# Compliance of Marsh Phosphorus Concentrations in A.R.M. Loxahatchee National Wildlife Refuge with Interim Levels Required under the Consent Decree

**prepared for**

**U.S. Department of the Interior**

**by**

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## Summary

The State/Federal Consent Decree established interim and long-term levels for phosphorus concentrations at 14 monitoring sites in Arthur R. Marshall Loxahatchee National Wildlife Refuge. Interim levels became effective in February 1999. The more stringent long-term levels will become effective in December 2006. The interim levels were designed to provide water quality equivalent to that observed in the 1978-1979 base period for Outstanding Florida Waters. Despite reductions in phosphorus loads and exceedance frequencies subsequent to full-scale operation of STA-1W (July 2000) and STA-2 (July 2001), interim levels have been exceeded one or more times in each of the four years since they went into effect. There has been no "*substantial evidence that the exceedances were due to error or extraordinary natural phenomena*". These are the criteria specified in the Consent Decree for scientific interpretation of exceedances by the Technical Oversight Committee (TOC). It is likely that they reflect exterior phosphorus loads that are still excessive, despite the load reductions accomplished by full-scale operation of STA-1W and diversion of S6 loads to STA-2 since July 2001. Since that time, exceedances of interim levels have occurred in each year and marsh P concentrations have been above median values that occurred in 1978-1979 at a given stage (water level) in 17 out of 20 (81%) of the months.

Compliance during the most recent reporting period (April 2002-March 2003, which included one monthly exceedance in July 2002) does not diminish the fact that exceedances have already occurred and is not a reliable indicator of current marsh status. Exceedances have generally not occurred in previous dry seasons, when external loadings are low and the marsh drains towards the rim canal. Exceedances have occurred during periods of high phosphorus loads, increasing stage, and hydraulic gradients sloping from the exterior rim canal towards the marsh. These conditions are conducive to transporting phosphorus to the marsh.

Because of the inherent variability in marsh phosphorus dynamics and monitoring procedures, compliance status has been expectedly variable from one reporting period to the next. This variability is factored into the statistical model used to derive the interim limits. Prudent management decisions should be based upon interpretation of the cumulative record and trends observed in the marsh and STA performance, not upon a highly variable monthly signal.

When an exceedance occurs, the Consent Decree instructs the TOC to determine whether "*there is substantial evidence that it is due to error or extraordinary natural phenomena*". This determination does not require a complete understanding of processes responsible for observed patterns in the data or a detailed mechanistic model of phosphorus dynamics, although development of such a model is an important long-term objective. There has been no demonstration that errors occurred or that the exceedances were caused by extraordinary natural phenomena. There is considerable evidence that they were related to external phosphorus loads and therefore man-induced.

Given the complexities and time lags associated with phosphorus cycling and transport in the marsh, as well as inherent sampling variability, it is not realistic to expect clear spatial patterns to appear in the data in each month or to expect direct correlations among phosphorus concentrations, conservative tracers, site locations, and exterior phosphorus loads at specific stations on a monthly basis. Such patterns have appeared in some months, however. Independent data analyses performed by SFWMD demonstrate a spatial correlation between elevated P concentrations and conservative tracers at the marsh site that is closest to the rim canal and exterior discharges (Site 4, near the ACME pump stations). It is likely that the other monitoring sites are located too far from inflow points (S5A, STA-1W, ACME) to detect direct correlations, although such correlations are likely to exist on longer time scales and with various time lags. Elevated P concentrations at Site 4 have contributed to, but not exclusively caused, the exceedances in the 14-station geometric mean. Had this station been excluded from calculation of the 14-station geometric mean in July 2002, the geometric mean would been would still exceeded the interim level. Based solely upon SFWMD's analysis, there is no justification for ascribing the exceedances to error or extraordinary natural phenomena.

Elevated concentrations of conservative tracers (such as conductivity or chloride) establish the fact that water from the exterior rim canal containing high concentrations of phosphorus penetrates at least as far as the outer ring (~50%) of marsh stations. Much of the associated phosphorus load is probably taken up by the marsh before reaching the sites, as evidence by elevated soil phosphorus concentrations in marsh areas adjacent to canals. Exceedances of marsh P levels and overall phosphorus mass balances on the Refuge are strong indicators that phosphorus continues to accumulate in the marsh vegetation and soils. This process of phosphorus accumulation is known to cause significant and long-term imbalance in flora and fauna.

The amount of phosphorus accumulation in the marsh is directly related to the magnitude of exterior phosphorus loads discharged into the Refuge. Aside from achieving marsh P levels, the Consent Decree requires an 85% reduction in the average phosphorus load to the Refuge, relative to average 1979-1988 loads. This would be equivalent to an average phosphorus load of 17 metric tons/yr. This goal would be 20 mt/yr if allowance were made for the load associated with diversion of additional flows from Lake Okeechobee to compensate for reductions in runoff volume due to implementation of agricultural Best Management Practices (BMP's).

Through implementation of BMP's and full-scale operation of Stormwater Treatment Areas (STA's), the load-reduction requirement was first achieved on a 12-month rolling-average basis in July 2001. The load to the Refuge generally remained below 20 mt/yr through June 2002. An uptrend developed after that, however, and the load reached 42 mt/yr in the most recent 12-month period (April 2002 – March 2003), 40 mt/yr of which was attributed to STA-1W outflows and bypasses. This uptrend occurred during a period when rainfall was slightly below average. It can be traced largely to diversion of high flow volumes and associated phosphorus loads from Lake Okeechobee to STA-1W, resulting in overloading of the treatment area to levels that were three times the design average to achieve a 50 ppb outflow concentration and twice the 31-year maximum design load. As a consequence, the recent 12-month average load to the Refuge was approximately twice the maximum load allowed under the Consent Decree. While the TOC recently adopted a concentration-based compliance test for load-reduction, the test assumes that the treatment areas are operated within their design ranges, except for extraordinary climatic events.

At least partially as a consequence of this overloading, there was a significant deterioration in the STA treatment performance. Outflow concentrations from STA-1W increased from 35 ppb in July 2000, when full-scale operation began and inflow loads were within the design range, to 53 ppb in the most recent 12-month interval (April 2002 – March 2003). The 3-month flow-weighted mean outflow concentration has reached 80 ppb. There is also visual evidence of recent deterioration in the treatment vegetation communities. Some of this deterioration in performance may have been caused by unanticipated difficulties in maintaining the desired vegetation and shut-down of one of the treatment cells to allow for construction activities associated with STA optimization in 2003.

Obviously, overloading the 50 ppb design is not consistent with Consent Decree requirements to achieve an 85% load reduction or with achieving interim and long-term phosphorus levels in the Refuge. Furthermore, it does not help optimization efforts to achieve an outflow concentration of 10 ppb, which would be required to maintain a healthy balance of flora and fauna throughout the marsh. Until loads are brought down to the design levels, attempts at STA optimization to achieve 10 ppb will be fruitless and continuing to achieve the interim treatment goal of 50 ppb will even be in jeopardy.

There are significant technical challenges and unknowns associated with construction and operation of large-scale biological treatment systems, particularly when the objective is to achieve low outflow P concentrations. The load reductions accomplished to date through BMP's and STA's represent remarkable achievements. Because these control measures have (with some exceptions) performed better than expected in the plan conceived under the Consent Decree, it is likely that the cumulative load reductions to the Everglades accomplished since 1994 have also exceeded expectations. BMP's (achieving average load reductions of about 50%) and two of the treatment areas (STA-2 and STA-6, with recent outflow concentrations of 17 ppb and 26 ppb, respectively) continue to perform better than expected relative to the interim 50 ppb treatment objective, although additional measures will be needed to achieve STA outflow concentration levels consistent with meeting water quality standards in the marsh by December 2006.

If the TOC determines that there is not "*substantial evidence that [an exceedance] is due to error or extraordinary natural phenomena*", Consent Decree instructions are as follows:

> *"...based upon review of monthly trends for the 14 station mean and other relevant information, the TOC members will forward their opinions and recommendations to their respective agencies for relevant action"*

An immediate focus on the Refuge is recommended to provide assurance that interim and long-term marsh phosphorus levels will be achieved on schedule. The fact that compliance with interim P levels improved after full-scale STA operation suggests that it will continue to improve if loads are further reduced.

Specific actions proposed for discussion by TOC include:

1. Evaluate whether existing and currently-planned measures for reducing phosphorus loads to the Refuge are sufficient to provide assurance that interim marsh P levels will be achieved in 2003-2006 and that long-term levels will be achieved by December 2006.

2. Develop and implement any additional structural and operational measures necessary to accomplish the above objectives.

3. Develop and implement operational strategies to avoid overloading of STA-1W with releases from Lake Okeechobee and to ensure that the facility is operated well within its design range.

4. Conduct intensive monitoring, data analysis, and reporting to adequately characterize the extent of impacted areas in the Refuge, to improve understanding of marsh P dynamics, and to provide timely and complete information to support management decisions; and

5. Further develop hydraulic and phosphorus cycling models for use in designing and operating treatment facilities, predicting local impacts on the marsh, and characterizing the overall phosphorus budget of the Refuge.

## Introduction

The State/Federal Consent Decree established interim and long-term levels for phosphorus concentrations at 14 monitoring sites in Loxahatchee National Wildlife Refuge (Figure 1). The interim levels were designed to provide water quality equivalent to that observed in the 1978-1979 base period for Outstanding Florida Waters. The number and locations of the monitoring sites were constrained by the design of a sampling program conducted by SFWMD in 1978-1983. Regression analyses of that data were performed to derive the interim levels as a function of stage (water level). The model accounts for variations associated with stage, time (i.e., trend within the 1978-1983 period), and other random variations not reflected by stage and time. The random term reflects natural processes occurring in the marsh, random man-induced variations, as well as random sampling errors. Averaging across sites and adjusting for stage enables a focus on trends in the data by reducing random variations in the monthly compliance results. Interim levels were set at the 90$^{th}$ percentile of the 1978-1979 data distribution. To further allow for random variations, an exceedance is considered to occur when monthly marsh P concentrations exceed the interim levels in 2 or more months over a period of 12 consecutive sampling events, skipping months when the levels are not in effect because of extremely low stage. For simplicity, this is referenced as the “12-month test” below, even though it has spanned a longer time period (up to 15 months) in periods with low stage.

## Compliance Status

Interim levels went into effect under the Consent Decree in February 1999. If the frequency distribution of phosphorus concentrations were consistent with that measured in 1978-1979, about 10% of the monthly values would exceed interim levels. Between February 1999 and March 2003, monthly values exceeded interim levels in 7 out of 50 months (14%) (Figure 2). Within this period, loads from S5A were reduced when full-scale operation of STA-1W began in July 2000. In addition, loads from S6 were diverted away from the Refuge in July 2001. Comparing the data before and after implementation of both measures (July 1, 2001), the monthly exceedance frequency dropped from 17% to 10%. As demonstrated below, these events are not random, but generally associated with periods of elevated phosphorus transport, rising stage, and flow from the exterior rim canal into the marsh.

Applying the 12-month test used for determination of compliance, interim levels were exceeded in 12-month periods ending in: September 1999-November 2000, October-November 2001, and July-October 2002. Compliance with the 12-month test improved after the load reductions occurred. While this is evidence that compliance has improved in response to load-reduction measures, at least one exceedance of the 12-month test occurred in each of the four years. It is clear that compliance has not yet been consistently achieved.

If recent data were consistent with 1978-1979 conditions, we would expect 50% of the values to be above the “target”, or 50$^{th}$ percentile of the 1978-1979 data, as predicted from the stage/concentration regression equation used to derive the interim levels (Figures 3, 4). The target was exceeded in 73% and 81% of the months before and after July 1, 2001. This statistic does not appear to have improved in response to load reduction measures and frequencies are well above 50%. This is further evidence that concentrations in the marsh are not yet consistent with 1978-1979 conditions.

While it is encouraging that there was only one exceedance of the interim levels in the most recent 12-month period (April 2002 - March 2003), exceedances have generally not occurred in the dry seasons of previous years ( Figure 2 ) or under hydraulic conditions present during the past few months (Figures 8,9). The data tracked the 50$^{th}$ percentile of the 1978-1979 distribution since in the past few months (Figure 3). Similar patterns were observed in the winters of 1999, 2001, and 2002 but were followed by exceedances later in each year. Given the expected random, seasonal, and stage-dependent variability from one reporting period to the next, prudent management of the system cannot be based only upon results of the most recent quarterly TOC report. Because of the inherent statistical variability, the cumulative record of compliance and trends should be examined in interpreting the data to support management actions.

Recent data indicate that interim levels are not being consistently achieved. Based upon the historical record, achieving compliance with the more stringent long-term levels by December 2006 will be more difficult (Figure 5). The hypothesis that exceedences are triggered by external loads is further supported by the fact that consistent compliance with long-term levels occurred only during the 2001 drought, when phosphorus loads were very low.

## Data Interpretations

Despite improvements in the past two years, interim levels were exceeded in each of the four years since they became effective (Figure 2). When an exceedance occurs, the Consent Decree instructs the TOC to determine whether "*there is substantial evidence that it is due to error or extraordinary natural phenomena*". This determination requires limited causal interpretation of the data and related factors. Dismissal of an exceedance requires conclusive demonstration that it was caused by error or extraordinary natural phenomena. There has been no such demonstration. This determination does not require a complete understanding of processes responsible for observed patterns in the data or a detailed mechanistic model of phosphorus dynamics, although development of such a model is an important long-term objective.

The potential role of phosphorus recycling from the marsh induced by drying and subsequent reflooding of the marsh was discussed in TOC's previous letter to the Consent Decree principals regarding the October 2001 exceedance. The statistical model used to derive the interim levels already accounts for stage dependence and other random sources of variability that were present in the 1978-1983 calibration period. An increase in the amount of P recycling attributed to this process would, in itself, be a symptom of increased nutrient enrichment because is known that excess P is trapped by the marsh and then recycled. There is currently insufficient justification for explaining the exceedances based upon this hypothesis or characterizing it as an extraordinary natural phenomenon.

