APPENDIX B – PROPOSED TRIGGERS GUIDING YEAR ROUND DPM OPERATIONS

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PROPOSED TRIGGERS GUIDING YEAR-ROUND DPM OPERATIONS OF THE S152, BASED ON STATISTICAL ANALYSES OF CANAL WATER TP VARIATION

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Summary

1. Overview - The proposed S152 operational strategy utilizes a decision tree (**Figure 8-1**) which is used to ensure that the S152 will be open when TP at the S152 is <= 10 ppb and ensure that for a given water year the geometric mean during operations will be <= 10 ppb.
2. Data and Analyses Performed - The decision tree uses month-specific regressions to predict S151 geomean TP (GMTP) one month in advance. The regressions predict S151 GMTP as a function of previous month's S151 GMTP, average L67A canal stage and average marsh-to-canal stage difference. Data used are S151 TP grab samples from 2003-2017, collected mostly biweekly. Regression model components differ month-to-month, as different sets of covariates work best depending on time of year.
3. Decision Tree Part 1 – The decision to open S152 is based regression forecasts of TP for the following month. The decision tree assumes monitoring and compliance data will be collected biweekly at the S152. (Note - in special cases when immediate opening of the structure is needed, the week-to-week dynamic trigger can also be used to open the structure)
4. Decision Tree Part 2 – The decision to continue operations is based on forecasts of GMTP into the following month. This step functions similarly to the "January Trigger" (Rule 4) of the original operational strategy, in which the GMTP forecast includes all observed data during operations and regression-based predictions of GMTP for the next month.
5. S151 vs S152 TP difference - Paired S151 & S152 data (since 2013) show S152 TP is significantly lower than S151, by ~1.1-1.3 ppb (depends on time of year). Since the decision tree uses S152 data for operations and compliance, we therefore propose using the regression models using S151 data corrected for the S152/S151 difference: in this case, all S151 data were transformed by subtracting 1ppb. Overall, the corrected model (**Table 8-1**) performed very well in identifying months when TP was acceptable for starting flow: over the July-October period, there were only 2 instances of incorrectly predicting <=10 ppb and both had relatively low observed TP (11 and 12 ppb).
6. Additional regressions to refine and to predict S151 TP 2 months in advance (for greater operational flexibility) are in progress and may be proposed at a later time.

1. Background

The objectives of this document are (1) to evaluate key environmental covariates in explaining monthly variation in geometric mean water P concentrations (water GMTP) at the S-151 (**see map in Figure 1-1**), and (2) use covariates and S151 data to develop preliminary triggers to guide operations of the S-152 for the Decomp Physical Model (DPM) and assure low water TP inflow concentrations.

Previous analyses conducted by Saunders and Sklar (2011) used data encompassing 2003-2010 to test covariates explaining interannual and monthly water column TP variation in the L67A canal. The analyses focused on TP concentrations during the original DPM operational window; October to January, (DPM Science Plan 2010), the months consistently exhibiting the lowest TP values. These analyses showed that S-151 water TP exhibited relatively higher values during years 2006 and 2007, compared to other years (≤10 ppb) and that high values corresponded with relatively low stages in interior WCA-3A marshes (based on EDEN8 stages) (Saunders and Sklar, 2011). They also found that previous months' TP, including 1-month and 2-month lags, could be used to explain variability in TP.

Examination of all months over the study period highlight that water GMTP ≤10 ppb or ≤11 ppb may occur in months outside of the October through January window (**Table 1-1**). The analyses presented here focus on the covariates that best explained TP variation in previous analyses (**Table 1-2;** Saunders and Sklar, 2011) but also include analyses of all months, new covariates (e.g., marsh-canal stage difference; additional information on fire events), and slightly more complex statistical models given the larger sample size (N = 13 to 15, depending on the month) compared to the previous analyses (N= 6-8). With the larger sample size the models are more robust, providing decreased uncertainty in the factors explaining the GMTP at S152.

Table 1-1. Monthly Geometric Mean TP (GMTP) and summary statistics of grabs samples collected at the S-151. Summaries based on the period from January 2003 to January 2017. Sample size variation is due to the absence of samples in that month for a given year. Because TP at the S-152 structure is approximately 1 ppb lower than S-151 TP (**see Section 9**), the far right column indicates the percent of years when GMTP ≤ 11 ppb as a proxy for the percent of years when S-152 GMTP ≤ 10 ppb.

Month	Geometric Mean	Std Dev	Std Err Mean	Upper 95% Mean	Lower 95% Mean	N	% of years GMTP ≤ 10 ppb	% of years GMTP ≤ 11 ppb
May	**0.022**	0.010	0.003	0.029	0.018	14	0%	0%
June	**0.021**	0.011	0.003	0.030	0.017	14	7%	7%
July	**0.016**	0.011	0.003	0.024	0.012	14	14%	43%
Aug	**0.013**	0.005	0.001	0.017	0.011	13	31%	38%
Sep	**0.011**	0.003	0.001	0.013	0.010	13	54%	69%
Oct	**0.010**	0.002	0.000	0.011	0.009	13	69%	85%
Nov	**0.009**	0.001	0.000	0.010	0.009	13	85%	100%
Dec	**0.009**	0.002	0.000	0.011	0.009	14	79%	86%
Jan	**0.010**	0.002	0.001	0.012	0.009	15	67%	87%
Feb	**0.012**	0.004	0.001	0.015	0.010	14	21%	57%
Mar	**0.014**	0.004	0.001	0.017	0.012	14	7%	29%
Apr	**0.018**	0.008	0.002	0.025	0.015	14	7%	7%

Table 1-2. List of environmental covariates examined to explain variability in water TP data. Parameters with high explanatory power may be used as triggers to aid operational rules for the DPM structure. * = new covariate that was not tested in previous analyses in Saunders and Sklar (2011).

Covariate	Description of statistical test or expected relationship
Serial correlation (month-to-month)	Evaluate regression of monthly water TP as a function of water TP in previous months.
WCA3A marsh stage	Are higher stages in WCA3A marsh correlated with high/lower water TP in canal? Do high marsh stages effectively dilute water TP in the Miami and L67A canals?
L67A canal stage *	Are higher stages in the canal correlated with high/lower water TP in canal?
Stage difference (WCA3A marsh vs L67A canal) *	During dry-downs, it expected that some movement of sediment into the canal may occur. As water slopes (marsh-to-canal) steepen, it is hypothesized that some sediments on or near the canal bank may be mobilized, entering the canal water column raising water column TP.
Upstream P sources	Evaluate regression of monthly water TP as a function of flow-weighted TP at inflow structures to WCA3A in months before and during DPM operational window.
Rainfall patterns	Basin-specific monthly rainfall. Evaluate regression of monthly water TP as a function of rainfall in months preceding or during DPM operational window.
Extreme events	Does extreme high (or low) water TP follow extreme storm events (high rainfall or high wind)? Does water TP tend to increase after nearby fires?

Figure 1-1. Map of DPM study area, the S152 culvert structure (which delivers water to the DPM study area), the EDEN8 stage gages in WCA-3A marsh, Site 69W stage gage (located in the L67A canal), the S151 culvert structure (at the intersection of the L67A and Miami Canals), and the S9A structure.

2. Data Sources

Water TP data for the S-151 structure were obtained from "DBHYDRO", the South Florida Water Management District's hydrometerologic, water quality, and hydrogeologic data retrieval system (URL: http://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu; SFWMD, 2017). For each year, monthly geometric means were generated in JMP v.12 statistical software.

Stage data were downloaded as daily values from the Everglades Depth Estimation Network (EDEN) stage EDEN 8 (located in the marsh; values in feet NAVD88) and Site 69W (located in the L67A canal; values in feet NAVD88) (Conrads and Petkewish, 2009) and then summarized into monthly averages. Note that EDEN 8 values from January 2003 to July 2006 are hindcasted values from EDEN 8 (Conrads and Petkewish, 2009).

Daily difference values between marsh and canal stages were calculated by Stage Difference = EDEN8 and Site 69W (values in feet). These differences were then summarized into monthly averages.

Upstream P sources: All flow data and TP data from the S9 and S9A structures were obtained from "DBHYDRO", the South Florida Water Management District's hydrometerological, water quality, and hydrogeologic data retrieval system (URL: http://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu; SFWMD, 2011).

Rainfall data were obtained from basin-specific estimates for WCA-3 (based on DBHYDRO data) and can be found on the SFWMD website (SFWMD URL: https://www.sfwmd.gov/weather-radar/rainfall-historical/monthly)

Tropical storm information is summarized from the National Oceanic and Atmospheric Administration (http://www.aoml.noaa.gov/hrd/hurdat/DataByYearandStorm.htm).

Fire location information (based on satellite imagery) are available from the USDA Forest Service Active Fire Mapping Program (https://fsapps.nwcg.gov/afm/).

3. Simple linear regression models: Serial correlation, stage variation and stage difference

The strength of the linear relationships (adjusted R^2) between predicted water TP at the S151 based on individual regressions with water TP and stage-related covariates during the month prior are summarized in **Table 3**. Scatterplots showing correlations between water TP with previous month's TP and previous month's canal stage (generally the stage-related covariate with the highest explanatory power) are provided in **Figures 3-1** and **3-2**. Simple linear regressions indicate previous month's stage and stage difference generally have the most explanatory power early in the water year (May, June, and July) while previous month's TP has greater explanatory power in mid-wet season months from August to October. Explanatory power of the November, December and January TP is low, likely a result of the low variability and low values of TP in those months. Stage difference (marsh – canal) has greater explanatory power in late dry season months of March and April. In general, canal stages (site 69W) explain more of the variability in TP than interior marsh stages (EDEN8).

Table 3. Adjusted R^2 values of simple linear regressions of interannual variation in monthly S-151 GMTP as a function of the prior month's geometric mean TP at S-151, prior month's mean stage in the L67A canal (from site 69W), prior month's mean marsh stage in interior WCA-3A (from site EDEN8), and the prior month's difference in stage between the interior marsh and the canal. Color codes range from low adjusted R^2 values (red) to high values (green). Data used spans January 2003 to January 2017. Regressions were conducted in JMP v.13.

