D R A F T

Analysis of Uncertainty in Shark River Slough TP Compliance Calculations

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Introduction

Hydrologic restoration plans for Everglades National Park (ENP) include changes in the magnitude and mode of flow delivery to Shark River Slough (SRS). In 2013, the Everglades Technical Oversight Committee (TOC) formed a subcommittee to develop a framework and methods for measuring flows and Total Phosphorus (TP) concentrations at new inflow structures. These are required to track compliance with the Long-Term Limits (LTLs) for the combined ENP inflow concentrations, as specified under the Settlement Agreement (USA & State of Florida, 1992). The state parties have raised concerns about the potential impact of uncertainty in the new measured flows and concentrations on risk of exceeding the LTLs.

One new inflow is the S356 pump station (currently operational) contains a mixture of inflows from the WCA-3B, which would be considered in measuring compliance, and from seepage flows recycled from ENP via the L31N canal, which would be excluded from the compliance calculations because they do not represent new inflows to the Park. While relatively precise measurements of S356 flows are made based upon pump records, measurement of recycled L31N flows would be less precise because they occur in an open channel that flows in two directions, depending on hydraulic conditions.

Another new inflow is the Blue Shanty (BS) flow-way, a feature of the Central Everglades Planning Project (CEPP) (Alternative 4R, USACOE, 2015), which would divert a portion of flow otherwise discharged thru S333 and send it thru a ~2,800 acre portion of WCA-3B marsh into Northeast SRS. While the BS flow-way would have a beneficial impact on compliance risk because of P removal along the flow-way, measurement of the combined outflows and flow-weighted-mean (FWM) concentrations would likely be subject to greater error, as compared with measurements of inflows and concentrations thru the existing structures that are used to determine compliance (S12ABCD, S333, S334, S356, S355AB). Estimation of total outflows would require integration of velocity measurements made in the open marsh along the degraded L-29 levee. Alternatively, the BS outflow volumes could be estimated with a simple water budget calculation after calibration. Likewise, estimation of FWM concentration would require grab sampling along a transect and integration with the flow measurements.

Despite the greater effort, the USGS has successfully made similar measurements of flow along ENP marsh transects (Schaffranek & Ball, 2016; USGS, 2006).

After nearly 5 years of intermittent discussions on the measurement error topic, the TOC subcommittee has been unable to reach agreement on a path forward. A more complete assessment of measurement errors associated with the compliance determinations in general might facilitate agreement on this topic. This report evaluates the uncertainty in the computed Shark River Slough (SRS) inflow volumes, concentration, and loads driven by random errors in the flow and concentration measurements at individual structures. Measurement errors are estimated based upon historical flow gauge calibration data and replicate TP samples collected at ENP inflow structures. Given the uncertainty in the measurement error estimates, ranges of values are assumed in the analysis. Flow and concentration sampling errors are expressed as percentages of the measured values. By applying a first-order error analysis (Walker, 1982), potential errors in the yearly flow-weighted-mean ENP inflow concentration (FWM), basin total flow, LTL, and the compliance metric (FWM-LTL) are estimated based upon data from Water Years 2008-2017. First-order analysis are confirmed by Monte Carlo simulation. Since significant flows thru S355AB and S356 occurred only in Water Year 2016, that year is used as the primary basis for estimating sensitivity to measurement errors and alternative magnitudes for S356 and L31N flows. Another scenario evaluates the potential impact of the CEPP Alternative 4R on the error estimates and compliance metrics.

Appendix A Theory

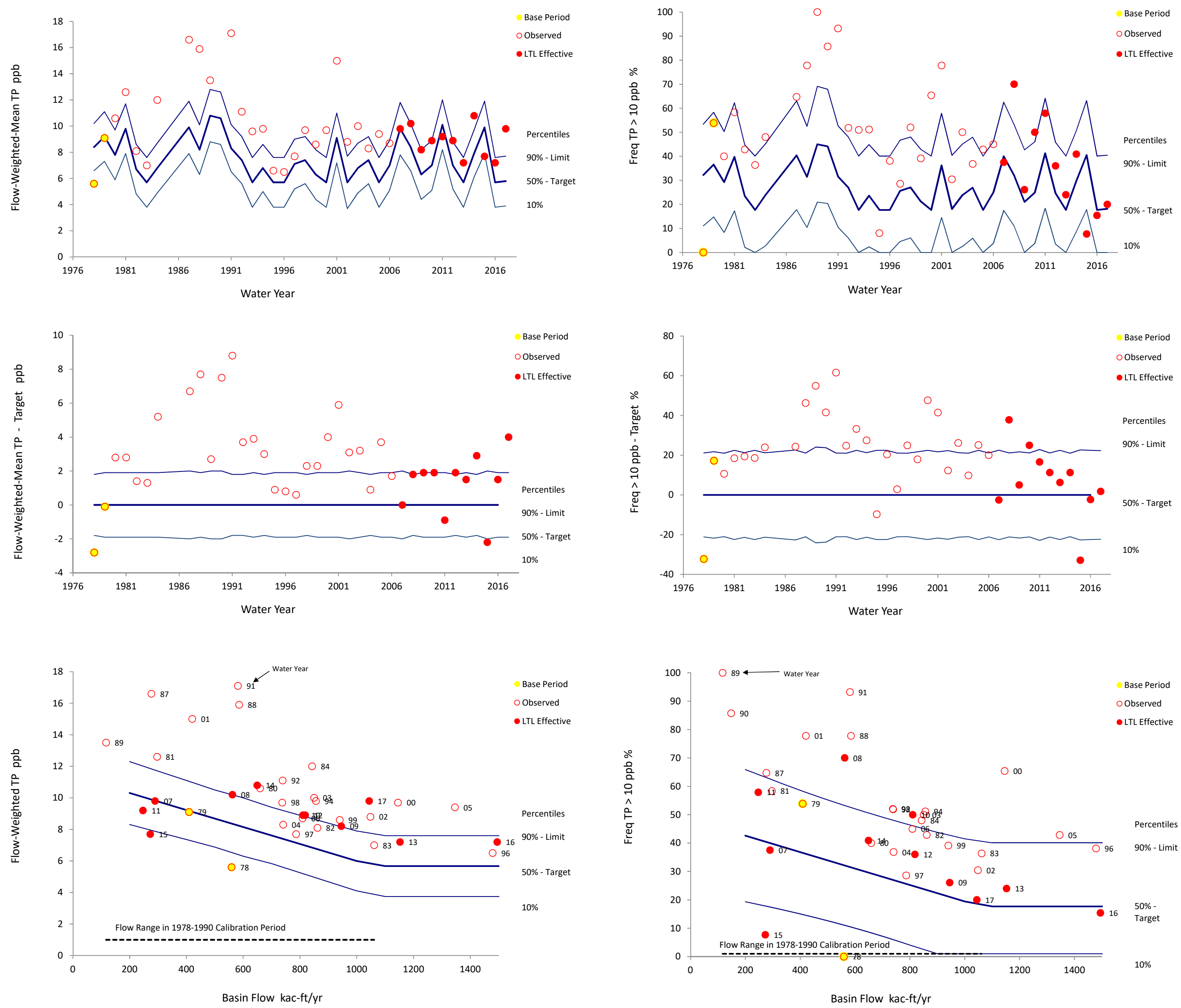
The Appendix A compliance model was developed from regression analysis of flow and concentration data collected between 1978 and 1990. Details of the underlying theory and derivations are contained in the 1992 Settlement Agreement (USA vs. State of Florida, 1992), Appendix E of the Everglades SWIM Plan (SFWMD,1993), Walker (2000), & Walker (2013). Tracking of ENP inflow concentrations and compliance over the 1978-2007 period is shown in Figure 1. The model considers three primary sources of variance in the annual flow-weighted-mean TP concentration (FWM) in SRS inflows:

- Hydrology. Variations correlated with basin total flow, which reflect wet-year vs. dry-year influences on water quality. Hydrologic factors correlated with basin flow include WCA-3A stage and rainfall. Analysis of 1991-2013 data collected after the Appendix A base period (Walker, 2013 , Slide 40) indicates that the slope of the negative correlation between FWM concentration and basin flow has not changed relative to the base period. Figure 2 extends the period of record thru WY 2017 and leads to the same conclusion.

- Trend. Variations correlated with time, to permit adjustment of the data to reflect the distribution of TP concentrations during the Outstanding Florida Waters (OFW) baseline period (1978-1979). Achieving compliance with the Settlement Agreement requires reduction of inflow TP concentrations to levels observed in that period. Analysis of 1991-2013 data (Walker, 2013, Slides 41 & 42) indicate that the long-term increasing trend observed in the 1978-1990 data has been

Figure 1

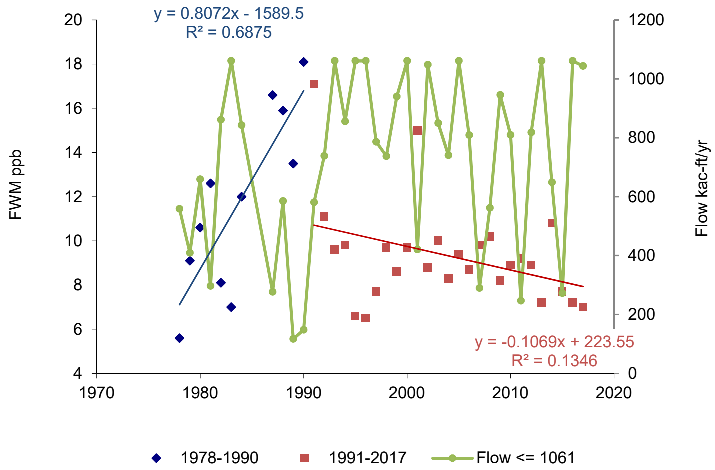
Compliance with Shark River Slough Long-Term Phosphorus Limits

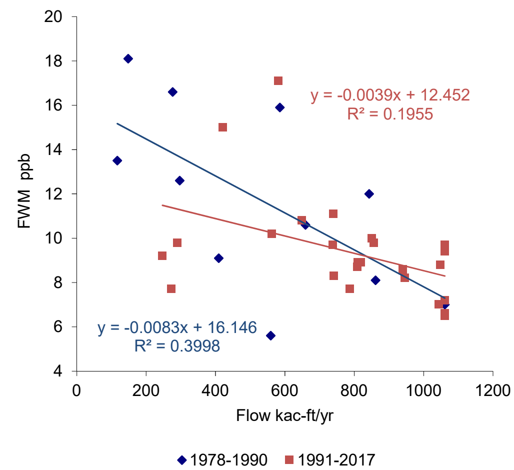


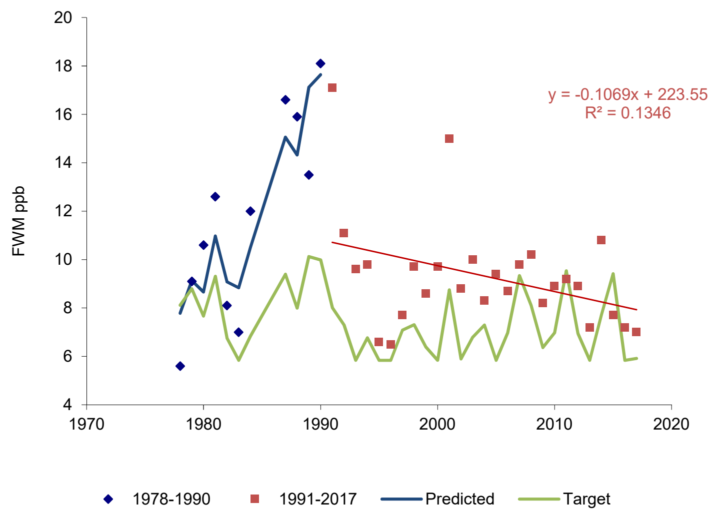
Base Period: Observed FWM, 1978-1979, OFW Base Period
Observed: Observed FWM, 1978 - 2006
LTL Effective: Observed FWM, 2007 - 2017, Long-Term Limits effective
WY 2017 Result: Attributed to Extraordinary Natural Phenomenon by TOC

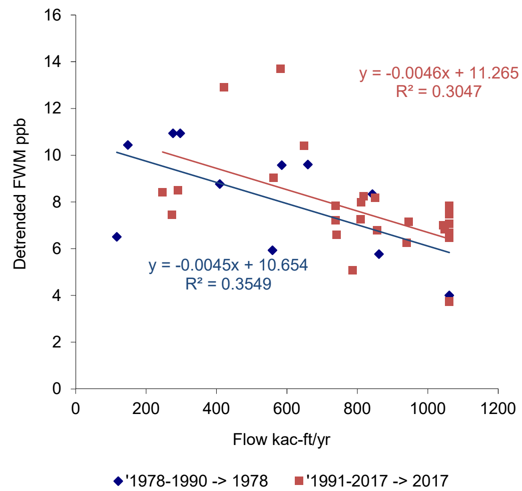
Figure 2

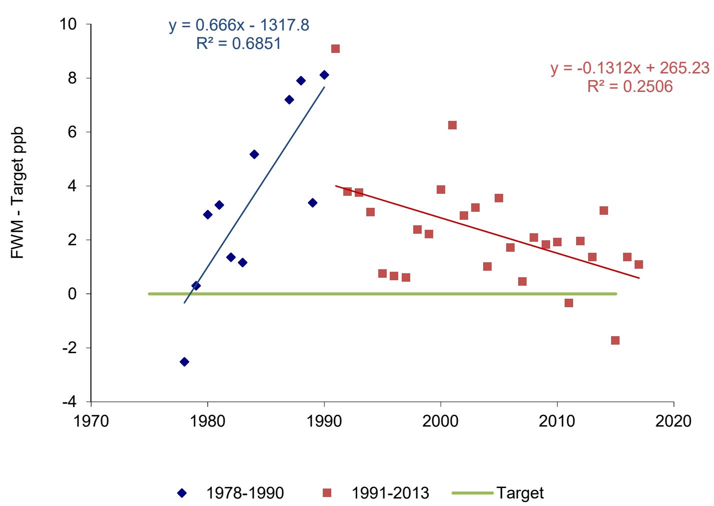
Analysis of Shark River Slough Inflow TP Compliance Data, 1978-2017











1991-2013 Flows Constrained to Max 1061 kac-ft/yr

Comparison of Conc vs. Flow Regression Slopes

Period	Slope	Std Error	t	p
Data				
1978-1990	-0.0083	0.0034	-1.18	0.25
1991-2013	-0.0039	0.0016		no change
Detrended				
1978-1990	-0.0045	0.0020	0.01	0.99
1991-2013	-0.0046	0.0014		no change

June 12, 2017 Sample Excluded (Extraordinary Natural Phen.)

reversed to the point where recent data are approaching compliance. Figure 2 extends the period of record thru WY 2017 and leads to the same conclusion.

- Random Variations. Attributed to natural variations that are not explained by flow or trend, uncertainty in the regression slopes for flow and trend, and random measurement errors. Measurement errors reflect random errors in flow measurements, laboratory phosphorus analyses, and sample collection.

The LTL used in compliance determinations is set at the upper 90th percentile of the expected distribution of measured values if the distribution were consistent with 1978-1979 conditions. The Long-Term Target (LTT) represents the 50th percentile of that distribution. The Appendix A calibration indicates the LTL exceeds the LTT by 1.8-2.1 ppb, depending on yearly basin flow. The difference between the LTL and LTT reflects the Random Variations term of the regression model. These variations have standard deviations of 1.3-1.5 ppb, depending on flow.

The objective of this analysis is to evaluate the measurement error component of the Random Variations term in the model and determine its effect on the compliance determination. Results indicate that the measurement error component of the Water Year 2016 FWM concentration (when all of the current inflow structures were monitored) was characterized by a standard deviation ranging from 0.11 to 0.14 ppb, depending on the assumed measurement errors in the structure daily flows and TP concentrations. This is very small relative to the total random deviation (1.3 to 1.5 ppb) inherent in the compliance model. In fact, the total measurement error is not much higher than the round-off scale (0.1 ppb) applied to the compliance calculations. It is therefore unlikely that measurement errors account for a significant portion of the total random variance already considered in the model. Flow measurement errors account for only 0.1 to 12.5% of the total error variance in the ENP inflow FWM concentration, while concentration measurement errors account for 87.7 to 99.9% of the total variance.

SRS Monitoring Network

Figure 3 shows the locations of current and future structures used for the Appendix A compliance determination. Following is a list of alternative combinations of structures used for computing the combined flow-weighted-mean concentration (FWM) and basin total flows that determine compliance:

1. S12A + S12B + S12C+ S12D + Max(0, S333-S334) + S355A + S355B

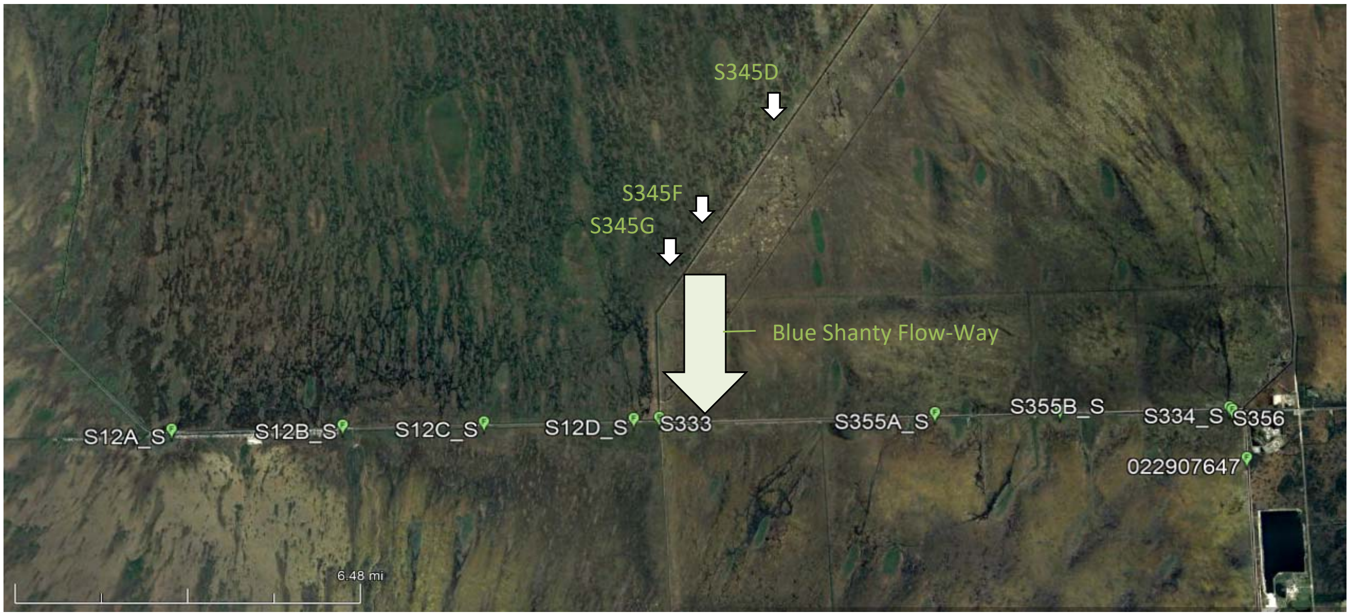
2. (1) + S356

3. (1) + (S356 – L31N)

4. (1) + (S356 – L31N) + Blue Shanty

Figure 3

Monitoring Network



022907647 = L31N Mile 1

CENTRAL EVERGLADES PLANNING PROJECT (CEPP) TENTATIVELY SELECTED PLAN – ALTERNATIVE 4R2

STORAGE AND TREATMENT

- Construct A-2 FEB and integrate with A-1 FEB operations
- Lake Okeechobee operation refinements within LORS

DISTRIBUTION/CONVEYANCE

- Diversion of L-6 flows, Infrastructure and L-5 canal improvements
- Remove western ~2.9 miles of L-4 levee (west of S-8 3,000 cfs capacity)
- 360 cfs pump station at western terminus of L-4 levee removal
- Backfill Miami Canal and Spoil Mound Removal ~1.5 miles south of S-8 to I-75

DISTRIBUTION/CONVEYANCE

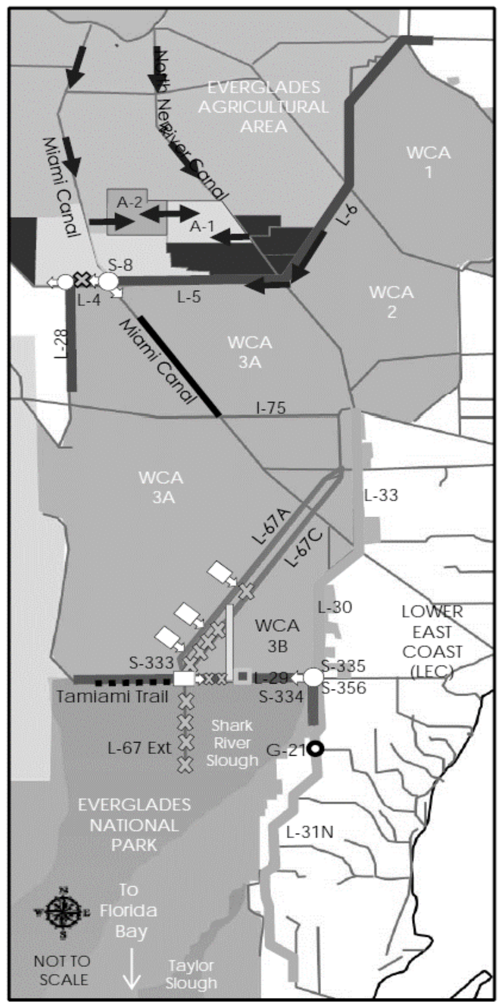
- Increase S-333 capacity to 2,500 cfs
- Two 500 cfs gated structures in L-67A, 0.5 mile spoil removal west of L-67A canal north and south of structures
- Construct ~8.5 mile levee in WCA 3B, connecting L-67A to L-29
- Remove ~8 miles of L-67C levee in Blue Shanty flowway (no canal back fill)
- One 500 cfs gated structure north of Blue Shanty levee and 6,000-ft gap in L-67C levee
- Remove ~4.3 miles of L-29 levee in Blue Shanty flowway, divide structure east of Blue Shanty levee at terminus of western bridge
- Tamiami Trail western 2.6 mile bridge and L-29 canal max stage at 9.7 ft (FUTURE WORK BY OTHERS)
- Remove entire 5.5 miles L-67 Extension levee, backfill L-67 Extension canal
- Remove ~6 mile Old Tamiami Trail road (from L-67 Ext to Tram Rd)

SEEPAGE MANAGEMENT

- Increase S-356 pump station to ~1,000 cfs
- Partial depth seepage barrier south of Tamiami Trail (along L-31N)
- G-211 operational refinements; use coastal canals to convey seepage

Note: System-wide operational changes and adaptive management considerations will be included in project.

