Preliminary Evaluation of the Potential Water Quality Impacts of Implementing a New Rainfall-Driven Formula for Guiding Flow Deliveries to Shark River Slough

Prepared for

U.S. Department of the Interior

By

William, W. Walker, Jr., Ph.D.

bill@wwwalker.net

May 17, 2010

Table of Contents

Introduction

The Everglades Restoration Transition Plan (ERTP) team is developing strategies for managing ENP inflows to provide hydrologic, water quality, and ecological benefits. Optimization of flow deliveries to ENP is a challenge, given multiple criteria for restoring and protecting the upstream and downstream marsh, competing management objectives for flood control and water supply, structural and operational constraints, complexity of the upstream marsh/canal system, and uncertainty in forecasting future conditions. For those reasons, future management of the inflows is likely to be adaptive in nature, as opposed to a fixed recipe. Quantifying the impacts and benefits of alternative strategies for adaptively managing the inflows is likewise difficult without specific quantitative operational rules and assumptions.

A new rainfall-driven formula to guide flow releases is one of the potential changes in operation being considered for the ERTP (Neidrauer, 2010). Because it is a prescribed recipe, the hydrologic benefits of this change can be quantified using the South Florida Water Management Model (2x2 Model) , which simulates the entire Central and Southern Florida Flood-Control Project with a 2-mile grid resolution, while accounting for variations in climate over a 35-year period, project features, and operational constraints. Modeling results indicate that operations driven by this formula could potentially provide a 10% increase the long-term average flow delivered to ENP's Shark River Slough (SRS), relative to operation using the existing rainfall formula.

The 2x2 simulations also provide a partial basis for evaluating water quality changes potentially resulting from implementing the new formula. This report initiates such an evaluation, specifically with respect to total phosphorus (TP) concentrations in discharges from WCA-3A into SRS. Excessive phosphorus in inflows has been demonstrated to have significant adverse impacts on wetland water quality and ecology. Restoration and protection of ENP and other Everglades marshlands with respect to nutrient enrichment are required under a Settlement Agreement (SA) reached between state and federal agencies in 1991, and entered into a Consent Decree in 1992 (USA et al., 1992). Water quality sensitivities to changes in operation are evaluated using a variety of simplifying assumptions, TP concentrations measured at SRS inflow structures over the past ten years, and daily simulated inflows at each structure under each operating scenario. Evaluation metrics include the combined inflow concentrations to SRS, as well as the long-term risk of exceeding P limits established under the SA.

Settlement Agreement Phosphorus Limits

One SA requirement is to reduce SRS inflow P concentrations to levels measured in 1978-1979, adjusted to remove pre-existent anthropogenic impacts and accounting for hydrologic and natural variations. Compliance with the SA is determined by comparing the measured annual flow-weighted mean inflow TP concentration (FWM) with a Long-Term Limit (LTL) computed from total inflow (Appendix A, USA et al, 1992; Walker, 1999; 2000). The LTL equations were derived from a regression model relating historical FWMs to total inflow (S12 + S333) and water year (at the time, defined as October 1 – September 30, 1978-1990). The flow term was included to account for the observed negative correlation between FWM concentration and flow. The year term was included to account for increasing trends in structure TP concentrations observed over the 1978-1990 period (Walker, 1991). The LTLs were set at the 90th percentile of the FWM predicted by the regression model for the 1978-1979 baseline period. Setting the annual limit at the upper 90th percentile accounted for natural and sampling variations; however, the intent was to improve water quality conditions towards the 50th percentile. The regression model was calibrated to measured FWM concentrations in discharges through the S12s, which more closely reflected natural discharges from the WCA3A marsh and had significantly lower TP concentrations, as compared with the canal-driven inflows through S333.

Compliance with the LTL (effective in WY 2008) is tracked by the SA Technical Oversight Committee on a 12-month rolling-average basis (SFWMD, 2010a). At the end of each Water Year (Sept 30), the compliance determination is made by comparing the LTL (computed from total flow) with the measured combined flow-weighted mean concentration for inflows to western (S12s) and northeastern (NESRS) portions of Shark River Slough. The NESRS component is computed using measured concentrations at S333 and net inflow volume to NESRS (Max (0, S333 flow - S334 flow), computed on a daily basis). In the future, any new sources of inflow (e.g. S355, S356) will be monitored and included in the compliance calculations.

Table 1 summarizes monitoring data and compliance results for the past decade. Although the LTL was not effective prior to WY 2007, the WY 2000-2006 data are useful for evaluating trends and calibrating the methodology for evaluating potential operational impacts. The observed FWM decreased from 10.4 ppb in WY 2000-2004 to 9.2 ppb in WY 2005-2009. Compliance with the LTL is expected to provide a long-term-average FWM concentration of approximately 8 ppb for the range of flows measured in 1978-1990. That target is somewhat lower (7.2 ppb) for the higher range of flows measured in 2000-2009.

The LTL is exceeded when the measured FWM is above the LTL computed from basin flow. The risk of exceeding the LTL increases as the average difference between the measured FWM and LTL increases. That difference decreased from an average of 1.5 ppb in WY 2000-2004 to an average -0.1 ppb WY 2005-2009. The FWM exceeded the LTL in 4 out of 5 years between WY 2000-2004, as compared with 1 out of 5 years in WY 2005-2009. Measured FWMs in WYs 2008 and 2009 were essentially equal to the LTLs (within 0.1 ppb), although results for WY 2008 have been disputed because of data QA/QC issues (Walker, 2009). The apparent improvements may to some extent reflect reductions in TP loads to WCA-3A resulting from implementation of upstream P control measures during this period (SFWMD, 2010b). Despite apparent improvements, the measured FWM was above the Long-Term Target (50th percentile of the 1978-1979 distribution) in 9 years out 10 in WY 2000-2009.

Declining trends in TP concentrations and loads at WCA-3A inflow structures (SFWMD, 2010b) and planned implementation of additional P source controls suggest that SRS inflow P concentrations and risk of exceeding the LTLs may decrease further in the future. In WY 2005-2009, the FWM averaged 8.1 ppb at the S12s and 13.6 ppb at S333 (Table 1). As long as TP concentrations in the individual marsh and canal outflows remain above 1978-1979 background levels (approximately 7-8 ppb), changes in water management affecting water levels in WCA-3A and/or the spatial distribution of inflows may have adverse impacts on water quality and compliance with the SA limits. The SA makes no assumptions about the spatial distribution or operational rule for delivering water to SRS, which varied significantly over the 1978-2009 period, but does require restoration of both water quality and hydrology. It will be difficult to accomplish both objectives until structure TP concentrations are sufficiently reduced.

Hydrologic Simulations

The potential hydrologic impacts of operating under the New Rainfall Formula (NRFF) have been evaluated by comparing two 35-year SFWMM simulations provided by Neidrauer (2010):

- **ECB (Existing Condition Baseline)**, Run ID = ECB09CN; reflects operations driven by the current rainfall formula. The operational target is to deliver 55% of the flow to NESRS and 45% to the S12s.

- **NRFF (New Rainfall Formula)**, Run ID = NRFF5070; reflects operations driven by the modified rainfall formula. The operational objective in these simulations was to deliver 50% of the natural flow volume predicted by the formula and to distribute 70% of that delivered flow to NESRS and 30% to the S12s.

Setting the NRFF target at 30% of the natural flow (vs. 50%) is another option being considered and would presumably have less impact on hydrology and water quality; however that option is not reflected in the 2x2 simulations provided and s is not considered here. The predicted SRS inflow volumes and spatial distributions under each scenario differ from the targets derived from the formulas because various structural and operational constraints are applied in the 2x2 simulations. Yearly time series for each simulation are compared in Figures 1 and 2. Average results are summarized in Table 2.

Most of the 10% increase in total flow associated with the NRFF is delivered through S333 into NESRS. Average inflow to western SRS (S12s) increases by 5% and flow to the eastern SRS (S333-S334) increases by 29% (Table 2). Figure 2 shows the spatial distribution of inflows for each simulation and year. Changes in spatial distribution (more flow to NESRS) are more evident in dry years (e.g., 1973, 1974, & 1990) than in average or wet years.

Compared with historical (WY 2000-2009) conditions, each simulation predicts a greater percentage of flow to NESRS (vs. S12s), smaller percentage flow delivered at low stage, and smaller percentage bypassing NESRS through S334 (Table 2). To some extent, these differences reflect the fact that the simulations represent a different period of record (WY 1966-2000). The comparison is also difficult because the historical data would have been influenced by implementation of the Interim Operations Plan (Walker, 2004), as well as other changes in system infrastructure and management.

The simulations show smaller percentages of S333 flow bypassing NESRS and discharged through S334 (4-9%), as compared with the historical percentage (38%). If future reductions in S334 flow do not occur, the 2x2 simulations may provide a conservative basis for evaluating water quality impacts, which depend in part on the percentage of the total WCA-3A outflow delivered to NESRS (S333-S334) relative to the S12s.

Changes in total flow volume, spatial distribution, and/or WCA-3A stage resulting from the change in operation could have adverse or beneficial impacts on SRS inflow TP concentrations. Based upon the inverse correlation between concentration and flow inherent in the LTL regression equation derived from 1978-1991 data, the 10% increase in total flow under the NRFF would tend to decrease inflow concentrations. Changes in the other factors under the NRFF would tend to increase concentrations, however. Changes in spatial distribution and stage are plotted against WCA-3A total outflow (S12+S333) for each simulation in Figure 3. The differences between the NRFF and ECB simulations are generally more pronounced in dry years as compared with wet years. The percent of the total flow through the S12s (vs. NESRS) decreases from 81% to 77%. The frequency of low stage in WCA-3A increases from 36 to 41%, using 9.5 feet as a benchmark for evaluating the risk of encountering high TP concentrations in WCA-3A outflows (Walker, 2004). The fraction of the total flow volume delivered at stage < 9.5 feet increases from 7 to 10%.

