Thermal Structures in Kinbasket Reservoir

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Overview

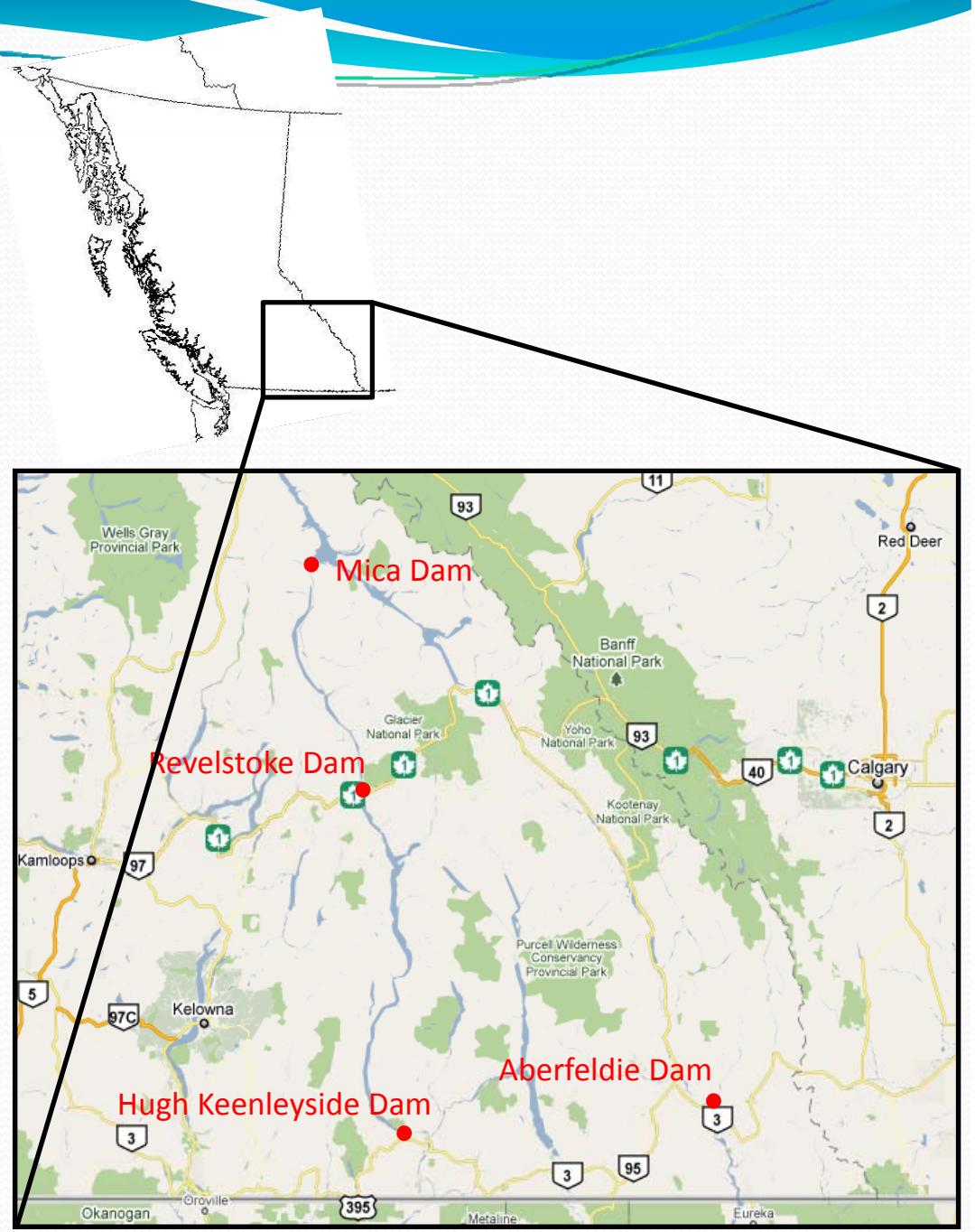
- Objectives
- Study location
- Thermistor chain measurements
  - Typical profiles
  - Fluctuating profiles
  - Spectral analysis
- Theoretical calculations
- Dam operation oscillations

Objectives

- NSERC HydroNet Project
  - *Predict the risk of fish entrainment in reservoirs due to generation operations*
  - Fish entrainment partially function of reservoir forebay thermal characteristics
- Study objective
  - Understand reservoir thermal dynamics and how hydropower operations affects them

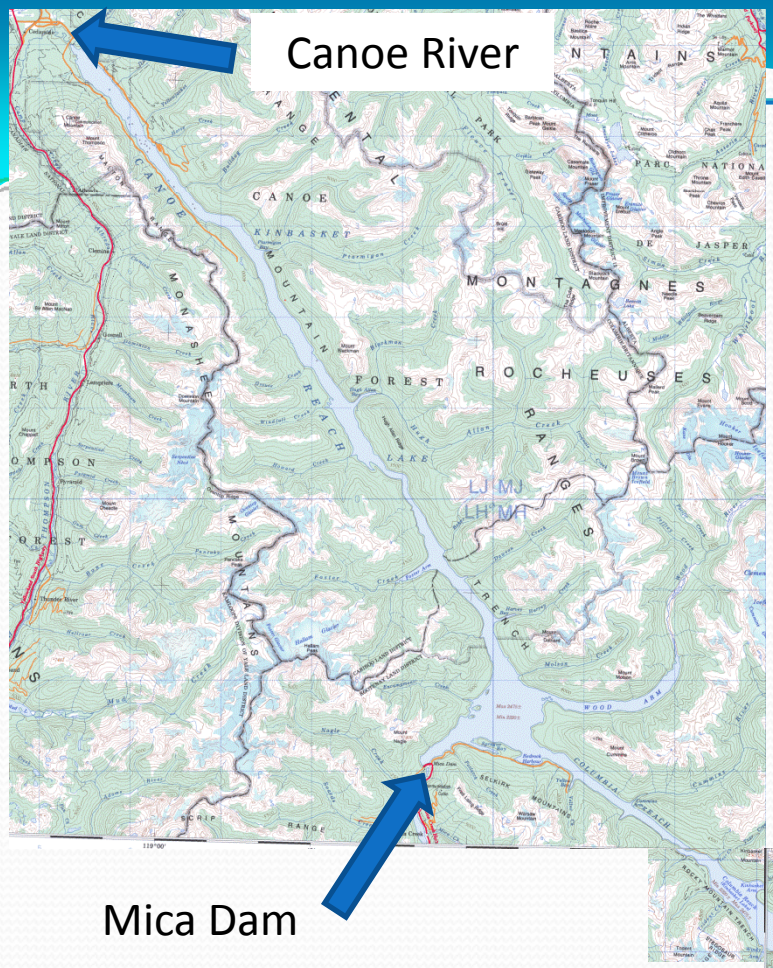
Study Sites

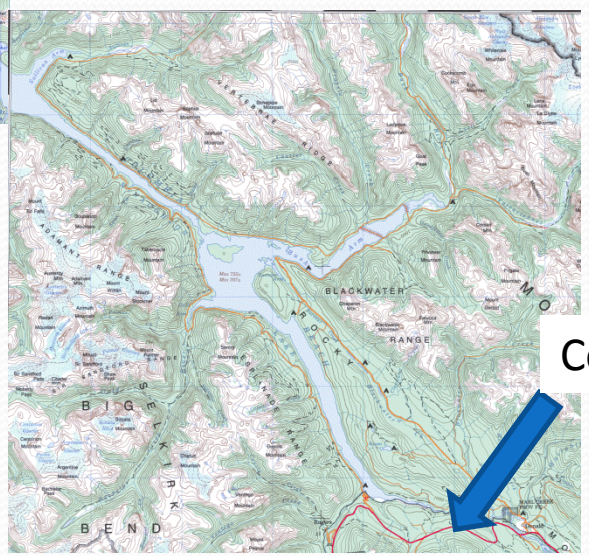
- Four reservoirs
  - Columbia River:
    - Mica Dam
    - Revelstoke Dam
    - Hugh Keenleyside Dam
  - Bull River:
    - Aberfeldie Dam



Current Study Location

- Mica Dam (Kinbasket Reservoir)
  - Columbia Reach (100 km)
  - Canoe Reach (90 km)
  - Local Dam Reach (15 km)