FEB | STA | Pump | Backfill | Levee Removal | Seepage Barrier
Gated Structure | Divide | Levee | Old Tamiami Trail Removal



Method 1 represents the network utilized historically, before there was significant flow thru S356 and S355AB. Significant flows thru S355A and S355B first occurred in WY 2016, when their combined flows amounted to 1.1% of the total basin flow. Since no phosphorus samples were collected at S355A/B on the days when samples were collected at other structures for compliance determination, concentrations are estimated by interpolating between S355A/B sampling dates. While interpolation is not part of the official protocol for compliance calculations, it is performed for the purposes of the error analysis to provide complete concentration data for all inflow structures. While a slightly different formula would combine the S355AB and S333 flows before subtracting the S334 flows (Max(0, S333+S355AB-S334)), this has identical results for WY 2016 because there were no discharges thru S334 on days when S355AB was sampled for determining compliance.

Method 2 considers flows thru pump station S356. Substantial flow thru S356 first occurred in WY 2016. There has been considerable discussion among TOC representatives regarding the monitoring network and calculation methods to be utilized in the future, as S356 flows are expected to increase. Method 2 utilizes S356 flows and concentrations in computing the annual ENP inflow FWM and the Basin total flow used to compute the LTL. In Water Year 2016, S356 flow amounted to 3.4% of the total basin flow. Sensitivity to a hypothetical 2-fold increase in S356 flows is explored.

Method 3 also accounts for reverse (northerly) flows from L31-North, which are subtracted from S356 flows pumped into the Park. In WY 2016, L31N reverse flows measured at Mile 1 averaged 7.7% of the S356 flows. Reverse flows would essentially represent seepage recycled from ENP and not represent a new net source. Most of the S356 flow in WY 2016 apparently reflected seepage from WCA-3B and flows passing thru S335, which would represent net sources to ENP. Since future compliance calculations would be based upon flows measured at L31N Mile 0 located at the junction of L31N and L29 canals (not currently monitored) and seepage recycling would be expected to increase because of higher ENP marsh stages, it is likely that reverse flows would be higher than flows measured historically at Mile 1. Accordingly, reverse flows via L31N are assumed to represent 10-20% of the S356 flows (two scenarios) for purposes of this analysis. Alternative estimates for S356 and L31N can be easily explored.

Method 4 includes a hypothetical new inflow representing diversions from the L67 canal thru WCA-3B and the Blue Shanty (BS) flow-way (Figure 3). Based upon Regional Simulation Model (RSM, SFWMD (2005)) flows for CEPP Alternative 4R, this inflow is assumed to represent 46% of the historical inflow from S333. Approximately 16% would be diverted directly into WCA-3B via structure S345D and 30% would be diverted into the BS flow-way via S345F & S345G. For simulation purposes, TP concentrations in the L67 diversions are assumed to equal measured concentrations at S333. To account for P uptake along the WCA-3B/BS flow-way, TP concentrations in the discharges to Northeast Shark River Slough (NESRS) are assumed to equal the combined FWM concentration in discharges thru S12ABC, which have been representative of marsh sheet flow in recent years (~6 ppb). This scenario is intended to provide rough estimates of the impacts of measurement errors in BS flow and concentration on future compliance determination.

The assumption that BS outflow concentrations will be approximately equal to those typical of S12ABC (~marsh sheet flow) has been tested by applying DMSTA (Walker & Kadlec, 2005) to the BS flow-way and comparing the predicted outflow concentrations to those historically measured at S12ABC between 2000 and 2017 (Figure 4). A previous DMSTA calibration to WCA-3A (Walker, 2018) had a calibrated K value of 7 m/yr and a Z1 value of 75 cm (see DMSTA's P cycling Model). These compare with default calibrations of K = 16 m/yr and Z1=40 cm for an emergent marsh. The lower K value and higher Z1 value for WCA-3A likely reflect high topographic relief and short-circuiting of canal flows thru WCA-3A, especially under low stage conditions. The default value for Z1 (40 cm) is used in simulating the BS flow-way, which would have topographic relief more similar to the STA and wetland areas used to develop DMSTA's emergent calibration. Assuming the WCA-3A calibrated K value of 7 m/yr, Figure 4 shows that predicted average outflow concentrations agree with observed S12ABC concentrations in WY 2000-2017, particularly in later years after WCA-3A responded to reductions in external loads associated with STA implementation and S12ABC concentrations approached marsh background.

Corresponding DMSTA simulations of the BS flow-way using Regional Simulation Model (RSM) flow simulations for CEPP Alternative 4R are shown in Figure 5. Inflow concentrations are estimated using a regression equation the predicts TP concentrations at S12D+S333 as a function of WCA-3A stage and year (long-term trend). DMSTA simulations are compared with outflow concentrations predicted from a regression equation for TP concentration at S12A+S12B+S12C. Using the regression equations, the inflow and outflow concentration time series are detrended to Water Year 2017. The stage regression equations are derived from an ongoing effort to evaluate the effects of the Combined Operations Plan (COP) on ENP inflow TP concentrations (Walker, 2018). These results support the assumption that Blue Shanty and adjacent WCA-3B outflows to Northeast SRS will have concentrations similar to those measured at S12ABC.

Uncertainty in Flow Measurements

Potential flow measurement errors for the inflow structures are estimated based upon information provided by SFWMD (2017), Li & Ansar (2017), and Imru & Wang (2004) and by the USGS (2016). To reflect the uncertainty associated with the error assumptions, low, average and high estimates are developed for each structure. Low estimates reflect uncertainty in the regression slope relating measured flow to rated flow (computed from stage or pump operation), as assumed in SFWMD analyses of data from S333, S334, and S356 (cited above). High estimates reflect uncertainty in the regression slope plus residual errors (measured flow – rated flow). Because the instantaneous field measurements used for calibration of the rating curves are subject to error, the residual error over-estimates the error associated with the reported daily-mean values. The average error estimates used as a base case for sensitivity analyses are simply the average of the low and high estimates. All of the estimates assume that flow measurement errors

Figure 4

DMSTA Simulations of Blue Shanty Flow-Way Based upon Historical Data

Flows Diverted from S333, Inflow Concentrations Based upon Values Measured at S333

Observed Outflow Concentrations (Red Symbols) Based upon Values Measured at S12ABC

Observed Outflow Volumes = Predicted Outflow Volumes (No Data)

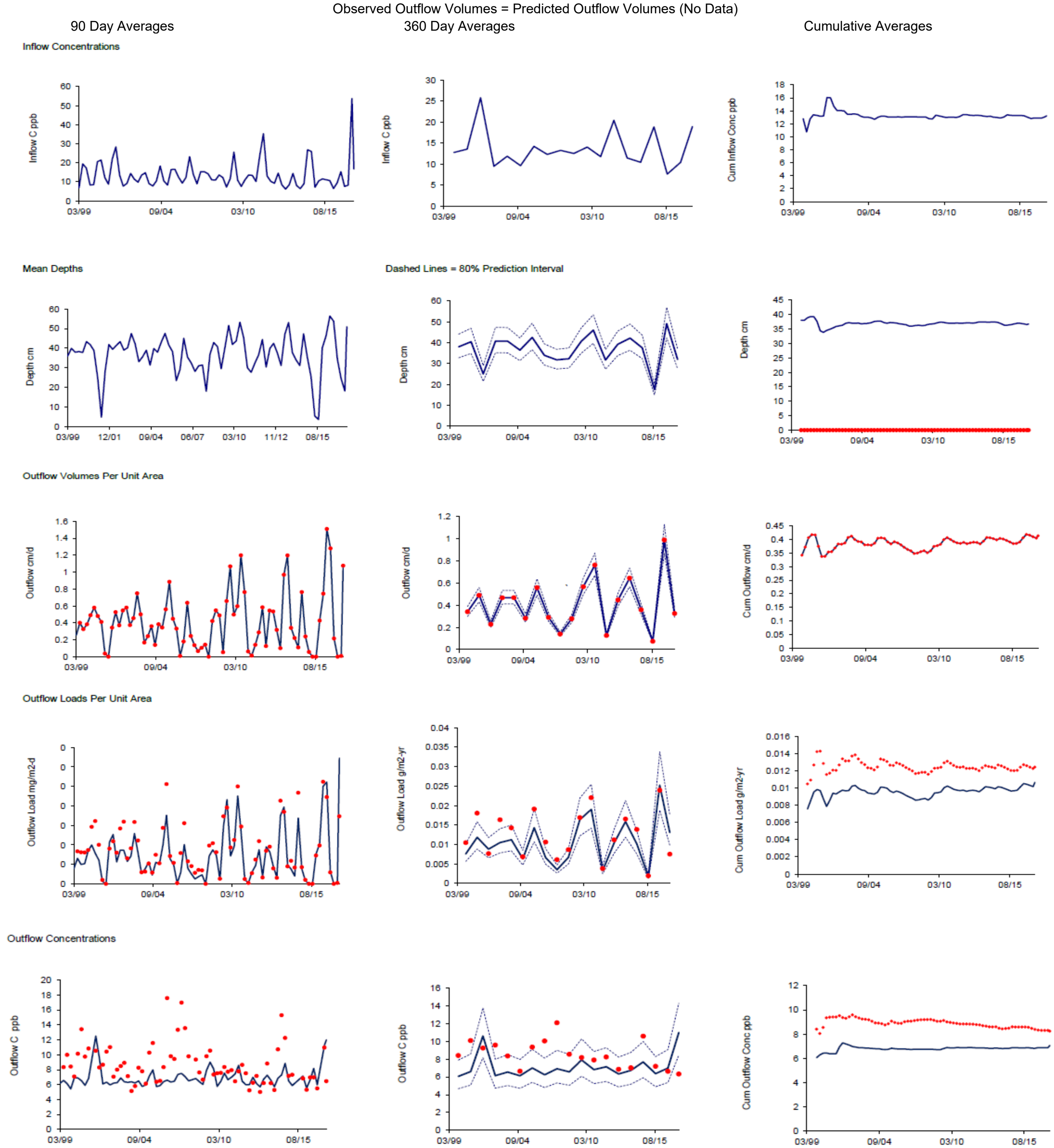


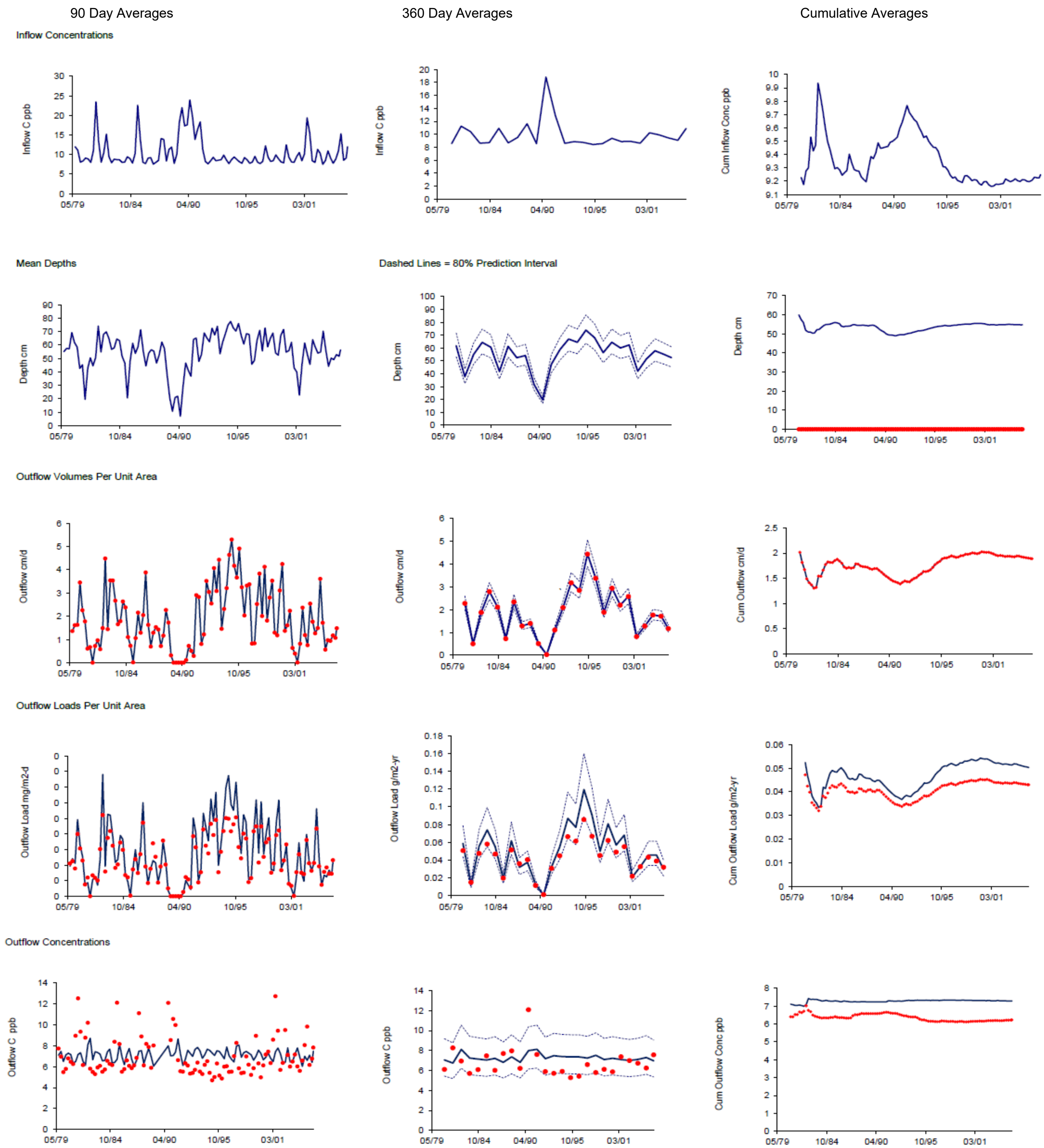
Figure 5

DMSTA Simulations of Blue Shanty Flow-Way Based upon RSM Flows

Inflows Based upon RSM Simulations (S345FG), Inflow Concentrations = S333/S12D Concentrations Predicted from WCA-3A Stage Regressions

Observed Outflow Concentrations (Red Symbols) = S12ABC Concentrations Predicted from WCA-3A Stage Regressions

Observed Outflow Volumes = Predicted Outflow Volumes (No Data)



are serially independent at a time scale of 14 days (sampling interval for Appendix A compliance determination). Serial independence was also assumed in the SFWMD analyses cited above.

Table 1 lists and graphs estimates of flow measurement error for each structure. Appendix A contains graphs of the daily flow calibration data and lists error statistics for each monitored inflow. Flow calibration data listed in the SFWMD reports are used to estimate measurement errors for S333, S344, and S356. Measurement errors in S12ABCD and L31N-Mile 1 flows are based upon historical flow rating curves and calibration measurements reported by the USGS (2016).

Error estimates are listed for 3 additional USGS stations along the L31N Canal at Miles 3, 4, & 7 (Table 1). While these are not used in the analysis, they provide a basis for comparison with the Mile 1 values. It is apparent that error estimates for L31N stations are higher than the error estimates for the other inflow structures used in the compliance determination. This reflects challenges in measuring flows in open channels. To provide a sensitivity analysis, measurement error estimates at Mile 0 (hypothetically used in the compliance calculation) are set at 100% or 300% of the Mile 1 values. Only 4 out of 56 calibration measurements at Mile 1 (Appendix A, Page A-8) were below zero, which reflects reverse flows that would be used in compliance determination. The analysis therefore assumes that error estimates based primarily on positive flow measurements are representative of negative flows.

Because the USGS makes frequent field measurements of flow at the S12 structures and interpolates errors (observed flow – rated flow) between the field measurement dates, it is likely that the daily flow measurement errors for these structures are over-estimated. An approximate adjustment for this interpolation process is made by reducing the residual variance by a factor $(1 - r^2)$, where r = correlation between residual error and date. This essentially removes any long-term trend from the residuals, which would contribute to serial correlation. The RSEs of the daily residuals range from 9 to 21% without adjustment and 8 to 16% with adjustment (Table 1). Removing the trend in the residuals still provides a conservative basis for the error analysis because it does not remove all of the serial correlation and the adjusted values still include random errors in the field flow measurements used for calibration of the rating curves.

Measurement error estimates for yearly flow data are needed for evaluating the uncertainty associated with the annual total basin flow used to compute the LTL. If flow measurement errors were serially independent on a daily basis, the standard error of the yearly flows would be 5.2% of the standard error of the daily flows ($1 / 365^{0.5}$). Because this is unlikely, the standard error in the yearly total flow is estimated by assuming an effective sample size equal to the number of sampling dates in each year (maximum 26). As noted above, errors in the biweekly sampled flows are assumed to be serially independent. With this assumption, the yearly standard errors would average 19.6% of the assumed daily standard errors ($1 / 26^{0.5}$), which vary by structure. While there is greater uncertainty in the yearly standard error estimates, alternative values can be easily tested. Since results indicate that LTL error variance is very small relative to

Table 1

Uncertainty in Daily & Yearly Flow Measurements

			Regression Observed vs. Rated			Daily Flows ----> Low RSE *						High RSE	Yearly Flows		USGS vs. COE Flows WY 2004-2011 RSE of Difference	
Structure	First	Last	Count	Slope	Slope SE	Slope RSE%	Mean Flow cfs	Resid SE cfs	Resid RSE%	Resid Corr with Date	Adj Resid RSE%	Total RSE%	Low RSE%	High RSE%	Daily	Yearly
S12A	07/31/08	08/09/17	52	0.928	0.011	1.2%	319	30	9.5%	-0.52	8.2%	8.3%	0.2%	1.6%	14%	6%
S12B	10/07/08	09/15/17	63	0.952	0.011	1.2%	343	35	10.2%	-0.41	9.3%	9.4%	0.2%	1.8%	14%	10%
S12C	10/01/99	09/15/17	160	1.027	0.011	1.0%	705	99	14.1%	-0.33	13.3%	13.3%	0.2%	2.6%	16%	11%
S12D	10/31/00	09/15/17	176	0.927	0.014	1.5%	659	141	21.3%	0.66	16.0%	16.1%	0.3%	3.2%	19%	8%
S333	04/07/83	06/26/14	34	0.829	0.014	1.7%	686	74	10.8%		10.8%	10.9%	0.3%	2.1%		
S334	04/17/98	10/15/13	12	0.712	0.019	2.7%	330	35	10.6%		10.6%	10.9%	0.5%	2.1%		
S355B	no calibration data															
S355A	no calibration data															
S356	-----2005 -----		4	0.966	0.003	0.3%	323	2.4	0.7%		0.7%	0.8%	0.1%	0.2%		
L31N - M1	11/01/08	09/07/16	56	0.931	0.022	2.3%	391	87	22.2%		22.2%	22.4%	0.5%	4.4%		
L31N - M3	09/16/04	10/23/15	45	1.001	0.016	1.6%	453	60	13.3%		13.3%	13.4%	0.3%	2.6%		
L31N - M4	03/21/07	09/07/16	57	0.980	0.030	3.1%	436	90	20.5%		20.5%	20.8%	0.6%	4.1%		
L31N - M7	08/09/94	10/25/16	108	0.945	0.011	1.1%	498	69	13.8%		13.8%	13.9%	0.2%	2.7%		

Slope based upon regression of measured instantaneous flows against rated flows, zero intercept

Values used in uncertainty Analysis

L31N values assume the current DBHYDRO values are based upon calibrated rating equation.

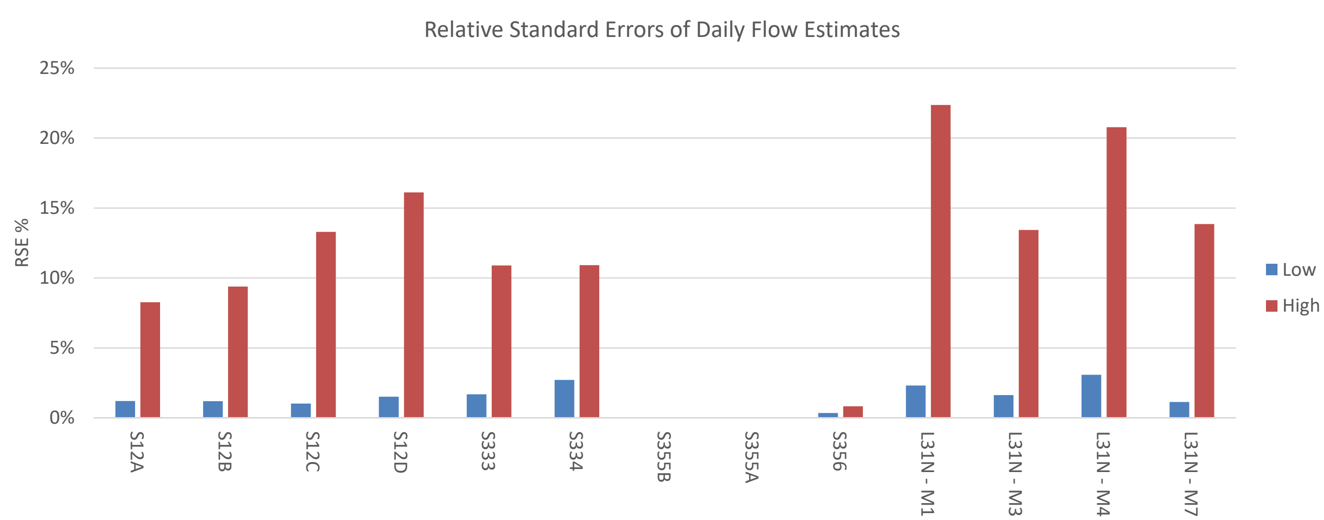
* Slope RSE% = Method used in SFWMD Document: "Uncertainty Analysis for S333 and S334", 2017.

Total RSE % = [(Slope RSE%)2 + (Adj Resid RSE %)2] 0.5

Effective sample size used in computing yearly RSEs based upon daily RSEs = 26

S12X residual RSEs approximately adjusted for trend to account for interpolation of deviations from rating curve by USGS.

Adj RSE = RSE (1 - r2) 0.5



the ENP Inflow FWM error variance, the impact of uncertainty in the annual flow measurements on errors in the compliance metric (FWM – LTL) is small.

In addition to measurement error, differences between the provisional S12ABCD flows reported by the Corps of Engineers and the final values reported by the USGS also contribute to error in the flows historically used for determining compliance. Prior to WY 2012, provisional flows reported by the USGS and obtained via the COE were utilized in determining compliance. Since WY 2012, the compliance determination has been deferred until the final versions of the USGS flow estimates are available. Assuming that the final values are more accurate than the provisional values, the flows used for compliance determination prior to WY 2012 are subject to an additional error component. Differences between the COE flows and final USGS flows (from DBHYDRO preferred keys) on a daily and annual basis for Water Years 2004-2011 are shown in Appendix A (pages A-8, A-9). The standard deviations of the differences are 14-19% on a daily basis and 6-11% on a yearly basis. The total error variance in the daily and annual flows in Water Years prior to 2012 is assumed to equal the sum of the variance due to measurement error and the variance due to the differences between the provisional and final flow data.