Impacts on Long-Term TP Concentrations

Evaluating the water quality impacts of changes in operation is difficult because such changes would alter stage, flow, and P transport patterns through the upstream WCA-3A marsh and canal system. The magnitudes and interactions among those factors are difficult to evaluate without a model that simulates P dynamics in the upstream marsh and canal system. While also required under the SA (Appendix C), such a model would be relatively complex. The SFWMD is reportedly developing a P transport model coupled with the HSRM, but the timetable and ultimate utility of the model are unknown. Accordingly, simplistic assumptions are necessary to estimate order-of-magnitude changes in FWM concentration potentially resulting from changes in operation based upon the hydrologic modeling results and historical TP data. Preliminary evaluations are developed below on a long-term and annual basis.

The long-term (35-year) LTL and FWM inflow concentrations computed for each operational scenario under various assumptions are summarized at the bottom of Table 2 and discussed below:

1. **LTL dependent on total WCA-3A outflow.** Evaluating the impact on compliance limits (LTLs) is straightforward because they are computed directly from the simulated WCA-3A total outflows using the SA formula (Table 1). The mean limit decreases from 9.5 ppb for ECB to 9.2 ppb for the NRFF. The net change is -0.3 ppb or 3%. The mean target (50^{th} percentile of 1978-1979 concentration) is also computed directly from flow and decreases by a similar magnitude (from 7.6 to 7.2 ppb).

2. **FWM dependent on total WCA-3A outflow**. If the yearly FWM is assumed to follow the SA regression model and depend only on the total WCA-3A outflow (S12s + S333), the change in operation would trigger a net decrease in the long-term FWM from 7.6 ppb to 7.2 ppb for structure TP concentrations in the range of those experienced in 1978-1979. The risk of exceeding the LTL for a given distribution of concentrations depends on the difference between the FWM and LTL. In this case, there would be no net impact on that risk because the changes in the LTL and FWM would be of similar direction and magnitude.

3. **FWM dependent on spatial distribution of flow**. If the yearly FWM is assumed to depend only on the spatial distribution of inflows, the change in FWM can be estimated by applying the historical FWMs measured at the individual structures to the simulated flows. This method also assumes that the change in operation would not change the long-term FWM concentrations at the individual structures. If the calculation is calibrated to WY 2000-2004 data, the SRS FWM increases from 10.3 ppb for ECB to 10.5 ppb for the NRFF. When calibrated to WY 2005-2009 concentrations, the FWM increases from 9.6 ppb to 9.8 ppb. The increases reflect the shift in flow distribution towards the east and the higher TP concentrations at S333 (14 ppb) relative to the S12s (7-10 ppb) in WY 2005-2009. The corresponding risk of exceeding the LTL would increase because the average difference between the LTL and FWM would increase by ~0.5 ppb, as compared with the range of -1.9 to +4.0 ppb observed in WY 2000-2009 (Table 1).

4. **FWM dependent on WCA-3A stage and spatial distribution.** If the FWM is assumed to depend on stage and the distribution of flows, the analysis is considerably more complicated because of the observed variability in TP concentration across structures and sensitivity of concentrations to fluctuations in stage on relatively short time scales (Figure 4). As described further below,

multiple regression models that predict daily variations in S12 and S333 FWM concentrations based upon stage and season have been calibrated to historical data and applied to the simulated daily flows and stage for each operating scenario. Using this method, the long-term FWM SRS inflow concentration increases from 9.7 to 9.9 ppb. The net change in FWM is similar to that obtained by applying the long-term FWM concentrations at each structure (Method 3 above).

The above results indicate that the change in long-term FWM SRS inflow concentration ranges from -0.3 ppb to +0.2 ppb for various assumptions. The differences in concentration approach the 0.1 ppb round-off convention used in the LTL compliance determination and would be difficult to measure in the context of the expected year-to-year variations The differences are also small relative to the random variations inherent in the compliance formula, as reflected by the average difference between the LTL and target (~ 2 ppb, Table 1).

Impacts on Yearly TP Concentrations

While the projected impacts of changes in operation on the long-term FWMs appear to be small, measurable impacts could occur under specific conditions, particularly in dry years when changes in operation are predicted to have greater impacts on hydrologic factors likely to influence water quality, including the spatial distribution of inflows, frequency of low stage, and percentage of flow delivered at low stage (Figures 2 and 3). Figure 4 compares FWM concentrations in the combined outflow from WCA-3A (S12x+S333) measured on a weekly-biweekly basis with corresponding values for WCA-3A stage and total outflow. The bottom panel shows correlations between concentration and stage for periods of rising and falling stage, based upon the antecedent 30-day change. Concentrations increase dramatically at low stage, particularly when stage is rising. In an attempt to capture these dynamics, multiple regressions that predict daily TP concentrations as a function of stage, rate of increase in stage, and season (Julian day) have been calibrated to the historical FWM concentration for the combined WCA-3A outflow (S12+S333, Figure 5), the S12s (Figure 6) and S333 (Figure 7). The regressions explain between 59% and 70% of the variance in concentration and between 81% and 96% of the variance in load measured across sampling events, with residual standard errors of 20-25%. These results indicate that much of the variation in SRS TP concentrations from one sampling event to the next can be predicted based upon WCA-3A stage on the sampling date, stage 30 days prior to the sampling date, and season. The regressions have been calibrated to data from WY 2001-2009. Decreasing trends detected in model residuals (observed – predicted) ranging from 1.5 to 2.3 %/year are consistent with the overall decreases in yearly FWM concentrations and LTL excursion frequency (Table 1). Data from WY 2000 have been excluded from the regressions because the models generally under-predicted FWMs in that year and stable calibrations are desired for purposes of the analysis. By filtering out variations related to stage and season, the regressions provide an improved basis for tracking long-term trends in the TP concentration data.

The regressions for S12 and S333 FWM concentrations have been applied to the simulated daily flows and stage under each operating scenario. Figure 8 shows the resulting yearly time series of FWM concentrations (S12, NESRS, Total), SA Long-Term Limits computed from total flow, and difference between the FWMs and the LTLs for each operating scenario (NRFF-ECB). Figure 9 shows cumulative frequency distributions of changes in yearly FWM inflow concentrations for each part of the Slough. Increases are evident in about 50% of the years. The 90^{th} percentile increases are 0.5 ppb for the S12s, 2 ppb for the NESRS, and 1 ppb for the combined SRS inflow. Corresponding 35-year maximum increases are 1 ppb, 2.2 ppb, and 1.2 ppb, respectively.

The change (NRFF-ECB) in the compliance determinant (SRS FWM – LTL) exceeds the 0.1 ppb round-off convention for determining compliance in 74% of the years (Figure 9). The estimated 90th percentile increase is 1.6 ppb and the maximum increase is 3 ppb. The overall LTL excursion frequencies increase from 71% to 86 % for the 2001-2009 distribution of TP concentrations. The change in operation is predicted to trigger a net change in the compliance determination (i.e., shifts the FWM-LTL value from a negative to positive value) in 3 out of the 35 years (1979, 1987, & 2000, Figure 8). The bottom panel of Figure 9 shows that changes in FWM and compliance determinant are positively correlated with increases in SRS inflow volume; i.e. that the potential water quality impacts are correlated with the potential hydrologic benefits.

Figure 10 shows the simulated excursion frequency as a function of long-term FWM concentration for each operating scenario. These results have been developed by rescaling the 2001-2009 calibrations to long-term FWMs ranging from 6 to 12 ppb. At the upper end of this range, the simulated difference in excursion frequency (NRFF – ECB) is approximately 10%. As TP concentrations approach the compliance target (7.2 – 7.6 ppb, Table 2), which reflects 1978-1979 conditions, the excursion frequency approaches 0% for each operating scenario. If TP concentrations were reduced to 1978-1979 levels, the proposed operational changes to provide hydrologic benefits could be implemented without triggering LTL excursions or other adverse water quality impacts, provided that the system is actually operated in ways that are consistent with the assumptions built into the 2x2 simulations.

Conclusions

1. Evaluating the potential water quality impacts of operating under the new rainfall formulas is difficult because of system complexity, differences between actual and hypothetical operations represented in the 2x2 simulations, and lack of a mechanistic model to simulate flow and P transport in the upstream marsh/canal system. At best, the preliminary analyses described above provide order-of-magnitude estimates that require a variety of simplifying assumptions.

2. The analysis indicates that operating under the NRFF could decrease the long-term average FWM concentration in the combined inflows to Shark River Slough by ~0.4 ppb or increase it by ~0.2 ppb, depending on modeling assumptions. Measuring changes in the long-term FWM of this magnitude would be difficult in the context of random year-to-year variations, although measurable changes could occur in specific years.

3. Most of the variation in historical SRS TP concentrations from one sampling event to the next can be predicted based upon WCA-3A stage on the sampling date, stage 30 days prior to the sampling date, and season. Regression equations calibrated to WY 2001-2009 data could be

used (a) to forecast water quality impacts of alternative operating strategies (coupled with 2x2 simulations), (b) to support real-time operational decisions on gate opening & closing; and (c) to facilitate tracking long-term trends in the inflow concentrations by factoring out variations related to stage and season. Further refinement and testing of these equations and their potential applications are recommended.

4. Simulations indicate that potential water quality impacts would vary significantly from year to year, depending on climatologic and hydrologic conditions, and would be generally more pronounced in dry years than in wet years. The 35-year maximum increase in SRS FWM inflow concentration is on the order of 1-2 ppb. Implementing the NRFF as prescribed could have adverse water quality impacts triggered by reductions in WCA-3A stage, increases in total flow delivered at low stage, and/or shift in flow distribution from the western to eastern portions of SRS. These factors should be considered in developing long-term operational strategies, as well as in making real-time operational decisions.