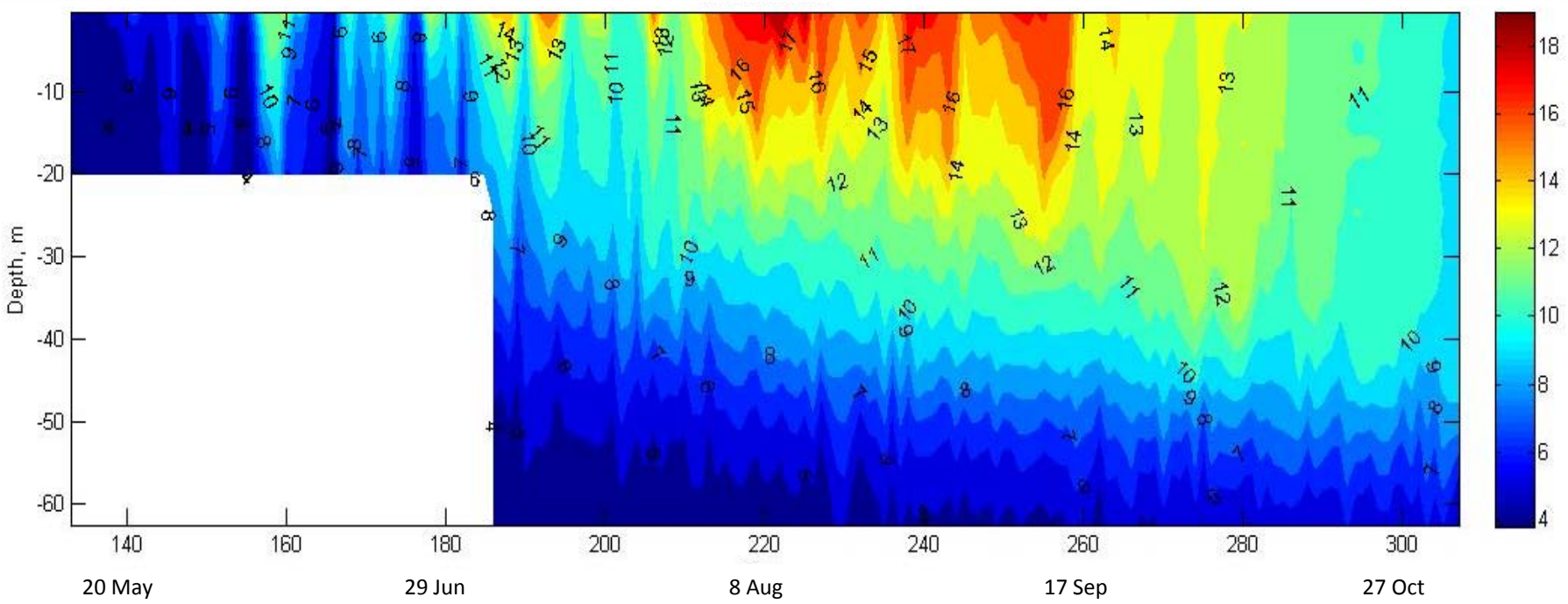


Thermistor Chain

- ~300m from dam face
- 30 Onset Tidbit v2 thermistors
  - Approximately 2m spacing
  - Temperature profile measurement every 5 min
  - Installed in 2 sections
    - Top 20m on May 13, 2011
    - Bottom 40m on July 5, 2011

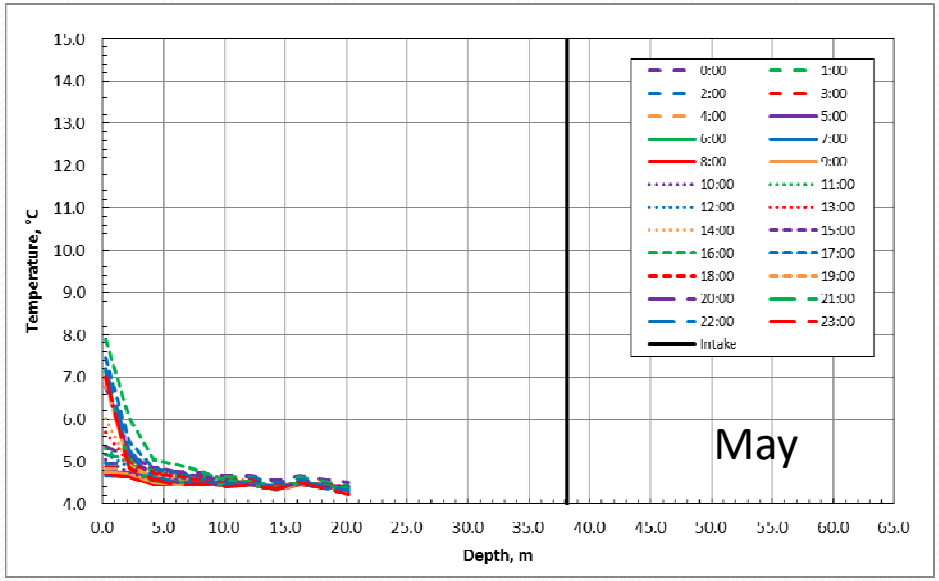
Temperature Contours

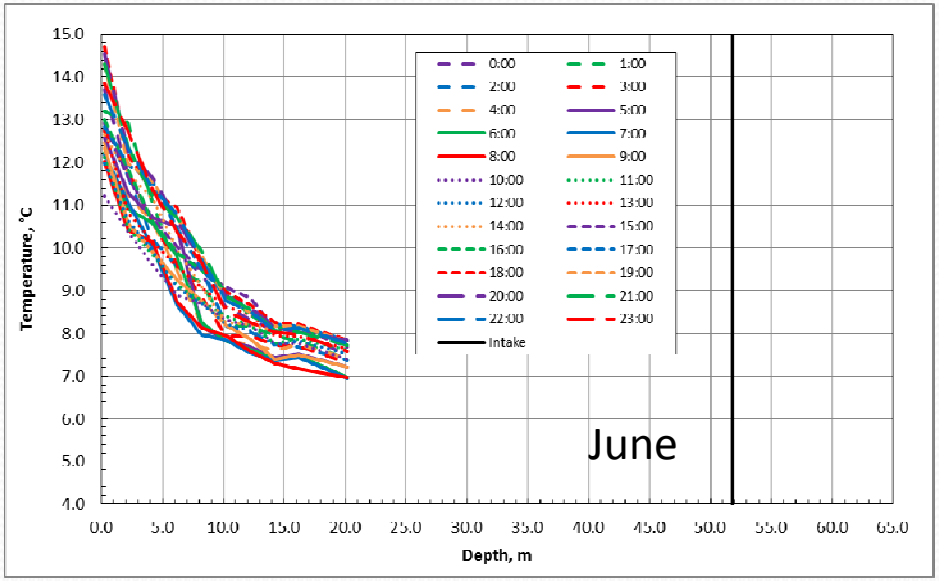
- From May 13 – November 3, 2011
- Averaged daily



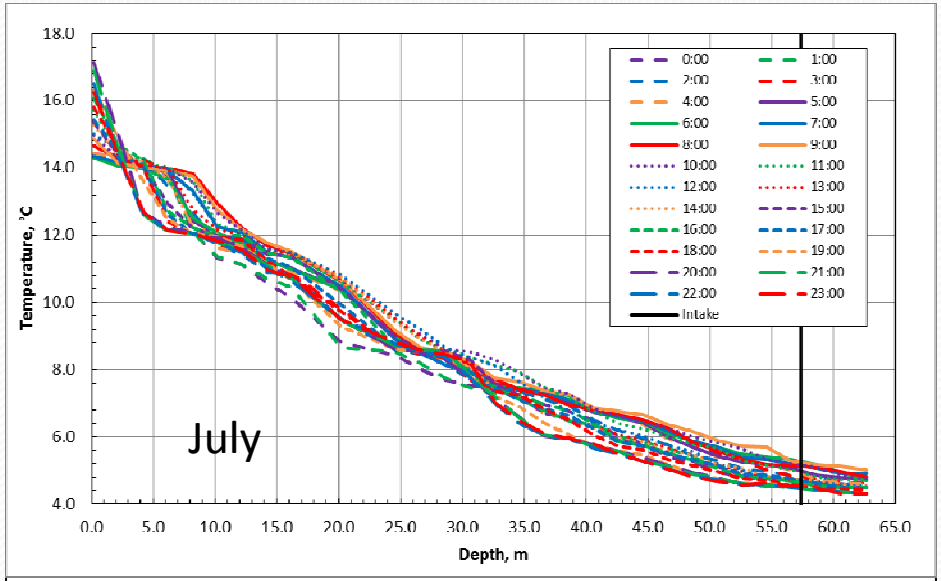
Typical Temperature Profiles

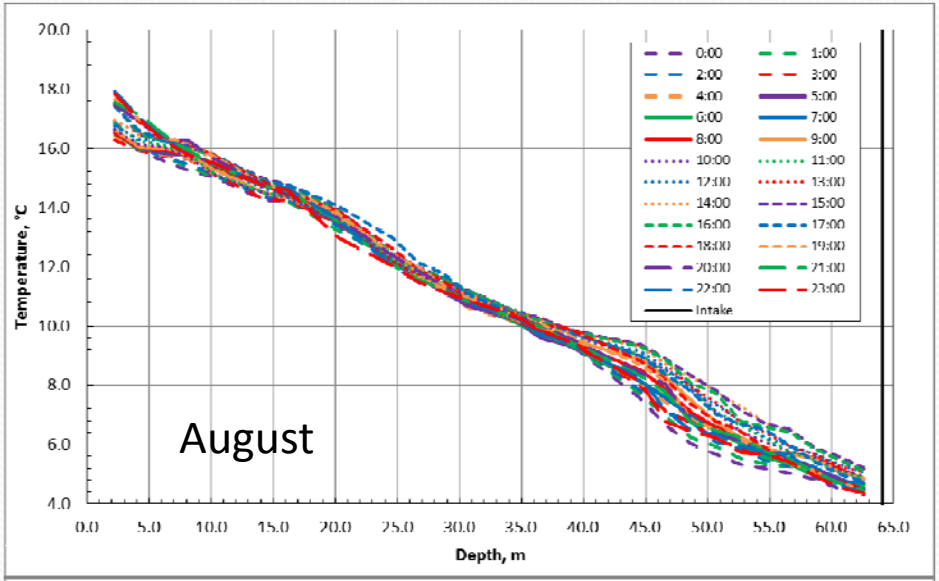
- May: homogeneous
- June, July, August: continuous stratification
  - Linear temperature gradient from surface to intake depth
- September, October: development of mixed surface layer