All of the measurement error estimates assume that the flow gauges have been adequately calibrated to provide unbiased estimates. A report by SFWMD (2017) indicates that the rating curves utilized to compute DBHYDRO daily flows thru S333 and S334 were based upon default values for the discharge coefficient (0.75). Regressions of flow calibration measurements against rated flows (Appendix A, Page A-5) indicate discharge coefficients of 0.829 +/- 0.014 for S333 and 0.712+/-0.019 for S334 (Page A-6). The periods of record were 1984–1998 (34 dates) for S333 and 1999-2013 (12 dates) for S334. This indicates that S333 DBHYDRO daily flows under-estimate the actual values by an average of 9.5% (1-.75/.829). Similarly, S334 DBHYDRO flows over-estimate the actual values by 5.3% (0.75/0.712 -1). Applied to the WY 2016 sampled flows, the S333-S334 flow difference computed from DBHYDRO data under-estimates the true value by 16%. This bias is ignored for purposes of the error analysis, but it is worthy of further consideration by the TOC subcommittee because it could have a significant impact on compliance determinations and on evaluating the benefits of restoration projects designed to increase flows to NESRS. 1984-1998

Uncertainty in Concentration Measurements

Uncertainty in TP concentration measurements is estimated based upon 204 pairs of field replicate grab samples collected at all ENP inflow structures between 1993 and 2017, as retrieved from DBHYDRO (SFWMD, 2017). The total error variance among field replicates is attributed to variance in laboratory TP analyses and variance in sample collection. To account for improvement in the precision of laboratory measurements in WY 2003, when the TP minimum detection limit decreased from 4 to 2 ppb, the calibration dataset is divided into two periods: WY 1993-2002 (132 pairs) and WY 2003-2016 (72 pairs). Figure 6 shows results and error statistics for each period. Relative standard deviations among field replicates are 10.0% for WY 1993-2002 and

Figure 6

Estimation of Uncertainty in TP Concentration Measurements

Lab Analytical Error

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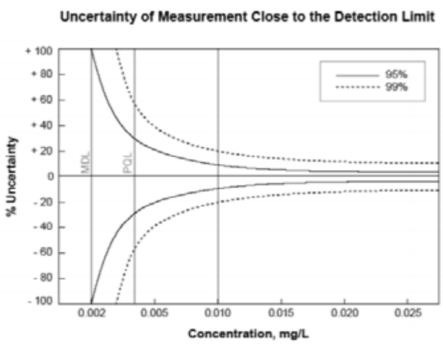


Figure 1. Estimated uncertainties at the 95% and 99% CI relative to the MDL and PQL of the TP measurement process.

Pooled Estimates of Replicate Sample Error, TP < 20 ppb
Includes Sampling Error & Lab Analytical Error

Water Years	1993-2002	2003-2017
Paired Replicates	132	72
Mean ppb	9.3	8.7
Std Deviation ppb	0.93	0.66
Rel Std Dev (CV) % Used in Error Analysis	10.0%	7.6%

Uncertainty in Lab Measurement
WY 2003-2017 (MDL = 2 ppb)

Conc	95%	Rel Error	Std Error
2	100%	51.0%	1.02
3	50%	25.5%	0.77
5	23%	11.7%	0.59
10	8%	4.1%	0.41
15	4%	2.0%	0.31

Variability in Replicate Samples - 2 Intervals , WY 2003-2017

Interval	Mean	Count	Rel SD	Std Dev
<10 ppb	6.4	50	7.8%	0.50
10-20 ppb	13.9	22	7.4%	1.03

Variability in Replicate Samples - 2 Intervals , WY 1993-2002

Interval	Mean	Count	Rel SD	Std Dev
<10 ppb	6.9	86	12.4%	0.85
10-20 ppb	13.7	46	7.8%	1.07

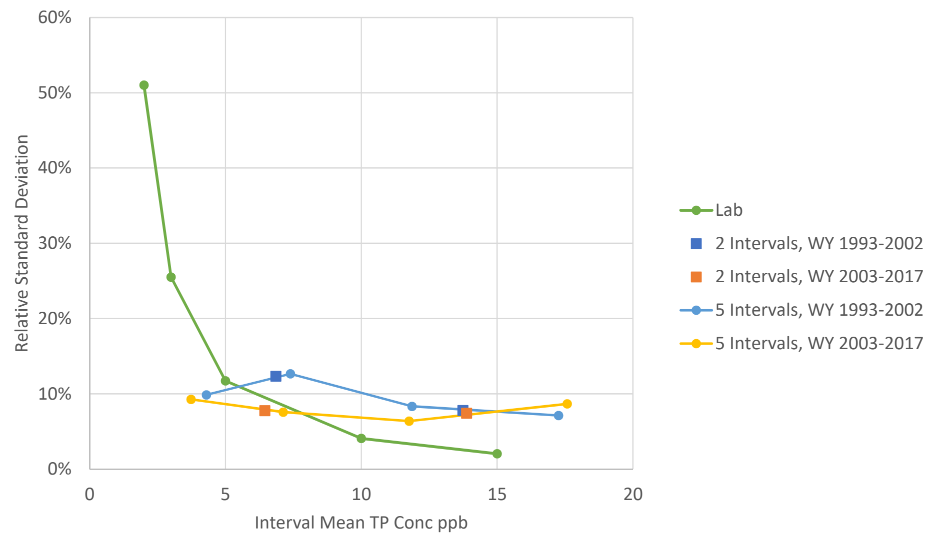
Variability in Replicate Samples - 5 Intervals , WY 2003-2017

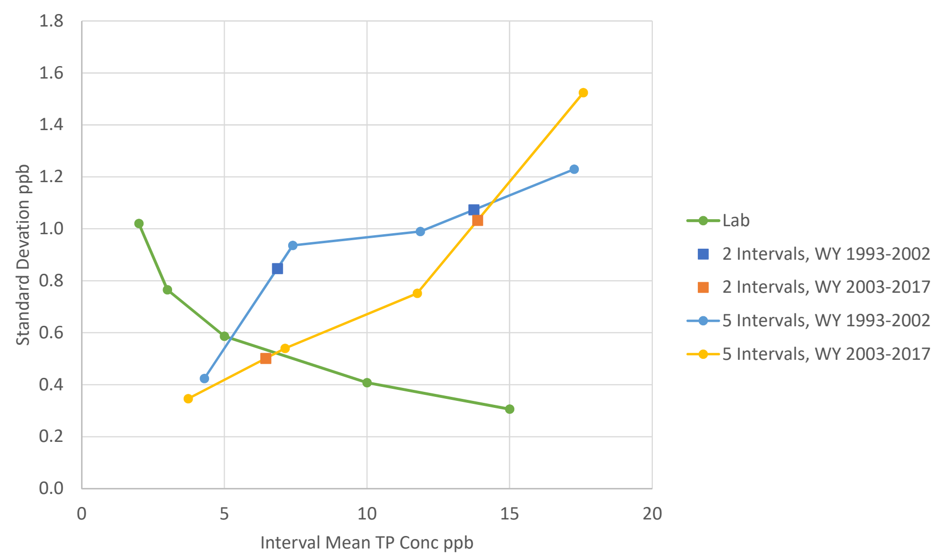
Interval	Mean	Count	Rel SD	Std Dev
<=5	3.7	10	9.3%	0.35
6-10	7.1	40	7.6%	0.54
11-15	11.8	14	6.4%	0.75
16-20	17.6	8	8.7%	1.52

Variability in Replicate Samples - 5 Intervals , WY 1993-2002

Interval	Mean	Count	Rel SD	Std Dev
<=5	4.3	15	9.9%	0.42
6-10	7.4	71	12.7%	0.94
11-15	11.9	30	8.3%	0.99

Paired Replicate Samples, ENP Structure Sites, WY 1996-2017





7.6% for WY 2003-2016. The reduction is consistent with the improvements in the precision of laboratory P measurements and, perhaps, refinements to sampling methods and QA/QC procedures.

The confidence intervals for laboratory analyses after WY 2002 (SFWMD, 2016) are plotted against TP concentration in the upper left corner of Figure 6. These correspond to relative standard errors ranging from ~50% to ~2% for TP concentrations ranging from ~2 to ~15 ppb (Figure 6 upper right). Most of the decrease occurs at concentrations between 2 and 4 ppb, which are rarely reported at the ENP inflow structures. To estimate the total replicate variance, paired samples with average concentrations below 20 ppb are binned into 5 concentration intervals. As compared with the variance associated with laboratory analyses, the variance among field replicates is much more stable, with relative standard deviations ranging from ~10% to ~8% for TP concentrations ranging from ~4 to ~18 ppb. As shown in the lower right of Figure 6, the total standard error expressed in concentration units varies from 0.5 to 1.5 ppb over the same concentration range. Pooled estimates of relative standard error (10% and 7.6%) for the two time periods are used in the uncertainty analysis.

Error Analysis Framework

A first-order error analysis is utilized to estimate the standard error of ENP inflow FWM and Long-Term Limit based on flows and concentrations measured in a given water year and the assumed measurement errors in flow and concentration. The FWM analysis also requires estimates of the relative standard error (RSE) associated with daily flows and sampled TP concentrations on dates used for compliance determination. The LTL analysis requires estimates of the RSE associated with the total annual flow thru each structure.

The general formulas for a first order error analysis applied to estimate the combined inflow volume, load, and FWM concentration from a given structure and water year are:

$$Y = F\ (Q_1, Q_2, Q_3,..Q_N, C_1, C_2, C_3,.. C_N)$$

$$\mathrm{Var}\ (Y) = \mathrm{Sum}_N\ [\ (dF / dQ_i)^2\ \mathrm{Var}\ (Q_i) + (dF / dC_i)^2\ \mathrm{Var}\ (C_i)\ ]$$

$$\mathrm{Var}\ (Q_i) = (Q_i\ eQ)^2$$

$$\mathrm{Var}\ (C_i) = (C_i\ eC)^2$$

Where,

Y	=	Computed value (flow, load, or FWM concentration)
Sum_N	=	Sum across N sampling dates
Q_i	=	Observed flow on sampling date i
C_i	=	Observed concentration on sampling date i
eQ	=	Flow measurement error, as a fraction of the reported value
eC	=	Concentration measurement error, as a fraction of the reported value
dF/ dQ_i	=	First derivative of F with respect to Q_i
dF/ dC_i	=	First derivative of F with respect to C_i

Var () = Measurement error associated with a given variable

This formula assumes that the measurement errors for flow (eQ) and FWM concentration (eC) are expressed as relative standard errors (fraction of measured value), that the errors are serially independent, and that measurement errors in flow and concentration are independent of each other. Note that the measurement relative standard errors (eQ, eC) are not the same as the relative standard deviations of the reported measurements, which are typically much higher.

After some algebra, the corresponding equations for the water-year total flow, load, and FWM concentration for a given structure and water year are:

$QT = Sum_N (Q_i)$

$Var(QT) = Sum_N (Q_i \; eQ)^2$

$LT = L_f \; Sum_N (Q_i C_i)$

$Var(LT) = Sum_N (Q_i^2 C_i^2) (eQ^2 + eC^2)$

$FWM = LT / QT / L_f$

$Var(FWM) = Sum_N [(Q_i C_i)^2] / QT^2 eC^2 + Sum_N [(Q_i (C_i - FWM))^2] / QT^2 eQ^2$

Where,

Q_i	Daily flow on sampling date i (cfs)
C_i	Concentration on sampling date i (ppb)
QT	Total sampled flow across all sampling dates (cfsd)
LT	Total sampled load across all sampling dates (kg)
eQ	Assumed relative standard error of daily flow measurements
eC	Assumed relative standard error of concentration measurements
FWM	Combined flow-weighted-mean concentration at given structure (ppb)
L_f	Load units conversion factor = 0.00245 kg/cfsd-ppb

Since measurement errors are assumed to be independent across structures, the totals and variances for flow and load are summed across structures to compute the totals and variances of the combined ENP inflow:

$QTS = Sum_M (QT_j)$

$LTS = Sum_M (LT_j)$

$FWMS = LTS / QTS / L_f$

$Var(QTS) = Sum_M (Var (QT_j))$

$Var (LTS) = Sum_M (Var (LT_j))$

$Var(FWMS) = Sum_M [(QT_j \; FWM_j \; eFWM_j / QTS)^2] + Sum_M [(QT_j (FWM_j - FWMS) \; eQTS / QTS)^2]$

Where,

Sum_M	=	Total across M structures
QT_j	=	Total sampled flow for structure j across all sampling dates (cfsd)
LT_j	=	Total sampled load for structure j across all sampling dates (kg)
QTS	=	Total annual flow on sampling dates across all structures (cfsd)
LTS	=	Total annual load on all sampling dates across all structures (kg)
FWMS	=	Combined annual FWM concentration for ENP inflows (ppb)
eFWM	=	Relative standard error of FWM for a given structure (fraction)
eQTS	=	Relative standard error of total sampled flow for a given structure (fraction)

The formulas for estimating the total and error variance of the basin total annual flow are:

$$QTY_j = Sum_D (Q_d)$$

$$QTYB = Sum_M (QTY_j)$$

$$Var (QTY_j) = (QTY_j \; eQY_j)^2$$

$$Var (QTYB) = Sum_M (Var (QTY_j))$$

Where,

Q_d	=	Daily mean flow on day j for given structure and year
QTY_j	=	Total annual flow for structure j
Sum_D	=	Sum over all days in the water year
QTYB	=	Basin total annual flow summed over M structures
Sum_M	=	Sum over M structures
eQY_j	=	Assumed relative standard error of the annual total flow for structure j

The formulas for estimating the LTL and its error variance are:

For basin total flow <= 1061 kac-ft/yr:

$$LTL = 11.38 - 0.00538 \; QTYB + 1.397 \; (2.493 - 0.00231 \; QTYB + 0.0000017 \; QTYB^2)^{0.5}$$

$$Var(LTL) = [d \; LTL / d \; QTYB]^2 \; Var (QTYB)$$

$$d \; LTL / d \; QTYB = -0.00538 + (-0.00161+0.000002375 \; QTYB) \times (2.493-0.00231 \; QTYB +0.0000017 \; QTYB^2)^{-0.5}$$

For basin total flow > 1061 kac-ft/yr:

$$LTL = 7.6 \text{ ppb}$$

$$Var (LTL) = 0$$

The formulas for estimating the Long-Term Target (LTT, ppb) and its error variance are:

For basin total flow <= 1061 kac-ft/yr:

$$LTT = 11.38 - 0.00538 \; QTYB$$

$$Var(LTT) = [d \; LTT/ d \; QTYB]^2 \; Var (QTYB)$$

d LTT / d QTYB = -0.00538

For basin total flow > 1061 kac-ft/yr:

LTT = 5.7 ppb

Var (LTT) = 0

Results

Tables 2 and 3 contain results of the error analysis applied to data from Water Year 2016. Assumptions and results for the sampled flows, loads, FWM concentrations, basin total flows, and LTLs are shown. While the FWMs and LTLs are normally rounded to the nearest 0.1 ppb in determining compliance, they are not rounded here to show sensitivity and increase error analysis precision. Details include partitioning of sampled flows and loads across the inflow structures. Totals are presented for the three combinations of structures described above. Daily flows at S334 exceeding those measured at S333 are not utilized in the calculations; accordingly, they are excluded from the water balance and error calculations. The remaining S334 flows and loads are subtracted from those measured at S333, but the error variances in the S334 flows and loads are added to the S333 values.

Table 2 shows results for average flow measurement errors and concentration errors for the 2003-2017 period. Rounded to the nearest 0.1 ppb, the combined FWM inflow concentration is 7.2 ppb for each of the three combinations of structures. The standard error of the FWM is 0.12 ppb, or 1.7% of the combined FWM concentration for each combination of structures. These results reflect the fact that flows thru S356 and S355AB amounted to only 5% of the total sampled inflow. Table 3 shows the corresponding results for the Basin total flow, LTL, and compliance metrics.

Figure 7 shows the partitioning of error variance sources across structures for sampled flow, sampled load, and basin total flow. Structures S12D, S333, & S334 account for a net total of 60% of the sampled flow and 66% of the total sampled load. The combined measurement errors for S12D, S333, & S334 account 79% of the error variance in the total sampled flow and 92% of the error variance in the total sampled load.

The LTL is 7.6 ppb and the standard error of the limit is 0 ppb for each combination of structures. This reflects the fact that the WY 2016 basin total flow exceeded 1,061 kac-ft/yr, above which the LTL is independent of basin flow.

For all structures combined, the compliance metric (FWM-LTL) is -0.43 ppb and it’s standard error is 0.12 ppb (rounded to 2 decimal places) for each combination of structures. The standard error is small relative to the total random error inherent in the Appendix A model (1.40 ppb). Expressed in terms of variance (standard error squared), flow and concentration measurement errors account for 0.8% of the inherent model error.

Table 2

Error Analysis for Annual Flow-Weighted-Mean Concentration   Average Flow Error

Water Year 2016   Scenario: Average Flow Error

Summary of Results	Basin Total Flow kac-ft/yr			FWM Concentration ppb							% of Error Due to Flow Meas		
Structures	Total	Std Error	RSE	Target	Limit	Limit SE	RSE	FWM	FWM SE	RSE	Flow	Conc	Load
S12X+(S333-S334)+BS+S355AB	1445	11.5	0.8%	5.67	7.60	0.00	0.0%	7.24	0.128	1.8%	100%	15%	45%
+S356	1495	11.5	0.8%	5.67	7.60	0.00	0.0%	7.19	0.122	1.7%	100%	15%	45%
+S356-L31N	1490	11.5	0.8%	5.67	7.60	0.00	0.0%	7.19	0.123	1.7%	100%	15%	45%

	Water Year Sample Data				Sum of Squares					Assumed		Variance of Annual Total			Total as % of Net Inflow		Variance as % of Net Inflow		Relative Std Error			Standard Error			% Error Due to Flow Meas		
Structure	Sampled Flow cfsd	FWM Conc ppb	Sampled Load kg	Samples	Flow	Conc	Load	C - FWM	Q x (C - FWM)	Flow RSE	Conc RSE	Flow	Conc	Load	Flow	Load	Flow	Load	Flow	Conc	Load	Flow	Conc	Load	Flow	Conc	Load
S12A	1303	6.3	20	6	307017	244	72	3.4	247709	4.7%	7.6%	688	0.0414	0.58	2.8%	2.4%	0.3%	0.2%	2.0%	3.2%	3.8%	26.2	0.203	0.76	100%	1%	28%
S12B	1879	6.2	29	7	585945	299	134	9.9	473150	5.3%	7.6%	1641	0.0370	1.15	4.0%	3.5%	0.6%	0.4%	2.2%	3.1%	3.7%	40.5	0.192	1.07	100%	1%	33%
S12C	12915	5.9	186	24	9793435	1095	1820	77.9	18287907	7.2%	7.6%	50239	0.0111	19.88	27.5%	22.6%	19.9%	6.5%	1.7%	1.8%	2.4%	224.1	0.105	4.46	100%	5%	47%
S12D	17297	7.2	305	26	14271081	1721	4167	145.6	73530671	8.8%	7.6%	110827	0.0154	56.51	36.9%	36.9%	43.8%	18.5%	1.9%	1.7%	2.5%	332.9	0.124	7.52	100%	12%	57%
S333	17579	10.8	466	25	17367196	2919	15479	501.3	491991940	6.3%	7.6%	68740	0.0548	150.96	37.5%	56.4%	27.2%	49.5%	1.5%	2.2%	2.6%	262.2	0.234	12.29	100%	12%	41%
-S334	-6587	13.8	-222	14	4195483	2138	7116	442.0	142556255	6.8%	7.6%	19502	0.1740	74.31	-14.0%	-26.9%	7.7%	24.4%	2.1%	3.0%	3.9%	139.6	0.417	8.62	100%	9%	45%
Blue Shanty	0	0.0	0	0	0	0	0	0.0	0	18.9%	0.0%	0	0.0000	0.00	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	0.000	0.00	100%	0%	0%
S355B	607	9.2	14	4	93778	376	51	37.3	790446	8.5%	7.6%	678	0.1510	0.67	1.3%	1.7%	0.3%	0.2%	4.3%	4.2%	6.0%	26.0	0.389	0.82	100%	10%	55%
S355A	12	6.0	0	1	144	36	0	0.0	0	8.5%	7.6%	1	0.2086	0.00	0.0%	0.0%	0.0%	0.0%	8.5%	7.6%	11.4%	1.0	0.457	0.02	100%	0%	55%
S356	2132	6.0	31	12	564999	734	125	109.4	564964	3.0%	7.6%	508	0.0267	0.84	4.5%	3.8%	0.2%	0.3%	1.1%	2.7%	2.9%	22.5	0.163	0.91	100%	0%	13%
-L31N	-213	6.0	-3	12	5650	734	1	109.4	5650	12.3%	7.6%	86	0.0285	0.03	-0.5%	-0.4%	0.0%	0.0%	4.4%	2.8%	5.2%	9.3	0.169	0.16	100%	7%	72%
Net Inflow																											
S12X+(S333-S334)+BS+S355AB	45005	7.24	797	107								252315	0.016	304	96%	97%	99.8%	99.7%	1.1%	1.8%	2.2%	502.3	0.128	17.44	100%	15.4%	45%
+S356	47137	7.19	829	119								252823	0.015	305	100%	100%	100.0%	100.0%	1.1%	1.7%	2.1%	502.8	0.122	17.46	100%	15.5%	45%
+S356-L31N	46923	7.19	826	131								252909	0.015	305	100%	100%	100.0%	100.0%	1.1%	1.7%	2.1%	502.9	0.123	17.46	100%	15.5%	45%

Equations	Total	Variance of Total	Relative SE of Total	Standard Error of Total	% Error Due to Flow Meas
Total Across Samples at Each Structure					
Total Sampled Flow	QT = Sum (Q)	VQT = Sum (Q^2) eQ ^2	eQT = SQT / QT	SQT = VQT^0.5	fqQT = 100%
Total Sampled Load	LT = Sum (Q x C x LF)	VLT = Sum [(Q C LF)^2] (eQ^2 + eC^2)	eLT = SLT / LT	SLT = VLT^0.5	fqLT = Sum [(Q C LF)^2] (eQ^2) / VLT
FWM Conc	FWM =LT / QT / LF	VFWM = Sum [(Q C LF)^2] eC^2 / QT^2 / LF^2 + Sum [(Q (C - FWM))^2] eQ^2 / QT^2	eFWM = SFWM/FWM	SFWM = VFWM^0.5	fqFWM = Sum [(Q (C - FWM))^2] eQ^2 / QT^2 / VFWM
Totals Across Structures					
Total Sampled Flow	QTS = Sum (QT)	VQTS = Sum (VQT)	eSQT = SQTS / QTS	SQTS = VQTS^.5	fqQTS = 100%
Total Sampled Load	LTS = Sum (LT)	VLTS = Sum (VLT)	eSLT = SLTS / LTS	SLTS = VLTS^.5	fqLTS = Sum [(fqLT VLT)^2] / VLTS
FWM Conc	FWMS = LTS / QTS / LF	VFWMS = Sum [(LT eFWM / QTS / LF)^2] + Sum [(QT (FWM - FWMS) eSQT / QTS)^2]	eFMWS = SFWMS / FWMS	SFWMS = VFWMS^.5	Sum { [fQFWM VFWM QT^2] + [QT (FWM-FWMS)]^2 eQ^2 } / QTS^2 / VFWMS

eQ	assumed constant relative standard error of daily flow measurement
eQy	assumed constant relative standard error of annual flow measurement
eC	assumed constant relative standard error of grab sample concentration
n	number of samples with positive flow
LF	units conversion factor; convert cfsd x ppb to kg = 0.002447
Sum	sum over sampling dates or structures

