D R A F T – For Discussion Purposes

Estimation of Water Quality Based Effluent Limits for Measuring Compliance with the Everglades Phosphorus Criterion

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Introduction

This report demonstrates various methods for deriving Water Quality Based Effluent Limits (QBEL's) to measure ultimate compliance of STA discharges with the 10 ppb phosphorus criterion for the Everglades marsh. It provides a basis for further development and discussion of assumptions and methods that could be used in the derivation.

The following initial assumptions are made for the purposes of this analysis:

1. Compliance is measured in the STA discharge (combined outflows from all discharge structures and pump stations, including any bypasses that cannot be attributed to extraordinary climatologic conditions). Since declining concentration gradients are known to develop in marsh regions downstream of discharges with elevated P concentrations, measuring compliance at the point of discharge (vs. marsh stations) is assumed to be necessary in order to ensure that the marsh between the point of discharge and the first marsh monitoring site is protected (i.e., to avoid a "mixing zone"). Measuring compliance in the STA discharge avoids difficulties and uncertainties associated with placement of marsh monitoring sites relative to distance from the discharge and uncertain flow paths within the marsh. It also avoids costs associated with establishing additional marsh monitoring sites.

2. Changes in concentration between the STA discharge and point of marsh entry are ignored. In some cases, an STA discharge may be mixed with other flows and P sources (e.g., seepage, sediment P release) in distribution or rim canals before entering the marsh. While some degree of phosphorus assimilation is also possible due to sedimentation in the canals, this is likely to be small since particulate phosphorus is readily removed in the STA's. The net effects of additional sources and assimilation between the STA discharge and point of entry into the marsh would be highly site-specific and difficult to evaluate, especially given changing plumbing scenarios. Furthermore, monitoring compliance at multiple sites where flow leaves the distribution/rim canals and enters the marsh would be much more difficult and costly than monitoring compliance in the STA discharge.

3. For consistency with conventional NPDES permits, the QBEL is expressed as a maximum yearly flow-weighted mean (FWM) concentration consistent with achieving compliance with water quality standards, assumed in this case to be a long-term geometric mean (LTGM) concentration of 10 ppb in the STA discharge. That latter is consistent with the treatment goal described in the Long-Term Plan (Burns & McDonnell, 2003). The QBEL is derived from statistical properties of STA discharge time series estimated from historical monitoring data and DMSTA simulations.

4. Consistent with derivations of existing STA permit limits (Walker, 1996; Nearhoof et al, 2005), the QBEL is estimated at the 90th percentile of the yearly FWM concentration (computed for May-April water years). A discharge permit would require the measured FWM to be below the QBEL in every year. Because of differences between the FWM and GM and because of the expected year-to-year variability in the concentration, the QBEL is will be higher than the Long-Term GM target of 10 ppb.

5. There is no distinction between STA discharges to previously impacted vs. un-impacted marshes. The QBEL is assumed to reflect the long-term response that is independent of marsh antecedent conditions.

QBEL derivations based upon DMSTA simulations (Walker & Kadlec, 2005) and recent STA monitoring data are described below.

Derivation Based Upon DMSTA Simulations

One QBEL recipe is based upon DMSTA (Dynamic Model for Stormwater Treatment Areas, Walker & Kadlec, 2005) simulations developed in the recent EAA Regional Feasibility Studies (ADA, 2005). The methodology is similar to that used in deriving the 50 ppb STA discharge permits (Walker, 1996; Nearhoof et al, 2005), but uses simulated as opposed to observed yearly time series:

1. Generate DMSTA output time series for each STA based input files supplied by ADA (2005). Forecasted STA performance under the '2006-2009' and '2010-2014 (Alternative 2)' plans is summarized in Table 1. Alternative 2 simulations are used as an example to derive the QBEL. Other alternatives for 2010-2014 and subsequent periods could be evaluated using a similar methodology. Simulations based upon regional hydrologic models (STA1-W, STA1-E, STA-2, STA-34) are 35 years in length. Simulations of STA-5 and STA-6 are based upon recent monitoring data (adjusted for changes in configuration/operation) and are 11 and 9 years in length, respectively. Consistent with DMSTA calibration procedures, simulations of each plan are averaged at 30-day intervals prior to computing summary statistics. Simulations of geometric means are less reliable for shorter averaging periods because of difficulties associated with simulating short-term variations in P cycling and hydraulics. Simulations of flow-weighted means are

independent of the assumed averaging period.

2. For each STA and Plan, summarize DMSTA output in terms of the following:

   a. Long-term flow-weighted-mean concentration (LTFWM = average load / average flow for the entire simulation period)

   b. Long-term geometric mean (LTGM) computed from 30-day flow-weighted mean time series.

   c. FWM and GM time series for May-April water years, again computed from 30-day DMSTA output time series. Water-year values are approximate because 30-day intervals do not necessarily correspond to water-year boundaries.

