t^{t+\Delta t} \sum \frac{\Phi}{\mathrm{Y}} V dt + \int_t^{t+\Delta t} \sum S \, V dt \tag{3}$$

where NB represents the number of inlet and outlet boundaries for the CV, $\sum_{k=1}^{NB}(-vTA)$ represents summation of the advective heat fluxes across the inlet and outlet boundaries of the CV, $\sum_{k=1}^{NB}\left(D \frac{\partial T}{\partial x} A\right)$ represents the sum of the dispersive heat fluxes across the inlet and outlet boundaries of the CV, and A is the cross sectional (m^2) of flow. Using an explicit time marching approximation for the CV depicted in Figure 1 yields Equation 4, which is expands to Equation 5.

$$\rho_w c_w \frac{T_i^{t+\Delta t} - T_i^t}{\Delta t} V_i = \rho_w c_w \sum_{k=1}^{NI} (-QT)_i^t + \rho_w c_w \sum_{k=1}^{NI} \left(D \frac{\partial T}{\partial x} A\right)_i^t + \left(\sum \frac{\Phi}{\mathrm{Y}} V\right)_i^t + \left(\sum S \, V\right)_i^t \tag{4}$$

$$\rho_w c_w \frac{T_i^{t+\Delta t} - T_i^t}{\Delta t} V_i = \overbrace{\rho_w c_w (QT)_{i-\frac{1}{2}}^t - \rho_w c_w (QT)_{i+\frac{1}{2}}^t}^{Advection} + \overbrace{\rho_w c_w \left(D \frac{\partial T}{\partial x} A\right)_{i+\frac{1}{2}}^t - \rho_w c_w \left(D \frac{\partial T}{\partial x} A\right)_{i-\frac{1}{2}}^t}^{Dispersion} + \overbrace{\left(\sum \frac{\Phi}{\Upsilon} V\right)_i^t + \left(\sum S\, V\right)_i^t}^{External\ Sources}$$

where fluxes out of the CV take on positive values, fluxes into the CV take on negative values, values with the superscripts t and $t + \Delta t$ represent values at the current time step and next time step respectively, values with the subscripts i, $i - \frac{1}{2}$, and $i + \frac{1}{2}$ represent values at the current CV, its left boundary, and right boundary respectively, Δt is the time step (s), and Q is the flow for the CV $\left(\frac{\mathrm{m}^3}{\mathrm{s}}\right)$.

External sources of heat fluxes, including latent heat from evaporation and condensation as well as sensible heat exchanges from conduction and convection with the atmosphere can be specified in the input file or retrieved from other models that are coupled to the STMComponent.

1.1 Advection

Several methods are available for discretizing the advection terms in Equation 5. These include the upwind, central and hybrid differencing methods. Additionally, several total variation diminishing (TVD; Harten, 1983) schemes are also available for problems that have sharp discontinuities in their solution domain. An exhaustive treatment of TVD schemes is provided by Versteeg and Malalasekera (2007) and are not described here.

For the first-order accurate upwind differencing scheme, the assumptions made for inlet and outlet advective heat fluxes for boundaries of the control volume are prescribed as follows:

$$\rho_w c_w (QT)_{i-\frac{1}{2}} = \rho_w c_w Q_{i-\frac{1}{2}} T_{i-1} \tag{5}$$

$$\rho_w c_w (QT)_{i+\frac{1}{2}} = \rho_w c_w Q_{i+\frac{1}{2}} T_i \tag{6}$$

For the second-order accurate central differencing scheme, the inlet and outlet advective heat fluxes at the boundaries of the control volume are interpolated using the inverse distance weighting (IDW) interpolation scheme as shown in equations 7 and 8.

$$\rho_w c_w (QT)_{i-\frac{1}{2}} = \rho_w c_w Q_{i-\frac{1}{2}} \frac{\left(T_{i-1}\left(x_{i-\frac{1}{2}} - x_{i-1}\right) + T_i\left(x_i - x_{i-\frac{1}{2}}\right)\right)}{x_i - x_{i-1}} \tag{7}$$

$$\rho_w c_w (QT)_{i+\frac{1}{2}} = \rho_w c_w Q_{i+\frac{1}{2}} \frac{\left(T_i\left(x_{i+\frac{1}{2}} - x_i\right) + T_{i+1}\left(x_{i+1} - x_{i+\frac{1}{2}}\right)\right)}{x_{i+1} - x_i} \tag{8}$$

