Considerations About Raising the Winter Minimum Pool Elevation

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- Raising the minimum pool elevation could affect water quality and fish habitat.
- Without sufficient pool level decrease in the winter, organic matter can build up in the sediments at the upper parts of the reservoir and cause more “internal nutrient cycling”, especially in the Little Saluda embayment.

The CE-QUAL-W2 Model was Used to Assess Lake Murray Impacts

- The CE-QUAL-W2 model was used to evaluate holding the pool elevation up through out the year to determine the effects on water quality and fish habitat.
- The model that was setup for eight years to evaluate the effects of operations on water quality and fish habitat was used to assess how water quality would be affected by setting the minimum pool elevation to that being considered under relicensing.
- The evaluation assessed striped bass habitat in the main body of the lake and temperature and DO in the releases.
- The model was used to assess potential water quality concerns in the Little Saluda embayment.

Evaluation of Raised Pool Levels

Scenarios Considered:

- 354(Jan1) to 358(May1⇨Sept1) to 354(Dec 31)
- 350(Jan1) to 358(May1⇨Sept1) to 350(Dec 31)

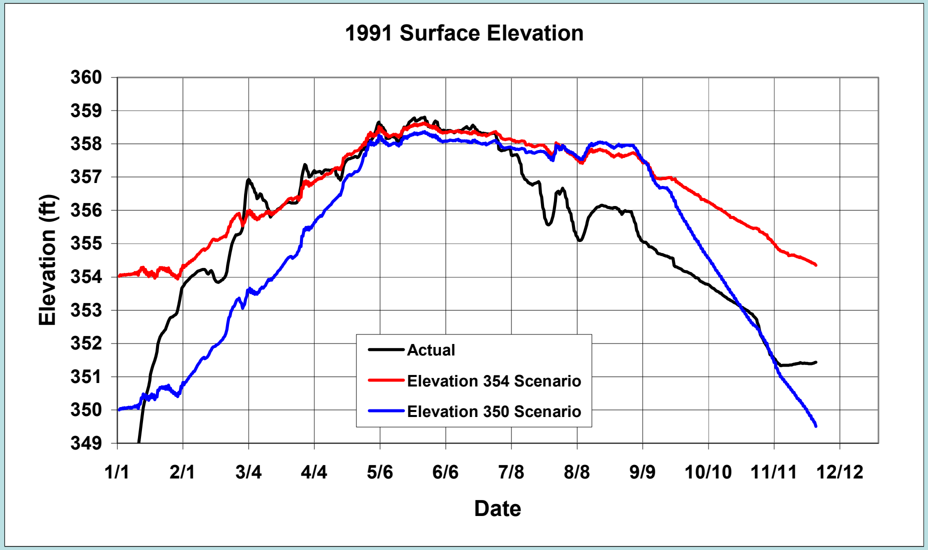
Assumptions:

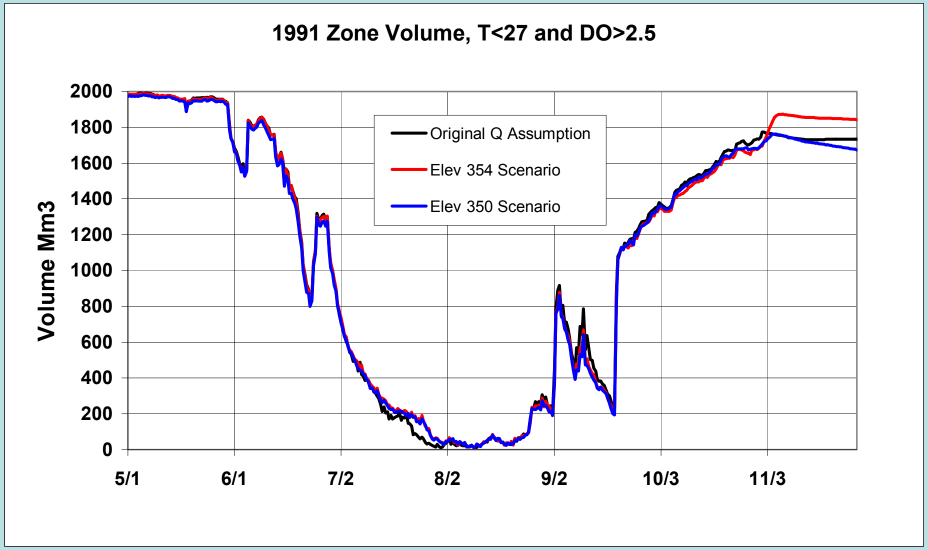
- Assumed 500 cfs for minimum release
- Assumed reserve generation averaged 3hr every two weeks at 18,000 cfs
- Balance of releases were assumed to be used to supplement system demand

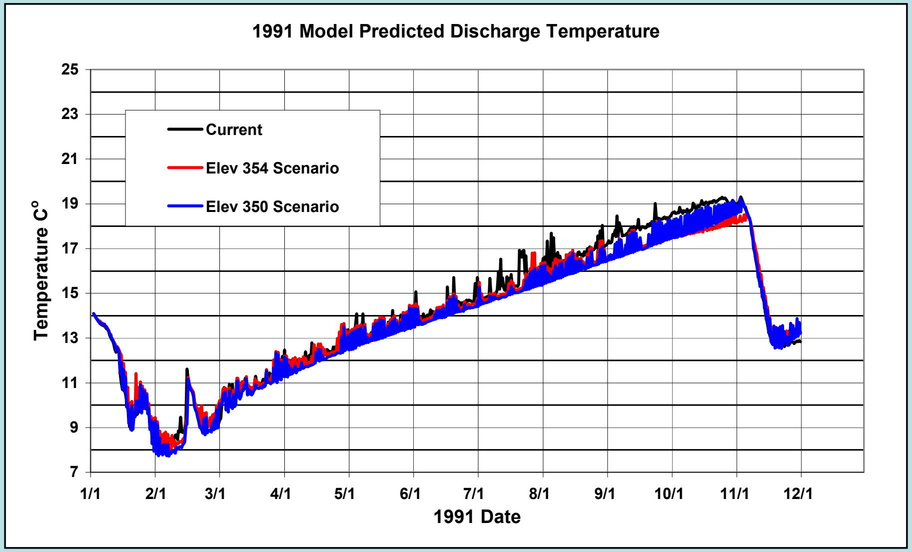
Approach:

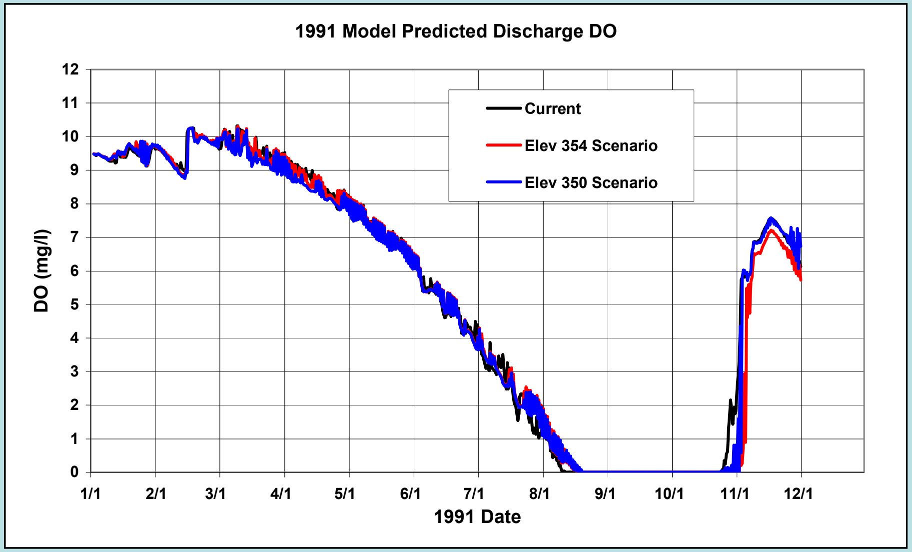
- The above scenarios were developed by KA using daily average flows using HEC-ResSim
- CE-QUAL-W2 was run using daily average flows and release flows were adjusted so that target pool levels were attained
- Using the daily average flows that were adjusted using the CE-QUAL-W2 model the hourly flows for each day were developed using the assumptions above

1991 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO

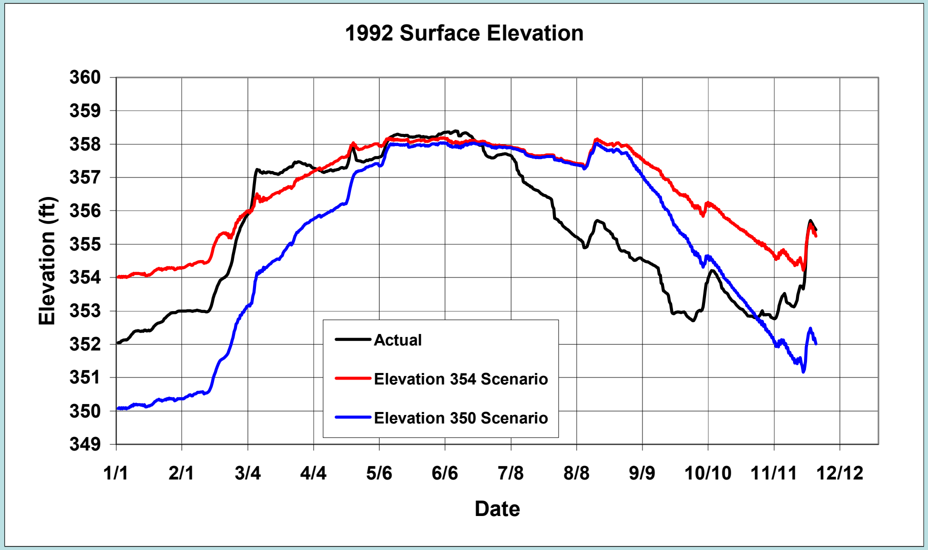


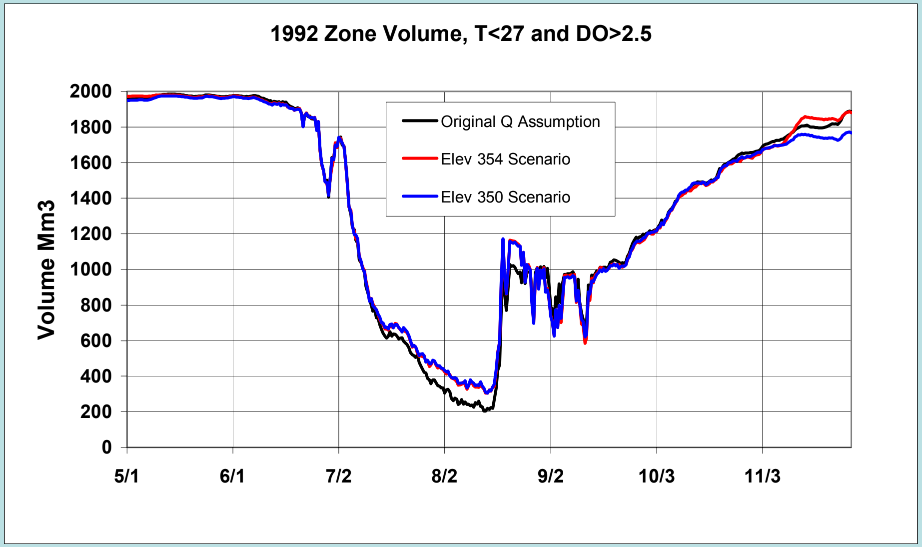


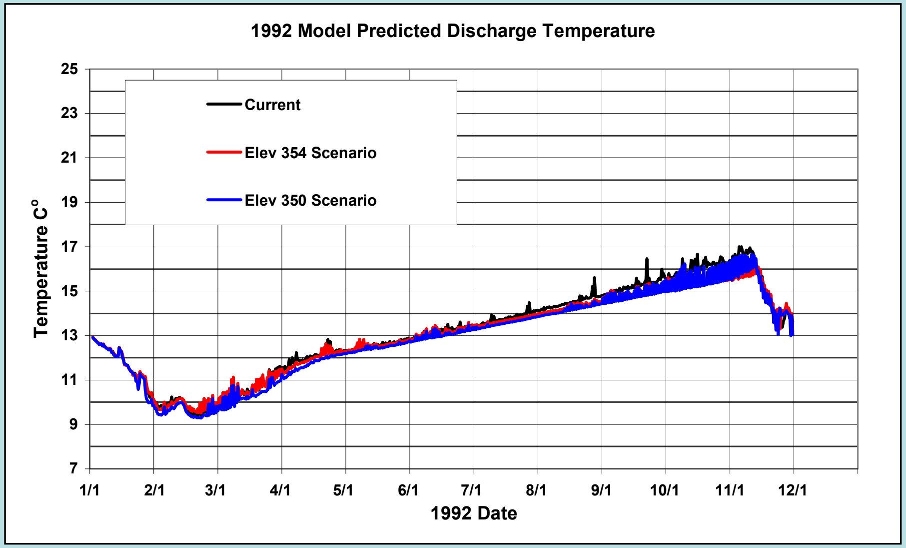


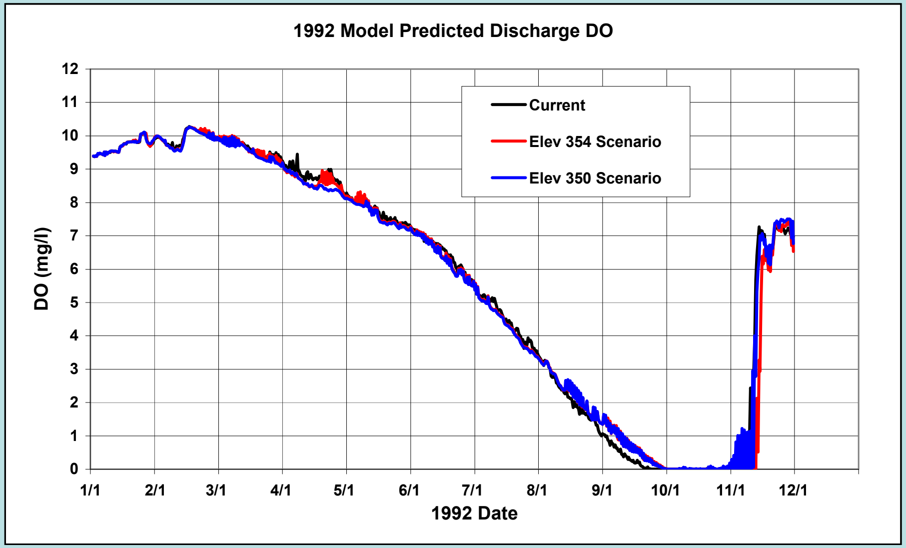


1992 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO

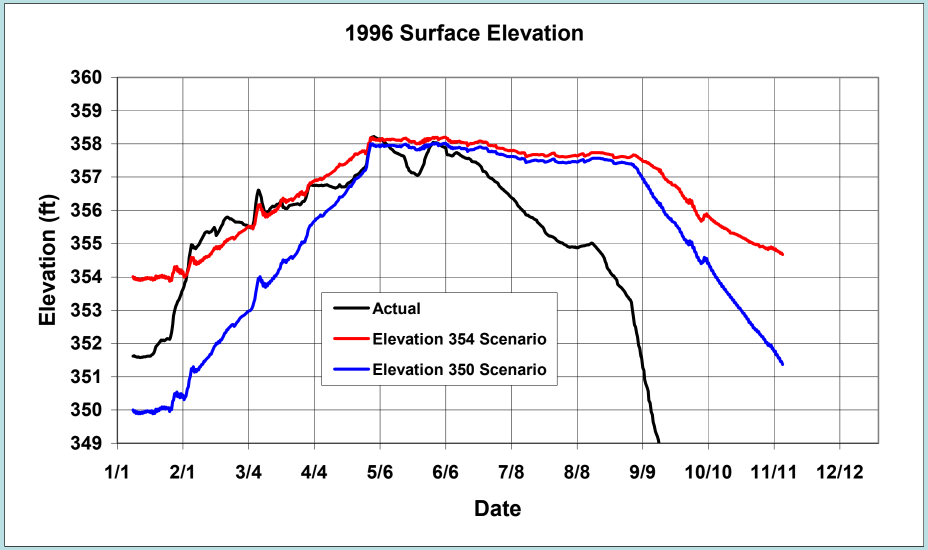


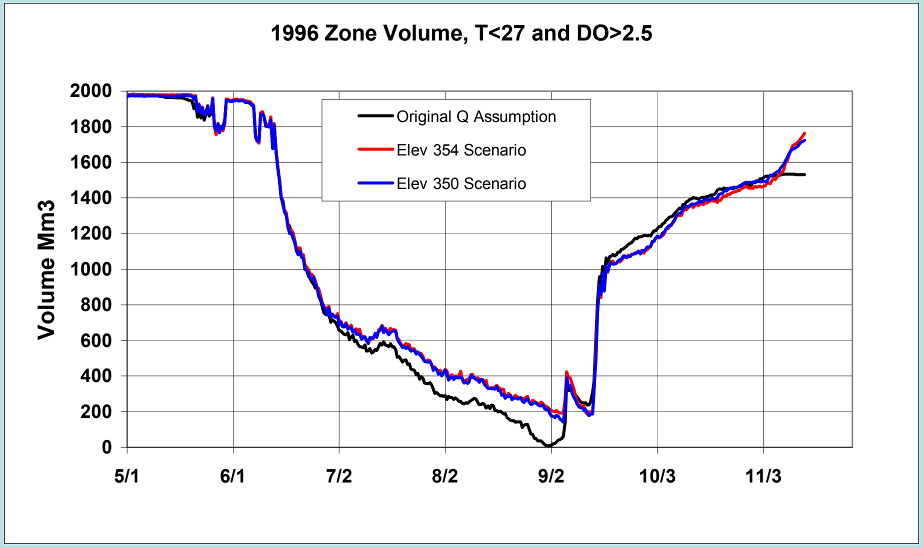


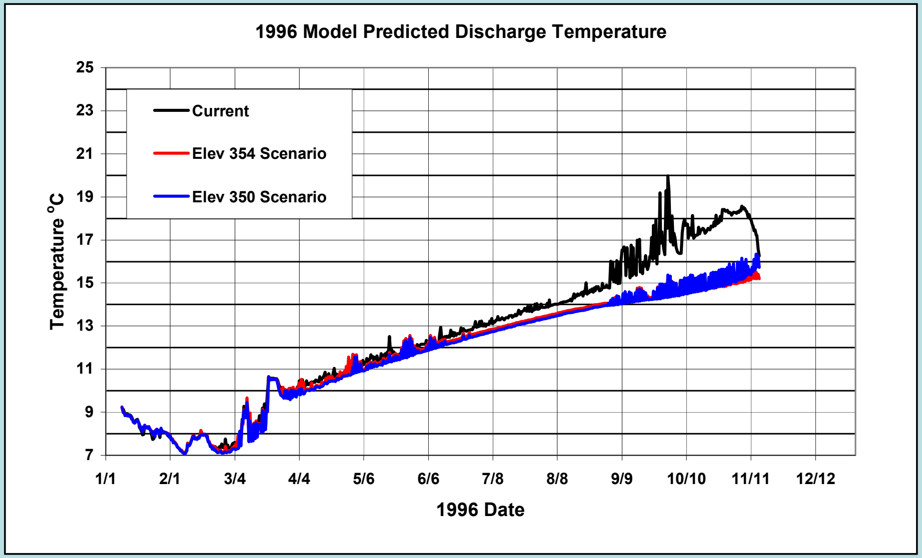


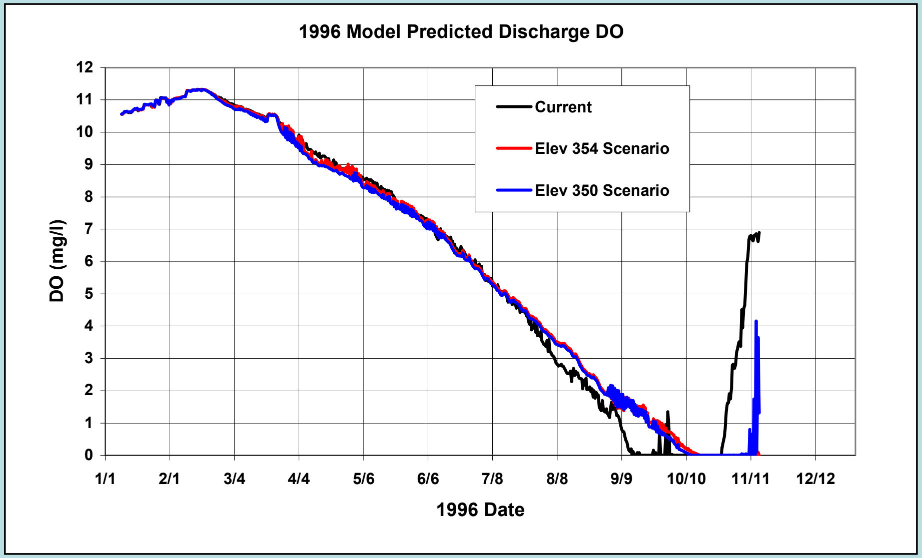


1996 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO

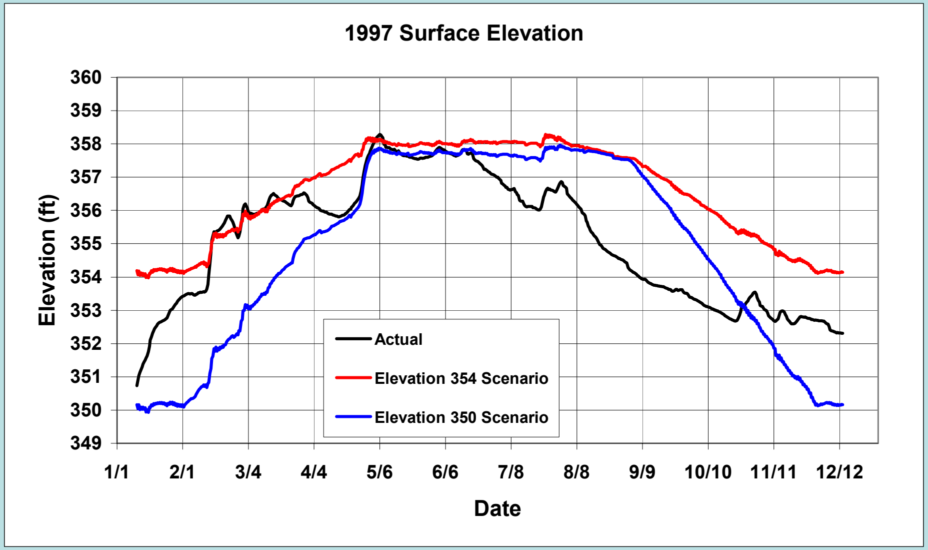


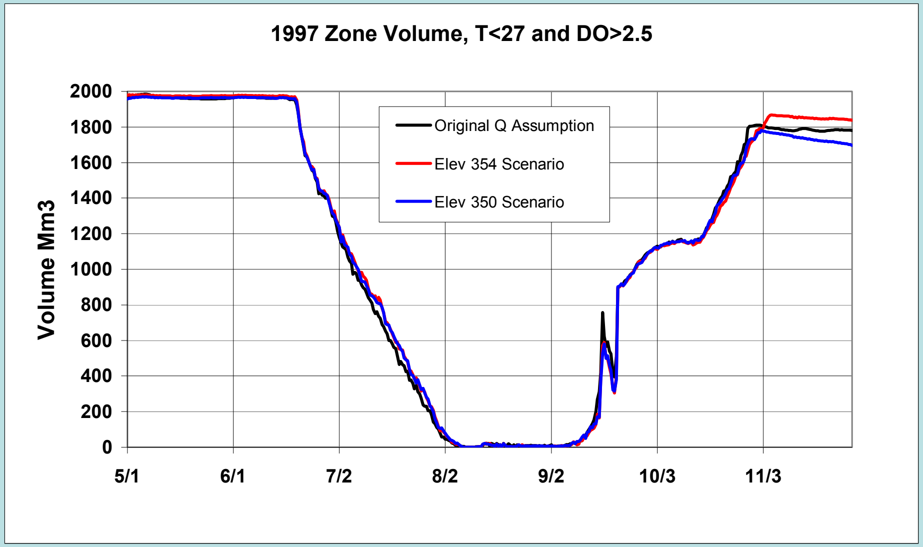


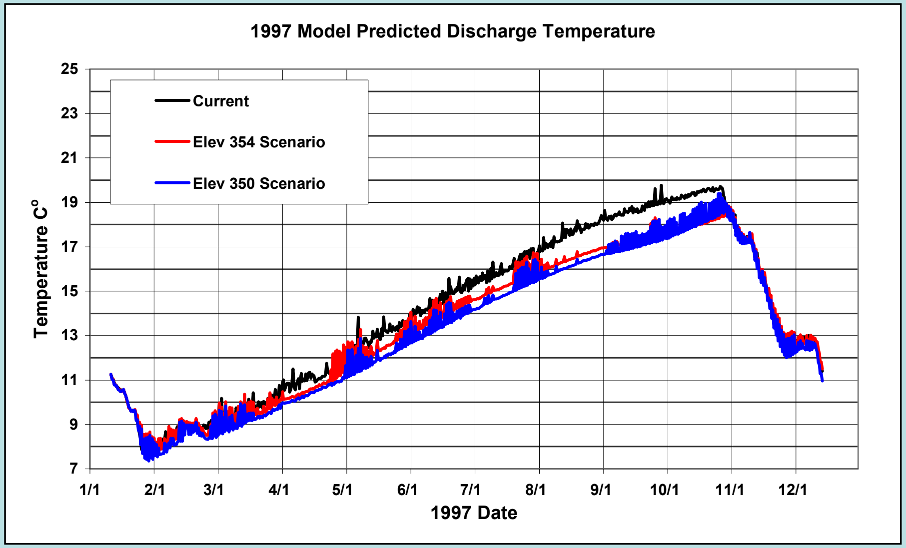


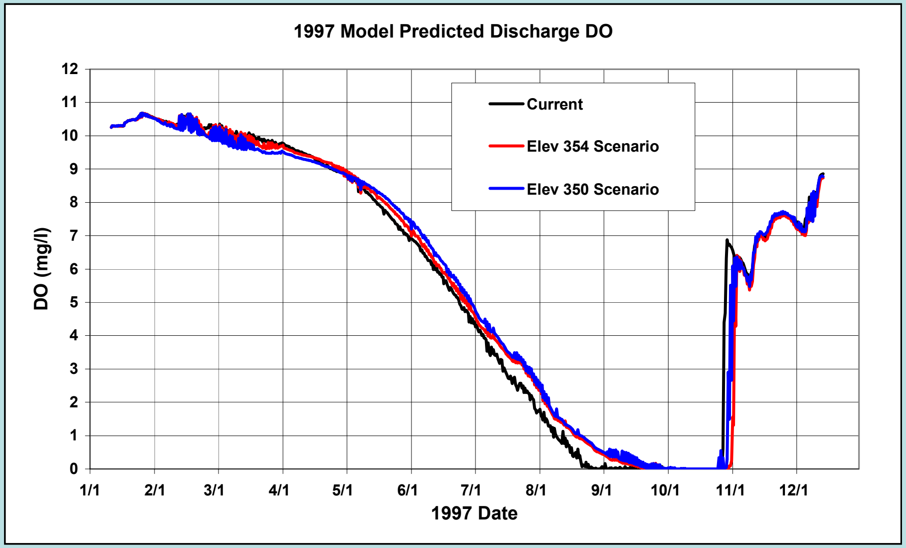


1997 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO









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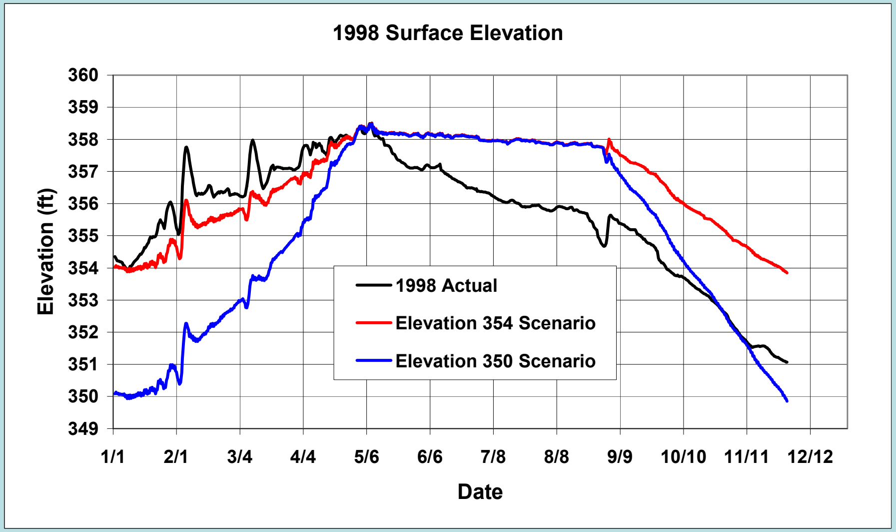
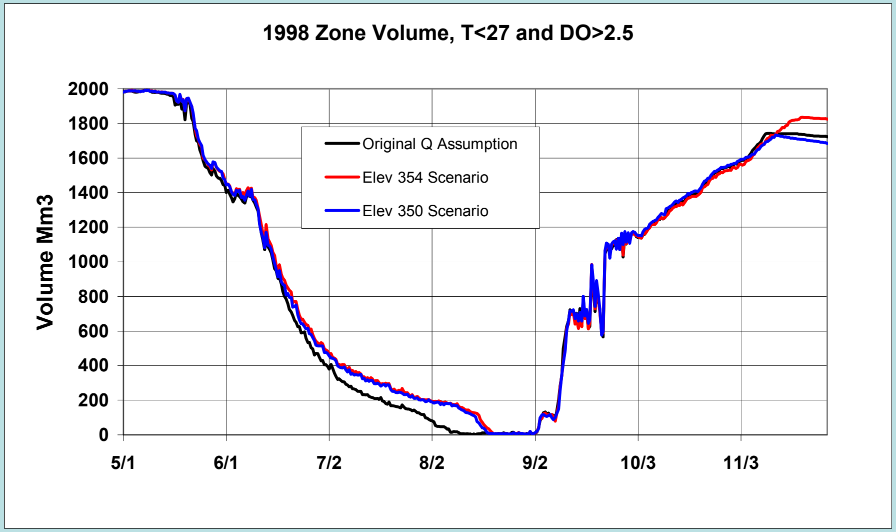
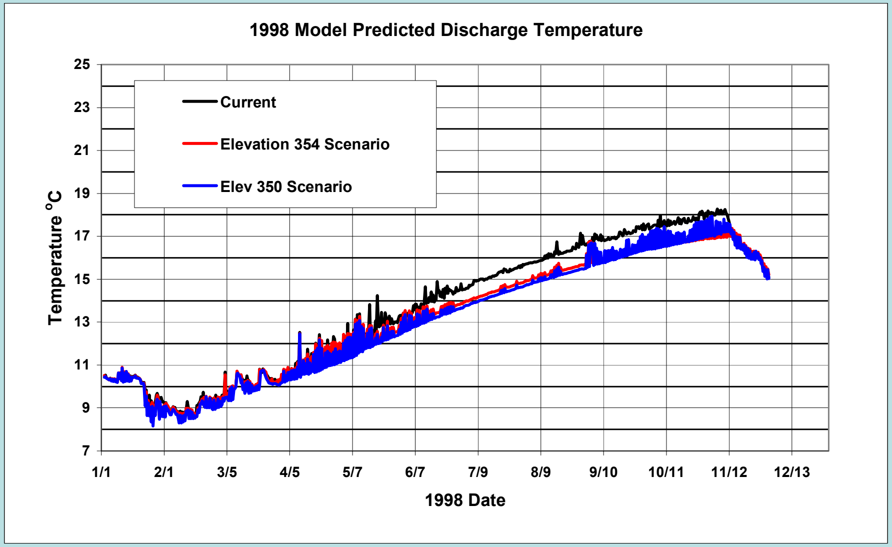
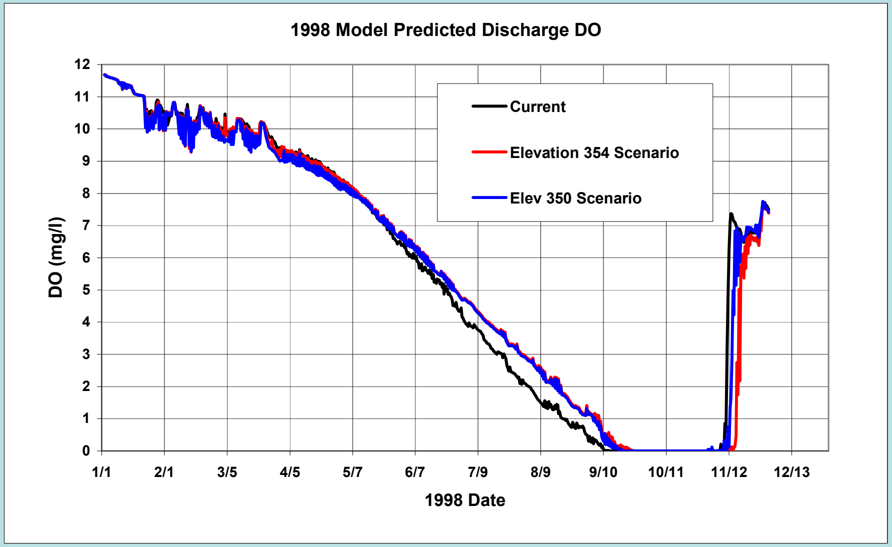
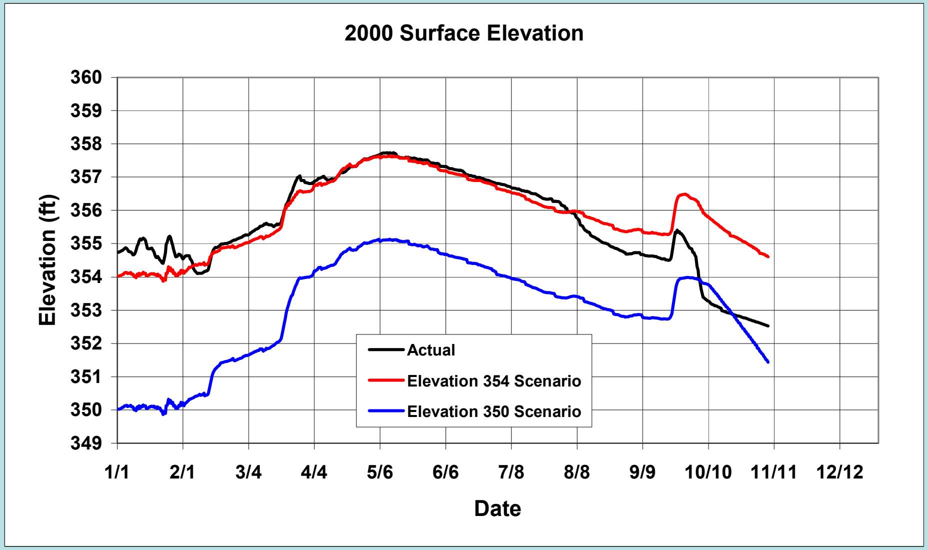


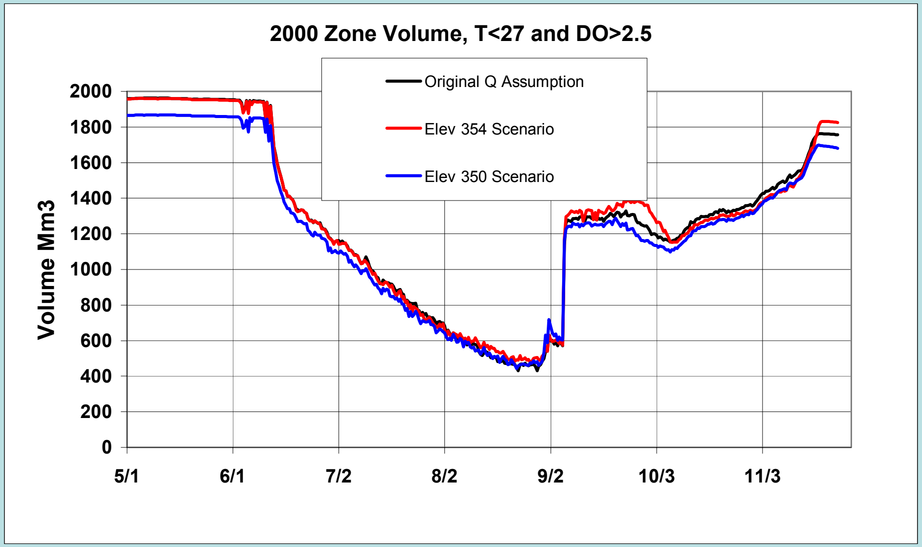


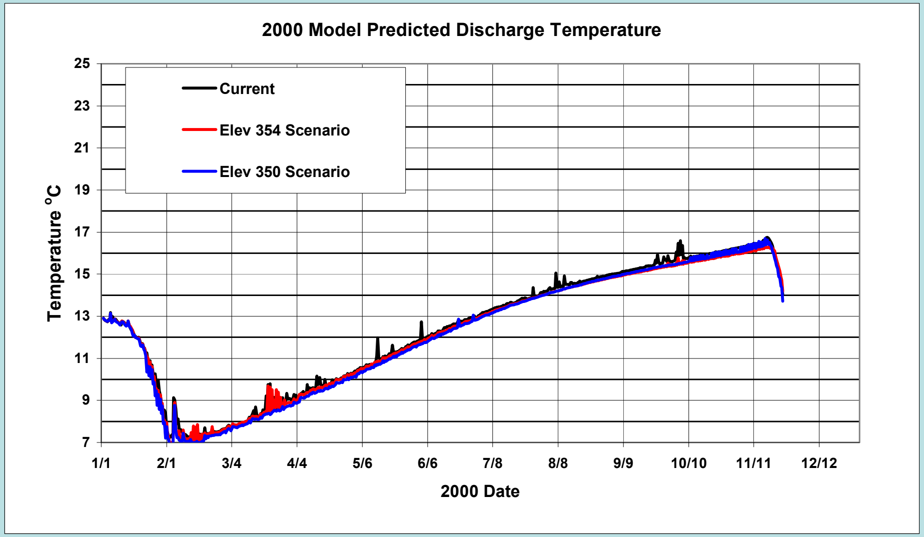


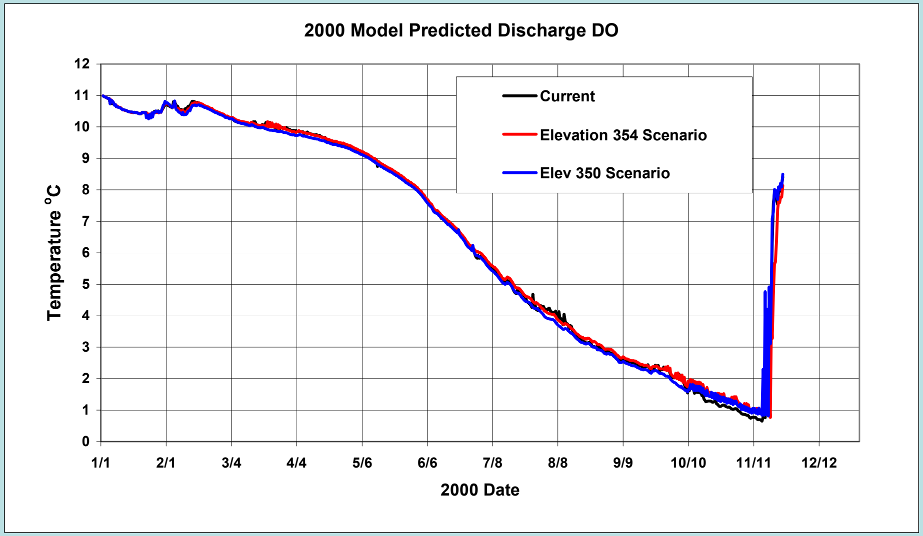


2000 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO









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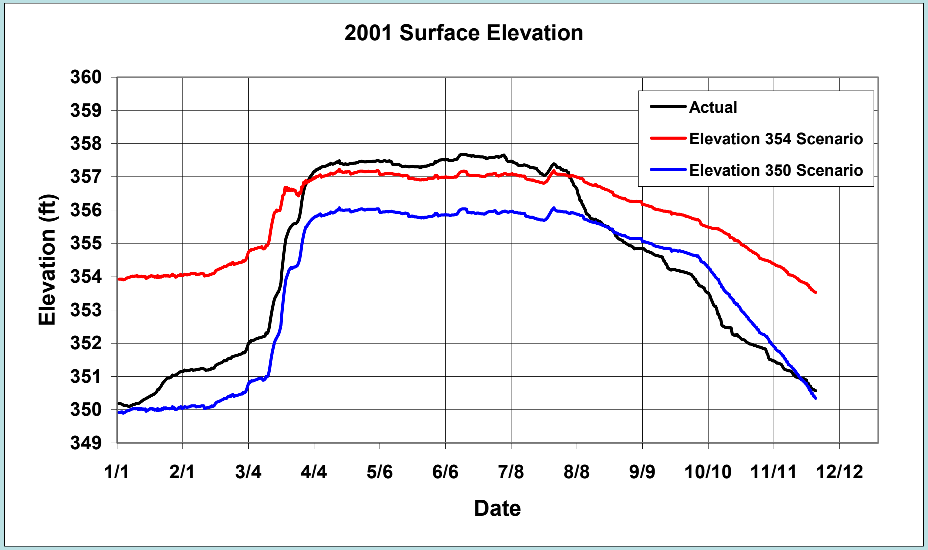

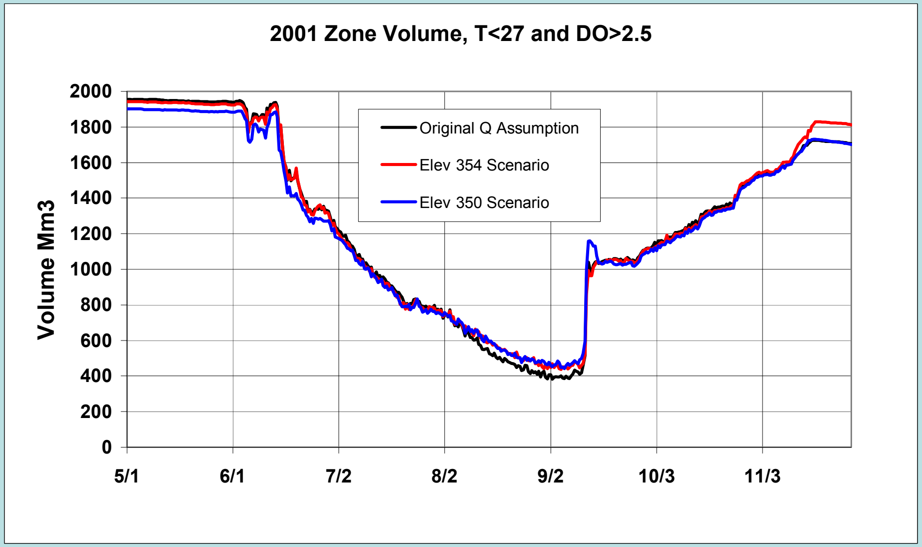

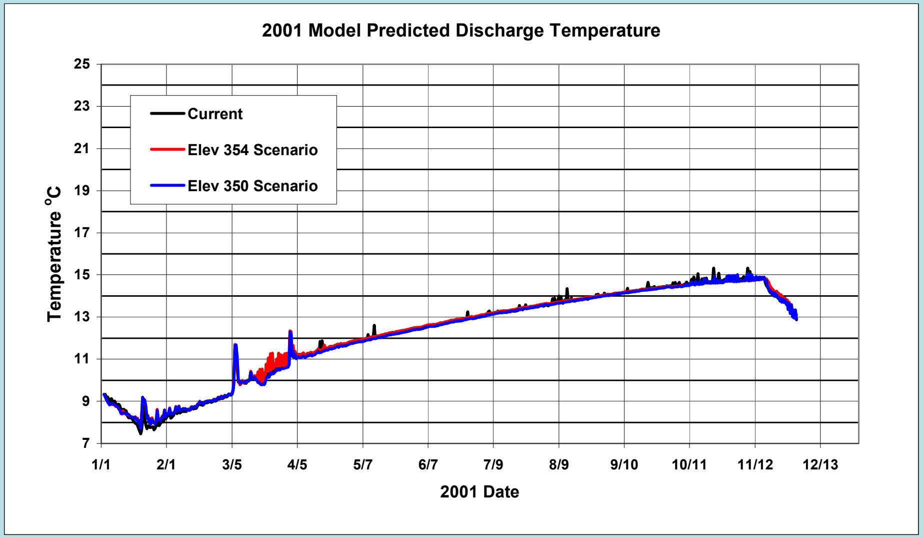

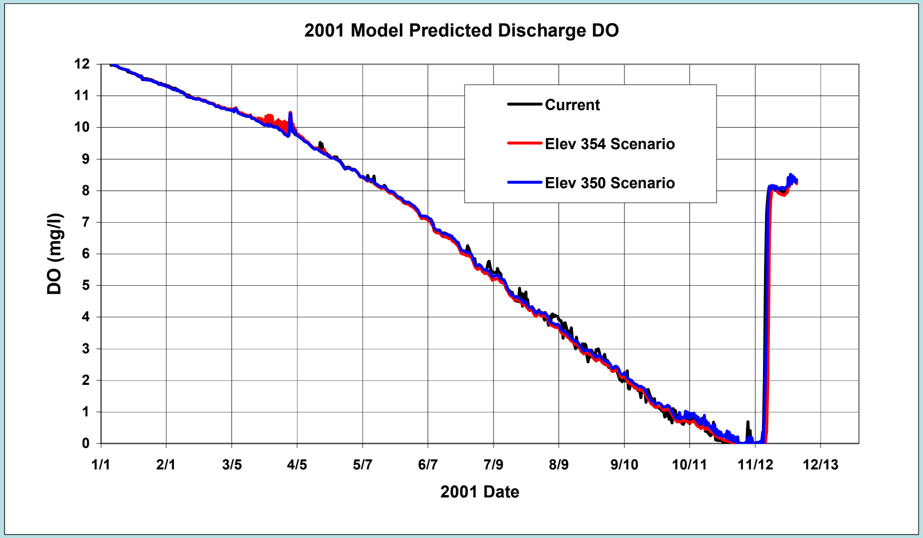

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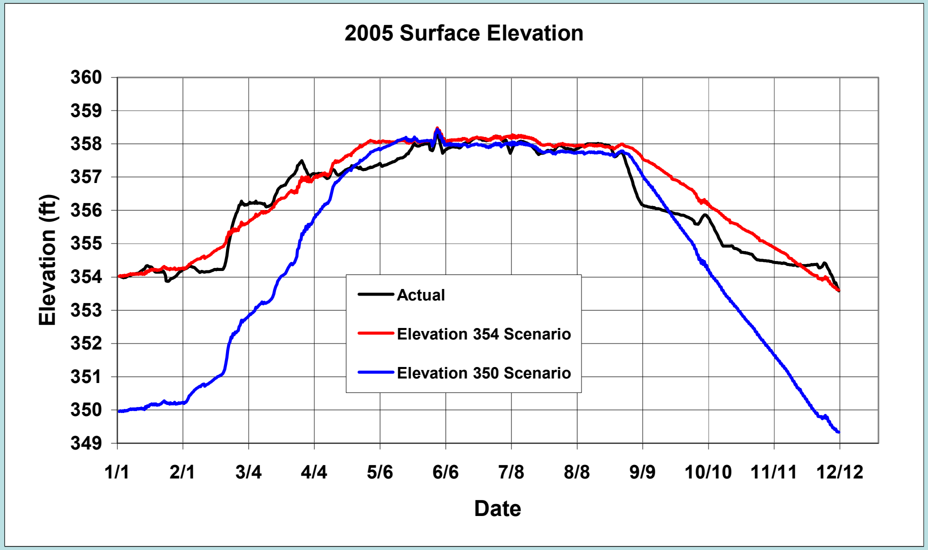
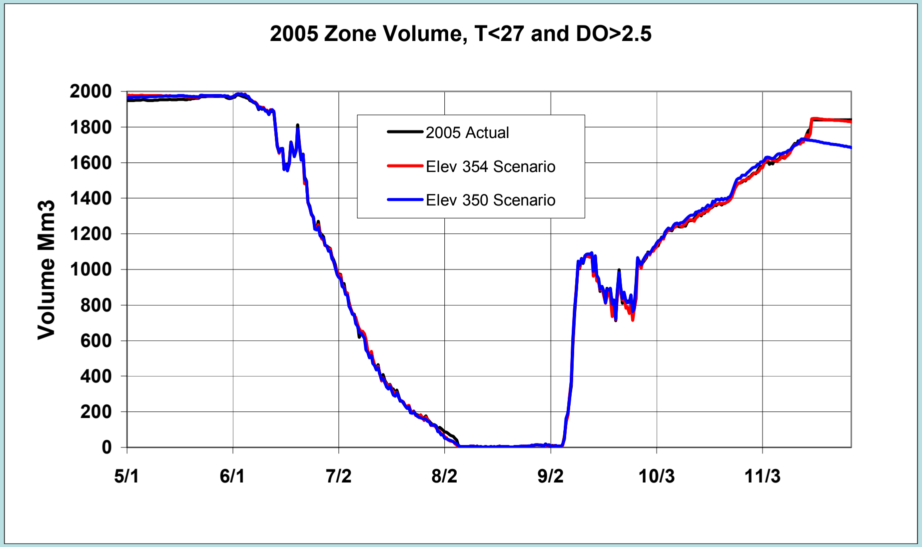
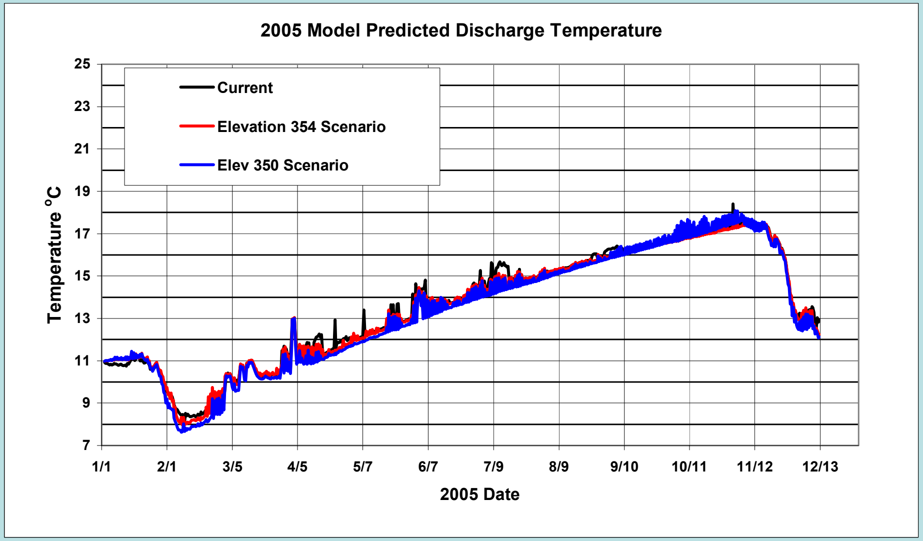
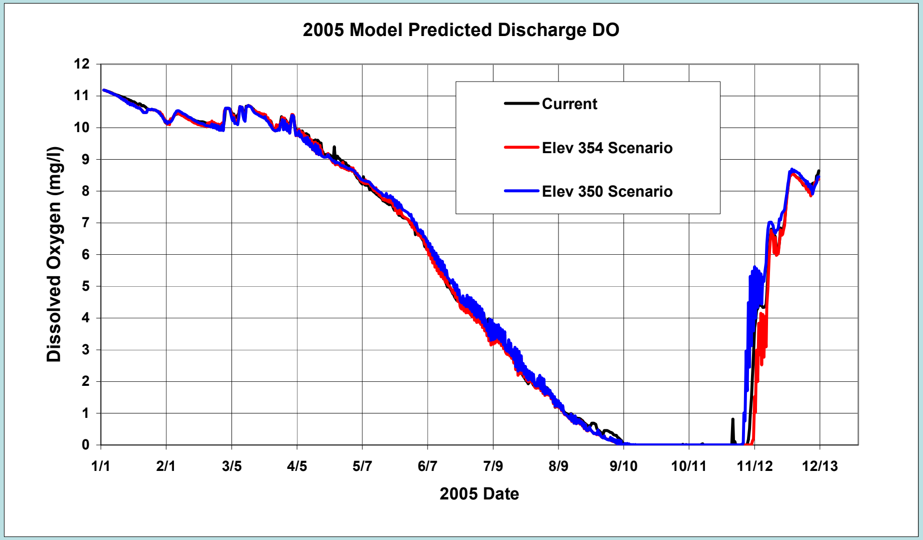


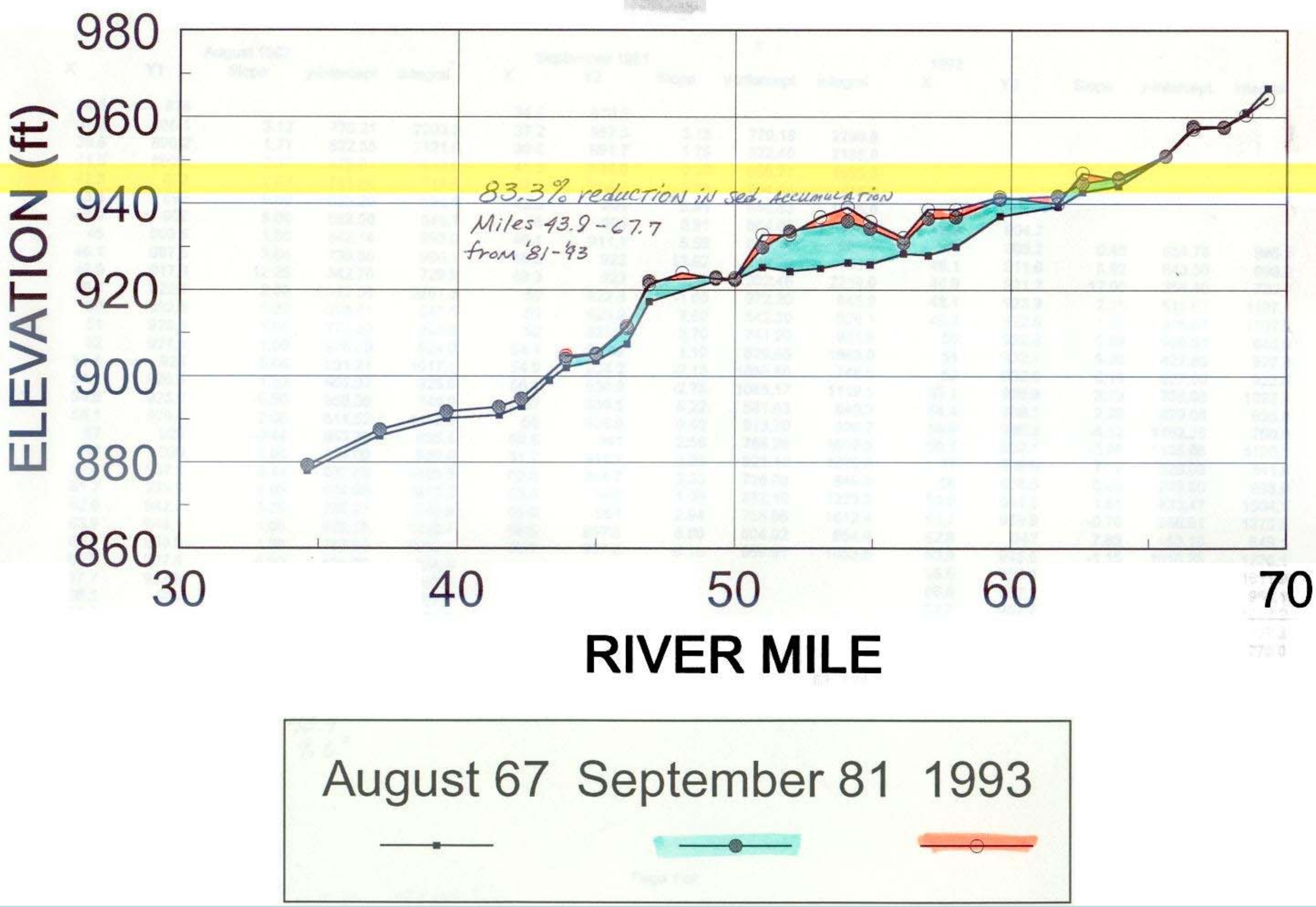






Experiences with Sediments from Douglas Reservoir

DOUGLAS RESERVOIR STREAMBED PROFILE

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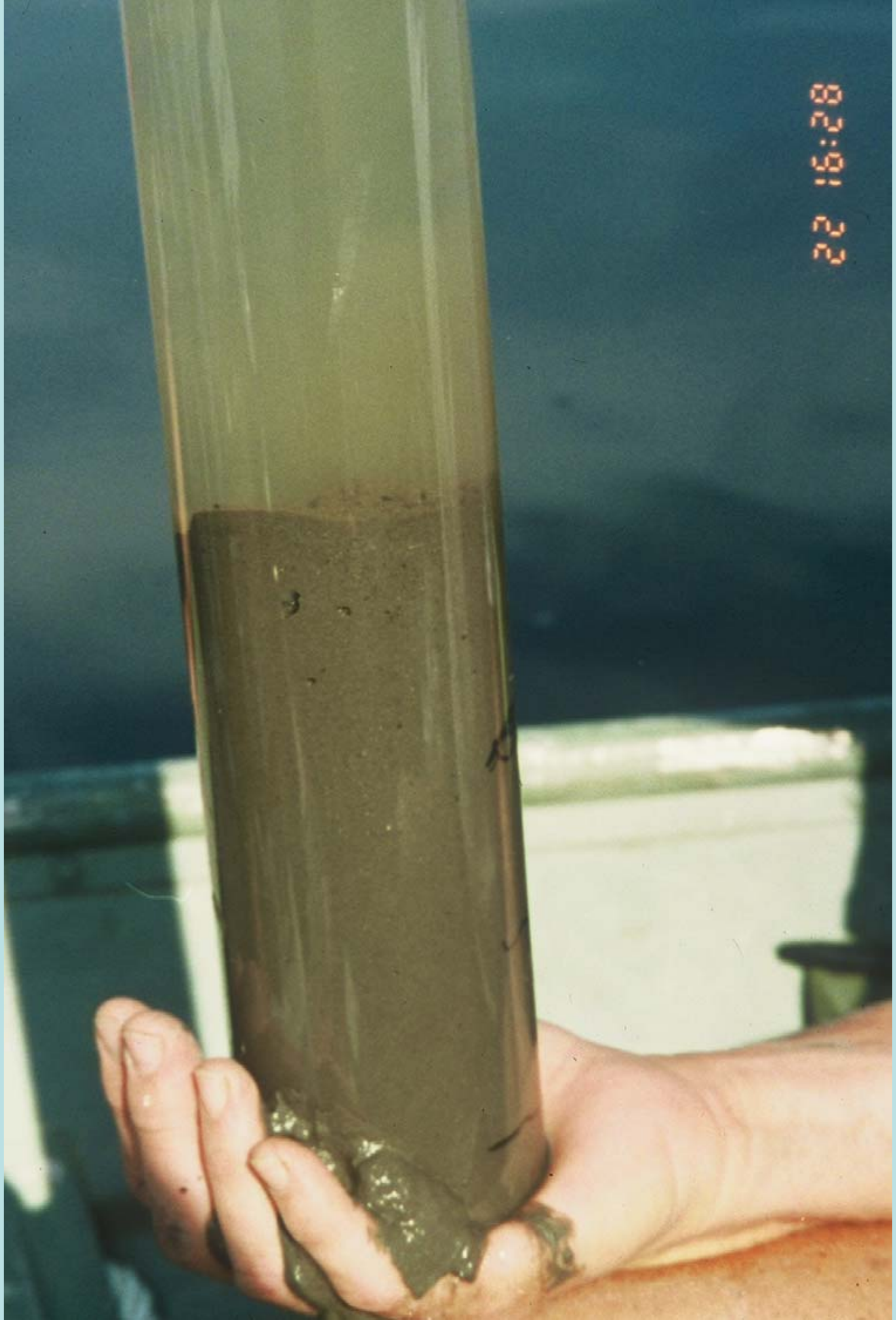
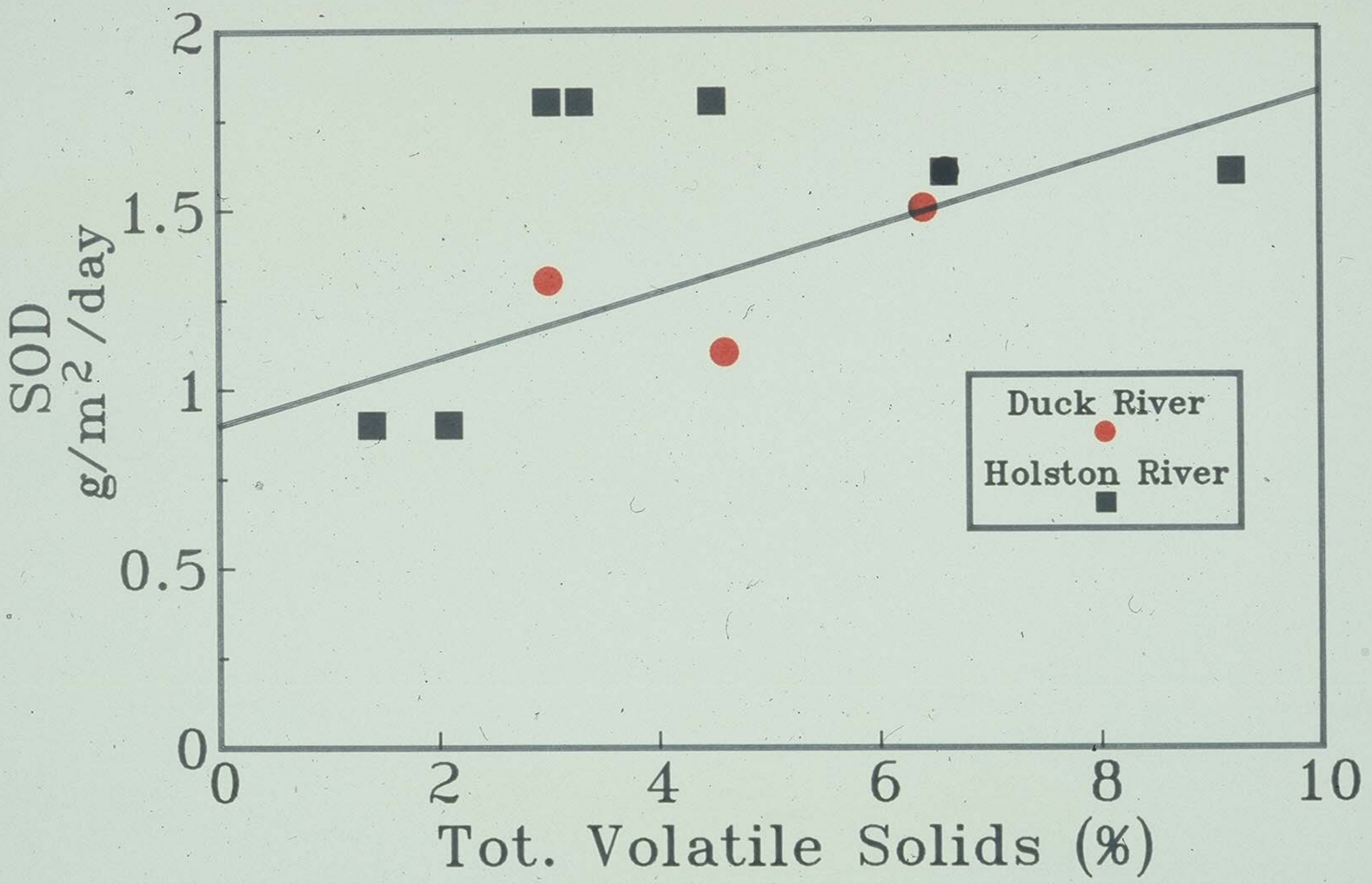




SOD
g/m2 /day
2
1.5
1
0.5
0
0
2
4
6
8
10
Tot. Volatile Solids (%)
Duck River
Holston River


22 14:01


22 13:58


22 13:58


22 15:27

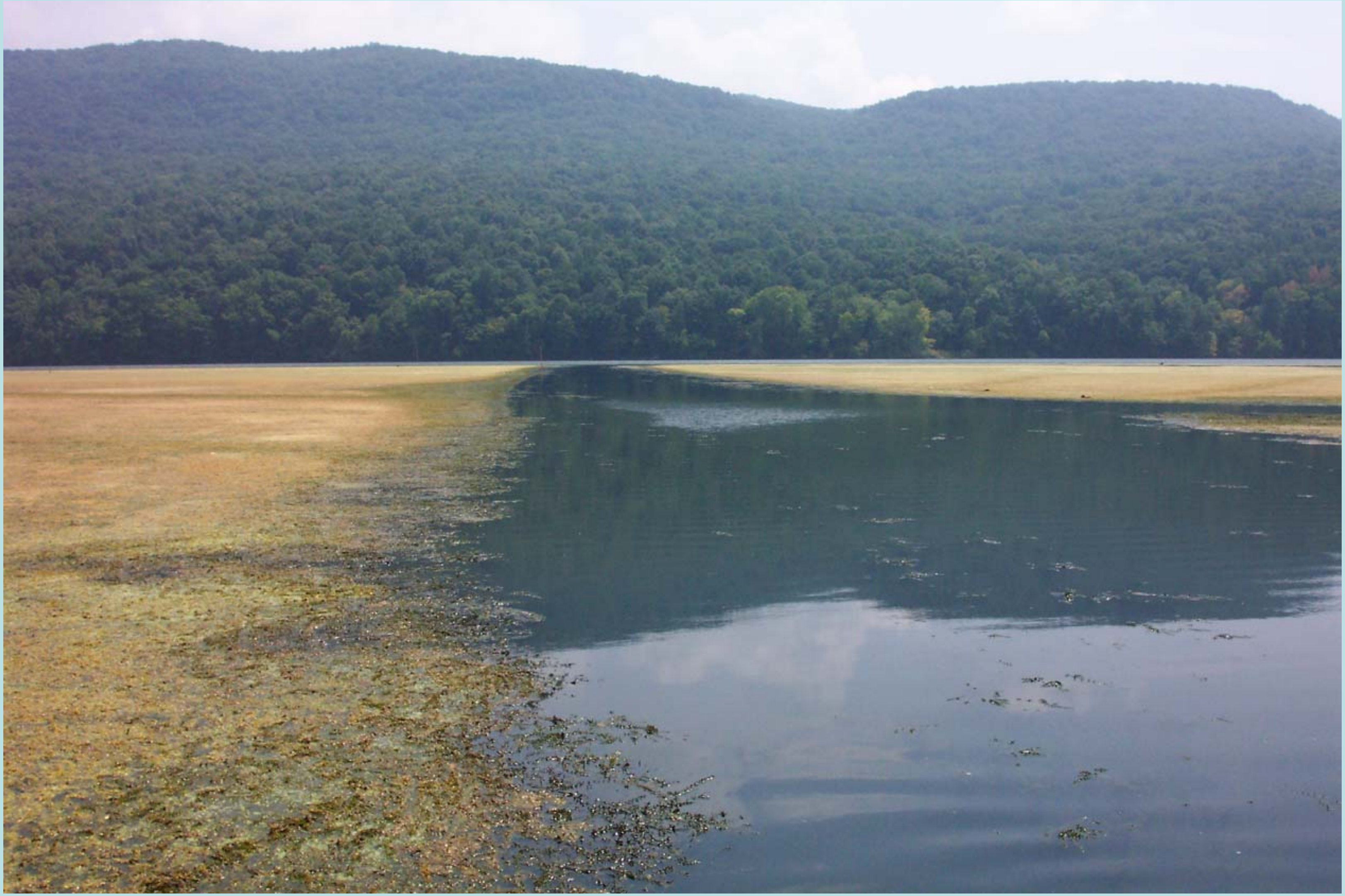

22 14:02


14:06

Aquatic Plants

•Affected by depth of water
•Affected by clarity of water
•Preferred by some fishermen (mainly large mouth bass?), disliked by other lake users
•Surface area exposed by dropping minimum pool to 350’ instead of 354’
•Exposure of plants to dry and freezing conditions causes plants to be reduced

Aquatic Plants on lakes with 5 ft and less annual variation in pool levels



Sedimentation In Coves

- Can cause more weeds if current sediment is not deep enough, and then these weeds can trap more sediment
- = f(watershed size, land uses in watershed, hydrology of watershed, types of soil, frequency of high runoff, location within/without channel (velocity, erosion is important), minimum pool level, frequency/duration of minimum pool level occurring increases opportunity for sediment to be moved to lower depths of the lake and avoid build up that is difficult to be moved,
- Recommend: drop pool elevation to 350ft annually whenever the inflow at Chappells is greater than 1200 cfs in November of the previous year

Little Saluda Embayment

- Greater impact on water quality is expected to occur in the Little Saluda River embayment, especially upstream from the bridge on SC Hwy 391.
- This is a relatively large embayment with a small watershed; therefore, the residence time of water in this embayment can be longer than the comparable region of the upper part of the main stem of Lake Murray.
- If minimum pool elevation is raised, there will be less water exchange between this embayment and the main body of Lake Murray, and there would be less scouring of organic and inorganic sediments during the winter months.
- This would lead to increased “internal cycling” of nutrients in this embayment to the point that it may become insensitive to nutrient loads from the watershed because the release of nutrients in the sediments of the embayment could be sufficient to support eutrophic conditions in the embayment.
- In some cases this condition can lead to the formation of algal mats on the water, and these mats of algae are known to significantly affect water quality and water uses.

Assessment of Changes in SOD and Internal Nutrient Cycling

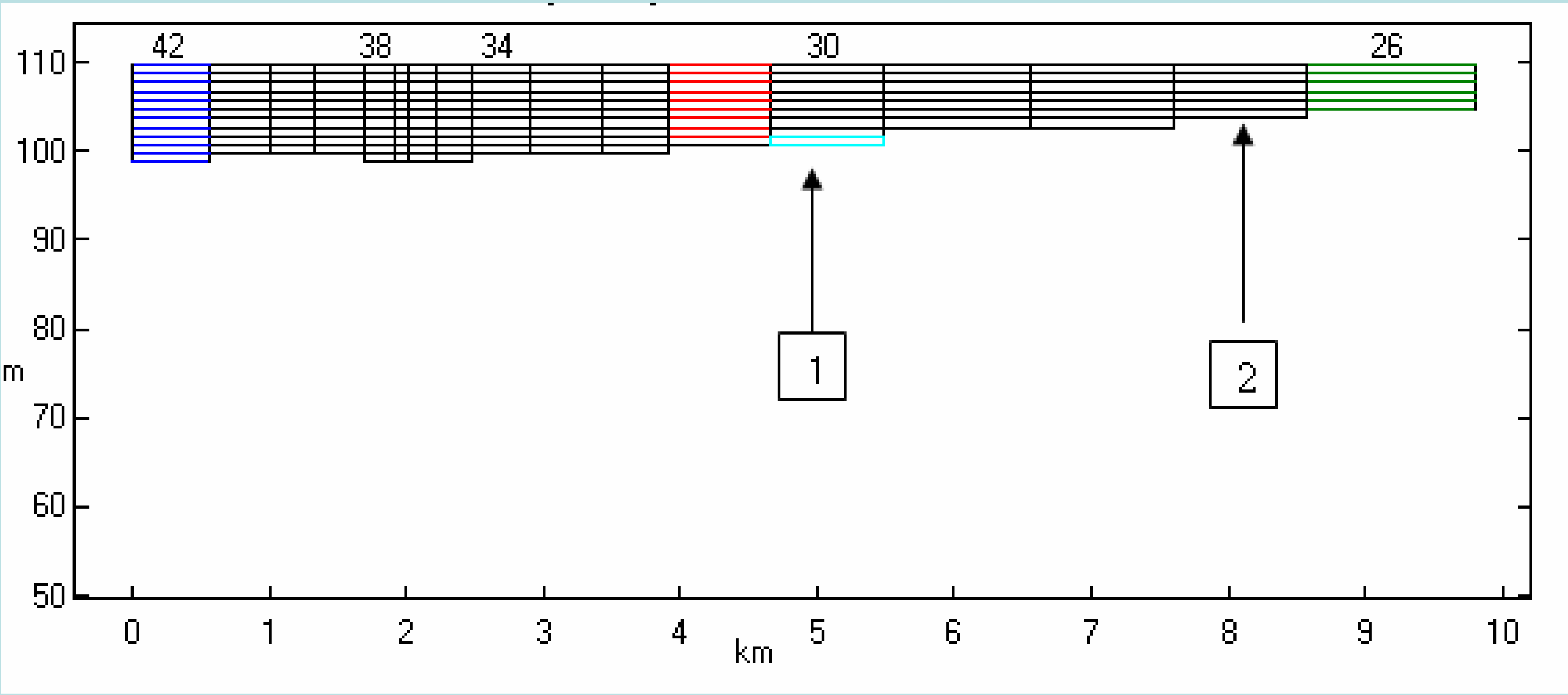
- One factor that is being assessed is the likelihood for SOD (sediment oxygen demand) to increase up to levels seen at other projects in the SE USA (based on model derived values at 20 projects plus SOD measurements conducted by EPA at many projects).
- This is being supported by seasonal SOD dynamics measured at Douglas Reservoir (TVA).
- The evaluation involved running two SOD levels: current estimated level and 2x the current level.
- The model was run for a low flow year.

Model Application to Little Saluda Embayment

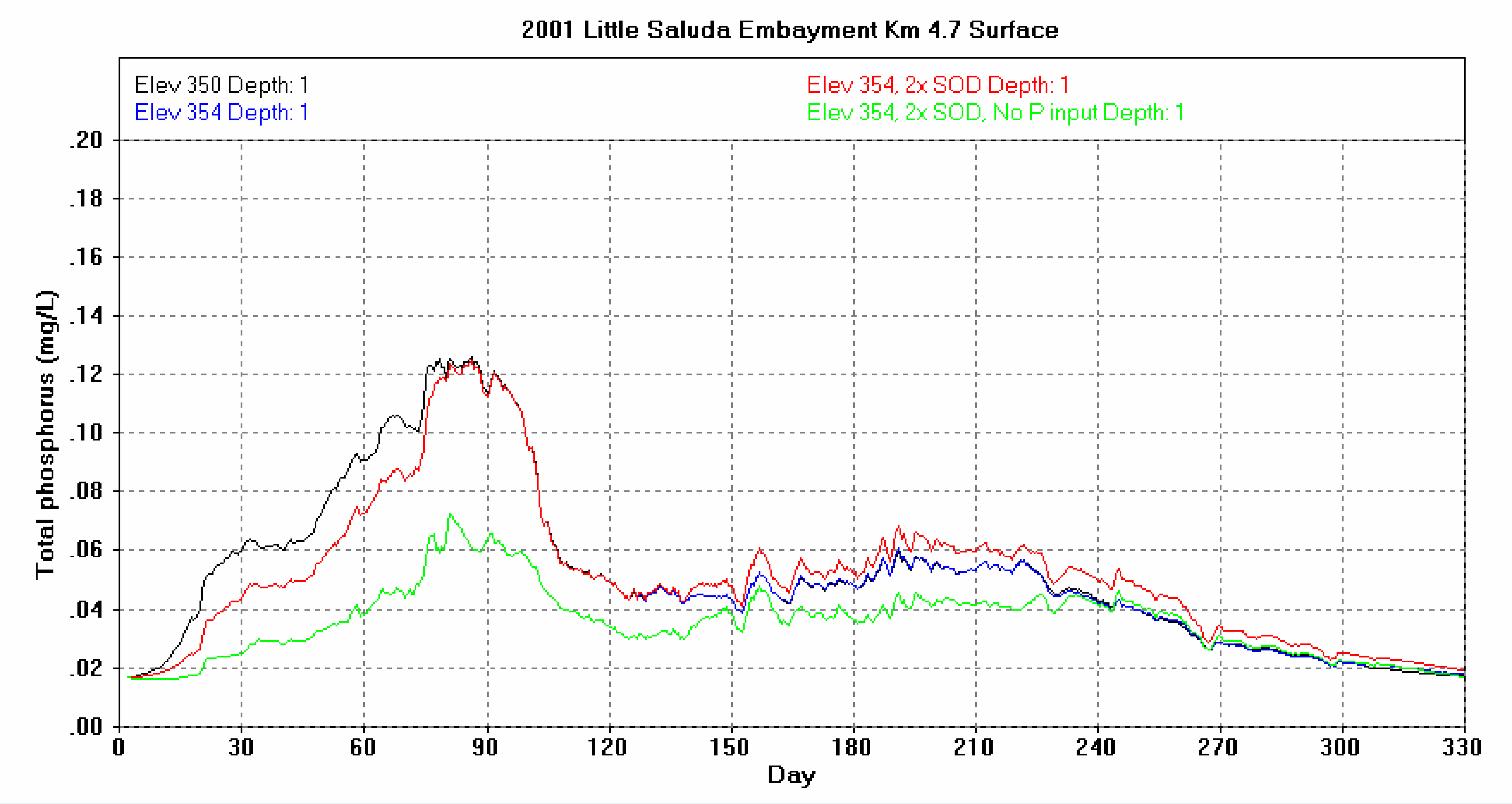
2001 Comparison of:

- Calibration case,
- Case with SOD doubled in the Little Saluda Embayment and upper Lake Murray , and
- The last case with SOD doubled with no phosphorus inputs from inflows.

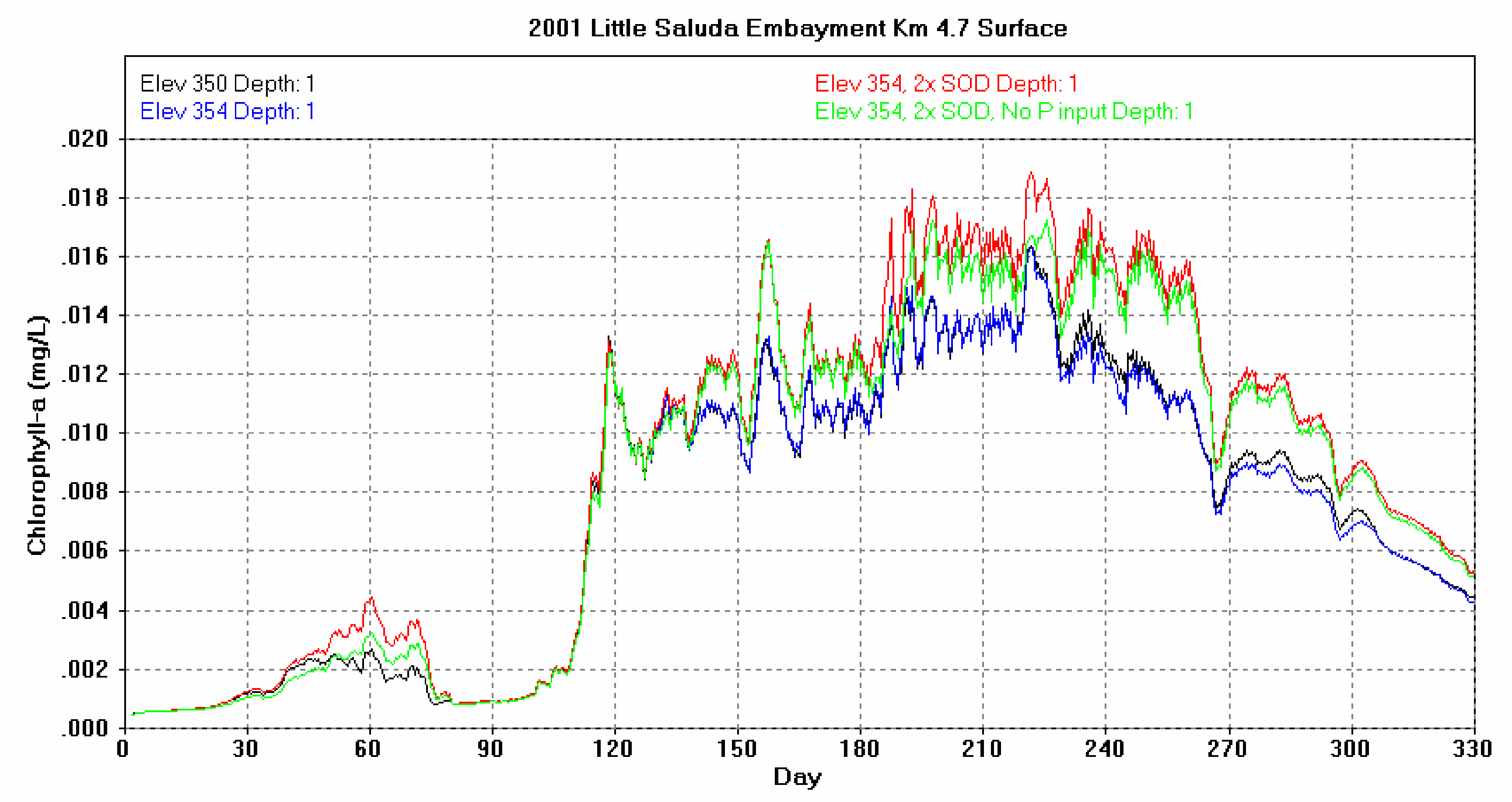
Side View of Little Saluda Bathymetry



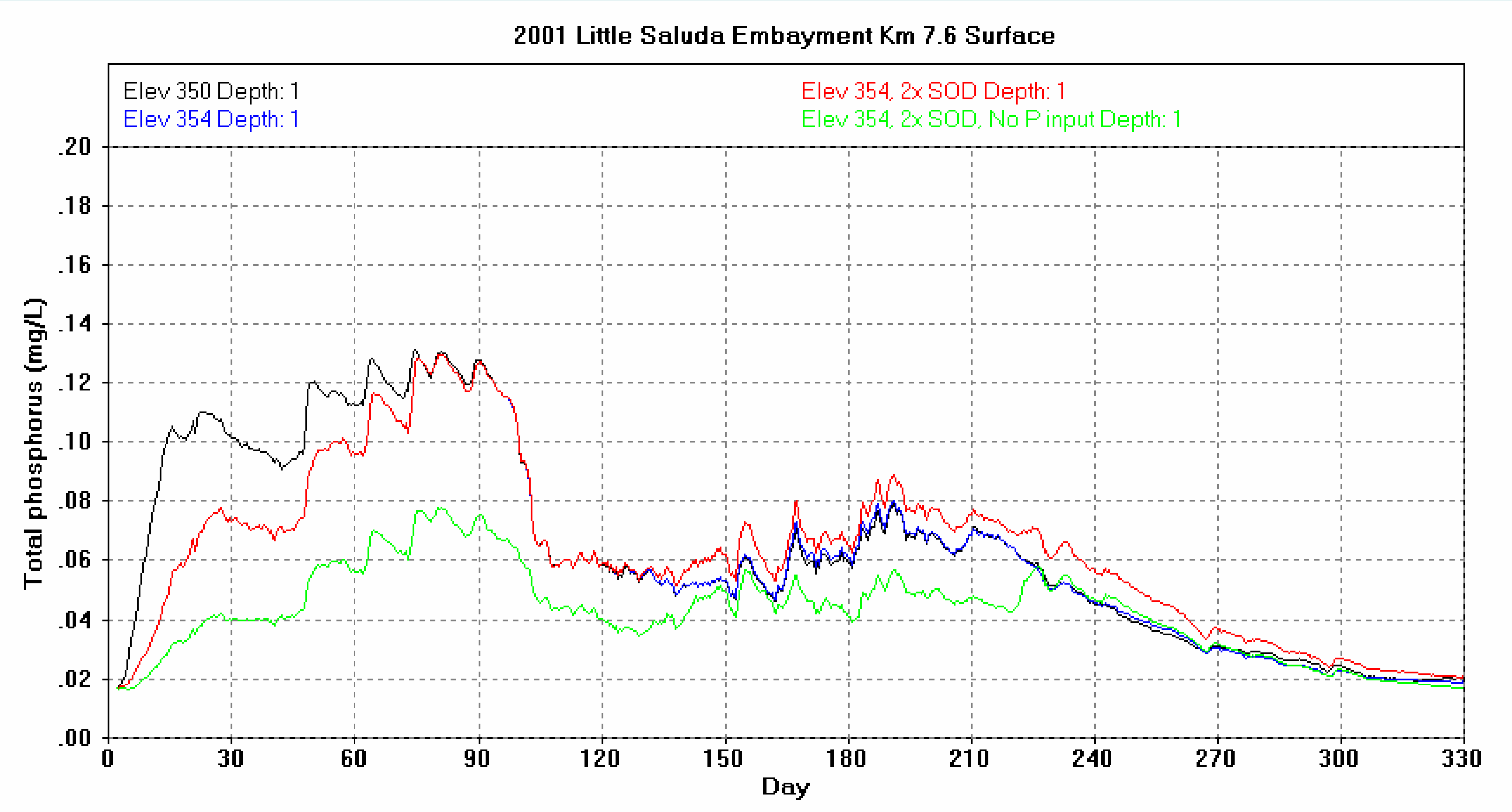
Total Phosphorus at the surface at location 1



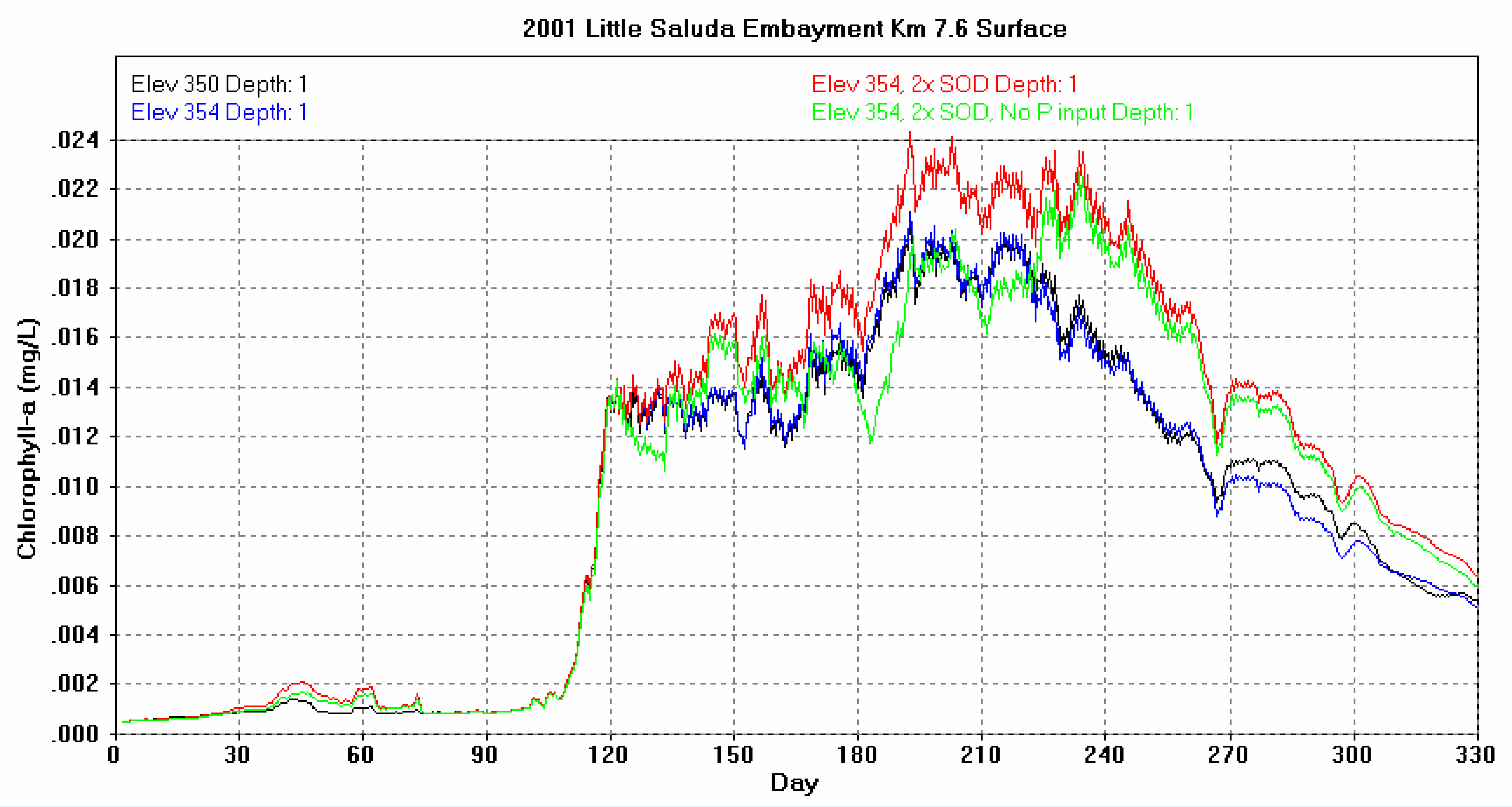
Chlorophyll *a* near the surface at location 1



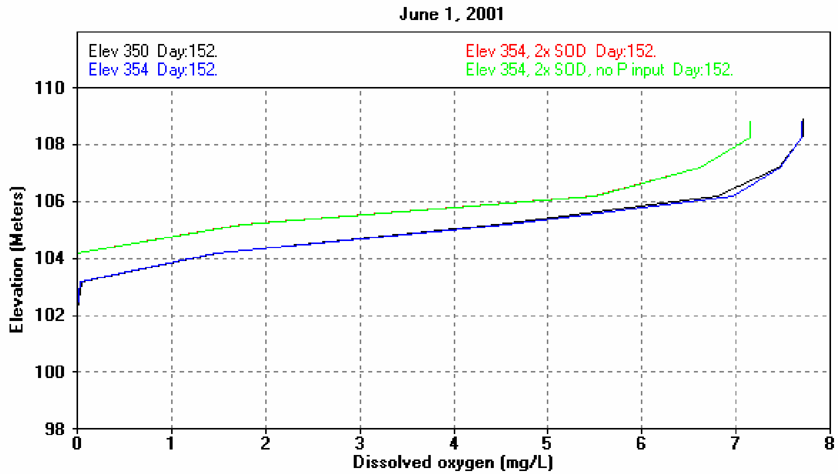
Total Phosphorus at the surface at location 2

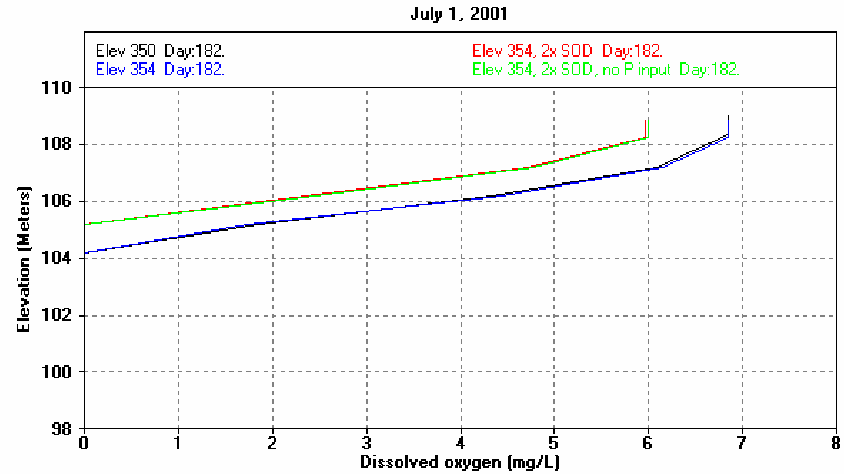


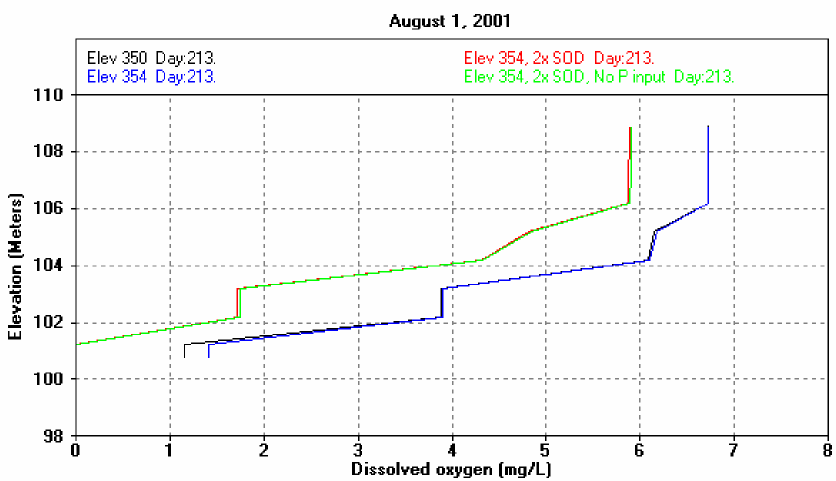
Chlorophyll *a* near the surface at location 2

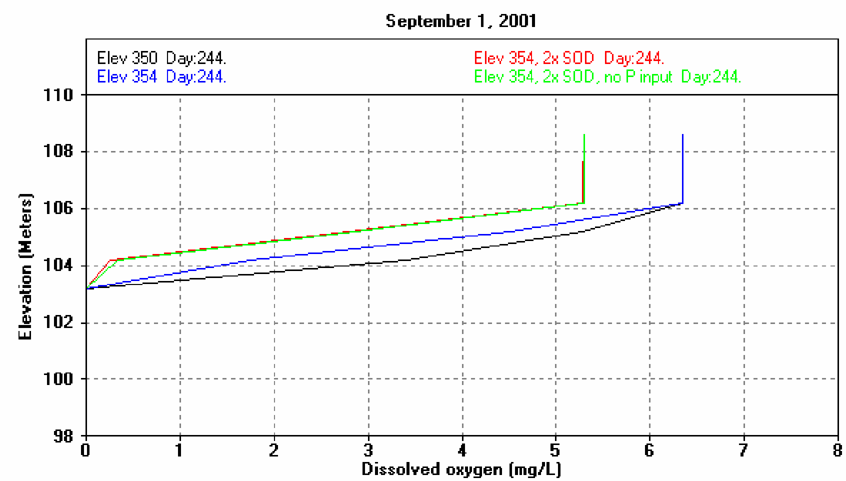


DO Profiles in the Little Saluda Embayment—Location 1, Km 4.7

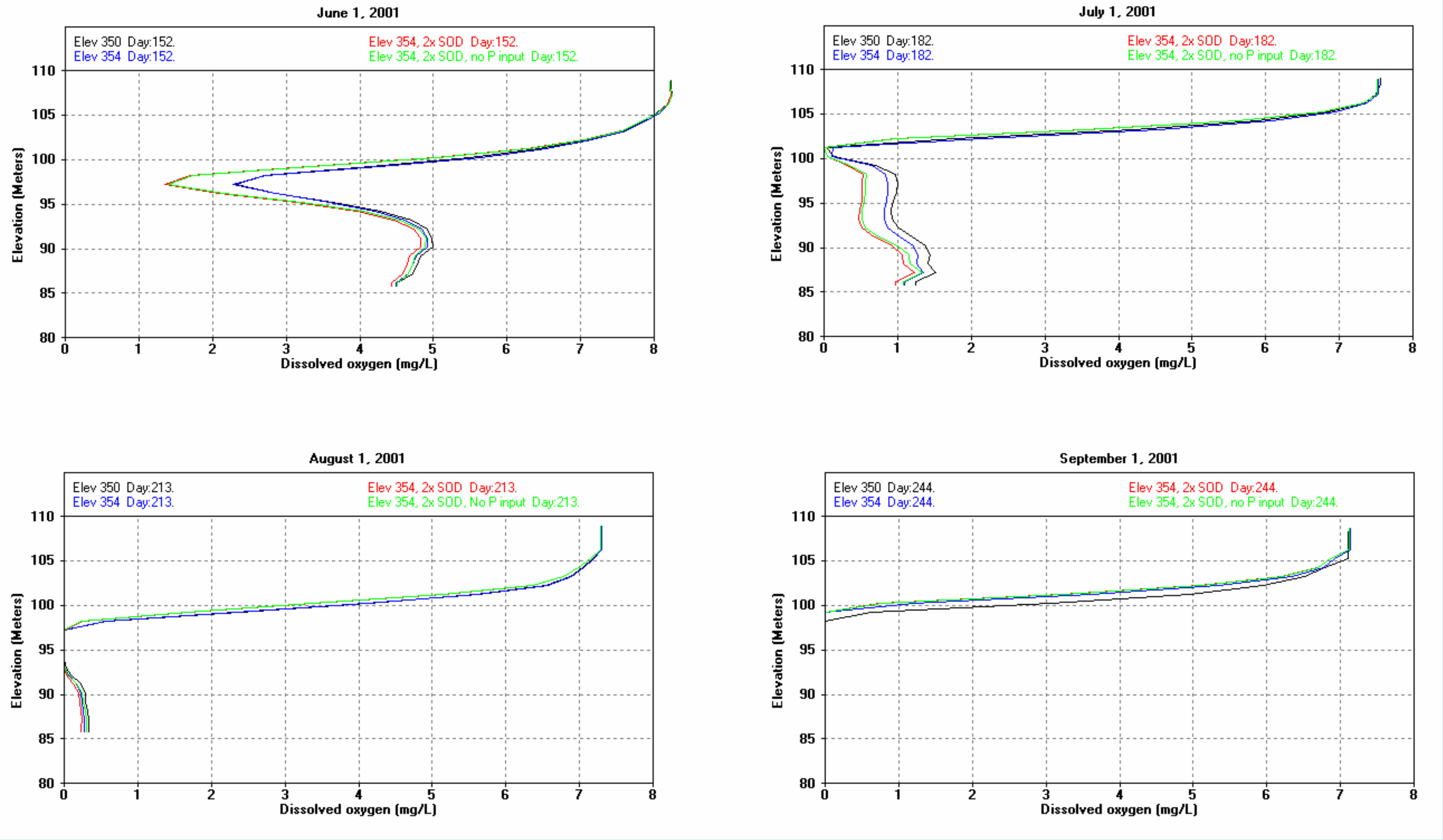






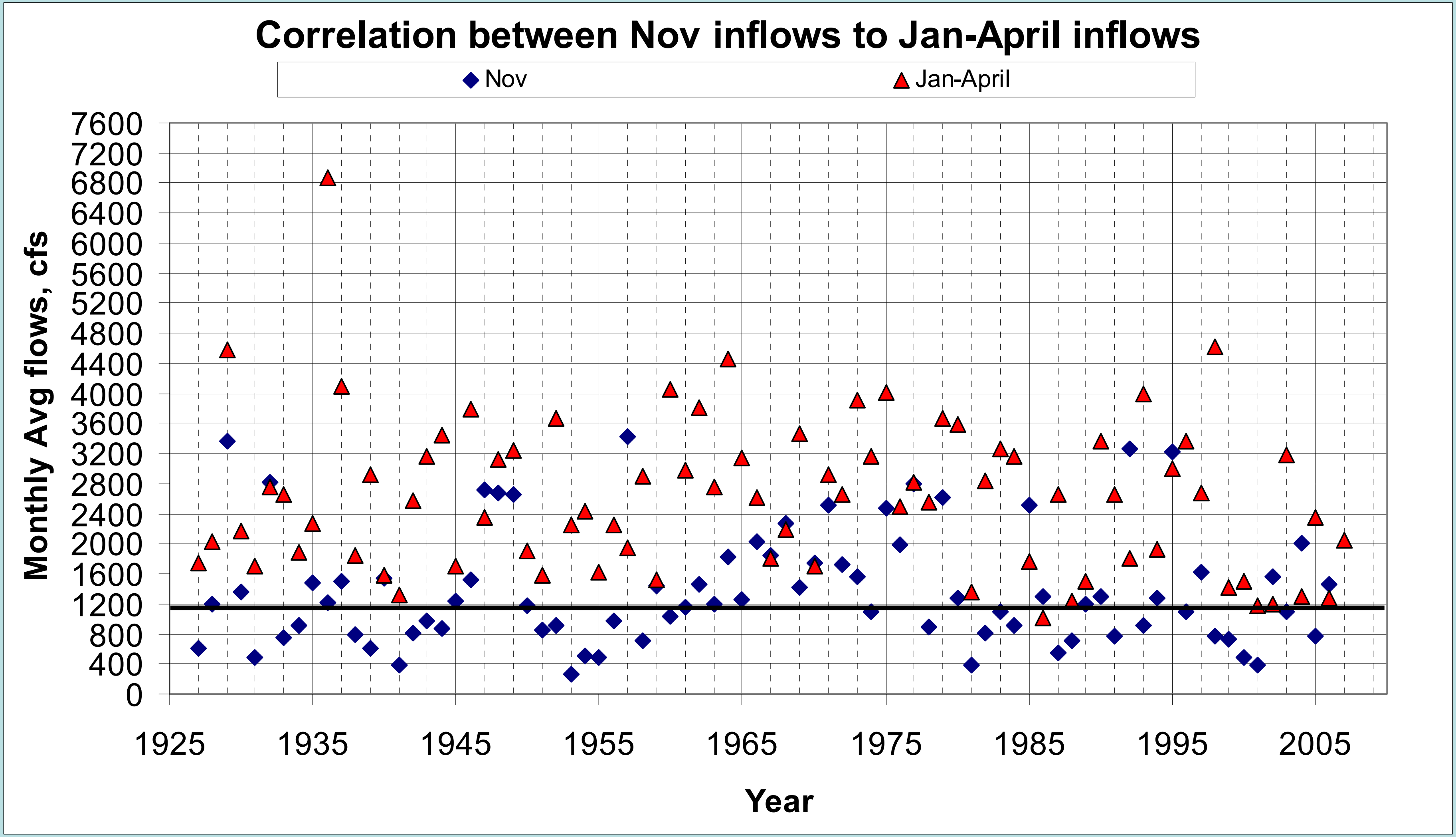


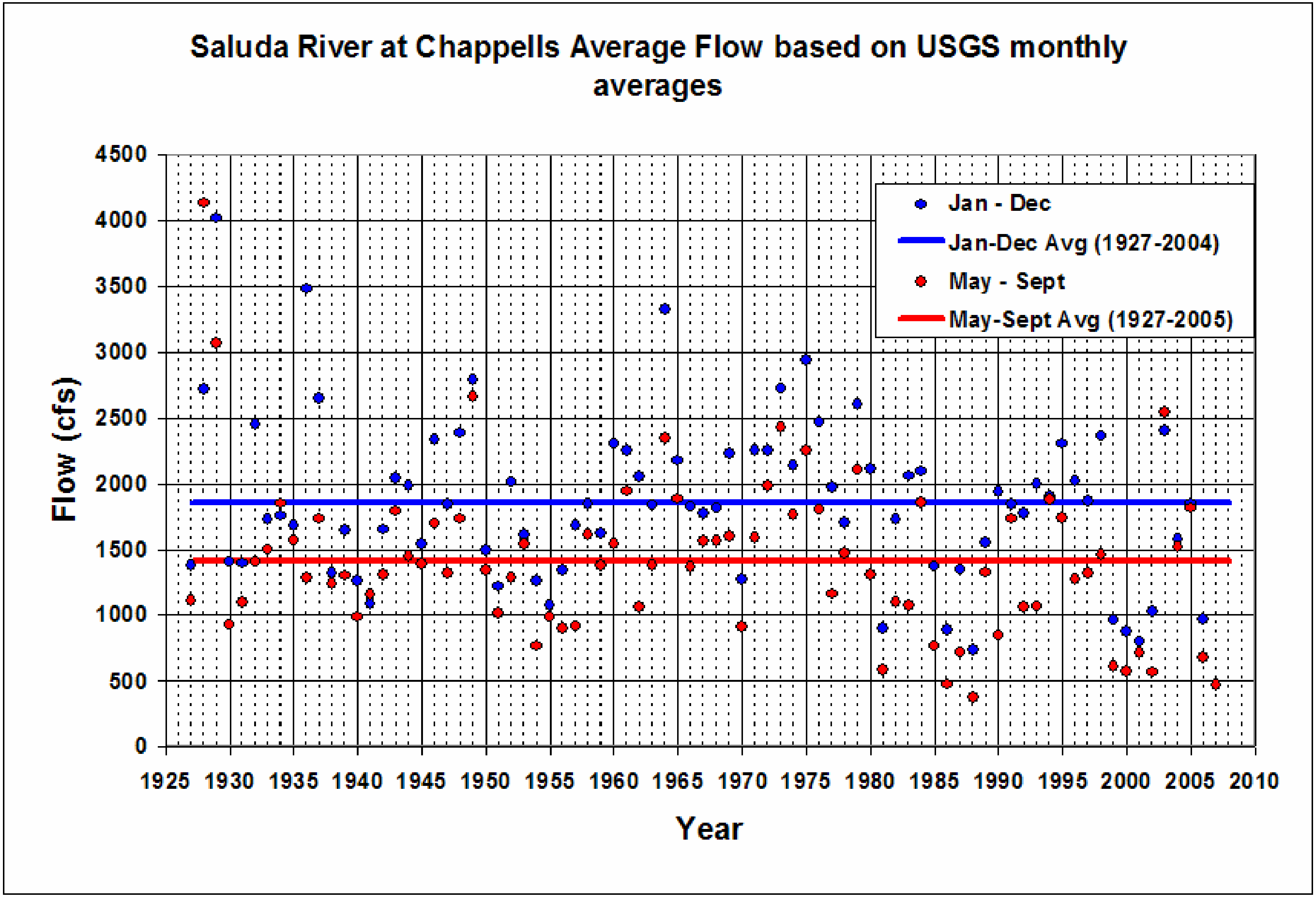
DO profiles on main branch, 26 km upstream of dam (near Rocky Creek)



	avg daily flow for Previous Nov, cfs	Winter min. pool, ft	Summer max pool, ft	avg daily flow Jan-April, cfs	Jan-April, ac-ft less min Q and reserve generation, multiplied by DA/evap multiplier	
1927	1,145			1,750	448,600	
1928	602			2,018	540,492	
1929	1,189			4,572	1,417,025	
1930	3,367			2,176	594,889	
1931	1,356			1,708	434,186	
1932	491			2,763	796,347	
1933	2,824			2,654	758,681	
1934	745			1,891	496,820	
1935	918			2,274	628,351	
1936	1,486			6,878	2,208,530	
1937	1,223			4,095	1,253,318	
1938	1,492			1,846	481,547	
1939	782			2,911	847,141	
1940	617			1,580	390,084	
1941	1,534			1,313	**298,536**	short, but 80, 01, and 02 filled with ~ this much flow
1942	385			2,567	729,080	
1943	809			3,160	932,426	
1944	973			3,448	1,031,439	
1945	864			1,702	432,126	
1946	1,234			3,796	1,150,787	
1947	1,519			2,345	652,632	
1948	2,721			3,124	920,157	
1949	2,684			3,249	963,057	
1950	2,661			1,902	500,852	
1951	1,175			1,590	393,516	
1952	859			3,678	1,110,375	
1953	909			2,243	617,712	
1954	265			2,422	679,316	
1955	509			1,617	403,040	
1956	477			2,251	620,543	
1957	965			1,947	516,296	
1958	3,417			2,892	840,534	
1959	706			1,522	370,179	
1960	1,443			4,050	1,237,788	
1961	1,028			2,985	872,538	
1962	1,148			3,801	1,152,503	
1963	1,459			2,753	792,830	
1964	1,203			4,458	1,378,071	
1965	1,831			3,142	926,163	
1966	1,262			2,624	748,557	
1967	2,027			1,808	468,334	
1968	1,840			2,185	597,720	
1969	2,277			3,468	1,038,132	
1970	1,424			1,706	433,585	
1971	1,739			2,917	849,029	
1972	2,516			2,652	758,252	
1973	1,727			3,917	1,192,229	
1974	1,570			3,162	933,284	
1975	1,097			4,014	1,225,519	
1976	2,478			2,492	703,169	
1977	1,981			2,824	817,283	
1978	2,792			2,561	726,849	
1979	886			3,670	1,107,372	
1980	2,617	351	359	3,578	1,075,884	filled
1981	1,282	350	357	1,358	**314,151**	**filled**
1982	380	354	359	2,830	819,084	
1983	818	354	359	3,268	969,406	
1984	1,100	353	359	3,153	929,938	
1985	917	353	357	1,754	449,801	
1986	2,523	352	357	1,017	**196,949**	**filled**
1987	1,293	354	358	2,647	756,450	
1988	551	351	357	1,227	**269,192**	**filled**
1989	715	353	359	1,505	364,344	filled
1990	1,190	355	358	3,357	1,000,208	special drawdown
1991	1,293	345	358	2,662	761,598	filled
1992	768	350	358	1,797	464,559	filled
1993	3,269	354	358	4,002	1,221,315	
1994	907	350	358	1,929	509,947	filled
1995	1,267	355	358	3,003	878,715	
1996	3,232	352	358	3,369	1,004,241	filled
1997	1,090	348	358	2,683	768,634	filled
1998	1,621	354	358	4,623	1,434,442	
1999	768	350	358	1,423	**336,288**	**filled**
2000	732	354	358	1,504	364,259	
2001	481	350	358	1,174	**251,003**	**filled**
2002	385	350	357.4	1,196	**258,296**	**filled**
2003	1,555	xx	xx	3,182	939,977	did not fill due to operations
2004	1,099	xx	xx	1,304	**295,670**	did not fill due to operations
2005	2,006	354	358	2,358	657,351	
2006	773	348	352	1,272	**284,593**	06 did not get filled from 348
2007	1,462	356	357	2,039	547,699	07 at 356 did not attain 358
	41	13 at 350	24 at 357-359	3	747,430	mean
	41+10		2 < 357	3+1		70 years > 364,000 ac-ft; 9 years < 364,000 ac-ft
	81 years total	looks like it's not winter pool that affects summer pool, but summer hydrology				364,000 ac-ft of inflow is estimated inflow needed to raise pool from 350 to 358
	note Jan-Apr flow is 77% greater than the avg of the rest of the months					

Comparison between November and Jan-April inflows to Lake Murray from Chappells. When November inflows are greater than 1200 cfs, the Jan-April inflows are sufficient to fill Lake Murray from elevation 350 to 358 93% of the time.




Saluda River at Chappells Average Flow based on USGS monthly averages
Jan - Dec
Jan-Dec Avg (1927-2004)
May - Sept
May-Sept Avg (1927-2005)
Flow (cfs)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year

Concerns for Increasing the Winter Minimum Pool Level from 350’ to 354’ Every Year

- Sediment accumulation in coves, especially Little Saluda River
- Aquatic plants increasing around the lake, especially the Little Saluda River embayment
- Organic and nutrient accumulation in sediments of embayments, especially the Little Saluda River embayment
- Water quality and algae in the Little Saluda River embayment could already be controlled by internal-cycling (i.e., insensitive to nutrients in inflows creeks), and increasing the minimum winter pool to 354’ could cause worse conditions
- Probable impact on the TMDL process on the Little Saluda River embayment
- Modeling at this point can involve only sensitivity analyses since data are inadequate to calibrate the model

Conclusions Regarding the Minimum Winter Pool Level

- Regarding the assessment of setting the minimum winter pool level at elevation 354’, under summer conditions it appears that two-thirds of the phosphorus in the water column in the Little Saluda River embayment was caused by internal phosphorus cycling. This finding indicates that the phosphorus cycling in Little Saluda embayment is sensitive to organic matter that is formed and settles to the bottom sediments in the embayment. It is also interesting to note for the case where phosphorus loads are reduced to zero that chlorophyll a is reduced for the early part of the summer but not for the latter part of the summer.
- There is a potential for the internal cycling of phosphorus in the Little Saluda embayment to impact SCDHEC’s TMDL considerations on the Little Saluda River embayment.

Conclusions Regarding the Minimum Winter Pool Level

- Regarding considerations for developing a policy for winter minimum pool levels, based on data for 1980 through 2007, the winter pool level was down to about 350 ± 2' about half the time. It would be best to maintain this frequency of drawing the lake down to this level each year or risk poorer water quality (sediment accumulation, weeds, increased nutrient cycling from the sediments especially in embayments, and greater potential TMDL designation by DHEC that could lead to very expensive sediment treatments) compared to current conditions.
- Maintaining the frequency of drawing the lake down to 350' for an average of every two years should not be difficult based on historical inflows and pool level data as well as taking advantage of using November flows to predict the years when Jan-Apr flows would likely be sufficient.
- One interesting observation is that it appears that the minimum winter pool level has very little to do with attaining and maintaining a summer pool level at elevation 358 ± 1'. It appears that it is the lack of sufficient inflows during the summer period that causes the pool elevation to drop like it did in 2007 as well as in other years with low summer flows.

Conclusions Regarding the Minimum Winter Pool Level (cont.)

- The months with highest average flows are Jan-April (i.e., the flow for these four months averages 77% greater flow than for the other months of the year), and based on data from 1927-2007 (81 years), only 9 years had what appeared to be “challenging” low flows that might prevent the lake from being filled to 358’; however, for the years where pool level data were available (1980-2007) there was only 1 year when the 358 ± 1’ was not attained: 2006. During 1980-2007, there were 8 years with “challenging” low flows available to fill the pool to 358 ± 1’, but 2006 was the only year that this goal was not attained.
- Based on data from 1927-2007, when Nov mean flows were 1200 cfs or greater at Chappells, the Jan-Apr flows were sufficient to safely attain the 358 ± 1’ goal. The Nov mean flow of 1200 cfs was equaled or exceeded for 41 of the 81 years of record. Using this approach, the pool level in the winter could be dropped to 350’ on an average frequency of every 2 years. Considering these 41 years, 3 of the years had “challenging” low flows that might prevent the lake from being filled to 358 but 2 of these years occurred during the period 1980-2007 when pool level data were available and in both of these years the 358 ± 1’ goal was attained.
- Although there is more likelihood of having greater flows for the period Jan-Apr when flows are high for the previous Nov, the consequence of dropping the winter pool elevation to 350 every year and not attaining the 358 ± 1’ goal is not great: the estimated maximum number of years when the goal would not be attained is about 1 in 10 years, but based on actual experience between 1980 and 2007 it would likely be closer to 1 in 25-50 years. Again, when the summer pool drops after the 358 ± 1’ goal is attained, it is because of low summer inflows, minimum flow provision, and high evaporation.

Conclusions Regarding the Minimum Winter Pool Level, cont.

Other parts of the lake are likely to be impacted by raising the minimum pool level to elevation 354:

- Sediments and suspended solids that enter the lake from tributaries, and they settle and accumulate near the inflow region to the lake. Dropping the pool level periodically on a regular basis causes these sediments to be resuspended and redeposited to deeper locations in the lake where they do little harm.
- Dropping the pool level also causes aquatic plants to be killed or “die back” by freezing conditions. Exposure of plants to dry and freezing conditions causes plants to be reduced. This process is likely controlling weeds in Lake Murray to some extent, especially in the Little Saluda embayment.
- Raising the pool level causes sediments to accumulate where aquatic weeds can grow and take root. After they establish roots, the plants cause even more sediment to accumulate. Once such sediment complexes get established, normal periodic scouring action (i.e., scouring flows every few years like every other year or annually) is not sufficient to re-suspend these sediments. So in some ways this is practically an irreversible impact.
- The phenomena of sediment accumulation in reservoirs at their inflow areas is a complex process dependent on many factors: watershed size, land uses in watershed, hydrology of watershed, types of soil, frequency of high runoff, location within/without channel (velocity, erosion is important), and minimum pool level. The frequency/duration of minimum pool level occurring increases opportunity for sediment to be moved to lower depths of the lake and avoid build up that is difficult to be moved.

Model Assessment of Factors Affecting In-Lake Water Quality and Reservoir Releases

RCG Presentation   November 6, 2007

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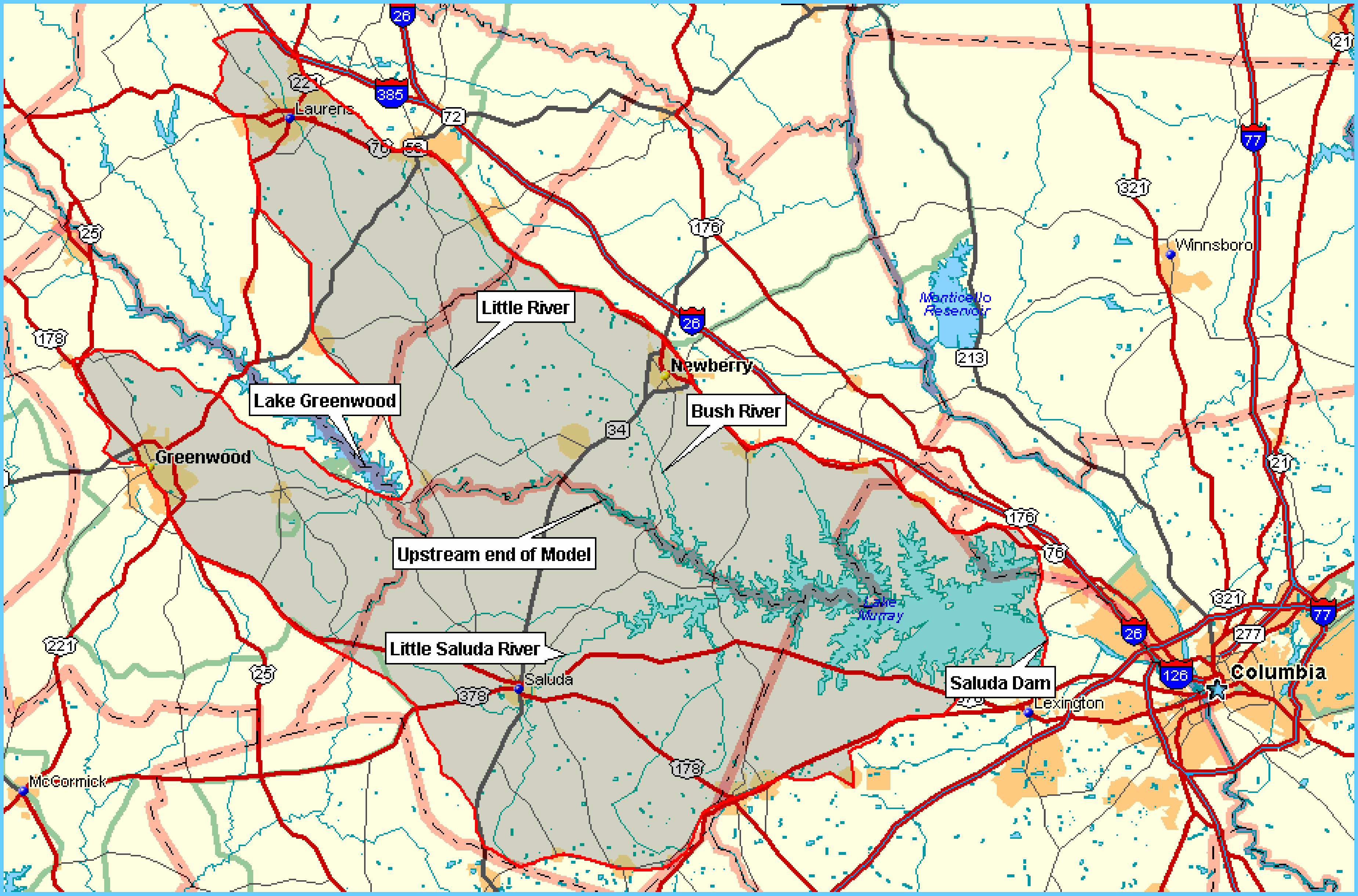
REMI ***Reservoir Environmental Management, Inc***

Lake Murray Watershed

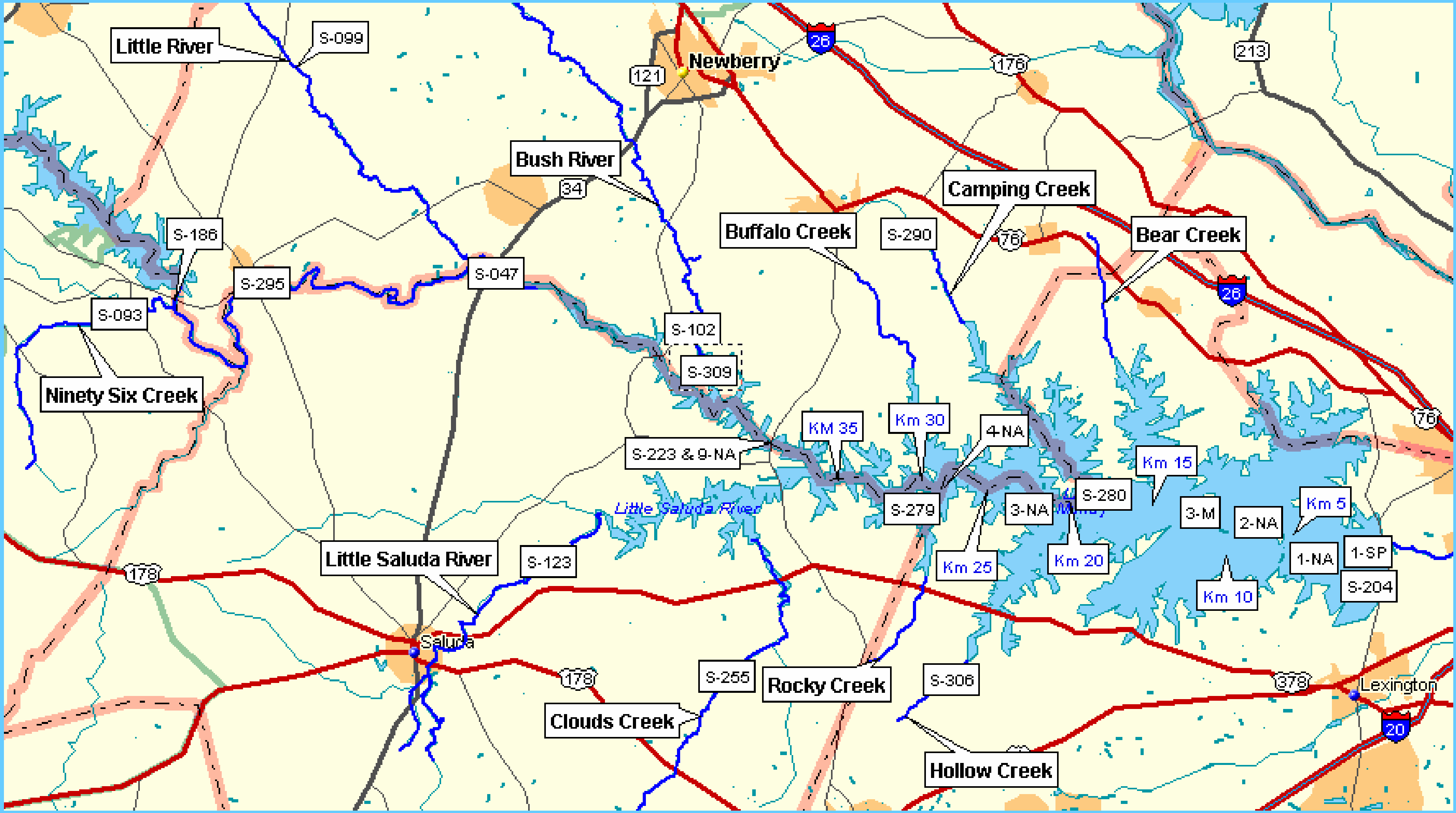


Physical Characteristics of Lake Murray

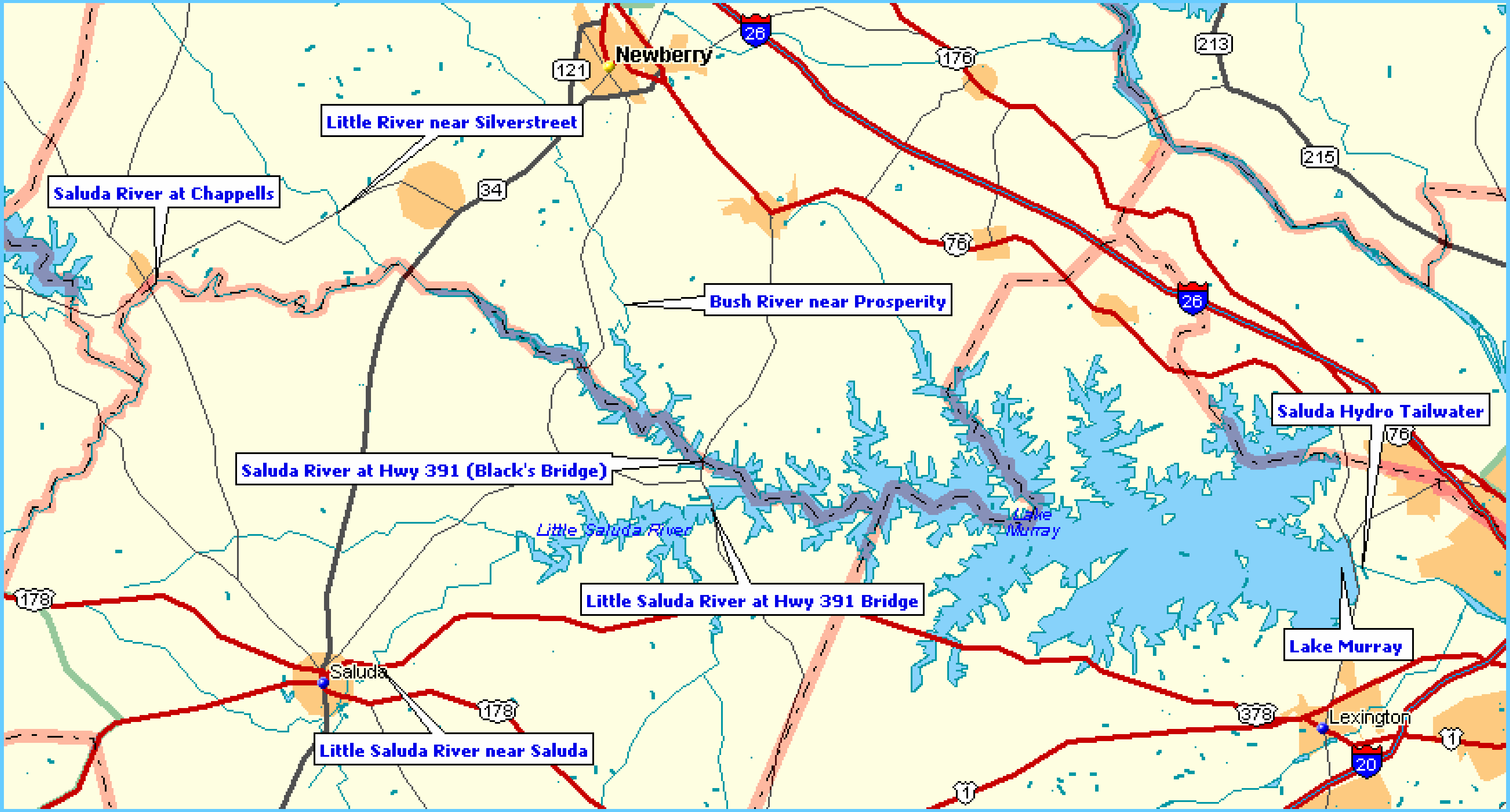
	U.S. Customary System	Metric System
Maximum depth	175 feet	53.3 m
Total lake volume	2,317,000 ac-ft	2,636 hm^3
Average Annual Flow	2778 cfs	78.7 cms
Nominal Residence Time	417 days	417 days
Depth of outlets, Units 1-4	175 feet	53 m
Depth of outlets, Unit 5	78 feet	23.5 m
Flow Capacity - Units 1-4	3000 cfs (each)	85 cms
Flow Capacity, Unit 5	6000 cfs	170 cms

Saluda Hydro and Lake Murray are owned by SCE&G

Primary SCDHEC and SCE&G Monitoring Stations used for Lake Murray Water Quality Analyses



Lake Murray Watershed Showing Location of USGS Monitors



Relicensing Issues Identified by the Water Quality Technical Working Committee

- The causes of striped bass fish kills reported in previous years, especially factors related to Saluda Hydro operations
- The effects of Unit 5 operations on striped bass habitat and entrainment of blue-back herring
- Determination of operational changes that might increase habitat for striped bass and blue-back herring
- Assessment of pool level management alternatives
- Track any impacts that could occur to the tailwater cold-water fishery due to potential operational changes

Factors to be Considered in Addressing Relicensing Issues

- Annual flow regimes
- Pool level management
- Unit 5 operations in combination with Units 1-4
- In-lake and release water quality
- Habitat for striped bass and blue-back herring
- Water quality, meteorological, and operations data over the period 1990-2005
- Emphasis will be placed on reservoir from Blacks Bridge to Saluda Dam

Plan for Using CE-QUAL-W2 to Address the Water Quality TWC Relicensing Issues

1. Analyze water quality, meteorological, flow, and operations data for the period of study
2. Calibrate CE-QUAL-W2 model for 1996, 1992, 1997
3. Set up CE-QUAL-W2 for the years when major striped bass fish kills occurred and selected years when they did not occur
4. Use the models to develop temperature and DO criteria for tolerable striped bass habitat
5. Run models to identify the causes that apparently contributed to the fish kills
6. Use the models to explore ways to minimize such fish kills in the future, evaluate effects of proposed pool operations, and develop unit operations protocol to improve water quality

Overview of Findings

- Nutrient loads are the primary cause for impacts to striped bass habitat, blue-back herring entrainment, and low DO in the turbine releases.

- High flow, especially during March-June, is the primary cause for fish kills considering current nutrient loads (higher flows introduce greater mass of nutrients and organic matter to the lake, cause the bottom of the lake to warm, reducing habitat and increasing the rate of DO depletion)

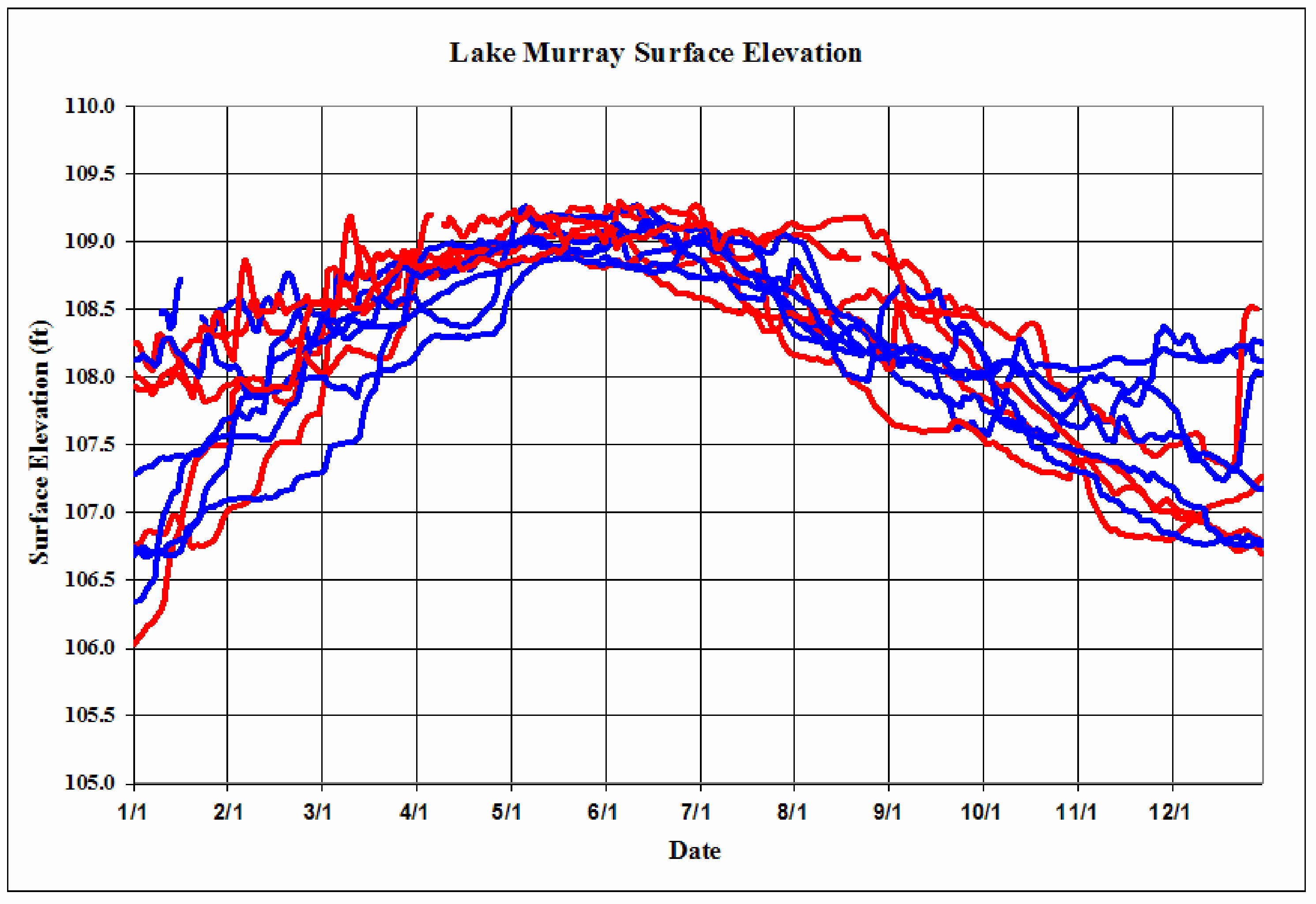
- Meteorological conditions can affect striper habitat

- Model results indicate that the temperature and DO range of tolerable striper habitat in Lake Murray is approximately:

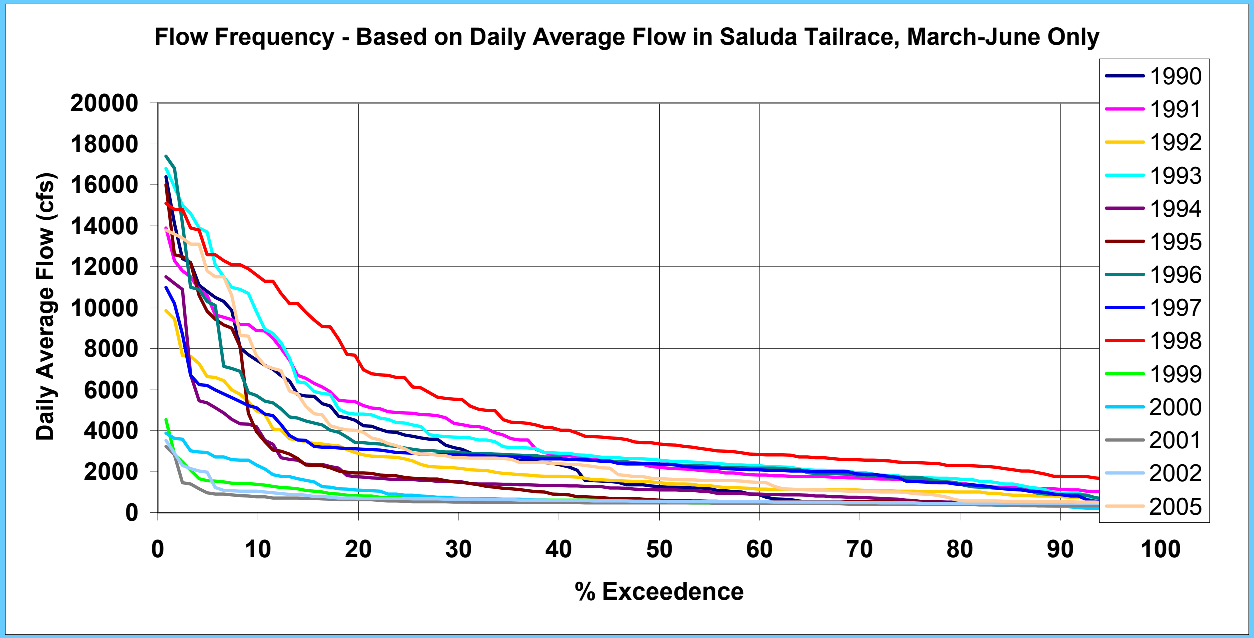
$$T < 27^{o}C \text{ and } DO > 2.5 \text{ mg/l}$$

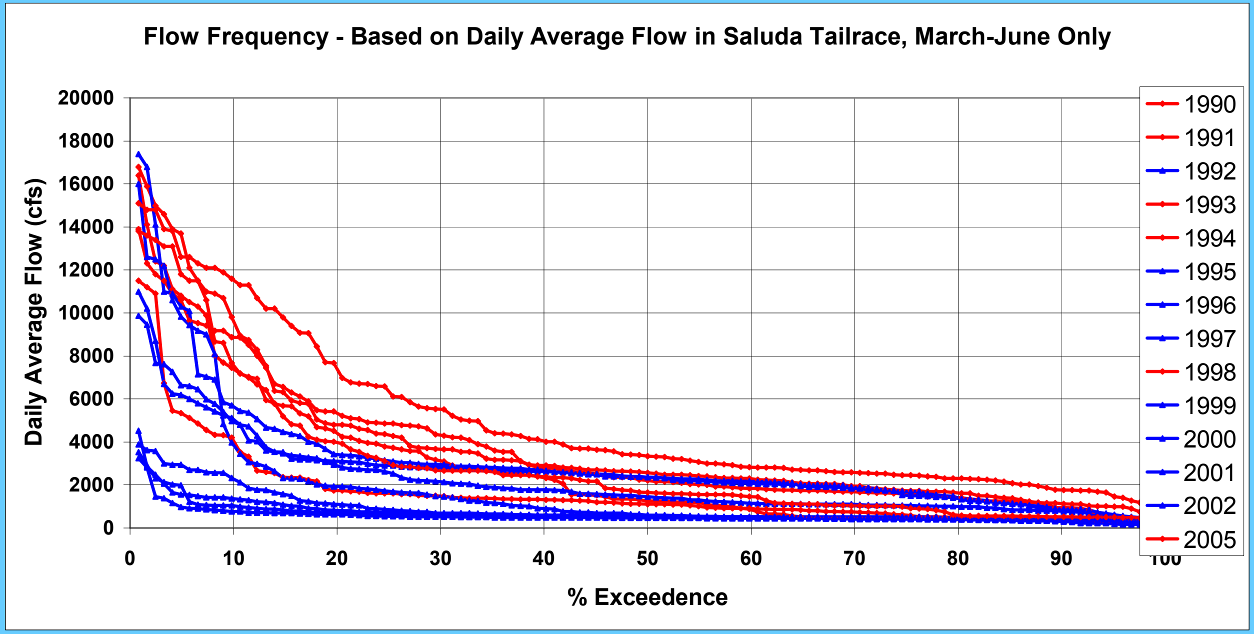
- Higher summer pool levels and preferential use of Unit 5 helps preserve colder bottom water and was predicted to improve DO, increase striper habitat, and enhance temperature in the tailwater

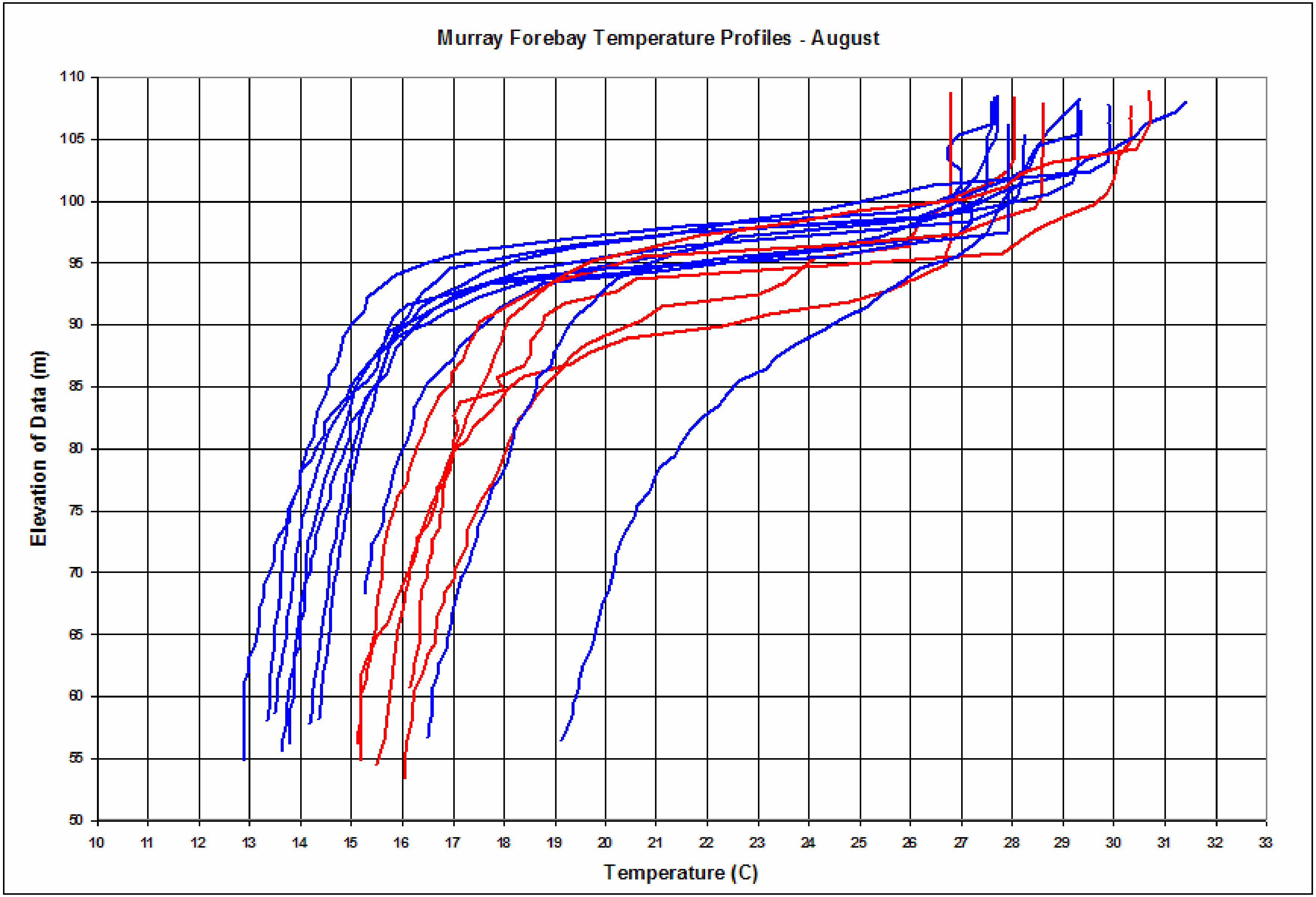
Lake Murray Surface Elevation 1990-2005
Typical Years Only (no special drawdowns)
Years with documented striped bass kills are red



Flow Frequency – Saluda River Below Lake Murray







Murray Forebay Temperature Profiles - August
Elevation of Data (m)
Temperature (C)
110
105
100
95
90
85
80
75
70
65
60
55
50
10
11
12
13
14
15
16
17
18
19
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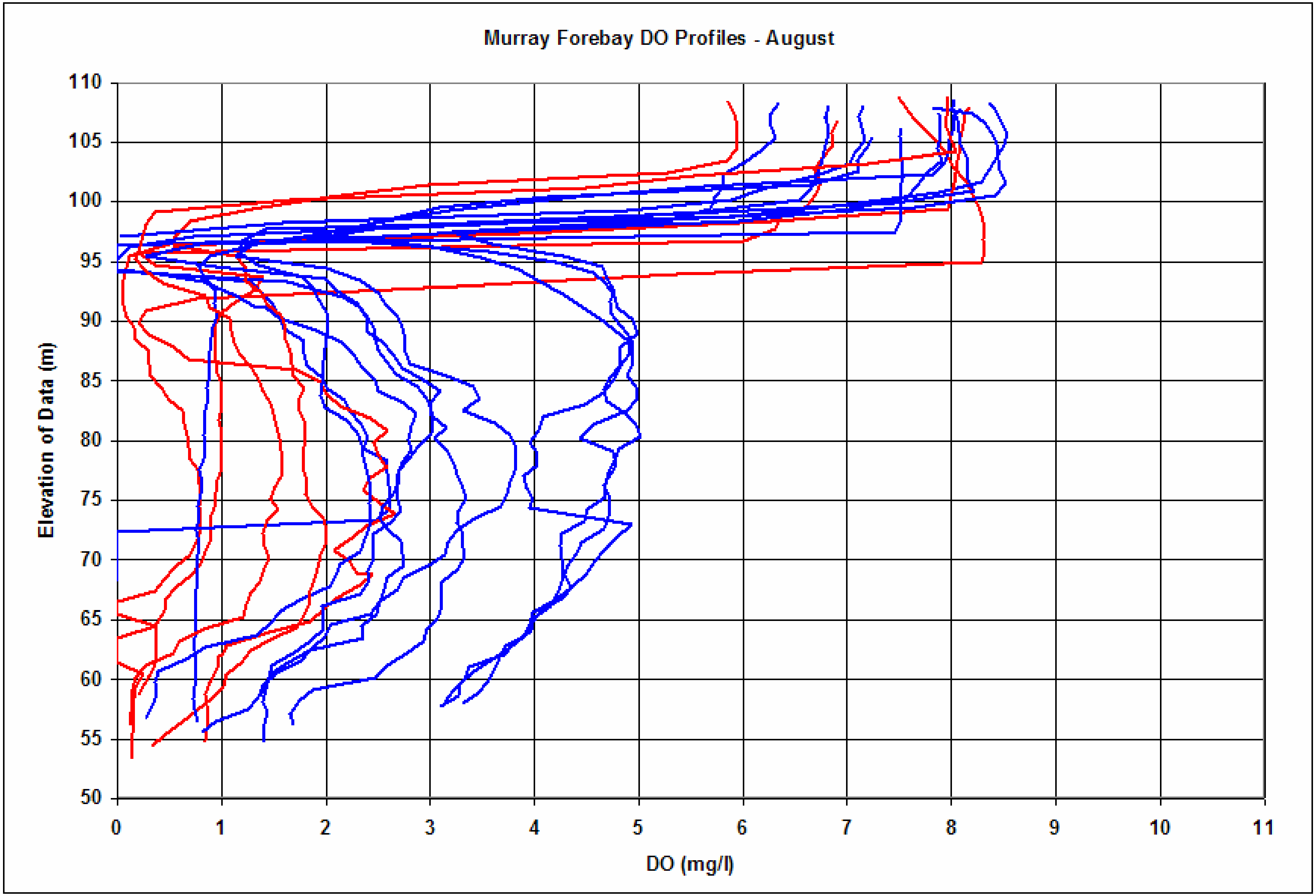
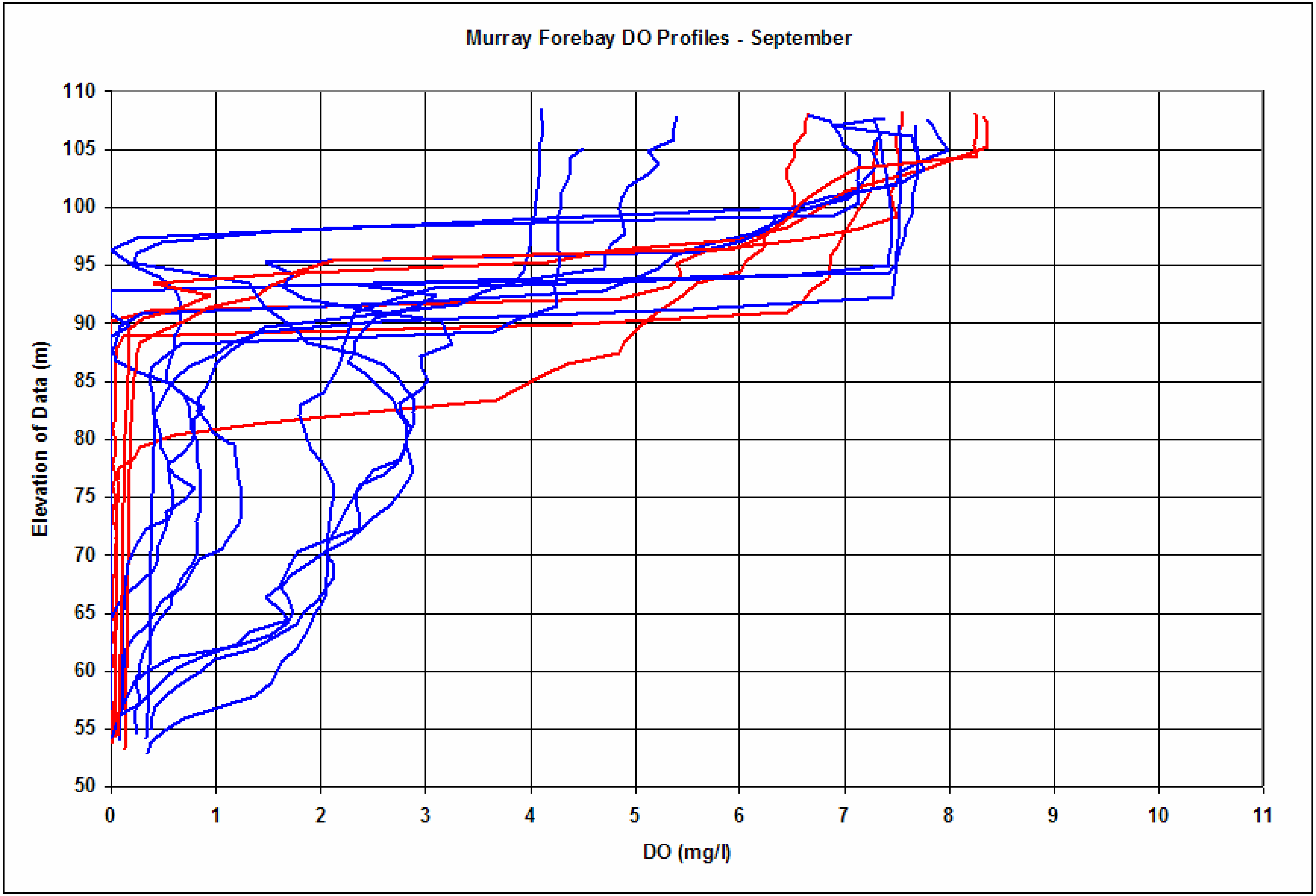
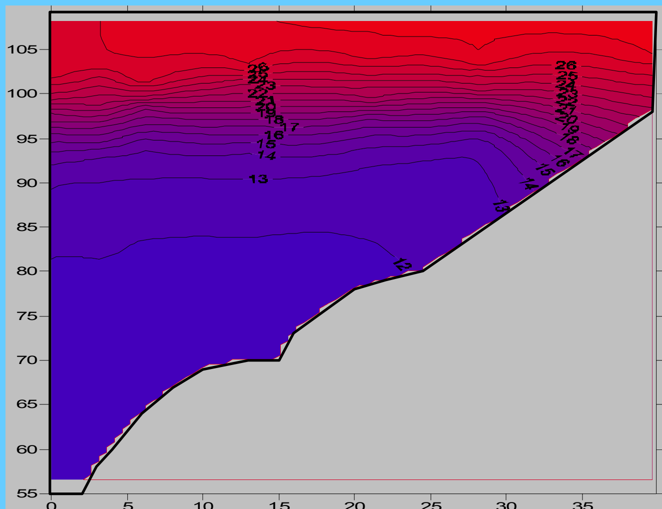
32
33


Murray Forebay DO Profiles - August
Elevation of Data (m)
DO (mg/l)
110
105
100
95
90
85
80
75
70
65
60
55
50
0
1
2
3
4
5
6
7
8
9
10
11

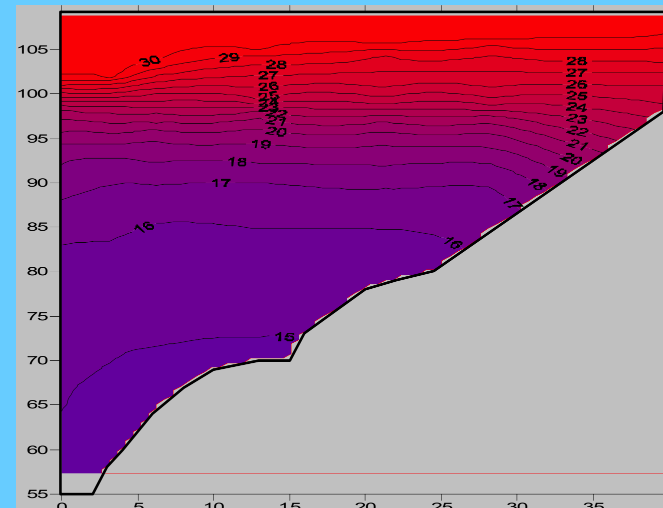

Murray Forebay DO Profiles - September
Elevation of Data (m)
110
105
100
95
90
85
80
75
70
65
60
55
50
0
1
2
3
4
5
6
7
8
9
10
11
DO (mg/l)

Lake Murray Contour Plots

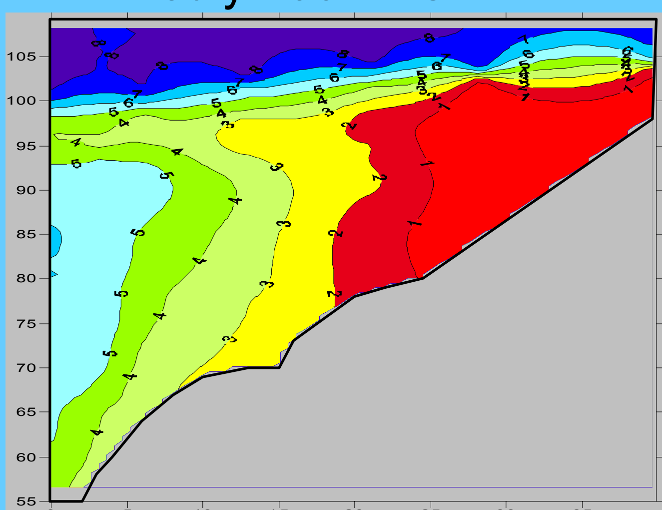
July 2002 Temperature



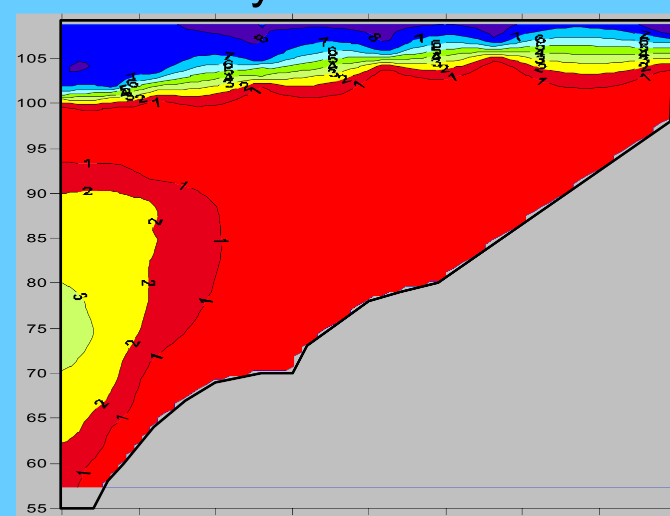
July 2005 Temperature



July 2002 DO

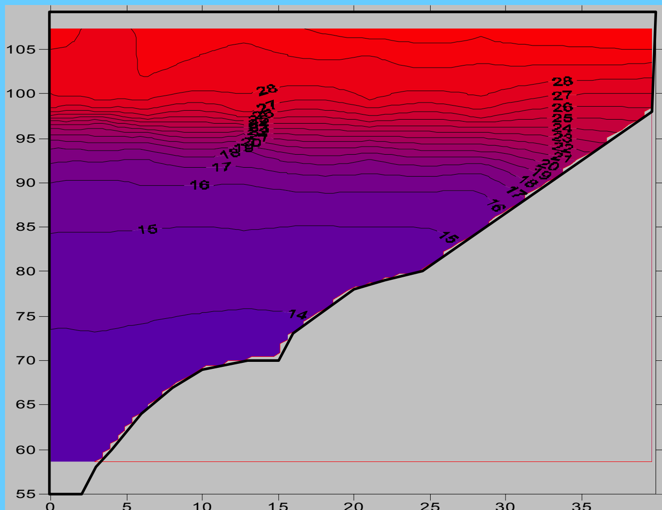


July 2005 DO

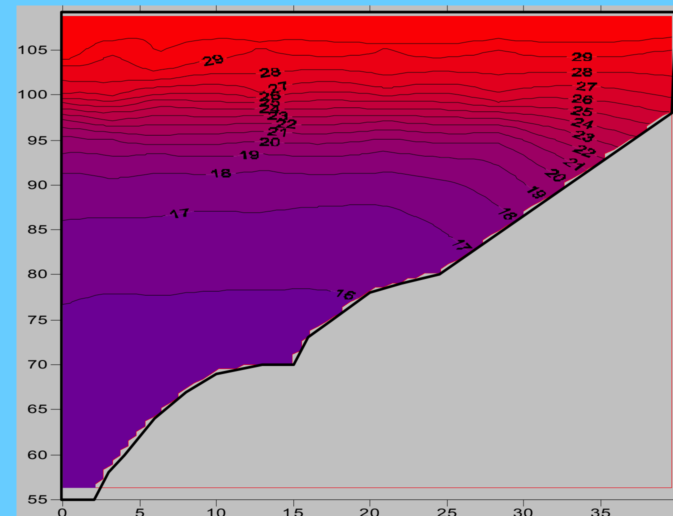


Lake Murray Contour Plots

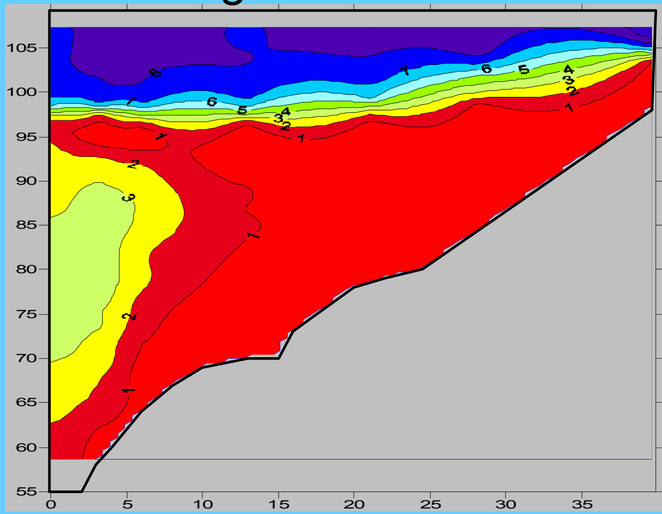
August 2002 Temperature



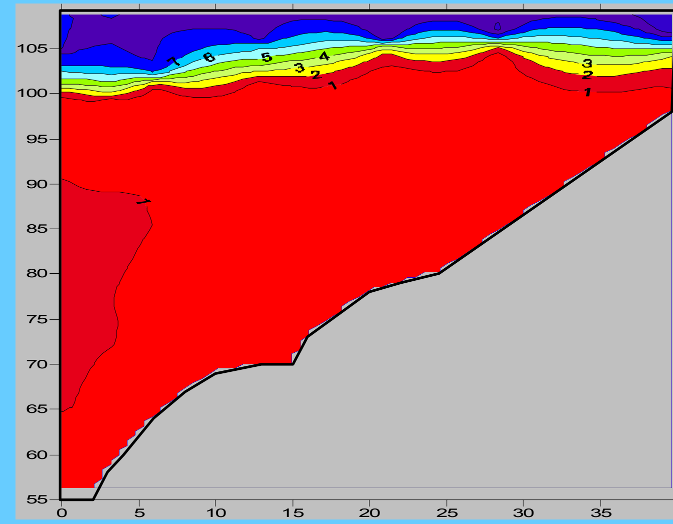
August 2005 Temperature



August 2002 DO

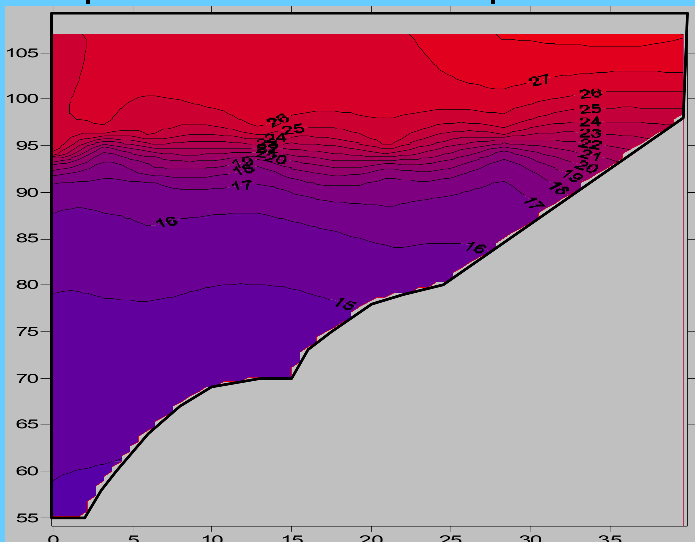


August 2005 DO

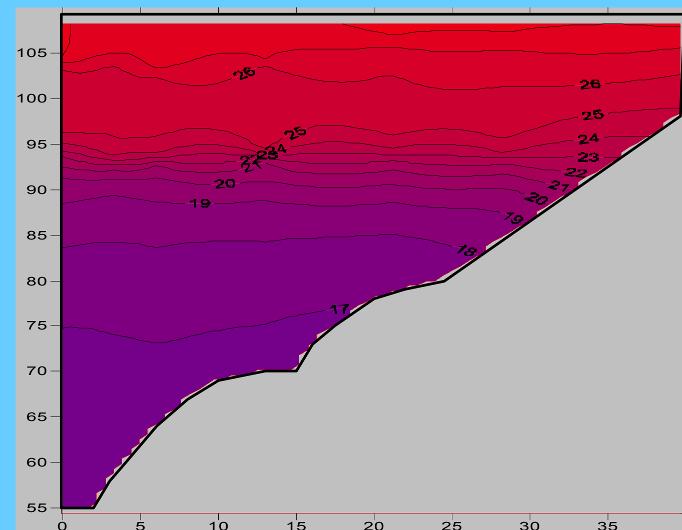


Lake Murray Contour Plots

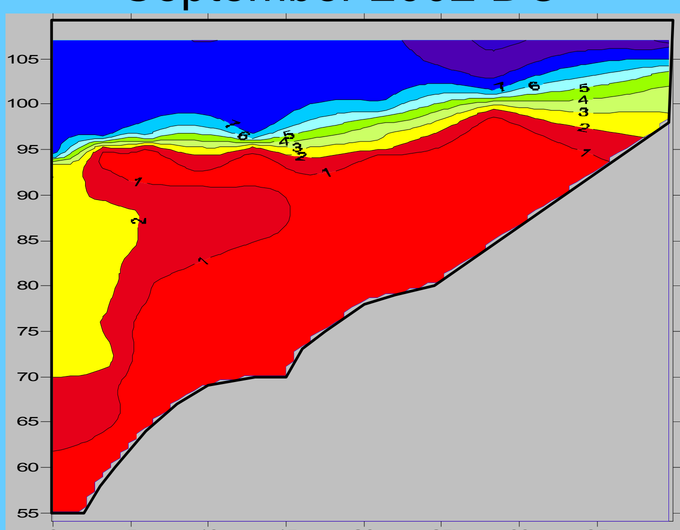
September 2002 Temperature



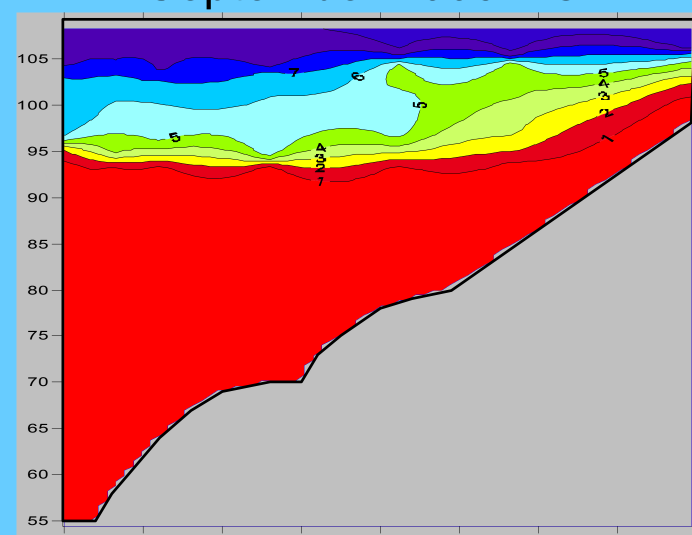
September 2005 Temperature



September 2002 DO



September 2005 DO

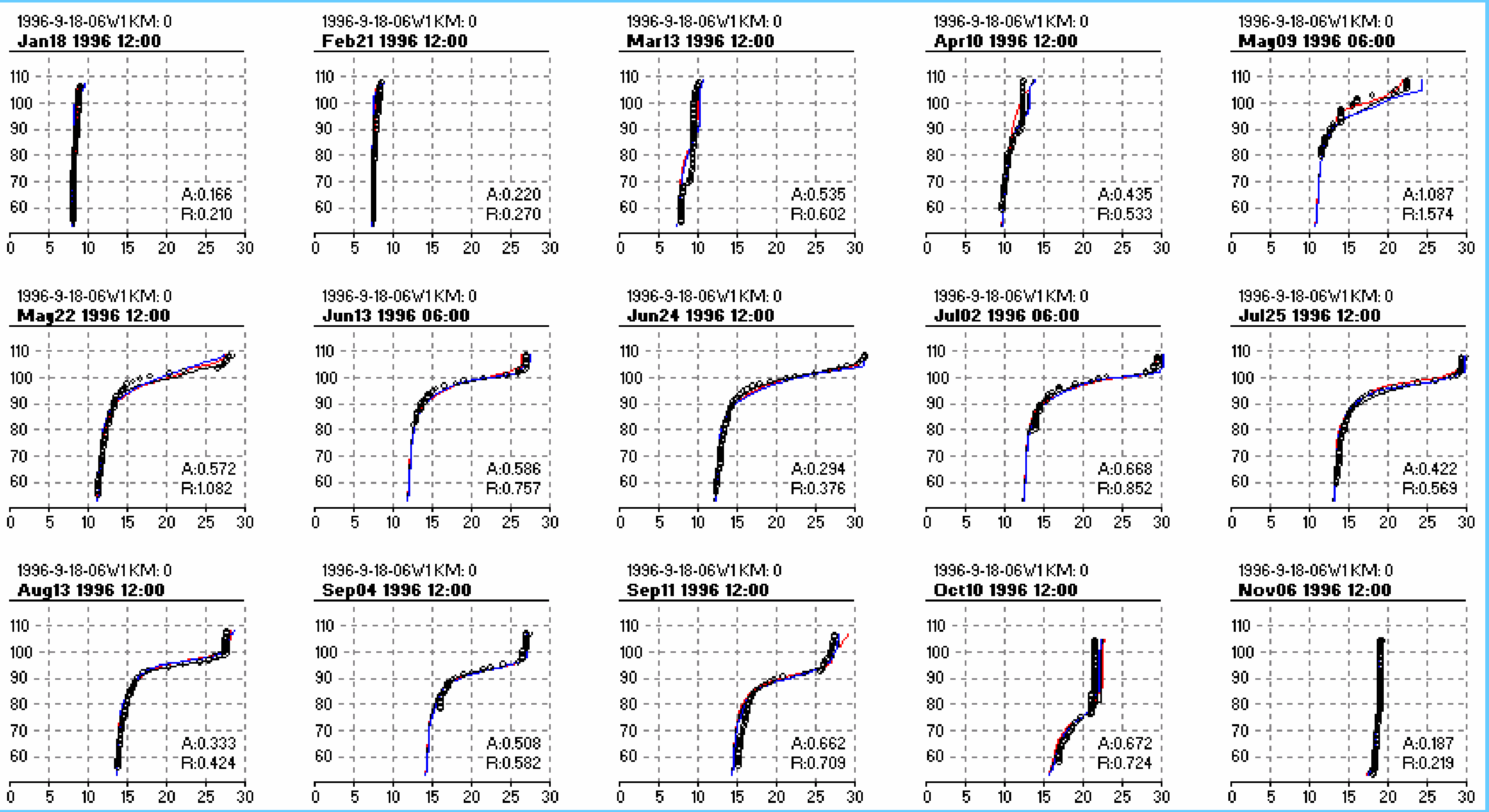


Model Calibration

- Model was originally calibrated to 3 years: 1992, 1996 and 1997; then confirmed for 1991, 1998, 2000, 2001, and 2005
- Model FSOD was reduced 3 years (1997, 1998, 2000) to improve DO calibration; all other model settings remained the same for all the years

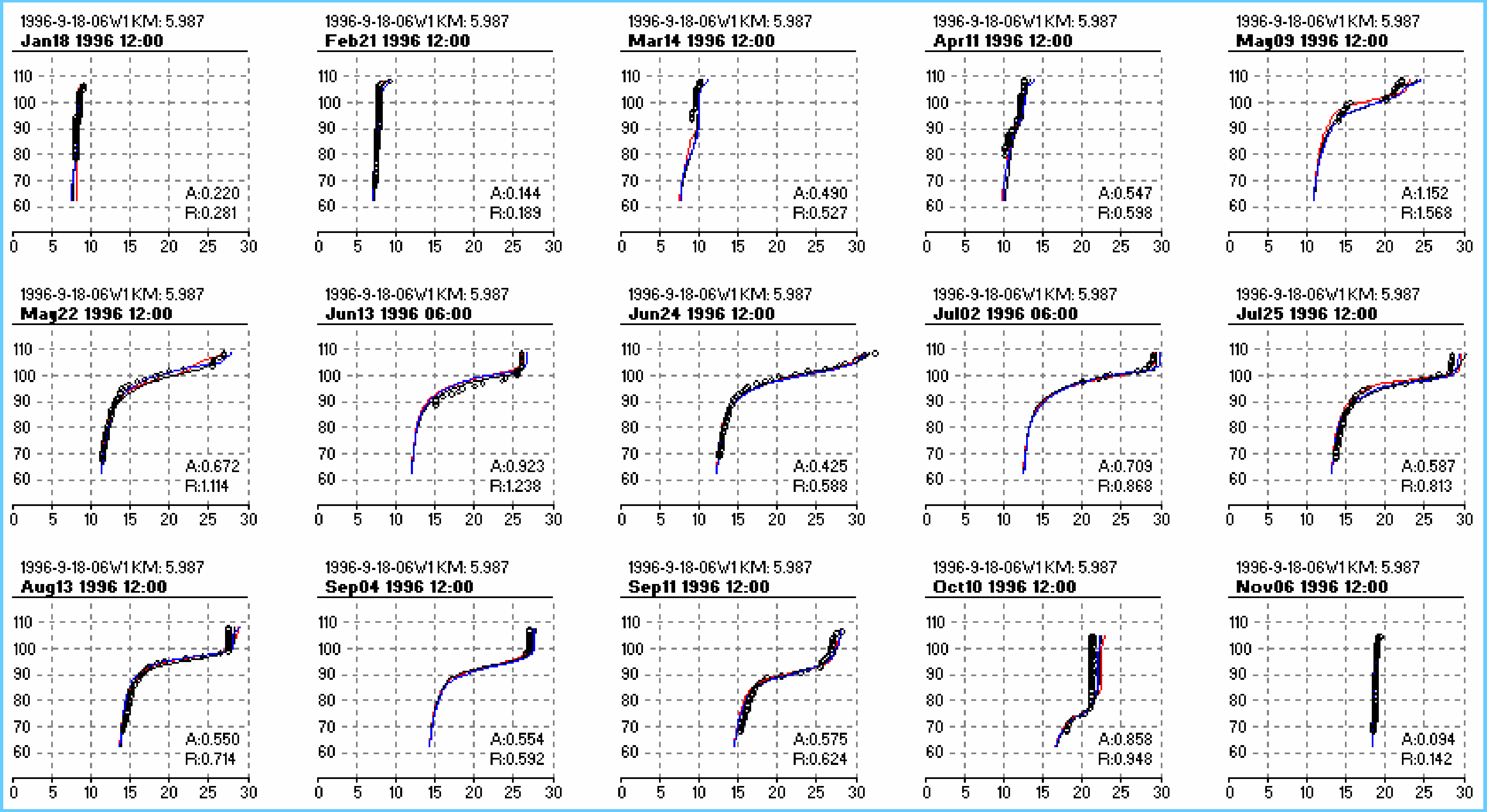
1996 Lake Murray Forebay Temperature Profiles

Model vs. Data [Overall Statistics: ABS = 0.46, RMS = 0.66]



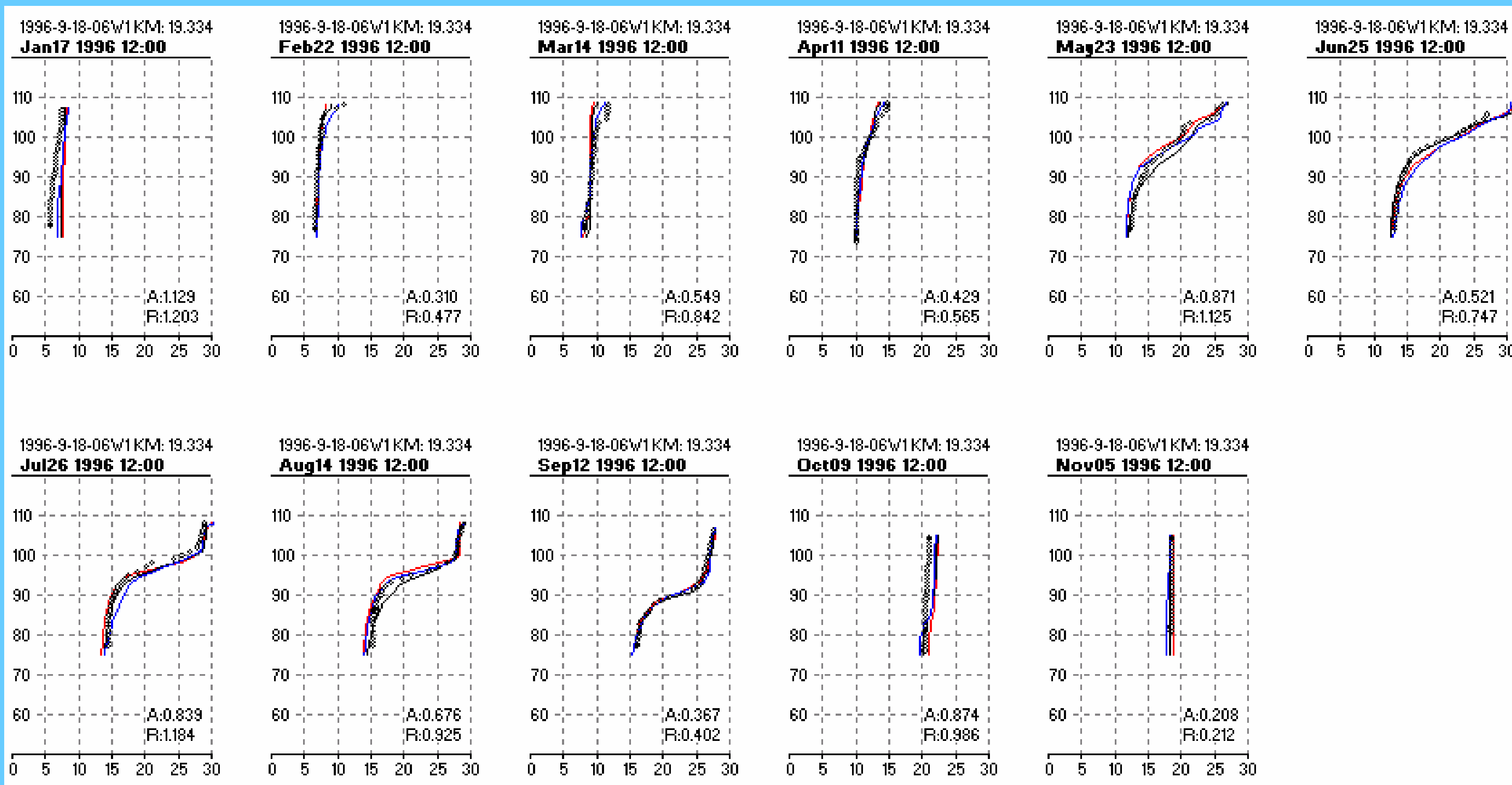
1996 Lake Murray Temperature Profiles – 6 Km Upstream of Dam

Model vs. Data [Overall Statistics: ABS = 0.53, RMS = 0.77]



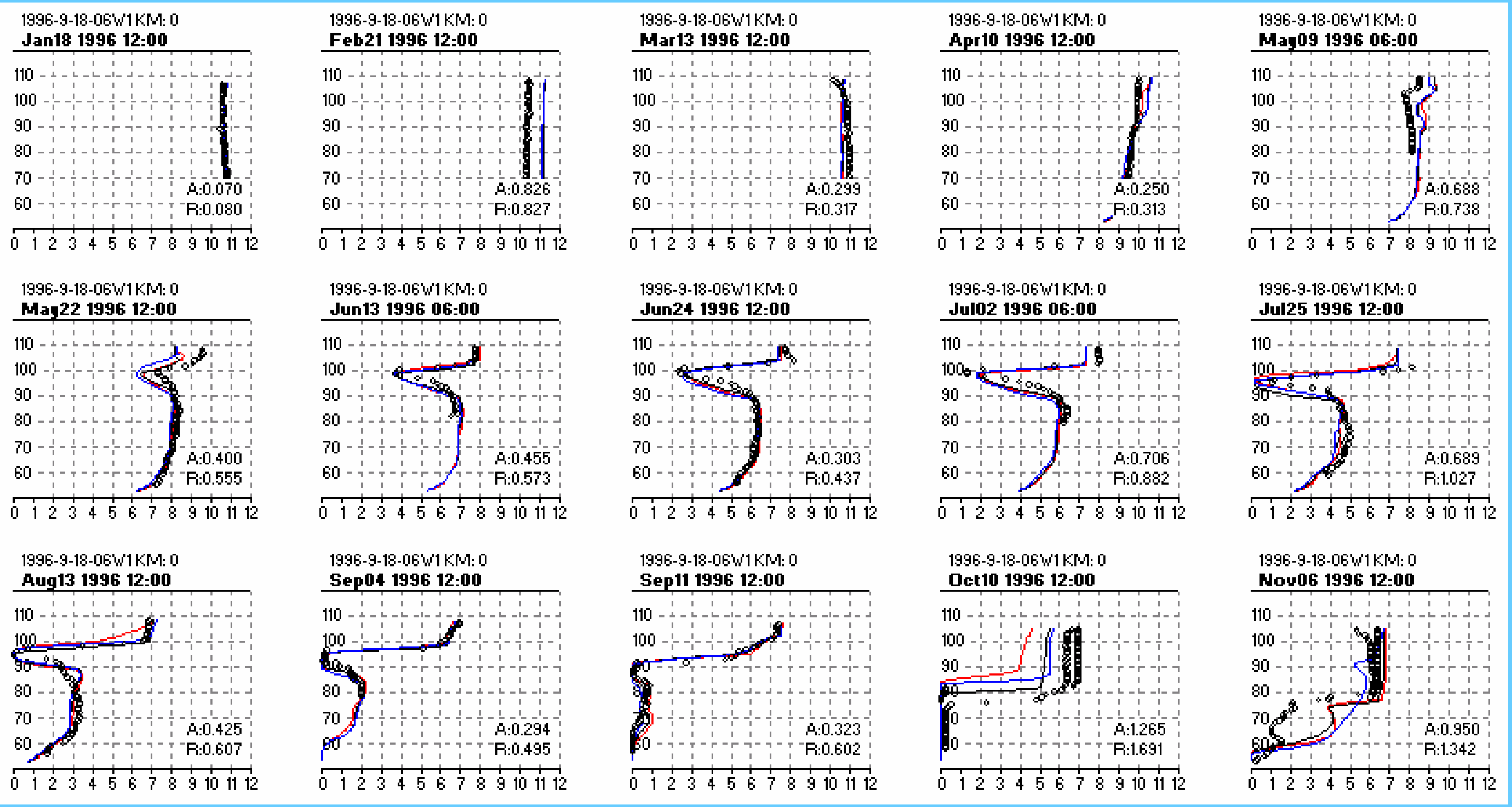
1996 Lake Murray Temperature Profiles – 19 Km Upstream of Dam

Model vs. Data [Overall Statistics: ABS = 0.62, RMS = 0.85]



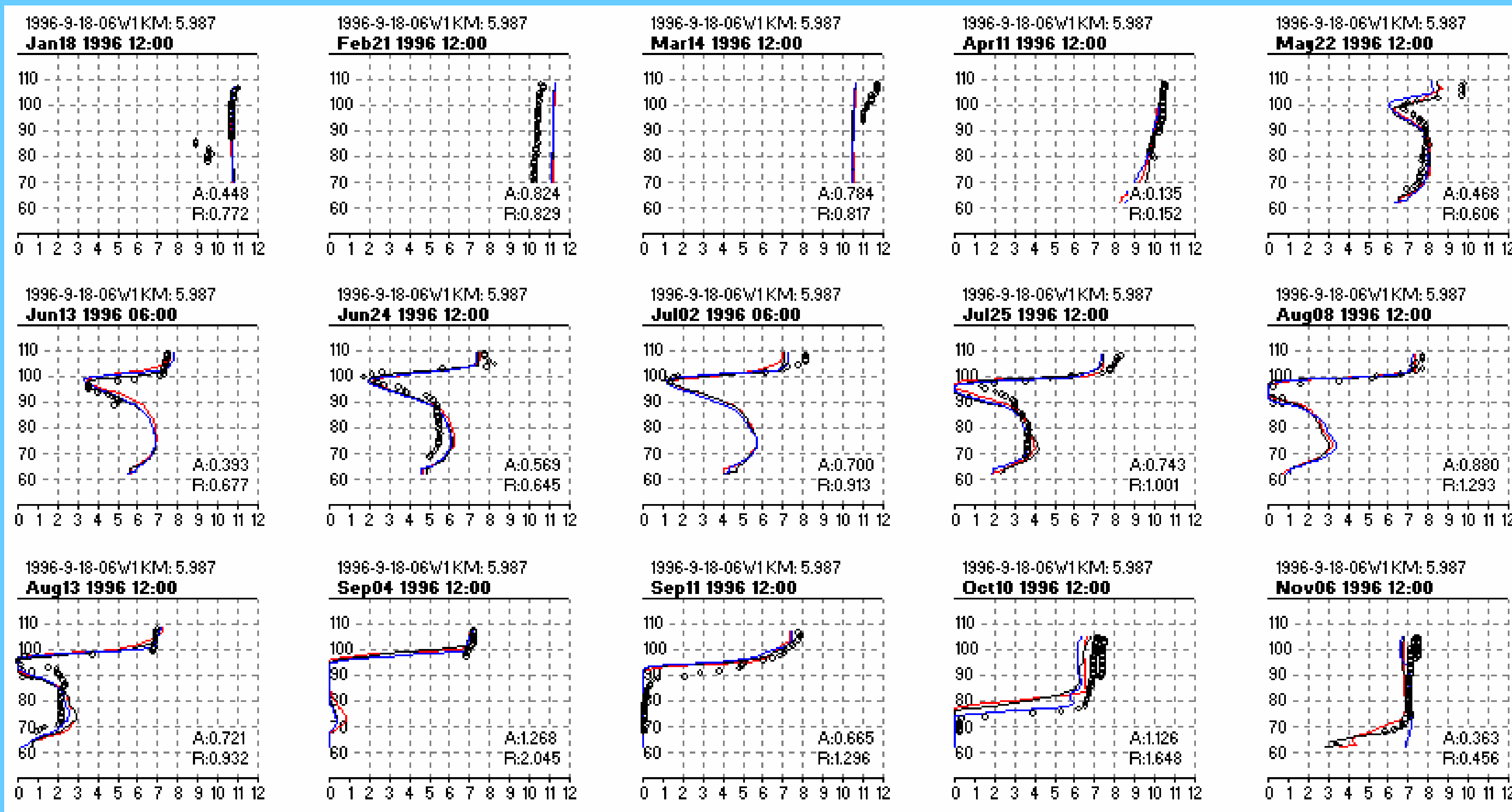
1996 Lake Murray Forebay DO Profiles

Model vs. Data [Overall Statistics: ABS = 0.57, RMS = 0.89]



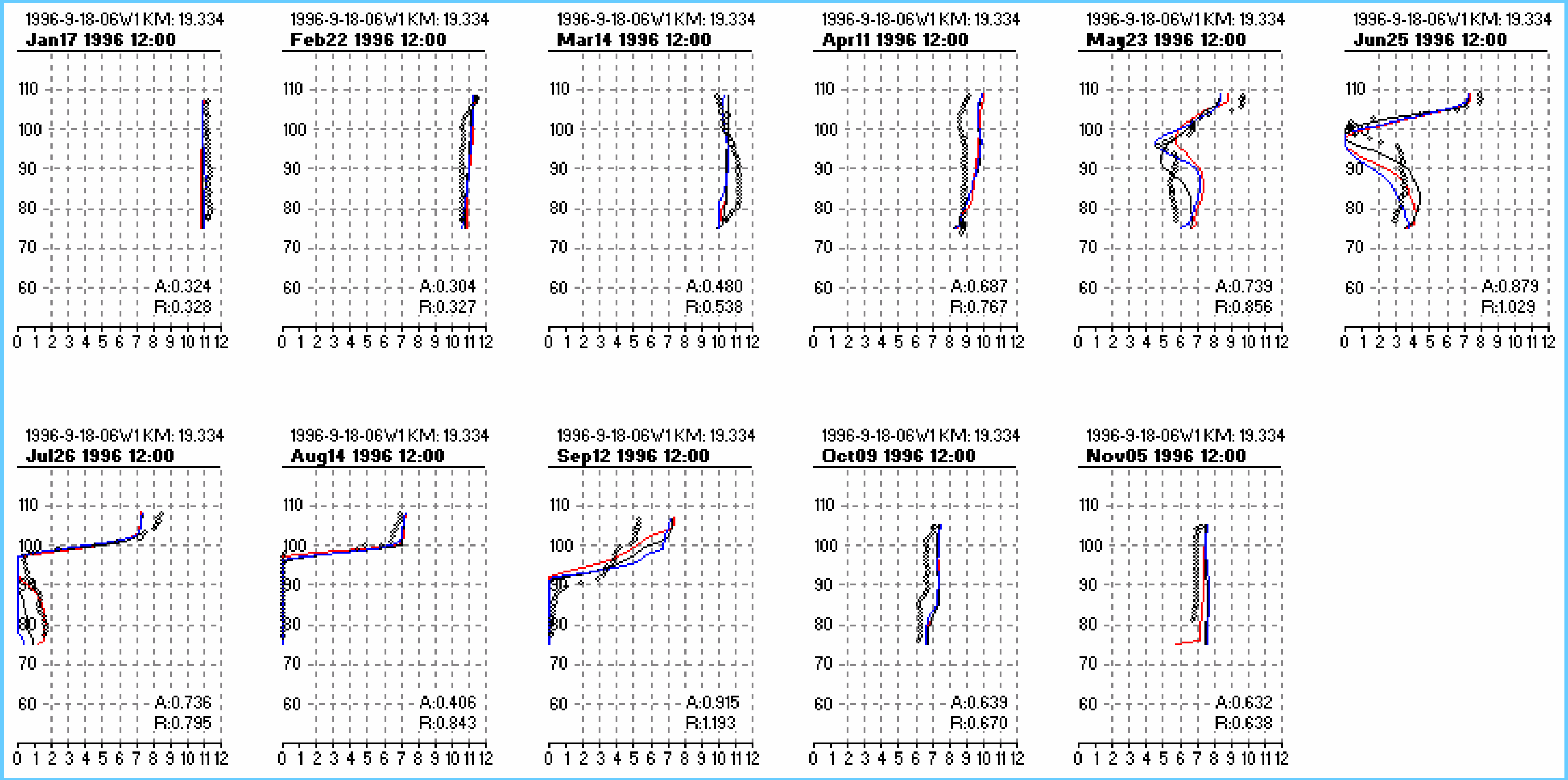
1996 Lake Murray DO Profiles – 6 Km Upstream of Dam

Model vs. Data [Overall Statistics: ABS = 0.65, RMS = 1.00]



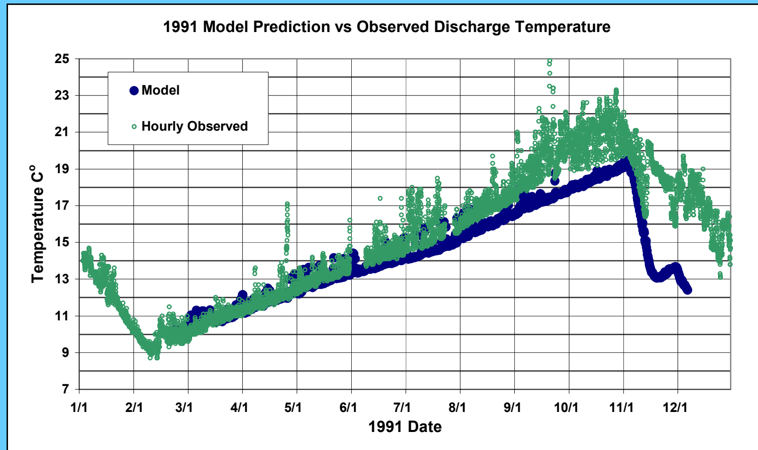
1996 Lake Murray DO Profiles – 19 Km Upstream of Dam

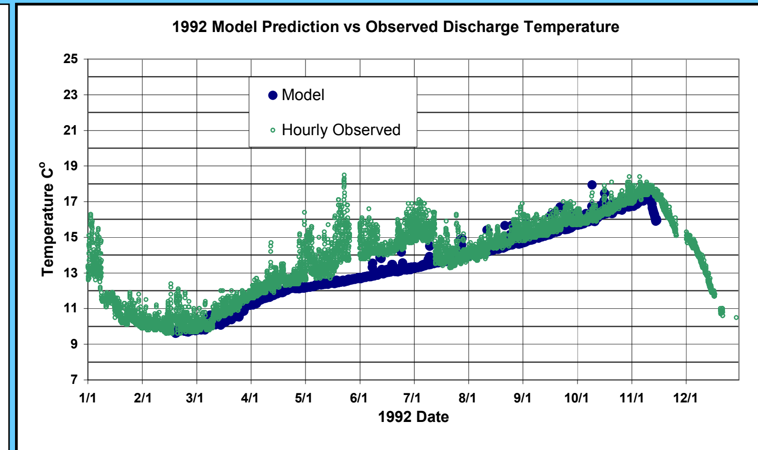
Model vs. Data [Overall Statistics: ABS = 0.61, RMS = 0.77]

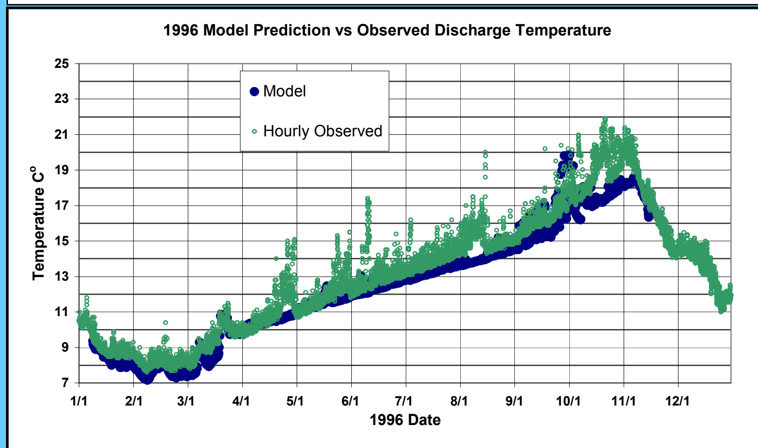


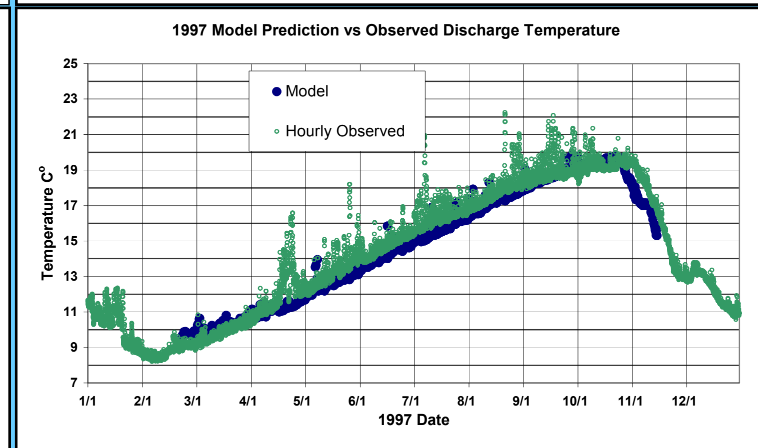
Release Temperature

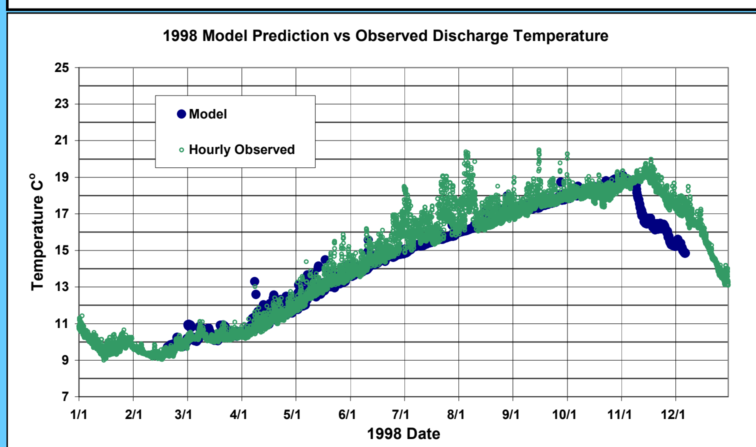
Model vs. Data

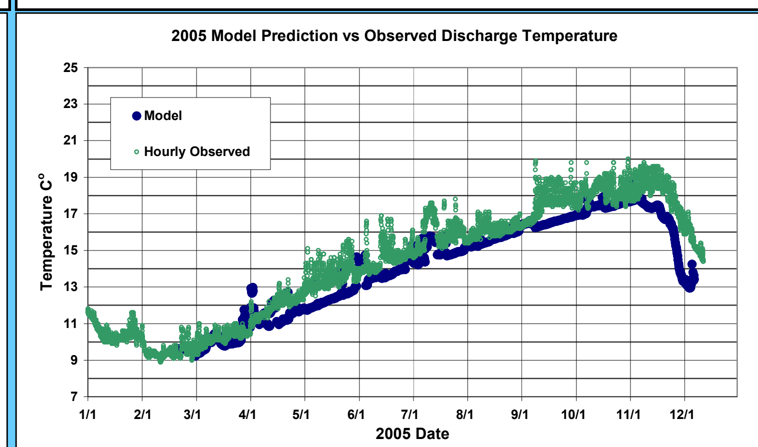






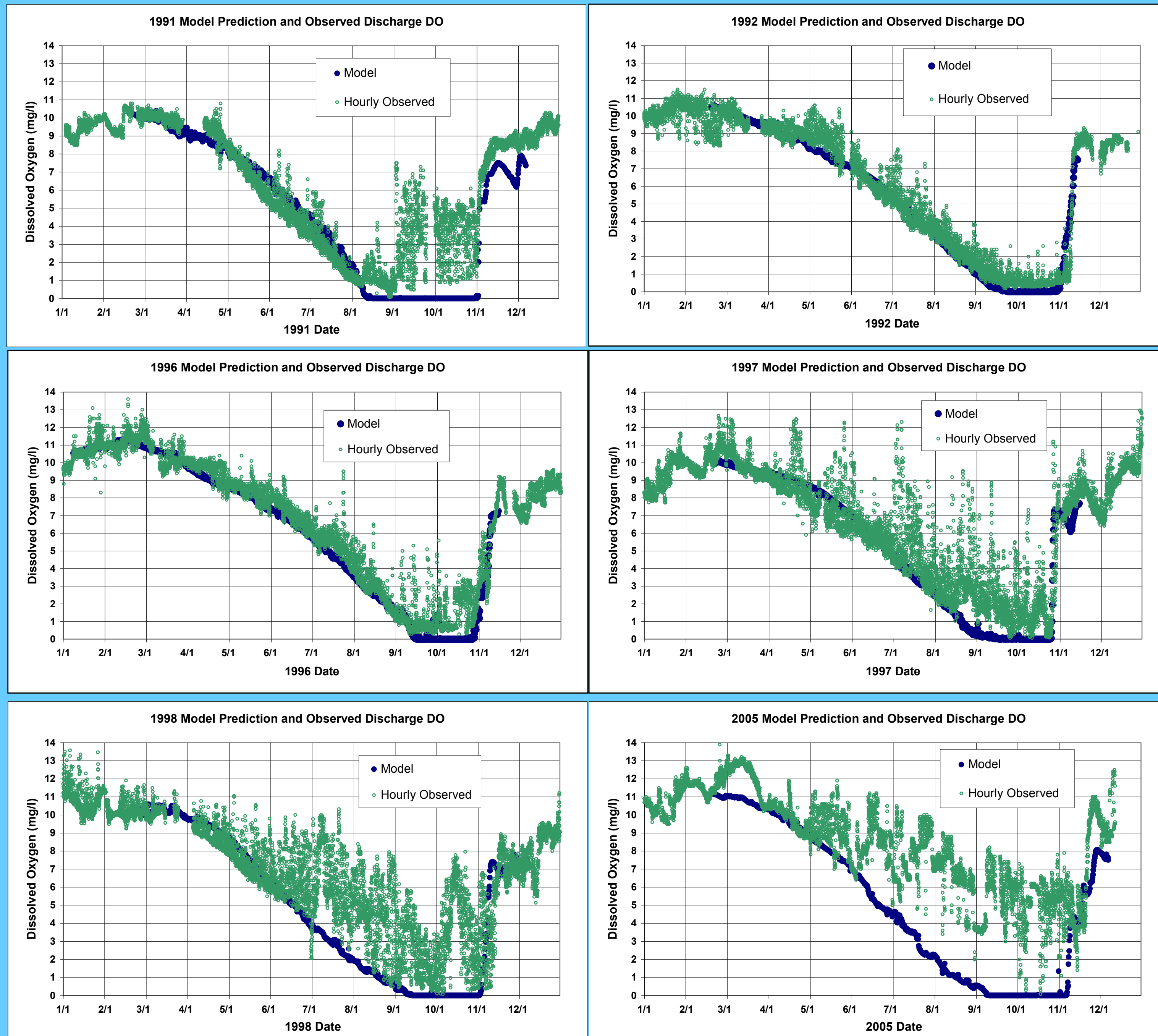




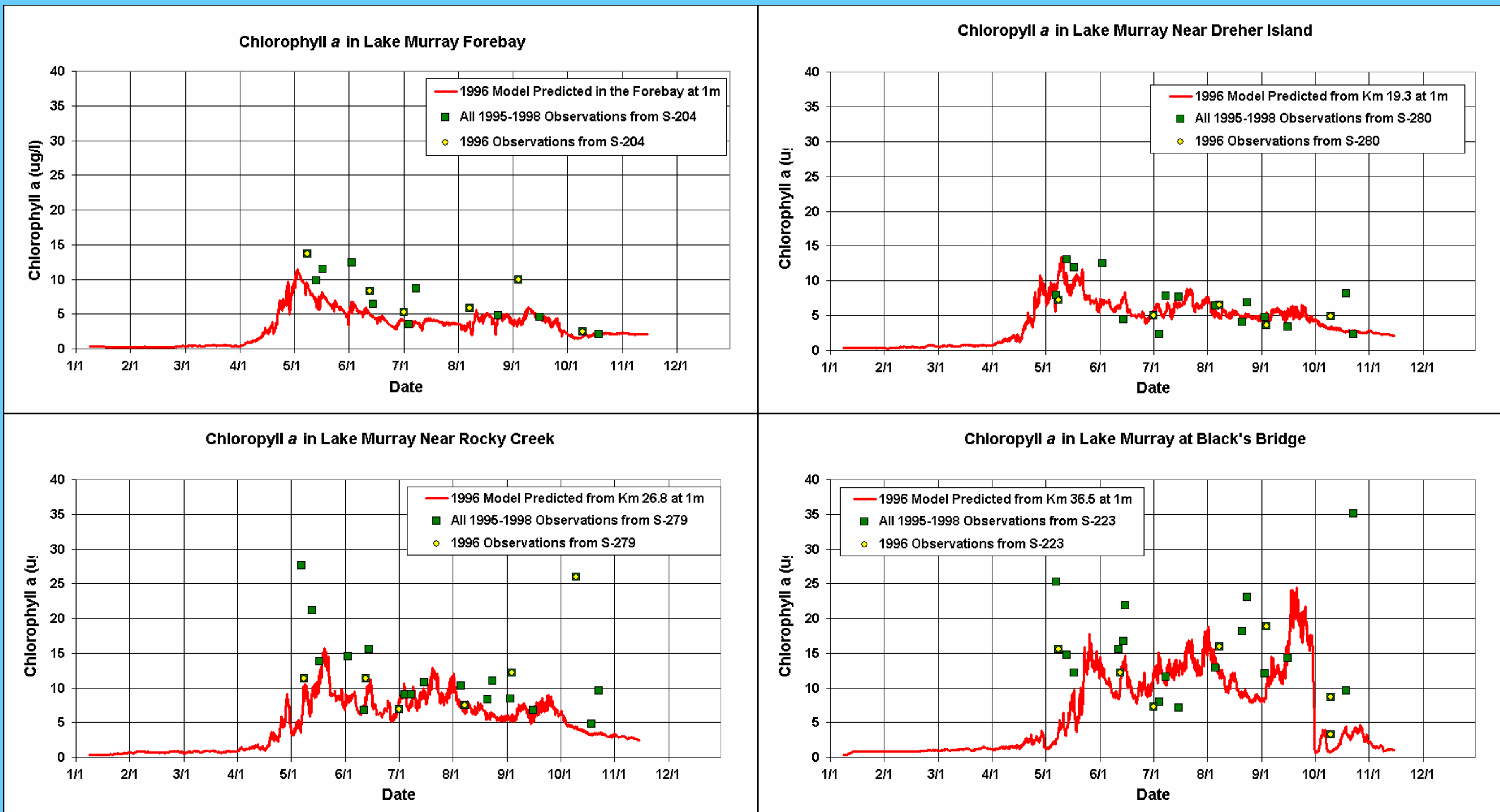


Release DO

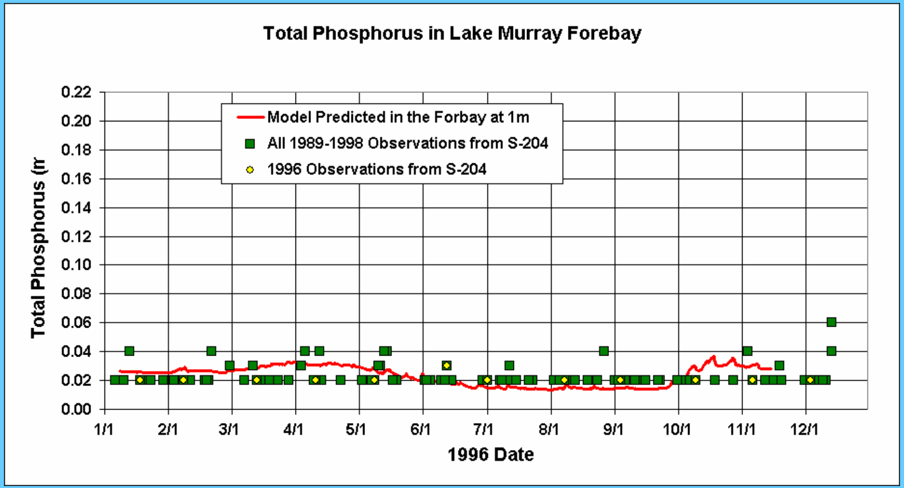
Model vs. Data

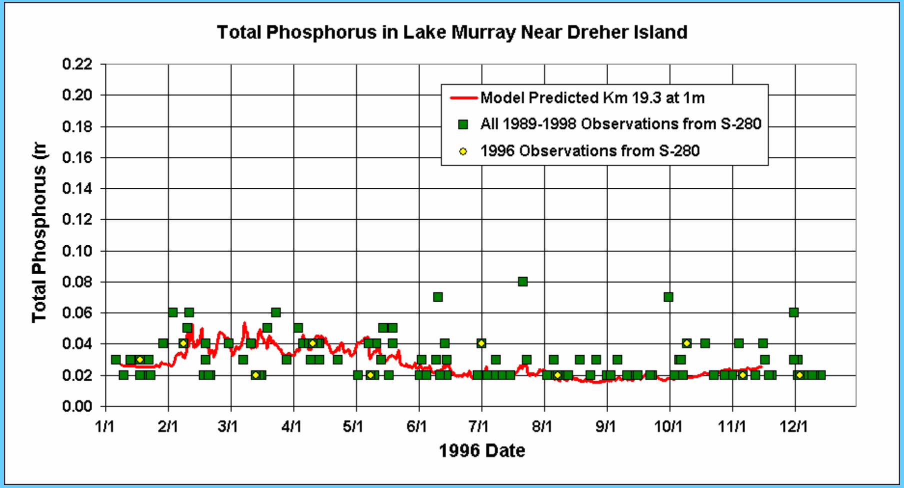


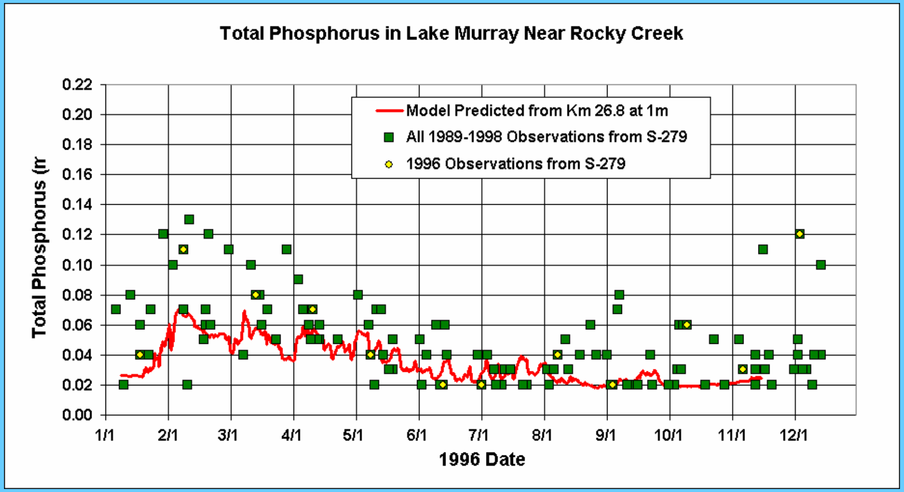
1996 Chlorophyll *a* at Four Locations in Lake Murray
Model vs. Data