3. Compute a QBEL for any STA by rescaling the simulated yearly time series for Alternative 2 (as an example) so that the LTGM = 10 ppb; i.e. multiply each yearly concentration by a constant scale factor, equal to the ratio of 10 ppb and the simulated LTGM. The same scale factor is applied both to the FWM and GM time series. This rescaling assumes that the year-to-year coefficient of variation (standard deviation / mean) is independent of concentration. Compute the QBEL as the 90th percentile of the rescaled FWM time series. The percentile is estimated by fitting a log-normal distribution to the yearly time series (Walker, 1996; Nearhoof et al., 2005). Results are similar when the 90th percentiles are computed directly from the ranked time series.

Comparisons of the 2006-2009, 2010-2014, and QBEL simulations demonstrate the expected progress towards achieving the long-term goal over the next decade. Results are summarized in the following:

- Table 2 – QBEL's Derived from DMSTA Simulations
- Figure 1 – Summary of DMSTA Simulation Results
- Figure 2 – Simulations of 2006-2009 Plans
- Figure 3 – Simulations of 2010-2014 (Alternative 2) Plans
- Figure 4 – QBEL's Derived from 2010-2014 Simulations

QBEL estimates range from 14.3 to 16.7 ppb, with a geometric mean of 15.1 ppb.

Derivation Based Upon STA Monitoring Data

An alternative QBEL derivation is based directly on STA monitoring data. While this approach is limited by the relatively short record (3-7 Years vs. 9-35 years for the DMSTA simulations), it has the advantage of not being subject to modeling uncertainty. The derivation is built upon the most recent derivation of the STA yearly permit limit (68.2 ppb) consistent with a long-term flow-weighted-mean concentration of 50 ppb (Nearhoof et al., 2005) and utilizes the same dataset.

The following equation rescales the 68.2 ppb annual limit consistent with LTFWM = 50 ppb to a QBEL consistent with LTGM = 10 ppb:

$$QBEL = 10 \times (LTFWM / LTGM) \times (68.2 / 50) = 13.6 \ (LTFWM / LTGM)$$

Calibration involves estimation of the LTFWM/LTGM ratio. The geometric mean discharge concentrations (LTGM) are computed using grab samples collected at discharge structures on days with positive flow. When multiple structures are involved, a flow-weighted composite discharge concentration is computed across structures before computing the geometric mean concentration across sampling dates in each water year. Grab samples are used (vs. weekly flow-weighted composites) to compute geometric means in order to best simulate sampling at a hypothetical marsh site located immediately downstream of the combined discharge. Only grab samples are used to measure marsh compliance with the Everglades Phosphorus Criterion. Flow-weighted-mean concentrations (LTFWM) are computed using weekly flow-weighted composite samples, as normally used in measuring compliance with discharge permits.

Figure 5 compares yearly flow-weighted and geometric mean discharge concentrations measured at 5 STA's over a total of 24 water years. These are the same STA's and water years used by Nearhoof et al (2005) to derive the 68.2 ppb limit. Both year-to-year variance and LTFWM/LTGM ratios vary across STA's. Less variability is apparent in the ENR Project (G-251), most likely because that facility was operated at relatively steady flows. More variability is apparent in STA-6, most likely because it dries out in most years and significant concentration spikes are observed when wet-season discharges begin. Figure 5 indicates a strong correlation between yearly FWM's and GM's across all sites. The geometric mean estimate of the FWM/GM ratio (1.18, SE = 0.04) provides a reasonable fit, especially as the geometric mean approaches 10 ppb (the most relevant range for QBEL estimation).

Results of QBEL calculations are summarized Table 3. Estimates of LTFWM/LTGM ratios vary from 1.06 to 1.37 for the various STA's. Corresponding QBEL estimates range from 14.4 to 18.7 ppb. Because of the limited number of years available for each STA, the individual QBEL estimates are relatively uncertain. A pooled QBEL estimate is based upon the geometric mean of the LTFWM/LTGM ratios computed across all STA's and water years (geometric mean = 1.18, standard error = 0.04). The corresponding pooled QBEL estimate is 16.0 ppb (standard error = 0.5 ppb). A similar pooling procedure was used by Nearhoof et al (2005). These estimates could be refined by adding results from Water Year 2005 to the dataset.

Because of relatively high variance in outflow concentrations (Figure 5) and relatively long operating period, results from STA-6 may have a relatively strong influence on the QBEL derivation. The dry-out routinely experienced is not typical of the other STA's or of any of the DMSTA simulations (including STA-6). Similarly, the low variance in the G-251 (ENRP) data is not typical of the full-scale STA's. Sensitivity of the QBEL derivation to inclusion vs. exclusion of these data should be explored.

