D R A F T

Test for Evaluating Performance of Stormwater Treatment Areas

prepared for

U.S. Department of Interior

by

William W. Walker, Jr., Ph.D.
Environmental Engineer
1127 Lowell Road
Concord, Massachusetts 01742
508-369-8061

January 3, 1996

Introduction

The 1991 Settlement Agreement requires design and construction of Stormwater Treatment Areas (STA's) to achieve a long-term-average, flow-weighted-mean phosphorus concentration of 50 ppb or less at points of discharge from the Everglades Agricultural Area (EAA) to the Water Conservation Areas (WCA's). The program is being implemented under the 1994 Everglades Forever Act to achieve a somewhat broader range of objectives. This report describes a methodology for testing STA compliance with treatment requirements specified in the Settlement Agreement. The test accounts for expected year-to-year variability in performance and for potential deviations attributed to extreme hydrologic conditions. Further refinements can be developed in response to comments provided by the Everglades Technical Oversight Committee, which will be responsible for implementing the test and for interpreting results.

Assumptions

The Settlement Agreement requires long-term-average load reductions of approximately 80% to the WCA's and 85% to Loxahatchee National Wildlife Refuge, relative to loads which were discharged through the Everglades Agricultural Area (EAA) pump stations (S5A, S6, S7/S150, & S8) during the October 1978 - September 1988 base period. These load reductions were contemplated to result from a control program consisting of Best Management Practices and STA's designed to achieve a long-term average flow-weighted-mean concentration of 50

ppb. It is assumed that compliance with treatment requirements will be achieved if both the following conditions are met:

1. The long-term-average, flow-weighted-mean concentration in the combined inflows to the Water Conservation Areas is 50 ppb or less. The combined WCA inflows include outflows from STA's1E, 1W, 2, 34, and 6 and any direct discharges to the WCA's (flows bypassed around the STA's). STA-5 is excluded from this calculation because it treats runoff exclusively from the C-139 basin and was not considered in the Settlement Agreement STA configuration.

2. The long-term average, flow-weighted-mean concentration in the combined inflows to the Refuge is 50 ppb or less. The combined Refuge inflows include outflows from STA-1E and STA-1W and bypassed flows.

Applied to monitoring data from each set of combined inflows, the test identifies years when compliance with the 50 ppb long-term average is unlikely. Although the test could be used to evaluate performance of individual STA's, this type of application is assumed to be beyond the scope of the Settlement Agreement.

The test is designed to operate on a yearly time step. An estimate of temporal variance is required in order to account for the expected year-to-year variance in performance (above and below the 50 ppb long-term average). The estimate is derived from historical monitoring data collected at EAA Pump Stations (WCA inflow points). It is assumed that year-to-year variance in STA outflow concentrations will be similar to year-to-year variance in STA inflow concentrations, as estimated from historical WCA inflow data. The variance estimate (and resulting limit concentration) can be refined using yearly time series of measured STA outflow concentrations, when such data are available.

Methodology

The test is applied to the measured flow-weighted-mean concentration in each combined inflow summarized at 12-month intervals ending April 30. The May-April water year used for tracking EAA phosphorus load reductions. Following the structure of the EAA Regulatory Rule, the test includes two components:

1. One-Year Limit Test. This test is exceeded if the flow-weighted-mean concentration exceeds the limit concentration in any water year. The limit is derived to have a low probability of occurrence (~10%) in a yearly time series with a long-term average flow-weighted-mean

concentration of 50 ppb. The proposed limit (derived below) is 76 ppb. The test assumes that year-to-year variance in STA outflows will be similar to year-to-year variance in STA inflows, as estimated from historical EAA Pump Station data (adjusted for differences in scale).

2. Three-Year Target Test. This test is exceeded if the yearly concentration exceeds the target concentration (50 ppb) in three or more consecutive years. This is based upon a coin-toss model; the probability of three consecutive heads is $.5^3$ or 12.5%.. It does not require an estimate of variance, but assumes that the probability of encountering a yearly concentration above the long-term flow-weighted-mean is approximately 50%. This assumption is supported by the fact that medians and flow-weighted-means are approximately equal in historical data from EAA Pump stations and WCA outflow stations.

The following section describes the calibration of the limit test. The power of each test to detect deviations in performance is evaluated by applying it to rescaled historical WCA inflow and outflow time series.