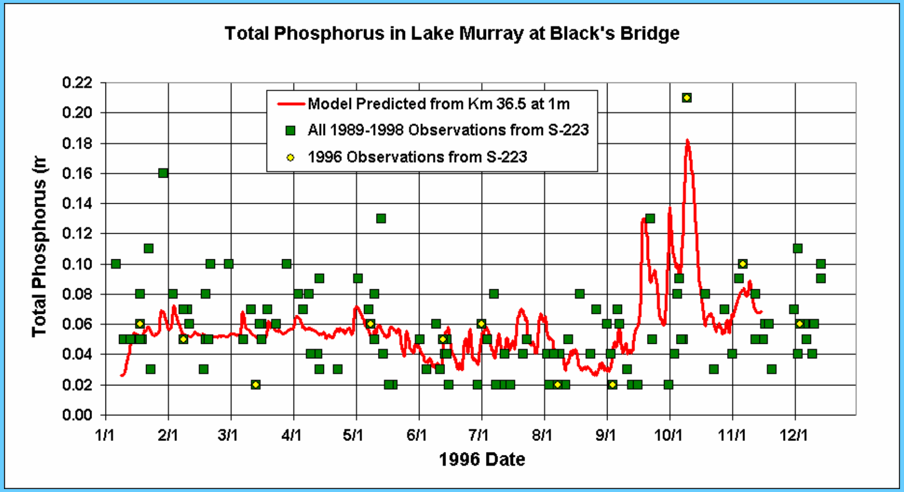


Comparison of Modeled Derived versus Measured Total Phosphorus for 1996 at Four Locations in Lake Murray

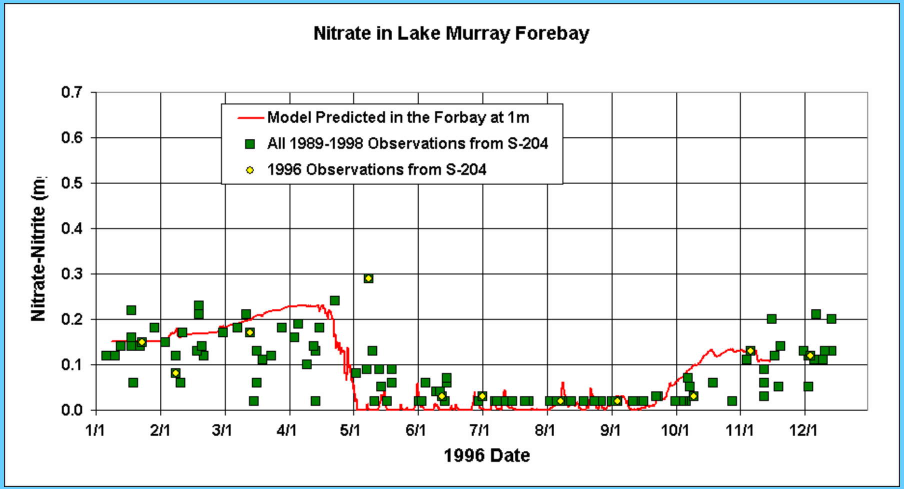


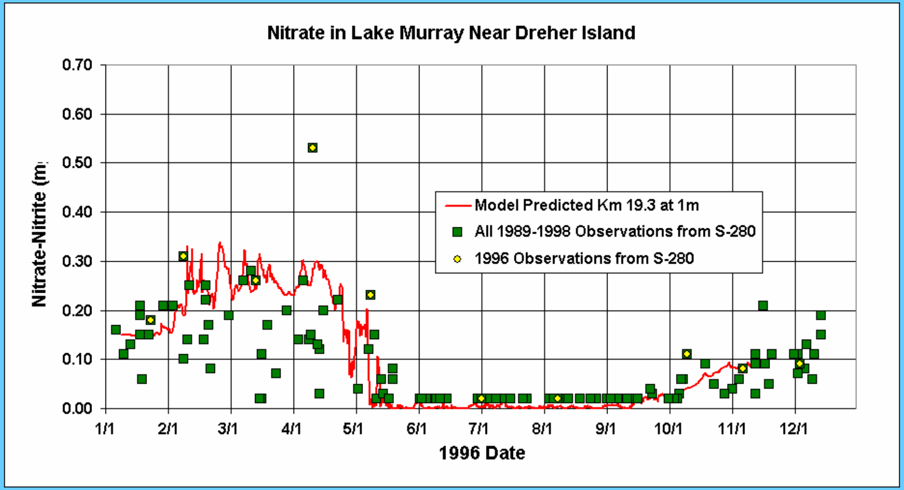


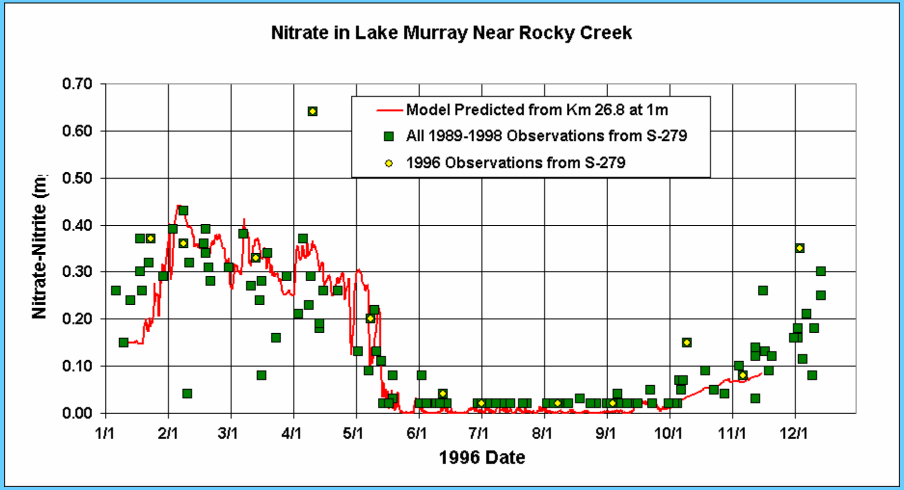


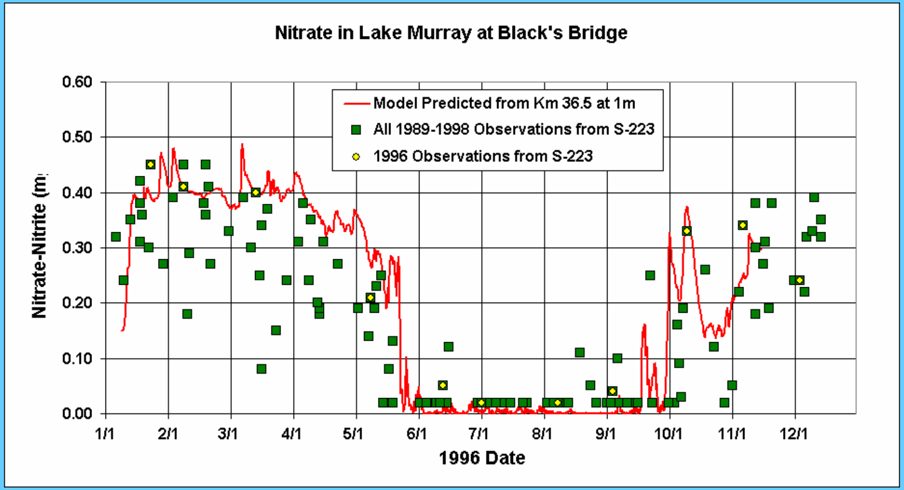


Comparison of Modeled versus Measured Nitrate for 1996 at Four Locations in Lake Murray

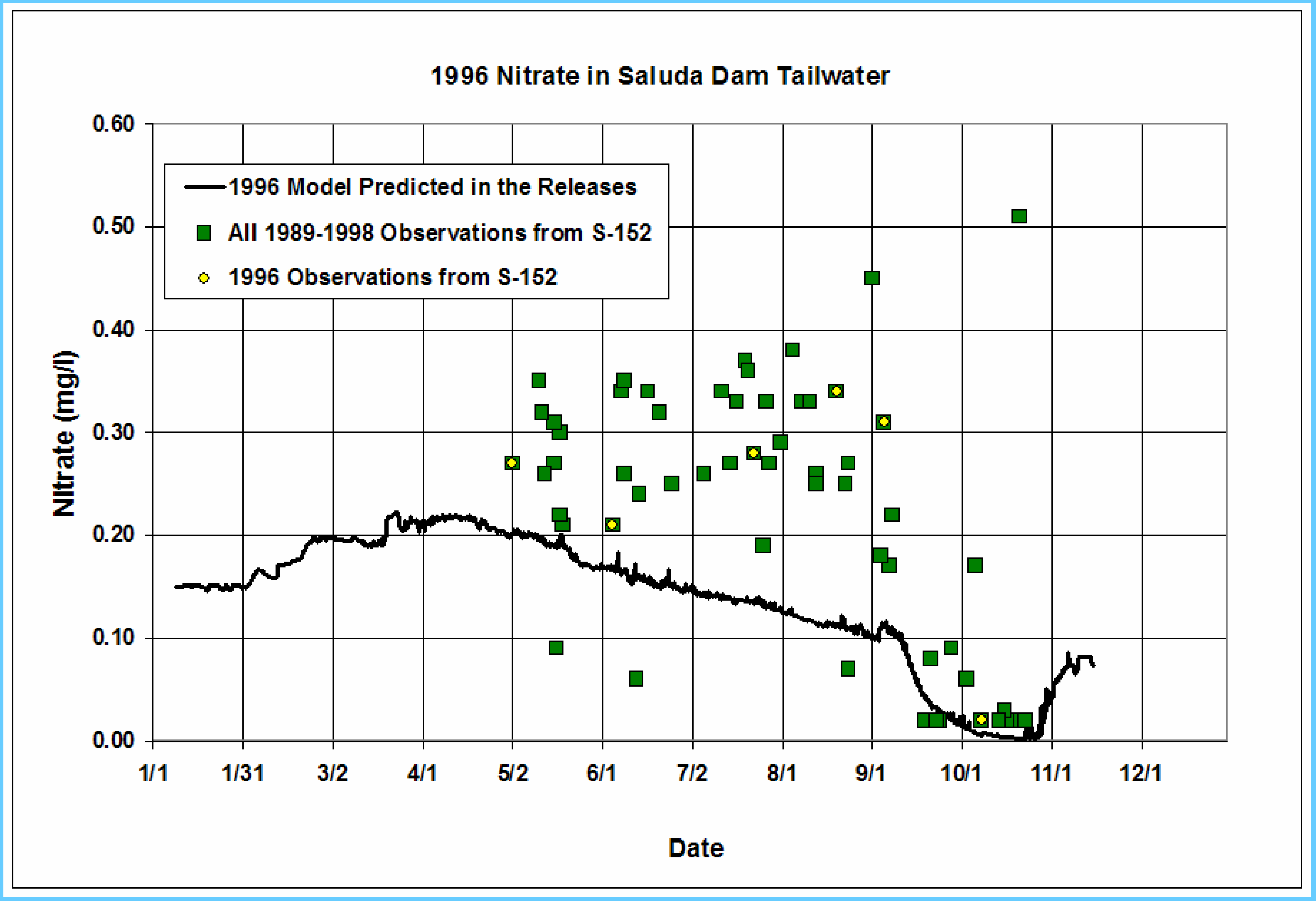




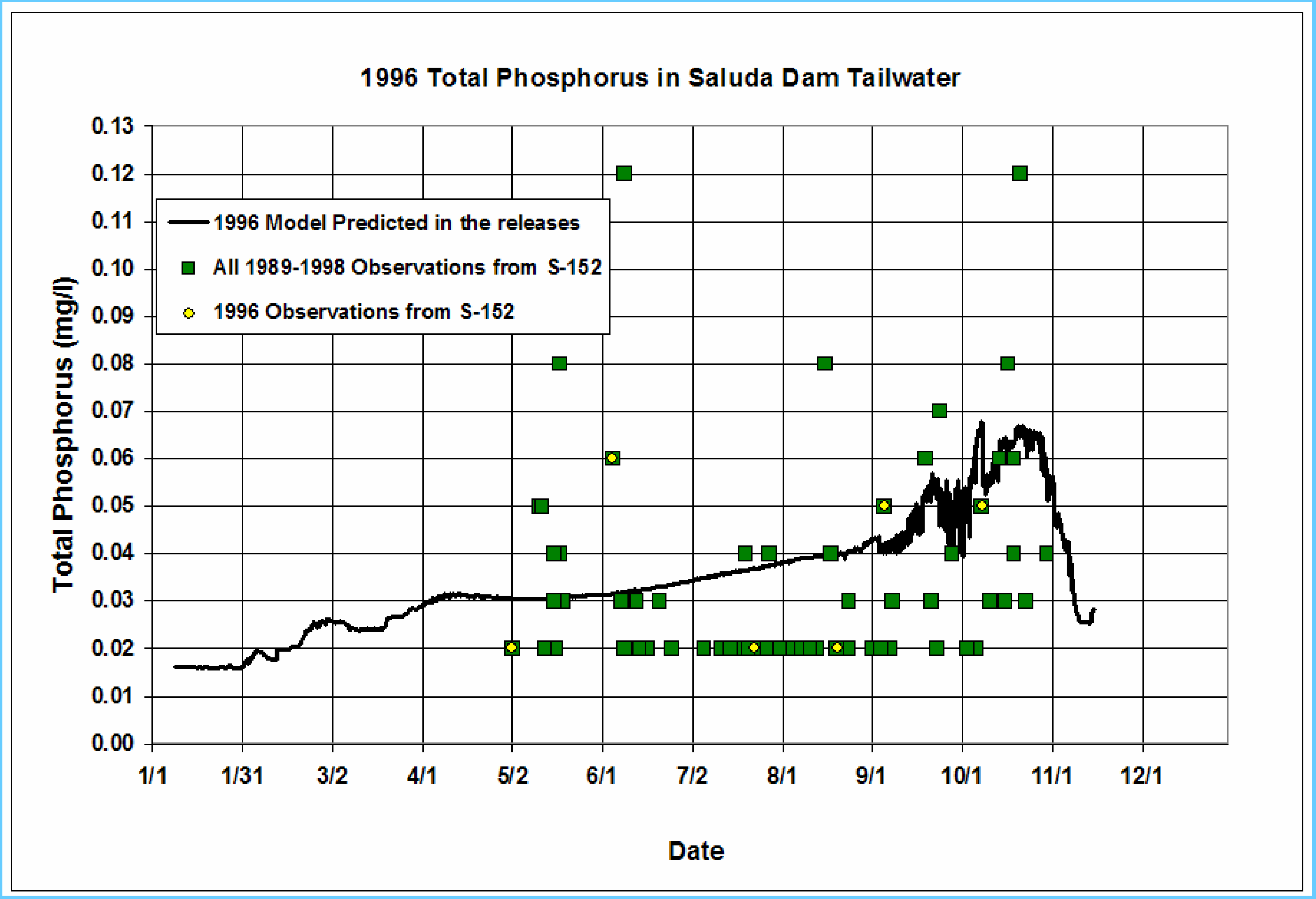




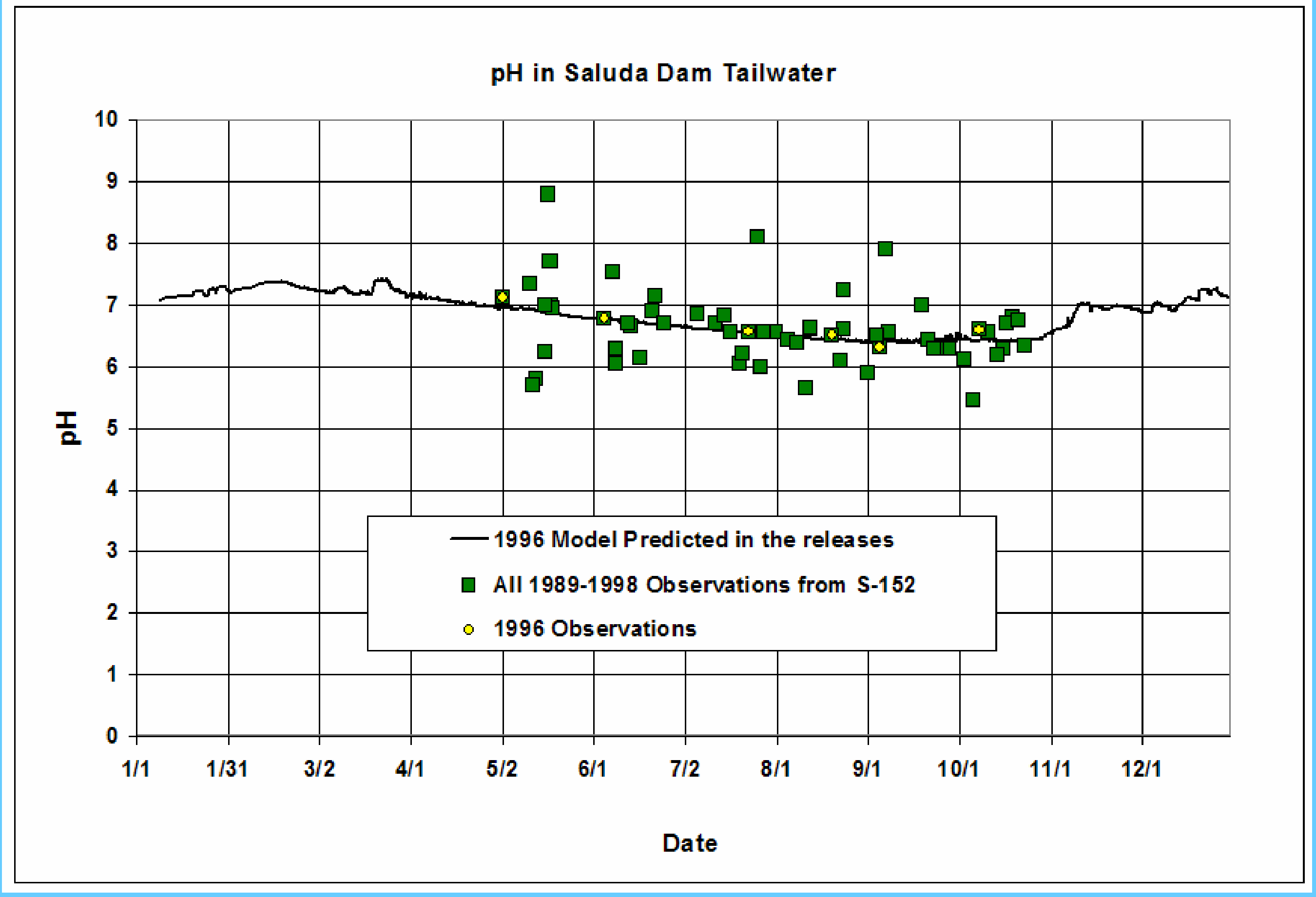
1996 Nitrate in the Releases
Model vs. Data



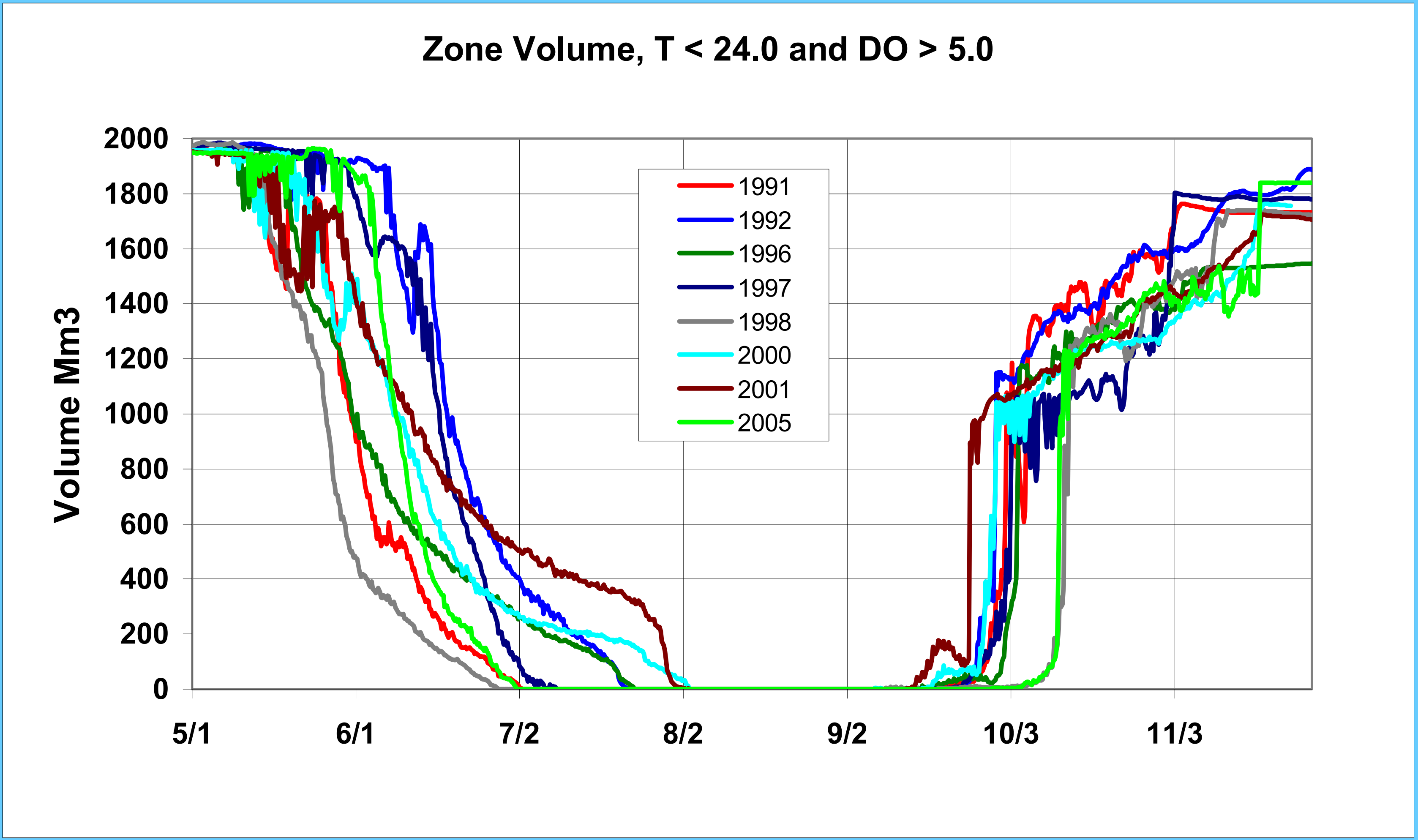
1996 Total Phosphorus in the Releases
Model vs. Data



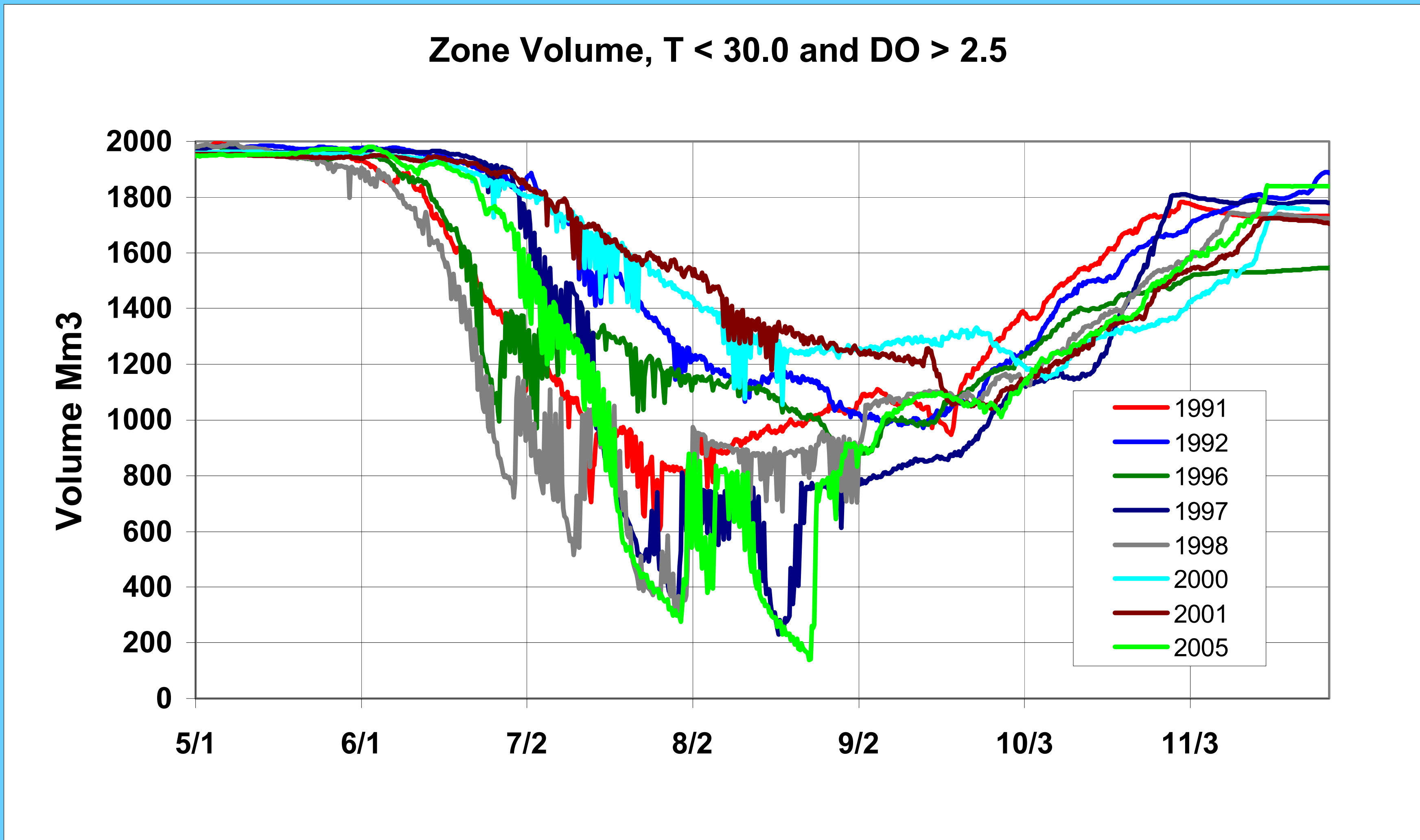
1996 pH in the Releases
Model vs. Data



Zone Volume Plots- “Optimal” Habitat

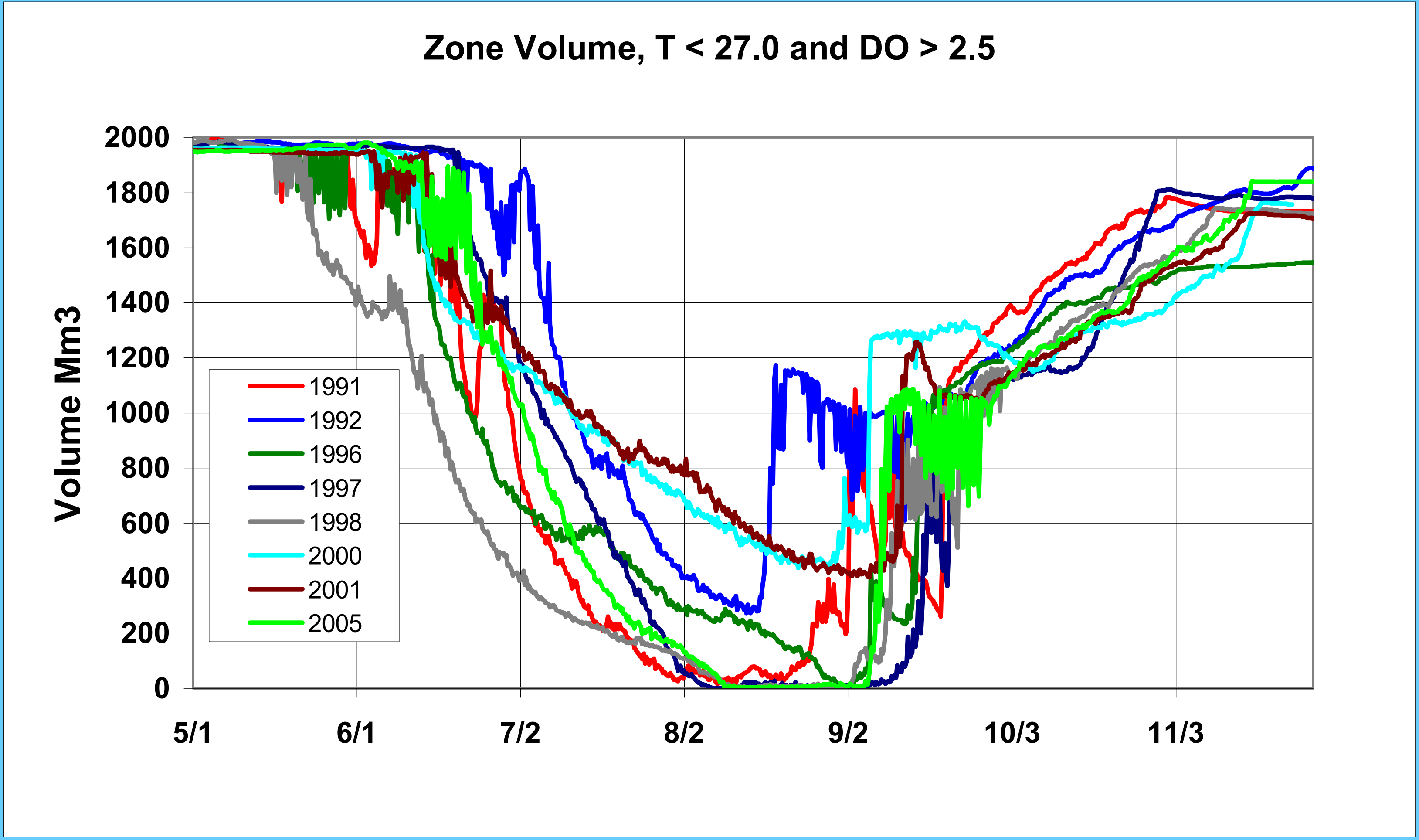


Zone Volume Plot - “Unsuitable” Habitat



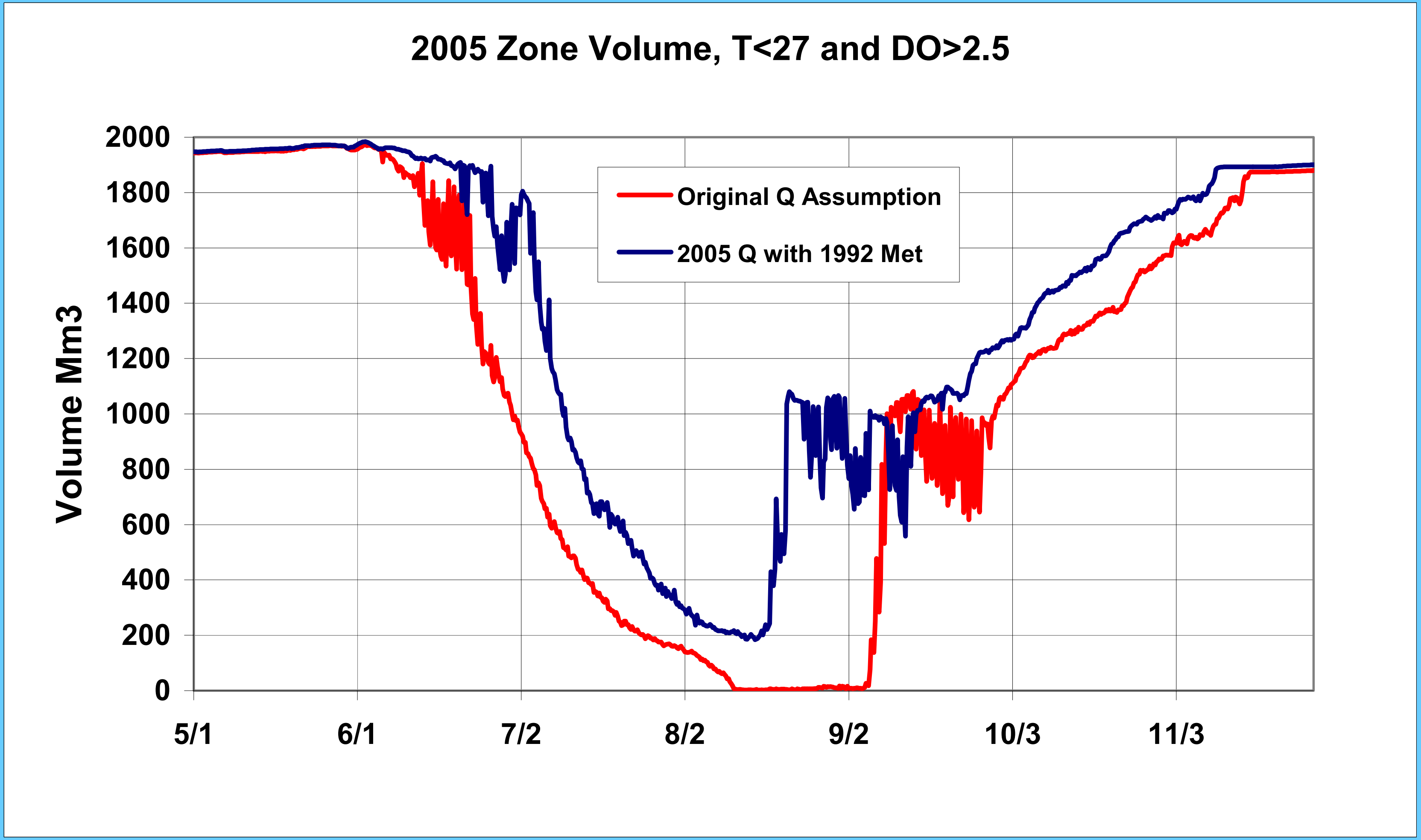
Zone Volume Plot - "Sub-optimal" Habitat

Year	Documented Dates of Fish Kills	Fish Kill Count
1991	7/19 - 8/16	3139
1998	7/30 - 8/10	456
2005	August	742



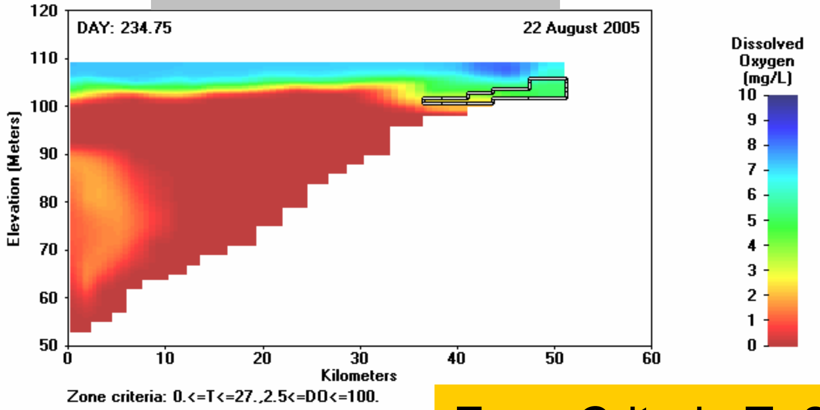
Meteorological Data Sensitivity

striper habitat is not depleted when 1992 met conditions are applied to 2005 flows

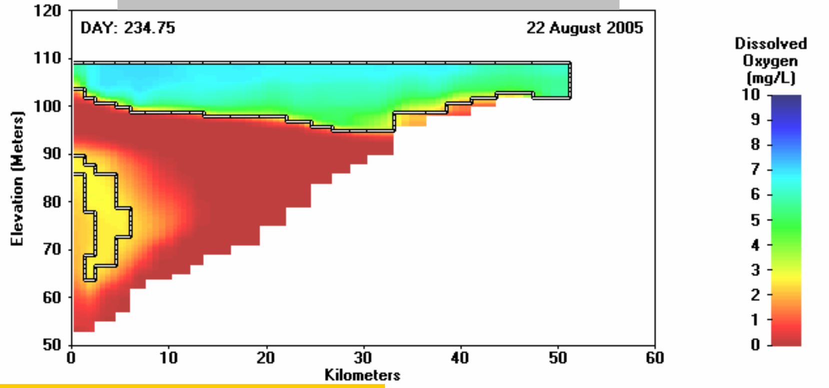


2005 Animation

DO – 2005 Q and Met

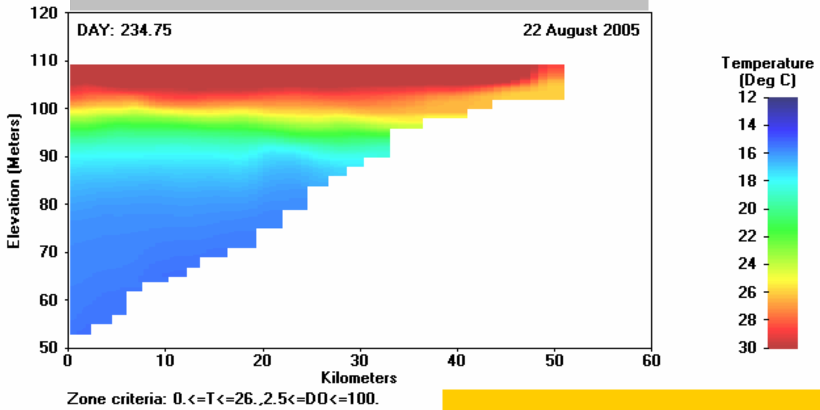


DO – 2005 Q and 1992 Met

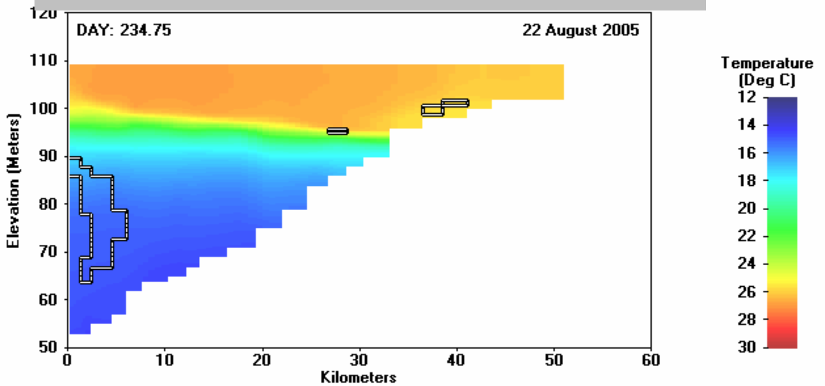


Zone Criteria T<27°T and DO > 2.5 mg/l

Temperature – 2005 Q and Met



Temperature – 2005 Q and 1992 Met

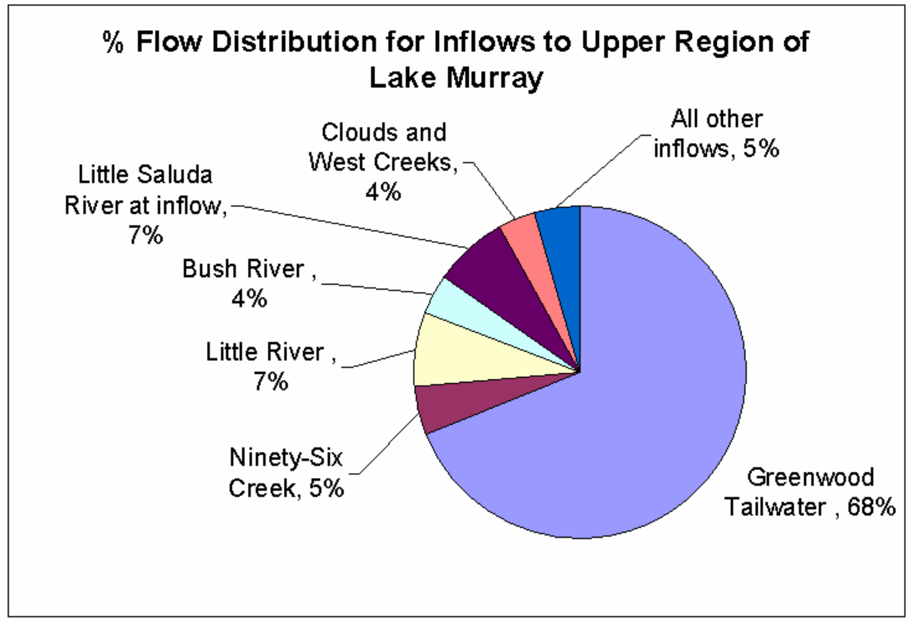


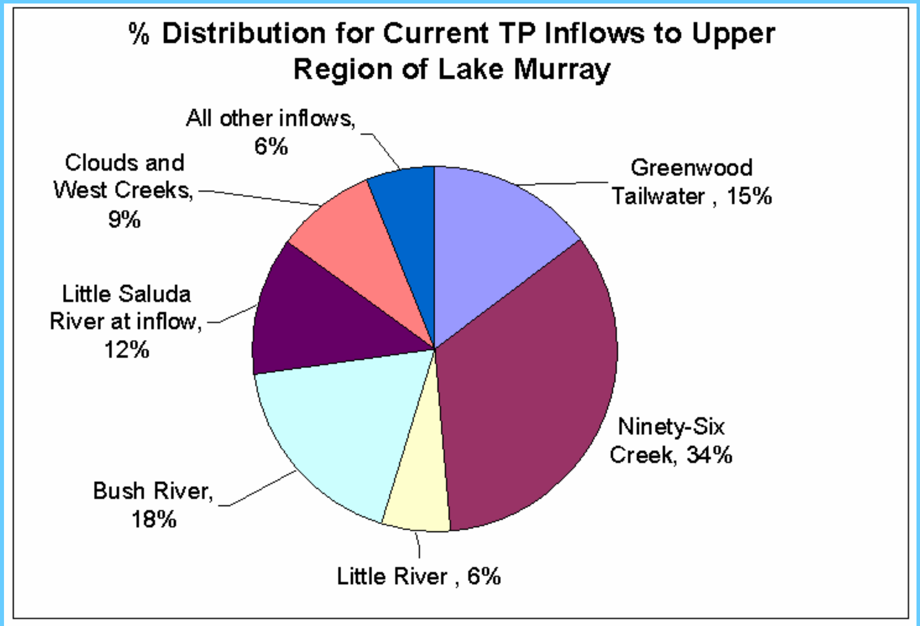
Zone Criteria T<26°T and DO > 2.5 mg/l

Issues Addressed by Focusing on Phosphorus and Using the CE-QUAL-W2 Two-Dimensional Water Quality Model

- low DO in the releases from Saluda Hydro,
- restrictions for operating Unit 5 due to entrainment of blue-back herring,
- eutrophication in the upper regions of Lake Murray,
- DO less than the State standard in the inflow regions of the lake,
- reduced striped bass habitat in the lake due to low DO in the regions of the lake where their temperature preferences occur, and
- low pH in Lower Saluda River (LSR)

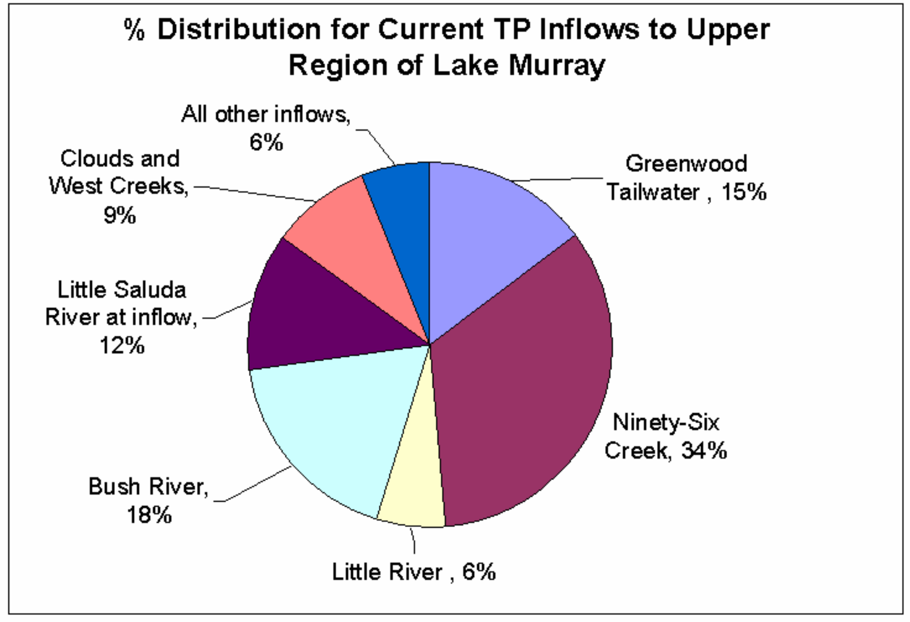
Inflow and Phosphorus Loads to Upper Regions of Lake Murray



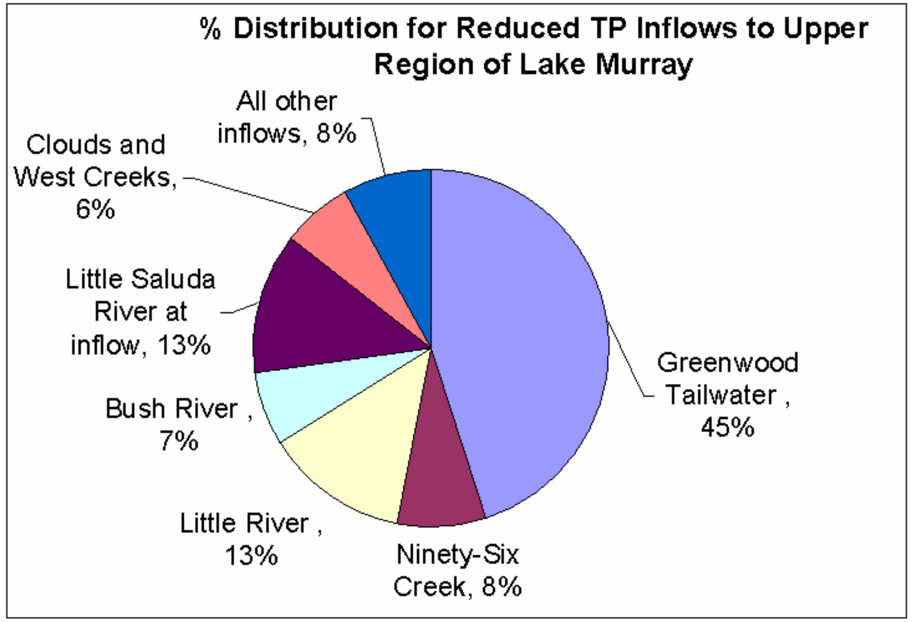


Distribution of TP Loads to the Upper Region of Lake Murray

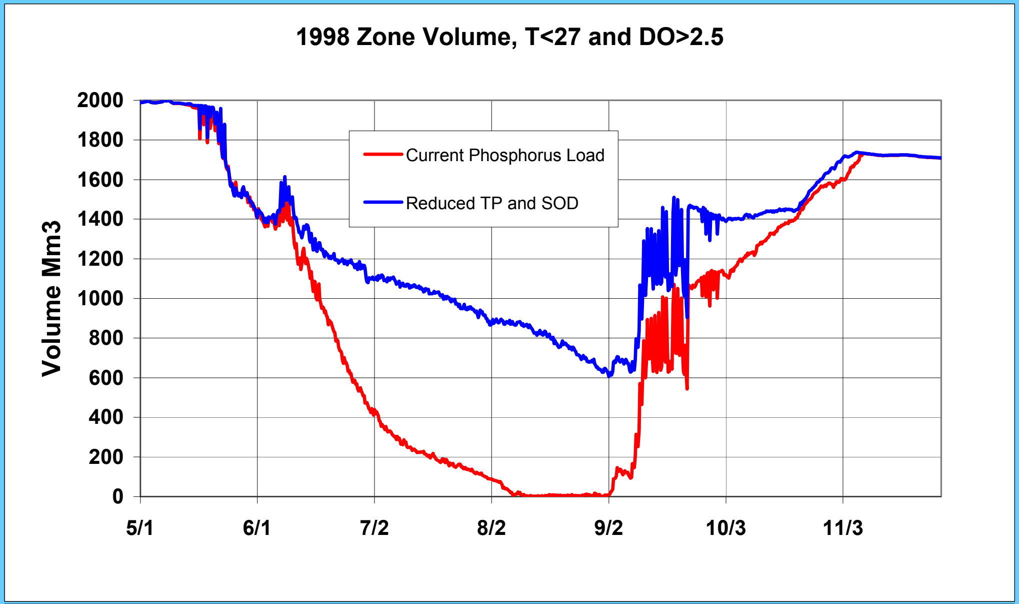
Current

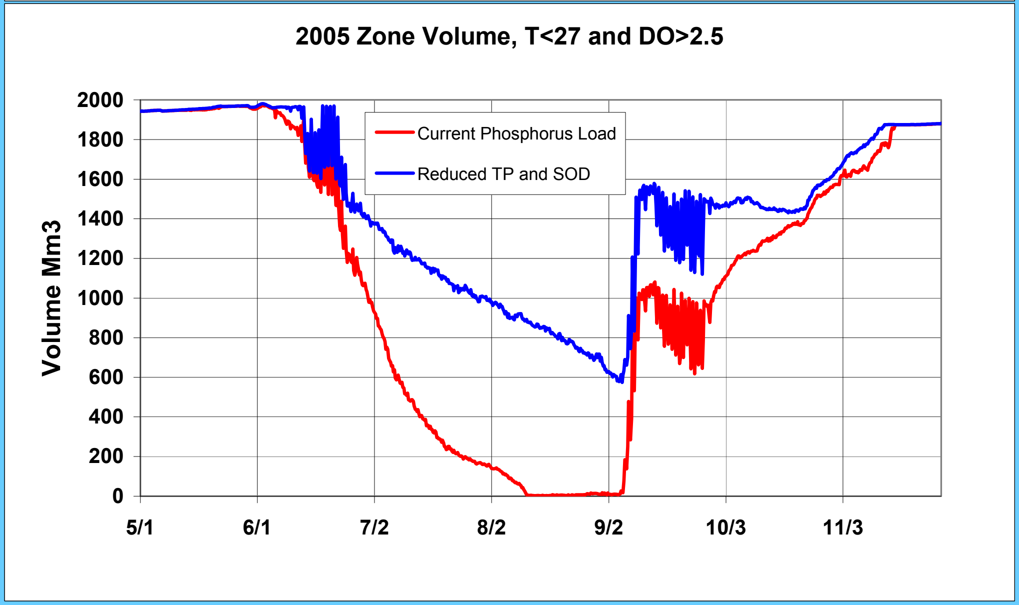


Assumed Reductions in TP



Comparison of Current Phosphorus Load and Reduced Phosphorus Scenario





Relicensing Issues Identified by the Water Quality Technical Working Committee

- The causes of striped bass fish kills reported in previous years, especially factors related to Saluda Hydro operations
- The effects of Unit 5 operations on striped bass habitat and entrainment of blue-back herring
- Determination of operational changes that might increase habitat for striped bass and blue-back herring
- Assessment of pool level management alternatives
- Track any impacts that could occur to the tailwater cold-water fishery due to potential operational changes

Sensitivity to Operations

- Original outflow assumption for all modeled years:

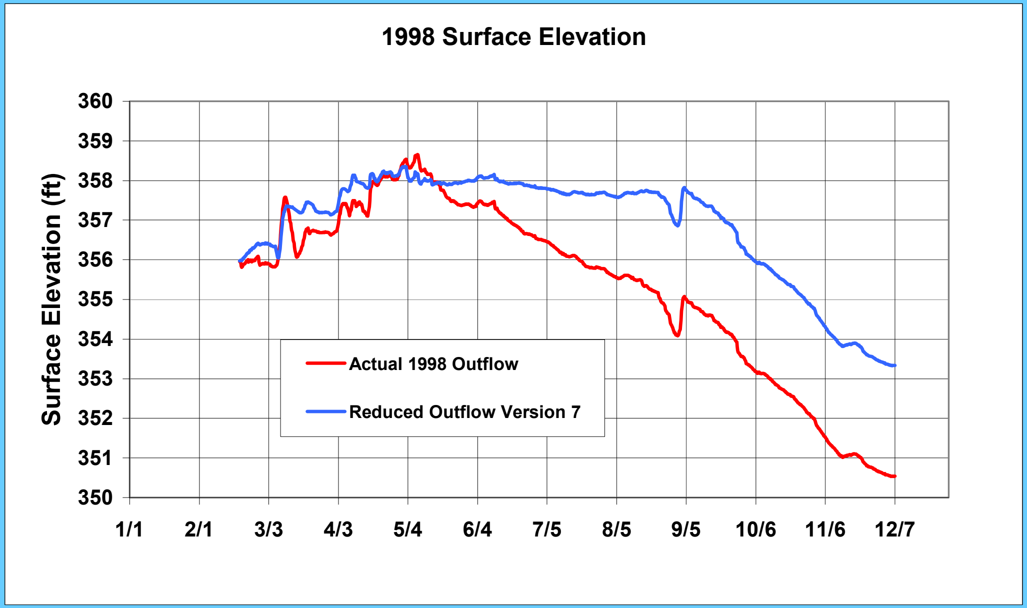
  Units 1, 2 and 4 – Q < 9,600 cfs

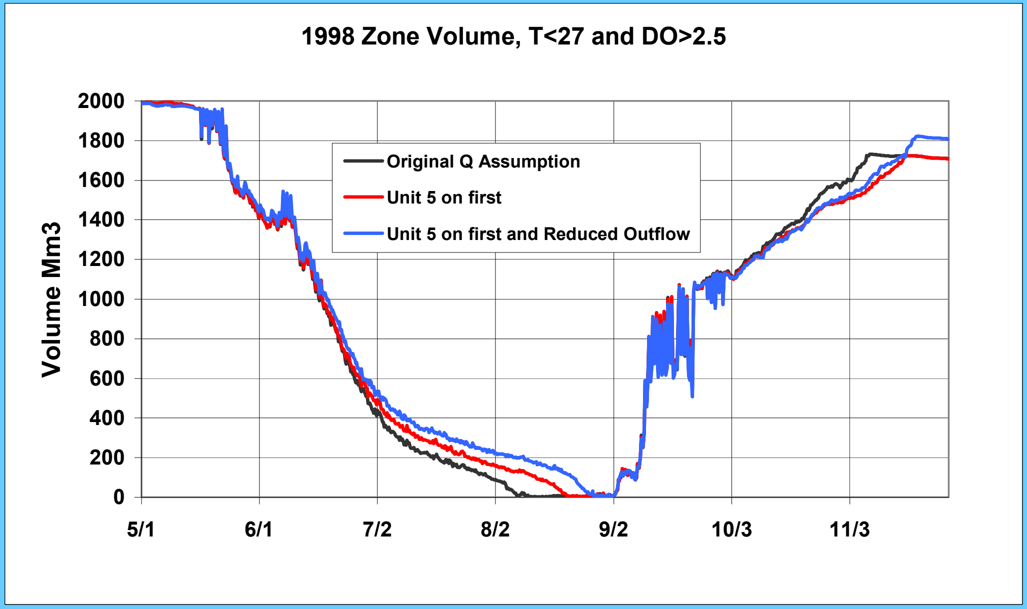
  Unit 5 – 9,600 < Q < 15,600 cfs

  Unit 3 – Q > 15,600 cfs

- When Unit 5 is operated first (Q < 6,000 cfs), cooler bottom water is conserved and availability of striper habitat improves
- Maintain summer pool level near elevation 358’

Pool Level Management with 1998 Model

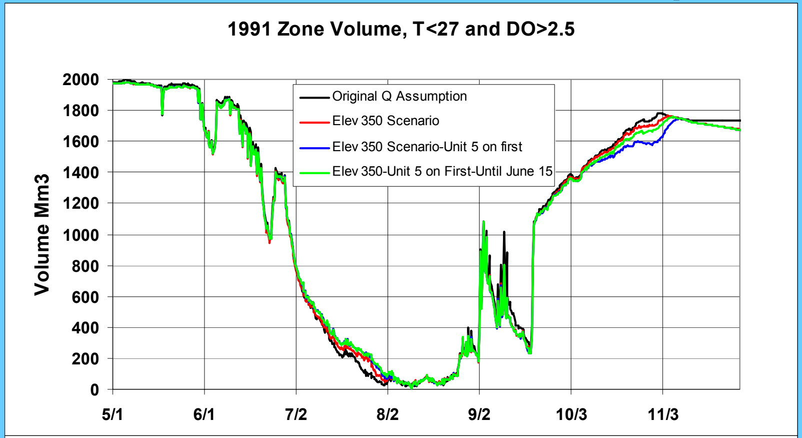


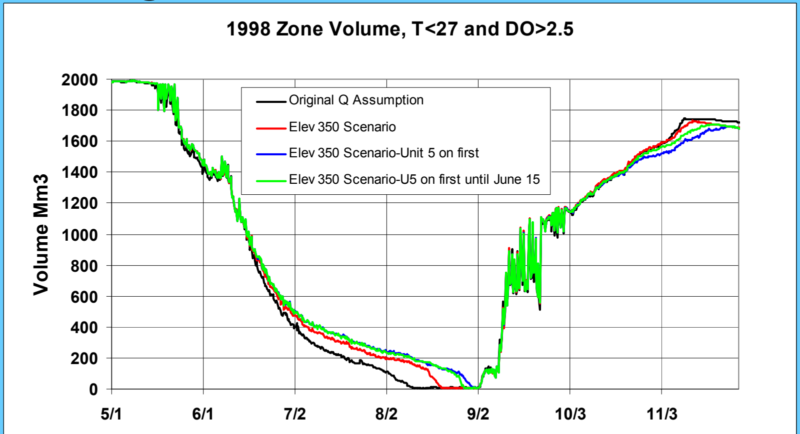


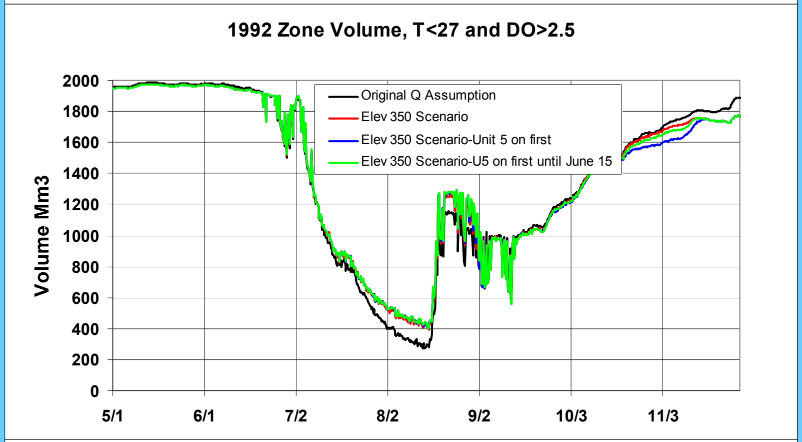
Animations

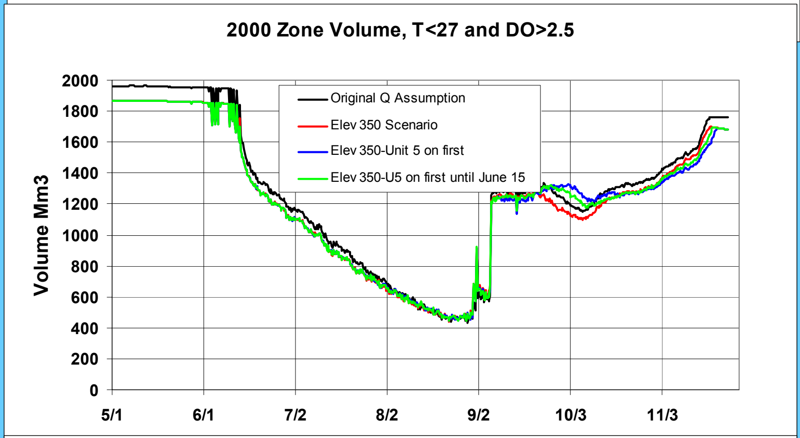
- Year with fish kills vs year without fish kills
- 1998 with and without operational enhancements

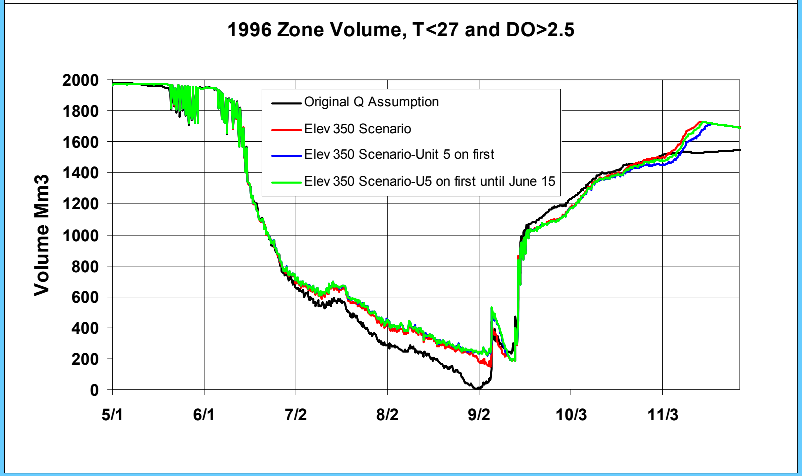
Striped Bass Habitat—Comparison of Current Operations and Promising Operational Changes











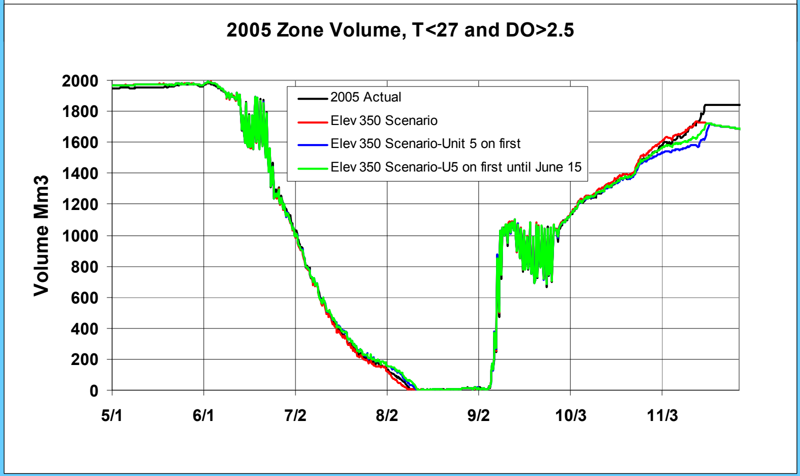
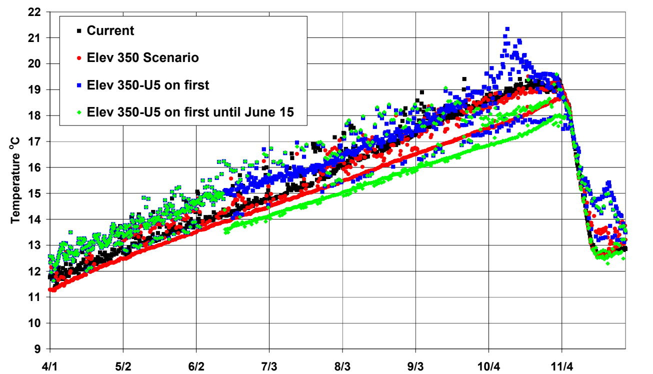


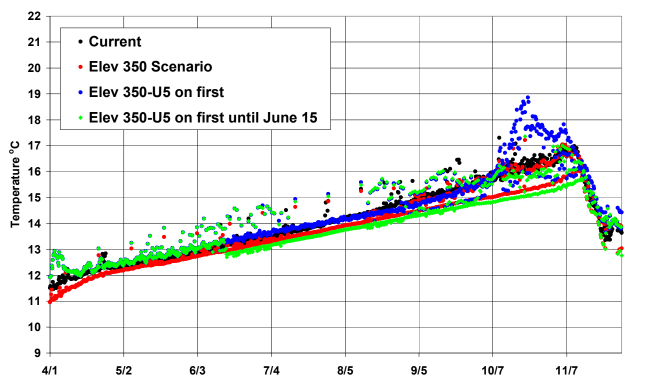
Table 4-1. Temperature increases in the tailwater between Saluda Hydro and the USGS monitor at Columbia.

Generation levels and months of operation	Mean temperature increase, ^{o}C	Mean temperature increase + 2*Std Deviation, ^{o}C
Less than 1000 cfs, May-Sept	3.2	6.4
2500-3000 cfs, May-Sept	1.3	2.9
5000-6000 cfs, May-Sept	1.0	2.0
2500-6000 cfs, Oct	0.7	1.5

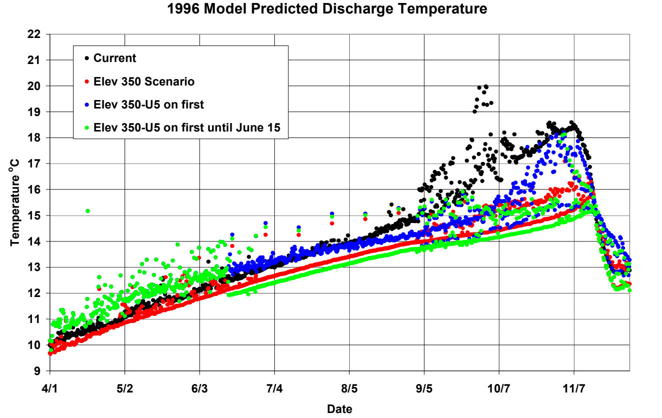
Tailwater Temperature—Comparison of Current Operations and Promising Operational Changes



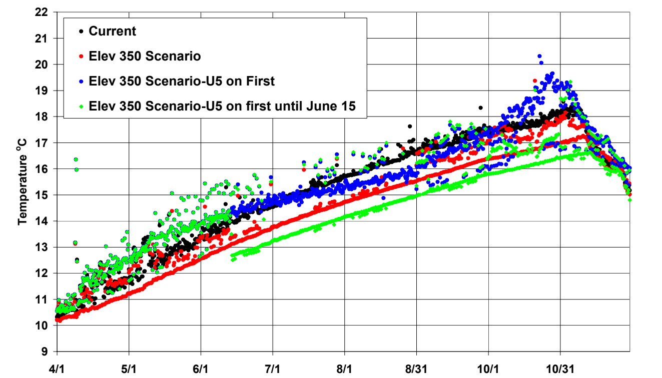
1991 Model Predicted Discharge Temperature



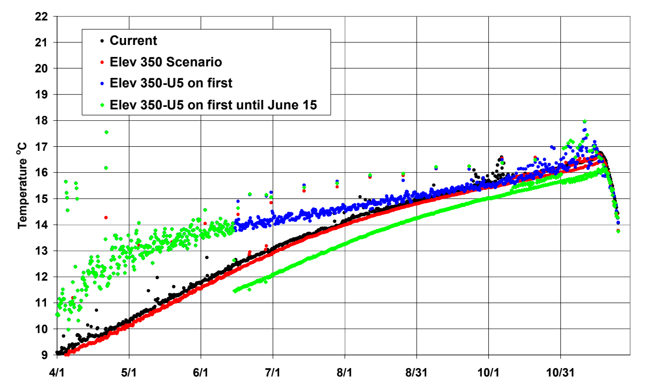
1992 Model Predicted Discharge Temperature



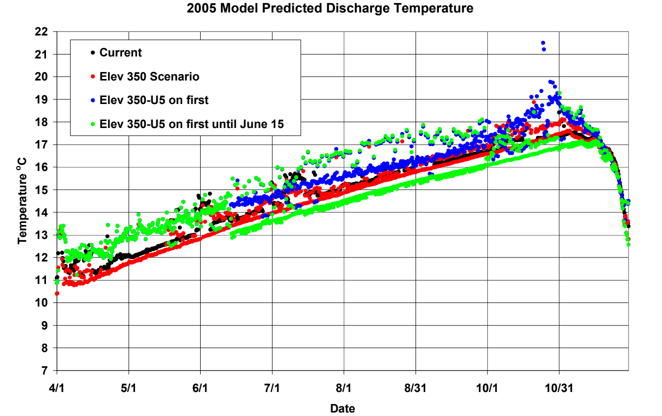
1996 Model Predicted Discharge Temperature



1998 Model Predicted Discharge Temperature

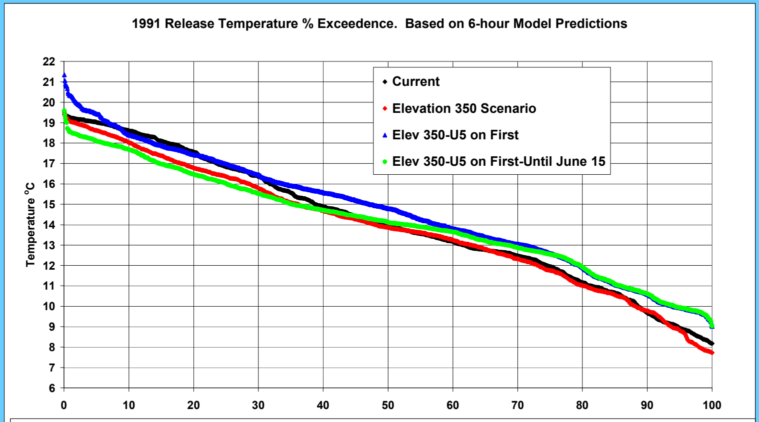


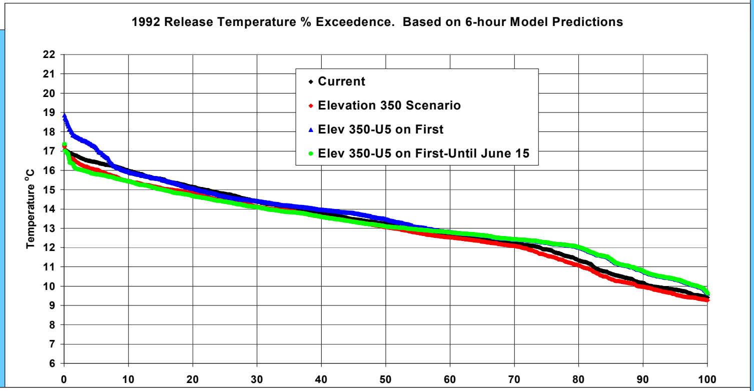
2000 Model Predicted Discharge Temperature

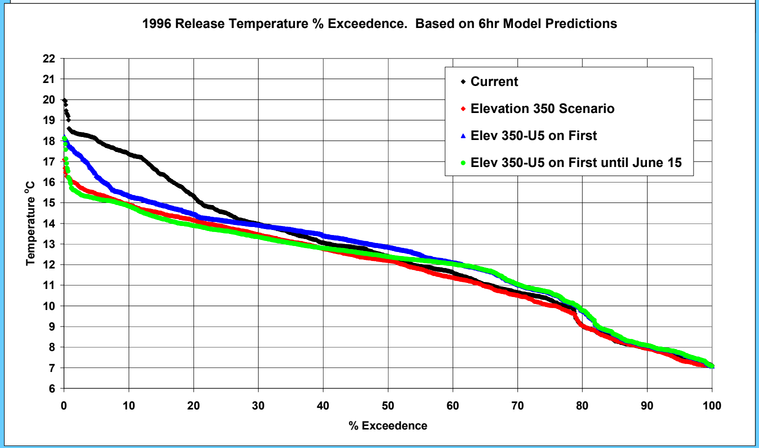


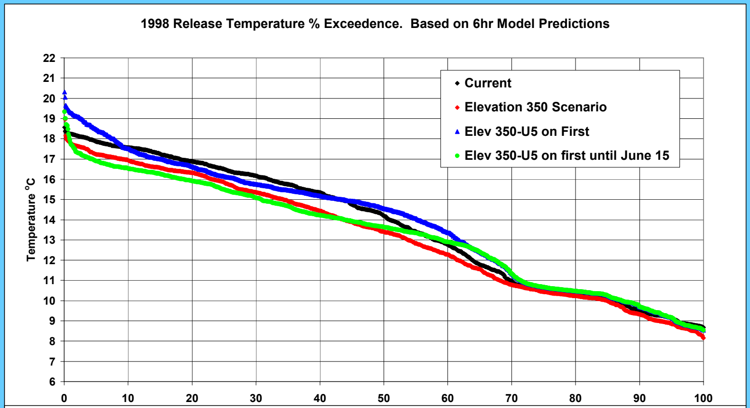
2005 Model Predicted Discharge Temperature

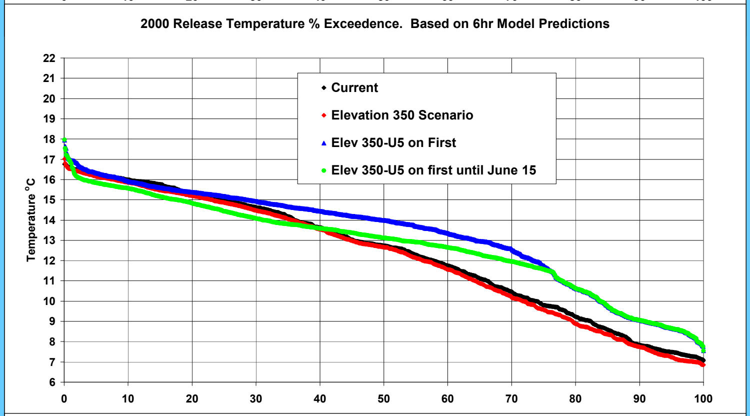
Tailwater Temperature—Comparison of Current Operations and Promising Operational Changes using Frequency of Exceedence

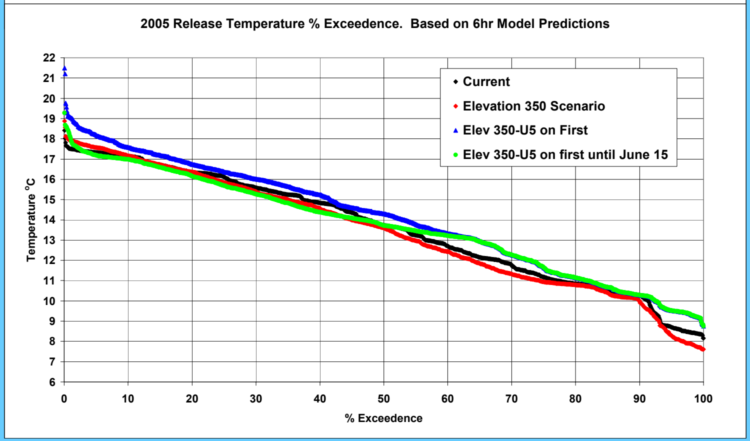












Conclusions for In-lake Water Quality and Fish Habitat

- Nutrients loads to Lake Murray are the single dominant factor that can enhance striped bass habitat
- High flow, especially during March-August, is the primary cause for fish kills
- Higher flows cause the bottom of the lake to warm which in turn increases the rate of DO depletion
- Flow is a dominant factor, but cannot be controlled to avoid fish kills
- Meteorological conditions can affect striper habitat, but cannot be used to develop operating policies
- Model results indicate that the temperature and DO range of tolerable striper habitat in Lake Murray is approximately: T < 27 oC and DO > 2.5 mg/l
- Model results show that preferential use of Unit 5 helps preserve cooler bottom water resulting in improved DO and increased striper habitat in some years
- Maintaining the summer pool level at 358 either increases or has no effect on striped bass habitat. Of the eight years modeled, there was noticeable improvement in the volume of striped bass habitat in four years. The other four years showed either slight improvement or no change. One of the years that showed no change was 2005, which stands to reason since in 2005 the pool level was held up until September 1.
- The combination of Unit 5 preferential operations and maintaining the summer pool level at 358 can further increase striped bass habitat. Of the eight years modeled, there was noticeable improvement in the volume of striped bass habitat in three years. The other five years showed either slight improvement or no change.
- The combination of Unit 5 preferential operations and maintaining the summer pool level at 358 can improve water quality in the releases. There was noticeable improvement in temperature in the releases in five of the eight years that were modeled.
- Unit 5 operations after August or September do not effect striped bass habitat

Recommendations

- The following protocol for unit operations was developed: for minimum flows, use units 1,3,or4 June 15 thru Dec 1 and U5 for Dec 1 to June 15. For generation flows (i.e., flows > minimum flow), use Unit 5 preferentially for 11 months of the year: November 1 until October 1 of the following year, and use Units 1-4 preferentially in October.

- These results of using the proposed unit operations protocol showed the following:
    - Temperature in the releases was improved for all years, compared to other unit operational procedures. The temperature at the 5 to 20% levels of exceedence frequency was usually cooler, and at the 80% levels of exceedence frequency was usually warmer. This characteristic for temperature exposure for fish is best for trout fish growth rates. The maximum temperatures for the proposed protocol were usually about the same as the next-best alternatives for this consideration, but temperature results for near-maximum levels was much better for the proposed protocol.
    - The proposed protocol for turbine unit operations for minimum flows and generation flows had very little or no effect on striped bass habitat enhancements achieved previously by increasing summer pool levels and using Unit 5 preferentially for 1991, 1992, 1996, 2000, 2001, and 2005. For 1997 and 1998, striped bass habitat was marginally impacted by the proposed protocol for turbine unit operations and the impacts were considerably less than the improvements provided by the higher summer pool level and Unit 5 preferential operations in the months preceding June 15.

The End

Effects of Reservoir Operations on Water Quality and Fish Habitat in Lake Murray and Saluda Releases

Andy Sawyer and Jim Ruane, REMI

August 7, 2007

Relicensing Issues Identified by the Water Quality Technical Working Committee

- The causes of striped bass fish kills reported in previous years, especially factors related to Saluda Hydro operations
- The effects of Unit 5 operations on entrainment of blue-back herring
- Determination of operational changes that might increase habitat for striped bass and blue-back herring
- Track any impacts that could occur to the tailwater cold-water fishery due to potential operational changes

Factors Considered to Address Relicensing Issues

- Annual flow regimes
- Pool level management
- Unit 5 operations
- In-lake and release water quality
- Habitat for striped bass and blue-back herring
- Water quality, meteorological, and operations data over the period 1990-2005
- Emphasis will be placed on section of reservoir from Blacks Bridge to Saluda Dam

Plan for Using CE-QUAL-W2 to Address the Water Quality TWC Relicensing Issues

1. Analyze water quality, meteorological, flow, and operations data for the period of study

2. Set up CE-QUAL-W2 for the years when major striped bass fish kills occurred

3. Run models to identify the causes that apparently contributed to the fish kills

4. Use the models to explore ways to avoid such fish kills in the future

Preliminary Findings Reported in March

- High flow, especially during March-August, is the primary cause for fish kills
- Higher flows cause the bottom of the lake to warm which in turn increases the rate of DO depletion
- Meteorological conditions can affect striper habitat
- Model results indicate that the temperature and DO range of tolerable striper habitat in Lake Murray is approximately:

$$T < 27^{o}C \text{ and } DO > 2.5 \text{ mg/l}$$

- Preferential use of Unit 5 helps preserve colder bottom water and was predicted to improve DO and increase striper habitat

Preliminary Conclusions Reported in May

- Nutrients are the single dominant factor that can enhance striped bass habitat
- Flow is a dominant factor, but cannot be controlled to avoid fish kills
- Met conditions can be a periodic factor that alleviates otherwise dominant factors like flow
- Striped bass habitat conditions can be improved in some years by maintaining high summer pool levels (~ elev. 358 ft)
- Unit 5 preferential operations can improve striped bass habitat in some years

Next Steps Selected at May Meeting

1. **For selected years, finalize assessment (i.e., assess changes in releases) of operating guide for U5 preference for "first on, last off" operation using the hourly releases**

2. **For selected years, finalize assessment of maintaining summer pool levels at 358**

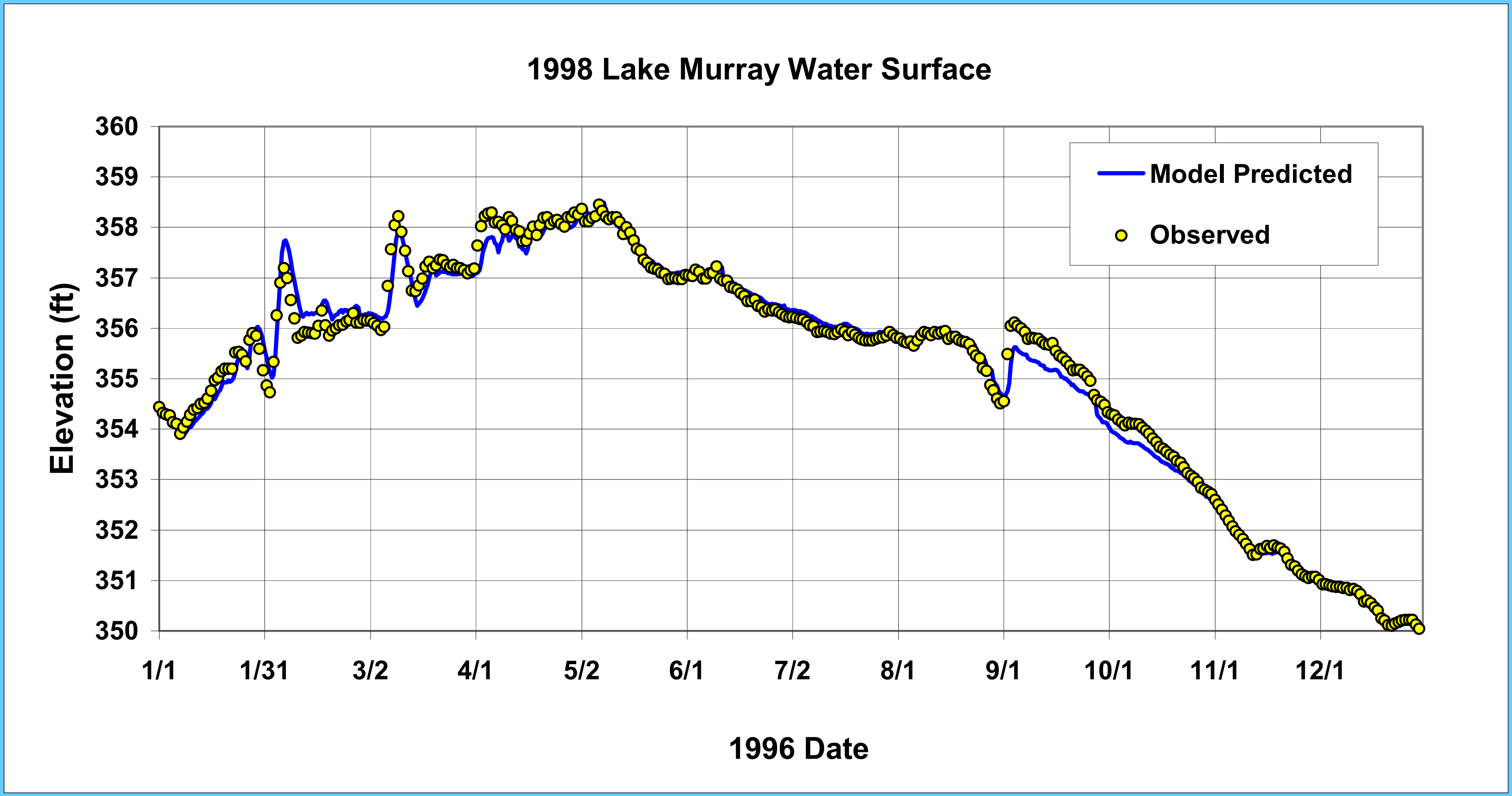
3. **For selected years, finalize assessment of the combination of maintaining summer pool levels at 358 with U5 preference for "first on, last off" operation using the hourly releases**

4. **Analyze additional years, especially a low flow year**

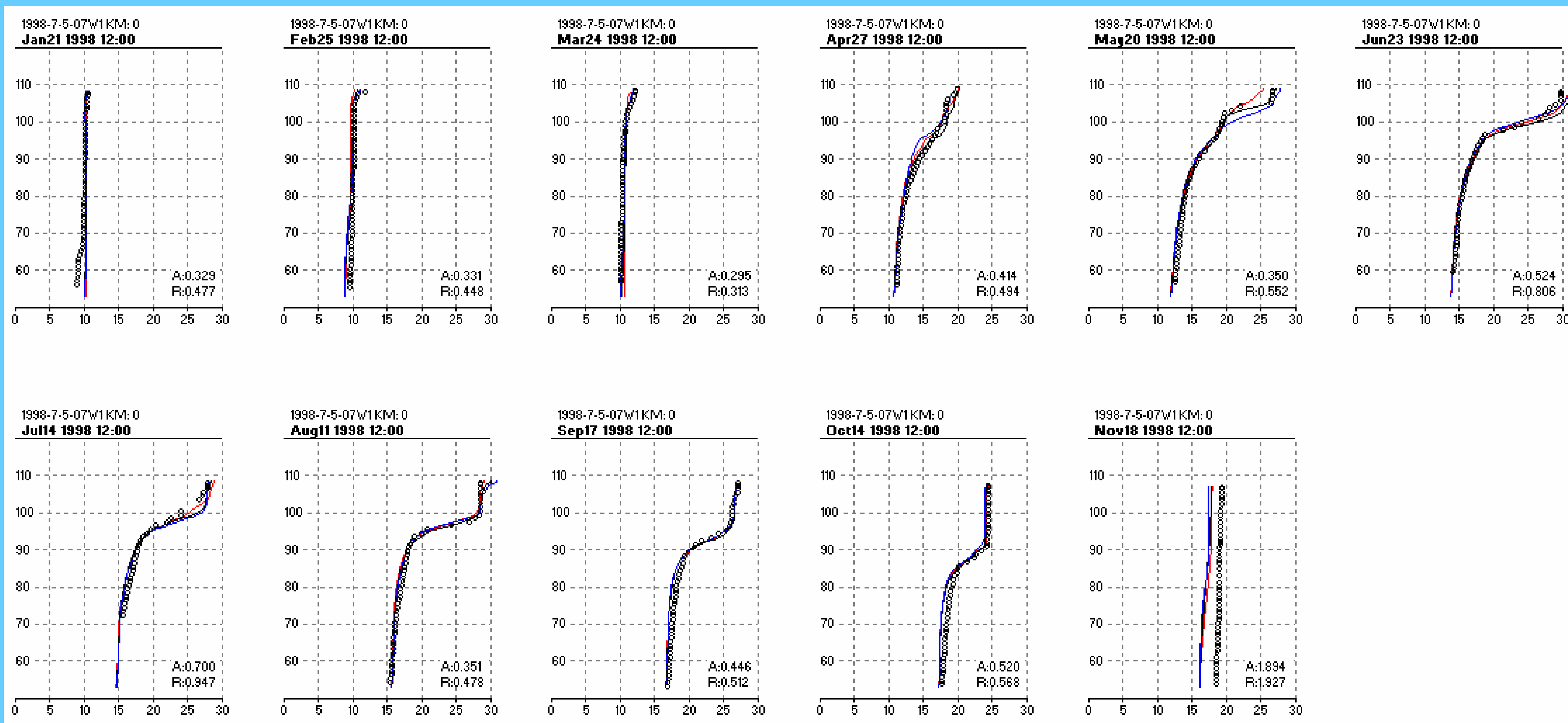
5. **Assess effects of minimum winter pool level, including effects on Little Saluda embayment, increased SOD, internal nutrient cycling, aquatic plants, sedimentation in coves**

1998 Model Calibration

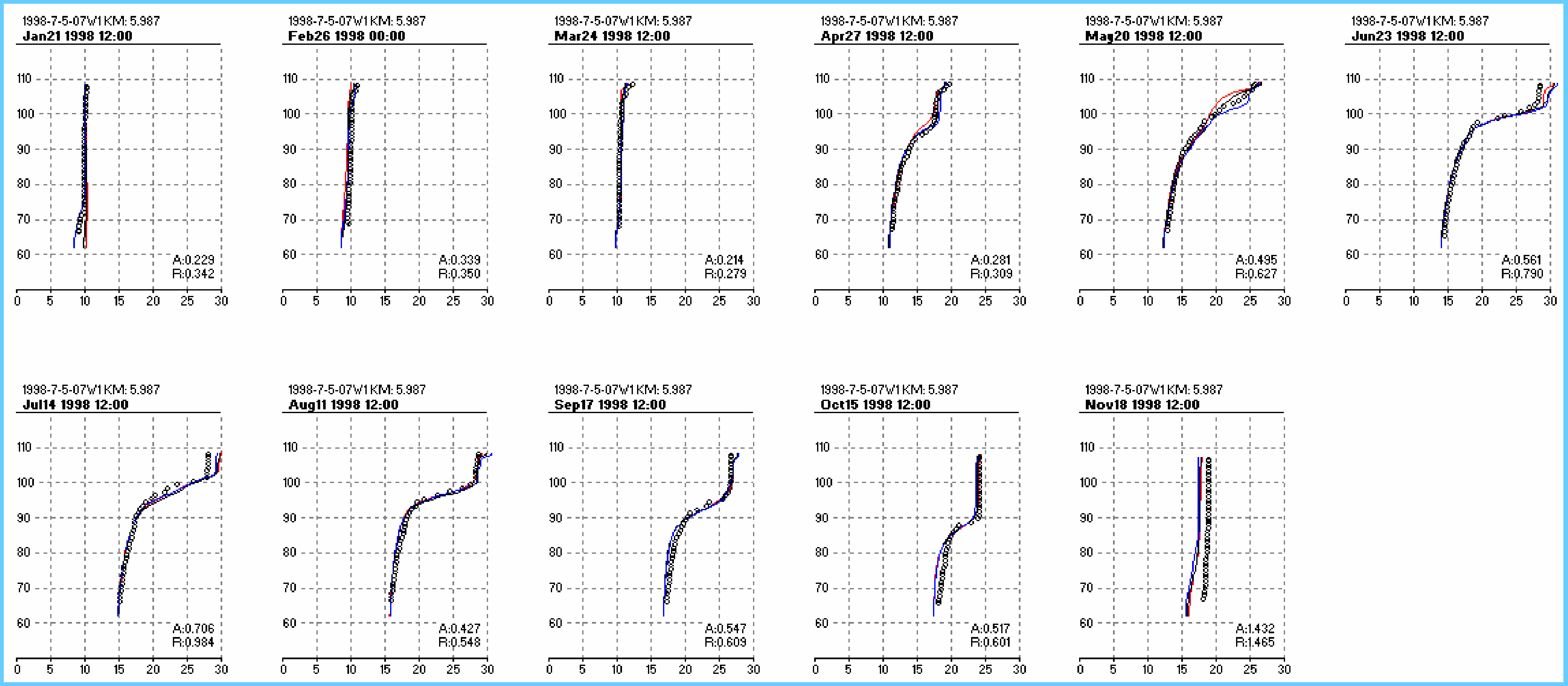
1998 Lake Murray Water Surface
Model vs. Data



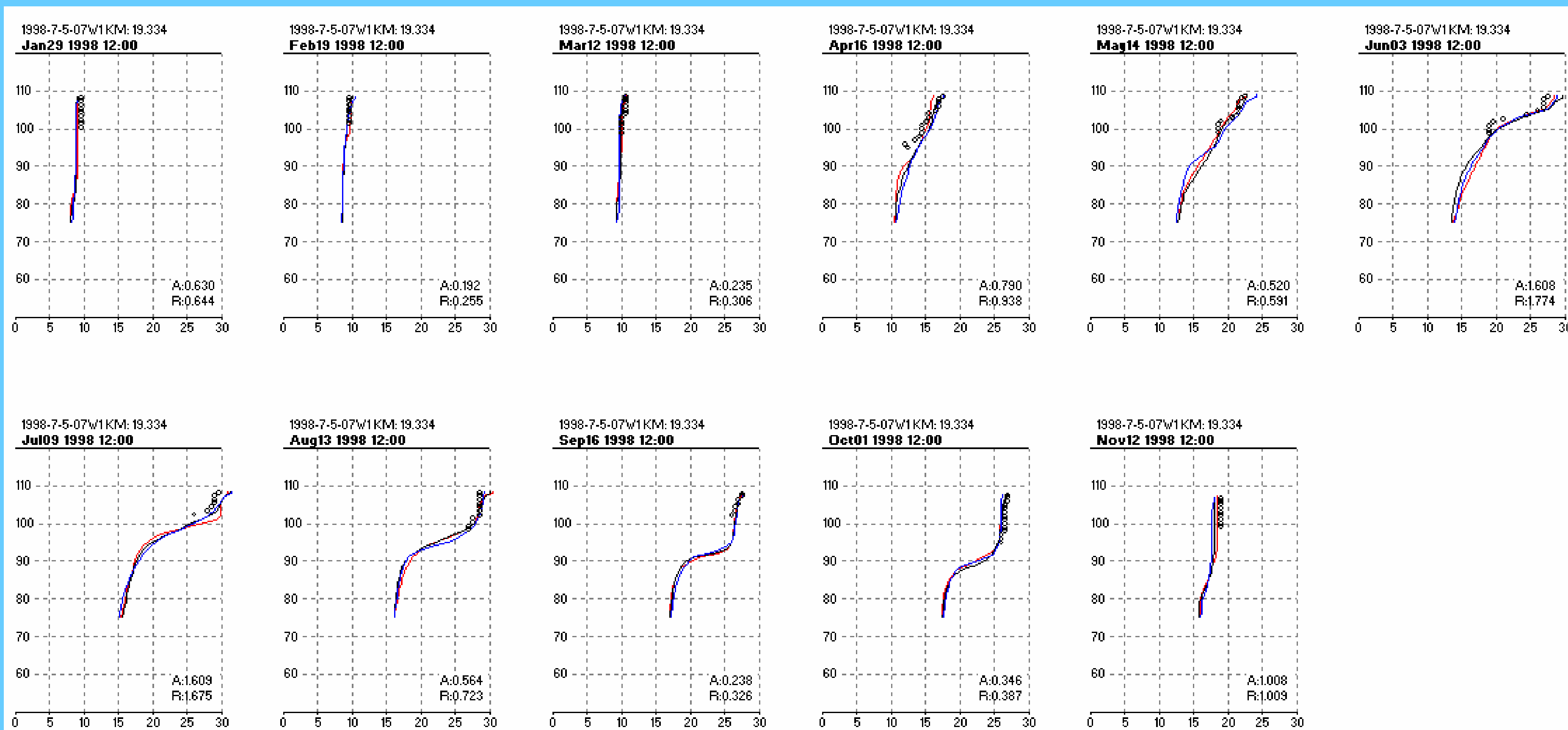
1998 Lake Murray Temperature Profiles
Forebay
Model vs. Data



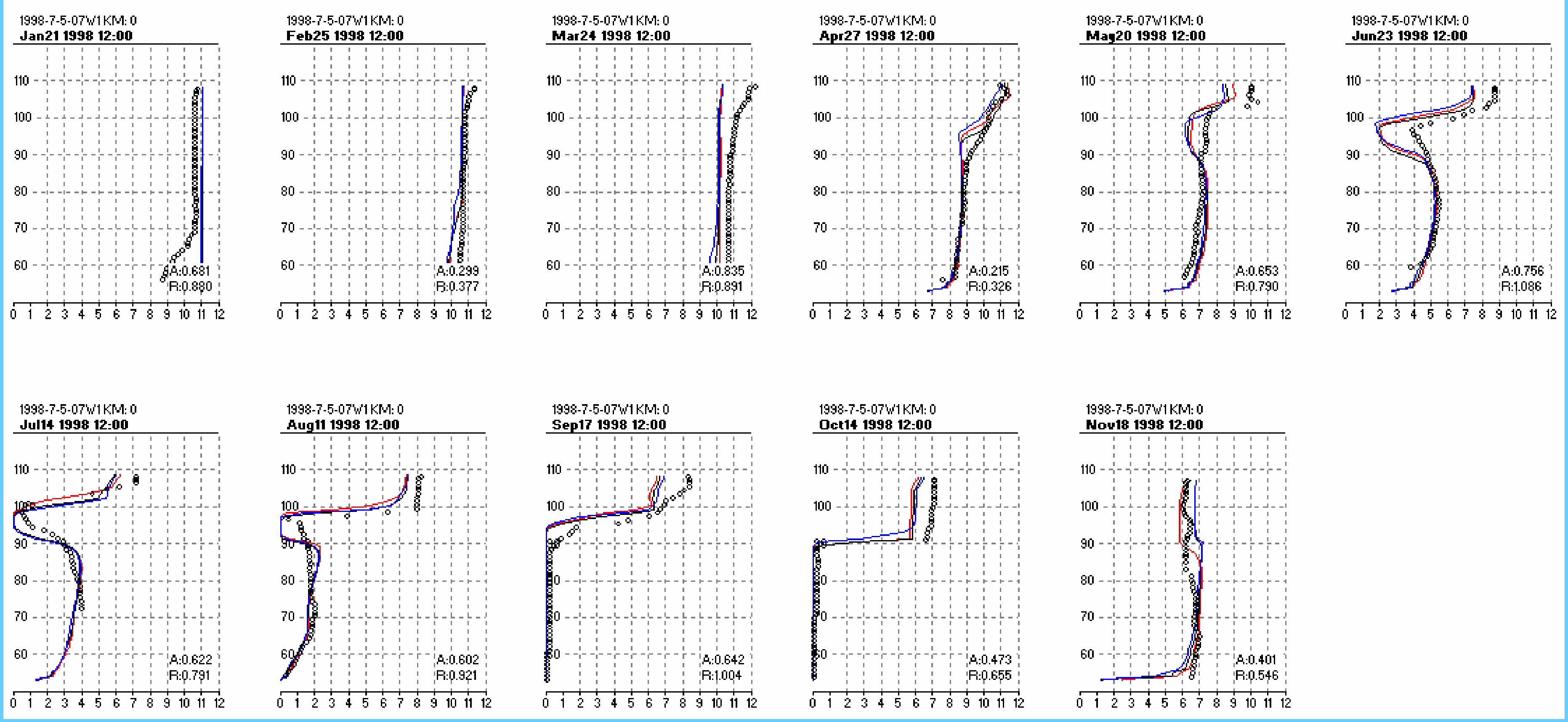
1998 Lake Murray Temperature Profiles
6 Kilometers Upstream of Dam
Model vs. Data



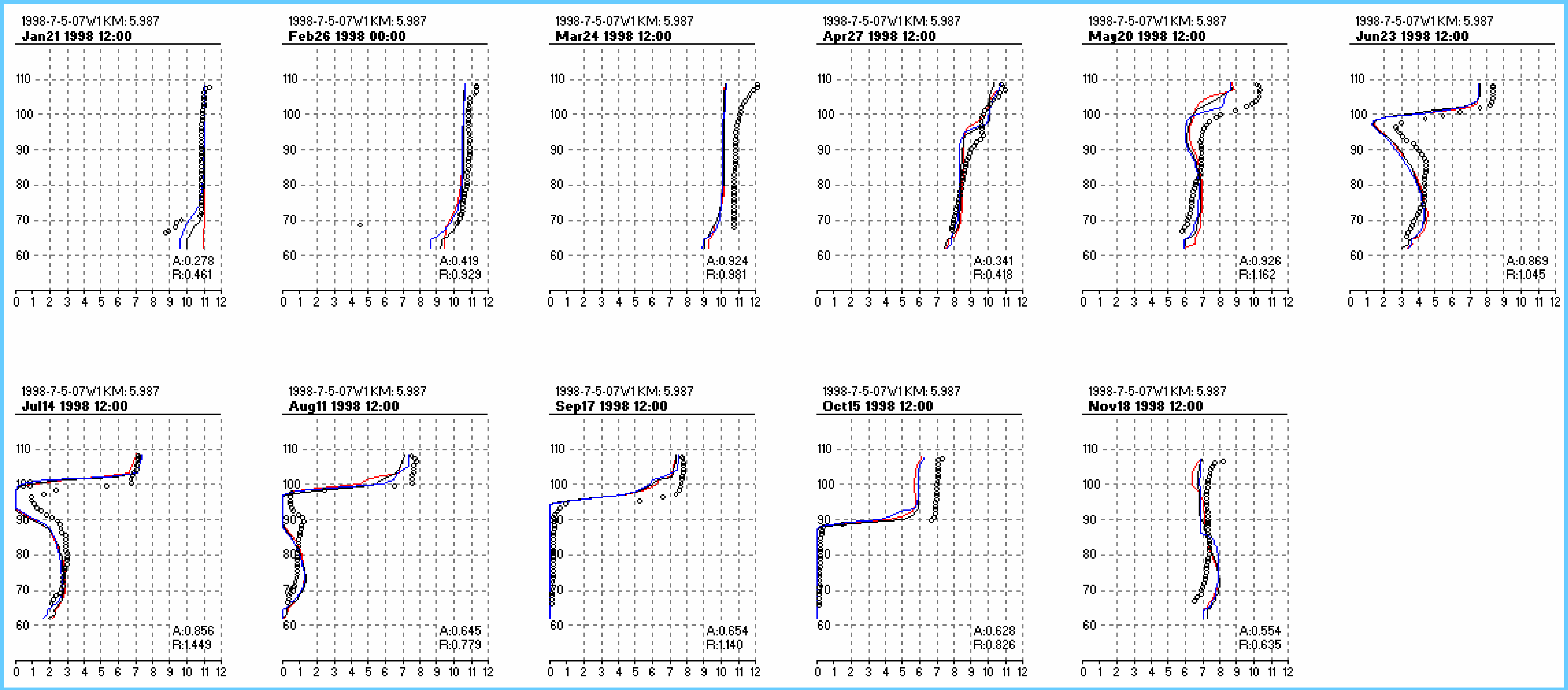
1998 Lake Murray Temperature Profiles
19 Kilometers Upstream of Dam
Model vs. Data



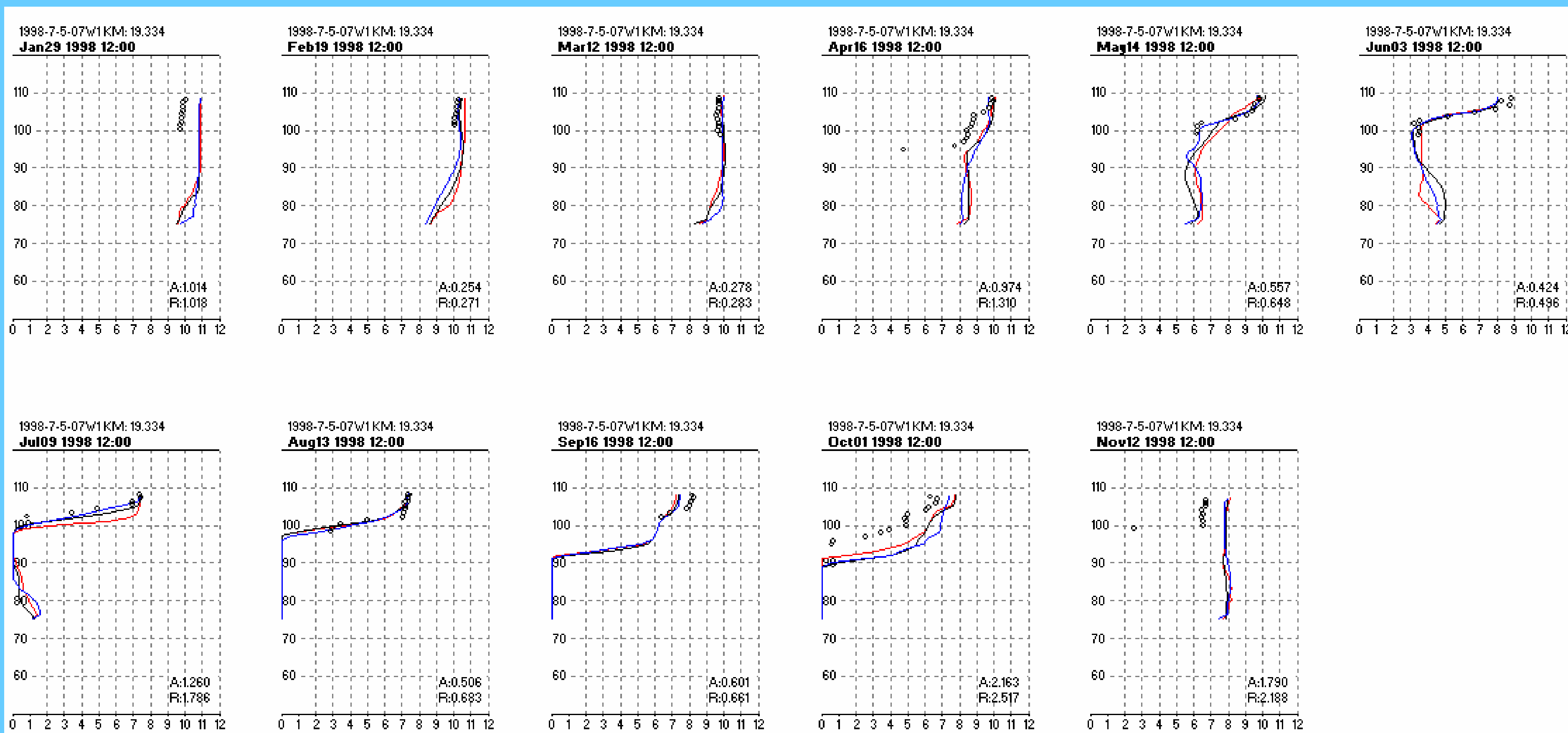
1998 Lake Murray DO Profiles
Forebay
Model vs. Data



1998 Lake Murray DO Profiles
6 Kilometers Upstream of Dam
Model vs. Data



1998 Lake Murray DO Profiles
19 Kilometers Upstream of Dam
Model vs. Data



Calibration Statistics for Temperature and DO Profiles

Temperature

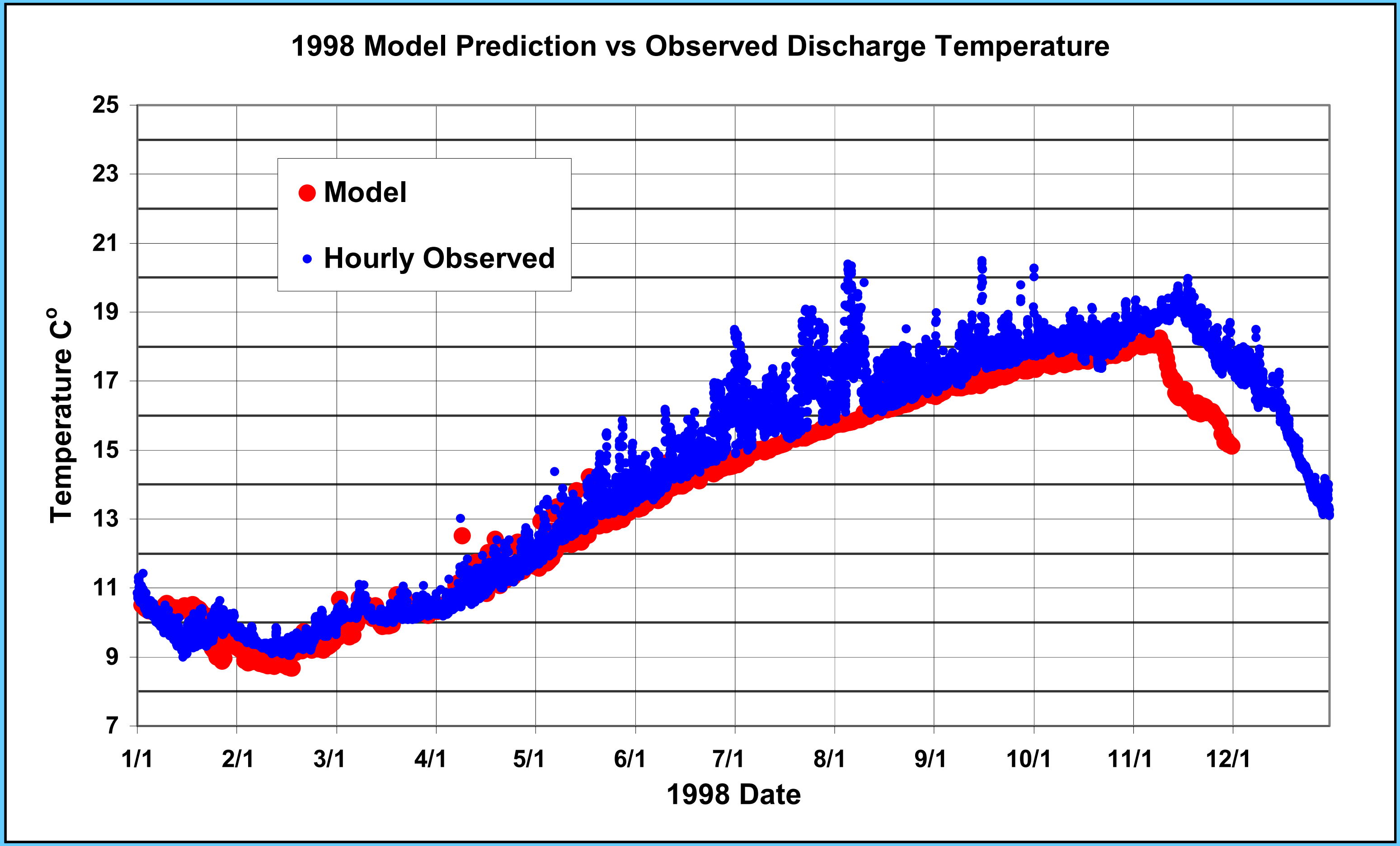
	Kilometers From Dam									
	0.0		6.0		19.3		Little Saluda Embayment		Mean	
Year	AME	RMS	AME	RMS	AME	RMS	AME	RMS	AME	RMS
1991	0.55	0.75					1.05	1.27	**0.80**	**1.01**
1992	0.81	1.11	0.79	1.18	0.65	0.78	1.45	1.96	**0.93**	**1.26**
1996	0.44	0.68	0.52	0.78	0.64	0.90	0.80	1.11	**0.60**	**0.87**
1997	0.45	0.67	0.44	0.61	0.70	0.96	1.23	1.60	**0.70**	**0.96**
1998	0.56	0.80	0.52	0.71	0.69	0.91	0.83	1.08	**0.65**	**0.88**
2000	0.54	0.73	0.58	0.77	0.79	1.02	1.21	1.65	**0.78**	**1.04**
2001	0.54	0.72	0.67	0.83	0.79	0.89	1.23	1.53	**0.81**	**0.99**
2005	0.53	0.73	0.57	0.70	0.58	0.74	1.03	1.23	**0.68**	**0.85**
Mean	**0.55**	**0.77**	**0.59**	**0.80**	**0.69**	**0.89**	**1.10**	**1.43**	**0.73**	**0.97**

DO

	Kilometers From Dam									
	0.0		6.0		19.3		Little Saluda Embayment		Mean	
Year	AME	RMS	AME	RMS	AME	RMS	AME	RMS	AME	RMS
1991	0.83	1.44					1.51	2.00	**1.17**	**1.72**
1992	0.60	0.95	0.67	0.95	0.89	1.20	1.66	2.13	**0.95**	**1.31**
1996	0.59	0.95	0.71	1.04	0.58	0.75	0.81	1.08	**0.67**	**0.95**
1997	0.89	1.38	0.87	1.27	0.86	1.16	1.86	2.58	**1.12**	**1.60**
1998	0.56	0.79	0.65	0.94	0.93	1.35	1.24	1.66	**0.84**	**1.18**
2000	0.87	1.22	1.14	1.48	0.99	1.24	1.69	2.17	**1.17**	**1.53**
2001	0.70	1.18	0.89	1.38			1.76	2.17	**1.12**	**1.58**
2005	0.84	1.53	0.76	1.16	0.94	1.42	1.87	2.37	**1.10**	**1.62**
Mean	**0.73**	**1.18**	**0.81**	**1.17**	**0.86**	**1.19**	**1.55**	**2.02**	**0.99**	**1.39**

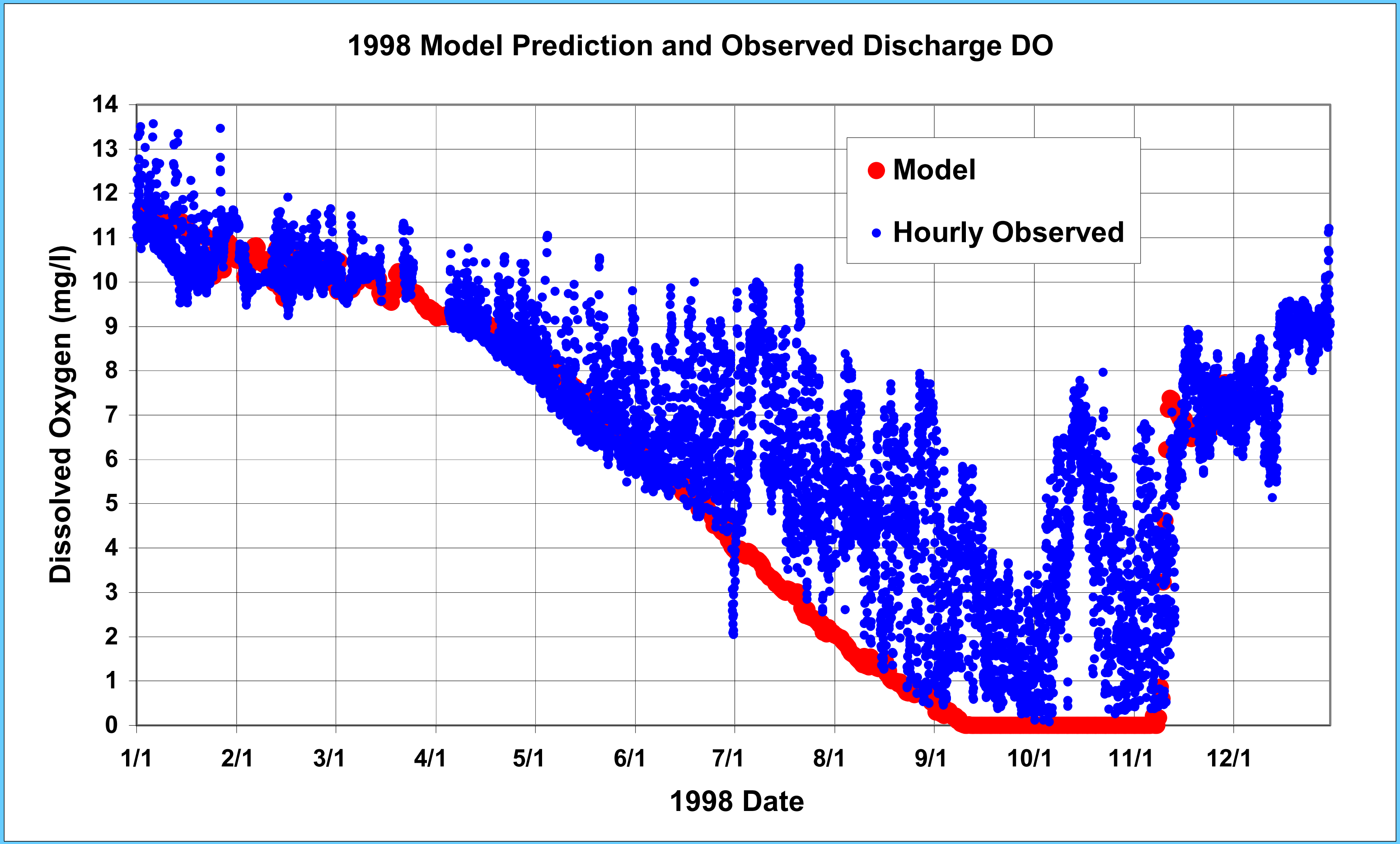
Release Temperature

Model vs. Data



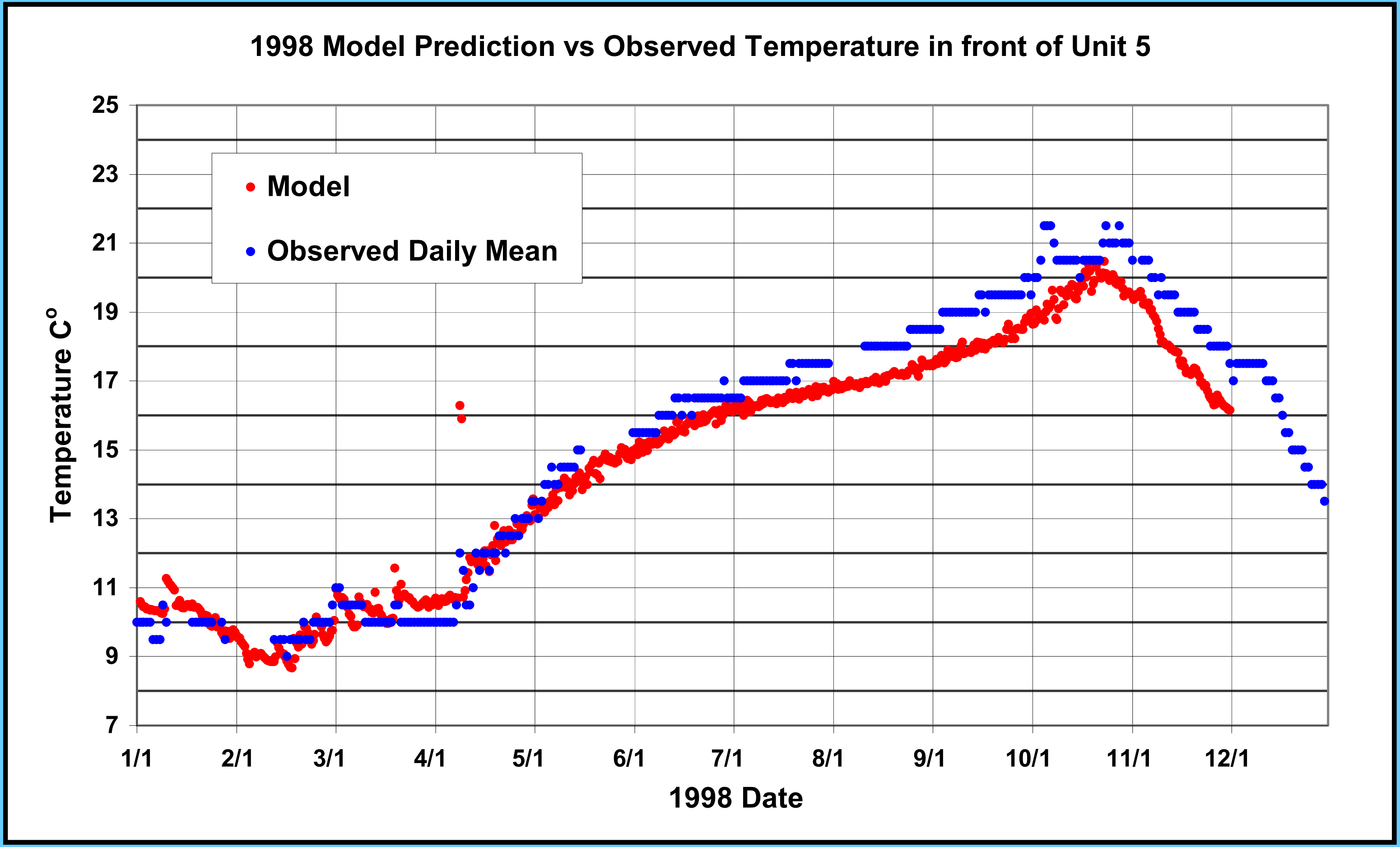
Release DO

Model vs. Data



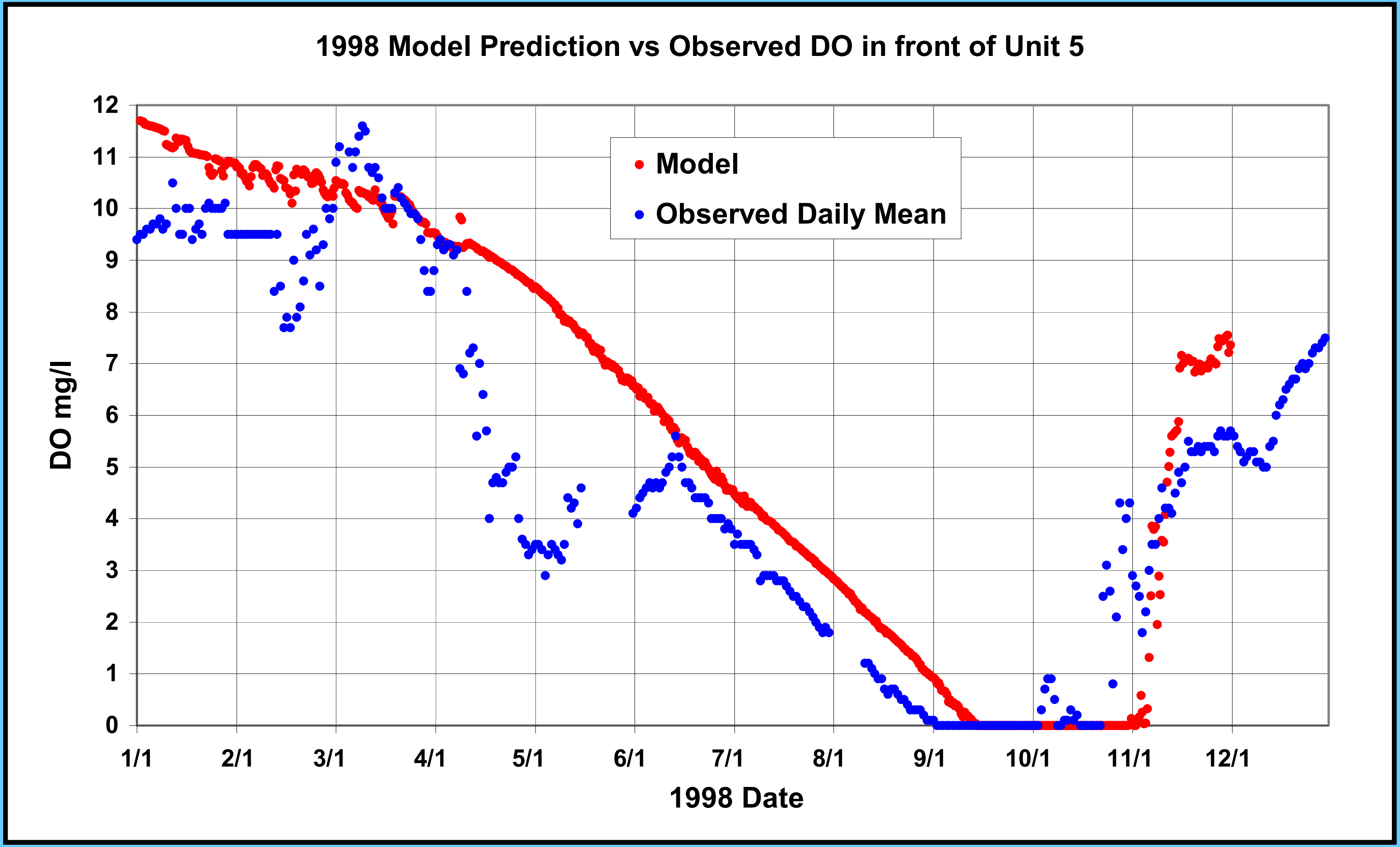
Temperature in Front of Unit 5

Model vs. Data

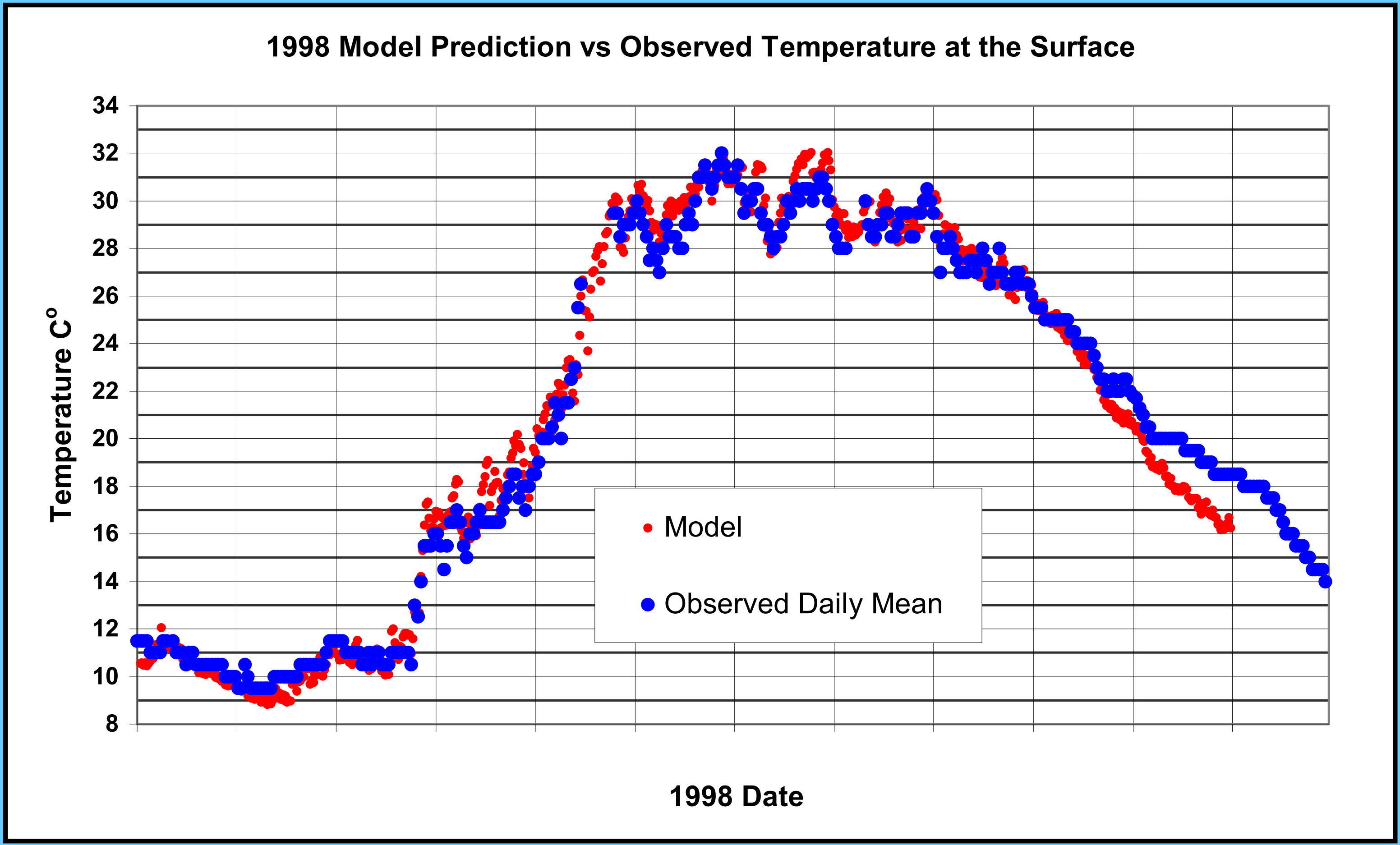


DO in Front of Unit 5

Model vs. Data

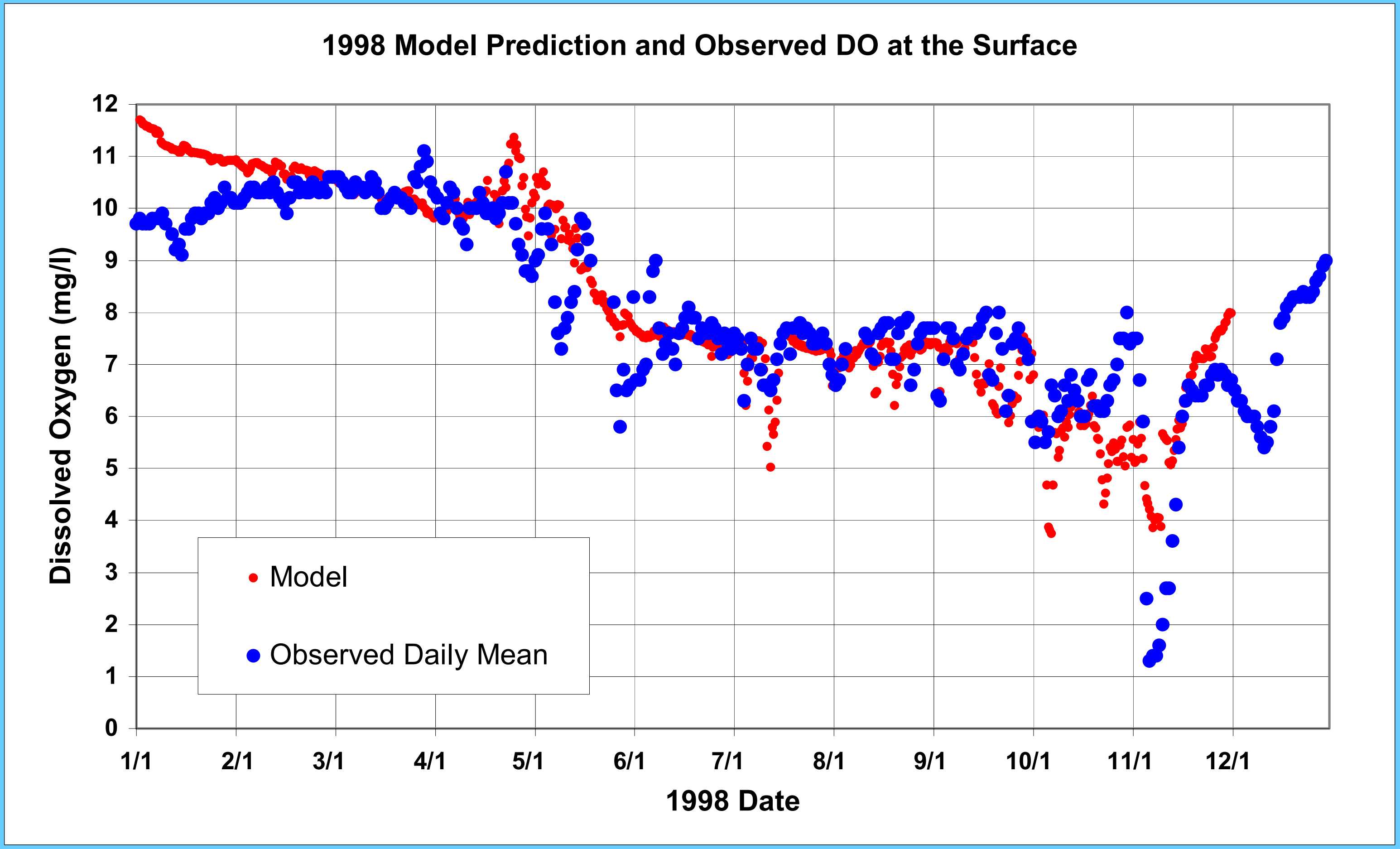


Temperature at the Surface
Model vs. Data

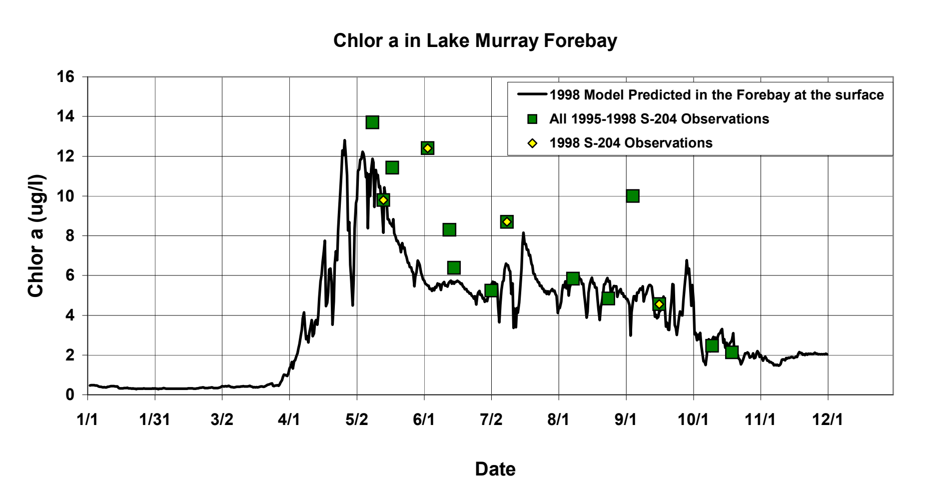


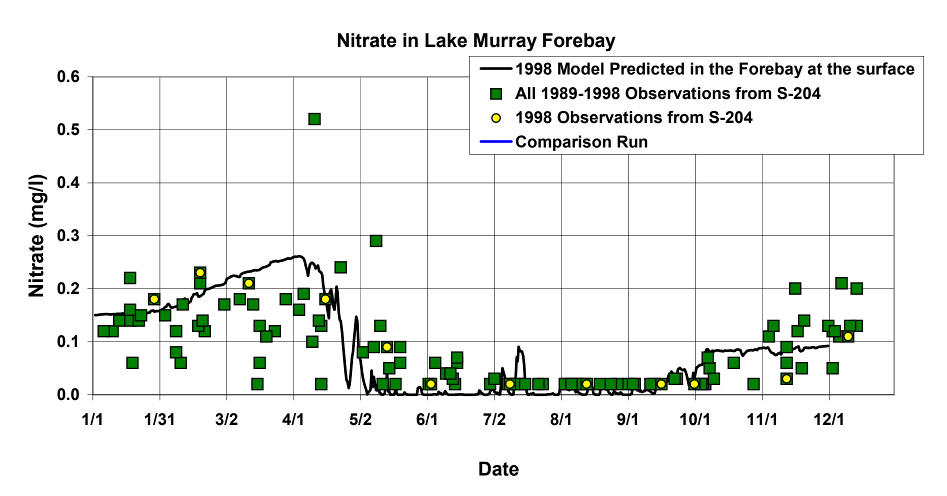
DO at the Surface

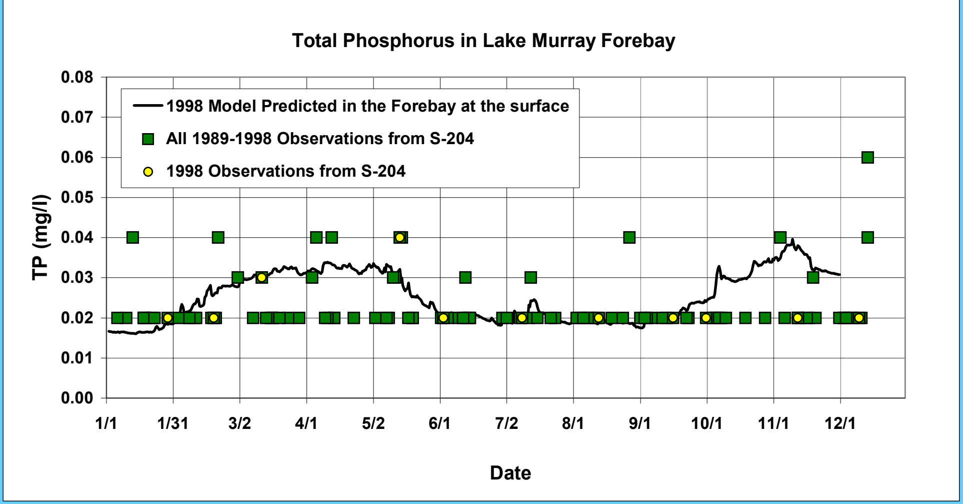
Model vs. Data

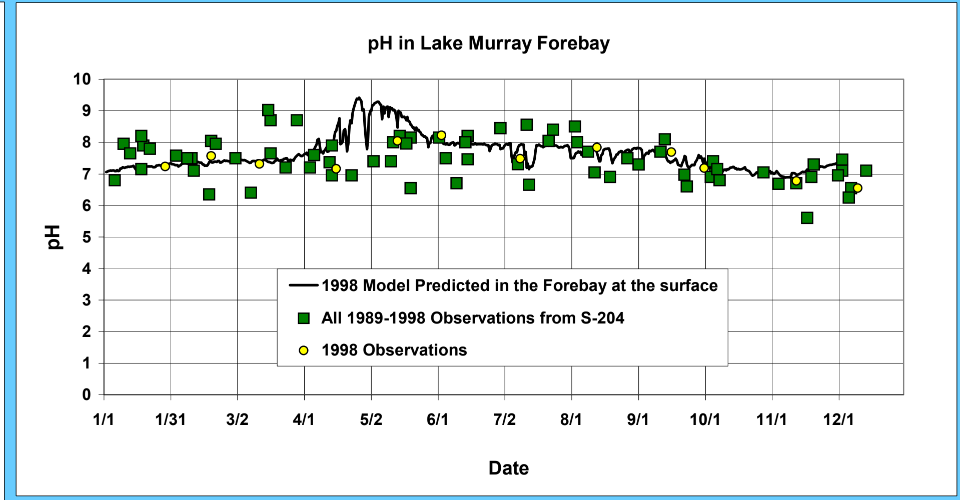


1998 - Other Water Quality Constituents
Forebay Surface
Model vs. Data



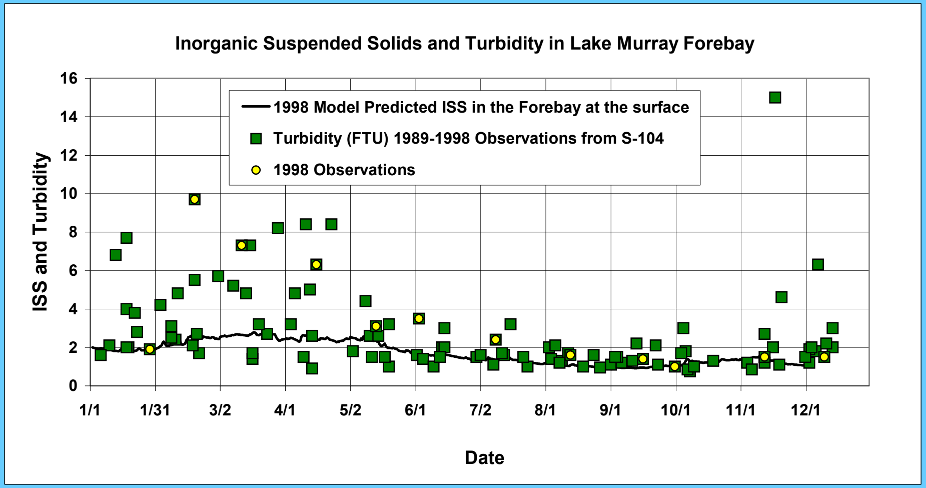


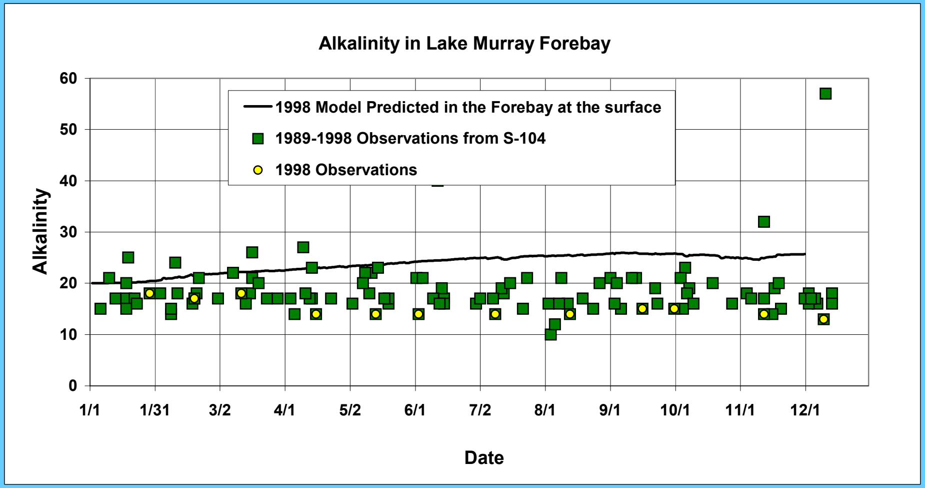


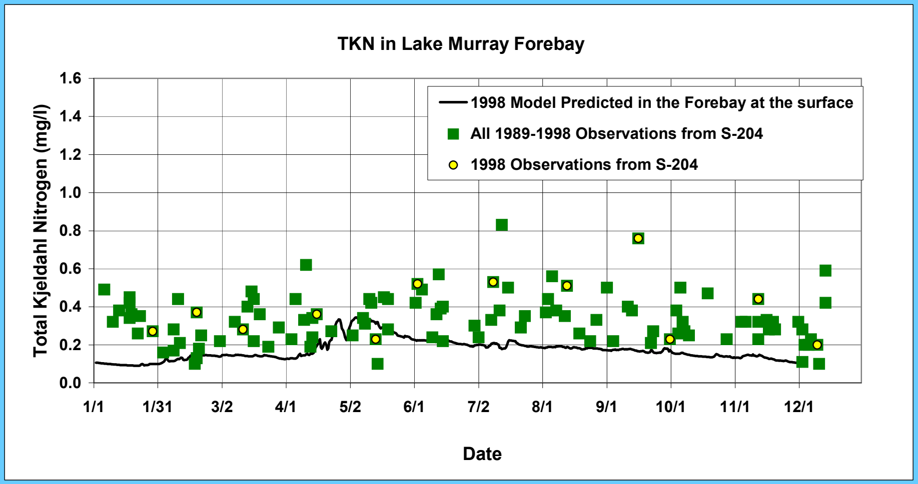


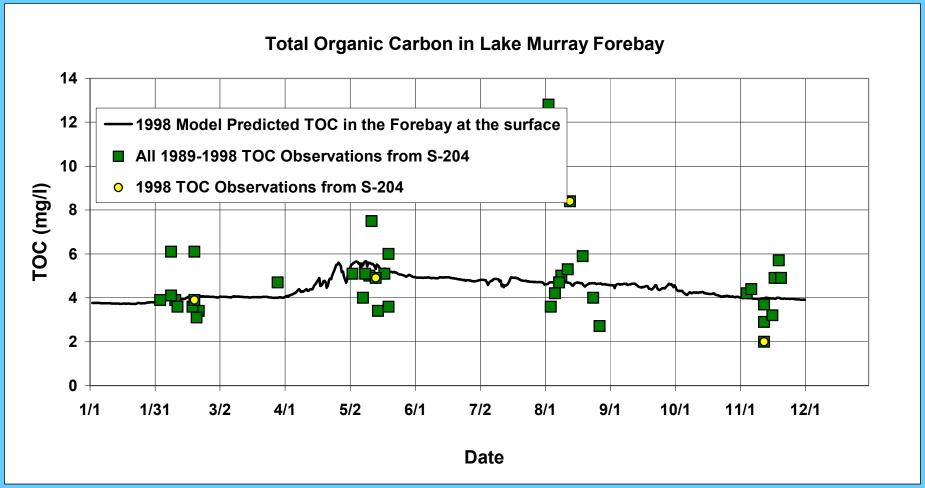
1998 - Other Water Quality Constituents

Model vs. Data









Evaluation of Raised Pool Levels

Scenarios Considered:

- 354(Jan1) to 358(May1⇨Sept1) to 354(Dec 31)
- 350(Jan1) to 358(May1⇨Sept1) to 350(Dec 31)

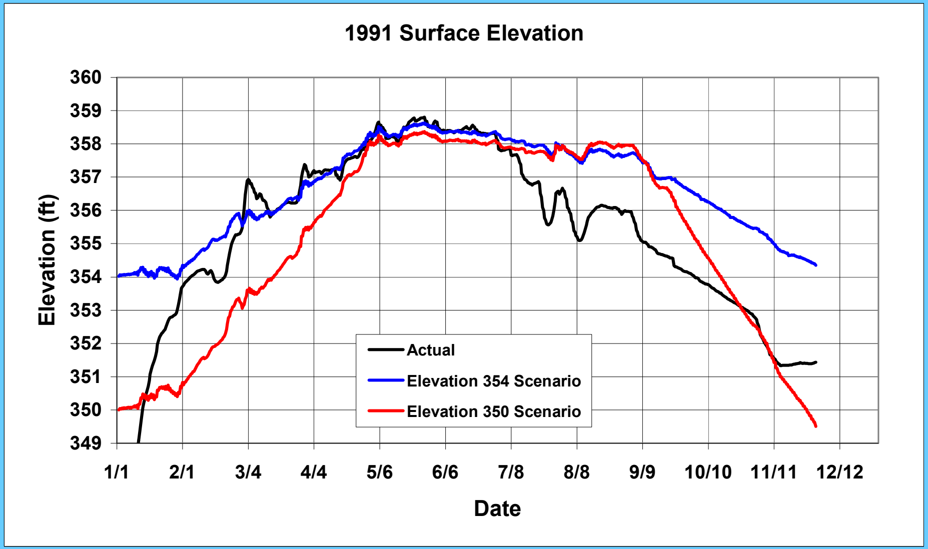
Assumptions:

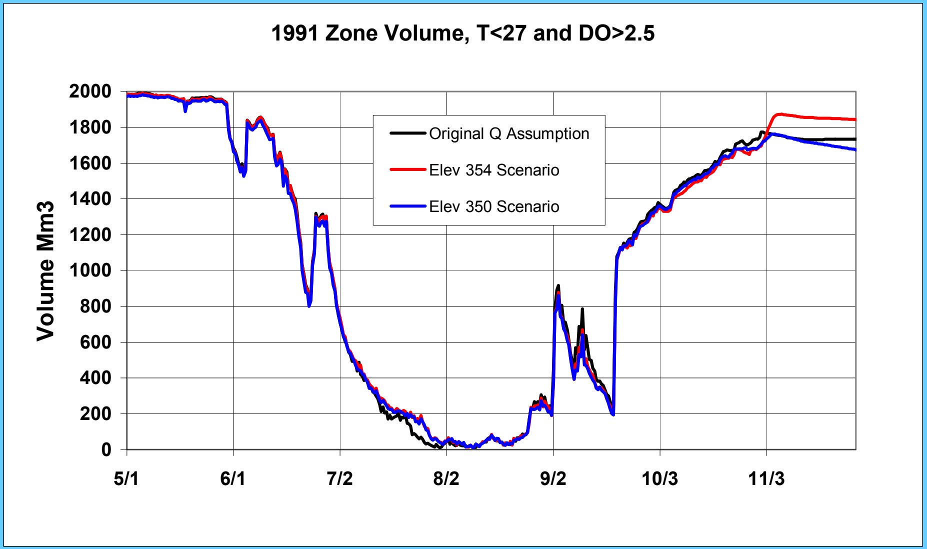
- Assumed 500 cfs for minimum release
- Assumed reserve generation averaged 3hr every two weeks at 18,000 cfs
- Balance of releases were assumed to be used to supplement system demand

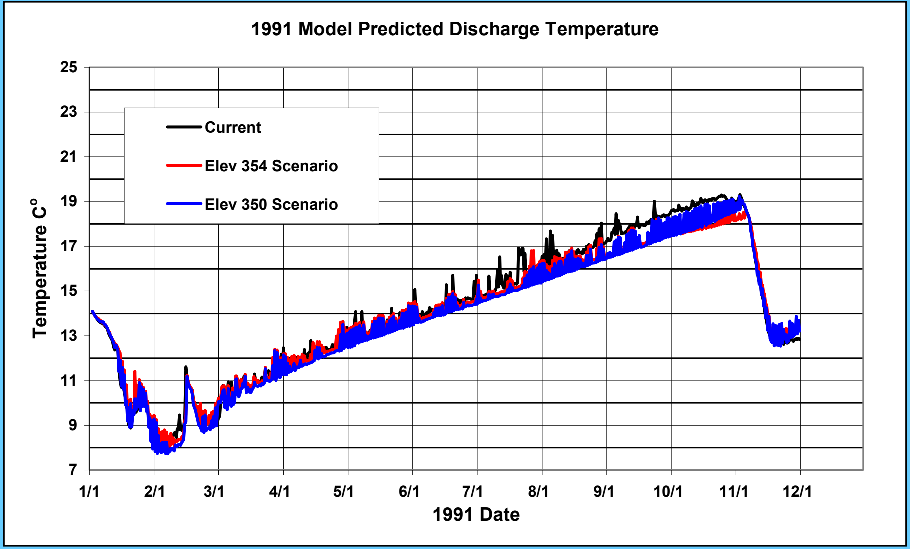
Approach:

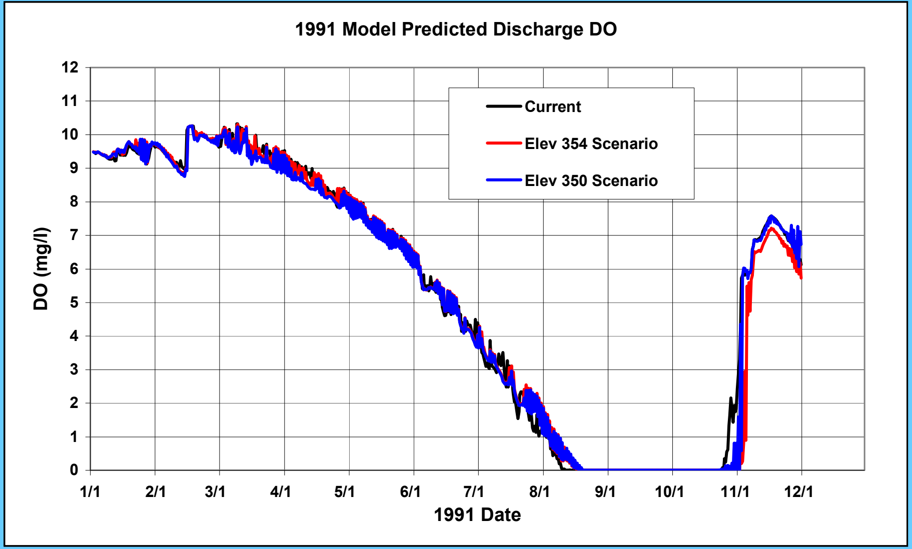
- The above scenarios were developed by KA using daily average flows using HEC-ResSim
- CE-QUAL-W2 was run using daily average flows and release flows were adjusted so that target pool levels were attained
- Using the daily average flows that were adjusted using the CE-QUAL-W2 model the hourly flows for each day were developed using the assumptions above

1991 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO









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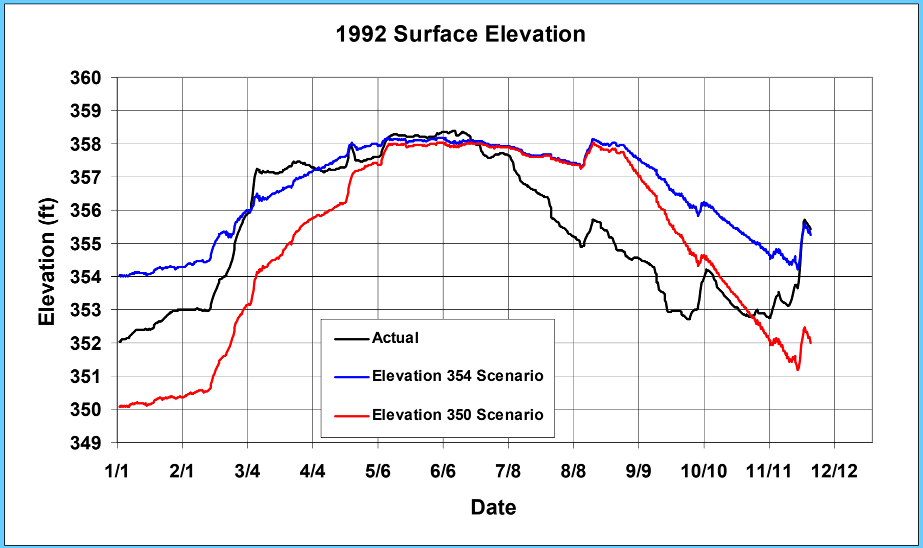
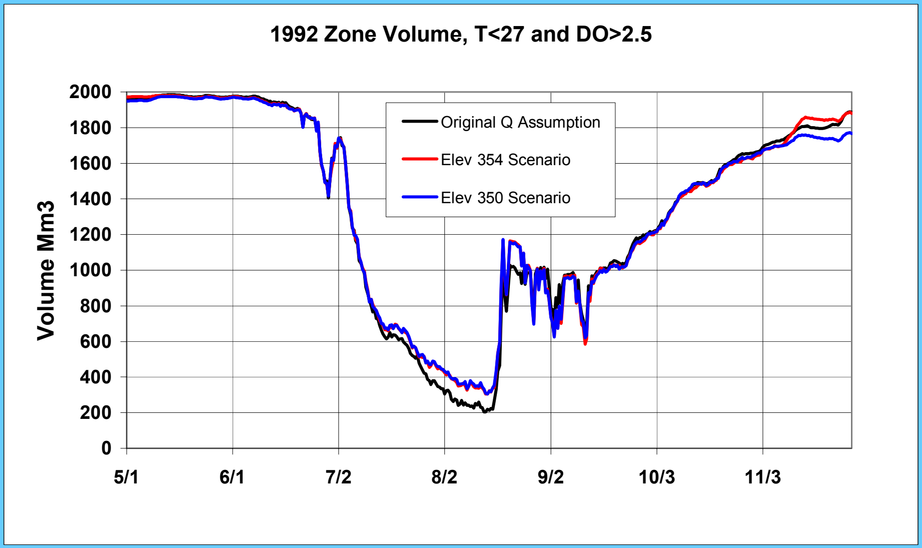
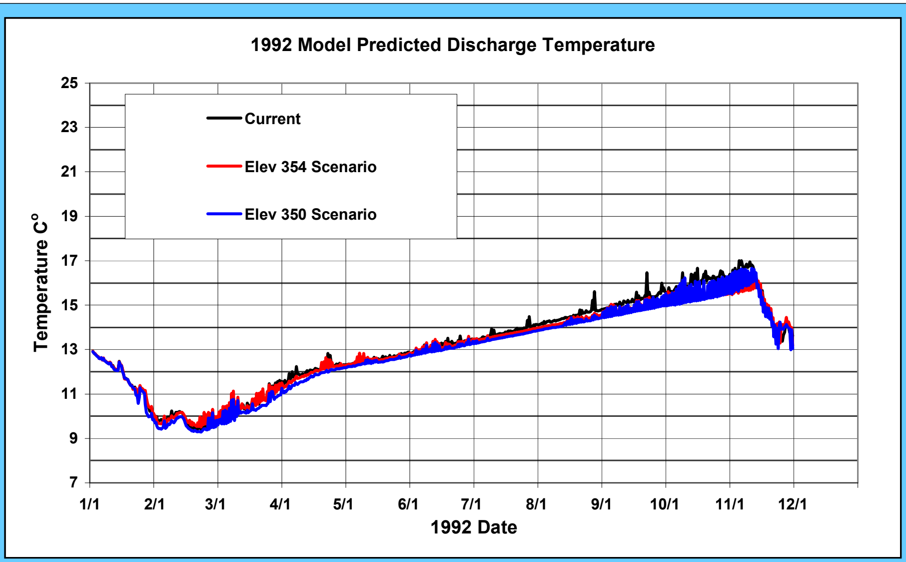
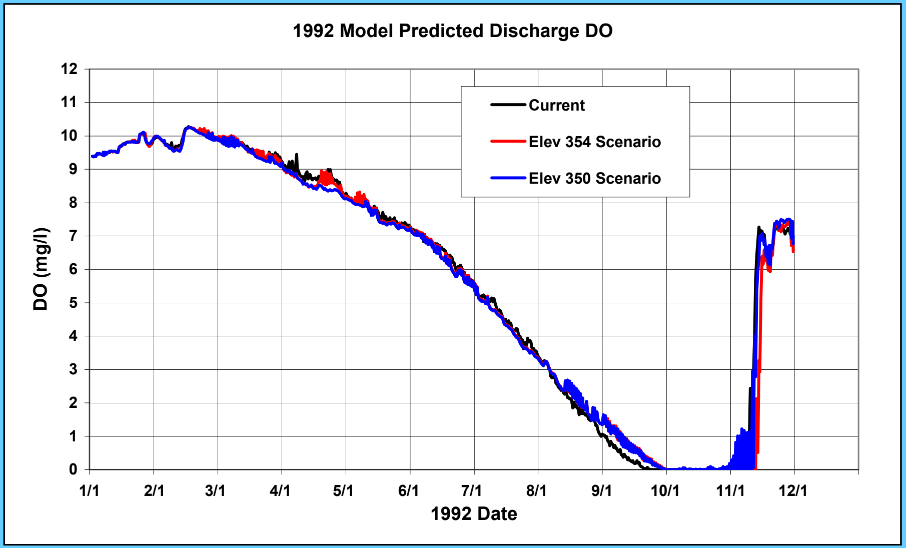
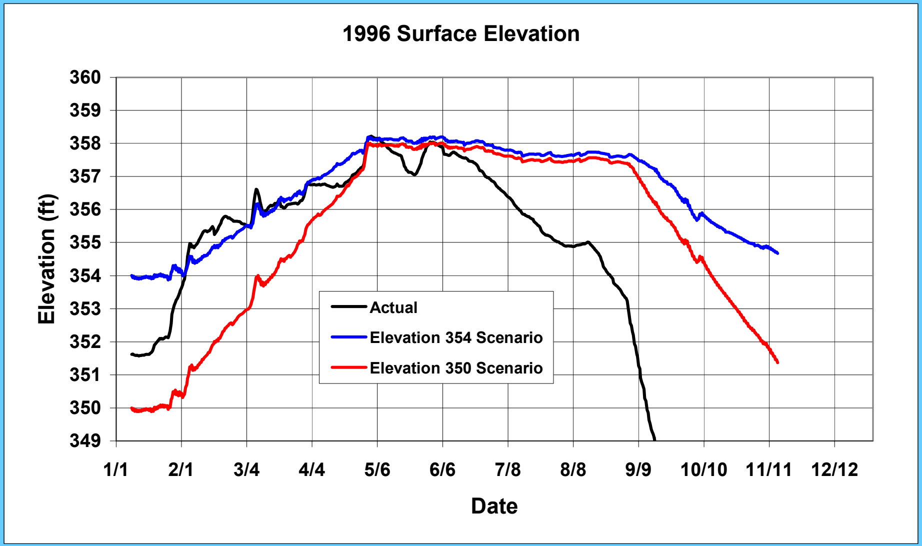


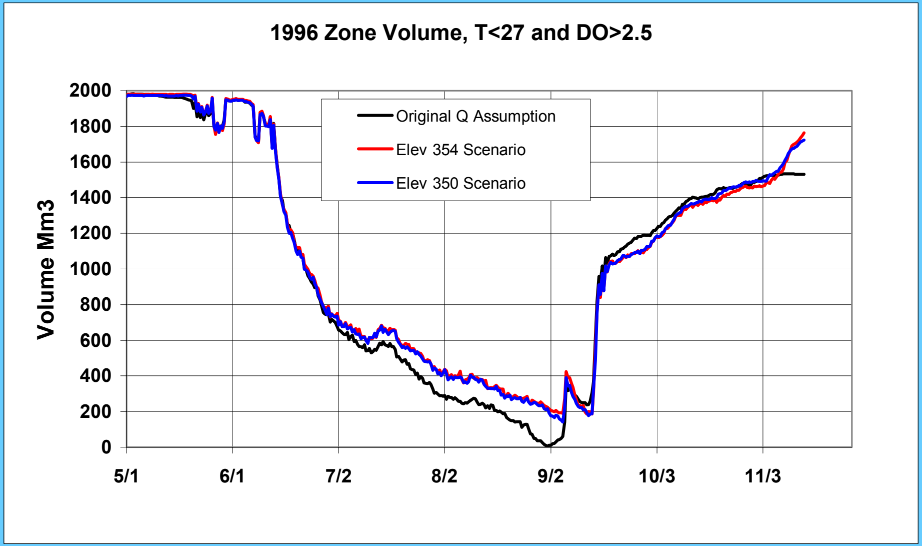


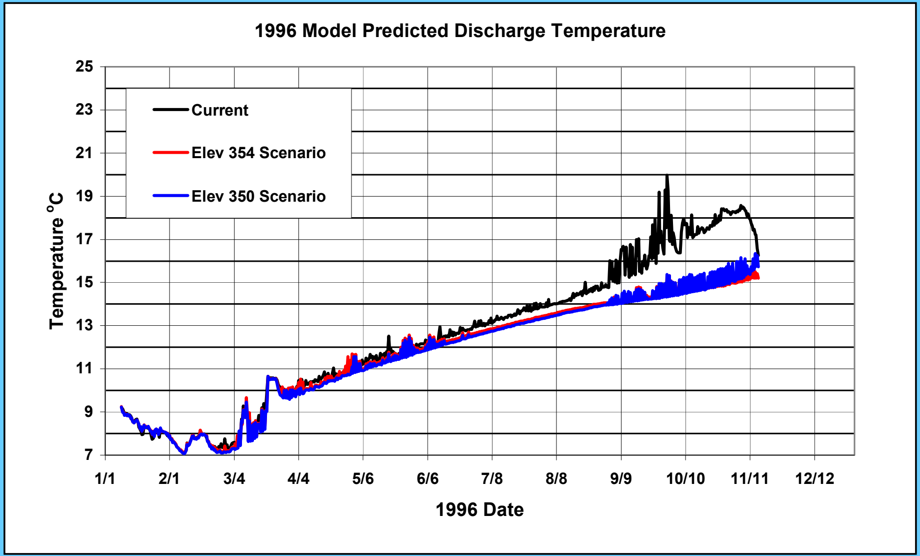


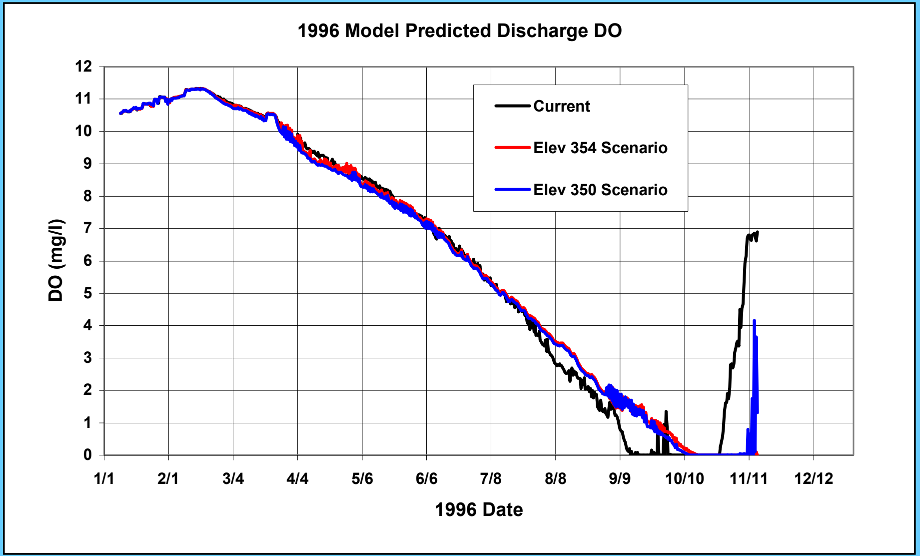


1996 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO

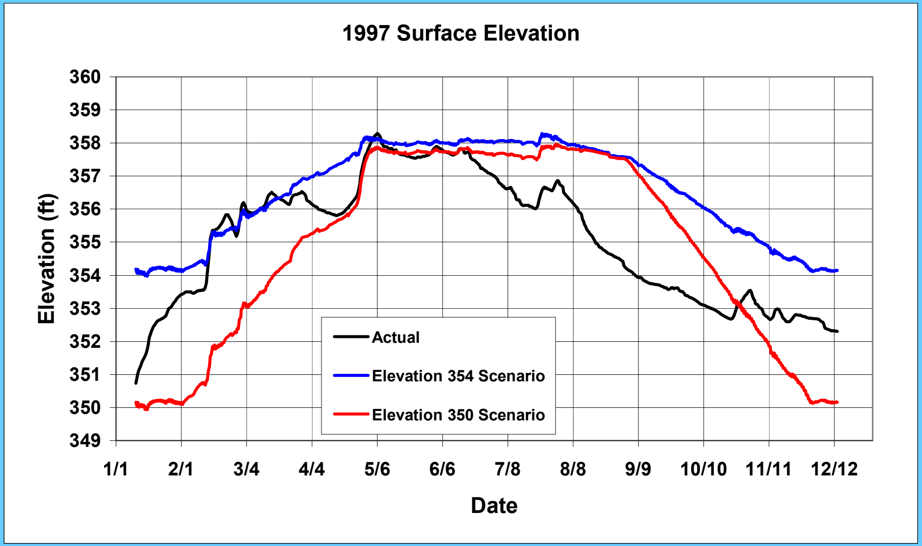


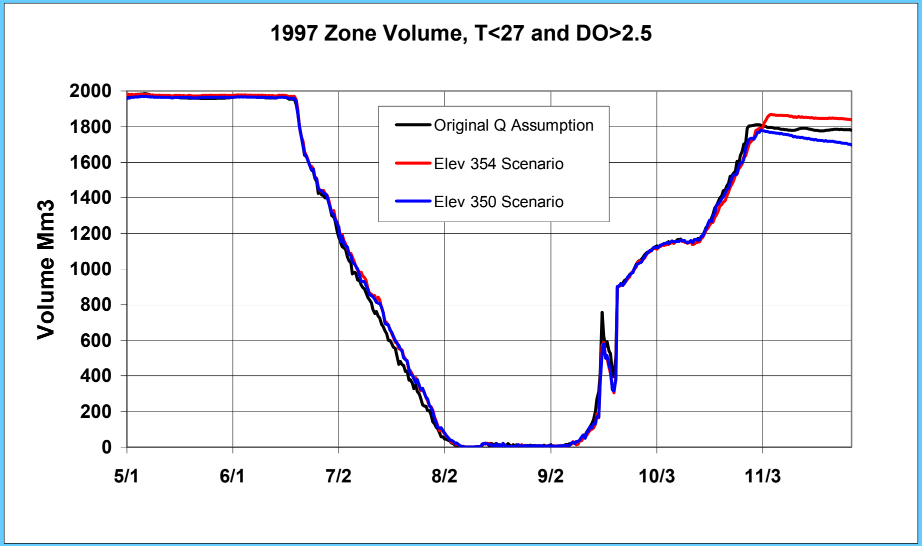


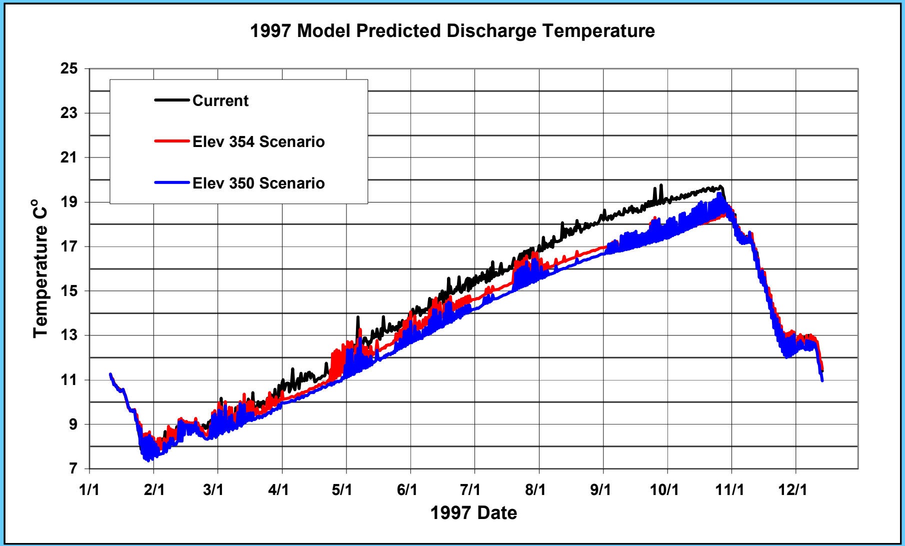


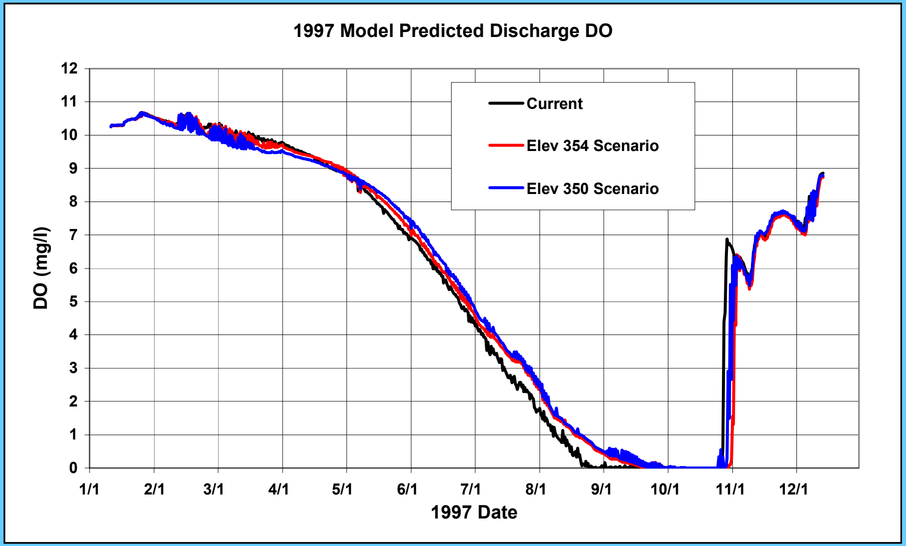


1997 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO









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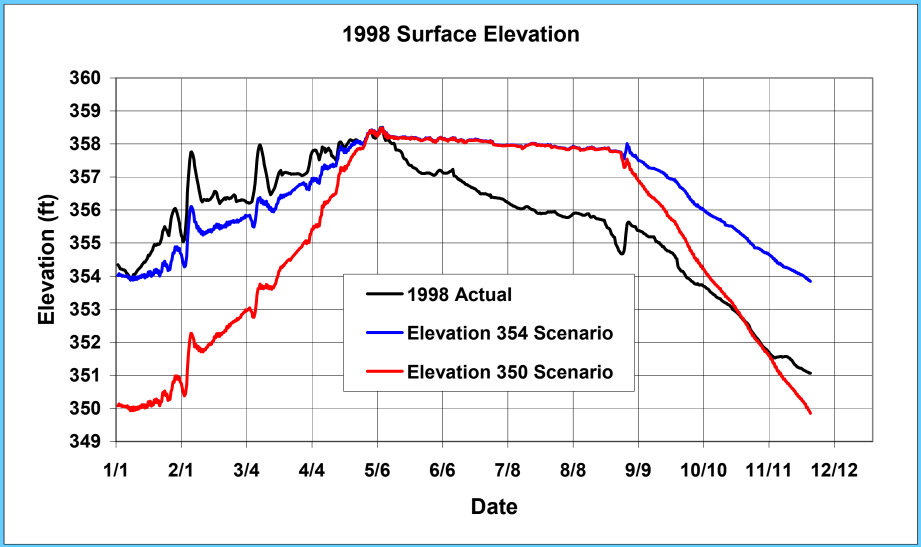
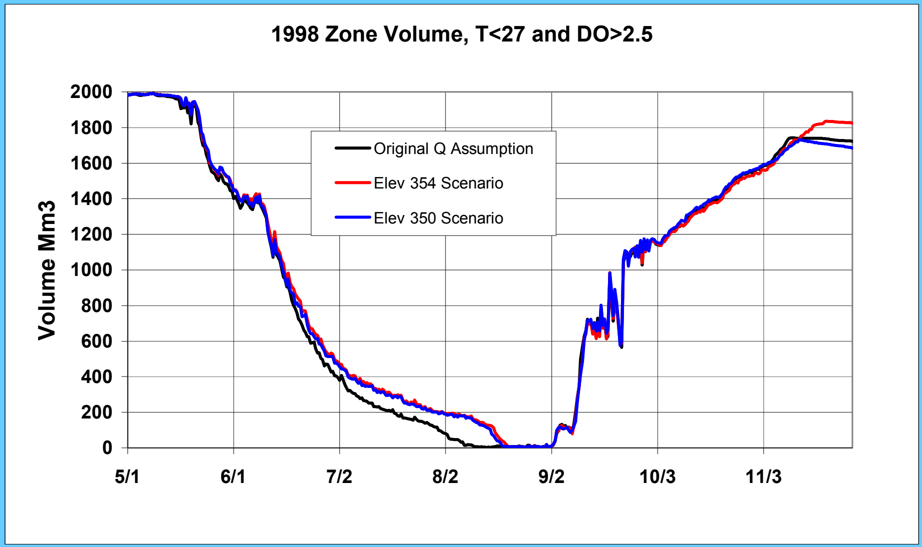
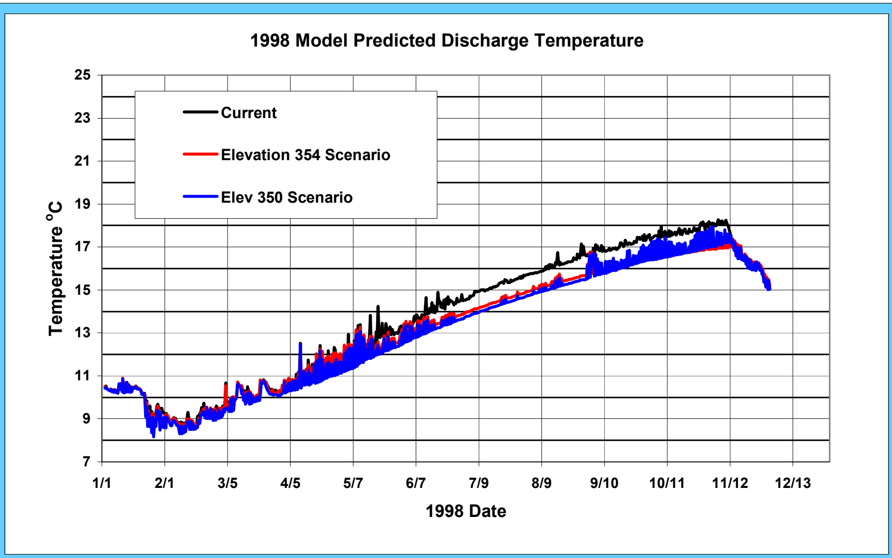
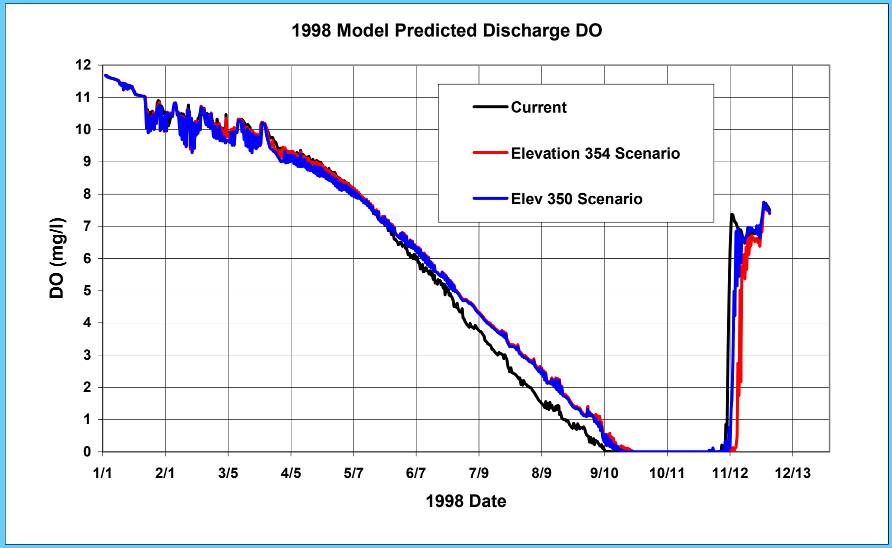
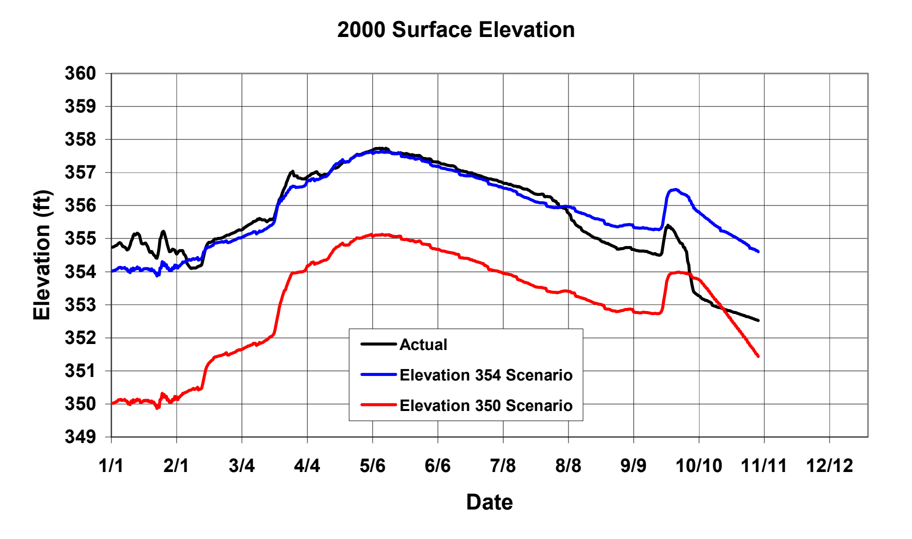


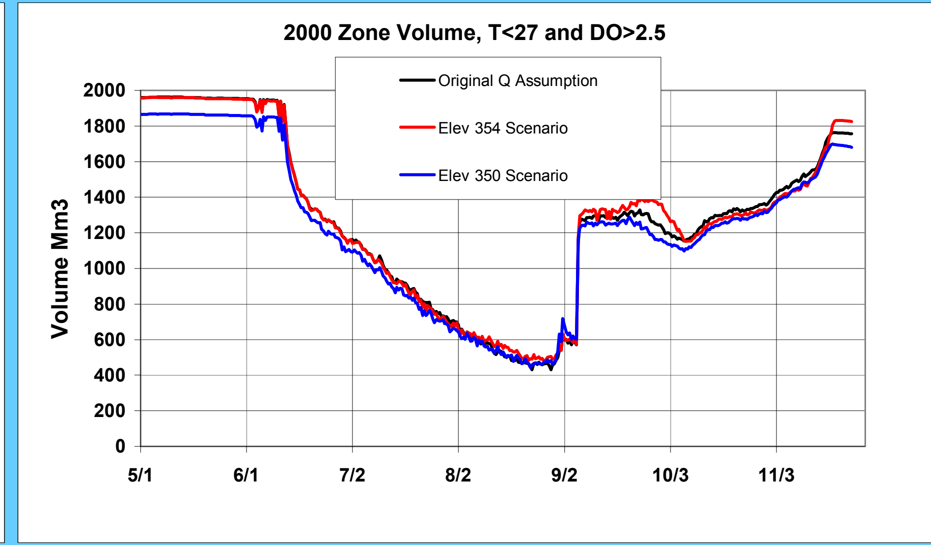


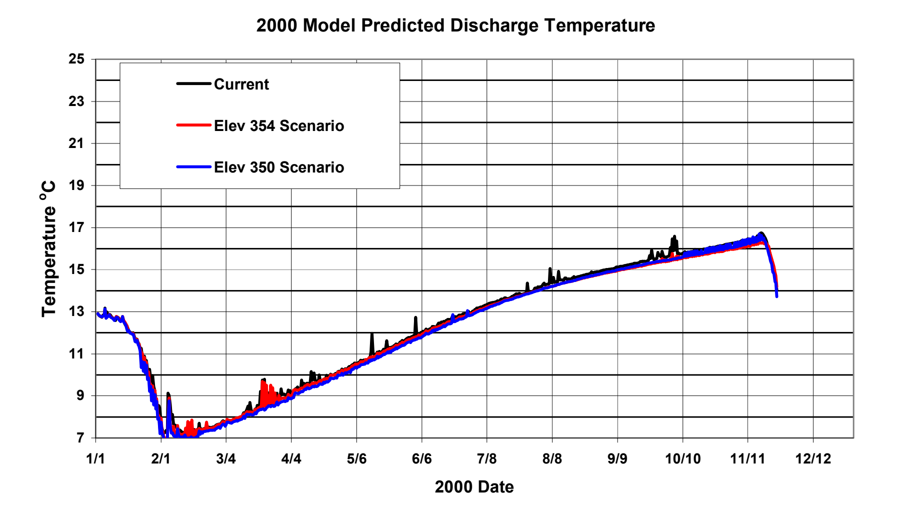


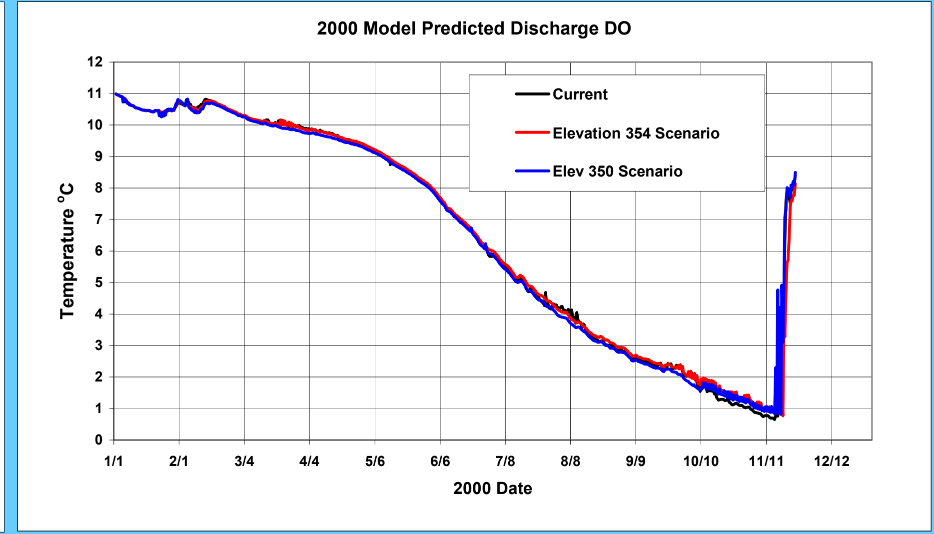


2000 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO

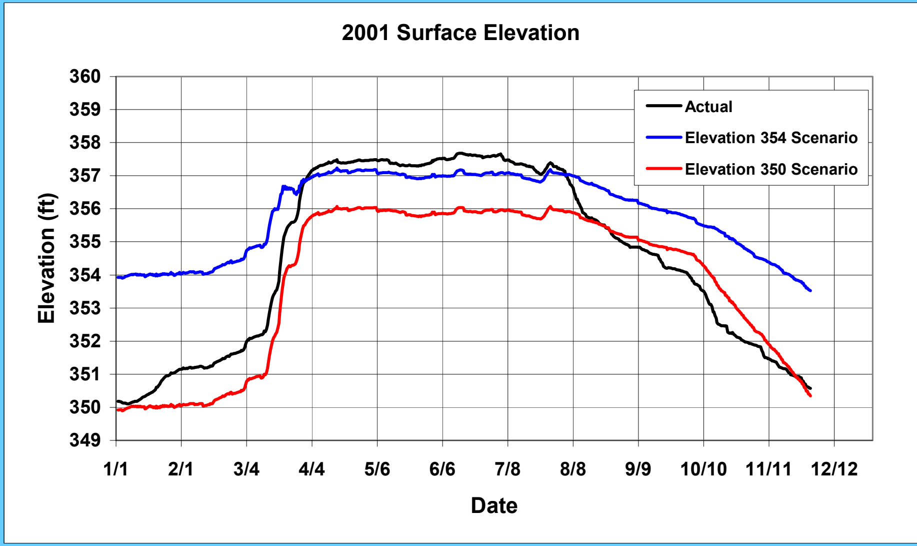


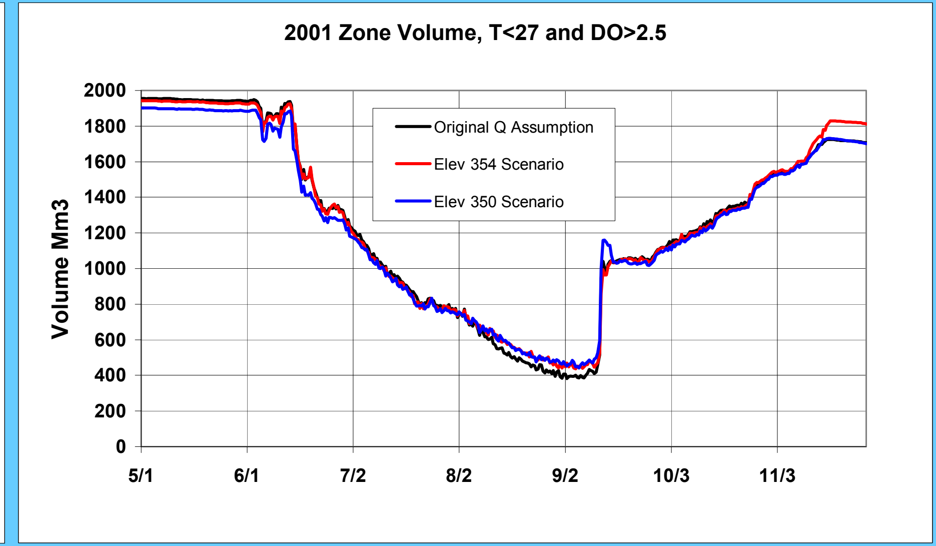


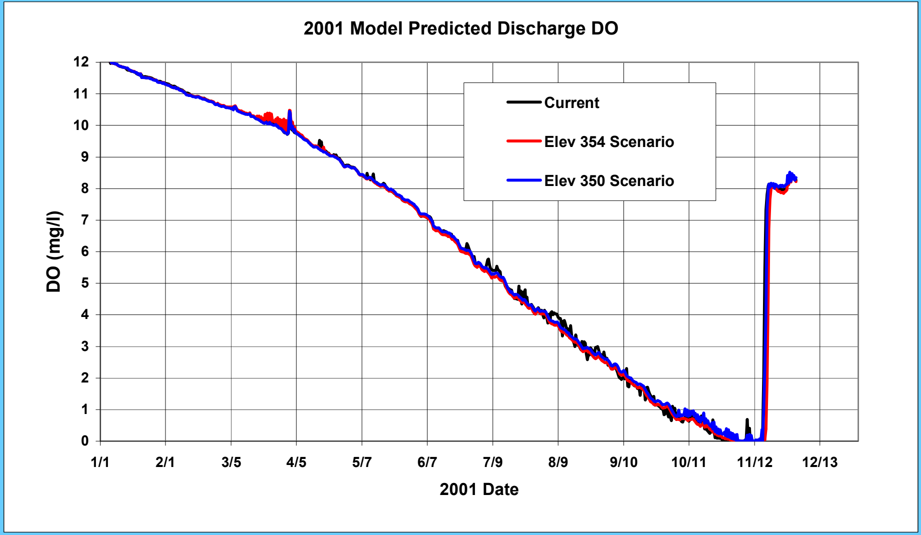


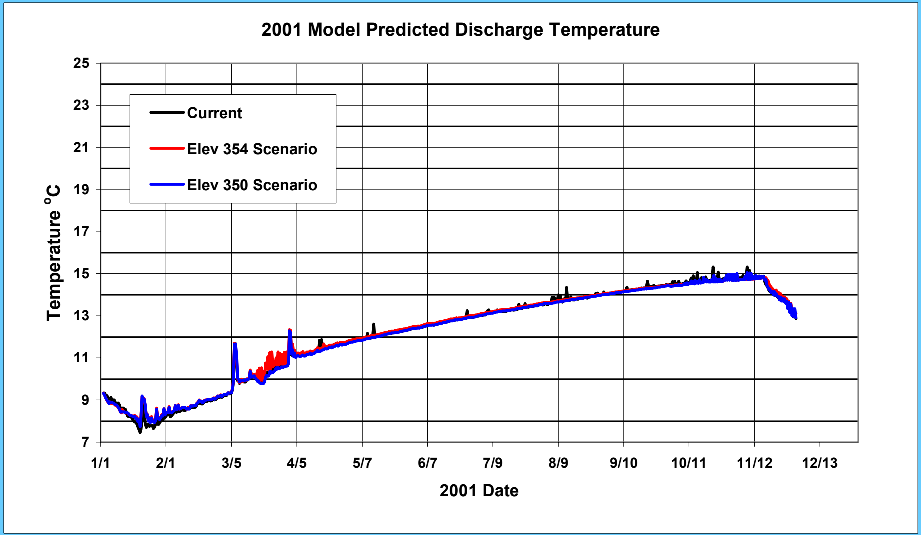


2001 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO

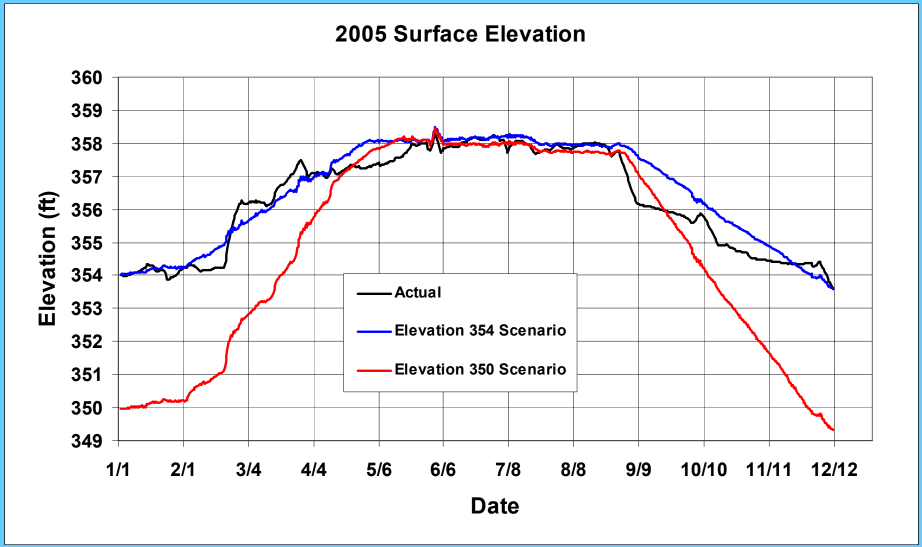


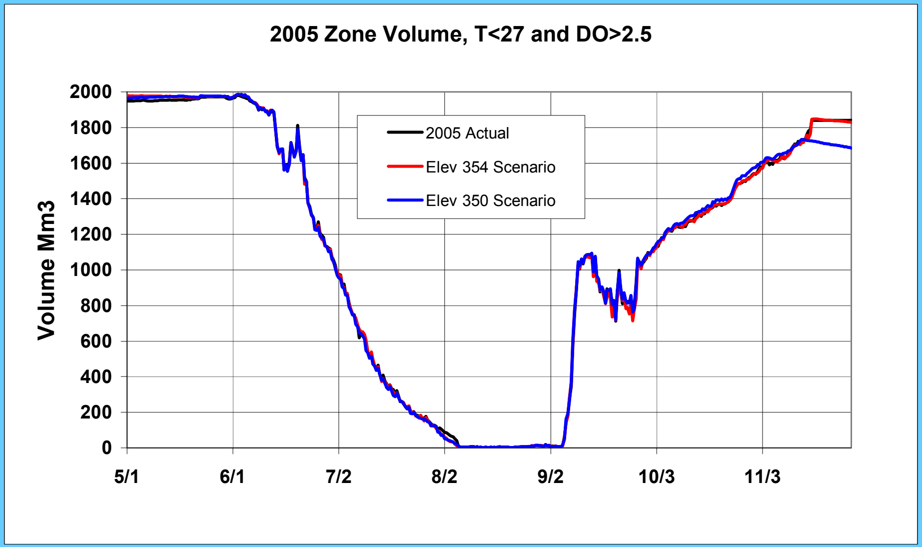


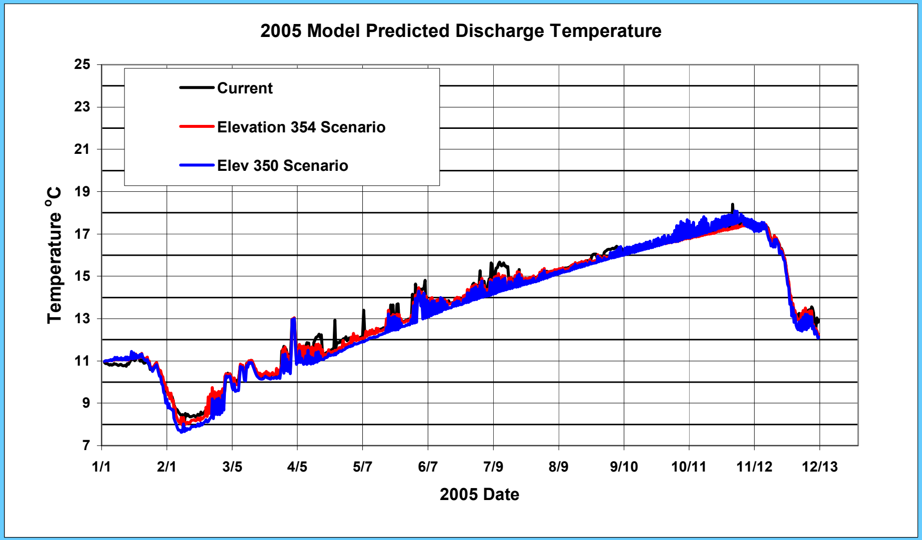


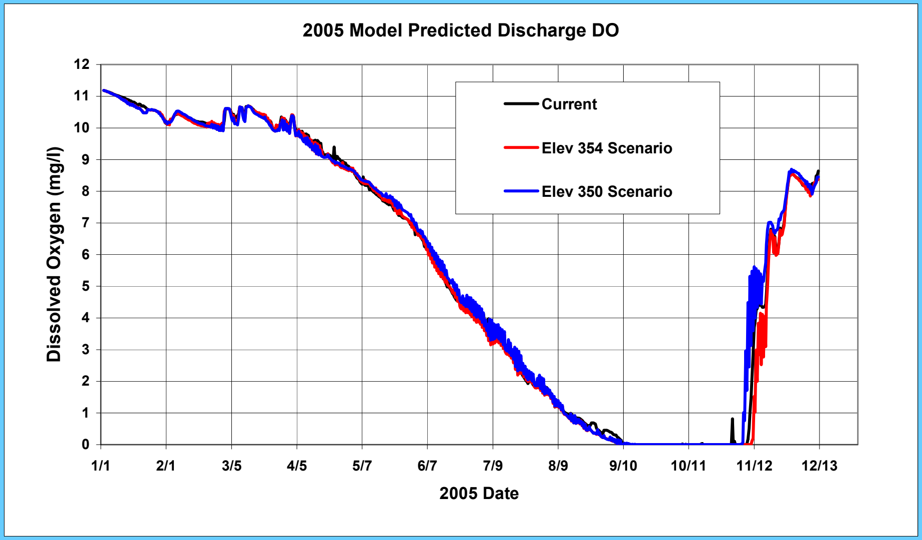


2005 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO

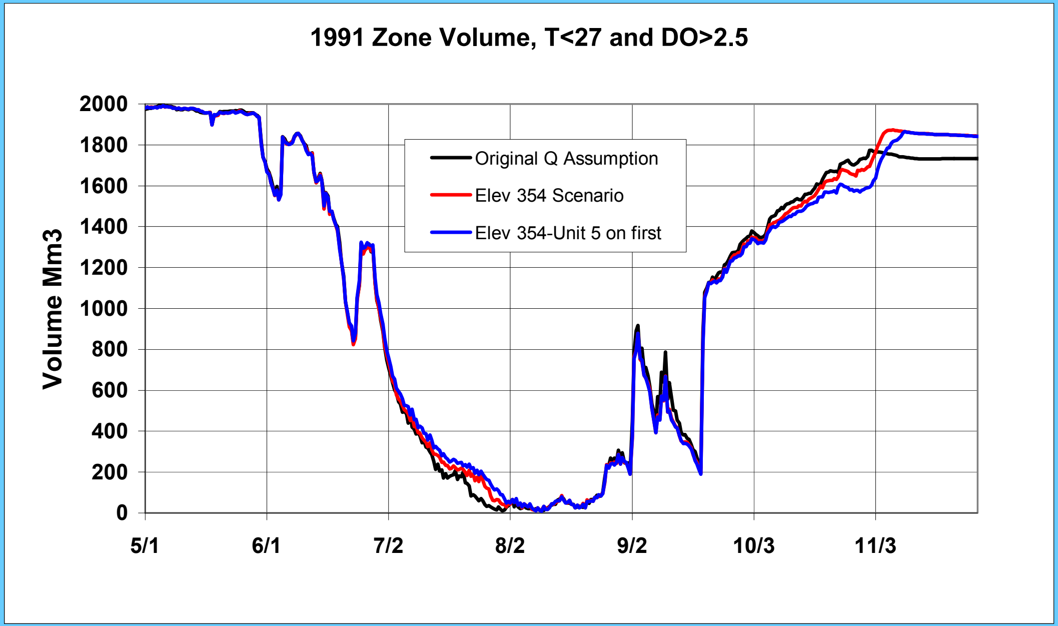


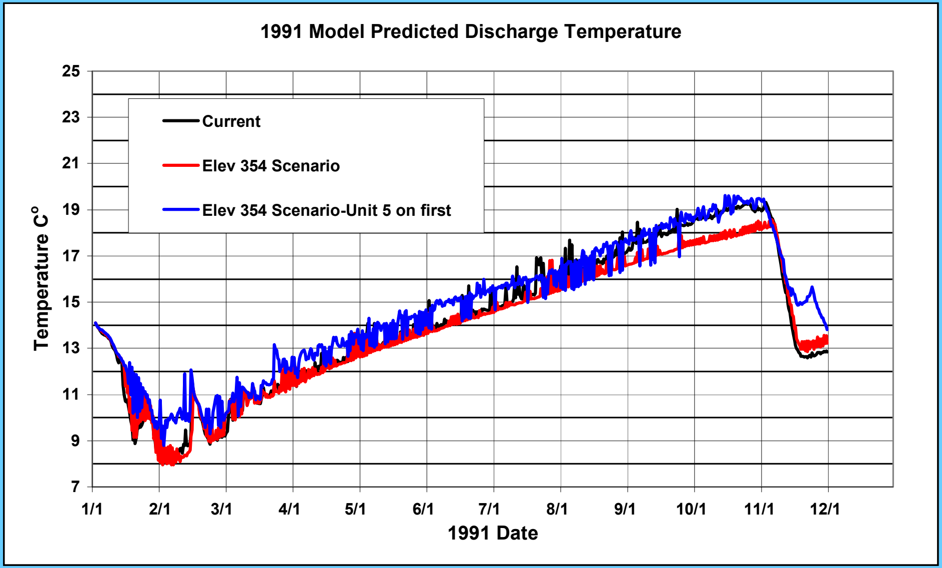


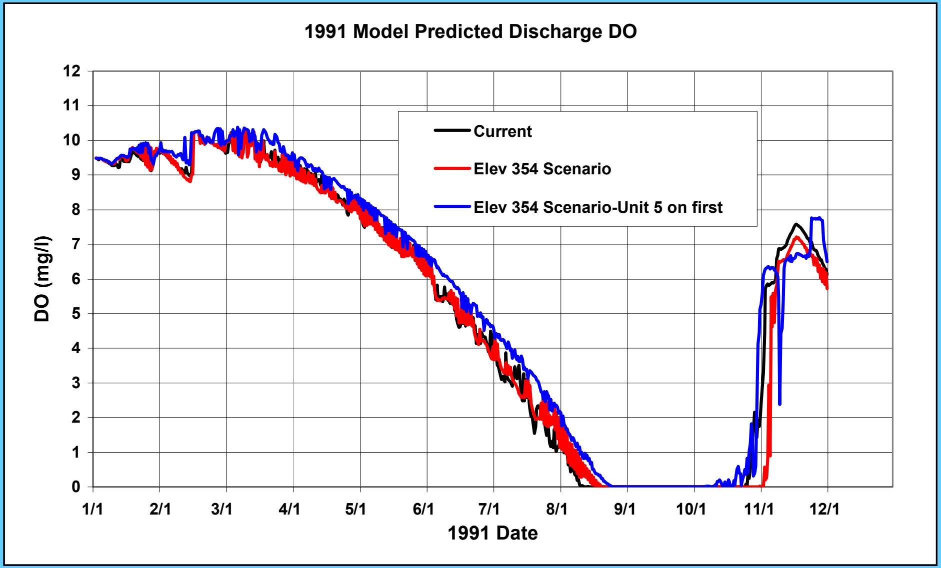




1991 Pool Level Management and Unit 5 on First







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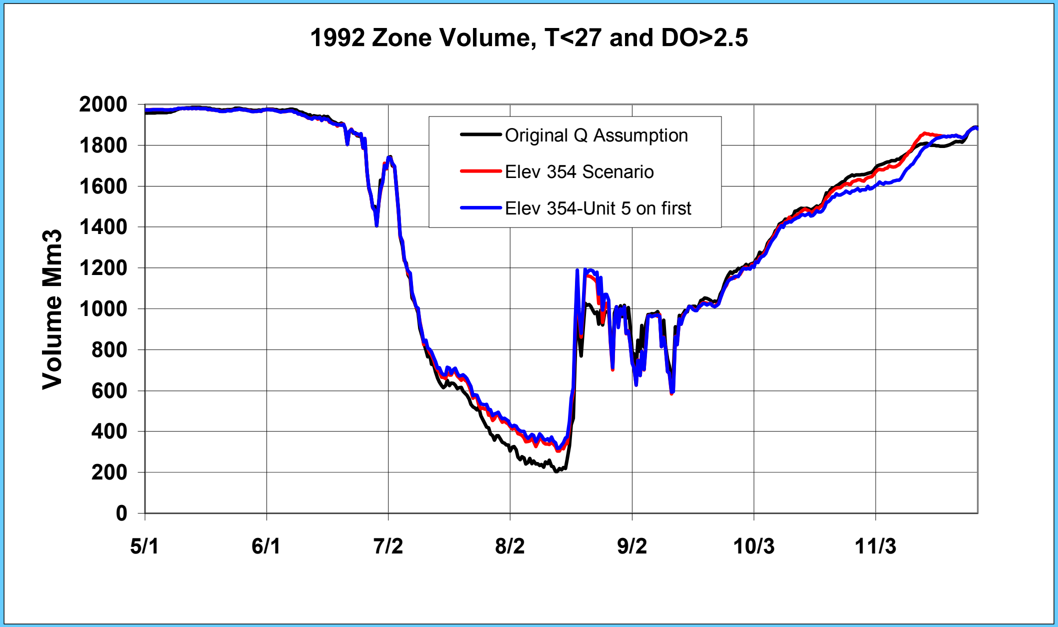
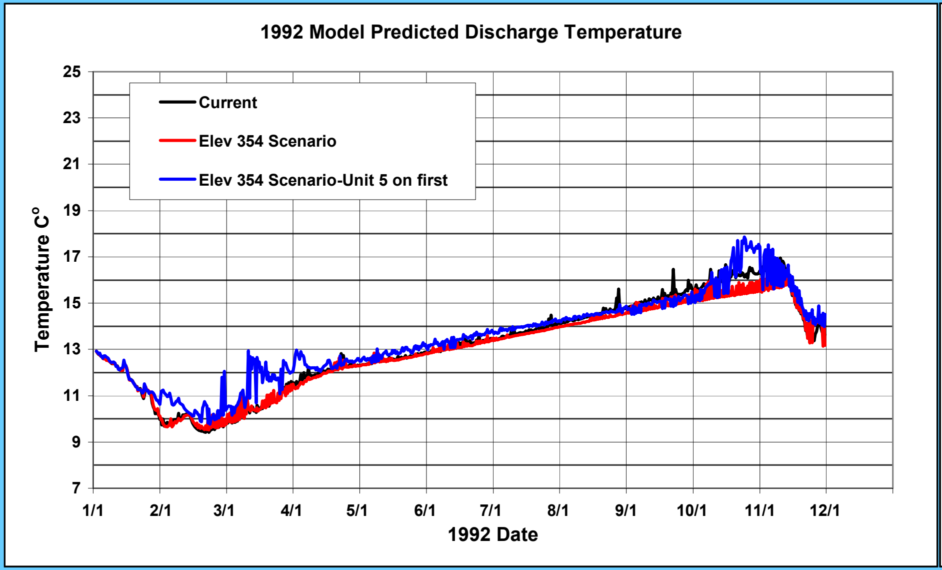
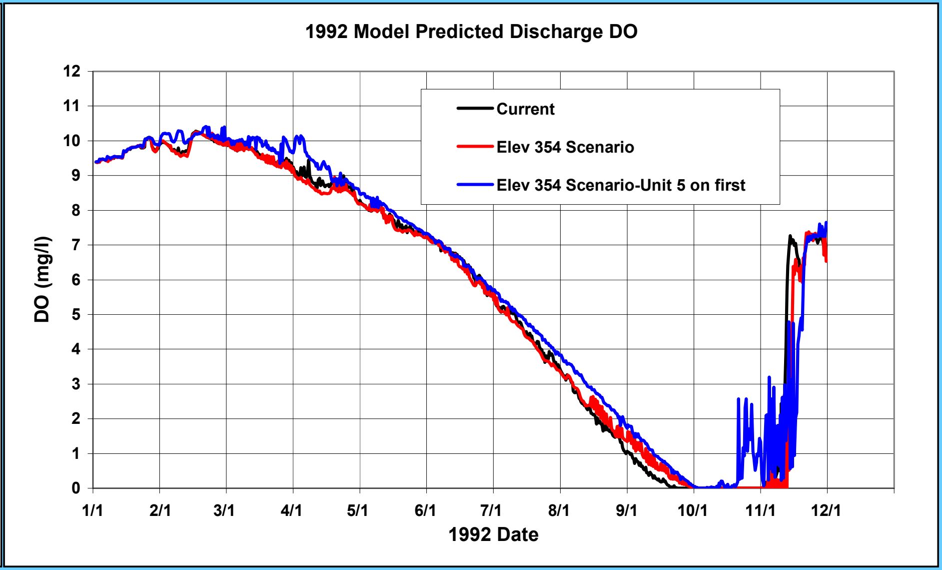
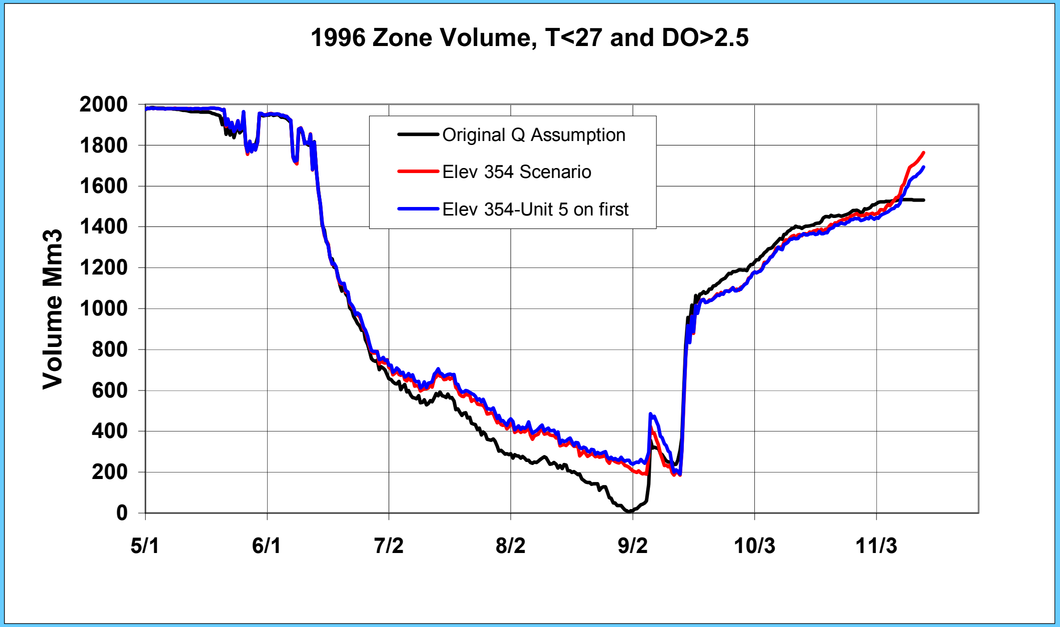
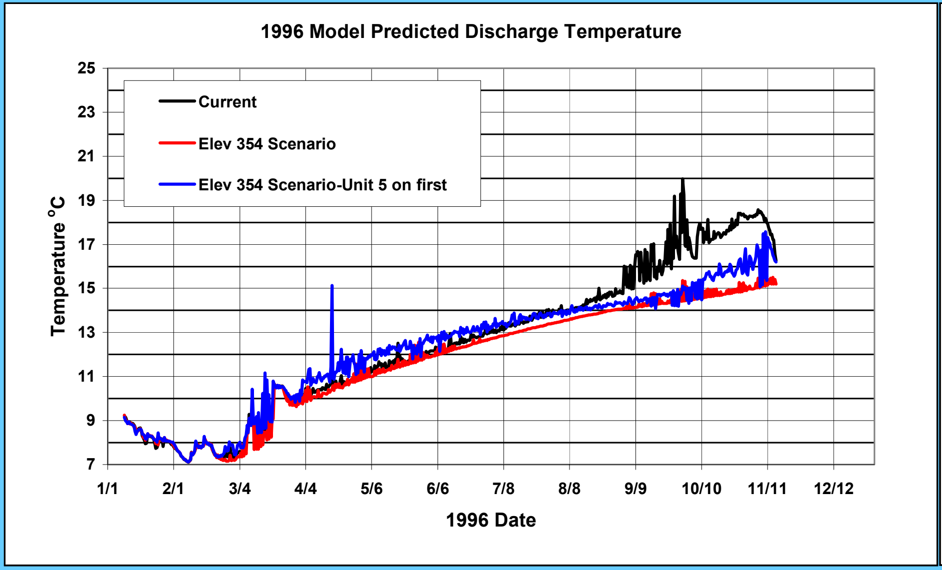