5. The risk of exceeding the SA Long-Term P Limits depends on the difference between the actual FWM concentrations and LTL computed from total flow in each year. When calibrated to structure TP data from 2001-2009, the analysis indicates that operating under the NRFF could increase the average difference between the FWM and LTL by ~0.5 ppb, as compared with a range of -2 to +4 ppb observed in WY 2000-2009. Based upon the 35-year simulation, the long-term excursion frequency would increase from 71% under the ECB to 86% under the NRFF.

6. The historical LTL excursion frequency decreased from 80% in WY 2000-2004 to 10-20% in WY 2005-2009. If the excursion frequency and TP concentrations at the individual structures continue to decrease, the analysis demonstrates that the overall risk of excursions and sensitivity to changes in operation made to improve hydrology will also decrease.

7. Evaluating the potential water quality impacts of implementing the new rainfall formula, as well as other operational changes being considered by the ERTP team, is handicapped by lack of a coupled hydrologic and P-transport model for WCA-3A. Development of such a model is recommended. With further refinements, the simple empirical methods applied above may be useful for developing and implementing operational strategies that consider management objectives for hydrology, wildlife management, and water quality within the significant constraints imposed by the existing elevated TP concentrations and dynamics at the individual SRS inflow structures.

References

Neidrauer, C., "Simulated Performance of the New Rainfall-Driven Flow Formula for the Everglades' Shark Slough", presented to the Everglades Restoration Transition Plan (ERTP) Team, November 9, 2009. http://www.wwwalker.net/doi/refs/nrdf_performance_ertp1_nov2009cn_neidrauer.pdf

South Florida Water Management District, Everglades Technical Oversight Committee, Settlement Agreement Reports, 2010. https://my.sfwmd.gov/portal/page/portal/pg_grp_sfwmd_era/pg_sfwmd_era_techovercommittee

South Florida Water Management District, South Florida Environmental Report, 2010b. https://my.sfwmd.gov/portal/page/portal/PG_GRP_SFWMD_SFER/PG_SFWMD_SFER_HOME

USA, SFMWD, Florida DER, Everglades Settlement Agreement, Case No. 88-1886-CIV / Hoeveler, U.S. District Court, Southern District of Florida, 1992. http://www.wwwalker.net/doi/refs/settlement_agreement_1991_rev_1995.pdf

Walker, W.W., "Long-Term Water Quality Trends at Inflows to Everglades National Park", Water Resources Bulletin, Vol. 27, No. 1, February 1991. http://www.wwwalker.net/pdf/wqtrends91.pdf

Walker, W.W., "Long-Term Water Quality Trends in the Everglades", in Reddy et al, Phosphorus Biogeochemistry in Subtropical Environments, Lewis Publishers, 1999. http://www.wwwalker.net/doi/ever_trends_1999.pdf

Walker, W.W., "Interim Phosphorus Standards for the Everglades", in G. Gibson et al., Nutrient Criteria Technical Guidance Manual, Lakes & Reservoirs, Appendix B, U.S. Environmental Protection Agency, Office of Water, EPA-822-B000-001, April 2000. http://wwwalker.net/pdf/pcriteria_everglades_epa2000.pdf

Walker, W.W., "Water Quality Assessment of the Interim Operations Plan: Phosphorus Concentrations and Loads", prepared for U.S. Department of the Interior, January 2004. http://www.wwwalker.net/doi/iop_wq_www_jan_06_2004.pdf

Walker, W.W., "Comments on the Compliance Report for Shark River Slough Inflow Phosphorus Limits in Water Year 2008", prepared for U.S. Department of the Interior, June 2009. http://www.wwwalker.net/doi/enp_srs_compliance_wy_2008_www_062309_final.pdf

List of Tables

List of Figures

Table 1 Historical Flow, Phosphorus, & Compliance Data

Water Year	Flows kac-ft/yr										S12 / SRS Flow	Stage	< 9.5 ft		FWM TP Concentration (ppb)									LTL Compliance Calc.				
	S12A	S12B	S12C	S12D	S12X	S333	S334	NESRS	SRS	Q Basin		Mean, ft	Time %	Flow %	S12A	S12B	S12C	S12D	S12X	S333	NESRS	SRS	S12+S333	SRS*	Limit	SRS-Lim	Target	SRS-Targ
2000	158	152	300	326	936	209	45	165	1101	1145	0.85	10.2	0.39	0.07	11.0	7.7	6.8	9.3	8.5	15.2	17.1	9.8	9.8	9.7	7.6	2.1	5.7	4.0
2001	40	43	96	117	296	125	1	124	420	421	0.70	9.6	0.52	0.02	11.4	9.1	10.3	12.8	11.3	24.5	24.6	15.2	15.2	15.0	11.0	4.0	9.1	5.9
2002	119	158	268	300	846	202	46	156	1002	1048	0.84	10.2	0.23	0.03	8.7	6.9	7.6	10.8	8.7	9.6	9.5	8.9	8.9	8.8	7.7	1.1	5.7	3.1
2003	90	83	191	261	625	225	105	121	746	850	0.84	10.2	0.13	0.05	7.5	6.7	8.8	12.9	10.1	11.4	10.9	10.2	10.4	10.0	8.7	1.3	6.8	3.2
2004	68	64	211	232	575	129	49	82	658	704	0.87	9.9	0.37	0.06	9.0	6.1	6.2	9.8	8.0	9.6	10.2	8.2	8.3	8.4	9.4	-1.0	7.6	0.8
2005	182	180	335	388	1086	260	186	75	1161	1346	0.94	10.5	0.16	0.03	8.4	6.4	7.4	11.2	8.8	13.9	18.1	9.4	9.8	9.4	7.6	1.8	5.7	3.7
2006	89	117	248	253	708	101	68	35	743	809	0.95	10.0	0.32	0.01	7.5	7.5	7.4	10.9	8.7	12.3	13.8	8.9	9.1	8.5	8.9	-0.4	7.0	1.4
2007	22	27	55	65	170	120	36	84	254	290	0.67	9.3	0.62	0.04	6.9	7.2	7.7	9.9	8.4	13.2	12.0	9.6	10.4	9.9	11.8	-1.9	9.8	0.0
2008	63	68	117	167	414	148	6	142	556	562	0.74	9.9	0.23	0.05	6.5	7.1	9.3	10.6	9.0	12.9	13.0	10.0	10.0	10.2	10.2	0.0	8.4	1.8
2009	89	123	210	244	666	282	146	138	804	948	0.83	10.1	0.27	0.03	5.9	5.7	6.1	8.0	6.7	14.3	16.5	8.4	9.0	8.2	8.2	0.0	6.3	1.9
2000-2009	92	102	203	235	632	180	69	112	745	812	0.85	10.0	0.32	0.04	8.1	6.8	7.4	10.4	8.5	13.4	14.3	9.4	9.6	9.8	9.1	0.7	7.2	2.6
2000-2004	95	100	213	247	656	178	49	130	785	834	0.83	10.0	0.33	0.04	9.5	7.2	7.6	11.1	9.1	13.1	14.1	10.0	10.0	10.4	8.9	1.5	7.0	3.4
2005-2009	89	103	193	224	609	182	89	95	704	791	0.87	10.0	0.32	0.03	7.0	6.5	7.3	9.9	8.1	13.6	14.4	8.9	9.3	9.2	9.3	-0.1	7.4	1.8

NESRS = S333-S334; S12X = S12A+B+C+D; SRS Total = S12X + NESRS; Q Basin = S12x + S333 = WCA-3A Total Outflow

WCA-3A Stage = Average of 3A-3, 3A-4, & 3A-28 Gauges

SRS* = FWM Based upon Data from Biweekly Compliance Sampling Events; Other FWMs Based upon All Grab Samples

Long-Term Limit (90th Percentile) Exceeded (Effective WY 2007) Limit = 11.38 - 0.00538 * Q + 1.397 * (2.493 - 0.00231 * Q + 0.0000017 * Q ^ 2) ^ 0.5

Long-Term Target (50th Percentile) Exceeded Target = 11.38 - 0.00538 * Q , Q = Min (S12 + S333 Flow, 1061 kac-ft/yr)

