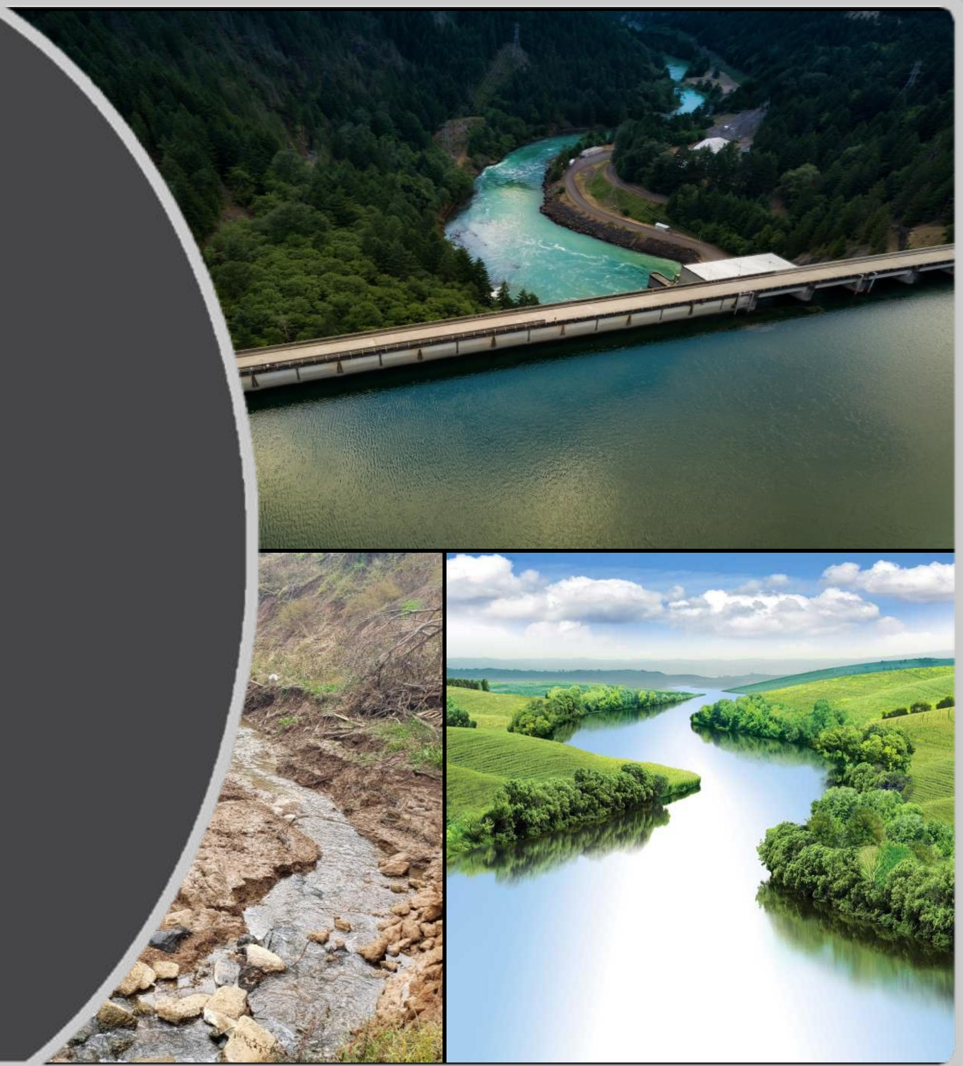
WATER TEMPERATURE CASE STUDY