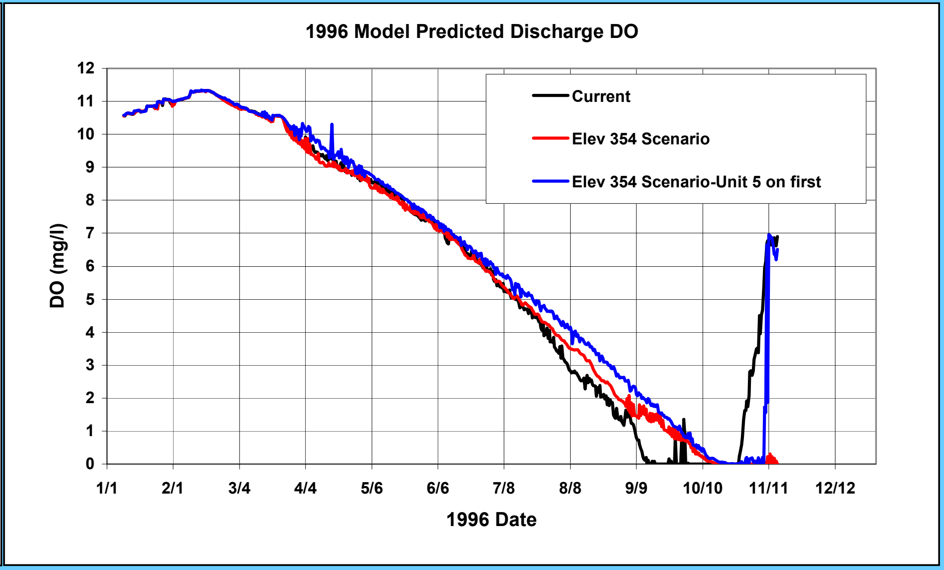




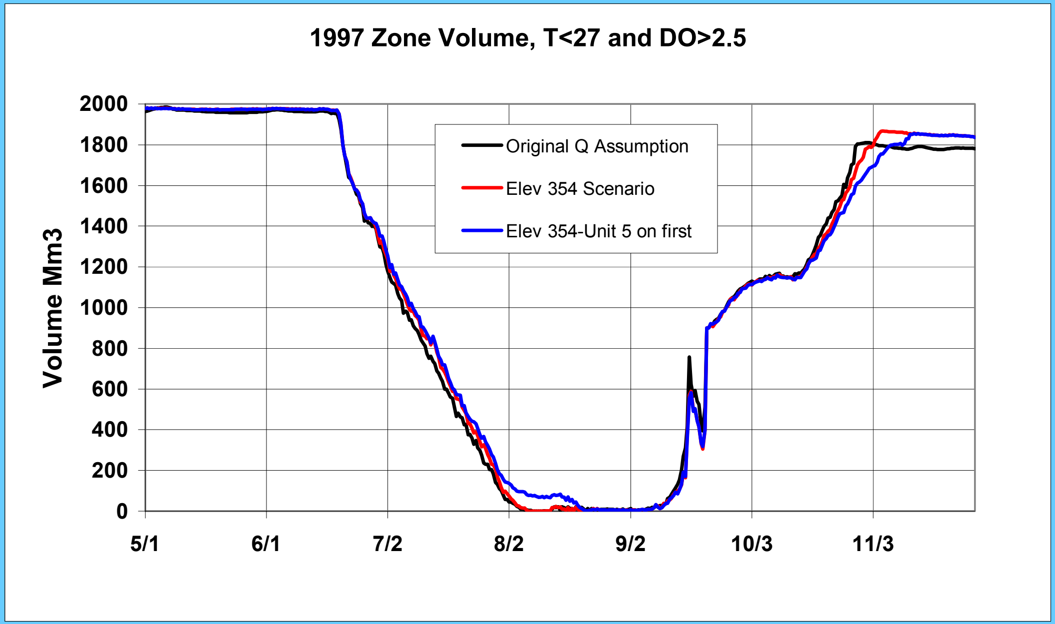
1996 Pool Level Management and Unit 5 on First

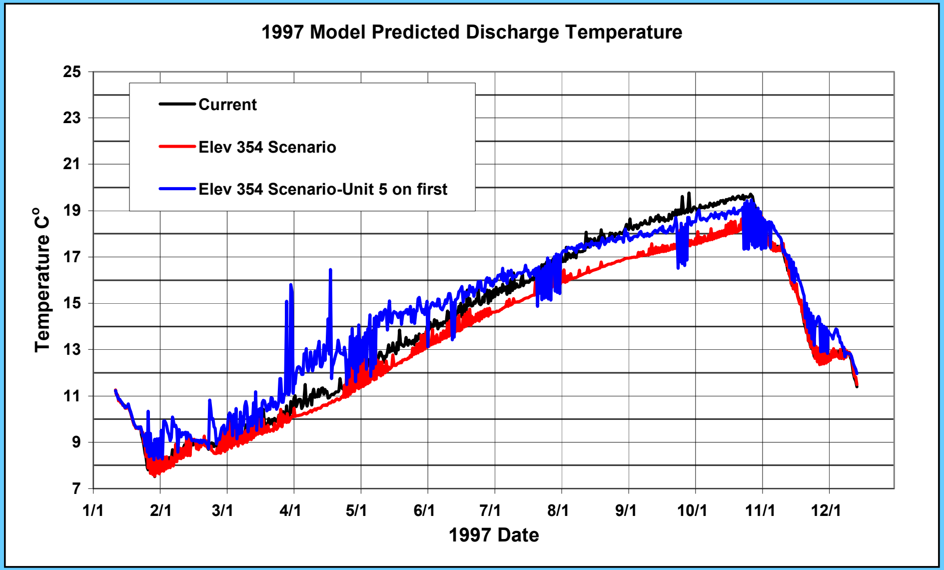


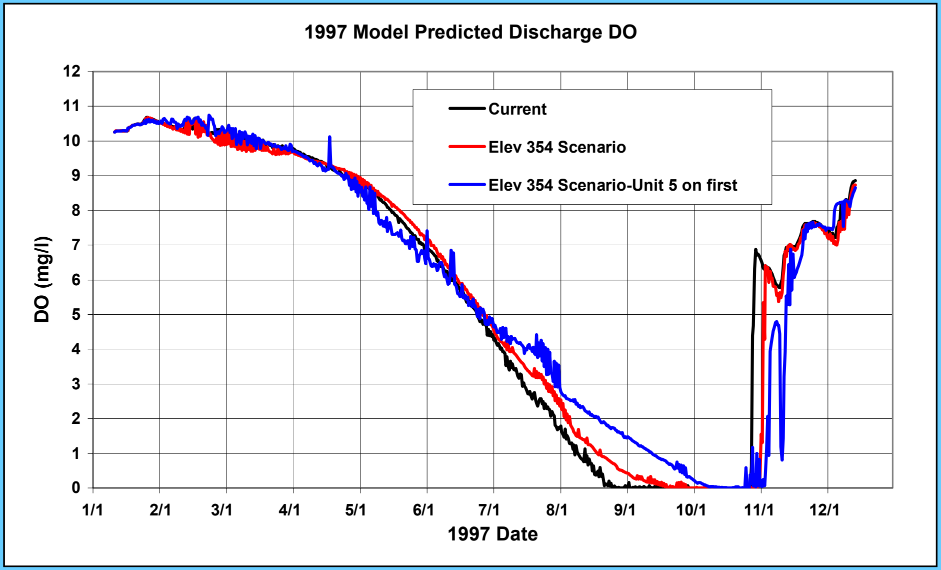




1997 Pool Level Management and Unit 5 on First







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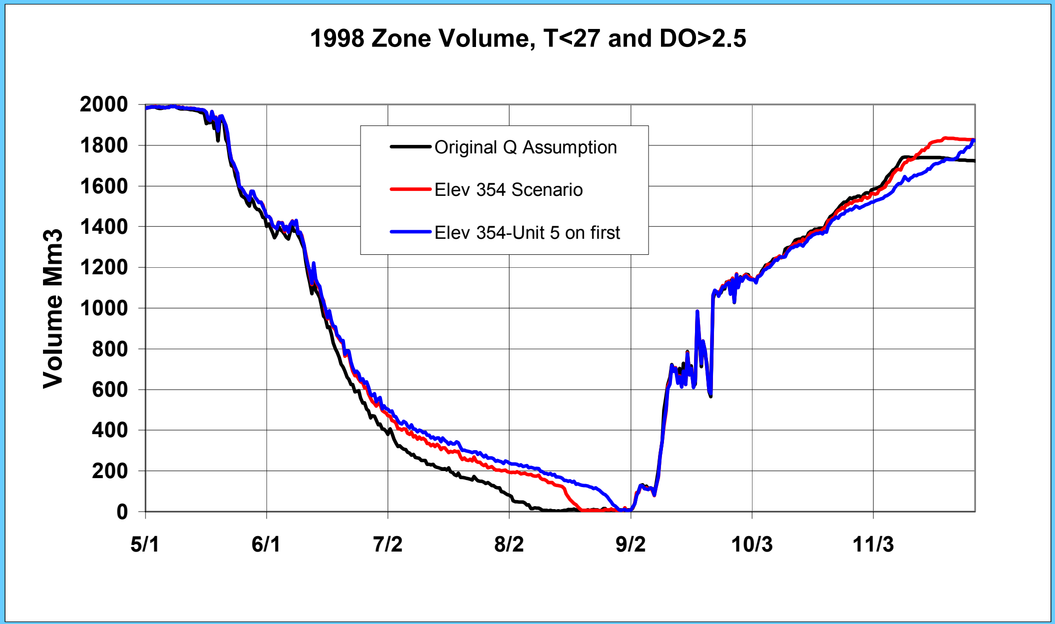
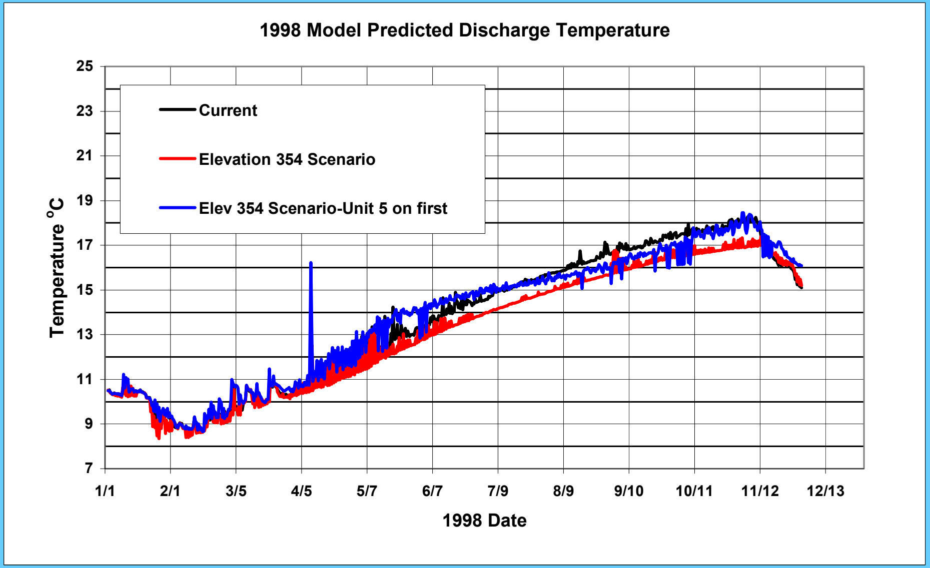
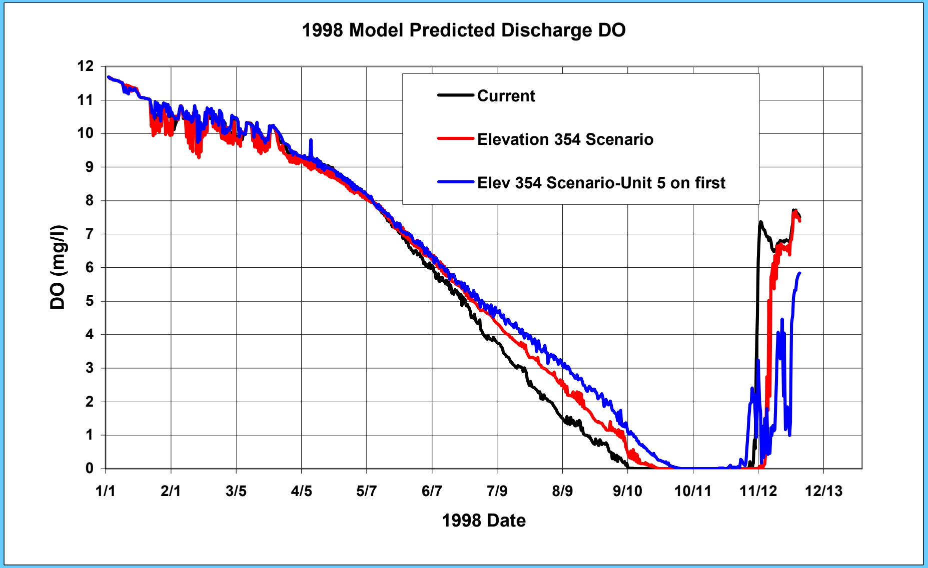
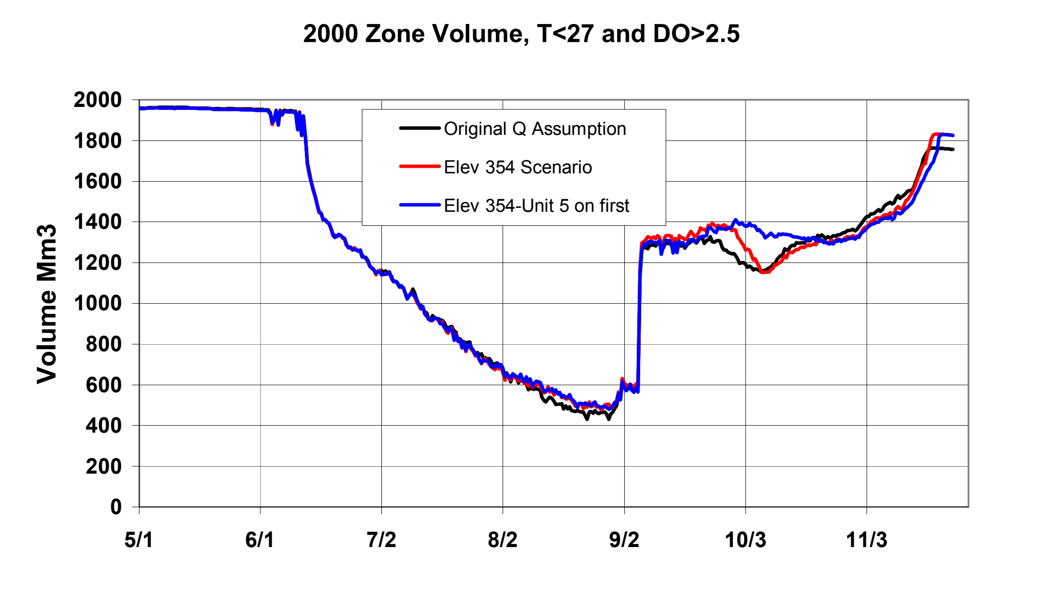
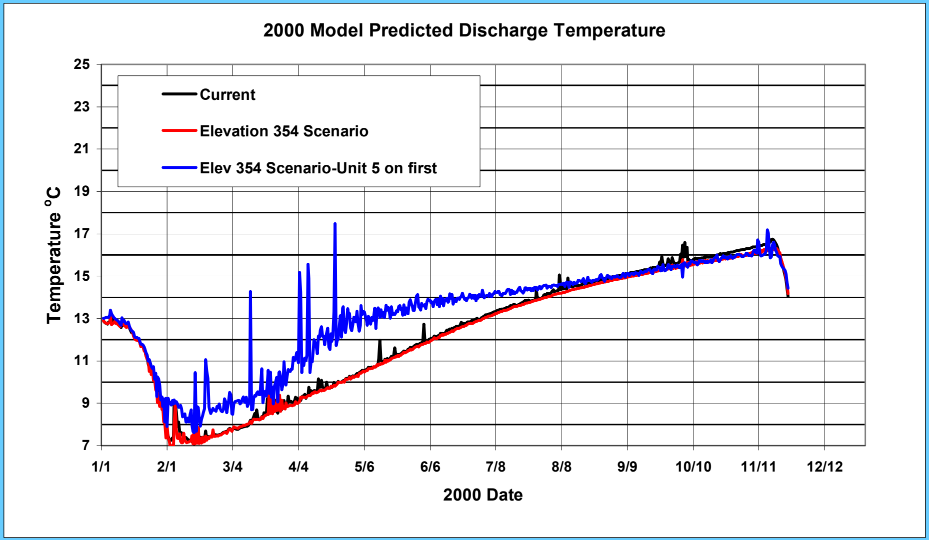


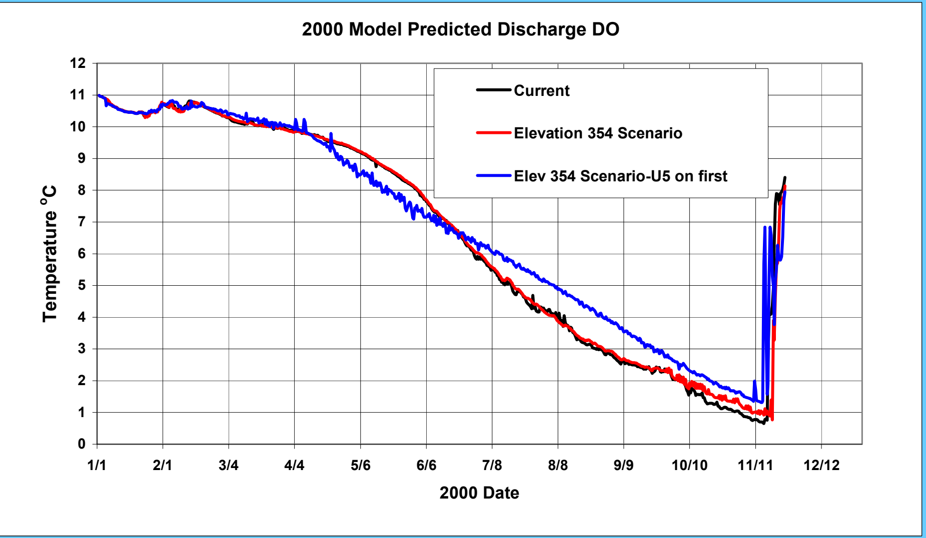




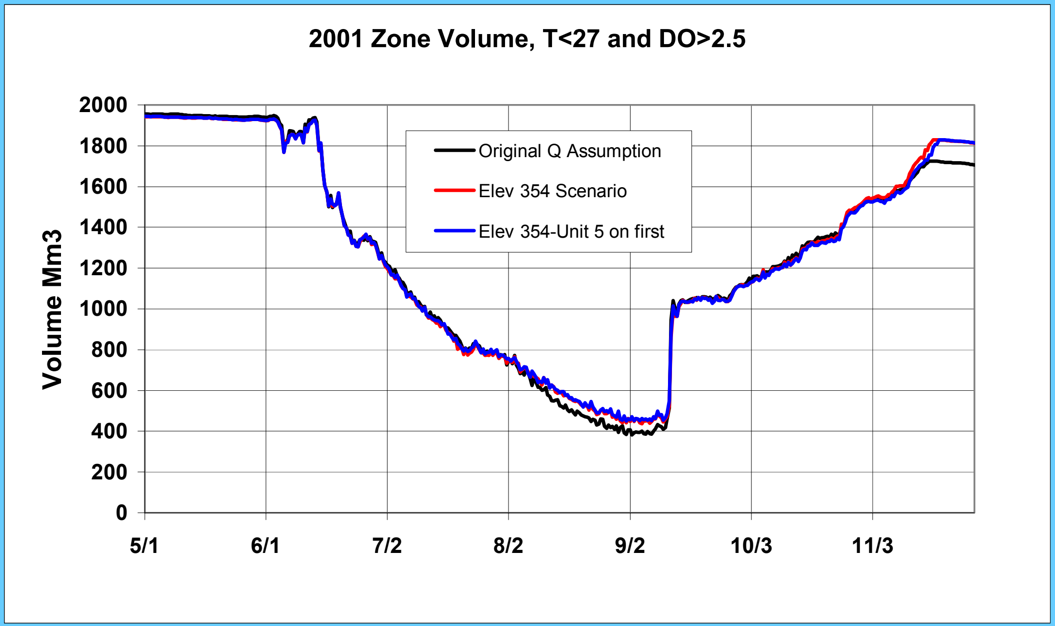
2000 Pool Level Management and Unit 5 on First

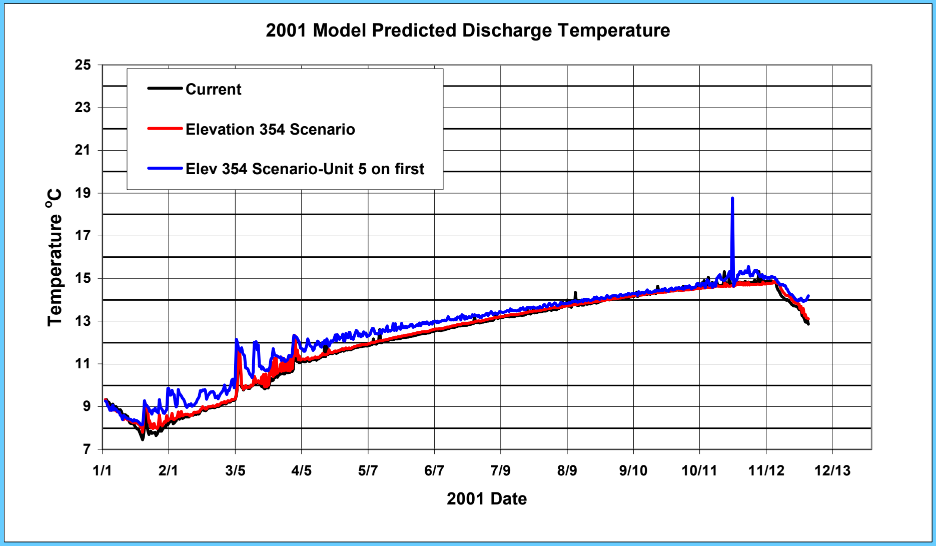


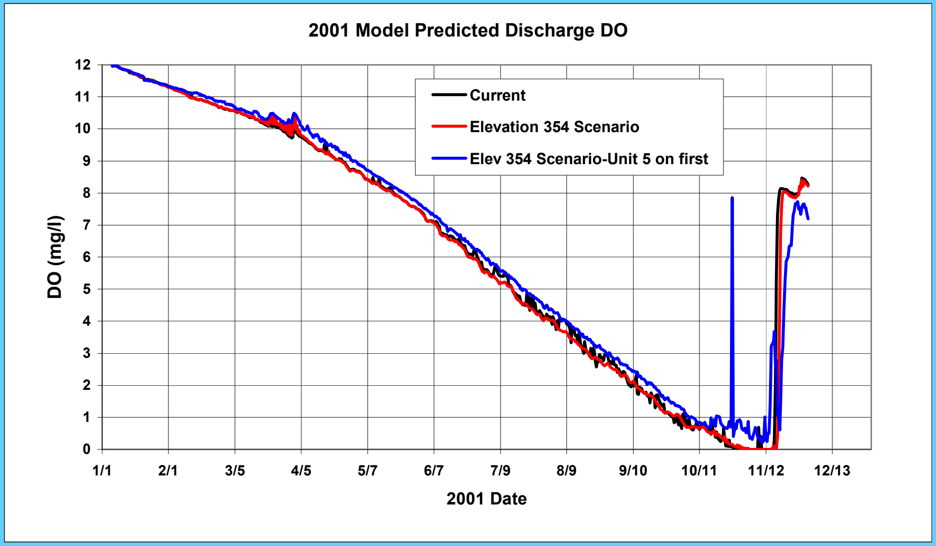




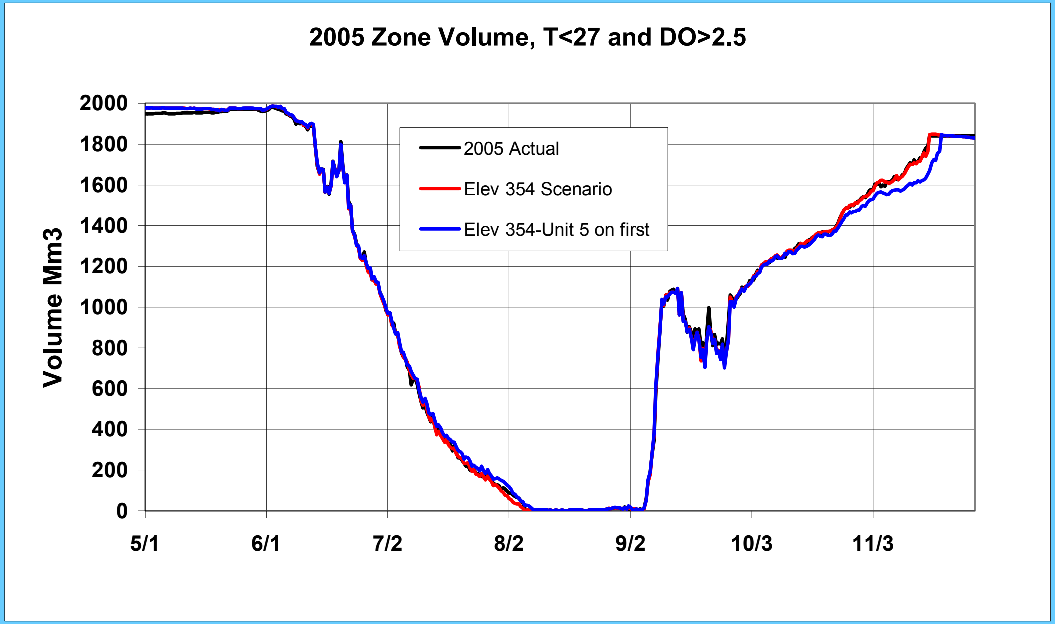
2001 Pool Level Management and Unit 5 on First

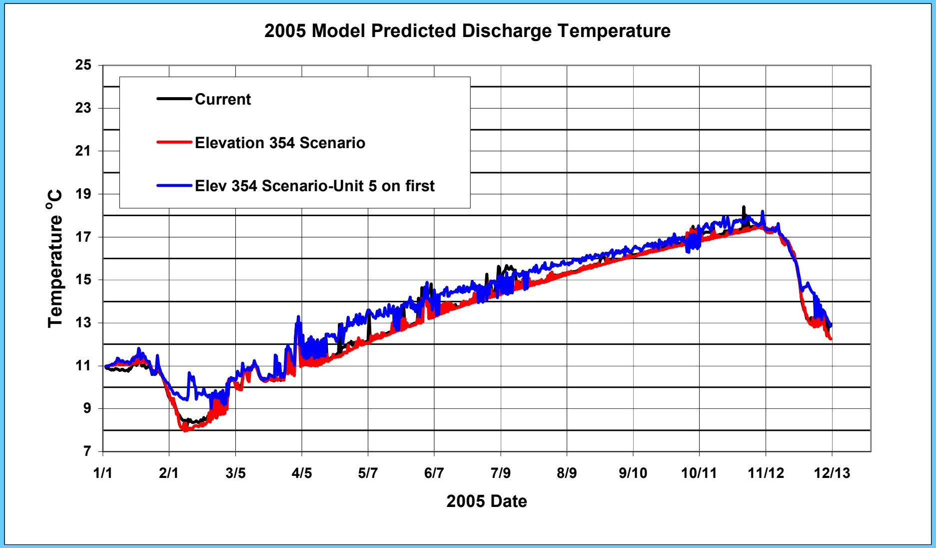


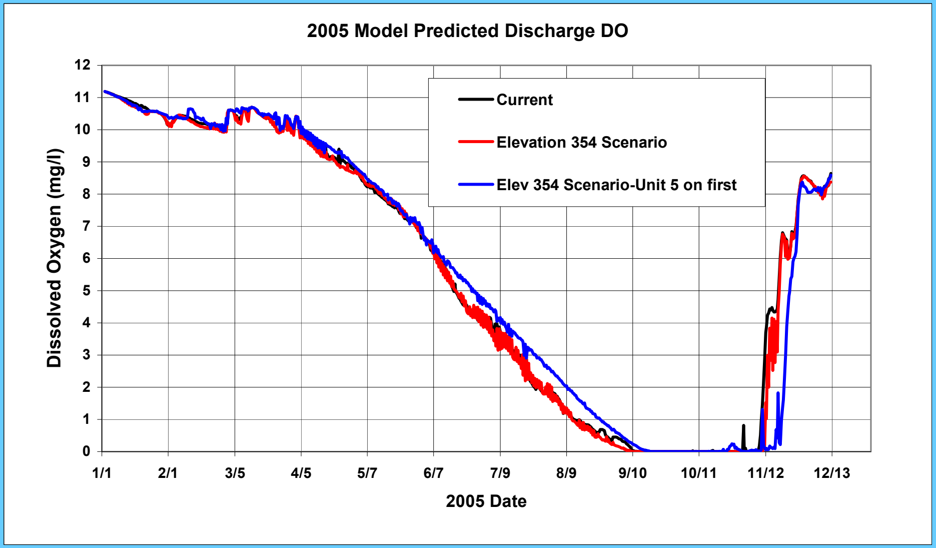




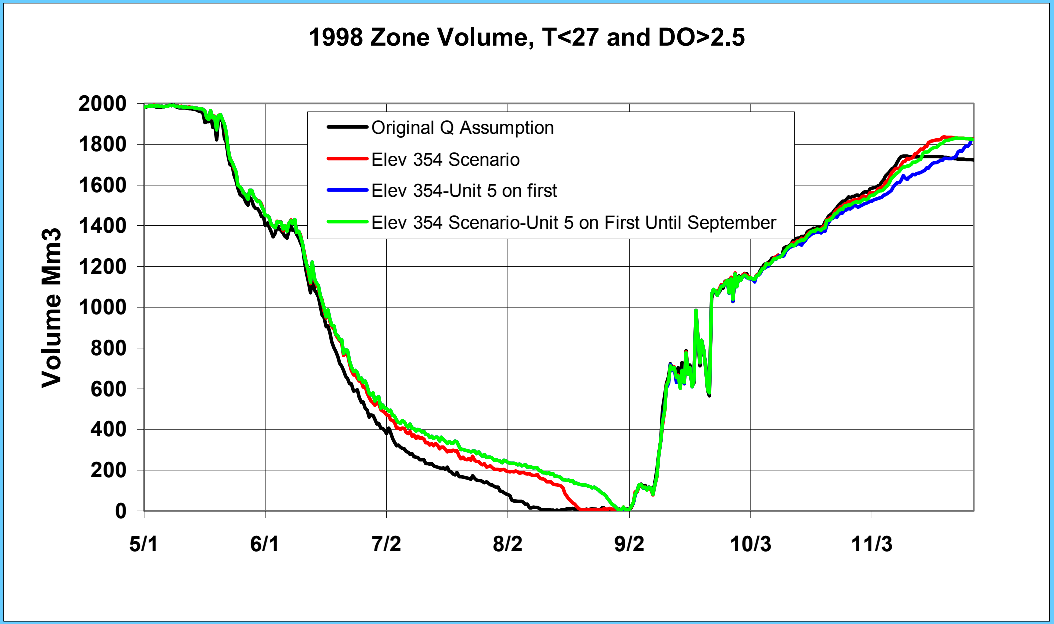
2005 Pool Level Management and Unit 5 on First

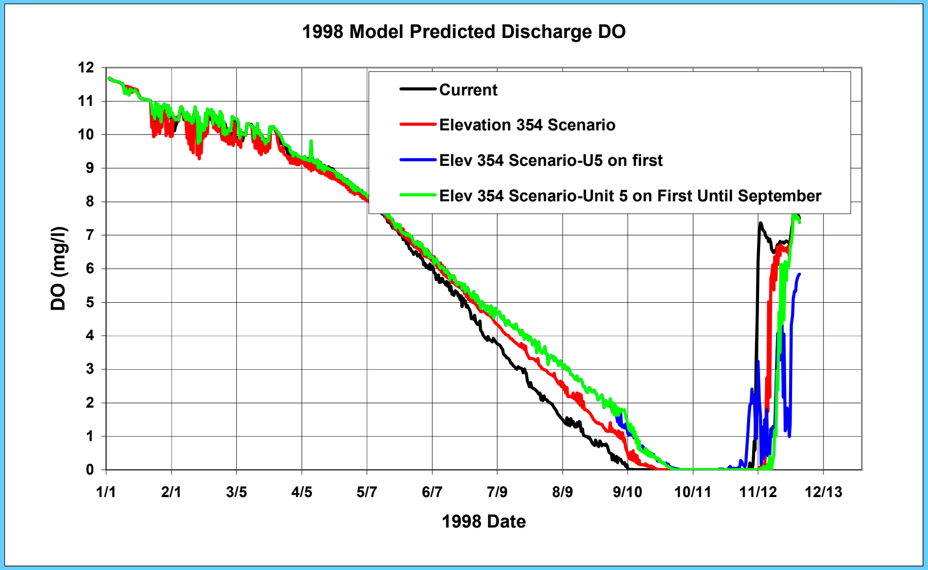


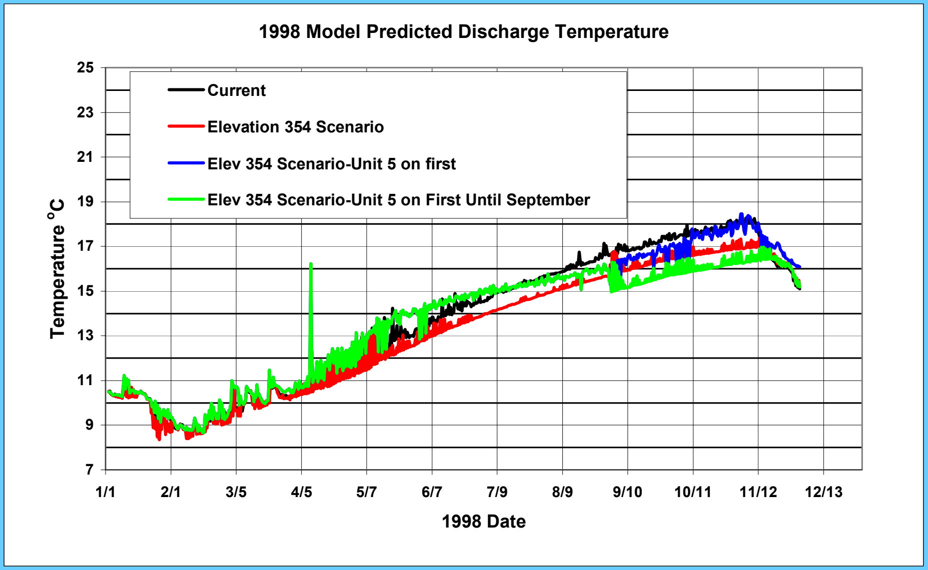




1998 Pool Level Management and Unit 5 on First Until September When the Bottom Units are used for the first 12,800 cfs







Conclusions

- Unit 5 preferential operations can improve striped bass habitat in some years.
- Maintaining the summer pool level at 358 increases striped bass habitat in some years.
- The combination of Unit 5 preferential operations and maintaining the summer pool level at 358 can further increase striped bass habitat in some years. It can also improve water quality in the releases.
- When the discharge temperature from Unit 5 reaches 15^{o} C, the minimum flow should be released through a bottom unit.
- Unit 5 operations after August or September do not effect striped bass habitat.

CE-QUAL-W2 Model Applications to Examine the Effects of Operations on Fish Habitat in Lake Murray

Meeting to Report on Preliminary Results

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May 22, 2007

Relicensing Issues Identified by the Water Quality Technical Working Committee

- The causes of striped bass fish kills reported in previous years, especially factors related to Saluda Hydro operations
- The effects of Unit 5 operations on entrainment of blue-back herring
- Determination of operational changes that might increase habitat for striped bass and blue-back herring
- Track any impacts that could occur to the tailwater cold-water fishery due to potential operational changes

Factors Considered in Addressing Relicensing Issues

- Annual flow regimes
- Pool level management
- Unit 5 operations
- In-lake and release water quality
- Habitat for striped bass and blue-back herring
- Water quality, meteorological, and operations data over the period 1990-2005
- Emphasis will be placed on section of reservoir from Blacks Bridge to Saluda Dam

Plan for Using CE-QUAL-W2 to Address the Water Quality TWC Relicensing Issues

1. Analyze water quality, meteorological, flow, and operations data for the period of study

2. Set up CE-QUAL-W2 for the years when major striped bass fish kills occurred as well as other years

3. Run models to identify the causes that apparently contributed to the fish kills

4. Use the models to explore ways to avoid such fish kills in the future, with emphasis on project operations

Preliminary Findings

- High flow, especially during March-August, is the primary cause for fish kills

- Higher flows cause the bottom of the lake to warm which in turn increases the rate of DO depletion

- Meteorological conditions can affect striper habitat

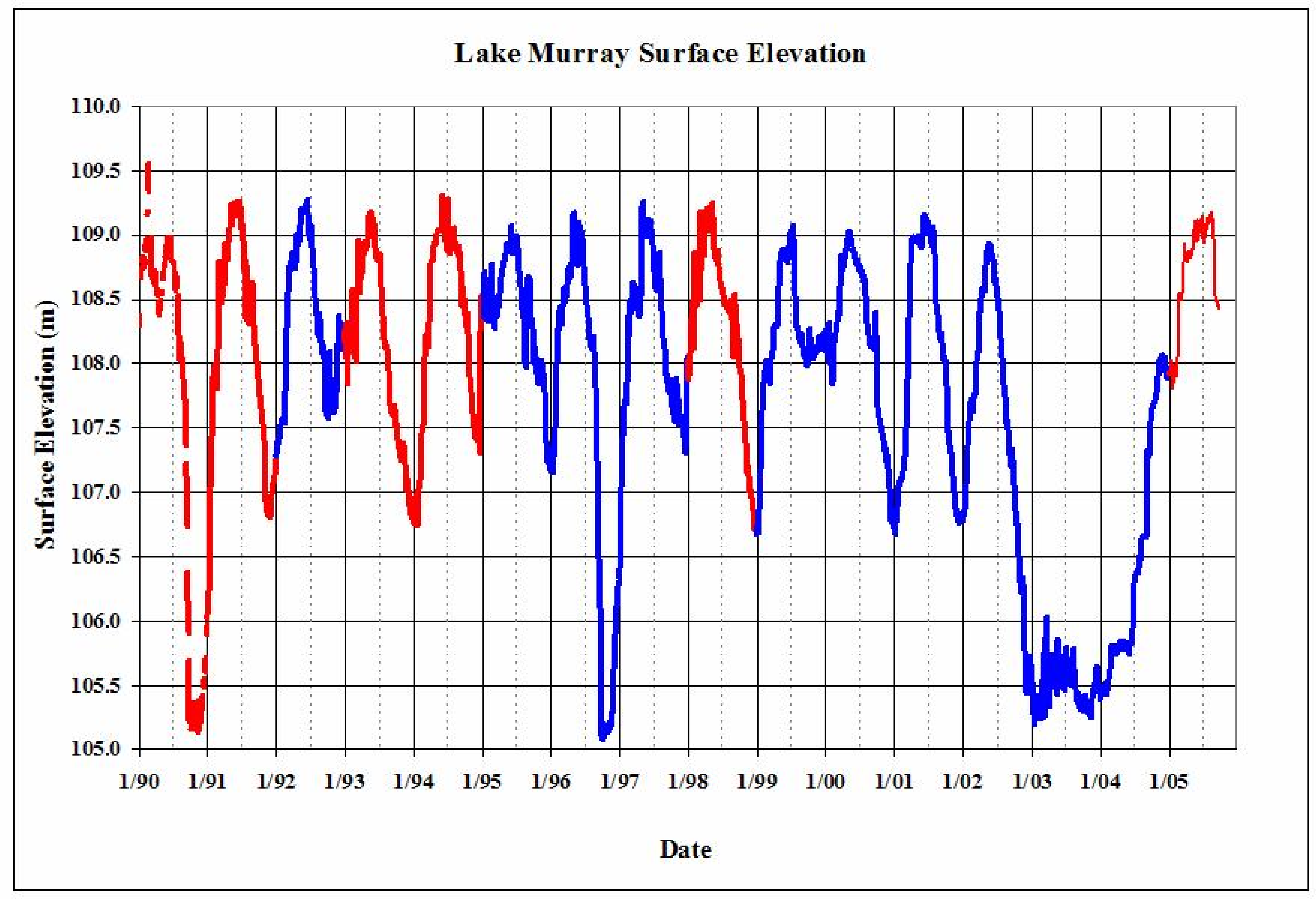
- Model results indicate that the temperature and DO range of tolerable striper habitat in Lake Murray is approximately:

$$T < 27^{o}C \text{ and } DO > 2.5 \text{ mg/l}$$

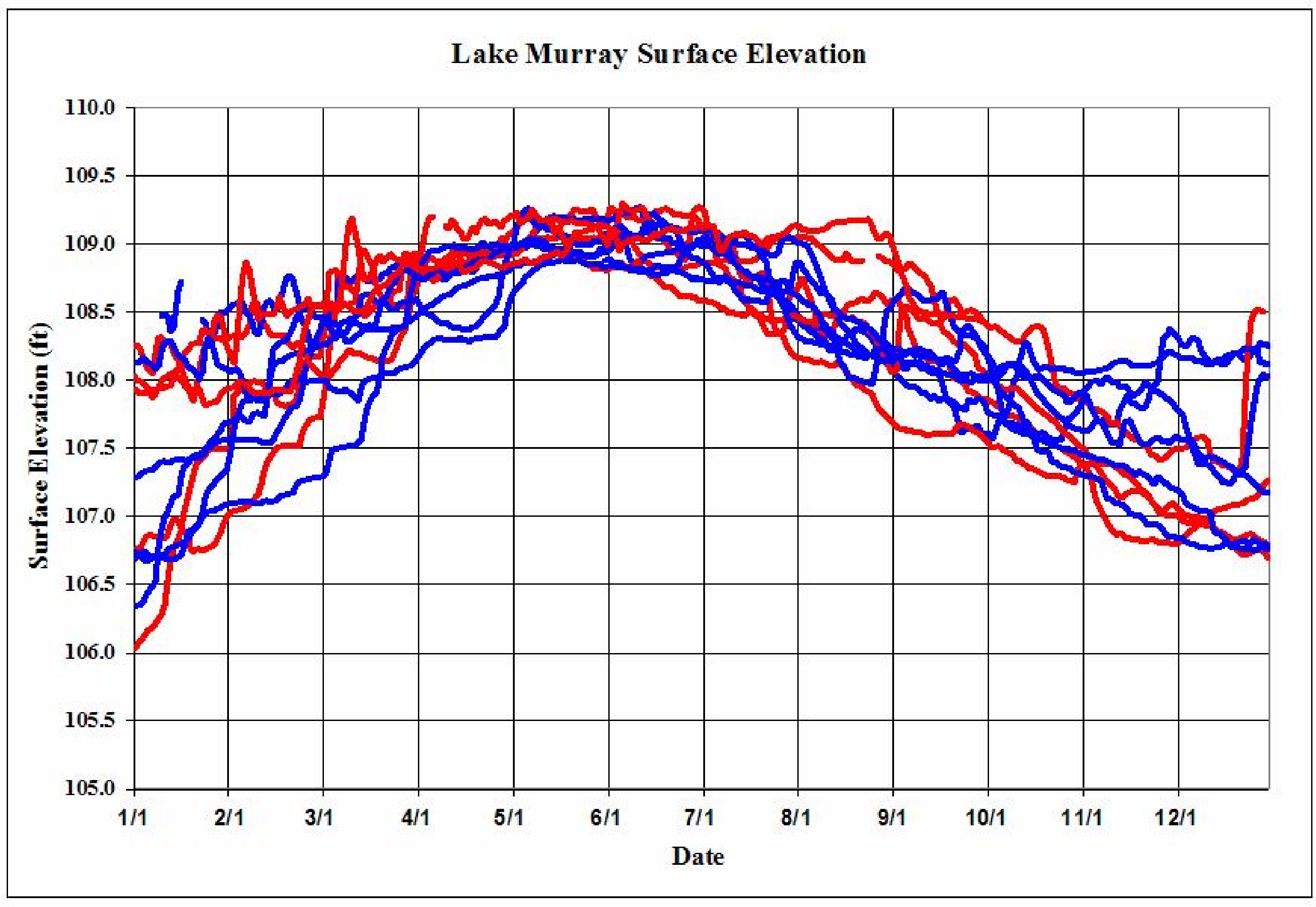
- Preferential use of Unit 5 helps preserve colder bottom water and was predicted to improve DO and increase striper habitat

Lake Murray Surface Elevation 1990-2005

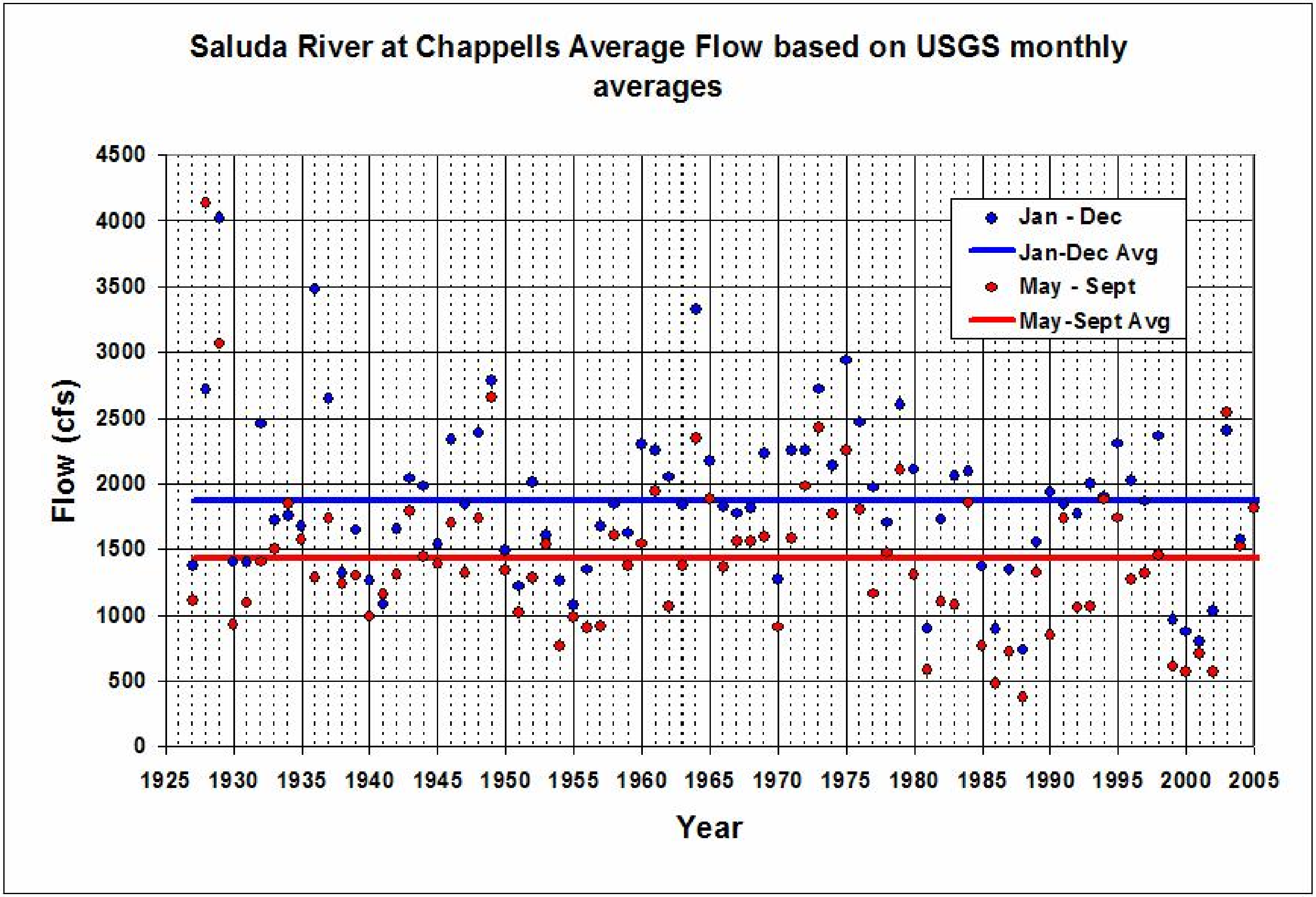
Years with documented striped bass kills are red



Lake Murray Surface Elevation 1990-2005
Typical Years Only (no special drawdowns)
Years with documented striped bass kills are red

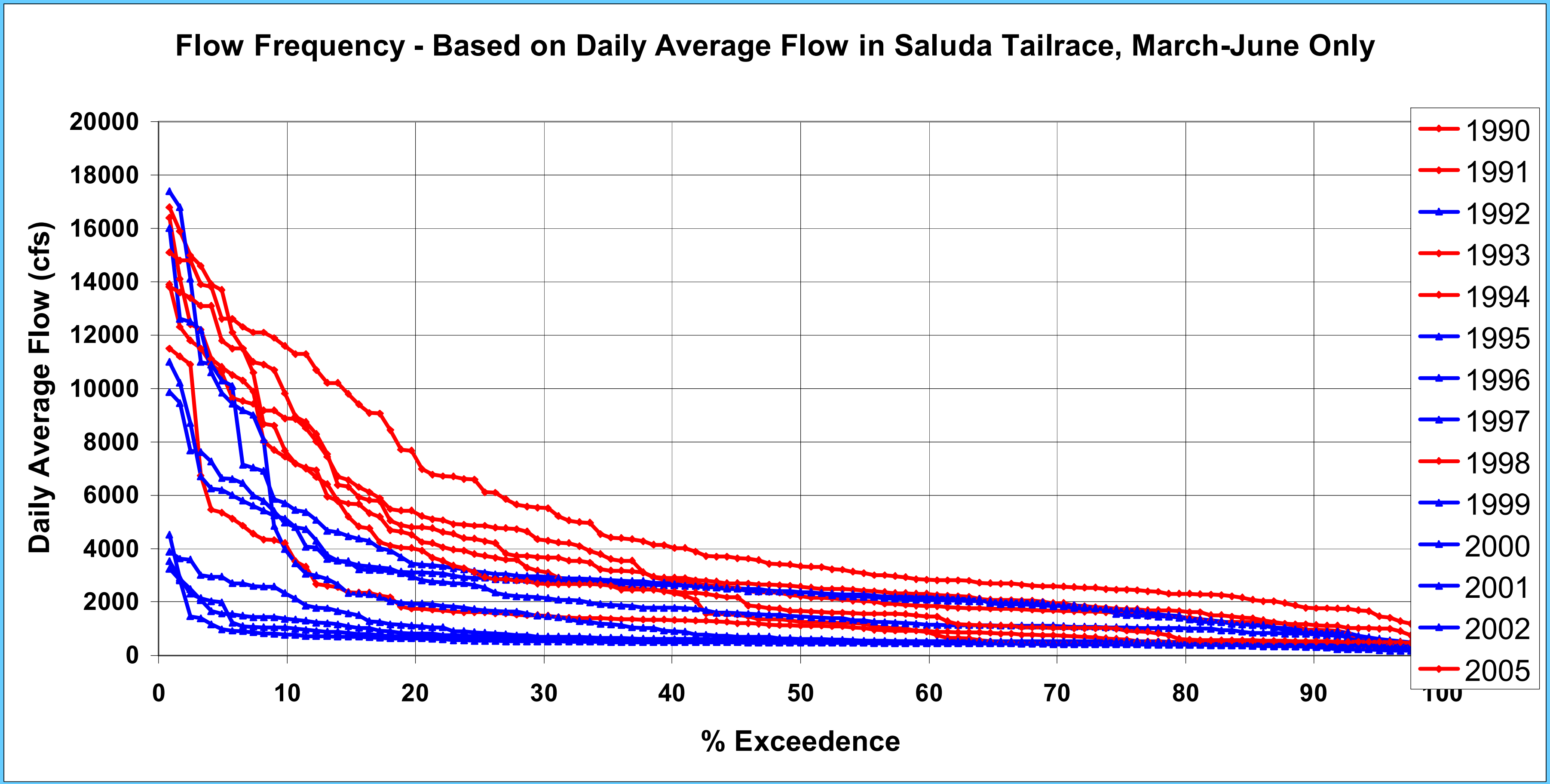


Average Annual Flow – Saluda River at Chappells



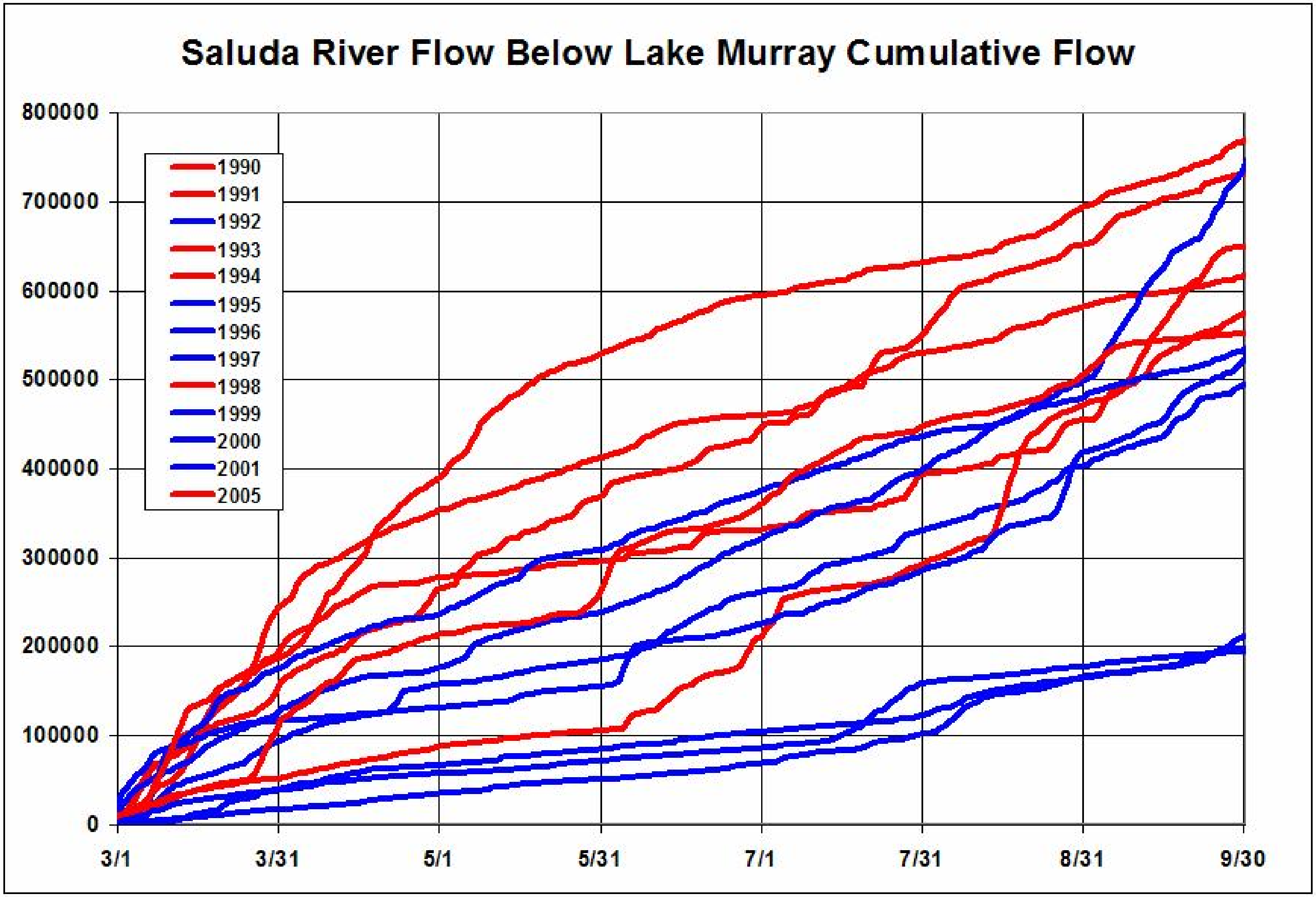
Excel Table with Monthly Average Flow Below Saluda

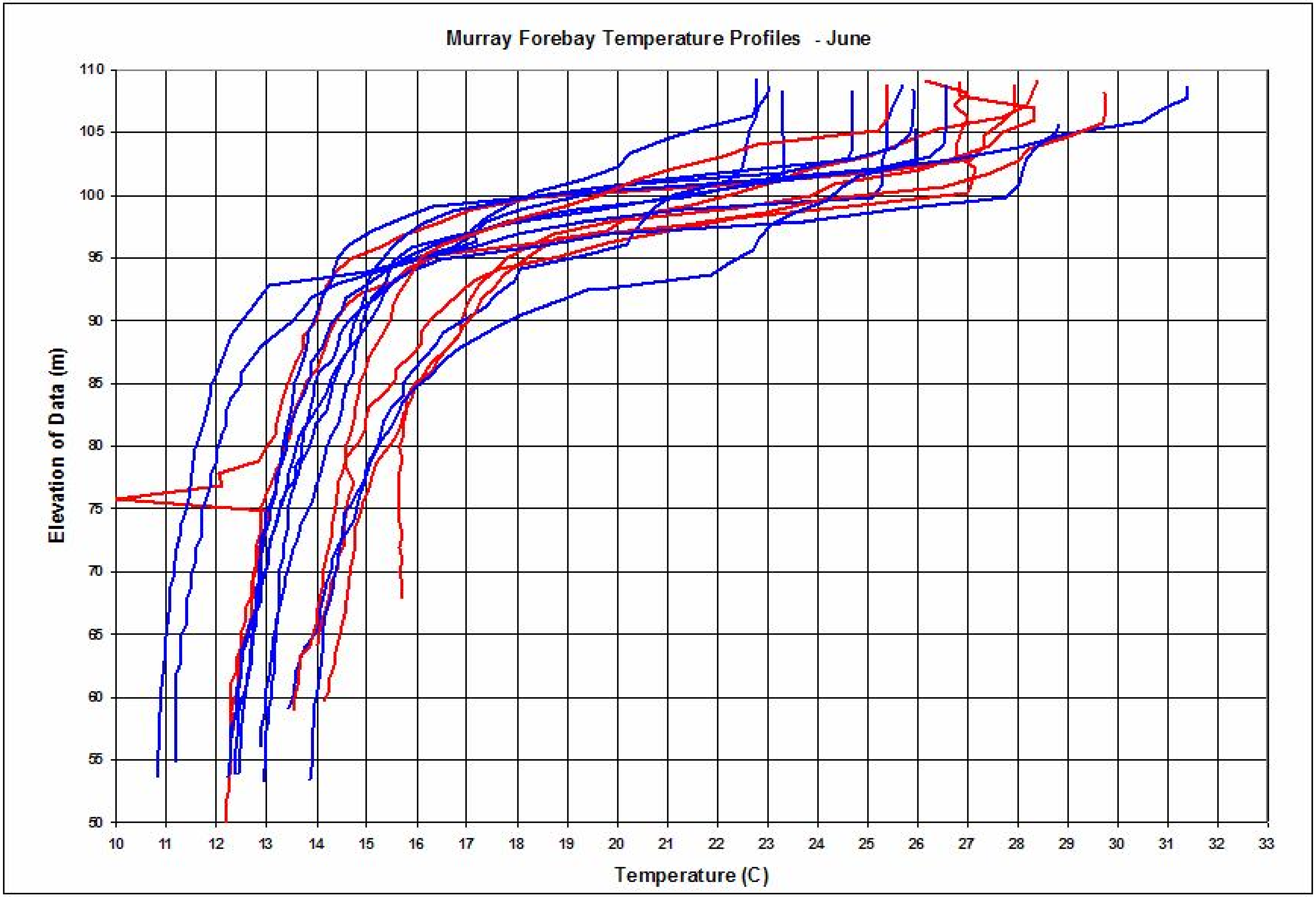
Flow Frequency – Saluda River Below Lake Murray



Cumulative Outflow – March-December

Years with documented striped bass kills are red





Murray Forebay Temperature Profiles - June
Elevation of Data (m)
Temperature (C)
110
105
100
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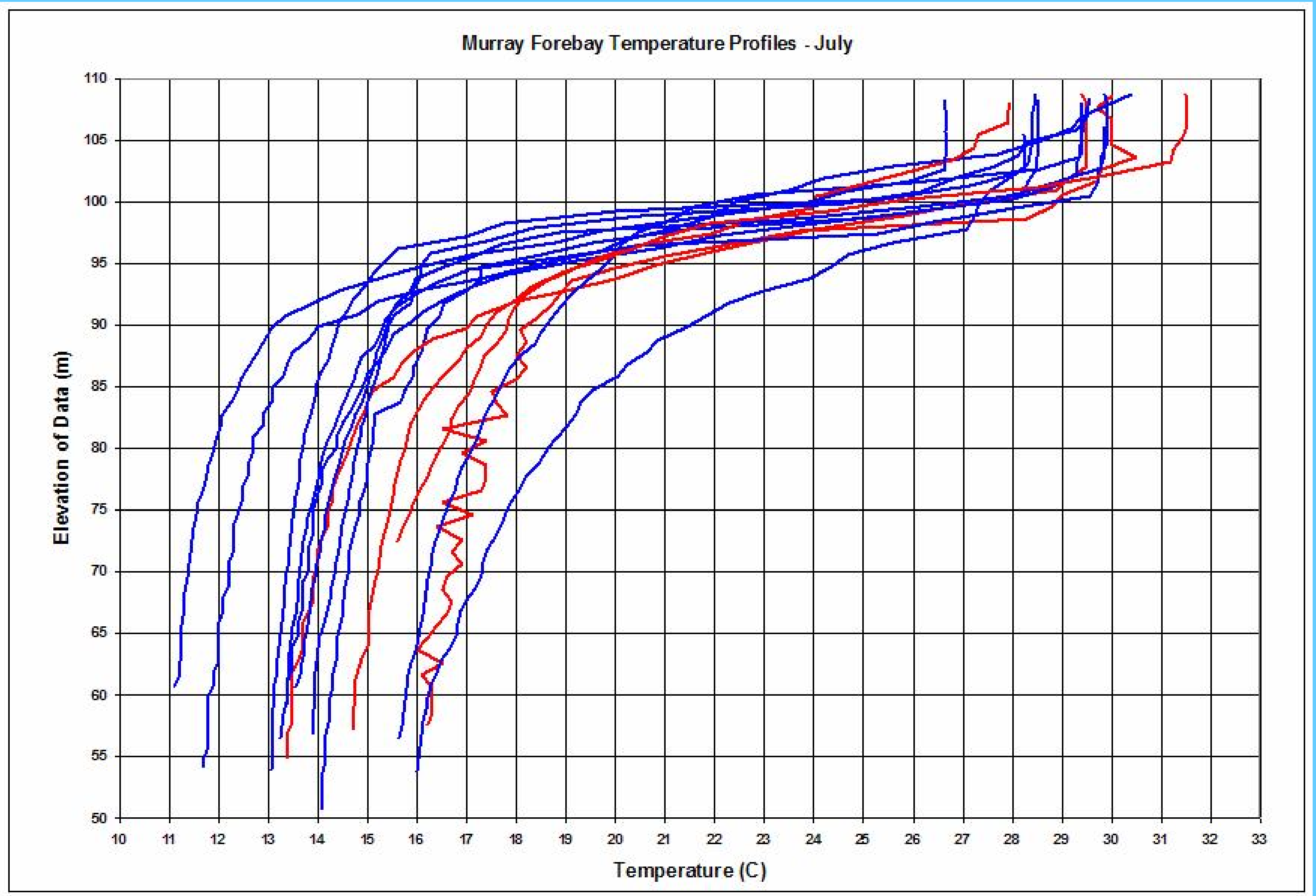
Murray Forebay Temperature Profiles - July
Elevation of Data (m)
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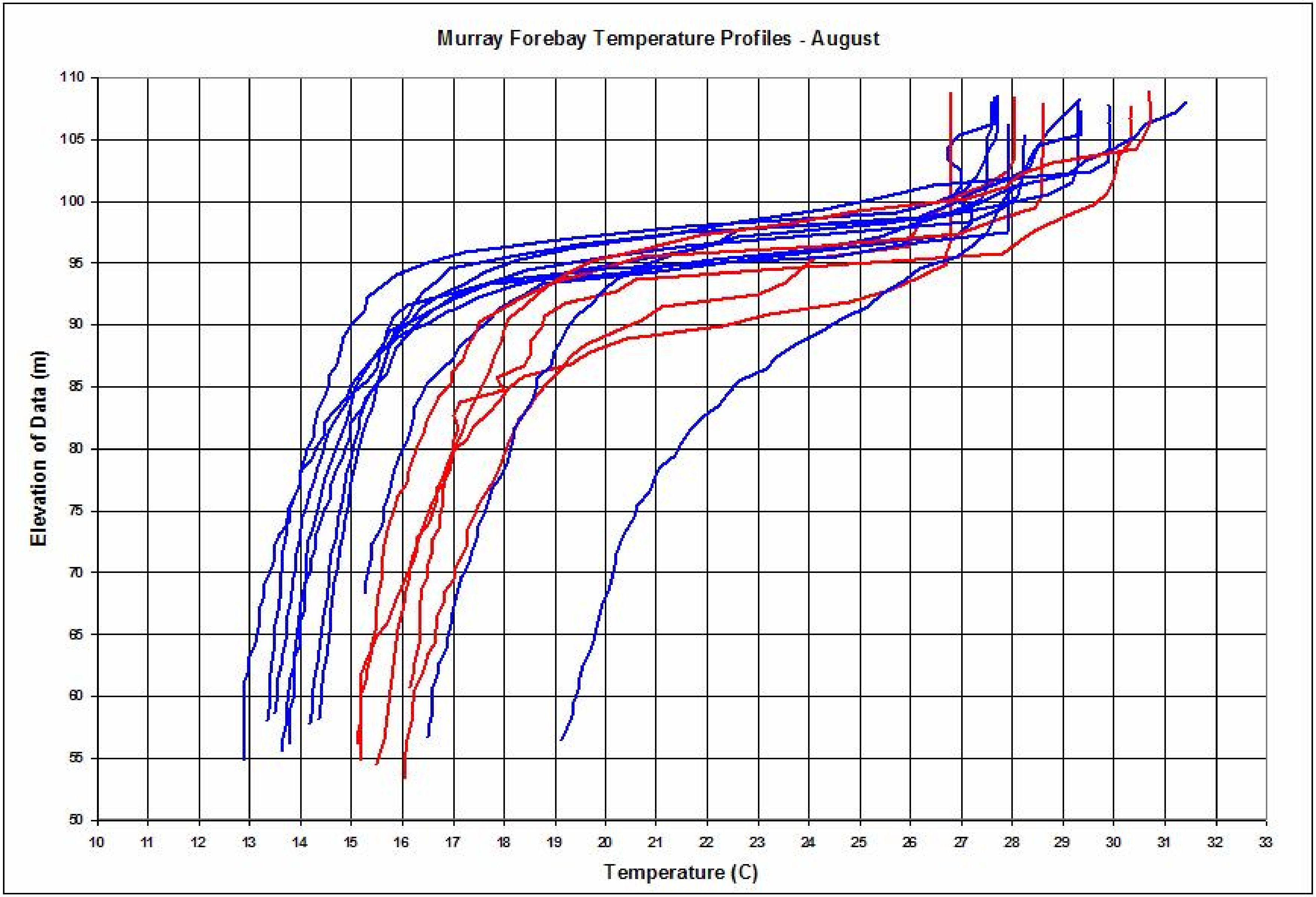
Temperature (C)



Murray Forebay Temperature Profiles - August
Elevation of Data (m)
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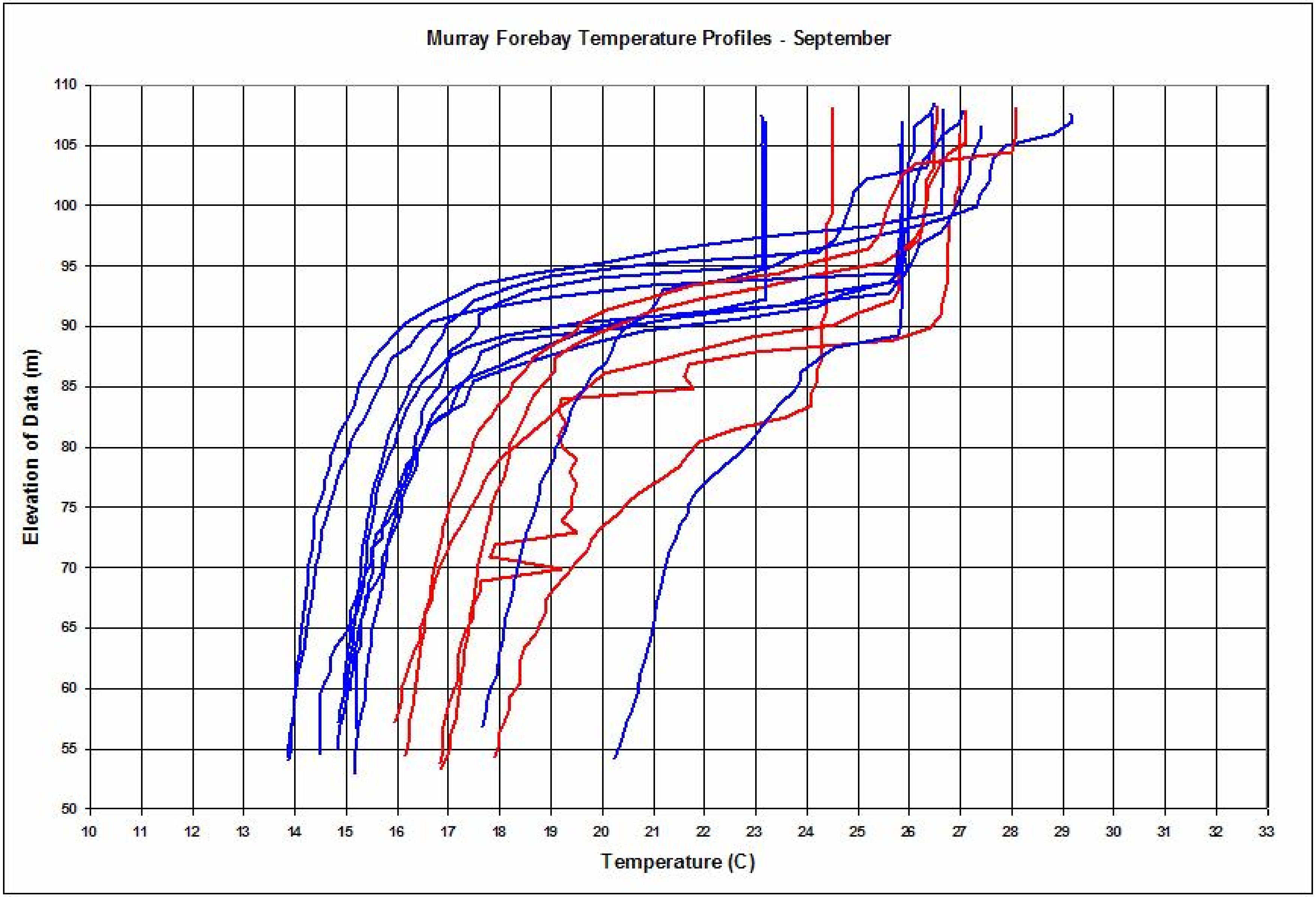
Temperature (C)



Murray Forebay Temperature Profiles - September
Elevation of Data (m)
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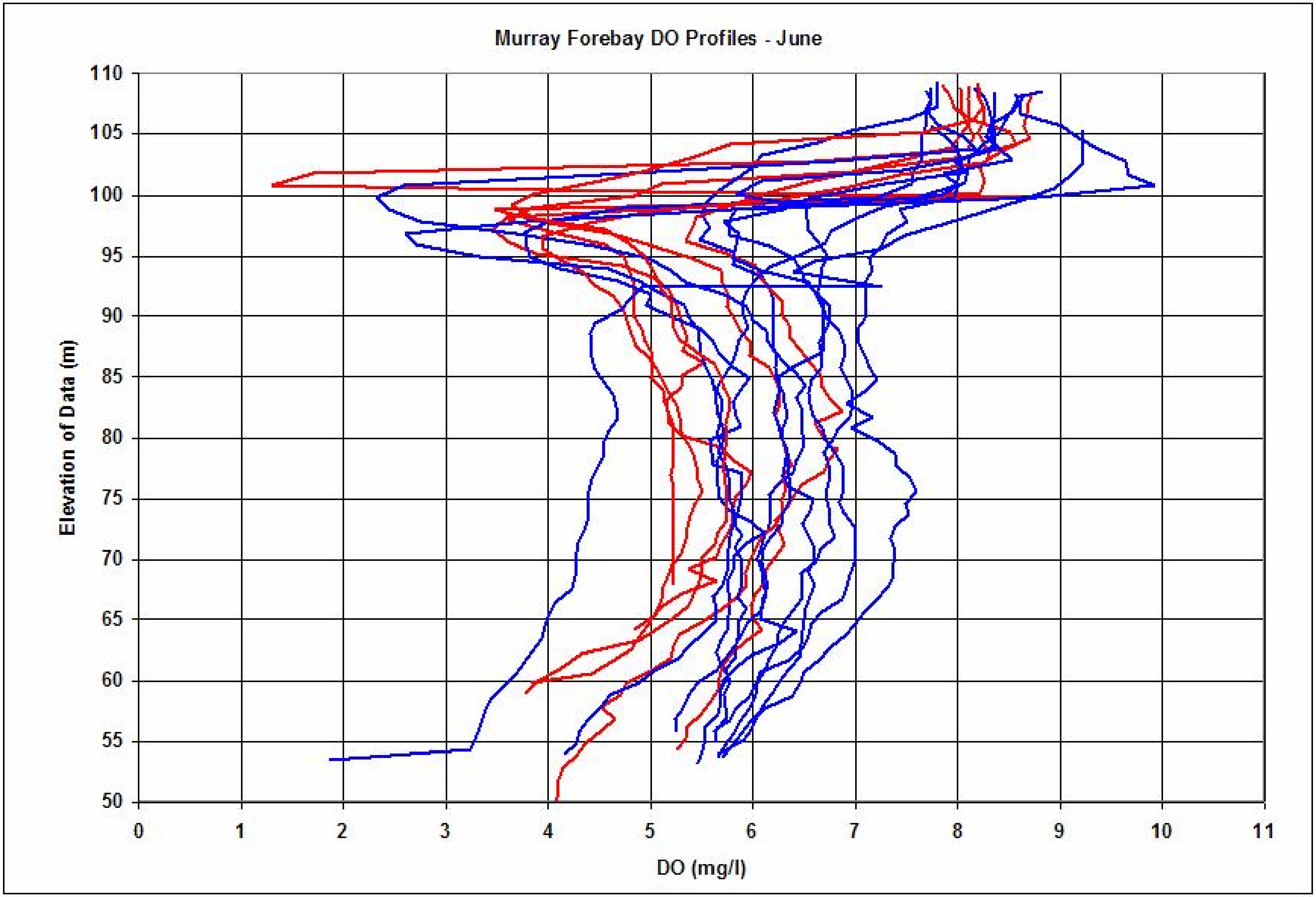
Temperature (C)


Murray Forebay DO Profiles - June
Elevation of Data (m)
DO (mg/l)
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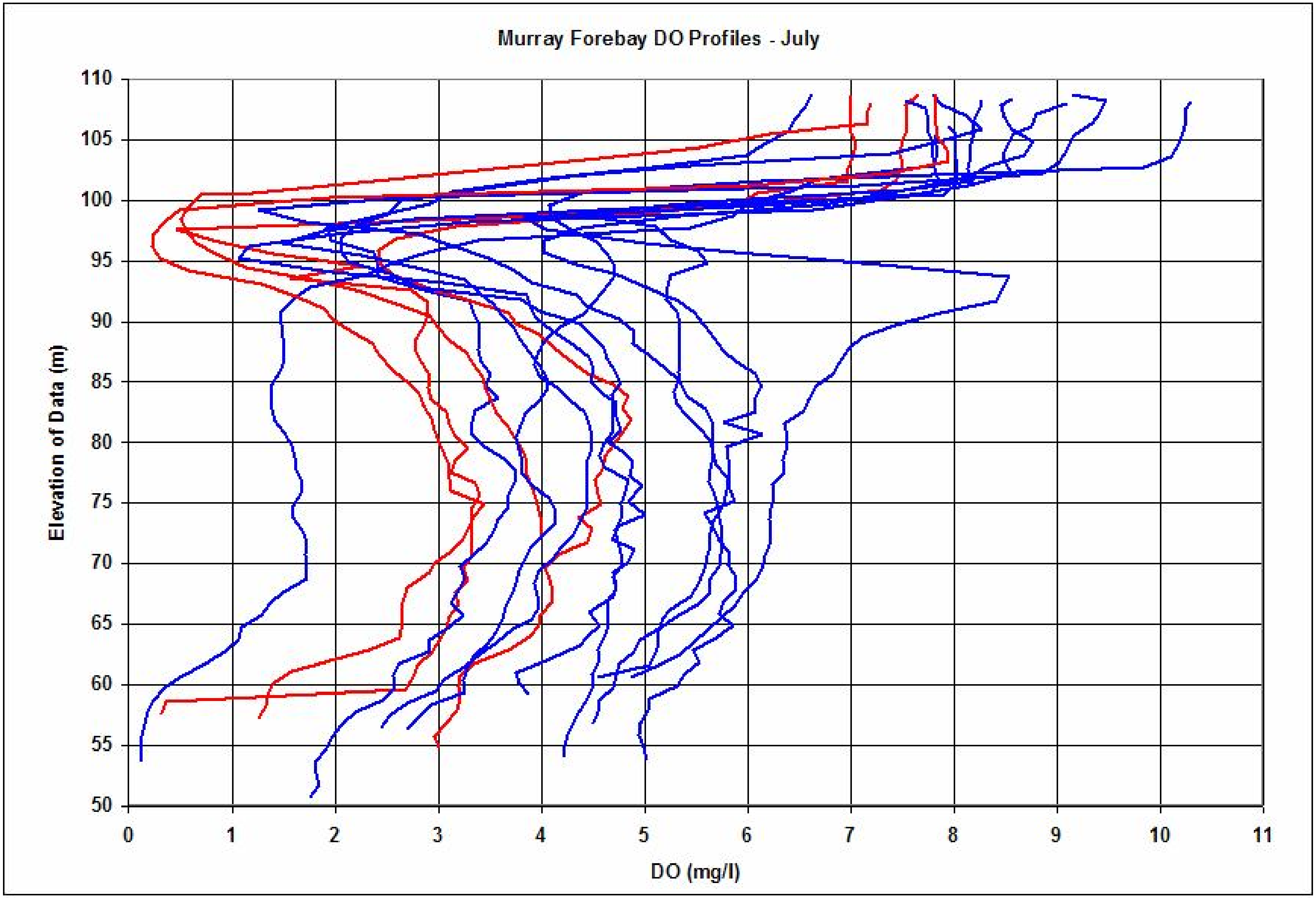

Murray Forebay DO Profiles - July
Elevation of Data (m)
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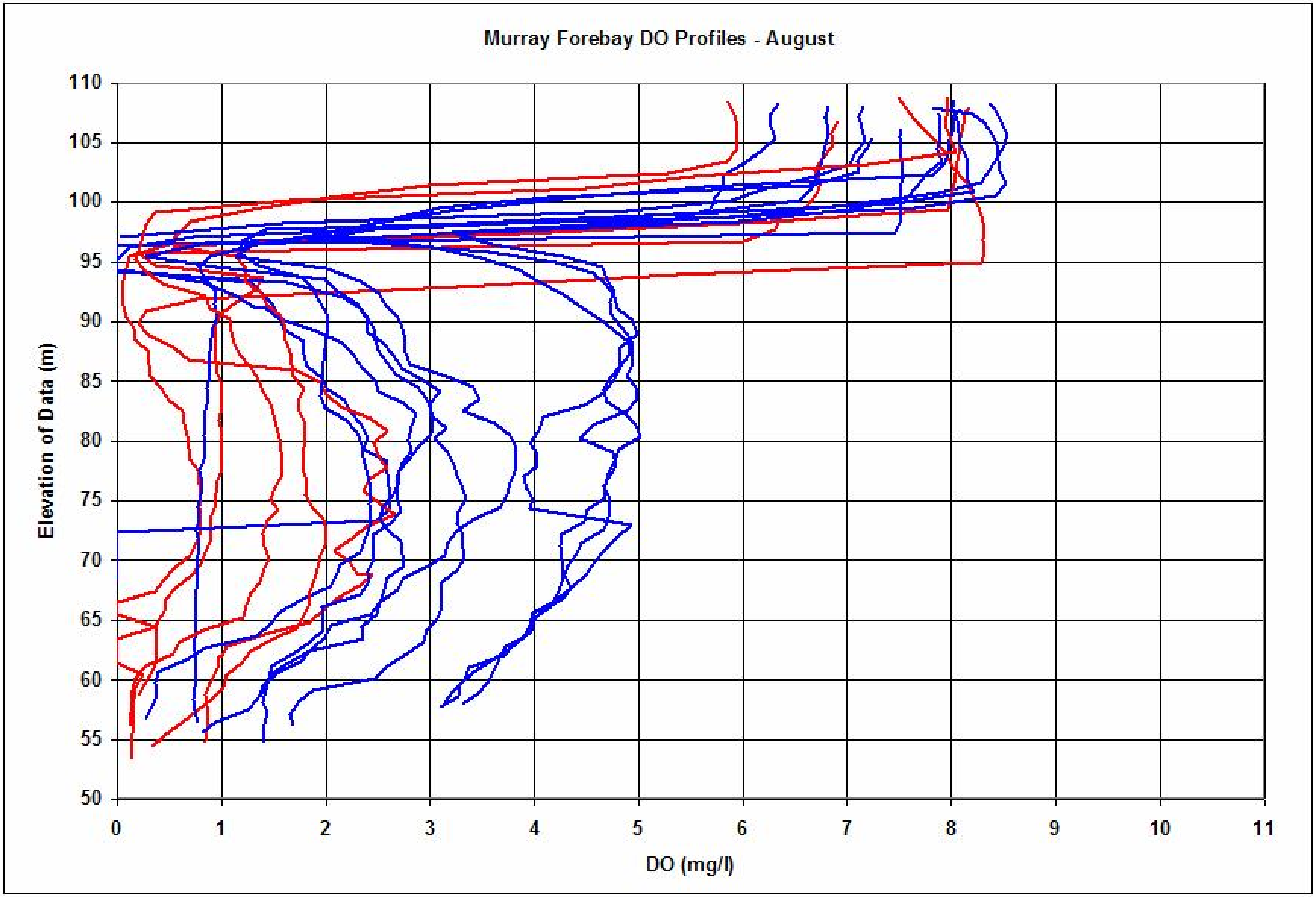
DO (mg/l)



Murray Forebay DO Profiles - August
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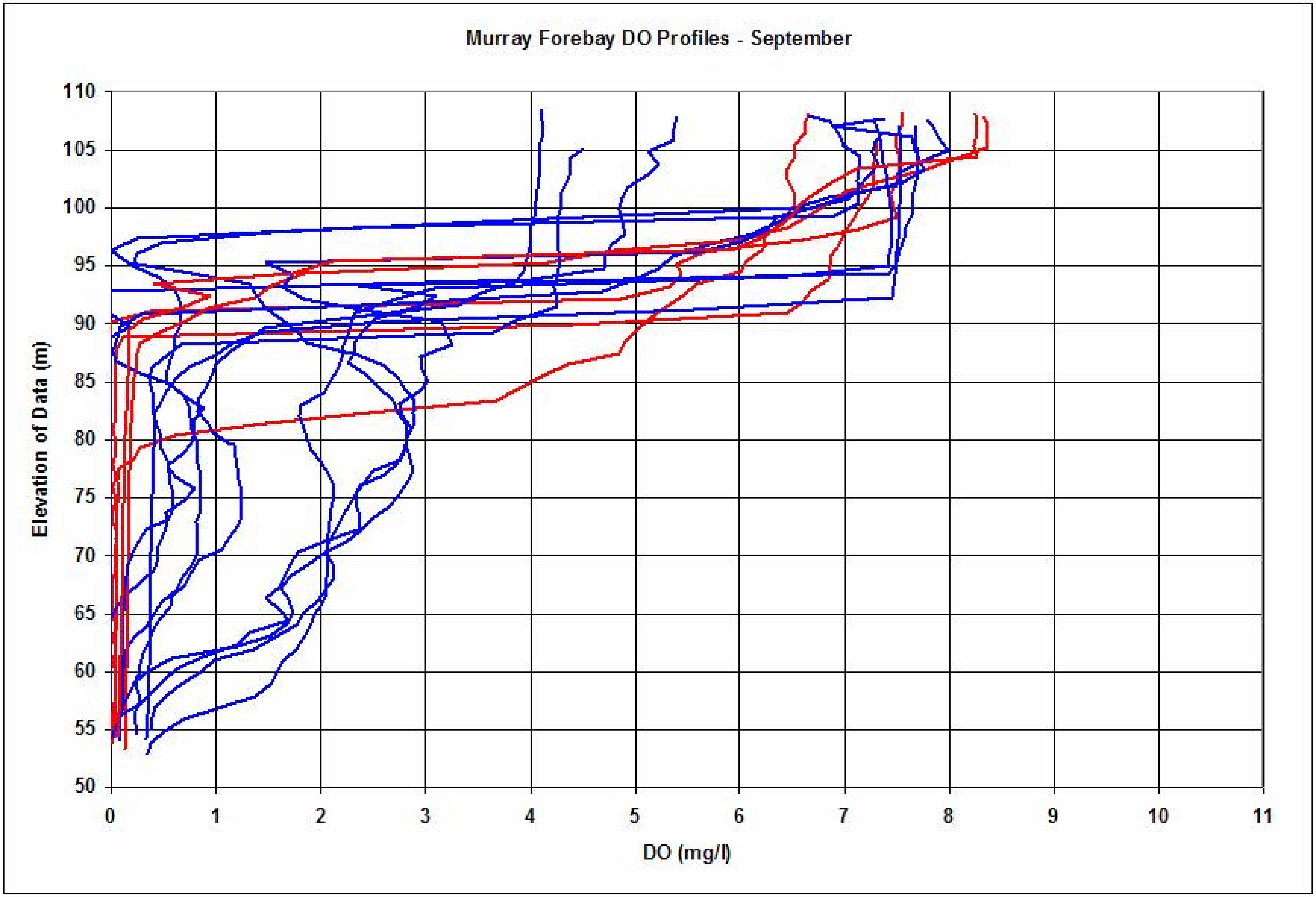
Elevation of Data (m)
DO (mg/l)



Murray Forebay DO Profiles - September
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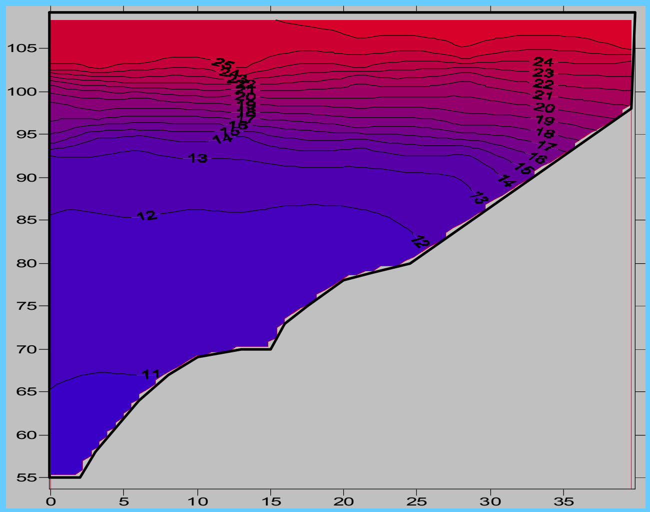
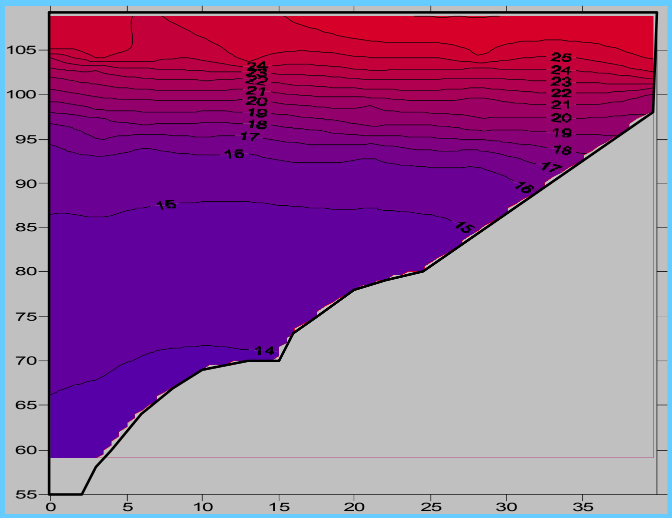
Lake Murray Contour Plots

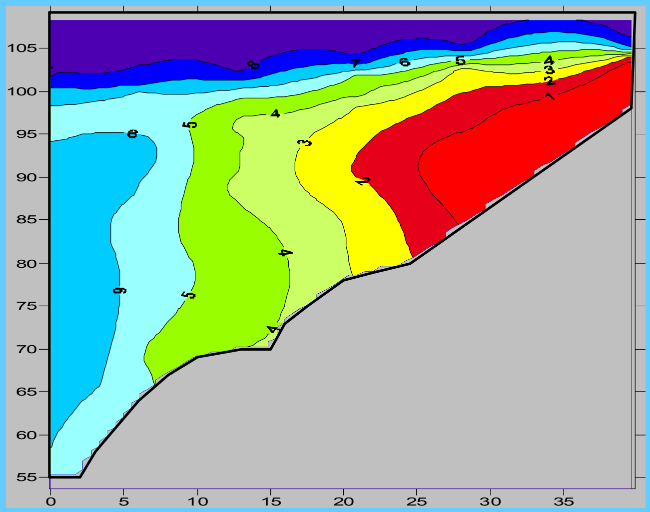
June 2002 Temperature



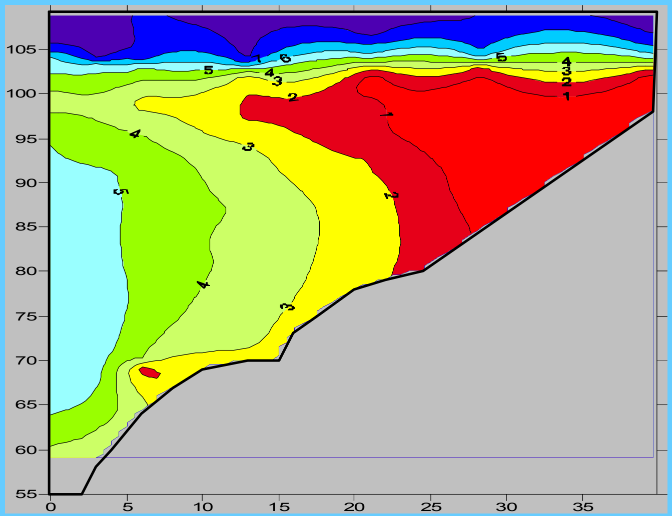
June 2005 Temperature



June 2002 DO

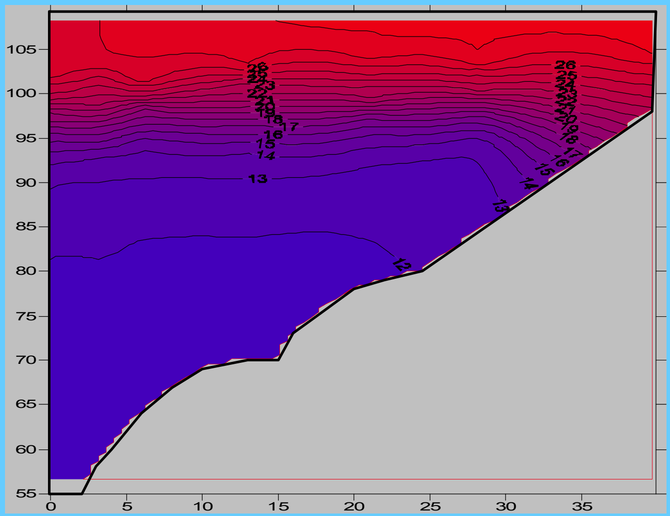


June 2005 DO

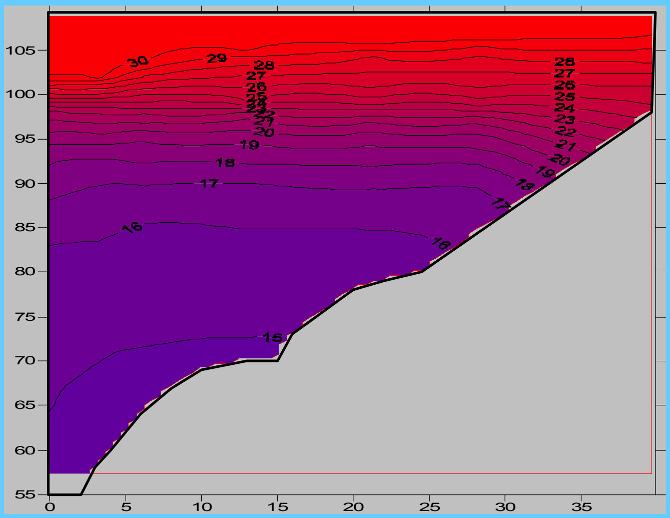


Lake Murray Contour Plots

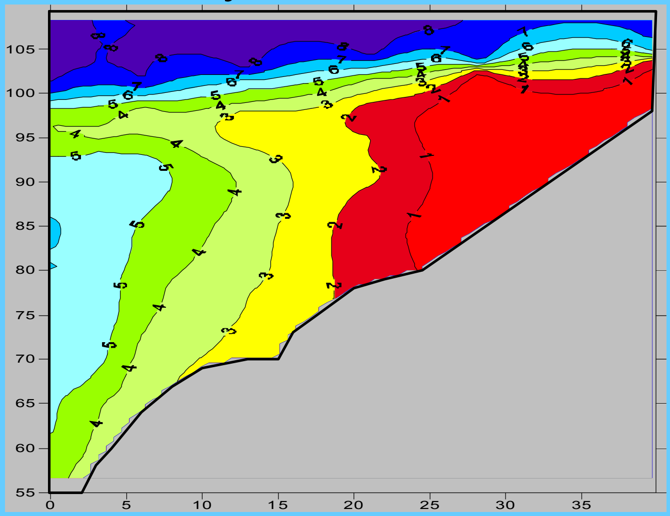
July 2002 Temperature



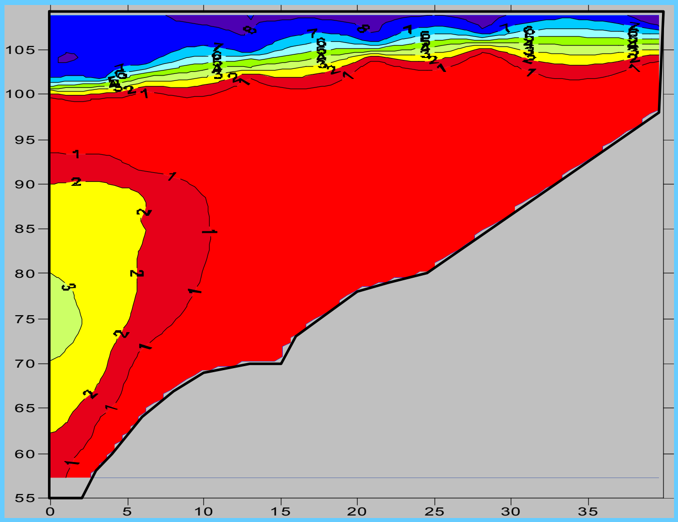
July 2005 Temperature



July 2002 DO

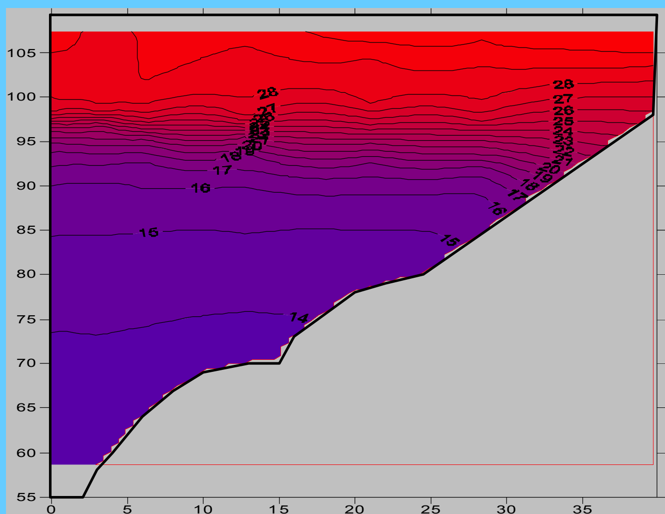


July 2005 DO

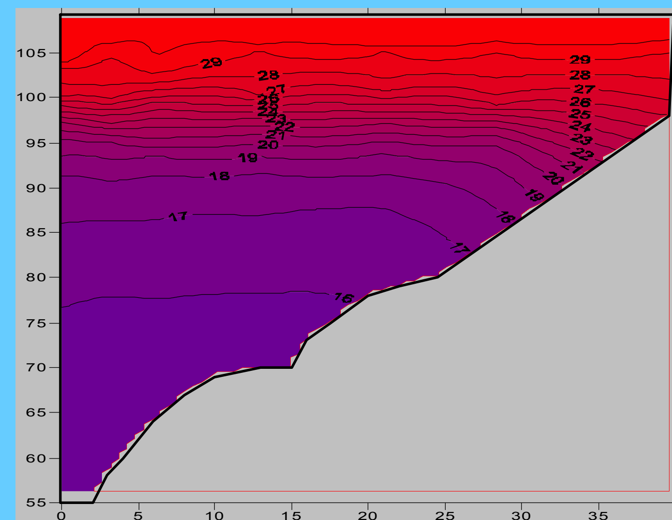


Lake Murray Contour Plots

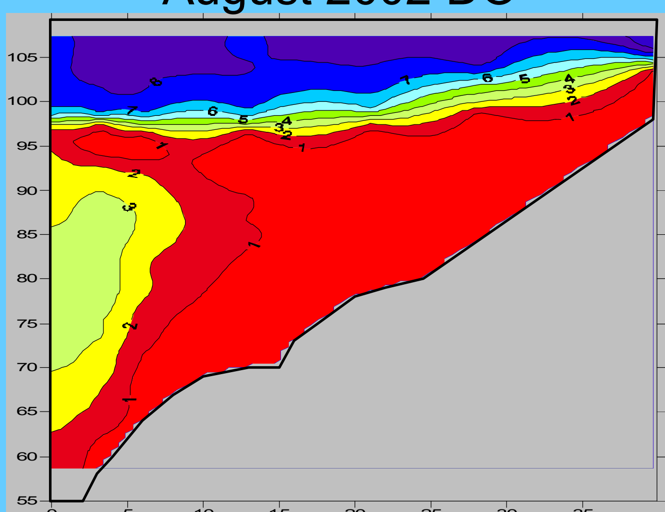
August 2002 Temperature



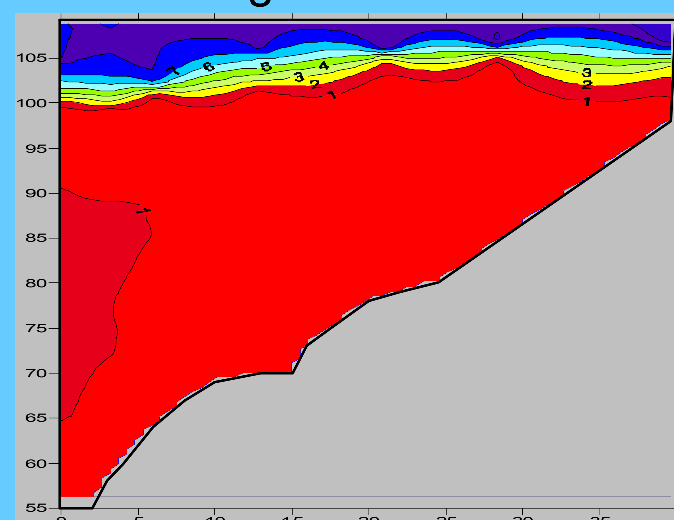
August 2005 Temperature



August 2002 DO

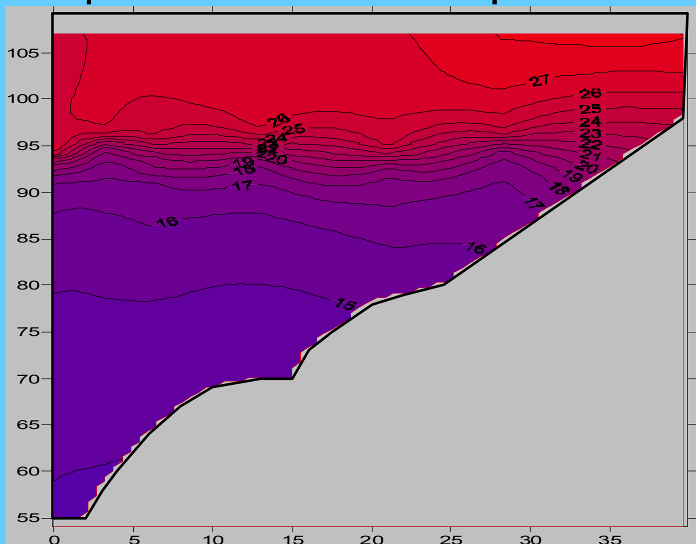


August 2005 DO

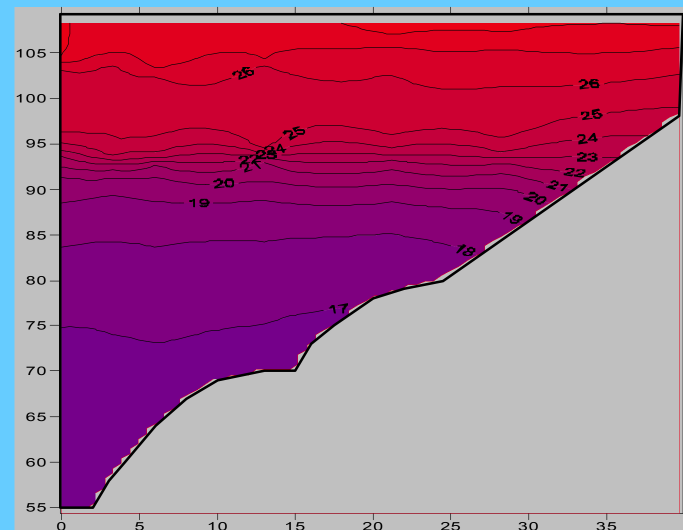


Lake Murray Contour Plots

September 2002 Temperature



September 2005 Temperature



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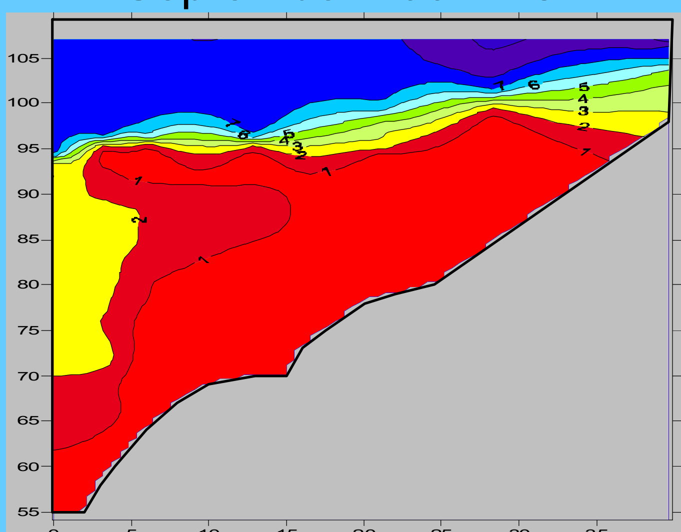
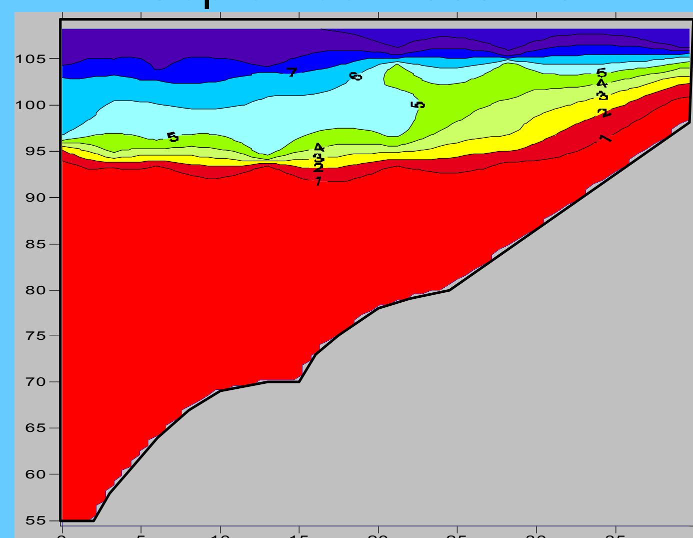


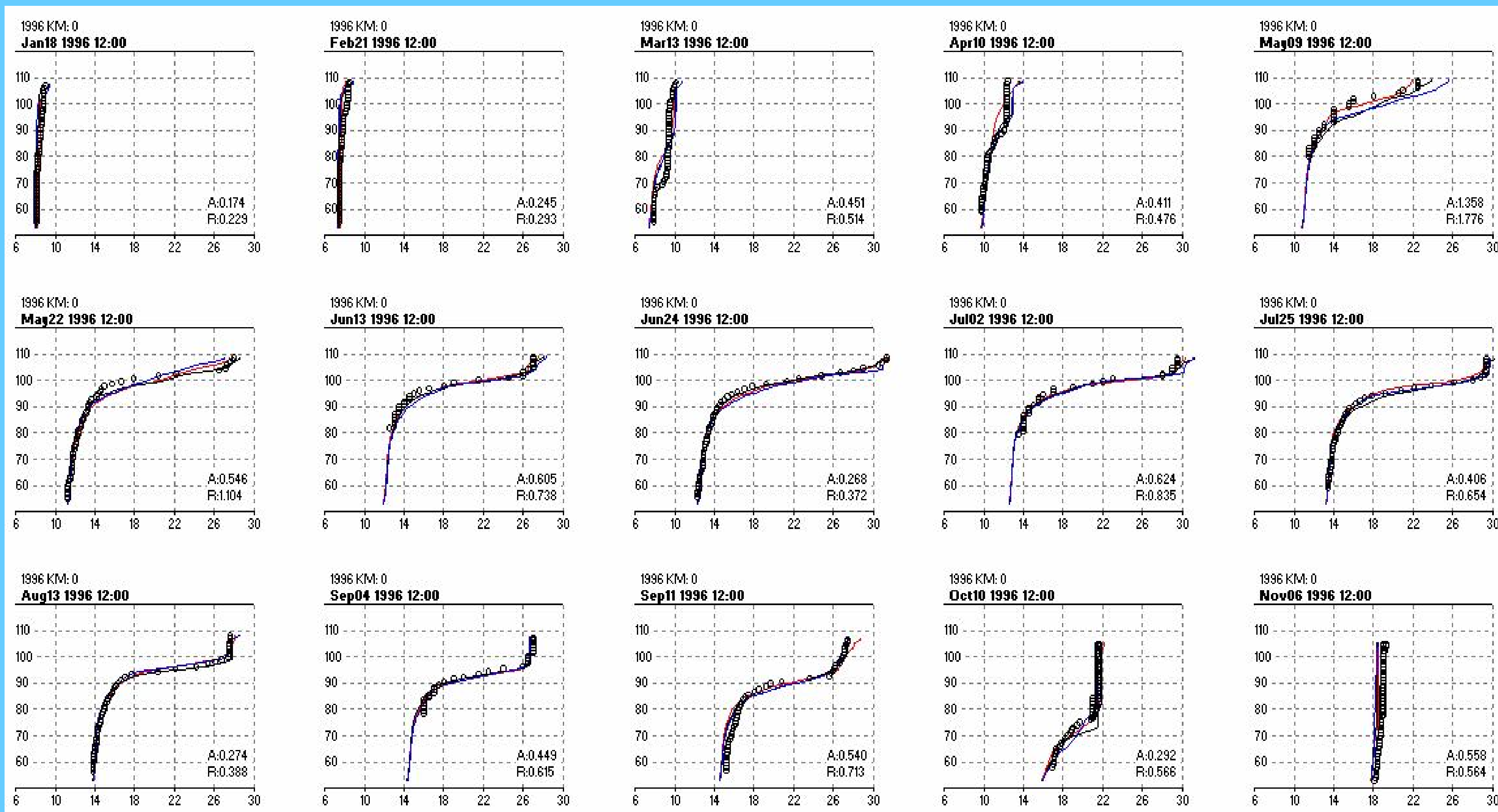
September 2005 DO



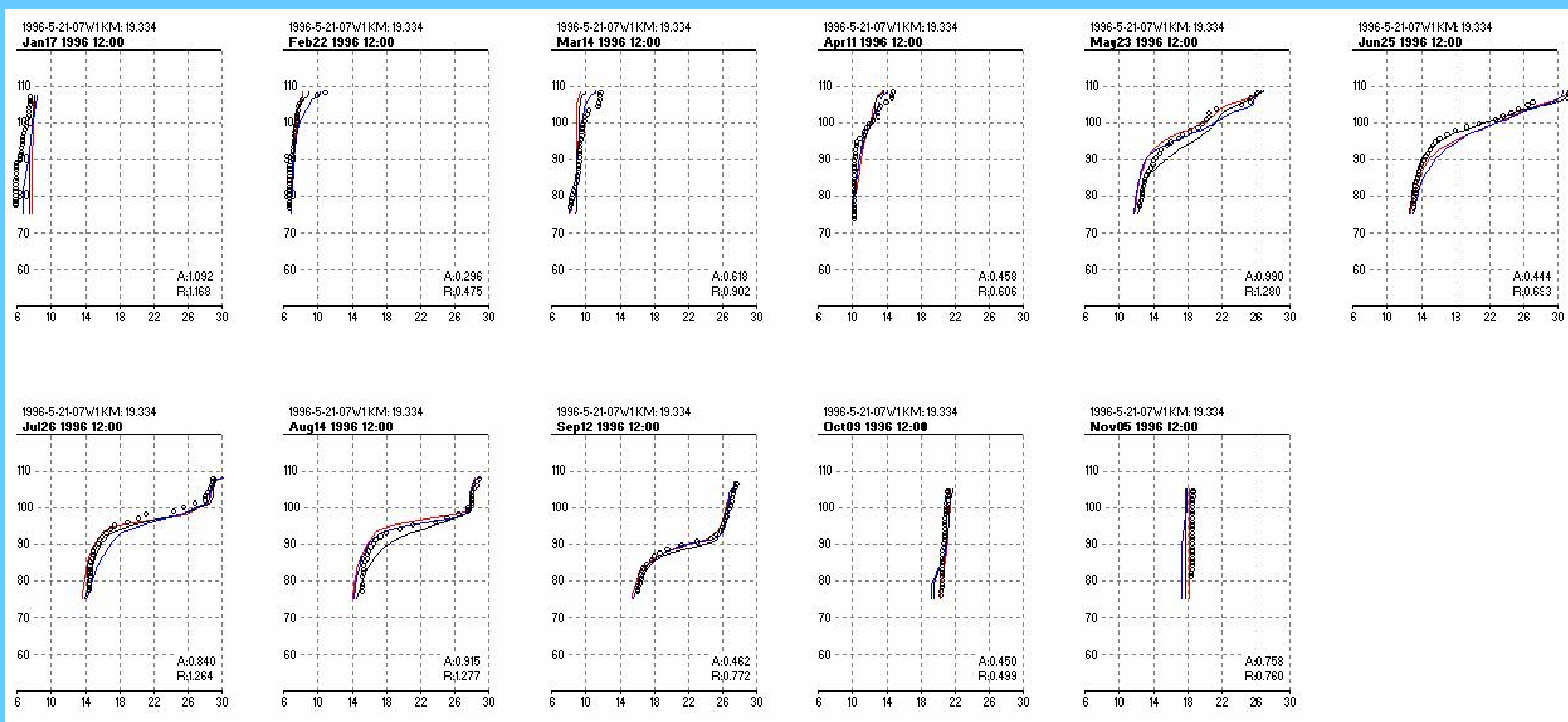
Model Calibration

- Model was originally calibrated to 3 years: 1992, 1996 and 1997
- Model SOD was adjusted in each of the 3 years to improve DO calibration

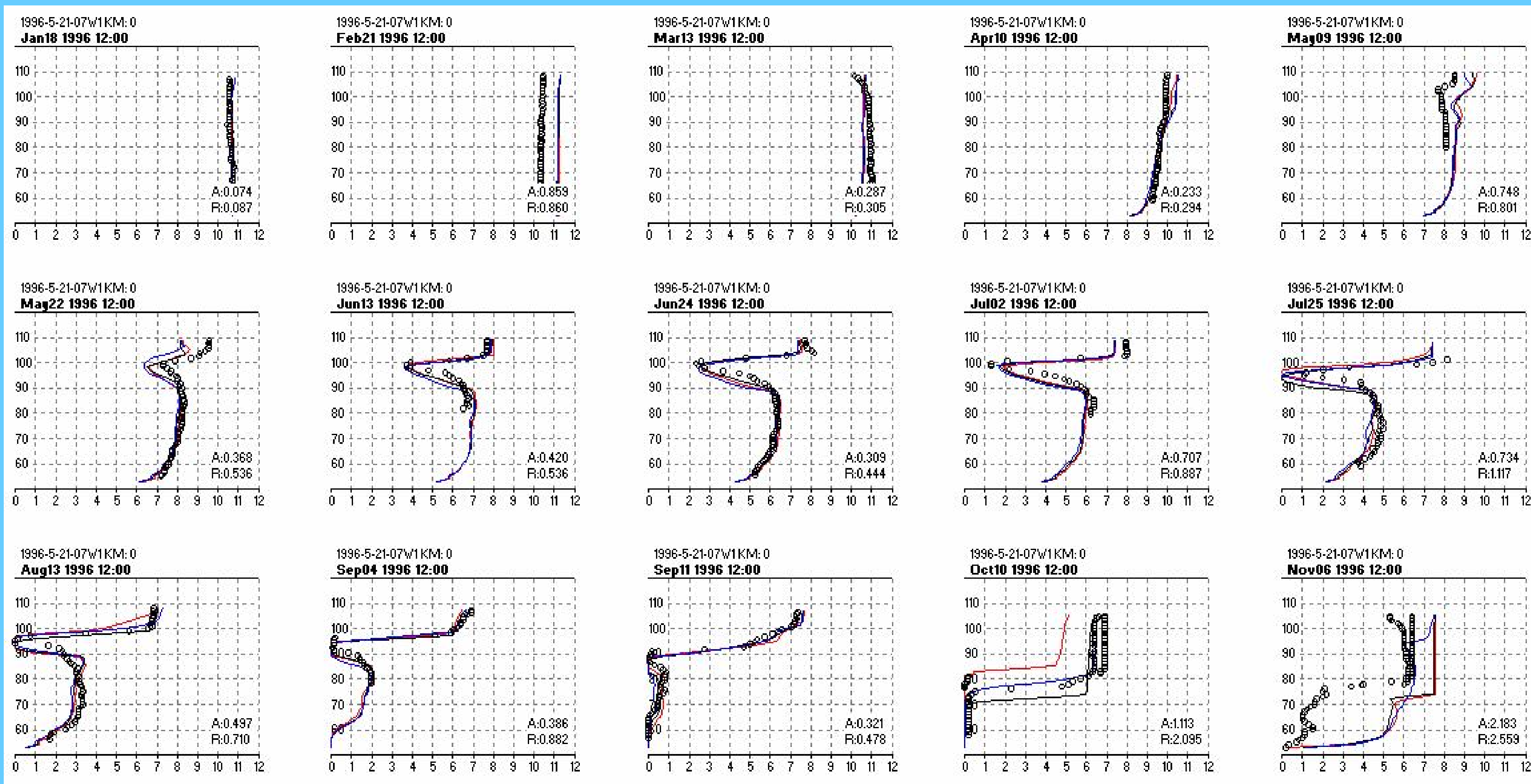
1996 Lake Murray Temperature Profiles
Forebay
Model vs. Data



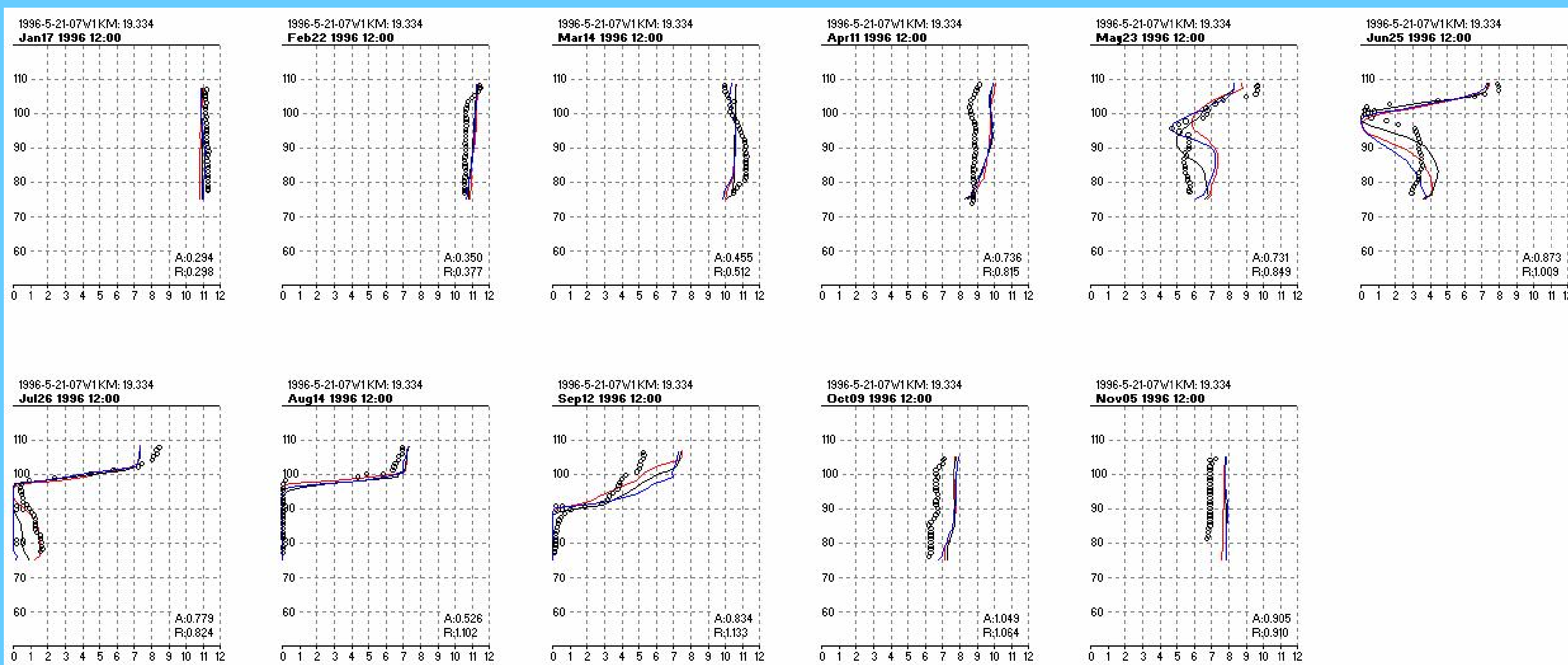
1996 Lake Murray Temperature Profiles
19 Kilometers Upstream of Dam
Model vs. Data



1996 Lake Murray DO Profiles
Forebay
Model vs. Data

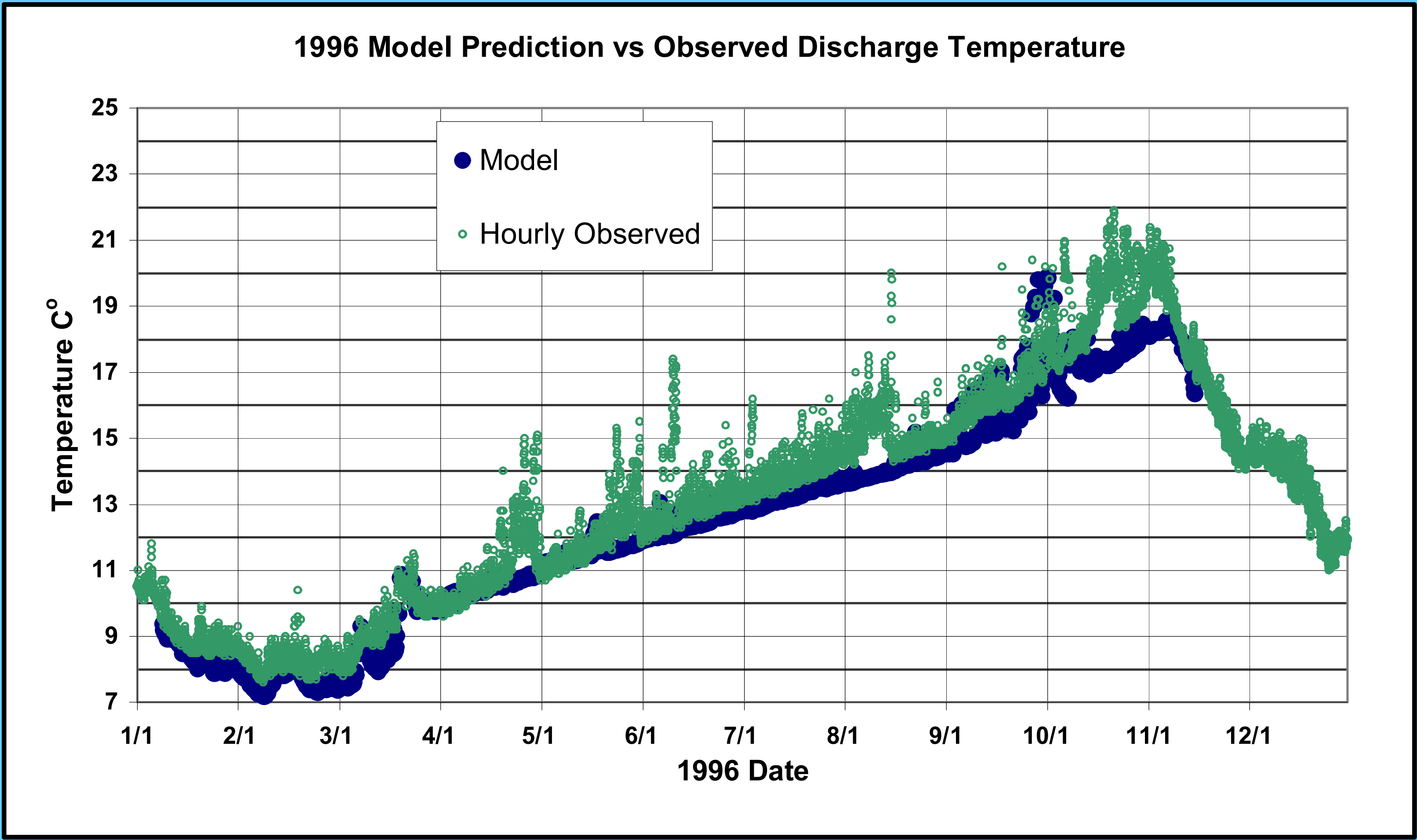


1996 Lake Murray DO Profiles
19 Kilometers Upstream of Dam
Model vs. Data



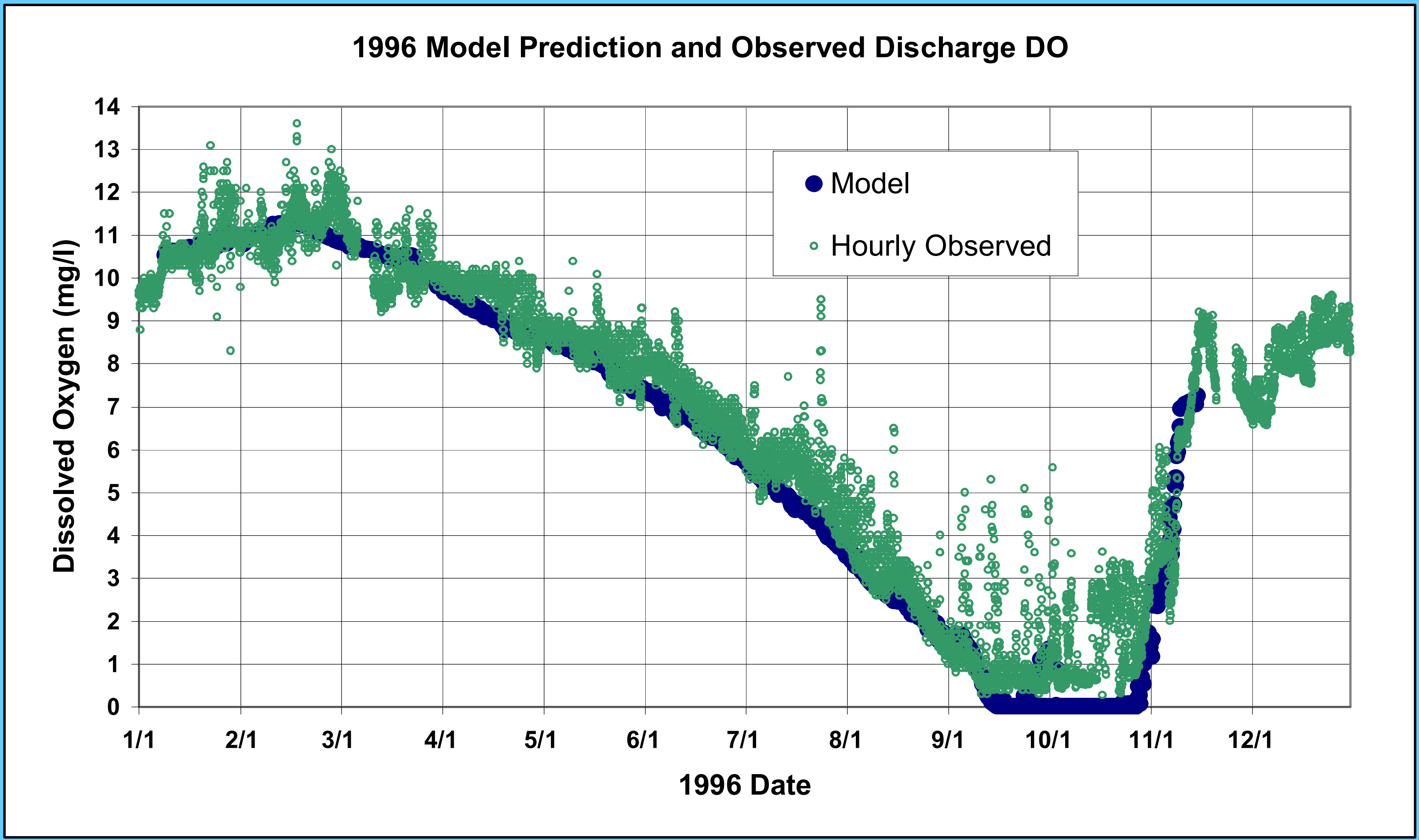
Release Temperature

Model vs. Data



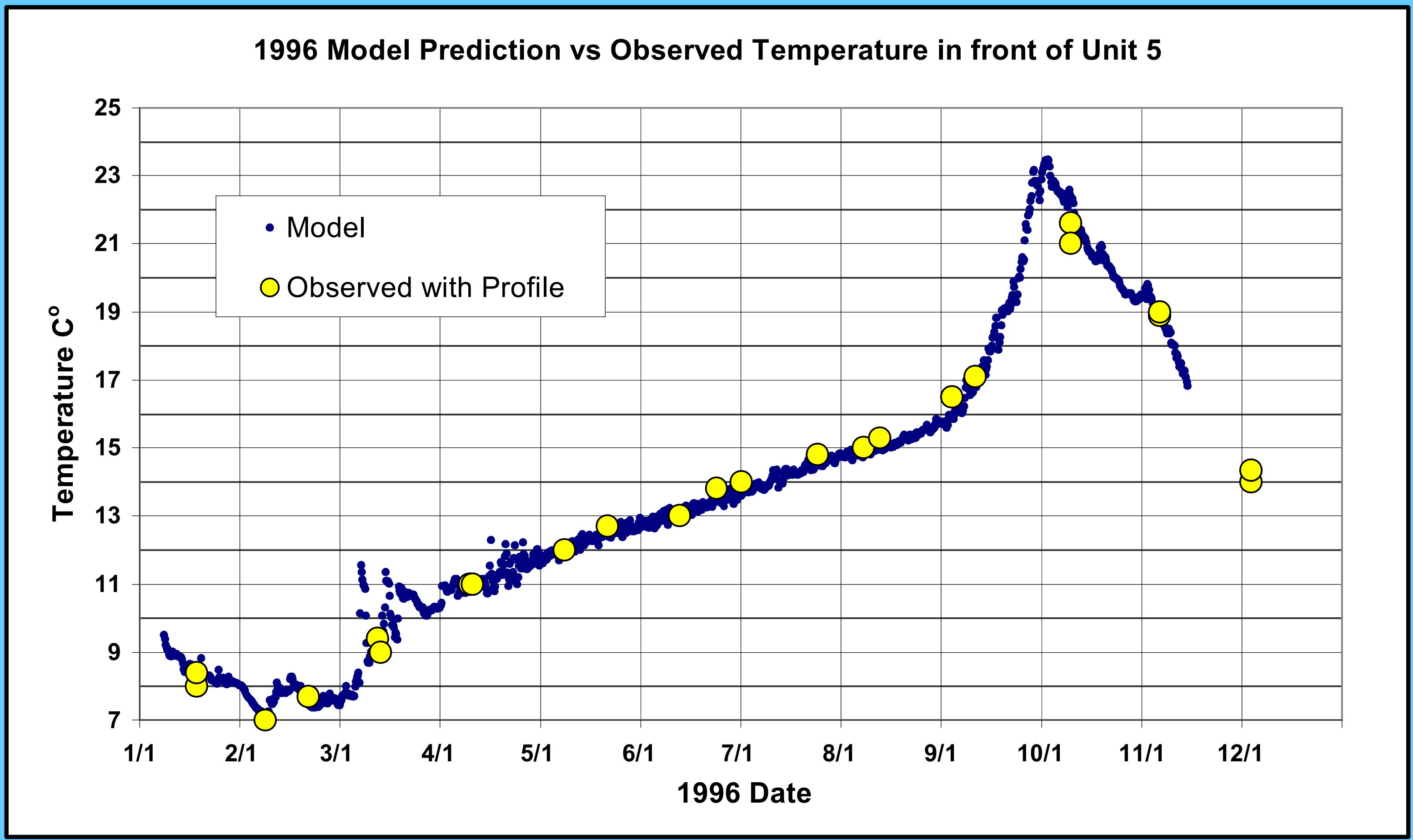
Release DO

Model vs. Data



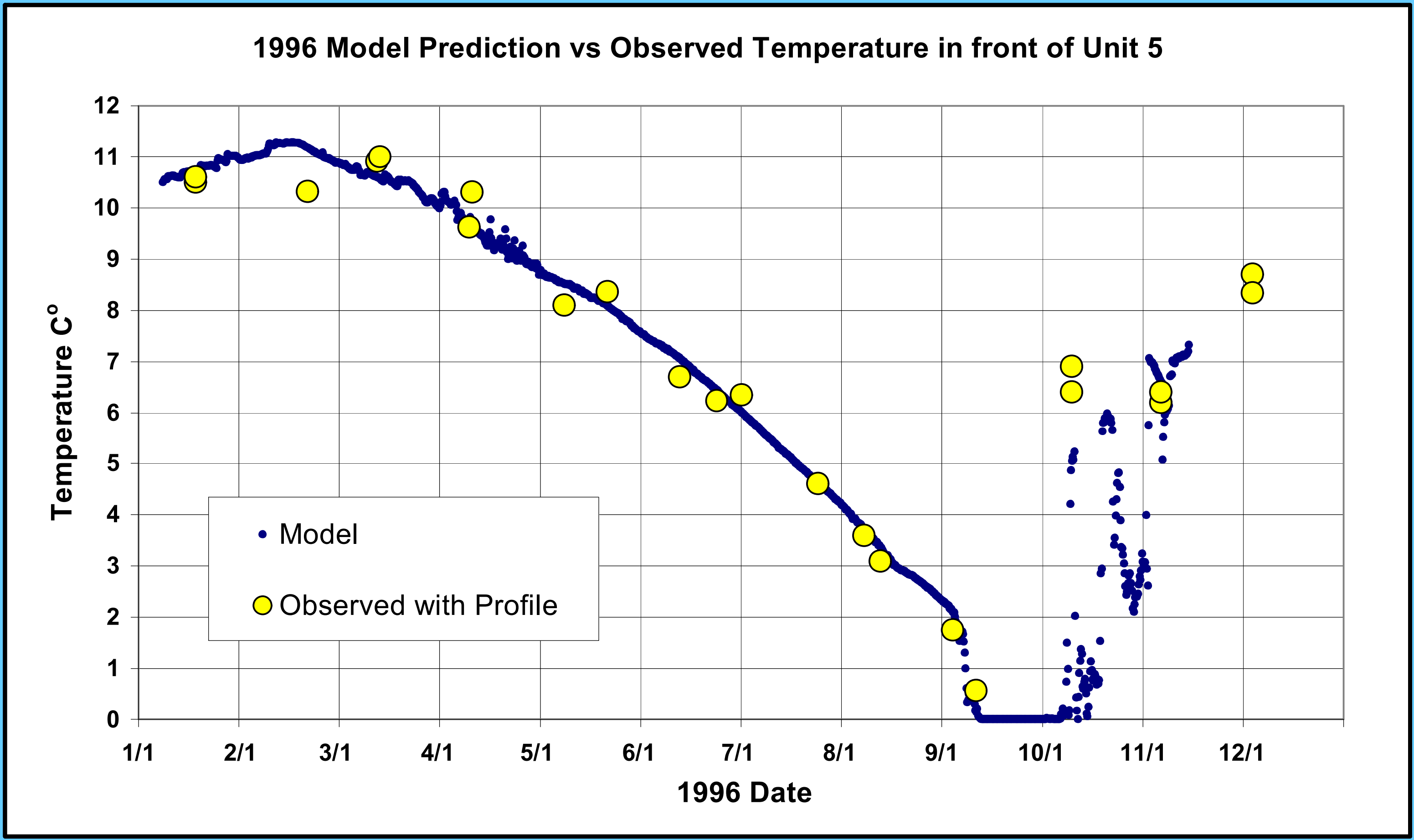
Temperature in Front of Unit 5

Model vs. Data

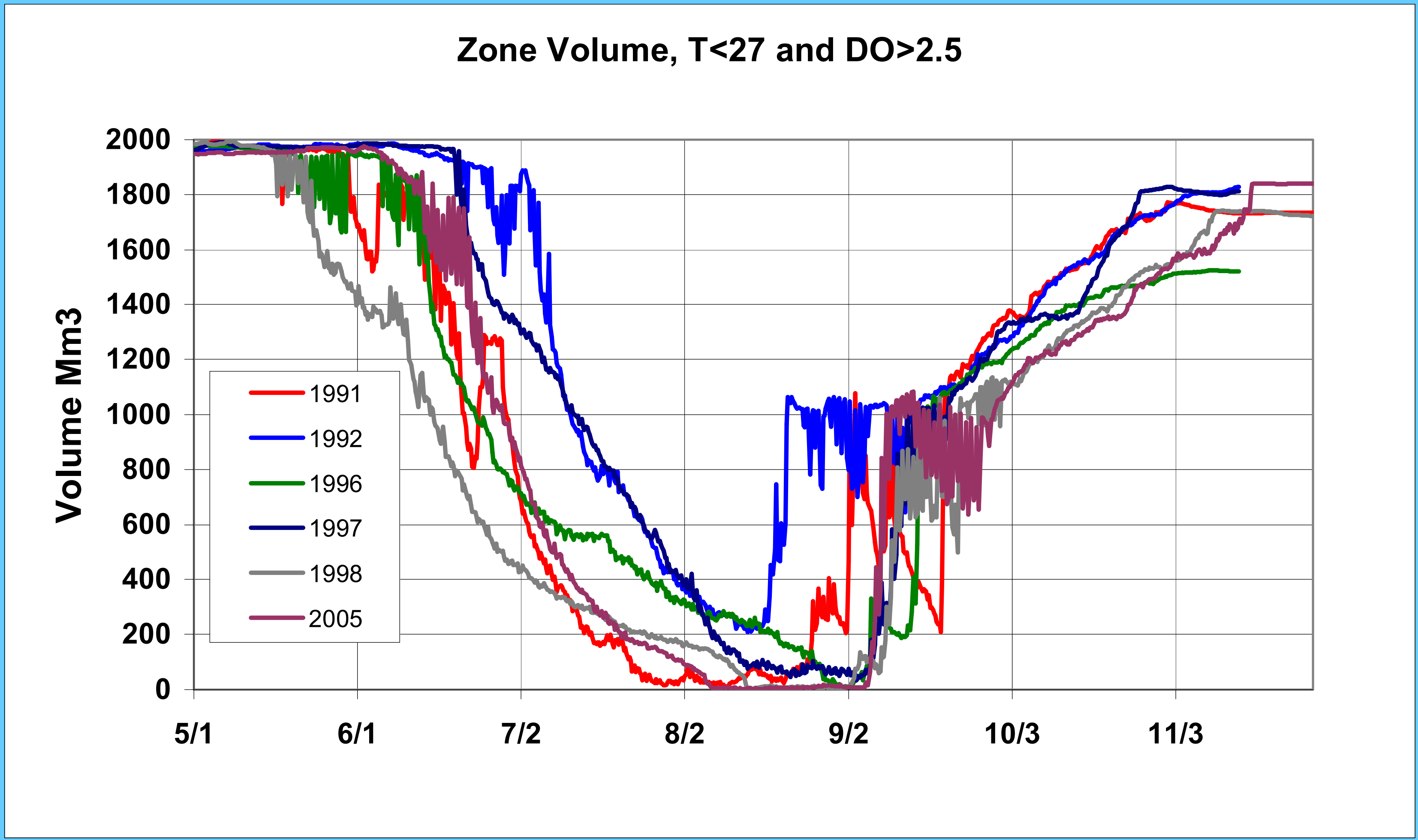


DO
in Front of Unit 5

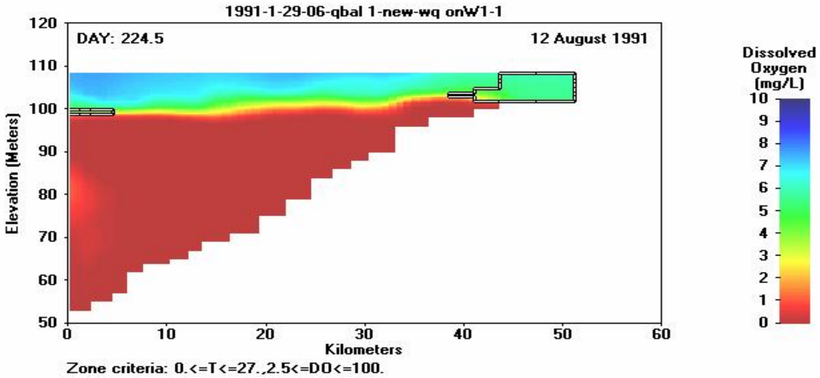
Model vs. Data

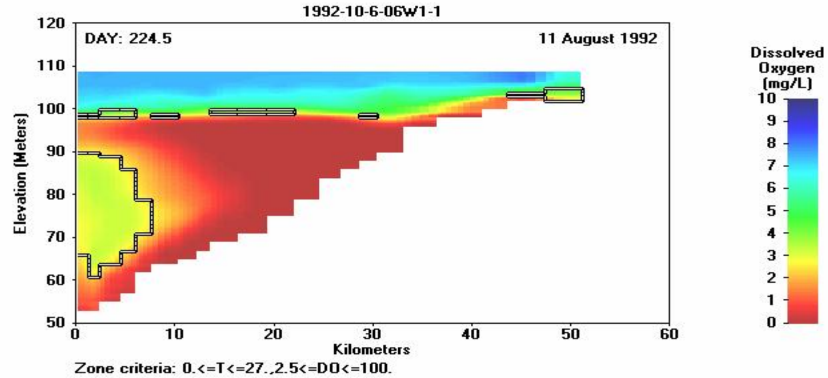


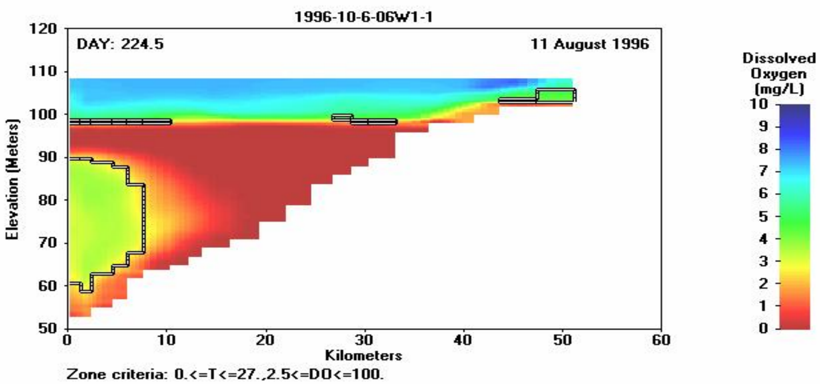
Striped Bass Habitat in Lake Murray

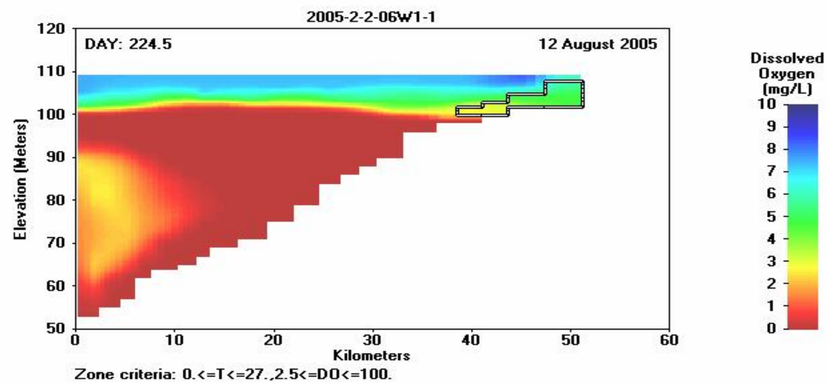


DO Animation with Striped Bass Habitat Highlighted









Sensitivity to Operations

- Original outflow assumption for all modeled years:

  Units 1, 2 and 4 – Q < 9,600 cfs

  Unit 5 – 9,600 < Q < 15,600 cfs

  Unit 3 – Q > 15,600 cfs

- When Unit 5 is operated first (Q < 6,000 cfs), cooler bottom water is conserved and availability of striper habitat improves

Evaluation of Raised Pool Levels

Scenarios Considered:

- 354(Jan1) to 358(May1⇨Sept1) to 354(Dec 31)
- 350(Jan1) to 358(May1⇨Sept1) to 350(Dec 31)

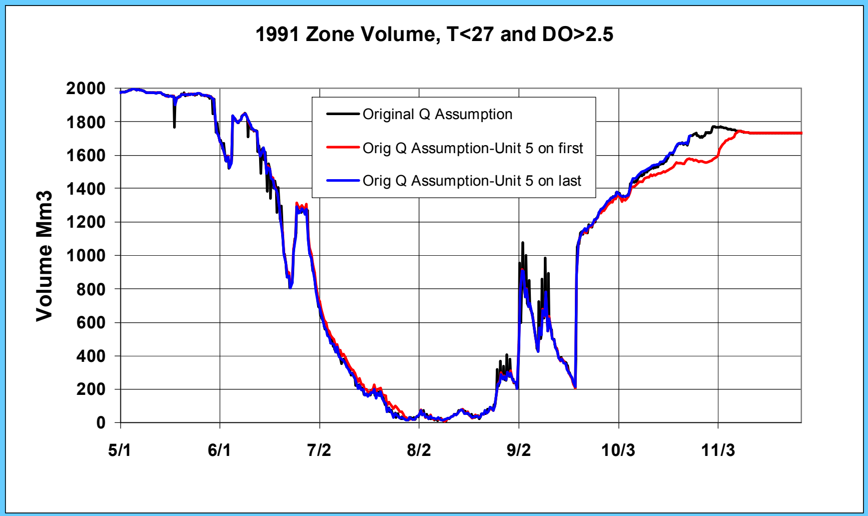
Assumptions:

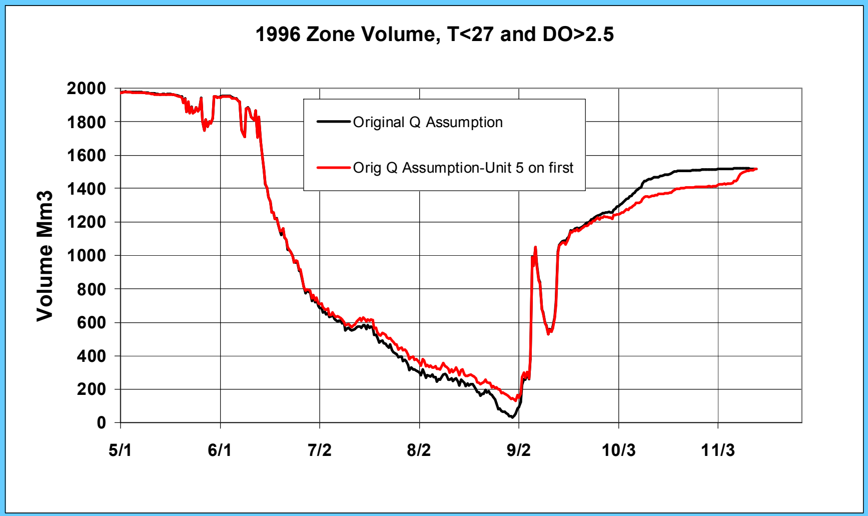
- Assumed 500 cfs for minimum release
- Assumed reserve generation averaged 3hr every two weeks at 18,000 cfs
- Balance of releases were assumed to be used to supplement system demand

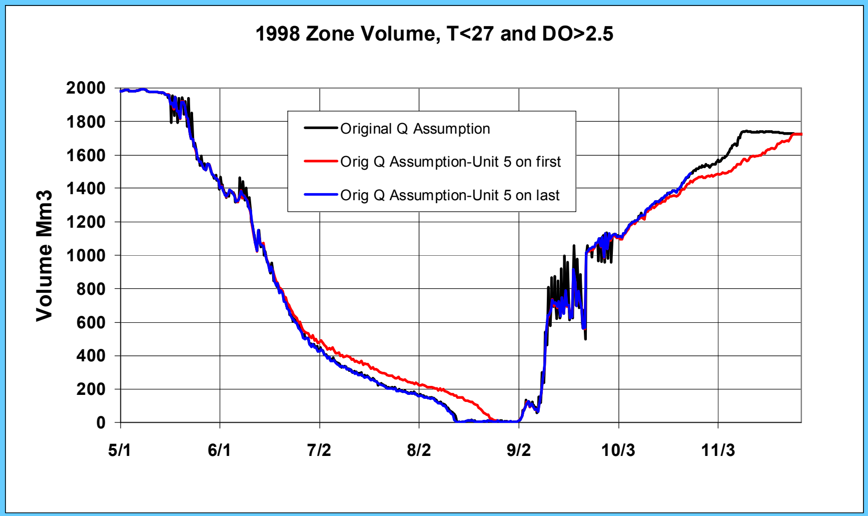
Approach:

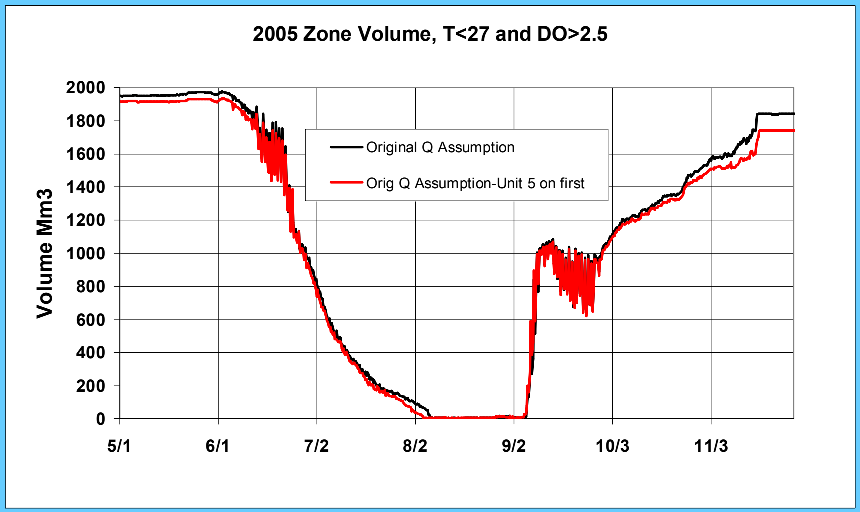
- The above scenarios were developed by KA using daily average flows using HEC-ResSim
- CE-QUAL-W2 was run using daily average flows and release flows were adjusted so that target pool levels were attained
- Using the daily average flows that were adjusted using the CE-QUAL-W2 model the hourly flows for each day were developed using the assumptions above

Comparison of Original Flow Assumption and Alternative Unit 5 Operation Scenarios



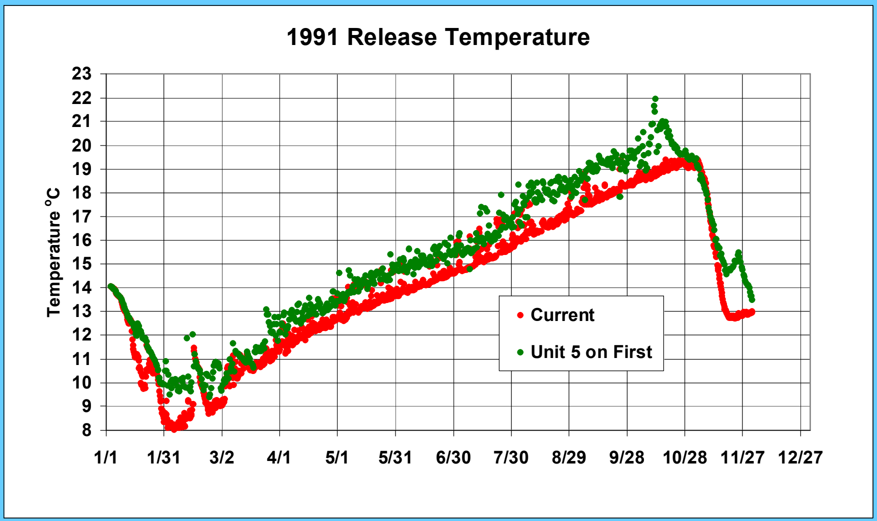


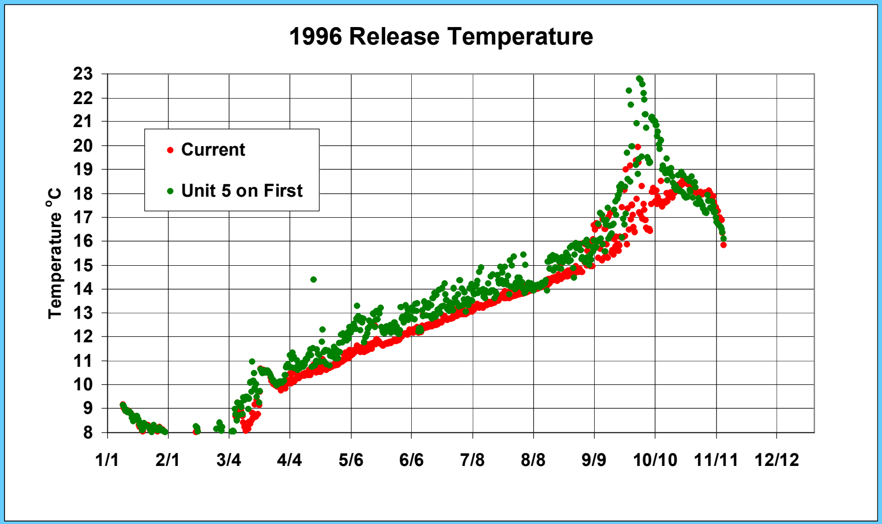


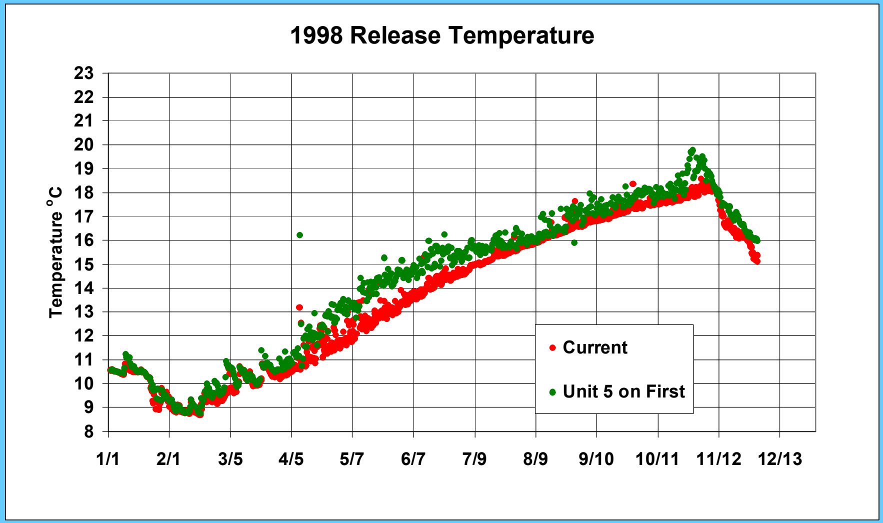


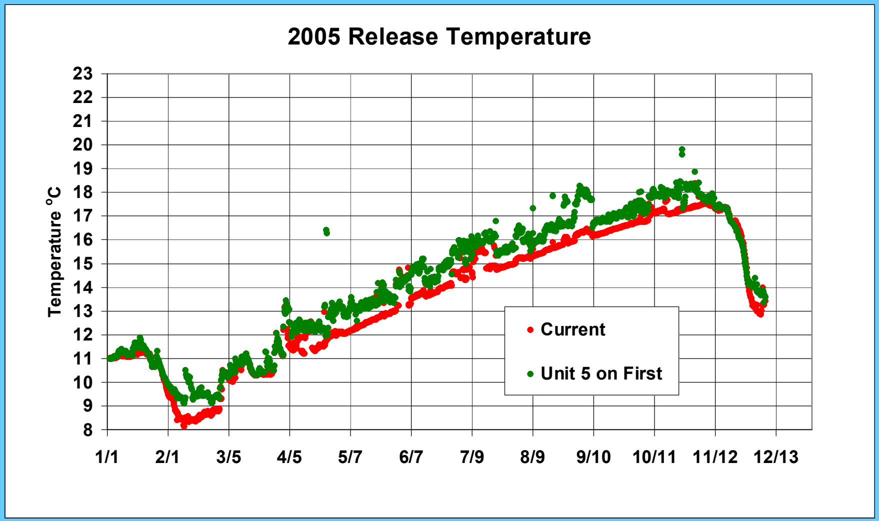
1998 Animation
Comparison of Original Flow Assumption and Unit 5 on First Scenario

Tailrace Temperature - Comparison of Original Flow Assumption and Unit 5 on First Scenario

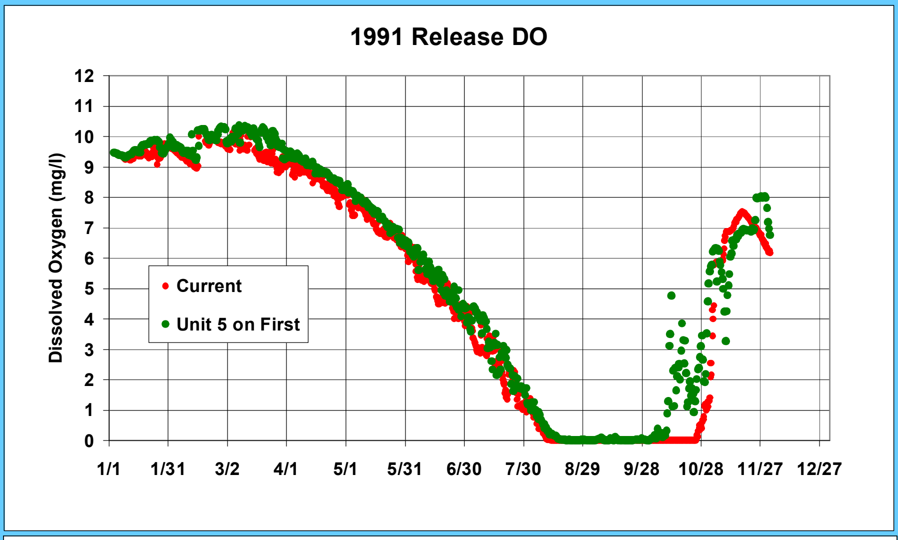


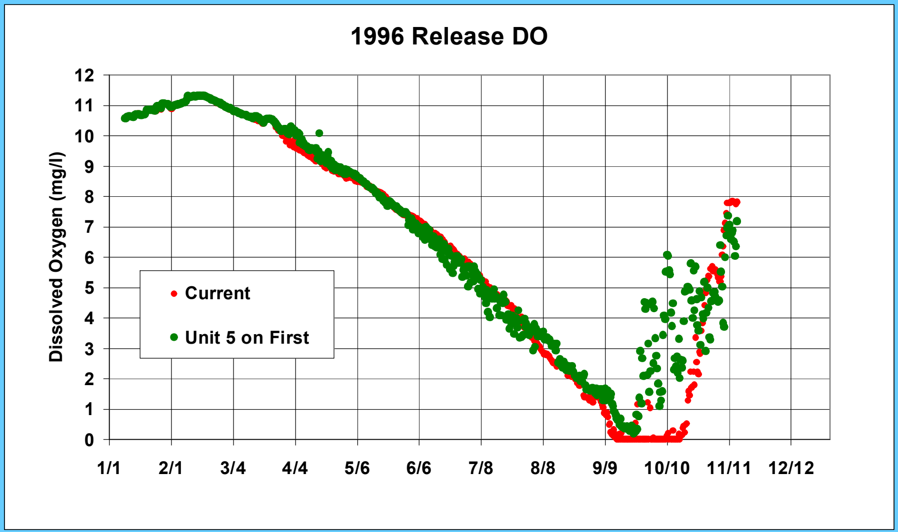


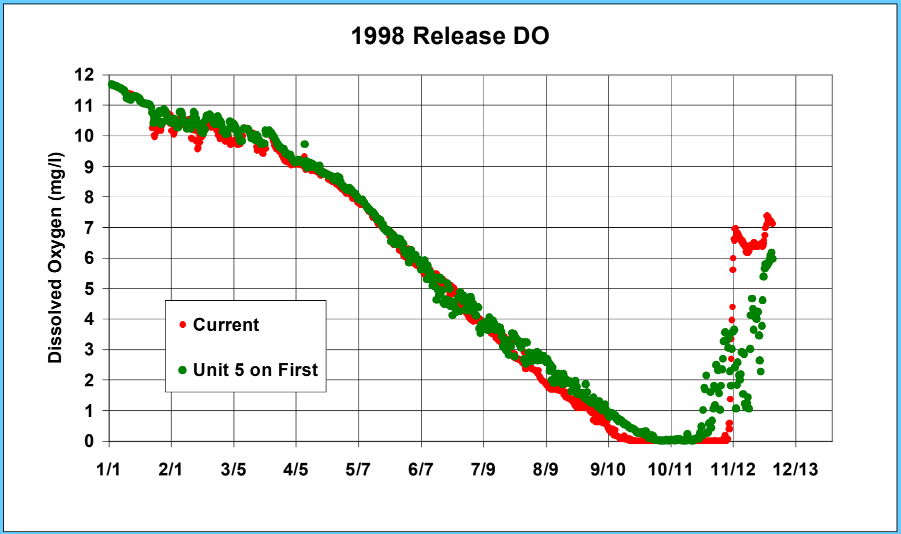


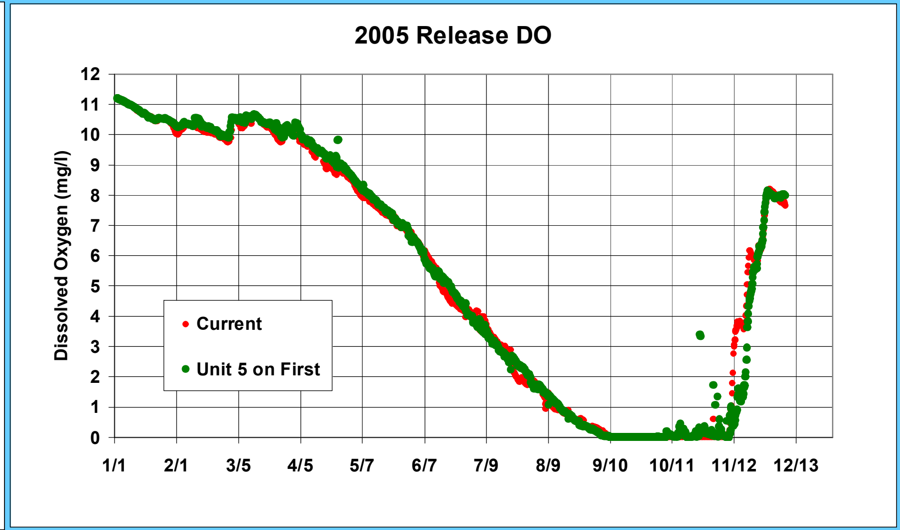


Tailrace DO - Comparison of Original Flow Assumption and Unit 5 on First Scenario

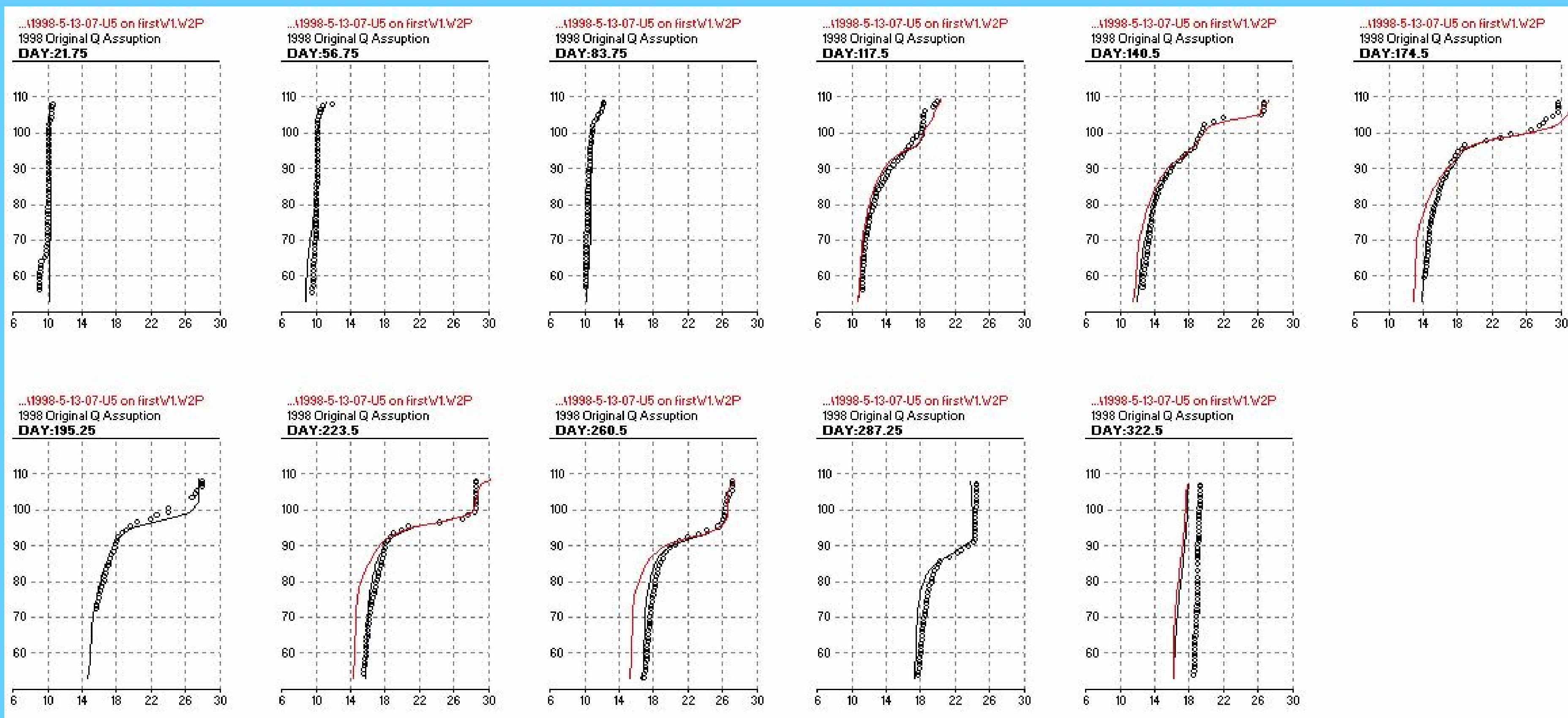




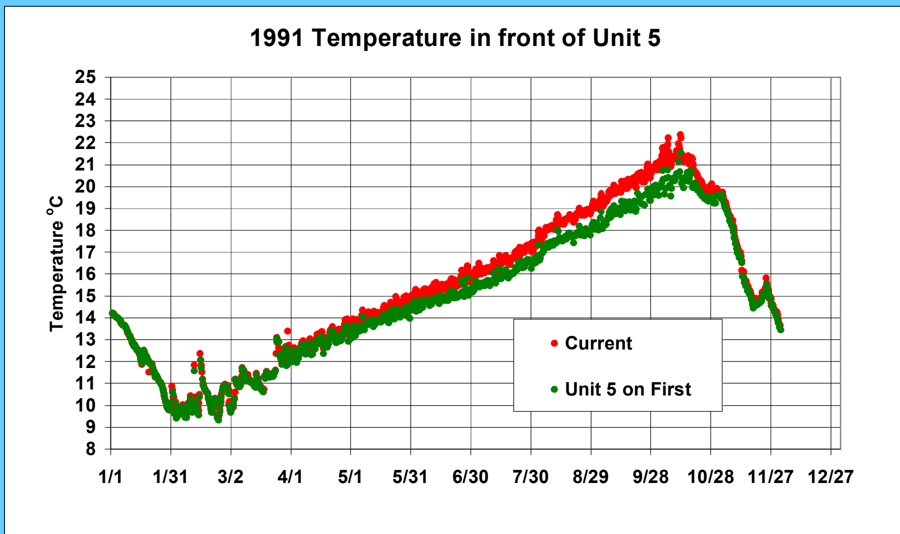


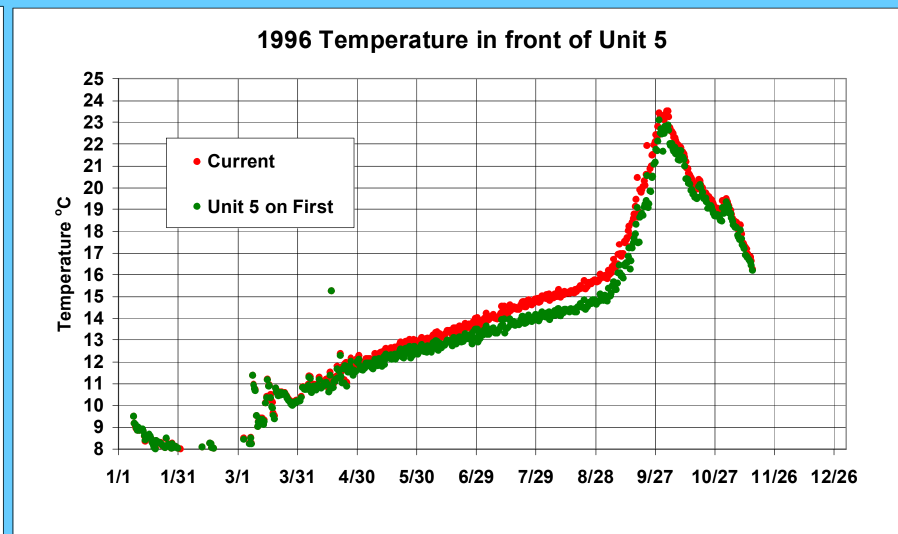


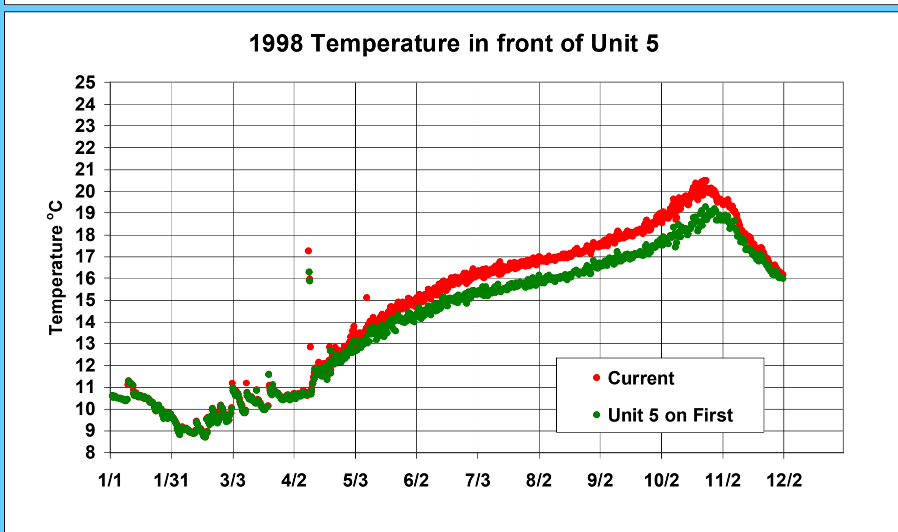
Forebay Temperature Profiles – Comparison of Original Flow Assumption and Unit 5 on First Scenario

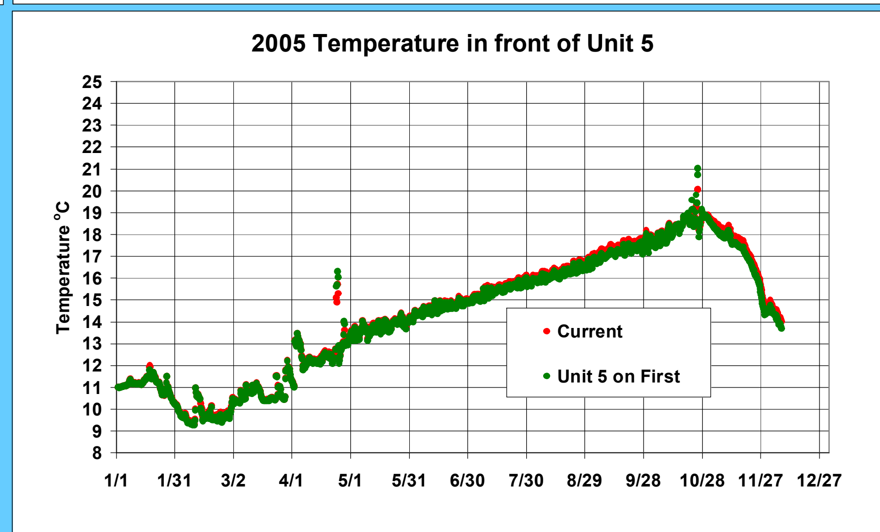


Temperature at the Intake to Unit 5
Comparison of Original Flow Assumption and Unit 5 on First Scenario

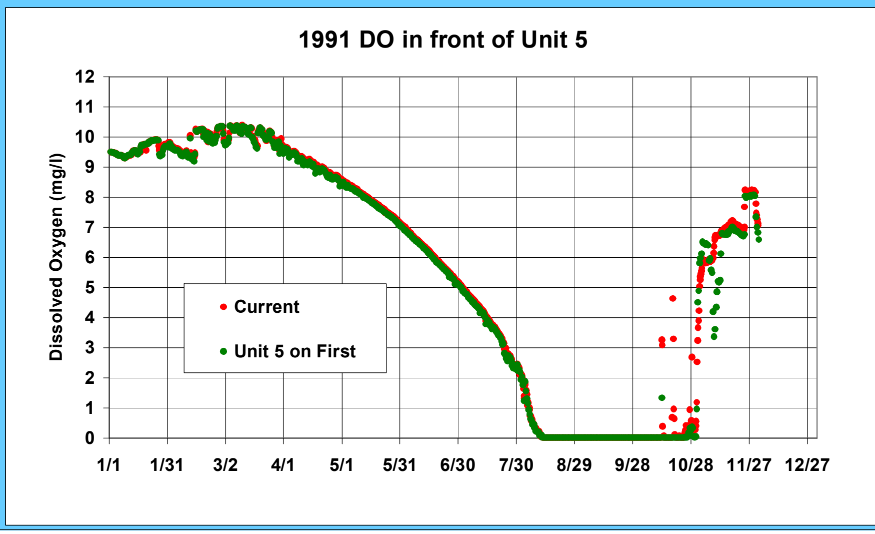


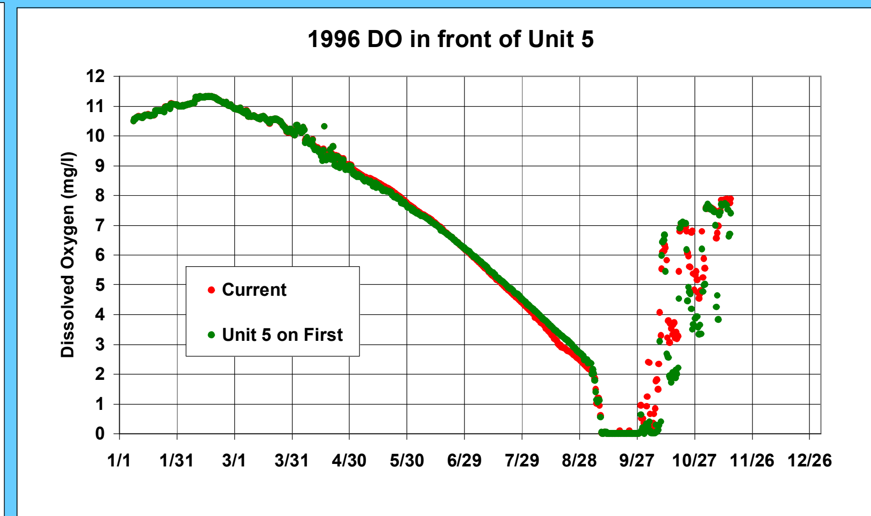


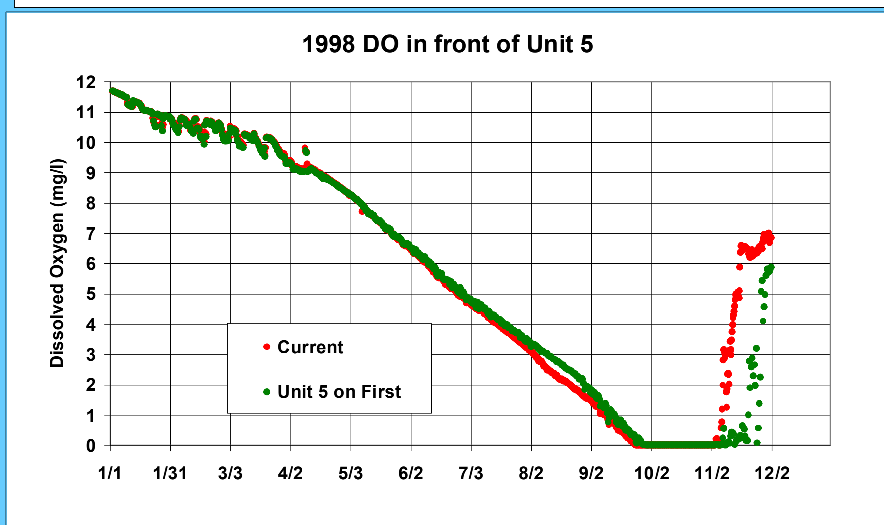


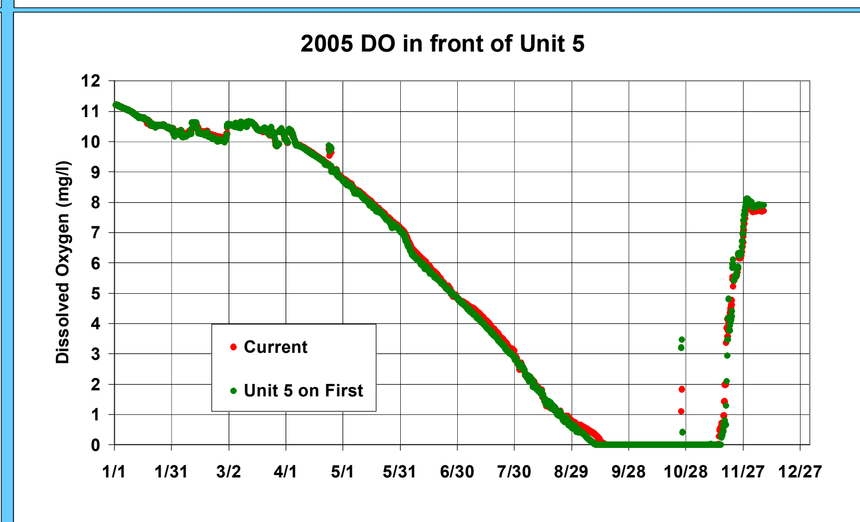


DO at the Intake to Unit 5
Comparison of Original Flow Assumption and Unit 5 on First Scenario