While the upwind differencing scheme is stable, it is only first order accurate, which gives rise to false diffusion. This contrasts with the central differencing scheme, which although second-order accurate, does not possess the transportiveness property (i.e., ability to account for flow direction as well as the upwind scheme especially for highly advective flows) (Versteeg and Malalasekera, 2007). The hybrid differencing scheme proposed by Spalding (1972) attempts to split these tradeoffs be assessing whether advection or dispersion is the dominant transport mechanism. The hybrid differencing scheme proceeds by first estimating the Peclet number (Pe) at the face of the control volume of interest as follows:

$$Pe_{i-\frac{1}{2}} = \frac{v_{i-\frac{1}{2}}}{\left(\frac{D_{i-\frac{1}{2}}}{x_i - x_{i-1}}\right)} \tag{9}$$

The flux through that face of the control volume is then estimated as follows:

$$\rho_w c_w (QT)_{i-\frac{1}{2}} = \rho_w c_w Q_{i-\frac{1}{2}} \left[f_{i-1}\, T_{i-1} \left(1 + \frac{1}{f_{i-1} Pe_{i-\frac{1}{2}}} \right) + f_i T_i \left(1 - \frac{1}{f_i Pe_{i-\frac{1}{2}}} \right) \right] \text{ for } -2 < Pe_{i-\frac{1}{2}} < 2 \quad (10)$$

$$\rho_w c_w (QT)_{i-\frac{1}{2}} = \rho_w c_w Q_{i-\frac{1}{2}} T_{i-1} \text{ for } Pe_{i-\frac{1}{2}} \geq 2 \quad (11)$$

$$\rho_w c_w (QT)_{i-\frac{1}{2}} = \rho_w c_w Q_{i-\frac{1}{2}} T_i \text{ for } Pe_{i-\frac{1}{2}} \leq -2 \quad (12)$$

where f_{i-1} and f_i are the IDW interpolation factors for the current and left control volumes that surround the boundary under consideration respectively.

1.2 Dispersion

The spatial gradients of temperature at inlet and outlet of the CV used for computing dispersion in Equation 4 is discretized numerically as follows:

$$\left. \frac{\partial T}{\partial x} \right|_{i-\frac{1}{2}} = \frac{T_i - T_{i-1}}{x_i - x_{i-1}} \quad (13)$$

$$\left. \frac{\partial T}{\partial x} \right|_{i+\frac{1}{2}} = \frac{T_{i+1} - T_i}{x_{i+1} - x_i} \quad (14)$$

Following the QUAL2K model, the STMComponent adopts the formulations by Fischer *et al.* (1979) to calculate longitudinal dispersion when it is not explicitly provided as follows:

$$D_i = 0.11 \frac{v_i^2 B_i^2}{Y_i U_i^*} \quad (15)$$

where B_i is the channel width (m), Y_i is the mean flow depth (m), and U_i^* is shear velocity $\left(\frac{m}{s}\right)$ of the CV. The shear velocity is calculated as:

$$U_i^* = \sqrt{g Y_i S_i} \quad (16)$$

where S_i is the channel slope. The computed dispersion coefficient is compared with the numerical dispersion estimated using Equation 17.

$$E_i = \frac{v_i(x_{i+1} - x_{i-1})}{2} \tag{17}$$

If the computed numerical dispersion is less than the computed dispersion in Equation 17, $D_i - E_i$ is used as the dispersion coefficient used in Equation 4 otherwise, the dispersion coefficient is set to zero.

1.3 Mass Balance at Junctions

Following Islam and Chaudhry (1998), internal junctions where 3 or more elements meet are treated as internal boundary conditions, where constituent concentrations or temperatures are estimated using the simple mass balance equation shown in Equation 18. This equation assumes complete mixing at the junction.

$$T_j = \frac{\sum_{i=1}^{M} Q_i T_i}{\sum_{i=1}^{M} Q_i} \tag{18}$$

where T_j is the temperature/constituent concentration at the junction of interest $\left(°C, \frac{kg}{m^3}\right)$, M is the number of elements with flows entering the junction, Q_i is the flow from incoming element i $\left(\frac{kg}{m^3}\right)$, and T_i is the temperature/constituent concentration in the incoming element i $\left(°C, \frac{kg}{m^3}\right)$.