Discussion

Pooled QBEL estimates (15.1 ppb based upon DMSTA simulations vs. 16.0 ppb based upon STA monitoring data) are similar to the 15 pp yearly limit for GM concentrations at individual marsh sites under the state's 4-Part test for assessing marsh status with respect to the P criterion. Given the modeling uncertainties, data limitations, and assumptions built into the derivations, these values should not be considered significantly different. QBEL estimates derived from the data tend to be slightly higher than estimates derived from DMSTA simulations (Table 3). This is expected to some extent, because DMSTA simulations are not likely to capture all of the year-to-year variance in concentration. In addition, geometric means are computed differently (from 30-day flow-weighted composites in the model-based derivation vs. from daily grab samples in the data-based derivation).

One question is whether initial QBEL estimates should be based upon pooled results, as opposed to results for individual STA's, given the strengths and limitations of both the monitoring data and DMSTA simulations. A pooled estimate could be set initially and refined in subsequent permit cycles as additional data and improved simulations are available for the individual STA's.

References

ADA Engineering Inc. & Burns & McDonnell Inc. "Everglades Agricultural Area Regional Feasibility Study", prepared for South Florida Water Management District, October 2005.

Burns & McDonnell, Inc, "Everglades Tributary Basins – Long-Term Plan for Achieving Water Quality Goals", prepared for South Florida Water Management District, October 2003.

Nearhoof, F., K. Weaver, G. Goforth, & S. Xue, "Test for Determining Achievement of the Initial 50 ppb TBEL for Everglades Stormwater Treatment Areas", May 2005.

Walker, W.W., "Test for Evaluating Performance of Stormwater Treatment Areas", prepared for U.S. Department of the Interior, 1996.

Walker & Kadlec, "Dynamic Model for Stormwater Treatment Areas", prepared for U.S. Department of the Interior and U.S. Army Corps of Engineers, 2005. http://www.wwwalker.net/dmsta

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Table 1 EAARFS Results for 2006-2009 & 2010-2014 (Alternative 2) (ADA, 2005)

2006-2009 Simulations

Table 4.1 Summary Projections for all STAs, for Period 2006-2009

Parameter	Units	Summary of DMSTA2 Results by Treatment Area and Case						
		STA-1W	STA-1E	STA-2	STA-3/4	STA-5*	STA-6	
		2006 Mod	2006 Mod	2006 Base	2006 Base	2006 Base	2006 Base	All
Effective Treatment Area	acres	6,670	6,175	8,140	16,543	6,167	2,197	45,892
Average Annual Inflow								
Volume	1,000 ac-ft	175.1	242.9	343.6	643.1	159.1	78.6	1642.4
TP Load	metric tons	37.7	41.16	43.3	64.94	39.14	8.30	234.52
FWM TP Concentration	ppb	174.3	137	102	82	199	86	116
Average Annual Outflow								
Volume	1,000 ac-ft	176.7	240.9	347.5	624.2	149.7	70.7	1609.7
FWM TP Concentration								
Upper Confidence Limit	ppb	16.7	19.3	17.1	16.2	16.7	11.8	16.8
Mean Estimate	ppb	20.3	25.2	21.0	20.1	39.7	14.3	22.6
Lower Confidence Limit	ppb	25.2	32.3	25.7	24.8	113.1	17.6	34.1
Geometric Mean TP Conc.								
Upper Confidence Limit	ppb	9.8	---	11.2	11.9	11.2	7.7	---
Mean Estimate	ppb	13.5	---	15.0	15.6	33.4	10.3	---
Lower Confidence Limit	ppb	18.5	---	19.7	20.1	66.7	13.7	---
TP Load (Using Mean FWM Conc.)	metric tons	4.43	7.48	8.90	15.46	7.3	1.25	44.84
Summary of Bypass Volumes and Loads								
Bypass Volume, TP Load and TP Concentration for each Treatment Area								
Volume	1,000 ac-ft	16.7	71.5	0.5	50.7	0.0	0.0	139.4
TP Load	metric tons	2.47	9.41	0.04	4.73	0.00	0.00	16.64
FWM TP Concentration	ppb	120	107	66	76	---	---	97

* At STA-5, upper confidence limit reported based on the assumption that the three downstream cells act as SAV_3; lower confidence limit reported based on the assumption that the three downstream cells act as EMG_3. Mean estimate of outflow concentration and outflow TP load taken as average of those two conditions

