CE-QUAL-W2

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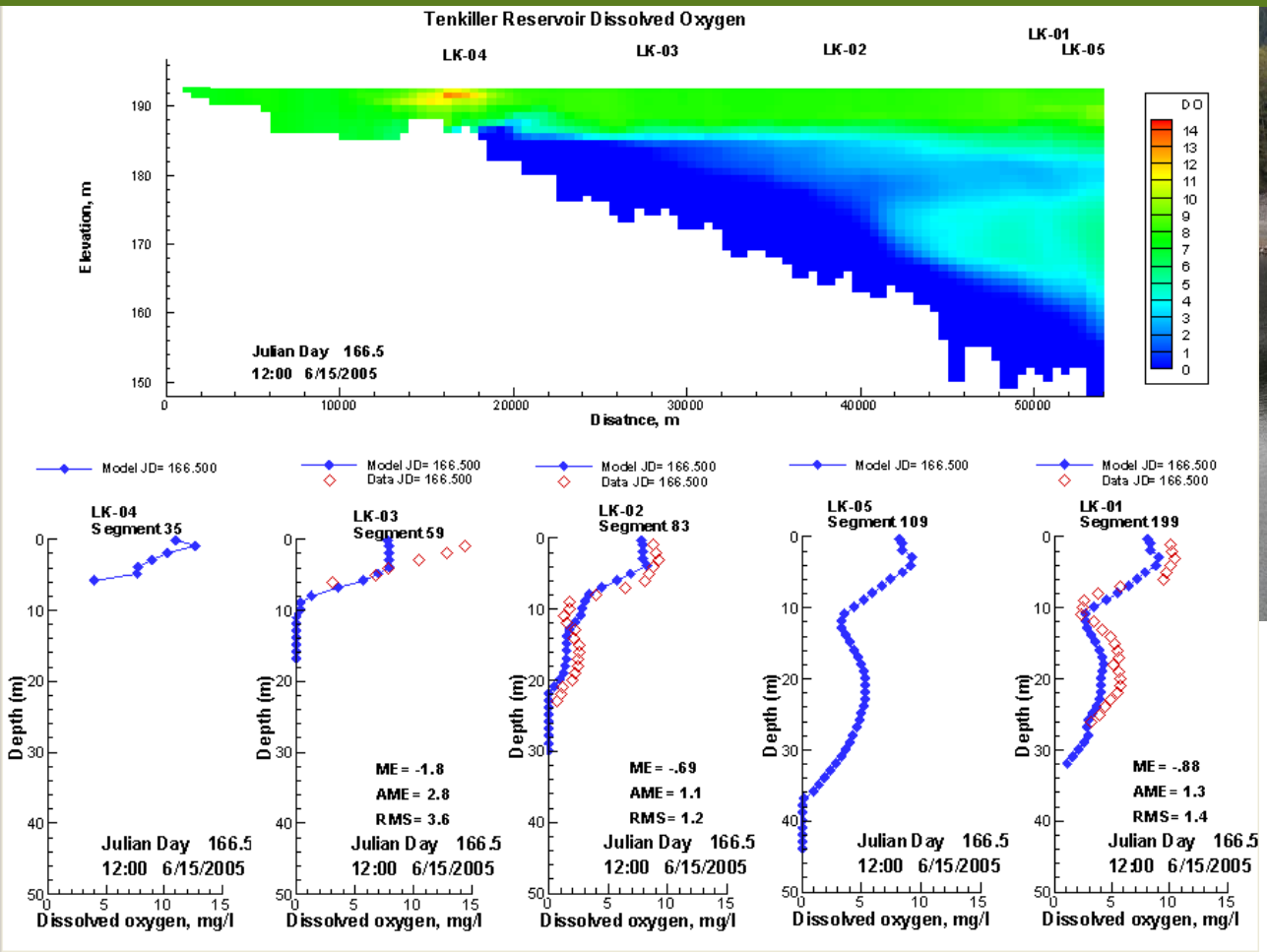
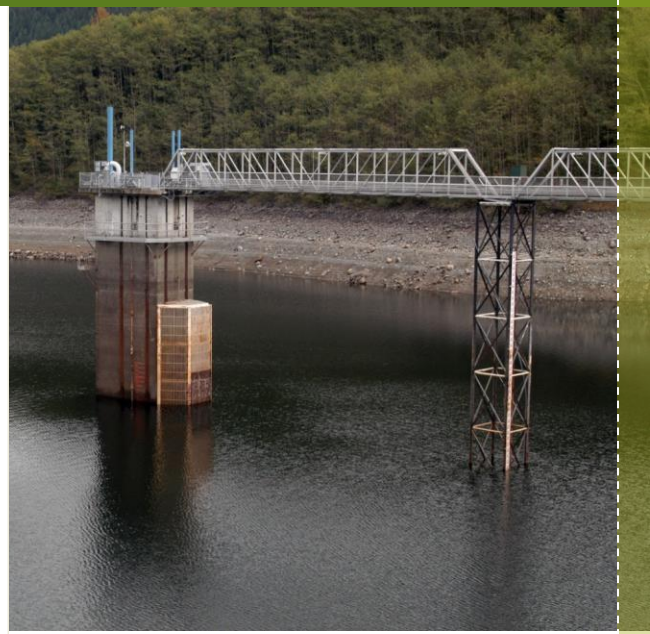
Department of Civil and Environmental Engineering



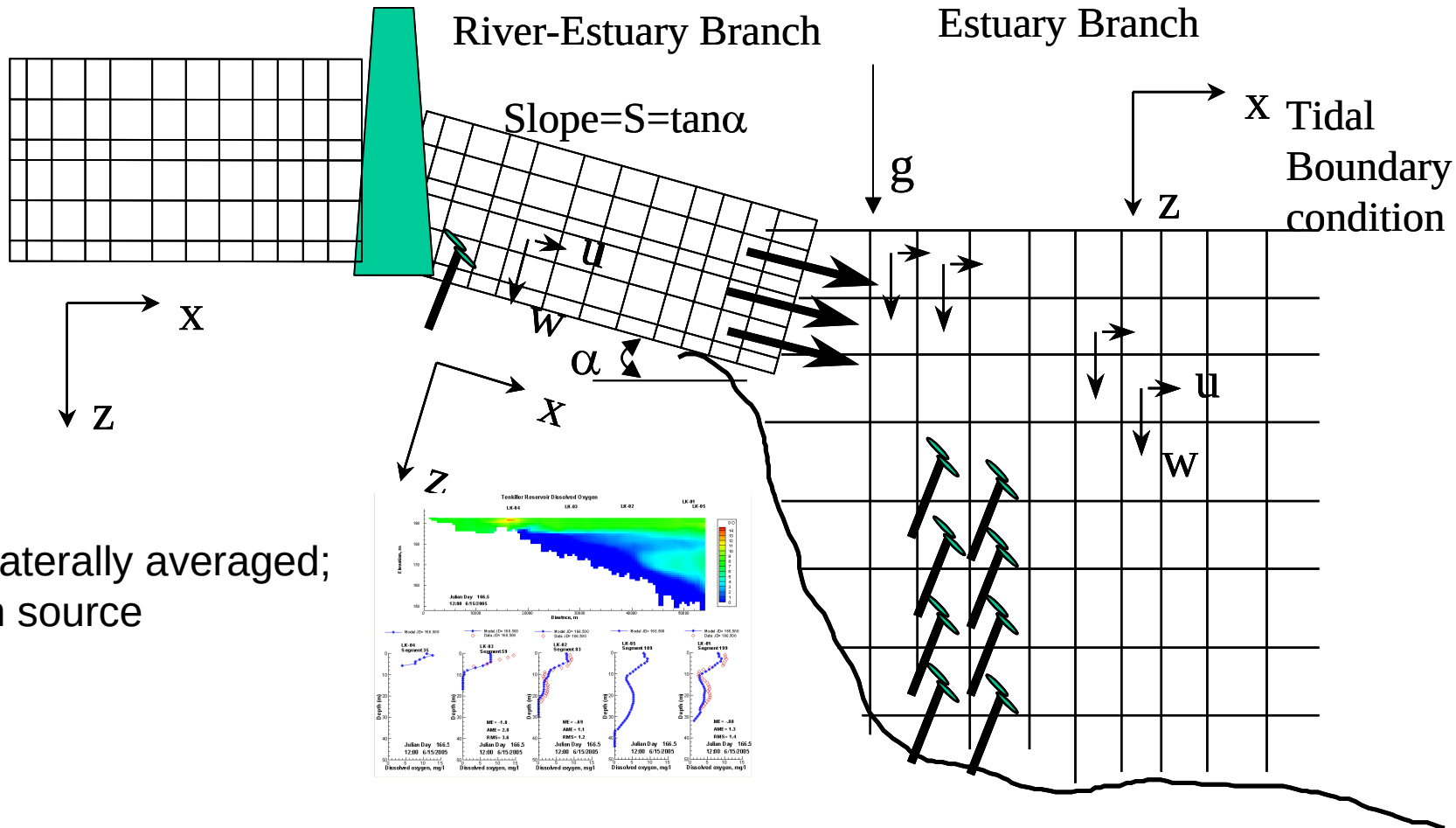


Portland State UNIVERSITY

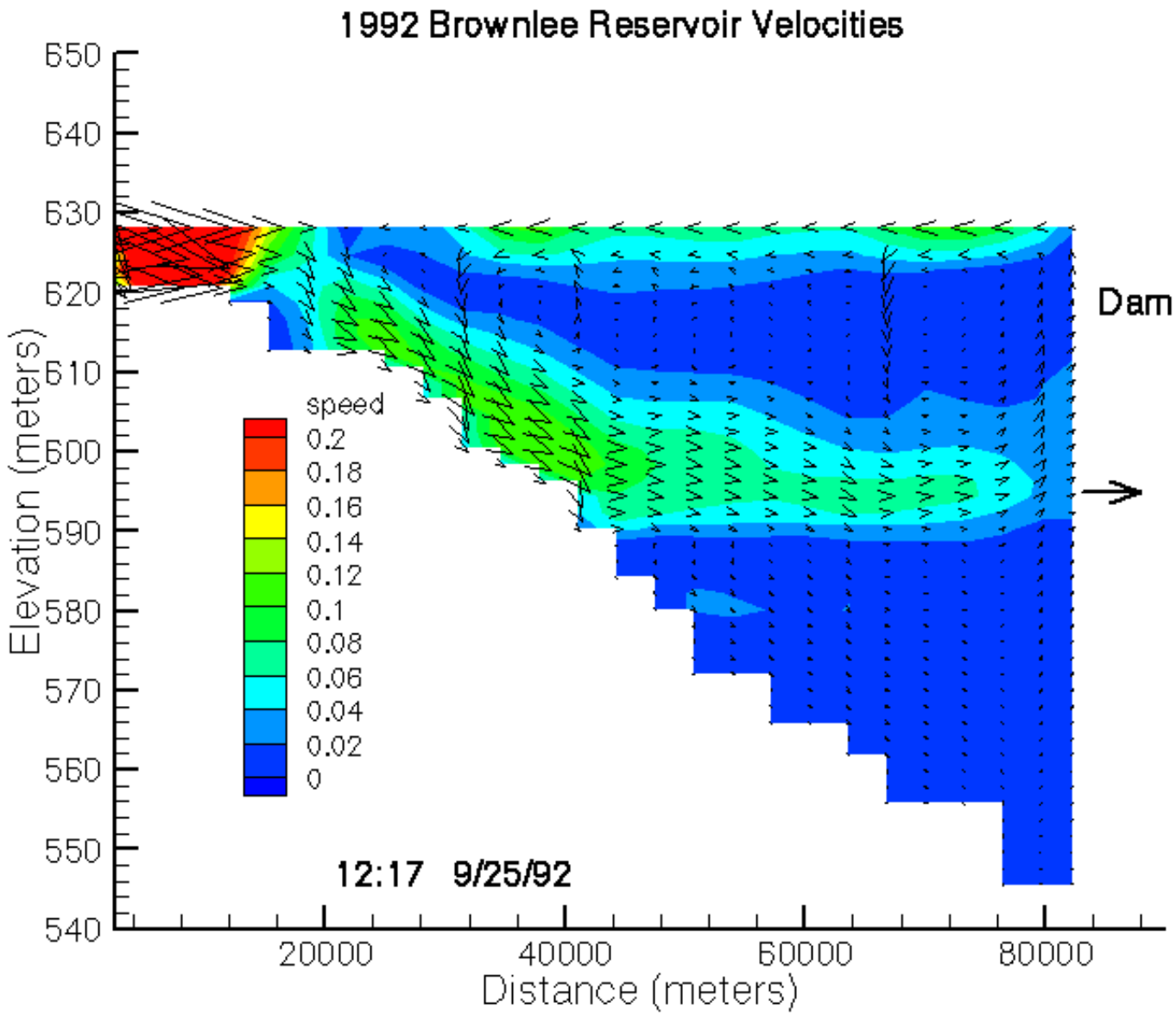
CE-QUAL-W2

- Background of CE-QUAL-W2
  - Governing equations and limitations
  - Model state and derived variables
- Example application
- How to set-up and run CE-QUAL-W2
- CE-QUAL-W2 planned enhancements

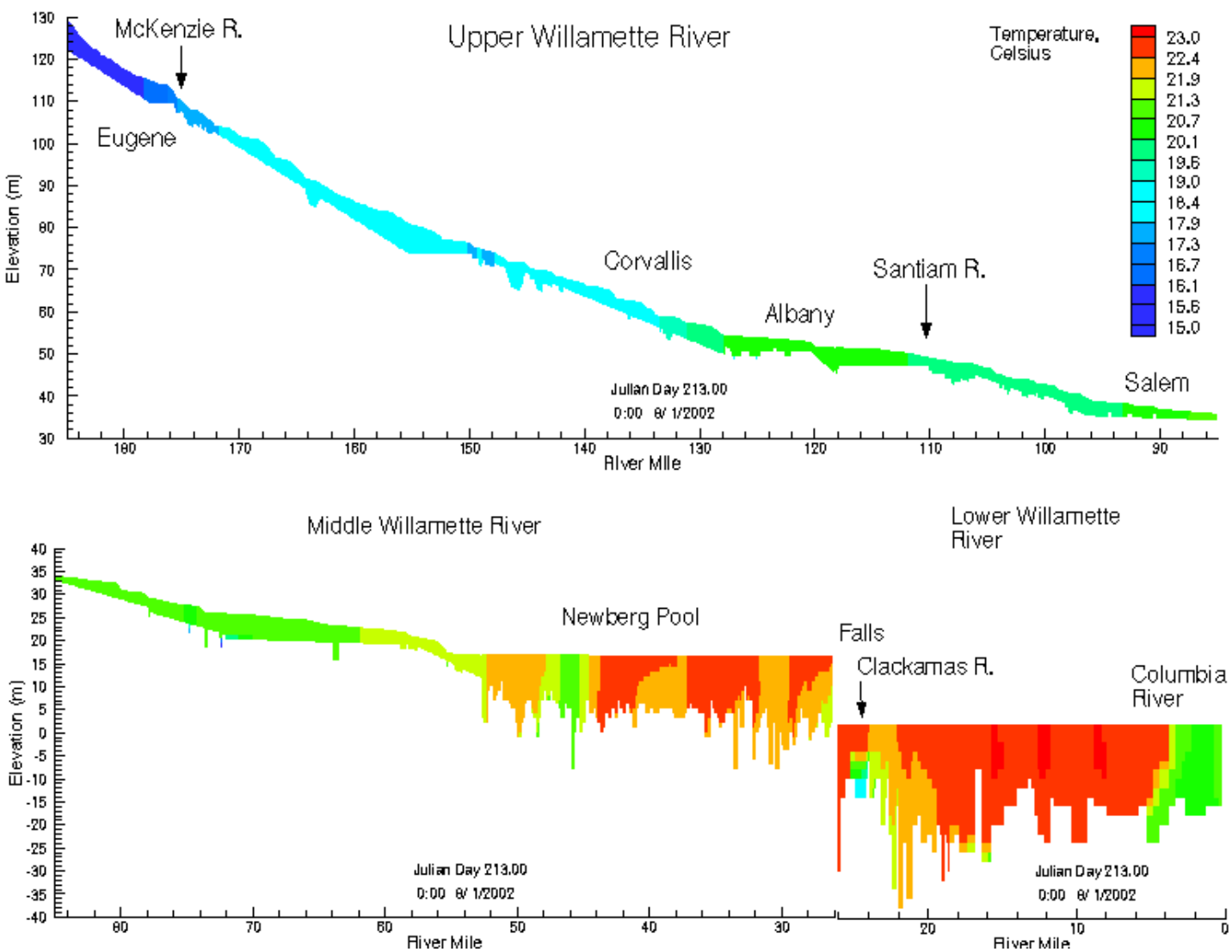
CE-QUAL-W2



2D, laterally averaged; open source


1992 Brownlee Reservoir Velocities
650
640
630
620
610
600
590
580
570
560
550
540
Elevation (meters)
20000
40000
60000
80000
Distance (meters)
speed
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Dam
12:17 9/25/92

River Modeling – Estuary Modeling



CE-QUAL-W2 Governing Equations

Equation	Version 3 governing equations
x- momentum	$\frac{\partial UB}{\partial t}+\frac{\partial UUB}{\partial x}+\frac{\partial WUB}{\partial z}=gB\sin\alpha+g\cos\alpha B\frac{\partial\eta}{\partial x}-\frac{g\cos\alpha B}{\rho}\int_{\eta}^{z}\frac{\partial\rho}{\partial x}dz+$ $\frac{1}{\rho}\frac{\partial B\tau_{xx}}{\partial x}+\frac{1}{\rho}\frac{\partial B\tau_{xz}}{\partial z}+qBU_x$
z-momentum	$0=g\cos\alpha-\frac{1}{\rho}\frac{\partial P}{\partial z}$
free surface equation	$B_\eta\frac{\partial\eta}{\partial t}=\frac{\partial}{\partial x}\int_{\eta}^{h}UBdz-\int_{\eta}^{h}qBdz$
continuity	$\frac{\partial UB}{\partial x}+\frac{\partial WB}{\partial z}=qB$
equation of state	$\rho=f(T_w,\Phi_{TDS},\Phi_{ss})$
Conservation of mass/heat	$\frac{\partial B\Phi}{\partial t}+\frac{\partial UB\Phi}{\partial x}+\frac{\partial WB\Phi}{\partial z}-\frac{\partial\left(BD_x\frac{\partial\Phi}{\partial x}\right)}{\partial x}-\frac{\partial\left(BD_z\frac{\partial\Phi}{\partial z}\right)}{\partial z}=q_\Phi B+S_\Phi B$

Algorithms for τ_{xz} : Several different algorithms available

k-ε Turbulence Model

Use 'TKE' as the designator for the turbulence model

$$\nu_t = C_\mu \frac{k^2}{\varepsilon}$$

k-ε Turbulence Model

This involves the solution of the following PDEs

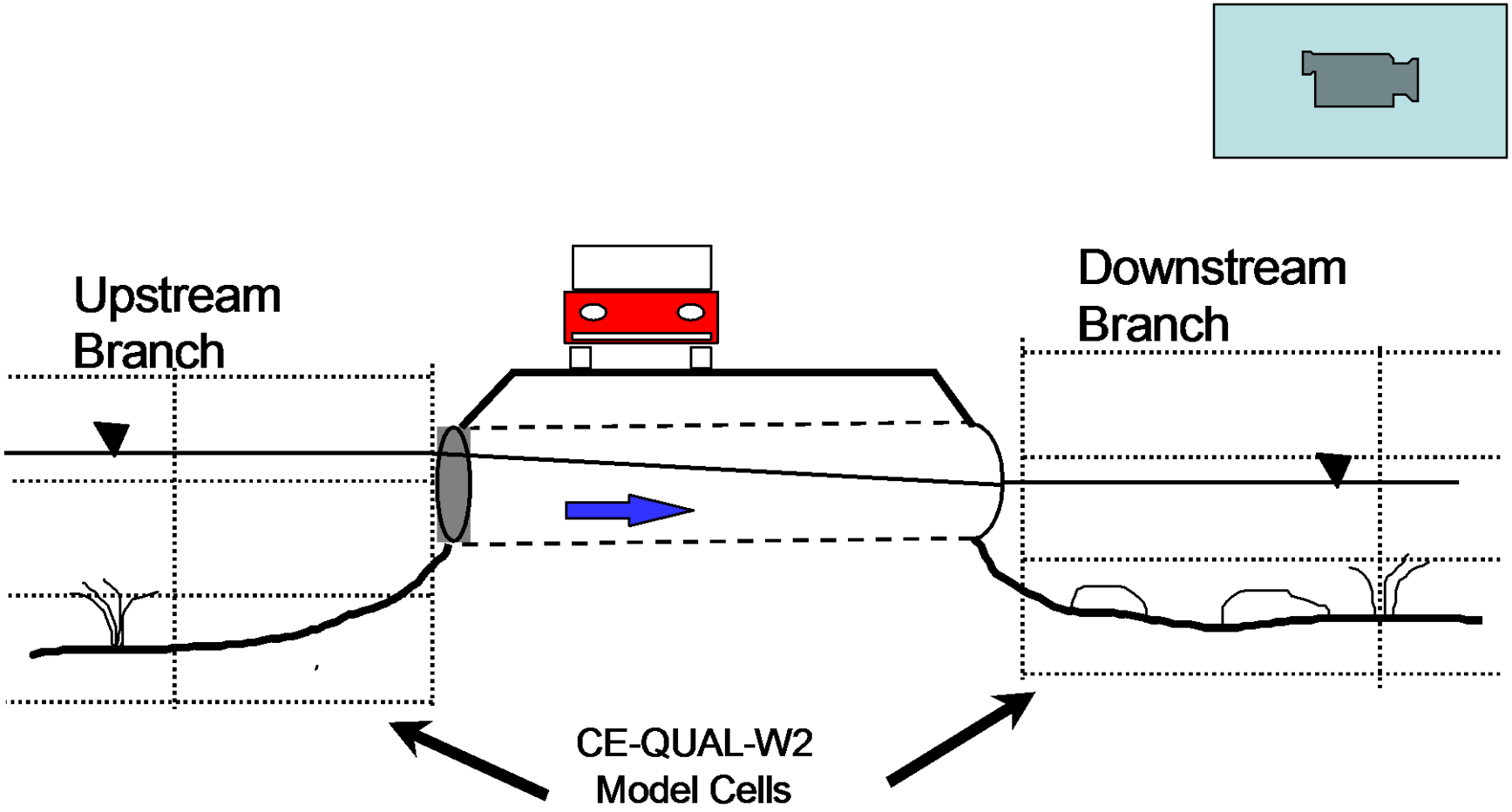
$$\frac{\partial kB}{\partial t}+\frac{\partial kBU}{\partial x}+\frac{\partial kBW}{\partial z}-\frac{\partial}{\partial z}\left(B\frac{\nu_t}{\sigma_k}\frac{\partial k}{\partial z}\right)$$

$$-\frac{\partial}{\partial x}\left(B\frac{\nu_t}{\sigma_k}\frac{\partial k}{\partial x}\right)=B\left(P+G-\varepsilon+P_k\right)$$

$$\frac{\partial \varepsilon B}{\partial t}+\frac{\partial \varepsilon BU}{\partial x}+\frac{\partial \varepsilon BW}{\partial z}-\frac{\partial}{\partial z}\left(B\frac{\nu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial z}\right)$$