Recent data analyses by SFWMD have revealed a correlation between elevated phosphorus concentrations and conductivities at marsh station 4. Of all the sites in the existing network, this site is closest to an inflow point (ACME Improvement District Pumps, Figure 1). Because inflows have much higher conductivities than the interior marsh, elevated conductivity is a signal that water from the inflow (or adjacent rim canal) reaches the marsh site. The P concentration at Site 4 in July 2002, when the most recent monthly exceedance occurred, was 21 ppb, as compared with a range of 6-12 ppb at the other sites (Figure 11). This elevated concentration contributed to, but did not exclusively cause, the exceedance. If data from Site 4 are excluded, the geometric mean drops from 11.2 to 10.7 ppb, which is still above the interim level of 9.7 ppb. Elevated P concentrations at Site 4 have also been observed in other months when exceedances occurred (Figure 16). For example, the concentration at Site 4 in June 1999 was 46 ppb, as compared with a range of 9-17 ppb at other sites. SFWMD's analysis of data from Site 4 alone provides a basis for rejecting the hypothesis that the exceedances were caused by extraordinary natural phenomena.

Further data analyses described below are consistent with the hypothesis that exceedances are related to external phosphorus loads to the Refuge from one or more sources (Figure 1). Details are given in the legends of the figures cited below:

1. Interim levels were exceeded in months with high stage, after the Refuge had been recently refilled with runoff and rainfall under its seasonal regulation schedule (Figure 6).

2. Monthly exceedances occurred during or immediately following phosphorus loading events (Figure 7). Decreases in the average and peak loads over the 1999-2002 period (attributed to full-scale operation of STA-1W and STA-2) are consistent with the observed decrease in exceedance frequencies. Exceedances are therefore correlated with loads over both short and long time scales.

3. When exceedances occurred, water-surface elevations in discharge tail-waters and rim canal were consistently above the average marsh elevations. These hydraulic conditions would be conducive to transport of water with elevated phosphorus concentrations from the rim canal into the marsh. (Figures 8,9).

4. Conservative tracer data (conductivity, chloride, sodium, calcium) indicate that inflow and rim-canal waters consistently penetrate at least as far as the outer ring of interior marsh sites (Figures 10, 17). Penetration to interior sites is indicated on some sampling dates.

5. In July 2002 (date of last exceedance), marsh phosphorus concentrations were elevated at northern sites closest to the inflow points (Figure 11). This event was preceeded by high rainfall and high external loads (Figure 7) and hydraulic gradients sloping towards the marsh (Figure 8,9). While the elevated P concentrations at some of the northern sites may have been related to their relatively shallow depths, there is no basis for assuming that depths were the only factor, especially given the relative proximity of these sites to the inflow points.

6. Spatial and temporal variations within each year show that exceedances are often associated with loading events, rising stage, and elevated P concentrations at northern sites (Figures 10 - 16). Elevated P concentrations were sometimes observed under low stage at southeastern interior sites, but decreased rapidly following re-flooding and did

> not trigger exceedances because the compliance model accounts for stage-related variations. Interpreting the spatial P distribution on any date is complicated by long water residence times, P uptake and recycling ("spiraling") in the marsh, and variations in antecedent load, stage, rainfall, water depths, wind, water chemistry, etc. Based upon replicate sampling studies, random variations attributed to sampling and phosphorus analyses are on the order of 18%. This is comparable to the spatial (20%) and temporal (22%) variability in the historical marsh data (W. Walker, Report to TOC, March 1999).

Based upon the above observations, we do not support the interpretation that the exceedances were due to error or extraordinary natural phenomena. It is likely that they are direct consequences of phosphorus loadings that are still too high to allow achievement and maintenance of interim P levels.

## Trends in Phosphorus Load

Elevated concentrations of conservative tracers establish the fact that water from the exterior rim canal containing high concentrations of phosphorus penetrates at least as far as the outer ring of marsh stations. Much of the associated phosphorus load is probably taken up by the marsh before reaching the sites, as evidenced by elevated soil phosphorus concentrations in marsh areas adjacent to the rim canal (Figure 18). Exceedances in marsh P levels, as well as phosphorus mass balances on the Refuge, are strong indicators that phosphorus continues to accumulate in the marsh vegetation and soils. Mass balances in the 2003 Everglades Consolidated Report show an inflow load of 18.8 mtons/yr, an outflow load of 12.8 mtons/yr, and a retained (inflow-outflow) load of 6.0 mtons/yr for the May 2001-April 2002 period.

Phosphorus uptake by marsh vegetation and soils has been shown to occur rapidly and have significant long-term ecological consequences leading to imbalance in flora an fauna. For example, vegetation transects studied by Florida International University (FIU) indicate that a cattail "front" marched from 2 km to 4 km east of the S6 discharge between 1989 and 1999 (Childers et al., JEQ, Feb 2003). Other ecological effects of enrichment have been documented in threshold research conducted in the Refuge by SFWMD and FIU.

The amount of phosphorus accumulation in the marsh is directly related to the magnitude of exterior phosphorus loads discharged into the Refuge and hydraulic conditions controlling phosphorus transport from the discharge regions into the marsh. Aside from achieving marsh P levels, the Consent Decree requires an 85% reduction in the average phosphorus load to the Refuge, relative to average 1979-1988 loads. This would be equivalent to a load of 17 metric tons/yr. The goal would be 20 mt/yr if allowance is made for the P load associated with diversion of additional flows from Lake Okeechobee to compensate for reductions in runoff volume due to implementation of agricultural Best Management Practices (BMP's).

Through implementation of BMP's and full-scale operation of Stormwater Treatment Areas (STA's), the load-reduction requirement was first achieved on a 12-month rolling-average basis in July 2001 (Figure 19). The load to the Refuge generally remained below 20 mt/yr through June 2002. An uptrend developed after that, however, and the load reached 42 mt/yr in the most recent 12-month period (April 2002 – March 2003), 40 mt/yr of which was attributed to STA-1W outflows and bypasses.

The increasing trend in P load to the Refuge is directly related to overloading of STA-1W and subsequent deterioration in treatment performance (Figures 20,21). The high loads are not explained by high rainfall, which averaged 44 inches/yr at S5A in the 12-month period ending in March 2003, as compared with 50 in/yr in 1979-1988. The overloading is primarily related to routing of large flows and their associated P loads from Lake Okeechobee to S5A/STA-1W. Figure 20 compares yearly flows and P loads released from the Lake and reaching S5A with levels represented in the 31-year hydrologic record used in design calculations for STA-1W. The values exceeded the 31-year maximum design in 1999-2000 and after July 2002.

Figure 21 shows resulting STA-1W inflow P loads, outflow P concentrations, and outflow P loads. In the 12-month period ending in March 2003, the average P load into STA-1W reached 93 mt/yr, which was 3.0 times the average and 2.1 times the maximum yearly load in the 31-year baseline design dataset. At least partially as a consequence of this overloading, there was a significant deterioration in treatment performance (Figure 21). Outflow concentrations from STA-1W increased from 35 ppb in July 2000, when full-scale operation began and inflow loads were within the design range, to 53 ppb in the most recent 12-month interval (April 2002 – March 2003). The 3-month flow-weighted mean reached 80 ppb. Some of this deterioration in performance may have be caused by unanticipated difficulties in maintaining the desired vegetation and shut-down of one of the treatment cells to allow for construction activities associated with STA optimization in 2003. There is also visual evidence of recent deterioration in the treatment vegetation communities possibly related to phosphorus overloading and/or high flow velocities.

Despite very high outflow loadings from STA-1W in the past few months, the marsh interim levels were not exceeded in this period. This may reflect hydraulic conditions that were less conducive to transporting phosphorus into the marsh during this period (Figure 8). There may have been long-term effects on treatment performance, however, which would increase the risk of exceedences in the future.

Overloading the STA 50 ppb design is not consistent with Consent Decree requirements to achieve an 85% load reduction or with achieving interim and long-term phosphorus levels in the Refuge. It also hinders optimization efforts to achieve an outflow concentration of 10 ppb, which would be required to maintain a healthy balance of flora and fauna throughout the marsh. Potential remedies to overloading include reductions in lake releases, enhanced BMP's, and/or STA expansion. Until loads are brought down to the design levels, attempts at STA optimization to achieve 10 ppb will be fruitless and continuing to achieve the interim treatment goal of 50 ppb will even be in jeopardy.

Significant progress has been made in reducing loads to the Refuge and improving compliance with marsh P levels, but the objectives of maintaining interim levels (to provide water quality equivalent to 1978-1979 conditions) and achieving an 85% P load reduction relative to 1979-1988 conditions have apparently not been achieved. If phosphorus is being exported from previously impacted areas of the marsh, there would be a delay in the response of marsh P concentrations to reductions in external loads that have already occurred and exceedence frequencies may decrease over time with the existing loads. There is currently no means of determining the extent to which this is occurring, however. The Refuge continues to be a net sink for phosphorus (i.e. less flows out than flows in). There is no assurance that interim levels will be met under existing loading conditions, particularly given the recent performance of STA-1W. The fact that compliance with interim P levels improved after full-scale STA operation suggests that it will continue to improve if loads are further reduced. Given the association of exceedances with high-flow events, modification of pumping schedules to reduce peak flows might also decrease the hydraulic gradients that promote phosphorus transport from the inflow regions into the interior marsh and thereby decrease the risk of future exceedances.

## Recommended Actions

When an exceedance occurs and there is no substantial evidence that it was due to error or extraordinary natural phenomena, Appendix B of the Consent Decree provides that:

> *"based upon review of monthly trends for the 14 station mean and other relevant information, the TOC members will forward their opinions and recommendations to their respective agencies for relevant action."*

Accordingly, we offer the following list of potential actions for discussion by TOC:

1. Determine whether existing and currently-planned measures for reducing phosphorus loads to the Refuge are sufficient to provide assurance that interim marsh P levels will be achieved in 2003-2006 and that long-term levels will be achieved by December 2006.

2. Develop and implement any additional structural and operational measures considered necessary to accomplish the above objectives.

3. Develop and implement operational strategies to avoid overloading of STA-1W with releases from Lake Okeechobee and to ensure that the facility is operated well within its design range.

4. Correct deficiencies in the design of the existing monitoring network. Initiate more intensive spatial sampling (water column, soils, vegetation) in areas close to inflow points. These data would be used for diagnostic (not compliance) purposes.

5. Update baseline datasets (31-year set of flows and P loads) and model (DMSTA) calibrations used in STA-1W design calculations to ensure that they are consistent with recent monitoring data and current water management strategies.

6. Complete and refine the hydraulic model of the Refuge being developed by SFWMD. Expand the model to simulate mass transport and calibrate it to stage, flow, and conservative tracer data. Apply the model to assess penetration of pumped water into the marsh and to evaluate options for reducing that penetration.

7. Add a P cycling component to the Refuge model to allow forecasts and hindcasts of event-driven penetration into the marsh of phosphorus plumes from point discharges.

8. Develop simpler mass-balance models of the Refuge for flow, phosphorus, and conservative tracers. Use these models to track the overall water and phosphorus budgets and net phosphorus retention by the marsh.

9. Accelerate efforts to improve monitoring of flow, water level, and phosphorus concentrations in STA-1W. In particular, resolve apparent discrepancies in the water budget of the inflow distribution works to ensure that inflow loads to STA-1W and bypass loads to the Refuge are accurately measured.

10. Augment TOC quarterly reports to include water and phosphorus budgets on STA-1W and the Refuge

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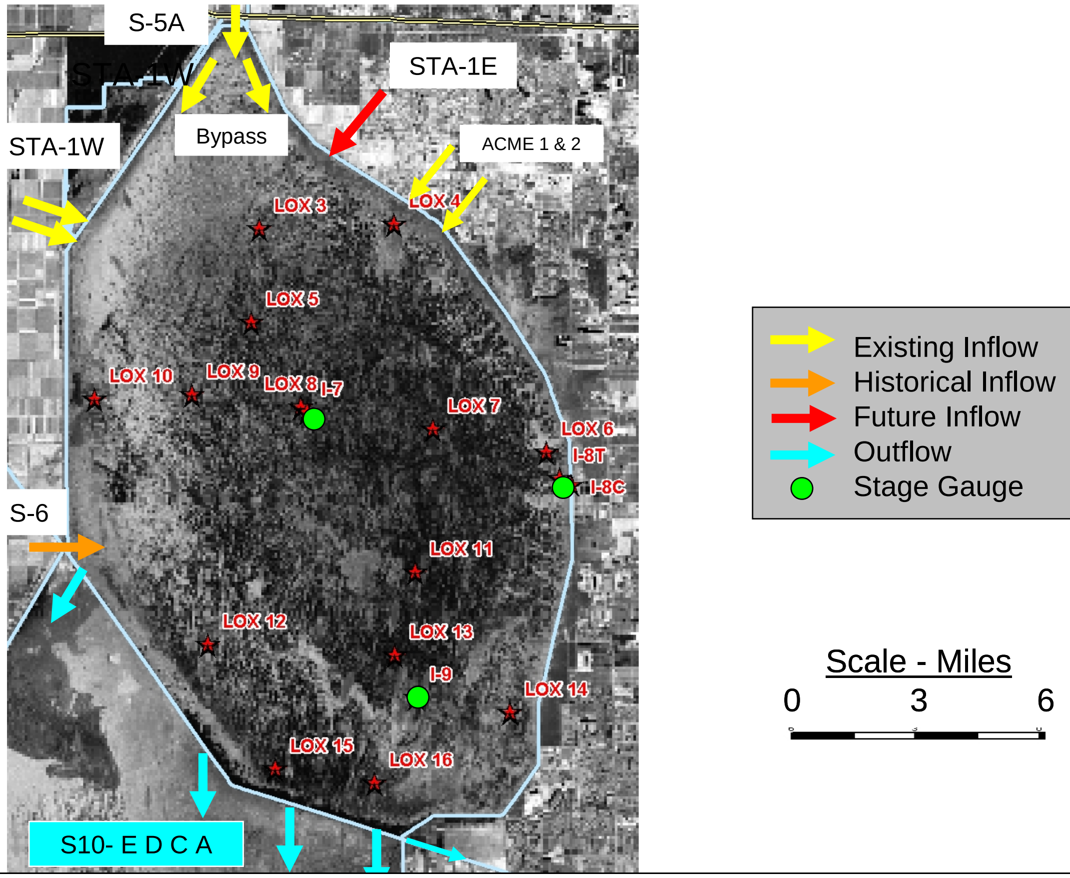