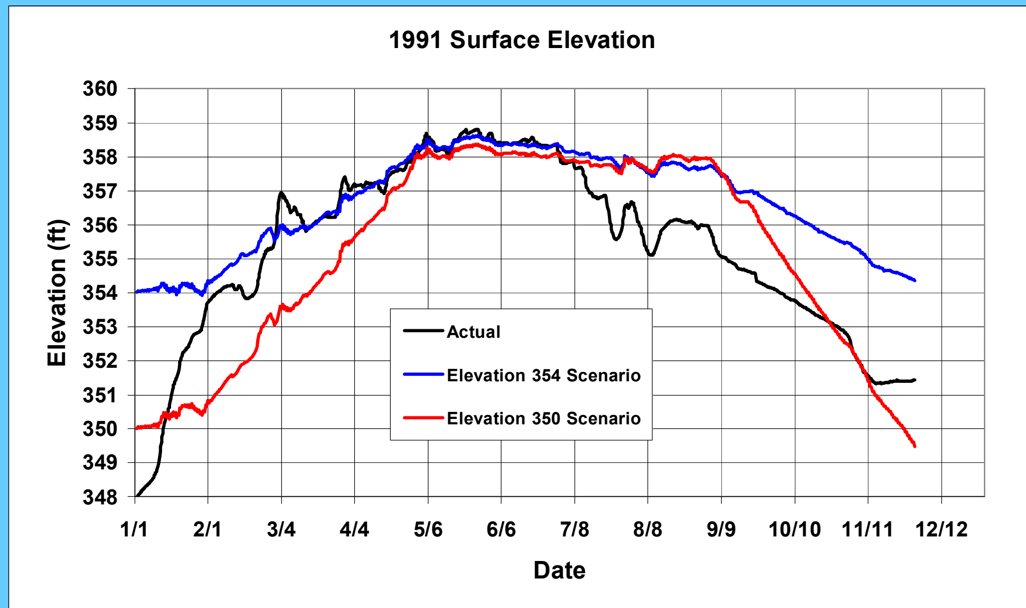


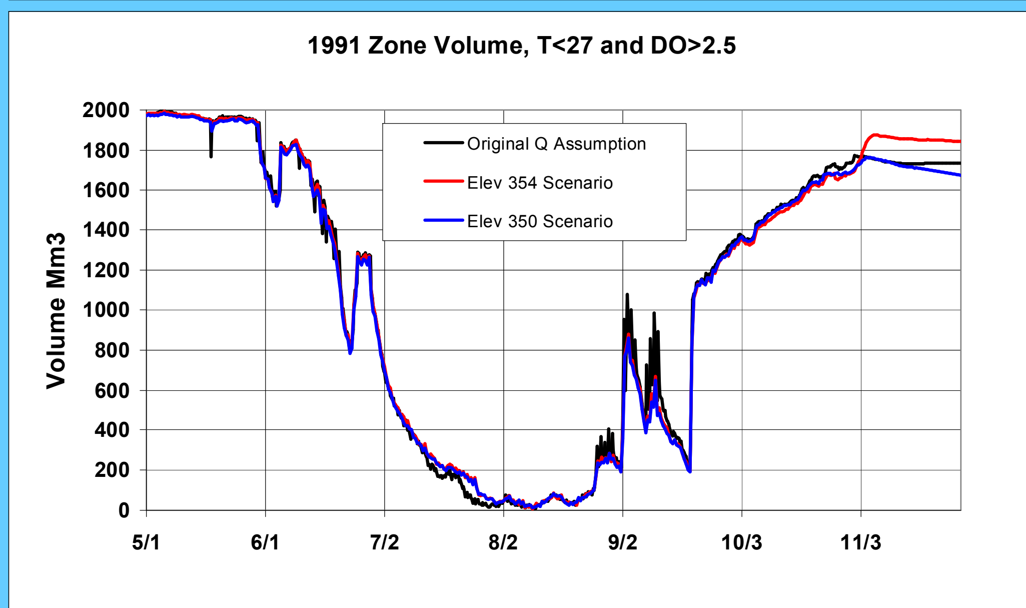




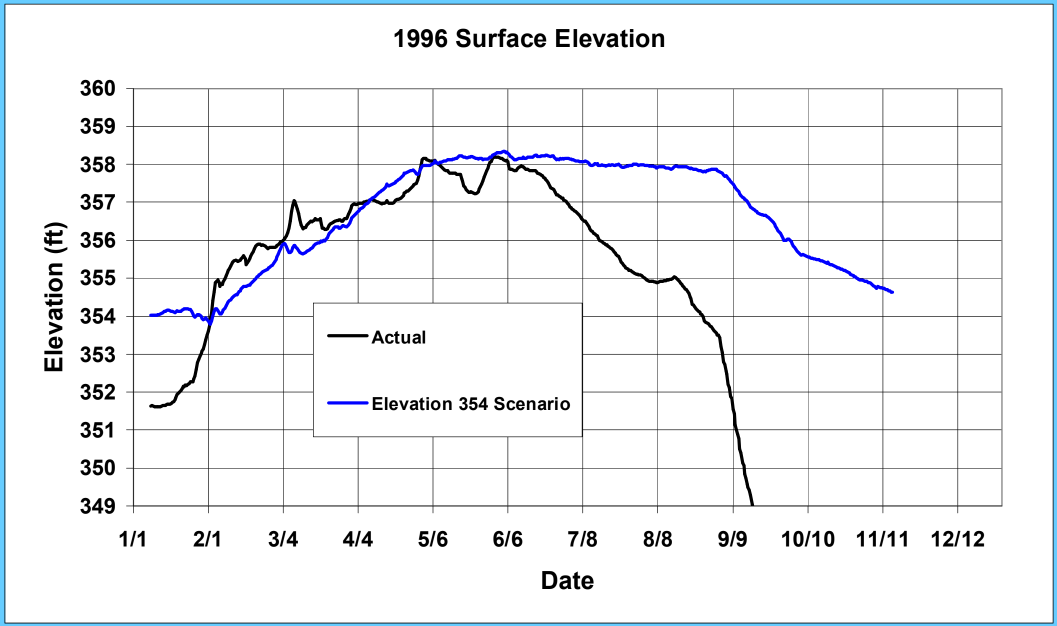


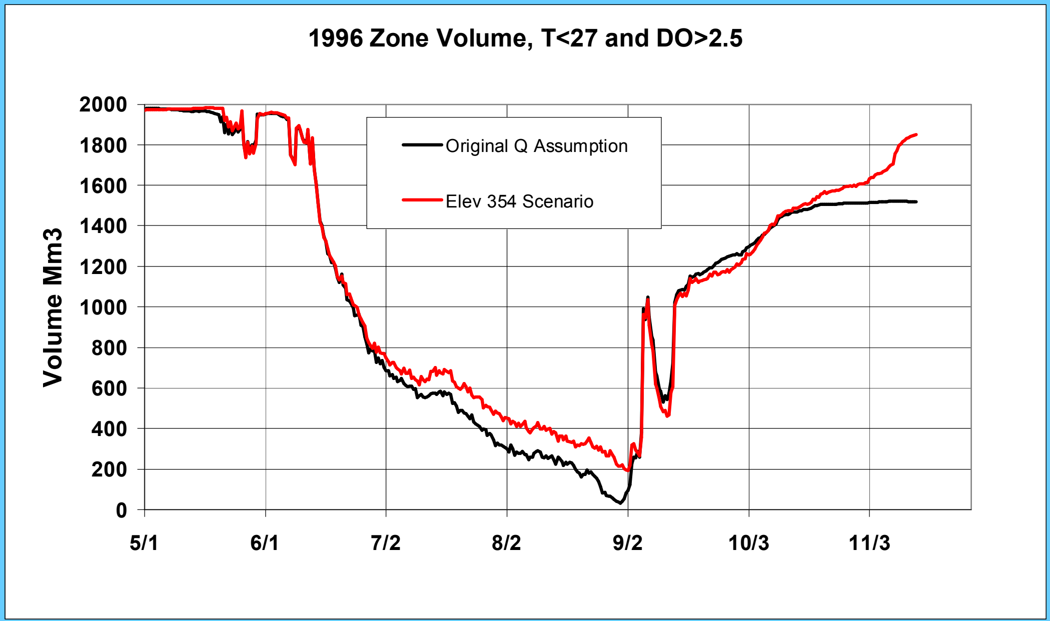
1991 Pool Level Management



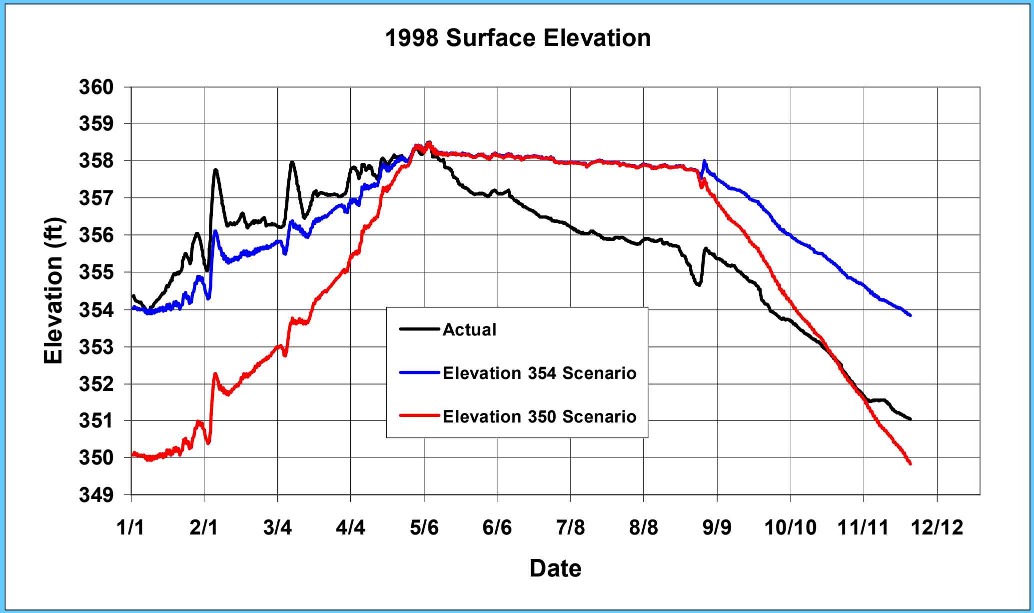


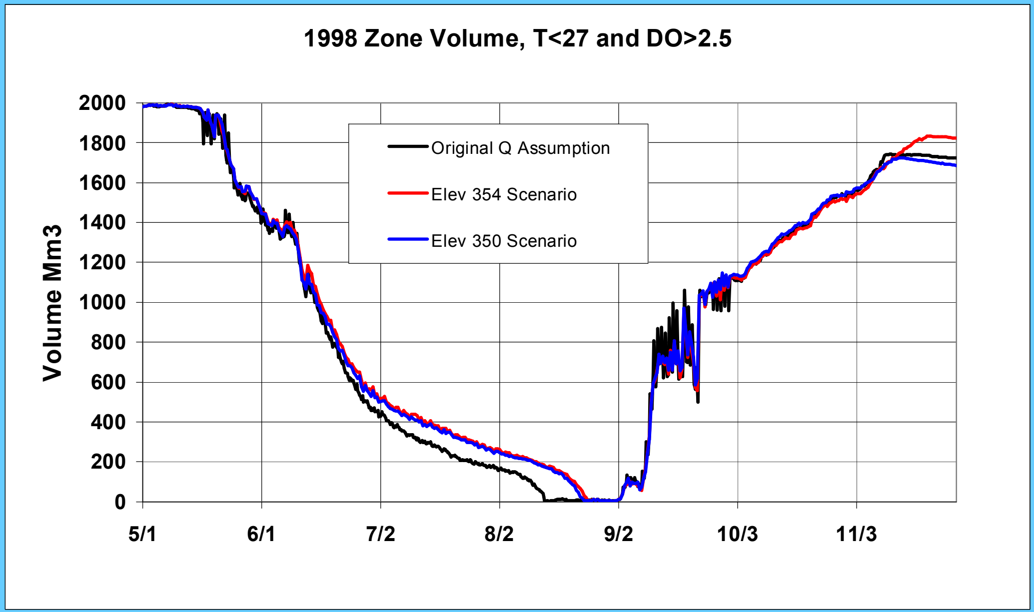
1996 Pool Level Management



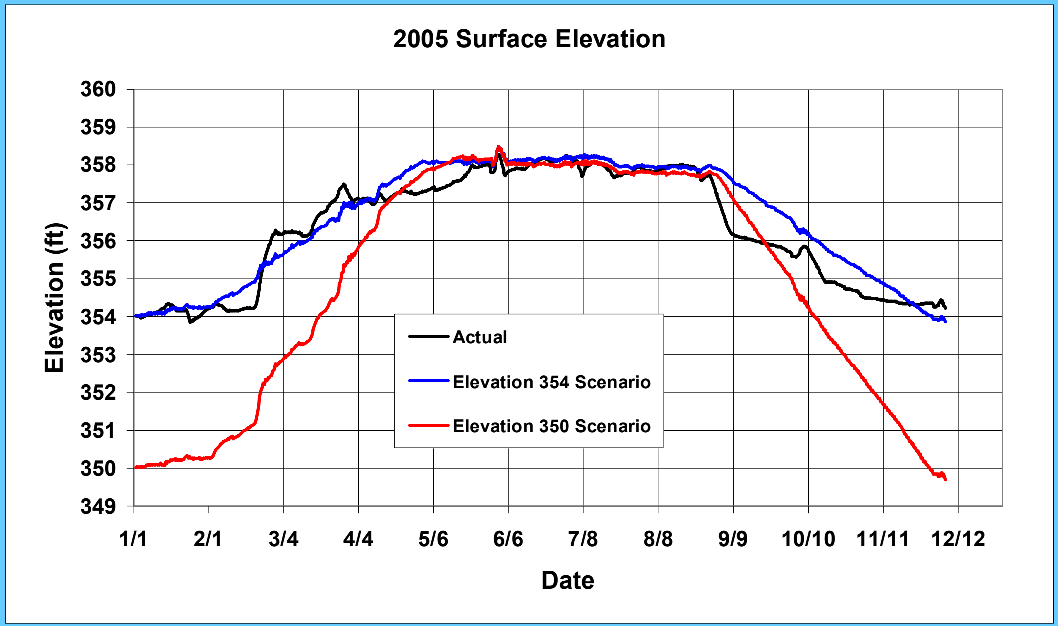


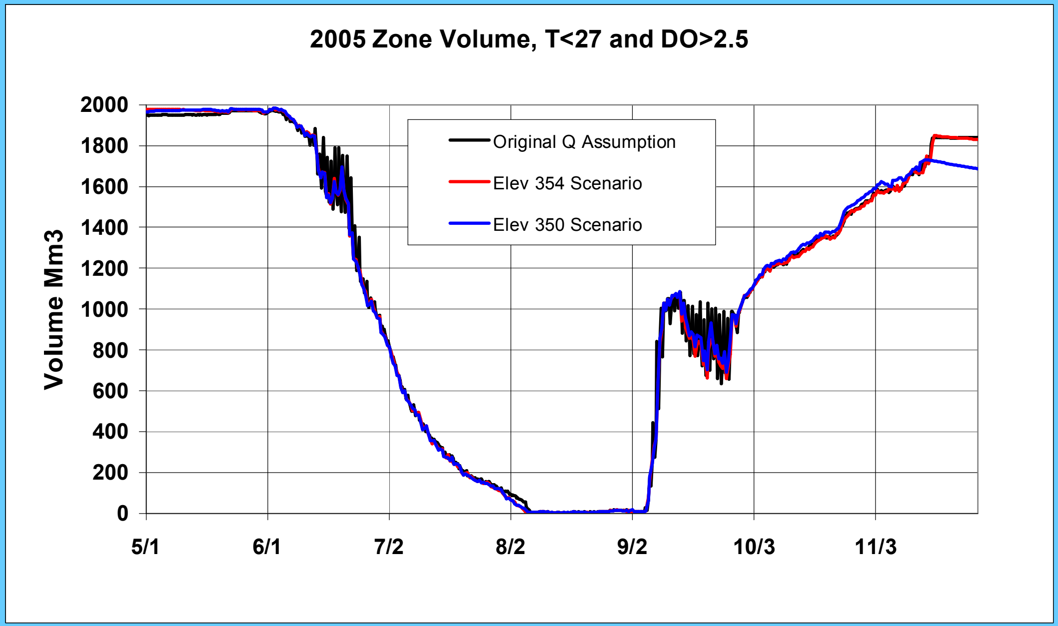
1998 Pool Level Management





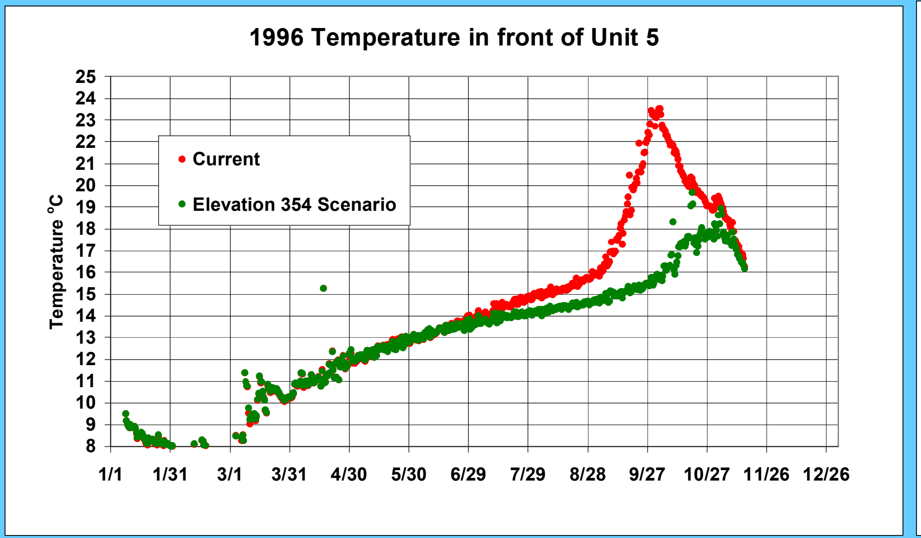
2005 Pool Level Management

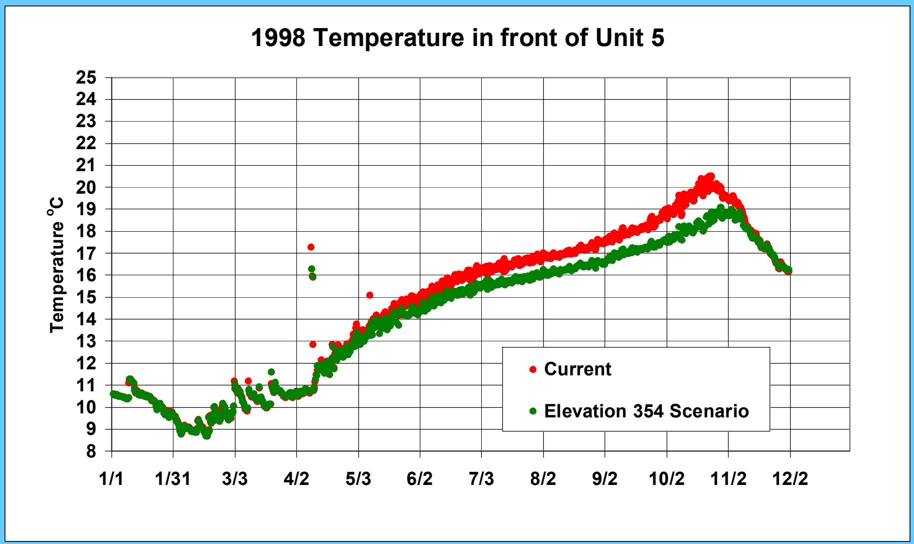


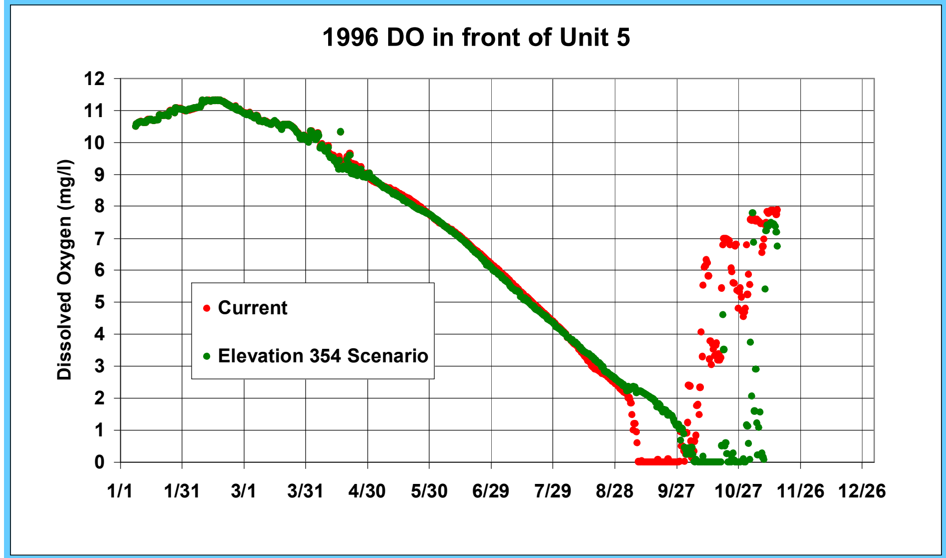


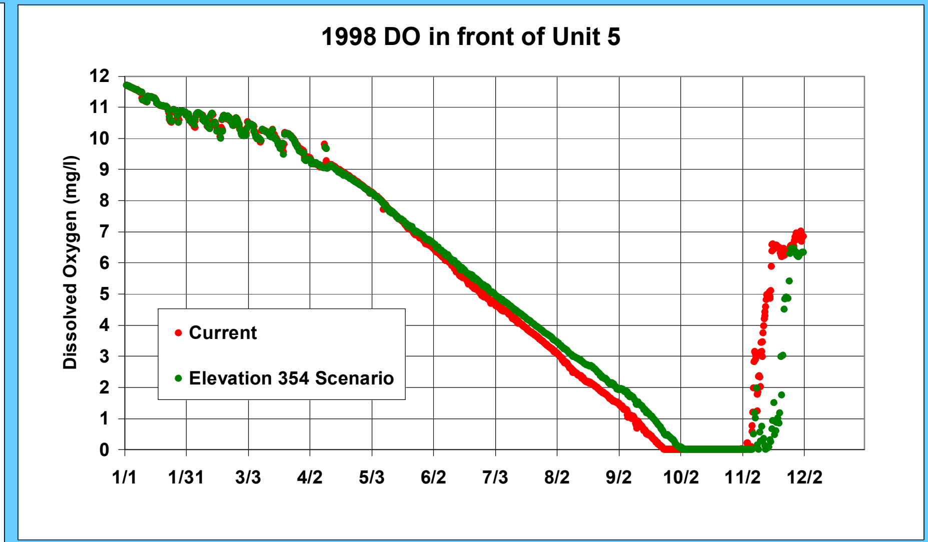
Excel Plots

Temperature and DO at the Intake to Unit 5 with Pool Level Management

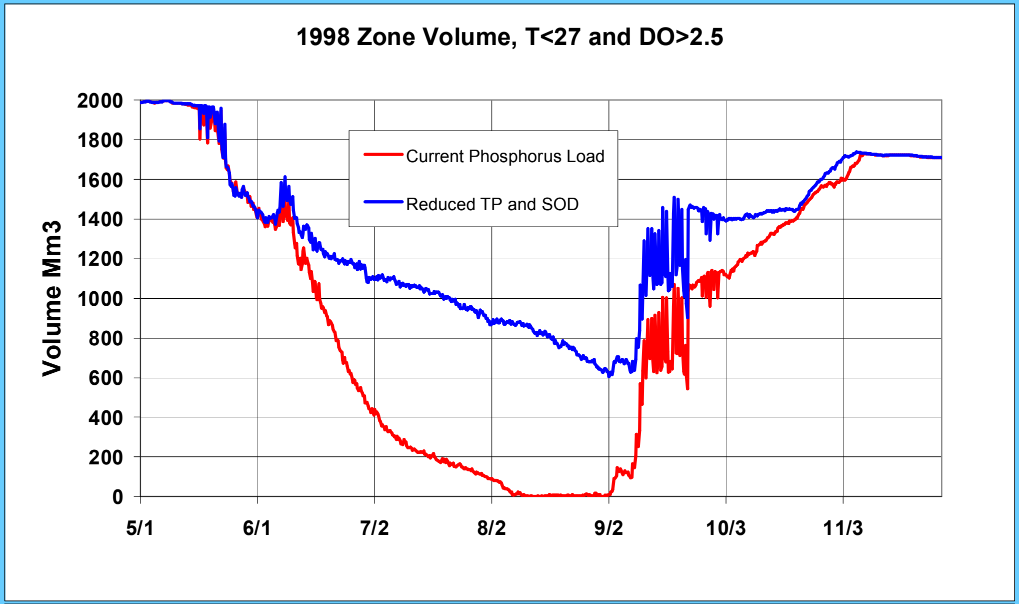


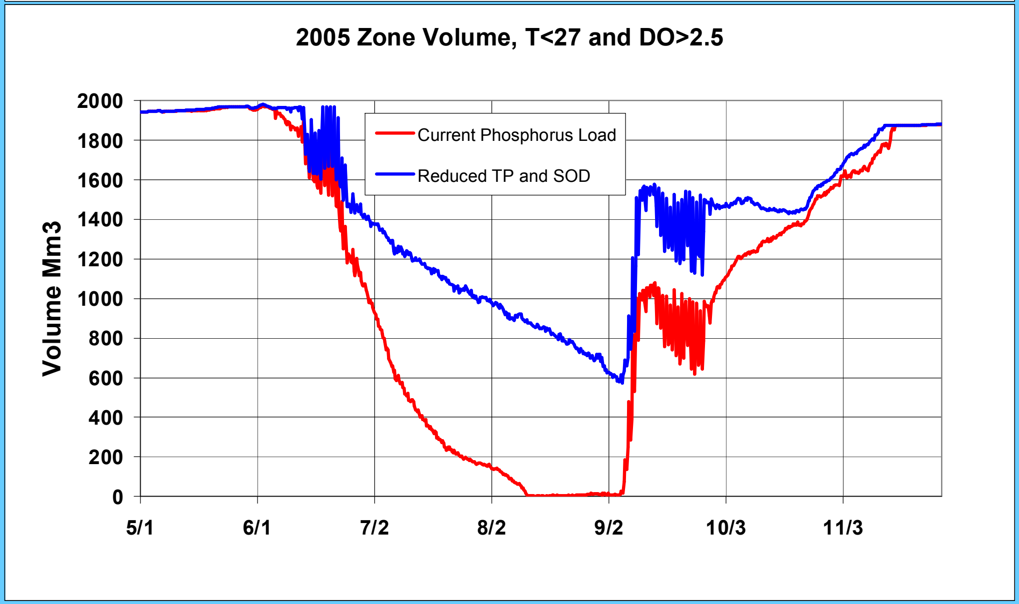






Comparison of Current Phosphorus Load and Reduced Phosphorus Scenario





Preliminary Conclusions

- Nutrients are the single dominant factor that can enhance striped bass habitat
- Flow is a dominant factor, but cannot be controlled to avoid fish kills
- Met conditions can be a periodic factor that alleviates otherwise dominant factors like flow
- Striped bass habitat conditions can be improved in some years by maintaining high summer pool levels (~ elev. 358 ft)
- Unit 5 preferential operations can improve striped bass habitat in some years

Next Steps

1. For selected years, finalize assessment (i.e., assess changes in releases) of operating guide for U5 preference for “first on, last off” operation using the hourly releases

2. For selected years, finalize assessment of maintaining summer pool levels at 358

3. For selected years, finalize assessment of the combination of maintaining summer pool levels at 358 with U5 preference for “first on, last off” operation using the hourly releases

4. Analyze additional years, especially a low flow year

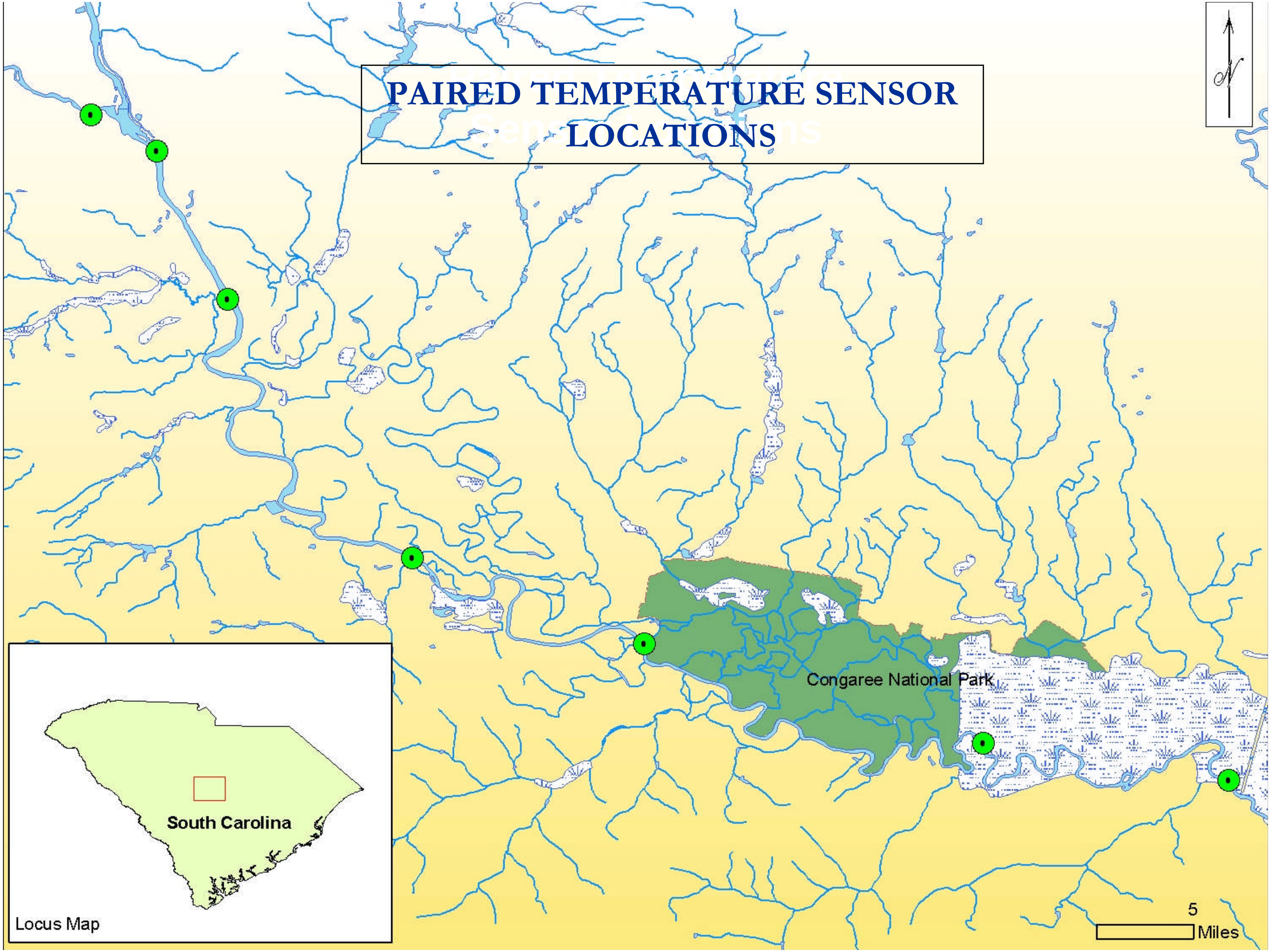
5. Assess effects of minimum winter pool level, including effects on Little Saluda embayment, increased SOD, internal nutrient cycling, aquatic plants, sedimentation in coves,

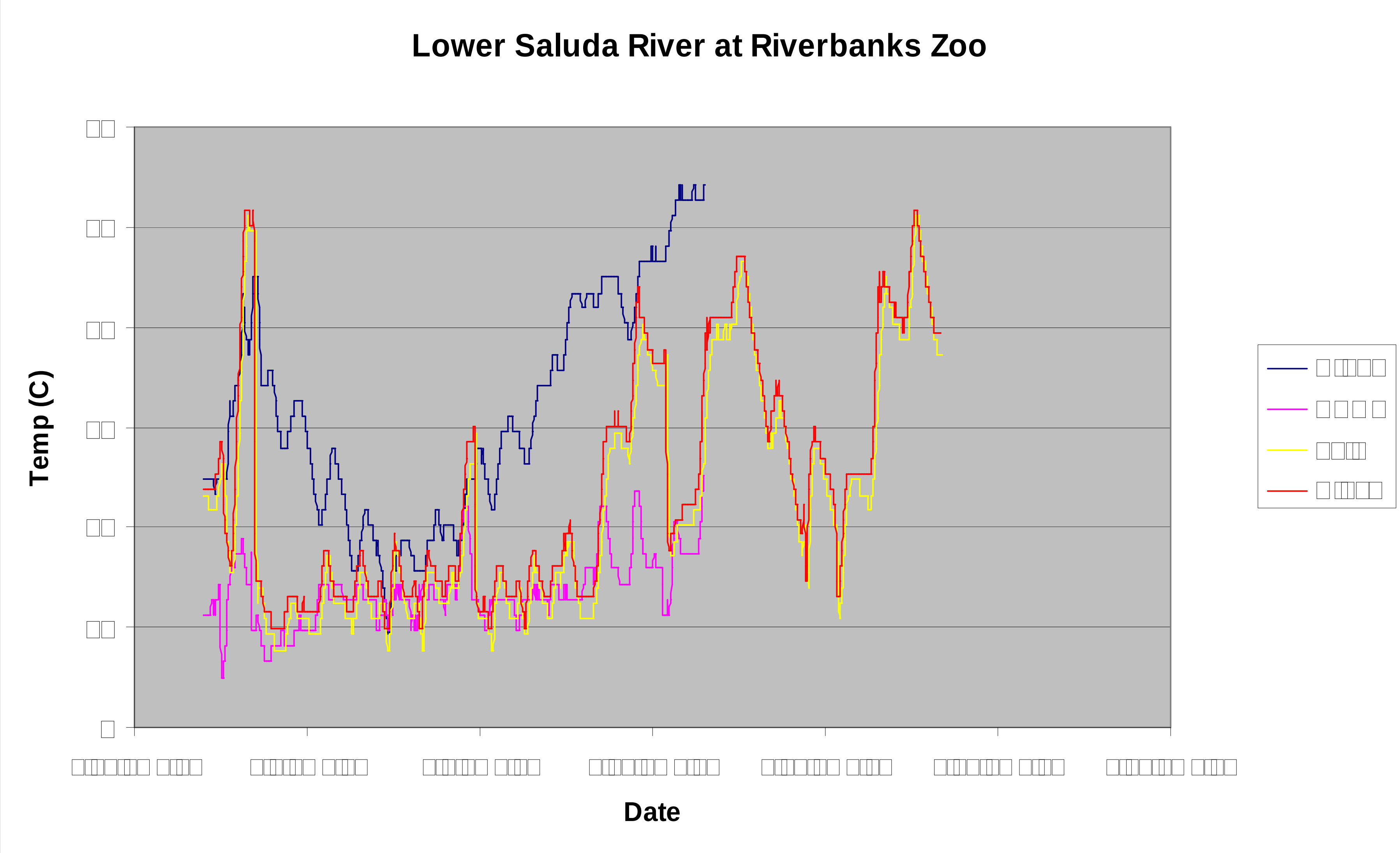
Lower Saluda and Congaree Rivers Temperature Study: Update

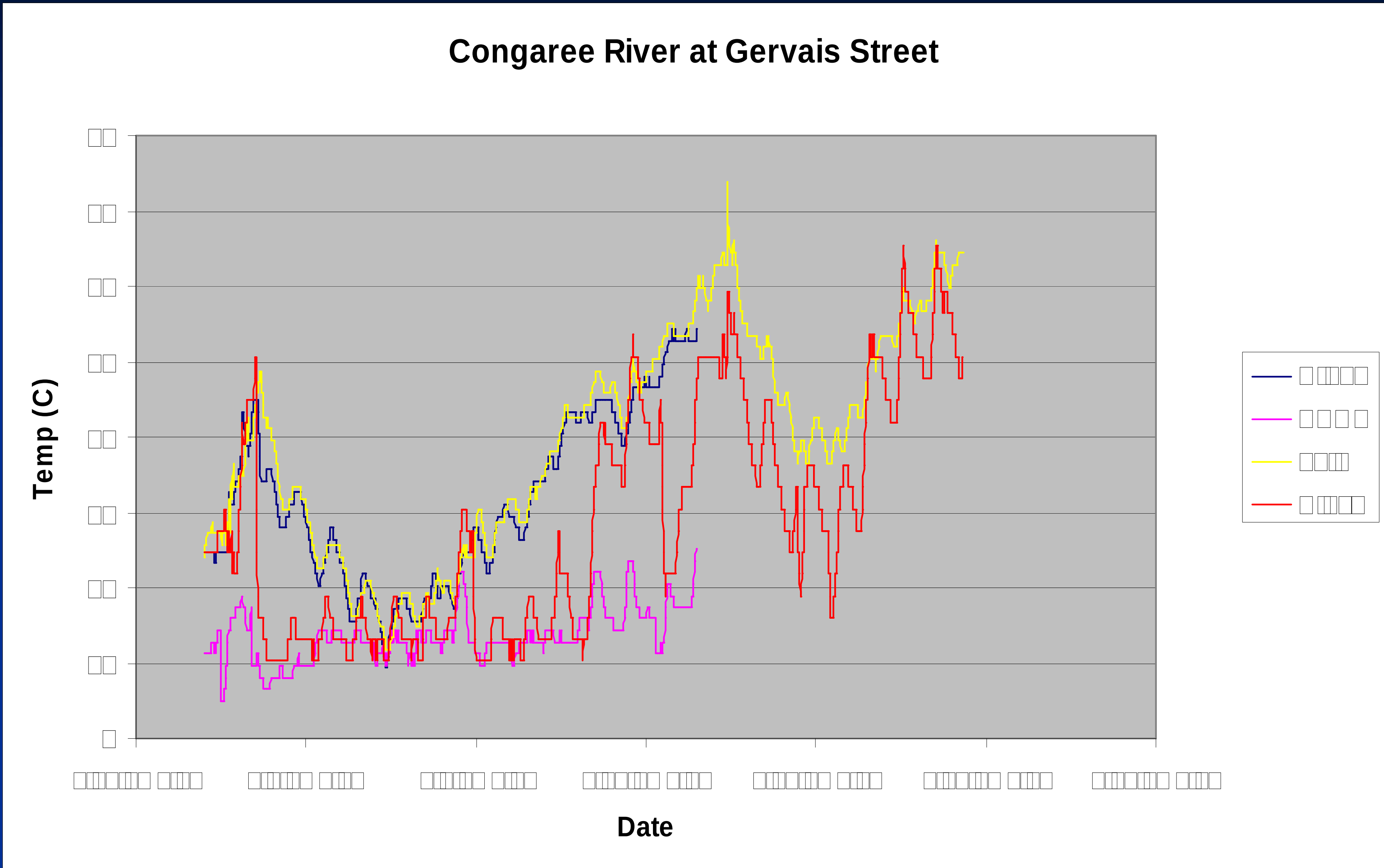
Water Quality Technical Working Committee Meeting

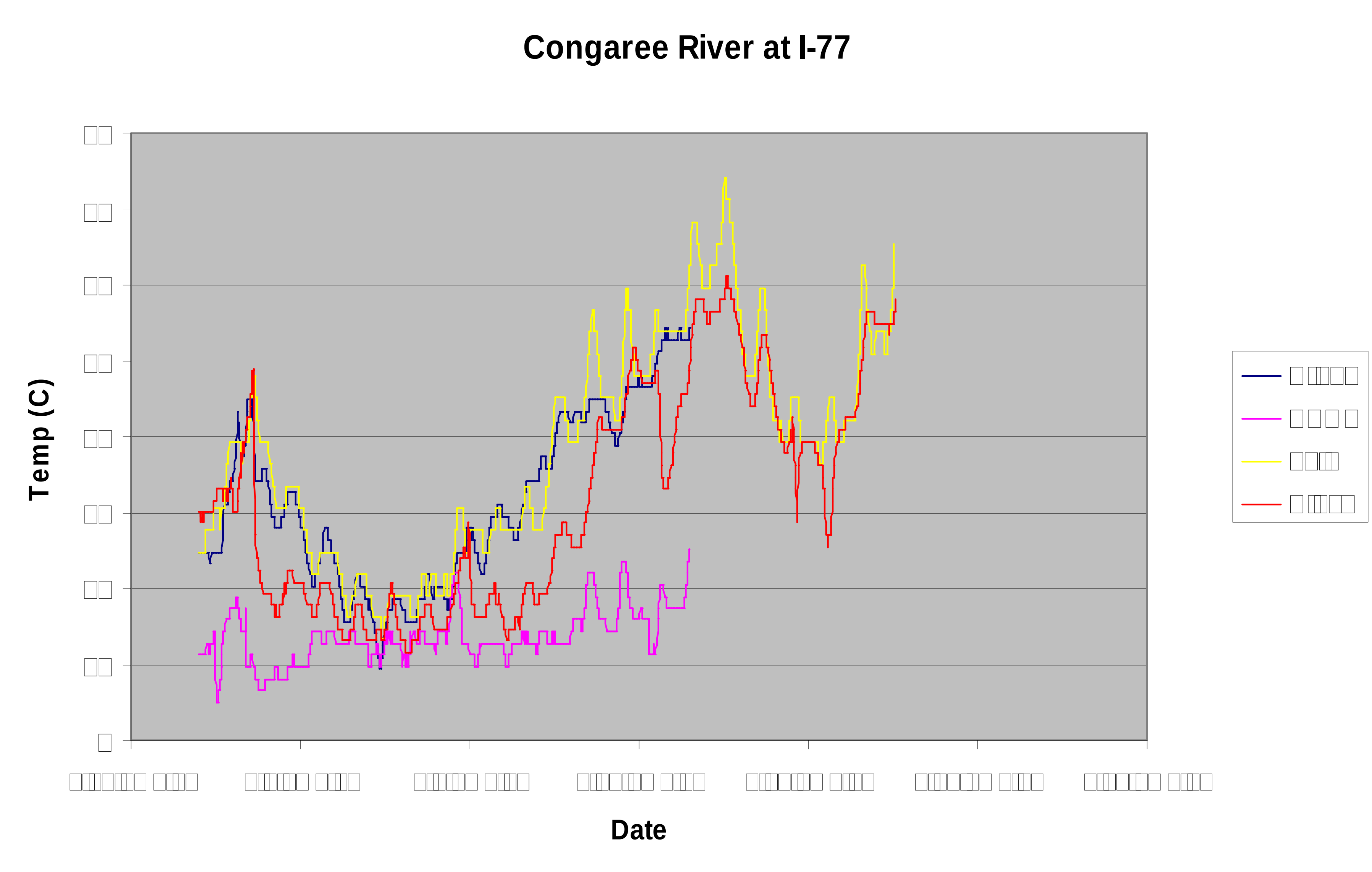
March 26, 2007

PAIRED TEMPERATURE SENSOR LOCATIONS

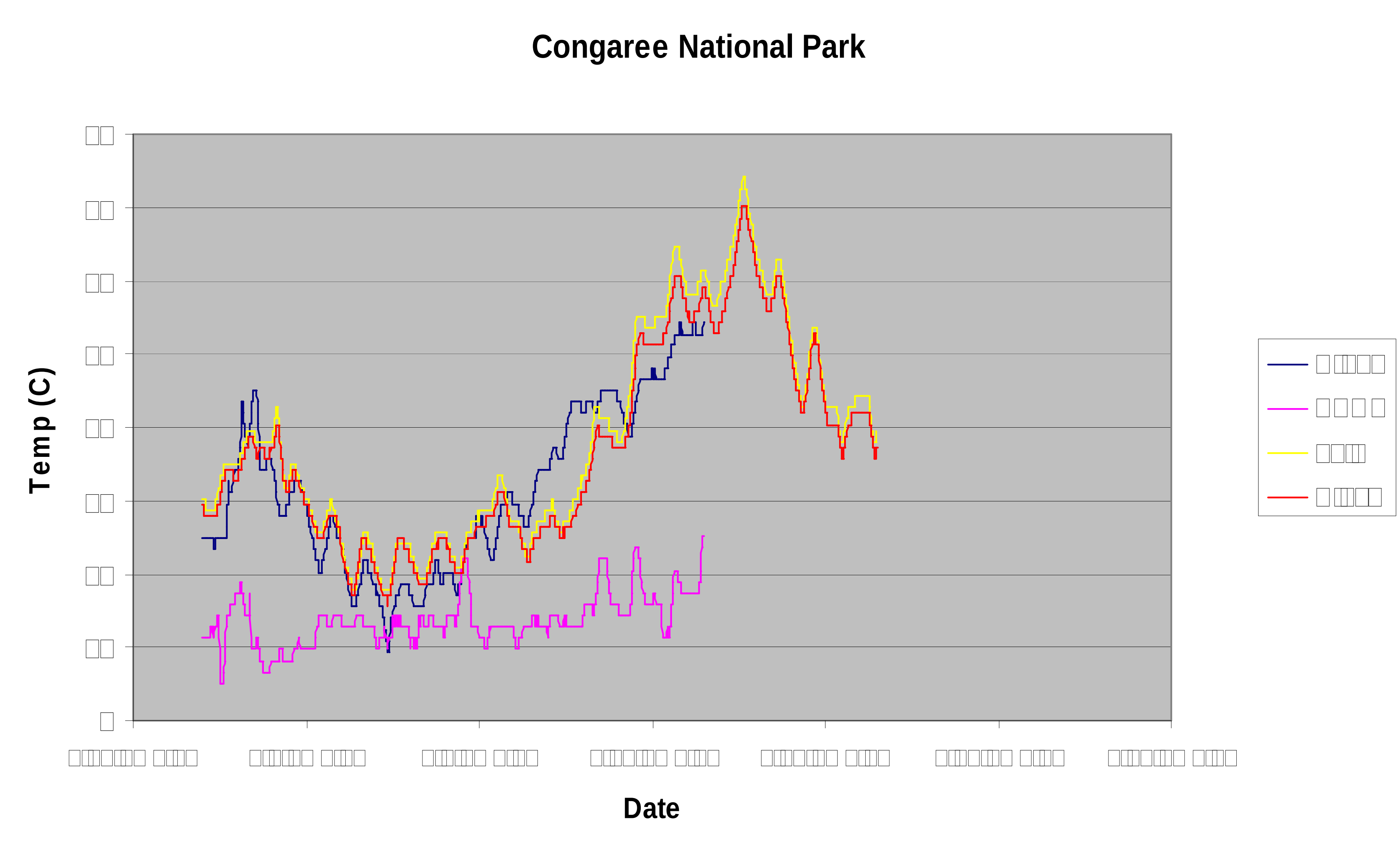



Lower Saluda River at Riverbanks Zoo
Temp (C)
Date


Congaree River at Gervais Street
Temp (C)
Date



Congaree River at I-77
Temp (C)
Date


Congaree National Park
Temp (C)
Date

Conclusions

- Congaree and Broad diverge from Saluda in early April
- Cross-sectional temperatures vary below confluence
- To date, data suggests that influence extends at least to I-77 Bridge

Challenges

- Vandalism / Theft
- Breakoffs (corrosion / snags / high flows)
- Inaccessibility of instruments due to high flows

Future Needs

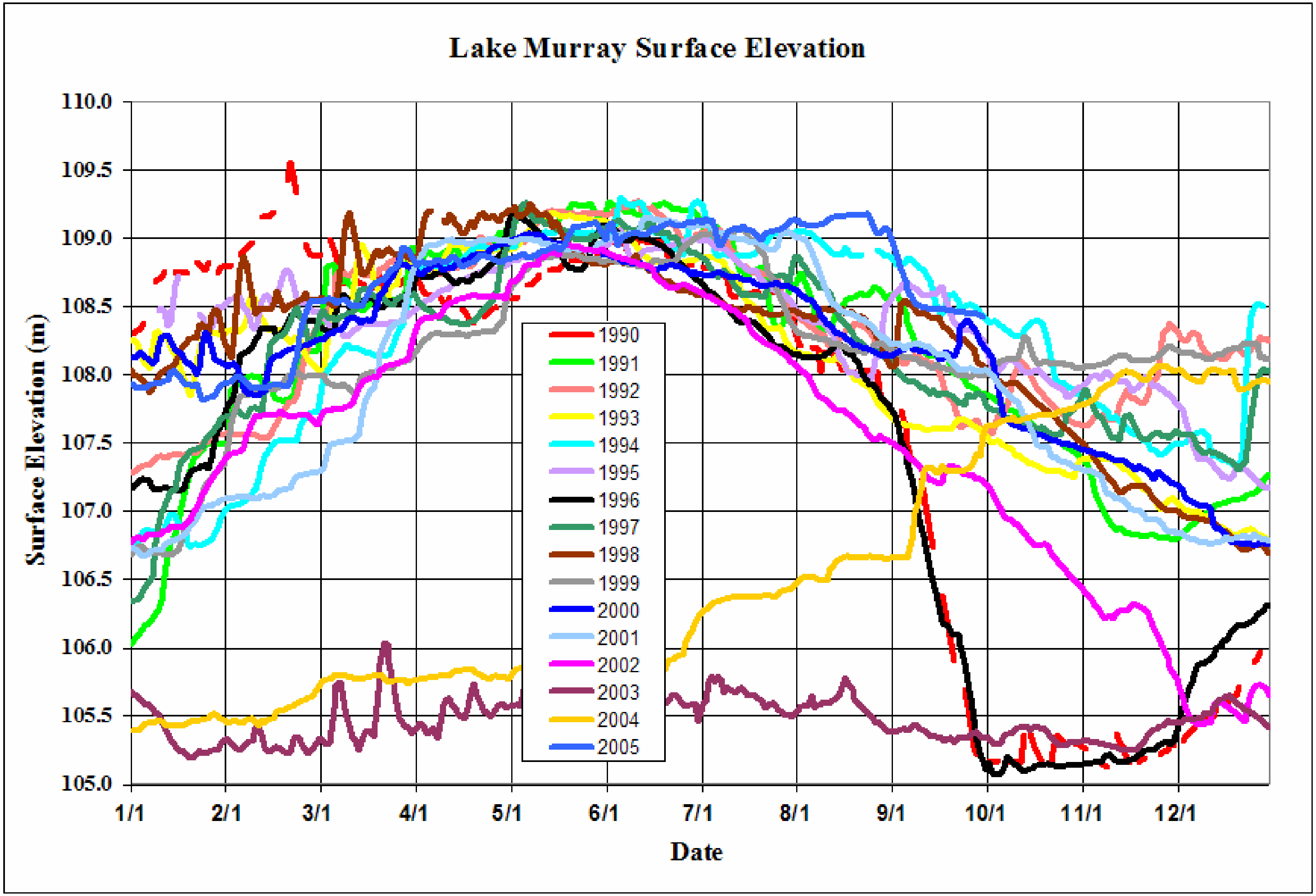
- Gather additional data through October 2007
- Evaluate temperature impacts under varying flow conditions (i.e. varying inflows/operations, normal precipitation)
- Appropriate statistical analysis methods
  - missing values
  - How to deal with errors (i.e. due disturbance of probe, etc.)

Update on Analyses of Factors Contributing to Historical Fish Kills in Lake Murray

Andy Sawyer and Jim Ruane, REMI

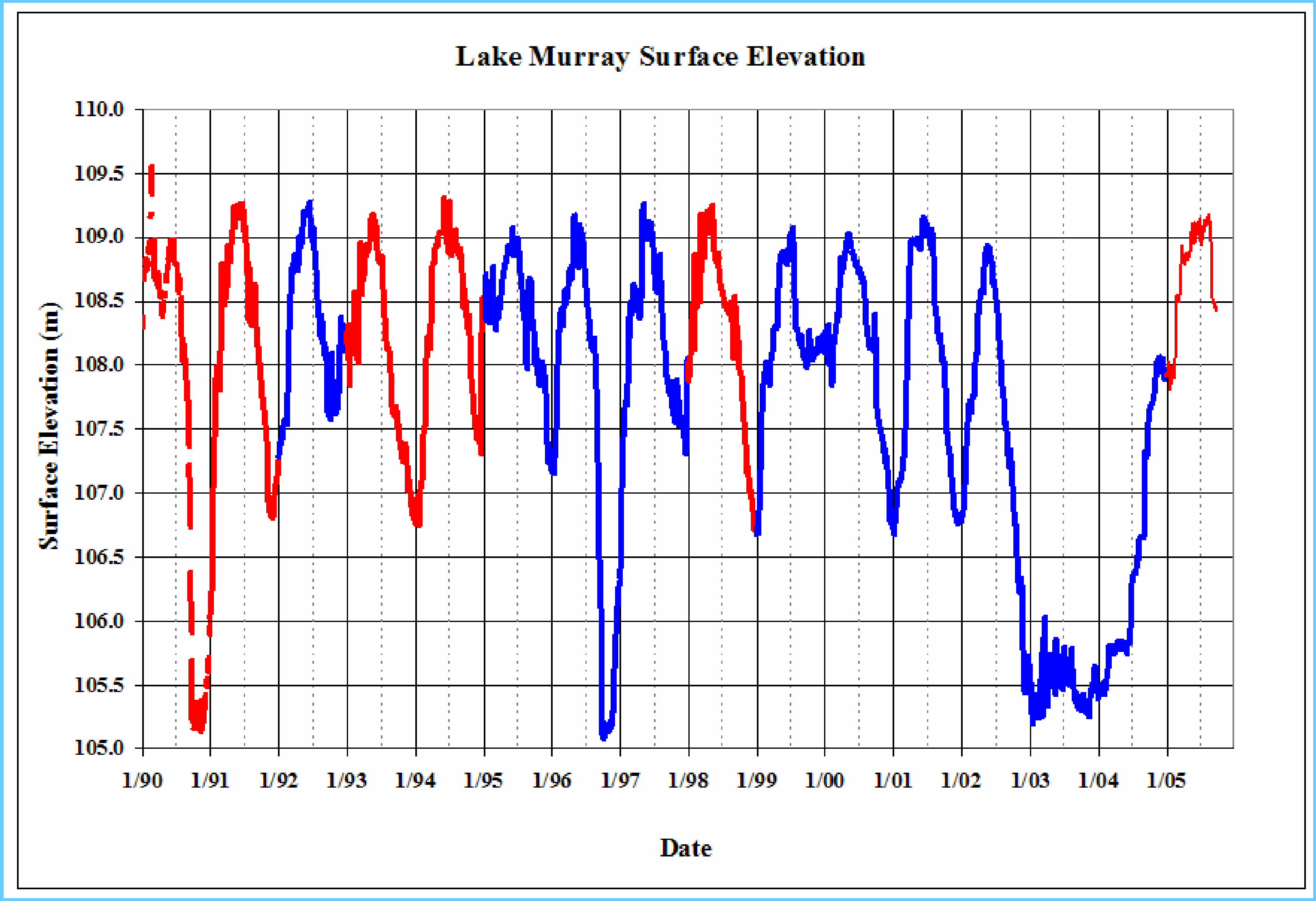
November 13, 2006

Lake Murray Surface Elevation 1990-2005

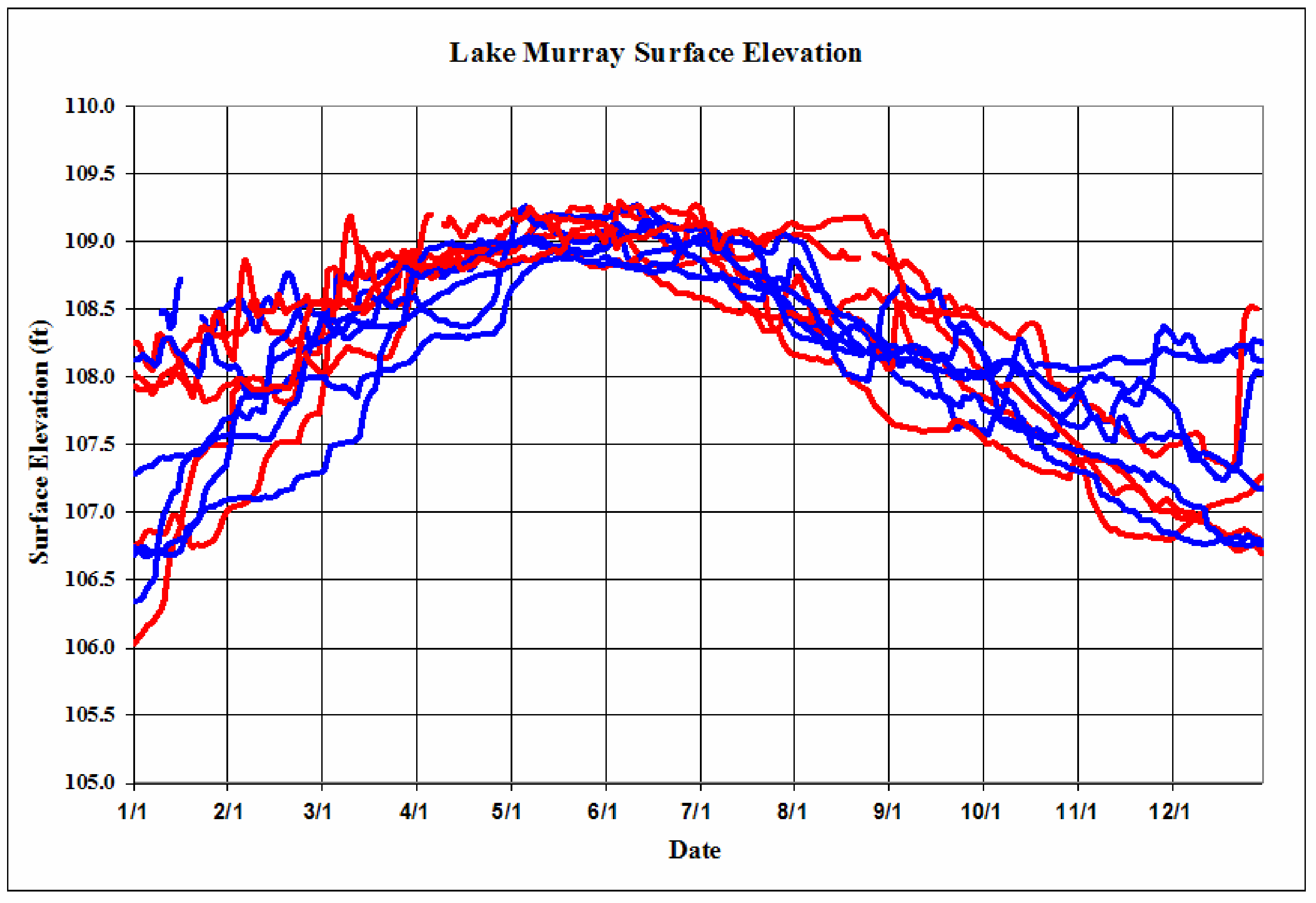


Lake Murray Surface Elevation 1990-2005

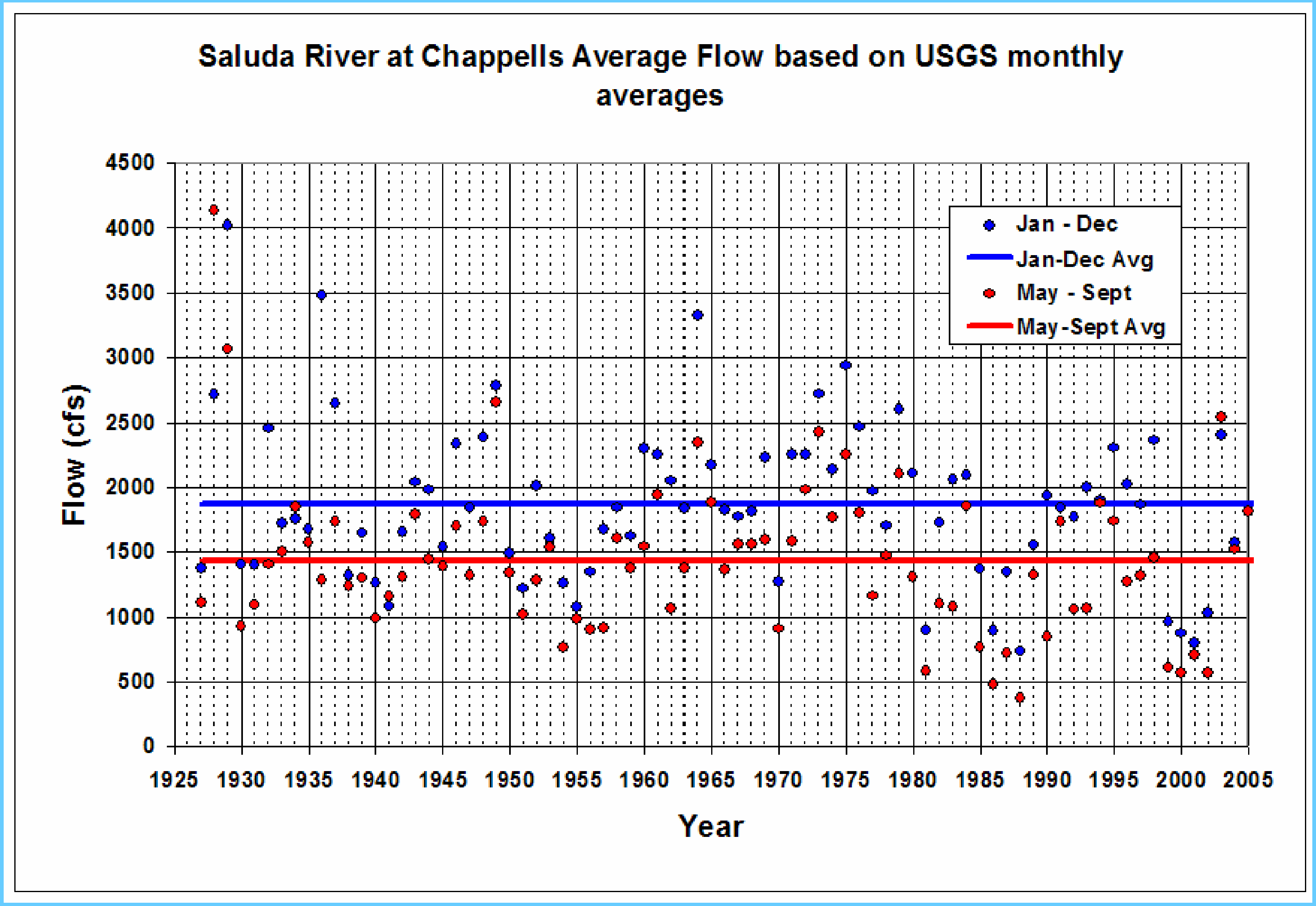
Years with documented striped bass kills are red



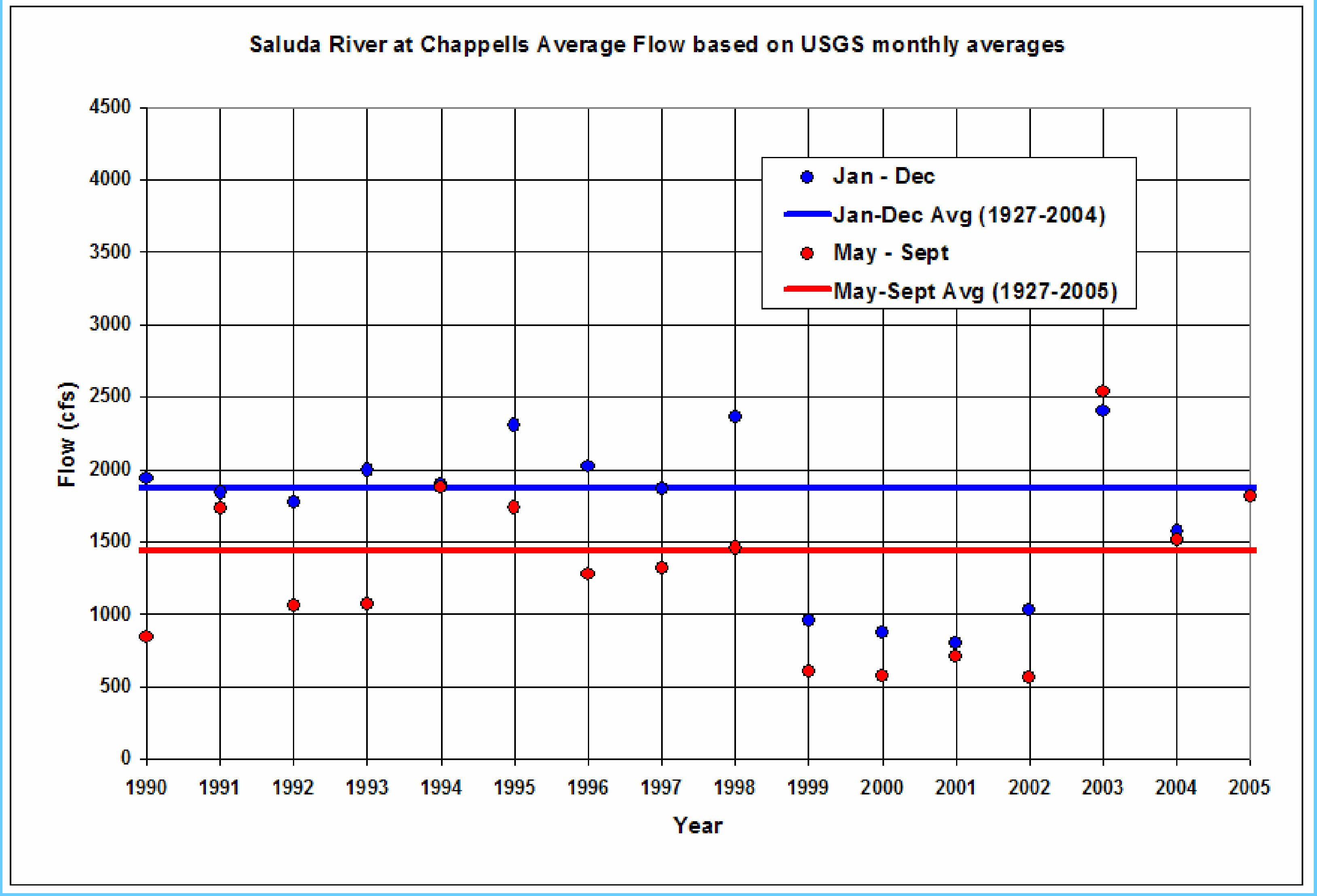
Lake Murray Surface Elevation 1990-2005
Typical Years Only (no special drawdowns)
Years with documented striped bass kills are red



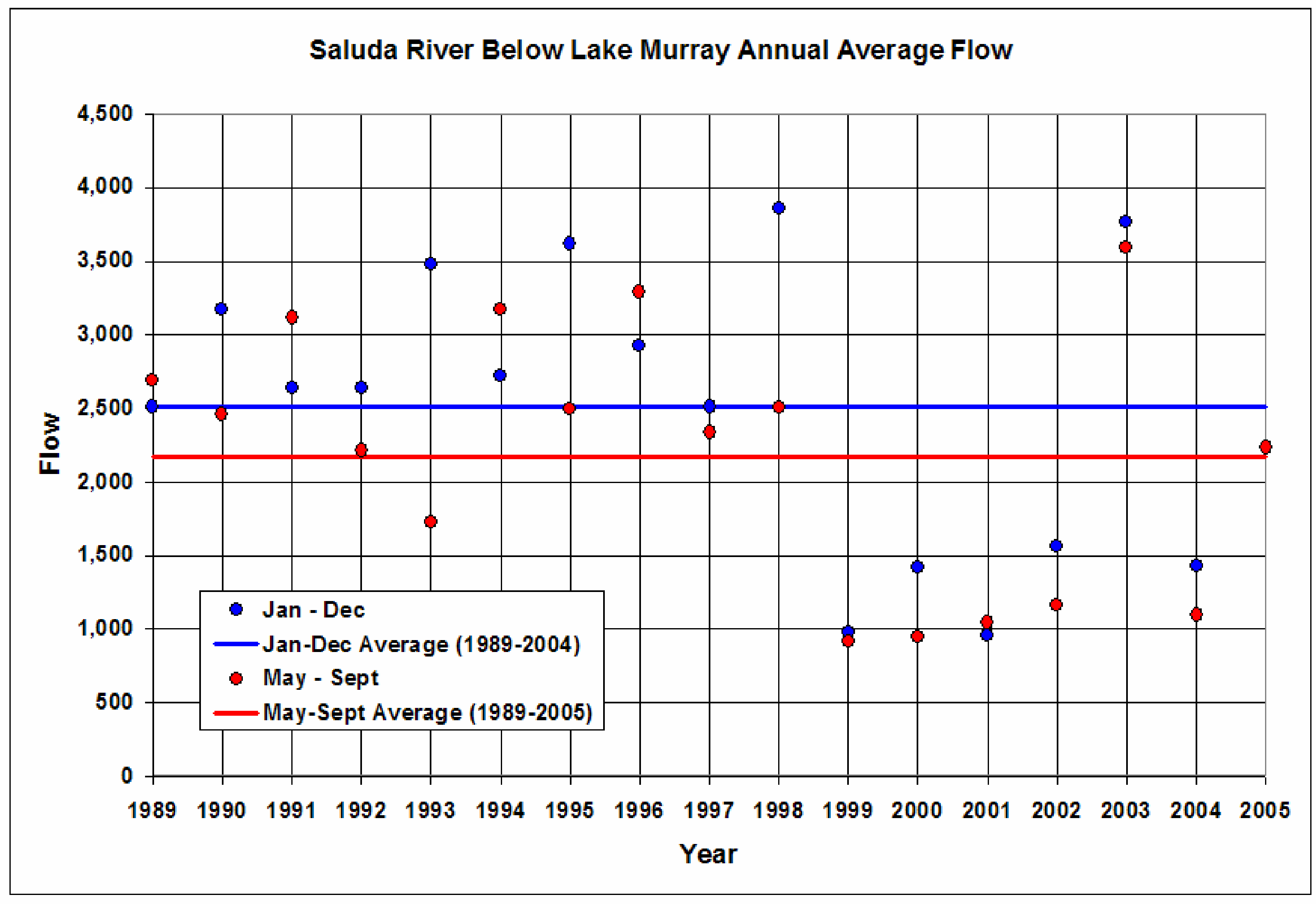
Average Annual Flow – Saluda River at Chappells



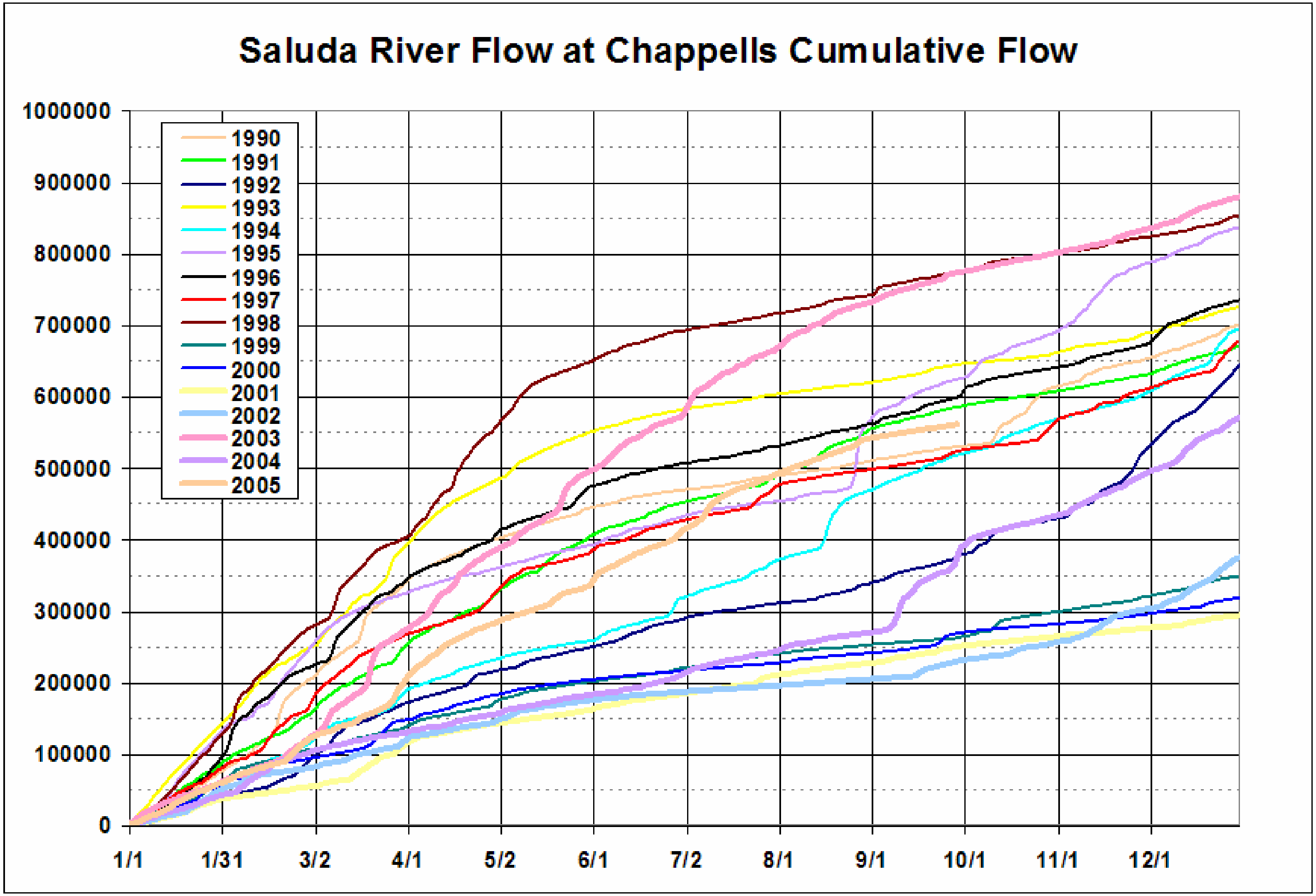
Average Annual Flow – Saluda River at Chappells 1990-2005



Average Annual Flow – Saluda River Below Lake Murray

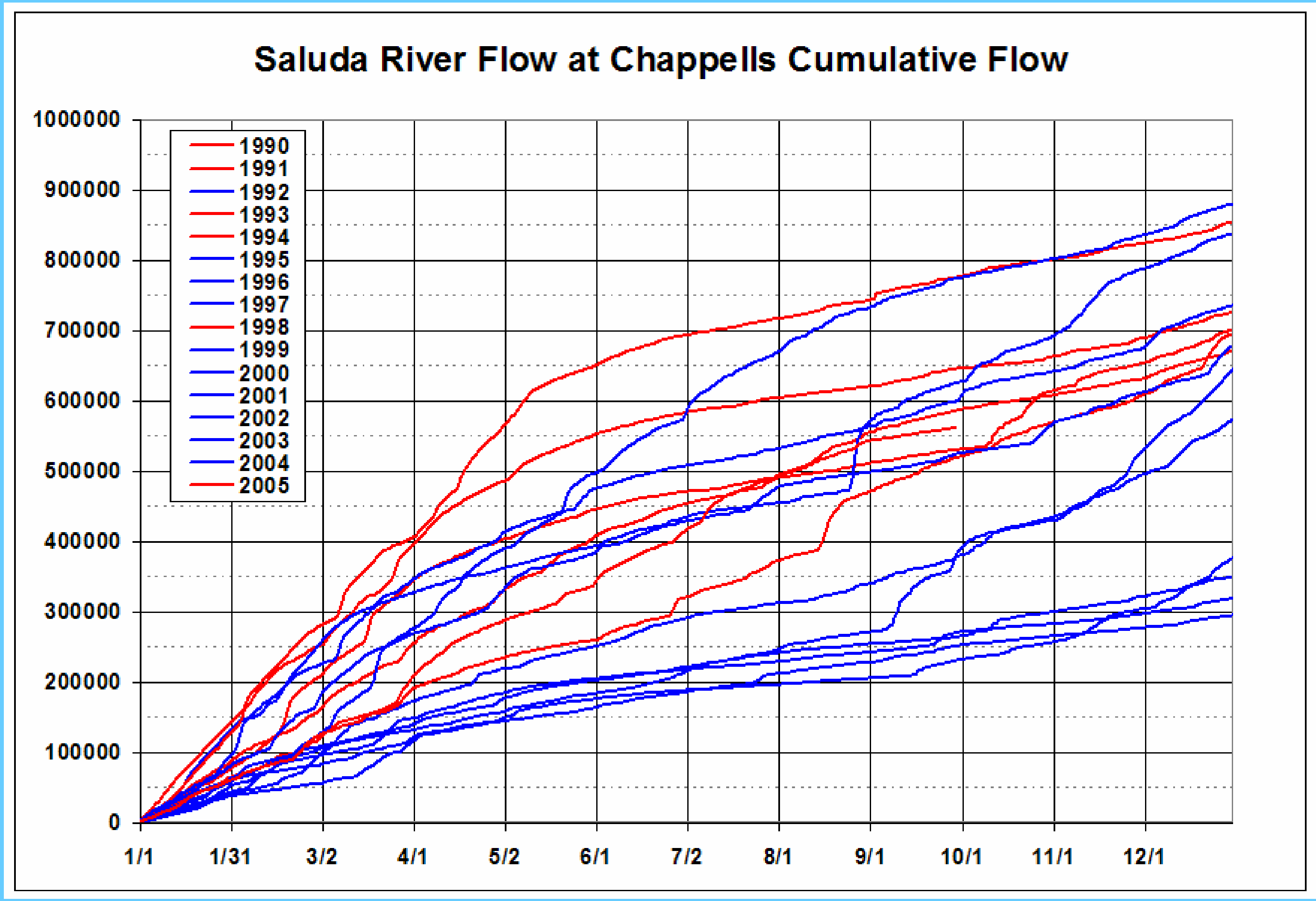


Cumulative Inflow

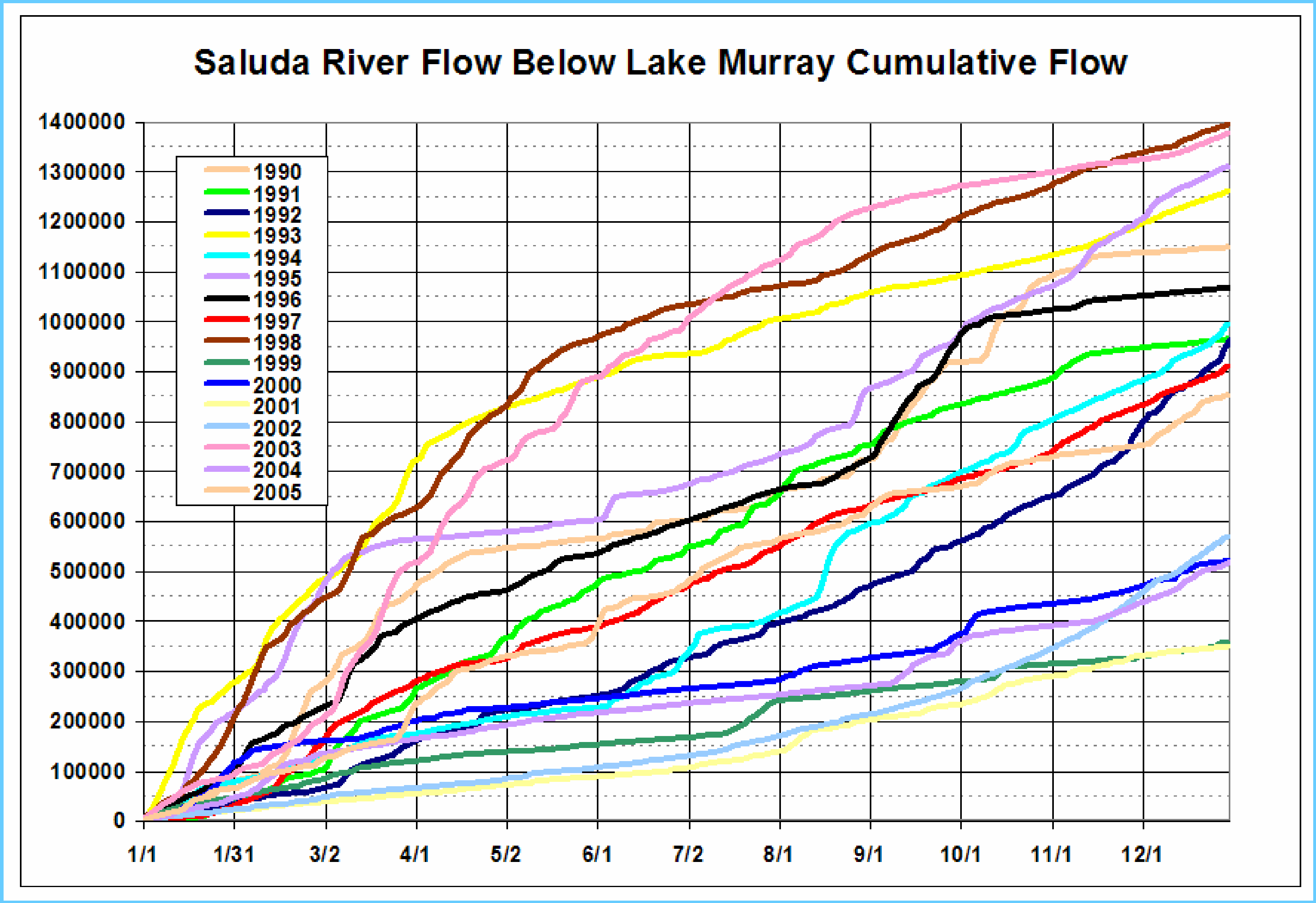


Cumulative Inflow

Years with documented striped bass kills are red

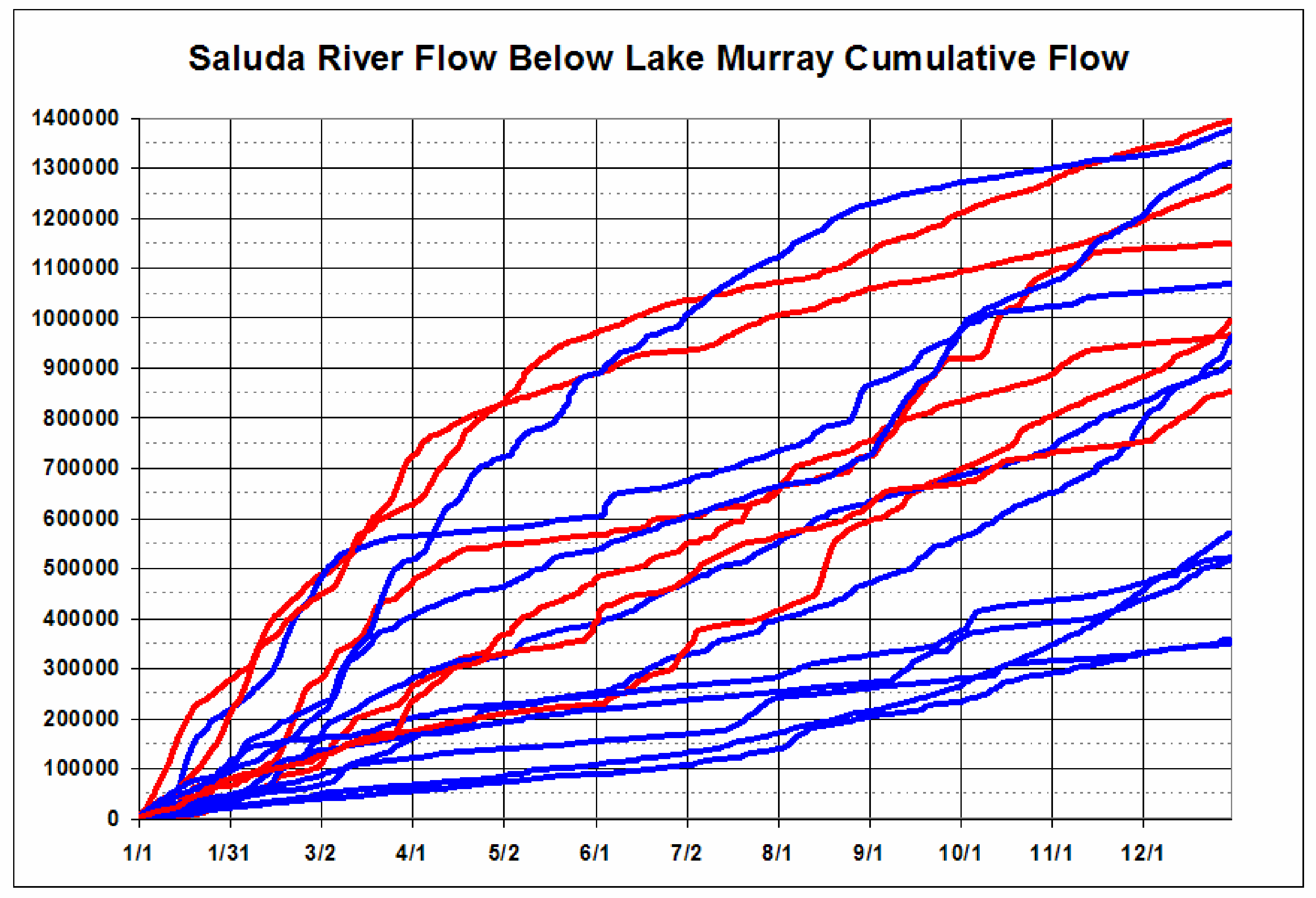


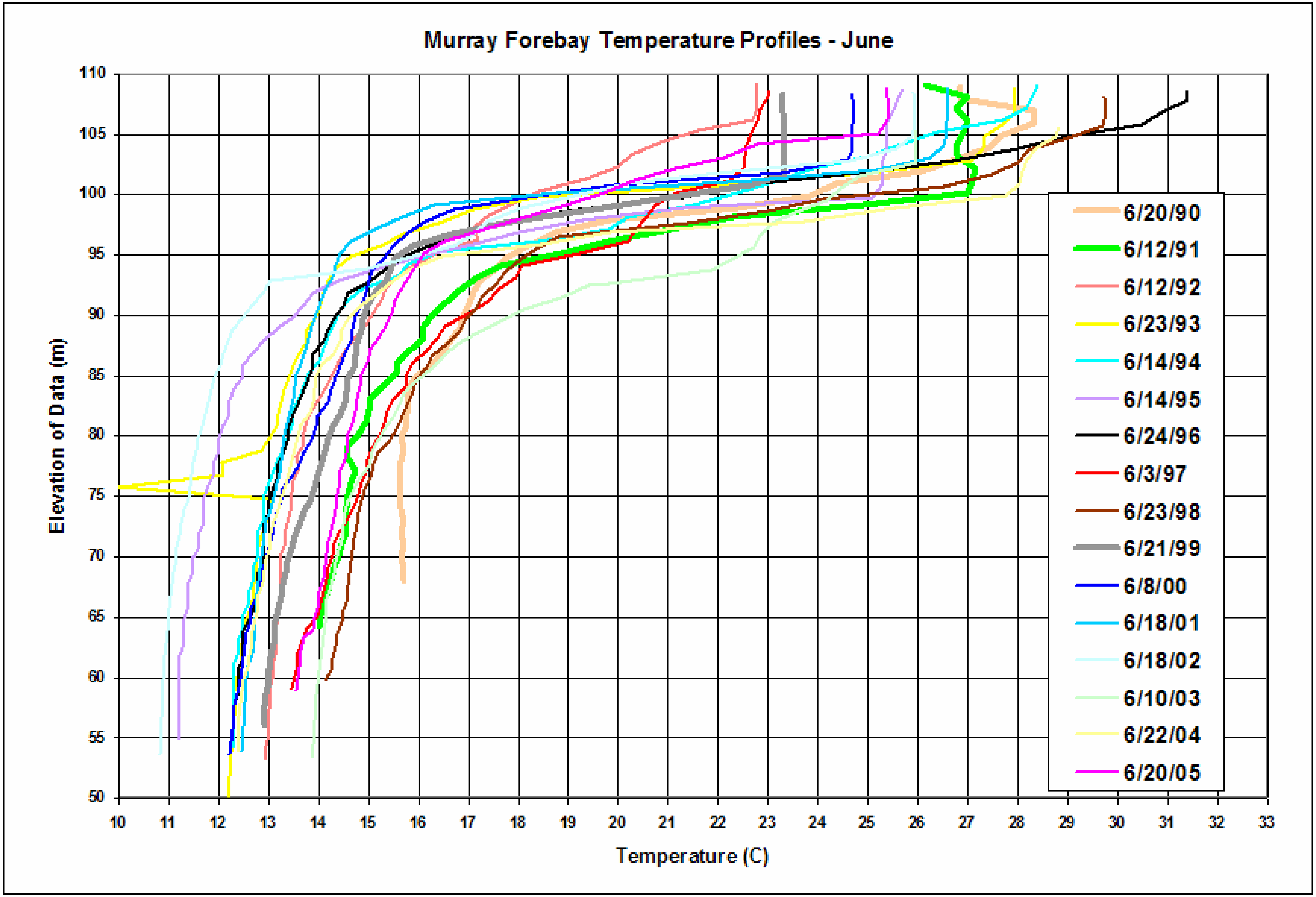
Cumulative Outflow



Cumulative Outflow

Years with documented striped bass kills are red





Murray Forebay Temperature Profiles - June
Elevation of Data (m)
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Temperature (C)
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6/12/91
6/12/92
6/23/93
6/14/94
6/14/95
6/24/96
6/3/97
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6/21/99
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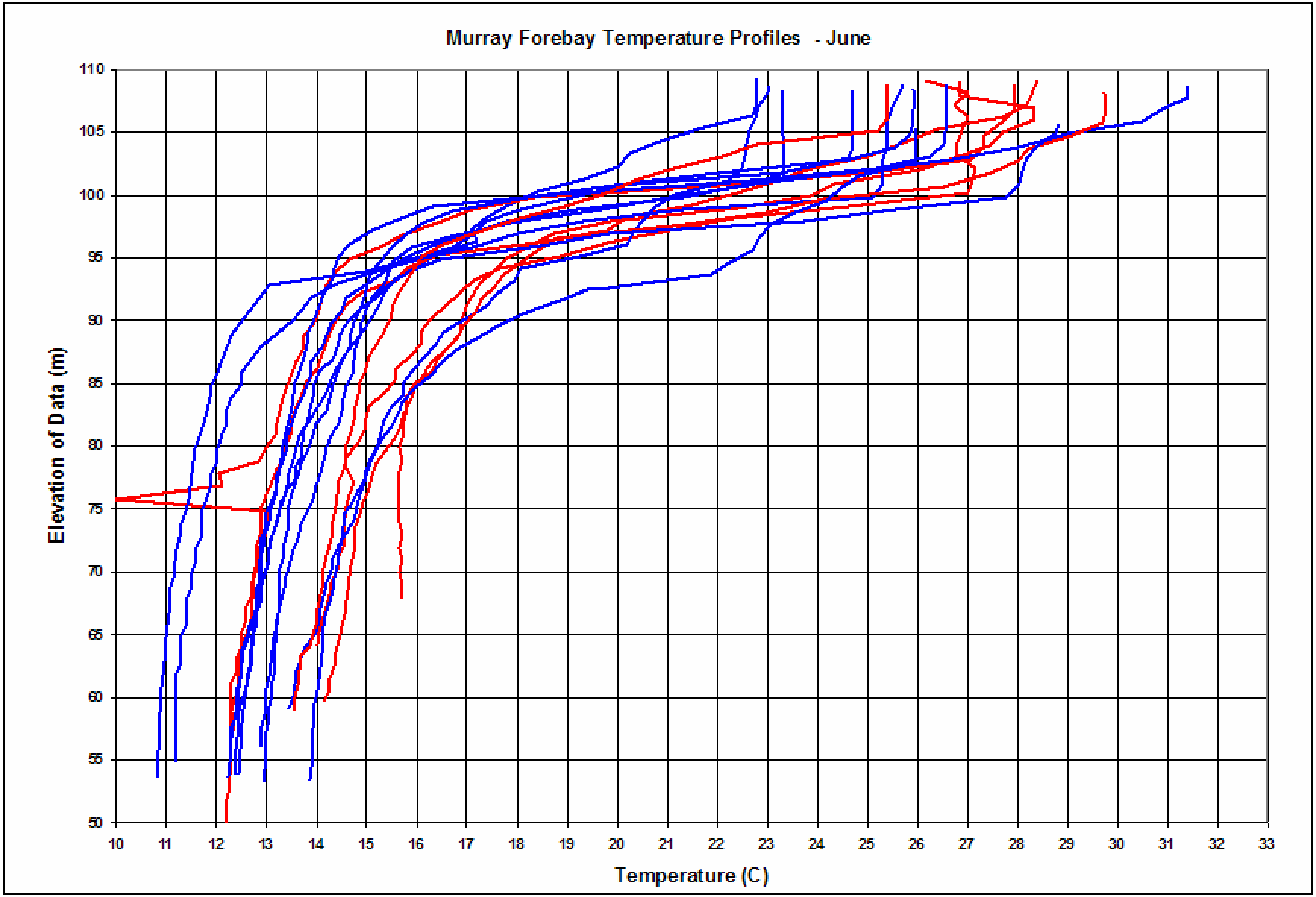
6/10/03
6/22/04
6/20/05



Murray Forebay Temperature Profiles - June
Elevation of Data (m)
Temperature (C)
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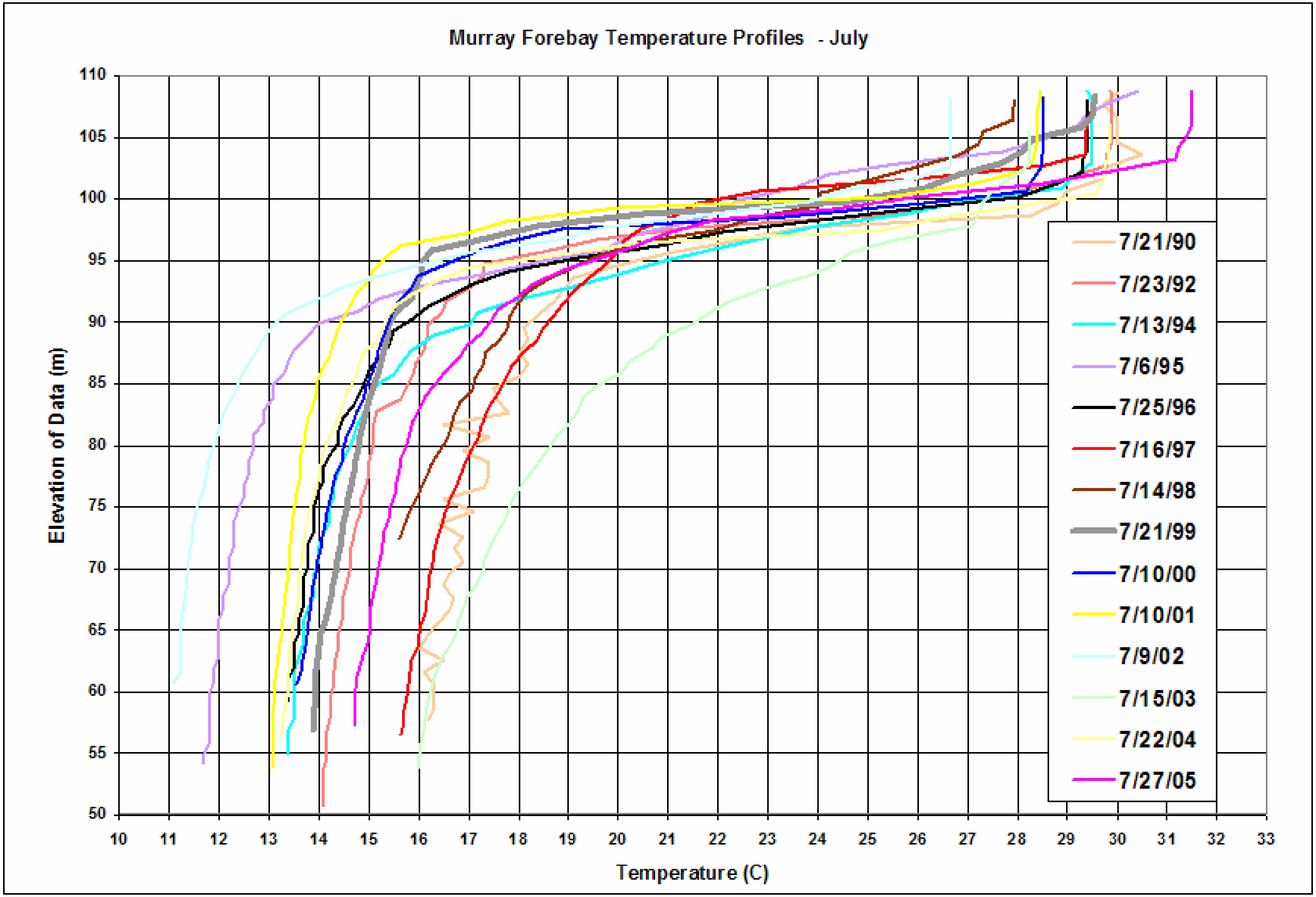

Murray Forebay Temperature Profiles - July
Elevation of Data (m)
Temperature (C)
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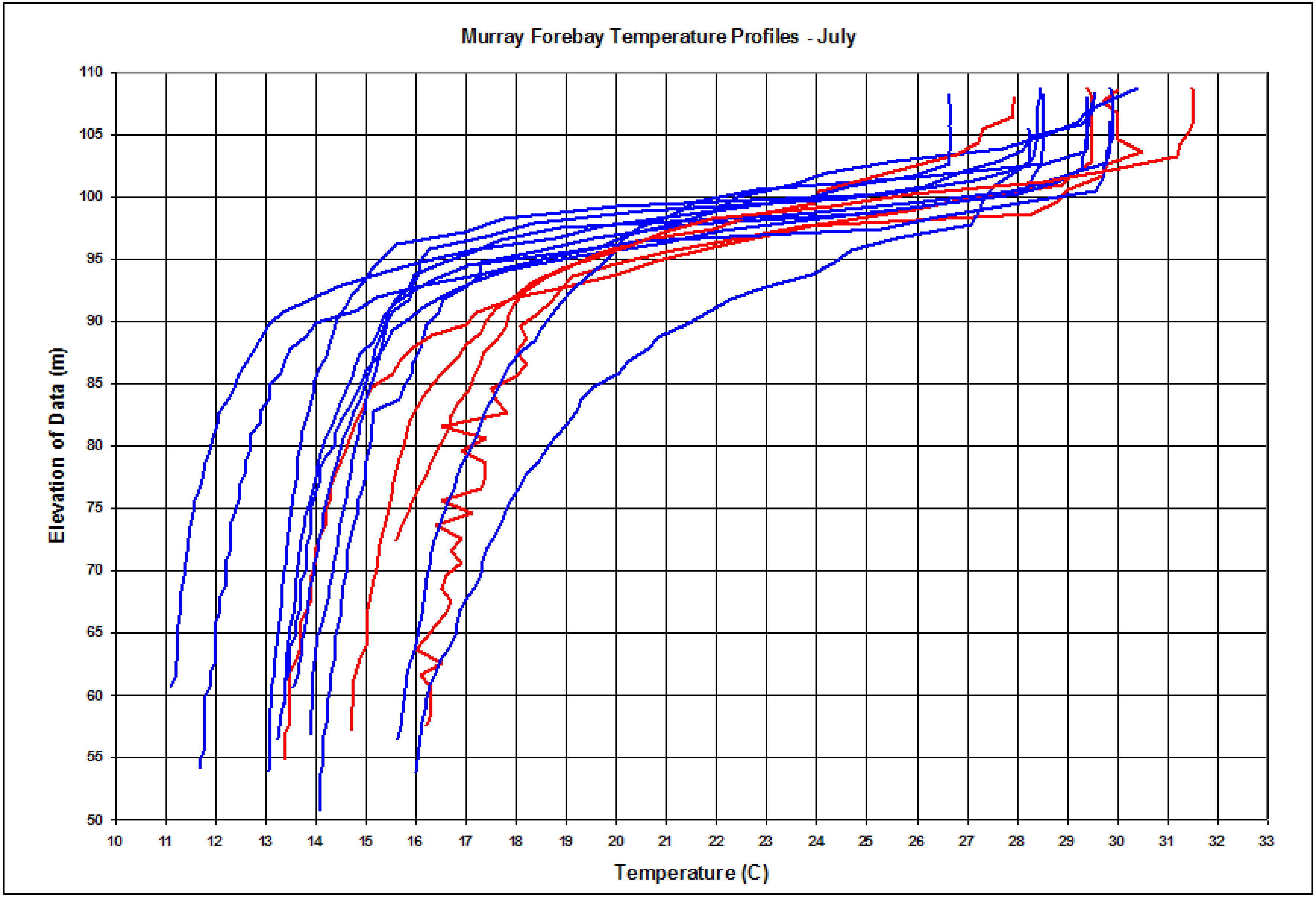

Murray Forebay Temperature Profiles - July
Elevation of Data (m)
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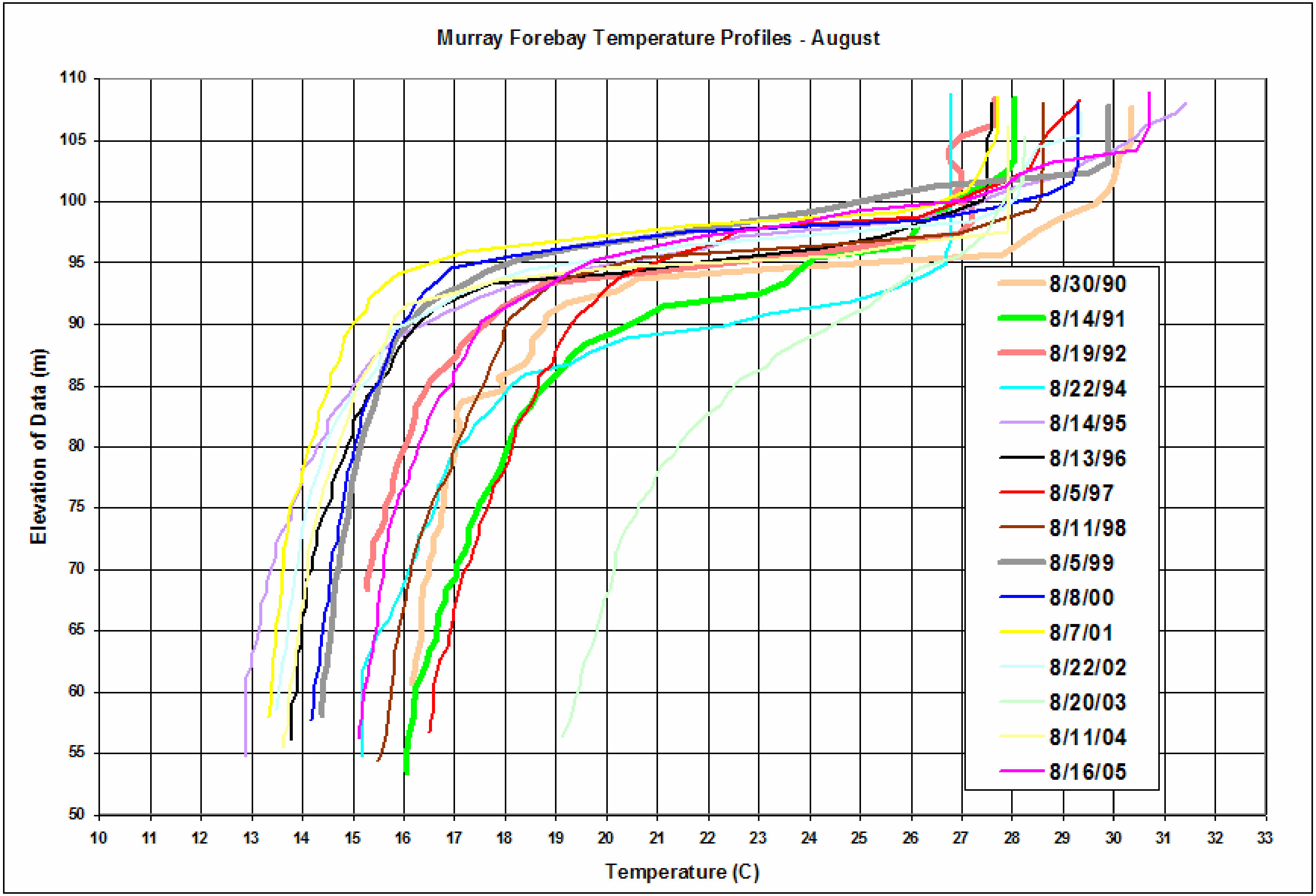
Temperature (C)



Murray Forebay Temperature Profiles - August
Elevation of Data (m)
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30
31
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33
Temperature (C)
8/30/90
8/14/91
8/19/92
8/22/94
8/14/95
8/13/96
8/5/97
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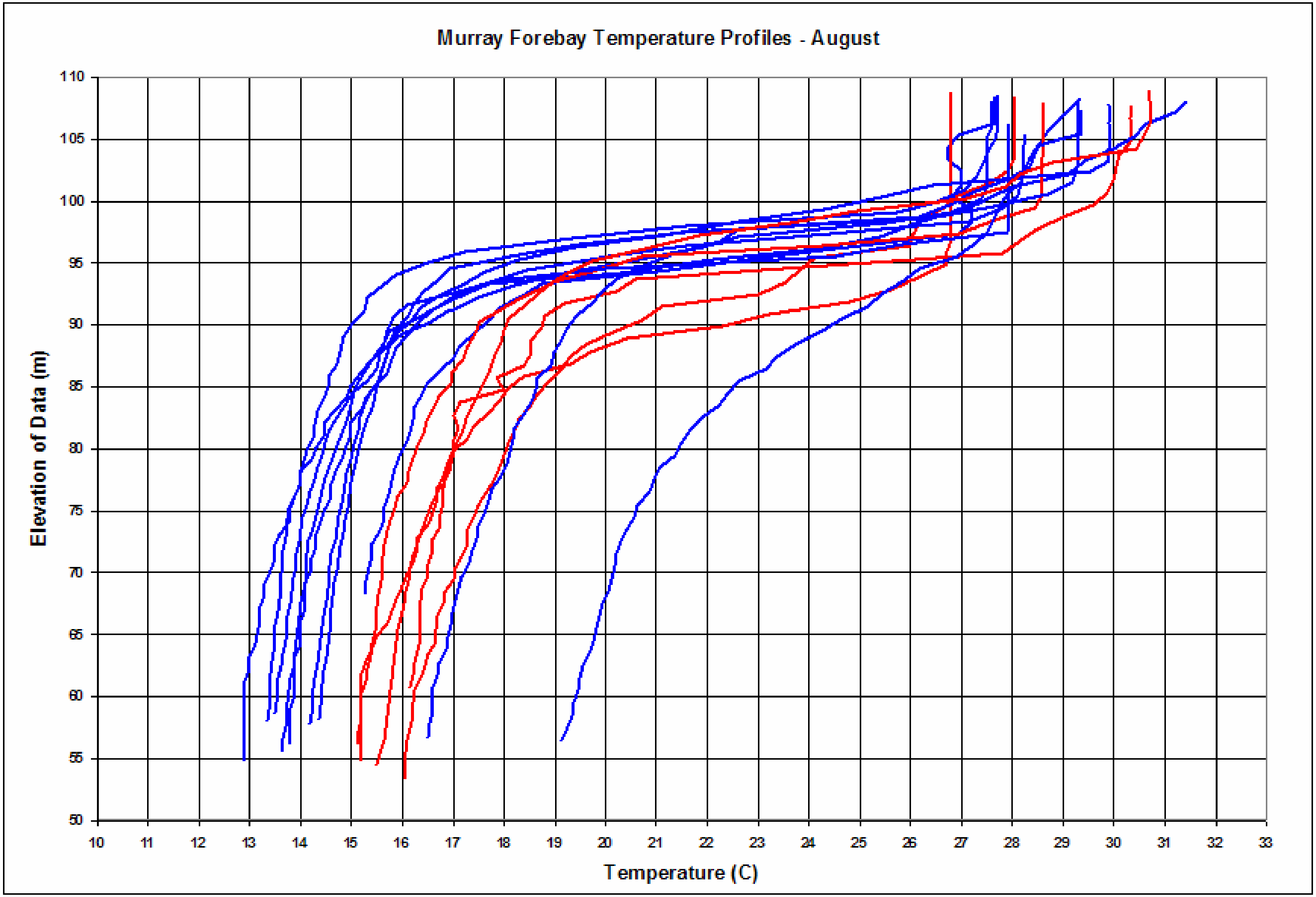
Murray Forebay Temperature Profiles - August
Elevation of Data (m)
Temperature (C)
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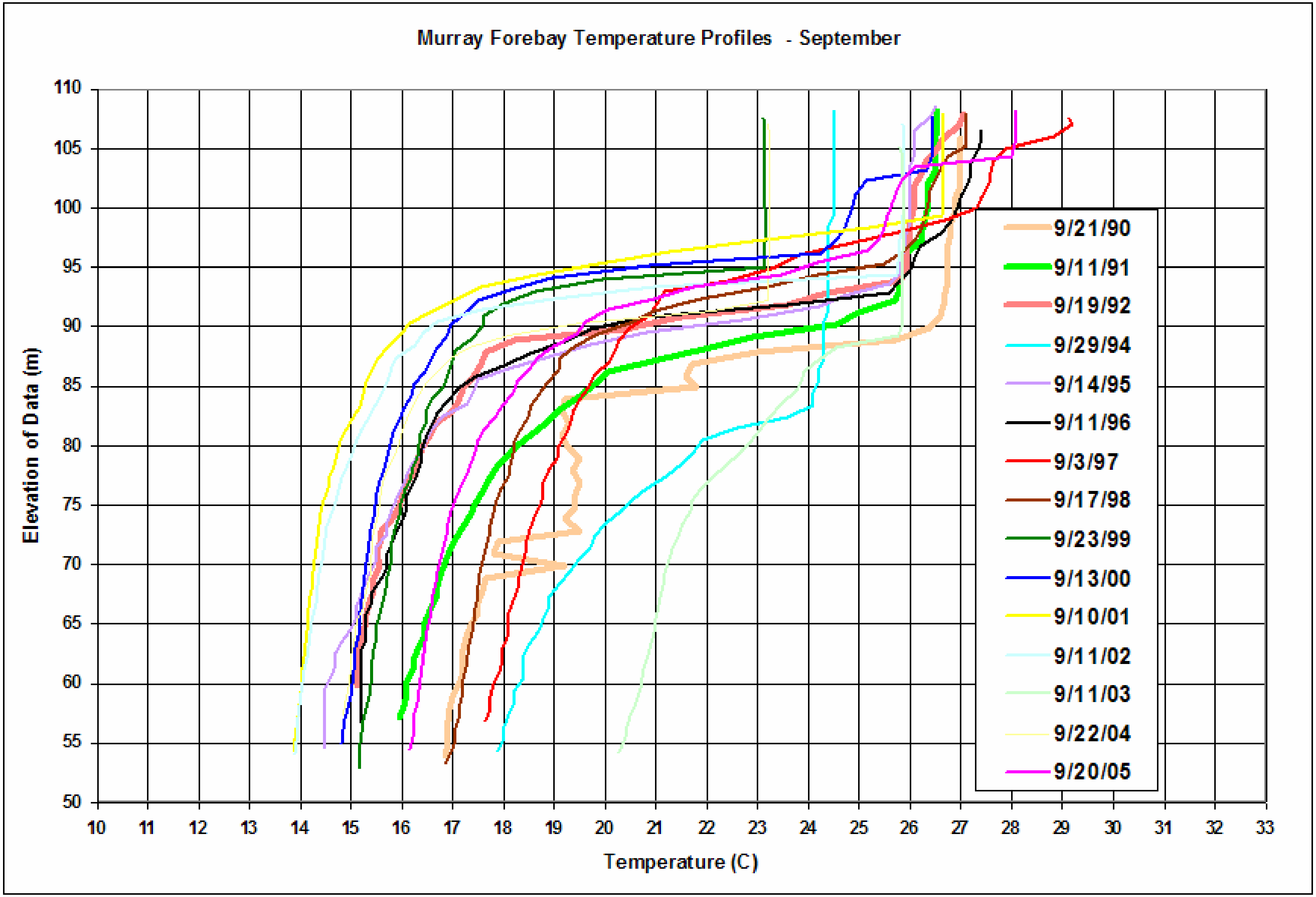
Murray Forebay Temperature Profiles - September
Elevation of Data (m)
Temperature (C)
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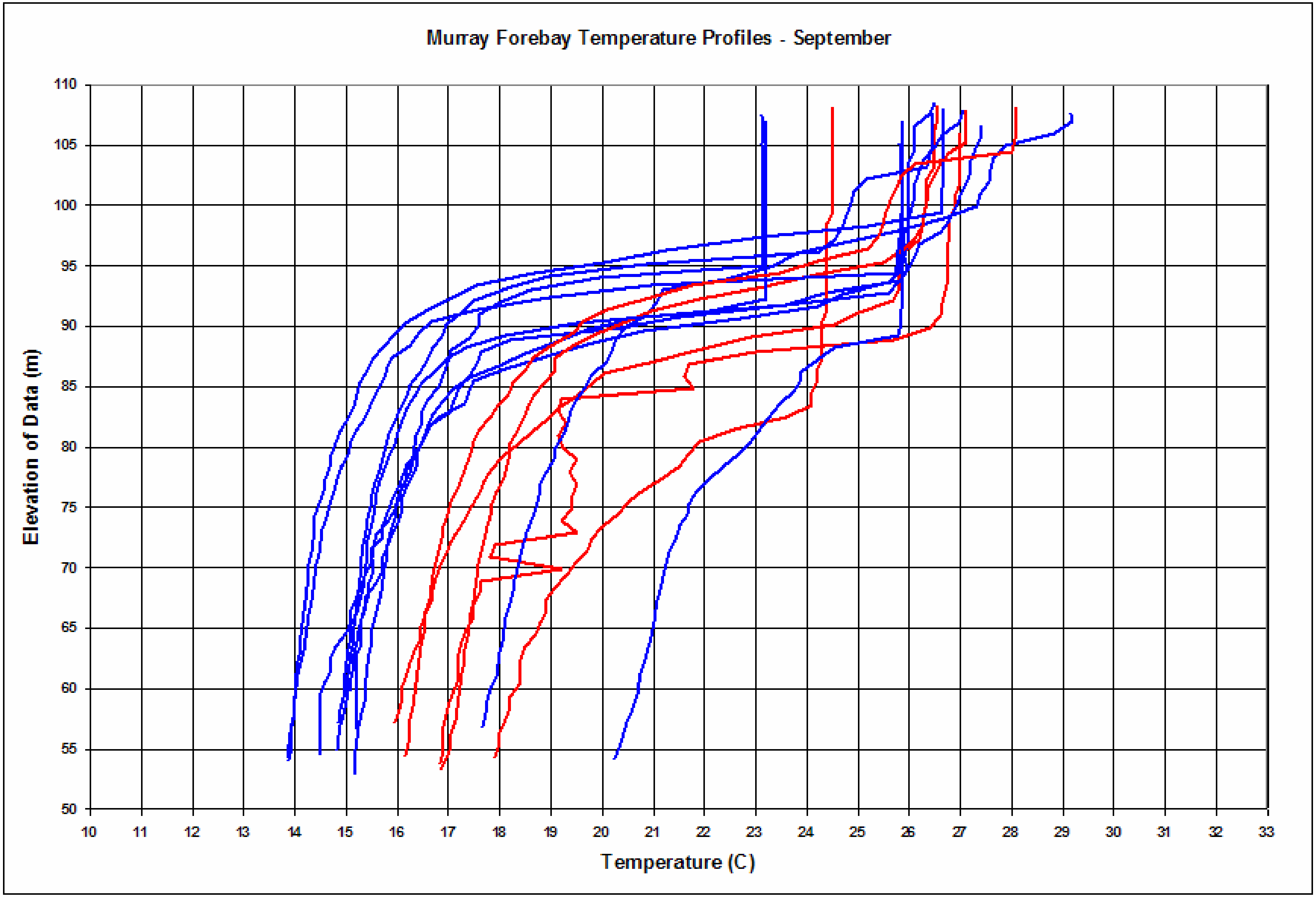
9/20/05



Murray Forebay Temperature Profiles - September
Elevation of Data (m)
Temperature (C)
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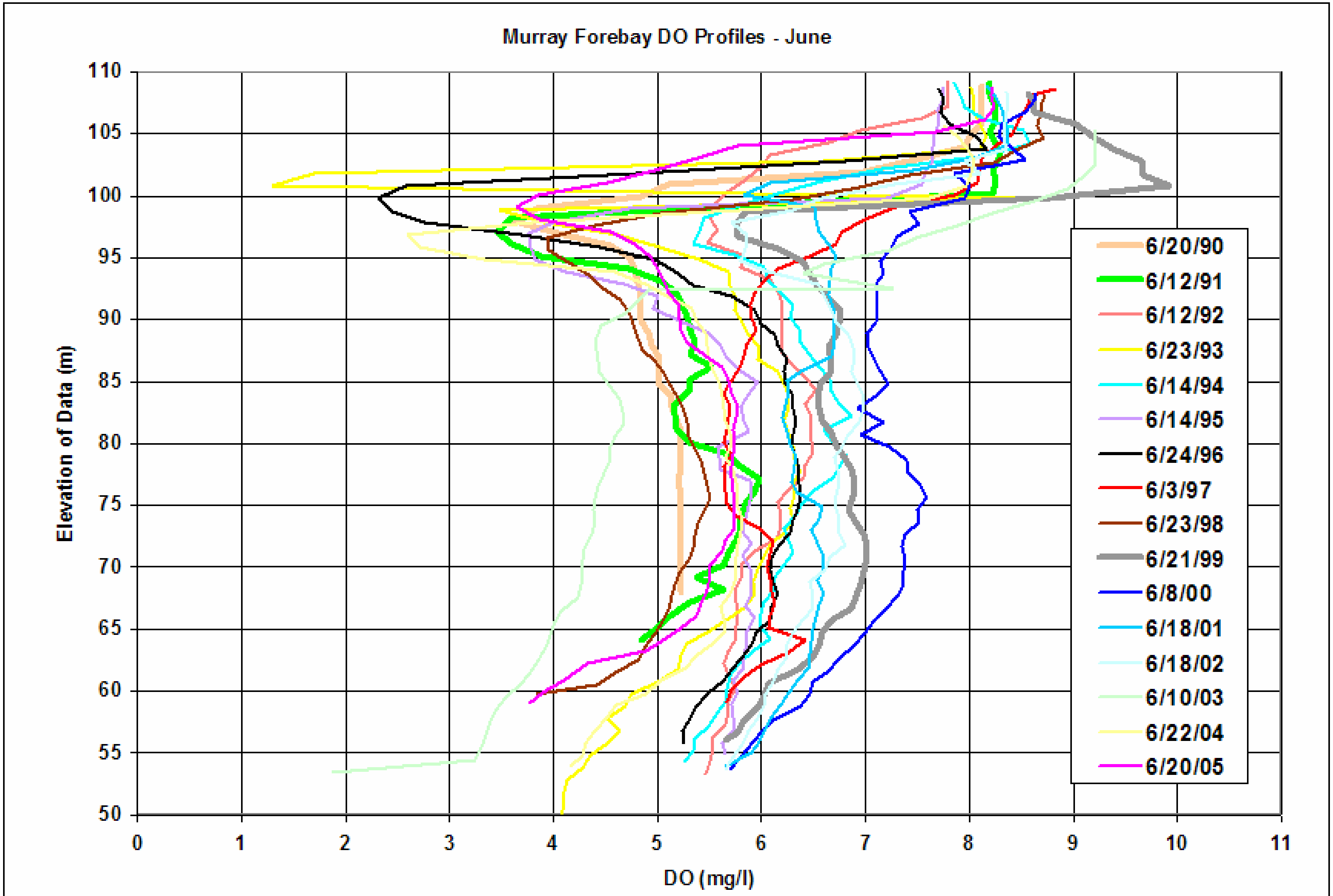

Murray Forebay DO Profiles - June
Elevation of Data (m)
110
105
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0
1
2
3
4
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6
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11
DO (mg/l)
6/20/90
6/12/91
6/12/92
6/23/93
6/14/94
6/14/95
6/24/96
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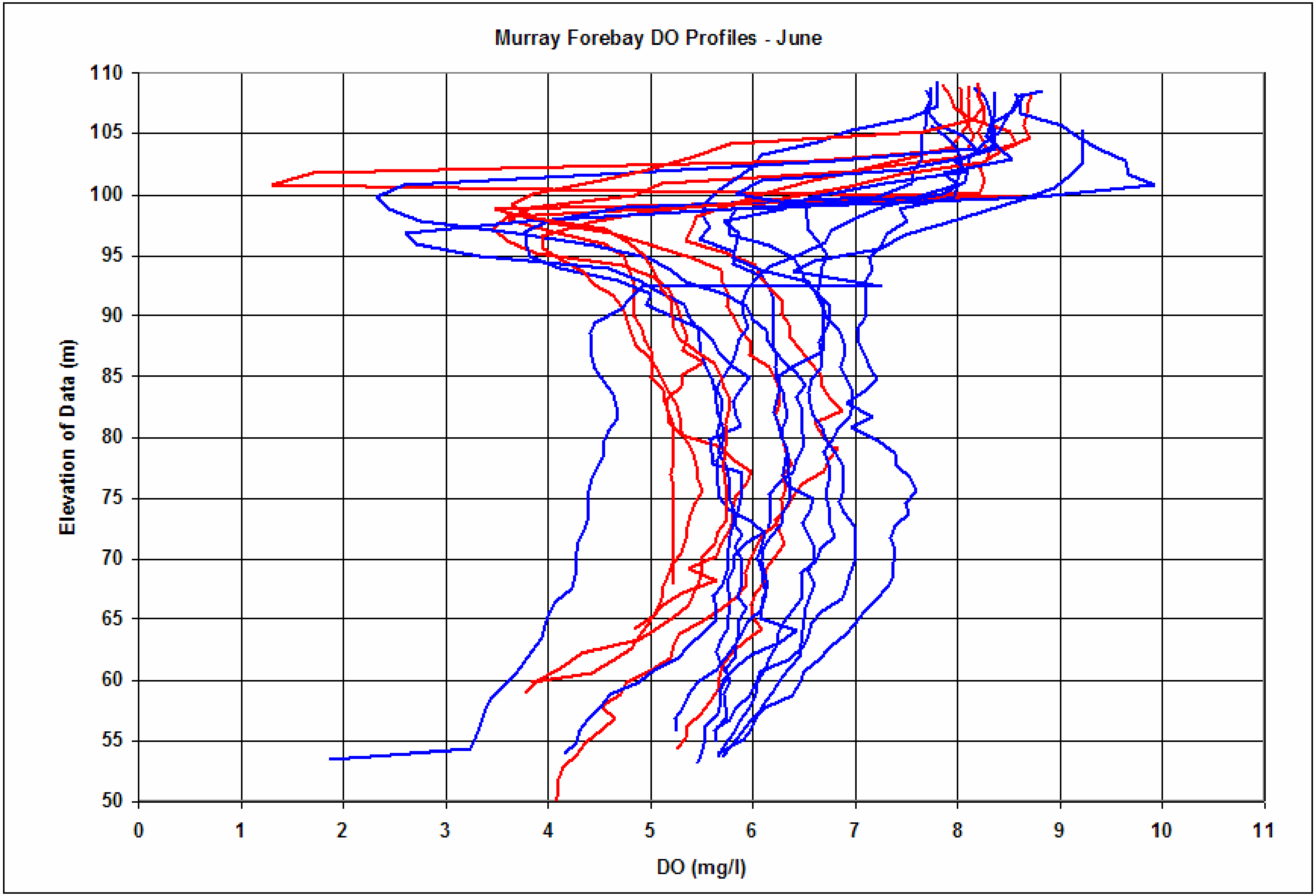
6/22/04
6/20/05



Murray Forebay DO Profiles - June
Elevation of Data (m)
DO (mg/l)
110
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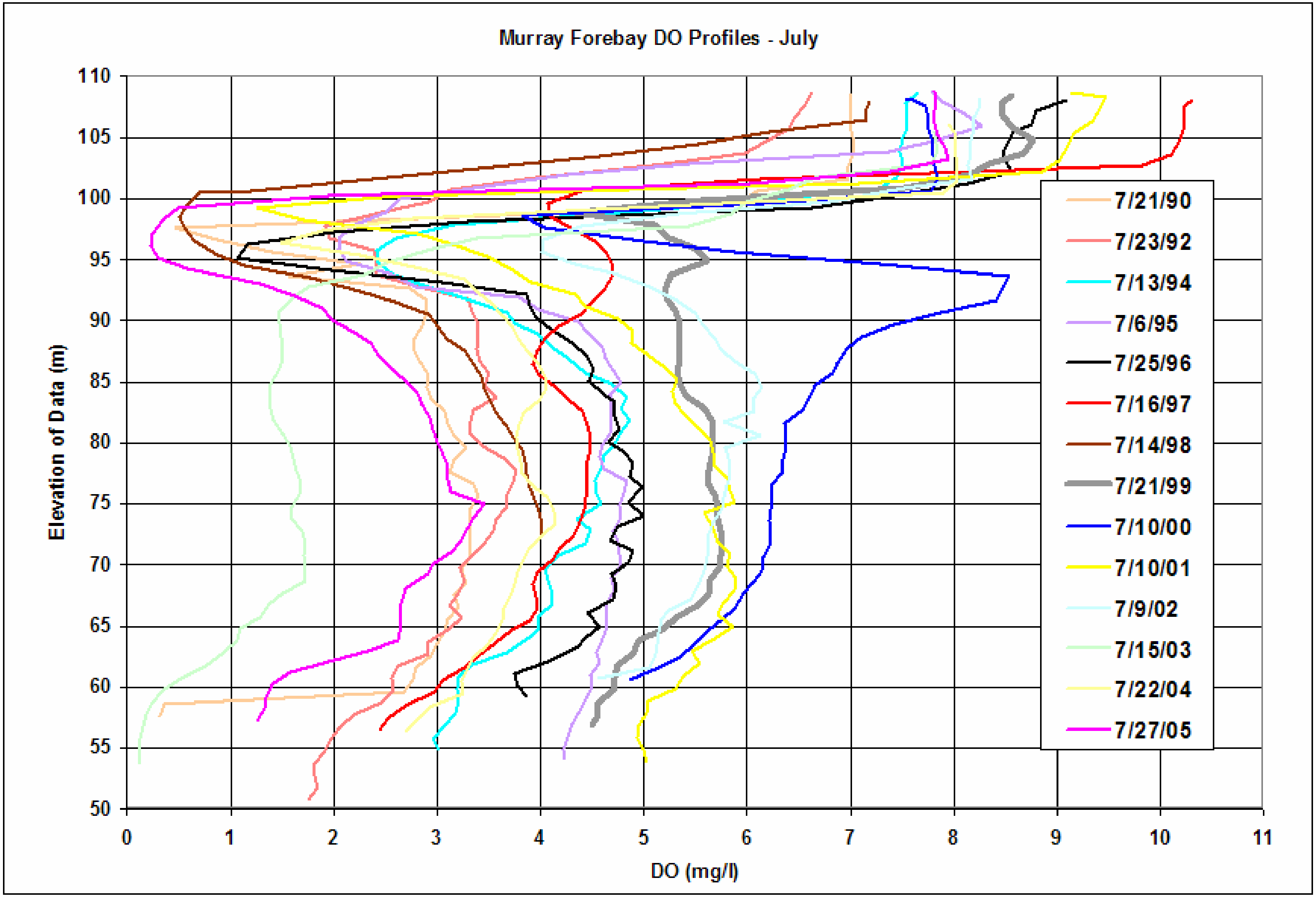

Murray Forebay DO Profiles - July
Elevation of Data (m)
DO (mg/l)
110
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7/6/95
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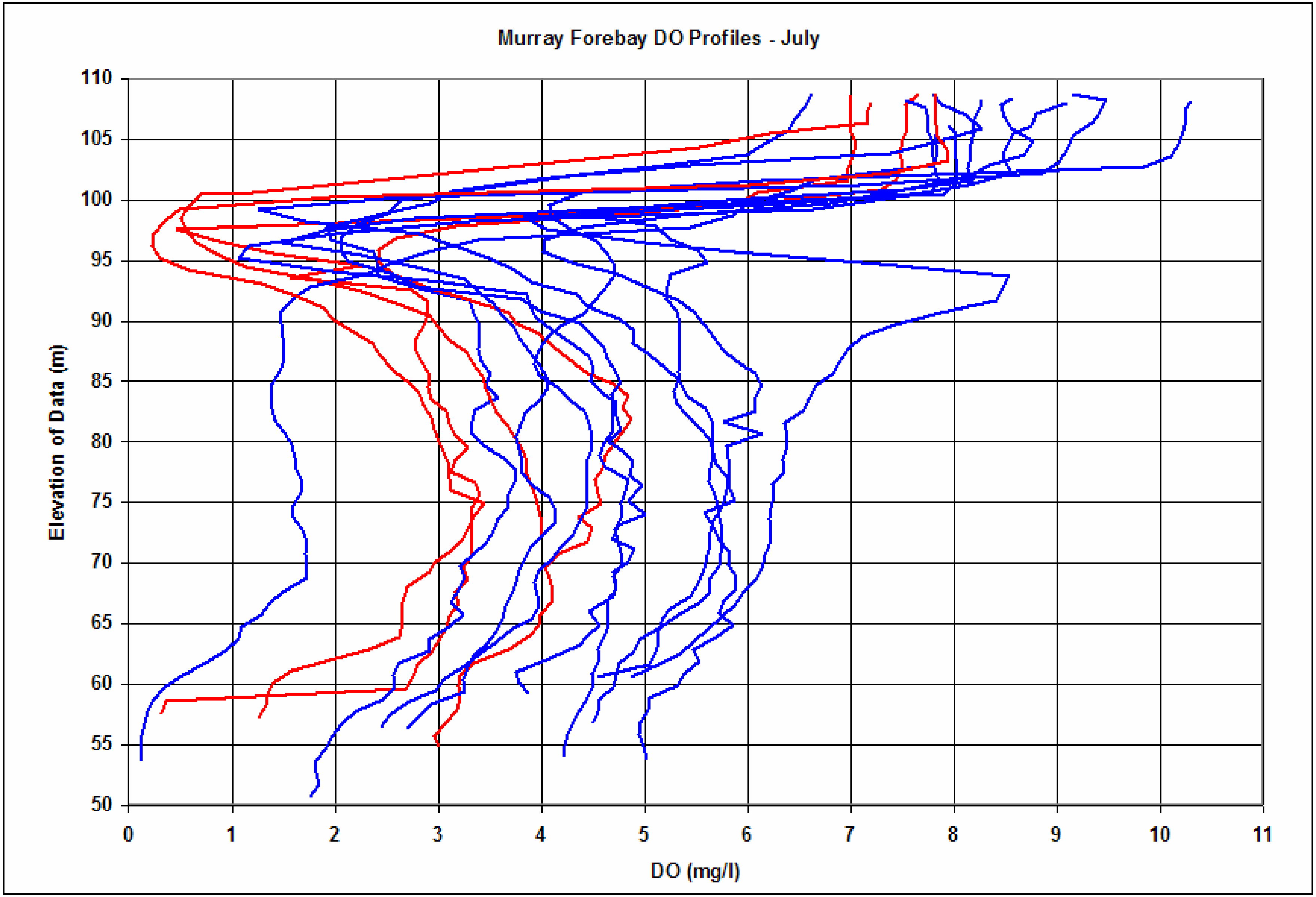
7/22/04
7/27/05



Murray Forebay DO Profiles - July
Elevation of Data (m)
DO (mg/l)
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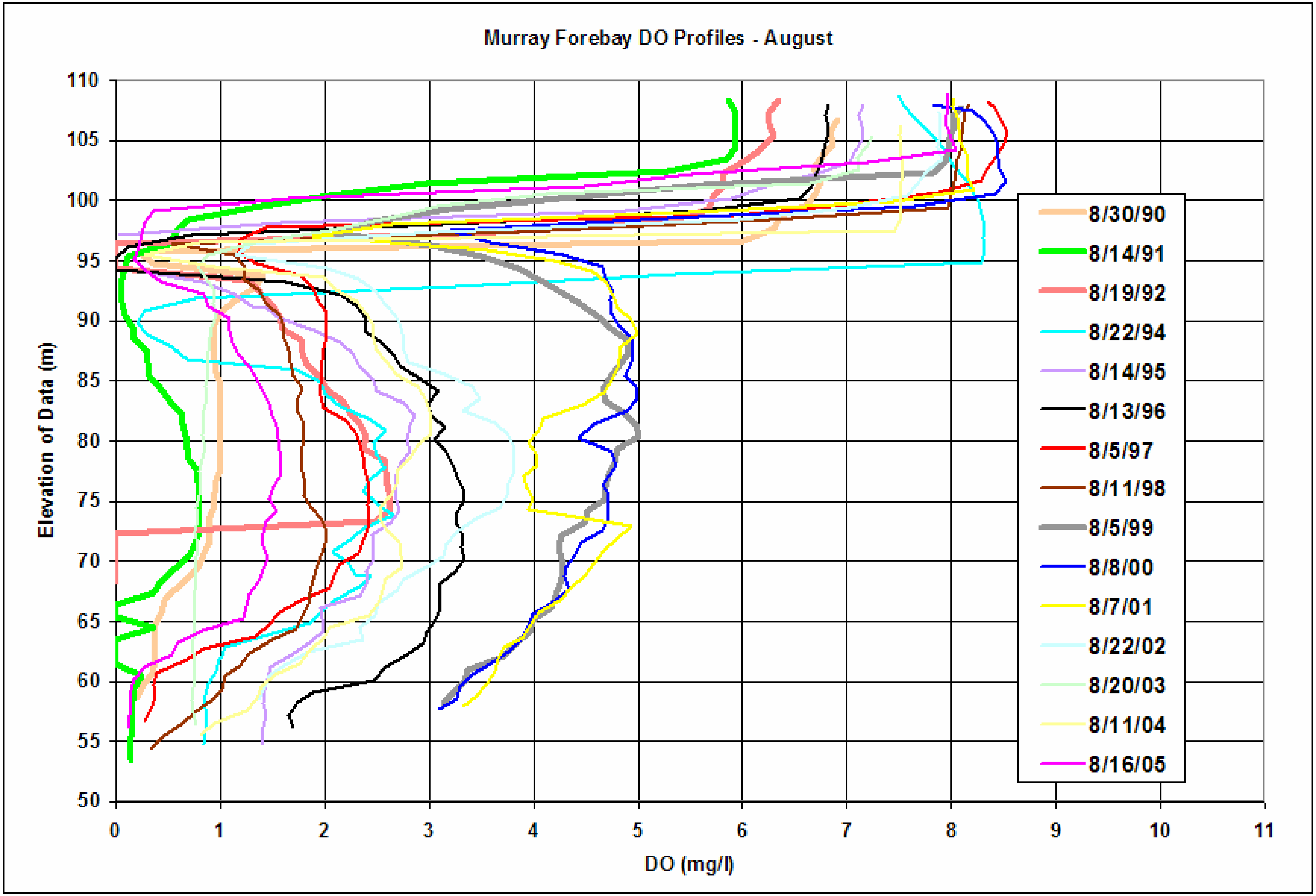
Murray Forebay DO Profiles - August
Elevation of Data (m)
DO (mg/l)
110
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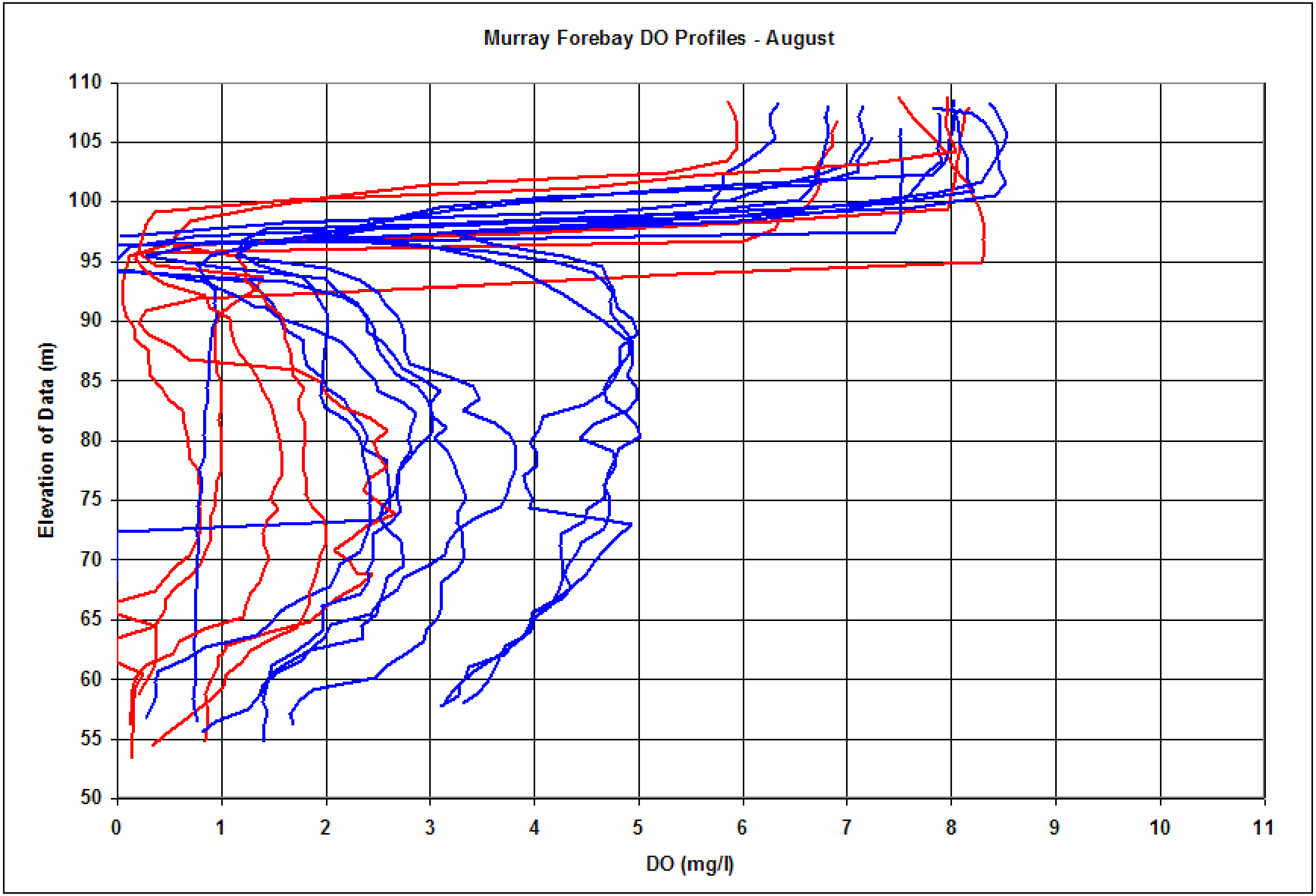
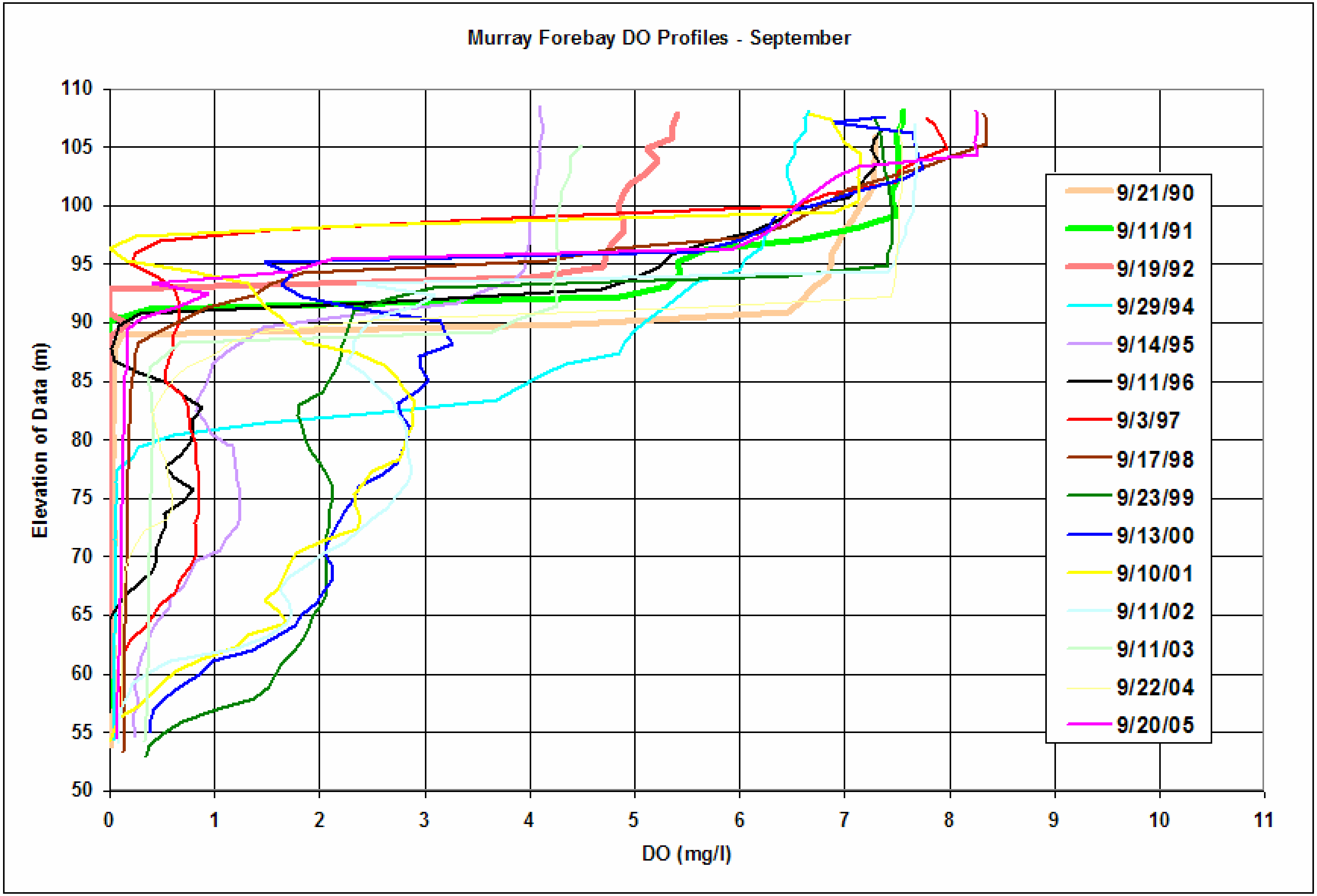
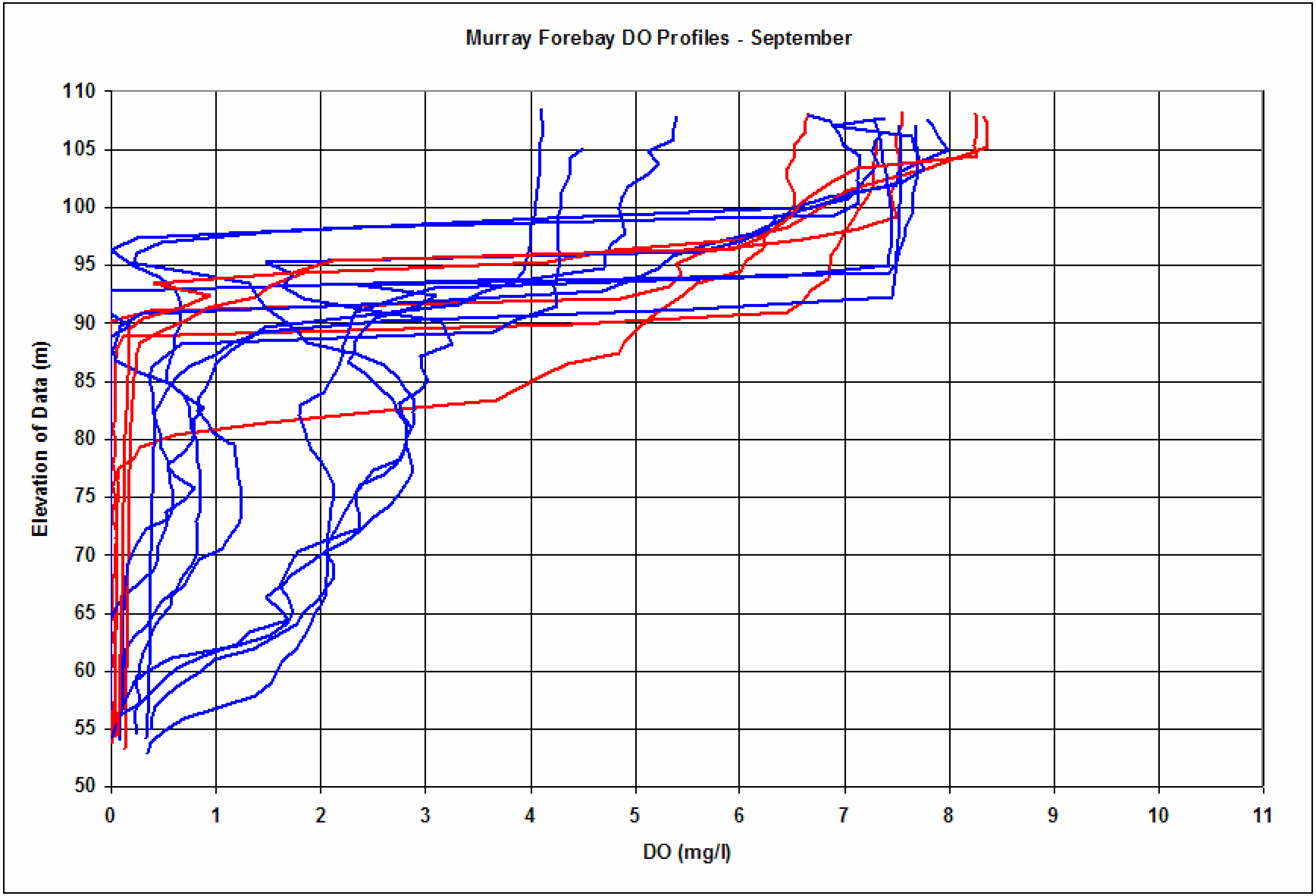
85
80
75
70
65
60
55
50
0
1
2
3
4
5
6
7
8
9
10
11
8/30/90
8/14/91
8/19/92
8/22/94
8/14/95
8/13/96
8/5/97
8/11/98
8/5/99
8/8/00
8/7/01
8/22/02
8/20/03
8/11/04
8/16/05



Murray Forebay DO Profiles - August
110
105
100
95
90
85
80
75
70
65
60
55
50
Elevation of Data (m)
0
1
2
3
4
5
6
7
8
9
10
11
DO (mg/l)



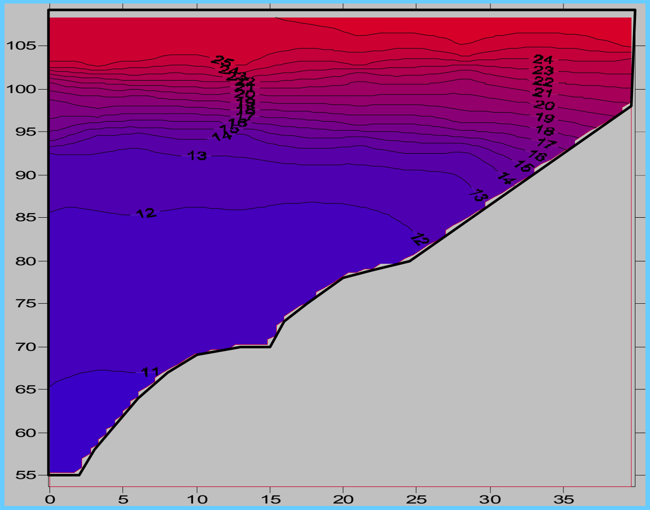
Murray Forebay DO Profiles - September
Elevation of Data (m)
110
105
100
95
90
85
80
75
70
65
60
55
50
0
1
2
3
4
5
6
7
8
9
10
11
DO (mg/l)
9/21/90
9/11/91
9/19/92
9/29/94
9/14/95
9/11/96
9/3/97
9/17/98
9/23/99
9/13/00
9/10/01
9/11/02
9/11/03
9/22/04
9/20/05



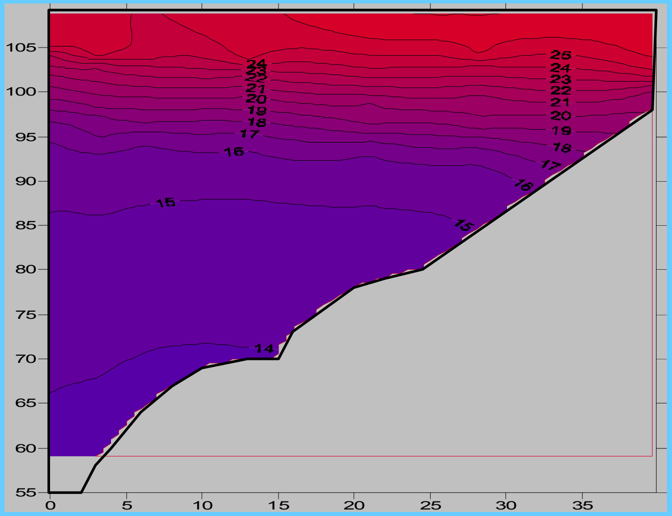
Murray Forebay DO Profiles - September
Elevation of Data (m)
110
105
100
95
90
85
80
75
70
65
60
55
50
0
1
2
3
4
5
6
7
8
9
10
11
DO (mg/l)

Lake Murray Contour Plots

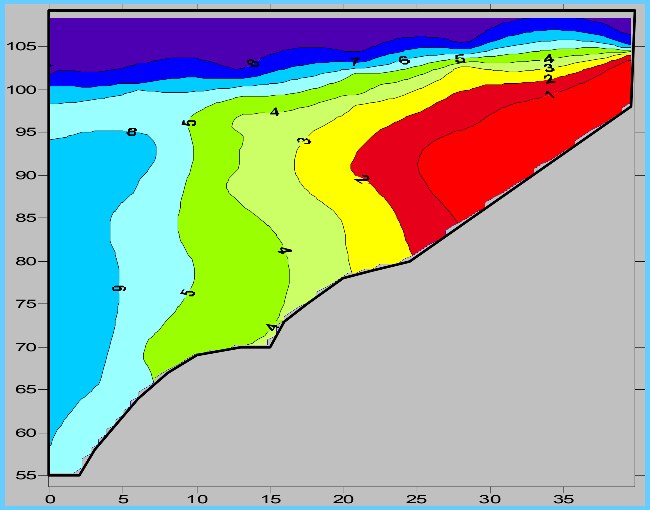
June 2002 Temperature



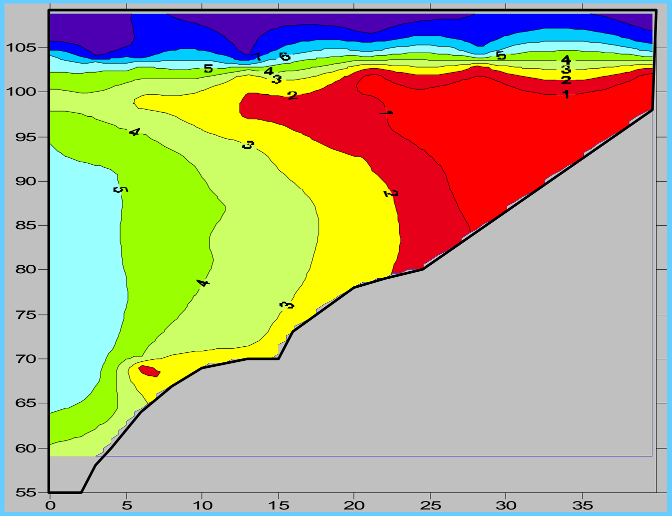
June 2005 Temperature



June 2002 DO

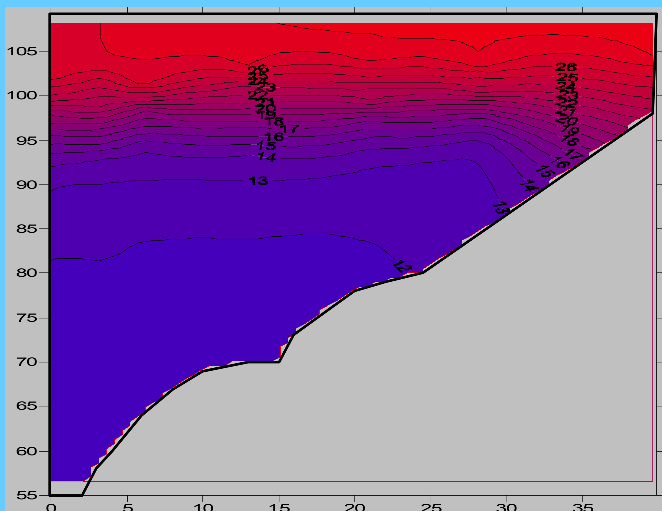


June 2005 DO

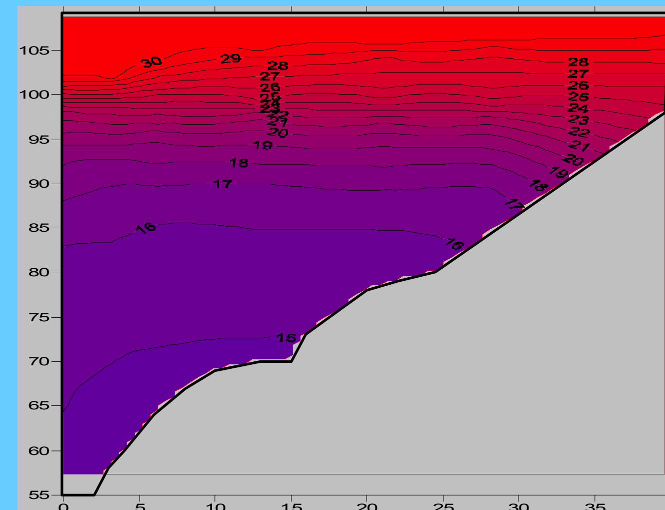


Lake Murray Contour Plots

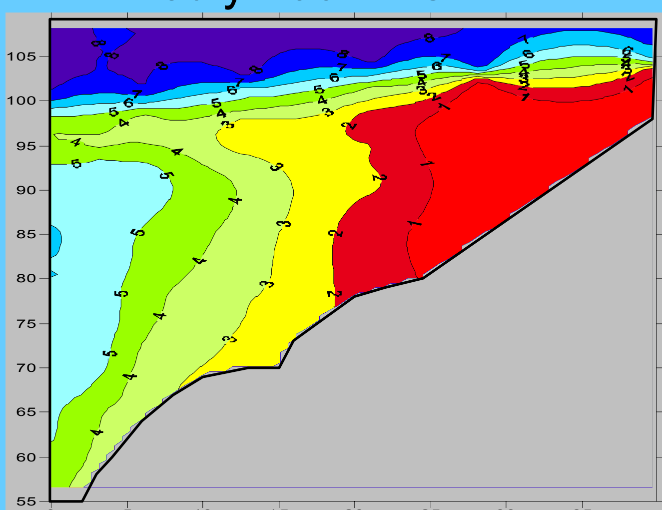
July 2002 Temperature



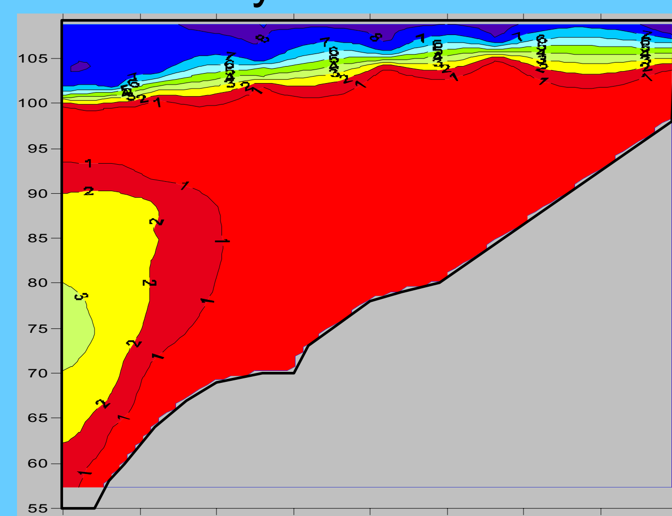
July 2005 Temperature



July 2002 DO

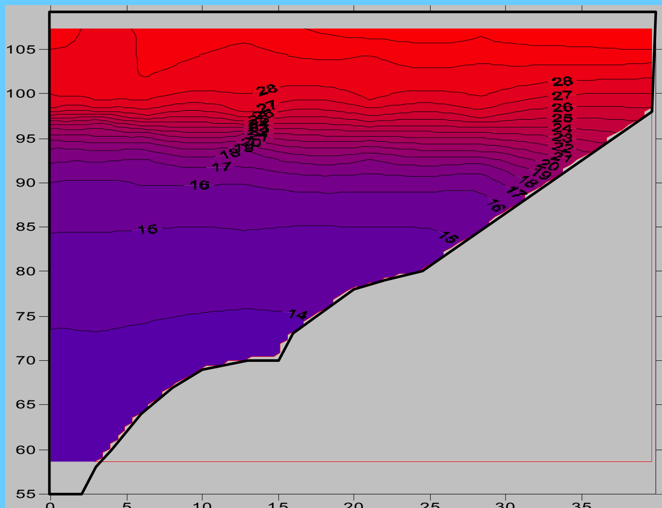


July 2005 DO

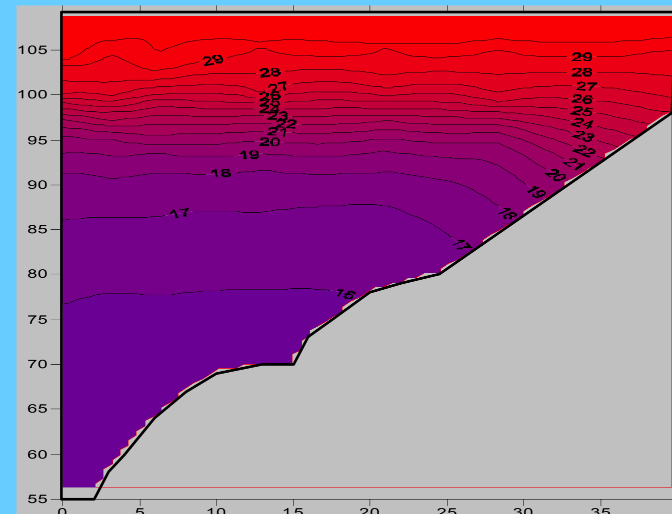


Lake Murray Contour Plots

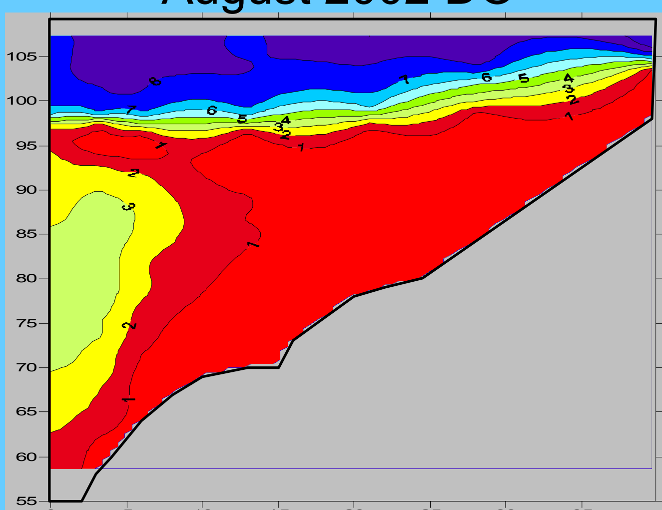
August 2002 Temperature



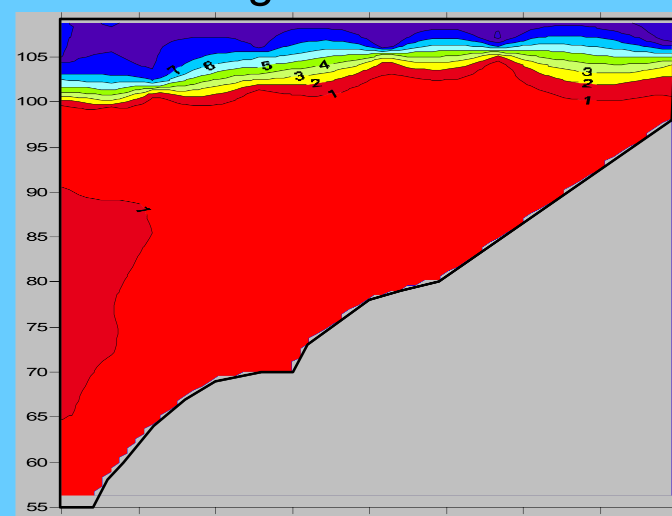
August 2005 Temperature



August 2002 DO

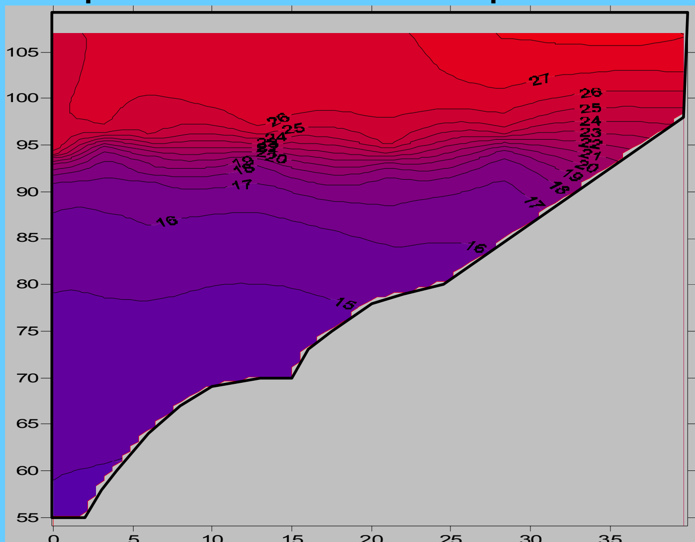


August 2005 DO

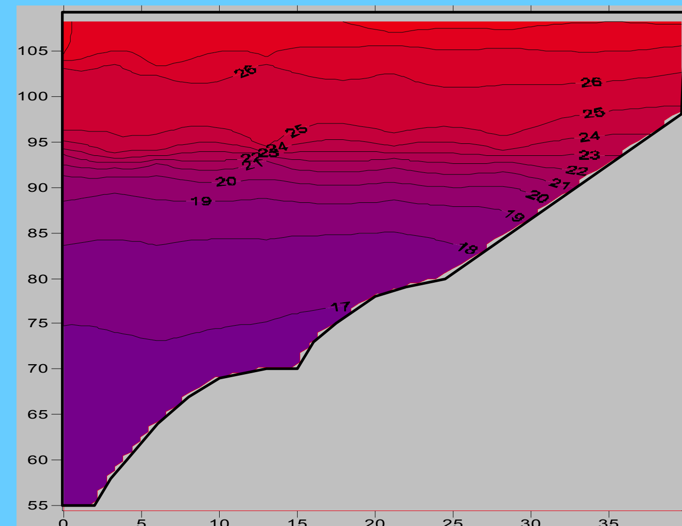


Lake Murray Contour Plots

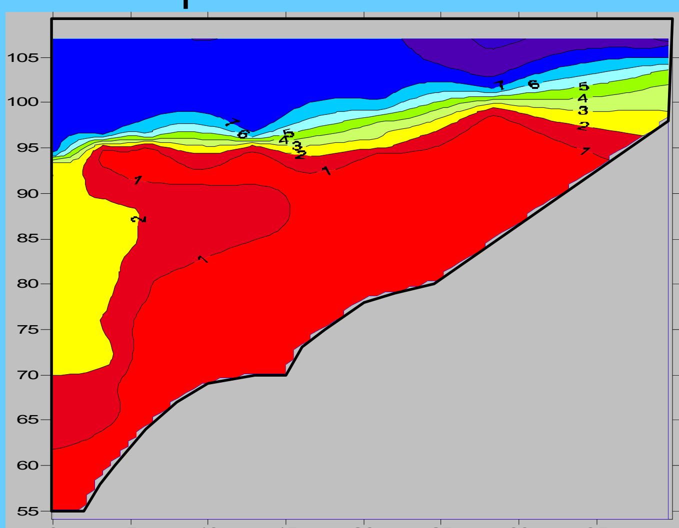
September 2002 Temperature



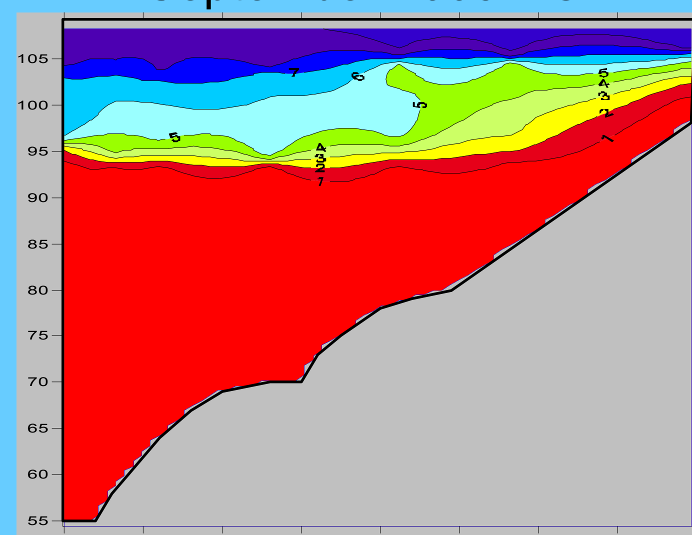
September 2005 Temperature



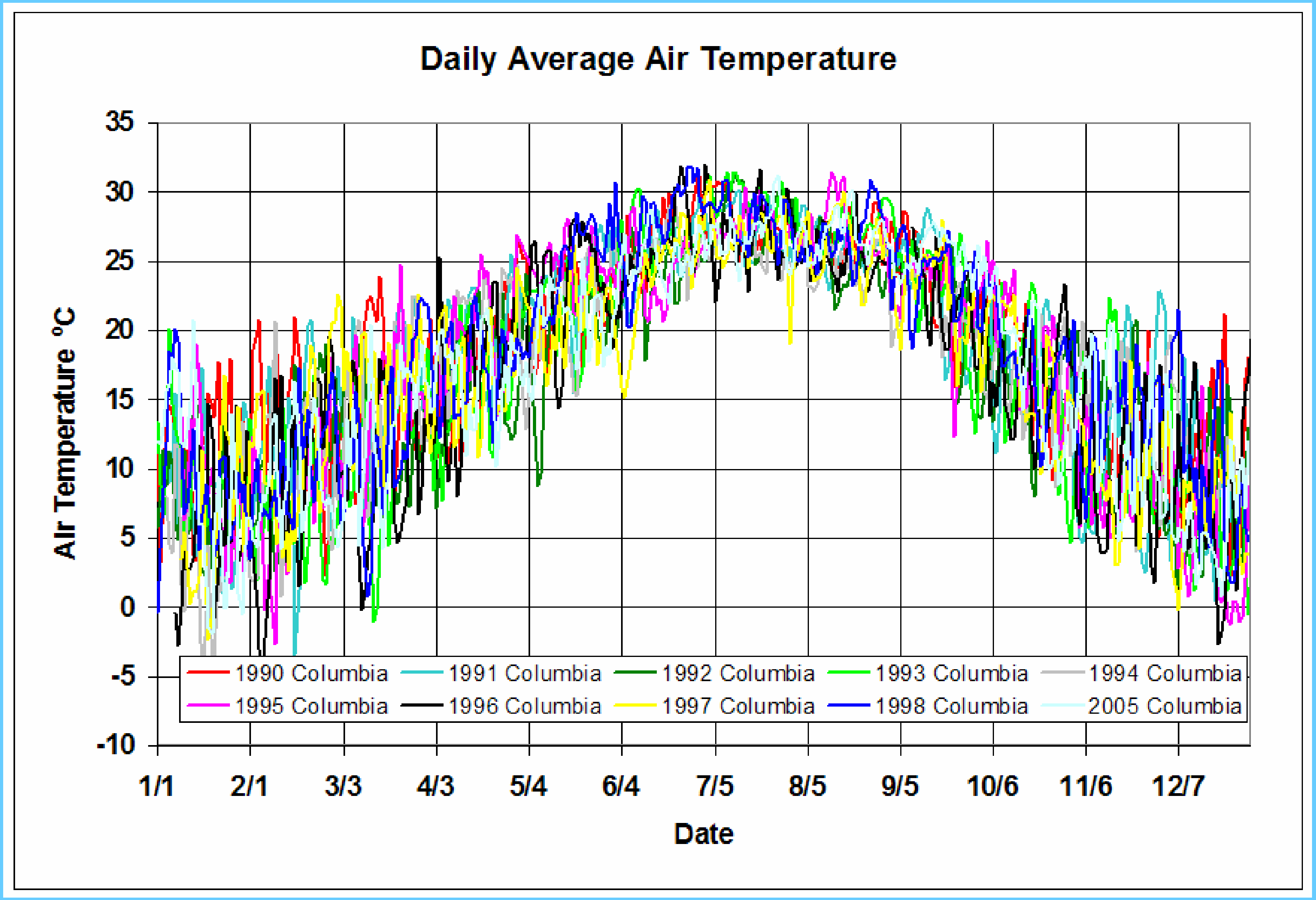
September 2002 DO



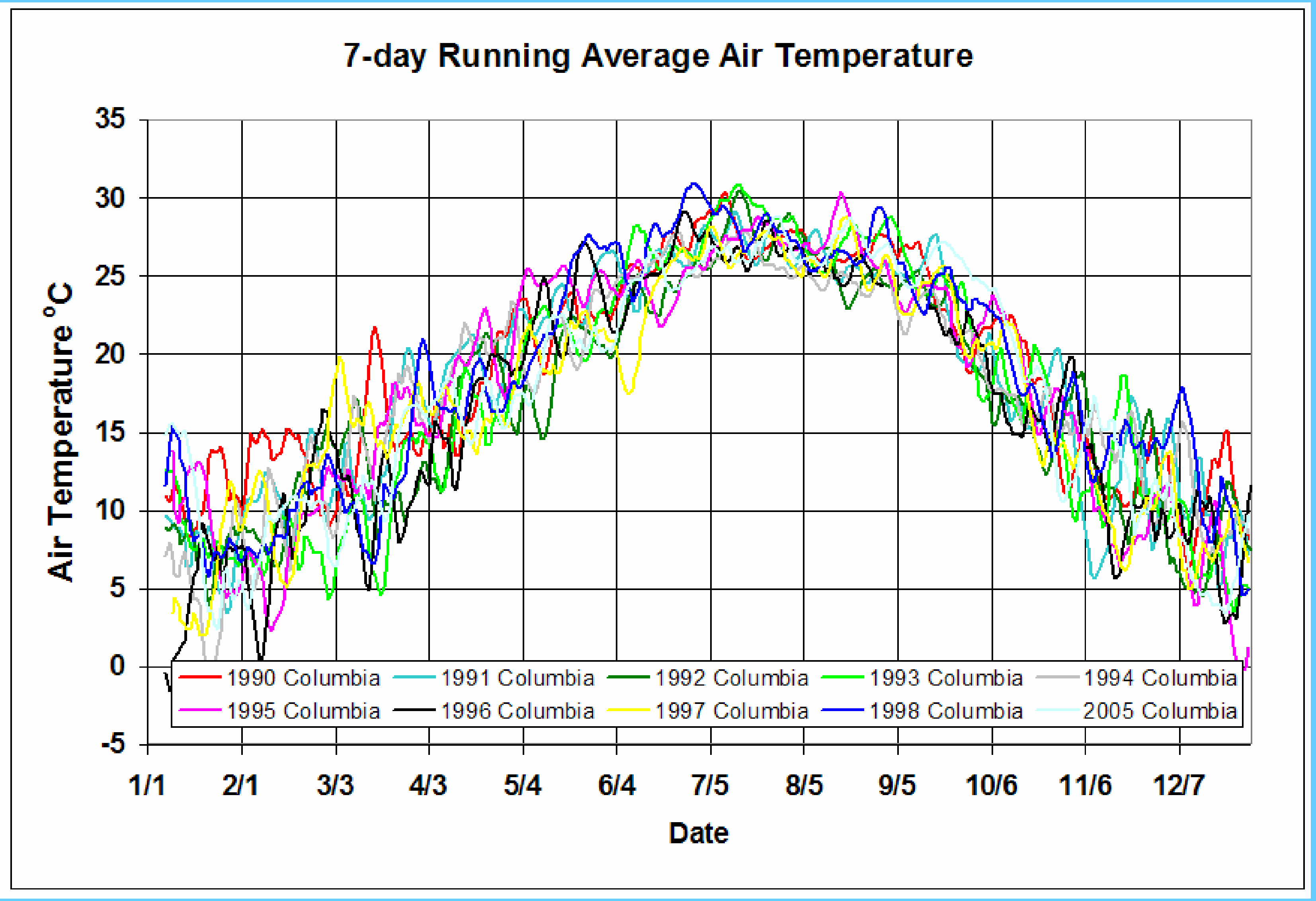
September 2005 DO



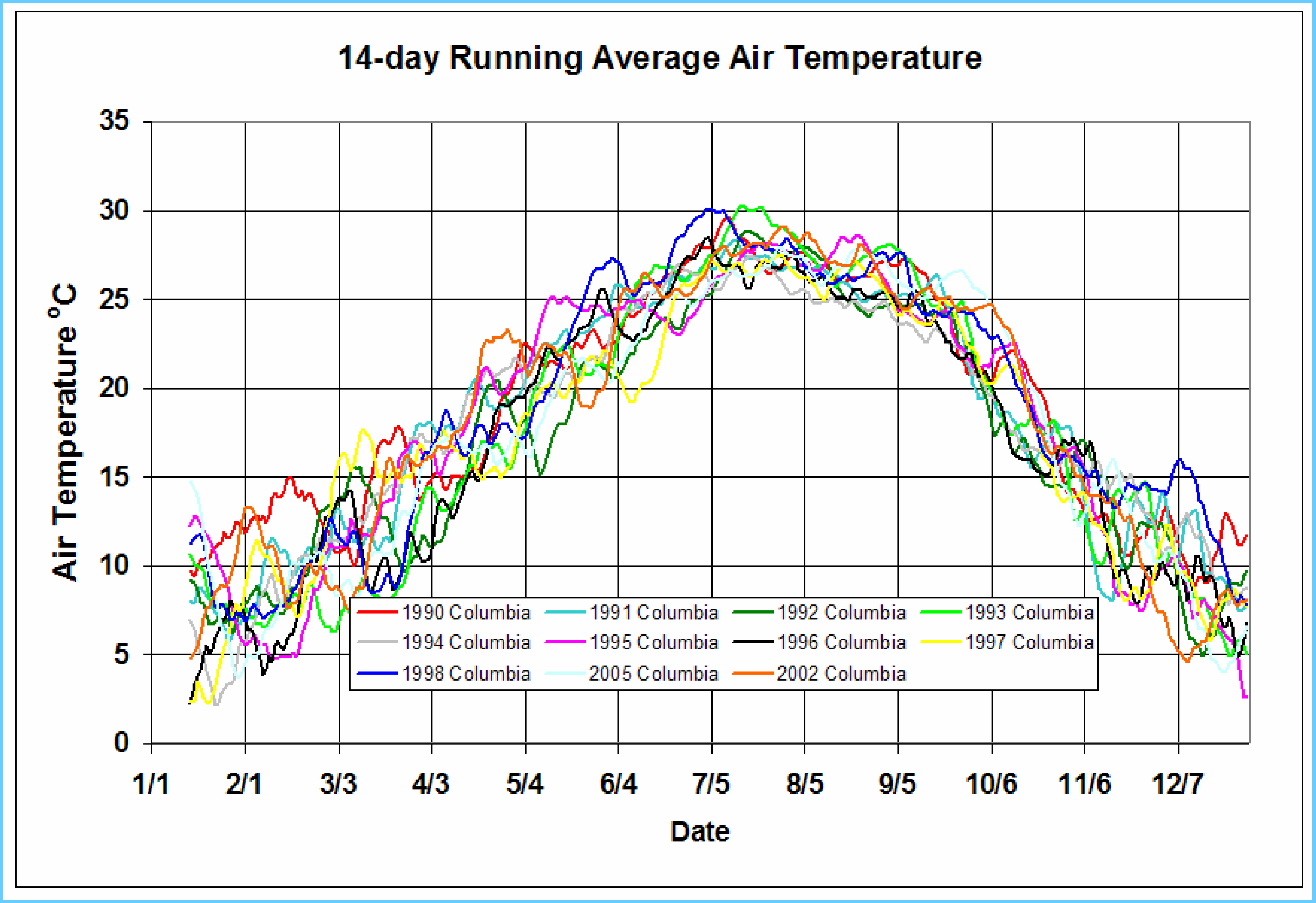
Columbia, SC Daily Average Air Temperature



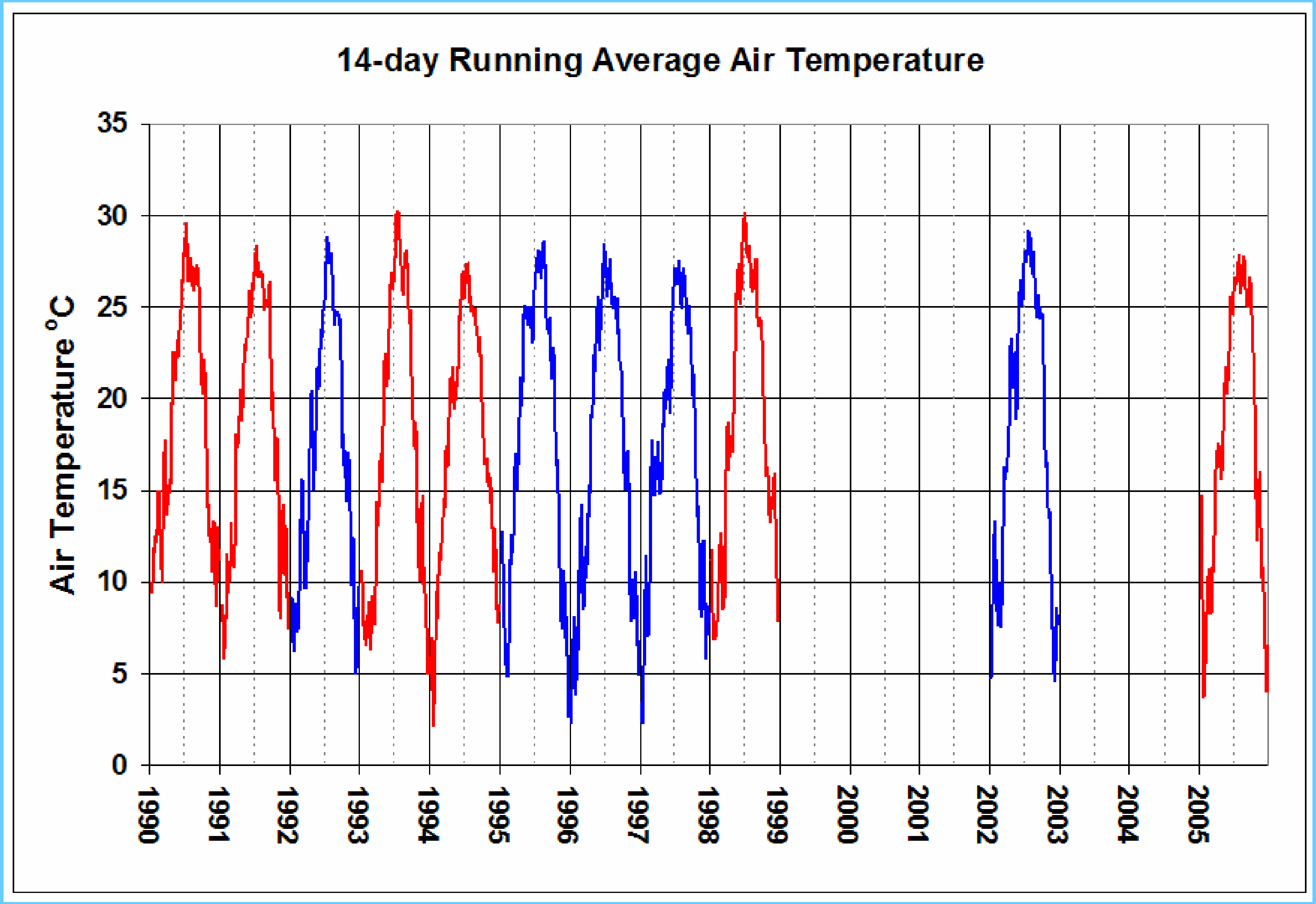
Columbia, SC 7-day Running Average Air Temperature



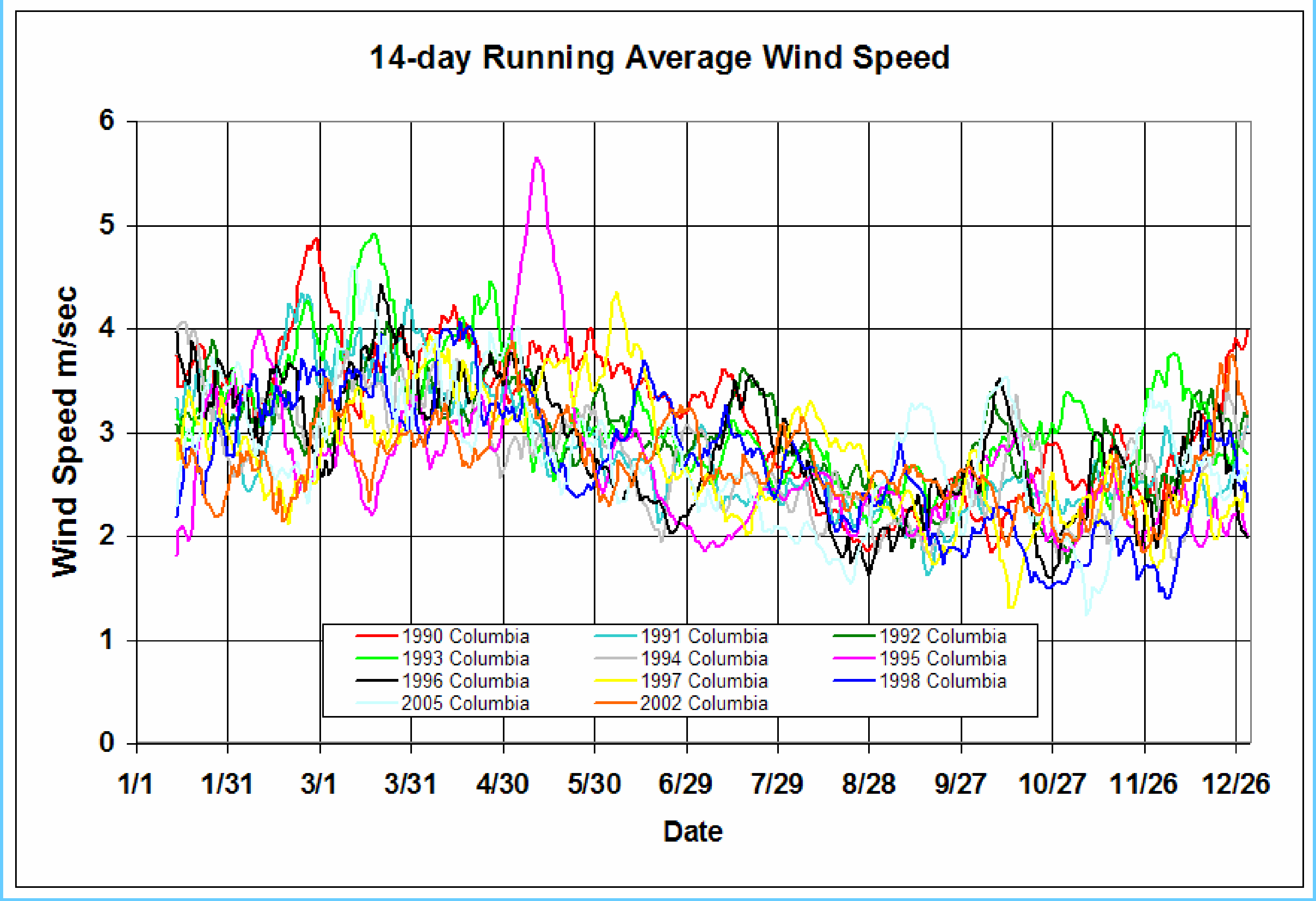
Columbia, SC 14-day Running Average Air Temperature



Columbia, SC 14-day Running Average Air Temperature
Years with documented striped bass kills are red



Columbia, SC 14-day Running Average Wind Speed



Next Steps

- Continue analyzing flow and met data
- More detailed analysis of operations
- Model selected years

Cone Valve Aeration Variables

- Amount of flow through the cone valve and in the tailwater
- Velocity of jet
- Head, pressure
- Hood vs no hood
- Angle of jet

Considerations: DO uptake, TDG, temperature

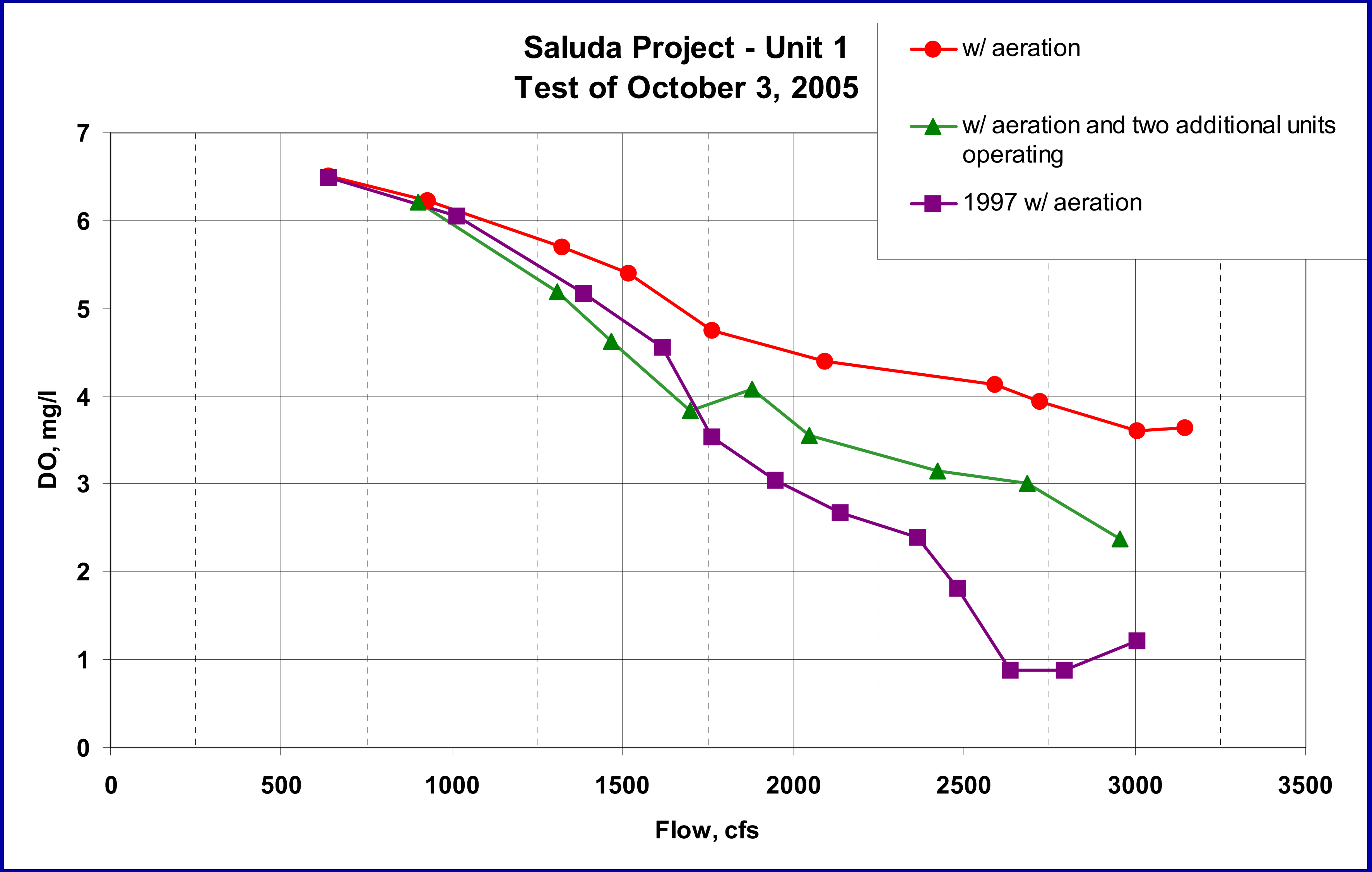
Summary of Test Results on the Cone Valve--September 27, 2006

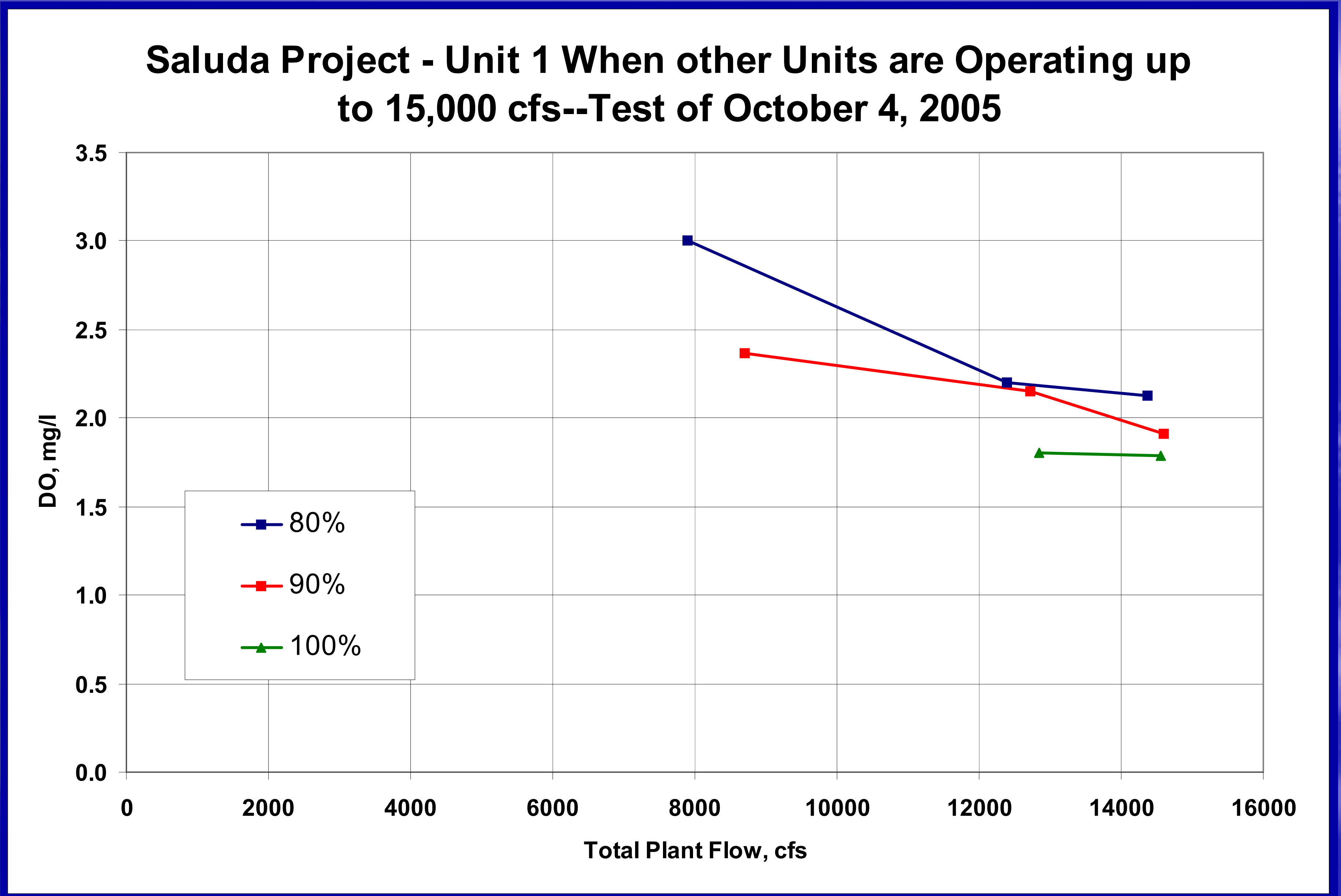
Test Conditions	Measured DO in total discharge	Calculated DO in the turbine releases using mass balance calcs	Calculated DO in the turbine releases and saturated DO in CV flow	Total Project Flow	DO added by CV flow assuming it is saturated	DO uptake induced by jet action of CV	Total DO added by CV	Total DO added by CV	Measured TDG in total discharge	Measured T in total discharge
	mg/L	mg/L	mg/L	cfs	mg/L	mg/L	mg/L	tons/day	psia	TEMP
Unit 4	2.9	2.8	2.8	2,700	0	0	0	1	13.60	16.04
Unit 4 + CV	5.5	2.8	3.2	2,950	0.4	2.3	2.8	24	14.30	16.67
Units 3&4 + CV	4.1	1.6	1.8	5,650	0.3	2.3	2.6	40	13.90	16.50
Units 1,3&4 + CV	3.8	2.1	2.3	8,350	0.2	1.5	1.7	39	13.83	16.41
Units 1,2,3&4 + CV	2.9	1.7	1.8	11,050	0.1	1.1	1.2	38	13.62	16.32
Units 1,2,3&4	1.6	1.7	1.7	10,800	0	-0.1	-0.1	-3	13.37	16.28

CV: cone valve

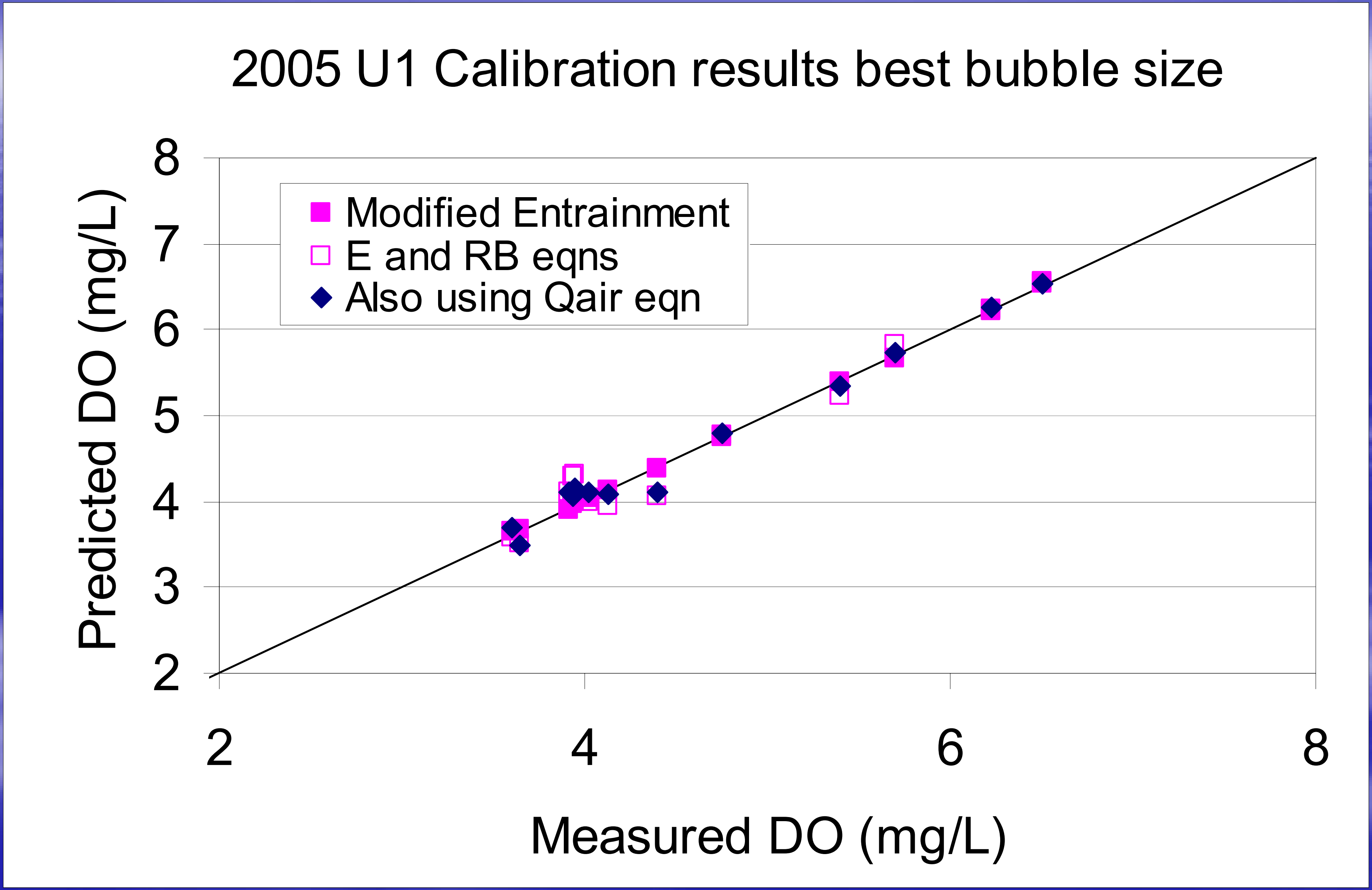
Notes:
1. the cone valve can add ~ 40 tons/day of DO to the total plant discharge…this would cost about $4000 per day if LOX was used
2. the cone valve appears to have the capability to increase DO in the discharge from Unit5 to about 4 mg/L using the existing hub baffles, or possibly with larger hub baffles

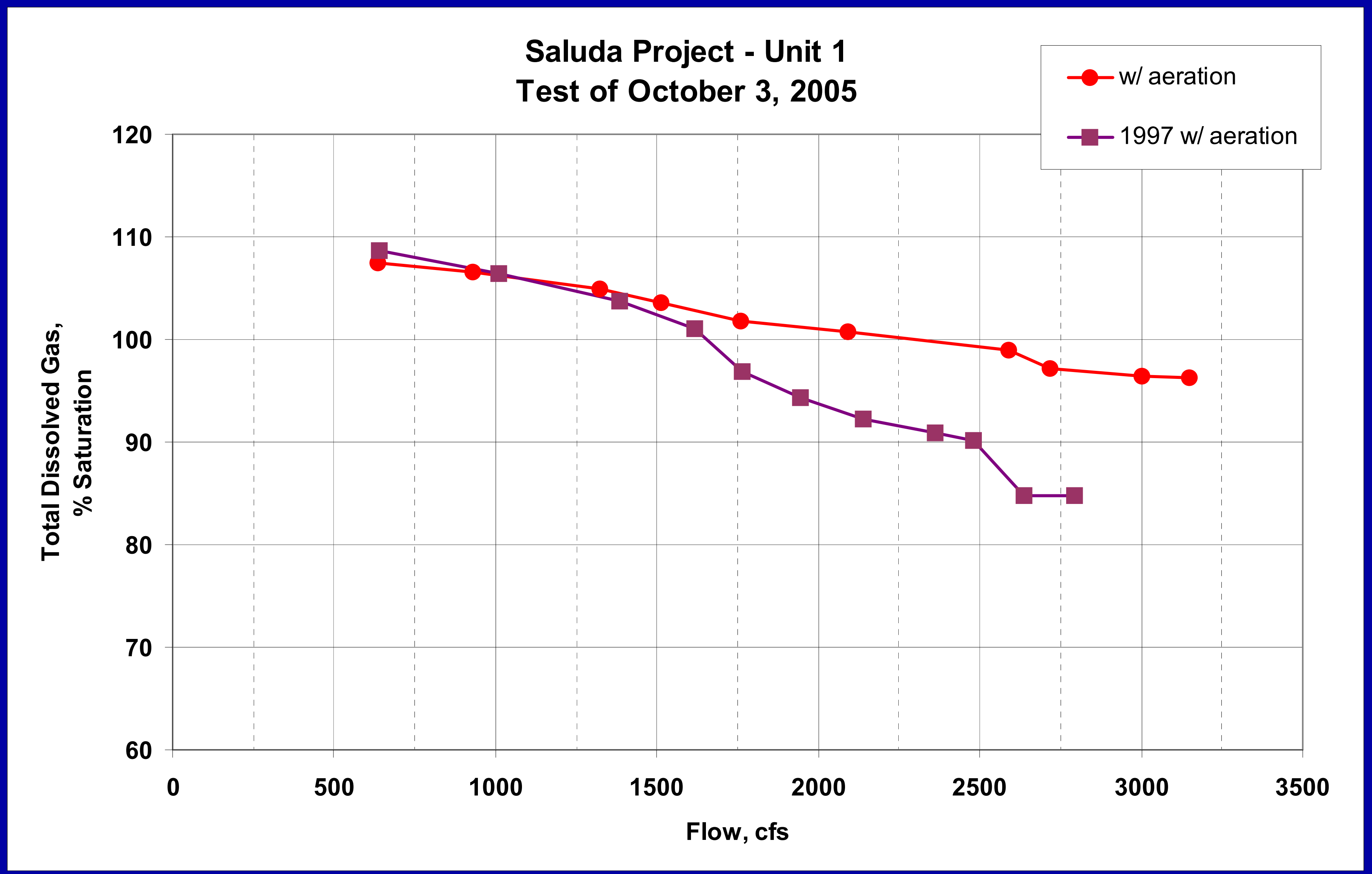
Test Conditions	Saturation DO at Meas. T in Total Discharge	Saturation DN at Meas. T in Total Discharge	Measured TDG in total discharge	Calculated DN based on DO and TDG Data	Calculated DN based on DN Saturation	Calculated Cone Valve Temperature	Calculated DN conc in CV	DN sat. based on est. temp.
	mg/L	mg/L	% sat.	% sat.	mg/L	celcius	mg/L	mg/L
Unit 4	10.00	16.38	92.52	109.4	17.9	16.04	17.9	16.38
Unit 4 + CV	9.86	16.18	97.28	108.3	17.5	23.47	13.27	14.38
Units 3&4 + CV	9.90	16.23	94.56	108.7	17.6	26.44	11.67	13.80
Units 1,3&4 + CV	9.92	16.26	94.08	108.9	17.7	28.40	10.93	13.49
Units 1,2,3&4 + CV	9.94	16.29	92.65	109.5	17.8	28.42	14.50	13.49
Units 1,2,3&4	9.94	16.30	90.95	110.9	18.1	16.28	18.1	16.30


Saluda Project - Unit 1
Test of October 3, 2005
w/ aeration
w/ aeration and two additional units operating
1997 w/ aeration
DO, mg/l
Flow, cfs
0
1
2
3
4
5
6
7
0
500
1000
1500
2000
2500
3000
3500

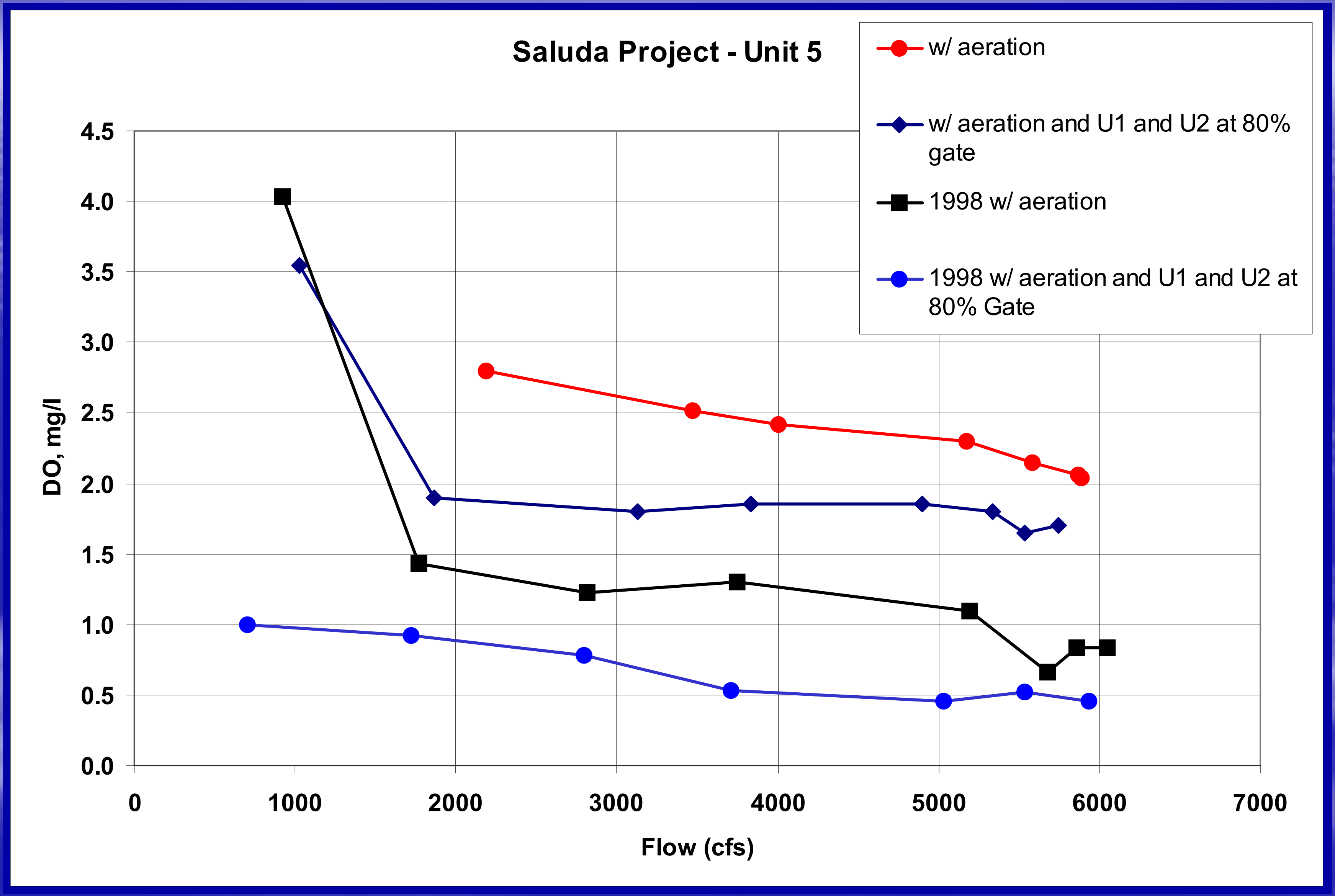


Before hub baffles were added, the minimum DO was 0.4 mg/L.