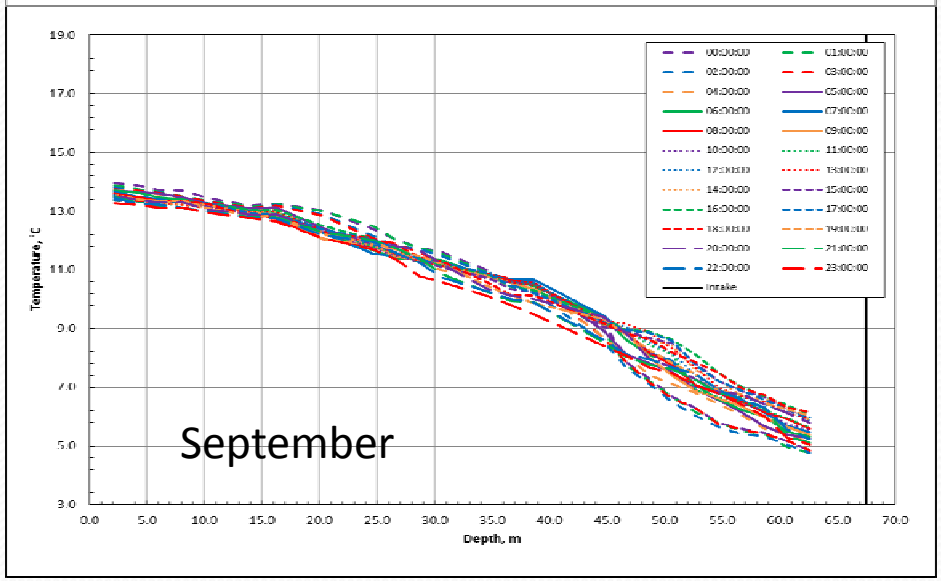


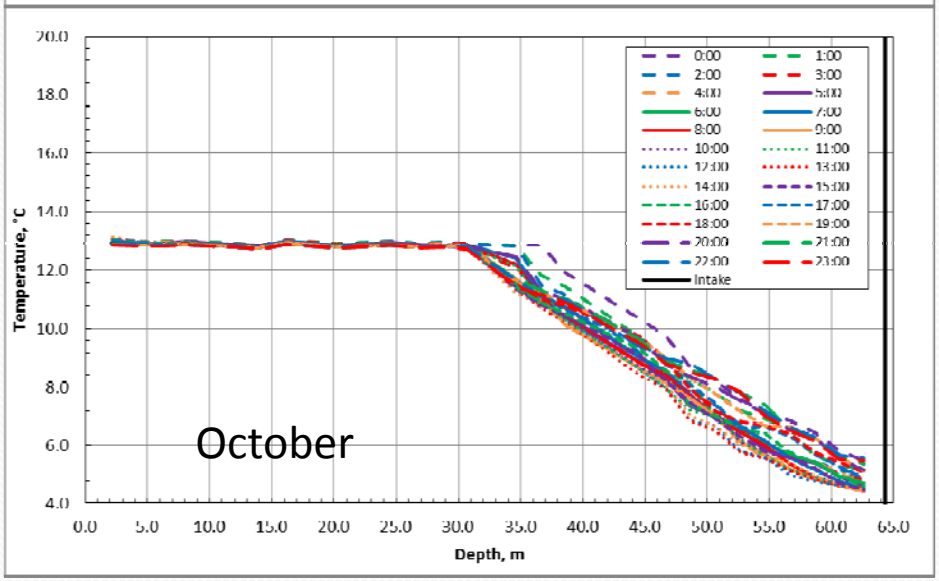


Typical Temperature Profiles



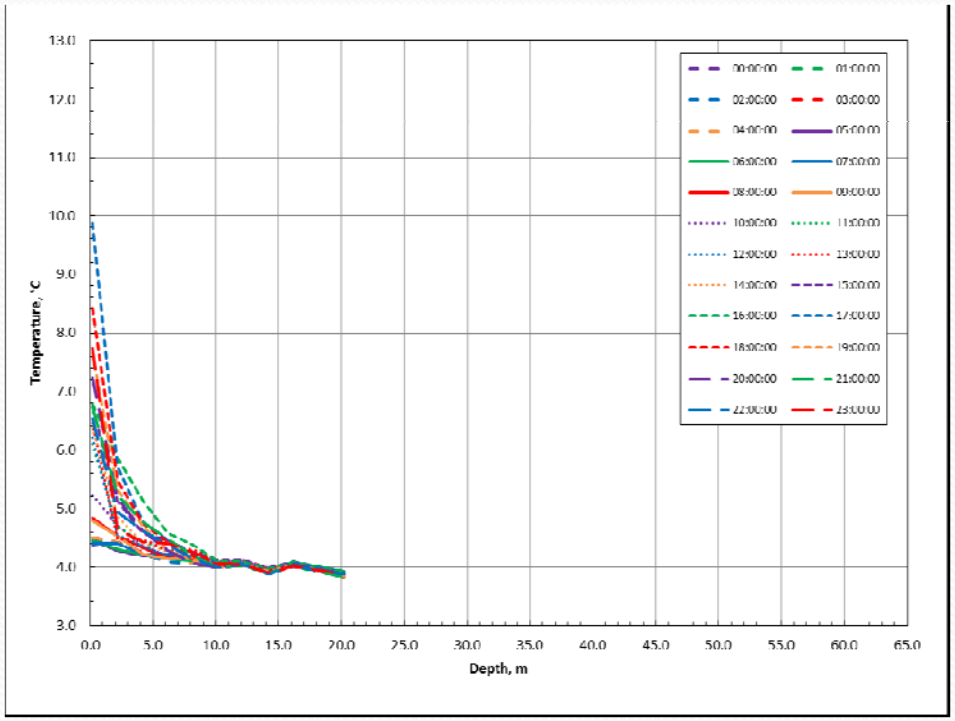


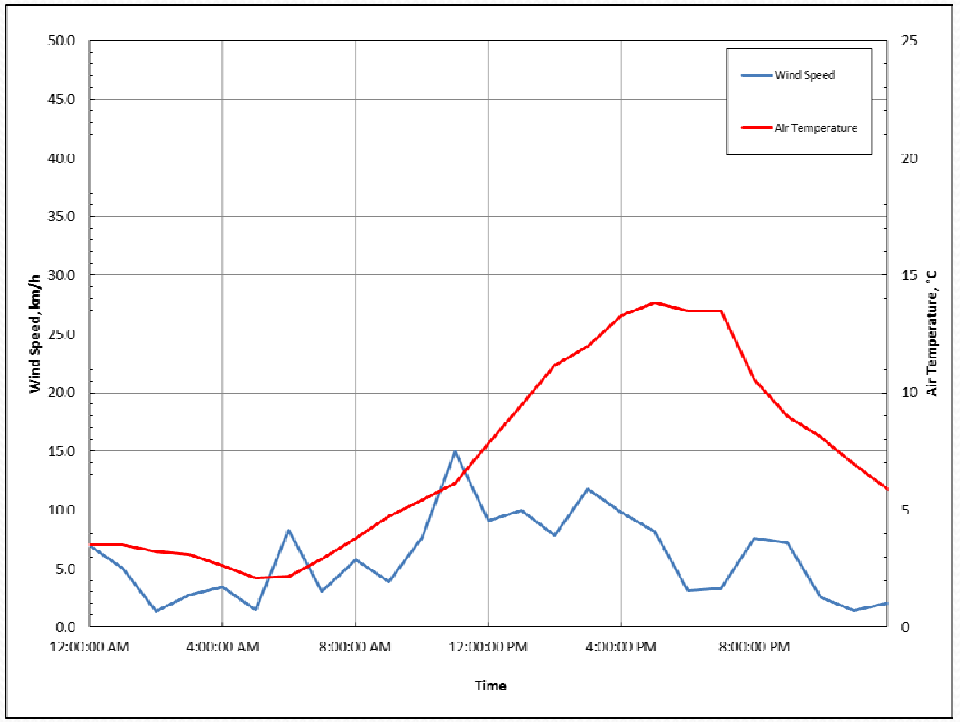




Temperature Fluctuations

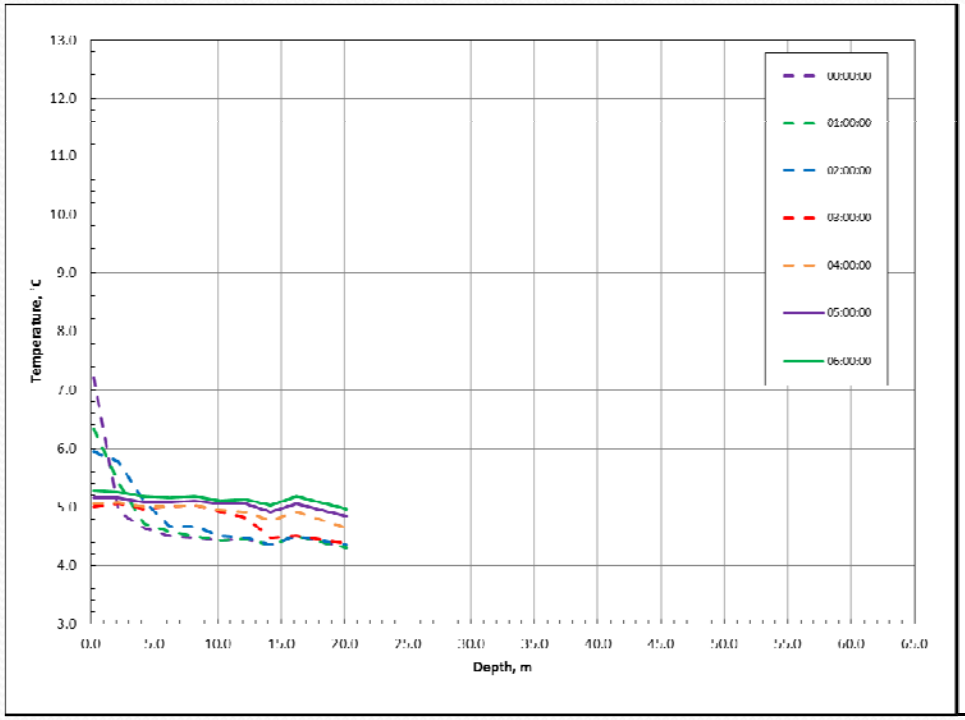
- May 18, 2011