WWW 5/17/2009

Table 2 Summary of Results

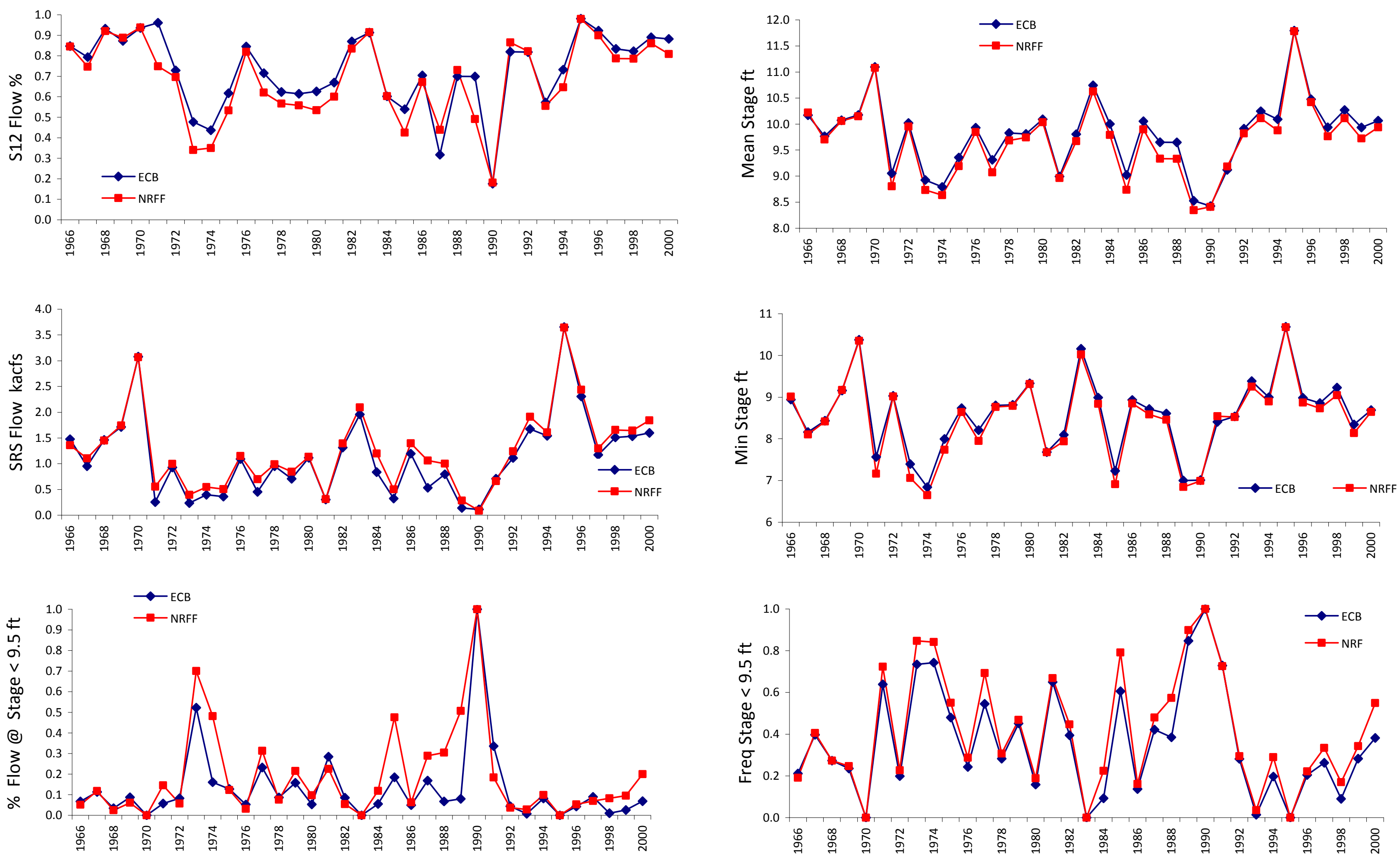
	WY 2000-9	WY 1966-2000		NRFF - ECB	
	Historical	ECB	NRFF	Change	% Change
Mean Flows (cfs)					
S12A	127	57	61	4	7%
S12B	140	161	173	12	7%
S12C	280	233	253	20	8%
S12D	325	462	474	12	3%
S333	249	239	304	65	24%
S334	95	22	13	-9	-53%
NESRS = S333-S334	155	216	291	75	29%
S12X	873	913	961	48	5%
S12X + S333	1121	1151	1265	114	9%
SRS = S12X + NESRS	1028	1129	1252	123	10%
SRS Q @ Stage < 9.5 ft	40	74	126	53	53%
Flow Distribution (% of Total WCA-3A Outflow)					
S12A	11	5	5	0	-1%
S12B	12	14	14	0	-1%
S12C	25	20	20	0	0%
S12D	29	40	37	-3	-2%
S333	22	21	24	3	4%
S334	8	2	1	-1	-15%
NESRS = S333-S334	14	19	23	4	5%
S12X	78	79	76	-3	-1%
S12X + S333	100	100	100	0	0%
SRS = S12X + NESRS	92	98	99	1	0%
SRS Q @ Stage < 9.5 ft	4	6	10	4	11%
Mean WCA-3A Stage ft	10.0	9.8	9.7	-0.1	-1%
Mean Yearly Min	8.6	8.6	8.5	-0.1	-1%
Mean Yearly Max	11.6	10.9	10.8	-0.1	-1%
Freq Stage < 9.5 ft	32%	36%	41%	5%	14%
SRS Flow % Stage < 9.5 ft	4%	7%	10%	4%	43%
S12 / S12+NESRS Flow	85%	81%	77%	-4%	-5%
Q Basin kac-ft/yr	812	834	916	82	9%
Mean LT Limit ppb	9.1	9.5	9.2	-0.3	-3%
Mean LT Target ppb	7.2	7.6	7.2	-0.4	-5%
Long-Term FWM SRS Inflow Conc ppb					
WY 2000-2004 Calib *	10.4	10.3	10.5	0.2	2%
WY 2005-2009 Calib *	9.2	9.6	9.8	0.2	2%
Stage Regression **		9.7	9.9	0.2	2%
Historical FWM Concentrations (ppb)					
Period	S12A	S12B	S12C	S12D	NESRS
WY 2000-2004	9.5	7.2	7.6	11.1	14.1
WY 2005-2009	7.0	6.5	7.3	9.9	14.4
% Change	-30%	-11%	-4%	-11%	2%

ECB	ECB09CN	Existing Condition Baseline, Target: 55% Delivered to NESRS
NRFF	NRFF5070	New Rainfall Formula: 50% of NRFF, 70% Delivered to NESRS

Q Basin = S12 + S333 Flow, Used to Compute Long-Term P Limit
WCA-3A Stage = Mean of Gauges 3A-3, 3A-4, & 3A-28
* FWM Concs Predicted from Historical FWM's & Simulated Flows
** FWM Predicted Using Daily Conc vs. Stage Regressions for S12s & S333

WWW 5/17/2009

Figure 1 Yearly Output from ECB & NRFF 2x2 Simulations



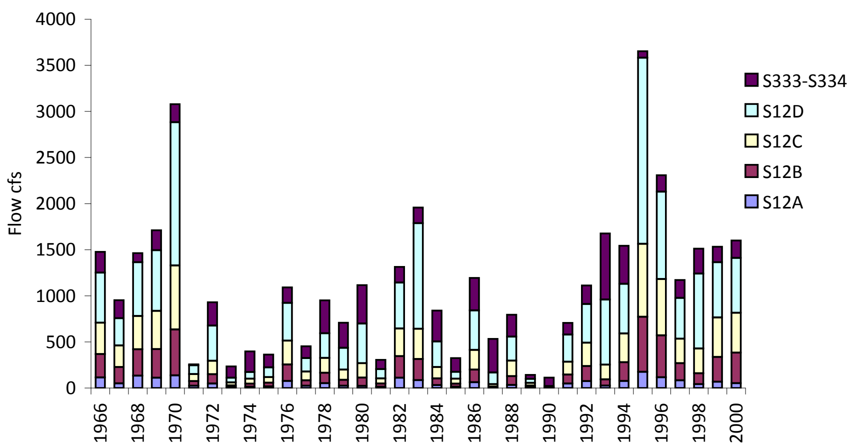
ECB = Existing Condition Baseline, NRRF = 50% of New Rainfall Formula

WCA-3A Stage = Average of 3A-3, 3A-4, & 3A-28 Gauges

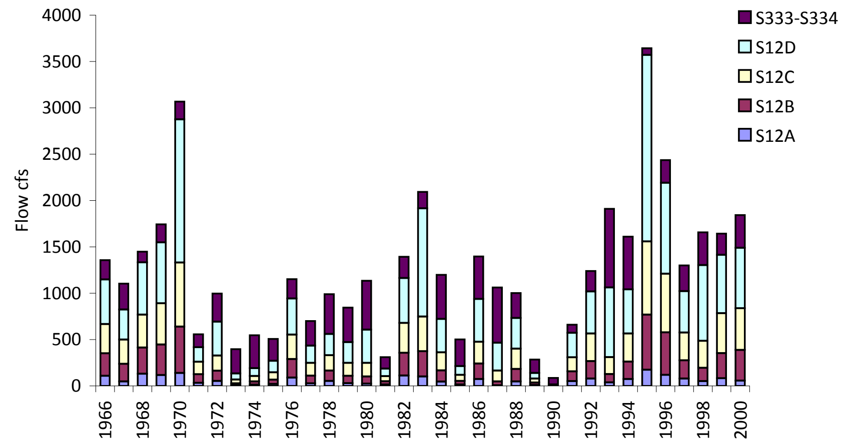
WWW 5/17/2009

Figure 2 Yearly SRS Inflow Volumes & Spatial Distribution for Each Operating Scenario