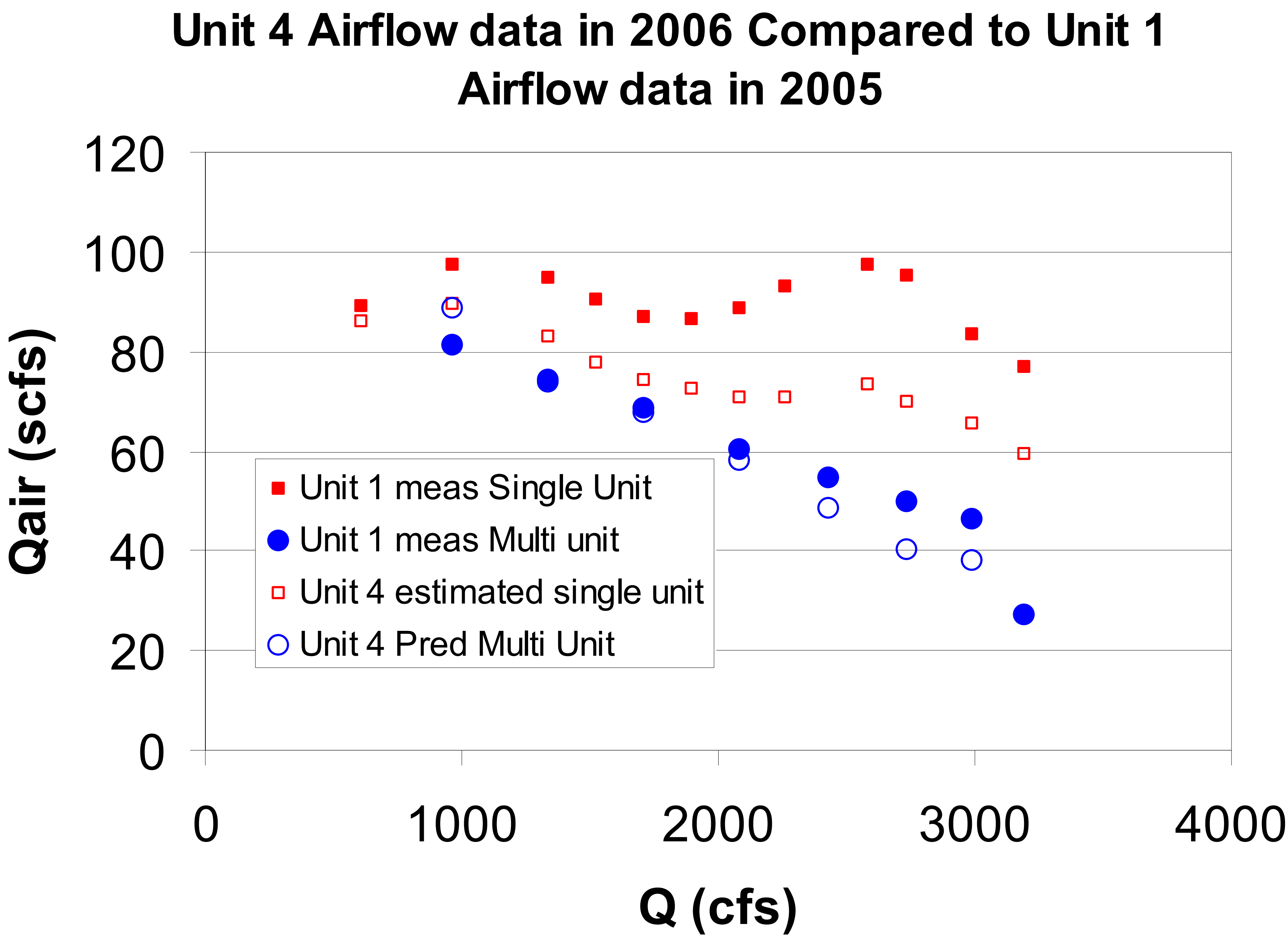

2005 U1 Calibration results best bubble size
Modified Entrainment
E and RB eqns
Also using Qair eqn
Predicted DO (mg/L)
Measured DO (mg/L)
2
3
4
5
6
7
8
2
4
6
8



Saluda Project - Unit 1
Test of October 3, 2005
w/ aeration
1997 w/ aeration
Total Dissolved Gas, % Saturation
120
110
100
90
80
70
60
0
500
1000
1500
2000
2500
3000
3500
Flow, cfs

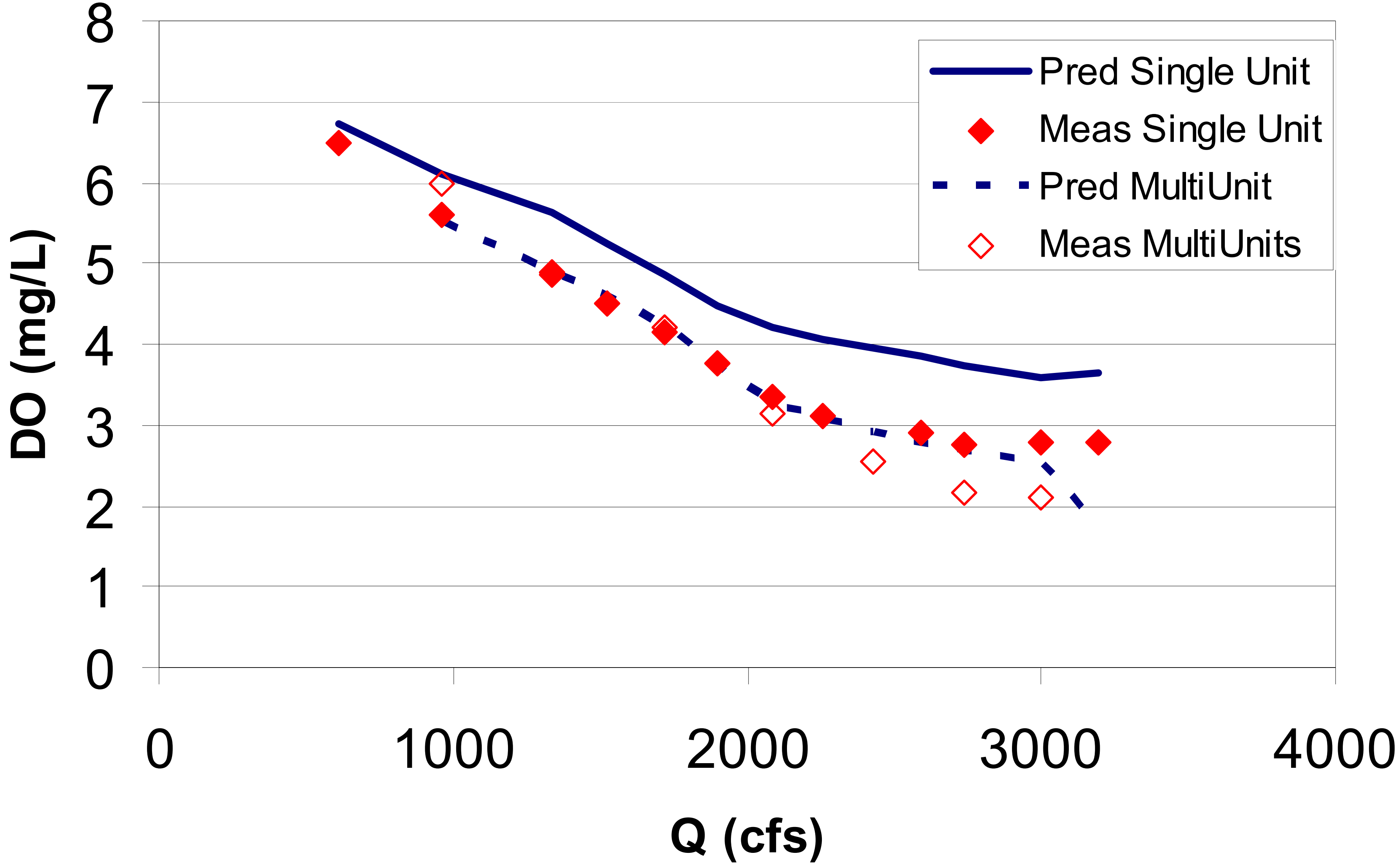


Peak project flow level for the 2005 U5 data was 11,100 cfs



Unit 4 Airflow data in 2006 Compared to Unit 1 Airflow data in 2005
Qair (scfs)
120
100
80
60
40
20
0
0
1000
2000
3000
4000
Q (cfs)
Unit 1 meas Single Unit
Unit 1 meas Multi unit
Unit 4 estimated single unit
Unit 4 Pred Multi Unit

Unit 4 DO data in 2006 Compared to Predicted DO Based on Unit 1 data in 2005



CE-QUAL-W2 Model for Lake Murray—Update on Calibration and Applications

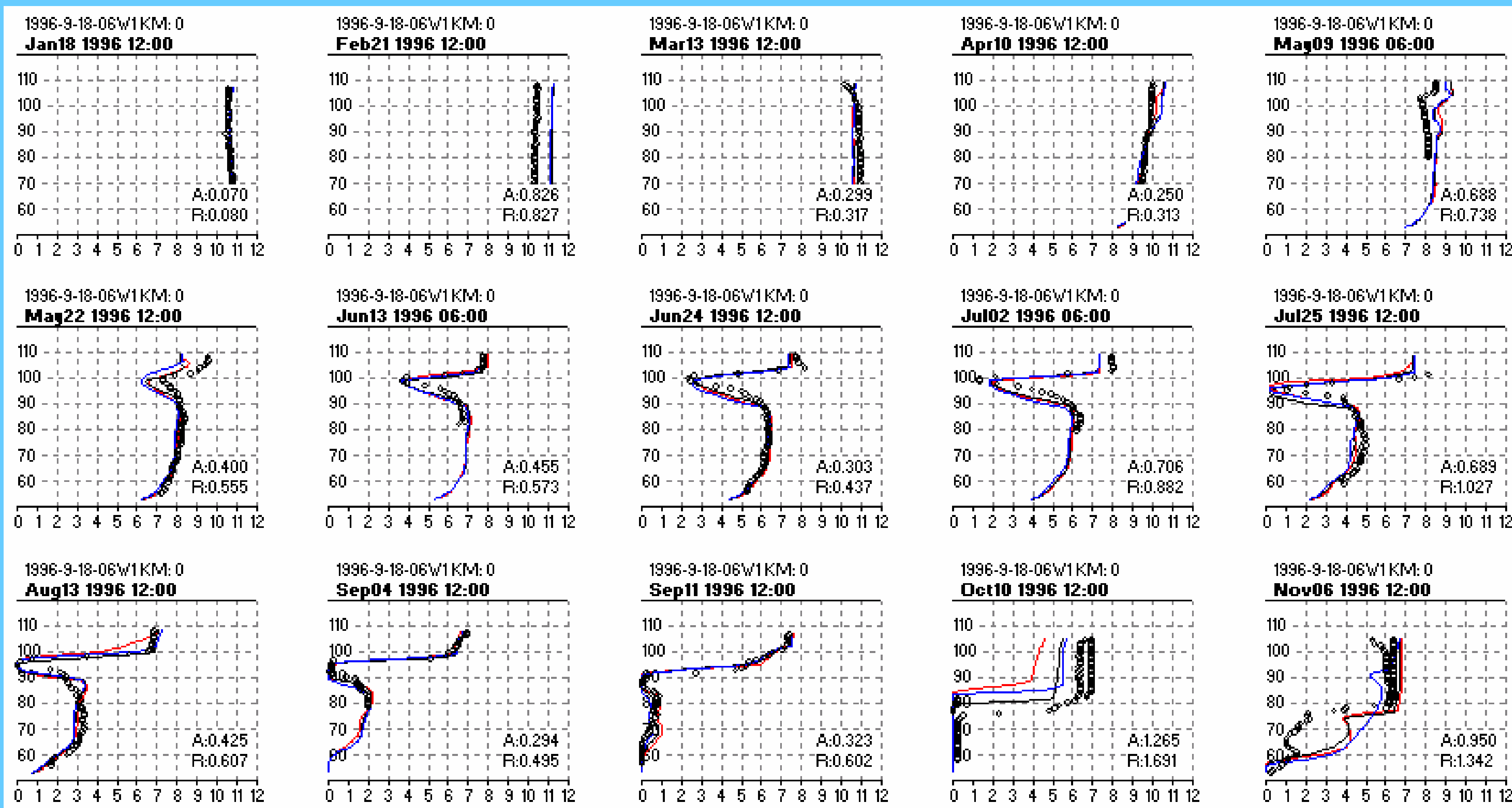
Presented by Andy Sawyer and Jim Ruane

Reservoir Environmental Management, Inc

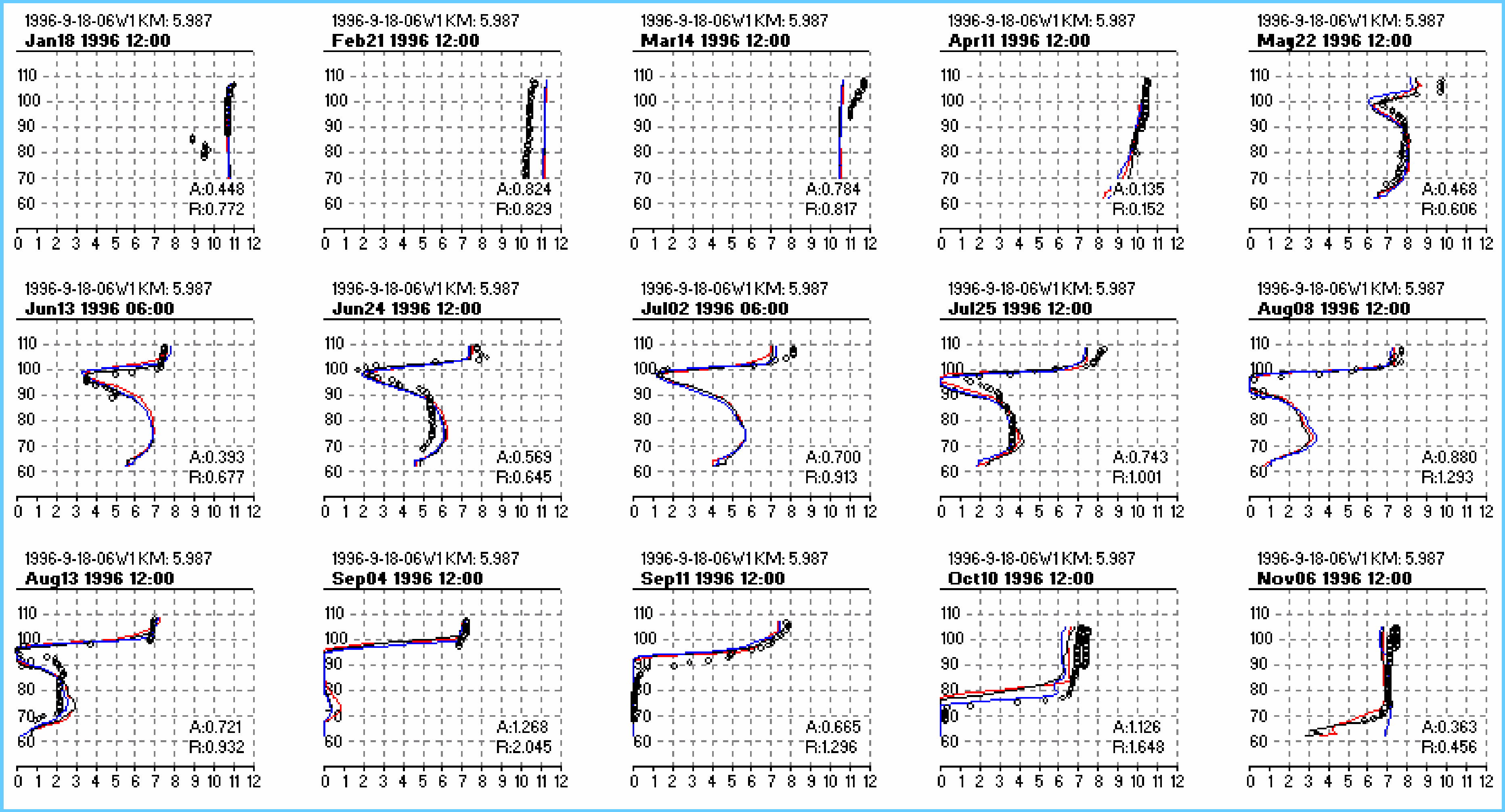
November 13, 2006

1996 Lake Murray Forebay DO Profiles

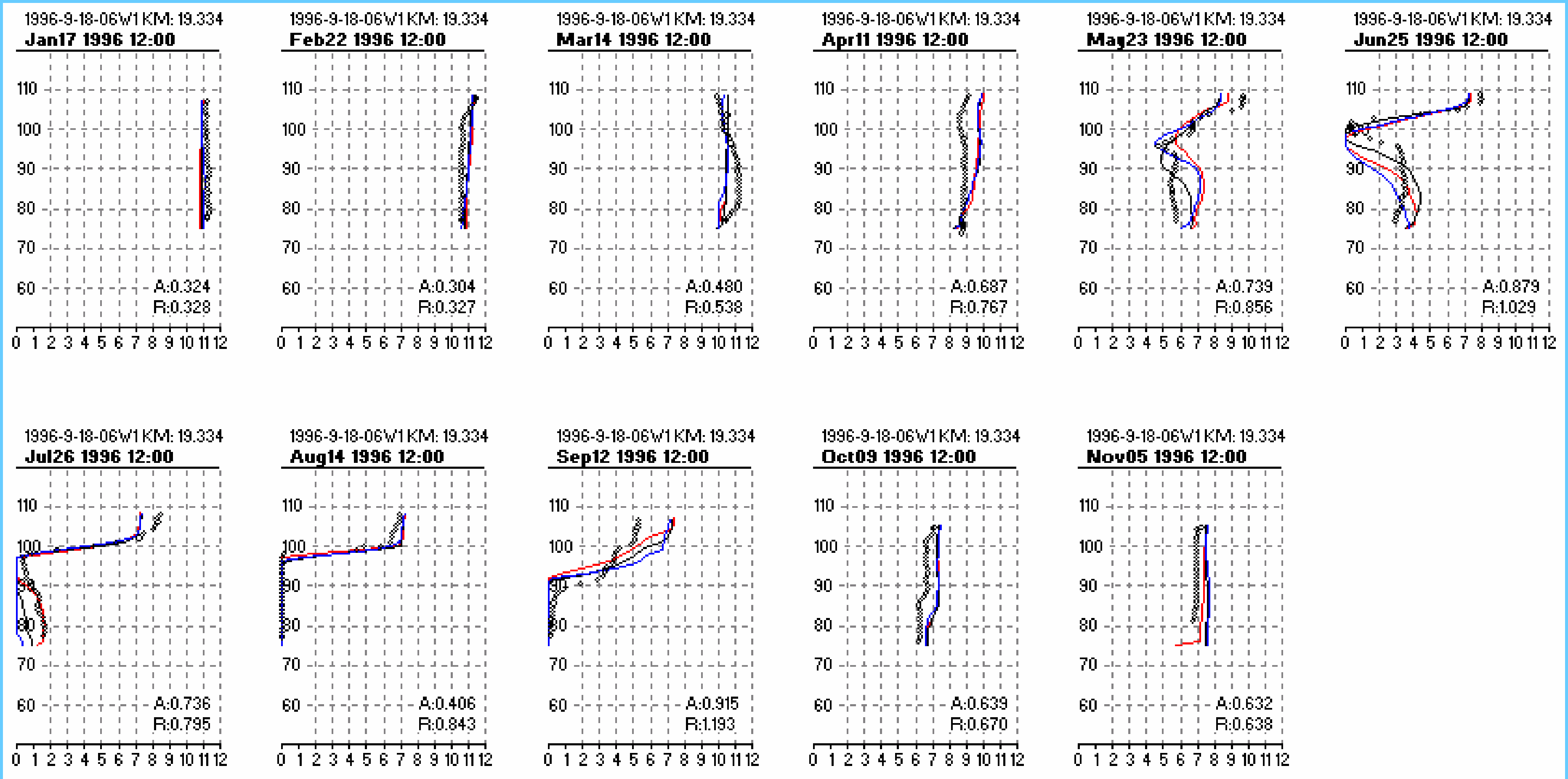
Model vs. Data [Overall Statistics: ABS = 0.57, RMS = 0.89]



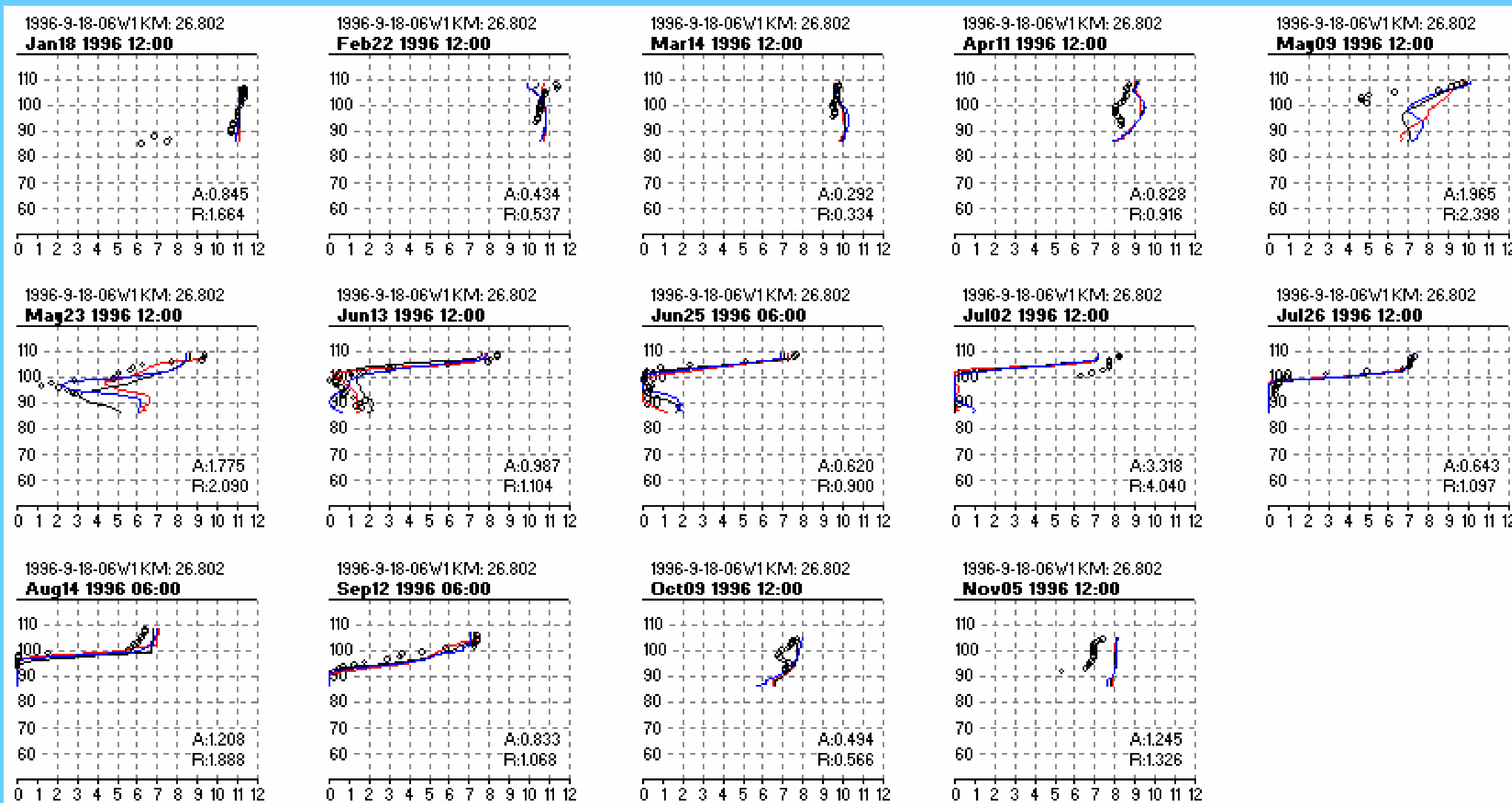
1996 Lake Murray DO Profiles – 6 Km Upstream of Dam
Model vs. Data [Overall Statistics: ABS = 0.65, RMS = 1.00]



1996 Lake Murray DO Profiles – 19 Km Upstream of Dam
Model vs. Data [Overall Statistics: ABS = 0.61, RMS = 0.77]



1996 Lake Murray DO Profiles – 27 Km Upstream of Dam
Model vs. Data [Overall Statistics: ABS = 1.01, RMS = 1.54]



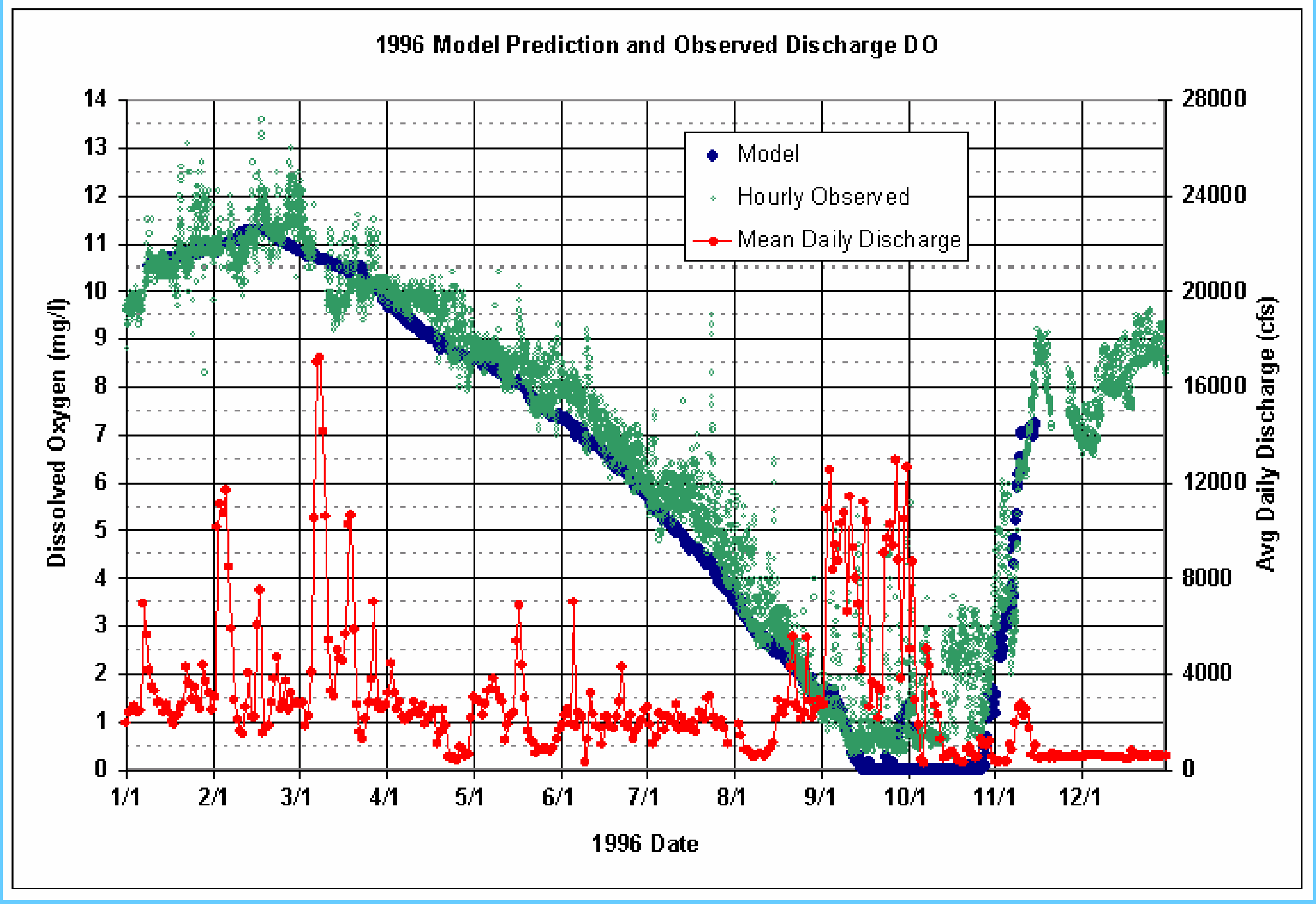
1996 Statistics

	Kilometers From Dam									
	0.0		6		19		27		Overall	
	AME	RMS	AME	RMS	AME	RMS	AME	RMS	AME	RMS
Temperature	0.49	0.67	0.57	0.80	0.63	0.84	0.94	1.28	0.66	0.90
DO	0.56	0.86	0.86	1.21	0.56	0.75	0.68	0.99	0.67	0.95

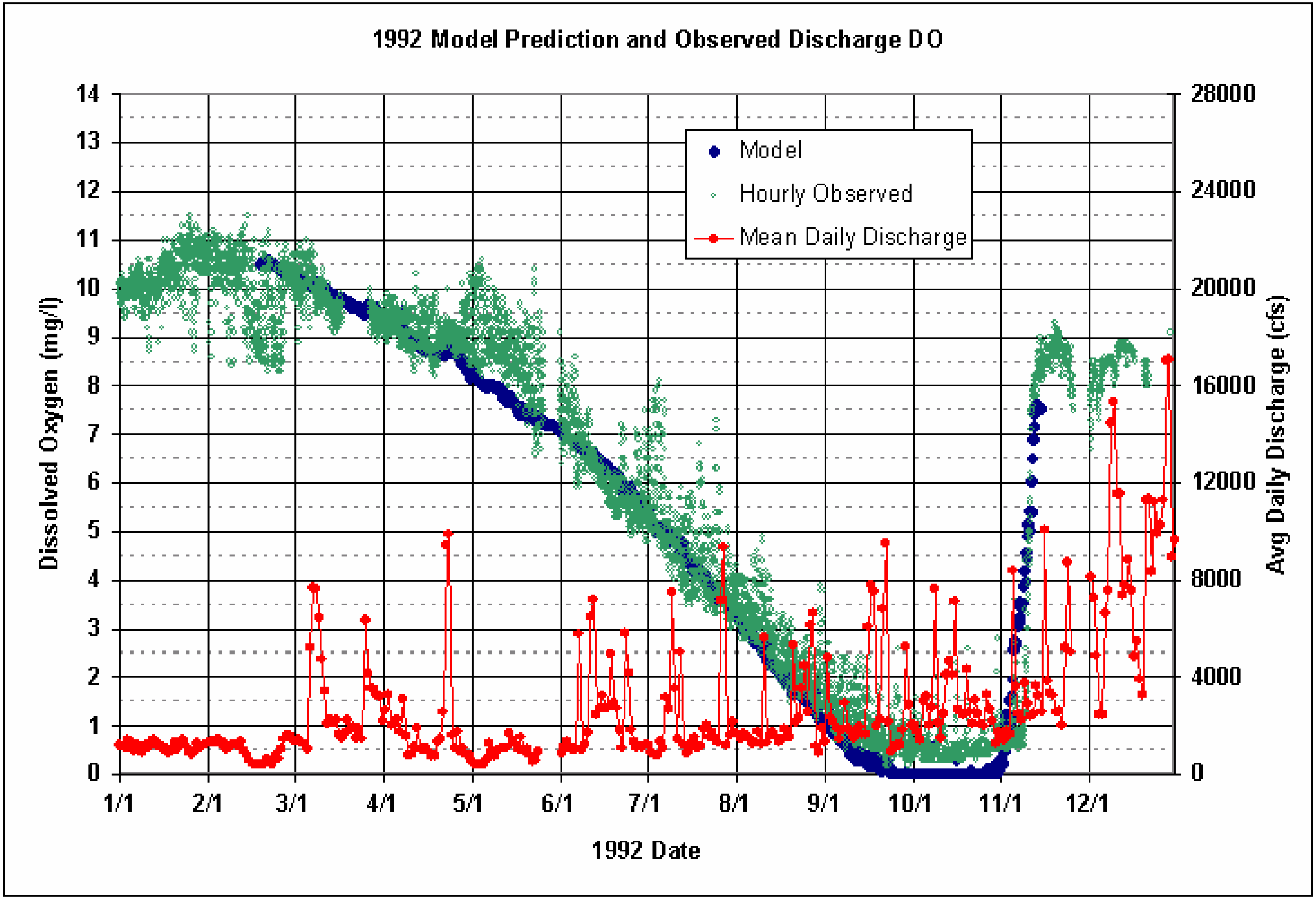
1996 DO

		Kilometers From Dam									
		0.0		6.0		19.3		26.8		Average	
Date	Julian Day	AME	RMS	AME	RMS	AME	RMS	AME	RMS	AME	RMS
1/17-18	17-18	0.07	0.08	0.45	0.77	0.32	0.33	0.85	1.66	**0.42**	**0.71**
2/21-22	52-53	0.83	0.83	0.82	0.83	0.30	0.33	0.43	0.54	**0.60**	**0.63**
3/13-14	73-74	0.30	0.32	0.78	0.82	0.48	0.54	0.29	0.33	**0.46**	**0.50**
4/10-11	101-103	0.25	0.31	0.14	0.15	0.69	0.77	0.83	0.92	**0.48**	**0.54**
5/9-10	130-131	0.69	0.74	0.47	0.61			1.97	2.40	**1.04**	**1.25**
5/22-23	143-144	0.40	0.56	0.39	0.68	0.74	0.86	1.78	2.09	**0.83**	**1.04**
6/13	165	0.46	0.57	0.57	0.65			0.99	1.10	**0.67**	**0.77**
6/24-25	176-177	0.30	0.44	0.70	0.91	0.88	1.03	0.62	0.90	**0.63**	**0.82**
7/2	184	0.71	0.88	0.74	1.00			3.32	4.04	**1.59**	**1.97**
7/25-26	207-208	0.69	1.03	0.88	1.29	0.74	0.80	0.64	1.10	**0.74**	**1.05**
8/13-14	226-227	0.43	0.61	0.72	0.93	0.41	0.84	1.21	1.89	**0.69**	**1.07**
9/4	248	0.29	0.50	1.27	2.05					**0.78**	**1.27**
9/11-12	255-257	0.32	0.60	0.67	1.30	0.92	1.19	0.83	1.07	**0.68**	**1.04**
10/9-10	283-284	1.27	1.69	1.13	1.65	0.64	0.67	0.49	0.57	**0.88**	**1.14**
11/5-6	310-311	0.95	1.34	0.36	0.46	0.63	0.64	1.25	1.33	**0.80**	**0.94**
	Overall	**0.57**	**0.89**	**0.65**	**1.00**	**0.61**	**0.77**	**1.01**	**1.54**	**0.65**	**1.00**

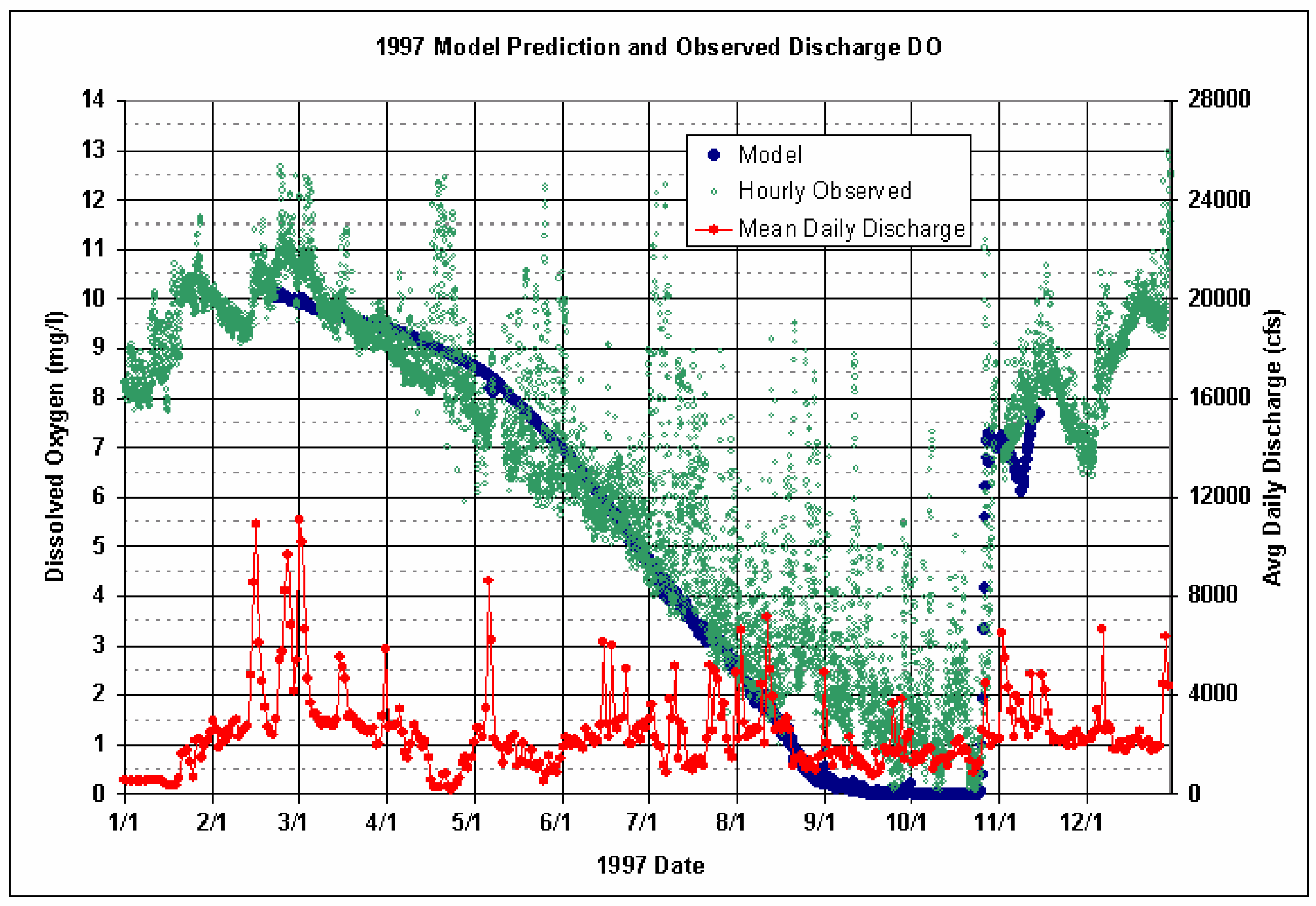
1996 Comparison of Modeled versus Measured Saluda Release DO



1992 Comparison of Modeled versus Measured Saluda Release DO

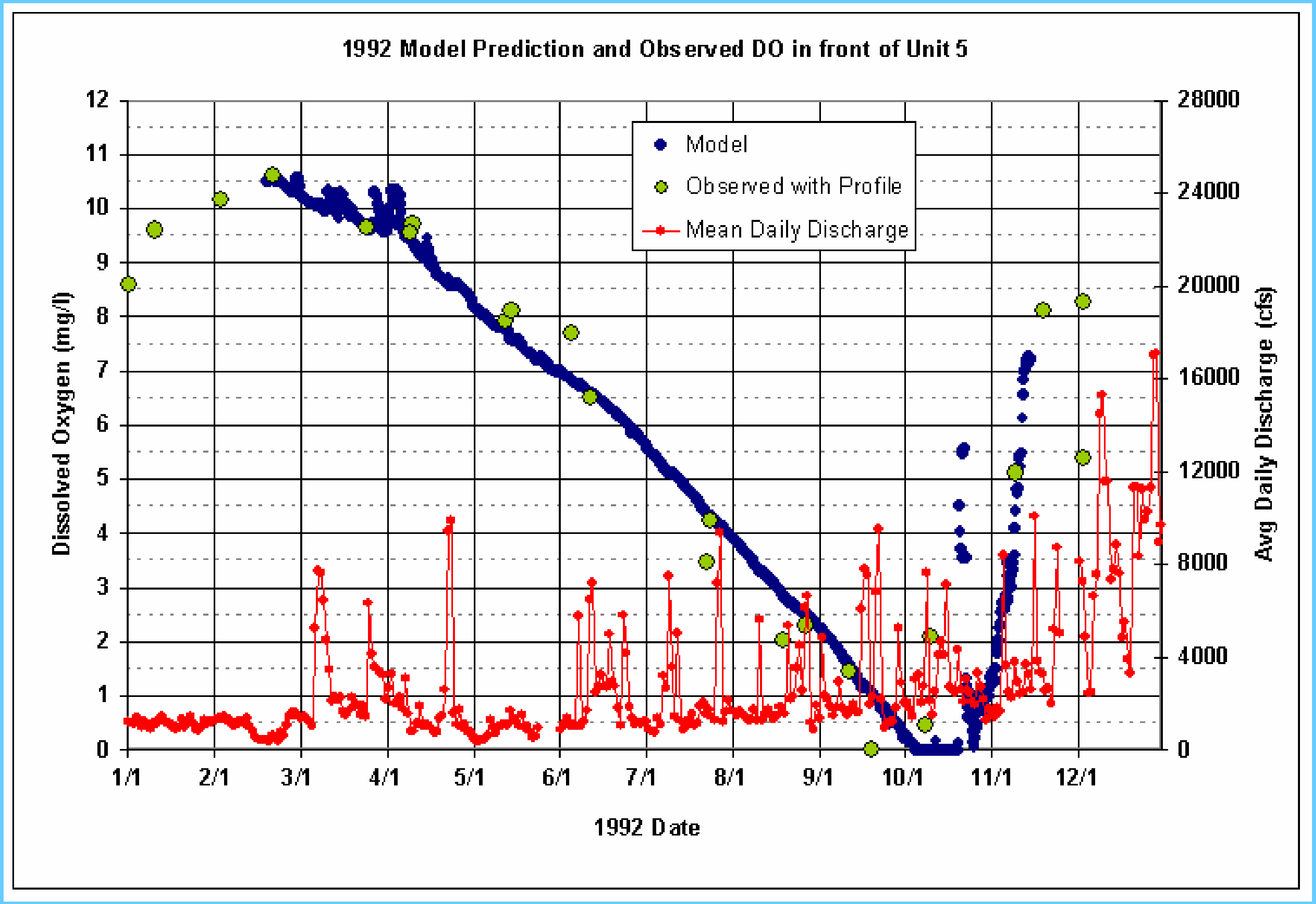


1997 Comparison of Modeled versus Measured Saluda Release DO

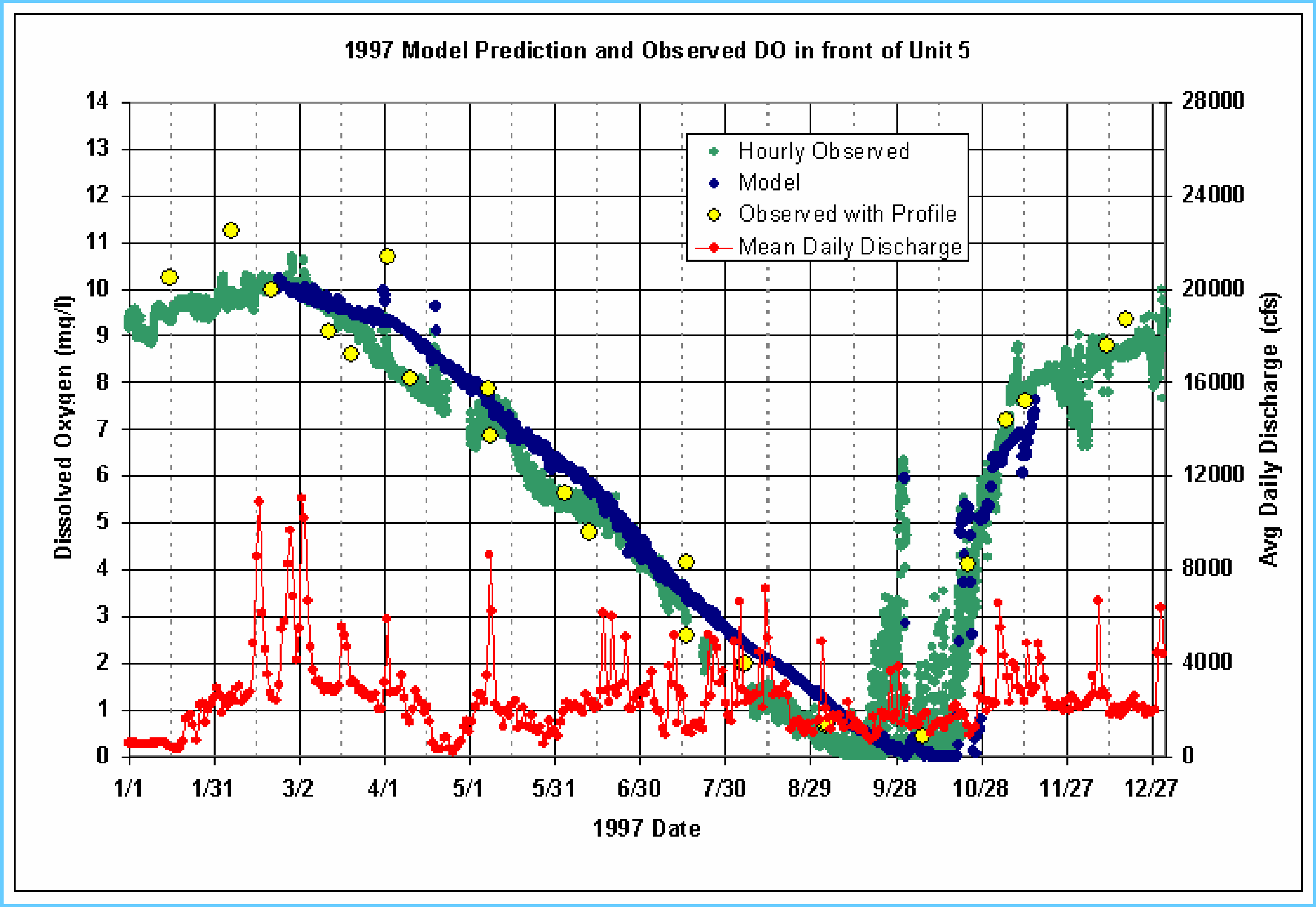


1996 Modeled versus Measured DO at the level of the Unit 5 Intake

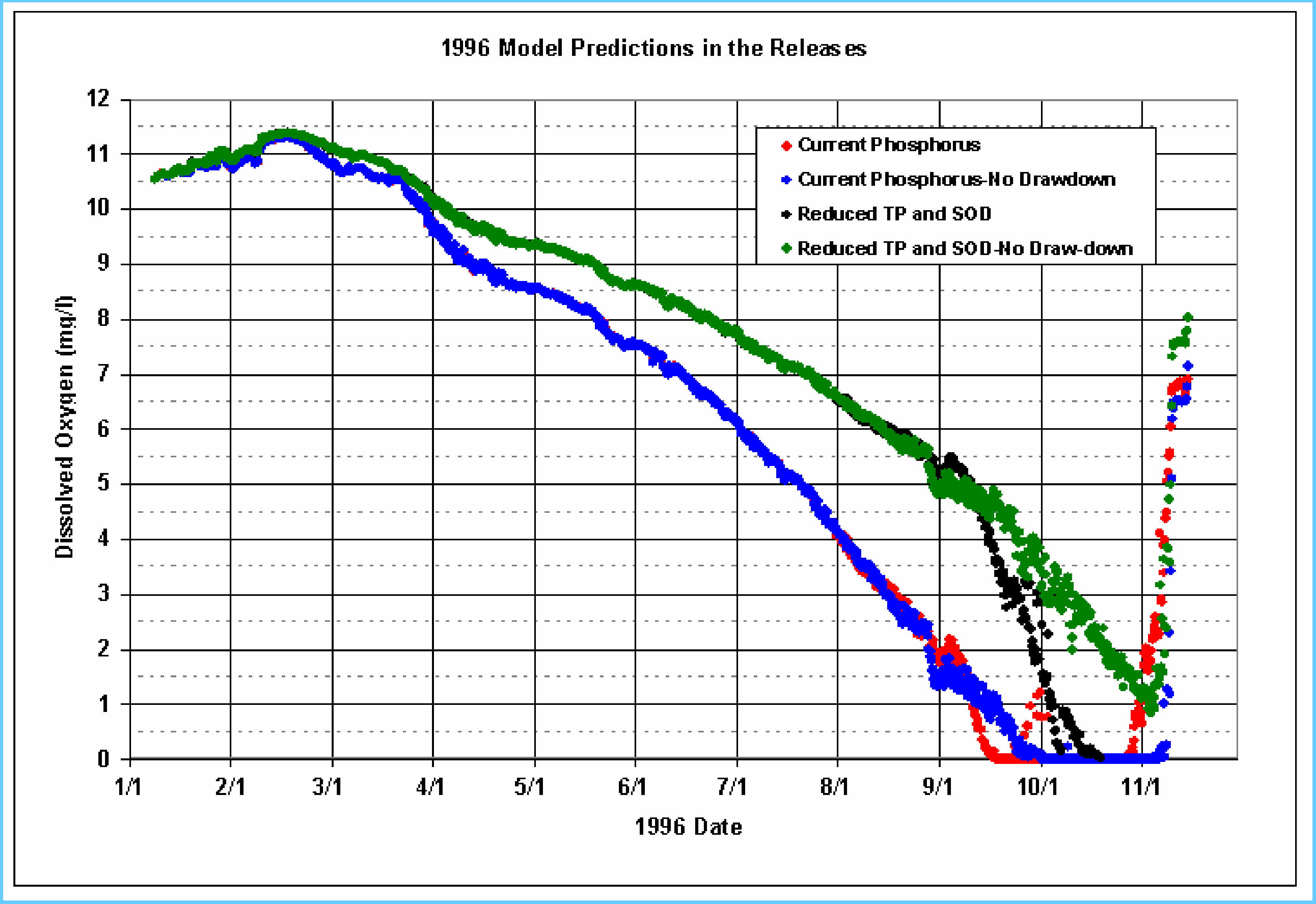
1992 Modeled versus Measured DO at the level of the Unit 5 Intake



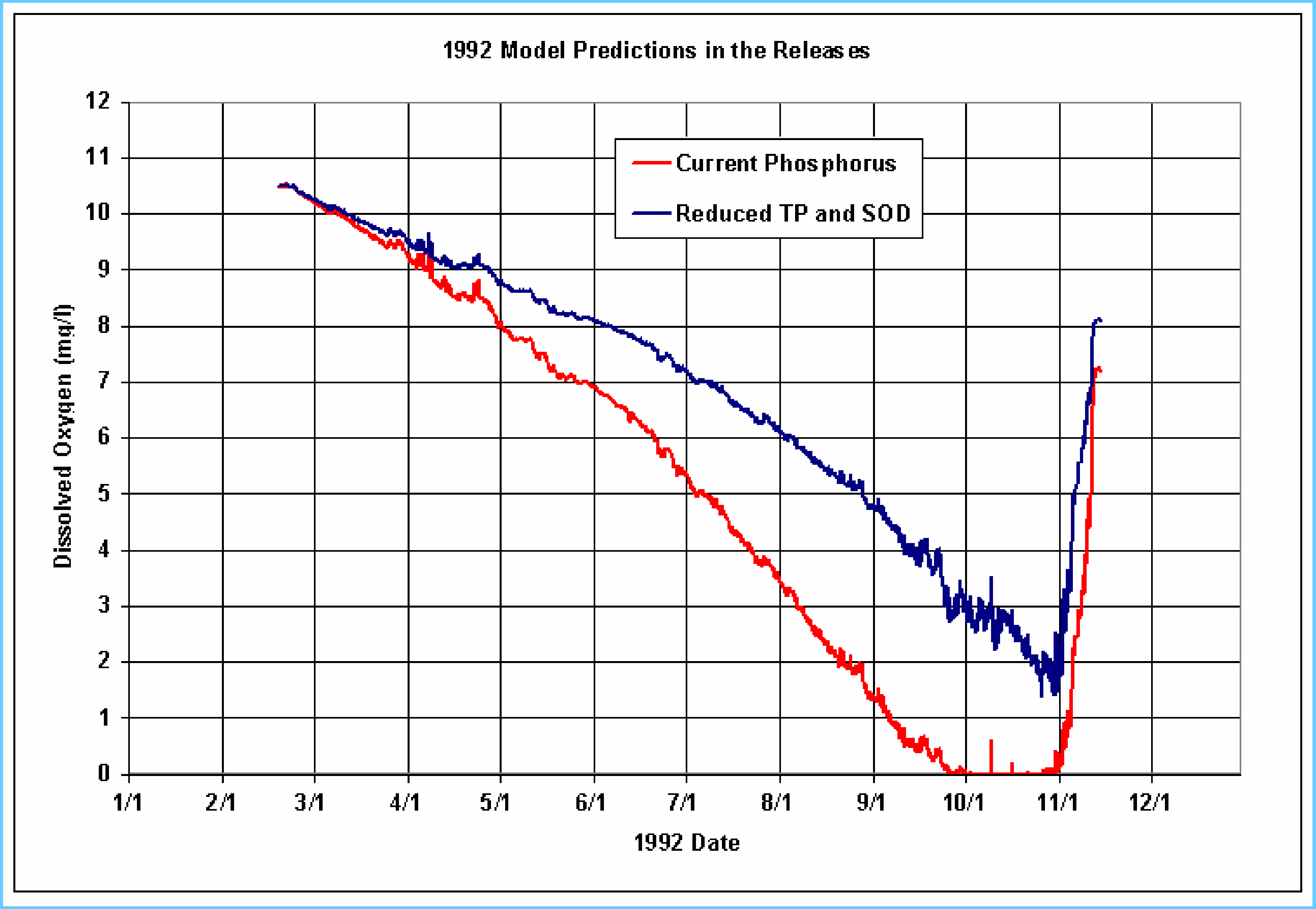
1997 Modeled versus Measured DO at the level of the Unit 5 Intake



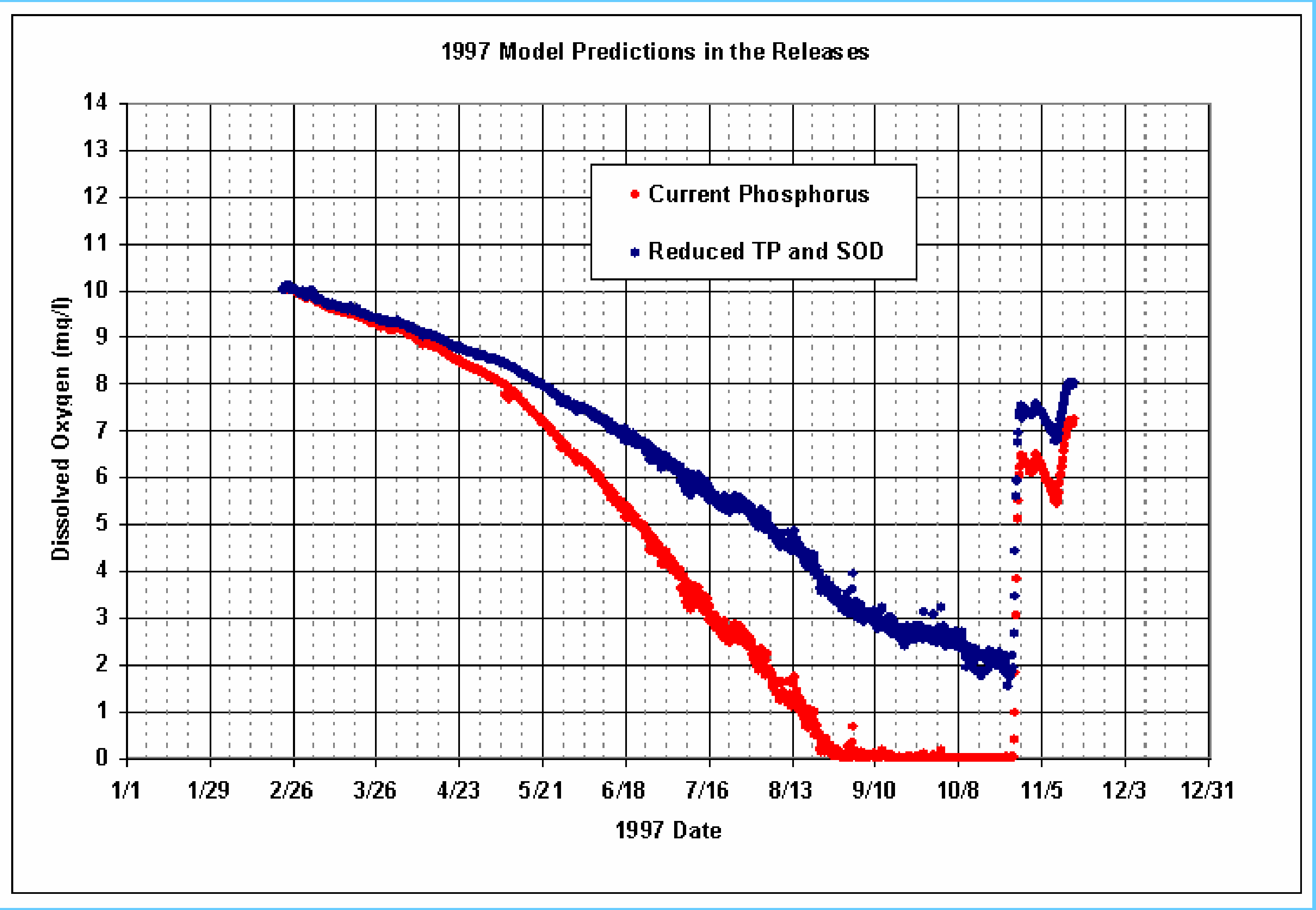
1996 Discharge DO for Current and Reduced Phosphorus, and without the Special Drawdown



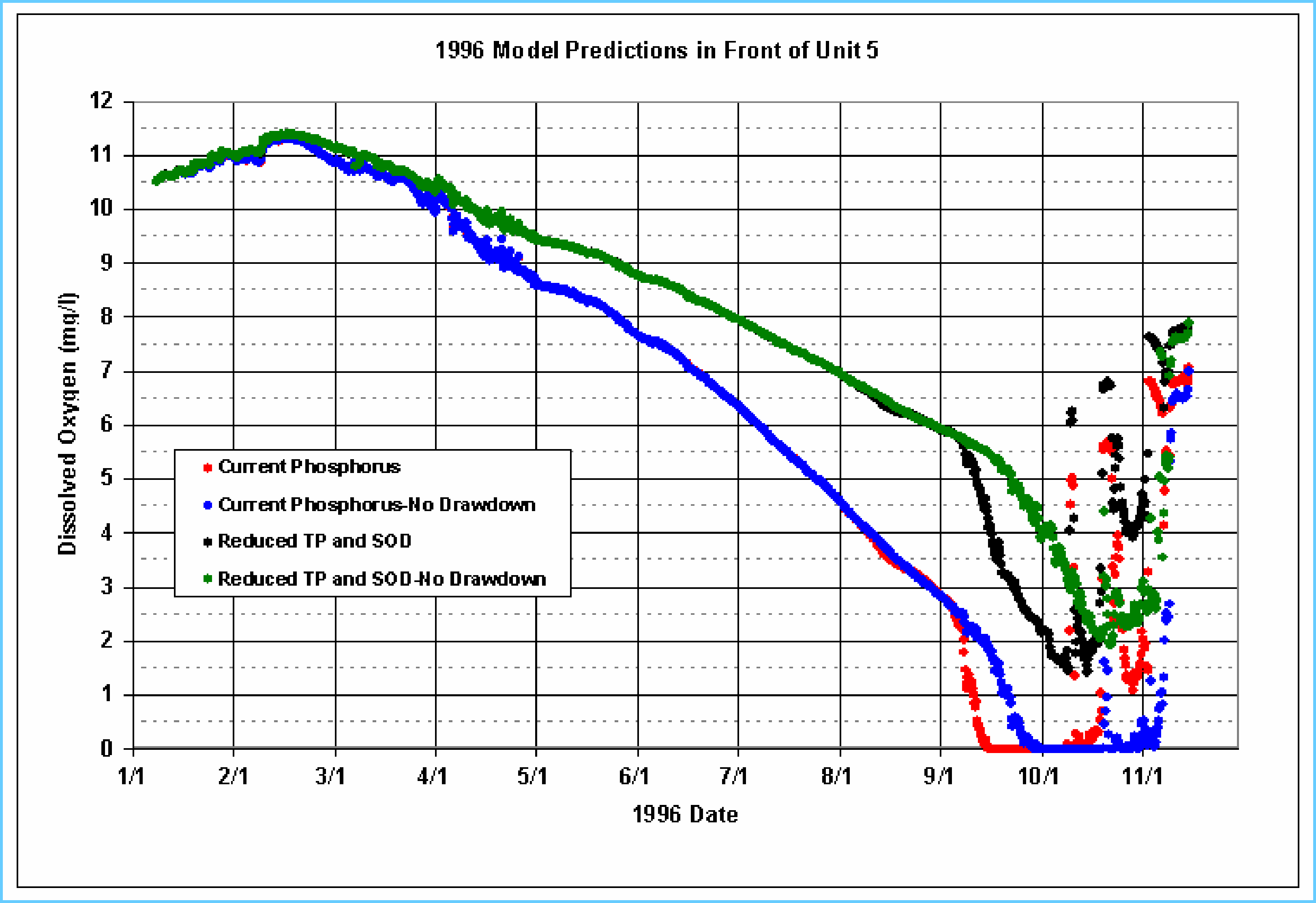
1992 Discharge DO for Current and Reduced Phosphorus



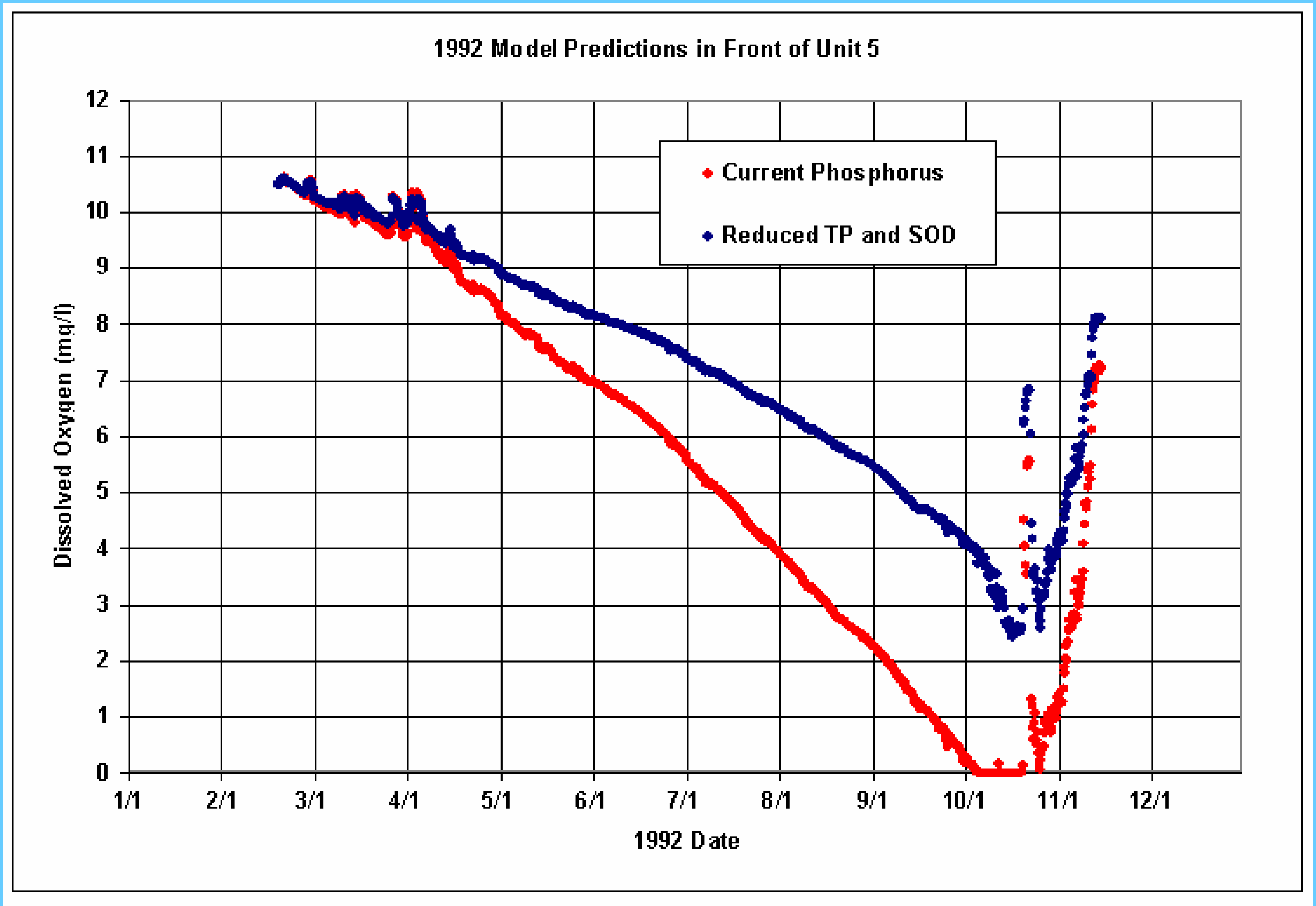
1997 Discharge DO for Current and Reduced Phosphorus



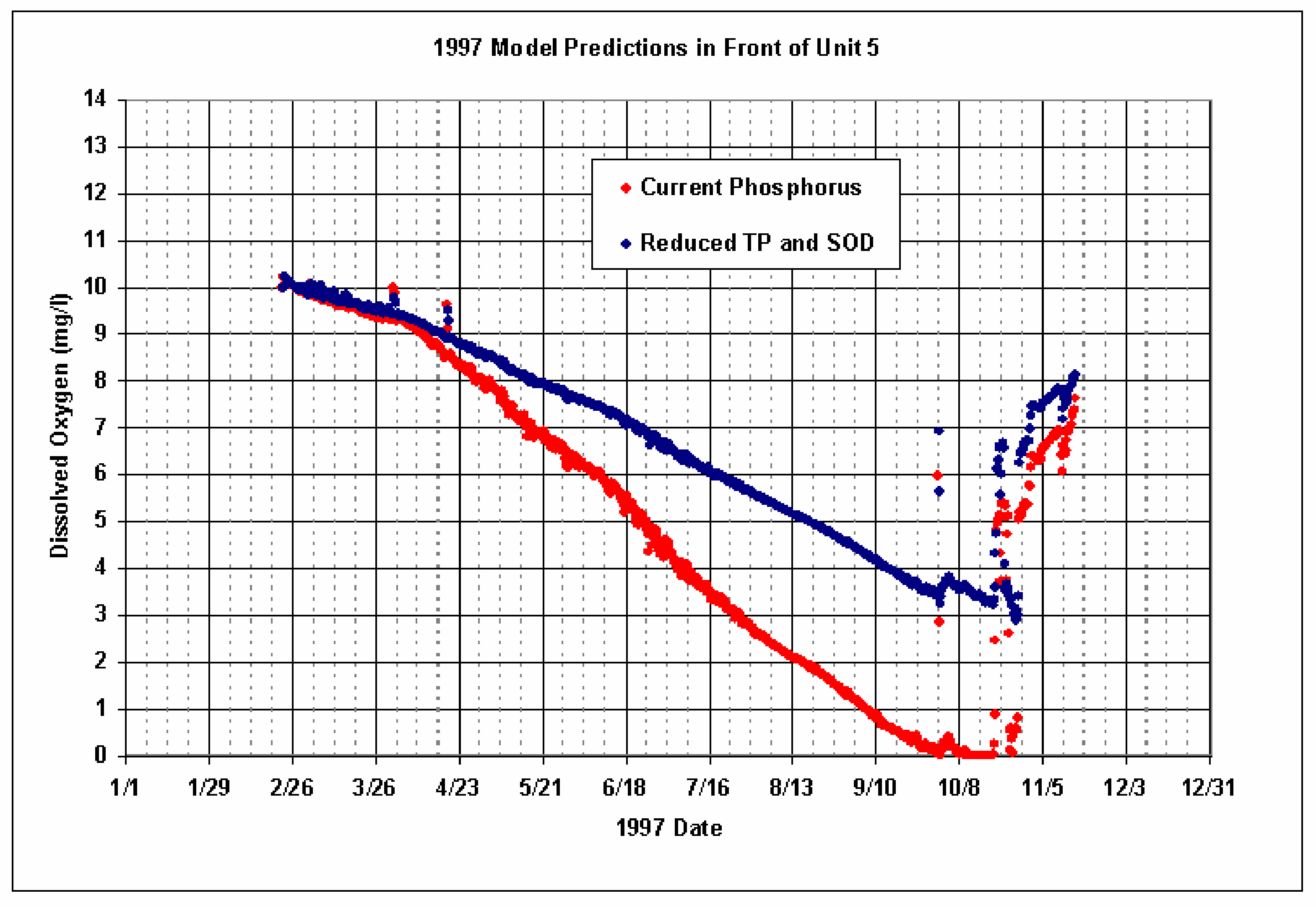
1996 DO at the Elevation of the Unit 5 Intake for Current and Reduced Phosphorus, and without the Special Drawdown



1992 DO at the Level of the Unit 5 Intake for Current and Reduced Phosphorus



1997 DO at the Level of the Unit 5 Intake for Current and Reduced Phosphorus



The End

CE-QUAL-W2 Model for Lake Murray—Progress Report on Calibration and Applications

Presented by Andy Sawyer and Jim Ruane

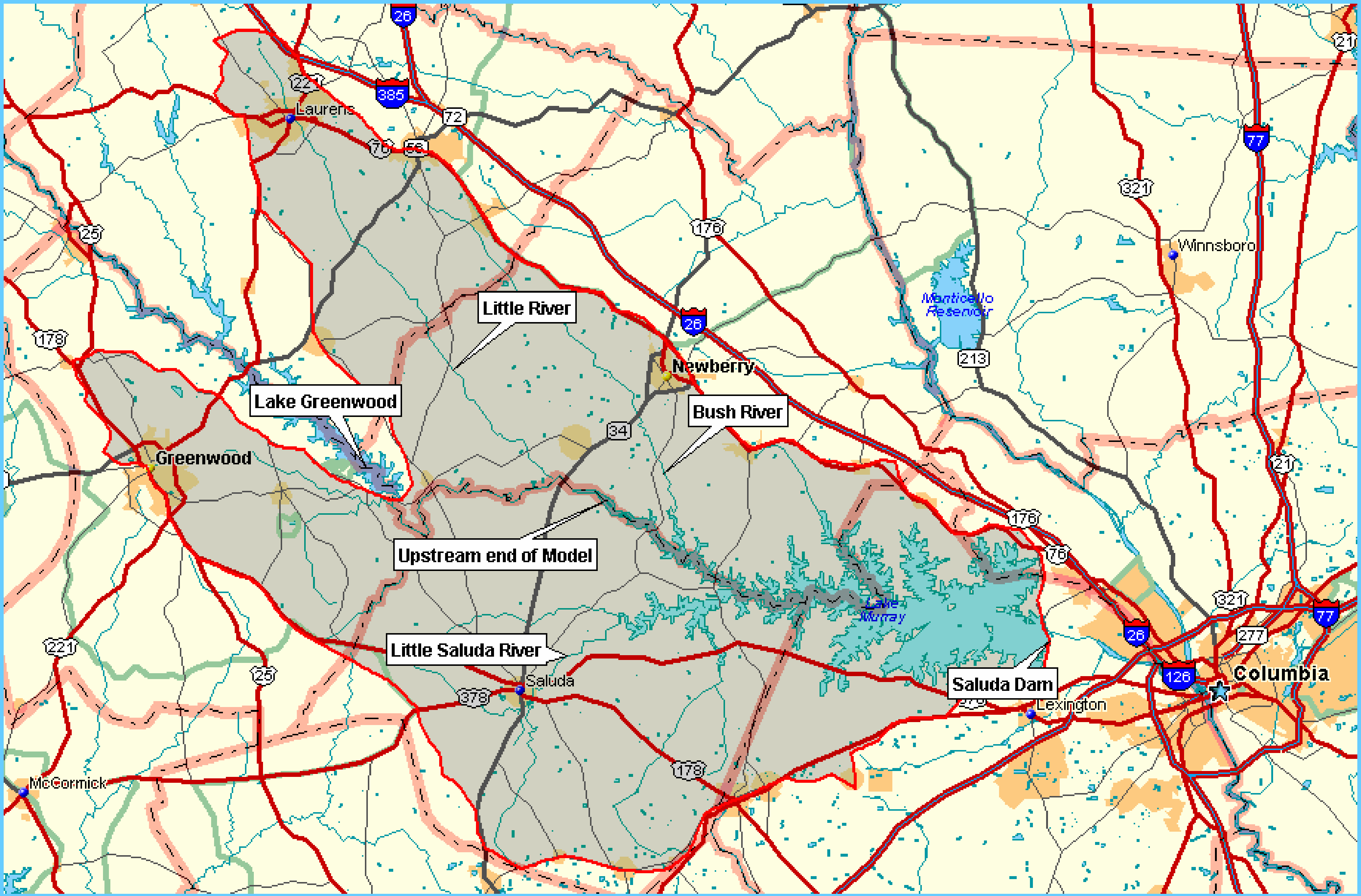
Reservoir Environmental Management, Inc

August 23, 2006

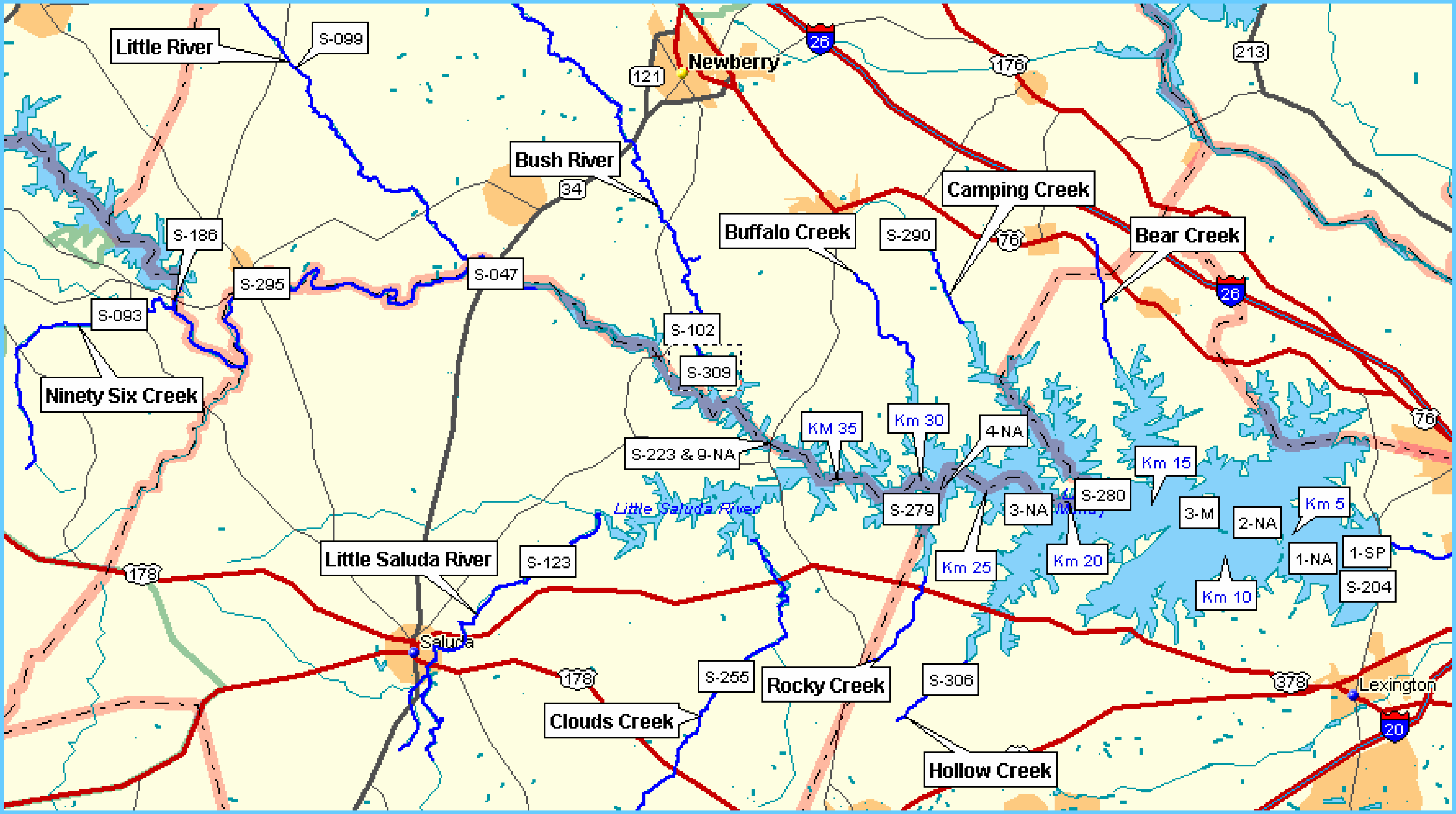
Overview of Presentation

- Present the calibration of the CE-QUAL-W2 model that will be used to simulate water quality in Lake Murray
- Illustrate use of the model to explore management strategies for improving water quality and uses of the lake

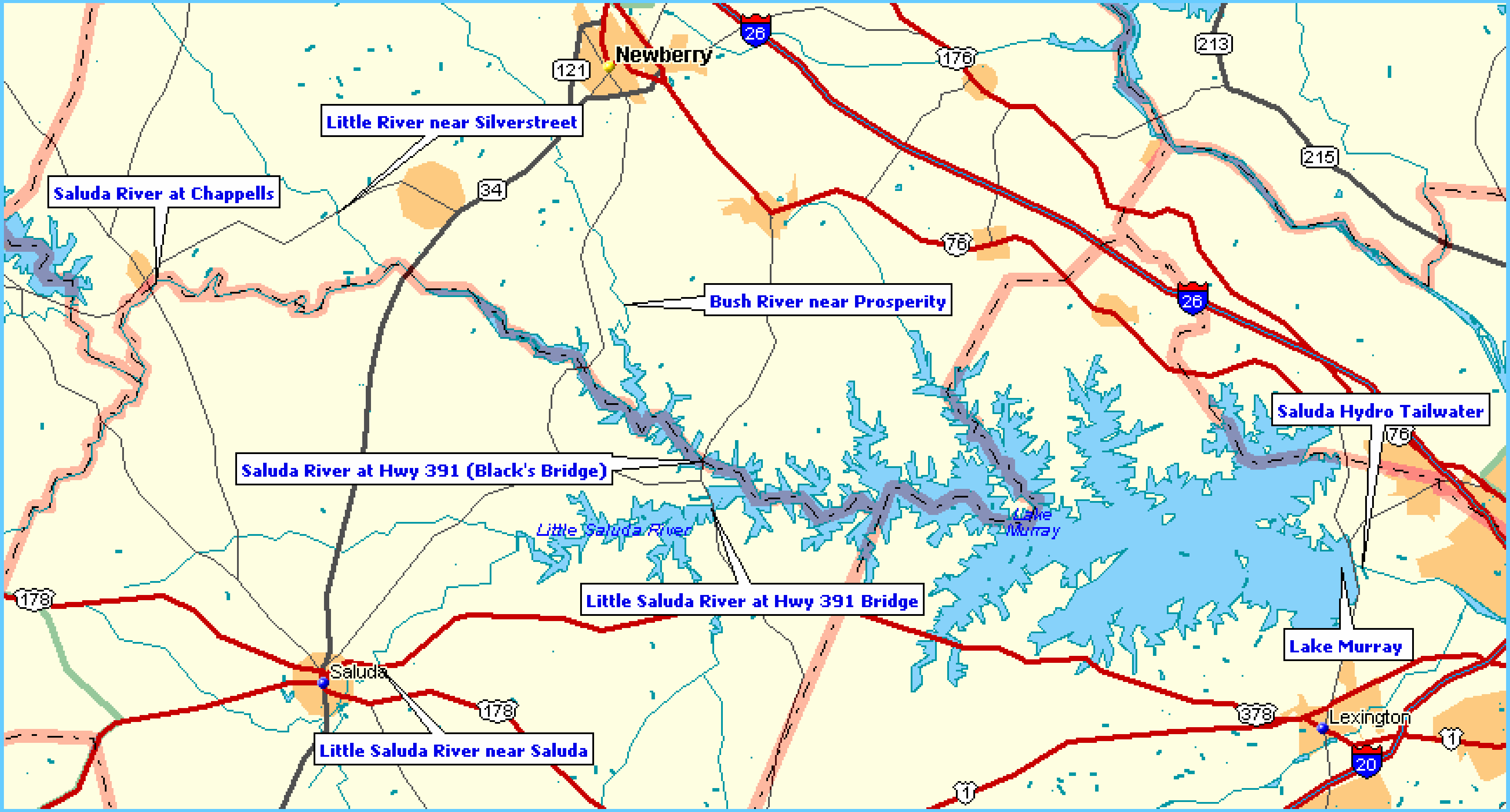
Lake Murray Watershed



Primary SCDHEC and SCE&G Monitoring Stations used for Lake Murray Water Quality Analyses



Map of Lake Murray Watershed Showing Location of USGS Monitors



Summary of Key Issues to be Addressed Using the CE-QUAL-W2 Model

- Low DO in the releases from Saluda Hydro,
- Restrictions for operating Unit 5 due to entrainment of blue-back herring,
- Effects of project operations and water quality on Striped Bass habitat, including fish kills that have occurred in the past
- DO less than the State standard in the inflow regions of the lake,

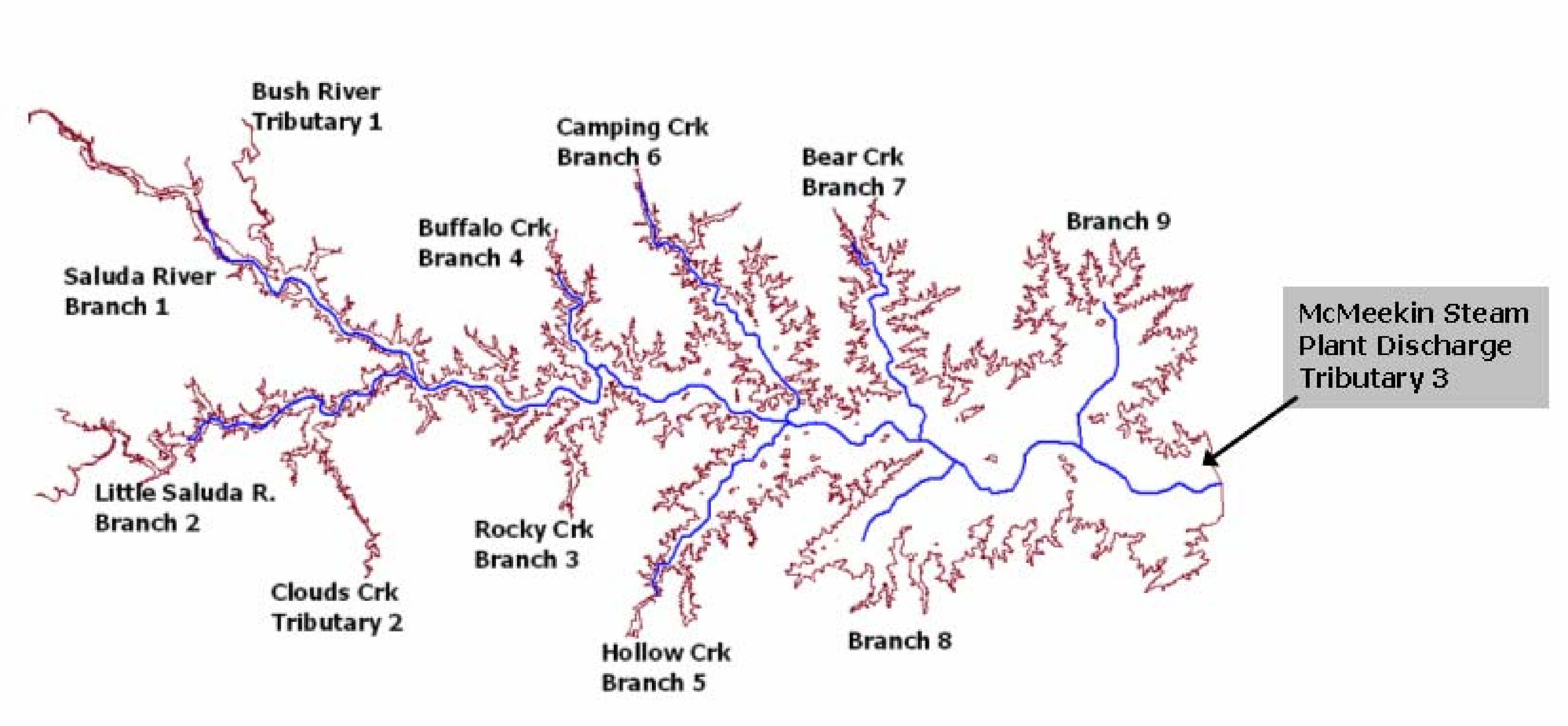
Other issues not being addressed at this time using the model:

- low pH in Lower Saluda River (LSR)
- eutrophication in the upper regions of Lake Murray

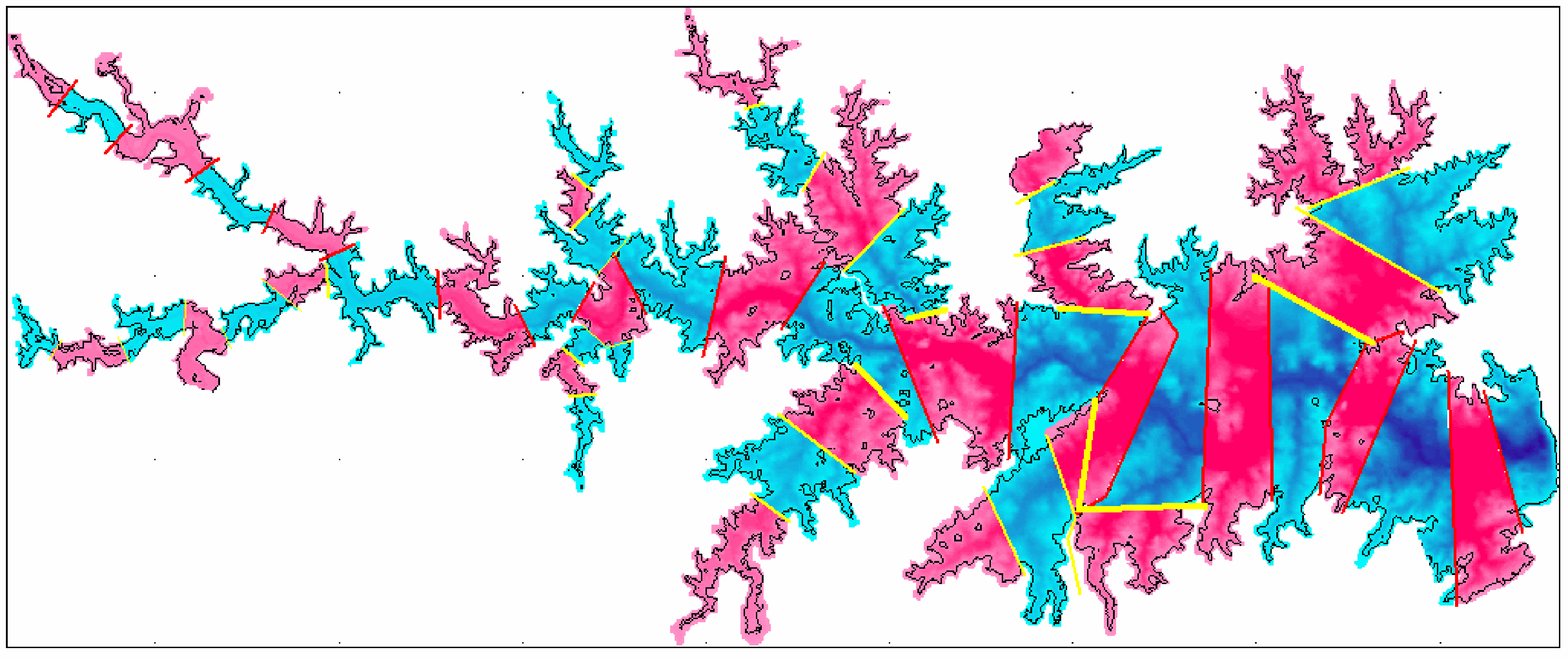
Physical Characteristics of Lake Murray

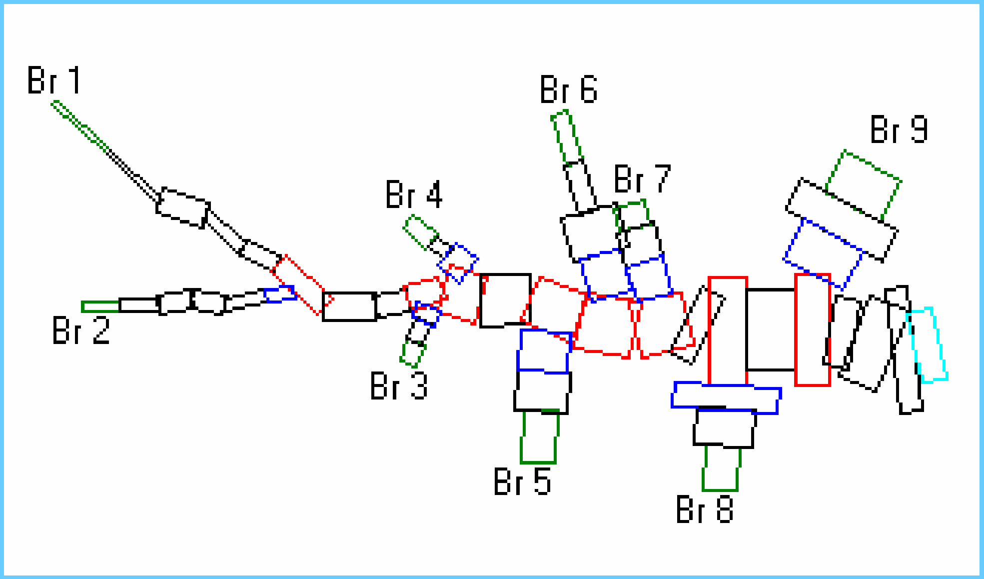
	U.S. Customary System	Metric System
Maximum depth	175 feet	53.3 m
Total lake volume	2,317,000 ac-ft	2,636 hm^3
Average Annual Flow	2778 cfs	78.7 cms
Nominal Residence Time	417 days	417 days
Depth of outlets, Units 1-4	175 feet	53 m
Depth of outlets, Unit 5	110 feet	33.5 m
Flow Capacity - Units 1-4	3000 cfs	85 cms
Flow Capacity, Unit 5	6000 cfs	170 cms

Plan view of Lake Murray with all Branches and Tributaries that are Included in the Model

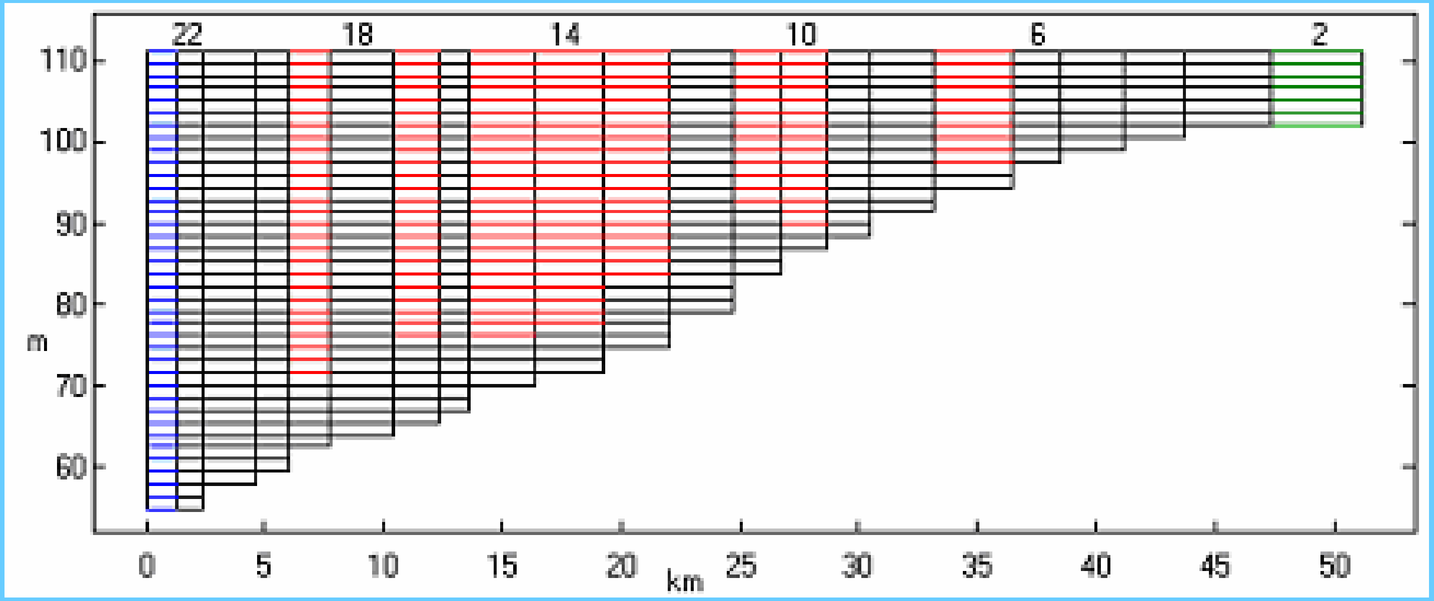


Plan View of Lake Murray Showing CE-QUAL-W2 Segmentation

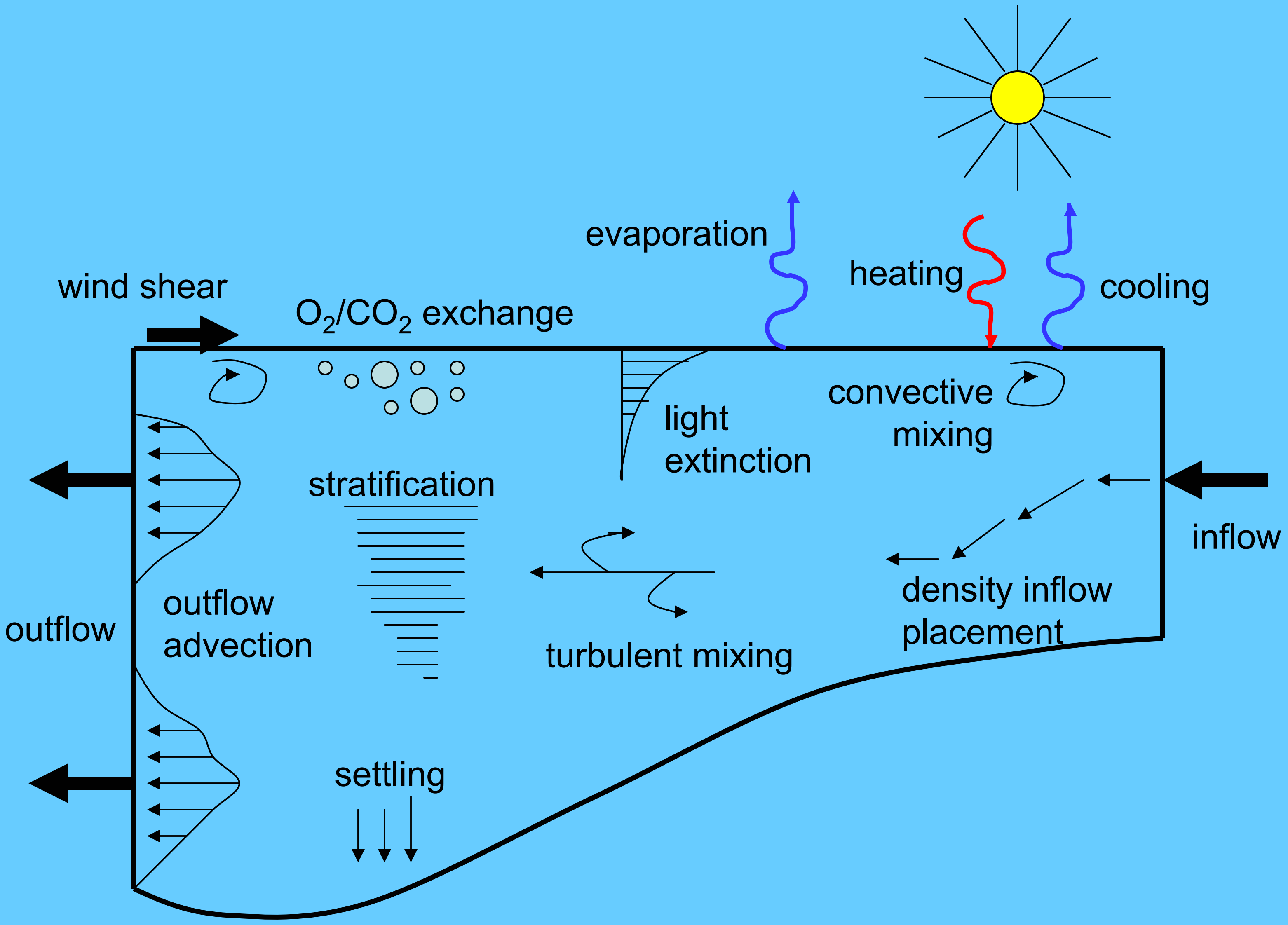




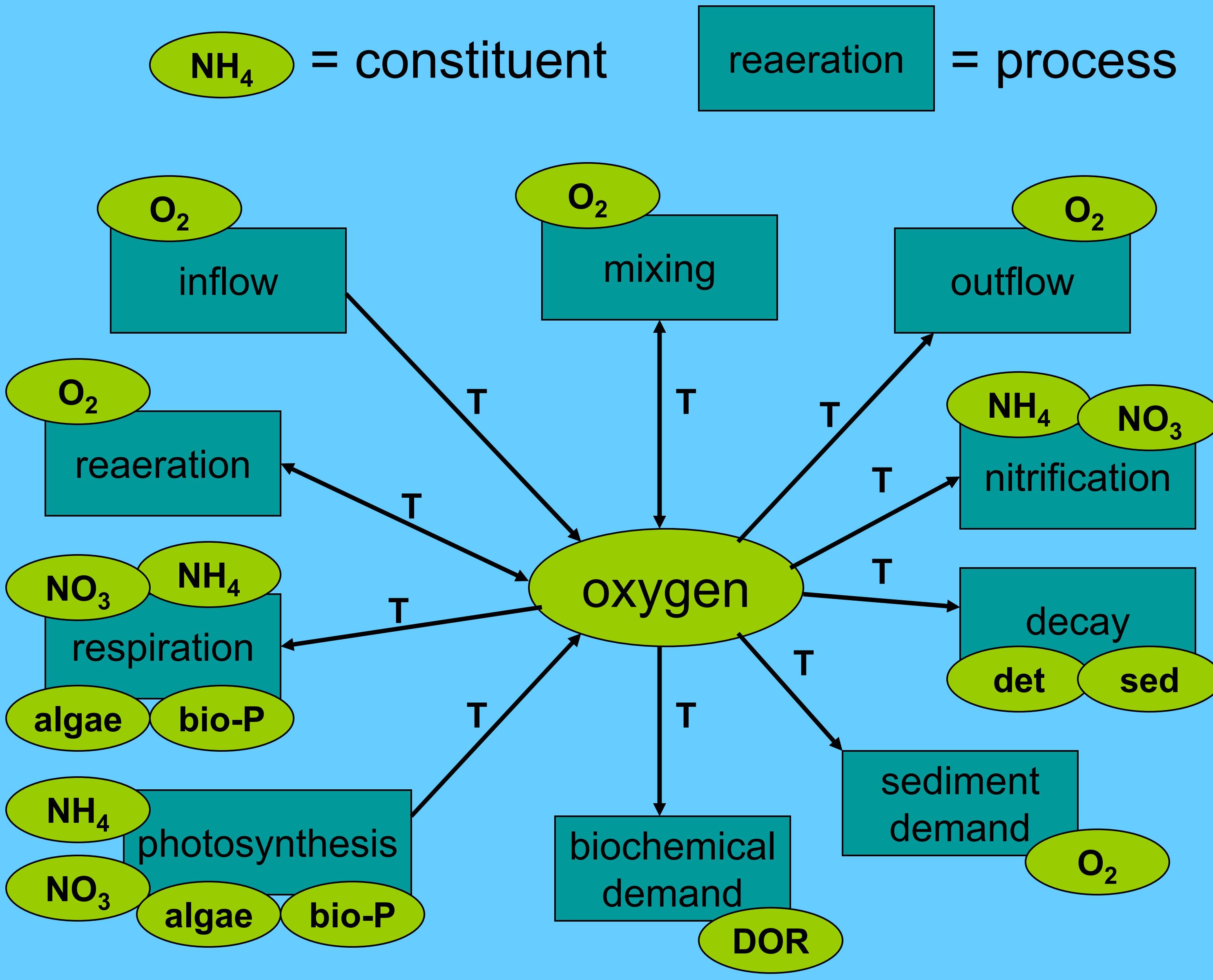
CE-QUAL-W2 Bathymetry for the Main Branch (Branch 1) of Lake Murray



Physical processes



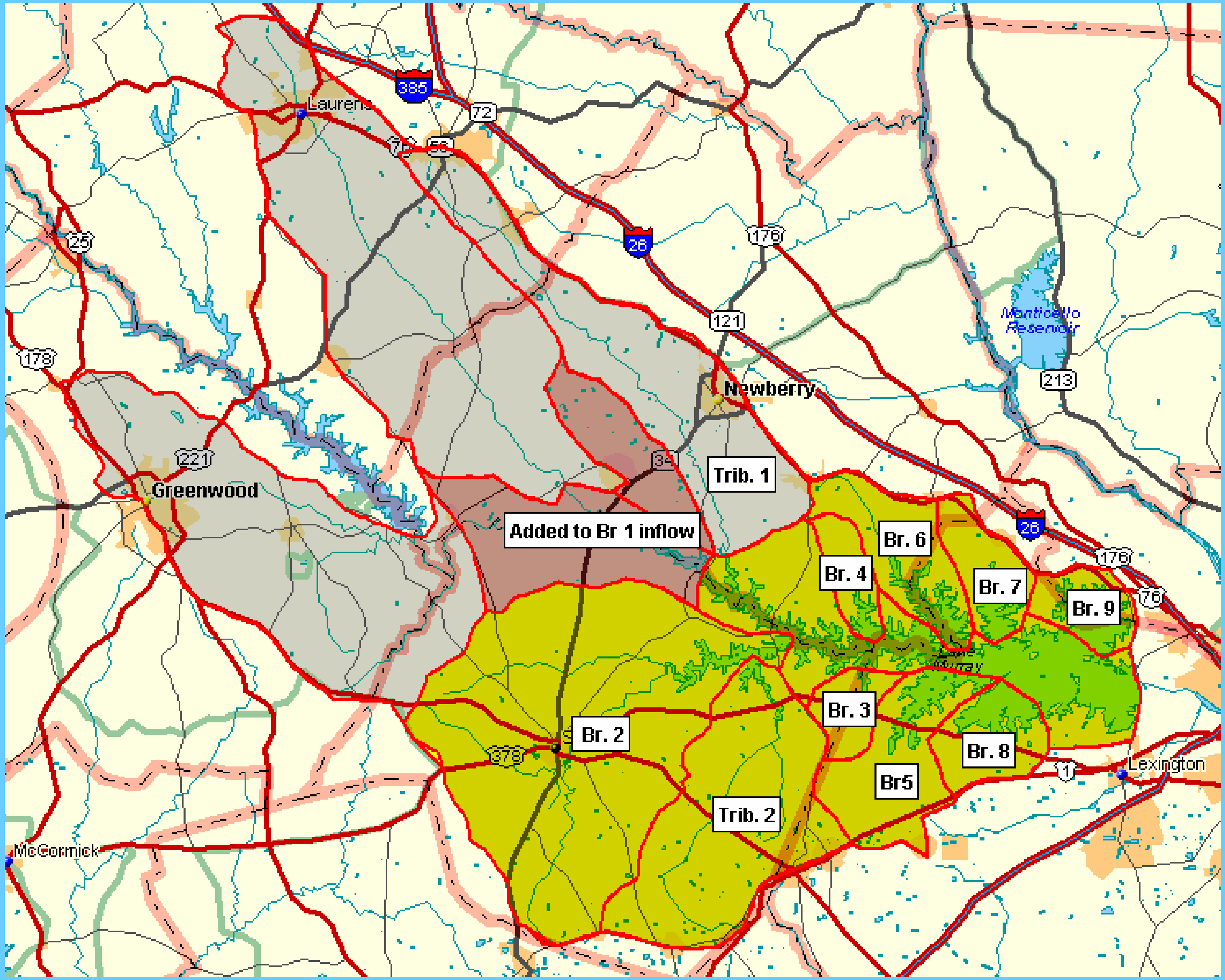
Highly coupled constituents



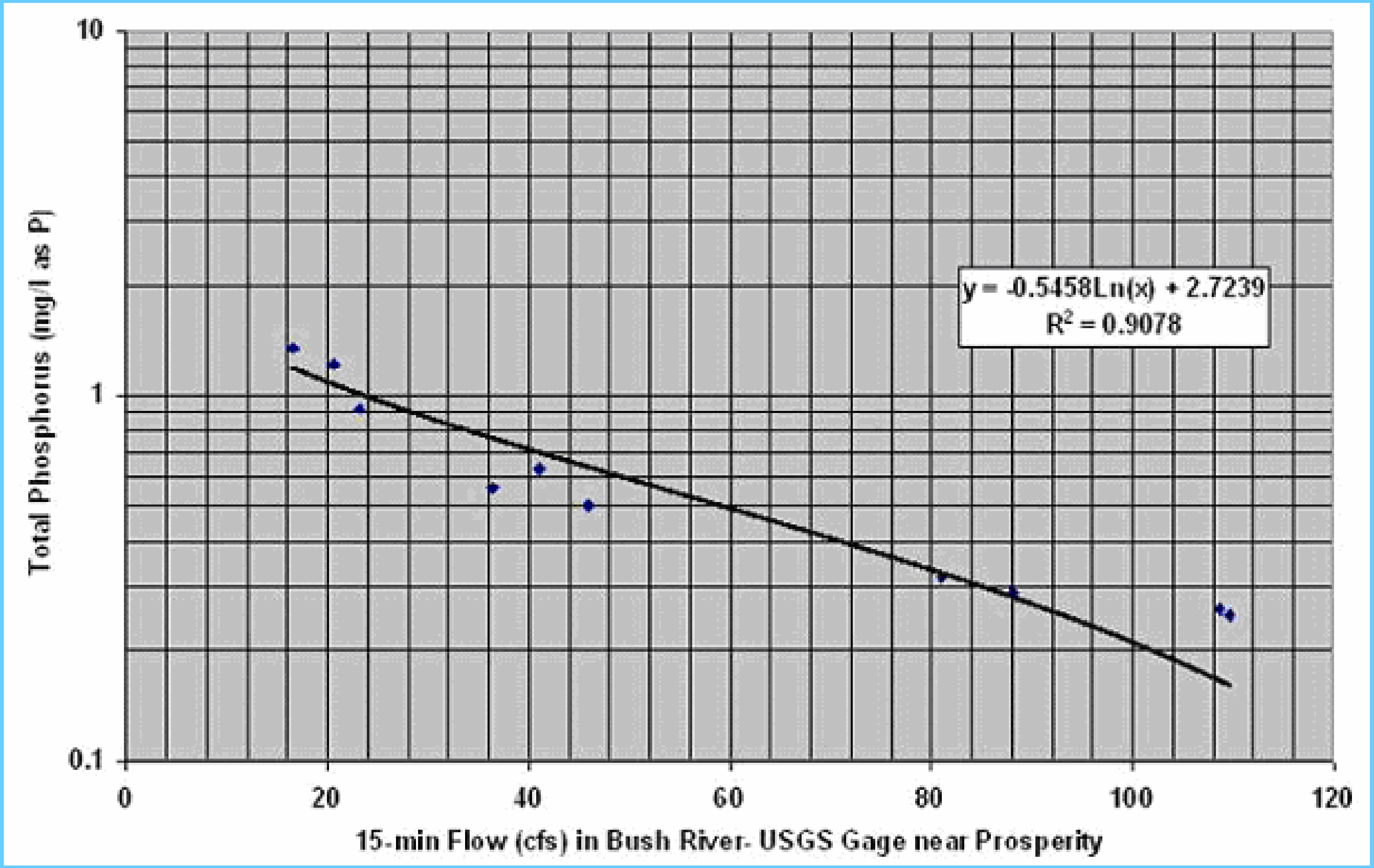
Model Upgrade Features

- Increased calibration focus at station located 6 Km (~ 4mi) upstream from the dam (for fish habitat issues)
- Refined withdrawal zone for Unit 5 (for fish habitat issues and DO in the releases)
- Sensitivity to TP in Saluda River inflow to Lake Murray
- Upgraded features for organic matter (labile and refractory nutrient cycling, sediment releases)
- Phosphorus settling
- Wuest wind drag coefficient to allow more mixing at low wind speeds

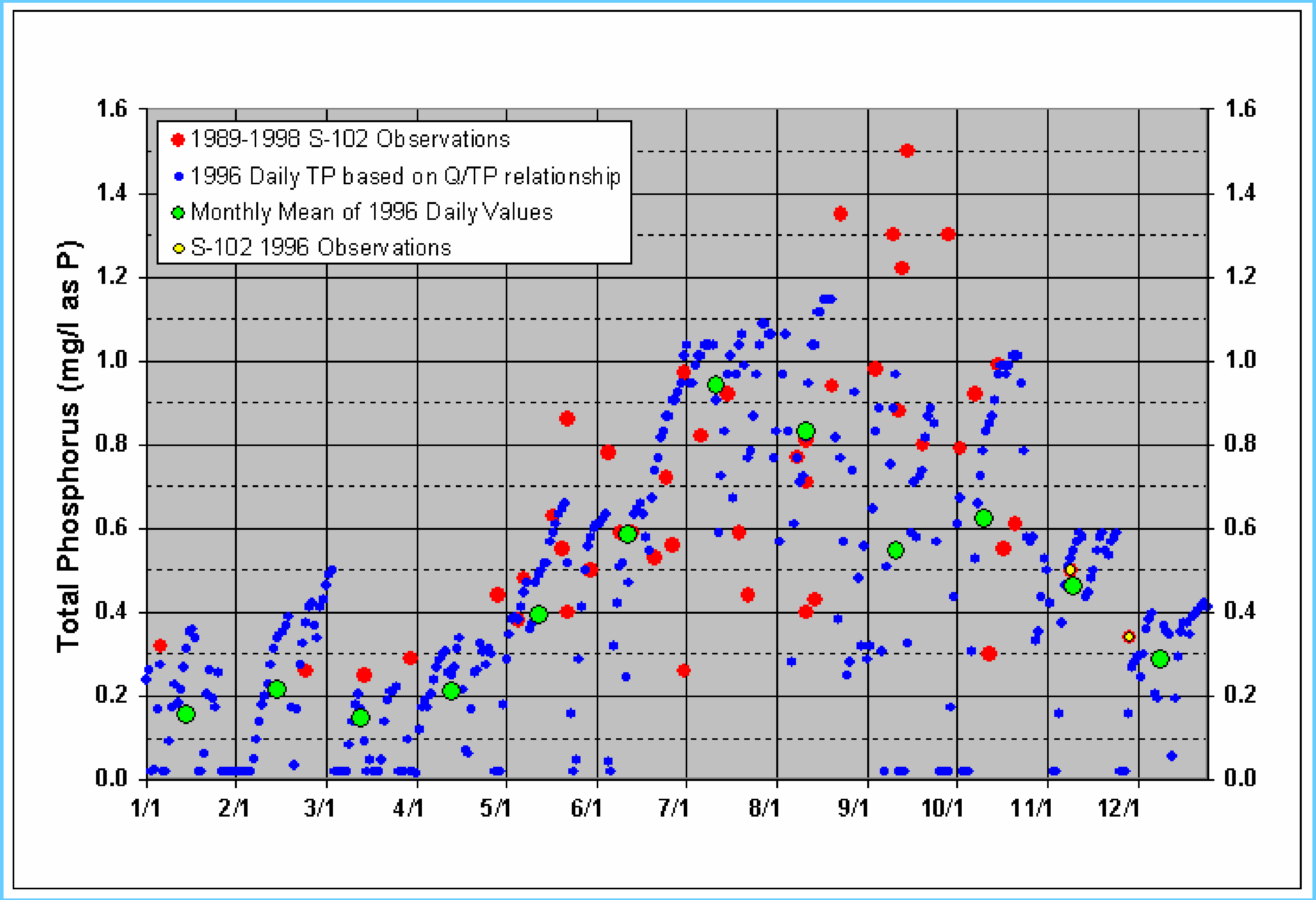
Map of Subwatershed Drainage Area Boundaries



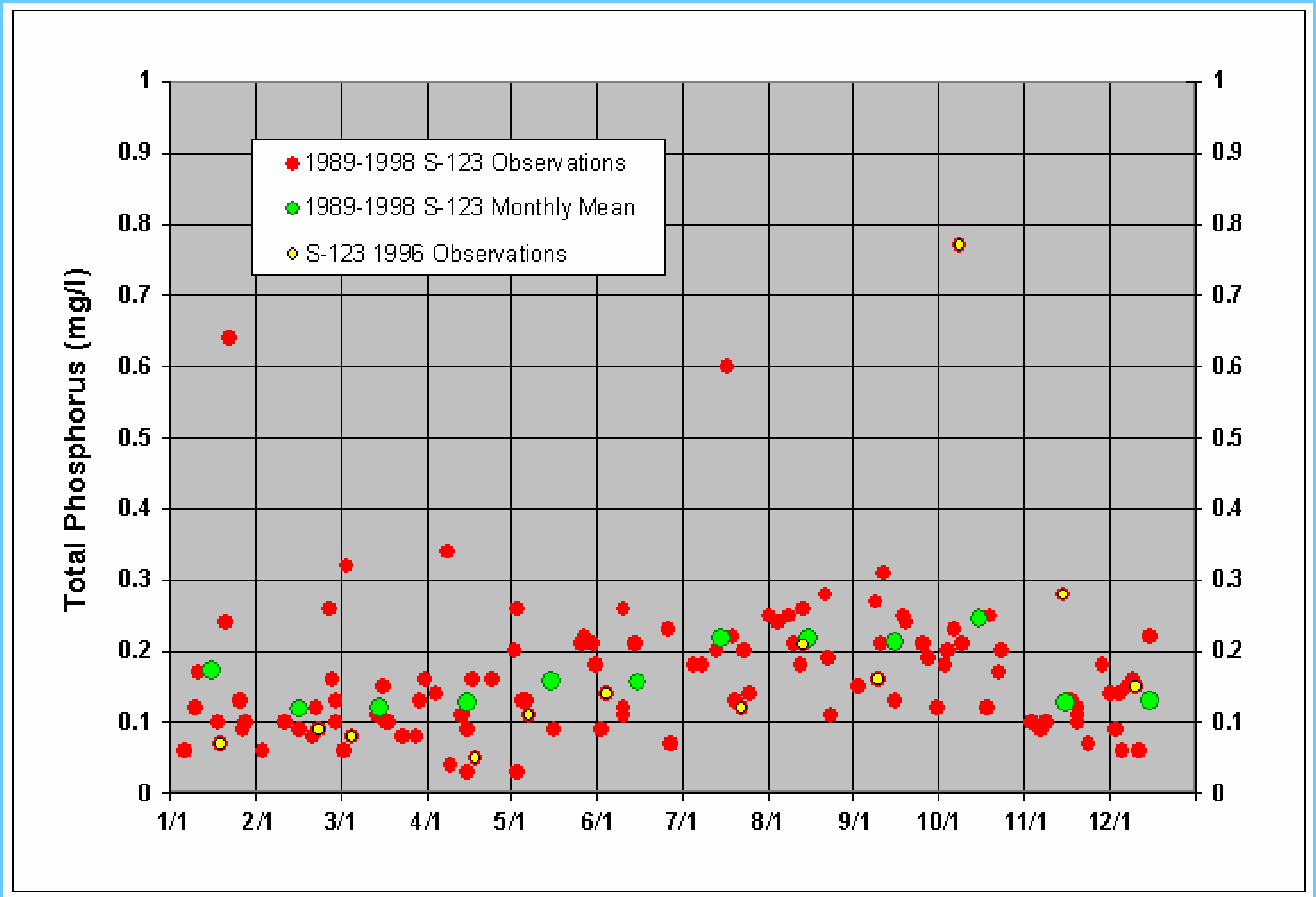
Phosphorus versus Flow Relationship found in the Bush River (Station S-102) using 1997 data



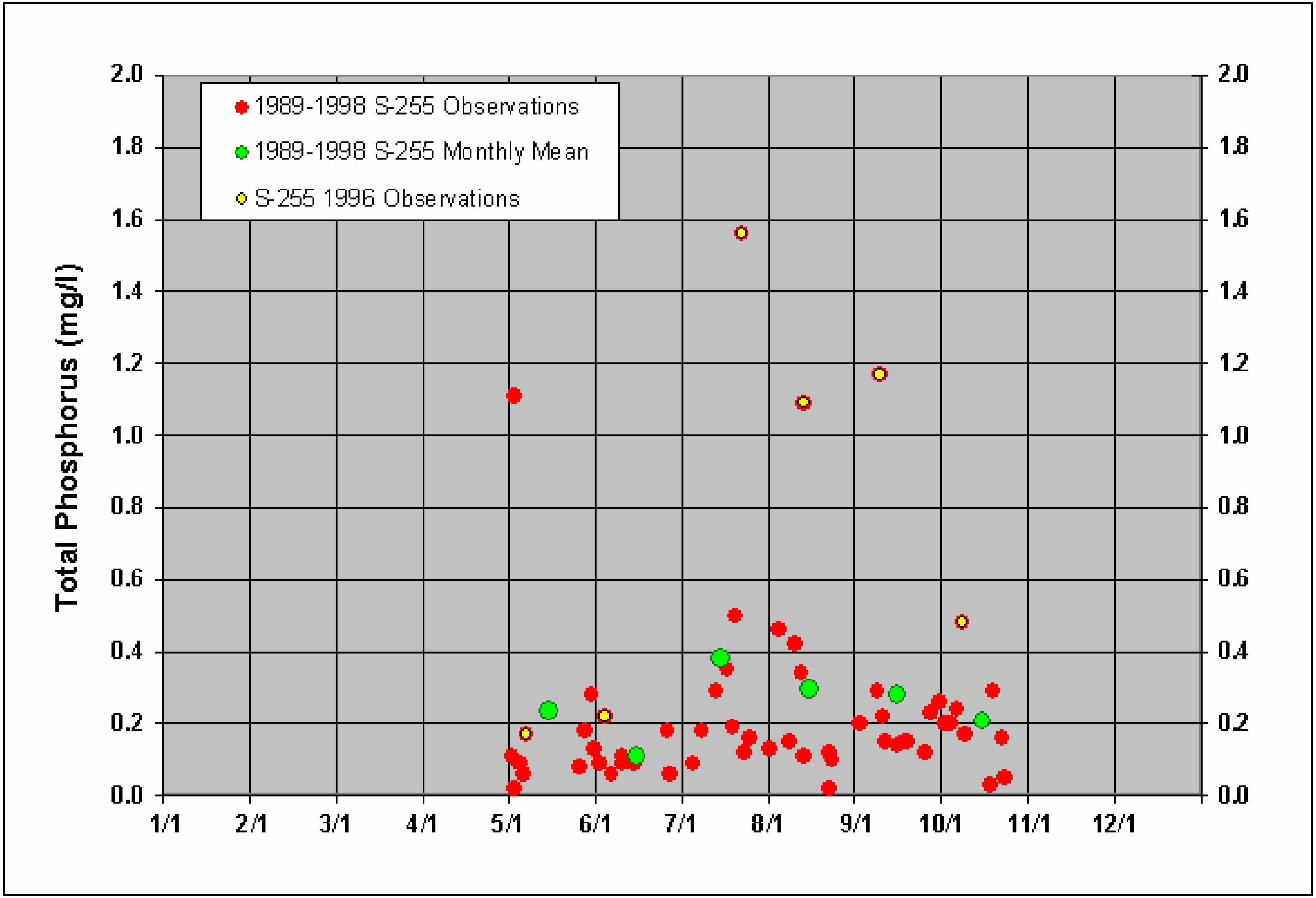
1996 Inflow Phosphorus Analysis for Bush River Inflow to Lake Murray



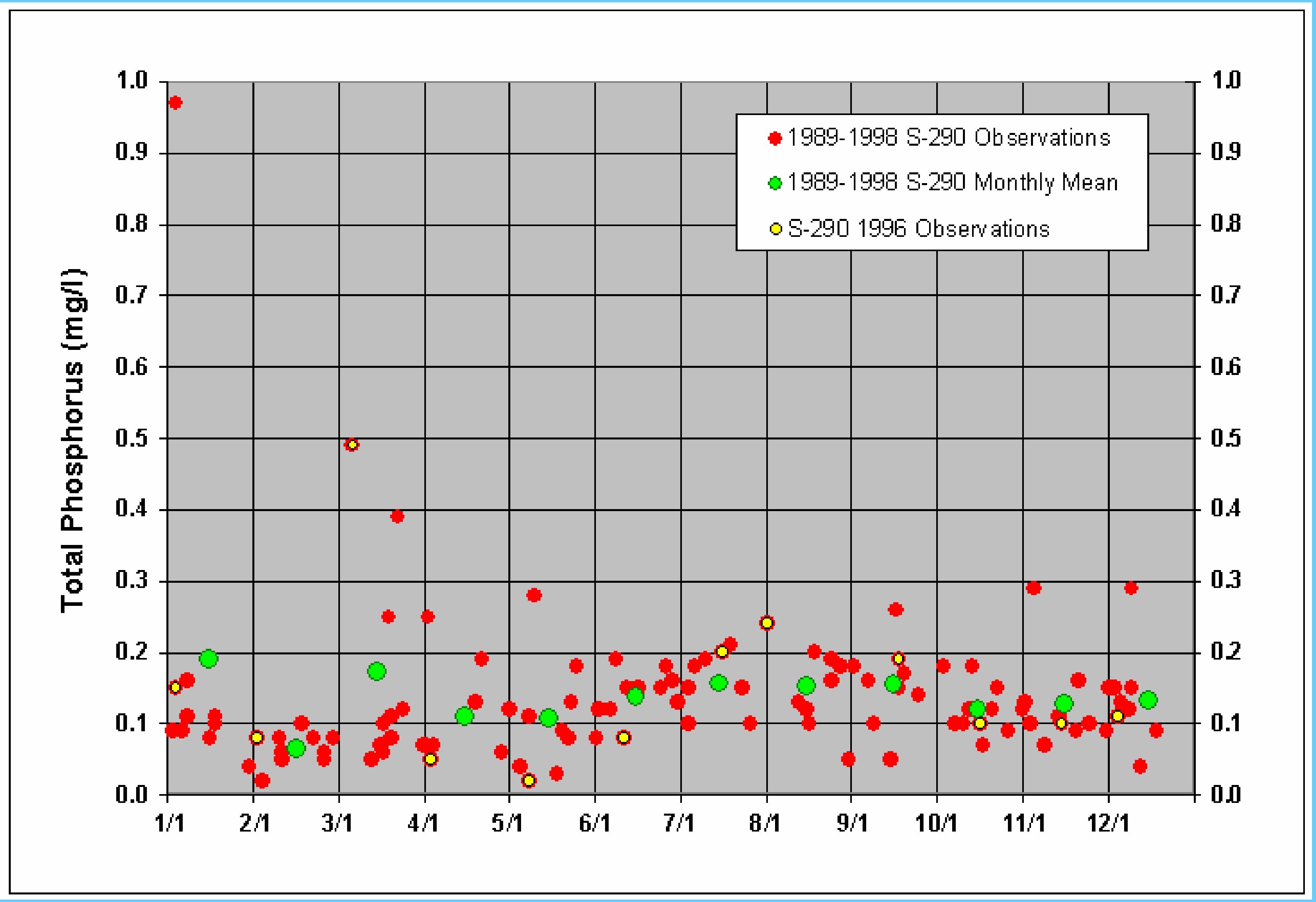
Total Phosphorus in the Little Saluda River



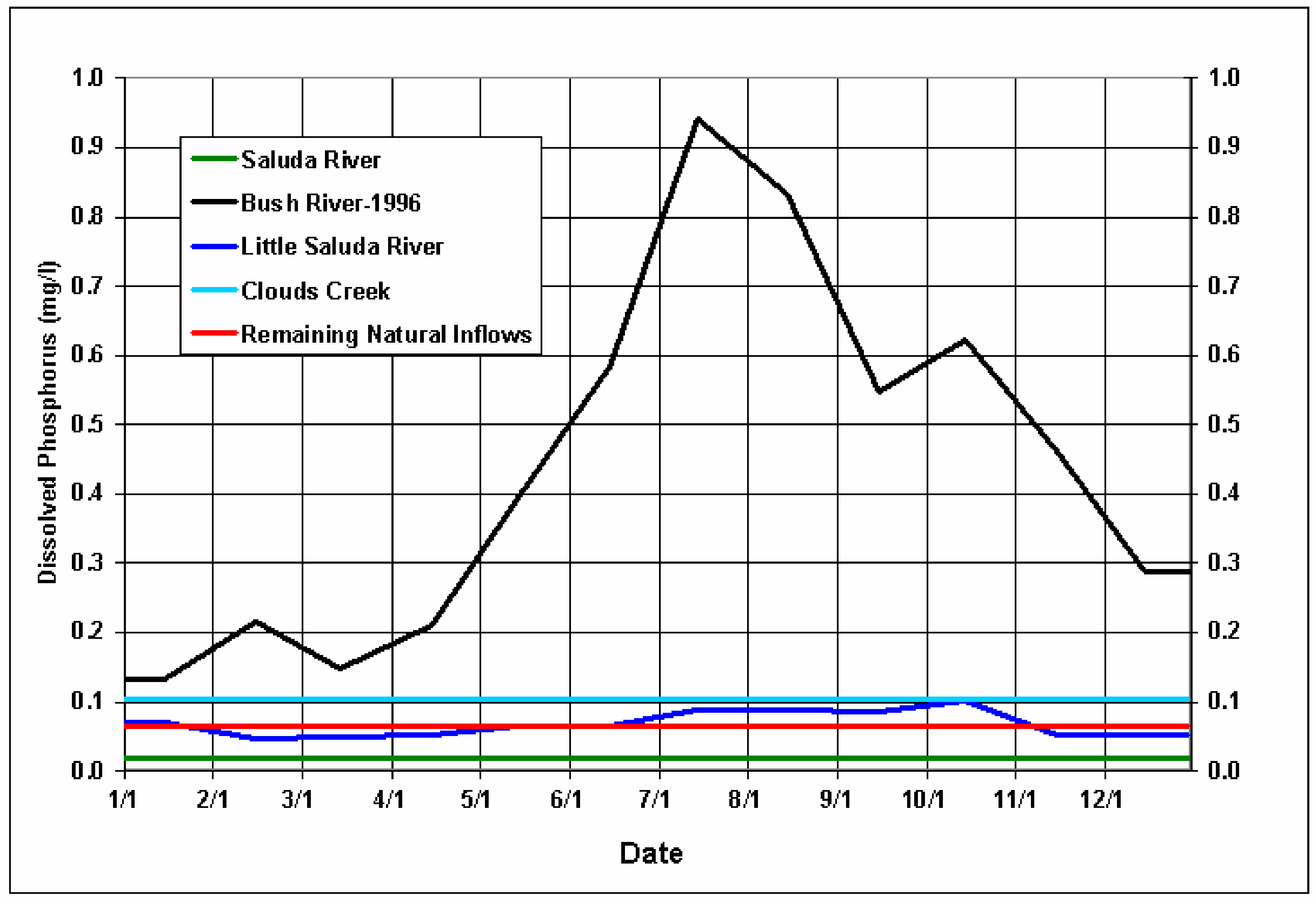
Total Phosphorus Clouds Creek



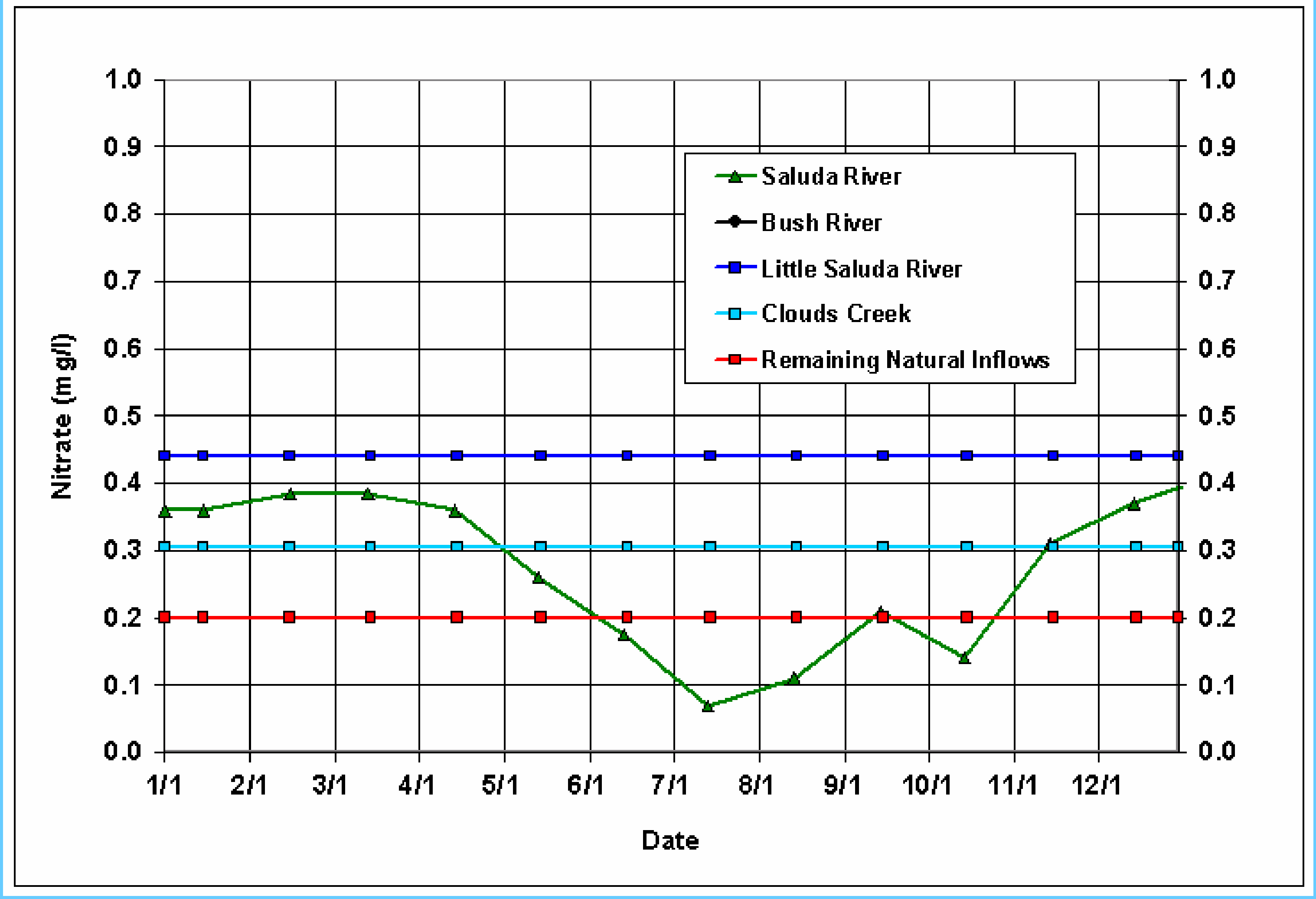
Total Phosphorus in Camping Creek



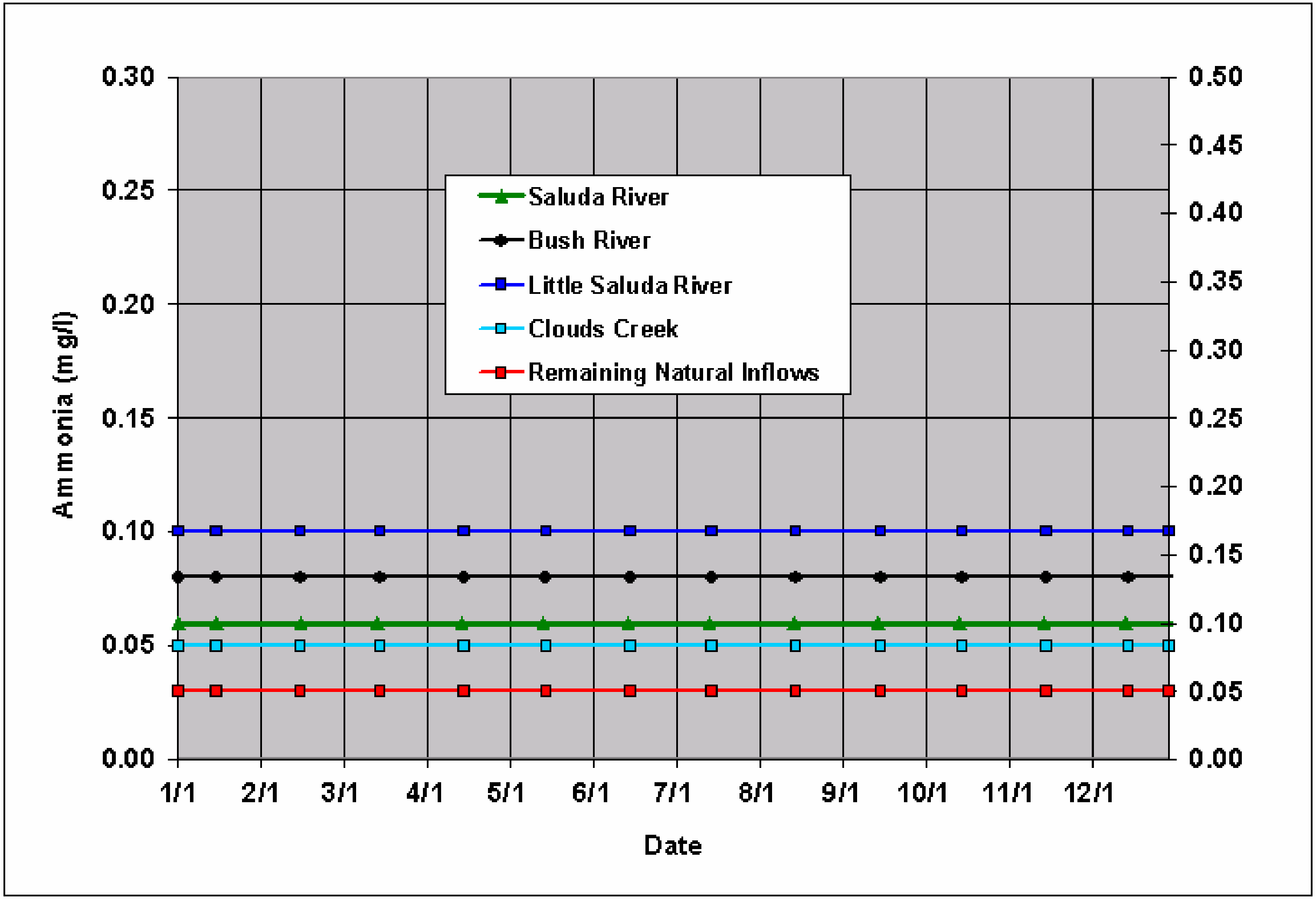
Inflow Dissolved Phosphorus Concentrations for Model Inflows to Lake Murray



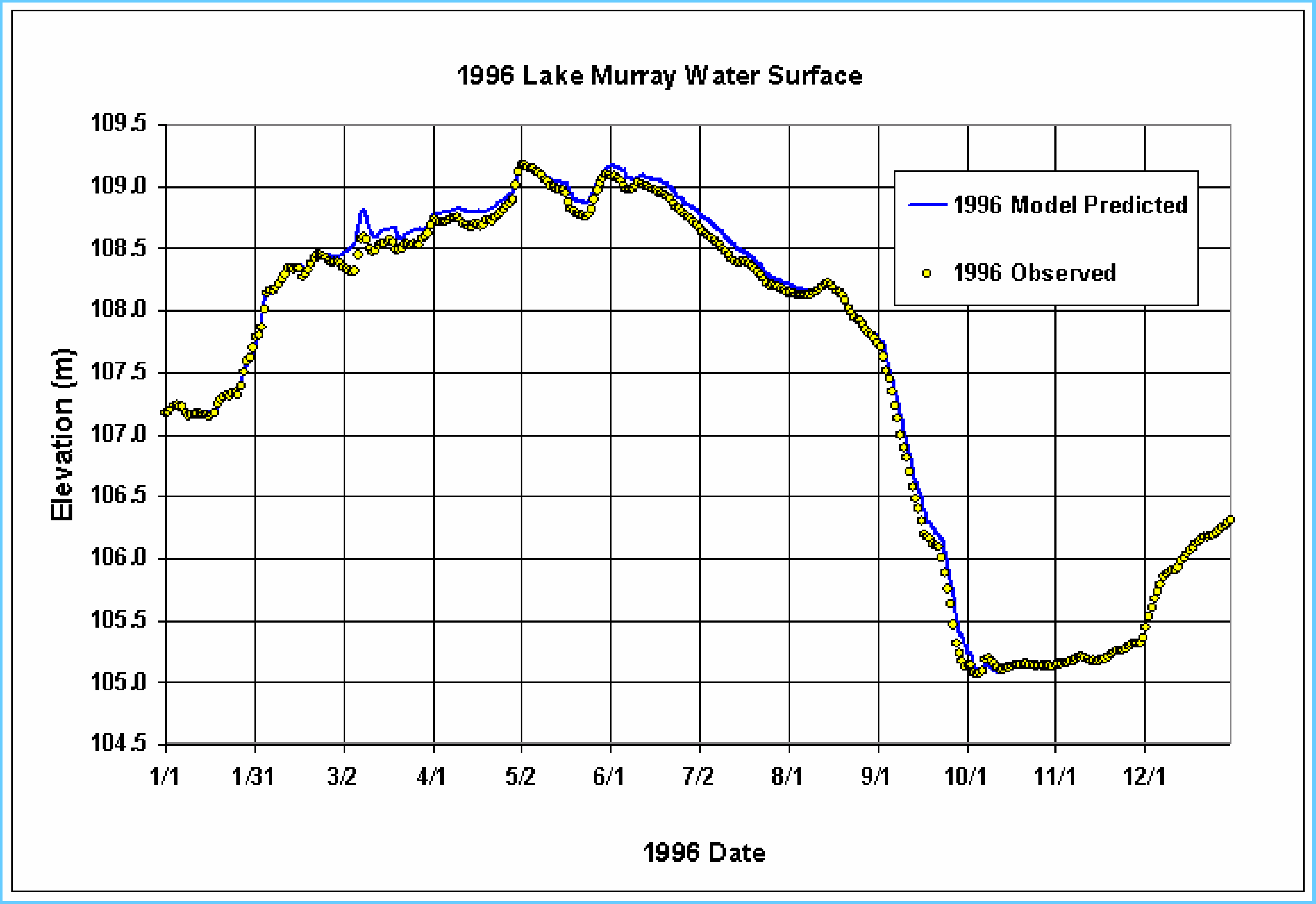
Nitrate Concentrations in the Inflows to the Lake Murray CE-QUAL-W2 Model



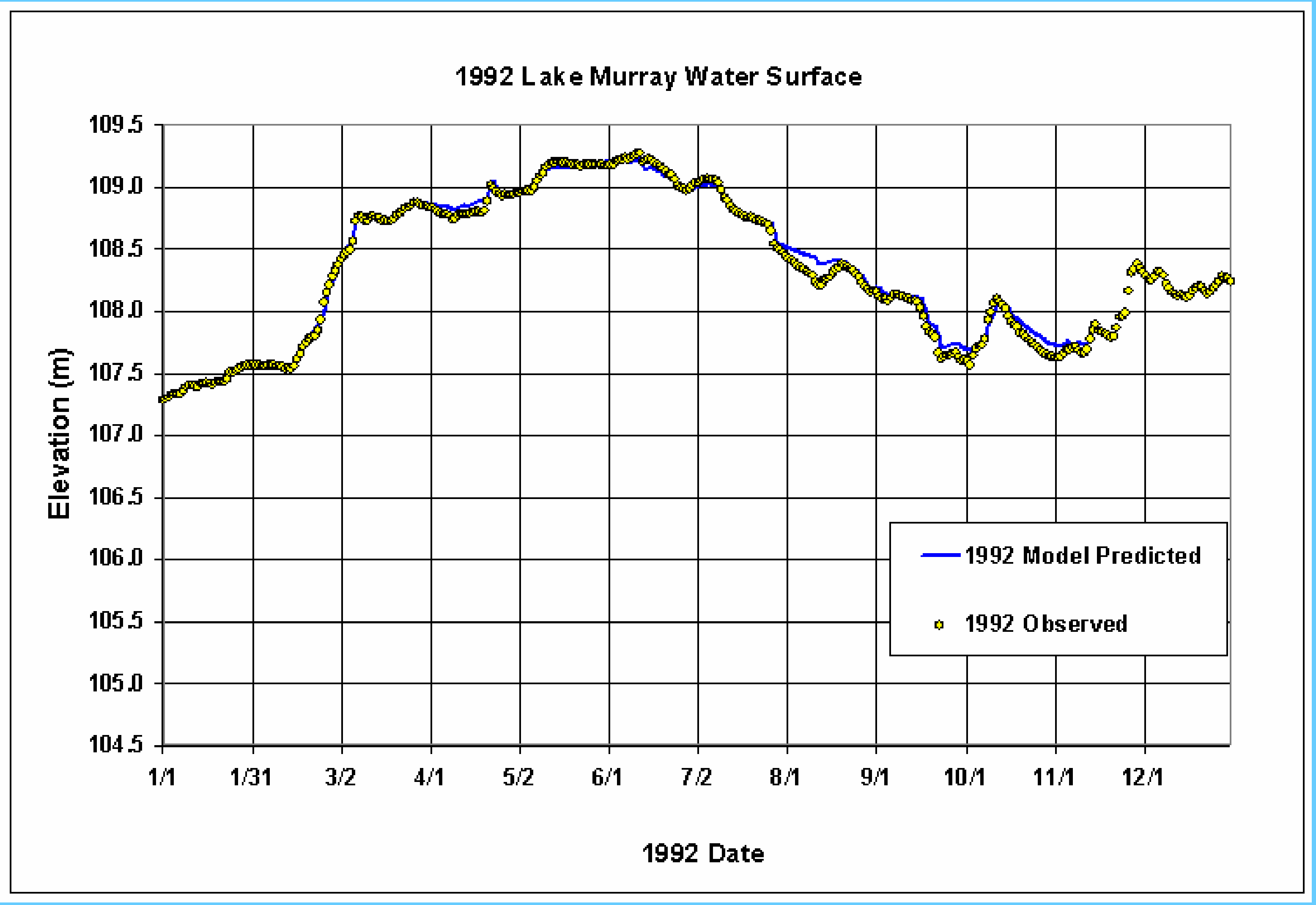
Ammonium Concentrations in the Inflows to the Lake Murray CE-QUAL-W2 Model



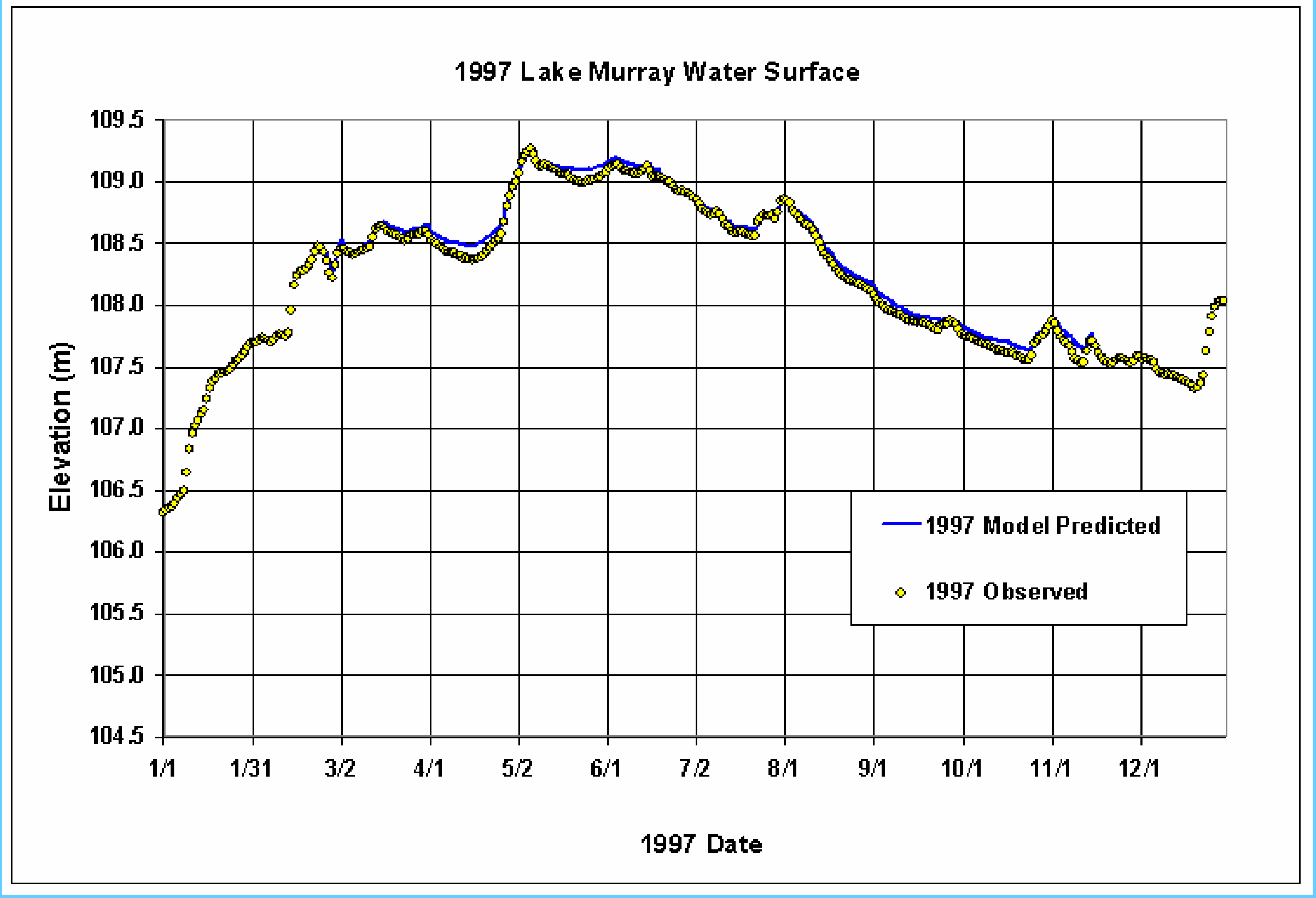
1996 Modeled and Measured Lake Murray Headwater Elevations



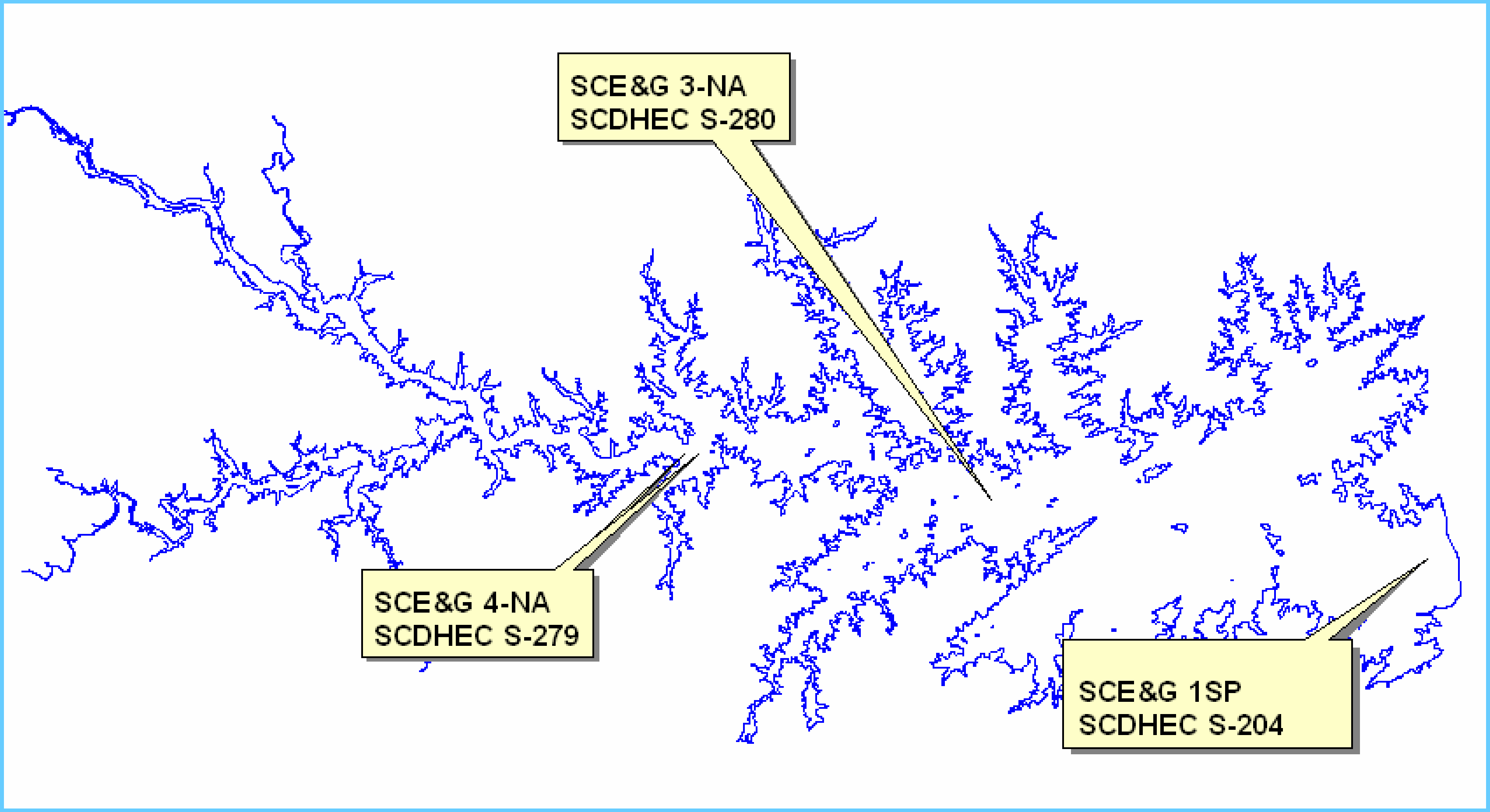
1992 Modeled and Measured Lake Murray Headwater Elevations



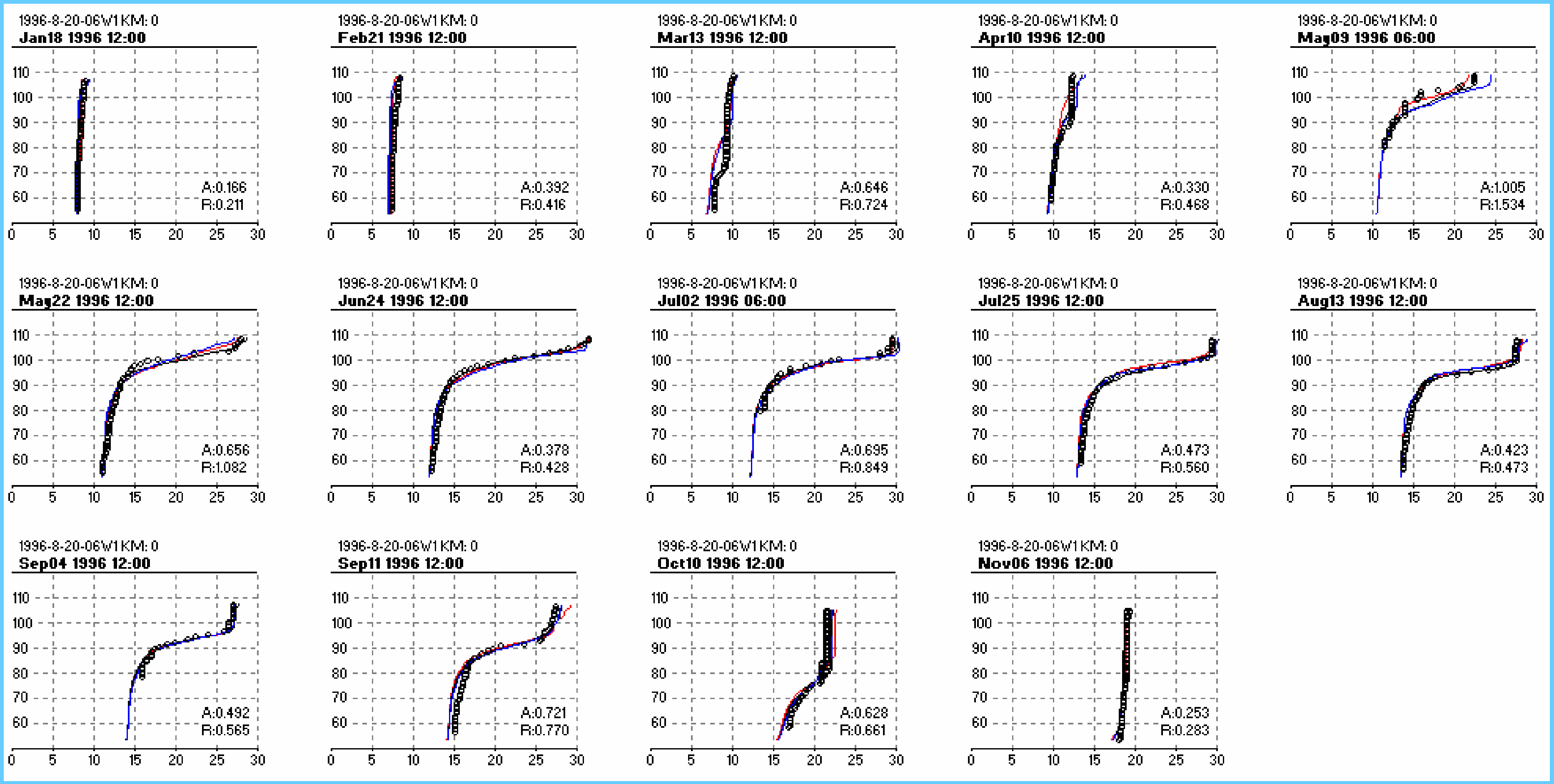
1997 Modeled and Measured Lake Murray Headwater Elevations



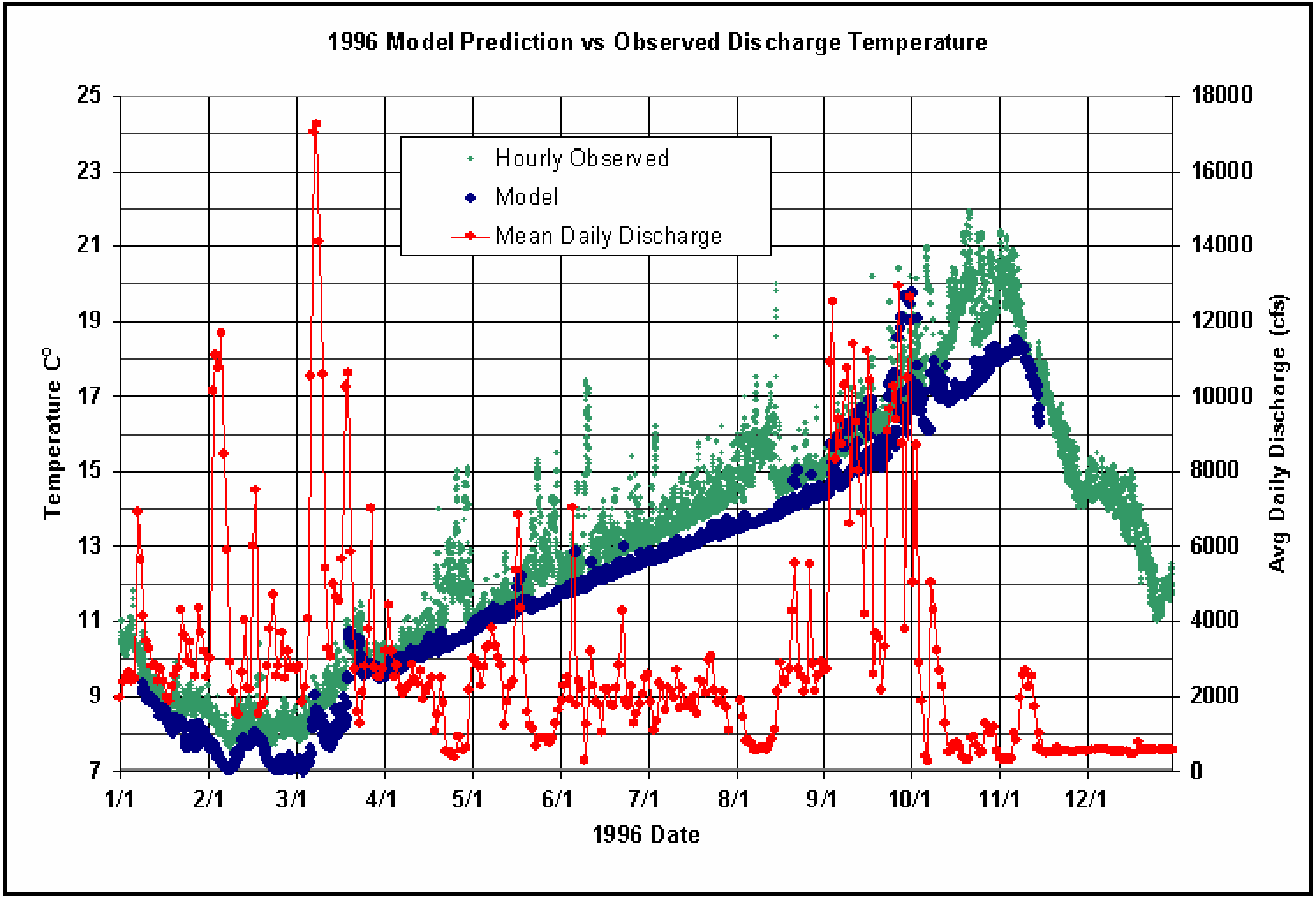
Primary Water Quality Calibration Locations



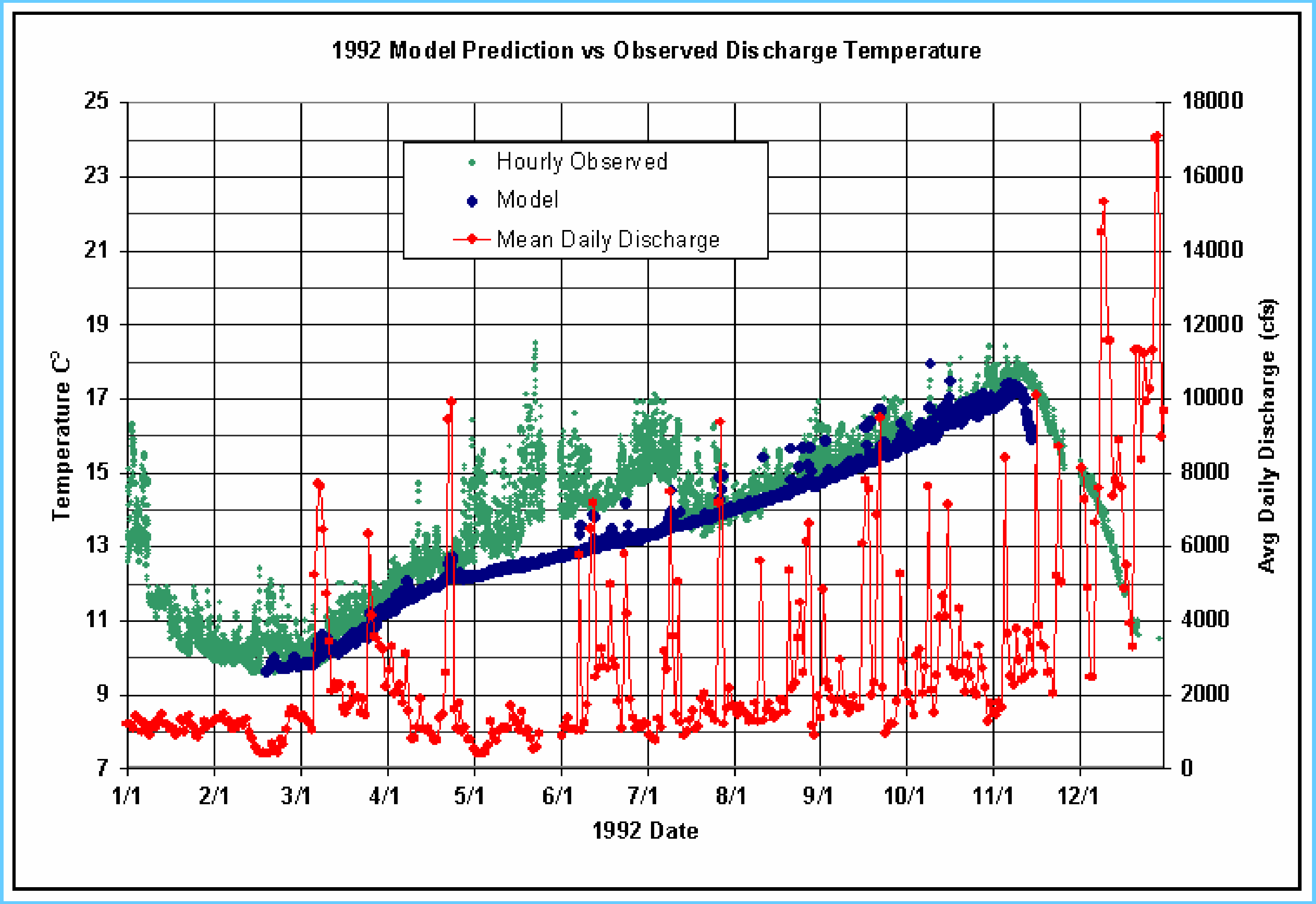
1996 Lake Murray Forebay Temperature Profiles
Model vs. Data



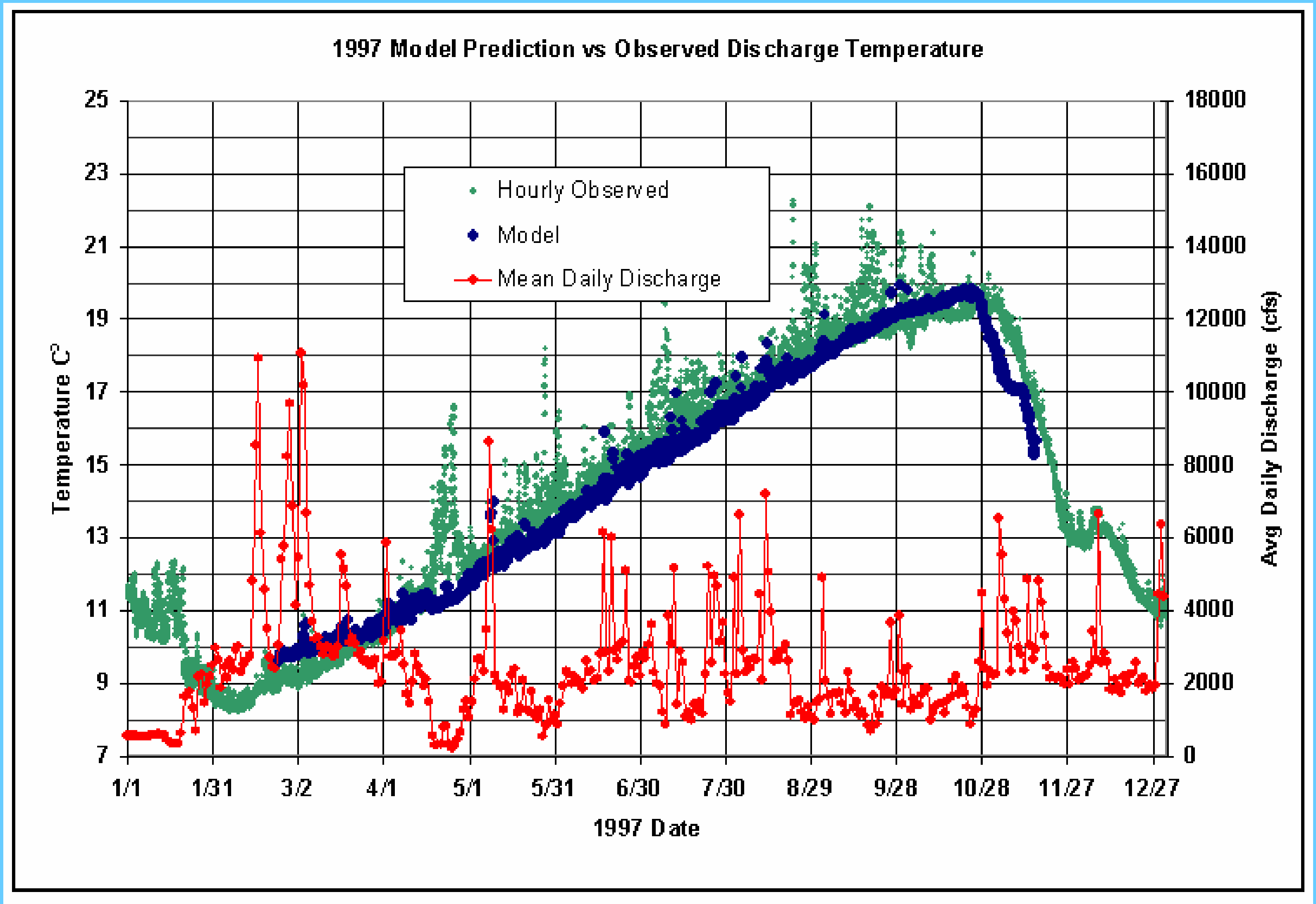
1996 Comparison of Modeled versus Measured Saluda Release Temperatures



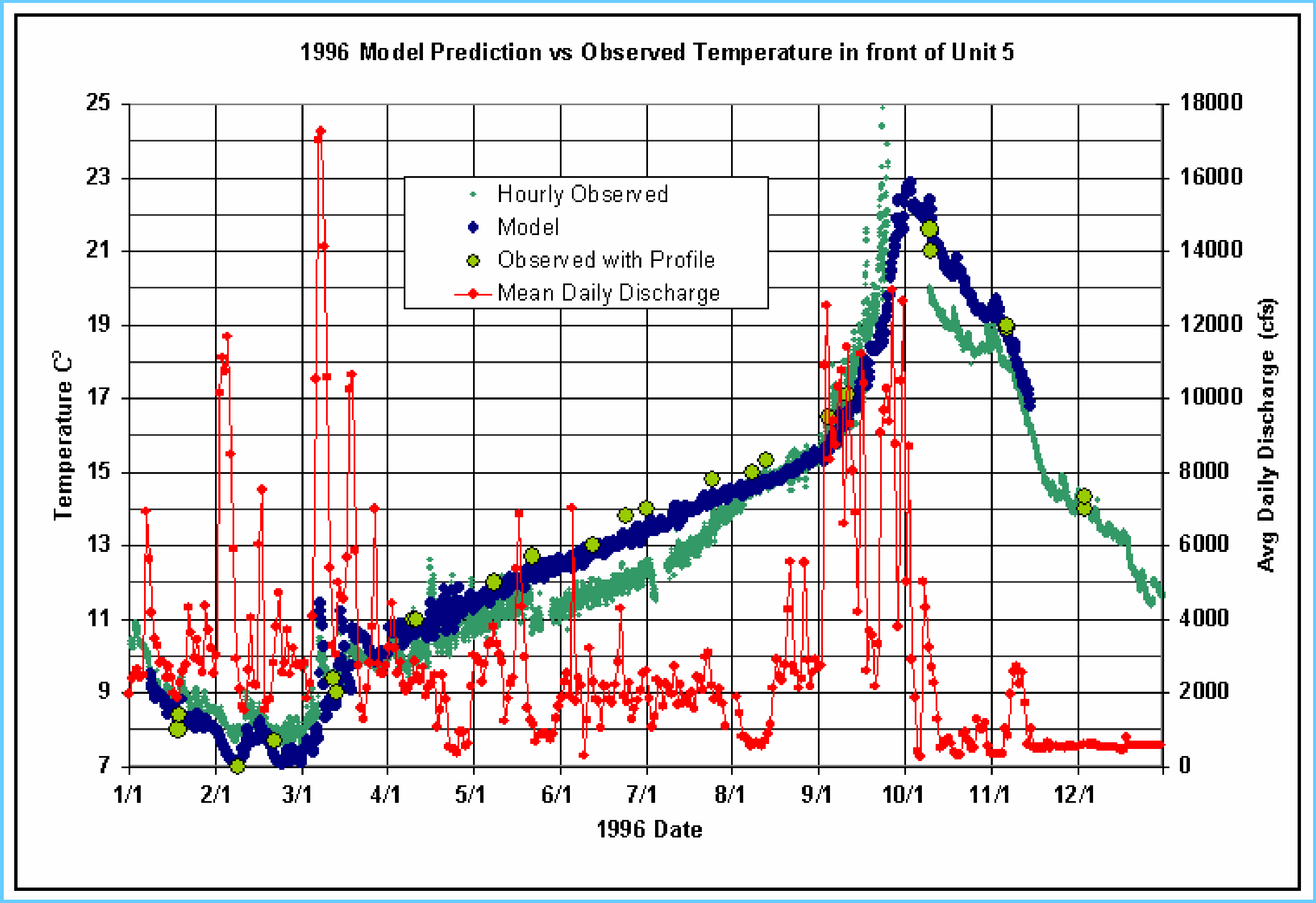
1992 Comparison of Modeled versus Measured Saluda Release Temperatures



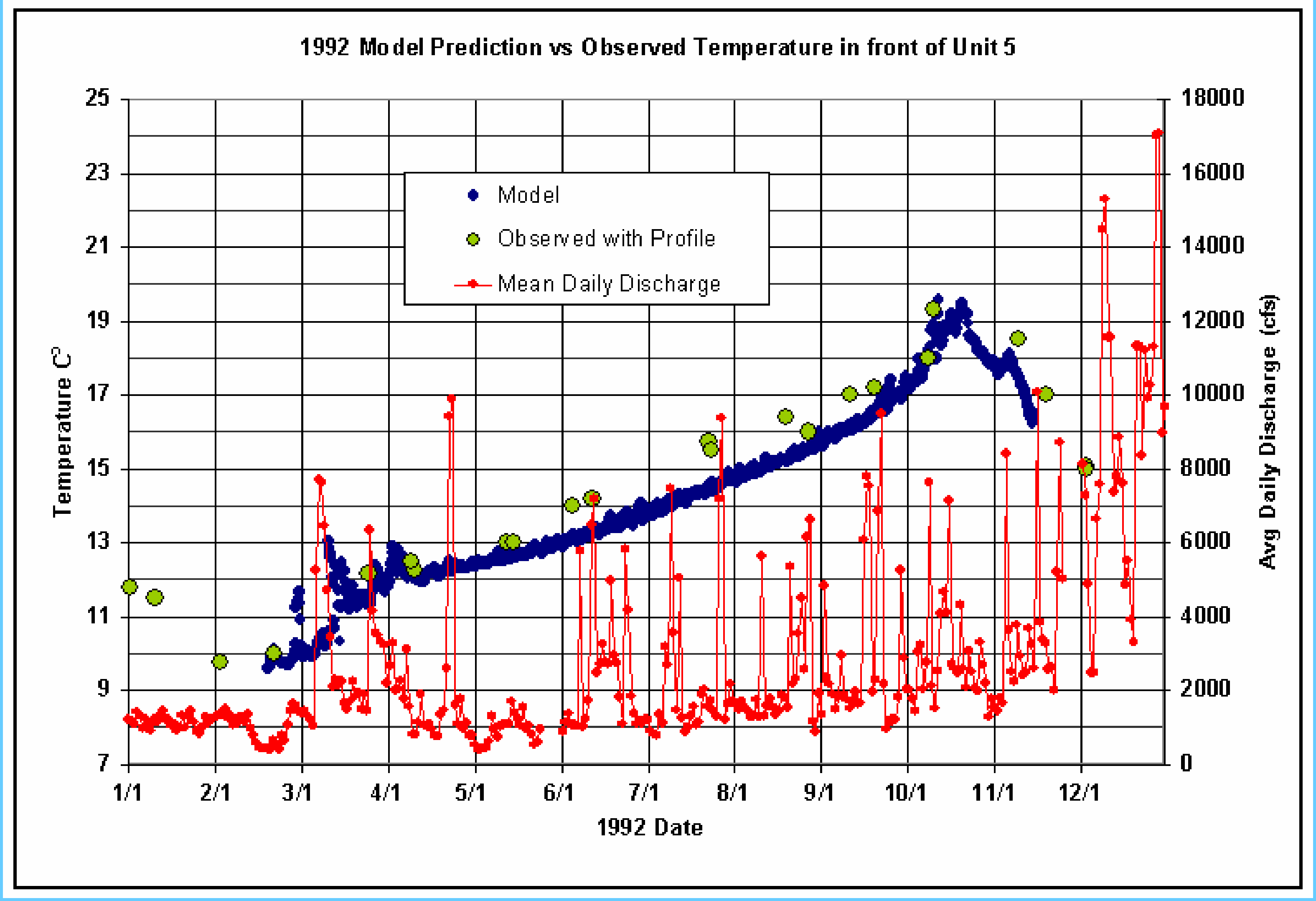
1997 Comparison of Modeled versus Measured Saluda Release Temperatures



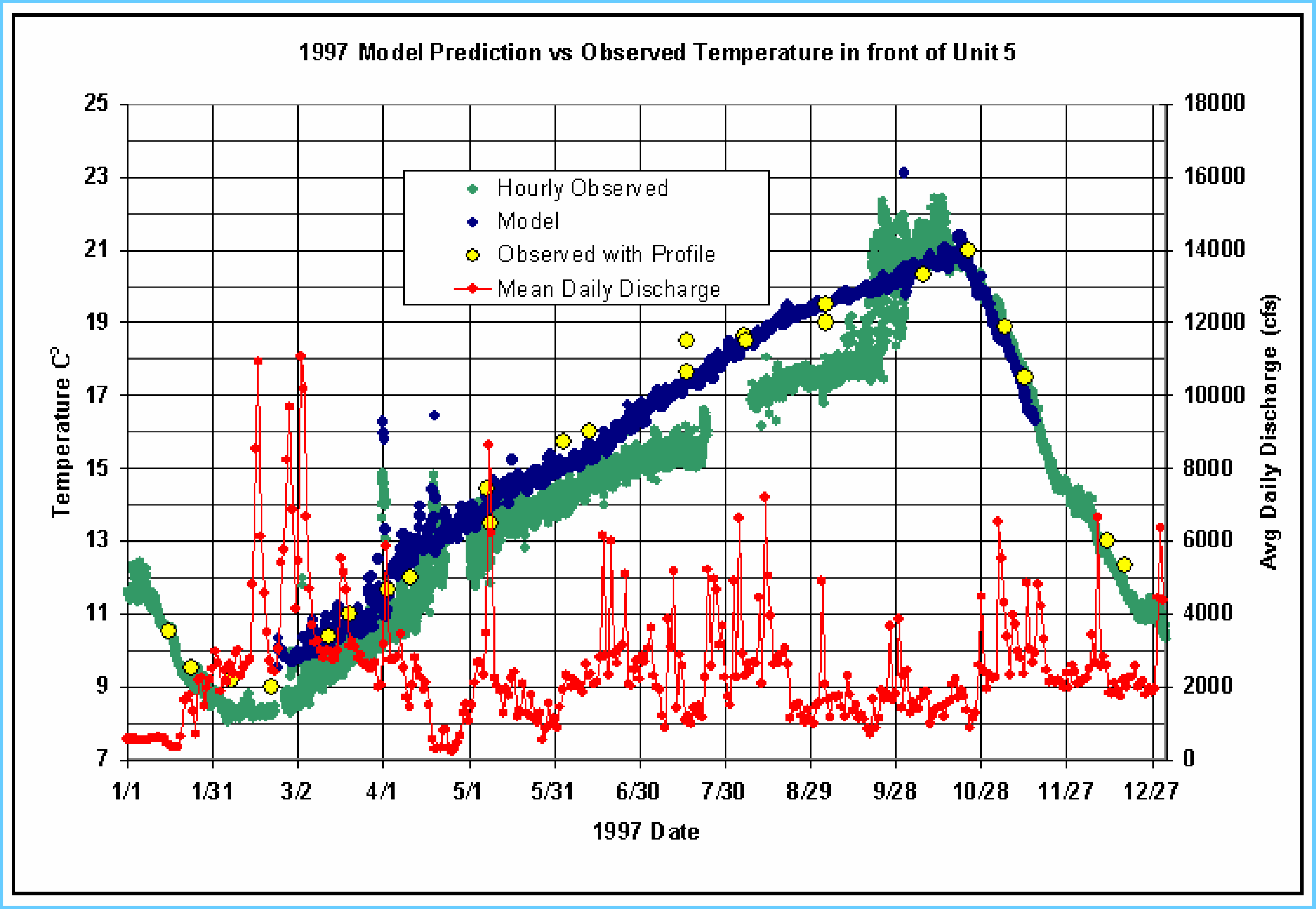
1996 Comparison of Modeled versus Measured Temperature in Front of the Unit 5 Intake



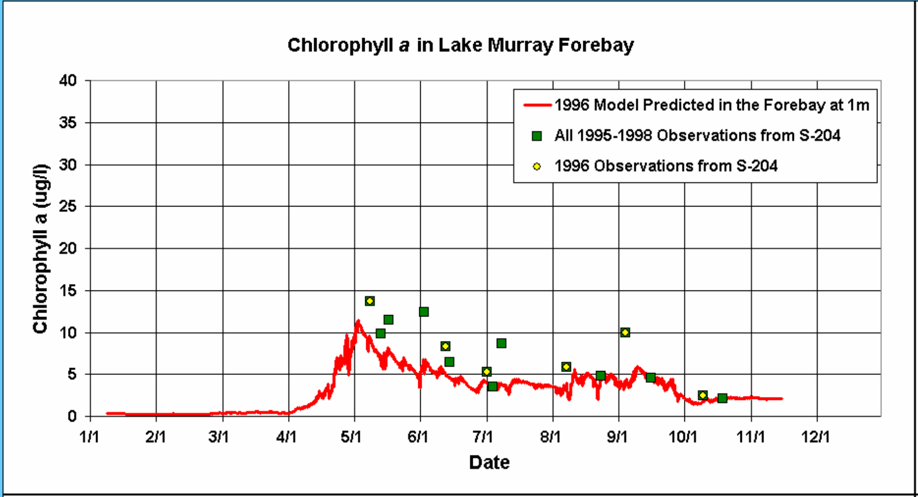
1992 Comparison of Modeled versus Measured Temperature in Front of the Unit 5 Intake

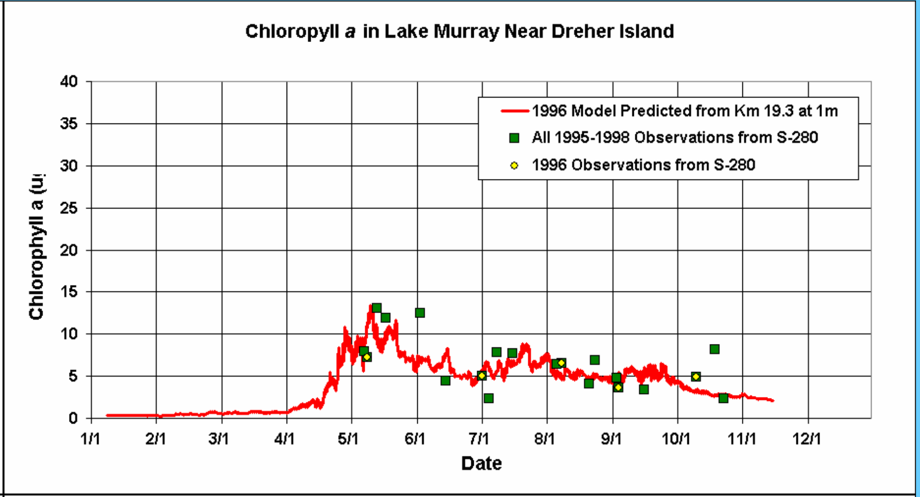


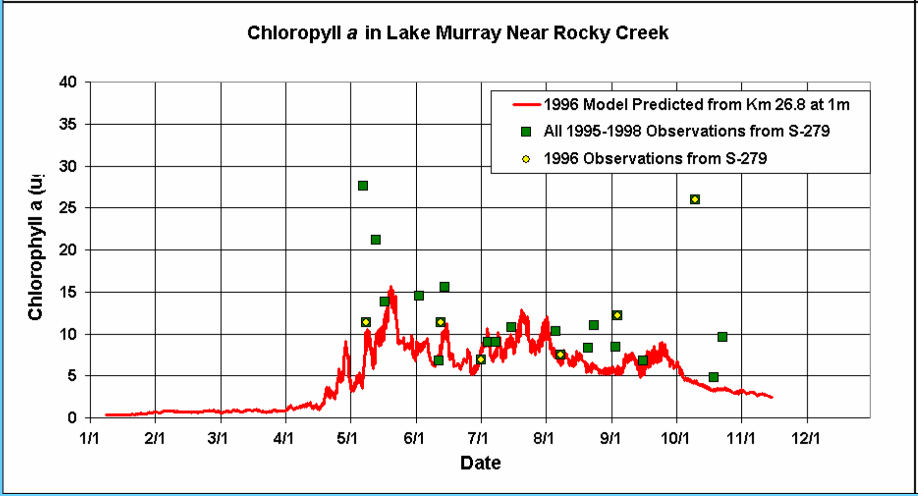
1997 Comparison of Modeled versus Measured Temperature in Front of the Unit 5 Intake

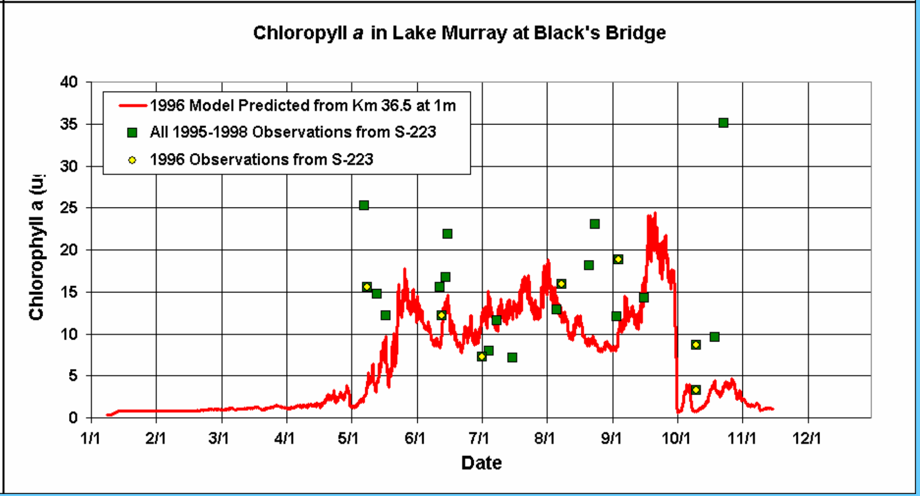


1996 Chlorophyll *a* at Four Locations in Lake Murray
Model vs. Data

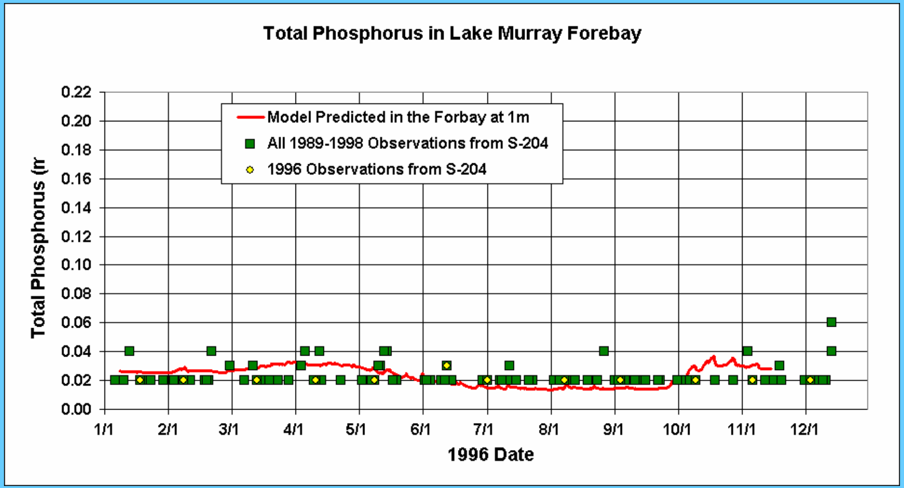


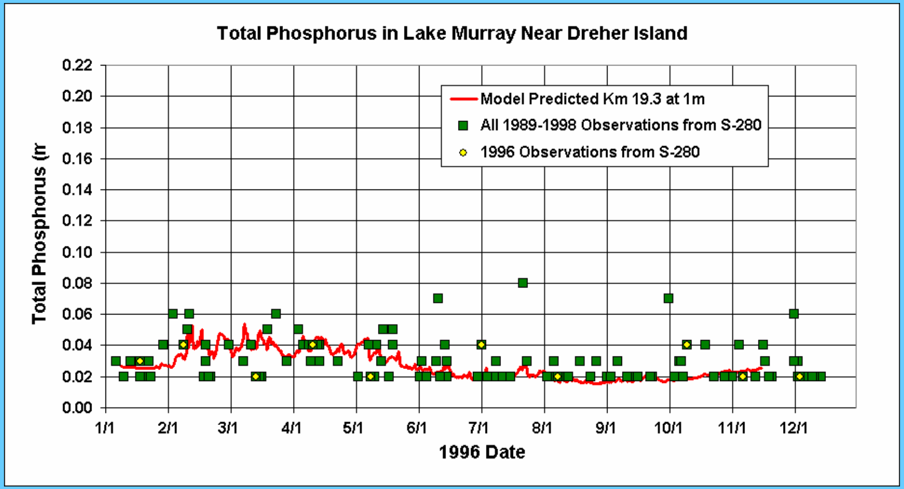


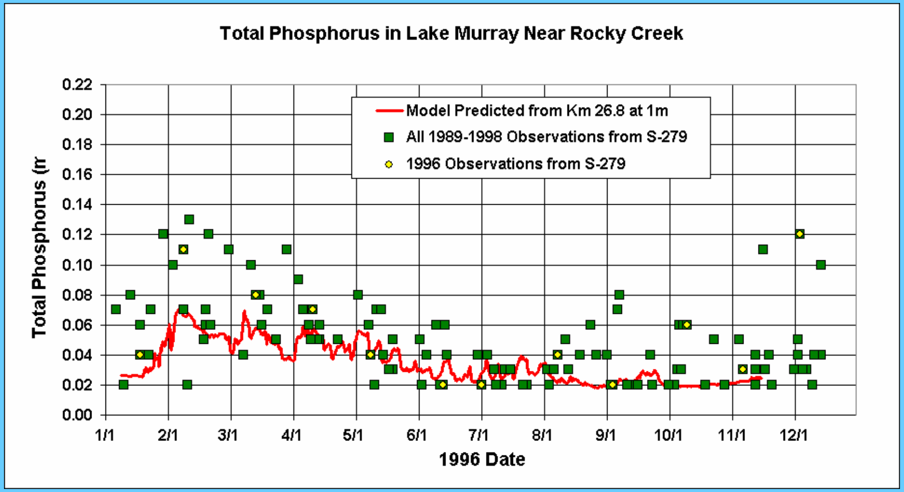


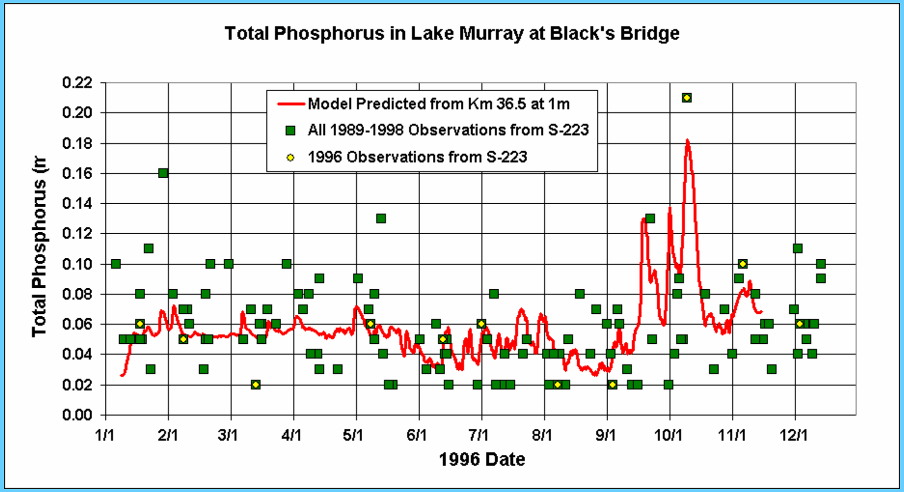


Comparison of Modeled Derived versus Measured Total Phosphorus for 1996 at Four Locations in Lake Murray

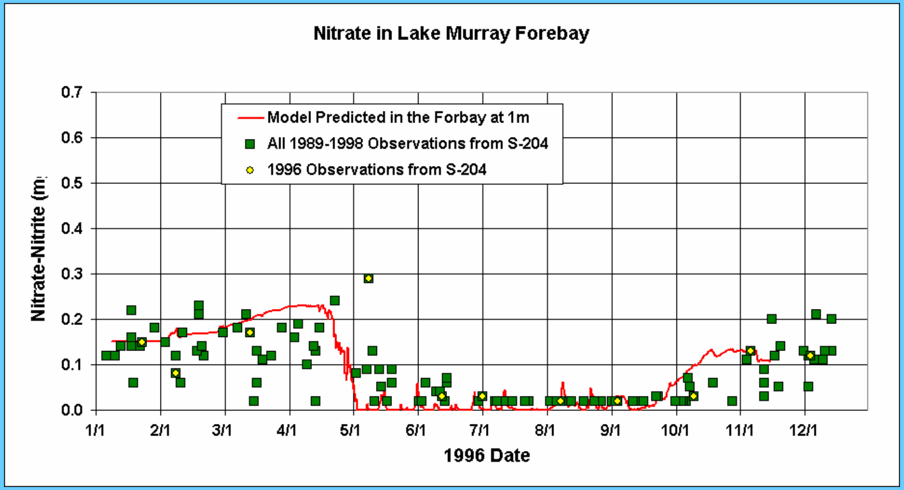


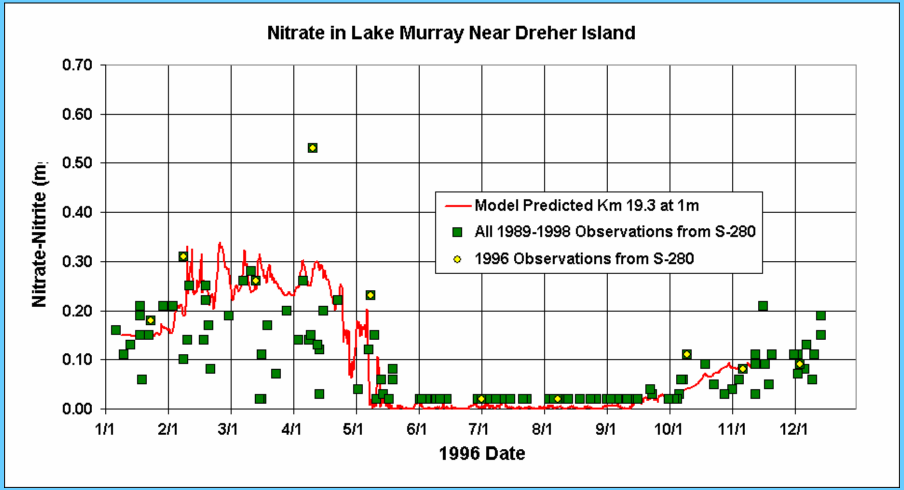


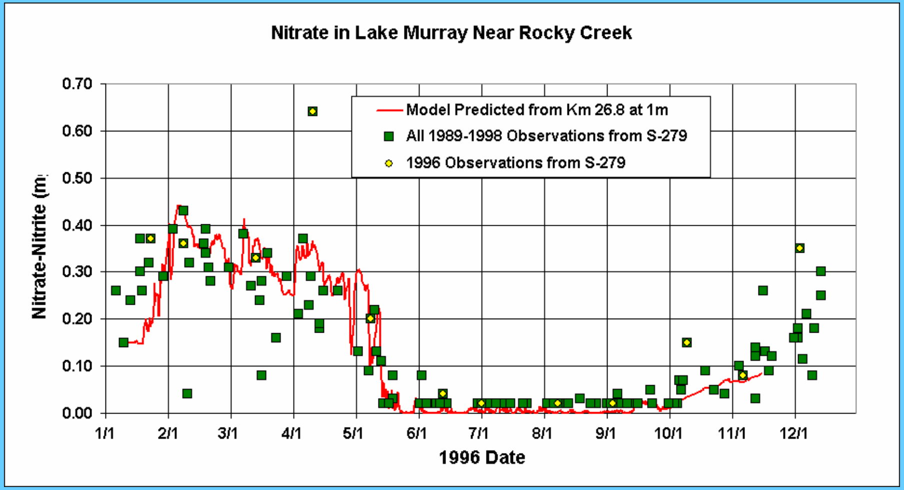


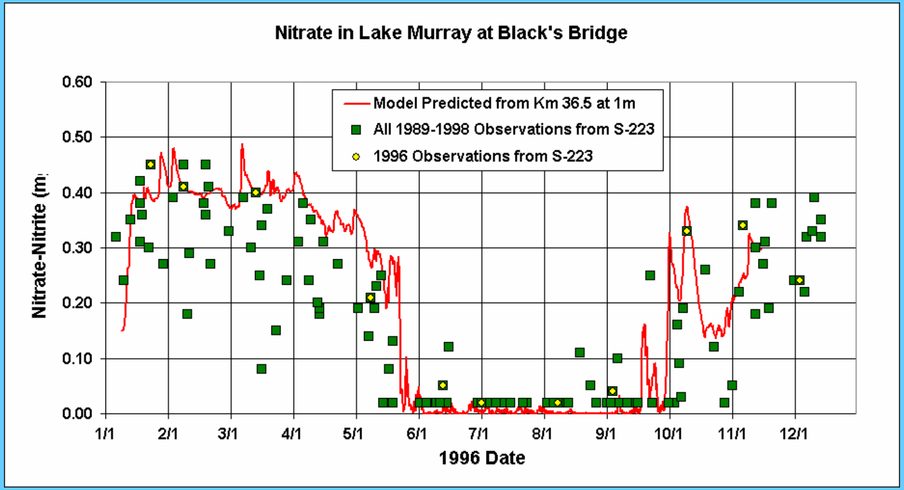


Comparison of Modeled versus Measured Nitrate for 1996 at Four Locations in Lake Murray