  - Steep temperature gradient at surface
  - Mild winds, high air temperature

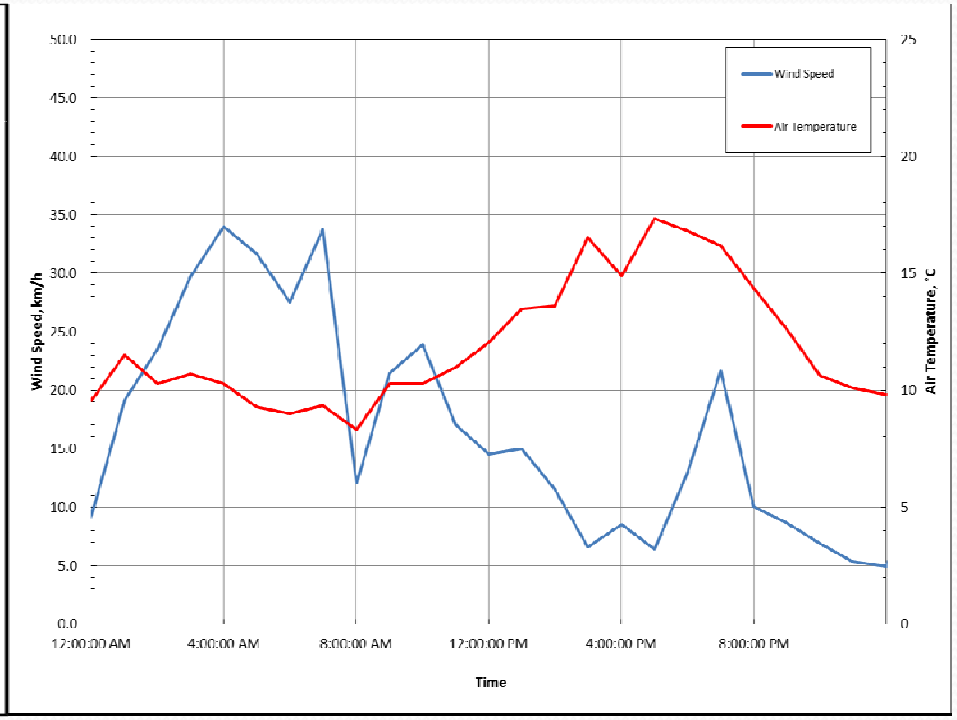




Temperature Fluctuations

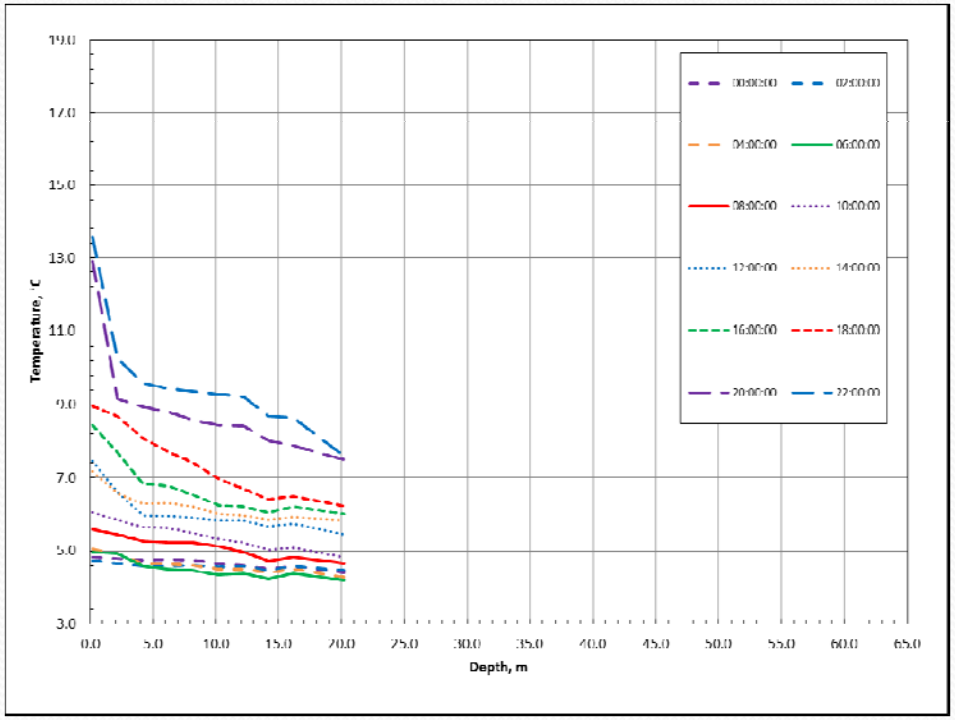
- May 24, 2011
  - Temperature gradient changes to homogeneous profile
  - Consistently high winds