1.4 Evaporation and Condensation Heat Fluxes

Evaporation/condensation is a function of the sensible heat carried with the evaporated water, the latent heat of evaporation, density of water, and the evaporative rate as expressed in Equation 19 (Webb and Zhang, 1997; Evans *et al.*, 1998; Boyd and Kasper, 2003).

$$\Phi_{evap} = -\rho_w L_e E \tag{19}$$

where L_e is the latent heat of vaporization $\left(\frac{J}{kg}\right)$ and E is the evaporative rate $\left(\frac{m}{s}\right)$. The latent heat of vaporization is estimated as a weak function of water temperature using Equation 20 (Martin and McCutcheon, 1998).

$$L_e = 1000(2499 - 2.36T) \tag{20}$$

where T is the water temperature in the channel (℃).

Several approaches are available to estimating the evaporative rate including mass transfer methods, explicit energy balance methods, and combination methods that combine both mass and energy balance methods. In the STMComponent, a mass balance method is implement. However, work is ongoing to incorporate other methods. Following Dingman (2008), the evaporative rate is estimated using Equation 21.

$$E = f(\vec{w})(e_s^w - e_a) \tag{21}$$

where e_s^w is the saturation vapor pressure of the evaporating surface (kPa), e_a is the actual vapor pressure (kPa), and $f(\vec{w})$ is a wind function used to estimate the adiabatic portion of evaporation (Boyd and Kasper, 2003). e_s^w is computed using Equation 22 (Raudkivi, 1979; Chapra, 2008).

$$e_s^w = 0.61275e^{\left(\frac{17.27T}{237.3+T}\right)} \tag{22}$$

The actual vapor pressure (e_a) is calculated as a function of relative humidity (H) and saturation vapor pressure (e_s) using Equation 23.

$$e_a = \frac{H}{100\%} e_s \tag{23}$$

where e_s is computed using equation 24.

$$e_s = 0.61275e^{\left(\frac{17.27T_a}{237.3+T_a}\right)} \tag{24}$$

where T_a is air temperature in $(°C)$.

Extensive observations have yielded Equation 25 as the general form of the wind function (Martin and McCutcheon, 1998; Shanahan *et al.*, 1984).

$$f(\vec{w}) = a + b\vec{w} \tag{25}$$

where a and b are empirical coefficients with units $kPa^{-1}ms^{-1}$ and kPa^{-1} respectively and $\vec{w}$ is the wind speed measured approximately 2 meters above the water surface $\left(\frac{m}{s}\right)$. Several authors have proposed values for these coefficients including Dunne and Leopold (1978), who proposed the values $1.505 \cdot 10^{-8}$ and $1.6 \cdot 10^{-8}$ for the coefficients a and b respectively. These values are used as the defaults in the STMComponent but can be overridden by user specified coefficients.

1.5 Convective and Conductive Heat Fluxes

Estimating sensible heat lost or gained through conduction/convection with air in the atmosphere is typically performed using the Bowen ratio (B_r), which relates latent heat to sensible heat (Equation 26) (Bowen, 1926; Webb and Zhang, 1997; Evans *et al.*, 1998; Westhoff *et al.*, 2007; Glose *et al.*, 2017).

$$B_r = \frac{\Phi_{sensible}}{\Phi_{evap}} \tag{26}$$

Martin and McCutcheon (1998) prescribed equation 26 for estimating the Bowen ratio.

$$B_r = \frac{\Phi_{sensible}}{\Phi_{evap}} = C_B \frac{P_a}{P}\left(\frac{T-T_a}{e_s^w-e_a}\right) \tag{27}$$

where C_B is a Bowen's coefficient usually equal to 0.0651 $\left(\frac{kPa}{°C}\right)$, P_a is atmospheric pressure (kPa), and, P is a reference pressure at sea level (kPa). While the ratio $\frac{P_a}{P}$ is often assumed to be unity, the pressure difference cannot be neglected in higher elevations (Martin and McCutcheon, 1998). For example, McCutcheon (1990) found $\frac{P_a}{P} = 0.83$ for the Arkansas River and the Pueblo Reservoir in Colorado at an elevation 1460m.

1.6 Longwave Back radiation

Longwave back radiation from the stream surface is calculated from the attenuated form of the Stefan- Boltzmann law (McCutcheon, 1990) as follows:

$$\Phi_{back\ radiation} = \varepsilon_w \sigma {T_w}^4 \tag{28}$$

where ε is the emissivity of the material, T_a is water temperature in the channel (K), and σ is the Stefan-Boltzmann constant $\left(\frac{W}{m^2K^4}\right)$.

