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

RCG Presentation November 6, 2007

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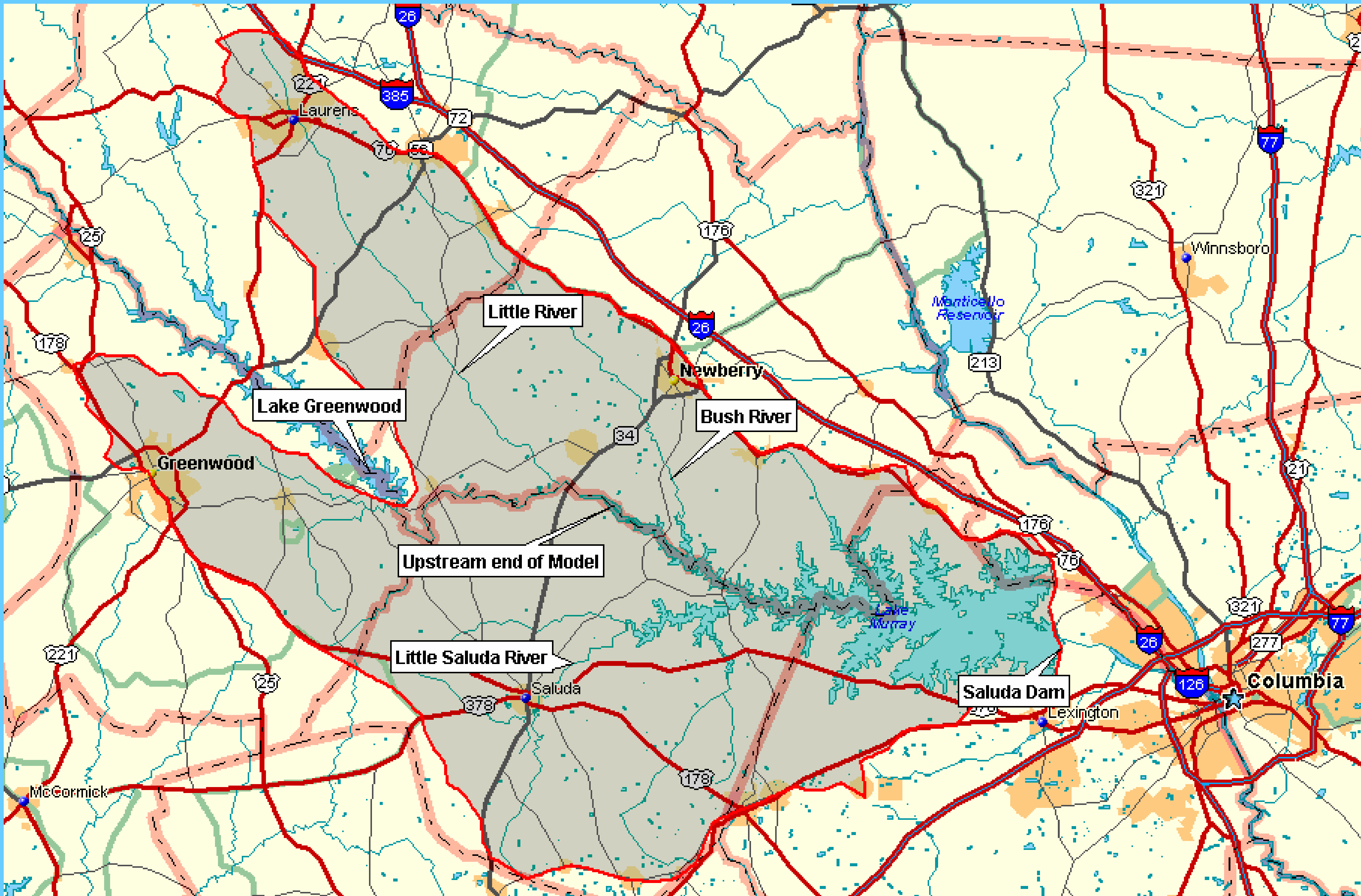
REMI ***Reservoir Environmental Management, Inc***

Lake Murray Watershed

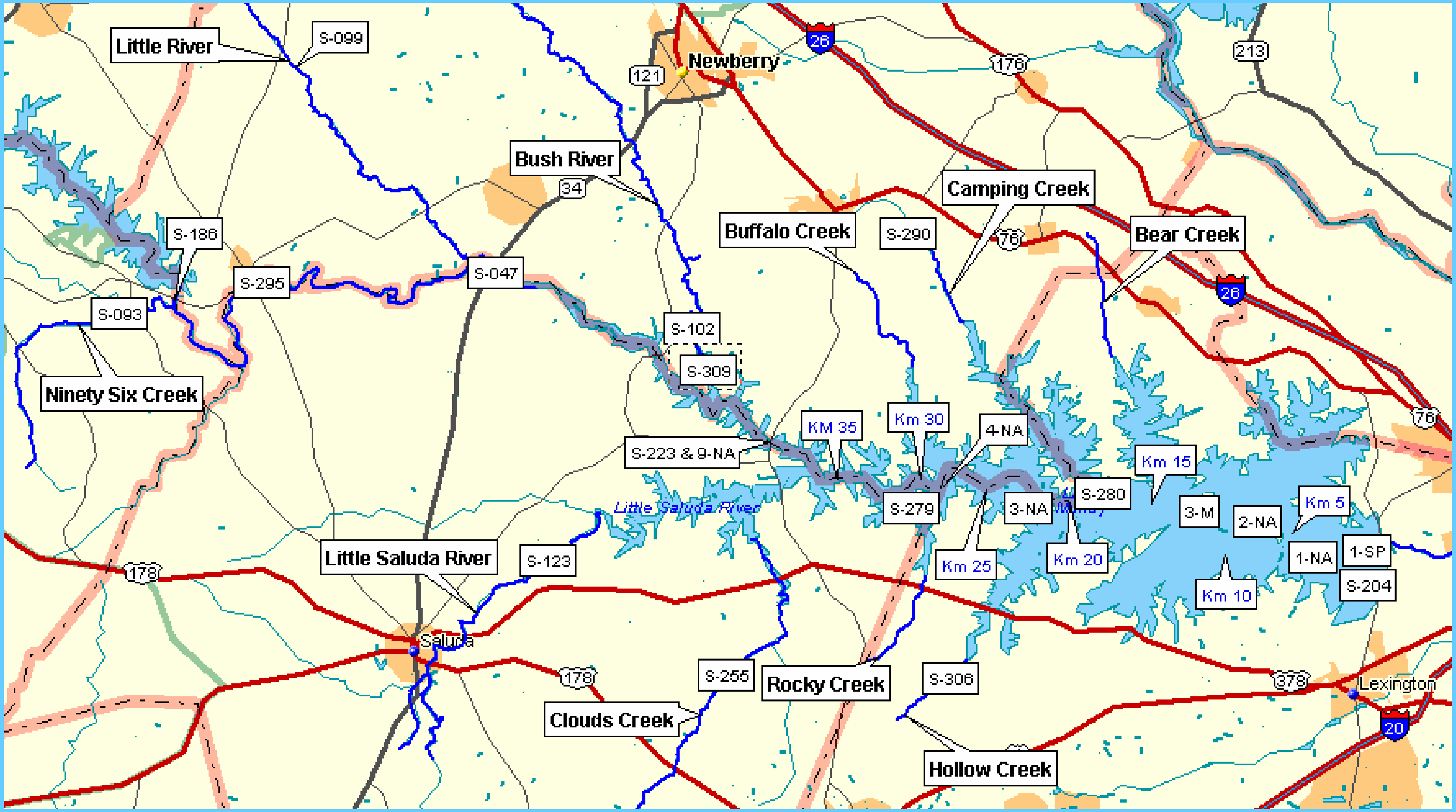


Physical Characteristics of Lake Murray

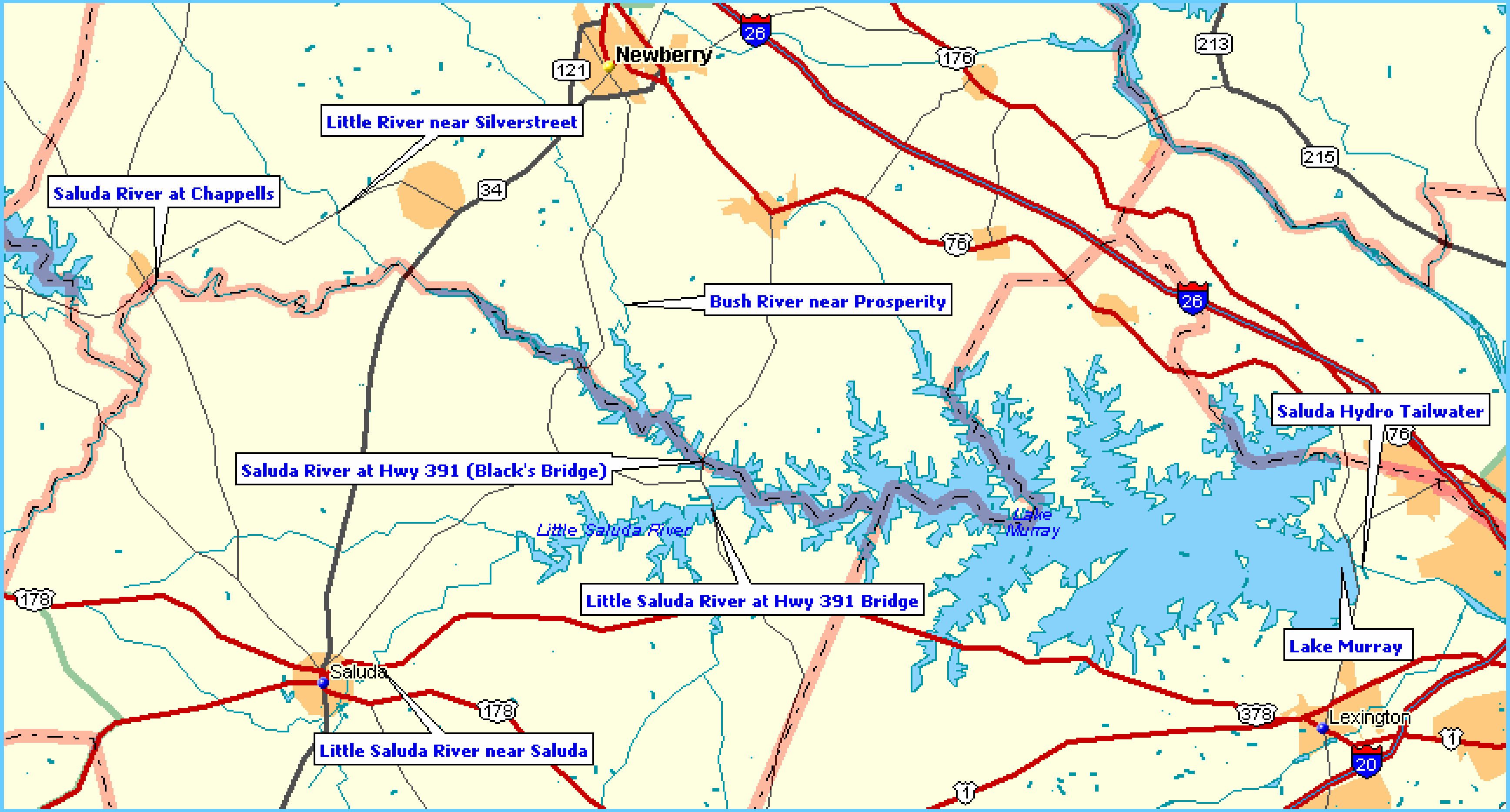
	U.S. Customary System	Metric System
Maximum depth	175 feet	53.3 m
Total lake volume	2,317,000 ac-ft	2,636 hm^3
Average Annual Flow	2778 cfs	78.7 cms
Nominal Residence Time	417 days	417 days
Depth of outlets, Units 1-4	175 feet	53 m
Depth of outlets, Unit 5	78 feet	23.5 m
Flow Capacity - Units 1-4	3000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

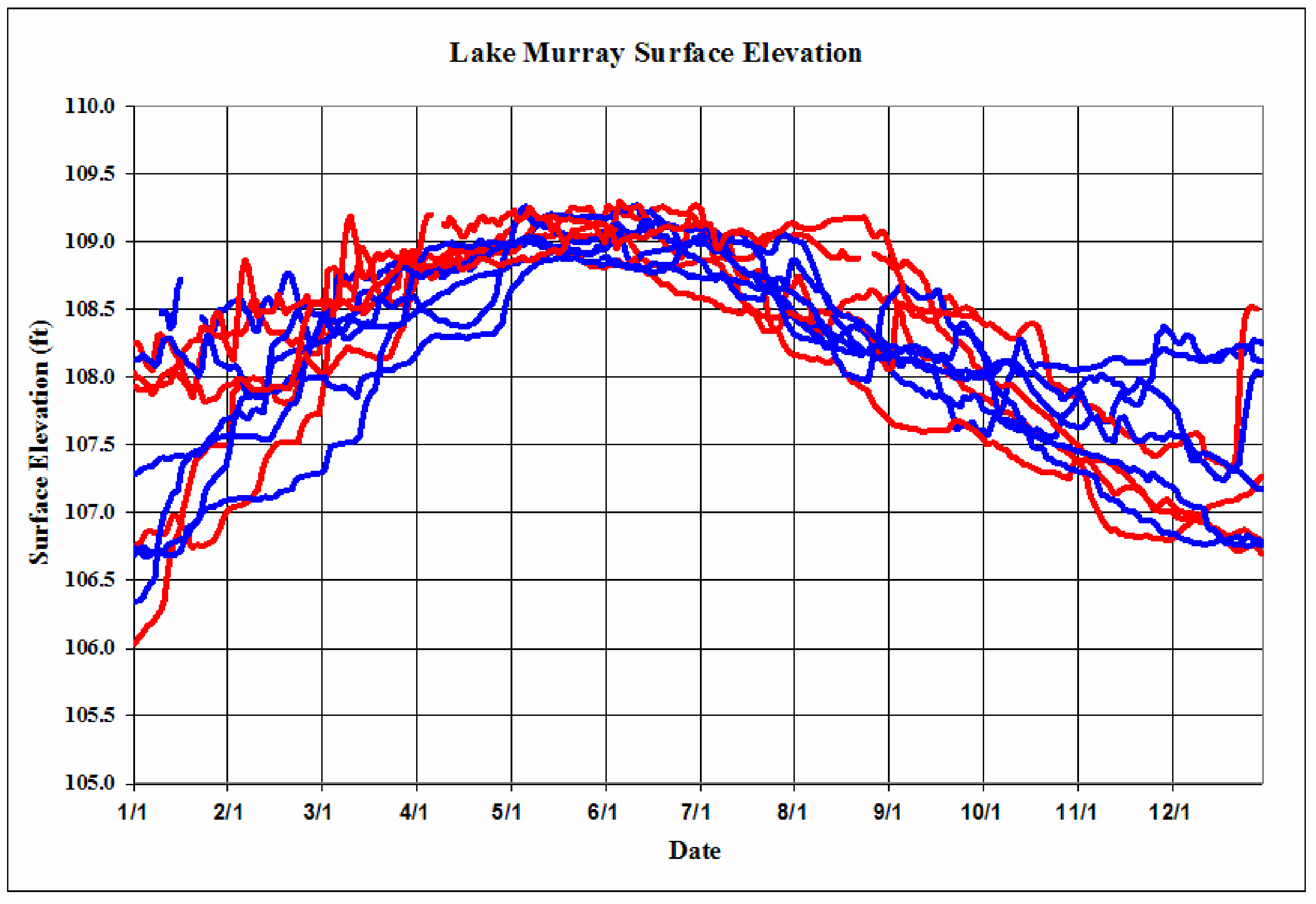
- Meteorological conditions can affect striper habitat

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

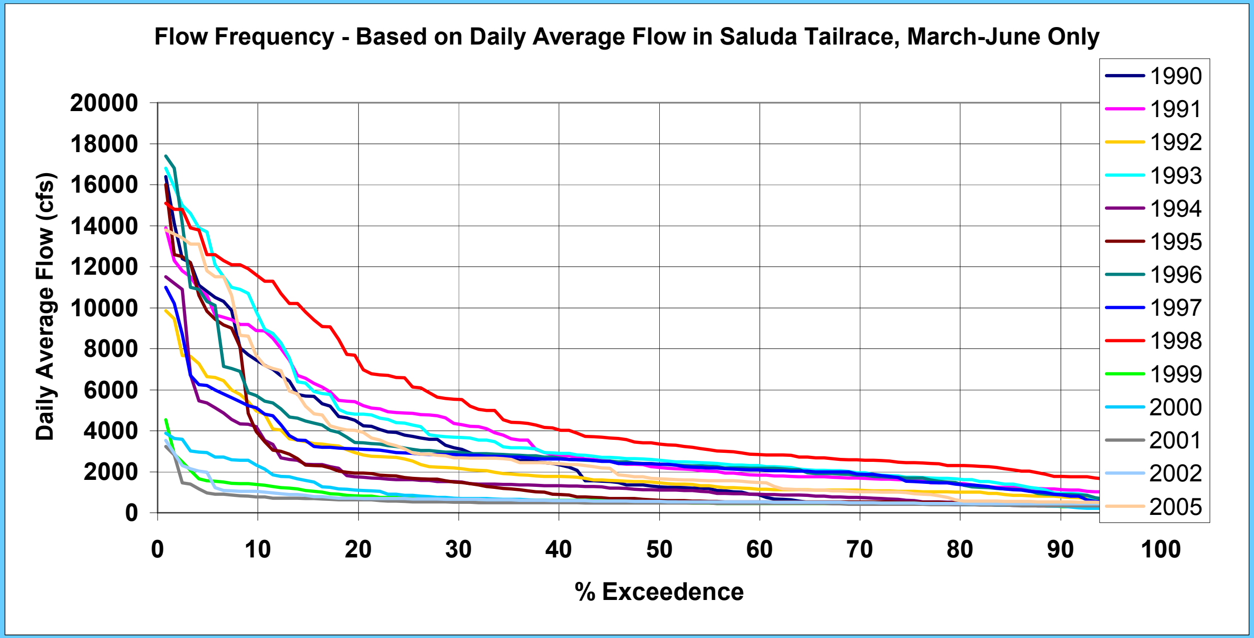
$$T < 27^{o}C \text{ and } DO > 2.5 \text{ mg/l}$$

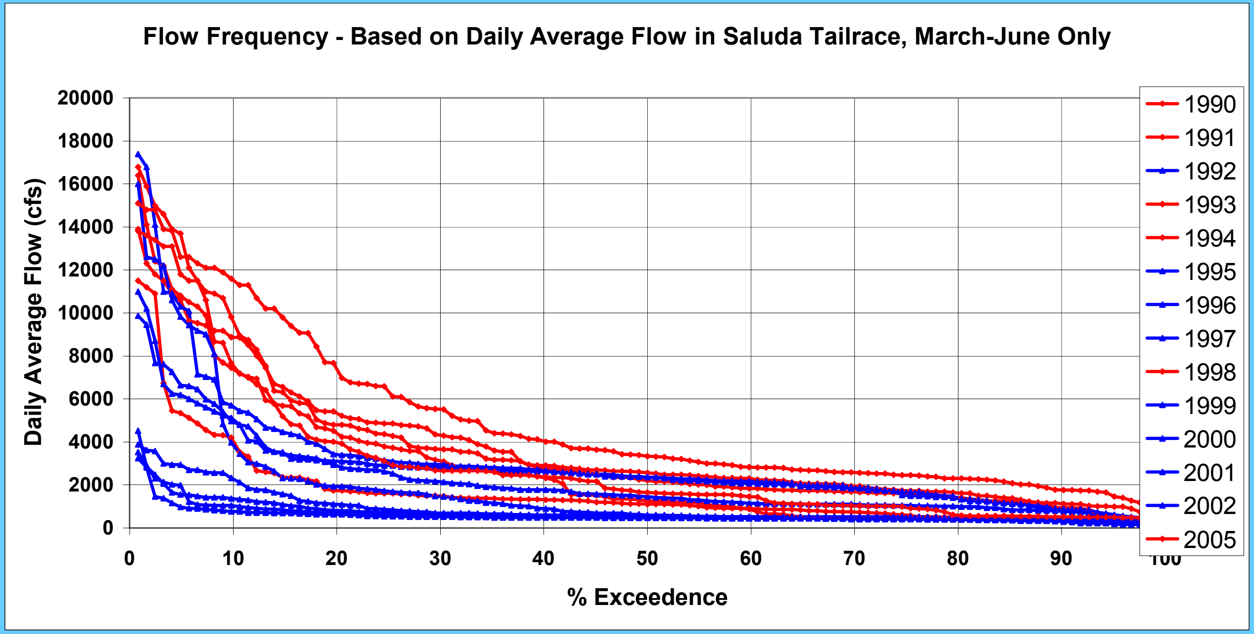
- Higher summer pool levels and preferential use of Unit 5 helps preserve colder bottom water and was predicted to improve DO, increase striper habitat, and enhance temperature in the tailwater

