Attachment H –
Assumptions and Modeling Report

Evaluation of Alternatives to Achieve Phosphorus WQBELs in Discharges to the Everglades Protection Area

prepared for

U.S. Environmental Protection Agency

By

William W. Walker, Jr., Ph.D
Environmental Engineer
Concord, Massachusetts
http://www.wwwalker.net

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The following summarizes key assumptions and modeling results for alternative plans to achieve Water Quality Based Effluent Limits (WQBELs) for total phosphorus concentrations in discharges from Stormwater Treatment Areas (STAs) into the Everglades Protection Area. It is assumed that follow-up studies will be performed to optimize features of selected alternative(s), as well as to evaluate schedule and cost factors in order to provide a basis for selecting the final design.

1) The design target for STA outflow concentrations is 11.5 ppb, expressed long-term (40-year) flow-weighted mean outflow concentration (LTFWM). This target is approximately equivalent to a long-term geometric mean (LTGM) of 9.3 ppb, based upon the statistical derivation of the WQBEL. The target provides a margin of safety for achieving the P Criterion (LTGM= 10 ppb) and reducing the risk of exceeding the WQBELs.

2) Treatment objectives can be achieved using various combinations of (a) expanded Stormwater Treatment Areas (STAs), (b) Flow Equalization Basins (FEBs), (c) diversion of flows with relatively low P concentrations from the C51 East basin into the Refuge STAs, and (d) distribution of flows across the FEBs and STAs to optimize performance.

3) For purposes of design, no additional phosphorus source controls beyond those in place during 2005-2009 are assumed. Source controls, further optimization of the STA designs and operation, and other measures may be implemented by SFWMD to provide an additional margin of safety and reduce the risk of exceeding the WQBEL.

4) The existing treatment facilities do not include FEBs. In the scenarios evaluated, FEB maximum depths range from 8 to 44 feet, as compared with STA maximum depths of ~4 feet. Their primary functions are to improve STA performance by storing and attenuating

peak flows during wet periods and by releasing flow during dry periods to help maintain STA water levels and vegetation. FEBs provide operational flexibility for real-time regional water management (e.g. balancing flows across STAs; facilitating STA maintenance). These benefits provide an additional margin of safety that is not reflected in the model simulations. Optimization of the FEB parameters in subsequent design studies may improve performance and provide additional operational flexibility.

5) Average source flows, phosphorus loads, and phosphorus concentrations that provide a basis for design are listed in Table 1. The datasets have been developed jointly with SFWMD.

6) Flows are derived from Restoration Strategies Baseline South Florida Water Management Model (RSB2X2) daily simulation of WY 1966-2005 (May 1, 1966 – April 30, 2005) hydrologic conditions with current infrastructure.

7) Source concentrations are based upon monthly flow-weighted means computed from monitoring data collected between Water Years 2005-2009 (May 1, 2004 to April 30, 2009). Phosphorus concentrations in releases from Lake Okeechobee to STA-34 are based upon data collected at the lake outlet structure.

8) It is assumed that average STA inflow volumes, concentrations, and loads computed from 2005-2009 data and 2x2 simulated flows will not increase in the future.

9) To account for reductions in watershed area associated with STA or FEB construction, source flows and loads are reduced based upon the ratio of the effective treatment area of the project to the existing watershed area in the basin containing the project.

10) For initial planning purposes, the effective treatment area (surface area at normal operating depth) for each STA or FEB is increased by 10% to estimate the total amount of land required. This accounts for the associated infrastructure (pumps, canals, levees, roads, etc). The 10% factor will be adjusted in detailed design depending on the actual site locations and STA/FEB configuration, as long as the effective treatment area of the final project is not less than that specified in the planning scenarios.

11) Each scenario is designed to treat all of the flow discharged from the source basins over the 40-year simulation period (WY 1966-2005). More detailed hydraulic analyses will be needed to design the infrastructure and operations needed to guarantee that there will be no untreated bypasses around the STAS into the Everglades under hydrologic conditions that are reflected in the 40-year simulation period. Infrastructure and operational plans will be provided to divert infrequent extreme event flows that exceed STA treatment capacity to the coast or other locations outside of the Everglades Protection Area.

12) None of the WQBEL scenarios rely on future construction or operation of projects that are outside of the scope of those specified in the scenarios (e.g. CERP or other restoration projects).

13) The selected alternative will not decrease the average inflow to Loxahatchee Refuge or adversely impact water levels, as evaluated with the Refuge water balance model (SRSM) and its associated performance measures. Preliminary analyses indicate that each of the scenarios meets the Refuge water needs according to these criteria. This will be confirmed before selecting a final alternative in the subsequent design phase.

14) The Dynamic Model for Stormwater Treatment Areas (DMSTA, Walker & Kadlec, 2005, http://www.wwwalker.net/dmsta) is used to simulate the hydraulics and phosphorus removal performance of the FEBs and STAs. DMSTA was developed explicitly for this purpose and calibrated to extensive monitoring data from the STAs, test cells, and other treatment wetlands. The model has been used in several feasibility and detailed design studies performed by SFWMD and its contractors over the 2001-2010 period. Despite inherent modeling uncertainties and limitations, the SFWMD, state, and federal agencies have agreed that this is the best available tool for use in design. Summary of model input values is provided in Table 2.

15) Modeling uncertainty is estimated at ± 15% of the predicted LTFWM for each STA. The total forecast uncertainty is likely to be greater because of variability in future climatologic conditions and uncertainty in the assumed source flows and phosphorus loads. In addition to the margin of safety inherent in the specified design target (equivalent to a LTGM = 9.3 vs. 10 ppb), additional measures can be taken to account for performance uncertainty and reduce risk of exceeding the WQBEL (e.g., source controls, further STA optimization, research and monitoring to improve treatment technology).

16) The scenarios (Table 3) include four basic alternatives (A, B, C, D) involving different combinations of expanded STAs, FEBs, and diversion of additional flow into the Everglades from the C51 East Basin. Each scenario is simulated with a final configuration (full-scale operation) and interim configuration (partial construction, accelerated to achieve WQBEL in STA34 and improve performance of the other STAs). For comparison purposes, the scenarios also include the existing STAs with and without Compartments B & C in operation.

17) Table 4 summarizes the water and phosphorus balances for each STA and scenario. WQBEL excursion frequencies are calculated from the yearly outflow FWM time series for each STA. Based upon WQBEL derivation results, the yearly FWM is divided by 1.23 to estimate the outflow geometric mean. Under full operation (Scenarios A, B, C, D), the predicted number of excursion events over the 40 year record ranges from 0 to 3. The results do not account for the inherent uncertainty in climate, source datasets, STA vegetation management, and modeling. Implementing source controls and additional measures not assumed in the design calculations will provide a margin of safety and reduce the risk of exceeding the WQBEL in the context of the uncertainties associated with forecasting project performance.

18) The STA/FEB expansion requirements and outflows to the EPA and Lake Worth for each alternative under full operation are summarized below. The total area requirements vary over a relatively narrow range (41-44 kac). The C51E Diversion/FEB scenarios (C & D) provide significant increase in total flow to the Everglades without substantially increasing the total area requirements relative to Scenarios A & B.

Full Operation	New	New Effective Area kac			Total	Outflow kaf/yr	
Scenario	Inflow	STA	FEB	Total	kac	To Ever	Estuary
A - East & Cent STA	-	30.6	7.0	37.6	41.4	1416	273
B - East STA, Cent FEB	-	28.5	10.0	38.5	42.4	1408	203
C - C51 FEB, Cent STA	C51E	30.0	8.7	38.7	42.5	1584	16
D - C51 FEB, Cent FEB	C51E	27.0	12.7	39.7	43.6	1574	16

Table 1- Source Flows & Phosphorus Loads (Prior to STA Expansion) *

Source	Flow kac-ft/yr	Load mt/yr	Conc ppb
S5A Runoff to WPB	235.4	53.0	182
298 - EBWCD	24.2	14.7	492
S361 Runoff to STA1E	9.7	0.9	73
C51 West + ACME	159.7	32.2	163
L8 Runoff to C51W Canal	25.0	4.2	135
S352 Urban Water Supply	2.3	0.3	103
Total STA-1W+1E	456.3	105.2	187
S5A Runoff to STA2	61.0	16.0	213
S6 Runoff to STA2	181.2	27.8	124
ESWCD & 715 to Hills	31.0	6.3	165
Total STA-2 + Comp B	273.2	50.2	149
S7 Runoff to STA34	121.5	18.1	121
S7 Runoff to Comp B (redirected)	142.2	21.0	120
S8 Runoff to STA34	219.4	28.3	104
298 - SSD	5.2	0.7	112
298 - SFCD	19.1	2.6	112
298 - SSDD	6.9	1.2	139
C139_G136 to STA34	11.7	3.0	209
S354 Lake Urban WS	19.6	3.7	153
S351 Lake Urban WS	6.8	1.5	178
S354 Lake Reg Release	58.5	12.4	172
Total STA-34	611.0	92.5	123
C139 South Runoff	176.6	50.1	230
C139 North Runoff (L1/G136)	2.4	0.7	234
C139 Annex	21.3	2.6	97
STA6 Water Supply	6.8	1.4	171
Total STA 5-6	207.1	54.8	214
Total All Basins	1547.6	302.7	158
C51E Diversion Option			
Total C51E Runoff	202.6	23.9	96
C51E Diverted to STA1W/E	187.1	22.1	96
C51E Discharged to Estuary	15.6	1.9	96

* Assumptions and data developed jointly with SFWMD.

Table 2 – Summary of DMSTA Modeling Assumptions	
Parameter	Comments
General	Except where noted, DMSTA parameters for the existing STA cells are derived from the values assumed in the September 2009 update of the Long-Term Plan and/or updates specified in SFWMD simulations of WQBEL scenarios. Detailed model parameters are specified in the DMSTA input file for each scenario.
Simulation Dates	Start Date: 1/1/1965 (SFWMM Output); Output Dates: 5/1/1965-4/30/2005 (Water Years 1966-2005)
Number of Iterations	1 iteration. The initial P storage in each cell is initialized at the average value predicted from the previous model run; this enables simulation with 1 iteration provided that the each scenario is simulated at least twice in the course of the design process.
Atmospheric Deposition	Assumed in DMSTA calibration and previous design studies. Dry deposition 20 mg/m^2-yr; Rainfall P Concentration = 10 ppb.
Duty Cycle Factor	Duty Cycle = 0.95 for STAs; refers to the portion of time that an STA is offline for major maintenance or rehabilitation activities. A value of 0.95 is meant to correspond to an STA being offline 5% of the time (1 year out of every 20 years). This assumption is consistent with historical STA operations after startup periods. Duty Cycle = 1.0 for FEBs; minimal vegetation management
DMSTA Vegetation Types	EMG: Emergent or unmanaged vegetation on previously farmed or disturbed soils SAV: Cells managed to promote submersed aquatic vegetation (SAV); generally deeper then emergent cells PSTA: Periphyton treatment area on limerock/shellrock substrate PEW: Pre-Existent Wetland; emergent or unmanaged veg. on previous wetland or undisturbed soils RES: Deep (8-44 ft); open water; dominated by algae and floating vegetation, as opposed to emergent or submersed vegetation. Current STAs contain various combinations of emergent and SAV. STA-2 cell 2 is modeled using the PEW calibration (existing). The EMG/SAV split for new cells in the eastern & central basins is 33/67, typical of the existing STAs.

	The EMG/PEW split for new cells in the western basin is 60/40. Downstream cells in each flow path of the existing and expanded STAs in the western basin are modeled using the PEW calibration. Maintenance of SAV in the western basin has proven to be difficult because of high seepage rates, frequent dry-out, and low calcium levels in the basin runoff. The RES calibration is used for FEBs. None of the cells are modeled with the PSTA calibration, although conversion to periphyton communities may be a future management option.
Inflow Fraction	Total cell area in each flow path / total STA area; balances hydraulic loads across flow paths within each STA
Mean Width of Flow Path	As constructed for existing cells. The width of new flow paths is computed from area assuming a 3/1 length to width ratio along each EMG/SAV flow path. A length/width ratio of 1.0 is assumed to FEBs. Performance is insensitive to width assumptions.
Number of Tanks in Series	A TIS value of 1 is used for FEBs. Consistent with previous design assumptions, a TIS value of 3 is used in each new STA cell. This assumes that the cell will be constructed and managed to provide relatively even ground surface and flow distribution across the width of each flow path (minimal short-circuiting) and contain at least one internal levee to separate the emergent and SAV communities.
FEB Release Series	Release to STAs to help maintain water levels in droughts. Computed based upon 30-day antecedent average ET – Rainfall multiplied by the downstream STA area. If ET exceeds rainfall, a proportionate release is made; potential release from C51 FEB for urban water supply; release for maintenance of Refuge stage (minimum total inflow to STA1E+W from all sources = 500 cfs for June-October; not optimized). Minimum drawdown depth = 0.5 ft.
FEB Depth Series	Monthly regulation schedule specified for FEBs. Range from 0% in wet season (to capture storms) to 80% of capacity in dry season (stores water for use in STA irrigation, urban water supply); To be optimized in final design.
FEB Outflow Hydraulic Coefficients	Slope = 1; intercept varied to provide specified mean hydraulic residence time in the FEB (90 days in western FEB, 60 days in central FEB, 30 days in FEB). Values adjusted based upon simulated water levels, flow capture, and flow attenuation; to be optimized in final design.
STA Outflow Control Depth	~1.25 ft. No outflow below this level; typical of existing STA cells
STA Outflow Hydraulic Coefficients	Slope = 4, Intercept = 1; typical values calibrated to existing STA cells

STA Bypass Triggers	Each STA is assumed to treat all of the simulated flow without bypass. Simulated water levels and inflow volumes are generally consistent with that assumption, but will be confirmed in detailed design, which will provide suitable infrastructure to avoid untreated bypass.
FEB Bypass Triggers	Maximum depth varies with design (12 ft for West, 8 ft for Central, 44 ft for Eastern FEB (C51E Project Design)); Maximum inflows (2500, 3000, and 2000 cfs, respectively); to be optimized in final designs.
Seepage Rates	Generally consistent with seepage rates assumed in previous simulations of the existing STAs (.005 – 0.2 cm/d/cm) ; seepage rates in STA-34 are reduced by 75% relative to SFWMD simulations to be more consistent with the observed overall water budget of STA-34. No seepage losses assumed for FEBs; seepage rates to be considered in final design (could be released to STAs or recycled to FEB).
Seepage Recycling	No seepage recycling is included in the simulations. This is conservative with respect to maintaining STA water levels. Any seepage recycling in new cells would depend on cell location and configuration relative to existing cells. Seepage collection and recycling will be optimized in detailed designs.

Table 3 – Scenario Definitions and Results

All Scenarios: Long-Term Flow-Weighted-Mean Design Target = 11.5 ppb (equivalvent to LT Geometric Mean ~ 9.3 ppb), 2005-2009 Source TP Concentrations

			Inflow Conc ppb			STA Expan. (Effective)*				FEB Effective Area				FEB Vol.	FEB+STA		Outflow FWM ppb ***					Outflows kac-ft/yr			
ID	Label	Description	West	Cent	East	West	Cent	East	Total	West	Cent	East	Total	kac-ft	Effect	Total	West	34	2+B	East	Total	WCA1	2A+3A	Total	Estuary
1	Current **	Current System without Comp B & C	214	131	187	8.9	24.8	11.8	45.5						45.5	50.0	**29.7**	**25.5**	**33.2**	**34.6**	**30.1**	448	1050	1497	273
2	Current + Comp B & C **	Current System with Comp B & C	214	131	187	13.0	31.7	11.8	56.5						56.5	62.1	**18.3**	**15.7**	**20.3**	**34.1**	**23.0**	448	1042	1490	203
3	A - East & Cent STA	STA Expansion in East & Central; 12-ft FEB in West	219	131	187		15.6	15.0	30.6	7.0			7.0	84	37.6	41.4	11.4	11.5	11.5	11.4	11.5	429	987	1416	273
4	B - East STA, Cent FEB	8-ft FEB in Comp A2, STA in Comp A1,; 12-ft FEB in West; STA expansion in East	219	131	187		13.5	15.0	28.5	7.0	3.0		10.0	108	38.5	42.4	11.5	11.3	11.3	11.4	11.4	429	979	1408	203
5	A/B-Interim (4 yrs)	Interim Plan for Scenarios 3 or 4; A1 Operated as 4 ft FEB; balance flows to achieve WQBEL in STA34; Meanwhile construct A2 8-ft FEB (or STA), Convert A1 FEB to STA, expand STA1W; 12-ft FEB in West	214	132	188						15.0		15.0	60	15.0	16.5	**18.3**	11.2	**18.2**	**31.9**	**20.4**	448	975	1397	228
6	C - C51 FEB, Cent STA	C51E Diversion & 44-ft Rockpit / FEB + STA Expansion in East & Central; 12-ft FEB in West	219	131	160		22.0	8.0	30.0	7.0		1.7	8.7	157	38.7	42.5	11.1	11.5	11.5	11.5	11.5	444	1140	1584	16
7	D - C51 FEB, Cent FEB	C51E Diversion & Rockpit/FEB in East; 8-ft FEB, STA Exp in A1 & A2, 12-ft FEB in West	219	132	160		19.0	8.0	27.0	7.0	4.0	1.7	12.7	189	39.7	43.6	11.5	11.5	11.5	11.5	11.5	444	1130	1574	16
8	C/D - Interim (4 Yrs)	Interim Plan for Scenarios 6 or 7; C51E rockpit partially complete (6 ft vs. 44 ft final); divert L8 flows to coast; some S5A to west; no C51E diversion; A1 Operated as 4 ft FEB; achieve WQBEL in STA34; Meanwhile construct other project components (FEB in Comp A2, Complete C51 Rockpit, STA1W Expansion)	214	132	188						15.0	1.7	16.7	70	16.7	18.4	**18.3**	11.3	**19.2**	**30.4**	**20.0**	389	1004	1393	226

* Preliminary Designs Subject to More Detailed Analysis and Optimization. Approximate Model Uncertainty +/- 15% of Predicted Outflow Concentrations.

** Existing & Planned STA Effective Areas listed for Scenarios 1 & 2; STA Expansion areas listed for other scenarios; West = STA-5, STA-6, Comp C; Central = STA-34, Comp B, STA-2; East = STA-1W & STA-1E.

***** Bold Fonts Indicate STA's Not Achieving 11.5 ppb LTFWM Target (Existing Conditions or Interim Plans)**

Table 4 - STA Mass Balances & Performance

Scenario 1 Existing STAs

	Effect	STA Inflows			STA Outflows			30-Day Hydraulic Load			Depth	Settling	FEB Area	Depth	WQBEL Excursions / 40 Yrs		
	Area	Flow	Load	Conc	Flow	Load	Conc	Mean	Max	CV	Freq	Rate	kac	ft	Yearly	>2 Yrs	Both
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d	-	< 10 cm	m/yr			FWM > 18	GM > 10	Tests
STA1E	5.1	194	37.3	155	185	6.5	28.2	3.2	20.1	0.88	0%	26			29	35	37
STA1W	6.7	262	68.0	210	263	12.7	39.1	3.3	20.6	1.02	0%	26			40	38	40
STA2B	8.2	273	50.2	149	275	11.3	33.2	2.8	14.0	0.98	0%	20			40	38	40
STA34	16.5	611	92.6	123	601	18.9	25.5	3.1	13.1	0.85	1%	23			37	38	40
STA5	6.1	143	37.8	214	125	4.8	30.9	2.0	8.9	0.96	1%	18			40	38	40
STA6	2.8	64	17.0	214	48	1.6	26.5	1.9	8.7	0.96	7%	20			39	38	40
Total	45.5	1548	302.7	158	1497	55.7	30.1										

Scenario 2 Existing STAs + Compartments B & C

	Effect	STA Inflows			STA Outflows			30-Day Hydraulic Load			Depth	Settling	FEB Area	Depth	WQBEL Excursions / 40 Yrs		
	Area	Flow	Load	Conc	Flow	Load	Conc	Mean	Max	CV	Freq	Rate	kac	ft	Yearly	>2 Yrs	Both
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d	-	< 10 cm	m/yr			FWM > 18	GM > 10	Tests
STA1E	5.1	221	44.1	162	211	8.8	34.0	3.6	20.8	0.86	0%	26			38	38	40
STA1W	6.7	236	61.2	210	237	10.0	34.1	2.9	18.6	1.02	0%	26			40	38	40
STA2B	15.1	474	79.9	137	478	12.0	20.3	2.6	13.0	0.99	0%	25			25	38	40
STA34	16.5	410	62.8	124	401	7.8	15.7	2.1	8.5	0.82	1%	23			5	23	24
STA5	7.9	126	33.4	214	106	2.4	18.3	1.3	6.1	0.96	2%	17			18	34	35
STA6	5.1	81	21.4	214	57	1.3	18.3	1.3	6.0	0.96	8%	17			16	34	35
Total	56.5	1548	302.7	158	1490	42.3	23.0										

Scenario 3 A- STA Expansion

	Effect	STA Inflows			STA Outflows			30-Day Hydraulic Load			Depth	Settling	FEB Area	Depth	WQBEL Excursions / 40 Yrs		
	Area	Flow	Load	Conc	Flow	Load	Conc	Mean	Max	CV	Freq	Rate	kac	ft	Yearly	>2 Yrs	Both
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d	-	< 10 cm	m/yr			FWM > 18	GM > 10	Tests
STA1E	5.1	109	20.4	152	102	1.5	11.6	1.8	7.1	0.75	0%	26			0	2	2
STA1W	21.7	321	78.9	199	327	4.6	11.3	1.2	7.0	0.95	0%	21			2	0	2
STA2B	15.1	248	46.1	151	253	3.6	11.5	1.4	6.9	0.98	0%	20			0	0	0
STA34	32.1	602	91.6	123	583	8.3	11.5	1.6	6.6	0.85	1%	21			0	1	1
STA5	7.9	122	24.3	161	101	1.4	11.4	1.3	3.7	0.61	0%	20	7.0	12	0	3	3
STA6	5.1	78	15.5	161	50	0.7	11.5	1.3	3.7	0.61	2%	19			0	2	2
Total	87.1	1479	276.7	152	1416	20.0	11.5										

Scenario 4 B- STA Expansion with A2 FEB

	Effect	STA Inflows			STA Outflows			30-Day Hydraulic Load			Depth	Settling	FEB Area	Depth	WQBEL Excursions / 40 Yrs		
	Area	Flow	Load	Conc	Flow	Load	Conc	Mean	Max	CV	Freq	Rate	kac	ft	Yearly	>2 Yrs	Both
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d	-	< 10 cm	m/yr			FWM > 18	GM > 10	Tests
STA1E	5.1	107	20.1	152	100	1.4	11.4	1.7	7.1	0.75	0%	26			0	1	1
STA1W	21.7	322	79.2	199	328	4.6	11.4	1.2	7.0	0.95	0%	21			2	0	2
STA2B	15.1	252	46.8	150	258	3.6	11.3	1.4	7.0	0.98	0%	21			0	0	0
STA34	30.0	589	85.5	118	570	8.0	11.3	1.6	7.0	0.81	0%	22	3.0	8	0	0	0
STA5	7.9	122	24.3	162	101	1.4	11.4	1.3	3.7	0.61	0%	20	7.0	12	0	3	3
STA6	5.1	78	15.5	162	50	0.7	11.5	1.3	3.7	0.61	2%	19			0	2	2
Total	85.0	1470	271.3	149	1408	19.7	11.4										

Table 4 - STA Mass Balances & Performance (ct.)