2010-2014 (Alternative 2) Simulations

Table 5.10 – Summary Projections for all STAs, Alternative 2 for 2010 - 2014

Parameter	Units	Summary of DMSTA2 Results by Treatment Area and Case							
		STA-1W	STA-1E	STA-2	EAASR A-1	STA-3/4	STA-5	STA-6	
		STA1W_Alt2	STA1E_Alt2	STA2_Alt2	2010 Base	STA34_Alt2	2010 (Ave)	Sec1_USSO_SAV	All
Effective Treatment Area	acres	6,670	6,175	15180	16,000	16,543	13,150	897	58,615
Average Annual Inflow									
Volume	1,000 ac-ft	238.6	180.9	324.0	416.9	382.2	159.1	40.2	1742.0
TP Load	metric tons	51.3	29.05	41.5	46.8	40.98	39.14	4.88	253.72
FWM TP Concentration	ppb	174	130	104	91	87	199	98	118
Average Annual Outflow									
Volume	1,000 ac-ft	239.4	177.6	565.0	235.1	598.4	159.2	40.3	1540.5
FWM TP Concentration									
Upper Confidence Limit	ppb	22.1	11.9	12.2	71.7	15.0	8.2	14.1*	---
Mean Estimate	ppb	27.3	15.6	14.9	76.2	18.3	15.3	17.1	16.4
Lower Confidence Limit	ppb	34.2	20.6	18.5	81.1	22.6	30.7	20.8	---
Geometric Mean TP Conc.									
Upper Confidence Limit	ppb	17.2	8.4	9.2	68.9	11.3	4.7	10.5	---
Mean Estimate	ppb	22.1	11.8	11.8	74.4	14.2	11.5	13.4	---
Lower Confidence Limit	ppb	29.0	16.6	15.5	80.4	18.3	26.5	17.2	---
TP Load (Using Mean FWM Conc.)	metric tons	8.05	3.42	10.36	22.08	13.49	3.01	0.85	31.13
Summary of Bypass Volumes and Loads									
Bypass Volume, TP Load and TP Concentration for each Treatment Area									
Volume	1,000 ac-ft	14.2	36.3	0.8	0.0	120.8	0.0	0.0	172.0
TP Load	metric tons	2.23	4.69	0.09	0.00	10.58	0.00	0.00	17.58
FWM TP Concentration	ppb	127	105	84	---	71	---	---	83

Notes:

(1) Surface area of EAASR Compartment A-1 excluded from computation of total effective treatment area

(2) Average annual inflows to STA-3/4 listed above include only direct inflow at G-370 and G-372; outflow from EAASR Compartment A-1 also directed to STA-3/4

(3) Outflows from EAASR Compartment A-1 excluded from computation of total outlfows, as they are directed to STA-3/4

(4) At STA-1E,STA-2 and STA-5, FWM TP concentrations include estimates below the lower calibration range limit of 15 ppb for SAV_3

(5) At STA-5, upper confidence limit reported based on the assumption that the six downstream cells act as SAV_3; lower confidence limit reported based on the assumption that the six downstream cells act as EMG_3. Mean estimates of outflow concentrations and outflow TP load taken as the average of the estimates for those two conditions.

(6) STA-1W, STA-2, STA-3/4 analyzed in DMSTA2 as a part of a network with the EAASR Compartment A-1. The 7/01/2005 version of DMSTA2 is not structured to compute the upper confidence limit of TP concentrations in a network simulation. The upper confidence limits for both FWM and Geometric mean TP concentrations were estimated as described in Parts 3, 5, 6 and 7 of this document.

(7) Average annual inflows to STA-2 listed above include only direct inflow at S-6; outflow from STA-1W also directed to STA-2

(8) Outflows from STA-1W are excluded from total outflows, as they are directed to STA-2

Table 2 QBEL's Derived from DMSTA Simulations

Plan	STA1W	STA1E	STA2	STA34	STA5	STA6
2006-2009 Simulations - Table 4.1 (ADA, 2005) - Figure 2						
DMSTA Case	2006 MOD	2006 MOD	2006 BASE	2006 BASE	2006 BASE	2006 BASE
YEARS	35	35	35	35	11	8
LTGM	14.8	20.4	16.5	16.5	50.7	11.6
LTFWM	20.3	25.2	21.0	20.1	57.5	14.7
FWM90	24.4	30.5	24.1	23.2	72.7	18.5
2010-2014 (Alternative 2) Simulations - Table 5.10 (ADA, 2005) - Figure 3						
DMSTA Case	STA1W_ALT2	STA1E_ALT2	STA2_ALT2	STA34_ALT2	2010 Base EMG	S1_USSO_SAV
YEARS	35	35	35	35	11	9
LTGM	22.1	11.8	11.8	14.2	17.1	13.7
LTFWM	27.3	15.6	14.9	18.3	21.0	17.2
FWM90	33.2	20.0	17.1	21.0	24.1	20.8
QBEL - 2010-2014 Simulations Rescaled to LTGM = 10 ppb - Figure 4						
LTGM	10.0	10.0	10.0	10.0	10.0	10.0
LTFWM	12.4	13.2	12.6	12.9	12.3	12.5
QBEL = FWM 90	14.9	16.7	14.5	15.0	14.3	15.3