Assumes eQ and eC are independent

Assumes Average L31N Conc = Average S356 Conc

red cells are input assumptions

Table 3

Error Analysis for Basin Total Flow and Compliance Metrics

Average Flow Error

Water Year 2016

Basin Total Yearly Flow kac-ft/yr

Structure	Total	RSE	Variance	Std Error	RSE
S12A	41	0.9%	0.15	0.4	0.9%
S12B	55	1.0%	0.33	0.6	1.0%
S12C	368	1.4%	26.69	5.2	1.4%
S12D	486	1.7%	70.47	8.4	1.7%
S333	477	1.2%	34.63	5.9	1.2%
Blue Shanty	0	3.7%	0.00	0.0	0.0%
S355B	17	1.7%	0.08	0.3	1.7%
S355A	0	1.7%	0.00	0.0	1.7%
S356	51	0.6%	0.09	0.3	0.6%
-L31N	-5	2.4%	0.02	0.1	2.4%
Basin Total Flow					
S12X+S333+ BS + S355B+S355A	1445	0.8%	132.4	11.5	0.8%
+S356	1495	0.8%	132.4	11.5	0.8%
+S356-L31N	1490	0.8%	132.5	11.5	0.8%

<u>Equations</u>	<u>Total</u>	<u>Variance of Total</u>
Total for Each Structure Across All Days		
Total Annual Flow	QTy = Sum (Q)	VQTy = (QTy x eQy)^2
Totals Across Structures		
Basin Total Flow	QTyB = Sum (QTy)	VQTyB = Sum (VQTy)

<u>LTL Equations</u>

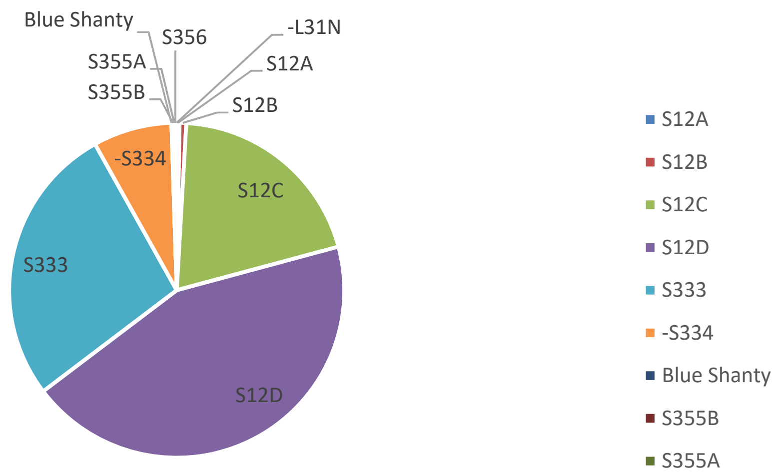
Long-Term Limit for QTyB <= 1061 kac-ft/yr	11.38 - 0.00538 * QTyB + 1.397 * (2.493 - 0.00231 * QTyB + 0.0000017 * QTyB ^ 2) ^ 0.5
	= 7.6 ppb for QTyB > 1061 kac-ft/yr
Flow Derivative of Limit for QTyB <= 1061 kac-ft/y	-0.00538 + (-0.00161+0.000002375*QTyb) * (2.493-0.00231*QTyb+0.0000017*QTyb^2)^-0.5
	= 0 for QTyB > 1061 kac-ft/yr
Long-Term Target for QTyB <= 1061 kac-ft/yr	11.38 - 0.00538 * QTyB
	= 5.7 for QTyB > 1061 kac-ft/yr
Flow Derivative of Target for QTyB <= 1061 kac-f	-0.00538
	= 0 for QTyB > 1061 kac-ft/yr

<u>Equations:</u>	<u>For Current Year</u>	<u>S12X+333+S355AB</u>	<u>+S356</u>	<u>S356-L31N</u>
FWM Rounded	Flow-Weighted-Mean Concentration, Rounded to Nearest 0.1	7.242	7.187	7.192
Basin Flow	Total Yearly Flow Across Structures	1445	1495	1490
Target	Compliance Equation	5.67	5.67	5.67
Limit	Compliance Equation, Rounded to Nearest 0.1 ppb	7.63	7.63	7.63
FWM - Target		1.57	1.52	1.52
FWM - Limit		-0.383	-0.438	-0.433
Flow Derivative (Target)	For Flow < 1061 kac-ft/yr	-0.00538	-0.00538	-0.00538
Flow Derivative (Target)	For Current Year	0	0	0
Flow Derivative (Limit)	For Flow < 1061 kac-ft/yr	-0.00427	-0.00423	-0.00423
Flow Derivative (Limit)	For Current Year	0	0	0
Std Error (FWMS)	From Error Analysis for Sampling Dates	0.128	0.122	0.123
Std Error (Basin Flow)	VQTyB ^ 0.5	11.50	11.51	11.51
Std Error (Target)	Abs [Target Flow Deriv Year x Std Error (Yearly Flow)]	0	0	0
Std Error (FWMs - Target)	(Std Error (FWMS) ^2 + Std Error (Target) ^2) ^0.5	0.128	0.122	0.123
Std Error (Limit)	Abs [Limit Flow Deriv Year x Std Error (Yearly Flow)]	0	0	0
Std Error (FWMs - Limit)	(Std Error (FWMS) ^2 + Std Error (Limit) ^2) ^0.5	0.128	0.122	0.123
t	Student's t Statistic in Appendix A Model Derivation	1.397	1.397	1.397
App A Model Inherent Std Err (ISE)	(Limit - Target) / t	1.40	1.40	1.40
App A Model Inherent Variance	ISE ^ 2	1.96	1.96	1.96
Measurement Error Variance	Std Error (FWMs - Limit) ^ 2	0.02	0.01	0.02
Measurement / Model Variance	Std Error (FWMs - Limit) ^ 2 / ISE ^ 2	0.83%	0.76%	0.77%

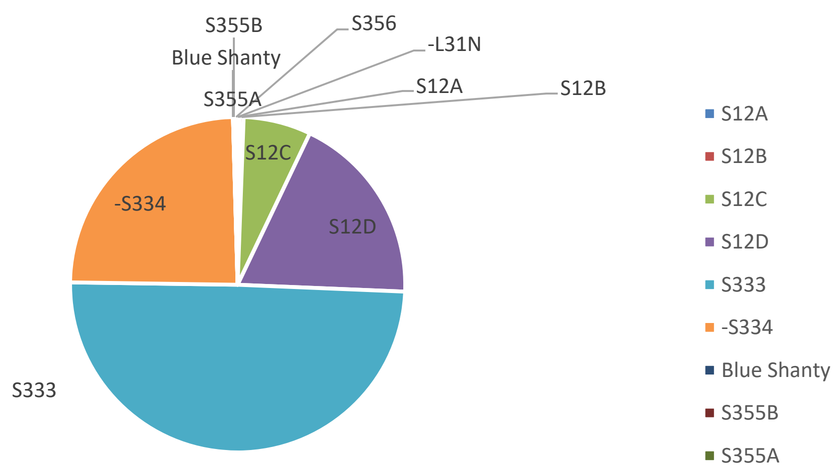
Figure 7

Variance Components of Sampled Flow, Sampled Load, & Total Basin Flow

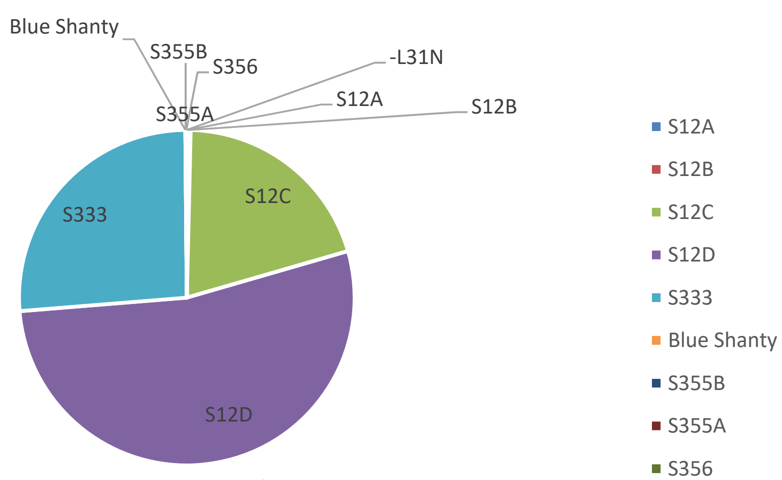
Year = 2016 Scenario: Average Flow Error



Variance Components of Total Sampled Flow



Variance Components of Total Sampled Load



Variance Components of Total Basin Flow

This indicates that measurement errors of the assumed magnitudes have no significant impact on the risk of exceeding the LTL.

The combined errors in flow measurement account for 15% of the error variance in the total inflow FWM and for 0-12% for the individual structures (Table 2, far right). The remainders are due to random errors in concentration measurement. This reflects the fact that errors in flow measurement impact both the numerator and denominator of the formula for computing the FWM (= Sum (Q C) / Sum Q). For example, a positive error in Q would increase both the numerator and the denominator, and would tend to cancel itself out. The above equation for Var(FWMS) indicates that measurement errors in flow (eQ) would not contribute to the variance in the FWM at a given structure if the measured concentrations were constant (FWM_j = FWMS for each sample). Conversely, the FWMs at structures with higher variance in concentration would be more sensitive to measurement errors in flow.

Sensitivity Analysis

Given the uncertainty in the flow and concentration measurement error estimates, it is useful to explore a wider range of measurement error estimates. Table 4 shows the combined FWM error for daily flow RSEs ranging from 0 to 32% and for daily concentration RSEs ranging from 0 to 16% for Water Year 2016. For each scenario, the same RSE values are applied to each structure. The standard error in the combined FWM inflow concentration ranges from 0.00 to 0.33 ppb, which is still small relative to the inherent model error (1.4 ppb). The outlines in Table 3 indicate FWM standard errors of 0.09 to 0.19 ppb for concentration RSE values of 6 to 10%, which spans the calibration range (Figure 6), and for flow RSE values of 2 to 16%, which spans the calibration range for individual structures (low to high RSE values in Table 1). The corresponding ranges in the relative standard error of the combined FWM are 0 to 4.6% overall and 1.3 to 2.6% within the calibration range, respectively (Table 4, bottom)

Table 5 shows the sensitivity of the results to various measurement error assumptions, flow assumptions, and time periods. Shaded cells show assumptions and results that differ from the base case (WY 2016, average flow measurement errors, and 2003-2016 concentration measurement error). To show sensitivity, the results are rounded to 3 decimal places, even though only one decimal place would be of practical significance. As discussed above, the inherent standard error in the Appendix model (1.3 to 1.5 ppb) is the yardstick for determining whether the reported measurement errors in the FWM are of practical significance. Figure 8 contains bar charts of results for each of the sensitivity analysis scenarios. The following scenarios are compared:

A. Columns (1,3,2). Results Assuming Low, Average, and High estimates for flow measurement error. The FWM standard errors (SEs) are 0.114, 0.123, and 0.140 ppb, respectively.

B. Column 4. Measurement errors estimated for WY 2003-2011. The daily and annual flow errors were increased to account for use of COE flows instead of final USGS

Table 4

Uncertainty in Annual FWM vs. Assumed Daily Flow & Concentration Sampling Errors

Standard Error of Annual FWM ppb

RSE of Sample Flow *	Relative Standard Error of Measured FWM Conc ppb *								
0.33	0%	2%	4%	6%	8%	10%	12%	14%	16%
0%	0.00	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24
2%	0.01	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24
4%	0.03	0.04	0.07	0.09	0.12	0.15	0.18	0.21	0.24
6%	0.04	0.05	0.07	0.10	0.13	0.15	0.18	0.21	0.24
8%	0.06	0.07	0.08	0.11	0.13	0.16	0.19	0.22	0.24
10%	0.07	0.08	0.09	0.11	0.14	0.17	0.19	0.22	0.25
12%	0.09	0.09	0.11	0.12	0.15	0.17	0.20	0.23	0.25
14%	0.10	0.11	0.12	0.14	0.16	0.18	0.20	0.23	0.26
16%	0.12	0.12	0.13	0.15	0.17	0.19	0.21	0.24	0.26
18%	0.13	0.13	0.14	0.16	0.18	0.20	0.22	0.25	0.27
20%	0.15	0.15	0.16	0.17	0.19	0.21	0.23	0.25	0.28
22%	0.16	0.16	0.17	0.18	0.20	0.22	0.24	0.26	0.29
24%	0.17	0.18	0.18	0.20	0.21	0.23	0.25	0.27	0.29
26%	0.19	0.19	0.20	0.21	0.22	0.24	0.26	0.28	0.30
28%	0.20	0.21	0.21	0.22	0.24	0.25	0.27	0.29	0.31
30%	0.22	0.22	0.23	0.24	0.25	0.26	0.28	0.30	0.32
32%	0.23	0.23	0.24	0.25	0.26	0.28	0.29	0.31	0.33

Relative Standard Error of Annual FWM %

RSE of Sample Flow *	Relative Standard Error of Measured FWM Conc ppb *								
	0%	2%	4%	6%	8%	10%	12%	14%	16%
0%	0.0	0.4	0.8	1.2	1.6	2.1	2.5	2.9	3.3
2%	0.2	0.5	0.8	1.3	1.7	2.1	2.5	2.9	3.3
4%	0.4	0.6	0.9	1.3	1.7	2.1	2.5	2.9	3.3
6%	0.6	0.7	1.0	1.4	1.8	2.1	2.5	2.9	3.4
8%	0.8	0.9	1.2	1.5	1.8	2.2	2.6	3.0	3.4
10%	1.0	1.1	1.3	1.6	1.9	2.3	2.7	3.1	3.4
12%	1.2	1.3	1.5	1.7	2.0	2.4	2.8	3.1	3.5
14%	1.4	1.5	1.6	1.9	2.2	2.5	2.8	3.2	3.6
16%	1.6	1.7	1.8	2.0	2.3	2.6	3.0	3.3	3.7
18%	1.8	1.9	2.0	2.2	2.5	2.7	3.1	3.4	3.8
20%	2.0	2.1	2.2	2.4	2.6	2.9	3.2	3.5	3.9
22%	2.2	2.3	2.4	2.5	2.8	3.0	3.3	3.6	4.0
24%	2.4	2.5	2.6	2.7	2.9	3.2	3.5	3.8	4.1
26%	2.6	2.7	2.7	2.9	3.1	3.3	3.6	3.9	4.2
28%	2.8	2.9	2.9	3.1	3.3	3.5	3.8	4.0	4.3
30%	3.0	3.1	3.1	3.3	3.4	3.7	3.9	4.2	4.5
32%	3.2	3.3	3.3	3.5	3.6	3.8	4.1	4.3	4.6

Assumed Flow & Concentration Errors Applied to Each Structure   Water Year   2016