Scenario 5 A/B - Interim Plan without C51E Div/FEB

	Effect	STA Inflows			STA Outflows			30-Day Hydraulic Load			Depth	Settling	FEB Area	Depth	WQBEL Excursions / 40 Yrs		
	Area	Flow	Load	Conc	Flow	Load	Conc	Mean	Max	CV	Freq	Rate	kac	ft	Yearly	>2 Yrs	Both
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d	-	< 10 cm	m/yr			FWM > 18	GM > 10	Tests
STA1E	5.1	161	32.2	162	152	3.8	20.5	2.6	9.7	0.74	0%	28			20	35	36
STA1W	6.7	270	68.0	204	270	12.8	38.3	3.4	20.6	0.99	0%	27			40	38	40
STA2B	15.1	425	72.6	139	429	9.6	18.2	2.3	11.7	0.98	0%	25			16	35	37
STA34	16.5	393	47.6	98	383	5.3	11.2	2.0	8.8	0.77	1%	24	15.0	4	0	1	1
STA5	7.9	126	33.4	214	106	2.4	18.3	1.3	6.1	0.96	2%	17			18	34	35
STA6	5.1	81	21.4	214	57	1.3	18.3	1.3	6.0	0.96	8%	17			16	34	35
Total	56.5	1455	275.2	153	1397	35.2	20.4										

Scenario 6 C - C51E Div/FEB, STA Expan

	Effect	STA Inflows			STA Outflows			30-Day Hydraulic Load			Depth	Settling	FEB Area	Depth	WQBEL Excursions / 40 Yrs		
	Area	Flow	Load	Conc	Flow	Load	Conc	Mean	Max	CV	Freq	Rate	kac	ft	Yearly	>2 Yrs	Both
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d	-	< 10 cm	m/yr			FWM > 18	GM > 10	Tests
STA1E	5.1	123	18.7	123	116	1.6	11.5	2.0	7.0	0.70	0%	27	1.7	44	0	1	1
STA1W	14.7	327	63.2	157	328	4.7	11.5	1.9	8.6	0.57	0%	28			1	0	1
STA2B	15.1	291	64.0	178	296	4.2	11.5	1.6	7.0	0.97	0%	26			0	1	1
STA34	38.5	718	110.3	125	693	9.8	11.5	1.6	6.8	0.87	1%	21			0	1	1
STA5	7.9	122	24.2	161	101	1.4	11.4	1.3	3.8	0.61	0%	20	7.0	12	0	3	3
STA6	5.1	78	15.5	161	50	0.7	11.5	1.3	3.7	0.61	2%	19			0	2	2
Total	86.5	1659	296.0	145	1584	22.5	11.5										

Scenario 7 D -C51E Div/FEB, A2 FEB/ STA

	Effect	STA Inflows			STA Outflows			30-Day Hydraulic Load			Depth	Settling	FEB Area	Depth	WQBEL Excursions / 40 Yrs		
	Area	Flow	Load	Conc	Flow	Load	Conc	Mean	Max	CV	Freq	Rate	kac	ft	Yearly	>2 Yrs	Both
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d	-	< 10 cm	m/yr			FWM > 18	GM > 10	Tests
STA1E	5.1	123	18.7	123	116	1.6	11.5	2.0	7.0	0.70	0%	27	1.7	44	0	1	1
STA1W	14.7	327	63.2	157	328	4.7	11.5	1.9	8.6	0.57	0%	28			1	0	1
STA2B	15.1	291	64.0	178	296	4.2	11.5	1.6	7.0	0.97	0%	26			0	1	1
STA34	35.5	706	103.1	118	683	9.7	11.5	1.7	7.4	0.83	0%	22	4.0	8	0	2	2
STA5	7.9	122	24.3	162	101	1.4	11.4	1.3	3.7	0.61	0%	20	7.0	12	0	3	3
STA6	5.1	78	15.5	162	50	0.7	11.5	1.3	3.7	0.61	2%	19			0	2	2
Total	83.5	1647	288.8	142	1574	22.4	11.5										

Scenario 8 C/D - Interim Plan with C51E Div/FEB

	Effect	STA Inflows			STA Outflows			30-Day Hydraulic Load			Depth	Settling	FEB Area	Depth	WQBEL Excursions / 40 Yrs		
	Area	Flow	Load	Conc	Flow	Load	Conc	Mean	Max	CV	Freq	Rate	kac	ft	Yearly	>2 Yrs	Both
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d	-	< 10 cm	m/yr			FWM > 18	GM > 10	Tests
STA1E	5.1	117	21.9	152	110	1.7	12.9	1.9	8.1	0.77	0%	26	1.7	6	2	3	5
STA1W	6.7	281	66.0	190	279	12.8	37.3	3.5	21.6	0.95	0%	27			40	38	40
STA2B	15.1	453	78.7	141	458	10.9	19.2	2.5	12.3	0.98	0%	25			22	35	39
STA34	16.5	393	47.8	98	384	5.3	11.3	2.0	8.8	0.77	1%	24	15.0	4	0	2	2
STA5	7.9	126	33.4	214	106	2.4	18.3	1.3	6.1	0.96	2%	17			18	34	35
STA6	5.1	81	21.4	214	57	1.3	18.3	1.3	6.0	0.96	8%	17			16	34	35
Total	56.5	1451	269.1	150	1393	34.4	20.0										

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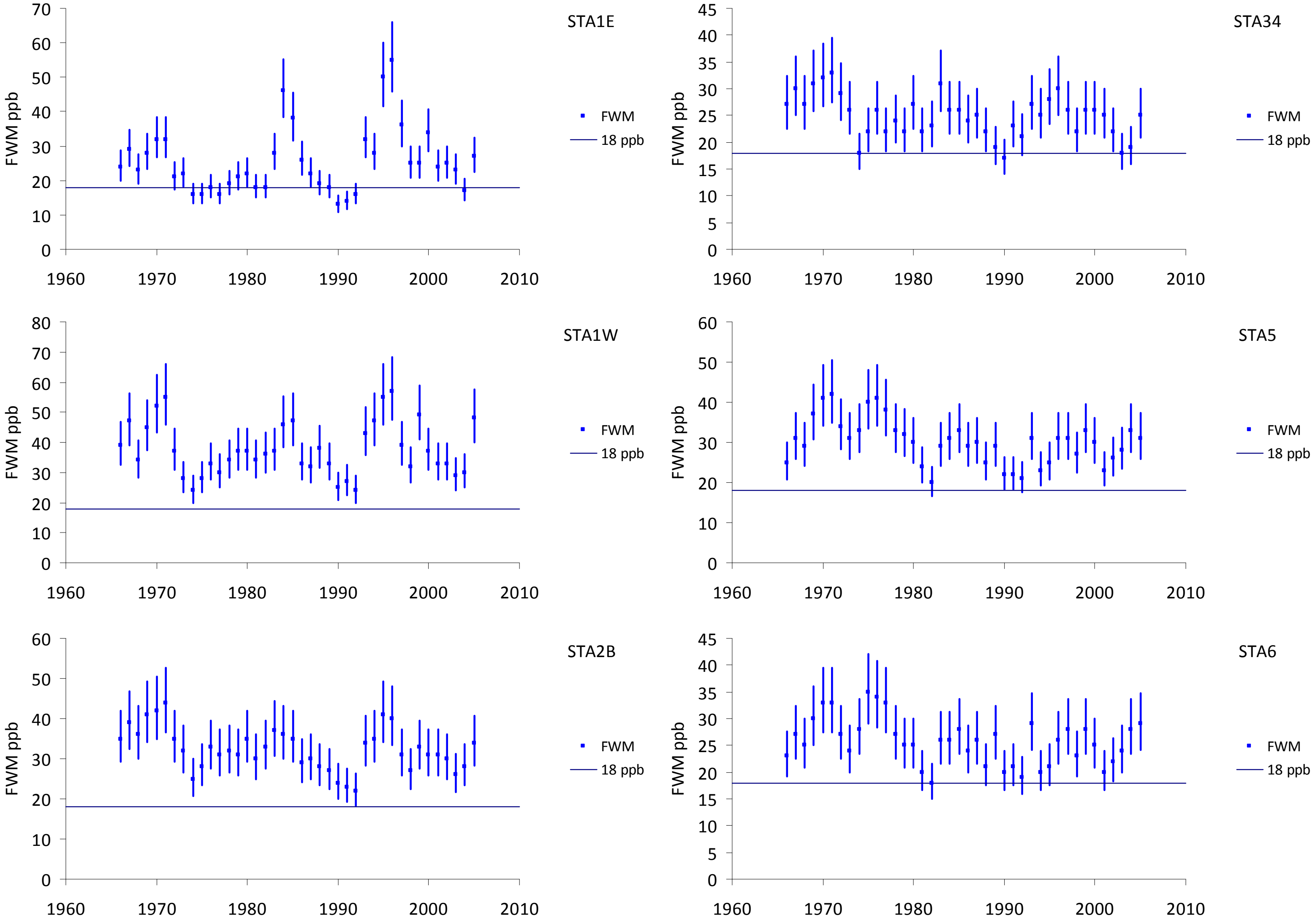
prepared for
U.S. Environmental Protection Agency
By
William W. Walker, Jr., Ph.D
Environmental Engineer
Concord, Massachusetts
http://www.wwwalker.net

Sept 2, 2010

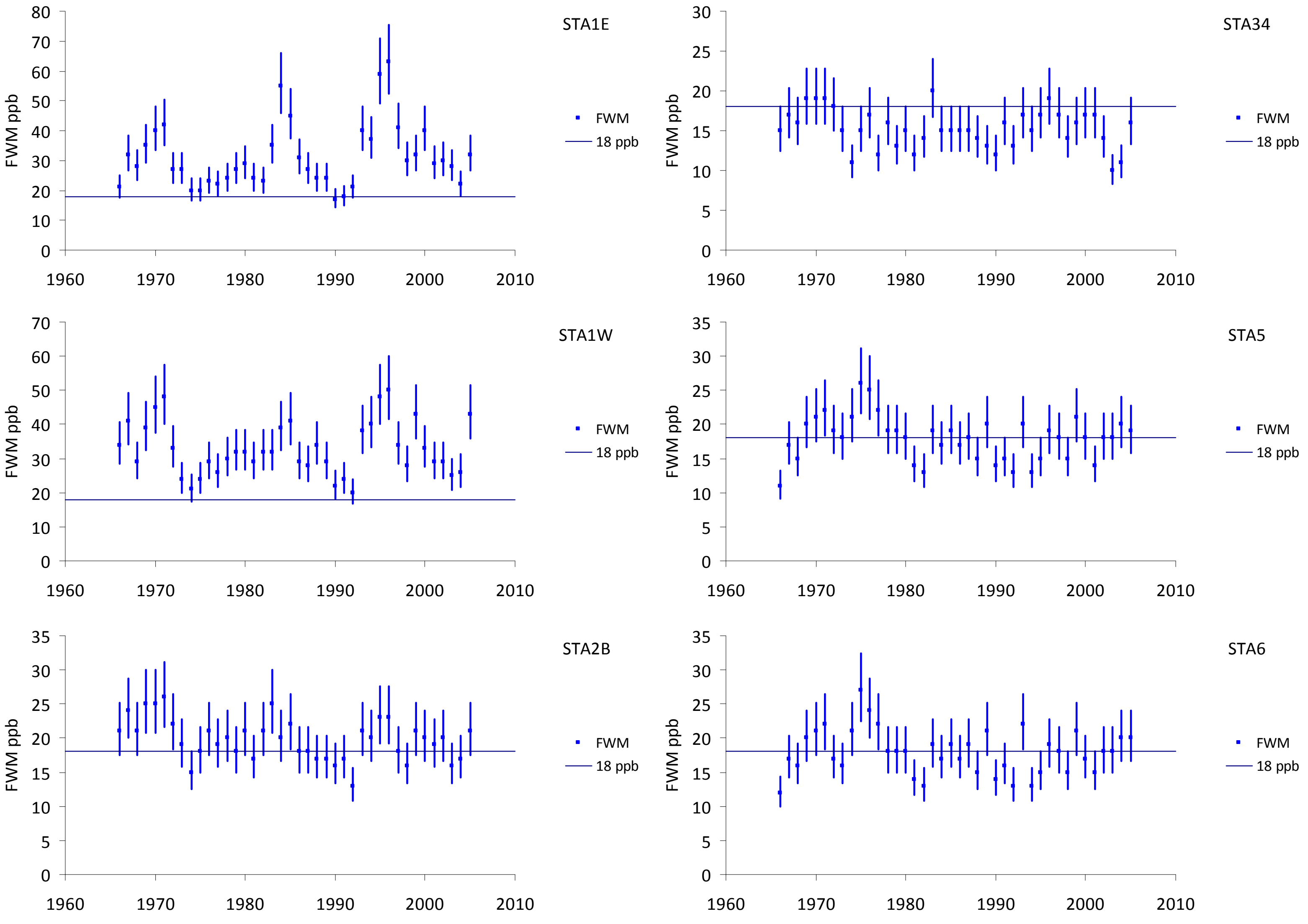
Attachment 1 : Yearly Flow-Weighted Mean Time Series for Each Scenario

Scenario 1 Existing STAs 80% Confidence Intervals for Yearly Flow-Weighted Means



Model Predictions +/- 20%; Rounded to nearest ppb. Solid Line = 18 ppb WQBEL.

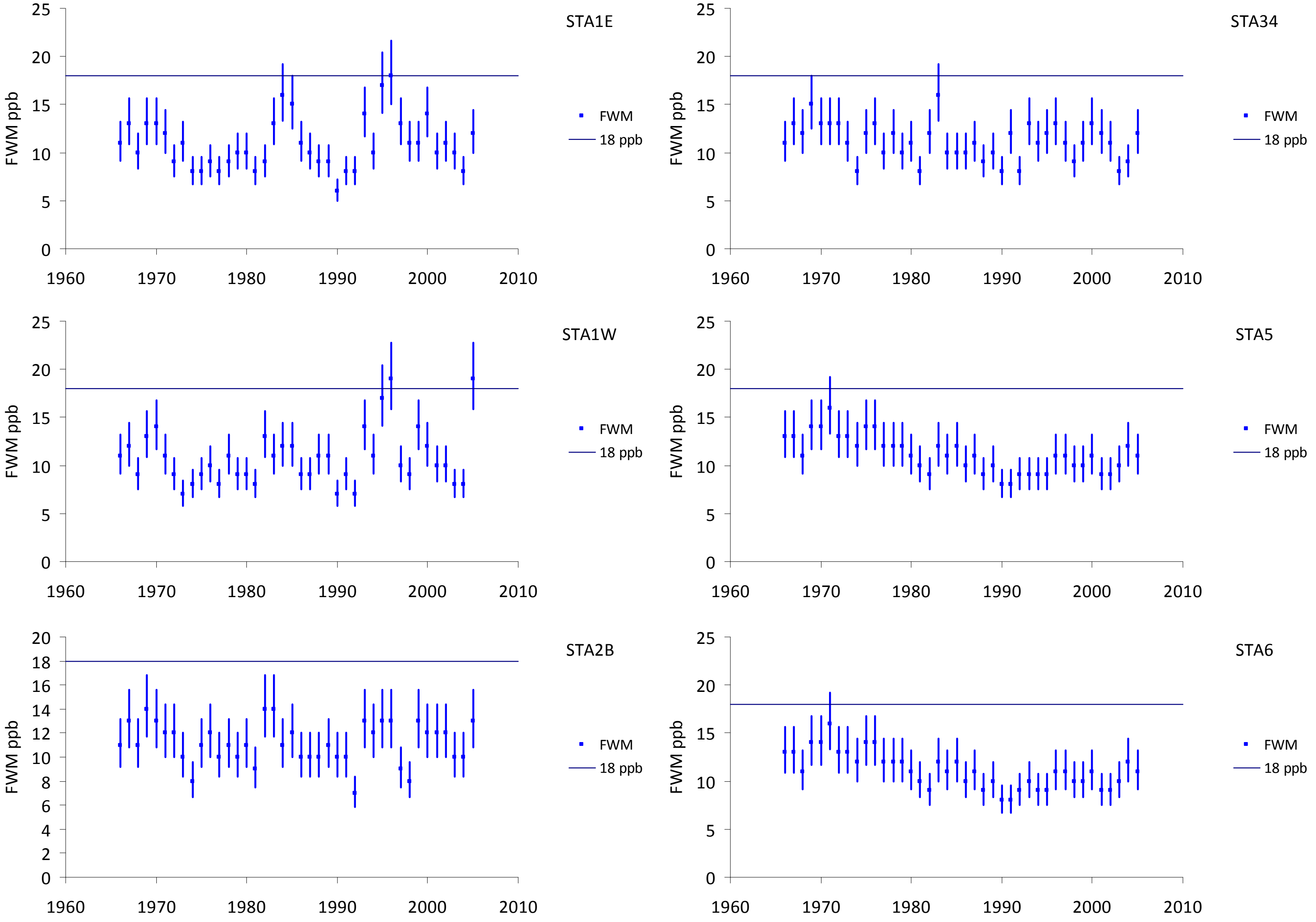
Scenario 2 Existing STAs + Compartments B & C 80% Confidence Intervals for Yearly Flow-Weighted Means



Model Predictions +/- 20%; Rounded to nearest ppb. Solid Line = 18 ppb WQBEL.

Scenario 3   A- STA Expansion

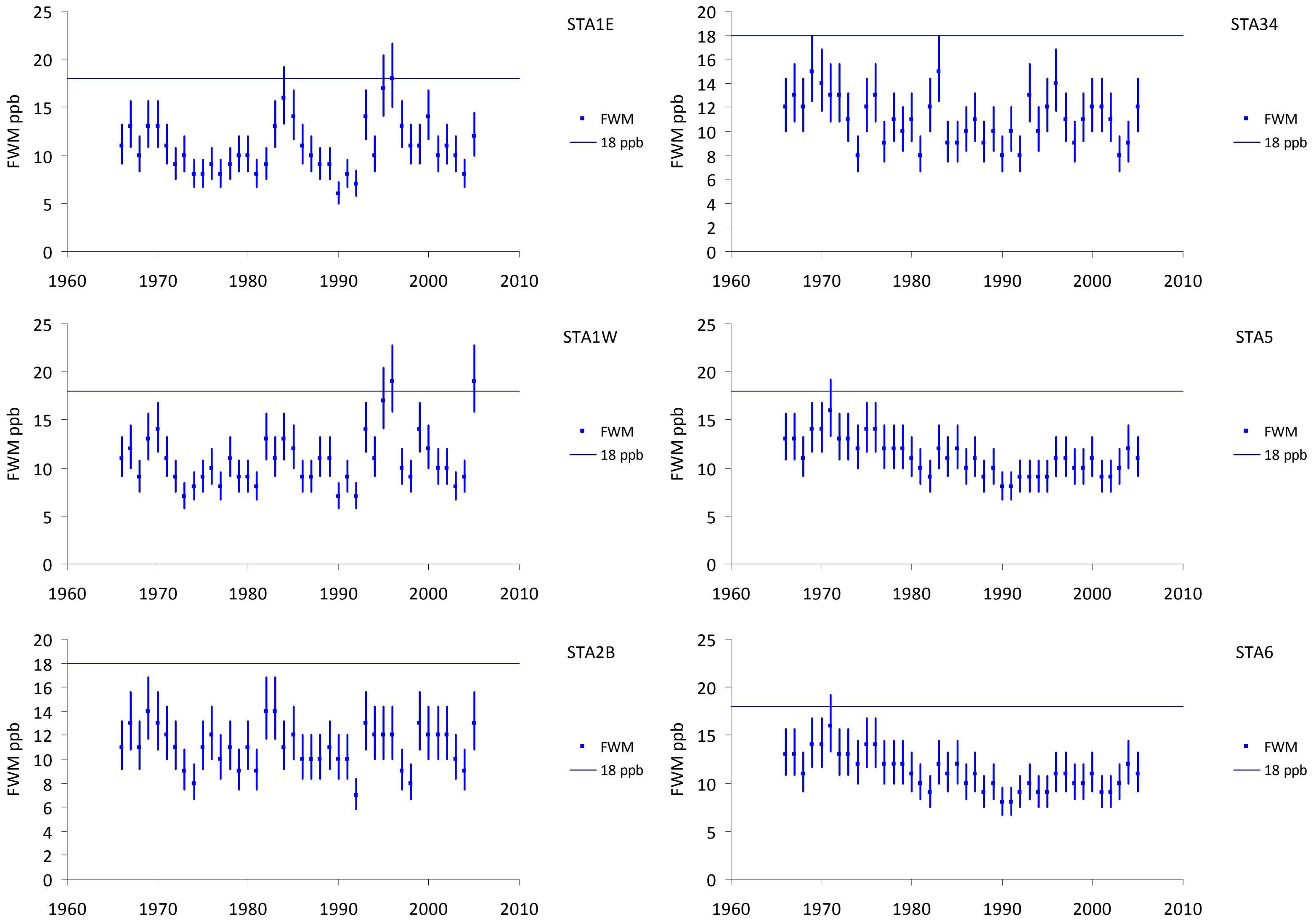
80% Confidence Intervals for Yearly Flow-Weighted Means



Model Predictions +/- 20%; Rounded to nearest ppb. Solid Line = 18 ppb WQBEL.

Scenario 4 B- STA Expansion with A2 FEB

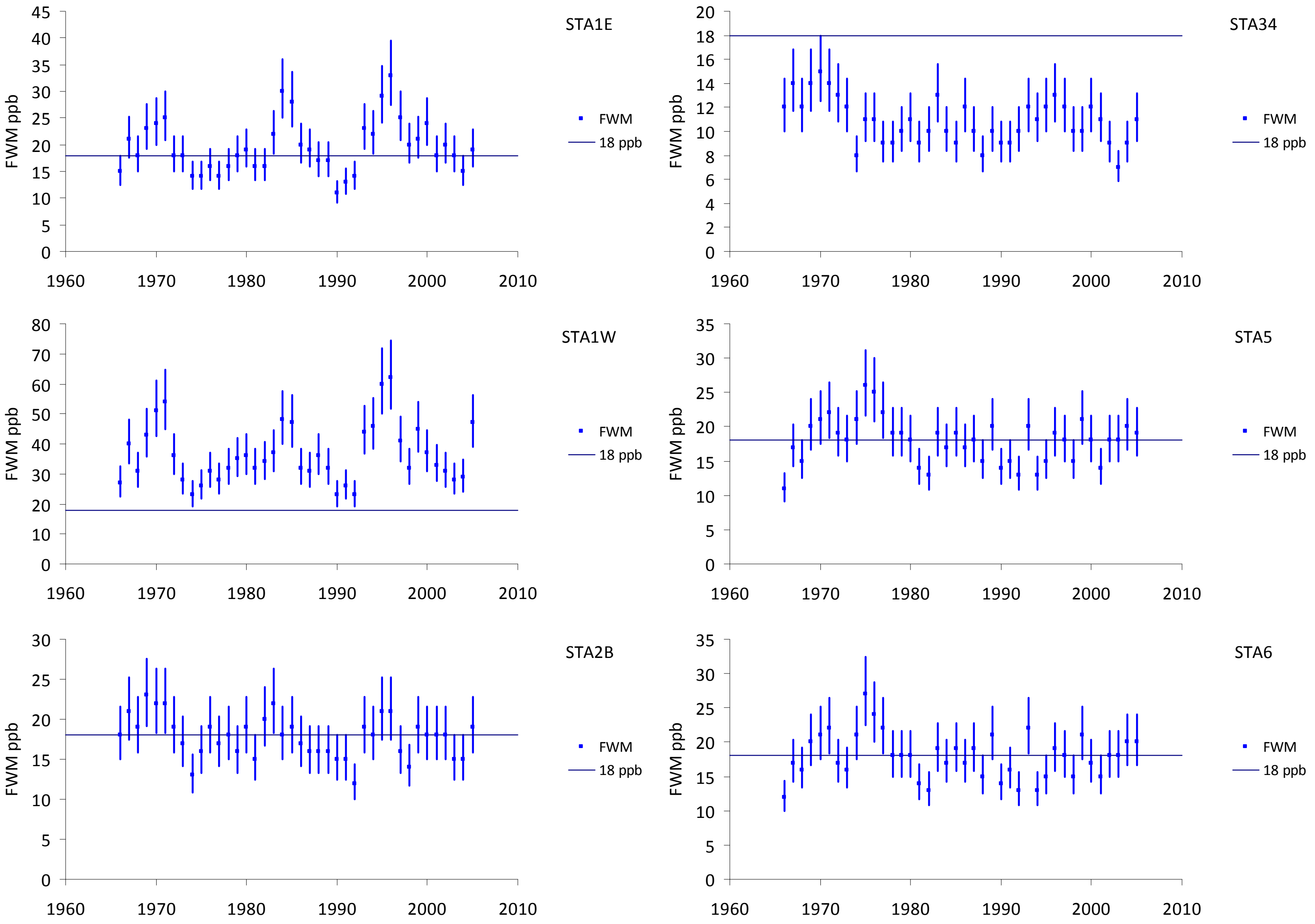
80% Confidence Intervals for Yearly Flow-Weighted Means



Model Predictions +/- 20%; Rounded to nearest ppb. Solid Line = 18 ppb WQBEL.

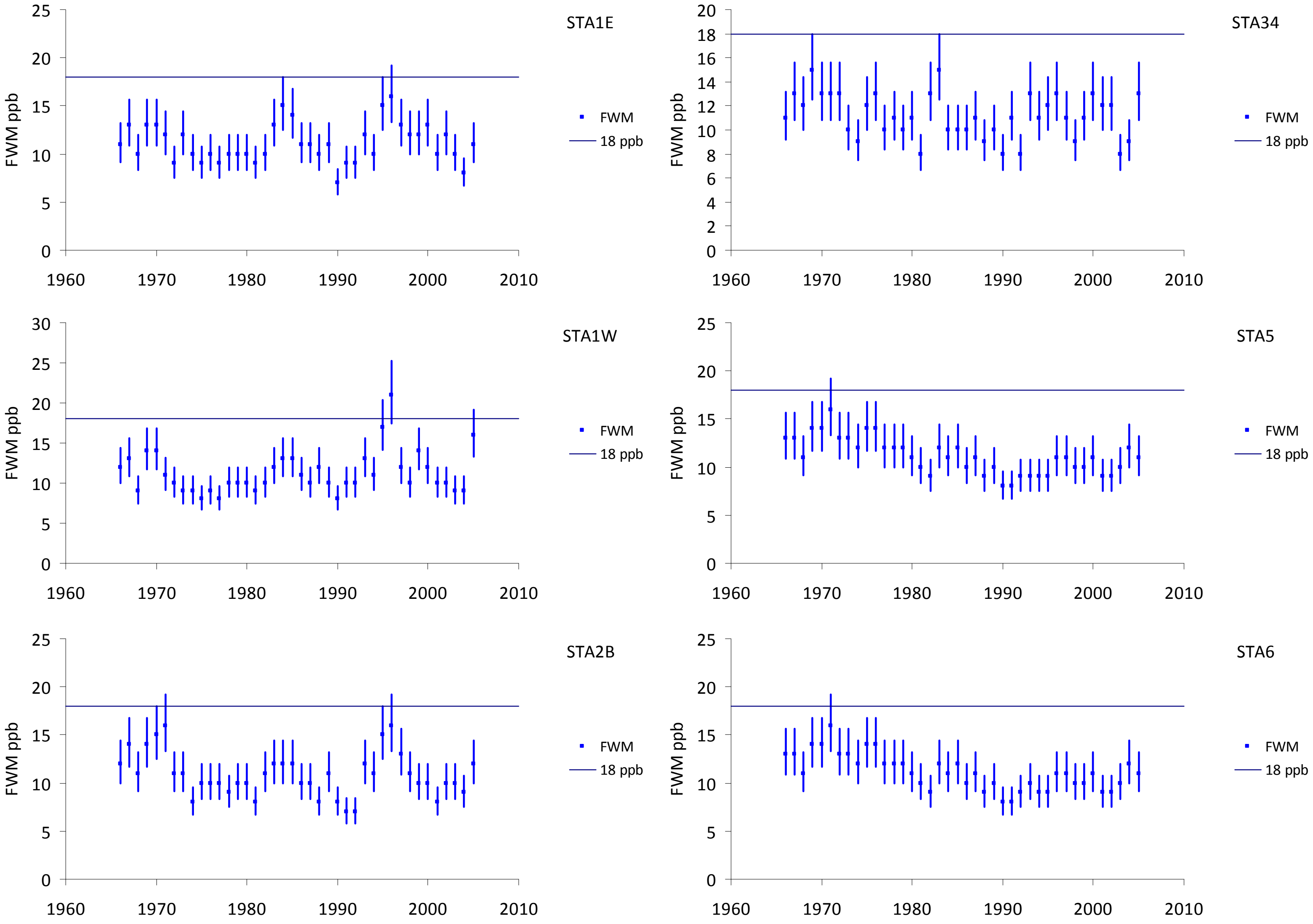
Scenario 5 A/B - Interim Plan without C51E Div/FEB

80% Confidence Intervals for Yearly Flow-Weighted Means



Model Predictions +/- 20%; Rounded to nearest ppb. Solid Line = 18 ppb WQBEL.