Calibration

Yearly time series of flow, phosphorus load, and flow-weighted-mean concentration have been derived from flow and sample data retrieved from SFWMD data bases. The data set includes two groups of stations:

1. EAA Pump Stations (S5A, S6, S7, & S8) (WCA Inflows)

2. WCA Outflow Stations (S10A,C,D, S11A,B,C, S12A,B,C,D, & S333)

Each time series spans 16 water years (May 1979 - April 1995). The EAA Pump Stations (representing major STA inflows) are used for calibrating the limit concentration. The WCA Outflow Stations (representing, to various extents, outflows from marsh communities) are used for model testing.

For each station, yearly time series have been developed using the load calculation methodology employed in the EAA Regulatory Rule, as refined for the C-139 Basin Rule. The methodology includes outlier screening and adjusts for differences between grab-sample and composite-sample results.

The data set reflects year-to-year variation in concentration at stations with "known" long-term (~16-year) means. To generate random series, long-term variations in the historical data (uptrends and/or downtrends) are removed using a

polynomial regression of the following form:

$$\ln(C_y) = a_0 + a_1 y + a_2 y^2 + r_y$$

$$\ln(C_f) = \text{Mean}(\ln(C_y)) + r_y$$

where,

C_y = observed yearly flow-weighted-mean concentration (ppb)
C_f = yearly concentration with long-term variance component removed
y = water year (1980 - 1995)
a_i = regression coefficient
r_y = residual (error) term for each water year
Mean = average over all water years

To transform each station into a "pseudo" STA with a long-term average outflow concentration of 50 ppb, filtered concentrations are rescaled as follows:

$$C_s = C_f (50 / C_m)$$

$$C_m = \sum C_f Q_y / \sum Q_y$$

where,
C_s = rescaled yearly flow-weighted-mean concentration (ppb)
C_m = long-term flow-weighted-mean concentration (ppb)
Q_y = flow for year y (hm^3)

Following the EAA regulatory rule (without adjustment for rainfall), the limit concentration is derived by fitting a lognormal frequency distribution to the rescaled concentration data for each group of stations:

$$m = \sum \ln (C_s) / n$$

$$s^2 = \sum [\ln(C_s) - m]^2 / d$$

$$d = k (n - 3)$$

$$L_p = \exp (m + s t_p)$$

where,
m = log mean
s = log standard deviation

n = number of years per station = 16
k = number of stations (= 4 for EAA Pumps, = 11 for WCA Outflows)
d = degrees of freedom in s
L_p = limit concentration with exceedence probability p (ppb)
t_p = 1-tailed t statistic, significance level p

Derivation of the limit based upon pooled station data is desirable to increase precision. Because they are developed primarily from composite sampling, annual load and concentration estimates are more precise for the EAA Pump stations. Only grab samples (in some cases as few as 1 sample per year) are available for estimating loads at WCA outflow stations. The Pump Station data are more representative of the expected sampling methodologies for STA outflows. For this reason, the Pump Station data are used for calibration (deriving the limit concentration) and the WCA Outflow data are used for testing (comparing observed and predicted exceedence frequencies).

Results

Table 1 lists summary statistics derived from three sets of stations (EAA Pump Stations, WCA Outflows, and WCA Outflows excluding the S11 stations). A limit concentration of 76 ppb is derived fom the EAA Pump Stations. The limit has exceedence frequencies of 7.8%, 10.0%, and 7.6% in each station group, respectively. These are approximate estimates of the probability of exceeding the limit if the long-term flow-weighted-mean is exactly 50 ppb. Based upon sample size and the binomial distribution, the observed exceedence frequencies do not vary significantly among station groups. The sensitivity of exceedence frequency to limit concentrations ranging from 70 to 90 ppb is also listed in Table 1. Use of the higher limit derived from all WCA outflow data (84 ppb) is not recommended because of limitations in the monitoring data (discussed above) and because the observed 76-ppb excursion frequency for this group (10.0%) is consistent with the 10% significance level assumed for the limit test.

Figures 1 and 2 and show rescaled time series for EAA Pump Stations and WCA Outflow Stations, respectively, in relation to the target (50 ppb) and limit (76 ppb) concentrations. Compared with other outflow stations, the S11 stations have higher variability and exceedence frequencies. Closer examination of the sample data indicate that spikes at the S11's tend to be associated with reflooding of WCA-2A following droughts (1982, 1985, 1991). For climate conditions observed in the 1979-1988 design period, this type of variance is not expected for the STA's because they will be maintained in a continuously wet condition. Third station group in Table 1 shows lower excursion frequencies and derived limit concentrations for the WCA outflow stations when data from the S11's are excluded.