**Figure 1: Loxahatchee National Wildlife Refuge Inflows, Outflows, and Monitoring Sites**

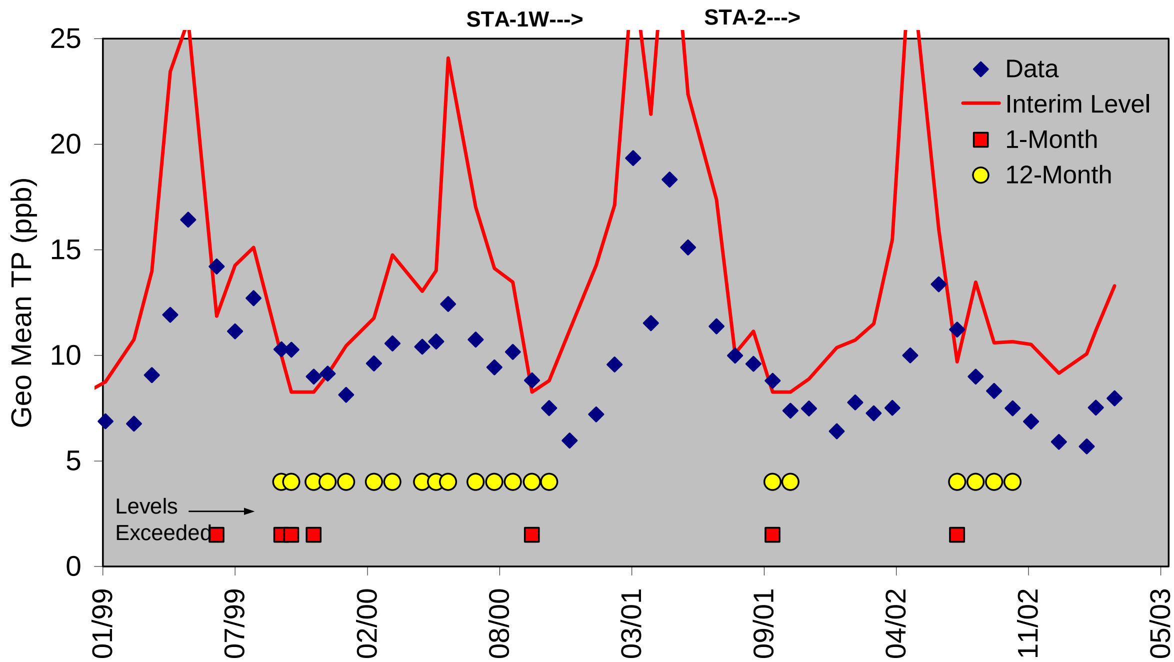



**Figure 2: Compliance with Interim Levels, February 1999 thru March 2003.**

Red line shows interim levels computed from marsh stage. Yellow circles show months when the data failed the 12-month test (>= 2 monthly exceedances). Red squares show months when the data exceeded interim levels. Blue diamonds show observed geometric means at 14 marsh sites.

Interim levels went into effect under the Consent Decree in February 1999. If the frequency distribution of phosphorus concentrations were consistent with those measured in 1978-1979, about 10% of the monthly values would exceed interim levels. Between February 1999 and March 2003, the exceedance rate was 14%. The exceedance rate dropped from 17% to 10% after July 2001, when both STA-1W and STA-2 were in full scale operation.

The 12-month test used for determination of compliance was exceeded in 3 periods. While this is evidence that compliance has improved in response to load-reduction measures, at least one exceedance of the 12-month test occurred in each of the four years. The expected exceedance rate for this test is 0%, absent conclusive evidence that it can be explained by error or extraordinary natural phenomena.

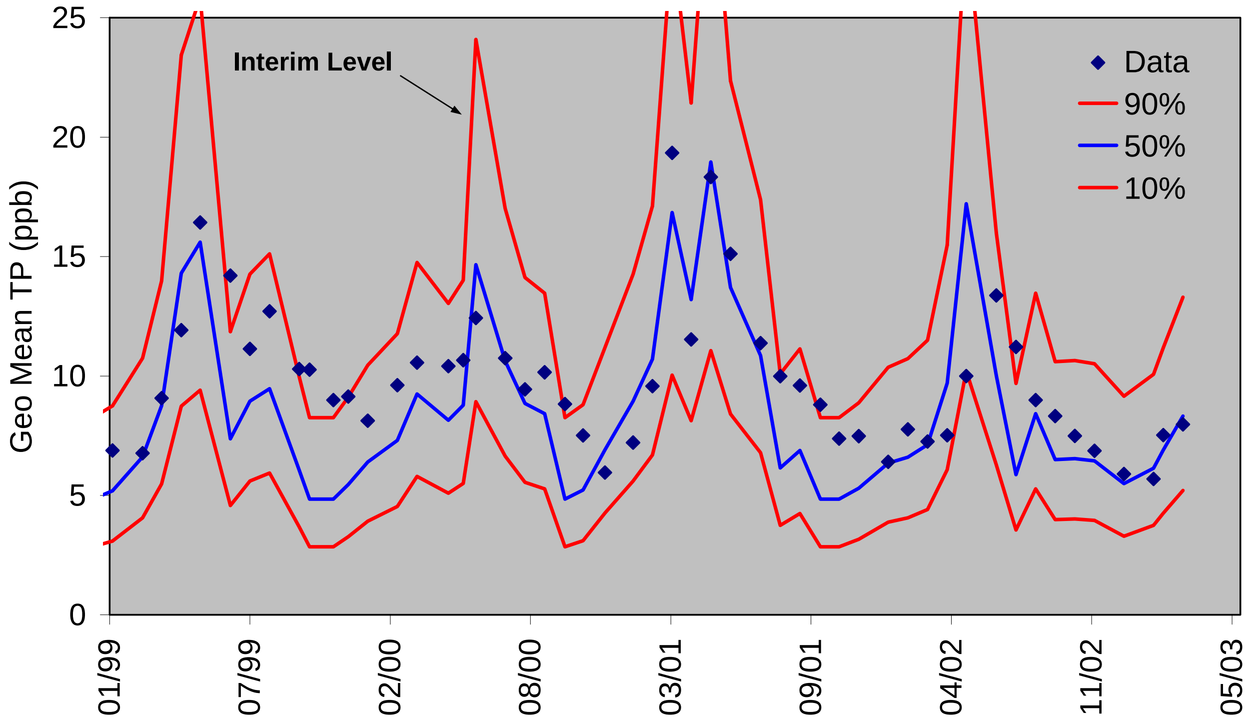



**Figure 3: Observed Values vs. Confidence Interval for 1978-1979 Conditions.**

Symbols show observed geometric means for the 14 marsh sites. Lines show 10th, 50th and 90th percentiles for 1978-1979.

If marsh P concentrations were similar to those observed in 1978-1979, we would expect 50% of the data points to be above the blue line 50% line or "target" and 50% to be below it. Between February 1999 and March 2003, 78% of the monthly values were above the target. The rates were 73% and 81% before and after July 2001, when STA-1W and STA-2 were fully operational. If phosphorus is being exported from previously impacted areas of the marsh, there would be a delay in the response of marsh P concentrations to reductions in external load. There is currently no means of determining the extent to which this is occurring, however.

The data track the target line in recent months. However, the same pattern was present in previous years during winter and followed by exceedances when stage increased later in the year.

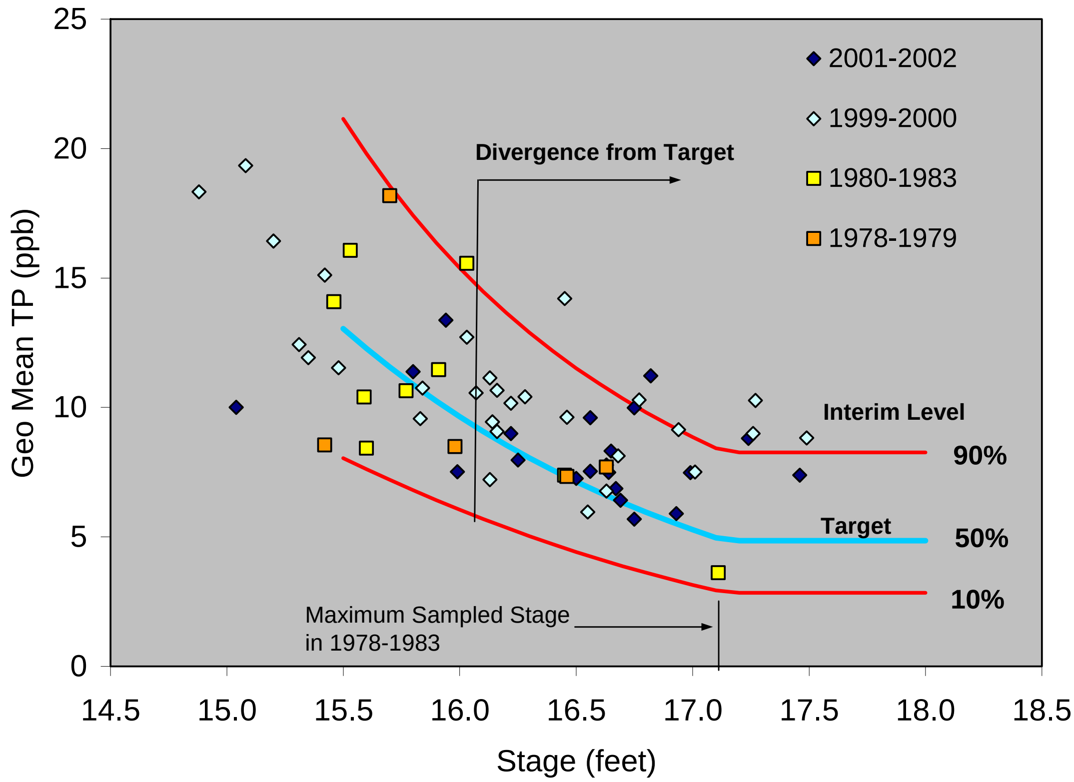



**Figure 4: Geometric Means vs. Stage**

Lines show percentiles for 1978-1979 predicted by the base regression equation. Symbols show observed geometric means in four time intervals. The 1980-1983 data are adjusted to 1978-1979 using the base regression equation. This adjustment reduces the observed values by 38% to reflect the increasing trend observed in 1978-1983. To reflect the range of stages observed in 1978-1983, the confidence interval flattens out at stages >17.14 feet. This procedure (specified in the Consent Decree) avoids extrapolation of the regression equation beyond the range of the 1978-1983 data. The 1999-2000 data are from February 1999 through June 2001, prior to full-scale operation of STA-1W and STA-2. The 2001-2002 data are from July 2001 through March 2003.

Four out of the seven monthly exceedances occurred at stages >17.1 Ft. 88% of the values exceeded the target line (50$^{th}$ percentile) at stages >16.1 feet. Concentrations are likely to be more sensitive to external loads under high-stage conditions when external loads are relatively high and hydraulic gradients slope from the rim canal towards the marsh (Figures 7, 8). Concentrations at stages > 17 ft appear to have decreased between 1999-2000 and 2001-2002, but there are only a few observations in this range.

The 1999-2002 data appear to be consistent with the 1978-1979 data at stages <16.1 feet. This is true even at extremely low stage (<15.41 feet), when compliance is not tested. Concentrations would be insensitive to external loads because the marsh tends to drain towards the rim canal under low-stage conditions. Interpretation of low-stage data is difficult, however, because 1978-1983 samples were collected using crude methods (bucket dropped from hovering helicopter), as compared with current refined methods. Because the risk of sample contamination by sediment particles at low water levels was greater historically, actual marsh concentrations at low stage may have been lower than those reported in 1978-1983.

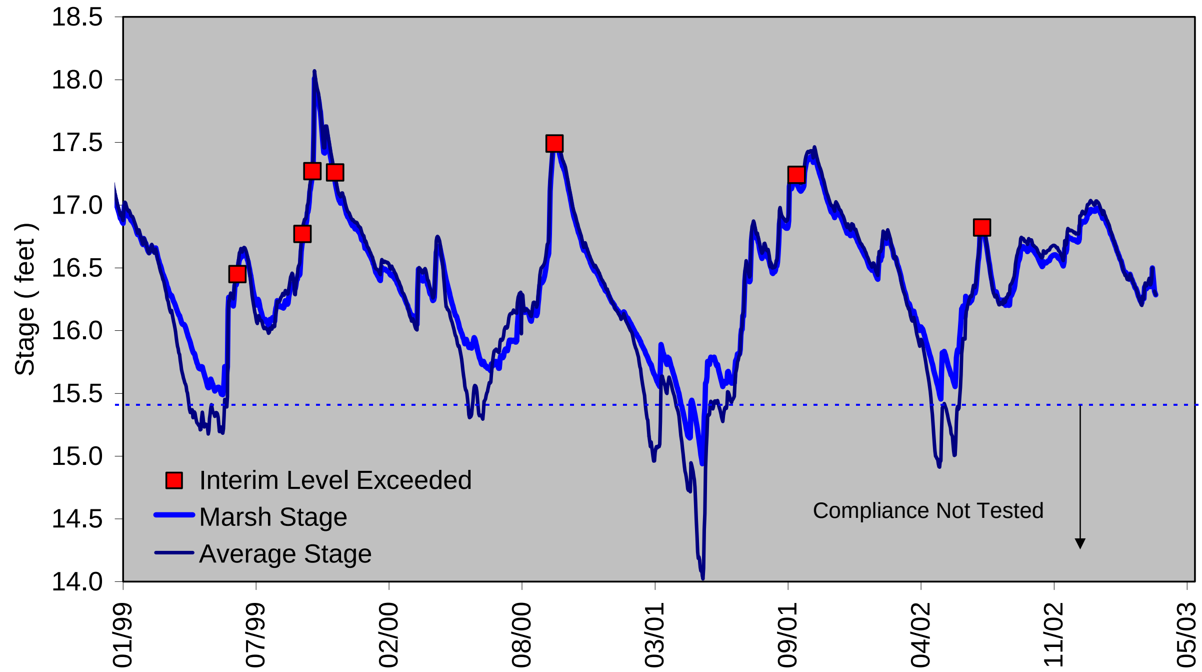



**Figure 5: Exceedances of Interim Levels vs. Stage**

Red squares indicate months when interim levels were exceeded. The black line shows the average daily stage used on computing the levels (mean of gauges 1-7, 1-9, & 1-8C). The blue line shows the average marsh stage (mean of 1-7 & 1-9). The 1-8C gauge is probably not representative of the marsh at low stage because it is located in the rim canal on the eastern site of the Refuge (Figure 1).