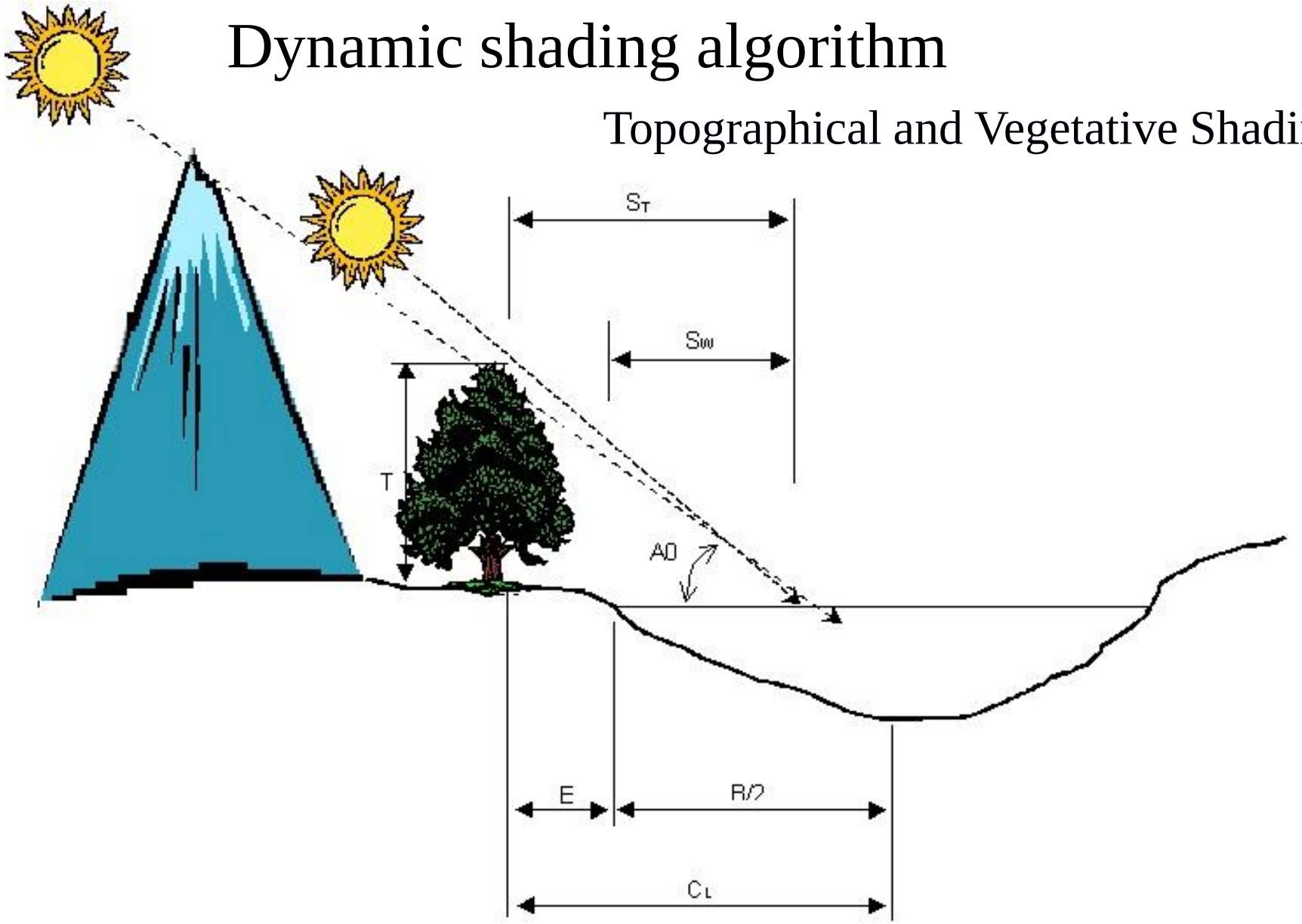
$$-\frac{\partial}{\partial x}\left(B\frac{\nu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x}\right)=B\left(C_{\varepsilon 1}\frac{\varepsilon}{k}P+C_{\varepsilon 2}\frac{\varepsilon^2}{k}+P_\varepsilon\right)$$

Internal Hydraulic Structures

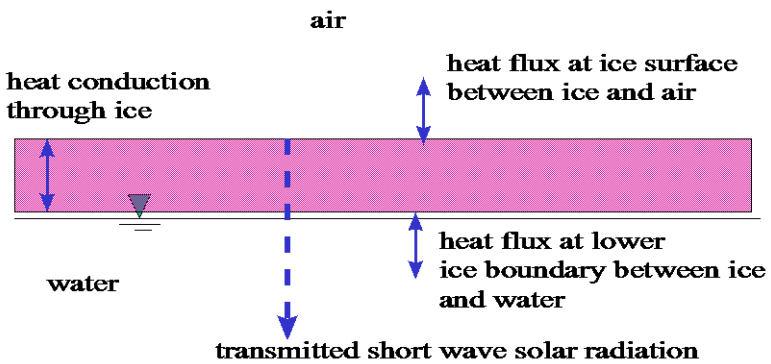


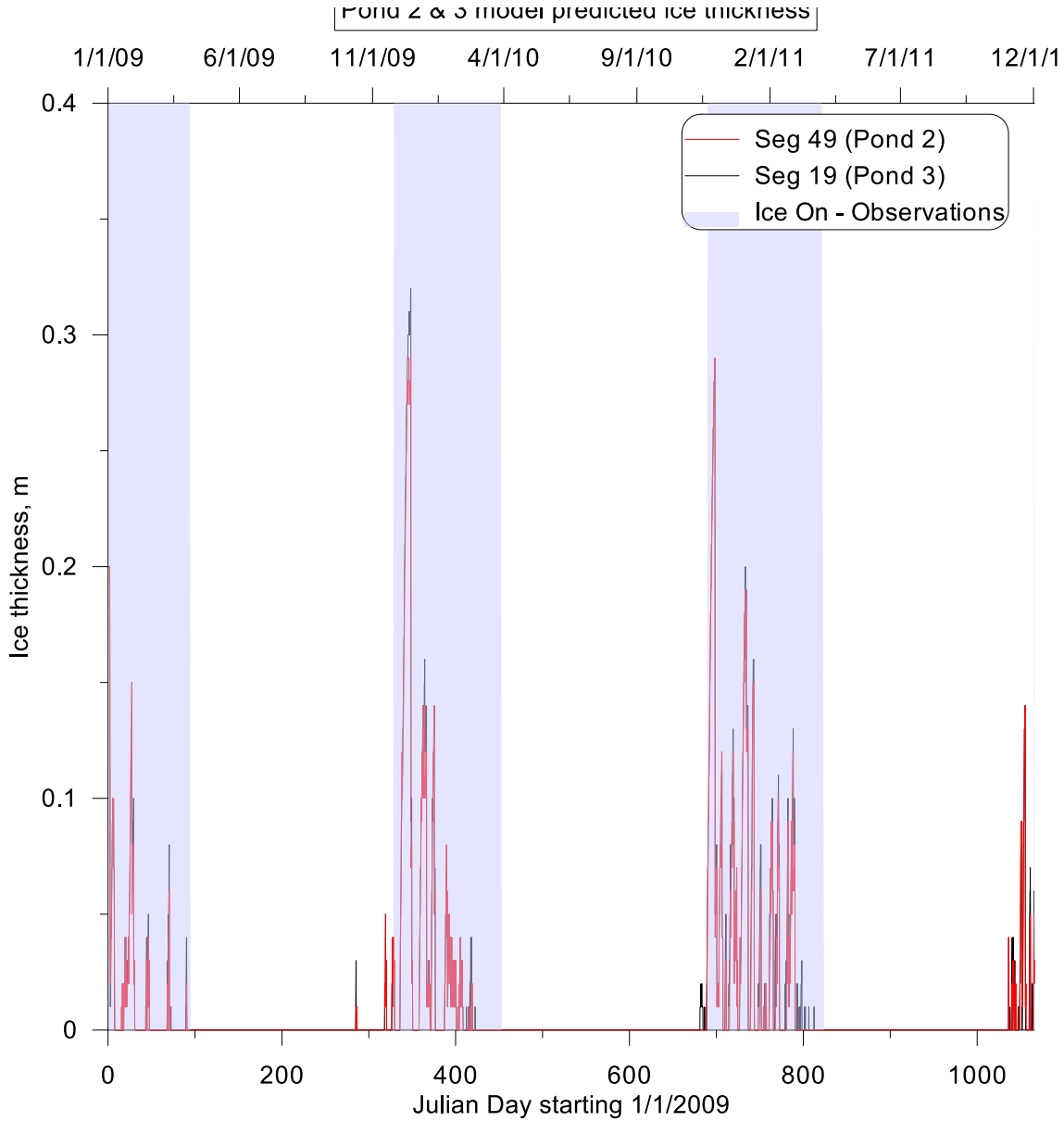
Dynamic shading algorithm

Topographical and Vegetative Shading



Model predictions of ice cover

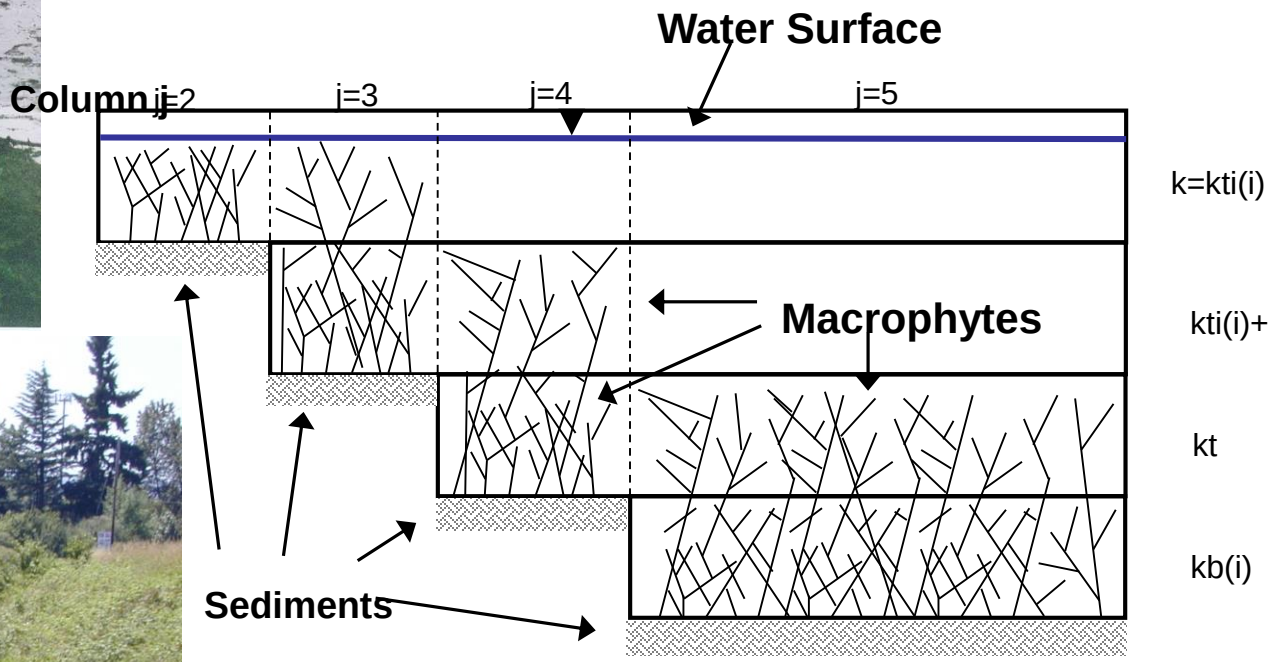




Water quality state variables

- any number of generic constituents:
  - conservative tracer(s)
  - water age or hydraulic residence time
  - coliform bacteria(s)
  - contaminant(s)
- any number of inorganic suspended solids groups
- any number of phytoplankton groups
- any number of epiphyton/periphyton groups
- any number of CBOD groups
- any number of zooplankton groups
- any number of macrophyte groups
- ammonium
- nitrate-nitrite
- bioavailable phosphorus (SRP)
- labile dissolved organic matter
- refractory dissolved organic matter
- labile particulate organic matter
- refractory particulate organic matter
- total inorganic carbon
- alkalinity
- total iron
- dissolved oxygen
- organic sediments
- LDOM-P and LDOM-N
- LPOM-P and LPOM-N
- RDOM-P and RDOM-N
- RPOM-P and RPOM-N
- any # of CBODN and CBODP groups

Columbia Slough, Oregon – macrophyte model



Model set up

Download model zip file

Unzip file into respective directories

Copy model executables into example directories, let's look at the DeGray Reservoir example

examples	11/17/2013 11:44 PM	File folder	
Excel macro utility for writing files in W2 fo...	11/17/2013 11:45 PM	File folder	
executables	11/17/2013 11:45 PM	File folder	
source	11/17/2013 11:45 PM	File folder	
W2ControlGUI	11/17/2013 11:45 PM	File folder	
W2tools post-processor integrated with W...	11/17/2013 11:45 PM	File folder	
waterbalance	11/17/2013 11:45 PM	File folder	
v37.zip	10/7/2013 10:18 AM	Compressed (zippe...	35,127 KB
W2_Version_3.71_Release_Notes.pdf	10/3/2013 12:28 PM	Adobe Acrobat Doc...	470 KB
W2V3 manual371_rev12.pdf	10/7/2013 10:03 AM	Adobe Acrobat Doc...	12,462 KB

Model set-up

Develop the Model Grid – this involves developing a bathymetry file for each water body. Inputs are in text file format or csv format

CSV file format

Excel format – use Excel macro utility to write out as a csv file

Model set-up: CSV format

$																																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
DLX	1046.4	1046.4	1046.4	965.9	965.9	764.7	764.7	1046.4	1046.4	1073.2	1073.2	1073.2	1126.9	1126.9	1180.5	1180.5	1180.5	912.2	912.2	912.2	804.9	804.9	804.9	804.9	804.9	858.5	858.5	858.5	1006.1	1006.1	457.3	457.3	724.4	724.4	724.4	804.9	804.9	804.9		
ELWS	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1	430.1		
PHI0	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	3.142	4.7	4.7	4.7	4.7	4.7	4.7		
FRIC	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70		
LAYERH																																						K		ELEV
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1
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0.5	0	0	0	0	0	0	0	0	0	0	40	100	90	100	184	184	184	311	311	311	396	396	369	369	369	436	436	436	391	391	422	0	0	74	74	283	283	0		18
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0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	30	40	353	353	353	271	271	352	0	0	0	0	0	0	0		29
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	30	340	340	340	257	257	344	0	0	0	0	0	0	0		30
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	322	322	322	243	243	334	0	0	0	0	0	0	0		31
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	296	296	296	227	227	324	0	0	0	0	0	0	0		32
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	134	134	210	210	312	0	0	0	0	0	0	0		33
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0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	117	117	241	0	0	0	0	0	0	0		37
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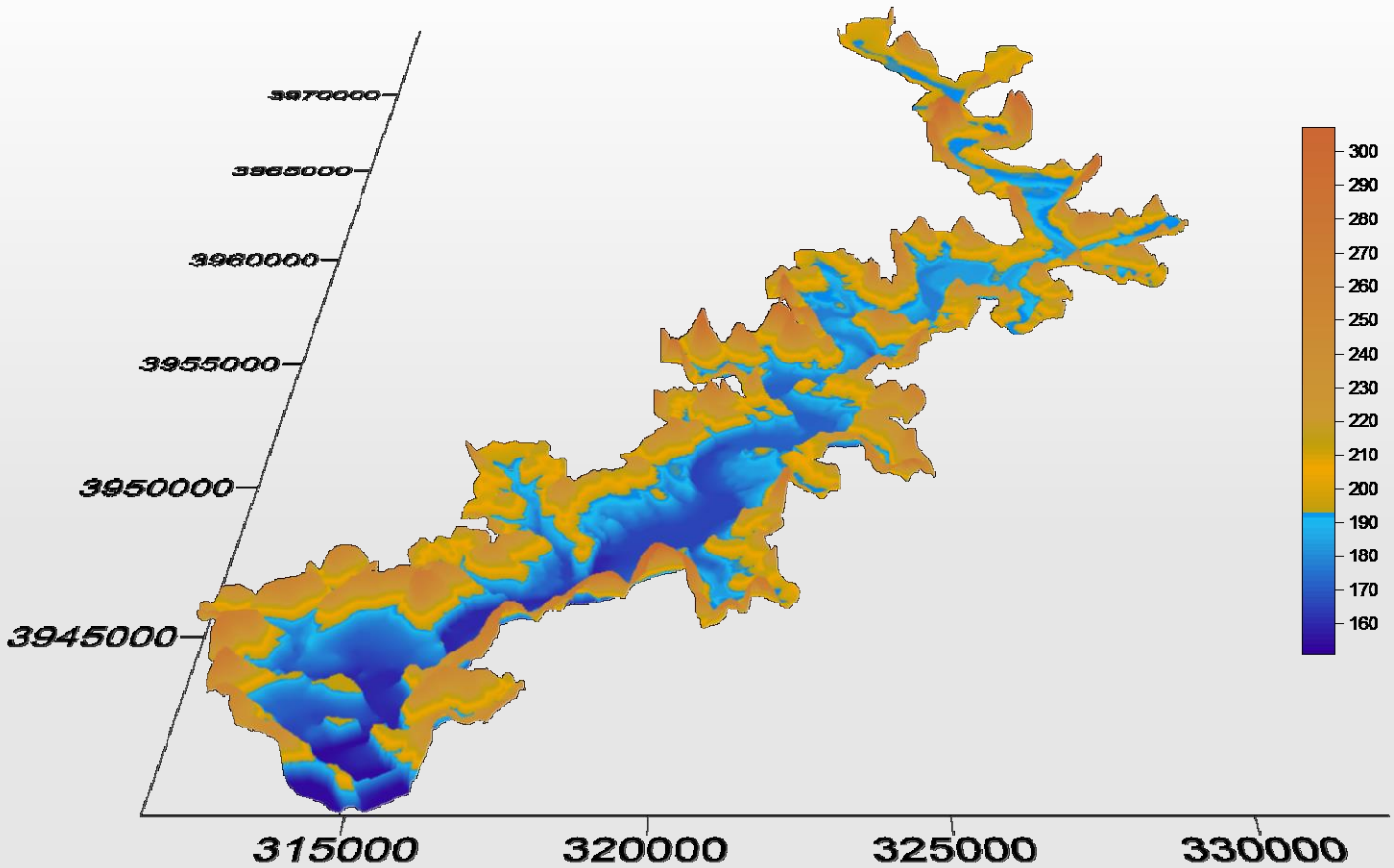
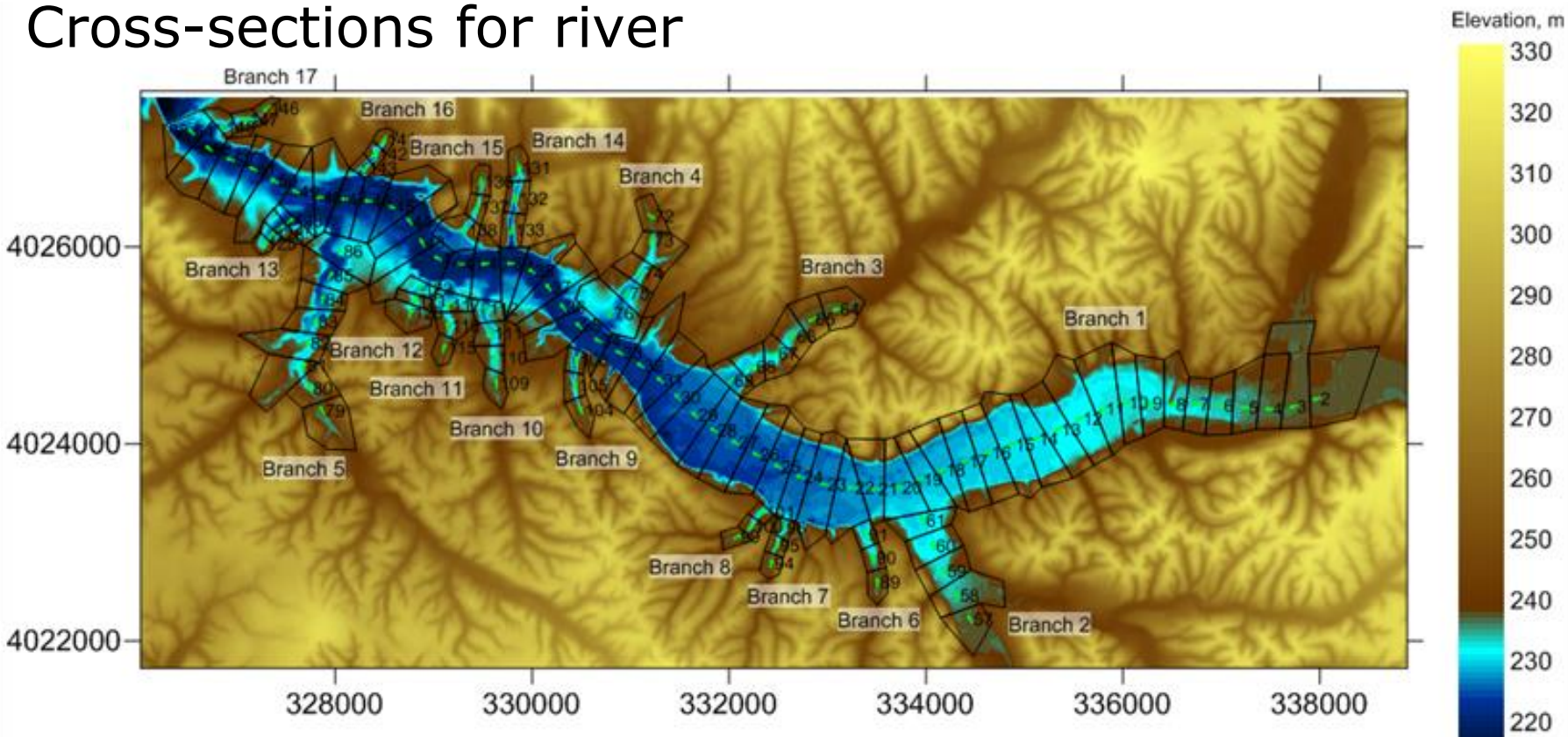
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		40

Model set-up: Bathymetry



Bathymetry

- Topographic map
- Sediment range surveys
- Volume-area-elevation table
- Cross-sections for river

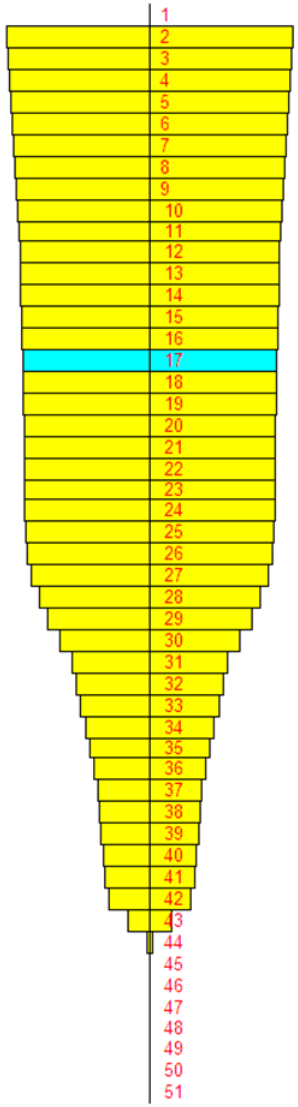


Note

CE-QUAL-W2 allows the specification of

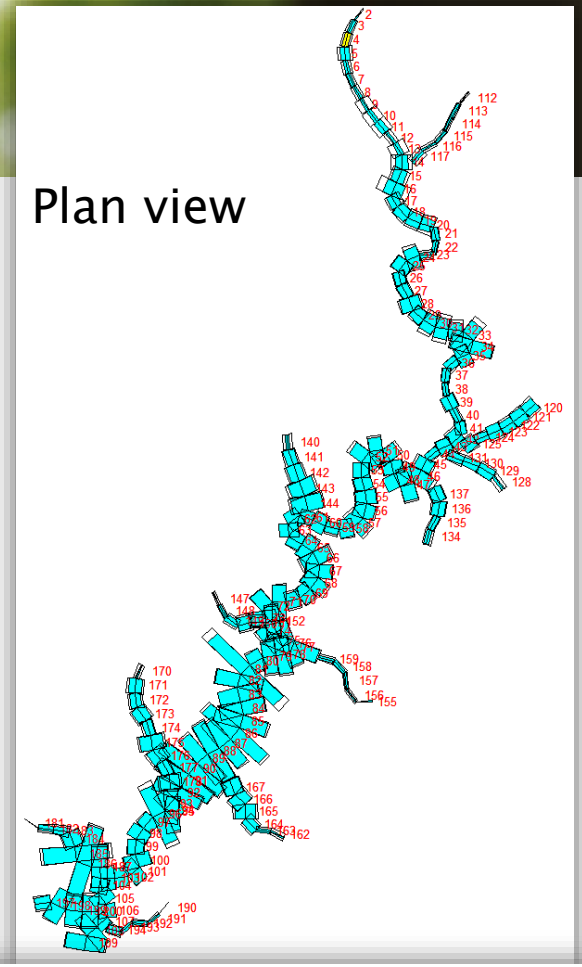
- **waterbodies** (a collection of model branches that have similar turbulence closure and water quality parameter values and meteorological forcing; a river and a reservoir)
- **branches** (a collection of model segments with variable model slope; a river with different slopes or a reservoir with multiple sidearms)
- **segments** (a longitudinal segment of length Δx)
- **layers** (a vertical layer of height Δz).

