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)

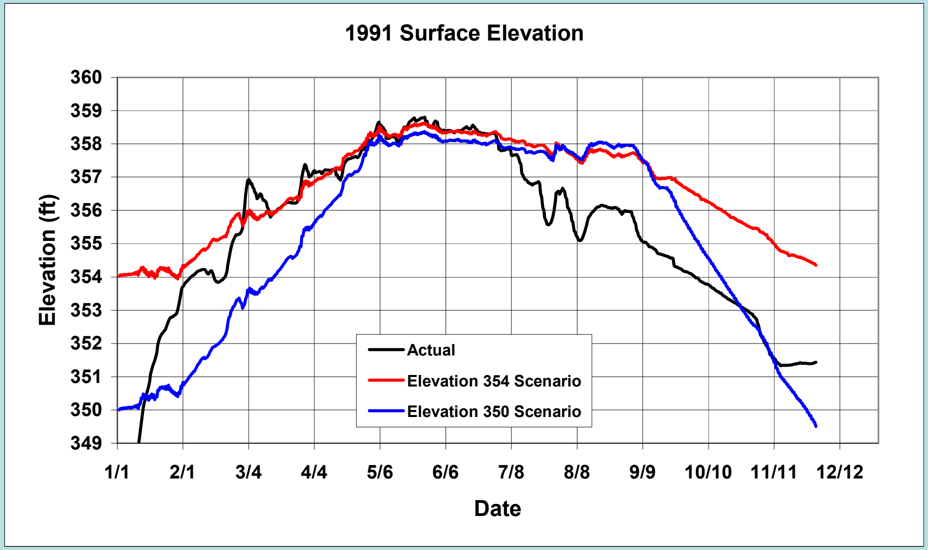
Assumptions:

- 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

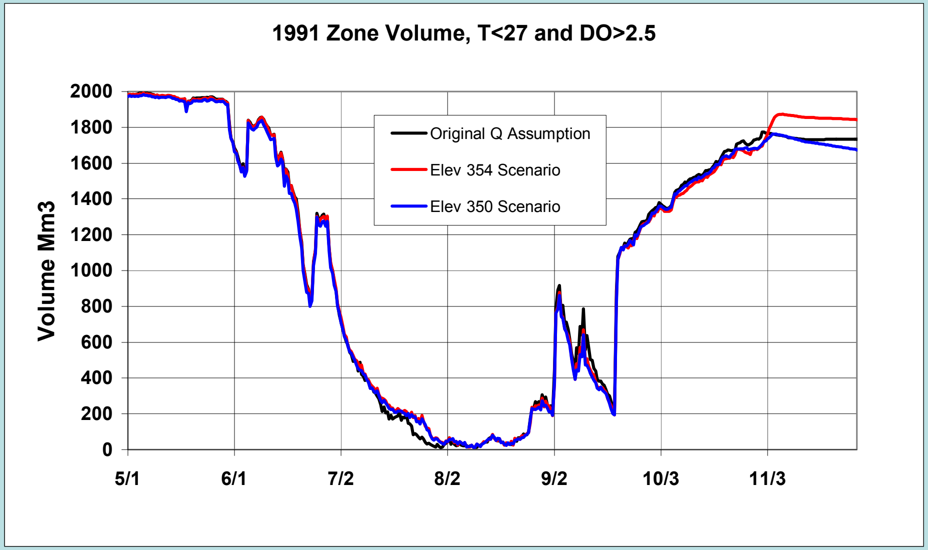
Approach:

- 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

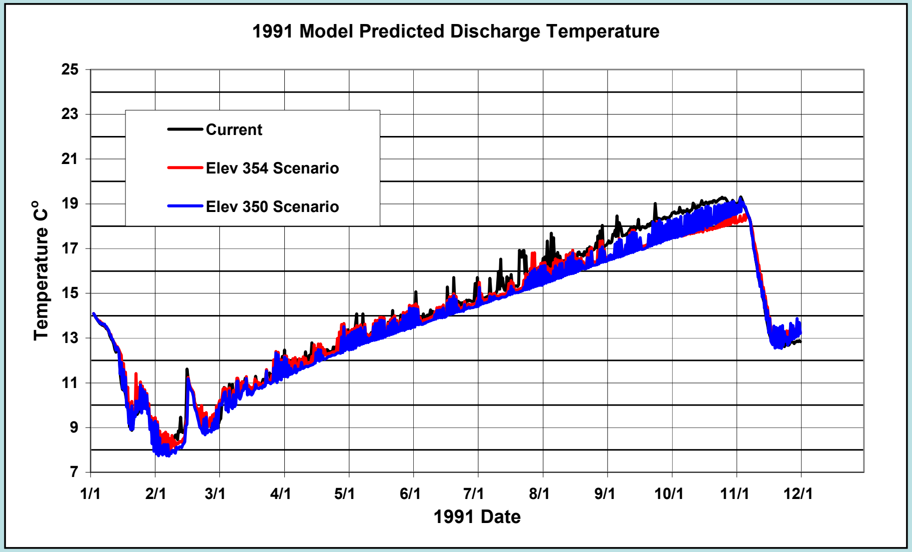
1991 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO



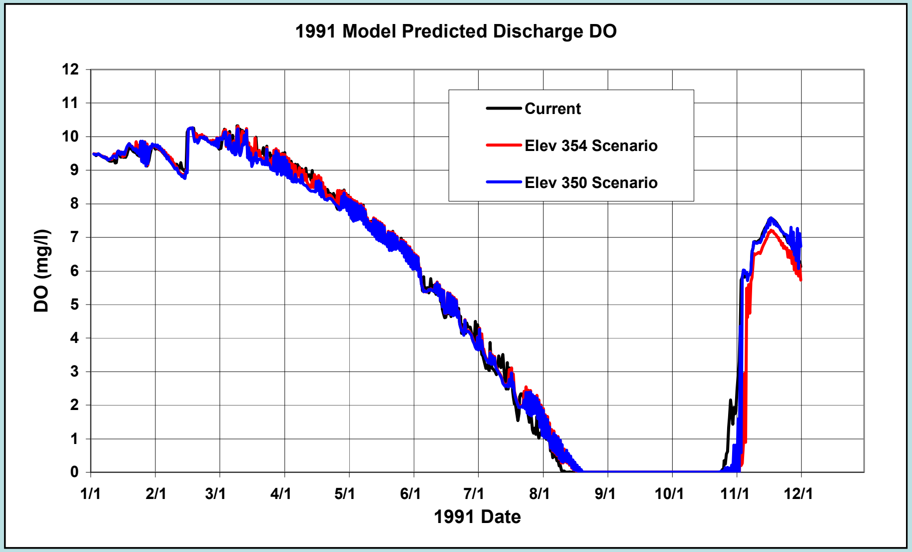
1991 Surface Elevation



1991 Zone Volume, T<27 and DO>2.5



1991 Model Predicted Discharge Temperature



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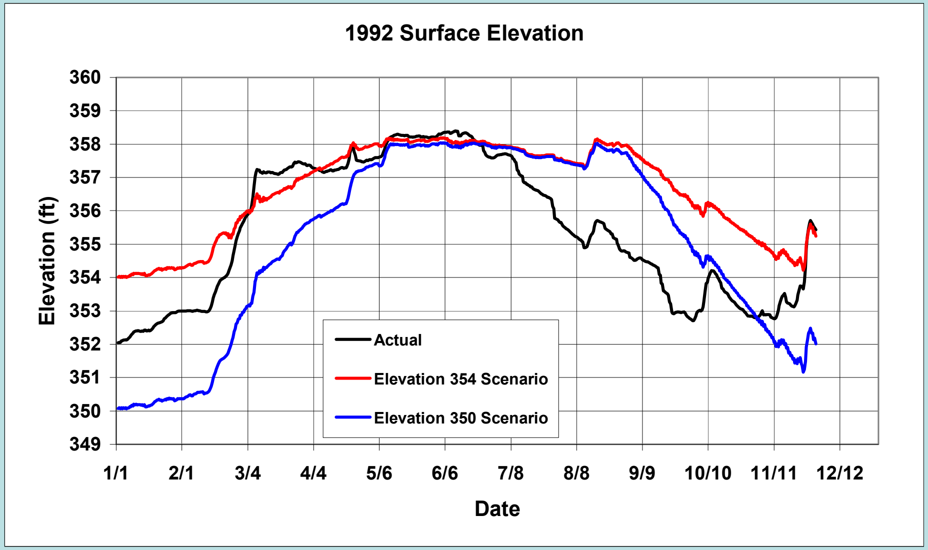
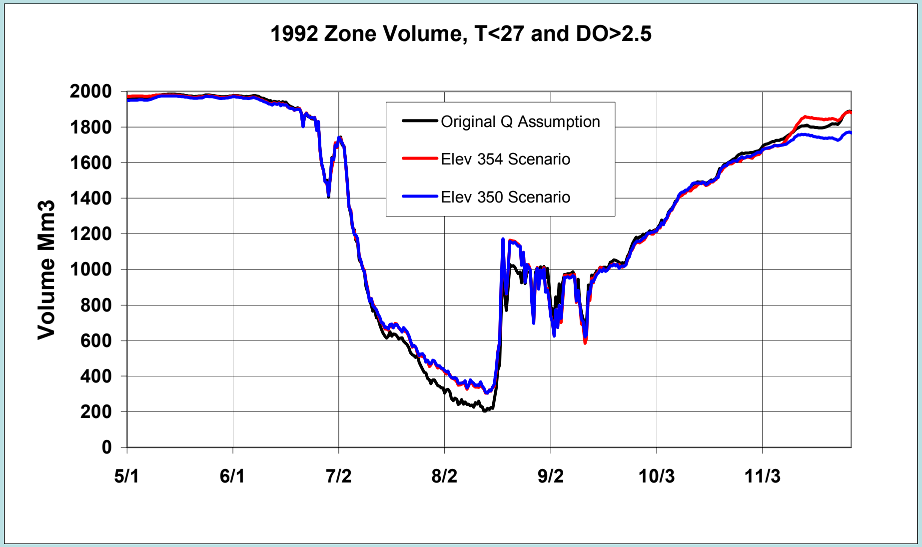
1992 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO


1992 Surface Elevation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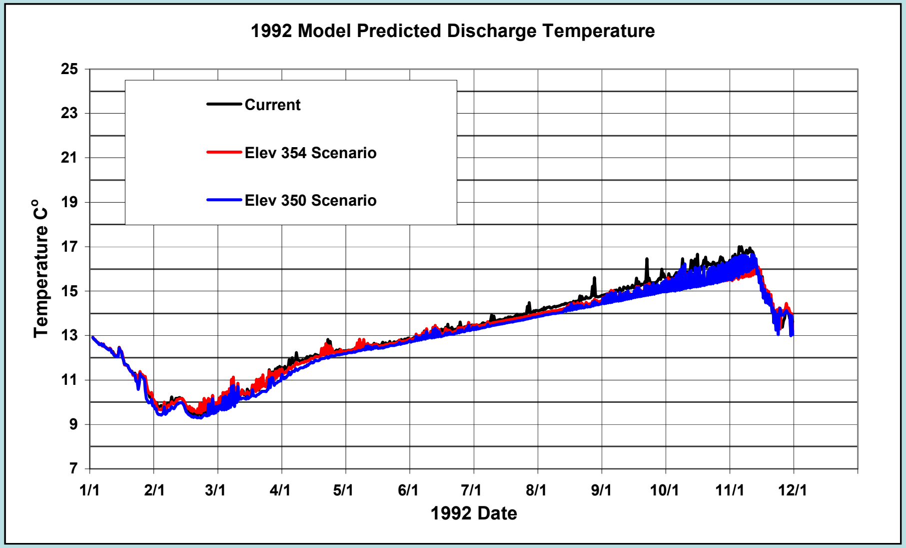
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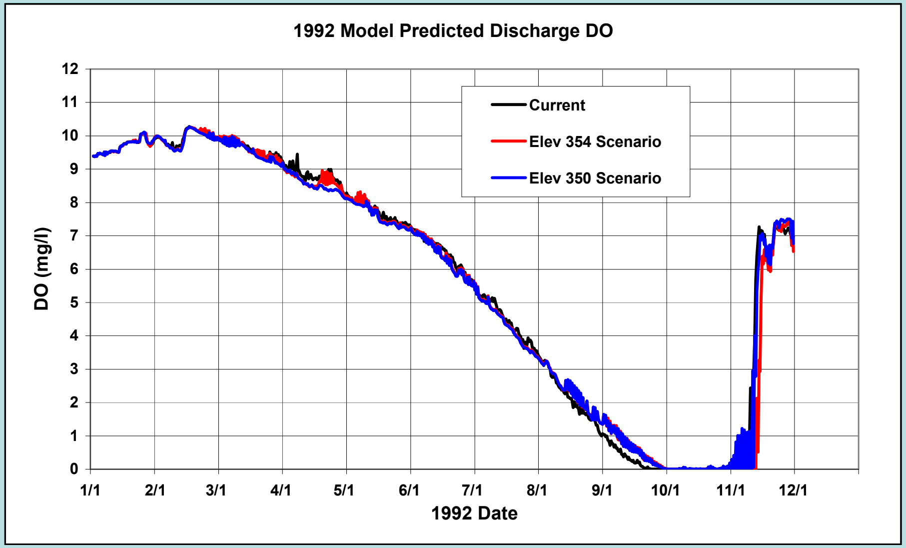
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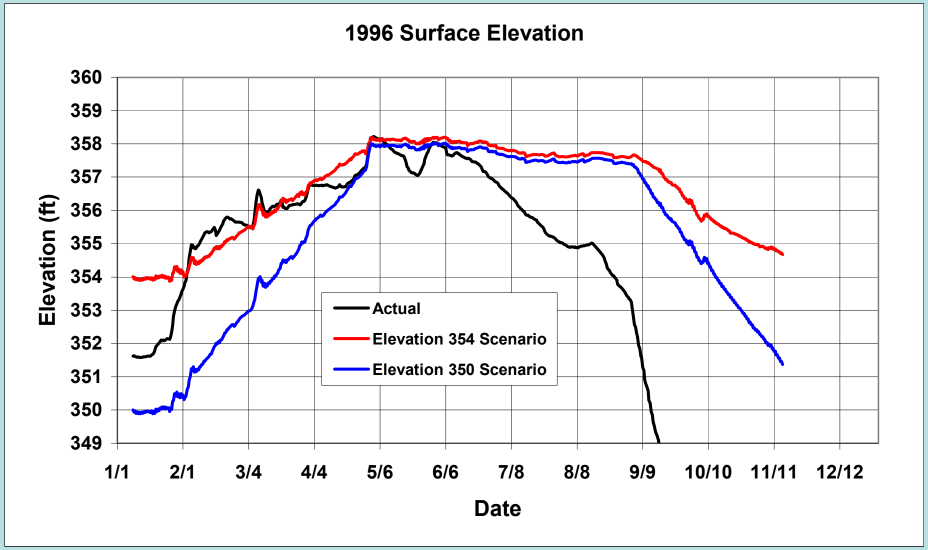
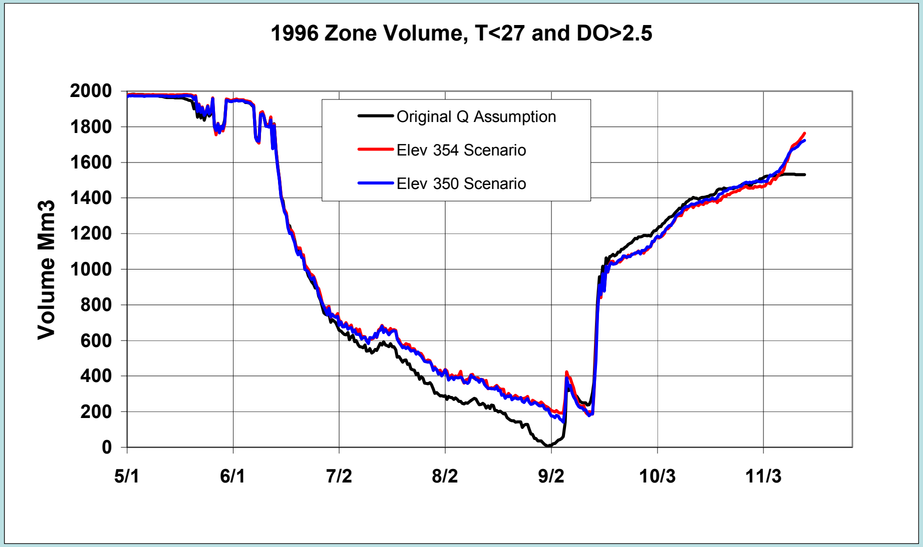
1996 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO


1996 Surface Elevation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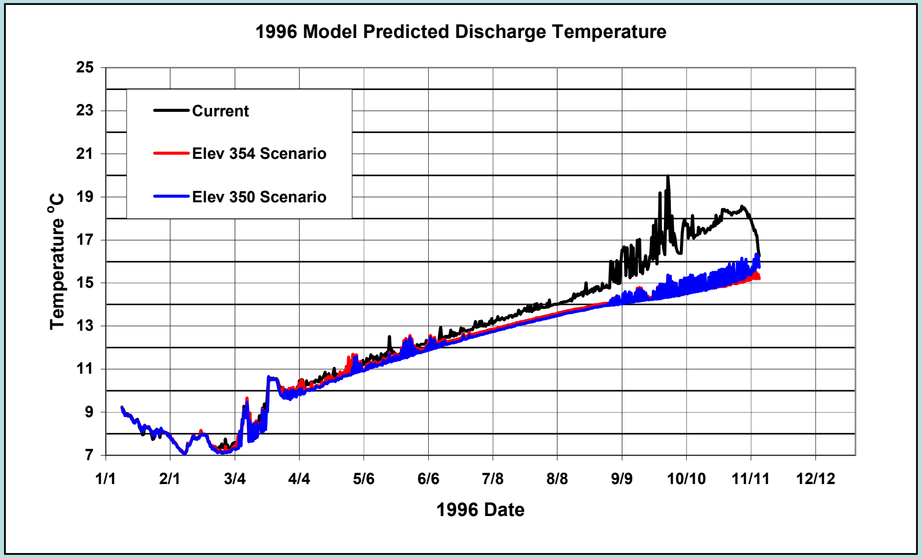
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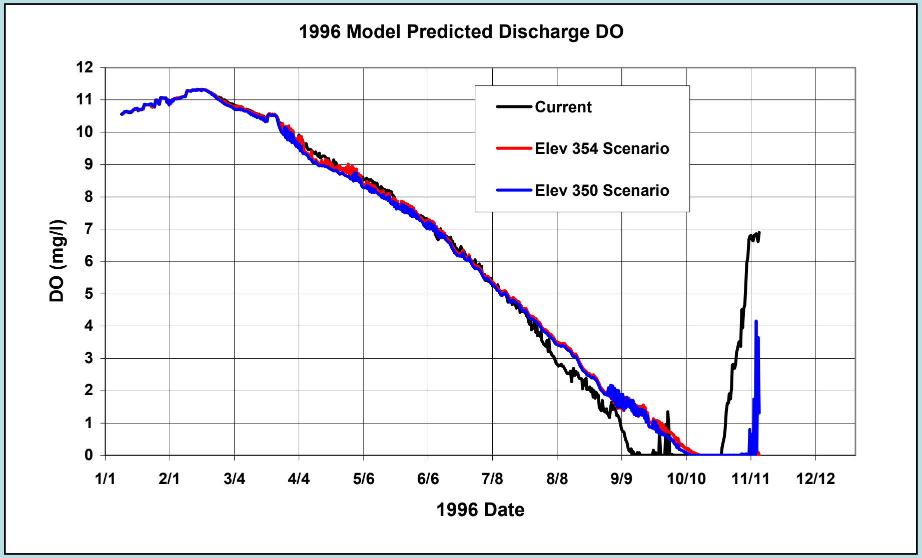
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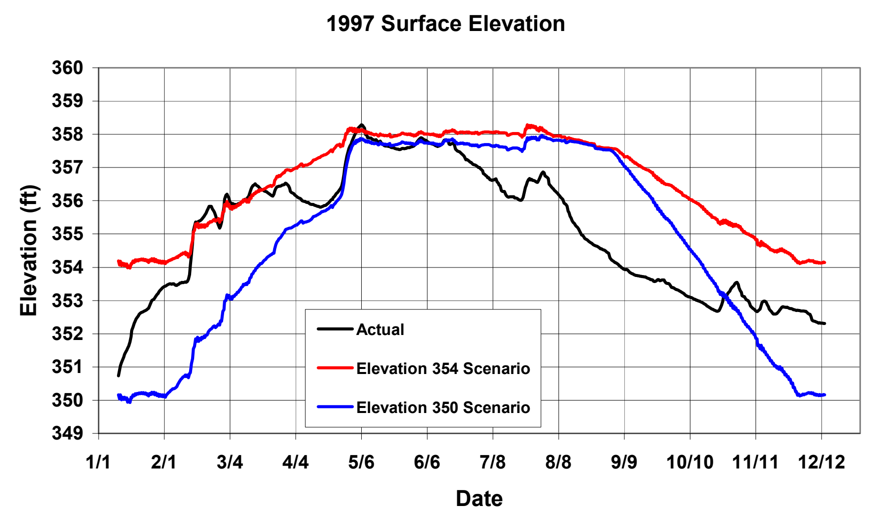

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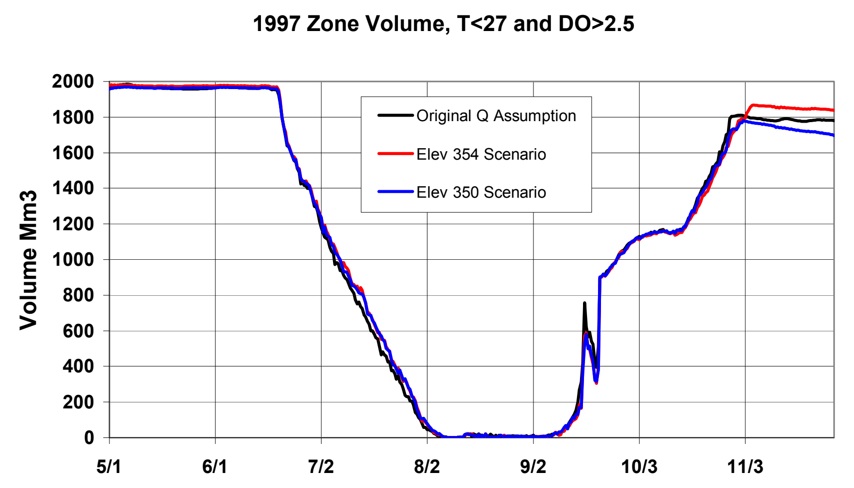

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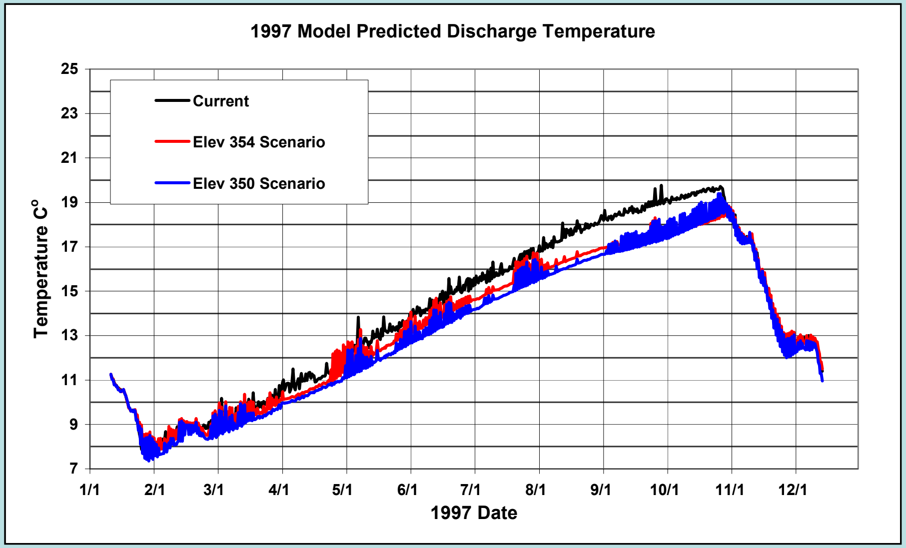

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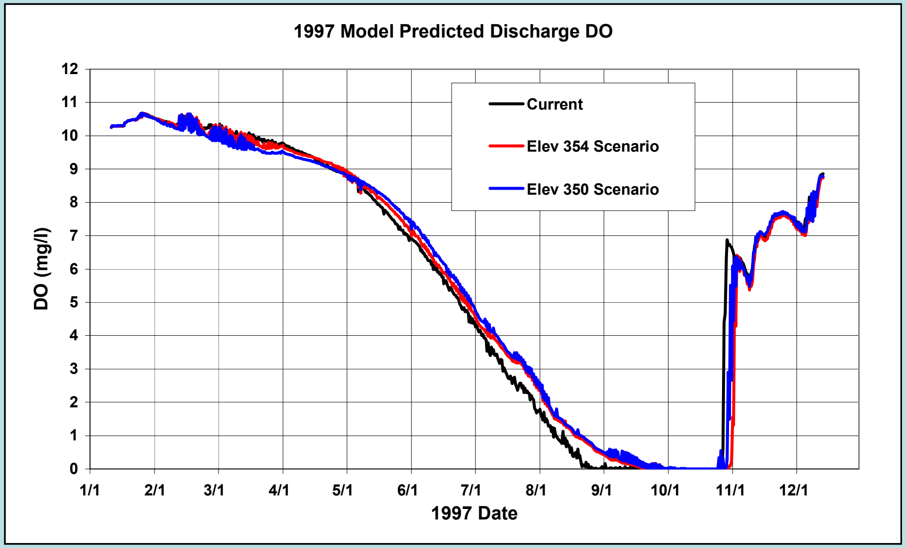

