Preliminary Application of DMSTA to the C-44 Water Management Project

prepared for

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By

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May 21, 2004

The Dynamic Model for Stormwater Treatment Areas (DMSTA) simulates the hydrology and phosphorus dynamics of treatment wetlands (http://www.wwwalker.net/dmsta). Its basic function is to predict treatment efficiency, as measured by outflow concentration and load reduction for a given inflow time series and design. DMSTA has been used extensively to design treatment areas for restoration and protection of the Everglades (http://www.sfwmd.gov/org/erd/bsfboard/bsfsboard.htm). The model has been calibrated and tested against data from approximately 70 systems containing a variety of vegetation types and ranging in scale from experimental tanks to full-scale treatment areas. It has also been tested against limited data from lakes and treatment areas north of Lake Okeechobee (http://www.wwwalker.net/dmsta/ws).

This report describes preliminary applications of DMSTA to the C-44 reservoir/STA project (CDM, "Water Resources Analysis for the C-44 Water Management Project", prepared for Aquacalma, April 2004) (Figure 1). The objective is to predict phosphorus removal in the reservoir and STA components, given simulated flow and depth time series provided by CDM for a typical project design scenario. Two basic purposes of the project are to provide dynamic flood storage and phosphorus removal for local runoff and regulatory releases from Lake Okeechobee. Given the variety of inflow scenarios, design scenarios, and specific treatment objectives, the intent of the present analysis is not to predict the likelihood of meeting specific design targets, but to develop and demonstrate a framework that can be used in the conceptual design phase of the project.

While the reservoir is expected to be sparsely vegetated because of its depth regimes, some phosphorus removal is expected to occur via direct sedimentation and uptake by phytoplankton (suspended algae). The DMSTA reservoir submodel was developed using phosphorus budget data from reservoirs, natural lakes, and stormwater detention areas located throughout the USA (http://www.wwwalker.net/pdf/dbasins.pdf), but has been subject to limited calibration and testing in Florida or in systems with highly variable depth regimes, as expected in the C44 reservoir. Because of its relatively shallow and steady depth regimes, the STA component is expected to be dominated by rooted emergent vegetation, such as cattails, unless otherwise intensively managed to foster other vegetation types. DMSTA has received extensive calibration and testing under these conditions. Phosphorus removal per unit area and concentration is expected to be significantly higher in the STA, as compared with the reservoir component.

While the model is well-equipped to simulate the STA component of the project, its ability to simulate the reservoir and other specific features of the project is more limited. In a separate project for the Corps of Engineers, DMSTA is currently being refined to address limitations typically encountered in CERP applications, particularly those involving reservoirs. In order to perform this preliminary analysis using the existing model, certain accommodations must be made. These generally involve separate computations, simplifying assumptions, and minor temporary patches to the program code. With future refinements to DMSTA, as well as to the design and hydraulic simulations of the facility, improved performance forecasts will be possible under the conceptual design phase of this study.

Specific adjustments and simplifying assumptions made in this preliminary analysis include:

1. Although the current STA design includes two primary sections (East and West) and approximately 20 individual treatment cells, the project is modeled as two treatment cells in series consisting of the reservoir (7,656 acres) and single STA (3,388 acres). This assumption is justified based upon the uniform hydraulic loading to the STA sections, as represented in the hydraulic simulations provided.

2. The reservoir is assumed to be completely mixed by wind currents for the purpose of predicting the average outflow concentration to the STA. It is not possible or necessary in this context to simulate specific mixing patterns and spatial concentration gradients within the reservoir driven by wind, the two inlet locations (C23 and C44), and morphometry.

3. The STA is modeled as two tanks-in-series to represent some degree of plug flow hydraulics.

4. Daily reservoir depths are derived directly from CDM hydrologic simulations. DMSTA is not currently configured to simulate the reservoir outlet operating rules embodied in this design scenario. A temporary patch to the DMSTA code has been implemented to enable this computation. Outflow rates from the reservoir and STA are predicted based upon water balance and closely track those predicted by CDM's hydraulic model (Figure 2).

5. Average net seepage losses are adjusted to match average rates predicted by CDM's model. Seepage accounts for 0.8% and 0.2% of the reservoir and STA water budgets, respectively.

6. Phosphorus removal in the reservoir is simulated using the existing DMSTA algorithm (http://www.wwwalker.net/dmsta/doc/theory/reserv.htm) and second-

order removal rate coefficient of 0.04 m^3/mg-yr. An empirical model derived from Corps of Engineer reservoir data predicts a range of 0.02 to 0.08 m^3/mg-yr based upon the mean surface water load (11 m/yr) and inflow SRP/Total P ratio (~0.54) for the C44 reservoir. A range of 0.02 to 0.10 m^3/mg-yr is indicated in data from Florida lakes and reservoirs north of Lake Okeechobee being compiled to support DMSTA refinements. This dataset includes nearby Lake Istokpoga (K_2 = 0.045 m^3/mg-yr. This portion of the model has received limited testing in systems with highly fluctuating water levels. Because of the uncertainty associated with this parameter, a sensitivity analysis is performed for a range of 0.02 to 0.08 m^3/mg-yr.

7. Phosphorus uptake in the STA is predicted using the DMSTA default calibration for emergent vegetation.

8. DMSTA is currently coded to permit one outlet per treatment cell, i.e. each cell discharges either out of the system or to another cell. The C44 reservoir discharges in two directions: to the STA and back to the C44 via the perimeter canal. In order to simulate this configuration, it is assumed that the concentration in backflow equals the concentration of the pumped inflow. This essentially drives the reservoir based upon the difference between the pumped inflow and backflow on any day. Because actual backflow concentrations would be expected to be lower than the inflow concentrations, this assumption results in a conservative estimate of phosphorus removal in the reservoir. The effect is small, however, because backflow accounts for only 5% of the pumped inflow and the increase in reservoir hydraulic residence time resulting from this assumption would partially compensate for the over-estimation of backflow concentration.

9. Because outflows from the reservoir and STA back into the C44 canal via the perimeter canal occur in close proximity to the reservoir pump intake, there is potential for these outflows to be drawn into the intake, particularly during periods when external inflows to the C44 canal are low. This would tend to reduce the inflow concentration to the project, as compared with a more typical scenario with the project outflows isolated from the intake. A dynamic flow and phosphorus budget of the canal in the vicinity of the project is formulated to simulate this phenomenon. Inputs to the canal segment include project outflows and net inflows to the C44 (after deduction of irrigation demand and discharge to Lake Okeechobee). The canal segment is assumed to be completely mixed. Refinements to the canal phosphorus and water budget modeling are needed to support future development of a conceptual design.

10. Average inflow concentrations are based upon concentration and flow data downloaded from SFWMD's DBHYDRO database (Appendix). Computed flow-weighted mean concentrations and values assumed in the simulations are listed in Table 1. Given the large discrepancy between the observed flow-weighted mean concentration at C23S48 (448 ppb) and that specified by SFWMD for the C23 diversion (216 ppb), simulations are performed using each of these values.

The simulations use a 1982-2002 daily hydrologic time series generated by CDM using the STELLA model (case = 'C23 STA 673 NoRecirc'). Results using a central estimate for the reservoir P removal rate parameter (K_2 = 0.04 m^3/mg-yr) are summarized in the following figures:

Figure 2 - Weekly Mean Flows & Depths (C23 STA 673 NoRecirc)
Figure 3 - Project Flows & Concentrations (TP = 216 ppb)
Figure 4 - Phosphorus Fluxes (C23 TP = 216 ppb)
Figure 5 - Project Flows & Concentrations (C23 TP = 448 ppb)
Figure 6 - Phosphorus Fluxes (C23 TP = 216 ppb)

Although the STELLA model run is labeled 'NoRecirc', recycle from the STA discharge to the reservoir pump is predicted to occur when the external inflows are low, as driven by the canal water budget and as reflected in the difference between the C44 external inflow concentration and pump inflow concentration (Figures 3 & 5). Even during high runoff periods, any inflows to the C-44 would have to mix with one of the STA discharge (east or west) before reaching the reservoir intake pump.

The sensitivity of the project net phosphorus load reduction (reservoir inflow – reservoir backflow – STA outflow) to assumed values for K_2 and C23 TP concentration is as follows:

TP Reduction (mt/yr)	C23 TP (ppb)	
K_2 (m^3/mg-yr)	216	448
0.02	21.9	33.1
0.04	23.8	35.8
0.08	25.8	38.6

The predicted reductions range from 22 to 39 mt/yr. Different assumptions regarding the TP concentration of the C23 inflows have the largest effect on the results.

For K_2 = .04 mg/m^3-yr and C23 TP = 216 ppb, the net load reduction is 23.8 mt/yr. Net retention rates are 12.7 mt/yr in the reservoir and 12.2 mt/yr in the STA, for a total of 24.9 mt/yr (Figure 4). The difference between the net reduction (inflows-outflows = 23.8 mt/yr) and net retention (storage in bottom sediments = 24.9 mt/yr) is attributed to the atmospheric and seepage components of the phosphorus budgets. Although the reservoir removes slightly more phosphorus, its removal per unit area and concentration is much lower, as compared with the STA (4.3 m/yr vs. 14 m/yr, respectively).

Simulations have been repeated for the 'C23 STA673 Recirc' scenario in which the project is operated with higher pumping rates (inducing additional recirculation from the project outflows to the inflows) and higher reservoir levels (reducing flood storage). Results are shown in Figures 7-9 for C23 TP = 216 ppb and K_2 = 0.04 m^3/mg-yr.

As shown in Figure 8, flows pumped into the project from the C44 frequently exceed the external inflows to the canal. The resulting additional recirculation reduces the flow-weighted-mean reservoir inflow concentration from 114 to 74 ppb, relative to the previous scenario. The flow-weighted-mean STA outflow concentration is reduced from

61 to 48 ppb. As a consequence, high recirculation rates provide no benefit in terms of net load reduction (23.7 vs. 23.8 mt/yr), despite the higher flow rates. These results are subject to limitations of the canal phosphorus budget algorithm, which requires refinement, as discussed above.

Neither of the above scenarios can be considered optimal with respect to treatment or flood storage objectives. Design variables expected to influence treatment efficiency include ratio of reservoir to STA area, pumping schedules, reservoir operating rules (stage/discharge relationship), and depth regimes. The optimal design would also depend critically on the flows to be processed (runoff only vs. runoff + Lake regulatory releases), which, in turn, would depend upon the extent to which regulatory releases are reduced in the future through implementation of other CERP projects. With refinements to the canal and phosphorus budget calculations, the modeling framework demonstrated here can be used to explore design alternatives in the next phase of this study. Planned refinements to DMSTA's structure and reservoir calibrations will also be useful in the next phase.

