Temperature Modeling of the Pend Oreille River

Model Calibration

Boundary Hydroelectric Project FERC No. 2144

Seattle City Light

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January 8, 2007

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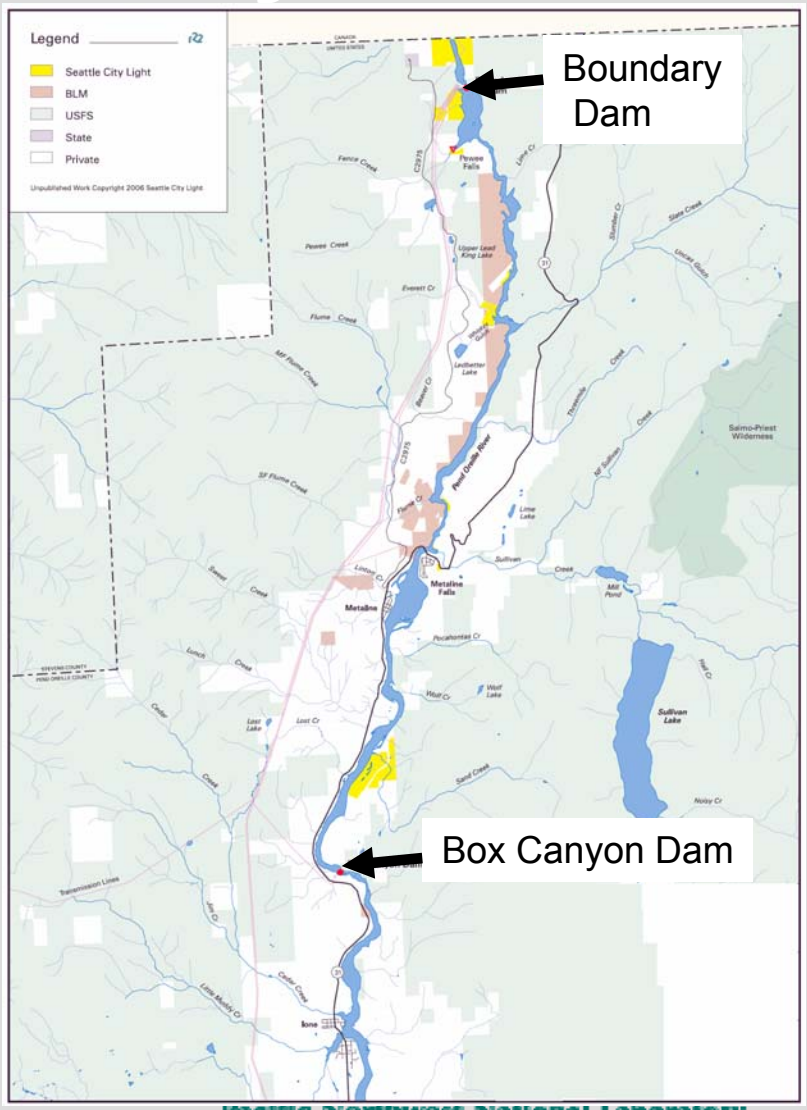
Introduction – Study Area

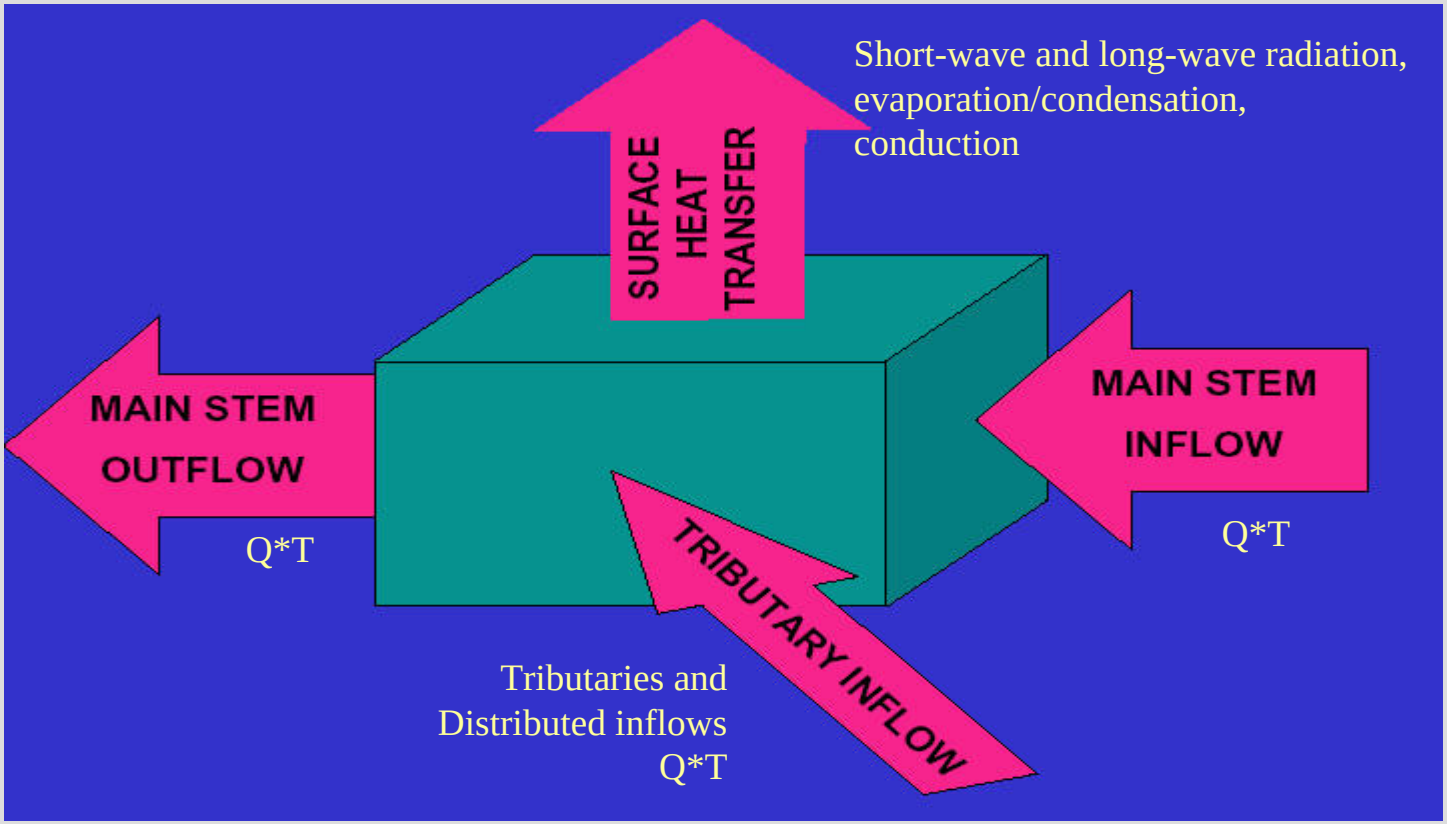
- Pend Oreille River
- Dams
  - Albeni Falls Dam– RM 90.1
  - Box Canyon Dam – RM 34.5
  - Boundary Dam – RM 17.0
  - Seven Mile Dam – RM 6.0
- International Boundary – RM 16.0



Study Objectives

- Develop a predictive model of temperature
  - Box Canyon Dam to International Boundary
- Modeling based evaluation
  - Existing Condition
    - Understanding of physical processes
    - Water and heat balance
  - Condition without project
  - Analysis of alternatives, as needed

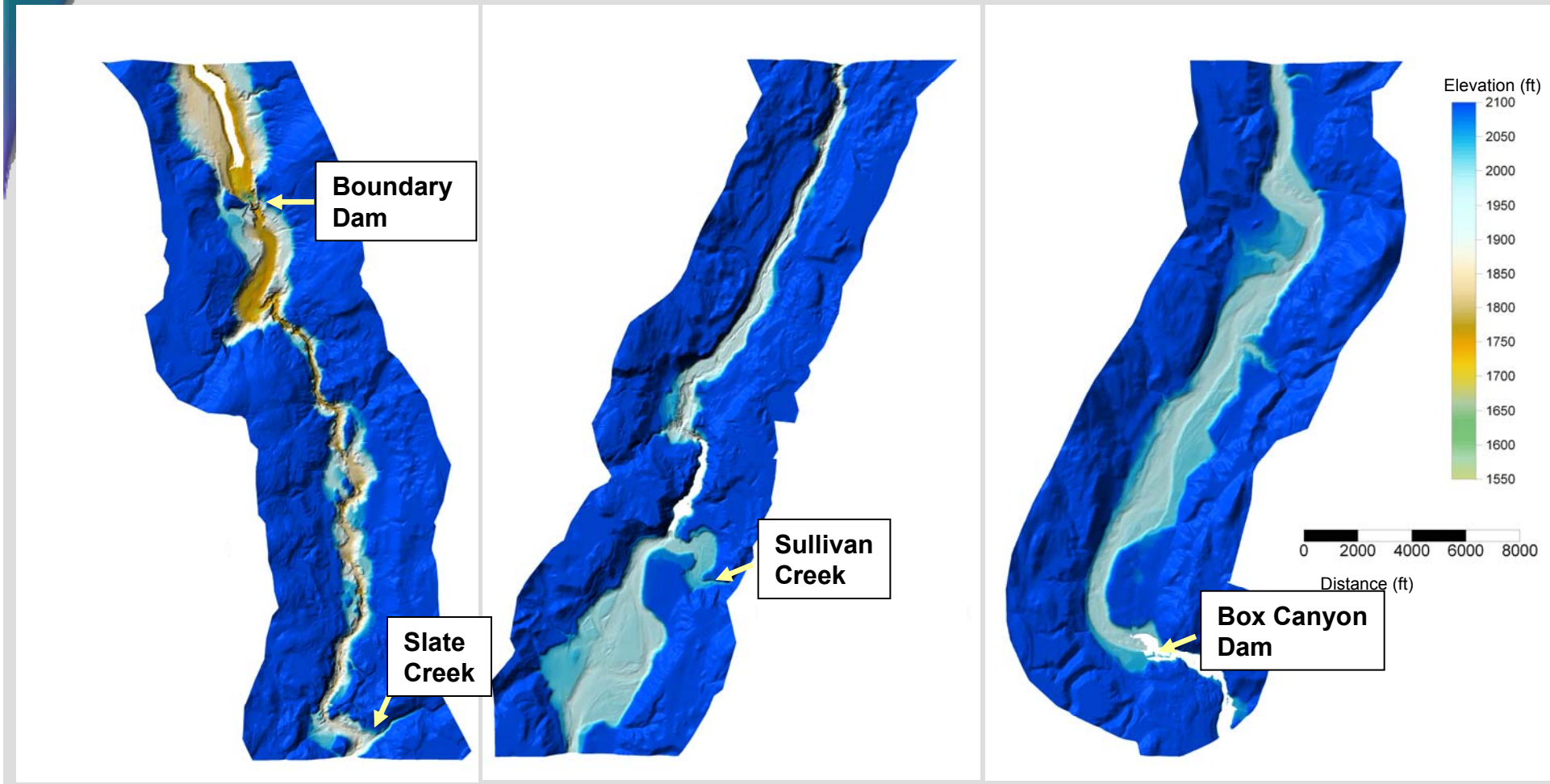
Thermal Energy Budget Model



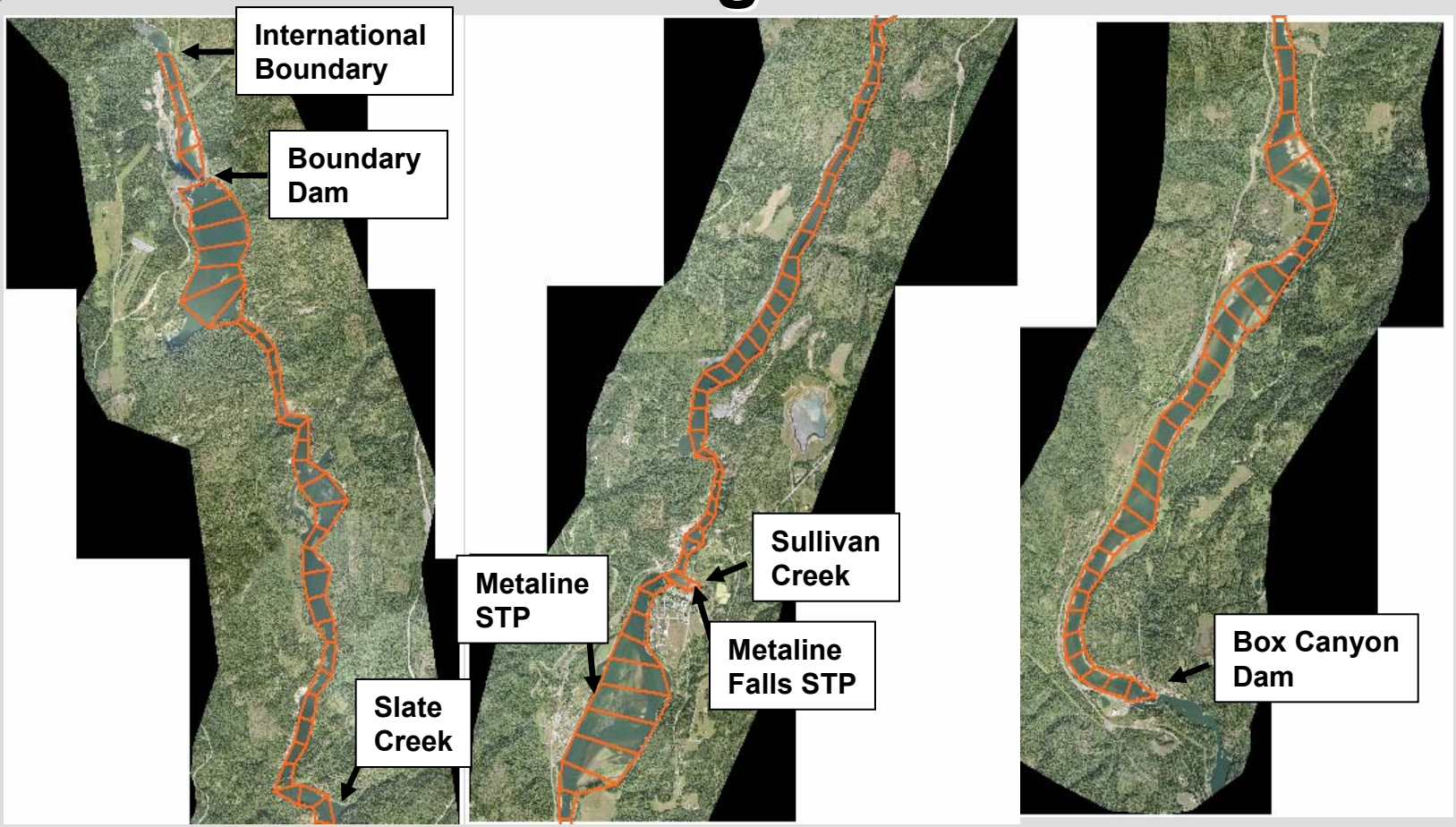
Boundary Reservoir Model Calibration

- Steps
  - Develop model grid
  - Prepare model inputs
    - Flows
    - Temperature and meteorological data preparation
  - Compute flow balance
  - Compute topographic shade
  - Calibration to measured temperatures
    - Time series
    - Profiles

