Development and Application of Cayuga Lake Model (CLM2D)

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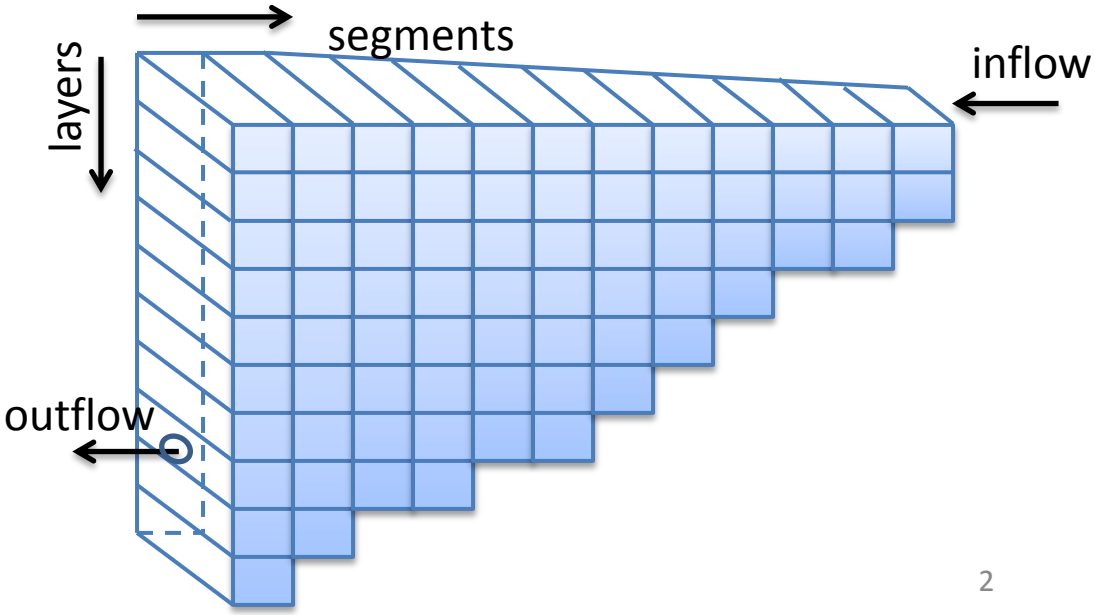
Technical Briefing (CLTAC)
Cayuga Lake Modeling Project
May 19, 2014
Albany, NY

Two-Dimensional Model

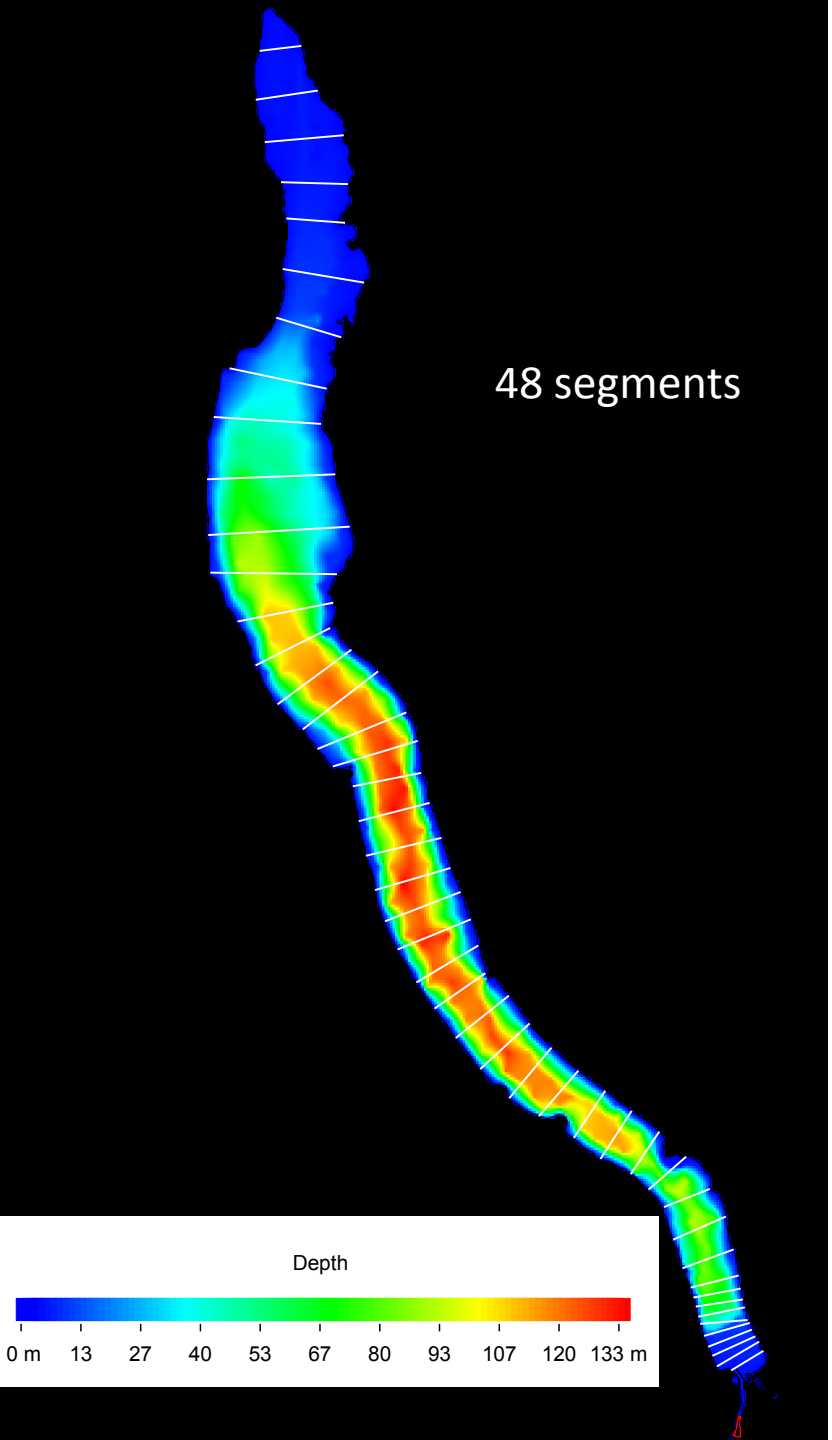
- CE-QUAL-W2 (W2; US Army Corps of Engineers): dynamic, laterally averaged, two dimensional (longitudinal-vertical) model
- applied successfully to 100s of waterbodies worldwide
- hydrodynamic submodel predicts water surface elevations, velocities, and temperatures
- provides transport framework for a water quality model

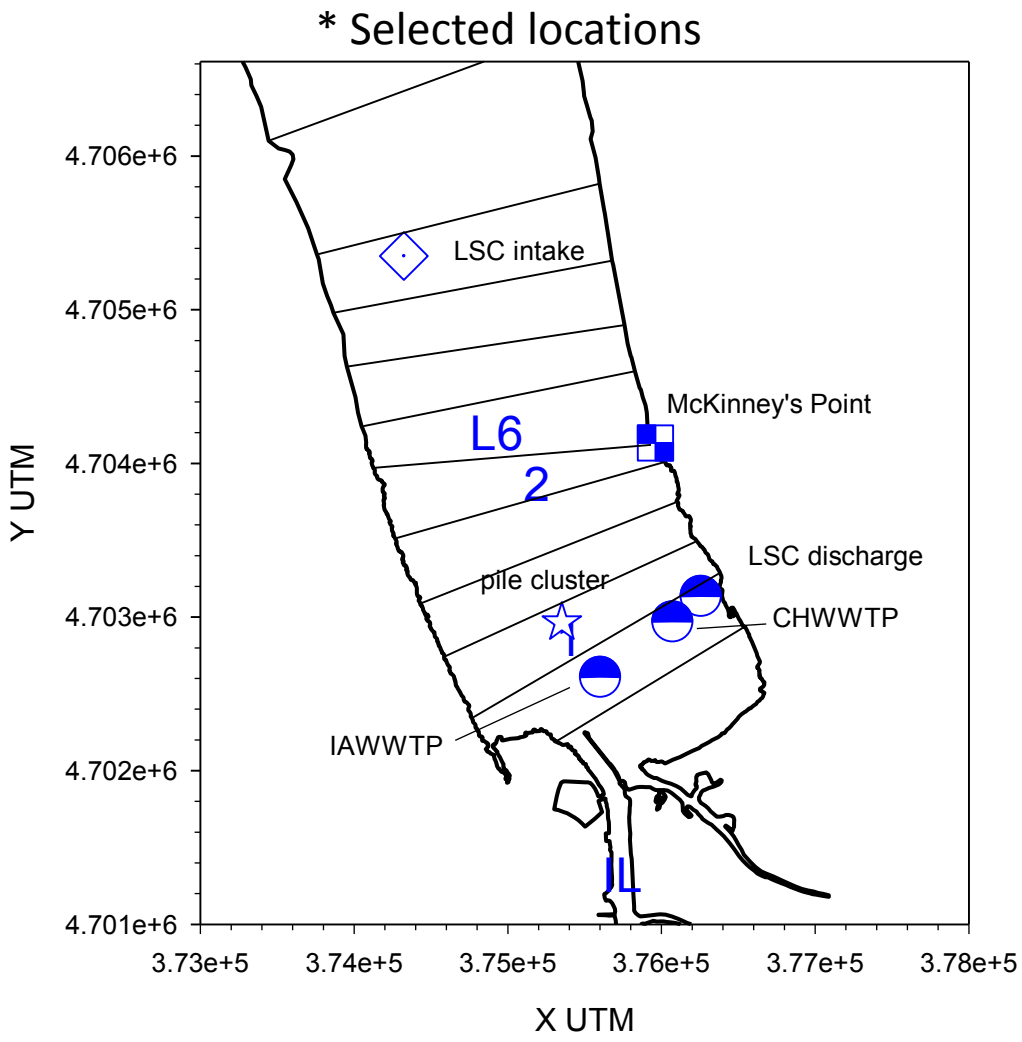


Model Setup

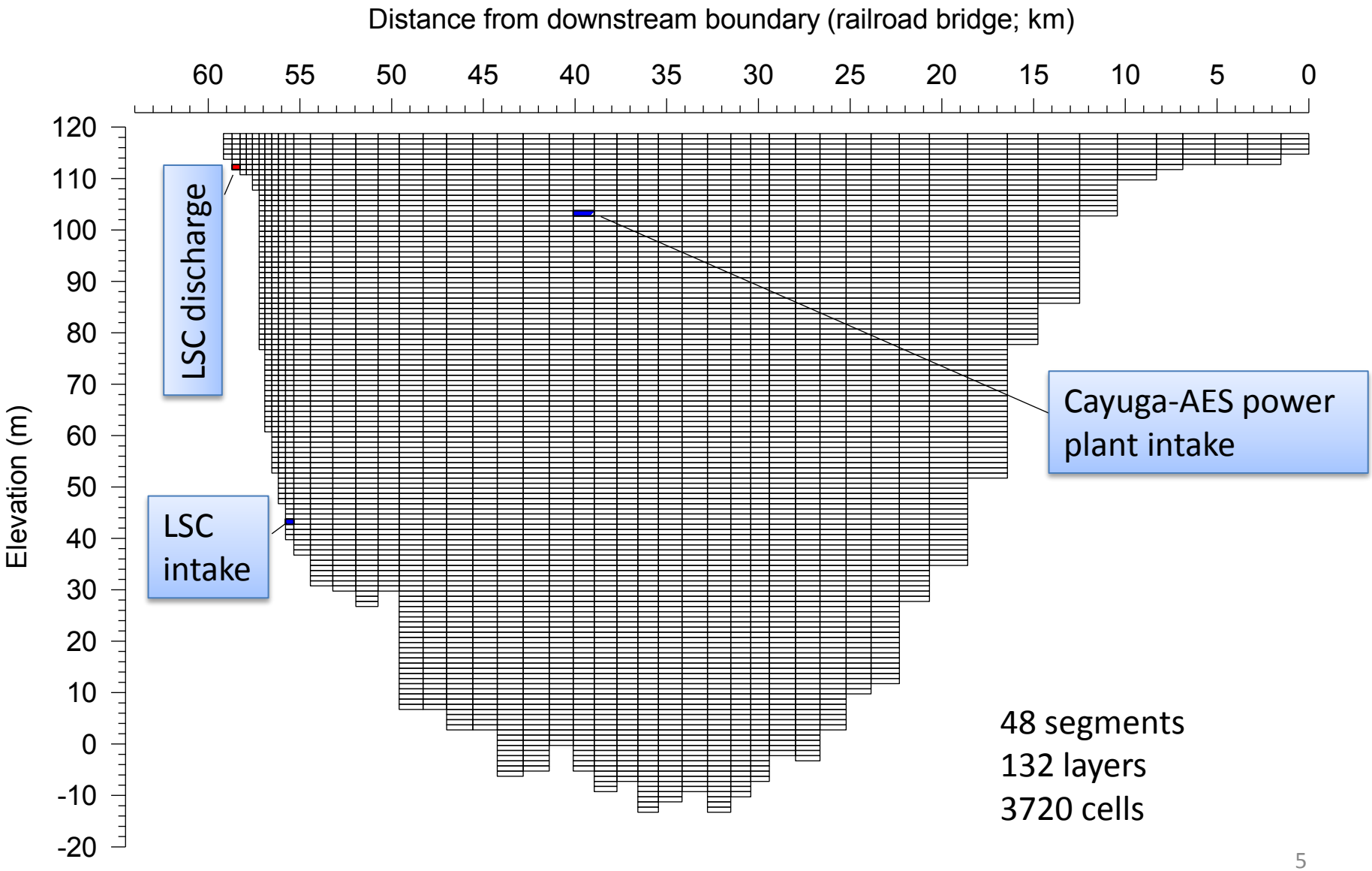
Datasets used for model development and application	
Model Run	Year
Calibration	2013
Validation – primary	2012
Validation – secondary	1998–2006
Hindcast (extended application); probabilistic water quality simulations, if needed	1987–1997, 2007–2011

