Horse Creek Water Quality Analysis Using Generalized Linear Mixed Models
Technical Memo
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Introduction

Environmental data tend to deviate from a normal distribution and can be impacted by the unique characteristics of a sampling location. Generalized linear mixed models (GLMMs) can be used to predict the probability of an outcome (including a binary response) using inputs of fixed and random effects. Fixed effects are those variables that are assumed to have a constant effect on an outcome. Random effects are characteristics unique to a given sample, such as the influence of unquantified aspects of the sampling location. Input data may be normal or non-parametric and either continuous or categorical (Bolker et al., 2009).

In this analysis, GLMMs were used to predict the probability of exceeding State water quality thresholds (per Chapter 62-302.531, F.A.C.) for Class I and Class III waters in Horse Creek under the proposed minimum flows for the system (Ghile et al., 2023). A similar application of GLMMs was used by Janicki Environmental, Inc. (JEI) through Applied Technology & Management, Inc. (ATM) in their 2018 analysis of water quality in the Chassahowitzka River (ATM and JEI 2018).

Most of Horse Creek is considered Class III water, however, approximately 10 miles of the creek is classified as a Class I surface water as it approaches the confluence with the Peace River, in Florida Department of Environmental Protection (DEP) waterbody identification number (WBID) 1787A2 (Figure 1, ATM and JEI 2021). The most recently adopted Verified List for Horse Creek (July 15, 2022) designates one WBID impaired for *Escherichia coli* (WBID 1939; Figure 1). Two WBIDs were added to the Study List to investigate dissolved oxygen percent saturation impairment (WBIDs 1826A and 1915; Figure 1). One WBID (WBID 1787B) had previously been listed for total phosphorus impairment but has recently been delisted. Apart from a statewide total maximum daily load (TMDL) for mercury (DEP 2013), the DEP has not established a TMDL or basin management plan for any waterbody within the Horse Creek.