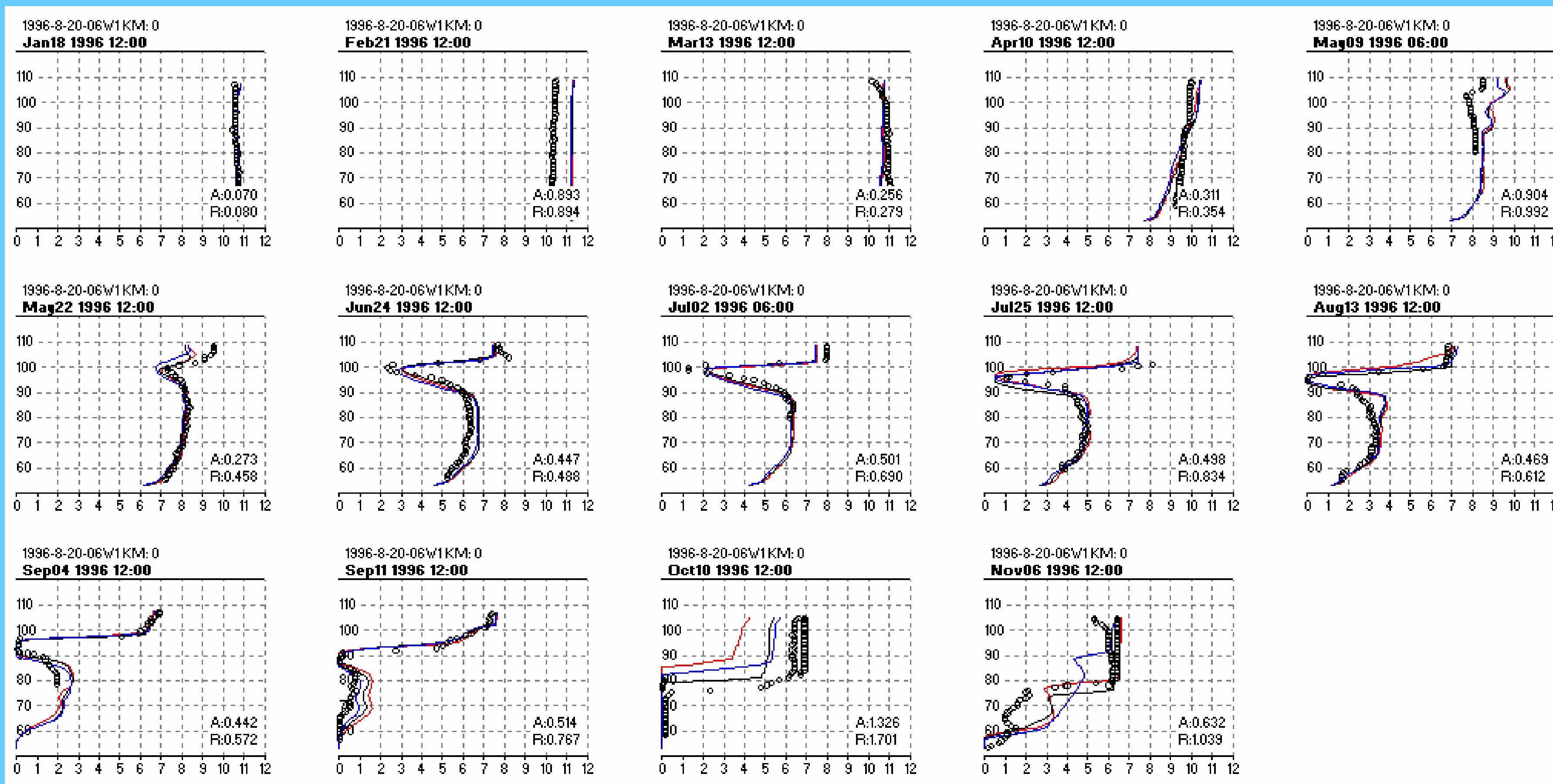




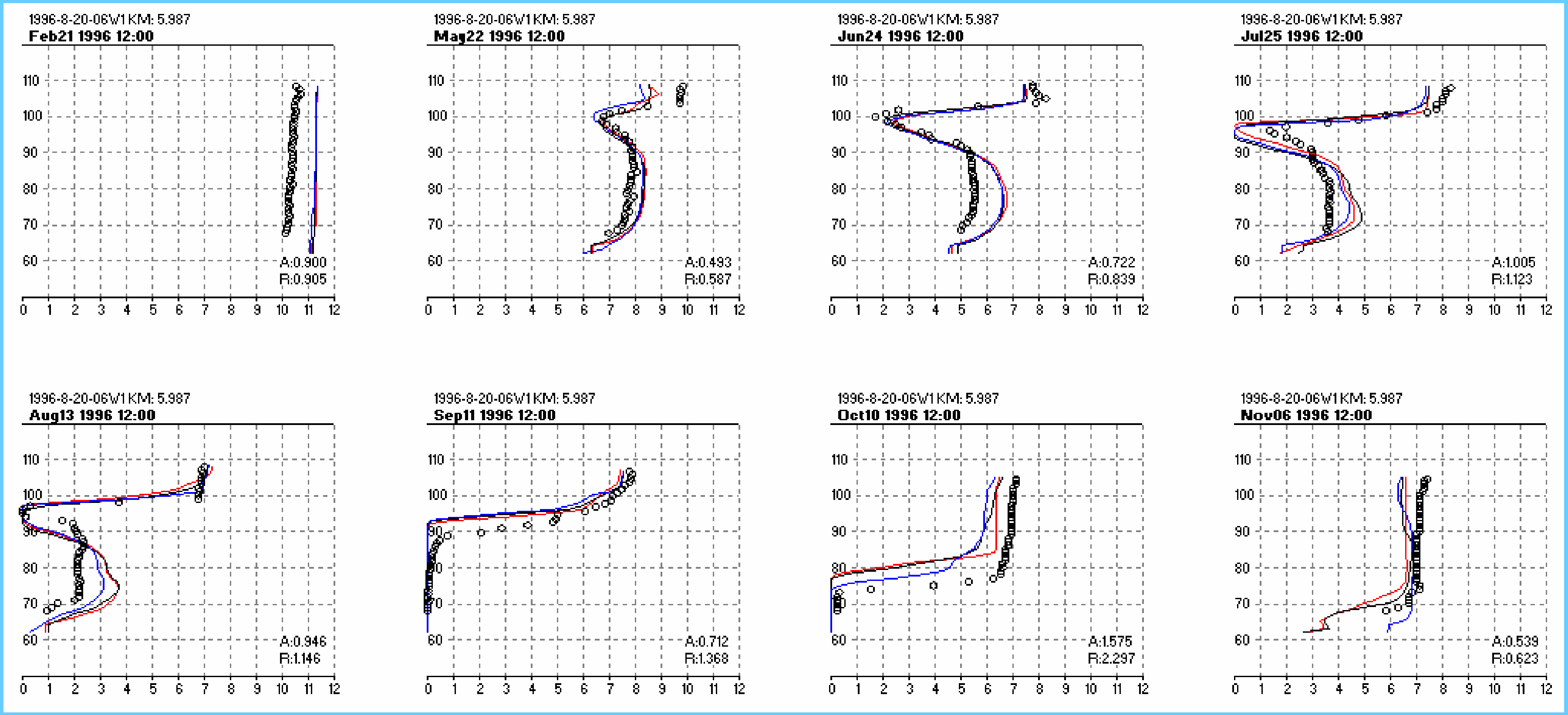




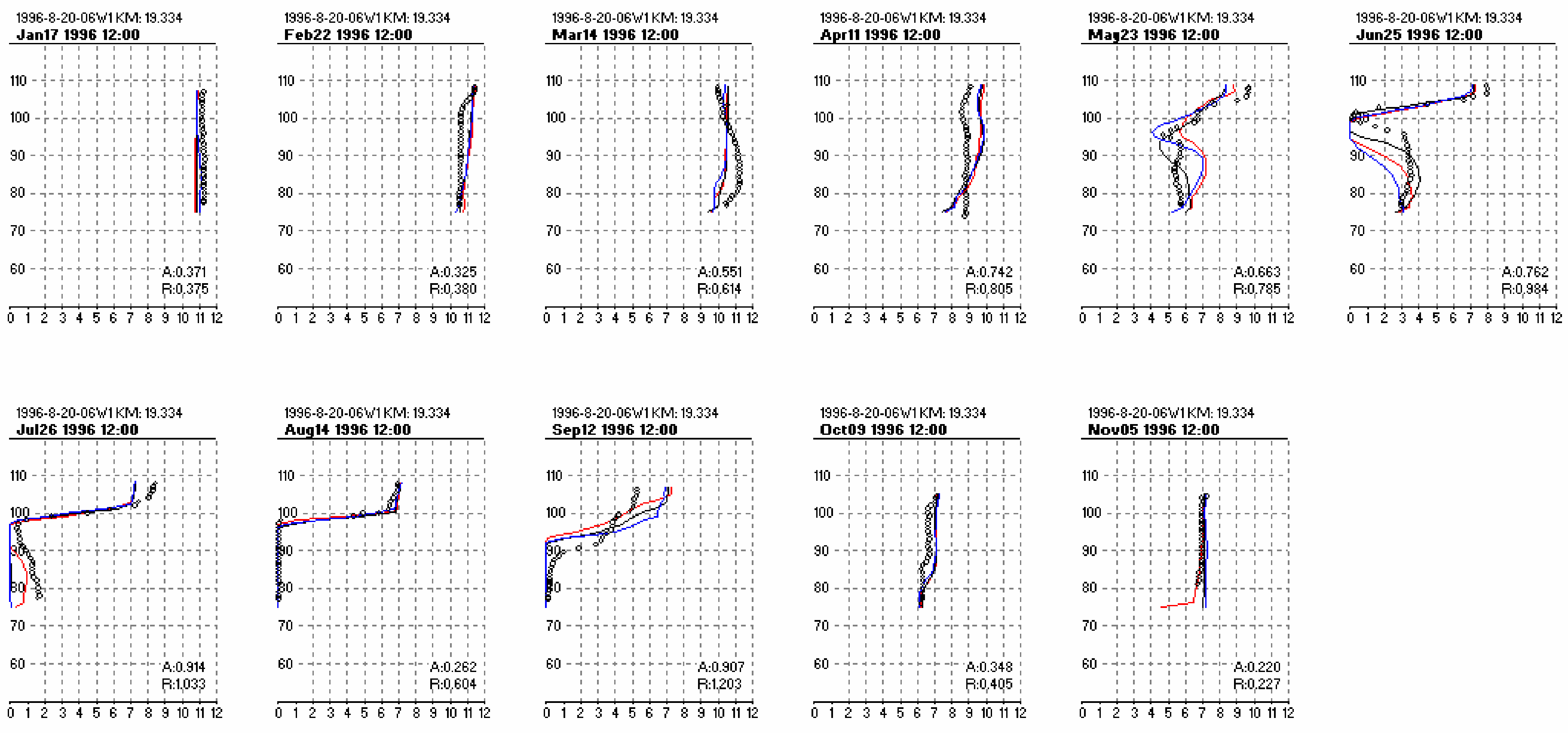
1996 Lake Murray Forebay DO Profiles
Model vs. Data



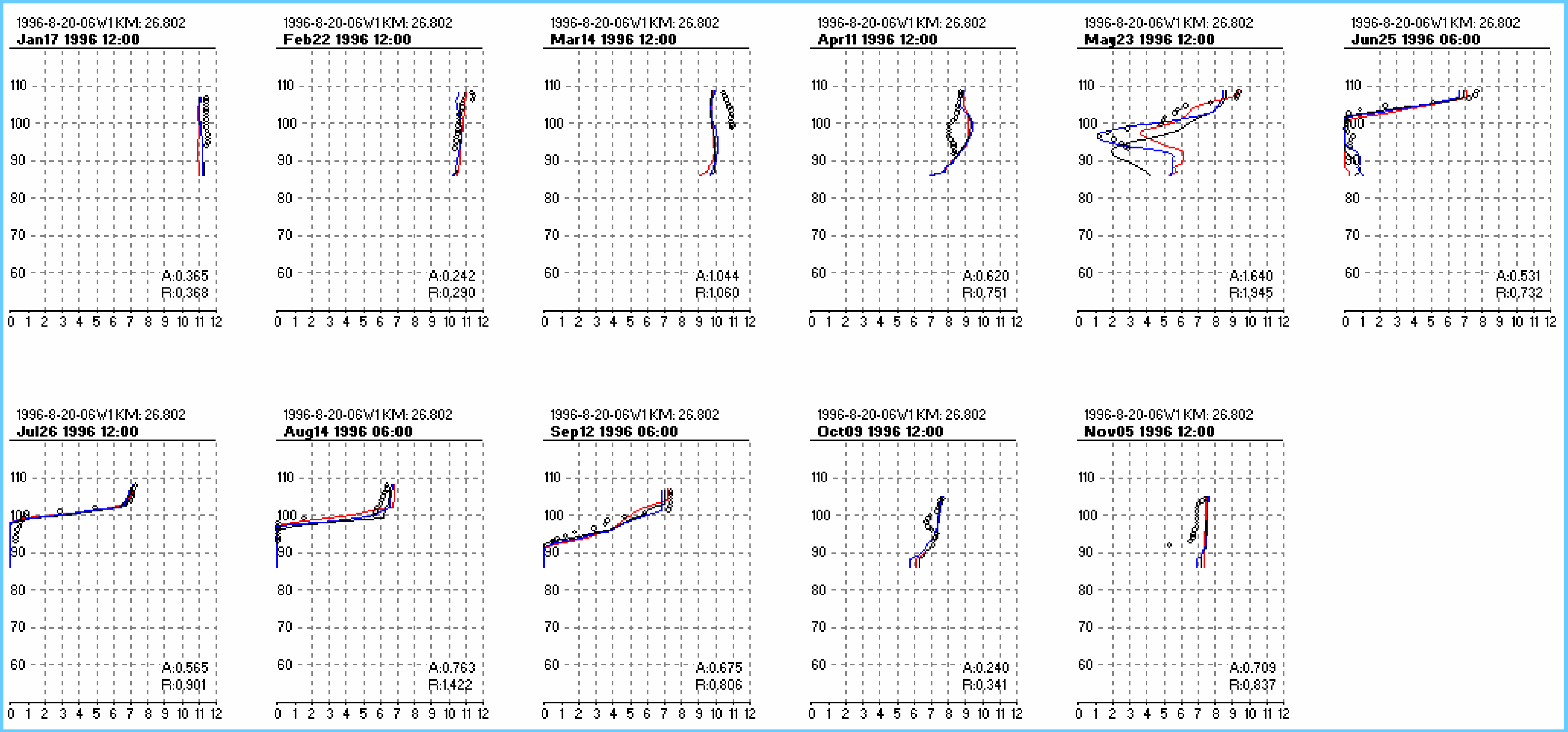
1996 Lake Murray DO Profiles – 6 Km Upstream of Dam
Model vs. Data



1996 Lake Murray DO Profiles – 19 Km Upstream of Dam Model vs. Data



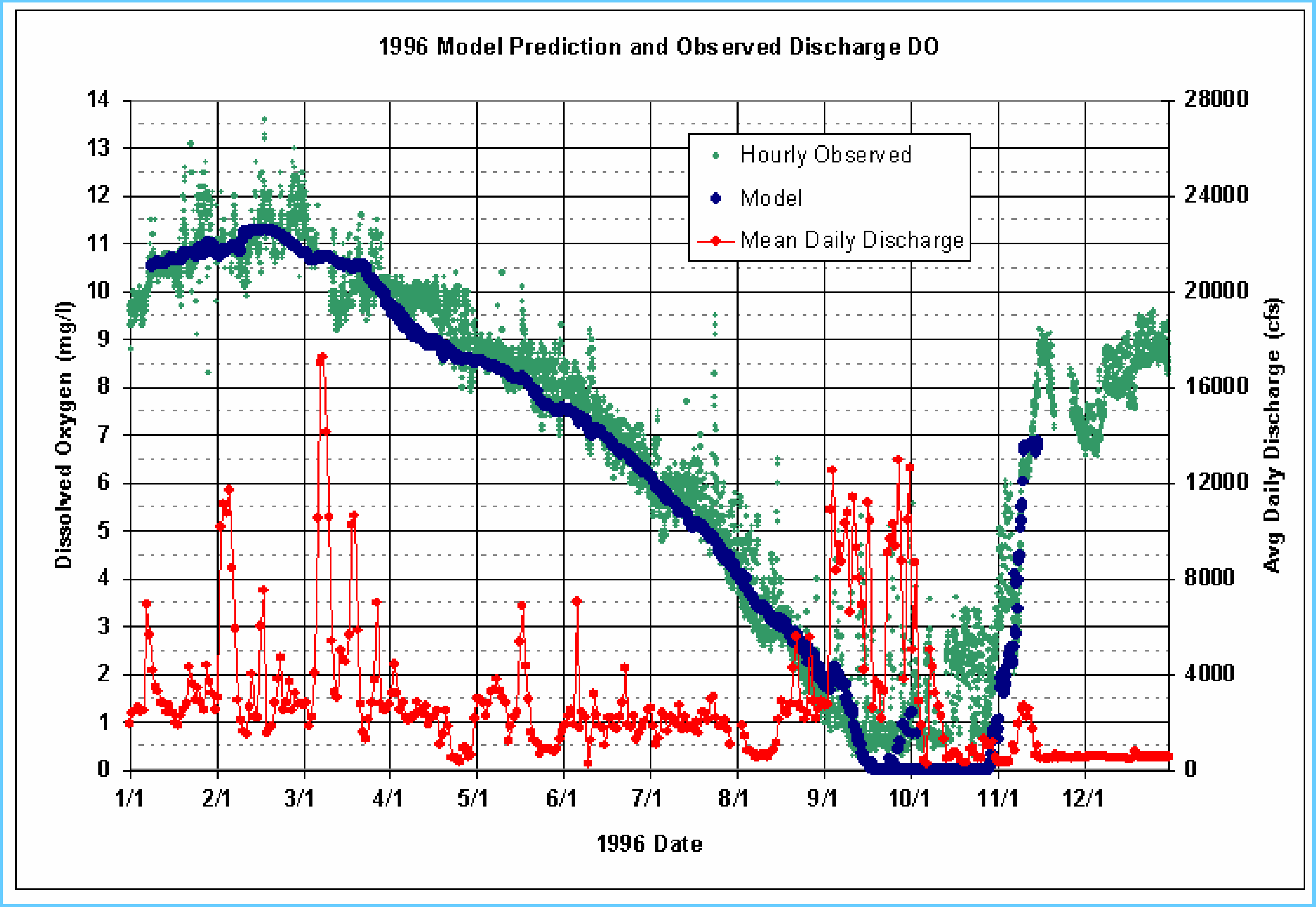
1996 Lake Murray DO Profiles – 27 Km Upstream of Dam Model vs. Data



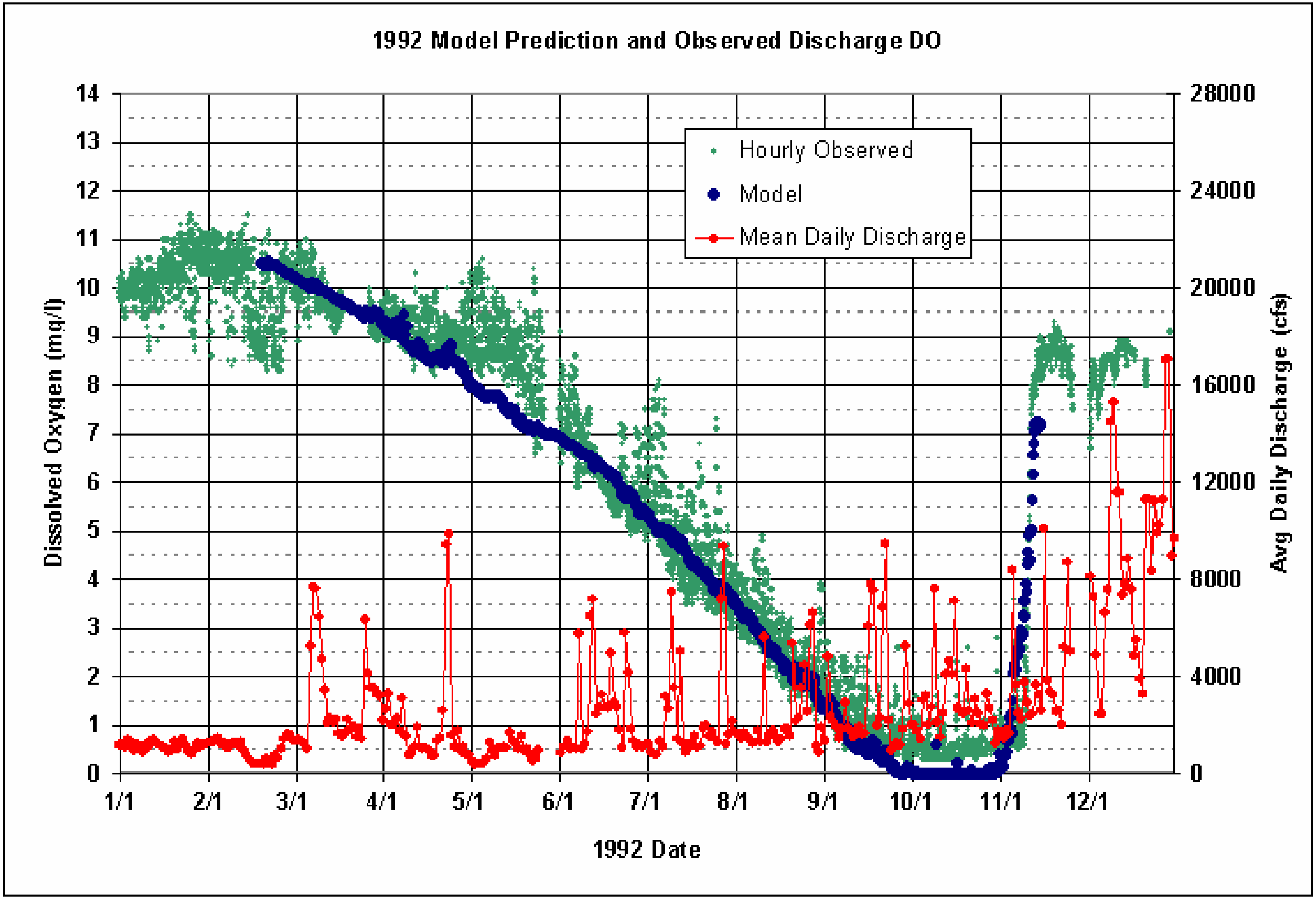
1996 Statistics

	Kilometers From Dam									
	0.0		6		19		27		Overall	
	AME	RMS	AME	RMS	AME	RMS	AME	RMS	AME	RMS
Temperature	0.49	0.67	0.57	0.80	0.63	0.84	0.94	1.28	0.66	0.90
DO	0.56	0.86	0.86	1.21	0.56	0.75	0.68	0.99	0.67	0.95

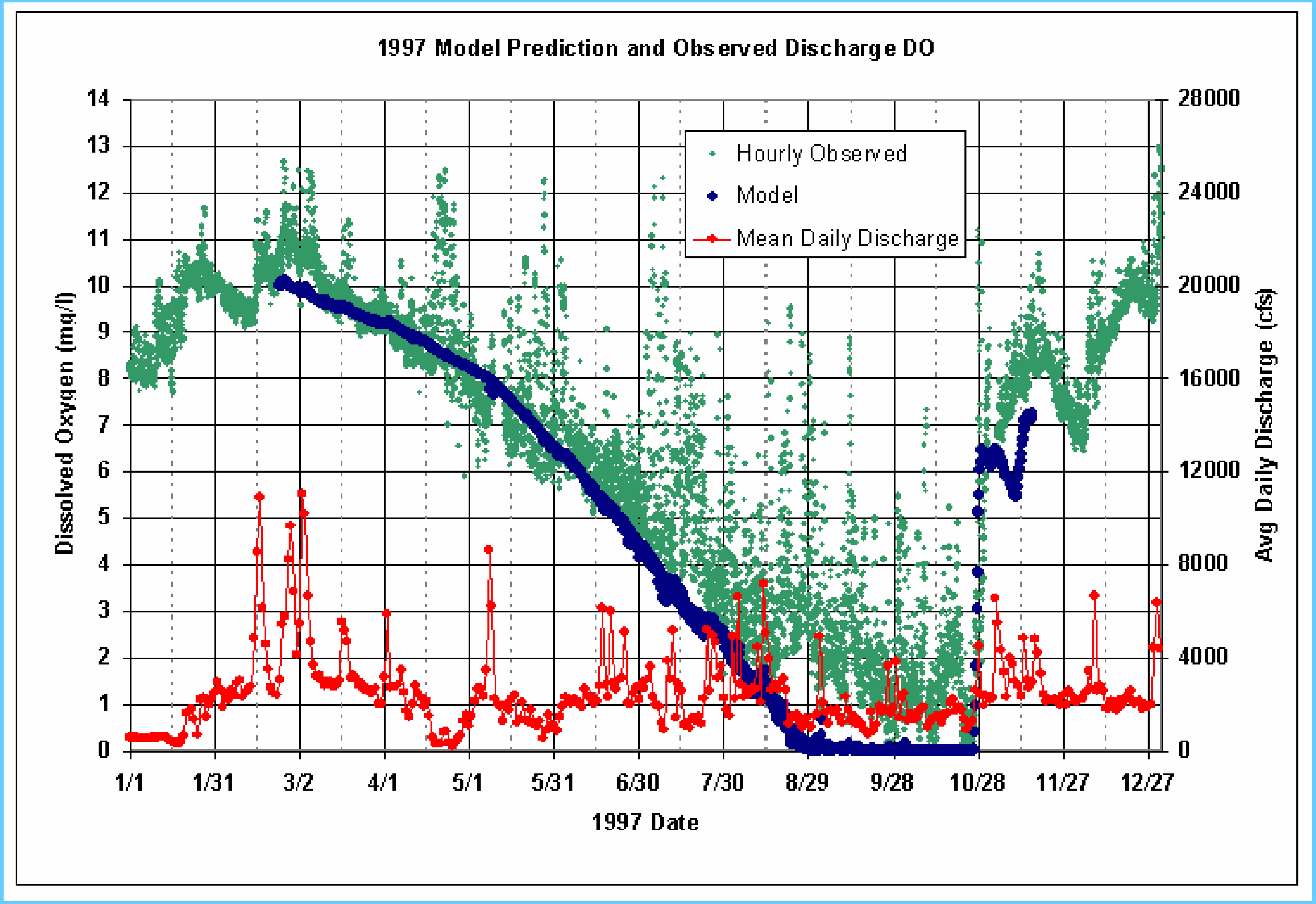
1996 Comparison of Modeled versus Measured Saluda Release DO



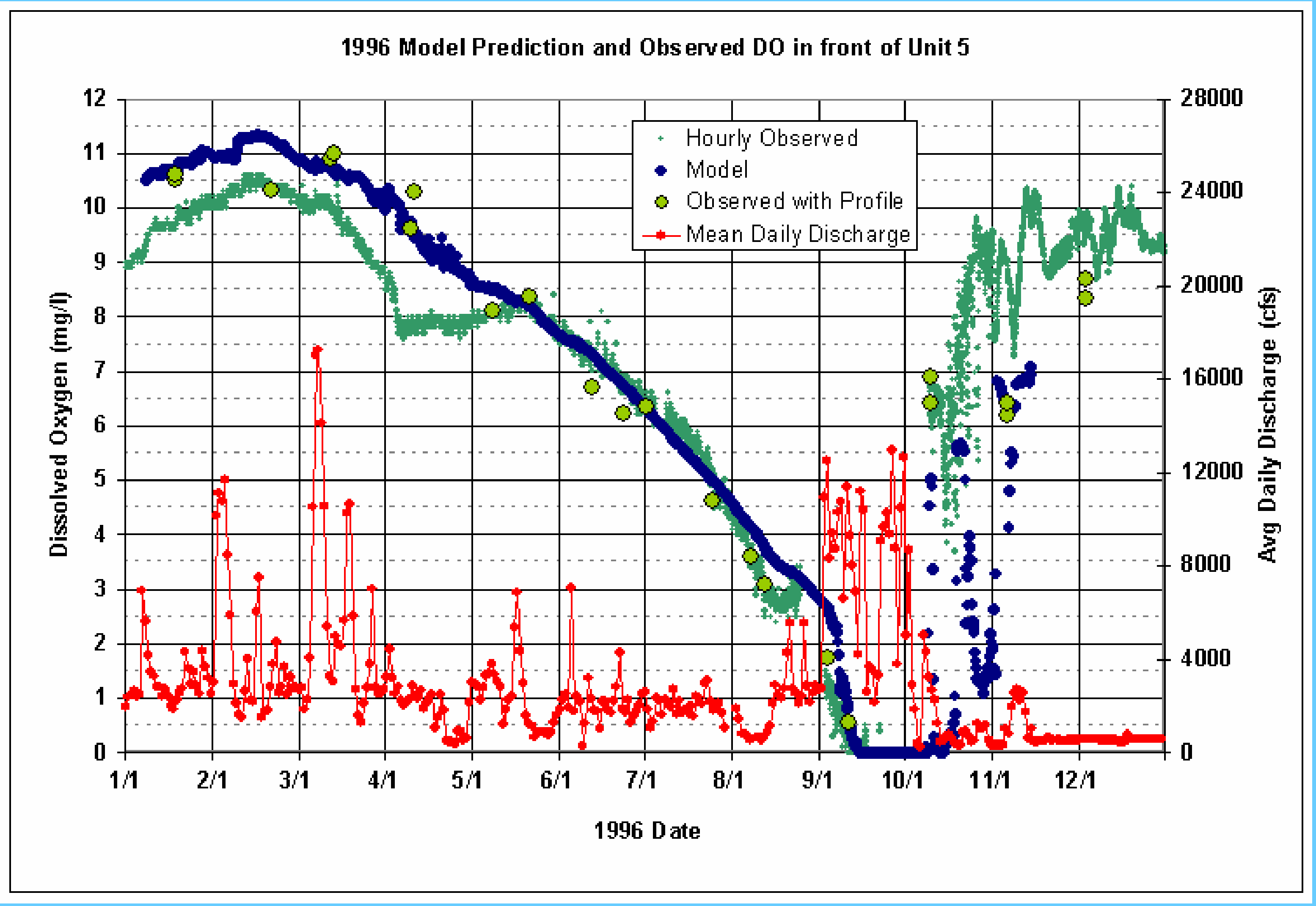
1992 Comparison of Modeled versus Measured Saluda Release DO



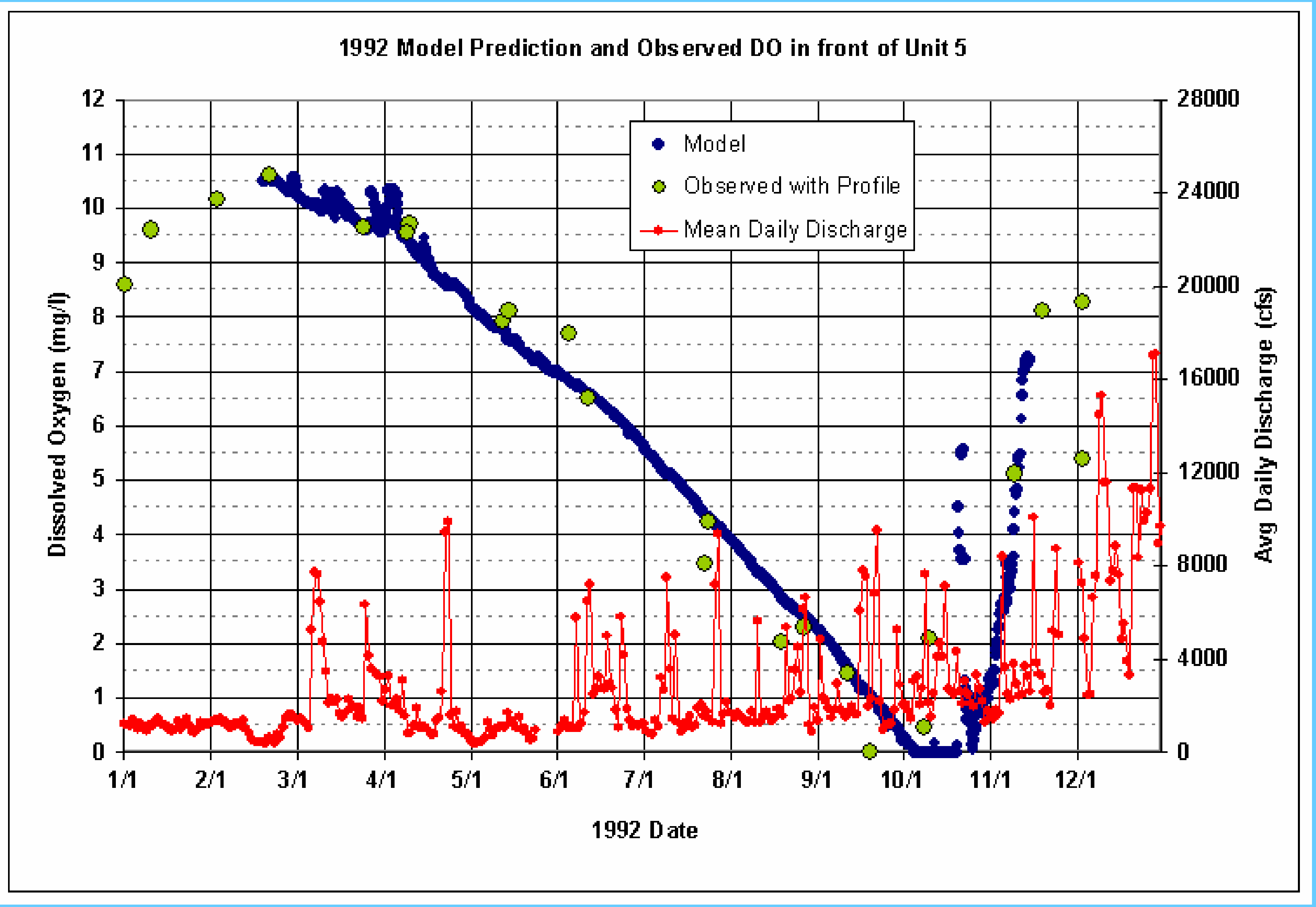
1997 Comparison of Modeled versus Measured Saluda Release DO



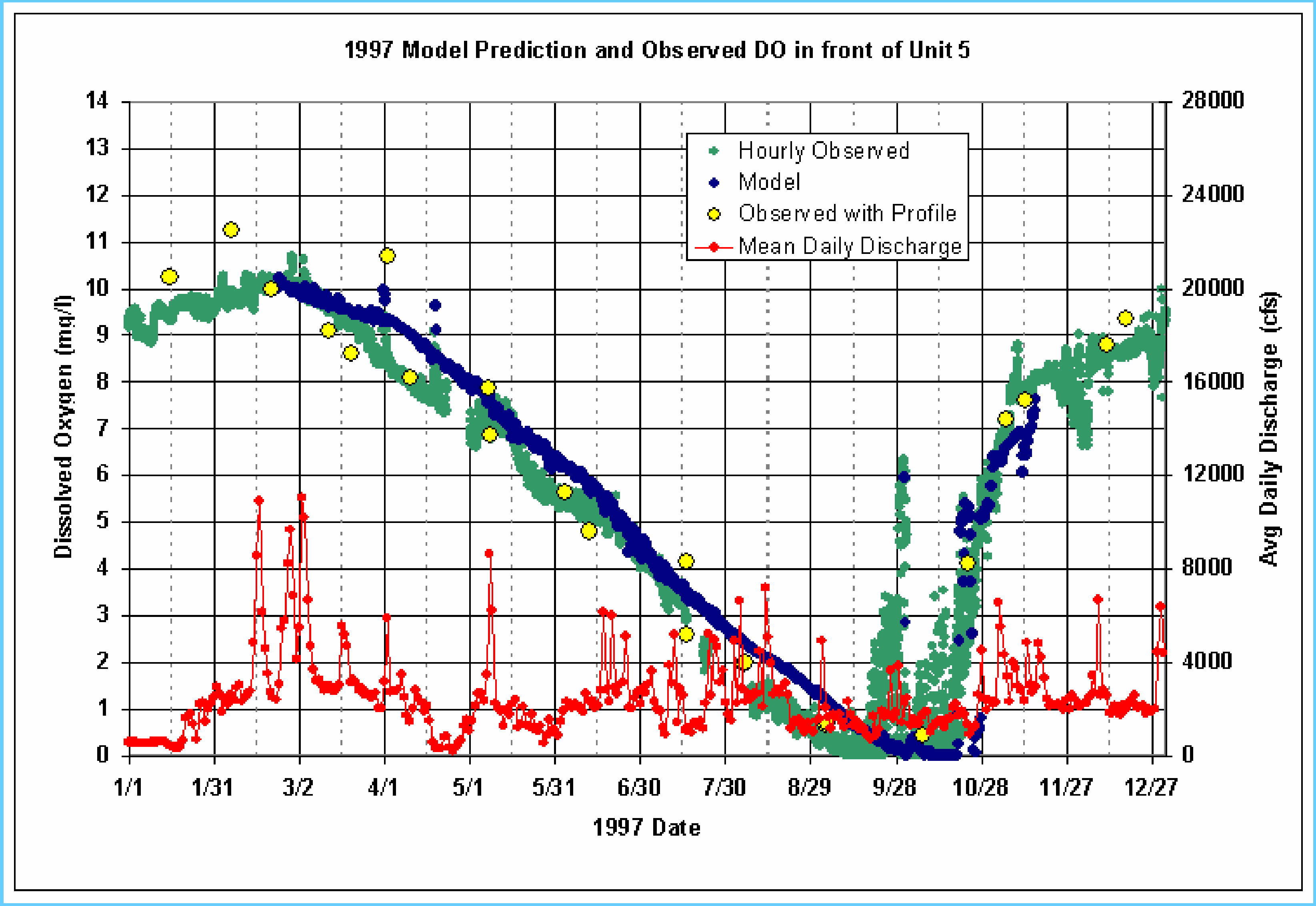
1996 Modeled versus Measured DO at the level of the Unit 5 Intake



1992 Modeled versus Measured DO at the level of the Unit 5 Intake

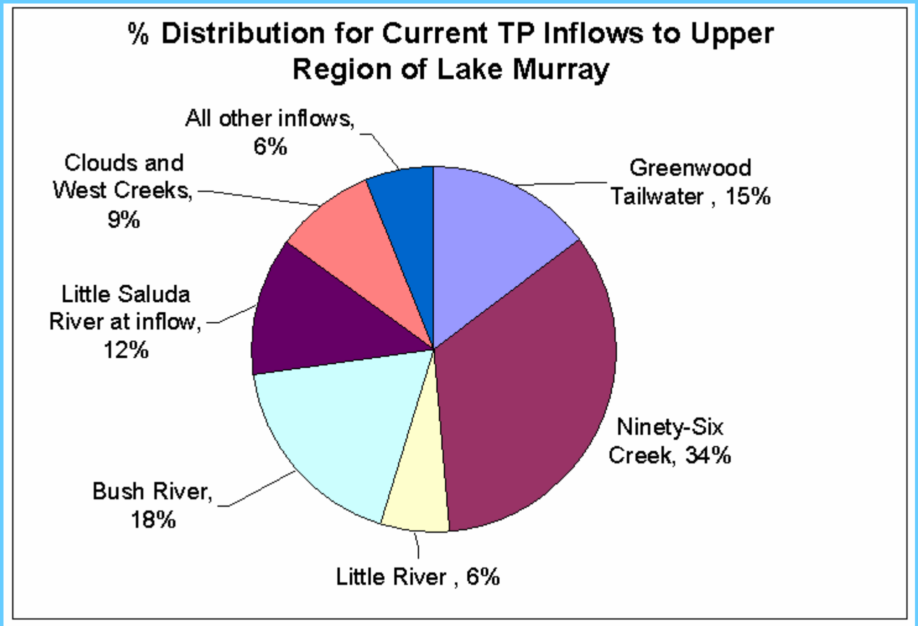


1997 Modeled versus Measured DO at the level of the Unit 5 Intake

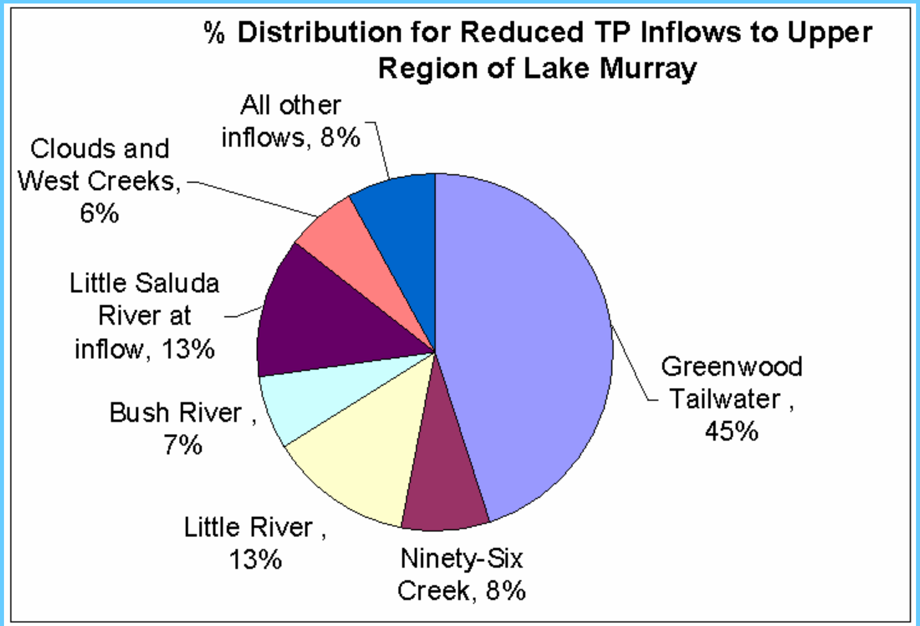


Distribution of TP Loads to the Upper Region of Lake Murray

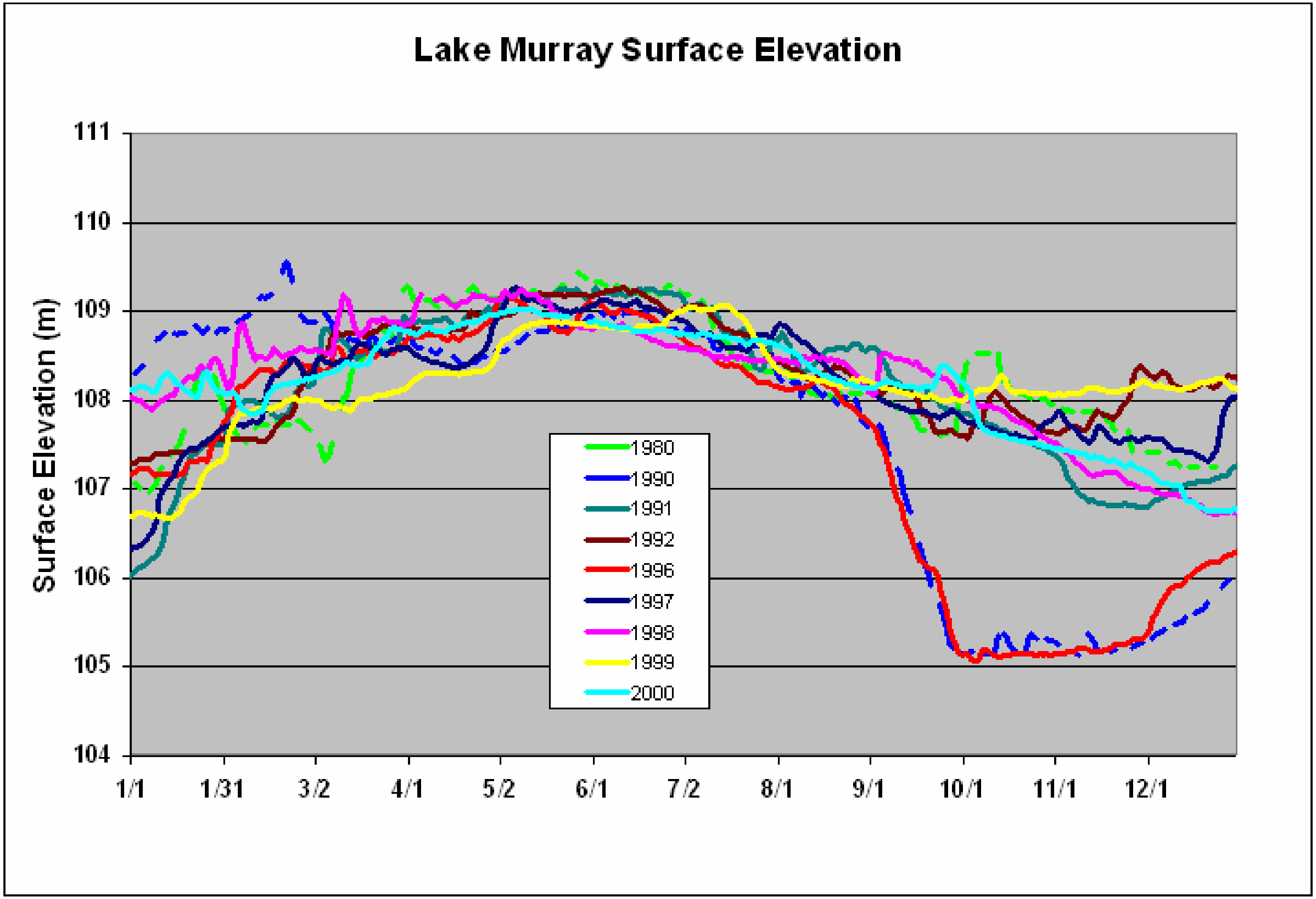
Current



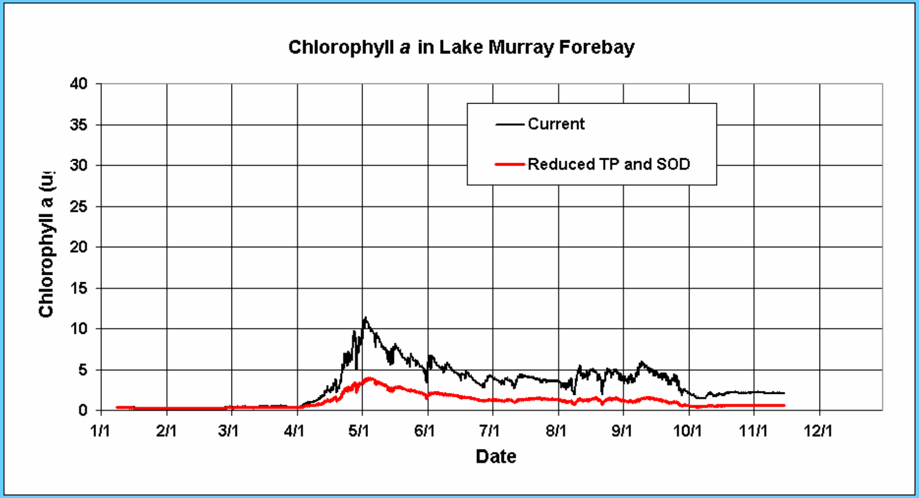
Assumed Reductions in TP

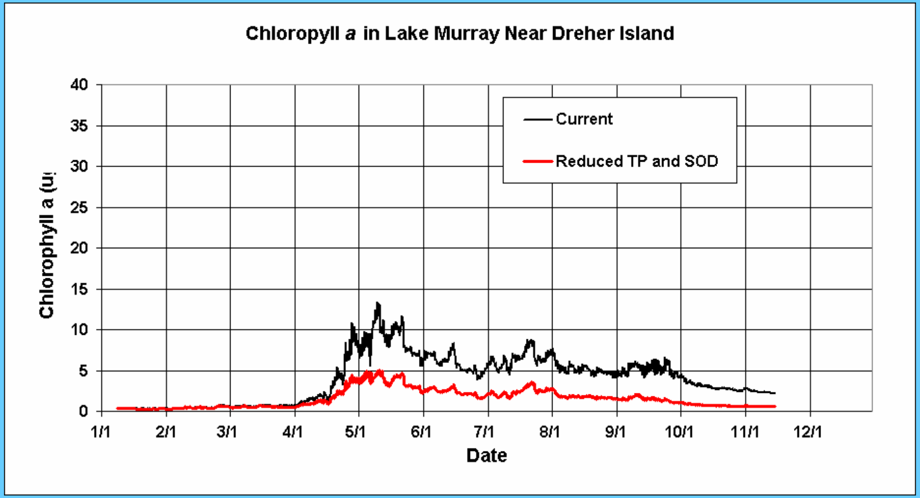


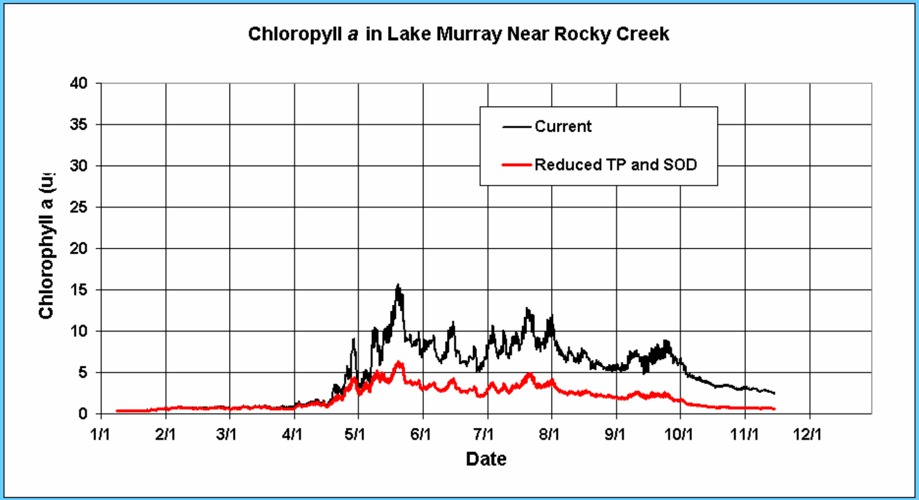
Comparison of Water Surface Elevations for Various Years at Lake Murray

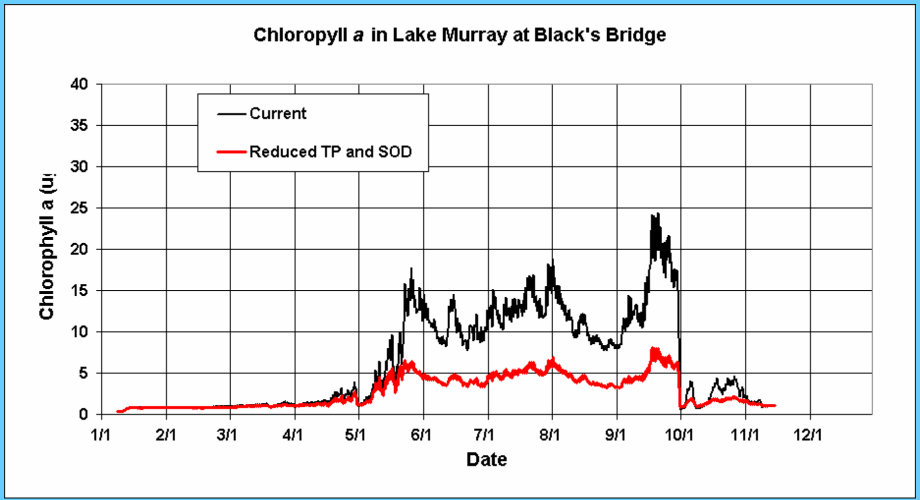


Comparison of 1996 Current and Reduced Phosphorus Predictions of Chlorophyll *a* at 1 Meter Depth at Four Locations in Lake Murray

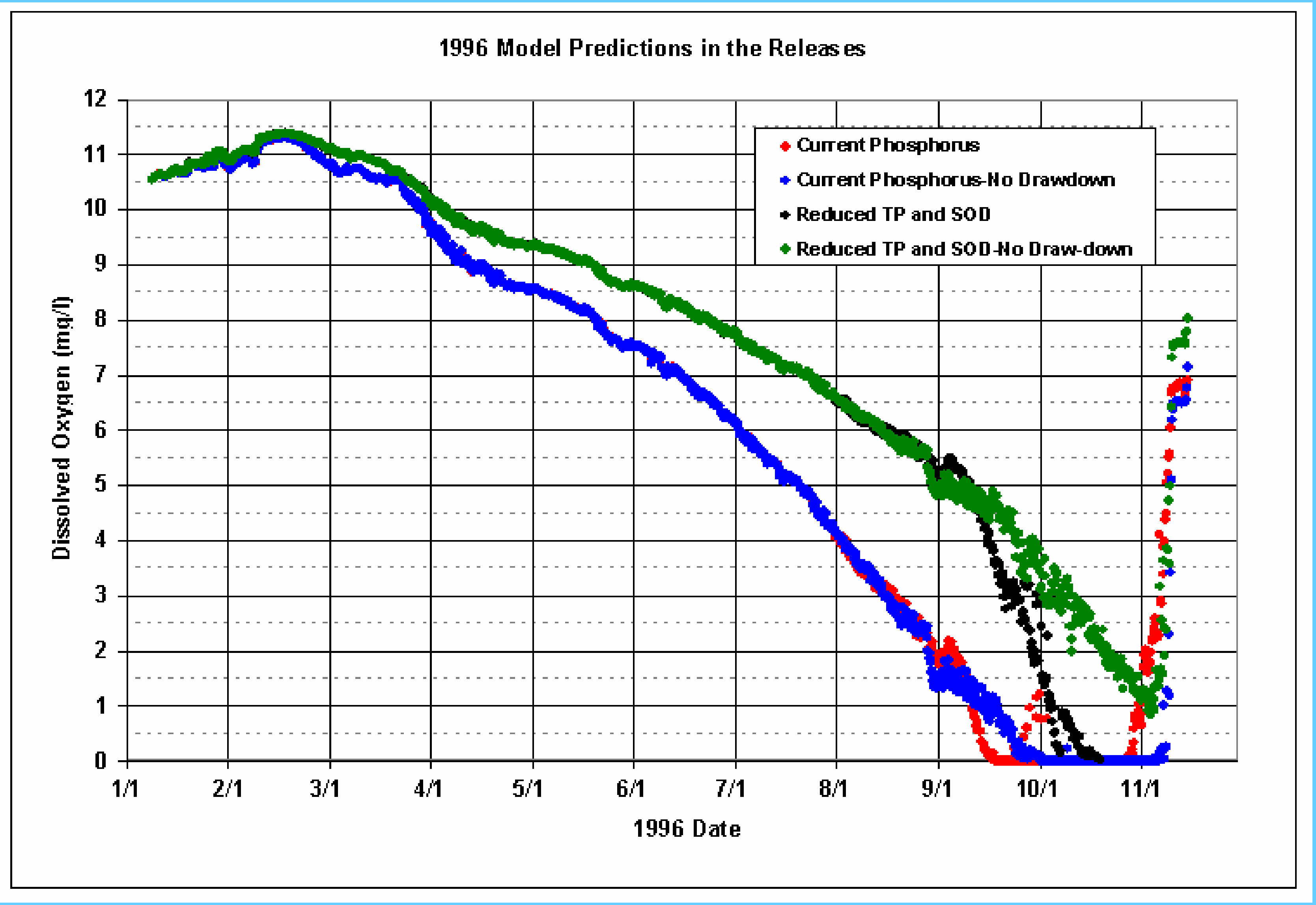




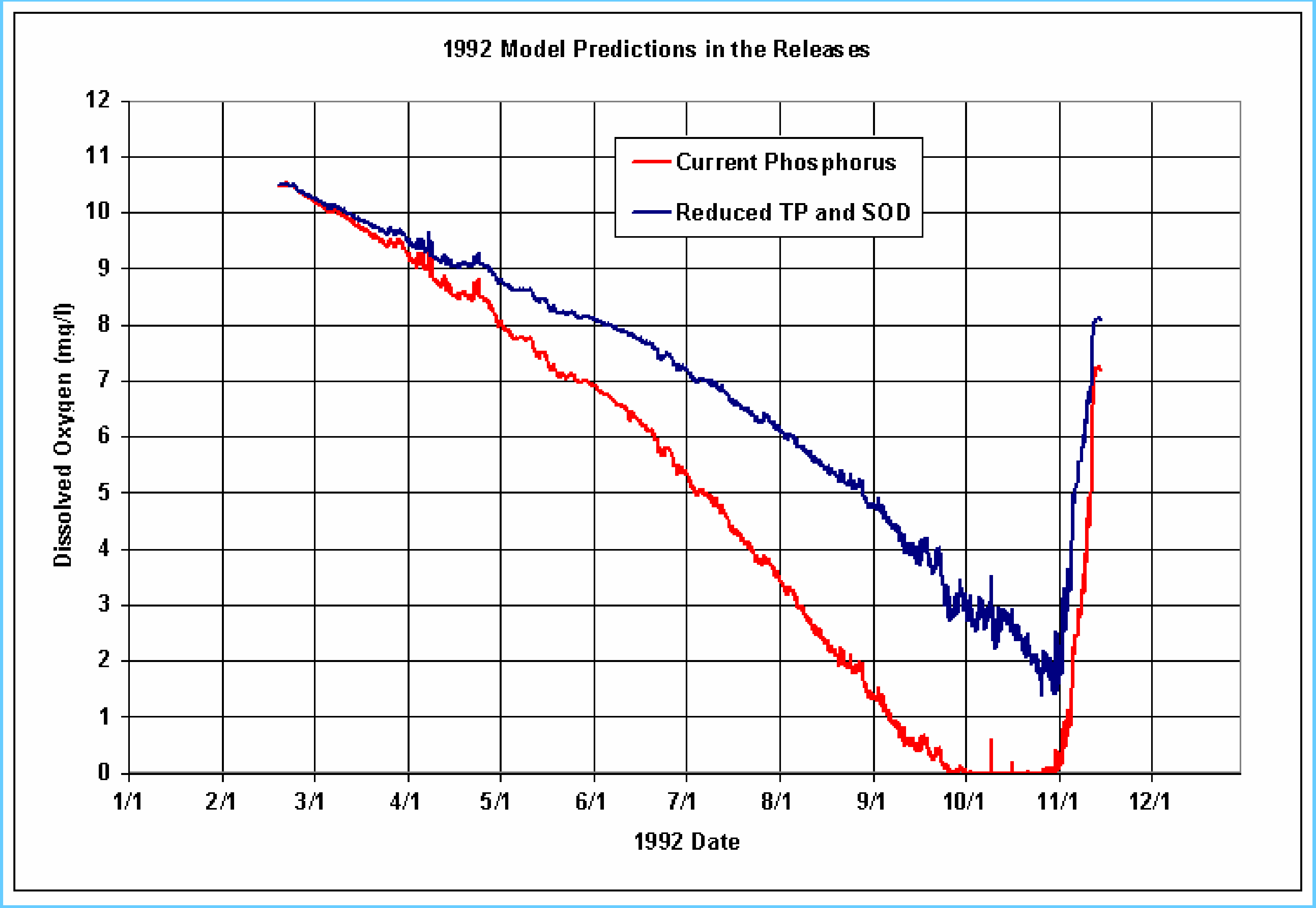




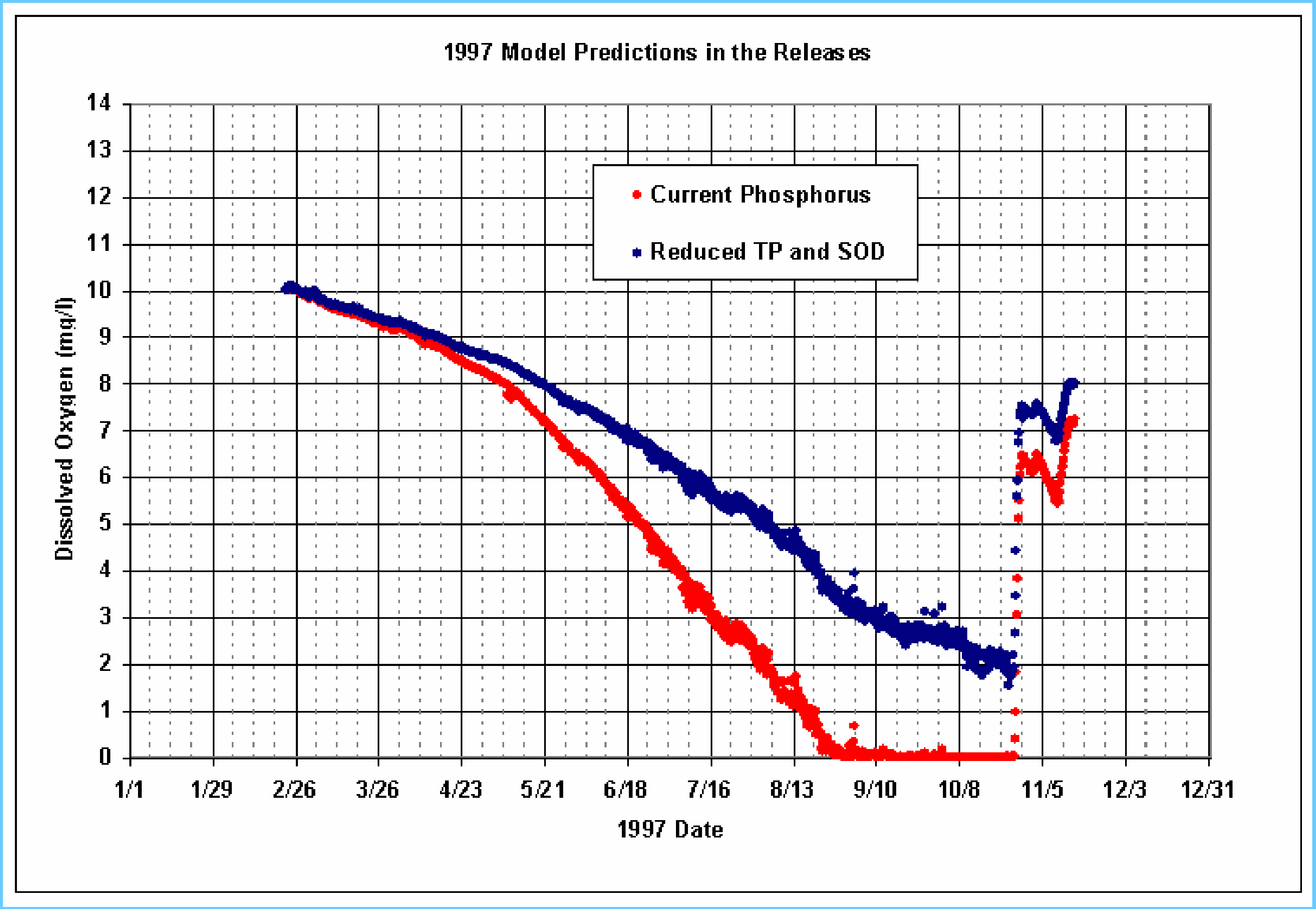
1996 Discharge DO for Current and Reduced Phosphorus, and without the Special Drawdown



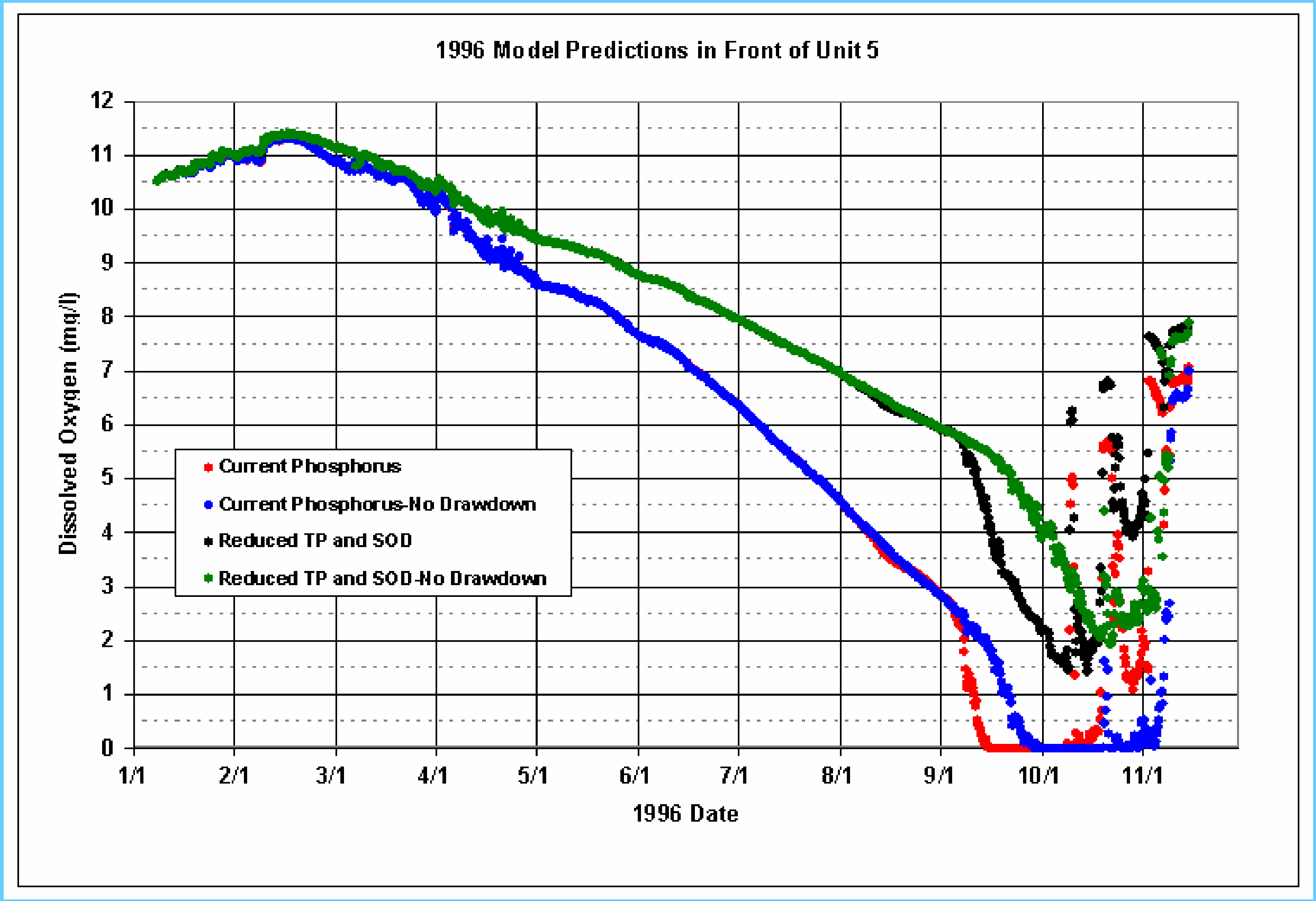
1992 Discharge DO for Current and Reduced Phosphorus



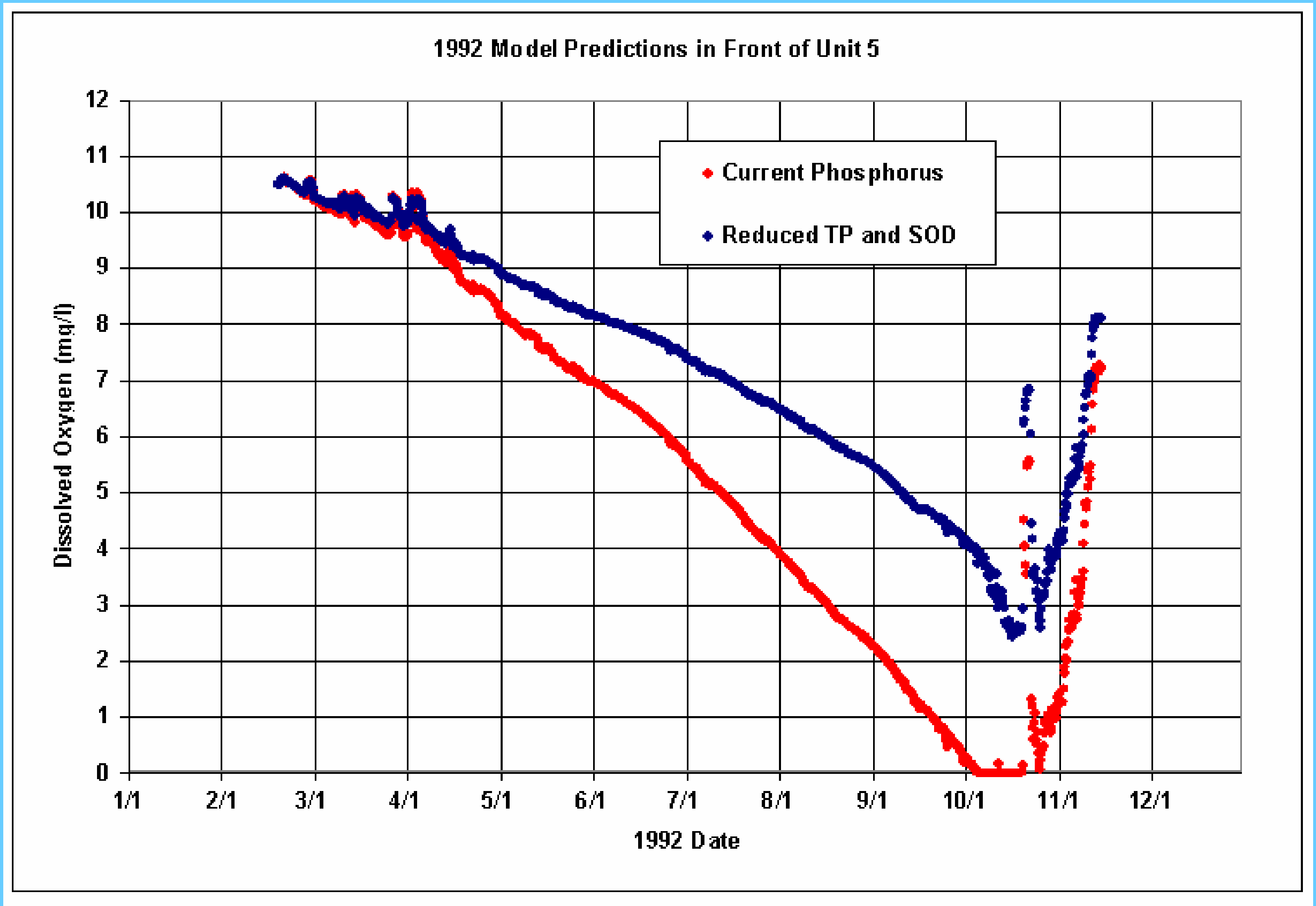
1997 Discharge DO for Current and Reduced Phosphorus



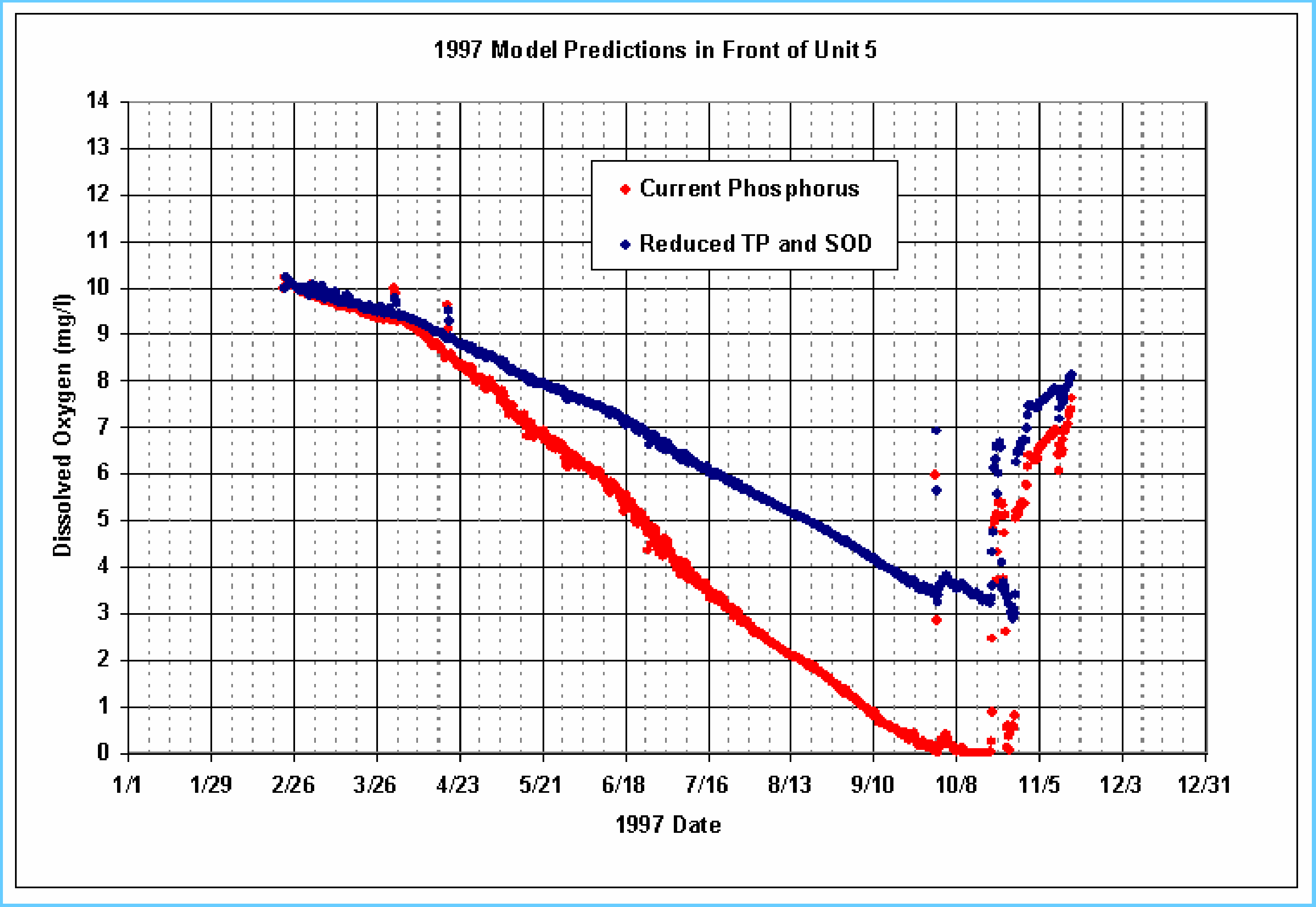
1996 DO at the Elevation of the Unit 5 Intake for Current and Reduced Phosphorus, and without the Special Drawdown



1992 DO at the Level of the Unit 5 Intake for Current and Reduced Phosphorus

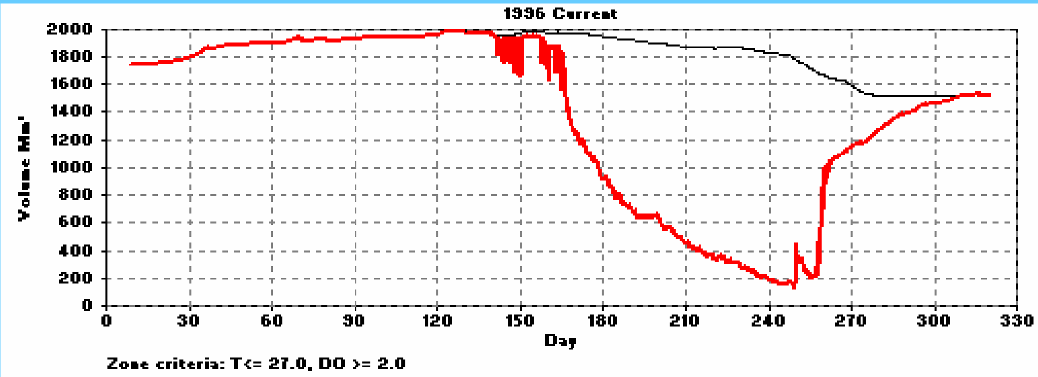


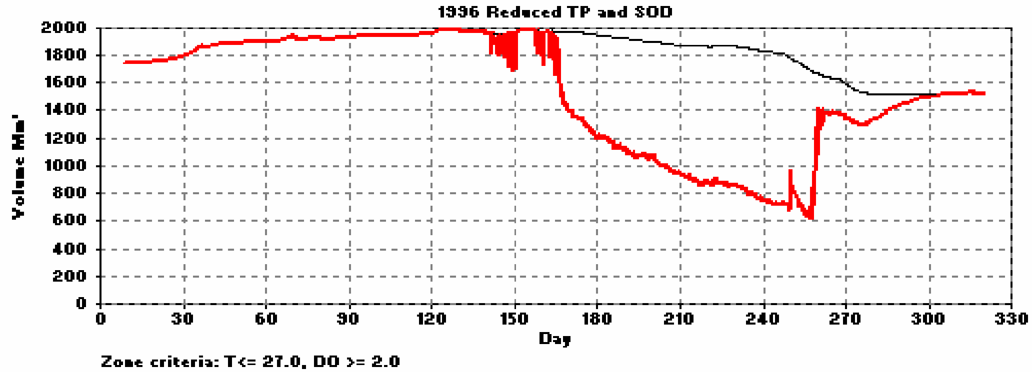
1997 DO at the Level of the Unit 5 Intake for Current and Reduced Phosphorus

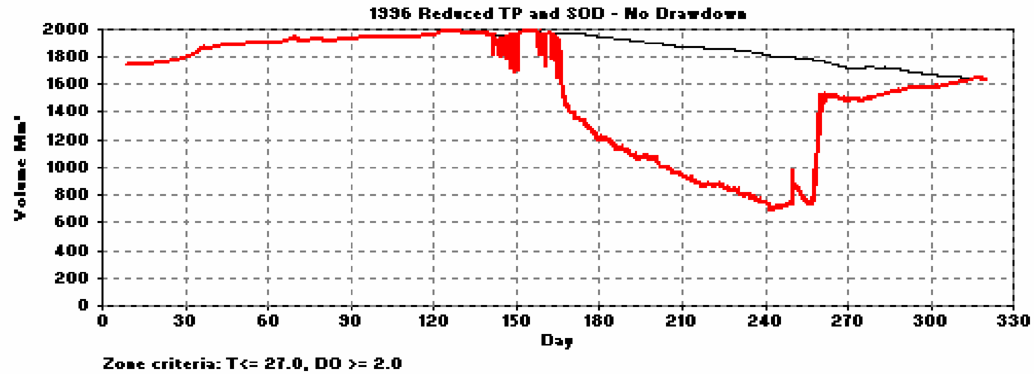


Temperature, DO, Age and Chlorophyll a Animation

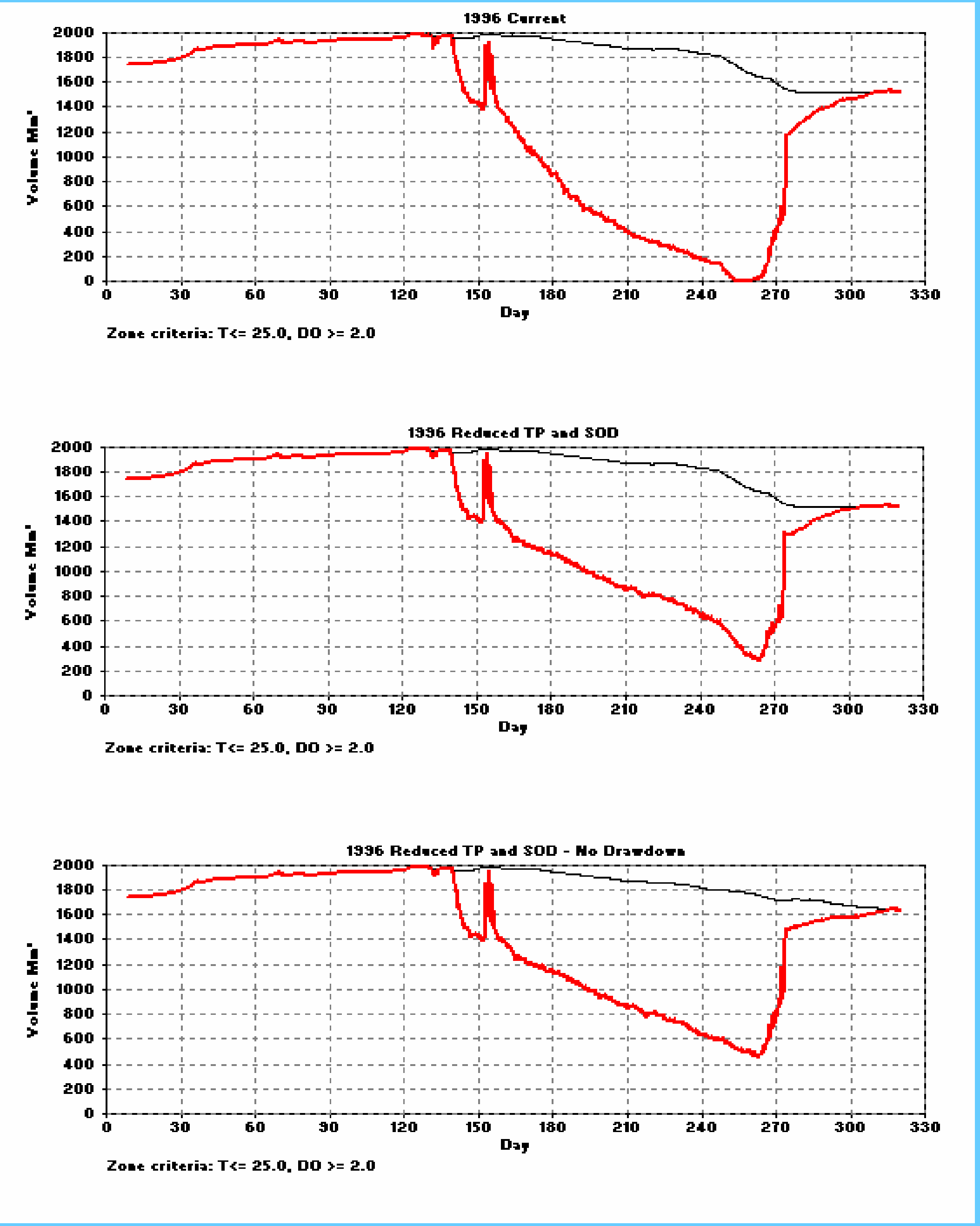
Temp < 27 and DO > 2



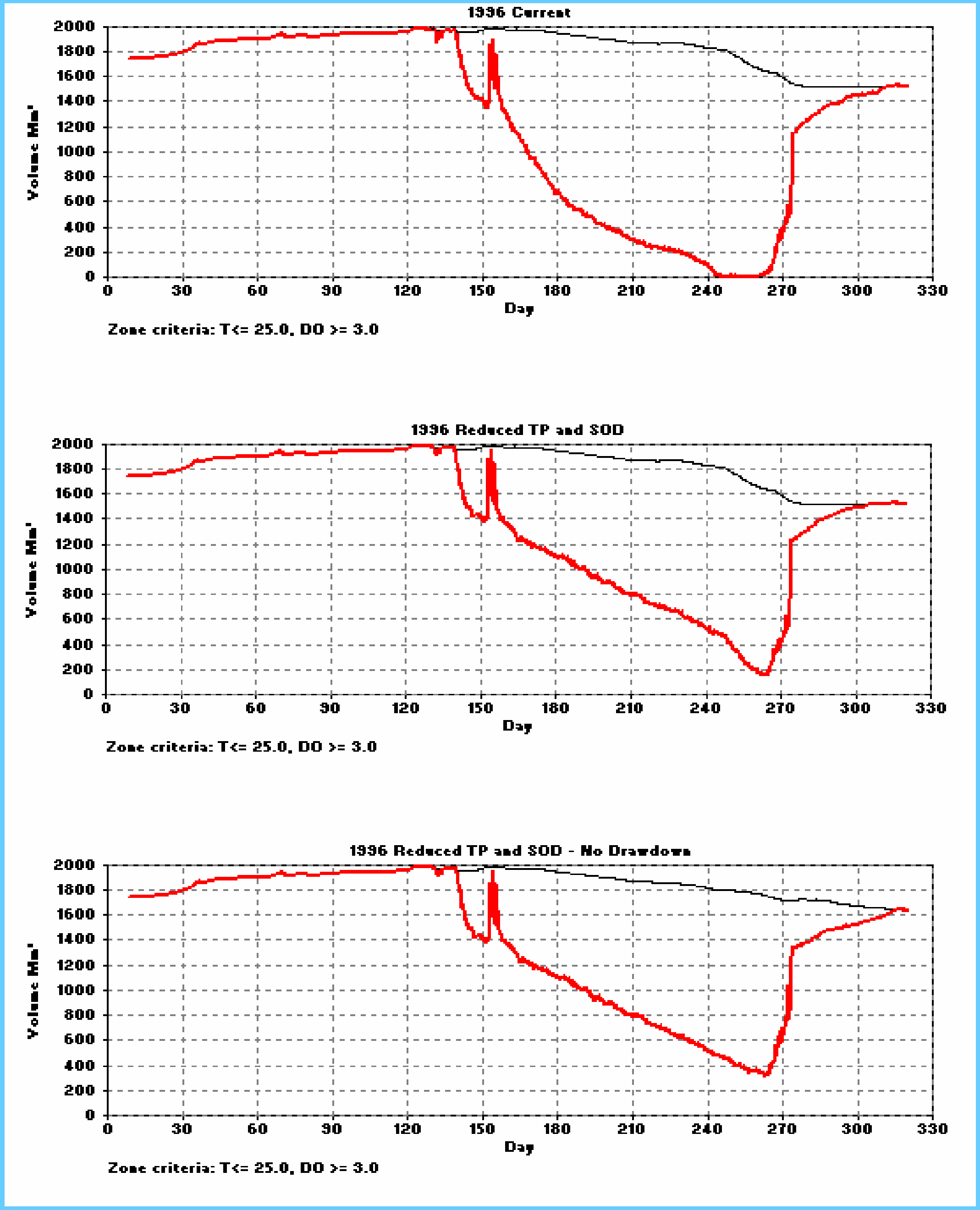




Temp < 25 and DO > 2



Temp < 25 and DO > 3



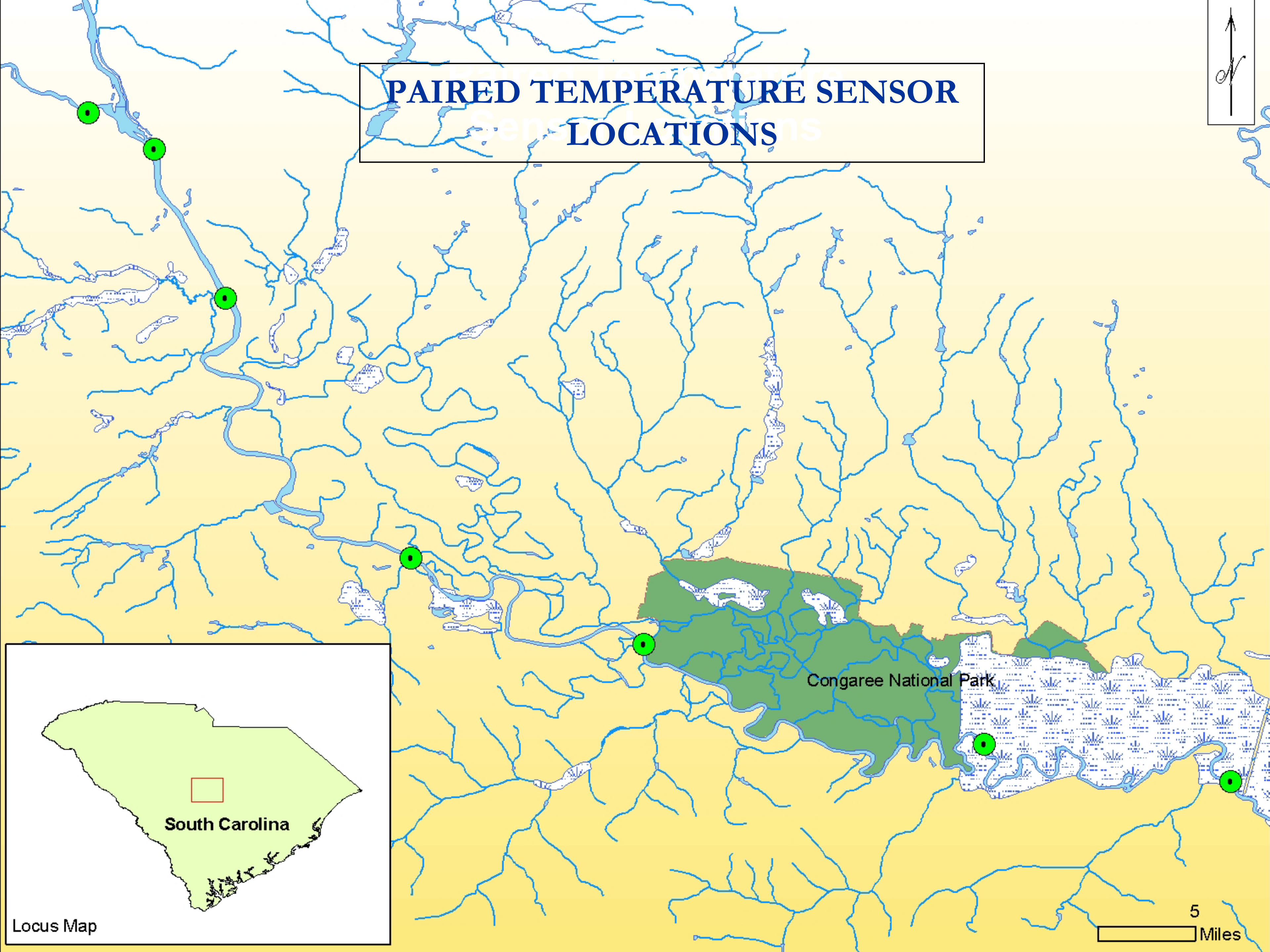
METRICS – Murray 1996	Current	Current-No Drawdown	Reduced TP and SOD	Reduced TP and SOD-No Drawdown
MEAN TOTAL RESERVOIR VOLUME (MM3)	2684	2738	2684	2738
SUM OF VOLUME-DAYS (MM3-DA) WITH DO > 5 MAY-OCT	336403	340241	411162	415248
SUM OF VOL-DAYS (MM3-DA) WITH DO > 5 MAY-OCT AS % OF TOTAL VOL-DAYS MAY-OCT	69%	68%	84%	82%
MINIMUM VOLUME (MM3) WITH DO > 5 MG/L	1267	1263	1581	1689
MINIMUM %VOLUME WITH DO > 5 MG/L	47%	47.30%	65.60%	64.10%
SUM OF VOLUME-DAYS (MM3-DA) WITH DO > 4 MAY-OCT	361968	365365	436548	442955
SUM OF VOL-DAYS (MM3-DA) WITH DO > 4 MAY-OCT AS % OF TOTAL VOL-DAYS MAY-OCT	74%	73%	89%	88%
MINIMUM VOLUME (MM3) WITH DO > 4 MG/L	1345	1352	1714	1881
MINIMUM %VOLUME WITH DO > 4 MG/L	50%	51%	72%	75%
SUM OF VOLUME-DAYS (MM3-DA) WITH DO < 1 MG/L	70304	80120	9610	9901
SUM OF VOL-DAYS (MM3-DA) WITH DO < 1 AS % OF TOTAL VOL-DAYS	8.4%	9.4%	1.1%	1.2%
MAXIMUM VOLUME (MM3) WITH DO < 1 MG/L	926	916	181	170
MAXIMUM %VOLUME WITH DO < 1 MG/L	35%	35%	8%	7%
Striper Preferred Habitat				
SUM OF VOLUME-DAYS (MM3-DA) WITH T<20 AND DO>4 MAY-OCT	109194	117674	154380	166211
SUM OF VOL-DAYS (MM3-DA) WITH T<20 AND DO>4 AS % OF TOTAL VOL-DAYS MAY-OCT	22%	23%	32%	33%
MINIMUM VOLUME (MM3) WITH T<20 AND DO>4	0	0	0	61
MINIMUM %VOLUME WITH T<20 AND DO>4	0.0%	0.0%	0.0%	2.4%
Striper Maximum Tolerable Habitat				
SUM OF VOLUME-DAYS (MM3-DA) WITH T<27 AND DO>2 MAY-OCT	276016	279486	340103	352189
SUM OF VOL-DAYS (MM3-DA) WITH T<27 AND DO>2 AS % OF TOTAL VOL-DAYS MAY-OCT	56%	56%	69%	70%
MINIMUM VOLUME (MM3) WITH T<27 AND DO>2	154	136	806	870
MINIMUM %VOLUME WITH T<27 AND DO>2	6%	5%	33%	33%
SUM OF KM-DAYS WITH DO < 5 MG/L AT SURFACE	48	21	2	2
MAX CONTIG. DISTANCE (KM) WITH DO < 5 AT SURFACE	7.6	7.6	0.0	0.0
MAX CONTIG. DISTANCE (KM) WITH DO < 3 AT SURFACE	0	0	0	0
MINIMUM RELEASE DO (MG/L)	0.0	0.0	0.0	0.8
NUMBER OF DAYS WITH RELEASE DO < 5 MG/L	111	112	58	72
NUMBER OF DAYS WITH RELEASE DO < 3 MG/L	83	86	42	37
MAXIMUM CHL-A CONCENTRATION (UG/L)	29.4	27.2	14.7	10.4
MEAN SURFACE CHL-A CONCENTRATION (UG/L) APR-AUG	5.8	5.8	2.3	2.3

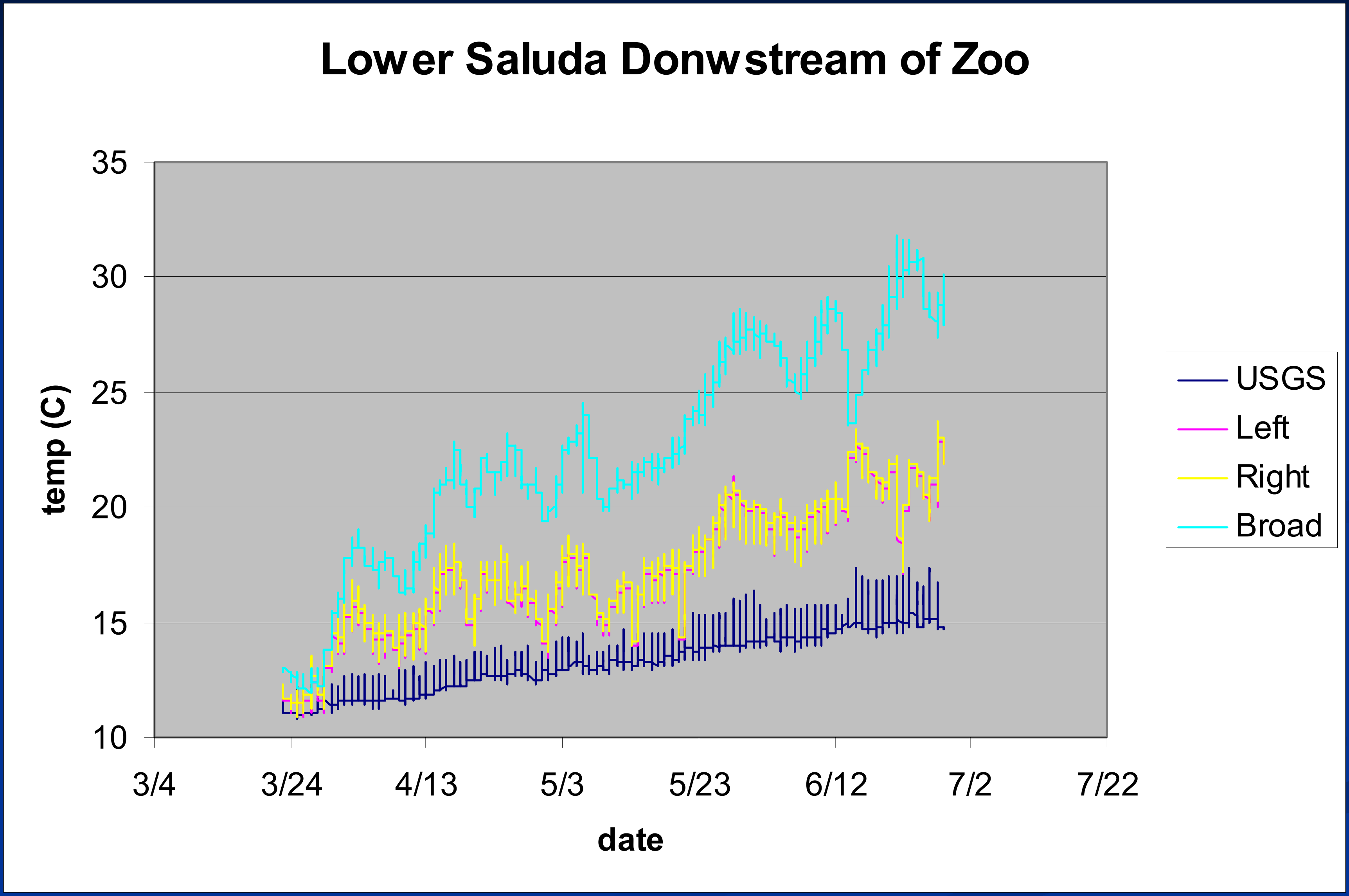
The End

Lower Saluda and Congaree Rivers Temperature Study: Update

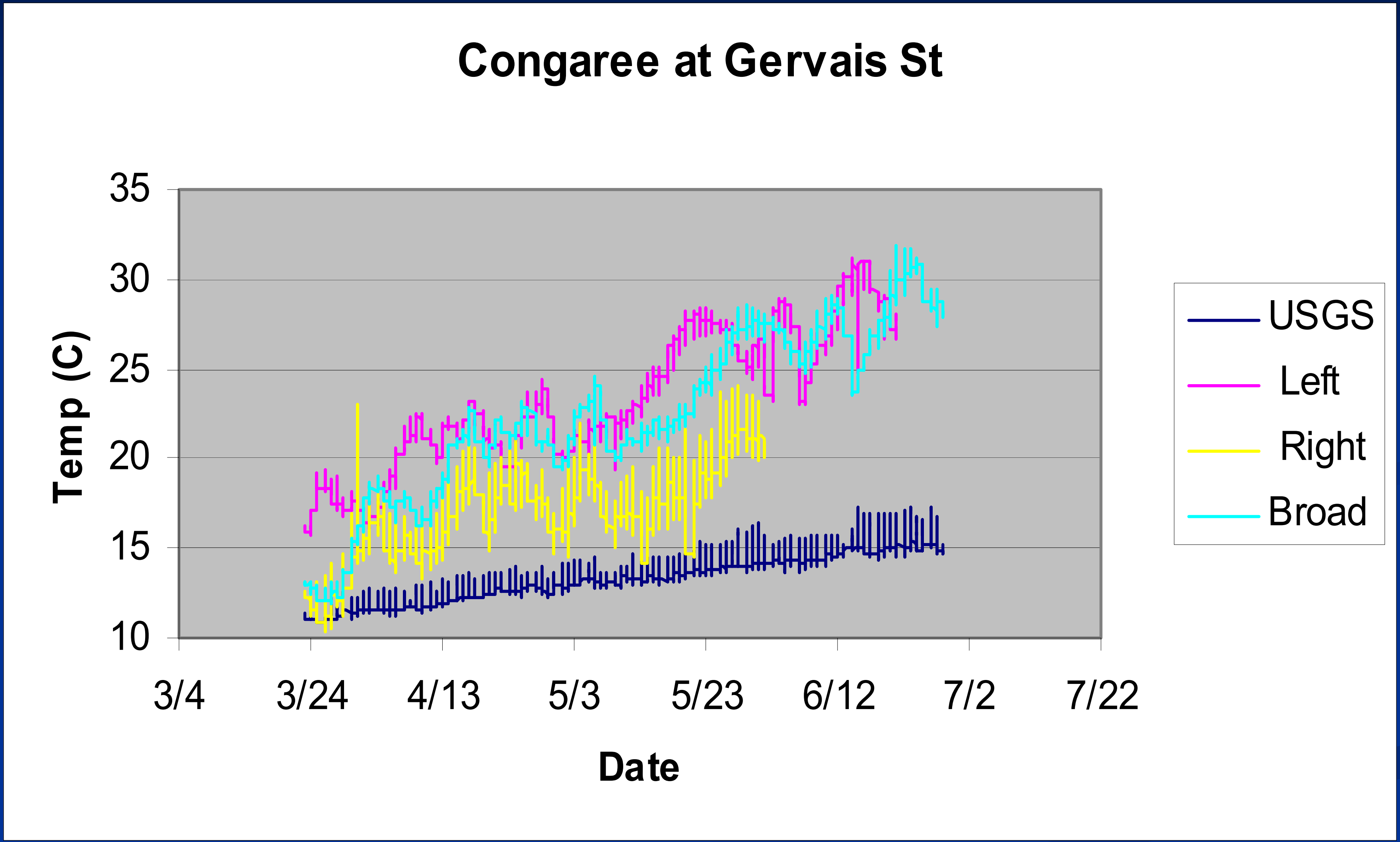
Water Quality Technical Working Committee Meeting

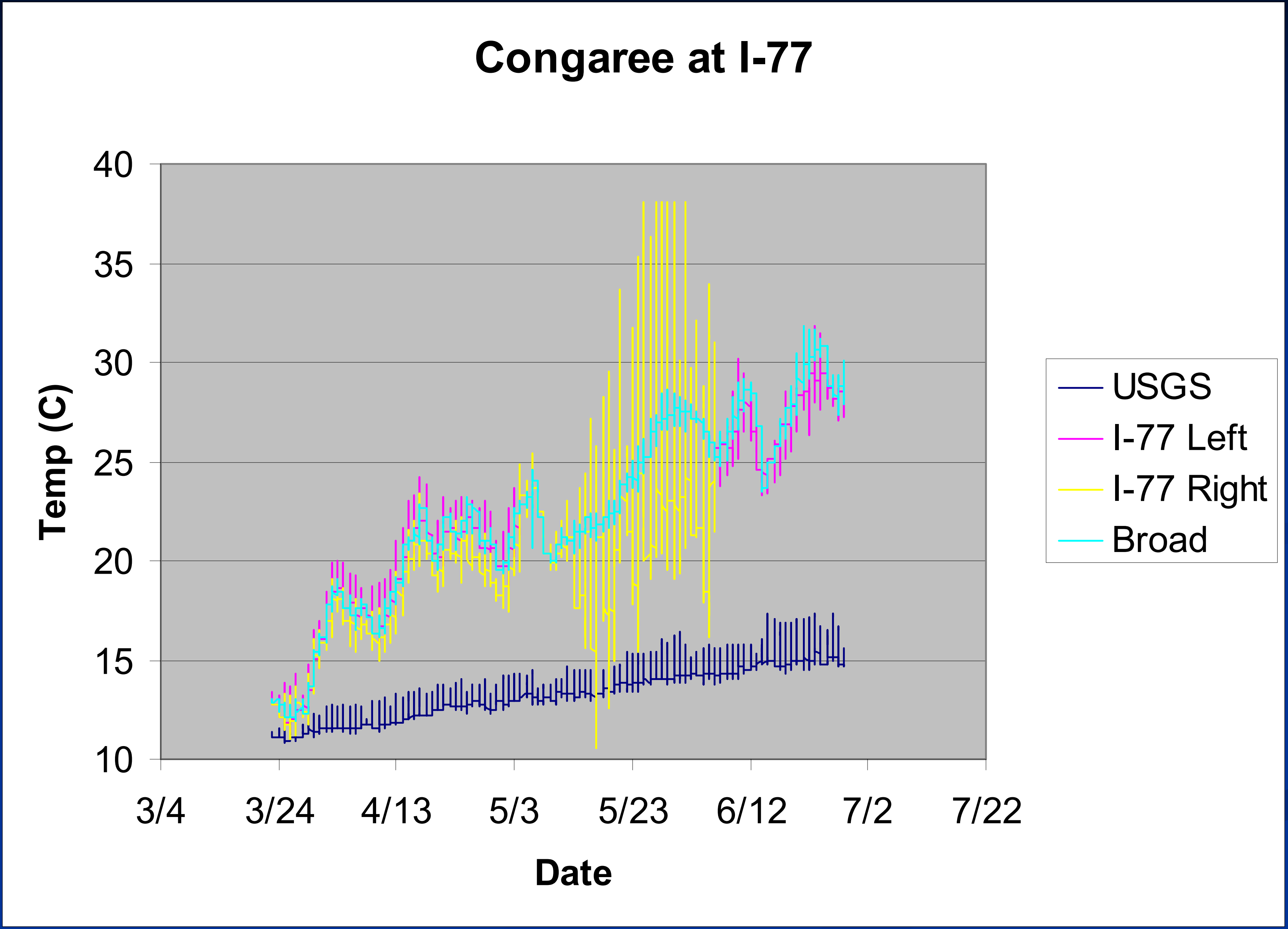
August 23, 2006


PAIRED TEMPERATURE SENSOR LOCATIONS
Congaree National Park
South Carolina
Locus Map
5
Miles

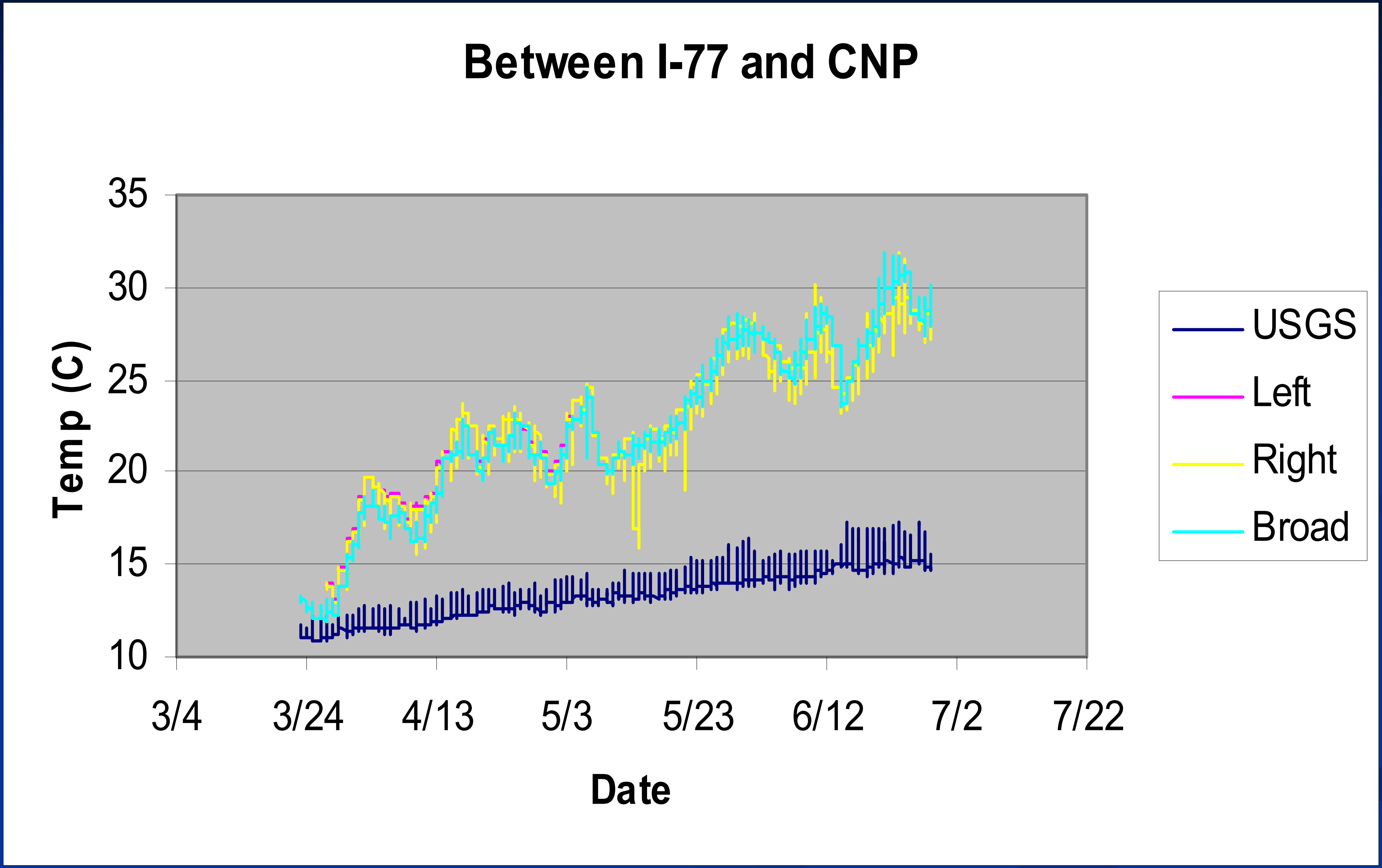


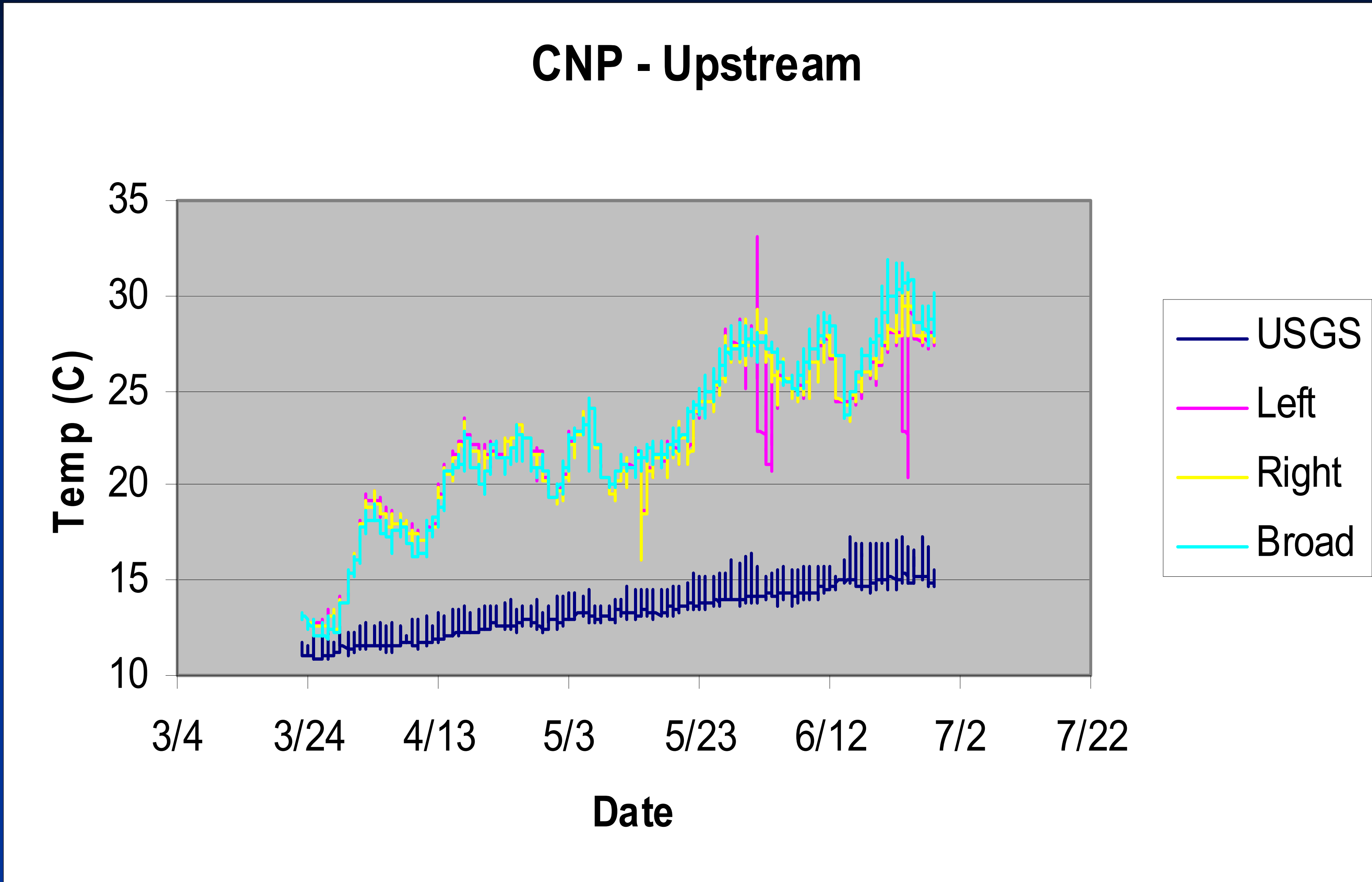
Lower Saluda Donwstream of Zoo
temp (C)
35
30
25
20
15
10
3/4
3/24
4/13
5/3
5/23
6/12
7/2
7/22
date
USGS
Left
Right
Broad


Congaree at Gervais St
35
30
25
20
15
10
Temp (C)
3/4
3/24
4/13
5/3
5/23
6/12
7/2
7/22
Date
USGS
Left
Right
Broad

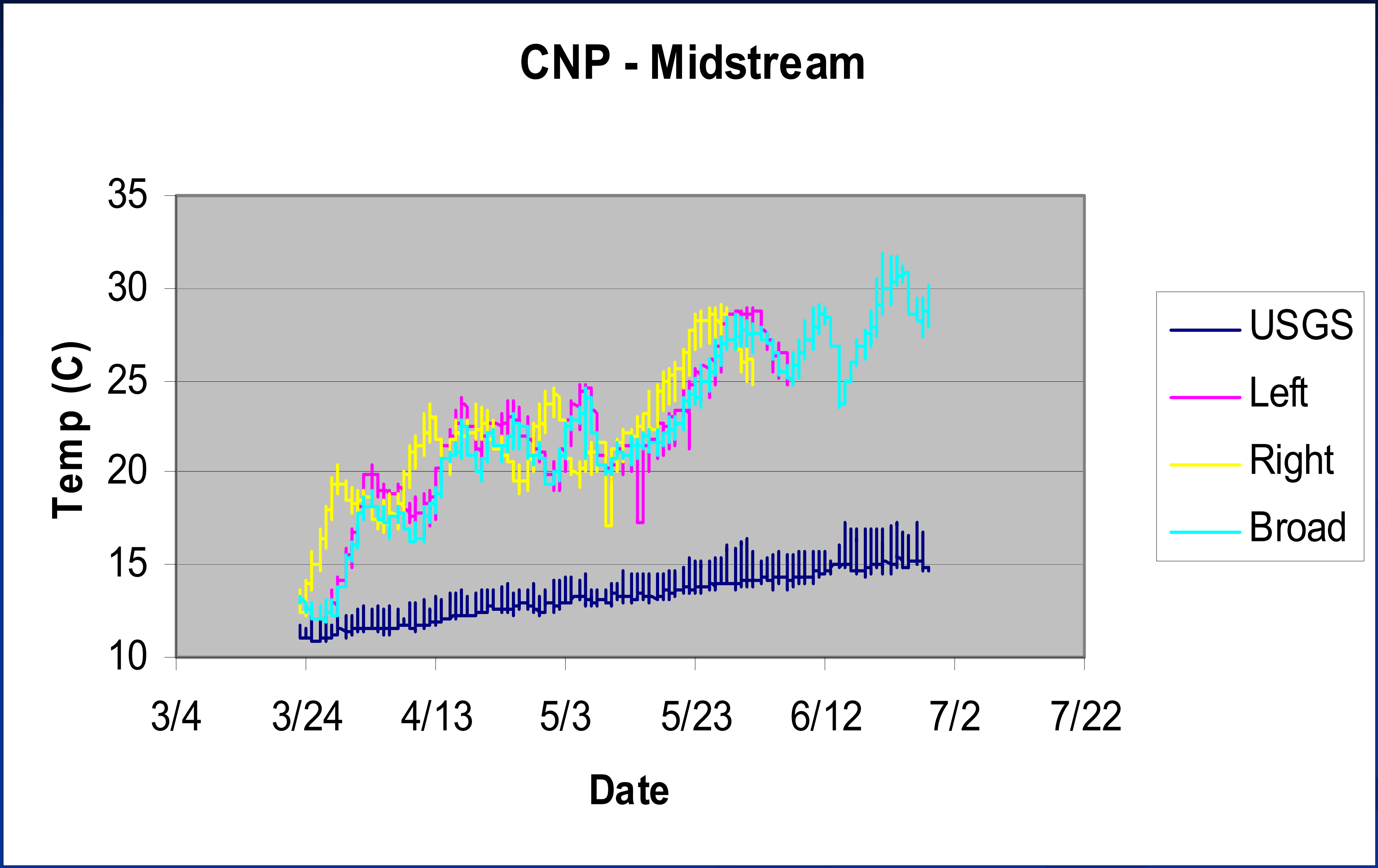


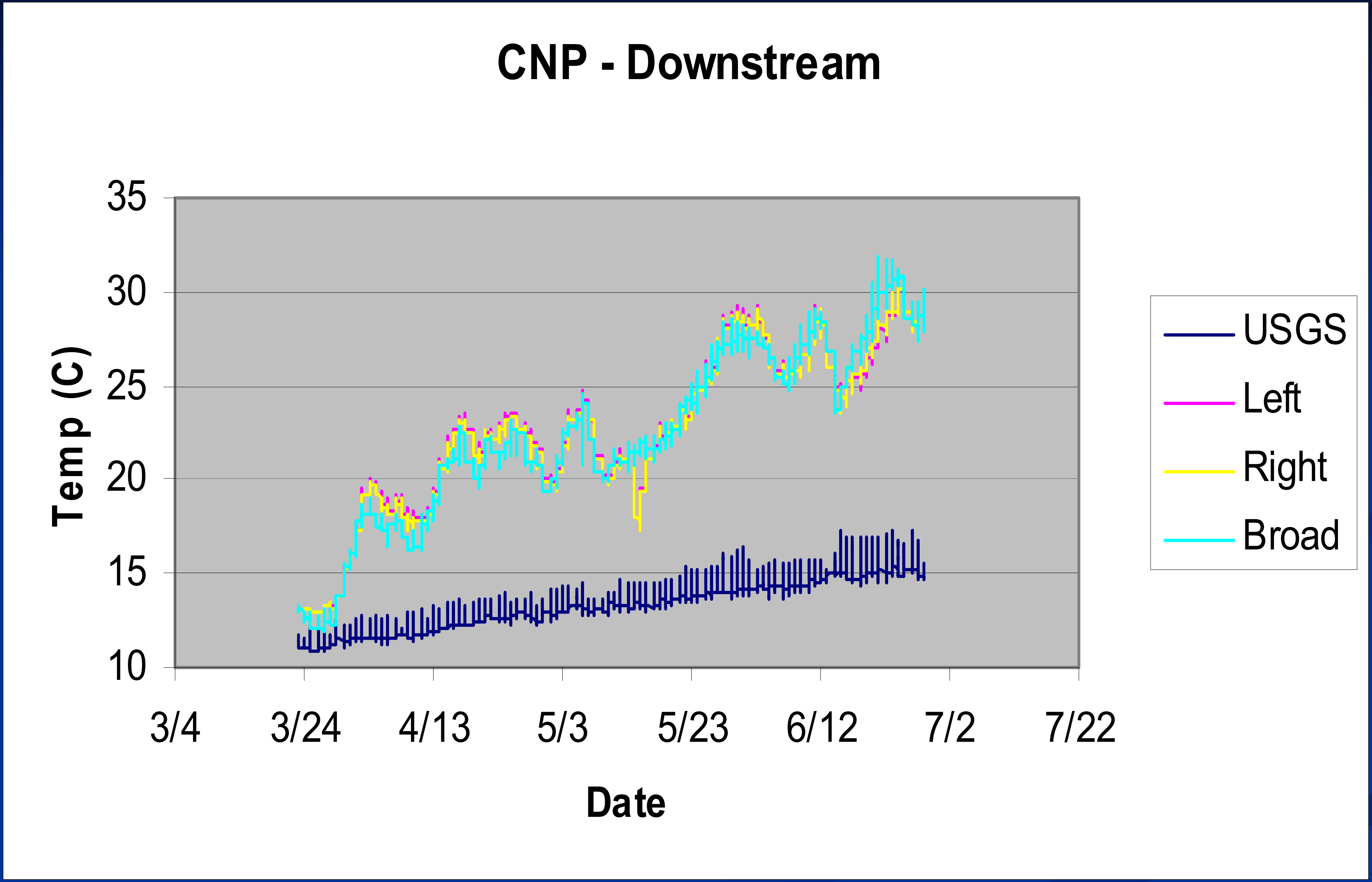
Congaree at I-77
Temp (C)
40
35
30
25
20
15
10
3/4
3/24
4/13
5/3
5/23
6/12
7/2
7/22
Date
USGS
I-77 Left
I-77 Right
Broad


Between I-77 and CNP
Temp (C)
35
30
25
20
15
10
3/4
3/24
4/13
5/3
5/23
6/12
7/2
7/22
Date
USGS
Left
Right
Broad



CNP - Upstream
Temp (C)
35
30
25
20
15
10
3/4
3/24
4/13
5/3
5/23
6/12
7/2
7/22
Date
USGS
Left
Right
Broad


CNP - Midstream
Temp (C)
35
30
25
20
15
10
3/4
3/24
4/13
5/3
5/23
6/12
7/2
7/22
Date
USGS
Left
Right
Broad



CNP - Downstream
Temp (C)
35
30
25
20
15
10
3/4
3/24
4/13
5/3
5/23
6/12
7/2
7/22
Date
USGS
Left
Right
Broad

Conclusions

- Congaree and Broad diverge from Saluda in early April
- Cross-sectional temperatures vary below confluence
- To date, data suggests that influence extends at least to I-77 Bridge

Challenges

- Vandalism / Theft
- Breakoffs (corrosion / snags / high flows)
- Inaccessibility of instruments due to high flows

Future Needs

- Gather additional data through October 2007
- Evaluate temperature impacts under varying flow conditions (i.e. varying inflows/operations, normal precipitation)
- Appropriate statistical analysis methods
  - missing values
  - How to deal with errors (i.e. due disturbance of probe, etc.)

LMA WATER QUALITY MONITERING PROGRAM

- Began planning process in early January 06
- Met with DHEC Jan. 18 to discuss & get ideas for formulating plan.
- Initially plans were to focus on monitoring for fecal coliform and total phosphorus in coves.
- Five different cove types were identified for monitoring.
- Nine coves are currently being monitored on a monthly basis.

COVE TYPES

- TYPE I: Densely populated cove on septic/drain fields.
- TYPE II: Reference cove undeveloped and sparsely populated.
- TYPE III: Cove with marina(s)
- TYPE IV: Agricultural watershed drains into cove.
- TYPE V: Cove targeted for multi unit housing with accompanying docks/marina.

SAMPLE COLLECTION

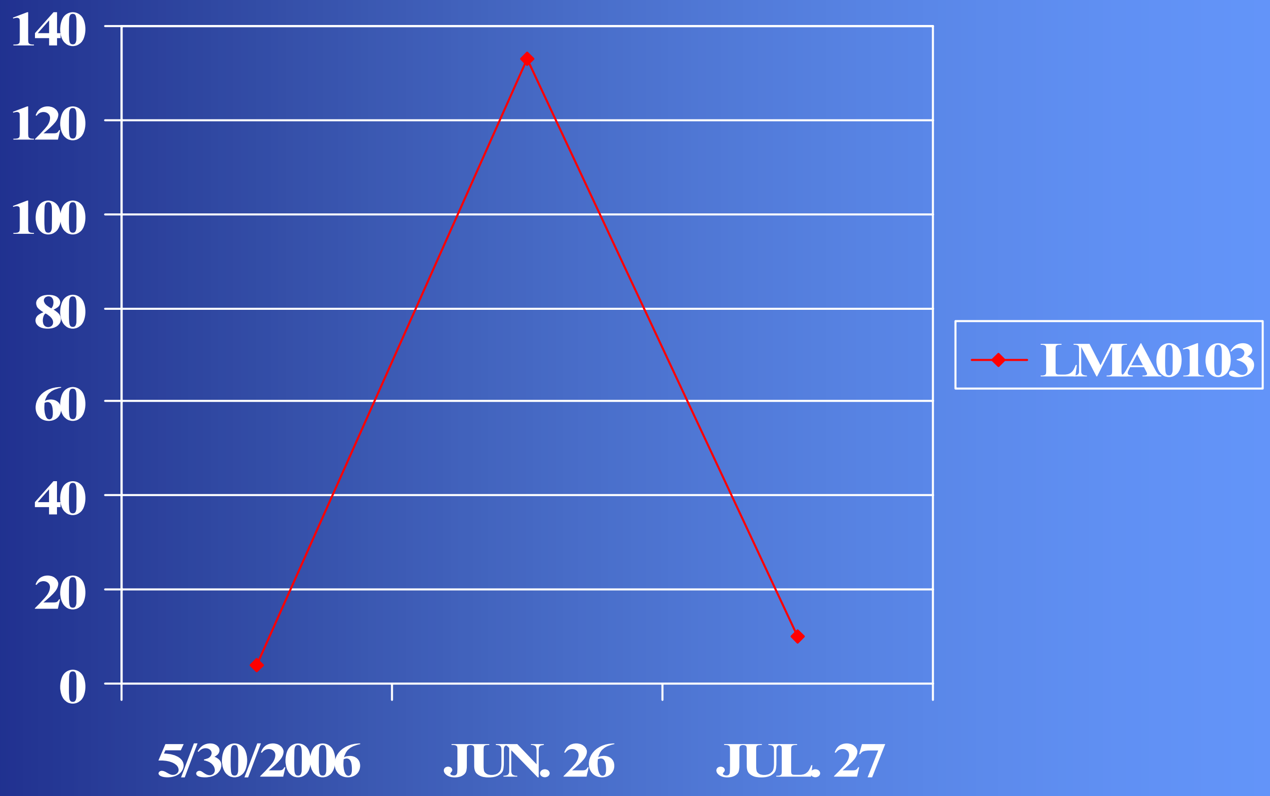
- LMA representative accompanied DHEC when they were collecting water samples to observe and learn from their sample collecting techniques.
- LMA developed a protocol for collecting water samples.
- Samples are placed on ice when collected & transported to the lab. within 6 hours of collection.
- Chain-of-custody forms are carefully filled out and go with the samples to the laboratory.
- Sample collection logs are maintained for each collection site.
- Samples are analyzed by Data Resources Inc., a DHEC certified laboratory.
- We maintain frequent contact with DHEC and share our results with them.

FECAL COLIFORM

COVES	May 30	June 26	July 27
LMA 0101	BDL	8	25
LMA 0102	2 est.	23	BDL
LMA 0103	4 est.	133	10
LMA 0104	7	14 est.	4 est.
LMA 0201	BDL	Not Sampled	Not Sampled
LMA 0301	BDL	40	23
LMA 0302	38	4 est.	10
LMA 0401	10 est.	5	5
LMA 0501	7	4 est.	40

BDL = Below Detectable Level

FECAL COLIFORM



TOTAL PHOSPHORUS mg/l

COVES	May 30	June 26	July 27
LMA 0101	BDL	BDL	0.53
LMA 0102	BDL	BDL	0.11
LMA 0103	BDL	BDL	0.05
LMA 0104	BDL	BDL	0.15
LMA 0201	BDL	Not Sampled	Not Sampled
LMA 0302	BDL	BDL	0.10
LMA 0301	BDL	BDL	0.47
LMA 0401	BDL	0.14	0.10
LMA 0501	BDL	BDL	0.07

BDL = Below Detectable Level

DISSOLVED OXYGEN

- Nothing brings more concern about water quality than fish kills.
- Summer/late summer fish kills are often the result of insufficient dissolved oxygen.
- There is good documentation that high phosphorus levels contribute to low dissolved oxygen levels.
- Phosphorus contributes to algae growth.
- In deep water algae die and decompose lowering oxygen levels.

LAKE ERIE PHOSPHORUS/DO RELATIONSHIPS

1"In general, less phosphorus in the water in the spring will result in fewer algae growing, which in turn means less organic matter to decompose. Less decomposition activity would take less dissolved oxygen from the water. As a result of phosphorus control programs, we could expect that the severity of oxygen depletion, the duration of the minimum oxygen levels and the amount of the Central Basin area affected would all be reduced."

1 US EPA Dissolved Oxygen Depletion in Lake Erie

LMA's DESIRE IS TO LOWER POLLUTANTS COMING INTO THE LAKE

- Identify most prominent entry points and contributors to ABOVE STANDARD phosphorus levels.
- Educate home owners on proper lawn fertilization.
- In general, centipede lawns do not need phosphorus.
- Educate home owners on the need to establish buffer zones between the lake and maintained landscape.

LMA NEEDS TO EXPAND OUR WATER QUALITY MONITORING PROGRAM

- We will begin monitoring for chlorophyll-a at all sample sites where phosphorus exceeds the freshwater standard of 0.06 mg/l.
- We would like to purchase 3 Eureka Multiprobes which will allow us to monitor for:
- Temperature
- Dissolved Oxygen
- PH
- Conductivity
- Depth

Water Quality Data Analysis and CE-QUAL-W2 Modeling for Lake Murray

Presented by Andy Sawyer and Jim Ruane

Reservoir Environmental Management, Inc

December 7, 2005

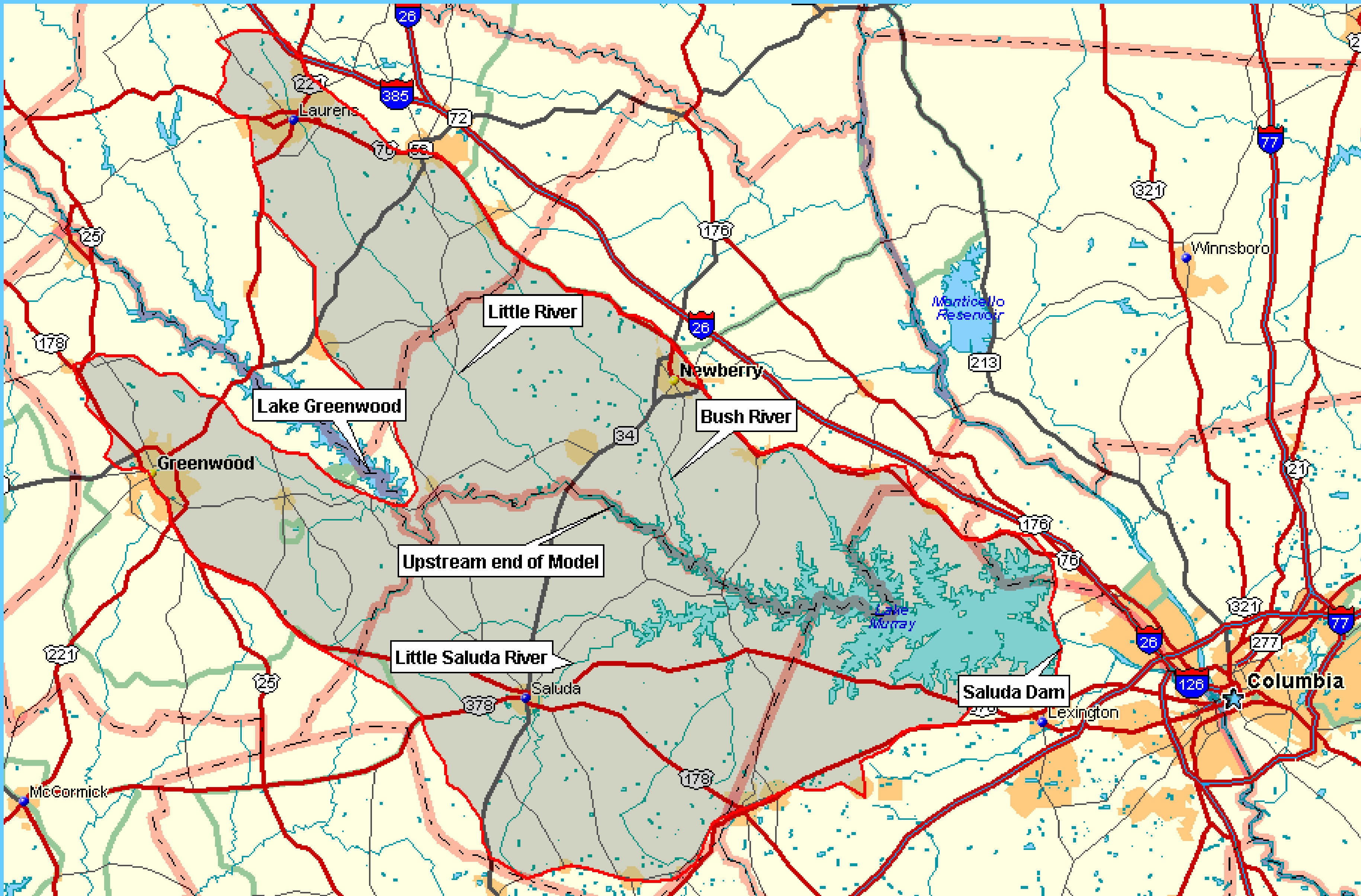
Overview of Presentation

- Review water quality data, especially for dominant constituents that affect water quality in Lake Murray and its releases
- Present the calibration of the CE-QUAL-W2 model that's used to simulate water quality in Lake Murray
- Illustrate use of the model to explore management strategies for improving water quality and uses of the lake

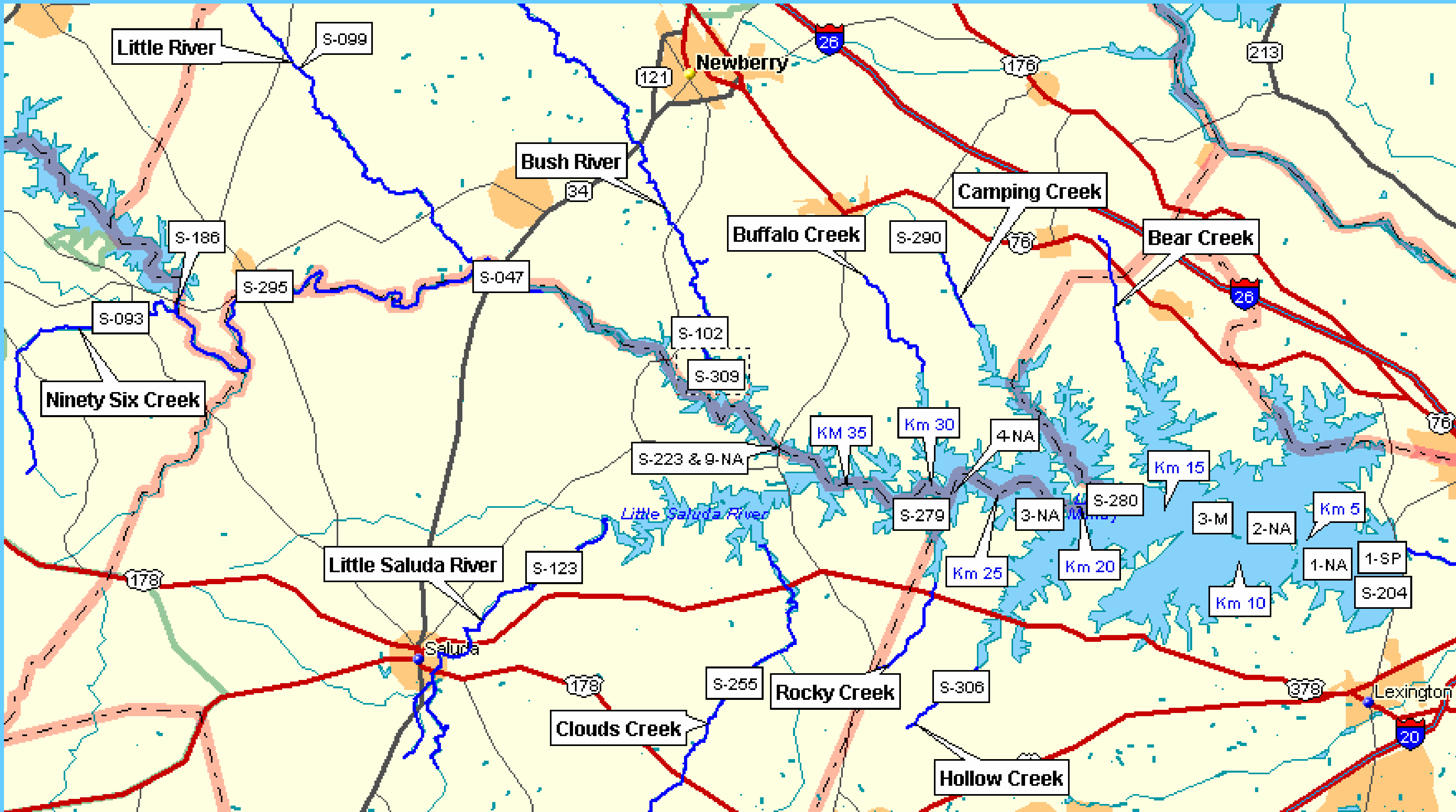
Preliminary Assessment of Historical Data through 1998

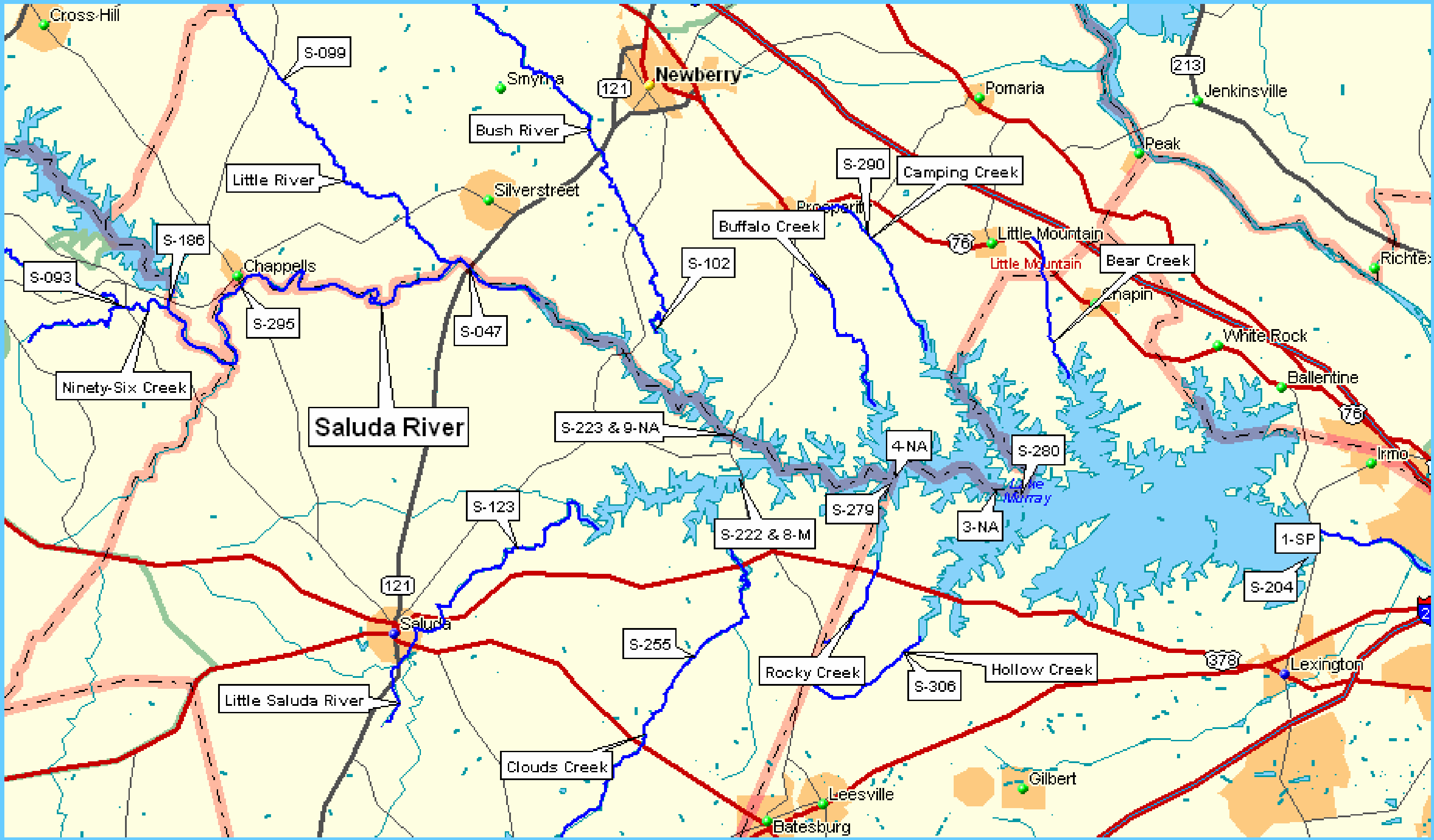
- This assessment was conducted in preparation for relicensing, using the available data at the time of the assessment in 2001
- Available data were organized using the DASLER software program
- Also, reports on water quality were reviewed: ERC report, prepared for relicensing in 1975; and DHEC reports in 1995 and 1998
- Some of the key findings will be presented in the first part of this presentation

Lake Murray Watershed



Primary SCDHEC and SCE&G Monitoring Stations used for Lake Murray Water Quality Analyses

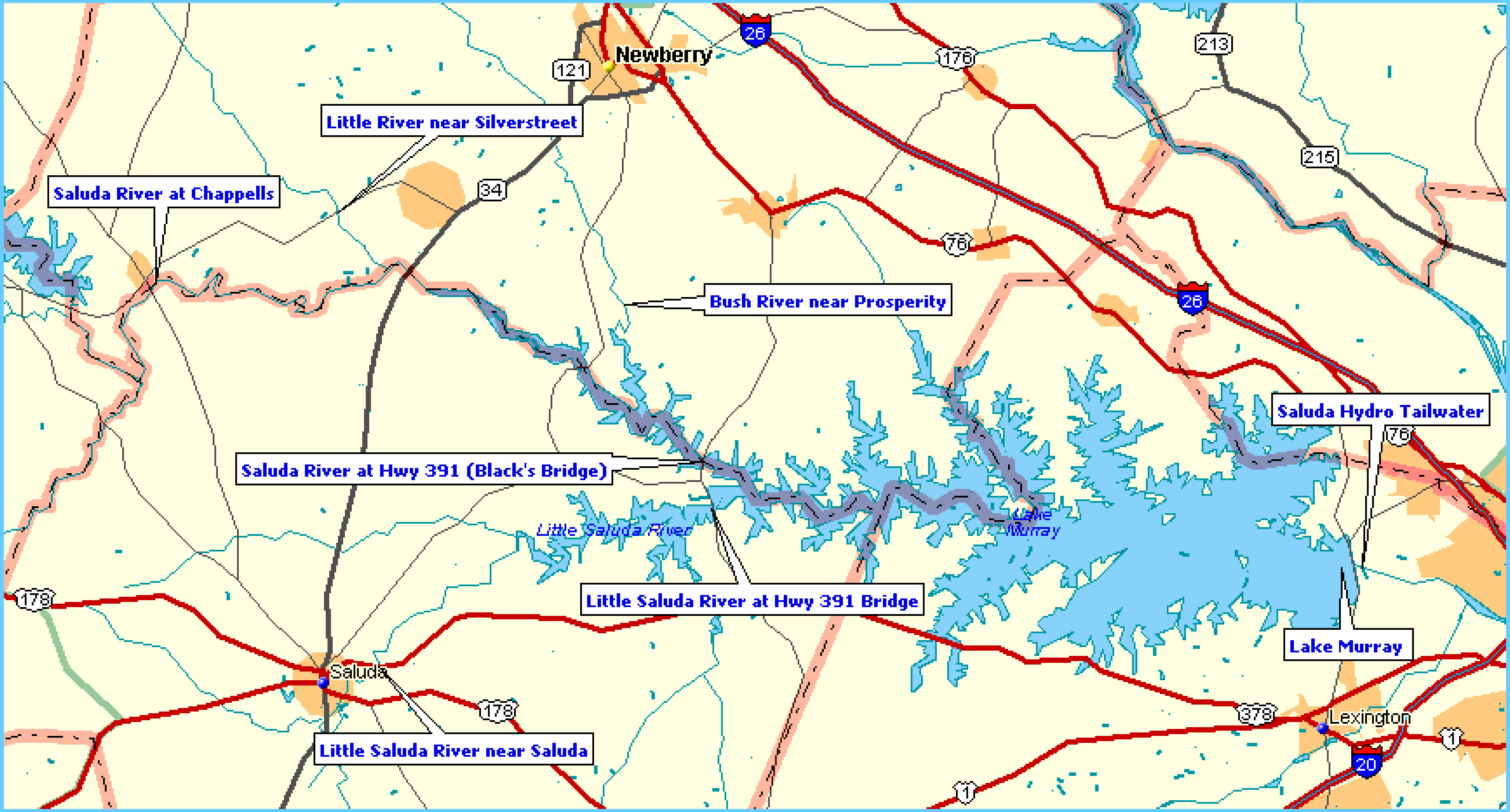


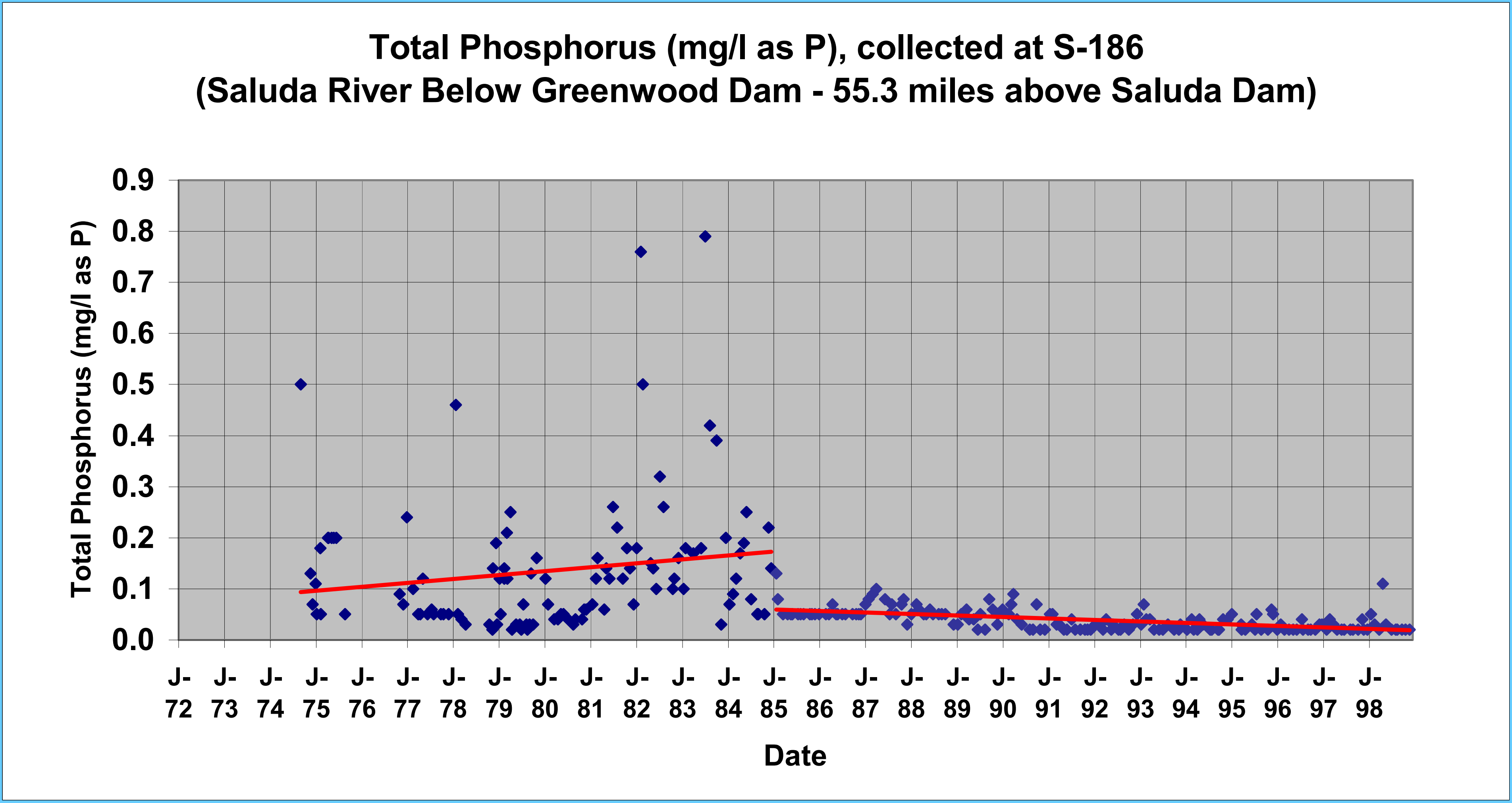


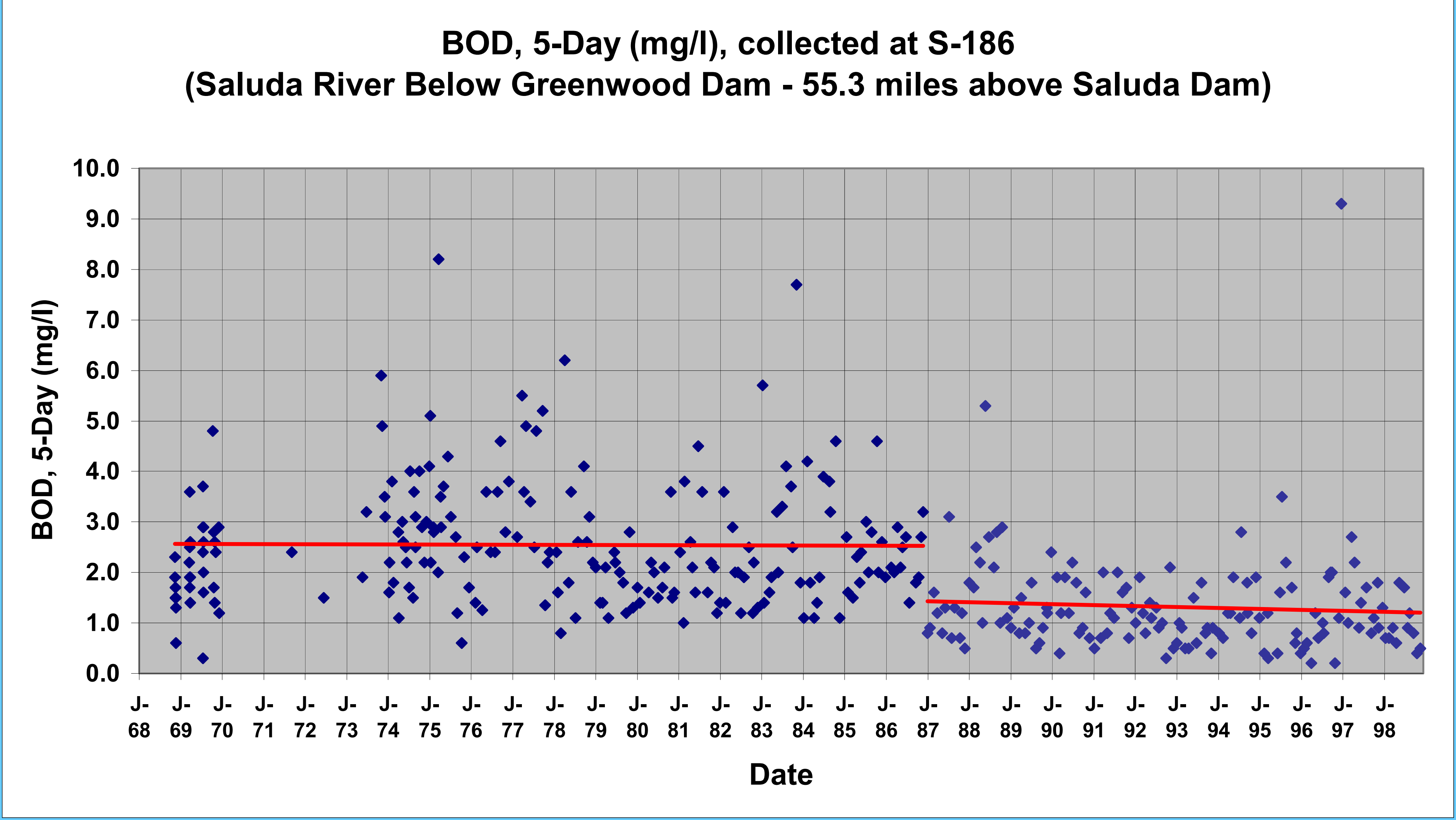
Stations with “S” prefix are SCDHEC monitoring stations

Others are SCE&G Monitoring Stations

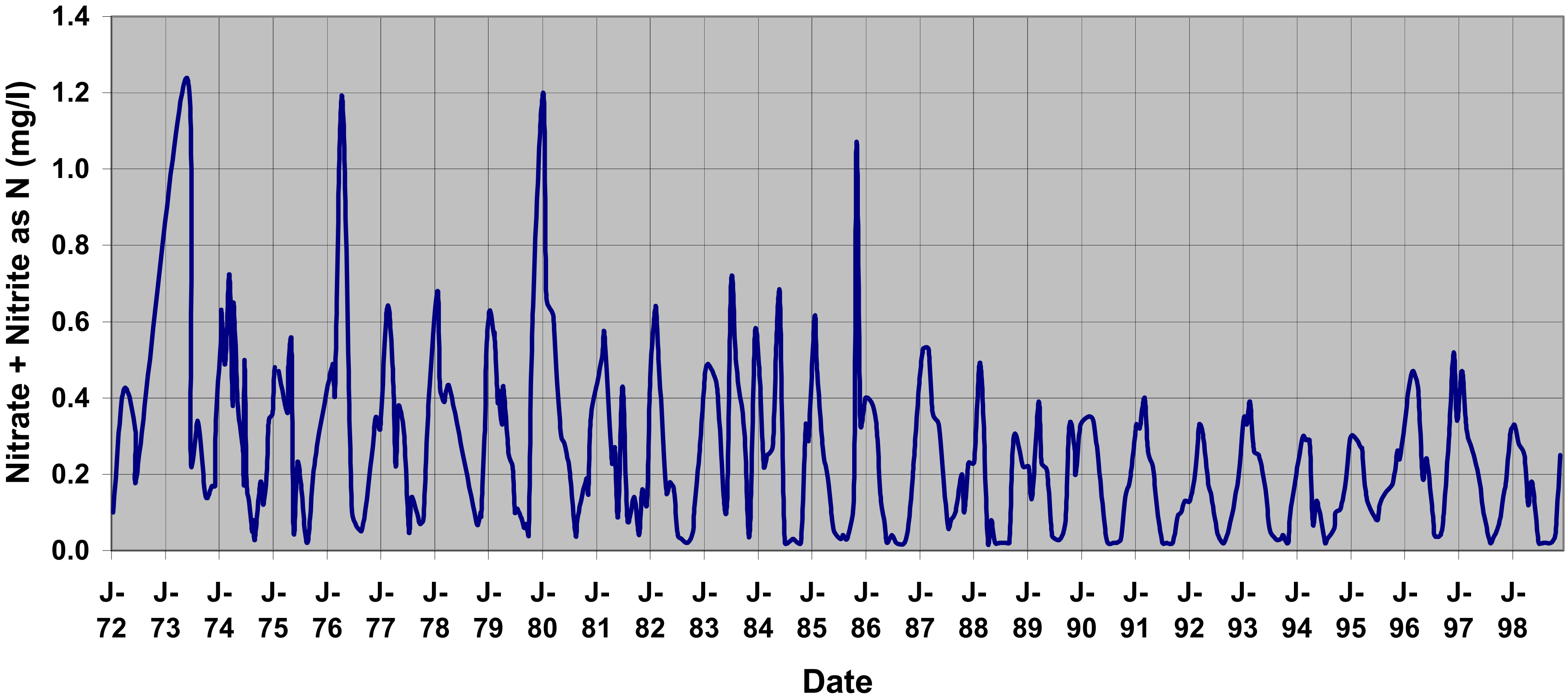
Map of Lake Murray Watershed Showing Location of USGS Monitors

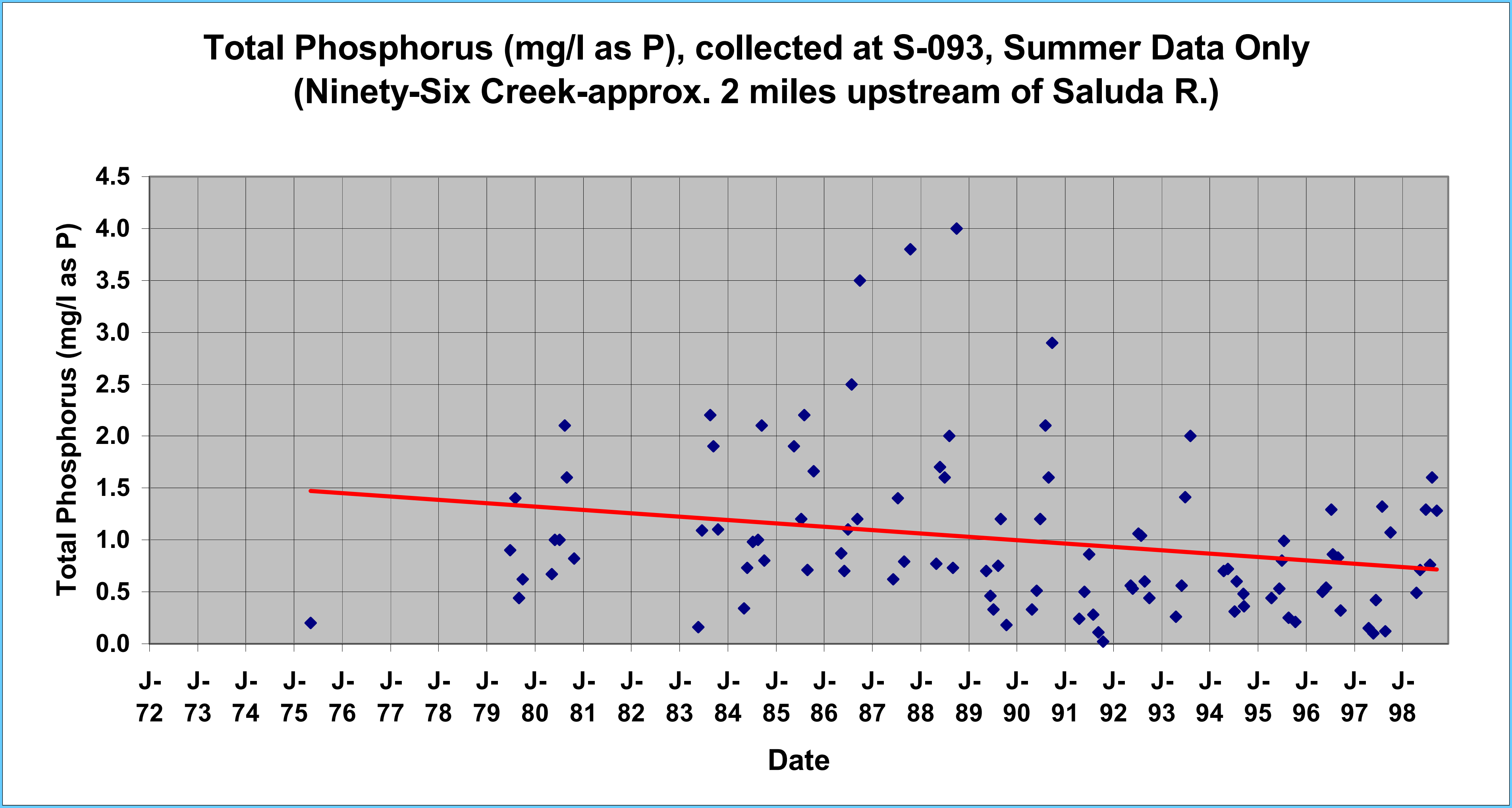



Total Phosphorus (mg/l as P), collected at S-186
(Saluda River Below Greenwood Dam - 55.3 miles above Saluda Dam)
Total Phosphorus (mg/l as P)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
J-72 J-73 J-74 J-75 J-76 J-77 J-78 J-79 J-80 J-81 J-82 J-83 J-84 J-85 J-86 J-87 J-88 J-89 J-90 J-91 J-92 J-93 J-94 J-95 J-96 J-97 J-98
Date


BOD, 5-Day (mg/l), collected at S-186
(Saluda River Below Greenwood Dam - 55.3 miles above Saluda Dam)
BOD, 5-Day (mg/l)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
J-68
J-69
J-70
J-71
J-72
J-73
J-74
J-75
J-76
J-77
J-78
J-79
J-80
J-81
J-82
J-83
J-84
J-85
J-86
J-87
J-88
J-89
J-90
J-91
J-92
J-93
J-94
J-95
J-96
J-97
J-98
Date

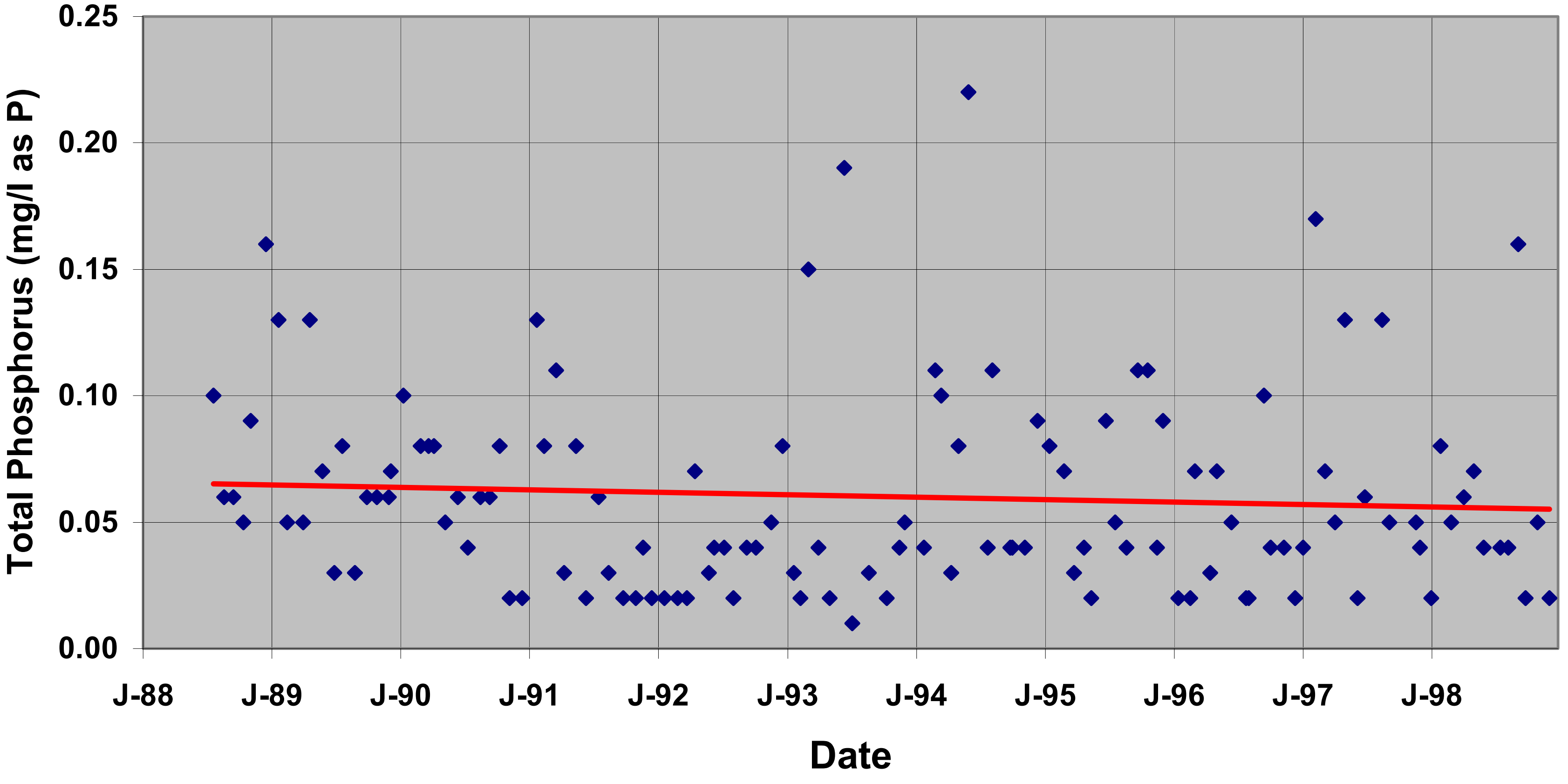
Nitrate + Nitrite as N (mg/l), collected at S-186
(Saluda River Below Greenwood Dam - 55.3 miles above Saluda Dam)

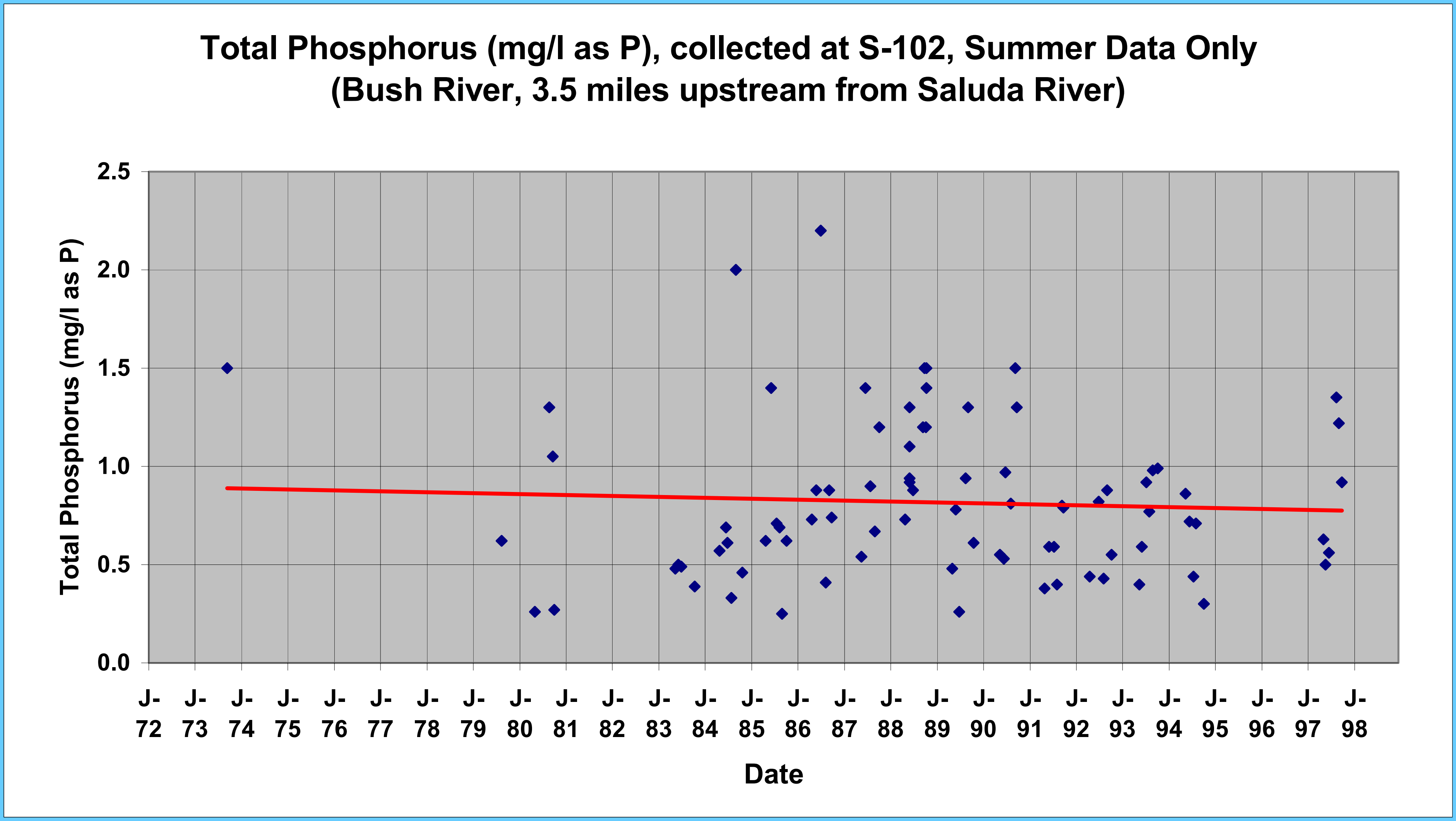


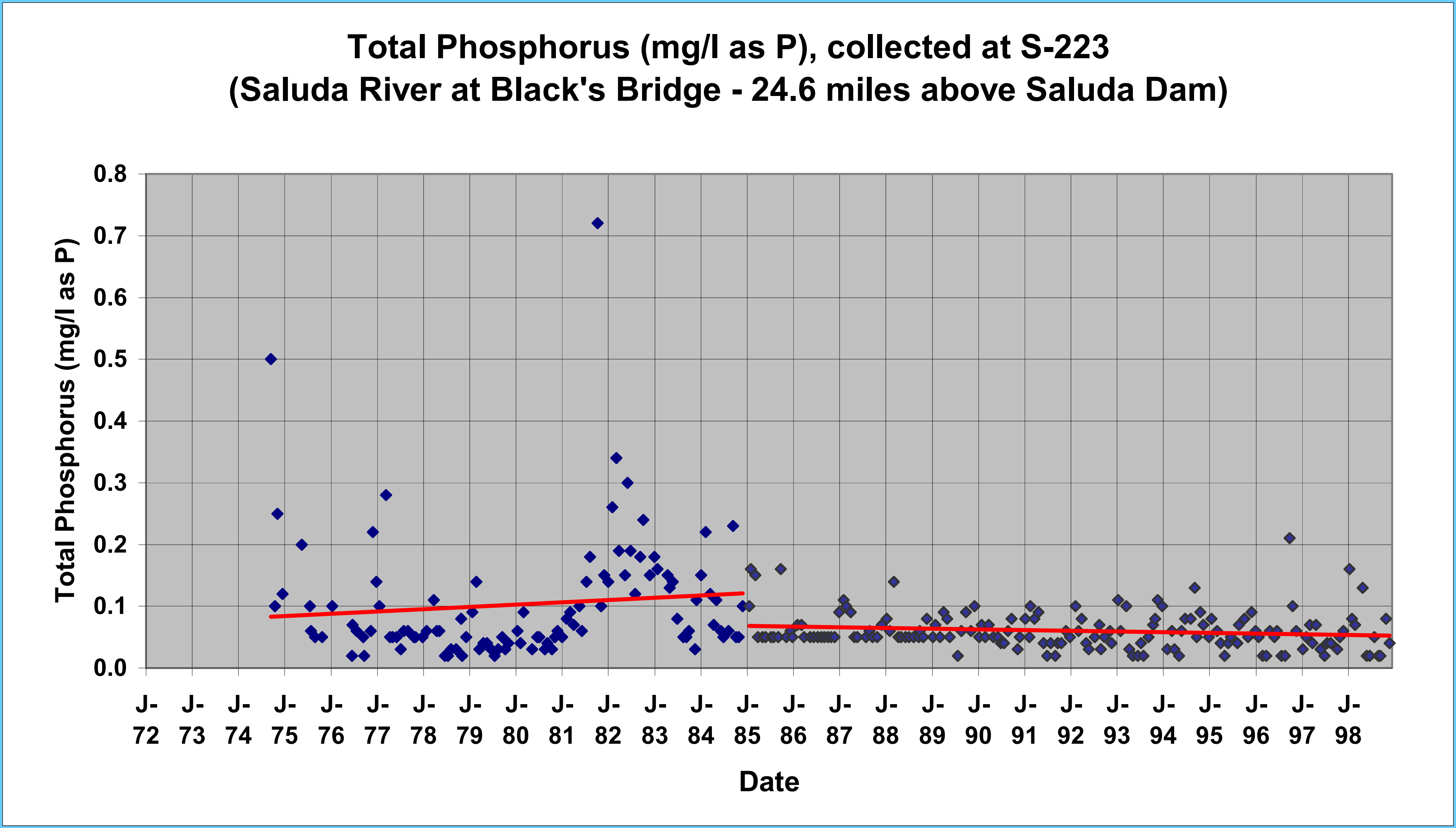


Total Phosphorus (mg/l as P), collected at S-093, Summer Data Only
(Ninety-Six Creek-approx. 2 miles upstream of Saluda R.)
Total Phosphorus (mg/l as P)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
J-72
J-73
J-74
J-75
J-76
J-77
J-78
J-79
J-80
J-81
J-82
J-83
J-84
J-85
J-86
J-87
J-88
J-89
J-90
J-91
J-92
J-93
J-94
J-95
J-96
J-97
J-98
Date

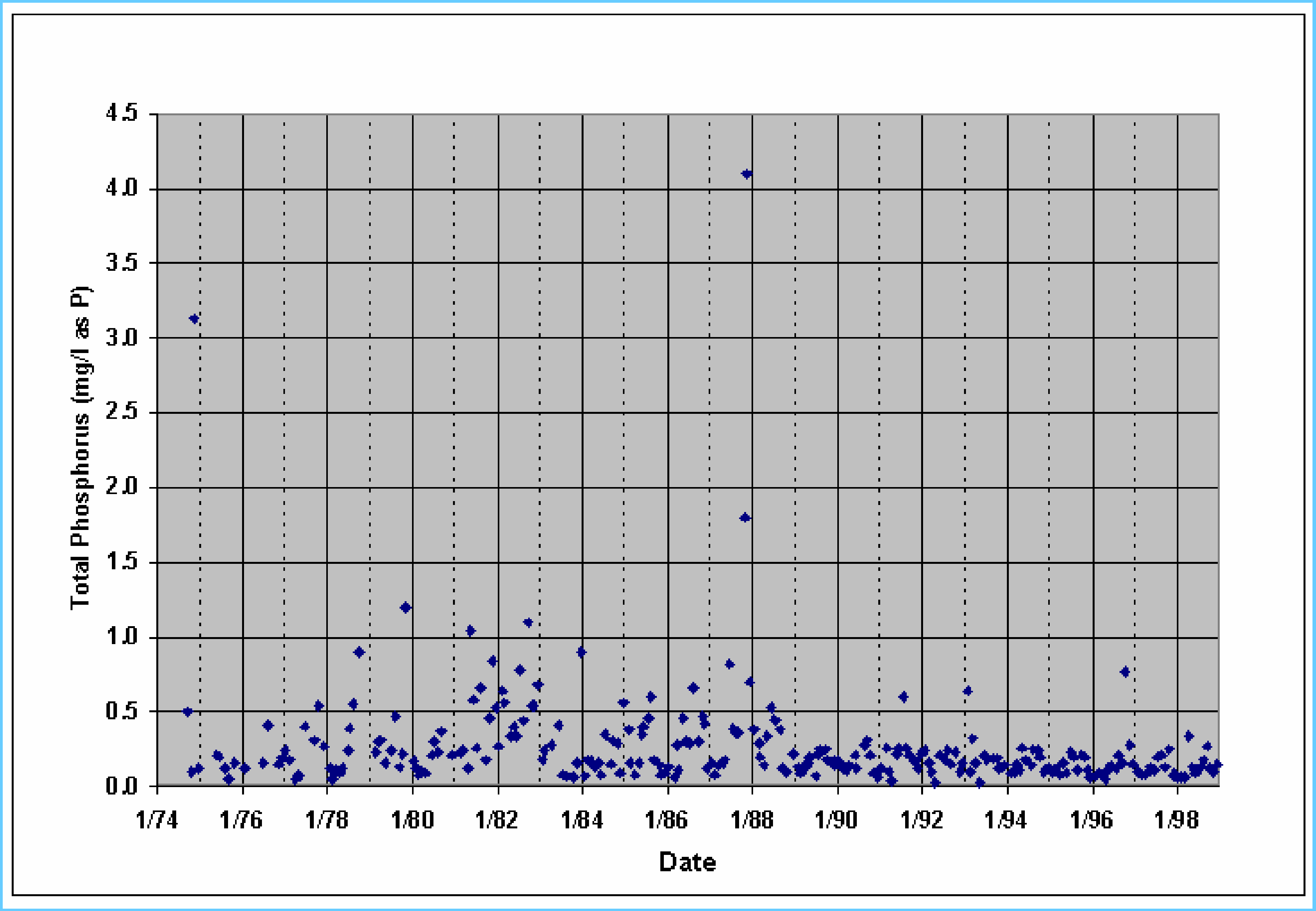
Total Phosphorus (mg/l as P), collected at S-295
(Saluda River - 48.4 miles above Saluda Dam)



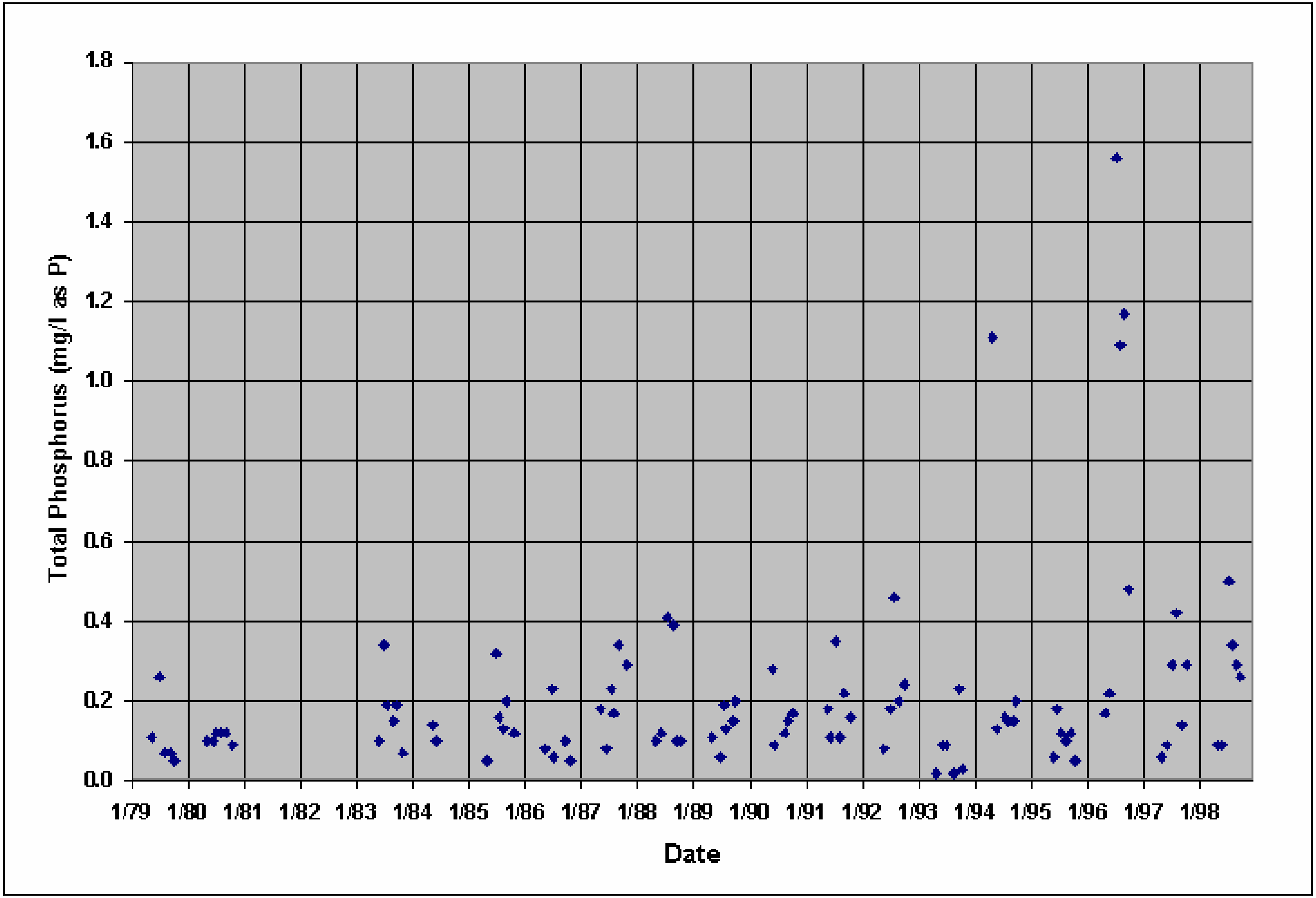

Total Phosphorus (mg/l as P), collected at S-102, Summer Data Only
(Bush River, 3.5 miles upstream from Saluda River)
2.5
2.0
1.5
1.0
0.5
0.0
Total Phosphorus (mg/l as P)
J-72
J-73
J-74
J-75
J-76
J-77
J-78
J-79
J-80
J-81
J-82
J-83
J-84
J-85
J-86
J-87
J-88
J-89
J-90
J-91
J-92
J-93
J-94
J-95
J-96
J-97
J-98
Date

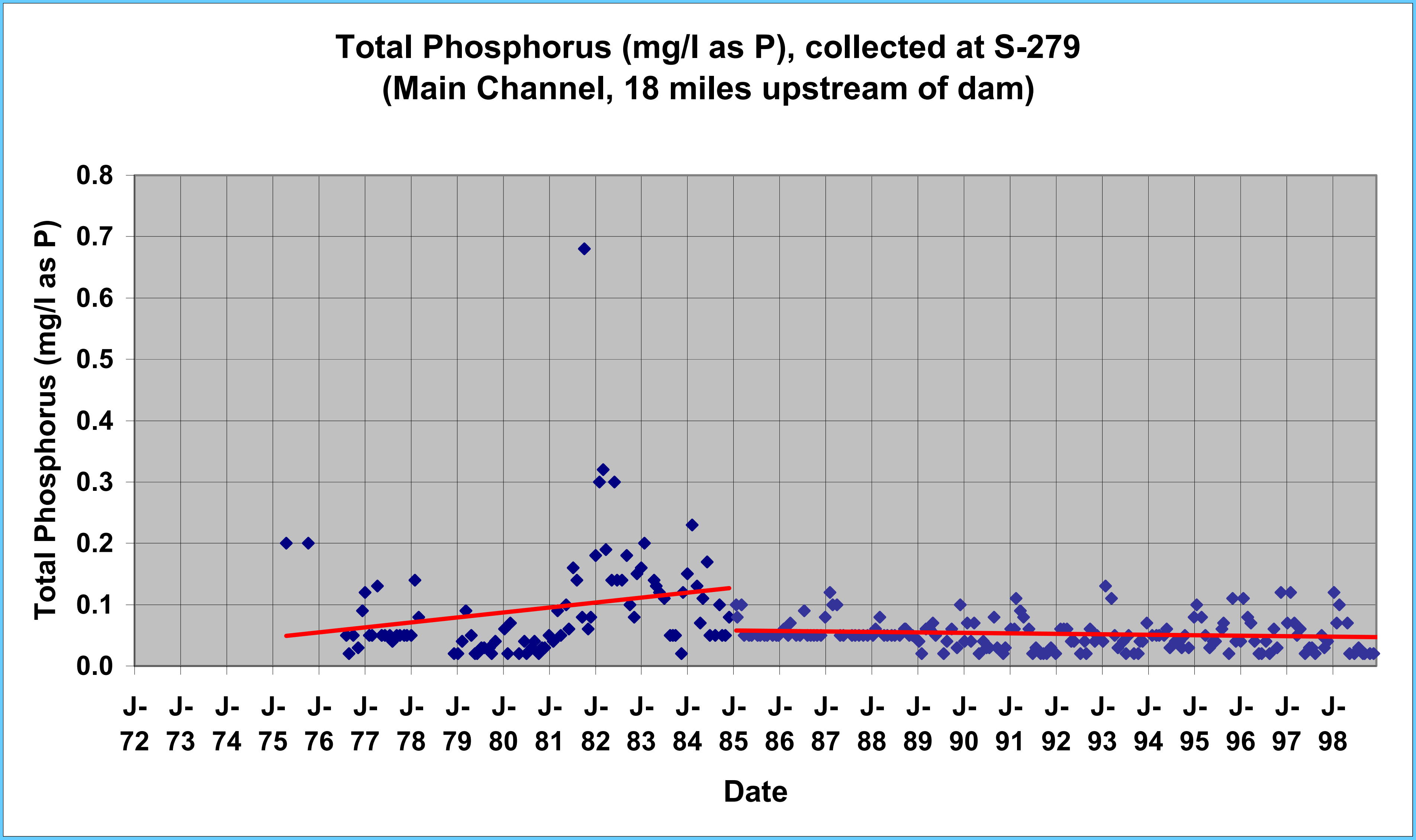

Total Phosphorus (mg/l as P), collected at S-223
(Saluda River at Black's Bridge - 24.6 miles above Saluda Dam)
Total Phosphorus (mg/l as P)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
J-72 J-73 J-74 J-75 J-76 J-77 J-78 J-79 J-80 J-81 J-82 J-83 J-84 J-85 J-86 J-87 J-88 J-89 J-90 J-91 J-92 J-93 J-94 J-95 J-96 J-97 J-98
Date

TP Measured in the Little Saluda River (SCDHEC Station S-123)

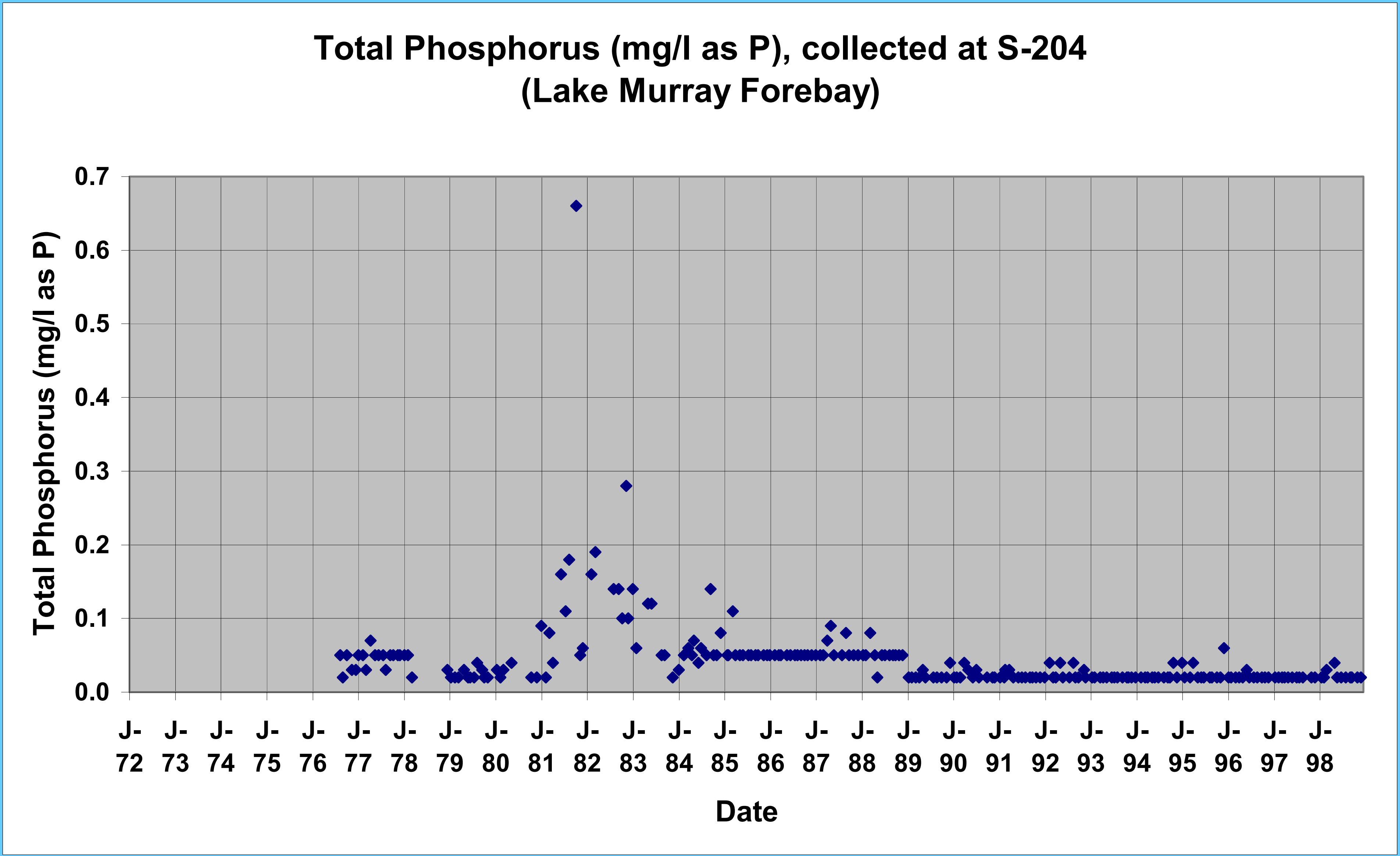


TP Measured in Clouds Creek
(SCDHEC Station S-255)



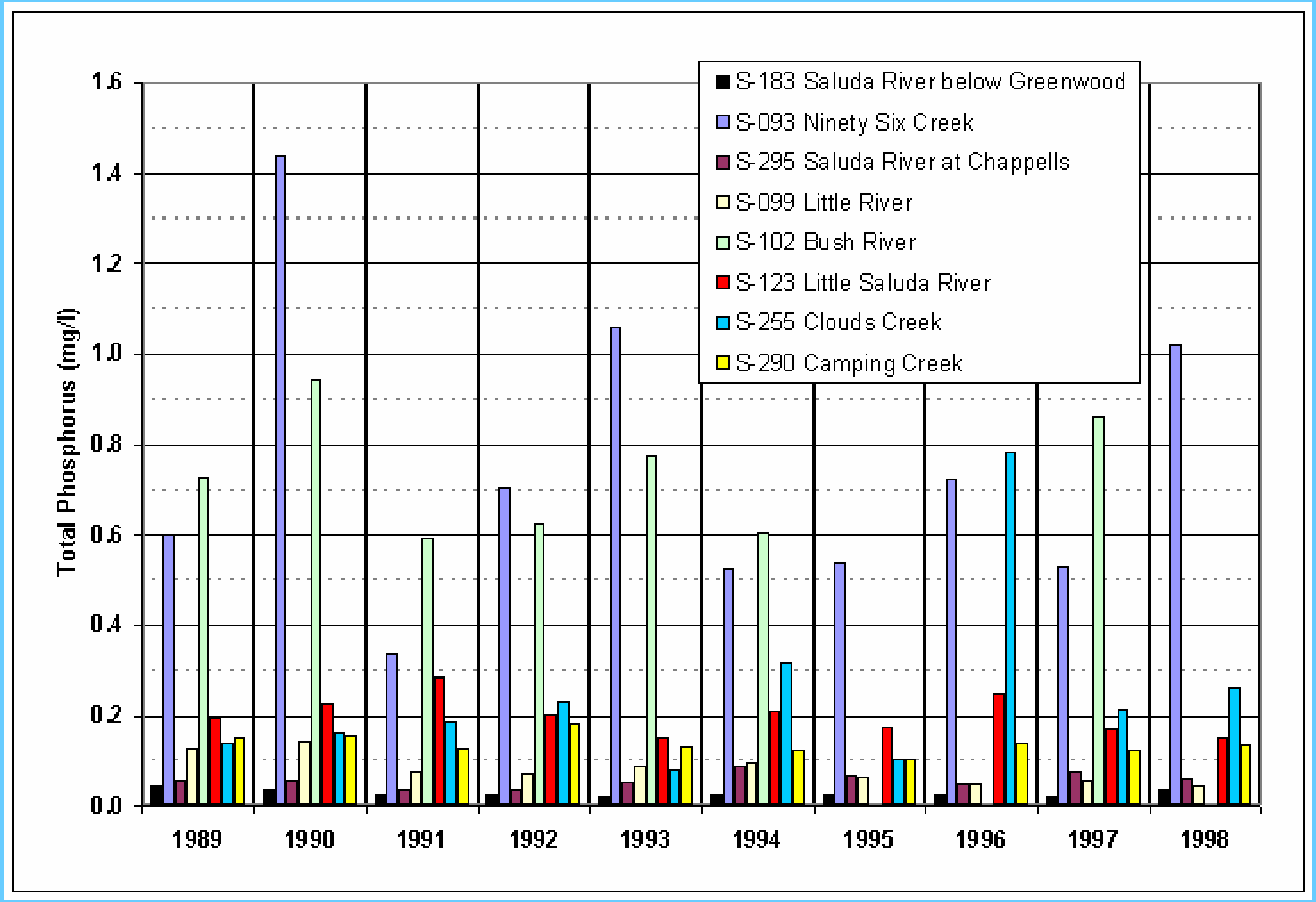


Total Phosphorus (mg/l as P), collected at S-279
(Main Channel, 18 miles upstream of dam)
Total Phosphorus (mg/l as P)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
J-72
J-73
J-74
J-75
J-76
J-77
J-78
J-79
J-80
J-81
J-82
J-83
J-84
J-85
J-86
J-87
J-88
J-89
J-90
J-91
J-92
J-93
J-94
J-95
J-96
J-97
J-98
Date



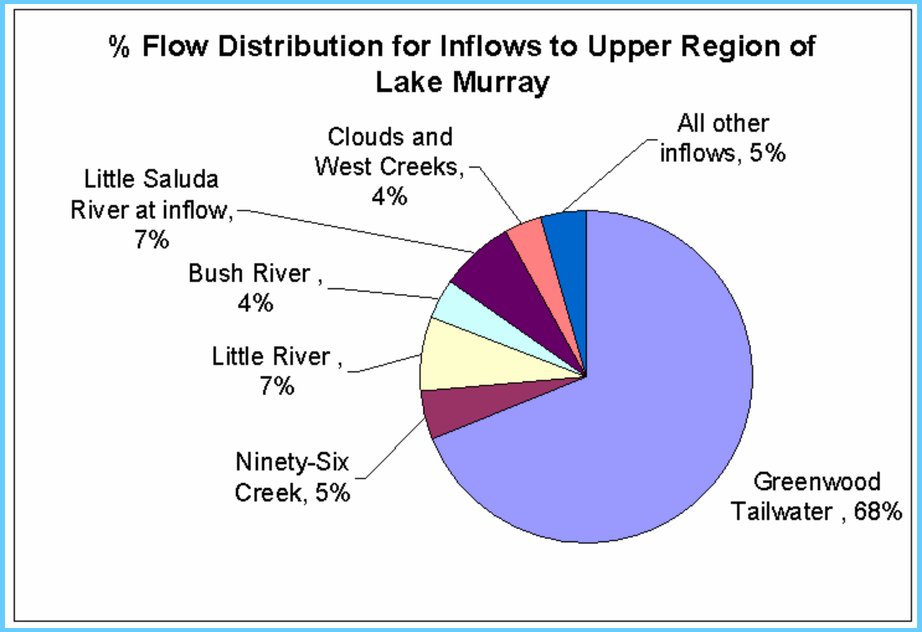
Total Phosphorus (mg/l as P), collected at S-204
(Lake Murray Forebay)
Total Phosphorus (mg/l as P)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
J-72
J-73
J-74
J-75
J-76
J-77
J-78
J-79
J-80
J-81
J-82
J-83
J-84
J-85
J-86
J-87
J-88
J-89
J-90
J-91
J-92
J-93
J-94
J-95
J-96
J-97
J-98
Date

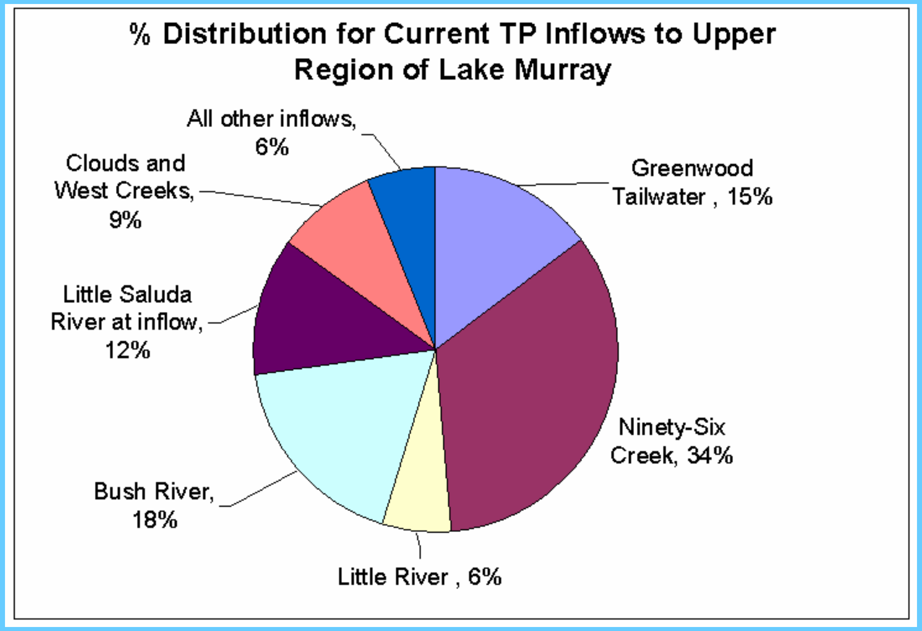
May-October Means of TP Measured at SCDHEC Stations Located in the Inflows to Lake Murray



	Mean Streamflow (cfs)	Percent of Total Flow
Saluda Hydro	2683	100
Lake Murray Direct Inflows		
Saluda River at inflow	2098	78.2
Bush River	92	3.4
Little Saluda River	180	6.7
Clouds and West Creek	89	3.3
Beaver Dam Creek	26	1.0
Camping Creek	31	1.2
Hollow and Horse Creeks	39	39
all other local drainage	129	4.8
Between inflow and Saluda Dam	585	21.8
Upstream Inflows		
96 Creek	115	
Little River	182	

Inflow and Phosphorus Loads to Upper Regions of Lake Murray





Percent contributions to the upper regions of Lake Murray of total phosphorous loadings and mean stream flows

Lake Murray Tributary	Mean Streamflow %	Phosphorus Load %	Ratio of Phosphorus Load to Flow
Bush River	4	18	4.5
Little Saluda River	7	12	1.7
Clouds and West Creeks	4	9	2.2
Ninety-Six Creek	5	34	6.8
Little River	7	6	0.9
Saluda River	68	15	0.2
All other flows	5	6	1.2

Summary of TP, chlorophyll *a*, and secchi depth conditions at various locations in the inflows and Lake Murray – Includes DHEC data only

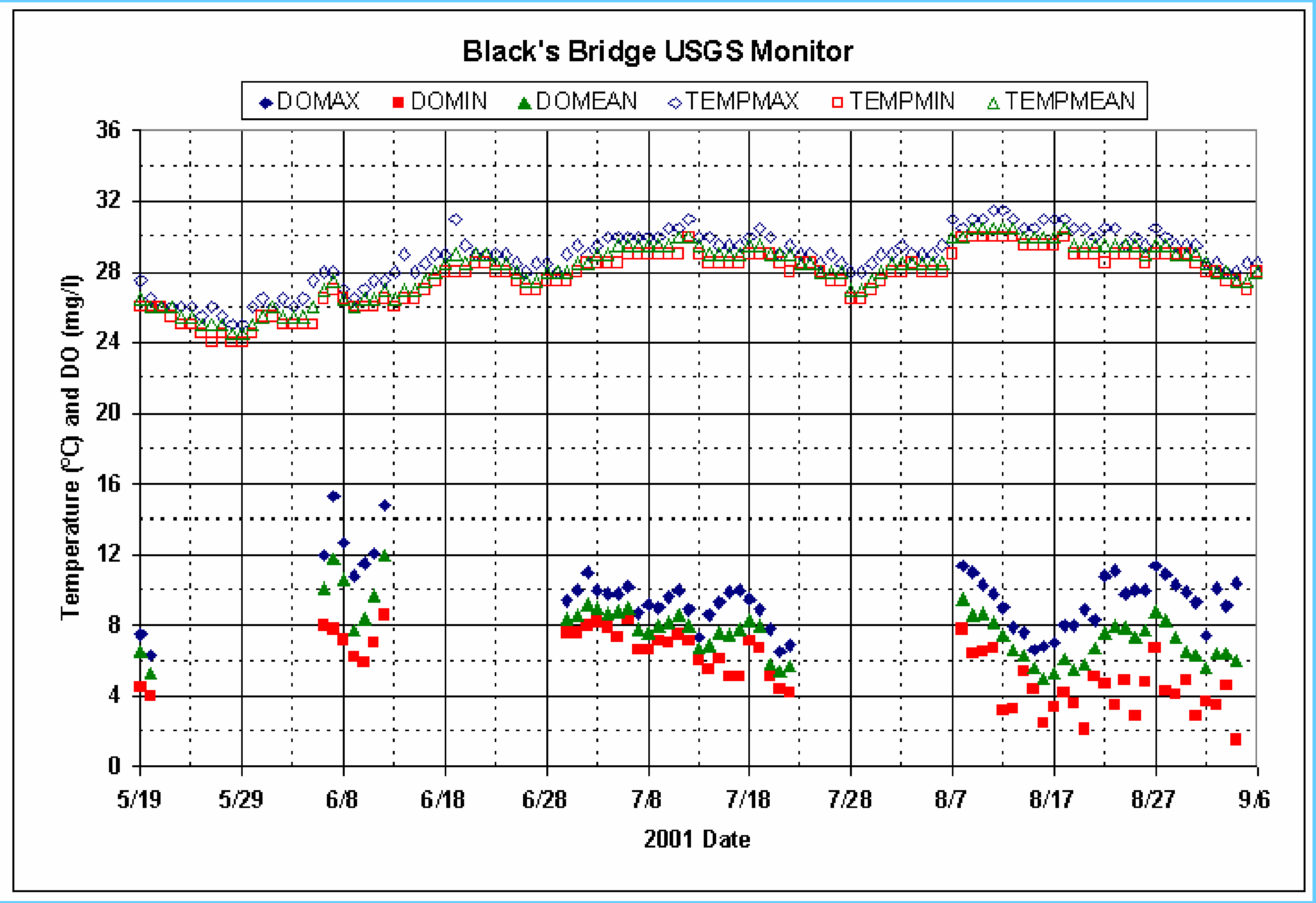
	Total Phosphorus (mg/l)	Chlorophyll *a* (µg/l)	Secchi depth (m)
Greenwood Dam (S-186)	**0.022**	**No data**	**No data**
Ninety-Six Creek (S-093)	**0.74**	**No data**	**No data**
Little River (S-099)	**0.08**	**No data**	**No data**
Bush River Embayment (S-309)	**0.12**	**28.6**	**0.7**
Clouds Creek (S-255)	**0.25**	**No data**	**No data**
Blacks Bridge (S-223)	**0.06**	**14.77**	**1.01**
Rocky Creek (S-279)	**0.05**	**11.9**	**1.4**
Dreher Island (S-280)	**0.03**	**6.5**	**2.0**
4.2 Miles from Saluda Dam (S-273)	**0.02**	**5.5**	**2.8**
Ballentine Embayment (S-274)	**0.02**	**5.7**	**2.4**
Forebay (S-204)	**0.02**	**7.3**	**2.7**

Summary of DO conditions at 14 reservoirs with residence times similar to Lake Murray and various inflow phosphorus conditions

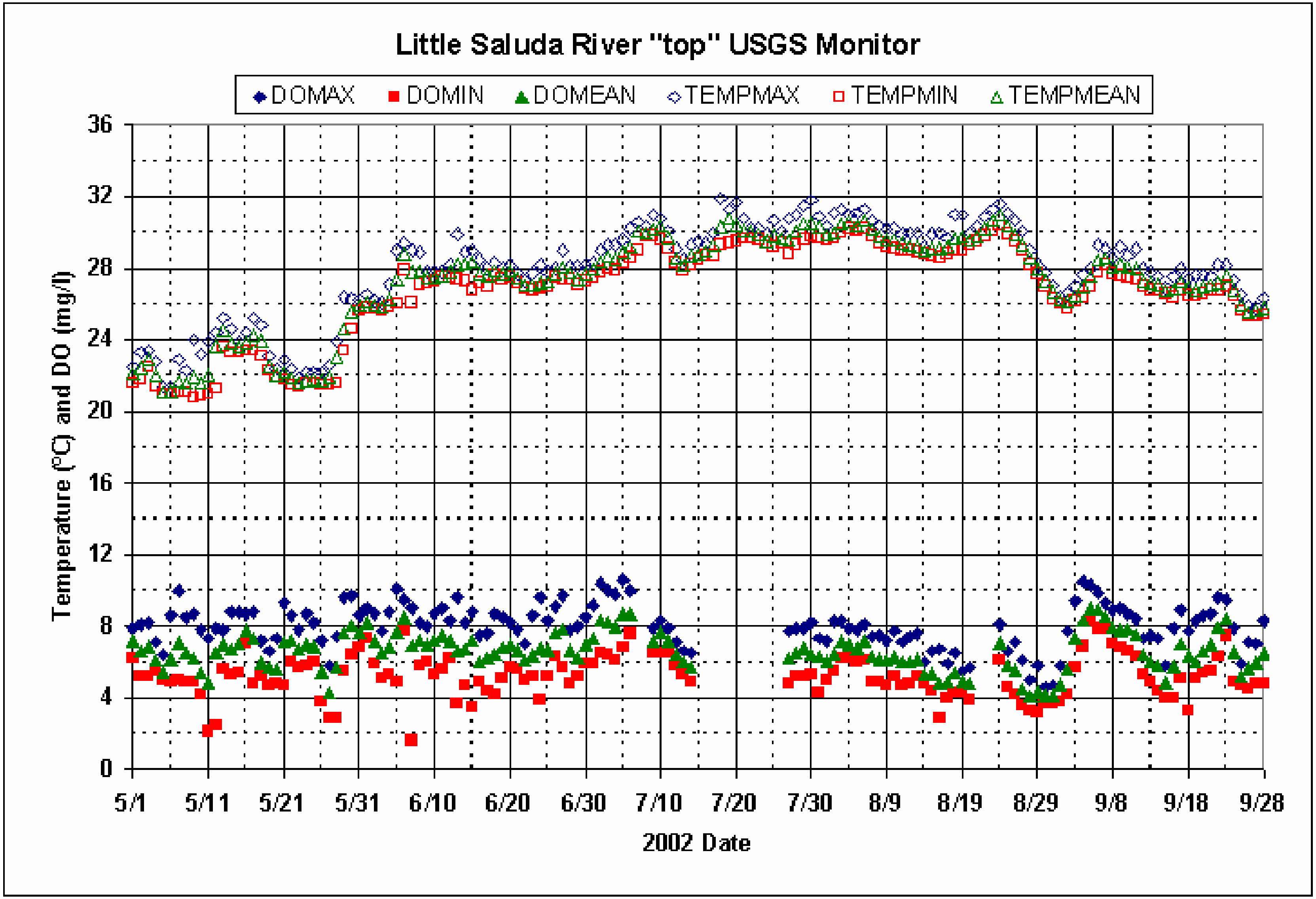
Relationship Between Low DO and Phosphorus for Hydropower Reservoirs with Residence Times of About 400 Days