1.7 Solvers

The STMComponent solves Equation 4 using several ordinary differential equation (ODE) solvers including the classical fourth order Runge-Kutta method (i.e., RK4) or the adaptive step size controlled fifth order Runge-Kutta-Cash-Carp (RKQS, Cash and Karp, 1990) method. Alternatively, users can select variable multistep methods including the Adams-Moulton (i.e., ADAMS) formulas or the Backward Differentiation Formulas (i.e., BDF) that are provided through the CVODE (Hindmarsh *et al.*, 2017) external ODE solver library.

2. Input File Format

The STMComponent input file format is illustrated below. Values can be separated by space, tab, or comma delimiters. Delimiters can be any length.

```
[OPTIONS]
START_DATETIME 5/01/2017 0:00:00
END_DATETIME   5/10/2017 0:00:00
REPORT_INTERVAL 900.0

[OUTPUTS]
;;OUTPUT_TYPE    FILEPATH
;;=======================
NETCDF ./green_river_test2.nc

[SOLUTES]
;;SOLUTE_NAME  SOLVER_TYPE  SOLVER_ABS_TOL  SOLVER_REL_TOL
;;==========================================================
Salinity    ADAMS    1E-10    1E-8

[ELEMENTJUNCTIONS]
;;JUNCTION  X          Y          Z
;;===================================
J1          0.0        0.0        1717.0
J2          1000.0     0.0        1717.0
J3          2000.0     0.0        1717.0

[ELEMENTS]
;;ELEMENT  FROMJUNCTION  TOJUNCTION  LENGTH  DEPTH  XSECTION_AREA  WIDTH  SLOPE  FLOW  DISPERSION_COEFF  TEMPERATURE  SOLUTE1_CONC
;;=============================================================================================================================
E1         J1            J2          1000    0.1    5.4            54     0.0021  0.010  0.000            5.500        0.1
E2         J2            J3          1000    0.1    5.4            54     0.0021  0.010  0.000            5.500        0.1

[UNIFORM_HYDRAULICS]
;;START_ELEMENT    END_ELEMENT    VARIABLE    TYPE    VALUE/FILEPATH
;;=================================================================

[NON_UNIFORM_HYDRAULICS]
;;VARIABLE  FILEPATH
;;==================
FLOW     ./flow.csv
DEPTH    ./depth.csv
XSECTION_AREA ./xsection_area.csv

[BOUNDARY_CONDITIONS]
```

```
;;JUNCTION  VARIABLE     TYPE   VALUE/FILEPATH
;;============================================
J1         TEMPERATURE    FILE    ./hw_temp.csv

[POINT_SOURCES]
;;ELEMENT  VARIABLE      TYPE    VALUE/FILEPATH
;;===================================================
E104       TEMPERATURE   FILE    ./yampa_temp_flux.csv

[NON_POINT_SOURCES]
;;START_ELEMENT   START_ELEMENT_LFACTOR    END_ELEMENT    END_ELEMENT_LFACTOR    VARIABLE    TYPE    VALUE/FILEPATH
;;==================================================================================================================

[UNIFORM_RADIATIVE_FLUXES]
;;START_ELEMENT    END_ELEMENT    TYPE    VALUE/FILEPATH
;;=====================================================
E1               E150          FILE    ./rad_flux.csv

[NON_UNIFORM_RADIATIVE_FLUXES]
;;FILEPATH
;;==================

[UNIFORM_METEOROLOGY]
;;START_ELEMENT    END_ELEMENT    VARIABLE          TYPE    VALUE/FILEPATH
;;=========================================================================
E1               E150          RELATIVE_HUMIDITY FILE    ./rel_humid.csv
E1               E150          AIR_TEMPERATURE    FILE    ./air_temp.csv
E1               E150          WIND_SPEED         FILE    ./wind_speed.csv

[NON_UNIFORM_METEOROLOGY]
;;VARIABLE    FILEPATH
;;====================
```

Tag	Values	Required	Description
[OPTIONS]			
START_DATETIME	Simulation start date and time with format MM/dd/yyyy hh:mm:ss	Yes	Simulation start time must be less than the end time
END_DATETIME	Simulation end date and time with format MM/dd/yyyy hh:mm:ss	Yes	
REPORT_INTERVAL	Model reporting interval in units of seconds	Yes	This value must be specified and must be greater than zero but less than the simulation period
USE_ADAPTIVE_TIME_STEP	Yes/No indicating whether to use the adaptive time step option	No	The adaptive time step is computed as the smallest time step computed from the Courant condition. Default = Yes.