Longitudinal Grid

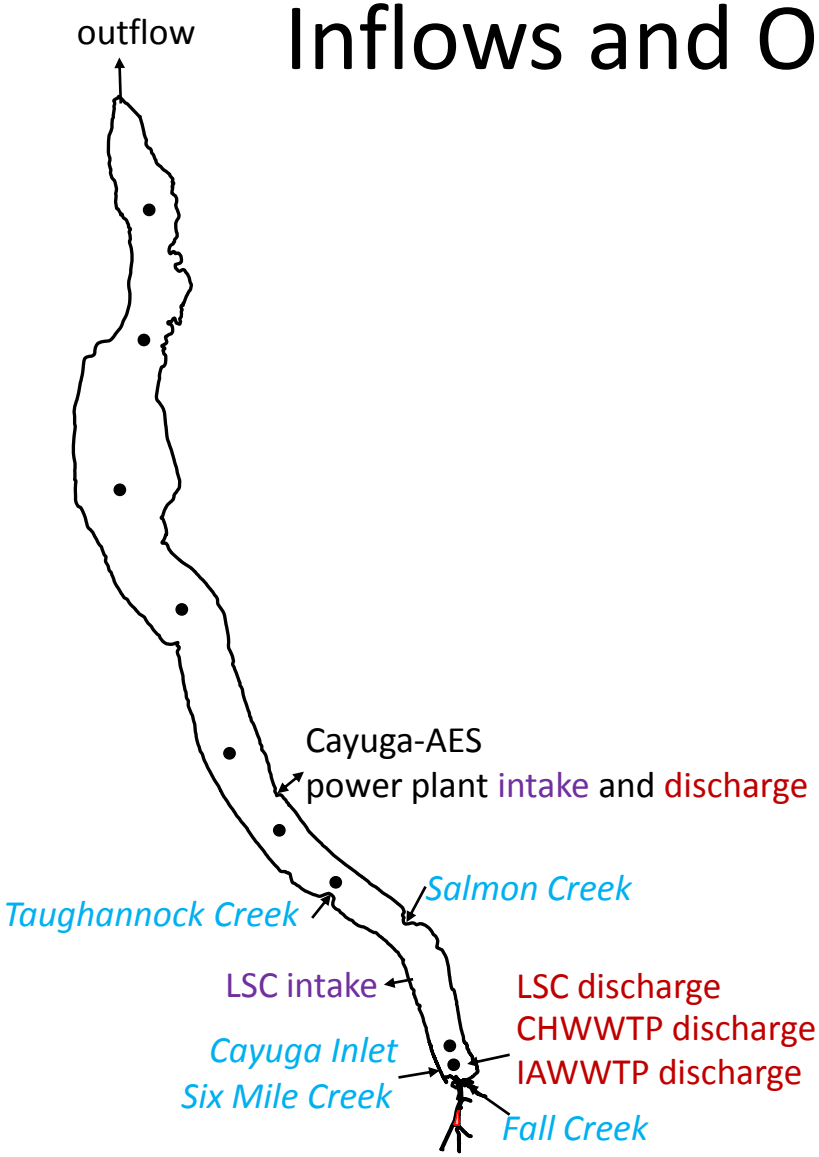




Longitudinal-Vertical Grid - Cayuga Lake



Inflows and Outflows



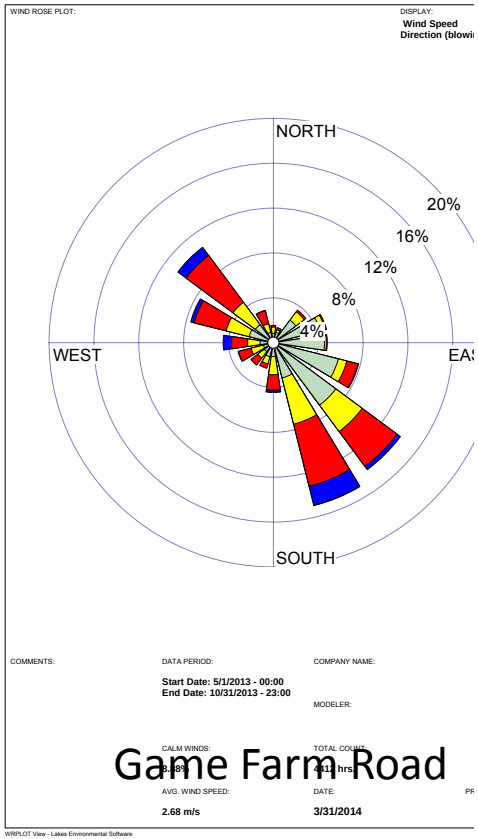
5 Tributary Inputs
4 Point Source Inputs
2 Withdrawals
1 Outflow
distributed inflows for minor tributaries

Meteorological Data

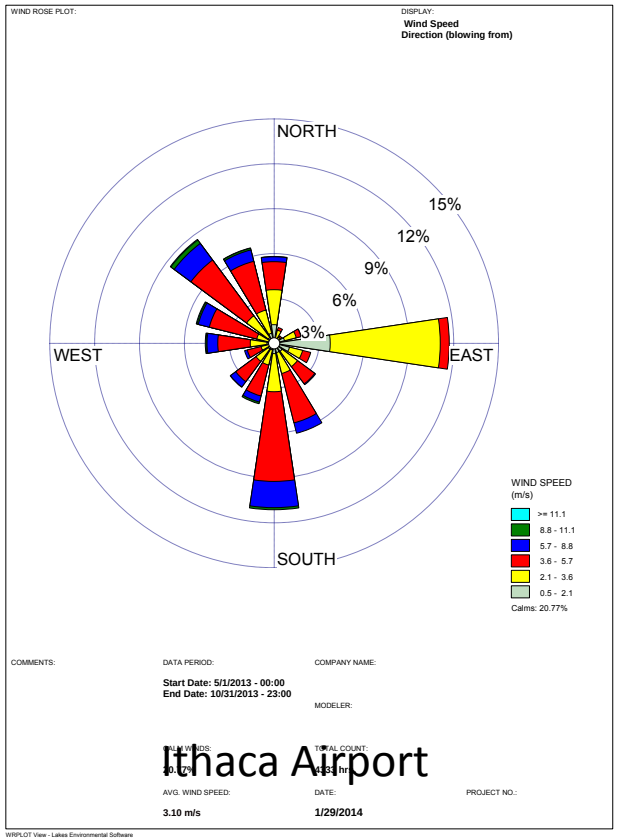
- air temperature, dewpoint temperature, wind speed, wind direction, solar radiation

Meteorological Data Source	Availability	Notes
Piling Cluster (Cornell University)	10/27/2011–12/31/2013	10 min frequency; missing air T and dew T for 1/3/2013– 5/13/2013 were filled-in with the data from Ithaca Airport
Game Farm Road (Cornell University)*	1987–2013	hourly frequency; missing data (0.8% days) were filled-in with the data from Ithaca Airport
Ithaca Airport (NOAA)*	1996–2013	hourly frequency; missing data (0.2% days)
***Wind speed data from Game Farm Road and Ithaca Airport were adjusted to the height of wind measurement (8 m) at the piling cluster location, according to logarithmic boundary layer.**		

tribution (Wind Rose Plots)
May–October, 2013



Game Farm Road



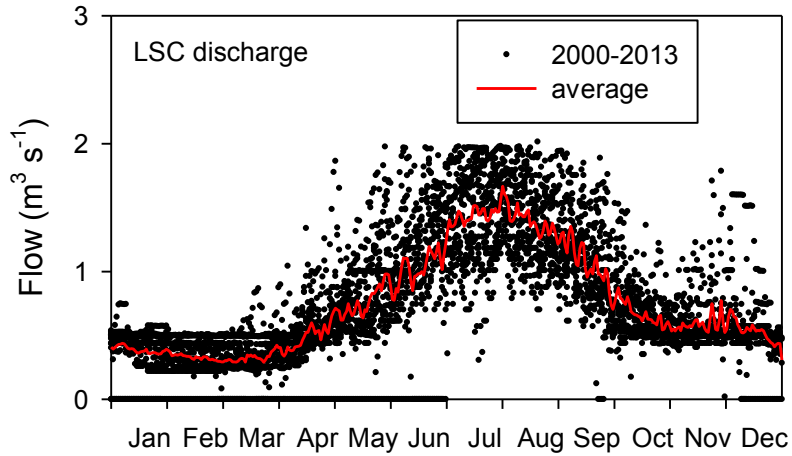
Ithaca Airport

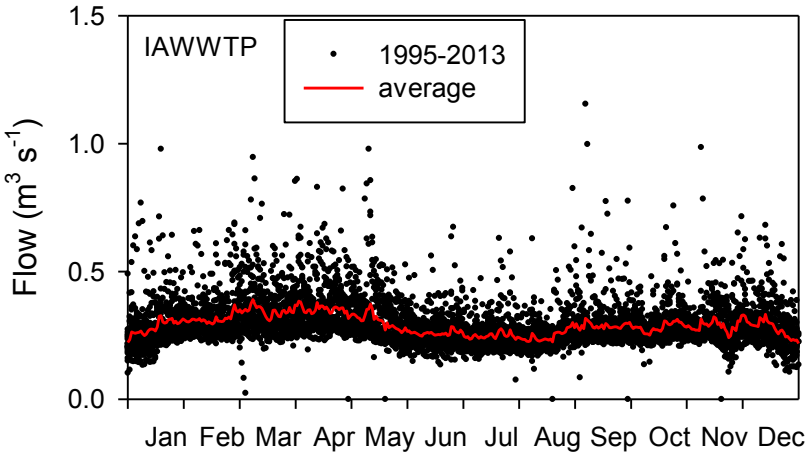
WIND SPEED
(m/s)

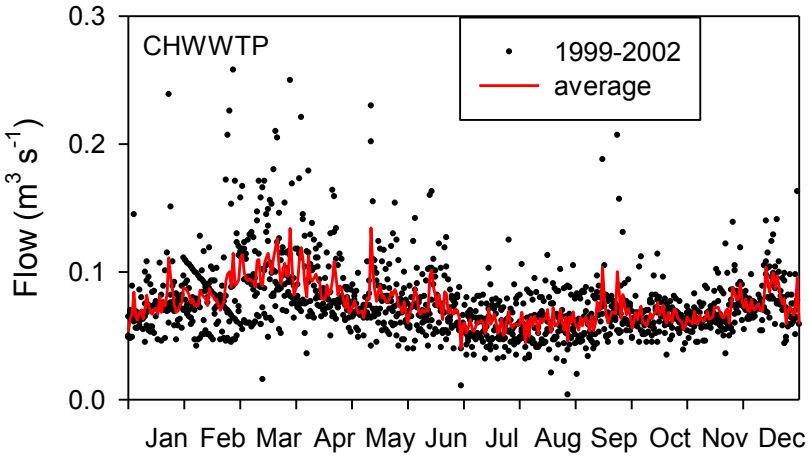
- >= 11.1
- 8.8 - 11.1
- 5.7 - 8.8
- 3.6 - 5.7
- 2.1 - 3.6
- 0.5 - 2.1