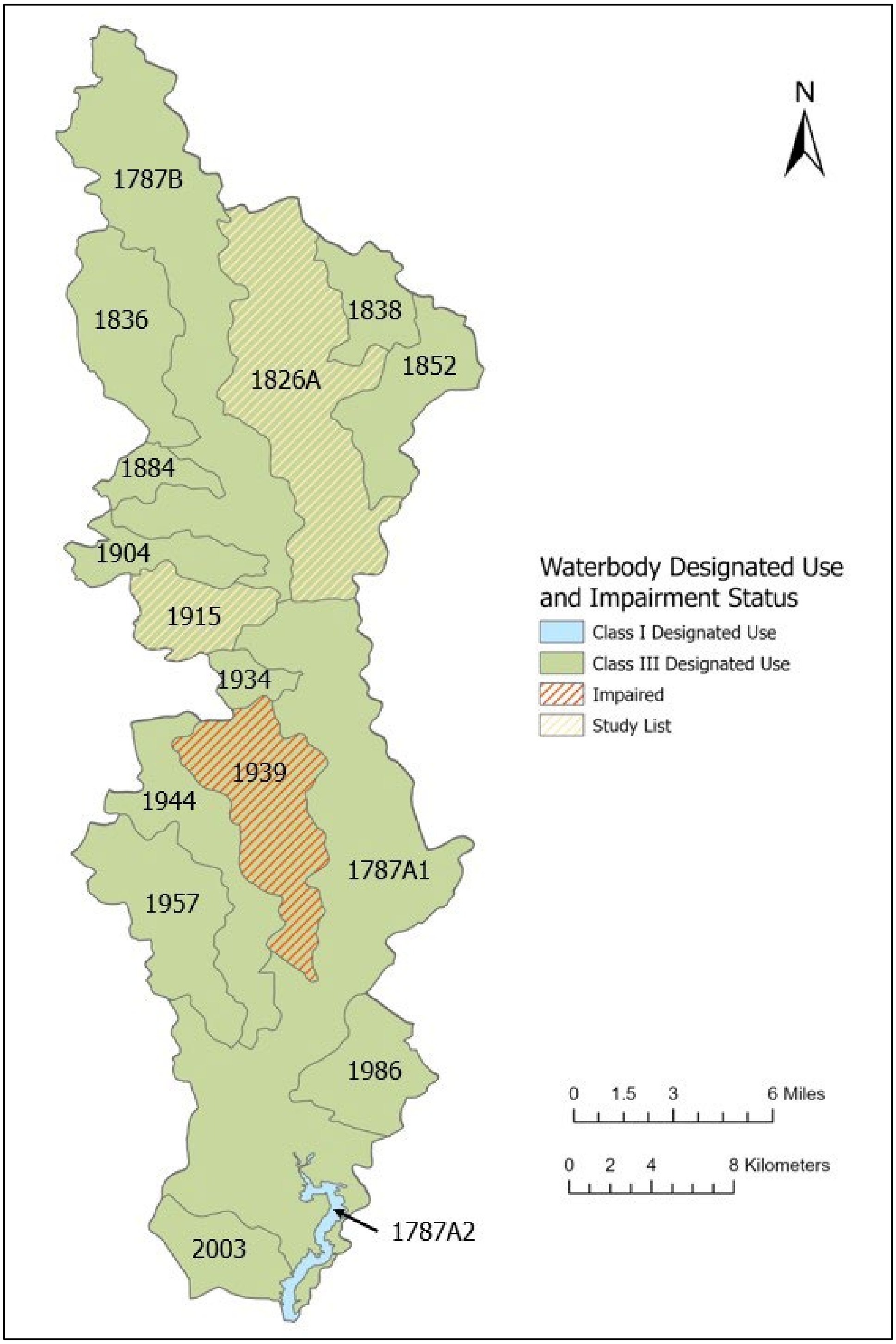

Figure 1. Location of waterbodies by waterbody identification number (WBID) within the Horse Creek watershed, colored according to designated use classification, impairment status, and inclusion on the study list, according to the DEP's Impaired Waters Rule Run 60 and the Verified List adopted in 2022.

Data

Water quality samples from the DEP, Horse Creek Stewardship Program (HCSP), Southwest Florida Water Management District (SWFWMD) and United States Geological Survey (USGS) were used in this analysis (Figure 2). The available period of record (POR) and frequency of sampling varied by the sampling agency (Table 1). For consistency with data quality assurance, all water quality data used were pulled from the DEP Impaired Waters Rule Run 59 database, provided by Janicki Environmental, Inc (JEI) through Applied Technology and Management, Inc (ATM and JEI 2021). Baseline (unimpacted) flow data developed for the USGS Horse Creek at SR72 near Arcadia, FL (No. 02297310) were matched to dates of sample collection. The baseline flow record development is described in Ghile et al., 2023.

