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Preliminary Evaluation of STA Expansion to Achieve Treatment Objectives for Inflows to Loxahatchee National Wildlife Refuge

prepared for

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By

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Introduction

To begin the process of restoring and protecting the Everglades from adverse impacts of nutrient enrichment, the 1992 Settlement Agreement (SA) formulated an interim, technology-based control program to reduce total phosphorus concentrations at inflow points to the Everglades Protection Area (EPA) from historical levels (150-200 ppb) to 50 ppb or less using agricultural Best Management Practices (BMP's) and wetland stormwater treatment areas (STA's). The interim design was refined (B&M, 1994) and implemented over the 1994-2004 period. The SA anticipated that marsh concentrations at or below 10 ppb (later adopted as a Class III water quality criterion by the Florida Department of Environmental Protection in 2003) would be required to eliminate imbalance in flora and fauna caused by nutrient enrichment, as required by December 2006.

As the 50 ppb STA's were constructed and operated, extensive research was conducted on various spatial scales to develop and screen alternative technologies capable of treating inflows down to the 10 ppb level. The 2001 Basin-Specific Feasibility Study (BSFS, B&M et al, 2002) and 2003 Longterm Plan (LTP, B&M, 2003) developed strategies to achieve treatment objectives by optimizing existing STA's and integrating then with federal hydrologic-restoration projects. Both studies projected long-term geometric mean concentrations of ~10 ppb in STA discharges after implementation of all control measures and stabilization of STA vegetation. While both the BMP's and STA's have for the most part performed better than expected, achieving discharge concentration of 10 ppb without additional source-control measures and/or STA expansion would be difficult, given that the STA's were initially designed to achieve 50 ppb. The uncertainty associated with the STA optimization measures, performance forecasts, and the potential need for additional measures were acknowledged.

The LTP established an adaptive process to achieve compliance with the P criterion by 2016, while incorporating new information derived from research, monitoring, and model refinements. For several reasons, the flows and phosphorus loads to be treated in both the BSFS and LTP were under-estimated. Given updated estimates of inflow volumes and loads, the EAA Regional Feasibility Study (EAARFS, ADA et al., 2005) examined two primary alternatives for allocating flows across basins to make optimal use of existing STA's (~41,000 acres), expanded STA's (~18,000 acres), a new reservoir (~10,000 acres), and flow diversions to accomplish treatment objectives. The EAARFS projected long-term geometric means (GM's) ranging from 10 to 15 ppb and flow-weighted-means (FWM's) ranging from 13 to 19 ppb in STA discharges under the currently-preferred Alternative 1.

Performance data (SFWMD, 2007; Table 5-2) indicate that three STAs (1W, 1E, & 5) have had significantly higher outflow concentrations (FWM = 55 - 125 ppb), as compared with others (2, 34, & 6, FWM = 19 - 21 ppb). Inflow loads more than twice the design values have contributed significantly to under-performance of STA's 1W & 5 (Walker & Kadlec, 2003; Walker, 2005). The EAARFS remedy for STA-5 provides an additional 9,000 acres of treatment area (in Compartment C). The EAARFS remedy for STA-1W (Alternative 1) would reduce the inflow to STA-1W by diverting 47% of the S5A basin runoff west to other basins that would have expanded treatment capacity. With that diversion, the phosphorus loads to STA-1E would also be reduced because it would no longer be used as a "relief valve" to treat excess runoff that cannot be handled by STA-1W. Unlike each of the other EAA basins, no additional treatment area was considered for the S5A basin discharging into STA-1W/E and the A.R.M. Loxahatchee National Wildlife Refuge (Refuge).

EAARFS Alternative 1 was selected without systematically evaluating the potential impacts of inflow diversions on water levels and ecology of the Refuge. Adverse impacts could result from the reduction in average inflow and shift in the distribution of inflow (high-flow events accounting for a greater proportion the total inflow, as described below). Table 1 summarizes historical and projected inflows to the Refuge under various alternatives. The average inflow from runoff sources would be reduced by 25% relative to that provided with an expanded STA-1W treating all of the basin runoff (303 vs. 402 kac-ft/yr), as compared with the 1995-2006 average of 524 kac-ft/yr[1]. Given the significant decrease relative to historical flows, there is considerable uncertainty as to whether the water needs of the Refuge can be met with the additional flow diversion planned under Alternative-1.

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[1] The projected inflows under either alternative are below the 1995-2006 average because of other diversions implemented under the 1994 Conceptual Plan and/or implicit in other EAARFS assumptions, (L8 runoff, S6 and partial S5A diversions to STA-2, elimination of lake regulatory releases, reduction in watershed area associated with STA construction) which were partially offset by diversions into the Refuge from the EBWCD-298 district and C51-W basin into the Refuge via STA-1W and E. In addition, projected inflows from runoff do not include historical urban water-supply deliveries from Lake Okeechobee, assumed to be untreated under EAARFS, estimated at <28 kac-ft/yr (see Figure 3).

This report develops approximate estimates of the additional treatment area required to accomplish the treatment objective for STA-1W (GM = 10 ppb) while treating all of the inflows and without diverting flow away from the Refuge. Results are compared with EAARFS Alternative-1. Sensitivities to assumed inflow volumes, inflow concentrations, and vegetation P removal efficiency are explored.

Results generally indicate that a 2 to 3-fold expansion of the existing treatment area (6,670 acres) would be required without additional source-control measures (BMP's) and a 1.5 to 1.8-fold expansion with additional BMP's (hypothetically reducing the average historical inflow concentration from 174 to 100 ppb). The area ranges reflect different inflow and modeling assumptions. Aside from providing more inflow to the Refuge relative to Alternative 1, the analysis indicates that an expanded STA would substantially reduce the risk of untreated hydraulic bypass during high-flow periods (which could account for ~20% of the inflow phosphorus loads to the Refuge under Alternative 1), greater operational flexibility, and lower flow-weighted-mean discharge concentrations, particularly at high flows when intrusion of the STA discharge into the Refuge marsh is most likely to occur.

Assumptions

To allow direct comparison with Alternative 1 (ALT-1), basic assumptions regarding sources of inflow and STA performance are identical to those made in the EAARFS (ADA et al, 2005), with the exception that the S5A runoff diversion is eliminated. Alternative inflow scenarios are also explored. As reflected in the 34% higher runoff assumed in the subsequent derivation of the STA 1W/E discharge limits for 2006-2009 (TBEL's, Goforth et al, 2007), some of the EAARFS assumptions are already outdated and optimistic, given the objective to design an STA that will meet performance expectations with some degree of confidence. It is recommended that all assumptions be reviewed and updated to support future evaluations of treatment alternatives, as scheduled under the LTP. Basic assumptions made in the analysis include:

1. The expanded STA treats runoff from the EAA S5A basin and EBWCD-298 district without new diversions beyond those specified under the 1994 Conceptual Plan (~20% of S5A runoff). The average runoff volume is 250 kac-ft/yr, as compared with 131 kac-ft/yr under Alternative 1.

2. STA-1E treats only runoff from C51-W and ACME-B, as prescribed under EAARFS Alternative 1 (average inflow = 172 kac-ft/yr). STA-1E is not used as a relief valve for treating excess S5A runoff when STA-1W is overloaded.

3. Runoff from the L8 basin is diverted to other basins, accomplished by modified water management and/or planned CERP projects.

4. No regulatory releases from Lake Okeechobee are discharged into STA-1W, STA-1E, or the Refuge via the West Palm Beach or L8 canals.

5. No treatment capacity is provided for Lake releases to STA's 1W, 1E or Refuge for urban water supply. These include releases made when the Refuge stage is below 14.5 ft (assumed under EAARFS to bypass the marsh) and releases made at higher stage, as required under the current regulation schedule to offset urban water-supply withdrawals from the Refuge[2]. The EAARFS assumes that urban water supply releases will be either discharged into the Refuge untreated or directed around the Refuge so that it is no longer used as a reservoir for the urban areas, as recommended previously (Walker, 2005).

6. The existing footprint of STA-1W is preserved, with optimization measures and all model input parameters identical to those assumed in the EAARFS simulations of Alternative 1.

7. The existing STA-1W will recover from historical damage associated with overloading and hurricanes.

8. Optimization measures will be 100% successful and viable SAV communities will be maintained with performance similar to that observed in STA1W Cells 4 and 5B prior to September 2004.

9. STA Performance will be consistent with existing DMSTA calibrations, which are based upon data collected prior to September 2004 (Walker & Kadlec, 2005). Since outflow concentrations of most STA's have increased since then, it is possible that these calibrations produce optimistic forecasts, at least to the extent that the increased outflow concentrations reflect changes in P cycling parameters, as opposed to increases in inflow load. Additional uncertainty is associated with DMSTA application below its calibration range for constructed wetlands (>14

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[2] Data on the flows released from Lake Okeechobee to the STA's/Refuge explicitly for urban water-supply purposes are not readily available, but upper bounds can be placed and considered in relation to the total runoff estimates (131 and 250 kac-ft/yr with and without the ALT-1 diversion). The total Lake release reaching the S5A inflow complex via the West Palm Beach canal averaged about 28 kac-ft/yr in 2004-2007 (after regulatory releases were reportedly stopped, see Figure 3), as compared with the EAARFS estimate of 17 kac-ft/yr (EAARFS Appendix G, Table 6.8), only 0.01 kac-ft/yr of which was assumed to be treated in STA 1W/E (EAARFS Appendix G, Table 6.11). The total lake water-supply releases (28 or 17 kac-ft/yr) are upper bound estimates of flow reaching the STA's/Refuge because some of it is discharged as water supply north to the L8 basin or east via the C51 canal. The average outflow from the Refuge to Lake Worth via G94ABC was 44 kac-ft/yr in WY 2001-2006 (period with available data). This is also an upper bound estimate of water-supply flow from the Lake because some of it is likely to have come from runoff. The total flow discharged into the Refuge (treated or untreated, from runoff or lake) when the stage was less than 14.5 ft averaged 8 kac-ft/yr in WY 1996-2005. That is an upper-bound estimate of the average inflow from the Lake at low stage because an unknown portion of it would have come from runoff. Such flows are likely to be higher in drought years and could be higher in the future. It is also possible that Lake releases could reach the STAs/Refuge via the L8 canal. Historical estimates are not readily available, but the EAARFS assumed that no such flows would occur.

ppb), although simulations of natural wetlands with concentrations < 10 ppb have been reasonably successful. Pending calibration updates to recent data, simulations are performed for "Base" and "Conservative" parameter values for each vegetation type in order to reflect uncertainty in treatment efficiency. As defined in the DMSTA software, these values reflect uptake rates at the 50th and 10th percentiles of the calibration range for each vegetation type, respectively.