MAX_TIME_STEP	The maximum time step in seconds that can be used when the adaptive timestep option is selected. This also serves as the default time step when the adaptive timestep option is turned off.	No	Default = 0.5 seconds
MIN_TIME_STEP	The minimum time step in seconds that can be used when the adaptive timestep option is selected.	No	Default = 0.0001 seconds
TIME_STEP_RELAXATION_FACTOR	A relaxation factor typically greater than 0 but less than 1.0 that is multiplied by the adaptive timestep calculated	No	Default = 0.8
NUM_INITIAL_FIXED_STEPS	The minimum timestep is used for this specified number of times at the beginning of the simulation to ensure the stability of the model at the onset of the simulation	No	Default = 2
ADVECTION_MODE	The advection mode to use in computing the spatial derivatives. Options are UPWIND/CENTRAL/HYBRID/TVD	No	UPWIND: Upwind differencing scheme (Default) CENTRAL: Central differencing scheme HYBRID: Adaptive scheme that used upwind or central depending on the Peclet number TVD: Total variation diminishing scheme
TVD_SCHEME	If TVD scheme is selected, this option can be specified to indicate what specified TVD scheme to use. This option has not been implemented yet.	No	
COMPUTE_DISPERSION	Yes/No indicating whether to include dispersion	No	Default = No
TEMP_SOLVER	Temperature solver type to use. Options are RK4/RKQS/ADAMS/BDF	No	RK4: Fourth order Runge Kutta. Fastest but step size needs to be small. RKQS: Adaptive Step Size method that used the 5^{th} order Cash-Karp Runge-Kutta method ADAMS: Adams-Moulton formulas from CVODE. Default. Recommended. BDF: Backward differentiation formulas from CVODE
TEMP_SOLVER_ABS_TOL	Solver convergence absolute tolerance	No	Default = 1e-8
TEMP_SOLVER_REL_TOL	Solver convergence relative tolerance	No	Default = 1e-4
WATER_DENSITY	Density of water kg/m^3	No	Default = 1000
WATER_SPECIFIC_HEAT_CAPACITY	Specific heat capacity of water (J/kg/C)	No	Default = 4184
EVAPORATION	Yes/No indicating whether to turn evaporation on or not.	No	Default = No
CONVECTION	Yes/No indicating whether to turn of sensible heat fluxes	No	Default = No. Additionally7, it will not be computed if evaporation is turned off.
WIND_FUNC_COEFF_A	Wind function coefficient A (m/kPa/s)	No	Default = 1.505 * 10e-8
WIND_FUNC_COEFF_B	Wind function coefficient B (kPa)	No	Default = 1.600 * 10e-8
BOWENS_COEFF	Bowens equation coefficient (kPa/C)	No	Default = 0.061
PRESSURE_RATIO	Pressure ration between atmosphere and reference pressure at sea-level	No	Default = 1.0
NUM_SOLUTES	Number of solutes	No	Default = 0
VERBOSE	Yes/No whether to print intermediate output summary to console.	No	Default = No
PRINT_FREQ	Number indicating the number of timesteps between console prints	No	Default =10
FLUSH_TO_DISK_FREQ	Number of outputs to save in memory before writing to disk	No	Default = 10

[OUTPUTS]			
OUTPUT_TYPE	CSV/NETCDF	Yes	NETCDF output recommended because more extensive outputs are written
FILE_PATH	Path to save file	Yes	
[SOLUTES]			
SOLUTE_NAME	Name of solute without spaces	Yes	Solute names must match the number of solutes specified
SOLVER_TYPE	Solver type to use. Options are RK4/RKQS/ADAMS/BDF	Yes	
SOLVER_ABS_TOL	Solver convergence absolute tolerance	Yes	
SOLVER_REL_TOL	Solver convergence relative tolerance	Yes	
[ELEMENTJUNCTIONS]			
JUNCTION	Identifier for the upstream and downstream junctions of computation elements	Yes	Identifiers must be unique short strings
X	X location of element junction	Yes	Are not used in the computation but are necessary for coupling to see which elements overlap
Y	X location of element junction	Yes	Are not used in the computation but are necessary for coupling to see which elements overlap
Z	Z location of element junction	Yes	Are not used in the computation but are necessary for coupling to see which elements overlap
[ELEMENTS]			
ELEMENT	Identifier for computational element	Yes	Identifiers must be unique short strings
FROMJUNCTION	Upstream junction identifier	Yes	
TOJUNCTION	Downstream junction identifier	Yes	
LENGTH	Length of element (m)	Yes	
DEPTH	Flow depth of element (m)	Yes	
XSECTION_AREA	Flow cross sectional area of element (m^2)	Yes	
WIDTH	Flow width of element (m)	Yes	
SLOPE	Slope of element	Yes	
FLOW	Flow in element (m^3/s)	Yes	
DISPERSION_COEFF	Dispersion coefficient to use (m^2/s)	Yes	
TEMPERATURE	Temperature of water in element (C)	Yes	
SOLUTE_CONC1	Concentration of first solute if initialized	No	Added multiple times up to the number of solutes specified
[BOUNDARY_CONDITIONS]			
JUNCTION	Junction identifier	Yes	
VARIABLE	Temperature or name of solute	Yes	
TYPE	File/Value indicating whether values are to be read from an external file or a single value	Yes	
VALUE/FILEPATH	Value of file path to read the time varying boundary condition	Yes	Time series file must have a first row with header information. Subsequent rows must have datetime and values comma or tab separated.