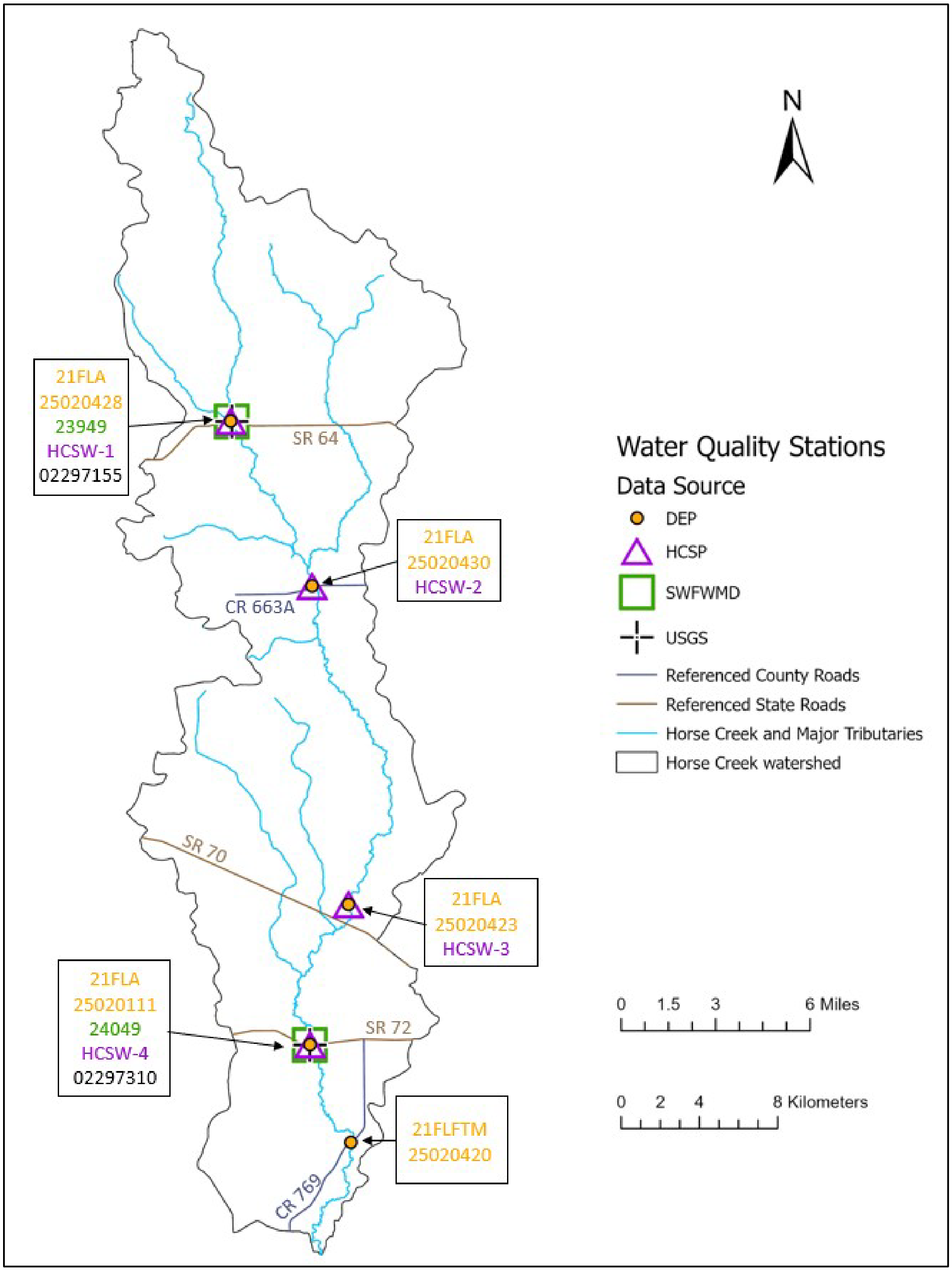

Figure 2. Locations of the water quality sampling sites throughout Horse Creek considered during analysis. Baseline flow data was based on flows at the USGS station 02297310 (USGS Horse Creek at SR72 near Arcadia, FL), adjusted for groundwater withdrawals.

Table 1: Sampling information for each water quality parameter in the GLMM analysis, including station name data source, number (n) of samples, the start and end dates of the period of record (POR), and the approximate sampling frequency over the POR.

Parameter	Station Name	Source	Samples (n)	POR	Approximate Sampling Frequency
Total Dissolved Solids	HCSW-1	HCSP	175	10/2003 - 12/2018	Monthly
	HCSW-2	HCSP	167	10/2003 - 12/2018	Monthly
	HCSW-3	HCSP	177	10/2003 - 12/2018	Monthly
	HCSW-4	HCSP	180	10/2003 - 12/2018	Monthly
	23949	SWFWMD	86	1/2006 - 3/2019	Monthly 2006 -2011, bimonthly through 2019
	24049	SWFWMD	93	1/2006 - 3/2019	Monthly 2006 -2011, bimonthly through 2019
Dissolved Calcium	HCSW-1	HCSP	172	10/2003 - 12/2018	Monthly
	HCSW-2	HCSP	164	10/2003 - 12/2018	Monthly
	HCSW-3	HCSP	174	10/2003 - 12/2018	Monthly
	HCSW-4	HCSP	177	10/2003 - 12/2018	Monthly
	23949	SWFWMD	152	1/2000 - 3/2019	Monthly 2000 - 2011; bimonthly through 2019
	24049	SWFWMD	169	1/2000 - 3/2019	Monthly 2000 - 2011; bimonthly through 2019
Dissolved Sulfate	HCSW-1	HCSP	176	10/2003 - 12/2018	Monthly
	HCSW-2	HCSP	168	10/2003 - 12/2018	Monthly
	HCSW-3	HCSP	178	10/2003 - 12/2018	Monthly
	HCSW-4	HCSP	181	10/2003 - 12/2018	Monthly
	23949	SWFWMD	135	1/2000 - 11/2015	Monthly 2000 - 2011; bimonthly through 2015
	24049	SWFWMD	152	1/2000 - 11/2015	Monthly 2000 - 2011; bimonthly through 2015
Total Nitrogen	HCSW-1	HCSP	176	10/2003 - 12/2018	Monthly
	HCSW-2	HCSP	168	10/2003 - 12/2018	Monthly

