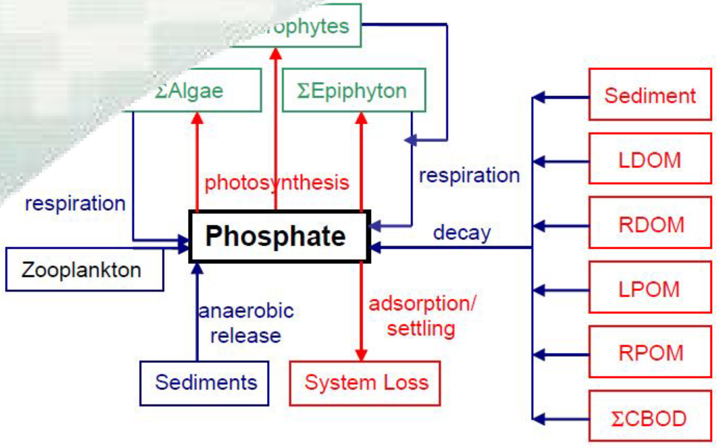
2015 Ambient Water Quality Conditions in Pipestem Reservoir and Application of the CE-QUAL-W2 Hydrodynamic and Water Quality Model



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Omaha District Water Quality

March 1, 2016

US Army Corps of Engineers

BUILDING STRONG®

Drivers for WQ Management and Monitoring at District Projects

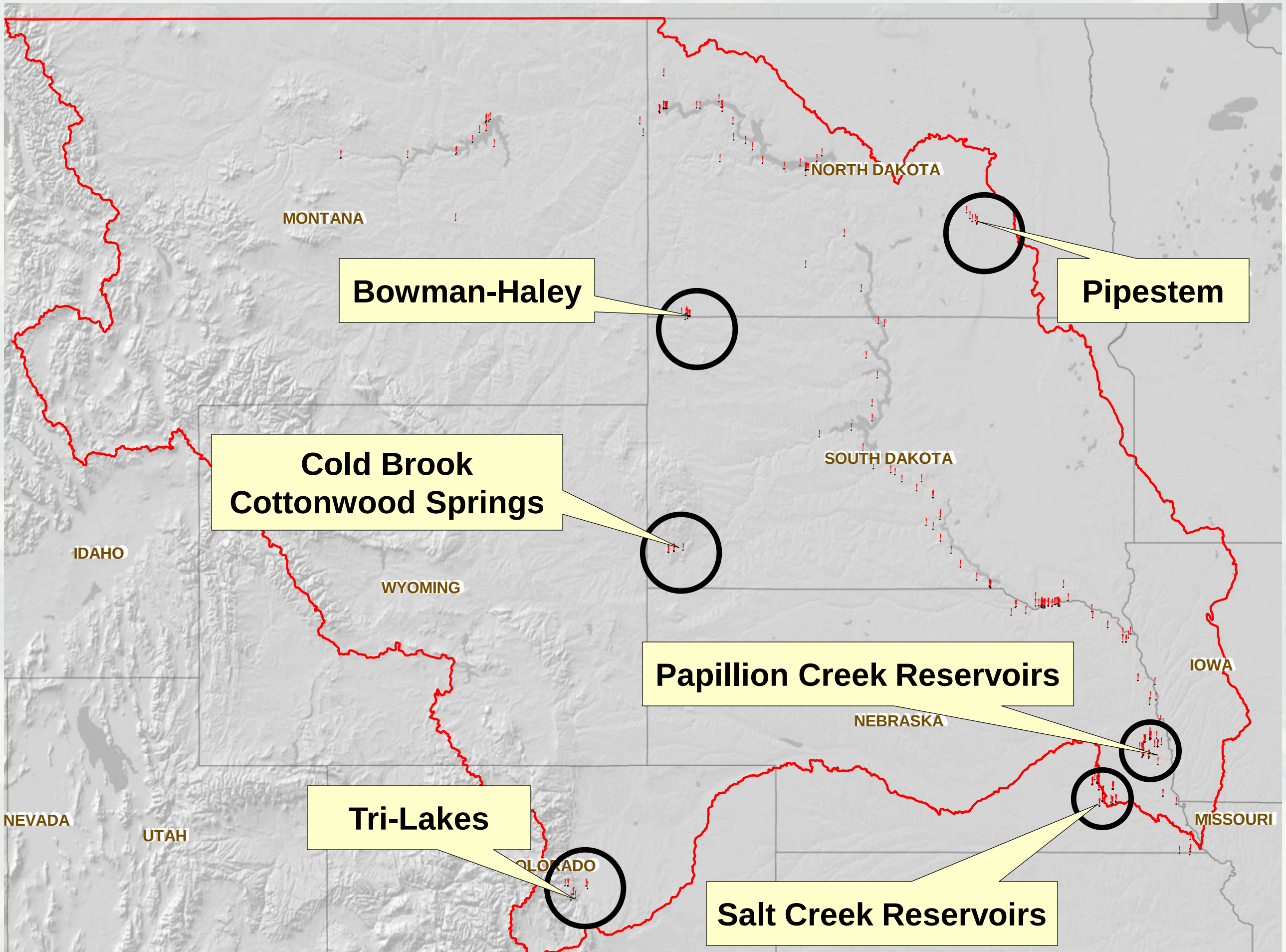
- Implement ER 1110-2-8154, *"Water Quality and Environmental Management for Corps Civil Works Project"* (31-May1995).
- District WQ Management Program promotes leadership, stewardship, and responsible management of aquatic resources at District Projects, and compliance with water quality laws and regulations.
- Primary WQ Monitoring Question: How does reservoir regulation and dam operation impact water quality at District Projects?

ER 1110-2-8154

- **National WQ Management Policy**

  "It is national policy that the Federal government, in the design, construction, management, operation, and maintenance of its facilities, shall provide leadership in the nationwide effort to protect and enhance the quality of our air, water, and land resources. <u>Federal facilities shall comply with all Federal, State, Interstate, and Local requirements in the same manner and extent as other entities</u>."

Water Quality Monitoring at the Tributary Projects

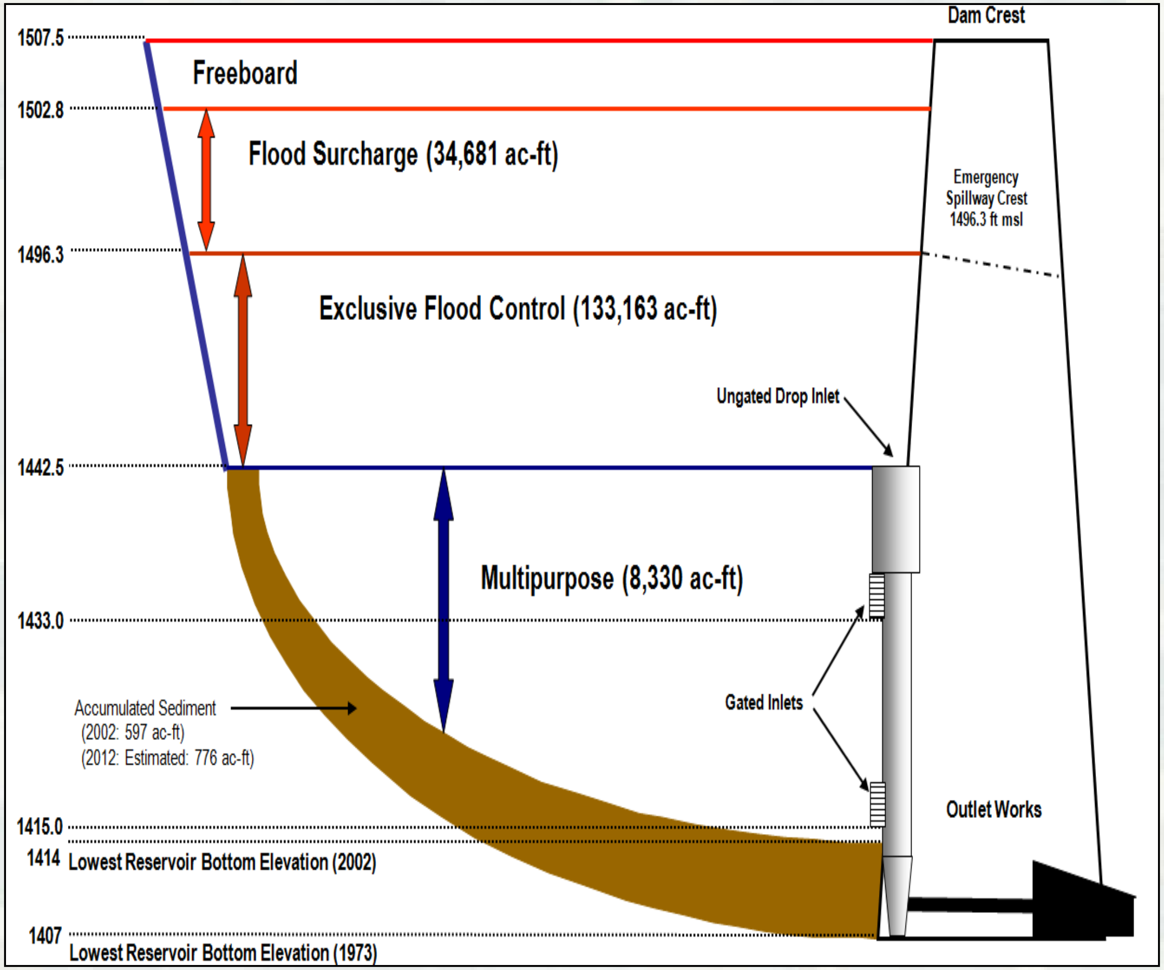


- In addition to the monitoring WQ conditions in the Missouri River Mainstem System, The Omaha District WQ Team monitors water quality at 19 tributary reservoirs.
- Pipestem Reservoir is routinely monitored every 3 years as part of our ND/SD Tributary Projects Monitoring Plan.
- We have Historical WQ data for Pipestem dating back to 1973. Monthly growing season data exists from 1974-1998.

Pipestem Project Background

- Impoundment of Pipestem Creek, located 3 miles northwest of Jamestown, North Dakota.
- Reservoir reached its initial fill in May 1974.
- The watershed is largely agricultural and rangeland.
- Authorized purposes of Pipestem Reservoir are flood control, recreation, fish and wildlife, and water quality.
- On 2014 ND Section 303(d) List, recreational use is supported but threatened due to nutrients/eutrophication.
- Dissolved oxygen conditions under ice cover have been a concern since as early as 1976.

Pipestem Project Overview



- Ungated drop inlet with a weir elevation of 1442.5 ft-msl.
- Intake structure has two 4'x7' hydraulic slide service gates and two low level gates.
- The two low level gates are 3'x3' foot slide gates at invert elevations 1433.0 and1415.0 ft-msl.
- 1415.0 ft-msl intake is located 180' upstream of the outlet structure.

More Background

- In March of 2013 North Dakota Game and Fisheries personnel monitored hypoxic conditions beneath ice cover that lead to a winterkill in the reservoir.
- To minimize the spatial extent of the winterkill the low-level gate was used to draw influent water towards the dam to potentially provide refugia in the upper reservoir.
- To further evaluate water quality conditions and the effects of using the low-level gate the Corps is applying the CE-QUAL-W2 (W2) model.
- In 2015 an intensive WQ survey was implemented to collect the data necessary to apply the W2 model.

2015 Intensive Survey

- **U.S. Army Corps of Engineers. 2015.** “Quality Control Plan for the 2015 Intensive Survey of Pipestem Reservoir”. QCP number: SPS-PIPSTM-001. Water Control and Water Quality Section, Hydrologic Engineering Branch, Engineering Division, Omaha District, U.S. Army Corps of Engineers.

- **Monitoring Station Locations and Numbers**

Station Location	Latitude	Longitude	Station Number
Near Dam, Deepwater	46º57’47.08”	98º45’10.77”	PIPLKND1
Mid-Lake, Deepwater	46º58’15.12”	98º47’33.98”	PIPLKML1
Up-Lake	46º58’30.13”	98º49’42.74”	PIPLKUP1
Inflow	47° 0'29.66”	98°51'48.42”	PIPNF1
Releases	46º57’37.03”	98º45’12.25”	PIPRL1

2015 Station Locations

Sample Types and Collection Frequency

- Near Dam and Mid-Lake Locations
  - Grab samples were collected monthly from May to September using a Van Dorn Sampler at two depths at the deepwater mid-lake sites: near-surface and near-bottom. The near-surface samples were collected at one-half the measured Secchi depth; the near-bottom samples were collected ½ meter above the lake bottom. The near dam location also had phytoplankton and zooplankton samples collected in May, July, and September.
- Up-Lake Location
  - Near Surface grab samples were collected monthly from May to September using a Van Dorn Sampler. The near-surface samples were collected at one-half the measured secchi depth.
- Inflow and Outflow Locations
  - Near Surface grab samples were collected monthly from April to October, and again in January of 2016.
- Field Measurements
  - At in reservoir locations profile measurements were taken from the reservoir surface to bottom in ½ meter increments. A profile measurement was taken from the waters surface at inflow and outflow locations. Profile measurements were collected using a Hydrolab DS5 Datasonde. Values for temperature, dissolved oxygen (DO), pH, conductivity, redox (ORP), turbidity, and chlorophyll *a* were recorded with each sampling event.