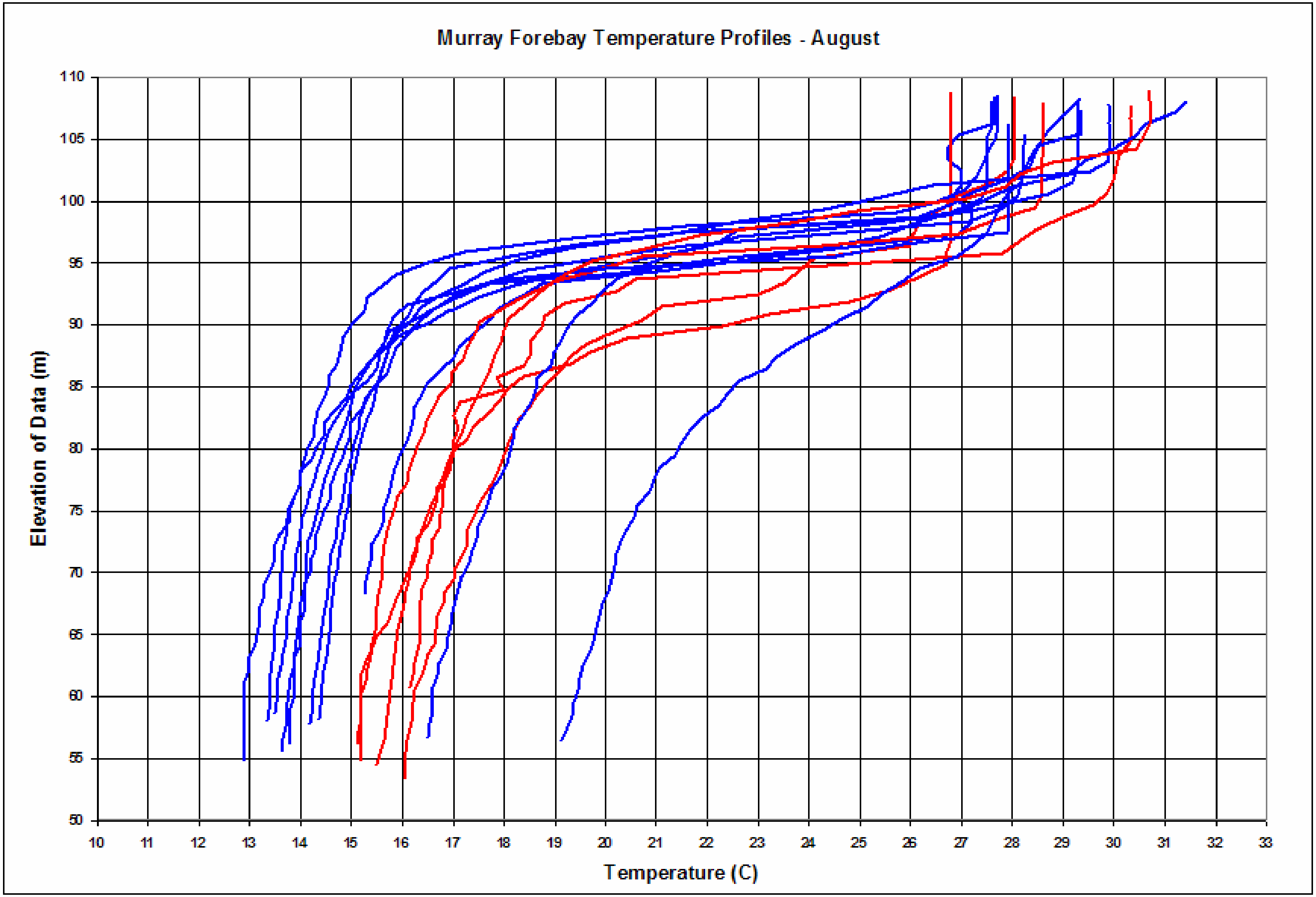
Lake Murray Surface Elevation 1990-2005
Typical Years Only (no special drawdowns)
Years with documented striped bass kills are red



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
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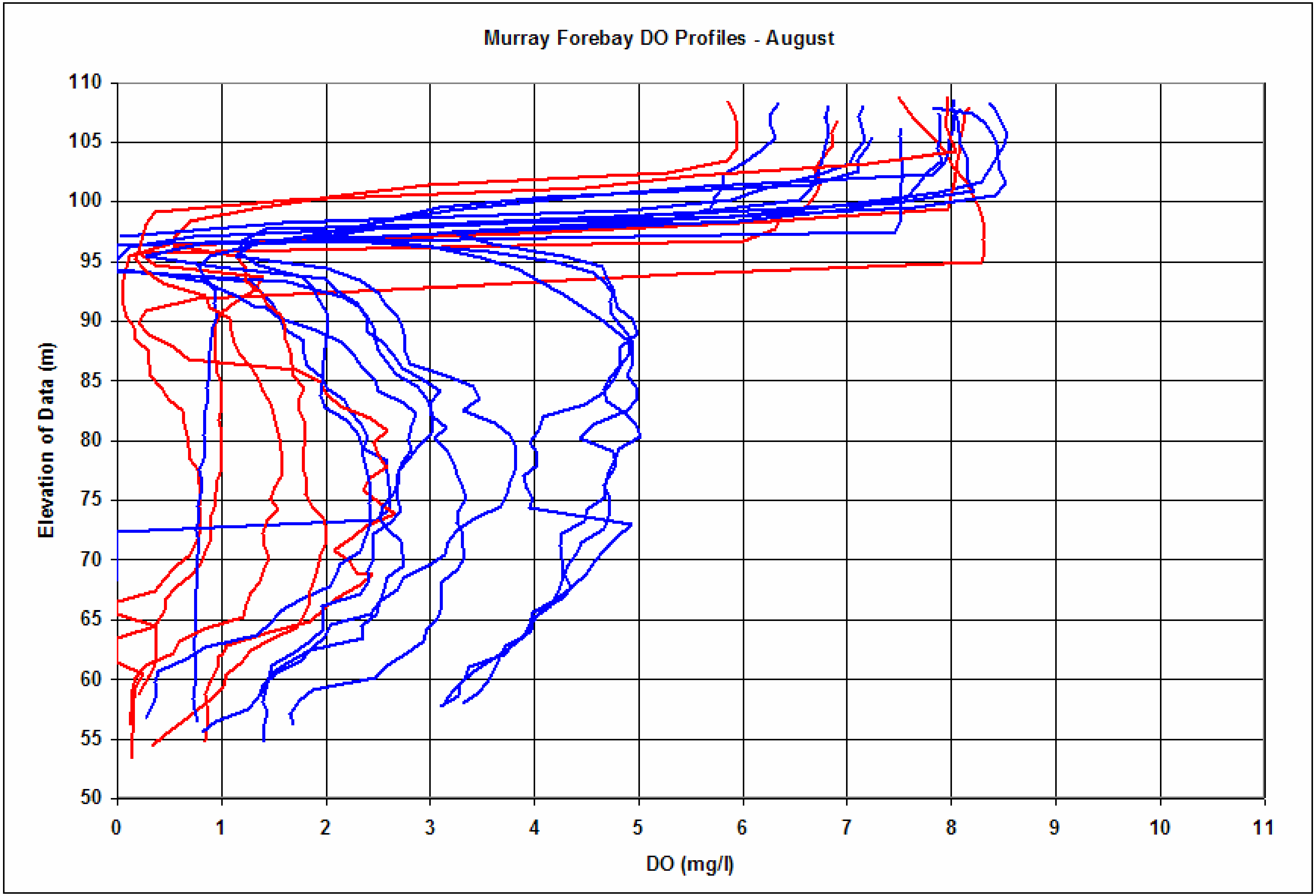
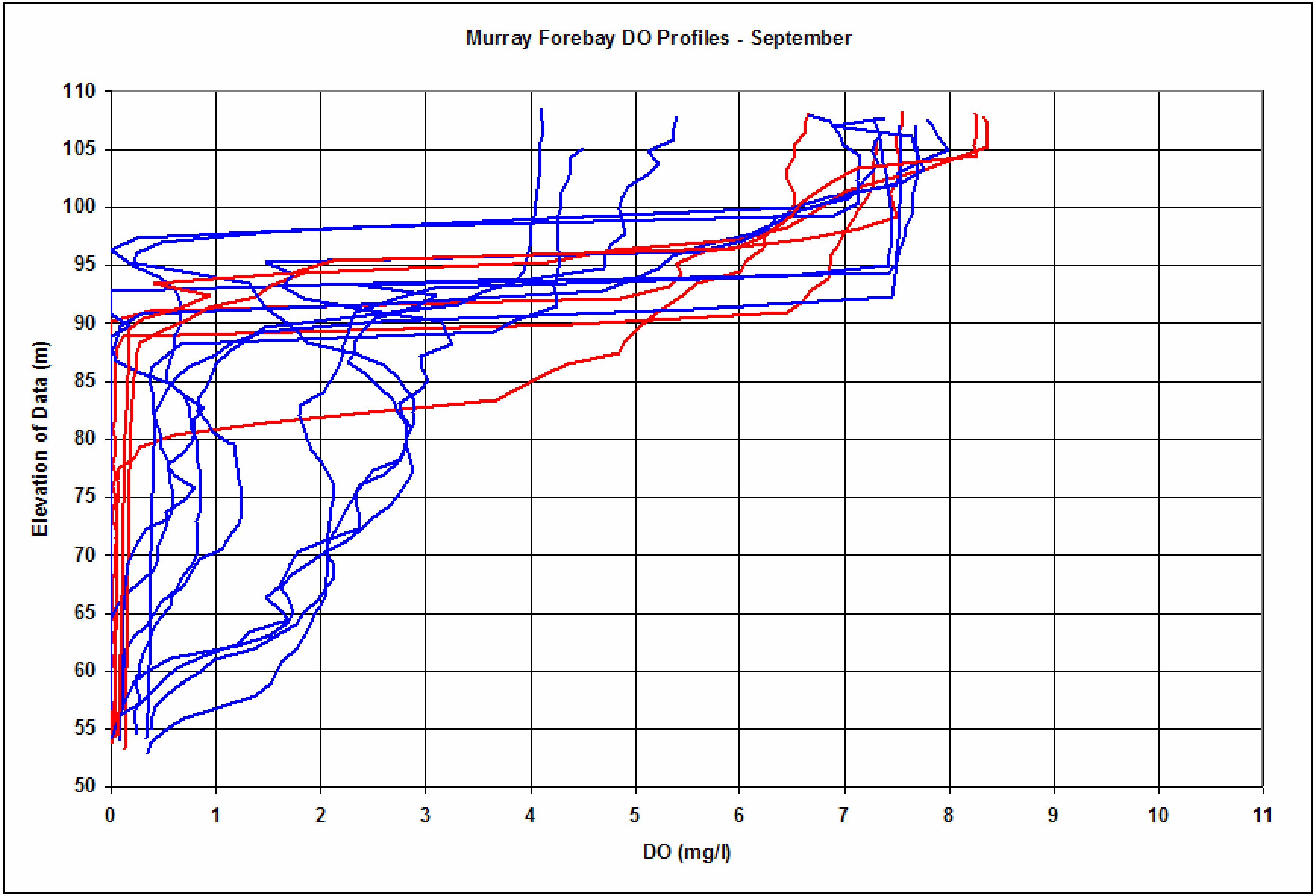


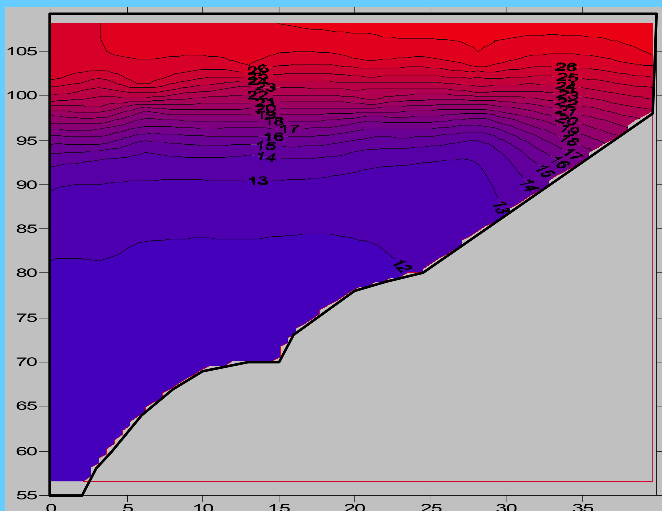
Murray Forebay DO Profiles - August
Elevation of Data (m)
110
105
100
95
90
85
80
75
70
65
60
55
50
0
1
2
3
4
5
6
7
8
9
10
11
DO (mg/l)



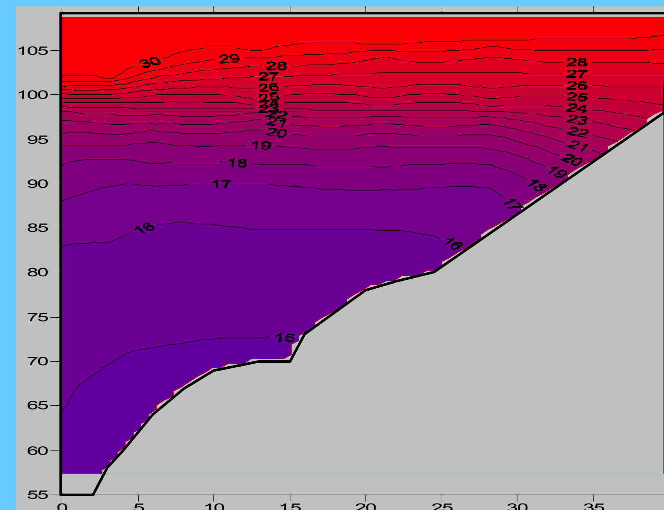
Murray Forebay DO Profiles - September
Elevation of Data (m)
110
105
100
95
90
85
80
75
70
65
60
55
50
0
1
2
3
4
5
6
7
8
9
10
11
DO (mg/l)