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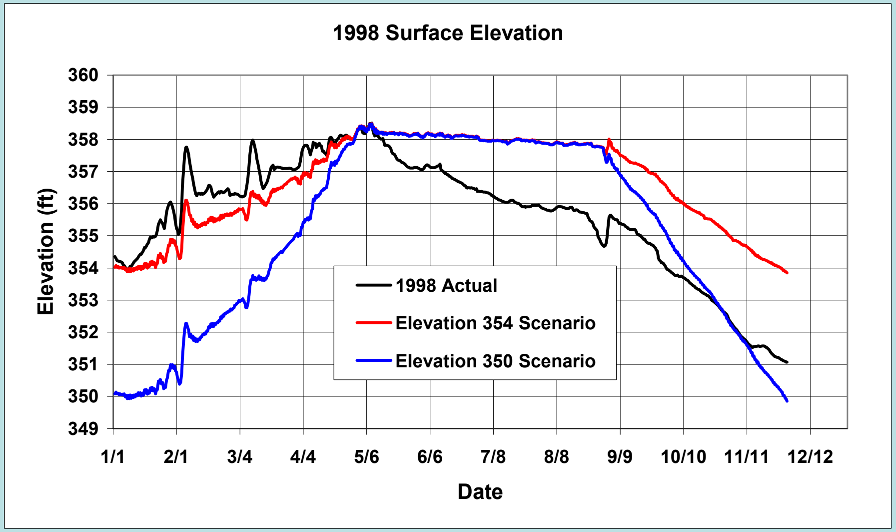
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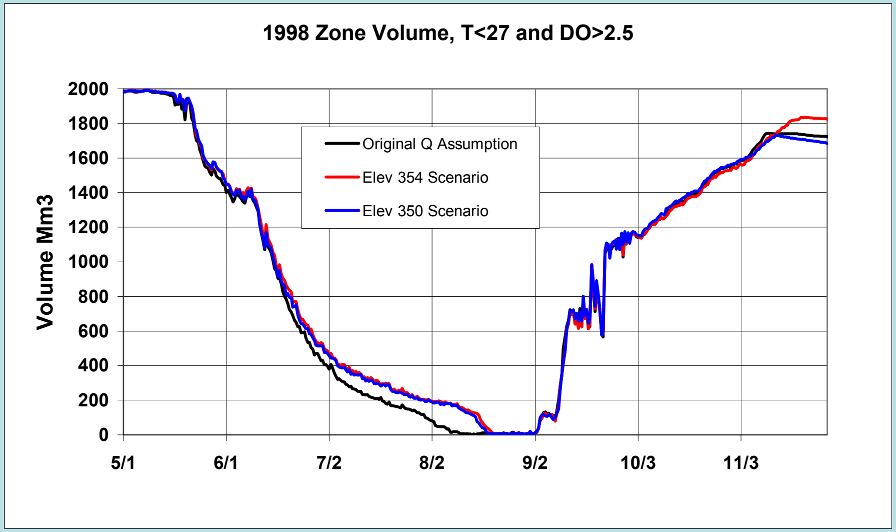
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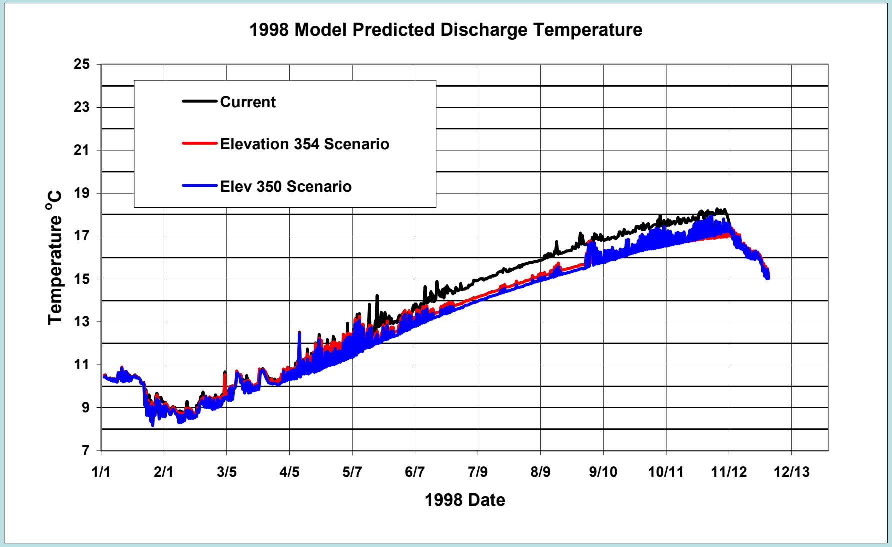
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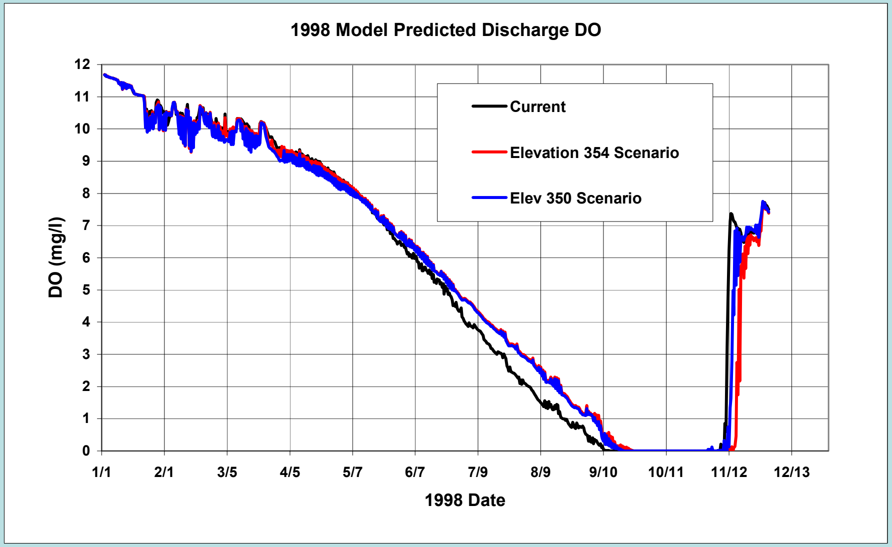
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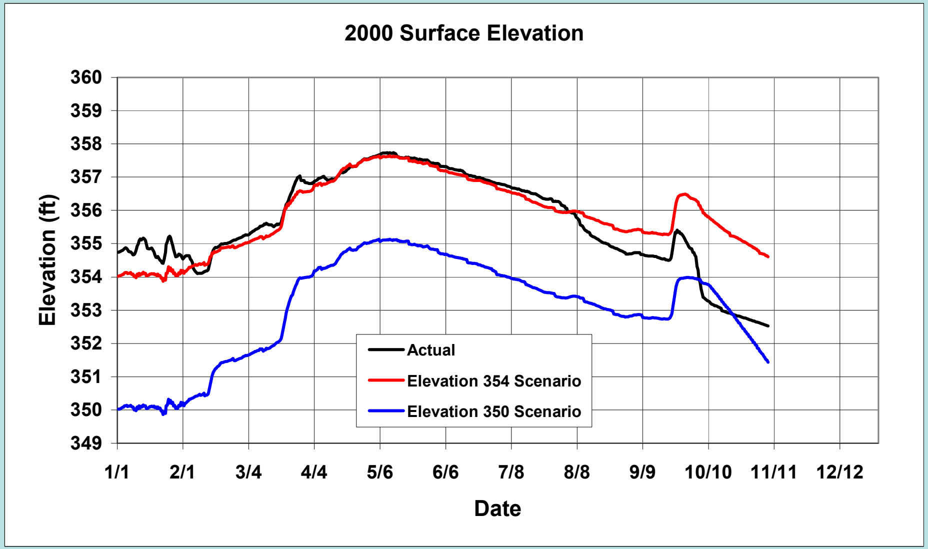
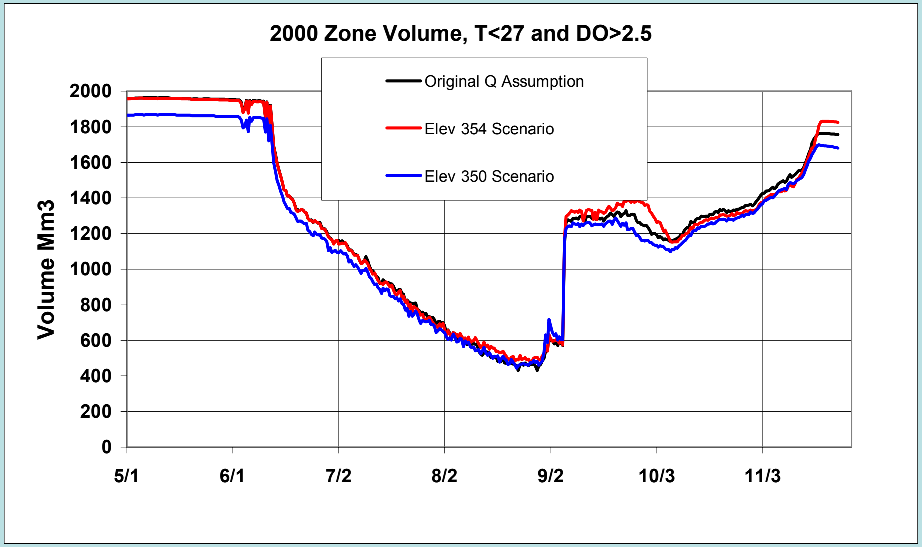
2000 Surface Elevation, Volume of Striper Habitat and Discharge Temperature and DO