Parameters Analyzed

Parameter	Near Surface	Near Bottom	Inflow	Releases
Alkalinity, Total	X	X	X	X
Total Organic Carbon (TOC)	X	X	X	X
Dissolved Organic Carbon (DOC)	X	X	X	X
CBOD (5-Day)	X	X	X	X
Chlorophyll *a*, Total	X		X	
CDOM	X	X	X	
Dissolved Solids, Total	X	X	X	X
Ammonia, Total	X	X	X	X
Kjeldahl Nitrogen, Total	X	X	X	X
Nitrate/Nitrite, Total	X	X	X	X
Microcystins, Total	X			
Phosphorus, Orthophosphorus	X	X	X	X
Phosphorus, Total	X	X	X	X
Phosphorus, Dissolved	X	X	X	X
Sulfate, Dissolved	X	X	X	X
Suspended Solids, Total	X	X	X	X
Metals, Total (Fe, Mn)	X	X	X	X
Metals, Dissolved (Fe, Mn)	X	X	X	X
Silica (Total)	X	X	X	
Silica (Dissolved)	X	X	X	
Metals, Total (Hg, Se)*	X			
Metals Scan (Dissolved)*	X			
Pesticide Scan**	X			
Plankton – Phytoplankton***	X			
Plankton – Zooplankton***	X			
Secchi Depth	X	X	-	-

- Only analyzed in August. Dissolved metals to be analyzed: aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, silver, thallium, and zinc. Total metals to be analyzed: iron, manganese, mercury, and selenium. Hardness will be calculated from dissolved Ca and Mg concentrations.

** One complete pesticide scan in May at the deepwater site. Rapid Assay for acetochlor, atrazine, and metholachlor at all times. The complete pesticide scan includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin.

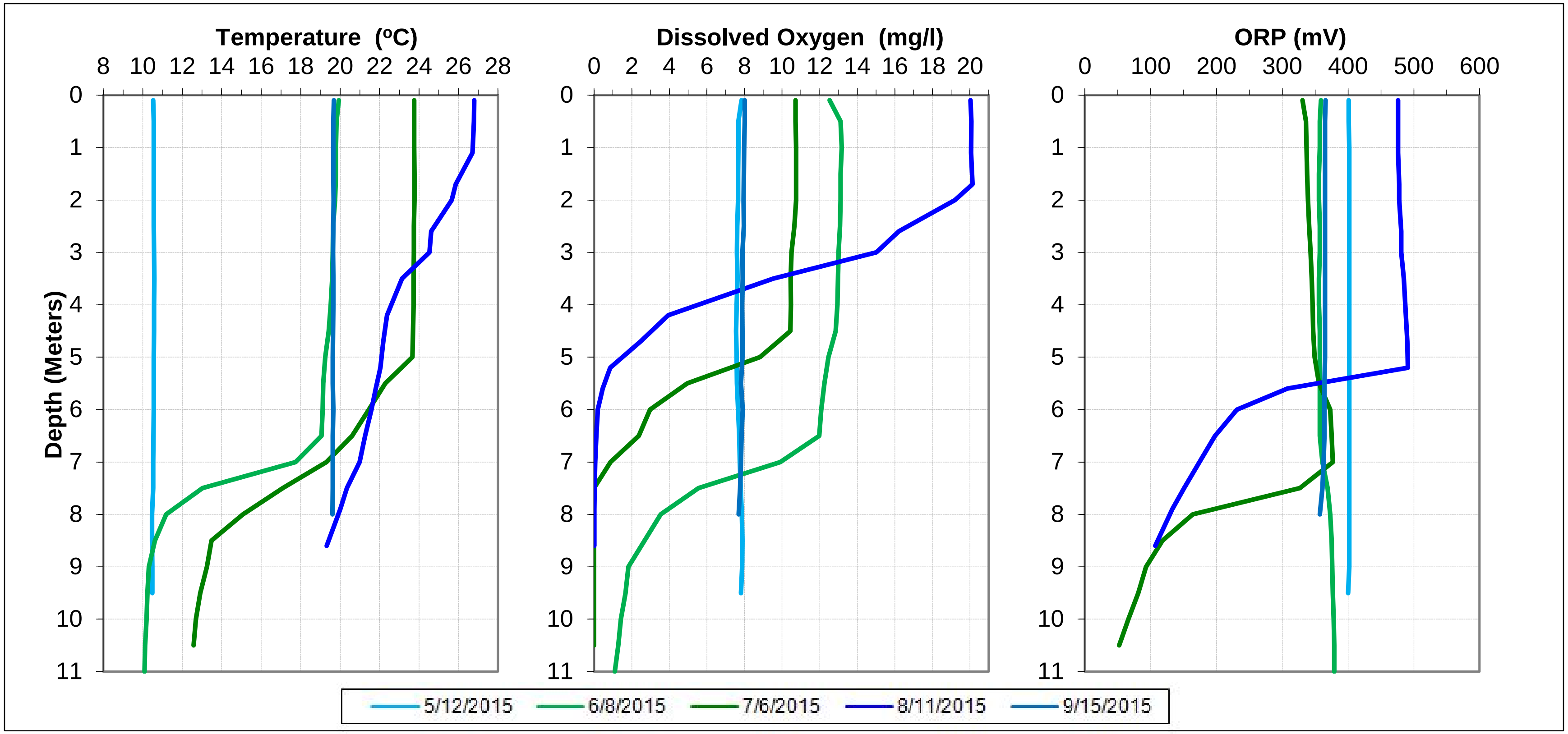
*** Zooplankton and Phytoplankton to be collected at the Near Dam location only.

Seasonal Near Dam Results

Parameter	Det.Limit	No. Obs.	Mean	Median	Minimum	Maximum
Lake Depth (m)	0.1	5	9.5	8.9	8.5	11.0
Water Temp (°C)	0.1	100	17.8	19.6	10.1	26.8
Elevation, Surface (ft)	0.1	5	1446.8	1446.1	1442.1	1451.5
Secchi (in)	1	5	48	39	24	96
Turbidity, Fd (NTU)	0.1	99	7.7	3.6	0.0	72.9
ORP (mV)	1	100	353	365	52	491
Sp. Cond. (umho/cm)	1	100	1295	1296	1221	1408
Oxygen, Diss (mg/l)	0.1	100	7.7	7.8	0.0	**20.1**
O2 Sat, Diss (%)	0.1	100	87.7	90.8	0.0	**261.9**
pH (SU)	0.1	100	8.4	8.4	7.4	**9.9**
Chlorophyll a (ug/l)	3	5	**27**	29	n.d.	50
Chlorophyll a, FP (ug/l)	3	100	**30**	31	n.d.	66
CBOD 5-Day (mg/l)	0.8	10	5.2	4.0	0.8	13.0
Solids, Dissolved (mg/l)	1	10	956	950	876	1040
Solids, Susp. Tot (mg/l)	4	10	15	14	n.d.	31
Ammonia, Tot (mg/l)	0.02	10	0.49	0.22	n.d.	**2.04**
Kjeldahl, Tot (mg/l)	0.03	10	2.14	2.00	1.70	2.99
NO2+NO3, Tot (mg/l)	0.03	10	0.10	0.05	n.d.	0.40
Phos, Tot (mg/l)	0.005	10	**0.27**	0.15	0.02	1.14
Phos, Diss (mg/l)	0.01	10	**0.23**	0.07	n.d.	1.12
Ortho, Phos, Diss. (mg/l)	0.003	10	**0.22**	0.06	0.01	1.11
TOC (mg/l)	0.2	10	14.1	14.5	11.6	16.1
DOC (mg/l)	0.2	10	13.5	13.6	11.5	15.5
Alkalinity, Tot (mg/l)	0.6	10	258	255	227	296
Sulfate, Diss (mg/l)	0.05	10	443	451	407	468
Iron, Tot (ug/l)	10	10	134	100	20	490
Iron, Diss (ug/l)	10	10	n.d.	n.d.	n.d.	20
Manganese, Tot (ug/l)	3	10	1017	715	260	3530
Manganese, Diss (ug/l)	3	10	1006	700	210	3590
CDOM (ug/l)	10	10	95	101	71	110

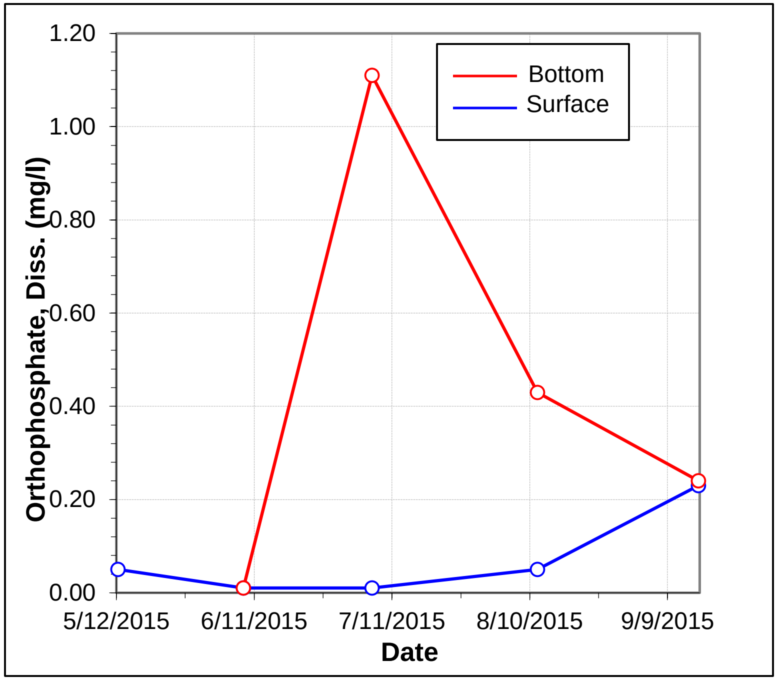
Reservoir Stratification

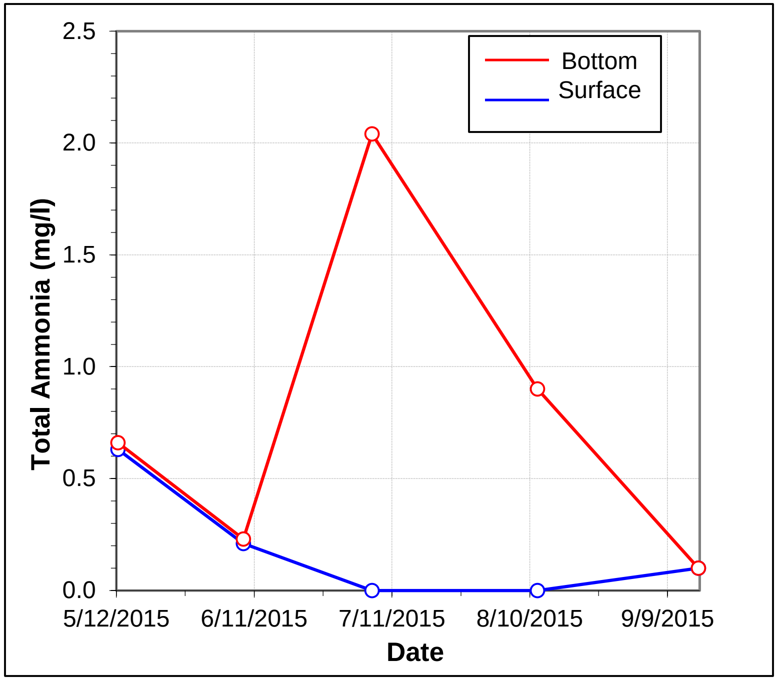
- Thermal stratification sets up near the dam in late May and persists through mid September.



Internal Nutrient Load

- During anoxic periods sediment bound phosphate is released into the water column and becomes readily available for algal uptake in the surface water following turnover.
- Ammonification occurs as bacteria decompose organic matter that has settled into the hypolimnion. This increases ammonia concentrations and utilizes oxygen.