DMSTA files for EAA Regional Feasibility Studies (ADA, 2005), summarized in Table 2
Missing Rainfall & ET data in STA5 & STA6 input files filled with observed data
All simulations run with 30-day averaging interval
All STA5 simulations use Emergent calibrations
QBEL derived from 2010-2014 Alternative 2 time series - rescaled to LTGM = 10 ppb
QBEL would not apply to STA1W because it discharges to STA2 (vs. Refuge) Under Alternative 2

LTGM = Long-term geometric mean (ppb) computed from 30-Day flow-weighted composites
LTFWM = Long-term flow-weighted mean (ppb) = average load / average flow
FWM 90 = 90th percentile FWM computed from yearly FWM time series

FWM 90 = EXP (A1 + A2 Z90)
A1 = Mean [LN (FWM)]
A2 = Standard Deviation [LN (FWM)]
Z90 = Standard Normal Variate with 10% Tail = Excel NORMSINV(.9) = 1.282

Table 3 QBEL's Derived from STA Monitoring Data

STA	WATER YEARS		LTGM	LTFWM	LTGM / LTFWM	QBEL	DMSTA QBEL
ENRP (G-251)	6	1995-2000	21.0	22.2	1.06	14.4	
STA-1W	4	2001-2004	35.4	47.1	1.33	18.1	14.9
STA-1E							16.7
STA-2	3	2002-2004	14.0	16.2	1.16	15.8	14.5
STA-34							15.0
STA-5	4	2001-2004	93.6	106.7	1.14	15.5	14.3
STA-6	7	1998-2004	14.2	19.4	1.37	18.7	15.3
Combined	24				1.18	16.0	15.1
Standard Error					0.04	0.5	

LTGM = Geometric mean discharge concentration for period of record (ppb)
Computed from weekly grab samples collected on days with positive flow
Grab concentrations composited across discharge structures on each sampling date
Simulates hypothetical marsh site immediately downstream of combined discharge

LTFWM = Flow-weighted mean concentration for period of record (ppb)
Computed from composite samples (grabs when composites are missing)

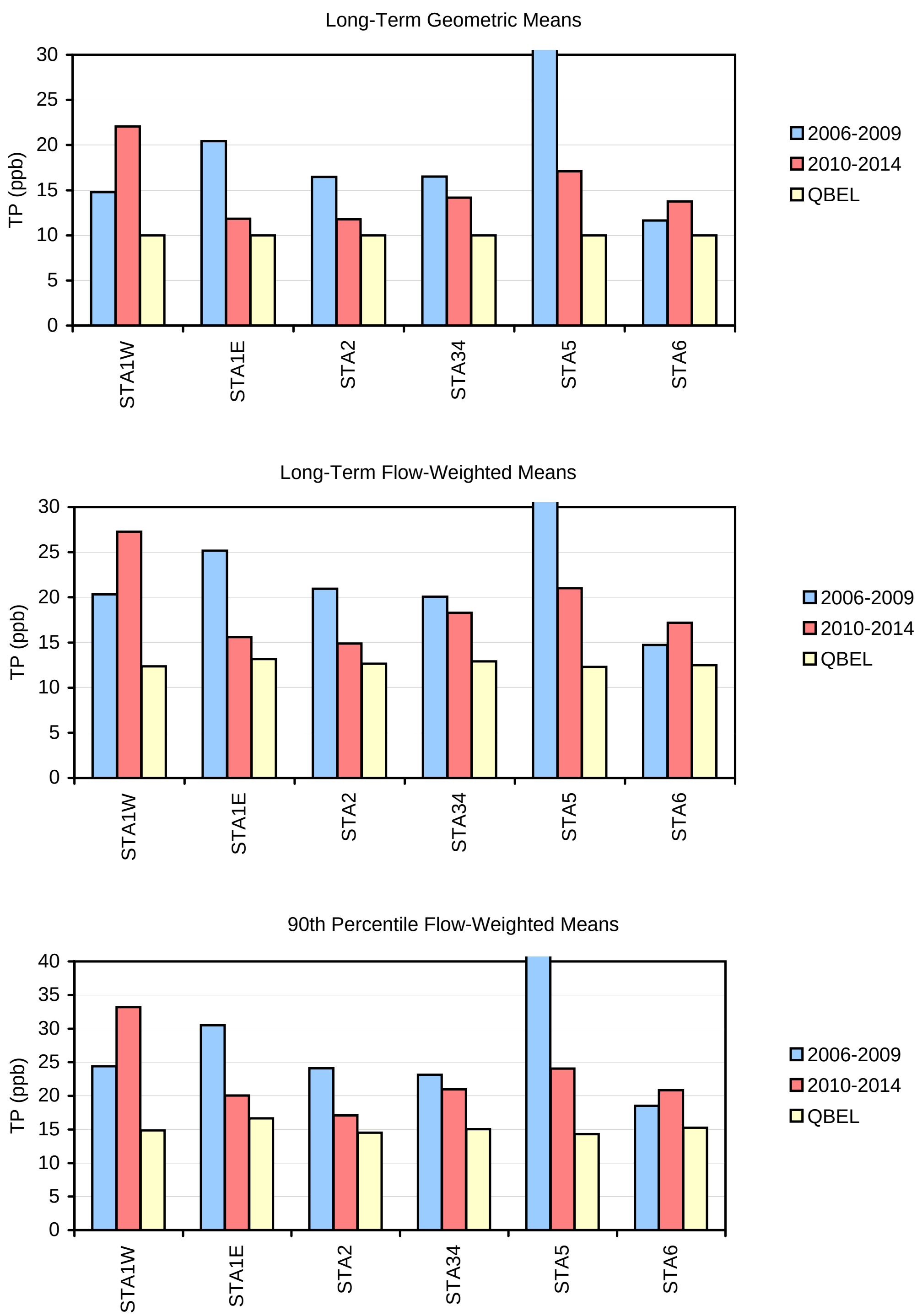
LIMIT50 = Yearly discharge limit for LTFWM of 50 ppb = 68.2 ppb (Nearhoof et al, 2005)