2000 Surface Elevation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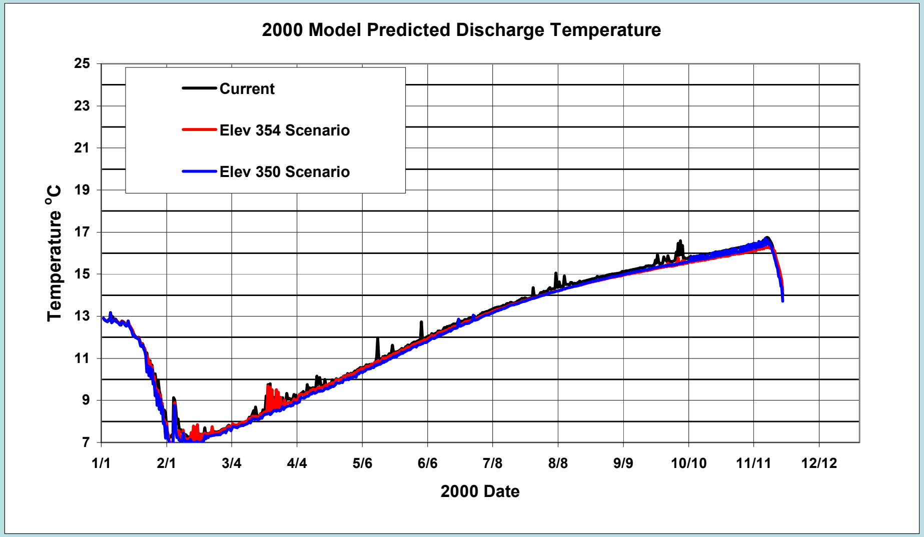
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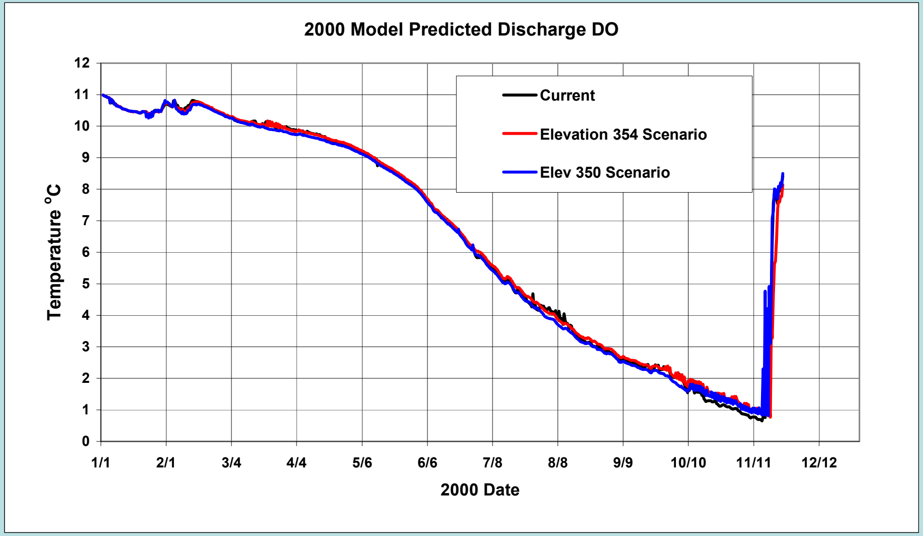
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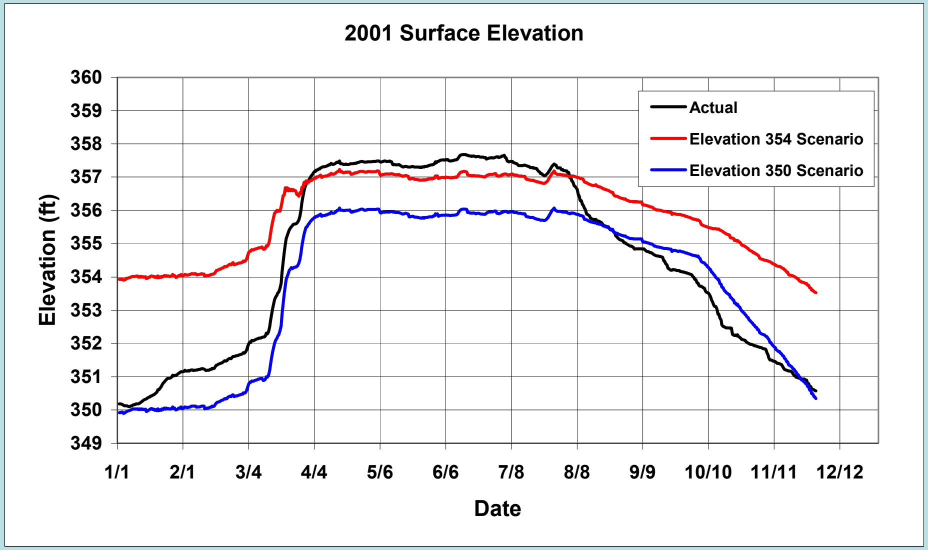
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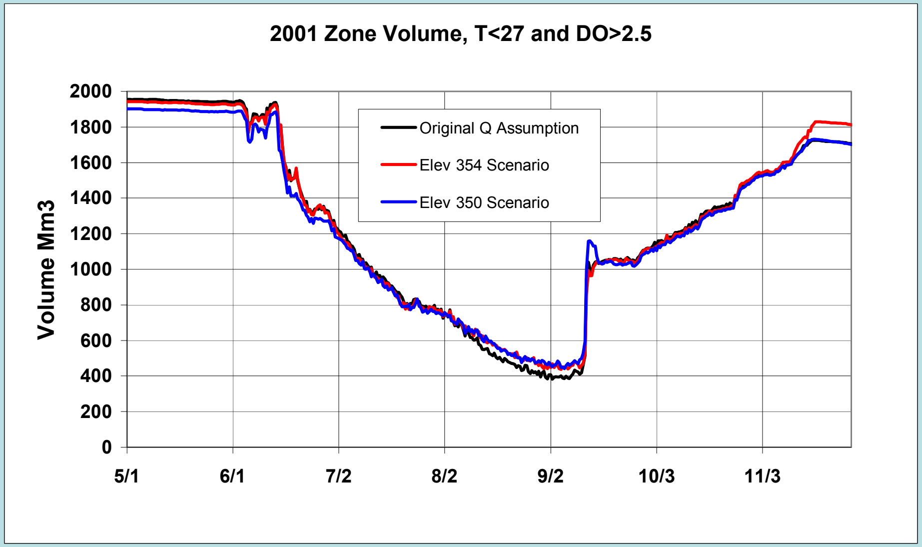
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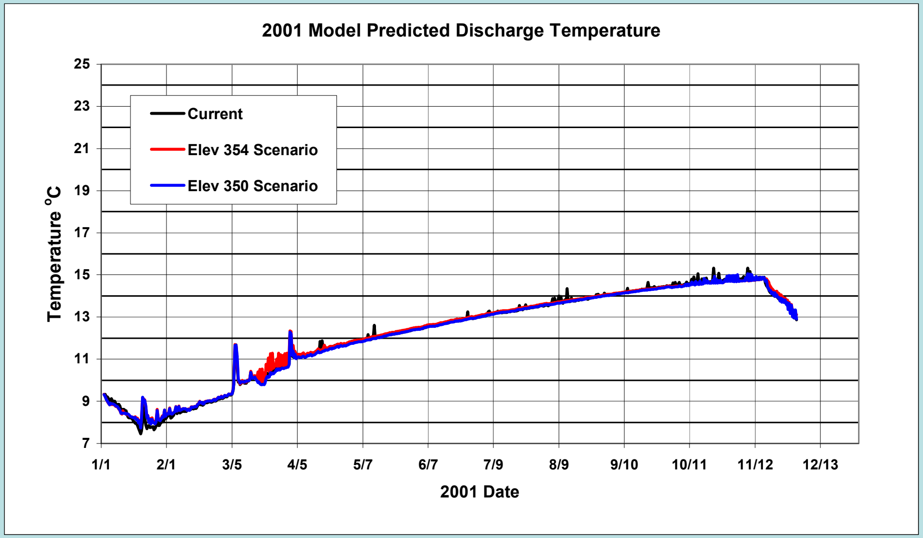
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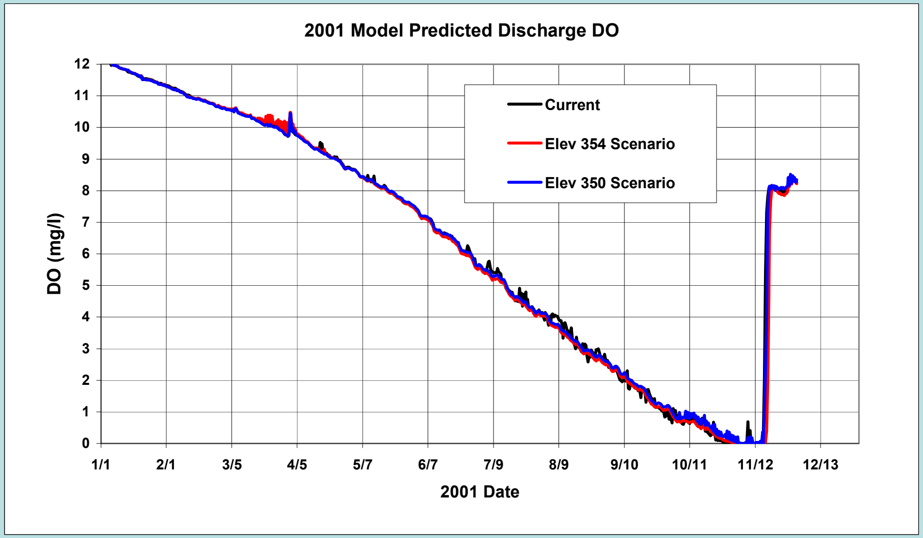
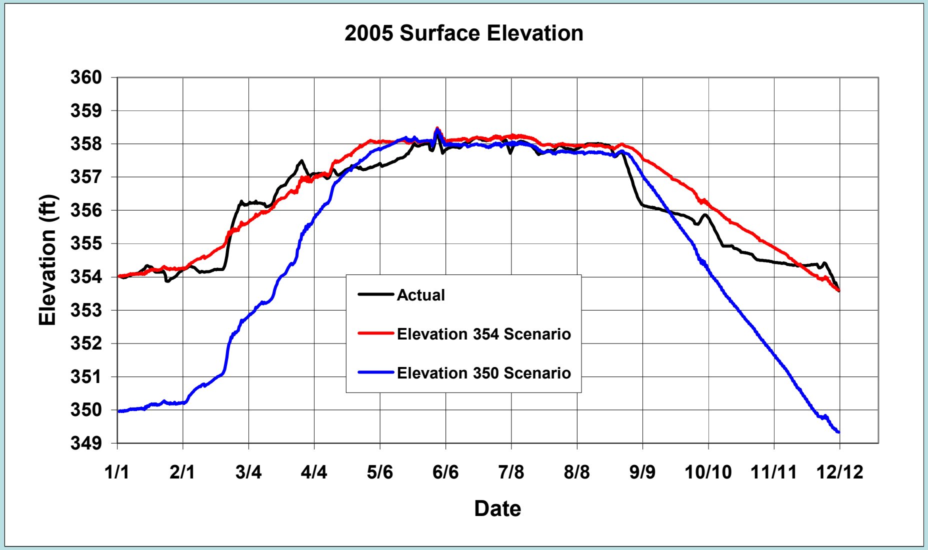
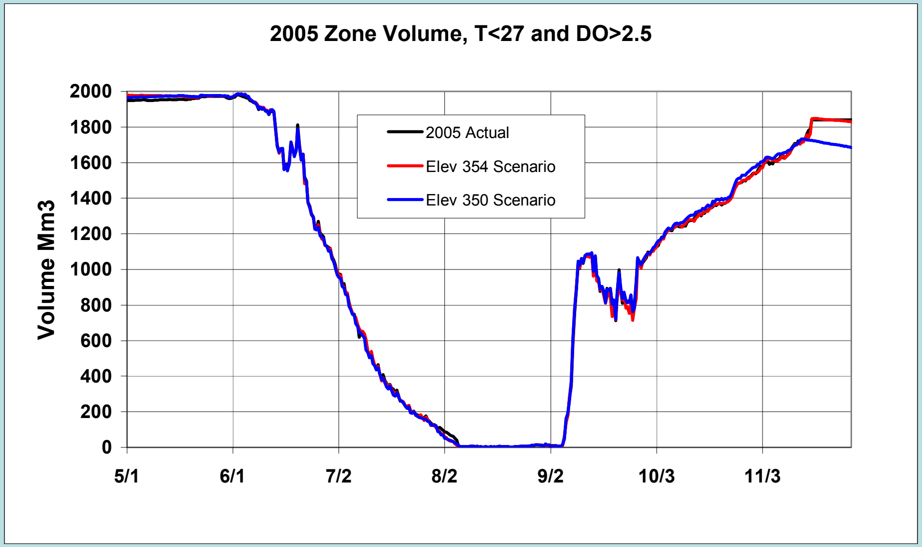

2001 Model Predicted Discharge DO

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


2005 Surface Elevation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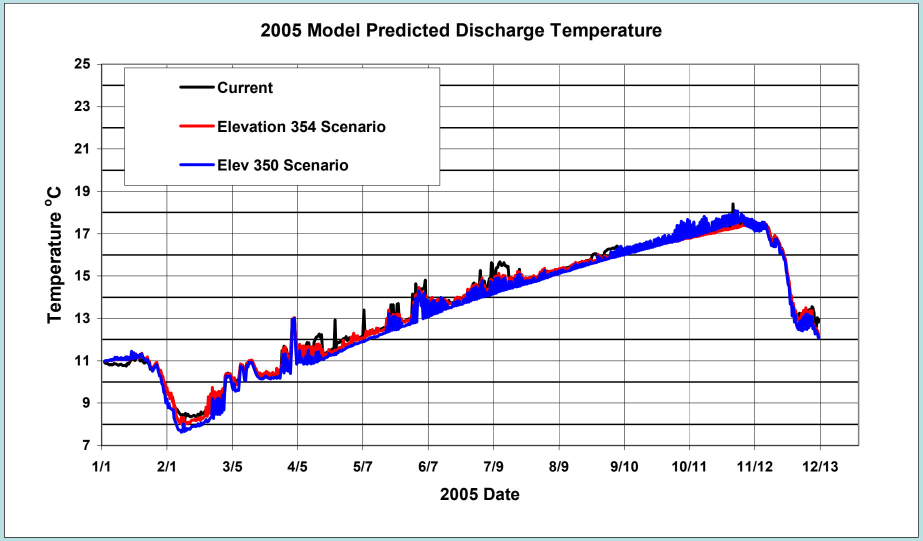
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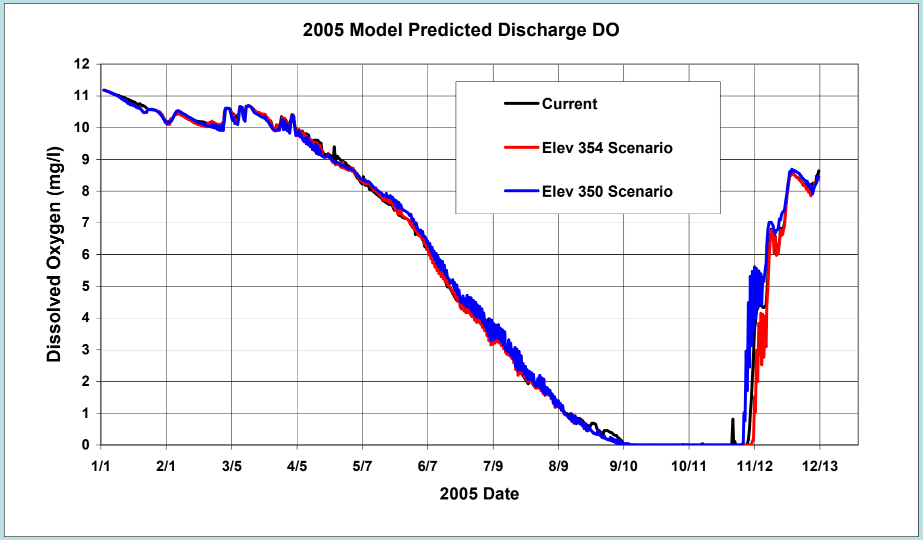
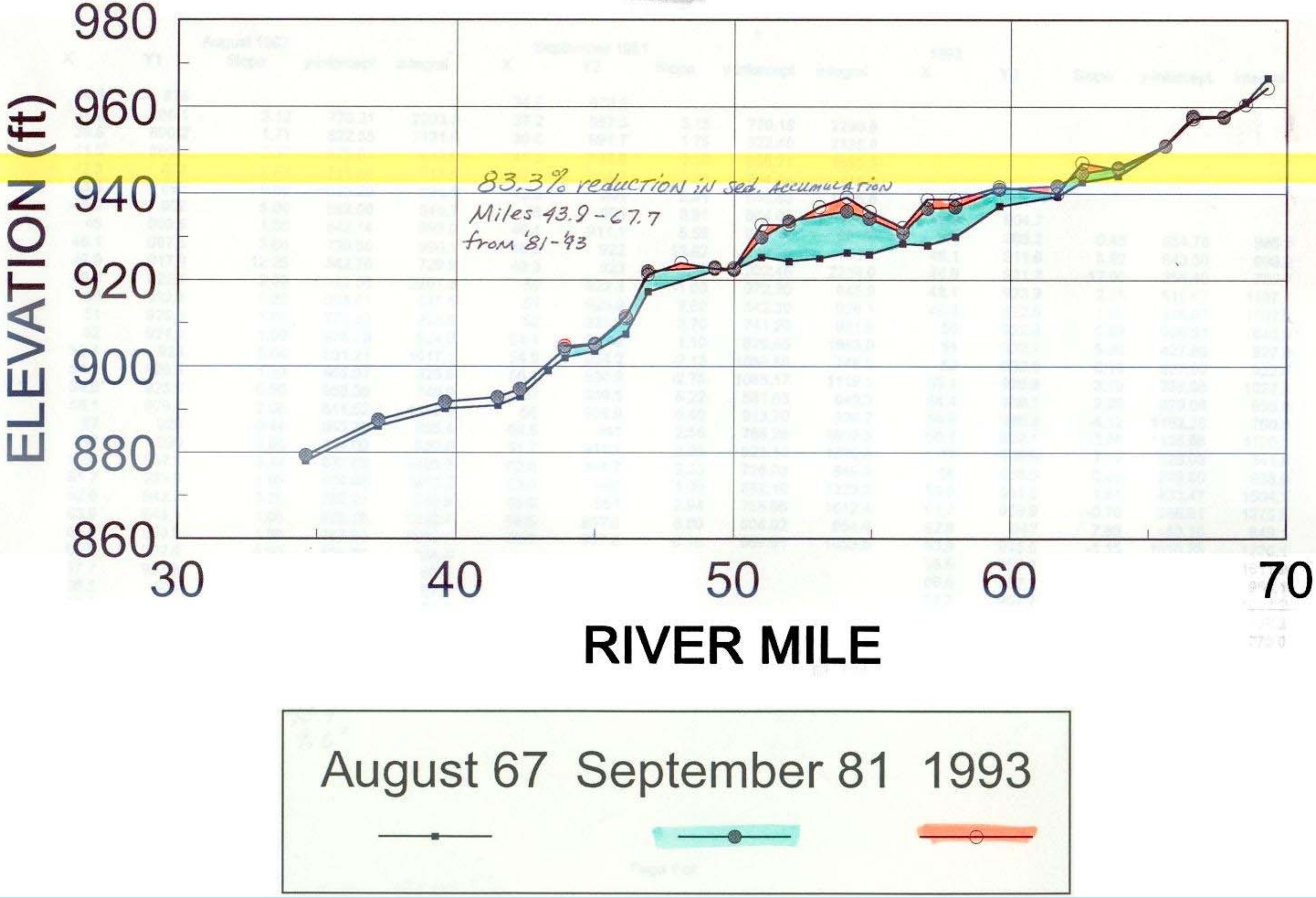