Seasonal Mid Lake Results

Parameter	Det.Limit	No. Obs.	Mean	Median	Minimum	Maximum
Lake Depth (m)	0.1	5	5.5	4.5	4.3	7.4
Water Temp (°C)	0.1	59	19.3	19.7	9.7	26.0
Secchi (in)	1	5	32	32	13	48
Turbidity, Fd (NTU)	0.1	59	13.9	6.2	0.0	69.1
ORP (mV)	1	59	375	385	150	405
Sp. Cond. (umho/cm)	1	59	1311	1322	1220	1367
Oxygen, Diss (mg/l)	0.1	59	8.8	9.0	0.0	17.3
O2 Sat, Diss (%)	0.1	59	101.0	106.6	0.0	222.3
pH (SU)	0.1	59	8.5	8.3	7.8	**9.8**
Chlorophyll a (ug/l)	3	5	**39**	41	3	**70**
Chlorophyll a, FP (ug/l)	3	59	**39**	35	3	**92**
CBOD 5-Day (mg/l)	0.8	8	8.1	8.0	3.0	14.0
Solids, Dissolved (mg/l)	1	10	972	964	864	1070
Solids, Susp. Tot (mg/l)	4	10	22	22	9	47
Ammonia, Tot (mg/l)	0.02	10	0.32	0.25	n.d.	0.77
Kjeldahl, Tot (mg/l)	0.03	10	2.25	2.20	1.56	3.06
NO2+NO3, Tot (mg/l)	0.03	10	0.08	n.d.	n.d.	0.38
Phos, Tot (mg/l)	0.005	10	**0.23**	0.22	0.05	0.46
Phos, Diss (mg/l)	0.01	10	**0.16**	0.12	0.02	0.39
Ortho, Phos, Diss. (mg/l)	0.003	10	**0.14**	0.12	0.02	0.39
TOC (mg/l)	0.2	10	14.3	14.6	10.9	16.6
DOC (mg/l)	0.2	10	13.7	14.3	11.1	15.2
Alkalinity, Tot (mg/l)	0.6	10	265	263	247	286
Sulfate, Diss (mg/l)	0.05	10	448	456	411	464
Iron, Tot (ug/l)	10	9	414	360	80	1080
Iron, Diss (ug/l)	10	9	30	n.d.	n.d.	230
Manganese, Tot (ug/l)	3	9	846	730	480	1240
Manganese, Diss (ug/l)	3	9	810	730	430	1200

Seasonal Up Lake Results

Parameter	Det.Limit	No. Obs.	Mean	Median	Minimum	Maximum
Lake Depth (m)	0.1	5	2.7	2.8	1.2	4.0
Water Temp (°C)	0.1	15	16.9	19.7	7.4	26.1
Secchi (in)	1	4	22	21	10	36
Turbidity, Fd (NTU)	0.1	15	19.4	14.5	5.3	52.5
ORP (mV)	1	15	396	389	365	414
Sp. Cond. (umho/cm)	1	15	1307	1337	1245	1389
Oxygen, Diss (mg/l)	0.1	15	9.9	10.0	6.7	10.8
O2 Sat, Diss (%)	0.1	15	105.4	113.4	78.3	130.3
pH (SU)	0.1	15	8.5	8.3	8.2	**9.3**
Chlorophyll a (ug/l)	3	5	**38**	19	12	**107**
Chlorophyll a, FP (ug/l)	3	15	**54**	19	12	**113**
CBOD 5-Day (mg/l)	0.8	4	6.3	5.0	n.d.	15.0
Solids, Dissolved (mg/l)	1	5	976	1010	852	1020
Solids, Susp. Tot (mg/l)	4	5	26	20	15	41
Ammonia, Tot (mg/l)	0.02	5	0.30	0.29	n.d.	0.68
Kjeldahl, Tot (mg/l)	0.03	5	2.18	2.24	1.50	3.19
NO2+NO3, Tot (mg/l)	0.03	5	0.08	n.d.	n.d.	0.32
Phos, Tot (mg/l)	0.005	5	**0.28**	0.29	0.08	0.55
Phos, Diss (mg/l)	0.01	5	**0.19**	0.15	0.04	0.44
Ortho, Phos, Diss. (mg/l)	0.003	5	**0.18**	0.17	0.03	0.42
TOC (mg/l)	0.2	5	14.4	15.3	11.0	15.7
DOC (mg/l)	0.2	5	14.2	14.4	11.9	15.7
Alkalinity, Tot (mg/l)	0.6	4	274	269	260	300
Sulfate, Diss (mg/l)	0.05	5	451	450	414	491
Iron, Tot (ug/l)	10	4	303	235	n.d.	740
Iron, Diss (ug/l)	10	4	5	n.d.	n.d.	20
Manganese, Tot (ug/l)	3	4	735	695	640	910
Manganese, Diss (ug/l)	3	4	688	645	590	870

Inflow and Outflow Sample Results

Inflow

Parameter	Det.Limit	No. Obs.	Mean	Median	Minimum	Maximum
Water Temp (°C)	0.1	8	17.0	17.9	1.5	30.0
Stream Flow (cfs)	0.1	8	10.3	4.4	0.0	37.0
Turbidity, Fd (NTU)	0.1	8	31.1	22.7	12.2	82.2
ORP (mV)	1	8	406	395	334	495
Sp. Cond. (umho/cm)	1	8	1452	1414	1334	1652
Oxygen, Diss (mg/l)	0.1	8	10.2	10.3	6.3	12.7
O2 Sat, Diss (%)	0.1	8	110.7	118.2	68.4	151.3
CBOD 5-Day (mg/l)	0.8	9	3.7	4.0	0.0	7.0
pH (SU)	0.1	8	8.2	8.3	7.4	8.4
Alkalinity, Tot (mg/l)	0.6	9	343	346	285	405
Solids, Susp. Tot (mg/l)	4	8	1079	1065	954	1240
Solids, Dissolved (mg/l)	1	8	59	42	27	119
Ammonia, Tot (mg/l)	0.02	8	0.11	n.d.	n.d.	**0.85**
Kjeldahl, Tot (mg/l)	0.03	8	1.63	1.53	1.21	2.69
NO2+NO3, Tot (mg/l)	0.03	8	0.02	n.d.	n.d.	0.11
Phos, Tot (mg/l)	0.005	8	0.24	0.22	0.09	0.43
Phos, Diss (mg/l)	0.01	8	0.07	0.06	n.d.	0.19
Ortho, Phos, Diss. (mg/l)	0.003	8	0.07	0.06	n.d.	0.18
TOC (mg/l)	0.2	8	11.9	12.2	6.9	15.1
DOC (mg/l)	0.2	8	11.3	12.2	6.8	15.1
Sulfate, Diss (mg/l)	0.05	8	456	446	375	556
Iron, Tot (ug/l)	10	7	1203	950	640	2650
Iron, Diss (ug/l)	10	7	11	n.d.	n.d.	30
Manganese, Tot (ug/l)	3	7	666	620	270	960
Manganese, Diss (ug/l)	3	7	309	200	120	530
CDOM (ug/l)	10	8	86	85	48	132
Chlorophyll a (ug/l)	6	7	27	23	17	49

Releases

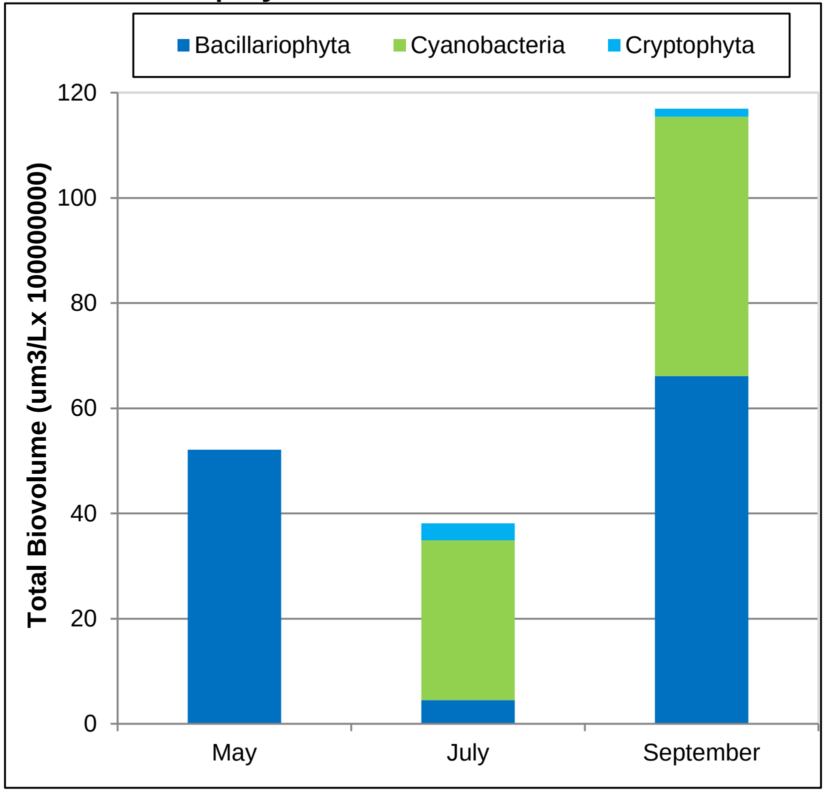
Parameter	Det.Limit	No. Obs.	Mean	Median	Minimum	Maximum
Water Temp (°C)	0.1	5	18.6	20.5	3.3	25.9
Stream Flow (cfs)	0.1	5	78.2	78.3	11.2	156.0
Turbidity, Fd (NTU)	0.1	5	60.9	14.8	0.0	249.2
ORP (mV)	1	5	355	358	308	397
Sp. Cond. (umho/cm)	1	5	1363	1320	1301	1548
Oxygen, Diss (mg/l)	0.1	5	9.4	9.3	8.2	11.4
O2 Sat, Diss (%)	0.1	5	104.0	100.3	87.6	118.9
CBOD 5-Day (mg/l)	0.8	4	6.3	5.0	4.0	11.0
pH (SU)	0.1	5	8.6	8.4	7.7	**9.7**
Alkalinity, Tot (mg/l)	0.6	4	252	246	242	272
Solids, Dissolved (mg/l)	1	4	947	954	912	968
Solids, Susp. Tot (mg/l)	4	4	27	27	14	39
Ammonia, Tot (mg/l)	0.02	4	0.20	0.20	0.10	0.30
Kjeldahl, Tot (mg/l)	0.03	4	2.27	2.19	1.64	3.05
NO2+NO3, Tot (mg/l)	0.03	4	0.12	0.04	n.d.	0.38
Phos, Tot (mg/l)	0.005	4	0.21	0.18	0.05	0.44
Phos, Diss (mg/l)	0.01	4	0.13	0.11	0.01	0.29
Ortho, Phos, Diss. (mg/l)	0.003	4	0.12	0.09	0.02	0.27
TOC (mg/l)	0.2	4	14.6	14.4	13.7	15.8
DOC (mg/l)	0.2	4	14.3	14.3	13.2	15.6
Sulfate, Diss (mg/l)	0.05	4	460	462	448	466
Iron, Tot (ug/l)	10	4	230	165	80	510
Iron, Diss (ug/l)	10	4	n.d.	n.d.	n.d.	n.d.
Manganese, Tot (ug/l)	3	4	700	610	470	1110
Manganese, Diss (ug/l)	3	4	508	475	390	690

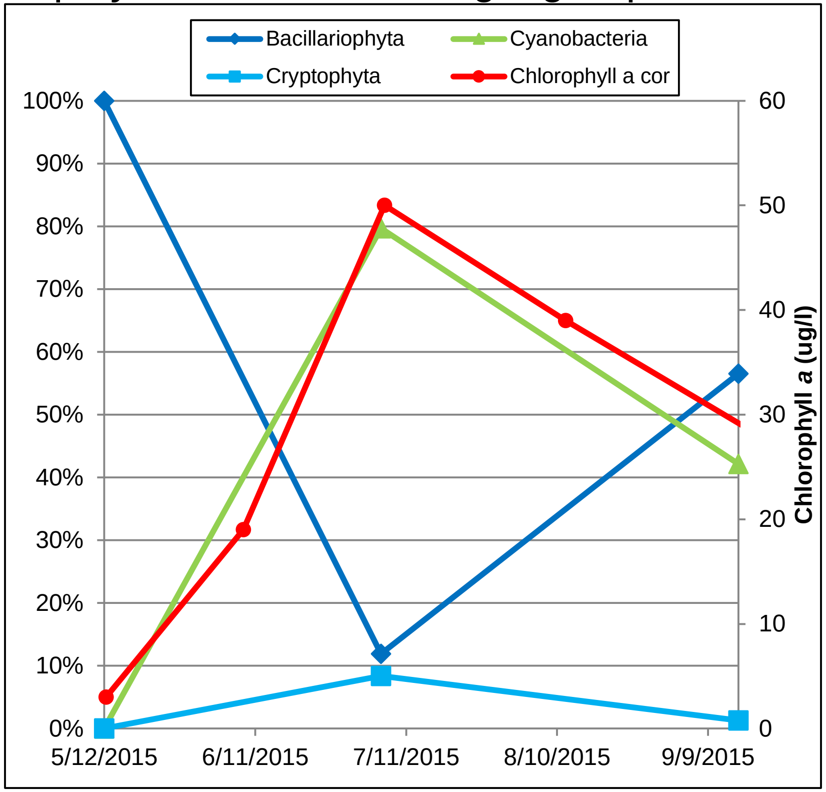
Inflow and Outflow Sample Results

- During the early growing season very little DIN was observed in inflow samples. This is likely due to sample collection during periods of low flow and denitrification.
- The low level gate was not open during the August reservoir releases sample event. The high pH values observed reflect conditions observed in the bottom of the water column.