Exceedances generally occurred after periods of rising stage, when the Refuge was refilled with runoff and rainwater under its regulation schedule. During periods of low stage, rim canal elevation tends to be below the marsh elevation (divergence of blue & black lines). This indicates that the marsh drains to the canal during these periods.

One hypothesis is that the exceedances reflect phosphorus recycling from marsh vegetation & soils following rewetting. This, in itself, would be a symptom of nutrient enrichment because the amount of recycling would be expected to increase with overall level of enrichment. This process, if important, would have also influenced the historical data, as well as the recent data. Therefore, it does not explain the recent exceedances.

Another hypothesis is that the exceedances reflect external P loads, which tend to be higher during periods of rising stage. This is tested further in the following Figures 6-8.

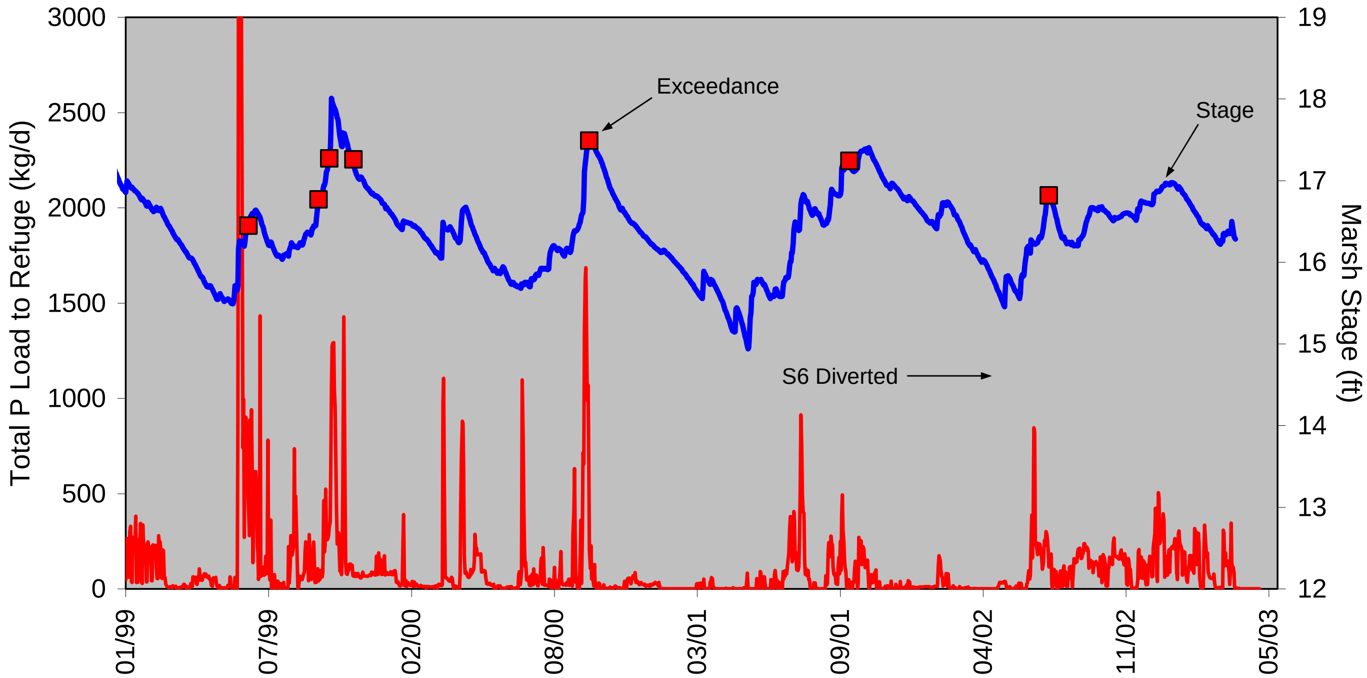



**Figure 6: Exceedances of Interim P Levels vs. Refuge Phosphorus Load.**

Red squares indicate months when interim levels were exceeded. The red line shows daily P load to the Refuge (kg/day). The blue line shows daily stage.

The loads include discharges from STA-1W (G251 & G310), STA-1W bypass, S6 (diverted to STA-2 in July 2001), and discharges from the Acme Improvement District (Pumps 1 & 2). These sources accounted for 84%, 6%, 0%, and 10%, respectively, of the average load to the Refuge between July 2001 and March 2003, when STA-1W was fully operational. Computation of bypass loads is complex because of the configuration of the STA-1W distribution works and ongoing calibration of flow gauges. The values reflected here are lower-bound estimates. Additional loads from the L8 basin through S5AS are not reflected here, but are thought to be small.

The temporal patterns are consistent with the hypothesis that exceedances are related to phosphorus loads. Exceedances occurred during or following each of the four highest loading events. Peak and average loads decreased after July 2001, when STA-1W and STA-2 were in full scale operation.

The increasing load after mid 2002 is primarily attributed to high levels of discharge from Lake Okeechobee into STA-1W, high rainfall in June 2002, and increases in STA-1W outflow concentration (Figures 18, 19).

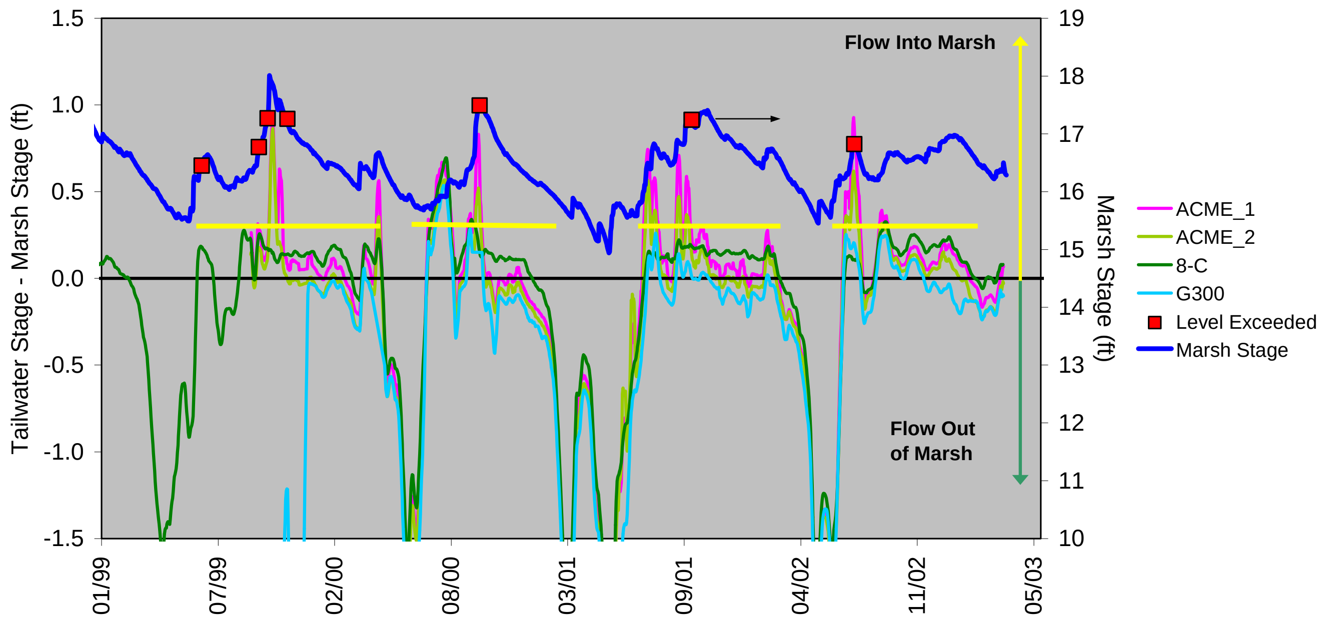



**Figure 7: Exceedances of Interim P Levels vs. Stage Differential on East Side**

Red squares indicate months when interim levels were exceeded. The blue line shows average daily marsh stage (surface-water elevations at 1-7 & 1-9). Yellow lines indicate periods when inflow tail-water stages generally exceeded the average marsh stage, based upon data from discharges on the east side of the Refuge (Figure 1). The other lines show 7-day rolling-average stage differentials ("tailwater stage – marsh stage") for each inflow (ACME 1 & 2, G300) and for the rim canal (8-C).

Because water flows downhill, a positive stage differential moves water from the inflow region into the marsh. External loading events generate spikes in stage differential, which transport phosphorus into the marsh and are often associated with exceedance of marsh P levels.

Although marsh P concentrations have been below interim levels since August 2002, the maximum marsh stage during that period was below maximum stages that occurred in previous years when interim levels were exceeded. Stage differentials were negative in February & March 2003, so P transport into the marsh would not have occurred during that period. The same patterns are evident for inflows on the west side of the Refuge (Figure 8).

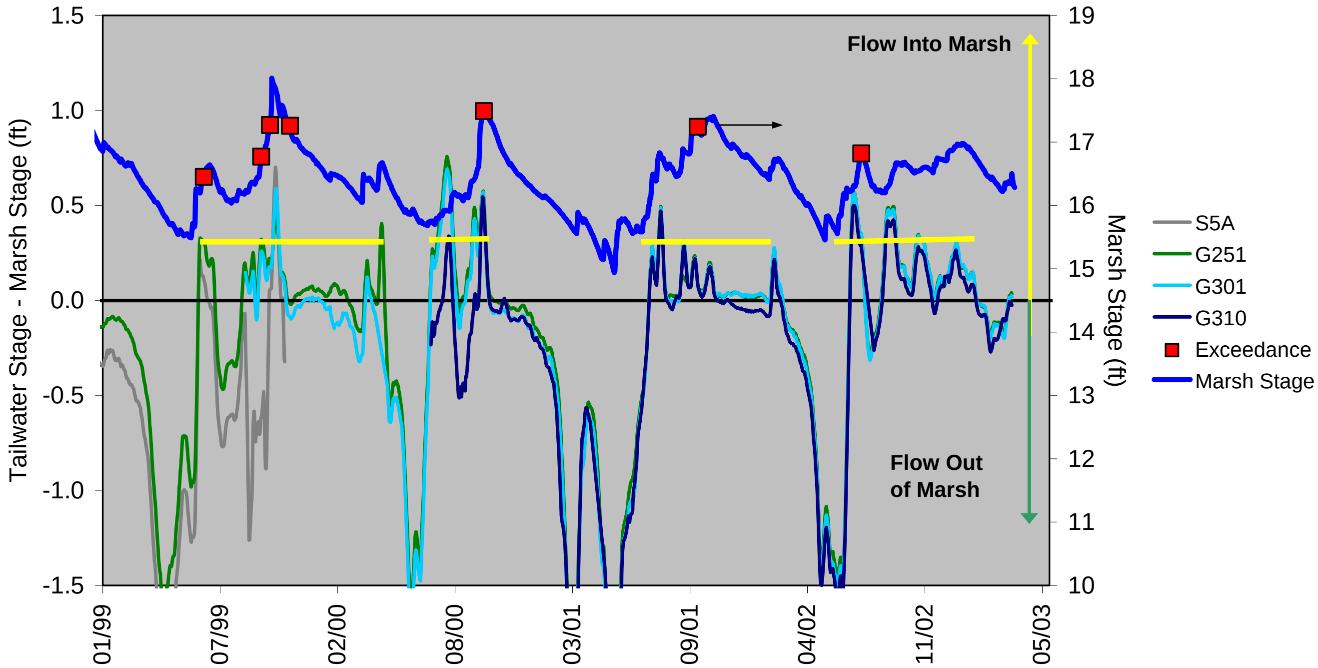



**Figure 8: Exceedances of Interim P Levels vs. Stage Differential on West Side**

Red squares indicate months when interim levels were exceeded. The blue line shows average daily marsh stage (surface-water elevations at 1-7 & 1-9). Yellow lines indicate periods when inflow tail-water stages generally exceeded the average marsh stage, based upon data from discharges to the west side of the Refuge (Figure 1). The other lines show 7-day rolling average stage differentials for each inflow (S5A, G310, G251, G301).

While the patterns are similar, the magnitude and duration of positive stage differentials are somewhat less pronounced on the west side, as compared with the east side (Figure 7). This would be expected because of the higher conveyance capacity of the rim canal on the west side.