Bathymetry
Battelle's Data Coverage



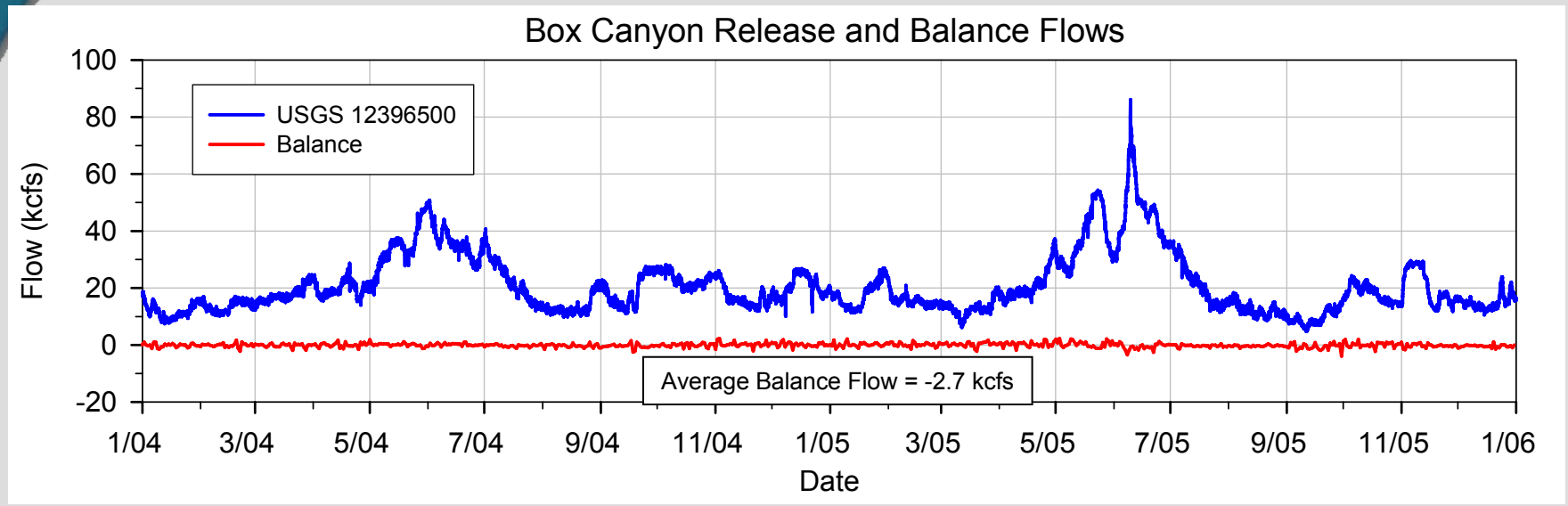
Model Segmentation

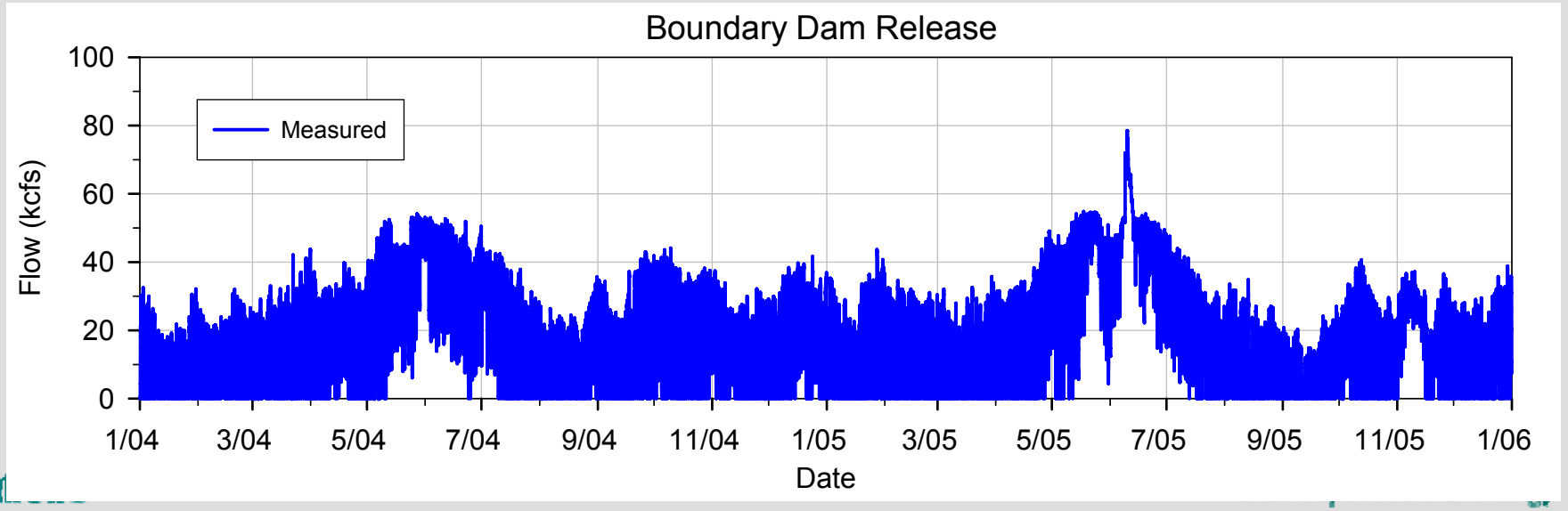


CE-QUAL-W2 Model Configuration

- Number of model segments: 117
  - 4 branches and waterbodies
- Segment
  - Length
    - Average: 870-ft (265 m)
    - Range: 590 to 1,220-ft (180 to 373-m)
  - Width
    - Average: 694-ft (212-m)
    - Range: 227 to 3,061-ft (69 to 933-m)
- Layers
  - Number: 50
  - Thickness: 6.56-ft (2-m)
- Tributaries
  - Sullivan Creek
  - Slate Creek
- Dischargers
  - Metaline STP
  - Metaline Falls STP (combined with Sullivan Creek)
- Boundary Dam release elevations
  - Powerhouse: 1903-ft (580-m)

Flows
Box Canyon and Boundary Reservoir

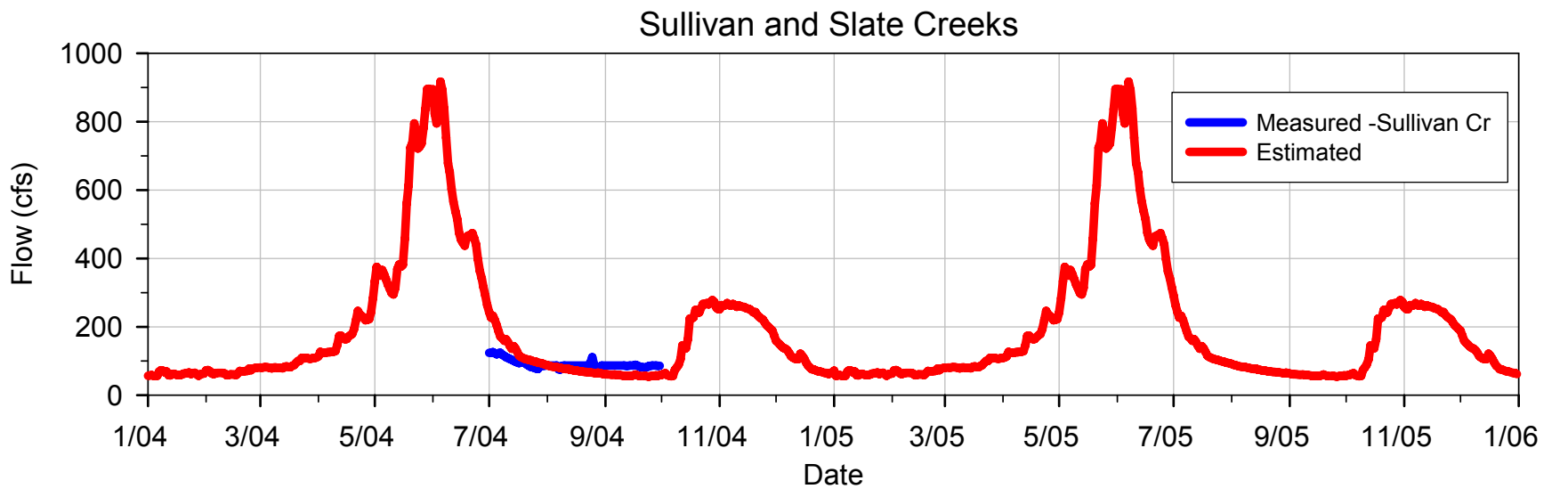




Flows

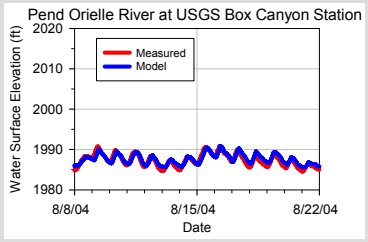
Tributaries

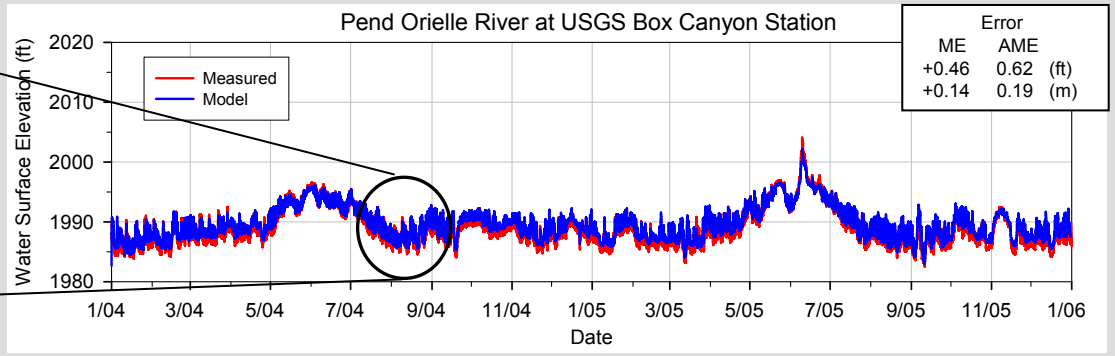
- Measured flow only for Sullivan Creek
  - 1995-2002 and summer 2004
- Estimated flow is 25th-percentile of 1995-2002 data
  - Based on comparison of average flow for July-September
- Assumed Slate Creek flow scaled from Sullivan Creek flow based on watershed areas

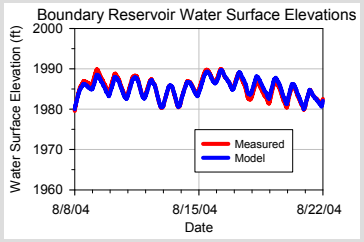


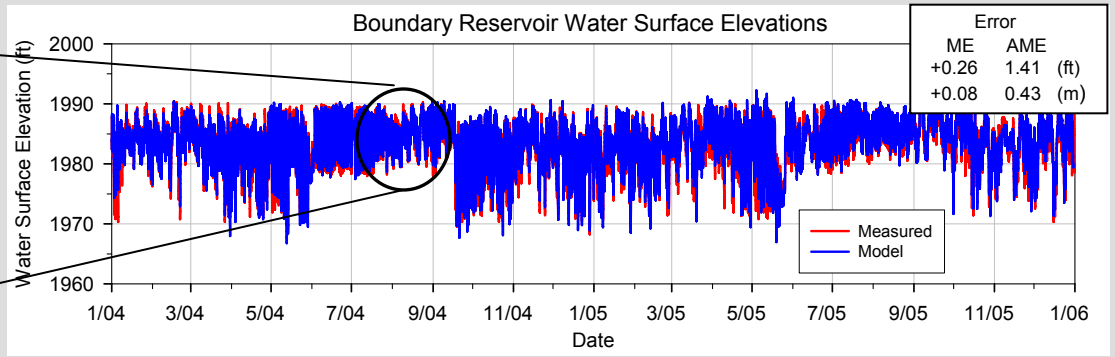
Pend Oreille River, Boundary Reservoir and Boundary Dam Tailwater