Model Set-up: Grid

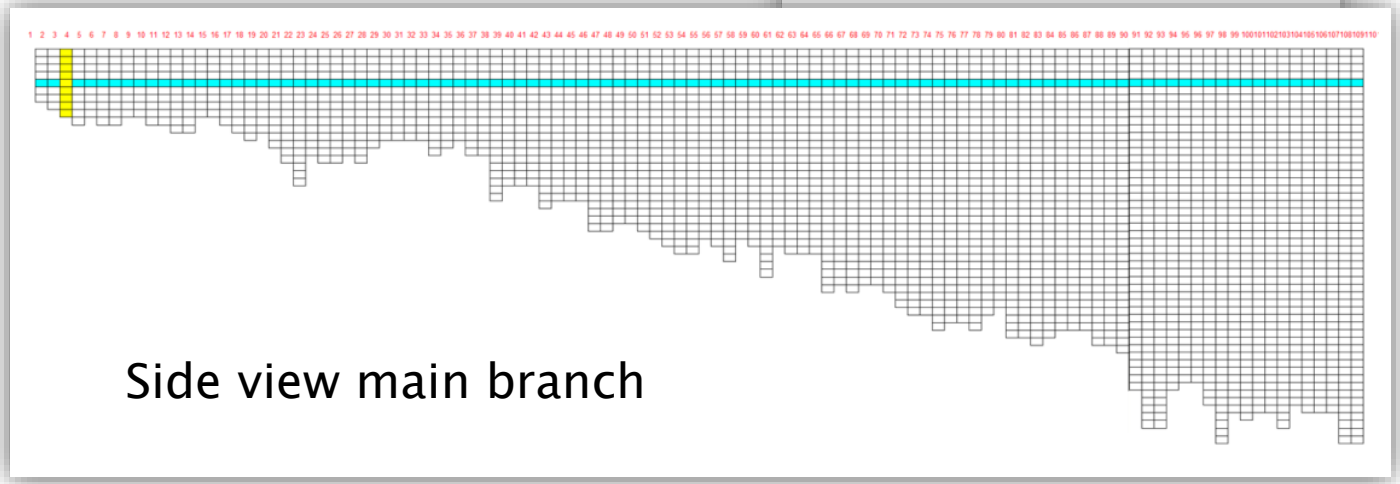


Segment end view

200 model segments, 13 branches, 500 m segment length, 1 m vertical layer height, 51 vertical layers



Plan view



Side view main branch

Model set-up

Construct all boundary condition files – flow rates, temperatures, and concentrations for all inflows, meteorological conditions for each waterbody, water levels for head BCs, shading for each segment, wind sheltering file for segments as a f(time)

All input files are text files; Use Excel macro to develop model input files

Boundary condition and calibration data

Model set-up data

Meteorological data

- Air temp, dew point temp, wind speed/direction, cloud cover, solar radiation

Inflows

Outflows

Water quality boundary data (temp, nutrients, organic matter, DO, SS, etc.)

Model calibration data

Water level data

Temperature profiles and continuous probes in outflow

Dissolved oxygen and nutrient profiles and grab samples

Algae data

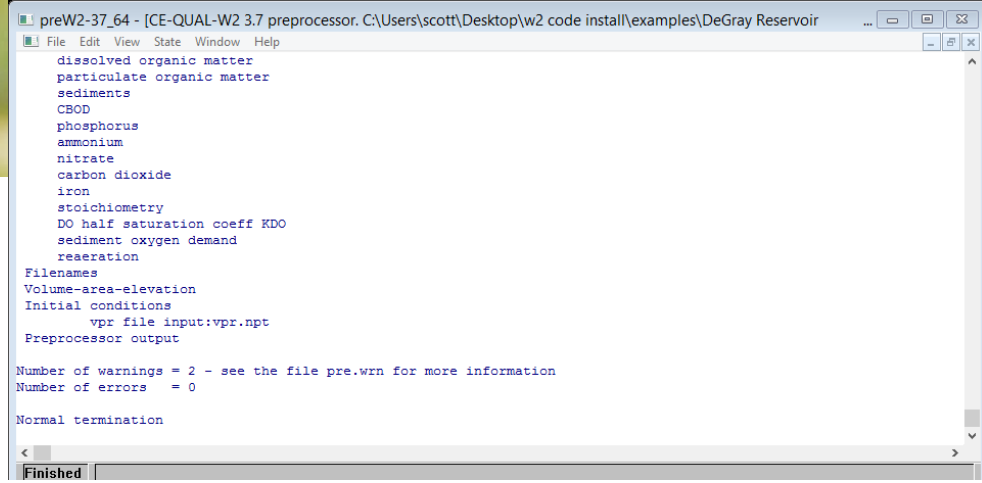
Secchi disk depth

….

Model set-up

Edit the Control File – this file, **w2_con.npt**, is the central file for describing how the model will run. This file tells the code when the model starts, ends, where the inflows/outflows are located, names of files, kinetic parameters, and items you cannot even imagine. Open this file in a text editor or open it using the GUI **W2Control37.exe**

Model set-up

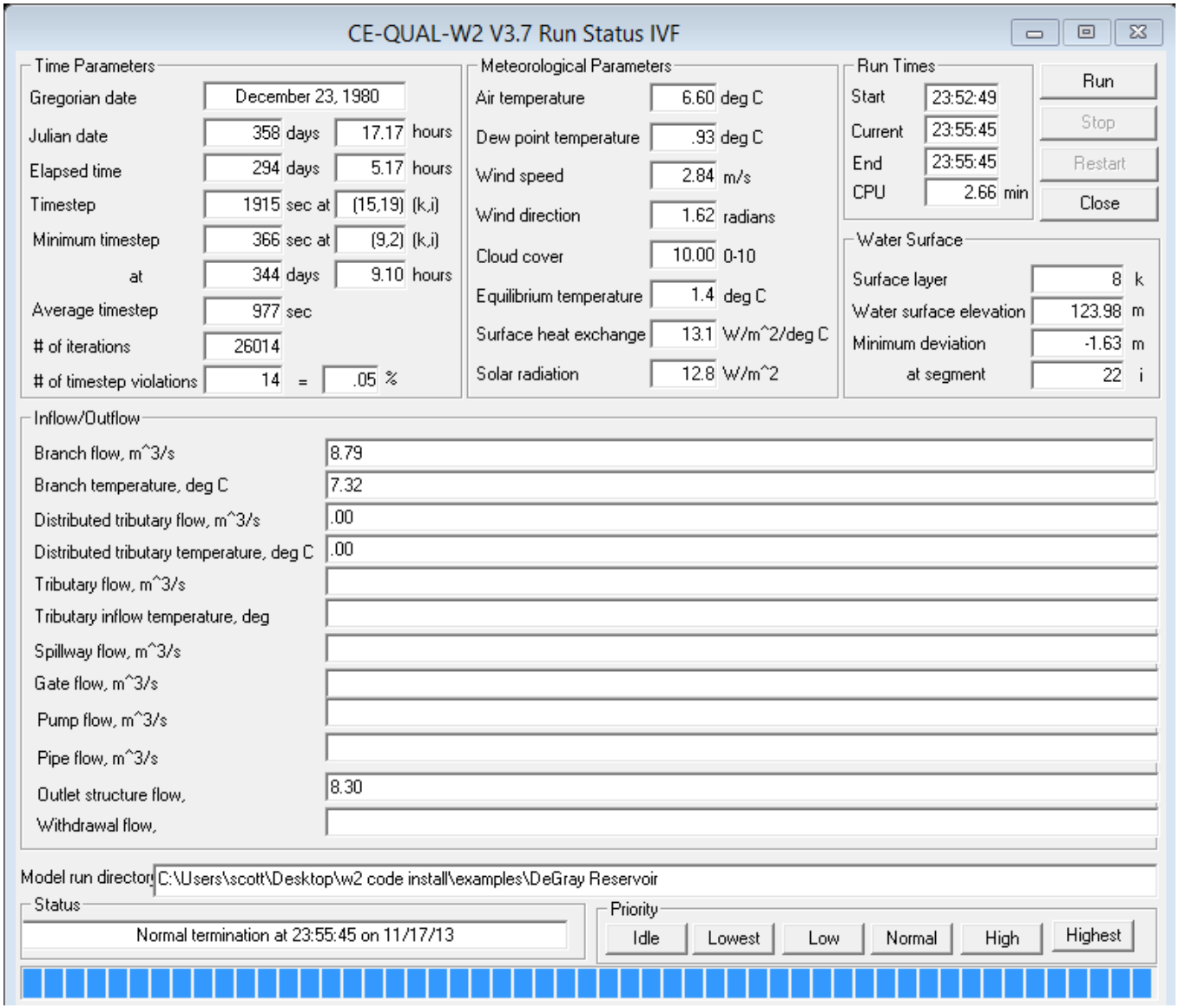


Run the Preprocessor – this file, **preW2-37_64.exe**, checks for model errors in the control file, bathymetry file, and all boundary condition files. Double click on the executable and look at the preprocessor screen. This file writes out between 1 to 3 files: **pre.opt** (an echo of input data and other useful items), **pre.err** (if fatal errors), and **pre.wrn** (if warnings). Make sure you look at **pre.wrn** and **pre.err** files.

Model run

Run the W2 Model – the file **w2_ivf64.exe** is the W2 model code. Double click on the w2 executable and notice the dialog box and the dynamic animation boxes for the simulation.

Model run

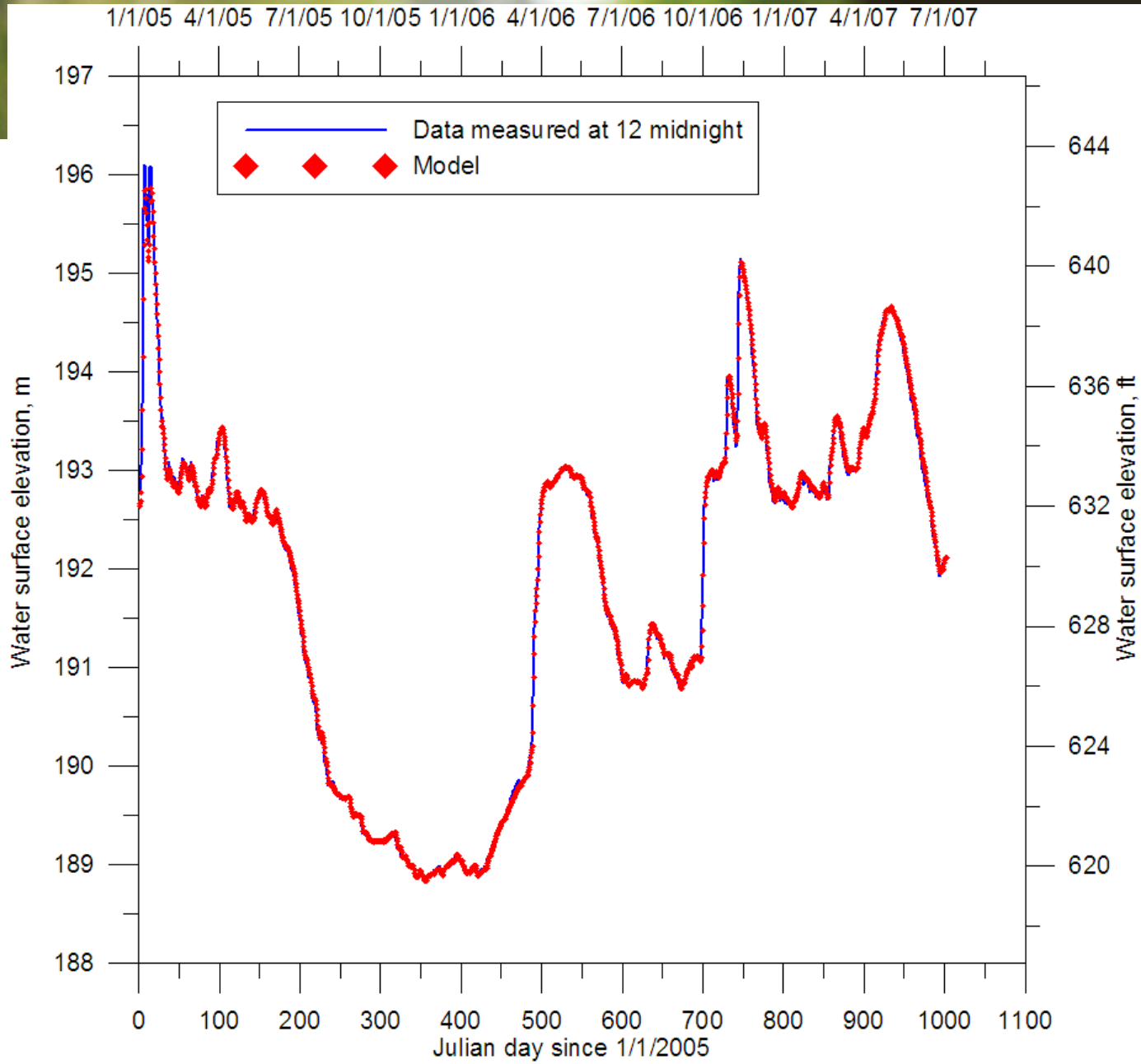

CE-QUAL-W2 V3.7 Run Status IVF
Time Parameters
Gregorian date December 23, 1980
Julian date 358 days 17.17 hours
Elapsed time 294 days 5.17 hours
Timestep 1915 sec at (15,19) (k,i)
Minimum timestep 366 sec at (9,2) (k,i)
at 344 days 9.10 hours
Average timestep 977 sec
# of iterations 26014
# of timestep violations 14 = .05 %
Meteorological Parameters
Air temperature 6.60 deg C
Dew point temperature .93 deg C
Wind speed 2.84 m/s
Wind direction 1.62 radians
Cloud cover 10.00 0-10
Equilibrium temperature 1.4 deg C
Surface heat exchange 13.1 W/m^2/deg C
Solar radiation 12.8 W/m^2
Run Times
Start 23:52:49
Current 23:55:45
End 23:55:45
CPU 2.66 min
Run
Stop
Restart
Close
Water Surface
Surface layer 8 k
Water surface elevation 123.98 m
Minimum deviation -1.63 m
at segment 22 i
Inflow/Outflow
Branch flow, m^3/s 8.79
Branch temperature, deg C 7.32
Distributed tributary flow, m^3/s .00
Distributed tributary temperature, deg C .00
Tributary flow, m^3/s
Tributary inflow temperature, deg
Spillway flow, m^3/s
Gate flow, m^3/s
Pump flow, m^3/s
Pipe flow, m^3/s
Outlet structure flow, 8.30
Withdrawal flow,
Model run directory C:\Users\scott\Desktop\w2 code install\examples\DeGray Reservoir
Status
Normal termination at 23:55:45 on 11/17/13
Priority
Idle
Lowest
Low
Normal
High
Highest

Evaluate model results

Evaluate OUTPUT files or Model Results – W2 outputs files have an extension 'opt'. Typical files include snapshot files (such as **snp.opt** – user defined name), time series files (such as **tsr_1_seg31.opt**) at a point, and spreadsheet files (such as **spr.opt**). Many of these can be used with Excel for easy plotting. You can use Tecplot360 or the w2_post post-processor for contour plots, animations, and profile plots.

Tenkiller Water Level

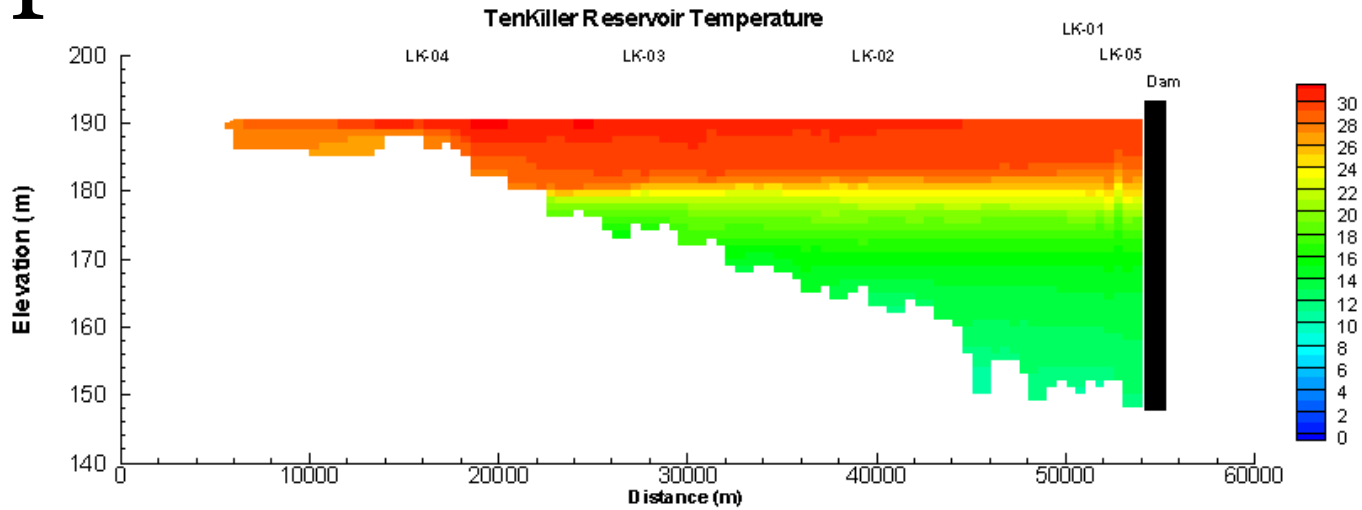
Water balance utility used for lake/reservoir water balance determination

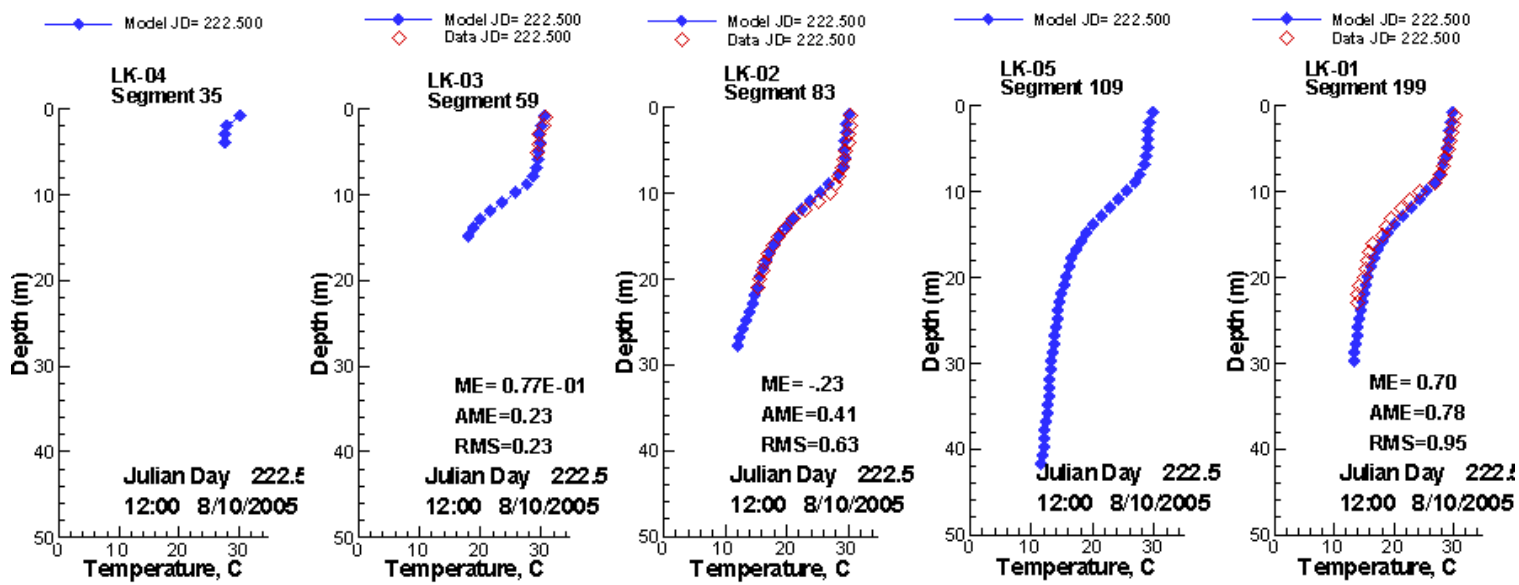


Location	# of comparisons, N	Mean error, m	Absolute mean error, m
Segment 109 at Tenkiller dam	1002	0.00	0.02