Phytoplankton Data

- Diatoms dominate in May; once DIN concentrations are depleted and water temperature rises Cyanobacteria dominate the algal assemblage.
- Chlorophyll *a* concentrations are shown to display interaction with algal groups.

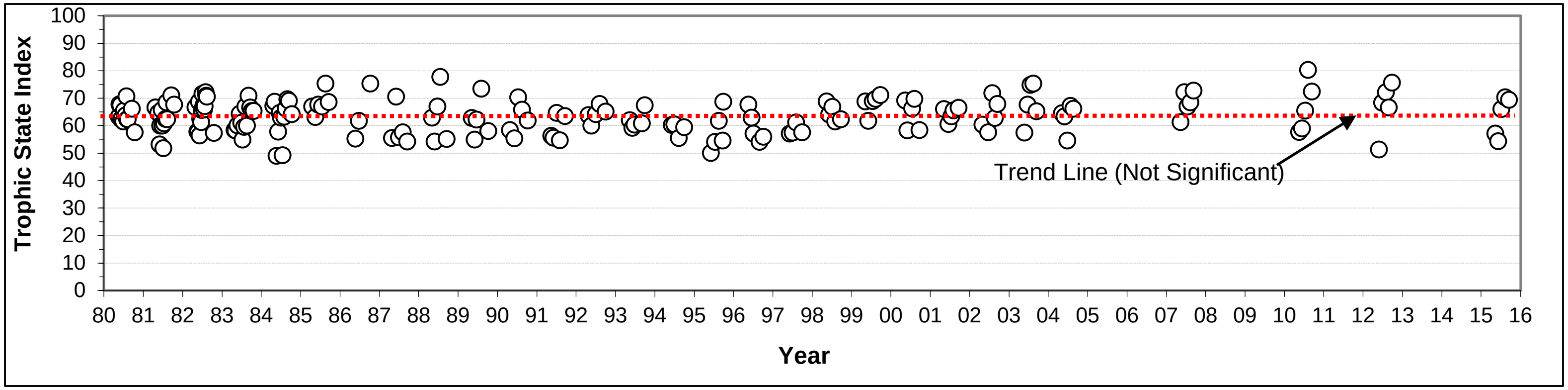




2015 Intensive Survey (Discussion)

- DO depletion under ice cover is likely caused by eutrophication. The sediment oxygen demand outweighs the reservoir supply.

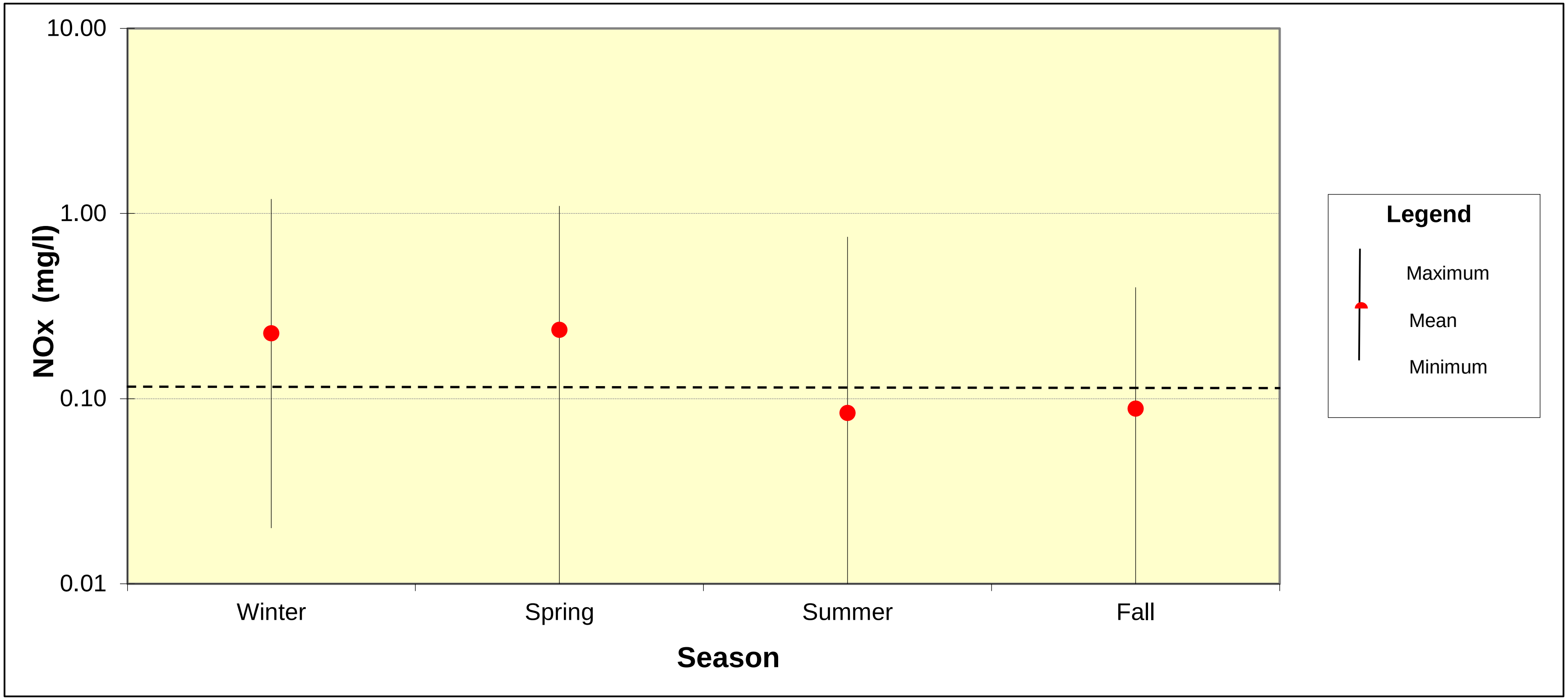
- Using Carlsons Trophic State Index (1977), Pipestem Reservoir has remained eutrophic to hypereutrophic with no significant trend since it was filled. The conditions measured in 2015 are in line with these results.



- The internal nutrient load likely plays a significant role in the reservoir nutrient budget.

2015 Intensive Survey (Discussion)

- 2015 and historical inflow nutrient concentrations follow a characteristic pattern similar to those observed in some streams of the Upper Mississippi River (Lee et al., 2012).



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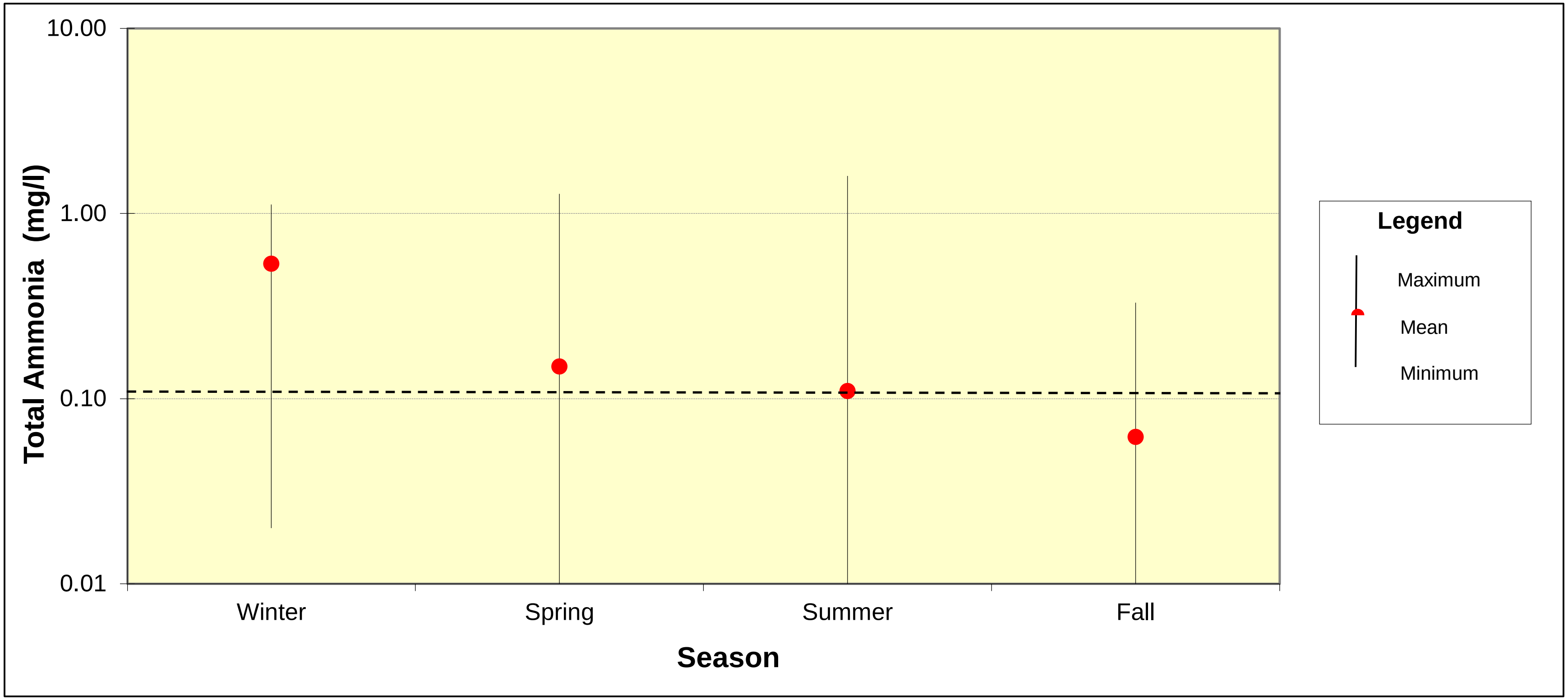
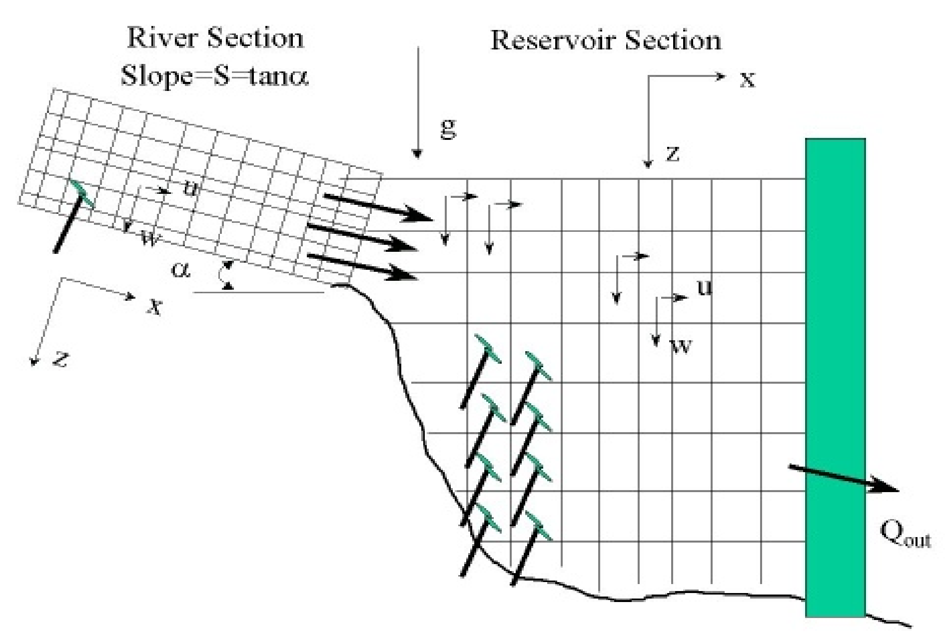
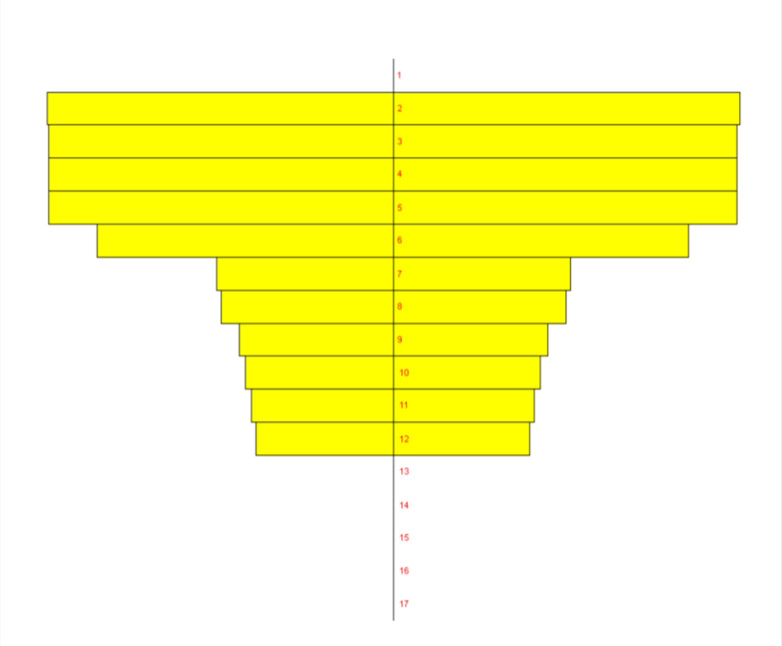


