Attachment G –
WQBEL Technical Support Document

Technical Support Document
Derivation of the Water Quality Based Effluent Limit (WQBEL) for Phosphorus in Discharges to the Everglades Protection Area

United States Environmental Protection Agency
August 24, 2010

This report documents the United States Environmental Protection Agency's (USEPA) derivation of the Water Quality Based Effluent Limit (WQBEL) to be applied in National Pollutant Discharge Elimination System (NPDES) permits for discharges from the Stormwater Treatment Areas (STAs) into the Everglades Protection Area (EPA). The WQBEL is calculated to protect the designated use[1] of the Everglades by ensuring the State of Florida water quality criterion for total phosphorus of 10 parts per billion (ppb) as a long-term geometric mean is not exceeded in the receiving waters of the Everglades.

The WQBEL for STAs 1E, 1W, 2, 3/4, 5, 6, and other future STAs, has two components, both of which must be met. TP concentrations in the discharge from each STA may not exceed either:

Part 1: 10 ppb as an annual geometric mean in more than two consecutive years; or
Part 2: 18 ppb as an annual flow-weighted mean

Both parts of the WQBEL are necessary to assure that the long-term criterion of 10 ppb is met at each STA. The background and statistical approach for derivation of each WQBEL component is described below.

I. The Total Phosphorus Criterion

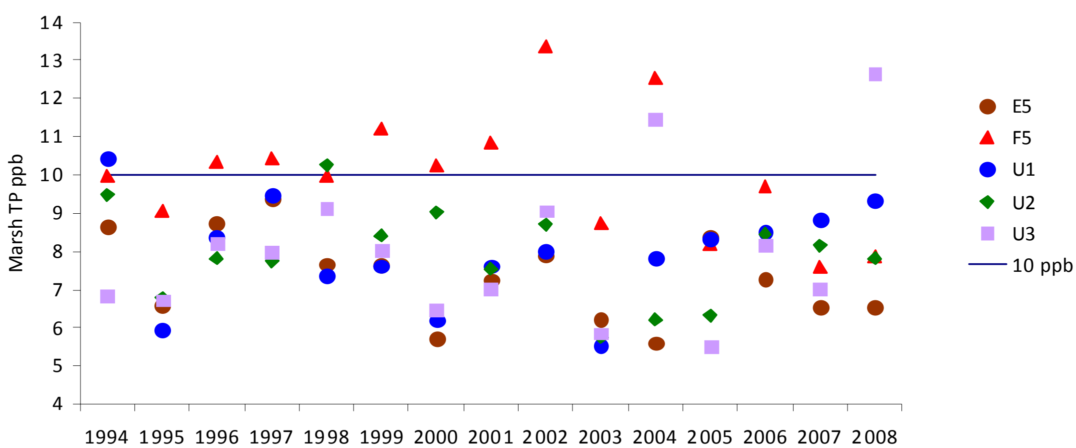
Since the WQBEL is derived from and must comply with the underlying water quality standard, it is important to understand the underlying phosphorus criterion for the Everglades Protection Area. In 2005, the Florida Department of Environmental Protection (FDEP) adopted and USEPA approved a numeric water quality criterion for Total Phosphorus (TP) for the EPA. The TP criterion is a long-term geometric mean of 10 parts per billion (ppb, or micrograms per liter) in surface water (Rule 62-302.540(4)(a), Florida Administrative Code (F.A.C.)). The criterion applies throughout all of the EPA, which includes the Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge), Water Conservation Areas (WCAs) 2 and 3, and Everglades National Park (Park). The 10 ppb geometric mean criterion is the numeric interpretation of the FDEP narrative nutrient criterion, which states, "In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna" (Rule 62-302.530(47)(b), (F.A.C.). The FDEP TP Rule is consistent with the State of Florida's Everglades Forever Act that specifies, "In no case shall such phosphorus criterion allow waters in the Everglades Protection Area to be

[1] The designated use of Everglades Protection Area is "Recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife" (Rule 62-302.540(4)(a), F.A.C., Rule 62-302.400(1)).

altered so as to cause an imbalance in the natural populations of aquatic flora or fauna" (Florida Statutes 373.4592(4)(e)2).

Surface water TP at reference sites in the Everglades varies spatially across water quality sampling stations and temporally at any given station. TP has been measured monthly since the 1970s at reference[2] locations within the Everglades marsh that are 10-20 miles downstream of stormwater inflows. TP concentrations at these unimpacted Everglades locations experience natural fluctuations such that annual geometric mean TP can exceed 10 ppb, with individual sample readings even higher (FDEP 2000, 2003, 2010a). In deriving the TP criterion, FDEP used data from 9 reference sites in the Refuge and WCA2A from 1994-2001, along with data from an additional site from 1978-2001, for a total of 55 "station-years" of data (FDEP 2003). Subsequent data verify the appropriateness of the derived criterion - from 1994 to 2008, the arithmetic mean of annual geometric means[3] at the five reference sites within WCA2A that were used to develop the TP criterion was: E5 7.3 ppb; F5 10.0 ppb; U1 8.0 ppb, U2 7.9 ppb; U3 8.0 ppb (Figure 1). Although annual geometric means varied at an individual site by a factor of two, and approached 13 ppb to 14 ppb at reference sites F5 and U3, the long-term average did not exceed 10 ppb at each site. These sites remain unimpacted (FDEP 2010a).

Figure 1. Natural variation in annual geometric mean TP concentration at five marsh reference sites within WCA2A, where the long-term 10 ppb criterion is met. These stations were used to derive the TP criterion.



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[2] A reference station is a location that identifies the background level of water quality in the Everglades. These sites exhibit the unaltered ecosystem structure and function that are typical of a location with no evidence of phosphorus impacts or imbalance. Reference sites are routinely used to develop water quality criteria.

[3] The arithmetic mean of annual geometric means at marsh stations is the calculation method that was used to derive the 10 ppb long-term geometric mean TP criterion (FDEP 2003). It is also the calculation method used to determine compliance with the TP criterion (FDEP 2006).

II. The Total Phosphorus Criterion Assessment Methodology for the Everglades Protection Area

The TP criterion rule for the EPA, approved by the USEPA, includes a four-part assessment methodology (four-part test) developed by FDEP (FDEP 2003, 2005a). The purpose of this test is to serve as an assessment method to determine whether the long-term (decades) 10 ppb geometric mean criterion is being achieved on a short-term (annual) basis. The four-part test places upper limits on TP concentration in the Everglades marsh using certain temporal and spatial scales to limit the variability in measured TP concentrations throughout the Everglades to the variability observed at the unimpacted marsh reference sites. USEPA's evaluations of this test have concluded that attaining these four concentration requirements together assures that the long-term TP concentration does not exceed the 10 ppb geometric mean criterion throughout the entire marsh (USEPA 2005, Walker 2004, 2005a).

The TP criterion is expressed as a geometric mean at ambient marsh stations. The geometric mean is often used to represent the central tendency of environmental data that are log-normally distributed and/or have a positive skew, as do phosphorus levels in the Everglades. The geometric mean has been used since the 1990s in the Everglades to determine compliance with phosphorus levels within the Refuge using data from 14 marsh stations (SFWMD 1992a; U. S. District Court, 2001).

The first three parts of the four-part test allow concentrations to be averaged across the network of marsh monitoring sites within the Everglades waterbody to address the natural spatial and temporal variability within the EPA. The fourth part of the test provides an annual maximum concentration not to be exceeded at any individual site (FDEP 2005a). The TP criterion was derived using data from Everglades freshwater open water sloughs, and, therefore, the four-part test is applied to marsh stations in these same aquatic habitats (62-302.540 (4)(d)1. FAC). Below are the four parts of the TP criterion assessment methodology.

> *Part one*: the *five-year* average of annual geometric means is not to exceed *10 ppb*, averaged *across* the network of marsh monitoring stations within the Everglades. This criterion was derived based on the central tendency and upper 95% confidence interval of the annual geometric mean TP concentrations measured at a group of reference sites in WCA2A and the Refuge over six to eight year periods of record (FDEP 2003, 2005a). This part of the test is supplemented by three additional parts which limit the allowable spatial and temporal variability.

> *Part two:* the *annual* geometric mean, when averaged *across* stations, is less than or equal to *11 ppb each year*. This value was derived as the upper 95th percent confidence limit using a pooled value of spatially averaged annual variances from individual sites within reference areas, and is intended to limit the temporal range of annual concentrations across the network of monitoring stations to the range exhibited by the network of reference sites.

Part three: the *annual* geometric mean, when averaged *across* stations, is less than or equal to *10 ppb* for *three of five years.* This is intended to limit the allowable temporal variability on a frequency of exceedance basis.

Part four: the *annual* geometric mean at all *individual* stations is less than or equal to *15 ppb.* This value is the 95th percentile of long-term annual geometric means estimated from annual values at five WCA2A reference sites (47 station-years of data, FDEP 2003, 2005a). The inclusion of an additional 25 station-years of data from five reference sites in the Refuge resulted in the same 15 ppb limit (FDEP 2003). FDEP concluded that an annual geometric mean above 15 ppb has less than a 5% chance (type I error) of occurring within the expected range of annual values from a long-term reference distribution of phosphorus data which is centered at 10 ppb (FDEP 2005a). In other words, if the annual geometric mean exceeds 15 ppb, then it is highly unlikely (<5% chance) that the long-term criterion is met. This part of the four-part test provides an upper bound for allowable annual geometric means at individual monitoring stations every year and is necessary to ensure that averaging across stations alone does not mask problems at individual sites, thereby allowing areas of the EPA to become impacted without detection.