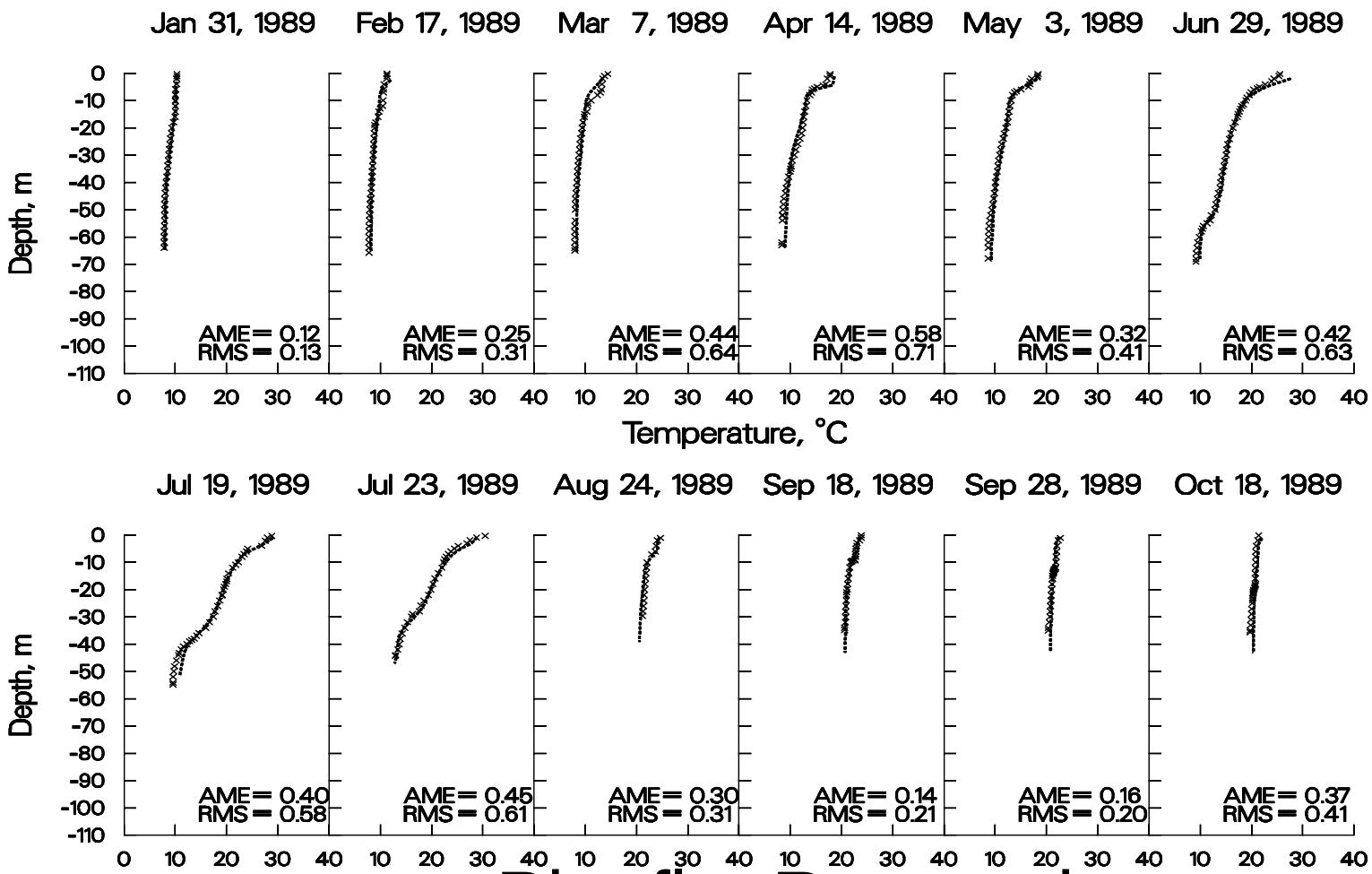
Temperature calibration

ME=-0.06C
AME=0.78C
117 profiles



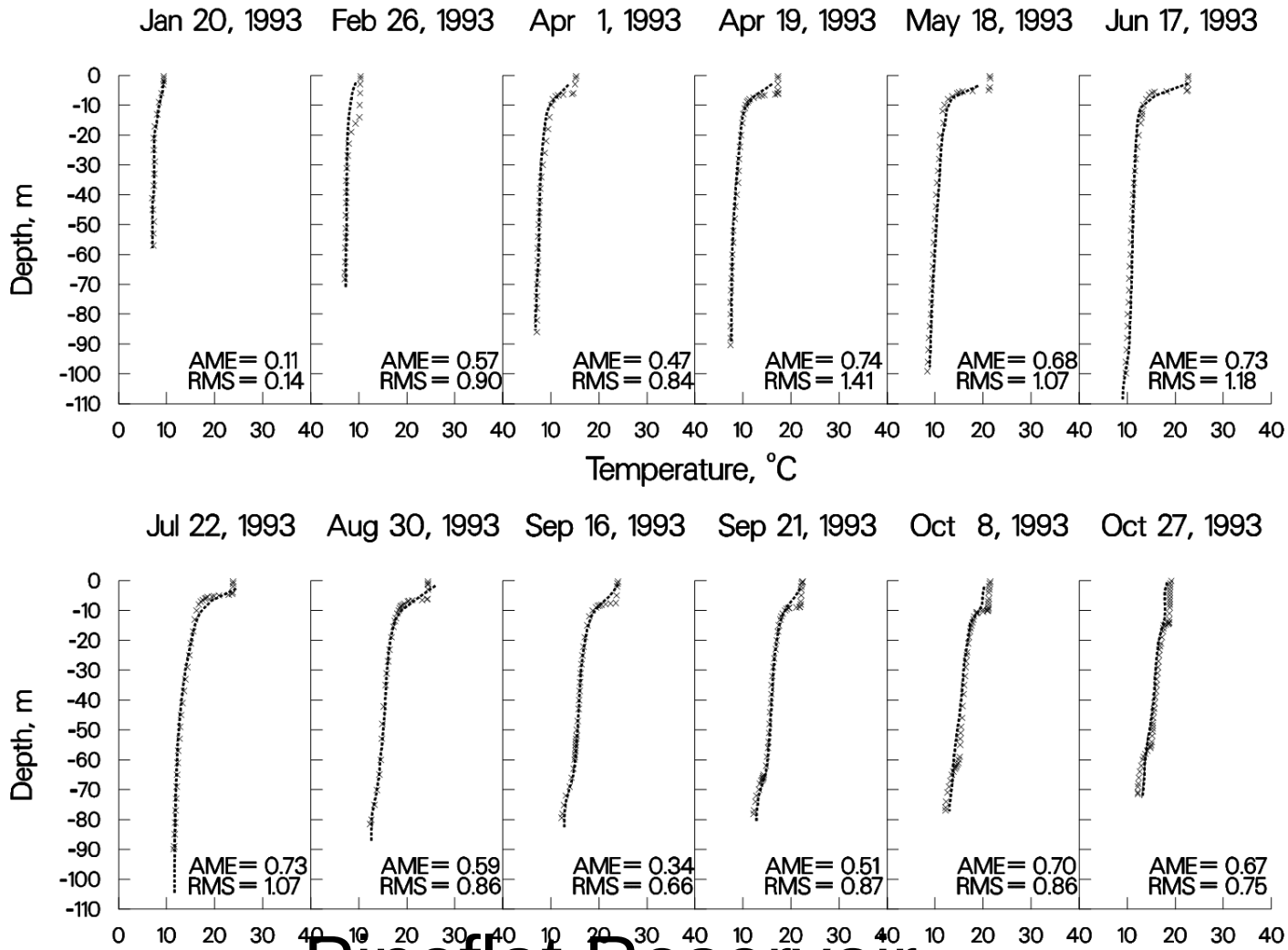


Thermal Calibration



Pineflat Reservoir

Thermal Calibration



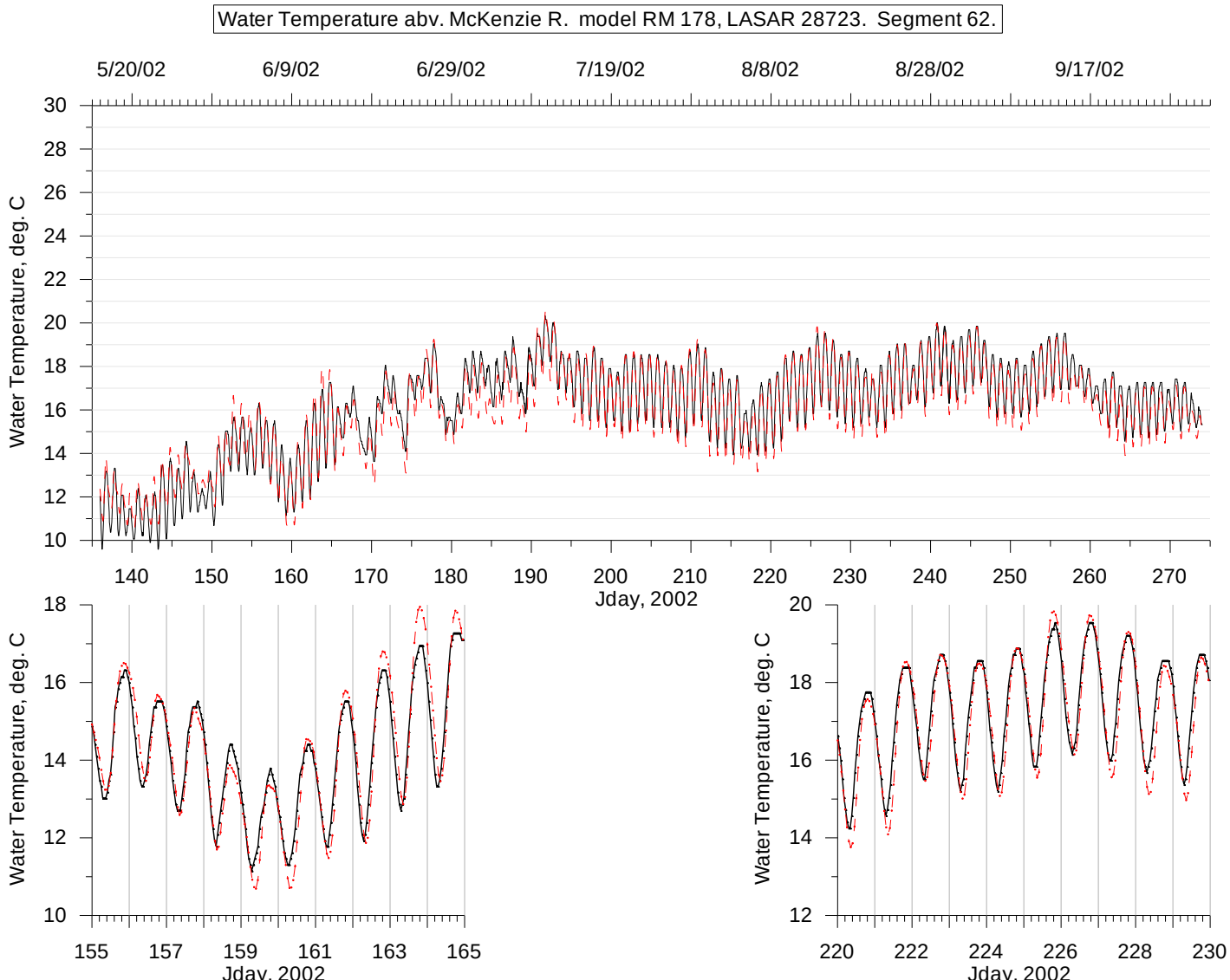
Pineflat Reservoir

Thermal Calibration in Rivers

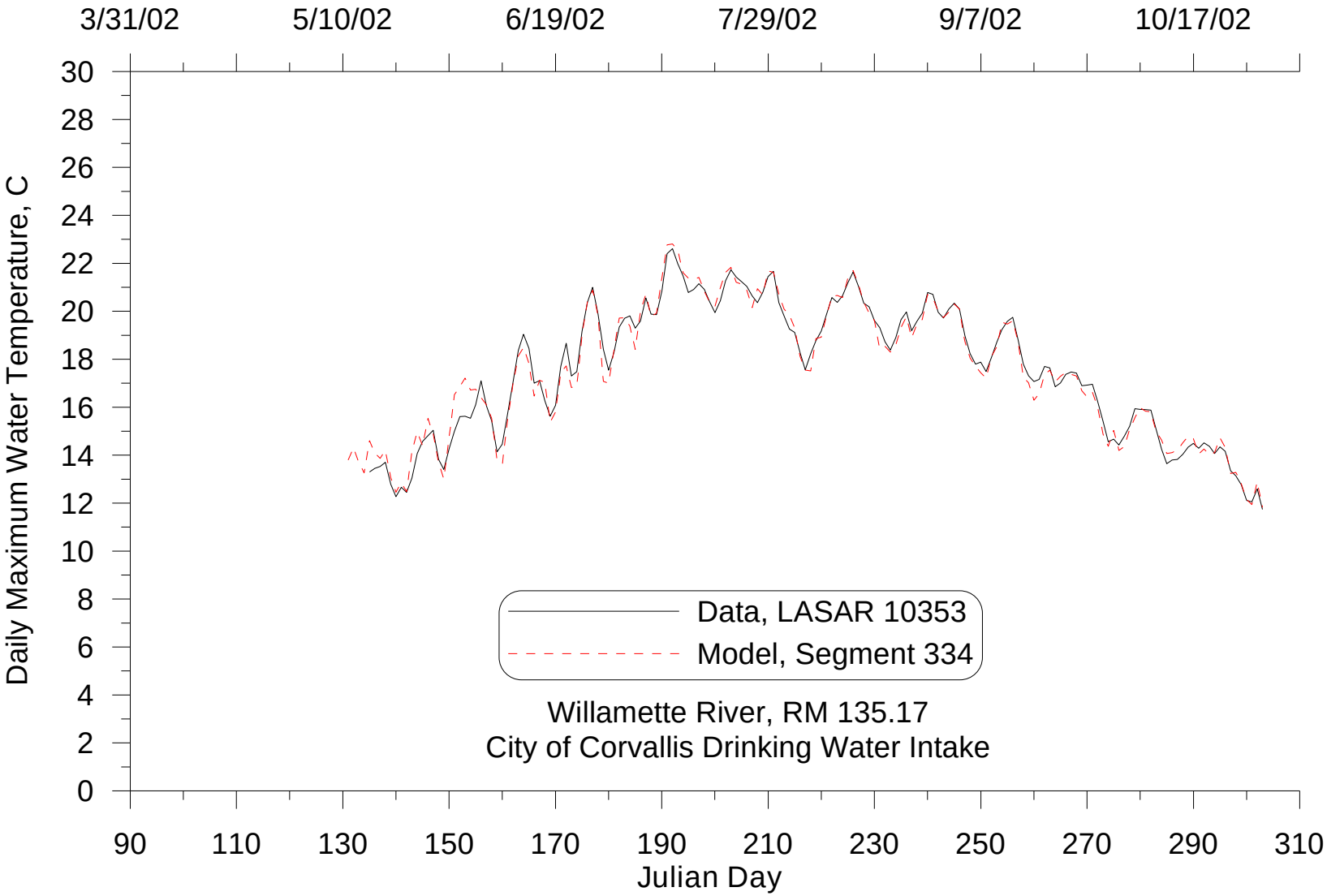
Easier than stratified systems – why?

Successful comparison of model predictions to field data are dependent on surface area, depth, and of course correct meteorological conditions and boundary conditions

Upper Willamette River Temperature



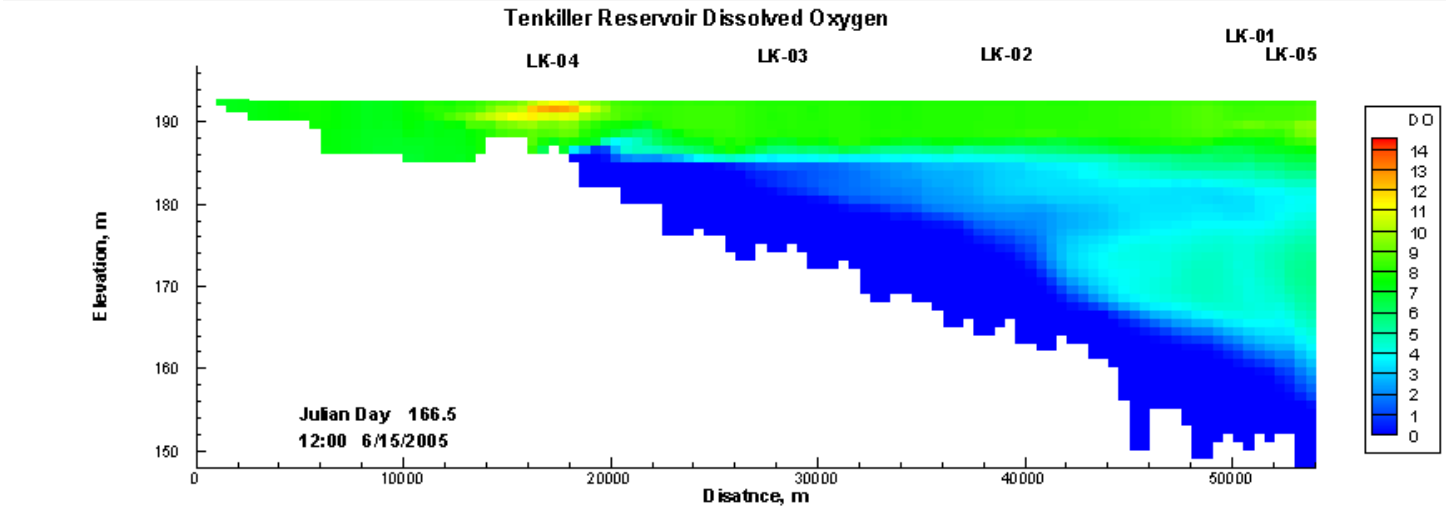
Upper Willamette River Daily Max Temperature

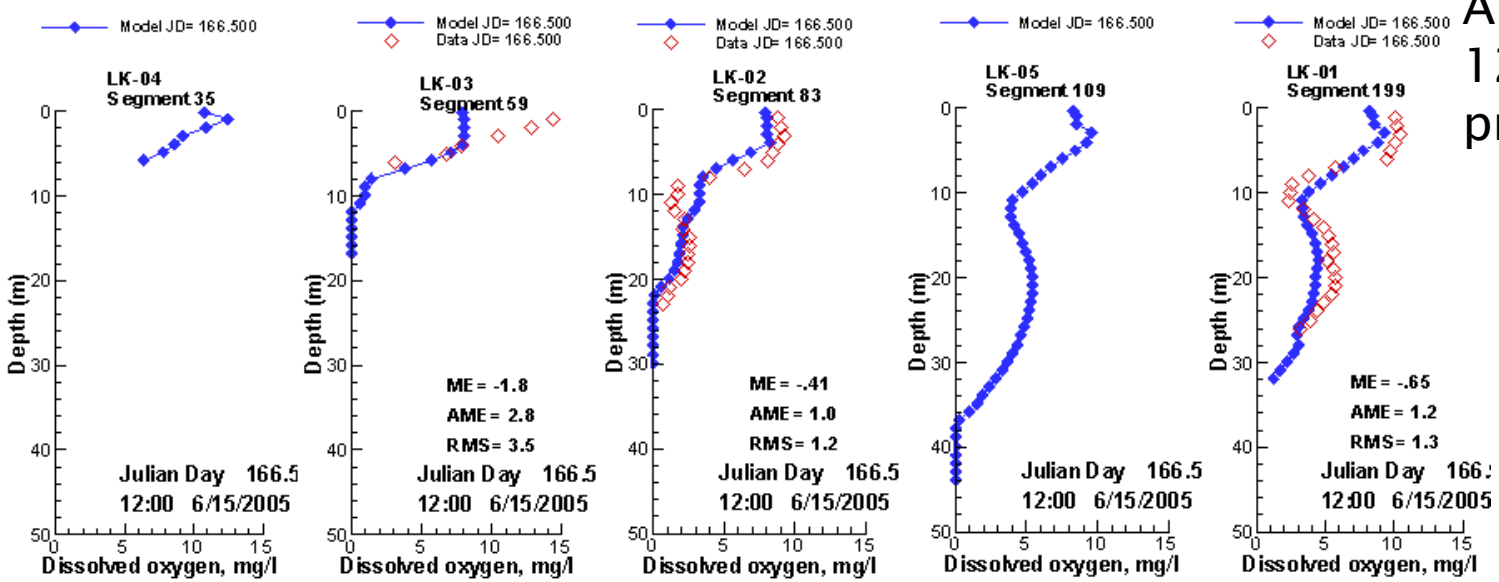


2001 Upper Willamette River Temperature Model – Data Error Statistics

Station Name	RM	Segment	#	ME, C	AME, C	RMS, C
Springfield	185.3	2	5040	0.016	0.040	0.051
abv_McKenzie	177.7	53	2362	-0.183	0.400	0.514
Harrisburg	162.0	156	5040	0.149	0.615	0.736
abv_Long Tom	151.6	227	5040	0.381	0.577	0.738
RM 147	147.4	255	5040	0.490	0.638	0.812
RM 141.7	142.4	287	5040	0.359	0.603	0.752
Corvallis	135.2	334	2520	0.206	0.485	0.619
Albany	120.2	434	2179	-0.109	0.370	0.472
Conser Rd	113.9	476	4967	0.023	0.454	0.580
River Rd	96.9	589	4958	-0.167	0.424	0.523
abv_rickreall	88.9	643	2520	0.126	0.630	0.824
Salem	84.7	666*	600	0.167	0.514	0.641