Range of Calibrated Error Estimates for Individual Structures

Table 5

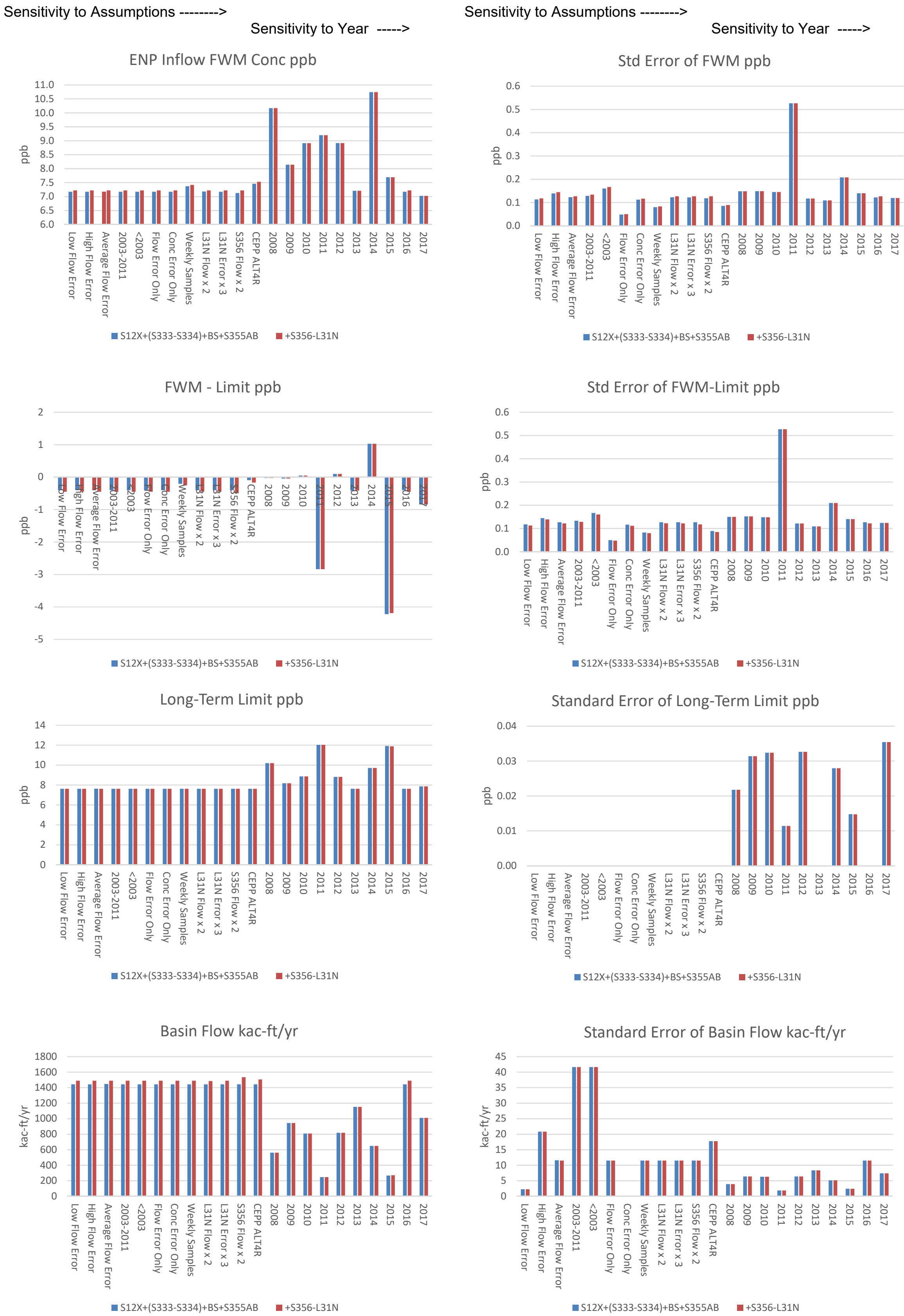
Sensitivity Analysis

	Sensitivity to Assumptions (2016 Data)------------------------->												Sensitivity to Year (Average Error Estimates) -->									
Scenario Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Inputs																						
Scenario Name	Low Flow Error	High Flow Error	Average Flow Error	2003-2011	<2003	Flow Error Only	Conc Error Only	Weekly Samples	L31N Flow x 2	L31N Error x 3	S356 Flow x 2	CEPP ALT4R	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Water Year	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Weekly Samples	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
S356 Flow Scale	1	1	1	1	1	1	1	1	1	1	2	1.35	1	1	1	1	1	1	1	1	1	1
L31N Flow / S356 Flow	10%	10%	10%	10%	10%	10%	10%	10%	20%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
L31N Flow Error / L31N M1 Error	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1
BS+WCA3B Flow/ S333 + BS Flow	0	0	0	0	0	0	0	0	0	0	0	0.46	0	0	0	0	0	0	0	0	0	0
BS+WCA3B Flow Error / S333 Error	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
BS+WCA3B Conc Error	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	11.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Alt4R S12ABCD Flow Adjustment	1	1	1	1	1	1	1	1	1	1	1	0.52	1	1	1	1	1	1	1	1	1	1
ALT4R S334 Flow Adjustment	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
TP Conc Measurement Error %	7.6%	7.6%	7.6%	7.6%	10.0%	0.0%	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%
Relative Standard Error of Structure Daily Flows																						
S12A	1.2%	8.3%	4.7%	15.2%	15.2%	4.7%	0.0%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%
S12B	1.2%	9.4%	5.3%	14.6%	14.6%	5.3%	0.0%	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%
S12C	1.0%	13.3%	7.2%	17.2%	17.2%	7.2%	0.0%	7.2%	7.2%	7.2%	7.2%	7.2%	7.2%	7.2%	7.2%	7.2%	7.2%	7.2%	7.2%	7.2%	7.2%	7.2%
S12D	1.5%	16.1%	8.8%	21.1%	21.1%	8.8%	0.0%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%	8.8%
S333	1.7%	10.9%	6.3%	6.3%	6.3%	6.3%	0.0%	6.3%	6.3%	6.3%	6.3%	6.3%	6.3%	6.3%	6.3%	6.3%	6.3%	6.3%	6.3%	6.3%	6.3%	6.3%
S334	2.7%	10.9%	6.8%	6.8%	6.8%	6.8%	0.0%	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%	6.8%
Blue Shanty	5.0%	32.7%	18.9%	18.9%	18.9%	18.9%	0.0%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%	18.9%
S355B	2.0%	15.0%	8.5%	8.5%	8.5%	8.5%	0.0%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%
S355A	2.0%	15.0%	8.5%	8.5%	8.5%	8.5%	0.0%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%
S356	1.0%	5.0%	3.0%	3.0%	3.0%	3.0%	0.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
L31N	2.3%	22.4%	12.3%	12.3%	12.3%	12.3%	0.0%	12.3%	12.3%	37.0%	12.3%	12.3%	12.3%	12.3%	12.3%	12.3%	12.3%	12.3%	12.3%	12.3%	12.3%	12.3%
Relative Standard Error of Structure Yearly Flows																						
S12A	0.2%	1.6%	0.9%	4.4%	4.4%	0.9%	0.0%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%
S12B	0.2%	1.8%	1.0%	6.8%	6.8%	1.0%	0.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
S12C	0.2%	2.6%	1.4%	8.0%	8.0%	1.4%	0.0%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%
S12D	0.3%	3.2%	1.7%	5.9%	5.9%	1.7%	0.0%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%
S333	0.3%	2.1%	1.2%	1.2%	1.2%	1.2%	0.0%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
Blue Shanty	1.0%	6.4%	3.7%	3.7%	3.7%	3.7%	0.0%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%	3.7%
S355B	0.4%	2.9%	1.7%	1.7%	1.7%	1.7%	0.0%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%
S355A	0.4%	2.9%	1.7%	1.7%	1.7%	1.7%	0.0%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%
S356	0.2%	1.0%	0.6%	0.6%	0.6%	0.6%	0.0%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
L31N	0.5%	4.4%	2.4%	2.4%	2.4%	2.4%	0.0%	2.4%	2.4%	7.3%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%
Results	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Number of Samples																						
S12X+(S333-S334)+BS+S355AB	107	107	107	107	107	107	107	217	107	107	107	120	64	90	92	46	79	95	60	27	107	71
+S356	119	119	119	119	119	119	119	237	119	119	119	132	64	90	92	46	79	95	60	27	119	71
+S356-L31N	131	131	131	131	131	131	131	257	131	131	131	144	64	90	92	46	79	95	60	27	131	71
RSE of Sampled Flow																						
S12X+(S333-S334)+BS+S355AB	0.2%	2.0%	1.1%	2.3%	2.3%	1.1%	0.0%	0.8%	1.1%	1.1%	1.1%	1.4%	1.4%	1.3%	1.2%	2.2%	1.1%	1.2%	1.2%	1.8%	1.1%	1.4%
+S356	0.2%	1.9%	1.1%	2.2%	2.2%	1.1%	0.0%	0.8%	1.1%	1.1%	1.0%	1.3%	1.4%	1.3%	1.2%	2.2%	1.1%	1.2%	1.2%	1.8%	1.1%	1.4%
+S356-L31N	0.2%	1.9%	1.1%	2.2%	2.2%	1.1%	0.0%	0.8%	1.1%	1.1%	1.0%	1.3%	1.4%	1.3%	1.2%	2.2%	1.1%	1.2%	1.2%	1.8%	1.1%	1.4%
RSE of Sampled Load																						
S12X+(S333-S334)+BS+S355AB	1.7%	3.0%	2.2%	2.8%	3.1%	1.5%	1.6%	1.4%	2.2%	2.2%	2.2%	1.6%	2.0%	2.3%	2.1%	6.6%	1.8%	2.0%	2.3%	2.6%	2.2%	2.4%
+S356	1.6%	2.9%	2.1%	2.7%	3.0%	1.4%	1.6%	1.4%	2.1%	2.1%	2.0%	1.5%	2.0%	2.3%	2.1%	6.6%	1.8%	2.0%	2.3%	2.6%	2.1%	2.4%
+S356-L31N	1.6%	2.9%	2.1%	2.7%	3.0%	1.4%	1.6%	1.4%	2.1%	2.1%	2.1%	1.5%	2.0%	2.3%	2.1%	6.6%	1.8%	2.0%	2.3%	2.6%	2.1%	2.4%
ENP Inflow FWM Conc ppb																						
S12X+(S333-S334)+BS+S355AB	7.24	7.24	7.24	7.24	7.24	7.24	7.24	7.42	7.24	7.24	7.24	7.62	10.18	8.16	8.91	9.20	8.89	7.21	10.84	7.69	7.24	6.99
+S356	7.19	7.19	7.19	7.19	7.19	7.19	7.19	7.37	7.19	7.19	7.14	7.53	10.18	8.16	8.91	9.20	8.89	7.21	10.84	7.69	7.19	6.99
+S356-L31N	7.19	7.19	7.19	7.19	7.19	7.19	7.19	7.37	7.20	7.19	7.15	7.54	10.18	8.16	8.91	9.20	8.89	7.21	10.84	7.69	7.19	6.99
Std Error of FWM ppb																						
S12X+(S333-S334)+BS+S355AB	0.118	0.145	0.128	0.135	0.168	0.050	0.117	0.084	0.128	0.128	0.128	0.085	0.150	0.153	0.145	0.527	0.119	0.111	0.214	0.140	0.128	0.129
+S356	0.113	0.139	0.122	0.129	0.160	0.048	0.112	0.081	0.122	0.122	0.118	0.081	0.150	0.153	0.145	0.527	0.119	0.111	0.214	0.140	0.122	0.129
+S356-L31N	0.114	0.140	0.123	0.129	0.161	0.048	0.113	0.081	0.123	0.123	0.119	0.081	0.150	0.153	0.145	0.527	0.119	0.111	0.214	0.140	0.123	0.129
RSE of FWM																						
S12X+(S333-S334)+BS+S355AB	1.6%	2.0%	1.8%	1.9%	2.3%	0.7%	1.6%	1.1%	1.8%	1.8%	1.8%	1.1%	1.5%	1.9%	1.6%	5.7%	1.3%	1.5%	2.0%	1.8%	1.8%	1.8%
+S356	1.6%	1.9%	1.7%	1.8%	2.2%	0.7%	1.6%	1.1%	1.7%	1.7%	1.6%	1.1%	1.5%	1.9%	1.6%	5.7%	1.3%	1.5%	2.0%	1.8%	1.7%	1.8%
+S356-L31N	1.6%	1.9%	1.7%	1.8%	2.2%	0.7%	1.6%	1.1%	1.7%	1.7%	1.7%	1.1%	1.5%	1.9%	1.6%	5.7%	1.3%	1.5%	2.0%	1.8%	1.7%	1.8%
Perecent of FWM Error Due to Flow Meas.																						
S12X+(S333-S334)+BS+S355AB	1.6%	34.8%	15.4%	23.8%	15.3%	100.0%	0.0%	13.4%	15.4%	15.4%	15.4%	16.2%	9.1%	17.1%	7.6%	24.5%	8.8%	10.4%	22.0%	3.1%	15.4%	9.2%
+S356	1.6%	34.9%	15.5%	23.7%	15.3%	100.0%	0.0%	13.5%	15.5%	15.5%	15.4%	15.7%	9.1%	17.1%	7.6%	24.5%	8.8%	10.4%	22.0%	3.1%	15.5%	9.2%
+S356-L31N	1.6%	34.9%	15.5%	23.7%	15.3%	100.0%	0.0%	13.5%	15.5%	15.5%	15.4%	15.8%	9.1%	17.1%	7.6%	24.5%	8.8%	10.4%	22.0%	3.1%	15.5%	9.2%
Longterm Limit ppb																						
S12X+(S333-S334)+BS+S355AB	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	10.195	8.183	8.864	12.040	8.821	7.626	9.715	11.918	7.626	7.866
+S356	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	10.195	8.183	8.864	12.040	8.821	7.626	9.715	11.884	7.626	7.865
+S356-L31N	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	7.626	10.195	8.183	8.864	12.040	8.821	7.626	9.715	11.887	7.626	7.865
Std Error of Long-Term Limit ppb																						
S12X+(S333-S334)+BS+S355AB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.031	0.032	0.011	0.033	0.000	0.028	0.015	0.000	0.035
+S356	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.031	0.032	0.011	0.033	0.000	0.028	0.015	0.000	0.035
+S356-L31N	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.031	0.032	0.011	0.033	0.000	0.028	0.015	0.000	0.035
RSE of Long-Term Limit %																						
S12X+(S333-S334)+BS+S355AB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.004	0.001	0.004	0.000	0.003	0.001	0.000	0.005
+S356	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.004	0.001	0.004	0.000	0.003	0.001	0.000	0.005
+S356-L31N	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.004	0.001	0.004	0.000	0.003	0.001	0.000	0.005
FWM - Limit ppb																						
S12X+(S333-S334)+BS+S355AB	-0.383	-0.383	-0.383	-0.383	-0.383	-0.383	-0.383	-0.204	-0.383	-0.383	-0.383	-0.008	-0.012	-0.024	0.049	-2.839	0.072	-0.414	1.122	-4.224	-0.383	-0.873
+S356	-0.438	-0.438	-0.438	-0.438	-0.438	-0.438	-0.438	-0.259	-0.438	-0.438	-0.489	-0.092	-0.012	-0.024	0.049	-2.839	0.072	-0.414	1.122	-4.190	-0.438	-0.872
+S356-L31N	-0.433	-0.433	-0.433	-0.433	-0.433	-0.433	-0.433	-0.253	-0.428	-0.433	-0.479	-0.084	-0.012	-0.024	0.049	-2.839	0.072	-0.414	1.122	-4.194	-0.433	-0.872
Std Error of FWM-Limit ppb																						
S12X+(S333-S334)+BS+S355AB	0.118	0.145	0.128	0.135	0.168	0.050	0.117	0.084	0.128	0.128	0.128	0.085	0.152	0.156	0.149	0.527	0.124	0.111	0.216	0.140	0.128	0.134
+S356	0.113	0.139	0.122	0.129	0.160	0.048	0.112	0.081	0.122	0.122	0.118	0.081	0.152	0.156	0.149	0.527	0.124	0.111	0.216	0.140	0.122	0.134
+S356-L31N	0.114	0.140	0.123	0.129	0.161	0.048	0.113	0.081	0.123	0.123	0.119	0.081	0.152	0.156	0.149	0.527	0.124	0.111	0.216	0.140	0.123	0.134
Basin Total Flow kac-ft/yr																						
S12X+(S333-S334)+BS+S355AB	1445	1445	1445	1445	1445	1445	1445	1445	1445	1445	1445	1445	562	945	810	247	818	1152	649	267	1445	1011
+S356	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1546	1513	562	945	810	247	818	1152	649	273	1495	1011
+S356-L31N	1490	1490	1490	1490	1490	1490	1490	1490	1485	1490	1536	1506	562	945	810	247	818	1152	649	272	1490	1011
Std Error of Basin Flow kac-ft/yr																						
S12X+(S333-S334)+BS+S355AB	2	21	12	42	42	12	0	12	12	12	12	18	4	6	6	2	6	8	5	2	12	7
+S356	2	21	12	42	42	12	0	12	12	12	12	18	4	6	6	2	6	8	5	2	12	7
+S356-L31N	2	21	12	42	42	12	0	12	12	12	12	18	4	6	6	2	6	8	5	2	12	7
RSE of Basin Flow %																						
S12X+(S333-S334)+BS+S355AB	0.2%	1.4%	0.8%	2.9%	2.9%	0.8%	0.0%	0.8%	0.8%	0.8%	0.8%	1.2%	0.7%	0.7%	0.8%	0.8%	0.8%	0.7%	0.8%	0.9%	0.8%	0.7%
+S356	0.2%	1.4%	0.8%	2.8%	2.8%	0.8%	0.0%	0.8%	0.8%	0.8%	0.7%	1.2%	0.7%	0.7%	0.8%	0.8%	0.8%	0.7%	0.8%	0.9%	0.8%	0.7%
+S356-L31N	0.2%	1.4%	0.8%	2.8%	2.8%	0.8%	0.0%	0.8%	0.8%	0.8%	0.8%	1.2%	0.7%	0.7%	0.8%	0.8%	0.8%	0.7%	0.8%	0.9%	0.8%	0.7%
Inherent App A Model Variance ppb^2																						
S12X+(S333-S334)+BS+S355AB	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.732	1.828	1.737	2.026	1.741	1.956	1.710	1.997	1.956	1.895
+S356	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.732	1.828	1.737	2.026	1.741	1.956	1.710	1.990	1.956	1.895
+S356-L31N	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.732	1.828	1.737	2.026	1.741	1.956	1.710	1.990	1.956	1.895
Variance of Measured FWM-Limit ppb^2																						
S12X+(S333-S334)+BS+S355AB	0.014	0.021	0.016	0.018	0.028	0.003	0.014	0.007	0.016	0.016	0.016	0.007	0.023	0.024	0.022	0.278	0.015	0.012	0.047	0.020	0.016	0.018
+S356	0.013	0.019	0.015	0.017	0.026	0.002	0.013	0.007	0.015	0.015	0.014	0.007	0.023	0.024	0.022	0.278	0.015	0.012	0.047	0.020	0.015	0.018
+S356-L31N	0.013	0.020	0.015	0.017	0.026	0.002	0.013	0.007	0.015	0.015	0.014	0.007	0.023	0.024	0.022	0.278	0.015	0.012	0.047	0.020	0.015	0.018
Measured / Inherent Variance %																						
S12X+(S333-S334)+BS+S355AB	0.72%	1.08%	0.83%	0.92%	1.44%	0.13%	0.70%	0.36%	0.83%	0.83%	0.83%	0.37%	1.33%	1.33%	1.27%	13.71%	0.88%	0.63%	2.73%	0.99%	0.83%	0.95%
+S356	0.66%	0.99%	0.76%	0.85%	1.31%	0.12%	0.65%	0.33%	0.76%	0.76%	0.71%	0.33%	1.33%	1.33%	1.27%	13.71%	0.88%	0.63%	2.73%	0.99%	0.76%	0.95%
+S356-L31N	0.66%	1.00%	0.77%	0.85%	1.33%	0.12%	0.65%	0.34%	0.78%	0.77%	0.72%	0.34%	1.33%	1.33%	1.27%	13.71%	0.88%	0.63%	2.73%	0.99%	0.77%	0.95%

Base Case = Water Year 2016 with Average Flow Error Estimates and 2003-2016 Concentration Error Estimates

Figure 8

Bar Charts of Sensitivity Analysis Results



flows in determining compliance prior to WY 2012. This increases the SE for all structures combined from 0.123 ppb to 0.129 ppb.

C. Column 5. Measurement errors estimated for years prior to 2003. Flow measurement errors equal to B above and concentration measurement errors based upon replicate samples collected prior to 2002, when the TP minimum detection limit was 4 ppb instead of 2 ppb. This increases the SE from 0.123 ppb to 0.161 ppb. Given the long-term improvements in QA/QC procedures, it is likely that measurement errors were higher during the 1979-1991 base period used for calibration of the Appendix A model.

D. Column 6. Considering measurement errors in flow only (concentration errors set to 0). This decreases the FWM SE from 0.122 ppb to 0.048 ppb.

E. Column 7. Considering measurement errors in concentration only (flow errors set to 0). This decreases the combined FWM SE from 0.122 ppb to 0.113 ppb. As indicated above, the SE is more sensitive to concentration measurement error than to flow measurement error. Random errors in concentration measurements account for 84.5% of the total error variance in the combined FWM concentration. This is fortunate because estimates of concentration measurement errors (Figure 6) are likely to be more accurate than estimates of flow measurement errors, which are based upon a variety of sources and a greater number of assumptions (Table 1, Appendix A).

F. Column 8. Use of weekly samples instead of biweekly samples for computing the ENP inflow FWM concentration and LTL. This decreases the SE from 0.123 ppb to 0.081 ppb.

G. Column 9. Doubling the assumed L31N flow relative to the base assumption (10% of S356 flow). This has no impact on the SE (0.123 ppb. This reflects the fact that the L31N and S356 concentrations are similar (~ 6 ppb and less variable than the S12X & S333 values) and that the L31N flow accounts for only 0.5-1.0% of the total ENP inflow and 0.4-0.8% of the total load.

H. Column 10. Increasing the assumed L31N flow measurement error by a factor of 3 (corresponding to a factor of 9-fold increase in measurement variance). This has no impact on the SE (0.123 ppb). This also reflects the fact that L31N and S356 concentrations are similar (~ 6 ppb) and that L31N flow accounts for only 0.5% of the total ENP inflow and 0.4% of the total load.

I. Column 11. Doubling the S356 flow. This decreases the FWM SE from 0.123 to 0.119 ppb. The low sensitivity reflects the fact that TP concentrations are lower and less variable relative to S12X+S333 and that S356 flow accounts for only 5% of the total ENP inflow volume.

J. Column 12. An approximate simulation of CEPP Alternative 4R (details described below).

K. Column 13-22. Results for individual Water Years 2008-2017. This shows the combined effects of hydrologic variability and variations in the flow and concentration measurement errors One outlier event was excluded (June 12, 2017, which has been associated with an extraordinary natural phenomenon by the TOC). SE values ranged from 0.111 to 0.527 ppb, as compared with 0.123 ppb for WY 2016. Measurement errors account for 0.6 to 13.7% of the inherent model error, as compared with 0.8% for WY 2016. The relatively low value for WY 2016 reflects the relatively high number of samples collected in that year (118), relative to the other years (27 – 92 samples). Structures were operating more often in WY 2016 because of the relatively high-flow conditions. The SE value was highest (0.527 ppb) in the driest year (2011, basin total flow = 247 kac-ft/yr) within the 2008-2017 period.

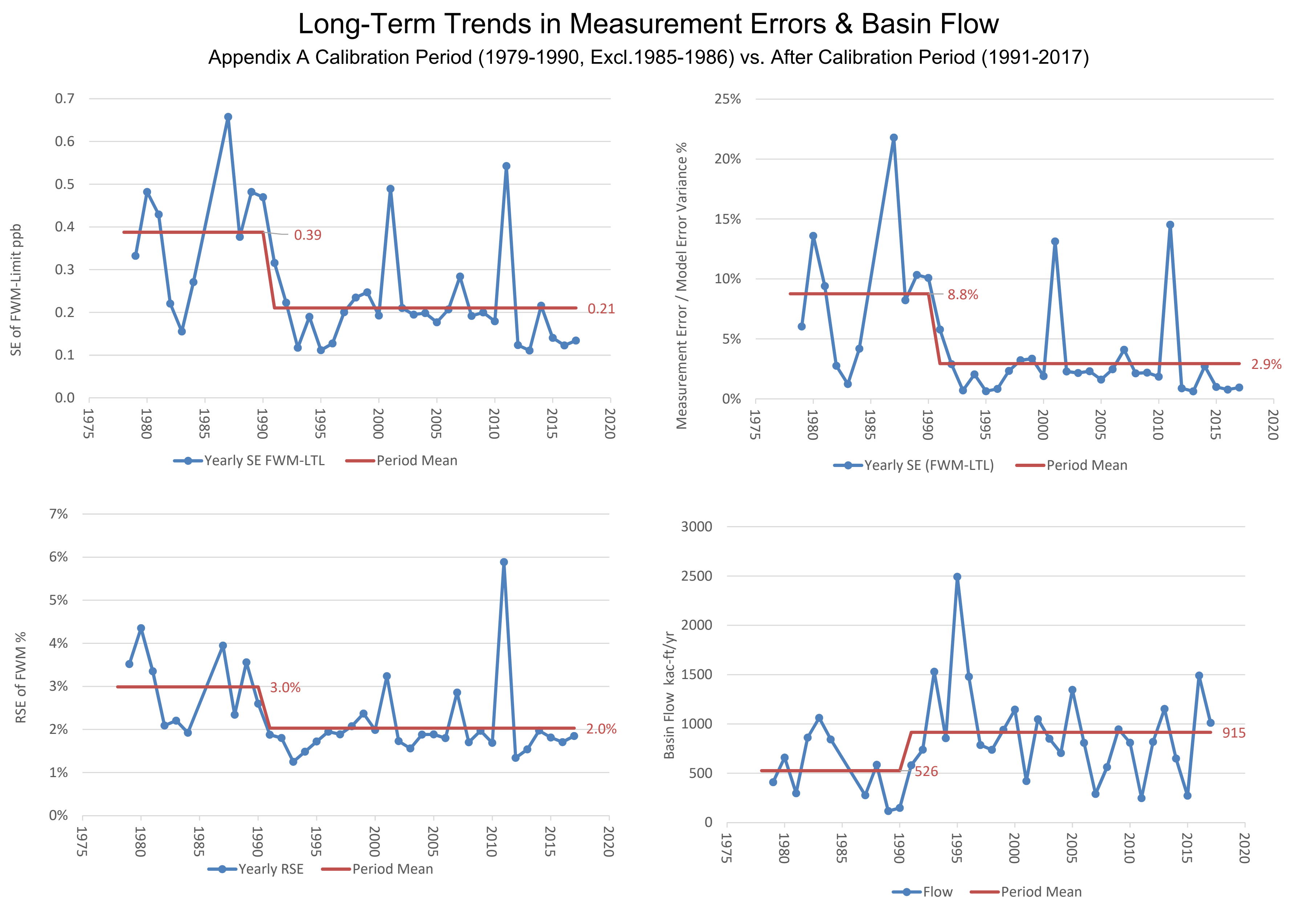
Analysis of the 1979-2017 dataset (Figure 9) indicates that the average standard error of the compliance metric (FWM – LTL) decreased from 0.39 ppb (3.0%) during the Appendix A calibration period (WY 1979-1990, excluding WY 1985 & 1986) to 0.21 ppb (2.0%) after that (WY 1991-2017). The corresponding reduction in the measurement error as a percent of the inherent model error decreased from 8.8% to 2.9%. These decreases reflect the combined effects of reductions in random flow and concentration measurement errors at individual structures, increases in average basin flow from 526 to 915 kac-ft/yr (providing a greater number of samples with positive flow per year), and decreases in FWM concentration. The reduction in measurement errors relative to the calibration period indicates that the LTLs, which were originally set at the 90th percentile of the OFW values, now correspond to a higher percentile. This, in turn, means that there is less risk of a false positive in the compliance determination, as compared with the maximum 10% risk assumed in the Appendix A derivation.

Figure 10 shows correlations between compliance metrics (SE of FWM-LTL and RSE of FWM) and related factors (Water Year, basin flow, number of samples with positive flow, and combined inflow FWM concentration). The SE (FWM-LTL) is negatively correlated with basin flow ($r^2 = 0.59$) and the number of samples ($r^2 = 0.2$). It is positively correlated with FWM concentration ($r^2 = 0.51$). This indicates that increases in basin flow and decreases in FWM are primarily responsible for the long-term declining trend in the SE of the ENP inflow FWM concentration (Figure 11). As described below, it is likely that further increases in basin flow and WCA-3A hydropattern restoration associated with CEPP and other restoration efforts would contribute to further reductions in the RSE of the ENP inflow FWM concentration and excursion risk.

Simulation of CEPP Alternative 4R

The sensitivity analysis (Table 5, Column 12) includes a hypothetical scenario that approximates the spatial distribution of flows under CEPP Alternative 4R, based upon 40-year-average RSM output. This involves spatial redistribution of ENP inflows from west to east and addition of the Blue Shanty Flow-Way, and an additional inflow to WCA-3B (Figure 3). Detailed results for this scenario are listed in Tables 6 and 7.