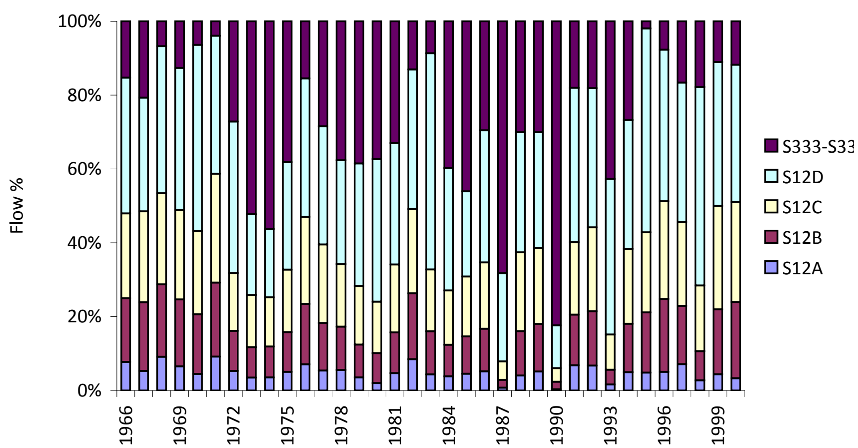
ECB Yearly Flows



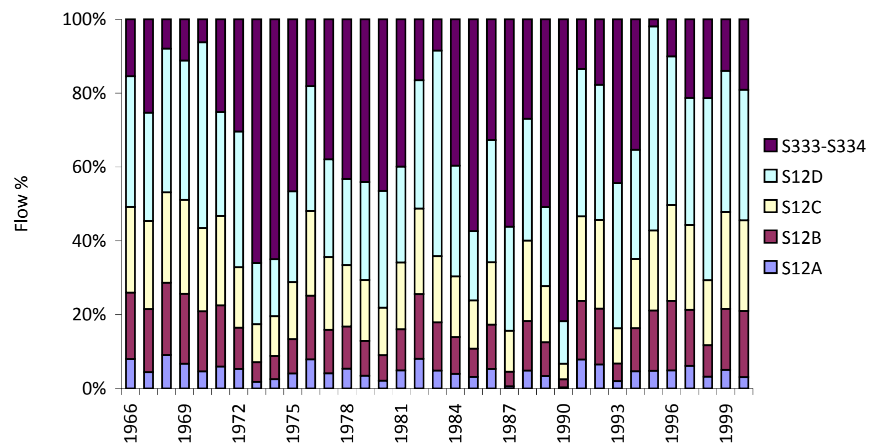
NRFF Yearly Flows



ECB Yearly Flow Distribution

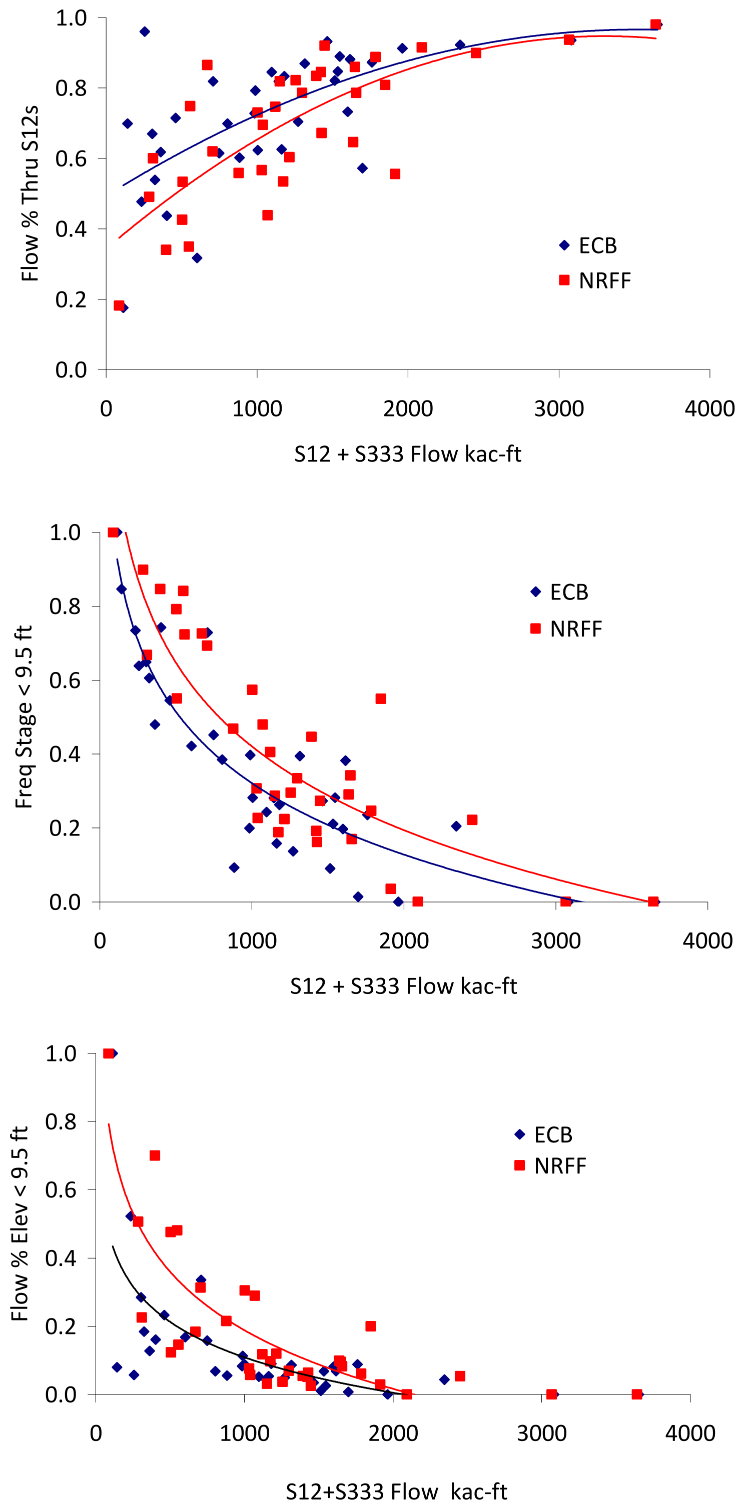


NRFF Yearly Flow Distribution



WWW 5/17/2009

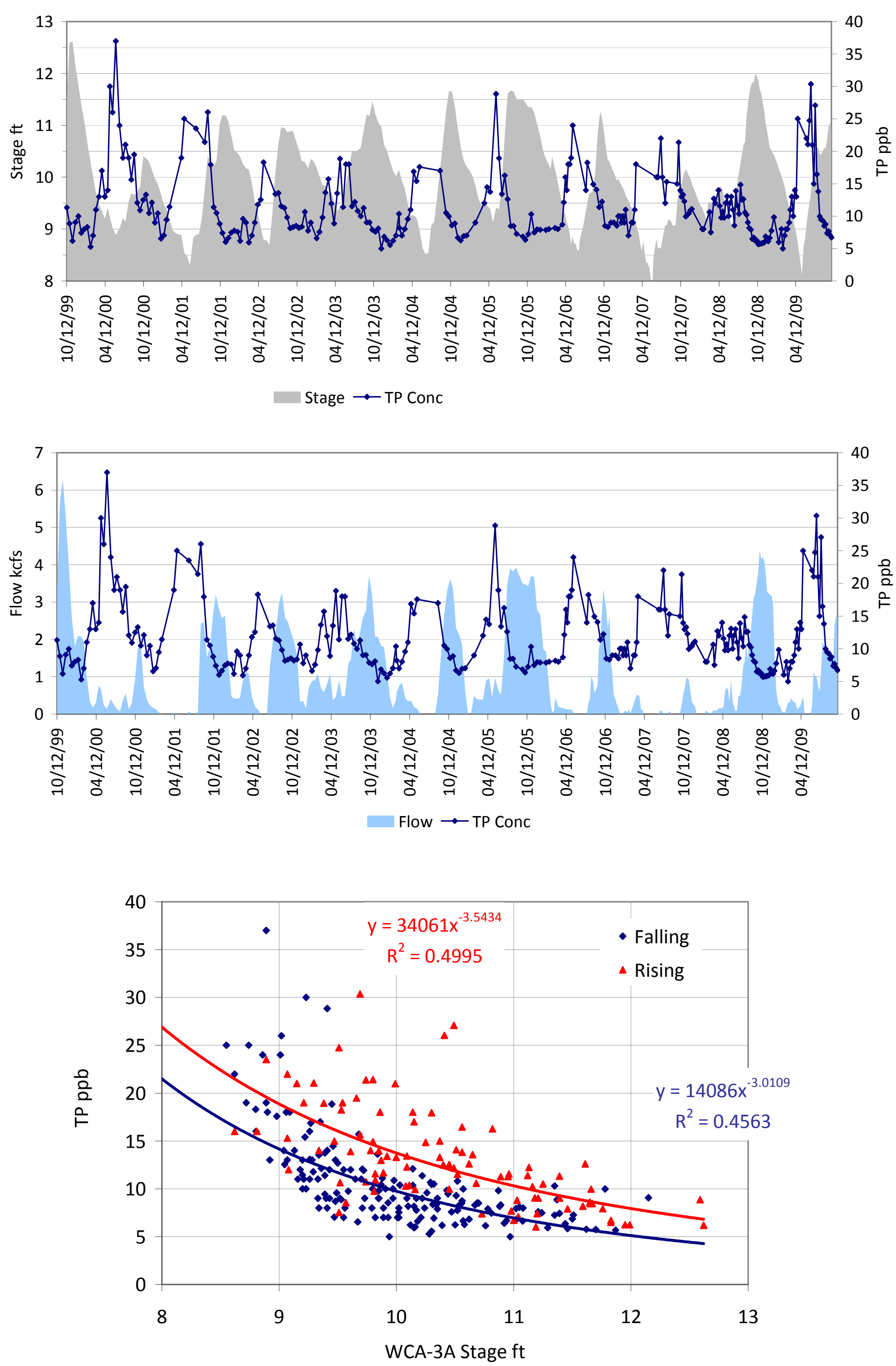
Figure 3 Hydrologic Factors Influencing TP Concentration vs. Total WCA-3A Outflow



WCA-3A Stage = Average of 3A-3, 3A-4, & 3A-28 Gauges

WWW 5/17/2009

Figure 4 Historical Basin Outflow TP Concentration vs. Stage & Flow



Top: TP & Stage vs. Sampling Date; FWM TP in Total Outflow from WCA-3A = S12s + S333