10. Expansion is simulated with a new flow path (33% emergent vegetation, 67% submersed (SAV)) operating in parallel with the existing STA. Flows are distributed so that the existing and new areas have equal hydraulic load (inflow per unit area). This could represent an addition to the existing STA-1W or construction of an entirely new STA somewhere else in the S5A watershed. Either would likely have multiple flow paths for operational and hydraulic reasons, but the assumed single path is sufficient for estimation purposes.

11. Inflow runoff volumes and loads are reduced based on the percentage reduction in the S5A watershed area resulting from the increase in STA size. Doubling the size of STA-1W would reduce the watershed area and inflows by about 5%.

12. The STA is assumed to be in full operation 100% of the time. No excess capacity is provided for optimization, maintenance, and operational flexibility. It is possible that some maintenance could be accomplished by shutting down single flow paths during the dry season and putting more flow into others, but resulting impacts on performance are not considered in the simulations and there would be a risk of overloading and hydraulic bypass if large storm events occur during maintenance periods.

Inflow Scenarios

Previous planning efforts have demonstrated that there is considerable uncertainty in the forecasted flows and loads used to predict STA performance and evaluate alternative designs. Under-estimation of flows and loads in the 2001 Basin-Specific Feasibility Study and 2003 Longterm Plan led to optimistic forecasts, insufficient treatment capacity, and further delays in achieving treatment objectives. Recent (2005-2007) increases in Lake and basin runoff concentrations already suggest that STA performance projections under the 2005 EAARFS may be optimistic. It seems prudent to consider uncertainty in the flows and loads as an explicit factor in future development and evaluation of treatment alternatives. Accordingly, simulations of design alternatives (expansion vs. EAARFS ALT-1) have been performed under four inflow scenarios:

1. **BASE**. The simulation is driven by daily time series of flow and concentration reflecting runoff from the S5A basin and EBWCD-298 district without the diversions associated with Alternative 1 (EAARFS "2006_ALL" dataset). Flows were derived from the regional hydrologic model (mean = 234 kac-ft/yr for Water Years 1996-2000). Runoff concentrations were calibrated to Water Year (WY) 1995-2004 data (FWM = 174 ppb). Results described below indicate that an

additional 6,000-9,500 acres (beyond the existing 6,670 acres) would be needed to achieve the treatment objective without flow diversion under this scenario.

2. **CI=100 ppb**. The inflow concentration is reduced from 174 to 100 ppb in order to reflect potential benefits of improved BMP performance in the S5A basin and EBWCD-298 district. Improved BMP's may be part of a cost-effective long-term solution, but were not considered as a potential control measure in any of the three previous design efforts, which considered only STA optimization, STA expansion, storage, and flow diversion, each of which has limitations. While runoff concentrations of 50-100 ppb have been achieved with BMP's in other EAA basins (Walker, 2006, Figure 13), they may not be achievable in S5A because of differences in peat, crop types, and/or higher P content of irrigation water. As shown in Figure 1, however, basin runoff concentrations decreased from ~200 ppb in the pre-BMP period (WY 1980-1988), to a range of 100-150 ppb as BMP's were implemented over the WY 1995-2004 period, during which there was a general downward trend. Since BMP's have apparently had no significant impact on runoff volumes, reductions in concentration and are good indicators of reductions in load. The 100 ppb concentration is not proposed as a specific BMP "goal", but assumed here to evaluate the potential sensitivity of STA expansion requirements to reductions in runoff concentration. Results indicate that an additional 2,670-5,500 acres would be needed to achieve the treatment objective under this scenario. As described below, values in the upper end of this range may be required in order to avoid hydraulic bypass during high-flow periods.

3. **CI=230 ppb**. Similar to concentrations measured in the total basin outflow at S5A and STA-1W inflow in WY 2005-2007 (Figure 1). Lake and runoff concentrations increased significantly after the September 2004 hurricanes and have remained high since then. WY 2005-2007 concentrations were similar to pre-BMP levels. The reasons for this increase are unknown, but possibly related to the increased P concentration in irrigation water released from the Lake. Evaluation of alternatives on the basis of the most recent concentration data is justified, given uncertainty as to the cause of the post-hurricane increase and no indication that concentrations started to recover over the WY 2005-2007 period. Results indicate that an additional 8,000-12,000 acres would be needed to achieve the treatment objective under this scenario.

4. **WY 2004-2006**. The EAARFS inflow volume is increased by 34% to match measured inflows at STA-1W in WY 2004-2006. Since the concentration is unchanged (FWM = 174 ppb), the increase in flow amounts to a 34% increase in load. This scenario was assumed in deriving the STA1W & STA-1E TBEL's for 2006-2009 (Goforth et al, 2007)[3]. Since it based on historical flows, it would

[3] While labeled as "L8" in the TBEL document (table on page 17, Goforth et al, 2007), the 34% increase far exceeds that which can be attributed to L8 runoff. The increase is more than twice the total historical load from the L8 basin to the S5A complex (6.9 mt/yr, EAARFS, App G, Table 5.2), a significant portion of which would be discharged into STA-1E or to the east via the C51 canal. In addition, an explicit

capture all urban water-supply flows that are otherwise ignored in the EAARFS inflow datasets (See Assumption 5 above). Results indicate that an additional 9,330-13,330 acres would be needed to achieve the treatment objective under this scenario.

The mean flows and loads associated with each of above scenarios are compared with historical (1980-2007) data representing the total outflow from the S5A basin in Figures 2 and 3. Because historical flows and loads were impacted to some extent by variations in rainfall and changes in the watershed (implementation of BMP's, STA construction, diversions into and out of the basin, changes in water management, etc), the data are not directly comparable with the simulations. The comparisons are useful, however, as general "reality check" on the inflow scenarios, which are based upon numerous assumptions, primarily related to system operation, hydrologic modeling, and calibration of runoff concentrations to 1995-2004 data.

Figure 2 shows scenario means relative to historical yearly time series of flow, load, concentration, and rainfall. The data are partitioned by source (EAA runoff, EBWCD-298 runoff, and Lake releases). The high lake releases in some years prior to 2004 (especially 2003) partially reflect regulatory discharges which were stopped in 2004, as assumed under all future EAARFS alternatives. Direct comparison of the scenario mean flows and loads with the yearly time series is complicated by rainfall-driven variations. For example, while the measured loads in WY 2006-2007 are similar to the scenario means, one would expect the measured loads to be significantly below average because of the severe drought. The concentration data provide a much more stable signal that is relatively independent of rainfall.

Figure 3 compares scenario means with historical means for 1995-2007 (post-BMP period), partitioned by source (runoff, water supply, regulatory release). While the scenario mean loads do not explicitly include urban water supply, they generally bracket the historical means, regardless of whether or not the water-supply loads are included. Assuming that there are no regulatory releases in the future, the ranges of conditions covered in the scenarios appear to be realistic in the context of the historical data and sufficient for estimating the approximate range of additional area required to treat all of the basin flows. Further analysis would be required to update and otherwise refine the inflow datasets for future use in forecasting STA performance and evaluating management alternatives, as scheduled for 2008 under the LTP.

Simulation Results

Figure 4 shows predicted log-term geometric mean (GM) outflow concentrations vs. surface area for each loading scenario. Surface area is expressed as a scale factor, i.e.

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allocation for L8 runoff was made in the STA-1E TBEL. The 34% adjustment essentially changed the base period for the simulations from 1960-2000 (which included a wide range of hydrologic conditions) to 2004-2006, which was heavily influenced by severe back-to-back hurricanes in August and September 2004 (see Figure 2).

multiple of the existing STA-1W effective treatment area (6,670 acres). Simulations have been performed for scale factors ranging from 1.0 to 3.0 using each DMSTA calibration. The base calibration (50th percentile uptake rates) indicates the scale factors ranging from 1.5 to 2.5 would be needed to achieve the treatment objective (GM = 10 ppb). The conservative calibration (10th percentile uptake rates) indicates that scale factors ranging from 1.8 to 3.0 would be required.

Figure 5 summarizes additional acreage requirements for each loading scenario and calibration. Base estimates range from 6,000 to 9,330 acres without additional BMP's vs. 2,670 acres with additional BMP's achieving a runoff concentration of 100 ppb. Conservative estimates are 9,500 to 13,330 acres without additional BMP's and 5,500 acres with additional BMP's. As discussed above (Assumption 12), these estimates assume that the STA is in full operation 100% of the time (i.e. there is no allowance for down time due to maintenance activities).

Comparisons with Alternative 1

Table 2 summarizes inflow assumptions and simulation results for Alternative 1 and expanded STA's sized based upon the 50th percentile DMSTA calibration under each inflow scenario. Geometric and flow-weighted mean outflow concentrations are compared in Figure 6. Results are shown for the third inflow scenario (CI=230 ppb, 2.2 X expansion, total area = 14,670 acres)[4]. Predicted flow-weighted and geometric means are similar for STAs sized under the other inflow scenarios (Table 2). Under the base inflow scenario (EAARFS), the predicted GM is 10 ppb for each alternative. The FWM for Alternative-1 is 19 ppb, as compared with 15 ppb for the expanded STA, assuming that all runoff is treated (no hydraulic bypass). Other loading scenarios for Alternative 1 have GM's ranging from 8 to 14 ppb and FWM's ranging from 15 to 24 ppb.