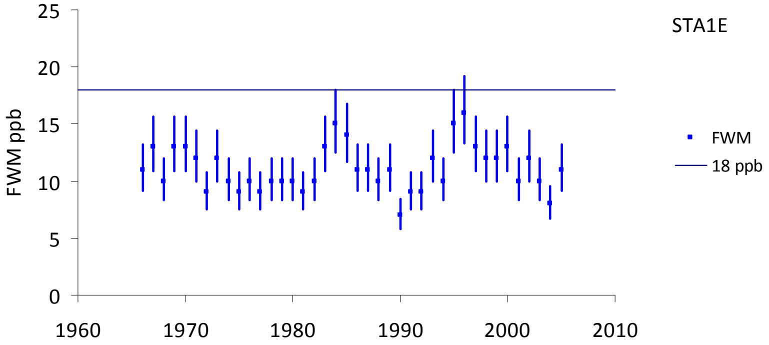
Scenario 6 C - C51E Div/FEB, STA Expan 80% Confidence Intervals for Yearly Flow-Weighted Means

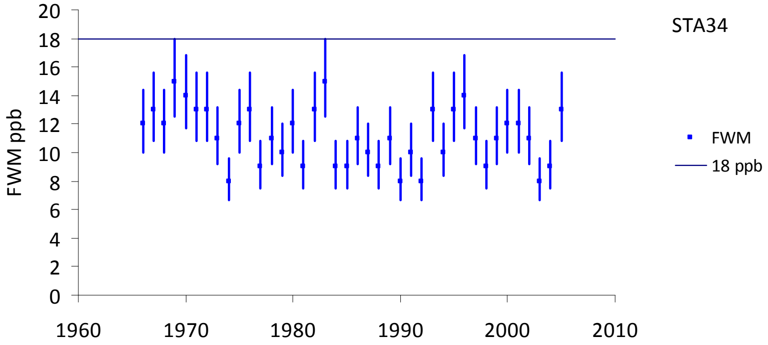


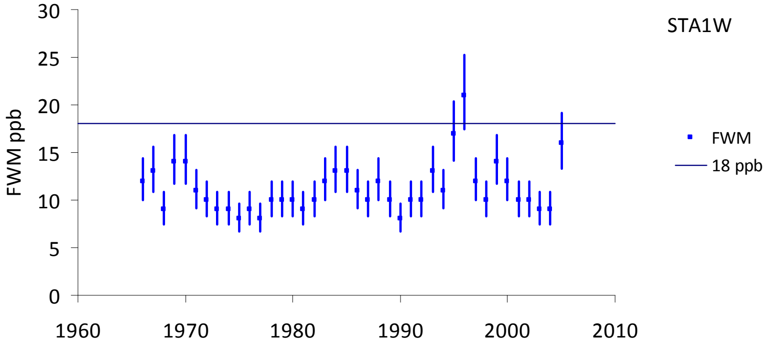
Model Predictions +/- 20%; Rounded to nearest ppb. Solid Line = 18 ppb WQBEL.

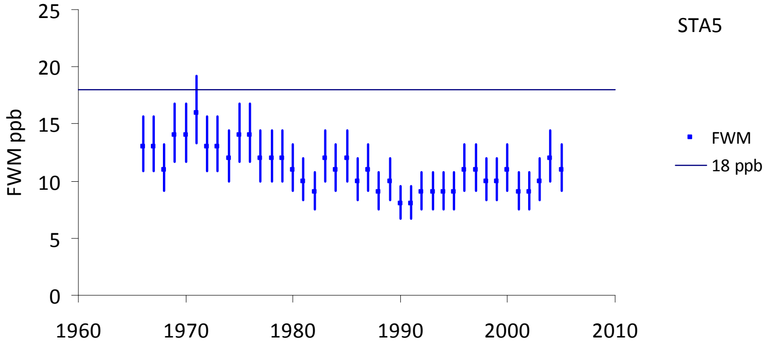
Scenario 7 D -C51E Div/FEB, A2 FEB/ STA

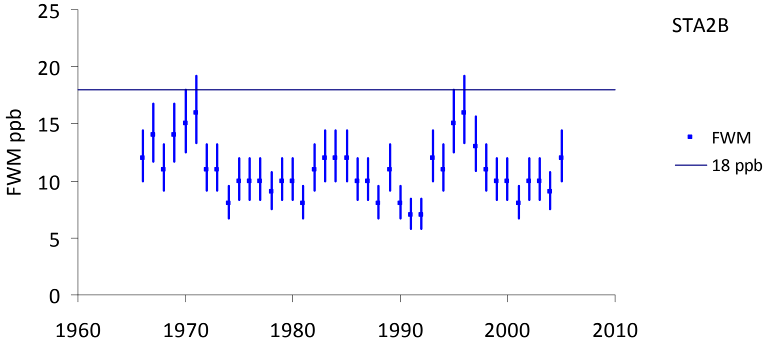
80% Confidence Intervals for Yearly Flow-Weighted Means

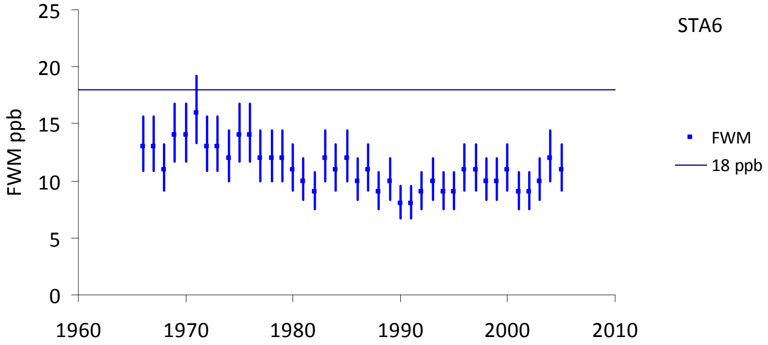






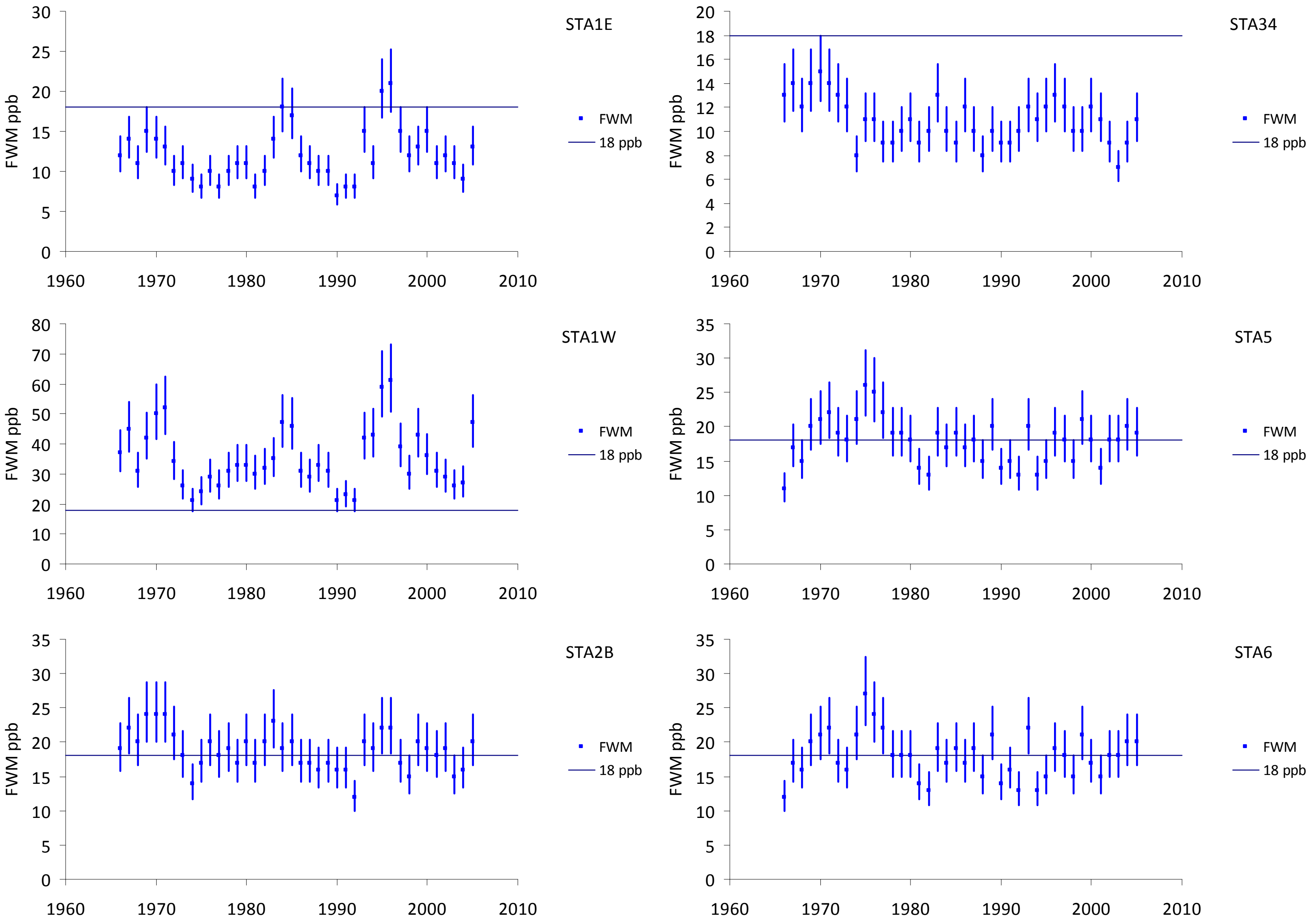






Model Predictions +/- 20%; Rounded to nearest ppb. Solid Line = 18 ppb WQBEL.

Scenario 8 C/D - Interim Plan with C51E Div/FEB 80% Confidence Intervals for Yearly Flow-Weighted Means



Model Predictions +/- 20%; Rounded to nearest ppb. Solid Line = 18 ppb WQBEL.

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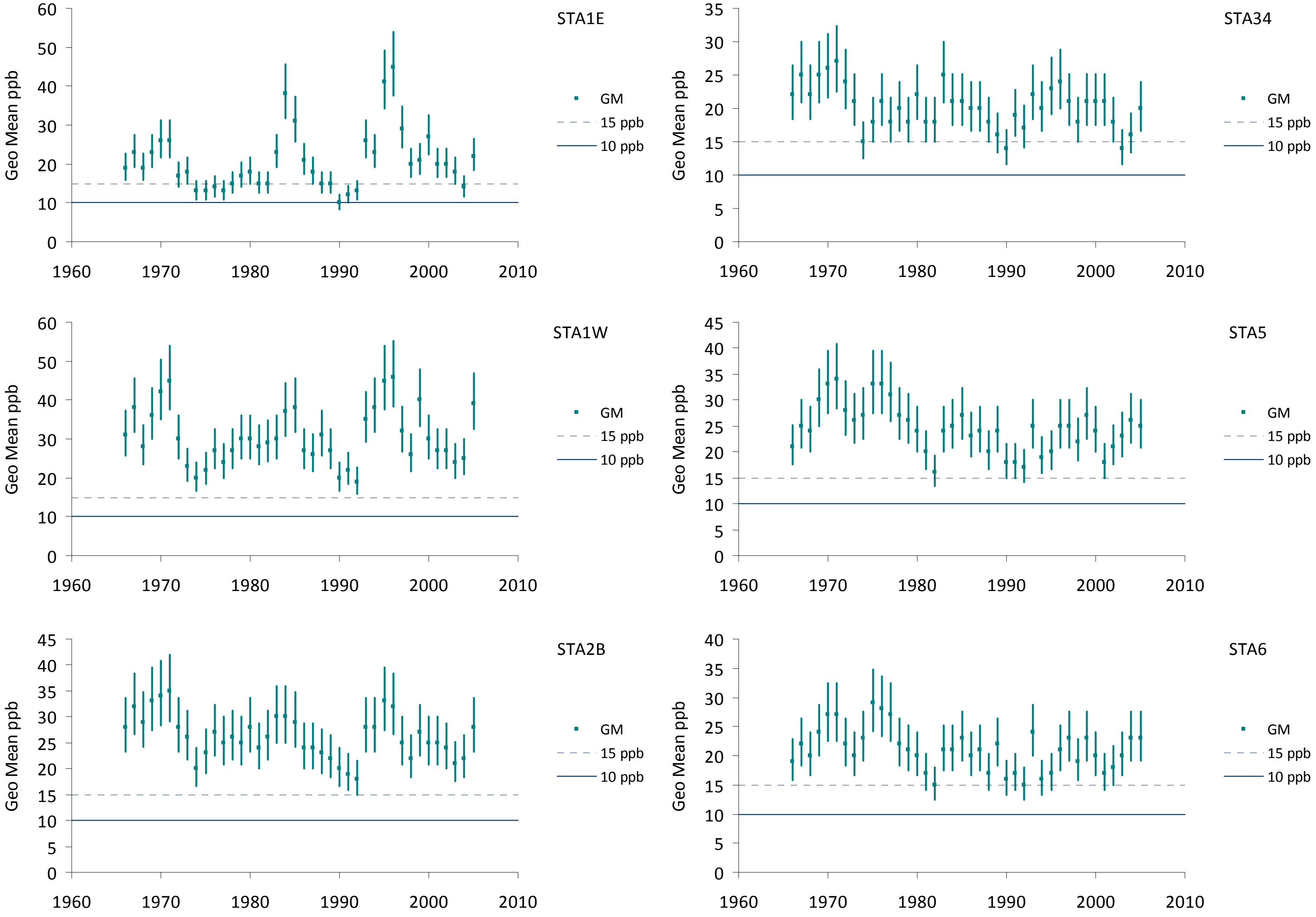
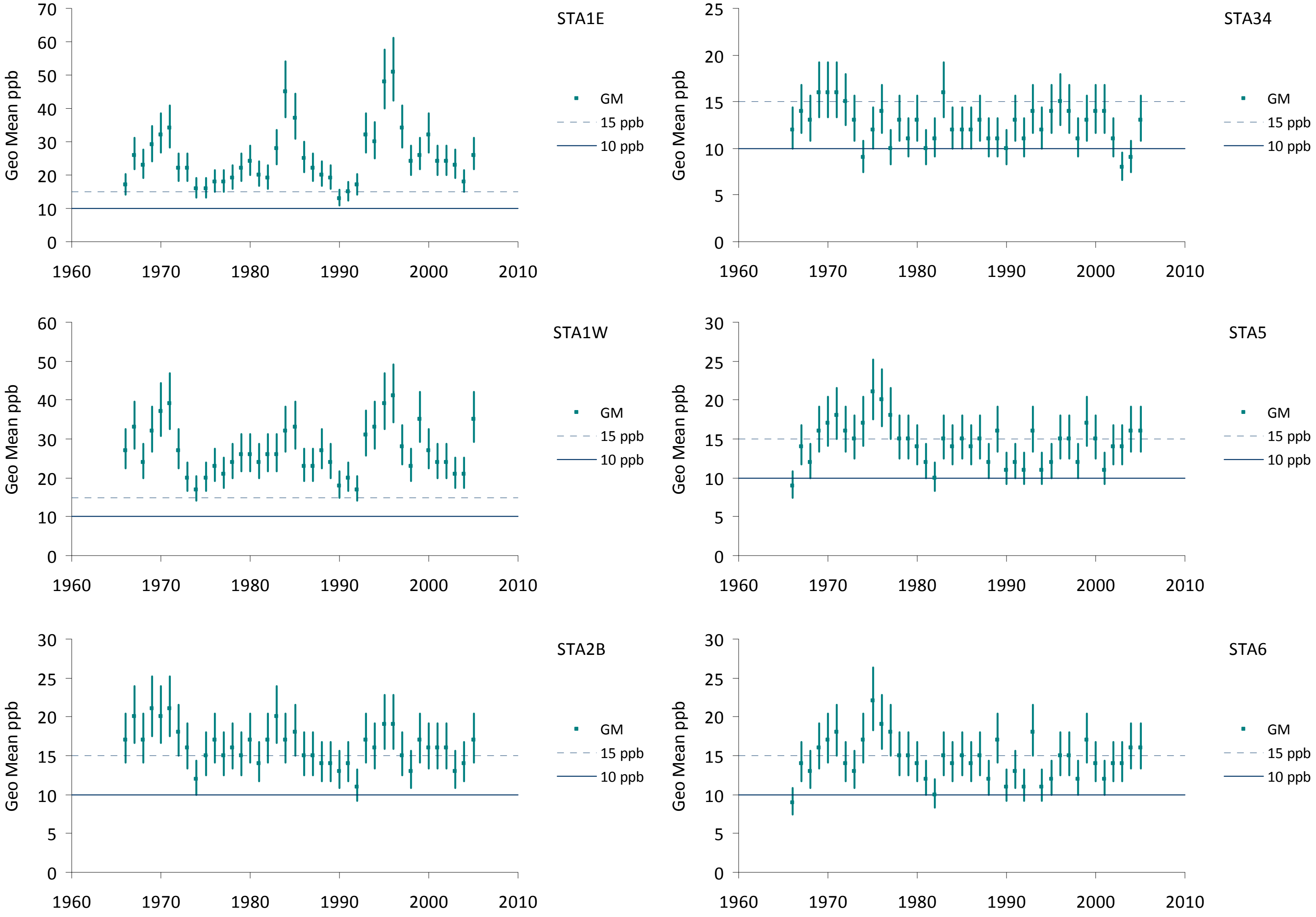
Attachment 2 : Yearly Geometric Mean Time Series for Each Scenario

Scenario 1 Existing STAs 80% Confidence Intervals for Yearly Geometric Means



Model Predictions +/- 20%; Yearly Geo Mean = FWM / 1.23. Solid Line = 10 ppb criterion. Dotted Line = 15 ppb limit for marsh sites in 4-Part Test

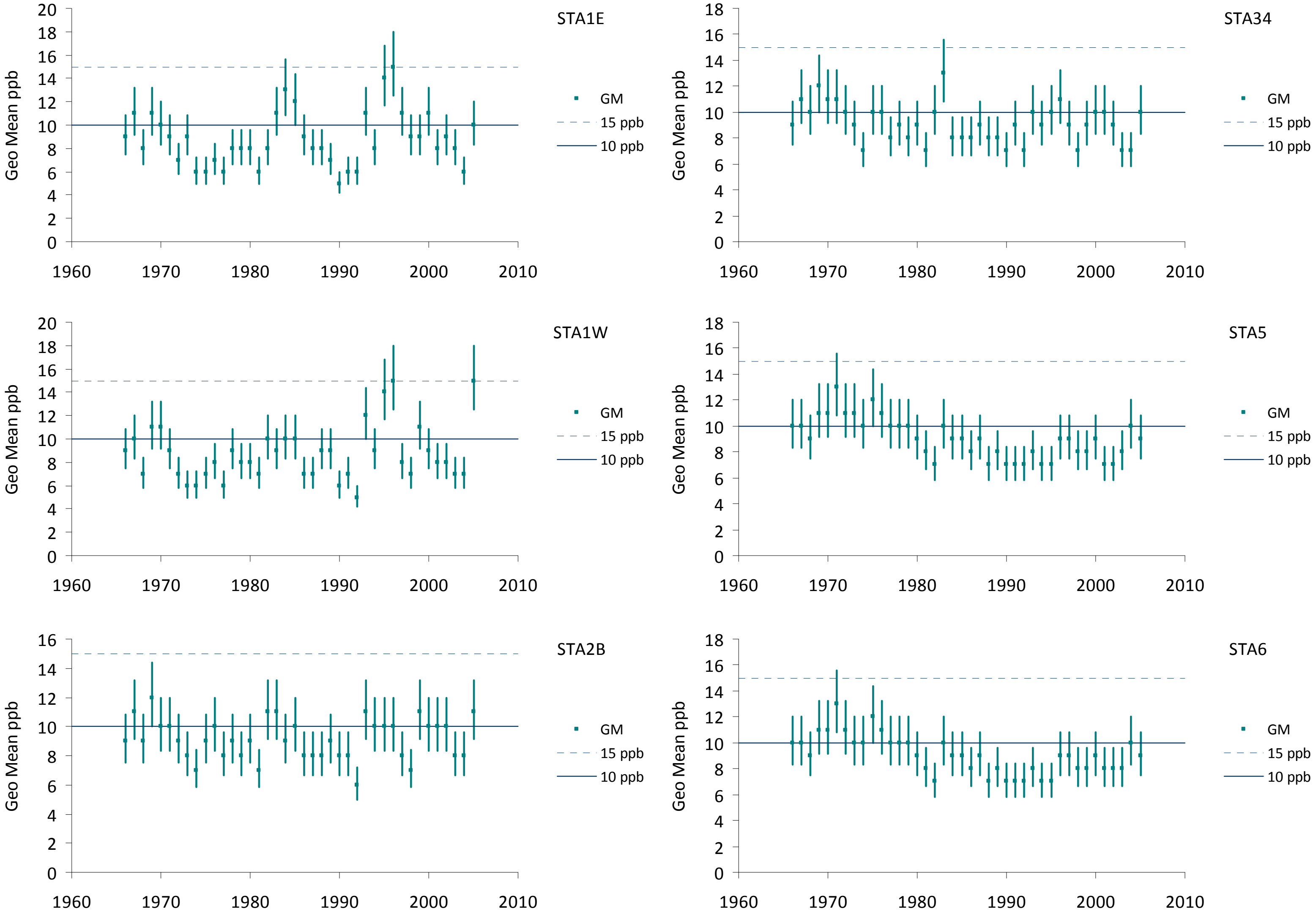
Scenario 2 Existing STAs + Compartments B & C 80% Confidence Intervals for Yearly Geometric Means



Model Predictions +/- 20%; Yearly Geo Mean = FWM / 1.23. Solid Line = 10 ppb criterion. Dotted Line = 15 ppb limit for marsh sites in 4-Part Test

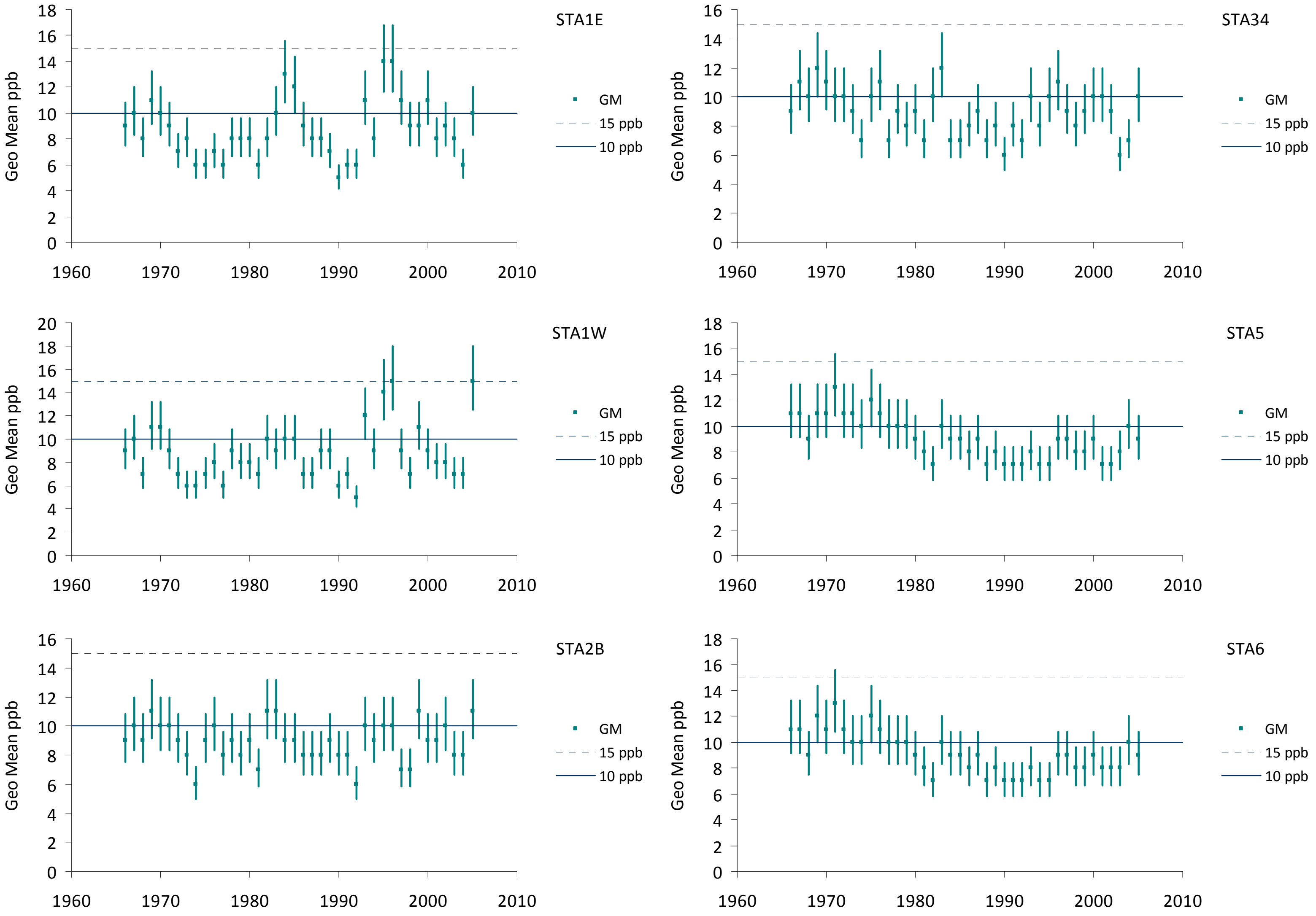
Scenario 3 A- STA Expansion

80% Confidence Intervals for Yearly Geometric Means



Model Predictions +/- 20%; Yearly Geo Mean = FWM / 1.23. Solid Line = 10 ppb criterion. Dotted Line = 15 ppb limit for marsh sites in 4-Part Test