2005 Model Predicted Discharge DO

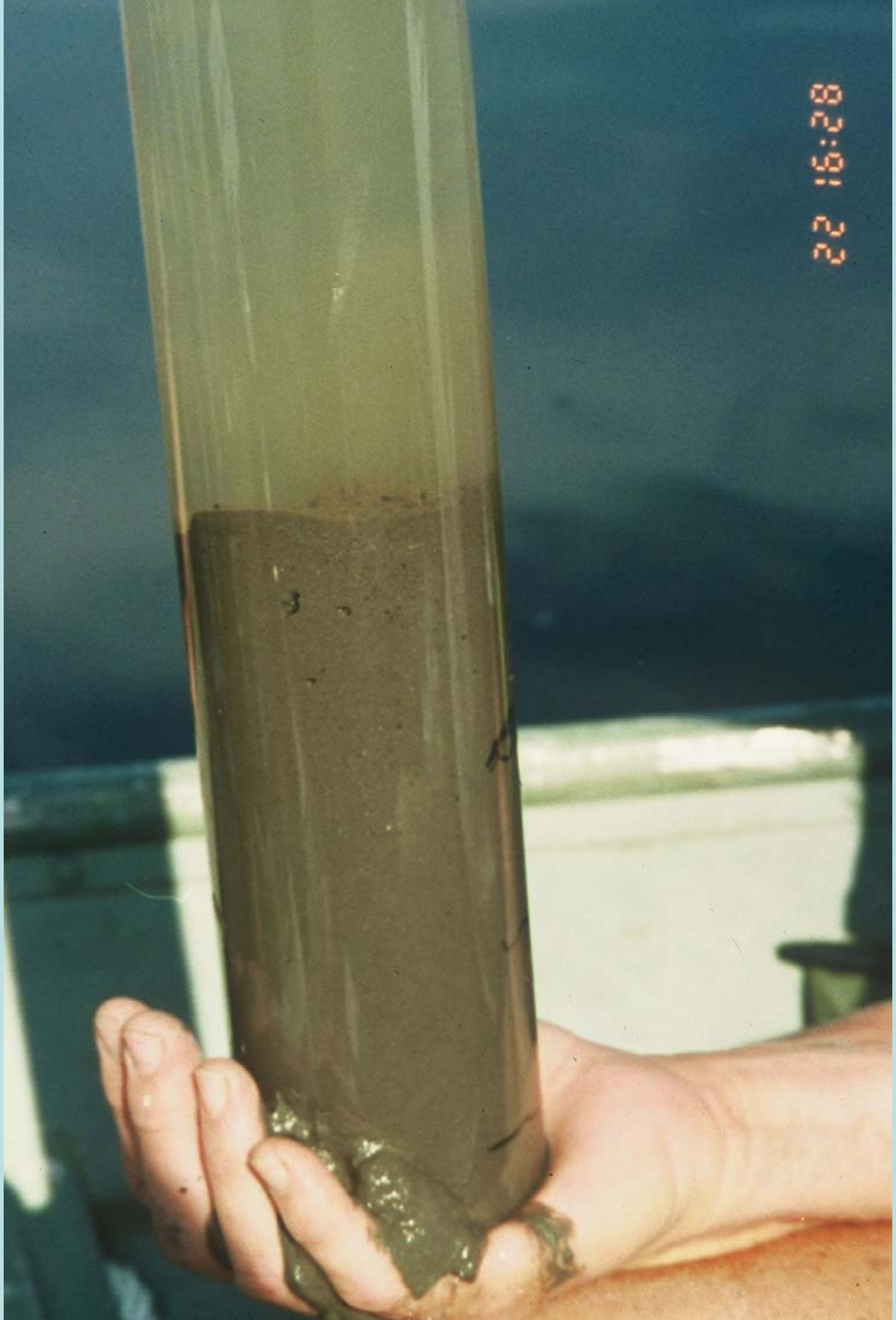
Experiences with Sediments from Douglas Reservoir