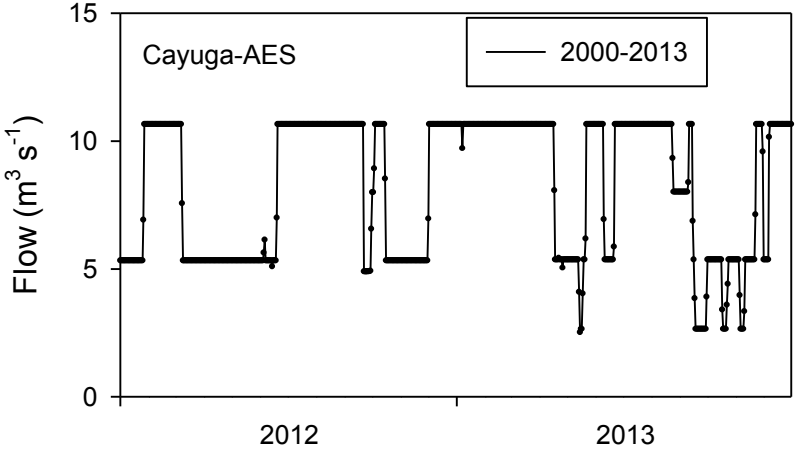
Calms: 0.02%

Point Source Inflows

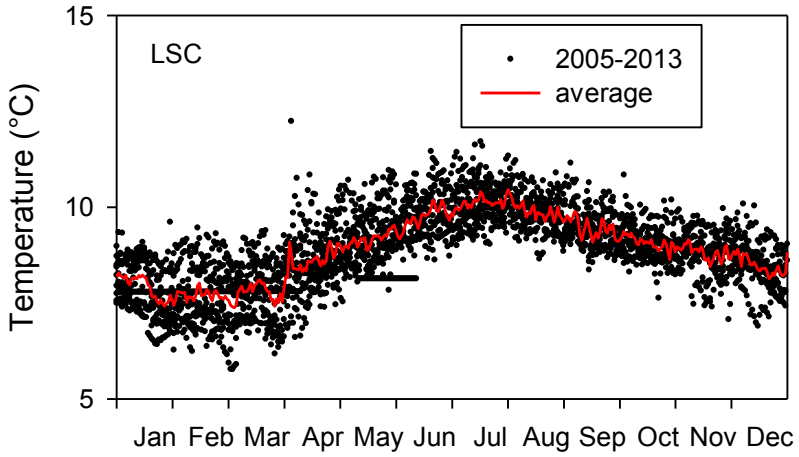


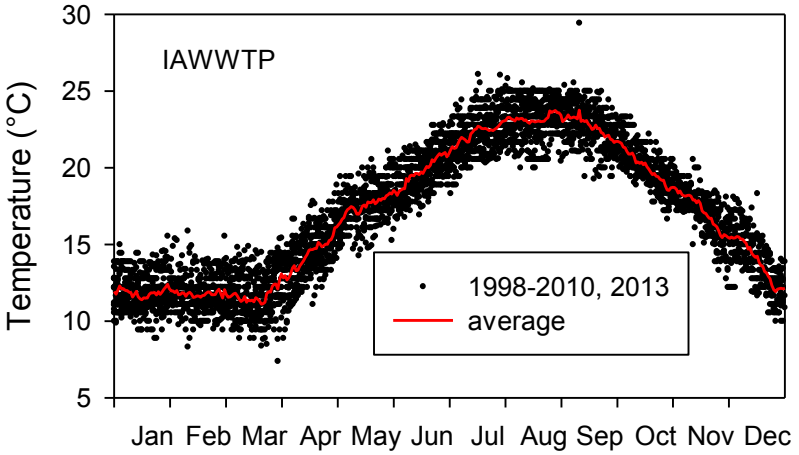






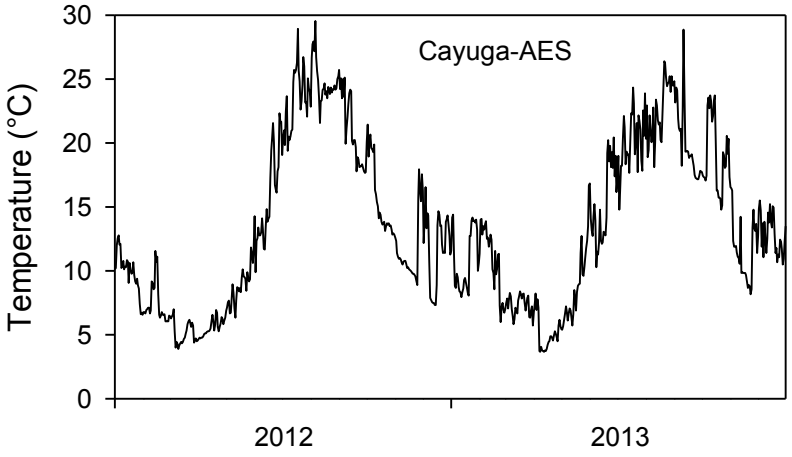
Point Source Inflow Temperatures





all years:
CHWWTP discharge temperature =
IAWWTP discharge temperature

Years < 2012:
Cayuga-AES discharge temperature =
Model-predicted Cayuga-AES
withdrawal temperature + 8.67 °C

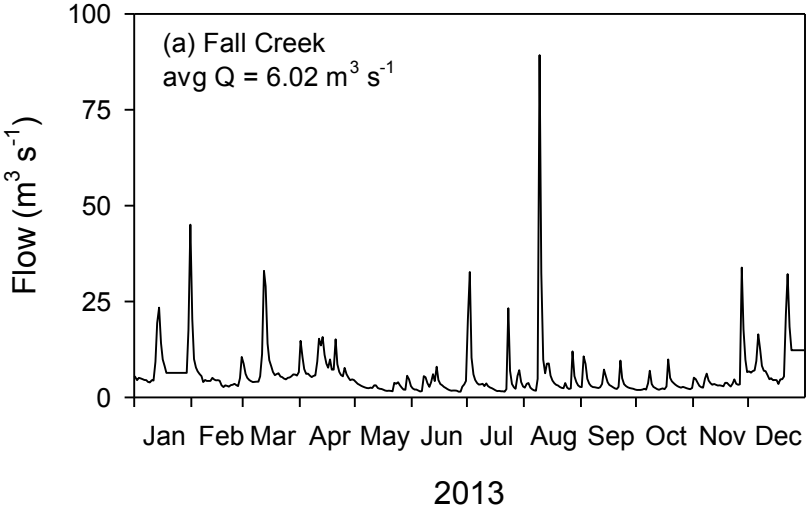


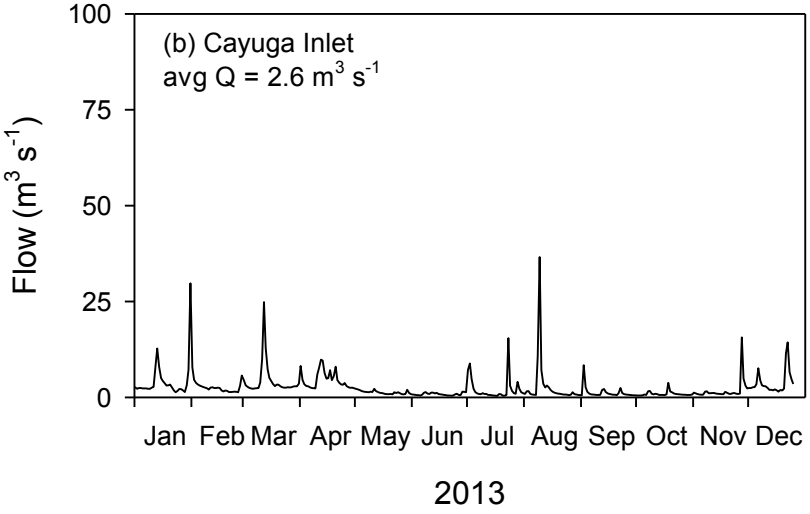
Tributary Data

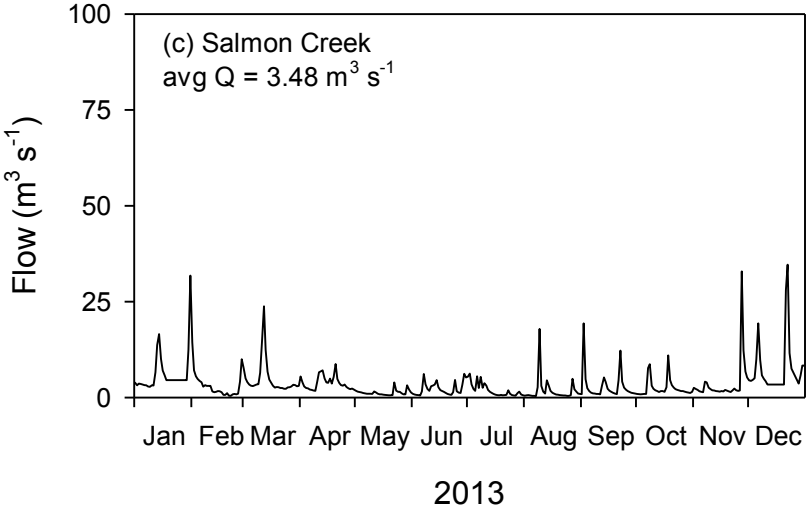
Tributary	Flow Records	Temperature Records
Fall Creek	1925-present	9/21/2011–11/18/2011; 5/13/2013–11/1/2013
Cayuga Inlet	1937-9/30/2011; 6/1/2012-present	5/9/2013–11/13/2013
Salmon Creek	2006-present	limited during 2013
Six Mile Creek	1995-present	limited during 2013

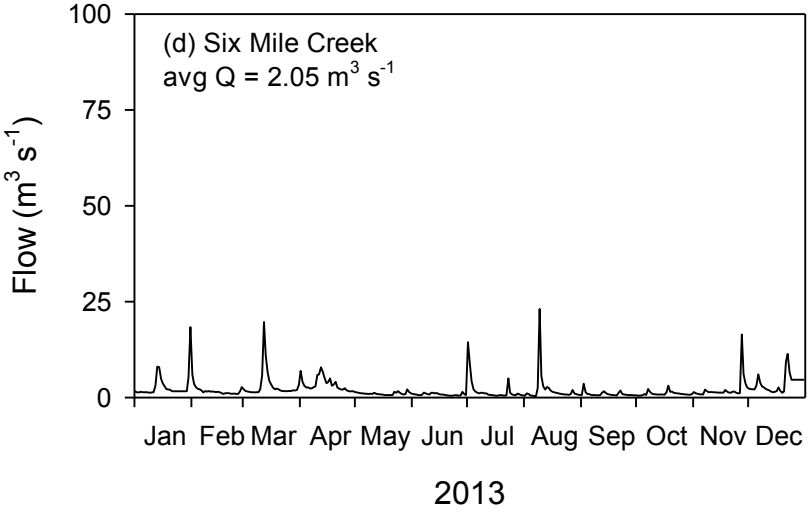
- unmonitored flow: pro-rated according to Fall Creek flow/watershed area
- unmonitored temperatures: adopted from USGS monitored temperature at Allen Creek near Rochester

Tributary Inflow









Model Performance

2013

- depth-profiles of temperature at selected sites and days [observations from Seabird Casts]
- color-contours of temperature at the LSC intake location [observations from thermistor string]
- timeseries plots of temperature at different depths at the LSC intake location [observations from thermistor string]
- timeseries plot of temperature at site 2 [observations from a single thermistor near surface]
- spectral analysis of thermistor string measurements

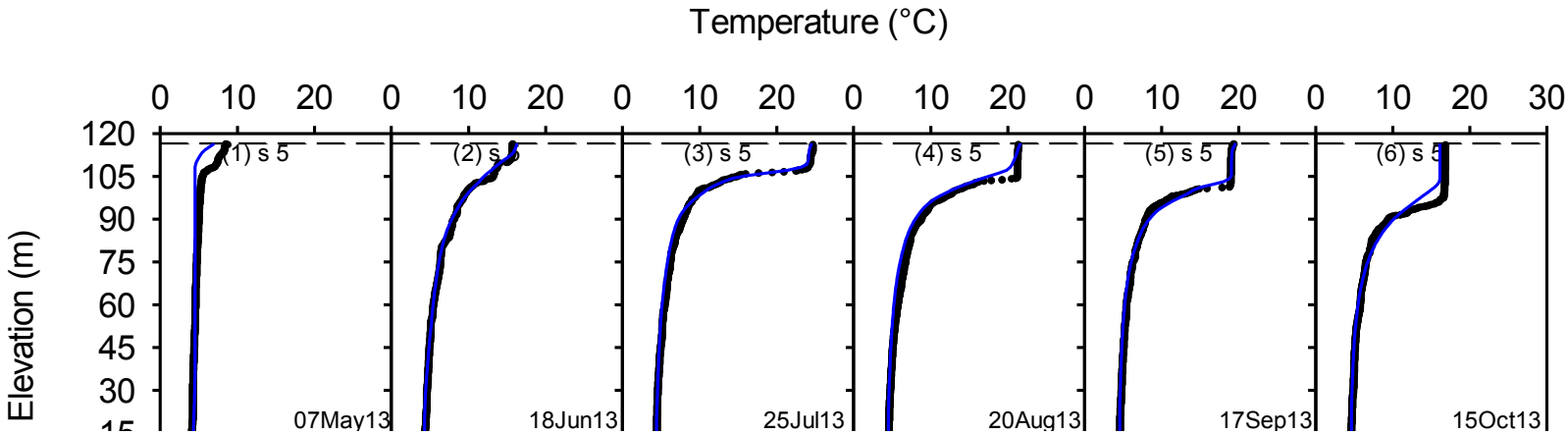
2012

- color-contours of temperature at the LSC intake location [observations from thermistor string]

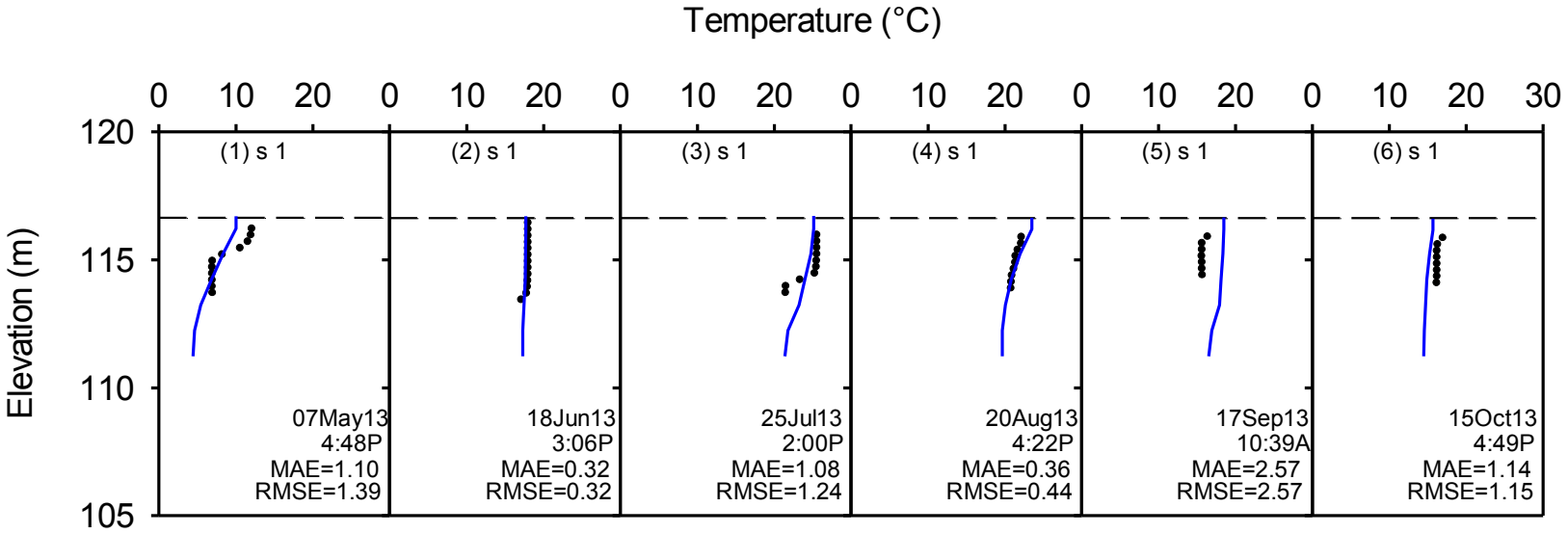
1998–2006

- timeseries plot of temperature at site near piling cluster [observations from a single thermistor at ~ 1 m deep]