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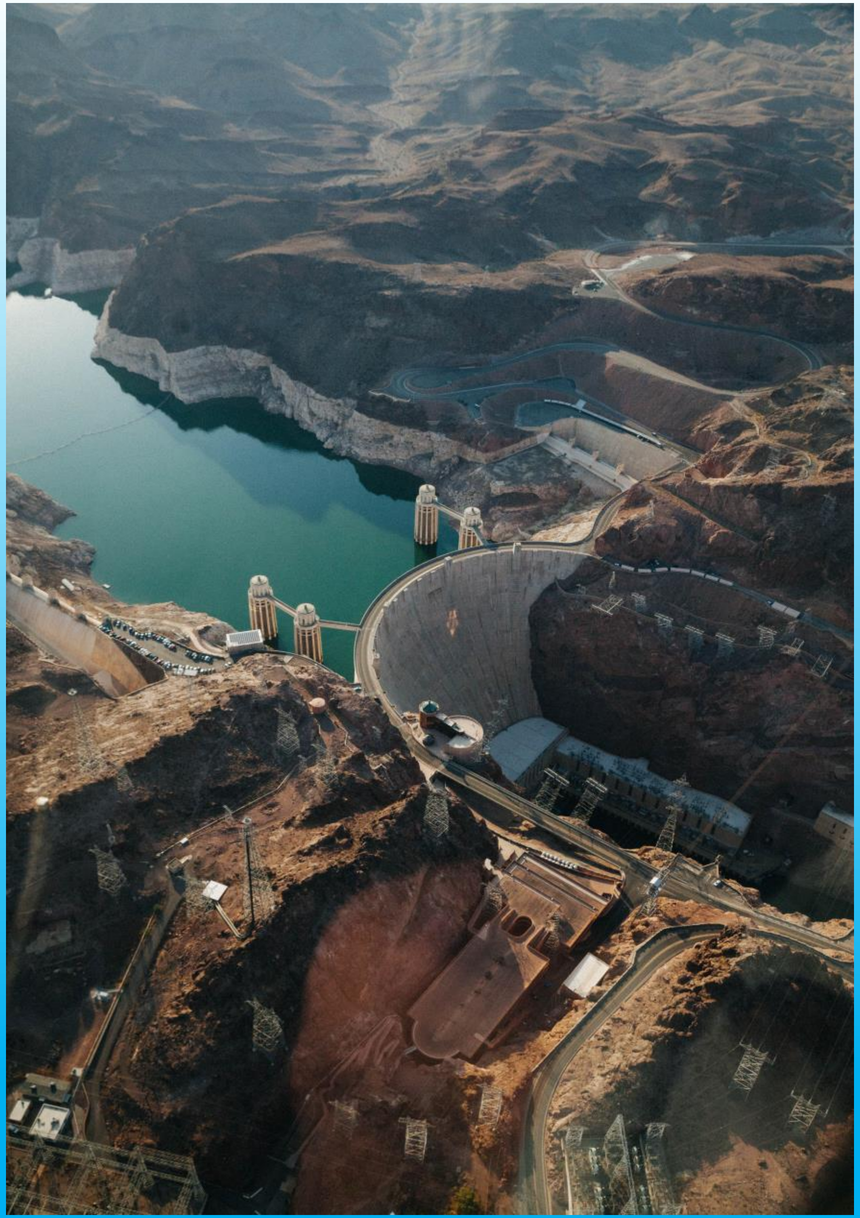
CE-QUAL-W2 Workshop