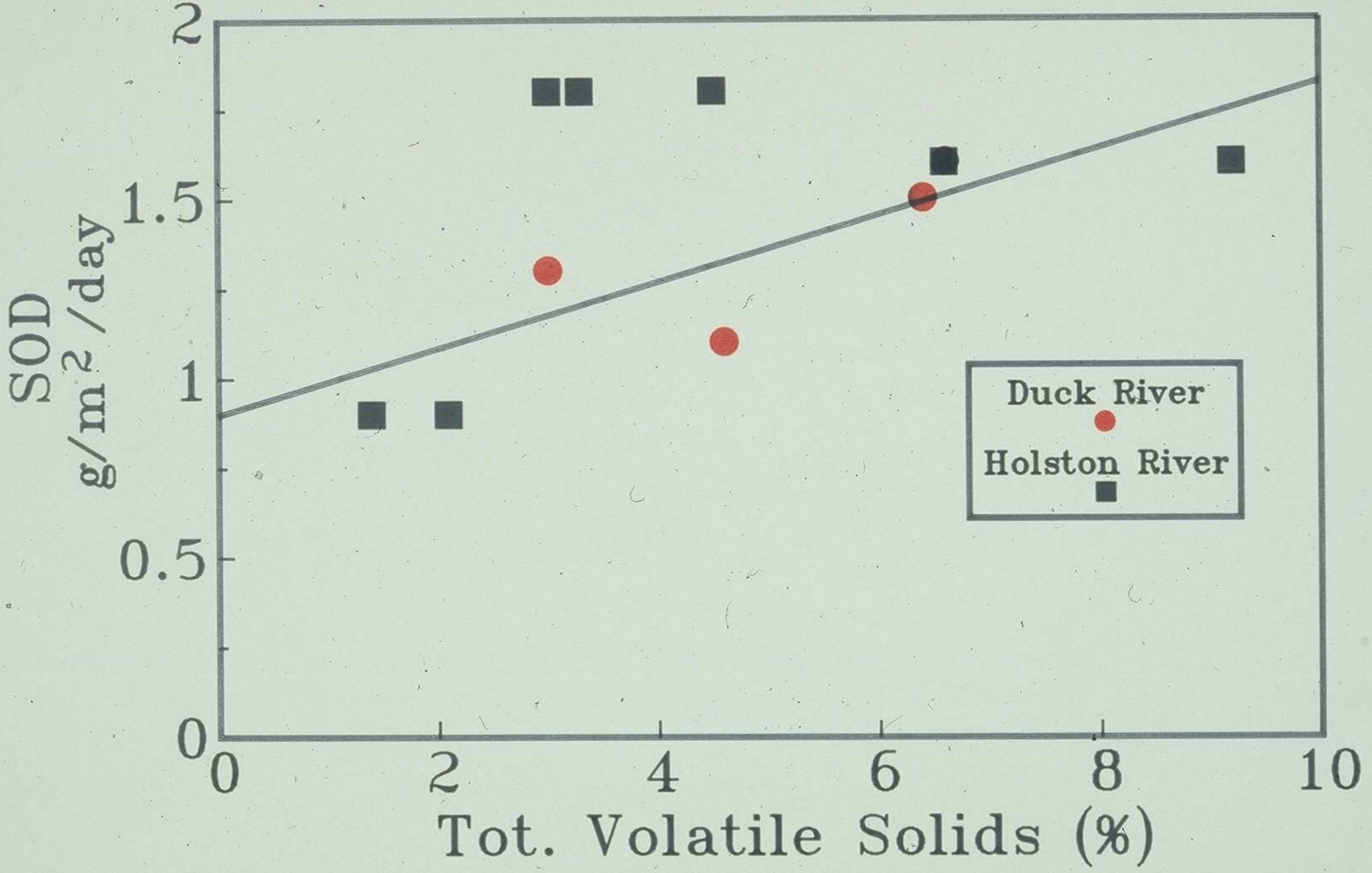
DOUGLAS RESERVOIR STREAMBED PROFILE



83.3% reduction in sed. accumulation
Miles 43.9 - 67.7
from '81-'93

9 22 '93


22 16:28


SOD
g/m^2 /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

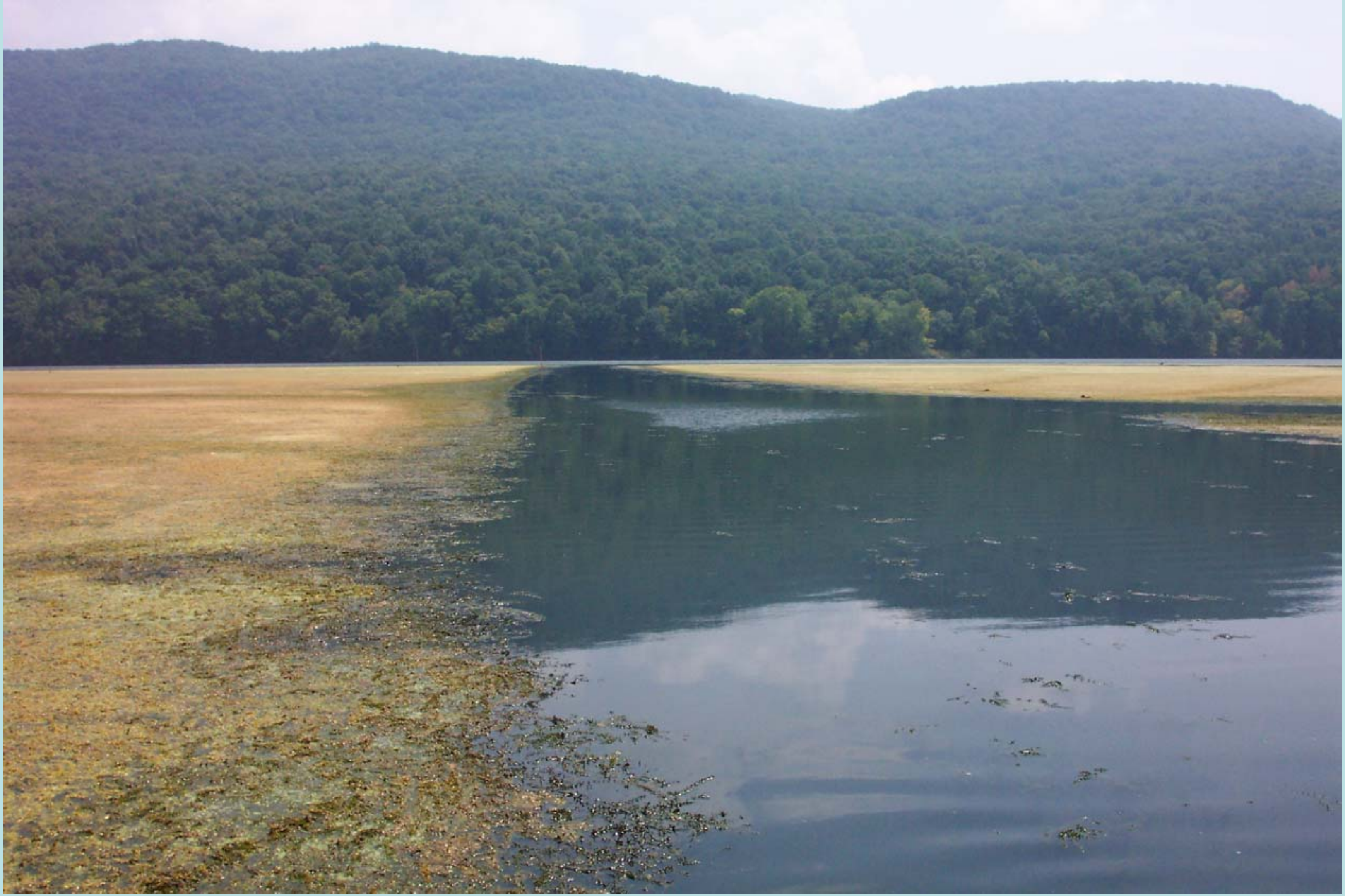

22 14:08


22 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

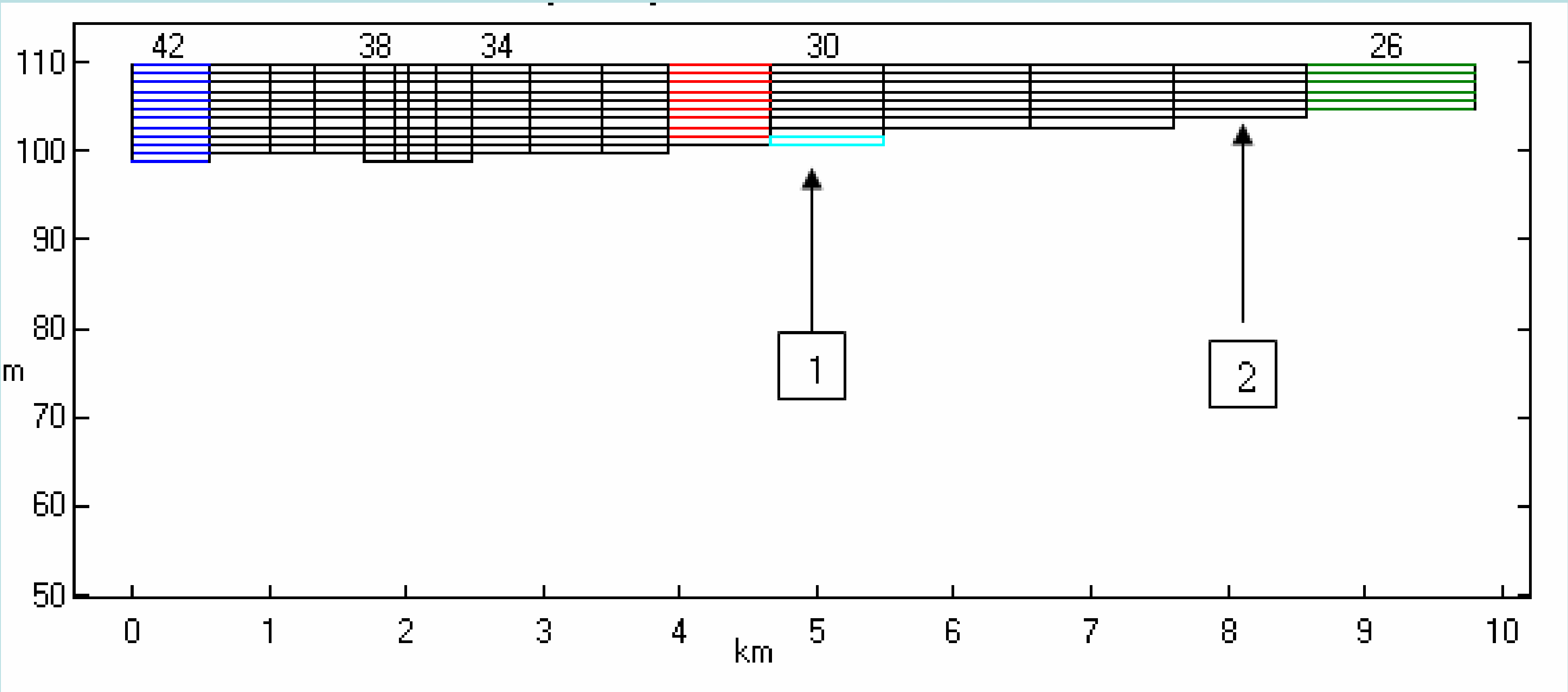
- One factor that is being assessed is the likelihood for SOD (sediment oxygen demand) to increase up to levels seen at other projects in the SE USA (based on model derived values at 20 projects plus SOD measurements conducted by EPA at many projects).
- This is being supported by seasonal SOD dynamics 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

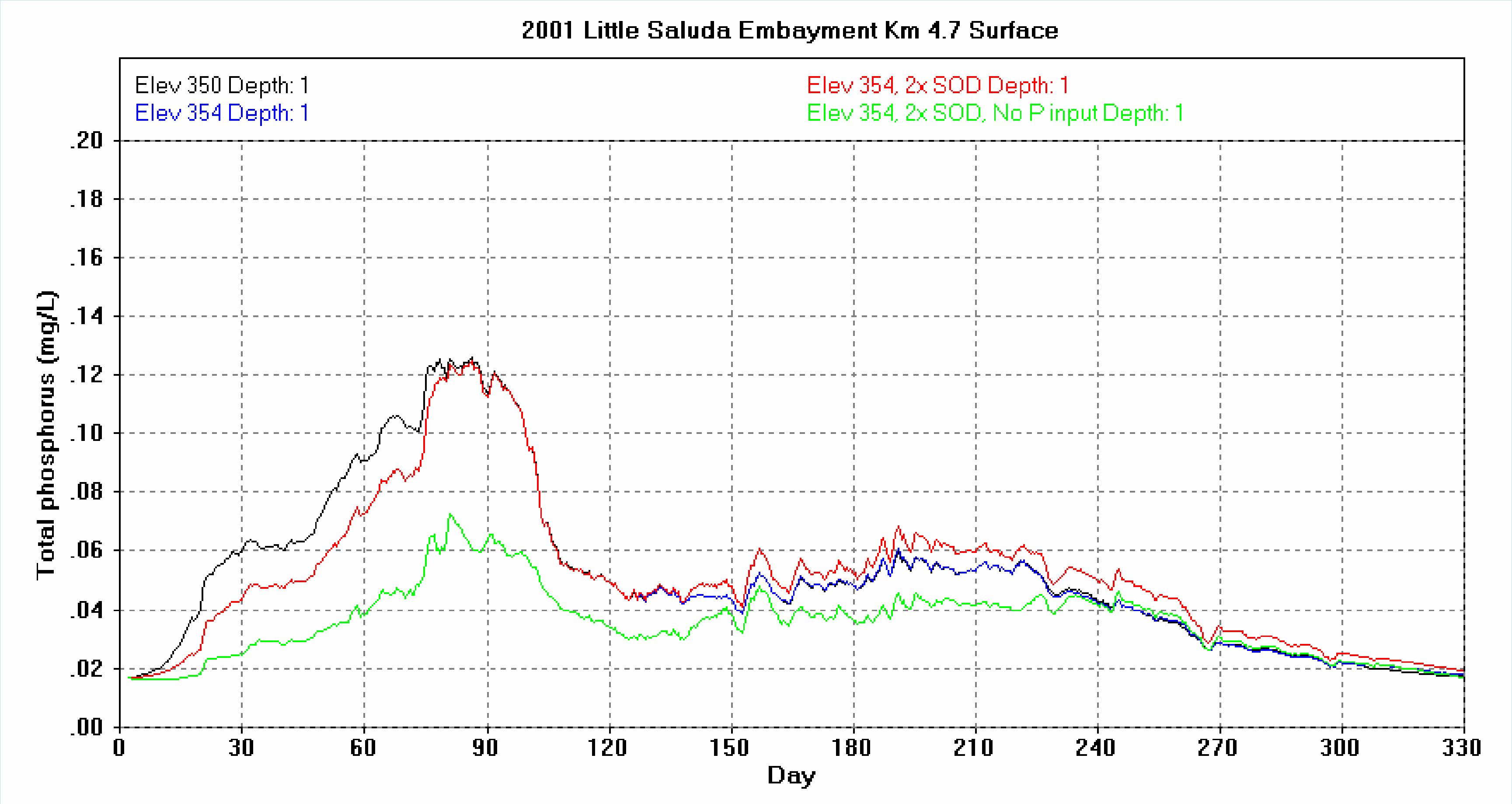
2001 Comparison of:

- 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.