Independent evaluation of the four-part test developed by FDEP found it to be an effective and protective methodology for determining attainment of the long-term phosphorus criterion on a short-term basis (Walker 2004, 2005a; USEPA 2005).

III. NPDES requirements

Where technology-based permit effluent limits are not adequate to attain the water quality criterion of a waterbody, the CWA and implementing regulations for the CWA's National Pollutant Discharge Elimination System (NPDES) program require that discharge limits in NPDES permits be set at levels to meet water quality standards (see CWA section 301(b)(1)(C) and 40 CFR § 122.44(d)(1) and (5)). These limits are known as WQBELs.

The NPDES regulations further require that WQBELs "derive from and comply with" all applicable water quality standards (see 40 CFR § 122.44(d)(1)(vii)(A)). USEPA recommends the use of statistical procedures that translate underlying water quality criteria into defensible, enforceable and protective WQBELs (USEPA 1996). Based on this underlying regulation and as a result of the translation, WQBELs may differ from the underlying water quality criterion. WQBELs are often expressed as both a long-term value and a short-term value. The simultaneous use of both values ensures that a given facility's long-term performance is maintained, while still allowing for some short-term variability (USEPA 1991).

NPDES regulations require that a WQBEL be expressed as maximum daily and monthly averages, unless impractical (see 40 CFR § 122.45(d)). However, as a technical matter, USEPA understands that expressing permit effluent limitations for nutrients like phosphorus over shorter terms (for example, as a daily maximum, weekly average, or monthly average) may be impractical and supports expression as annual permit limits since the effects of nutrients are expressed far afield and over longer time periods. Recent USEPA guidance for Chesapeake Bay permitting recognized this issue (USEPA 2004). USEPA is following the same approach for the WQBEL in this situation. Given the weekly and monthly variability in biological wetland treatment systems such as the STAs, monthly and daily limits are not appropriate.

IV. The two-part WQBEL for the Everglades Protection Area and its derivation

The WQBEL for STA 1E, 1W, 2, 3/4, 5, and 6 has two components, both of which must be met. Compliance with the WQBEL is determined on an annual basis. TP concentrations in the discharge from each STA may not exceed either:

Part 1: 10 ppb as an annual geometric mean in more than two consecutive years; or
Part 2: 18 ppb as an annual flow-weighted mean

The WQBEL was derived by using the statistical methods described below to apply the 10 ppb long-term geometric mean (GM) TP criterion directly to the discharge for each STA. The objective of the WQBEL is to determine whether the long-term (decades) 10 ppb criterion is met at the point of discharge on a short-term (annual) basis. If the WQBEL is met at each STA discharge, phosphorus will not be discharged into the Everglades at concentrations that will result in exceeding the criterion over the long-term (decades), nor will short-term exceedances be allowed that would result in local degradation of the receiving waters near the discharge points. The two-part WQBEL allows for expected year-to-year variability in the STA discharge TP concentration, as observed at the marsh reference sites used to develop the TP criterion, while attaining the long-term TP criterion.

A. Assumptions

The WQBEL derivation is based on several assumptions.

1) The two-part WQBEL will be applied to each STA on an annual water year (WY) basis (May – April).[4] In the case of multiple discharge structures from a STA, the maximum annual FWM limit (18 ppb) will be applied to the FWM TP concentration across all discharge points and pump stations sampled as identified in the permit, resulting in one annual FWM reported for the STA. The annual GM limit (10 ppb) will be applied to the GM of grab samples collected at each outflow structure on days when discharge is occurring, resulting in one annual GM reported for the STA. The present number of

[4] A Water Year is defined as May through April: WY 2010 is May of 2009 through April 2010. This reflects the annual hydrologic cycle in south Florida with the initiation of the wet season about May. This WY designation is used to calculate the annual marsh geometric mean TP values used to assess compliance with the TP criterion in the EPA. The May to April WY is also used to measure compliance with the EAA best management practice (BMP) regulatory rule and the C-139 Basin regulatory rule. The May to April WY also has been used to assess compliance with permit effluent limits for the STAs since 1996.

outflow structures for each STA is as follows: 1- STA1E; 2- STA1W; 1- STA2; 6 - STA3/4; 6- STA5; and 3- STA6.

2) The WQBEL is applied directly at the discharge from each STA. Changes in surface water TP concentration between the STA discharge point and the location where the discharge enters the marshes of the EPA are ignored for several reasons. For example, little water exists in the marshes during the dry season. Additionally, USEPA interprets Florida water quality standards to not allow mixing zones or credit for dilution for nutrients. Also, STA1E and STA1W discharge into a canal that flows unimpeded directly into the Refuge rim canal and marsh. At present, the other STAs discharge into canals which flow several miles before the water can enter EPA marshes. After hydropattern restoration efforts are in place, STA2 and STA3/4 will also discharge directly into EPA marshes. An STA discharge into a canal may be mixed with other water with a higher or lower TP concentration, and may also be subject to biogeochemical processes which could either increase (e.g., reflux of phosphorus from the sediment) or decrease (e.g., assimilation or adsorption) the TP concentration in the water prior to entry in the Everglades marsh. These potential changes are not considered in the application of the WQBEL. Thus, USEPA is neither considering the loss of, or the addition of, phosphorus between the discharge point and the Everglades marsh itself.

3) The derivation of the 18 ppb FWM WQBEL annual limit uses the 90th percentile of the data distribution for STA discharge data that are adjusted to simulate an STA facility discharging at the long-term TP criterion of 10 ppb. This approach is consistent with NPDES program guidance (USEPA 1991) and with the derivation of previous discharge limits in the Everglades (Walker 2000; Nearhoof et al. 2005; Goforth et al. 2007; FDEP 2010b). Since the 18 ppb annual limit was derived from weekly TP data, it is assumed that future calculations of STA annual average TP will use weekly data.

4) It is assumed that the Everglades marsh does not have a long-term net assimilative capacity above the TP criterion. This is consistent with the assumptions made to develop and adopt the 10 ppb long-term geometric mean criterion and previous determinations by USEPA and FDEP that a 10 ppb criterion is sufficiently protective and is not overly protective (USEPA 1999, 2005; FDEP 2003).

B. Database Development

Derivation of the 18 ppb FWM annual discharge limit requires a statistical model that accounts for the variability in TP at the STA discharge, and it requires determining the relationship between the annual geometric mean TP and flow-weighted mean TP at STA discharges. Each STA has daily flow data. There are two sets of TP concentration data at each STA discharge. TP concentrations were determined for water samples collected weekly in two ways: grab samples and flow-proportional samples. Annual geometric mean outflow TP concentrations were calculated over the period of record for each STA, using weekly TP data from grab samples collected at each outflow structure or pump on days when discharge was occurring. This approach is consistent with the grab-sampling methodology used in deriving the phosphorus criterion and testing compliance at marsh sites. Weekly TP data from flow-weighted composite samples were used along with discharge data to compute annual flow-weighted TP means. SFWMD provided annual flows and flow-weighted-mean discharge concentrations over the period of record for each STA. These were computed by SFWMD using the same datasets and procedures used in reporting compliance with the existing discharge limits (SFWMD, 2010a).

USEPA uses over 90% of the available "STA-years" of data generated from May 1995 through April 2010 for the seven STAs. This data set includes data from the Everglades Nutrient Removal Project (ENRP - a 3700-acre prototype STA which was operated with nearly uniform TP and hydraulic loading and later was expanded to become STA1W), STA1W itself, STA1E, STA2, STA3/4, STA5, and STA6 (Appendix 1). The performance of some STAs has been adversely influenced by excessive phosphorus loadings, extreme droughts (2001, 2007-2008), repair of damage sustained in severe hurricanes (STA1W 2005-2007) and initial construction problems (STA1E 2010). Performance has also been temporarily affected by partial operation due to implementation of measures designed to optimize performance, such as internal levee construction, vegetation management, and accompanying stabilization. The above factors are likely to have increased the variability of these STA discharges relative to that expected under long-term operations, although occasional future disturbances would be expected due to maintenance and vegetation management practices. However, in order not to have extreme values in the dataset which are not representative of stable STA operation, the data used for WQBEL derivation were screened in the following manner:

(1) STA startup periods were excluded;

(2) Data were excluded for STA1W for WY2005-2007 when performance was significantly impaired due to phosphorus overloading, hurricane damage, and construction associated with repair and optimization; and

(3) Data were excluded for STA1E in WY2010 because of vegetation loss and deterioration in performance due to construction problems resulting in excessive water depths.