Model Performance – Profiles 2013



site 5

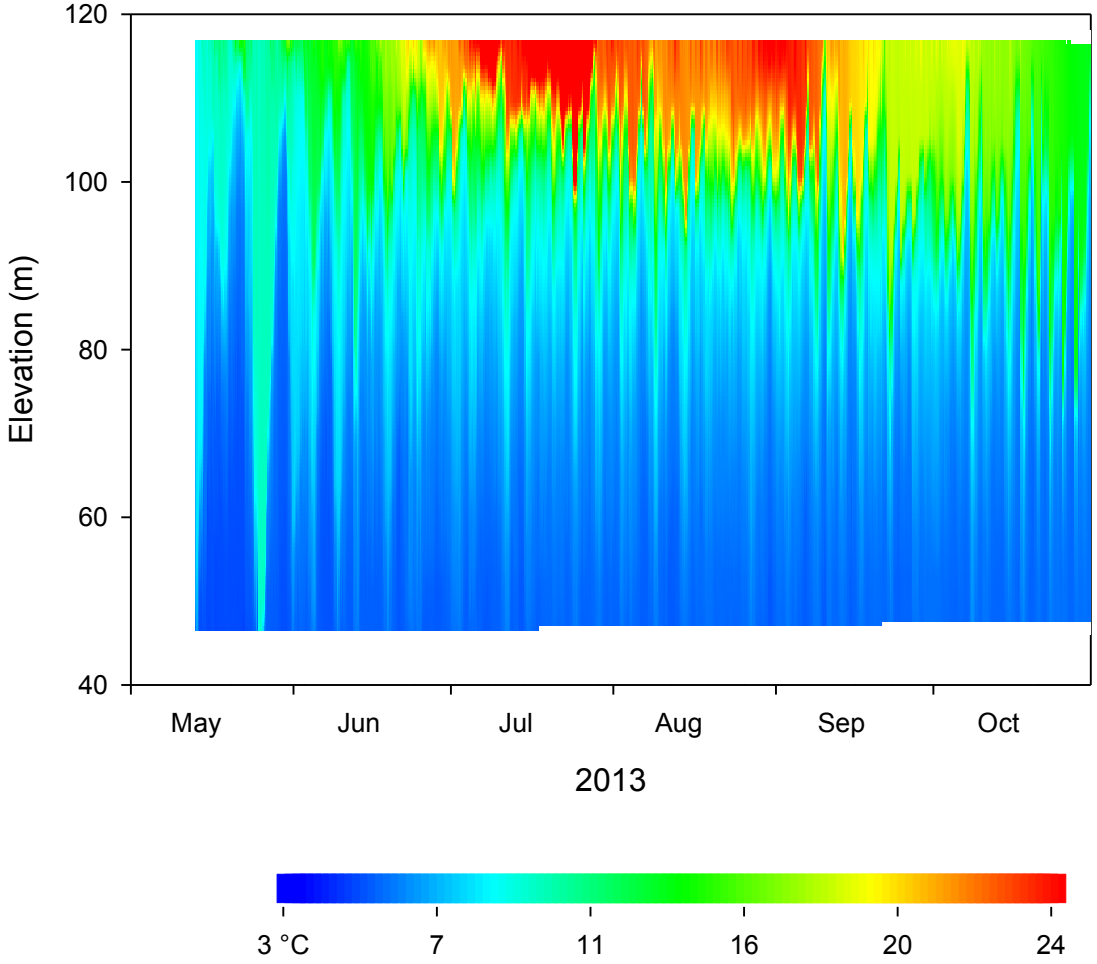


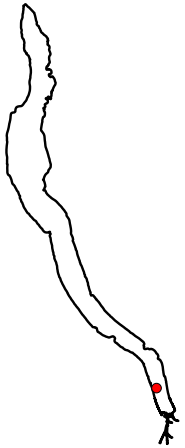
site 1

Observations 2013

Observed temperatures at LSC intake location

thermistor string temperature data at the LSC intake site





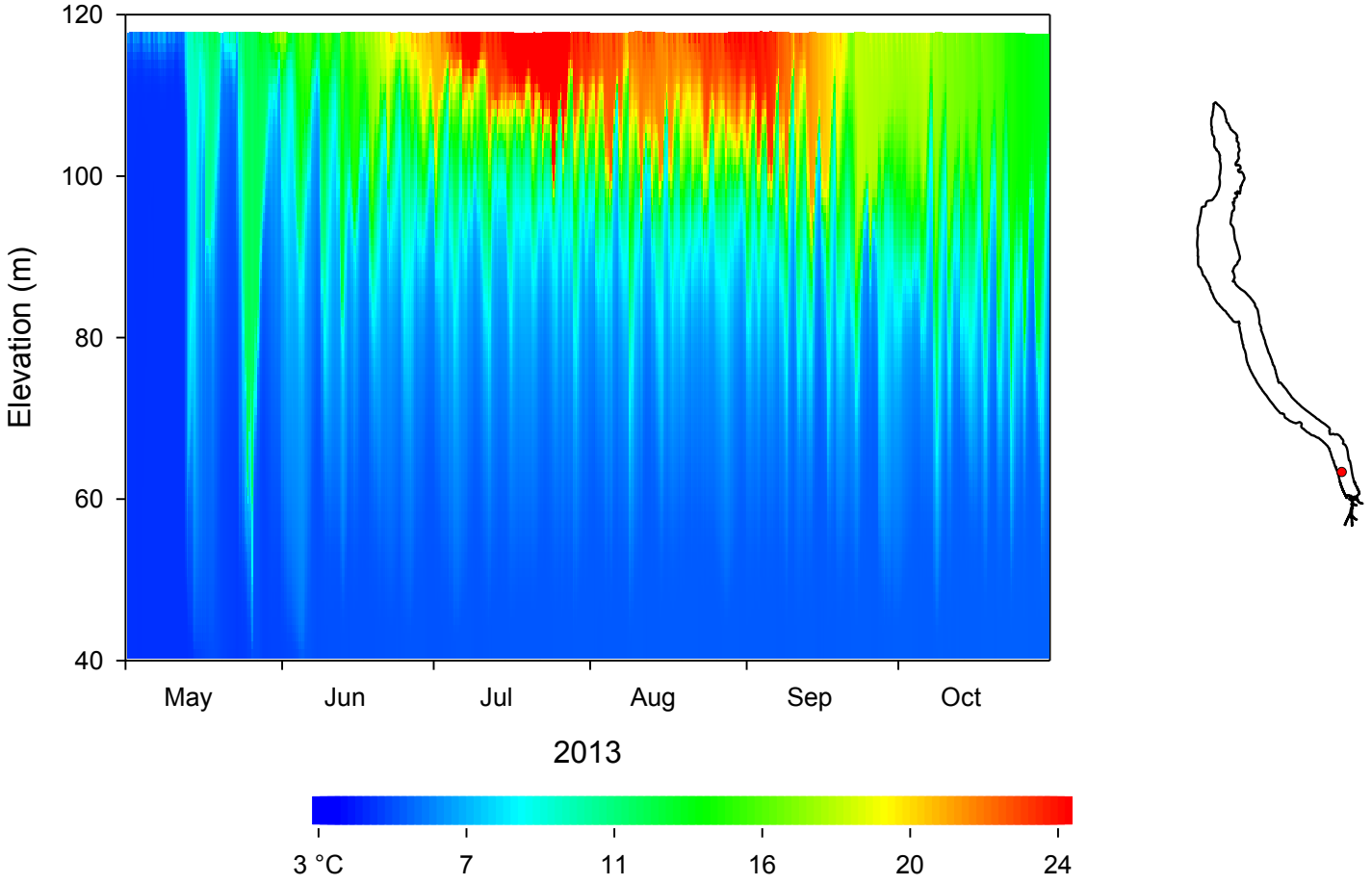
measurements were made every 30 sec at 5 m depth interval

data shown are at every 6 hours at 0.5 m depth interval

Model Performance – Predictions 2013

Predicted temperatures at LSC intake location

temperature predictions at the LSC intake site

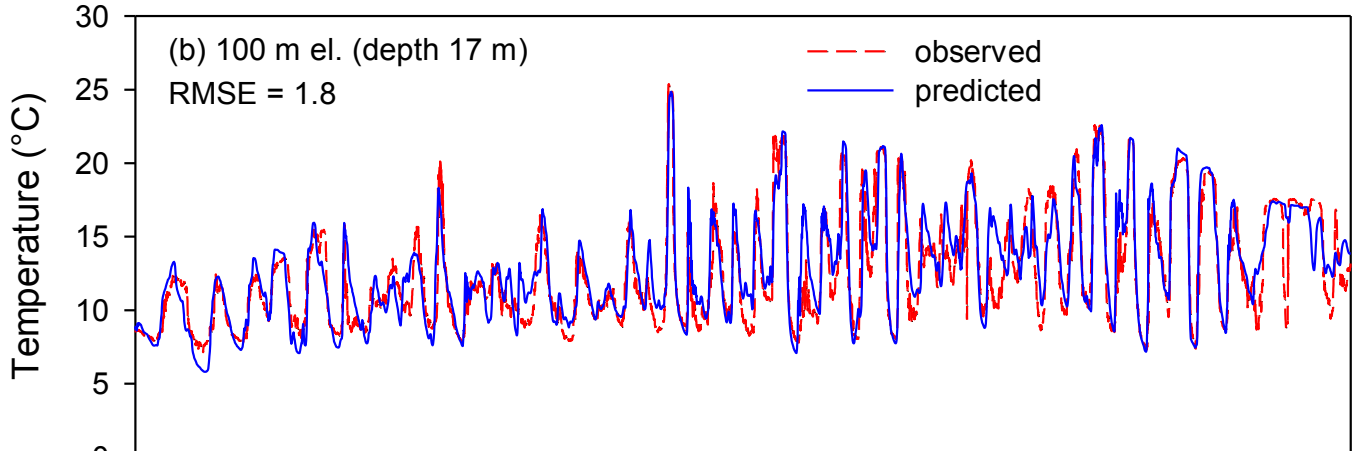


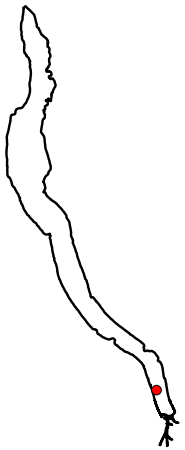
predictions shown are at every 6 hours at 1 m depth interval