			DateTime must have format MM/dd/yyyy hh:mm:ss
[POINT_SOURCES]			
ELEMENT	Identifier for computational element	Yes	
VARIABLE	HEAT/FLOW/solute name with units of J/s, m^3/s, and kg/s respectively	Yes	When FLOW is specified, the incoming flow is assumed to be the temperature of the element
TYPE	VALUE/FILE	Yes	
VALUE/FILEPATH	Numeric value or file path to timeseries file	Yes	
[NON_POINT_SOURCES]			
START_ELEMENT	Identifier for upstream computational element to apply the non-point source	Yes	
START_ELEMENT_LFACTOR	Fraction of the length of element to apply the source on the upstream element	Yes	
END_ELEMENT	Identifier for downstream computational element to apply the non-point source	Yes	
END_ELEMENT_LFACTOR	Fraction of the length of the element to apply the downstream source	Yes	
VARIABLE	HEAT/FLOW/solute name with units of J/s/m, m^3/s/m, and kg/s/m respectively	Yes	Value of source must be in source per unit length
TYPE	VALUE/FILE	Yes	
VALUE/FILEPATH	Numeric value or file path to timeseries file	Yes	
[UNIFORM_HYDRAULICS]			
START_ELEMENT	Identifier for upstream computational element to apply the hydraulics	Yes	
END_ELEMENT	Identifier for downstream computational element to apply the hydraulics	Yes	
VARIABLE	DEPTH/WIDTH/XSECTION_AREA/FLOW	Yes	
TYPE	VALUE/FILE	Yes	
VALUE/FILEPATH	Numeric value or file path to timeseries file	Yes	
[NON_UNIFORM_HYDRAULICS]			
VARIABLE	DEPTH/WIDTH/XSECTION_AREA/FLOW	Yes	
FILEPATH	File path to timeseries file	Yes	Column headers must correspond to element ids
[UNIFORM_RADIATIVE_FLUXES]			
START_ELEMENT	Identifier for upstream computational element to apply the radiation flues	Yes	
END_ELEMENT	Identifier for downstream computational element to apply the hydraulics	Yes	
TYPE	VALUE/FILE	Yes	
VALUE/FILEPATH	Numeric value or file path to timeseries file	Yes	Values must be in units of W/m^2
[NON_UNIFORM_RADIATIVE_FLUXES]			
FILEPATH	Path to time series file	Yes	Column header names must match element identifiers
[UNIFORM_METEOROLOGY]			
START_ELEMENT	Identifier for upstream computational element to apply the meteorology	Yes	

END_ELEMENT	Identifier for downstream computational element to apply the meteorology	Yes	
VARIABLE	RELATIVE_HUMIDITY/AIR_TEMPERATURE/WIND_SPEED	Yes	
TYPE	VALUE/FILE	Yes	
VALUE/FILEPATH	Numeric value or file path to timeseries file	Yes	
[NON_UNIFORM_METEOROLOGY]			
VARIABLE	RELATIVE_HUMIDITY/AIR_TEMPERATURE/WIND_SPEED	Yes	
FILEPATH	Filepath to timeseries file	Yes	Column header names must match element identifiers

References

Bowen, I.S., 1926. The Ratio of Heat Losses by Conduction and by Evaporation from Any Water Surface. Physical Review 27:779–787.

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