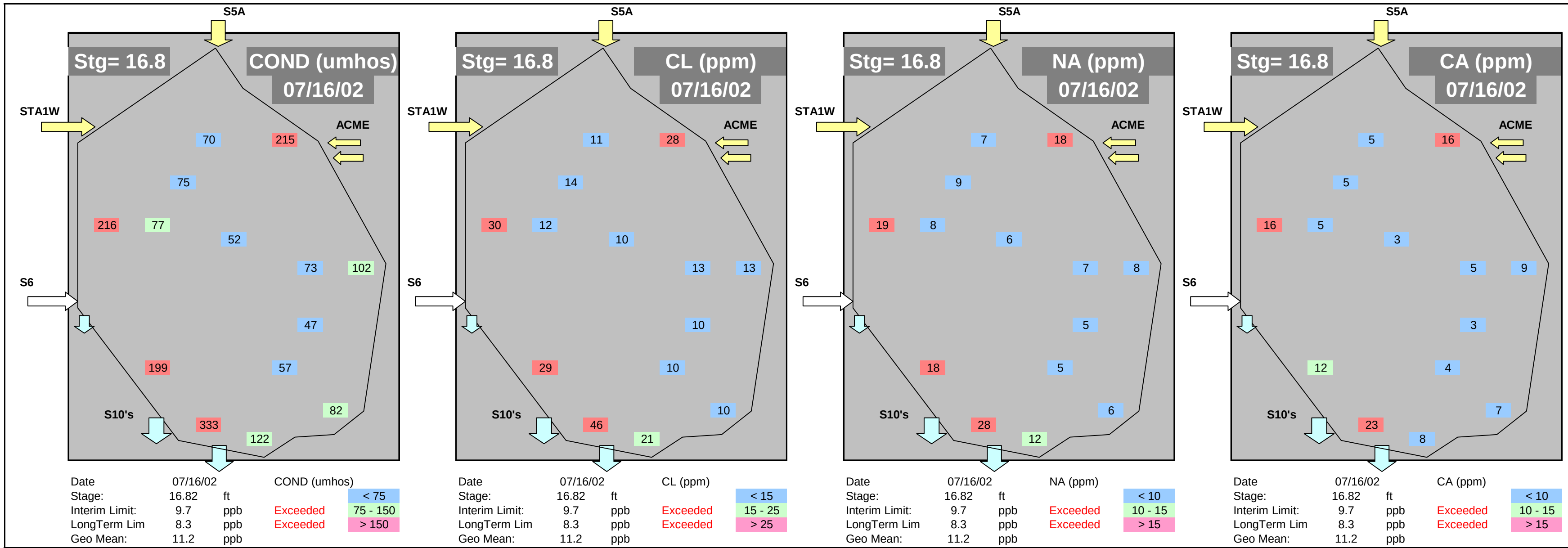



**Figure 9: Spatial Distribution of Inflow and Canal-Water Tracers in July 2002**

Maps show levels of conductivity, chloride, sodium, and calcium in July 2002 (most recent exceedance of interim levels). Blue, green, and red symbols indicate low, medium, and high ranges, as indicated in the map legends.

Elevated tracer levels in the outer ring of sites confirms that inflow/rim-canal water is transported into the marsh, as suggested by the hydraulic gradients (Figures 7 & 8). Inflows have much higher tracer levels, as compared with the central marsh fed mostly by rainwater. Since tracers are nearly conservative (not taken up by the marsh), spatial patterns reflect different mixtures of canal water and rainfall. As expected, "shapshots" of tracer distribution taken on other sampling dates vary, but the overall pattern is generally consistent (Figure 17). Theoretically, elevated tracer concentrations could occur during dry periods anywhere in the marsh because of evaporation (alligator-hole effect). The marsh stage was too high, however, to expect that this factor was important on this date.

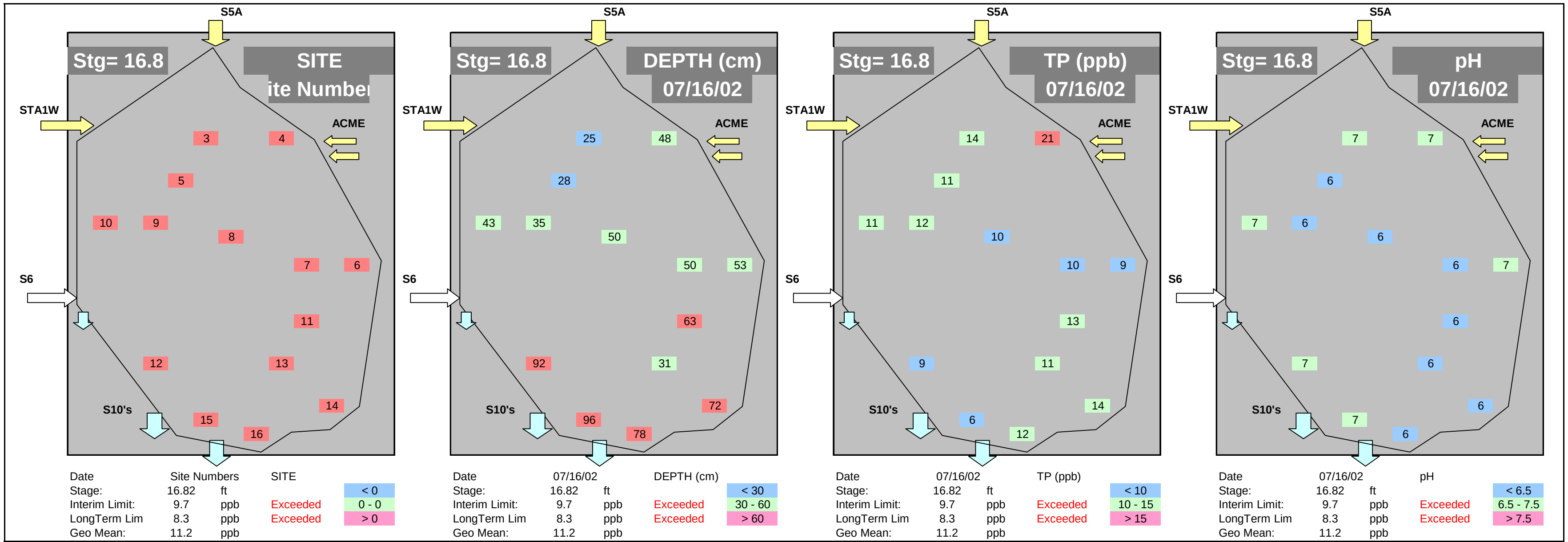



**Figure 10: Spatial Distribution of Water Depth, Phosphorus & pH in July 2002**

Maps show site number, water depth, TP, and pH in July 2002 (most recent exceedance of interim levels). Blue, green, and red symbols indicate low, medium, and high ranges, as indicated in the legends.

Water depths generally increase from northwest to southeast (a pattern typically observed). In addition, exterior sites tend to have greater depths than interior sites. Because the land generally slopes towards the south/southeast, sites in that corner may be most representative of water draining out of the marsh. Spatial variations in water surface elevation are much smaller than the variations in depth. Therefore, depth variations largely reflect variations in topography.

Interpreting the spatial P distribution on any date is complicated by long water residence times, P uptake and recycling ("spiraling") in the marsh, and variations in antecedent load, stage, rainfall, water depths, wind, water chemistry, etc. In addition, random variations attributed to sampling and phosphorus analyses are on the order of ±18% (one standard error). Elevated P levels were observed at the northwestern and southeastern sites. Northern sites are closest to inflows from STA-1W, S5A, and ACME. The interior northern sites (3, 5, 9) are relatively shallow, however, so direct inference of loading effects based upon spatial patterns is difficult. This snapshot was taken following a period of relatively high P loading, rising marsh stage, and hydraulic gradient towards the marsh interior (Figures 5-8), as well as heavy rainfall in June.

On this particular date, the highest P concentration (21 ppb) was observed at Site 4 (closest to the ACME discharges). The same pattern was observed in other months (Figures 11-14). Higher marsh P levels may have occurred adjacent to S6, S5A, and STA-1W, but went undetected because there were no monitoring sites in this vicinity. Elevated pH levels at exterior sites are typical of other dates (at times, >9). Typical pH gradients reflect a >10-fold difference in hydrogen ion content. Elevated pH would be an indicator of greater canal-water influence and/or higher plant productivity.

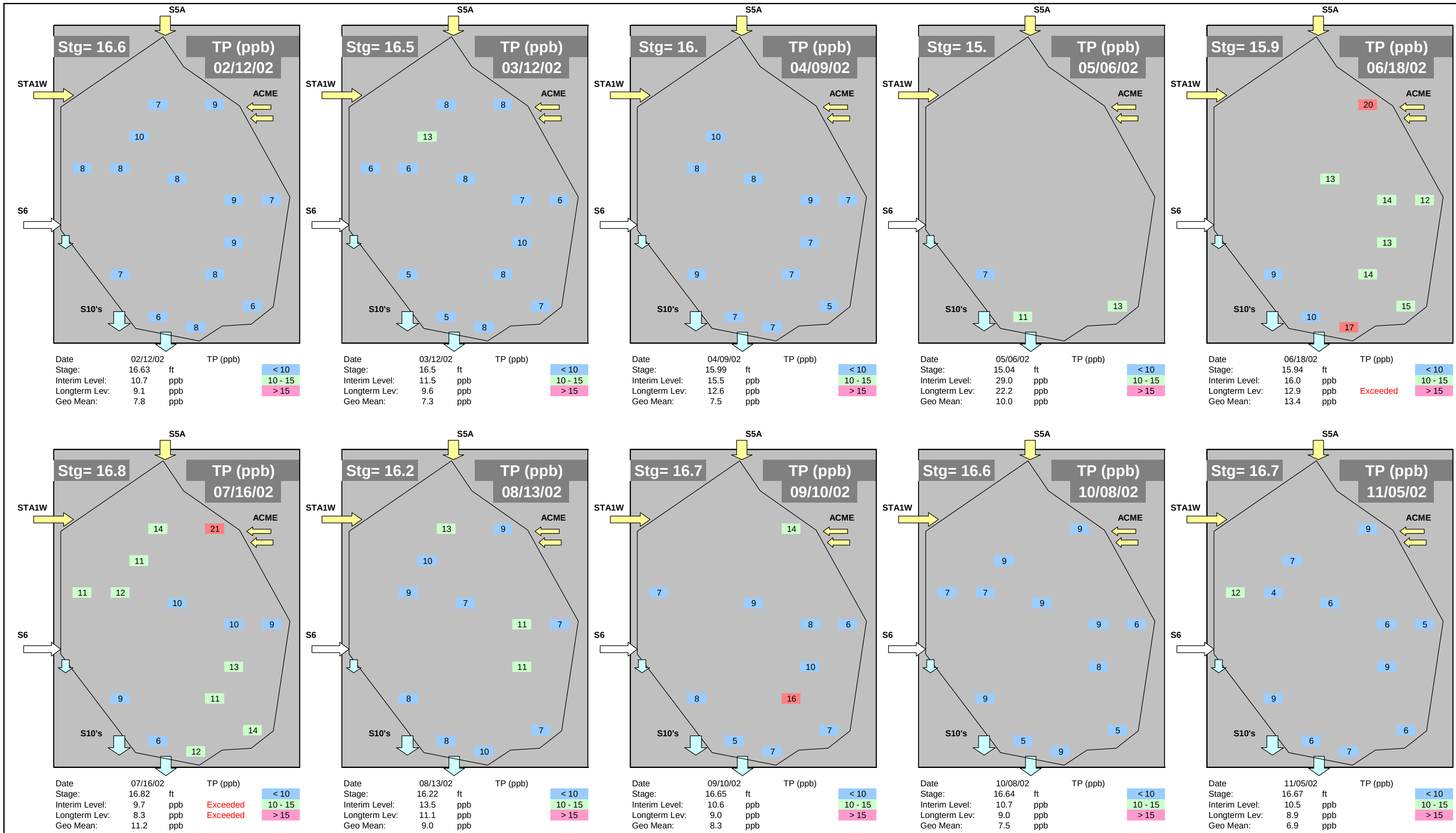



**Figure 11: Spatial and Temporal Variations in Total P - 2002**

P intervals are < =10 ppb (blue), 10-15 ppb (green), > 15 ppb (red). January & December are not shown. The pattern in January was similar to that observed in February-April. The pattern in December was similar to that observed in October-November. The interim level was exceeded in July. The long-term level was exceeded in June & July.

Relatively low P levels were observed in January through April, when loads were small and hydraulic gradients sloped away from the marsh (Figures 6, 7, 8). Surface elevation dropped to 15.0 feet in May, when most of the sites were dry. Concentrations increased in June & July when the marsh was refilled with runoff and rainfall and the hydraulic gradient sloped towards the marsh. Concentrations decreased after July due to P uptake by the marsh and dilution, as inflow P loads (Figure 6) and hydraulic gradients decreased (Figures 7, 8).