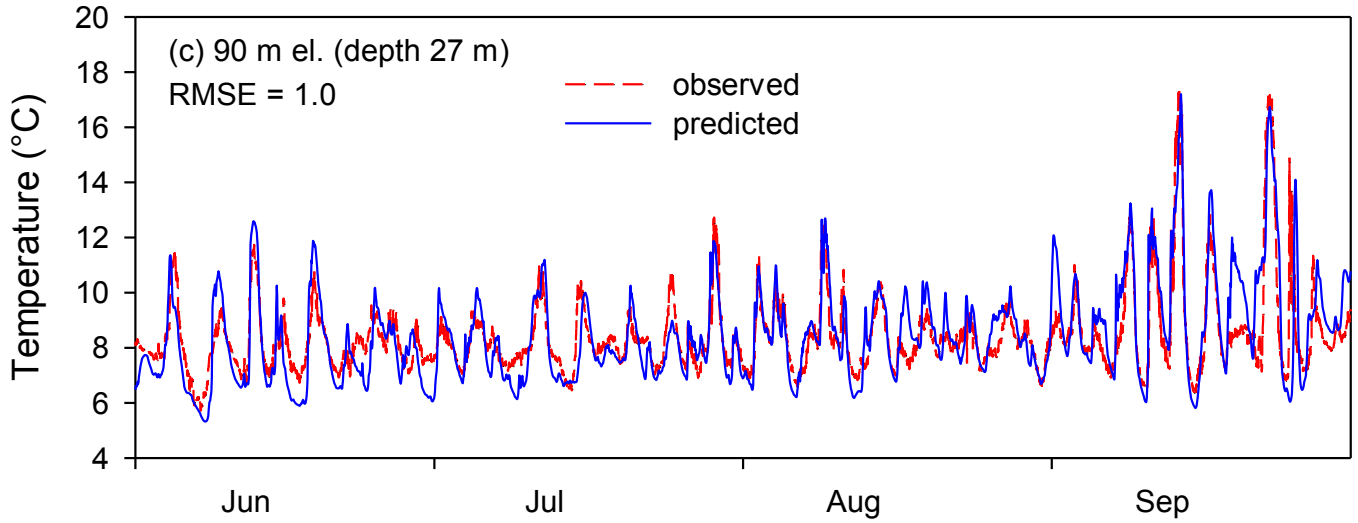
Model Performance – Timeseries

thermistor string at LSC intake location

measurements are shown as 15-min averages and predictions are shown 1/hour

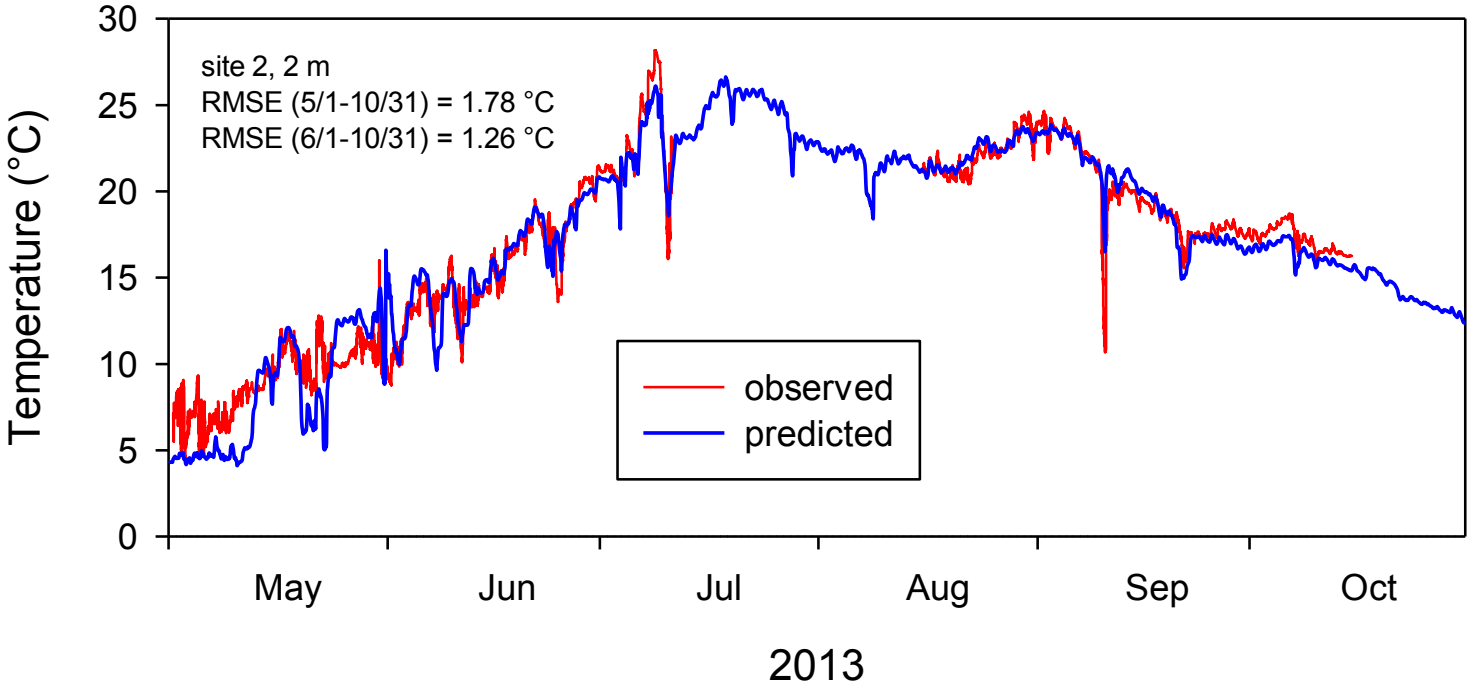


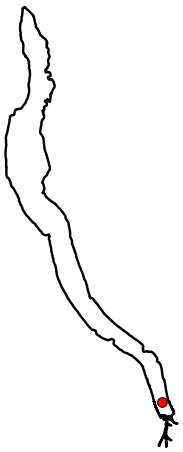




Model Performance – Timeseries

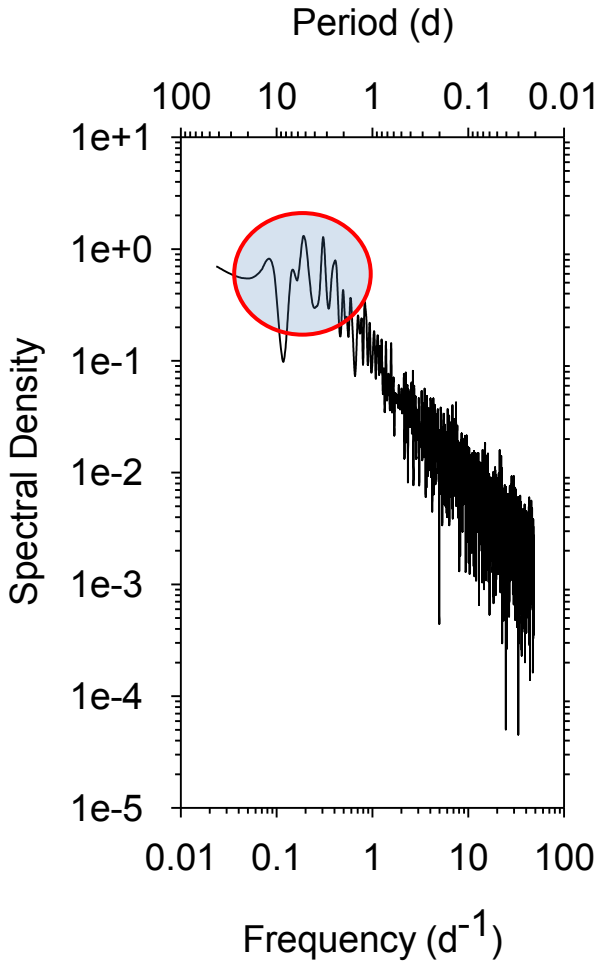
single thermistor at site 2, 2 m deep
measurements are shown at every 15-min interval and predictions are shown once every hour

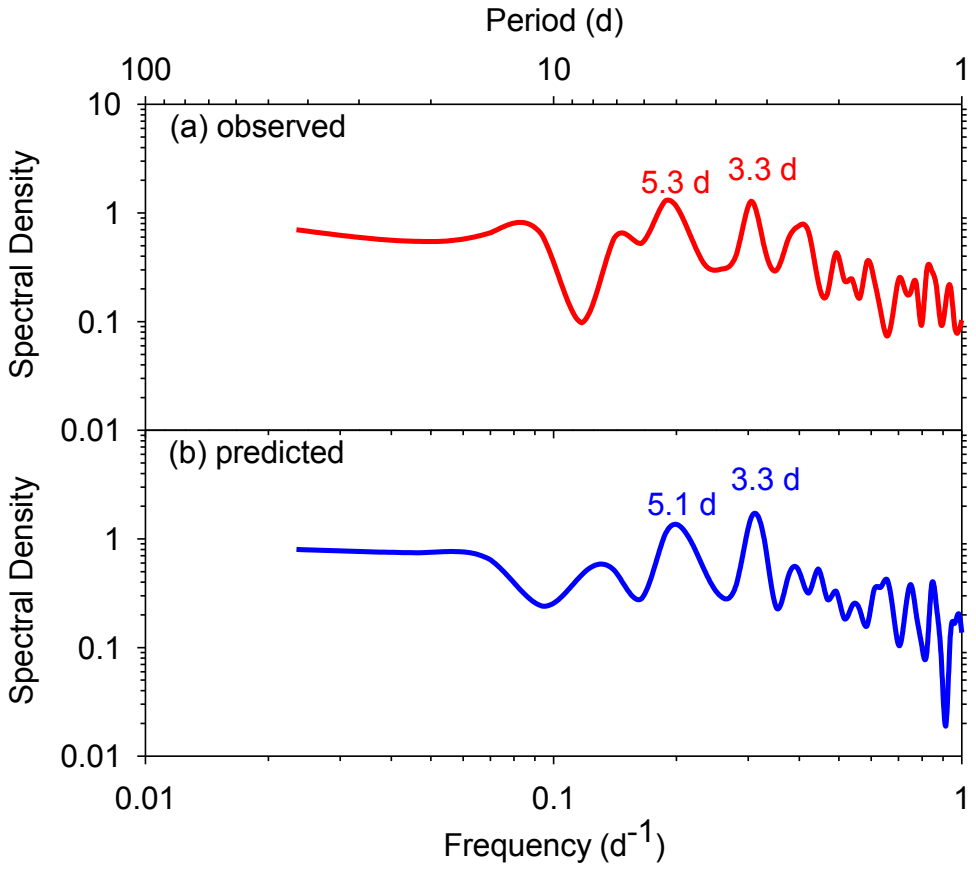




Model Performance – Spectral Analysis

- comparison of internal wave spectrum generated from thermistor string data and model predictions
- June 1–July 13, 2013; data from 100 m elevation (17 m deep) thermistor

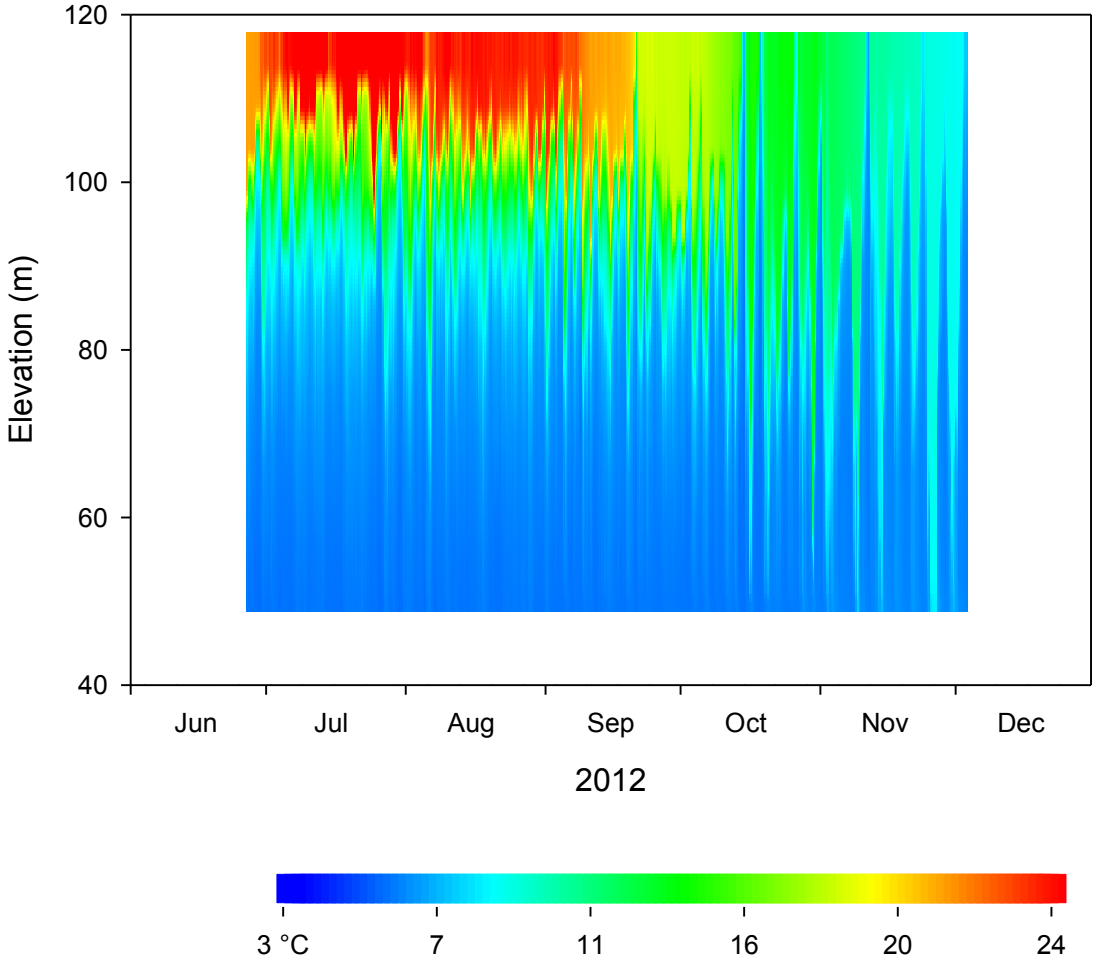


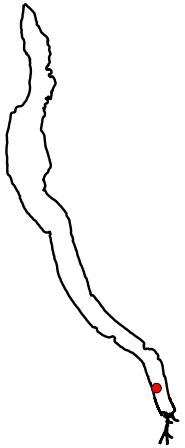


Observations 2012

Observed temperatures at LSC intake location

thermistor string temperature data at the LSC intake site





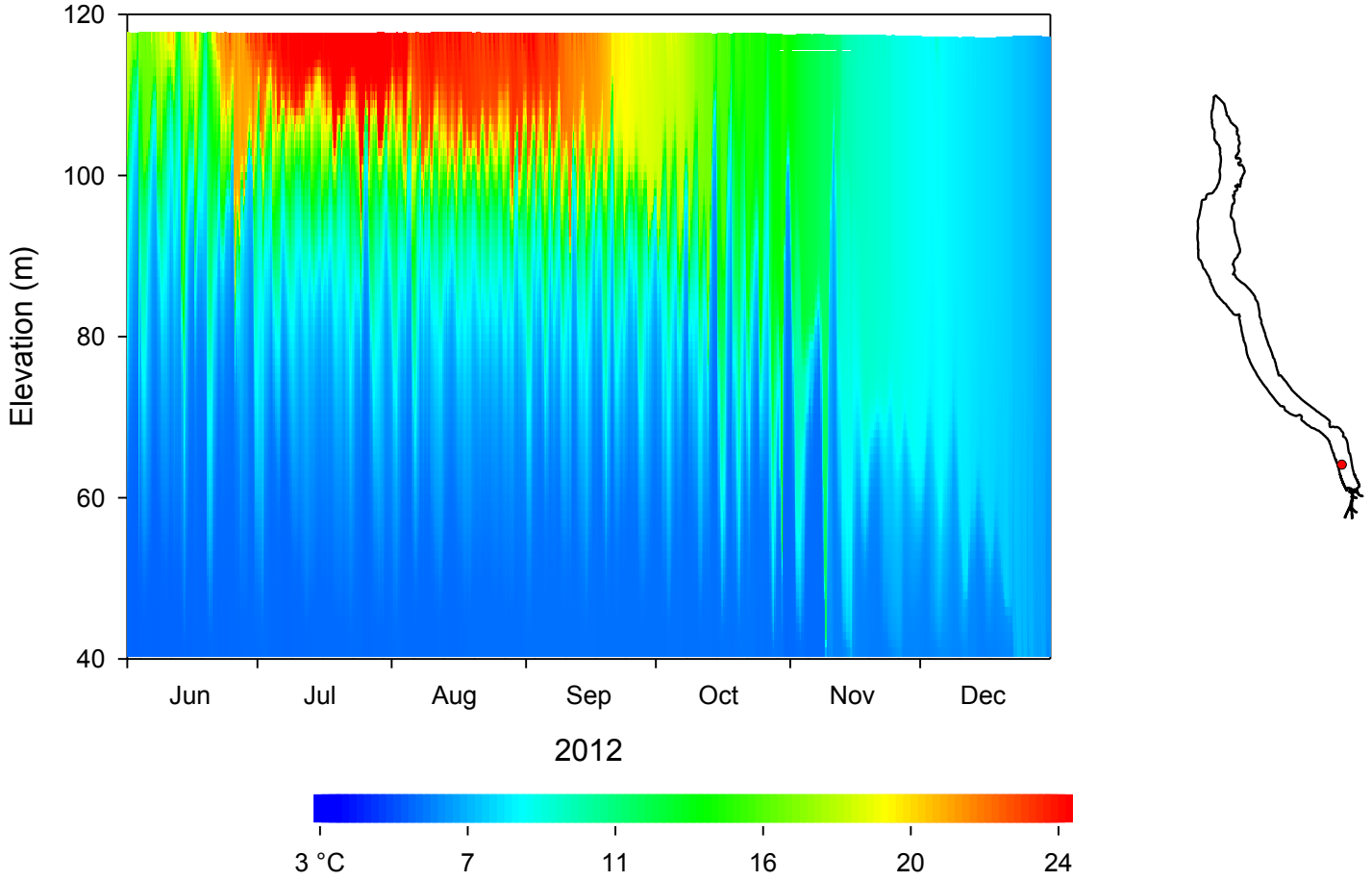
measurements were made every 30 sec at 5 m depth interval