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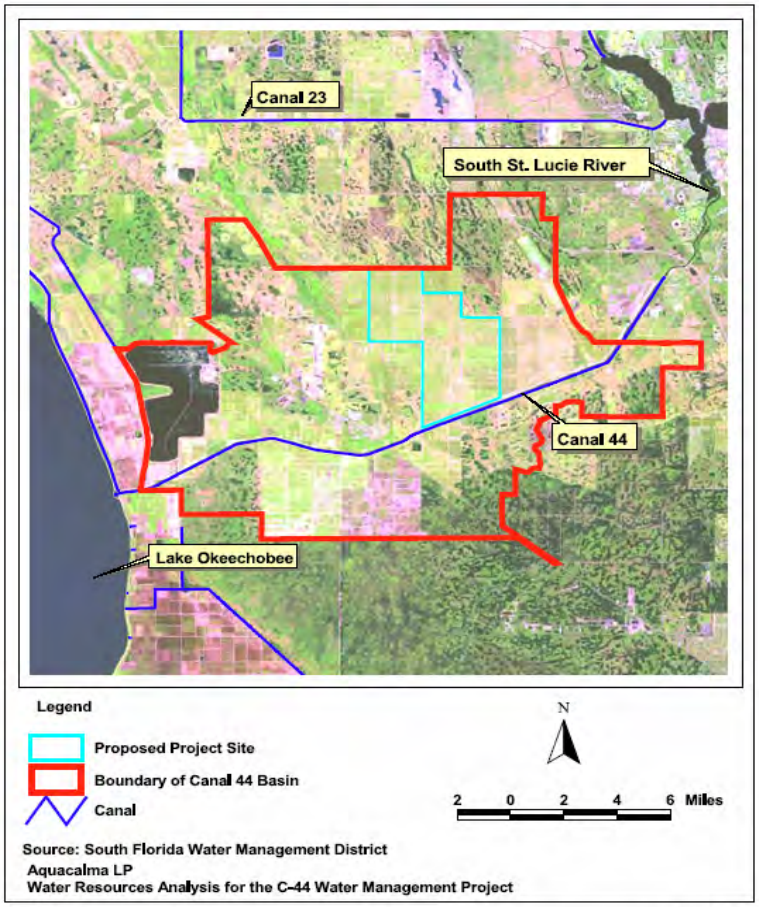
Phosphorus Concentration & Flow Data

Load computations performed using algorithm described in Walker & Havens, "Development and Application of a Phosphorus Balance Model for Lake Istokpoga, Florida", Lake & Reservoir Management, Vol. 19, No. 1, pp. 79-91, 2003.
http://www.wwwalker.net/pdf/istokpoga_2003.pdf

Table 1 Inflow Phosphorus Data

Description	Flow-Wtd TP (ppb)	Conc Site	Flow Site	Flow Sign
Data Summary				
C44- S308C from Lake	165	S308	S308	positive
C44 S308C to Lake	190	S308	S308	negative
S153	244	S153	S153	positive
C24 S80 - S308C (Net)	177	C44S80	S80-S308C	positive difference
C44 - S80 Gross	164	C44S80	S80	positive
C23 - S48	448	C23S48	S48	positive
C23 - S97	460	C23S97	S48	positive
Used in Simulations				
C44- Runoff + Baseflow	188	constant, from S80 Net & S308C to Lake		
S308C from Lake	165	daily time series, interpolated from S308C data		
S153	244	constant, from S153 data		
C23 (high)	448	constant, observed flow-wtd mean C23S48		
C23 (low)	216	constant, from SFWMD		
Irrigation Return	variable	computed from canal P budget		
S308 to Lake	variable	computed from canal P budget		
S80 Outflow	variable	computed from canal P budget		

Figure 1 Project Maps (CDM, 2004)



CDM

Figure 1-2
Project Location within the C-44 Basin

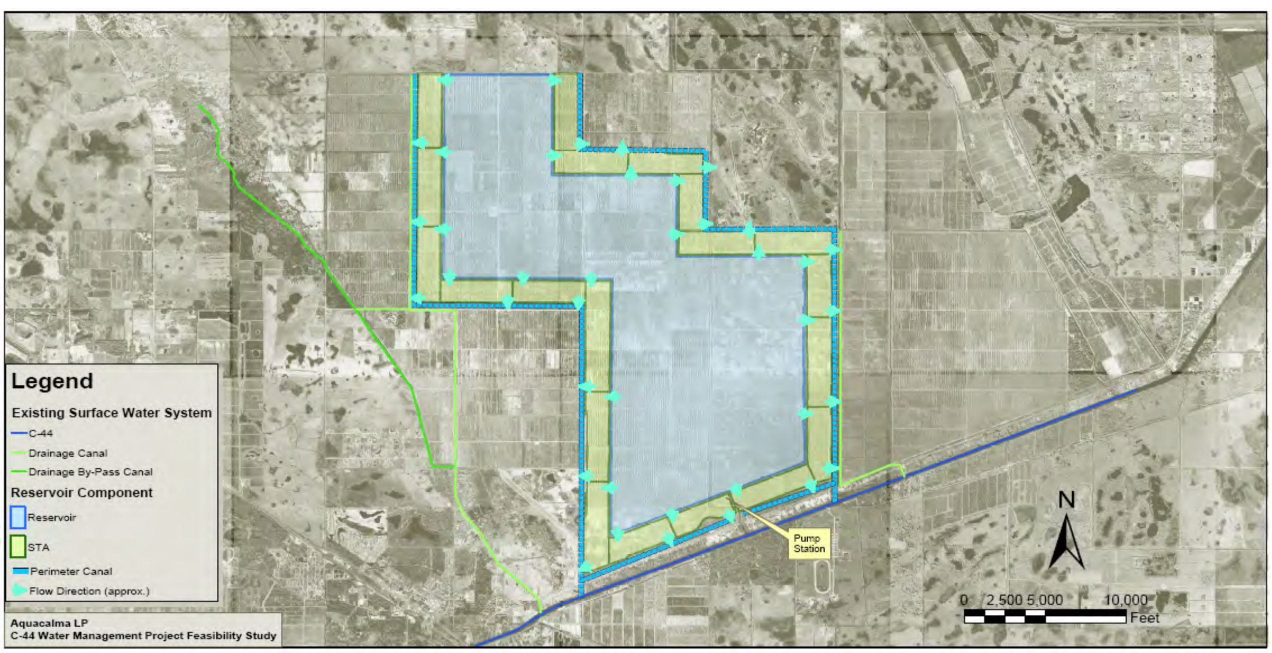


Figure 2 Weekly Mean Flows & Depths

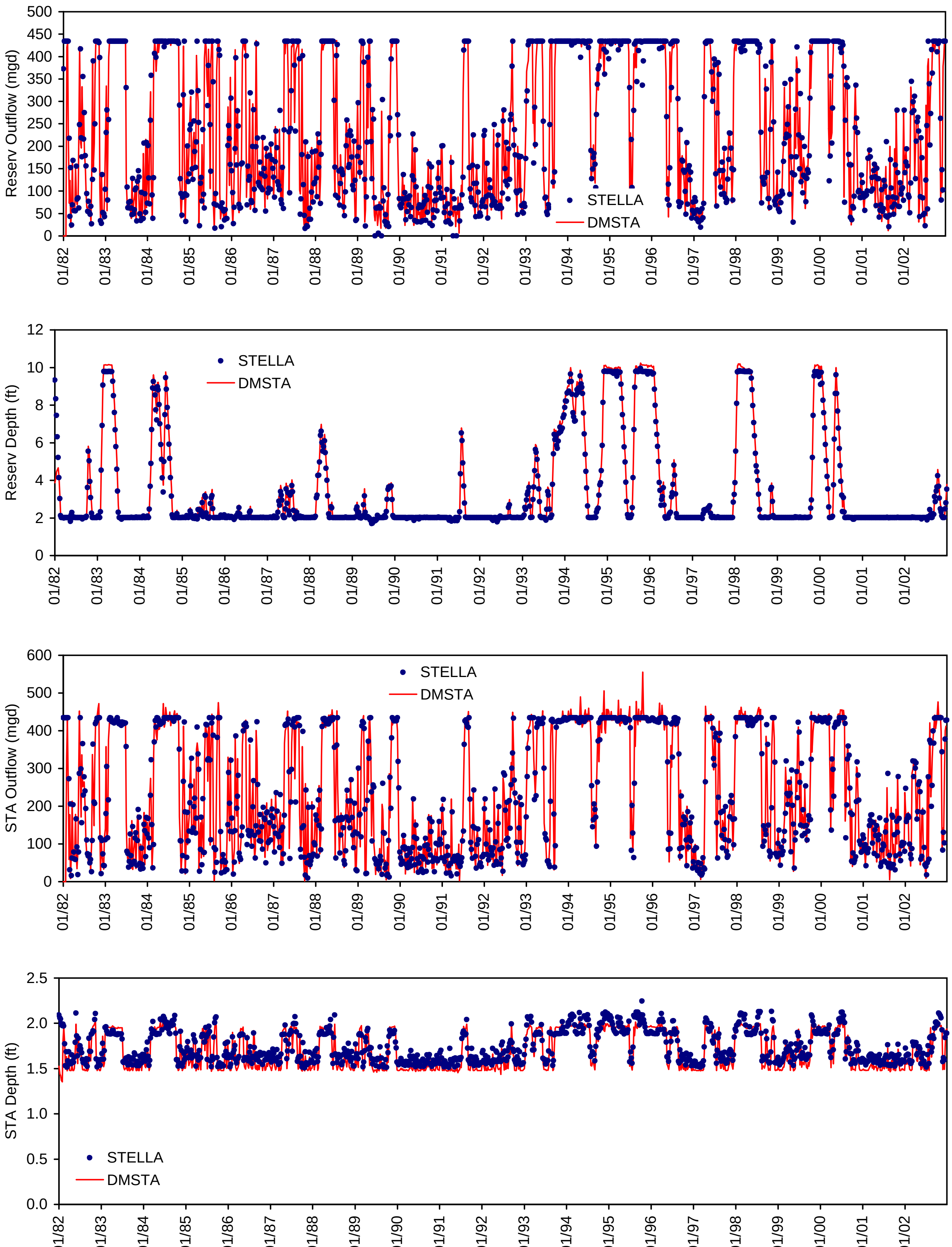
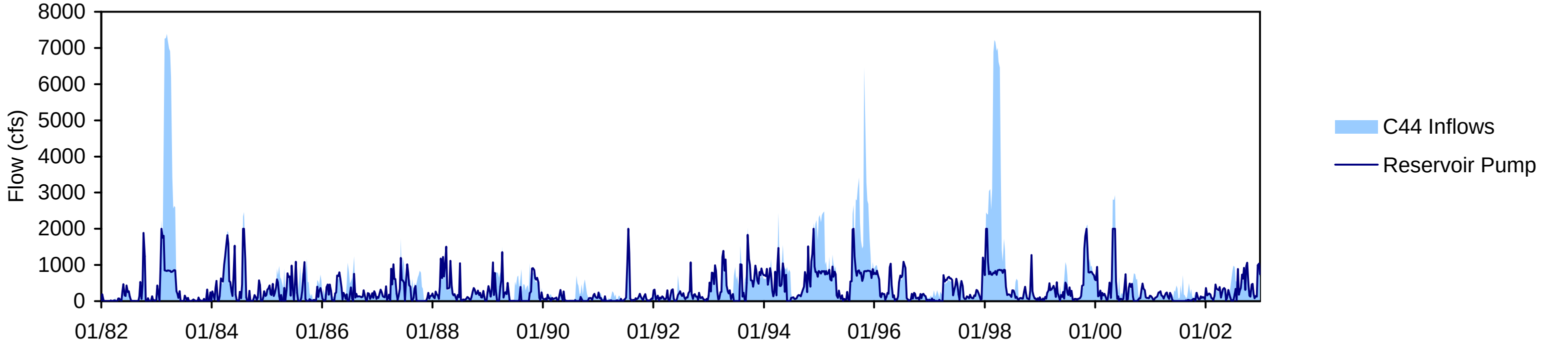
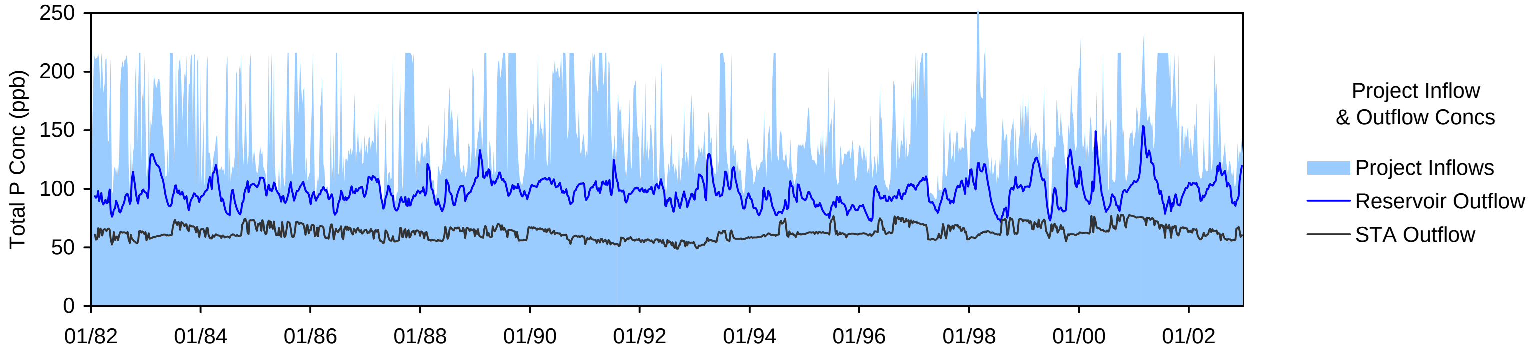