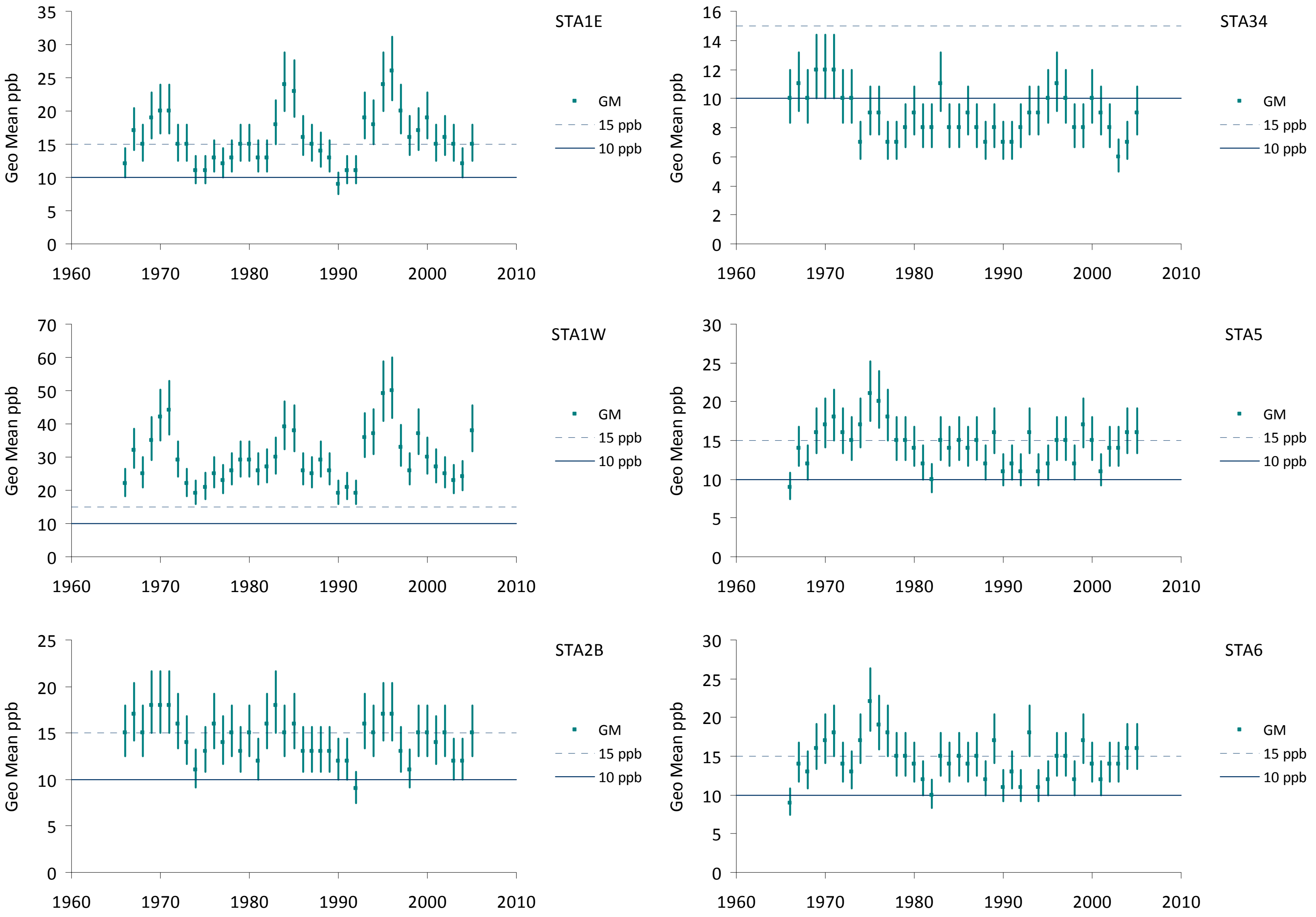
Scenario 4 B- STA Expansion with A2 FEB 80% Confidence Intervals for Yearly Geometric Means



Model Predictions +/- 20%; Yearly Geo Mean = FWM / 1.23. Solid Line = 10 ppb criterion. Dotted Line = 15 ppb limit for marsh sites in 4-Part Test

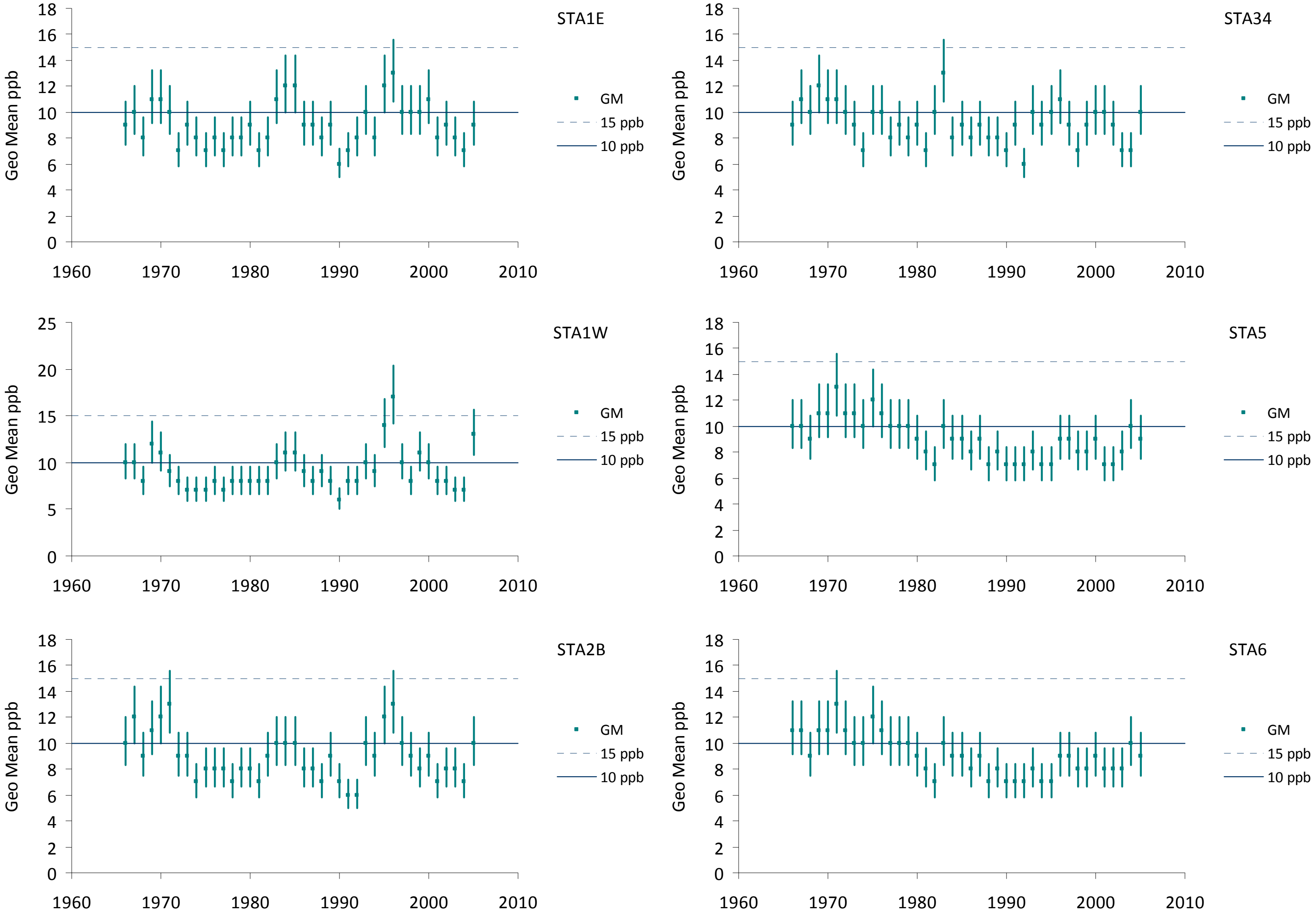
Scenario 5 A/B - Interim Plan without C51E Div/FEB

80% Confidence Intervals for Yearly Geometric Means



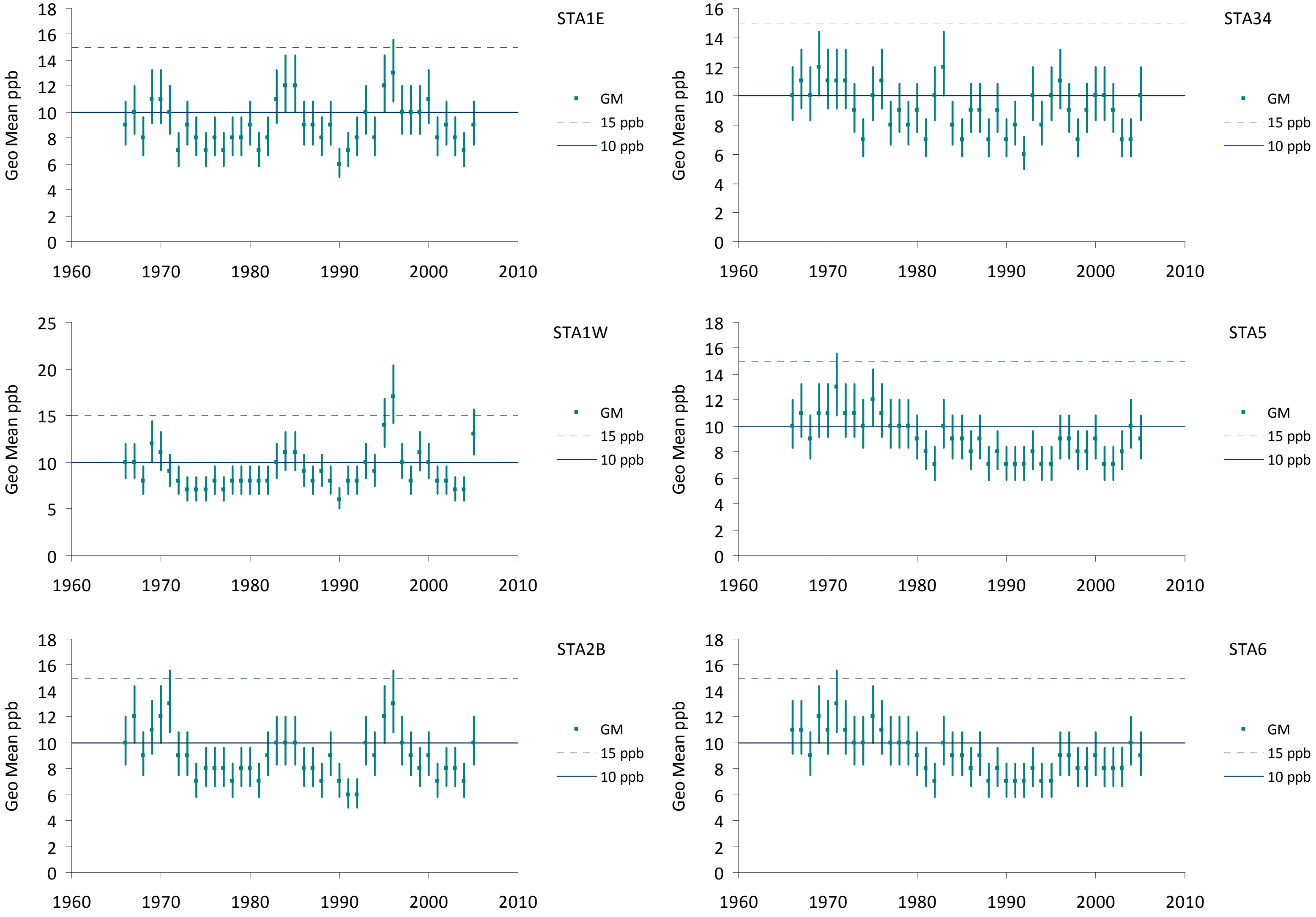
Model Predictions +/- 20%; Yearly Geo Mean = FWM / 1.23. Solid Line = 10 ppb criterion. Dotted Line = 15 ppb limit for marsh sites in 4-Part Test

Scenario 6 C - C51E Div/FEB, STA Expan 80% Confidence Intervals for Yearly Geometric Means



Model Predictions +/- 20%; Yearly Geo Mean = FWM / 1.23. Solid Line = 10 ppb criterion. Dotted Line = 15 ppb limit for marsh sites in 4-Part Test

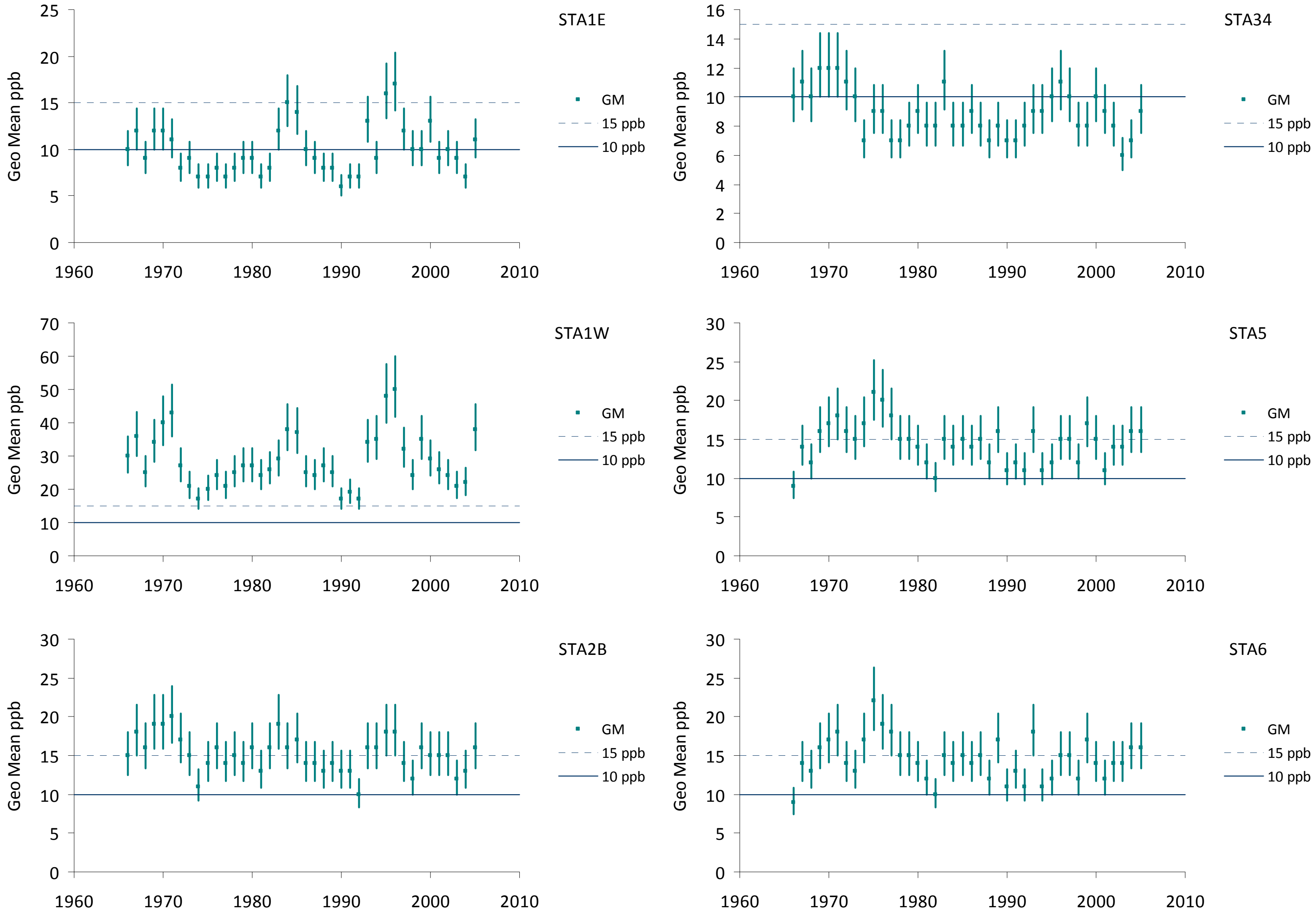
Scenario 7 D -C51E Div/FEB, A2 FEB/ STA 80% Confidence Intervals for Yearly Geometric Means



Model Predictions +/- 20%; Yearly Geo Mean = FWM / 1.23. Solid Line = 10 ppb criterion. Dotted Line = 15 ppb limit for marsh sites in 4-Part Test

Scenario 8 C/D - Interim Plan with C51E Div/FEB

80% Confidence Intervals for Yearly Geometric Means



Model Predictions +/- 20%; Yearly Geo Mean = FWM / 1.23. Solid Line = 10 ppb criterion. Dotted Line = 15 ppb limit for marsh sites in 4-Part Test

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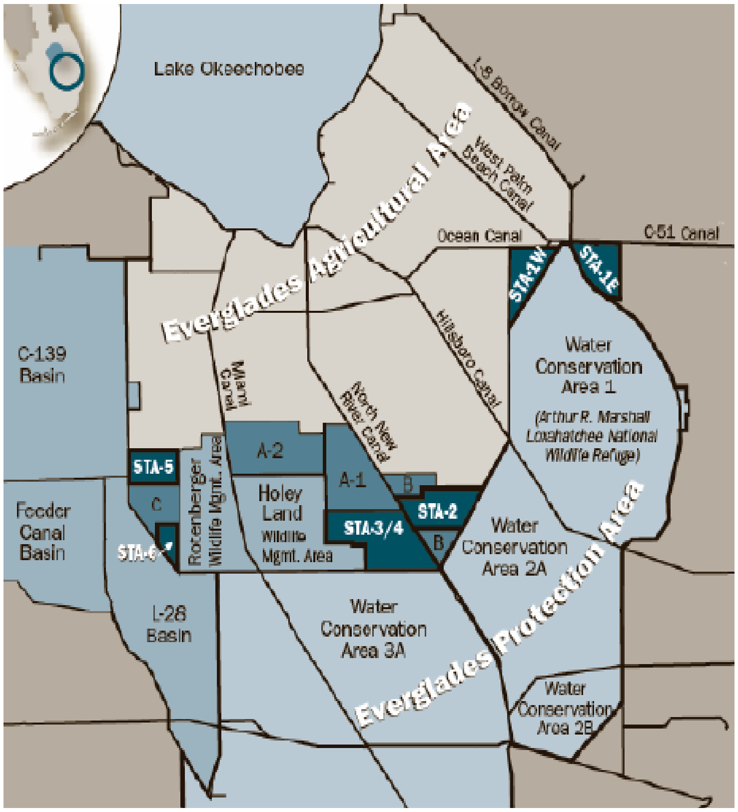
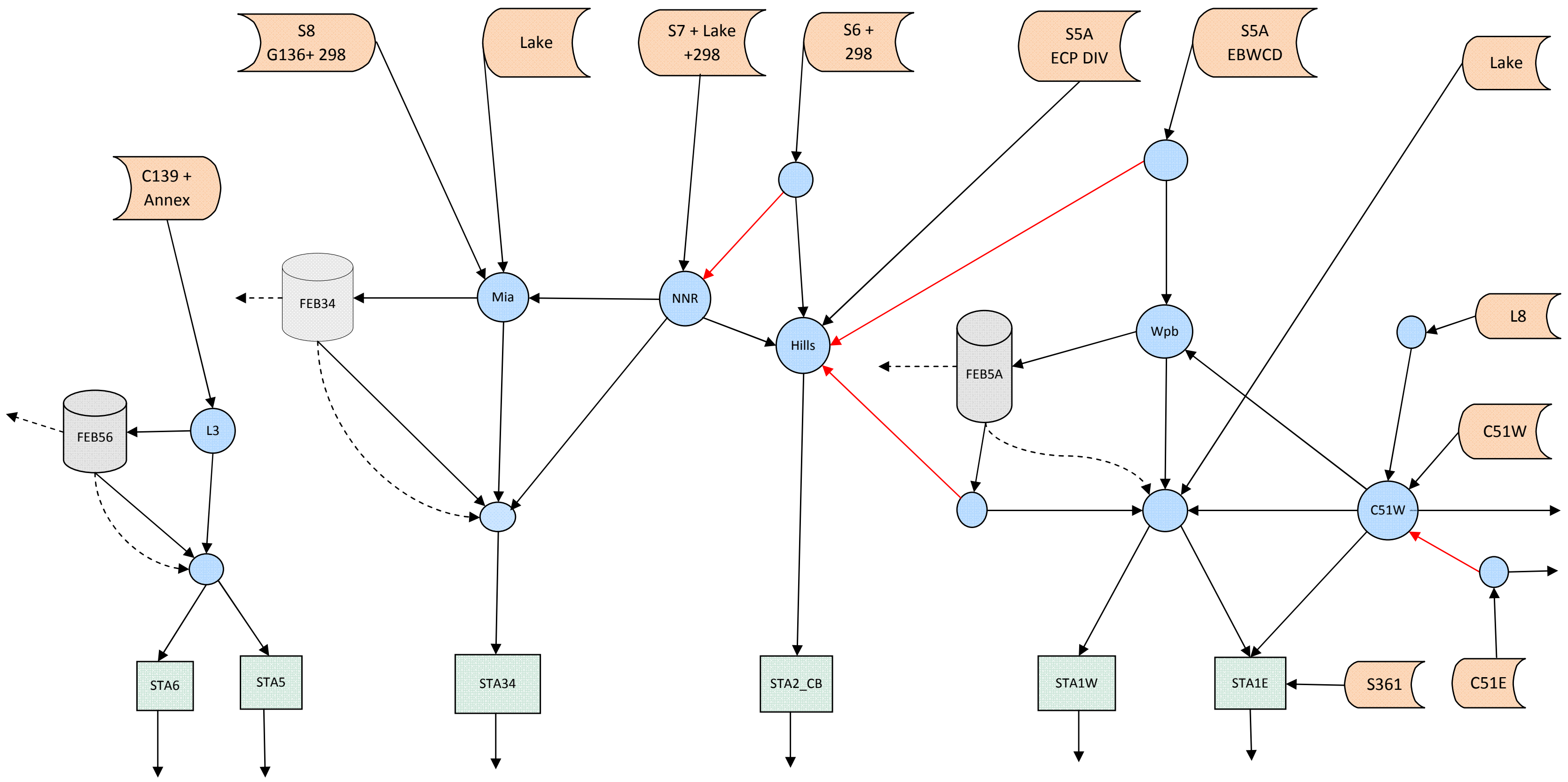
Attachment 3 : Scenario Flow Charts

Scenario	Description
0	Generalized Project Schematic
1	Existing STAs
2	Existing STAs + Compartments B & C
3	A- STA Expansion Only
4	B- STA Expansion with A1 STA & A2 FEB
5	A/B - Interim Plan with Temporary A1 FEB & Balance STA-34 Inflow
6	C - C51E Diversion /FEB, STA Expansion
7	D - C51E Diversion/FEB, A2 FEB+STA, A1 STA
8	C/D - Interim Plan with Temporary A1 FEB, Balance STA-34 Inflow, C51E Div/FEB



Generalized Flow Chart for WQBEL Scenarios



→ Flow Path

→ New Diversion

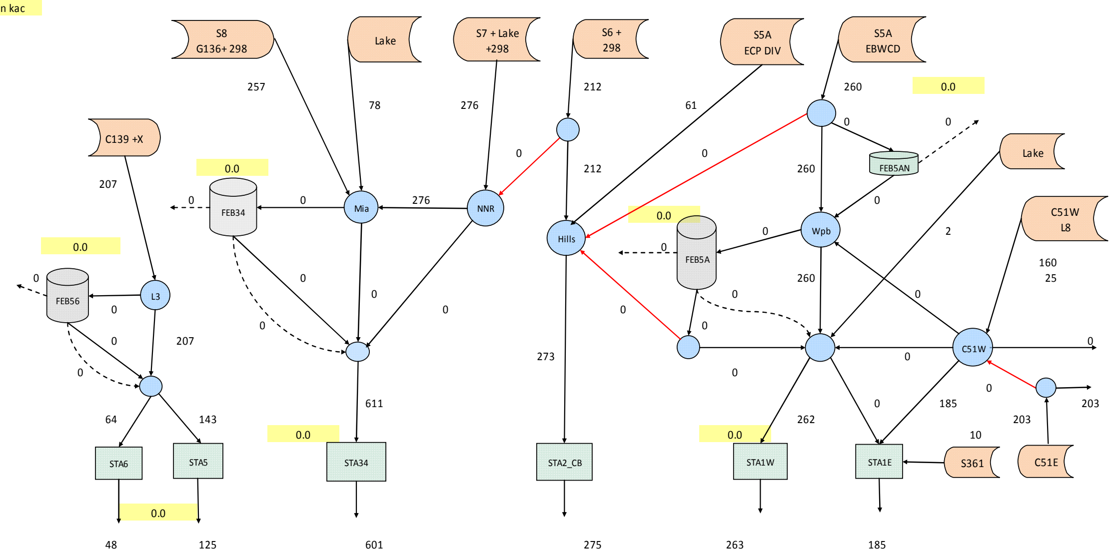
⇢ FEB Releases for STA Irrigation, Urban Water Supply (S5A), or Farm Irrigation (None Assumed)

Schematic reflects the general logic of the flow network, not specific locations of the project components

Expanded STA's are modeled as additional flow paths for STA-6, STA-34, and STA-1W.