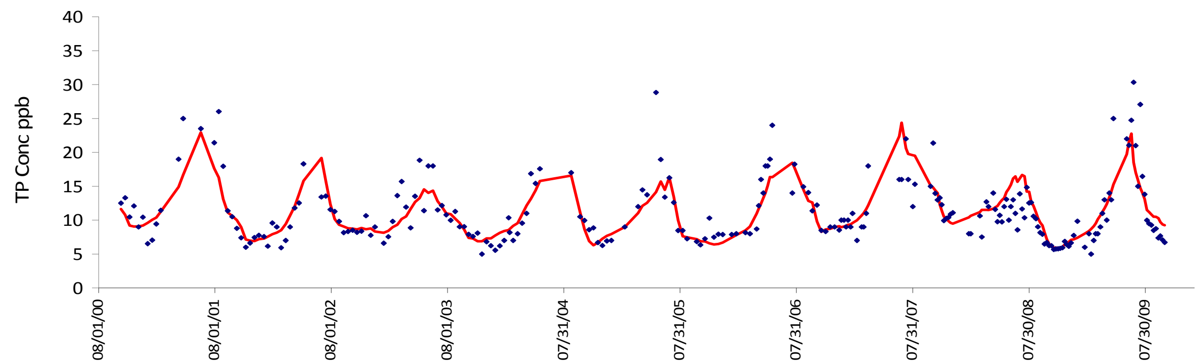
Middle: TP & Total Outflow vs. Sampling Date

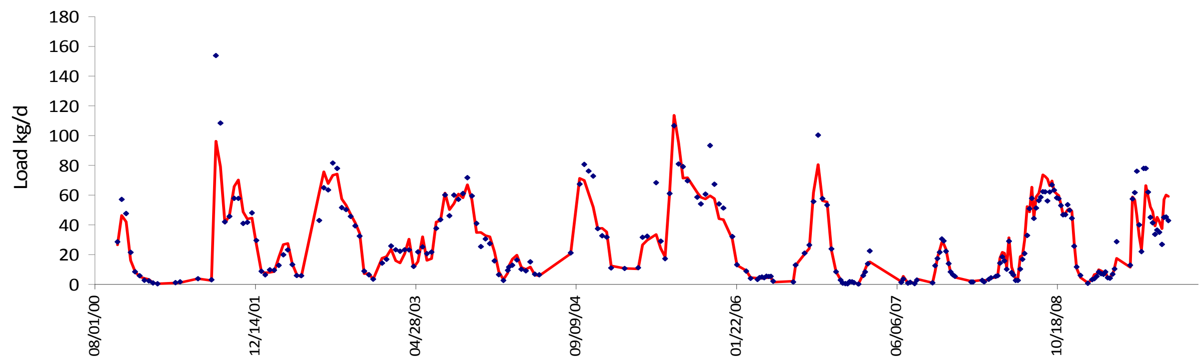
Bottom: TP Conc vs. WCA-3A Stage; Red Symbols = Samples Collected at Rising Stage
Stage Rising if 30-Day Increase > 0.1 feet; All Samples on Days with Postive Flow.
Risk of TP Spikes highest when flow is released when stage is low and rising.

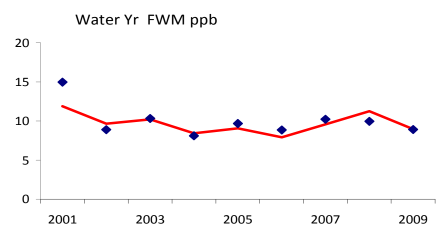
WCA-3A Stage = Average of 3A-3, 3A-4, & 3A-28 Gauges

WWW 5/17/2009

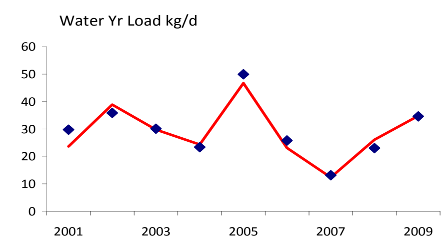
Figure 5 Regression Model for Daily TP Concentrations - S12s + S333







Regression Analysis for Structures:			S12+S333	
Period of Record:	10/01/00	thru	09/30/09	
Sampling Dates =	238			
R^2 Conc =	0.70		R^2 Load =	0.91
Residual Std Error =	21%			
Residual Trend =	-1.3	% per year		
Standard Error of Trend =	0.5	% per year		



Equation: Y = Ln (FWM TP Conc, ppb)

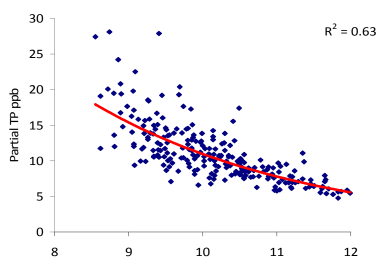
Term	Intercept	Stage	Rise	Rise2	Sin	Cos
Coefficient	5.777842	-0.33979	0.178134	0.093355	-0.07534	-0.18227
Std Error		0.027199	0.041569	0.042745	0.029628	0.026076

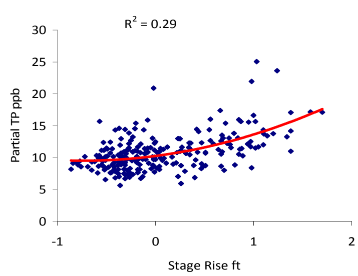
WCA-3A Stage = Average of 3A-3, 3A-4, & 3A-28 Gauges, feet

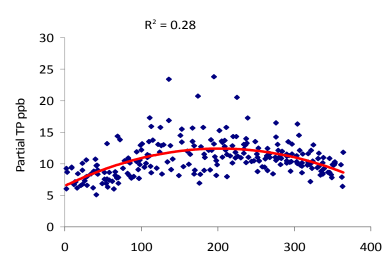
Rise = 30-Day Increase in Stage = Stage (T) - Stage (T - 30), feet

Seasonal Terms: Sine & Cosine (2 PI Julian day / 365.25), PI = 3.14259

Partial Correlation Plots:

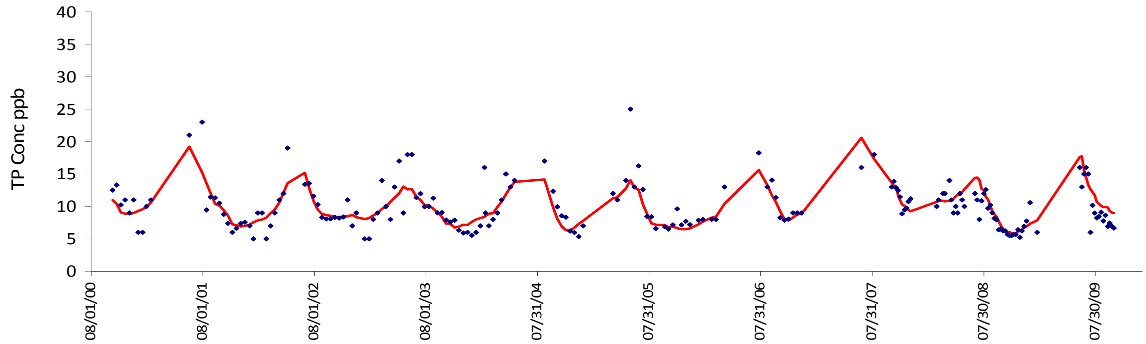


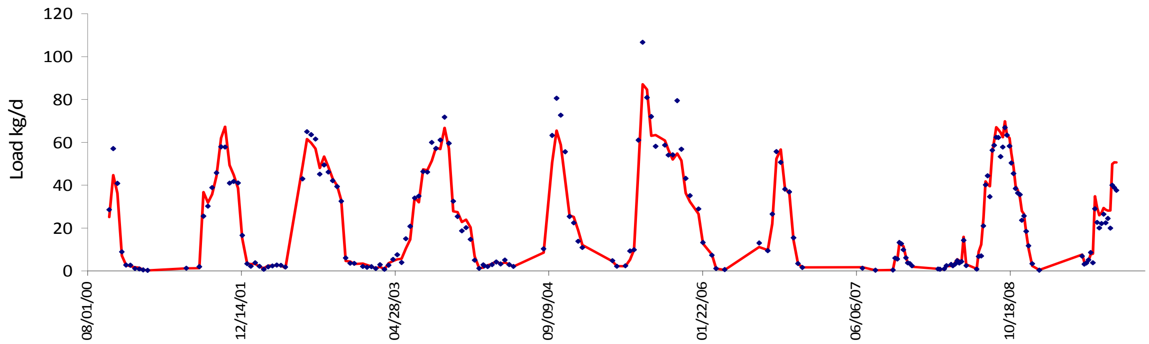


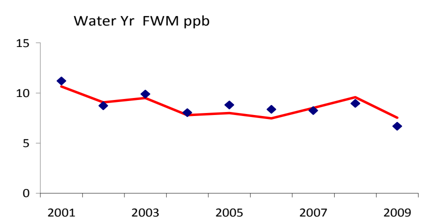


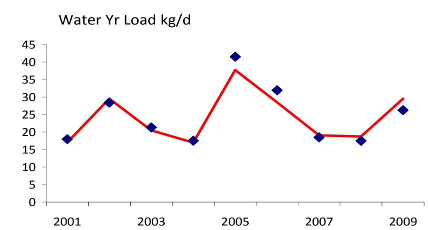
WWW 5/17/2009

Figure 6 Regression Model for Daily TP Concentrations - S12s









Regression Analysis for Structures:			S12	
Period of Record:	10/01/00	thru	09/30/09	
Sampling Dates =	191			
R^2 Conc =	0.63		R^2 Load =	0.96
Residual Std Error =	20%			
Residual Trend =	-1.3	% per year		
Standard Error of Trend =	0.5	% per year		

Equation: Y = Ln (FWM TP Conc, ppb)