Figure 3 **Project Concentrations & Flows** Case: C23 STA 673 NoRecirc





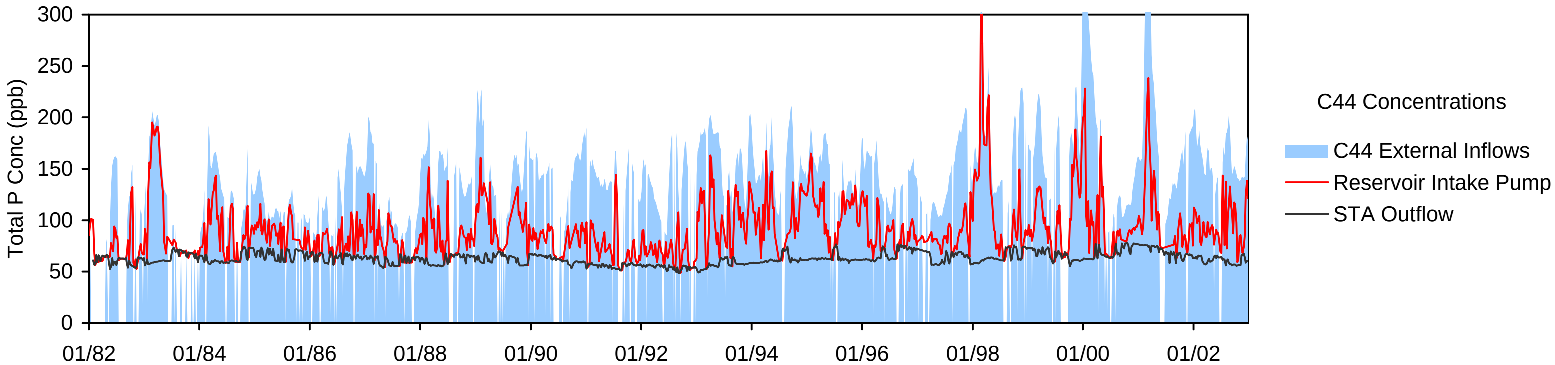
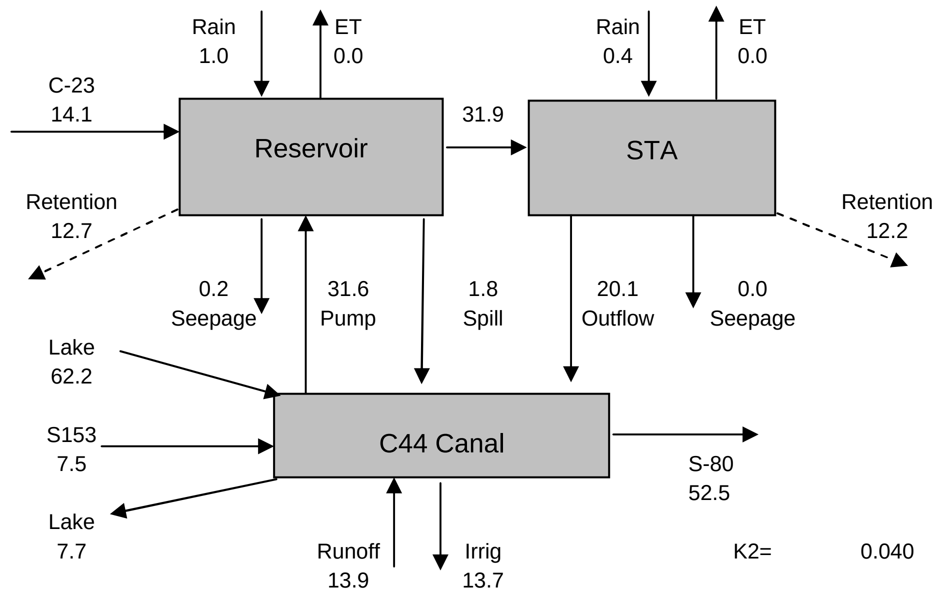


Figure 4 Phosphorus Fluxes (mt/yr) C23 STA 673 NoRecirc

C23 TP= 216 ppb



Period of Record: 1/1/1982 thru 12/31/2002

Term	Description	Flow kac-ft/yr	P Load mtons/yr	P Conc ppb
1	Lake Release via S308	298.2	62.2	169
2	Runoff to C44 via S153	24.9	7.5	244
3	Runoff to Lake via S308	52.5	7.7	119
4	C44 Basin Runoff + Base Flow	59.7	13.9	188
5	C44 Agricultural Withdrawals	75.7	13.7	147
6	Total External Inflows to C44	382.8	83.6	177
7	Reservoir Pump Intake	223.5	31.6	114
8	Reservoir Spill to C44	10.2	1.8	145
9	Seepage Loss from Reservoir	1.9	0.2	98
10	Phosphorus Retention in Reservoir		12.7	
11	C23 Basin Inflow	52.9	14.1	216
12	Precipitation on Reservoir	31.9	1.0	26
13	Evaporation from Reservoir	30.1		
14	Reservoir Outflow to STA	266.0	31.9	97
15	Precipitation on STA	14.1	0.4	26
16	Evaporation from STA	13.3		
17	Phosphorus Retention in STA		12.2	
18	Seepage Loss from STA	0.4	0.0	71
19	STA Discharge to C44	266.4	20.1	61
20	C44 Outflow at S-80	307.8	52.5	138
Sum	C44 Total Inputs	659.4	105.5	130
Sum	C44 Total Outputs	659.4	105.5	130
Sum	Project Surface Inflows	276.3	45.7	134
Sum	Project Surface Outflows	276.6	21.9	64
Net	Net Reduction in Project	-0.3	23.8	70

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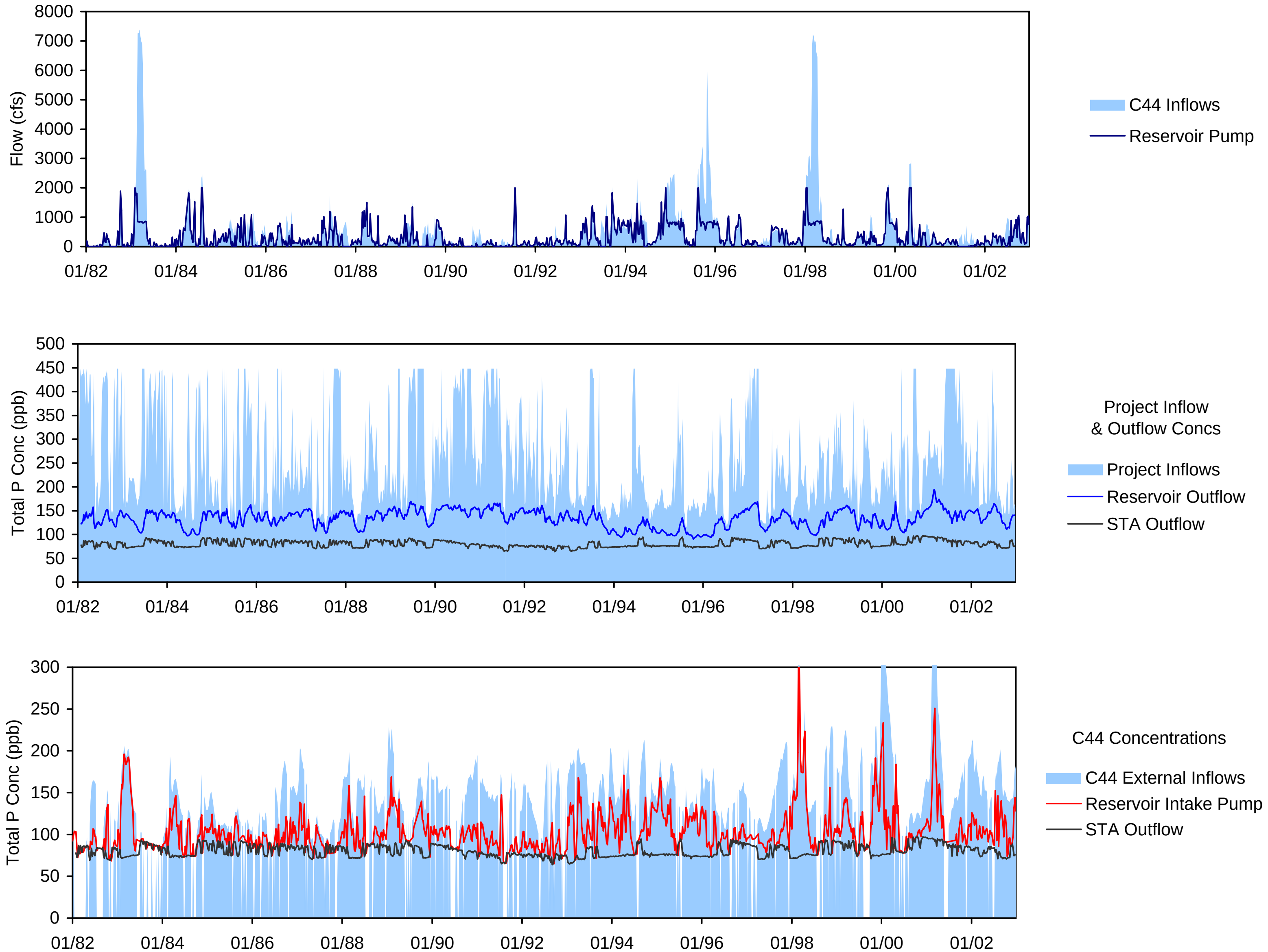
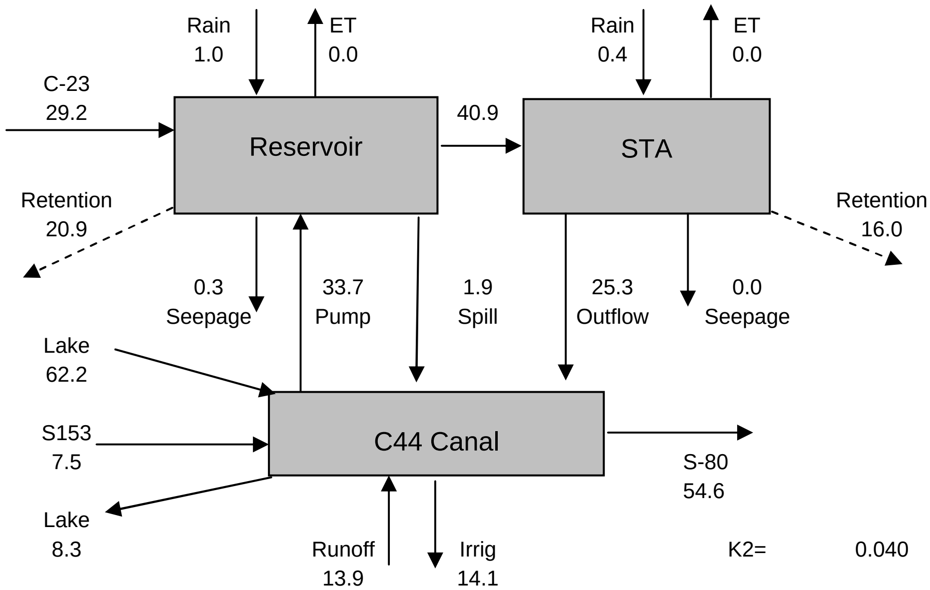
Figure 5 **Project Concentrations & Flows** Case: C23 STA 673 NoRecirc