As reflected in the last three columns of Table 2, simulations have been performed with and without a maximum 4-foot constraint on STA water depths. This is a typical operational criterion for triggering hydraulic bypass around the STA in order to avoid damage to STA structures and/or vegetation. Results indicate that there is substantially greater risk of bypass under Alternative 1 (3-5% of the inflow load) as compared with the expanded STA's (<1% of the inflow load). Bypass events are more important when expressed as a percentage of the total outflow load (25-25% vs. 0-4%) . Bypass has negligible impact on geometric means in all of the simulations, but increases the combined flow-weighted-mean discharge concentrations (STA outflow plus untreated bypass) by 1-4 ppb with ALT-1 vs. < 0.2 ppb for the expansion alternatives.

The bypass simulations described above use the hydraulic parameters assumed in the EAARFS simulations, except that the latter did not include the 4-foot depth constraint. There is considerable uncertainty in the hydraulic simulations and bypass predictions. A detailed analysis would be required to fully evaluate bypass, but these results are sufficient to indicate that the risk of bypass is substantially greater under Alternative 1, as

[4] The expanded STA-W (14,670 acres) in this example would be similar in size to the existing STA-34 (16,543 acres) and to the EAARFS expanded STA-5 (13,150 acres).

compared with the expanded STA alternatives. There may be operational remedies to this problem. While the excess flows could be diverted to STA-1E instead of the Refuge (similar to current operations), there is no allocation for the associated loads in STA-1E Alternative 1, which is assumed to treat only runoff from the C51W and ACME-B basins.

The higher FWM's and greater risk of bypass under Alternative 1 reflect the increased variability in STA inflows introduced by the selective diversion strategy. Because of limitations in canal conveyance capacity, the flow diversion would be limited to a maximum of 800 cfs, as compared with mean flow of 350 cfs and maximum flow of 4800 cfs without diversion. Model input time series indicate that flow events exceeding 4000 cfs for durations of 1 to 5 days occur at roughly a 1.5 to 2-year frequency. Alternative 1 would have a greater percentage impact on low to medium flows, as compared with high flows, when treatment efficiency would be lowest. The conventional strategy for treating stormwater runoff involves storage of peak flows and subsequent slow release to allow downstream treatment devices (detention ponds, infiltration basins, swales, wetlands..) to function at greater efficiency. That strategy shifts the flow distribution towards lower flows and reduces the relative importance of peak flows. Alternative 1 does just the opposite. That characteristic is reflected by spikes in the inflow volume and predicted outflow concentrations.

Time series and frequency distributions of weekly hydraulic loads (inflow / area) for each alternative are shown in Figure 7 and 8, respectively. Historical data from STA-1W during the period of full-scale operation are shown for comparison purposes. At higher hydraulic loads, treatment efficiency is lower, STA water depths are higher, and there is greater risk of hydraulic bypass triggered by high water levels. Peak hydraulic loads under ALT-1 (~16 cm/day) are about twice those projected with the expanded STA (~8 cm/day). The ALT-1 inflow spikes are similar to those experienced historically, particularly during periods when the STA was overloaded with inflows from Lake Okeechobee (2002-2003) and hurricane flows (2004). While the magnitudes would be similar, the frequency and duration of peak hydraulic loading events would be lower under ALT-1 as compared with historical conditions as a consequence of the diversion. ALT-1 would reduce the median (50th percentile) hydraulic load from ~12 to ~5 cm/day (Figure 8) and therefore be expected to provide an overall improvement in performance, but less of a remedy for problems experienced historically under high-flow conditions.

The risk of bypass and operational problems under ALT-1 should be given serious consideration, especially in the context of uncertainty about future flows, hurricane frequencies, hydrologic model uncertainties, and possibility that conveyance capacity assumed in the EAARFS simulations may not be available in some periods because of high stages in the western canals.

Regardless of whether or not bypass occurs, the consequences of higher and more variable hydraulic loads under Alternative 1 are evident in the yearly and monthly FWM time series:

1. Figure 9 plots yearly GM and FWM concentrations for each alternative. While each time series has a long-term GM = 10 ppb, the FWM exceeds 20 ppb in 6% of the years for the expanded STA, as compared with 31-34% for ALT-1 (with and without bypass). The 90th percentile yearly FWM's are 18 and 26-30 ppb, respectively.

2. Figure 10 plots monthly FWM concentrations for each alternative. The maximum monthly FWM exceeds 30 ppb in 8% of the water years for the expanded STA, as compared with 56-60% for ALT-1.

3. Figure 11 plots monthly FWM concentrations vs. STA outflow volume for each alternative. Divergence between the alternatives is particularly evident at medium to high flows, when predicted outflow concentrations for ALT-1 are about twice those for the expanded STA. Based on the concentration/flow regressions in Figure 9, the maximum monthly outflow concentration would be about 25 ppb for the expanded STA, as compared with 45-60 ppb under ALT-1 (without and with bypass). Figure 9 further illustrates that the expanded STA would provide more flow to the Refuge at lower concentrations, whereas ALT-1 would provide less flow (47% less on the average) at higher concentrations.

The elevated concentrations at high flows associated with Alternative 1 are of particular concern because STA outflows are more likely to penetrate the Refuge marsh from the rim canal under those conditions.

Conclusions

1) Estimates of additional treatment area required to accomplish treatment objectives for STA-1W without flow diversions contemplated under EAARFS Alternative 1 are described in this report. The assumed treatment objectives are to provide a long-term geometric mean concentration of 10 ppb in the STA outflow while treating all of the S5A and EBWCD-298 runoff without significant hydraulic bypass.

2) The analysis indicates that a 2 to 3-fold expansion of the existing STA-1W (6,670 acres) would be required without additional source-control measures (BMP's) and a 1.5 to 1.8-fold expansion by with additional BMP's (100 ppb runoff concentration). The ranges reflect different inflow and modeling assumptions.

3) There is some risk that predictions are optimistic (areas under-estimated) because model calibrations do not reflect the recent (2005-2007) STA performance data. In addition, the STA is assumed to be in full operation 100% of the time (no allowance for down time for maintenance activities).

4) As an example, detailed comparisons are made between EAARFS Alternative 1 treating 53% of the basin runoff at the 1995-2004 concentration (174 ppb) with a 8,000 acre expansion treating all runoff at recent (2004-2007) inflow concentrations (230 ppb). The expanded STA (14,670 acres) would be similar in size to the existing STA-34 (16,543 acres) and to EAARFS expanded STA-5 (13,150 acres). Compared with Alternative 1, the expanded STA would provide the following:

    a) Equivalent geometric mean outflow concentrations (range of 10 to 14 ppb, depending on model uncertainty)

    b) Lower flow-weighted-mean outflow concentration (15 vs. 19 ppb).

    c) Yearly and monthly flow-weighted mean outflow concentrations with substantially less variability and lower maximum concentrations.

    d) Lower outflow concentrations under high-flow conditions (~ 25 ppb vs. ~50-60 ppb), when the STA discharge would be most likely to penetrate the Refuge marsh (vs. remain in the rim canal).

    e) Less risk of hydraulic bypass under high-flow concentrations; i.e. greater probability that all of the basin flows will be treated.

    f) Less risk of damage to structures and vegetation resulting from high water levels during peak inflow periods. Unless there is significant untreated bypass, predicted maximum hydraulic loads (inflow per unit area) under Alternative 1 are similar to those experienced in the August-September 2004 hurricanes, though of lower duration. Maximum hydraulic loads would be reduced by approximately

50% with an expanded STA.

g) More flexibility for operation and maintenance as a consequence of lower mean and maximum hydraulic loads.

h) As a consequence of the higher assumed runoff concentration (230 vs. 174 ppb), less risk that future runoff loads and STA outflow concentrations are under-estimated; i.e. more robust performance forecasts.

i) Based upon preliminary comparison with historical flows and loads, sufficient capacity for treating urban water-supply releases from Lake Okeechobee to the STA's/Refuge, which were assumed to be nonexistent or untreated under EAARFS Alternative 1.

j) More inflow to the Refuge from the S5A basin (233 vs. 134 kac-ft/yr) and from all sources (402 vs. 303 kac-ft/yr), as compared with the 1995-2006 average total inflow of 524 kac-ft/yr.

k) Less risk of adverse hydrologic impacts on Refuge hydrology resulting from reductions in mean flow and changes in the timing of inflows under Alternative 1 (high flow periods accounting for a greater percentage of total inflow).

5) Further analysis is required to quantify flows and loads associated with urban water supply releases from Lake Okeechobee to the STA's and/or Refuge, which the EAARFS assumed would be eliminated or untreated regardless of Refuge stage. Based upon historical inflow data, the total flow is estimated to be less than 28 kac-ft/yr on average, or <9% of the runoff plus water-supply flows with the expanded STA, as compared with <18% for EAARFS Alternative 1. Flows delivered when the Refuge state is <14.5 ft are estimated to be <8 kac-ft/yr on average.

6) Future development of cost-effective alternatives could involve some combination of additional treatment area, additional BMP's, and limited diversions to accomplish the treatment objective without adverse impacts on Refuge hydrology. Such alternatives would require identification of specific tracts of land, updated inflow volume and concentration estimates, revised assumptions, updated model calibrations, policy/legal decisions regarding treatment of urban water supply flows, and a framework to evaluate Refuge hydrologic impacts.

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Table 1

Historical & Projected Inflows to the Refuge

Period	S5A Basin Rainfall Inches	Mean Inflow (kac-ft/yr) From STA1E	From STA1W	To Refuge	Notes
Historical Data					
WY 1980-1988	51.4			507	Consent Decree & BMP base period
WY 1995-2001	54.4			610	Under current regulation schedule; before S6 Diversion
WY 2002-2006	50.4			403	Under current regulation schedule; after S6 Diversion
WY 1995-2006	52.8			524	Under current regulation schedule
35-Year Averages (WY 1966-2000 Simulations)					
<u>2006-2009 Scenarios</u>					before L8 & other EAARFS diversions
TBEL Derivation	52.8	226	256	482	Goforth et al (2007)
EAARFS 2006-2009	52.8	241	177	418	ADA et al (2005)
<u>>2010? Scenarios</u>					After L8 & other EAARFS diversions (date uncertain)
EAARFS ALT-1	52.8	169	134	303	S5A runoff diversion to STA-2
EAARFS ALT-2	52.8	178	0	178	STA-1W outflow diversion to STA-2
STA1W 2.2 x Expansion	52.8	169	233	402	Required to treat all runoff at 2005-2007 inflow conc.