CE-QUAL-W2 MODEL (W2)

Side View	End View
	

- Unsteady flow two-dimensional hydrodynamic and water quality model

W2 Model Application

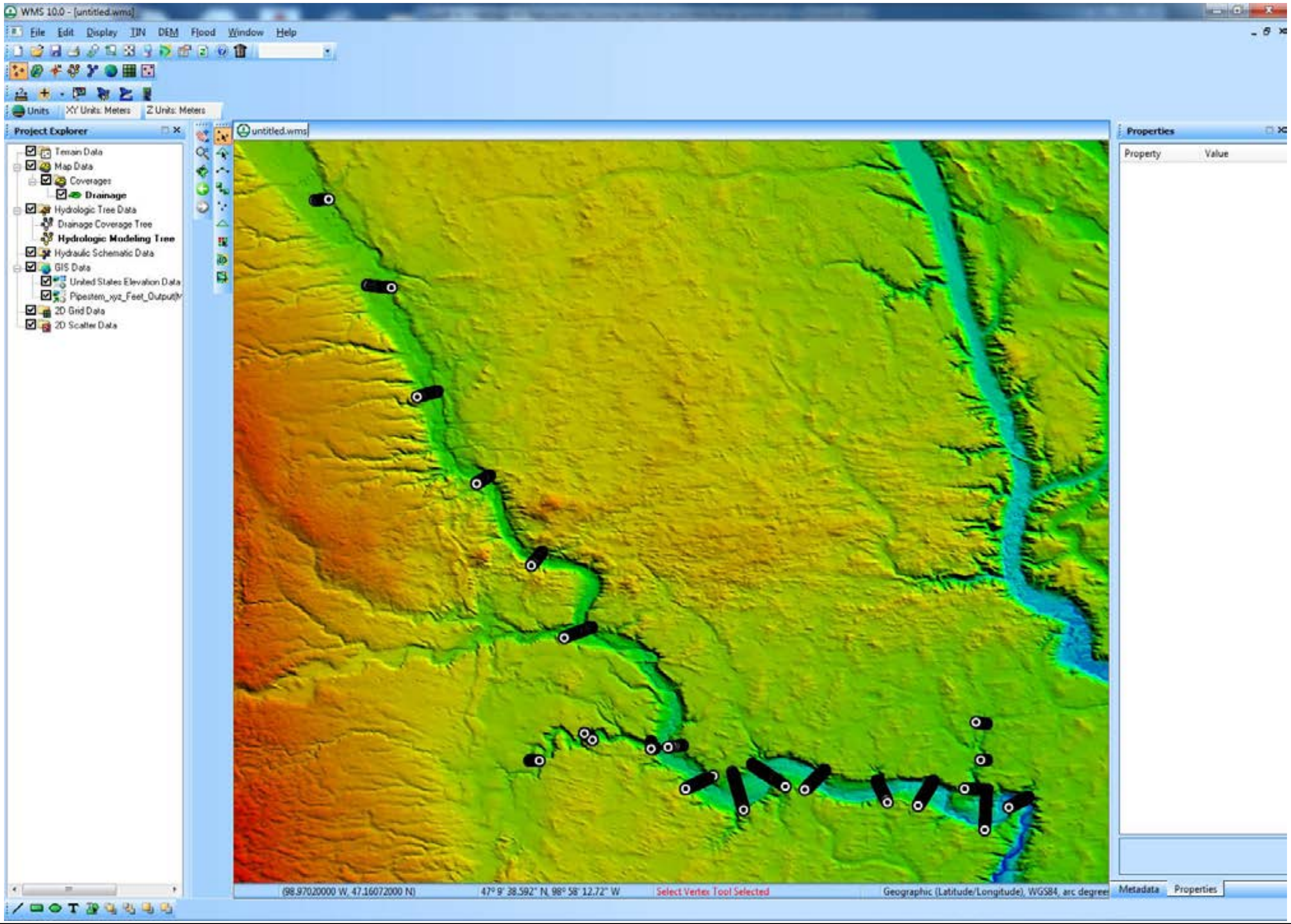
- Application of the W2 model is data intensive. The Pipestem Reservoir model is being done with the very minimum requirements necessary for WQ constituents to be simulated. More frequent inflow sampling will be necessary in the future if the model is to be further refined.
- "Garbage in, garbage out."
- Model input data includes engineering data, bathymetric survey data, hourly to sub-hourly meteorological data, flow data, inflow temperature data, water surface elevation data, and WQ field and constituent data at varying depths for calibration.
- A good understanding of the processes occurring in the reservoir and influent stream.

Pipestem Reservoir W2 Model Bathymetry

- The W2 bathymetry for Pipestem was generated using the Watershed Modeling System version 10 (WMS) and USACE survey data collected in 2002.
  - WMS is a computer environment for hydrologic analysis
  - Developed by BYU and USACE and currently maintained by AQUAVEO LLC.
  - Provides state of the art tools and GUI for many models (W2, HEC-HMS, HEC-RAS, HSPF, SWMM, Other Abbr.)
  - Very user friendly compared to other methods for creating a W2 bathymetry file. User guide was very strait forward.
  - W2 bathymetry effects everything else in the model.