Lake Murray Contour Plots

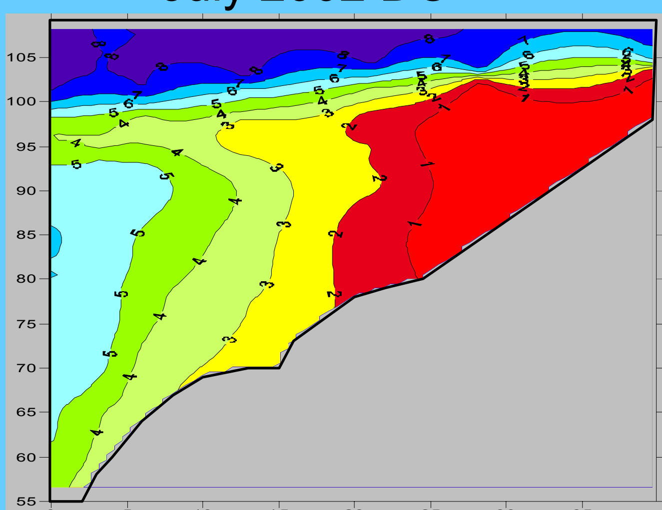
July 2002 Temperature



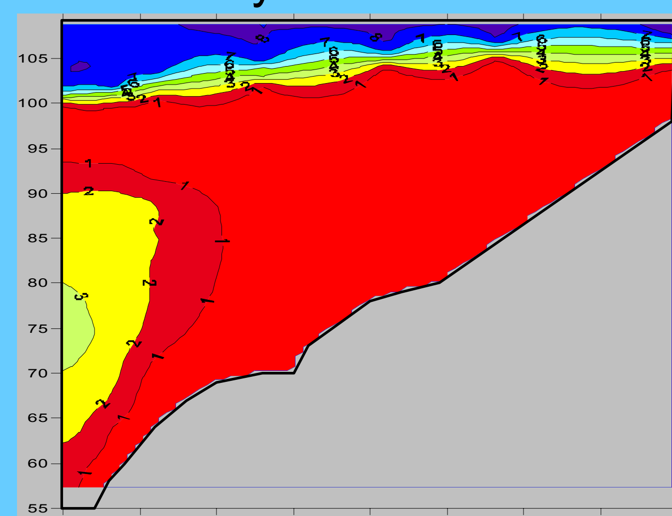
July 2005 Temperature



July 2002 DO

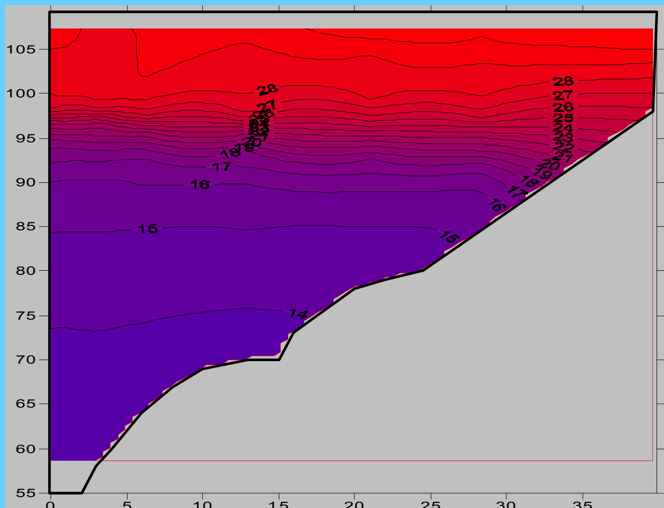


July 2005 DO

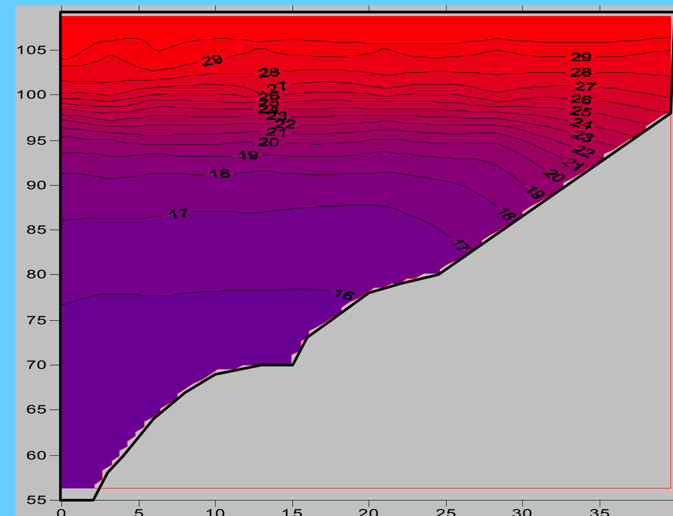


Lake Murray Contour Plots

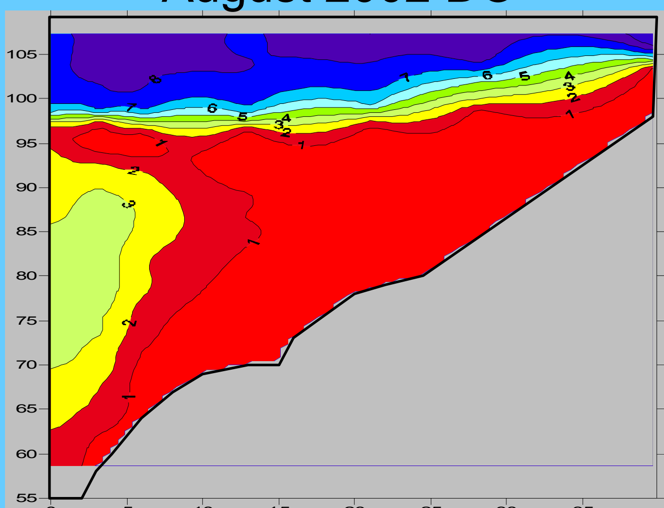
August 2002 Temperature



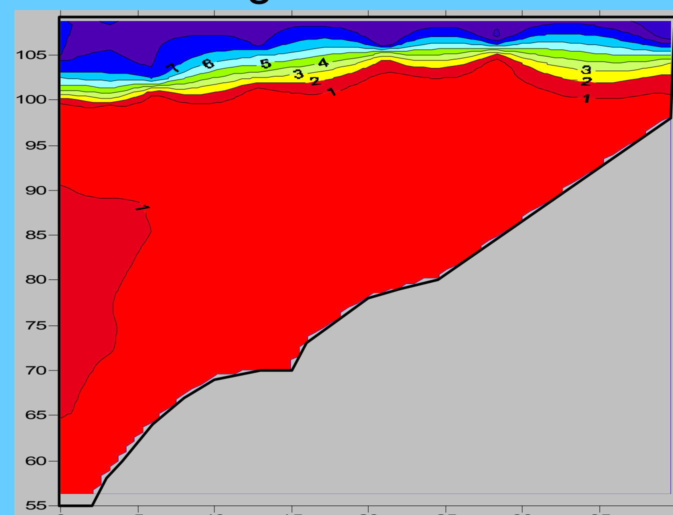
August 2005 Temperature



August 2002 DO

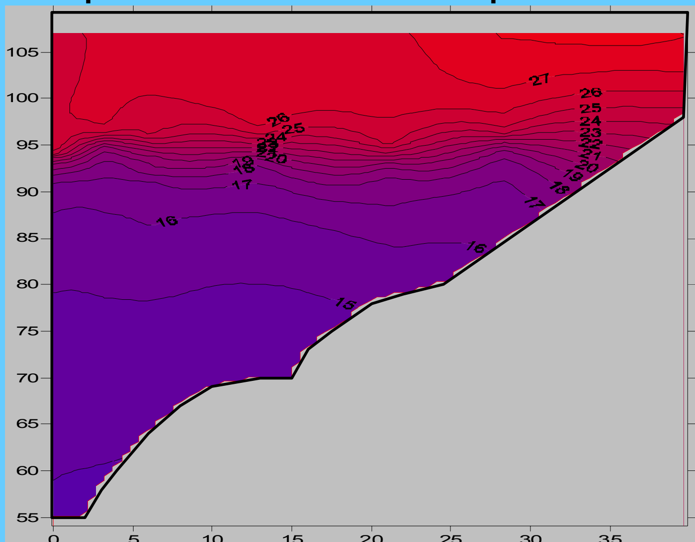


August 2005 DO

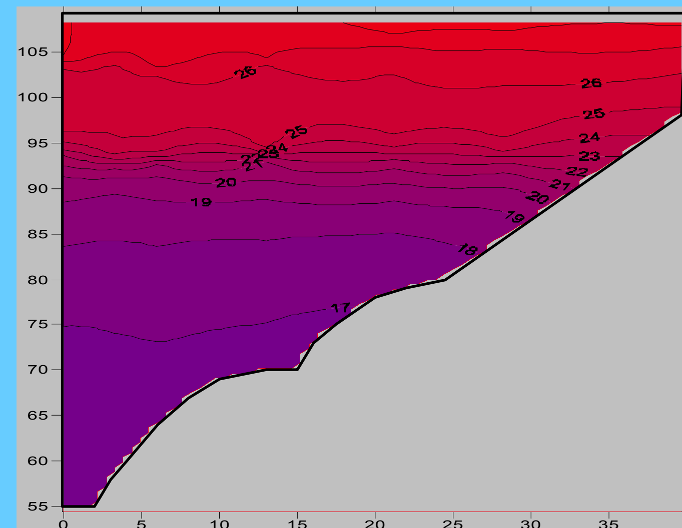


Lake Murray Contour Plots

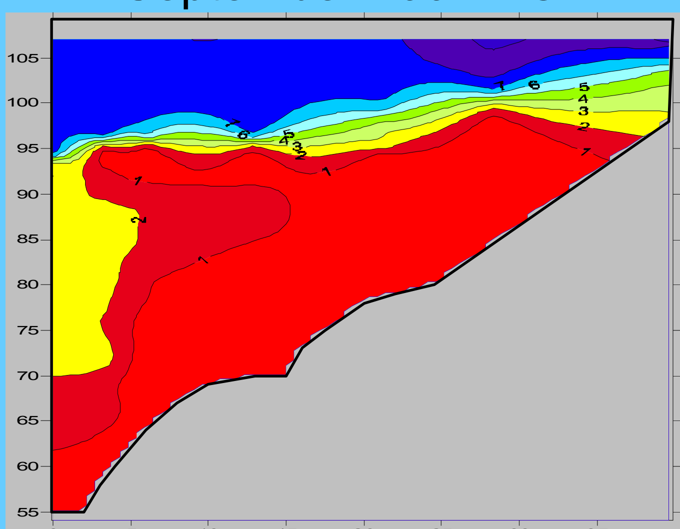
September 2002 Temperature



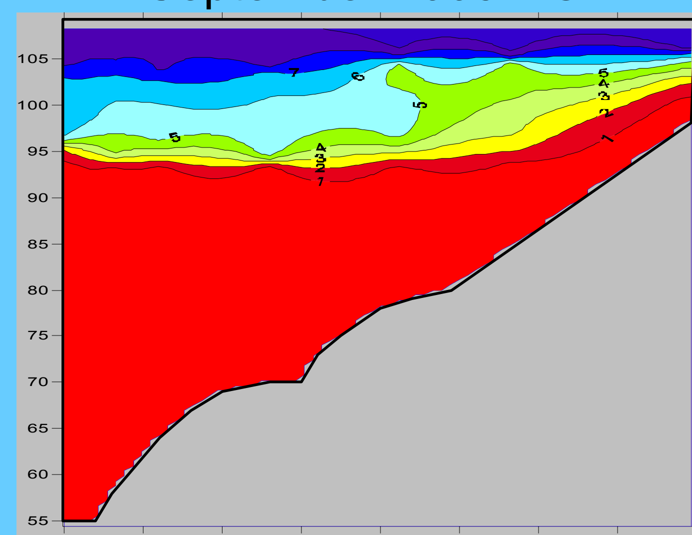
September 2005 Temperature



September 2002 DO



September 2005 DO

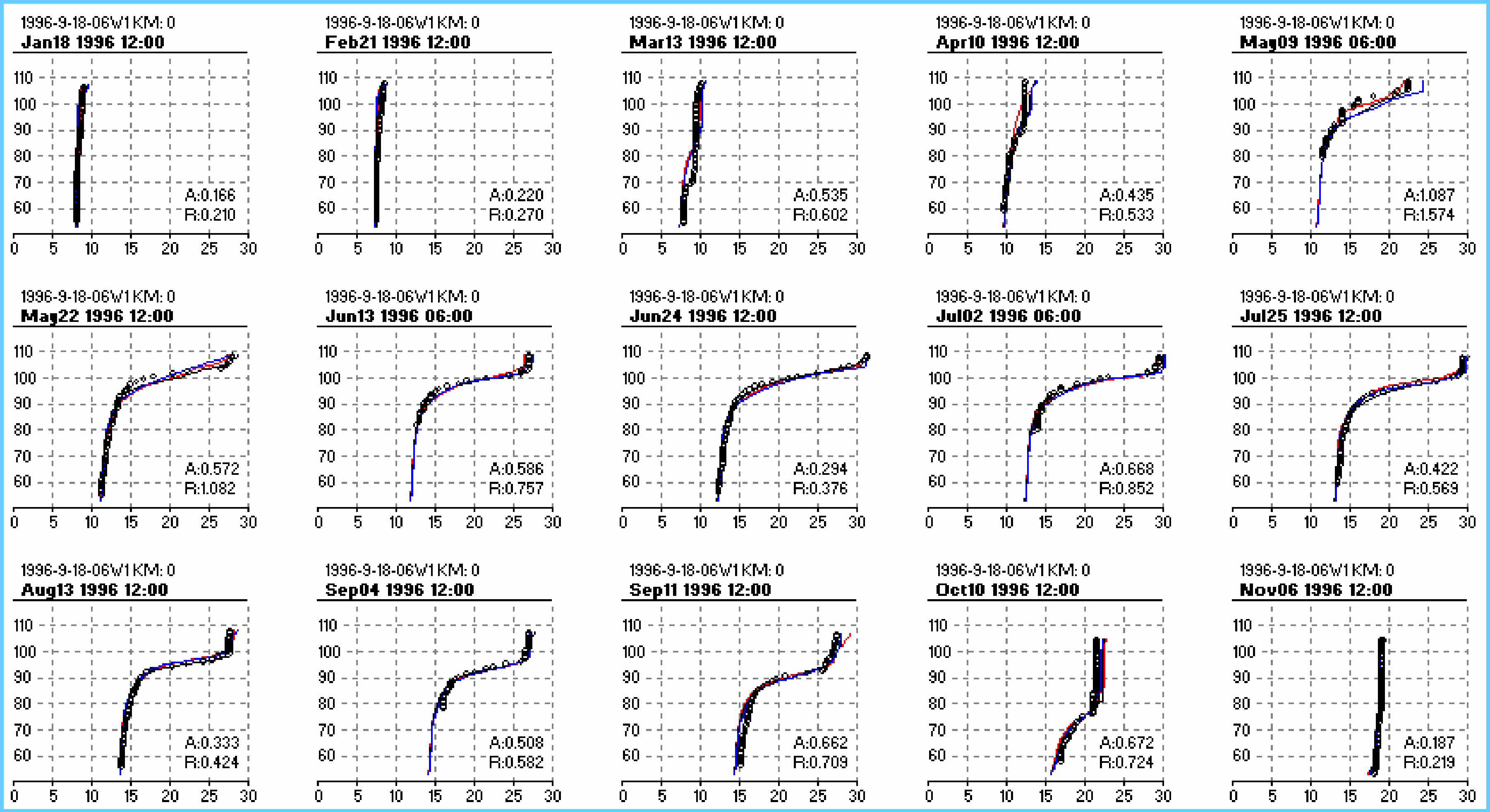


Model Calibration

- 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

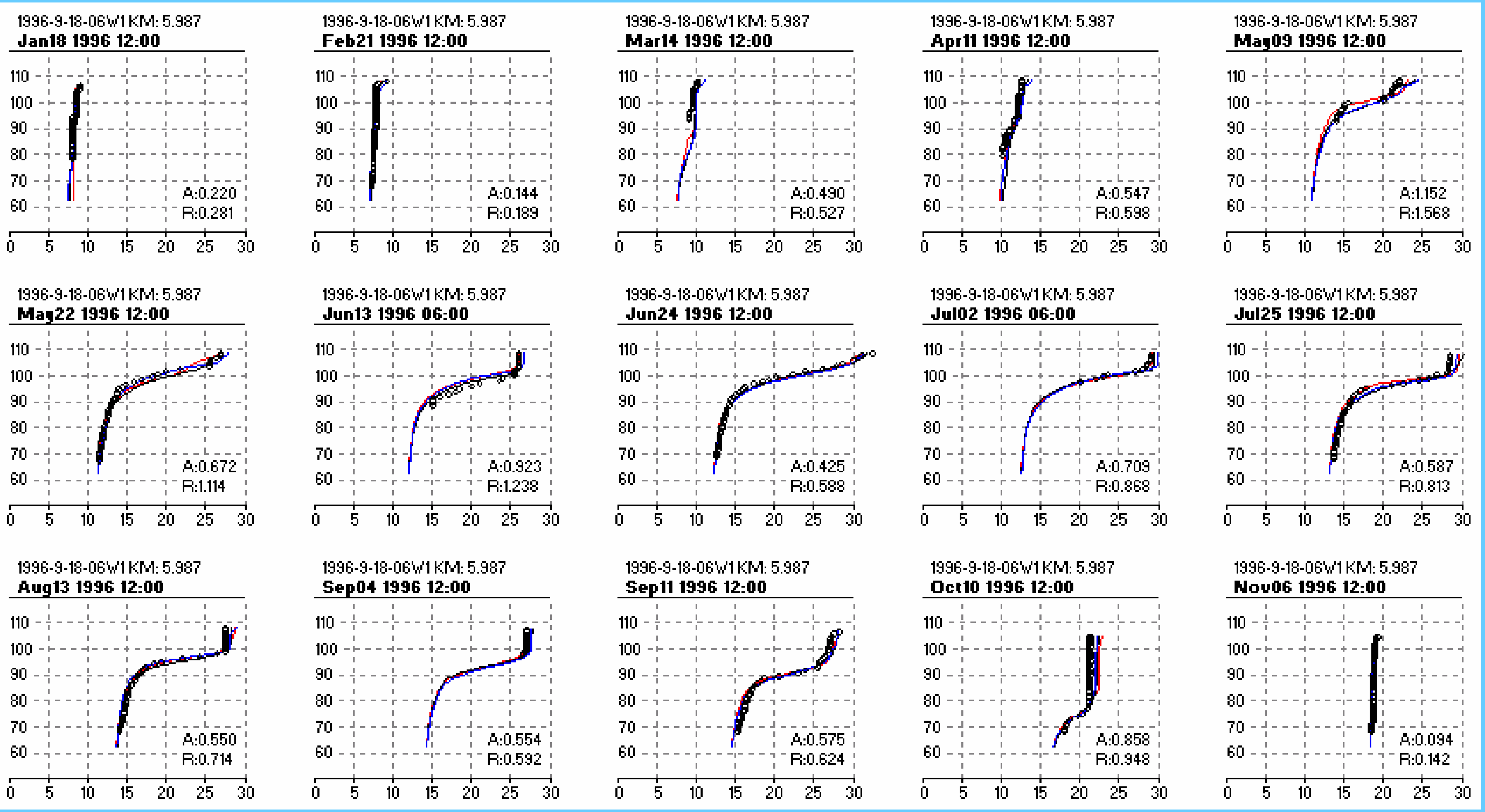
1996 Lake Murray Forebay Temperature Profiles

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



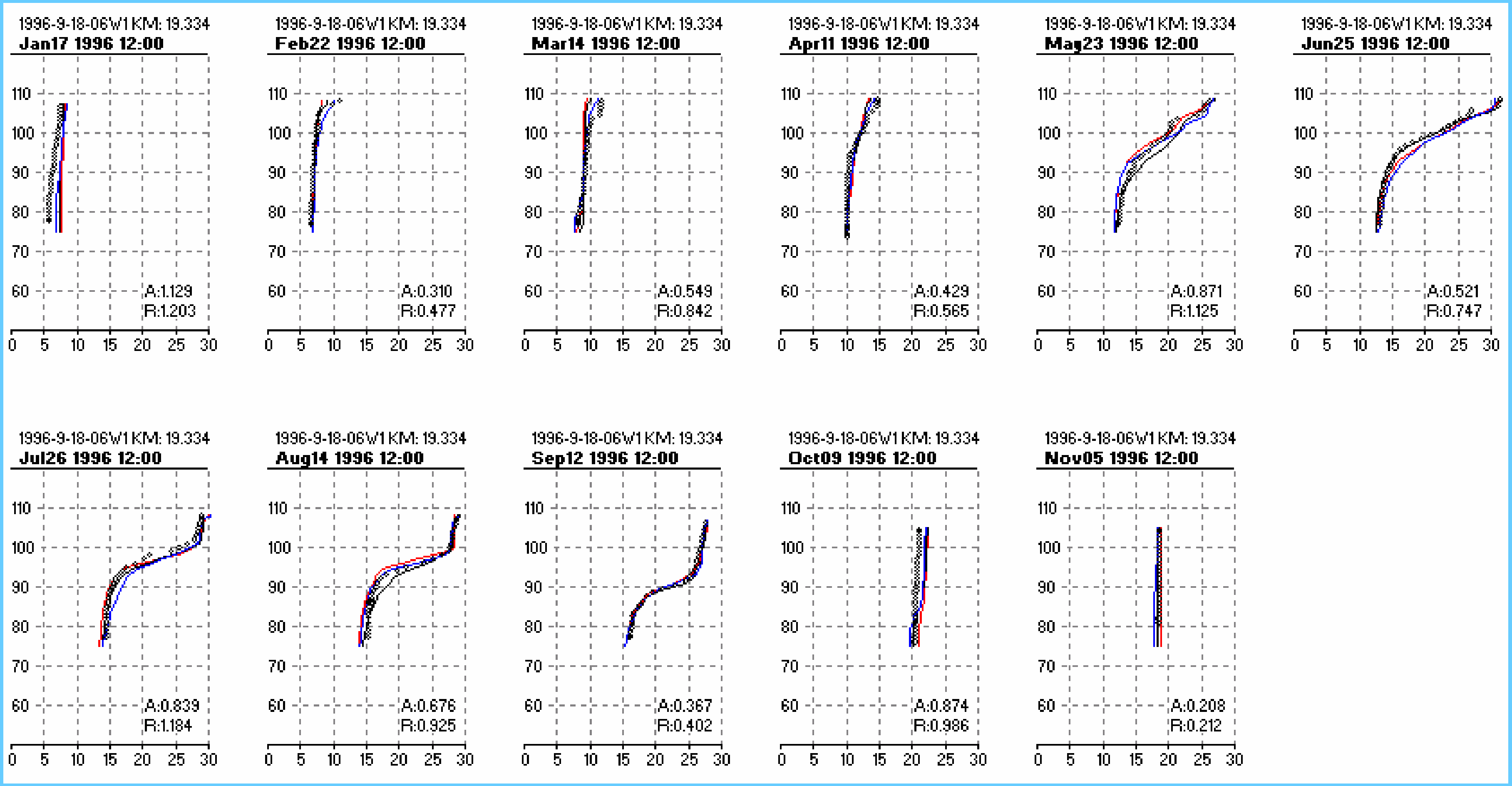
1996 Lake Murray Temperature Profiles – 6 Km Upstream of Dam

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



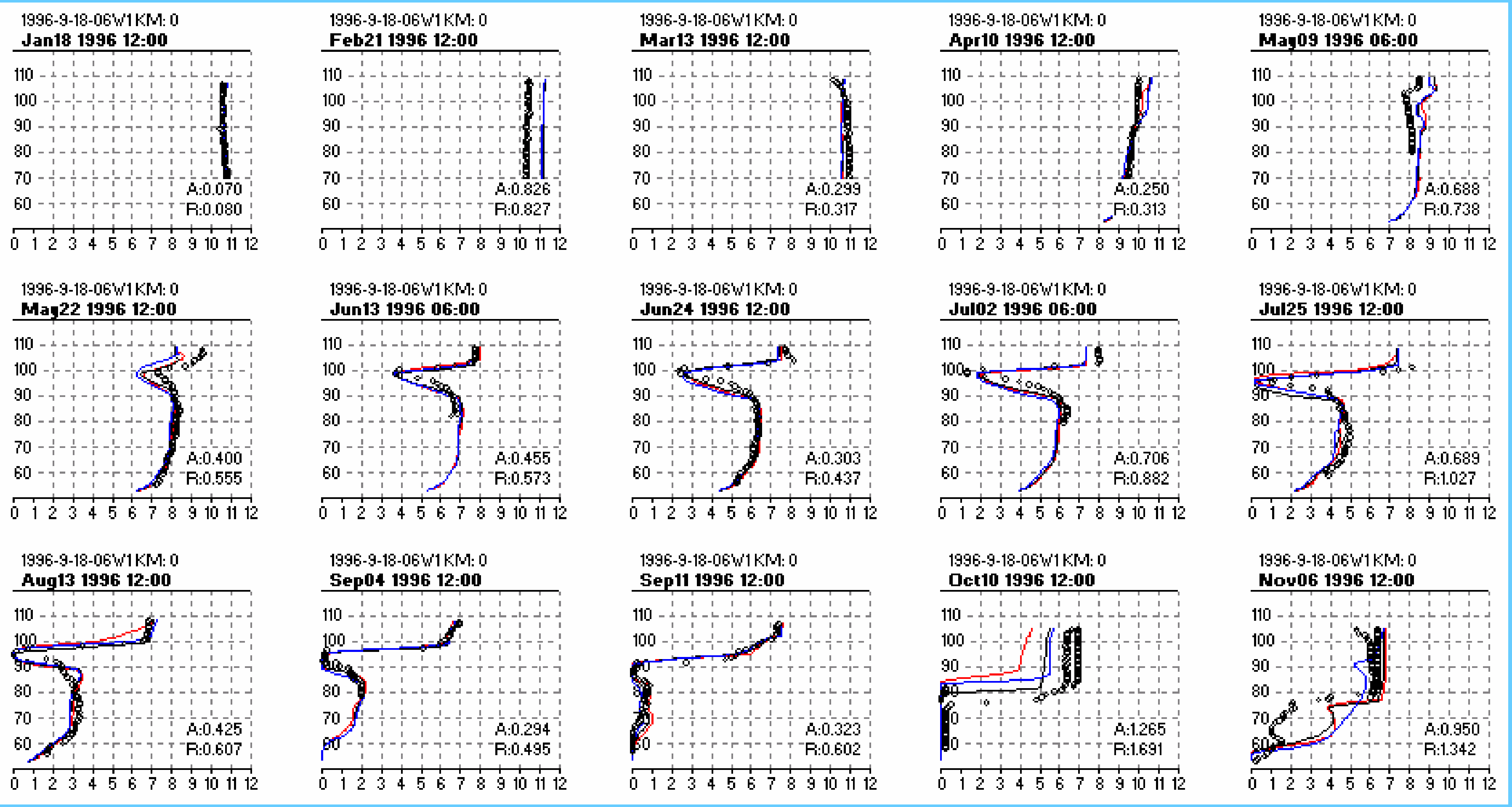
1996 Lake Murray Temperature Profiles – 19 Km Upstream of Dam