Historical flows to Refuge from all sources (STA's & Untreated)
Simulated flows from regional hydrologic model. STA-1E inflows from C51-W & ACME-B. STA-1W inflows from EAA & EBWCD-298.
S5A basin rainfall from EAA regulatory rule & regional hydrologic model.
Runoff is strongly dependent on rainfall
Historical data for 1995-2006 are most comparable to the 35-Year simulations, since mean rainfall = 52.8 in for each period.
Untreated Lake releases for urban water supply are not reflected in simulations (< 28 kac-ft/yr, Figure 3).

Table 2

Predicted Performance of Each Alternative under Each Inflow Scenario

Inflow Assumption	Total Area acres	New Area acres	STA Inflow Flow kac-ft	STA Inflow Load mt/yr	STA Inflow FWM ppb	STA Outflow Geo Mean (ppb) Base	STA Outflow Geo Mean (ppb) Conserv	STA Outflow FW Mean (ppb) Base	STA Outflow FW Mean (ppb) Conserv	Including Untreated Bypass Load % of Inflow	Including Untreated Bypass Load % of Outflow	Including Untreated Bypass Total FWM ppb
EAARFS Alternative 1 - Diverting 47% of Basin Runoff												
BASE	6670	0	131	25.8	159	10.2	13.4	18.9	21.9	2.7%	20.3%	20.8
CI=100	6670	0	131	16.2	100	7.9	9.9	15.1	17.0	2.7%	16.4%	16.1
CI=230	6670	0	131	34.2	211	12.4	16.8	21.9	26.2	2.7%	22.6%	24.7
WY 04-06	6670	0	176	34.6	159	14.0	18.5	23.9	28.3	4.8%	27.8%	27.2
Expanded STA-1W - Without Diversion												
BASE	12670	6000	238	51.2	174	10.2	13.5	15.3	18.6	0.1%	0.7%	15.4
CI=100	9330	2660	245	30.3	100	10.3	13.0	15.4	18.0	0.6%	3.9%	15.6
CI=230	14670	8000	234	66.6	230	10.1	13.6	15.1	18.6	0.0%	0.0%	15.1
WY 04-06	16000	9330	310	66.7	174	10.5	13.9	15.7	19.2	0.1%	1.1%	15.8

Inflow Scenario:

BASE — EAARFS assumed inflows, calibrated to 1995-2004 data.
CI=100 — Inflow conc = 100 ppb, achieved by BMP's in other EAA Basins
CI=230 — Inflow conc = 230 ppb, observed in WY 2005-2007
WY 04-06 — BASE adjusted to observed load in WY 2004-2006; used to derive STA-1W/E discharge limits for 2006-2009 (TBEL's)

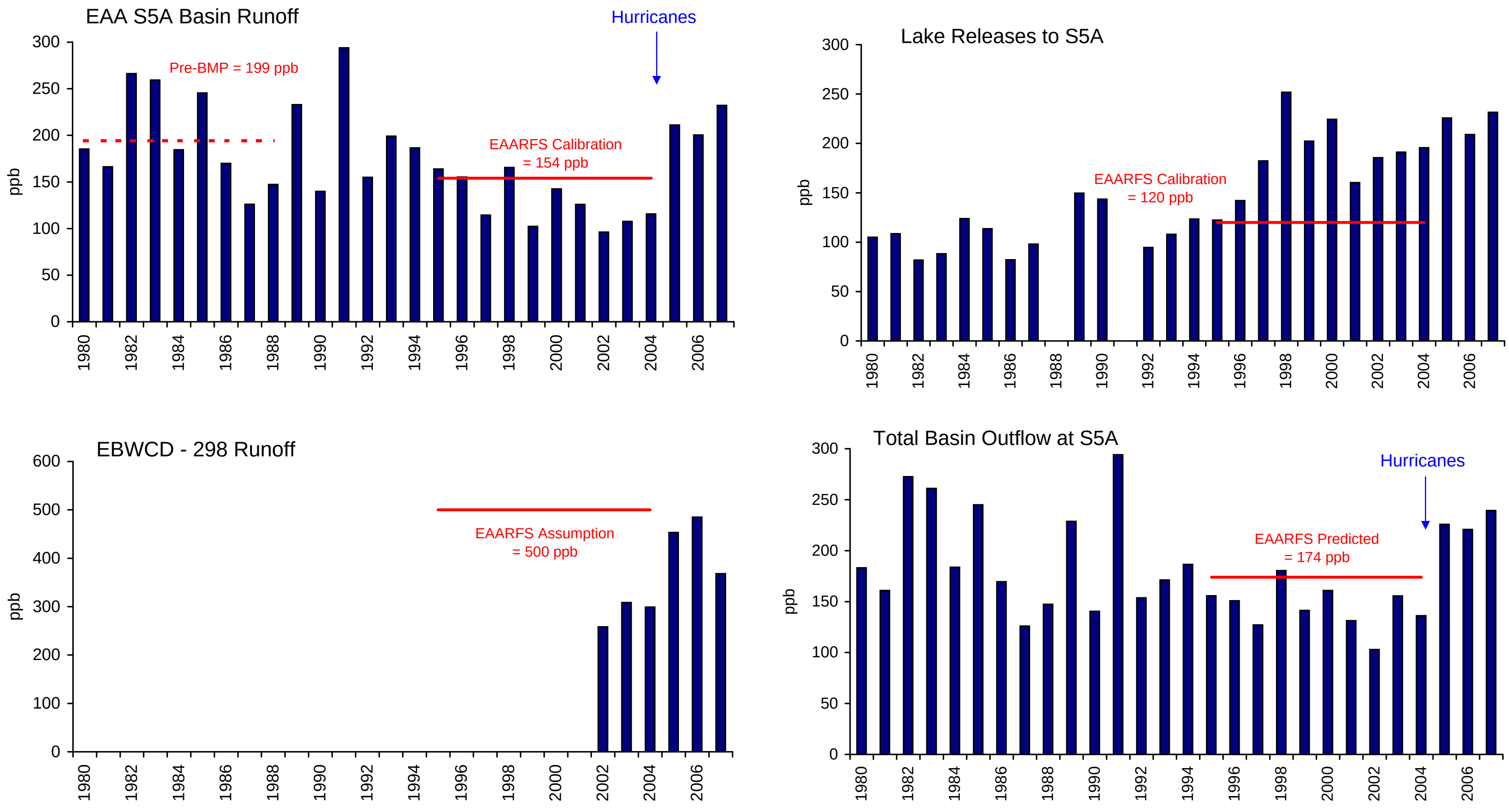
Expanded STA's are sized to meet 10 ppb outflow geometric means using base (50th percentile) DMSTA calibration

Predicted outflow concentrations:

Base = 50th percentile, Conserv = 10th percentile of DMSTA calibration range for vegetation P uptake rates.
Assume that all inflow is treated (no bypass)

Estimated bypass triggered when STA water depth exceeds 4 feet are shown in last column, expressed as percent of total inflow & outflow load.
Total FWM is the combined FWM concentration of the untreated bypass and the STA outflow using the base DMSTA calibration.

Figure 1
Phosphorus Concentrations in the S5A Basin



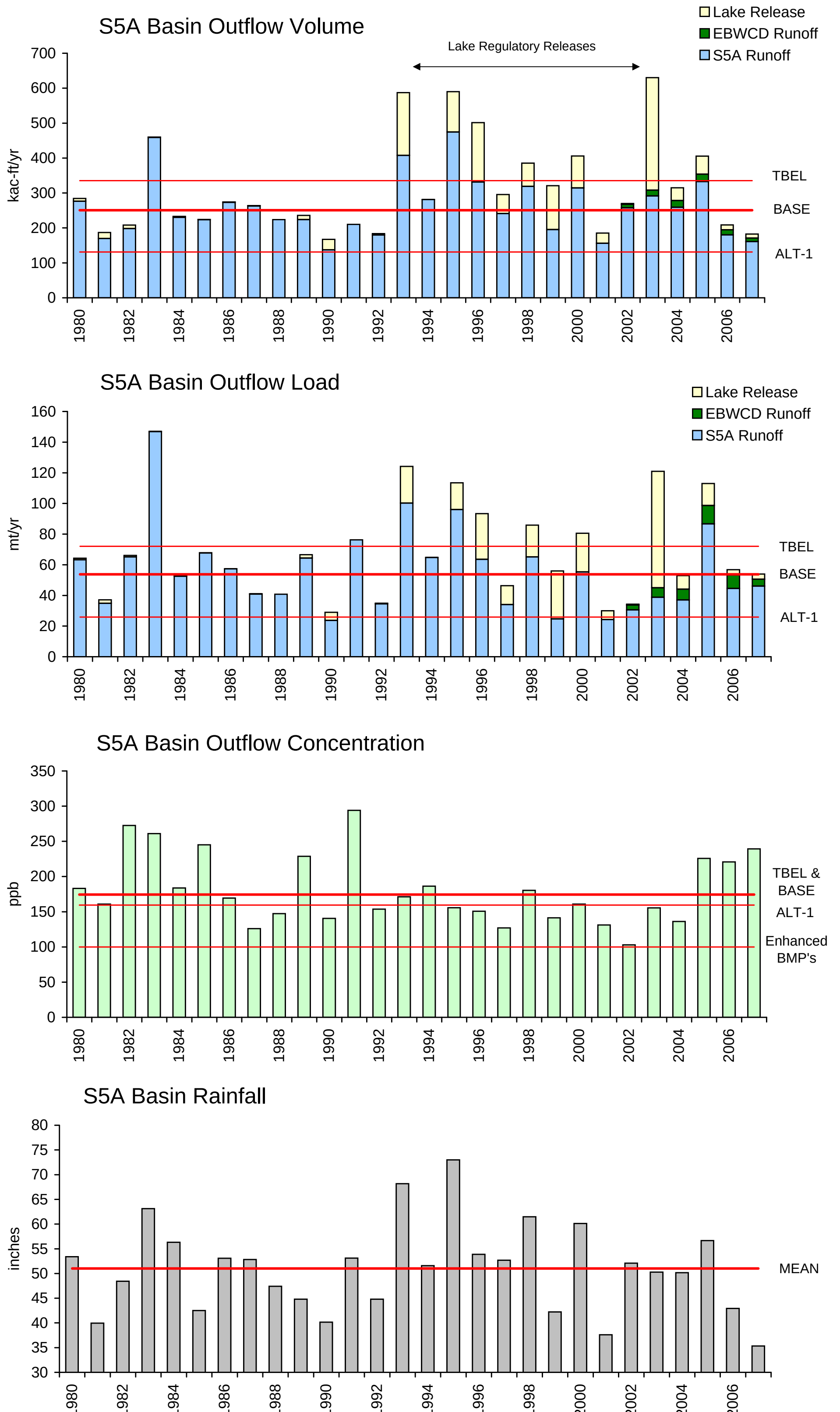
X-Axis = Water Year; Y-Axis = Flow-Weighted-Mean Concentration   Data from SFWMD EAA Regulatory Rule compliance calculations