QBEL = Yearly FWM discharge limit equivalent to LTGM of 10 ppb
10 x (LIMIT50 / 50) x (LTFWM / LTGM) = 13.6 x (LTFWM / LTGM)

Combined Computed from the geometric mean of GM/FWM ratios for all STA's and Water Years

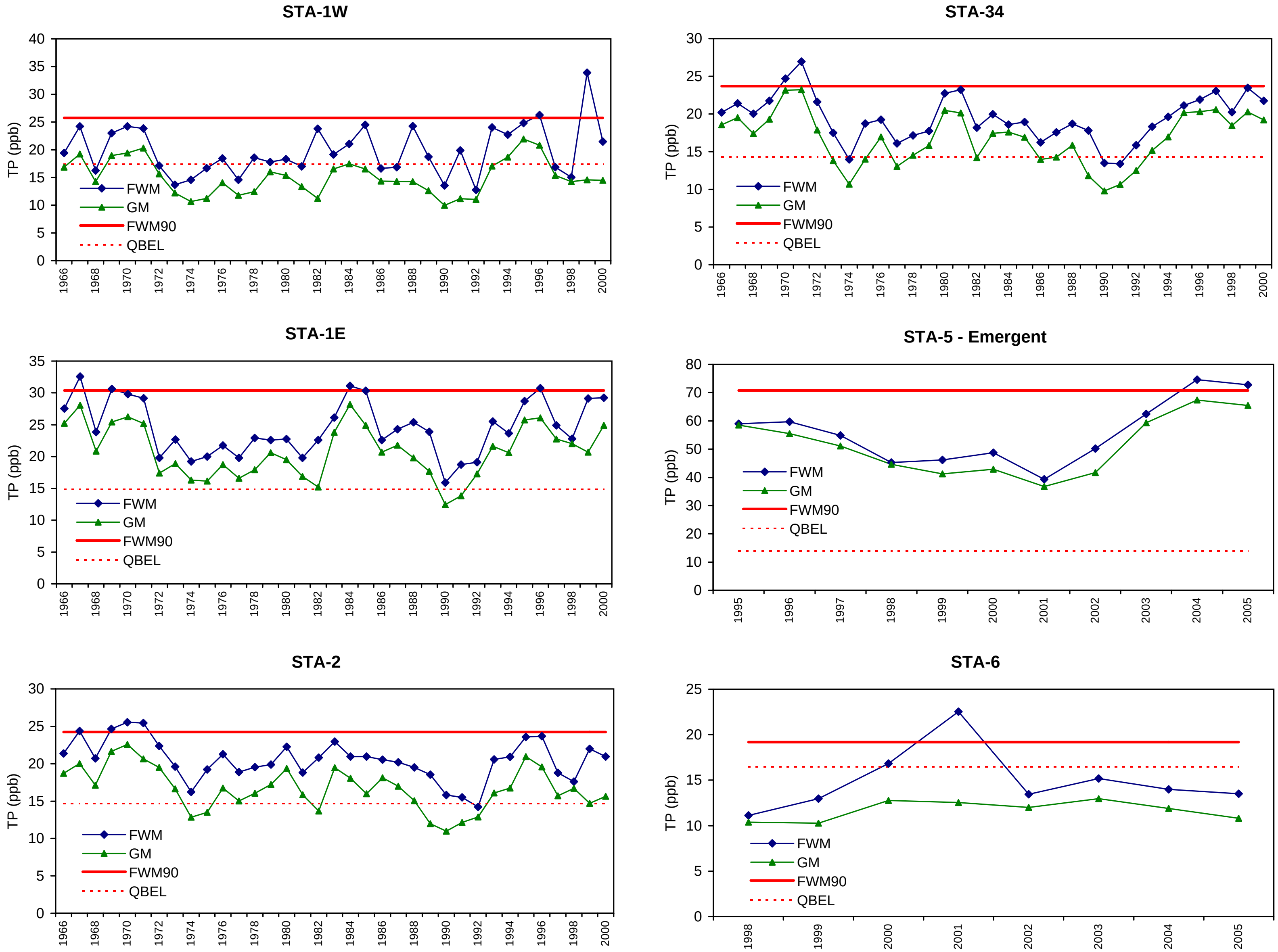
DMSTA QBEL = QBEL computed from DMSTA output for Alternative 2 (Figure 4, Table 2)