August 16 - 18, 2022

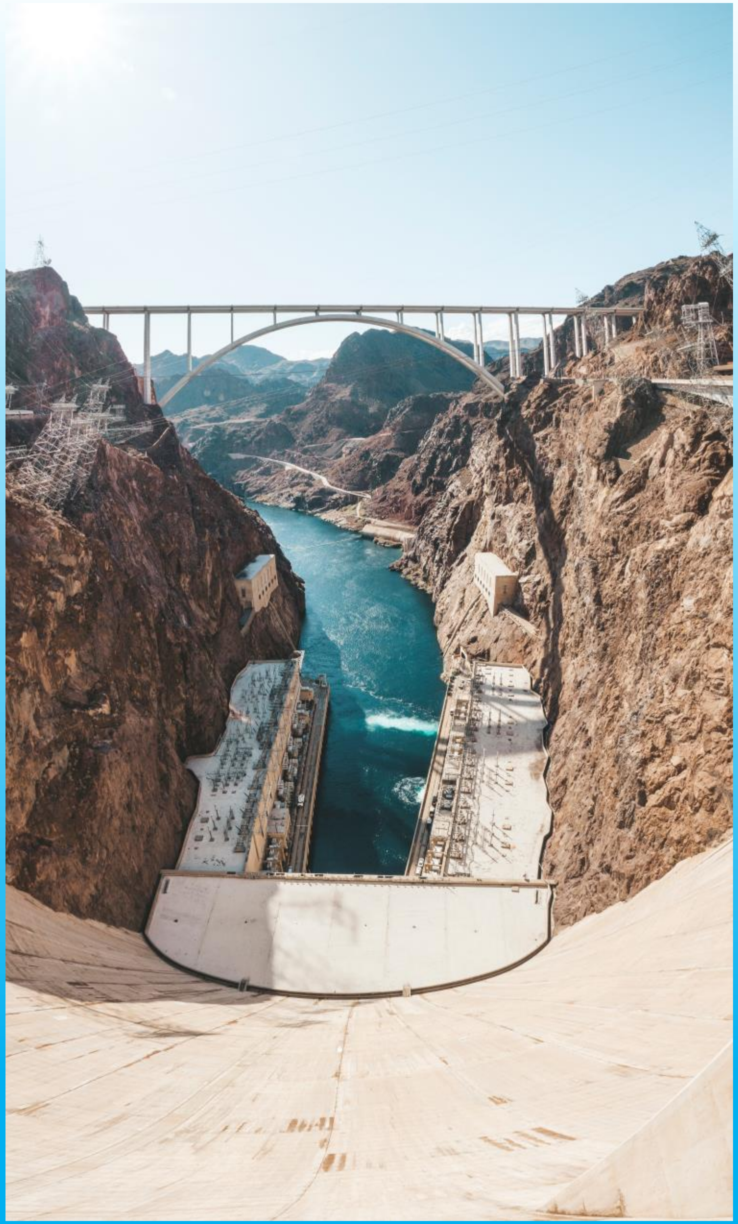
Case Study Overview

- We will offer a 15-minute case study demonstration, which will walk through the model files
- Participants will become familiar with the location of temperature inputs and outputs in CE-QUAL-W2.
- We will focus on where temperature-related parameters appear in the control file, and the input and output files associated with running a successful temperature model.
- We will tie the theory section of the user-manual to the input/output section of the user-manual.
- This will be followed by a case-study where water quality parameters are changed, and output is analyzed.



Start with an existing model

- We will use the DeGray Reservoir model, which is available automatically in the CE-QUAL-W2 download. It is currently set up to model sediment-diagenesis and vertical algae migration.
- We will edit it until it features only the essentials for modeling temperature.
- We are satisfied with the bathymetry and will not change it for this case study. It is simple, with one main waterbody and branch.



W2 Model Input Files

Organized by File Directory – for me, C:\Users\b2edhijm\Documents\Projects\ERDC Steiss\August 22 Tutorial\Temperature Workshop\Practice\DeGray Reservoir with sediment diagenesis and vertical algae migration2

File type	Label in Control File	File name	
Control File	-	w2_con.csv	Sets many heat-flux control parameters
Wind sheltering	WSC FILE WSCFN	wsc.npt	Wind func impacts both sensible and latent flux
Shading	SHDFN	shade.npt	Local shading – not cloud cover
Bathymetry	BTHFN	bth1.csv	
Meteorological	METFN	met.npt	Sets many heat-flux control parameters
Branch inflow	QINFN branch inflow	qin_br1_equal.npt	
	TINFN branch temp	tin_br1.npt	AD equation – boundary conditions
	CINFN branch conc	cin_br1.csv	
	QDTFN Distributed flow	qin_br1.npt	
Spillway/Gate	QGTFN	qgt.npt	

Advection Dispersion of Temp

Advection-Dispersion Equation Balance

$$\frac{\partial B\Phi}{\partial t}+\frac{\partial UB\Phi}{\partial x}+\frac{\partial WB\Phi}{\partial z}-\frac{\partial}{\partial x}\left[BD_x\frac{\partial \Phi}{\partial x}\right]-\frac{\partial}{\partial z}\left[BD_z\frac{\partial \Phi}{\partial z}\right]=q_\Phi B+S_\Phi B \qquad \textbf{(4-12)}$$

where:

- Φ = laterally averaged constituent concentration, $g\ m^{-3}$
- D_x = longitudinal temperature and constituent dispersion coefficient, $m^2\ sec^{-1}$
- D_z = vertical temperature and constituent dispersion coefficient, $m^2\ sec^{-1}$
- q_Φ = lateral inflow or outflow mass flow rate of constituent per unit volume, $g\ m^{-3}\ sec^{-1}$
- S_Φ = laterally averaged source/sink term, $g\ m^{-3}\ sec^{-1}$

Substitute H into the equation for Φ, which relates to temperature as:

$$T=\frac{H}{\rho C_p V}$$

$$H=\rho C_p V T$$

Units:

cgs system:

$$\frac{\cancel{cal}}{\frac{\cancel{g}}{\cancel{cm^3}}\ \frac{\cancel{cal}}{\cancel{g}\ {}^{o}C}\ \cancel{cm^3}} \Downarrow {}^{o}C$$

mks system:

$$\frac{\cancel{J}}{\frac{\cancel{kg}}{\cancel{m^3}}\ \frac{\cancel{J}}{\cancel{kg}\ {}^{o}C}\ \cancel{m^3}} \Downarrow {}^{o}C$$

1 cal = 4.168 J

HYD PRINT - Print in the SNP file	HNAME	FMTH	HMULT	HPRWBC1	HPRWB
NVIOL - Violations of time step	"Timestep violat	(I10)	1	ON	
U	"Horizontal velo	(f10.3)	1	ON	
W	"Vertical velocity	(f10.3)	1	OFF	
T	"Temperature [T	(f10.3)	1	ON	
RHO	"Density [RHO] g	(f10.3)	1	OFF	
AZ	"Vertical eddy vi	(f10.3)	1	OFF	
SHEAR	"Velocity shear s	(f10.3)	1	OFF	
ST	"Internal shear [	(f10.3)	1	OFF	
SB	"Bottom shear [	(f10.3)	1	OFF	
ADMX	"Longitudinal m	(f10.3)	1	OFF	
DM	"Longitudinal m	(f10.3)	1	OFF	
HDG	"Horizontal dens	(f10.3)	1	OFF	
ADMZ	"Vertical momen	(f10.3)	1	OFF	
HPG	"Horizontal pres	(f10.3)	1	OFF	
GRAV	"Gravity term ch	(f10.3)	1	OFF	

- Temperature is included in the hydraulic calculations because it affects parameters like density and viscosity, i.e., we don’t need to turn this on and off.
- We will need initial and boundary conditions (BC) for this – BCs for temperature in the tin_br1.npt file

Kinetics – Equilibrium Model or Term by Term?

Sources/Sinks from manual:

Term-by-term surface heat exchange is computed as:

$$\Phi_n = \Phi_s - \Phi_{sr} + \Phi_a - \Phi_{ar} - \Phi_{br} - \Phi_e - \Phi_c \quad \textbf{(4-13)}$$

where:

ϕ_n: net surface heat flux, $W\ m^{-2}$

ϕ_s: incoming short-wave solar radiation, $W\ m^{-2}$

ϕ_{sr}: reflected short-wave solar radiation, $W\ m^{-2}$

ϕ_{sn}: net short-wave solar radiation, ϕ_s-ϕ_{sr}, $W\ m^{-2}$

ϕ_a: incoming long-wave atmospheric radiation, $W\ m^{-2}$

ϕ_{ar}: reflected atmospheric long-wave radiation, $W\ m^{-2}$

ϕ_{br}: back long-wave radiation, $W\ m^{-2}$

ϕ_e: evaporative heat loss, $W\ m^{-2}$

ϕ_c: conductive heat loss, $W\ m^{-2}$

Heat Exchange Parameters in .xslm interface:

HEAT EXCHANGE	WB1	WB2	WB3	W
H SLHTC - Heat computations - Equilibrium (ET) or Term-by-term (TERM)	TERM			
SROC - Read in Short wave solar radiation ON or OFF	OFF			
RHEVAP - Use Ryan-Harleman Evap Model - for cooling ponds ON or OFF	OFF			
METIC - Interpolate meteorological data ON or OFF	ON			
FETCHC - Heinz Stefan Lake fetch correction - there is already an internal fetcl	OFF			
AFW - Evaporation coefficient	9.2			
BFW - Evaporation coefficient	0.46			
CFW - Evaporation coefficient	2			
WINDH - Wind height measurement above ground surface, m	10			

EQ process is described on pages 101-102 of manual part 2.