EAARFS calibrations based on 1995-2004 data. Predicted total basin outflow reflects S5A and EBWCD runoff only (used in evaluation of Alternative 1)

S5A basin runoff concentrations approached 100 ppb in 1999-2003 (vs. pre-BMP mean = 199 ppb), but increased to pre-BMP levels after the September 2004 hurricanes.

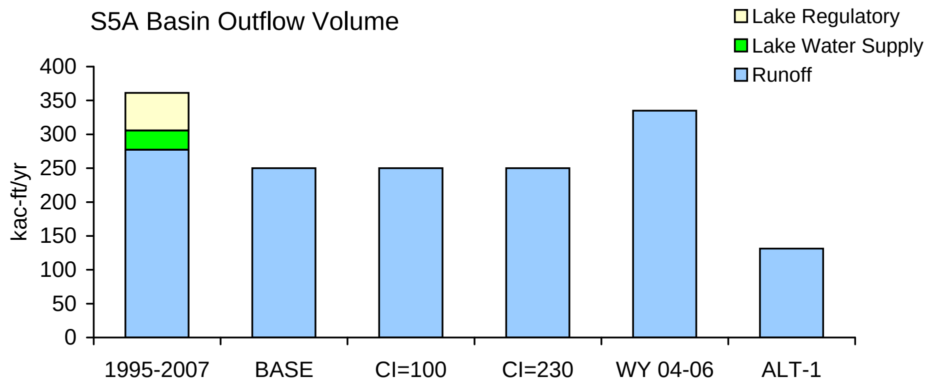
EAARFS calibration for lake releases (120 ppb) is low relative to the compliance data because it was based on concentrations measured at S5A vs. point of release from Lake (S352). Lake releases are not treated under Alternative 1.

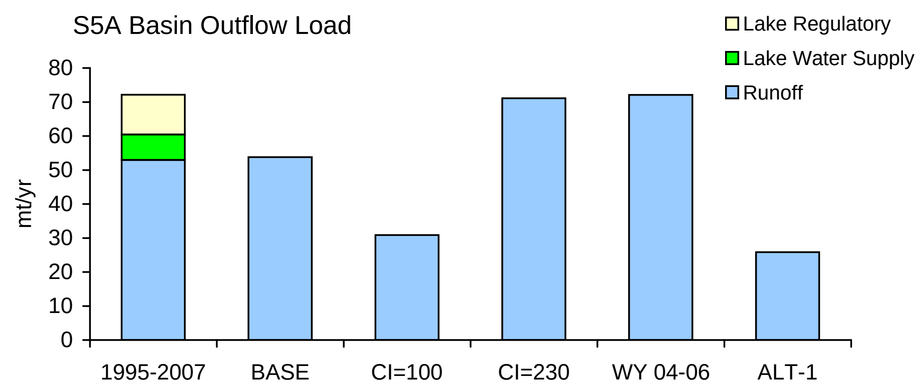
Figure 2
Yearly Historical S5A Basin Outflows vs. Simulated Means



Bars show dData from SFWMD EAA Regulatory Rule compliance calculations.
Lines show mean values for alternative inflow scenarios.

Figure 3
Mean Historical & Simulated S5A Basin Outflows

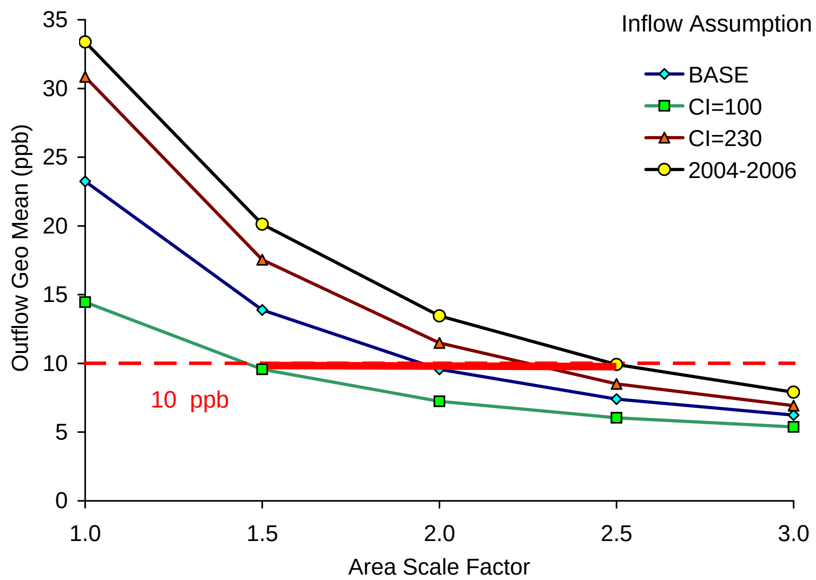


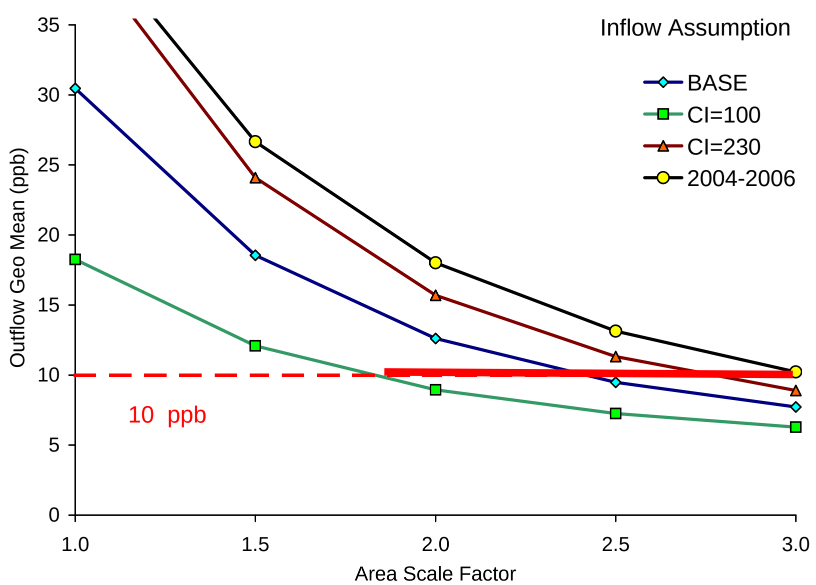


	Historical	Simulated Inflows (1965-2000 Hydrology)				
	1995-2007	BASE	CI=100	CI=230	WY 04-06	ALT-1
Flows kac-ft/yr						
Runoff	277	250	250	250	335	131
Lake W Supply	28	0	0	0	0	0
Lake Regul.	56	0	0	0	0	0
Total	361	250	250	250	335	131
Excluding Reg.	306	250	250	250	335	131
TP Load mt/yr						
Runoff	52.9	53.8	30.9	71.1	72.1	25.8
Lake W Supply	7.5	0.0	0.0	0.0	0.0	0.0
Lake Regul.	11.7	0.0	0.0	0.0	0.0	0.0
Total	72.1	53.8	30.9	71.1	72.1	25.8
Excluding Reg.	60.4	53.8	30.9	71.1	72.1	25.8
FWM C ppb	162	174	100	230	174	159
Excluding Reg.	160	174	100	230	174	159

Historical data reflect post-BMP period (WY 1995-2007).
Lake water-supply release estimated as average of WY 2004-2007 total lake release.
No regulatory releases assumed in that period or in any of the simulations.
Urban water-supply release to the STA's/Refuge would be less than that 28 kac-ft/yr
because a portion is discharged to other basins (see text).