Data were included from the initial phase of STA-1W (ENRP WY 1996-2000), which was operated at relatively steady flows that may not be representative of all future STAs. Data also were included for STA5 in WY2007 and STA6 in WY 2007-2008 when the coincidence of extreme drought, construction, and implementation of optimization measures contributed to elevated TP concentrations in the discharges. Retaining these data from STA1W, STA5 and STA6 in the data set used for WQBEL derivation provide a broader basis for calibration and a range of variability to account for future performance and disturbances. These retained data are indicative of conditions that USEPA reasonably expects to recur. The resulting period of record STA data used to develop the WQBEL (50 STA-years) is sufficient compared with the number of station-years of data used to derive the TP criterion (55) and the four-part test (72). The STA outflow data that were used for WQBEL derivation are shown in Appendix 1.

C. The requirement not to exceed a geometric mean of 10 ppb in more than two consecutive years.

The first part of the WQBEL requires that 10 ppb as an annual geometric mean (GM) is not exceeded in more than two consecutive years. This part of the test is based directly upon the long-term TP criterion and is independent of the historical STA discharge data. This part of the WQBEL is expressed as a geometric mean because the criterion is expressed as a geometric mean. As noted above, the geometric mean is often used to represent the central tendency of environmental data that are log-normally distributed and/or have a positive skew, as do phosphorus levels in the Everglades. The annual geometric mean will be computed using weekly grab samples collected at each discharge structure on days when there is flow. The use of the weekly grab samples to compute the annual geometric mean is consistent with how marsh data were used to derive the TP criterion and are used to assess compliance with the four-part test.

This two consecutive year requirement is non-parametric and is insensitive to the variability in the STA discharge concentration since it is based on the central tendency (the geometric mean) of the long-term criterion. Three years of data are required to determine compliance with this WQBEL requirement. A WQBEL test based on three years of data makes it possible to determine compliance with a criterion that is expressed as a long-term value (decades) in a shorter time period (three years), thereby providing protection against non-attainment of the water quality criterion in advance of a longer term measurement period such as five years.

Assuming random and statistically independent variations in the annual GMs, if an STA is discharging at the long-term criterion of 10 ppb, the probability of exceeding 10 ppb in 3 (more than 2) successive years would be 0.13 (= 0.5^N where N = number of years). This type I error rate of 0.13 is consistent with the 0.10 type I error rate (90^{th} percentile) used to derive the annual limit (see page 21). The requirement of not exceeding a limit in more than two consecutive years is already used in the TP control regulatory rules for the EAA basin and the C-139 basin (SFWMD 2010b).

D. Derivation of the requirement not to exceed 18 ppb flow-weighted annual average in any year

1) Use of the flow-weighted mean

The flow-weighted mean (FWM) is the most commonly used statistical expression of the central tendency to account for total phosphorus at discharge structures in the Everglades. All of the phosphorus limits and water quality standards applied at water discharge structures in the Everglades use FWM TP values. For the Park, FDEP's phosphorus rule specifies that achievement of the criterion will use phosphorus limits that are applied as FWM TP values at structures that discharge into the Park (Rule 62-302.540(4)(c), F.A.C.; SFWMD 1992a; Walker 1999; U. S. District Court 2001). The FWM concentration is the average concentration of phosphorus in the water, weighted proportionally for the volume of flow during the time of sampling:

$$[FWM] = \frac{\sum Flow \times Concentration}{\sum Flow}$$

Phosphorus data are collected weekly at STA discharge structures, and water flow rate is measured daily. Phosphorus samples taken during weeks when the flow is high are given proportionally greater weight in the calculation of the flow-weighted mean than are samples taken when the flow is low. Acute, high flow events result in a higher load of phosphorus discharged into the Everglades, as compared to weeks with the same concentration but less flow. Other statistical expressions of the central tendency or mean do not consider the flow rate when the TP concentration is sampled. Without the consideration of flow, mass loading of phosphorus is absent. Concentration alone without flow does not account for flow events that can affect the cumulative delivery of phosphorus to the receiving water body.

For the Everglades marsh, the loading of nutrients such as phosphorus is an important consideration in evaluating and addressing the impacts on the waterbody. The naturally nutrient-poor marshes of the Everglades are affected by both the concentration and the load of phosphorus. Once phosphorus is discharged into the Everglades, this mass or load of TP cycles within the Everglades marsh where it can continue to impact Everglades flora and fauna. The higher total load received from higher flows may accumulate in the marsh and affect the long-term observed concentrations in the marsh.[5]

Stormwater Treatment Area effluent TP and water volume tend to vary seasonally because of the seasonal nature of rainfall and stormwater runoff. Water volume and TP concentration also vary annually because of variation in rainfall and stormwater runoff across years. For example, summary data provided by South Florida Water Management District (SFWMD 2010a) indicate that from 2005-2009 the total volume of water treated each year by the six STAs ranged from about 774,000 acre-feet in water year 2008 to 1,556,000 acre-feet in 2005. Outflow FWM TP for individual STAs ranged from 13 ppb (STA 3/4 2009) to 193 ppb (STA5 2007).

Expressing the WQBEL as a FWM TP concentration includes consideration of not only concentration but load as well, and therefore protects the downstream Everglades from phosphorus loads. Loading rate (mass per time) is calculated as flow rate (volume per time) multiplied by concentration (mass per volume). For each STA, TP is sampled weekly via grab samples taken at the downstream side of each discharge structure. Flow-proportional composite samples are also taken weekly and analyzed for TP at these same locations to better account for the variation in discharge volume within the week. Weeks with high TP concentration and high discharge rate are of concern because of their potential to impact the Everglades. During the week of February 16, 2006 (week 1), STA1W discharged 127 ppb of

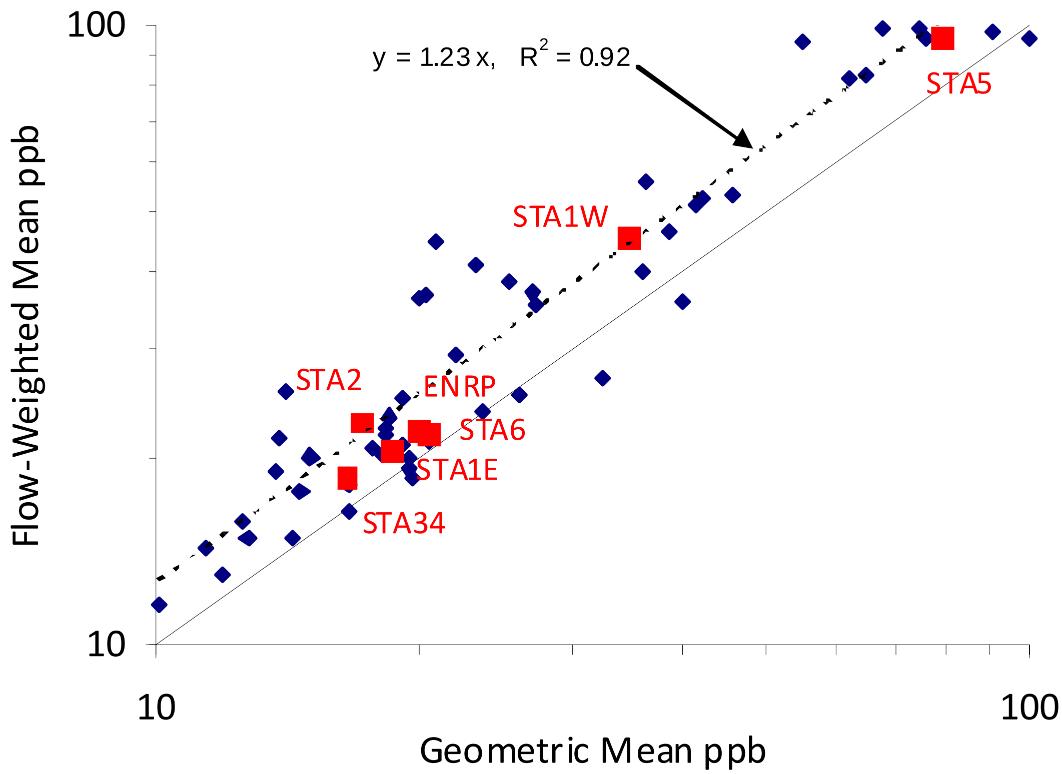
[5] Excess phosphorus causes systemic ecological responses in the Everglades such as changed algal (periphyton) communities, loss of water column dissolved oxygen, changes to invertebrate communities and the food web, and expansion of cattail with a decline in native sawgrass, sloughs and wet prairies (SFWMD 1992b; McCormick et al. 1999, 2002; FDEP 2000, 2001a, 2001b).

TP at a flow rate of 61 cubic feet per second (cfs) (weekly STA data from FDEP 2010). During the week of September 28, 2004 (week 2), this STA also discharged at 127 ppb, but at a much higher flow rate of 3115 cfs. The phosphorus load discharged during week two was about 50 times higher than during week one due to the much higher discharge rate, although the TP concentrations were identical. During the week of December 10, 2002 (week 3) STA1W discharged 63.5 ppb at a flow rate of 1240 cfs. Although the concentration discharged during week one was two times the concentration discharged during week three, the TP load discharged into the Everglades during week three was over ten times higher due to the much higher discharge rate. Only expressing the WQBEL as the geometric mean of TP at STA outflows does not consider the flow volume from the STA and, therefore, overlooks the discharge of high phosphorus loads when flows are high.