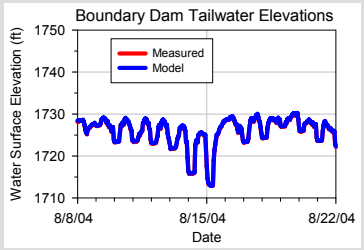
Water Surface Elevations

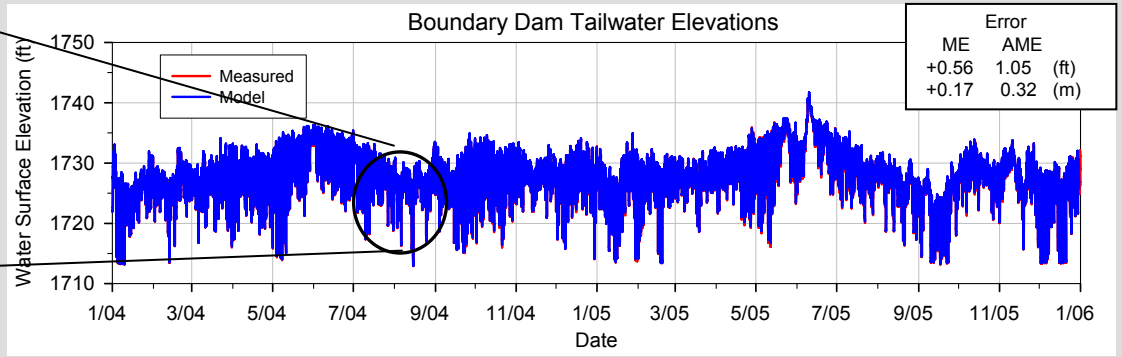












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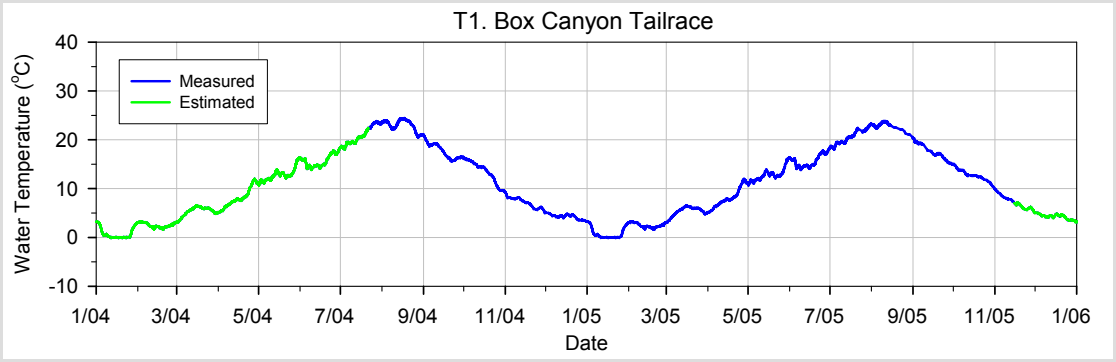
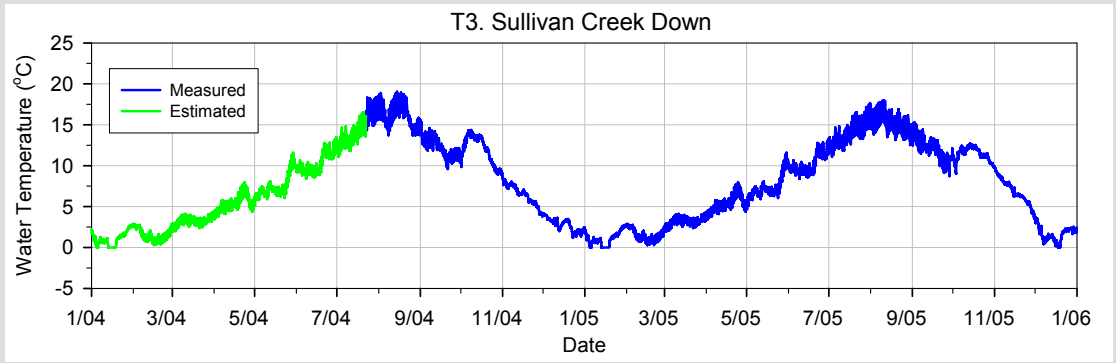
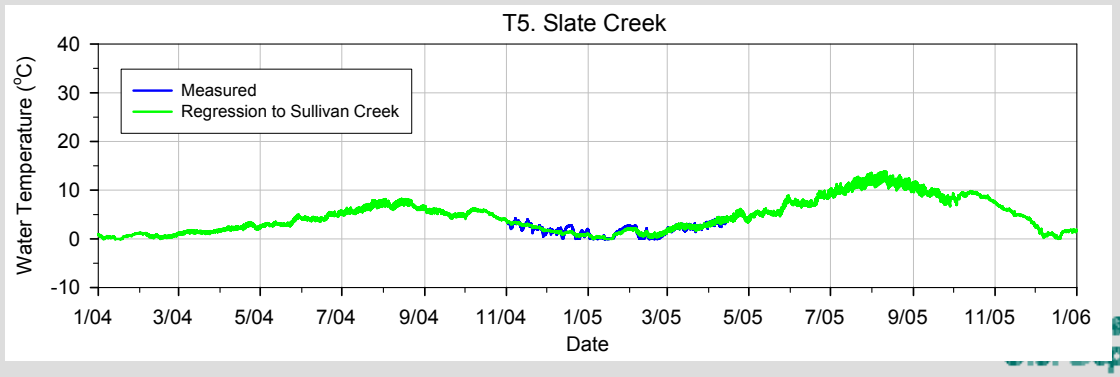
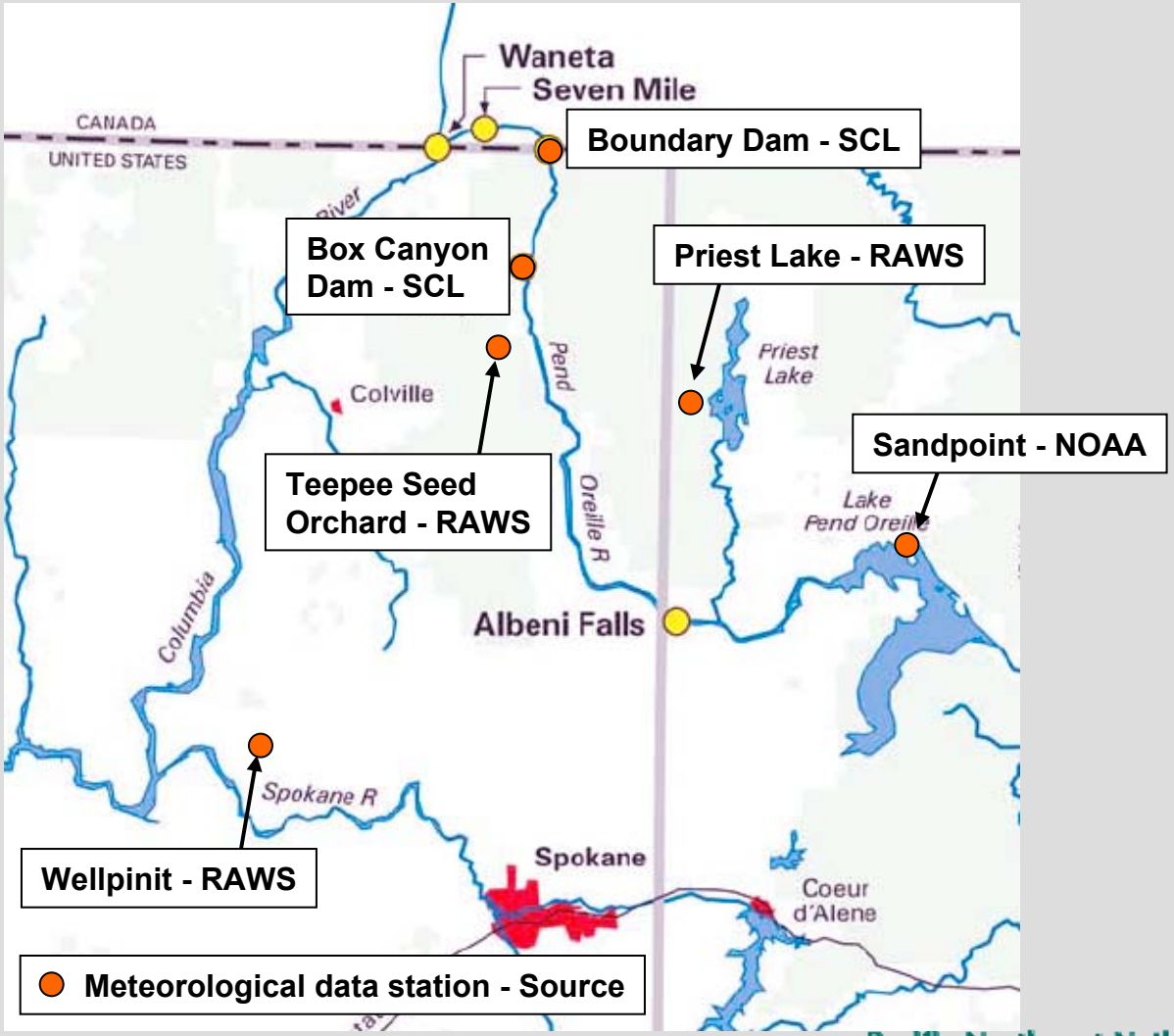
Inflow Temperatures
Box Canyon Dam Release and Tributaries



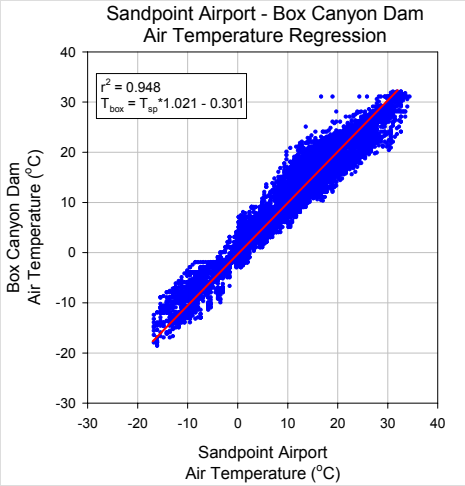
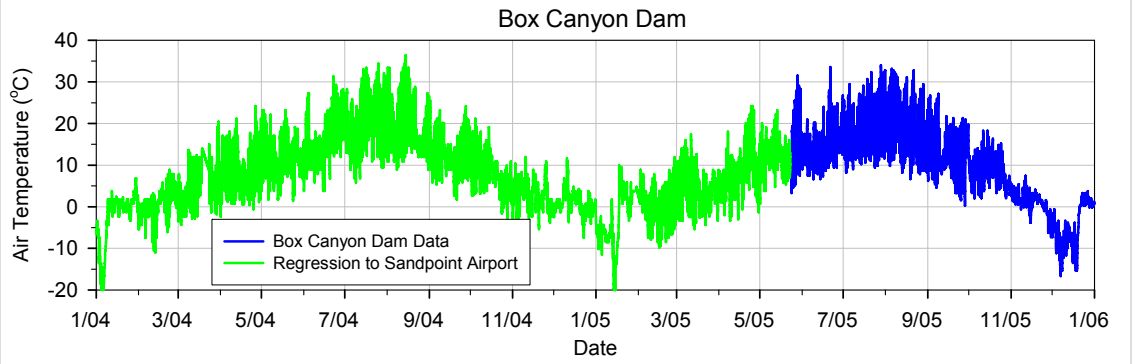
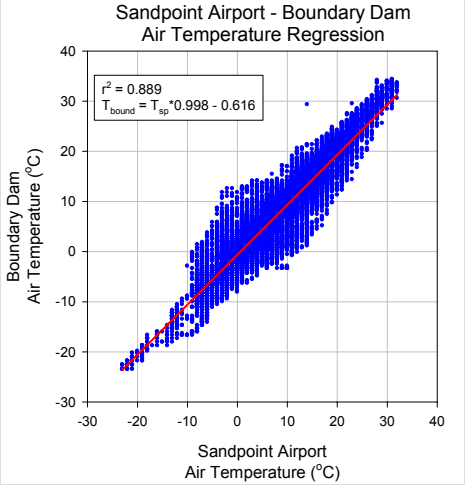
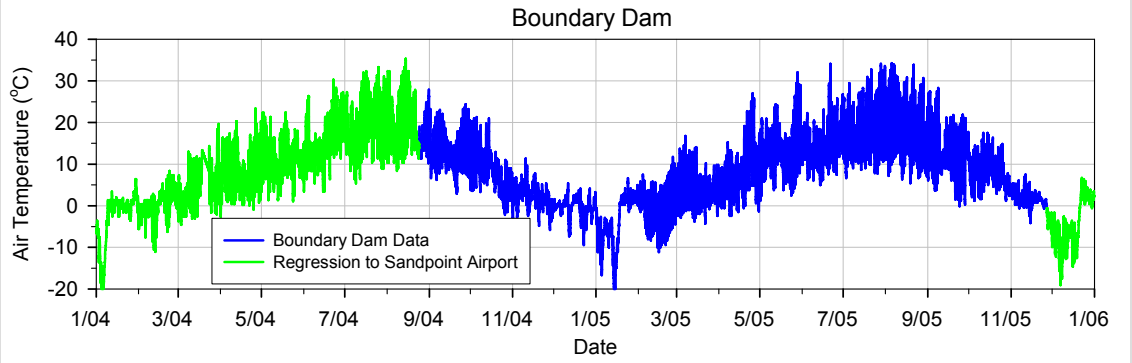




Meteorological Data
Station Locations



Meteorological Data
Air Temperature

	Regression	Input Data
Box Canyon Dam		
Boundary Dam		

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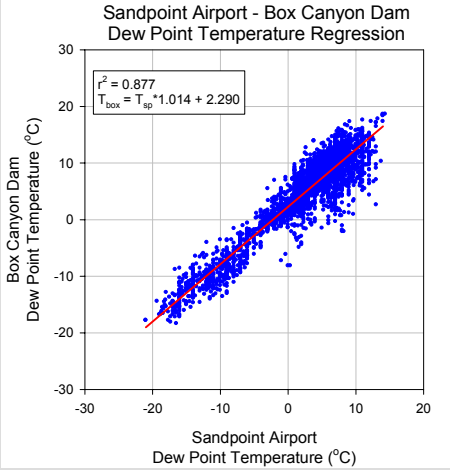
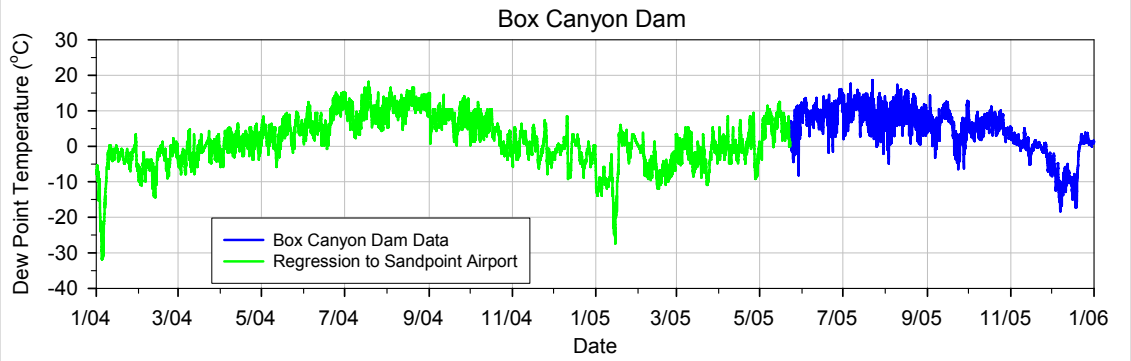
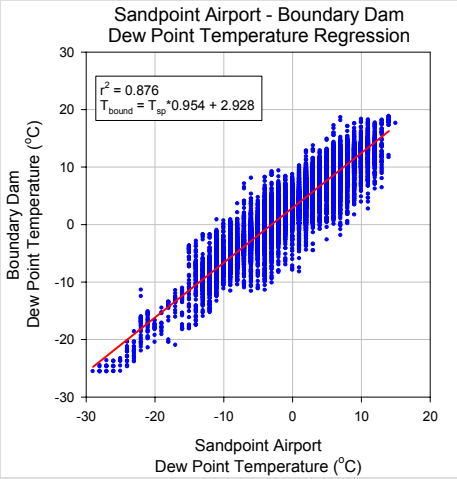
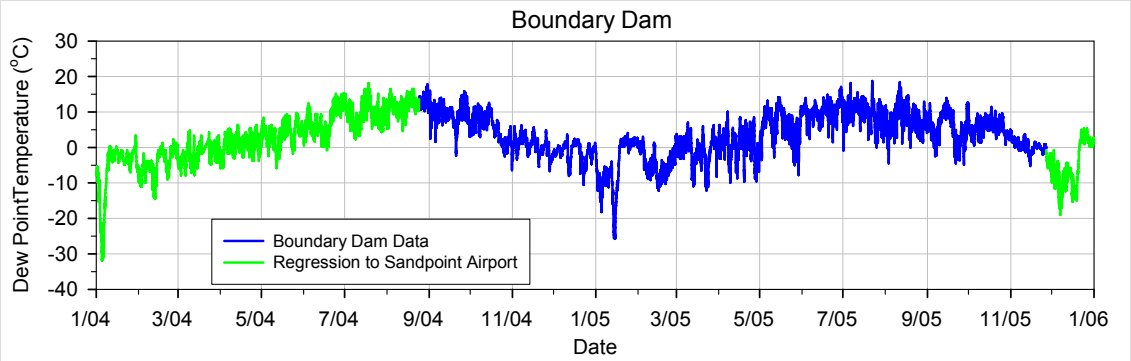
Meteorological Data
Dew Point Temperature