data shown are at every 6 hours at 0.5 m depth interval

Model Performance – Predictions 2012

Predicted temperatures at LSC intake location

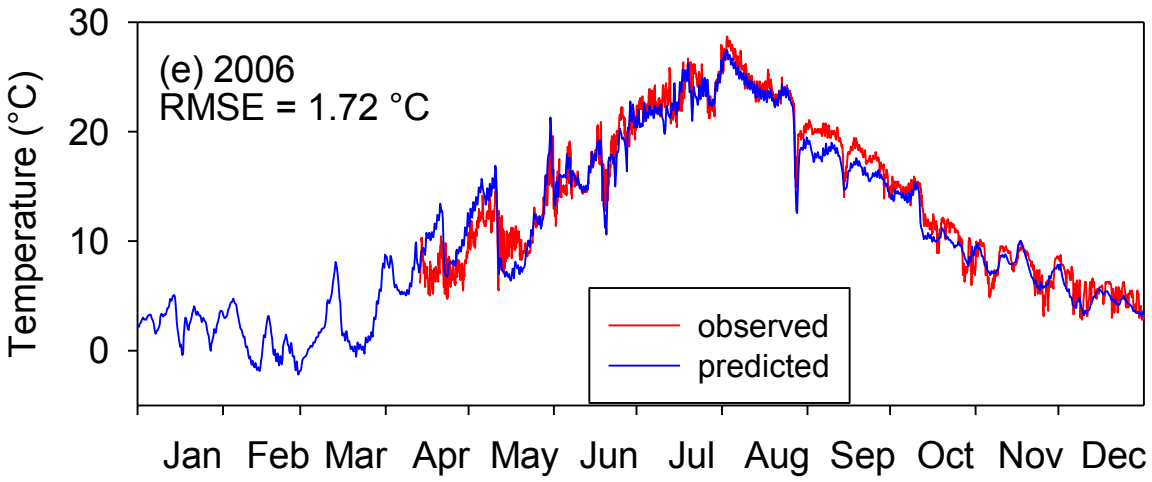
temperature predictions at the LSC intake site; model validation

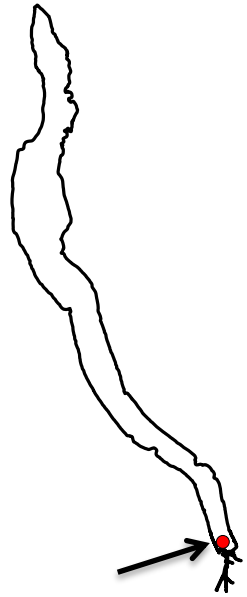


data shown are at every 6 hours at 1 m depth interval

Model Performance – 1998-2006

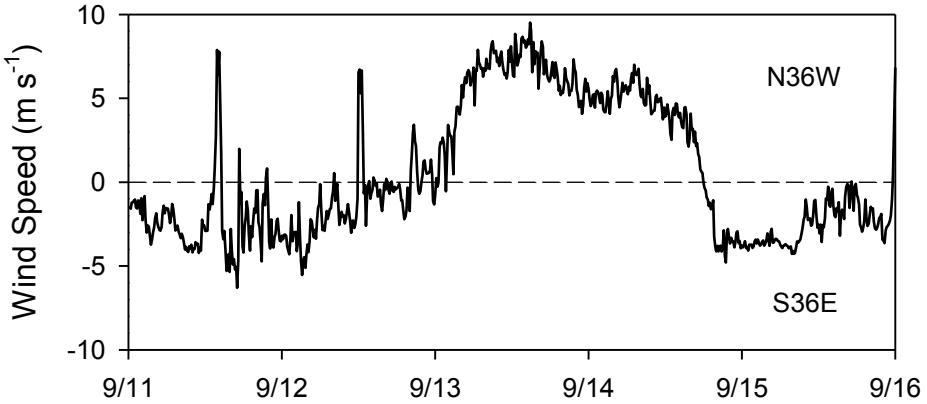
- Temperature observations were made with a single thermistor at a frequency of 1 per hour deployed near piling cluster ~ 1 m deep
- extended validation



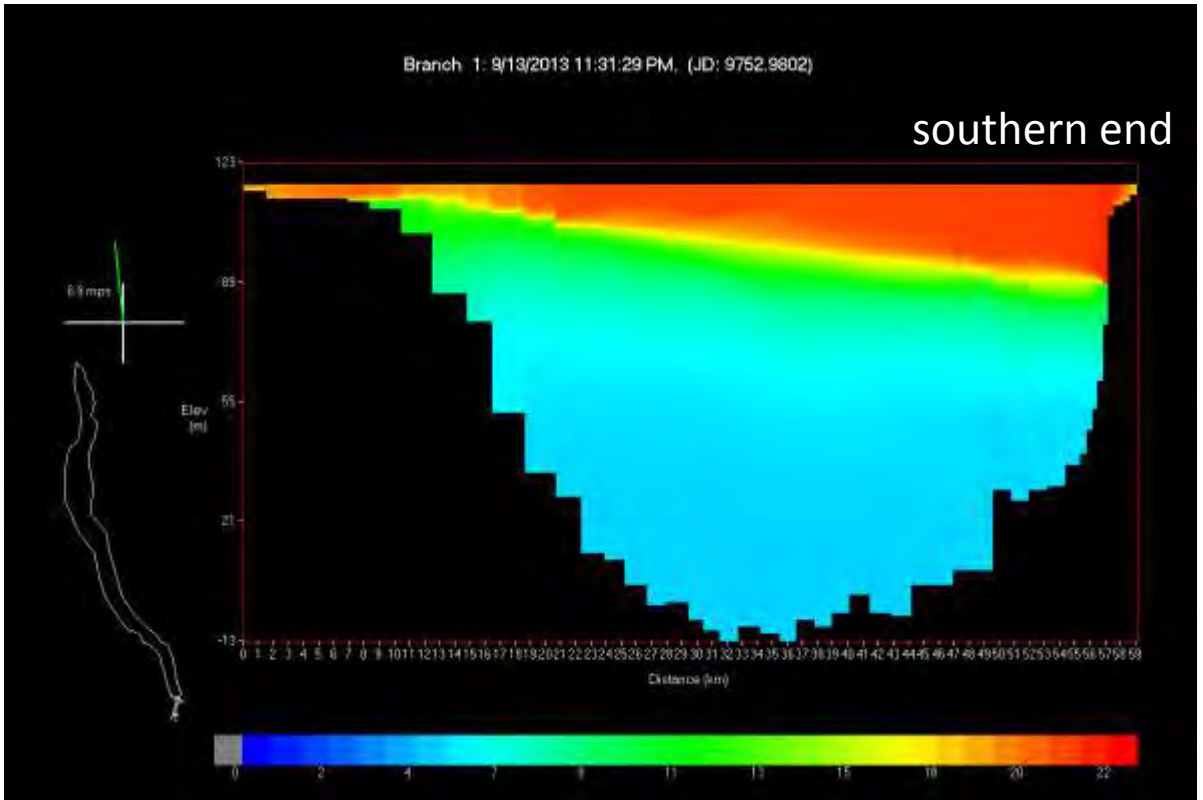


- RMSE is for April–October period

Visualization of Hydrodynamic Features



First horizontal mode linear internal wave
T1 = 80 hours
T1/4 = 20 hours
upwelling

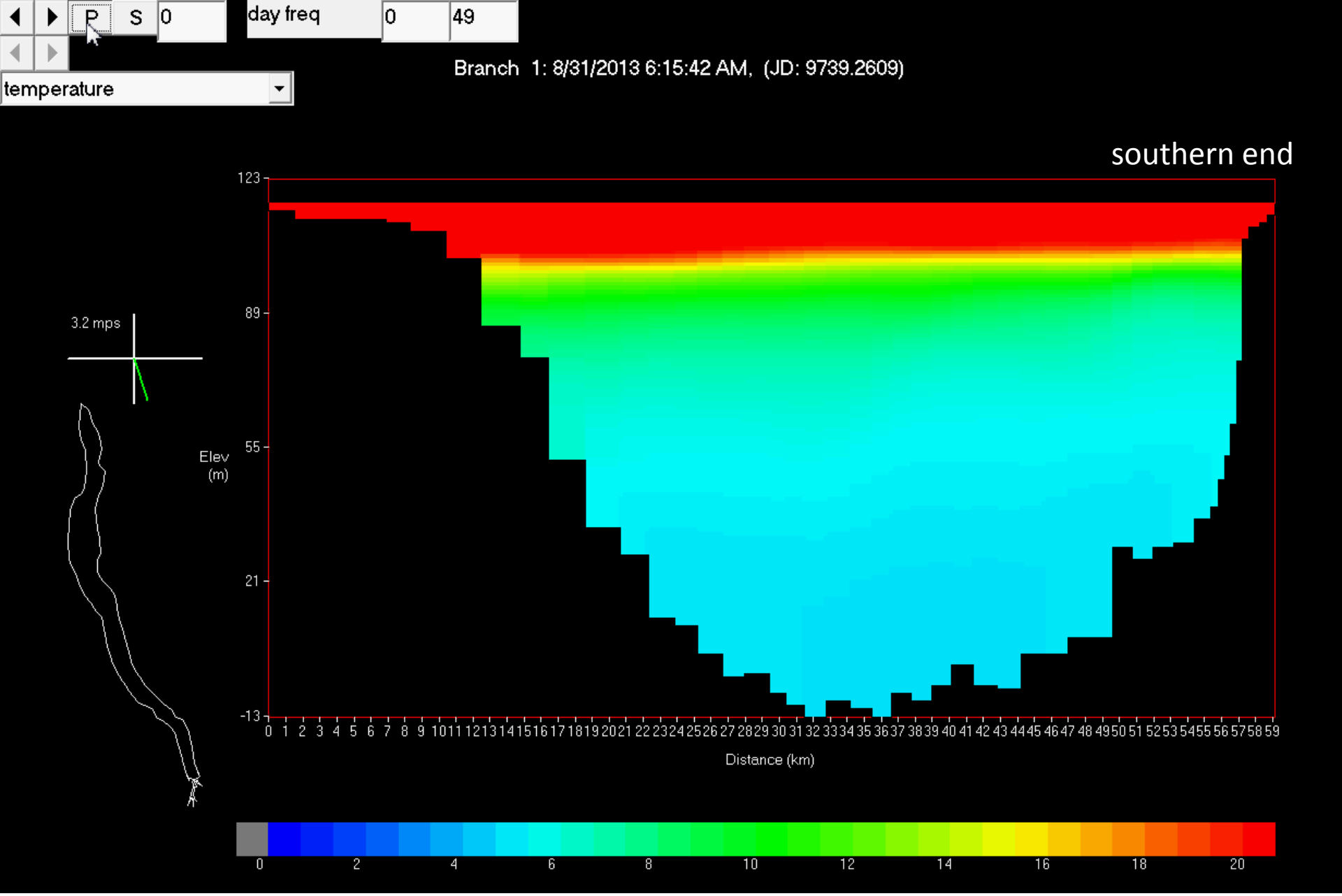


Visualization of Hydrodynamic Features

- a 58-seconds movie (10 hours of simulation per second of animation); captures internal wave field
- simulation of hydrodynamics in Cayuga Lake - September, 2013
- depiction of mixing mechanisms*
  - standing linear internal waves
  - progressive internal waves
  - internal wave breaking near shelf; localized intense turbulent mixing
  - internal surges and hydraulic jumps (interaction of waves with topographic features)
  - formation and propagation of nonlinear internal wave packets

- watch from the point of view of mixing, transport and redistribution of plankton and nutrients; transport and resuspension of sediments