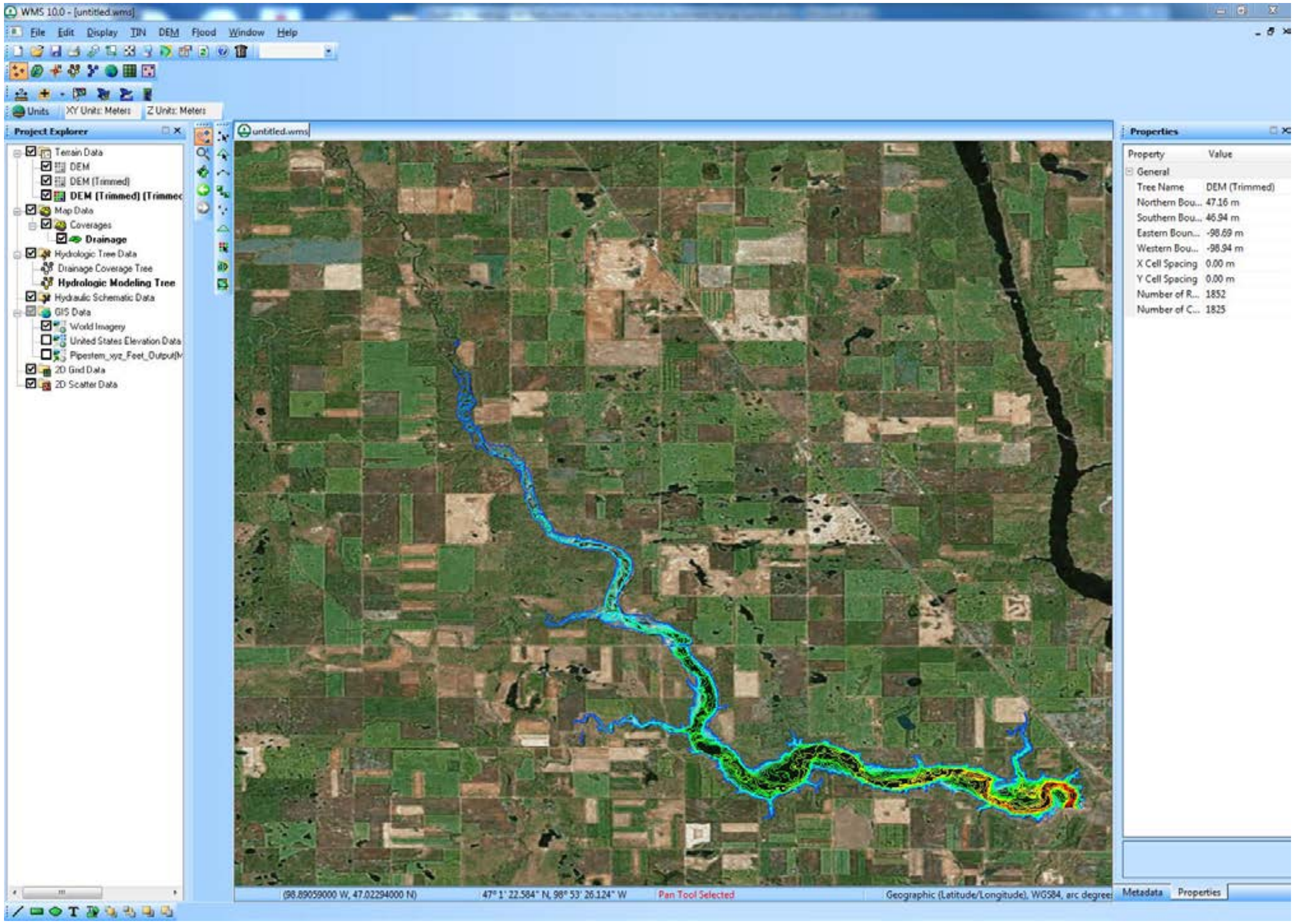
Pipestem Reservoir W2 Model Bathymetry

- United States Elevation Data (NED) (10m Resolution) in WMS



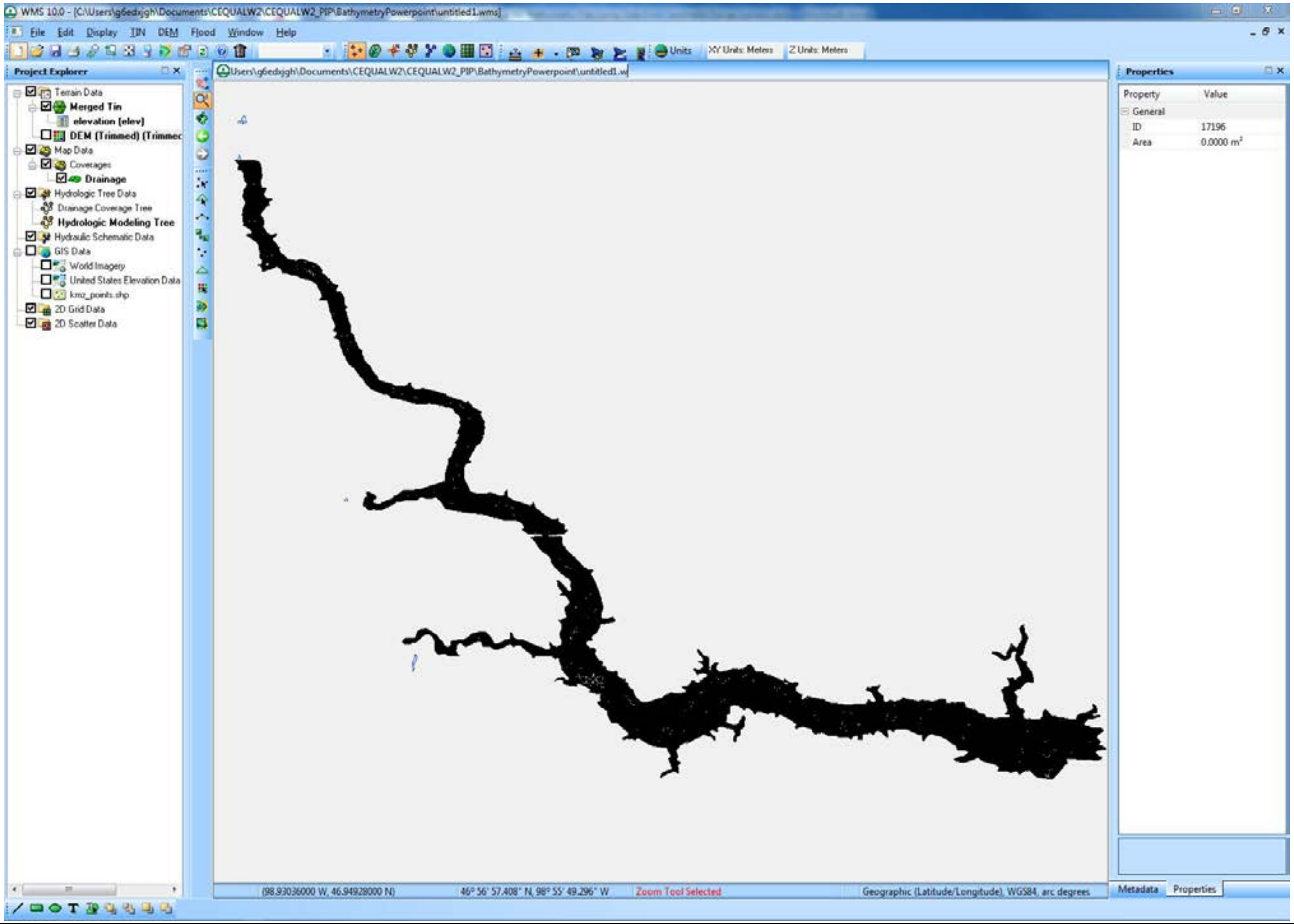
Pipestem Reservoir W2 Model Bathymetry

- DEM with survey data incorporated, contours, and Imagery in WMS



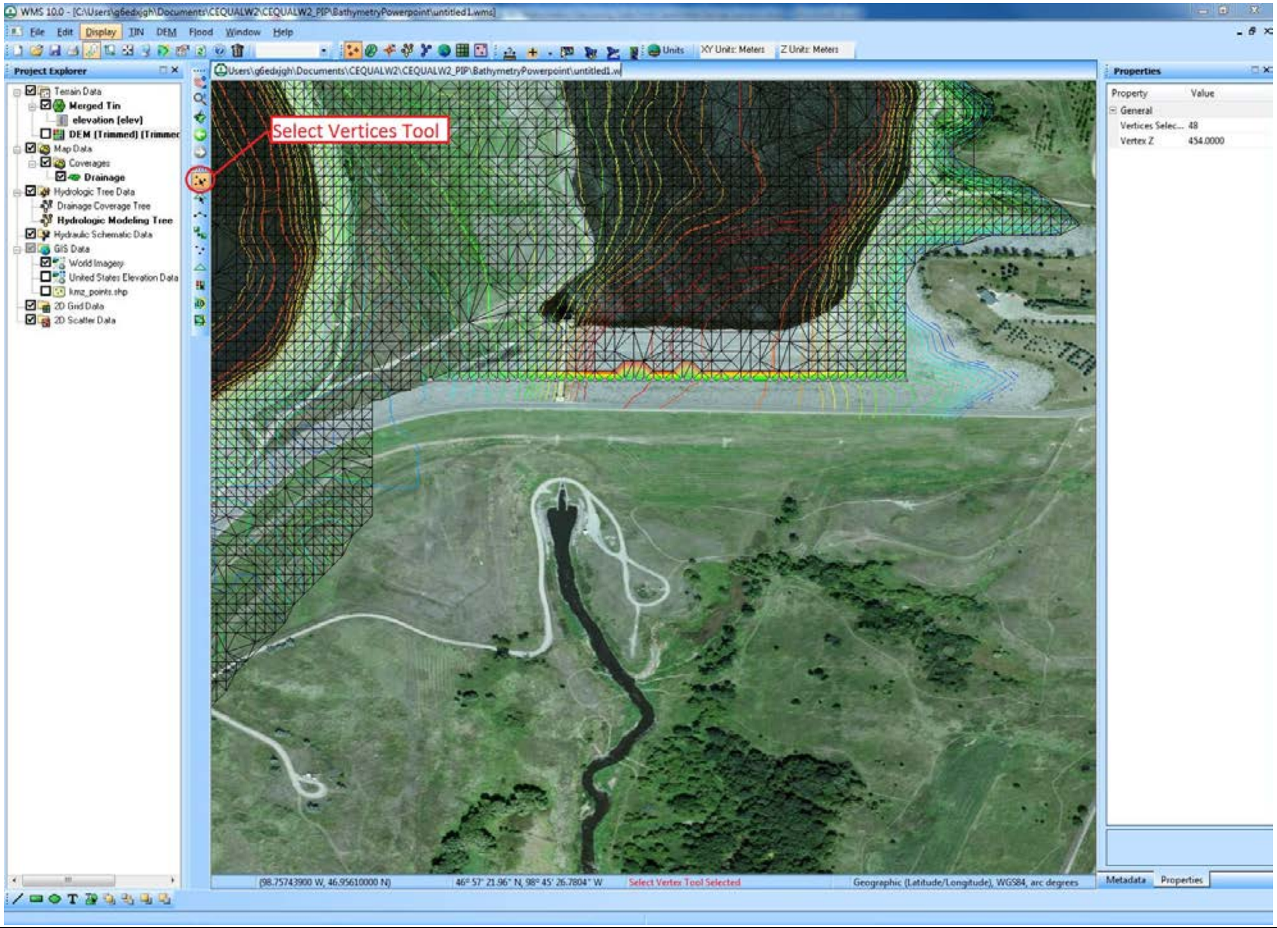
Pipestem Reservoir W2 Model Bathymetry

- TIN created in WMS



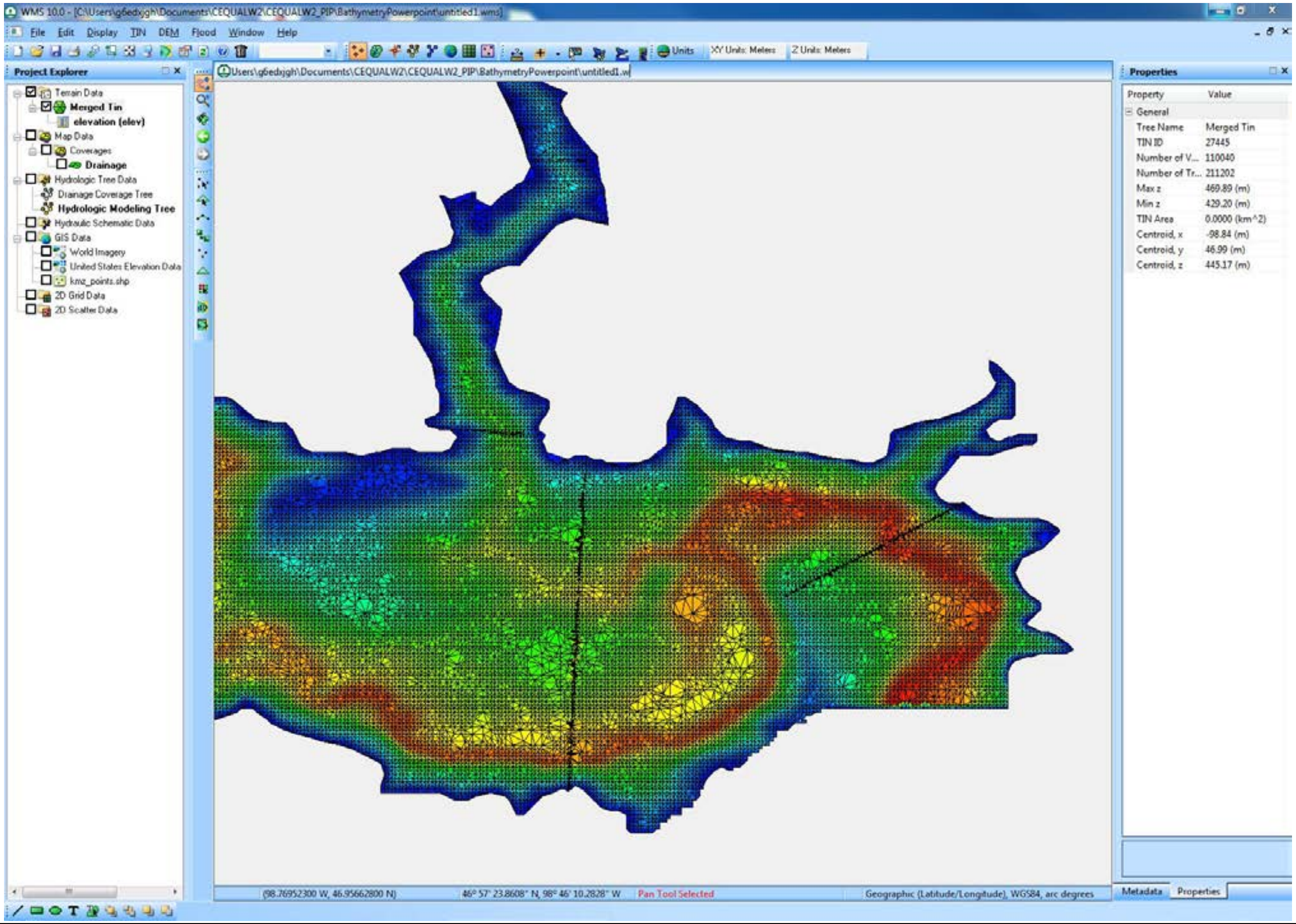
Pipestem Reservoir W2 Model Bathymetry

- Correcting the TIN vertices and Imagery in WMS



Pipestem Reservoir W2 Model Bathymetry

- Edited TIN near the dam with solid filled contours in WMS.



Pipestem Reservoir W2 Model Bathymetry

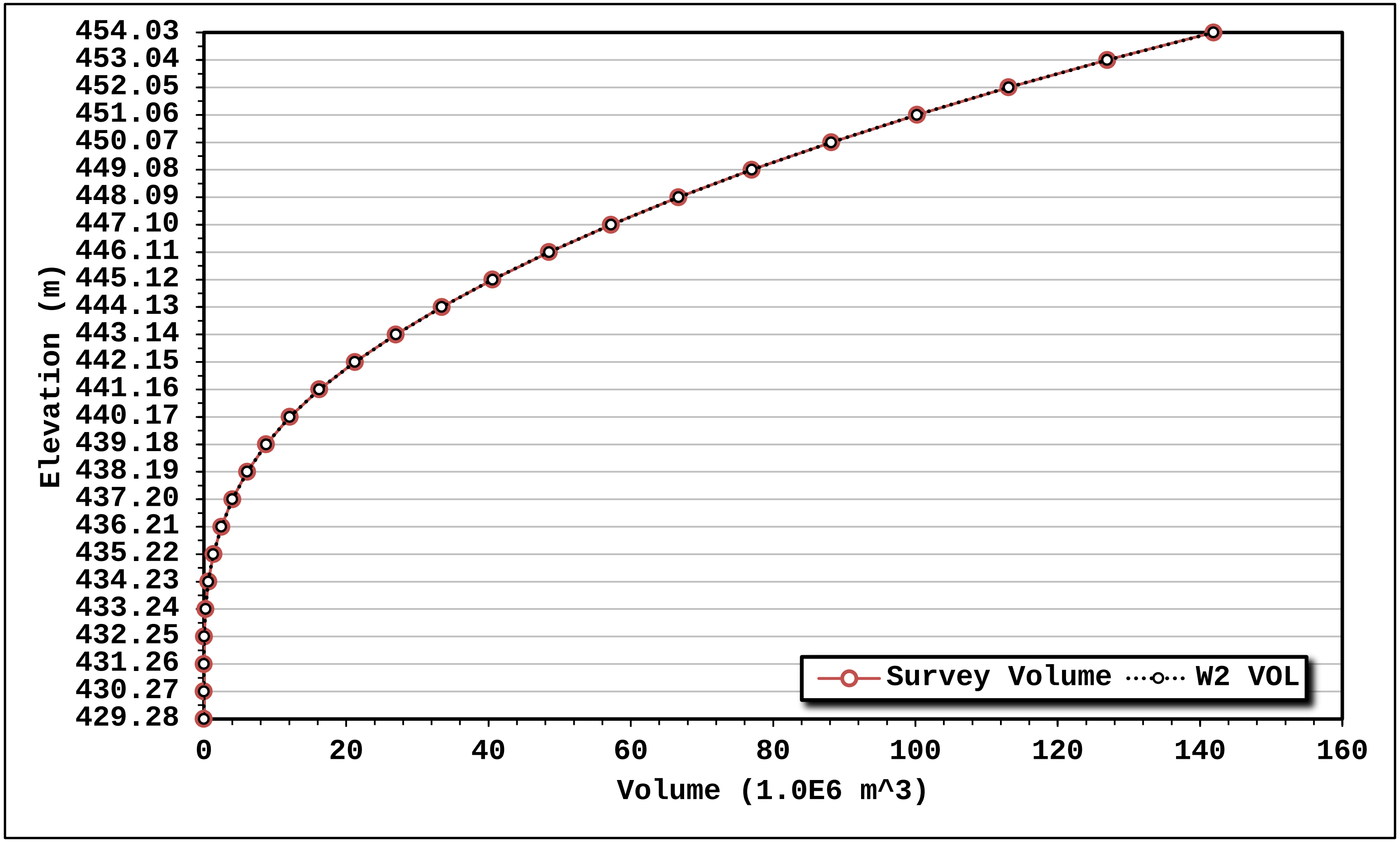
- Completed Bathymetry in Google Earth (image date 08/20/2006).