	Regression	Input Data
Box Canyon Dam		
Boundary Dam		

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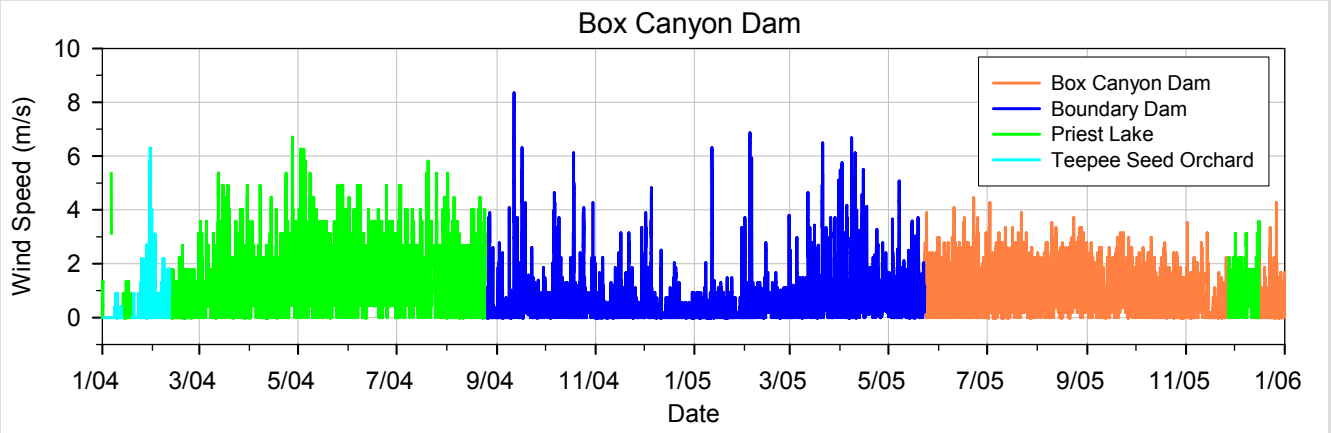
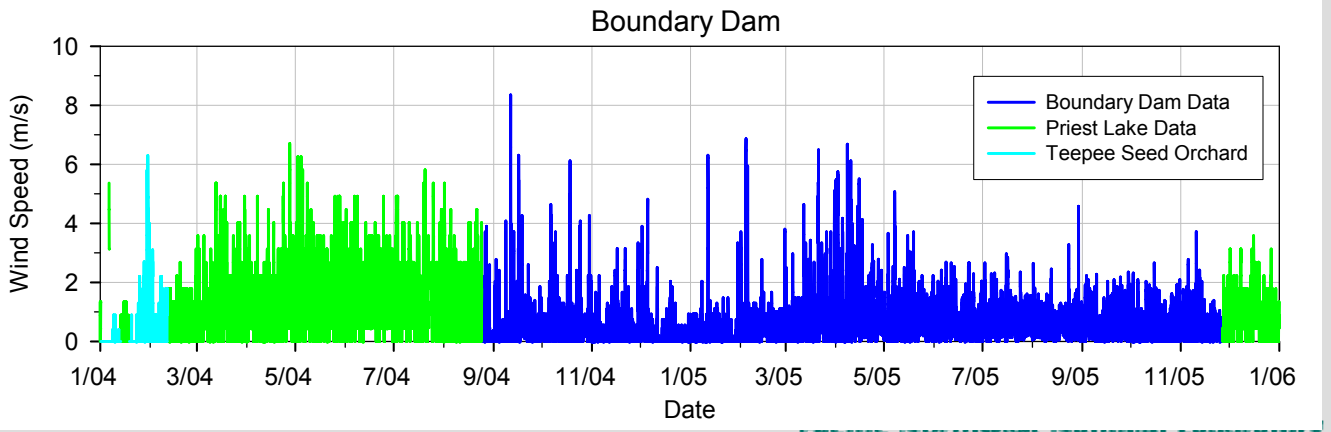
Meteorological Data
Wind Speed

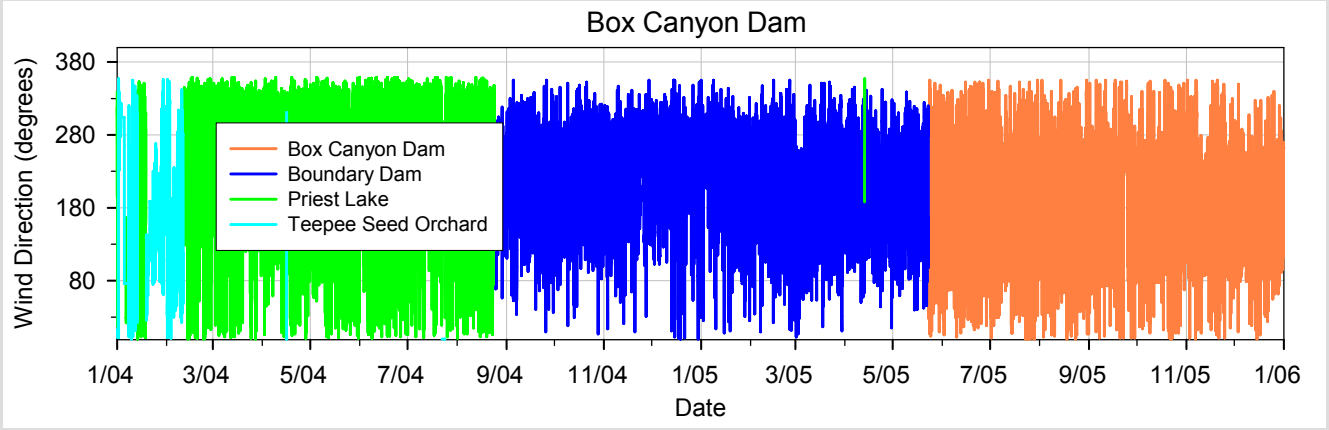
- Direct combination of data to fill data gaps

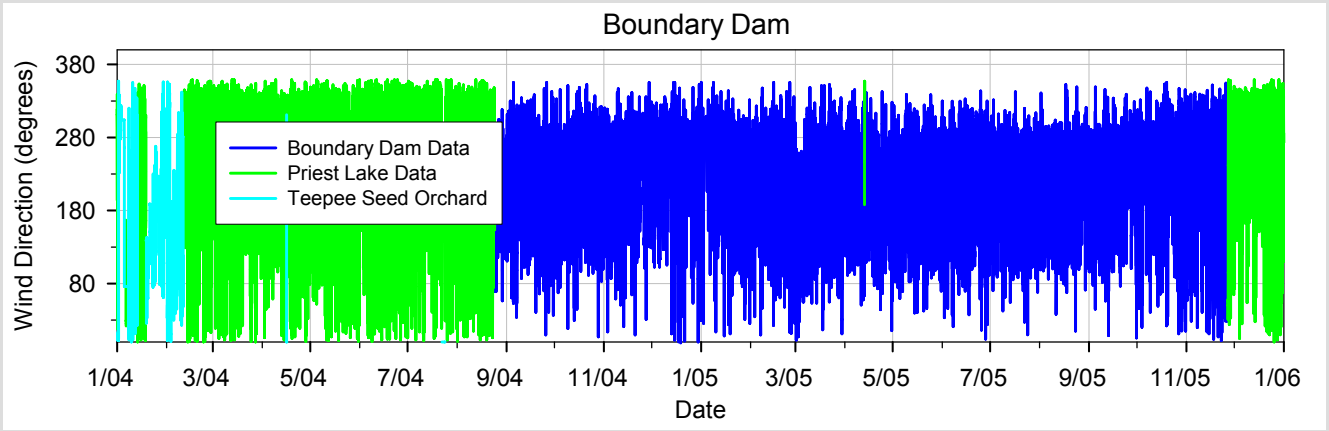




Meteorological Data
Wind Direction

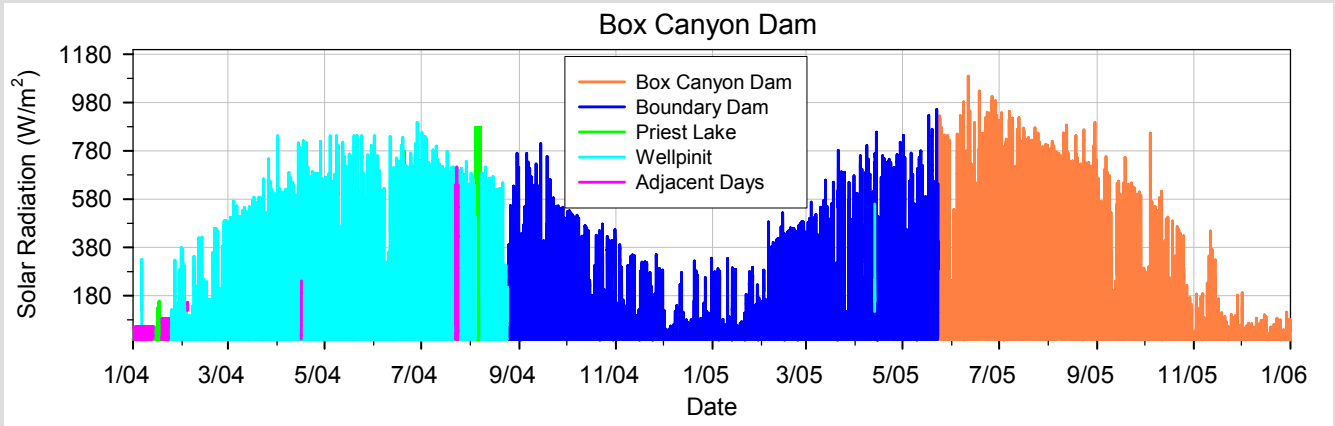
- Direct combination of data to fill data gaps