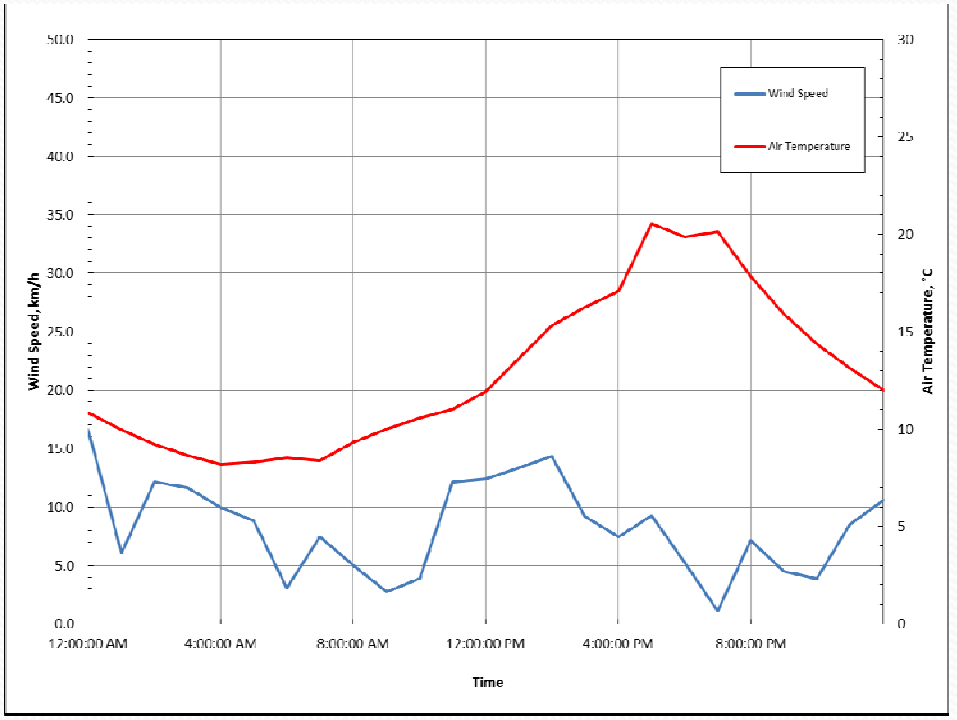




Temperature Fluctuations

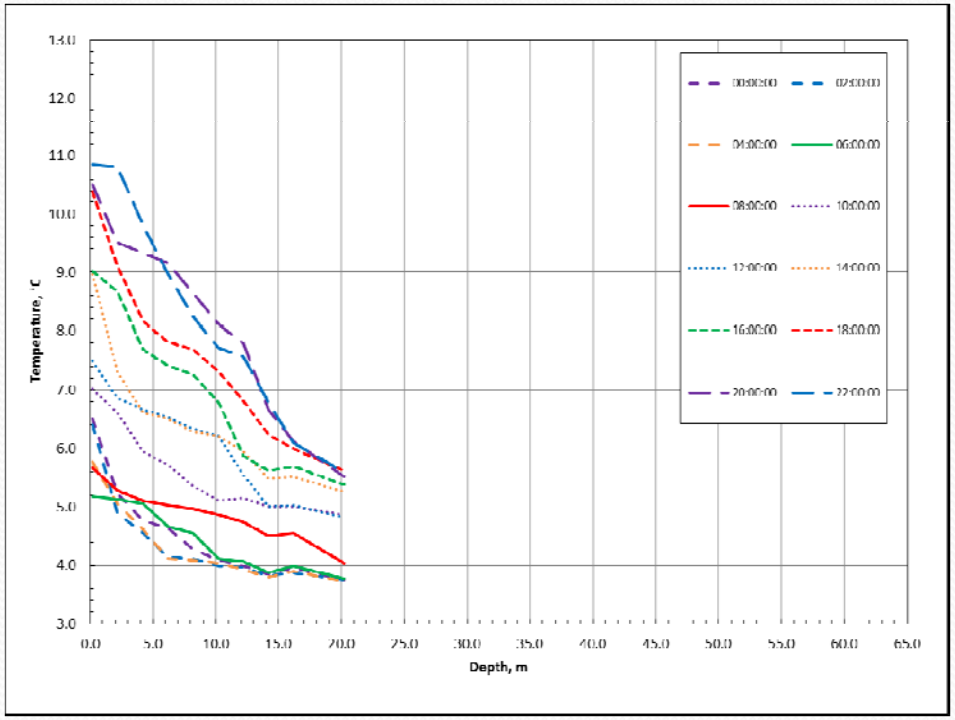
- June 26, 2011
  - Uniform and rapid increase in temperature
  - Low wind speed

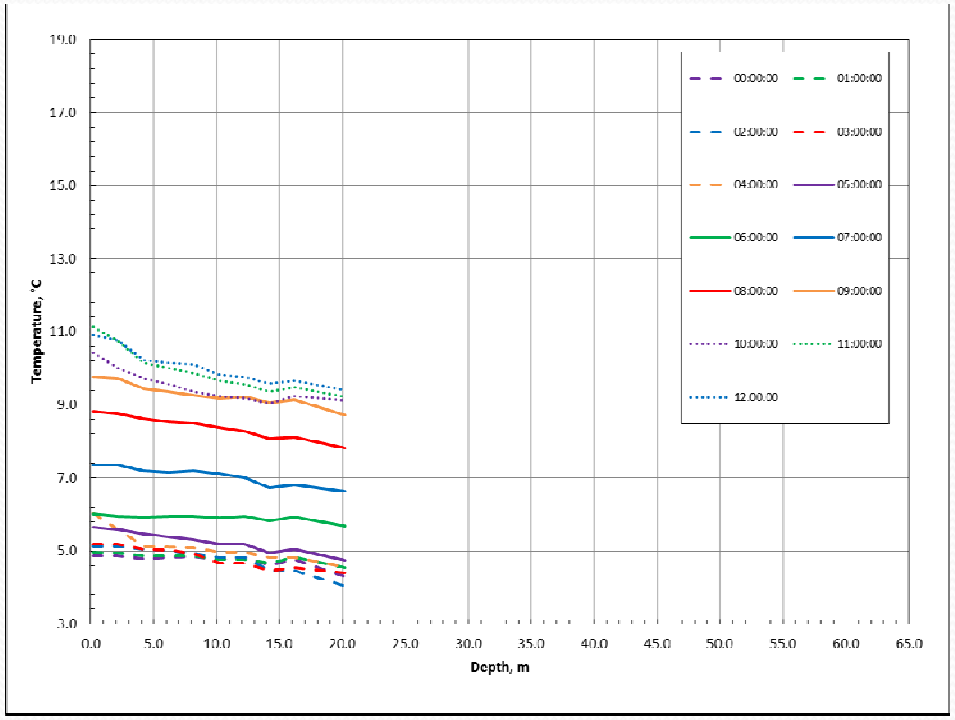




Temperature Fluctuations

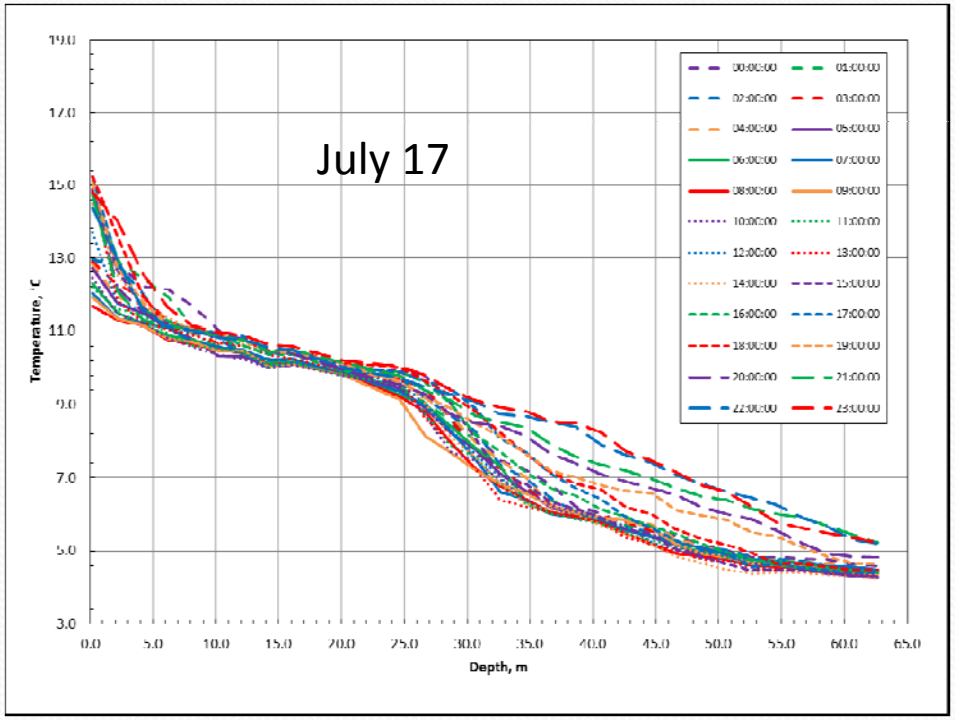
- June 5 and June 16, 2011
  - Wind speed below 10 km/h (on average)
  - Occurs approximately every 10 days
    - Internal seiche period