2) The relationship between the GM and FWM at STA discharges.

For each STA, the annual GM and FWM TP concentrations were calculated for each STA using the procedure described above. Figure 2 shows the correlation between the flow-weighted means and geometric means on a yearly basis, as well as for the total period of record by STA. The FWMs are approximately 20% higher than the GMs, both on an annual and long-term basis (LTFWM = 1.23 x LTGM, R^2 = 0.92). These results indicate that based on the same data, at the STA discharge the long-term TP geometric mean of 10 ppb (the criterion) is equivalent to a long-term TP flow-weighted mean of 12 ppb. The high percentage of explained variance (R^2 = 0.92) indicates a very strong relationship, one that can be reliably employed in this WQBEL derivation. Previous investigators also independently concluded that a long-term geometric mean of 10 ppb is equivalent to 12 ppb flow-weighted for STA discharges (FDEP 2010b).

Figure 2. Relationship between Flow-Weighted Mean (FWM) and Geometric Mean (GM) Total Phosphorus Concentrations in STA Discharges. Data are not rescaled.

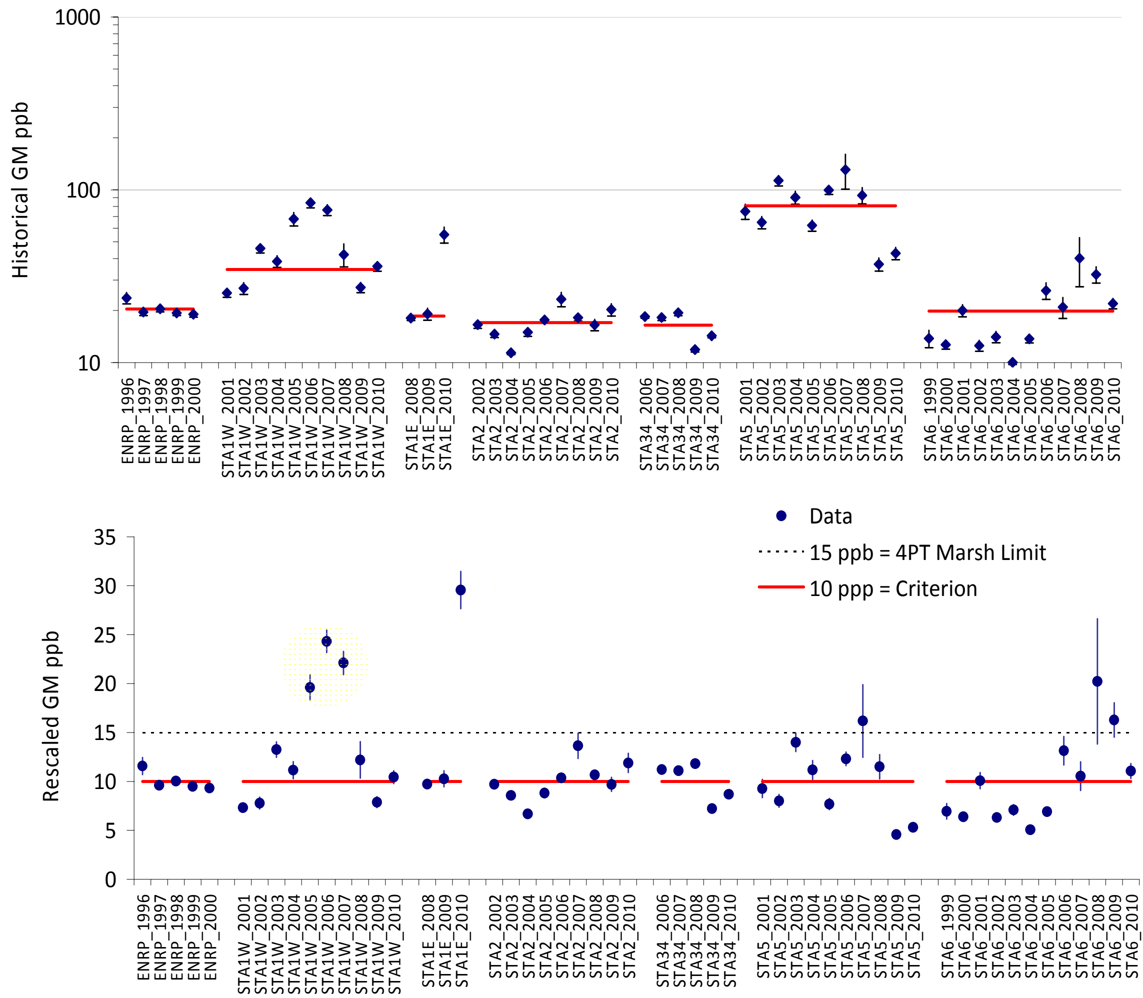


Historical monitoring data from each STA (not rescaled). Blue diamonds (♦) are the results for each STA-year; red squares (■) are the period of record result for each STA. The dotted line depicts the average ratio of the FWM to the GM across STAs and years (y = 1.23x). The FWMs of STA discharges typically exceed GMs by 23% on both an annual basis and a long-term basis. Long-term is the period of record for each STA, the longest of which is 12 years for STA6 (Appendix 1). This relationship between flow-weighted means and geometric means reflects the flow and concentration dynamics associated with STA discharges. The relationship is observed over a wide range of discharges and concentrations.

3) *Data rescaling*

Deriving the annual maximum WQBEL requires consideration of the variability of TP concentration at the STA discharge. Since none of the STAs are currently discharging at a long-term geometric mean of 10 ppb, the existing data could not be directly used to understand and address year-to-year variability. Therefore the historical data from each STA have been statistically adjusted or rescaled to simulate a STA discharge at the criterion (a long-term geometric mean of 10 ppb). The rescaling factor for each STA is computed as the ratio of the 10 ppb criterion divided by the arithmetic mean of the annual geometric mean TP concentrations at the point of discharge. This calculation procedure is consistent with the procedure used in the phosphorus water quality standards for computing long-term geometric mean concentrations at marsh sites under the four-part test compliance methodology (FDEP 2006). The summary of results by STA is provided in Appendix 3. The original and rescaled annual average STA discharge TP data are shown in Figure 3 (geometric means) and Figure 4 (flow-weighted means). Similar to reference sites in the Everglades marsh (Figure 1), annual average TP at STA discharges may vary while still attaining the long-term criterion.

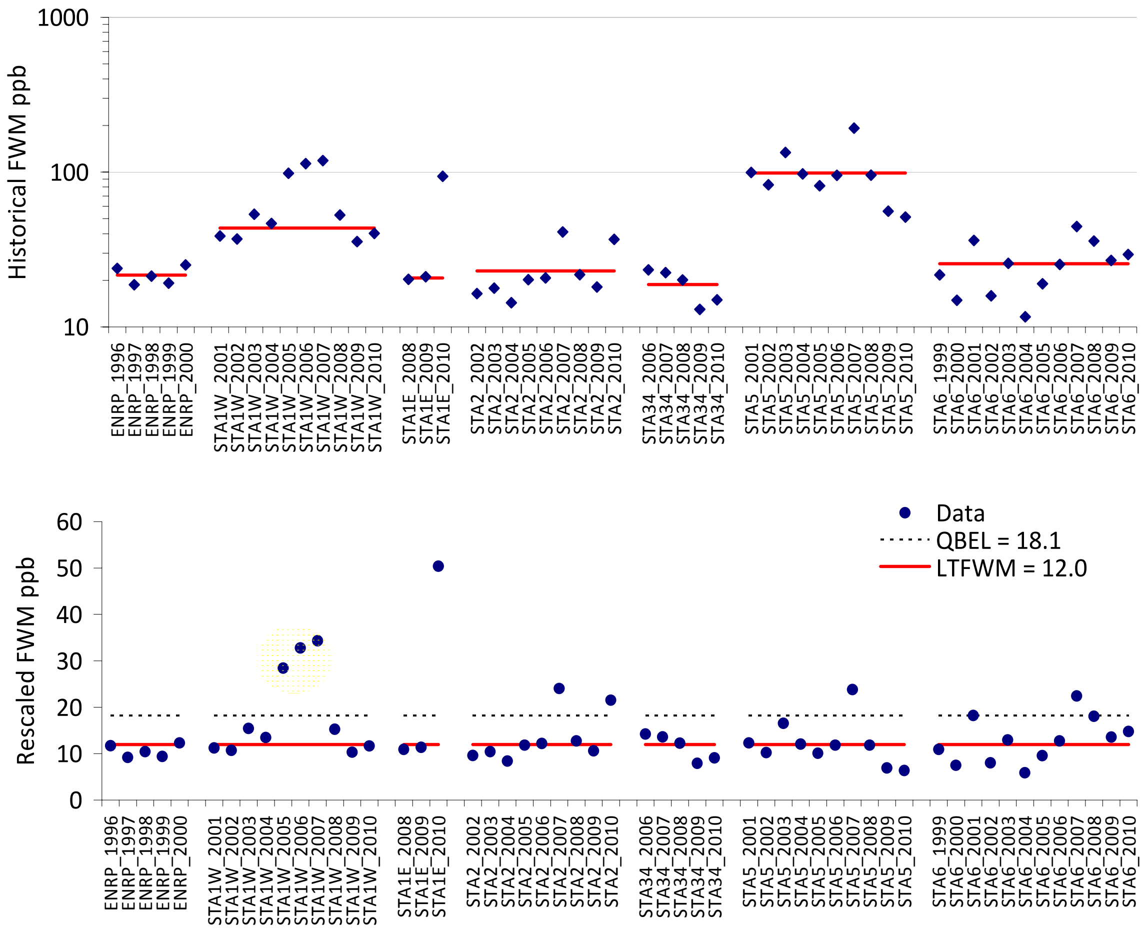
Figure 3. Period of record annual geometric mean TP concentration for each STA discharge.