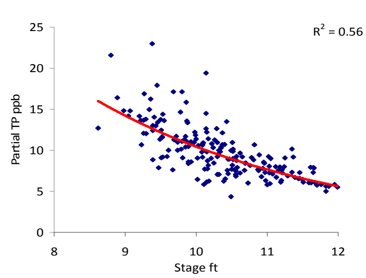
Term	Intercept	Stage	Rise	Rise2	Sin	Cos
Coefficient	5.422149	-0.30949	0.196901	0.007036	-0.07812	-0.13658
Std Error		0.030044	0.044485	0.042964	0.031827	0.029133

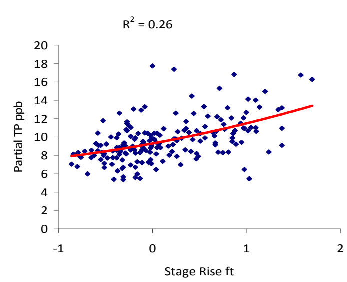
WCA-3A Stage = Average of 3A-3, 3A-4, & 3A-28 Gauges, Feet

Rise = 30-Day Increase in Stage = Stage (T) - Stage (T - 30), feet

Seasonal Terms: Sine & Cosine (2 PI Julian day / 365.25), PI = 3.14259

Partial Correlation Plots:





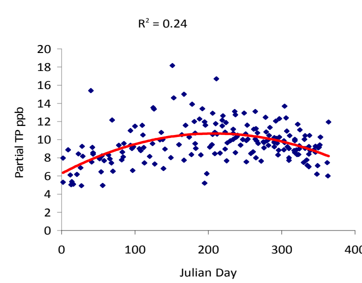
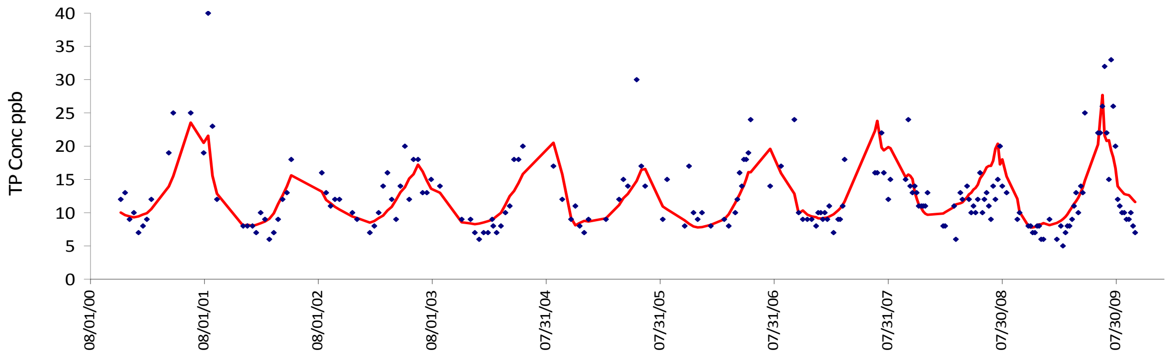
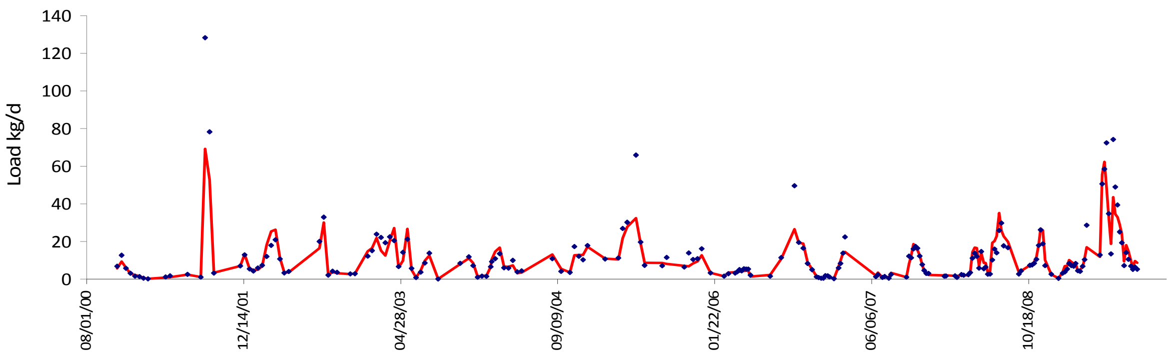
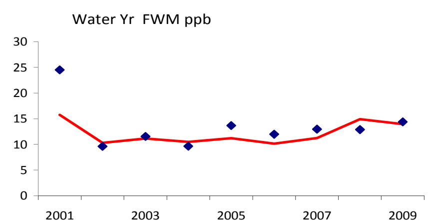


Figure 7 Regression Model for Daily TP Concentrations - S333



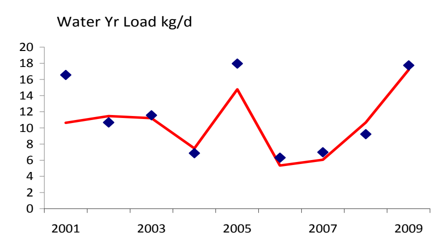


Regression Analysis for Structures:			S333	
Period of Record:	10/01/00	thru	09/30/09	
Sampling Dates =	199			
R^2 Conc =	0.59		R^2 Load =	0.81
Residual Std Error =	25%			
Residual Trend =	-2.3	% per year		
Standard Error of Trend =	0.6	% per year		



Equation: Y = Ln (FWM TP Conc, ppb)

Term	Intercept	Stage	Rise	Rise2	Sin	Cos
Coefficient	4.486708	-0.2028	0.148859	0.177922	-0.07843	-0.24897
Std Error		0.037454	0.052538	0.067387	0.038276	0.033066

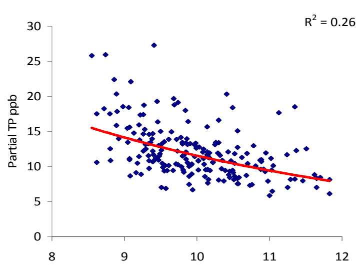


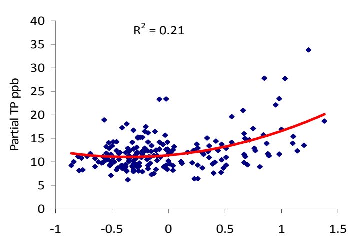
WCA-3A Stage = Average of 3A-3, 3A-4, & 3A-28 Gauges, Feet

Rise = 30-Day Increase in Stage = Stage (T) - Stage (T - 30), feet

Seasonal Terms: Sine & Cosine (2 PI Julian day / 365.25), PI = 3.14259

Partial Correlation Plots:





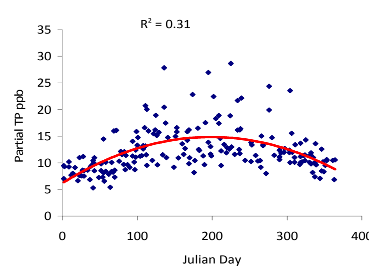
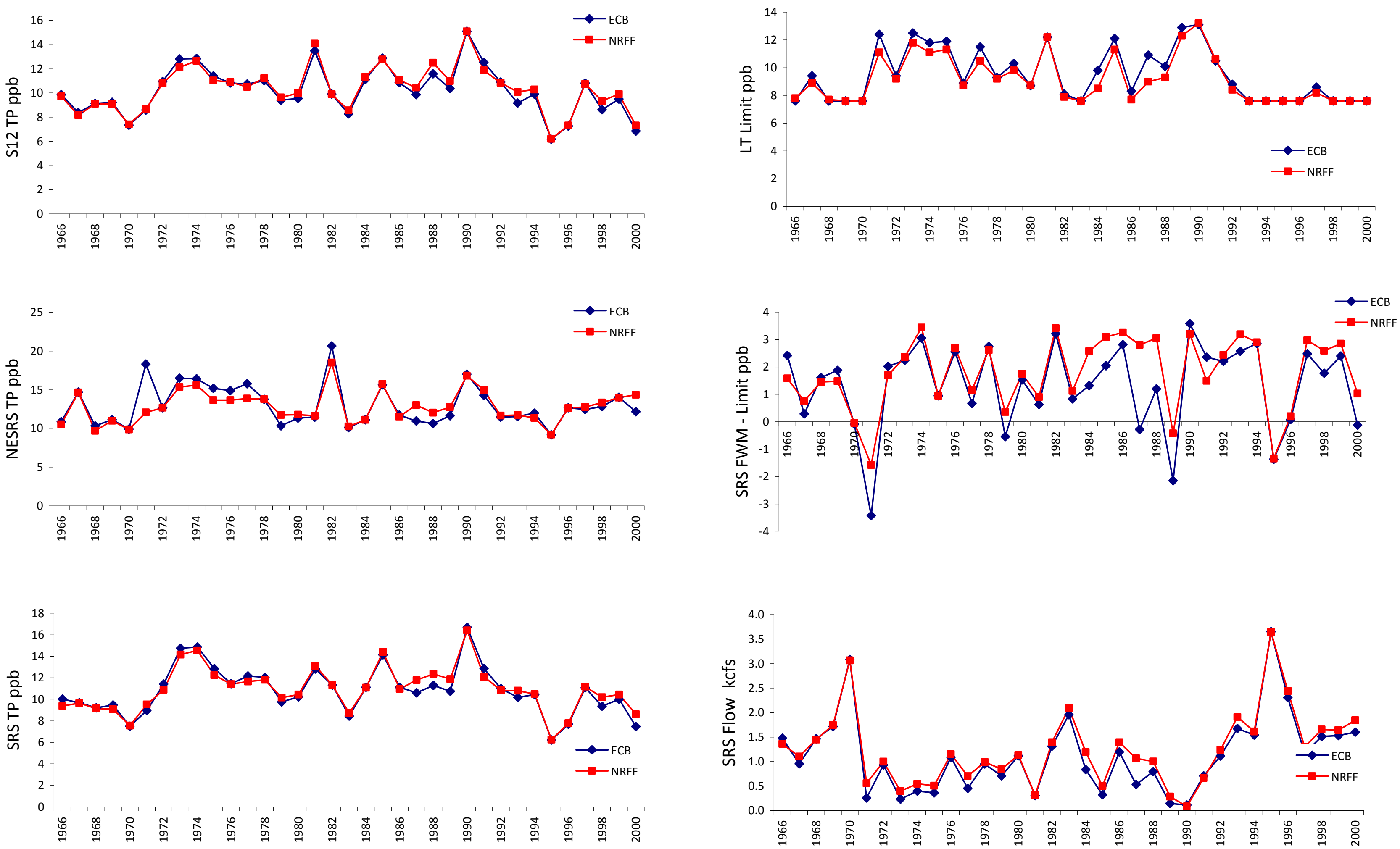