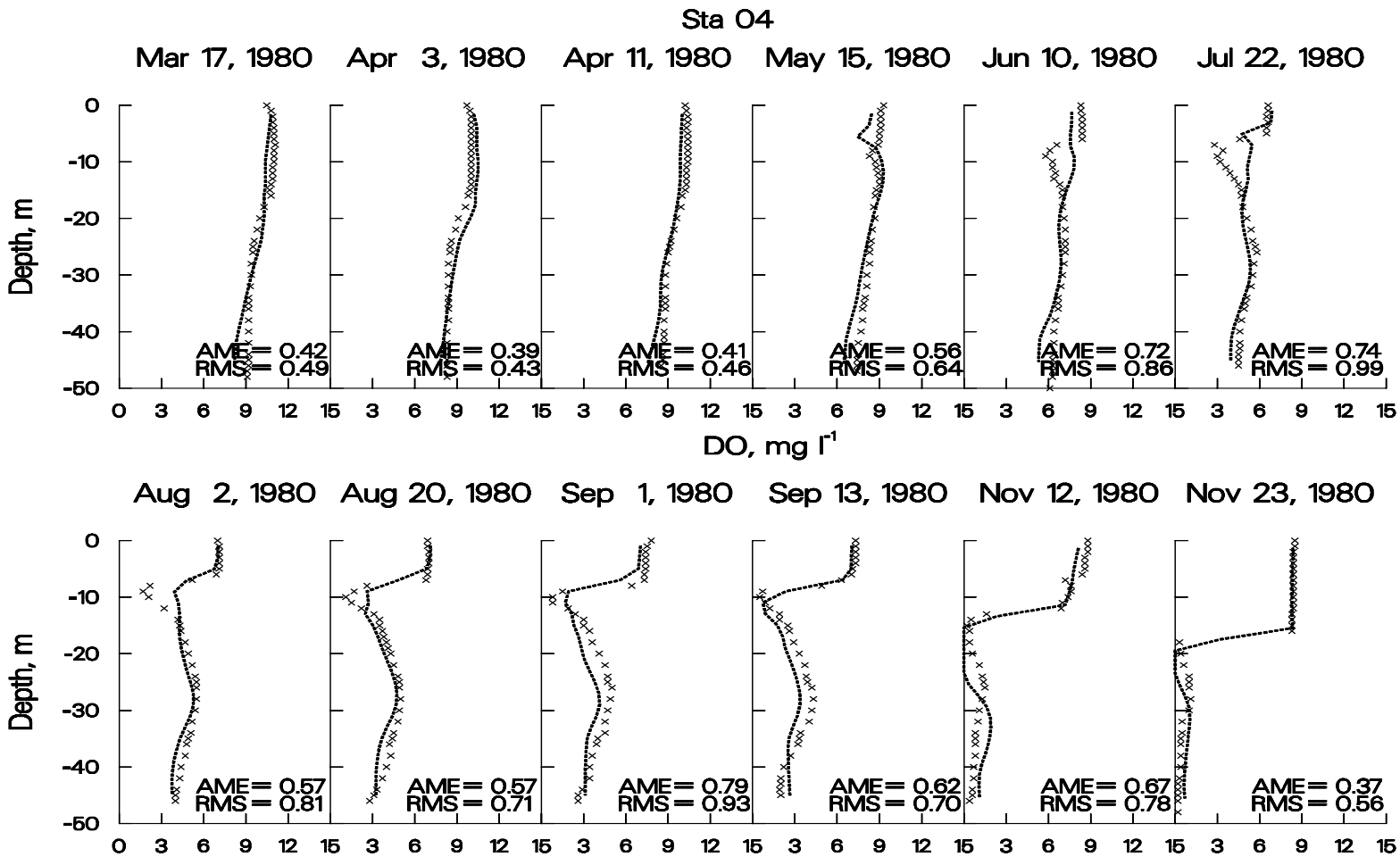
Dissolved oxygen calibration





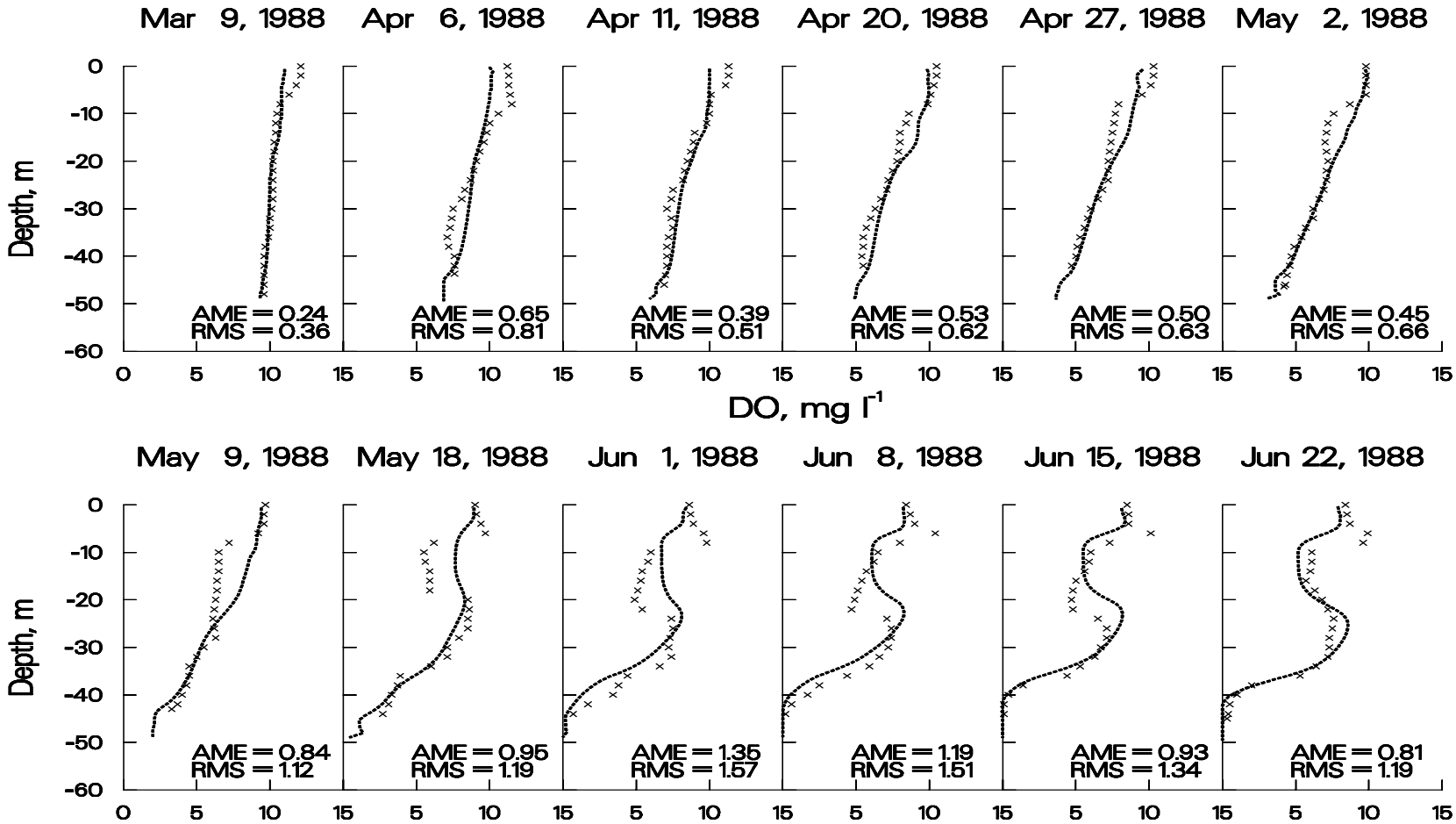
1.5 mg/l
AME
128
profiles

DO Calibration



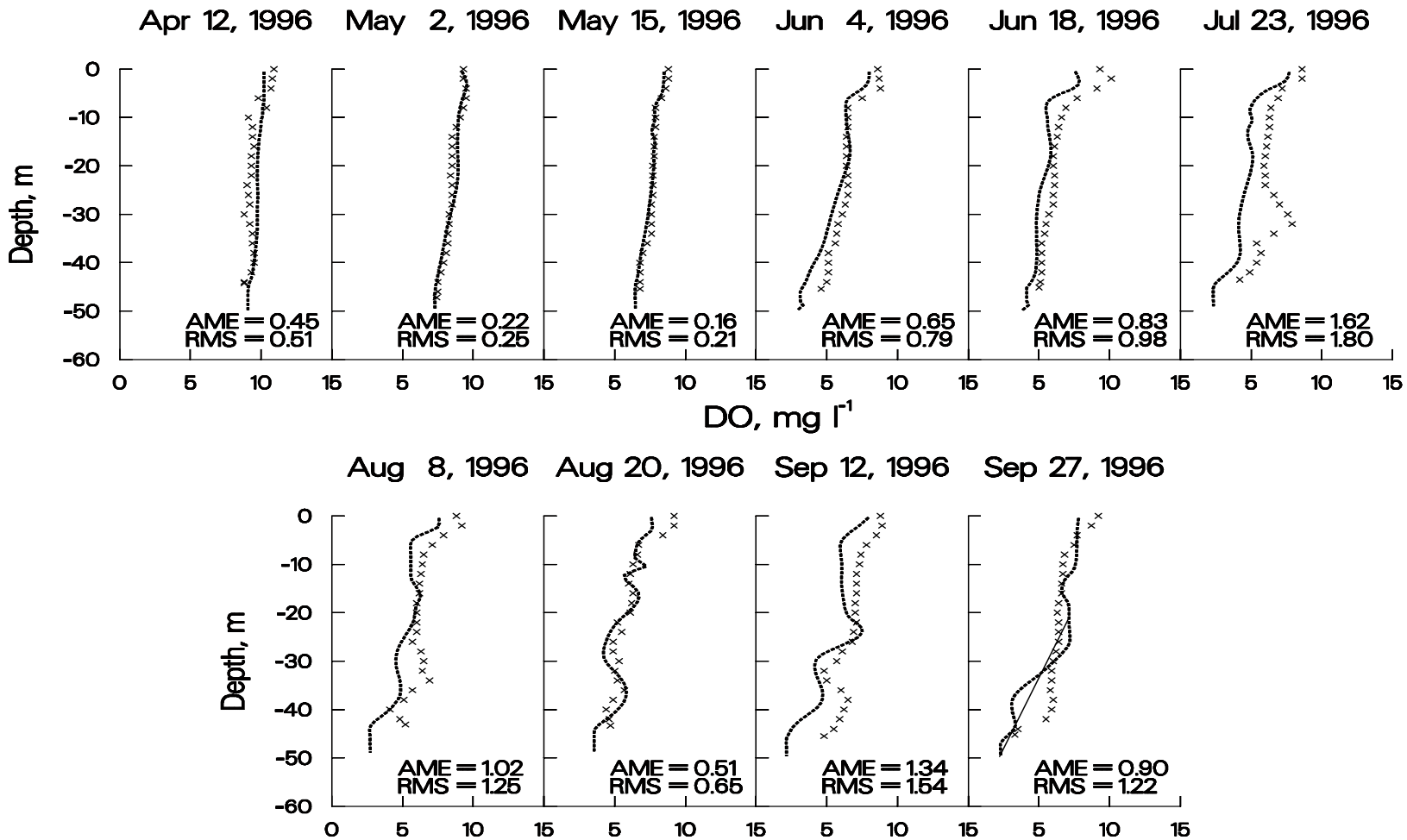
DeGray Reservoir

DO Calibration



Richard B. Russell Reservoir

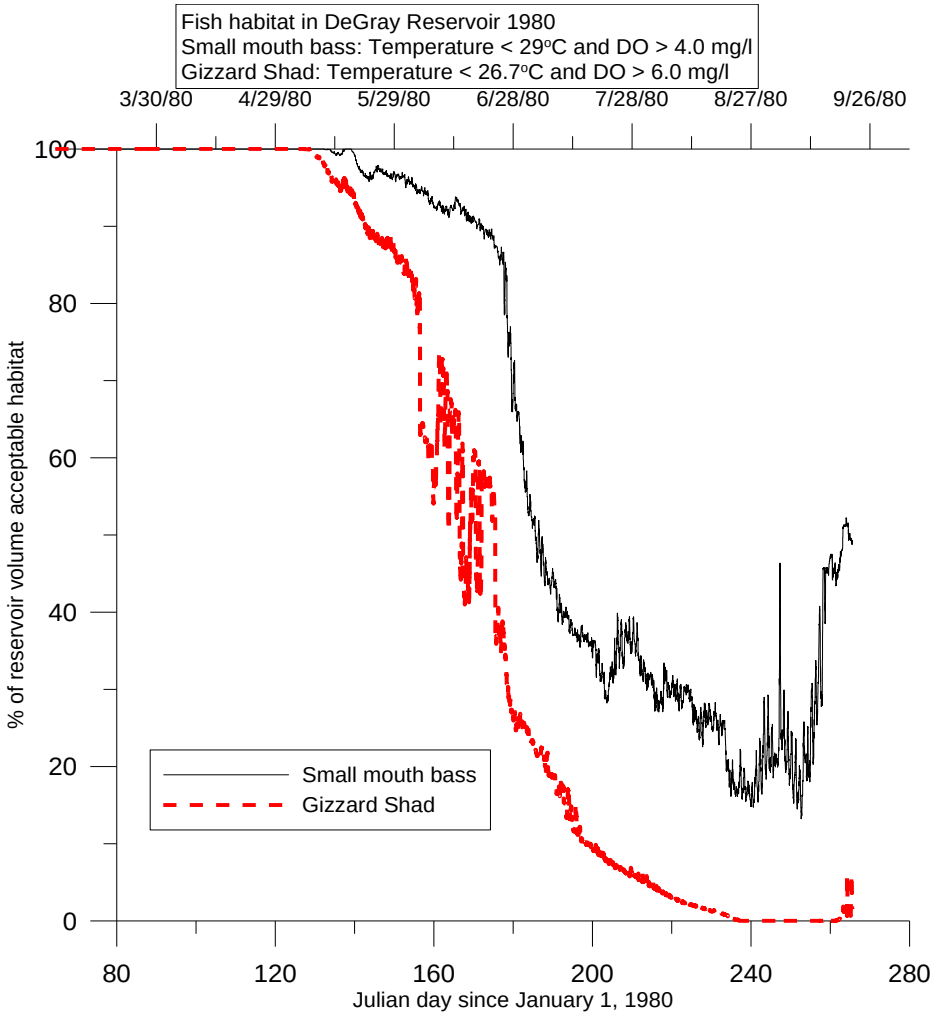
DO Calibration



Richard B. Russell Reservoir

Analysis of Model Calibration

- Temperature and dissolved oxygen habitat volumes
  - Determine species habitat volumes based on temperature and dissolved oxygen criteria

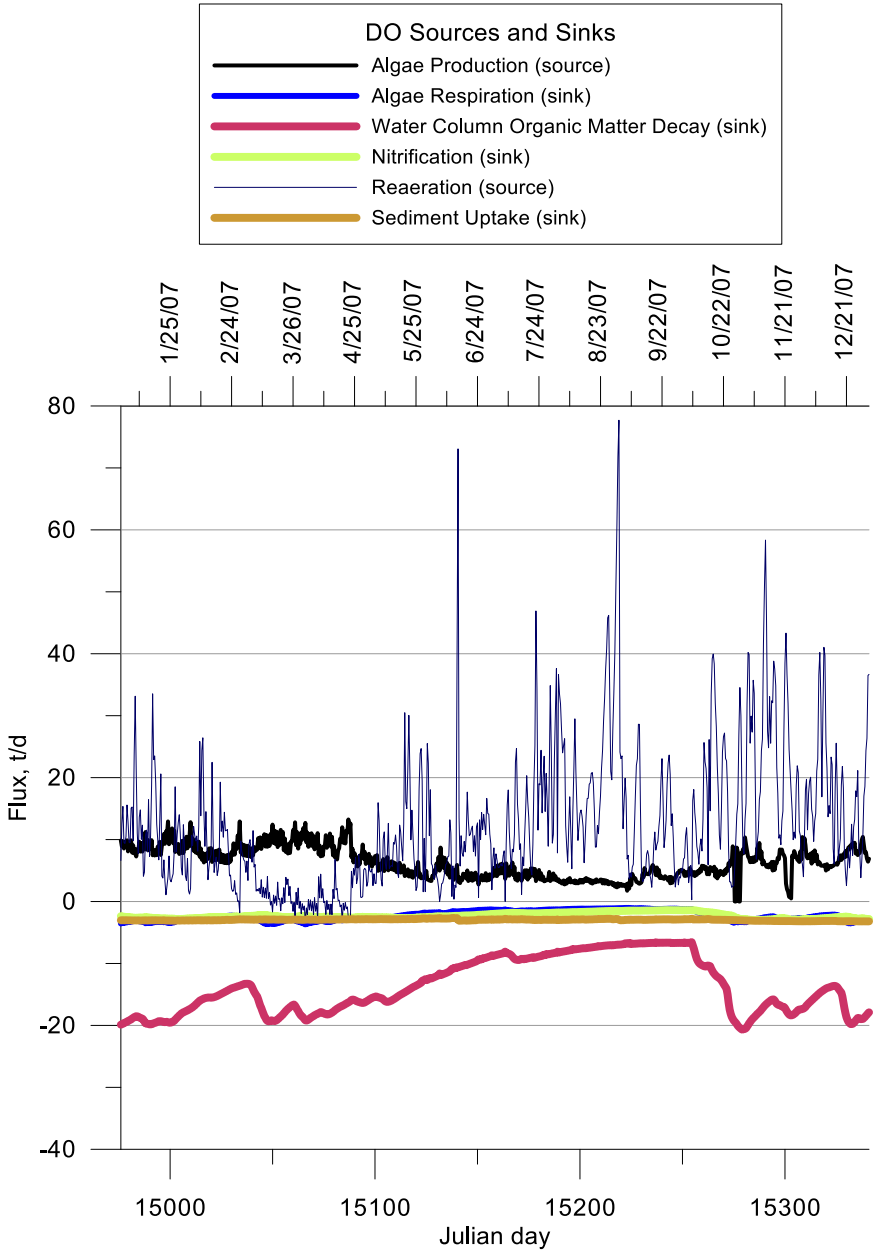


File: habitat3.opt in DeGray application

Analysis of Model Calibration

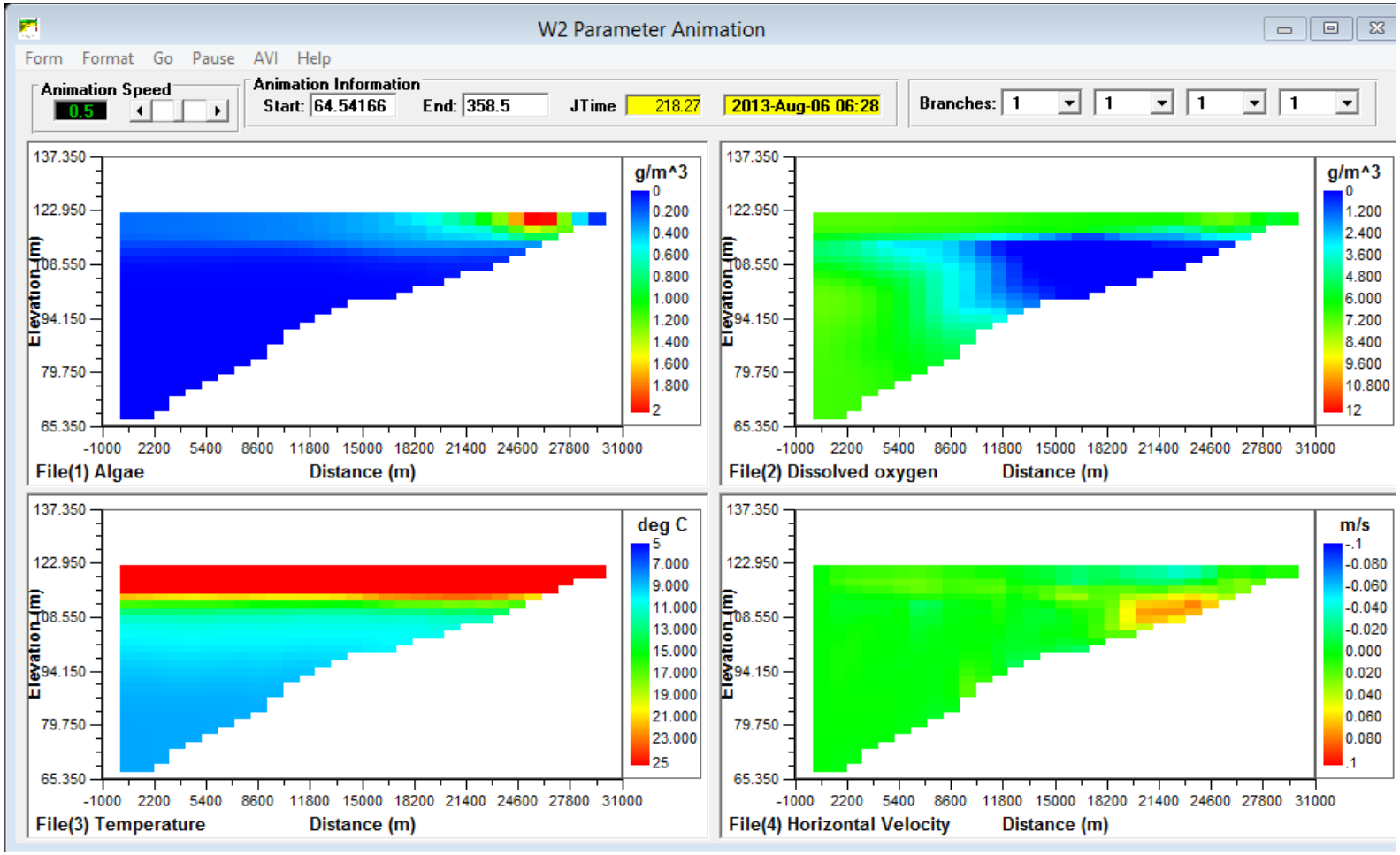
•I/O improvements: kinetic fluxes output – big picture look at model predictions

File: kwflux_jw1.opt and flx.opt in DeGray application

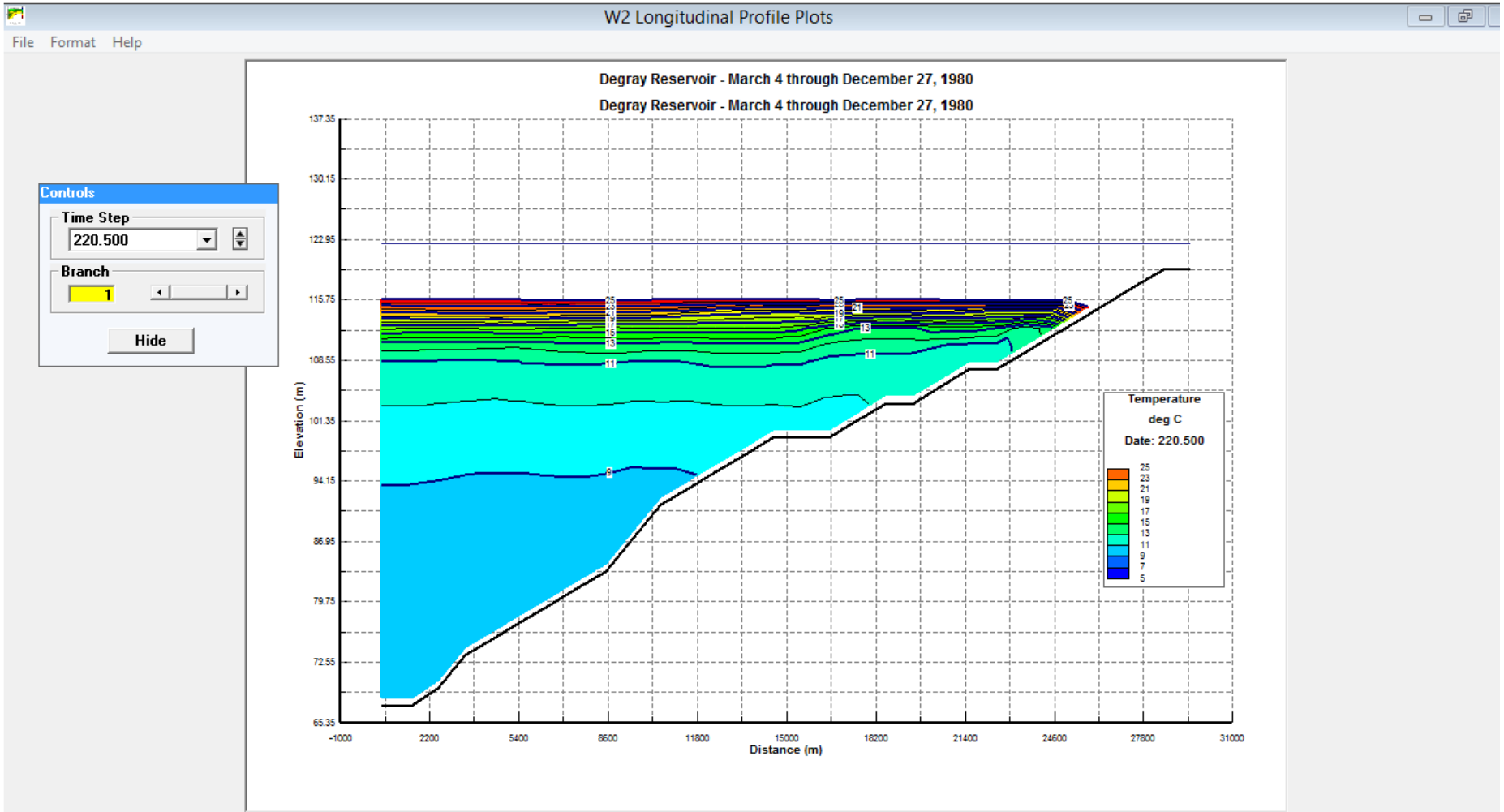


Use of model post-processor

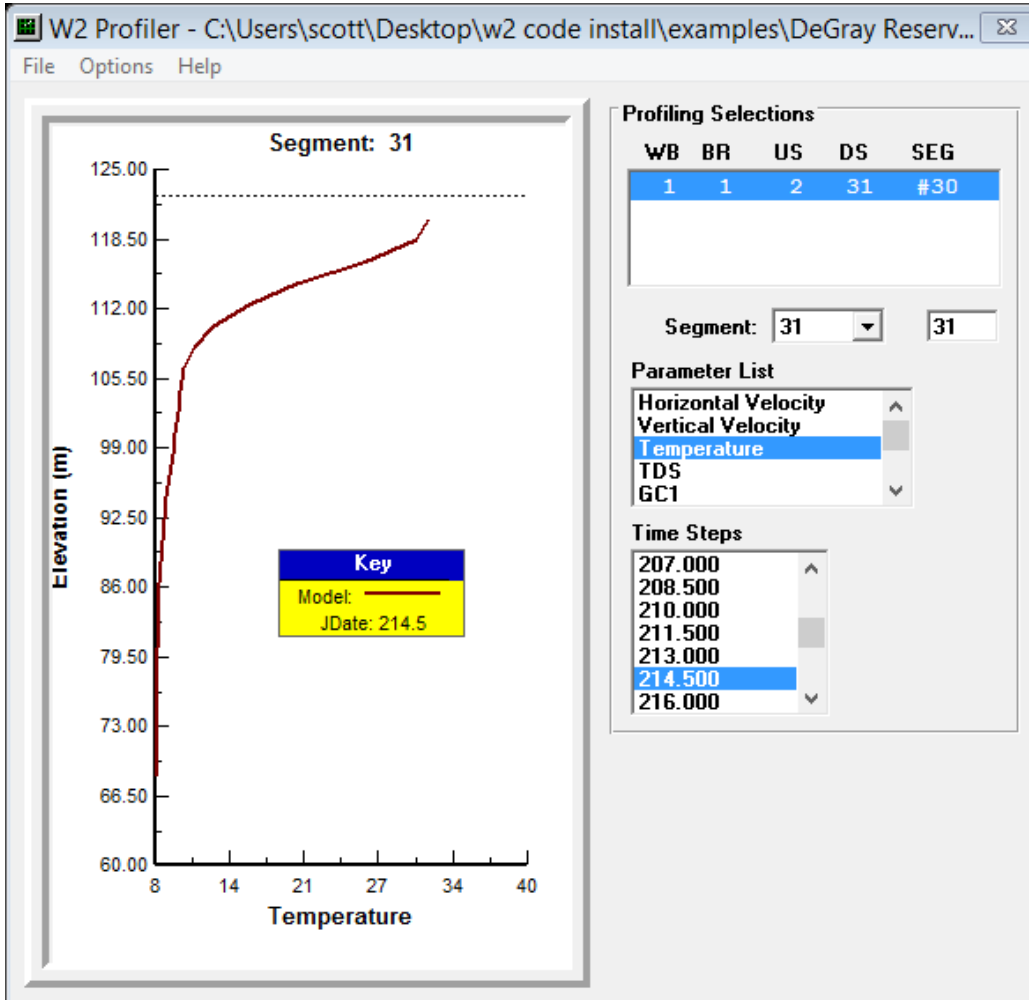
Animations – up to 4 animations at a time. Can generate AVI files.