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



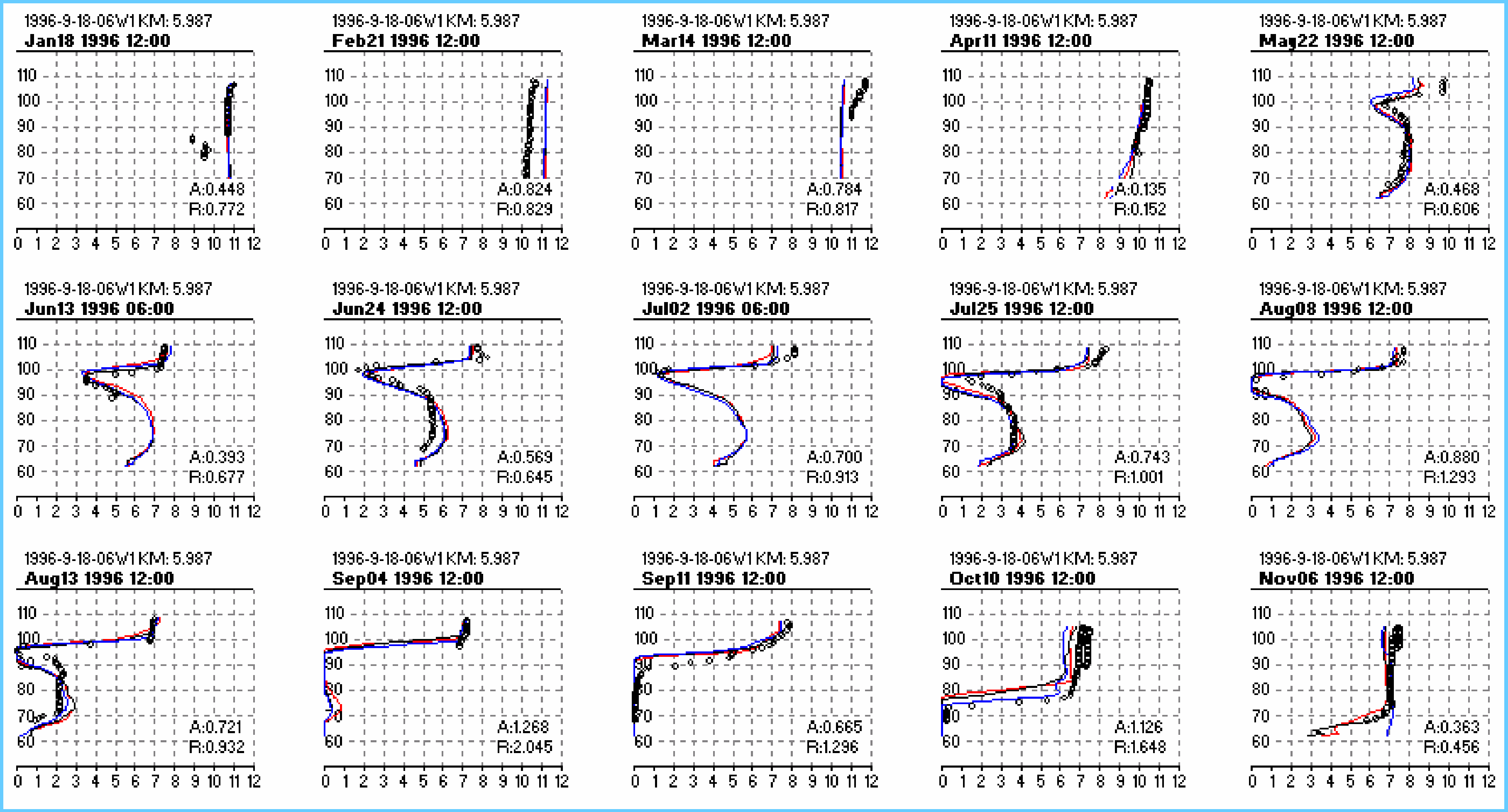
1996 Lake Murray Forebay DO Profiles

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



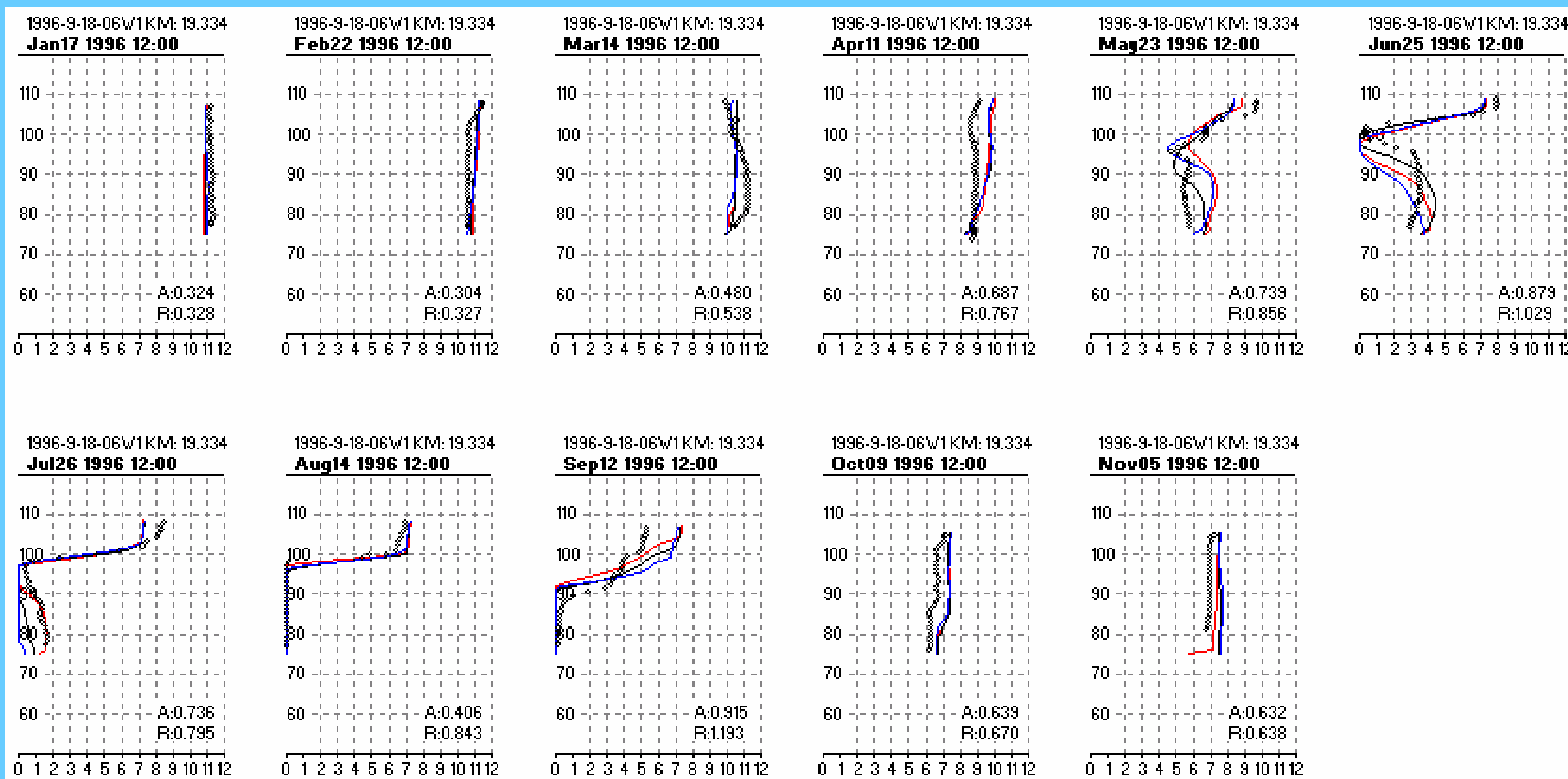
1996 Lake Murray DO Profiles – 6 Km Upstream of Dam

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



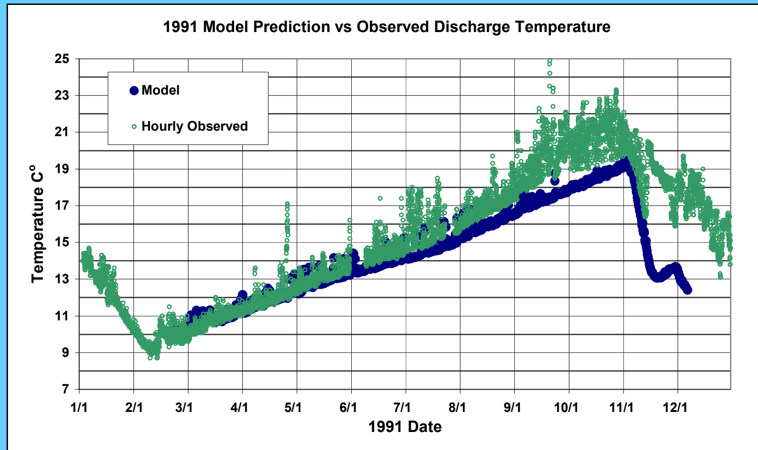
1996 Lake Murray DO Profiles – 19 Km Upstream of Dam

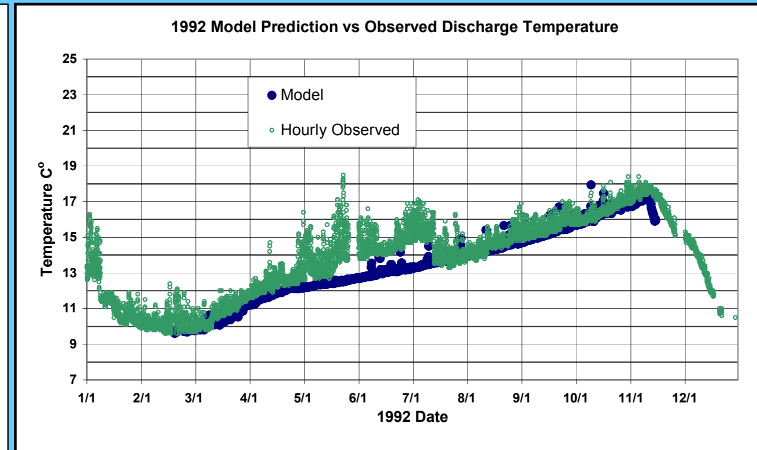
Model vs. Data [Overall Statistics: ABS = 0.61, RMS = 0.77]