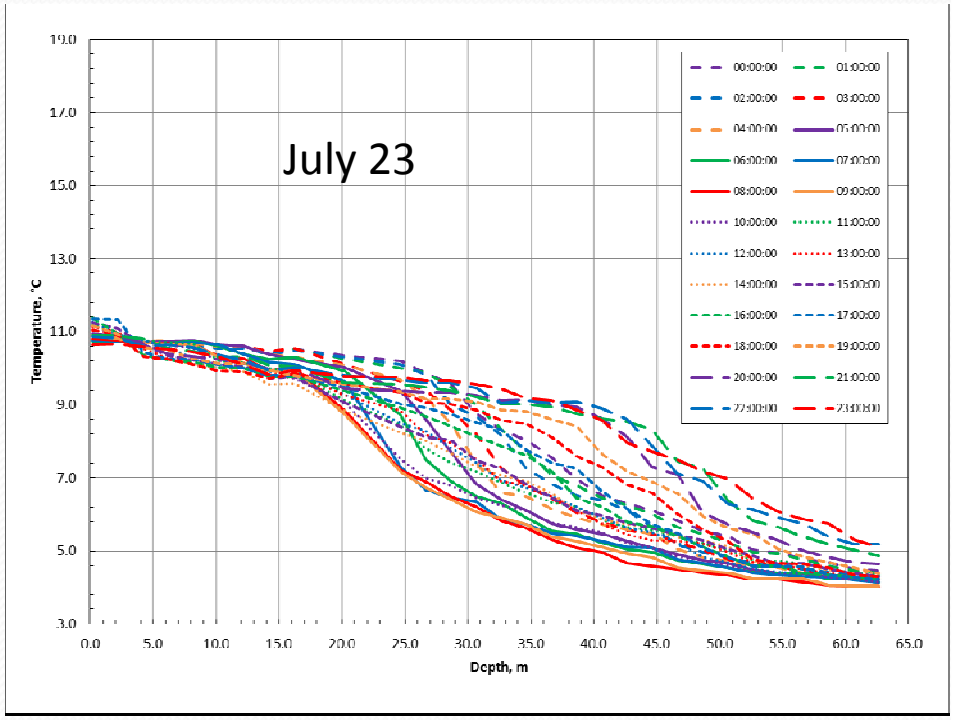




Temperature Fluctuations

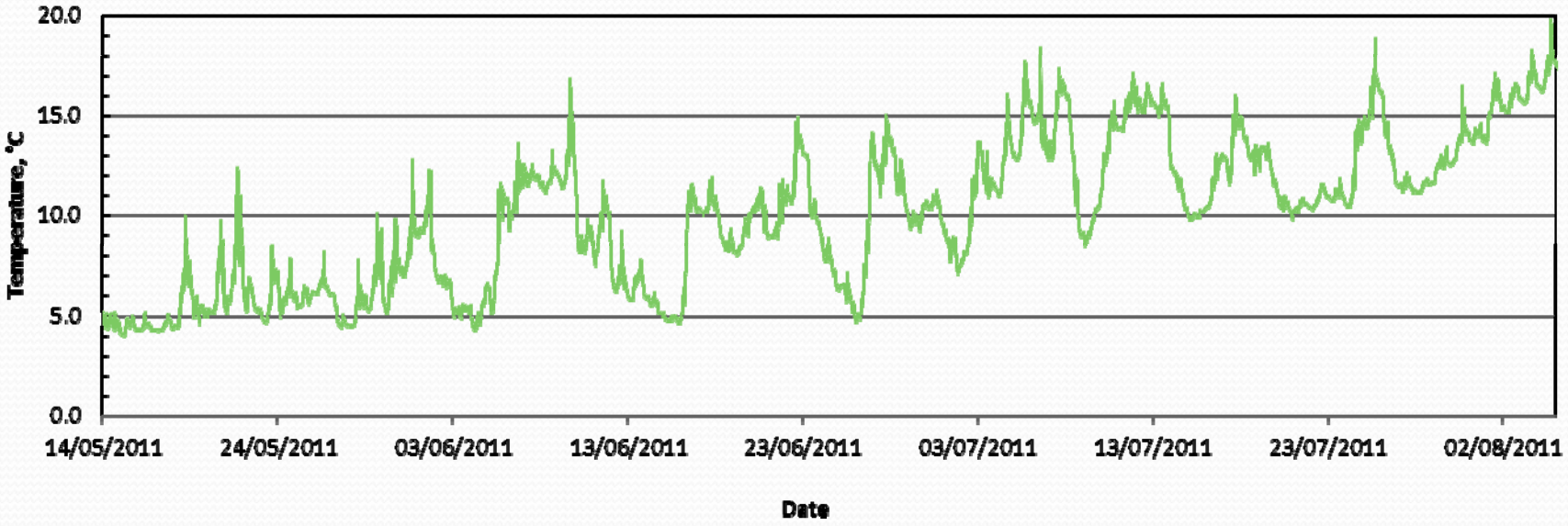
- Similar phenomena in July, August, September, October
  - Deeper, less substantial
  - More frequent: ~5 day period





Spectral Analysis

- Determines dominant frequency of a time series
- Seasonal changes
  - Divided time series into 30 day periods (overlapping)



Low Frequency Oscillations

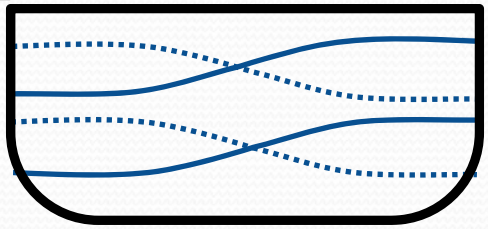
- Most dominant internal seiche periods

Period	11.3 Days	5.6 Days
May	-	-
June	0 – 27 m	0 – 27 m
July	-	28 – 64 m
August	-	28 – 64 m
September	-	28 – 64 m
October	-	54 – 64 m

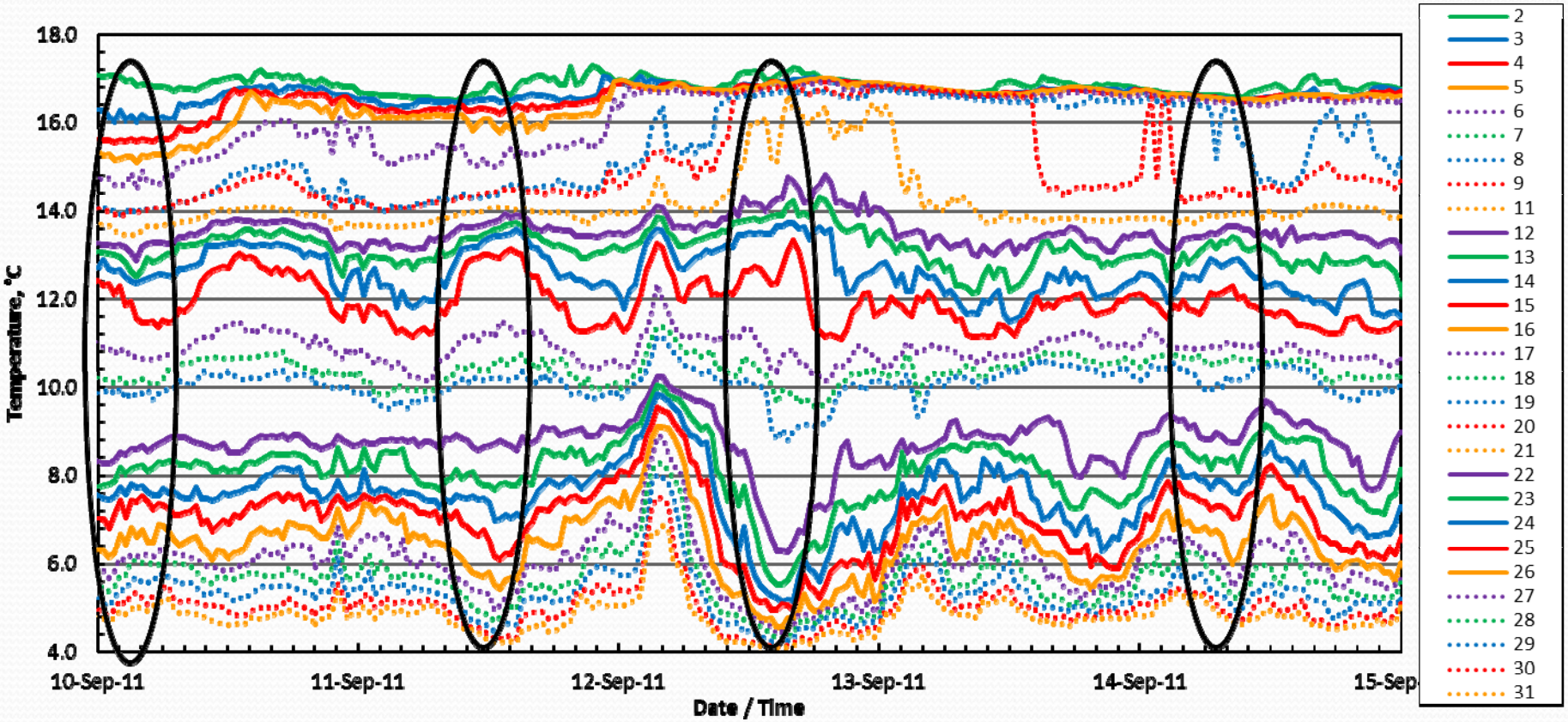
High Frequency Oscillations

- Three general internal seiche periods
  - 18 – 22 hours
  - 12 hours
  - 6 – 10 hour
- Top and bottom layers most dominant
- Middle layer less dominant

Multiple Vertical Modes



- Continuous stratification profile leads to excitation of multiple vertical modes (Vidal et al., 2005)