Figure 9



Long-Term Trends in Measurement Errors & Basin Flow
Appendix A Calibration Period (1979-1990, Excl.1985-1986) vs. After Calibration Period (1991-2017)
SE of FWM-Limit ppb
0.39
0.21
Yearly SE FWM-LTL
Period Mean
Measurement Error / Model Error Variance %
8.8%
2.9%
Yearly SE (FWM-LTL)
Period Mean
RSE of FWM %
3.0%
2.0%
Yearly RSE
Period Mean
Basin Flow kac-ft/yr
526
915
Flow
Period Mean

Figure 10

Factors Correlated With Measurement Errors in Compliance Metrics

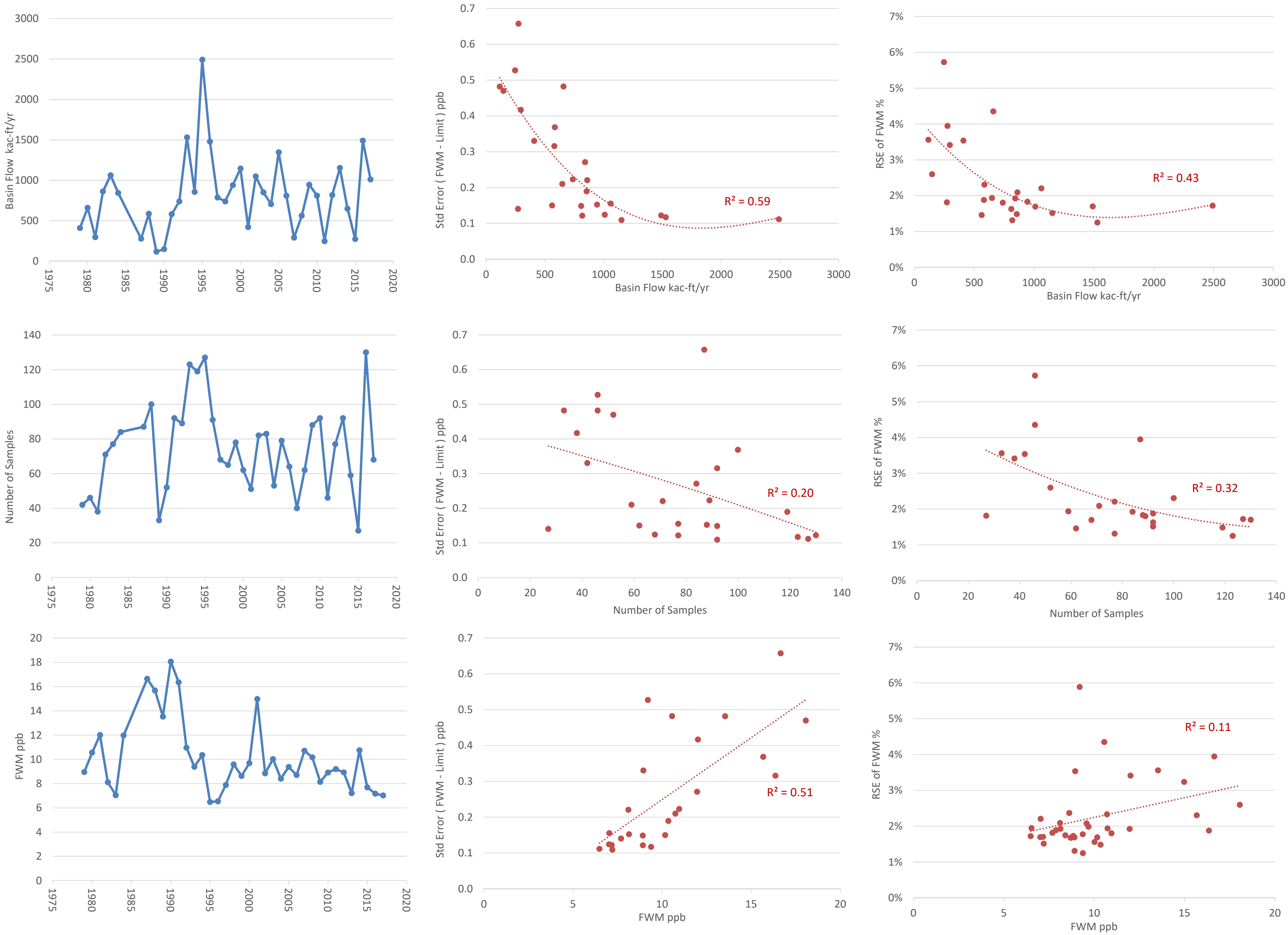


Table 6

Error Analysis for Annual Flow-Weighted-Mean Concentration CEPP ALT4R

Water Year 2016 Scenario: CEPP ALT4R

Summary of Results	Basin Total Flow kac-ft/yr			FWM Concentration ppb							% of Error Due to Flow Meas		
Structures	Total	Std Error	RSE	Target	Limit	Limit SE	RSE	FWM	FWM SE	RSE	Flow	Conc	Load
S12X+(S333-S334)+BS+S355AB	1445	17.8	1.2%	5.67	7.63	0.00	0.0%	7.62	0.085	1.1%	100%	16%	59%
+S356	1513	17.8	1.2%	5.67	7.63	0.00	0.0%	7.53	0.081	1.1%	100%	16%	59%
+S356-L31N	1506	17.8	1.2%	5.67	7.63	0.00	0.0%	7.54	0.081	1.1%	100%	16%	59%

	Water Year Sample Data				Sum of Squares					Assumed		Variance of Annual Total			Total as % of Net Inflow		Variance as % of Net Inflow		Relative Std Error			Standard Error			% Error Due to Flow Meas		
	Sampled	FWM	Sampled							Flow	Conc																
Structure	Flow cfsd	Conc ppb	Load kg	Samples	Flow	Conc	Load	C - FWM	Q x (C - FWM)	RSE	RSE	Flow	Conc	Load	Flow	Load	Flow	Load	Flow	Conc	Load	Flow	Conc	Load	Flow	Conc	Load
S12A	681	6.3	10	6	83978	244	20	3.4	67756	4.7%	7.6%	188	0.0414	0.16	1.3%	1.0%	0.0%	0.1%	2.0%	3.2%	3.8%	13.7	0.203	0.40	100%	1%	28%
S12B	983	6.2	15	7	160273	299	37	9.9	129420	5.3%	7.6%	449	0.0370	0.31	1.8%	1.5%	0.1%	0.1%	2.2%	3.1%	3.7%	21.2	0.192	0.56	100%	1%	33%
S12C	6755	5.9	97	24	2678788	1095	498	77.9	5002273	7.2%	7.6%	13742	0.0111	5.44	12.5%	9.8%	2.8%	2.3%	1.7%	1.8%	2.4%	117.2	0.105	2.33	100%	5%	47%
S12D	9046	7.2	159	26	3903555	1721	1140	145.6	20112771	8.8%	7.6%	30314	0.0154	15.46	16.7%	15.9%	6.2%	6.6%	1.9%	1.7%	2.5%	174.1	0.124	3.93	100%	12%	57%
S333	18094	9.6	427	26	14902997	3000	9229	480.4	301758309	6.3%	7.6%	58986	0.0309	90.01	33.4%	42.7%	12.0%	38.4%	1.3%	1.8%	2.2%	242.9	0.176	9.49	100%	12%	41%
-S334	0	0.0	0	0	0	0	0	0.0	0	6.8%	7.6%	0	0.0000	0.00	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	0.000	0.00	100%	0%	0%
Blue Shanty	15413	6.3	238	26	10814383	1189	2486	62.0	21828067	18.9%	11.4%	385233	0.0261	120.95	28.4%	23.8%	78.5%	51.6%	4.0%	2.6%	4.6%	620.7	0.161	11.00	100%	13%	73%
S355B	607	9.2	14	4	93778	376	51	37.3	790446	8.5%	7.6%	678	0.1510	0.67	1.1%	1.4%	0.1%	0.3%	4.3%	4.2%	6.0%	26.0	0.389	0.82	100%	10%	55%
S355A	12	6.0	0	1	144	36	0	0.0	0	8.5%	7.6%	1	0.2086	0.00	0.0%	0.0%	0.0%	0.0%	8.5%	7.6%	11.4%	1.0	0.457	0.02	100%	0%	55%
S356	2878	6.0	42	12	1029712	734	227	109.4	1029646	3.0%	7.6%	927	0.0267	1.52	5.3%	4.2%	0.2%	0.6%	1.1%	2.7%	2.9%	30.4	0.163	1.23	100%	0%	13%
-L31N	-288	6.0	-4	12	10297	734	2	109.4	10296	12.3%	7.6%	157	0.0285	0.05	-0.5%	-0.4%	0.0%	0.0%	4.4%	2.8%	5.2%	12.5	0.169	0.22	100%	7%	72%
Net Inflow																											
S12X+(S333-S334)+BS+S355AB	51591	7.62	962	120								489591	0.007	233	95%	96%	99.8%	99.3%	1.4%	1.1%	1.6%	699.7	0.085	15.26	100%	16.2%	59%
+S356	54469	7.53	1004	132								490518	0.007	235	101%	100%	100.0%	100.0%	1.3%	1.1%	1.5%	700.4	0.081	15.31	100%	15.7%	59%
+S356-L31N	54181	7.54	1000	144								490674	0.007	235	100%	100%	100.0%	100.0%	1.3%	1.1%	1.5%	700.5	0.081	15.32	100%	15.8%	59%

Equations	Total	Variance of Total	Relative SE of Total	Standard Error of Total	% Error Due to Flow Meas
Total Across Samples at Each Structure					
Total Sampled Flow	QT = Sum (Q)	VQT = Sum (Q^2) eQ ^2	eQT = SQT / QT	SQT = VQT^0.5	fqQT = 100%
Total Sampled Load	LT = Sum (Q x C x LF)	VLT = Sum [(Q C LF)^2] (eQ^2 + eC^2)	eLT = SLT / LT	SLT = VLT^0.5	fqLT = Sum [(Q C LF)^2] (eQ^2) / VLT
FWM Conc	FWM =LT / QT / LF	VFWM = Sum [(Q C LF)^2] eC^2 / QT^2 / LF^2 + Sum [(Q (C - FWM))^2] eQ^2 / QT^2	eFWM = SFWM/FWM	SFWM = VFWM^0.5	fqFWM = Sum [(Q (C - FWM))^2] eQ^2 / QT^2 / VFWM
Totals Across Structures					
Total Sampled Flow	QTS = Sum (QT)	VQTS = Sum (VQT)	eSQT = SQTS / QTS	SQTS = VQTS^.5	fqQTS = 100%
Total Sampled Load	LTS = Sum (LT)	VLTS = Sum (VLT)	eSLT = SLTS / LTS	SLTS = VLTS^.5	fqLTS = Sum [(fqLT VLT)^2] / VLTS
FWM Conc	FWMS = LTS / QTS / LF	VFWMS = Sum [(LT eFWM / QTS / LF)^2] + Sum [(QT (FWM - FWMS) eSQT / QTS)^2]	eFMWS = SFWMS / FWMS	SFWMS = VFWMS^.5	Sum { [fQFWM VFWM QT^2] + [QT (FWM-FWMS)]^2 eQ^2 } / QTS^2 / VFWMS

eQ assumed constant relative standard error of daily flow measurement

eQy assumed constant relative standard error of annual flow measurement

eC assumed constant relative standard error of grab sample concentration

n number of samples with positive flow

LF units conversion factor; convert cfsd x ppb to kg = 0.002447

Sum sum over sampling dates or structures

Assumes eQ and eC are independent

Assumes Average L31N Conc = Average S356 Conc

red cells are input assumptions

Table 7

Error Analysis for Basin Total Flow and Compliance Metrics CEPP ALT4R

Water Year 2016

Basin Total Yearly Flow kac-ft/yr

Structure	Total	RSE	Variance	Std Error	RSE
S12A	22	0.9%	0.04	0.2	0.9%
S12B	29	1.0%	0.09	0.3	1.0%
S12C	192	1.4%	7.30	2.7	1.4%
S12D	254	1.7%	19.28	4.4	1.7%
S333	502	1.2%	38.42	6.2	1.2%
Blue Shanty	428	3.7%	250.94	15.8	3.7%
S355B	17	1.7%	0.08	0.3	1.7%
S355A	0	1.7%	0.00	0.0	1.7%
S356	69	0.6%	0.16	0.4	0.6%
-L31N	-7	2.4%	0.03	0.2	2.4%
Basin Total Flow					
S12X+S333+ BS + S355B+S355A	1445	1.2%	316.1	17.8	1.2%
+S356	1513	1.2%	316.3	17.8	1.2%
+S356-L31N	1506	1.2%	316.3	17.8	1.2%

Equations	Total	Variance of Total
Total for Each Structure Across All Days		
Total Annual Flow	QTy = Sum (Q)	VQTy = (QTy x eQy)^2
Totals Across Structures		
Basin Total Flow	QTyB = Sum (QTy)	VQTyB = Sum (VQTy)

LTL Equations

Long-Term Limit for QTyB <= 1061 kac-ft/yr	11.38 - 0.00538 * QTyB + 1.397 * (2.493 - 0.00231 * QTyB + 0.0000017 * QTyB ^ 2) ^ 0.5
	= 7.6 ppb for QTyB > 1061 kac-ft/yr
Flow Derivative of Limit for QTyB <= 1061 kac-ft/y	-0.00538 + (-0.00161+0.000002375*QTyb) * (2.493-0.00231*QTyb+0.0000017*QTyb^2)^-0.5
	= 0 for QTyB > 1061 kac-ft/yr
Long-Term Target for QTyB <= 1061 kac-ft/yr	11.38 - 0.00538 * QTyB
	= 5.7 for QTyB > 1061 kac-ft/yr
Flow Derivative of Target for QTyB <= 1061 kac-f	-0.00538
	= 0 for QTyB > 1061 kac-ft/yr

Equations:	For Current Year	S12X+333+S355AB	+S356	S356-L31N
FWM Rounded	Flow-Weighted-Mean Concentration, Rounded to Nearest 0.1	7.618	7.533	7.541
Basin Flow	Total Yearly Flow Across Structures	1445	1513	1506
Target	Compliance Equation	5.67	5.67	5.67
Limit	Compliance Equation, Rounded to Nearest 0.1 ppb	7.63	7.63	7.63
FWM - Target		1.95	1.86	1.87
FWM - Limit		-0.008	-0.092	-0.084
Flow Derivative (Target)	For Flow < 1061 kac-ft/yr	-0.00538	-0.00538	-0.00538
Flow Derivative (Target)	For Current Year	0	0	0
Flow Derivative (Limit)	For Flow < 1061 kac-ft/yr	-0.00427	-0.00421	-0.00422
Flow Derivative (Limit)	For Current Year	0	0	0
Std Error (FWMS)	From Error Analysis for Sampling Dates	0.085	0.081	0.081
Std Error (Basin Flow)	VQTyB ^ 0.5	17.78	17.79	17.79
Std Error (Target)	Abs [Target Flow Deriv Year x Std Error (Yearly Flow)]	0	0	0
Std Error (FWMs - Target)	(Std Error (FWMS) ^2 + Std Error (Target) ^2) ^0.5	0.085	0.081	0.081
Std Error (Limit)	Abs [Limit Flow Deriv Year x Std Error (Yearly Flow)]	0	0	0
Std Error (FWMs - Limit)	(Std Error (FWMS) ^2 + Std Error (Limit) ^2) ^0.5	0.085	0.081	0.081
t	Student's t Statistic in Appendix A Model Derivation	1.397	1.397	1.397
App A Model Inherent Std Err (ISE)	(Limit - Target) / t	1.40	1.40	1.40
App A Model Inherent Variance	ISE ^ 2	1.96	1.96	1.96
Measurement Error Variance	Std Error (FWMs - Limit) ^ 2	0.01	0.01	0.01
Measurement / Model Variance	Std Error (FWMs - Limit) ^ 2 / ISE ^ 2	0.37%	0.33%	0.34%

The following adjustments to the WY 2016 simulation are made:

1. 46% of the historical S333 flows are diverted to the BS flow-way (30% via S345FG) or to WCA-3B (16% via S345D).

2. Concentrations in the corresponding Blue Shanty & WCA-3B outflows to Northeast SRS are assumed to equal the combined FWM concentration of S12ABC, which has been typical of marsh background conditions in recent years. This assumption is justified by the DMSTA simulations discussed above. Flow volumes discharged from the Blue Shanty flow-way or WCA-3B into NESRS are assumed to equal those discharged into these areas from the L67 canal.

3. Corresponding RSE values for flow are assumed to be 3 times the RSE values for S333. This amounts to a 9-fold increase in flow error variance. The concentration RSE value for 2003-2017 (7.6%) is increased to 11.4%. This amounts to 1.5-fold increase in RSE and a 2.25 fold increase in variance. These RSE increases may represent conservative estimates of error variance associated with measuring flows and FWM concentrations along a marsh transect.

4. The following additional adjustments are made to the spatial percentage distributions of 2016 flows so that they match the RSM spatial distribution:

    a. Historical S12ABCD flows to SRS are reduced by 48% and the remainder diverted to NE SRS via S333.

    b. S356 flows are increased by 35%

    c. S334 flows are eliminated.

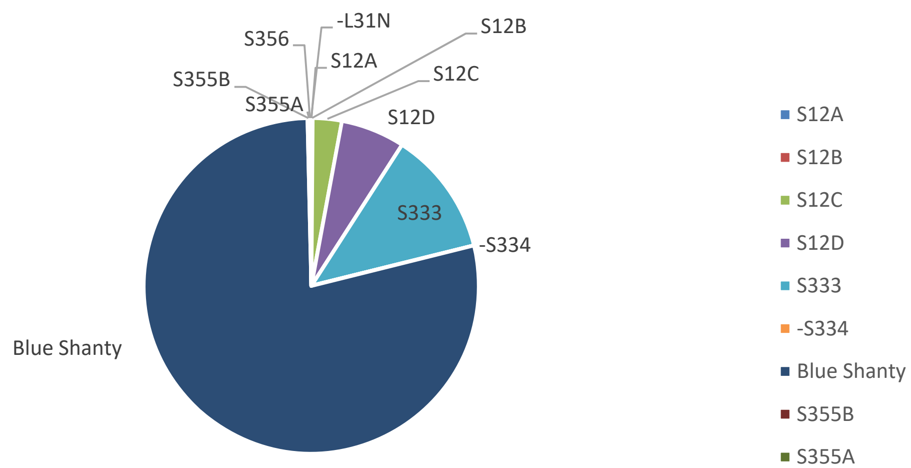
With these approximations of ALT4R, the ENP inflow FWM increases from 7.17 ppb to 7.54 ppb and SE decreases from 0.123 to 0.081ppb (Column 12 vs. Column 3 in Table 5). Despite the slight increase in FWM, it is still below the LTL for WY 2016 (7.6 ppb) and the slight reduction in standard error would decrease excursion risk. Despite the relatively high measurement error variances assumed for the AlT4R discharges thru Blue Shanty and WCA-3B to NE SRS, the standard error of the combined FWM decreases because there is a net shift in the distribution of loads and load measurement variance away from S12D and S333 to the Blue Shanty and the other AlT4R diversions and the S334 discharge is eliminated (Figures 11 & 12). The load error variance associated with these diversions is reduced because of the low outflow concentrations to NESRS relative to S12D and S333.

This analysis does not account for additional features of ALT4R that would tend to further reduce the ENP inflow FWM concentration and excursion risk, as described in a more complete analysis of CEPP alternatives with respect to Appendix A by Shafer & Walker (2013). These include hydropattern restoration in NW WCA-3A and filling of Miami Canal, which will decrease marsh dry-out frequencies and increase the proportion

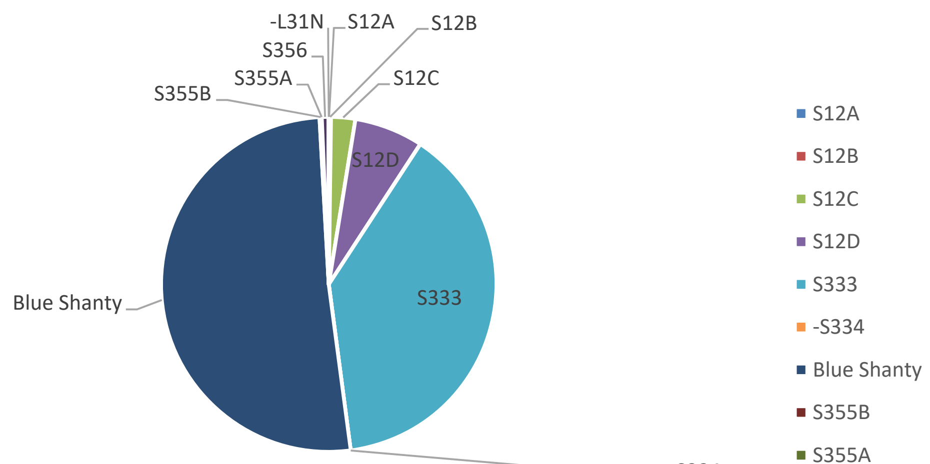
Figure 11

Variance Components of Sampled Flow, Sampled Load, & Total Basin Flow

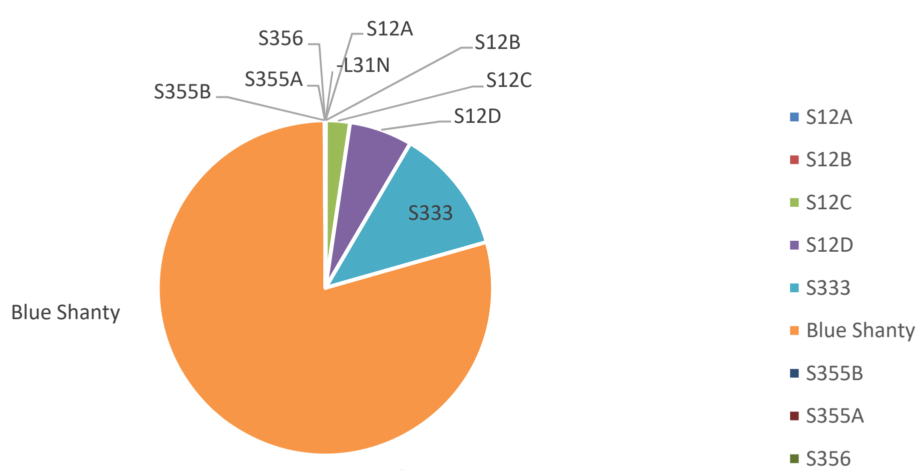
Year = 2016 Scenario: CEPP ALT4R



Variance Components of Total Sampled Flow



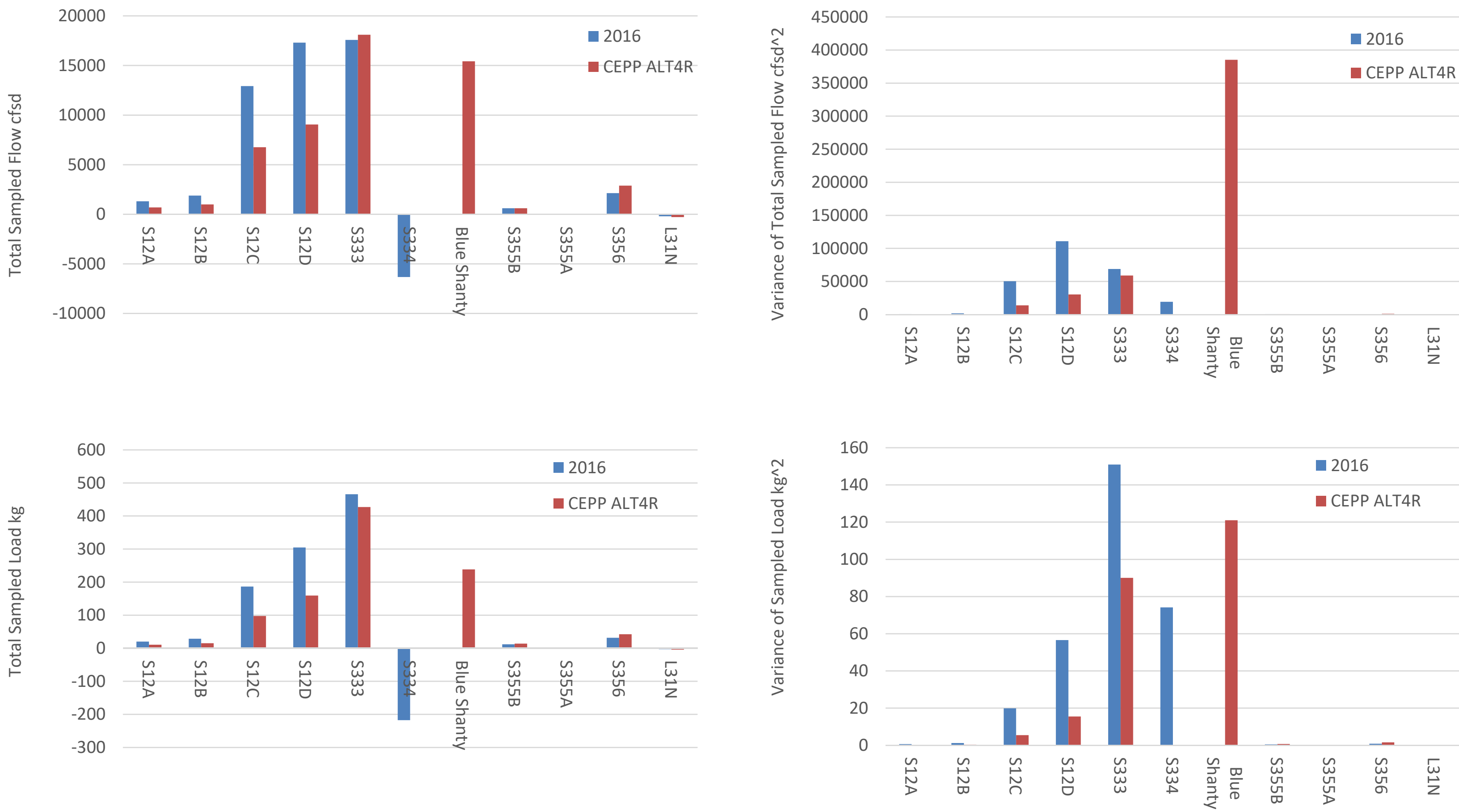
Variance Components of Total Sampled Load