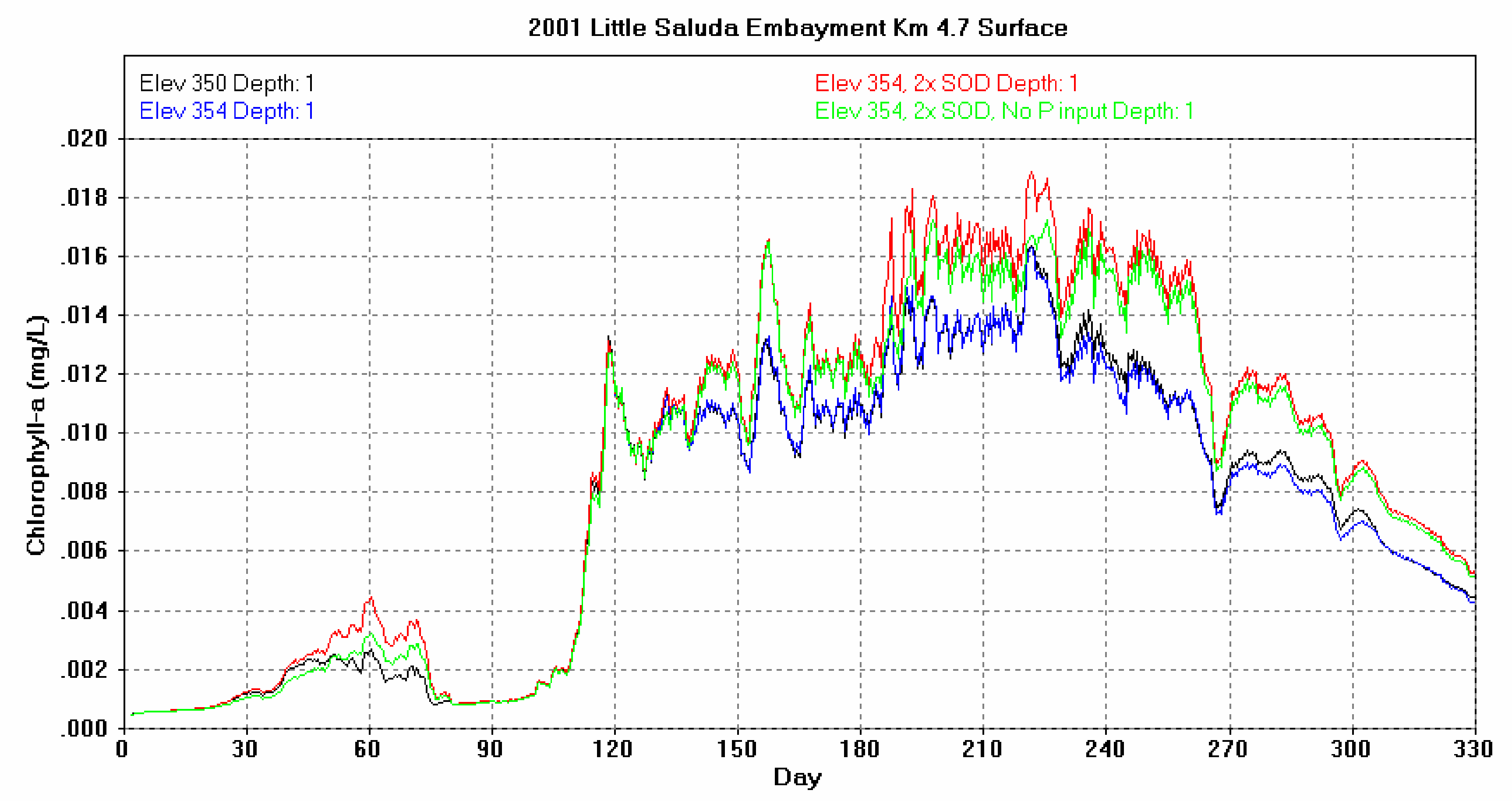
Side View of Little Saluda Bathymetry



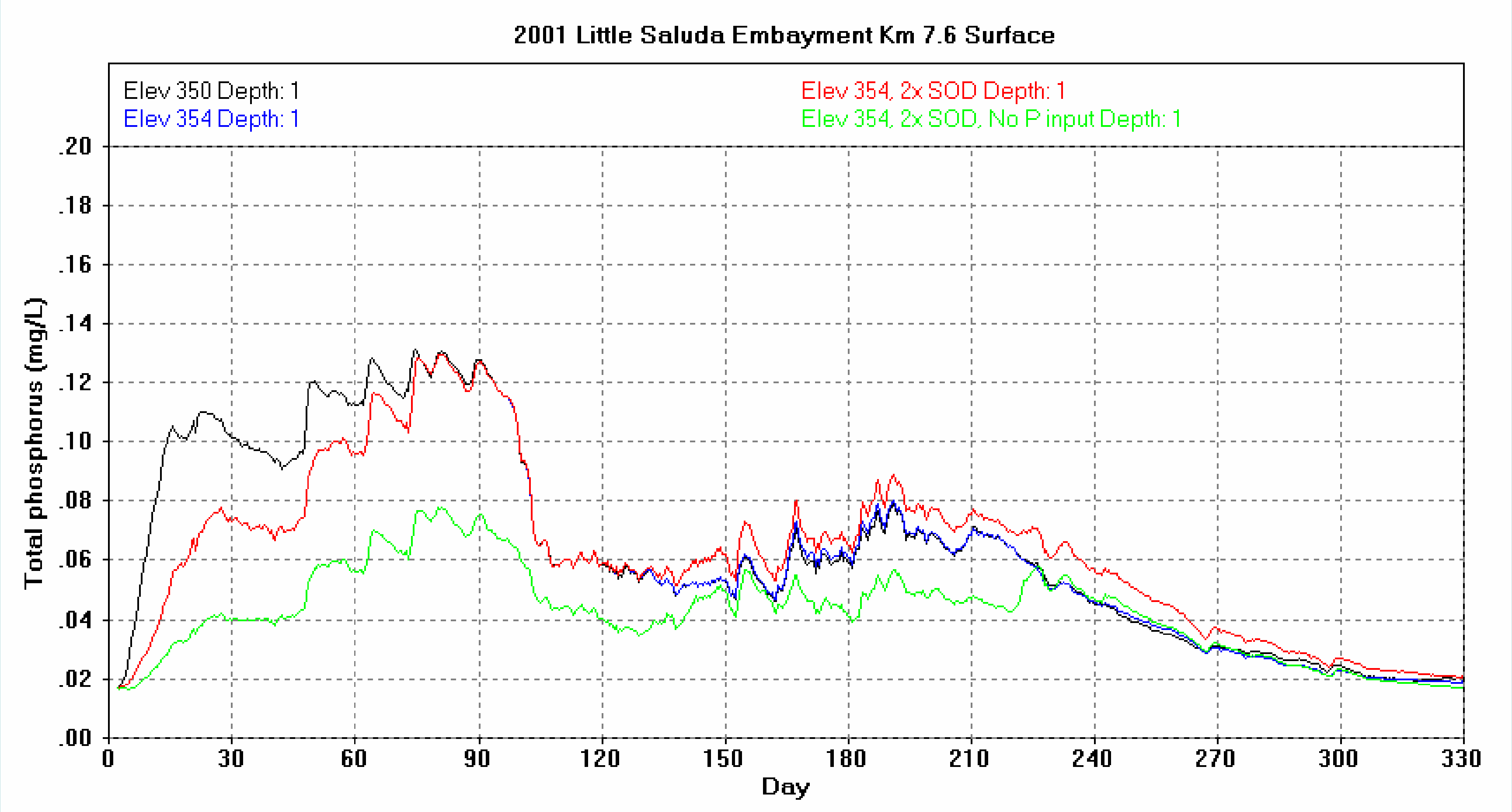
Total Phosphorus at the surface at location 1



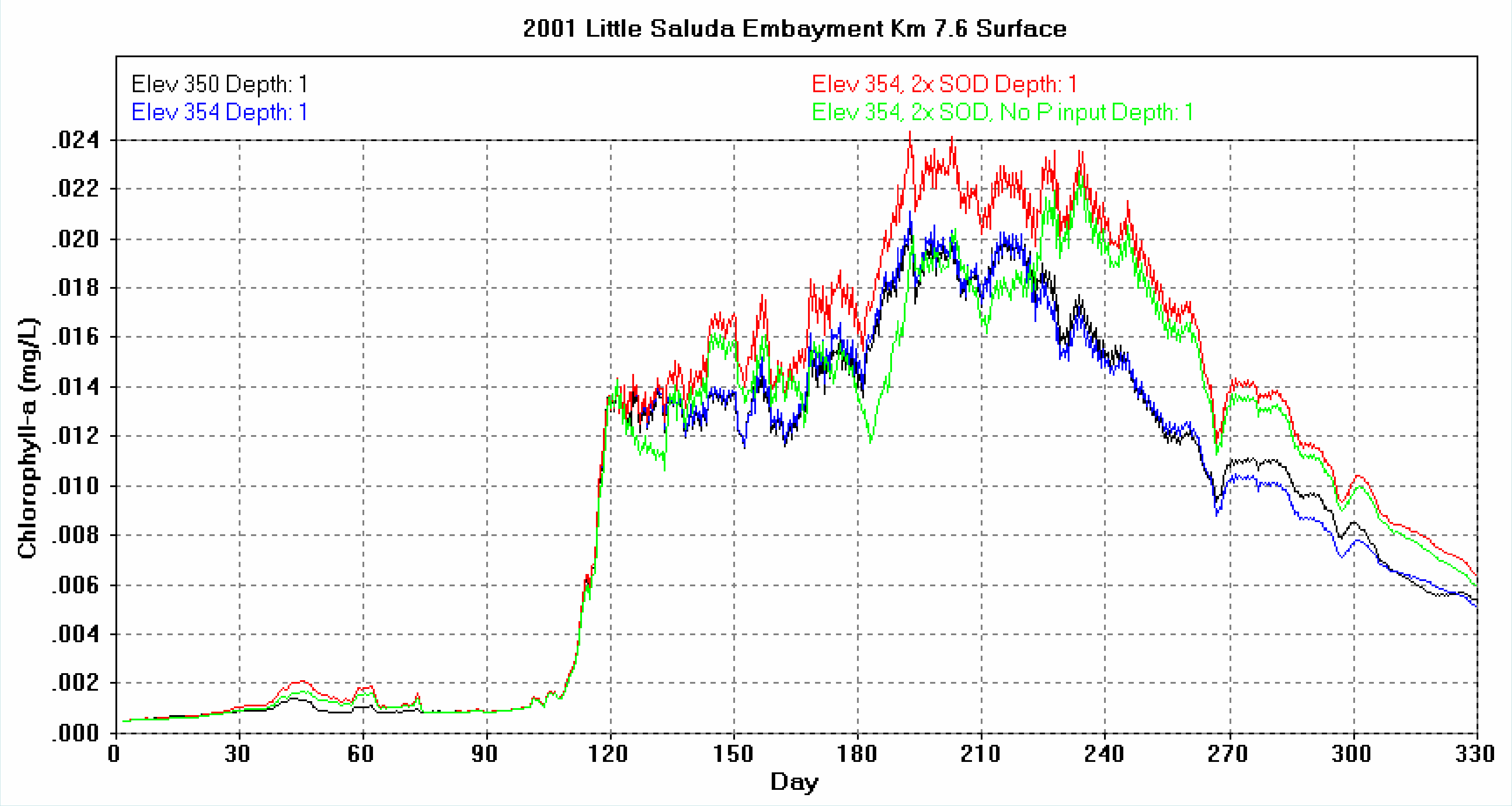
Chlorophyll *a* near the surface at location 1



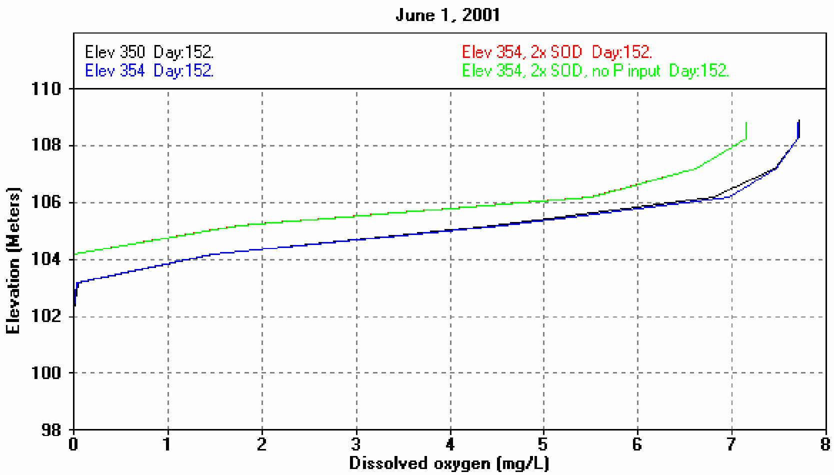
Total Phosphorus at the surface at location 2

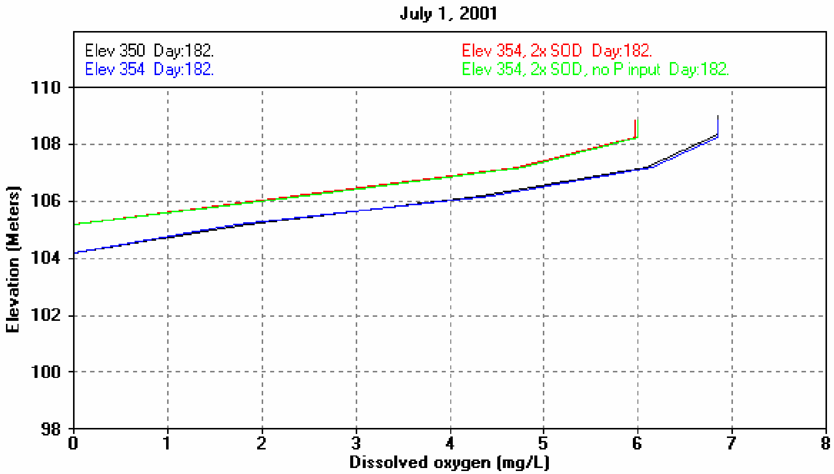


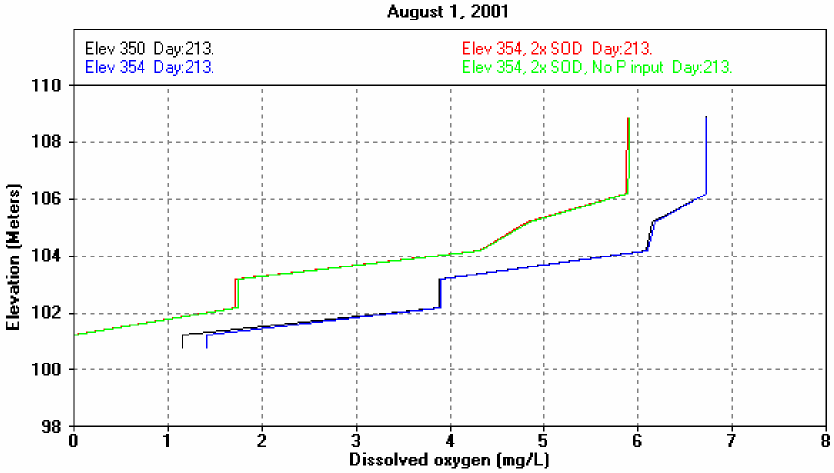
Chlorophyll *a* near the surface at location 2