Theoretical Calculations

- Wave like solutions from 2D motion equations
  - Exponential density distribution
  - Rectangular basin
  - Constant buoyance frequency
  - Small wave amplitudes

$$\omega_{jl} = N\left(\left(\frac{j^2}{j + \mu^{-2}i^2 + \frac{N^4L^2}{4\pi^2 g^2}}\right)^{1/2}\right)$$

i,j = # vertical nodes, # horizontal nodes

N = buoyancy frequency, $\sqrt{-\frac{g}{\rho}\frac{d\rho}{dz}}$

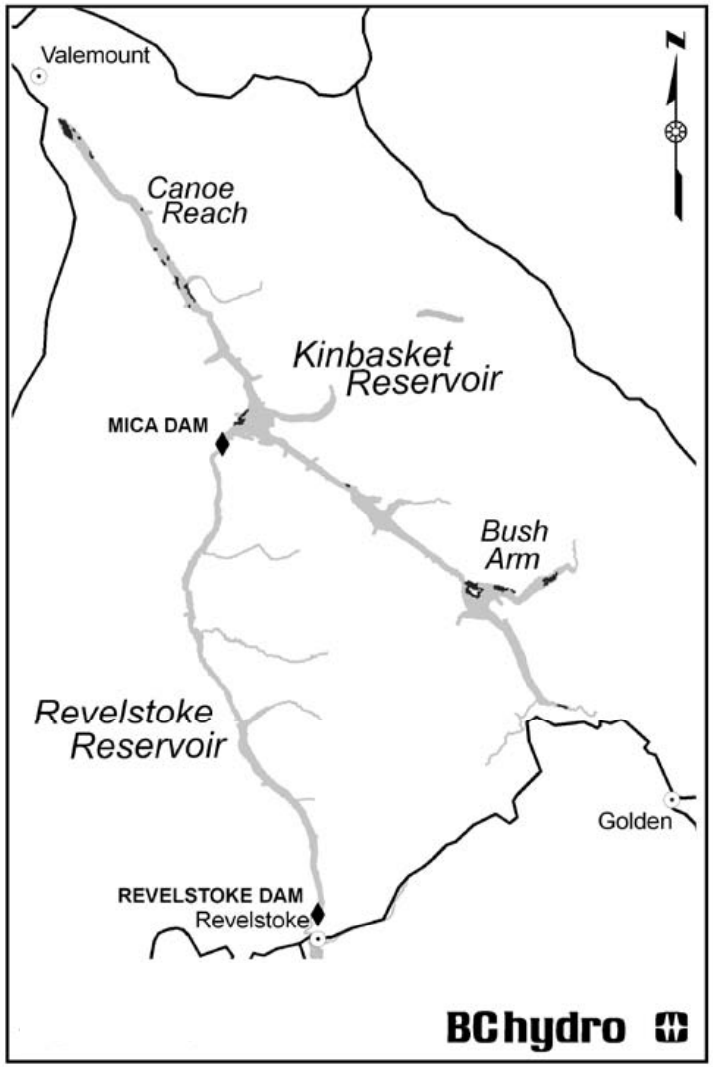
L = reservoir length, and

μ = H/L, where H = reservoir depth.

Theoretical Calculations

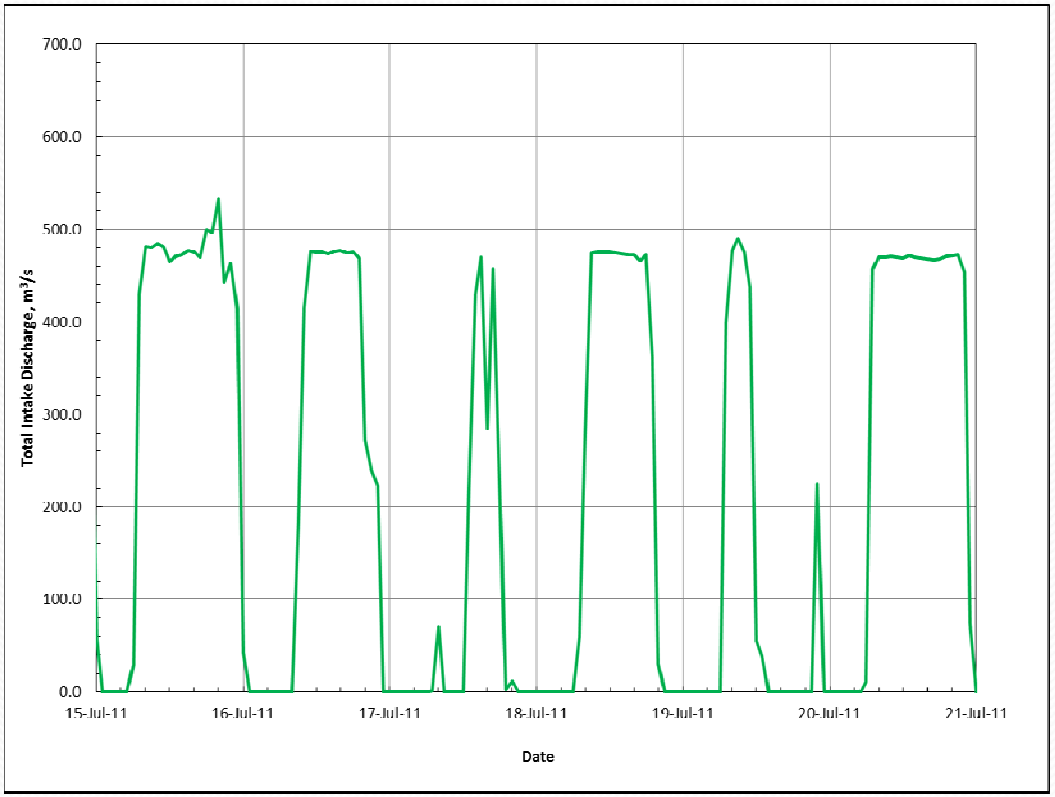
- Two reservoir lengths
  - Main reach – L1: 190 km
  - Local reach – L2: 15 km

Horizontal Nodes	j	1	1	1	1	1
Vertical Nodes	i	1	2	3	4	5
Length	**Timeframe**	**Period, T (days)**				
L1	Jun 1 - Jun 30	**4.5**	**9.0**	13.5	18.0	22.5
	Jun 16 - Jul 15	3.7	7.4	**11.1**	14.8	18.5
	Jul 1 - Jul 31	3.4	6.8	**10.2**	13.6	17.0
	Jul 16 - Aug 15	2.7	**5.4**	8.2	**10.9**	13.6
	Aug 1 - Aug 31	2.4	**4.7**	7.1	**9.5**	11.8
	Aug 16 - Sep 15	2.5	**4.9**	7.4	**9.9**	12.3
	Sep 1 - Sep 30	2.7	**5.4**	8.1	**10.7**	13.4
	Sep 16 - Oct 15	3.2	6.4	**9.5**	12.7	15.9
	Oct 1 - Oct 31	3.7	7.4	**11.0**	14.7	18.4
Length	**Timeframe**	**Period, T (hrs)**				
L2	Jun 1 - Jun 30	8.3	16.6	24.9	33.2	41.6
	Jun 16 - Jul 15	6.9	13.8	20.7	27.6	34.5
	Jul 1 - Jul 31	6.6	13.2	19.8	26.4	32.9
	Jul 16 - Aug 15	5.3	10.6	15.9	21.2	26.6
	Aug 1 - Aug 31	4.7	9.3	14.0	18.6	23.3
	Aug 16 - Sep 15	4.8	9.7	14.5	19.4	24.2
	Sep 1 - Sep 30	5.9	11.8	17.6	23.5	29.4
	Sep 16 - Oct 15	6.3	12.7	19.0	25.4	31.7
	Oct 1 - Oct 31	7.3	14.7	22.0	29.3	36.7