Shortwave Solar Radiation

File input or computed?

HEAT EXCHANGE	WB1	WB2	WB3	W
H SLHTC - Heat computations - Equilibrium (ET) or Term-by-term (TERM)	TERM			
SROC - Read in Short wave solar radiation ON or OFF	OFF			
RHEVAP - Use Ryan-Harleman Evap Model - for cooling ponds ON or OFF	OFF			
METIC - Interpolate meteorological data ON or OFF	ON			
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AFW - Evaporation coefficient	9.2			
BFW - Evaporation coefficient	0.46			
CFW - Evaporation coefficient	2			
WINDH - Wind height measurement above ground surface, m	10			

It is rare to have a good short-wave solar radiation data source. Therefore, W2 uses an empirical calculation of short-wave solar radiation based on solar altitude and other parameters, as described in the user-manual, page 95-96. Many of these parameters are based on lat/long and time of day.

Shortwave Solar Radiation – Cloud Cover and Shade

The shortwave solar radiation is dampened by a cloud cover factor that gets defined in the meteorological file.

The shortwave solar radiation is also dampened by a local shading factor defined in the **shade file.**

met - Notepad

File Edit Format View Help

1980 DeGray Reservoir meteorology

JDAY	TAIR	TDEW	WIND	PHI	CLOUD
1.000	2.2	-1.1	1.9	4.72	0.0
1.125	1.7	-1.1	2.3	4.37	0.0
1.250	0.0	-3.3	1.1	5.07	0.0
1.375	3.3	-0.6	2.3	4.37	0.0
1.500	11.1	1.1	2.7	5.07	0.0
1.625	13.9	-1.1	1.1	1.22	0.0
1.750	8.3	-0.6	2.3	2.62	0.0
1.875	6.7	-0.6	1.1	3.85	0.0
2.000	1.7	-1.7	0.0	0.00	0.0
2.125	1.1	-1.7	0.0	0.00	3.0
2.250	2.2	-1.1	1.9	4.02	3.0
2.375	5.0	1.1	2.3	4.37	8.0

W2 Shading Input File, Vegetatiand Topograpcalibratveg characteand correctetopography

Wahiawa

Segment	DynSh	TTEleLB	TTEleRB	ClDisLB	ClDiRB	SRFLB1	SRFLB2	SRFRB1	SRFRB2	TOPO1	TOPO2	TOPO3	TOPO4
1	1												
2	1												
3	1												
4	1												
5	1												
6	1												
7	1												
8	1												
9	1												
10	1												
11	1												
12	1												
13	1												
14	1												
15	1												
16	1												

Shortwave Solar Radiation – Penetration

Theory: Every cell in the model performs this computation.

Short wave solar radiation penetrates the surface and decays exponentially with depth according to Bear's Law (see Figure 53):

$$\phi_s(z) = (1-\beta)\phi_{sn} e^{-\eta z} \qquad \textbf{(4-26)}$$

where:

$\phi_s(z)$ =short wave radiation at depth z, $W\ m^{-2}$
β =fraction absorbed at the water surface
η =extinction coefficient, m^{-1}
ϕ_{sn} =net short-wave radiation reaching the surface, $W\ m^{-2}$

Model Input:
Extinction coefficient will be a combination of light extinction due to various constituents, such as suspended solids, algae, zooplankton, etc. Extinction will be a function of their concentrations.