Scenario: 1 Existing STAs Mean Flow kac-ft/yr

STA Expansion kac



									Totals
STA Outflow TP ppb	26.5	30.9		25.5	33.2	39.1		28.2	30.1
STA Expansion kac	0.0			0.0		0.0			0.0
STA Total Area kac	2.8	6.1		16.5	8.2	6.7		5.1	45.5
STA Outflow kacf/yr	48	125		601	275	263		185	1497
WCA Inflow kacft			774		275		448		1497

Inputs for Scenario EvenLess No Expansion or Source Control, Before Comp B & Comp C Operating

Diversion Rules

Diversion	Default	Diverted to	Fraction	Qmax	Description
C51E Diversion	C51W Canal	EAST	0	1000	
S5A Div (ECART)	S5A Div	HILLS_C	0	800	divert to hills
S5A Div (ECART)	S5A Div	HILLS_C	0	200	low-flow bypass to WPB
S5A Div to FEB	FEBS5A	FEBS5A_N	0		northern STA.FEB
FEB S5A Outflow	STA1DW	HILLS_C	0		diversion to Hills
C51W Outflow	EAST	STA1E	1		direct to STA1E
C51W Outflow	EAST	STA1_DW	1		direct to STA1DW
C51W Outflow	EAST	FEB_S5A	1		remainder to East
STA1W Distrib	STA1W	STA1E	0		WPB C STA1E
S6 Runoff	STA2CB	NNRC	0		S6 divert to NNR
NNR Canal	FEB34	STA34	0		NNR LowQ Bypass to STA34
STA56 Distrib	STA5	STA6	0.31		Balance STA56 Loads, Hint= 0.314

FEB Calculations	FEB_S5A	FEB_34	FEB_56	FEBS5A_N	
DMSTA calibration	RES_3	RES_3	RES_3	RES_3	
Area kac					blank to ignore FEB
HRT days	60	30	30	30	
Bypass Depth ft	44	8	4	4	
LowQ Bypass cfs	100	100	100	200	
Max Qin cfs	2000	4000	2000	1000	
Max Qout cfs	1000	500	500	100	
Control Depth ft	0.5	0.5	0.5	0.5	
Min Release Depth ft	0.5	0.5	0.5	0.5	
Regulation Schedule					not implemented
STA WS Release					not implemented
Farm WS Release					not implemented
Farm Irrig kac					not implemented

STA Expansion	STA1WX	STA34X	STA56X
Area kac			
Fraction SAV	0.67	0.67	0.4
Ehnanced	SAV_3	SAV_3	PEW_3

Base Period for Concs	1	1= 2005-2009,2 = 1995-2009		
Use Lake P Concs	TRUE	for S354 & S351 Lake Rleases		
C139 Load Reduc	0%	Max TP ppb	0	
STA Duty Cycle	0.95	New Lake Rel ka	0	
Target Conc ppb	12	Iterations	1	use iter=1 for testing, 2 for final
Output Interval Days	30	Other		
S5A Load Reduc	0%	Other		
Other		Other		

Watershed Areas	Land kac	Fraction	New STA kac	FEB kac	Runoff Rescale
Scale_s5A	133	1	0.0	0.0	1.00
Scale_S6	105	1			1.00
Scale_s7	120	1	0.0	0.0	1.00
Scale_s8	120	0			1.00
Scale_Annex	18	1	0.0	0.0	1.00

Mass Balance Summary EvenLess project_evenless.xls Run Date 9/1/10 19:58

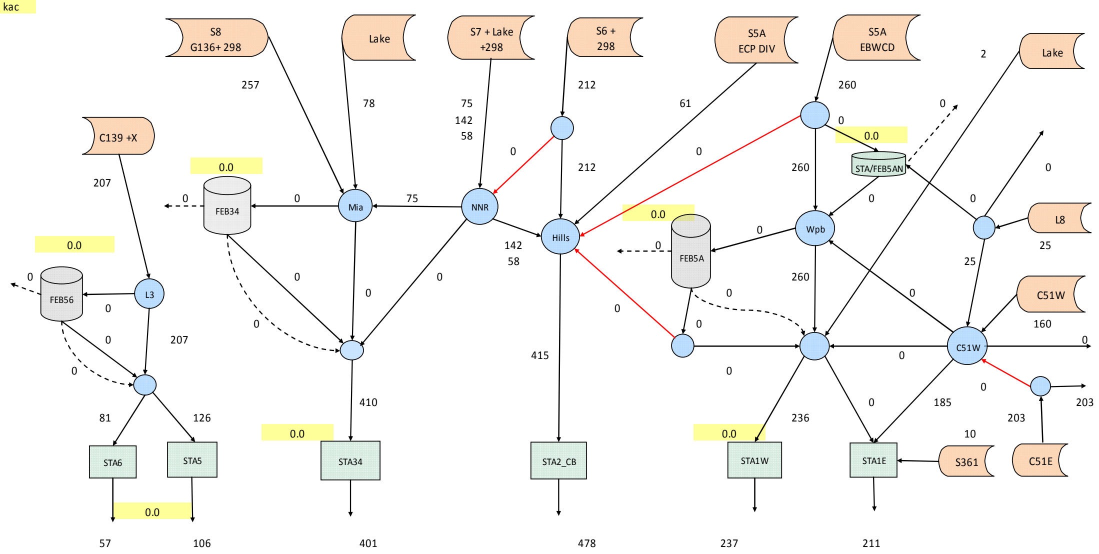
		Inflows			Outflows				
	Area	Flow	Load	Conc	Flow	Load	Conc	HLR	HLR Max
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d
STA1E	5.1	194	37.3	155	185	6.5	28.2	3.16	20.1
STA1W	6.7	262	68.0	210	263	12.7	39.1	3.28	20.6
STA2B	8.2	273	50.2	149	275	11.3	33.2	2.77	14.0
STA34	16.5	611	92.6	123	601	18.9	25.5	3.08	13.1
STA5	6.1	143	37.8	214	125	4.8	30.9	1.96	8.9
STA6	2.8	64	17.0	214	48	1.6	26.5	1.92	8.7
Total STA	45.5	1548	302.7	158	1497	55.7	30.1	2.84	

	Area	Flow	Load	Conc	Flow	Load	Conc	Depth cm	
FEBs	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	Mean	Min
FEBS5A_N	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_S5A	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_34	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_56	0.0	0	0.0	108	0	0.0	#N/A	0	0
Total FEB	0.0	0	0.0	#N/A	0	0.0	#N/A		

Input Time Series	Flow	Load	Conc	Flow	Flow CV	Flow Max
	kac-ft	mt	ppb	cfs	-	cfs
TS_FEBS5A_N	0.0	0.0	0	0	#N/A	0
TS_FEBS5A	259.5	67.7	211	358	1.87	5153
TS_STA1DW	2.3	0.3	103	3	9.50	666
TS_STA1W	0.0	0.0	0	0	#N/A	0
TS_STA1E	194.4	37.3	155	268	1.07	3318
TS_STA2B	273.2	50.2	149	377	1.94	3931
TS_FEB34	0.0	0.0	0	0	#N/A	0
TS_STA34	611.0	92.6	123	843	1.80	8891
TS_FEB56	207.1	54.8	214	286	1.20	4806
Total	1547.6	302.7	158	0	0.00	0

Scenario: 2 Existing STAs + Compartments B & C Mean Flow kac-ft/yr

STA Expansion kac



									Totals
STA Outflow TP ppb	18.3	18.3		15.7	20.3	34.1		34.0	23.0
STA Expansion kac	0.0			0.0		0.0			0.0
STA Total Area kac	5.1	7.9		16.5	15.1	6.7		5.1	56.5
STA Outflow kacf/yr	57	106		401	478	237		211	1490
WCA Inflow kacft			564		478		448		1490

Inputs for Scenario Nothing Existing Treatment Capacity; Comp B & Comp C Complete

Diversion Rules

Diversion	Default	Diverted to	Fraction	Qmax	Description
C51E Diversion	C51W Canal	EAST	0		
S5A Div (ECART)	S5A Div	HILLS_C	0		divert to hills up to qmax
S5A Div (ECART)	S5A Div	HILLS_C	0		low-flow bypass to WPB
S5A Div to FEB North	FEBS5A	FEBS5A_N	0		northern STA.FEB
FEB S5A Outflow	HILLS_C	STA1DW	0		diversion to Hills
C51W Outflow	EAST	STA1E	1		direct to STA1E
C51W Outflow	EAST	STA1_DW	0		direct to STA1DW
C51W Outflow	EAST	FEB_S5A	0		remainder to East
STA1W Distrib	STA1W	STA1E	0.1		WPB C STA1E
S6 Runoff	STA2CB	NNRC	0		S6 divert to NNR
NNR Canal	FEB34	STA34	0		NNR LowQ Bypass to STA34
STA56 Distrib	STA5	STA6	0.39		Balance STA56 Loads, Hint= 0.394
L8 to STA1N	C51W	FEBS5A_N	0		To FEB S5AN (Rest to C51W)
L8 to North	C51W	North	0		CERP
NNR to CB	STA34	Comp B	1		Original Design for Comp B =1
NNR to CB 2	STA34	Comp B	0.48		Additional NNR Diversion to CB

Mass Balance Summary Nothing project_nothing.xls Run Date 9/1/10 19:32

	Inflows				Outflows				
	Area	Flow	Load	Conc	Flow	Load	Conc	HLR	HLR Ma:
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d
STA1E	5.1	221	44.1	162	211	8.8	34.0	3.59	20.8
STA1W	6.7	236	61.2	210	237	10.0	34.1	2.95	18.6
STA2B	15.1	474	79.9	137	478	12.0	20.3	2.61	13.0
STA34	16.5	410	62.8	124	401	7.8	15.7	2.07	8.5
STA5	7.9	126	33.4	214	106	2.4	18.3	1.34	6.1
STA6	5.1	81	21.4	214	57	1.3	18.3	1.32	6.0
Total STA	56.5	1548	302.7	158	1490	42.3	23.0	2.29	
				STA1W+E	448.0	18.8	34.1		
				STA2+34+B	879.3	19.8	18.2		
				STA5+6	163.1	3.7	18.3		

FEB Calculations	FEB_S5A	FEB_34	FEB_56	FEBS5A_N	
DMSTA calibration	RES_3	RES_3	RES_3	EMG_3	
Area kac					
HRT days	14	14	30	30	
Bypass Depth ft	26.4	4	12	4	
LowQ Bypass cfs	200	400	50	100	
Max Qin cfs	2000	2775	2500	2000	
Max Qout cfs	1000	1000	500	500	
Control Depth ft	0.5	0.5	0.5	0.5	
Min Release Depth ft	0.5	0.5	0.5	0.5	Optional:
Regulation Schedule	FEB_REG	FEB_REG	FEB_REG		See FEB_Design Sheet
STA WS Release	REL_STA	REL_STA	REL_STA		See input series sheet
Farm WS Release				REL_FARM	""
Frac Irrig Demand	0.5			0.25	
Frac C51 Urban WS	1				
STA Expansion	STA1WX	STA34X	STA56X		
Area kac	0	0	0		
Fraction SAV	0.67	0.67	0.4		
Ehnanced	SAV_3	SAV_3	PEW_3		

	Area	Flow	Load	Conc	Flow	Load	Conc	Depth cm	
FEBs	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	Mean	Min
FEBS5A_N	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_S5A	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_34	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_56	0.0	0	0.0	68	0	0.0	#N/A	0	0
Total FEB	0.0	0	0.0	#N/A	0	0.0	#N/A		

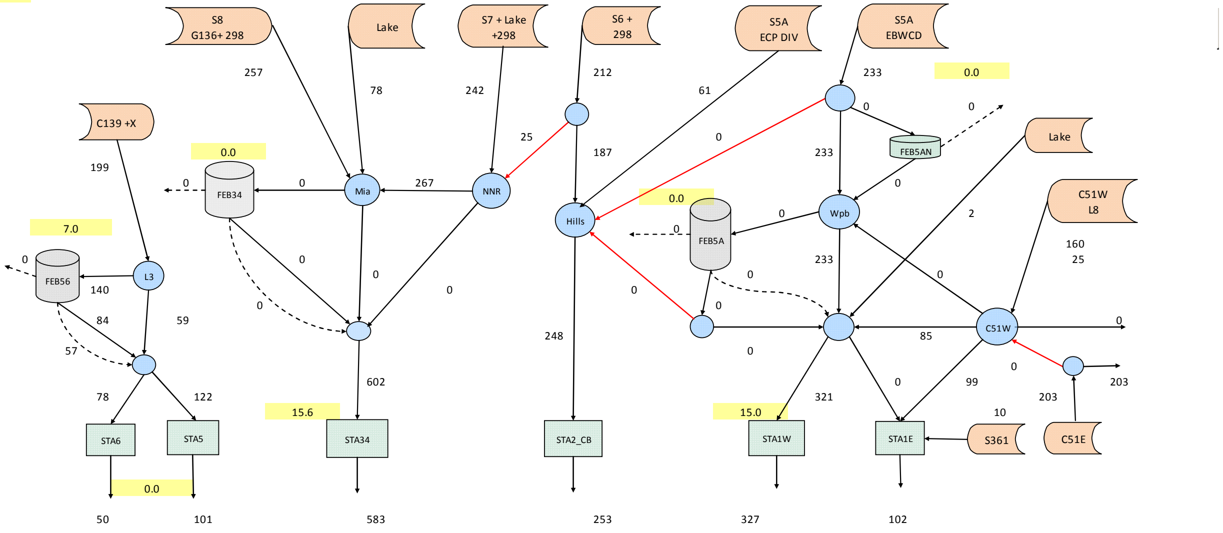
Input Time Series	Flow	Load	Conc	Flow	Flow CV	Flow Max
	kac-ft	mt	ppb	cfs	-	cfs
TS_FEBS5A_N	0.0	0.0	0	0	#N/A	0
TS_FEBS5A	259.5	67.7	211	358	1.87	5153
TS_STA1DW	2.3	0.3	103	3	9.50	666
TS_STA1W	0.0	0.0	0	0	#N/A	0
TS_STA1E	194.4	37.3	155	268	1.07	3318
TS_STA2B	473.7	79.9	137	654	2.02	6863
TS_FEB34	0.0	0.0	0	0	#N/A	0
TS_STA34	410.5	62.8	124	567	1.75	5959
TS_FEB56	207.1	54.8	214	286	1.20	4806
Total	1547.6	302.7	158	0	0.00	0

Base Period for Concs	1	1= 2005-2009,2 = 1995-2009		
Use Lake P Concs	TRUE	for S354 & S351 Lake Rleases		
C139 Load Reduc	0%	Max TP ppb	0	
STA Duty Cycle	0.95	New Lake Rel ka	0	
Target Conc ppb	11.5	Iterations	1	use iter=1 for testing, 2 for final
Output Interval	30	S5A/C51 Cmax	0	
S5A Load Reduc	0%	S678 Cmax	0	
Other		C139 Cmax	0	

Watershed Areas	Land kac	Fraction	New STA kac	FEB kac	Runoff Rescale
Scale_s5A	133	1	0.0	0.0	1.00
Scale_S6	105	1			1.00
Scale_s7	120	1	0.0	0.0	1.00
Scale_s8	120	0			1.00
Scale_Annex	18	1	0.0	0.0	1.00

Scenario: 3 A- STA Expansion Only Mean Flow kac-ft/yr

STA Expansion kac



								Totals
STA Outflow TP ppb	11.5	11.4		11.5	11.5	11.3	11.6	11.5
STA Expansion kac	0.0			15.6		15.0		30.6
STA Total Area kac	5.1	7.9		32.1	15.1	21.7	5.1	87.1
STA Outflow kacf/yr	50	101		583	253	327	102	1416
WCA Inflow kacft			734		253	429		1416

Inputs for Scenario Base_11_5 11.5 ppb Designs, 12 ft FEB in WB, STA Expansion in Other Basins

Diversion Rules

Diversion	Default	Diverted to	Fraction	Qmax	Description
C51E Diversion	C51W Canal	EAST	0	1000	
S5A Div (ECART)	S5A Div	HILLS_C	0	800	divert to hills
S5A Div (ECART)	S5A Div	HILLS_C	0	200	low-flow bypass to WPB
S5A Div to FEB	FEBS5A	FEBS5A_N	0		northern STA.FEB
FEB S5A Outflow	STA1DW	HILLS_C	0		diversion to Hills
C51W Outflow	EAST	STA1E	0.56	600	direct to STA1E
C51W Outflow	EAST	STA1_DW	1		direct to STA1DW
C51W Outflow	EAST	FEB_S5A	1		remainder to East
STA1W Distrib	STA1W	STA1E	0		WPB C STA1E
S6 Runoff	STA2CB	NNRC	0.12		S6 divert to NNR
NNR Canal	FEB34	STA34	0	100	NNR LowQ Bypass to STA34
STA56 Distrib	STA5	STA6	0.39		Balance STA56 Loads, Hint= 0.394

Mass Balance Summary Base_11_5 project_base_11_5.xls Run Date 9/1/10 21:42

		Inflows			Outflows				
	Area	Flow	Load	Conc	Flow	Load	Conc	HLR	HLR Max
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d
STA1E	5.1	109	20.4	152	102	1.5	11.6	1.77	7.1
STA1W	21.7	321	78.9	199	327	4.6	11.3	1.24	7.0
STA2B	15.1	248	46.1	151	253	3.6	11.5	1.37	6.9
STA34	32.1	602	91.6	123	583	8.3	11.5	1.56	6.6
STA5	7.9	122	24.3	161	101	1.4	11.4	1.29	3.7
STA6	5.1	78	15.5	161	50	0.7	11.5	1.27	3.7
Total STA	87.1	1479	276.7	152	1416	20.0	11.5	1.42	

FEB Calculations	FEB_S5A	FEB_34	FEB_56	FEBS5A_N	
DMSTA calibration	RES_3	RES_3	RES_3	RES_3	
Area kac			7		
HRT days	60	30	90	30	
Bypass Depth ft	44	12	12	4	
LowQ Bypass cfs	100	100	100	200	
Max Qin cfs	2000	4000	2500	1000	
Max Qout cfs	1000	500	500	100	
Control Depth ft	0.5	0.5	0.5	0.5	
Min Release Depth ft	0.5	0.5	0.5	0.5	
Regulation Schedule			FEB_REG		not implemented
STA WS Release			REL_STA		not implemented
Farm WS Release					not implemented
Farm Irrig kac					not implemented

		Treated Inflow			Outflows				
	Area	Flow	Load	Conc	Flow	Load	Conc	Depth cm	
FEBs	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	Mean	Min
FEBS5A_N	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_S5A	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_34	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_56	7.0	140	39.9	231	84	15.6	151	155	1
Total FEB	0.0	0	0.0	#N/A	0	0.0	#N/A		

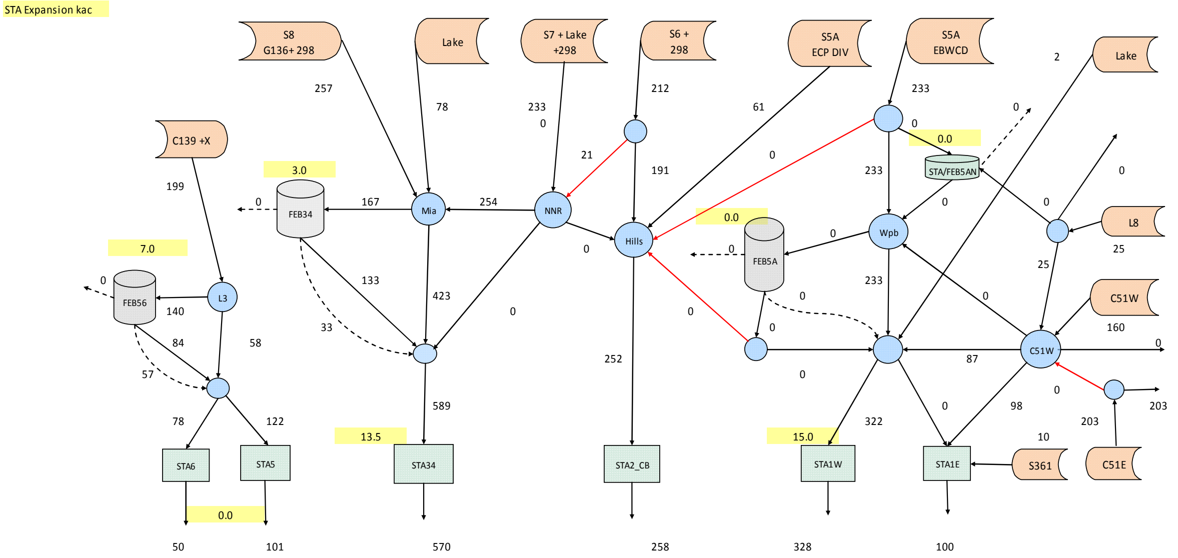
Input Time Series	Flow	Load	Conc	Flow	Flow CV	Flow Max
	kac-ft	mt	ppb	cfs	-	cfs
TS_FEBS5A_N	0.0	0.0	0	0	#N/A	0
TS_FEBS5A	233.0	61.7	214	322	1.87	4621
TS_STA1DW	87.8	17.2	158	121	1.38	2679
TS_STA1W	0.0	0.0	0	0	#N/A	0
TS_STA1E	108.9	20.4	152	150	0.89	644
TS_STA2B	247.7	46.1	151	342	1.93	3531
TS_FEB34	0.0	0.0	0	0	#N/A	0
TS_STA34	602.3	91.6	123	831	1.79	8698
TS_FEB56	198.8	53.8	219	274	1.20	4647
Total	1478.5	290.7	159	0	0.00	0

STA Expansion	STA1WX	STA34X	STA56X
Area kac	15	15.6	0
Fraction SAV	0.67	0.67	0.4
Ehnanced	SAV_3	SAV_3	PEW_3

Base Period for Concs	1	1= 2005-2009,2 = 1995-2009		
Use Lake P Concs	TRUE	for S354 & S351 Lake Rleases		
C139 Load Reduc	0%	Max TP ppb	0	
STA Duty Cycle	0.95	New Lake Rel ka	0	
Target Conc ppb	11.5	Iterations	1	use iter=1 for testing, 2 for final
Output Interval Days	30	Other		
S5A Load Reduc	0%	Other		
Other		Other		

Watershed Areas	Land kac	Fraction	New STA kac	FEB kac	Runoff Rescale
Scale_s5A	133	1	15.0	0.0	0.89
Scale_S6	105	1			1.00
Scale_s7	120	1	15.6	0.0	0.87
Scale_s8	120	0			1.00
Scale_Annex	18	1	0.0	7.0	0.61

Scenario: 4 B- STA Expansion with A1 STA & A2 FEB Mean Flow kac-ft/yr



									Totals
STA Outflow TP ppb	11.5	11.4		11.3	11.3	11.4		11.4	11.4
STA Expansion kac	0.0			13.5		15.0			28.5
STA Total Area kac	5.1	7.9		30.0	15.1	21.7		5.1	85.0
STA Outflow kacf/yr	50	101		570	258	328		100	1408
WCA Inflow kacft			721		258		429		1408

Inputs for Scenario Base_A1_RES_2 STA in A1, 8-ft FEB in A2,. 12-ft FEB in C139

Diversion Rules

Diversion	Default	Diverted to	Fraction	Qmax	Description
C51E Diversion	C51W Canal	EAST	0	1000	
S5A Div (ECART)	S5A Div	HILLS_C	0		divert to hills up to qmax
S5A Div (ECART)	S5A Div	HILLS_C	0		low-flow bypass to WPB
S5A Div to FEB North	FEBS5A	FEBS5A_N	0		northern STA.FEB
FEB S5A Outflow	HILLS_C	STA1DW	0		diversion to Hills
C51W Outflow	EAST	STA1E	0.55	600	direct to STA1E
C51W Outflow	EAST	STA1_DW	1		direct to STA1DW
C51W Outflow	EAST	FEB_S5A	0		remainder to East
STA1W Distrib	STA1W	STA1E	0		WPB C STA1E
S6 Runoff	STA2CB	NNRC	0.1		S6 divert to NNR
NNR Canal	FEB34	STA34	0		NNR LowQ Bypass to STA34
STA56 Distrib	STA5	STA6	0.39		Balance STA56 Loads, Hint= 0.394
L8 to STA1N	C51W	FEBS5A_N	0		To FEB S5AN (Rest to C51W)
L8 to North	C51W	North	0		CERP
NNR to CB	STA34	Comp B	0		Original Design for Comp B =1
NNR to CB 2	STA34	Comp B	0		Additional NNR Diversion to CB
Other					

Mass Balance Summary Base_A1_RES_ project_base_a1_res_2.xls Run Date 9/1/10 20:21

		Inflows			Outflows				
	Area	Flow	Load	Conc	Flow	Load	Conc	HLR	HLR M
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/(
STA1E	5.1	107	20.1	152	100	1.4	11.4	1.74	7.1
STA1W	21.7	322	79.2	199	328	4.6	11.4	1.24	7.0
STA2B	15.1	252	46.8	150	258	3.6	11.3	1.39	7.0
STA34	30.0	589	85.5	118	570	8.0	11.3	1.64	7.0
STA5	7.9	122	24.3	162	101	1.4	11.4	1.29	3.7
STA6	5.1	78	15.5	162	50	0.7	11.5	1.27	3.7
Total STA	85.0	1470	271.3	149	1408	19.7	11.4	1.44	
				STA1W+E	428.8	6.0	11.4		
				STA2+34+B	828.0	11.6	11.3		
				STA5+6	150.9	2.1	11.5		

		Treated Inflow			Outflows				
	Area	Flow	Load	Conc	Flow	Load	Conc	Depth cm	
FEBs	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	Mean	Min
FEBS5A_N	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_S5A	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_34	3.0	167	24.8	121	133	16.4	100	165	2
FEB_56	7.0	140	40.0	231	84	15.7	151	155	1
Total FEB	3.0	167	24.8	121	133	16.4	100		

FEB Calculations	FEB_S5A	FEB_34	FEB_56	FEBS5A_N	
DMSTA calibration	RES_3	RES_3	RES_3	EMG_3	
Area kac		3	7		
HRT days	30	30	90	30	
Bypass Depth ft	44	8	12	4	
LowQ Bypass cfs	200	400	100	100	
Max Qin cfs	2000	3000	2500	2000	
Max Qout cfs	1000	1000	500	500	
Control Depth ft	0.5	0.5	0.5	0.5	
Min Release Depth ft	0.5	0.5	0.5	0.5	Optional:
Regulation Schedule	FEB_REG	FEB_REG	FEB_REG		See FEB_Design Sheet
STA WS Release	REL_STA	REL_STA	REL_STA		See input series sheet
Farm WS Release	REL_URB+FARM			REL_FARM	""
Frac Irrig Demand	0.5			0.25	
Frac C51 Urban WS	1				
STA Expansion	STA1WX	STA34X	STA56X		
Area kac	15	13.5	0		
Fraction SAV	0.67	0.67	0.4		
Ehnanced	SAV_3	SAV_3	PEW_3		