Month	S-151 TP R^2	69W R^2	EDEN8 R^2	Stage Diffc. (EDEN8 - 69W) R^2
May	0.57	0.55	0.42	0.59
June	0.18	0.65	0.64	0.32
July	0.48	0.69	0.68	0.56
Aug	0.70	0.44	0.38	0.37
Sep	0.82	0.46	0.45	0.33
Oct	0.68	0.22	0.21	0.20
Nov	0.04	0.11	0.09	0.31
Dec	-0.04	0.31	0.31	-0.06
Jan	0.40	0.03	0.02	-0.04
Feb	0.03	-0.04	-0.06	0.10
Mar	-0.05	0.23	0.15	0.44
Apr	0.14	0.25	0.18	0.34

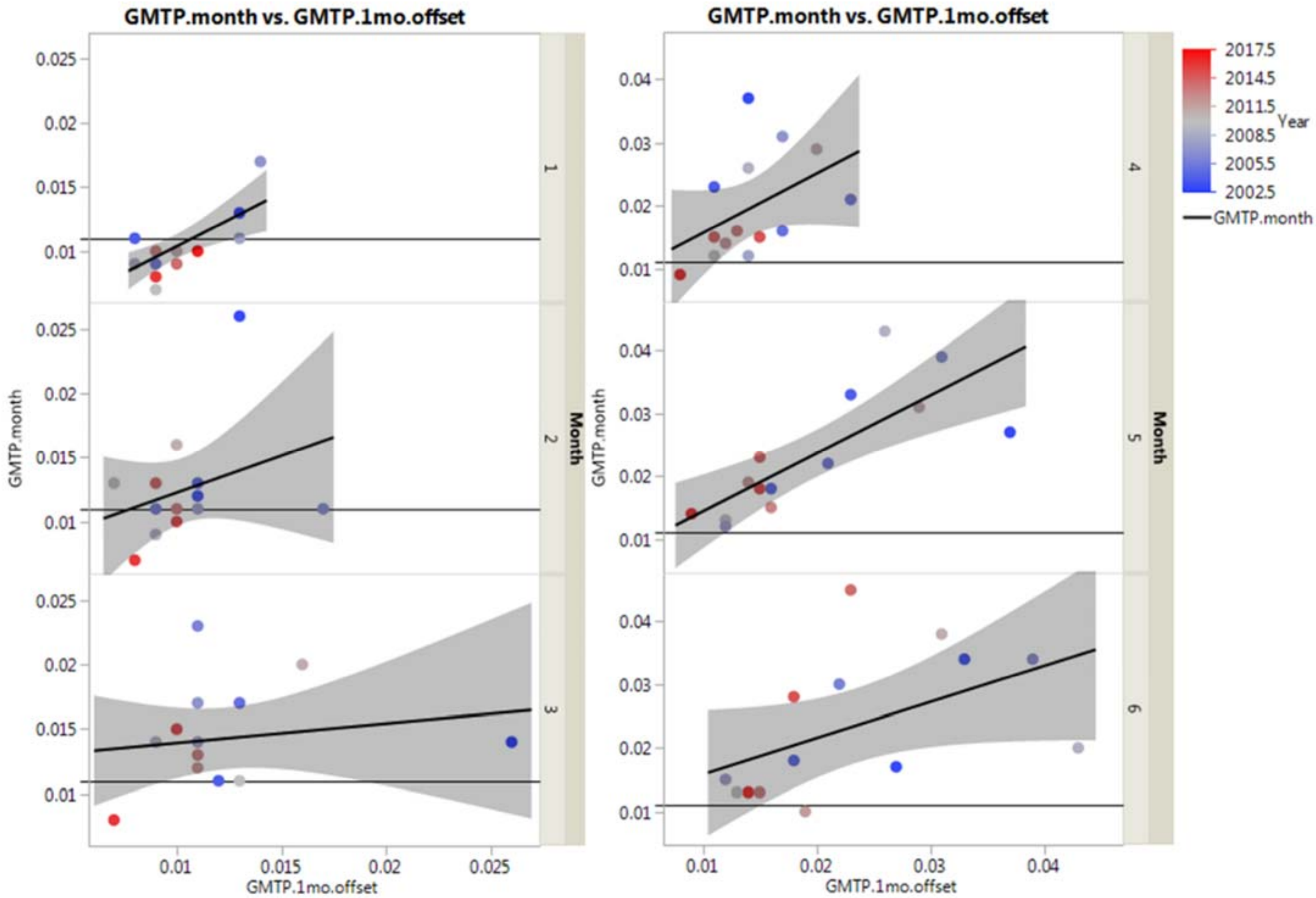


Figure 3-1. A. Monthly GMTP (mg P / L) at S-151 as a function of previous month's GMTP for months January through June, based on the 2003 to 2017 period of record. Horizontal lines indicate S-151 TP values of 11 ppb (which correspond to estimated 10 ppb at S-152). Simple linear regression and 95% confidence intervals were performed in JMP v.13. Color code of symbols indicates year order, from years early in the period of record (dark blue) to recent years (dark red). Month number (January = 1, February = 2, etc.) is shown to the right of each graph.

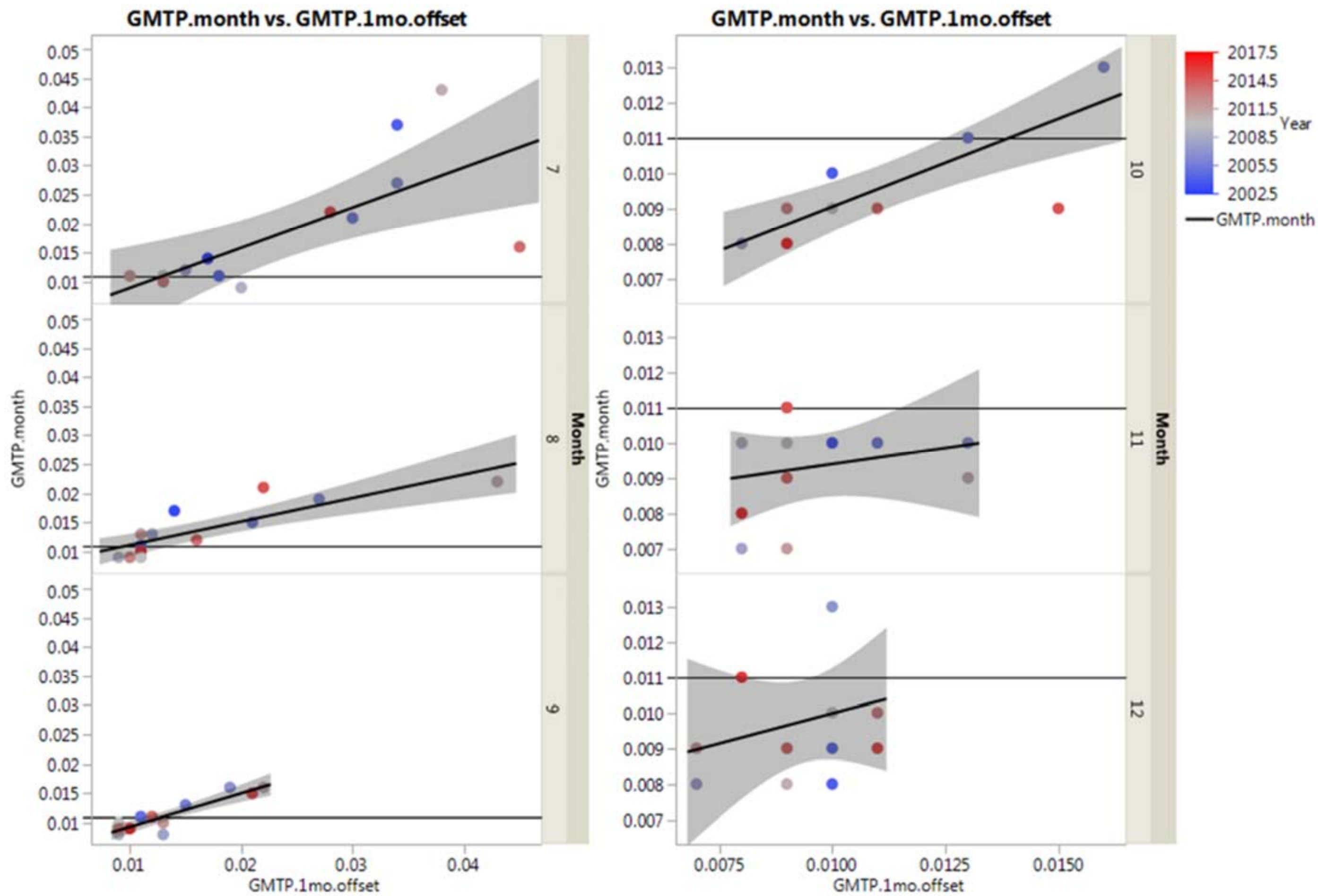


Figure 3-1 B. Monthly geometric mean TP (mg P / L) at S-151 as a function of previous month's GMTP, based on 2003-2017 period of record. Horizontal lines indicates a value of 11 ppb. Simple linear regression and 95% confidence intervals were performed in JMP v.13. Color code of symbols indicates year order, from years early in the period of record (dark blue) to recent years (dark red). Month number (July = 7, August = 8, etc.) is shown to the right of each graph.