Variance Components of Total Basin Flow

Figure 12

Variance Components of Sampled Flow & Load for 2016 and ALT4R Scenarios



Total Error Variance	Flow cfsd^2	Conc ppb^2	Load kg^2
2016	252606	0.0149	304.5
ALT-4R	490674	0.0066	234.6
Standard Errors	cfsd	ppb	kg
2016	503	0.122	17.5
ALT-4R	700	0.081	15.3

Totals	Flow cfsd	Conc ppb	Load kg
2016	47179	7.2	828
ALT-4R	54181	7.5	1000
RSEs	%	%	%
2016	1.1%	1.7%	2.1%
ALT-4R	1.3%	1.1%	1.5%

of the WCA-3A inflows that are distributed over the WCA-3A marsh, as opposed to being transported through the canal system to the Park (Shafer & Walker, 2013, Figures 6 & 7). Based upon RSM output for the Existing Condition Baseline (ECB) and ALT4R, the WCA-3A inflows that are not distributed over the marsh would decrease from 57% to 14% of the total WCA-3A outflows (S150, S9, and S9A being the only the direct canal discharges remaining). The increased drainage off the WCA-3A marsh back into the L67 canal would reduce P concentrations at S333.

This analysis also does not consider the likelihood that the long-term declining trend in ENP inflow concentration will continue in the future. There is considerable momentum in the historical trend in flow-adjusted concentrations between 1991 and 2017 (-0.13 ppb/yr, Figures 1 & 2). Declining trends in TP concentrations are evident in the combined flows thru S12ABC (-2.2 %/yr) and S12D+S333 (-1.7%/yr), adjusted for variations in WCA-3A stage (Walker, 2018). These trends reflect the combined effects of cumulative load reductions to the WCAs attributed to implementation of Best Management Practices in the Everglades Agricultural Area and operation of Stormwater Treatment Areas (STAs). While most of the concentration reductions occurred between 1991 and 2006, the continued downward trend reflects rinsing of P accumulated in the WCA soils and vegetation. Further reductions in external loads to WCA-3A loads are expected with attainment of the STA Water Quality Based Effluent Limits (WQBELs), which require a long-term FWM concentration less than 13 ppb. While STA-34 has been achieving the WQBEL in the past few years, STA-56 is not close to achieving it, with discharge concentrations exceeding 50 ppb in recent years. Loads to WCA-3A are currently dominated by discharges from the L3 canal and S140, both of which reflect STA-56 discharges. In addition, the Western Everglades Restoration Project (WERP, USACOE, (2018)) will significantly reduce or eliminate discharges from the Feeder Canal Basins (FCB) to WCA-3A by constructing new STAs, degrading the L28I canal, and diverting a portion of the flow to Big Cypress. It is possible that the elevated TP concentrations occasionally observed at S12A and S12B, relative to S12C, reflect transport of FCB loads south along the L28I and L28 South canals. The above analysis assumes that the historical downward trends do not continue, but are fixed at 2016 levels. Given the declining trends in upstream marsh TP levels and planned further reductions in external TP loads to WCA-3A, it is possible that the declining trends in ENP inflow TP levels will continue and that concentrations will be lower in the future. If the FWM decreases, the effects of measurement error on the compliance determination would also be expected to decrease, based upon the correlation between the FWM and the standard error of the compliance metric (FWM – Limit) shown in Figure 10 (bottom center).

Aside from the decreasing TP trends, it is possible that future improvements in operation will further reduce the risk of excursions. There is a potential for modifying operation of S333 and other inflow structures to limit discharges in periods with low and increasing stage in WCA-3A, when TP concentrations tend to be highest. Under an Adaptive Management Program being considered by the COE, adjustments to the volume and timing of discharges could be made based upon upstream stage and/or TP monitoring data. The objective would be to reduce the risk of exceeding the LTLs while still meeting hydrologic objectives and constraints. This type of operation would be significantly different from historical operations, which were made solely based upon hydrologic factors (flood control, water supply, regulation schedules, etc.) and without regard to water quality.

Conclusions

1. Results indicate that the measurement error component of the Water Year 2016 FWM concentration (when all of the current inflow structures were monitored) had a standard deviation ranging from 0.11 to 0.14 ppb (1.6% to 1.9%), depending on the assumed measurement errors in the structure daily flows. This is very small relative to the total random deviation (1.3 to 1.5 ppb) inherent in the Appendix A compliance model. The measurement error is not much higher than the round-off scale (0.1 ppb) applied to the compliance calculations. It is therefore unlikely that measurement errors account for a significant portion of the total random variance already considered in the model.

2. Analysis of the 1979-2017 dataset indicates that the average standard error of the ENP inflow FWM decreased from 0.39 ppb (3.0%) during the Appendix A calibration period (WY 1979-1990) to 0.21 ppb (2.0%) after that (1991-2017). Expressed as a fraction of the inherent Appendix A model variance, measurement error decreased from 8.8% to 2.9%. These decreases reflect reduction of random measurement errors in flow and TP concentration, decreases in the combined inflow FWM, and increases in basin total flow.

3. Based upon the range of standard errors estimated for individual structures, errors in flow measurement account for 1.6 to 35% of the total measurement error variance in the ENP inflow FWM concentration. The remainder is attributed to errors in concentration measurement estimated from replicate TP samples.

4. Because of relatively low flows and TP concentrations, the possible low precision of measuring open-channel reverse flows via the L31N will have no significant impact on precision of the ENP FWM concentration. The higher potential error in measuring L31N reverse flows is offset by the increase in S356 pumped flows, which are measured with much greater precision.

5. The TOC subgroup has considered a variety of methods to track new flows via S356 and L31N in measuring compliance. Explicit consideration of both is the only method that will consider new inflows from the WCAs via S356 while excluding flows recycled from the Park via L31N. This analysis indicates that the overall standard error of the total ENP inflow concentration is relatively small and would be insensitive to measurement errors in flow and concentration at these structures.

6. Because of P reductions within the Blue Shanty Flow-Way and WCA-3B associated with flow diversions under CEPP Alternative 4R, the possible low precision of flow and concentration measurements in the open marsh at the point of entry to NESRS will not have a significant impact on the precision of the ENP FWM concentration and compliance risk.

7. Flow calibration data provided by SFWMD indicates that the daily flow data currently in DBHYDRO under-estimate the discharges thru S333 by 9.5% and over-estimate the discharge thru S334 by 6.5%. The net inflow to ENP (S333-S334) is under-estimated by 16%. This warrants further consideration by the TOC because it could have a significant impact on compliance determinations and evaluating the benefits of restoration projects designed to increase flows to NESRS.

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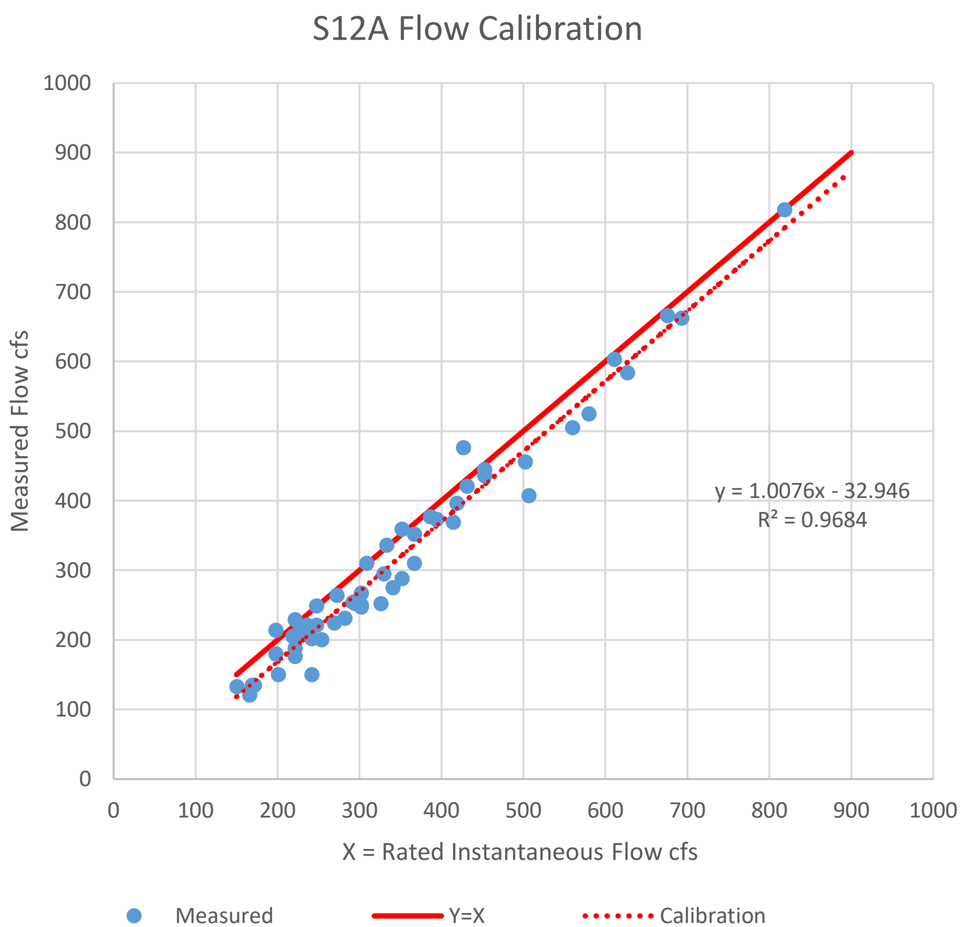
Appendix

A1 – A-7 Error Estimates for Flows at Individual Structures

A-8 – A9 USGS vs. COE Flows

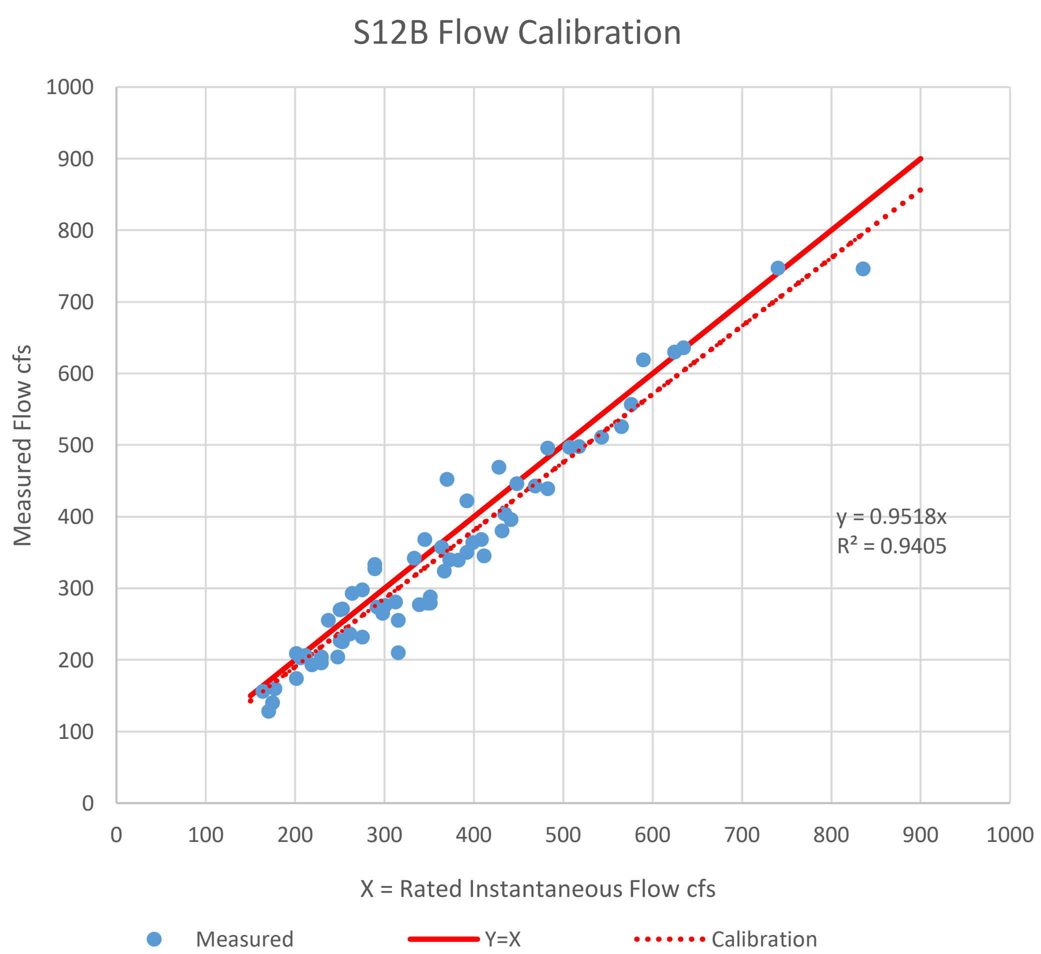
A-1



Regression Measured vs. Rated Flow		
Slope/Intercept	1.008	-32.946
SE Slope	0.026	
R2/SE	0.968	27.802
F/DOF	1533.486	50.000
Recalibrated Slope	1.008	
SE Slope	0.026	
Slope RSE	2.6%	use in error analysis (low estimate)
95% CI	4.3%	
Residual Standard Error		
Regression SE	27.8	
Measured Mean	319.4	
RSE%	8.7%	
Total Error	9.1%	Residual RSE%^{2} + Slope RSE^2 (high estimate)

Rating Curve for Water Years 2008-2017
Errors over-estimated because USGS interpolates errors between dates with velocity measurements. DBHYDRO daily flows reflect these adjustments.

A-2

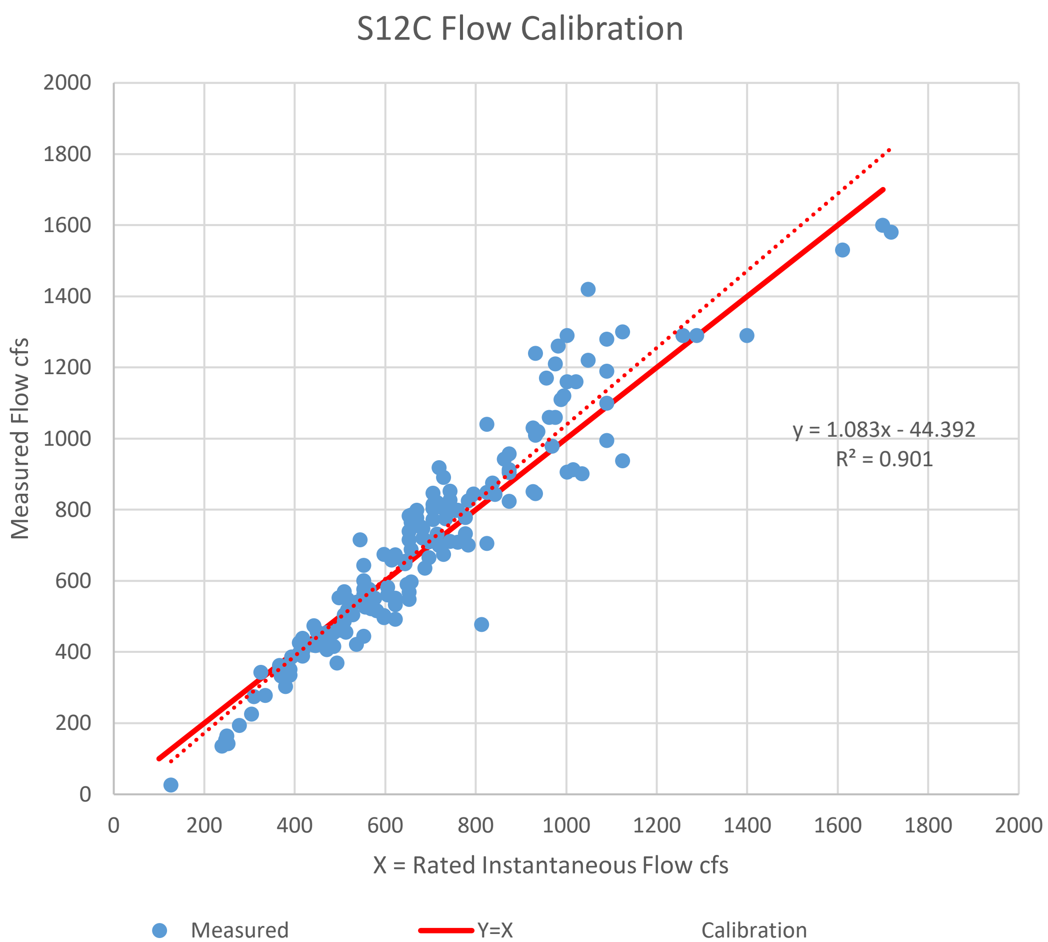


Regression Measured vs. Rated Flow		
Slope/Intercept	0.952	0.000
SE Slope	0.011	
R2/SE	0.991	35.050
F/DOF	7028.143	62.000
Recalibrated Slope	0.952	
SE Slope	0.011	
Slope RSE	1.2%	use in error analysis (low estimate)
95% CI	2.0%	
Residual Standard Error		
Regression SE	35.1	
Measured Mean	343.4	
RSE%	10.2%	
Total Error	10.3%	Residual RSE%^{2} + Slope RSE^2 (high estimate)

Rating Curve for Water Years 2009-2017

Errors over-estimated because USGS interpolates errors between
dates with velocity measurements. DBHYDRO daily flows reflect these adjustments.

A-3

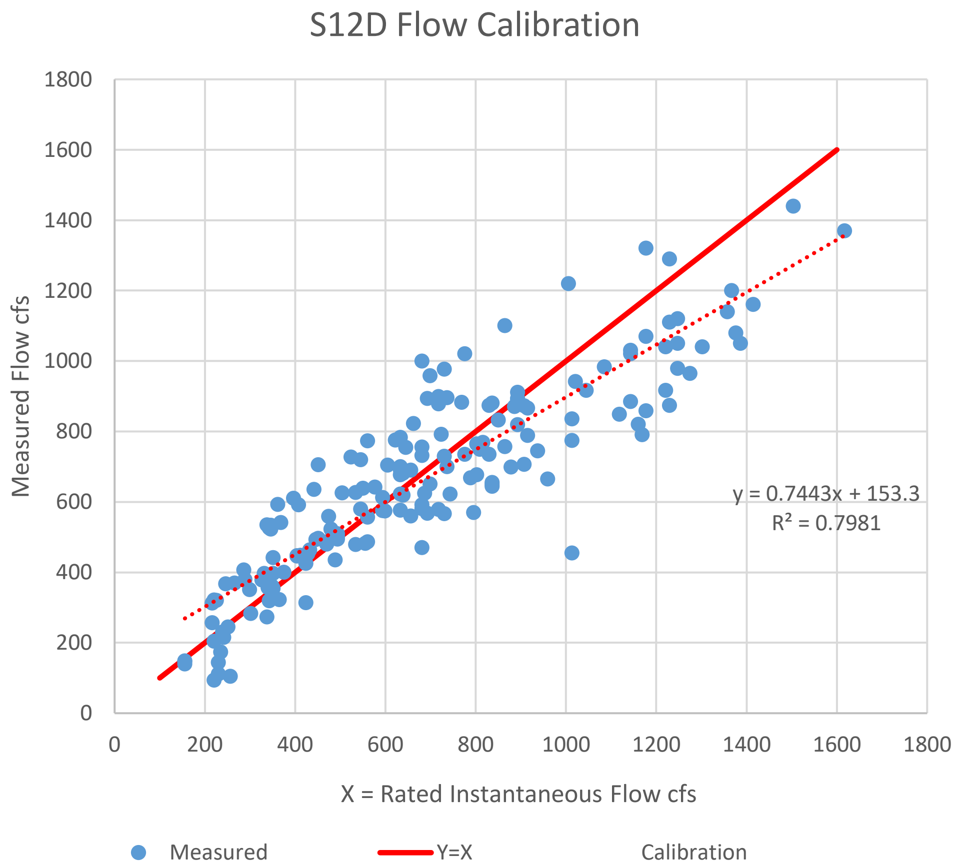


Regression Measured vs. Rated Flow			
Slope/Intercept	1.083	-44.39	
SE Slope	0.029		
R2/SE	0.901	97.98	
F/DOF	1438.283	158.00	
Recalibrated Slope	1.083		
SE Slope	0.029		
Slope RSE	2.6%	use in error analysis (low estimate)	
95% CI	4.4%		
Residual Standard Error			
Regression SE	98.0		
Measured Mean	704.6		
RSE%	13.9%		
Total Error	14.2%	Residual RSE%^{2} + Slope RSE^2 (high estimate)	

Rating Curve for Water Years 2000-2017

Errors over-estimated because USGS interpolates errors between
dates with velocity measurements. DBHYDRO daily flows reflect these adjustments.