Weekly Means C23 STA 673 NoRecirc C23 Inflow P = 448 ppb 5/21/2004

Figure 6 Phosphorus Fluxes (mt/yr) C23 STA 673 NoRecirc

C23 TP= 448 ppb



Period of Record: 1/1/1982 thru 12/31/2002

Term	Description	Flow kac-ft/yr	P Load mtons/yr	P Conc ppb
1	Lake Release via S308	298.2	62.2	169
2	Runoff to C44 via S153	24.9	7.5	244
3	Runoff to Lake via S308	52.5	8.3	128
4	C44 Basin Runoff + Base Flow	59.7	13.9	188
5	C44 Agricultural Withdrawals	75.7	14.1	151
6	Total External Inflows to C44	382.8	83.6	177
7	Reservoir Pump Intake	223.5	33.7	122
8	Reservoir Spill to C44	10.2	1.9	148
9	Seepage Loss from Reservoir	1.9	0.3	129
10	Phosphorus Retention in Reservoir		20.9	
11	C23 Basin Inflow	52.9	29.2	448
12	Precipitation on Reservoir	31.9	1.0	26
13	Evaporation from Reservoir	30.1		
14	Reservoir Outflow to STA	266.0	40.9	125
15	Precipitation on STA	14.1	0.4	26
16	Evaporation from STA	13.3		
17	Phosphorus Retention in STA		16.0	
18	Seepage Loss from STA	0.4	0.0	91
19	STA Discharge to C44	266.4	25.3	77
20	C44 Outflow at S-80	307.8	54.6	144
Sum	C44 Total Inputs	659.4	110.8	136
Sum	C44 Total Outputs	659.4	110.8	136
Sum	Project Surface Inflows	276.3	63.0	185
Sum	Project Surface Outflows	276.6	27.2	80
Net	Net Reduction in Project	-0.3	35.8	105

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Figure 7 **Weekly Mean Flows & Depths**

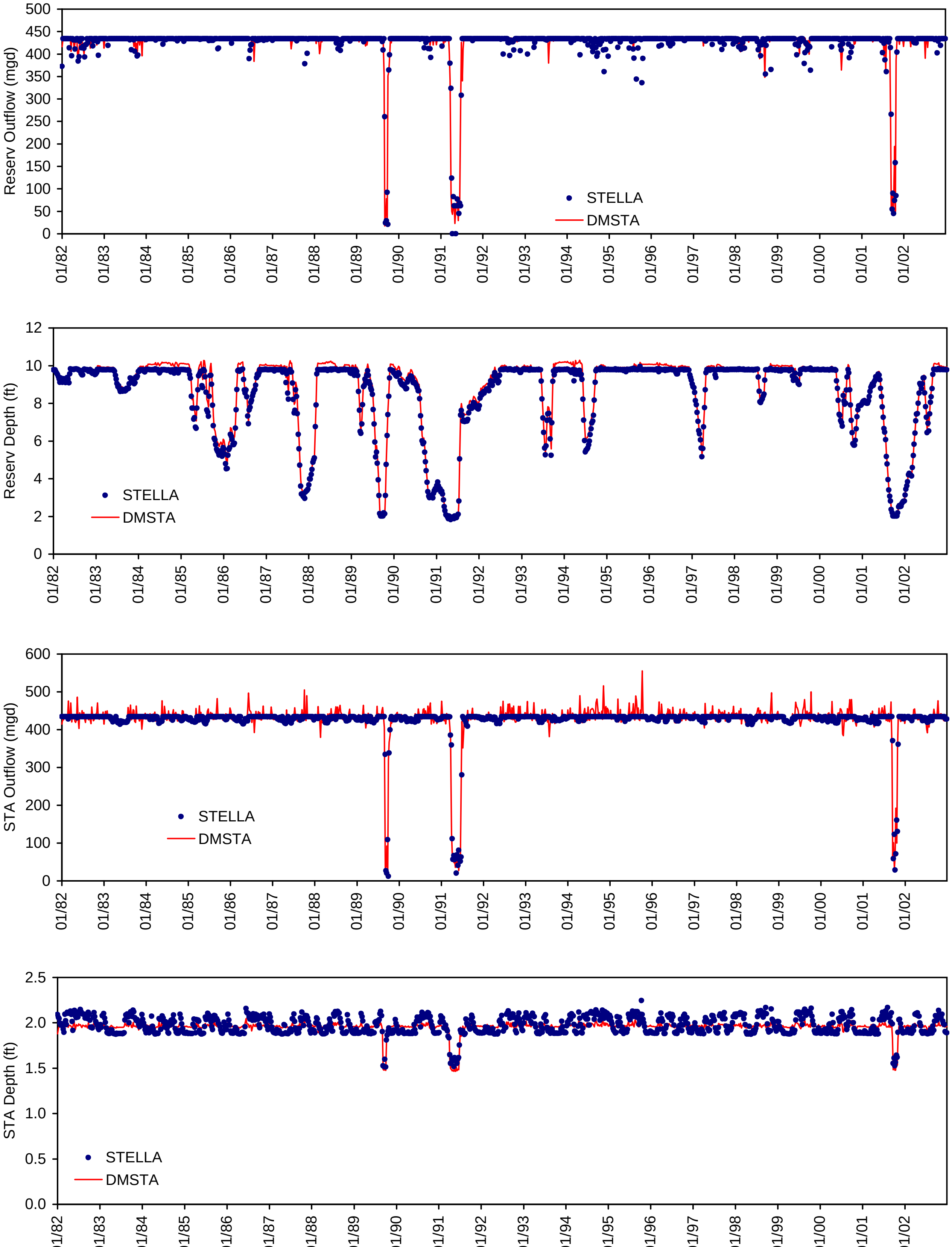
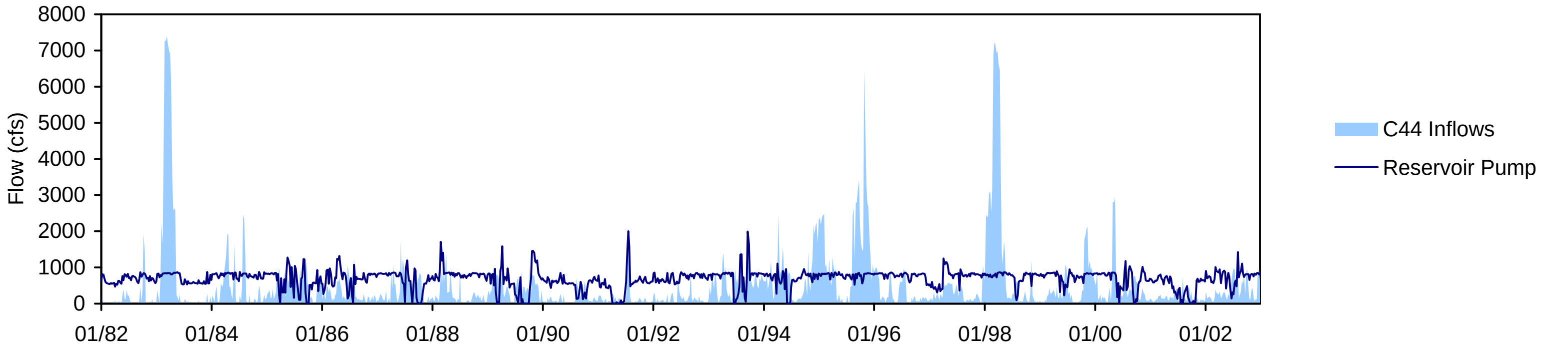
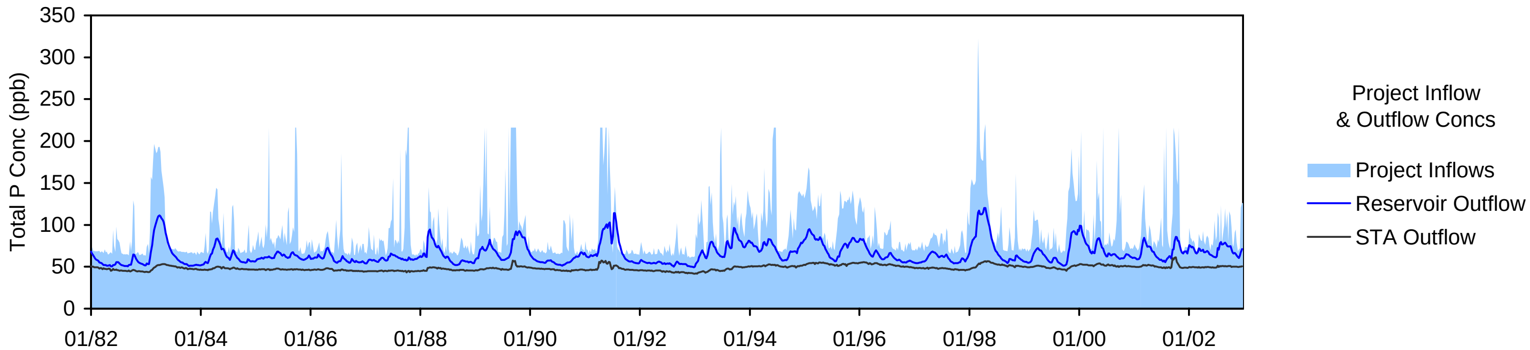


Figure 8 **Project Concentrations & Flows** Case: C23 STA 673 Recirc





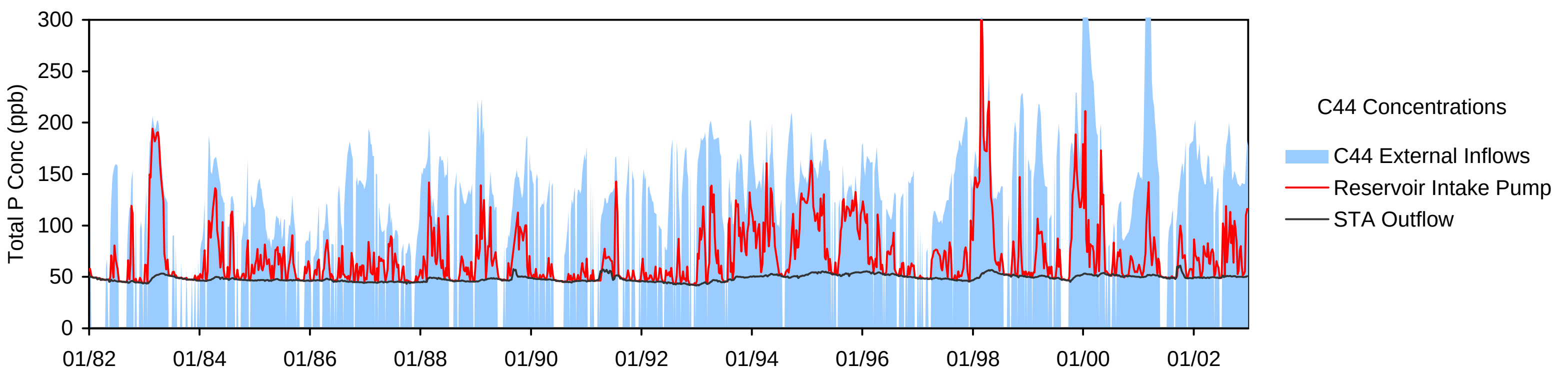
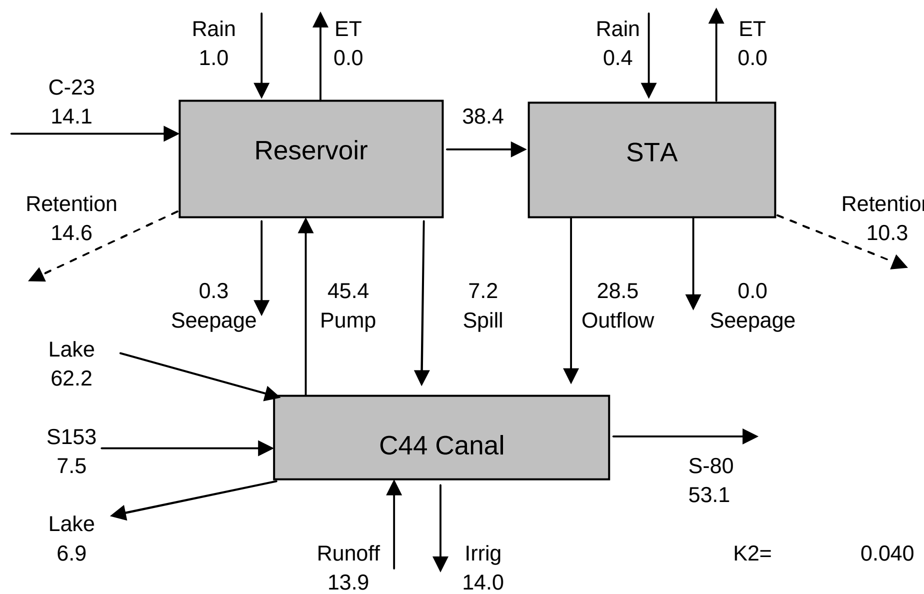