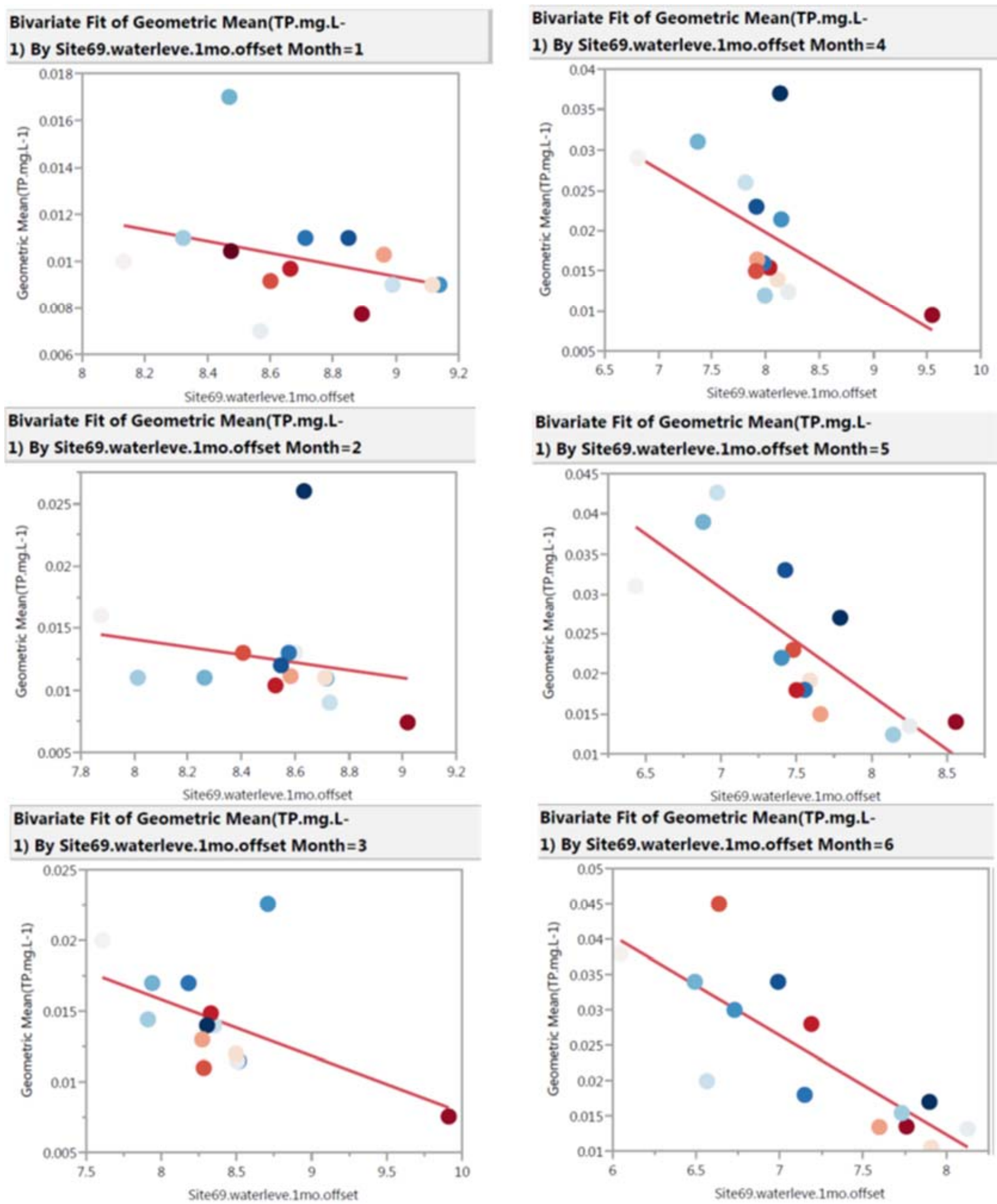


Figure 3-2. A. Monthly geometric mean TP (mg P / L) at S-151 as a function of previous month average canal stage (Site 69W), based on the 2003-2017 period of record. Simple linear regressions were performed in JMP v.13. Color code of symbols indicates year order, from years early in the period of record (dark blue) to recent years (dark red)

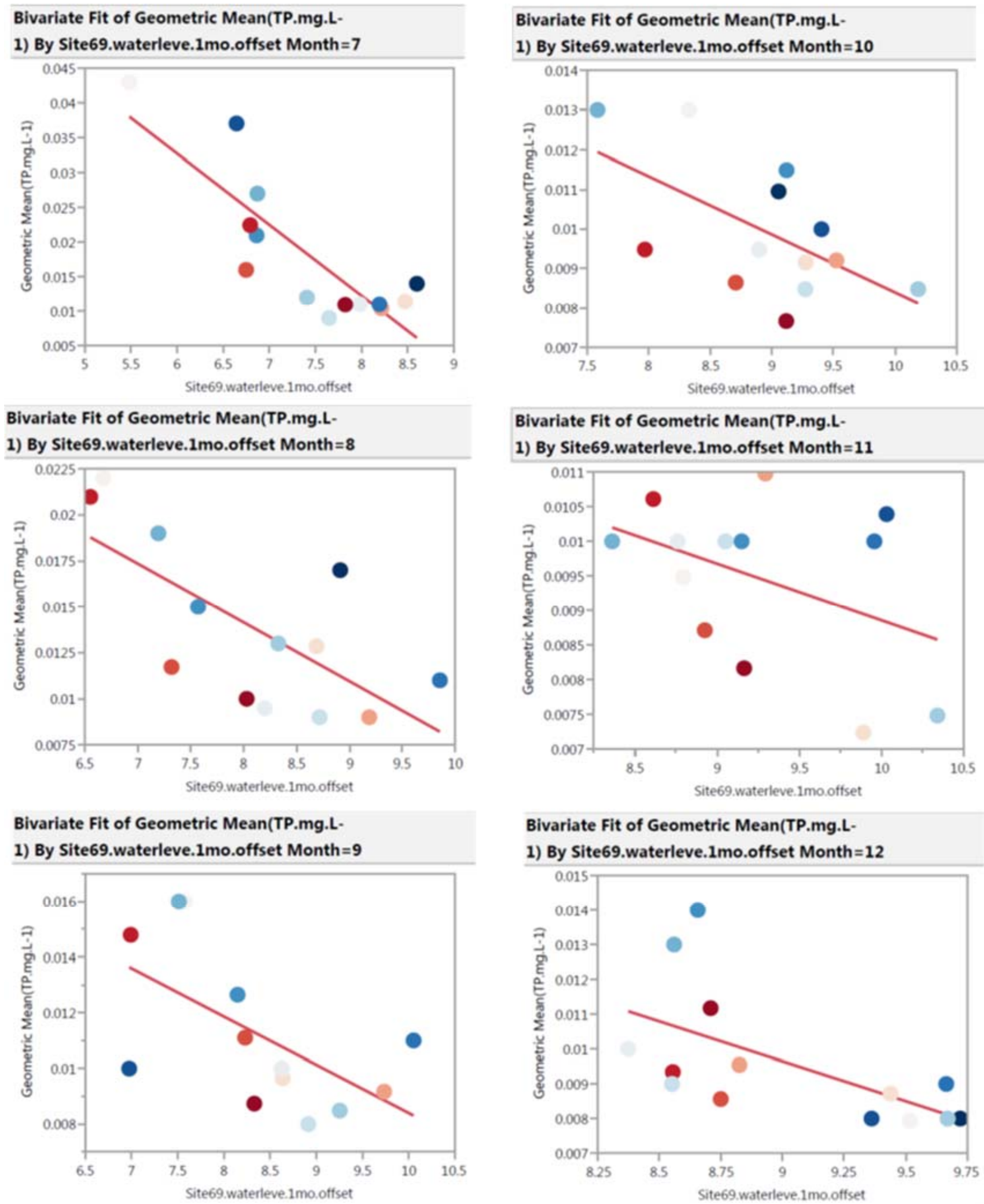


Figure 3-2 B. Monthly geometric mean TP (mg P / L) at S-151 as a function of previous month average canal stage (Site 69W), based on the 2003-2017 period of record. Simple linear regressions were performed in JMP v.13. Color code of symbols indicates year order, from years early in the period of record (dark blue) to recent years (dark red)

4. Serial correlation: multiple linear regression models

Multiple factor regression models (**Table 4**) were consistent with simple linear regression models, showing stage-related factors were the most significant factors for the months of June and July, while previous month's TP was typically more significant during the months of August through October. Stage difference increased in explanatory power in the late dry season months from March to May.

For some months, multiple variables improved the adjusted R^2 compared to the simple linear regression of the best performing single covariate. These months include May (adj. R^2 increased from 0.57 to 0.71, comparing **Table 3** and **Table 4**) and August (from 0.70 to 0.84, comparing **Table 3 and Table 4**), suggesting both stage and TP information would improve explanatory power compared to single parameter models. Model explanatory power was low for November and December. In some cases, previous month's TP was nonlinearly related to S-151 TP and improved adj. R^2 substantially for January (0.40 to 0.68).

Table 4. Multiple linear regression of S-151 GMTP as a function of the prior month's geometric mean TP at S-151 (linear + 2nd order terms), stage in the L67A canal (site 69W), and the difference in stage (in feet) between the interior marsh and the canal (EDEN8 – 69W). Model adjusted R^2's and p values of significant ($p < 0.05$) main effects are shown. Marginally significant factors at the $p < 0.20$ level are also shown to highlight potential secondary explanatory variables. Polynomial terms were tested for S-151 TP based on visual assessment of scatter plots. Color codes for R^2 values range from red (low values) to green (high values). Color codes for significant (darker blue) and marginally significant p values (lighter blue). Regressions were conducted in JMP v.13.

Month	Model adj. R^2	S-151 TP (p)	S-151 TP^2 **(p)**	69W (p)	Stage diffc.
May	0.71*	0.15			0.15
June	0.69*		0.08	0.05	
July	0.61			0.16	
Aug	0.84*	0.01		0.07	0.04
Sep	0.75	0.02			
Oct	0.70*	0.01			
Nov	0.34*		0.10		
Dec	0.01			0.13	
Jan	0.68*		0.02		
Feb	-0.09				
Mar	0.33				0.06
Apr	0.21				0.19

5. Serial correlation: multiple linear regression including an interaction term

The interaction term S-151 TP x stage difference was added to the multiple linear regression models in section 4, the results summarized in **Table 5**. The interaction term was evaluated based on the expectation that canal water TP could potentially be affected by marsh-to-canal slope but dependent on the current TP conditions in the marsh and canal. For example, during the wet season low marsh TP may not influence canal TP if low TP conditions already exist in the canal. The addition of an interaction term was significant or marginally significant ($P < 0.2$) and improved the model fit over the model with no interaction (**Table 5**) for the months of July (adj. R2 = 0.77 vs 0.61, respectively), February (0.19 vs -0.09) and May (0.77 vs 0.71, respectively), and November (0.46 vs 0.34, respectively).

Table 5. Multiple linear regression of S-151 GMTP as a function of the same variables as in **Table 4**, plus an interaction term of prior month's TP × stage difference. Model adjusted R^2's and p values of significant ($p < 0.05$) main effects are shown. Marginally significant factors at the $p < 0.20$ level are also shown to highlight potential secondary explanatory variables. Polynomial terms were tested for S-151 TP based on visual assessment of scatter plots. Color codes for R^2 values range from red (low values) to green (high values). Color codes for significant (darker blue) and marginally significant p values range (lighter blue). Regressions were conducted in JMP v.13.

Month	Model adj. R^2	S-151 TP (p)	S-151 TP^2 (p)	69W (p)	Stage Diffc.	S-151 TP x Stage Diffc.
May	0.77	0.05			0.16	0.10
June	0.67		0.17	0.06		
July	0.77		0.05			0.03
Aug	0.82	0.02		0.10	0.07	
Sep	0.71	0.03				
Oct	0.71	0.02				
Nov	0.46	0.10				0.16
Dec	0.06			0.16		
Jan	0.66		0.02			
Feb	0.19					0.08
Mar	0.31				0.07	
Apr	0.13				0.20	

6. Serial correlation: 2-month lag terms

Additional models were explored by evaluating the explanatory power of covariates offset by two months prior to the observed values. Using two month offsets in guiding S-152 operations were evaluated as they would provide greater lead time in preparing DPM monitoring activities associated with S-152 flow. Results are provided in **Tables 6-1** and **6-2.**

Table 6-1. Adjusted R^2 values of simple linear regressions of interannual variation in monthly S-151 GMTP as a function of the 2-month offset geometric mean TP at S-151, 2-month offset mean stage in the L67A canal (site 69W, ft. NAVD88), 2-month offset mean marsh stage in interior WCA-3A (Eden8, ft. NAVD88). Color codes range from low adjusted R^2 values (red) to high values (green). Regressions were conducted in JMP v.13.