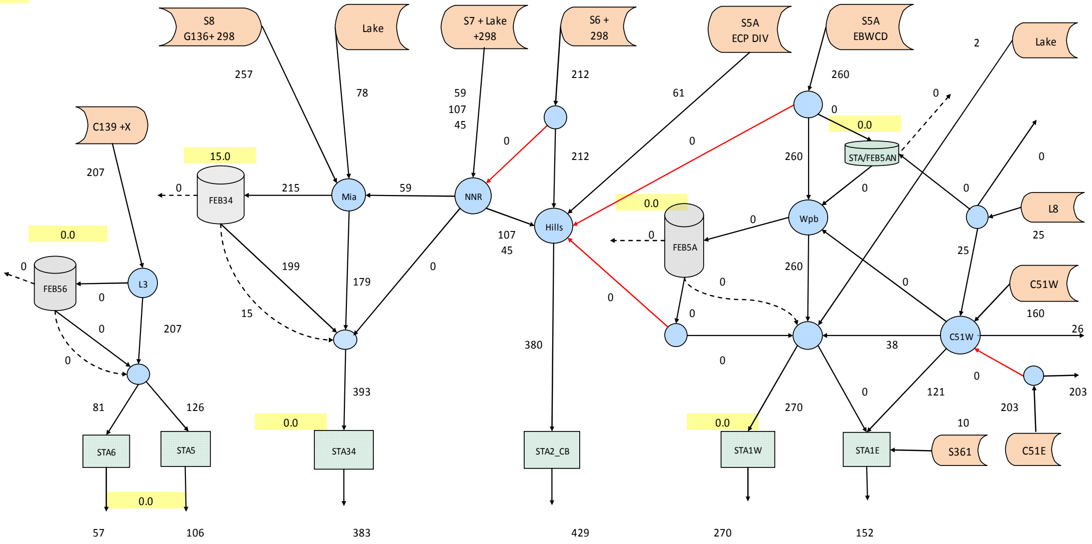
Input Time Series	Flow	Load	Conc	Flow	Flow CV	Flow Max
	kac-ft	mt	ppb	cfs	-	cfs
TS_FEBS5A_N	0.0	0.0	0	0	#N/A	0
TS_FEBS5A	233.0	61.7	214	322	1.87	4621
TS_STA1DW	89.4	17.5	158	123	1.36	2679
TS_STA1W	0.0	0.0	0	0	#N/A	0
TS_STA1E	107.3	20.1	152	148	0.89	644
TS_STA2B	252.0	46.8	150	348	1.93	3598
TS_FEB34	589.5	89.6	123	814	1.79	8494
TS_STA34	0.0	0.0	0	0	#N/A	0
TS_FEB56	198.8	53.8	219	274	1.20	4647
Total	1470.0	289.4	159	0	0.00	0

Base Period for Concs	1	1= 2005-2009,2 = 1995-2009		
Use Lake P Concs	TRUE	for S354 & S351 Lake Rleases		
C139 Load Reduc	0%	Max TP ppb	0	
STA Duty Cycle	0.95	New Lake Rel ka	0	
Target Conc ppb	11.5	Iterations	1	use iter=1 for testing, 2 for final
Output Interval	30	S5A/C51 Cmax	0	
S5A Load Reduc	0%	S678 Cmax	0	
Other		C139 Cmax	0	

Watershed Areas	Land kac	Fraction	New STA kac	FEB kac	Runoff Rescale
Scale_s5A	133	1	15.0	0.0	0.89
Scale_S6	105	1			1.00
Scale_s7	120	1	16.5	3.0	0.84
Scale_s8	120	0			1.00
Scale_Annex	18	1	0.0	7.0	0.61

Scenario: 5 A/B - Interim Plan with Temporary A1 FEB & Balance STA-34 Inflow Mean Flow kac-ft/yr

STA Expansion kac



									Totals
STA Outflow TP ppb	18.3	18.3		11.2	18.2	38.3		20.5	20.4
STA Expansion kac	0.0			0.0		0.0			0.0
STA Total Area kac	5.1	7.9		16.5	15.1	6.7		5.1	56.5
STA Outflow kacf/yr	57	106		383	429	270		152	1397
WCA Inflow kacft			546		429		422		1397

Inputs for Scenario Base_A1_FEB Interim Plan: A1 as FEB, No Additional STA in Central Basin

Diversion Rules

Diversion	Default	Diverted to	Fraction	Qmax	Description
C51E Diversion	C51W Canal	EAST	0	1000	
S5A Div (ECART)	S5A Div	HILLS_C	0		divert to hills up to qmax
S5A Div (ECART)	S5A Div	HILLS_C	0		low-flow bypass to WPB
S5A Div to FEB North	FEBS5A	FEBS5A_N	0		northern STA.FEB
FEB S5A Outflow	HILLS_C	STA1DW	0		diversion to Hills
C51W Outflow	EAST	STA1E	0.7	600	direct to STA1E
C51W Outflow	EAST	STA1_DW	0.6	1200	direct to STA1DW
C51W Outflow	EAST	FEB_S5A	0		remainder to East
STA1W Distrib	STA1W	STA1E	0.1		WPB C STA1E
S6 Runoff	STA2CB	NNRC	0		S6 divert to NNR
NNR Canal	FEB34	STA34	0		NNR LowQ Bypass to STA34
STA56 Distrib	STA5	STA6	0.39		Balance STA56 Loads, Hint= 0.394
L8 to STA1N	C51W	FEBS5A_N	0		To FEB S5AN (Rest to C51W)
L8 to North	C51W	North	0		CERP
NNR to CB	STA34	Comp B	1		Original Design for Comp B =1
NNR to CB 2	STA34	Comp B	0.49		Additional NNR Diversion to CB

Mass Balance Summary Base_A1_FEB project_base_a1_feb.xls Run Date 8/31/10 22:08

		Inflows			Outflows				
	Area	Flow	Load	Conc	Flow	Load	Conc	HLR	HLR Max
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d
STA1E	5.1	161	32.2	162	152	3.8	20.5	2.61	9.7
STA1W	6.7	270	68.0	204	270	12.8	38.3	3.38	20.6
STA2B	15.1	425	72.6	139	429	9.6	18.2	2.34	11.7
STA34	16.5	393	47.6	98	383	5.3	11.2	1.98	8.8
STA5	7.9	126	33.4	214	106	2.4	18.3	1.34	6.1
STA6	5.1	81	21.4	214	57	1.3	18.3	1.32	6.0
Total STA	56.5	1455	275.2	153	1397	35.2	20.4	2.15	
				STA1W+E	422.1	16.6	31.9		
				STA2+34+B	812.3	14.9	14.9		
				STA5+6	163.1	3.7	18.3		

		Treated Inflow			Outflows				
	Area	Flow	Load	Conc	Flow	Load	Conc	Depth cm	
FEBs	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	Mean	Min
FEBS5A_N	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_S5A	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_34	15.0	215	29.6	112	199	15.7	64	44	1
FEB_56	0.0	0	0.0	108	0	0.0	#N/A	0	0
Total FEB	15.0	215	29.6	112	199	15.7	64		

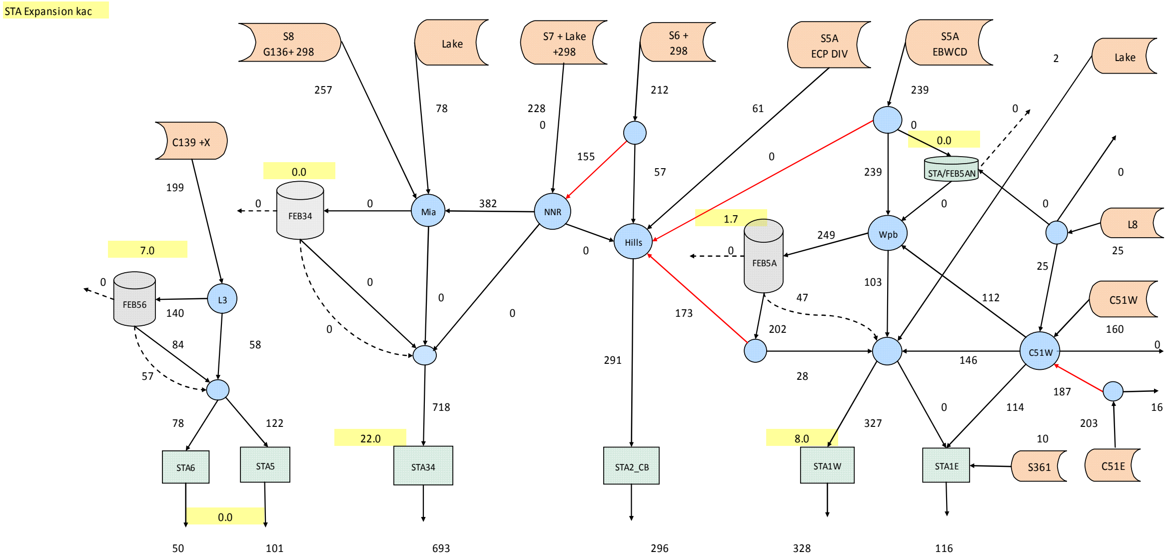
FEB Calculations	FEB_S5A	FEB_34	FEB_56	FEBS5A_N	
DMSTA calibration	RES_3	RES_3	RES_3	EMG_3	
Area kac		15	0		
HRT days	30	14	90	30	
Bypass Depth ft	44	4	12	4	
LowQ Bypass cfs	200	400	100	100	
Max Qin cfs	2000	2775	2500	2000	
Max Qout cfs	1000	1000	500	500	
Control Depth ft	0.5	0.5	0.5	0.5	
Min Release Depth ft	0.5	0.5	0.5	0.5	Optional:
Regulation Schedule	FEB_REG	FEB_REG	FEB_REG		See FEB_Design Sheet
STA WS Release	REL_STA	REL_STA	REL_STA		See input series sheet
Farm WS Release	REL_URB+FARM			REL_FARM	""
Frac Irrig Demand	0.5			0.25	
Frac C51 Urban WS	1				
STA Expansion	STA1WX	STA34X	STA56X		
Area kac	0	0	0		
Fraction SAV	0.67	0.67	0.4		
Ehnanced	SAV_3	SAV_3	PEW_3		

Input Time Series	Flow	Load	Conc	Flow	Flow CV	Flow Max
	kac-ft	mt	ppb	cfs	-	cfs
TS_FEBS5A_N	0.0	0.0	0	0	#N/A	0
TS_FEBS5A	259.5	67.7	211	358	1.87	5153
TS_STA1DW	40.6	7.9	157	56	1.74	1200
TS_STA1W	0.0	0.0	0	0	#N/A	0
TS_STA1E	130.5	24.6	153	180	0.85	644
TS_STA2B	424.6	72.6	139	586	2.00	6153
TS_FEB34	393.8	60.4	124	544	1.73	5579
TS_STA34	0.0	0.0	0	0	#N/A	0
TS_FEB56	207.1	54.8	214	286	1.20	4806
Total	1456.2	287.9	160	0	0.00	0

Base Period for Concs	1	1= 2005-2009,2 = 1995-2009		
Use Lake P Concs	TRUE	for S354 & S351 Lake Rleases		
C139 Load Reduc	0%	Max TP ppb	0	
STA Duty Cycle	0.95	New Lake Rel ka	0	
Target Conc ppb	11.5	Iterations	1	use iter=1 for testing, 2 for final
Output Interval	30	S5A/C51 Cmax	0	
S5A Load Reduc	0%	S678 Cmax	0	
Other		C139 Cmax	0	

Watershed Areas	Land kac	Fraction	New STA kac	FEB kac	Runoff Rescale
Scale_s5A	133	1	0.0	0.0	1.00
Scale_S6	105	1			1.00
Scale_s7	120	1	15.0	15.0	0.75
Scale_s8	120	0			1.00
Scale_Annex	18	1	0.0	0.0	1.00

Scenario: 6 C - C51E Diversion /FEB, STA Expansion Mean Flow kac-ft/yr



									Totals
STA Outflow TP ppb	11.5	11.4		11.5	11.5	11.5		11.5	11.5
STA Expansion kac	0.0			22.0		8.0			30.0
STA Total Area kac	5.1	7.9		38.5	15.1	14.7		5.1	86.5
STA Outflow kacf/yr	50	101		693	296	328		116	1584
WCA Inflow kacft			844		296		444		1584

Inputs for Scenario C51E_AA C51E Diversion, STA exp in CB, FEB in C139

Diversion Rules

Diversion	Default	Diverted to	Fraction	Qmax	Description
C51E Diversion	C51W Canal	EAST	1	1000	
S5A Div (ECART)	S5A Div	HILLS_C	0	300	divert to hills up to qmax
S5A Div (ECART)	S5A Div	HILLS_C	0	200	low-flow bypass to WPB
S5A Div to FEB North	FEBS5A	FEBS5A_N	0		northern STA.FEB
FEB S5A Outflow	HILLS_C	STA1DW	1	75	diversion to Hills
C51W Outflow	EAST	STA1E	0.31	600	direct to STA1E
C51W Outflow	EAST	STA1_DW	1	300	direct to STA1DW
C51W Outflow	EAST	FEB_S5A	1	0	remainder to East
STA1W Distrib	STA1W	STA1E	0		WPB C STA1E
S6 Runoff	STA2CB	NNRC	0.73		S6 divert to NNR
NNR Canal	FEB34	STA34	0		NNR LowQ Bypass to STA34
STA56 Distrib	STA5	STA6	0.39		Balance STA56 Loads, Hint= 0.394
L8 to STA1N	C51W	FEBS5A_N	0		To FEB S5AN (Rest to C51W)
L8 to North	C51W	North	0		CERP
NNR to CB	STA34	Comp B	0		Original Design for Comp B =1

Mass Balance Summary C51E_AA project_c51e_aa.xls Run Date 8/31/10 22:34

		Inflows			Outflows				
	Area	Flow	Load	Conc	Flow	Load	Conc	HLR	HLR Ma
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d
STA1E	5.1	123	18.7	123	116	1.6	11.5	2.00	7.0
STA1W	14.7	327	63.2	157	328	4.7	11.5	1.86	8.6
STA2B	15.1	291	64.0	178	296	4.2	11.5	1.61	7.0
STA34	38.5	718	110.3	125	693	9.8	11.5	1.55	6.8
STA5	7.9	122	24.2	161	101	1.4	11.4	1.29	3.8
STA6	5.1	78	15.5	161	50	0.7	11.5	1.27	3.7
Total STA	86.5	1659	296.0	145	1584	22.5	11.5	1.60	
				STA1W+E	444.0	6.3	11.5		
				STA2+34+B	989.4	14.0	11.5		
				STA5+6	150.9	2.1	11.4		

FEB Calculations	FEB_S5A	FEB_34	FEB_56	FEBS5A_N	
DMSTA calibration	RES_3	RES_3	RES_3	EMG_3	
Area kac	1.67		7		
HRT days	30	14	90	30	
Bypass Depth ft	44	4	12	4	
LowQ Bypass cfs	200	400	100	100	
Max Qin cfs	2000	4000	2500	2000	
Max Qout cfs	1000	1000	500	500	
Control Depth ft	0.5	0.5	0.5	0.5	
Min Release Depth ft	0.5	0.5	0.5	0.5	Optional:
Regulation Schedule	FEB_REG	FEB_REG	FEB_REG		See FEB_Design Sheet
STA WS Release	URB+STA+REF	REL_STA	REL_STA		See input series sheet
Farm WS Release				REL_FARM	""
Frac Irrig Demand	0.5			0.25	
Frac C51 Urban WS	1				
STA Expansion	STA1WX	STA34X	STA56X		
Area kac	8	22	0		
Fraction SAV	0.67	0.67	0.4		
Ehnanced	SAV_3	SAV_3	PEW_3		

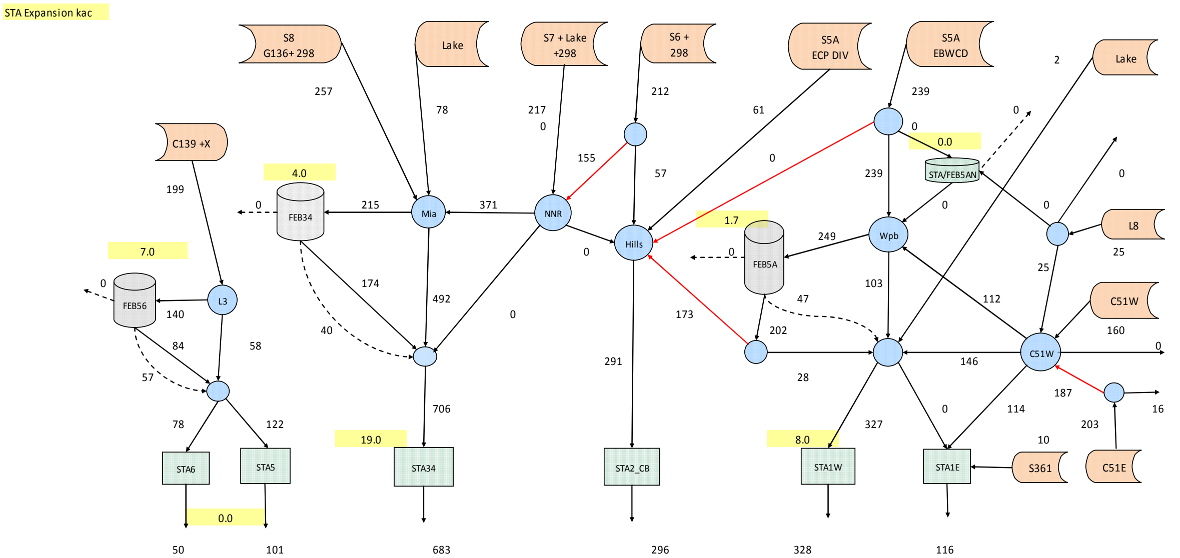
	Area	Flow	Load	Conc	Flow	Load	Conc	Depth cm	
FEBs	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	Mean	Min
FEBS5A_N	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_S5A	1.7	249	57.7	188	202	45.1	181	561	1
FEB_34	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_56	7.0	140	40.0	231	84	15.7	151	153	1
Total FEB	1.7	249	57.7	188	202	45.1	181		

Input Time Series	Flow	Load	Conc	Flow	Flow CV	Flow Max
	kac-ft	mt	ppb	cfs	-	cfs
TS_FEBS5A_N	0.0	0.0	0	0	#N/A	0
TS_FEBS5A	351.5	80.9	186	485	1.67	8130
TS_STA1DW	148.5	23.2	127	205	0.49	829
TS_STA1W	0.0	0.0	0	0	#N/A	0
TS_STA1E	123.3	18.7	123	170	0.88	644
TS_STA2B	118.3	25.2	173	163	1.80	1499
TS_FEB34	0.0	0.0	0	0	#N/A	0
TS_STA34	717.7	110.3	125	991	1.82	10491
TS_FEB56	198.8	53.8	219	274	1.20	4647
Total	1658.0	312.1	153	0	0.00	0

Base Period for Concs	1	1= 2005-2009,2 = 1995-2009		
Use Lake P Concs	TRUE	for S354 & S351 Lake Rleases		
C139 Load Reduc	0%	Max TP ppb	0	
STA Duty Cycle	0.95	New Lake Rel ka	0	
Target Conc ppb	11.5	Iterations	1	use iter=1 for testing, 2 for final
Output Interval	30	S5A/C51 Cmax	0	
S5A Load Reduc	0%	S678 Cmax	0	
Refuge Min Flow	500	C139 Cmax	0	See FEB_STA Sheet, Provision to direct more flow to refuge in dry years.

Watershed Areas	Land kac	Fraction	New STA kac	FEB kac	Runoff Rescale
Scale_s5A	133	1	9.7	1.7	0.91
Scale_S6	105	1			1.00
Scale_s7	120	1	22.0	0.0	0.82
Scale_s8	120	0			1.00
Scale_Annex	18	1	0.0	7.0	0.61

Scenario: 7 D - C51E Diversion/FEB, A2 FEB+STA, A1 STA Mean Flow kac-ft/yr



									Totals
STA Outflow TP ppb	11.5	11.4		11.5	11.5	11.5		11.5	11.5
STA Expansion kac	0.0			19.0		8.0			27.0
STA Total Area kac	5.1	7.9		35.5	15.1	14.7		5.1	83.5
STA Outflow kacf/yr	50	101		683	296	328		116	1574
WCA Inflow kacft			834		296		444		1574

Inputs for Scenario C51E_A1_RES_3 C51E Div + FEB, A2 8 ft FEB + STA Exp, A1 STA, C139 12 ft FEB

Diversion Rules

Diversion	Default	Diverted to	Fraction	Qmax	Description
C51E Diversion	C51W Canal	EAST	1	1000	
S5A Div (ECART)	S5A Div	HILLS_C	0	300	divert to hills up to qmax
S5A Div (ECART)	S5A Div	HILLS_C	0	200	low-flow bypass to WPB
S5A Div to FEB North	FEBS5A	FEBS5A_N	0		northern STA.FEB
FEB S5A Outflow	HILLS_C	STA1DW	1	75	diversion to Hills
C51W Outflow	EAST	STA1E	0.31	600	direct to STA1E
C51W Outflow	EAST	STA1_DW	1	300	direct to STA1DW
C51W Outflow	EAST	FEB_S5A	1	0	remainder to East
STA1W Distrib	STA1W	STA1E	0		WPB C STA1E
S6 Runoff	STA2CB	NNRC	0.73		S6 divert to NNR
NNR Canal	FEB34	STA34	0		NNR LowQ Bypass to STA34
STA56 Distrib	STA5	STA6	0.39		Balance STA56 Loads, Hint= 0.394
L8 to STA1N	C51W	FEBS5A_N	0		To FEB S5AN (Rest to C51W)
L8 to North	C51W	North	0		CERP
NNR to CB	STA34	Comp B	0		Original Design for Comp B =1

Mass Balance Summary C51E_A1_RES_:project_c51e_a1_res_3.xls Run Date 9/1/10 21:15

		Inflows			Outflows				
	Area	Flow	Load	Conc	Flow	Load	Conc	HLR	HLR Ma
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d
STA1E	5.1	123	18.7	123	116	1.6	11.5	2.00	7.0
STA1W	14.7	327	63.2	157	328	4.7	11.5	1.86	8.6
STA2B	15.1	291	64.0	178	296	4.2	11.5	1.61	7.0
STA34	35.5	706	103.1	118	683	9.7	11.5	1.66	7.4
STA5	7.9	122	24.3	162	101	1.4	11.4	1.29	3.7
STA6	5.1	78	15.5	162	50	0.7	11.5	1.27	3.7
Total STA	83.5	1647	288.8	142	1574	22.4	11.5	1.65	

STA1W+E	444.0	6.3	11.5
STA2+34+B	979.4	13.9	11.5
STA5+6	150.9	2.1	11.5

	Area	Flow	Load	Conc	Flow	Load	Conc	Depth cm	
FEBs	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	Mean	Min
FEBS5A_N	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_S5A	1.7	249	57.7	188	202	45.1	181	561	1
FEB_34	4.0	215	32.4	122	174	21.6	101	163	2
FEB_56	7.0	140	40.0	231	84	15.7	151	155	1
Total FEB	5.7	463	90.1	158	376	66.7	144		

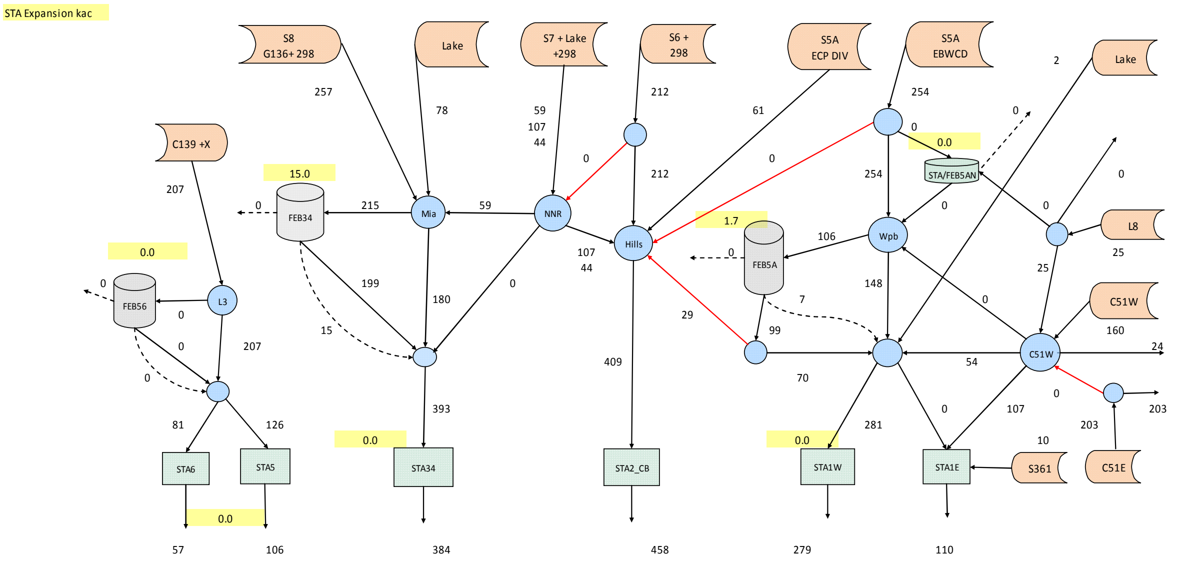
FEB Calculations	FEB_S5A	FEB_34	FEB_56	FEBS5A_N	
DMSTA calibration	RES_3	RES_3	RES_3	EMG_3	
Area kac	1.67	4	7		
HRT days	30	30	90	30	
Bypass Depth ft	44	8	12	4	
LowQ Bypass cfs	200	400	100	100	
Max Qin cfs	2000	2500	2500	2000	
Max Qout cfs	1000	1000	500	500	
Control Depth ft	0.5	0.5	0.5	0.5	
Min Release Depth ft	0.5	0.5	0.5	0.5	Optional:
Regulation Schedule	FEB_REG	FEB_REG	FEB_REG		See FEB_Design Sheet
STA WS Release	URB+STA+REF	REL_STA	REL_STA		See input series sheet
Farm WS Release				REL_FARM	""
Frac Irrig Demand	0.5			0.25	
Frac C51 Urban WS	1				
STA Expansion	STA1WX	STA34X	STA56X		
Area kac	8	19	0		
Fraction SAV	0.67	0.67	0.4		
Ehnanced	SAV_3	SAV_3	PEW_3		

Input Time Series	Flow	Load	Conc	Flow	Flow CV	Flow Max
	kac-ft	mt	ppb	cfs	-	cfs
TS_FEBS5A_N	0.0	0.0	0	0	#N/A	0
TS_FEBS5A	351.5	80.9	186	485	1.67	8130
TS_STA1DW	148.5	23.2	127	205	0.49	829
TS_STA1W	0.0	0.0	0	0	#N/A	0
TS_STA1E	123.3	18.7	123	170	0.88	644
TS_STA2B	118.3	25.2	173	163	1.80	1499
TS_FEB34	706.7	108.7	125	976	1.81	10310
TS_STA34	0.0	0.0	0	0	#N/A	0
TS_FEB56	198.8	53.8	219	274	1.20	4647
Total	1647.1	310.5	153	0	0.00	0

Base Period for Concs	1	1= 2005-2009,2 = 1995-2009		
Use Lake P Concs	TRUE	for S354 & S351 Lake Rleases		
C139 Load Reduc	0%	Max TP ppb	0	
STA Duty Cycle	0.95	New Lake Rel ka	0	
Target Conc ppb	11.5	Iterations	1	use iter=1 for testing, 2 for final
Output Interval	30	S5A/C51 Cmax	0	
S5A Load Reduc	0%	S678 Cmax	0	
Refuge Min Flow	500	C139 Cmax	0	See FEB_STA Sheet, Provision to direct more flow to refuge in dry years.