Figure 1 Summary of DMSTA Simulation Results



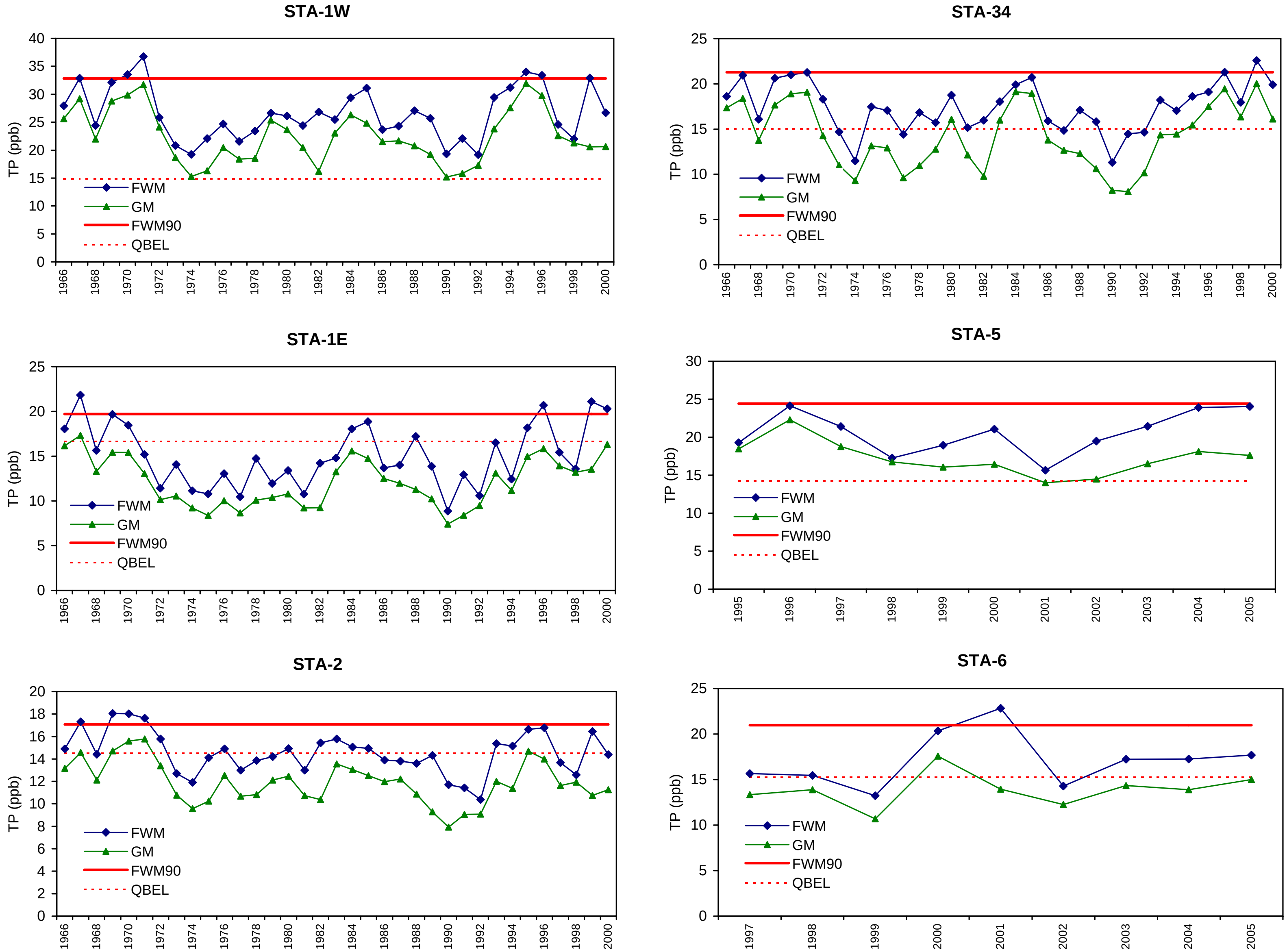
Results for STA-5 (off scale) are listed in Table 2