Figure 3 shows cumulative frequency distributions of yearly concentration for each station group in relation to values predicted by the lognormal distribution model calibrated to Pump stations (m = 3.871, s=0.349). The distributions generally fall within a factor of two relative to the long-term mean (25 to 100 ppb). Agreement of the model with each data set is good in the high concentration ranges, where the 76 ppb limit is derived. If a significance level of 5% (vs. 10%) were used to define the limit, the concentration would increase from 76 to 87 ppb. The 10% level is consistent with other Everglades compliance tests (EAA Regulatory Rule, ENP Inflow Limits, Refuge Marsh Levels).

The rescaled time series have also be used to evaluate the three-year target test. Observed excursion frequencies range from 6.5% to 8.7% in each station group (Table 1). This range represents the approximate probability of exceeding 50 ppb in three consecutive years if the long-term mean is exactly 50 ppb. Based upon a coin-toss model, the expected excursion frequency (probability of three heads) for a symmetric distribution is $.5^3$ or 12.5%. Deviations in distribution shape are apparently responsible for the lower observed frequencies.

When both the limit and the target tests are applied simultaneously, the frequency of exceeding either test ranges from 14.3% to 18.4%. This range estimates the probability of exceeding either test in any year if the long-term flow-weighted-mean is exactly 50 ppb. Results indicate that the tests are additive for these time series (i.e., exceedences of the limit test and target test always occur in different years).

Table 2 shows how the individual and joint exceedence frequencies vary with assumed significance level for the limit test (10% vs. 5%) and cutoff for the target test (3 vs. 4 years). While adjustments of this type would decrease the exceedence frequency for a 50 ppb time series, they would also weaken the test (decrease the probability of detecting long-term means above 50 ppb). Figure 4 plots exceedence frequency (either test) against long-term mean for each data set and for each set of test parameters evaluated in Table 2. These curves have been derived by applying the target and limit tests rescaled time series with long-term means ranging from 40 to 80 ppb.

Figure 5 shows historical inflow concentration time series for the Refuge and WCA's in relation to the 50 ppb target and 76 ppb limit concentrations. Dates for application of the test should be consistent with time schedules defined in the *(modified)* Settlement Agreement.

Extreme Hydrologic Conditions

Under both the Settlement Agreement and the Everglades Forever Act, STA configurations have been designed using flow and phosphorus load data for the

1979-1988 period. The STA's have been designed to treat runoff experienced during this period without bypassing any flows directly to the Water Conservation Areas and without requiring special flow allocations to maintain wet conditions in the STA's during drought periods. Consideration should be given to whether the performance test should be modified to account for extreme hydrologic conditions which were not encountered during the base period.

Both wet and dry extremes are of potential concern. On the high end, extreme storm events may require hydraulic bypass over relatively short time scales (days to weeks). Prolonged wet periods may cause the assimilative capacity of the STA's to be exceeded, even if no hydraulic bypass is necessary. On the low end, extreme droughts not experienced in the base period may require allocation and delivery of additional flow to maintain wet conditions and prevent mobilization of phosphorus stored in STA soils. If additional flow is not available for maintaining STA water levels, STA performance may be negatively impacted.

EAA rainfall data (Table 3) provide a frame of reference for interpreting future hydrologic conditions in relation to the 1979-1988 base period. Potential screening criteria based upon yearly rainfall include the following:

1. In testing EAA compliance with the EAA Regulatory Rule (40E-63), years when the "adjusted rainfall" exceeds the maximum value in the base period (63.8 inches) are excluded. The adjusted rainfall statistic is directly correlated with EAA phosphorus load during the base period. This criterion may also be appropriate for excluding data from the load-reduction compliance tests. This would tend to exclude extremely wet years when the assimilative capacity of the STA's may be exceeded.

2. The lowest EAA annual rainfall experienced during the base period was 35.1 inches. If lower rainfall is encountered in the future, it is assumed that an effort will be made to allocate additional water, as needed to maintain wet conditions in the STA's. If additional water is not available during extreme drought years and if STA performance is hindered as a result, it may not be appropriate to use data from such years in testing compliance.

As an alternative, exclusion based upon hydrologic criteria may be optional (e.g., exclude extreme years only if they would otherwise fail the compliance test). Additional hydrologic criteria employing shorter time steps (daily vs. annual) may be appropriate to accommodate STA bypass flows resulting from extreme storm events. Bypass flows are not anticipated under base-period hydrologic conditions. Unless they result from extreme storm events not experienced in the base period, any bypass flows which occur in the future would be combined with the STA

outflows in calculating annual flow-weighted-mean concentrations for use in compliance testing.

Summary

Procedures for applying the above methodology to evaluate compliance with the Settlement Agreement are summarized below:

1. Compliance will be tested in each water year (May-April) using monitoring data from STA outflows and bypass flows (untreated runoff discharged directly to the Refuge or WCA's). Calculations will exclude flows bypassed for urban water-supply purposes.