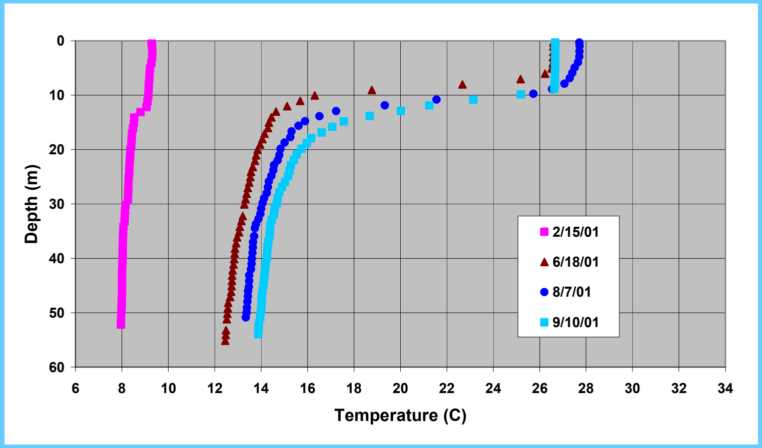
Name of dam	River	Max. depth, ft	Normal storage, ac-ft	Surf. area, ac	Drain. area, sq mi	Mean flow, cfs	Resi-dence Time	Zero DO in releases, annually?	COMMENTS	
BEAVER, AR	White	218	1,652,000	28,220	1186	1898	439	No	Low TP (0.02-0.04), but impacted by Fayettville	
BROKEN BOW, OK	Mountain Fork	175	920,000	14,200	754	1350	341	No	Low TP (0.03-0.04)	
BURTON, GA	Tallulah		108,000	2,775	118	142	385	No	Low TP (~ < 0.04)	
DEGRAY, AR	Caddo	171	654,700	13,400	453	725	455	No	Low TP (~ 0.02)	
HARTWELL, GA/SC	Savannah	185	2,550,000	55,950	2088	3670	347	Yes	low metalimnion DO in Seneca Arm, but not Tugaloo Arm; probably due to TP	TP load could be 80% of load to Lake Murray, and Hartwell has 56 days less residence time
LEWIS SMITH, AL	Sipsey Fork/ Warrior R	264	1,390,000	21,200	944	1510	464	No	Low TP (0.02-0.03)	
NANTAHALA, NC	Nantahala R	210	138,000	1,605	108	173	399	No	Low TP (~ 0.01)	
NARROWS, AR	Little Missouri	132	279,700	7,200	237	379	372	No	Low TP (0.02-0.04)	
PHILPOTT, VA	Smith	180	166,200	2,880	212	254	327	No	Low TP (0.02-0.03)	
SALUDA, SC	Saluda	170	2,118,000	50,000	2420	2683	398	Yes	High TP (0.08-0.1)	
SOUTH HOLSTON, TN	South Holston	240	657,500	7,580	703	980	338	No	Low TP (0.03), but low DO in metalimnion, probably due to elevated orthoP in one inflow	
TENKILLER, OK	Illinois	187	654,100	12,900	1610	805	410	probably	zero DO on bottom of lake; < 1 ppm in releases in Aug '95	receives high nutrients: ~ 0.08 TP; 12 TMDL sites in watershed for org/low DO
THORPE, NC	West Fork Tuckasegee	110	71,000	1,462	37	100	355	No	Low TP (~ 0.01)	
WATAUGA, TN	Watauga	309	568,700	6,430	468	710	404	No	Low TP (0.03)	
	Total projects where releases are greater than zero							**11**	**79** %	
	Total projects where releases have zero DO annually							**3**	**21**	
	Total projects							**14**	**100** %	

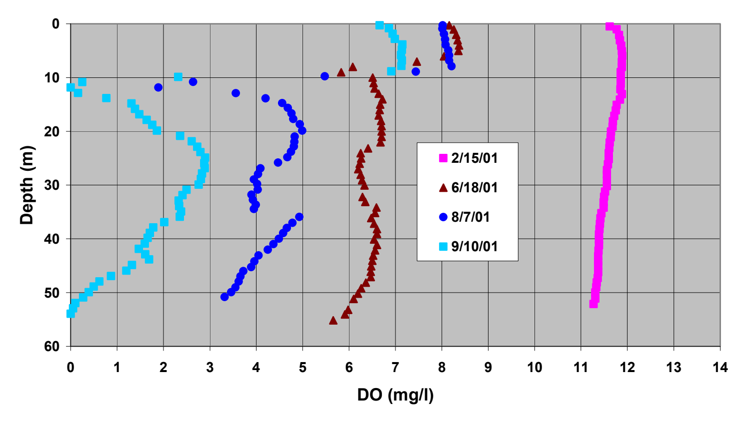
Daily DO and Temperature Data Collected at Hwy 391 Bridge

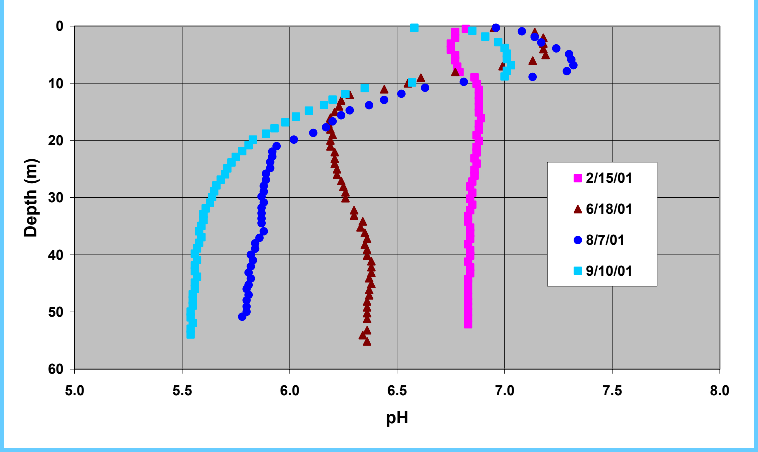


Daily DO and Temperature Data Collected on the Little Saluda River



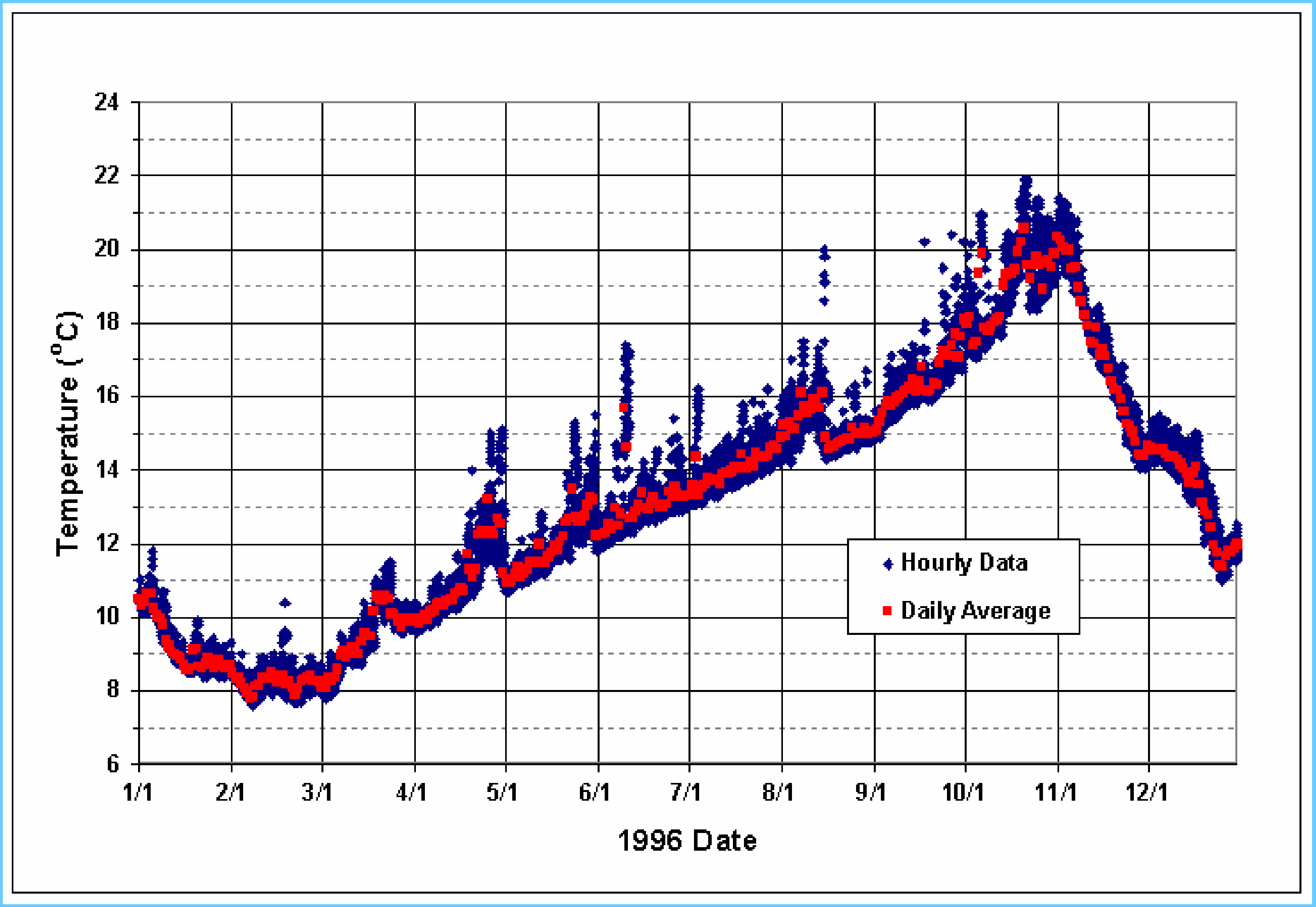




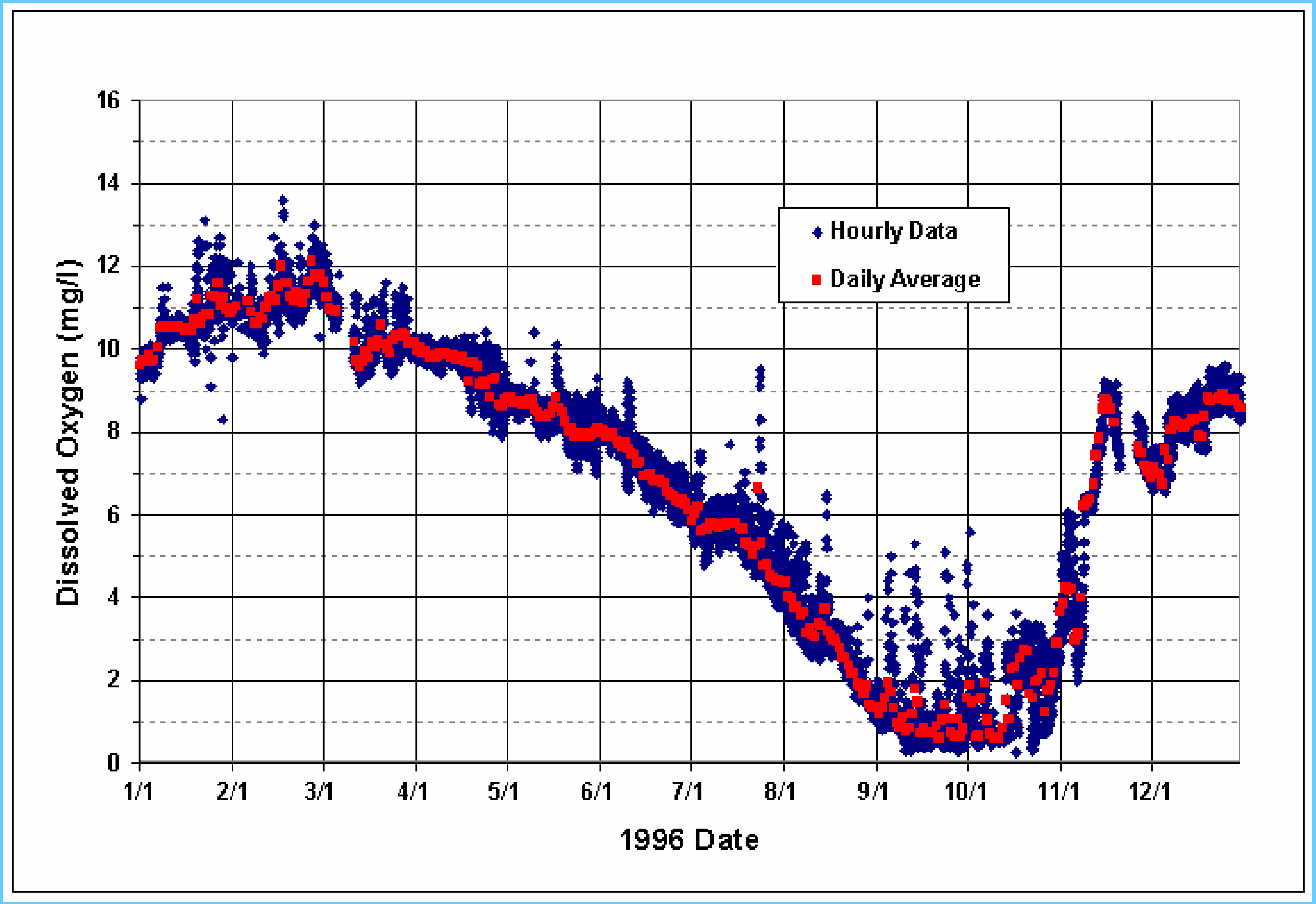


Temperature, DO, and pH profiles from 2001 showing the correlation between pH and low DO

Temperature Measured in the Saluda Hydro Tailrace in 1996



DO Measured in the Saluda Hydro Tailrace in 1996



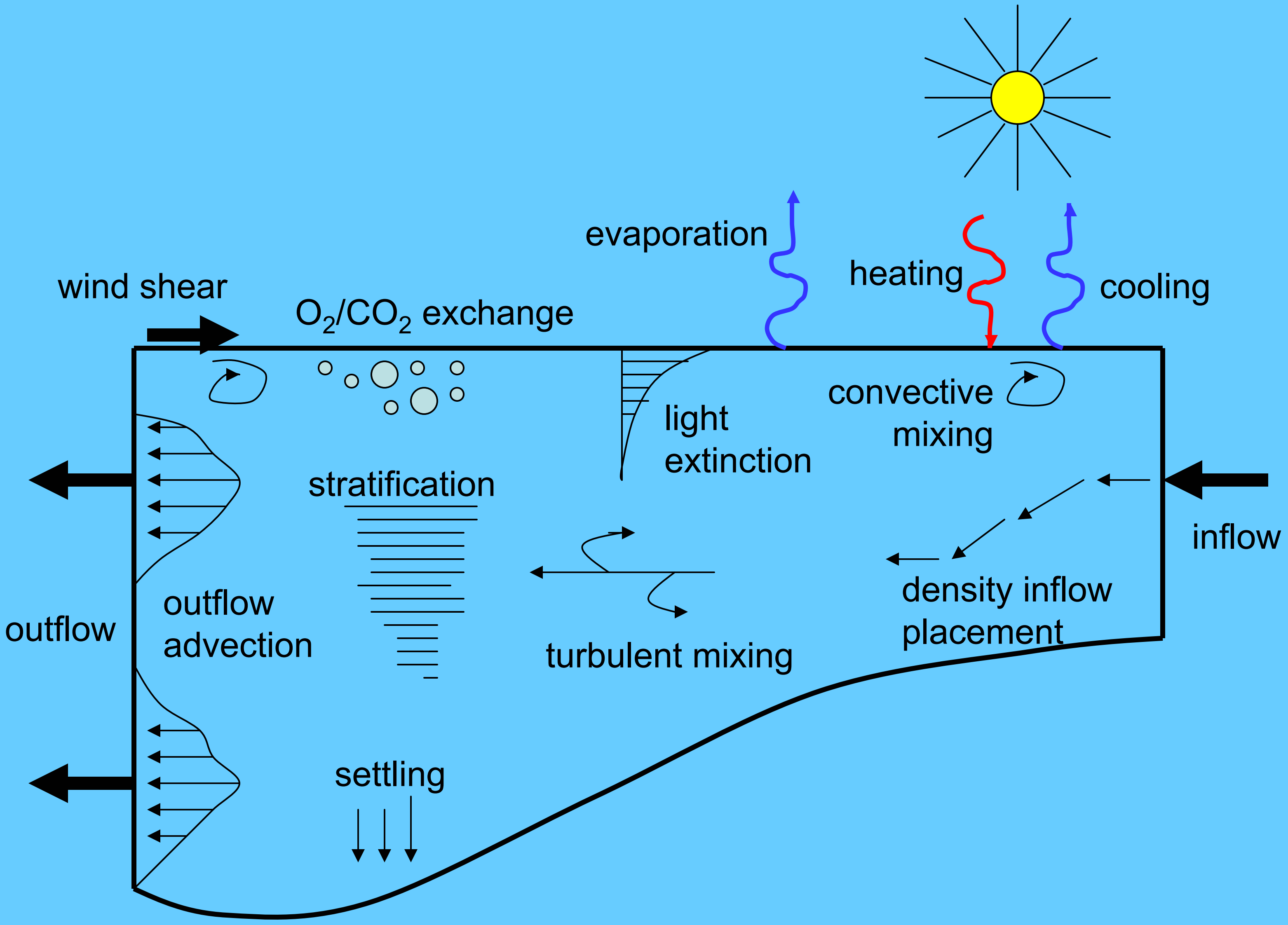
Summary of Key Issues at the Time of the 2001 Assessment and When the CE-QUAL-W2 Model Was Developed

- low DO in the releases from Saluda Hydro,
- restrictions for operating Unit 5 due to entrainment of blue-back herring,
- eutrophication in the upper regions of Lake Murray,
- DO less than the State standard in the inflow regions of the lake,
- reduced striped bass habitat in the lake due to low DO in the regions of the lake where their temperature preferences occur, and
- low pH in Lower Saluda River (LSR)
- Fecal coliforms were identified as an issue on several inflows to Lake Murray, but not on the lake itself
- Copper was identified as an issue, but this was State-wide

Lake thermal stratification

- Temperature affects the density of water, so lakes stratify—warmer water floats on top—most lakes stratify 5 to 10 months
- Significantly affected by meteorological conditions, inflow temperatures, residence time and outlet level, cooling water use
- Nominal residence times range from 1 day to 2 years
- Outlet levels range from the surface to the bottom
- Inflow temperature can be natural or affected by upstream reservoir releases and thermal discharges
- Temperature affects almost all other water quality issues

Physical processes



Focus: DO dynamics in <u>water</u>

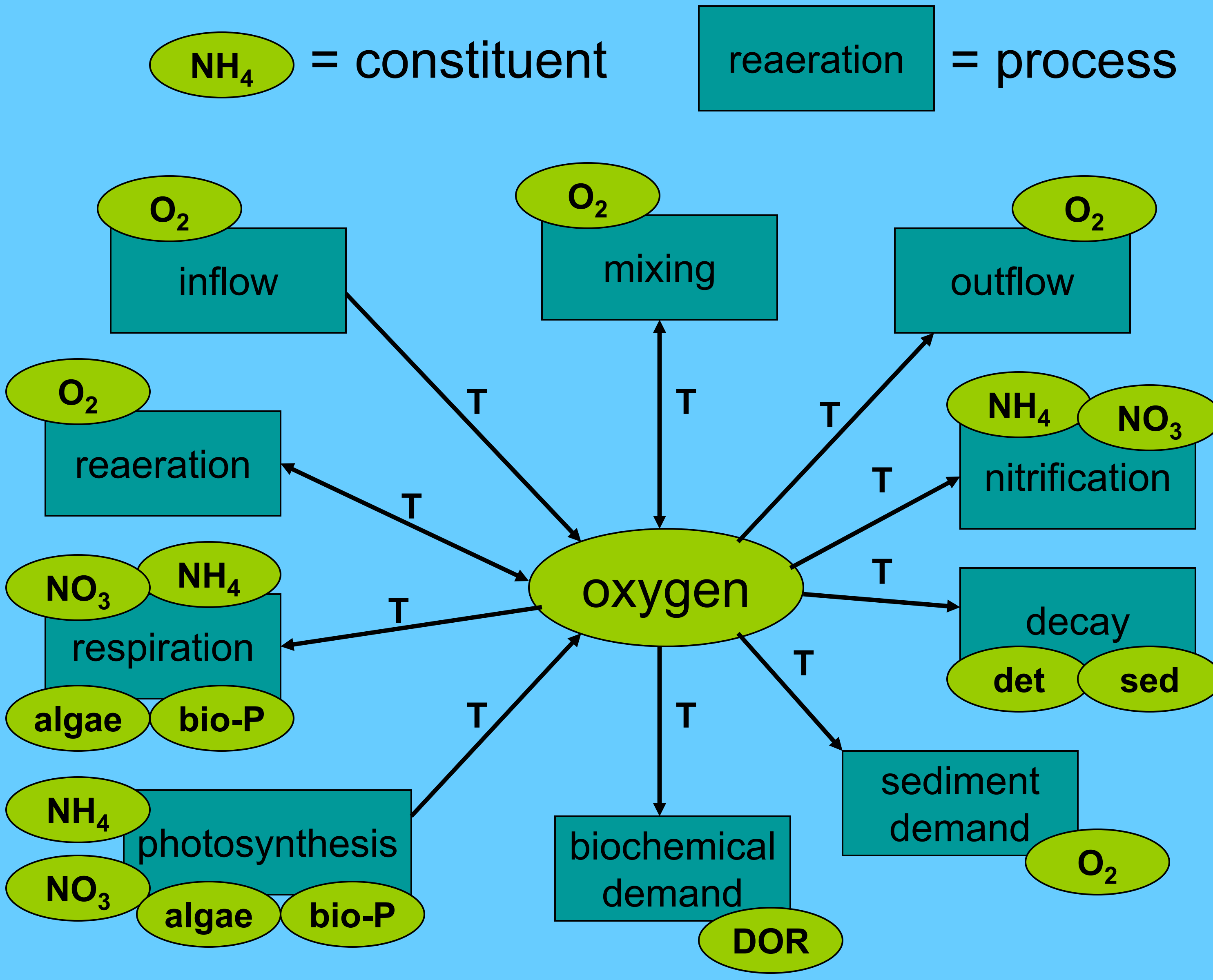
DO in clean water is often near saturation with respect to the atmosphere; however, many other "sources and sinks" affect DO:

- Plant photosynthesis produces DO
- DO is consumed by plant respiration and decomposition of organic matter in wastewater discharges, sediments, and dead plants/algae
- DO is also consumed in the oxidation of ammonia, sulfide, dissolved organic matter, and reduced iron
- DO can be lost to the atmosphere when it is supersaturated in water

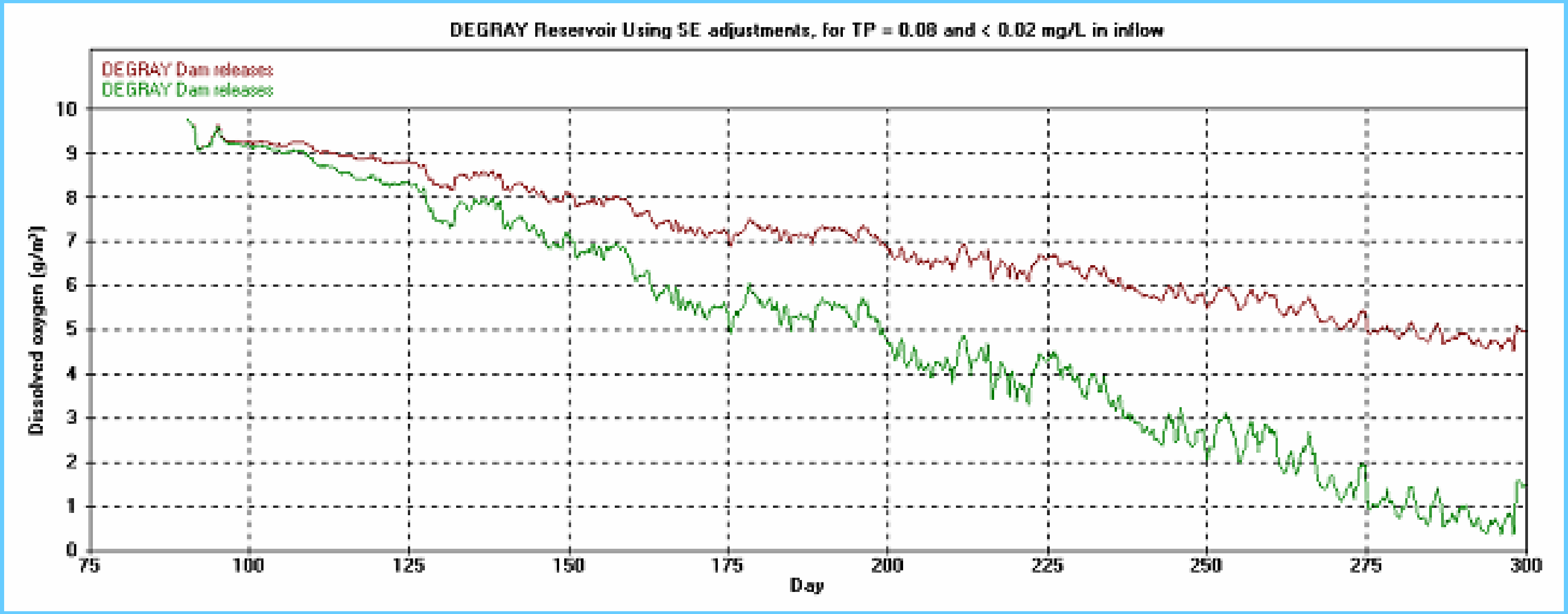
Focus: DO dynamics in reservoirs

- Thermal stratification affects contact of cooler water with the atmosphere and solar radiation; therefore, deeper water usually has lower DO
- Water currents affect the distribution of DO in reservoirs
- Algae grow in the surface layer and usually produce DO; then, they die and add organic matter to the deeper water where it is decomposed and DO is consumed
- Sediment oxygen demand also consumes DO
- Inflowing organic matter also decomposes and consumes DO
- Sediment releases of ammonia, sulfide, methane, and iron can also cause DO consumption
- Inflow DO
- Residence time, outlet levels/withdrawal zone, and water depth are significant variables that affect DO dynamics

Highly coupled constituents



CE-QUAL-W2 model results using the DeGray model to see how DO in the releases responds to higher levels of TP—the upper curve is for low TP levels

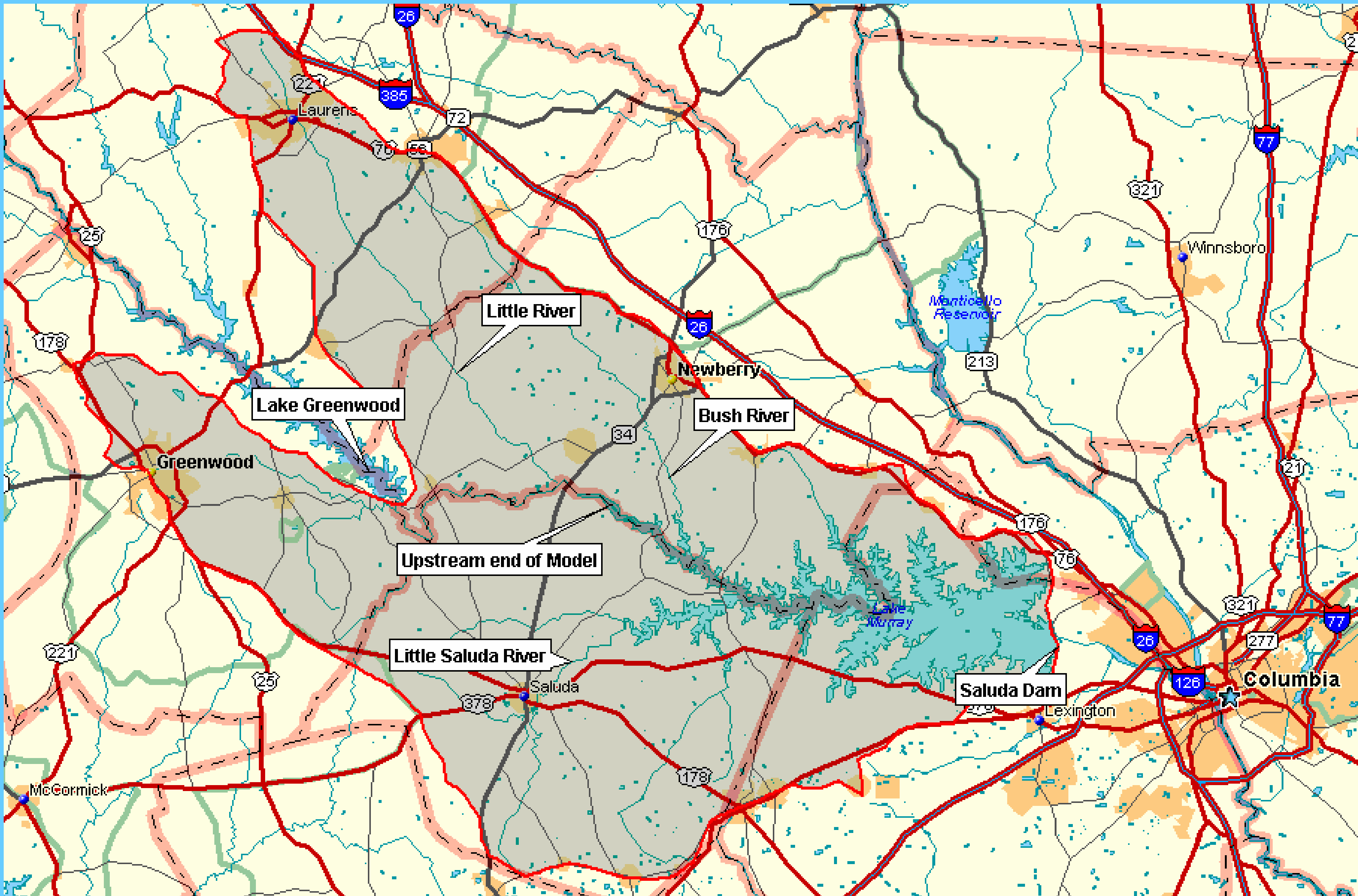


Issues Addressed by Focusing on Phosphorus and Using the CE-QUAL-W2 Two-Dimensional Water Quality Model

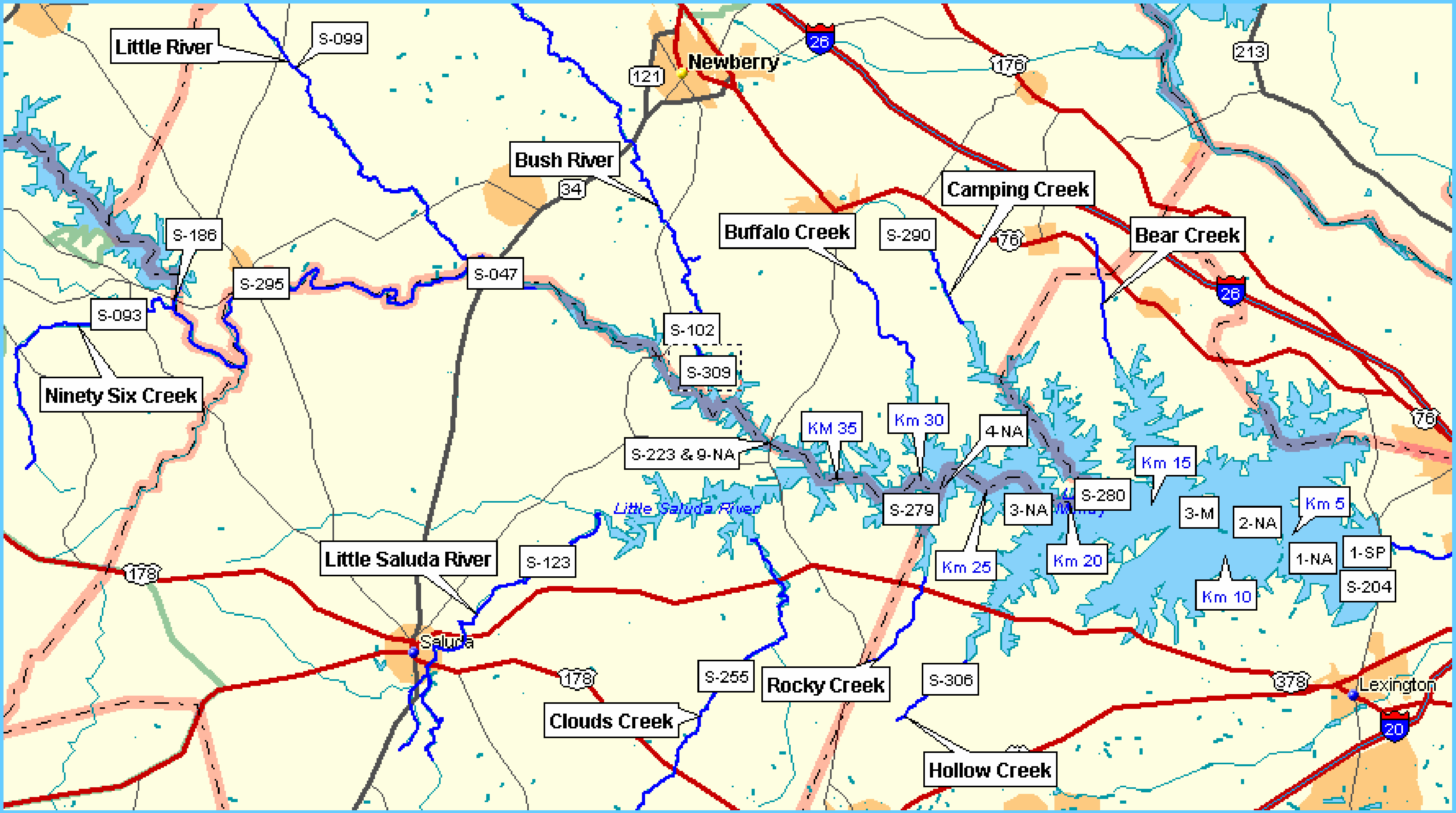
- low DO in the releases from Saluda Hydro,
- restrictions for operating Unit 5 due to entrainment of blue-back herring,
- eutrophication in the upper regions of Lake Murray,
- DO less than the State standard in the inflow regions of the lake,
- reduced striped bass habitat in the lake due to low DO in the regions of the lake where their temperature preferences occur, and
- low pH in Lower Saluda River (LSR)

Temperature, DO, Age and Chlorophyll a Animation

Lake Murray Watershed



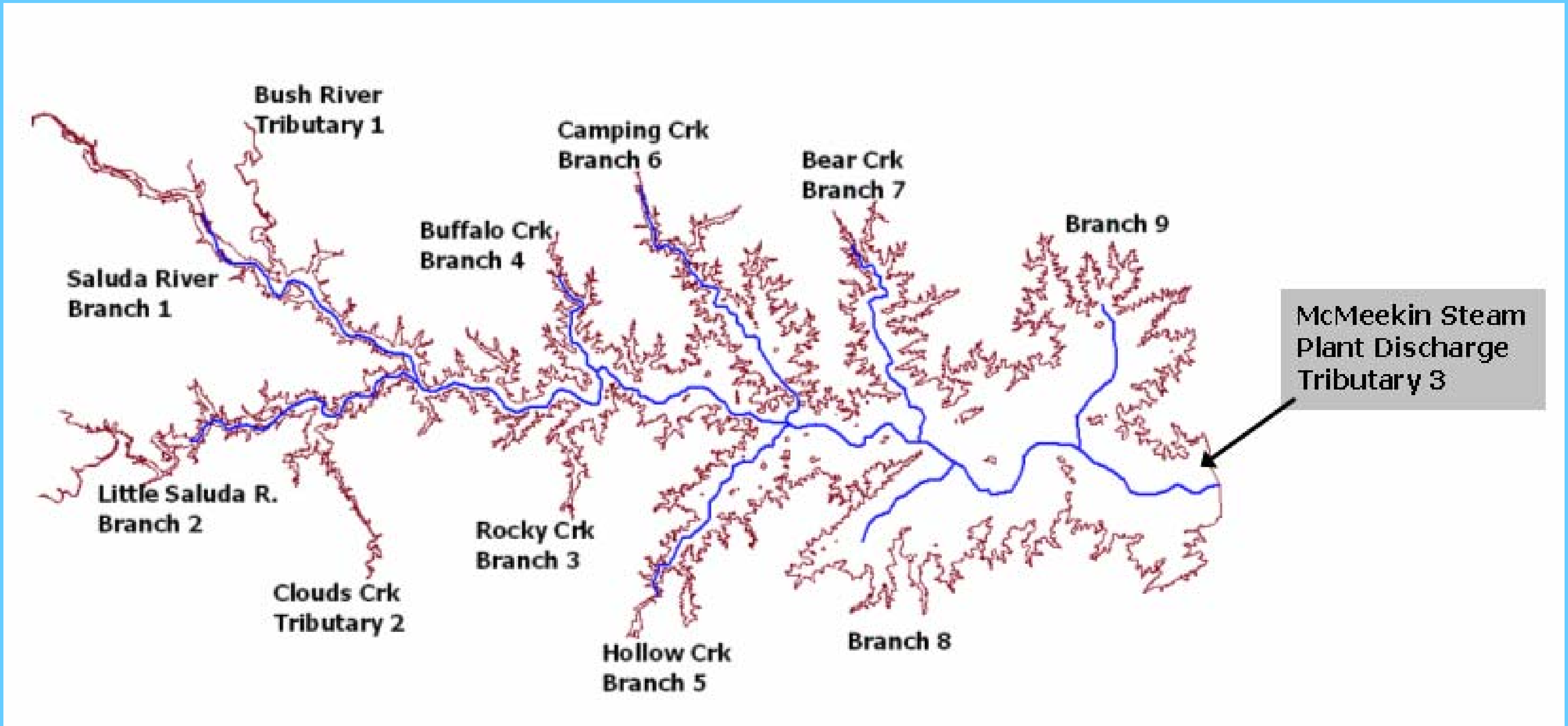
Primary SCDHEC and SCE&G Monitoring Stations used for Lake Murray Water Quality Analyses



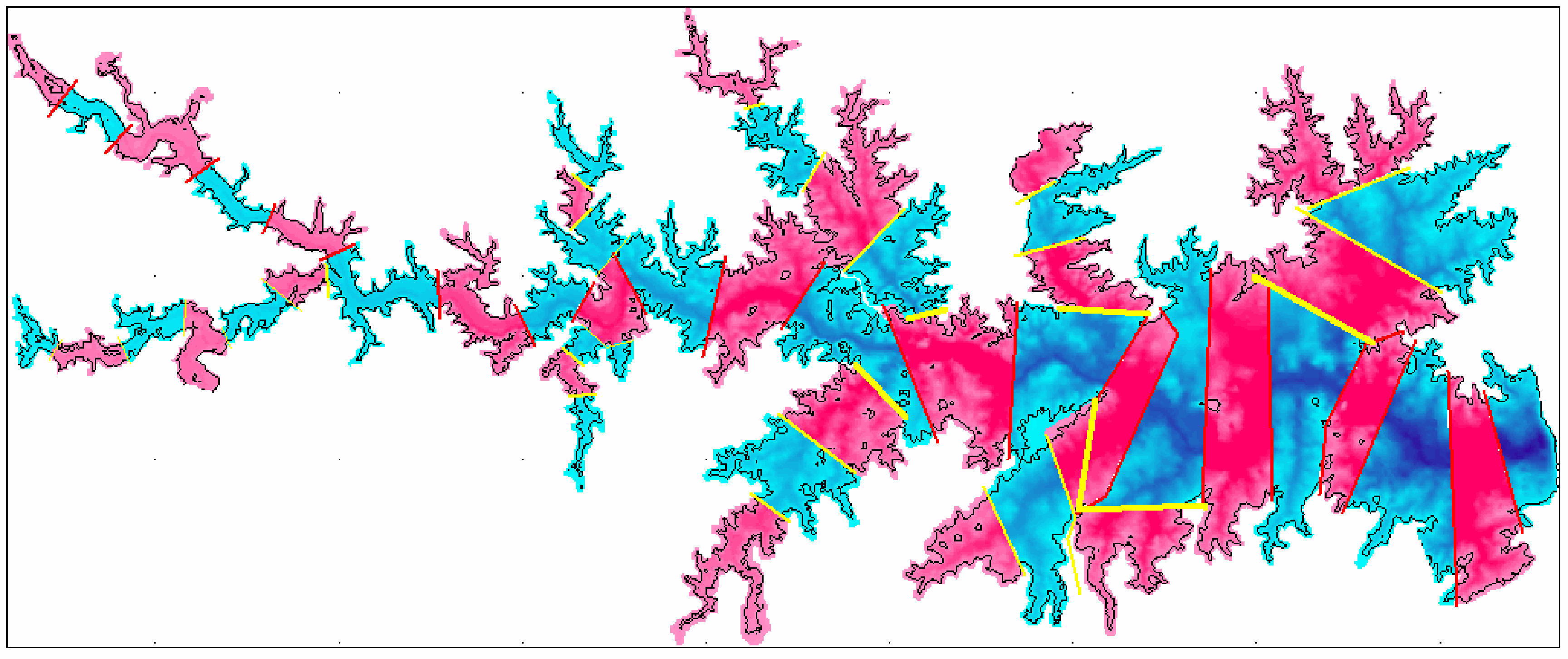
Physical Characteristics of Lake Murray

	U.S. Customary System	Metric System
Maximum depth	175 feet	53.3 m
Total lake volume	2,317,000 ac-ft	2,636 hm^3
Average Annual Flow	2778 cfs	78.7 cms
Nominal Residence Time	417 days	417 days
Depth of outlets, Units 1-4	175 feet	53 m
Depth of outlets, Unit 5	110 feet	33.5 m
Flow Capacity - Units 1-4	3000 cfs	85 cms
Flow Capacity, Unit 5	6000 cfs	170 cms

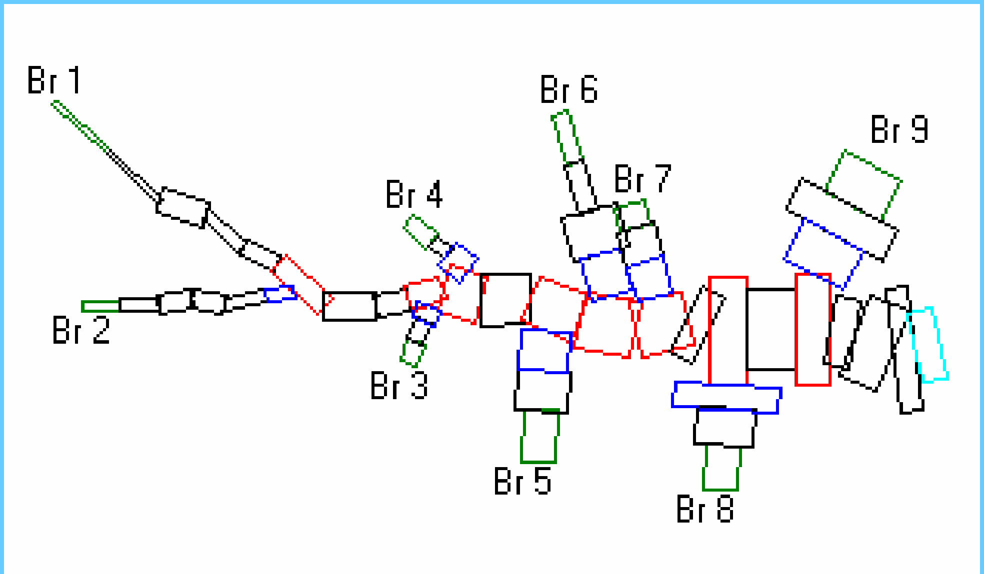
Plan view of Lake Murray with all Branches and Tributaries that are Included in the Model

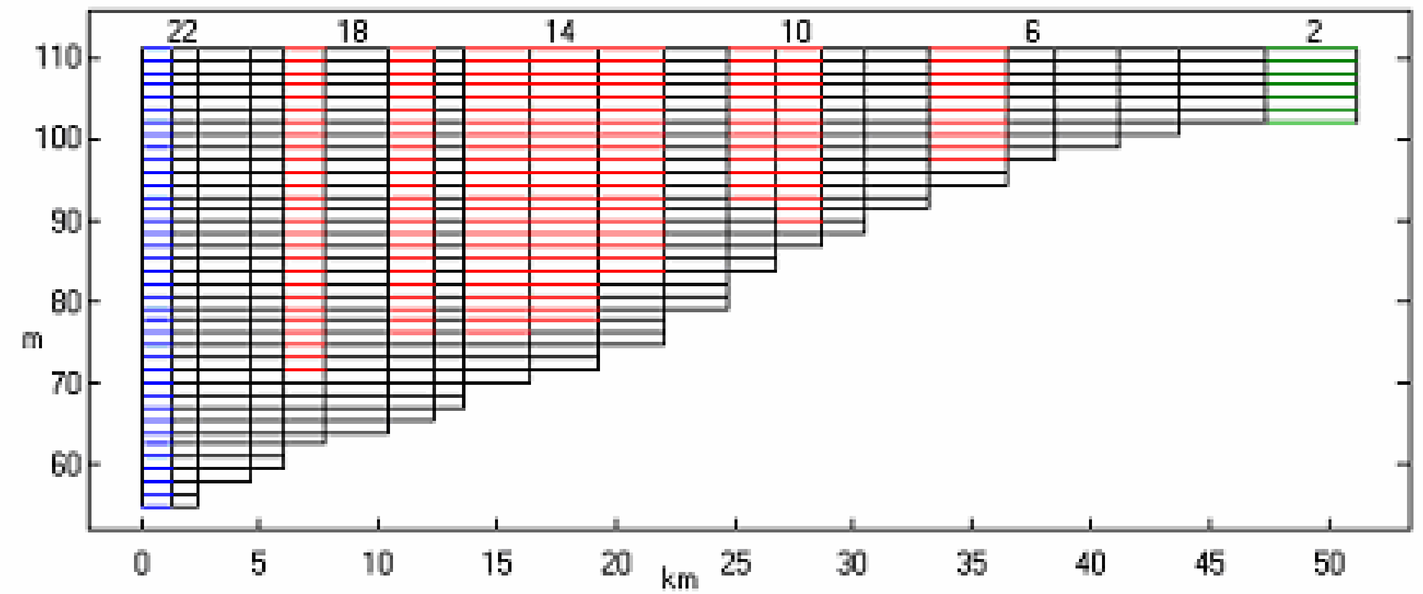


Plan View of Lake Murray Showing CE-QUAL-W2 Segmentation

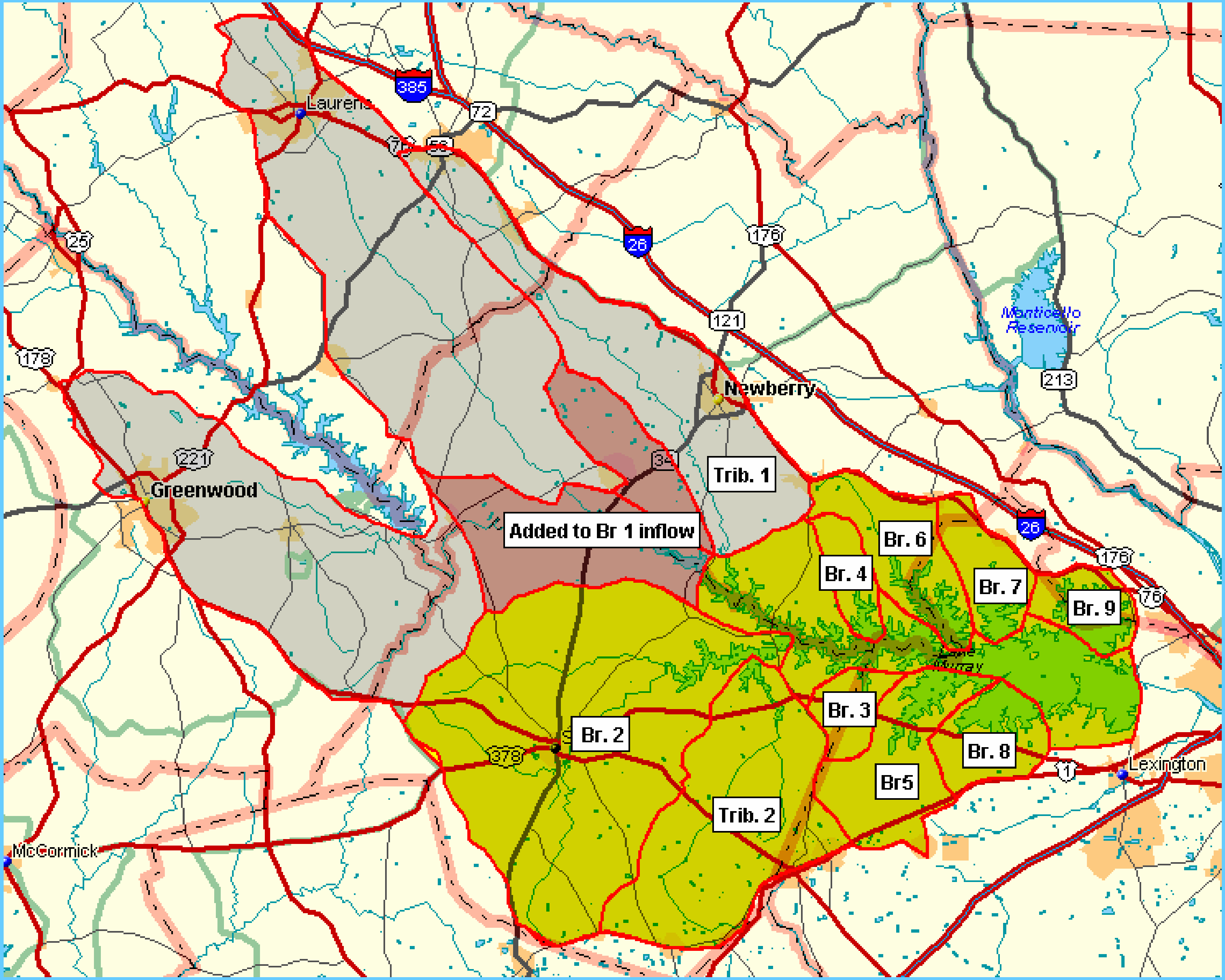


CE-QUAL-W2 Bathymetry for the Main Branch (Branch 1) of Lake Murray

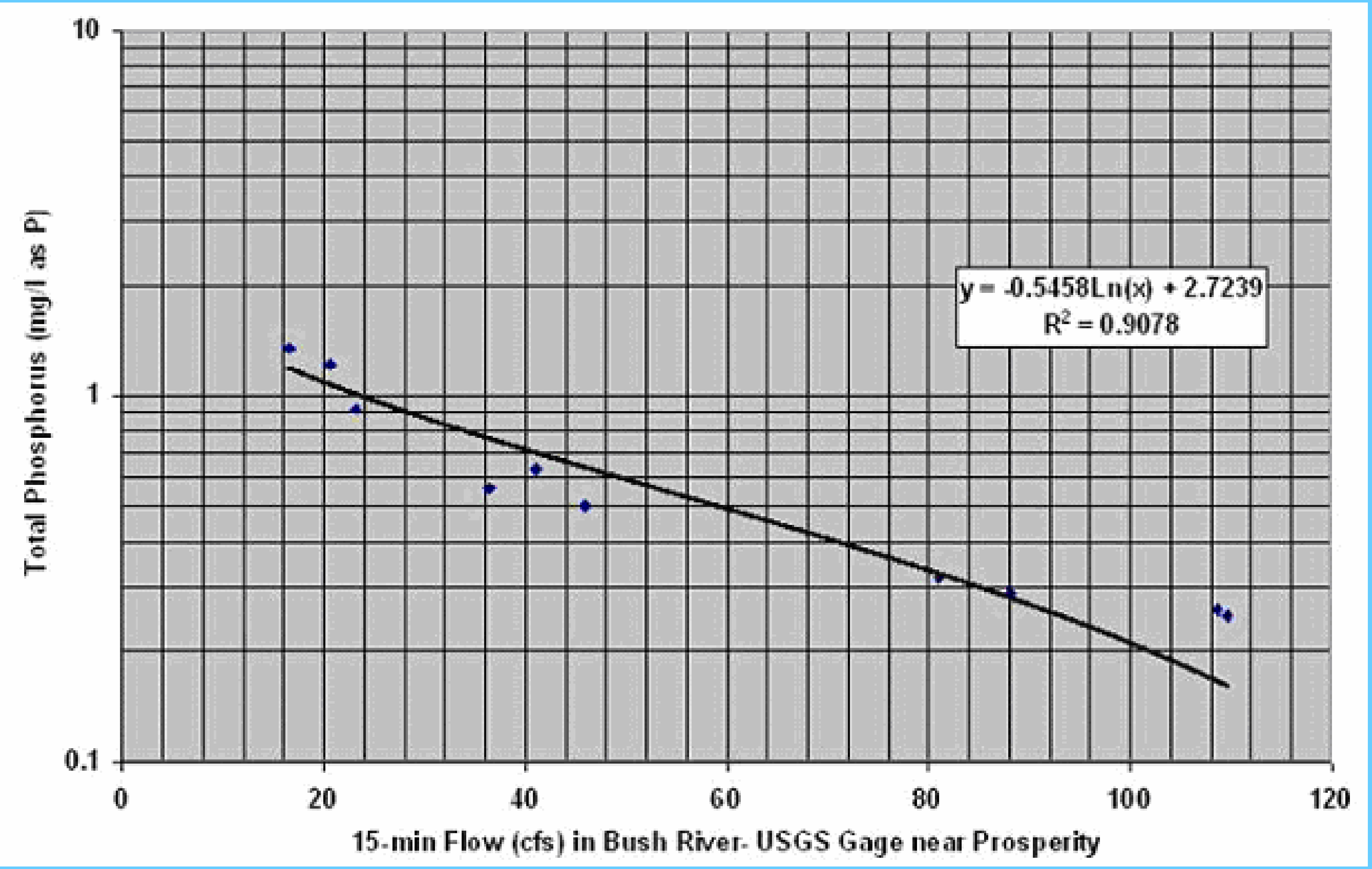




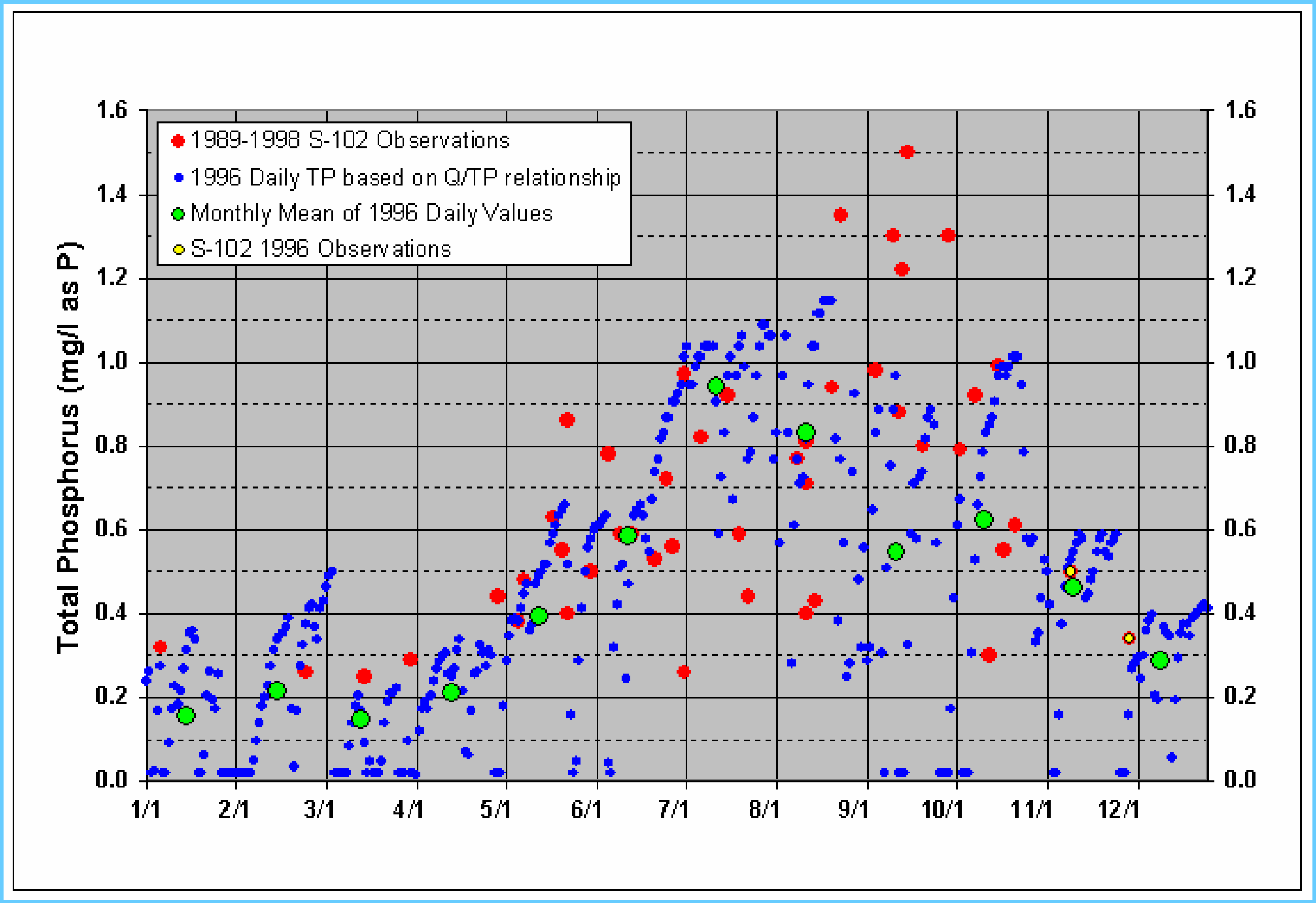
Map of Subwatershed Drainage Area Boundaries



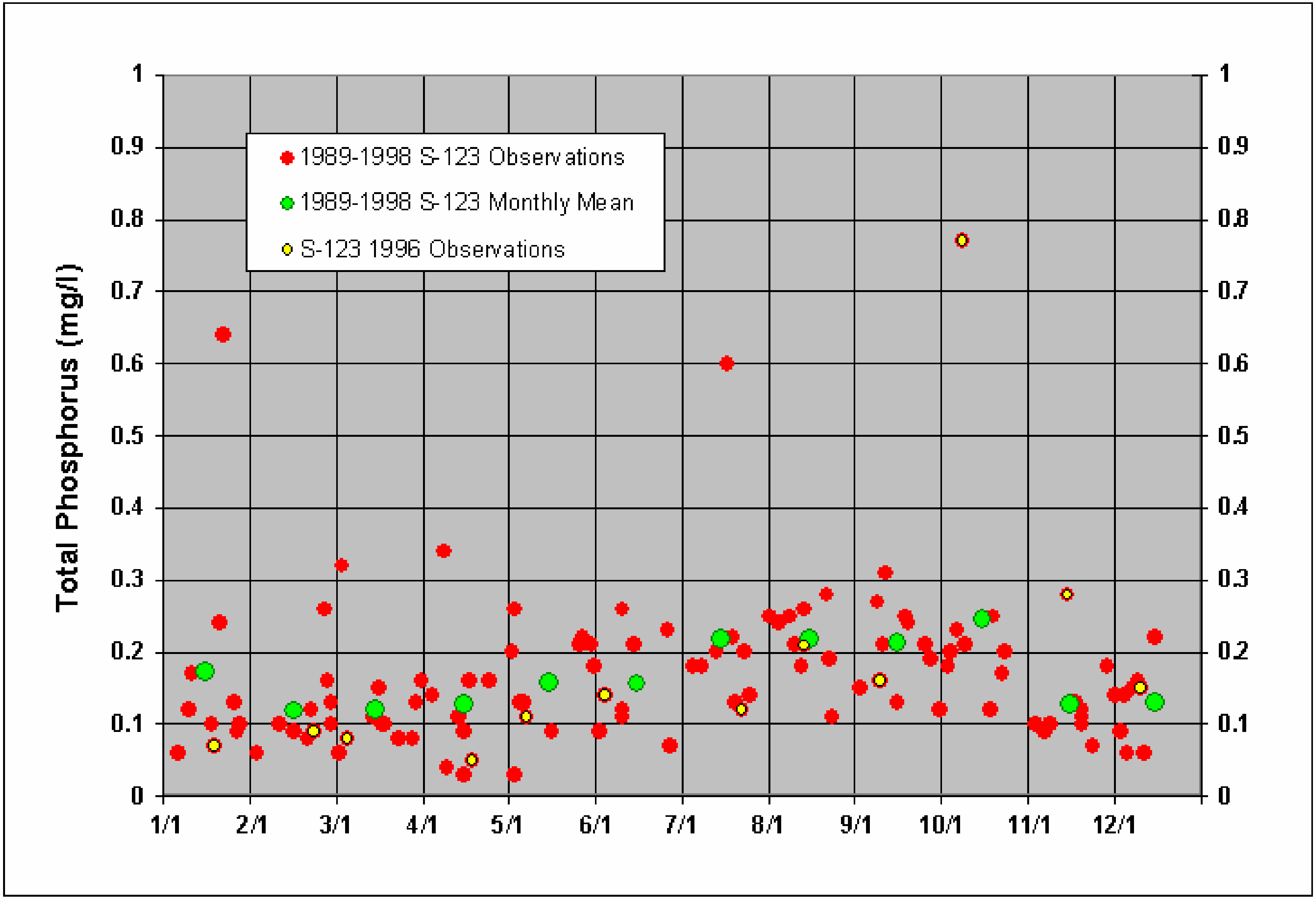
Phosphorus versus Flow Relationship found in the Bush River (Station S-102) using 1997 data



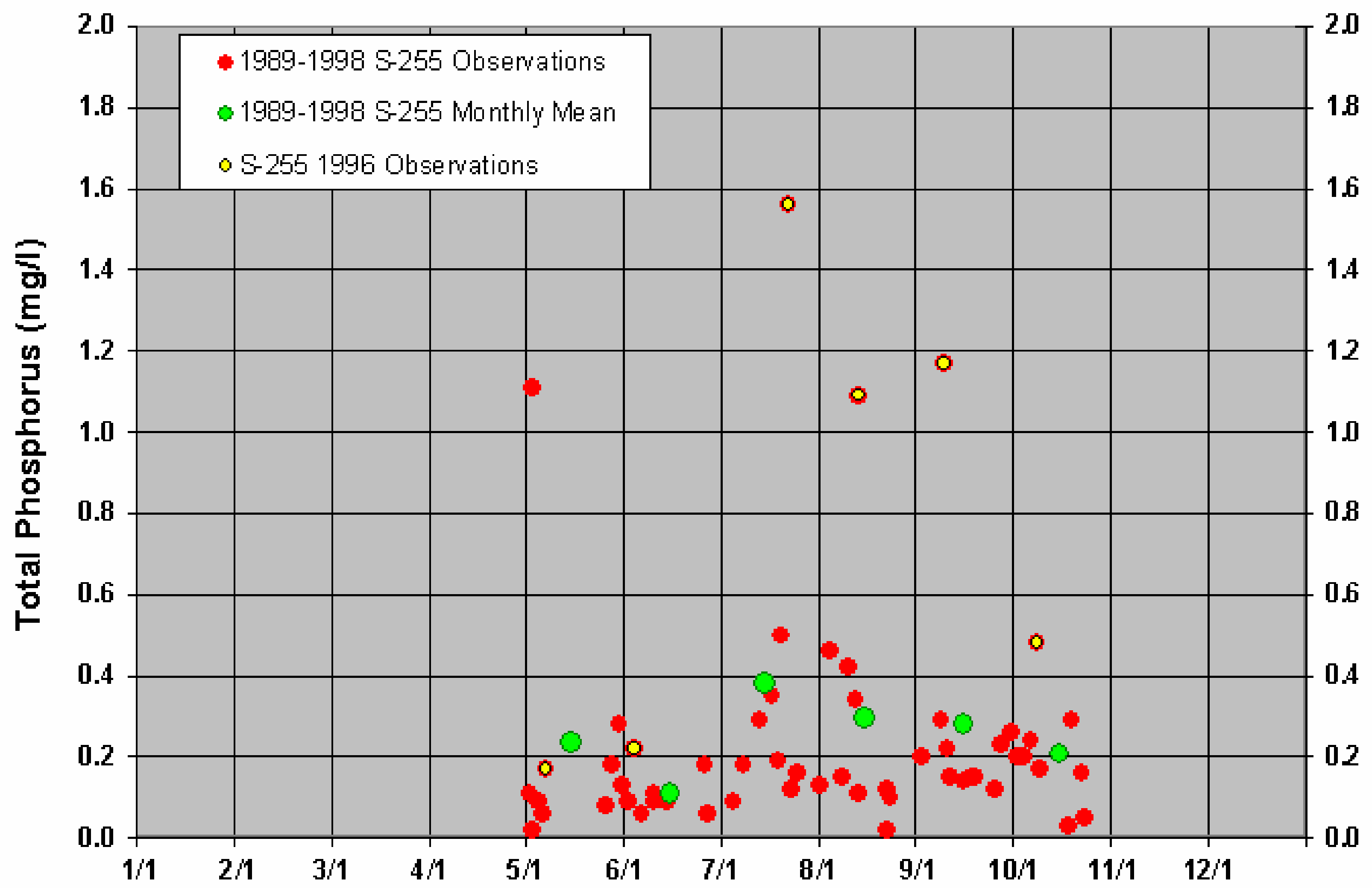
1996 Inflow Phosphorus Analysis for Bush River Inflow to Lake Murray



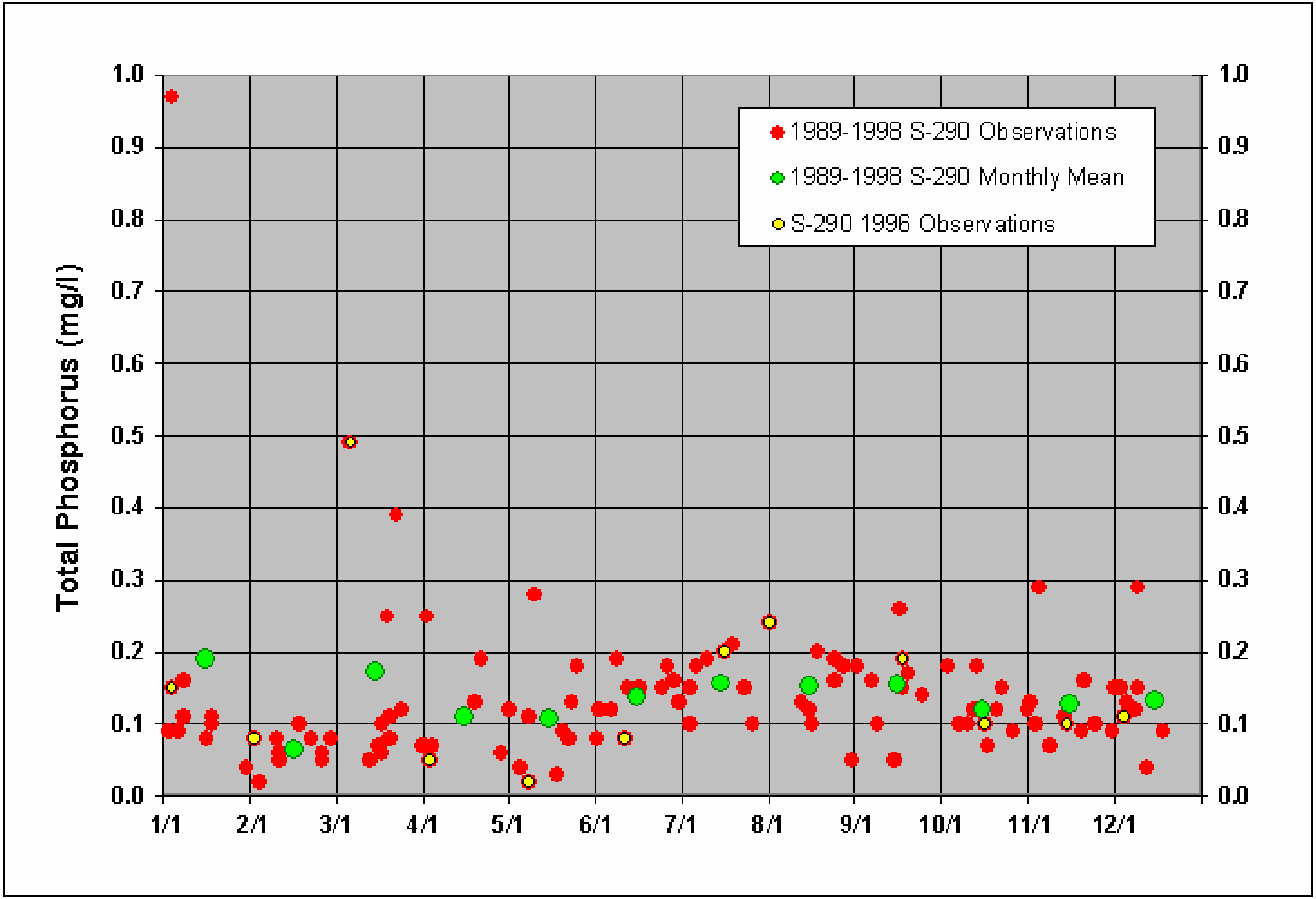
Total Phosphorus in the Little Saluda River



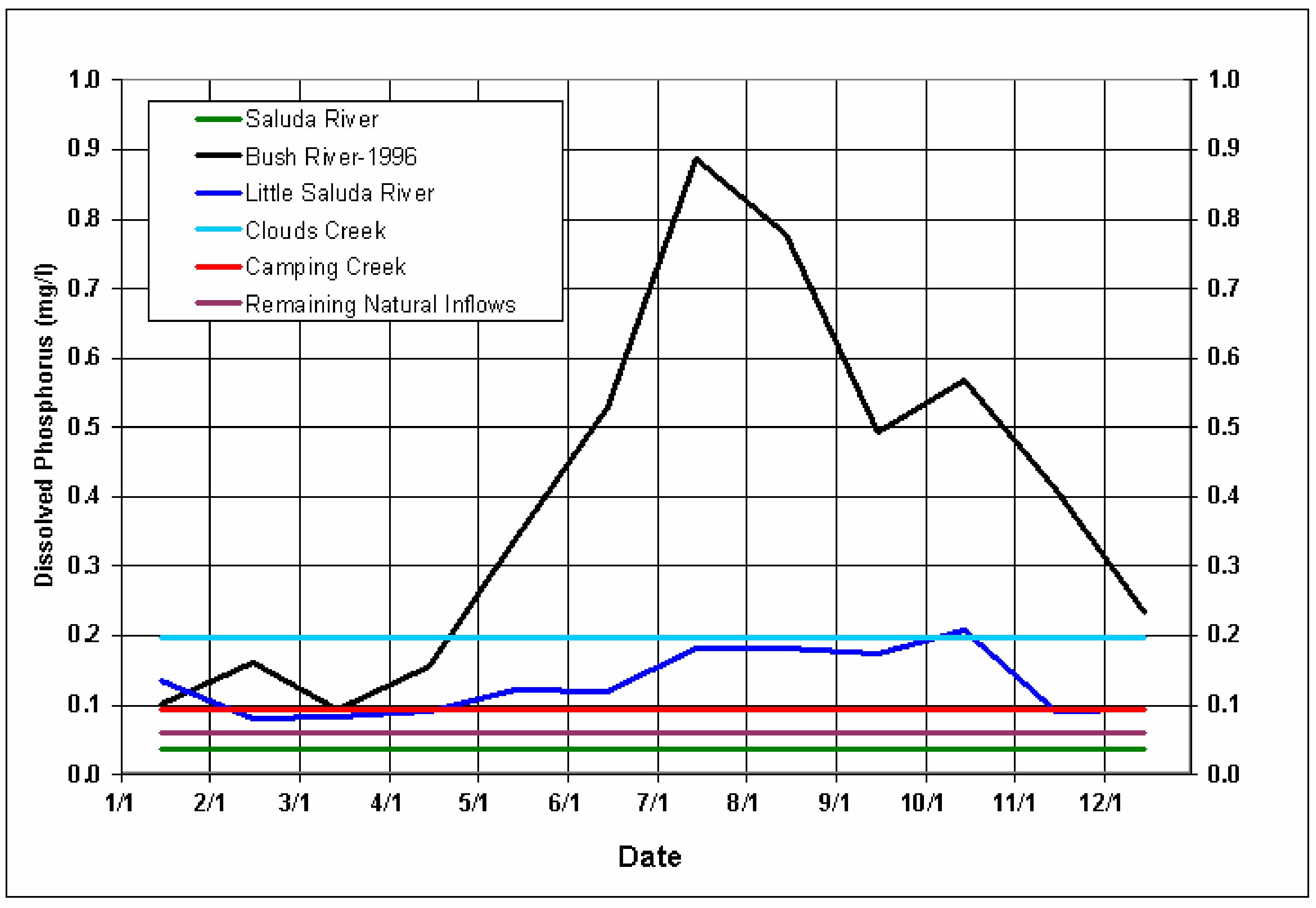
Total Phosphorus Clouds Creek



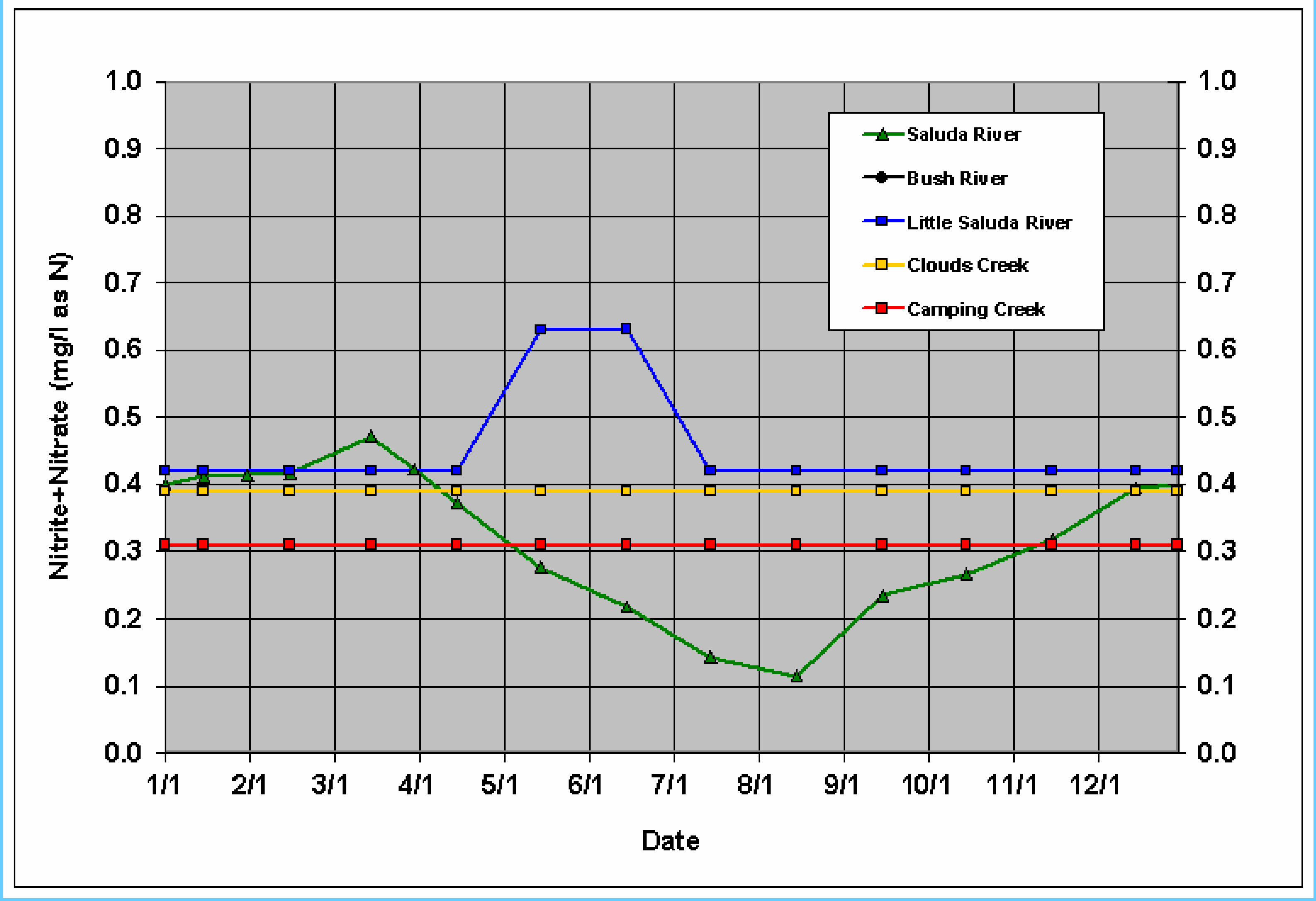
Total Phosphorus in Camping Creek



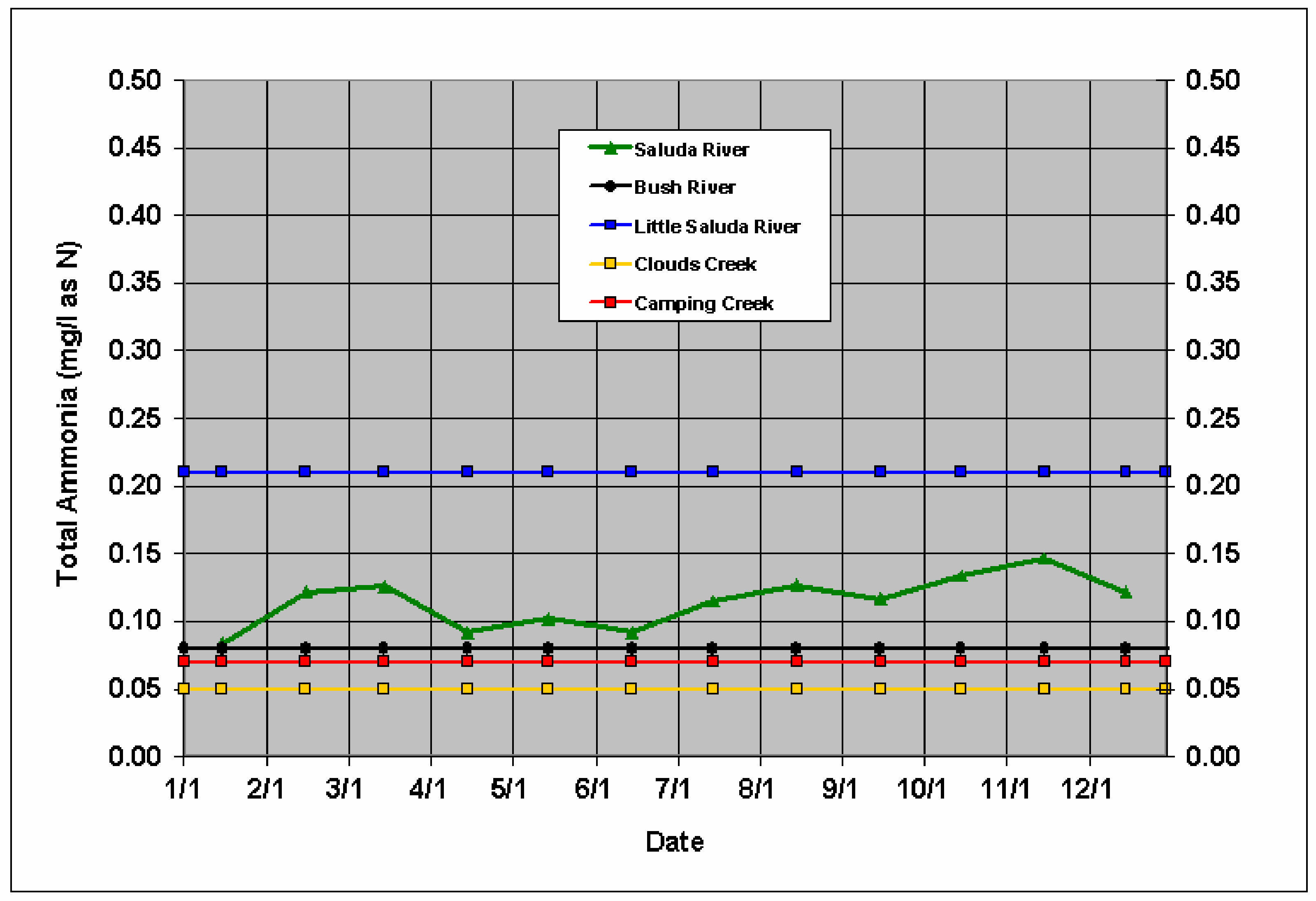
Inflow Dissolved Phosphorus Concentrations for Model Inflows to Lake Murray



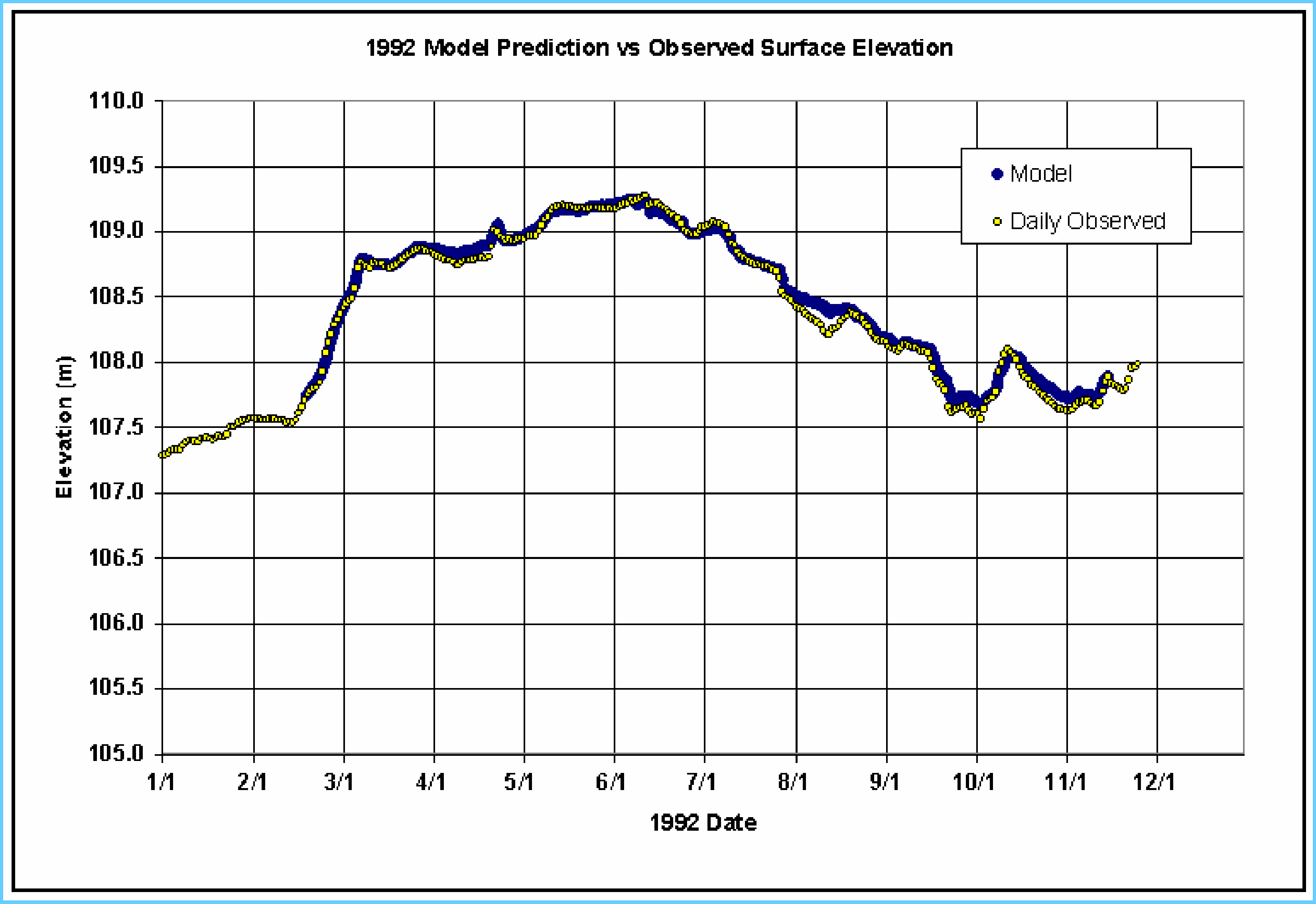
Nitrate Concentrations in the Inflows to the Lake Murray CE-QUAL-W2 Model



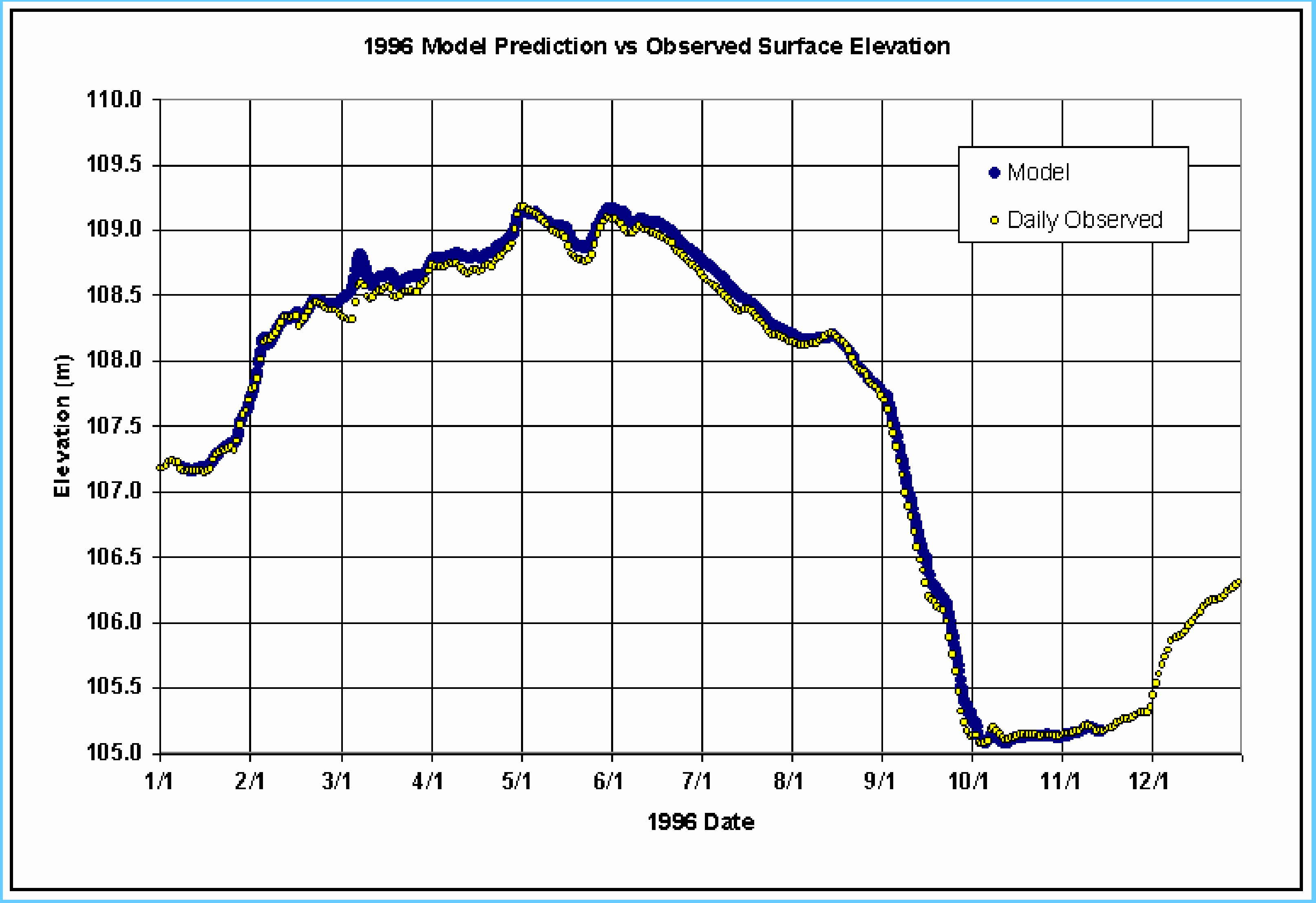
Ammonium Concentrations in the Inflows to the Lake Murray CE-QUAL-W2 Model



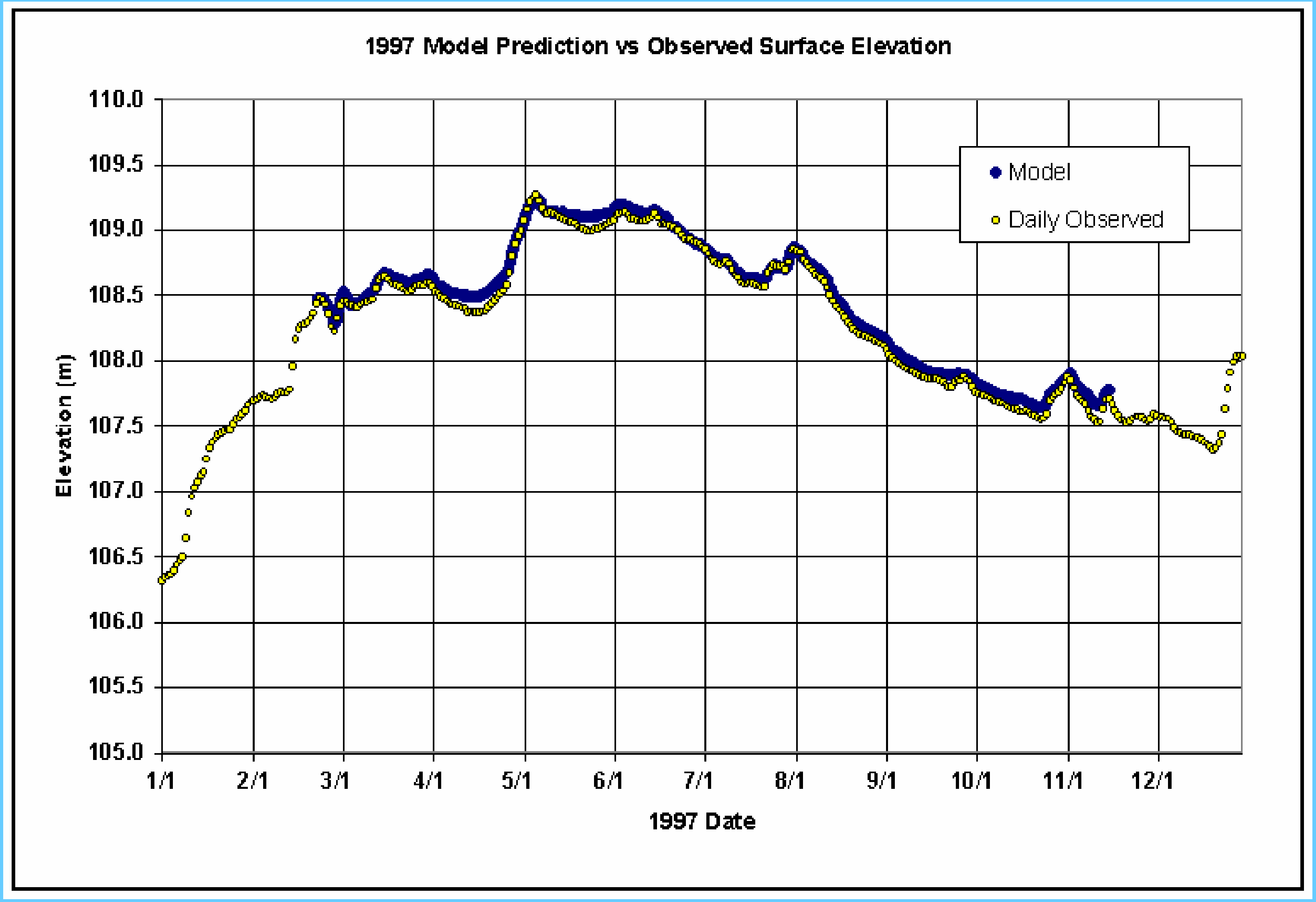
1992 Modeled and Measured Lake Murray Headwater Elevations



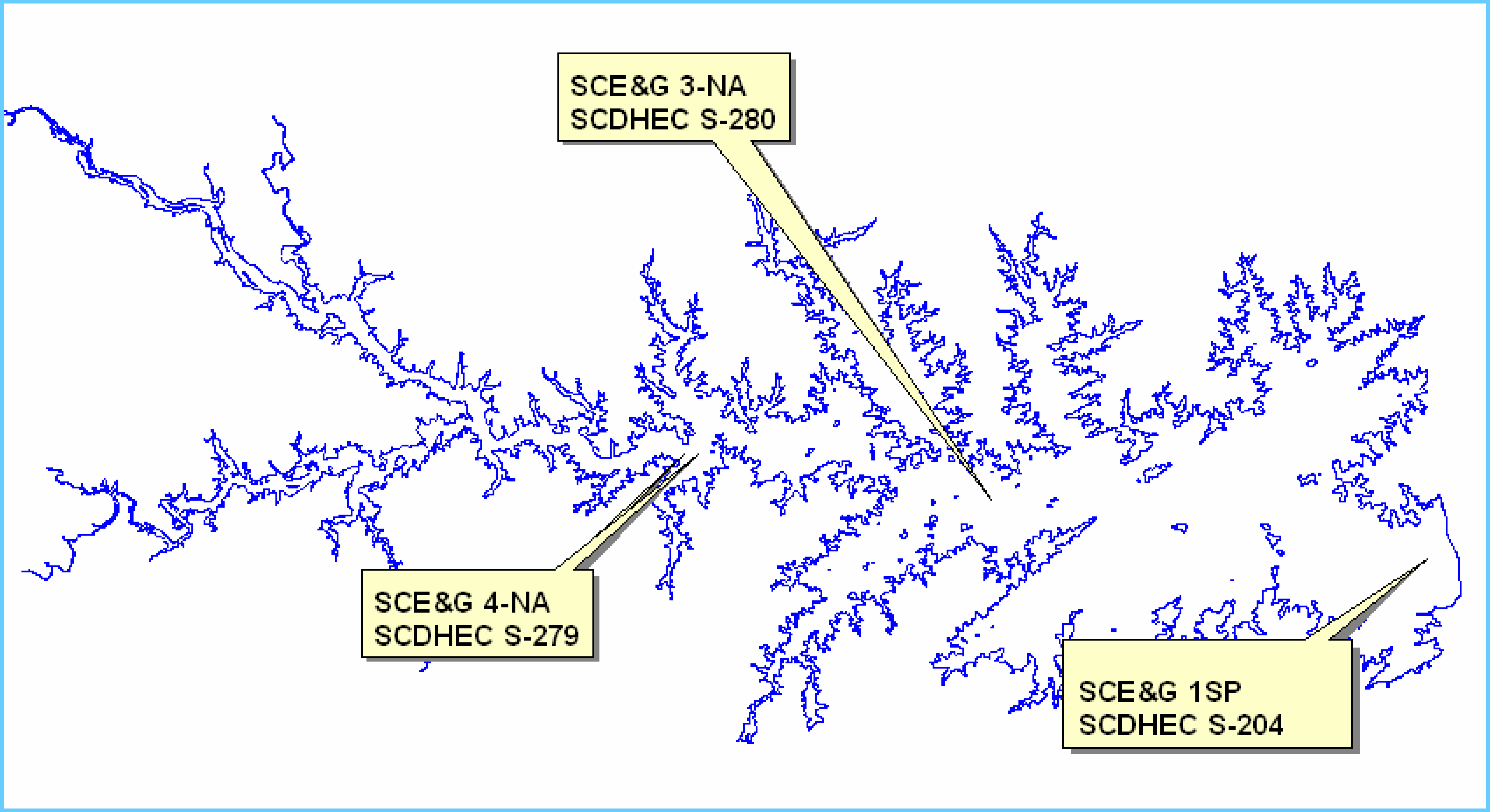
1996 Modeled and Measured Lake Murray Headwater Elevations



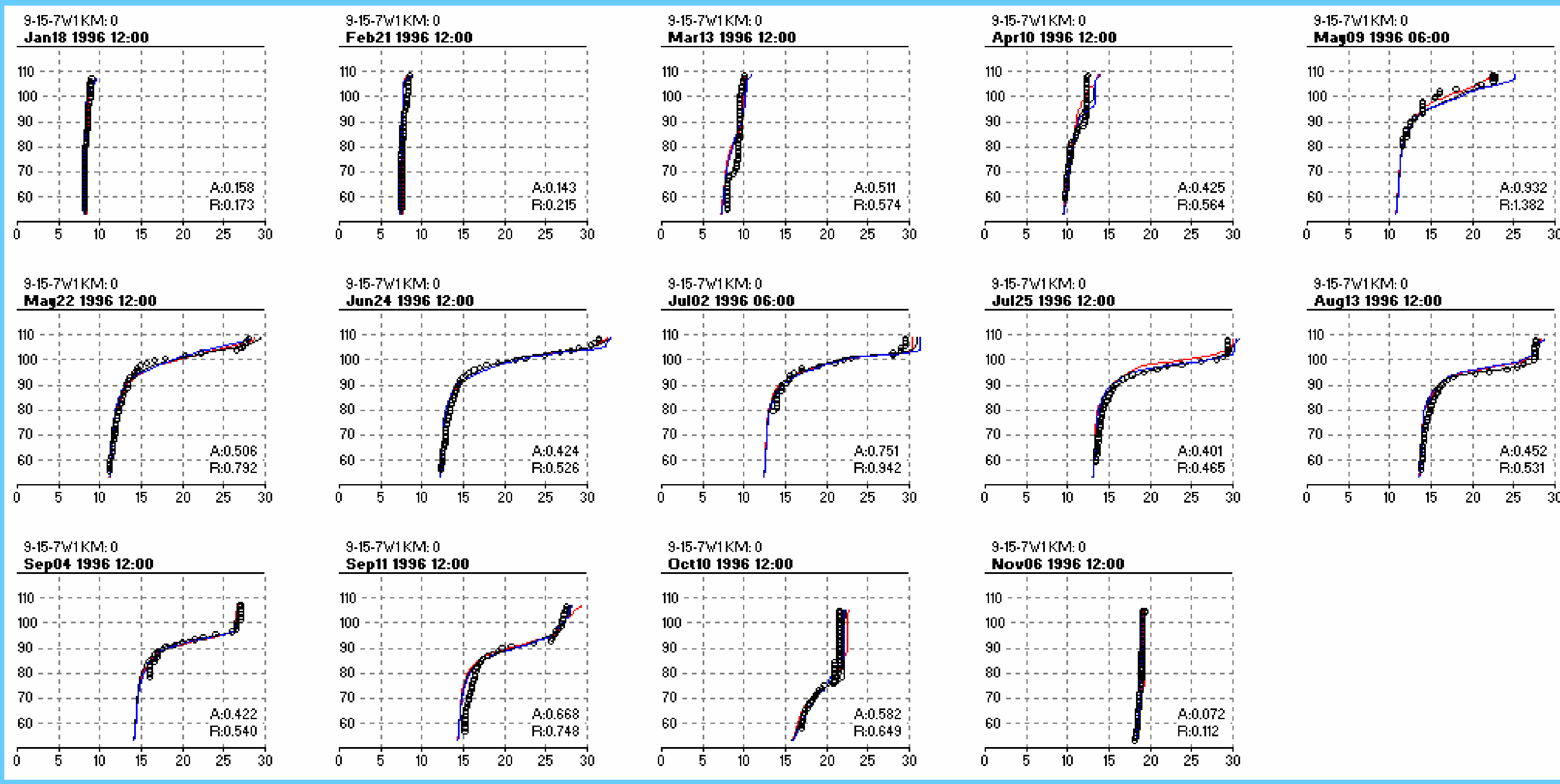
1997 Modeled and Measured Lake Murray Headwater Elevations



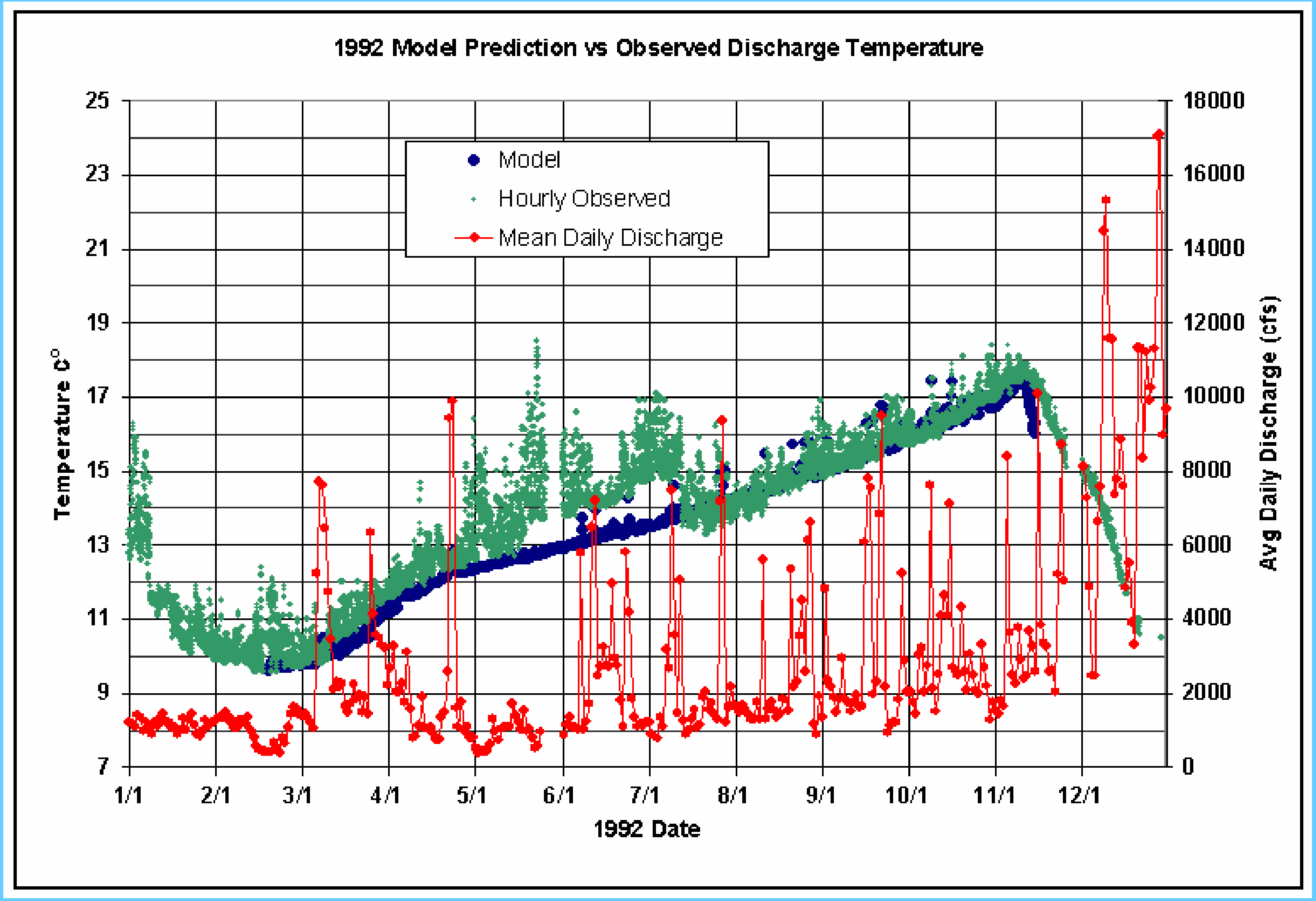
Primary Water Quality Calibration Locations



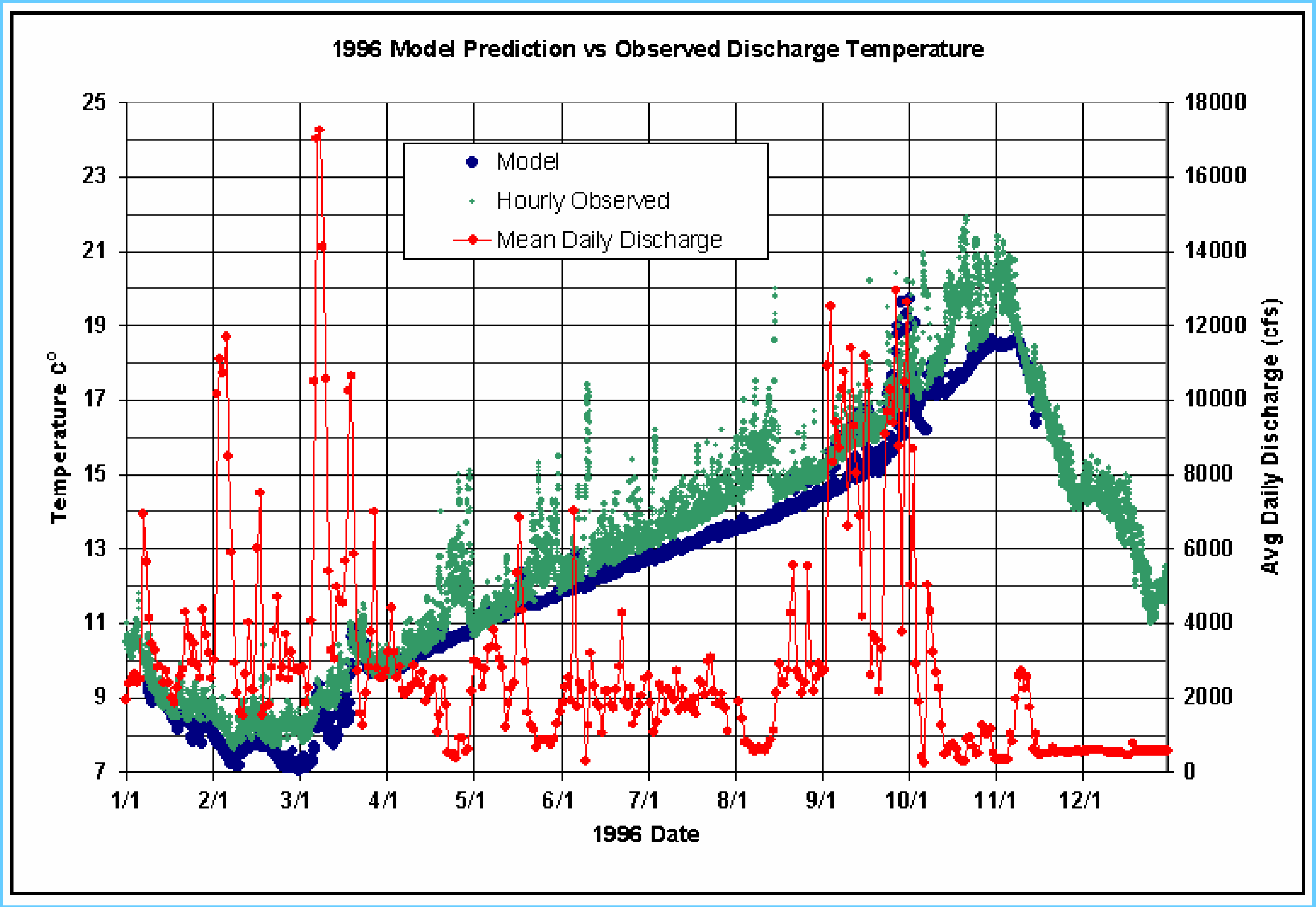
1996 Lake Murray Forebay Temperature Profiles
Model vs. Data



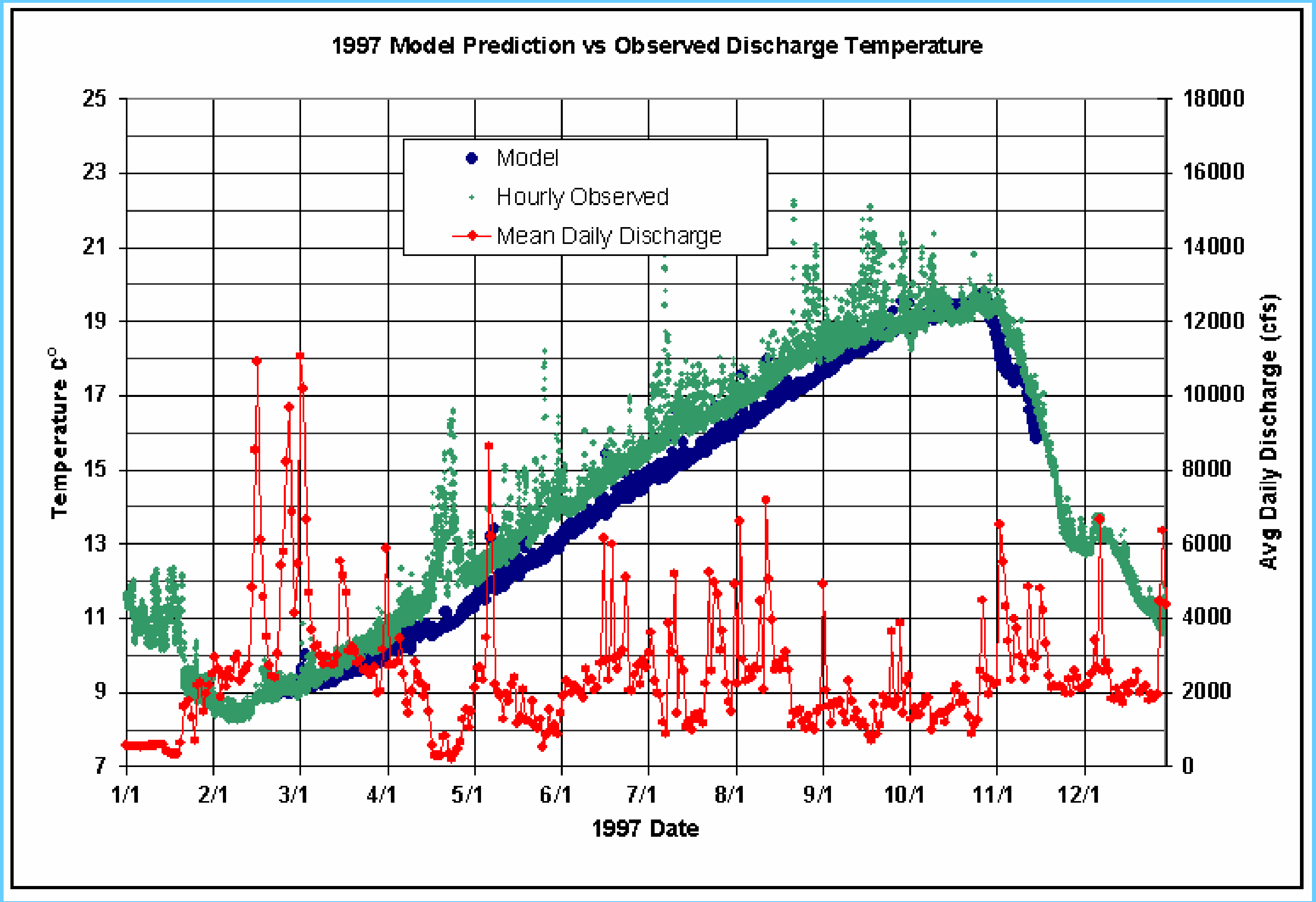
1992 Comparison of Modeled versus Measured Saluda Release Temperatures



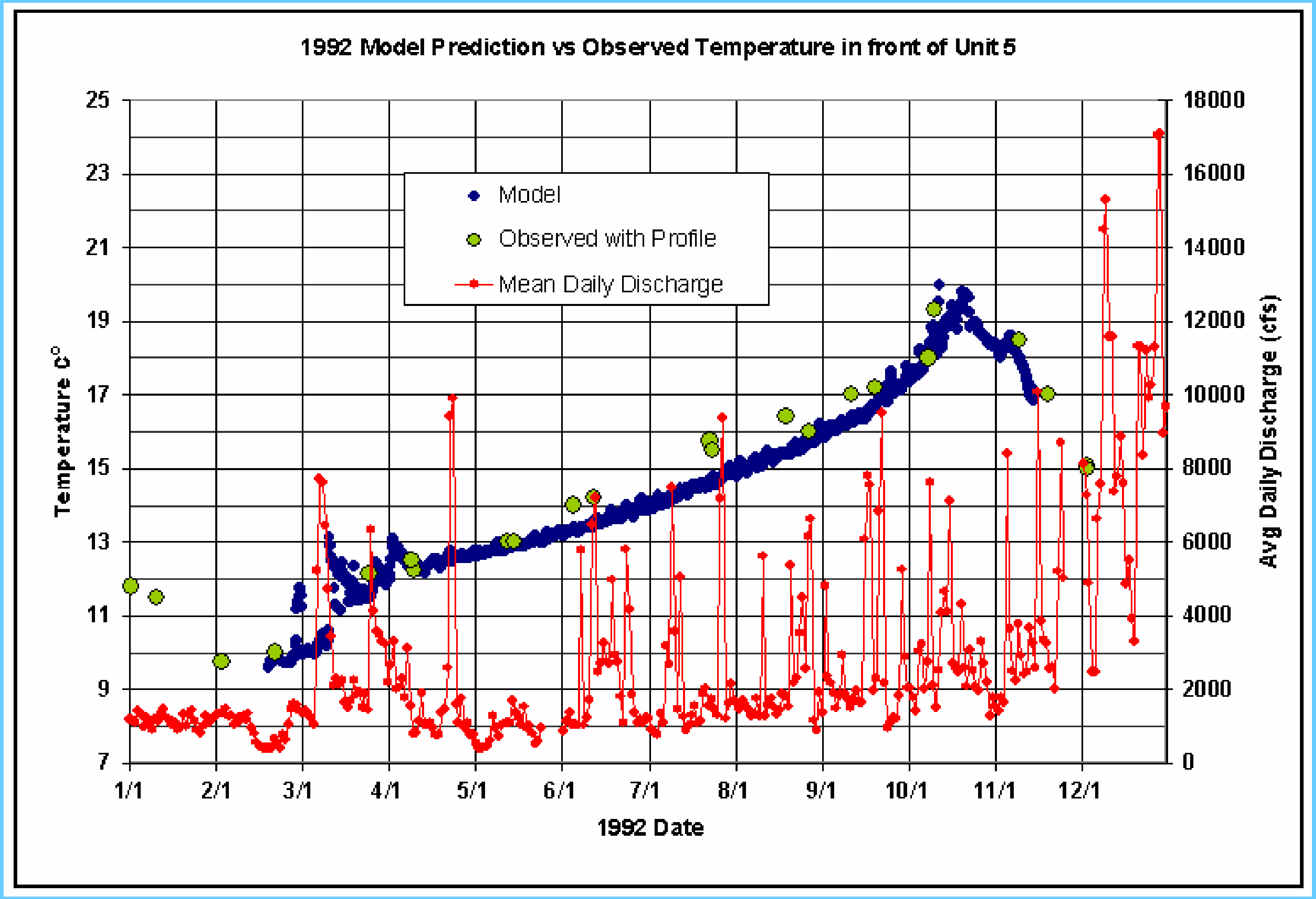
1996 Comparison of Modeled versus Measured Saluda Release Temperatures



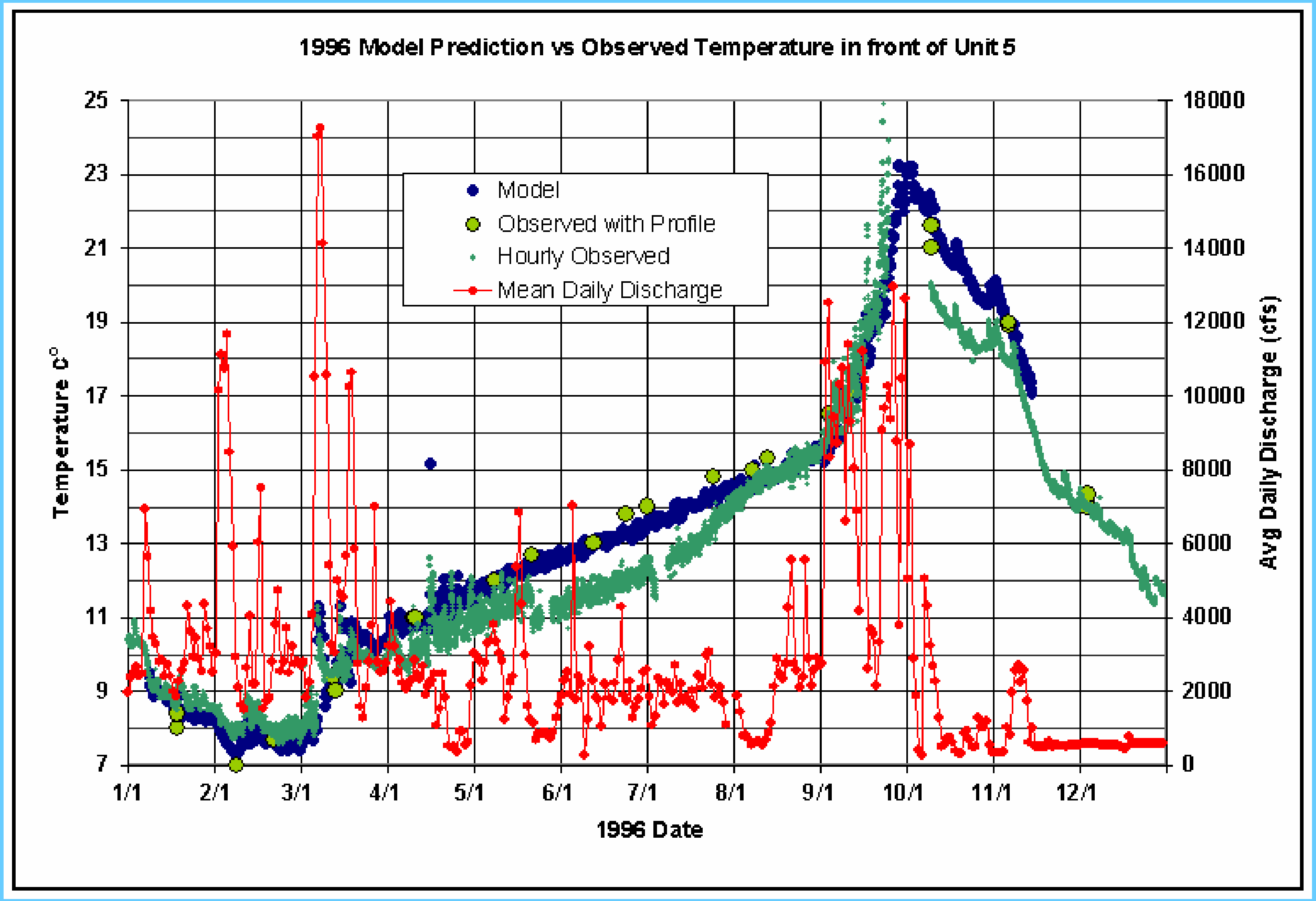
1997 Comparison of Modeled versus Measured Saluda Release Temperatures



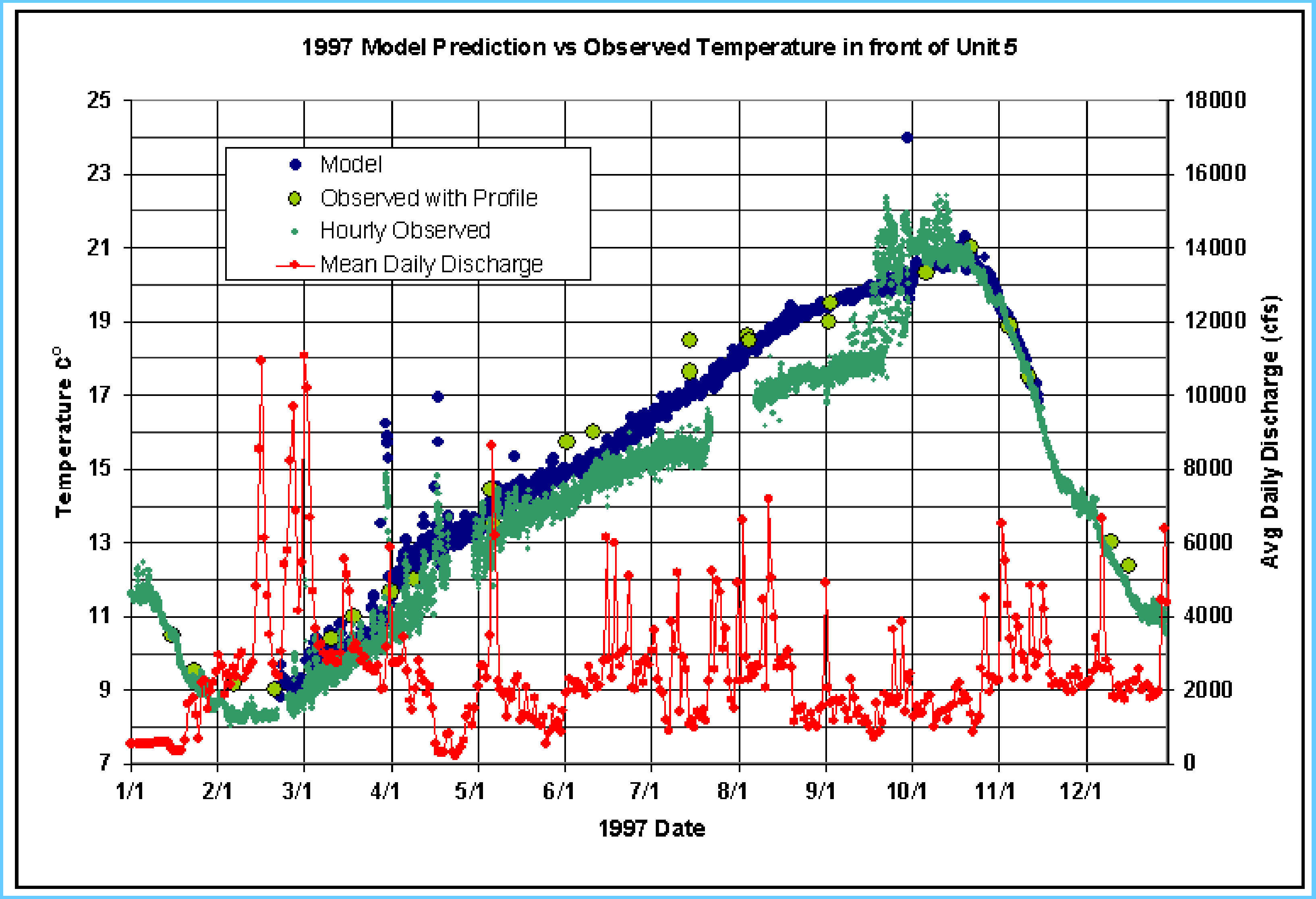
1992 Comparison of Modeled versus Measured Temperature in Front of the Unit 5 Intake



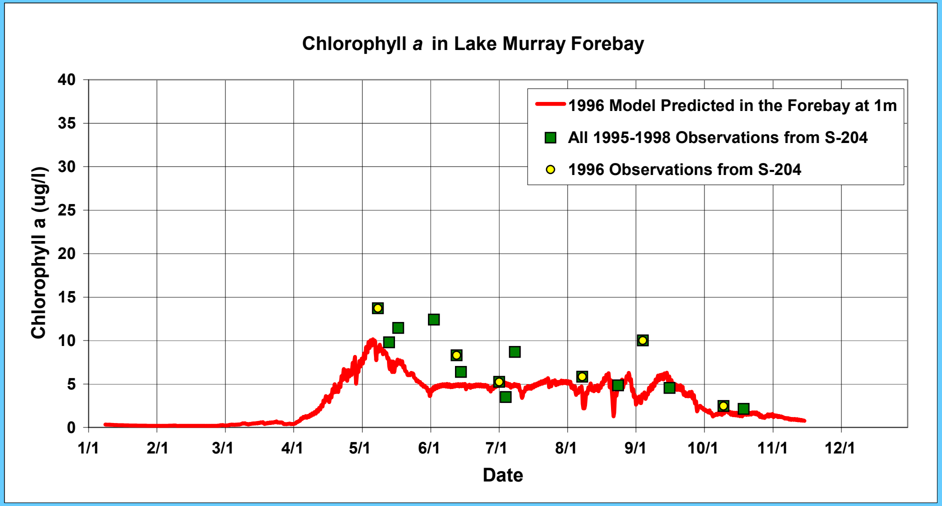
1996 Comparison of Modeled versus Measured Temperature in Front of the Unit 5 Intake

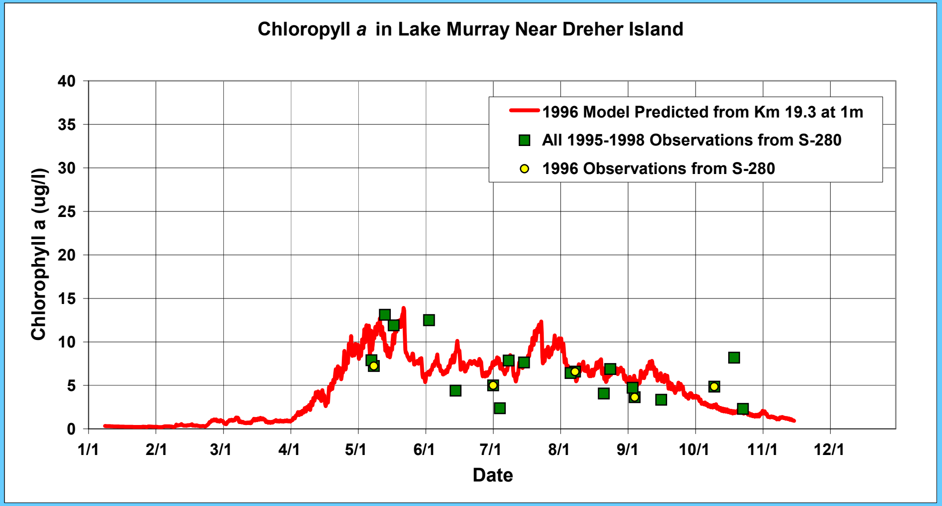


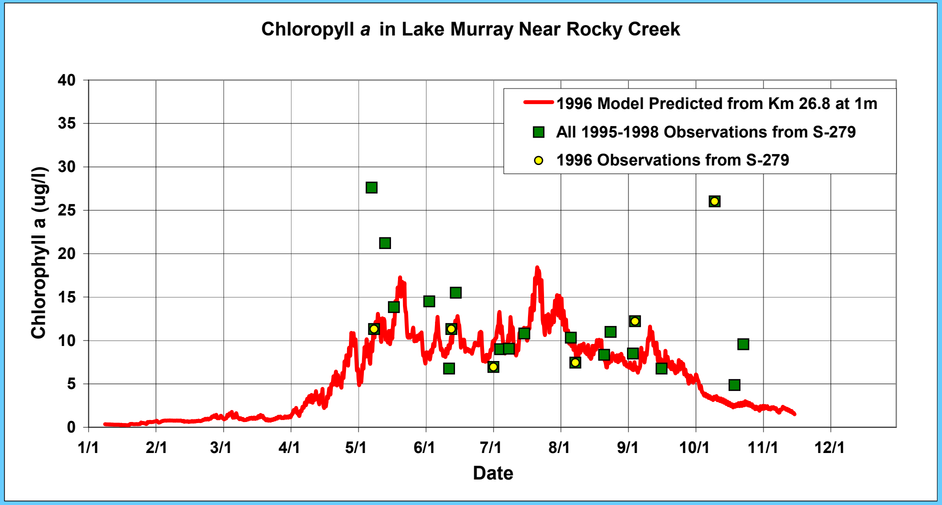
1997 Comparison of Modeled versus Measured Temperature in Front of the Unit 5 Intake

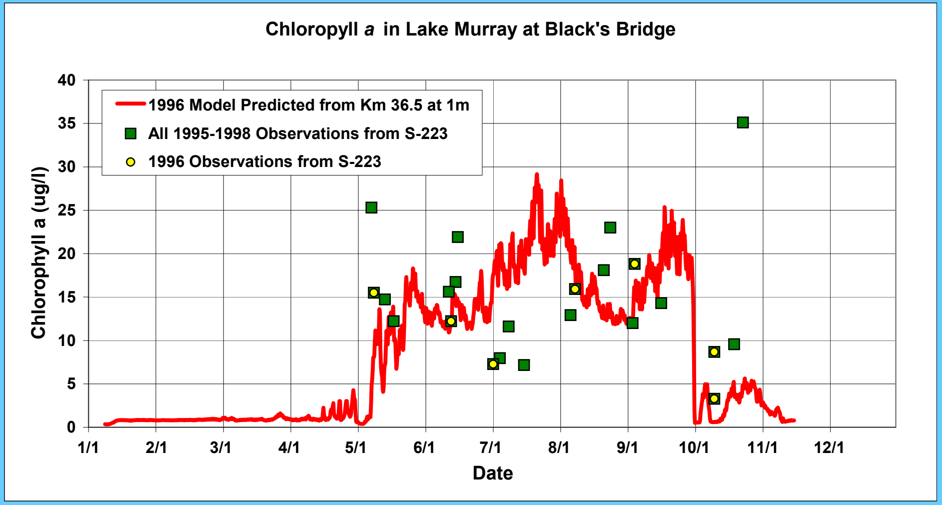


1996 Chlorophyll *a* at Four Locations in Lake Murray Model vs. Data

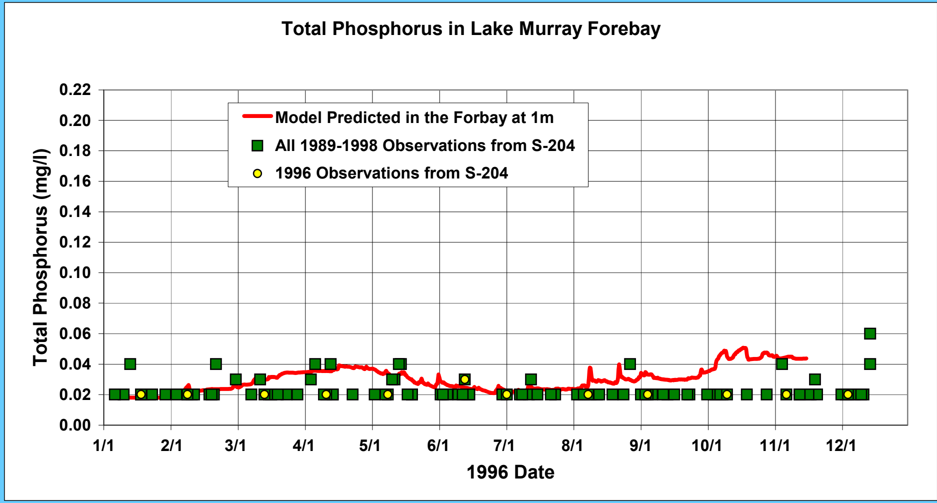


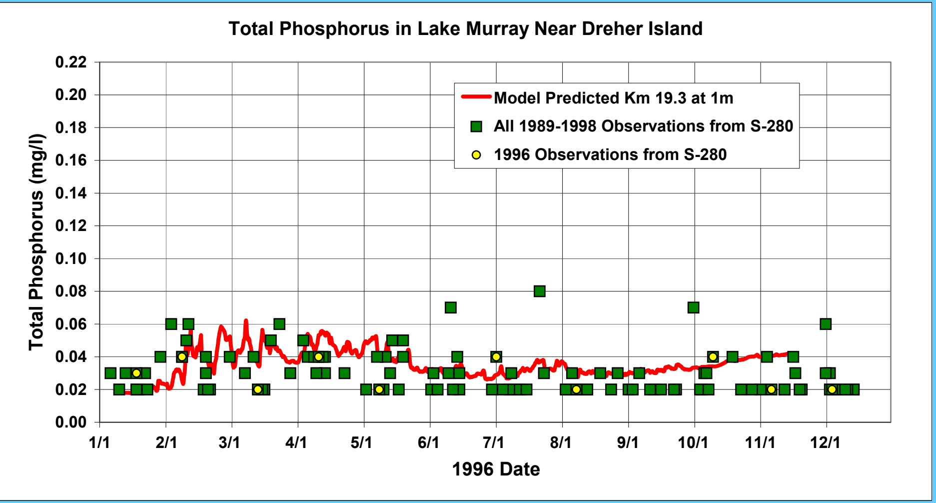


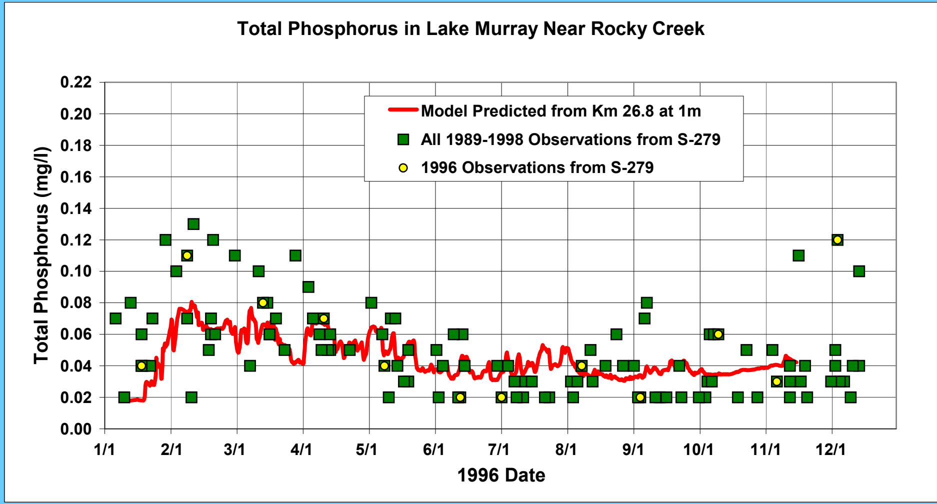


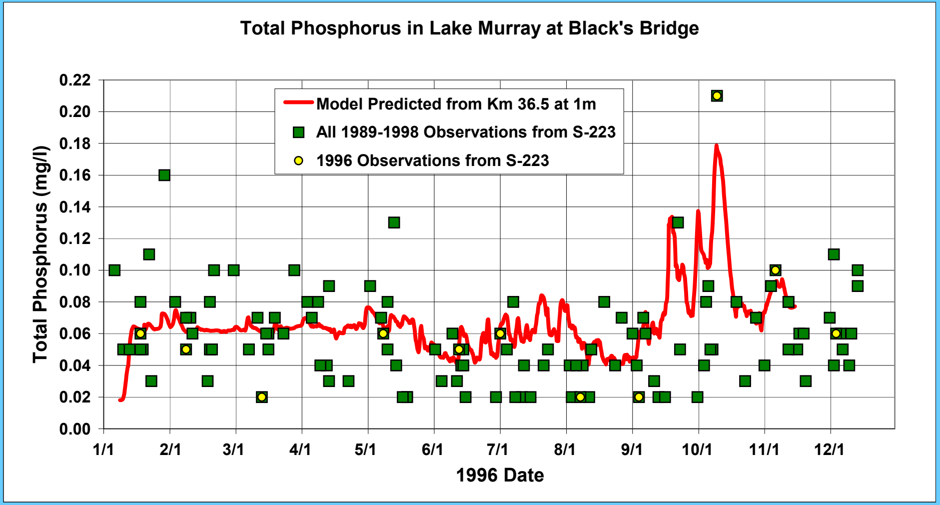


Comparison of Modeled Derived versus Measured Total Phosphorus for 1996 at Four Locations in Lake Murray

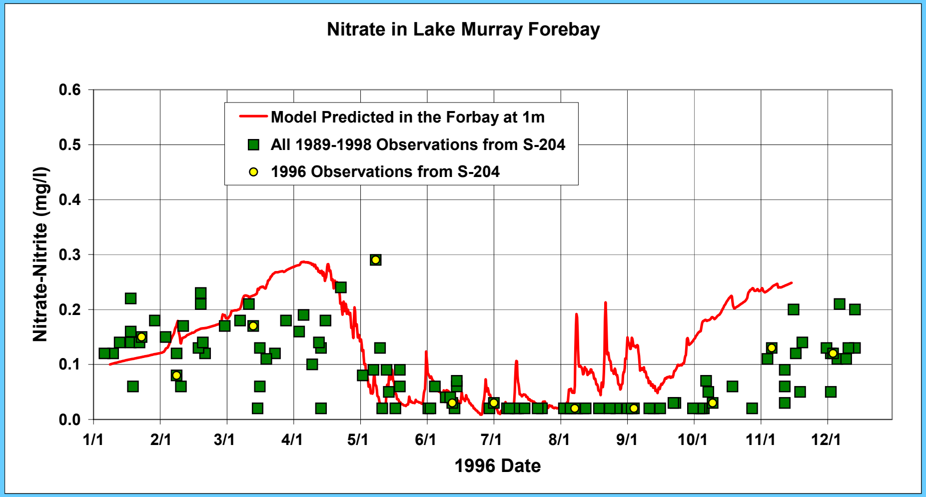


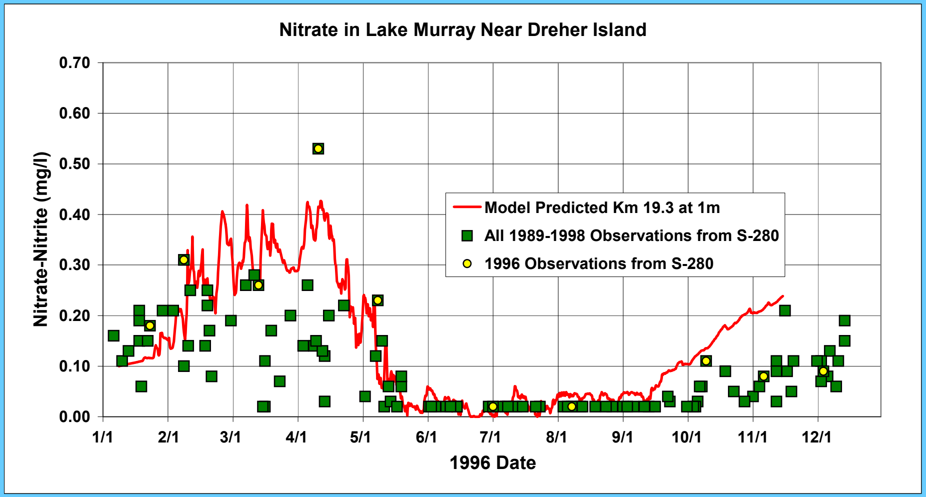


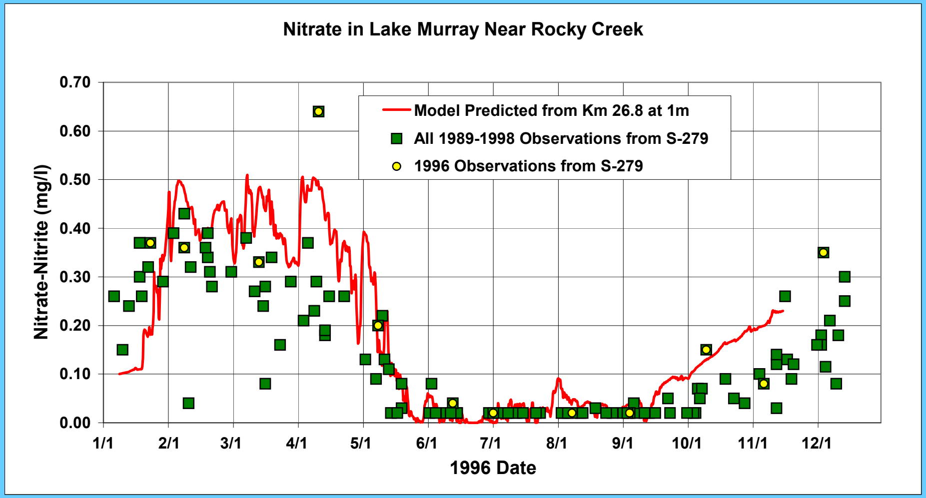


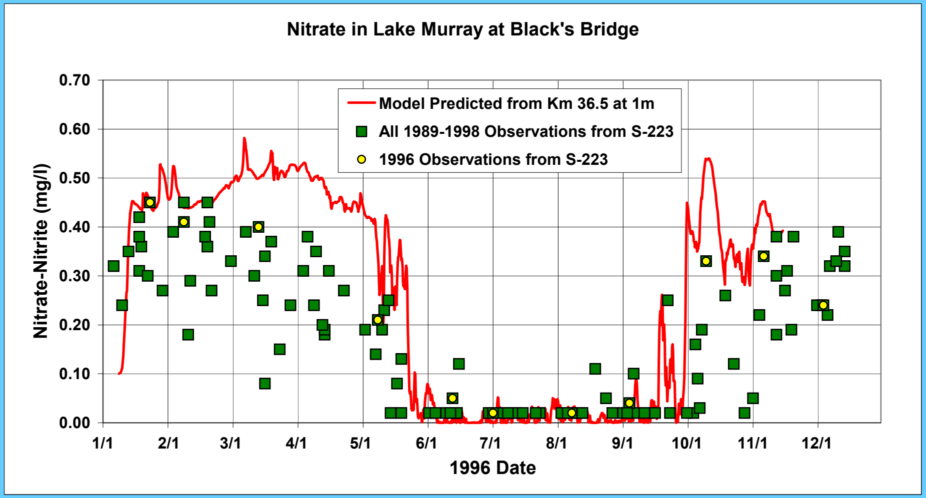


Comparison of Modeled versus Measured Nitrate for 1996 at Four Locations in Lake Murray

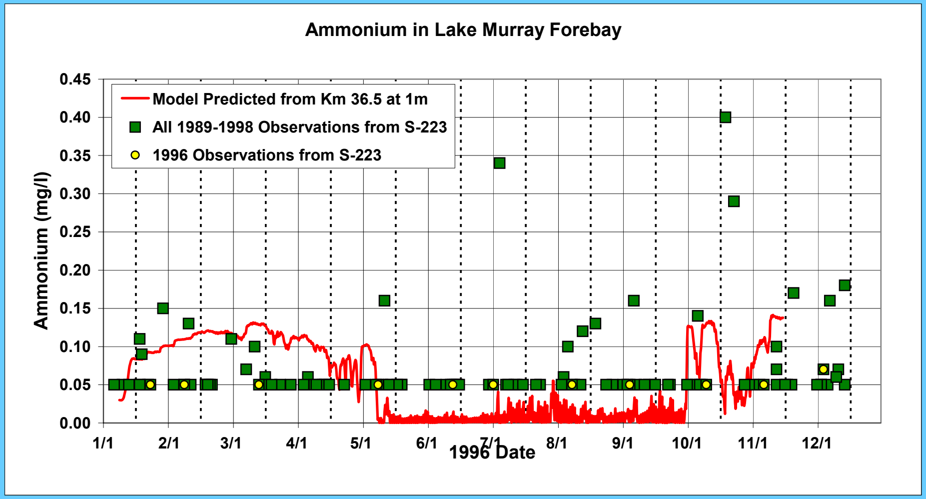


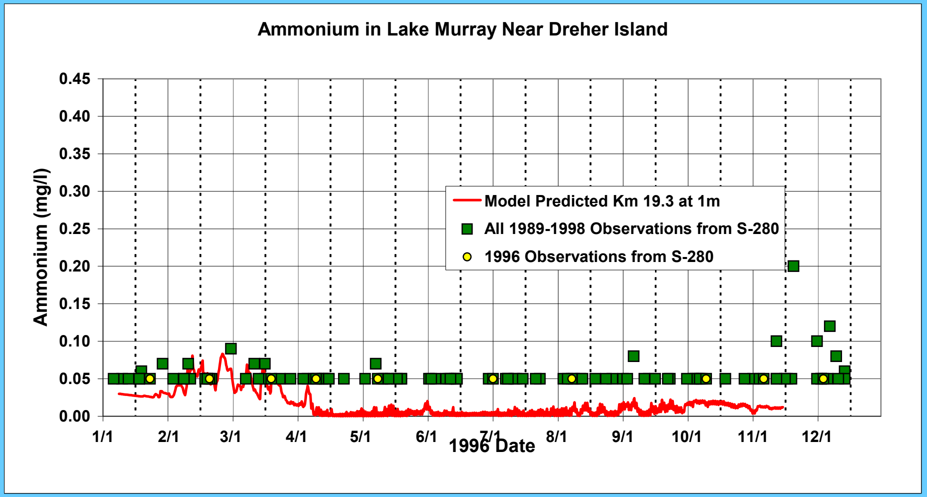


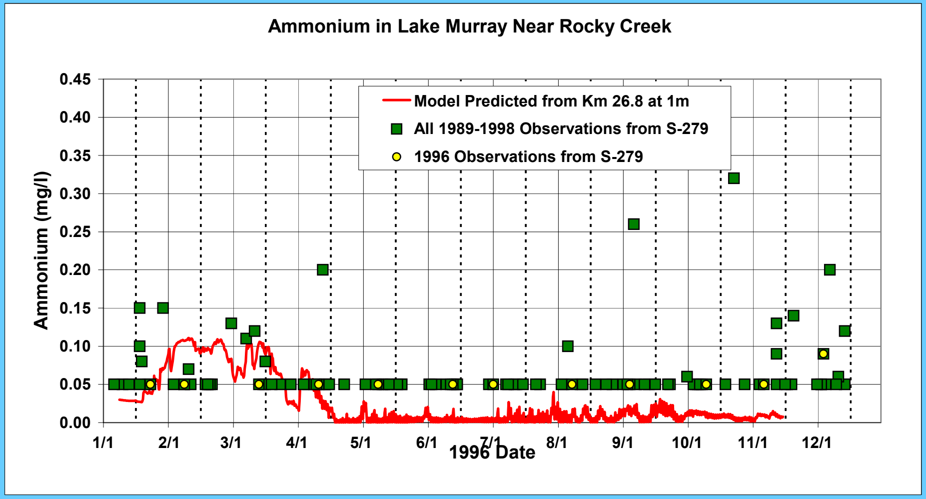


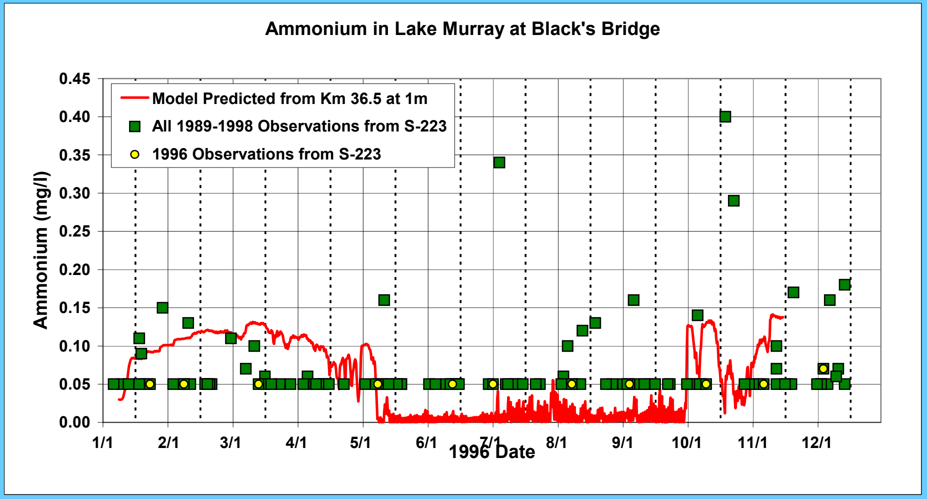


Comparison of Modeled versus Measured Ammonium for 1996 at Four Locations in Lake Murray

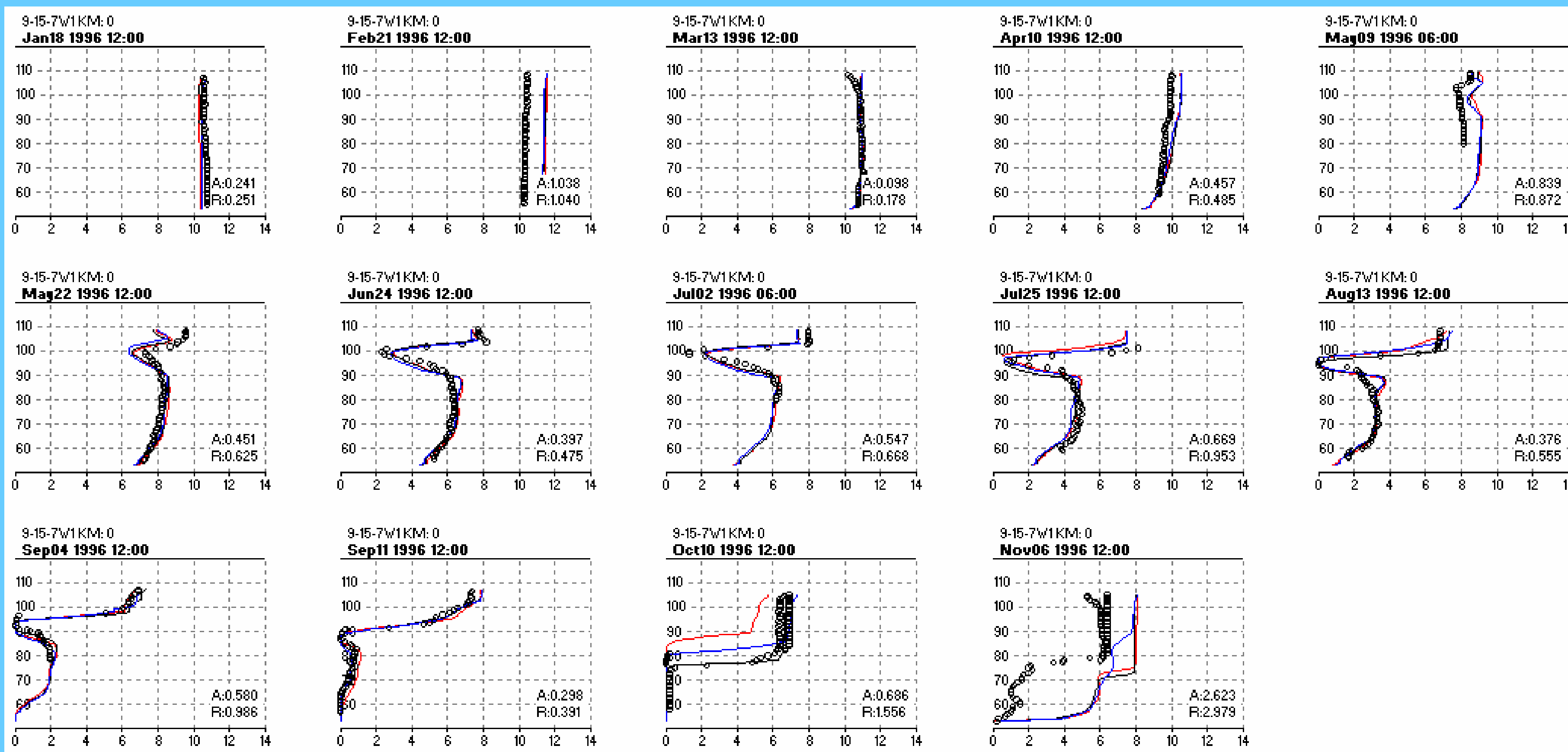




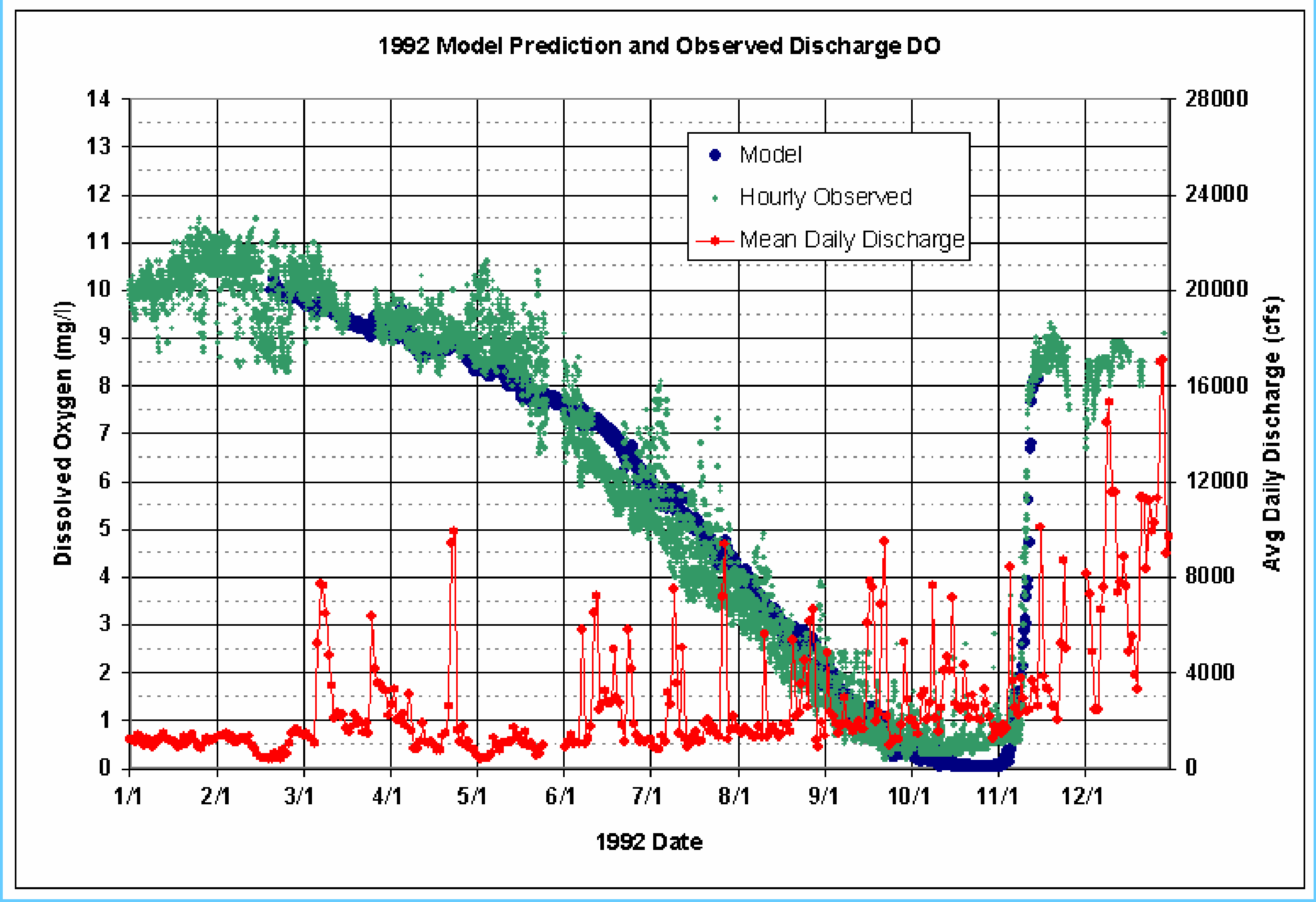




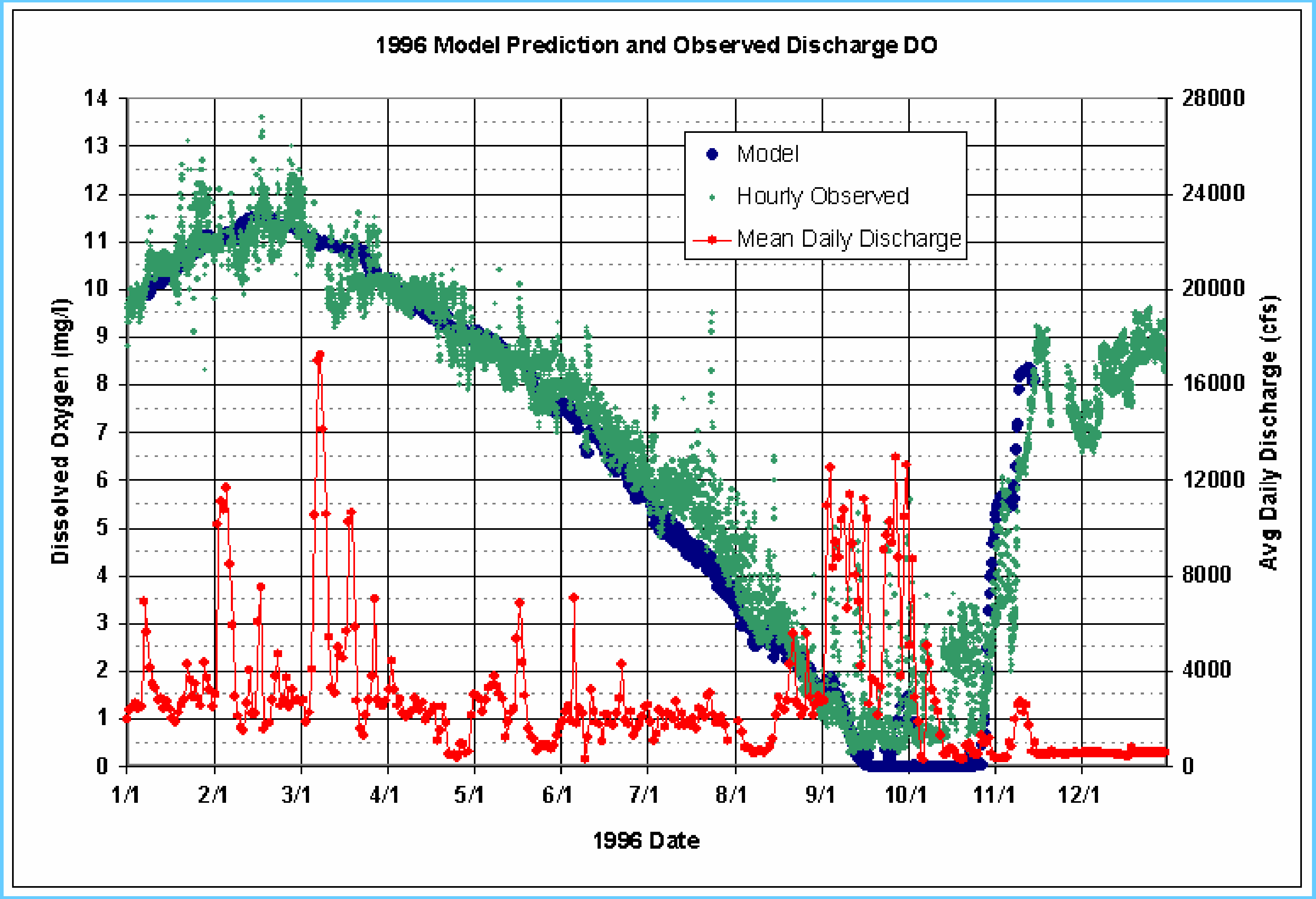
1996 Lake Murray Forebay Dissolved Oxygen Profiles
Model vs. Data



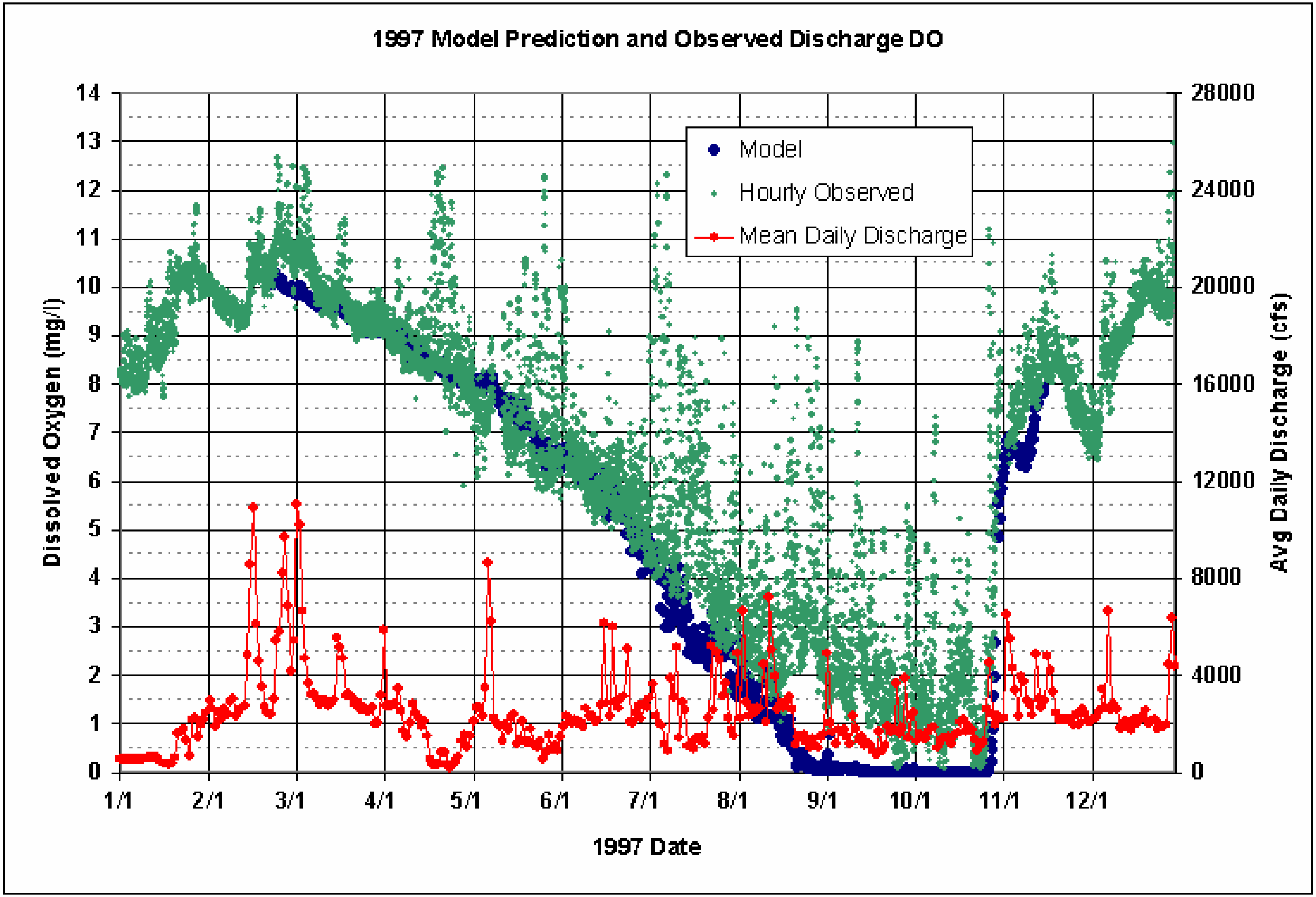
1992 Comparison of Modeled versus Measured Saluda Release DO



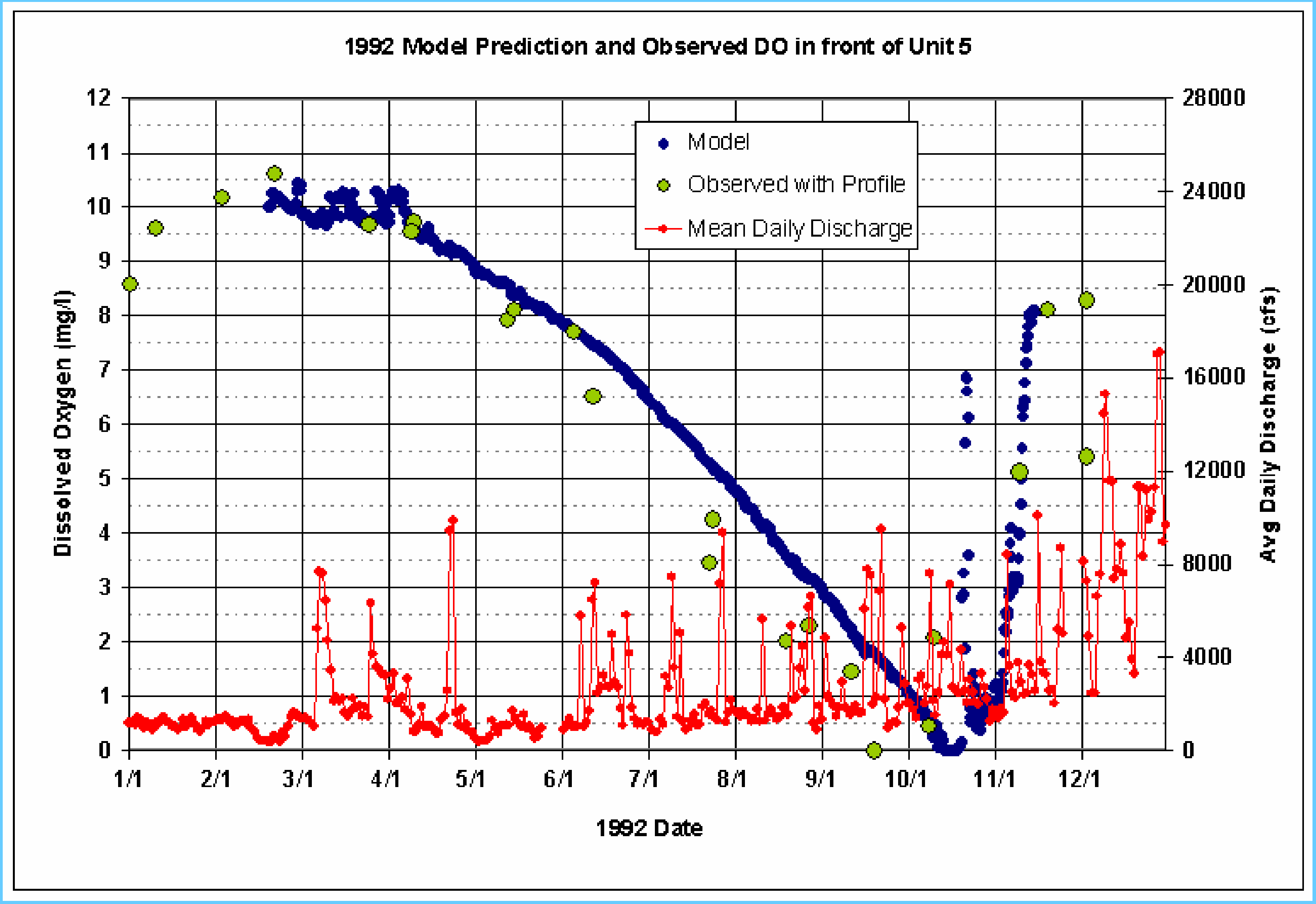
1996 Comparison of Modeled versus Measured Saluda Release DO



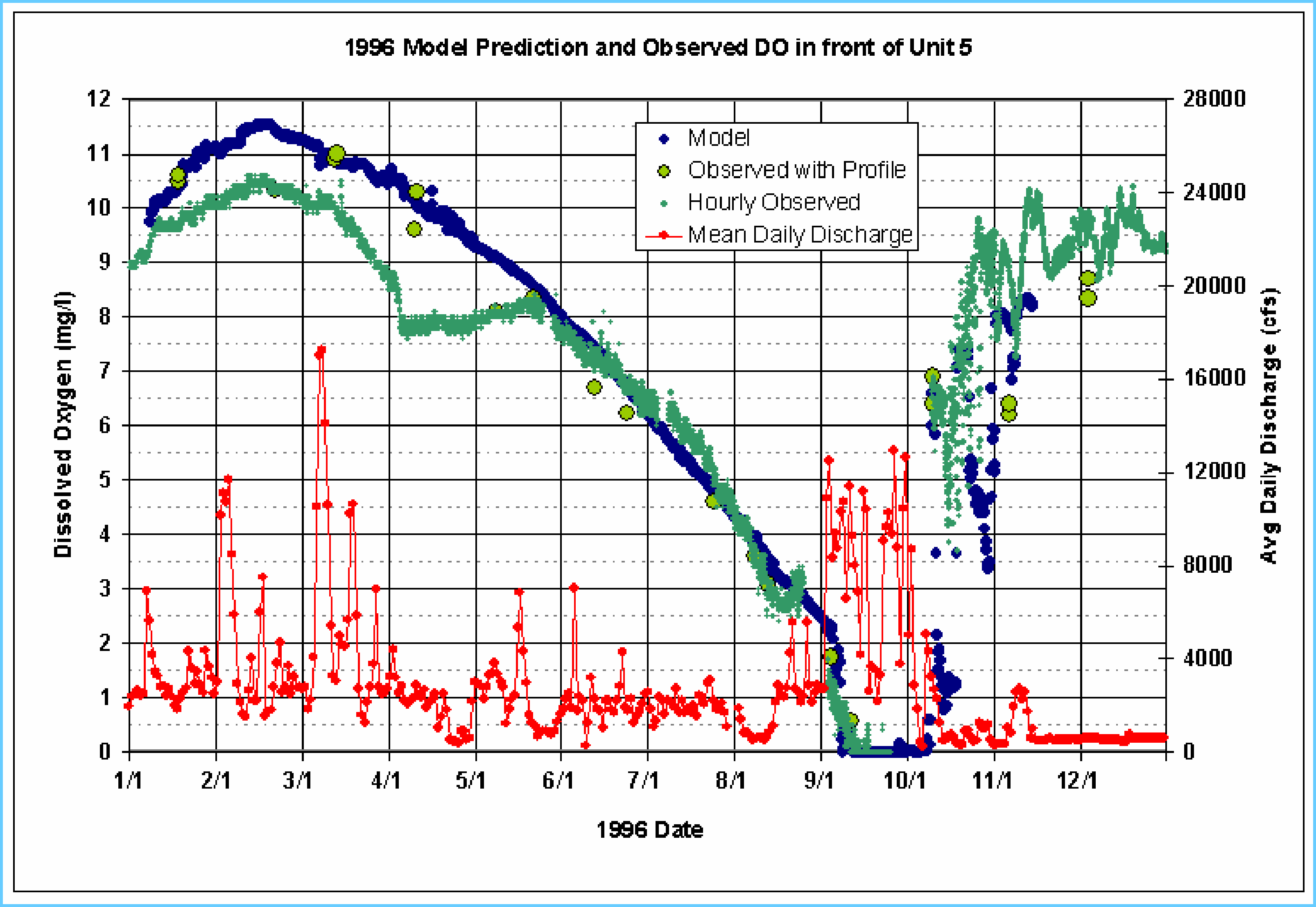
1997 Comparison of Modeled versus Measured Saluda Release DO



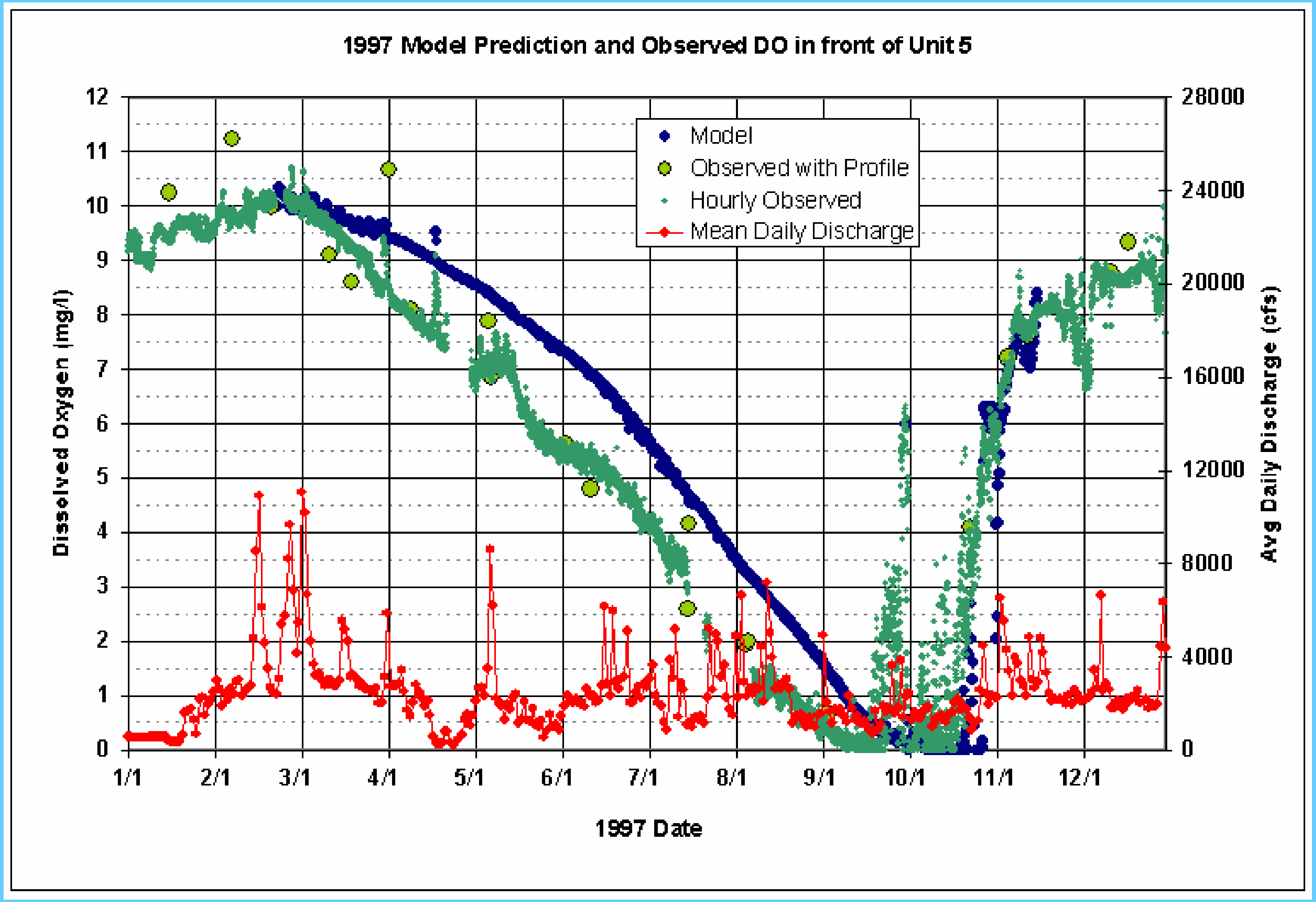
1992 Modeled versus Measured DO at the level of the Unit 5 Intake



1996 Modeled versus Measured DO at the level of the Unit 5 Intake



1997 Modeled versus Measured DO at the level of the Unit 5 Intake



1996 Statistics

1996 Temperature

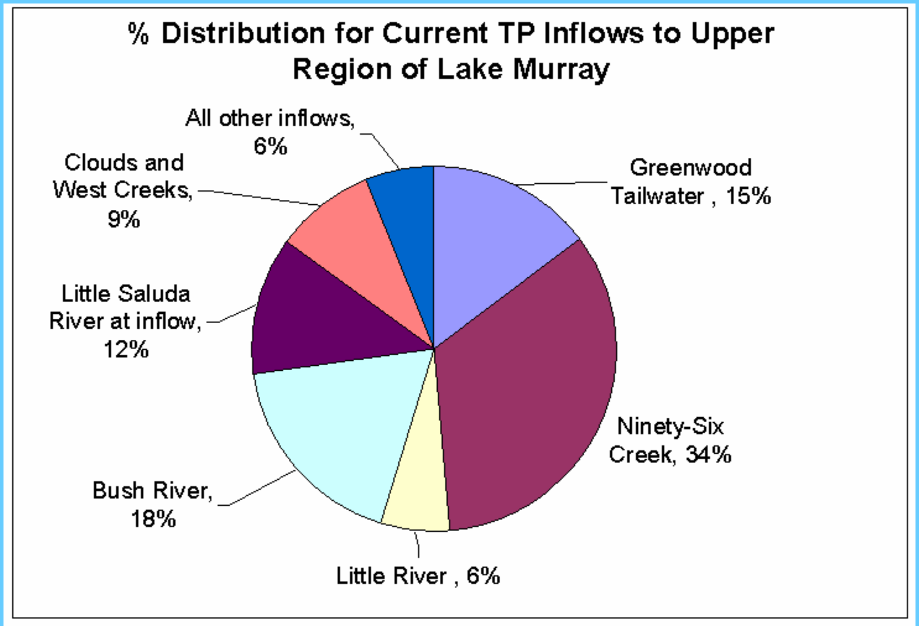
		Kilometers From Dam									
		0.0		2.5		12.3		19.3		Average	
Date	**Julian Day**	**AME**	**RMS**	**AME**	**RMS**	**AME**	**RMS**	**AME**	**RMS**	**AME**	**RMS**
2/21-22	**52-53**	0.14	0.22	0.12	0.13	0.25	0.47	0.22	0.44	**0.18**	**0.32**
3/13-14	**73-74**	0.51	0.57	0.47	0.51	0.48	0.52	0.52	0.70	**0.50**	**0.58**
4/10-11	**101-103**	0.43	0.56	0.43	0.51	0.50	0.60	0.46	0.60	**0.45**	**0.57**
5/22-23	**143-144**	0.51	0.79			0.69	1.03	0.63	0.85	**0.61**	**0.89**
6/24-25	**176-177**	0.42	0.53	0.46	0.69	0.43	0.63	0.54	0.80	**0.47**	**0.66**
7/25-26	**207-208**	0.40	0.47	0.60	0.73	0.67	0.94	0.61	0.75	**0.57**	**0.72**
8/13-14	**226-227**	0.45	0.53	0.40	0.47	0.45	0.63	0.76	1.09	**0.52**	**0.68**
9/11-13	**255-257**	0.67	0.75	0.56	0.62	0.39	0.52	0.17	0.21	**0.45**	**0.52**
10/9-10	**283-284**	0.58	0.65	0.50	0.57	0.91	0.99	0.83	0.90	**0.71**	**0.78**
11/5-6	**310-311**	0.07	0.11	0.17	0.18	0.19	0.22	0.04	0.05	**0.12**	**0.14**
		0.42	**0.52**	**0.41**	**0.49**	**0.50**	**0.65**	**0.48**	**0.64**	**0.45**	**0.57**

1996 DO

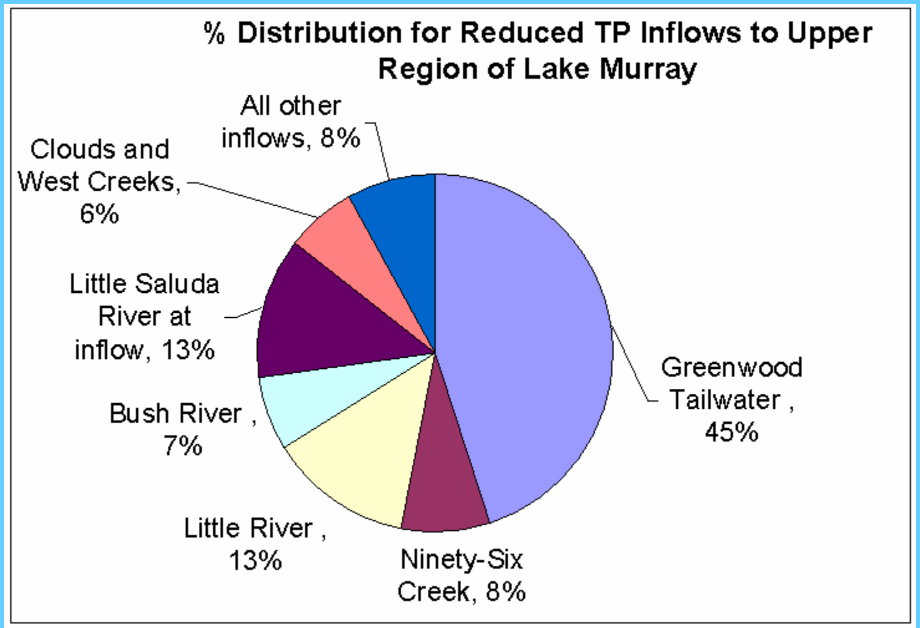
		Kilometers From Dam									
		0.0		2.5		12.3		19.3		Average	
Date	**Julian Day**	**AME**	**RMS**	**AME**	**RMS**	**AME**	**RMS**	**AME**	**RMS**	**AME**	**RMS**
2/21-22	**52-53**	1.04	1.04	1.04	1.04	0.62	0.67	0.78	0.82	**0.87**	**0.89**
3/13-14	**73-74**	0.10	0.18	0.21	0.23	0.24	0.28	0.48	0.56	**0.26**	**0.31**
4/10-11	**101-103**	0.46	0.49	0.56	0.59	0.82	0.88	1.10	1.21	**0.73**	**0.79**
5/22-23	**143-144**	0.45	0.63			0.39	0.44	0.74	0.85	**0.53**	**0.64**
6/24-25	**176-177**	0.40	0.48	0.75	0.87	0.62	0.74	0.64	0.92	**0.60**	**0.75**
7/25-26	**207-208**	0.67	0.95	1.01	1.27	0.49	0.73	0.91	0.99	**0.77**	**0.98**
8/13-14	**226-227**	0.38	0.56	0.82	0.98	0.50	0.62	0.62	1.20	**0.58**	**0.84**
9/11-13	**255-257**	0.30	0.39	0.24	0.45	0.60	0.93	0.79	1.12	**0.48**	**0.72**
10/9-10	**283-284**	0.69	1.56	0.93	1.52	0.83	0.90	1.36	1.37	**0.95**	**1.34**
		0.50	**0.70**	**0.69**	**0.87**	**0.57**	**0.69**	**0.82**	**1.00**	**0.65**	**0.81**

Distribution of TP Loads to the Upper Region of Lake Murray

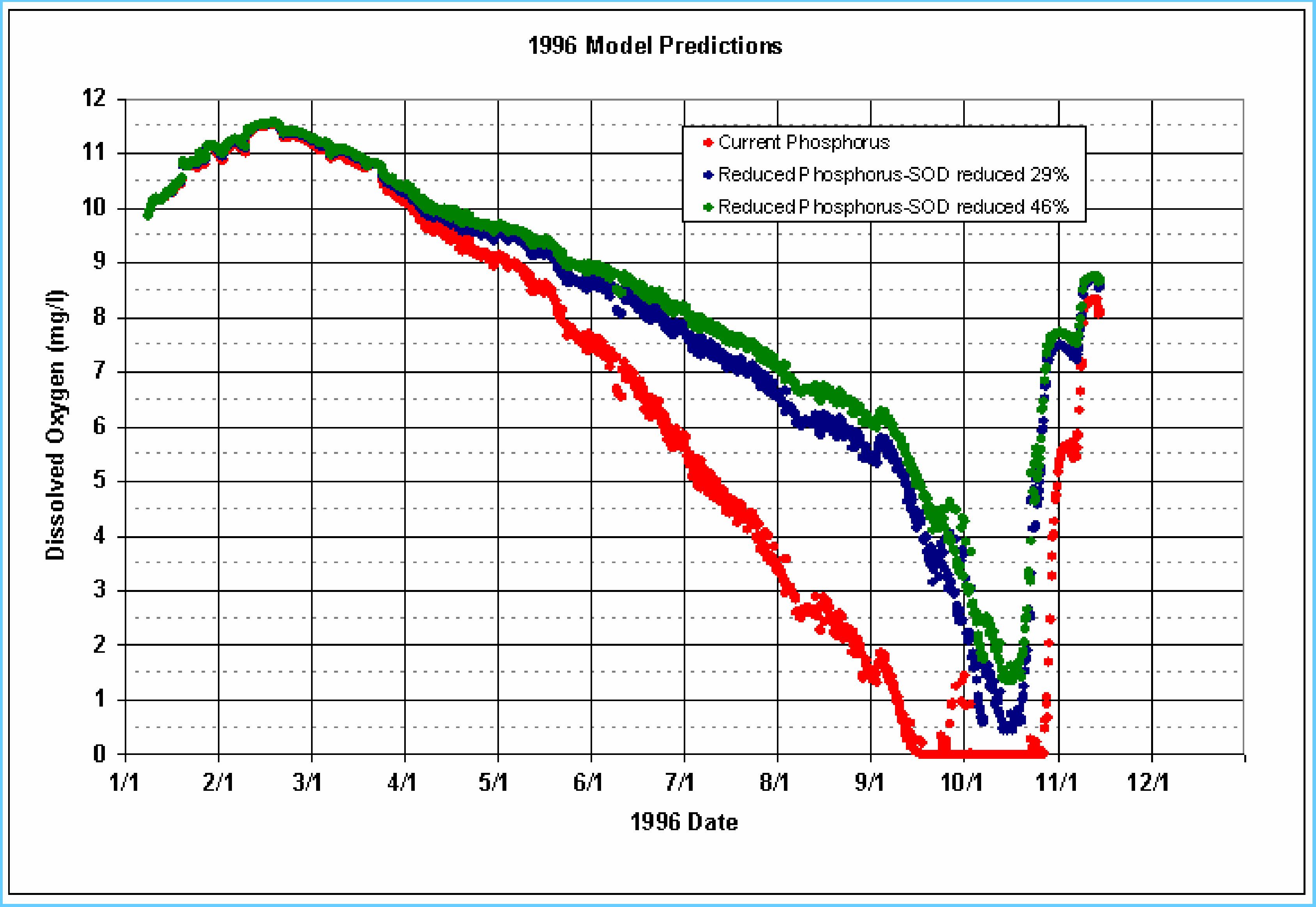
Current



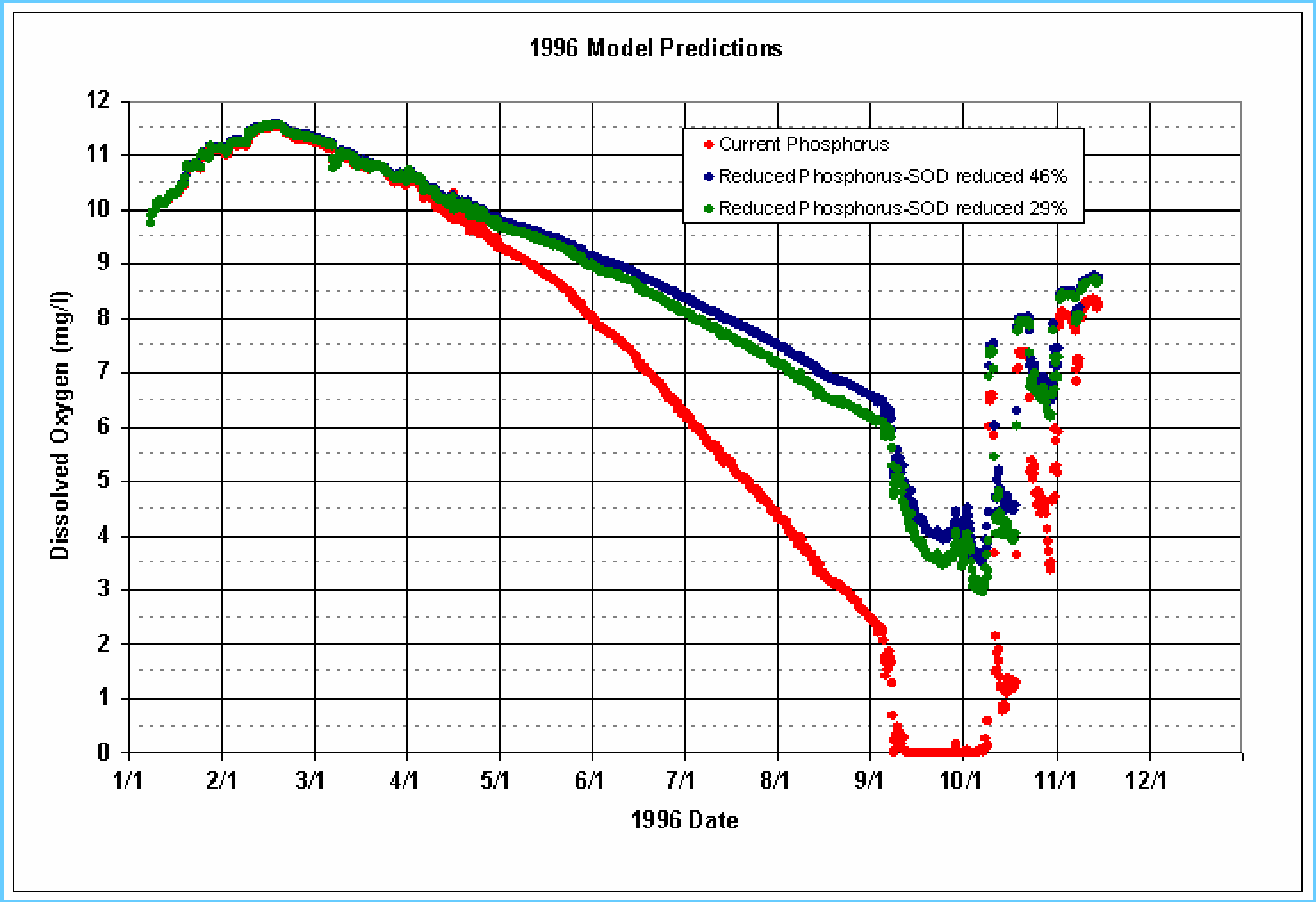
Assumed Reductions in TP



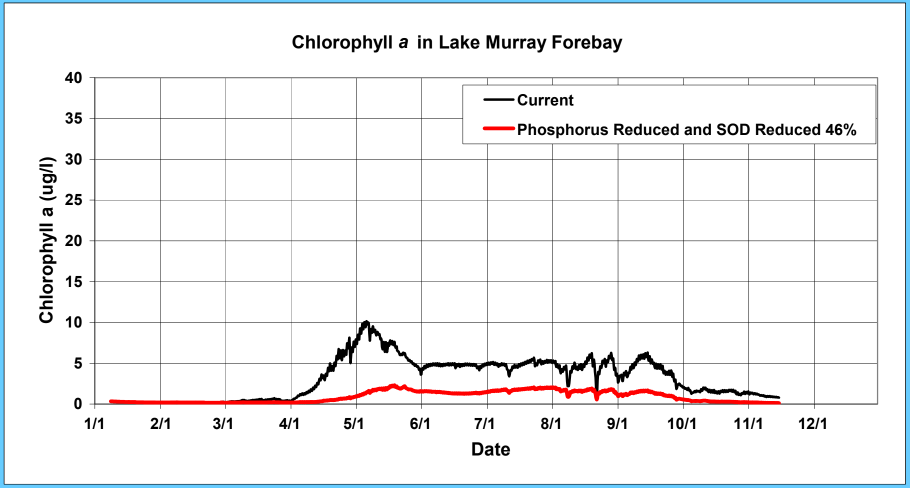
1996 Discharge DO for Current Phosphorus Loads and Two Scenarios for Reduced Phosphorus

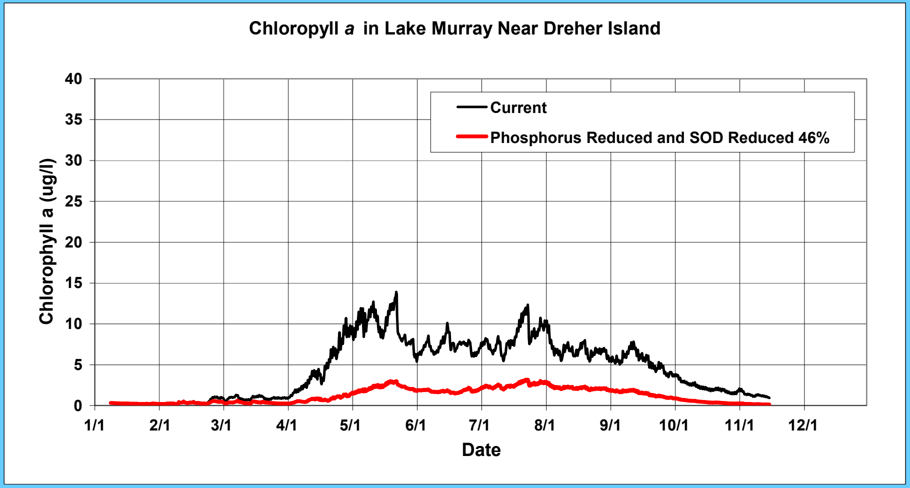


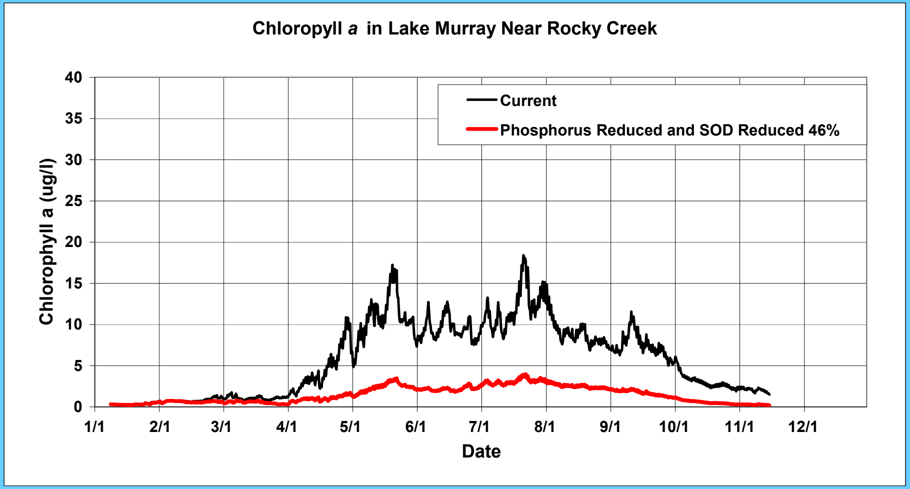
1996 DO at the Level of the Unit 5 Intake for Current and Reduced Phosphorus

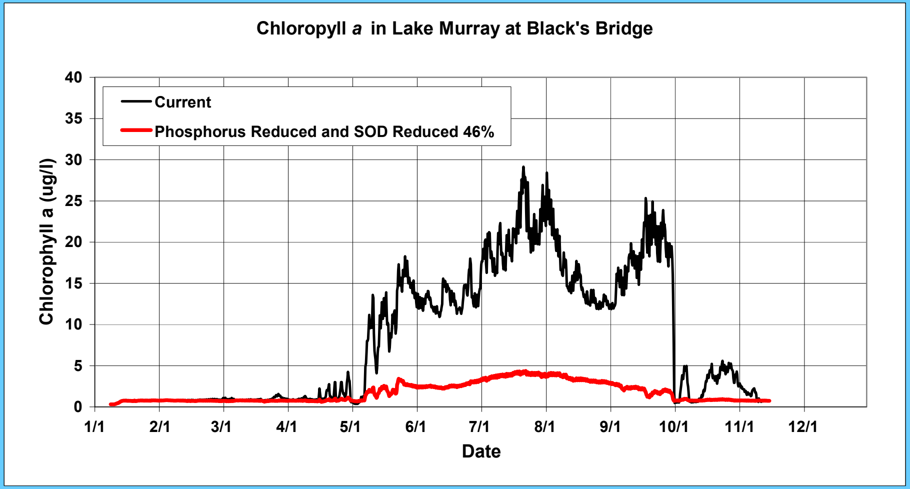


Comparison of 1996 Current and Reduced Phosphorus Predictions of Chlorophyll *a* at 1 Meter Depth at Four Locations in Lake Murray