Month	S-151 TP R^2	69W R^2	EDEN8 R^2
May	0	0.18	0.23
June	0.05	0.41	0.35
July	0.15	0.53	0.36
Aug	0.24	0.3	0.35
Sep	0.44	0.36	0.37
Oct	0.55	0.16	0.15
Nov	0.02	0	0
Dec	0.01	0.17	0.17
Jan	-0.09	-0.07	-0.07
Feb	-0.09	0.23	0.29
Mar	0.02	0.06	0.12
Apr	0.36	0.08	0.12

Table 6-2. Multiple linear regression of S-151 GMTP as a function of the 2-month offset GMTP at S-151 (linear + 2nd order terms), stage in the L67A canal (site 69W), and the difference in stage (in feet) between the interior marsh and the canal (EDEN8 – 69W). Model adjusted R^2's and p values of significant ($p < 0.05$) main effects are shown. Marginally significant factors at the $p < 0.20$ level are also shown to highlight potential secondary explanatory variables. Polynomial terms were tested for S-151 TP based on visual assessment of scatter plots. Color codes for R^2 values range from red (low values) to green (high values). Color codes for significant (darker blue) and marginally significant p values range (lighter blue) Regressions were conducted in JMP v.13. * indicate models with some improvement over a simple linear regression model (**Table 6-1**).

Month	Model adj. R^2	S-151 TP (p)	S-151 TP^2 (p)	69W (p)	Stage diffc. (p)
May	0.12				
June	0.24				
July	0.68 *			0.01	0.01
Aug	0.34				
Sep	0.43	0.09	0.21		
Oct	0.48	0.02			0.20
Nov	-0.23				
Dec	-0.09				
Jan	-0.44				
Feb	0.50 *			0.07	0.11
Mar	0.12			0.15	0.15
Apr	0.55 *		0.05	0.13	0.10

7. Other Covariates

Rainfall patterns in preceding months.

Average monthly rainfall for the WCA-3 basin is summarized in **Figure 7-1** for the 2003 to 2011 period. Interannual and seasonal variability in rainfall do not suggest 2006 or 2007 were anomalous in terms of rainfall before or during the DPM operational window, as confirmed by preliminary correlation analyses. No further data analyses were conducted

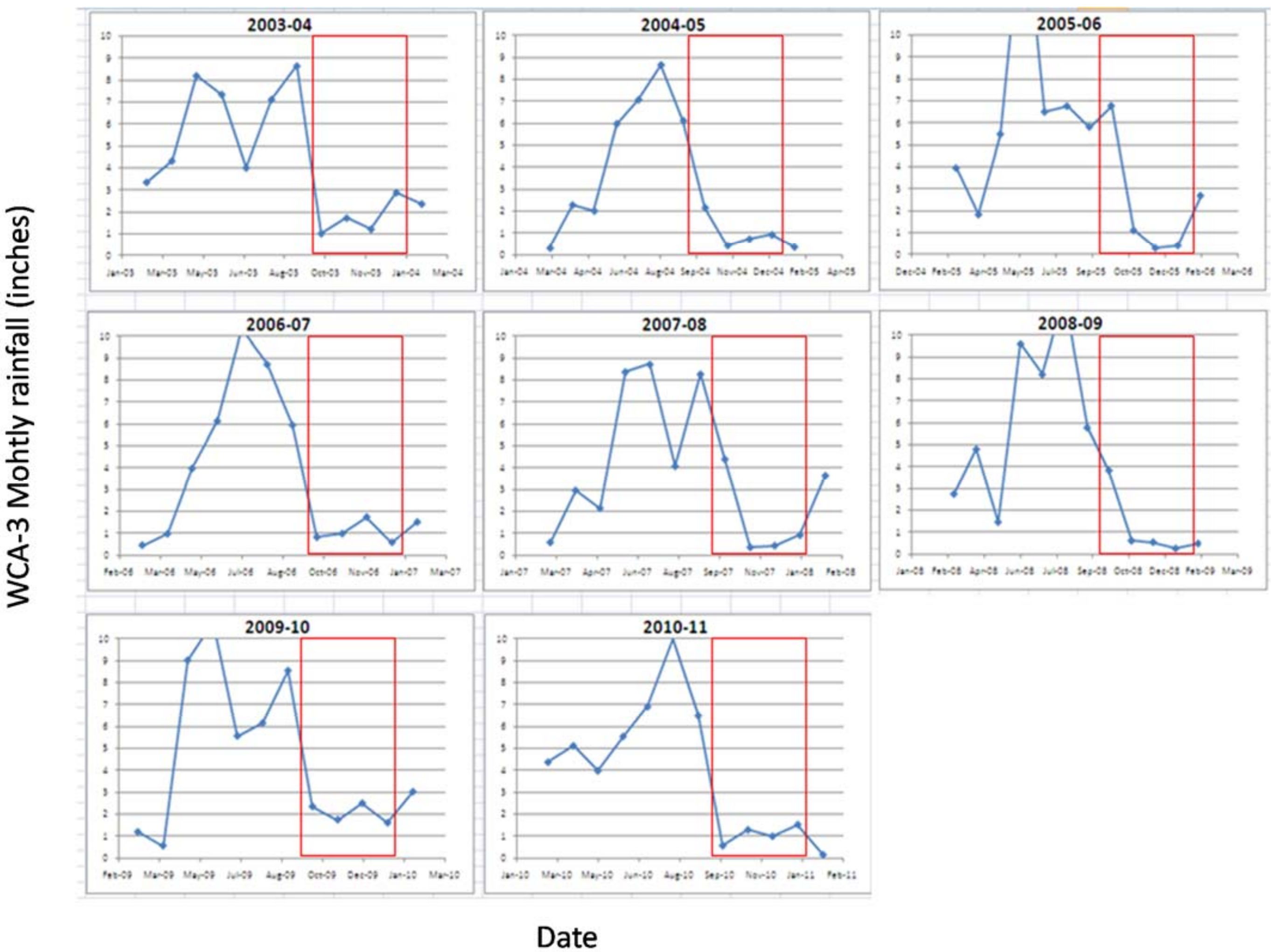


Figure 7-1. WCA3 basin monthly rainfall (SFWMD, URL: http://www.sfwmd.gov/portal/page/portal/xweb%20weather/rainfall%20historical%20%28monthly%29) ; SFWMD, 2011). Period outlined in red indicates months from September to January.

Upstream sources of P:

Average monthly flow from the S9 + S9A structures is shown in Figure 7-2 for the 2003 to 2010 period. Interannual and seasonal variability in flows does not suggest 2006 or 2007 were anomalous in the period before or during the DPM operational window. Preliminary correlation analyses indicate weak correlation with S-151 TP and no further data analyses were conducted. Preliminary correlations of total P load (flow x TP) from the S9 + S9A will be pursued in subsequent analyses.

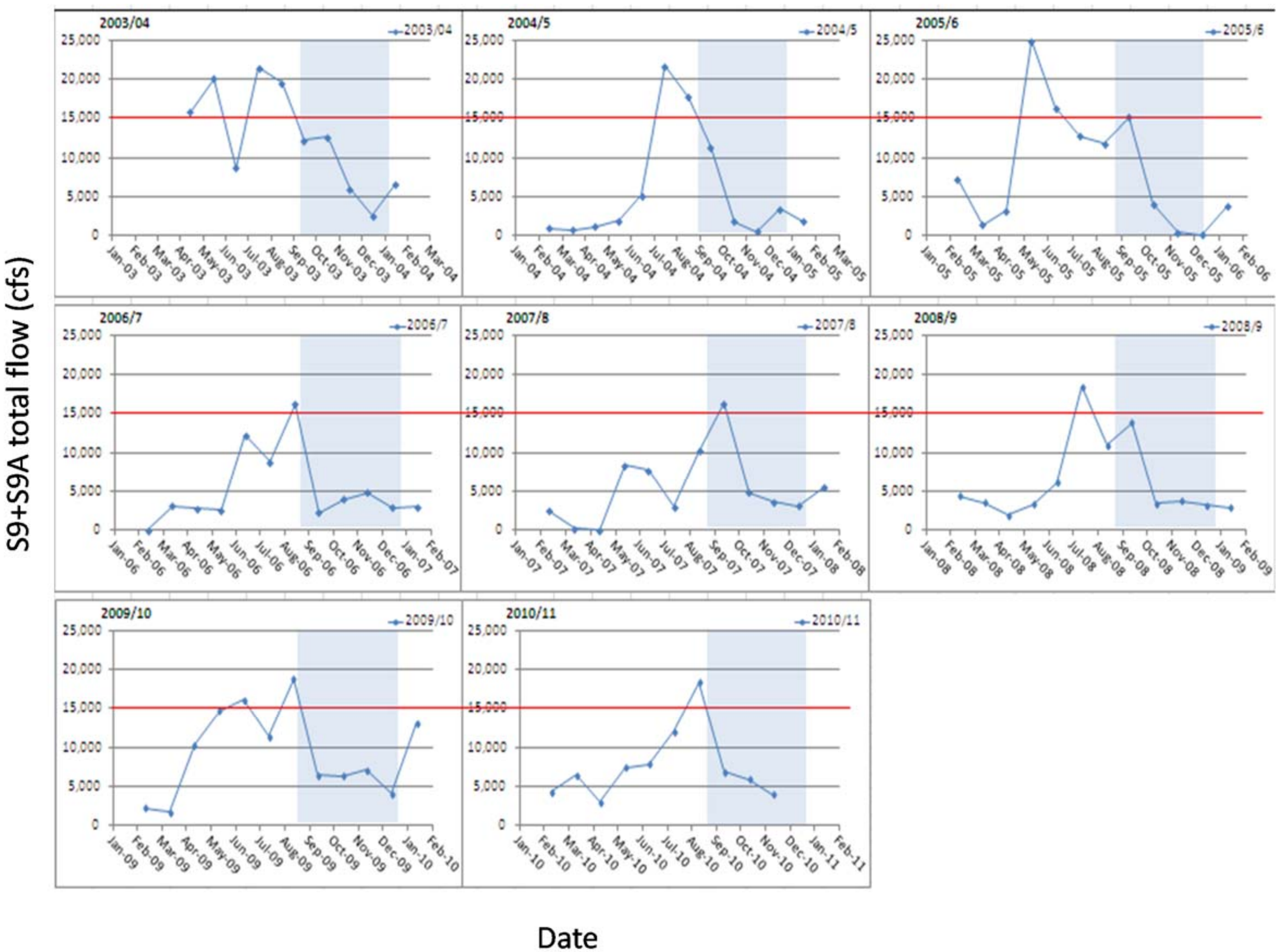


Figure 7-2. Monthly flow (cfs) from S9 + S9A structures, 2003-2010 (data from DBHYDRO, URL: http://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu; SFWMD, 2011). Period shaded in blue indicates months of proposed DPM operational window (September to January). Red horizontal lines are used as visual cues for comparing among years.