2. Compliance with treatment requirements for inflows to Loxahatchee National Wildlife Refuge will be assumed unless the Refuge annual inflow concentration is greater than 76 ppb in any year or is greater than 50 ppb in three or more consecutive years.

3. Compliance with treatment requirements for inflows to the WCA's will be assumed unless the WCA annual inflow concentration is greater than 76 ppb in any year or is greater than 50 ppb in three or more consecutive years.

4. Compliance will not be tested in water years when the EAA adjusted rainfall, as defined in SFWMD Rule 40E-63, exceeds 63.8 inches. Compliance will not be tested in water years when the EAA rainfall is less then 35.1 inches, if sufficient supplemental flows are not available to maintain wet conditions in the STA's. If a year is excluded based upon these criteria, results from adjacent years will be treated as consecutive in testing compliance.

5. Unless they result from extreme storm events not experienced in the 1979-1988 base period, bypass flows (discharge of untreated runoff directly to the Refuge or WCA's) will be combined with the STA outflows in calculating annual flow-weighted-mean concentrations for use in compliance testing. Further analyses and discussions are required to define such events.

List of Figures

List of Tables

Figure 1 - Rescaled EAA Pump Station Time Series

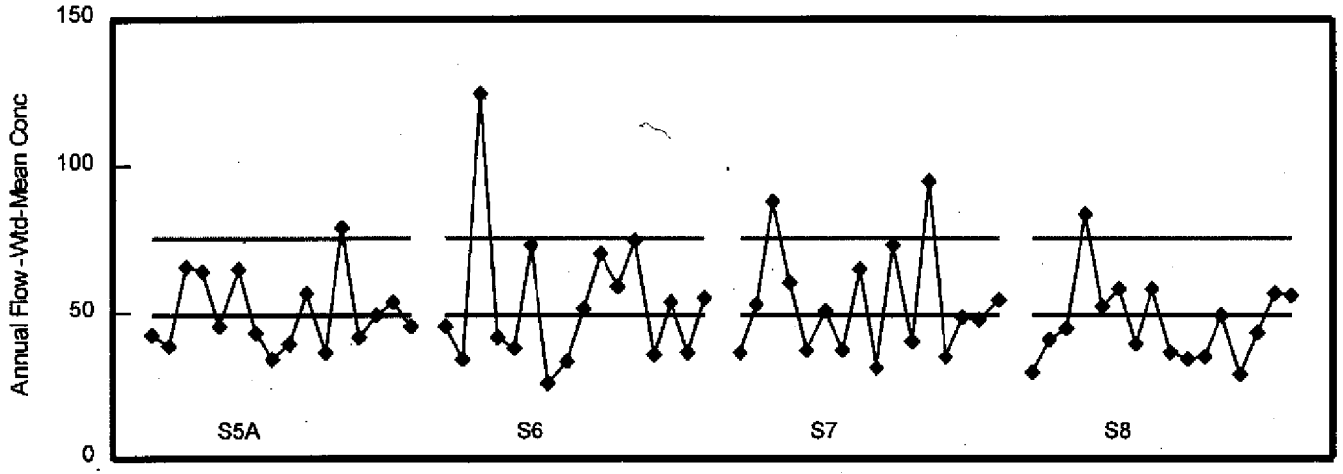


Figure 2 - Rescaled WCA Outflow Time Series

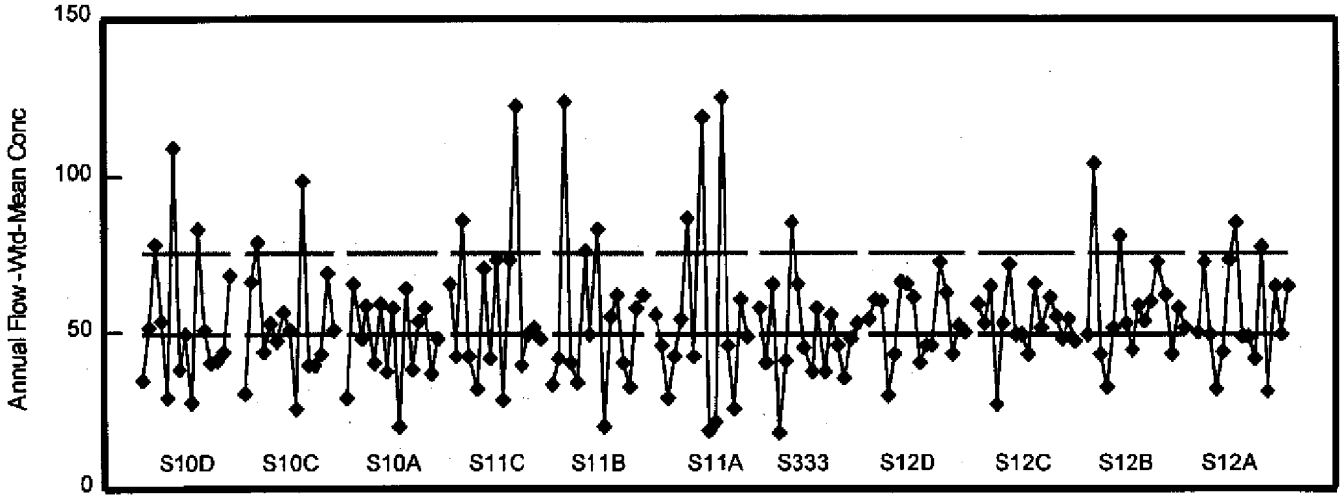
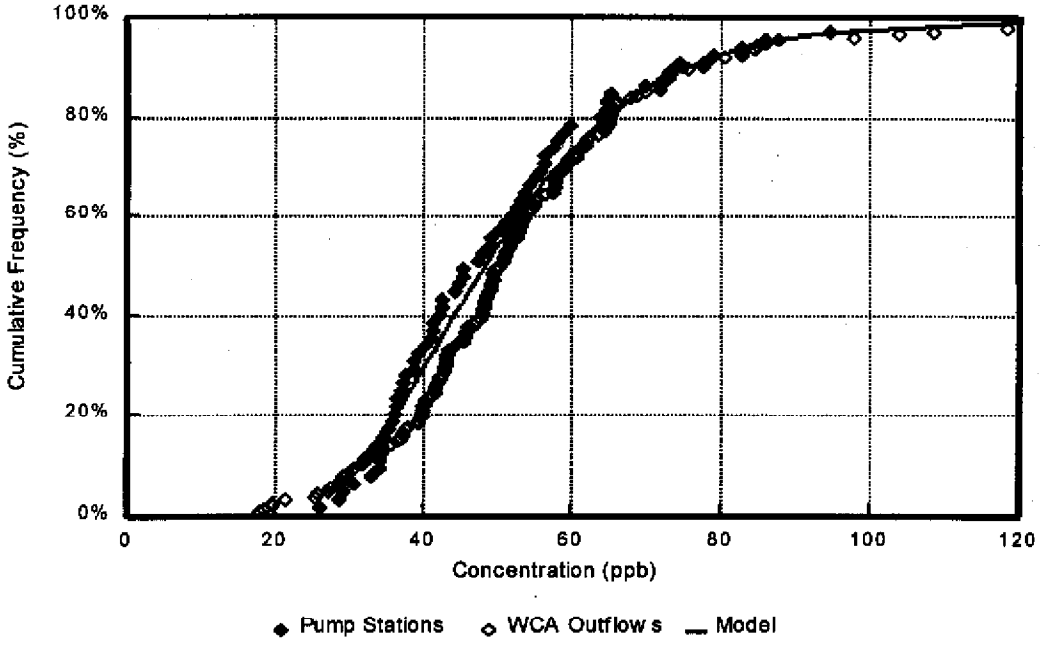
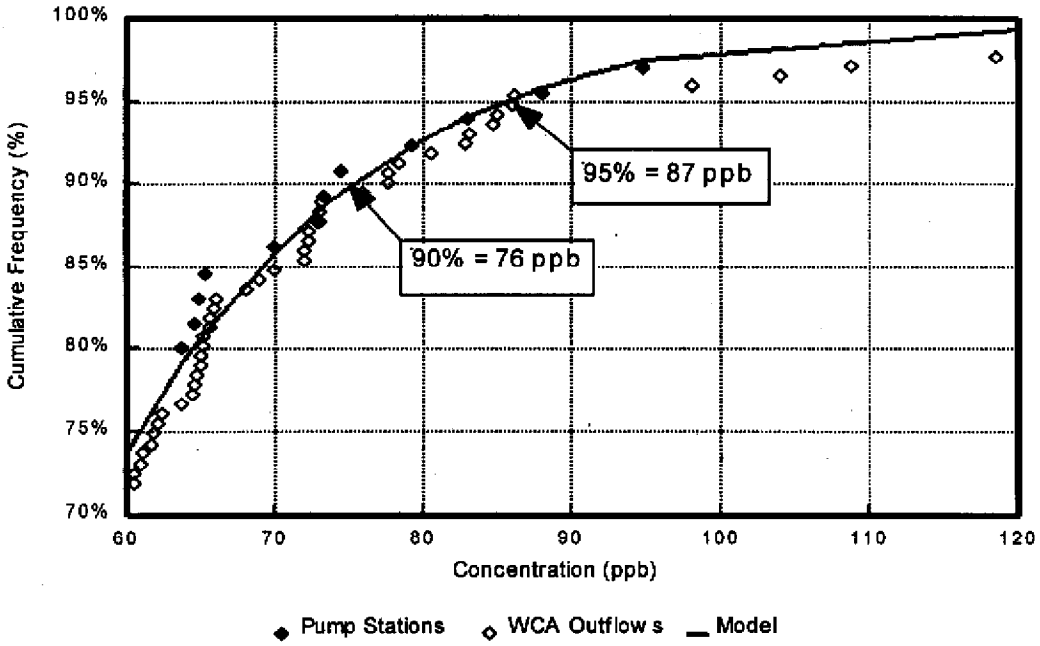