Figure 4
STA-1W Outflow Concentration vs. Treatment Area





Inflow Assumption

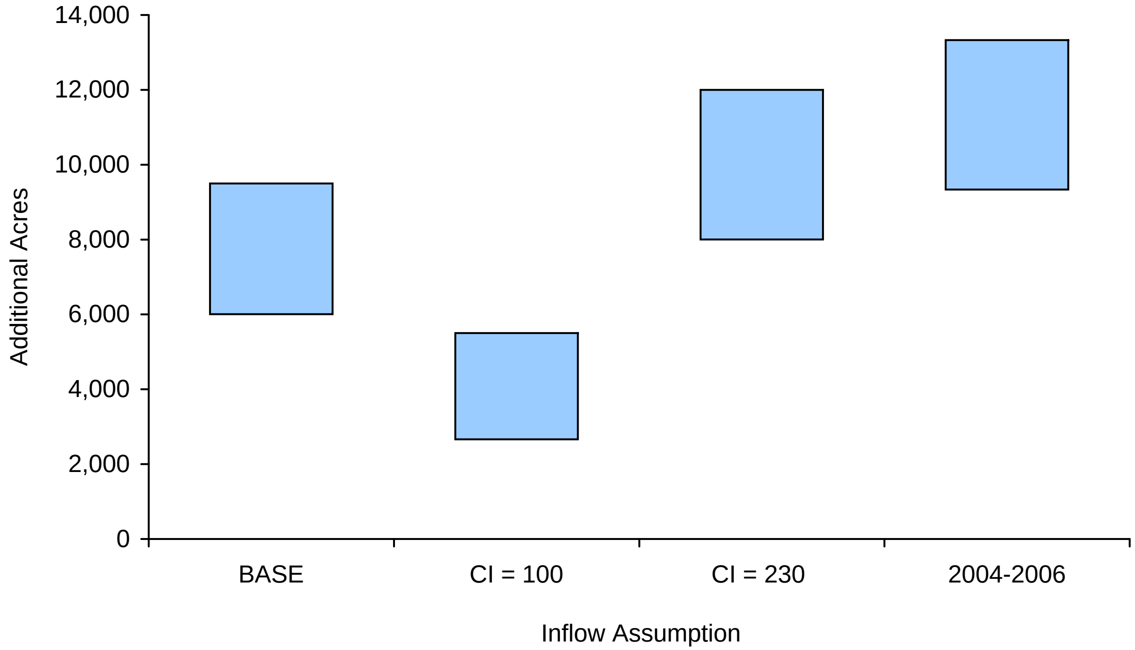
BASE	EAARFS inflow dataset reflecting runoff from S5A & EBWCD-298 without ALT-1 diversions. inflow concentration (174 ppb) calibrated to 1995-2004 data.
CI=100	Inflow concentration achieved with BMP's in other EAA basins
CI=230	Inflow concentration similar to 2004-2007 data at inflow to STA-1W
2004-2006	Measured flows in WY 2004-2006 (34% increase vs EAARFS dataset) Assumed in deriving the STA1W & STA-1E TBEL's for 2006-2009.

Scale Factor = New Area / Existing Area (6,670 acres).
The 50th and 90th percentile estimates reflect uncertainty in P uptake by vegetation (DMSTA calibrations)

Figure 5

Additional STA-1W Area Required to Meet Treatment Objective

Without Diverting Flow Away from the Refuge

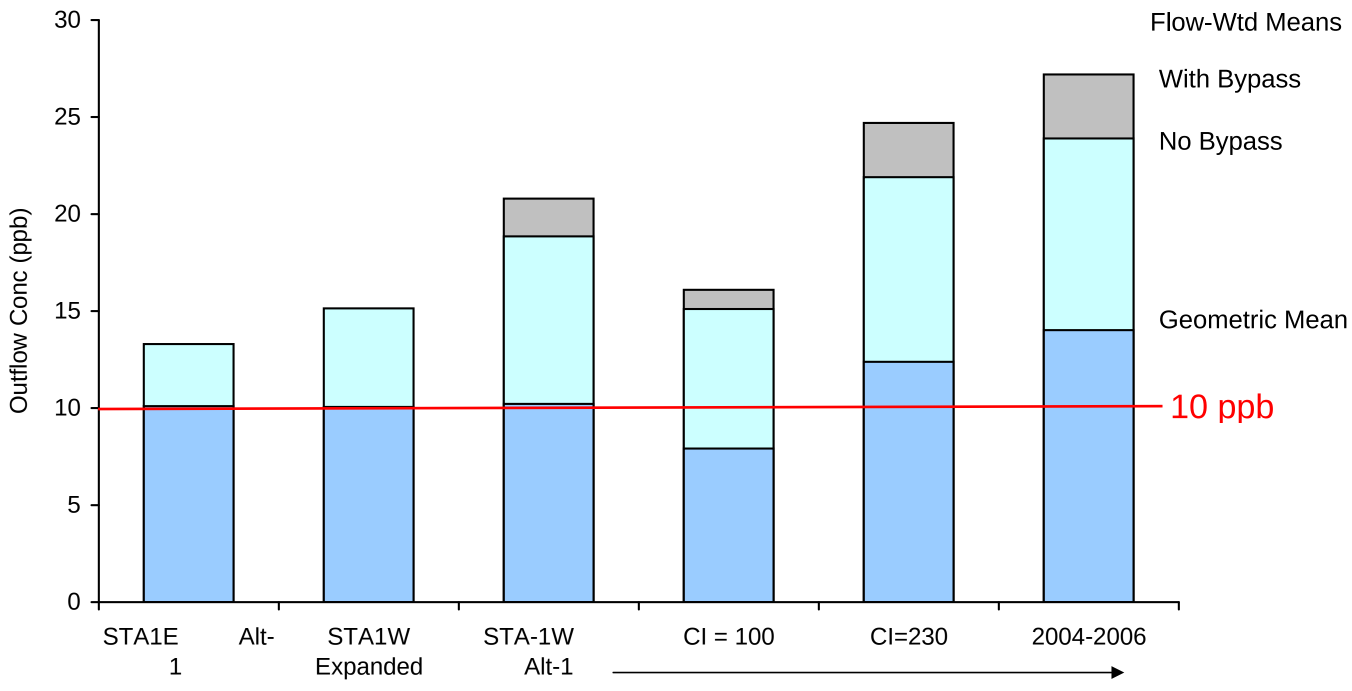


X-Axis reflects different inflow volume or concentration assumptions.
Y-Axis shows additional area required to meet treatment objective (long-term geometric mean = 10 ppb); existing area = 6670 acres
The range reflects uncertainty in P uptake by vegetation (10th - 50th percentiles of model calibration range)

Inflow Assumption	Flow	Load	Conc	Additional Acres *		
	kac-ft/yr	mt/yr	ppb	Low	High	Description
BASE	238	51	174	6,000	9,500	EAARFS Inflow Conc = 174 ppb, based upon 1995-2004 data
CI = 100	245	30	100	2,660	5,500	Inflow conc = 100 ppb, achieved by BMP's in other EAA Basins
CI = 230	234	67	230	8,000	12,000	Inflow conc = 230 ppb, observed in WY 2005-2007
2004-2006	310	67	174	9,330	13,330	Observed inflow volume in WY 2004-2006; used to derive TBEL's

Estimates assume STA in full operation 100% of the time (no allowance for maintenance).
EAARFS Alternative 1 would treat 131 kac-ft/yr and divert 119 kac-ft/yr to other basins without expanding the STA.

Figure 6
Performance of Expanded STA-1W & EAARFS Alternative 1 vs. Inflow Scenario

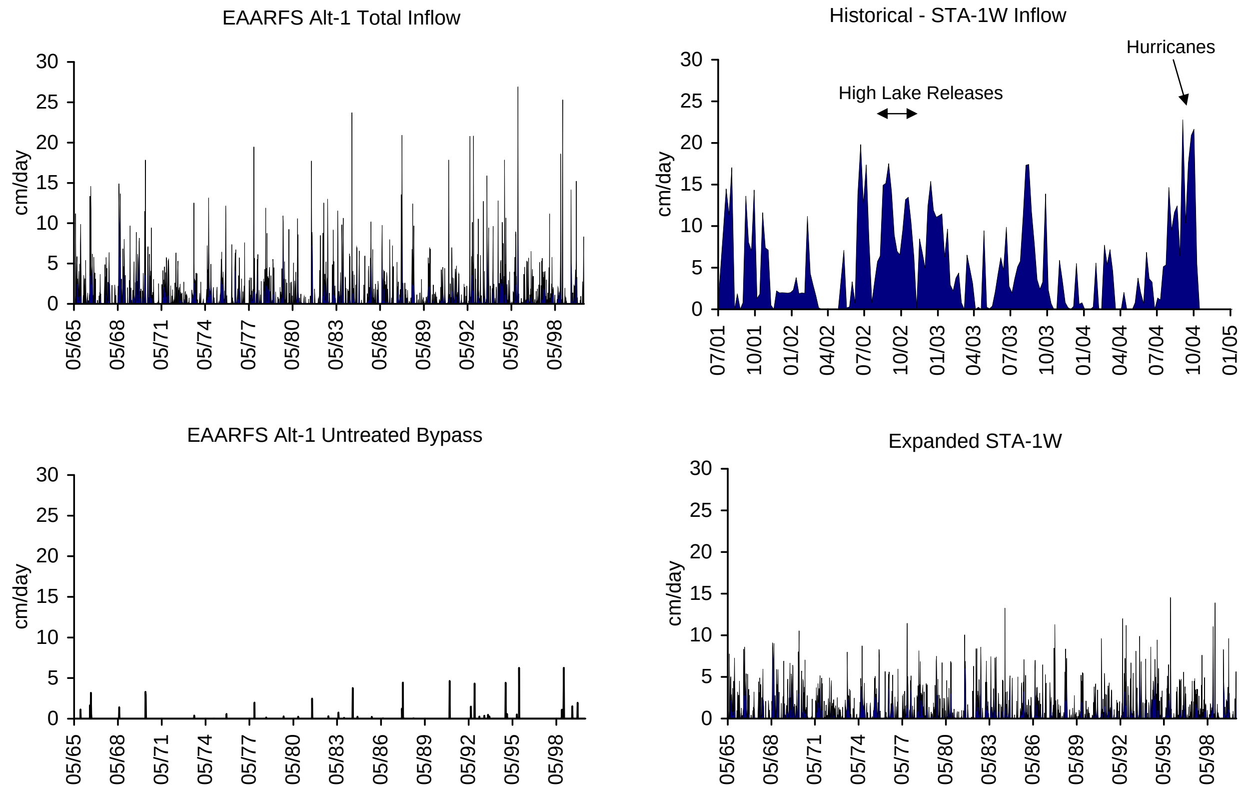


	Outflow Total P (ppb)			
		Flow-Wtd Mean		
Scenarios	Geo Mean	No Bypass	With Bypass	
STA1E Alt-1	10.1	13.3	-	STA-1E EAARFS Alternative 1; treats runoff from C51W & ACME-B
STA-1W Expanded	10.1	15.1	-	STA-1W expanded by 2.2x; treats all runoff from S5A & EBWCD; existing area = 6,670 ac.
STA-1W Alt-1	10.2	18.9	20.8	STA-1W EAARFS Alternative 1; 47% of runoff diverted to other basins
CI = 100	7.9	15.1	16.1	STA1W Alt-1, Inflow concentration = 100 ppb (achieved via BMP's in other EAA basins)
CI=230	12.4	21.9	24.7	STA1W Alt-1, Inflow conc = 230 ppb (similar to 2005-2007)
2004-2006	14.0	23.9	27.2	STA1W Alt-1 Flows assumed in TBEL derivation (34% increase vs. EAARFS dataset)

Long-term flow-weighted and geometric mean outflow concentrations (35-year simulation)
All predictions based upon 50th percentile estimates of vegetation P uptake rate.
Simulations indicate risk of bypass at high flows under Alternative 1.
Flow-weighted means shown without bypass (EAARFS assumption) and with bypass triggered when water depth exceeds 4 feet.