Tropical storm activity and fire disturbances

The summary of Florida tropical storm activity for the 2003-2017 period is given in **Table 7**. Monthly and interannual variations in S-151 water GM TP did not indicate any clear correspondence between periods of high or low tropical storm activity and anomalies in water TP in middle to late wet season months. All storm information are summarized from the National Oceanic and Atmospheric Administration (http://www.aoml.noaa.gov/hrd/hurdat/DataByYearandStorm.htm).

Fire activity near the L67A is currently being compiled. While the compilation of this information is still in progress, three fire events have occurred since 2011 in which substantial area had burned near the S-151 structure (>10,000 Ha). In two of these three years (2011 and 2015), relatively higher TP values were observed in September, although TP reduced to ≤ 10 ppb conditions rapidly suggesting fire impacts, if they occur, dissipate within weeks to a month or so post-fire.

Table 7. List of named storms in Florida (and approximate region of Florida affected) and fires near the L67A canal compared with water TP (units: ppb) at the S151, 2003-2017. "." Under TP columns indicate no sample collected during that month. Months September through January (except November) of 2006/7 and 2007/8, September and October of 2011 and September of 2015 are highlighted as anomalous months of high water TP. * = fire information is not completed for that year.

Sampling Window	Named Storms in S. Florida (+Date)	Other Named Storms in Florida (+Date, Location)	Fire Disturbance	Sep	Oct	Nov	Dec	Jan
2003/4	.	H Erika (Aug/SWFL) TS Henri (Sep/C.FL)	*	.	11	.	8	11
2004/5	H Francis (Aug-Sep) H Ivan (Sep) H Jeanne (Sep)	H Charley (Aug/SWFL)	*	10	10	10	8	11
2005/6	H Katrina (Aug) H Rita (Sep) TS Tammy (Oct) H Wilma (Oct)		*	11	.	10	9	9
2006/7	TS Ernesto (Aug)		*	**13**	**11**	10	**14**	**17**
2007/8		TS Barry (Jun/CFL) TS Olga (Dec/CFL)	*	**16**	**13**	10	**13**	**11**
2008/9	TS Fay (Aug)		*	8	8	7	8	9
2009/10			*	8	8	10	9	7

2010/11	TS Bonnie (July)		*	10	9	10	10	10
2011/12			Fire in WCA-3B, including pocket (Jun 2011)	**16**	**13**	9	8	9
2012/13		TS Debby (Jun/CFL)	*	10	9	7	9	10
2013/14		TS Andrea (Jun/NWFL)	*	9	9	11	10	9
2014/15			Fires north of S-151 in WCA-3A (Jun-Jul 2014)	11	9	9	9	10
2015/16			Fire in 3B pocket, NE of S-152 and SW of S-151 (Aug 2015)	**15**	9	11	9	8
2016/17	H Matthew (Oct 2016)		*	9	8	8	11	10

H = hurricane; TS = tropical storm; SWFL = Southwest Florida; CFL = Central Florida; NWFL = Northwest Florida

8. Application to S-152 Operations

We generated a preliminary suite of models, specific to month, to use as triggers for deciding when to open and continue operating the S-152. These "trigger" models (**Table 8-1**), based on 1-month's prior conditions, included only the significant terms based on the simple or multiple linear regression analyses presented in **Tables 3, 4** and **5**. In general, both TP and stage-related covariates were important and included in the models for early wet season months, while TP was more important in late wet season months. During dry season months of February – April, TP was typically driven mostly by marsh-to-canal stage difference.

Table 8-1. Recommended linear regression models, by month. Main effects included when interactions were significant. Two models are tested for May, with the marginally significant interaction term (model1) and without the marginally significant term (model2). Descriptions of the covariates are provided in **Table 5**.

Month	Model adj. R^2	Model Covariates
May	**0.78**	TP, Diff, TP x Diff (model1)
	0.74	TP, Diff (model2)
June	**0.72**	TP, TP^2, 69W
July	**0.78**	TP, TP^2, Diff, TP x Diff
Aug	**0.85**	TP, 69W, Diff
Sep	**0.82**	TP
Oct	**0.68**	TP
Nov	**0.55**	TP, Diff, TP x Diff
Dec	**0.31**	69W
Jan	**0.70**	TP, TP^2
Feb	**0.24**	TP, Diff, TP x Diff
Mar	**0.44**	Diff
Apr	**0.34**	Diff

Below are suggested, preliminary operational rules by which these models could be used to decide when to open and to continue operating the S-152. The rules assume that the target GMTP for the operational period during a water year is 10 ppb, but alternate criteria could be evaluated. The operational rules are also presented as a decision tree in **Figure 8-1**.

Part 1. Decision to Open:

The operational rules for opening the S-152 is as follows:

Step 1 – If stage and flow criteria for WCAs and the L-29 and L-67A canals are satisfied then evaluate the trigger model for opening S-152

Step 2 - Evaluate a trigger model to estimate future S-152 TP (*). If forecasted GMTP is ≤ 10 ppb, the recommendation is to open the S-152 for at least two weeks into the following month. If the GMTP > 10 ppb, the decision is to keep the S-152 closed and re-evaluate the GMTP when new data are available.

*Step 3- Whether to open the S-152 for 4 weeks into the following month depends on the trigger used to open the structure. If using the monthly regression model, the forecasted GMTP applies to the entire following month; therefore, the recommendation is to open the S-152 for the entire following month, re-evaluate forecasted GMTP in 4 weeks and go to **Part 2 (Decision to Continue or Stop Flow)**. If using the dynamic regression model, the monthly regression must be used to determine whether to open for 4 weeks into the following month, as the dynamic regression model cannot evaluate GMTP over that* *period of time. If the dynamic regression trigger recommends opening the structure (i.e., Yes to Step 2), but the monthly regression predicts GMTP > 10 ppb for the following month (No to Step 3), then the recommendation would be to re-evaluate the forecasted GMTP (for 4 weeks into the following month) as new data become available and go to* ***Part 2 – Decision to Continue or Stop Flow****).*

** Note: For deciding to open the S-152 the following month, the forecasted GMTP will be based on a trigger model. The trigger model used will vary, depending on the desired window for opening the structure and month. If opening the structure the following month is preferred, then the regression using a 1-month offset (****Table 8-1****) may be used for this determination. If operations are preferred to start within 1-2 weeks, then a dynamic regression trigger based on weekly or biweekly data (described in Saunders 2015) may be used.*

Based on the seasonal variation in TP over the period of record (**Table 1-1**), the first occurrence of ≤ 10 ppb GMTP is most likely to occur from July through November; therefore, operations are expected to start during this span of months. Given the 95% confidence interval of historic GMTP in November is ≤ 10 ppb (**Table 1-1**), we assume operations will occur in November in any given year, barring major disturbances.

A retrospective test of the ability of the trigger models using the 1-month offset to predict water TP of 10 ppb or less during the initial opening of the S-152 is provided by comparing observed versus predict GMTP values (**Figure 8-2**), also summarized by month in **Table 8-2** (left 4 columns). Accuracy of the model is needed for two reasons: to avoid instances of predicting ≤ 10 ppb and observing > 10 ppb (inadvertently flowing elevated-TP water), but also to avoid predicting > 10 ppb and observing ≤ 10 ppb (no flow despite low-TP).

Overall, the models tend to correctly predict ≤ 10 ppb (i.e., Decision to flow during low-TP) from August to November (66 correct TP predictions). Between the months of June and November, the model incorrectly predicts ≤ 10 ppb during elevated TP conditions in 8 instances across all years. However, in those cases, the observed TP was still relatively low. In 6 cases, observed TP was 11 ppb; in one, case TP was 12 ppb (July); and in one case, TP was 13 ppb (June). By contrast, these models missed 16 opportunities to flow (i.e., during low-TP) twice as many as for elevated TP predictions, and thus are conservative..

Part 2 - Decision to Continue or Stop Flow:

After flow has been initiated, the regression model using the 1-month offset (**Table 8-1**) along with TP data collected during flow is used to determine how far into the next month operations can continue. Given that the 95% confidence interval of historic GMTP in November is ≤ 10 ppb, we assume flow will occur through 4 weeks in November (at TP of 10 ppb), in any given year. The operational rule is as follows:

<u>Step 2</u> - Evaluate forecasted S-152 GMTP for 2 weeks into the following month (using available TP data and assumptions stated above). If forecasted GMTP is ≤ 10 ppb, the recommendation is to keep open the S-152 for at least two weeks into the following month, and go to Step 3. If the GMTP > 10 ppb, the decision is to close the S-152 and re-evaluate the GMTP when new data are available.

<u>Step 3</u> - Evaluate forecasted S-152 GMTP for 4 weeks into the following month (using available TP data assumptions stated above). If forecasted GMTP is ≤ 10 ppb, the recommendation is to keep open the S-152 through the entire following month and, after 4 weeks, to re-evaluate the forecasted GMTP (repeating Step 2). If the forecasted GMTP > 10 ppb for the following month, then the recommendation would be to keep S-152 open for two weeks into the following month, and, as soon as new data are available, to re-evaluate the forecasted GMTP for 4 weeks into the following month (repeating Step 2).