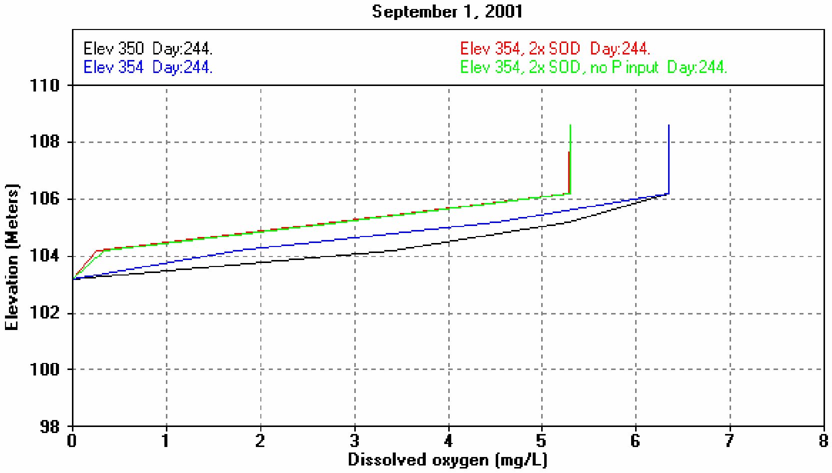


DO Profiles in the Little Saluda Embayment—Location 1, Km 4.7

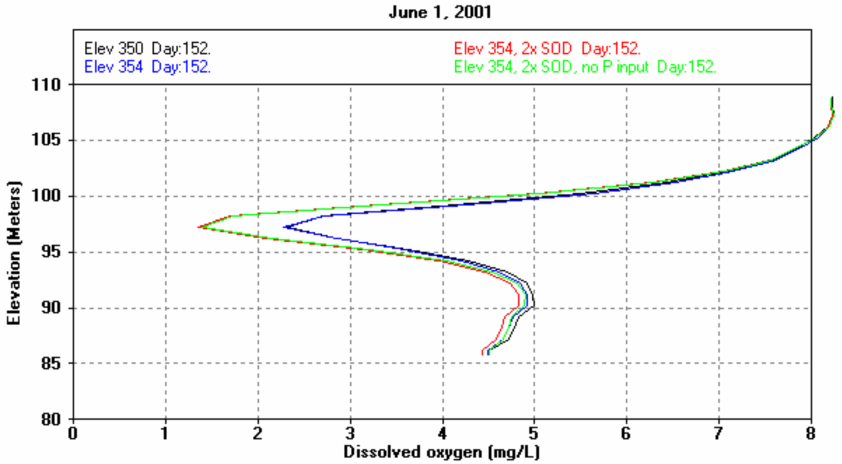

June 1, 2001


July 1, 2001


August 1, 2001


September 1, 2001

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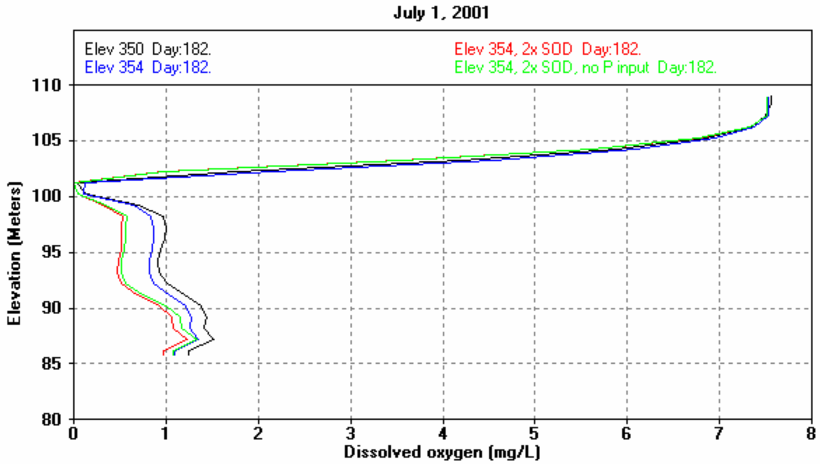
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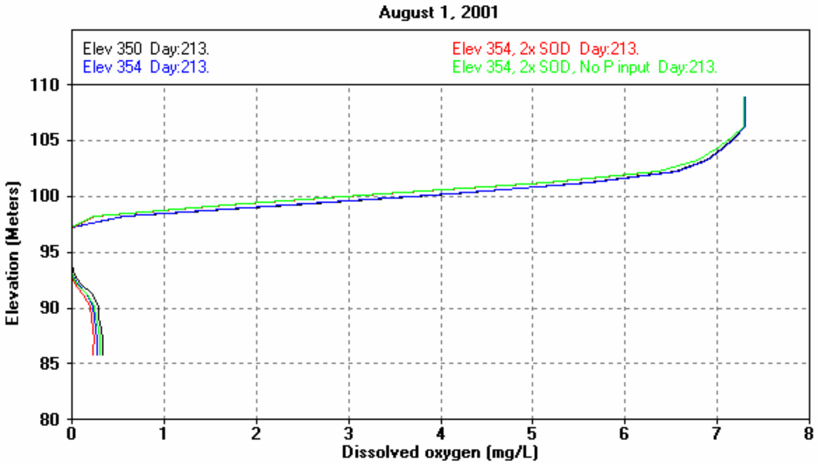
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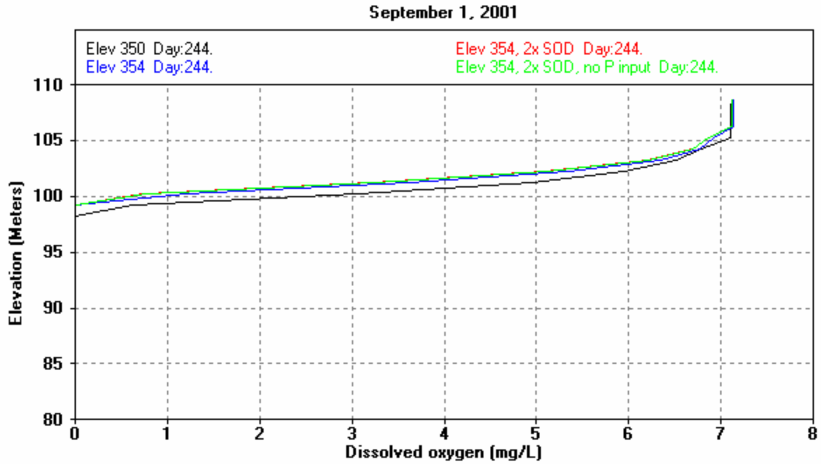
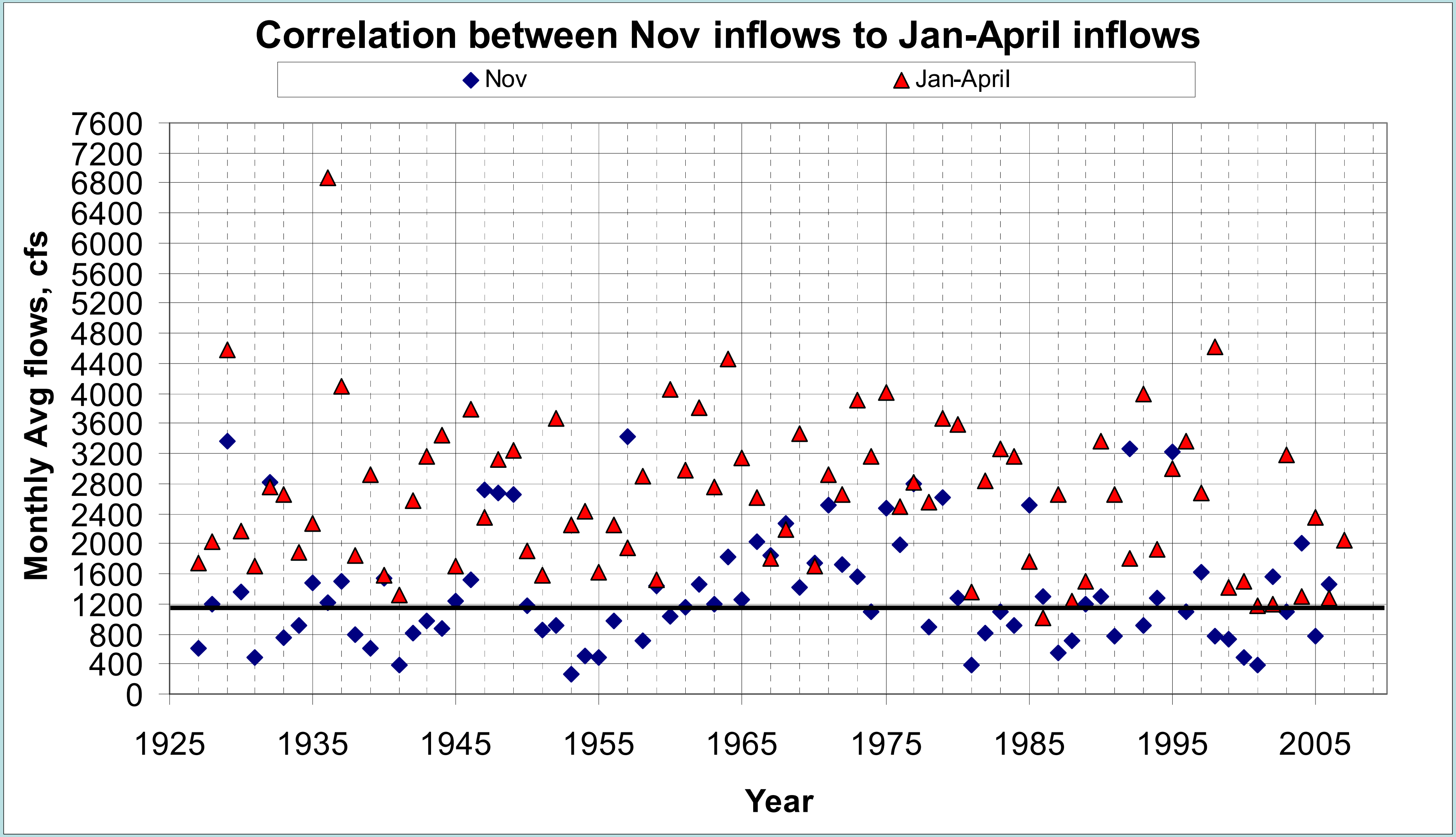
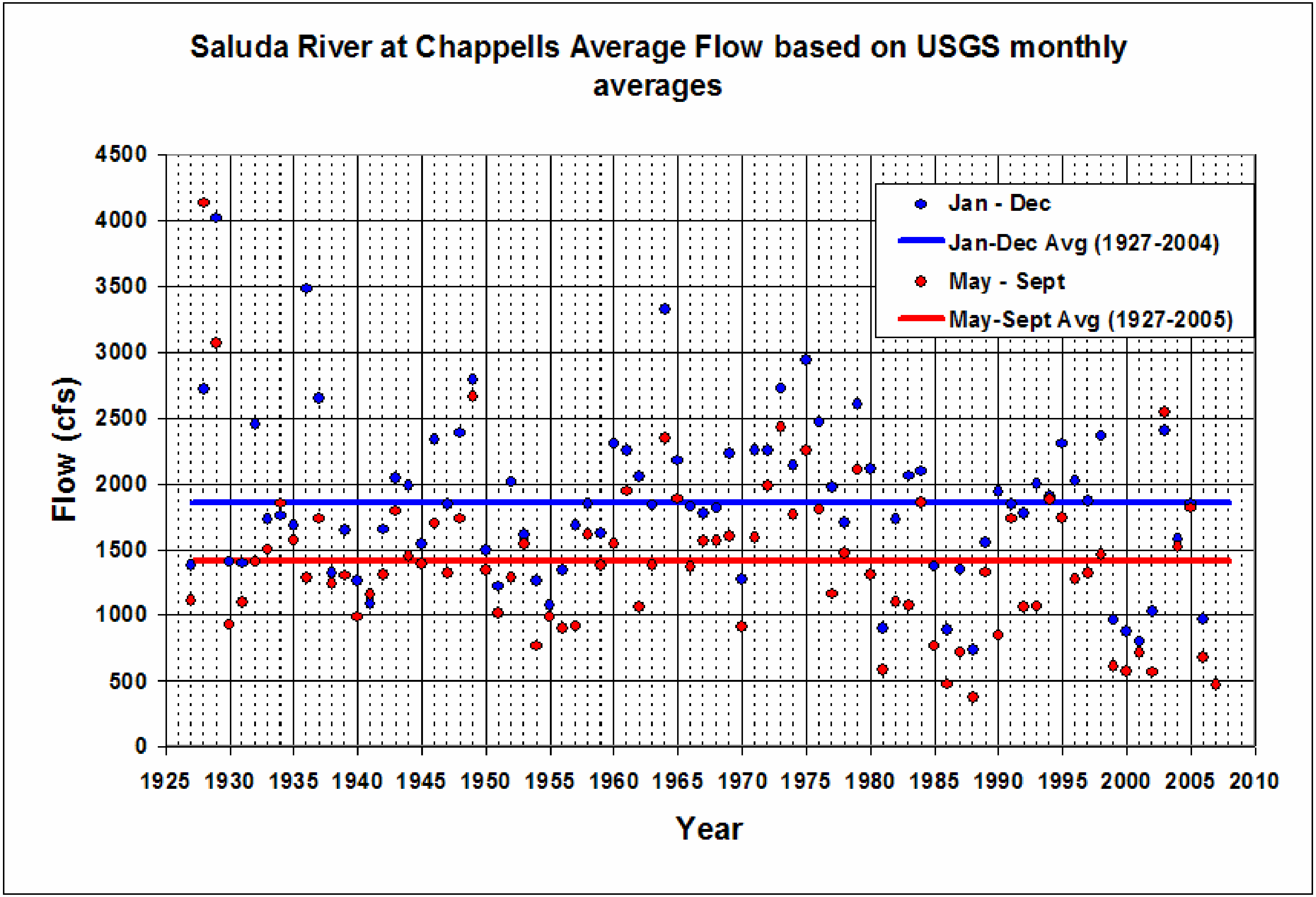

September 1, 2001

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

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.