Top: Annual geometric means. Red bars are the long-term geometric mean for each STA.

Bottom: Annual geometric means rescaled so that each STA discharge has a discharge at the long-term geometric mean criterion of 10 ppb. Data outliers that were excluded from the WQBEL derivation because they do not represent STAs in stable operation include STA-1W in WY 2005-2007 (overloading, hurricane damage, and repair) and STA-1E in WY 2010 (vegetation loss and deterioration in performance due to construction problems resulting in excessive water depths).

Figure 4. Period of record annual flow-weighted mean TP concentration for each STA.



Top: Annual flow-weighted means. Red bars are the long-term FWM mean for each STA.

Bottom: Annual FWMs rescaled so that each STA discharge has a long-term flow-weighted mean of 12 ppb, which is equivalent to a geometric mean of 10 ppb. Data outliers that were excluded from the WQBEL derivation because they do not represent STAs in stable operation include STA-1W in WY 2005-2007 (overloading, hurricane damage, and repair) and STA-1E in WY 2010 (vegetation loss and deterioration in performance due to construction problems resulting in excessive water depths).

4) Derivation of the Annual Maximum Discharge Limit

A maximum discharge limit is needed to assess compliance annually and to assure that STA discharges do not cause exceedances of the TP criterion in the EPA. The methodology used to derive the annual maximum discharge limit is similar to that used in previous derivations of the interim STA limit of 50 ppb (Walker 1996; Nearhoof et al., 2005) and in previous WQBEL derivations (FDEP 2005b; 2008; 2010b; Walker 2005b). In translating the 10 ppb long-term geometric mean (LTGM) criterion into the annual FWM discharge limit, USEPA considered the expected year-to-year variability in TP concentrations, as observed both at marsh monitoring sites and in the STA discharges, and differences between the geometric and flow-weighted annual mean values observed at STA discharges.

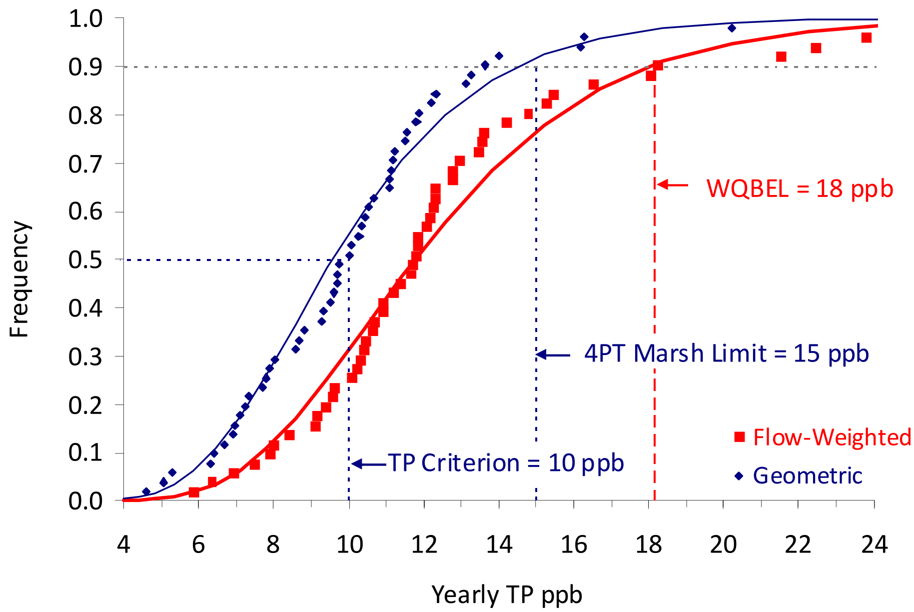
The statistical derivation (Appendix 2) involves fitting a log-normal distribution to the annual data, adjusted to reflect the expected variability in an STA FWM discharge that is in compliance with the 10 ppb long-term geometric mean criterion. Given that some individual STAs have only three or five years of data, data for all STAs were pooled. The data from each STA have been rescaled as described above to a long-term geometric mean of 10 ppb. Figure 5 presents frequency distributions of annual geometric and flow-weighted means for STA discharges in compliance with the phosphorus criterion. The annual maximum WQBEL is set at the 90th percentile of the frequency distribution of annual FWM values. An annual FWM above the 90th percentile would have only a 10% chance of occurring within the expected range of annual values from a long-term reference distribution of phosphorus discharge data which is centered at the TP criterion. The statistical result (18.2 +/- 0.5 ppb) is rounded to the nearest ppb to derive the 18 ppb FWM limit. This 18 ppb result is identical to the annual limit derived by FDEP (2010b) using STA data collected through April 2009.

A second method confirms the annual maximum WQBEL. The TP criterion four-part test limit that must be met every year at each marsh station is 15 ppb as a geometric mean. This is the marsh counterpart to the annual limit that must be met every year at each STA. As indicated above, annual FWMs in STA discharges average 23% higher than GMs (Figure 2). Simply translating the 15 ppb GM marsh limit directly into a FWM limit (FWM = 1.23 x GM) yields a WQBEL estimate of 18.45 ppb, which when rounded to 18 ppb is identical with the result obtained from the frequency distribution of the rescaled STA data. Together these results indicate that the available data and methodologies provide a WQBEL annual maximum limit that is consistent with the marsh maximum limit, and is consistent with achieving compliance with the TP criterion throughout the downstream marsh. A comparison of equivalent long-term and annual geometric and flow-weighted means is provided in Table 1.

Table 1. Comparison of Equivalent Annual and Long-Term Geometric Mean and Flow Weighted Mean TP Concentration Values. WQBEL requirements are in bold.

	Geometric Mean	Flow-weighted Mean
Long-term Limit	**10 ppb**	12 ppb
Annual Limit	15 ppb	**18 ppb**

Figure 5. Frequency Distributions of Annual Geometric and Flow-Weighted Means for STA Discharges in Compliance with the P Criterion.



Variations in annual FWMs (red) and GMs (blue) expected if the discharge had a long-term GM of 10 ppb or the equivalent long-term FWM of 12 ppb (12.0, Standard Error = 0.5 ppb). The difference between the distributions reflects the fact that at STA discharges FWMs are on average 23% higher than the GMs of STA Discharges (Figure 2). The solid line represents the statistical fit of rescaled STA data (log-normal distribution).

The 18 ppb WQBEL to be met each year is found at the intersection of the FWM distribution with the 90^{th} percentile (18.2 with an estimated uncertainty of +/- 0.5 ppb).

The distribution of geometric means is similar to the distribution at marsh sites used to derive the phosphorus criterion. The vertical blue line indicates the 90th percentile of the GM, which is the 15 ppb annual limit for compliance with the phosphorus criterion at marsh sites.

SE = Standard Error, approximate uncertainty in the LTFWM and WQBEL estimates.

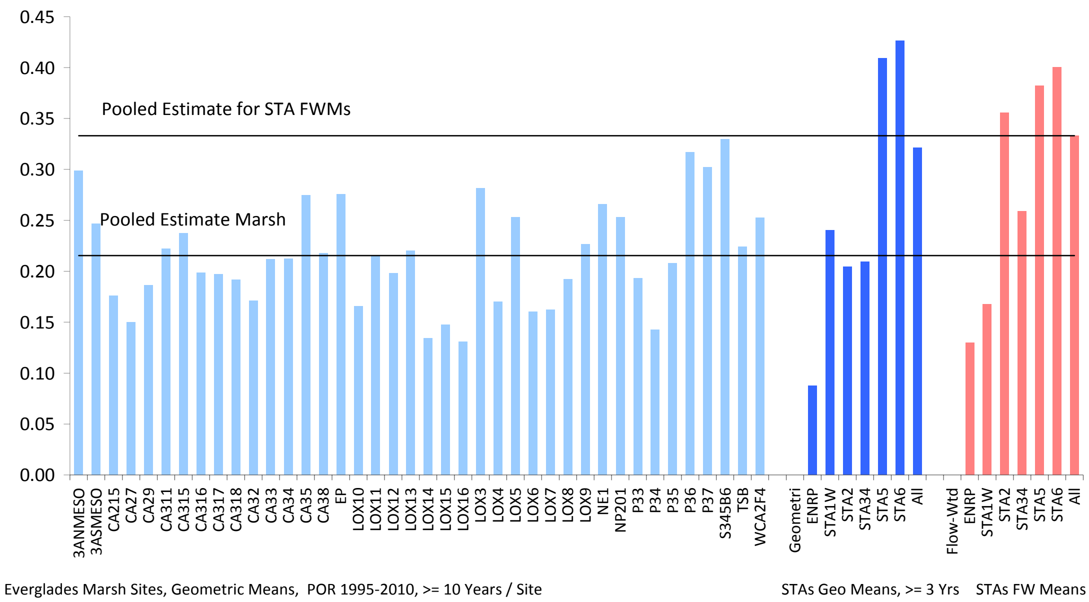
The concept of higher permit limits for shorter compliance periods is scientifically sound provided that the resulting WQBEL attains the water quality criterion (USEPA 1991). Shorter term compliance periods are also consistent with the four-part assessment test for the criterion, which includes a short-term requirement that the annual geometric mean of 15 ppb not be exceeded at each individual station. The corresponding STA effluent short-term annual limit is 18 ppb (FWM).