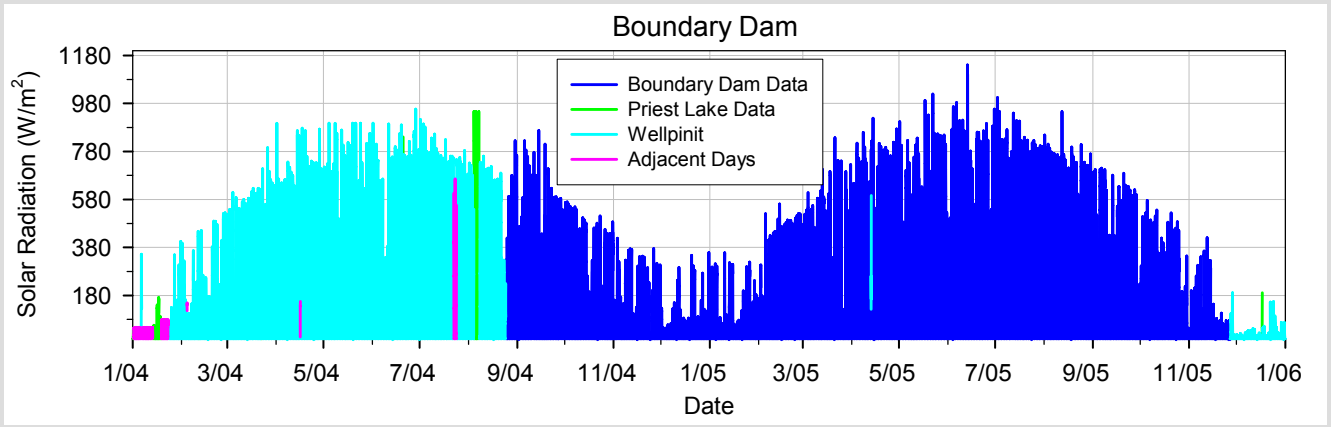




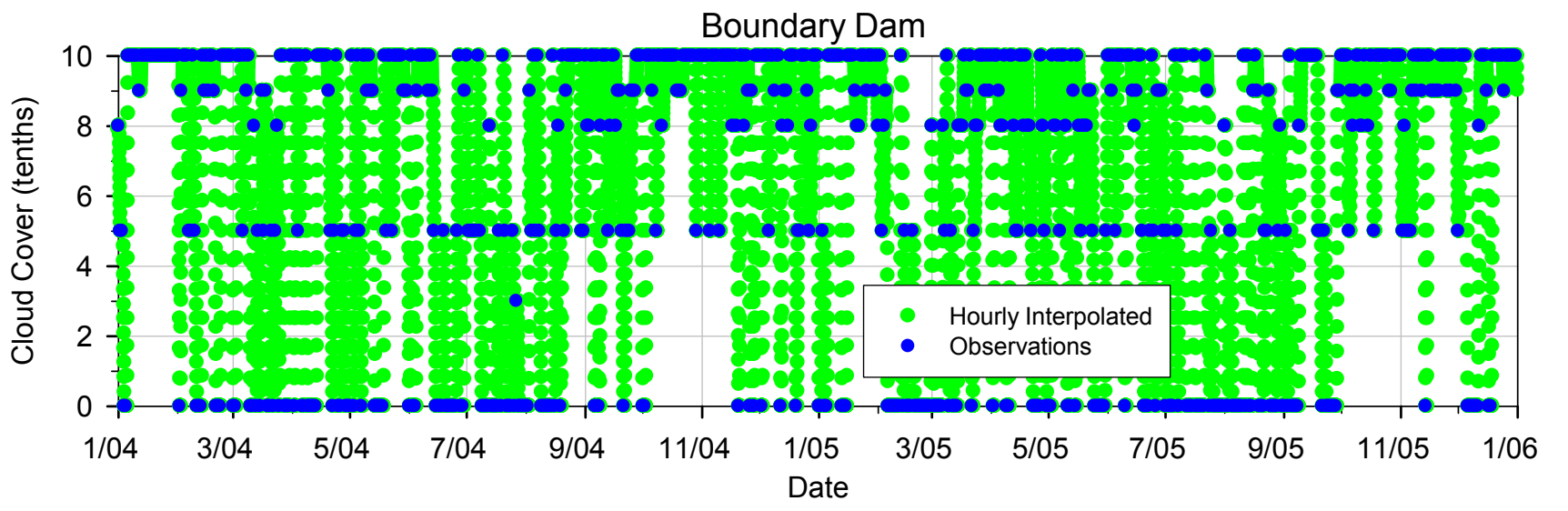
Meteorological Data
Solar Radiation

- Combination of scaled data to fill data gaps

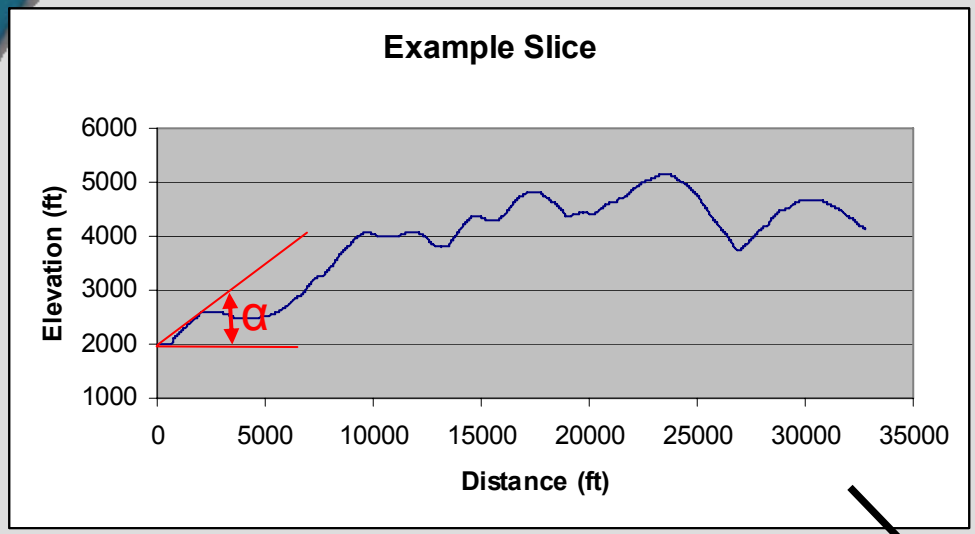


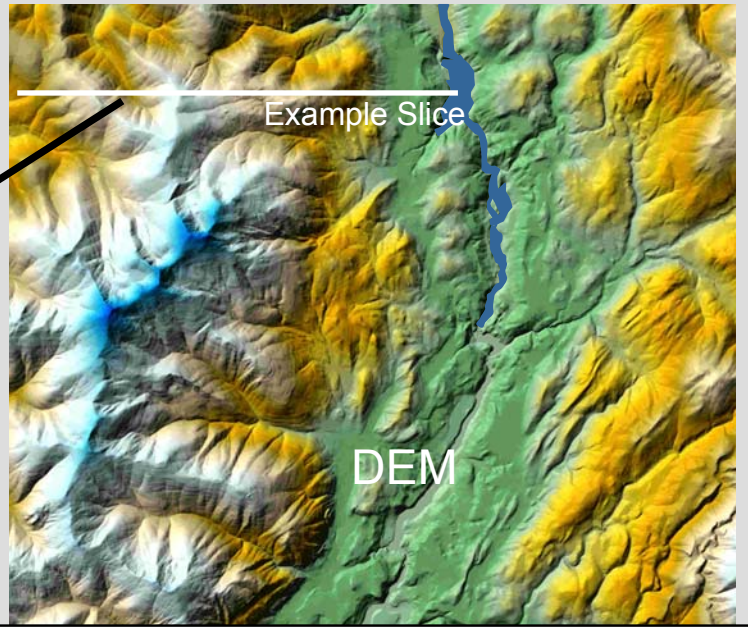


Meteorological Data
Cloud Cover



Shade Calculation

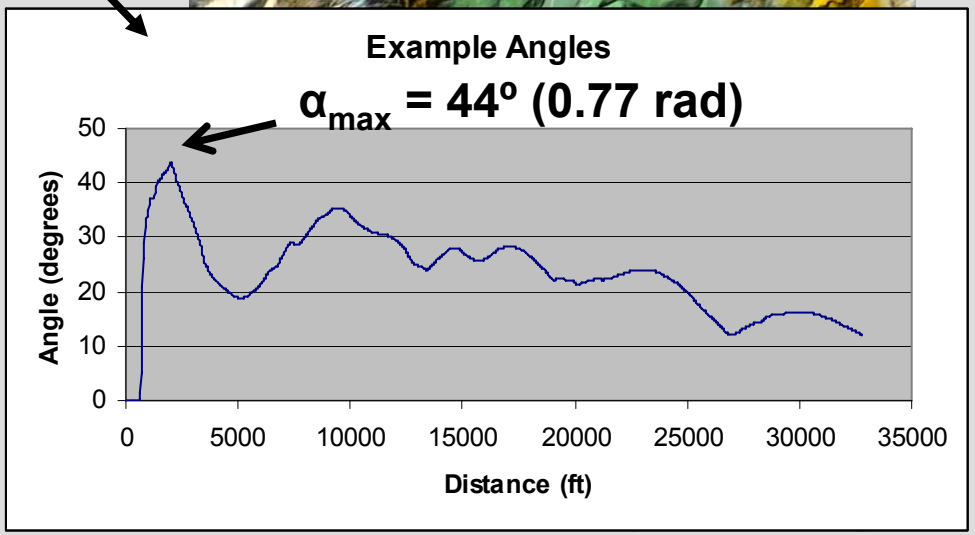




- Slices taken from center of grid segment at 20º angles
- Maximum angle used in shade simulations

$$S_f = f\left(\mathrm{A_o}, \mathrm{A_z}, \theta_s, \alpha_t, \alpha_v, d_{cl}, o_v\right)$$

- A_o and A_z are the solar altitude and azimuth,
- θ_s = segment orientation
- α_t = topographic angles,
- d_{cl} = distance of vegetation from the centerline
- o_v = opaqueness of the vegetation



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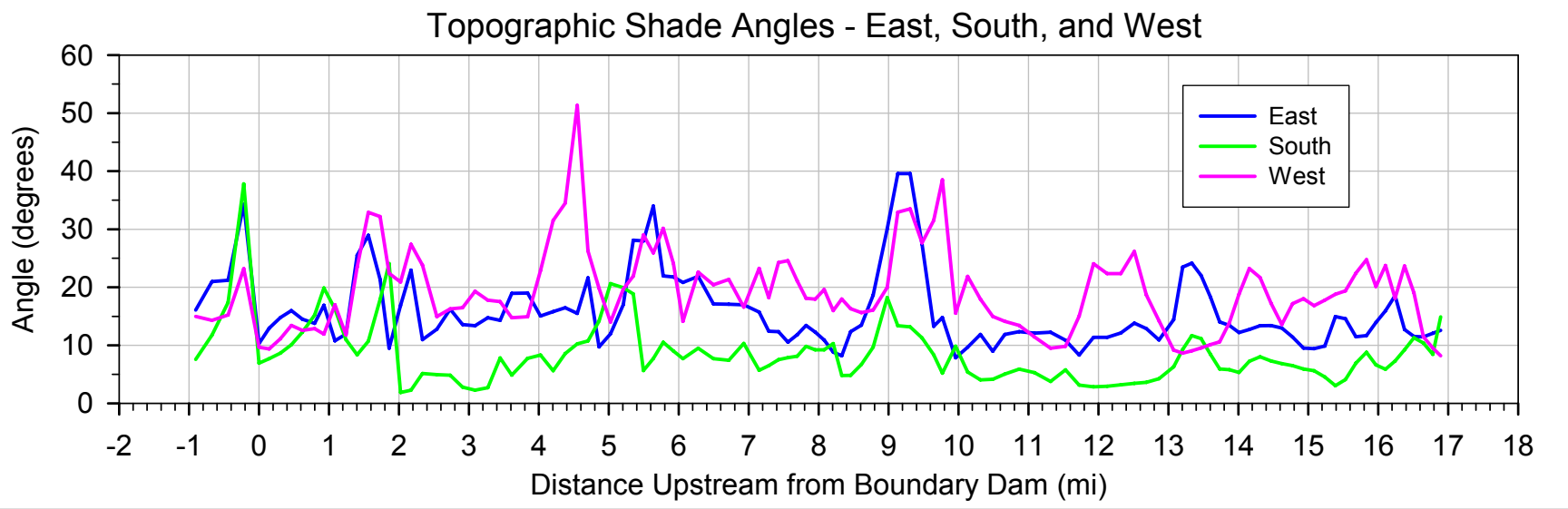
Topographic Shade

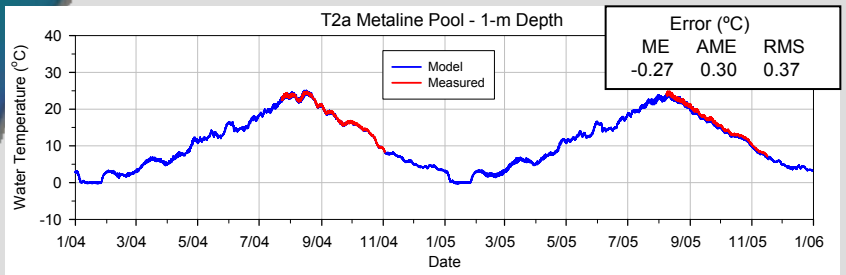


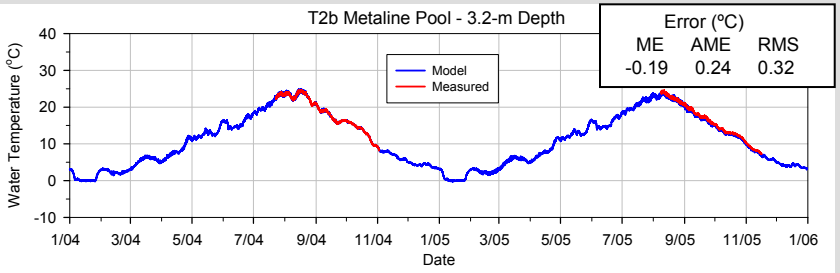
Temperature Calibration

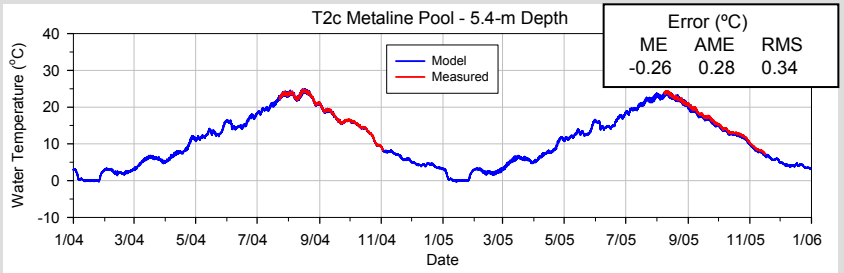
- Plots
  - Time series
    - T2. Metaline Pool
    - T6. Slate Pool
    - T7. Boundary Reservoir
    - T8. Boundary Tailrace
  - Profiles
    - V1. Wolf Creek
    - V2. Metaline Old
    - V3. Pend Oreille Mine
    - V4. Slate Creek
    - V5. Everett Creek
    - V6. Boundary Pool
- Error analysis

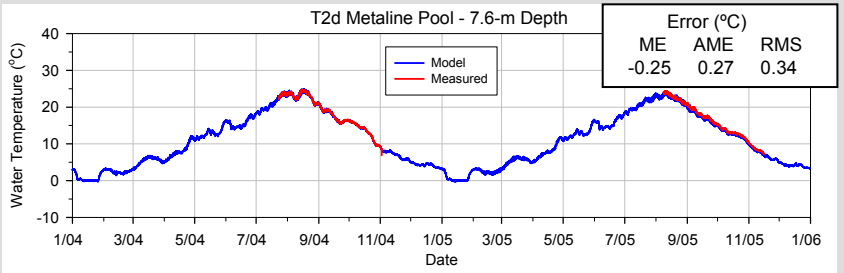
Water Temperature Measurement Locations

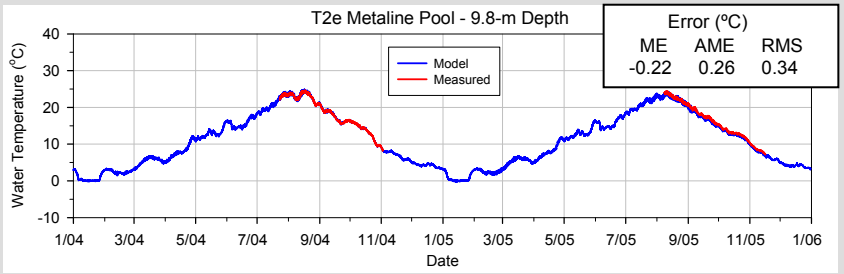
Temperature Calibration
T2. Metaline Pool Station











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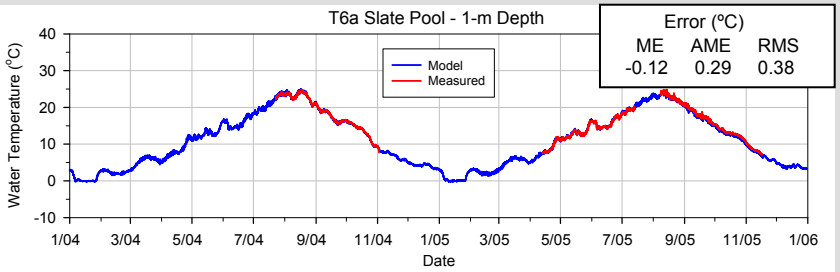
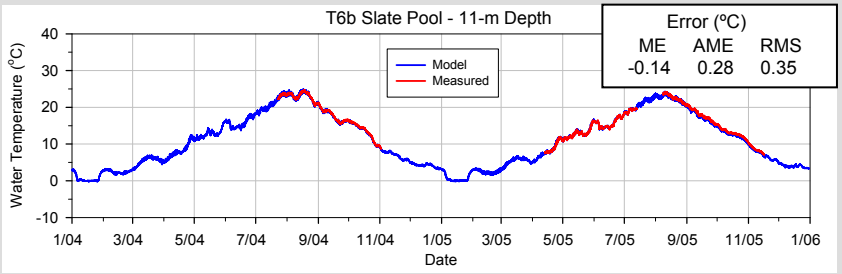
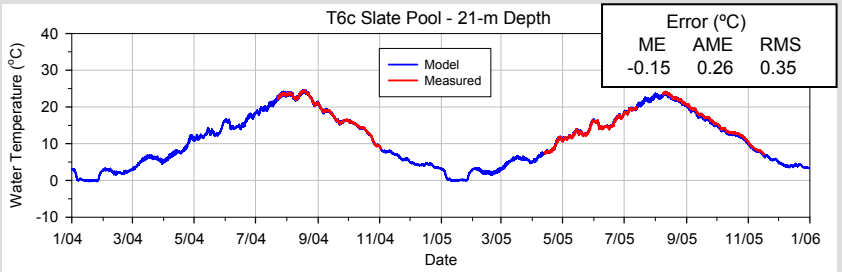
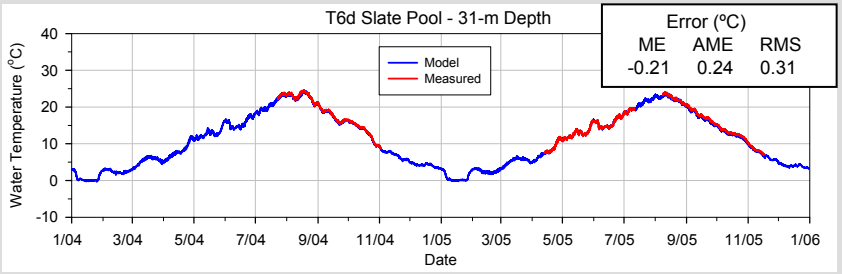
Temperature Calibration
T6. Slate Pool Station

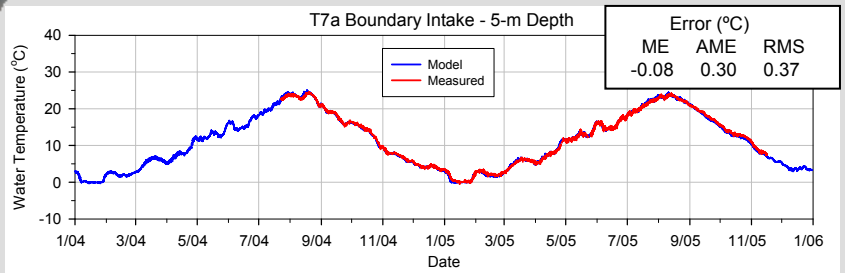


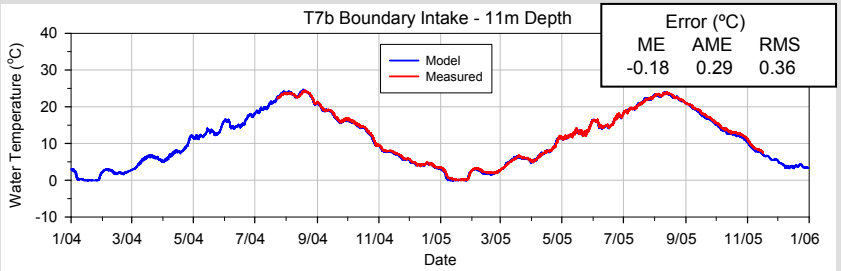


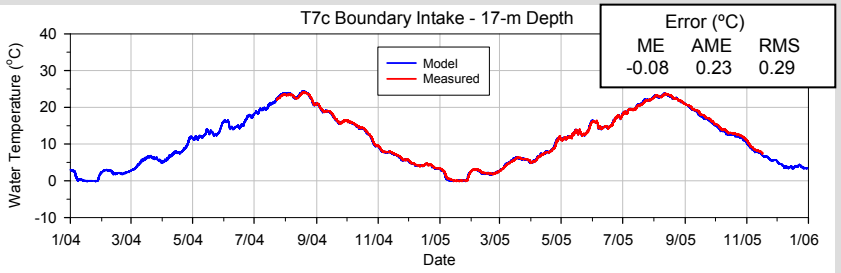


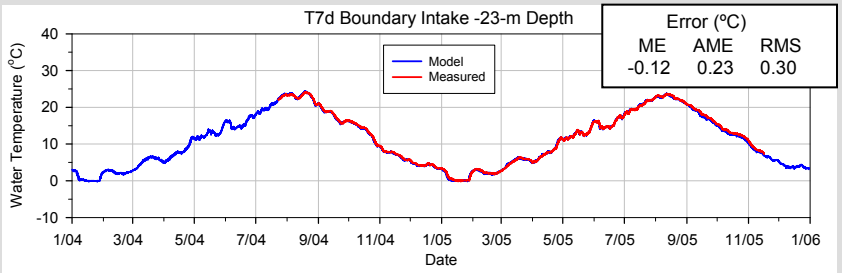


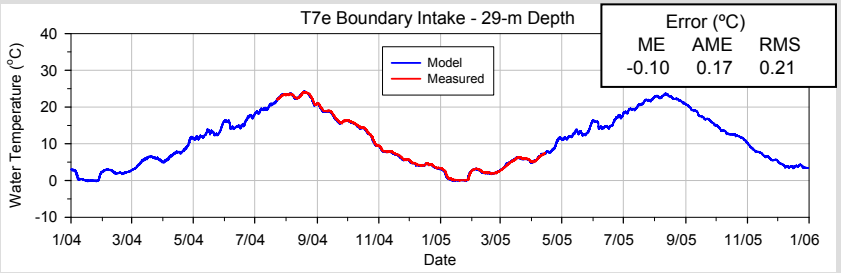
Temperature Calibration
T7. Boundary Intake Station