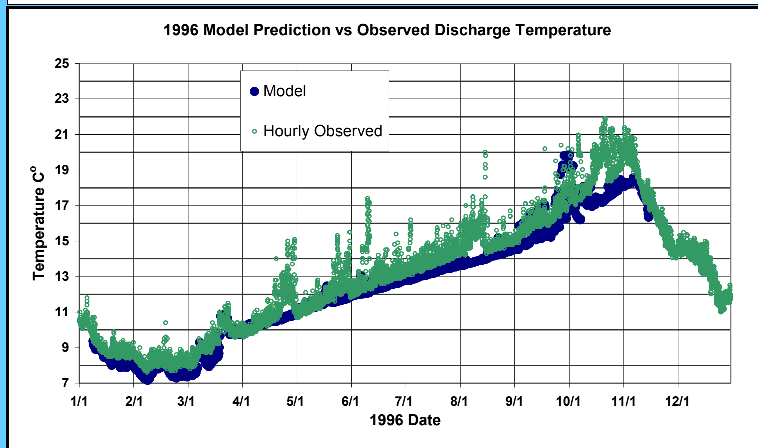


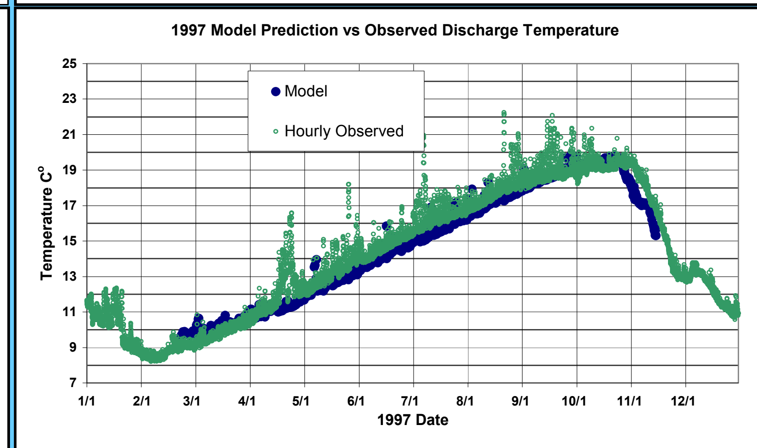
Release Temperature

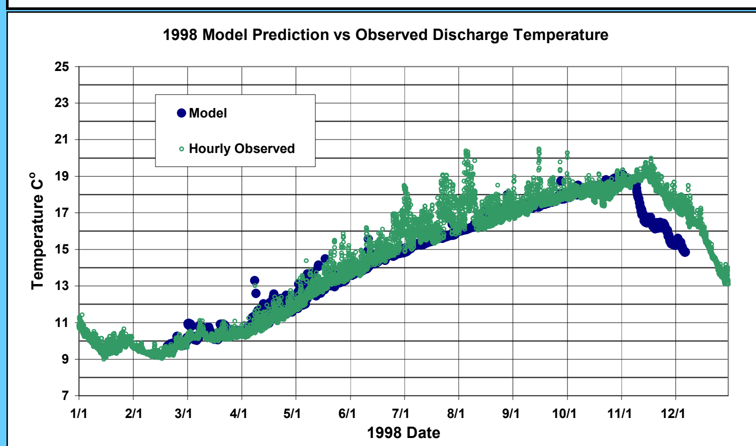
Model vs. Data

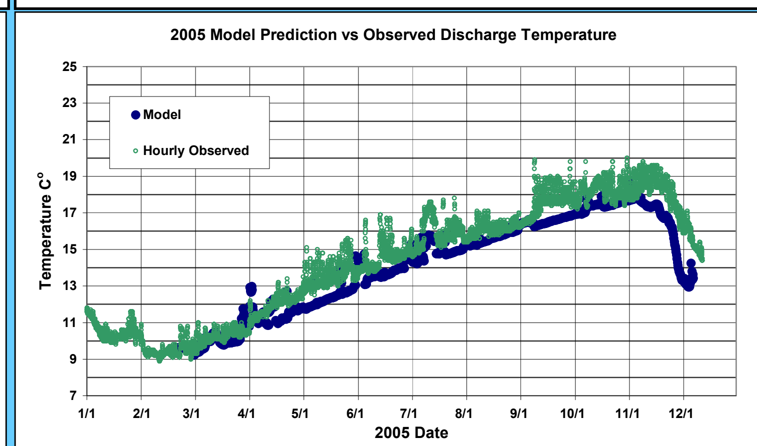






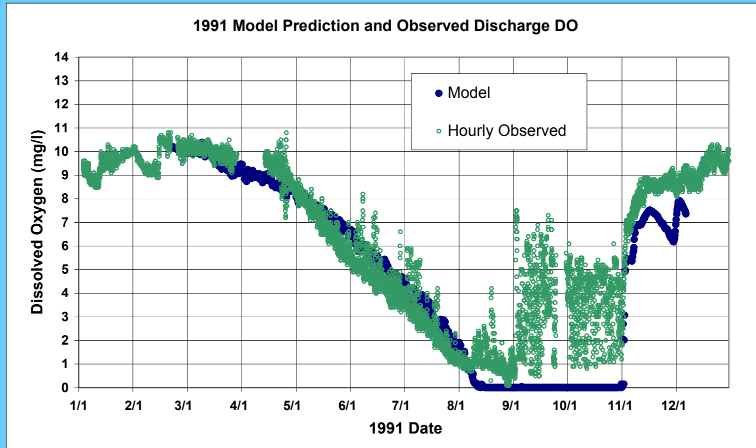


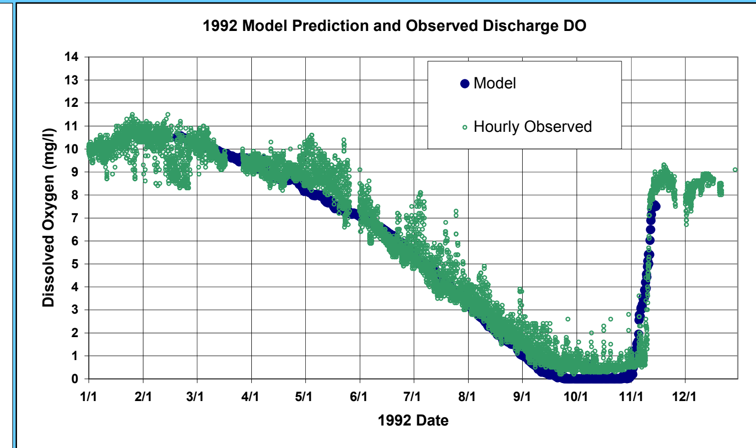


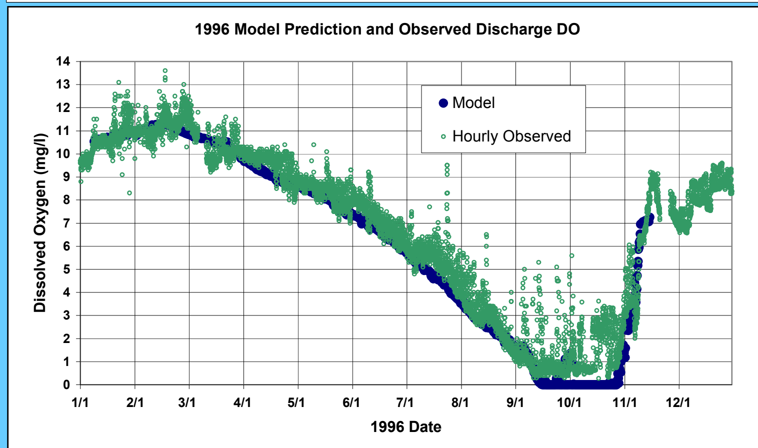


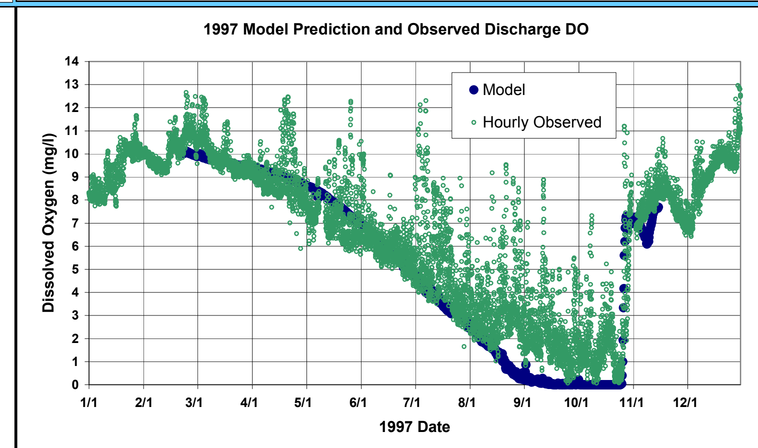
Release DO

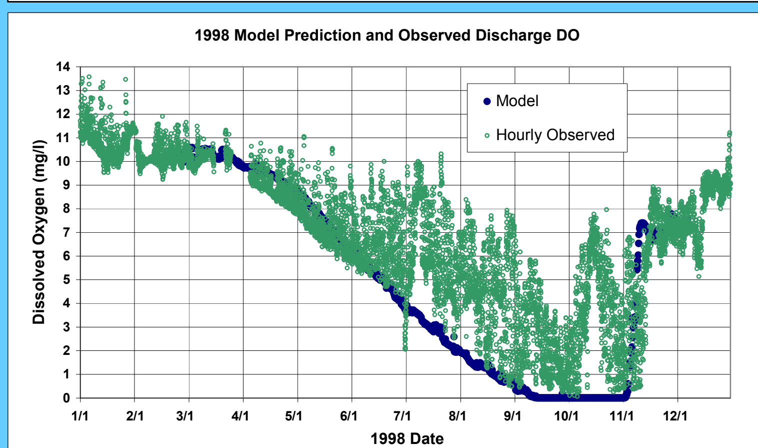
Model vs. Data

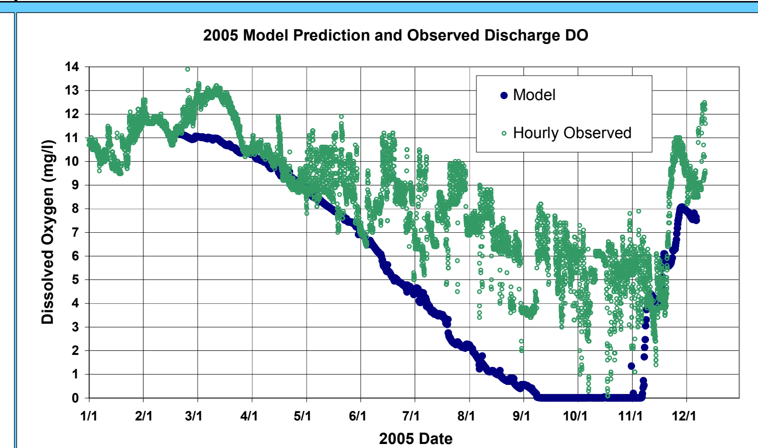




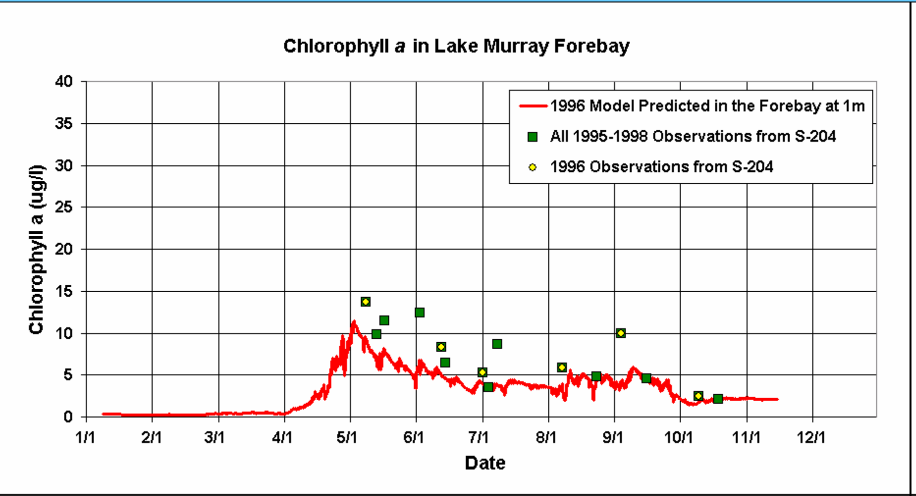


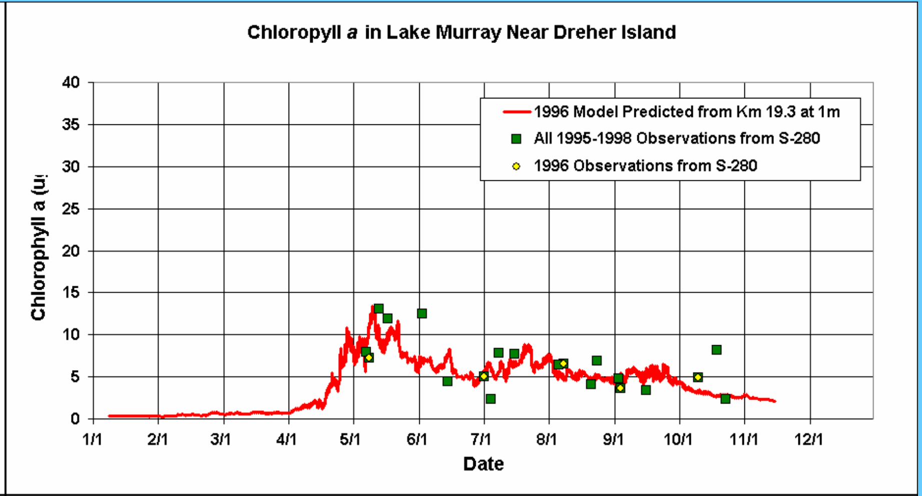


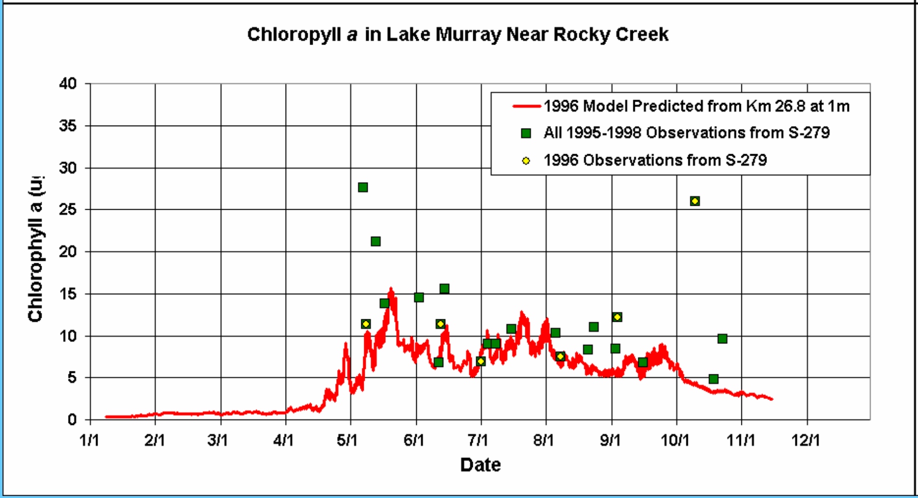


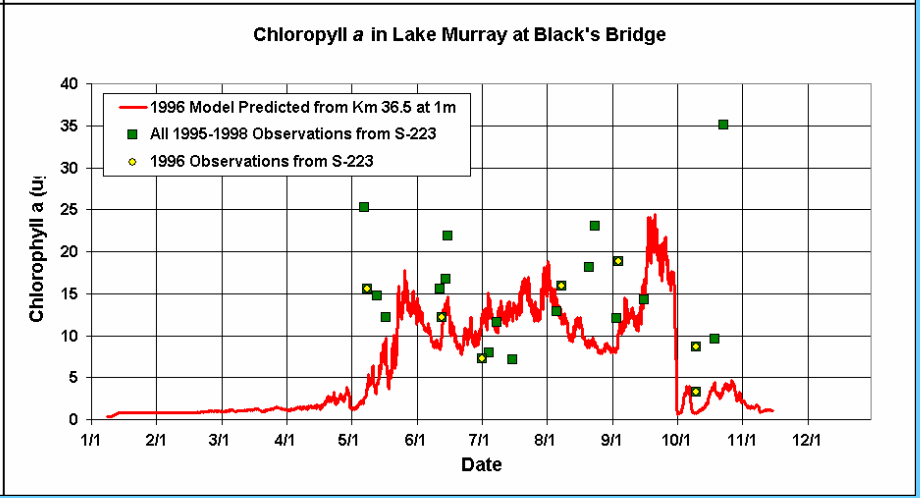


1996 Chlorophyll *a* at Four Locations in Lake Murray
Model vs. Data

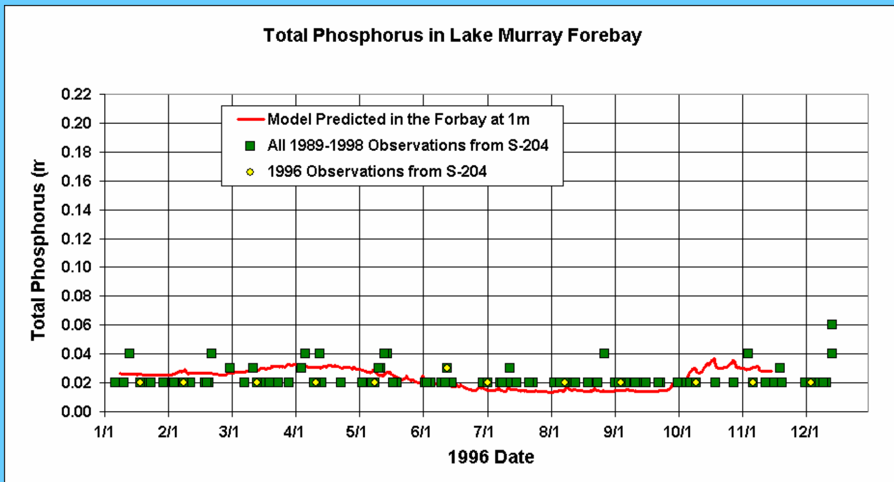


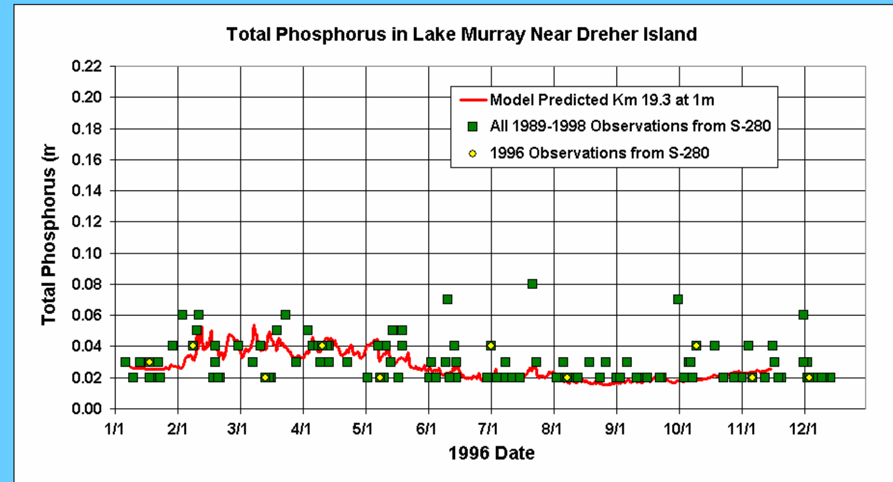


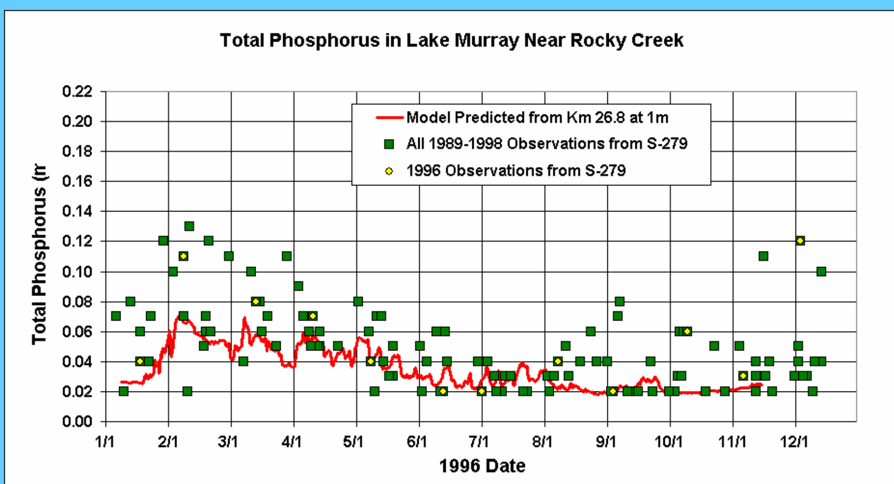


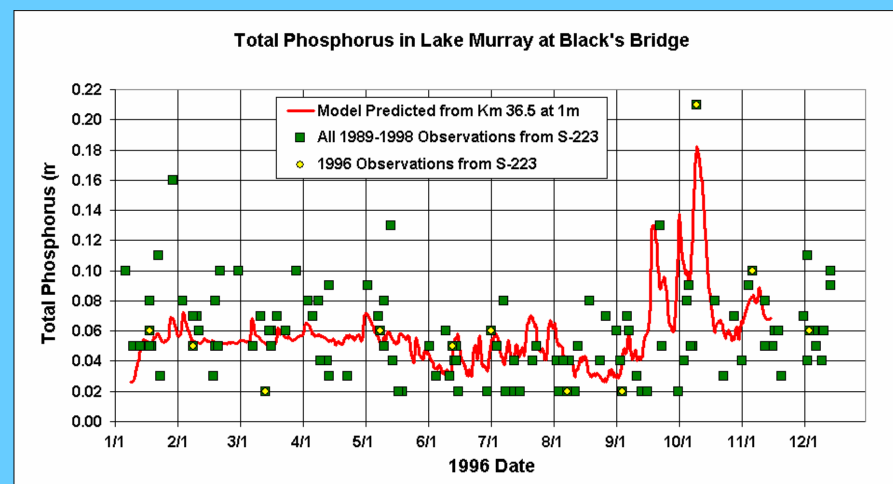


Comparison of Modeled Derived versus Measured Total Phosphorus for 1996 at Four Locations in Lake Murray

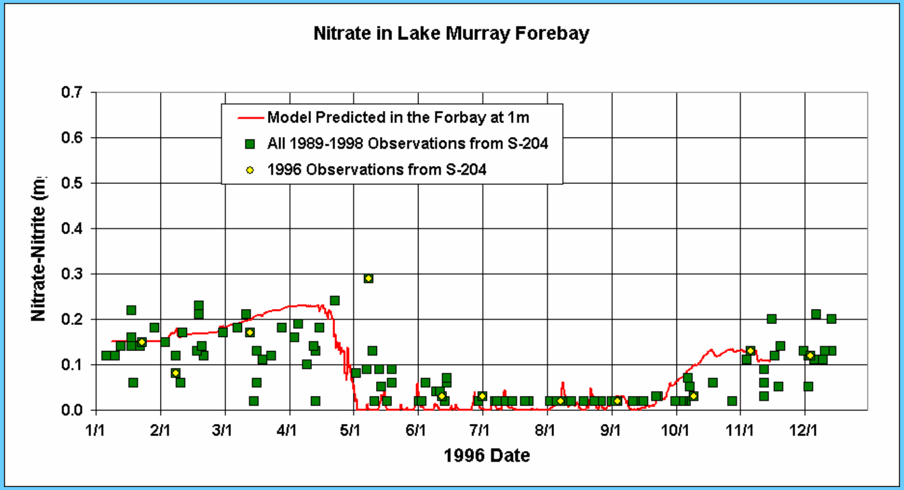


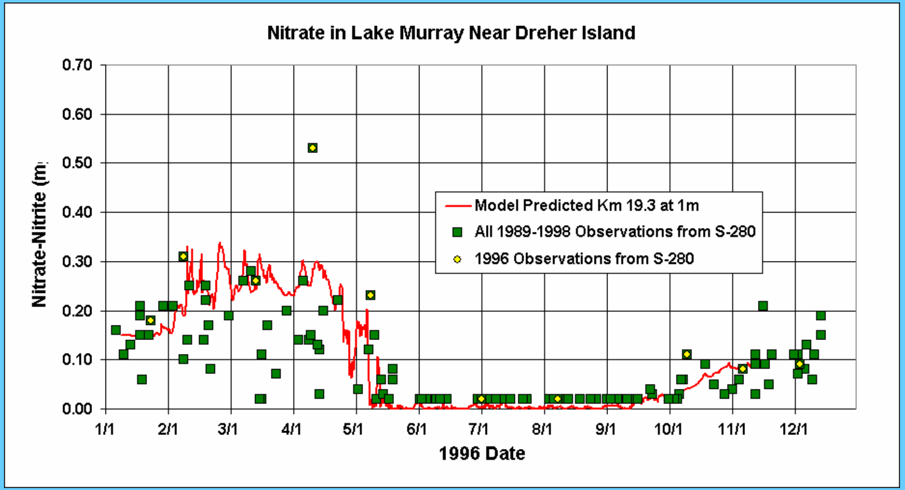


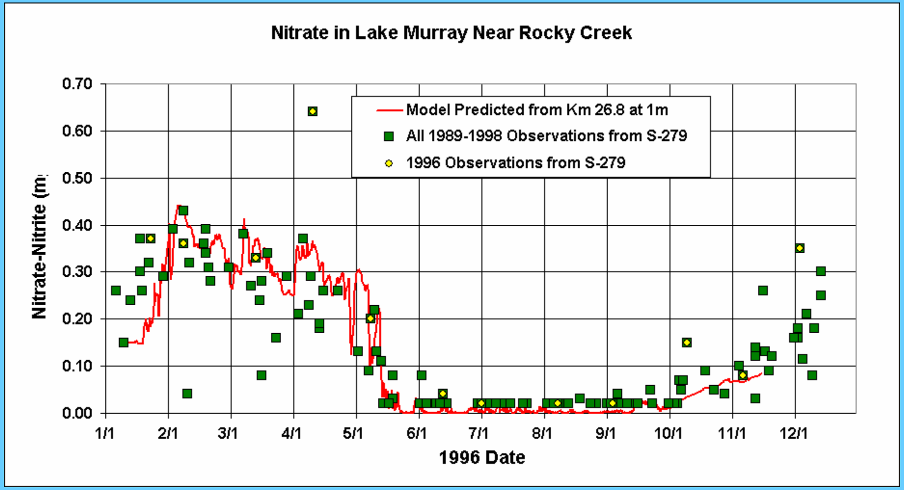


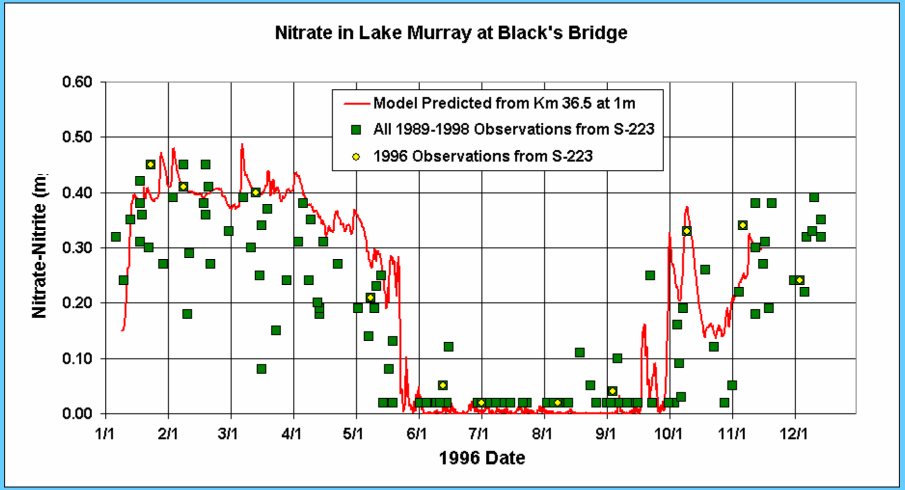


Comparison of Modeled versus Measured Nitrate for 1996 at Four Locations in Lake Murray