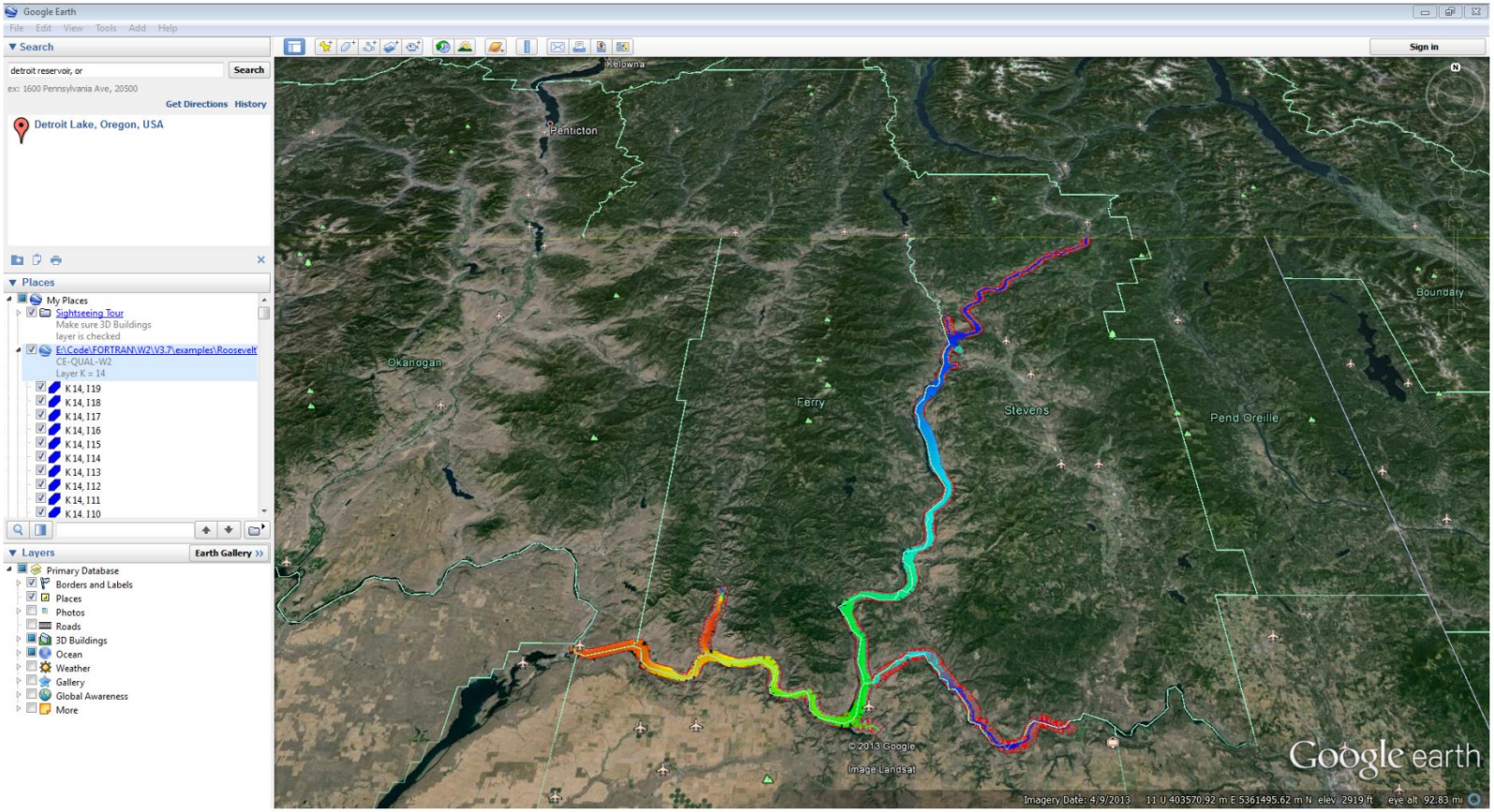
Model post-processor - contours



Model post-processor - profiles

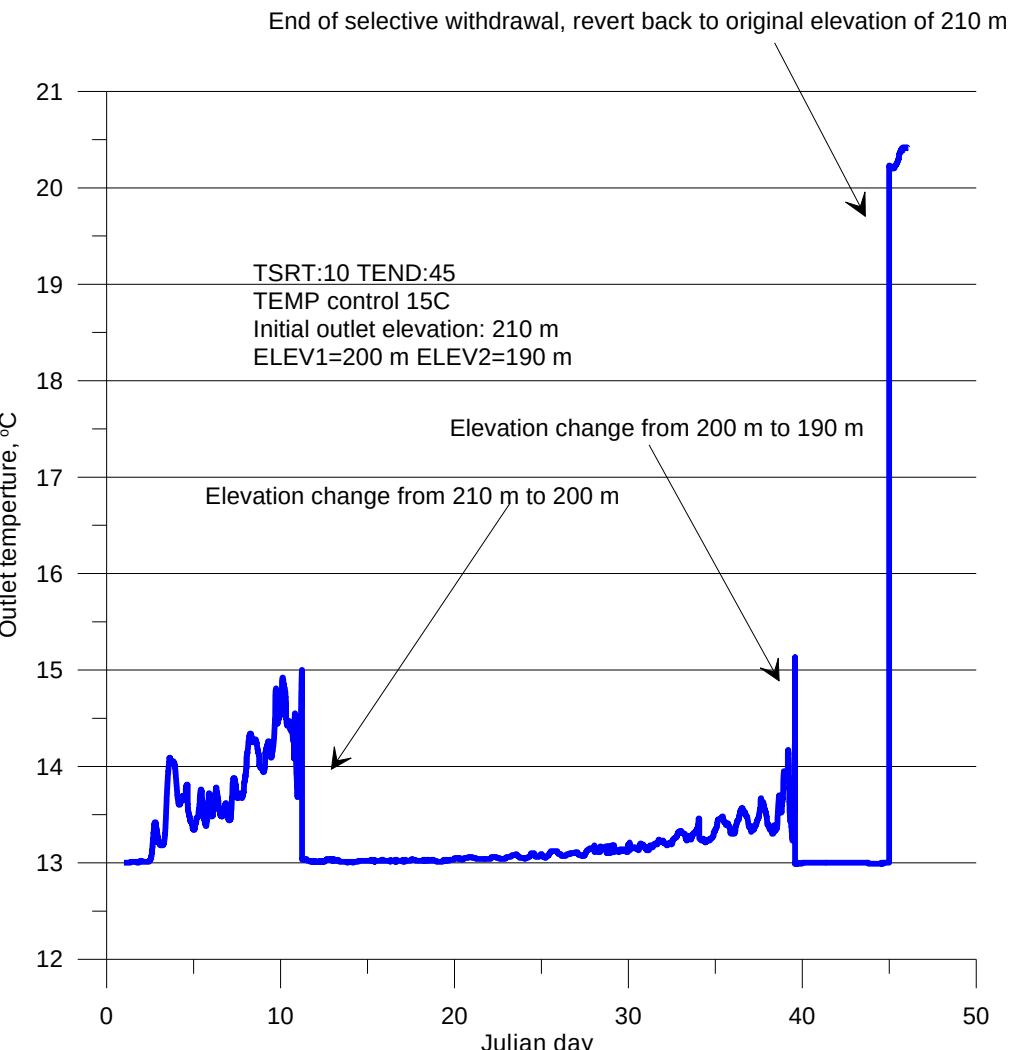


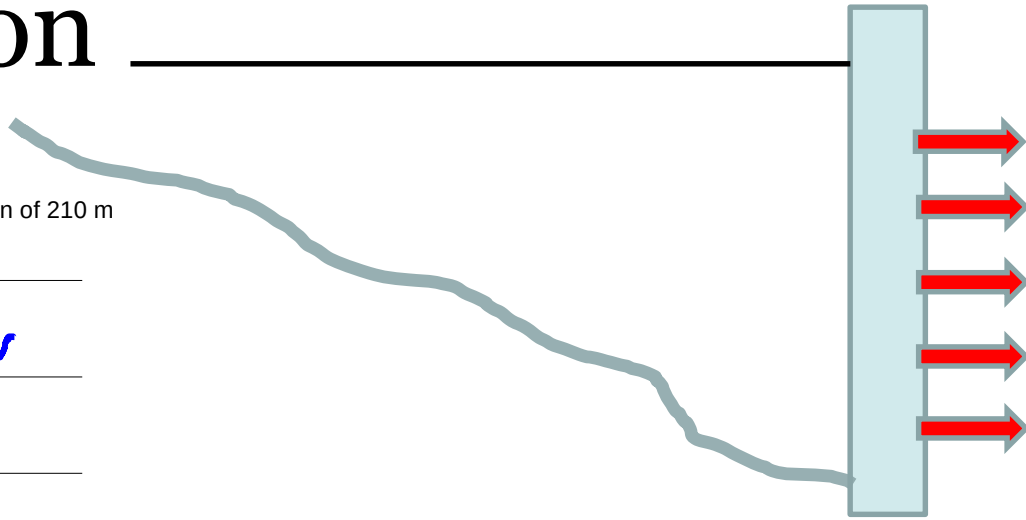
Model post-processor: Integration with Google Maps



Lake Roosevelt, WA, Water age

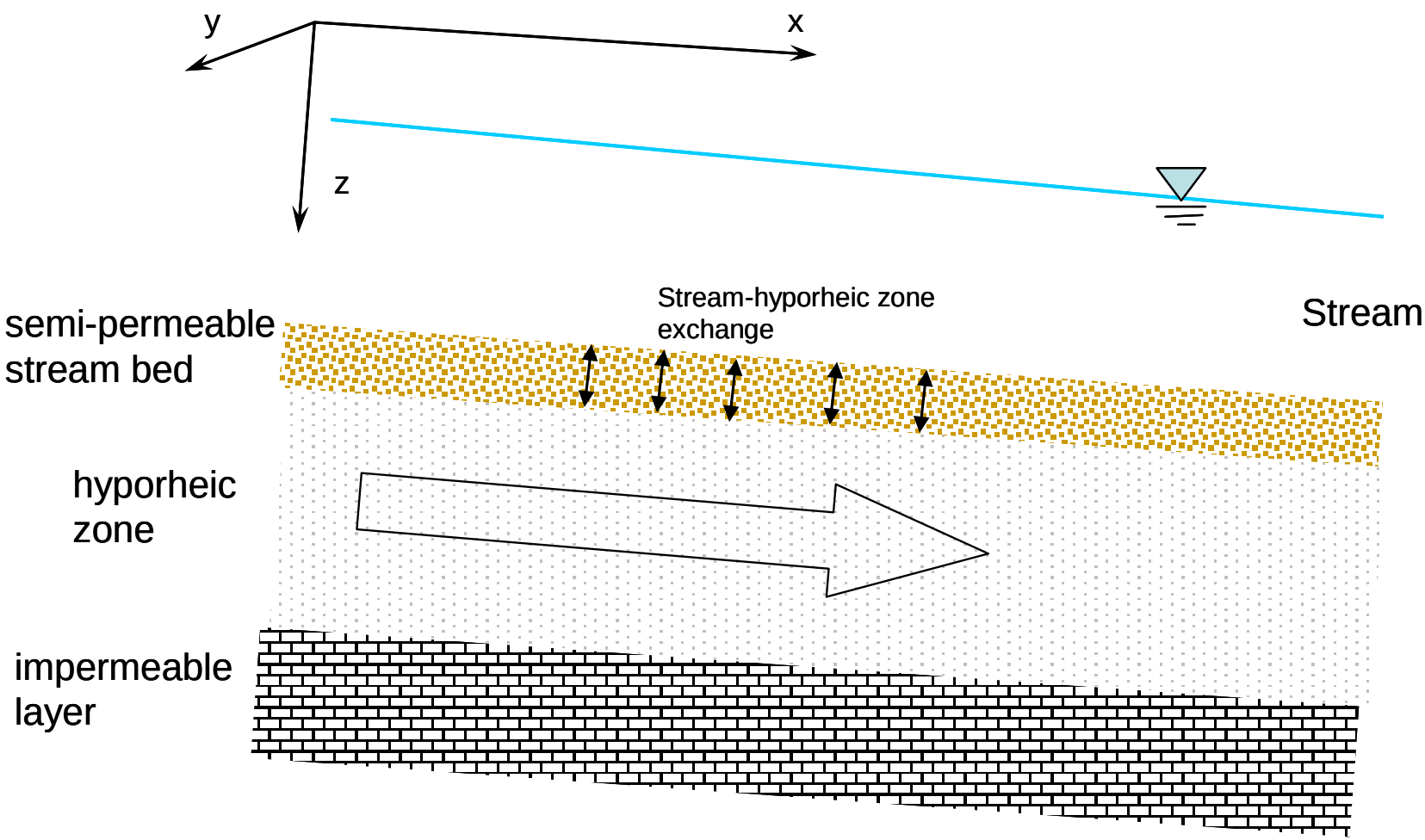
Auto-Port Selection





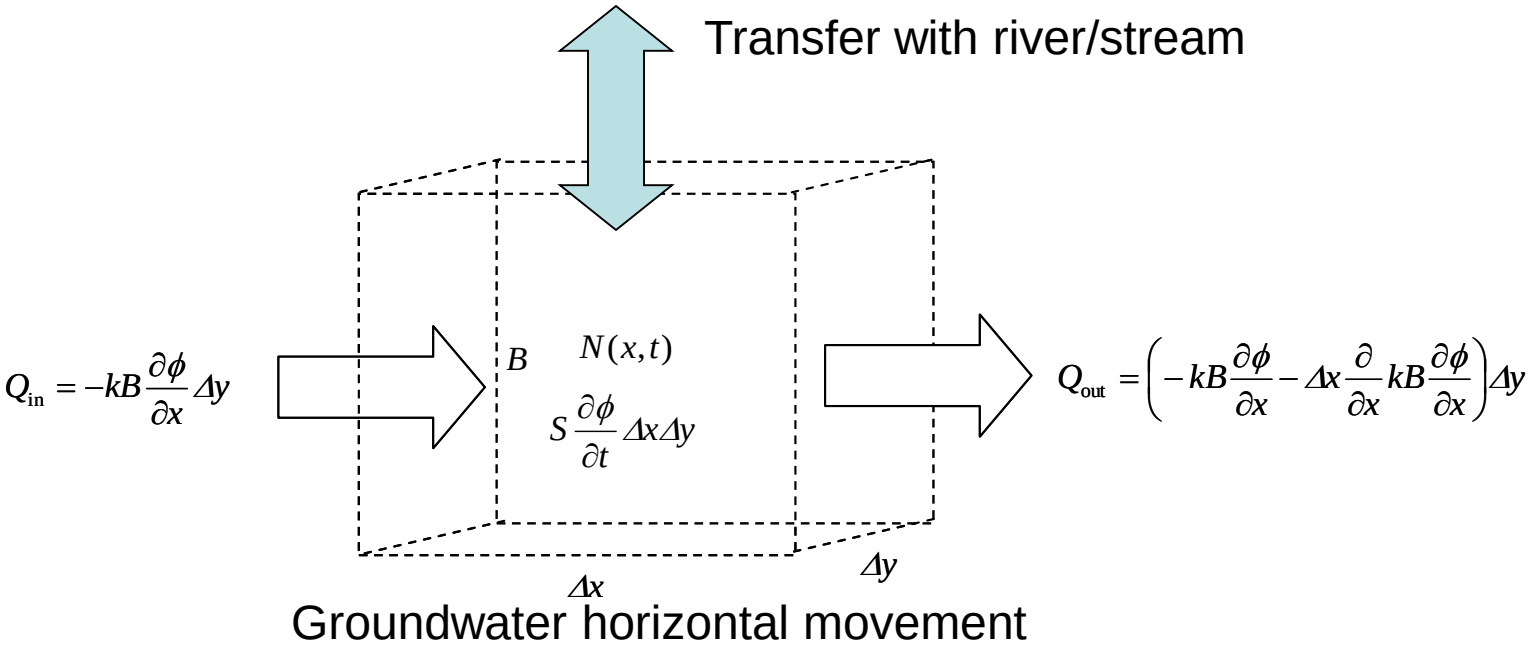
Current Directions

Hyporheic Flow



Hyporehic Flow

$$S\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial x} kB \frac{\partial \phi}{\partial x} + \frac{k'}{b'}\left(\phi_{\circ} - \phi\right)$$

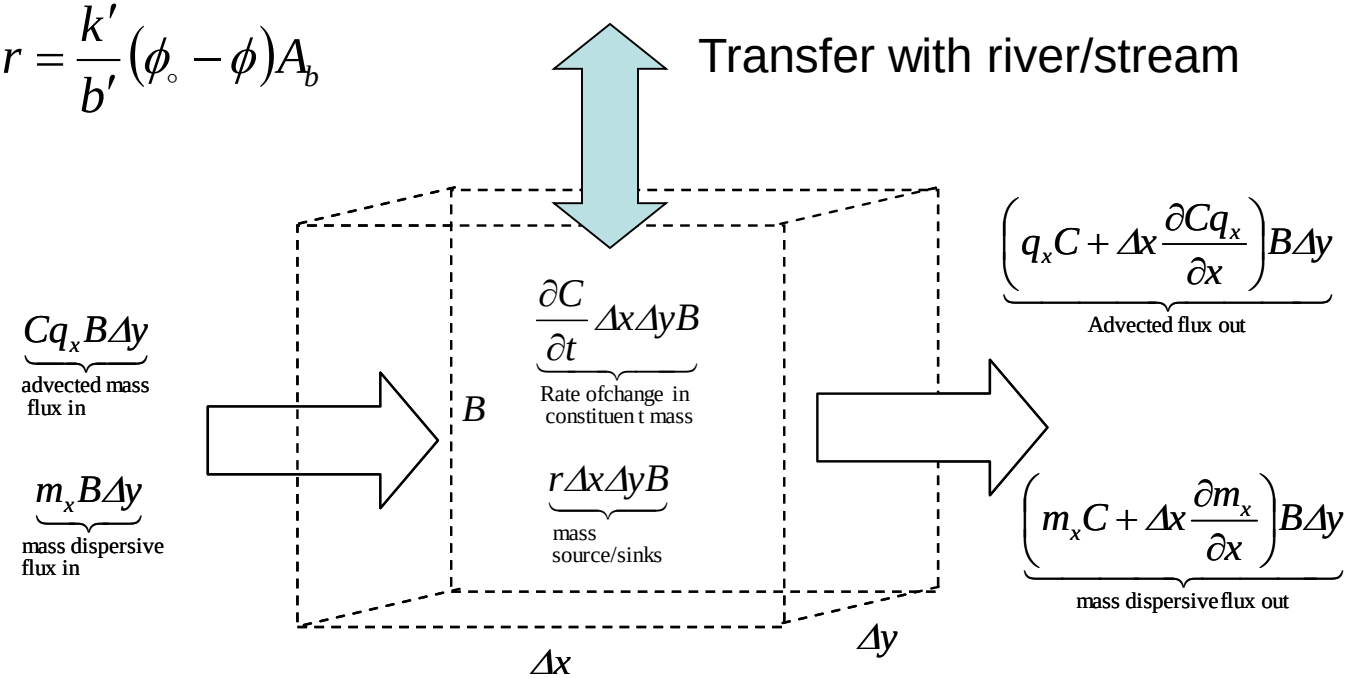


Hyporehic Flow

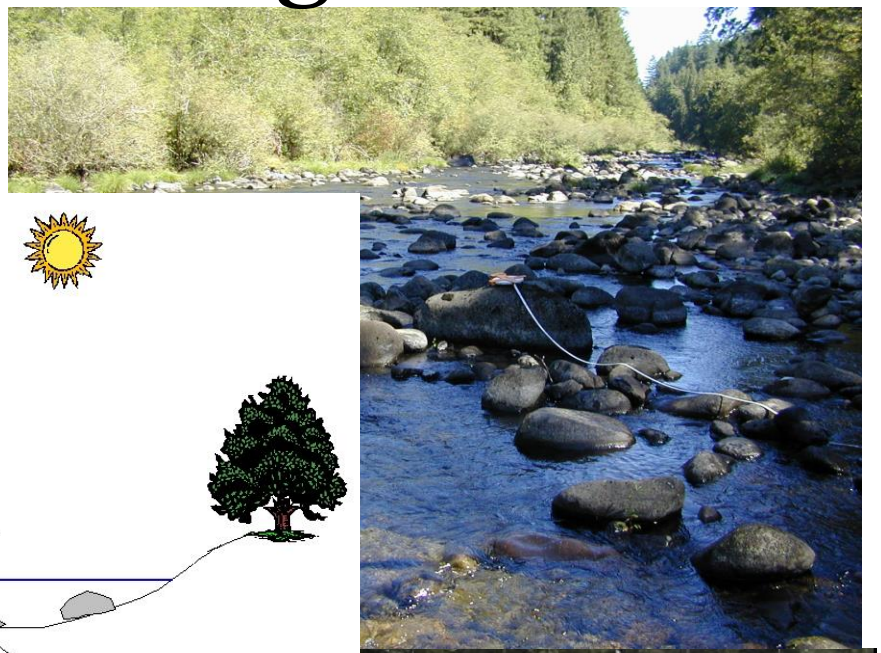
$$\frac{\partial C}{\partial t} + \frac{\partial C q_x}{\partial x} = \frac{\partial}{\partial x} D_x \frac{\partial C}{\partial x} + r$$

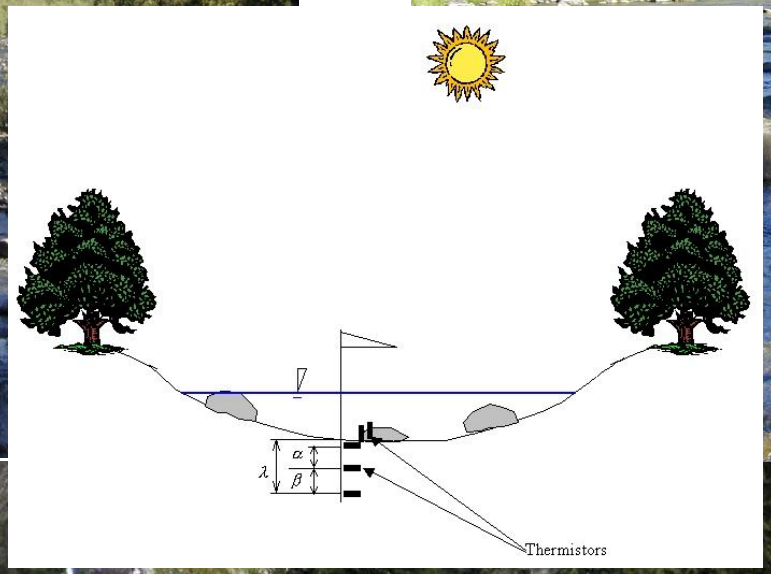
$$r = \frac{k'}{b'}\left(\phi_\circ - \phi\right) A_b$$