Figure 9 Phosphorus Fluxes (mt/yr) C23 STA 673 Recirc

C23 TP= 216 ppb



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Term	Description	Flow kac-ft/yr	P Load mtons/yr	P Conc ppb
1	Lake Release via S308	298.2	62.2	169
2	Runoff to C44 via S153	24.9	7.5	244
3	Runoff to Lake via S308	52.5	6.9	106
4	C44 Basin Runoff + Base Flow	59.7	13.9	188
5	C44 Agricultural Withdrawals	82.7	14.0	137
6	Total External Inflows to C44	382.8	83.6	177
7	Reservoir Pump Intake	497.8	45.4	74
8	Reservoir Spill to C44	72.4	7.2	81
9	Seepage Loss from Reservoir	3.3	0.3	66
10	Phosphorus Retention in Reservoir		14.6	
11	C23 Basin Inflow	52.9	14.1	216
12	Precipitation on Reservoir	31.9	1.0	26
13	Evaporation from Reservoir	30.1		
14	Reservoir Outflow to STA	476.7	38.4	65
15	Precipitation on STA	14.1	0.4	26
16	Evaporation from STA	13.3		
17	Phosphorus Retention in STA		10.3	
18	Seepage Loss from STA	0.4	0.0	52
19	STA Discharge to C44	477.0	28.5	48
20	C44 Outflow at S-80	299.3	53.1	144
Sum	C44 Total Inputs	932.3	119.3	104
Sum	C44 Total Outputs	932.3	119.3	104
Sum	Project Surface Inflows	550.6	59.5	88
Sum	Project Surface Outflows	549.5	35.8	53
Net	Net Reduction in Project	1.2	23.7	35

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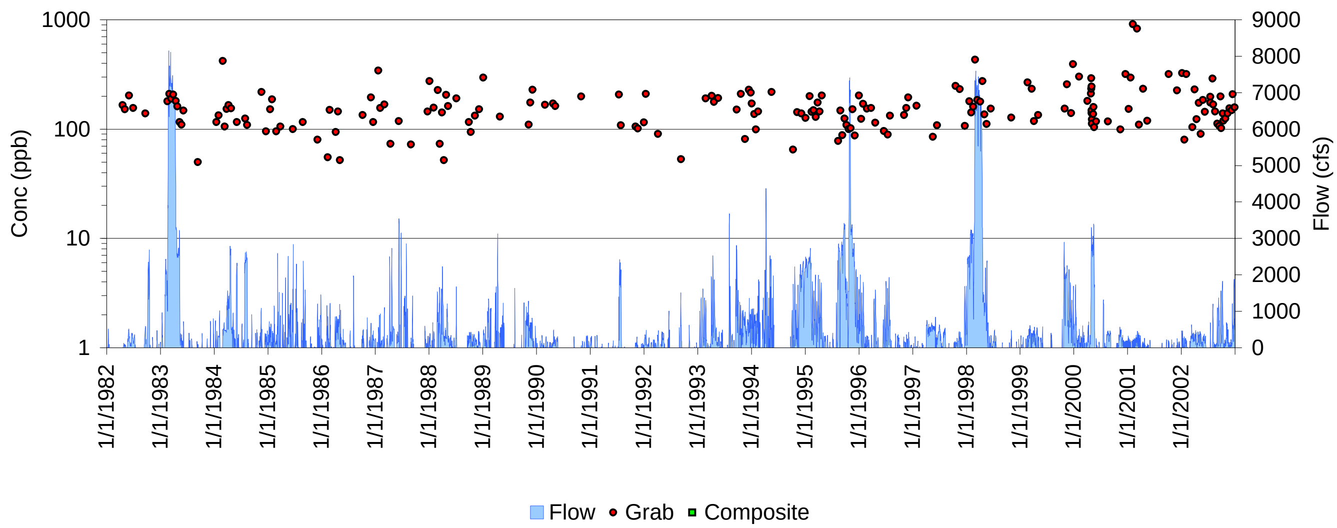
Appendix

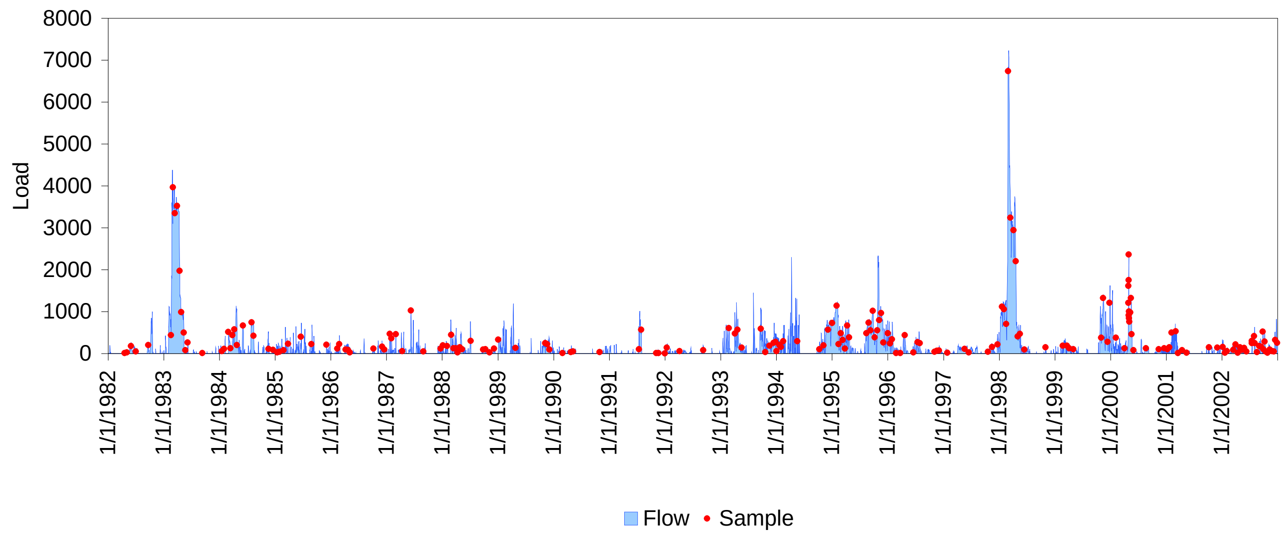
Phosphorus Concentration & Flow Data

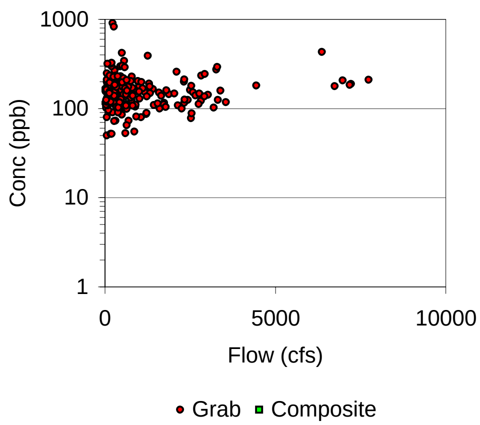
Load computations performed using algorithm described in Walker, W.W., & K. Havens, "Development and Application of a Phosphorus Balance Model for Lake Istokpoga, Florida", Lake & Reservoir Management, Vol. 19, No. 1, pp. 79-91, 2003.
http://www.wwwalker.net/pdf/istokpoga_2003.pdf

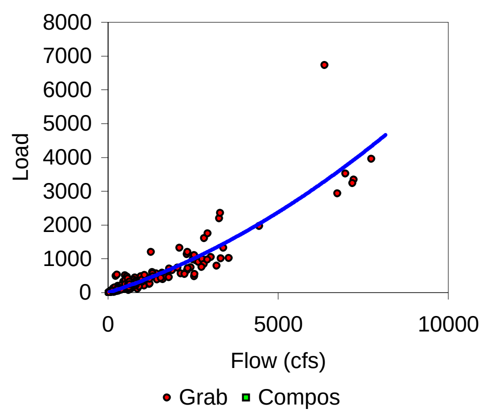
Daily Time Series

Site:	**C44S308C**	**Variable:**	**TP**	**Dates:**	**01/01/82**	**thru**	**12/31/02**
Mean Flow:	**410 cfs**	**Conc:**	**164.5 ppb**	**Load:**	**165.3**	**kg /day**	