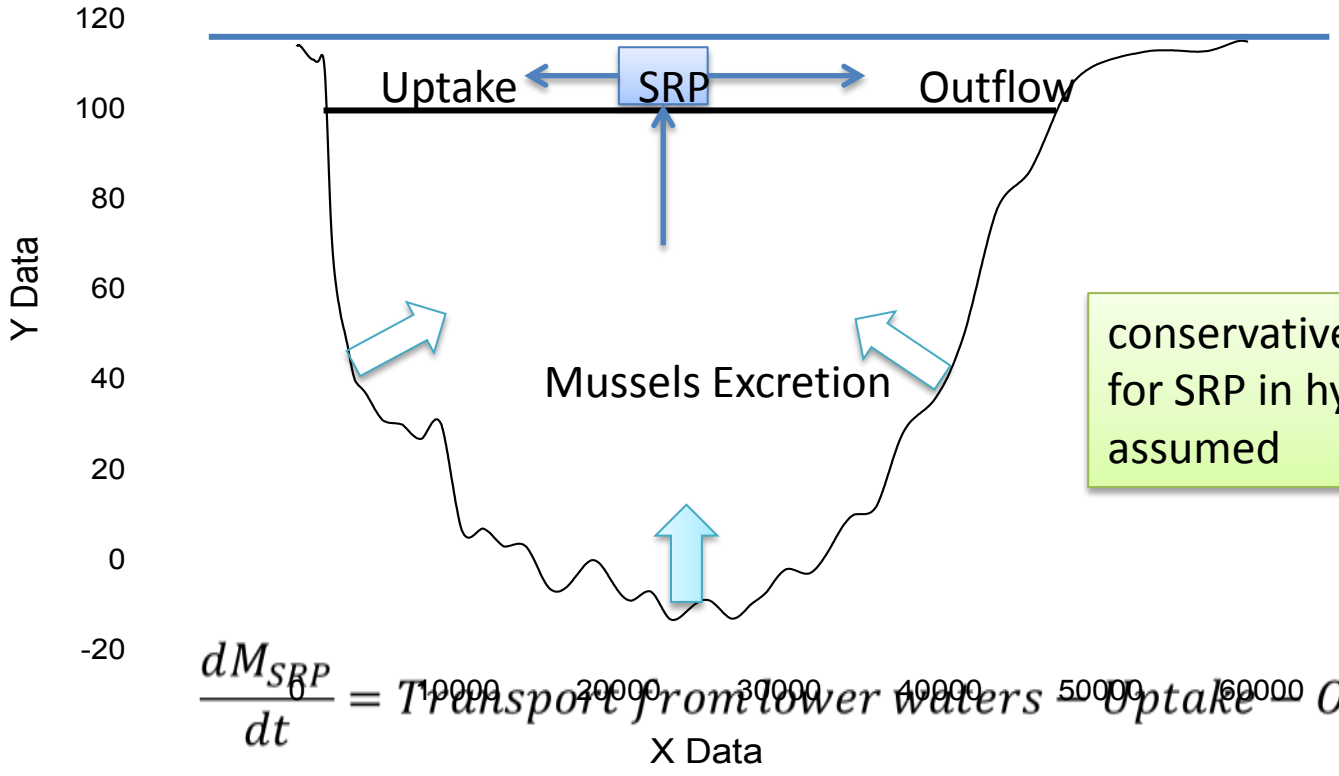
** details can be found in Fischer et al. (1979); Imberger (1985); Imboden and Wüest (1995); Boegman (2009)*



Cayuga Lake: 8/31/2013–9/26/2013

Model Application

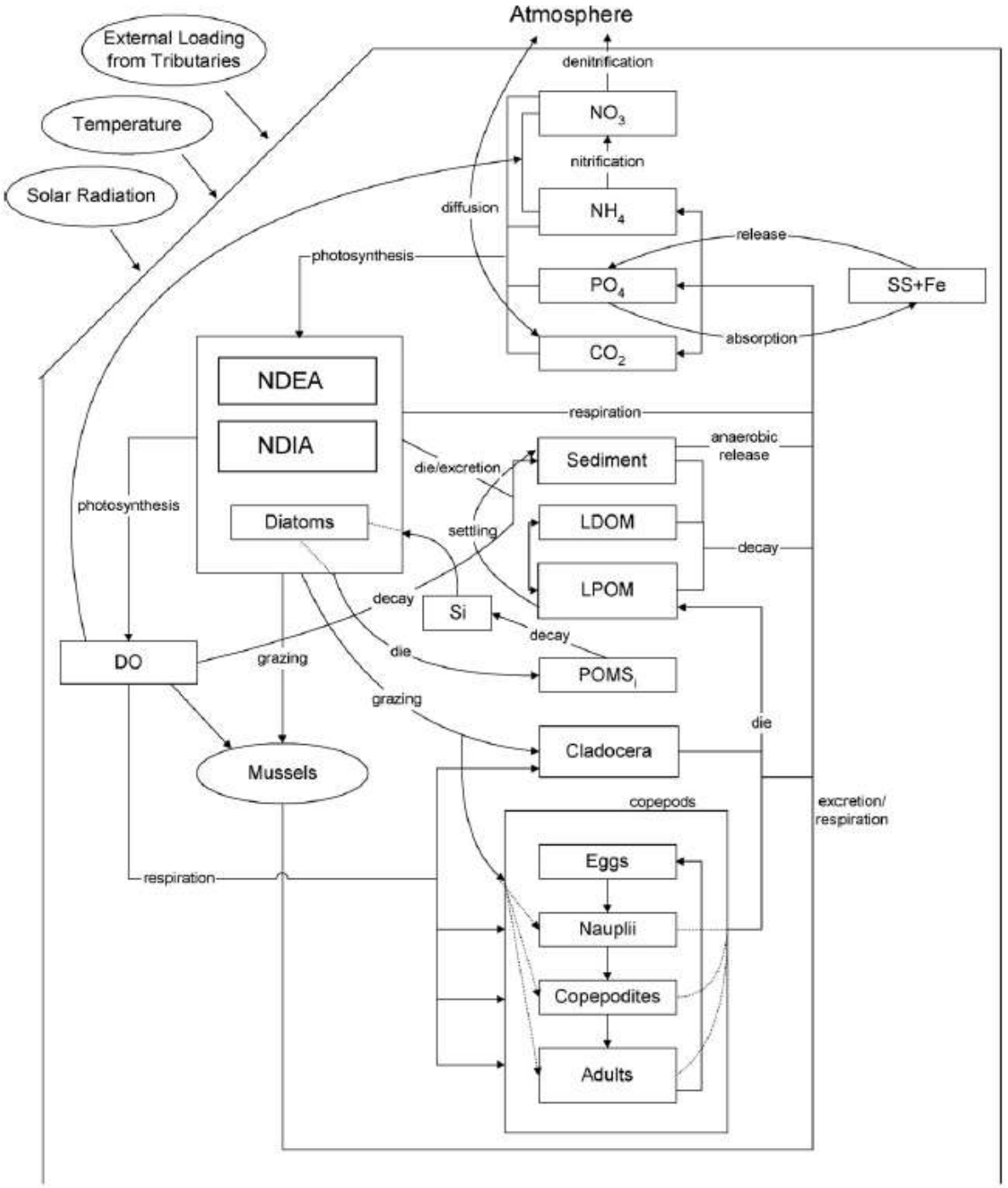
- using the transport framework as an analytical tool
- goal: evaluate implications of hypothetic mussel excretion for internal SRP cycling and the consistency of measured SRP profiles
- adopt an over simplified, epilimnion-only SRP model



conservative behavior for SRP in hypolimnion assumed

$$\frac{dM_{SRP}}{dt} = Transport\ from\ lower\ waters - Uptake - Outflow$$

At steady-state: $0 = Transport\ from\ lower\ waters - Uptake - Outflow$



Example of a Complex Water Quality Model

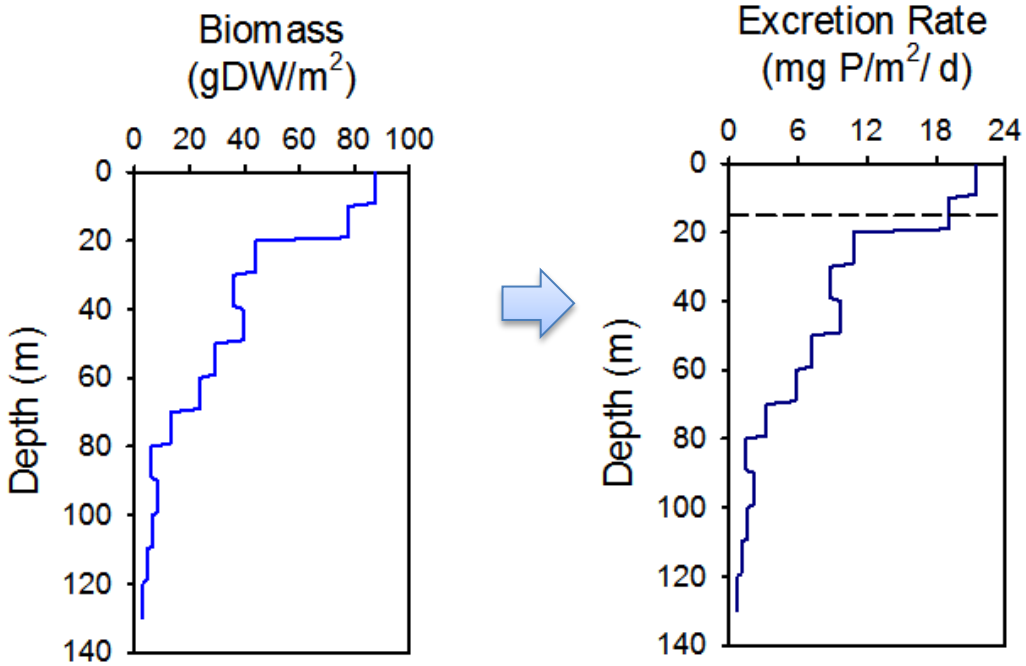
Zhang, Culver, Boegman (2008); Lake Erie

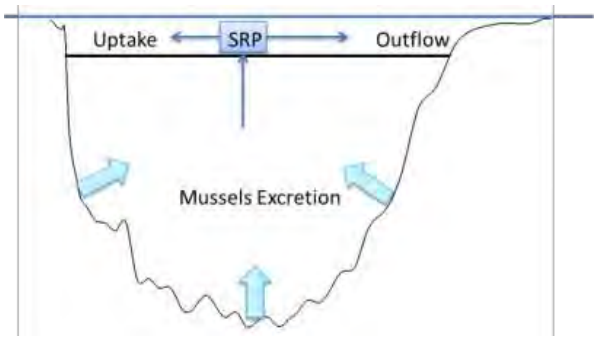
Estimation of Excretion Rate

- in-situ measurement difficult
- measure biomass density and apply a literature value of mass-specific excretion rate

$$Areal\ Excretion\ Rate\ \left(\frac{\mu g\ P}{m^2 hr}\right) = Biomass\left(\frac{gDW}{m^2}\right) \times 0.33\ \frac{\mu mol\ P}{gDW\ hr} \times 31\ \frac{\mu g}{\mu mol}$$

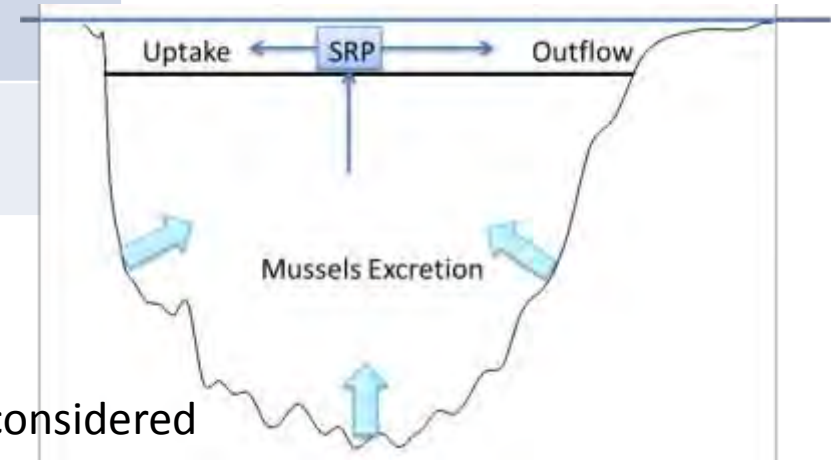
range: 0.084 – 0.66 µmolP/gDW/hr (n=10) *(Nalepa and Schloesser 2014)*





SRP Simulation Runs

Run ID	Excretion Rate (mg/m2/d) Specification	Uptake Rate (1/m)
Run 11	estimated depth-specific	0.0
Run 0	estimated depth-specific	0.1
Run 1	50% of estimated depth-specific	0.1
Run 14	estimated depth-specific	0.5