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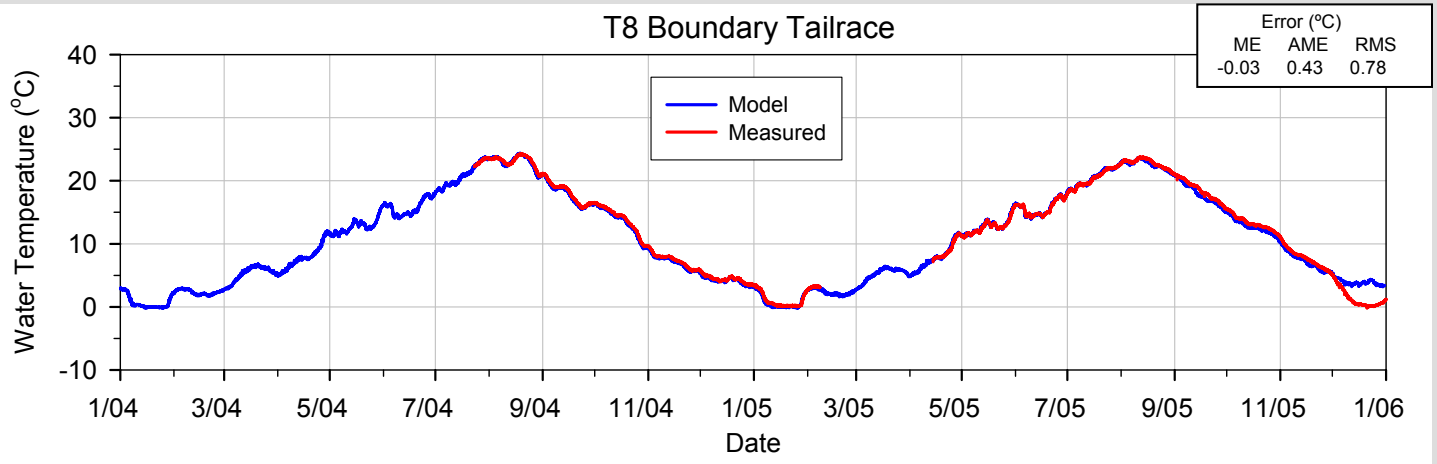
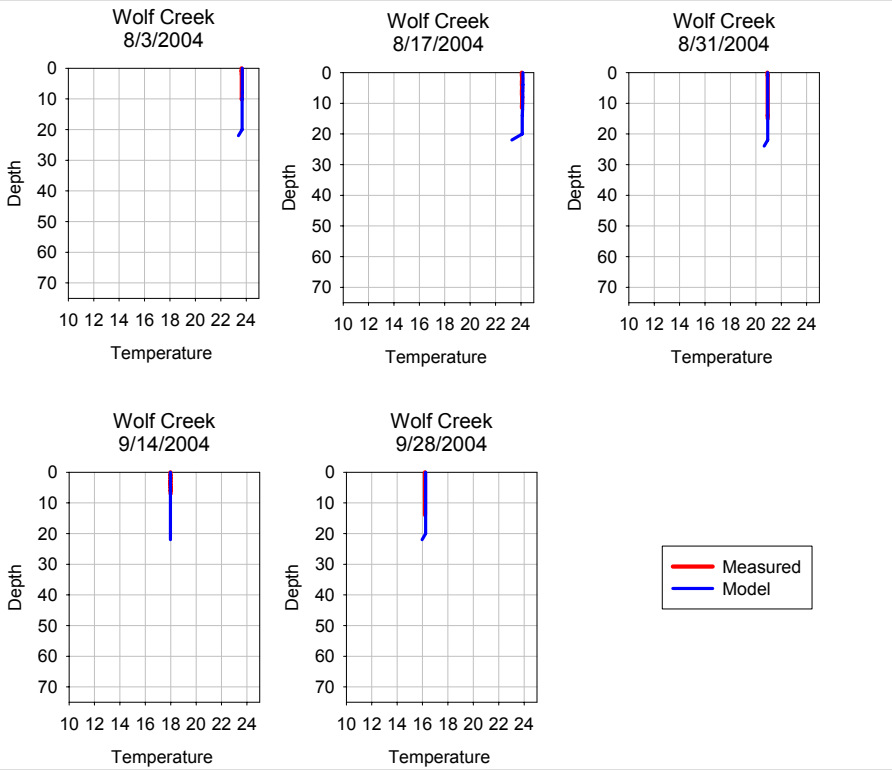
Temperature Calibration
T8. Boundary Dam Tailrace

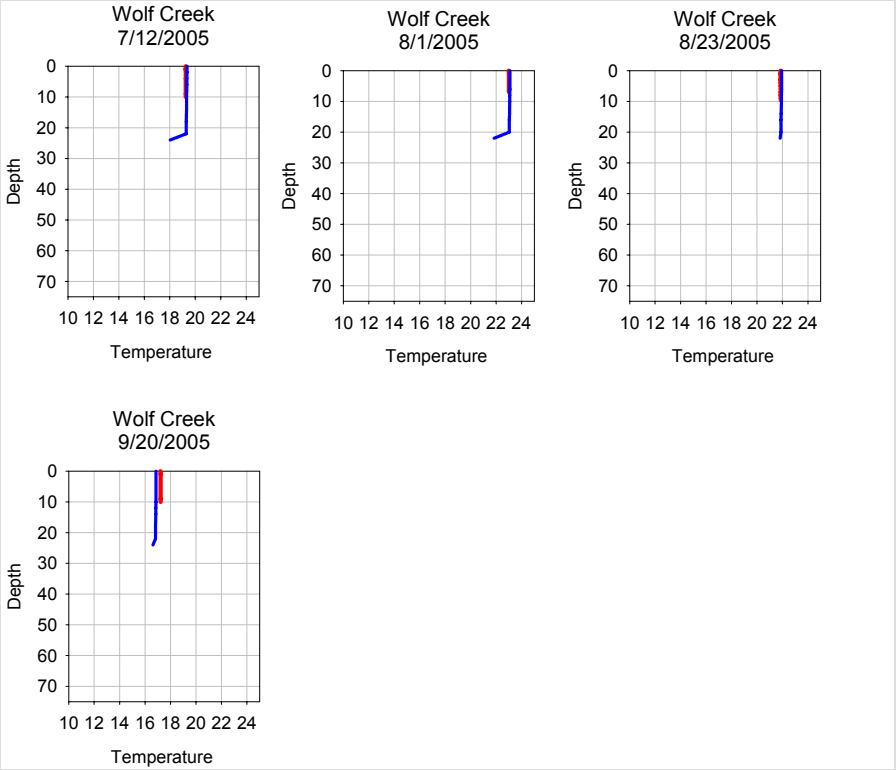


Temperature Calibration
Profiles – V1. Wolf Creek

2004



2005



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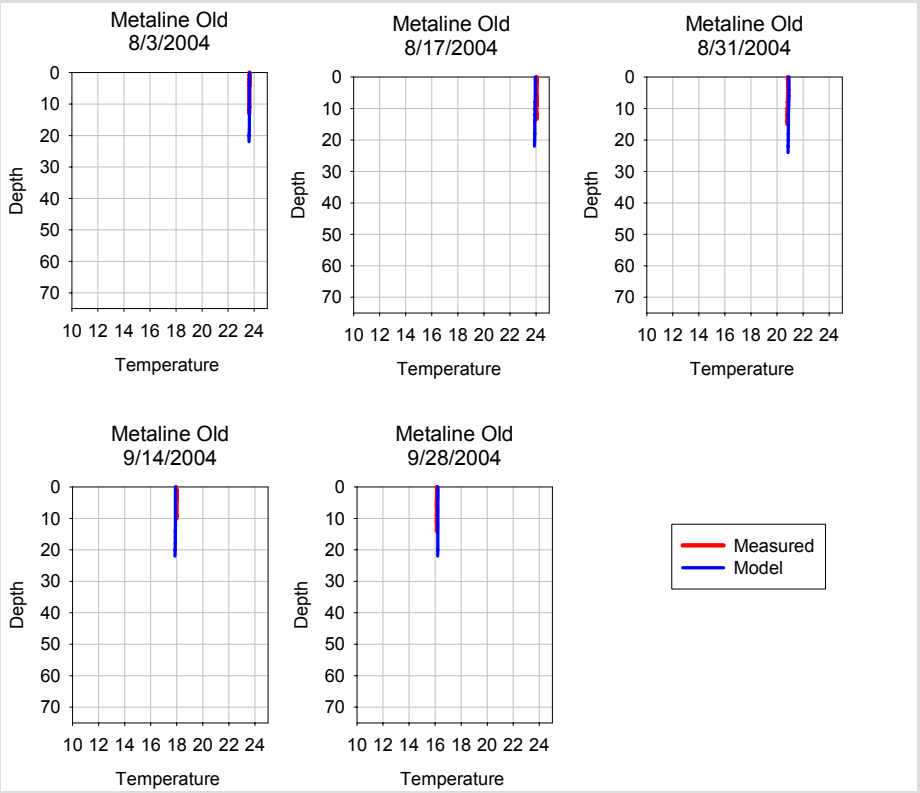
Temperature Calibration
Profiles – V2. Metaline Old

2004



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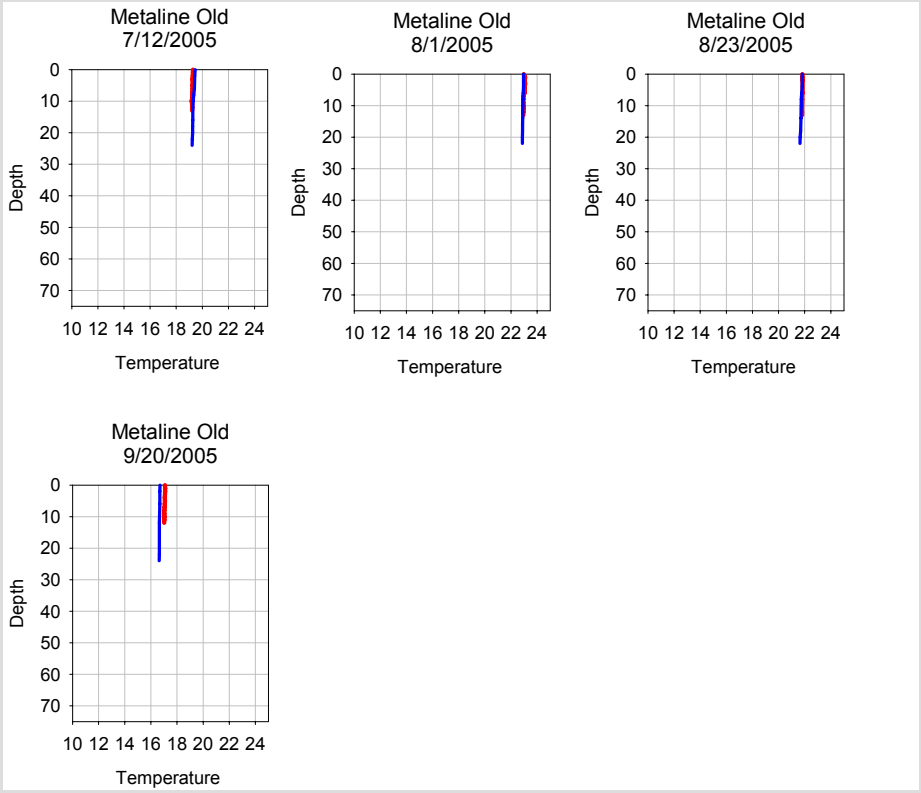

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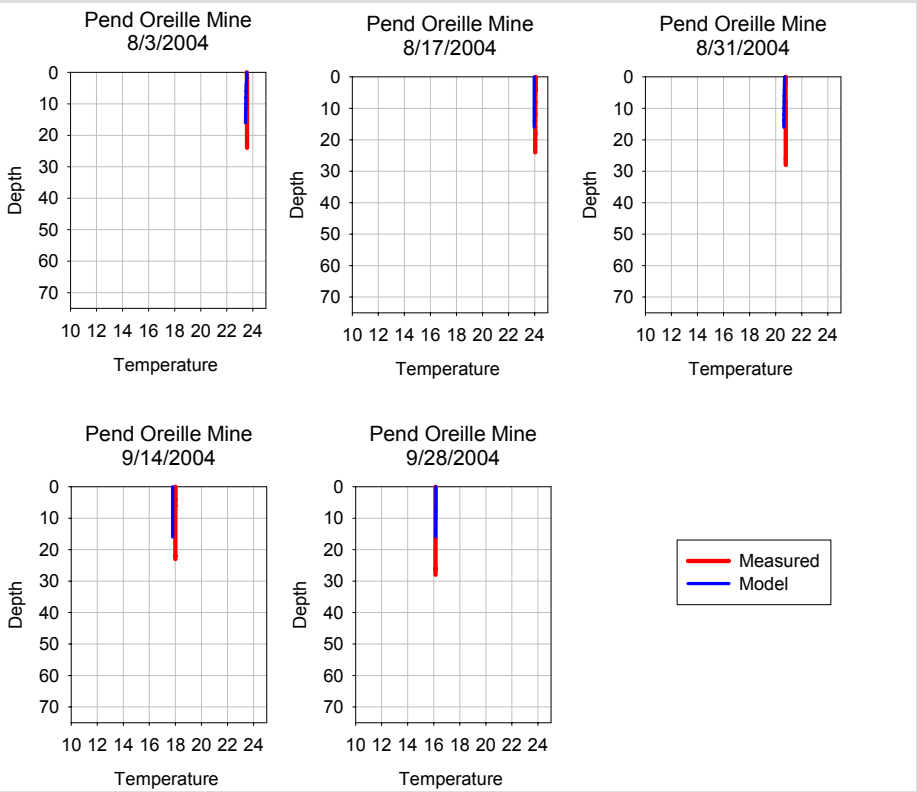
Temperature Calibration
Profiles – V3. Pend Oreille Mine