Figure 8 Yearly Simulated TP Concentrations for Each Operating Scenario



For each 2x2 model run, daily TP concentrations are predicted from daily WCA-3A stage using regression models for S12s (Fig 6) and S333 (Fig 7) calibrated to 2001-2009.
The daily TP concentrations are applied to the simulated flows to derive a yearly flow-weighted-mean concentration for each portion of the slough (S12x, NESRS, SRS = Total)

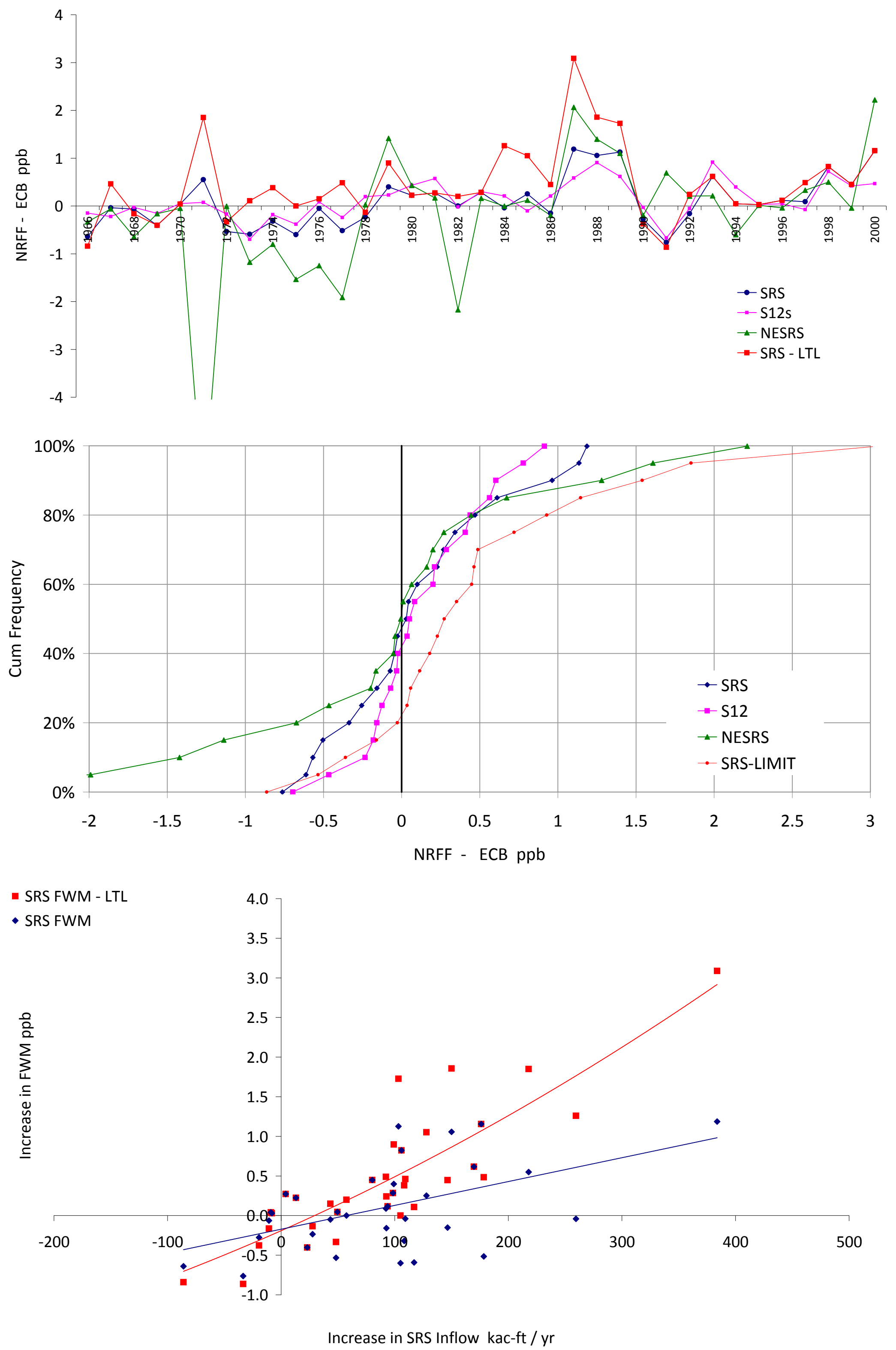
Upper Right: The SA Long-term Limit is predicted from yearly total outflow (S12+S333)

Middle Right: SRS FWM - Limit = statistic used to determine compliance with LRL, >0 indicates excursion.

Lower Right: Hydrologic benefits, as measured by the change in SRS total inflow.

WWW 5/17/2009

Figure 9 Frequency Distributions of Changes in Yearly FWM Concentration



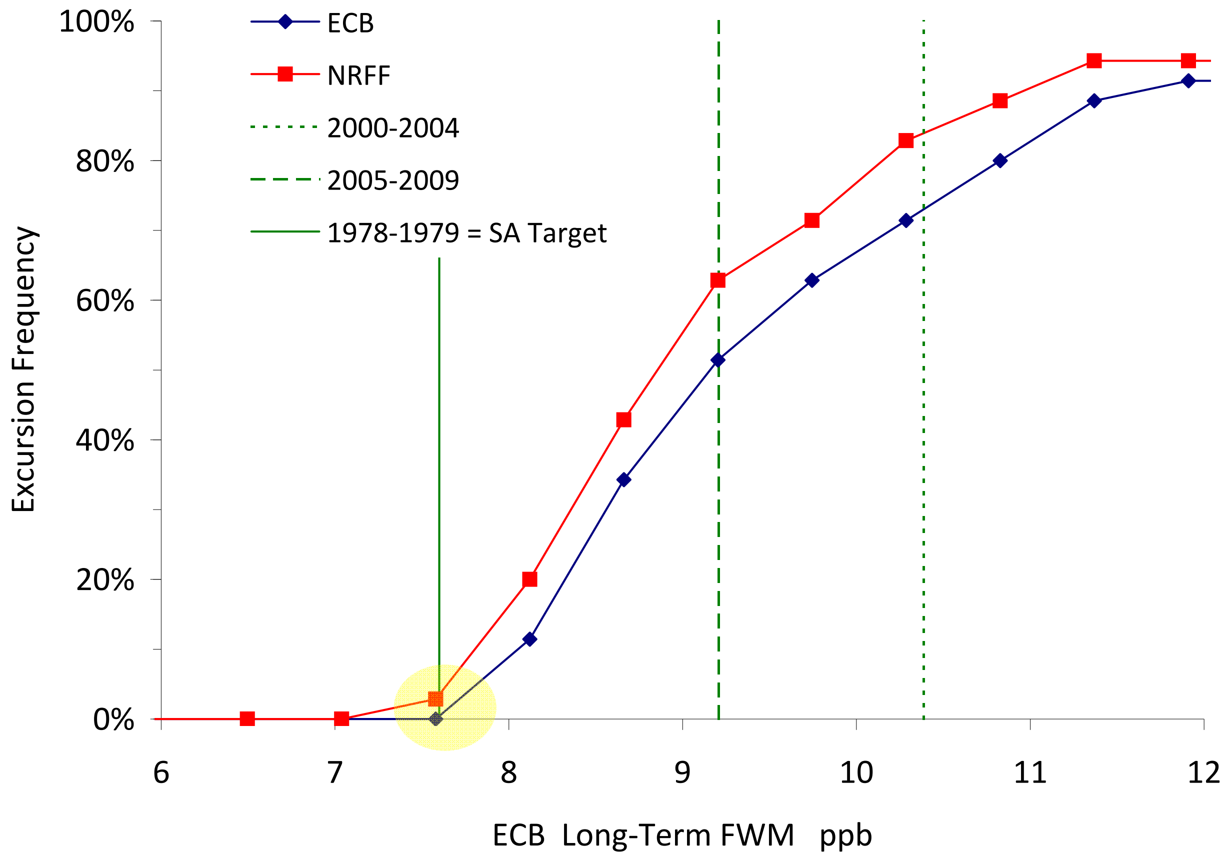
Yearly Time Series & Cumulative Frequency Distributions, Differences in Yearly TP Concentration (NRFF - ECP)

Computed for Different Portions of the Slough & the Compliance Determinant (SRS FWM - LT Limit)

Bottom Chart Correlates Changes in FWM with Changes in Flow i.e. Water Quality Impact vs. Hydrologic Benefit.

WWW 5/17/2009

Figure 10   LTL Excursion Frequency vs. Long-Term FWM Concentration



Frequency of Yearly SRS FWMs Exceeding Long-Term Limits Over 35-Year Simulation

Simulated FWMs Are Rescaled to Different Long-Term Means

WWW   5/17/2009