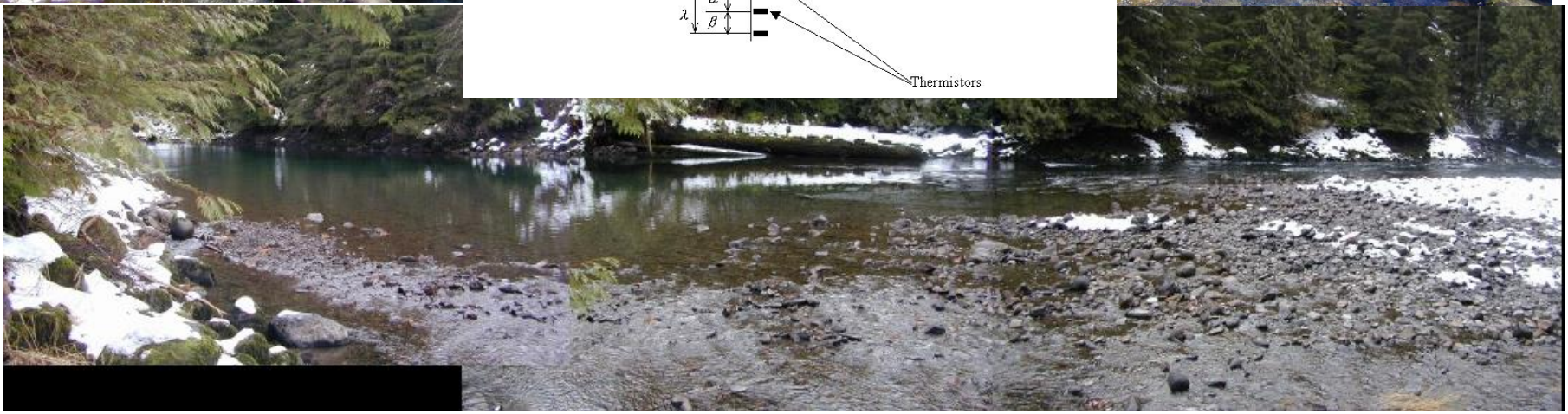
Transfer with river/stream



Channel Bottom Heating



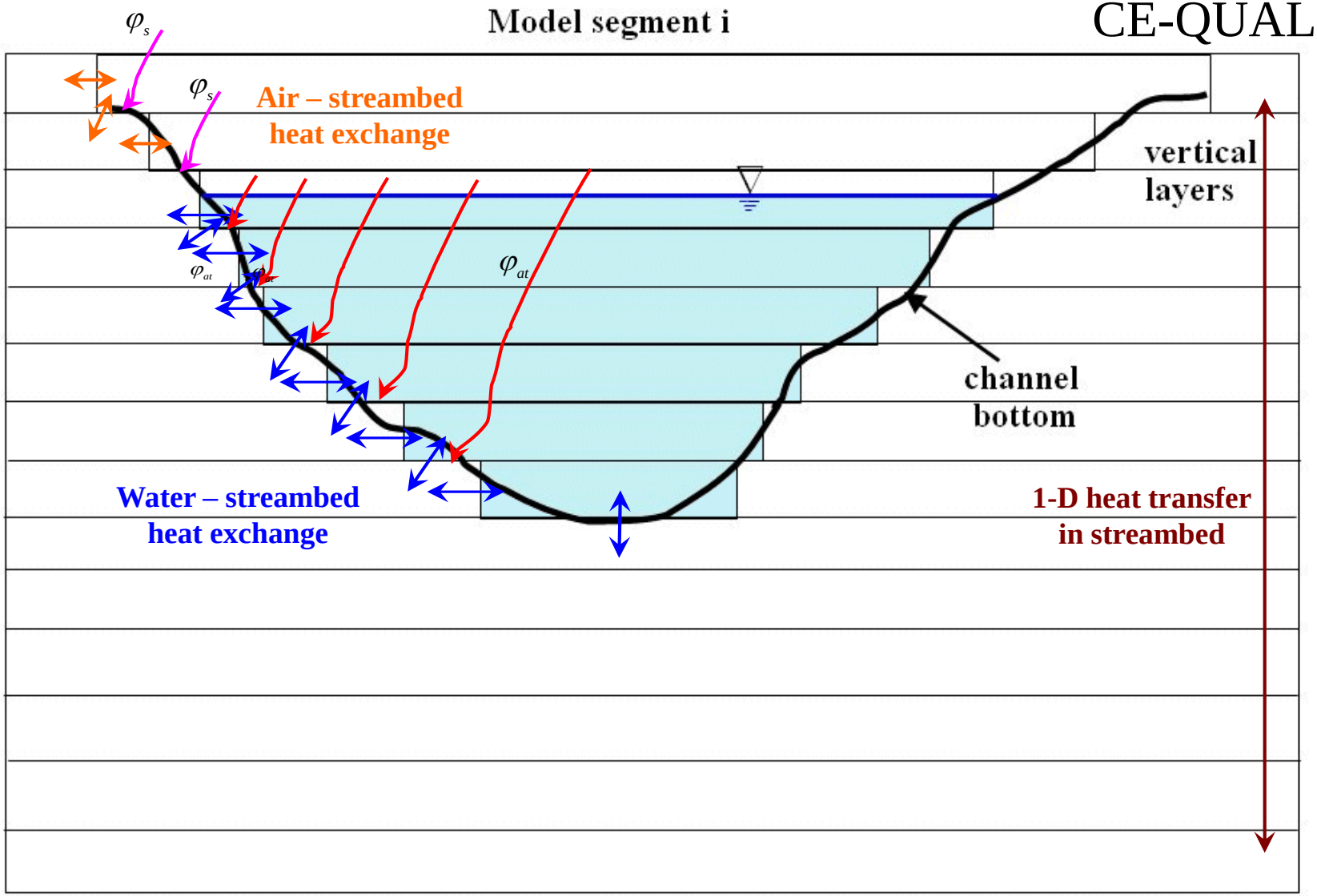




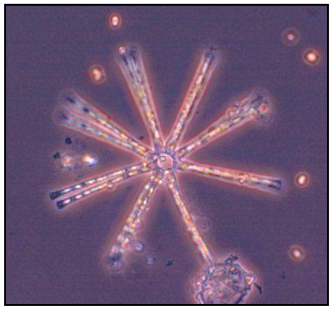
φ_{at}

Streambed Model

Implementation in CE-QUAL-W2



Bioenergetics Modeling



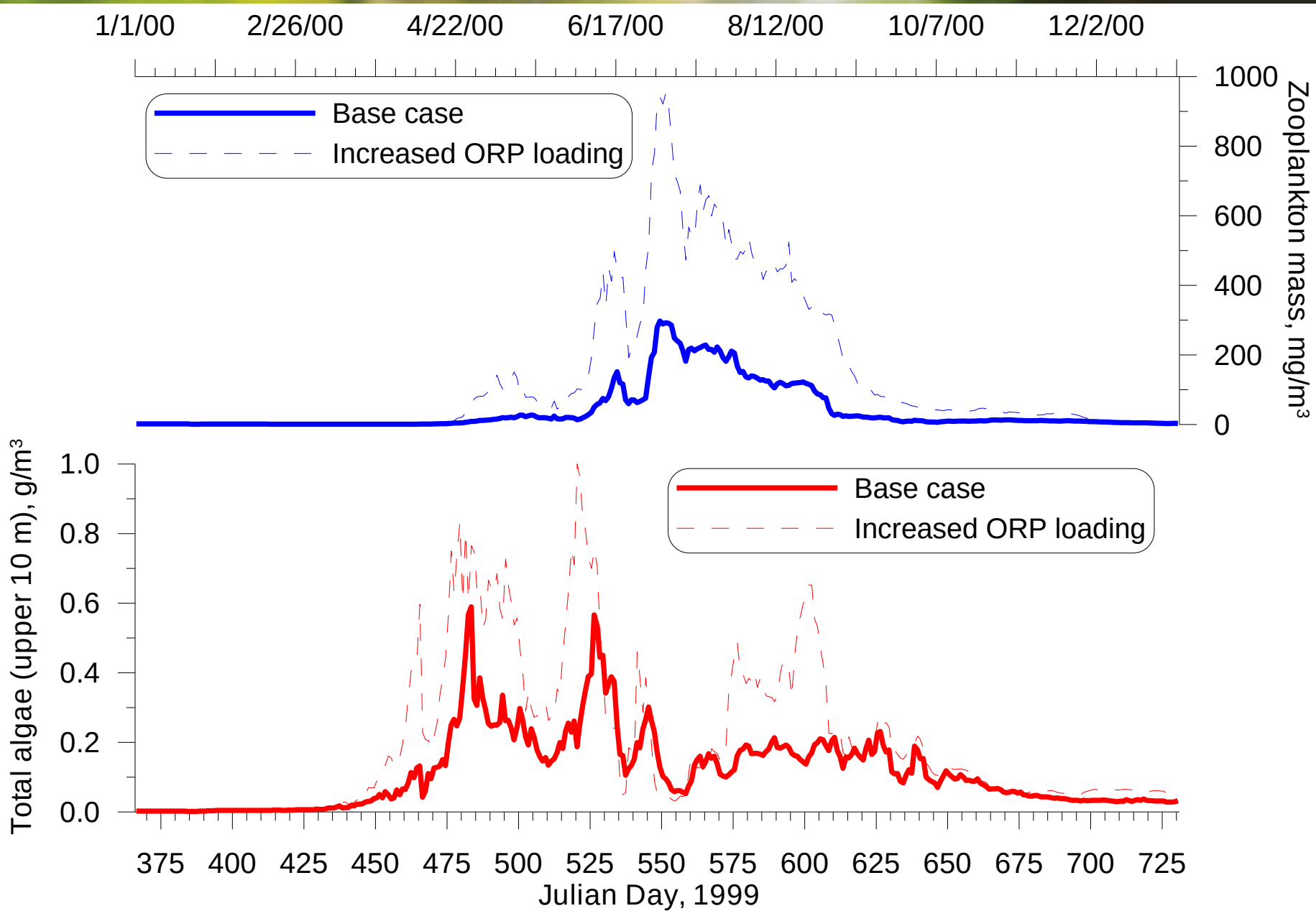
CE-QUAL-W2 Model

Zooplankton feeding rates, organic matter excretion

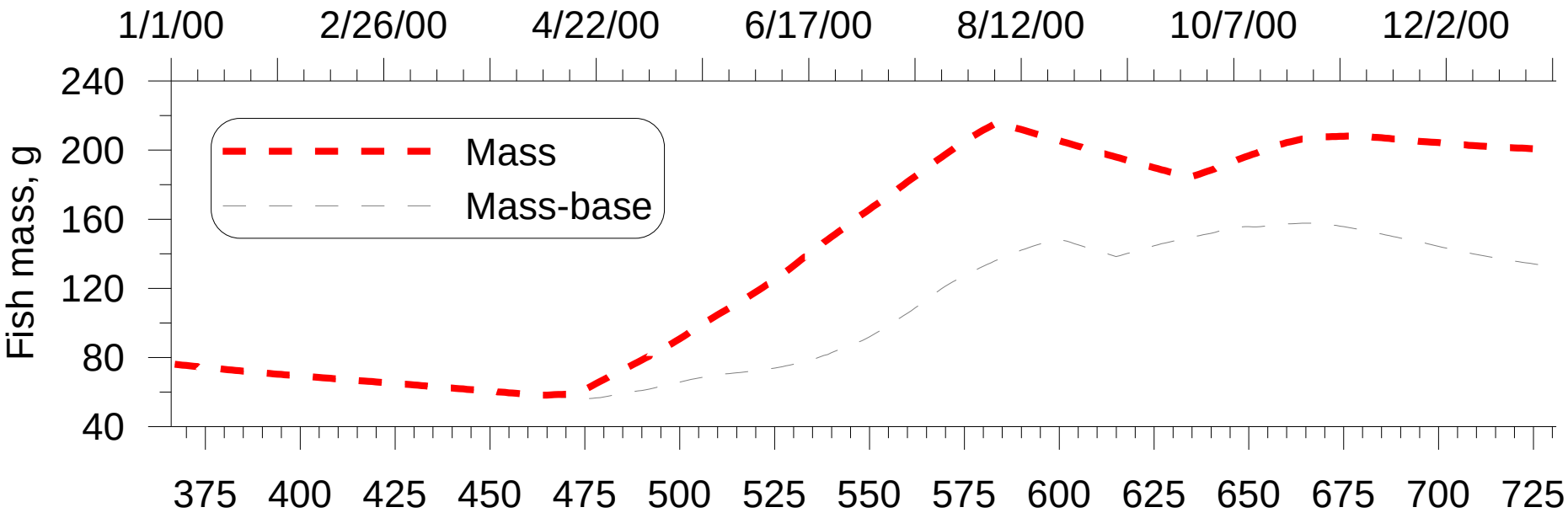
Temperature, zooplankton densities/species, and light as a f(location)

$$\overbrace{G}^{\text{growth}} = \overbrace{C}^{\text{consumption}} - \overbrace{(F+U)}^{\text{waste}} - \overbrace{(R \cdot ACTIVITY + S)}^{\text{metabolism}}$$

Impact of increased nutrient loadings



Increased P loading: effect on Fish mass – 50% increase!



Current Directions: Fish-Particle Bioenergetics Transport Model

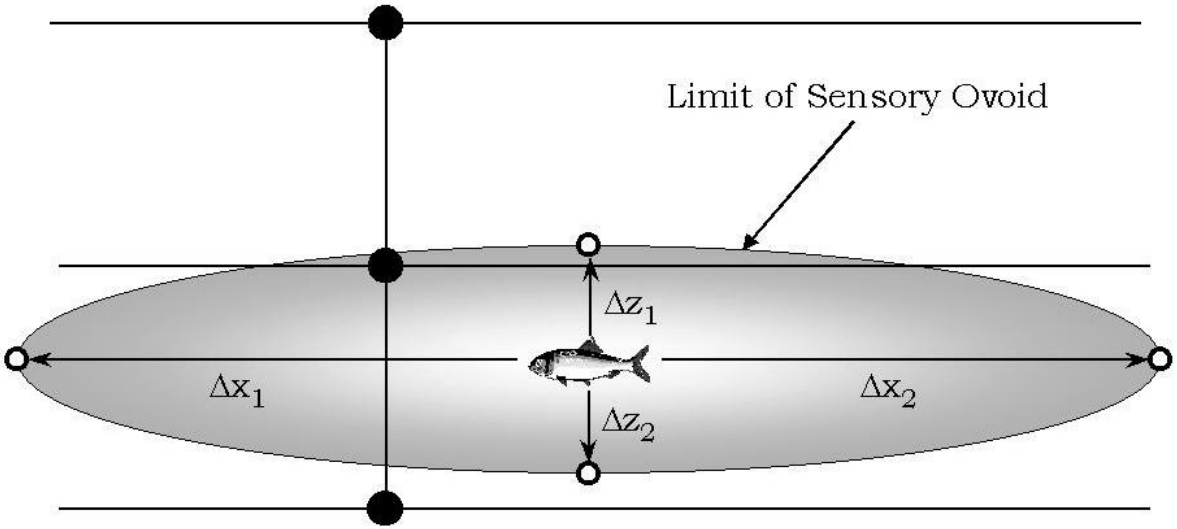
Passive- Andy

Volitional + Passive movement

Random Transport

Random+Passive

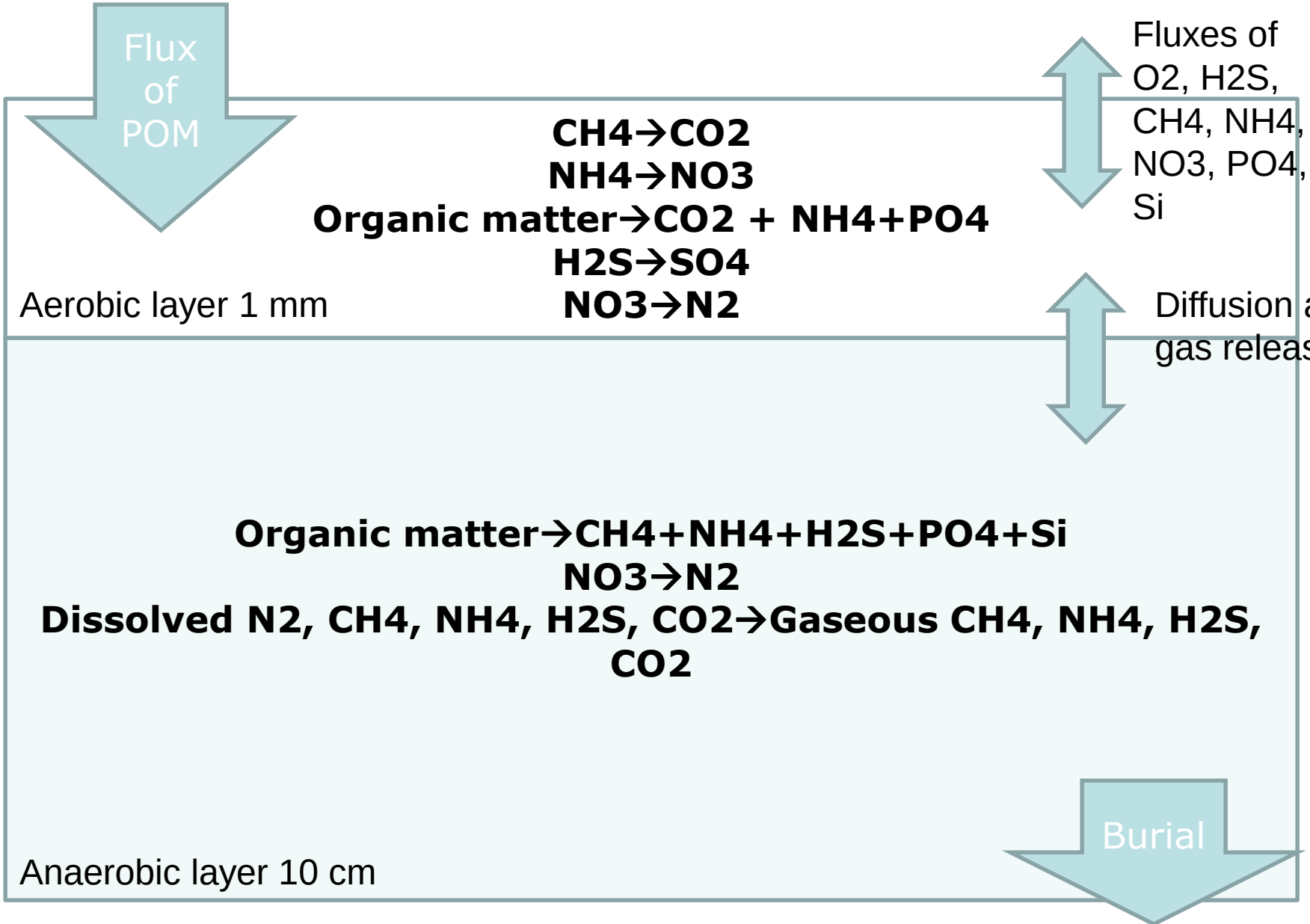
Fish behavior:Velocity



Nesler and Goodwin

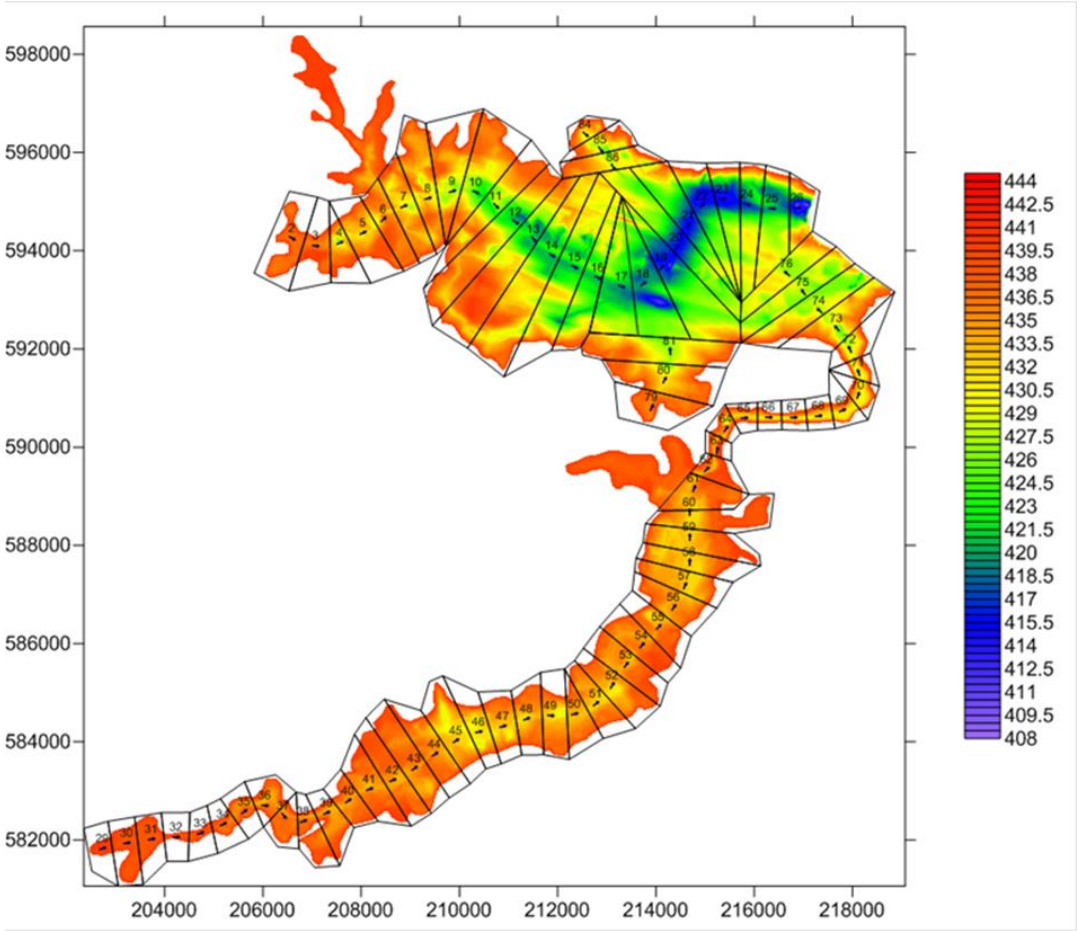
Sediment Diagenesis Model

Portland State UNIVERSITY

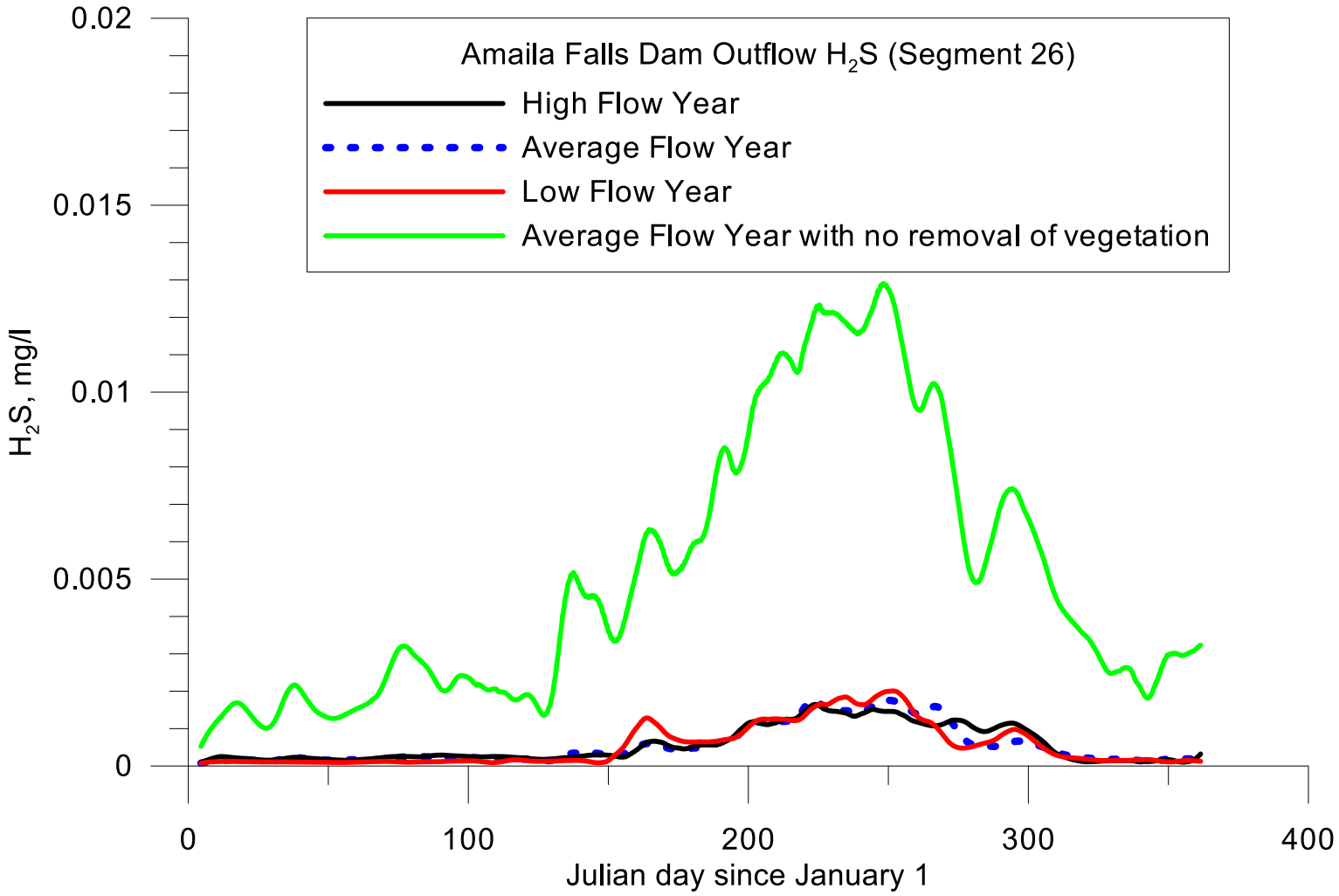


Guyana Hydroelectric Project

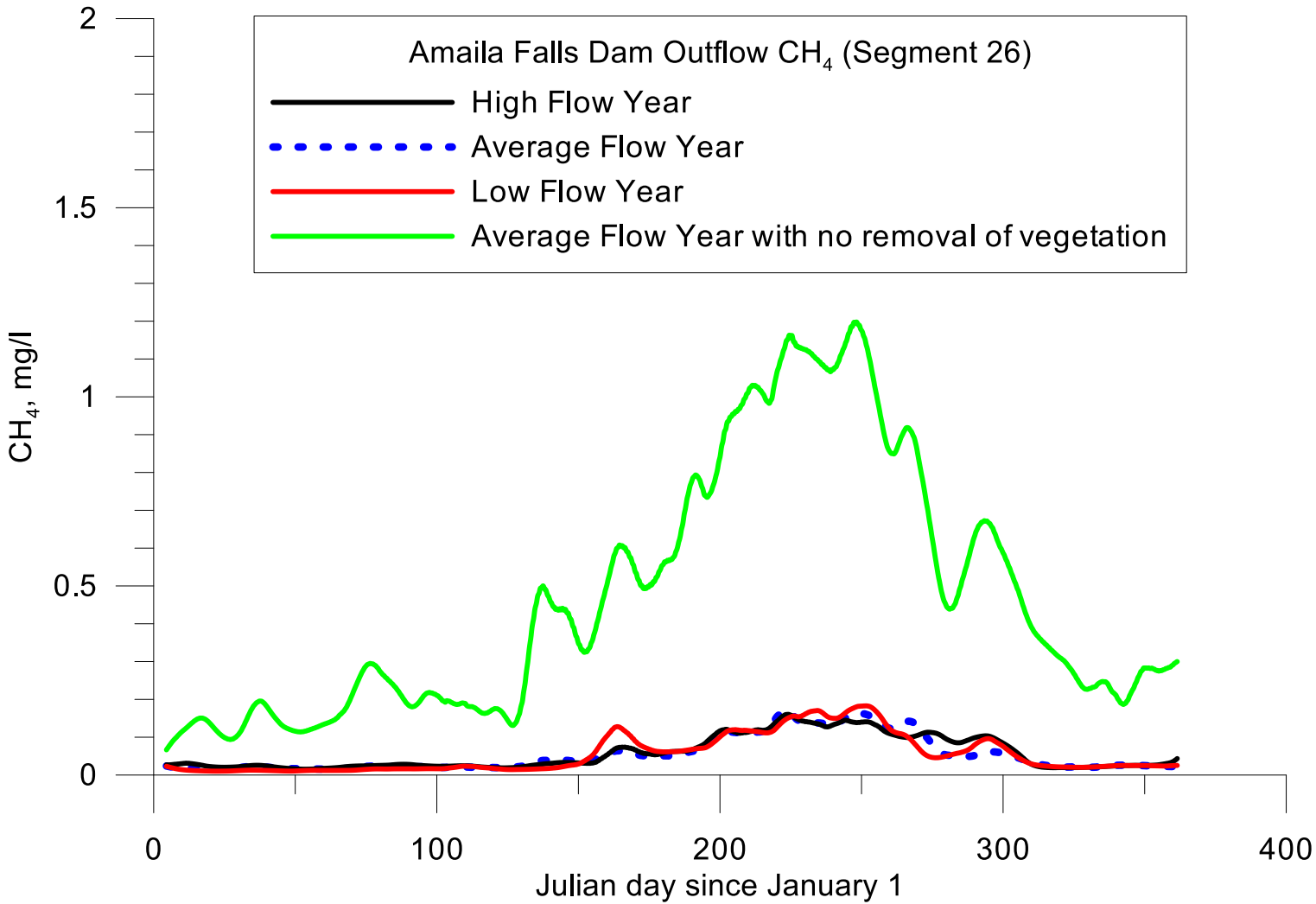
- Max. Surface Area – 23.3 km^2
- Model Segments 439 m to 635 m long
- Vertical Layer Thickness – 1 m