Figure 7

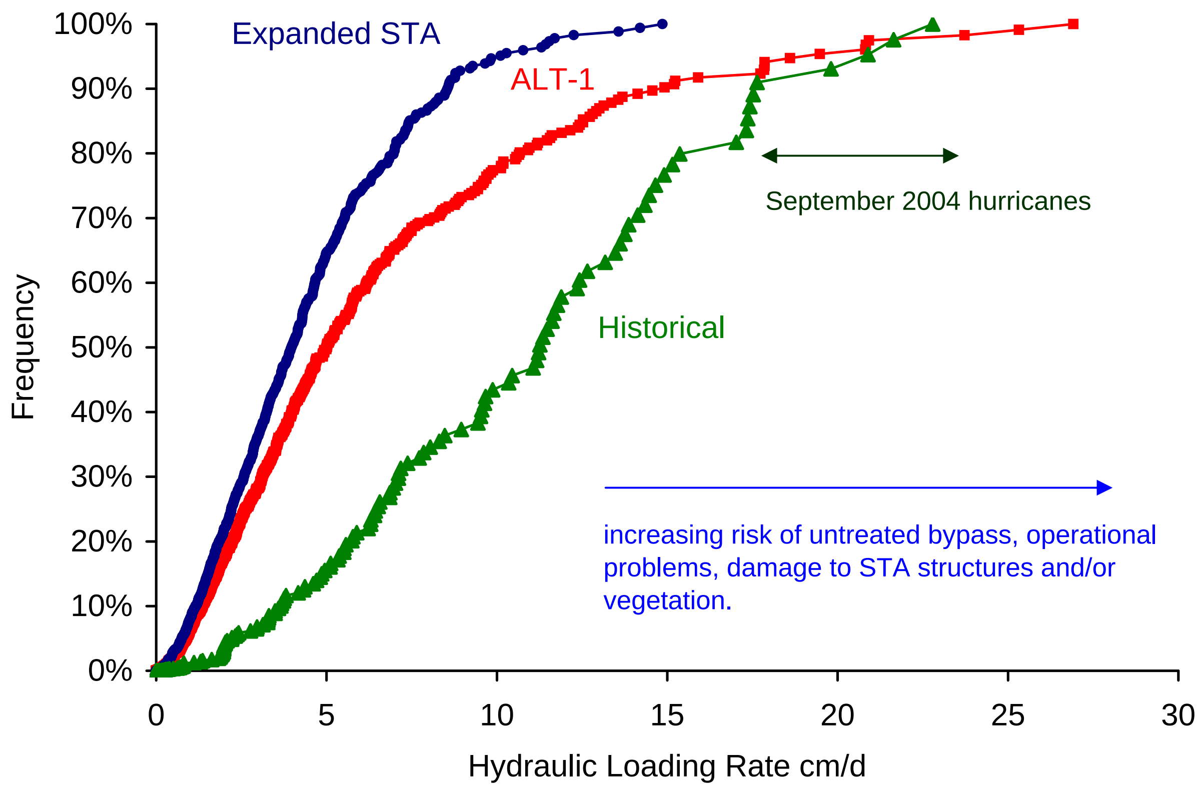
Simulated & Historical Hydraulic Loads



7-Day mean hydraulic loading rates (HLR = inflow/area) for STA-1W. 35-year Simulation (ALT-1 & Expanded) vs. Historical (July 2001-Oct 2004)
At high HLR's, treatment efficiency is lower and there is greater risk of operational problems, vegetation damage, and/or hydraulic bypass.
Left panels show results for ALT-1. Top =Total Inflow (to STA + Bypass). Bottom = Untreated bypass triggered when STA water depth exceeds 4 feet.
Upper right shows historical hydraulic loads to STA-1W (not including bypass). Peak values (15 - 25 cm/day) are similar to those predicted for ALT-1
Maximum HLR's for ALT-1 are similar to those experienced historically during periods of high lake releases and hurricanes.
Lower Right shows results for STA-1W expanded by 2.2 X (to 14,670 acres) to treat basin runoff at recent inflow concentrations (~230 ppb).
Maximum hydraulic loads are ~50% lower than those predicted under Alt-1 and no bypass is predicted.
Bypass simulations are approximate and a more detailed hydraulic analysis would be needed to fully evaluate.

Figure 8

Frequency Distribution of Hydraulic Loads for Each Alternative



HLR = hydraulic loading rate = STA inflow volume / STA area, assuming no bypass.

Y axis = percent of inflow volume occuring at or below given HLR, computed from weekly average inflows

STA-1W expanded by 2.2X (14,670 acres) to treat basin runoff at recent inflow concentrations (~230 ppb).

Historical inflow data from STA-1W measured at G302 for July 2001 - Oct 2004 (~full operation)

Either alternative reduces 50th percentile HLR's and will improve overall performance relative to historical.

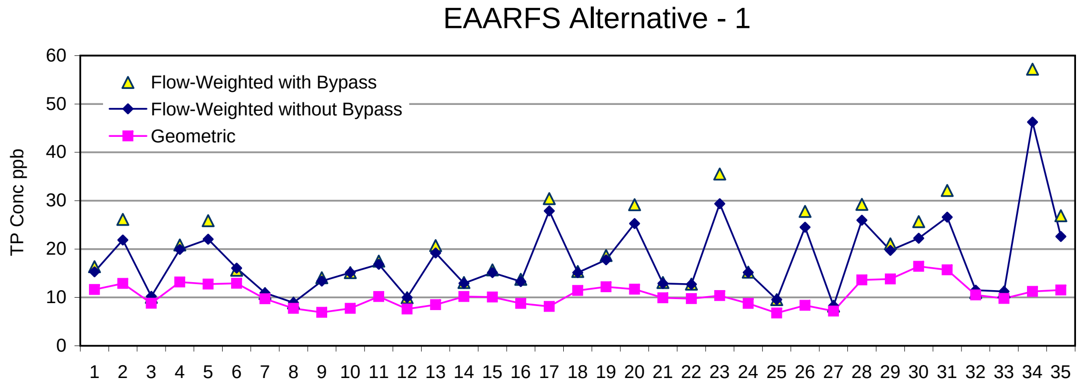
ALT-1 does not provide a remedy for problems experienced at high HLR's.

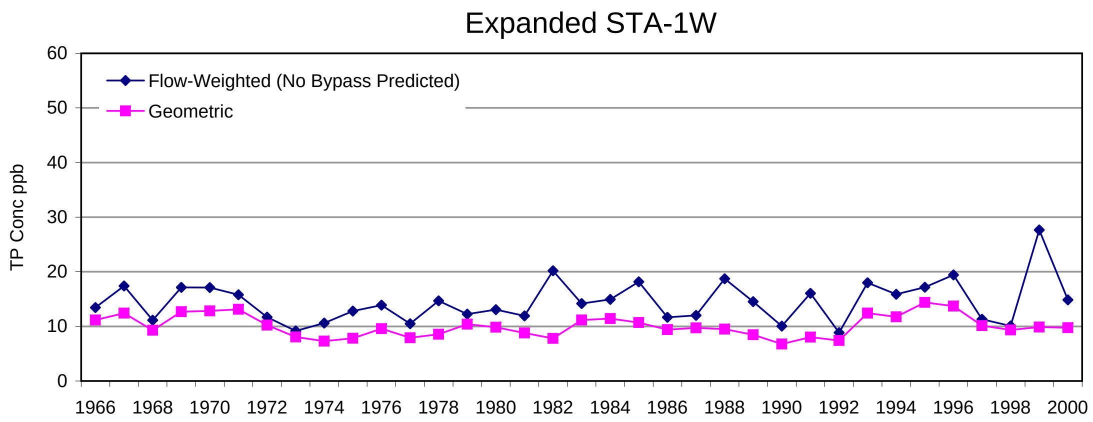
Higher HLR's are detrimental for the following reasons:

- Lower treatment efficiency
- Higher water depths, which may damage structures and/or vegetation
- Greater risk of hydraulic bypass (untreated discharge to Refuge)

Under Alt-1, ~15% of inflow occurs at HLR > 15 cm/d, vs. 0% for an expanded STA.