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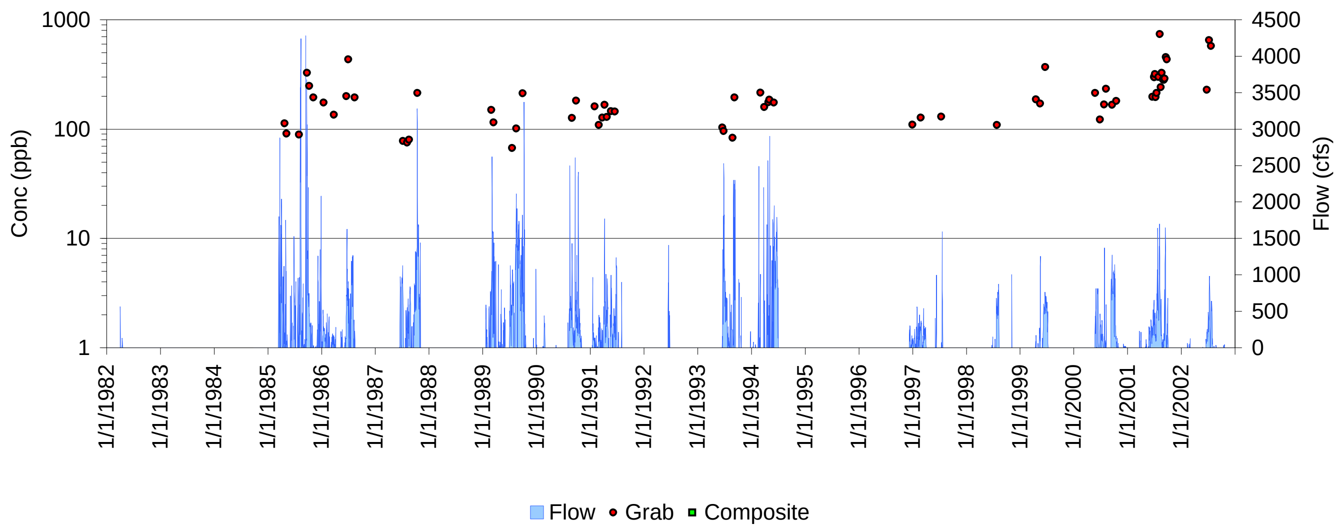
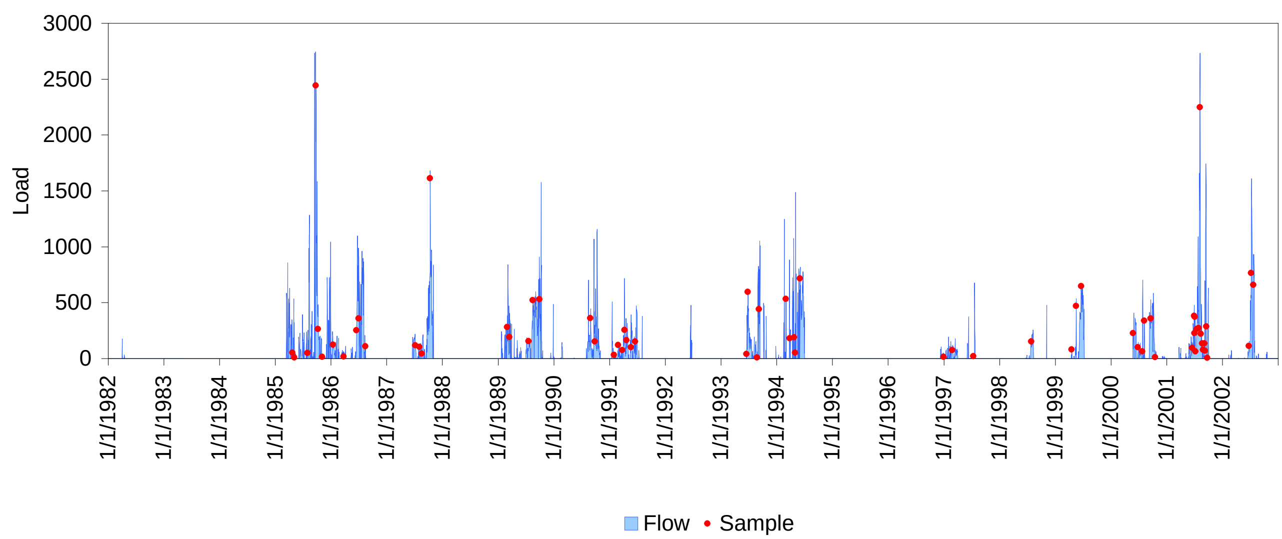
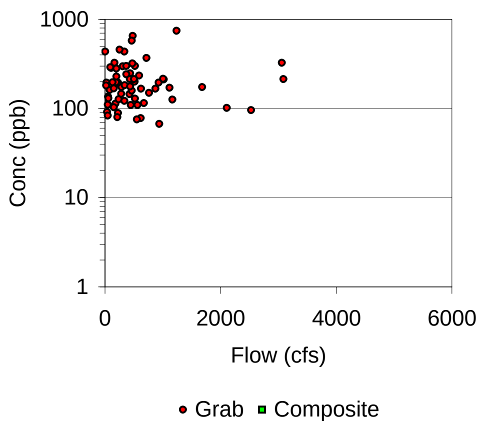
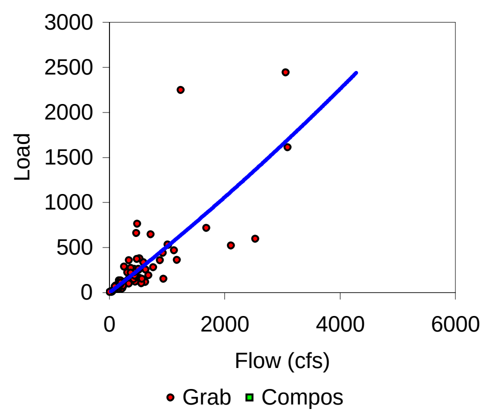
Daily Time Series

Site:	**S308_OUT**	**Variable:**	**TP**	**Dates:**	**01/01/82**	**thru**	**12/31/02**
Mean Flow:	**102 cfs**	**Conc:**	**190.2 ppb**	**Load:**	**47.5**	**kg /day**	



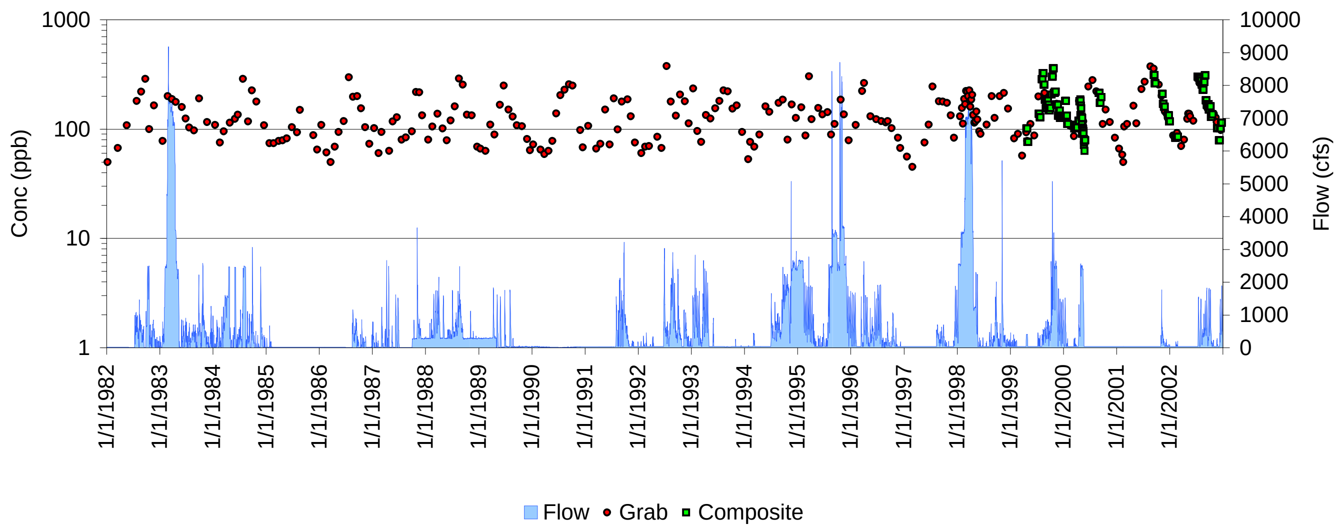


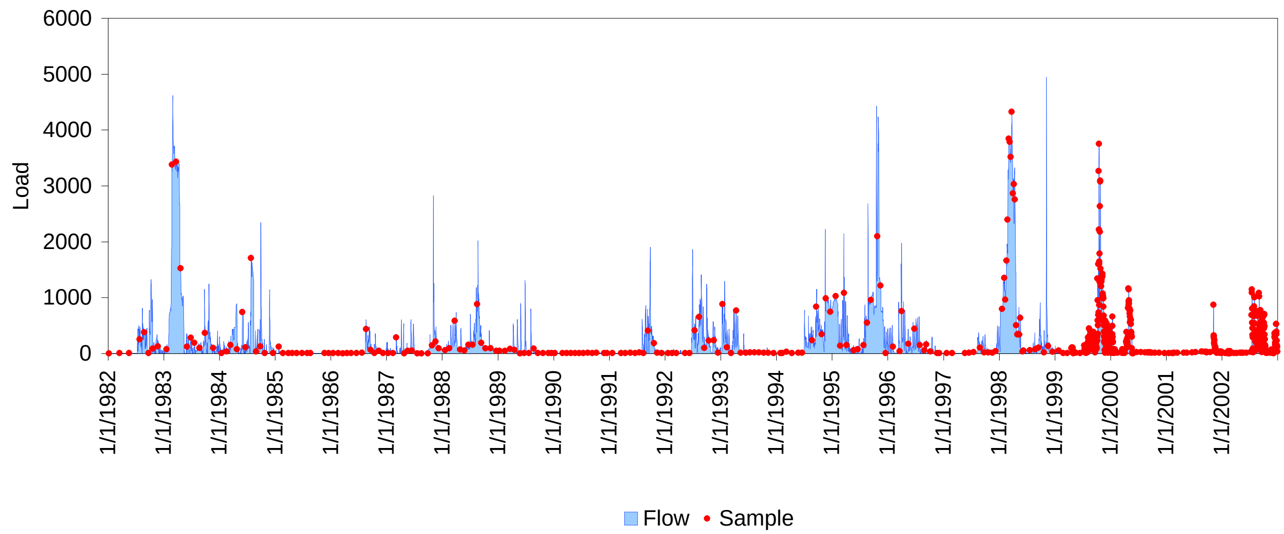


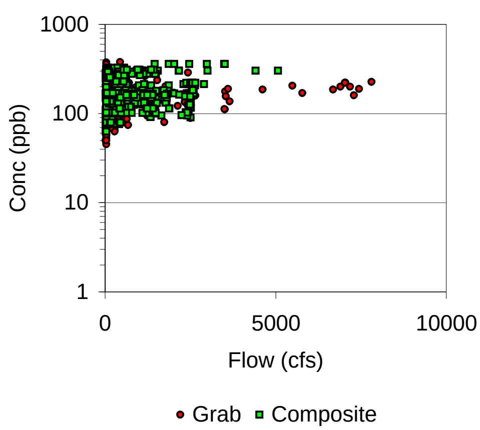


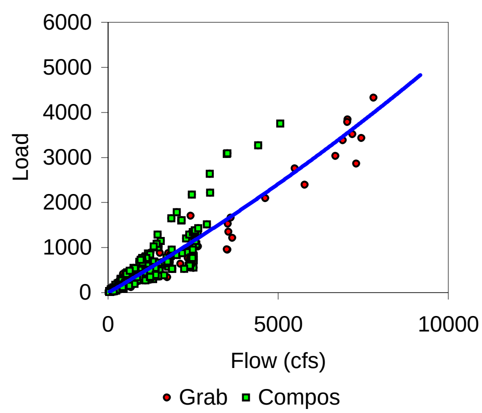
Daily Time Series

Site:	C44S80		Variable:	TP		Dates:	01/01/82	thru	12/31/02
Mean Flow:	493	cfs	Conc:	163.6	ppb	Load:	197.7		kg /day