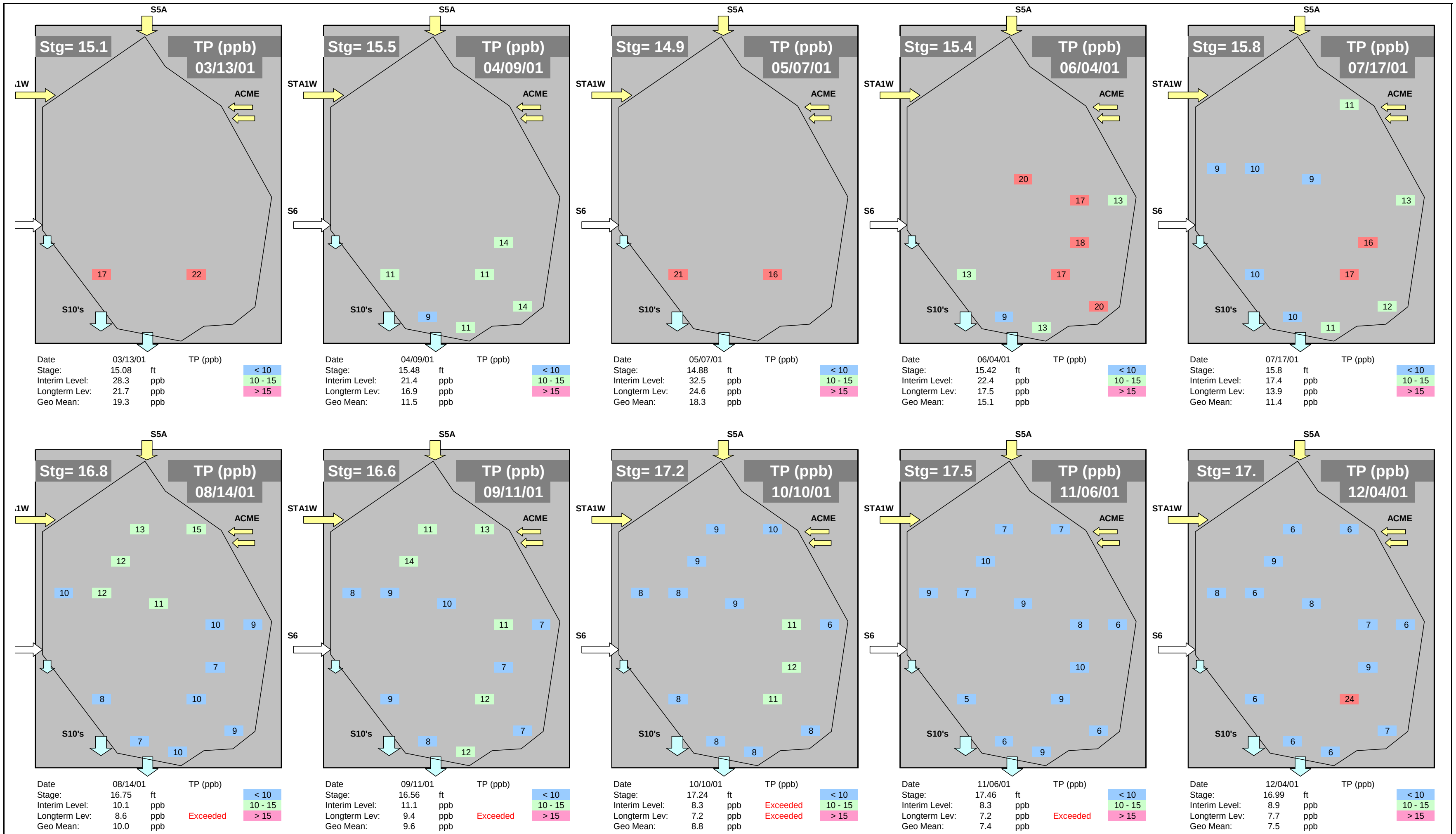
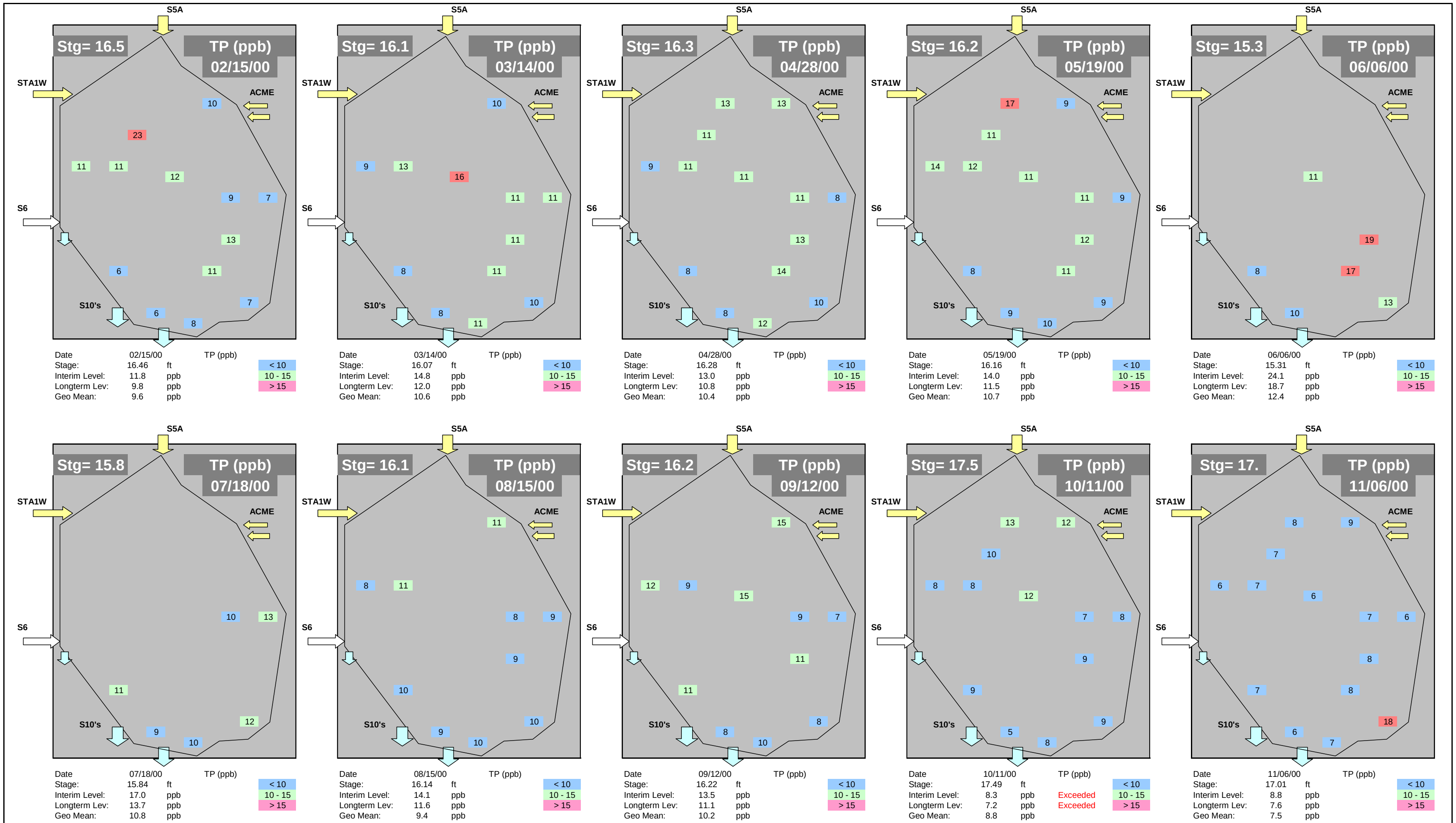



**Figure 12: Spatial and Temporal Variations in Total P - 2001**

Marsh P concentrations exceeded interim levels in October and exceeded long-term levels in August thru November.

Under a severe drought, stage remained relatively low through June. Despite the fact that P levels were frequently above 20 ppb at interior stations during this period, the marsh remained in compliance with interim levels because of the stage/concentration relationship reflected in the levels (Figure 4). Long-term levels were first exceeded in August, when the drought ended and stage increased from 15.8 to 16.8 ft. Highest P concentrations were observed at northern sites closest to inflow points. Concentrations at interior sites decreased significantly in August, relative to those observed during the antecedent drought.




## Figure 13: Spatial and Temporal Variations in Total P - 2000

Marsh P concentrations exceeded interim and long-term levels in October. Compared with 2001-2002, P loads to the Refuge were higher in 2000 because it was prior to diversion of S6. The compliance network does not include sites close to the S6 discharge. SFWMD transect monitoring (performed for research purposes) showed elevated P concentrations in this vicinity. P concentrations generally decreased from northwest to southeast between February and May. The water elevation dropped to 15.3 feet in June and P concentrations > 20 ppb were observed at southeastern interior sites as the marsh started to dry out. Concentrations dropped after gradual re-flooding in July through September. Interim & long-term levels were exceeded in October, when the stage increased from 16.2 to 16.5 feet and a pattern of elevated P concentrations at northern sites again emerged. The episode ended in November.

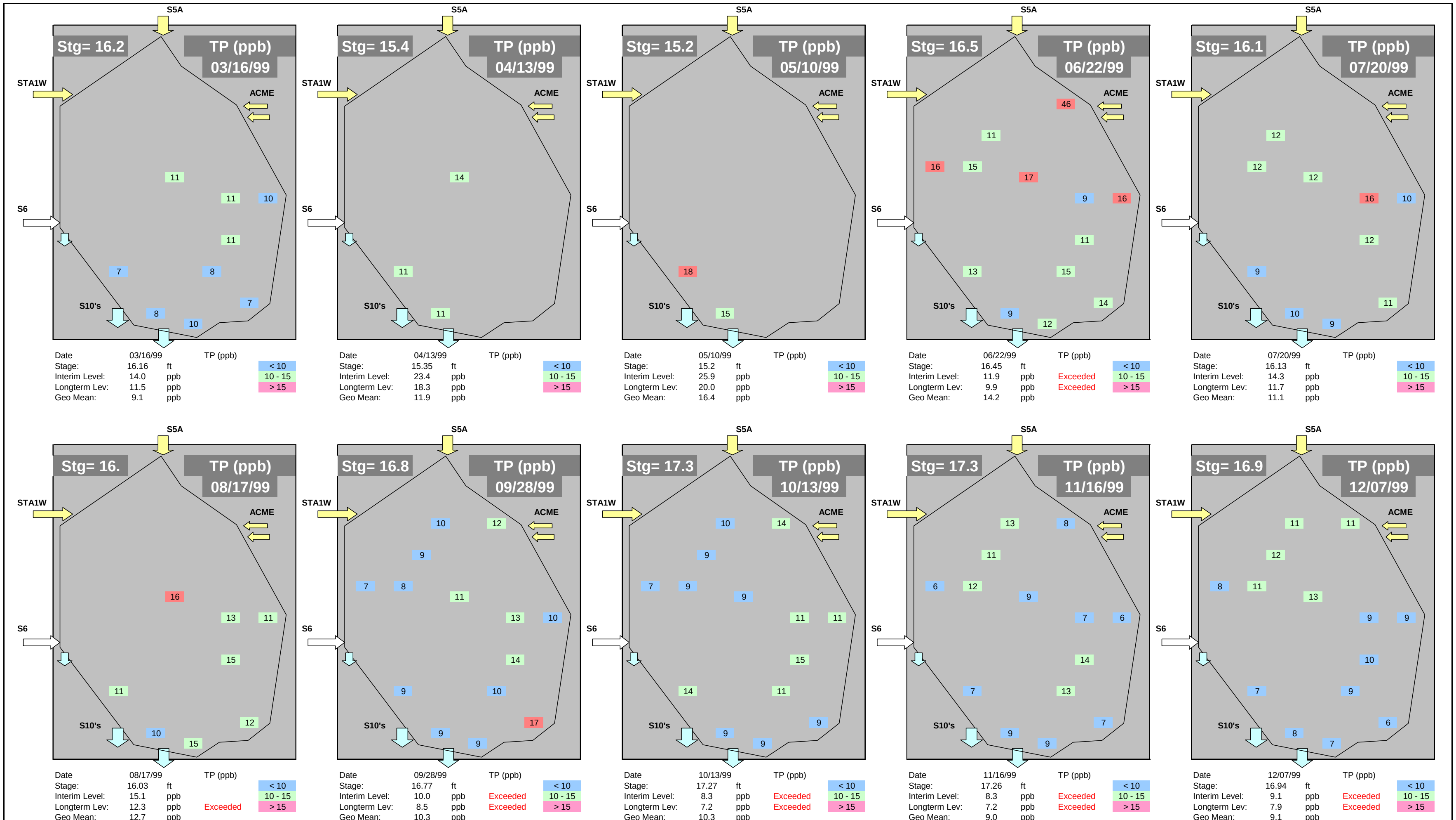



**Figure 14: Spatial and Temporal Variations in Total P - 1999**

Marsh P concentrations exceeded interim levels in June and September-December and long-term levels in June and August-December. The higher exceedance frequencies in 1999 are consistent with higher external P loads, as compared with 2000-2002. (Figure 6).

This year's episode began in May-June, when stage increased from 15.2 to 16.5 ft and interim levels were exceeded. High P concentrations were again observed at northern sites. Marsh P concentrations remained above interim and long-term levels through December.

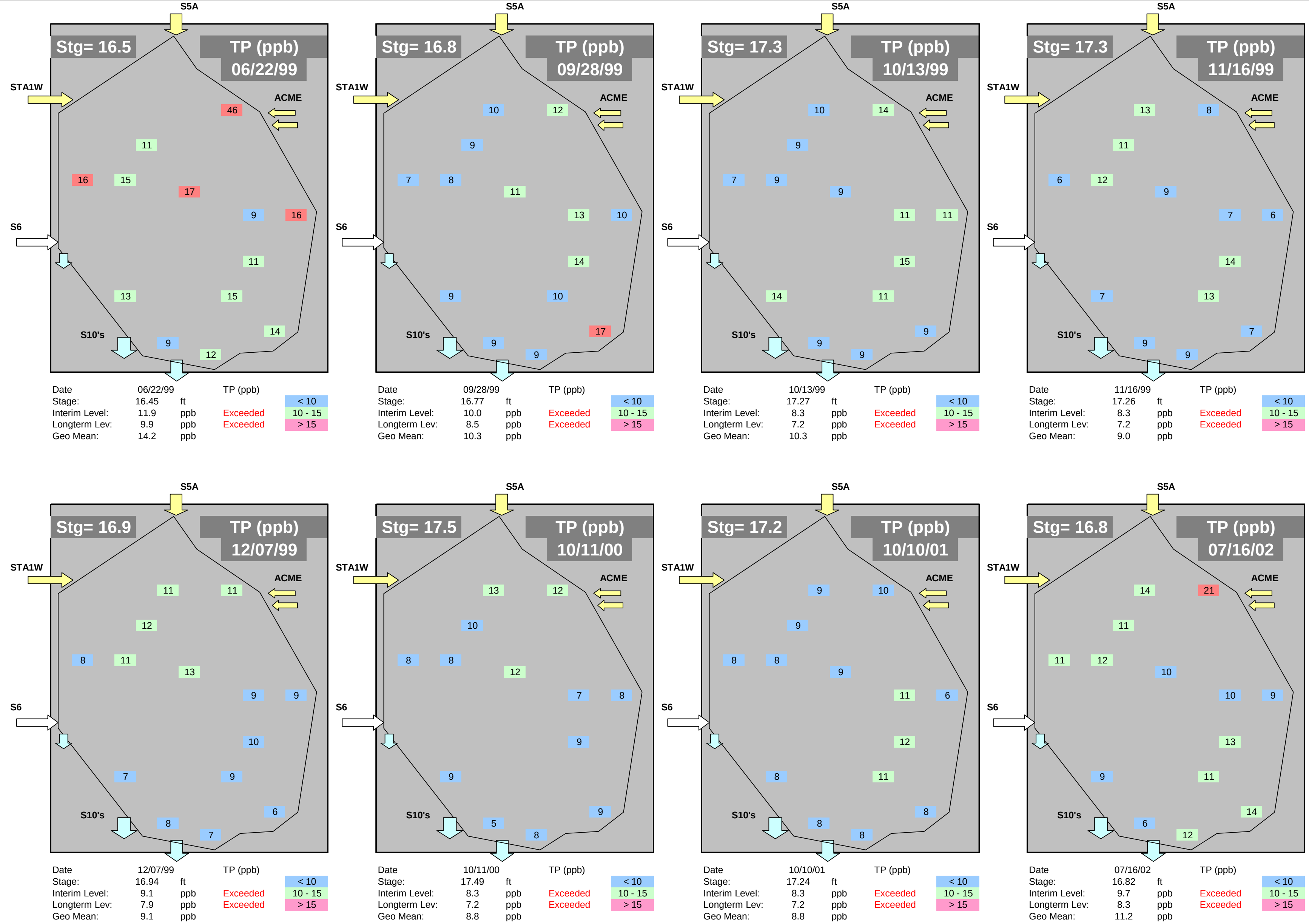



**Figure 15: Spatial Variations in Total P on Dates when Interim P Level Was Exceeded**

As demonstrated in the yearly displays (Figures 11-14), the data can be more readily interpreted when viewed as time sequences, as compared with isolated snapshots shown here. Patterns consistent with external loading influences (elevated P levels at the northern sites, particularly those closer to the rim canal) are evident on some dates. Shallower depths may have also contributed to higher P levels at some sites (Fig 11).