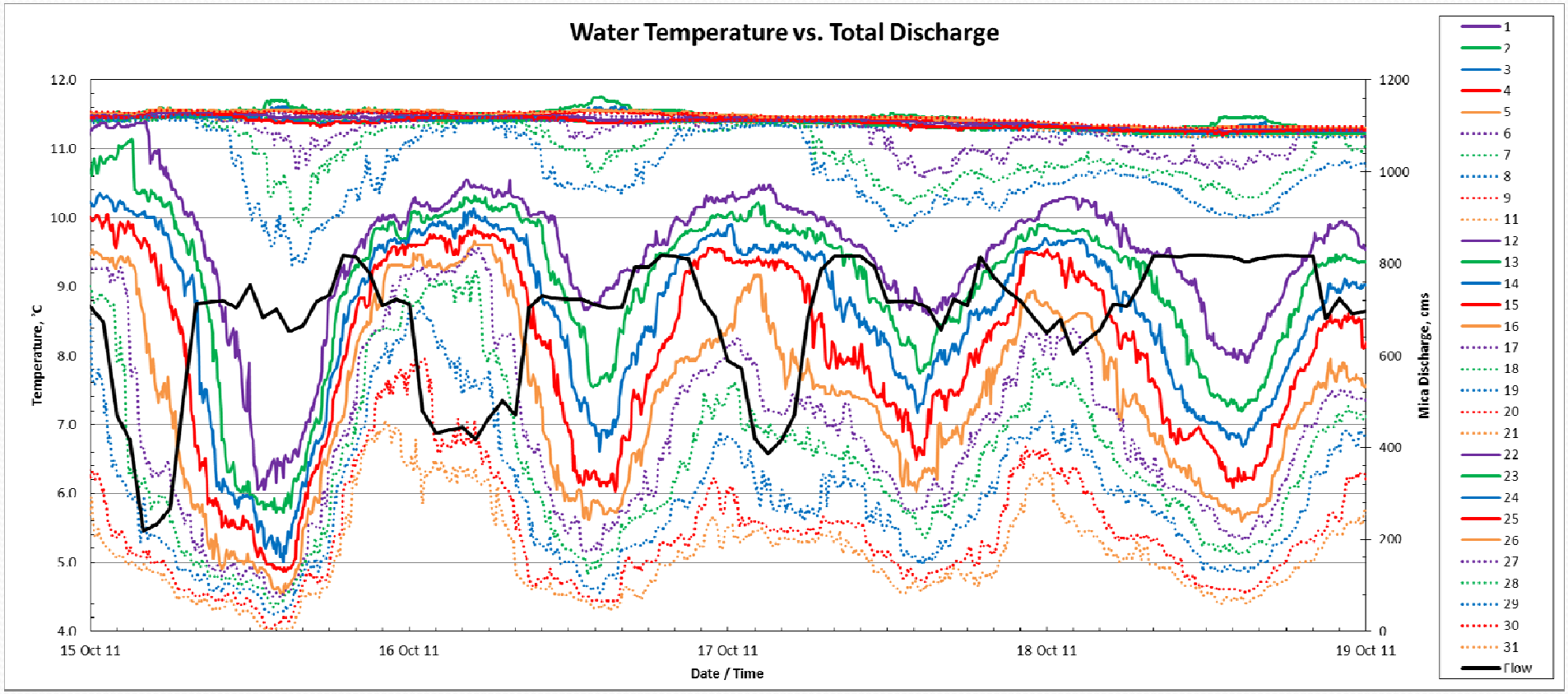
Dam Operations

- Diurnal fluctuations
  - Intakes turned up in morning, turned down in evening



Dam Operations and Oscillations

- Observed negative correlation in October

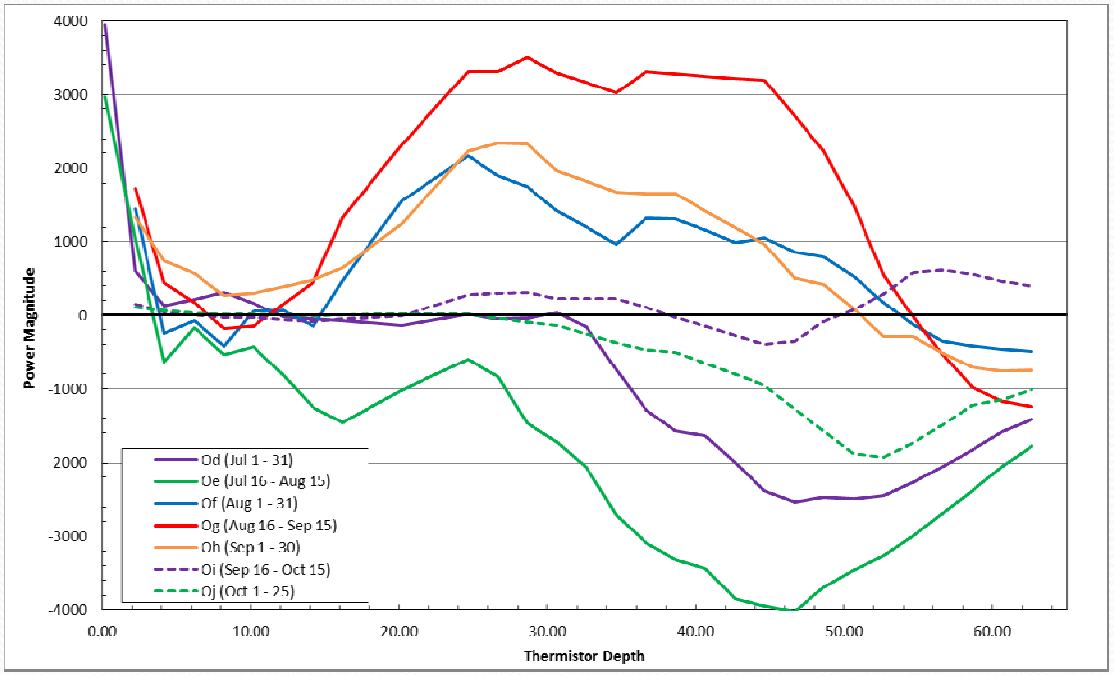


Covariance

- Measures the degree of correlation between time series
- Use cross spectral density function
- Dam operations vs. thermistor temperatures
- High correlations at 24 hrs period
  - Positive: temperature increase when discharge increased
  - Negative: temperature decrease when discharge increased

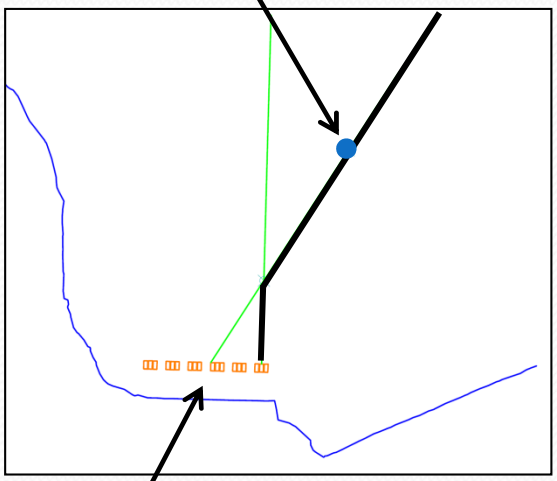
Covariance

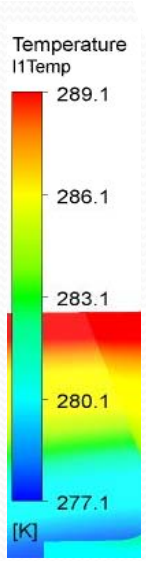
- Positive and negative correlations
  - Bottom thermistors almost all negatively correlated
  - Seasonal changes in reservoir level and discharge magnitude

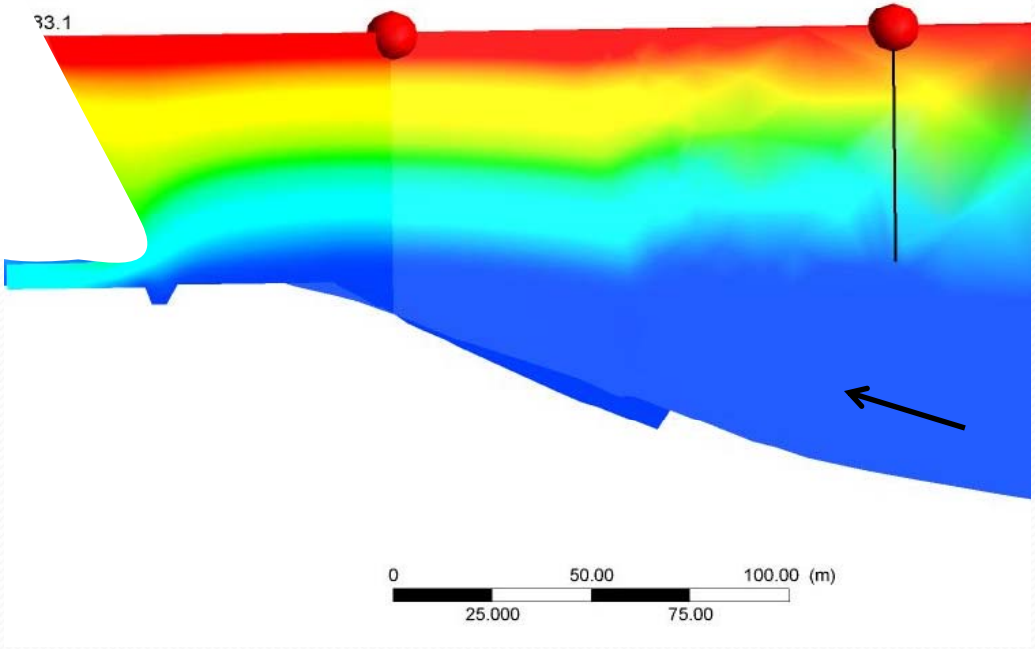


CFD Preliminary Results

- Cooler water pulled from deeper area at thermistor chain location







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Questions?