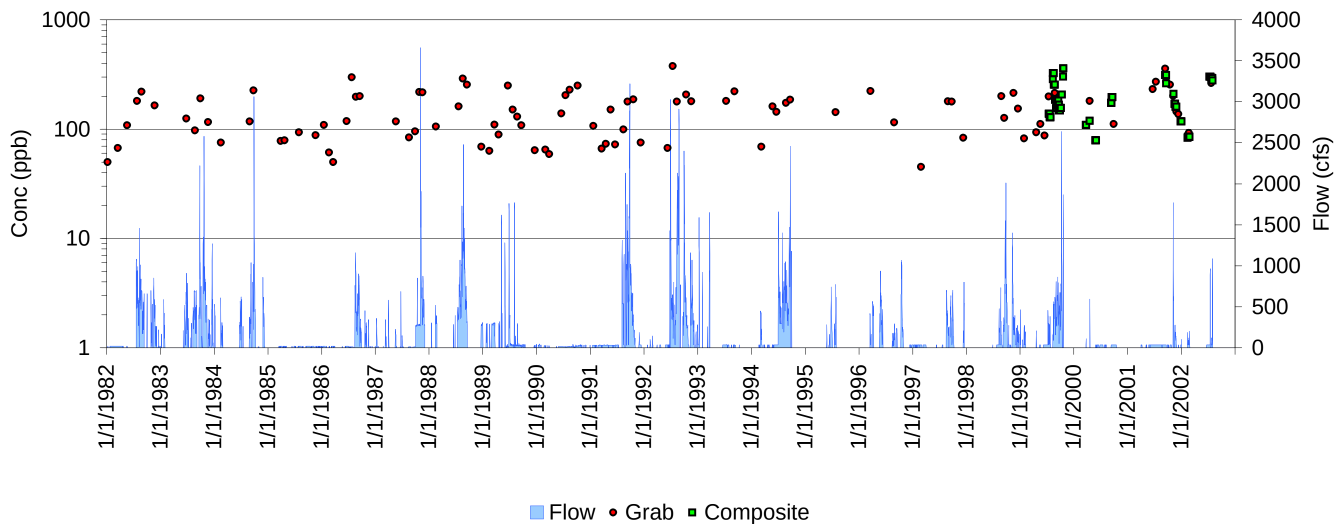


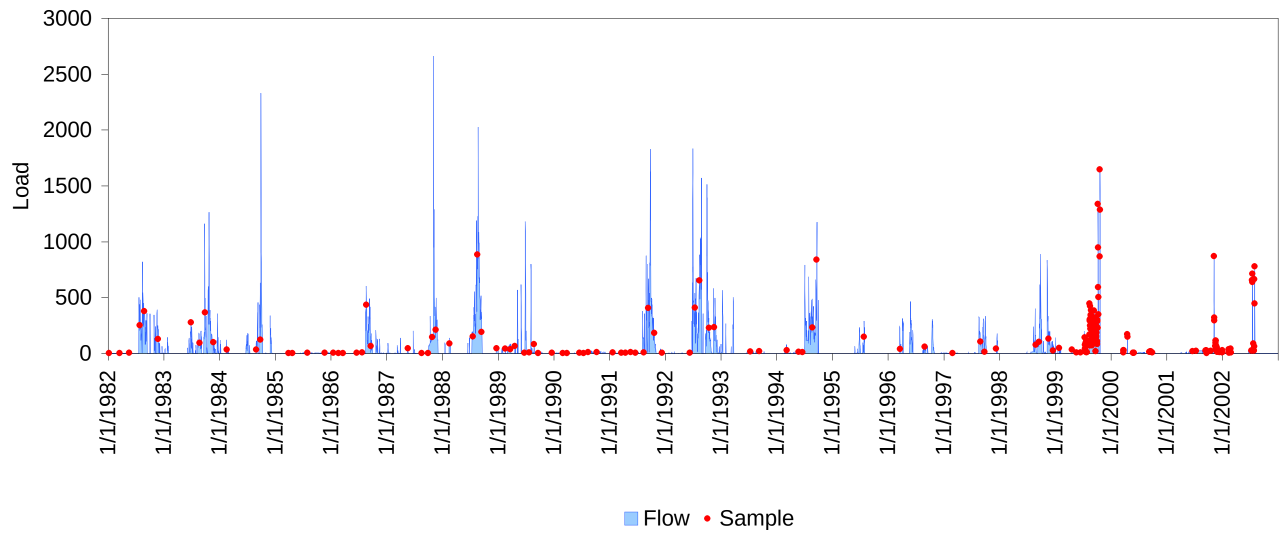


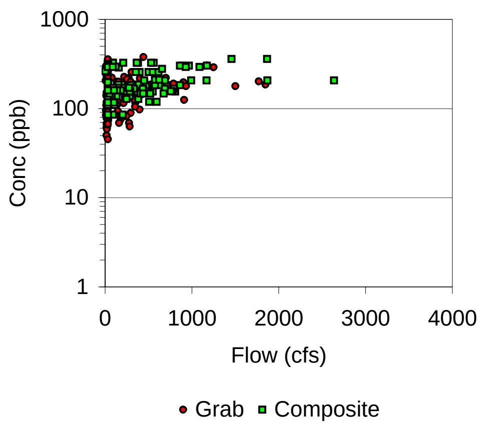
5/19/2004

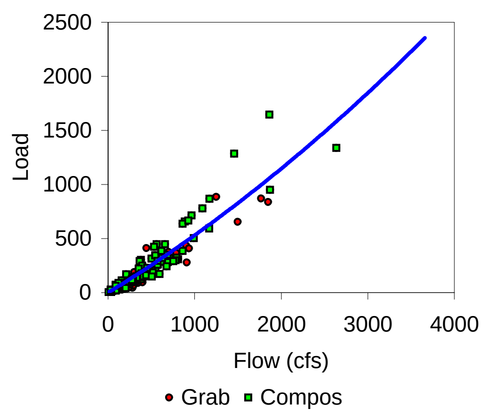
Daily Time Series

Site:	S80_NETB		Variable:	TP	Dates:	01/01/82	thru	12/31/02
Mean Flow:	95	cfs	Conc:	184.8	ppb	Load:	43.0	kg /day





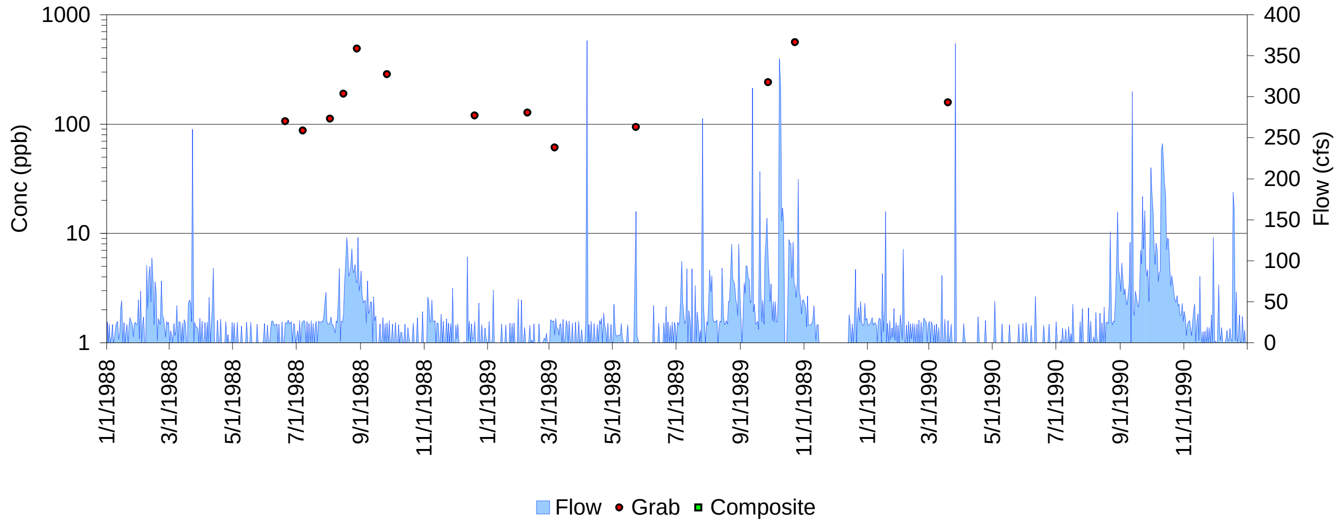


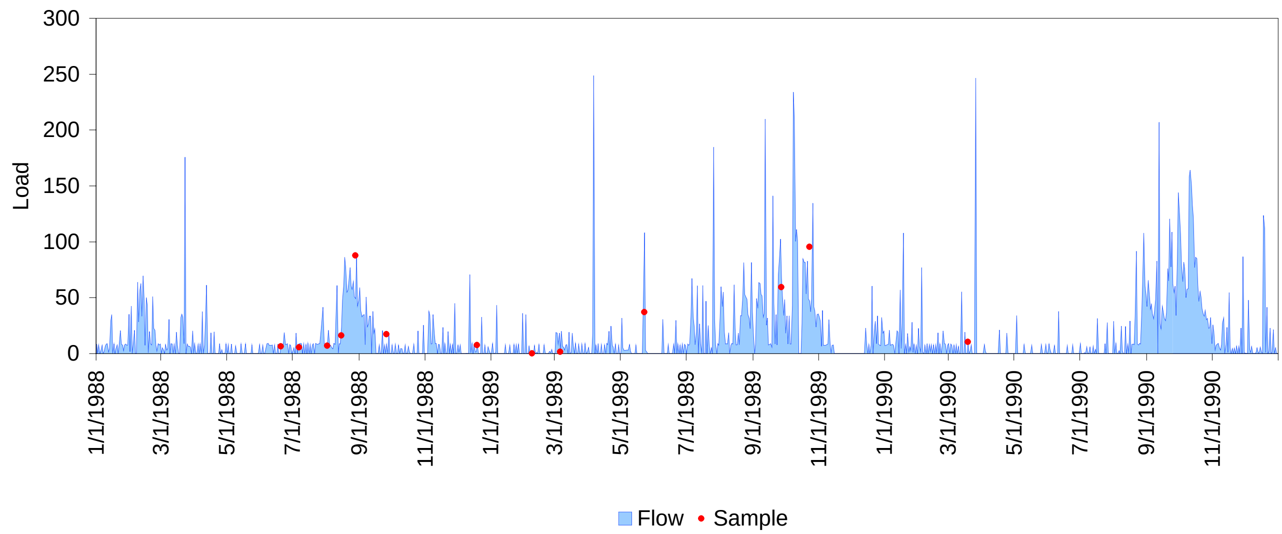


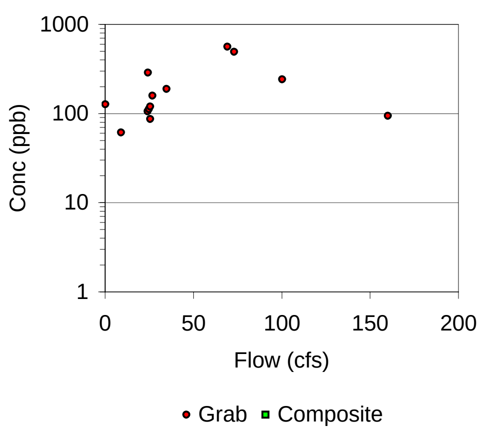
D R A F T 5/19/2004

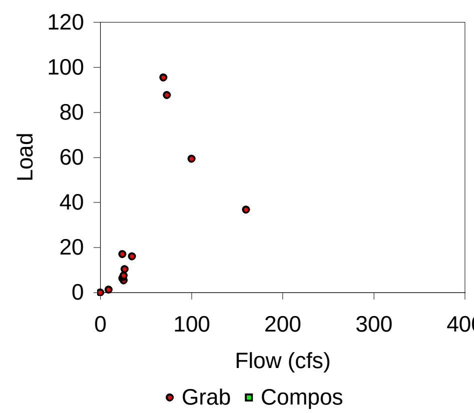
Daily Time Series

Site:	**S153**		**Variable:**	**TP**	**Dates:**	**01/01/88**	**thru**	**12/31/90**
Mean Flow:	**27**	**cfs**	**Conc:**	**244.2**	**ppb**	**Load:**	**16.1**	**kg /day**