Figure 3 - Cumulative Frequency Distributions

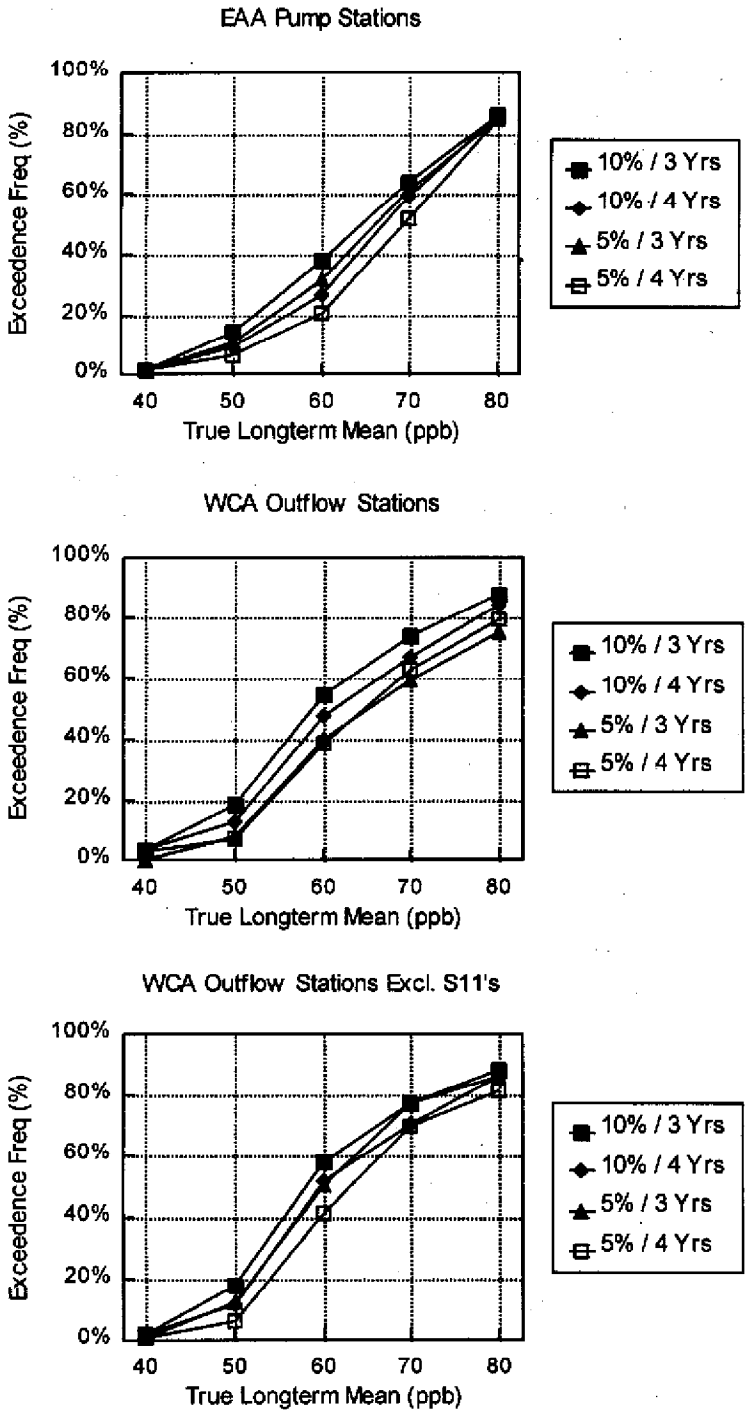




Yearly Flow-Weighted-Mean Total Phosphorus Concentrations
Rescaled to Long-term Flow-Weighted Mean of 50 ppb