Requiring a one-part WQBEL with only the requirement not to exceed 18 ppb (FWM) as an annual maximum limit is inadequate for assuring that the criterion is met at the STA effluent over the long-term. If the future variability in TP at the discharges is less than the variability assumed in the derivation, and the discharges are near 18 ppb, it is possible that STAs could discharge in a range that does not achieve compliance with the TP criterion (i.e. exceed a LTGM of 10 ppb or the equivalent LTFWM of 12 ppb) and still be in compliance with the annual FWM discharge limit of 18 ppb. The facility could be found to be "in compliance" while the long-term concentration at the effluent could be as high as 18.4 ppb (18 ppb after rounding), well above the LTFWM of 12 ppb. Moreover, USEPA (2005) and FDEP (2003) rejected a proposal for a long-term geometric mean TP criterion of 15.6 ppb as not being protective within the Everglades marsh, and concluded that based on nutrient threshold research, at a long-term criterion of 15.6 ppb imbalance has already occurred. FDEP concluded that "all of the information evaluated by the Department indicates that the proposed phosphorus criterion of 10 ppb would be protective of the natural flora and fauna in the EPA without being overly protective or below natural background values" (FDEP 2002, 2003). USEPA previously reviewed the scientific basis for the 10 ppb TP criterion and concurred with FDEP's conclusion during the 2005 Clean Water Act review of the TP rule (USEPA 2005). Therefore, an STA discharging at 18 ppb over the long-term would not meet the protective criterion.

The discharge must meet both requirements to be in compliance with the WQBEL. In essence, neither levels of TP in the discharge that would result in an exceedance of the water quality criterion on a long-term basis (10 ppb as a GM) nor levels that would exceed the single station maximum (15 ppb as an annual geometric mean) are allowed. The annual FWMs will be computed from STA outflow volume and concentration data using the methodology currently used by SFWMD in reporting compliance with the existing STA discharge permits. Compliance is evaluated based upon data collected in each Water Year (May - April). For compliance purposes the WQBEL and annual results will be rounded to the nearest whole number.

Figure 6 presents the year to year variability in marsh and STA discharge concentrations. The variability of TP observed at the STA discharges to date (0.33) is slightly higher than the variability observed at unimpacted marsh stations and STA3/4, the best performing STA (0.22). However, the variability observed at the ENRP was less than what occurs at Everglades marsh sites while the variability observed at STA 3/4 was comparable to marsh sites.

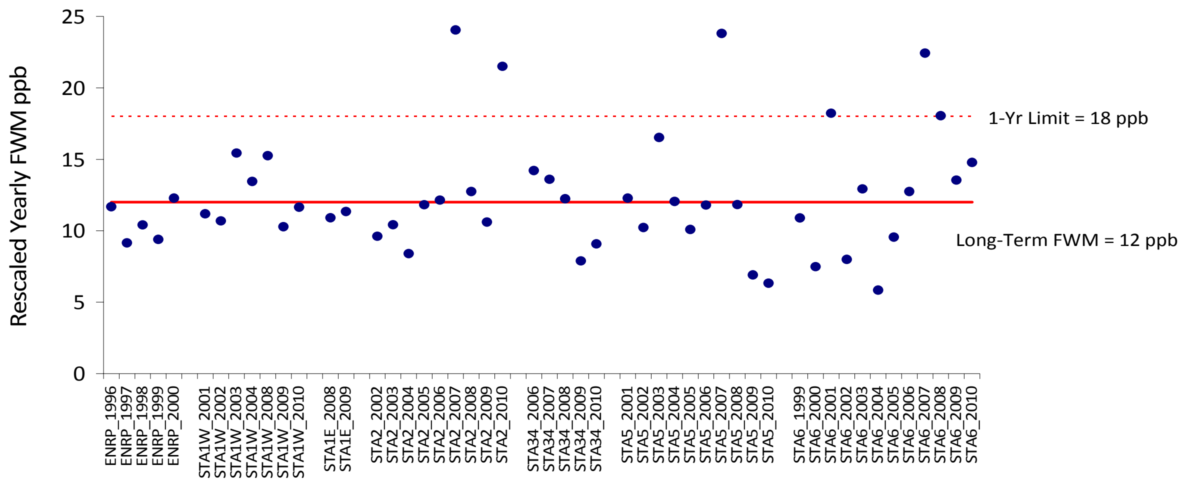
Figure 6. Year-to-Year Variability in Marsh and STA Discharge Concentrations



Year-to-year standard deviations in log-transformed TP concentrations. The y-axis is the natural logarithm of the standard deviation. Light blue bars represent marsh sites with at least 10 years of data. Geometric means (dark blue bars) and flow-weighted means (red bars) are shown at STA outflows with at least three years of data.

Figure 7 presents the STA data used to derive the WQBEL rescaled to the long-term TP criterion (FWMs top, GMs bottom). Annual average TP concentration at the STA discharge may vary while still attaining the WQBEL.

Figure 7. The two-part WQBEL. STA data used to derive the WQBEL are shown rescaled to the long-term TP criterion.



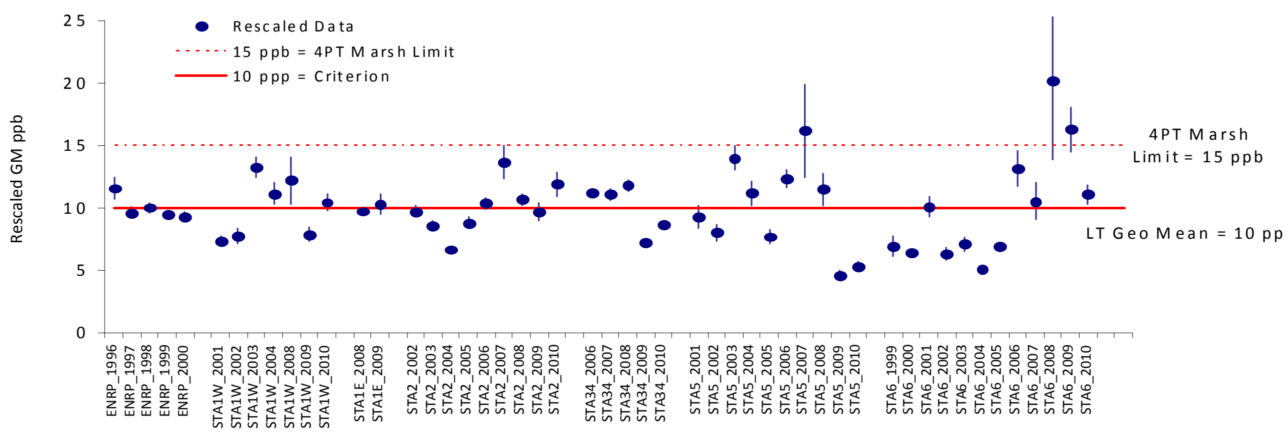
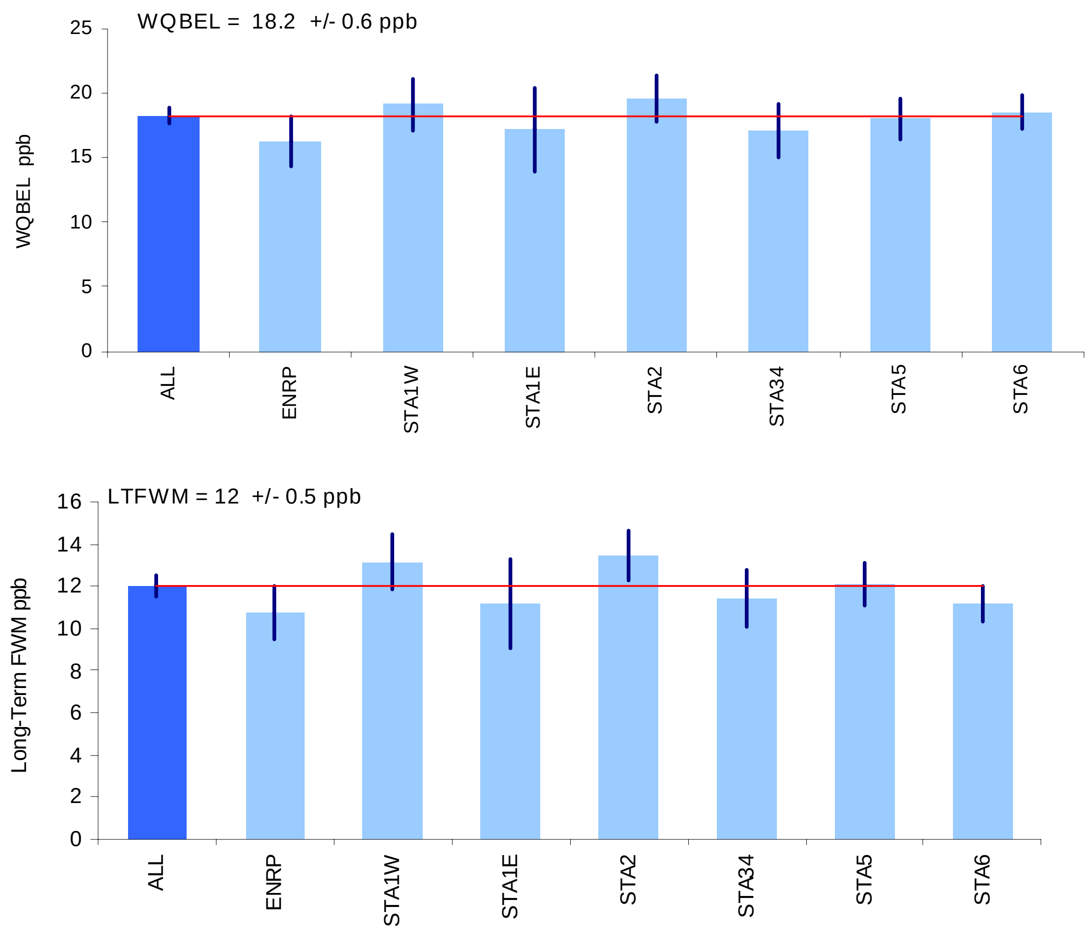