EX COEF	WB1	WB2
EXH2O - water light extinction- 1/m	0.45	
EXSS - suspended solids light extinction- 1/m	0.01	
EXOM - extinction organic matter- 1/(m mg/l)	0.2	
BETA - fraction short wave absorbed on surface	0.45	
EXC - Read in light extinction time series ON or OFF	OFF	
EXIC - Interpolation of light extinction time series ON or OFF	OFF	
ALG EXTINCTION	EXA1	EXA2
Algae light extinction- 1/(m mg/l)	0.2	
ZOO EXTINCTION	EXZ1	EXZ2
Zooplankton light extinction- 1/(m mg/l)	0.2	
MACRO EXTINCTION	EXM1	EXM2
Macrophyte light extinction- 1/(m mg/l)	0.01	

Longwave Radiation

- Longwave radiation from air to water and water back to air use the same formula, based on the temperature of the emitting body, the Stephan-Boltzmann coefficient, and the emissivity of the body.
- Emissivity is a function of vapor pressure, which can be calculated from the measured dew point.

```
ENTRY SURFACE_TERMS (TSUR)

! Partial water vapor pressure of air (mm hg)

!  EA = EXP(2.3026*(9.5*TDEW(JW)/(TDEW(JW)+265.5)+0.6609))         ! SW 6/10/2011
!  IF (TDEW(JW) > 0.0) EA = EXP(2.3026*(7.5*TDEW(JW)/(TDEW(JW)+237.3)+0.6609))
  EA = DEXP(2.3026D0*(7.5D0*TDEW(JW)/(TDEW(JW)+237.3D0)+0.6609D0))

! Partial water vapor pressure at the water surface

  IF(TSUR<0.0)THEN
  ES = DEXP(2.3026D0*(9.5D0*TSUR/(TSUR+265.5D0)+0.6609D0))
  ELSE
  ES = DEXP(2.3026D0*(7.5D0*TSUR/(TSUR+237.3D0)+0.6609D0))
  ENDIF
```

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```
1980 DeGray Reservoir meteorology

   JDAY     TAIR     TDEW     WIND      PHI    CLOUD
  1.000      2.2     -1.1      1.9     4.72      0.0
  1.125      1.7     -1.1      2.3     4.37      0.0
  1.250      0.0     -3.3      1.1     5.07      0.0
  1.375      3.3     -0.6      2.3     4.37      0.0
  1.500     11.1      1.1      2.7     5.07      0.0
  1.625     13.9     -1.1      1.1     1.22      0.0
  1.750      8.3     -0.6      2.3     2.62      0.0
  1.875      6.7     -0.6      1.1     3.85      0.0
  2.000      1.7     -1.7      0.0     0.00      0.0
  2.125      1.1     -1.7      0.0     0.00      3.0
  2.250      2.2     -1.1      1.9     4.02      3.0
  2.375      5.0      1.1      2.3     4.37      8.0
```

Fortran source code showing how vapor pressure is calculated

Latent Heat – Evaporation

Parameters that control evaporation are specified in the met data file and the control file.

Evaporative heat loss is computed as:

$$\phi_e = f(W_z)(e_s - e_a) \quad \textbf{(4-24)}$$

where:

$f(Wz)$ = evaporative wind speed function at wind height of z, $W\ m^{-2}\ mm\ Hg^{-1}$
e_s = saturation vapor pressure at the water surface, $mm\ Hg$
e_a = atmospheric vapor pressure, $mm\ Hg$

Evaporative heat loss depends on air temperature and dew point temperature or relative humidity. Surface vapor pressure is computed from the surface temperature for each surface cell on each iteration.

The model user can include different evaporation formulations using an evaporation wind speed formula of the form

$$f(W_z) = a + bW_z^c \quad \textbf{(4-27)}$$

where:

$f(Wz)$ = wind speed function with wind measured at height z, $W\ m^{-2}\ mm\ Hg^{-1}$
a = empirical coefficient, 9.2 default
b = empirical coefficient, 0.46 default
c = empirical coefficient, 2 default
W_z = wind speed measured at 2 m above the ground, $m\ s^{-1}$