A-4

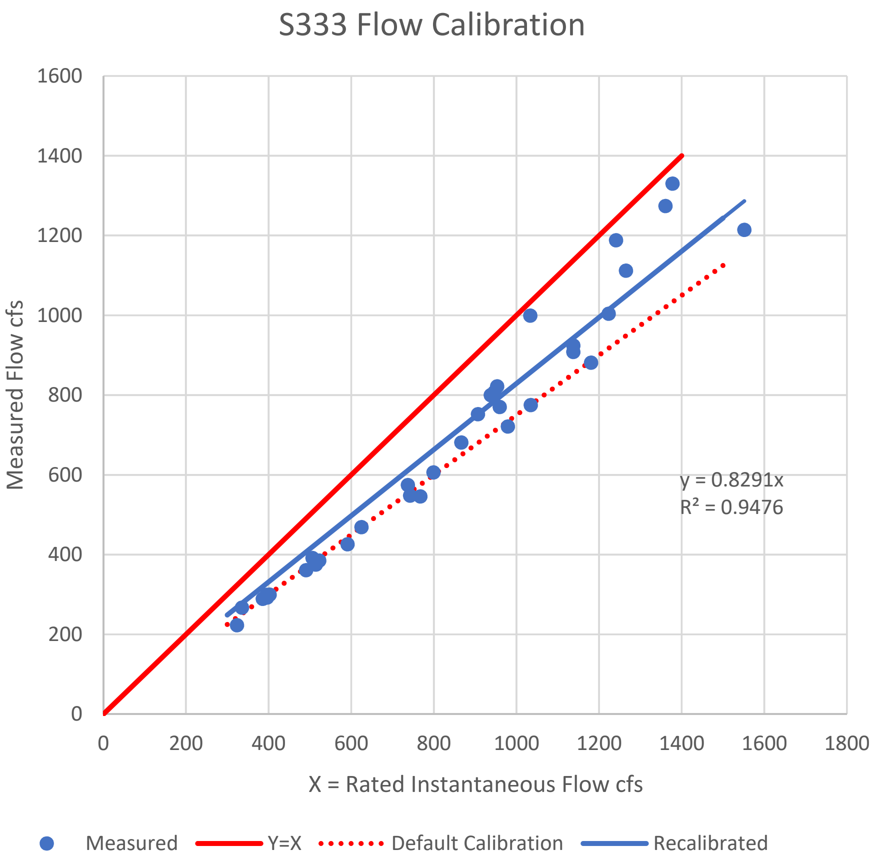


Regression Measured vs. Rated Flow		
Slope/Intercept	0.744	153.303
SE Slope	0.028	
R2/SE	0.798	123.9
F/DOF	687.9	174.0
Recalibrated Slope	0.744	
SE Slope	0.028	
Slope RSE	3.8%	use in error analysis (low estimate)
95% CI	6.3%	
Residual Standard Error		
Regression SE	123.9	
Measured Mean	659.5	
RSE%	18.8%	
Total Error	19.2%	Residual RSE%^{2} + Slope RSE^2 (high estimate)

Rating Curve for Water Years 2001-2017

Errors over-estimated because USGS interpolates errors between dates with velocity measurements. DBHYDRO daily flows reflect these adjustments.

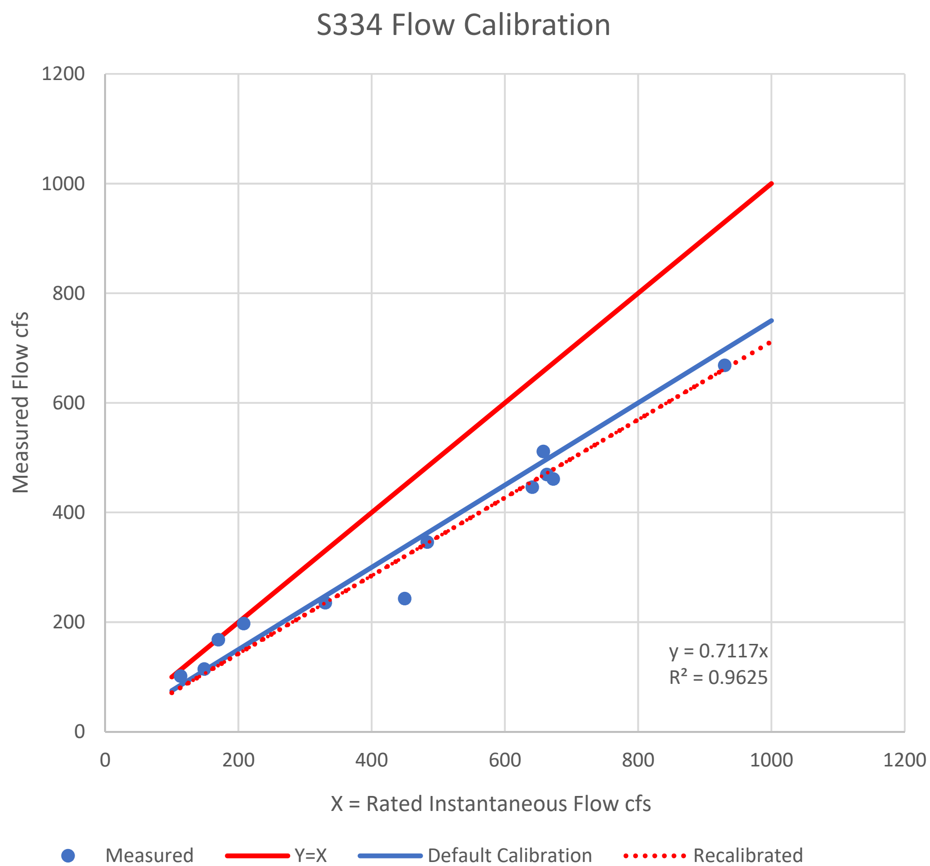
A-5



Regression Measured vs. Rated		
Slope/Intercept	0.829	0
SE Slope	0.014	
R2/SE	0.991	73.8
F/DOF	3529.1	33
Recalibrated Slope	0.829	discharge coefficient
SE Slope	0.014	
Slope RSE	1.7%	
95% CI	3.4%	
Residual Standard Error		
Regression SE	73.8	
Measured Mean	685.7	
Residual RSE%	10.8%	
Default Calibration Assumed for Flows in DBHYDRO		
Slope	0.75	default discharge coefficient
SE Slope	0.014	assume same as re calibrated slope
Slope RSE	1.9%	use in error analysis (low estimate)
Total Error	10.9%	Residual RSE%^{2} + Slope RSE^2 (high estimate)
DBHYDRO Flow Bias	-9.5%	(DBHYDRO - Recalibrated) / Recalibrated

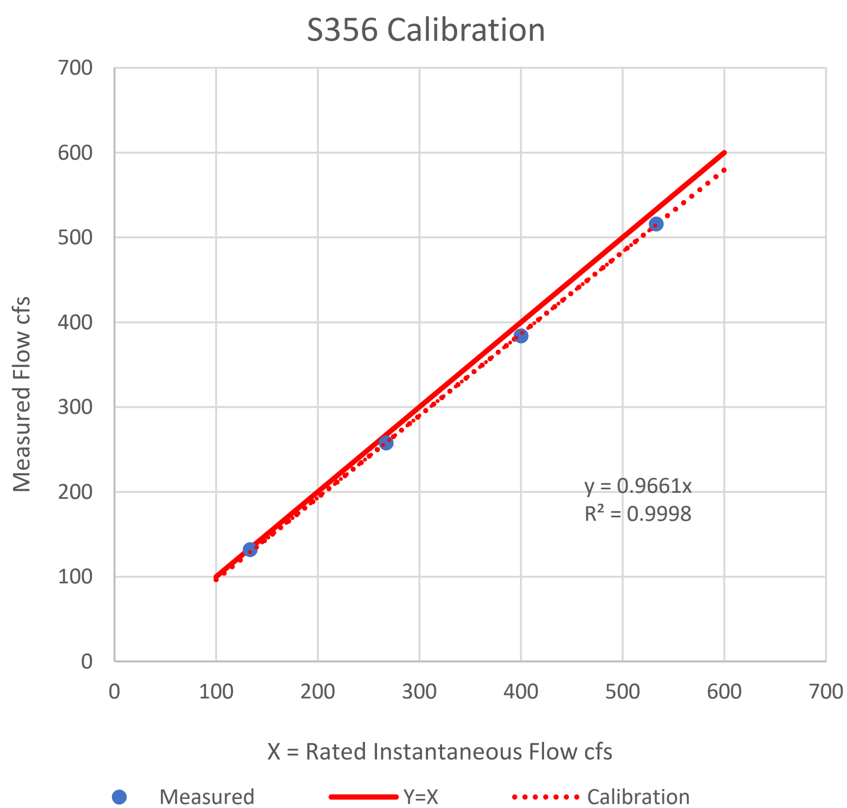
Existing values in DBHYDRO are based upon the default calibration.

A-6



Regression Measured vs. Rated			
Slope/Intercept	0.712	0.000	
SE Slope	0.019		
R2/SE	0.992	34.882	
F/DOF	12.000	0.000	
Recalibrated Slope	0.712	discharge coefficient	
SE Slope	0.019		
Slope RSE	2.7%		
Residual Standard Error			
Regression SE	34.9		
Measured Mean	329.8		
RSE%	10.6%	0	
Calibration Assumed for Flows in DBHYDRO			
Slope	0.75	default discharge coefficient	
SE Slope	0.019	assume same as re calibrated slope	
RSE%	2.6%	use in error analysis (low estimate)	
Total Error	10.9%	Residual RSE%^{2} + Slope RSE^2 (high estimate)	
DBHYDRO Flow Bias	5.4%	(DBHYDRO - Recalibrated) / Recalibrated	

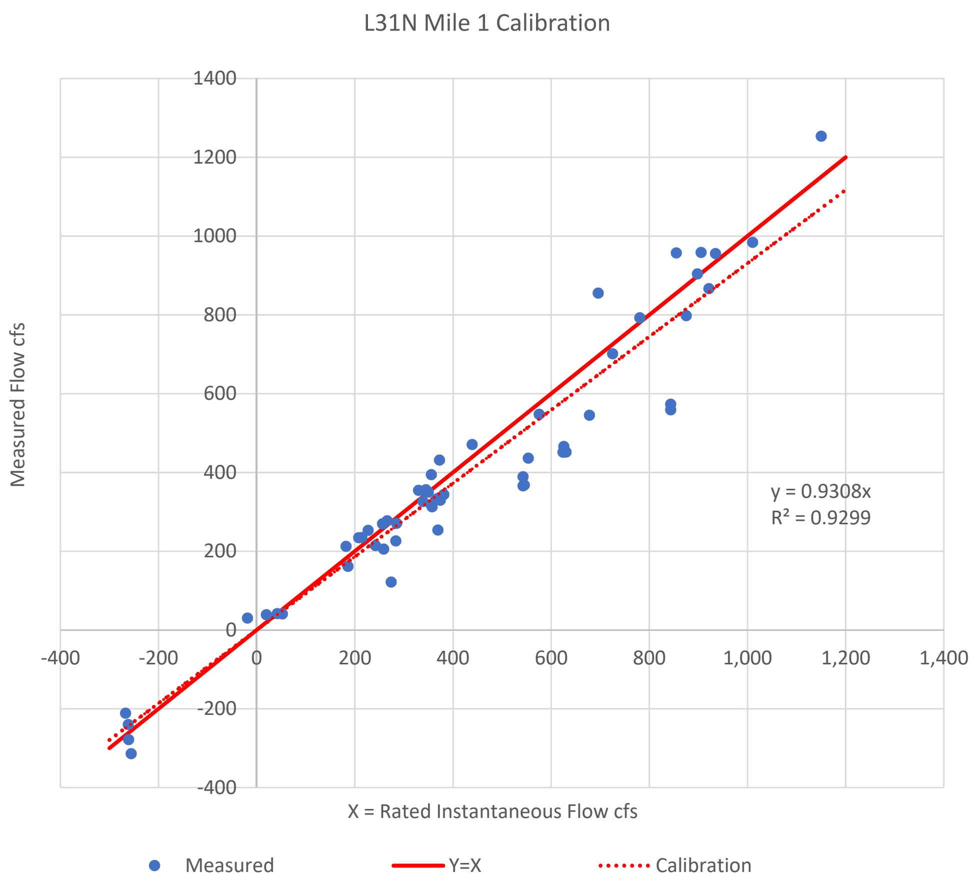
A-7



Regression Measured vs. Rated		
Slope/Intercept	0.966	0.000
SE Slope	0.003	
R2/SE	1.000	2.410
F/DOF	85661	3.000
Recalibrated Slope	0.966	
SE Slope	0.003	
Slope RSE	0.3%	use in error analysis (low estimate)
95% CI	0.8%	
Residual Standard Error		
Regression SE	2.4	
Measured Mean	322.5	
RSE%	0.7%	0
Total Error	0.8%	Residual RSE%^{2} + Slope RSE^2 (high estimate)

Flows in DBHYDRO Assumed to be Calibrated

A-8



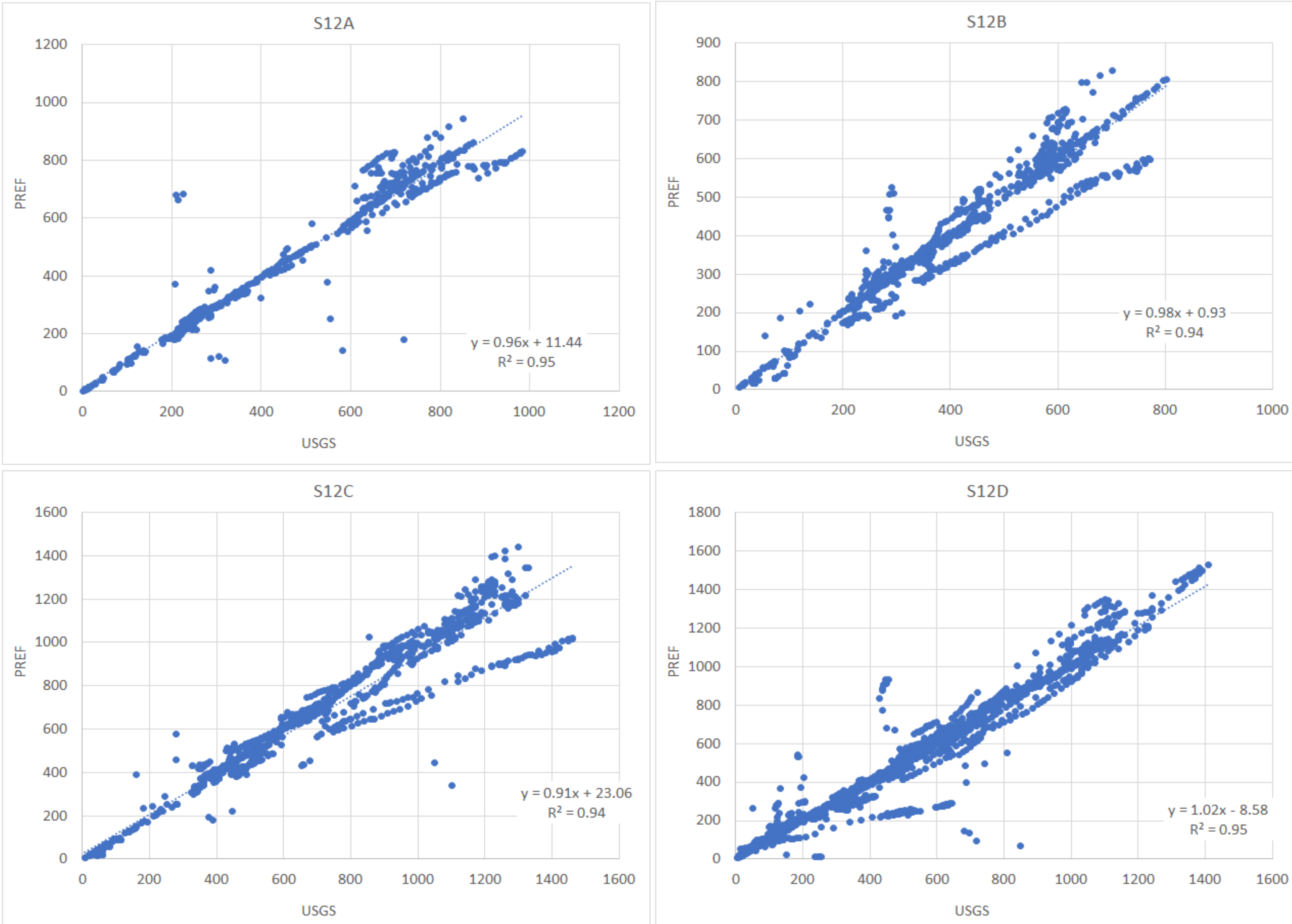
Regression Measured vs. Rated		
Calib Date Range	11/01/08	09/07/16
Slope/Intercept	0.931	0.000
SE Slope	0.022	
R2/SE	0.971	86.936
F/DOF	1862.0	55.000
Recalibrated Slope	0.931	
SE Slope	0.022	
Slope RSE	2.3%	use in error analysis (low estimate)
95% CI	3.9%	
Residual Standard Error		
Regression SE	86.9	
Measured Mean	390.9	
Residual RSE%	22.2%	
Total Error	22.4%	Residual RSE%^{2} + Slope RSE^2 (high estimate)

Flows in DBHYDRO Assumed to be Calibrated

Note:
Negative Flows are to the North (Used in Error Analysis)
Errors assumed to be equal to estimates for entire dataset.
A new site at Mile 0 potentially used to flows for compliance
Errors at Mile 0 assumed to equal errors at Mile 1
USGS Data

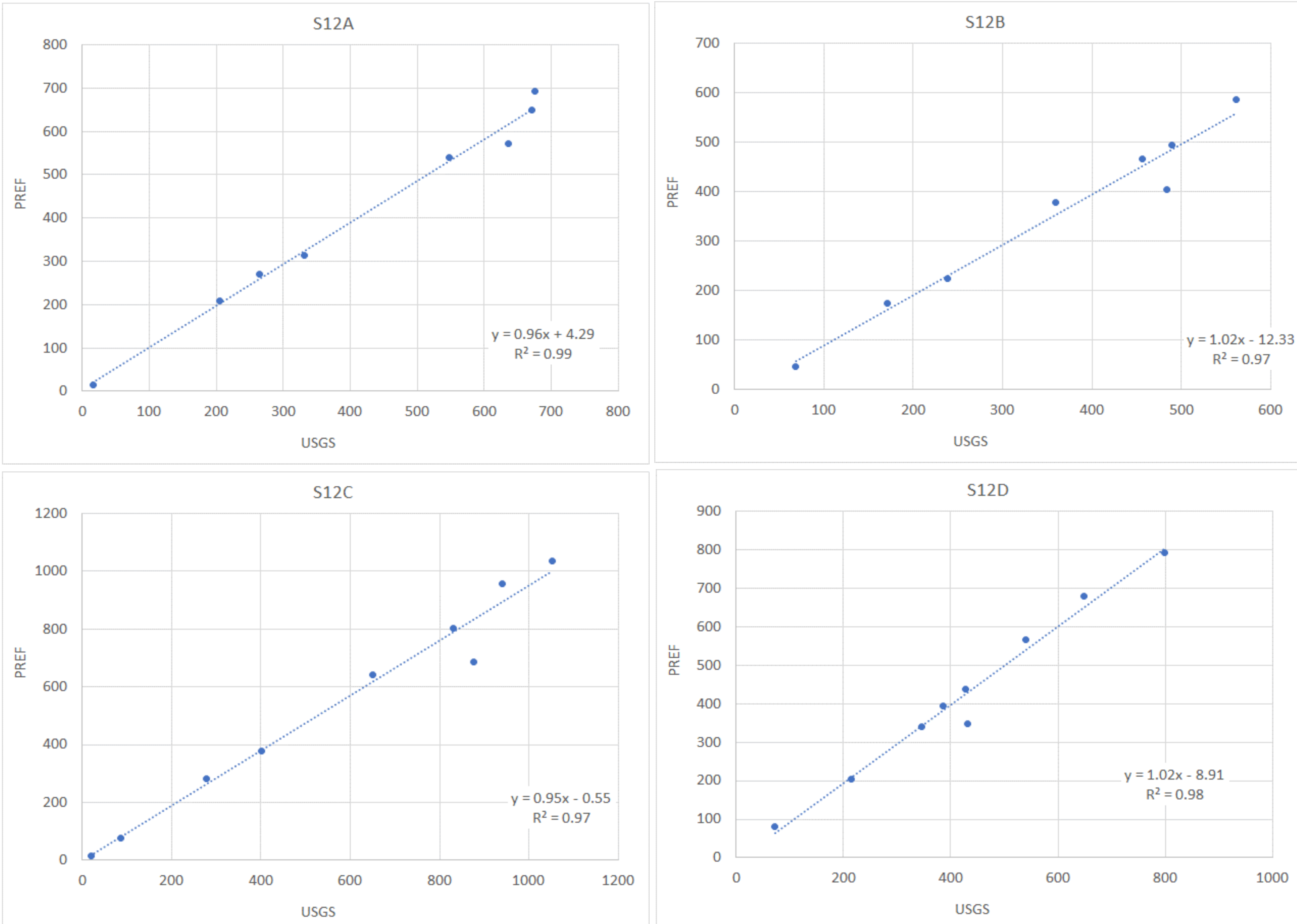
A-9

Correlation between DBHYDRO Preferred Flows & USGS Flows (CFS) Water Years 2004-2011 Daily Time Step



Error Statistics	S12A	S12B	S12C	S12D
Std Deviation (Preferred - USGS) / Mean USGS	14.4%	13.7%	15.7%	19.2%

Correlation between DBHYDRO Preferred Flows & USGS Flows (CFS) Water Years 2004-2011 Yearly Time Step



Error Statistics	S12A	S12B	S12C	S12D
Std Deviation (Preferred - USGS) / Mean USGS	6.1%	9.5%	11.2%	7.9%