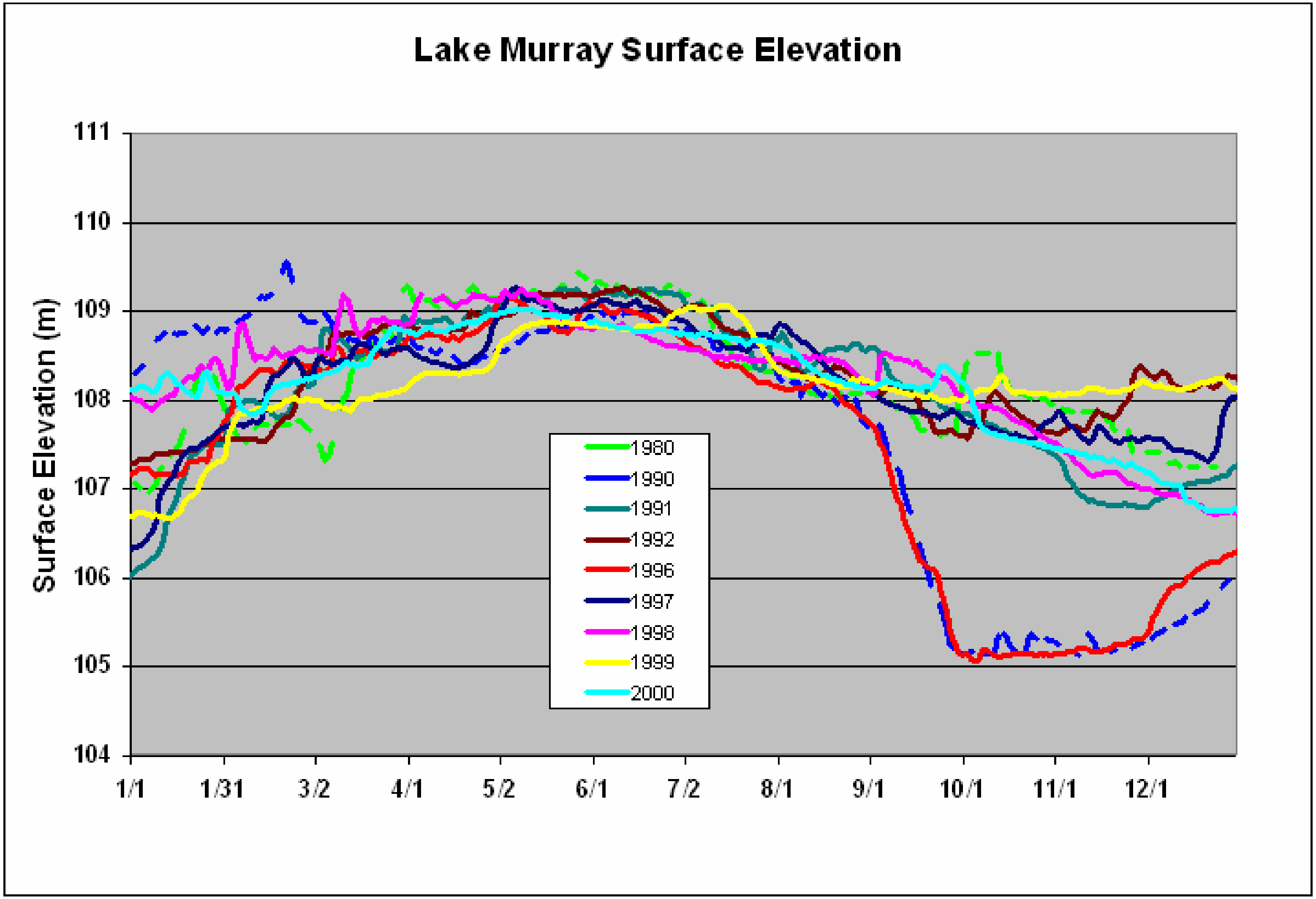




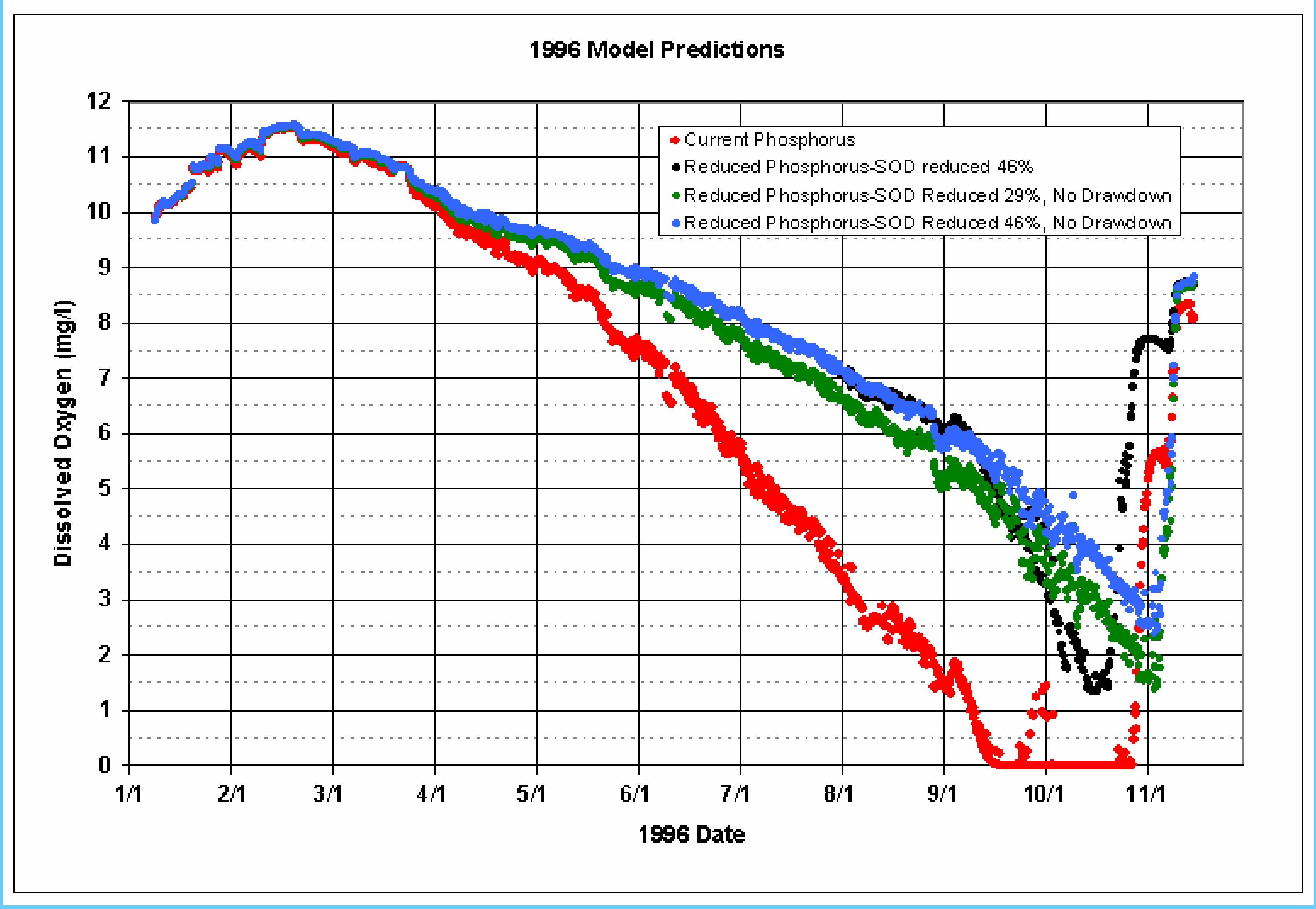
Animation

Current vs. Reduced Phosphorus

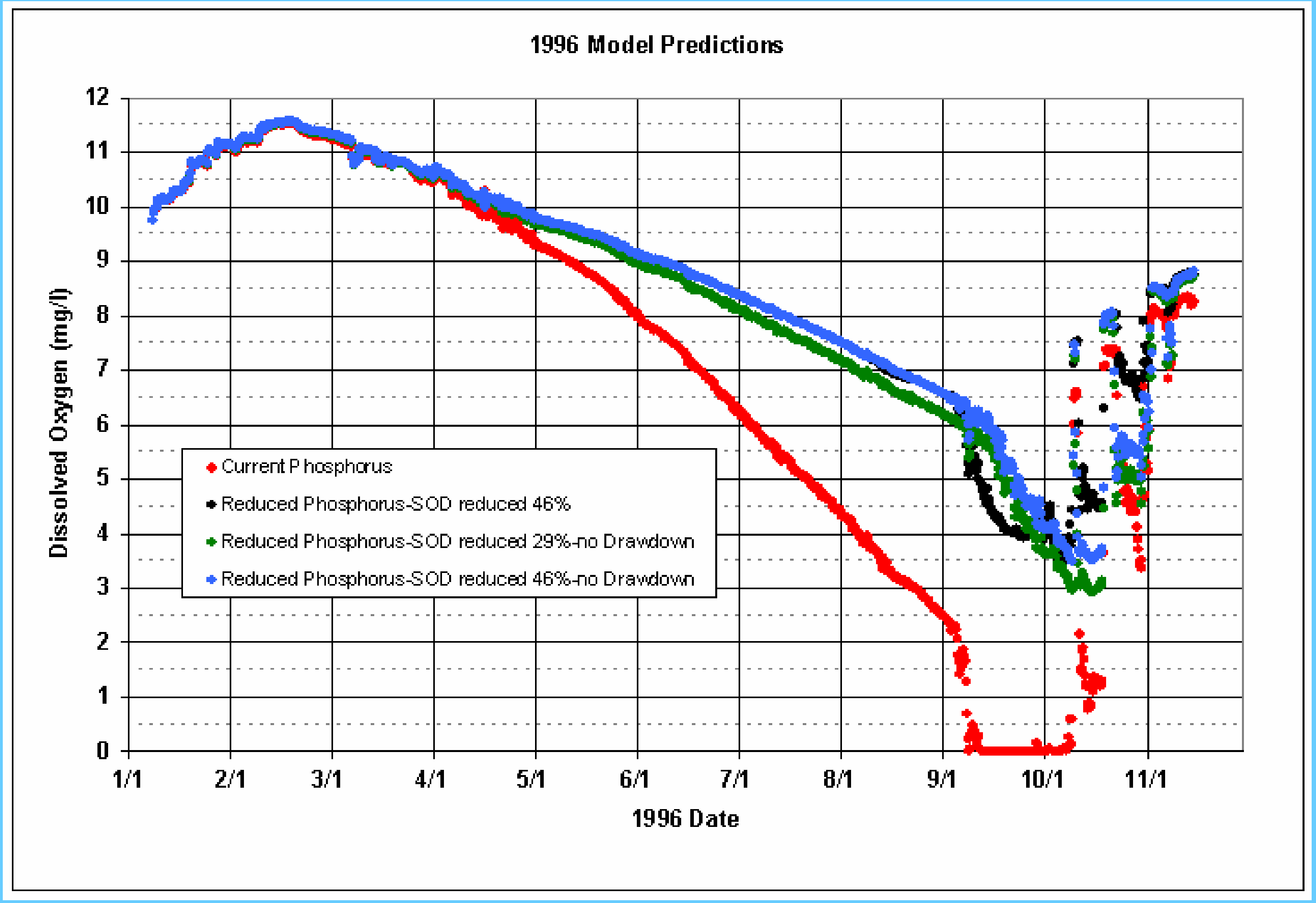
Comparison of Water Surface Elevations for Various Years at Lake Murray



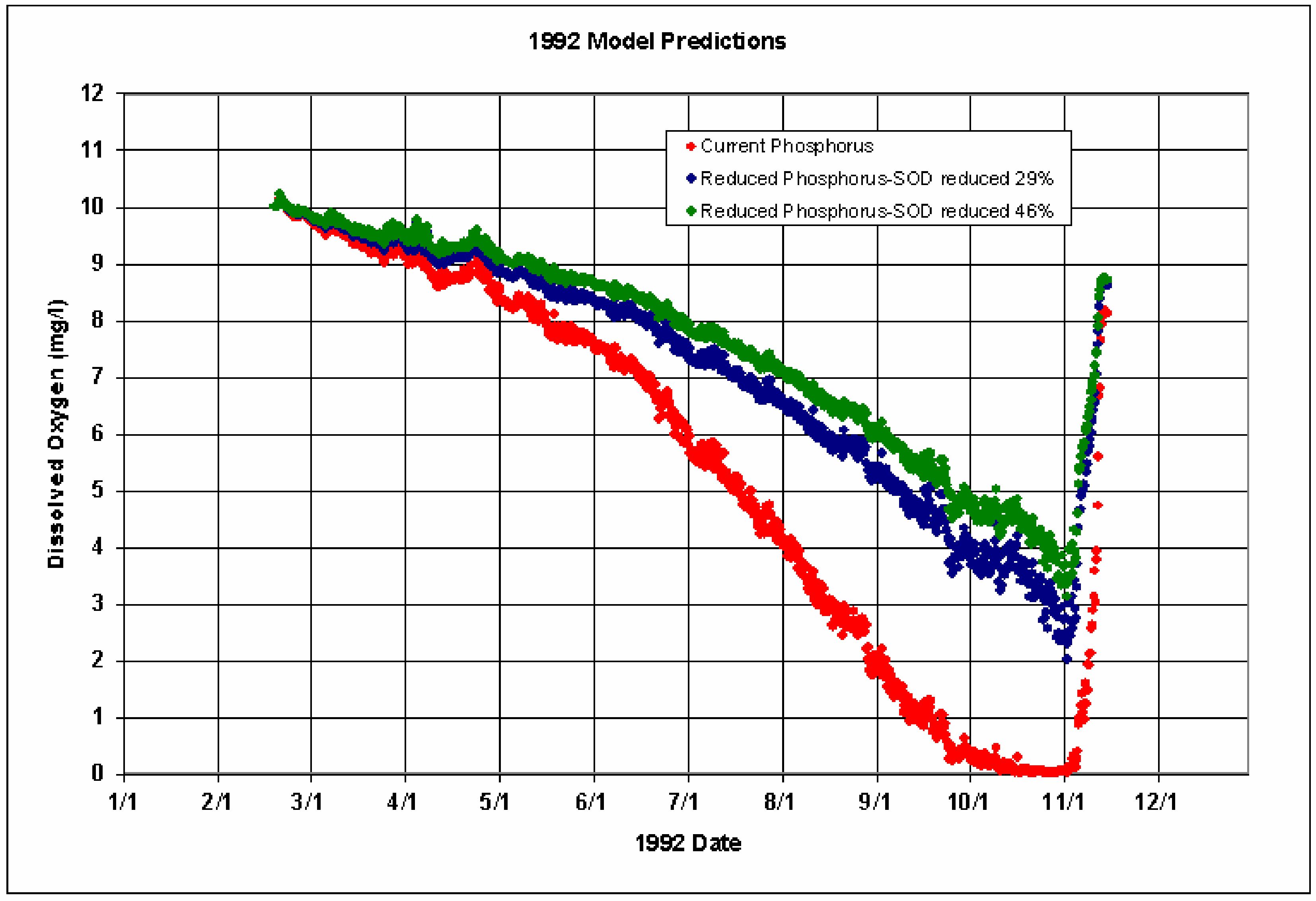
1996 Discharge DO for Current and Reduced Phosphorus, and without the Special Drawdown



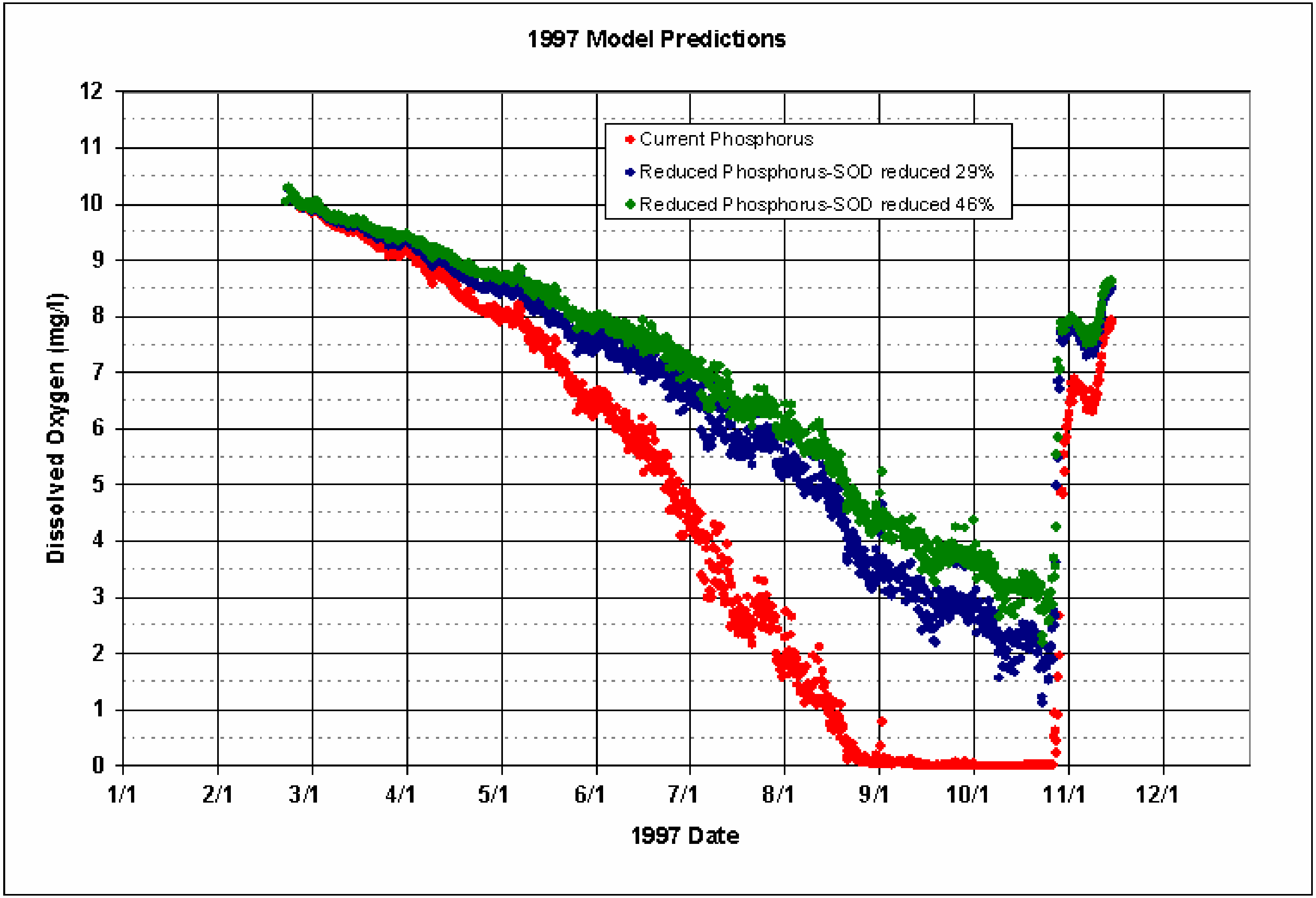
1996 DO at the Elevation of the Unit 5 Intake for Current and Reduced Phosphorus, and without the Special Drawdown



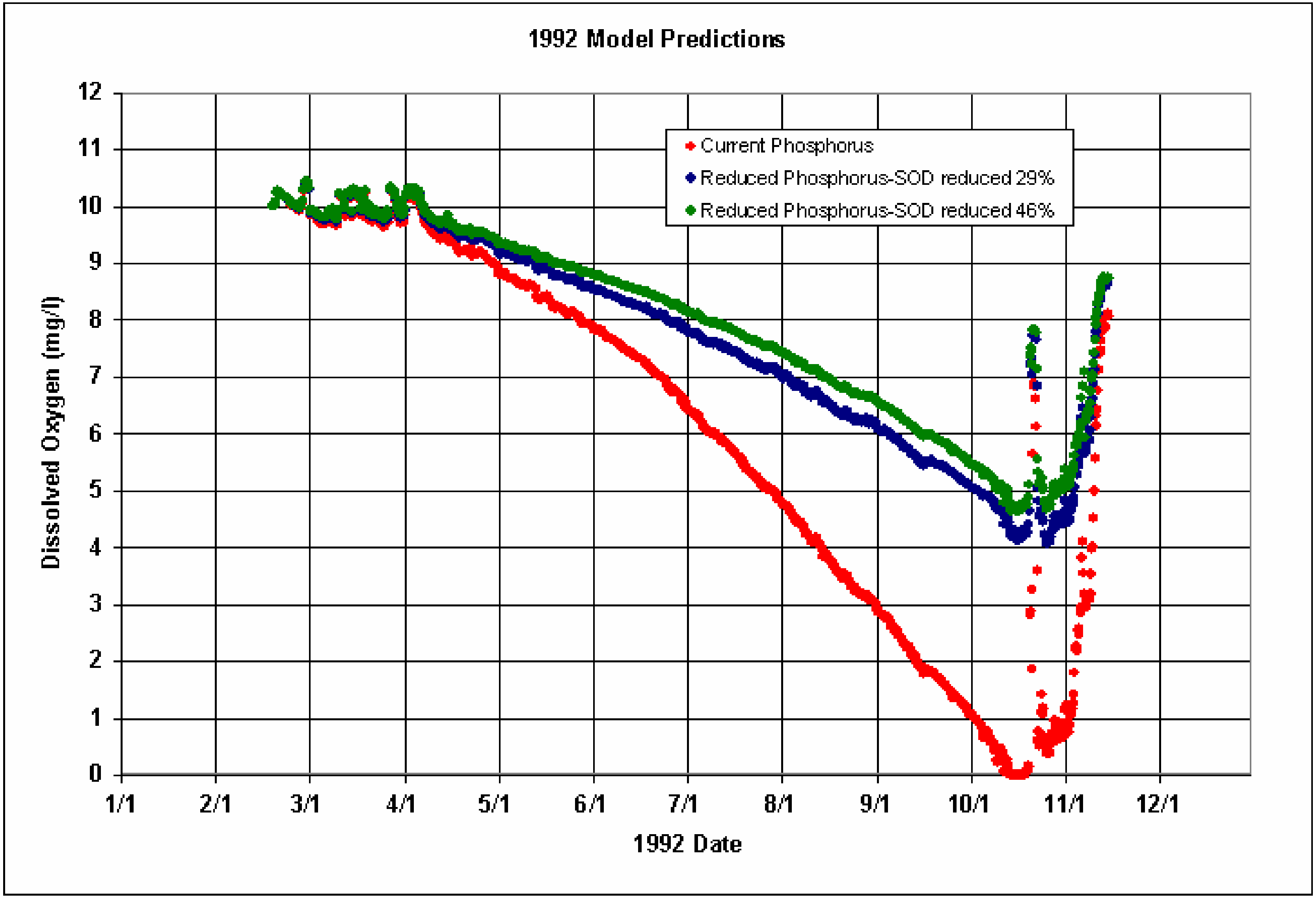
1992 Discharge DO for Current and Reduced Phosphorus



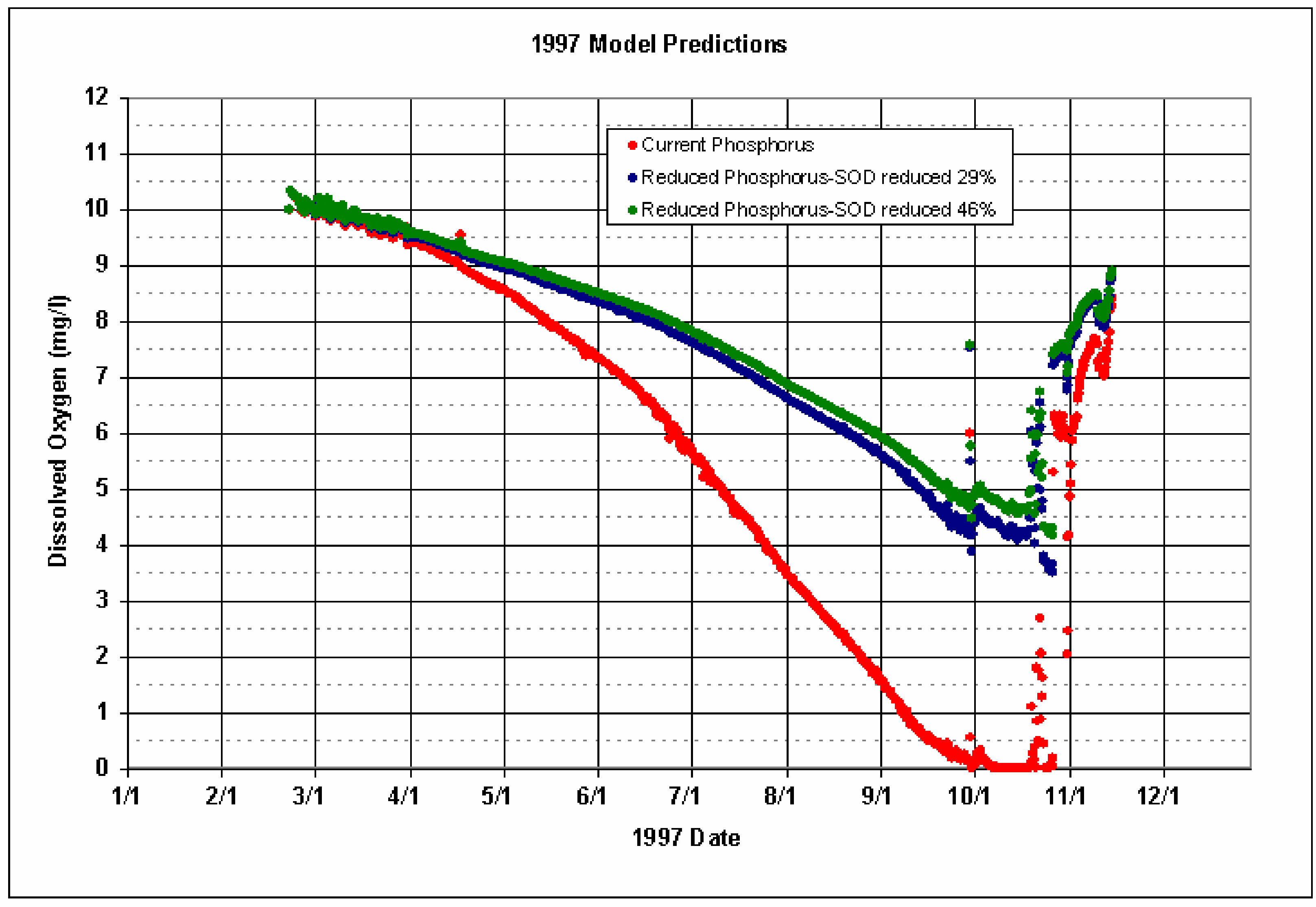
1997 Discharge DO for Current and Reduced Phosphorus



1992 DO at the Level of the Unit 5 Intake for Current and Reduced Phosphorus



1997 DO at the Level of the Unit 5 Intake for Current and Reduced Phosphorus



Animation

Striped Bass Habitat Highlighted

End

Water Quality Update

Lake Murray ----Lower Saluda River

December 7, 2005

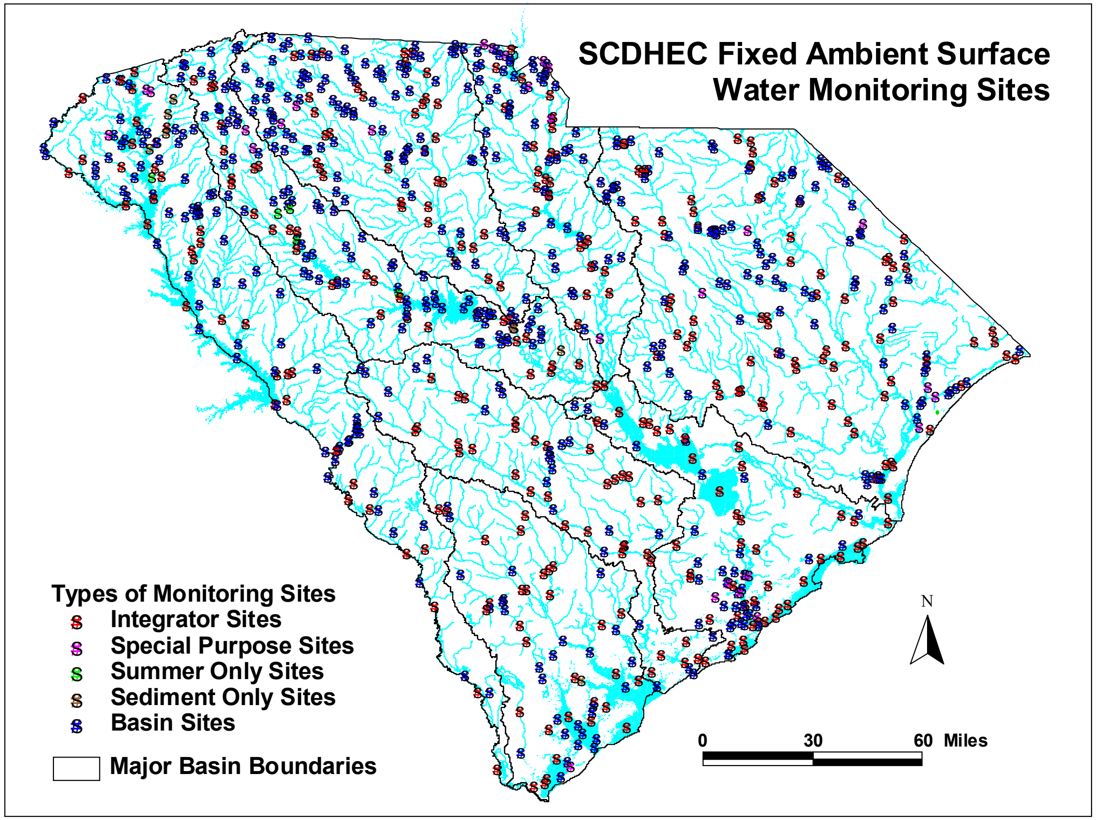
Andy Miller Watershed Manager

Saluda and Santee Basins

D H E C

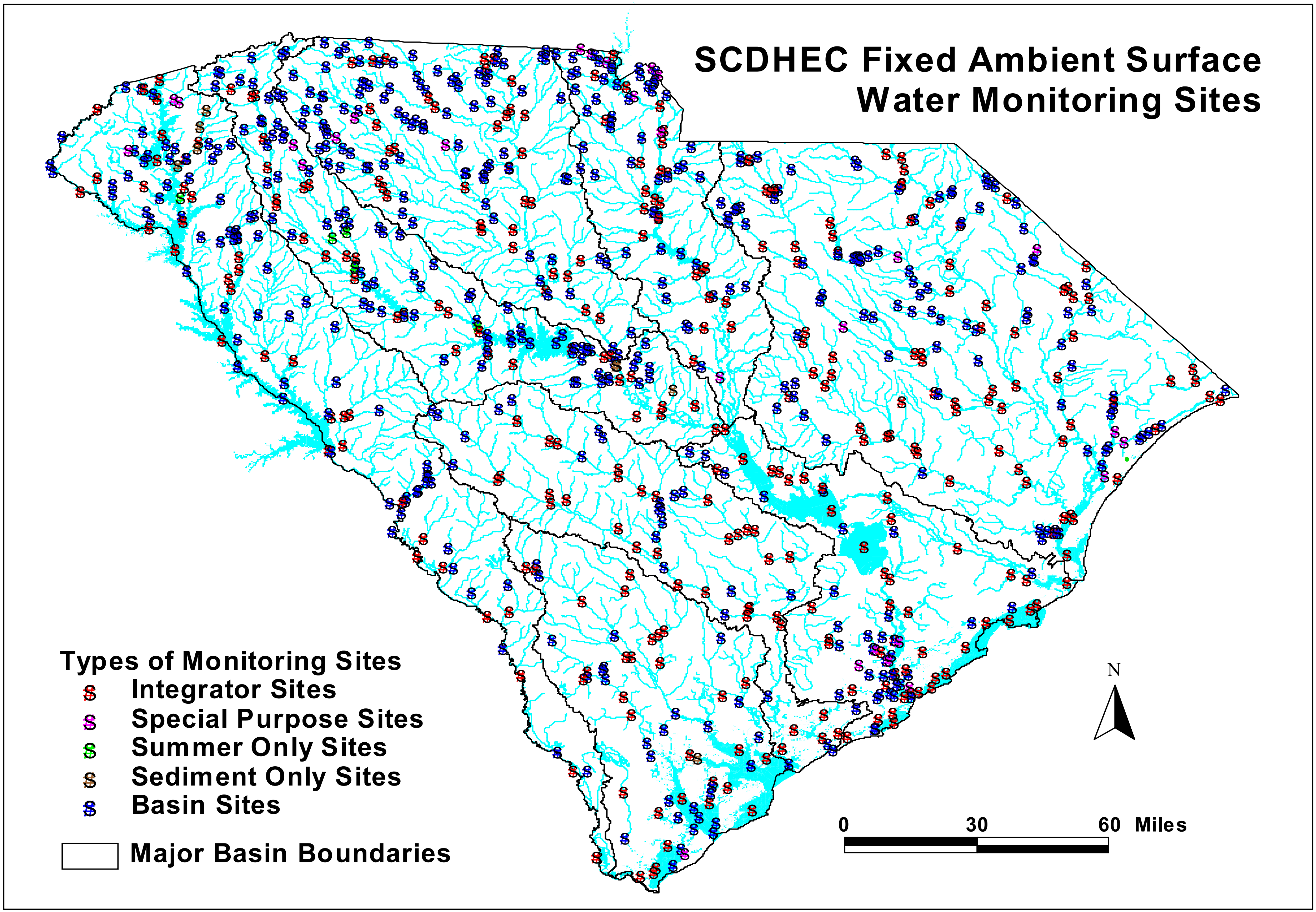
PROMOTE PROTECT PROSPER

State's Ambient Water Quality Monitoring Network



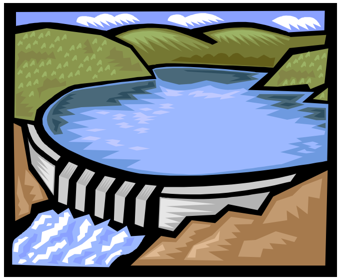
State's Ambient Water Quality Monitoring Network

- 1400 Stations State-wide
- 212,000 Water Quality Tests
  - Sampled by Regional Env. Quality Control Region Staff
  - Analysis at:
    - Field
    - Regional Labs
    - Central Lab-Parklane Rd Columbia


SCDHEC Fixed Ambient Surface Water Monitoring Sites
Types of Monitoring Sites
Integrator Sites
Special Purpose Sites
Summer Only Sites
Sediment Only Sites
Basin Sites
Major Basin Boundaries
N
0
30
60 Miles

Lake Murray –Lower Saluda Sites

- 41 Total Sites
  - 7 Integrator sites-Monthly every year
  - 23 Basin sites-Monthly every five years
  - 8 Random sites-Monthly for one year
  - 2 Special purpose-Monthly as needed
  - 1 Summer only



Lake Murray –Lower Saluda Sites

- 31 Lake Murray Watershed Sites
  - 18 Lake Sites
  - 14 Contributing watershed Stations
- 10 Lower Saluda Watershed Stations
  - 3 River stations
  - 7 Contributing watershed stations

Lower Saluda WQ Status '06

- 3 Sites meet criteria
  - S-152, S-298, S-149 Main stem of the L Saluda
- 7 Sites exceed criterion:
  - 6 fecal coliform
  - 4 aquatic macro invertebrates
  - 2 dissolved oxygen
  - 2 ph
  - 1 Mercury in fish tissue

New for '06:

S-149 Meets for FC

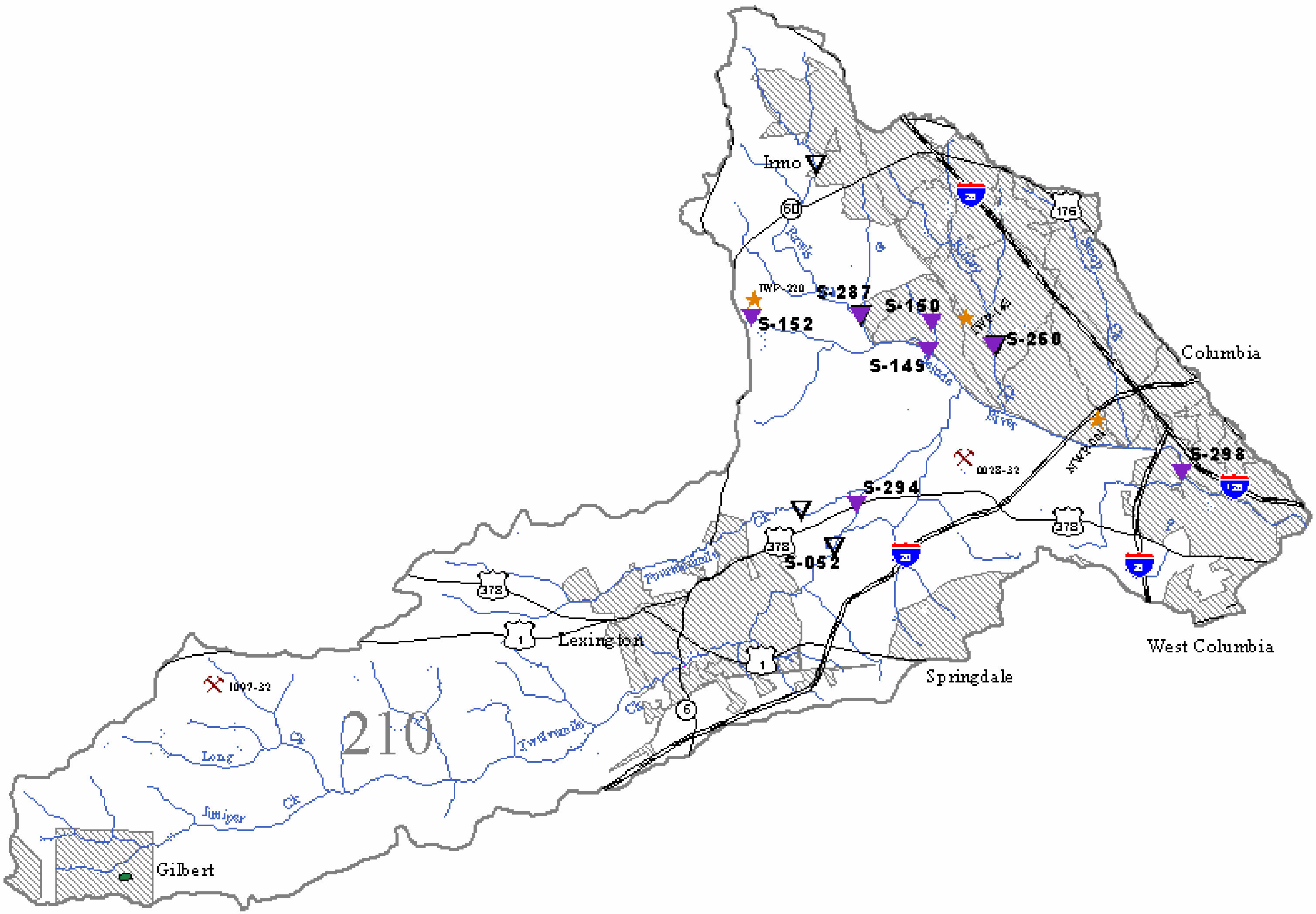
S-152 Meets for pH

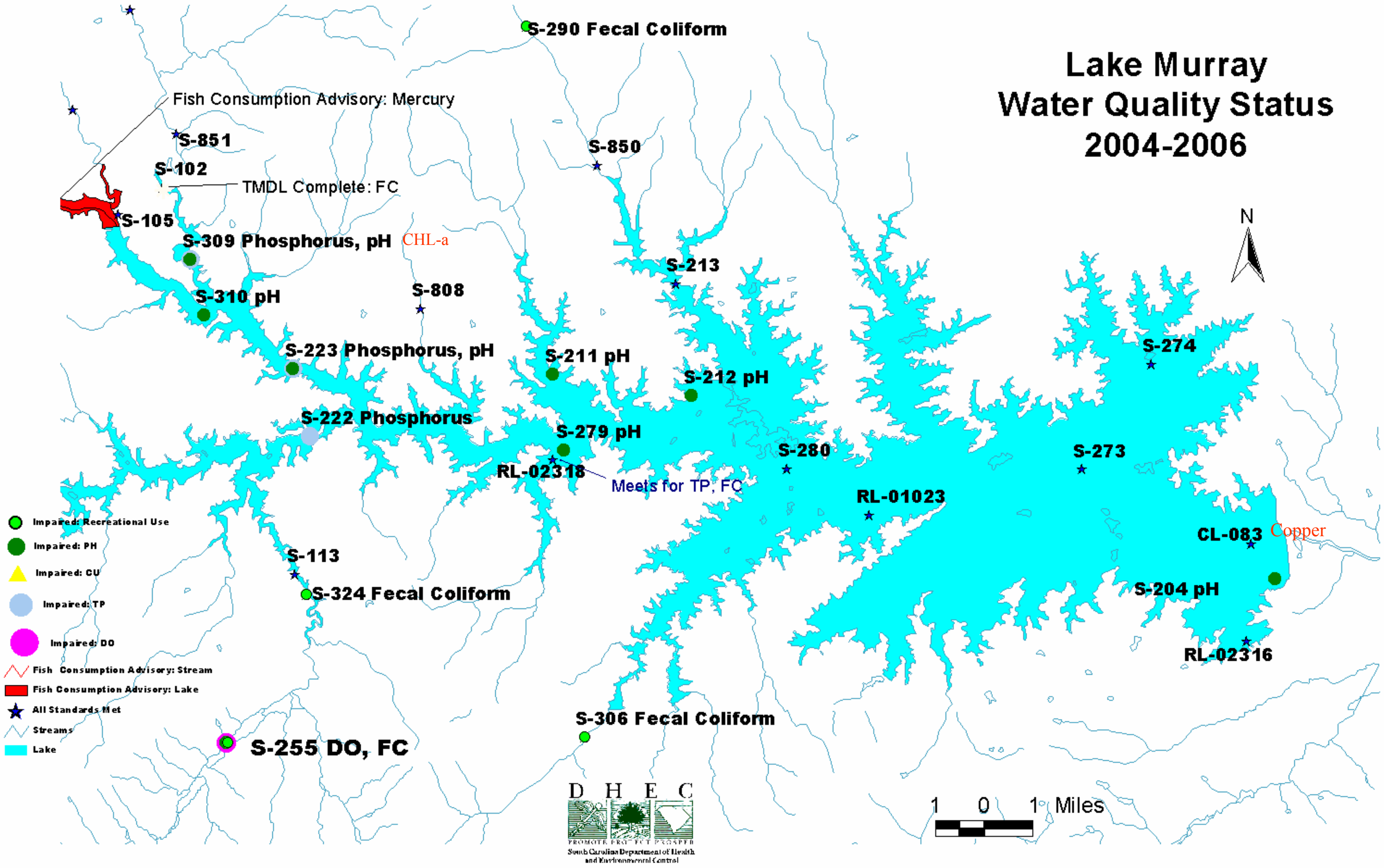
S-260 Exceeds for BIO

S-287 Exceeds for DO,pH

S-294 Exceeds for BIO,pH

Watershed Map Lower Saluda





Lake Murray
Water Quality Status
2004-2006
S-290 Fecal Coliform
Fish Consumption Advisory: Mercury
S-851
S-102
TMDL Complete: FC
S-105
S-309 Phosphorus, pH
CHL-a
S-850
S-213
S-808
S-310 pH
S-223 Phosphorus, pH
S-211 pH
S-212 pH
S-274
S-222 Phosphorus
S-279 pH
S-280
S-273
RL-02318
Meets for TP, FC
RL-01023
CL-083
Copper
S-113
S-324 Fecal Coliform
S-204 pH
RL-02316
S-306 Fecal Coliform
S-255 DO, FC
N
1 0 1 Miles
Impaired: Recreational Use
Impaired: PH
Impaired: CU
Impaired: TP
Impaired: DO
Fish Consumption Advisory: Stream
Fish Consumption Advisory: Lake
All Standards Met
Streams
Lake
D H E C
South Carolina Department of Health and Environmental Control

Lake Murray: WQ Status '06

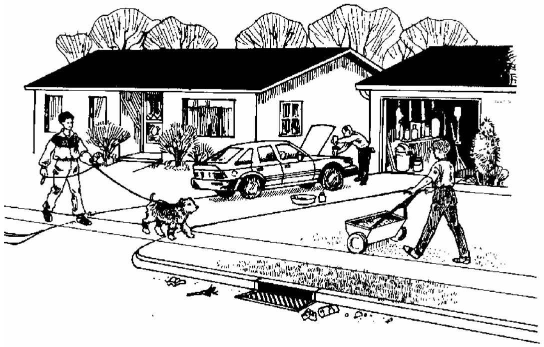
- Lake Stations
  - 9 Meet criteria(Eastern Side of Lake)
  - 10 Exceed criterion
    - 9 pH (High)
    - 2 Phosphorus
    - 1 Copper
    - 1 Chlorophyll-a
- Watershed Stations
  - 1 Meet criteria (Clouds Creek)
  - 13 Exceed criterion
  - 11 Fecal Coliform
    - 4 Dissolved Oxygen
    - 2 ph (low)
    - 1 Aquatic macro-invertebrates

New for 06:

S-279 now meets for P, FC
S-309 exceeds for chl-a
CL-083 exceeds for copper

Sources

- Point
  - Domestic wastewater treatment
  - Industrial
- Nonpoint
  - Urban
  - Agricultural
  - Atmospheric deposition



For further information

- SC list of Impaired Waters (303d list)
  - http://www.scdhec.gov/water/tmdl/index.html#303d
- South Carolina Surface Water Quality Program
  - http://www.scdhec.gov/water/html/surface.html

Call me:

- Andy Miller-Saluda-Santee Watershed manager
  - 803-898-4031

Developing a Site-Specific Dissolved Oxygen Standard for the Lower Saluda River

Fisheries and Wildlife and Water Quality
Resource Conservation Groups
Joint Meeting

December 7, 2005

Summary of DO Criteria and Standards

- Prior to the 1986 revision, the USEPA Criteria was a simple 5 mg/L minimum.
- This criterion was overprotective against acute mortality if rigorously applied.
- It was also potentially underprotective against chronic effects.
- In addition, states often used 5 mg/L as a daily mean value, allowing unacceptably lower true daily minima.

Criteria Improvement

- In the early 1980s EPA began developing new water quality criteria that included two numbers.
- One number protected against short-term lethal effects and the other protected against long-term chronic effects.
- A similar approach was needed to provide more adequate and scientific criteria for DO.

Key Features of the Latest EPA DO Criteria Approach

- The new DO criteria contained specific minima and long-term average concentrations for various habitats (e.g. cold-water fisheries).
- Growth was the most sensitive chronic effect and a 30-day moving average was recommended to protect growth.
- Monthly averages can be less protective by allowing continuous weeks of lower DO if they don't all happen to fall within the same month.

Latest EPA Trout-Water Criteria

- For survival of trout: a minimum of 3 mg/L.
- For growth protection: a 6.5 mg/L 30-day average.
- For sensitive cold-water invertebrates: a 4 mg/L minimum.

Site-specific DO Criteria

- Because the 6.5 mg/L 30-day mean is based upon continuous exposure to various DO levels in lab tests, EPA sought a way to apply these data to real-world situations with variable DO levels.
- **EPA and TVA jointly developed a fish growth model that integrates the growth effects of variable DO, allowing site-specific chronic standards to be set that are both protective and realistic**.

Model Calibration

- This modeling approach was used to develop a site-specific chronic standard for the LSR.

- To apply the TVA/EPA model to the LSR, Site-specific trout growth data were needed.

2002- 2003 Trout Growth Study

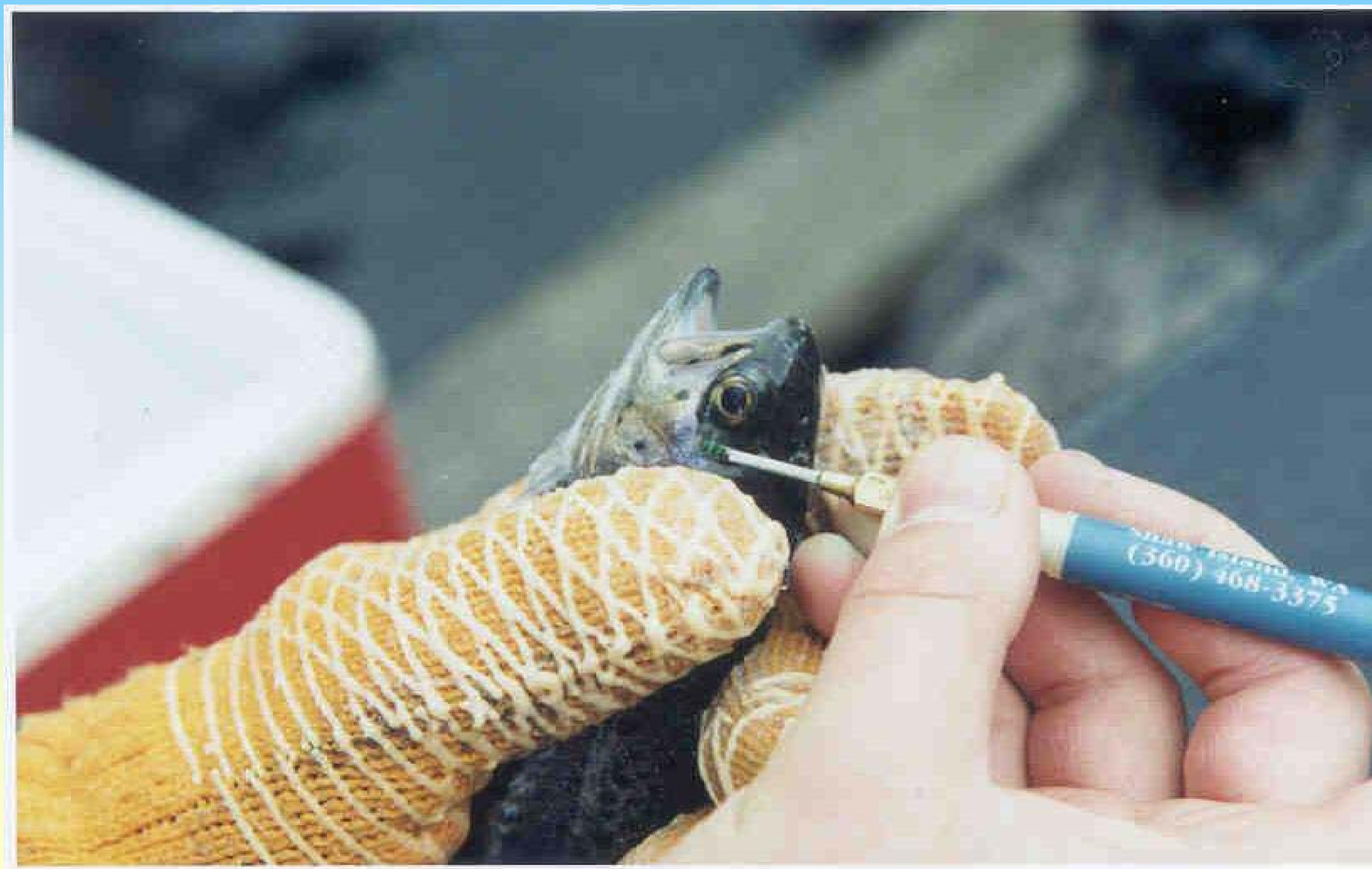
Objectives

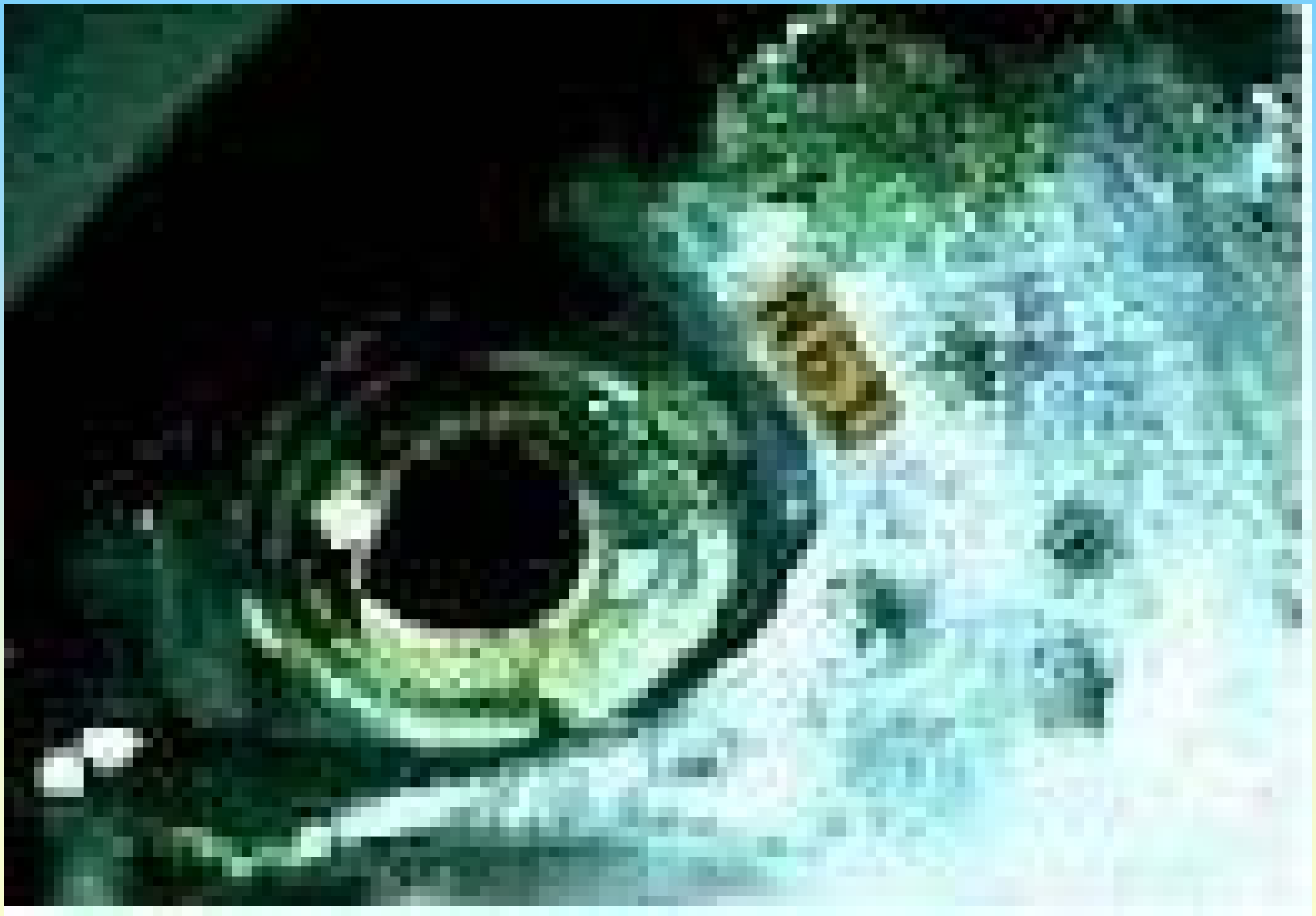
- Provide site-specific trout growth data for the LSR
- Provide a food availability term for the bioenergetics model
- Provide general indication of the suitability of current conditions in the LSR

Field Methods

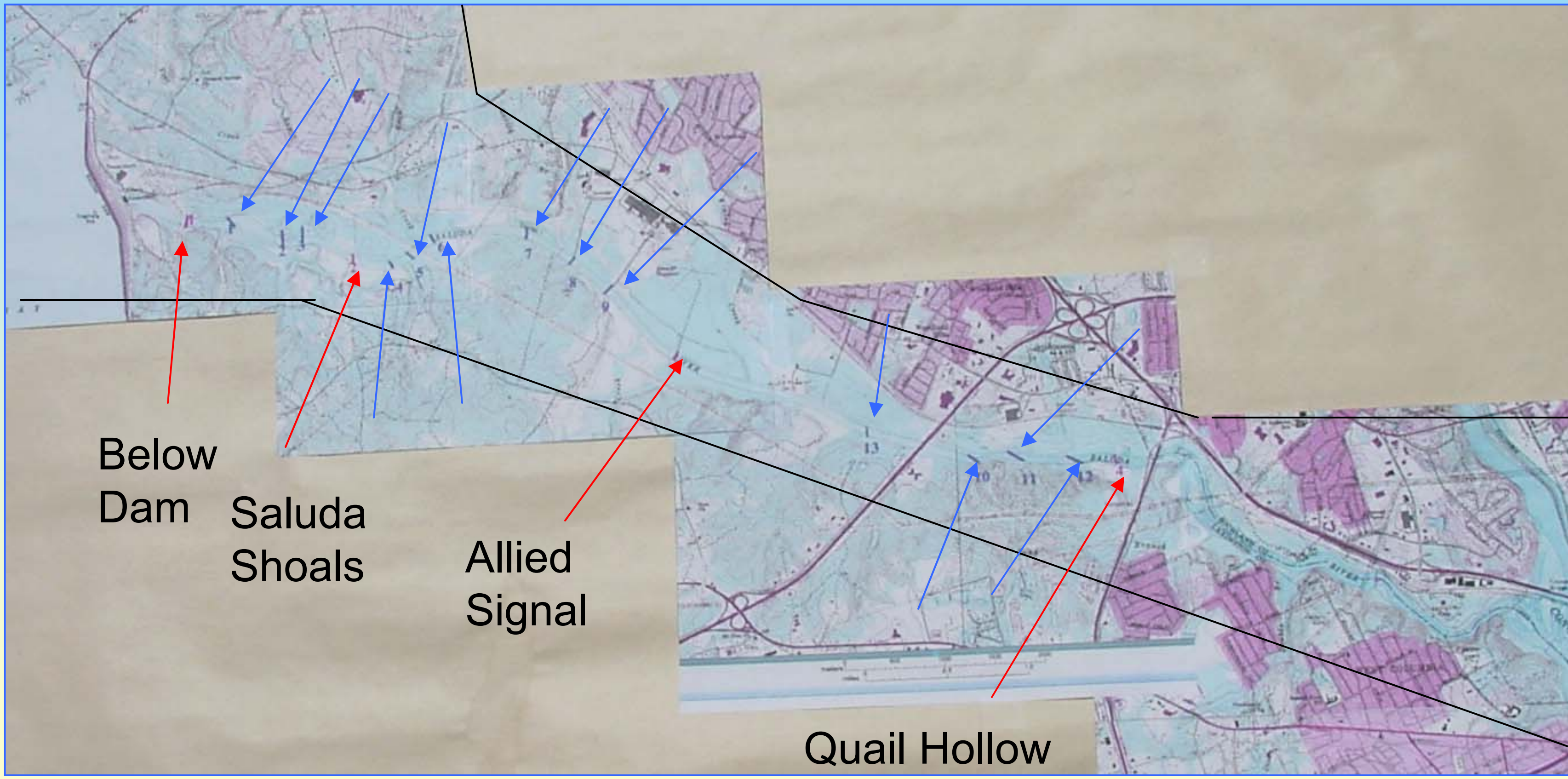
- Xxxxx rainbow trout were tagged at SCDNR's Walhalla Fish Hatchery
- Collaborative effort between Clemson University (USDA Coop Unit), SCDNR, SCE&G and Kleinschmidt

Vi-Alpha Tag Application





Release and Recapture Sites




N12WL


N12WL

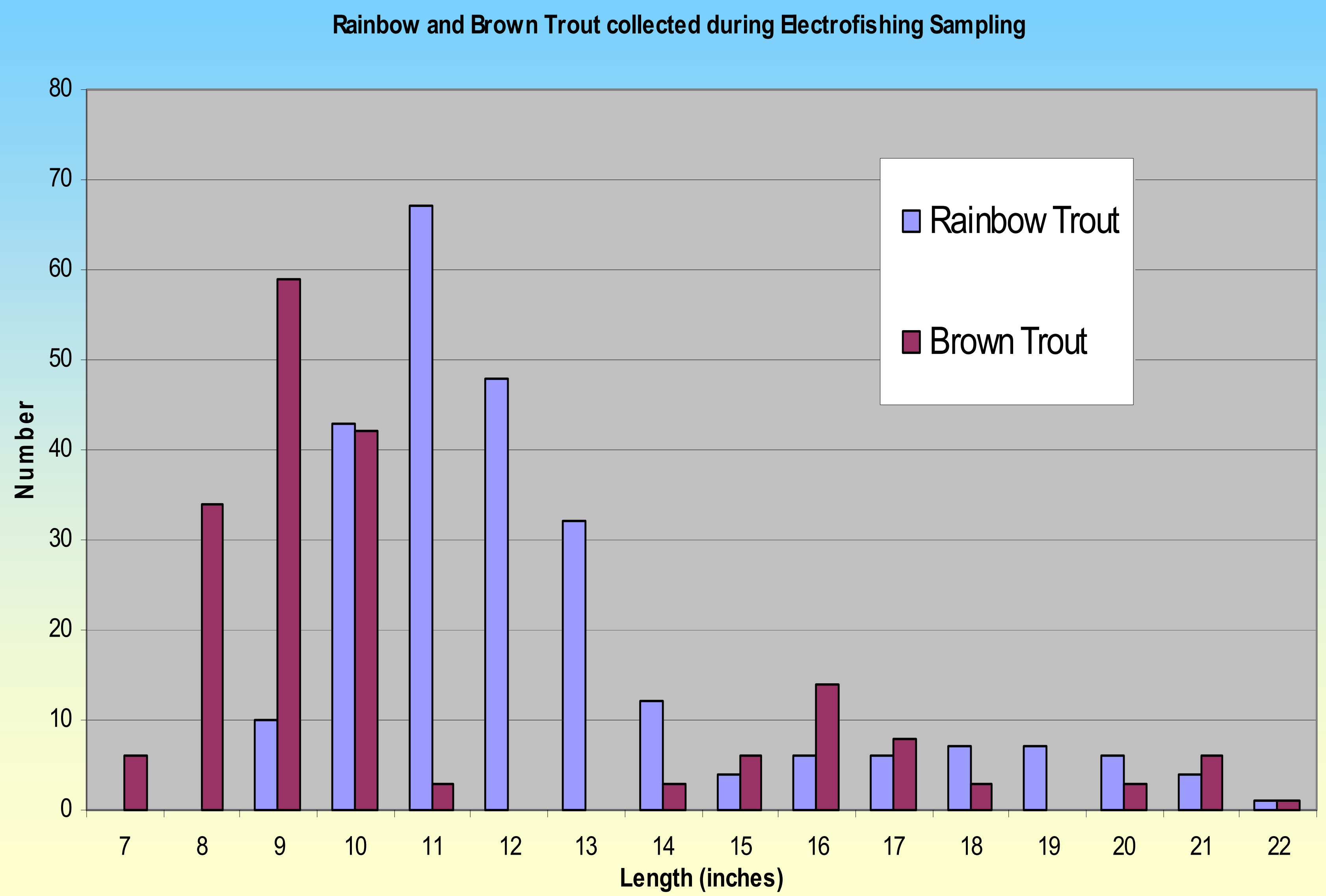
Recapture Results

- Fish collected in April, May and June through electrofishing and angler surveys

- Total of 111 fish recaptured

- Number of fish recaptured by stocking months

December	23
January	32
February	26
March	30


Rainbow and Brown Trout collected during Electrofishing Sampling
Number
0
10
20
30
40
50
60
70
80
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Length (inches)
Rainbow Trout
Brown Trout

Additional Trout Fishery Information Collected

- Total of 441 trout collected during sampling

253 Rainbow Trout: 225 – 550 mm (9 - 22 in)
188 Brown Trout: 175 – 550 mm (7 - 22 in)

37 Rainbow trout collected > 16 inches
35 Brown trout collected > 16 inches

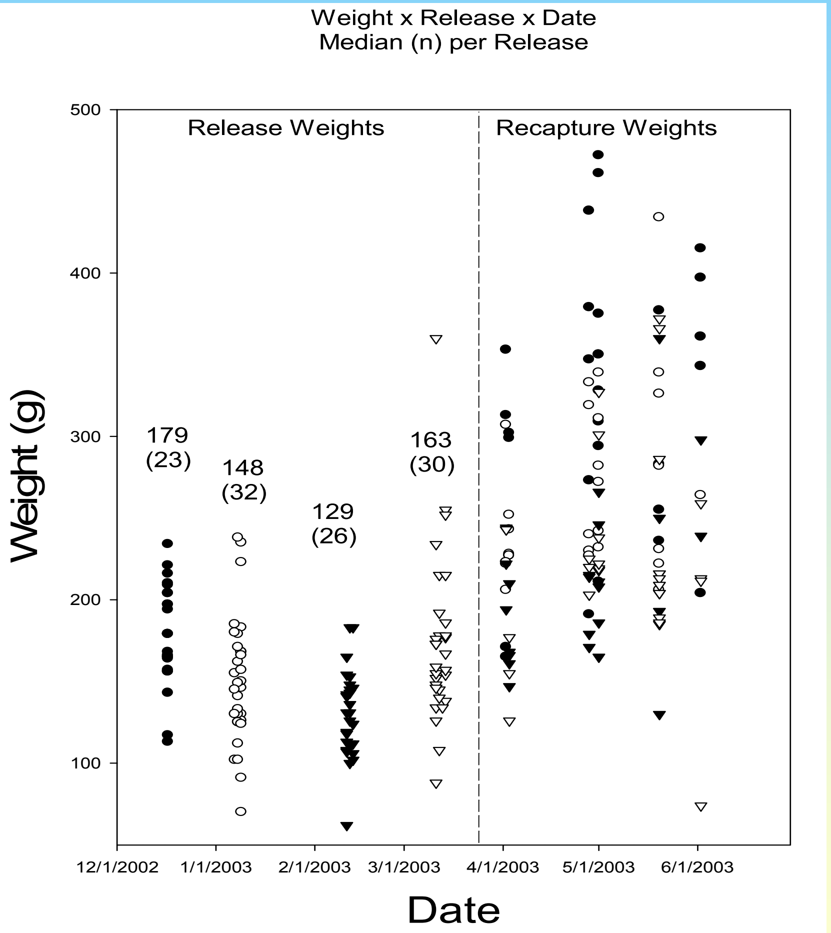
SCDNR collected 24 in brown trout during standardized sampling in May 2003

MODEL No. 118
wildco

General Observations

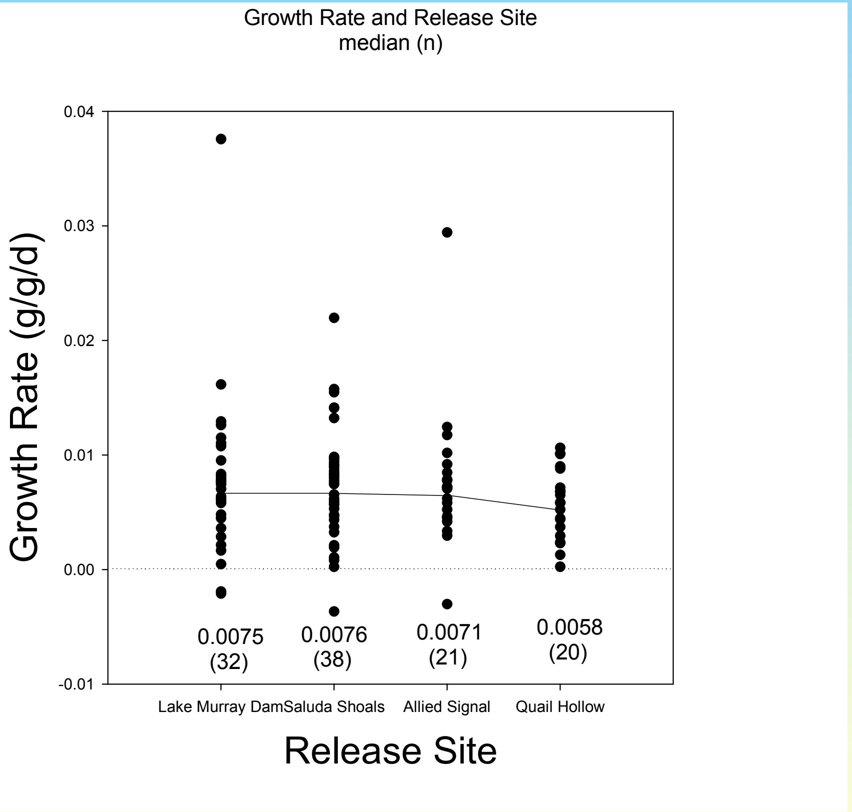
- Trout appear to be healthy
- Fish pressure for trout appears high
- Noticeable decline in trout numbers as striped bass moved in, especially small brown trout numbers
- Fisherman observed using rainbow trout as bait for Striped bass
- Movement of stocked trout limited but does sporadically occur
- Tagged Trout caught in Congaree River between Gervais Street Bridge and Railroad Trestle
- Trout appear to be feeding on Crayfish and Chironomids

Available Data from the Study



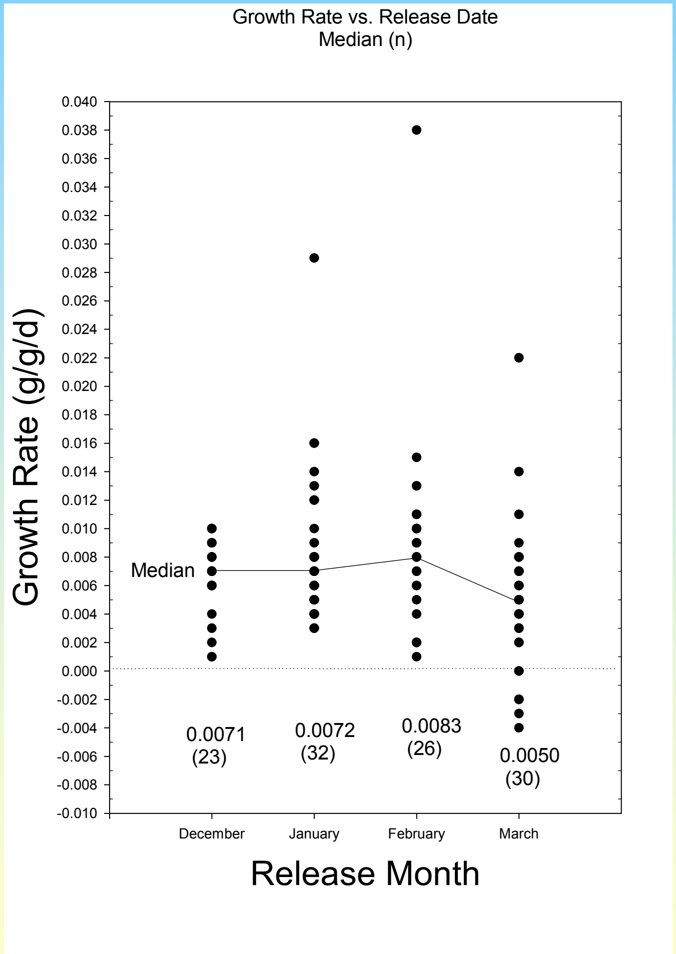
- A total of 111 fish were recaptured from the four releases.
- Detailed analysis of the data was needed to understand effects of size, movement in the stream, stocking site, stocking date and other factors.

Growth and Release Site



- Wide range in growth rate among individual fish at each sites
- Median growth rates similar among four sites, with but slightly lower at downstream site

Growth and Release Date



- Growth rates were similar between all release dates.
- Trout released in March grew at a slightly lower rate than other releases.

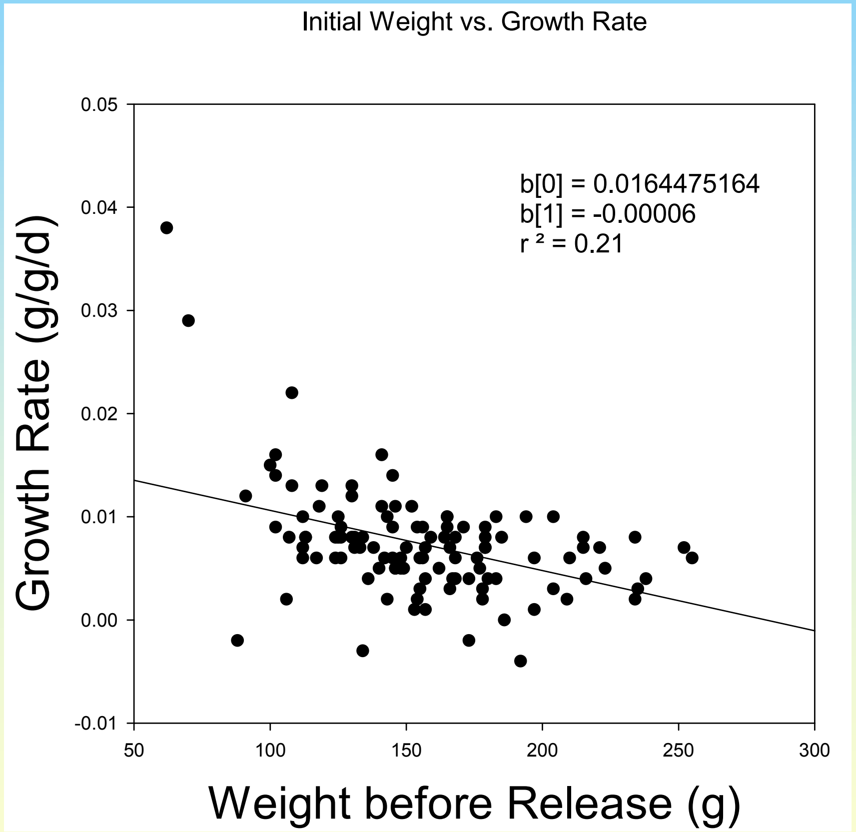
Median Growth Rates (g/g/d) by Site and Date of Release (n)

	Dec.	Jan.	Feb.	Mar.	All Months
Below Dam	0.0072 (2)	0.0070 (6)	0.0095 (11)	0.0048 (13)	0.0075 (32)
Saluda Shoals	0.0077 (11)	0.0083 (12)	0.0075 (9)	0.0063 (6)	0.0076 (38)
Allied Signal	0.0078 (6)	0.0065 (14)	No release	-0.0030 (1)	0.0071 (21)
Quail Hollow	0.0030 (4)	No release	0.0095 (6)	0.0055 (10)	0.0056 (20)
All Sites	0.0071 (23)	0.0072 (32)	0.0083 (26)	0.0056 (30)	0.0071 (111)

Factors with potential to influence growth in the study

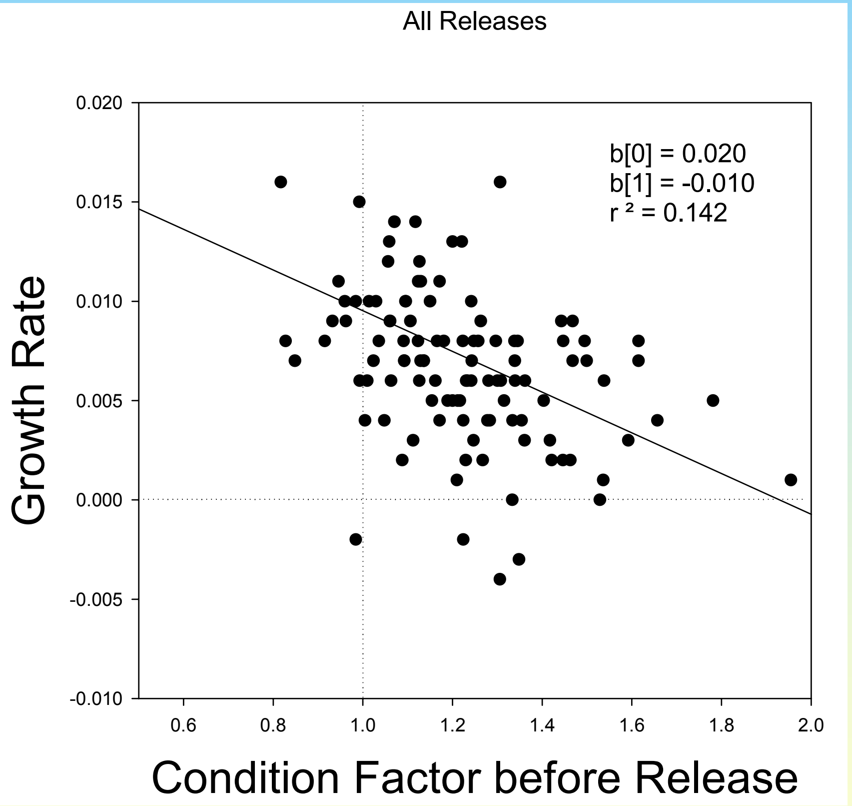
- Size of trout at release
- Condition of trout at release
- Location of recapture and possible residency
- Direction of movement after release (upstream or downstream)
- Distance traveled after release

Growth vs. Size at Release



- There was a slight tendency ($r^2 = 0.21$) of smaller fish to grow at a faster rate than larger fish.
- This is typical of fish with adequate rations.

Growth and Condition Factor

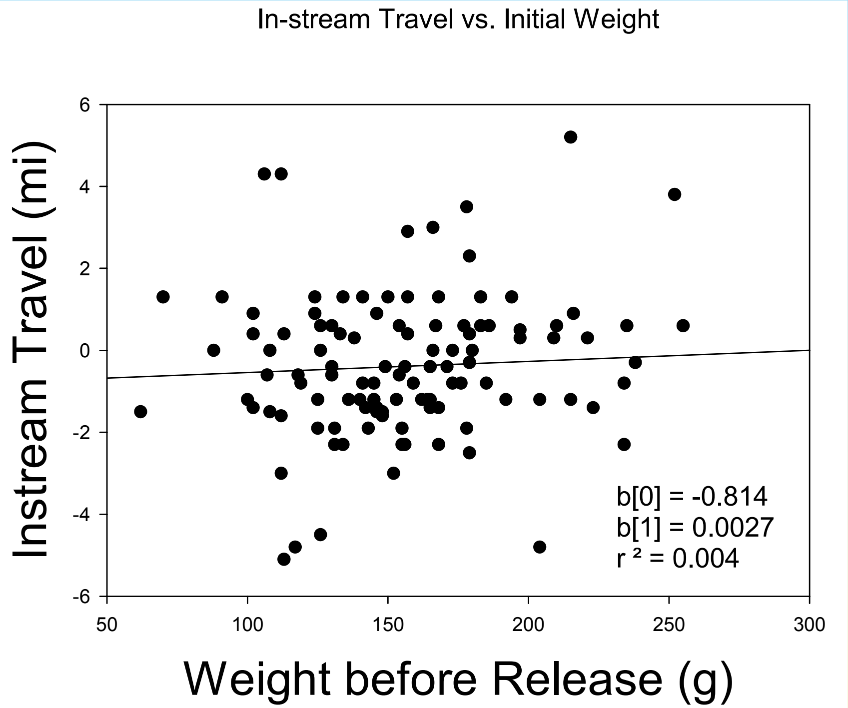


- There was also a tendency for higher growth rates for fish with lower initial condition factors.
- i.e., skinny fish grew faster than fat fish
- Effect of natural vs. hatchery environment

Summation of growth and size and condition at release

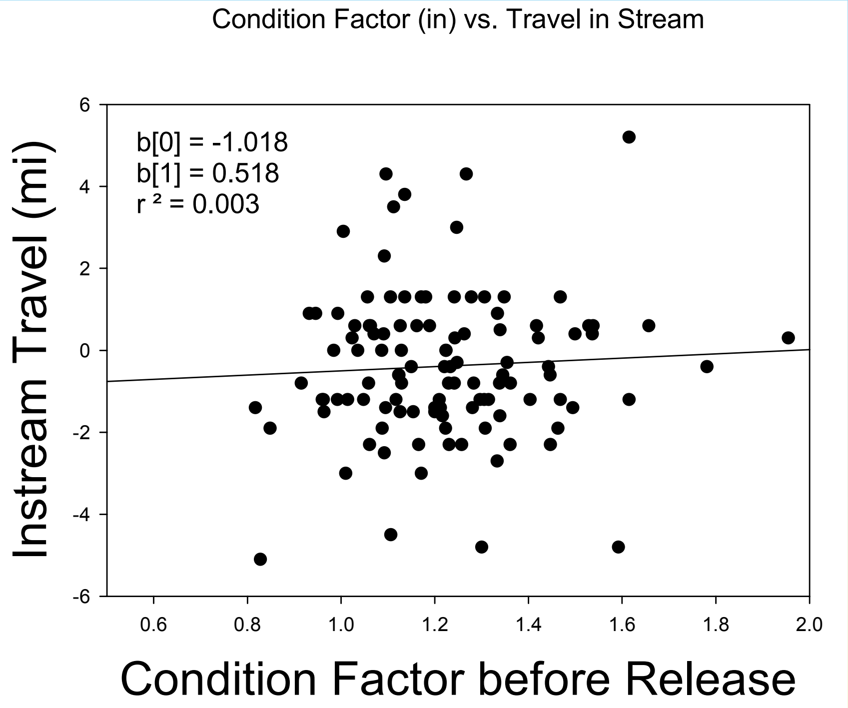
- Smaller fish grew a little faster than larger fish (both for initial weight and initial length)
- Fish with lower condition factors grew at a faster rate than fish with higher condition factors
- Condition factors tended toward a central value of about 1.1

Size and movement after release



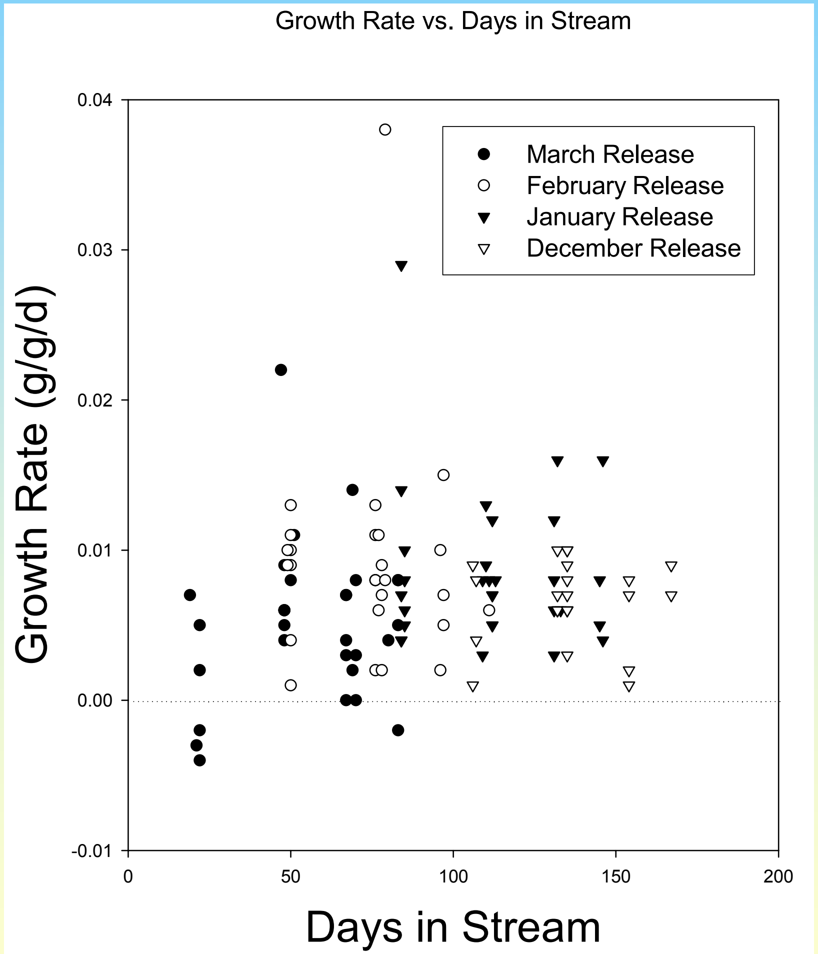
- There was no effect of size at release on distance or direction of travel after release
- Fish moved as much as five miles up- and down-stream
- No sampling below RM 3 (Quail Hollow)

Condition factor and movement after release



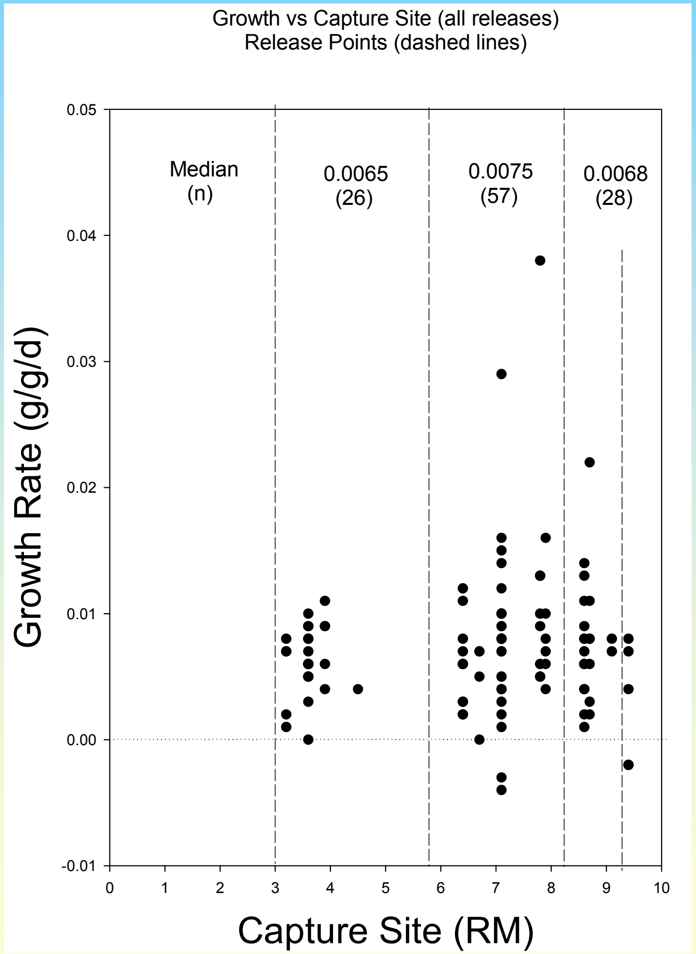
- There was no effect of condition factor on direction or distance traveled after release

Growth and time between release and recapture



- Except for the early recapture of fish from the March release, there was no clear relationship between time in stream and growth rate.
- All other releases were in the stream for 2 to 4 months before recapture

Growth and Recapture Site



- Fish recaptured between the two lowest release points showed slightly lower growth rates than fish in the upper four miles of the tailwater
- Upper areas see lowest DO levels

Decisions regarding bioenergetic model inputs

- There was a wide range of growth rates seen among the recaptured trout.
- Differences in growth rates were not greatly influenced by release site, release dates, size at release, condition at release, movement in stream, or recapture location.
- We decided to use the overall median growth rate from the study for determining general food availability for use in the bioenergetics model.

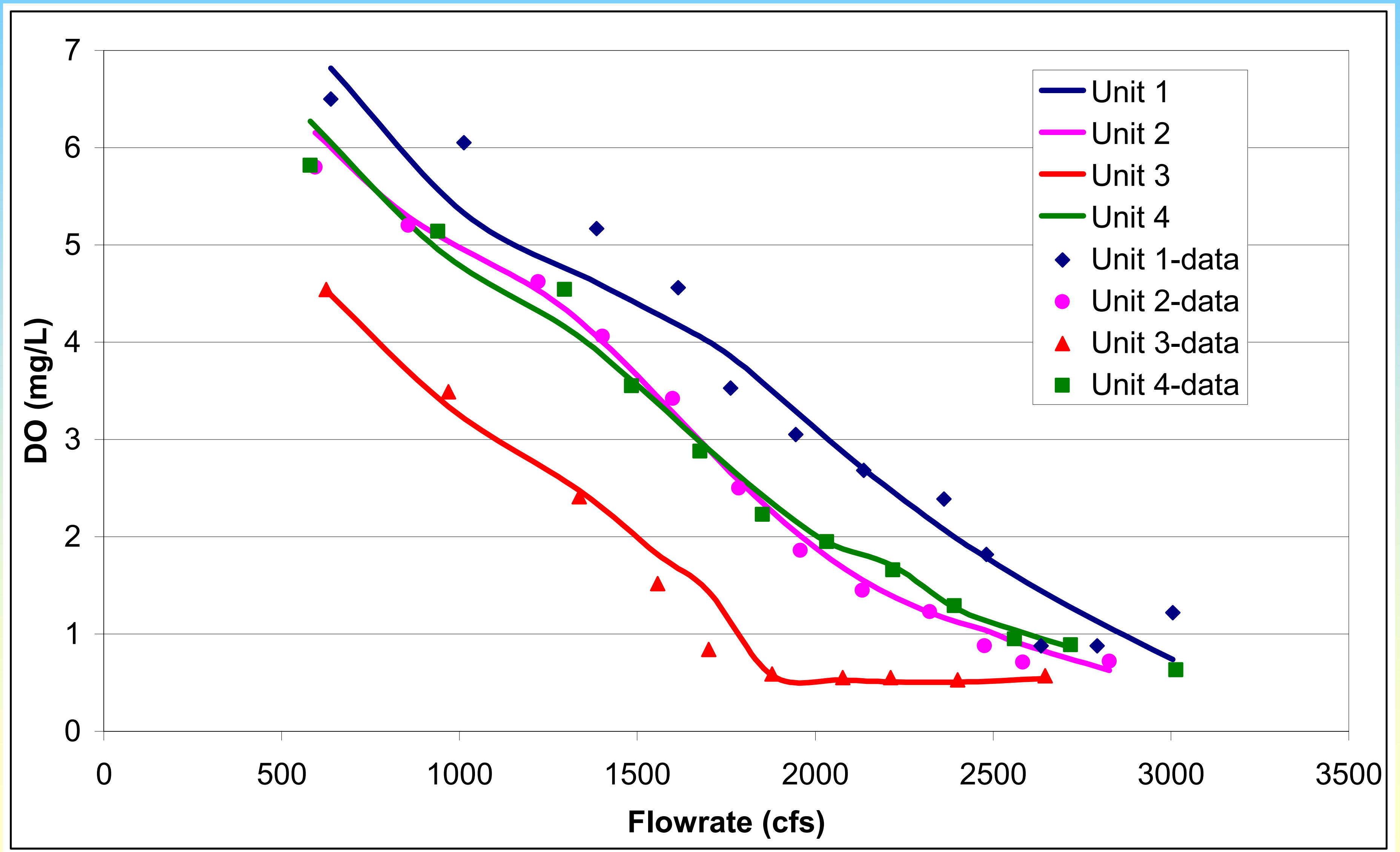
Saluda Tailwater Turbine Venting Model Calibration

Gary E. Hauser, P.E.
Loginetics, Inc.

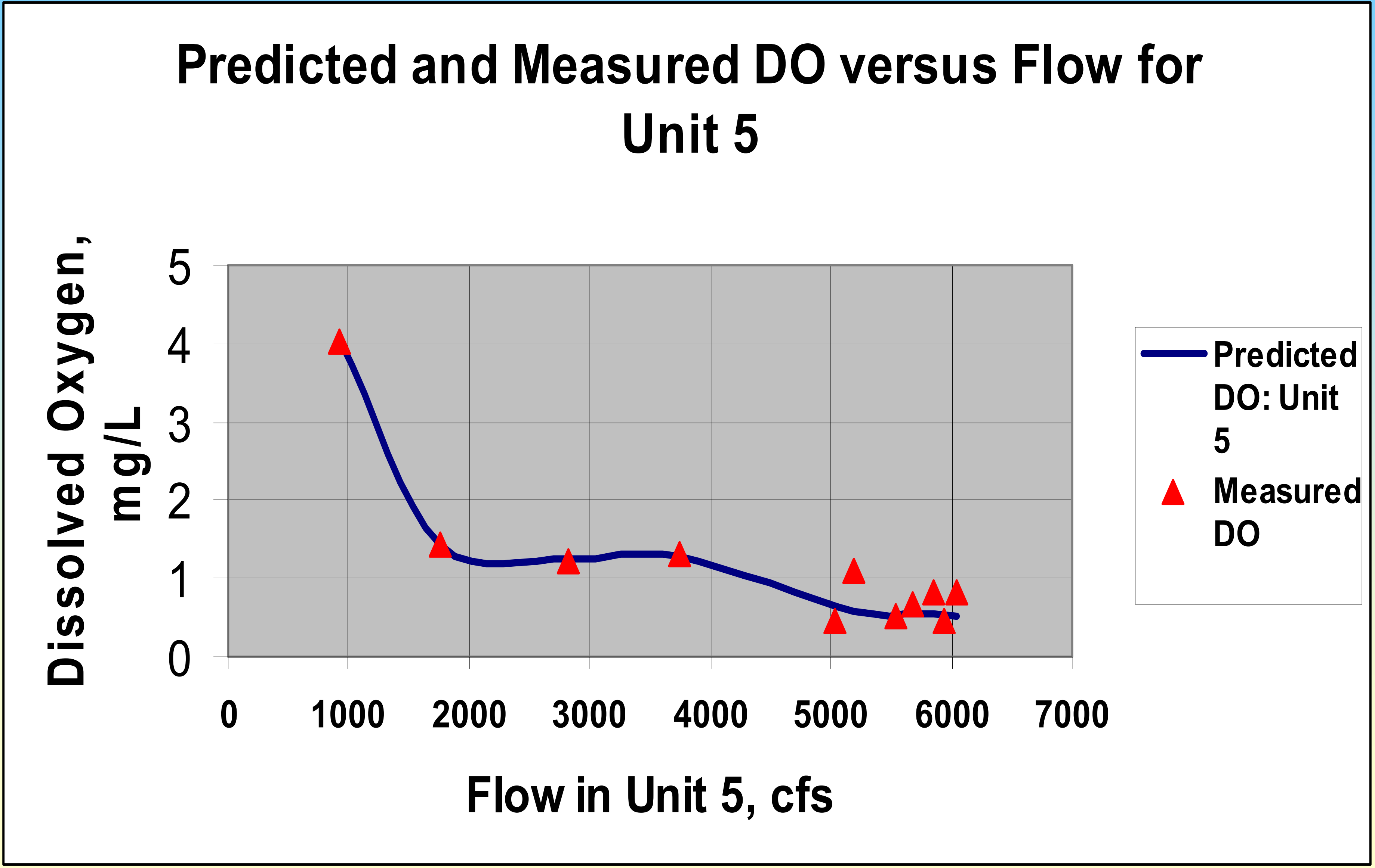
Gary E. Hauser, P.E.

- MS Civil Engineering, University of Kansas, water resources engineering
- 23 yrs on TVA reservoir release improvements team, responsible for reservoir and tailwater modeling and minimum flow/aeration technologies, especially aerating weirs, at 30 hydroprojects for TVA and other utilities.
- 12 yrs as leader of WQ modeling team - TVA Engineering Laboratory.
- Co-developer of EPA-TVA bioenergetics model to predict fish growth in fluctuating temperature and DO regimes.
- Developer of hydrodynamic, water quality, and fish habitat models for TVA River Modeling System.
- Author of 100+ technical publications on aeration and modeling to resolve hydropower environmental problems.
- 2 patents on aerating weir technologies.

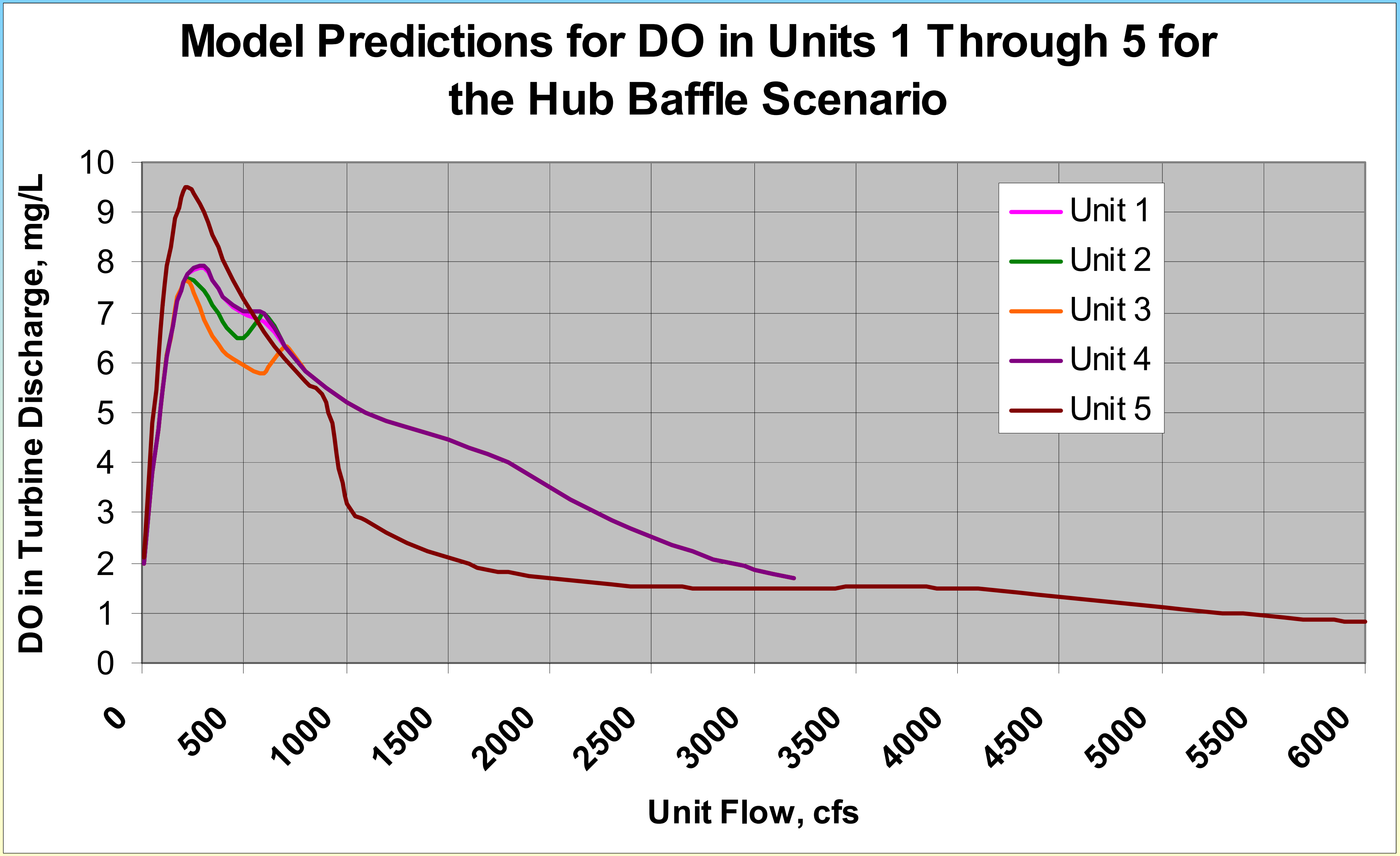
Turbine Venting Model Calibration



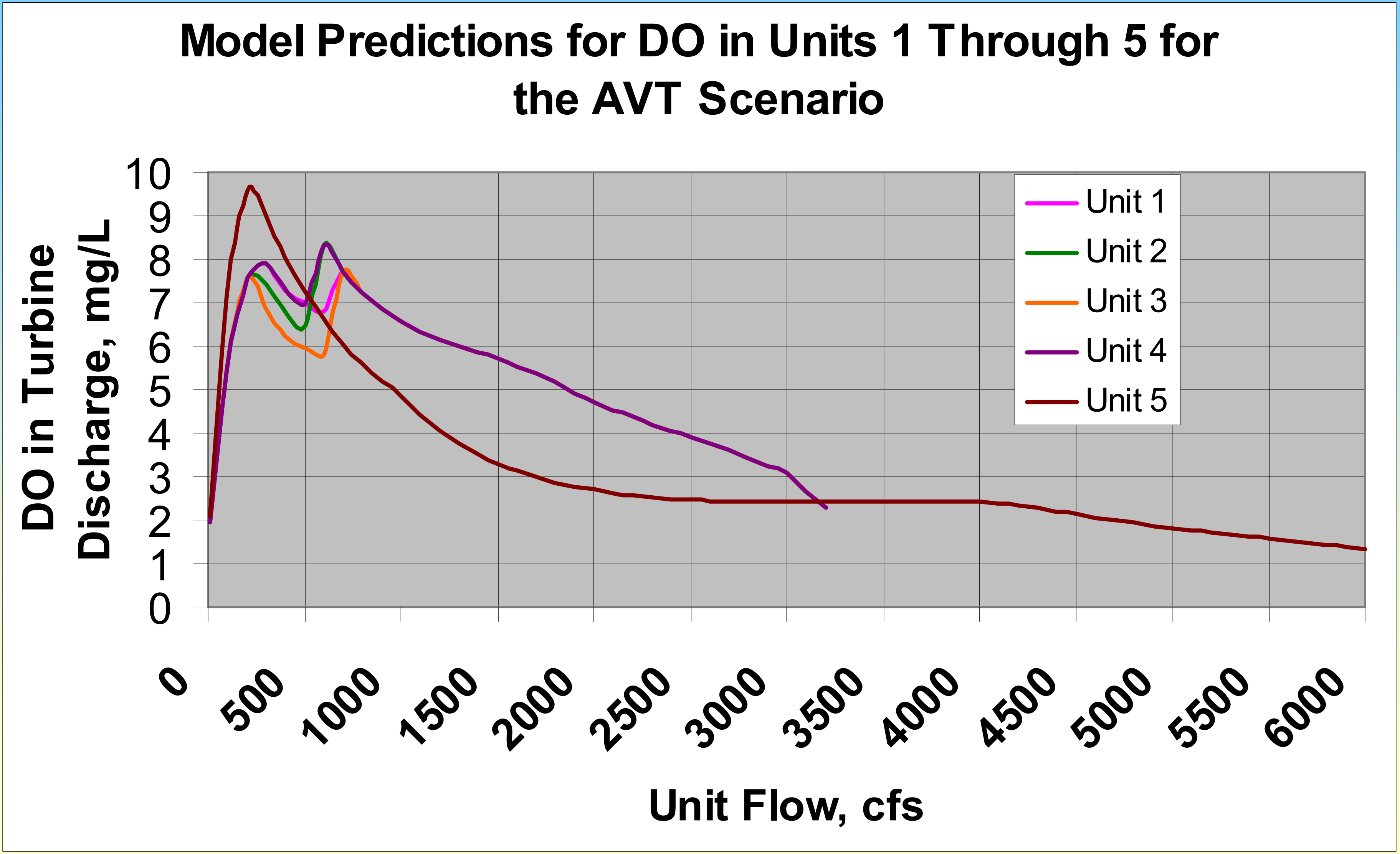
Turbine Venting Model Calibration



Turbine Venting Model DO Simulation



Turbine Venting Model DO Simulation

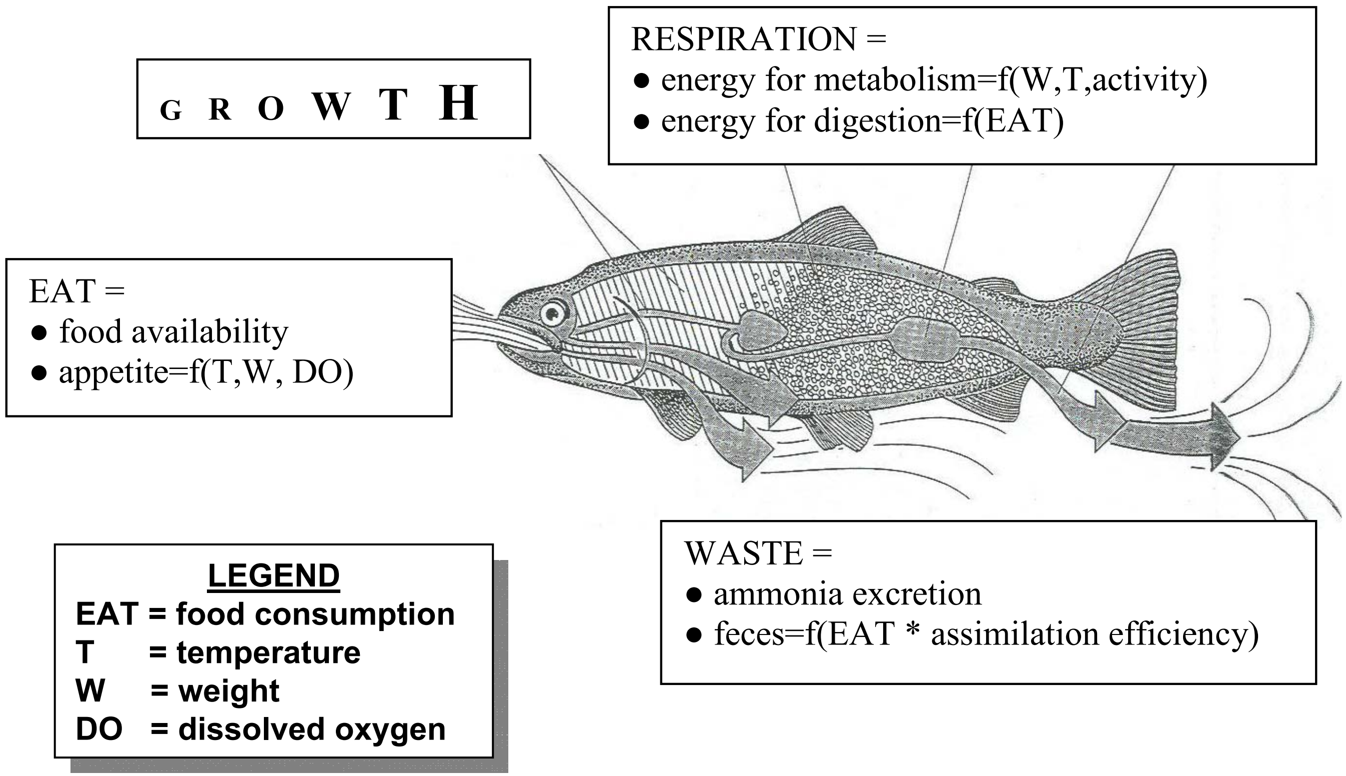


Saluda Tailwater Bioenergetics Model Calibration

Gary E. Hauser, P.E.
Loginetics, Inc.

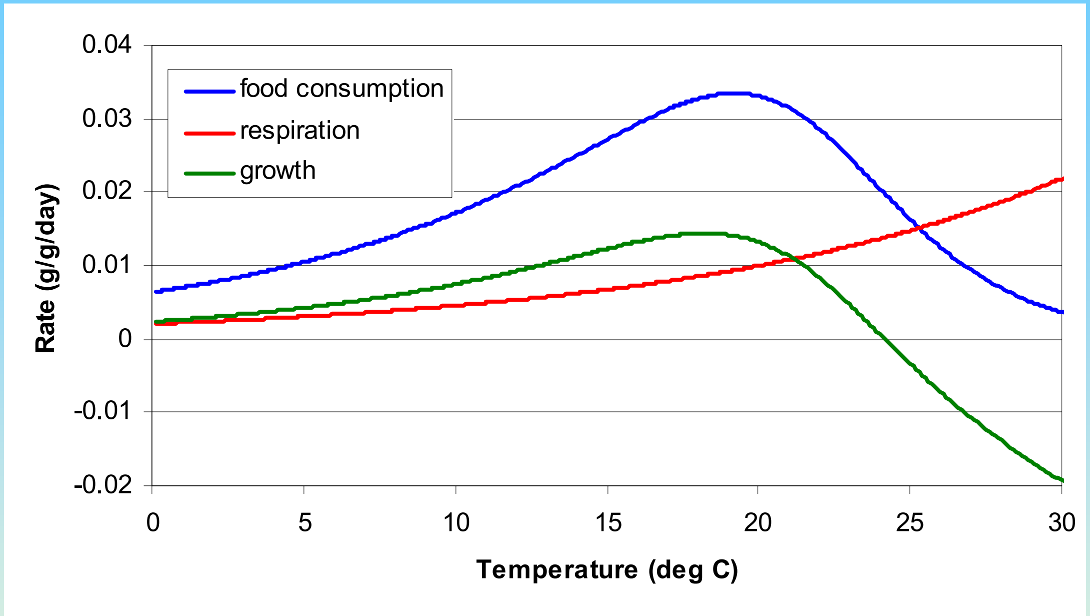
Overview of Bioenergetics Model Processes

Growth = Food Consumption - Waste - Respiration

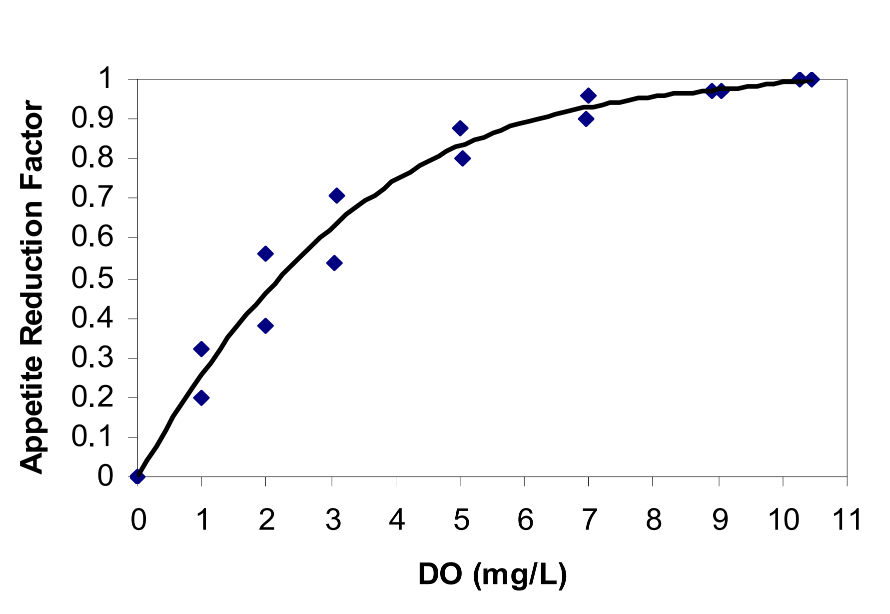


Bioenergetics Model Rainbow Trout Characteristics

RBT Food Consumption, Respiration = f (T)
Ref: From & Rasmussen (1984)



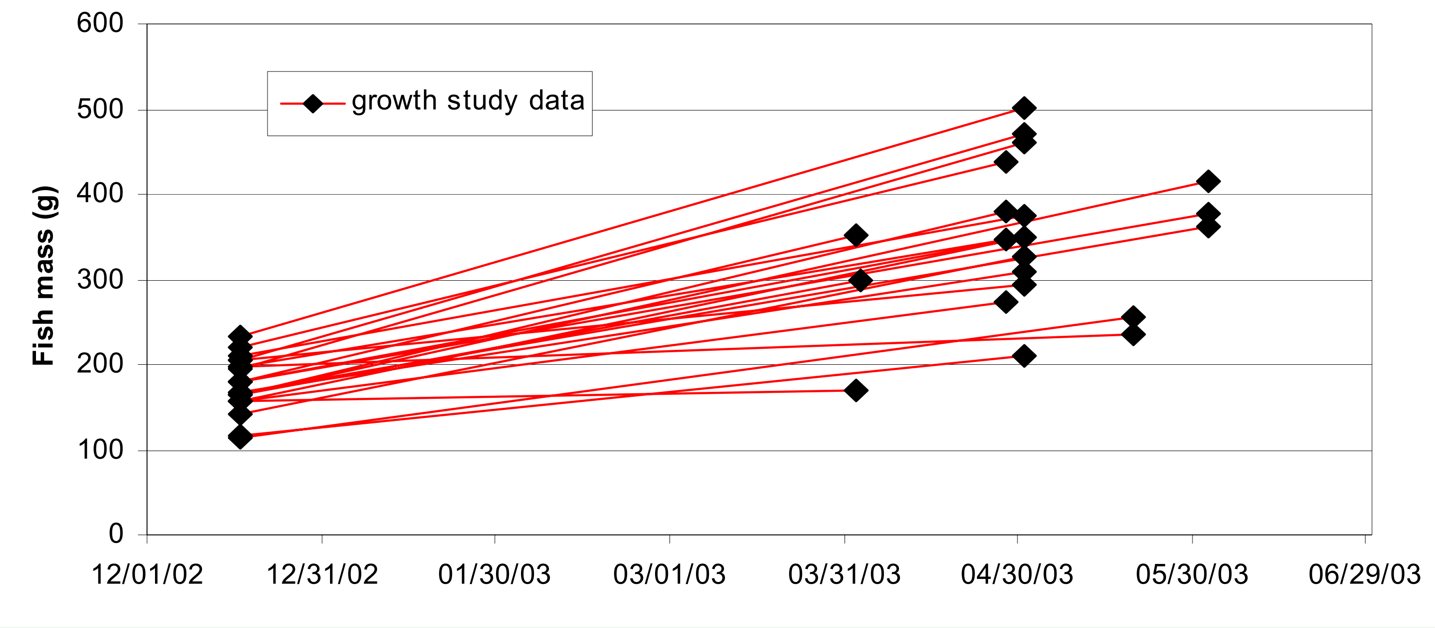
RBT Appetite = f (DO)
Ref: EPA-Duluth data



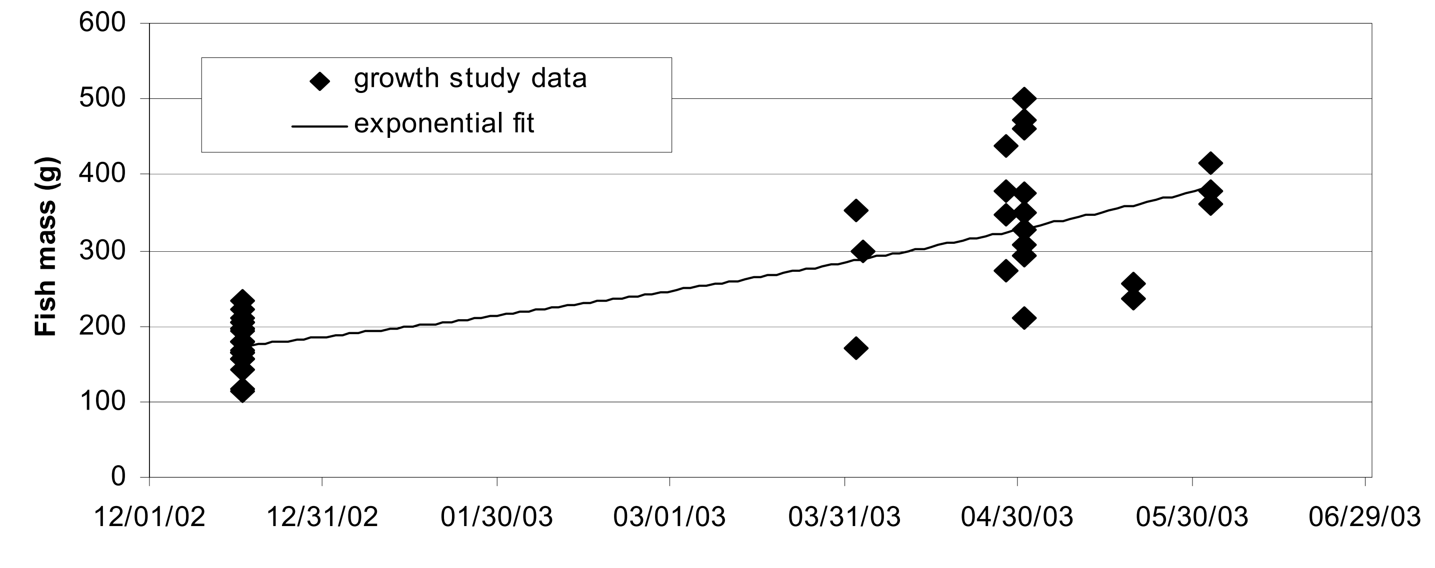
Calibration Process

- Calibrate tailwater model
- Run tailwater model: 1988-1989   2002-2003
- Run bioenergetics model for various food availability levels (fraction of appetite)
- Compare modeled vs measured growth
- Quantify food availability level that best matches growth study results

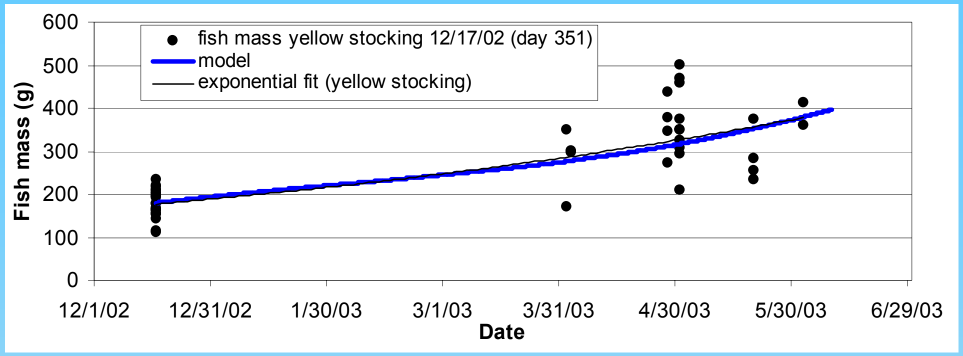
Use of 2002-2003 RBT Growth Data for Model Calibration

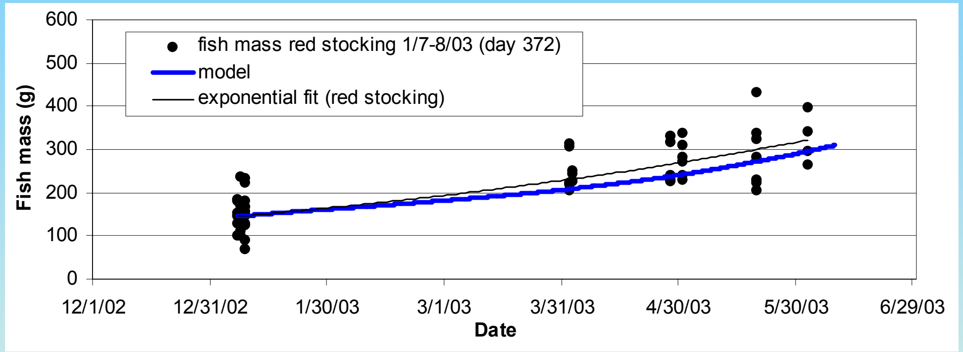


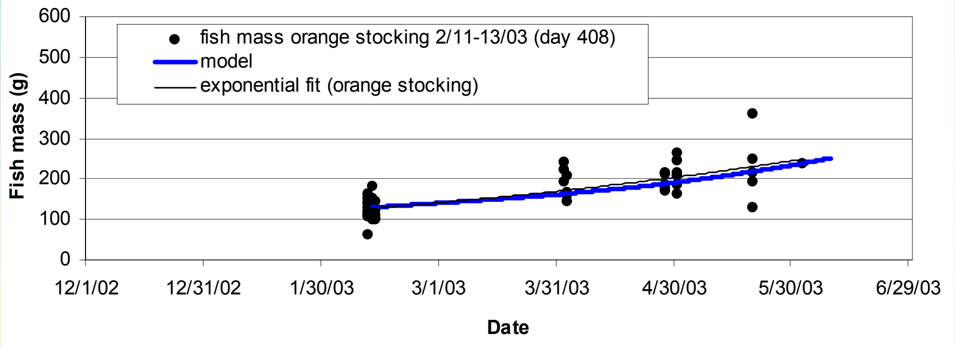
meaning of measurements

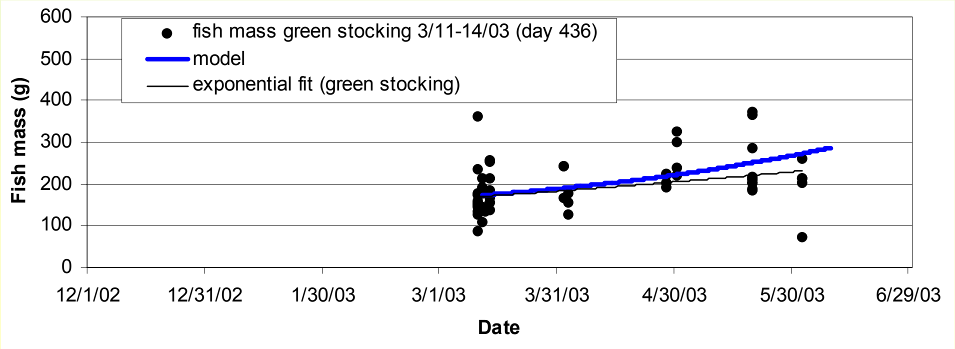


prepared for model calibration









Bioenergetics Model Calibration 2002-2003 Growth Study

Average growth = 0.67 in/mo

Food availability = 68% of maximum appetite

Growth Rate Comparison – SE Tailwaters								
Dam	State	Length (mi)	Period	Start size (in)	T (deg C)	DO (mg/L)	Grow rate (in/mo)	Notes
various	KY	--	current				0.5	per KDFWR staff – BT, RBT
Wolf Creek	KY	50	Apr-Nov 1997 Apr-Nov 1998 Apr-Nov 1999 Apr-Nov 2000 Apr-Nov 2001 Apr-Nov 2002	7.5 8.2 8.2 7.0 7.4 7.7	9-27 9-27 9-27 9-27 9-27 9-27	3-10 3-10 3-10 3-10 3-10 3-10	0.52 0.48 0.49 **0.71** **0.69** 0.54	Dreves (2003) KDFWR - BT
Center Hill	TN	26	Mar-Jul 1997	9.4		4-7	0.51	Devlin (1999) TTU - RBT
Norris	TN	30	Jan-May 1975 Jan-May 1985 abv weir Jan-May 1985 bl weir Jan-May 1986 abv weir Jan-May 1986 bl weir	9.3 7.5-8.0 7.5-8.0 7.0-7.5 7.0-7.5	7-10 5-9 5-9 6-10 6-10	>8 >8 >8 8-10 8-10	0.62 0.48 0.30 0.38 0.43	1993 TVA data - RBT bioenergetics model report weights using CF=1.1; growth probably T limited
South Holston	TN	14	Mar-July 1992 July-Sep 1992 Mar-Sep 1992 1997 – Mar. stocking 1997 – Sep stocking 1997	4.72 7.64 4.72	6-8 6-8 6-8 <22 <22 <22	8-12 8-12 8-12 >6 >6 >6	0.58 **1.69** **0.90** 0.35 0.63 0.43	1992 TVA - RBT data Most growth in late summer/fall when the DO=12 mg/L T=8 C Bettoli, et al (TTU) - RBT Bettoli, et al (TTU) - RBT Bettoli, et al (TTU) - BT
Wilbur	TN		1998 – Mar stocking 1998 – July stocking				0.27 0.19	Bettoli, et al (TTU) - RBT
Saluda	SC	10	Nov 1988-Apr 89 **Dec 2002-Jun 2003**	6 (40g) 10 (150g)	10-18 8-15	0.5-12 4-12	0.25 **0.67**	Before aeration - RBT **Current aeration - RBT**
Growth Rate Comparison – Other Locations								
Sierra Nevada streams	CA		Avg 1987-1996 site #1 (fall-spring) Avg 1987-1996 site #2 (fall-spring) Avg 1987-1996 site #1 (summer) Avg 1987-1996 site #2 (summer)	Age 0 Age 0 Age 1 Age 1	Avg 7.2 Avg 10.2 Avg 14.9 Avg 18.1		0.44 0.54 0.20 0.06	Railsback and Rose (1999) - RBT

Saluda Tailwater Bioenergetics Model Application

Modeled Effects of Aeration Options on Trout Growth

Gary E. Hauser, P.E.
Loginetics, Inc.

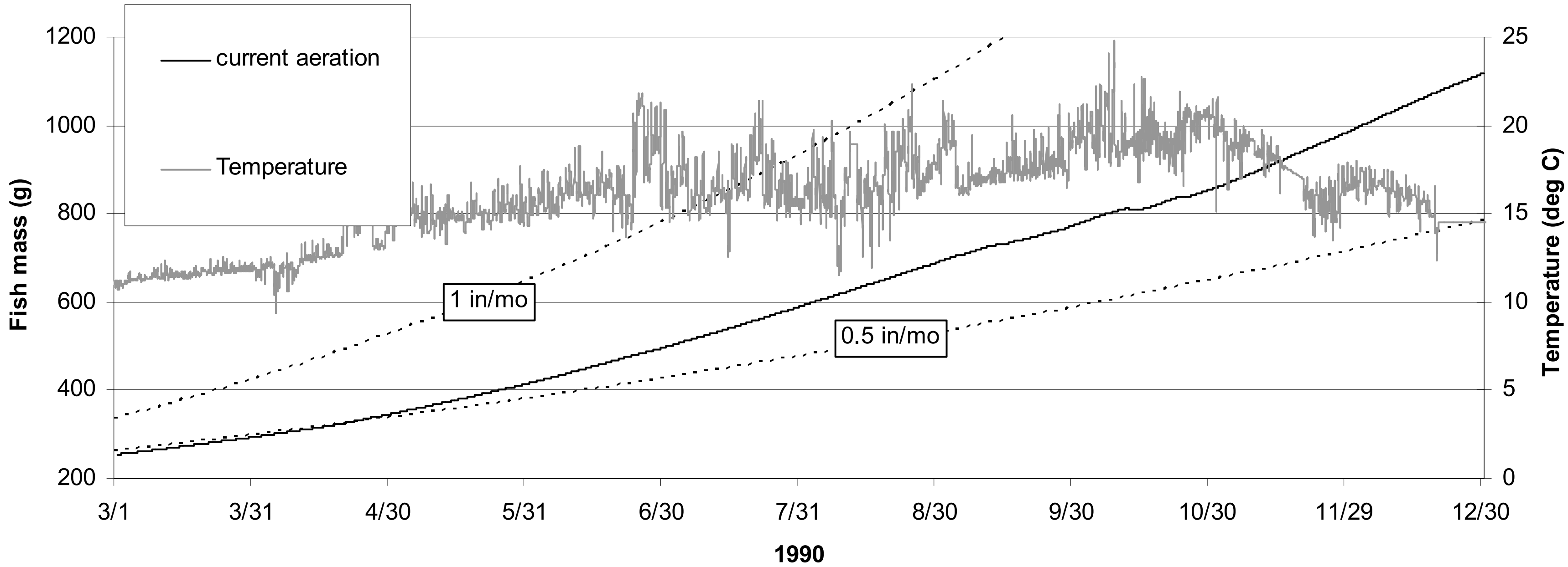
Notes on Growth Simulations For Various Aeration Options

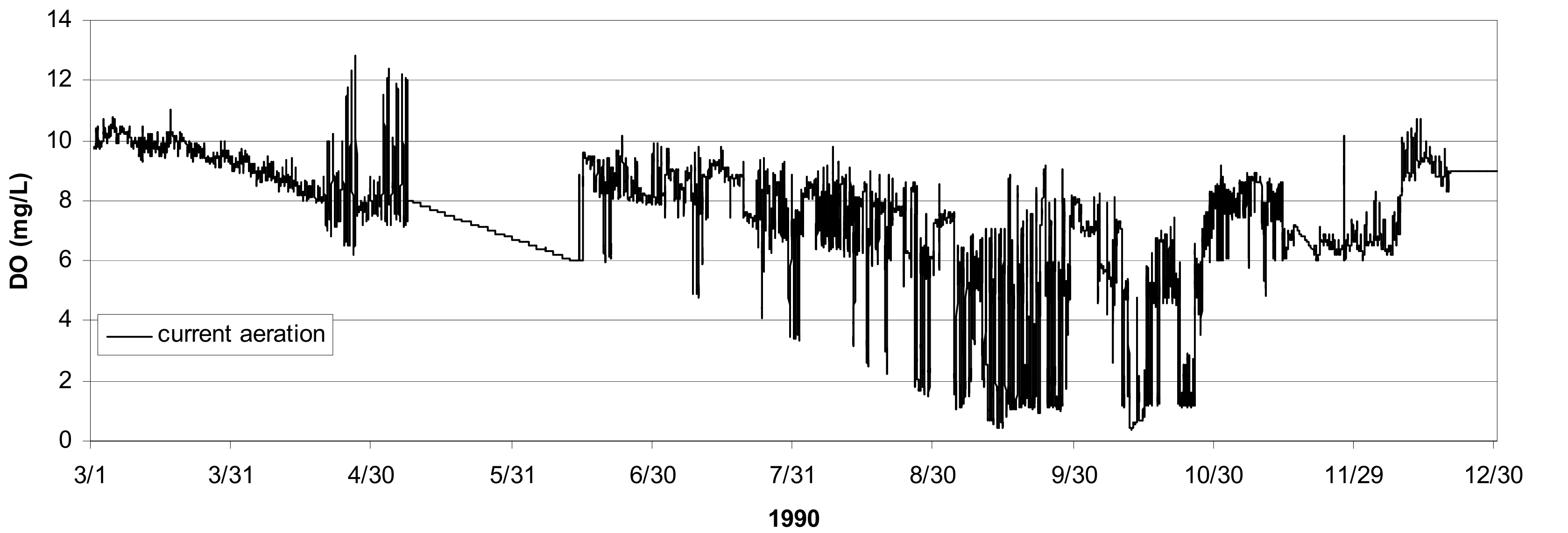
- Used turbine venting model release DO results directly
    - no tailwater aeration or photosynthesis-respiration
- Used measured temperature at monitor d.s. of dam.
- Used 68% food availability for all cases
- Growth based on temperature, DO, food availability
    - Avoidance, predation, competition not simulated
    - Mortality not simulated – negative growth only (could have mortality or avoidance if exposed to DO < 2)

Aeration Scenarios

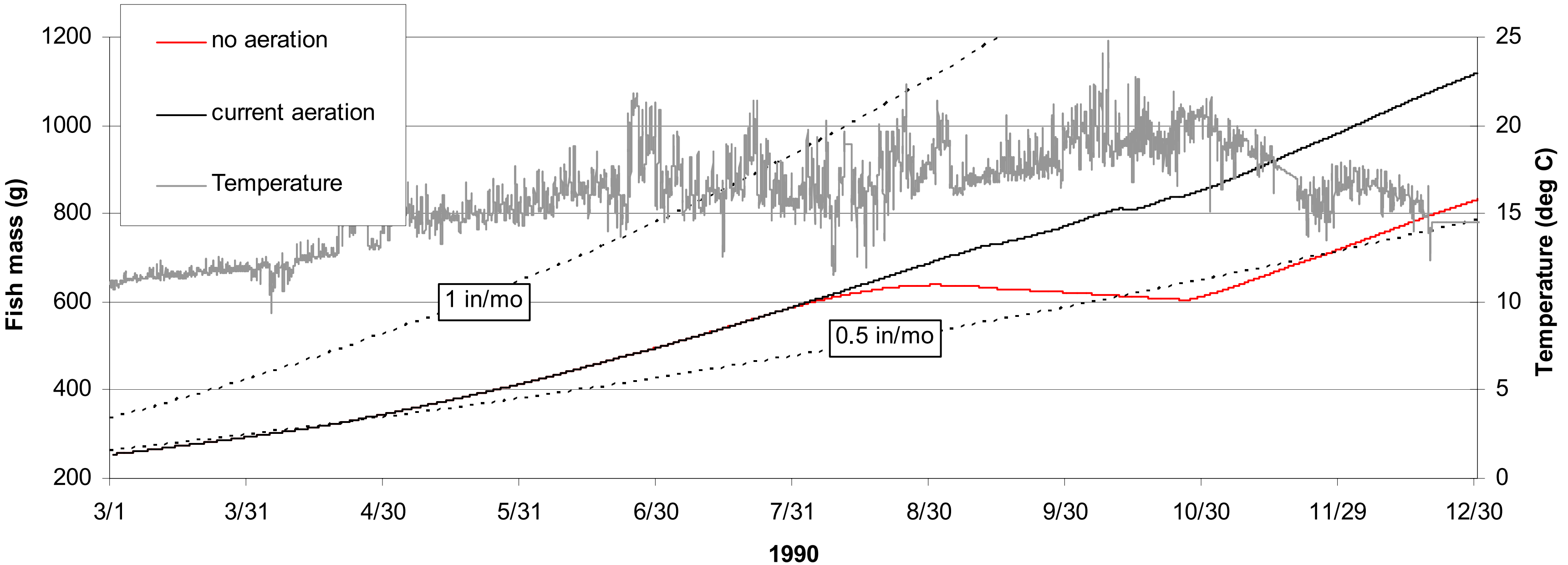
- No aeration
- Current aeration
- Hub baffles
- Auto - venting turbines (AVT)
- AVT with 4.0 mg/L minimum
- AVT with 6.0 mg/L minimum

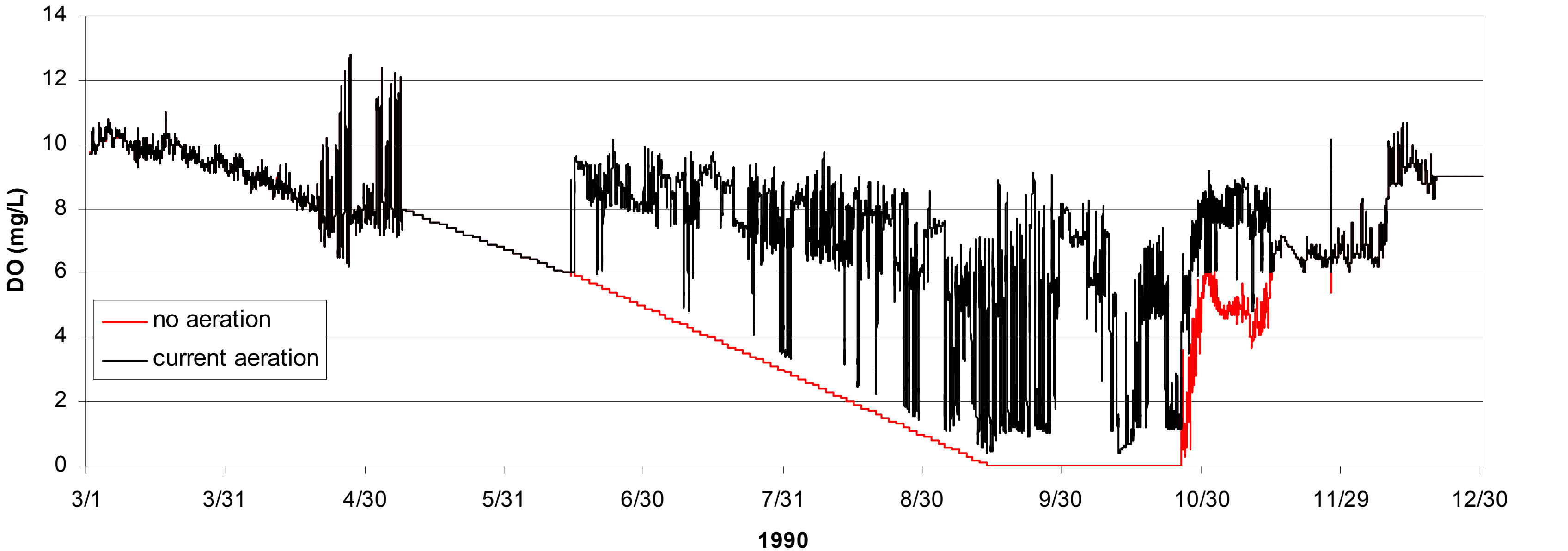
1990 (wet year)



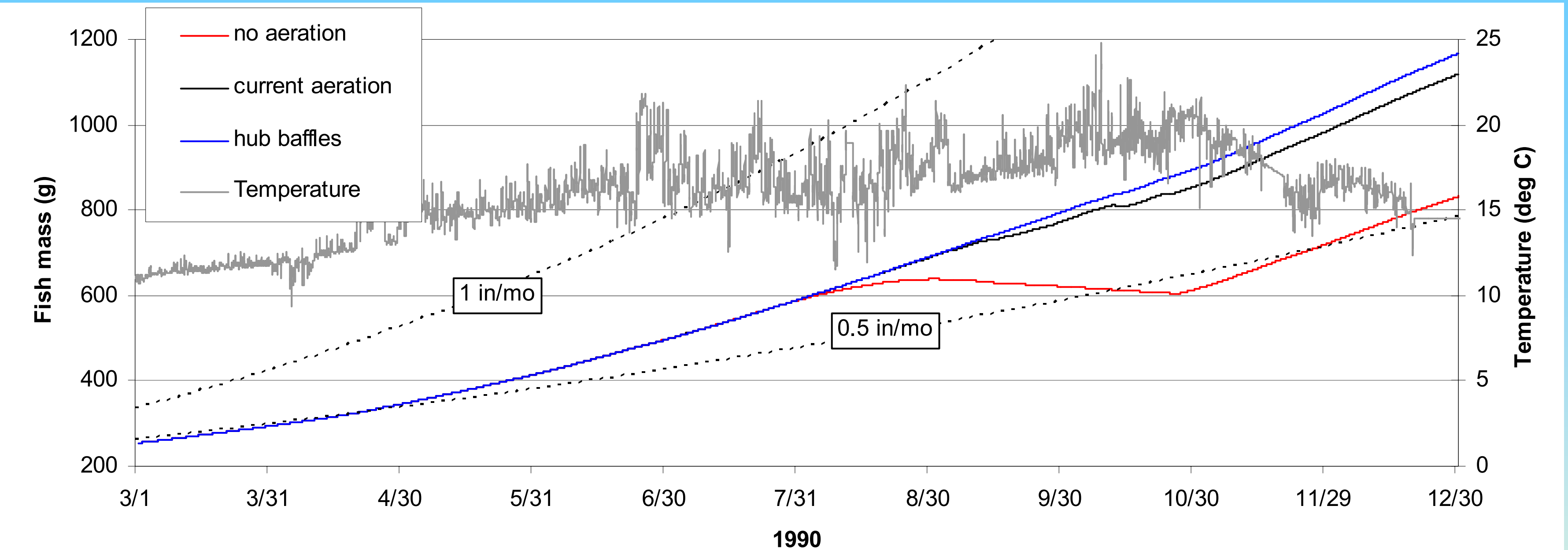


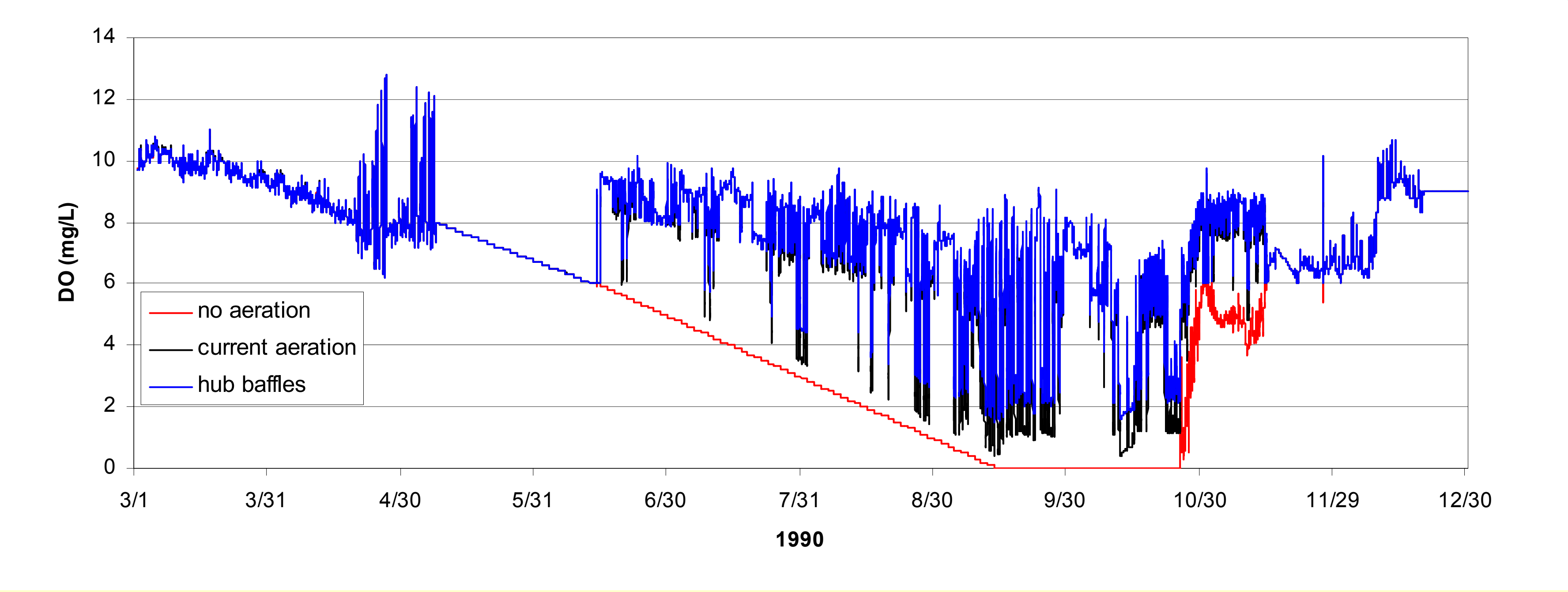
1990 (wet year)



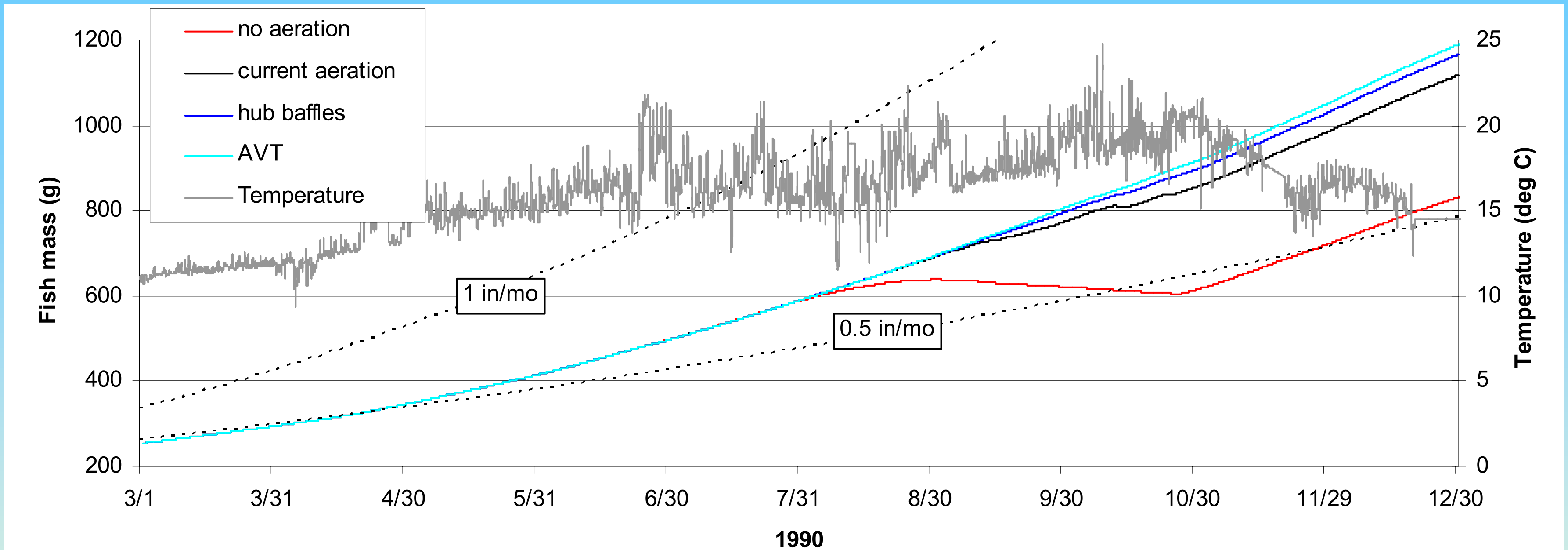


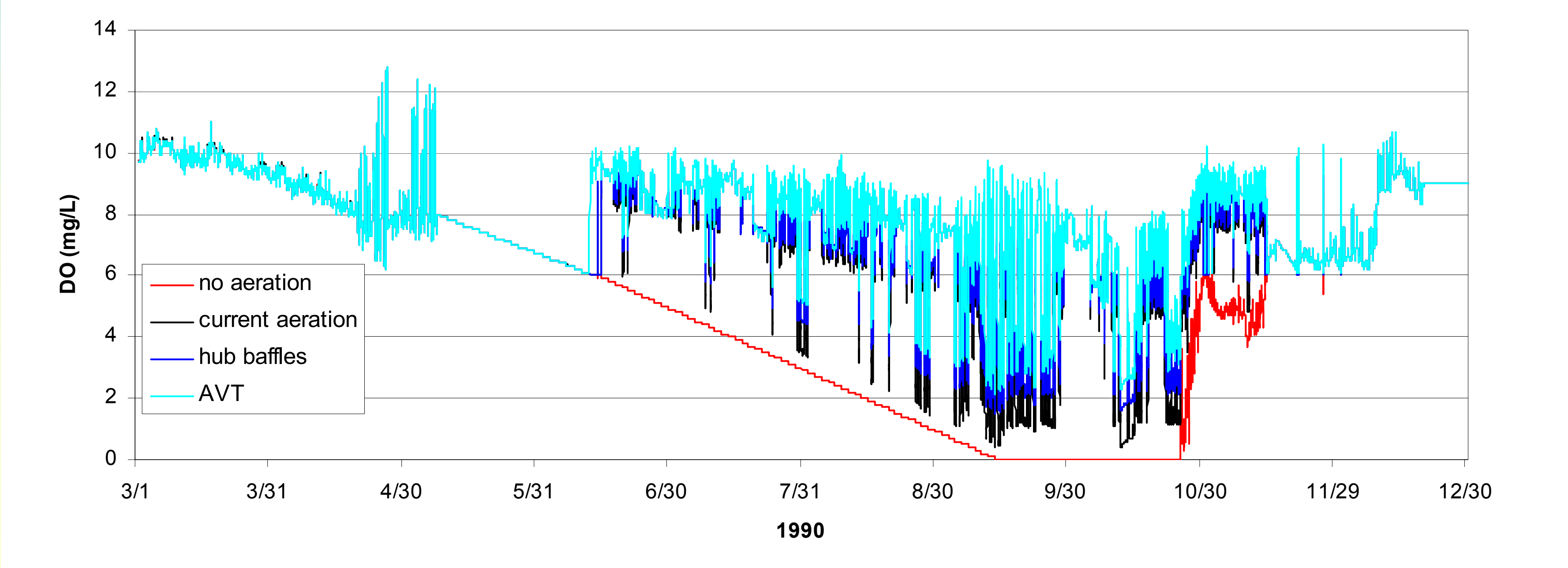
1990 (wet year)



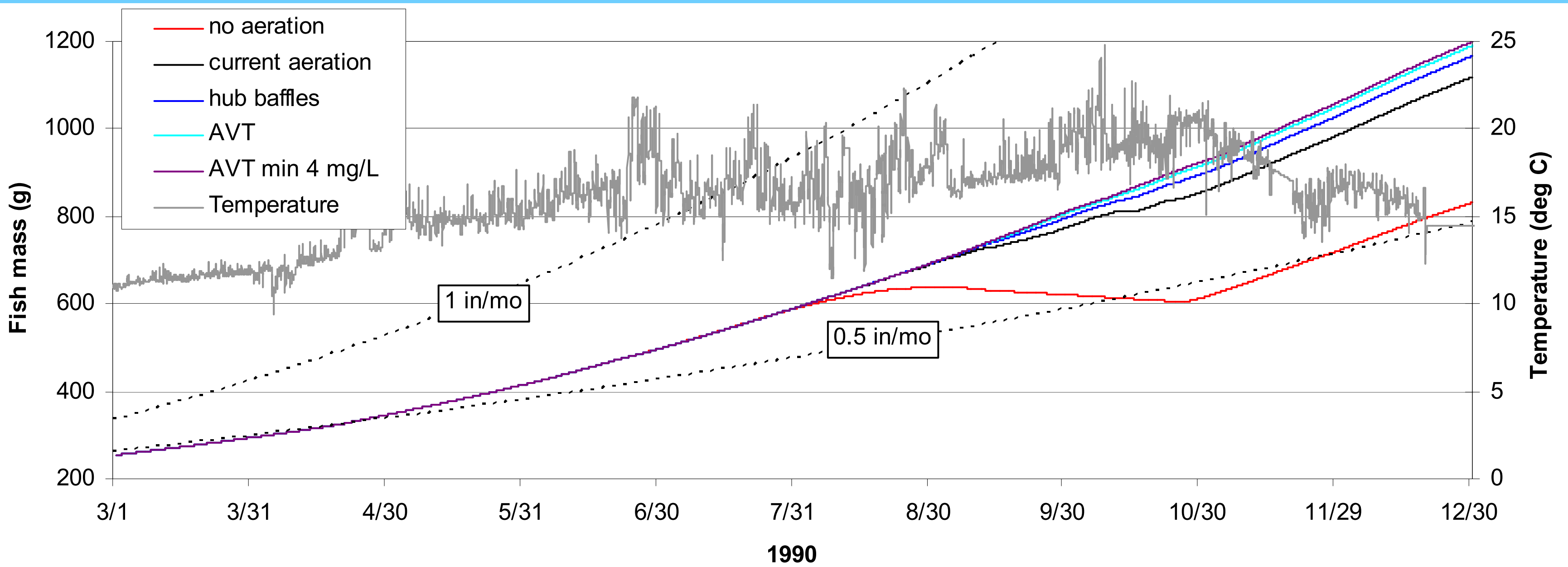


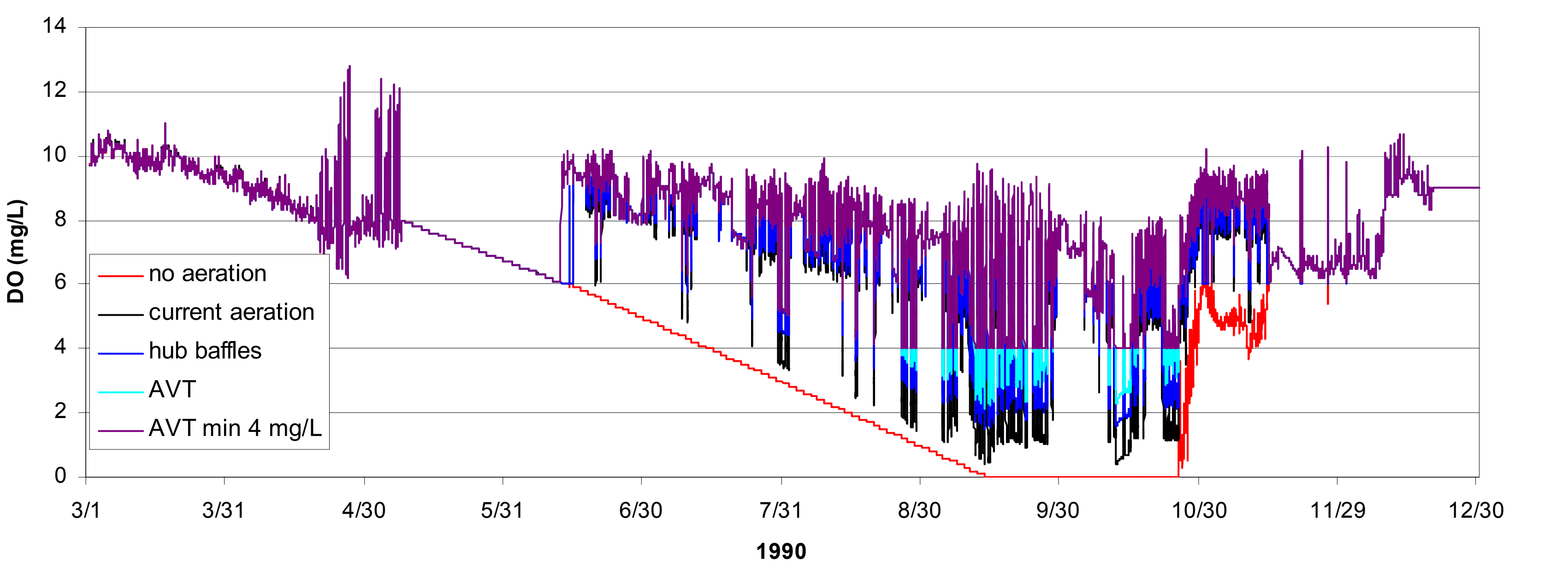
1990 (wet year)



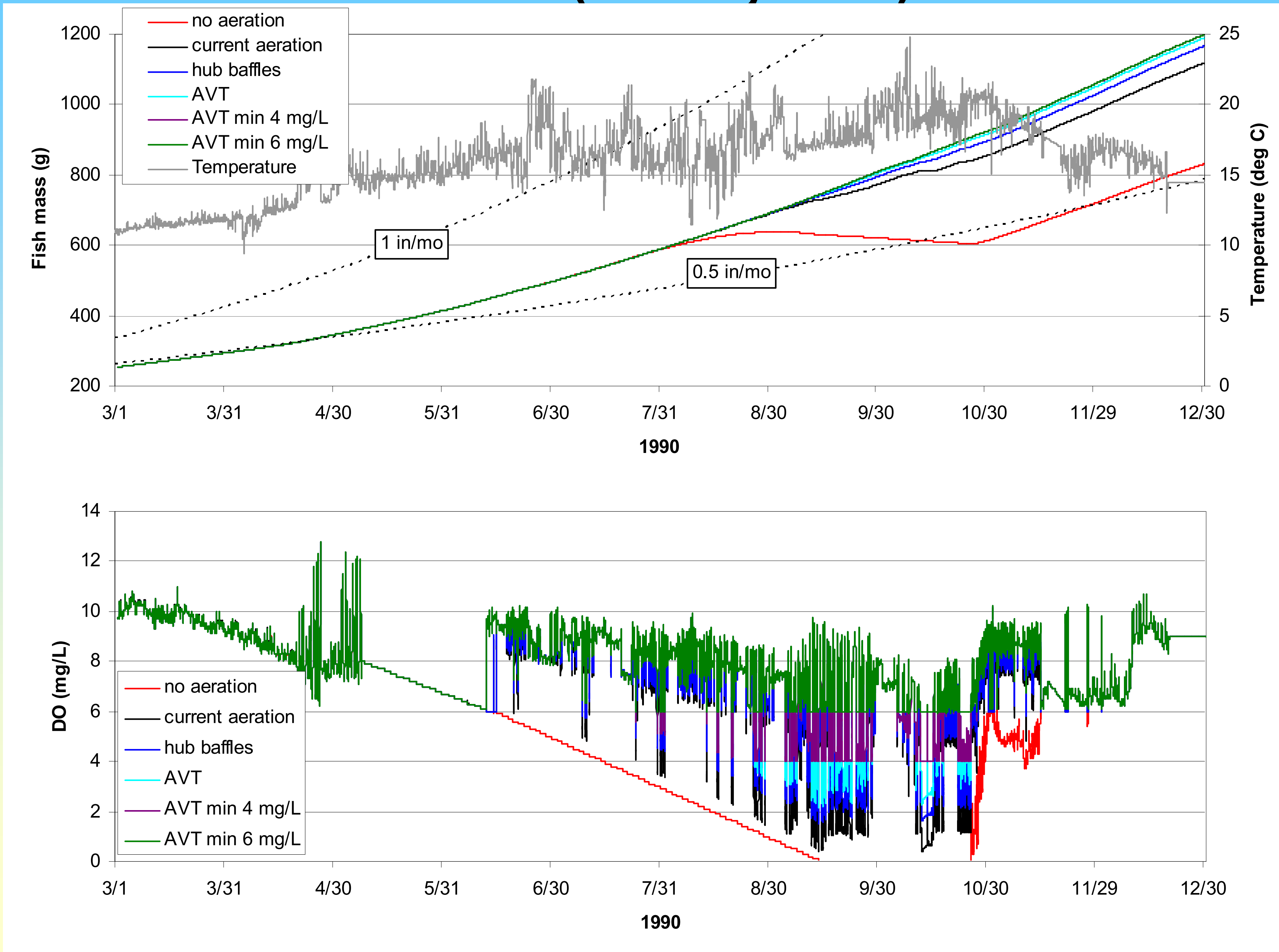


1990 (wet year)

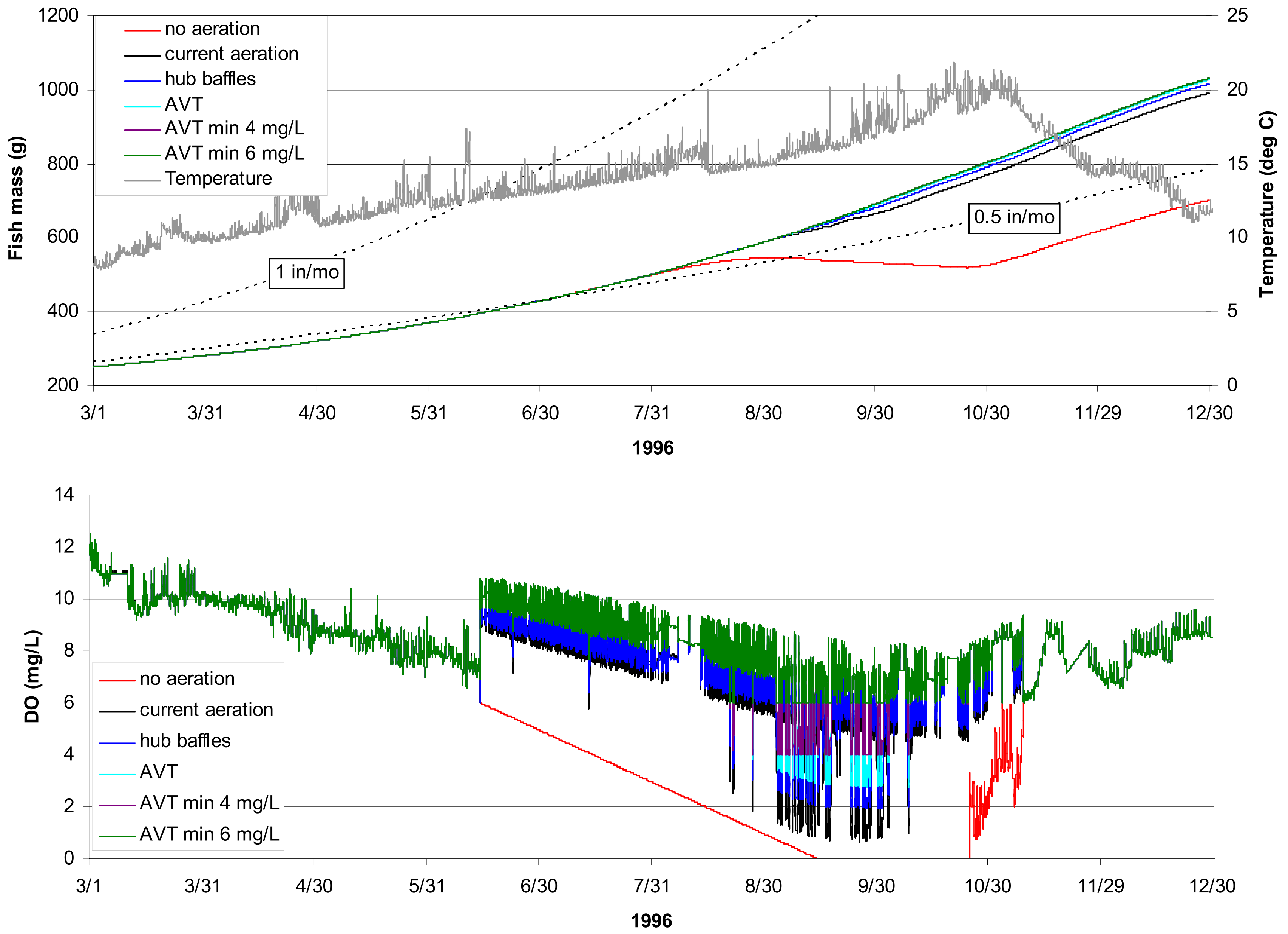




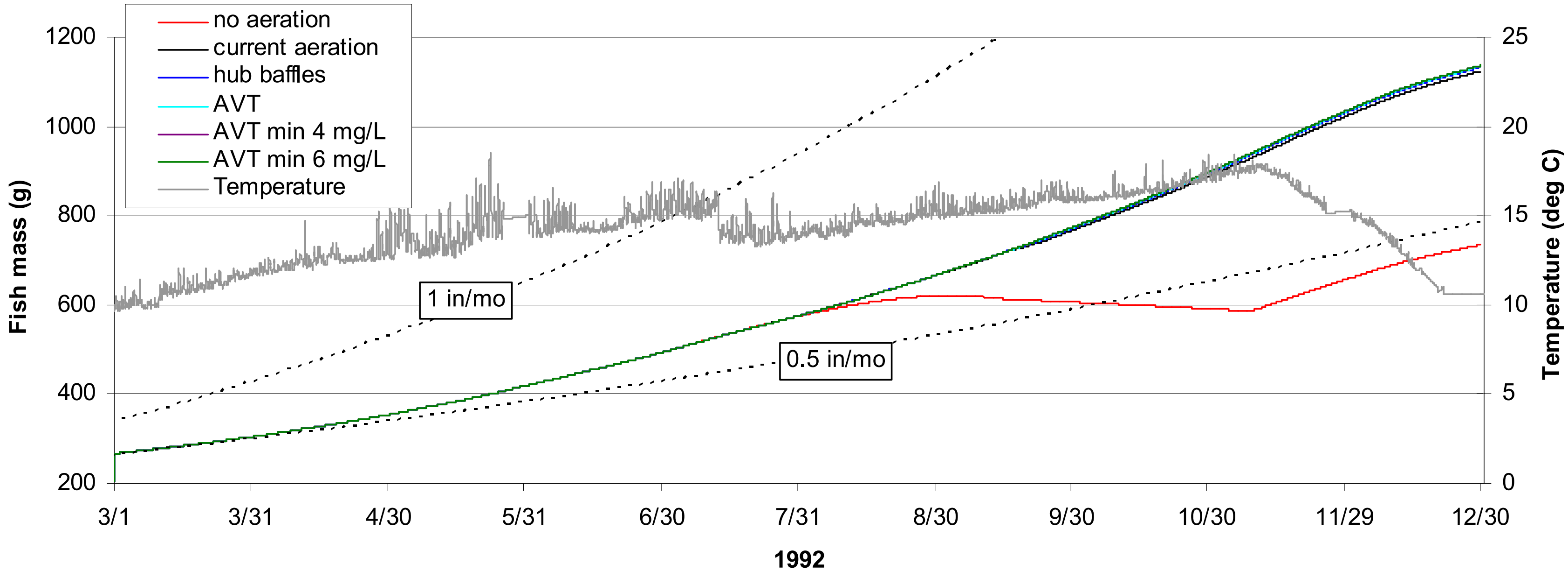
1990 (wet year)

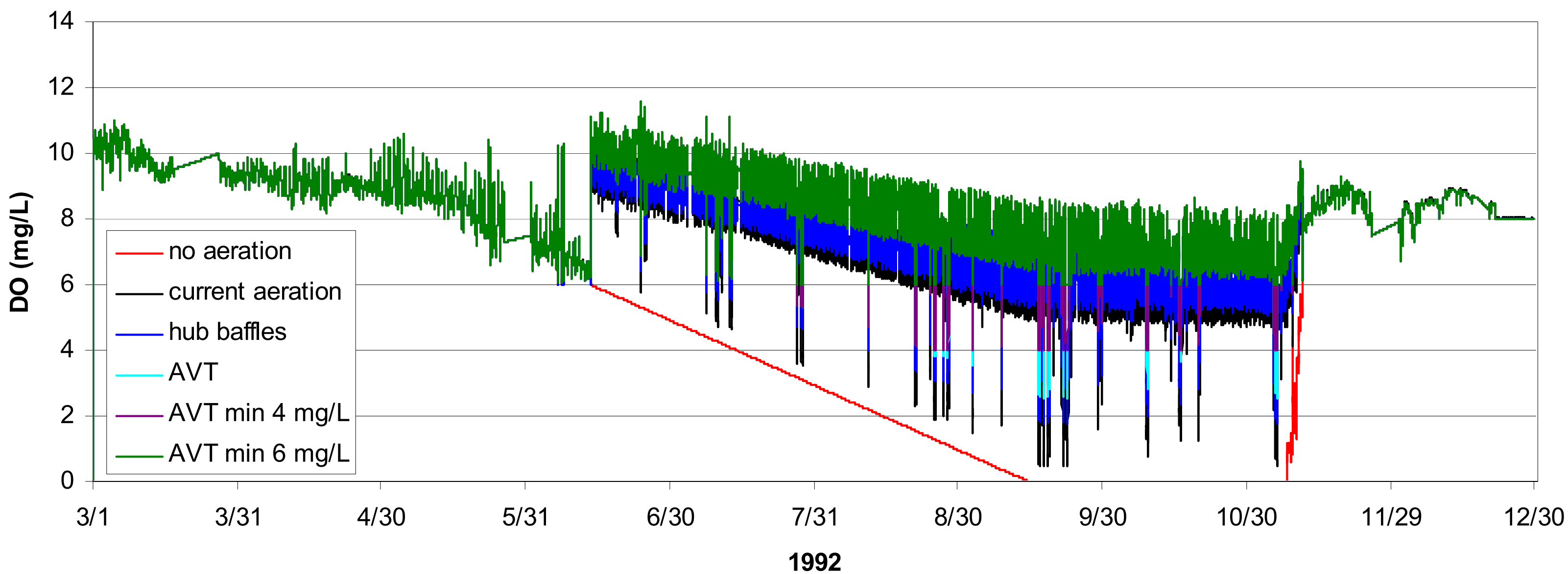


1996 (mod. wet year)

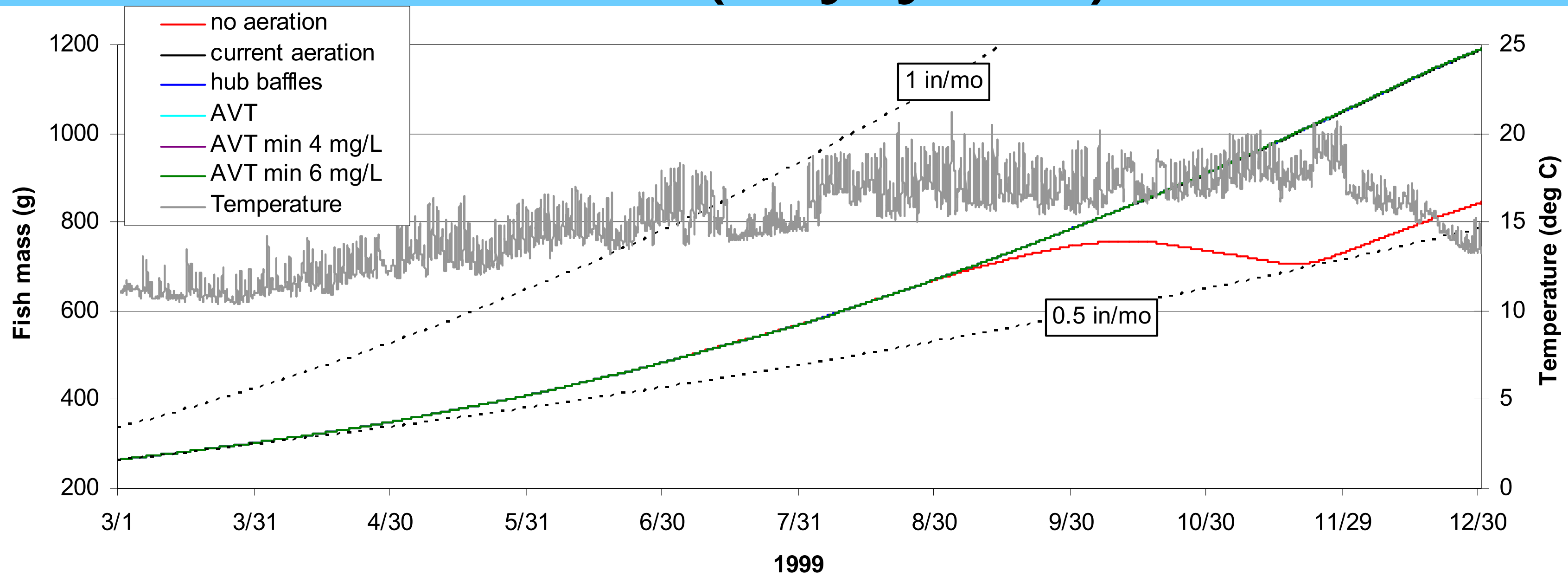


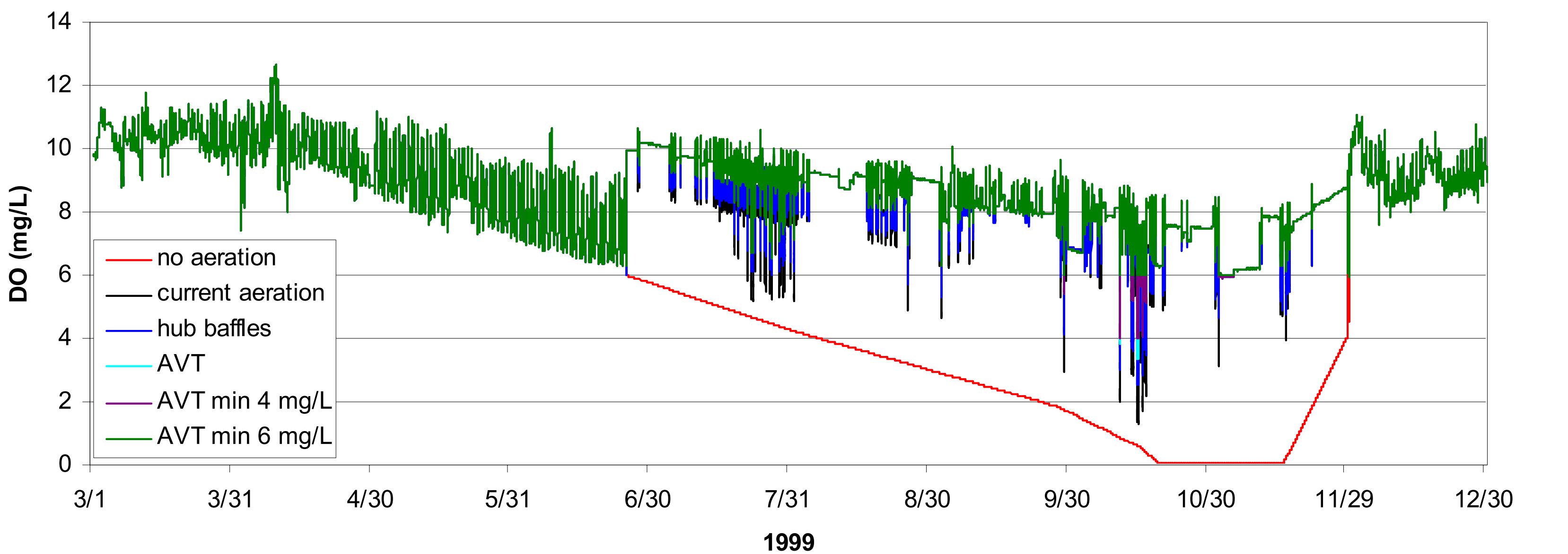
1992 (avg year)





1999 (dry year)



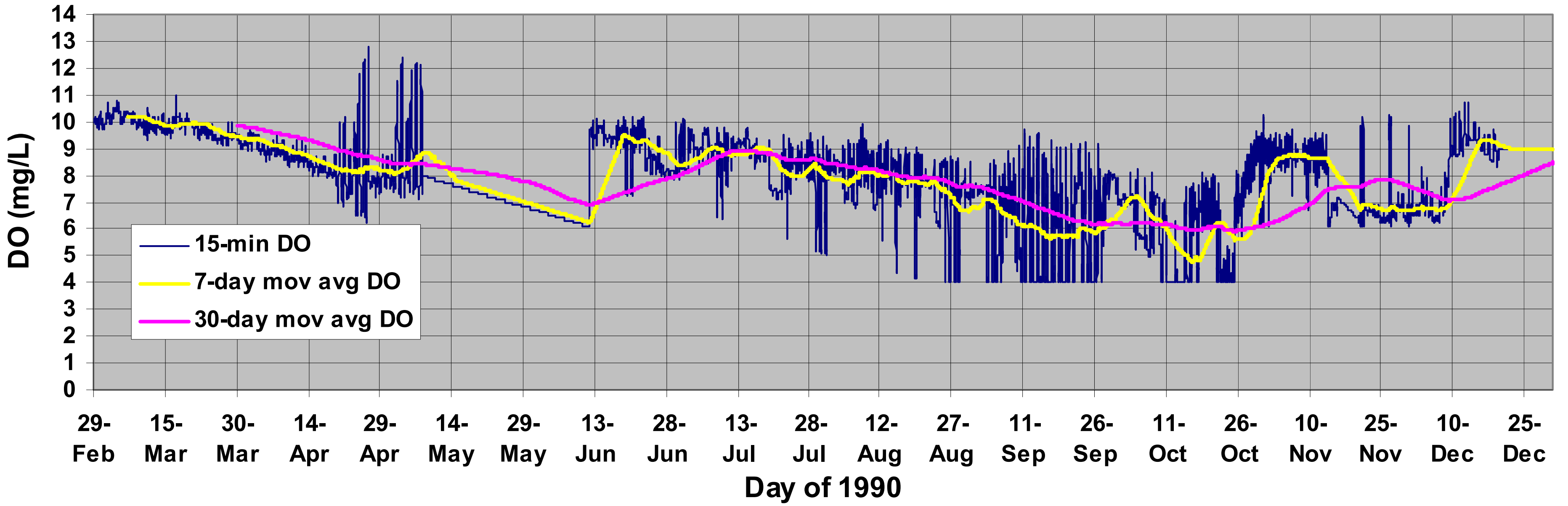


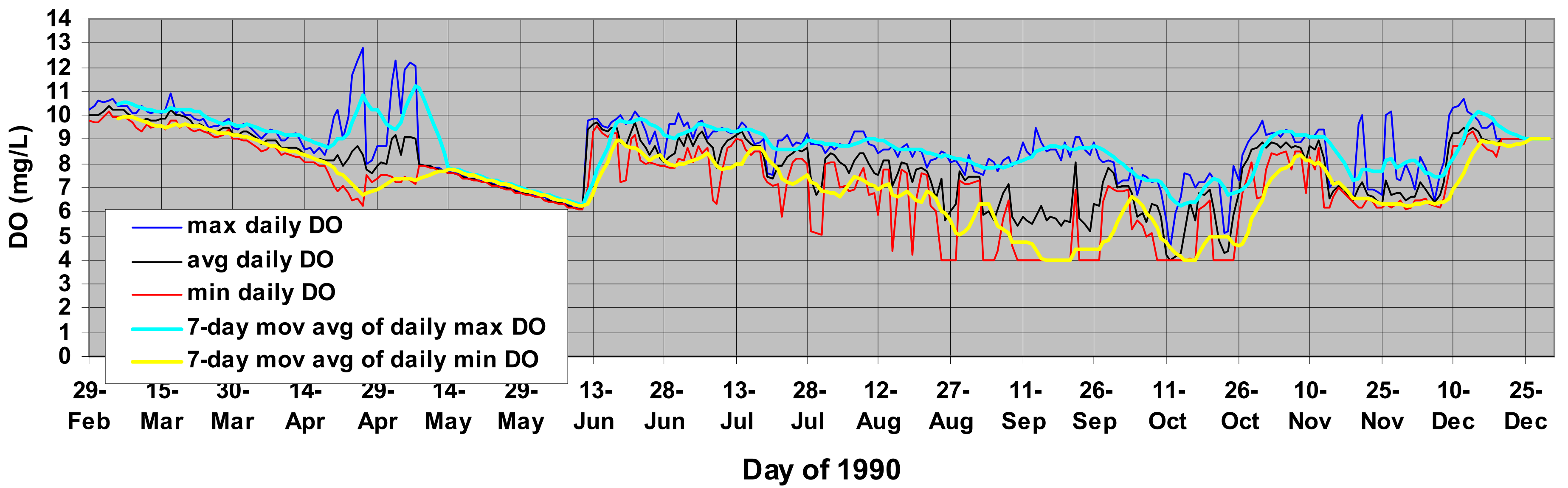
Results of the Study and Considerations for Setting The Site-Specific Standard for DO

Jim Ruane

Reservoir Environmental Management, Inc

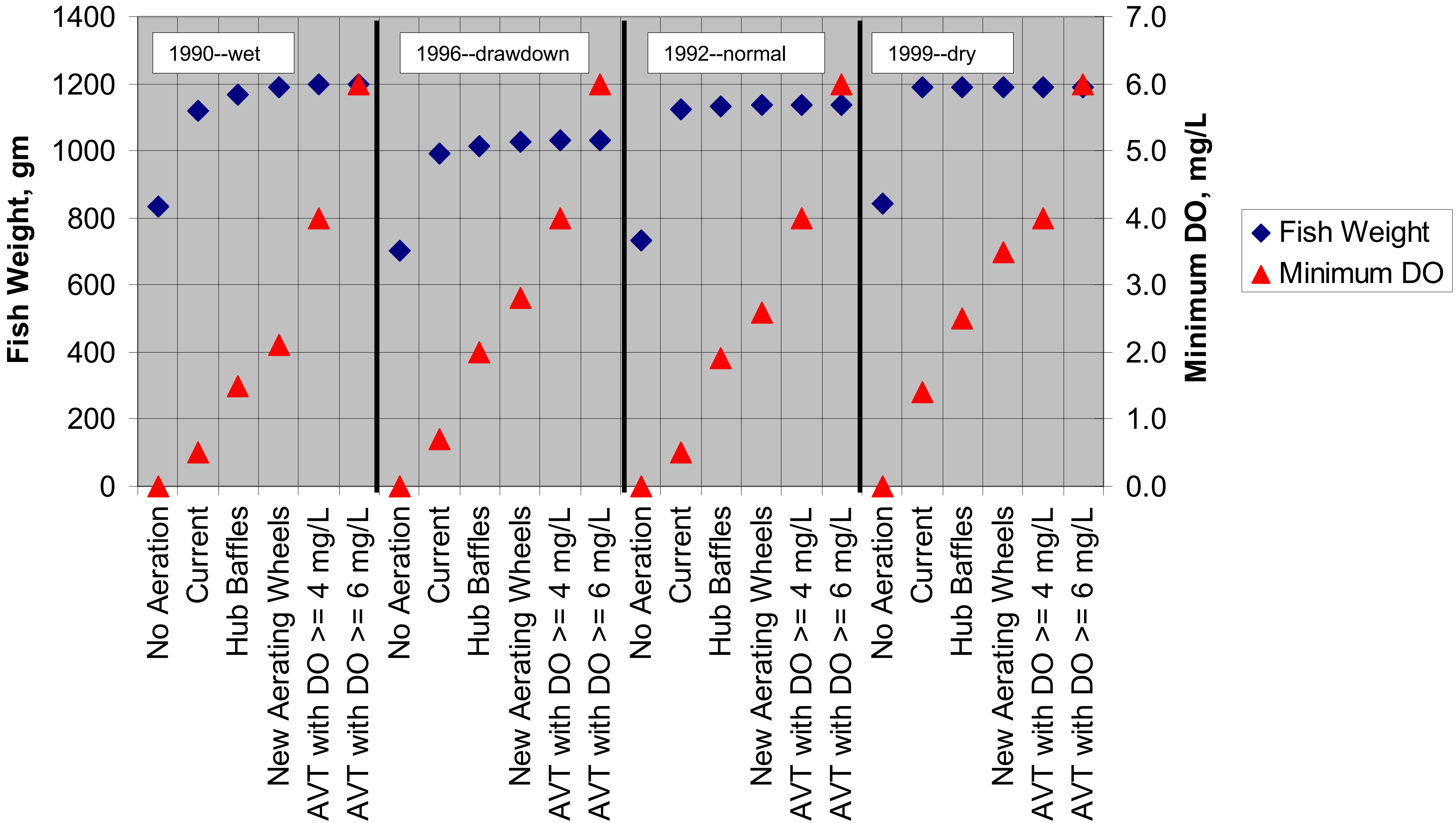
- I will present the results from the previous sections and compare the results of the fish modeling to DO metrics that summarize the DO conditions to which the fish were exposed in the fish model.
- The DO metrics presented here focus on those that might be considered for setting a site-specific standard. In considering regulatory DO standards it is important to set DO thresholds which are intended to be met or exceeded under defined conditions. Hence most of the discussion in the section regarding DO metrics will focus on the minimum values of each of the metrics.

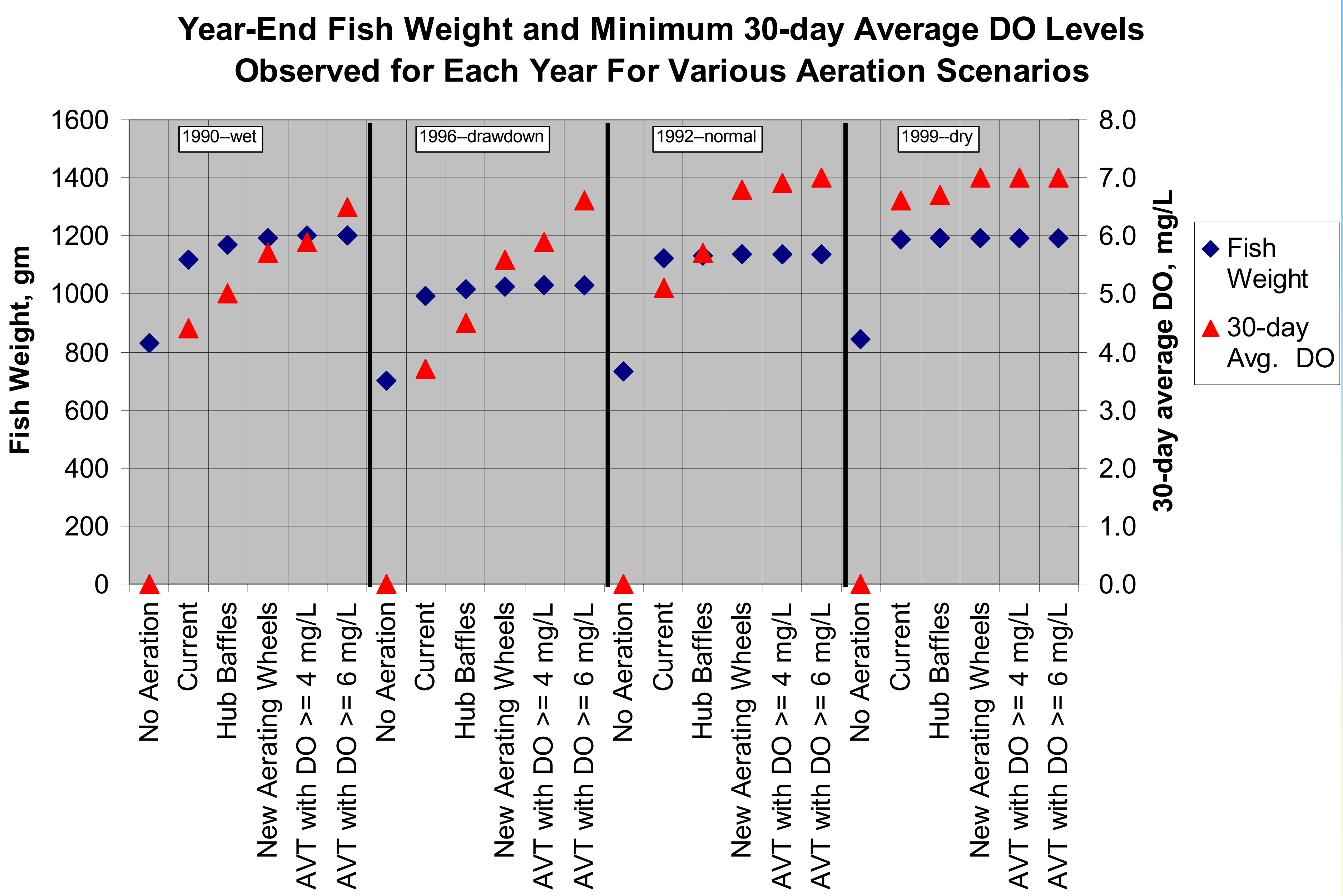




AVT Scenario with 4 mg/L Minimum DO

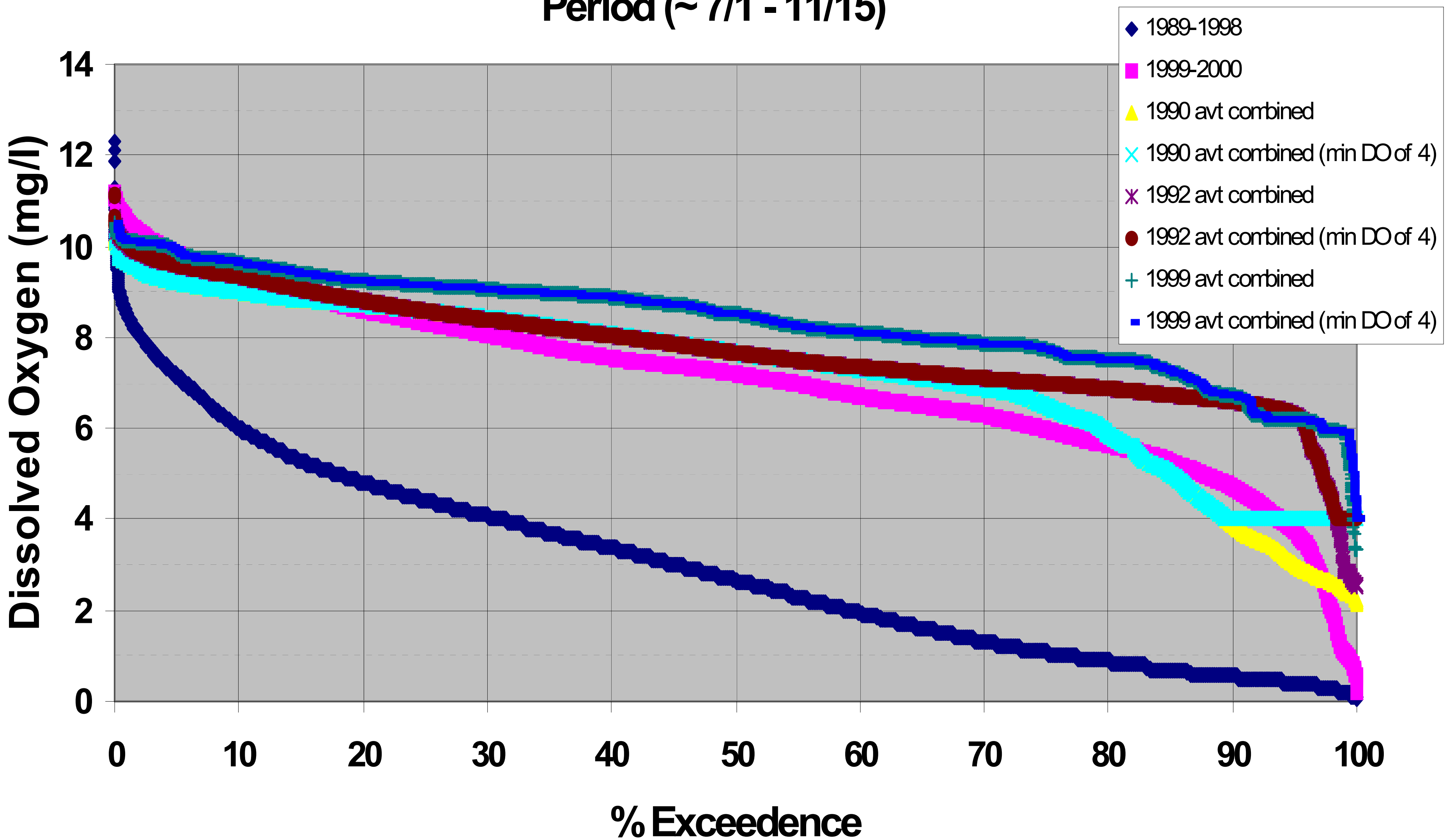
Year-End Fish Weight and Minimum Daily DO Levels Observed for Each Year For the Aeration Scenarios Considered





Year-End Fish Weight and Minimum 30-day Average DO Levels
Observed for Each Year For Various Aeration Scenarios
Fish Weight, gm
30-day average DO, mg/L
1990--wet
1996--drawdown
1992--normal
1999--dry
Fish Weight
30-day Avg. DO
0
200
400
600
800
1000
1200
1400
1600
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
No Aeration
Current
Hub Baffles
New Aerating Wheels
AVT with DO >= 4 mg/L
AVT with DO >= 6 mg/L

Percent of Time that Various Dissolved Oxygen Concentrations Would be Exceeded in Saluda Hydro Tailwater - for the Low DO Period (~ 7/1 - 11/15)



Current Conditions

- Current conditions of the fishery and invertebrate food supply are excellent by comparison to other southeastern hydropower tailwaters, even though DO concentrations have periodically dropped to about 1 mg/L during high flows.
- These fishery conditions can be attributed in large part to SCE&G aeration practices over the past 4 years, in conjunction with drought conditions that have occurred over this same period of time.

Current Conditions, cont.

- The most critical DO conditions occur during high flows. When special drawdowns of Lake Murray occur, especially in wet years, more water has been released during the time of year when DO in the discharges was at its lowest levels. Under these conditions (2 of the last 14 years), low DO occurred more frequently and for longer durations.
- Fish modeling indicates that the current aeration practice would result in good growth, i.e., 0.67 inches/month and year-end fish lengths of about 18 inches and weights of over 2 pounds.
- However, with additional aeration, small increases in growth might occur and mortality and avoidance would be less likely.

At least two DO metrics are needed for the site-specific standard:

1. one to protect against acute toxicity, and
2. one to ensure suitable fish growth.

These metrics should be selected to protect designated uses, as well as allow Saluda Hydro to operate as cost-efficiently as possible.

DO Metric for Acute Toxicity

- DHEC has specified that the minimum be no less than 4 mg/L, and this value is consistent with the EPA criteria for trout waters. (This EPA criterion was set in order to protect insect species that may be more sensitive than trout. EPA suggested a minimum value of 3 mg/L to avoid trout mortality.)
- The trout growth study on the LSR indicates that the 4 mg/L minimum DO is more than sufficient to provide for food supply and protect the trout against mortality.
- Considering that SCDHEC has set 4 mg/L as the minimum DO level, SCE&G has no practical alternative but to consider proposing 4 mg/L as the minimum DO level.

DO Metric For Growth

- The 30-day average DO metric was significantly better than any other metric for being correlated to fish growth, based on a comparison using the other DO metrics (daily average and 7-day average)
- Regression coefficients were determined for the relationships between year-end fish weight and the DO metrics, and R-square values were significantly higher for the 30-day average,
- Average DO metrics for shorter periods like daily and 7-day average fell below 5 mg/L intermittently for brief periods in 1990 and 1996 even when minimum DO was 4 mg/L

DO Metric For Growth, cont.

- An approach using the 30-day average, which best protects fish growth, is recommended in the EPA criteria document.

- Although a 30-day average differs from the daily average DO currently used by SC for most waters of the state, it is more protective as a growth metric when proposed along with a minimum DO standard.

- The 30-day average is more protective because it is a higher level of DO over a longer period of time, which is more important to growth.

Considerations for Setting the Standard

- A 30-day average of 5.5 mg/L can be used with immeasurable differences in weight or length relative to that attainable with a minimum DO of 6 mg/L.
- “Immeasurable” is defined to be 14 grams, 0.5 ounces, or 1/16 inches less than growth achieved using a minimum DO of 6 mg/L.
- The mean difference in year-end fish size with a 30-day average DO of 5.5 mg/L versus a minimum DO of 6 mg/L from all four years was 6 grams, 0.22 ounces, and 1/32 inches.
- Difference in growth in 1990 was also determined to be immeasurable: 12 grams, 0.45 ounces, and 1/16 inches.

More than any other metric, the 5.5 mg/L 30-day average satisfies both DHEC/EPA/DNR objectives for the trout put-grow-and-take use designation and SCE&G's objectives for cost-effective compliance in terms of capital costs, operational costs, and "operator difficulty" for complying with the target DO.

Site-Specific Considerations for Saluda Hydro

- The primary reason that a 5.5 mg/L, 30-day average DO is sufficient for the LSR: low DO values only occur an average of about 1 % of the time.
- DO is low when flow is high (about 10,000 cfs or more). Fishing experience is not likely to be impacted during low DO conditions since fishing is not as prevalent at high flows
- The 30-day average generally requires continuous monitoring. This is difficult to measure and maintain for point source dischargers on unregulated streams, but it is relatively easy to measure for hydropower discharges since continuous monitors are routinely installed.
- The 30-day average provides important flexibility needed for operations of a large hydropower project where the entire river passes through the project, i.e., the hydropower project is challenged to “treat” a whole river that discharges as much as 18,400 cfs, or almost 12,000 MGD or about 200 times the size of the wastewater discharge from the City of Columbia.

§401 Water Quality Certification Process for Federal Energy Regulatory Commission (FERC) Hydro Relicensing

D H E C
PROMOTE PROTECT PROSPER
South Carolina Department of Health and Environmental Control

Regulatory Authority

- **Section 401 Clean Water Act**
- **S.C. R. 61-101 Water Quality Certification**
  - S.C. R. 61-68 Water Classification & Standards.
  - S.C. R. 61-69 Classified Waters.
  - S. C. R. 19-450 Permits for Construction in Navigable Waters (new licenses).
  - Pollution Control Act

  - Through appropriate State Regulations, the 401 Water Quality Certification allows the Department to regulate hydroelectric facilities in a way that provides a reasonable assurance the water quality standards will not be contravened and that existing and classified uses of affected waterbodies will be maintained.

3-Stage Consultation

Traditional Approach

Application Filed

Third Stage

Request for 401 WQ Cert

Comment on Draft Application *

Draft Application

Study Completion

Second Stage

FERC Dispute Resolution?

Comments and Decision on Studies *

ICP & Joint meeting *

First Stage

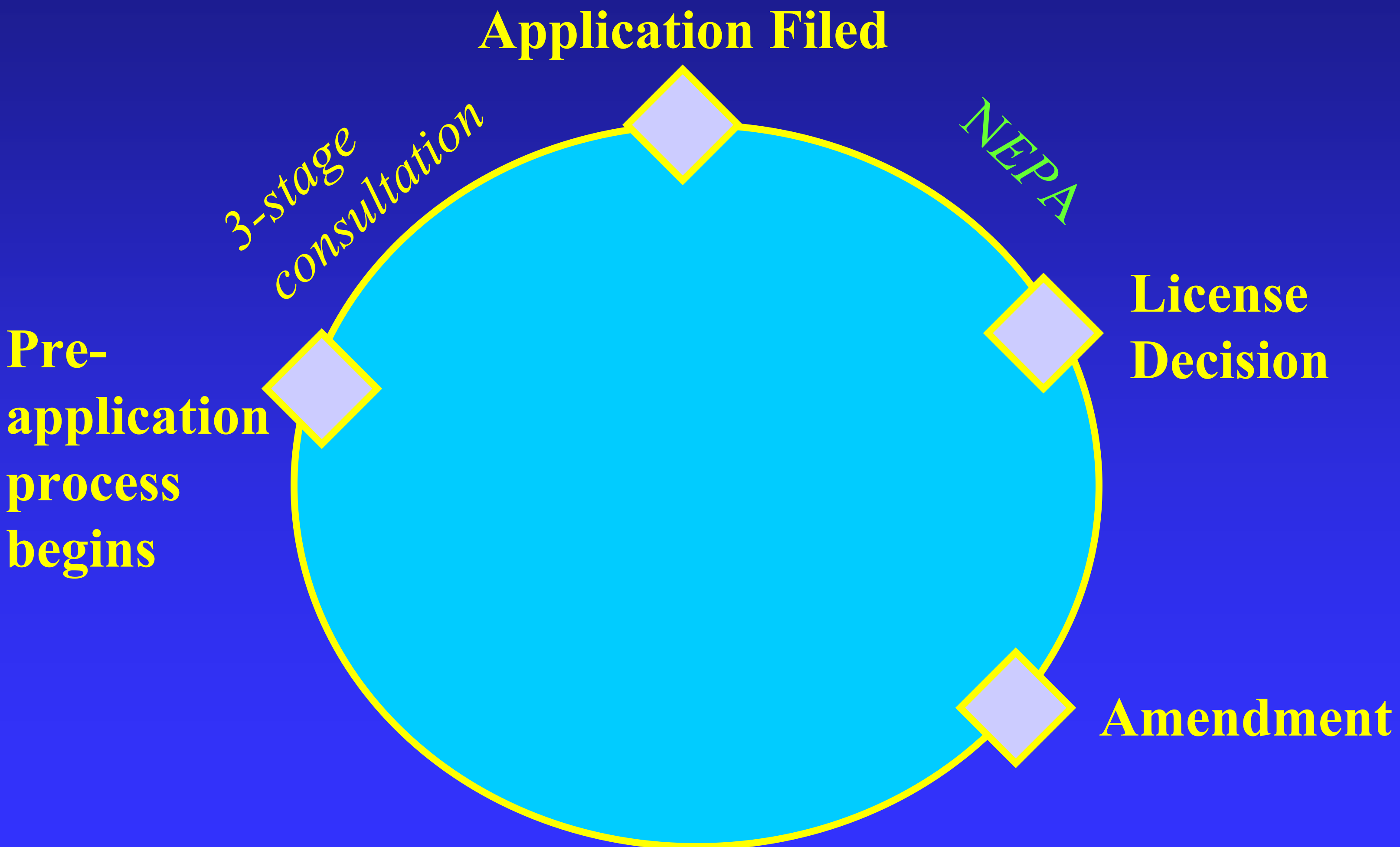
Notice of intent

Pre-application process begins

3-Stage Consultation

- **First Stage**
  - Initial review, project modifications, proposed studies
- **Second Stage**
  - Completion of studies, determination of mitigative measures, draft application
- **Third Stage**
  - Final application filed

Traditional Approach



401 Water Quality Certification Process

FERC Stage I

- **Receive and Review Initial Consultation Package**
  - Scope of Review for Operation of Hydro Facilities for Licensing/Relicensing May Include:
    - Water Quality
      - D.O. levels in water released from hydro facilities.
      - Temperature of water released from hydro facilities.
      - Other water quality parameters if influenced by hydro operation.

401 Water Quality Certification Process

– Scope of Review for Operation of Hydro Facilities for Licensing/Relicensing (continued).

- Minimum flow releases
  – Assimilative capacity for downstream NPDES discharges.
  – Aquatic life habitat (downstream or bypass reach).
- Endangered Species.
- Navigation (new licenses).

401 Water Quality Certification Process

FERC Stage I (continued)

- **Attend Interagency Meeting to Discuss Issues**
- **Provide Written Comments**
  - Scope of 401 Issues.
  - Additional information/data needed with justification.
  - Studies needed to provide additional data needed.

401 Water Quality Certification Process

FERC Stage II

- **Study Plans Finalized After Approval By Department**
- **Studies Completed**
  - Data and other technical information provided in reports
- **Applicant Submits Application For 401 Water Quality Certification**.
  - Department reviews application for completeness (study results reported/other technical information requested).
  - Other information required for processing application includes list of adjacent property owners and addresses, applicant contact information, cubic yards of fill/excavation if new license etc.

401 Water Quality Certification Process

- **Complete Application Starts 401 Process**
- **Department issues SCDHEC Public Notice**
  - Distributed to adjacent property owners, resource agencies, other interested parties.
    - Comments to be sent to Department within 30 days.
  - One year clock starts (Department has 1 year from Public Notice date to issue, waive, or deny certification).
    - Department has 180 to issue decision unless waiting for information/processing items from applicant (fee refunded if 180 days exceeded).

401 Water Quality Certification Process

Post Application Process (continued).

- Form sent notifying applicant of fee and newspaper affidavit requirements.
  - Applicant required to publish brief project description in newspaper .
  - Comments to be sent to Department within 15 days.
- Department Holds Public Hearing if at least 20 requests received.
  - Written comments to be sent to Department within 30 days of hearing.
- 401 Technical Review Process Officially Starts

401 Water Quality Certification Process

Post Application Process (continued)

- **Staff Assessment Prepared When Technical Review Complete**
  - Staff Assessment is the document supporting 401 decision and conditions.
  - Written Assessment addresses the water quality impacts of the project and makes conclusions concerning compliance with water quality standards and protection of classified uses.
  - Considers comments received.
  - Conditions are project specific, but may include minimum flow requirements (including bypass reaches), hydro operations addressing water quality (e.g., turbine venting) sediment passage, notification of downstream water users if water withheld, notification of fish kills etc.
  - Coastal Zone Consistency Certification and/or Navigable Waters Permit with Conditions Incorporated (if applicable).

401 Water Quality Certification Process

- **Notice of Proposed Decision (NOPD) Issued**
  - Notice lists conditions and has Staff Assessment attached
  - Notice is sent to applicant, adjacent property owners, resource agencies and other interested (commenting) parties.
  - Gives recipients opportunity to appeal 401 WQC decision within 15 days.
  - If Certification Decision Appealed Legal Department Processes in Accordance with Contested Case Procedures DHEC Regulation 61-72.
- **Final Certification Decision Issued** (if no appeal).
  - Certification letter with conditions issued to applicant

Application Filed

Public Notice of Application (Tendering)

Additional Study Requests, if any *

Adequacy Review

Public Notice (Acceptance)

Comments & Interventions *

Scoping Notice & Scoping Document 1

AIR and response to additional studies

Scoping Meeting *

Scoping Comments *

Scoping Document 2 and AIR

REA Notice

Rec., mandatory conditions *

Draft NEPA Document

NEPA Comments *

10(j) meeting

Final NEPA Document

License Decision

NEPA

Traditional Approach

Water Quality Standards

South Carolina Regulation 61-68,
Water Classifications and Standards

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South Carolina Department of Health
and Environmental Control

South Carolina Regulation 61-69 Classified Waters

- Contains the specific classification of listed waters
  - Not all waters are listed, but all are classified
- Contains site-specific water quality standards
  - Site-specific standards are only applicable to a specified waterbody

R.61-68.A. Purpose and Scope

- Three categories of water quality standards
  - Narrative and Numeric Criteria
  - Uses
  - Antidegradation Policy

R.61-68.B. Definitions

- Pollution Control Act
- Balanced indigenous aquatic community
- Biological Criteria
- Classified Uses
- Existing uses
- Fishing

R.61-68.B. Definitions

- Natural conditions
- No Discharge Zone
- Primary contact recreation
- Propagation
- Secondary contact recreation

R.61-68.C. Applicability of Standards

- Contains several important statements regarding how, when, and where water quality standards are applied such as:
  - Design flow conditions
  - Protection of ephemeral and intermittent streams as waters of the State
  - Protection and maintenance of downstream uses
  - Mixing zone provisions
  - Site-specific criteria provisions

R.61-68.D. Antidegradation Rules

- Protection of existing uses (Tier 1)
- Protection of high quality water (Tier 2)
  - Both Tier 1 and 2 are applied on a parameter-by-parameter approach
- Protection of exceptional waters (Tier 2½ and Tier 3)
  - Both Tier 2½ and 3 are applied on a designational approach

R.61-68.E. General Rules

- No waters of the State used for treatment purposes
- "Free froms"
- Use removal or downgrade provisions
- Variance provisions
- "Filling" provisions (§401 certification)

R.61-68.E. General Rules

- Nutrient criteria
- Temperature criteria
- Rules for applying in permitting activities
- Rules for evaluating ambient water quality
- Use of other scientifically-defensible information

R.61-68.F. Biocriteria

- General descriptions
- Use of reference conditions

R.61-68.G. Class Descriptions

- All classifications, designations, specific uses, and some specific criteria
- Freshwater (FW) Classification
- FW uses include the following: primary and secondary recreation, source of drinking water, freshwater aquatic life use, industrial, and agricultural

R.61-68.G. Class Descriptions

- Lake Murray is FW
  - Lake Murray is also a No Discharge Zone (NDZ) for marine sanitation devices
  - The tributaries to both Lake Murray and the lower Saluda River below the dam are also classed as FW

R.61-68.G. Class Descriptions

- FW also include specific criteria for items such as dissolved oxygen, temperature, and turbidity as well as the criteria listed in the appendix and narrative criteria listed in other sections of the regulation. There may also be site-specific criteria in R.61-69.

R.61-68.G. Class Descriptions

- Trout – Put, Grow, and Take (TPGT) Classification
- TPGT uses include all of the FW uses and also support growth of a stocked trout population
- Lower Saluda River is TPGT
- Lower Saluda has a site-specific DO water quality standard found in R.61-69
  - DO not less than daily average of 5 mg/l
  - A running thirty day average of 5.5 mg/l
  - With a low of 4.0 mg/l

R.61-68 Appendix

- Priority pollutants
- Nonpriority pollutants
- Organoleptic effects
- Additional Notes and modifications
- Ammonia