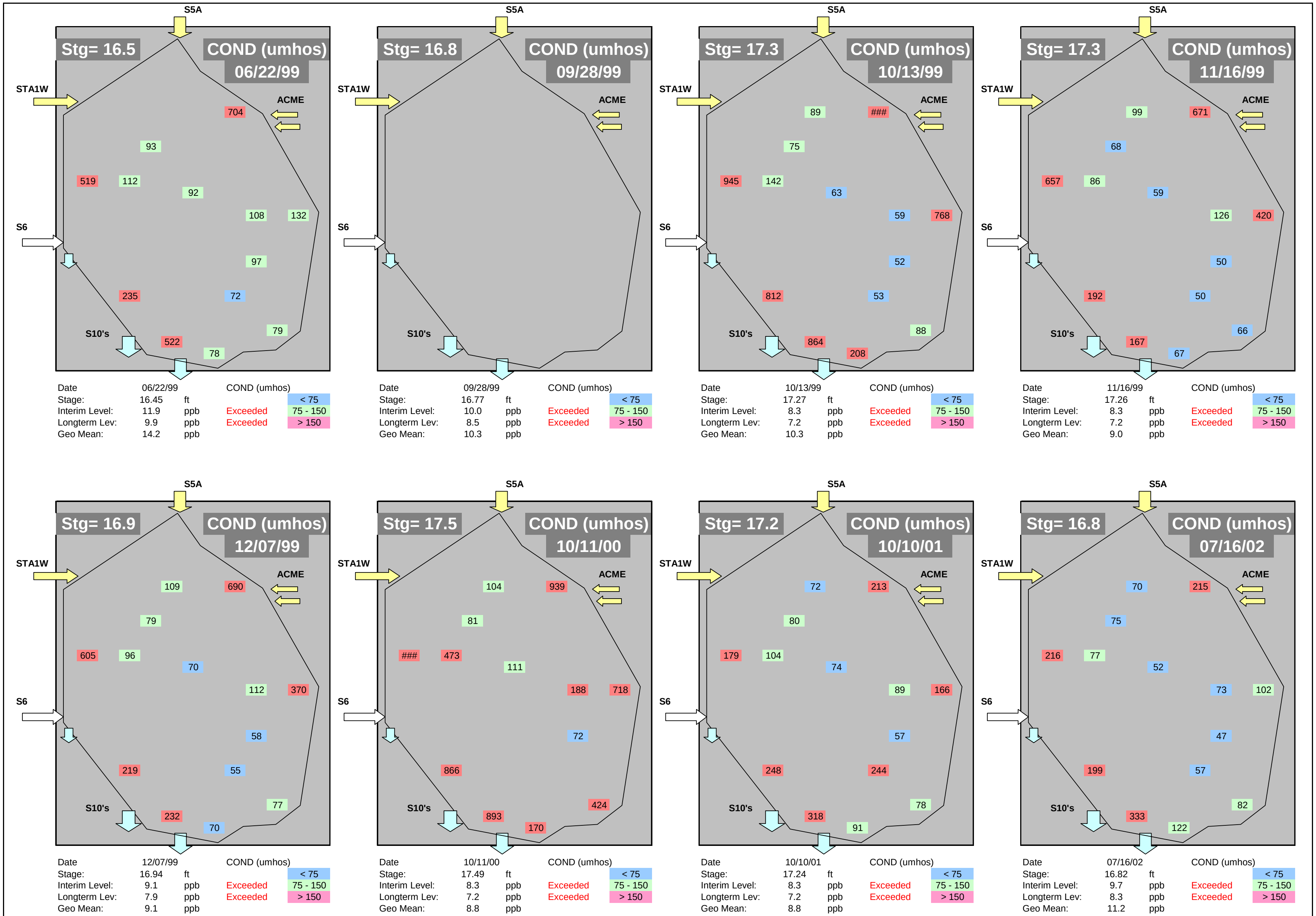



**Figure 16: Spatial Variations in Conductivity on Dates when Interim P Level Was Exceeded**

Elevated conductivity at exterior stations is evidence of inflow and rim-canal influences. Transport into the interior marsh is suggested on some dates (e.g. October 2001)

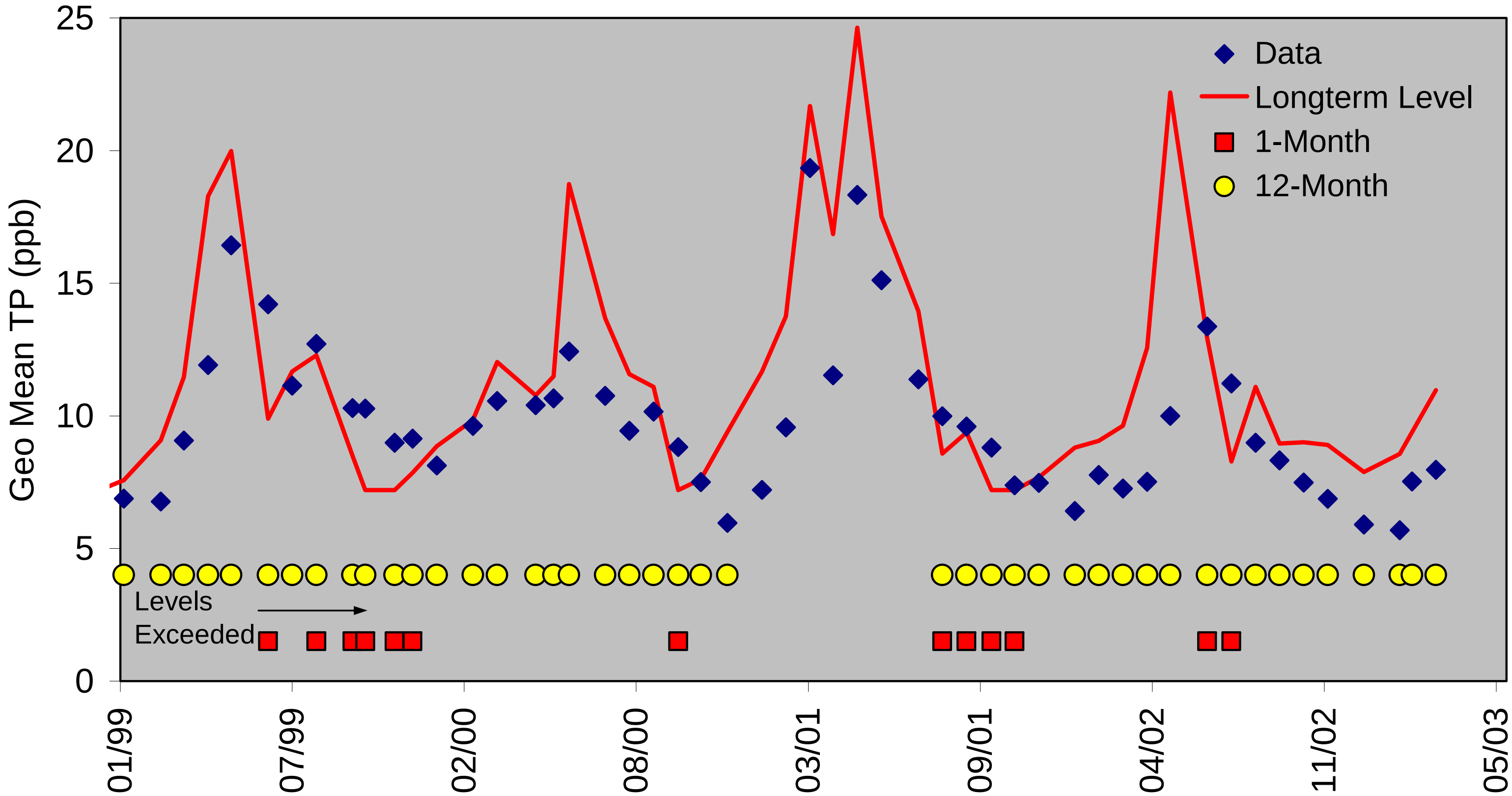



**Figure 17: Comparison with Long-term Levels, February 1999 thru March 2003**

Red line shows long-term level computed from marsh stage. Yellow circles show months when the data failed the 12-consecutive samples test (>= 2 monthly exceedances, skipping low-stage months). Red squares show months when the data exceeded long-term levels. Blue diamonds show observed geometric means at 14 marsh sites.

Long-term levels will not be in effect until December 2006. Overall, 26% of the monthly values were above the long-term levels. Had the levels been in effect, compliance with the 12-month test would have occurred only during the 2001 drought, when phosphorus loads were relatively low (Figure 19).

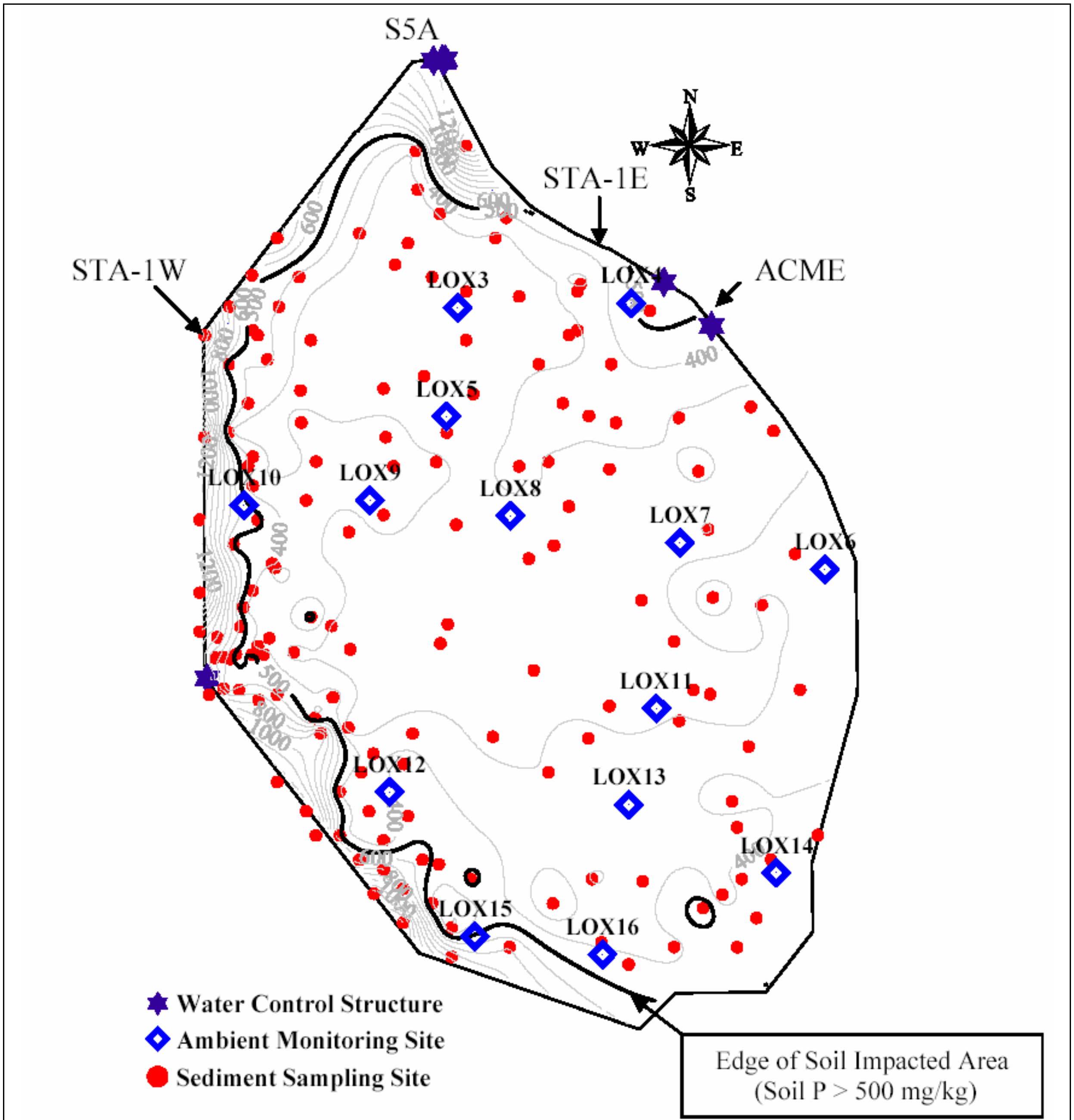



**Figure 18: Soil Phosphorus Contours**

Map produced by FDEP using data collected prior to full-scale operation of STA-1W and diversion of S6.