```
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  ELSE
  ES = DEXP(2.3026D0*(7.5D0*TSUR/(TSUR+237.3D0)+0.6609D0))
  ENDIF
```

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2.125	1.1	-1.7	0.0	0.00	3.0
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The model user can include different evaporation formulations using an evaporation wind speed formula of the form

$$f(W_z) = a + bW_z^c \quad \textbf{(4-27)}$$

where:

f(Wz) = wind speed function with wind measured at height z, $W\ m^{-2}\ mm\ Hg^{-1}$
a = empirical coefficient, 9.2 default
b = empirical coefficient, 0.46 default
c = empirical coefficient, 2 default
W_z = wind speed measured at 2 *m* above the ground, $m\ s^{-1}$

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METIC - Interpolate meteorological data ON or OFF	ON			
FETCHC - Heinz Stefan Lake fetch correction - there is already an internal fetcl	OFF			
AFW - Evaporation coefficient	9.2			
BFW - Evaporation coefficient	0.46			
CFW - Evaporation coefficient	2			
WINDH - Wind height measurement above ground surface, m	10			

Sensible Heat – Conduction and Convection

Surface heat conduction is computed as:

$$\phi_c = C_c f(W_z)(T_s - T_a) \quad \textbf{(4-25)}$$

where:

C_c = Bowen's coefficient, *0.47 mm Hg °C⁻¹* ← **Constant**

T_a = air temperature, *°C* ← **Met file**

Temperature Output Comparison

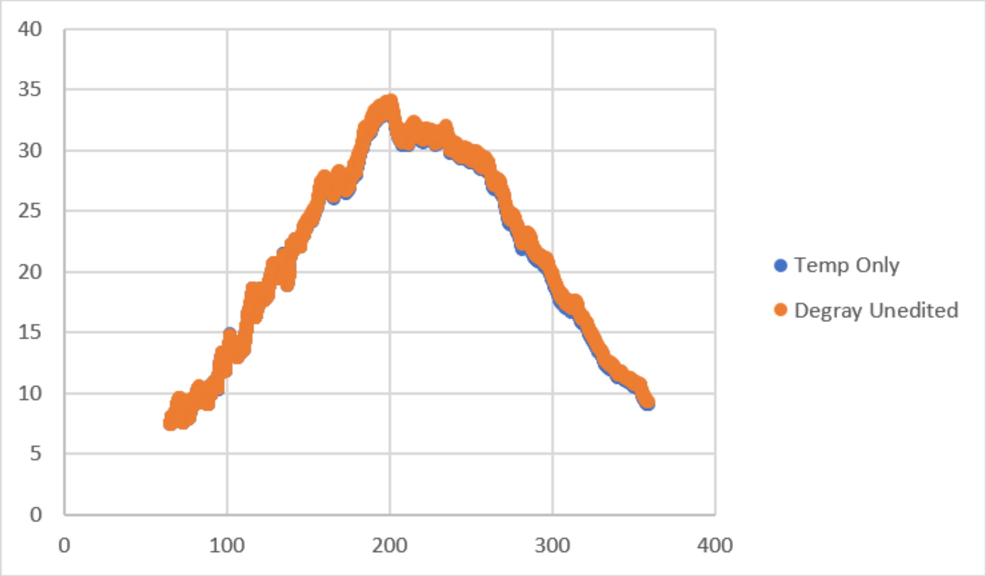
Model run with (1) default DeGray settings and with (2) all accessory modules and water quality calculations turned off.

MISCELLANEOUS	**NDAY**	SELECTC	HABTATC	ENVIRPC	AERATEC	INITUWL	ORGCC	SED_DIAG
	100	OFF	OFF	OFF	OFF	OFF	OFF	OFF

CST COMP - Water quality computations	**CCC**	LIMC	CUF	CO2PPM	CO2YRLY
CCC: Turn ON or OFF water quality calculations, LIMC: Limiting nutrient comp	OFF	ON	1	400	ON

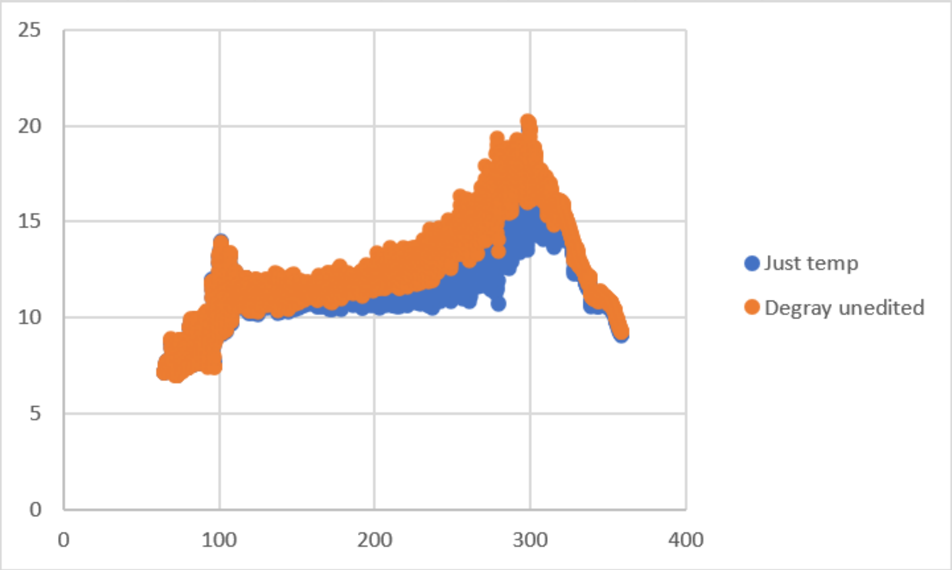
Comparison at Layer 2