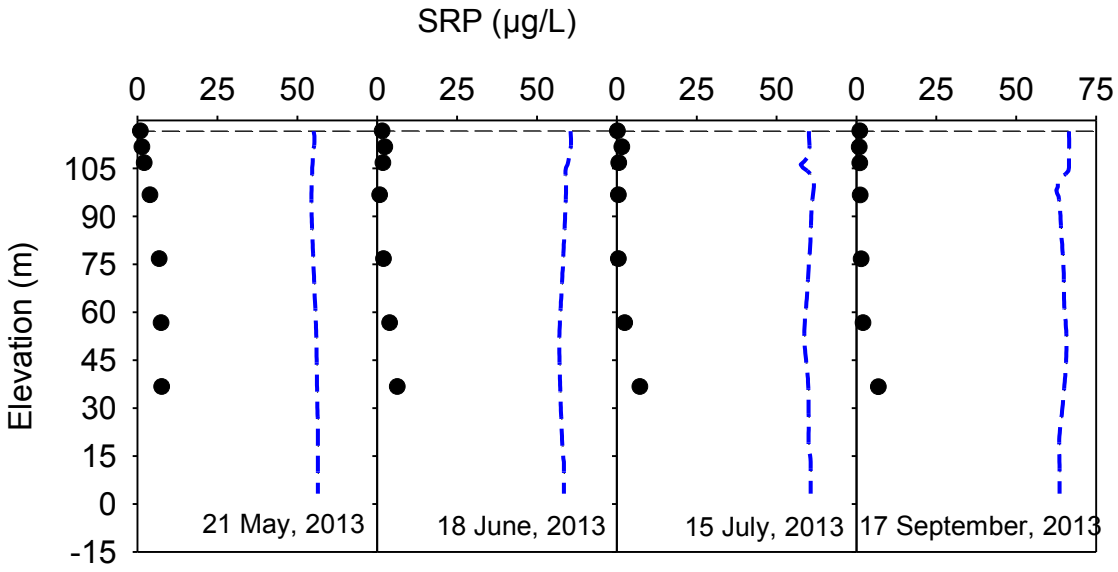


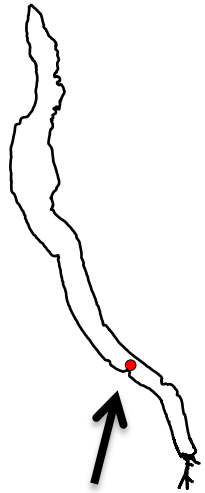
effects of environmental variables on excretion not considered

SRP Simulation Results

- site 3
- selected depth-profiles of SRP; May-September 2013

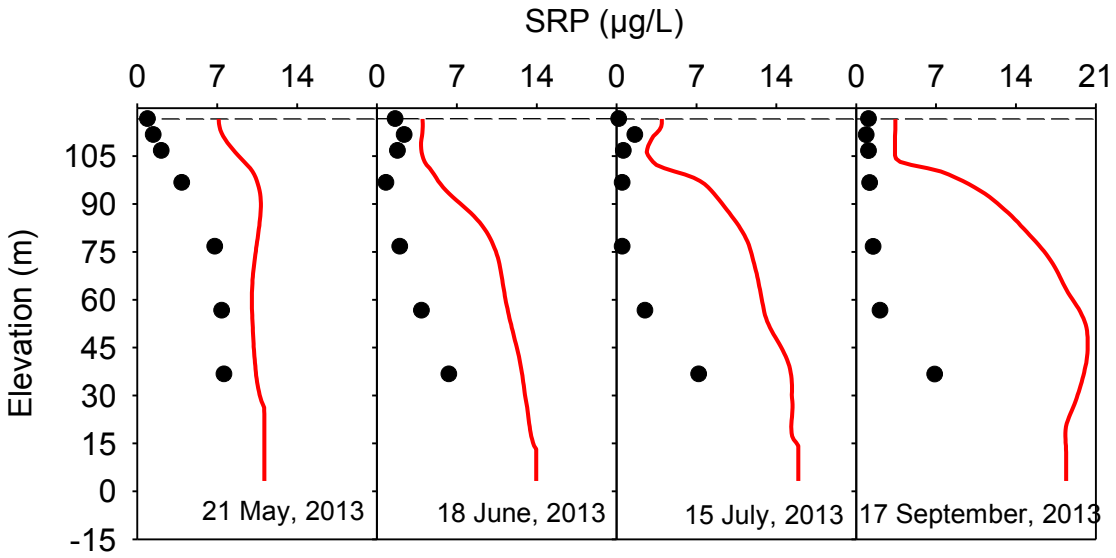
Run ID	Excretion Rate (mg/m2/d) Specification	Uptake Rate (1/m)
Run 11	estimated depth-specific	0.0



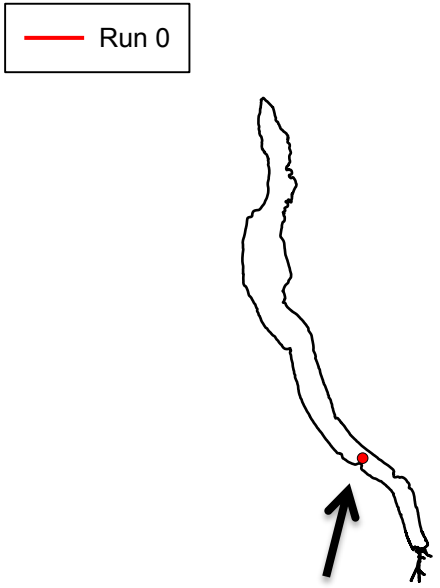


SRP Simulation Results

- site 3
- selected depth-profiles of SRP; May-September 2013

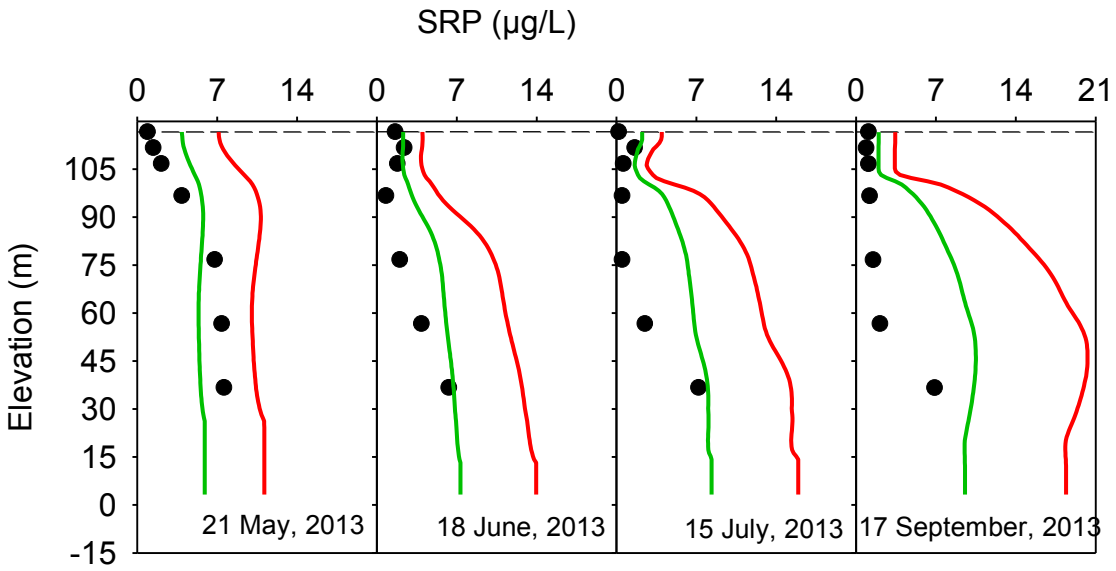


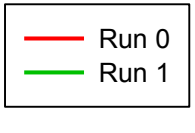
Run ID	Excretion Rate (mg/m2/d) Specification	Uptake Rate (1/m)
Run 0	estimated depth-specific	0.1

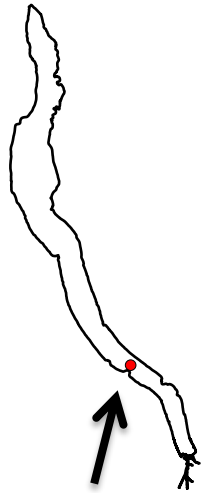


SRP Simulation Results

- site 3
- selected depth-profiles of SRP; May-September 2013



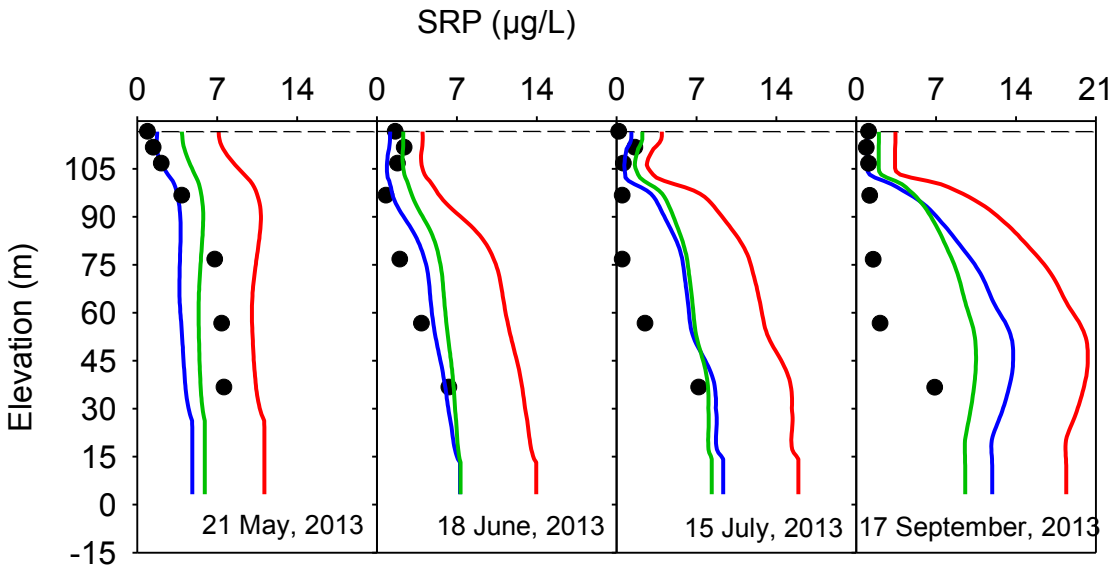


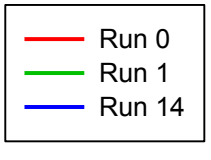


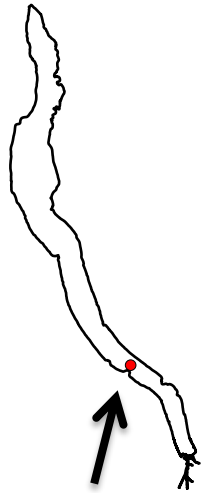
Run ID	Excretion Rate (mg/m2/d) Specification	Uptake Rate (1/m)
Run 0	estimated depth-specific	0.1
Run 1	50% of estimated depth-specific	0.1

SRP Simulation Results

- site 3
- selected depth-profiles of SRP; May-September 2013







Run ID	Excretion Rate (mg/m2/d) Specification	Uptake Rate (1/m)
Run 0	estimated depth-specific	0.1
Run 1	50% of estimated depth-specific	0.1
Run 14	estimated depth-specific	0.5

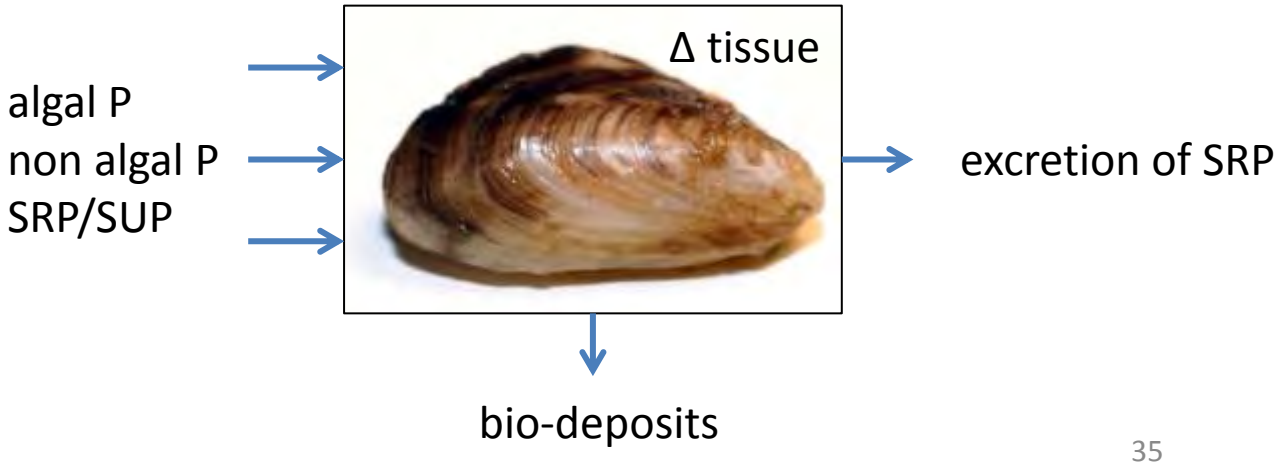
SRP Simulation Results

- phytoplankton uptake of SRP in the epilimnion is important
- SRP concentration gradient across the thermocline allows diffusion and causes the characteristic shape of the SRP depth-profile as observed in the lake
- in the deep hypolimnion, SRP appears to be in quasi-steady state
- low levels of SRP in the metalimnion ($z > 1\%$ light level) suggest action of a sink process

Mussels: Some Thoughts, Issues

- uncertainty in biomass specific excretion rate (0.33 µmolP/gDW/hr)
- effects of environmental variables (temperature, turbidity, phytoplankton, pH, salinity, Ca), substrate, and currents on excretion rate – largely unknown
- longitudinal variations in excretion rate
- full P cycle will be necessary to explain SRP in the lake
- processes to consider: adsorption/desorption; zooplankton excretion; phytoplankton respiration; losses from settling of detritus; bio-deposits (pseudo feces)

- other features of metabolism will need to be considered



Summary

- A 2-D hydrodynamic/transport model, CE-QUAL-W2, has been setup and successfully tested for Cayuga Lake
- The model has been calibrated to data collected in 2013 and validated for 2012, 1998-2006; additional testing in future
- This model will be ready to serve as the transport submodel for a forthcoming (Phase 2) water quality model for the lake
- A preliminary application of the model demonstrates the effects, and importance of mussels excretion of soluble reactive phosphorus

Further Model Applications

- additional tracer analysis
  - mussel fluxes
  - fate of interflows
  - travel times for events
  - south tributary transport
    - base flow
    - runoff events
- material budgets
- kinetic insights