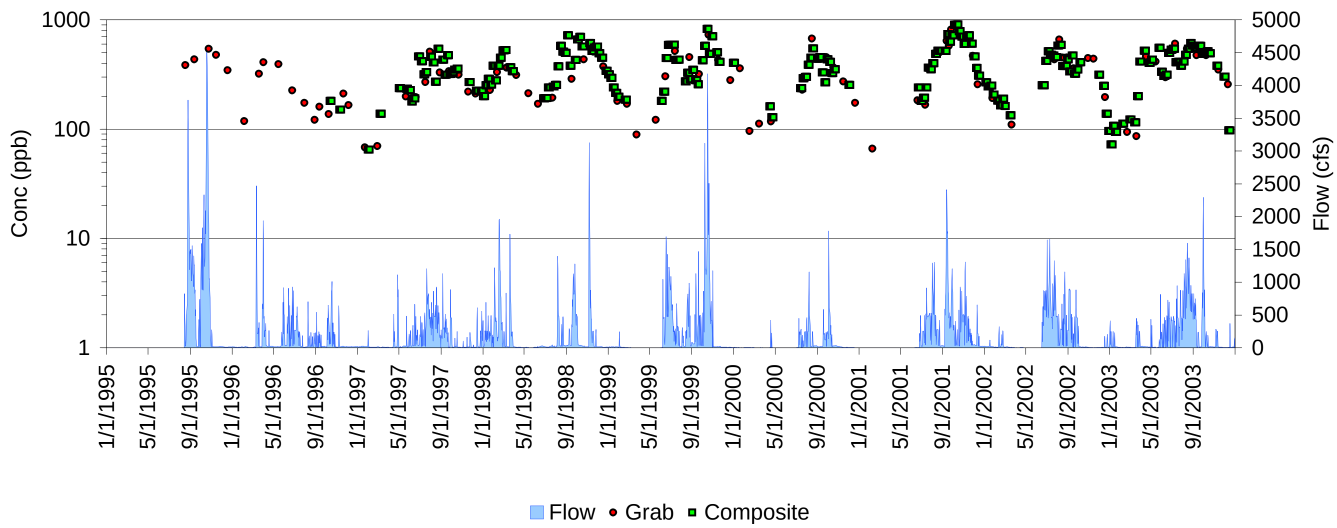


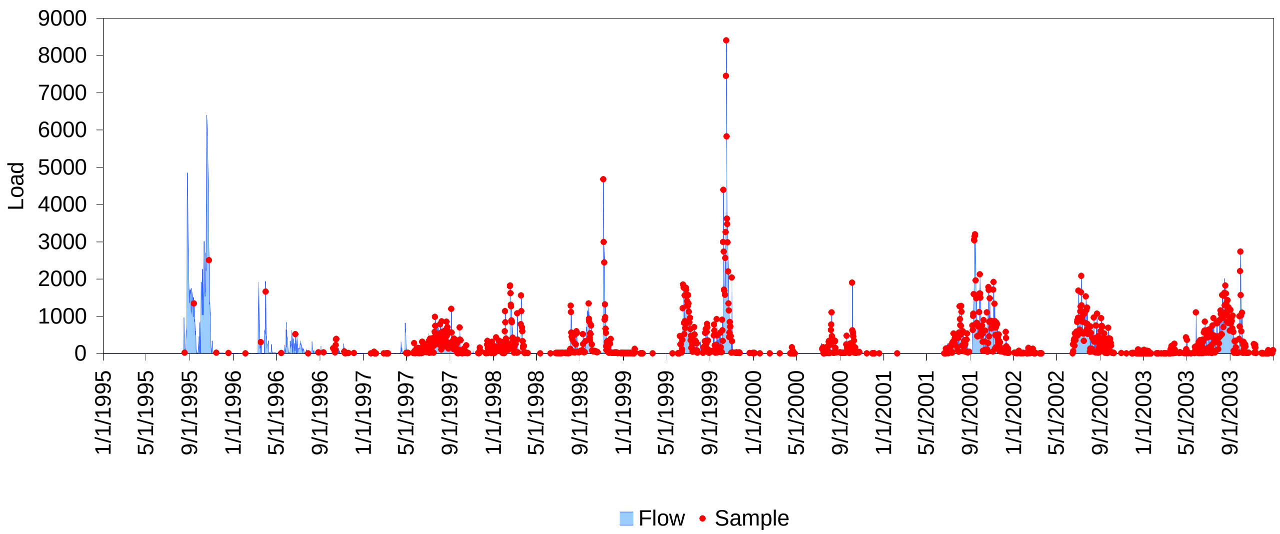


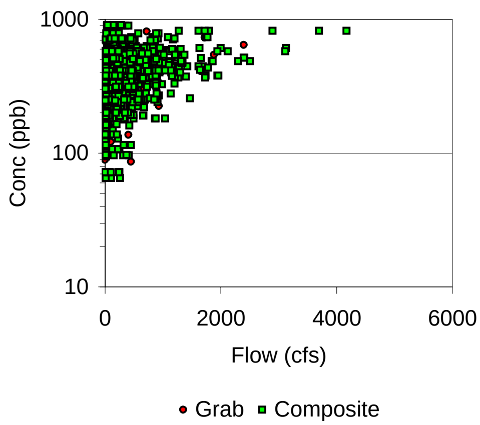
D R A F T 5/21/2004

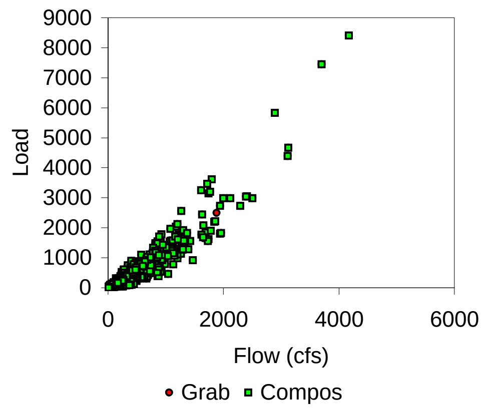
Daily Time Series

Site:	**C23S48**	**Variable:**	**TP**	**Dates:**	**01/01/95**	**thru**	**12/31/03**
Mean Flow:	**178 cfs**	**Conc:**	**448.4 ppb**	**Load:**	**194.9 kg /day**		





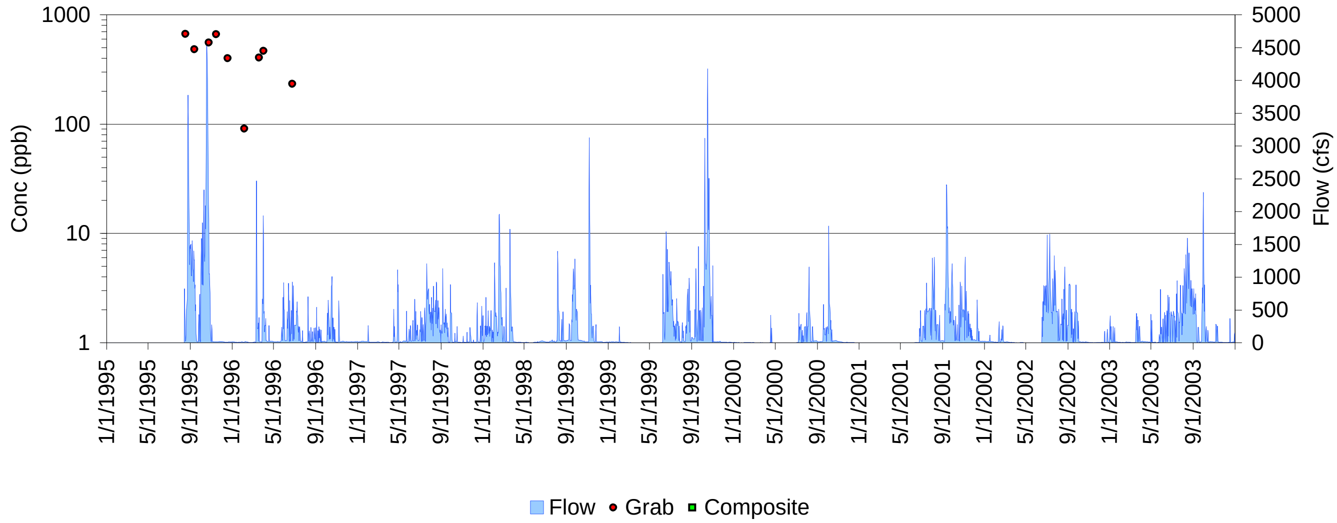


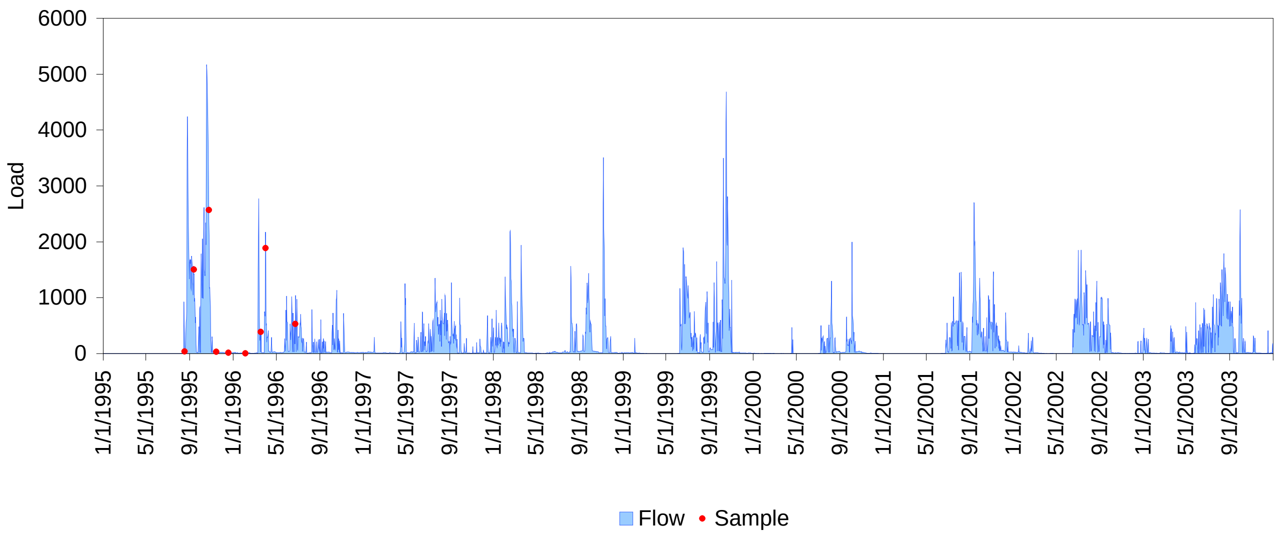


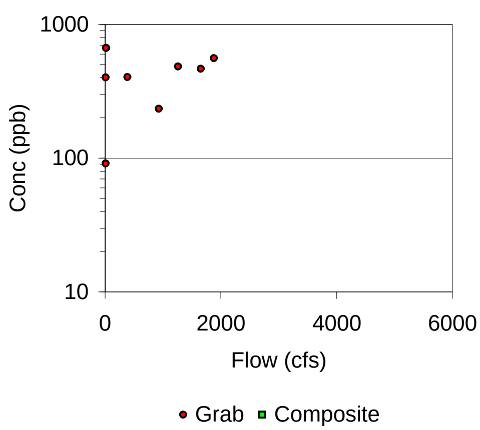
D R A F T 5/21/2004

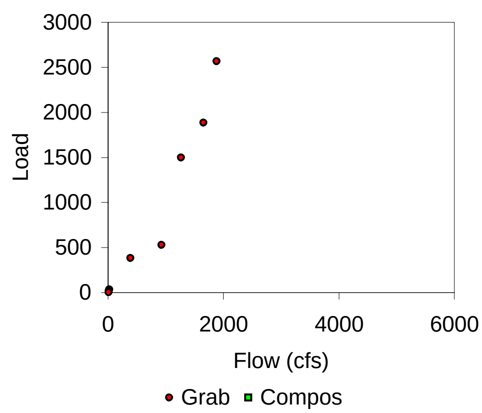
Daily Time Series

Site:	**C23S97**		**Variable:**	**TP**	**Dates:**	**01/01/95**	**thru**	**12/31/03**
Mean Flow:	**178**	**cfs**	**Conc:**	**461.7**	**ppb**	**Load:**	**200.7**	**kg /day**









D R A F T 5/21/2004