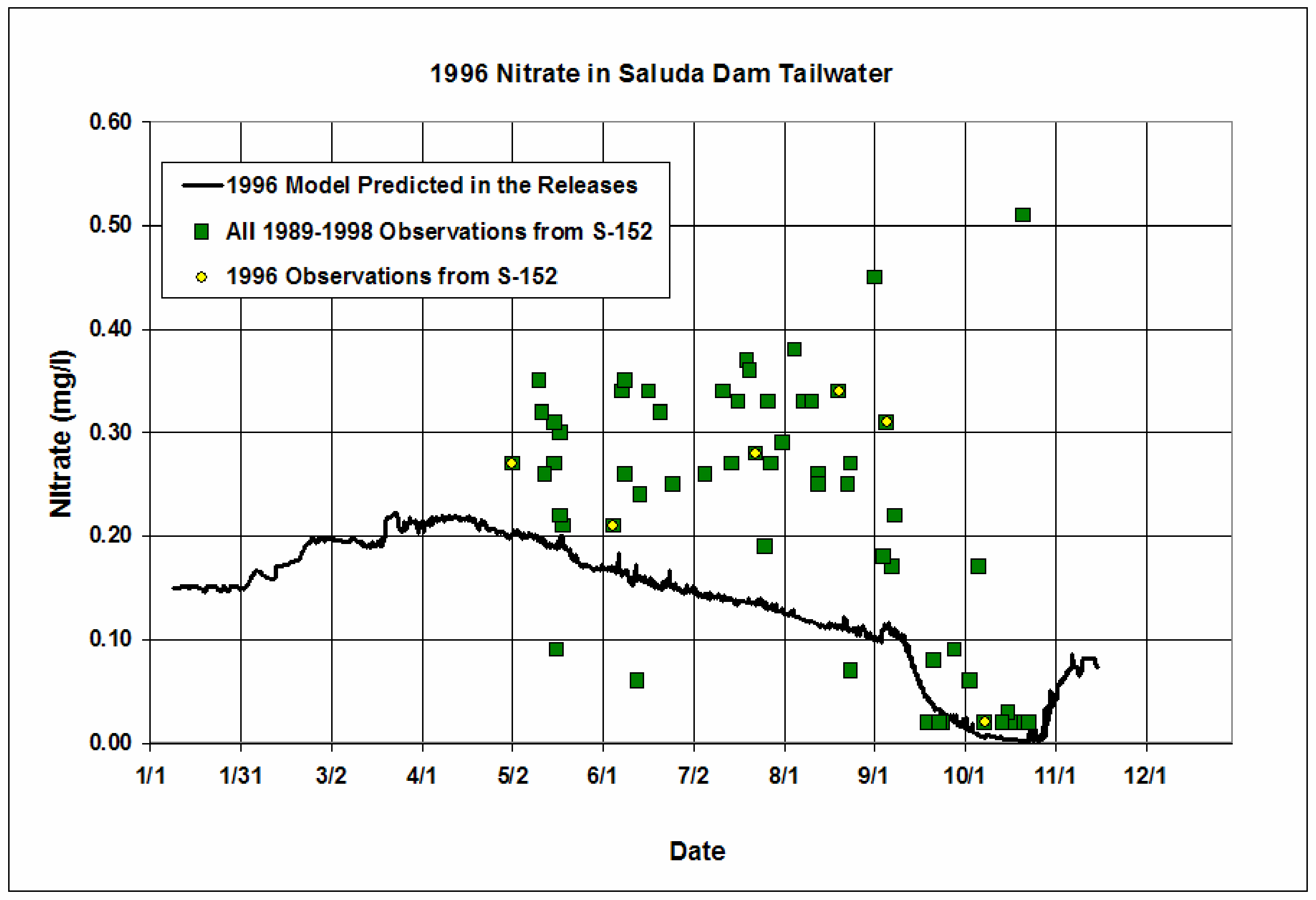




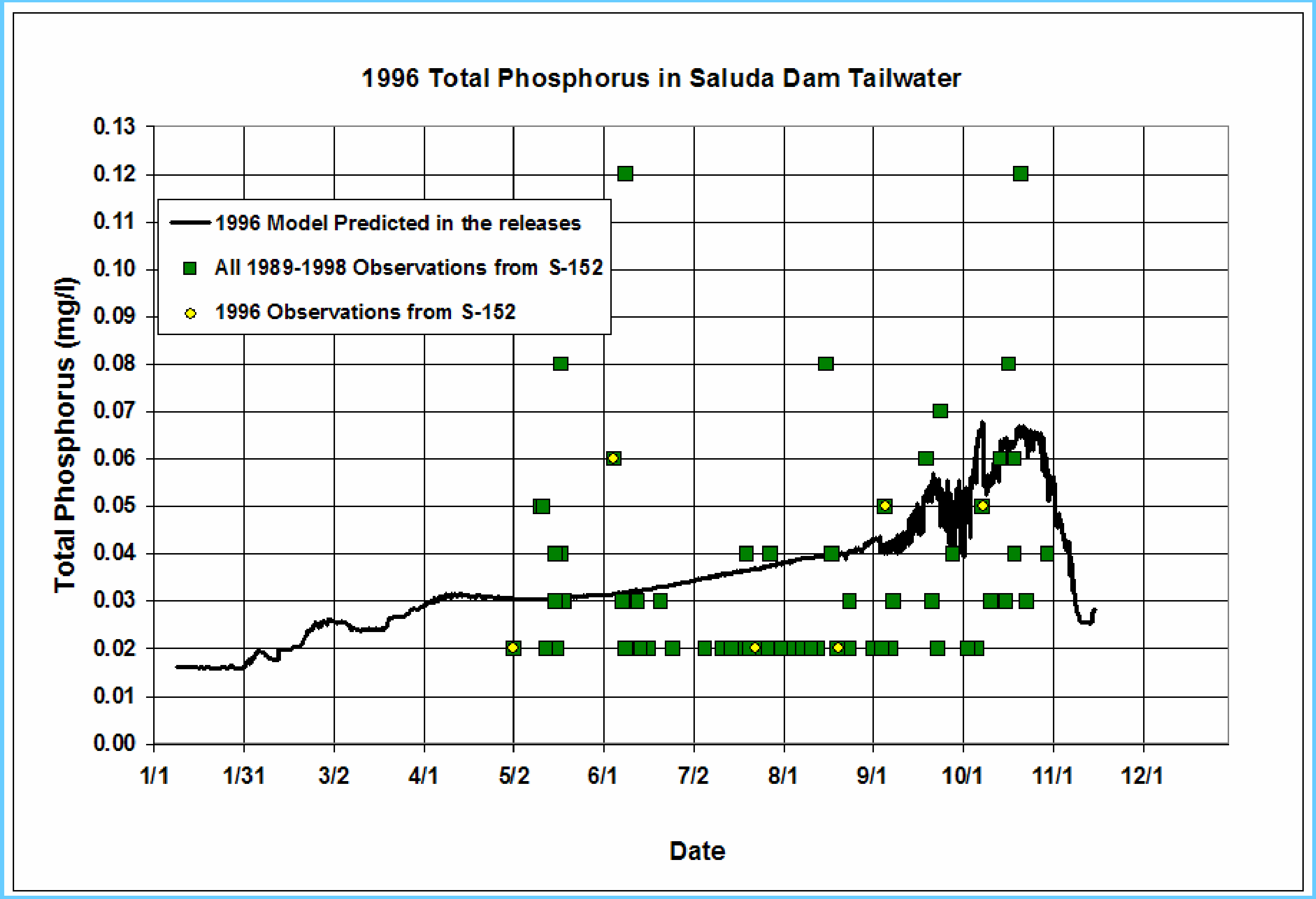




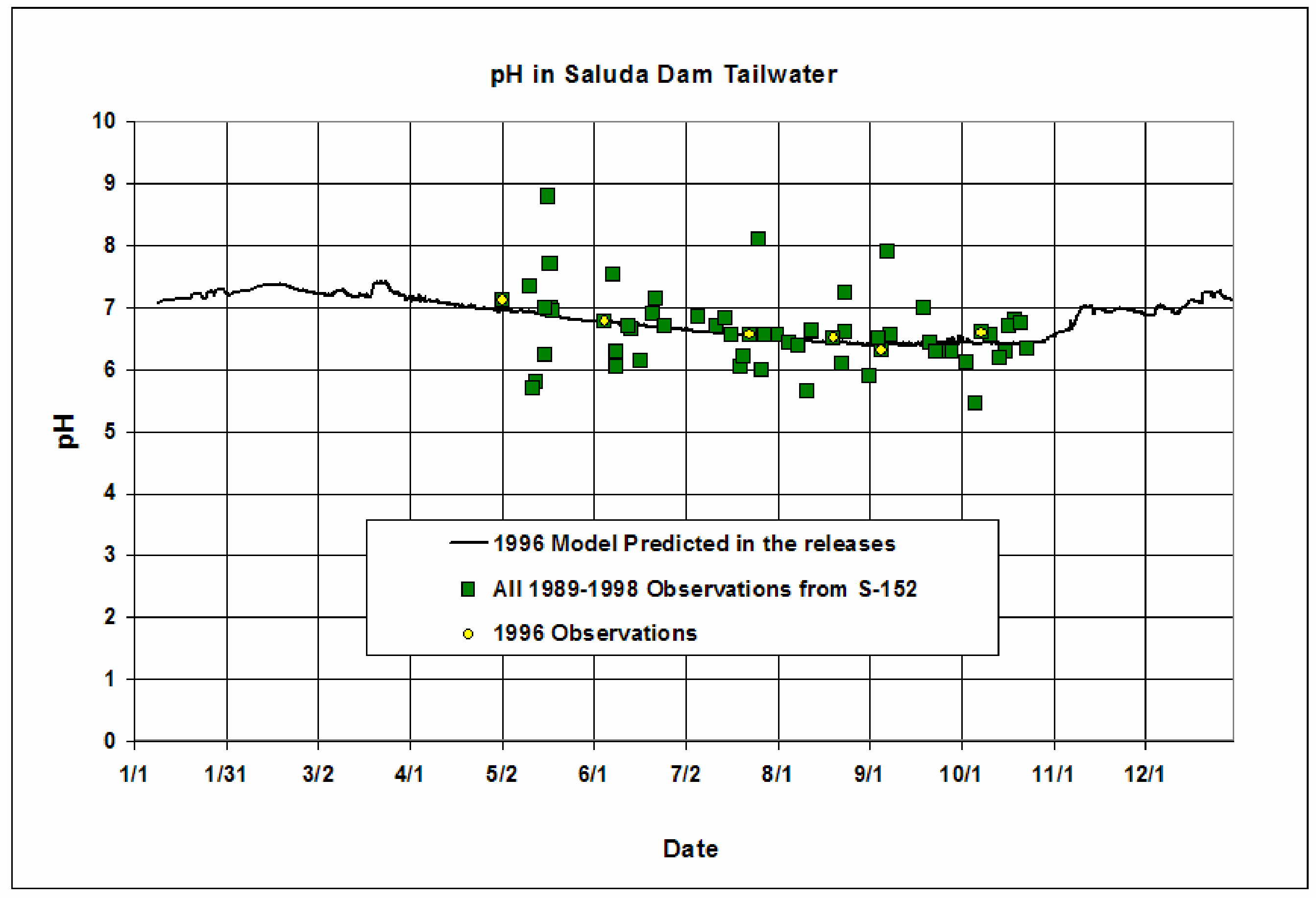
1996 Nitrate in the Releases
Model vs. Data



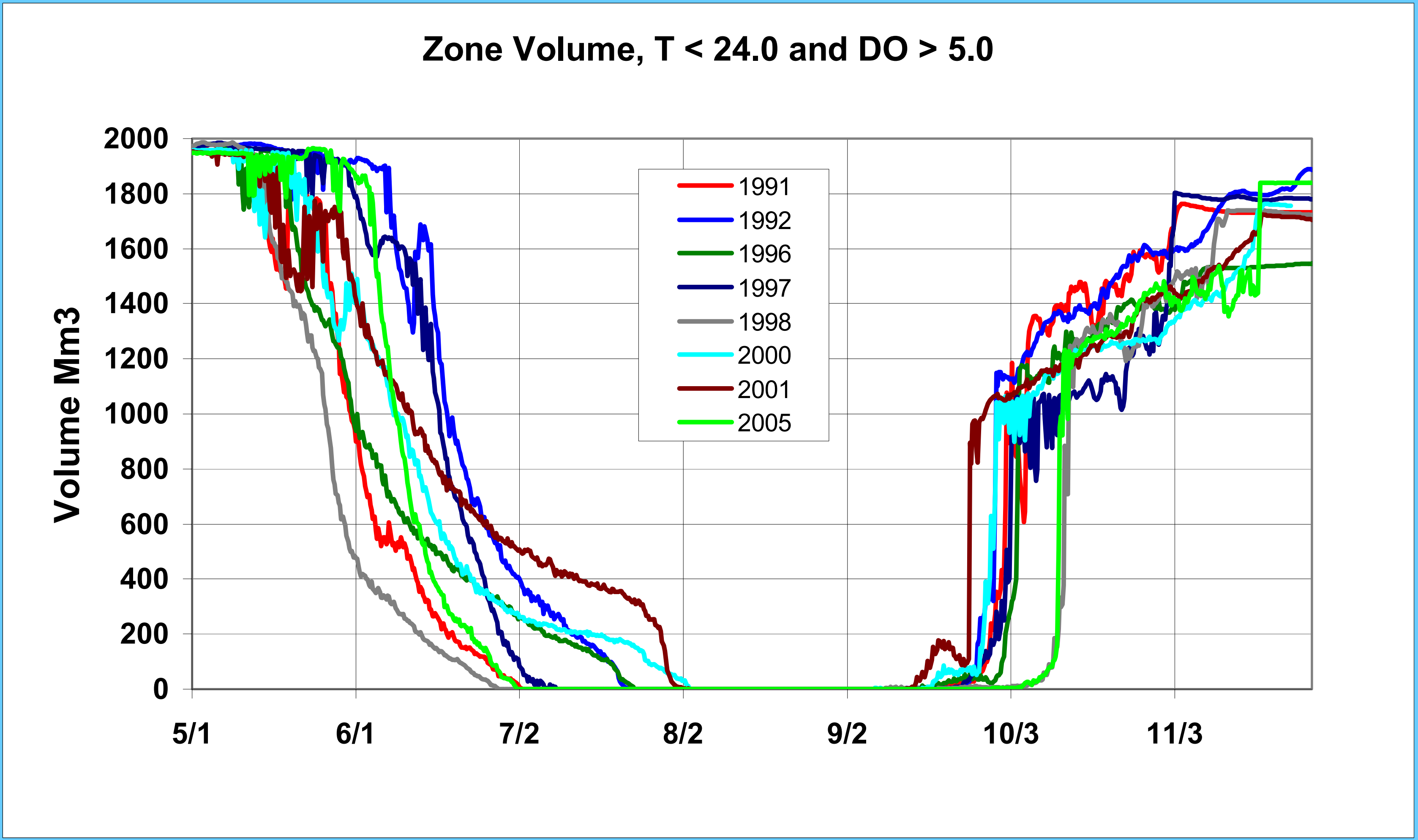
1996 Total Phosphorus in the Releases
Model vs. Data



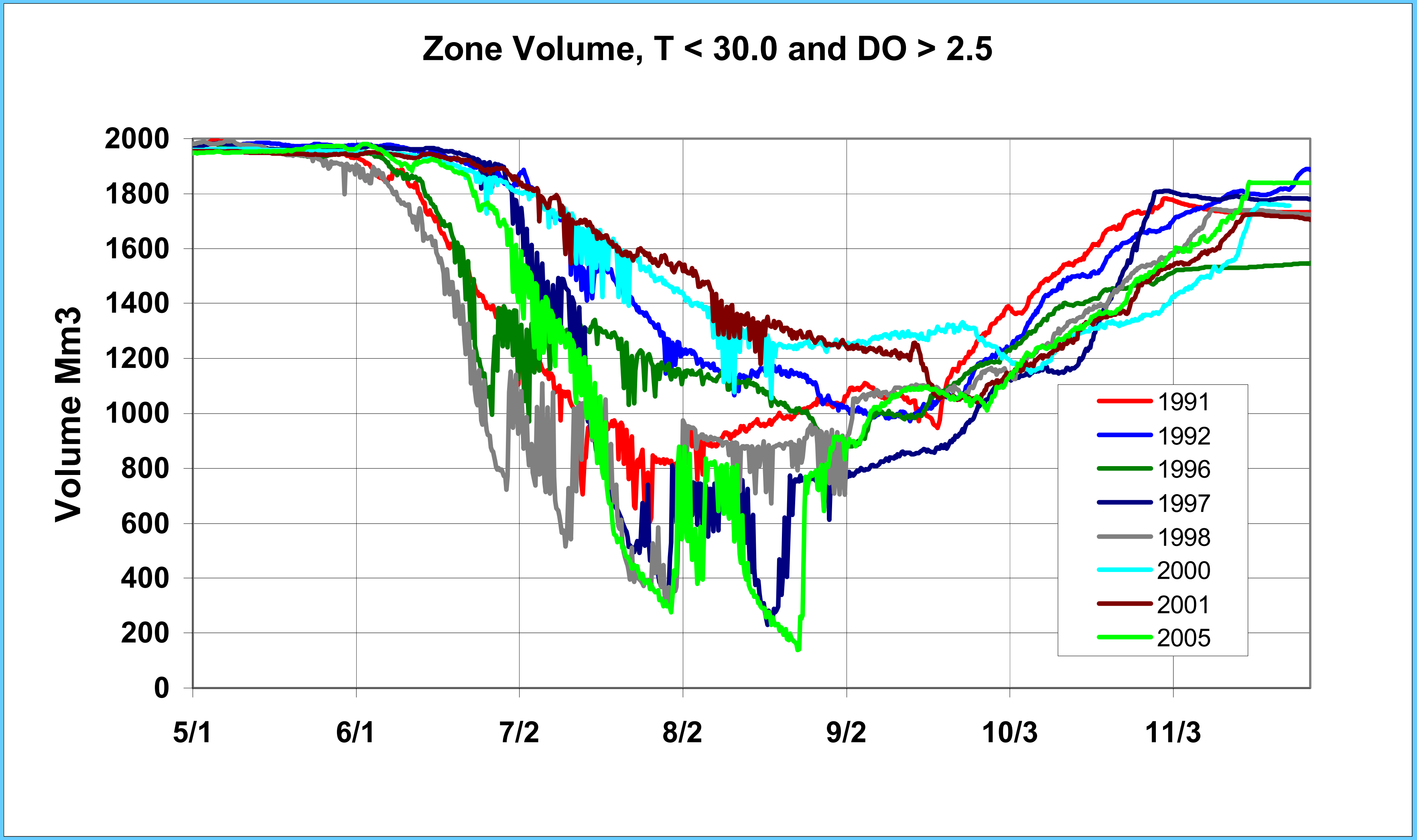
1996 pH in the Releases
Model vs. Data



Zone Volume Plots- “Optimal” Habitat

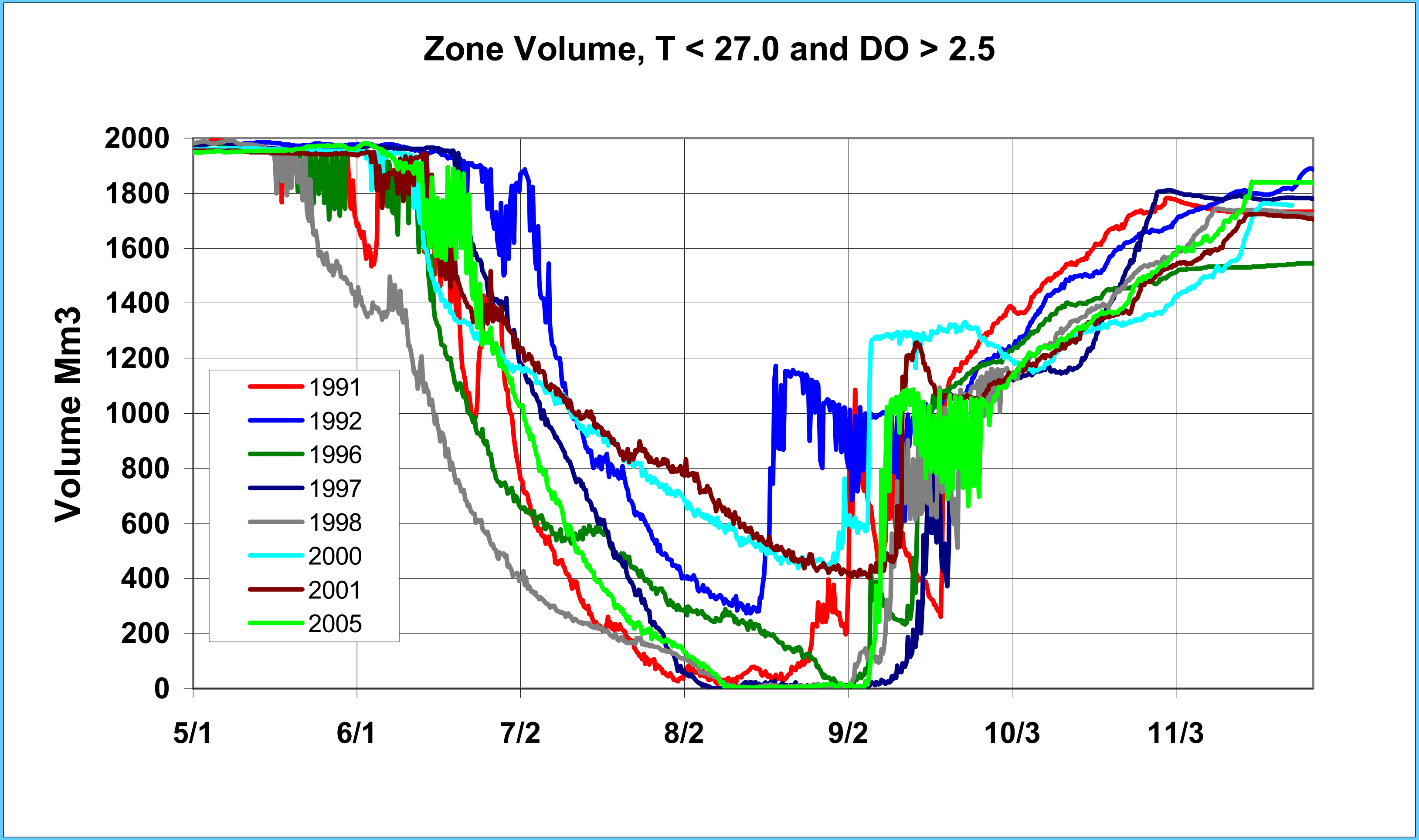


Zone Volume Plot - “Unsuitable” Habitat



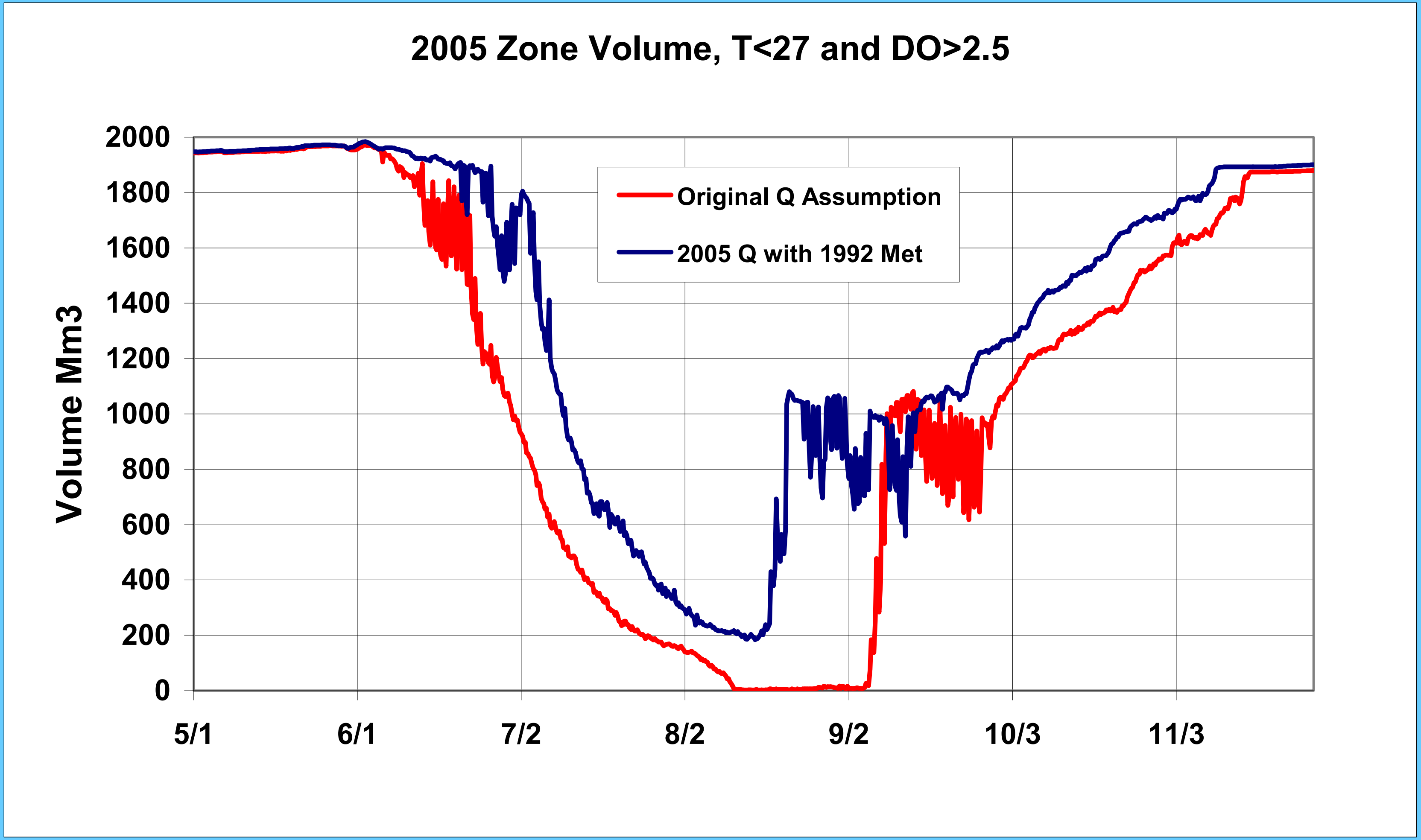
Zone Volume Plot - "Sub-optimal" Habitat