Figure 9
Yearly Outflow Concentrations for STA-1W Alternatives

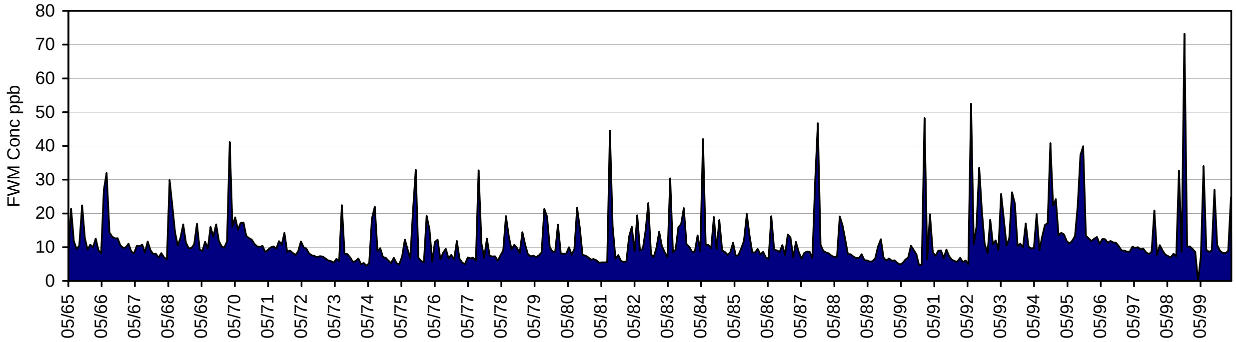




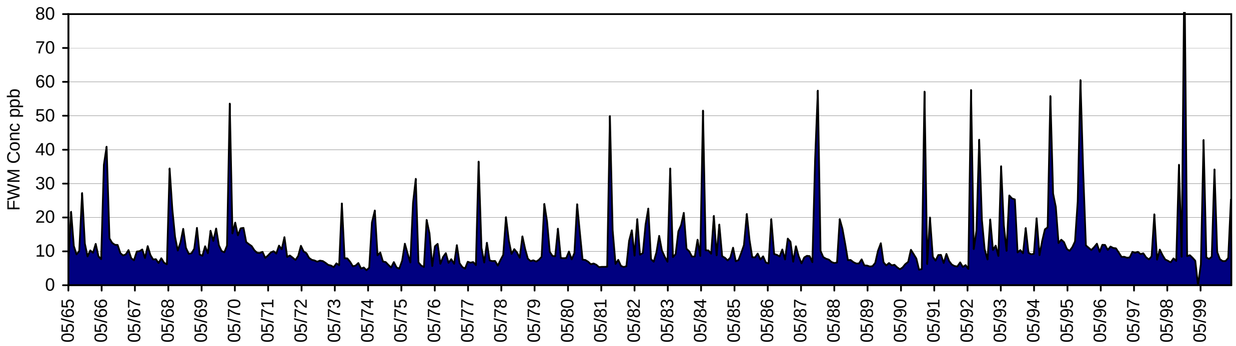
STA-1W expanded by 2.2 X (to 14,670 acres) to treat all basin runoff at recent inflow concentrations (~230 pppb).
Predicted long-term geometric-mean concentration = 10 ppb for each alternative.
Alt-1 has higher flow-weighted means because the diversion has greater percentage impact on low to medium flows.
This shifts the flow distribution towards high flows, when treatment efficiency of the STA is lowest.
For Alt-1, FWM exceeds 20 ppb in 11 out of 25 years (13 if bypass is included) vs. 2 out of 35 years for Expanded STA-1W
Bypass simulations are approximate and a more detailed hydraulic analysis would be needed to fully evaluate.

Figure 10
Monthly Outflow Concentrations for STA-1W Alternatives

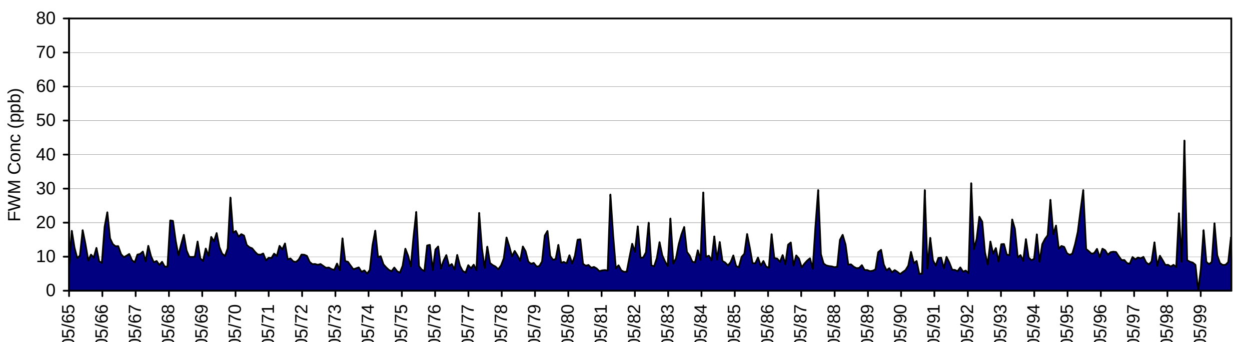
EAARFS Alternative 1 - Assuming No Bypass



EAARFS Alternative 1 - Including Potential Bypass



Expanded STA-1W



		LTFWM	Freq > 30 ppb
Top:	Alternative 1, STA outflow concentration assuming that all flow is treated (no hydraulic bypass); as assumed in EAARFS.	18.9	56%
Middle:	Alternative 1, FWM of STA outflow and untreated bypass, triggered when simulated STA water depth exceeds 4 feet.	20.8	64%
Bottom:	STA-1W expanded by 2.2 X to treat basin runoff at recent inflow concentrations (~230 ppb). No bypass is predicted.	15.1	8%

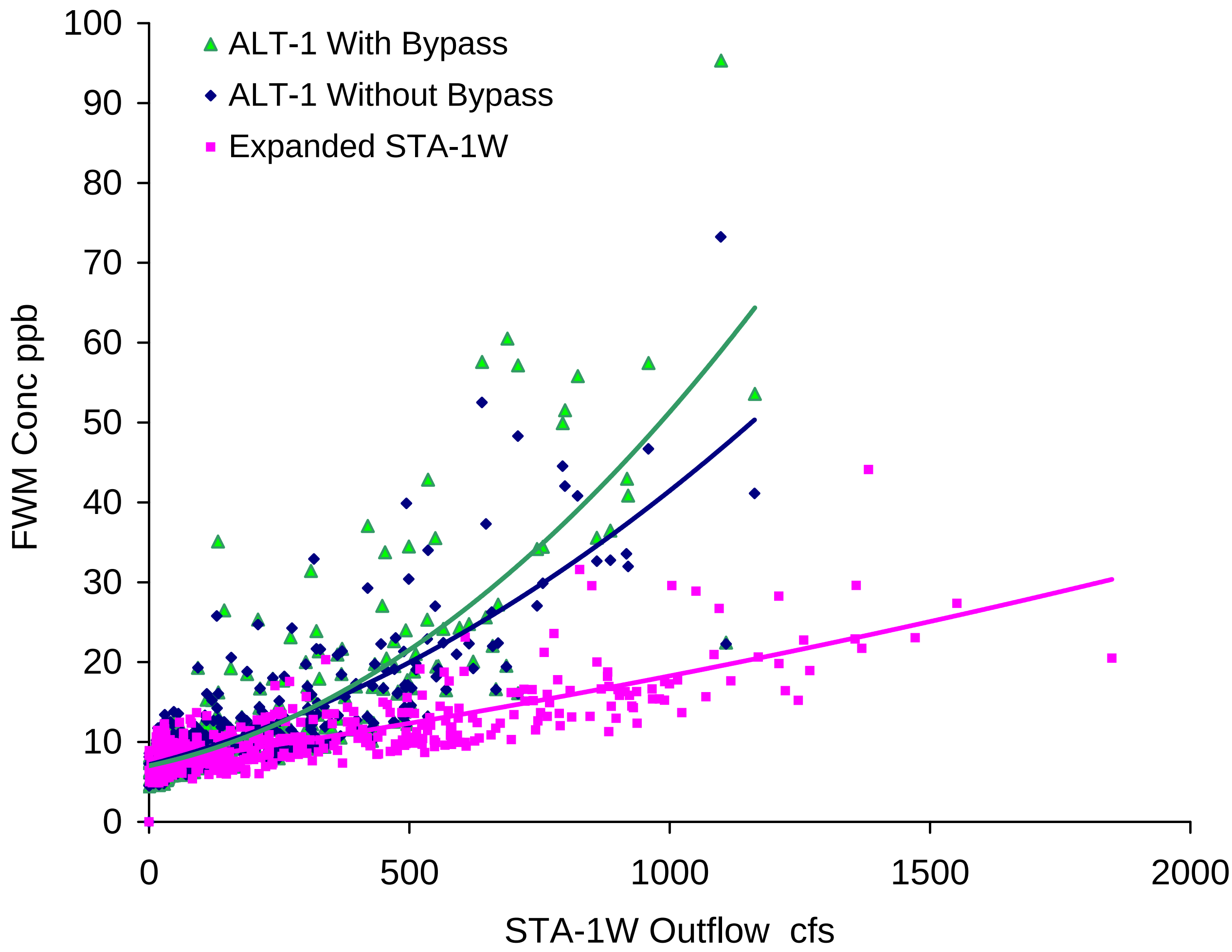
LTFWM — Long-term flow-weighted mean; Geometric mean ~ 10 ppb for each time series

Freq > 30 ppb — Percent of years with maximum monthly flow-weighted-means exceeding 30 ppb.

Concentration spikes occur in periods of high flow, when there is greater risk that discharge from the STA will penetrate the Refuge marsh.
Bypass simulations are approximate and a more detailed hydraulic analysis would be needed to fully evaluate.

Figure 11

Monthly Outflow Concentration vs. Flow for STA-1W Alternatives



Monthly flow-weighted-mean outflow concentration vs. outflow volume (35-year simulation).

STA-1W expanded by 2.2 X (to 14,670 acres) to treat all basin runoff at recent inflow conc. (~230 pppb).

ALT-1 With sypass results reflect combined untreated bypass & STA outflow. No bypass predicted for Expanded STA.

Lines are quadratic regressions to illustrate basic patterns

Each monthly time series has long-term geometric mean of ~10 ppb (without regard to flow)

Discharge from STA-1W is more likely to penetrate the Refuge marsh at high flows.

Compared with Alt-1, expanding STA-1W would provide more flow to the marsh at lower concentrations.