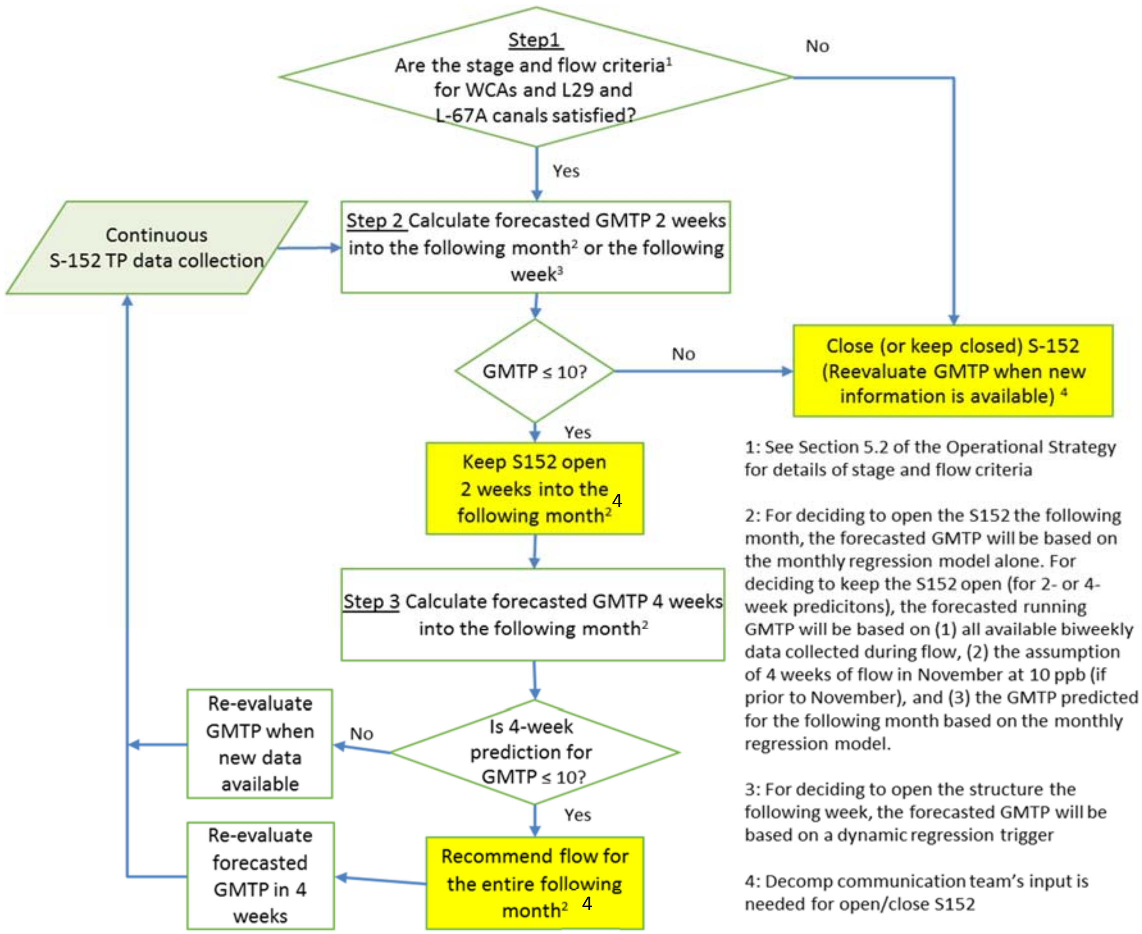


Figure 8-1. Decision tree for year-round operations of the S-152. This decision tree assumes conditions are based on previous stage and/or S-152 TP water quality data. Note that the data used to develop predictive models were from S-151, as a conservative surrogate for S-152. Trigger models used may depend on how fast operations are needed. For instance, if operations are desired within 1-2 weeks, trigger model can utilize the dynamic trigger model (based on week-to-week data, see Saunders 2015). If operations are desired for the following month, 1-month offset trigger models may be used (**Table 8-1**). 2-month offset trigger models are also being developed (see **Section 6**), but are not yet included in this application.

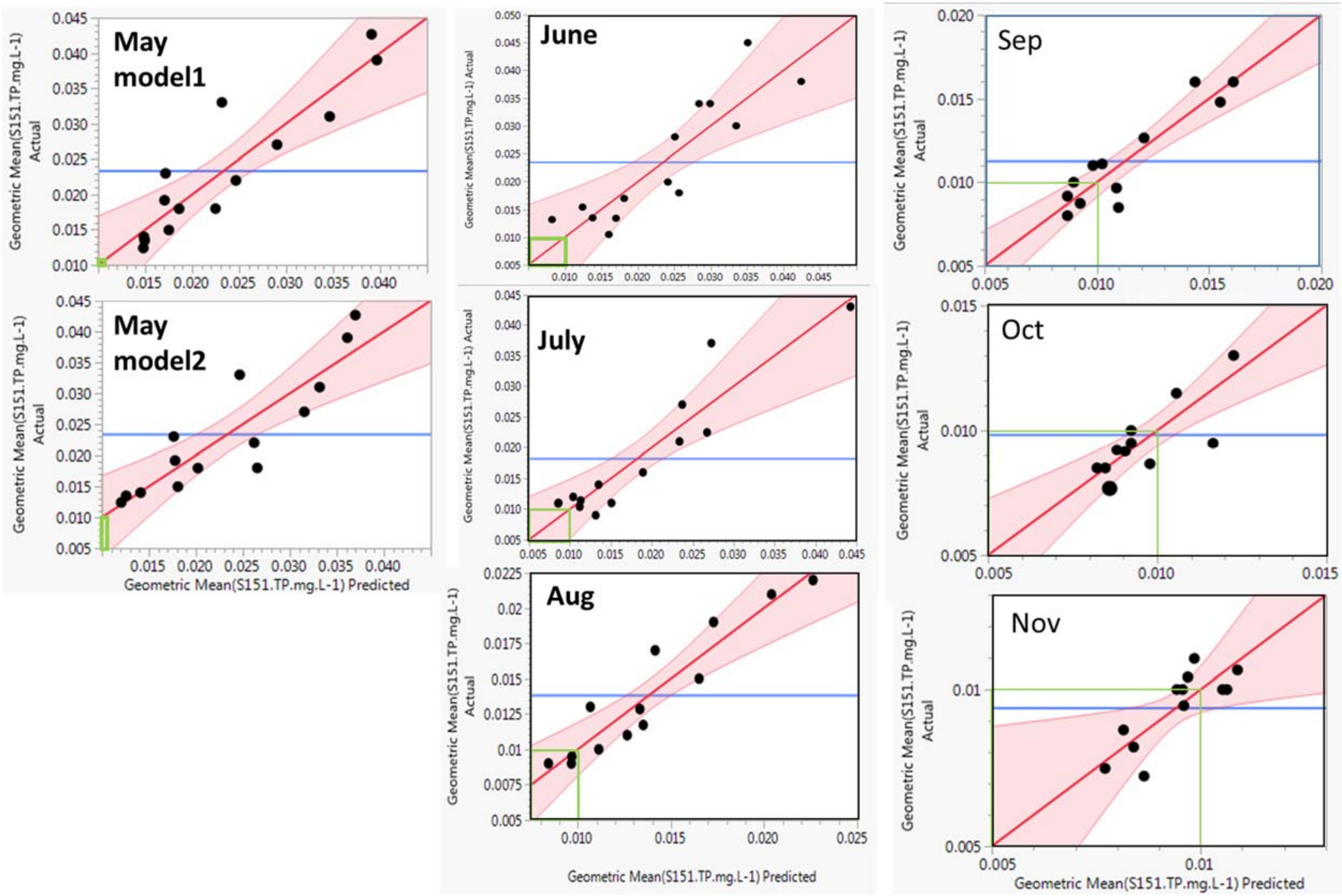


Figure 8-2. Observed versus predicted monthly GMTP based on the models listed in Table 8. The green lines indicate a value of 10 ppb for both observed and predicted values. Observed and predicted values are not rounded to the nearest integer