2004



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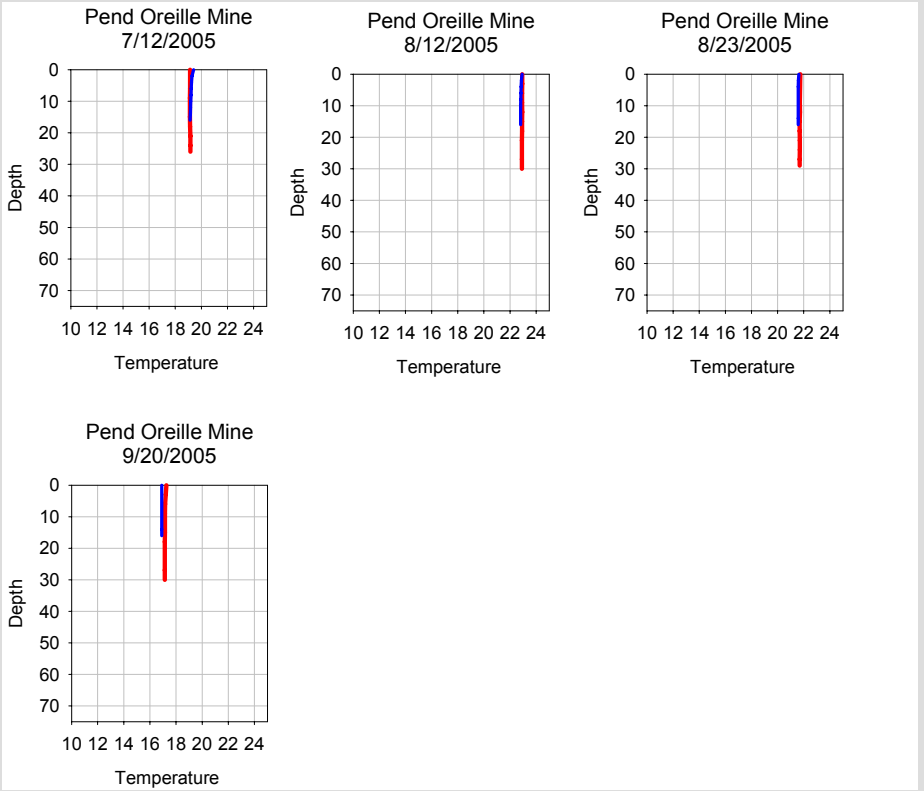

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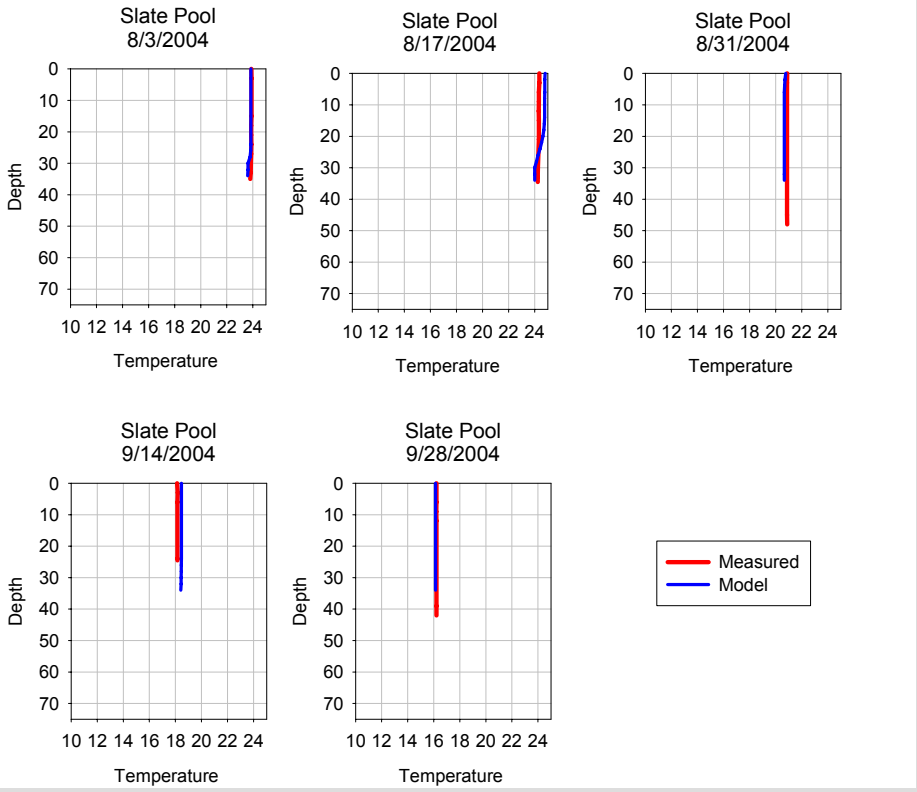
Temperature Calibration
Profiles – V4. Slate Creek

2004



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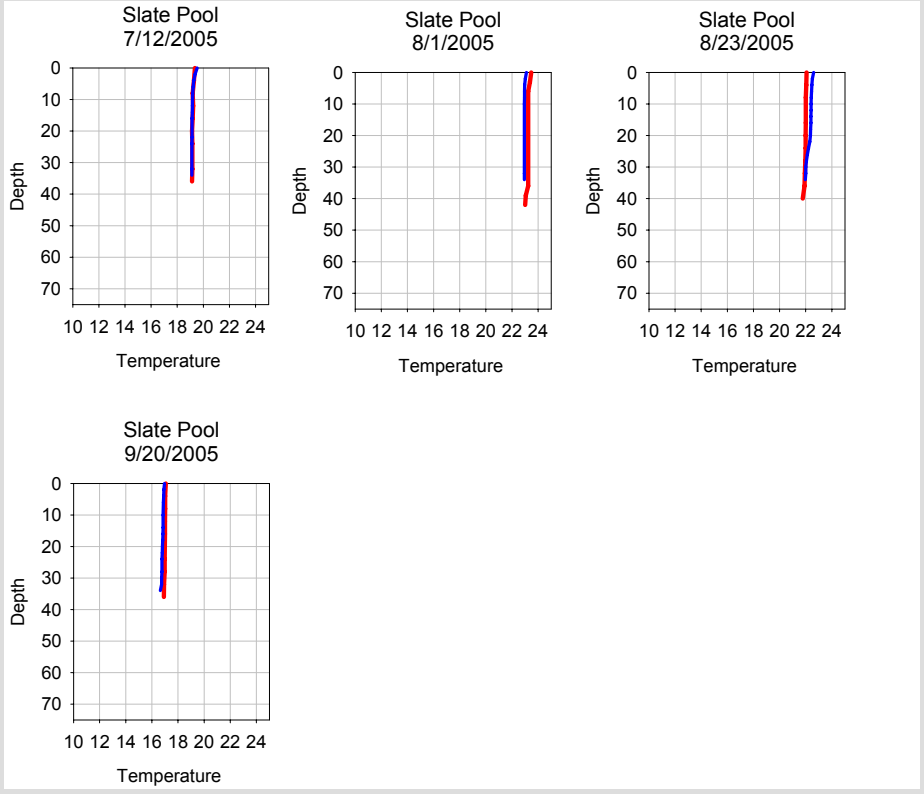
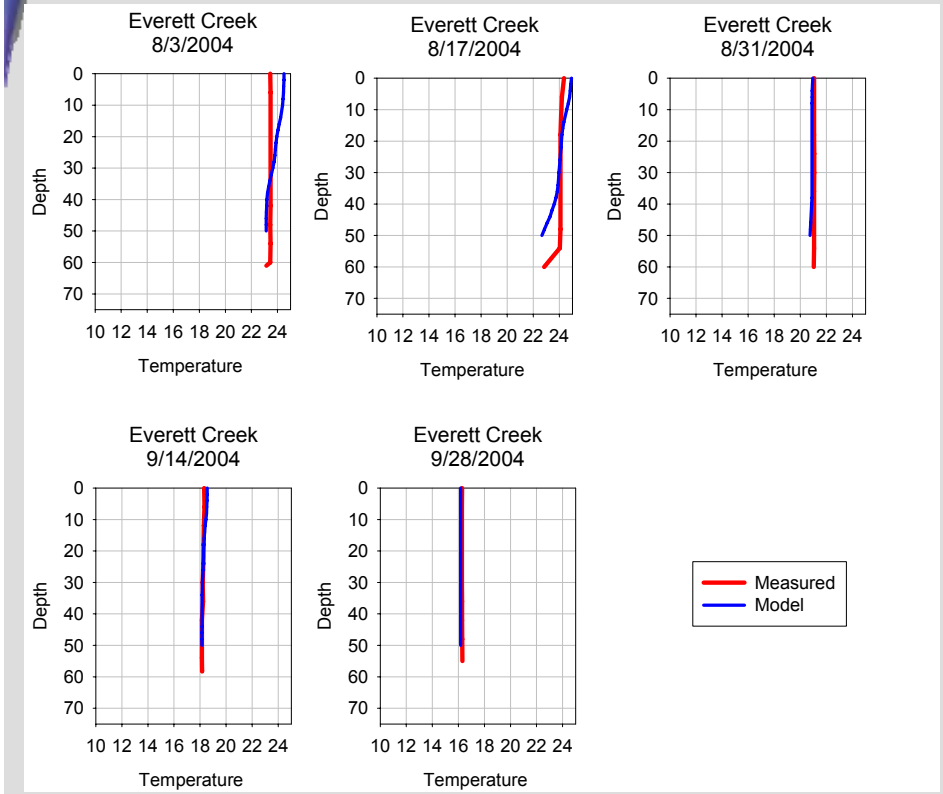


Temperature Calibration
Profiles – V5. Everett Creek

2004



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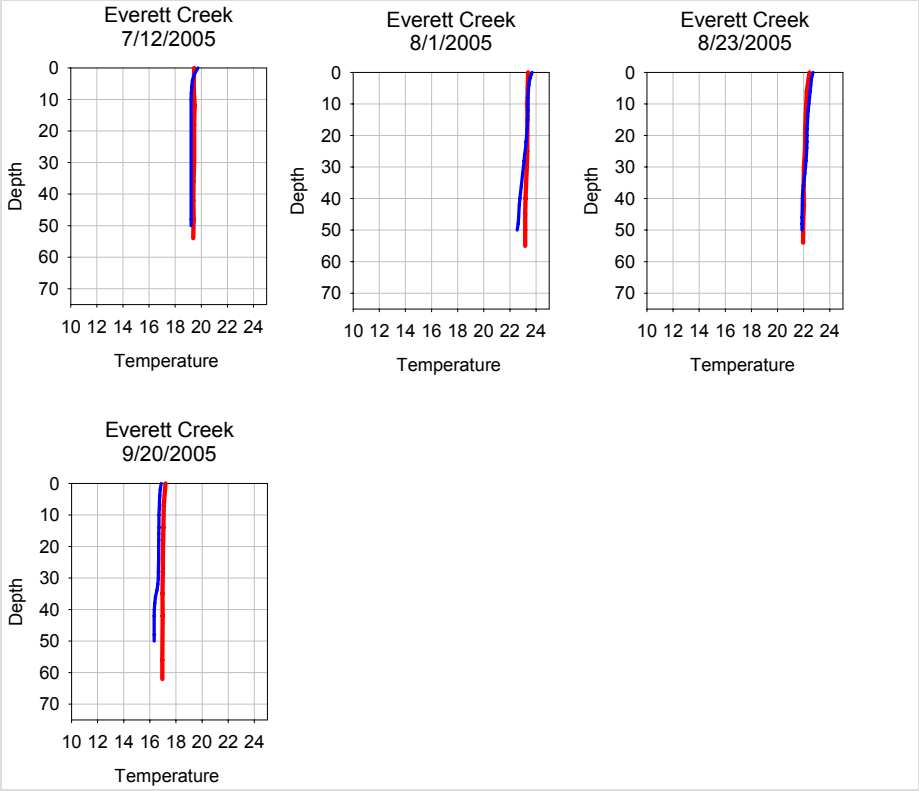

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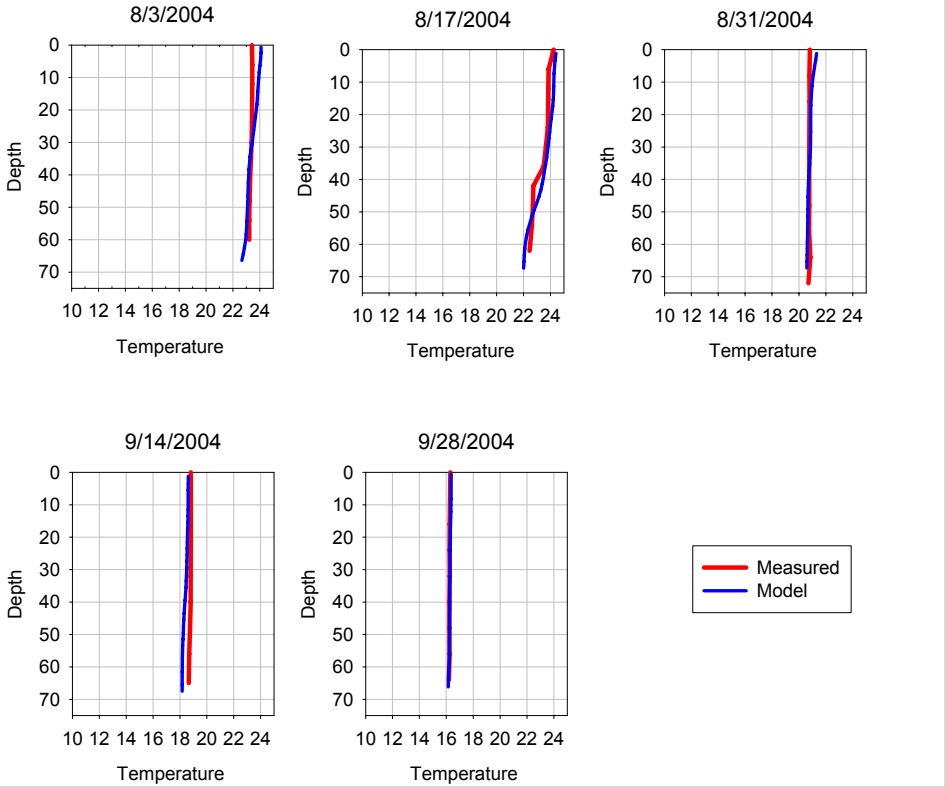
Temperature Calibration
Profiles – V6. Boundary Reservoir