Figure 8 presents the WQBEL compared to the long-term GM and FWM effluent TP for the seven individual STAs. Data from the periods of record for each of the STAs were rescaled to meet the 12 ppb LTFWM limit (bottom) and the annual 18 ppb maximum limit (top). Although there is some variation in the effluent concentrations across STAs due to their performance to date, the confidence limits overlap for all seven STAs and the concentrations are statistically indistinguishable. Therefore, USEPA appropriately pooled the STA data when deriving the WQBEL.

Figure 8. Long-term FWMs & QBELs estimated for individual STAs rescaled to a long-term flow-weighted mean of 12 ppb.



Rescaled Long-Term Flow-Weighted Means and 90th Percentiles (WQBELs) for pooled dataset and each STA.
Red lines are results for pooled dataset. Error bars are approximate 80% confidence intervals.

E) Excursion frequencies and type 1 error.

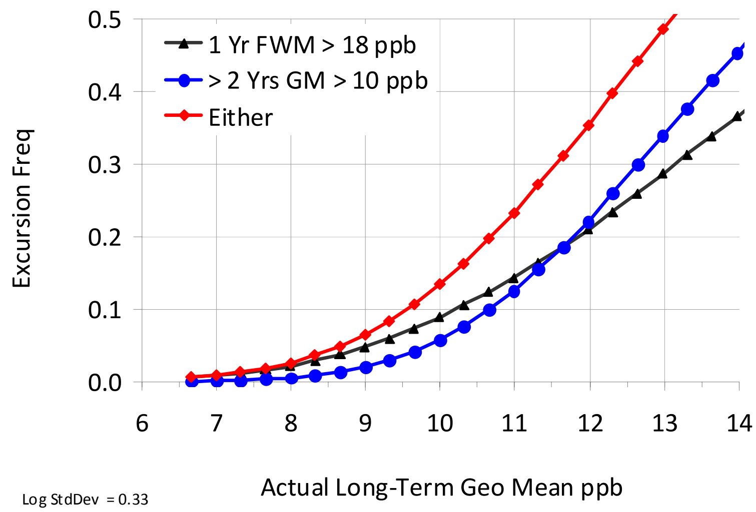
The application of any statistically derived WQBEL involves an assessment of the risk that a facility will be found to exceed the WQBEL when in fact the facility is actually discharging at or below the long-term criterion. This is referred to as a false positive rate (in statistical terms, this is a type I error). The false positive rate assumed for the development of the WQBEL is 10%. The opposite risk, that a facility will not be found to exceed the WQBEL when it is in fact discharging above the long-term criterion, is referred to as a false negative rate (in statistical terms, this is a type II error). The risks of type I and type II error cannot be avoided because of the inherent variability in the data.

The derivation of the marsh TP criterion for the Refuge and WCAs 2 and 3 used a significance level of 5% (FDEP 2003, 2005a). Compared to a 5% significance level, a significance level of 10% has two times the risk that the facility will be found to be out of compliance when it is meeting the long-term criterion. The phosphorus criterion limits for inflows to the Park used a significance level of 10% (SFWMD 1992a). Previous STA permit effluent limits used a significance level of 10% (Nearhoof et al. 2005; Goforth et al. 2007; FDEP 2010b). The statistical approaches that were used to develop the BMP program compliance test for the C-139 basin and for the EAA basin also used a significance level of 10% (SFWMD 2010b).

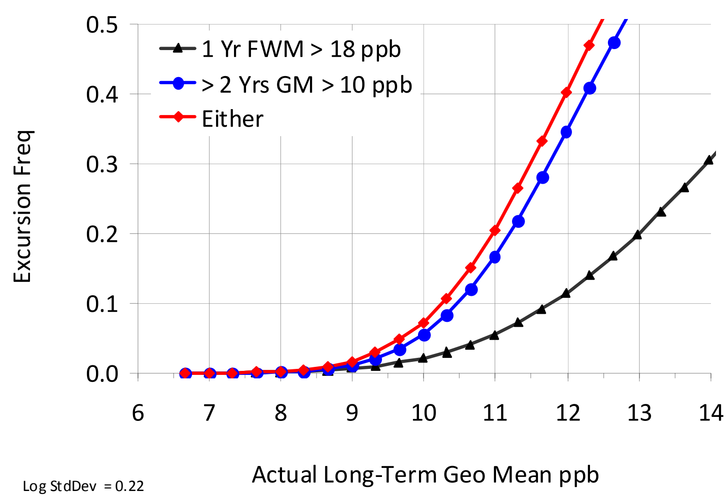
Figure 9 shows the expected annual excursion frequencies for each component of the test for STAs operating with long-term GM values ranging from about 6 to 14 ppb, as compared with the long-term GM of 10 ppb required to achieve compliance with the P criterion. Results are based upon 50,000 years of simulated discharge concentrations drawn from the log-normal distribution with the parameters calibrated to the rescaled historical monitoring data used to derive the annual limit (natural logarithm mean = 2.47, standard deviation = 0.33, Figure 6). Requiring more than one WQBEL test simultaneously results in a higher type I error rate (excursion frequency) than a single test because each individual test has a type I error. The resulting type I error for the two-part WQBEL assuming the current variance at STA discharges is estimated to be about 15% (Figure 9 top, intersection of either excursion frequency with 10 ppb LTGM). This variability in TP at the discharge is expected to decrease in the future as the STAs are designed and operated to achieve compliance with the criterion. The lower chart shows the excursion frequencies that would occur if the actual discharge variability were similar to marsh data or to STAs operating in the low concentration range (natural logarithm standard deviation = 0.22, Figure 6). STA 3/4 has operated with a TP variance at the discharge comparable to the Everglades marsh, while the ENRP had a variance lower than the Everglades marsh (Figure 6). With future operations, as STA discharges operate at a lower concentration range with the variance observed at STA 3/4 and the ENRP, the excursion frequency is projected to decrease to less than 10% (Figure 9 bottom, intersection of either excursion frequency with 10 ppb LTGM). As noted above, a 10% type I error or excursion frequency is consistent with previous regulatory requirements in the Everglades. It also provides a level of protectiveness for the Everglades.

Figure 9. Simulated Excursion Frequencies versus long-term GM.

Top: Variance estimated from all historical STA data:



Bottom: Variance estimated from marsh data and STA's in low concentration range (STA 3/4):



X Axis: LTFWM of STA discharge. An STA operating with a LTGM < 10 ppb would be in compliance with the phosphorus criterion. Y-Axis: Predicted excursion frequencies for each component of the two-part test. The red line depicts the probability that either of the tests will be exceeded in any year.

V. Summary

The WQBEL presented here for the STA discharges is derived from and complies with the 10 ppb geometric mean long-term TP criterion for the Everglades. The WQBEL for STA 1E, 1W, 2, 3/4, 5, and 6 and other future STAs that discharge into the EPA has two parts, both of which must be met. TP concentrations in the discharge from each STA may not exceed either:

Part 1: 10 ppb as an annual geometric mean in more than two consecutive years; or
Part 2: 18 ppb as an annual flow-weighted mean

The WQBEL is directly derived from and is equivalent to the 10 ppb geometric mean long-term TP criterion and it is directly applied to each STA outflow. Compliance with the WQBEL is determined on an annual basis. In the case of multiple discharge structures from a STA, the maximum annual FWM limit (18 ppb) will be applied to the FWM TP concentration across all discharge points and pump stations sampled as identified in the permit, resulting in one annual FWM reported for the STA. The annual GM limit (10 ppb) will be applied to the GM of grab samples collected at each outflow structure on days when discharge is occurring, resulting in one annual GM reported for the STA. For compliance purposes the WQBEL and annual results will be rounded to the nearest whole number.