Elevated soil P concentrations provide evidence of phosphorus transport into the marsh from the adjacent rim canal.

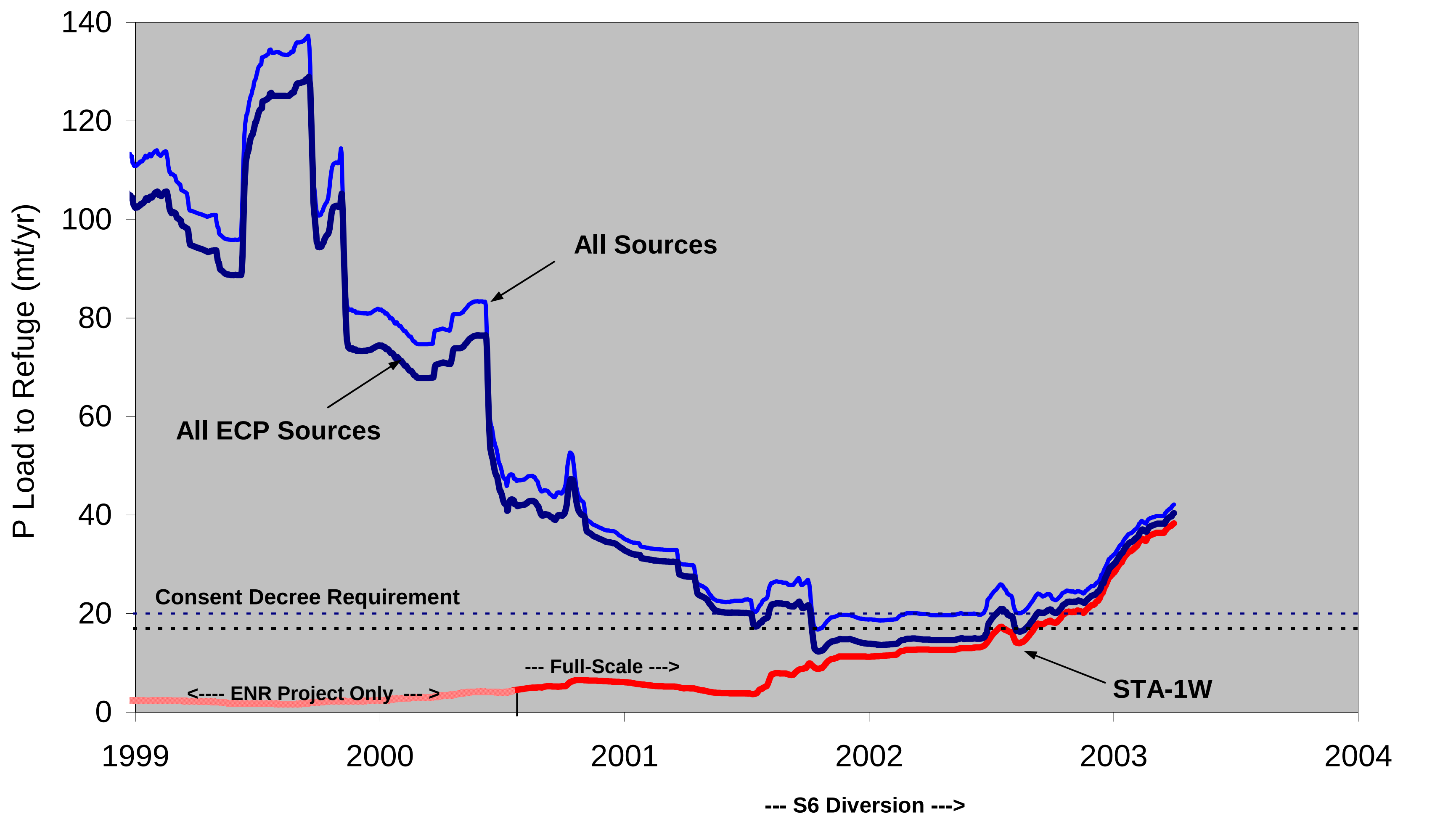



**Figure 19: Trends in Phosphorus Load to the Refuge**

The light blue line ("All Sources") shows load from all structures (S6, S5A, STA-1W bypass & outflow, ACME), as 365-day rolling averages. The dark blue line shows all sources excluding ACME. The Red line shows outflow load from STA-1W, which began full-scale operation in July 2000. Horizontal lines show the total load consistent with achieving the 85% reduction required under the Consent Decree, with and without allowance for BMP replacement water.

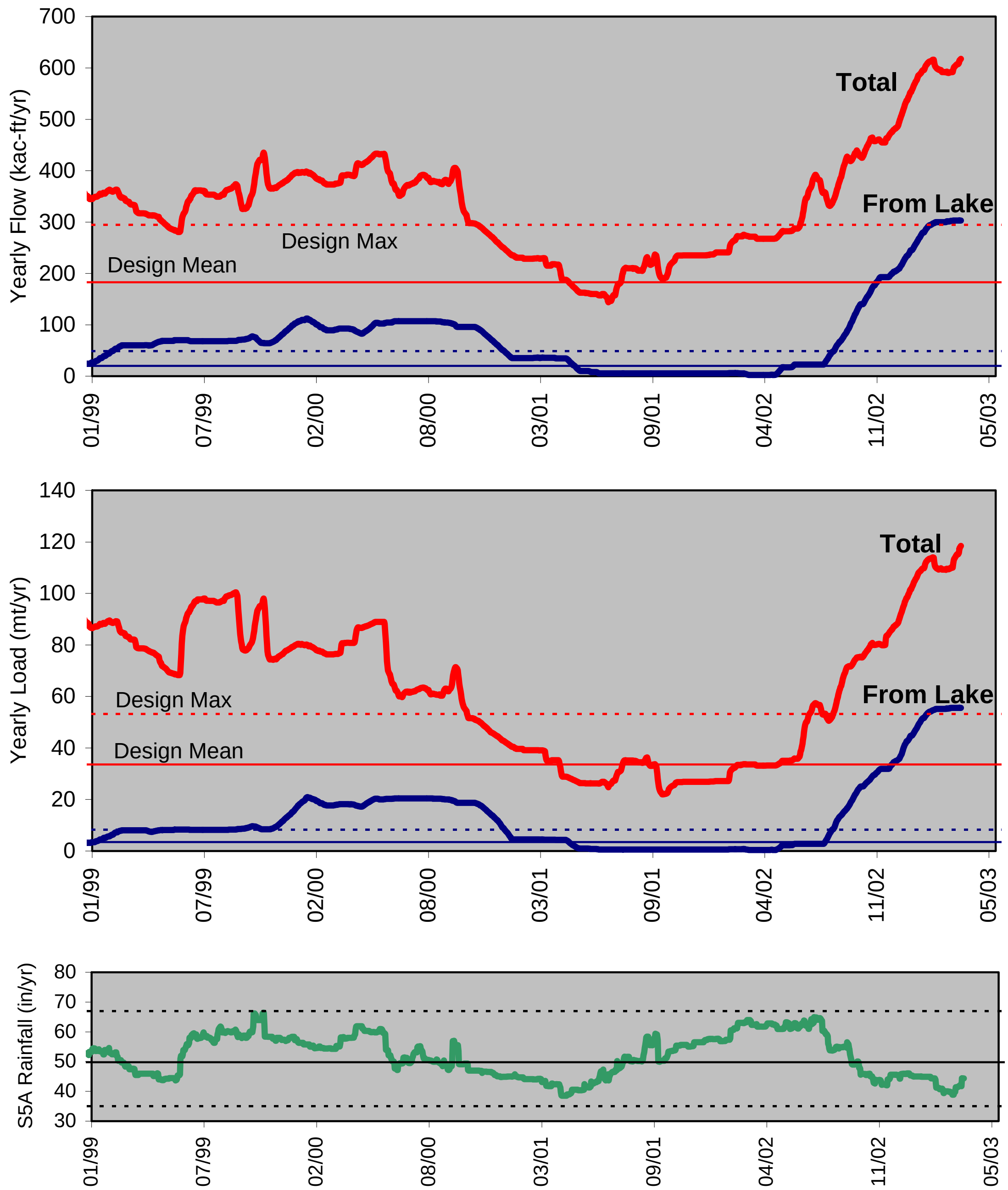



**Figure 20: West Palm Beach Canal Flow & Phosphorus Loads**

Heavy lines show recent flows, loads, and rainfall in the West Palm Beach Canal at S5A (365-day rolling averages). Red lines are total flows & loads. Blue lines are releases from Lake Okeechobee that reach S5A (flow thru), computed by methods used in the EAA Regulatory Rule. The data do not reflect flows & loads diverted to STA-2 after June 2001.

Horizontal lines show mean (solid) and maximum yearly (dashed) in the 31-year hydrologic time series used as a basis for designing STA-1W, also including flows from the West Palm Beach canal that will be treated in STA-1E. On average, 14% of the basin flow and 23% of the load are planned to be diverted to STA-1E, according to baseline datasets. The rainfall chart is based upon the 1979-2002 record at S5A.

Recent flows and loads from the basin exceed the STA design basis by a wide margin during a period when rainfall was within a normal range.

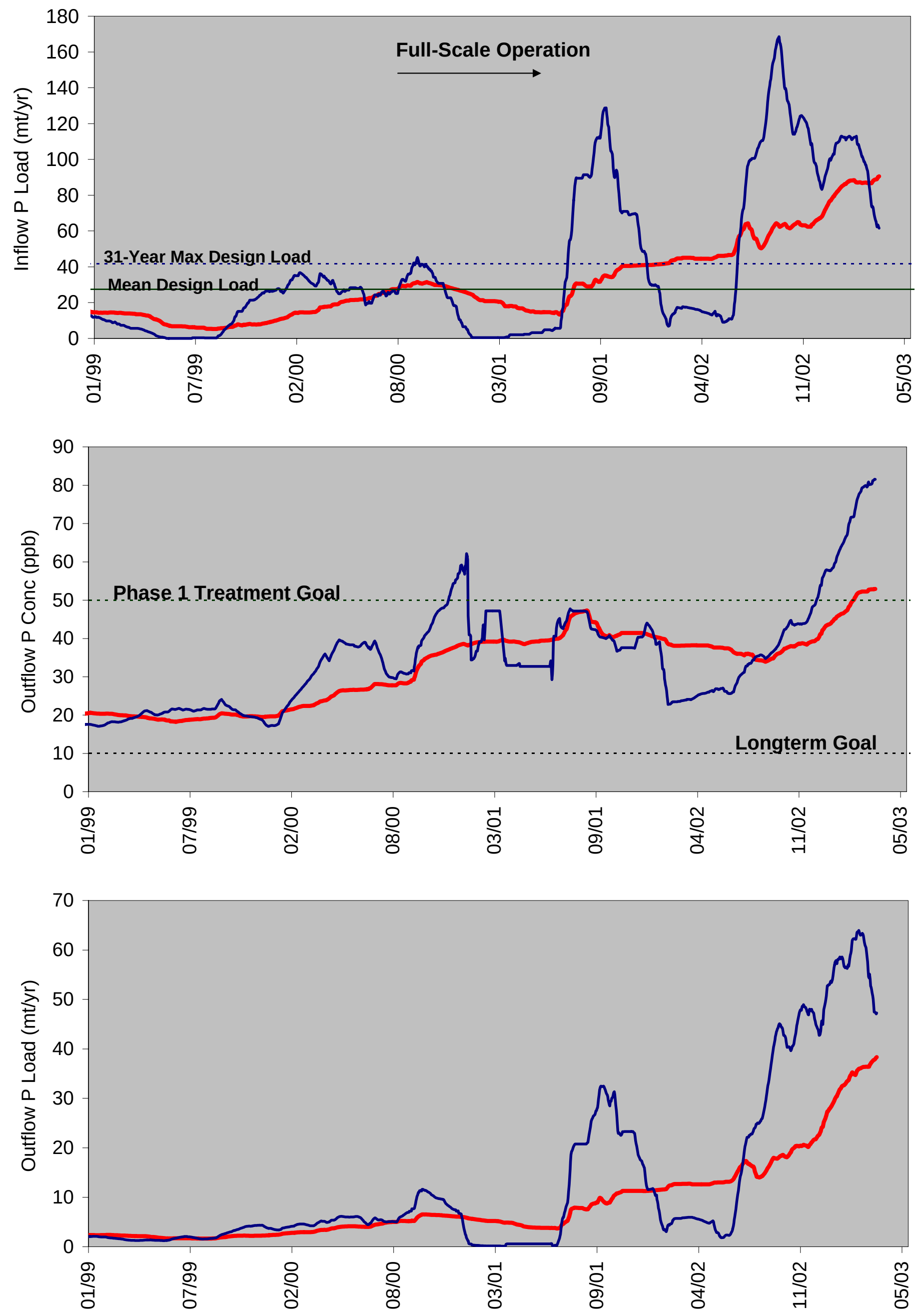



**Figure 21: Trends in STA-1W Inflow P Loads & Outflow P Concentrations**

Top chart shows inflow P loads to STA-1W (G302 + G250). Middle chart shows outflow P Concentrations (G310 + G251). Bottom chart shows outflow P loads. Blue lines are 90-day rolling averages. Red lines are 365-day rolling averages. Horizontal lines on top chart show mean and maximum yearly design inflow loads for STA-1W to achieve a 50 ppb outflow concentration with an emergent marsh, based upon 31-year hydrologic record. Horizontal lines on bottom chart show interim and long-term treatment goals for STA-1W outflow concentrations.

The performance of STA-1W has significantly deteriorated since it has been was operated at P loads exceeding the 31-year maximum design basis by a wide margin. This was during a period of below-average rainfall. The high loads are attributed to routing of high volumes and phosphorus loads from Lake Okeechobee to the STA. There is visible evidence of deterioration in the marsh vegetation (SAV) that was formerly treating water down to the 15 ppb level in portions of the STA.