Pipestem Reservoir W2 Model Bathymetry

- Completed Bathymetry in Google Earth (image date 09/06/2011).

Pipestem W2 Model Bathymetry

- W2 model vs. observed storage capacity curves.



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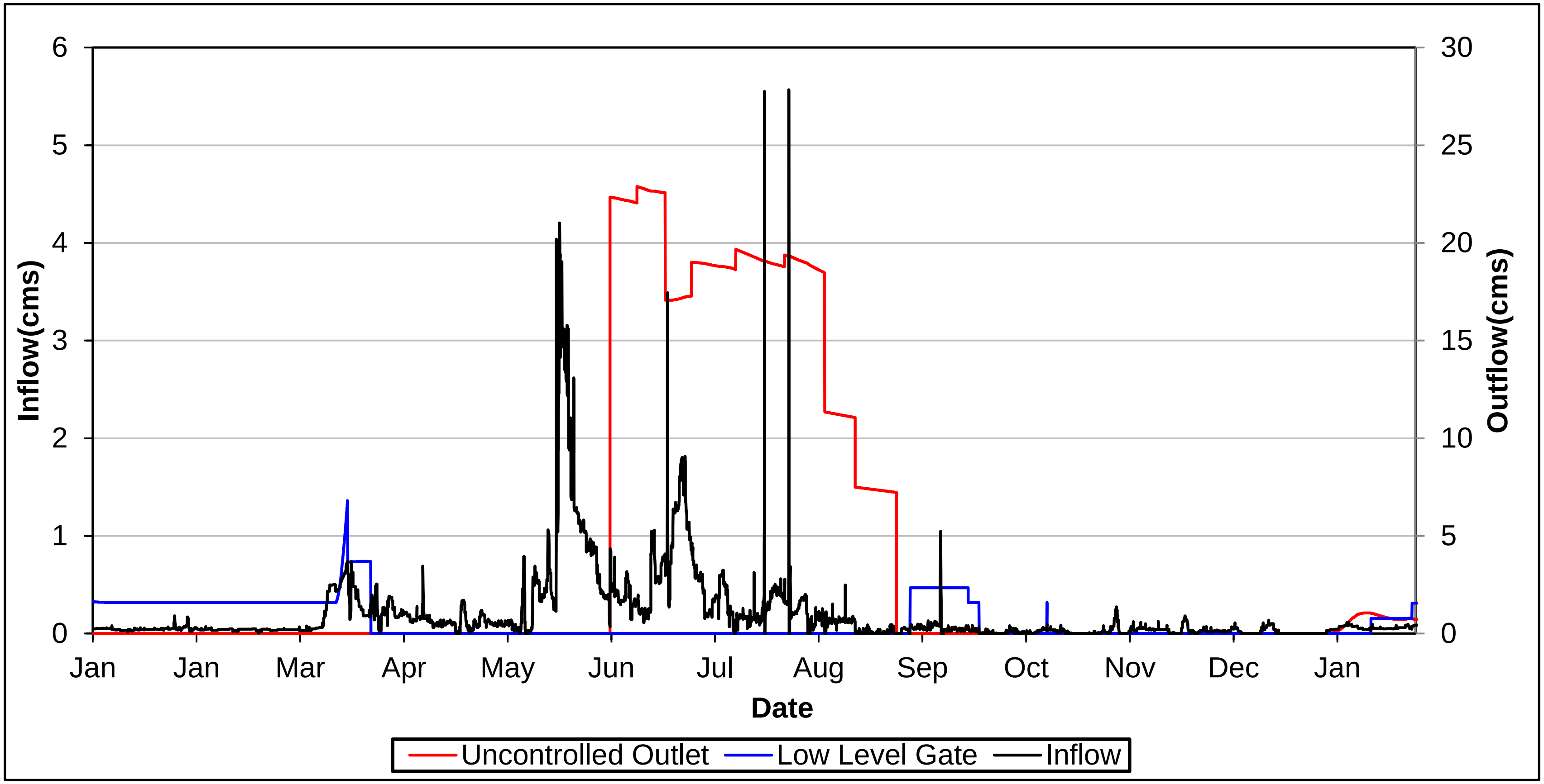
Pipestem W2 Model Meteorological Data

- Sub-hourly data from the Jamestown Airport was used for temperature, dew point, wind speed, cloud cover, and sky condition.
- Cloud Cover and sky condition were used to estimate model cloud cover on a 0-10 scale.
- Wind speed and direction measurements were taken when collecting samples to correlate actual lake conditions to those measured at the Jamestown Airport.
- Wind sheltering for each model segment was then adjusted according to the difference in measured wind speed lake conditions and the Jamestown Airport.

Pipestem W2 Model Flow Data

- Inflow and outflow data were obtained using the Corps Water Management System (CWMS).

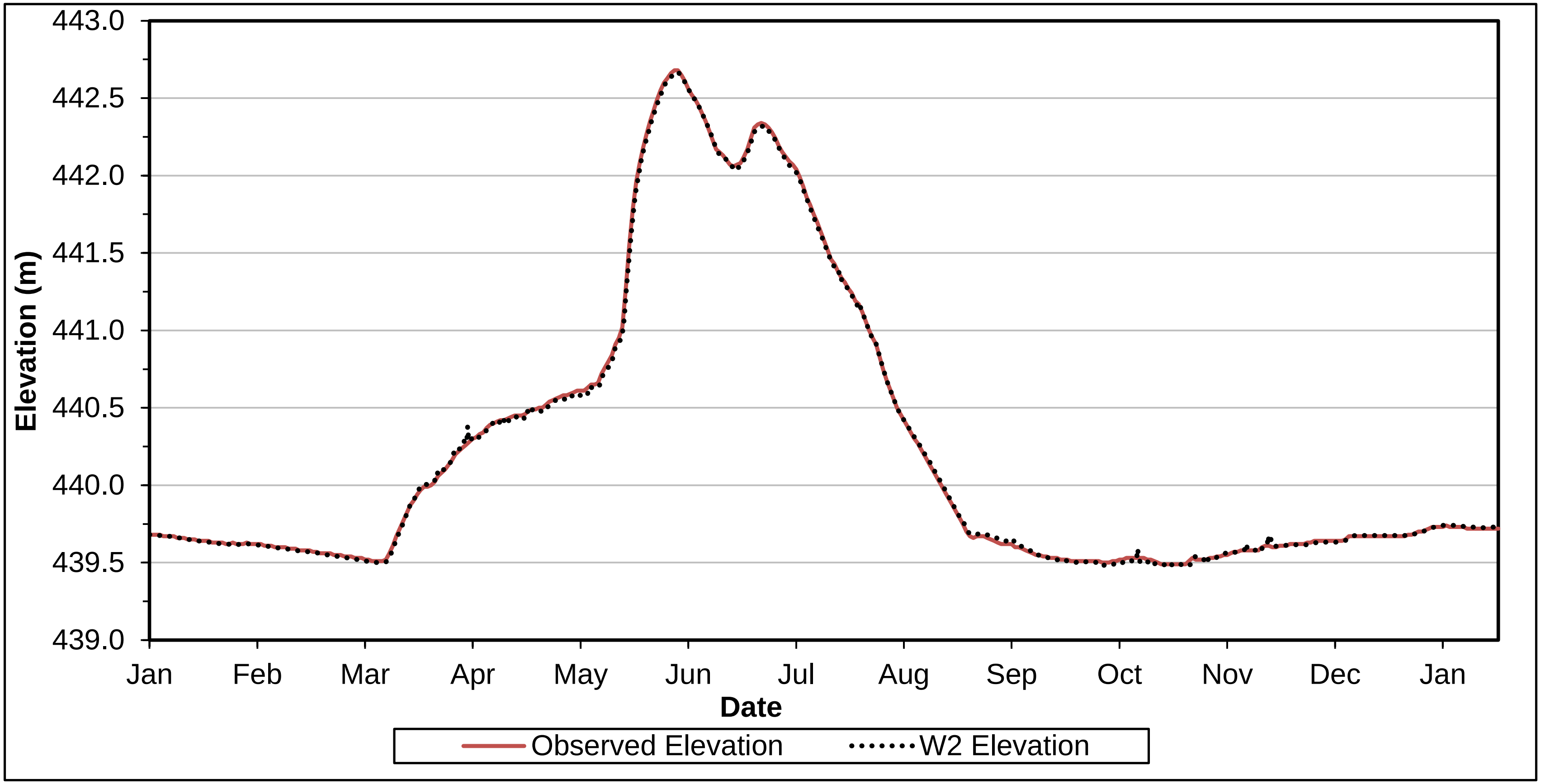


Pipestem W2 Model Calibration

- Does the model reproduce the observed physical, chemical, and biological conditions in the reservoir?
  - Hydrodynamic Calibration
  - Thermal Calibration
  - Water Quality Constituent Calibration (includes algal assemblage)
- The required model accuracy depends on use.