2004



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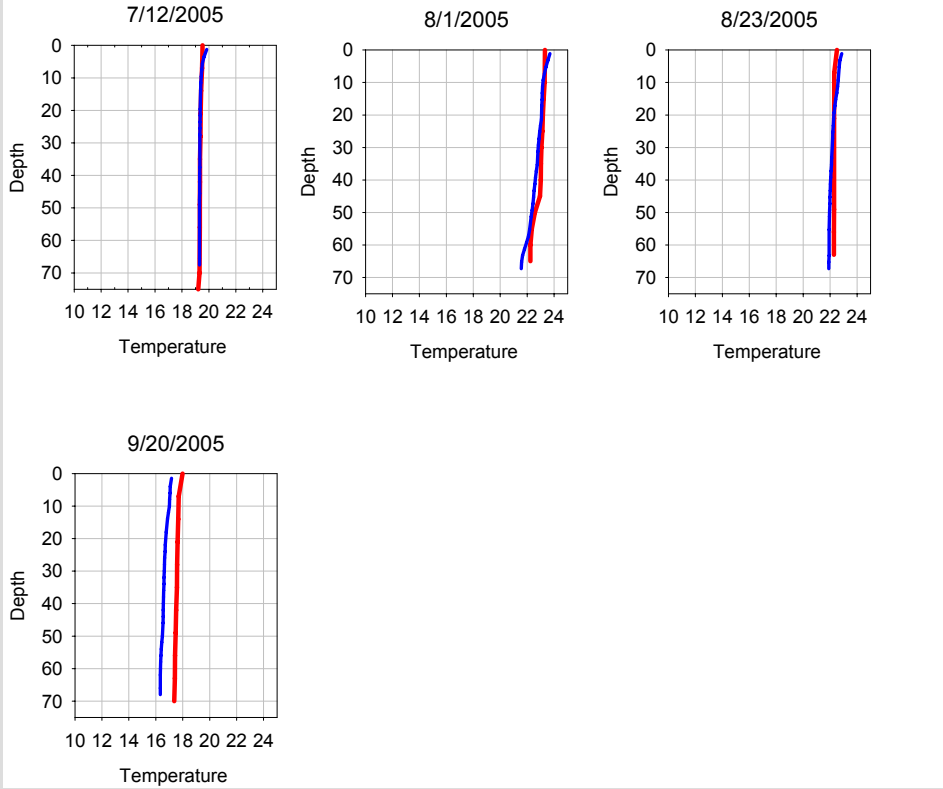


Temperature Calibration
Summary of Error Analysis

- Time Series (at measured time interval)

Station	Depth (m)	ME (ºC)	AME (ºC)	RMS (ºC)	N
T2. Metaline Pool	1	-0.267	0.298	0.367	14,537
	3.2	-0.188	0.243	0.317	14,536
	5.4	-0.257	0.278	0.339	14,537
	7.6	-0.249	0.272	0.336	14,538
	9.8	-0.218	0.264	0.344	14,538
T6. Slate Pool	1	-0.124	0.291	0.376	21,081
	11	-0.143	0.276	0.347	21,081
	21	-0.146	0.264	0.347	21,080
	31	-0.212	0.243	0.312	20,931
T7. Boundary Intake	5	-0.080	0.299	0.373	26,719
	11	-0.180	0.291	0.359	33,865
	17	-0.080	0.228	0.292	34,624
	23	-0.115	0.227	0.295	34,626
	29	-0.101	0.166	0.208	19,071
T8. Boundary Dam Tailwater	10	-0.027	0.425	0.785	32,847
Overall Averages		-0.14	0.27	0.40	338,611

Temperature Calibration
Summary of Error Analysis

- Daily Maximum

Station	Depth (m)	ME (ºC)	AME (ºC)	RMS (ºC)	N
T2. Metaline Pool	1	-0.194	0.279	0.337	203
	3.2	-0.092	0.220	0.274	203
	5.4	-0.143	0.231	0.280	203
	7.6	-0.129	0.223	0.272	203
	9.8	-0.103	0.238	0.292	203
T6. Slate Pool	1	-0.098	0.289	0.377	295
	11	-0.048	0.252	0.316	295
	21	-0.063	0.246	0.312	295
	31	-0.180	0.222	0.282	293
T7. Boundary Intake	5	-0.140	0.335	0.426	424
	11	0.015	0.309	0.383	203
	17	-0.061	0.219	0.280	481
	23	-0.096	0.209	0.277	481
	29	-0.084	0.145	0.182	265
T8. Boundary Dam Tailwater	10	-0.033	0.441	0.799	461
Overall Averages		-0.09	0.26	0.39	4,508

Temperature Calibration
Summary of Error Analysis

- Profiles

	ME (ºC)	AME (ºC)	RMS (ºC)	N
Overall Averages	-0.096	0.190	0.265	562

V6. Boundary Reservoir

Date	ME (ºC)	AME (ºC)	RMS (ºC)	N
8/3/04	0.139	0.282	0.344	11
8/17/04	0.143	0.295	0.327	12
8/31/04	0.060	0.172	0.219	9
9/14/04	-0.343	0.343	0.365	9
9/28/04	0.024	0.035	0.040	9
7/12/05	0.007	0.055	0.102	10
8/1/05	-0.199	0.268	0.308	14
8/23/05	-0.083	0.251	0.274	10
9/20/05	-0.914	0.914	0.922	10
Overall	-0.125	0.293	0.398	94

V5. Everett Creek

Date	ME (ºC)	AME (ºC)	RMS (ºC)	N
8/3/04	0.294	0.506	0.584	9
8/17/04	-0.088	0.431	0.544	9
8/31/04	-0.180	0.180	0.184	9
9/14/04	0.044	0.080	0.107	9
9/28/04	-0.116	0.116	0.116	9
7/12/05	-0.183	0.243	0.248	9
8/1/05	-0.214	0.266	0.337	11
8/23/05	0.040	0.148	0.160	9
9/20/05	-0.457	0.457	0.475	8
Overall	-0.094	0.267	0.351	82

V4. Slate Creek

Date	ME (ºC)	AME (ºC)	RMS (ºC)	N
8/3/04	-0.140	0.140	0.151	12
8/17/04	0.171	0.302	0.320	13
8/31/04	-0.217	0.217	0.220	12
9/14/04	0.286	0.286	0.286	10
9/28/04	-0.089	0.089	0.089	12
7/12/05	-0.038	0.069	0.076	9
8/1/05	-0.342	0.342	0.343	12
8/23/05	0.284	0.284	0.320	9
9/20/05	-0.173	0.173	0.178	9
Overall	-0.038	0.214	0.243	98

V3. Pend Oreille Mine

Date	ME (ºC)	AME (ºC)	RMS (ºC)	N
8/3/04	-0.119	0.119	0.132	9
8/17/04	-0.189	0.189	0.190	9
8/31/04	-0.118	0.118	0.121	9
9/14/04	-0.249	0.249	0.249	9
9/28/04	0.005	0.007	0.009	9
7/12/05	0.073	0.083	0.113	6
8/1/05	-0.155	0.155	0.161	6
8/23/05	-0.214	0.214	0.214	6
9/20/05	-0.322	0.322	0.324	7
Overall	-0.144	0.159	0.186	70

V2. Metaline Old

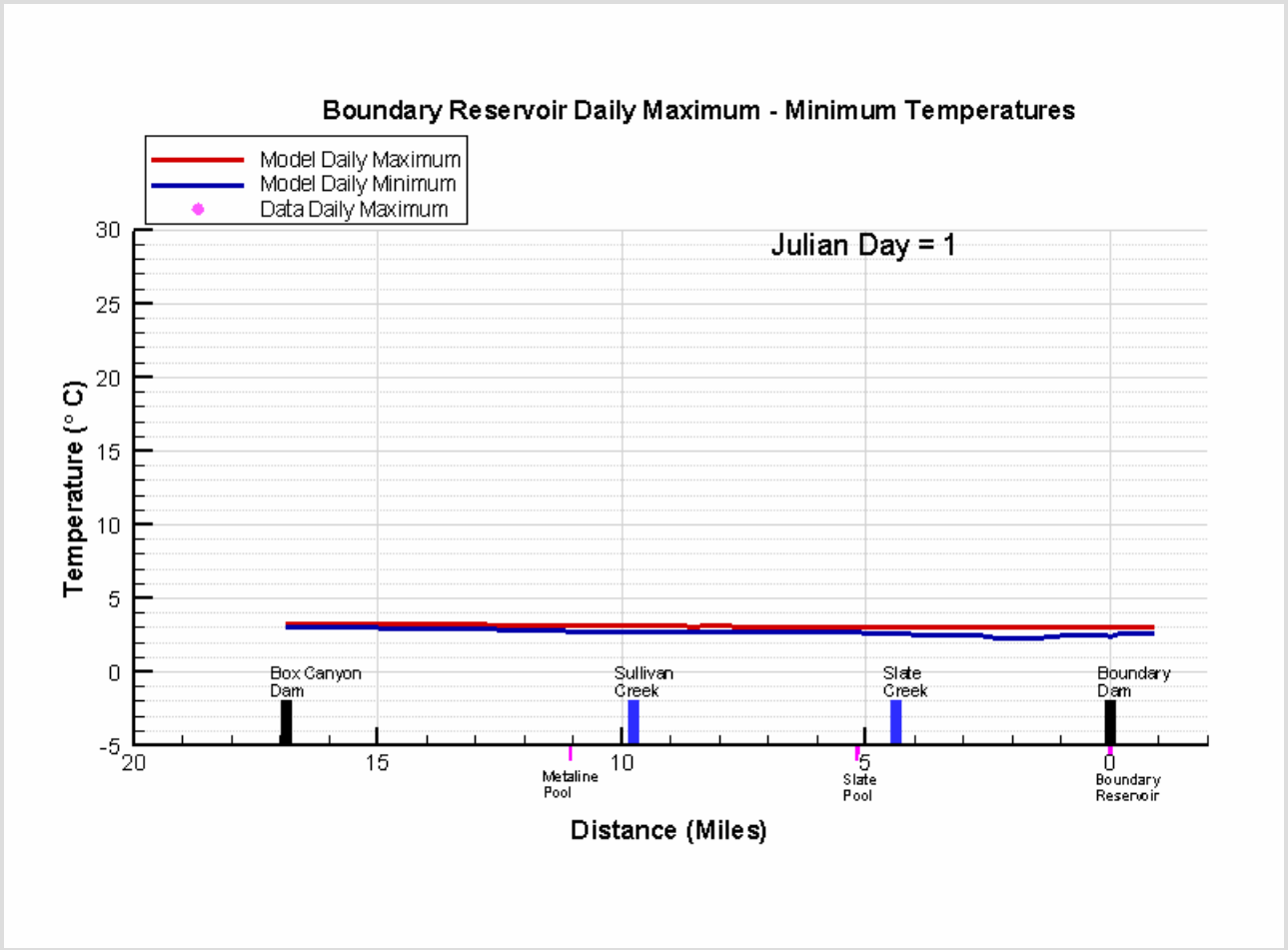
Date	ME (ºC)	AME (ºC)	RMS (ºC)	N
8/3/04	-0.048	0.048	0.049	12
8/17/04	-0.123	0.123	0.125	13
8/31/04	-0.031	0.031	0.032	13
9/14/04	-0.128	0.128	0.129	11
9/28/04	0.062	0.062	0.062	12
7/12/05	-0.082	0.082	0.084	13
8/1/05	-0.262	0.262	0.264	13
8/23/05	-0.220	0.220	0.220	12
9/20/05	-0.434	0.434	0.435	13
Overall	-0.143	0.156	0.201	112

V1. Wolf Creek

Date	ME (ºC)	AME (ºC)	RMS (ºC)	N
8/3/04	0.029	0.029	0.033	12
8/17/04	0.025	0.058	0.075	13
8/31/04	-0.003	0.019	0.041	13
9/14/04	-0.004	0.006	0.008	8
9/28/04	0.028	0.051	0.057	12
7/12/05	-0.013	0.014	0.017	11
8/1/05	-0.057	0.057	0.059	15
8/23/05	-0.031	0.031	0.033	11
9/20/05	-0.377	0.377	0.377	11
Overall	-0.043	0.071	0.130	106

Boundary Reservoir

Surface Layer Longitudinal Temperature Variation



Conclusions

- Model calibration complete
  - ME < 0.2 ºC
  - AME < 1.0 ºC
  - Errors at low end of range seen for other studies
- Next Steps
  - NTP
    - Model setup
      - Grid modification
      - Shade – topographic and vegetative
      - Upstream boundary conditions
    - Comparison to Existing Condition for evaluation of compliance to temperature standards
  - Alternatives analyses
  - Final report

Temperature Calibration
Error Statistics for Other CE-QUAL-W2 Applications

	Reservoir	# years	AME, °C		Reservoir	# years	AME, °C
1	Allatoona	4	0.6	36	Monroe	4	0.7
2	Alum Creek	1	0.5	37	Neely Henry	2	0.6
3	Barkley	1	0.5	38	Neversink	3	0.4
4	Bluestone	2	0.5	39	Norman	3	0.7
5	Brownlee	2	0.6	40	Oxbow	1	0.3
6	Bull Run 1	2	0.5	41	Oahe	2	0.9
7	Bull Run 2	2	0.7	42	Occoquan	1	0.9
8	Burnsville	1	0.9	43	Paint Creek	1	0.4
9	Caesar Creek	1	0.6	44	Paintsville	1	0.4
10	Cannonsville	5	0.7	45	Patoka	3	0.7
11	Cave Run	4	0.8	46	Pepacton	3	0.6
12	C.J. Strike	2	0.7	47	Pineflat	5	0.6
13	Croton	1	0.7	48	Powell	1	0.7
14	Cumberland	1	0.5	49	J. Percy Priest	3	0.8
15	Deer Creek, OH	1	0.4	50	Quabbin	1	0.7
16	Deer Creek, ID	5	0.8	51	Richard B. Russell	3	0.5
17	DeGray	8	0.9	52	Rhodiss	2	0.6
18	Fishtrap	1	0.8	53	Riffe	1	0.7
19	Fort Peck	2	0.7	54	Rimov	1	0.5
20	Francis Case	2	0.7	55	Rondout	3	0.5
21	Herrington	1	0.7	56	Sakakawea	2	0.7
22	Hickory	1	0.5	57	Schoharie	2	0.8
23	J.W. Flanagan	1	0.5	58	Shasta	1	0.6
24	Jordanelle	3	0.7	59	Shepaug	1	0.6
25	J. Strom Thurmond	5	0.9	60	Stonewall Jackson	2	0.5
26	James	1	0.6	61	Toledo Bend	1	0.7
27	Houston	6	0.5	62	Taylorsville	2	0.9
28	Lanier	2	0.9	63	Tolt	1	0.5
29	Loch Raven	1	0.9	64	Travis	1	0.3
30	Long Lake	1	0.5	65	Wabush	1	0.6
31	Lost Creek	1	0.6	66	Wachusett	4	0.7
32	Maumelle	2	0.7	67	Weiss	2	0.6
33	Mayfield	1	0.6	68	West Point	3	0.8
34	Moehnetalsperre	1	0.4	69	Walter F. George	2	0.6
35	Mountain Island	1	0.7	70	Youghiogheny	2	0.8

- **RISLEY (1997) - Tualatin River**
  - Max Mean Difference = 3 Deg C
  - Mostly < 1 Deg C
- **BATTELLE-MASS1 (2001) - Columbia River**
  - RMS Error = 0.59 - 1.52 Deg C
- **HDR/PORTLAND STATE/IPC (1999) - Snake River**
  - AME = 0.6-2.3 Deg C (1992 data)
  - AME = 0.5-2.0 Deg C (1995 data)
- **CHEN (1996) - Grande Ronde River**
  - Error = -2.20 - 8.28 Deg C (Summer Max)
  - Error = -1.21 - 7.69 Deg C (Avg 7-day Max)

	AME Range (ºC)	
	Min	**Max**
Overall Averages	0.3	0.9