EAA Pump Stations (S5A, S6, S7, S8)		StationYrs	64
WCA Outflow Stations (S12's, S333, S11's, S10's)		StationYrs	170
Model =	Lognormal Frequency Distribution		
	m = 3.871	s =	0.349
	90th Pctl 76	95th Pctl	87

Figure 4 - Power Series vs. Data Set & Test Parameters

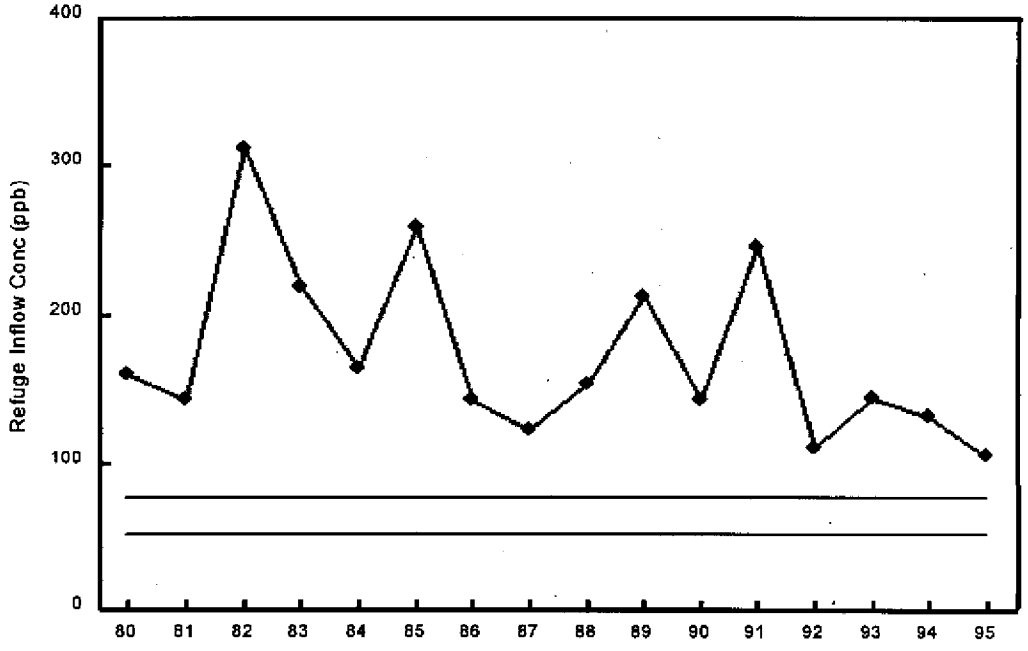


Test Parameters:

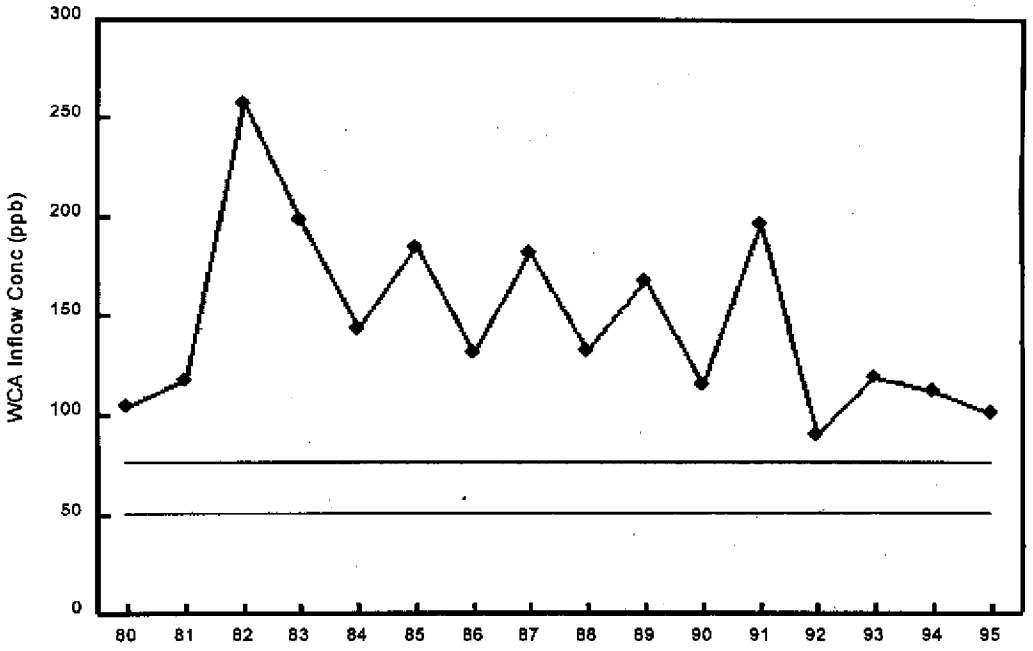
10% or 5% Signif. Level for Limit Test

3 vs. 4 Yrs Cutoff for Target Test

Figure 5 - Refuge & WCA Inflow P Concentrations



Stations: S5A S6 G251



Stations: S5A S6 S7 S8 S150 G251
G200 -G88

Target = 50 ppb Limit = 76 ppb

Table 1 - Summary of Results

Station Group	EAA Pumps	WCA Outflows	Excl. S11s WCA Outflows
Number of Stations	4	11	8
Number of Station-Years	64	170	125
Flow-Weighted-Mean (ppb)	50.0	50.0	50.0
Geometric Mean (ppb)	48.0	50.2	50.4
Ln Mean	3.871	3.916	3.919
Ln Standard Deviation	0.349	0.393	0.340
Target Test (Freq >50 ppb)			
One Year	43.8%	50.6%	52.8%
Three or More Consec. Yrs (a)	6.3%	8.2%	10.4%
Standard Error	3.2%	2.3%	2.9%
Limit Test			
90% Rejection Limit (ppb)	76	84	79
Frequency >Limit	7.8%	6.5%	5.6%
Standard Error	3.4%	1.9%	2.1%
Limit Test (EAA Pump Stations)			
90% Rejection Limit (ppb)	76	76	76
Frequency >Limit (b)	7.8%	10.0%	8.0%
Standard Error	3.4%	2.3%	2.4%
Limit Test or Target Test (a or b)	14.1%	18.2%	18.4%
Exceedence Freq. vs. Conc.			
70 ppb	12.5%	15.3%	12.0%
75 ppb	7.8%	10.6%	8.0%
80 ppb	6.3%	8.2%	5.6%
85 ppb	4.7%	5.3%	2.4%
90 ppb	3.1%	4.1%	2.4%

Table 2 - Sensitivity to Test Parameters

Test Parameters

Limit Signif.	10%	5%	10%	5%
Limit (ppb)	76	87	76	87
Strikeout	3	3	4	4

Exceedence Frequencies - EAA Pump Stations

Limit	7.8%	4.7%	7.8%	4.7%
Target	6.3%	6.3%	1.6%	1.6%
Either	14.1%	10.9%	9.4%	6.3%

Exceedence Frequencies - WCA Outflow Stations

Limit	10.0%	4.1%	10.0%	4.1%
Target	8.2%	8.2%	2.9%	2.9%
Either	18.2%	12.4%	12.9%	7.1%

Exceedence Frequencies - WCA Outflows, Excl. S11's

Limit	8.0%	2.4%	8.0%	2.4%
Target	10.4%	10.4%	4.0%	4.0%
Either	18.4%	12.8%	12.0%	6.4%

Limit Signif. = Significance Level for Defining One-Year Limit

Limit = One-Year Limit, Calculated from Pump Station Data

Strikeout = Number of Consecutive Years >50 ppb Triggering Exceedence of Target Test

Table 3 - EAA Runoff & Rainfall Time Series

Water Year	Flow kac-ft/yr	Total P Load mtons	Flow-Wtd. Conc. ppb	Rainfall Total Inches	Rainfall CV	Rainfall Skewness	Adjusted Rainfall Inches
80	1162	167	117	53.5	0.599	1.413	43.5
81	550	85	126	35.1	0.729	0.306	37.2
82	781	234	243	46.7	0.941	1.817	51.8
83	1965	473	195	64.4	0.667	0.332	63.8
84	980	188	155	49.8	0.656	0.369	48.6
85	824	229	225	39.7	0.794	0.162	45.9
86	1058	197	151	51.2	0.686	0.487	50.7
87	1286	293	185	52.0	0.764	1.085	52.2
88	701	140	162	43.4	0.649	0.635	40.8
Mean	1034	223	175	48.4	0.721	0.734	48.3
Minimum	550	85	117	35.1	0.599	0.162	37.2
Maximum	1965	473	243	64.4	0.941	1.817	63.8

Water Years Ending April 30

Adjusted Rainfall (EAA Regulatory Rule) = Total Rain x Exp [1.053 (CV - 0.7205) - 0.117 (Skew - 0.7339)]
CV & Skew computed from monthly rainfall totals