Requiring both parts of the WQBEL provides greater certainty that attainment of the WQBEL will result in attainment of the underlying 10 ppb long-term geometric mean TP criterion.

Inherent in this WQBEL derivation are the following conservative assumptions:

- There is no long-term net assimilative capacity in the canal between the STA discharge point and the Everglades receiving marsh.
- The criterion applies throughout the Everglades Protection Area, including the Everglades marsh at the edge of the waterbody. It is assumed that there is no long-term net assimilative capacity within these marshes above the criterion that would not trigger an imbalance.
- A significance level of 10% is used to establish the 18 ppb annual limit.
- The 18 ppb annual limit to be met every year is expressed as a flow-weighted mean, providing a limit that addresses TP loads.
- A two-part WQBEL is established, providing assurance that the long-term criterion with be attained at each STA. The requirement that the 10 ppb (GM) long-term criterion is not exceeded more than two consecutive years provides a statistical component that is robust to the inter-annual variability in TP at the STA discharge.

These factors together provide a margin of safety that will assure that compliance with the WQBEL will result in attainment of the TP criterion within the EPA.

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Appendix 1. Historical STA Outflow Data Used for WQBEL Derivation

STA	Water Yr	FWM ppb	Flow kac-ft	Grab Samples	Geo Mean ppb	Status (SFWMD)
ENRP	1996	24	172.4	47	24	
	1997	19	119	43	20	
	1998	21	81	48	21	
	1999	19	86	51	19	
	2000	25	121	83	19	
STA1W	2001	39	91	40	25	
	2002	37	268	36	27	
	2003	53	596	78	46	
	2004	47	298	48	39	Cell 2 off-line for tussuck removal and Cell 4 off-line for vegetation rehabilitation (4 months)
	2005	98	383	60	68	Western Flowway off-line for LTP enhanc, Northern flowway off-line for rehab/hurricane repairs (variable times)
	2006	113	138	49	84	""
	2007	119	126	52	76	Northern, Western and Eastern Flowways off-line for LTP Enhancements (variable times)
	2008	53	117	24	42	Eastern Flowway off-line for LTP Enhancements and Western Flowway off-line for Rehabilitation (4 months)
	2009	36	187	31	27	
	2010	40	221	40	36	
STA1E	2008	20	125	38	18	Eastern Flowway passed startup Sept 2007 and on-line but with flow restrictions due to PSTA project
	2009	21	149	26	19	Eastern Flowway on-line but with flow restrictions due to PSTA project
	2010	94	89	31	55	Western Flowway out of commission
STA2	2002	16	241	29	17	
	2003	18	308	39	15	
	2004	14	285	51	11	
	2005	20	371	51	15	
	2006	21	322	51	18	Begin load diversion from S5A Basin (G341 Closure)
	2007	41	218	27	23	
	2008	22	227	30	18	Cell 4 passed startup 9/21/07
	2009	18	291	22	17	
	2010	37	371	36	20	
STA34	2006	23	736	252	18	Western Flowway off-line for LTP Enhancements (6 months)
	2007	22	355	83	18	Western Flowway off-line for LTP Enhancements (1 month)
	2008	20	296	117	19	
	2009	13	459	143	12	
	2010	15	637	246	14	
STA5	2001	99	40	35	75	
	2002	83	126	78	65	
	2003	134	161	102	113	
	2004	97	136	96	90	
	2005	82	121	77	62	Cell 1B off-line for LTP Enhancements
	2006	95	201	92	100	Cells 2A and 2B off-line for LTP Enhancements
	2007	192	54	24	131	Cell 2B off-line for LTP Enhancements
	2008	96	7	7	76	
	2009	56	106	57	36	Cell 1A off-line for Rehabilitation; Southern Flowway passed startup 8/28/08
	2010	51	97	86	41	
STA6	1999	22	24	19	14	
	2000	15	59	30	13	
	2001	36	26	52	20	
	2002	16	22	67	13	
	2003	26	26	77	14	
	2004	12	29	68	10	
	2005	19	16	59	14	
	2006	25	23	47	26	
	2007	45	12	41	21	Section 1 off-line 2 months for LTP Enhancements
	2008	36	2	8	40	Section 2 passed startup 8/14/07
	2009	27	7	24	32	Section 1 Data Only (Section 2 Not Stabilized, No C139 Annex Pump)
	2010	29	14	56	22	""

Flows, FWMs, Status from SFWMD (2010); GM = geometric means of grab samples from outlet structures on days with flow; data are from SFWMD DBHYDRO database.

Appendix 2. Statistical Methodology

The objective is to estimate the two parameters of the log-normal distribution (mean, standard deviation) of early FWMs for a hypothetical STA in compliance with the phosphorus criterion (Long-Term Geometric Mean of 10 ppb). Computations are applied to log-transformed time series of yearly FWM concentrations for each STA, each rescaled to LTGM = 10 ppb.

$$y_{ij} = \ln(C_{ij})$$

$$m = \sum_{i=1}^{k} \sum_{j=1}^{n_i} y_{ij} / N$$

$$s_y^2 = \sum_{i=1}^{k} [\sum_{j=1}^{n_i} (y_{ij} - \bar{y}_i)^2] / (N - k)$$

$$df = N - k$$

$$L_p = \exp(m + s_y \cdot t_p)$$

where,

C_{ij}= FWM for year j and STA i, rescaled to LTGM = 10 ppb.

y_{ij}= ln [Cij]

$\bar{y}_i$ = mean Ln (FWM) for STA i across years

N = total number of STA-years

k = number of STAs

m = Mean of log-normal distribution across STAs and years (rescaled FWM)

s_y^2 = pooled year-to-year variance across STAs and years

s_y = pooled year-to-year standard deviation

df = degrees of freedom in s

L_p = limit FWM concentration with exceedance probability p

t_p = 1-tailed t statistic, significance level p and degrees of freedom df

$p = 0.10$

(adapted from FDEP, 2010b)

Appendix 3. Summary of Data & Calculations

STA	Years	Flow kac-ft/yr	Historical ppb LTFWM	SE	Historical ppb GM	SE
ENRP	5	116	22.0	1.3	20.4	0.8
STA1W	7	254	45.4	3.5	34.6	3.1
STA1E	2	137	20.7	0.4	18.6	0.5
STA2	9	293	22.9	3.0	17.1	1.1
STA34	5	497	18.8	2.3	16.5	1.4
STA5	10	105	95.5	10.4	78.9	9.5
STA6	12	22	22.2	2.9	19.9	2.6

	Rescaled Flow-Weighted Mean ppb (a)				Discharge Limits ppb	
Dataset	LTFWM	SE	Ln Mean	Ln SD	Limit	SE (b)
ALL	12.0	0.4	2.470	0.333	18.2	0.5
ENRP	10.8	1.0	2.352	0.130	16.2	1.5
STA1W	13.1	1.0	2.518	0.168	19.1	1.6
STA1E	11.1	1.6	2.409	0.028	17.1	2.5
STA2	13.4	0.9	2.540	0.356	19.5	1.4
STA34	11.4	1.1	2.408	0.259	17.1	1.6
STA5	12.1	0.8	2.457	0.382	18.0	1.2
STA6	11.2	0.7	2.484	0.401	18.5	1.0

Summary of Rescaled Data Statistic	Mean	Std Dev	Adjusted Std Dev (b)	Std Error
ln (GM)	2.26	0.302	0.322	0.05
ln (FWM)	2.47	0.312	0.333	0.05
ln (FWM / GM)	0.21	0.196	0.209	0.03
LT Flow-Wtd Mean	12.0	0.982	1.048	0.15
LT Geometric Mean	10.0			

Parameter	Value	Formula
Number of STAs	7	NSTAS
Number of STA-Years	50	NYEARS
Degrees of Freedom	43	DOF = NYEARS - NSTAS
LTFWM for LTGM = 10 ppb	12.0	Average of Rescaled FWMs across STAs and Years
Std Error of LTFWM	0.40	Standard Error of Rescaled FWMs across STAs and Years
Log Mean FWM	2.47	m = Mean (Ln Rescaled FWM)
Log Std Dev FWM	0.333	s = Standare Deviation (ln Rescaled FWM)
Assumed Tail Probability	0.1	p
Students-t	1.30	t = F (p, DOF), 1 Tailed
FWM Limit	18.2	Exp (m + s t)
Std Error of FWM Limit	0.50	SE of LTFWM x Limit / LTFWM

(a) Rescaled FWM = Observed FWM x 10 / Average of Yearly Geometric Means;
(b) LTFWM is flow-weighted mean of rescaled yearly FWMs for each STA
(c) SE for individual STAs uses pooled estimate of year-to-year standard deviation (0.33) in Ln FWM
(d) Adjusted Standard Deviation Using DOF instead of NYEARS - 1