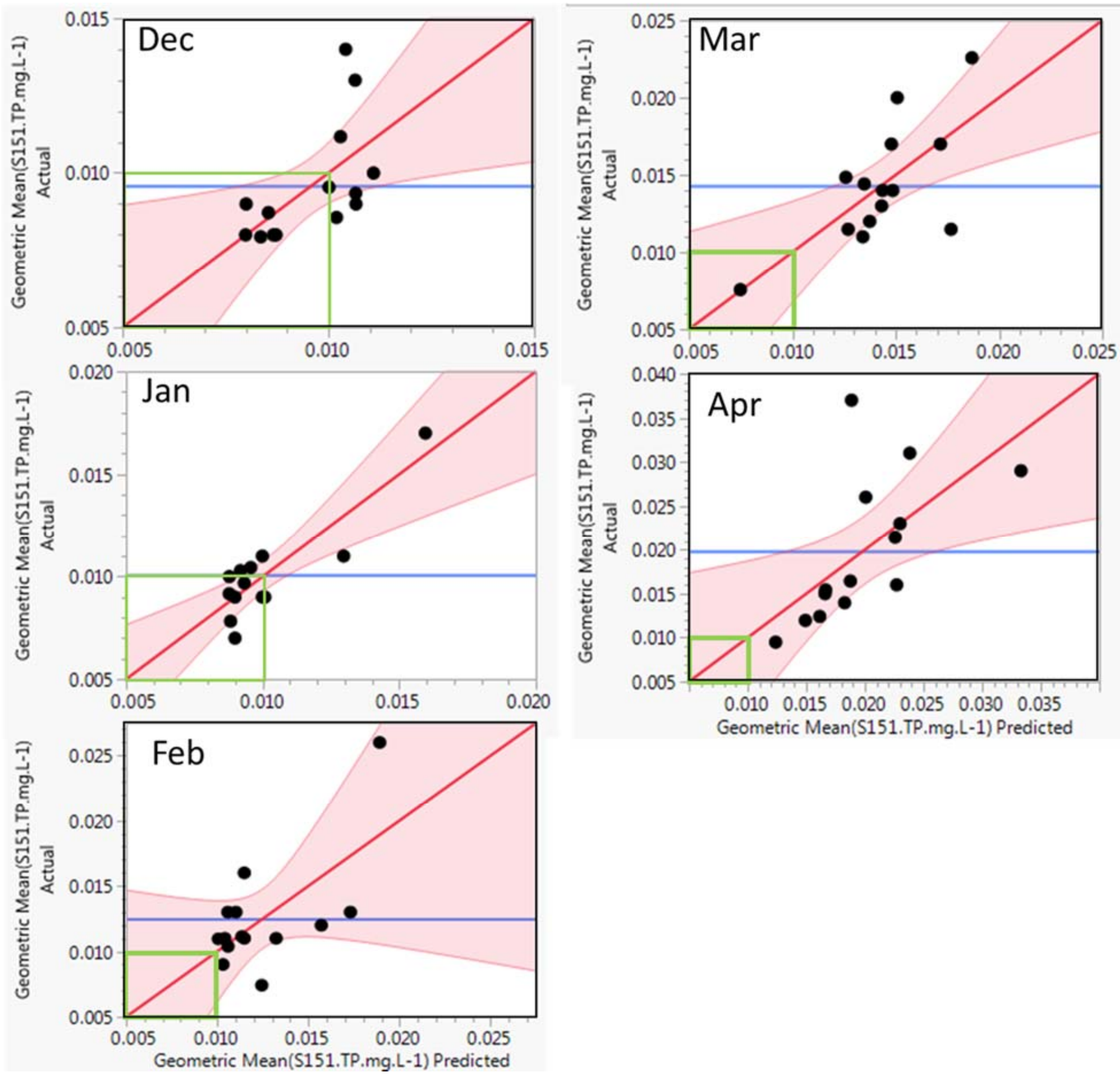


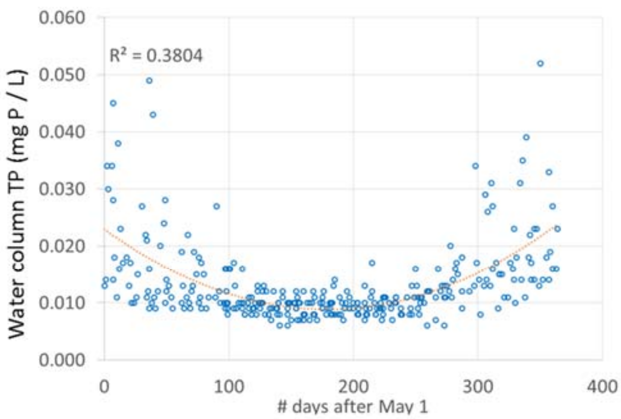
Figure 8-2. Observed versus predicted monthly GMTP based on the models listed in Table 8. The green lines indicate a value of 10 ppb for both observed and predicted values. Observed and predicted values are not rounded to the nearest integer

Table 8-2. For each month, the number of years where the trigger models (using 1-month offset) correctly predict GMTP ≤ 10 ppb (i.e., decision to flow during low TP); predict GMTP ≤ 10 ppb while observed GMTP > 10 ppb (i.e., decision to flow at elevated TP); and predict > 10 ppb while observed GMTP ≤ 10 ppb (i.e., decision not to flow during low TP). Values in parentheses indicate the observed "elevated" GMTP (ppb) when the model incorrectly predicts ≤ 10 ppb. Columns 2-4 show model results based regression analyses using raw historic S-151 TP data. Columns 5-7 show model results based regression analyses using transformed data to correct for the difference between S-152 and S-151 TP (i.e., TP = S-151 TP – 1ppb). Determinations are based on regression models listed in **Table 8-1** (* for May, models 1 and 2 give the same result). Comparisons between observed and predicted values utilized monthly GMTP values rounded to nearest integer.

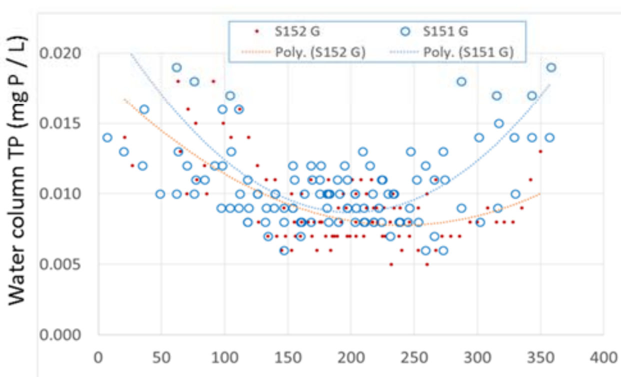
	Data used: S151 TP			**Data: S151 TP – 1 ppb**		
Month	**Flow at ≤ 10 ppb**	**Flow at elevated TP**	**No Flow at ≤ 10 ppb**	**Flow at ≤ 10 ppb**	**Flow at elevated TP**	**No Flow at ≤ 10 ppb**
May *	0	0	0	0	0	0
June	0	1 (13)	1	0	1 (12)	1
July	0	3 (12,11,11)	2	3	1 (11)	3
Aug	3	0	2	4	1 (12)	1
Sep	5	2 (11,11)	3	8	0	0
Oct	9	1 (11)	1	9	0	1
Nov	10	1 (11)	2	12	0	0
Dec	8	2 (14,11)	3	12	2 (12, 13)	0
Jan	9	2 (11,11)	0	11	0	1
Feb	1	2 (11,11)	2	6	3 (12, 15, 12)	2
Mar	1	0	0	1	0	3
Apr	0	0	1	0	0	1
Total	**46**	**14**	**17**	**66**	**8**	**16**

9. Adjustment of Operational trigger, based on difference in TP between S-151 and S-152

Using paired water samples collected at the S-151 and S-152 since October 2013, S-152 TP is significantly lower, by approximately 1 ppb, throughout the year (**Figures 9-1 and 9-2**). For months where the majority of paired samples have been collected (late-August through late-February, **Figure 9-2**), this difference is approximately 1.2-1.3 ppb. If water quality samples for both trigger and compliance determinations are to occur at the S-152 structure, the trigger models presented in **Table 8-1** would tend to overestimate S-152 TP and at times preclude operations when S-152 water quality is acceptable for flow. These models are based on reported values, and do not account for analytical uncertainty.

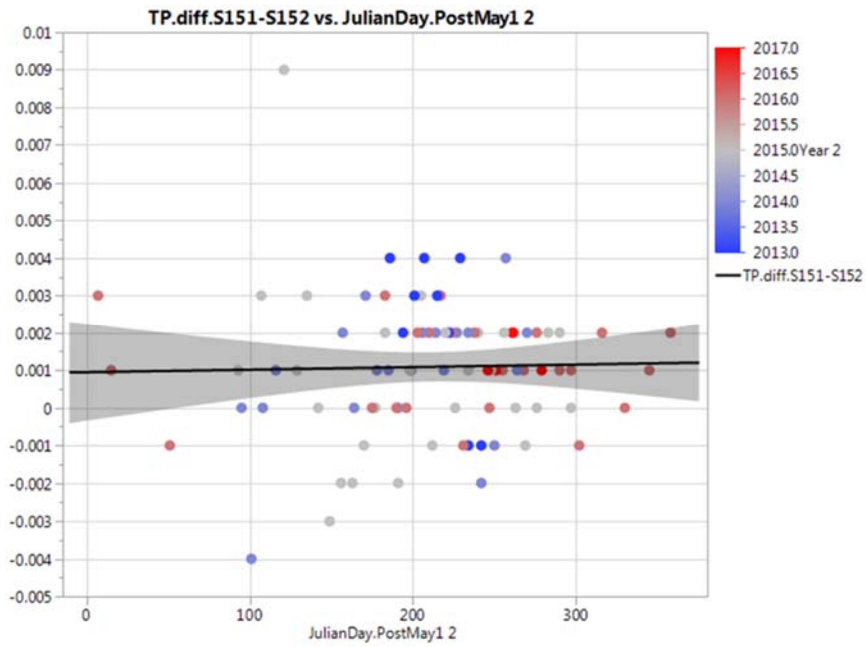


S151 grab sample water column TP (mg P / L) vs number of days after May 1. Jan 2003 – Jan 2017



S151 and S152 grab sample water column TP (mg P / L) vs number of days after May 1. collected from November 2013 – Jan 2017

Figure 9-1. Seasonal variation in S-151 TP (top) and seasonal variation in paired S-151 and S-152 samples from 2013-2017 (bottom).



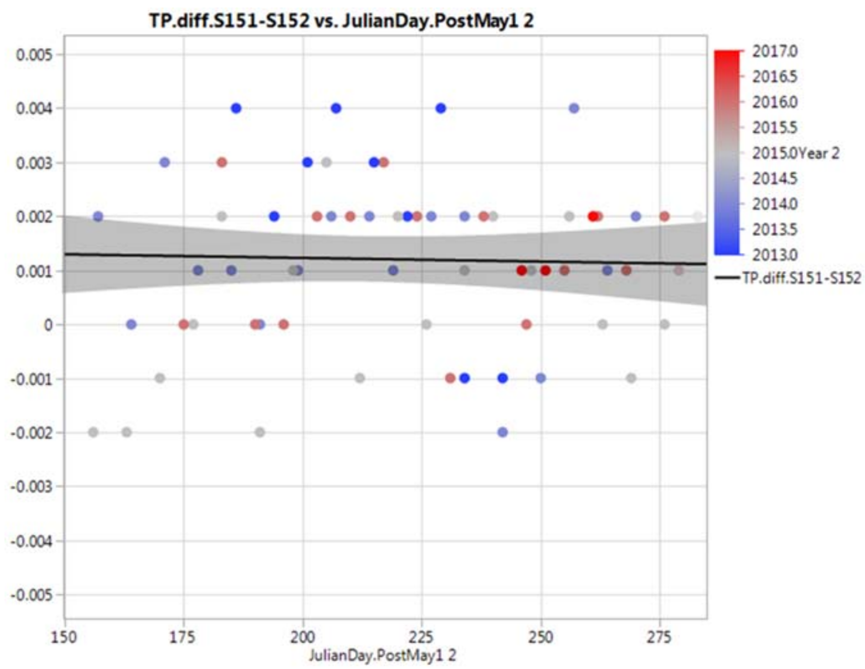


Figure 9-2. Seasonal variation in the difference between S-151 and S-152 TP data (y axis = S-151 TP – S-152 TP, ppb) as a function of the number of days after May 1, based on all available data (top) and the wet season period where prior sampling was concentrated (bottom).

To account for the significantly lower values of TP at S-152, the models selected as in **Table 8-1** for the above trigger were repeated, but using data transformed by subtracting 1 ppb from the raw S-151 data. **Figure 9-3** provides observed vs predicted TP values using the S-151 – 1ppb data set.

Table 9. Recommended trigger models based on data modified by subtracting 1ppb from S-151 TP values.

Month	Model adj. R^2	Model Covariates
May	**0.78**	TP, Diff, TP x Diff (model1)
June	**0.72**	TP, TP^2, 69W
July	**0.78**	TP, TP^2, Diff, TP x Diff
Aug	**0.85**	TP, 69W, Diff
Sep	**0.82**	TP
Oct	**0.68**	TP
Nov	**0.56**	TP, Diff, TP x Diff
Dec	**0.31**	69W
Jan	**0.70**	TP, TP^2
Feb	**0.24**	TP, Diff, TP x Diff
Mar	**0.44**	Diff
Apr	**0.34**	Diff

Observed versus predicted GMTP values are provided in **Figure 9-2** and summarized by month in **Table 8-2** (columns 5-7). Using the adjusted S-151 TP – 1ppb dataset, the models correctly predict ≤ 10 ppb (i.e., Decision to flow during low-TP) more often than the models generated with the original S-151 data across all months. Between June and November, the models resulted in a decision to flow during elevated TP conditions in only three instances. In all cases, observed GMTP was relatively low: 12 ppb in June and August and 11 ppb in July. The models also tended to be conservative in that they resulted in a decision not to flow in 16 instances, despite observed values of 10 ppb or less (**Table 8-2**, column 7).