Watershed Areas	Land kac	Fraction	New STA kac	FEB kac	Runoff Rescale
Scale_s5A	133	1	9.7	1.7	0.91
Scale_S6	105	1			1.00
Scale_s7	120	1	23.0	4.0	0.78
Scale_s8	120	0			1.00
Scale_Annex	18	1	0.0	7.0	0.61

Scenario: 8 C/D - Interim Plan with Temporary A1 FEB, Balance STA-34 Inflow, C51E Div/FEB Mean Flow kac-ft/yr



									Totals
STA Outflow TP ppb	18.3	18.3		11.3	19.2	37.3		12.9	20.0
STA Expansion kac	0.0			0.0		0.0			0.0
STA Total Area kac	5.1	7.9		16.5	15.1	6.7		5.1	56.5
STA Outflow kacf/yr	57	106		384	458	279		110	1393
WCA Inflow kacft			547		458		389		1393

Inputs for Scenario C51E_Interim Phase 1 - A1 as 4 ft FEB, C51 Rockpit 10 kacf (6/44 ft), 3 yrs), No STA expansion; Partial Diversion to West

Diversion Rules

Diversion	Default	Diverted to	Fraction	Qmax	Description
C51E Diversion	C51W Canal	EAST	0	1000	
S5A Div (ECART)	S5A Div	HILLS_C	0		divert to hills up to qmax
S5A Div (ECART)	S5A Div	HILLS_C	0		low-flow bypass to WPB
S5A Div to FEB North	FEBS5A	FEBS5A_N	0		northern STA.FEB
FEB S5A Outflow	HILLS_C	STA1DW	1	200	diversion to Hills
C51W Outflow	EAST	STA1E	0.6	700	direct to STA1E
C51W Outflow	EAST	STA1_DW	0.7	1000	direct to STA1DW
C51W Outflow	EAST	FEB_S5A	0		remainder to East
STA1W Distrib	STA1W	STA1E	0		WPB C STA1E
S6 Runoff	STA2CB	NNRC	0		S6 divert to NNR
NNR Canal	FEB34	STA34	0		NNR LowQ Bypass to STA34
STA56 Distrib	STA5	STA6	0.39		Balance STA56 Loads, Hint= 0.394
L8 to STA1N	C51W	FEBS5A_N	0		To FEB S5AN (Rest to C51W)
L8 to North	C51W	North	0		CERP
NNR to CB	STA34	Comp B	1		Original Design for Comp B =1
NNR to CB 2	STA34	Comp B	0.48		Additional NNR Diversion to CB

Mass Balance Summary

Run Date 8/31/10 20:26

		Inflows			Outflows				
	Area	Flow	Load	Conc	Flow	Load	Conc	HLR	HLR Ma
STA	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	cm/d	cm/d
STA1E	5.1	117	21.9	152	110	1.7	12.9	1.90	8.1
STA1W	6.7	281	66.0	190	279	12.8	37.3	3.51	21.6
STA2B	15.1	453	78.7	141	458	10.9	19.2	2.50	12.3
STA34	16.5	393	47.8	98	384	5.3	11.3	1.98	8.8
STA5	7.9	126	33.4	214	106	2.4	18.3	1.34	6.1
STA6	5.1	81	21.4	214	57	1.3	18.3	1.32	6.0
Total STA	56.5	1451	269.1	150	1393	34.4	20.0	2.14	
				STA1W+E	388.6	14.6	30.4		
				STA2+34+B	841.3	16.2	15.6		
				STA5+6	163.1	3.7	18.3		

FEB Calculations	FEB_S5A	FEB_34	FEB_56	FEBS5A_N	
DMSTA calibration	RES_3	RES_3	RES_3	EMG_3	
Area kac	1.7	15	0		
HRT days	14	14	90	30	
Bypass Depth ft	5.9	4	12	4	
LowQ Bypass cfs	200	400	50	100	
Max Qin cfs	2000	2775	2500	2000	
Max Qout cfs	1000	1000	500	500	
Control Depth ft	0.5	0.5	0.5	0.5	
Min Release Depth ft	0.5	0.5	0.5	0.5	Optional:
Regulation Schedule	FEB_REG	FEB_REG	FEB_REG		See FEB_Design Sheet
STA WS Release	REL_STA	REL_STA	REL_STA		See input series sheet
Farm WS Release				REL_FARM	""
Frac Irrig Demand	0.5			0.25	
Frac C51 Urban WS	1				
STA Expansion	STA1WX	STA34X	STA56X		
Area kac	0	0	0		
Fraction SAV	0.67	0.67	0.4		
Ehnanced	SAV_3	SAV_3	PEW_3		

		Treated Inflow			Outflows				
	Area	Flow	Load	Conc	Flow	Load	Conc	Depth cm	
FEBs	kac	kac-ft	mt	ppb	kac-ft	mt	ppb	Mean	Min
FEBS5A_N	0.0	0	0.0	#N/A	0	0.0	#N/A	0	0
FEB_S5A	1.7	106	27.5	210	99	20.9	171	108	5
FEB_34	15.0	215	29.7	112	199	15.7	64	45	1
FEB_56	0.0	0	0.0	68	0	0.0	#N/A	0	0
Total FEB	16.7	321	57.2	144	298	36.6	99		

Input Time Series	Flow	Load	Conc	Flow	Flow CV	Flow Max
	kac-ft	mt	ppb	cfs	-	cfs
TS_FEBS5A_N	0.0	0.0	0	0	#N/A	0
TS_FEBS5A	253.5	66.3	212	350	1.87	5032
TS_STA1DW	56.3	10.9	157	78	1.34	1000
TS_STA1W	0.0	0.0	0	0	#N/A	0
TS_STA1E	116.8	21.9	152	161	0.91	744
TS_STA2B	423.7	72.5	139	585	2.00	6132
TS_FEB34	394.7	60.5	124	545	1.73	5600
TS_STA34	0.0	0.0	0	0	#N/A	0
TS_FEB56	207.1	54.8	214	286	1.20	4806
Total	1452.2	286.9	160	0	0.00	0

Base Period for Concs	1	1= 2005-2009,2 = 1995-2009		
Use Lake P Concs	TRUE	for S354 & S351 Lake Rleases		
C139 Load Reduc	0%	Max TP ppb	0	
STA Duty Cycle	0.95	New Lake Rel ka	0	
Target Conc ppb	11.5	Iterations	1	use iter=1 for testing, 2 for final
Output Interval	30	S5A/C51 Cmax	0	
S5A Load Reduc	0%	S678 Cmax	0	
Other		C139 Cmax	0	

Watershed Areas	Land kac	Fraction	New STA kac	FEB kac	Runoff Rescale
Scale_s5A	133	1	1.7	1.7	0.97
Scale_S6	105	1			1.00
Scale_s7	120	1	15.0	15.0	0.75
Scale_s8	120	0			1.00
Scale_Annex	18	1	0.0	0.0	1.00

February 16, 2010

Modeling Phosphorus Dynamics in Everglades Wetlands and Stormwater Treatment Areas

William W. Walker, Jr. [1] and Robert H. Kadlec[2]

[1]Environmental Engineer, Concord, Massachusetts, bill@wwwalker.net
[2]Wetland Management Services, Chelsea, Michigan, rhkadlec@chartermi.net,

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Abstract

Longitudinal gradients in phosphorus (P) stored in the water column, vegetation, and soils develop in the wetlands where inflow P concentrations exceed background levels. Prior to the mid 1990's, the Everglades regional P gradient ranged from 100-200 $\mu g\ L^{-1}$ in marsh inflows to background levels of 4-8 $\mu g\ L^{-1}$. Subsequent implementation of P controls, including agricultural Best Management Practices (BMPs) and Stormwater Treatment Areas (STAs), reduced the average inflow concentration along the northern edge of the Water Conservations Areas (WCAs) to approximately 33 $\mu g\ L^{-1}$ in 2007-2009. Additional P controls are being implemented and further measures beyond those currently planned will be required to restore the entire marsh. This paper describes the evolution and application of relatively simple mass-balance models to simulate P storage and cycling processes along P gradients in the STAs and downstream marsh. The models are practical engineering tools that have been extensively applied to the design of Everglades regional P control plans involving combinations of source controls, water management, reservoirs, and STAs, as well as in simulating P dynamics in natural marshes immediately downstream of treated and untreated discharges.

Key Words

Everglades, phosphorus, modeling, marsh, engineering, wetland treatment areas

Introduction

As water with elevated phosphorus (P) moves through a wetland ecosystem, P is removed and a gradient of decreasing P concentration is produced along the flow path (Reddy et al., 1993; Craft et al., 1993a; Craft et al, 1993b; Walker, 1995; Kadlec & Walker, 1999). The water-column P gradient is typically accompanied by gradients of P storage in vegetation and soils (Figure 1). Phosphorus originating in inflows and atmospheric deposition is cycled within the marsh and ultimately stored in accreting peat or transported downstream. Historically, the water-column P gradient in the Everglades marsh ranged from 100-200 $\mu g\ L^{-1}$ at the inflows to background levels of 4-8 $\mu g\ L^{-1}$ (Figure 2). Nearly two decades of monitoring and research by the South Florida Water Management District (SFWMD) and other agencies have established that Everglades wetland ecosystems change dramatically along the P gradient and that native slough and sawgrass communities are viable only at P concentrations below 10 $\mu g\ L^{-1}$, expressed as a long-term geometric mean (Payne et al, 2003). With sheet flow hydraulics, water quality at the edge of the marsh is determined by the quality of the inflows. Restoring and protecting the entire marsh is likely to require inflow P concentrations equivalent to the marsh P criterion (Payne et al, 2008). This is in contrast to lakes or other well-mixed water bodies where inflows with concentrations exceeding water quality standards do not trigger violations of ambient standards because they are rapidly dispersed, diluted, and/or assimilated in receiving waters.

Spatial and temporal variations in the Everglades regional P gradient over the past three decades are shown in Figure 2. Substantial progress has been made since 1993 in reducing P concentrations in the inflows to the Water Conservation Areas (WCAs) through implementation of agricultural Best Management Practices (BMPs) and construction of Stormwater Treatment Areas (STAs) (SFWMD, 2009b). As these control measures were implemented, the combined WCA inflow concentration decreased from ~170 μg L^{-1} in 1980-1989 to ~61 μg L^{-1} in 2000-2009. Within the last decade, the three-year rolling-average inflow concentration decreased from ~64 μg L^{-1} in 2001-2004 to ~33 μg L^{-1} in 2007-2009. The historical reductions in inflow concentration have cascaded through the networks of canals and marshes to cause P concentration reductions in the outflows from each WCA (Figure 2). Further reductions in WCA inflow and outflow concentrations are expected to result from implementation of additional source-control and treatment measures.

The effect of the P control program is to displace the P gradient upstream of the marsh so that most of it occurs within STAs constructed on formerly agricultural land (Figure 1). At the same time, elevated P concentrations driving the gradient are reduced through implementation of BMPs. When long-term restoration objectives are achieved, the marsh gradient will be substantially reduced relative to historical conditions and have long-term geometric mean P concentrations ranging from 10 μg L^{-1} to background levels of 4-8 μg L^{-1}.

This paper describes the evolution of relatively simple mass-balance models to simulate P storage and cycling processes along P gradients in the STAs and marsh. In the context of the Everglades restoration effort, the models and associated software have provided practical engineering tools for designing P control measures involving combinations of source controls, regional water management, reservoirs, and STAs, as well as for simulating marsh responses to variations in flow and P load in transects downstream of WCA inflow points.

Model Evolution

The models described below were developed to support evaluation of multiple STA design alternatives by engineering professionals without requiring site-specific calibration data or specialized expertise in wetland modeling. Model simplicity results from aggregation of key variables and processes controlling phosphorus storage and cycling. The simplifying assumptions are supported by calibration and testing against several dozen datasets that describe phosphorus removal in experimental prototypes, field-scale test cells, full-scale STAs, and natural wetlands (Walker & Kadlec, 2001; 2005). These datasets provide bases for calibration and testing under a wide range of conditions (e.g. size, water depth, P concentration, P load, velocity, vegetation types, inflow variability) and for estimating uncertainty associated with model forecasts. While the modeling effort was initiated to support STA design, the fundamental concepts (mass balance, hydraulics, P cycling mechanisms) operating along a P gradient (Figure 1) also apply to natural wetlands. Differences between the STAs and naural marsh related such factors as water depth, hydraulic loads, antecedent soils, and vegetation are considered by explicitly including those factors in the model(s) or by defining limits of application consistent with calibration datasets.

Figure 3 shows P storage compartments and fluxes associated with four models that evolved over the 1995-2008 period (Kadlec, 1994; Walker, 1995; Walker & Kadlec, 1999; Walker & Kadlec, 2005; Kadlec, 2006). They involve different combinations of three fundamental storage compartments (water column, biota, soil) and associated net fluxes between compartments. While P generally moves in both directions between compartments via different mechanisms, the aggregated models simulate the net fluxes that ultimately drive the mass balance. Model structures represent P storage and net fluxes per unit area of marsh. These are coupled with hydraulic models to predict water movement and P transport. Excel spreadsheet software developed to support model applications is limited to relatively simple one-dimensional hydraulic models representing sheet flow along a marsh transect or STAs with individual treatment cells connected in series and/or parallel. The P cycling variables and equations can be translated to more complex hydraulic models capable of predicting two-dimensional flow and mass transport in an STA or marsh. For example, Chen et al (2009) have included DMSTA’s P cycling algorithms in a two-dimensional hydraulic model of WCA-1.

Models with greater complexity have been developed for describing water and phosphorus movement in STAs (Guardo and Tomasello 1995; HydroQual, 1998 Moustafa and Hamrick, 2000) and Everglades marsh (Fitz and Trimbel, 2006; Munson et al, 2002; Jawitz et al., 2008). They generally account for two-dimensional spatial and temporal variability and have several state variables and adjustable parameters. Most require enhanced computers, long run times, site-specific calibration data, and special expertise to calibrate and apply. These requirements generally preclude engineering applications to STA design. The Everglades Landscape Model (ELM, Fitz and Trimbel,2006) has been extensively used in the Everglades restoration effort. It simulates system-wide variations in marsh hydrology, water quality, soils, and vegetation in response to variations in marsh inflows and other factors projected to occur in response to long-term restoration efforts. The models described below can be used to evaluate localized impacts of discharges and to provide inflow boundary conditions for ELM applications to the entire Everglades marsh.

Steady-State STA Design Model (STADM)

The STA design model (STADM) (Walker, 1995) was used to develop initial designs for ~29,000 hectares of STAs to achieve a long-term flow-weighted mean outflow concentration of 50 $\mu g\ L^{-1}$ (Burns and McDonnell, 1994). A modified version that places a lower bound on P concentration (Kadlec, 1994; Kadlec and Wallace, 2009) was used in the initial design of STA-3/4 (Burns and McDonnell, 1999). Knowledge and experience gained through research, operation, and monitoring of these initial STAs subsequently provided a technical basis for optimizing and expanding the STAs to achieve lower P concentrations, as well as for improving the models to support that effort (SFWMD, 2009b).

The STADM simulates the long-term-average water-column P gradient along a marsh transect as a function of the average inflow volume, inflow load, flow-path width, and atmospheric deposition. The model includes one P storage compartment (water column) and three P fluxes: inflow, outflow, and net removal in the accreting peat (Figure 3).

hort-term variations in P storage and cycling in vegetation and soils are essentially embedded in the calibration. Because the design objective was expressed as a long-term flow-weighted mean, predictions of short-term variations in P concentration were not required to support the 50 μg L^{-1} STA designs. A steady-state model is not sufficient, however, for designing STAs to achieve lower P concentrations driven by highly pulsed inflows (see DMSTA, below)

The STADM assumes that the average net P removal rate per unit area is proportional to the average water-column concentration. No P removal is assumed to occur when the marsh is nearly dry (water depth < 30 cm). The proportionality constant ("net settling rate" = 10.2 +/- 1.4 meters/yr) was calibrated to peat accretion measurements along the P gradient in the WCA-2A marsh downstream of outflows from WCA-1 (Figure 2). The peat data provided an integral measure of net P removal over a 26-year period. Global distribution of fallout from nuclear bomb testing in 1963 placed a layer of radioactive Cesium-127 in the soil profile. The accumulated soil P was estimated by vertically integrating from the peak in Cesium-127 content to the surface using soil cores collected at 24 monitoring sites (Reddy et al., 1991, 1993; Craft and Richardson, 1993ab). The model was tested against limited water-column concentration data along the same marsh transects (Walker, 1995). Because of the limited quantity and the high spatial and temporal variability in the water column data, the integrated peat accretion data provided a preferred basis for calibrating the model to predict long-term P removal rates. Data from wetland treatment areas sufficient to support calibration were not available at the time of STADM development.

Effects of variability in the inflows, water depth, hydraulics, and vegetation types were embedded in the STADM calibration to the marsh. In applying the model to design the 50 μg L^{-1} STAs, it was assumed that STA vegetation types and P cycling processes would be similar to those in the upper portion of the P gradient in the WCA-2A marsh used for calibration (predominantly cattail). Potentials for regulating STA inflow volumes, flow distribution, water depths, and vegetation to optimize treatment suggested that the model calibrated to a natural wetland would generate conservative forecasts of

STA performance. Subsequent data from full-scale treatment cells with primarily emergent vegetation indicated an average net settling rate of 11.4 m/yr as compared with the STADM calibrated value of 10.2 m/yr (Walker & Kadlec, 2005). Average net settling rates computed for entire STAs with both emergent and submerged vegetation operated in design ranges have ranged from ~10 to ~25 m/yr.

Everglades Phosphorus Model (EPGM)

The Everglades Phosphorus Gradient Model (EPGM) (Walker & Kadlec, 1996; Kadlec & Walker, 1999) tracks P accumulation in soils along marsh transects downstream of inflows with P concentrations above marsh background levels (Figure 1, Figure 3). While not required for STA design, predictions of soil P variations in the marsh are useful because some ecosystem components are driven more by soil P content (cattails, other rooted vegetation) than by water-column concentration (periphyton, algae, invertebrates). There is substantially greater uncertainty associated with modeling the soil P compartment, as compared with modeling the water column. This uncertainty reflects inherent complexities of soil interactions with vegetation and water column, as well as limitations in soils data related to sampling artifacts and high spatial variability (Grunwald et al., 2004; Cohen et al., 2009). EPGM provides the simplest representation of the soil P compartment consistent with the data available for calibration.

The water-column component of EPGM is identical to the STA design model. Both assume sheet-flow hydraulics and are calibrated to data primarily from WCA-2A. Vertical mixing within the soil profile is assumed to be minimal. This assumption is supported by substantial vertical and longitudinal gradients in soil P content observed in the WCA-2A soil cores used for calibrating the STADM (Kadlec & Walker, 1999). The accumulation of soil mass in EPGM is driven by a correlation between soil mass accretion rate and soil P accretion rate calibrated to dated soil cores in WCA-2A and tested against limited data from other WCAs. This correlation determines a relationship between the average P content of accreting peat and the average P concentration in the water column (Kadlec & Walker, 1999). EPGM calibration to WCA-2A transect data indicates that soil accretion rates vary from 0.1 to 1.0 kg/m^2-yr and the P content of accreting peat varies from 500 to 1400 mg/kg as the average water column P varies from 5 to 100 μg L^{-1}.

EPGM has been applied to evaluate the potential impacts of distributing STA outflows with a P concentration of 50 μg L^{-1} into previously un-impacted marsh areas along the northern edge of the WCAs (Walker & Kadlec, 1996). Impacts are expressed in terms of marsh areas exceeding water-column and soil P criteria as a function of time as the soil P gradient (Figure 1) develops downstream of the STA outflows. Cattail densities are also predicted based upon an empirical correlation with soil P contents. The development of steady-state soil P profiles requires one or more decades, depending on the inflow concentration, initial soil P content, depth of soil being tracked, and marsh hydroperiod. Once the soil P profile is fully developed, the EPGM calibration to WCA-2A indicates that marsh areas with water-column P concentrations exceeding 10 μg L^{-1} correspond to areas with steady-state soil P contents exceeding ~650 mg/kg.

Dynamic Model for Stormwater Treatment Areas (DMSTA)

DMSTA (Walker & Kadlec, 2001-2005; Kadlec, 2006) was developed to support design of STAs to achieve outflow TP concentrations approaching the 10 μg L^{-1} criterion. Achieving low P levels requires designing an STA to operate within limited ranges of inflow P concentrations and loads, as well as optimizing vegetation types, water depths, and hydraulics to treat highly pulsed basin runoff. Consideration of these factors requires a dynamic model with an additional P storage compartment to represent labile phosphorus stored in vegetation and litter (Figure 4). This compartment regulates P uptake, recycling, and generation of stable P residuals stored in accreting peat. The initial structure and equations were similar to the autobiotic wetland P model described by Kadlec (1997). Those equations have been refined and calibrated to various emergent and submerged vegetation types (described below) based upon data from South Florida wetlands and treatment areas.

Whereas the STA design model assumed simple sheet-flow hydraulics downstream of the inflows, DMSTA allows simulation of full STA designs involving multiple treatment cells in series and/or parallel with seepage, bypass constraints based upon water depth or pump capacity, and outlet hydraulic controls (Figure 4). Design optimization generally involves specification of cell areas, configurations, depth regimes, hydraulic features, and target vegetation communities to achieve treatment objectives in a cost-effective manner. The model also has a capability for simulating regional networks of STAs and reservoirs, driven by 35-year daily flow time series generated by SFWMD’s regional hydrologic models (SFWMD, 2005). Marsh responses downstream of the STAs can also be simulated using the appropriate calibrations. The spreadsheet interface and limited input data requirements facilitate development and comparison of alternative STA designs.

The first version of DMSTA (Walker & Kadlec, 2001) was calibrated to data from approximately 70 treatment cells and wetlands ranging in size from 10^{-1} to 10^{7} m^{2}. Most of the treatment cell datasets were from experimental tanks and small-scale test cells with different vegetation types operated with constant inflows and water depths over periods of one to three years. Data from a treatment wetland (Boney Marsh) and a full-scale test facility (Everglades Nutrient Removal Project, Chimney et al, 2006) provided the primary bases for calibration. Calibrations were developed for periphyton, emergent vegetation, and submerged vegetation based upon data from the largest prototype in each category. A fourth category represented a transition from submerged vegetation to periphyton over a decreasing P gradient. Data from the smaller experimental platforms were used for testing calibrations in each vegetation category. This version of DMSTA was used in initial feasibility studies for enhanced STA designs (Burns and McDonnell, 2002; Brown and Caldwell, 2002).

With operation and intensive monitoring of the STAs by SFWMD, substantially more data from full-scale treatment cells and wetlands with dynamic inflows and water depths were available to support development of the second version of DMSTA (Walker and Kadlec, 2005). This most recent version includes calibrations for four wetland types (emergent, submerged, periphyton, and mixed vegetation on natural wetland soils), as well as a calibration for open-water reservoirs. The reservoir calibration is based upon data from shallow lakes in Florida (Burns & McDonnell, 2004) and developed to support evaluation regional plans involving networks of STAs and storage reservoirs planned for hydrologic restoration purposes (USACE, 2009).

Steady-state solutions of DMSTA's P cycling equations are mathematically equivalent to the K/C* model (Kadlec, 1994), which is similar to the STA Design Model (Figure 3). Calibrated settling rates are 13-22 m/yr for emergent vegetation, 43-64 m/yr for submerged vegetation, 18-31 μg L^{-1} for periphyton, 27-46 m/yr for mixed vegetation on natural wetland soils, and 3-9 m/yr for reservoirs. The wetland calibrations (first three categories) are in the 60th to 90th percentile range of the global distribution of settling rates, based upon data from 282 treatment wetlands (Kadlec and Wallace (2009). Each calibration is applicable under specific ranges of depth, velocity, and concentration, as determined by the calibration datasets. DMSTA is applicable to treatment cells that have reached a stable operational phase, a process that typically requires one to three years after construction to allow time for the establishment of vegetation and associated P cycles, depending on antecedent soils, water depths, and vegetation.

The second version of DMSTA has been applied in several feasibility and design studies providing treatment of additional flows and phosphorus loads from the source basins, as well as integration of STAs and storage reservoirs south and north of Lake Okeechobee (Burns and McDonnell. 2002, 2003; ADA, 2005; Brown and Caldwell, 2002,2005,2007; Black and Veatch, 2006; URS Inc, 2005; HDR Inc, 2006; Camp Dresser and McKee, 2007; Tetra Tech, 2008). While developed primarily for use in STA design and optimization, DMSTA can also be used as a diagnostic tool to facilitate interpretation of real-time monitoring data from the STAs. Variations in measured STA outflow concentrations reflect variations in inflow volumes, inflow P loads, water depths, climate, management, P cycling within wetland communities, measurement errors, and other random factors. It is difficult to evaluate the inherent P removal performance of the STA wetland community in the context of data variations induced by the other factors. DMSTA factors out the effects of hydrologic variations and STA operations that distribute inflows across cells and regulate water depths. This filtering provides a clearer signal of vegetation function and long-term performance relative to design simulations and management expectations.