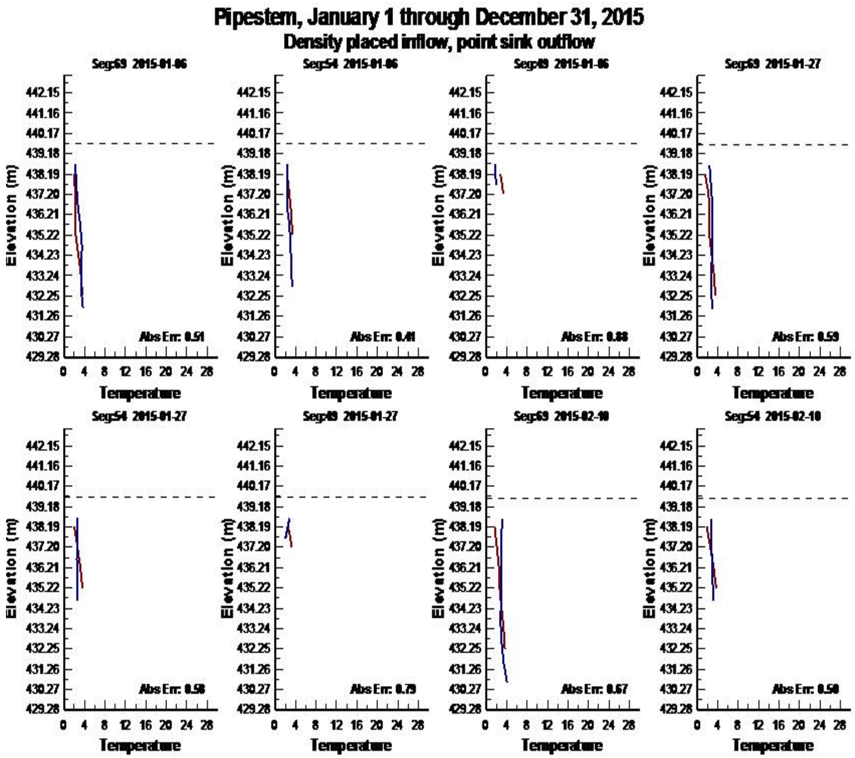
Pipestem W2 Model Calibration

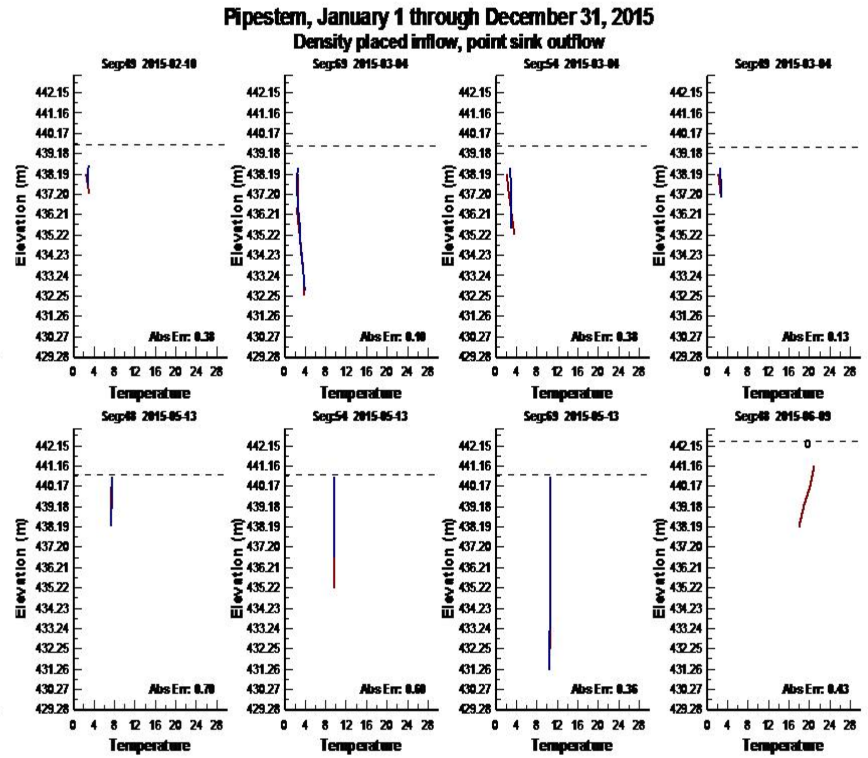
- Hydrodynamic Calibration



Pipestem W2 Model Calibration

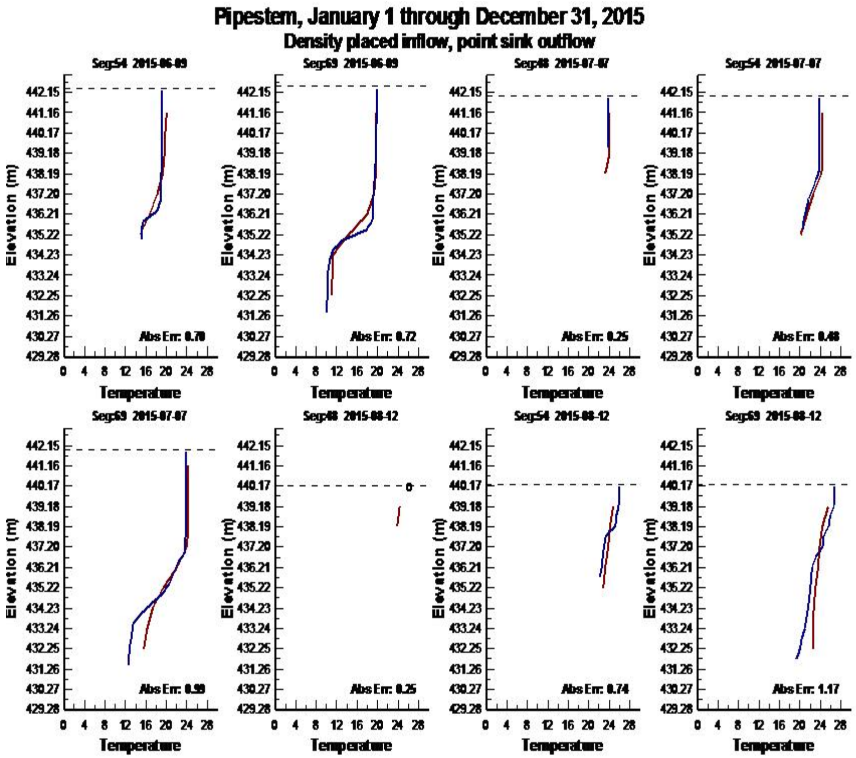
- Thermal Calibration, Error = 0.58°C

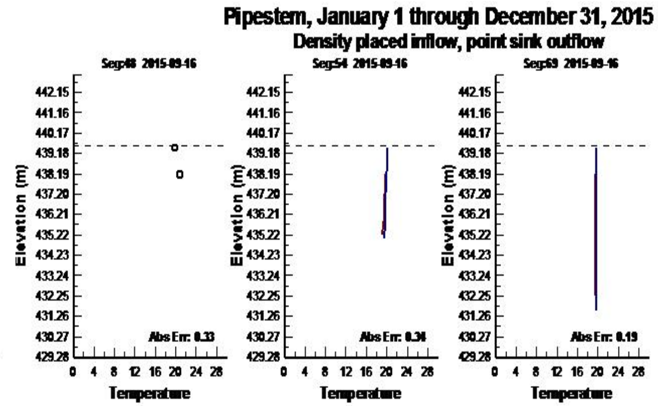




Pipestem W2 Model Calibration

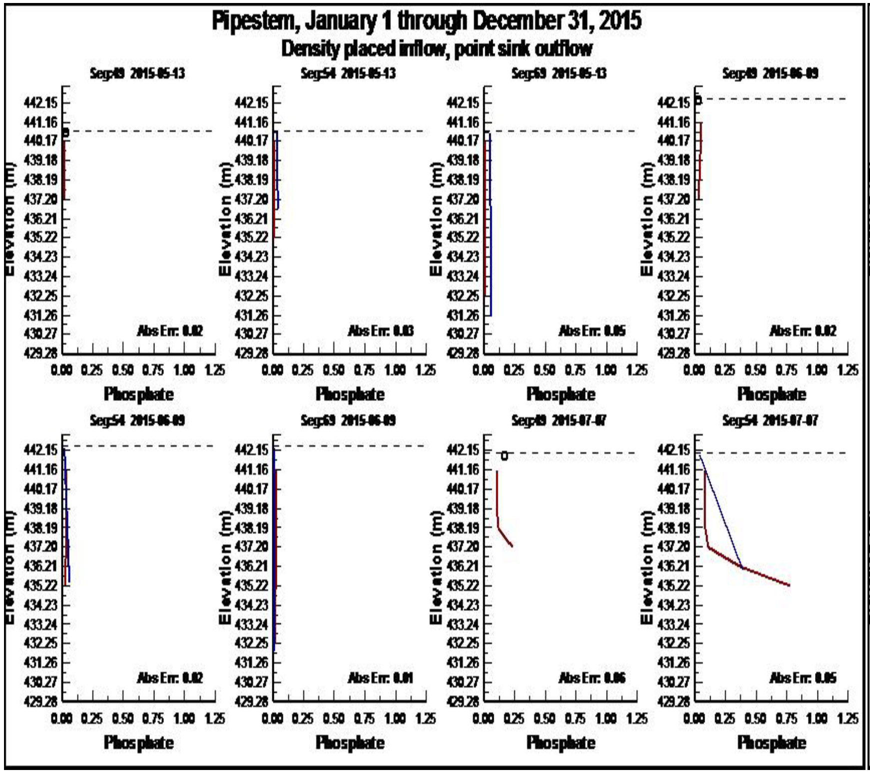
- Thermal Calibration, Error = 0.58°C

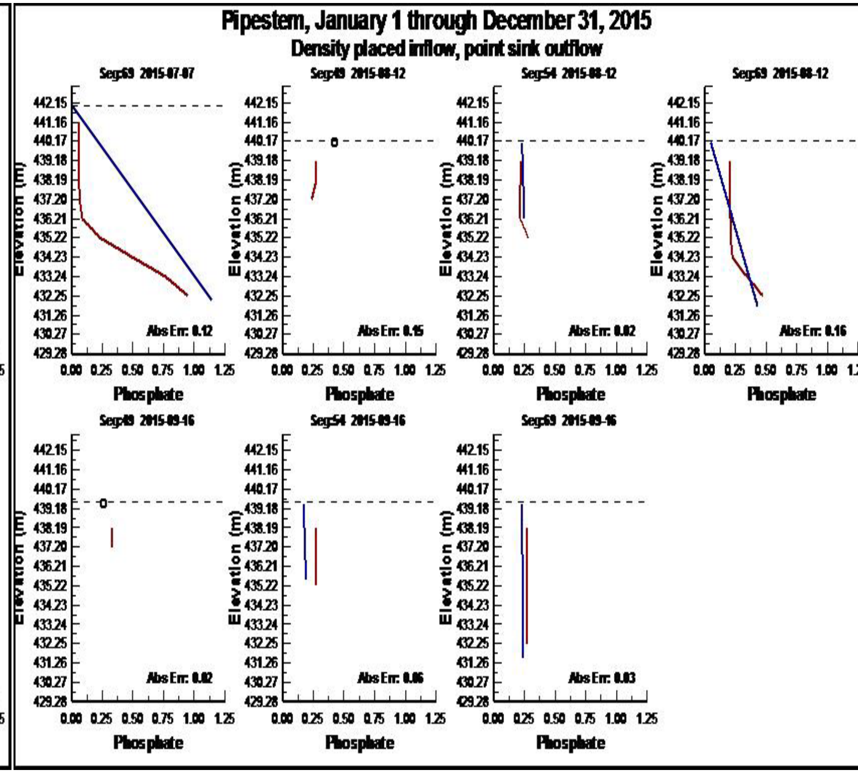




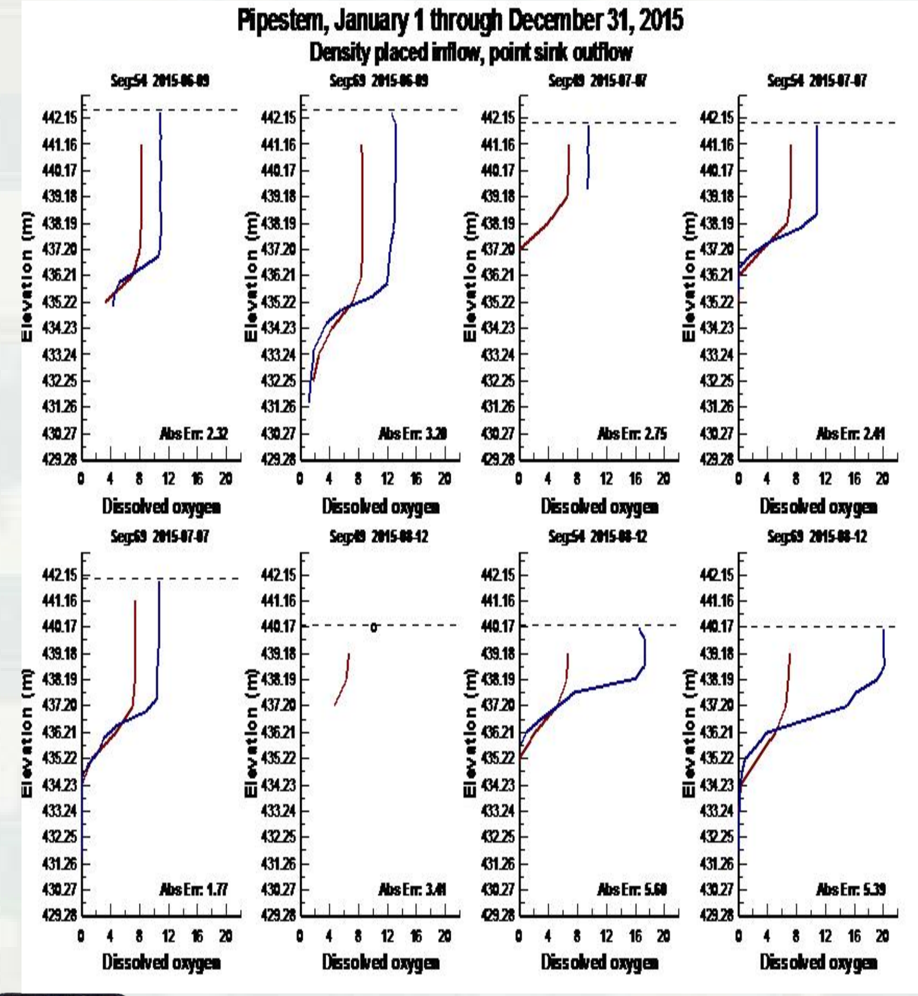
Pipestem W2 Model Calibration

- WQ Constituent Calibration, PO_4 = 0.05 mg/l





Pipestem W2 Model Calibration



- Do calibration does not reflect supersaturated conditions. Error = 2.0 mg/l.

Future Actions

- The SOD and inflow constituents must be better characterized during the winter months.
- Further Calibration of the model is necessary to accurately simulate epilimnetic DO super-saturation during algal blooms.
- Scenario testing of the effects of utilizing the low level gate.

Citations

Carlson, R.E., 1977, A trophic state index for lakes. *Limnology and Oceanography*. 22:2 361--369.

Lee, K.E., Lorenz, D.L., Petersen, J.C., and Greene, J.B., 2012, Seasonal patterns in nutrients, carbon, and algal responses in wadeable streams within three geographically distinct areas of the United States, 2007–08: U.S. Geological Survey Scientific Investigations Report 2012–5086, 55 p.