JUST TEMP		DEGRAY UNEDITED				
JDAY	Temp	JDAY	Temp	Difference	% Diff	Max % diff
64.5	7.4	64.5	7.4	0	0	0.0250392
64.604	7.515	64.604	7.517	0.002	0.000266	
64.701	7.557	64.701	7.56	0.003	0.000397	
64.806	7.561	64.806	7.562	0.001	0.000132	
64.903	7.575	64.903	7.576	0.001	0.000132	
65	7.599	65	7.6	0.001	0.000132	
65.104	7.594	65.104	7.592	-0.002	-0.00026	
65.201	7.538	65.201	7.536	-0.002	-0.00027	
65.306	7.491	65.306	7.489	-0.002	-0.00027	
65.403	7.52	65.403	7.519	-0.001	-0.00013	
65.5	7.718	65.5	7.724	0.006	0.000777	
65.604	7.962	65.604	7.992	0.03	0.003754	
65.701	8.078	65.701	8.114	0.036	0.004437	
65.806	8.026	65.806	8.064	0.038	0.004712	
65.903	7.973	65.903	8.011	0.038	0.004743	
66	7.93	66	7.969	0.039	0.004894	
66.104	7.889	66.104	7.928	0.039	0.004919	
66.201	7.85	66.201	7.887	0.037	0.004691	



Comparison at Layer 16

JUST TEMP			DEGRAY UNEDITED					
JDAY	Temp		JDAY	Temp		Difference	% Diff	Max % diff
64.5	7.2		64.5	7.2		0	0	0.256413148
64.604	7.186		64.604	7.186		0	0	
64.701	7.164		64.701	7.164		0	0	
64.806	7.129		64.806	7.129		0	0	
64.903	7.114		64.903	7.114		0	0	
65	7.131		65	7.132		0.001	0.00014	
65.104	7.195		65.104	7.195		0	0	
65.201	7.301		65.201	7.3		-0.001	-0.00014	
65.306	7.385		65.306	7.384		-0.001	-0.00014	
65.403	7.482		65.403	7.481		-0.001	-0.00013	
65.5	7.483		65.5	7.479		-0.004	-0.00053	
65.604	7.494		65.604	7.49		-0.004	-0.00053	
65.701	7.533		65.701	7.538		0.005	0.000663	
65.806	7.607		65.806	7.628		0.021	0.002753	
65.903	7.675		65.903	7.707		0.032	0.004152	
66	7.716		66	7.747		0.031	0.004002	
66.104	7.726		66.104	7.743		0.017	0.002196	
66.201	7.709		66.201	7.706		-0.003	-0.00039	
66.306	7.669		66.306	7.652		-0.017	-0.00222	
66.403	7.619		66.403	7.601		-0.018	-0.00237	
66.5	7.569		66.5	7.56		-0.009	-0.00119	
66.604	7.532		66.604	7.53		-0.002	-0.00027	
66.701	7.511		66.701	7.51		-0.001	-0.00013	



Questions?