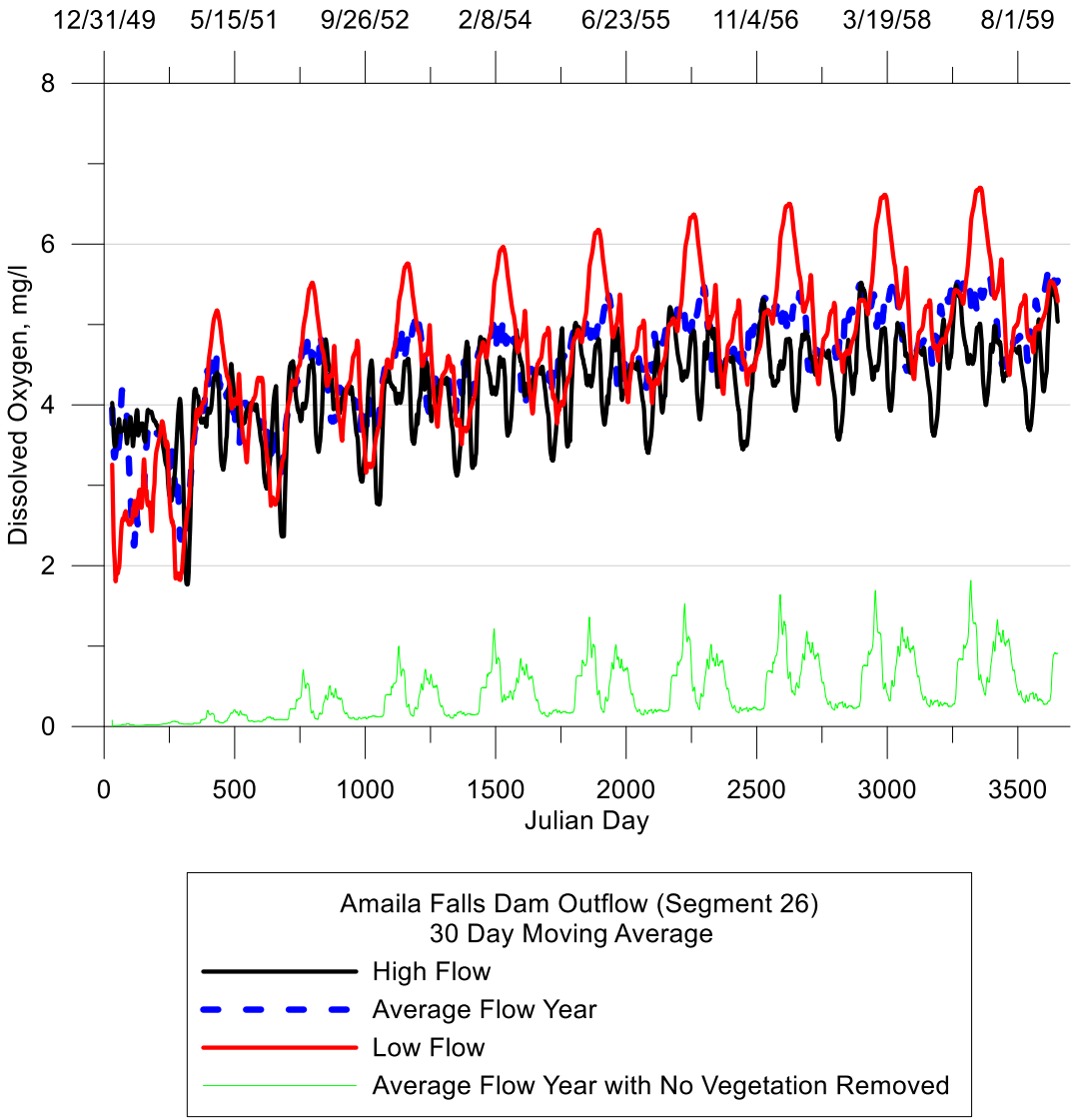
Dam Outflow of Hydrogen Sulfide



Dam Outflow of Methane



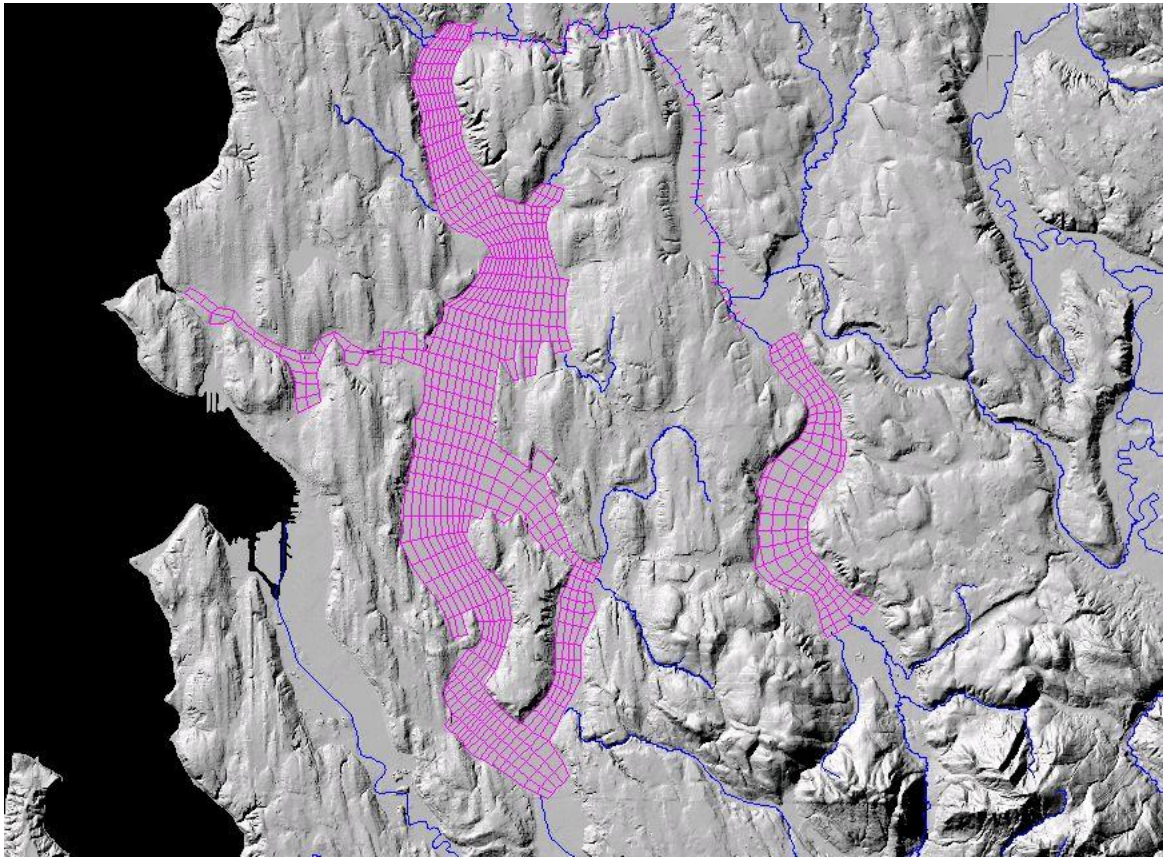
Dissolved Oxygen in Dam Outflow



Summary

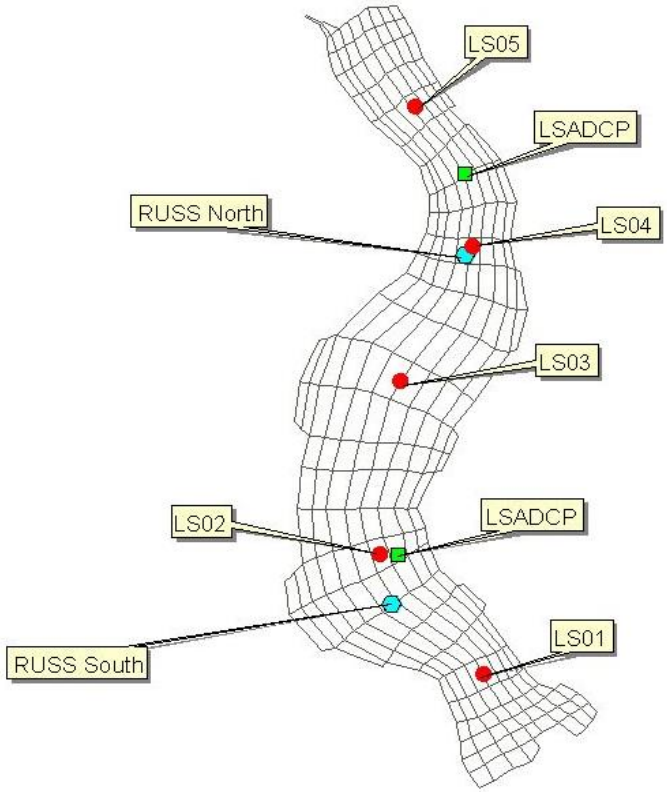
- CE-QUAL-W2 widely used 2D hydrodynamic and water quality model – open source
- New updates coming: sediment diagenesis model, fish bioenergetics and volitional movement, non-conservative alkalinity, …

3D vs 2D?

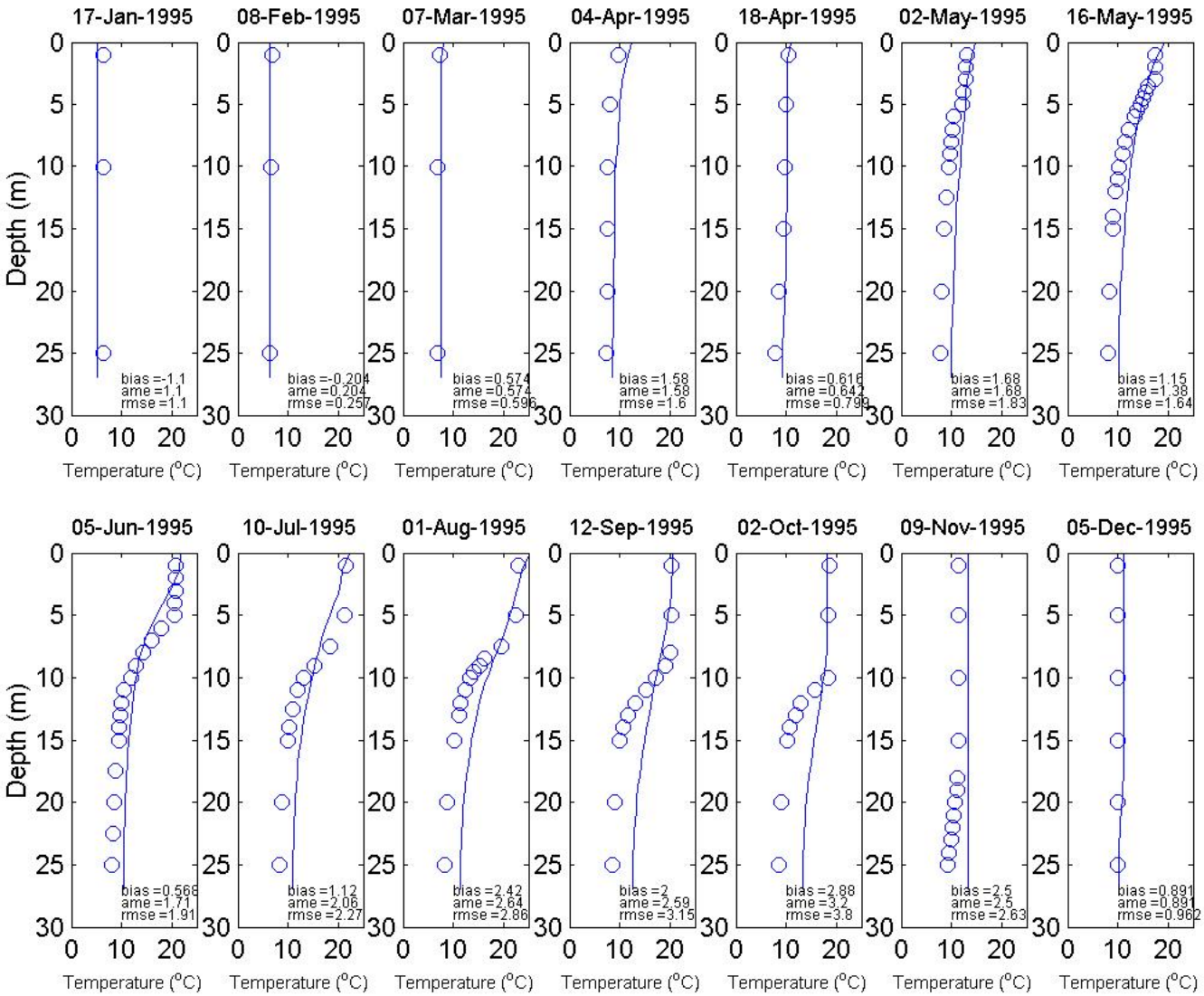


Example from Curtis DeGasperi,
King County

Sammamish Lake, Washington

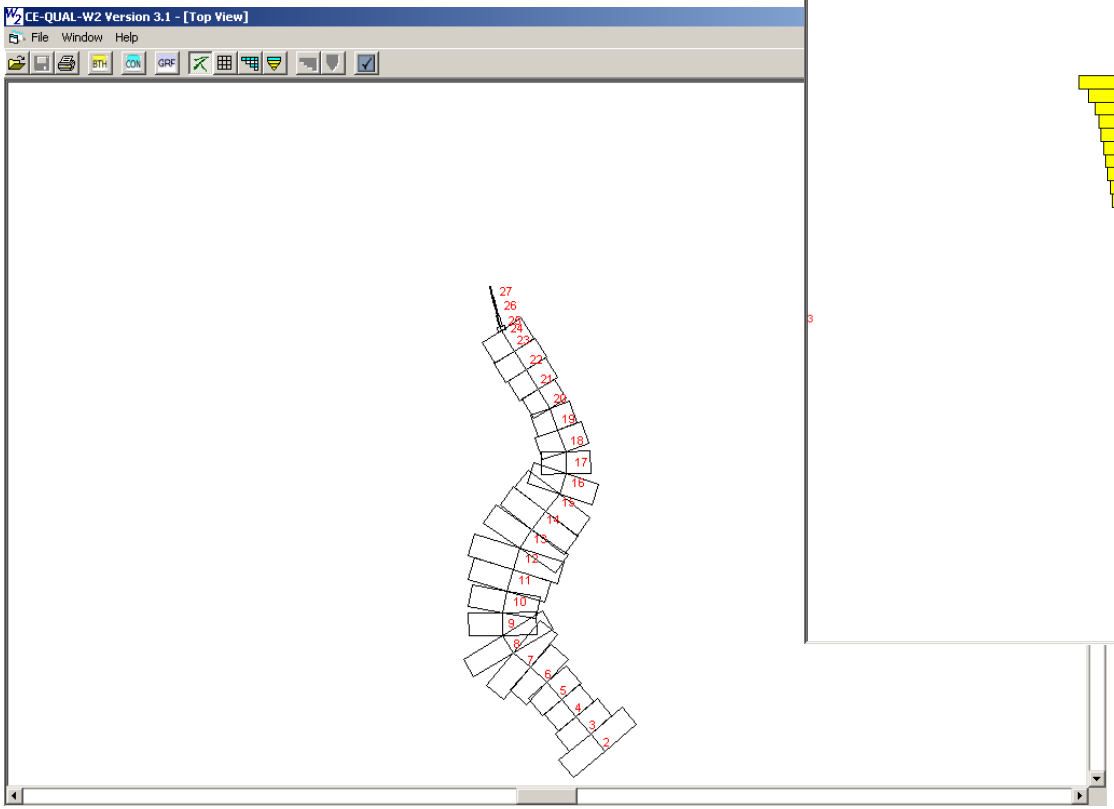


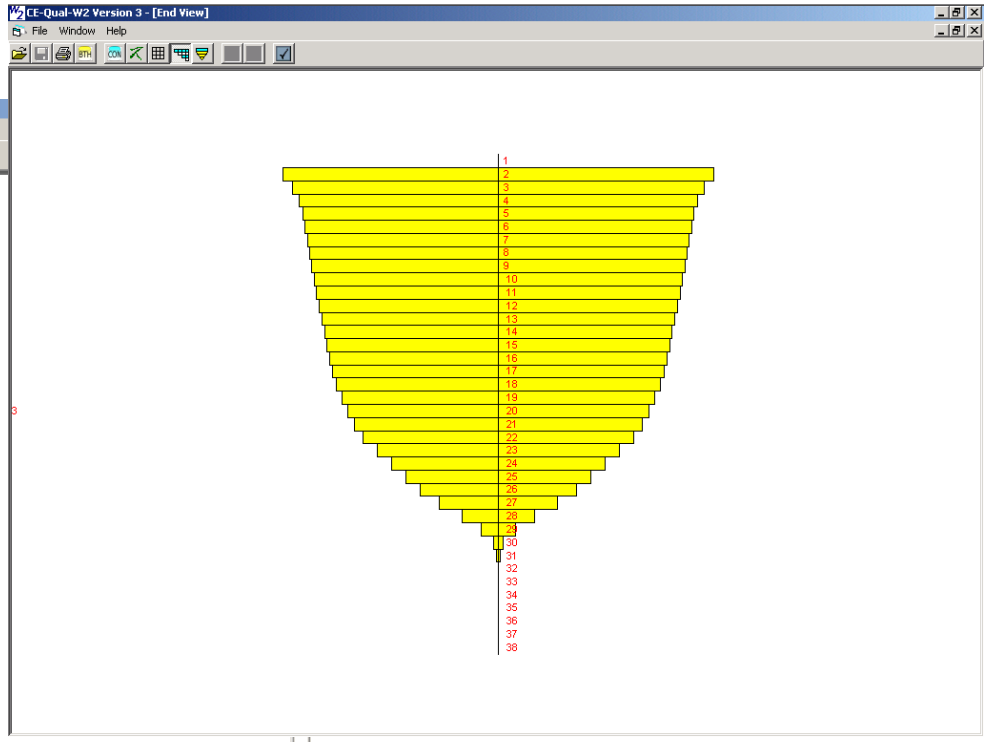
CH3D Model results



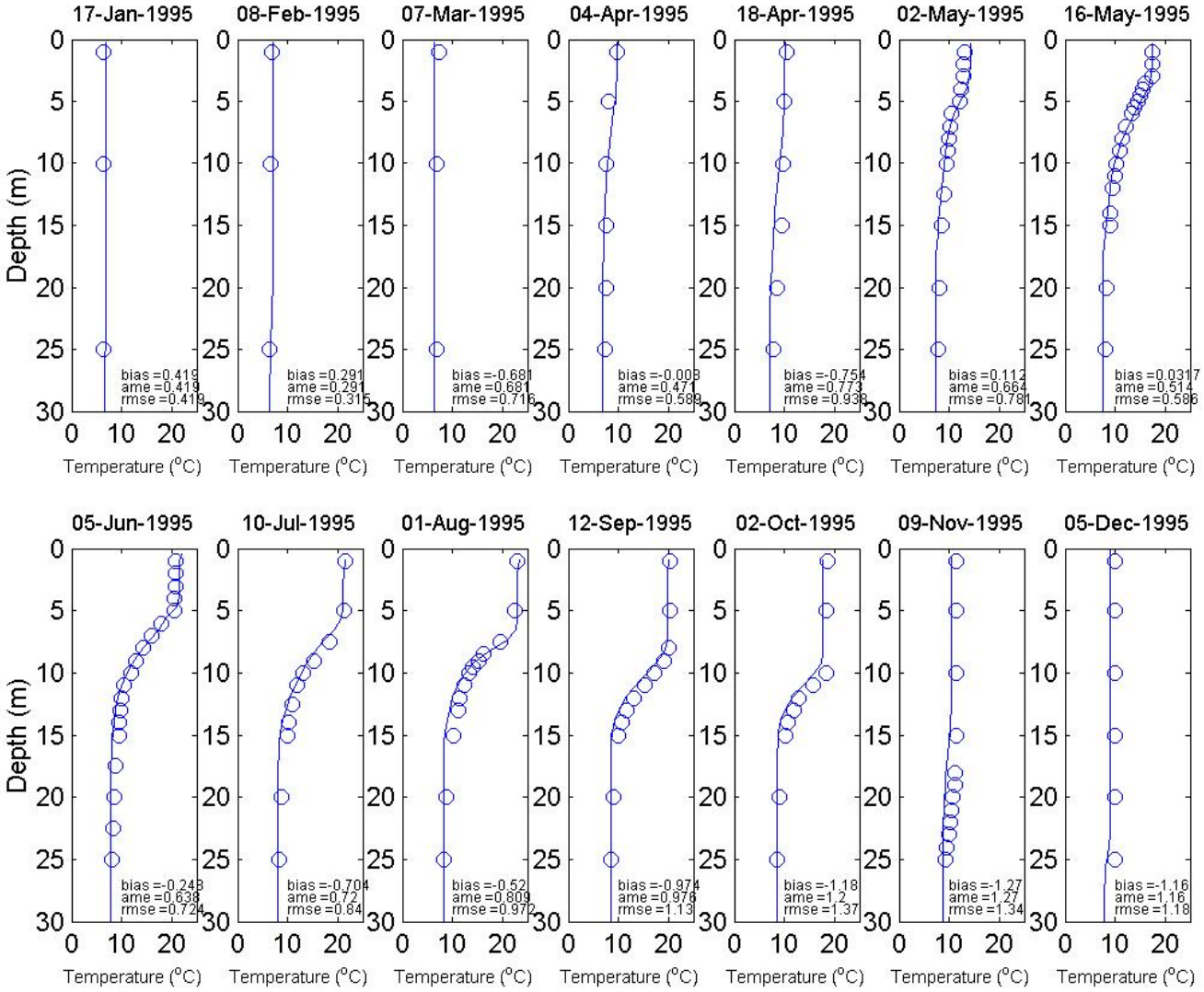
CE-QUAL-W2

Laterally Averaged 2-D water quality model





CE-QUAL-W2 Results – only 2-D



Model Run Time Differences

8 year simulation on a 3GHz Xenon (I know its old) from Curtis DeGasperi

CH3D: 16:40 hours

CE-QUAL-W2: 1:10 hours

Note in the end – both models had similar model vs data error.