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



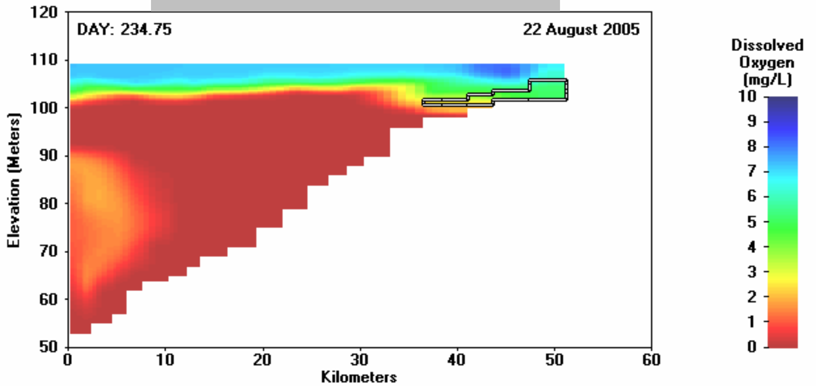
Meteorological Data Sensitivity

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



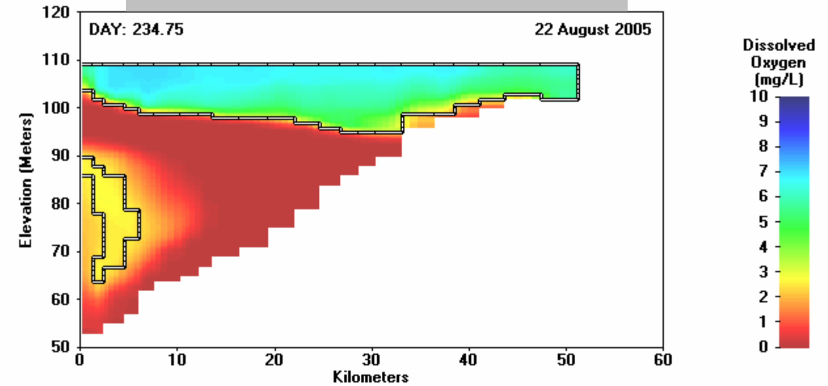
2005 Animation

DO – 2005 Q and Met



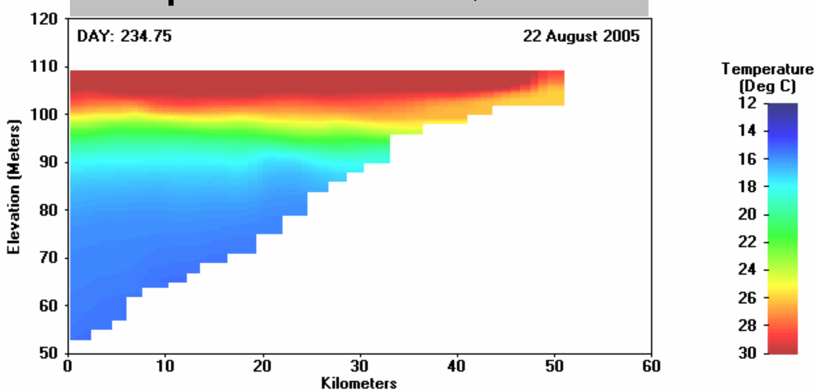
Zone criteria: 0.<=T<=27.,2.5<=DO<=100.

DO – 2005 Q and 1992 Met



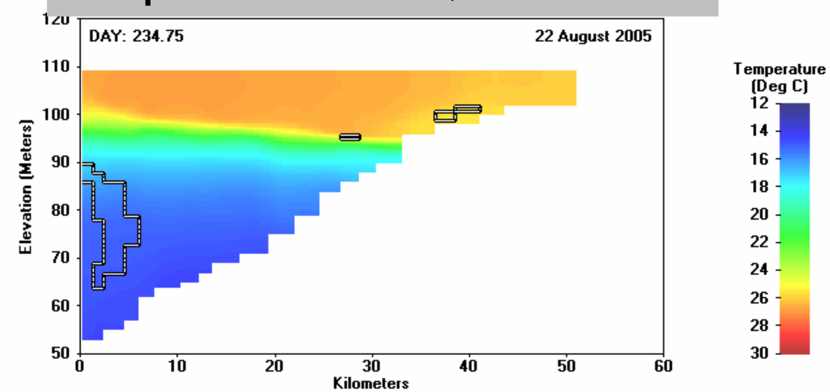
Zone Criteria T<27°T and DO > 2.5 mg/l

Temperature – 2005 Q and Met



Zone criteria: 0.<=T<=26.,2.5<=DO<=100.

Temperature – 2005 Q and 1992 Met

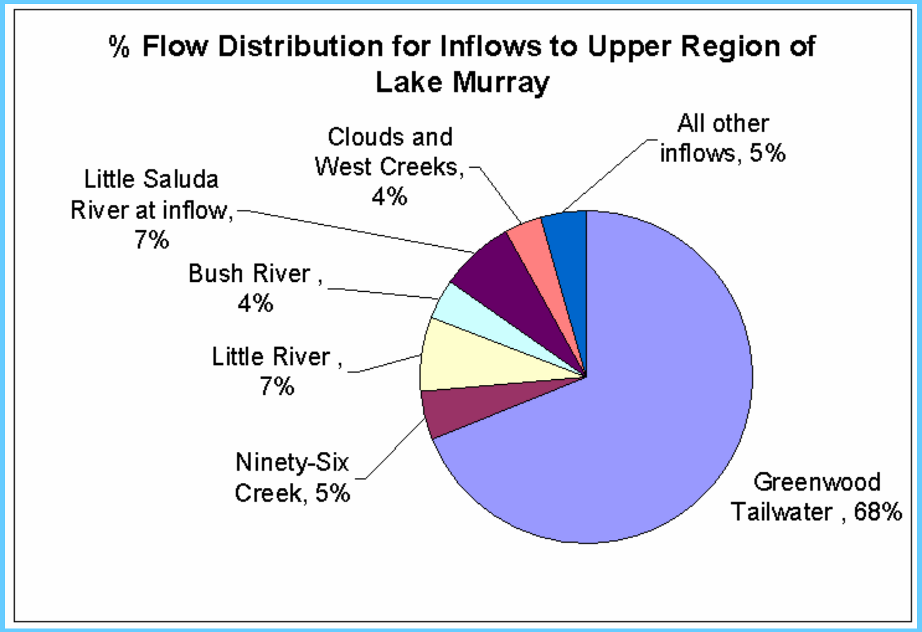


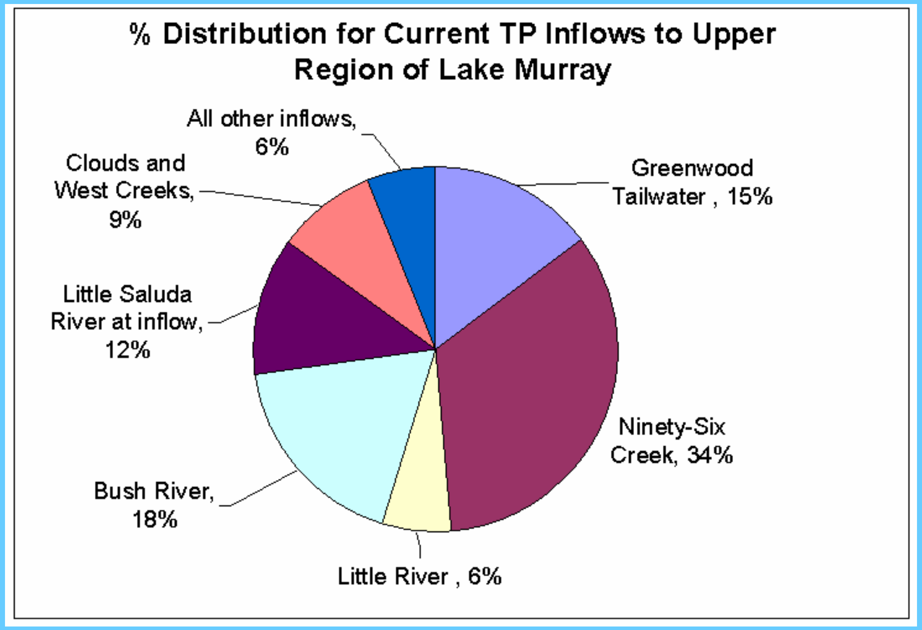
Zone Criteria T<26°T and DO > 2.5 mg/l

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)

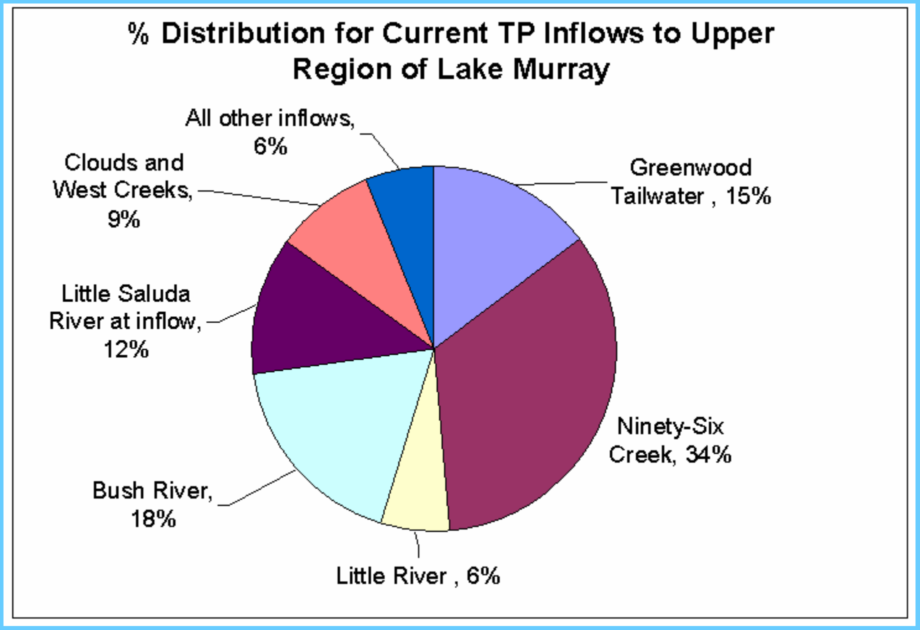
Inflow and Phosphorus Loads to Upper Regions of Lake Murray



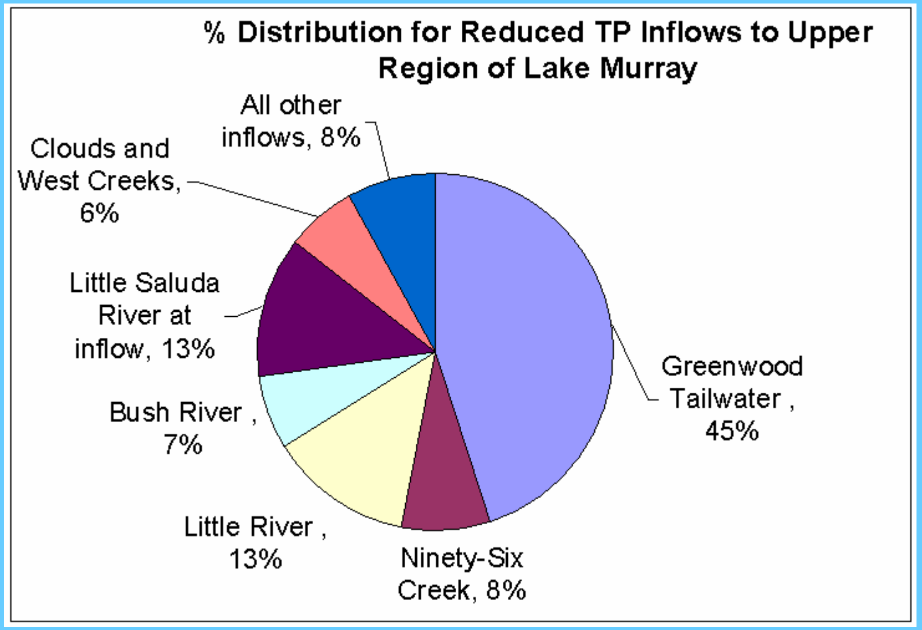


Distribution of TP Loads to the Upper Region of Lake Murray

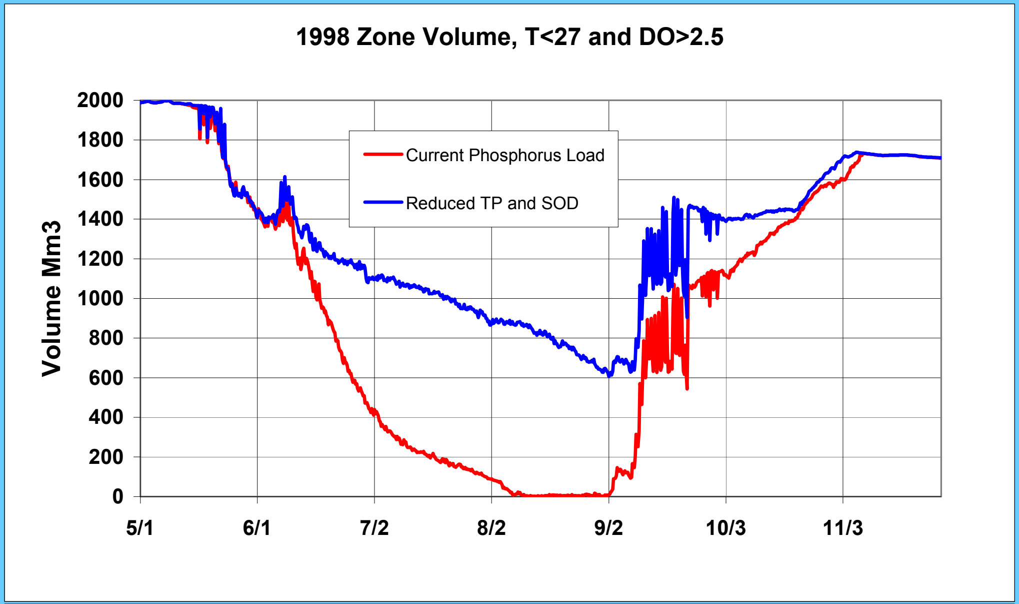
Current

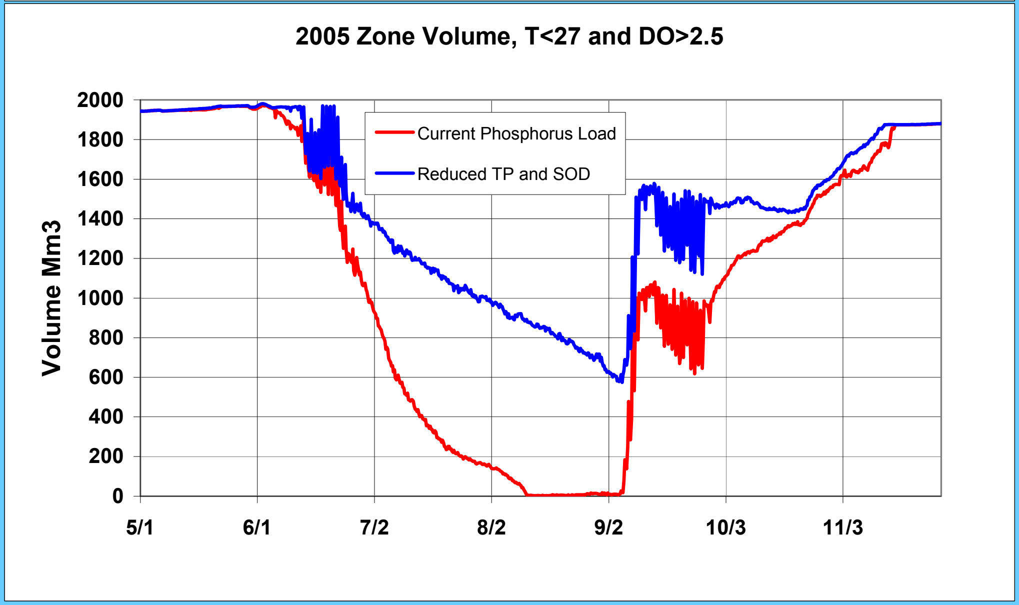


Assumed Reductions in TP



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:

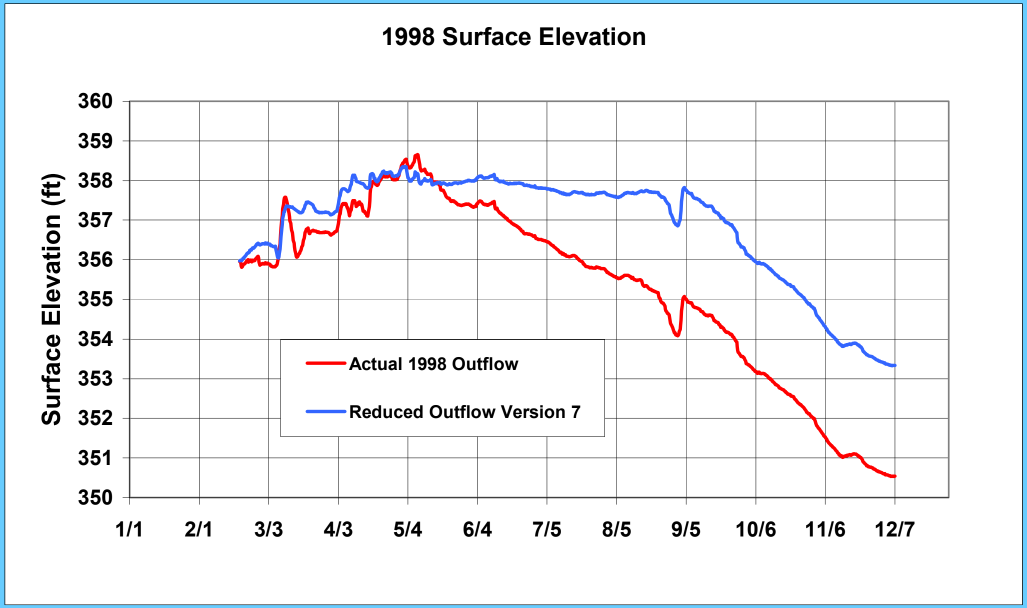
  Units 1, 2 and 4 – Q < 9,600 cfs

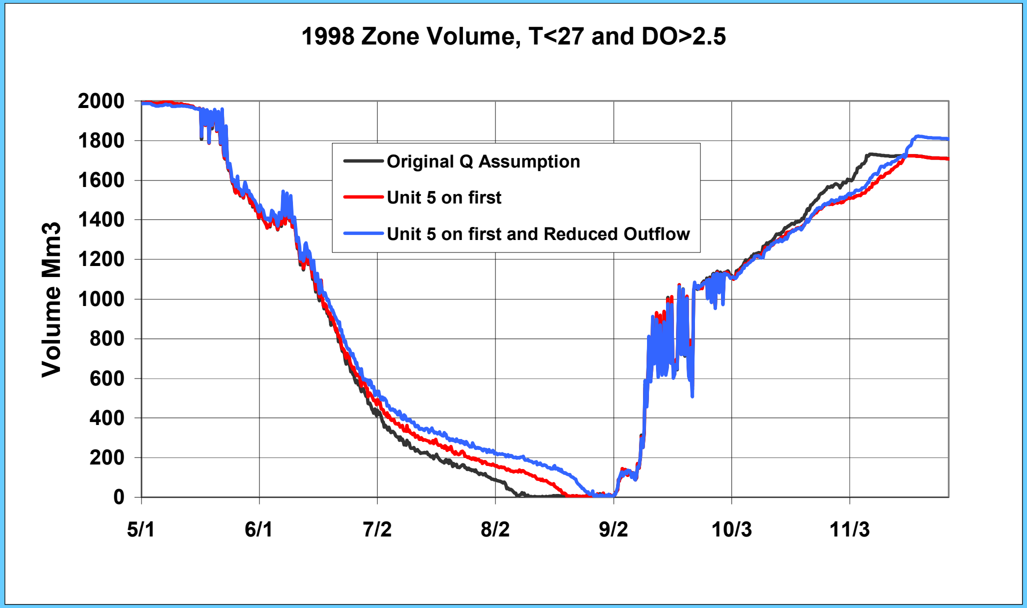
  Unit 5 – 9,600 < Q < 15,600 cfs

  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

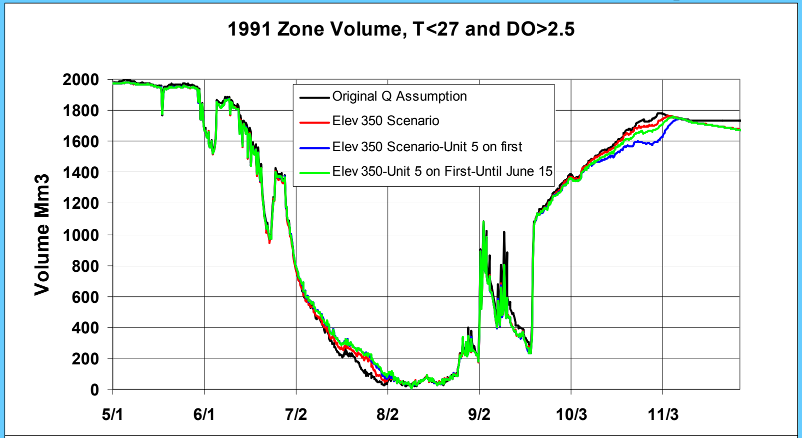


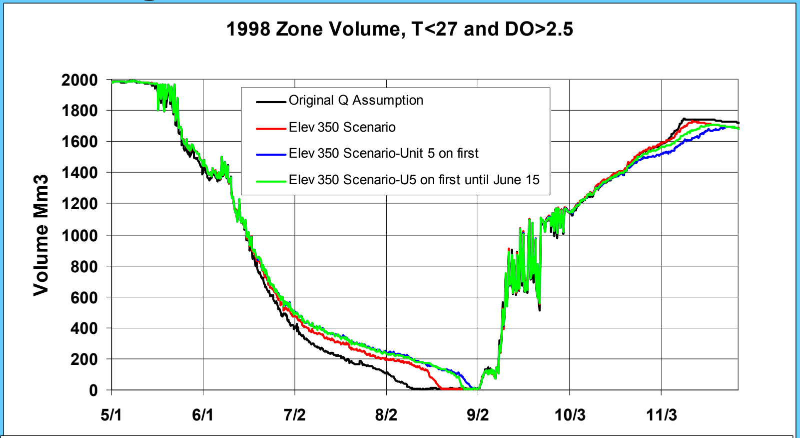


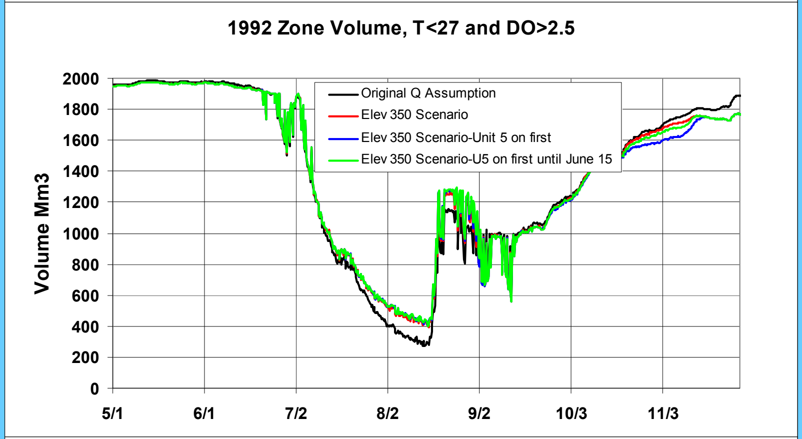
Animations

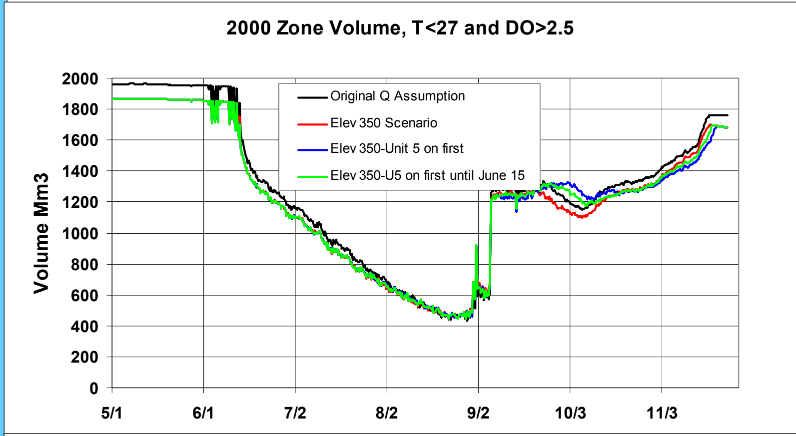
- Year with fish kills vs year without fish kills
- 1998 with and without operational enhancements

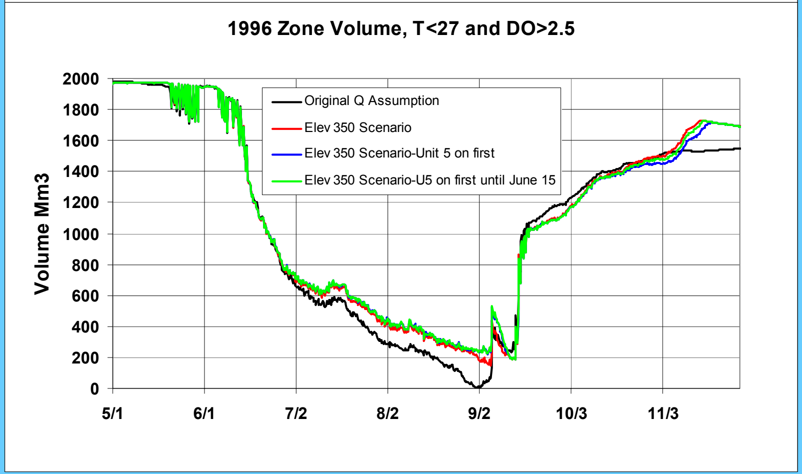
Striped Bass Habitat—Comparison of Current Operations and Promising Operational Changes











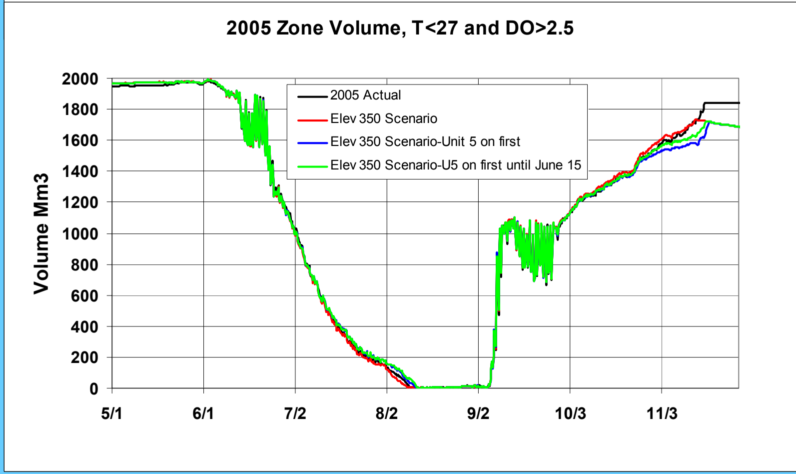
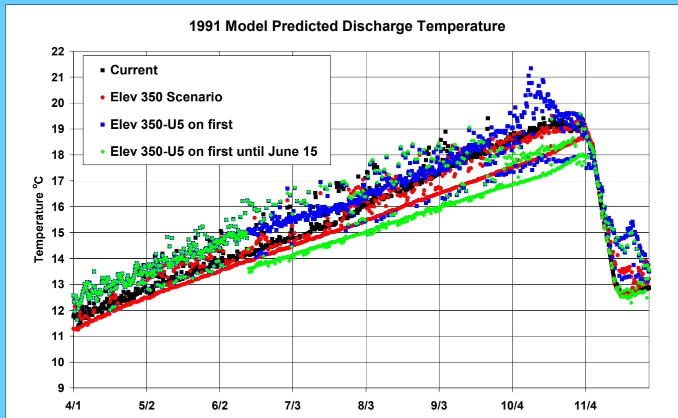
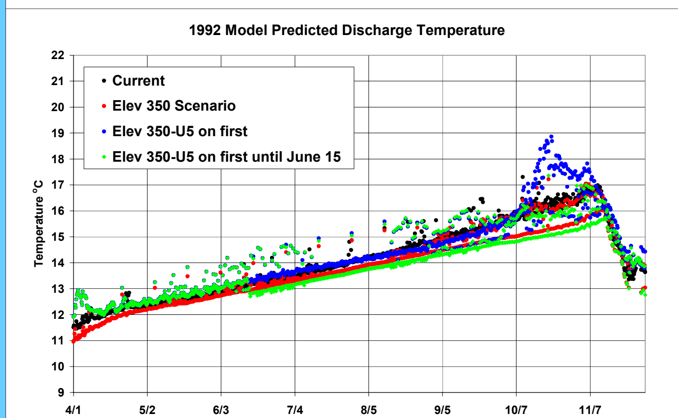


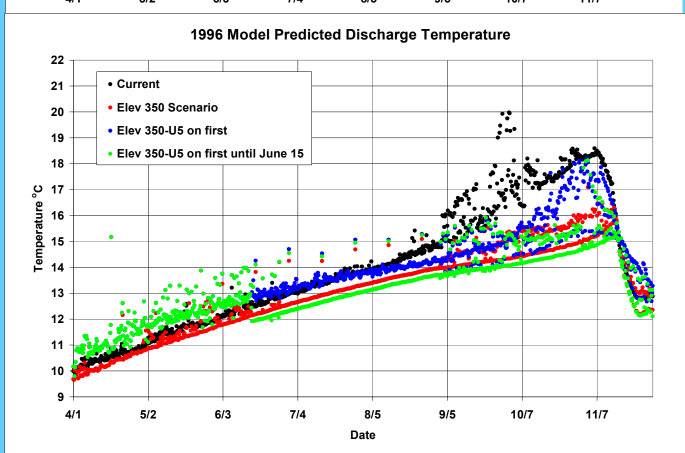
Table 4-1. Temperature increases in the tailwater between Saluda Hydro and the USGS monitor at Columbia.

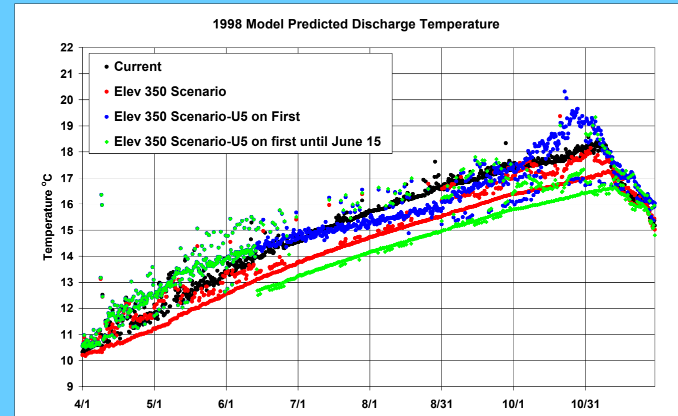
Generation levels and months of operation	**Mean temperature increase, °C**	**Mean temperature increase + 2*Std Deviation, °C**
Less than 1000 cfs, May-Sept	3.2	6.4
2500-3000 cfs, May-Sept	1.3	2.9
5000-6000 cfs, May-Sept	1.0	2.0
2500-6000 cfs, Oct	0.7	1.5

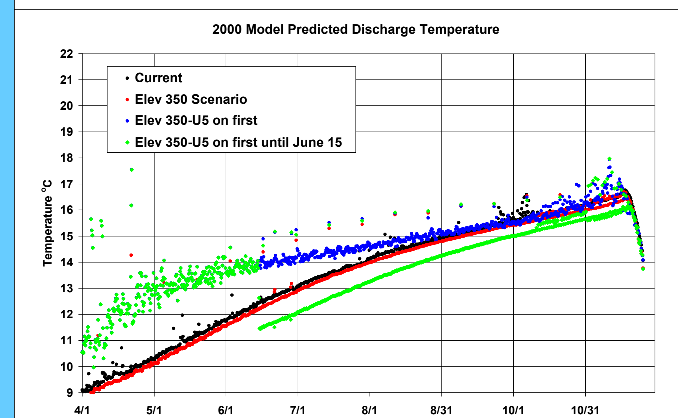
Tailwater Temperature—Comparison of Current Operations and Promising Operational Changes

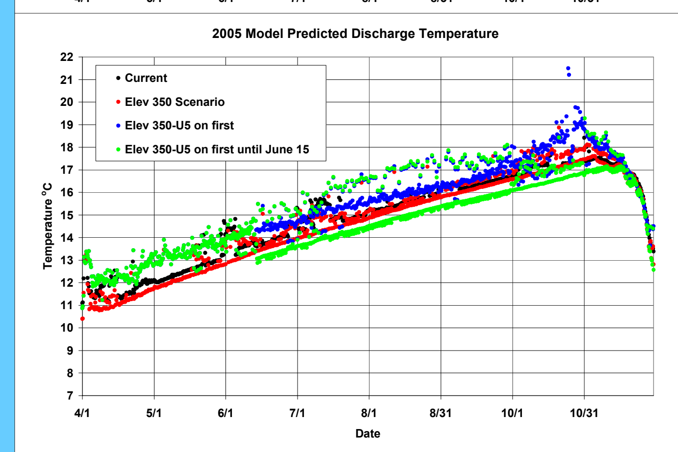




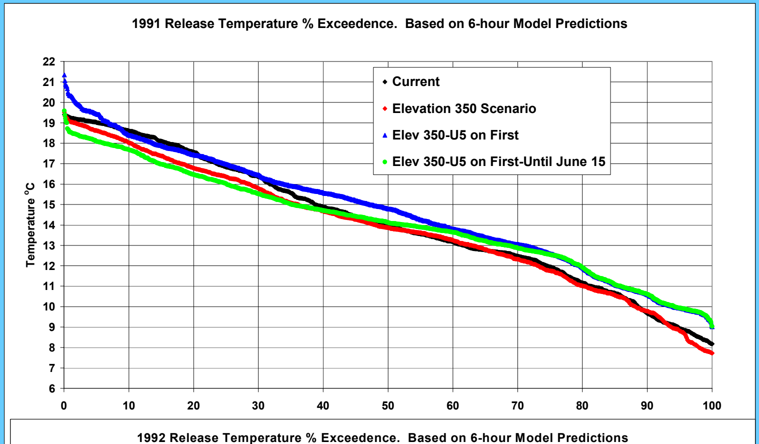


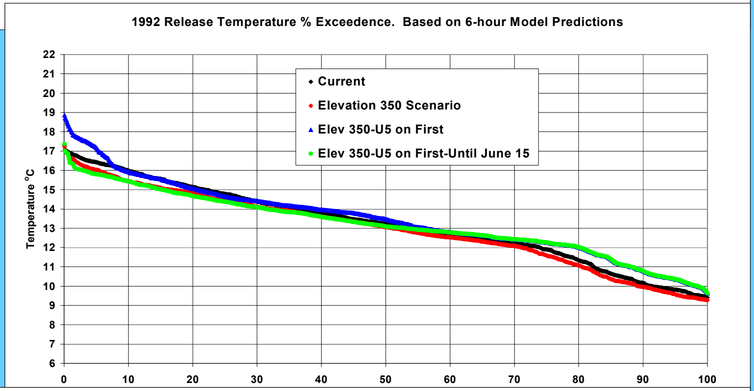


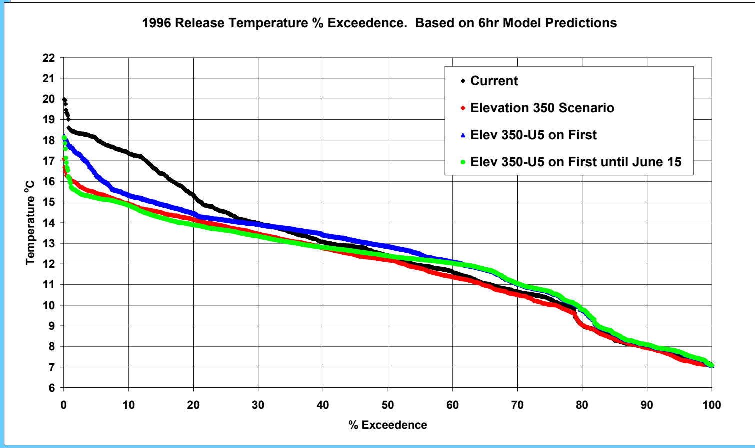


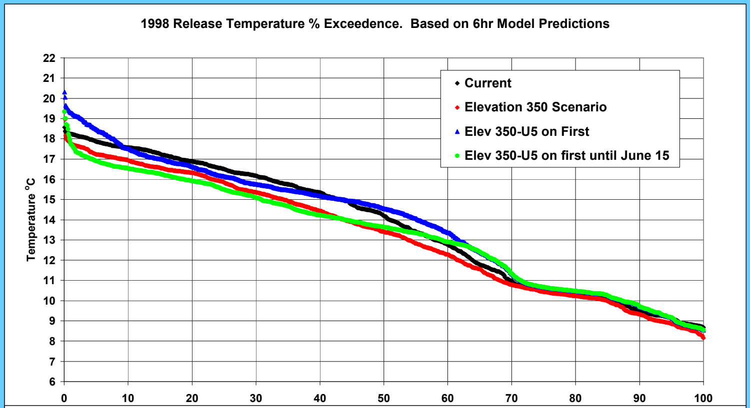


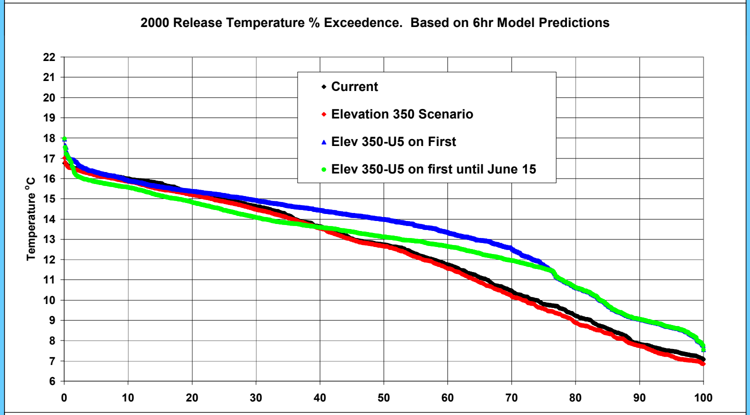
Tailwater Temperature—Comparison of Current Operations and Promising Operational Changes using Frequency of Exceedence

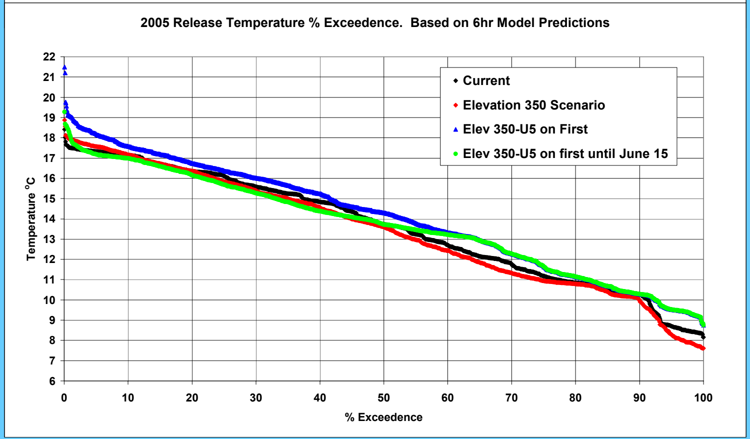












Conclusions for In-lake Water Quality and Fish Habitat

- 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