Figure 2 Simulations of 2006-2009 Plans



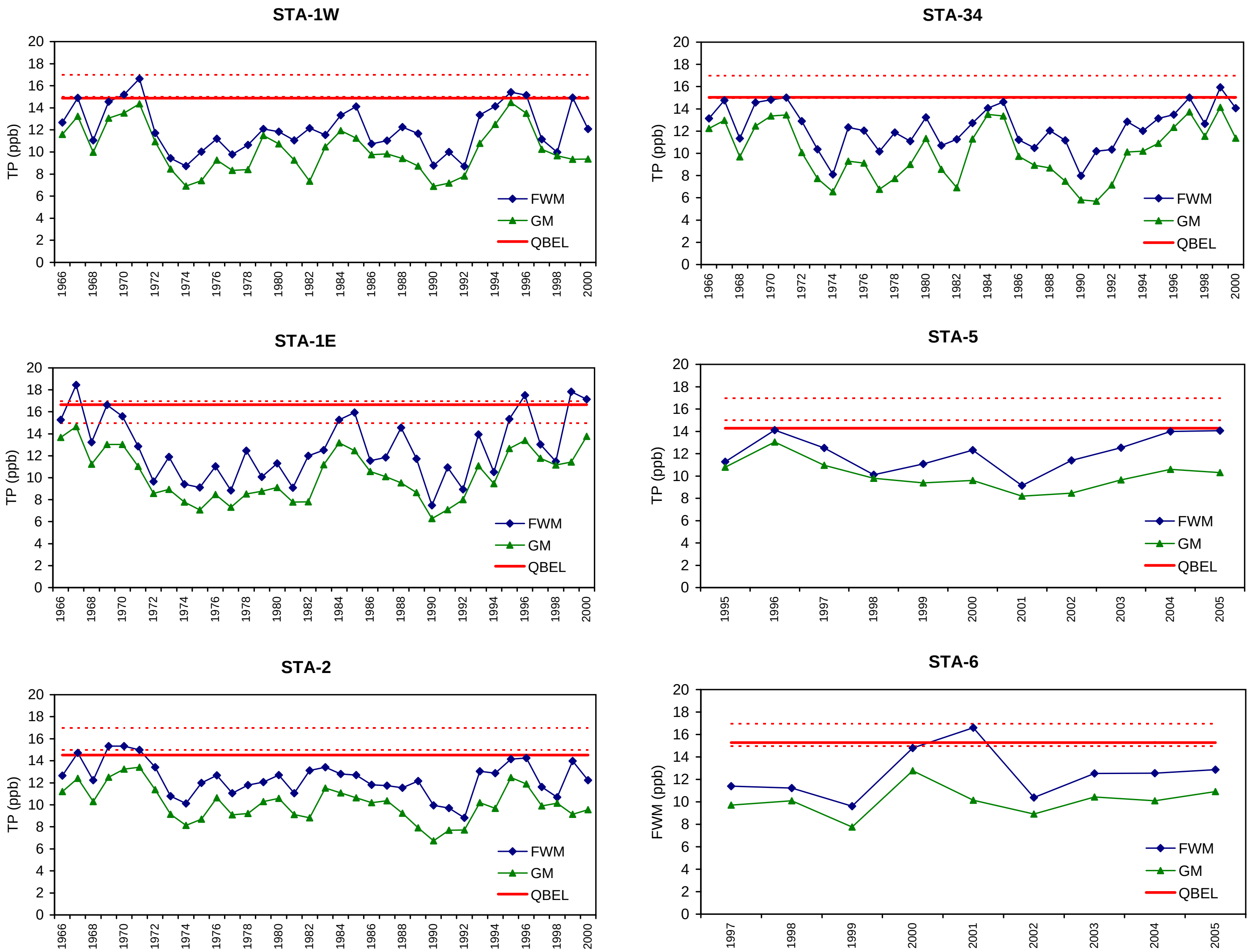
Solid Line = FWM90 = 90th percentile of Yearly FWM's for Simulated Plan
Dashed Line = QBEL derived from 2010-2014 Simulations, Rescaled to LTGM = 10 ppb; 90th Percentile of Yearly FWM's

Figure 3 Simulations of 2010-2014 (Alternative 2) Plans



Solid Line = FWM90 = 90th percentile of Yearly FWM's for Simulated Plan
Dashed Line = QBEL derived from 2010-2014 Simulations, Rescaled to LTGM = 10 ppb; 90th Percentile of Yearly FWM's

Figure 4 QBEL's Derived from 2010-2014 (Alternative 2) Simulations



Solid Line = QBEL computed fom rescaled time series (LTGM = 10 ppb), Alternative 2; 90th percentile of Yearly FWM's
Dashed lines = nominal QBEL range for all STA's (15 - 17 ppb)
QBEL would not apply to STA1W for Alt 2 because it discharges to STA-2 instead of the Refuge

Figure 5 Observed Flow-Weighted & Geometric Means