DMSTA's structure assumes that flow through each treatment cell is uniformly distributed across its width (sheet flow). While that assumption is consistent with typical design recommendations, hydraulic inefficiencies (short-circuiting, dead zones) can result from spatial variations in ground elevation and remnant farm canals that were not sufficiently filled or plugged at the time of construction (Guardo and Tomasello 1995; Dierberg et al., 2005; DB Environmental Labs, 2006). To some extent, the effects of these factors are embedded in the DMSTA calibrations and in the tanks-in-series model used to represent each cell (Kadlec and Wallace, 2009). DMSTA incorporates a depth-dependent P uptake function that reflects spatial variations in topography (typically +/- 30 cm relative to the mean ground elevation) and the resulting impacts on hydraulic efficiency. To account for extreme variations in topography, the design engineer has the option to adjust the effective treatment area, typically defined as the area flooded at normal operating depth (40 – 60 cm). Future refinements to include explicit consideration of topographic variations within each cell may improve model performance, particularly when water levels are relatively low and risk of short-circuiting is relatively high. While data requirements would limit applicability, the P cycling algorithm can also be superimposed on a full 2-dimensional hydraulic simulation of the STAs, as has been done for WCA-1 (Chen et al., 2009),

With continued operation and monitoring of the STAs, the database to support further refinement of DMSTA expanded more than three-fold between 2005 and 2009, measured in terms of cell-years. Future versions will provide updated calibrations and additional features useful for design and diagnostic applications.

Coupled DMSTA and EPGM

A fourth model under development links DMSTA and EPGM to simulate three aggregated P storage compartments (water column, vegetation, and soil, Figure 3). In the initial version, the structures and calibrations of the DMSTA and EPGM components are unchanged. The soil P compartment is driven by the predicted net accretion from the vegetation P storage compartment of DMSTA. The accretion rates are time-variable, as compared with the original EPGM driven by the steady-state water column concentration profile generated by the STADM.

The long-term decreasing trends in WCA inflow and outflow concentrations (Figure 2) suggest that water column P concentrations respond relatively rapidly to reductions in inflow P, despite the substantial of amounts of P stored in the soils of impacted marsh areas, release of which would delay the water column response. DMSTA testing results also indicate that explicit simulation of the soil P compartment may not be necessary for predicting water-column P variations in the natural marsh or in treatment cell outflows in response to trends in the inflow volumes or concentrations once STA vegetation (DMSTA P storage pool) is stabilized. Effects of soil P storage and exchanges with the water column and vegetation are currently embedded in DMSTA calibrations. Further testing against data in lower P ranges will be possible as STA performance improves and the natural marsh responds to decreasing P loads. Despite greater uncertainty and data limitations, explicit consideration of soil P may improve water-column P simulations in dry periods, which the effects of soil P reflux would be greatest (Pant and Reddy, 2003). While less important for STA design, explicit simulation of soil P levels may be useful for forecasting the spatial and temporal scales associated with restoration of rooted vegetation and other ecosystem components that respond more to soil P variations than to water column P variations.

The existing calibrations of DMSTA and EPGM provide a basis for estimating the time scales required for P stored in each compartment to equilibrate following a change in the long-term average water column P concentration (Figure 5). These scales depend upon the ratio of stored phosphorus to the average input P flux to each compartment computed from a steady-state solution of the P cycling model. Starting from a given set of initial conditions, time scales are expressed as the number of years required for 90% of the shift to new equilibrium distribution of stored P. Equilibration of storage compartments to an ambient P concentration of 10 μg L^{-1} involves time scales ranging from ~1 to 3 years for the vegetation P storage compartment, ~10 years for the 0-2 cm soil horizon, and ~50 years for the 0-10 cm soil horizon. Response times are shorter at higher P concentrations because of increases in the P cycling and soil accretion rates.

The temporal and spatial scales of marsh response to increasing or decreasing P loads are further illustrated in Figure 6. The preliminary model has been applied to simulate variations in P concentration and storage along the WCA-2A marsh transect in response to variations in inflow volume and P load over a 100 year period. The 1963-1995 period represents historical conditions when the marsh P gradient developed in response to increases in P load starting 1960's. P loads gradually decreased between 1995 and 2007 period with implementation of upstream P controls and flow diversions. A hypothetical reduction of inflow concentration to a long-term flow-weighted mean of 12 μg L^{-1} (approximately equivalent to a geometric mean of 10 μg L^{-1}) is imposed in 2008-2062 simulation period. Year-to-year variations in inflow volume and concentration around 12 μg L^{-1} have been estimated from variations in the historical time series. Soil P content in 1963 is initialized at 350 mg/kg based upon vertical soil P profiles in WCA-2A. Marsh response is expressed as areas exceeding various water column P and soil P criteria in each compartment. Areas are computed from the simulated distance along the transect and an average transect width of 10.5 km (Walker, 1995). As expected based upon the steady-state analysis (Figure 5), labile P storage in vegetation responds within a few years to the reduction in inflow concentration, whereas the soil compartments respond over several decades.

Processes not directly reflected in the existing model, such as soil P recycling induced by peat oxidation or mining of soil phosphorus by rooted vegetation, may decrease response times for P stored in the soil but increase the time scales for P stored in the vegetation and water column. One limitation of the EPGM component is that it was calibrated to soils cores collected in 1990-1991 and reflected marsh response to an increase in P load over the 1963-1990 period, when inflow P loads were generally increasing. Substantial data collected since then provide a basis for refining the structure and calibration in the coupled EPGM/DMSTA model. Recent data also provide a basis for testing the model in a recovery mode as the WCA2A marsh responds to further decreases in inflow P load. Data from soil and water column transects in other WCAs are also available to support further refinements (SFWMD, 2009b).

Future Applications to Everglades Restoration

Restoring the Everglades will require delivery of water with sufficient volume, timing, and quality to achieve hydrologic and water quality objectives. Implementation of hydrologic restoration measures will alter the quantities and timing of marsh inflows (USACE, 2009). Changes in timing could have positive or negative impacts on STA performance, depending on how they affect peak inflow volumes and P loads. DMSTA can play continued roles in engineering solutions to achieve both hydrologic and water quality goals. These solutions are likely to involve combinations of the following measures:

1. Additional BMPs to further reduce runoff P concentrations
2. Diversions to balance flows and P loads across STAs
3. Integration of reservoirs to attenuate peak inflows to the STAs
4. Further optimization of the hydraulics, vegetation, and operation of existing STAs
5. Additional STA expansion

Further refinement of the modeling tools will be possible with continued research and monitoring conducted under Florida’s Long-Term Plan (B&M, 2003; SFWMD, 2009b).

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Walker & Kadlec, GEER 2008 Figures

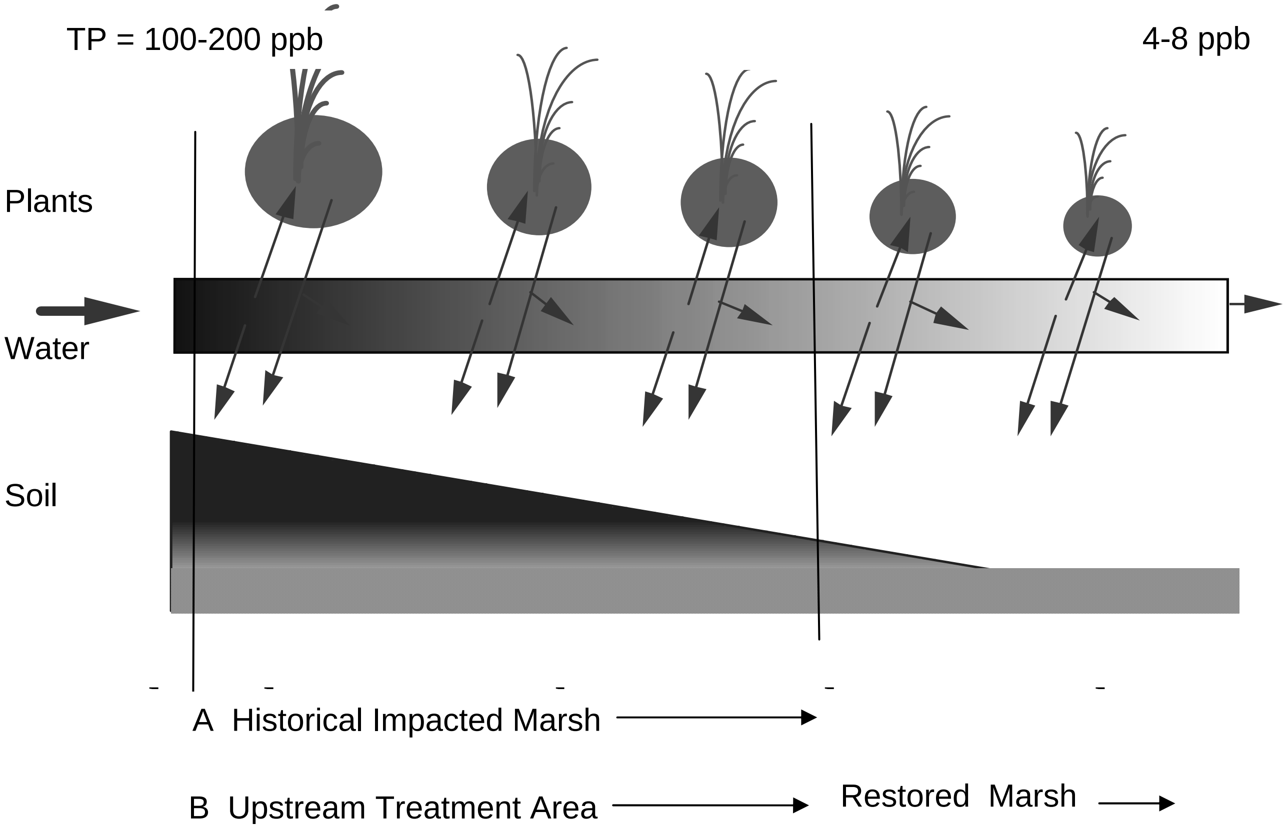


Figure 1

Phosphorus Gradient in Wetland Vegetation, Water Column, and Soils under Historical and Restored Conditions.

A - Historical conditions (before implementation of phosphorus controls). The P gradient is located entirely with the impacted natural marsh.

B - Future restored conditions (after full implementation of P controls). Most of the P gradient is moved upstream out of the natural marsh and located with wetland stormwater treatment areas constructed on adjacent agricultural lands. The remaining gradient within the marsh extends from 10 ppb in the treatment area outflows to marsh background levels.

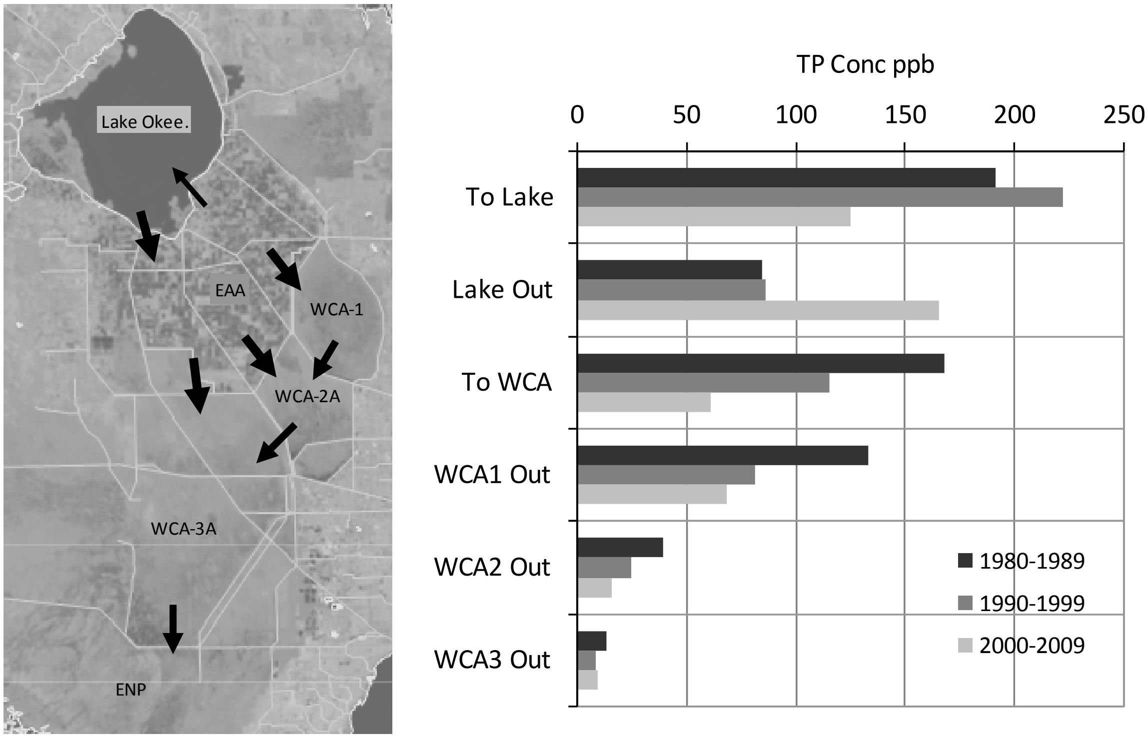


Figure 2

Long-Term Trends in the Everglades Regional Phosphorus Gradient

Phosphorus concentrations are flow-weighted means. Flow and concentration data are from DBHYDRO (SFWMD, 2009a)

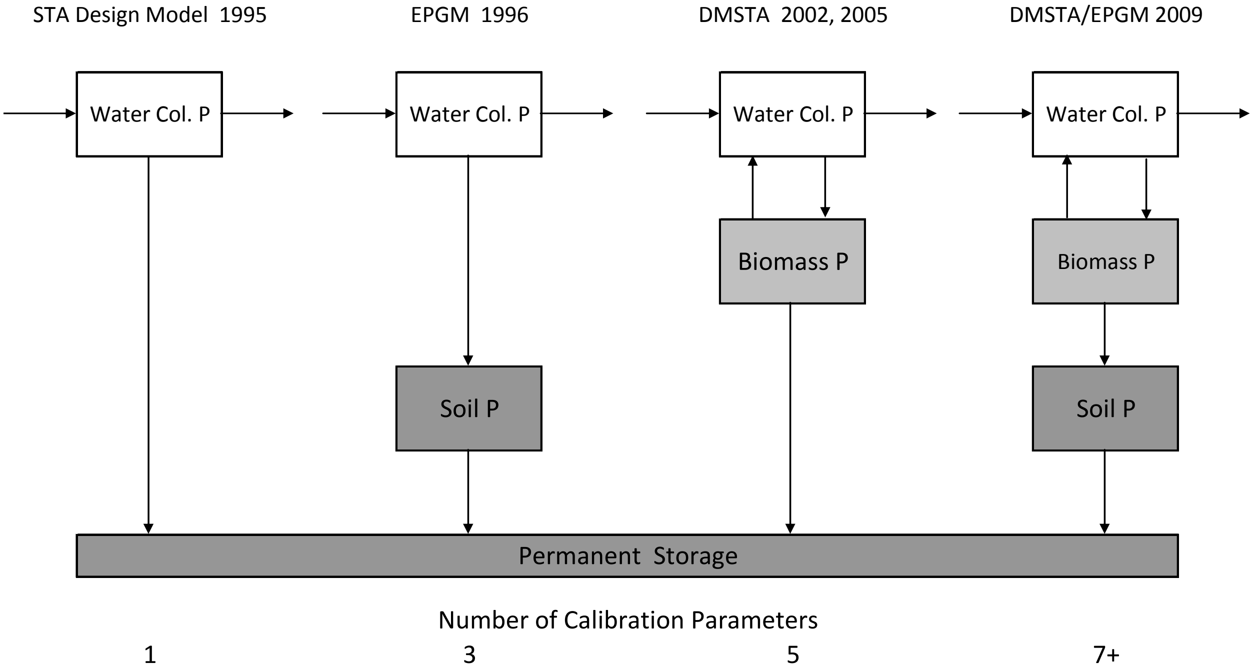
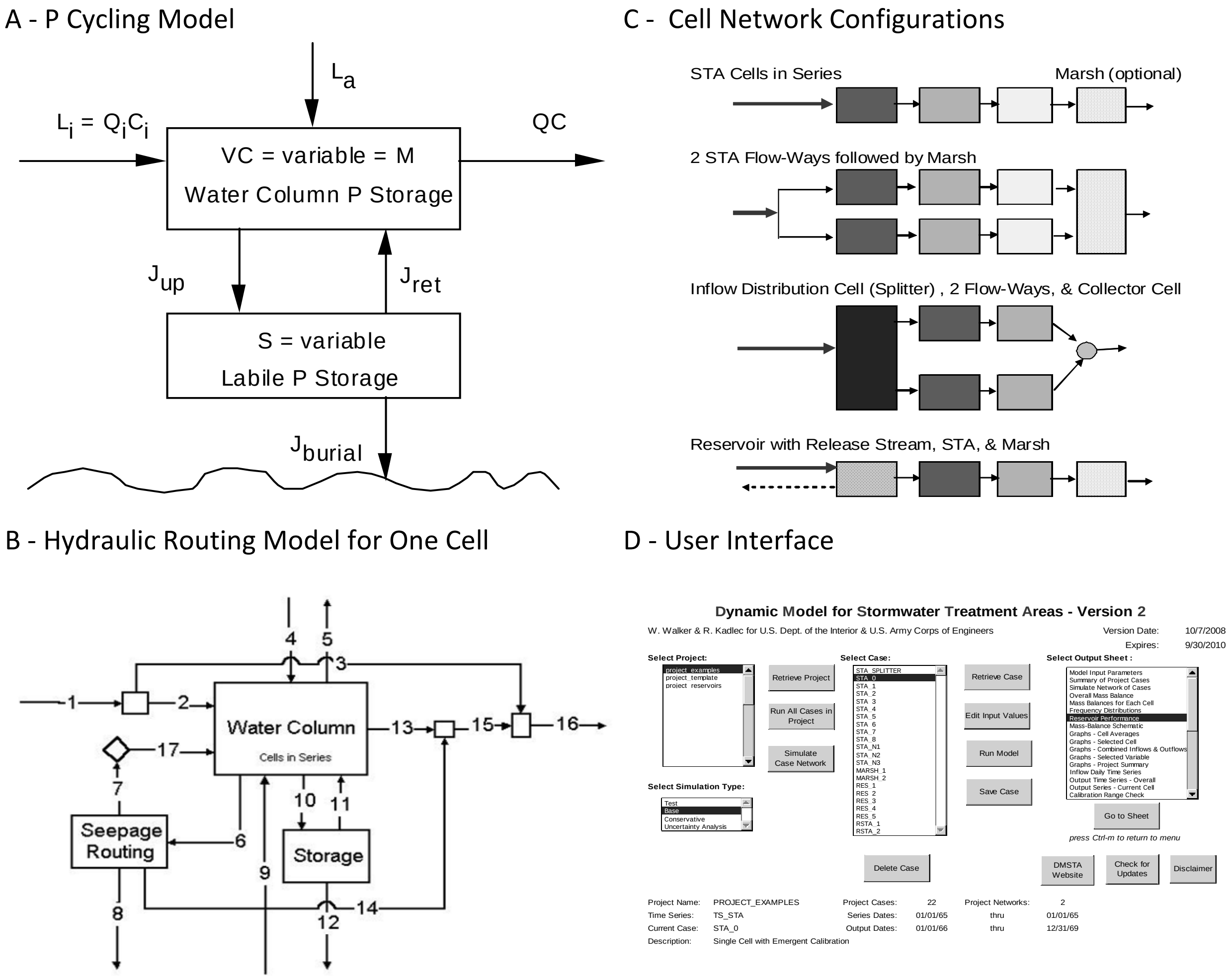


Figure 3

Evolution of Phosphorus Mass Balance Models with Increasing Complexity

Aggregated P compartments and net fluxes are shown for four mass balance models developed over the 1995-2009 period. Permanent storage represents burial of stable P forms in accreting peat. The number of calibrated parameters increases with model complexity.



A - P Cycling Model

B - Hydraulic Routing Model for One Cell

C - Cell Network Configurations

D - User Interface

Dynamic Model for Stormwater Treatment Areas - Version 2

W. Walker & R. Kadlec for U.S. Dept. of the Interior & U.S. Army Corps of Engineers

Version Date: 10/7/2008

Expires: 9/30/2010

Project Name: PROJECT_EXAMPLES
Time Series: TS_STA
Current Case: STA_0
Description: Single Cell with Emergent Calibration

Project Cases: 22
Series Dates: 01/01/65 thru 01/01/65
Output Dates: 01/01/66 thru 12/31/69

Project Networks: 2

Figure 4

Components of DMSTA

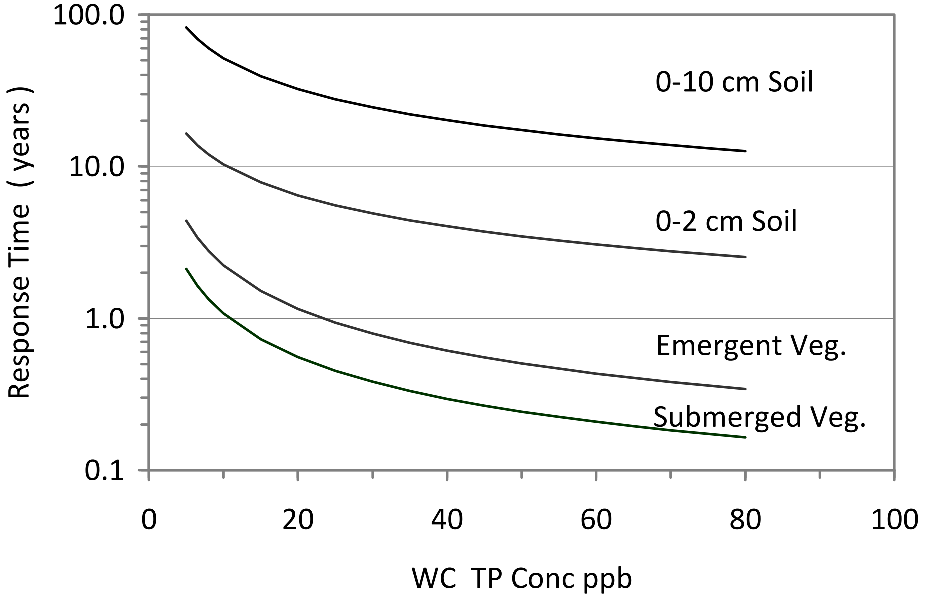


Figure 5

Time Scales of Phosphorus Storage in Wetland Soils and Vegetation

Represent approximate time required for P storage compartments to adjust to a change in the long-term average water-column P concentration. Computed from EPGM and DMSTA calibrations.

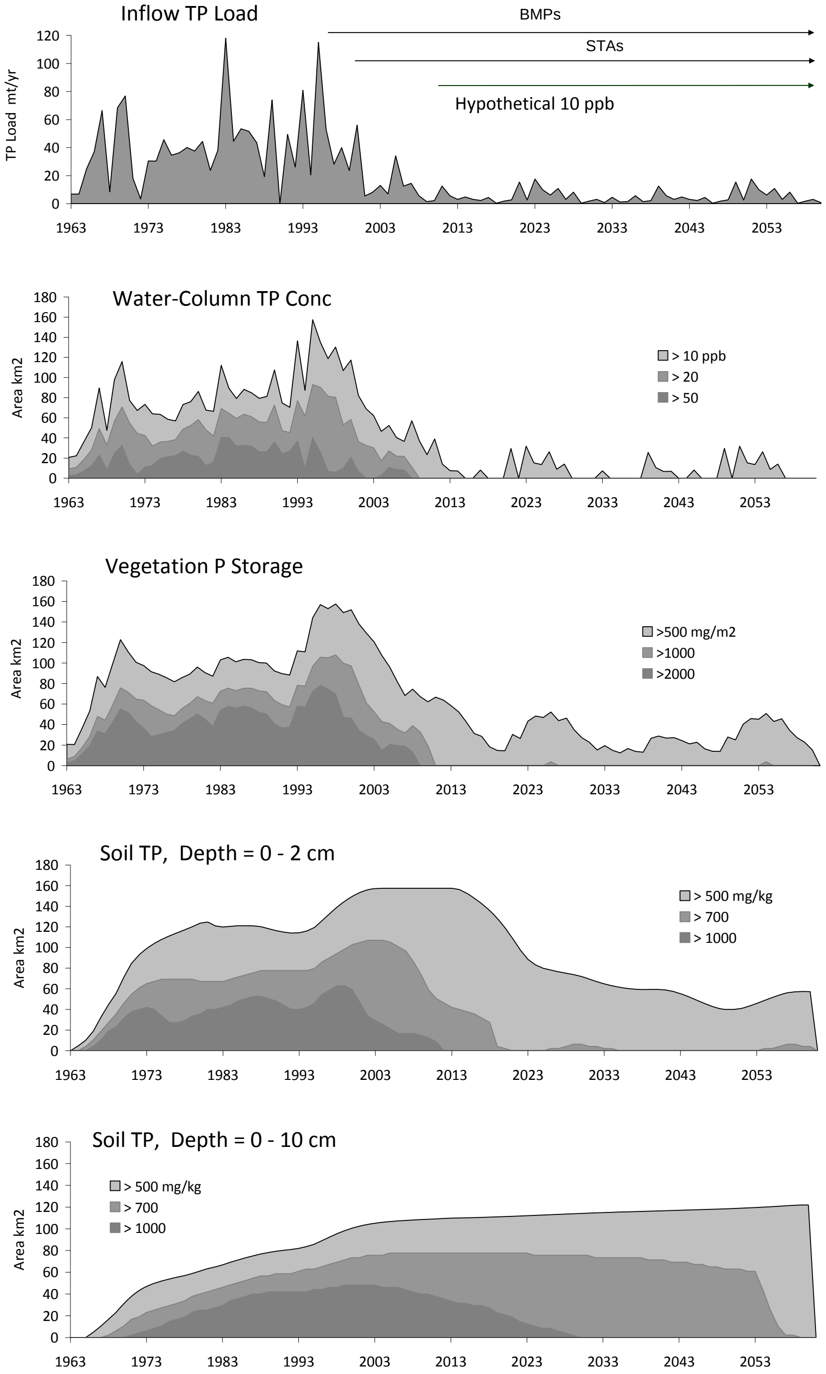


Figure 6

Simulation of WCA-2A Response to Reductions in Inflow P Concentration using the Coupled EPGM/DMSTA Models