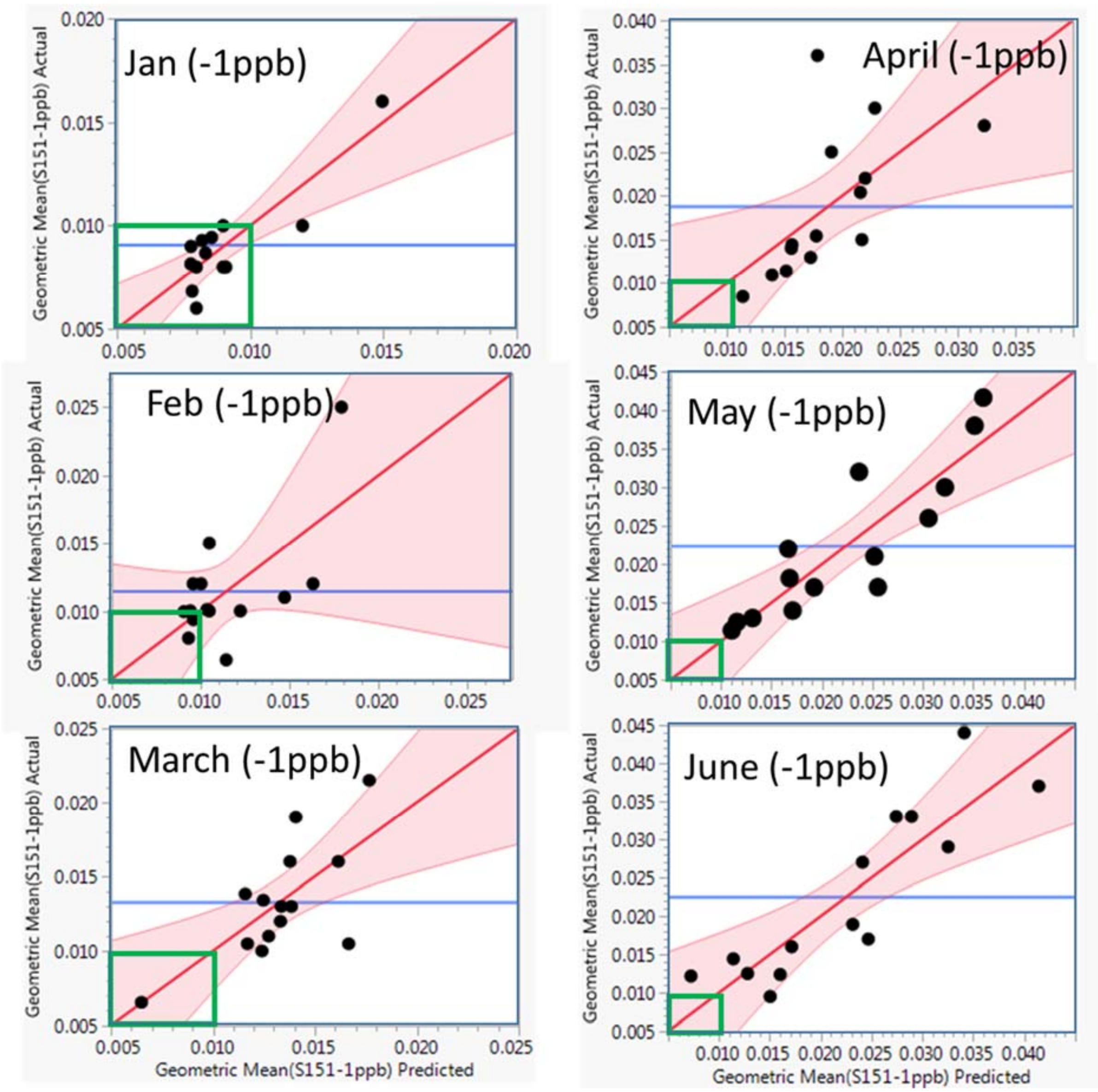
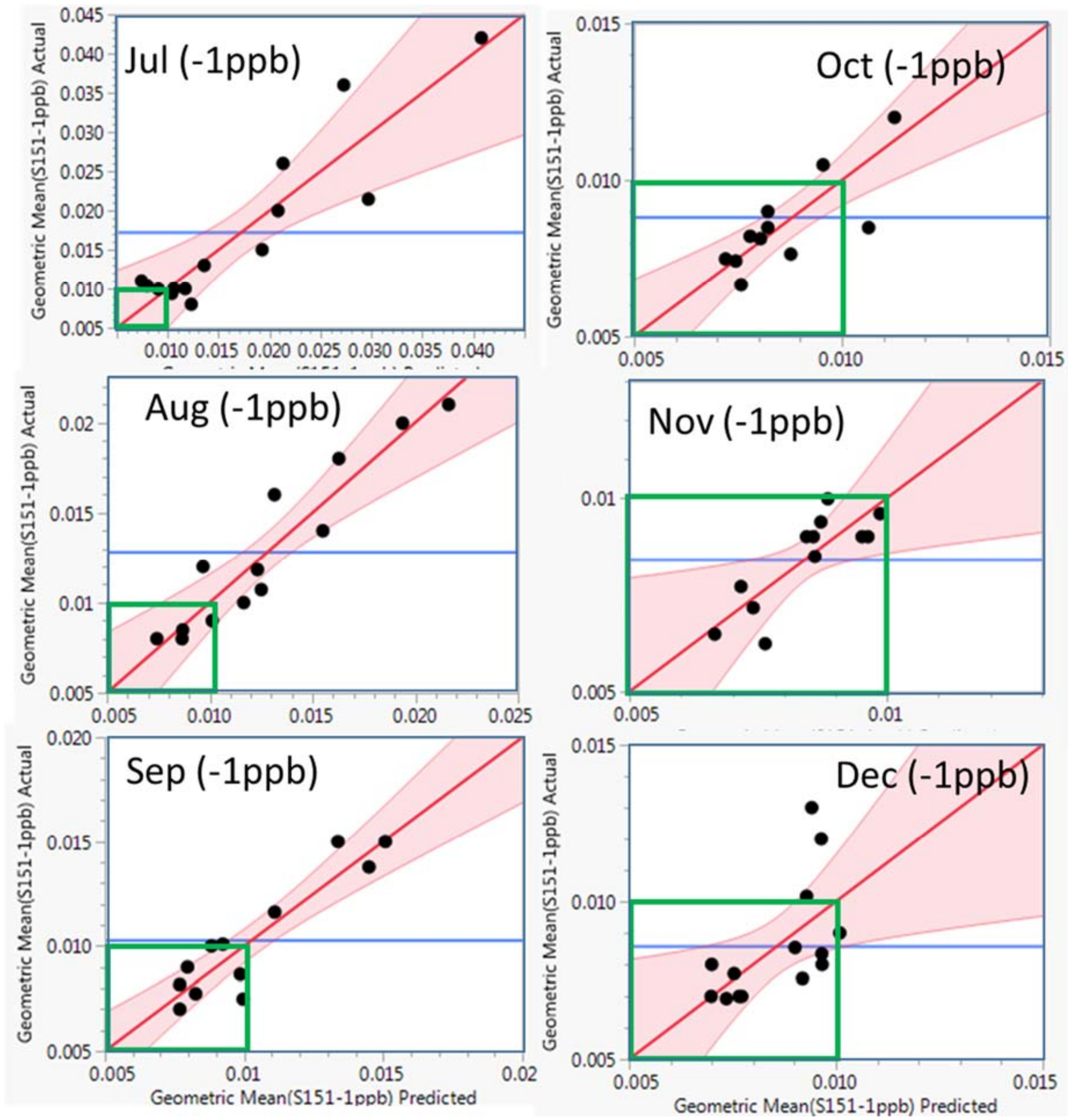


Figure 9-3A. Observed versus predicted monthly GMTP (units are mg P/L) based on the models listed in **Table 9**, in which S-151 TP data is adjusted by subtracting 1 ppb from the original values, consistent with the significant difference between S-151 and S-152 TP data. The green lines indicate a value of 10 ppb for both observed and predicted values. Observed and predicted values are not rounded to the nearest integer.



*** October not rounded

Figure 9-3B. Observed versus predicted monthly GMTP (units are mg P /L) based on the models listed in **Table 9**, in which S-151 TP data is adjusted by subtracting 1 ppb from the original values, consistent with the significant difference between S-151 and S-152 TP data. The green lines indicate a value of 10 ppb for both observed and predicted values. Observed and predicted values are not rounded to the nearest integer.

10. Conclusions

- Regression analyses were used to determine the extent to which the monthly geometric mean TP (GMTP) at S-151 could be explained by previous month's GMTP, the average monthly canal stage, and average monthly marsh-to-canal stage difference.

- The suite of covariates that best explain the interannual variation in TP data differ depending on the month. TP is explained more by canal stages earlier in the water year, and more by previous month's TP later in the water year. The regression models recommended for predicting TP in each month are summarized in **Table 8-1**.

- Utilizing these regression models as operational triggers, a two-step decision tree was proposed to determine when to open the S-152 structure (i.e., during GMTP ≤ 10 ppb conditions in the canal) and whether to continue or stop operations after it is opened.

- By comparing regression-predicted versus historic observed monthly GMTP values, we found regression models resulted in a decision to open the S-152 during observed low TP (≤ 10 ppb) conditions relatively successfully during the months from August to November. In the instances where the triggers incorrectly resulted in a decision to flow during elevated TP conditions, the observed TP was relatively low, 11 ppb in all but 1 case (12 ppb).

- Based on weekly data collected from 2013-2017, S152 TP is significantly lower than S-151 TP, by ~1 ppb. When repeating the regression models using a corrected dataset (S151 TP – 1 ppb), the regression models showed some improvement over models using the raw S-151 data. The regression models never resulted in a decision to flow during elevated TP conditions for the months of August through November. The models remain conservative, however, because in several years they still predicted > 10 ppb (no flow) during ≤ 10 ppb conditions.

- 2-month lag terms would provide improved lead time for the DPM science monitoring downstream of the S-152. Analyses using 2-month lag terms are currently being evaluated.

11. References

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South Florida Water Management District, October 28, 2011. DBHYDRO Browser User Documentation, 95p.