	HCSW-3	HCSP	178	10/2003 - 12/2018	Monthly
	HCSW-4	HCSP	181	10/2003 - 12/2018	Monthly
	23949	SWFWMD	180	8/1997 - 3/2019	Monthly 1997 - 2011; bimonthly through 2015
	24049	SWFWMD	193	8/1997 - 3/2019	Monthly 1997 - 2011; bimonthly through 2015
Total Phosphorus	211FLA 25020111	DEP	174	7/1972 - 4/1998	Variable; from 1 to 14 times per year
	23949	SWFWMD	182	8/1997 - 3/2019	Monthly 1997 - 2011; bimonthly through 2015
	24049	SWFWMD	195	8/1997 - 3/2019	Monthly 1997 - 2011; bimonthly through 2015
	02297310	USGS	126	5/1968 - 9/1999	Variable; from 1 to 7 times per year
Dissolved Oxygen Percent Saturation	21FLA 25020428	DEP	52	5/1972 - 7/1990	Variable; from 1 to 11 times per year
	21FLA 25020430	DEP	44	12/1972 - 7/1990	Variable; from 1 to 10 times per year
	21FLA 25020423	DEP	44	5/1972 - 8/1991	Variable; from 1 to 10 times per year
	211FLA 25020111	DEP	286	5/1972 - 4/1998	Variable; from 1 to 28 times per year
	21FLTM 25020420	DEP	190	5/2005 - 1/2018	Variable; from 1 to 26 times per year
	HCSW-1	HCSP	66	1/2013 - 12/2018	Monthly
	HCSW-2	HCSP	56	1/2013 - 12/2018	Monthly
	HCSW-3	HCSP	67	1/2013 - 12/2018	Monthly
	HCSW-4	HCSP	66	1/2013 - 12/2018	Monthly
	02297310	USGS	177	5/1968 - 9/1999	Variable; from 1 to 9 times per year

Methods

To predict the probability of State water quality threshold exceedances with flow reductions (a binomial response), GLMMs were created for total dissolved solids, sulfate, dissolved calcium, total nitrogen, total phosphorus, and dissolved oxygen percent saturation using the glmer function in the lme4 package in R programming language (Bates et al. 2015, R Core Team 2021). Models were run for each analyte, considering combinations of the continuous variables (flow) and categorical variables (season, river kilometer) and the interaction terms among them as fixed effects. All models considered "Station," a random effect term. “Season” is defined as the quarter of the calendar year in which samples were taken, beginning in January. This seasonal term was intended to incorporate the impact of variables like temperature, light availability, and biological activity during traditional seasons of the year. If the model failed to converge with baseline flows, the log of flows was taken. The successful model with the lowest Akaiki Information Criteria (AIC) score was selected for further analysis.

The predict function in R was then applied to the selected model to predict the probability of State water quality threshold exceedance at a given flow and location. Flow reduction scenarios were run according to the recommended minimum flow conditions (Table 2) to determine if the minimum flows would increase the likelihood of 0.5 probability threshold exceedance of State water quality criteria compared to baseline conditions.

Table 2: Proposed minimum flows for Horse Creek based on flows at the USGS Horse Creek at SR72 near Arcadia, FL (No. 02297310) gage that have been adjusted for withdrawal effects.

Flow-Based Block	If Adjusted Flow, in Cubic Feet per Second (cfs) on the Previous Day is:	Minimum Flow is:
1	≤ 15 cfs	100% of the flow on the previous day
2	> 15 cfs and ≤ 78 cfs	88% of the flow on the previous day
3a	> 78 cfs and ≤ 172 cfs	86% of the flow on the previous day
3b	> 172 cfs ≤ 644 cfs	88% of the flow on the previous day
3c	> 644 cfs	92% of flow on the previous day

Results

Total Dissolved Solids

Data from HCSP stations HCSW-1 through HCSW-4 and SWFWMD stations 23949 and 24049 were utilized in the creation of GLMMs for total dissolved solids. A time series of data from each station is shown in Figure 3. Exceedance of the State Class I water threshold of 500 mg/L TDS was utilized as the binary response. Over the POR for total dissolved solids data, exceedance was rare above Block 1 (>15 cfs) flows. Occasional exceedance (9 out of 57 samples) occurred at station HCSW-4 during Block 2.

The GLMM model for total dissolved solids with the lowest AIC (350.6) considered baseline flow, season, river kilometer, and the interaction between baseline flow and season. When all data were visualized, the likelihood of surpassing the 0.5 probability exceedance threshold for total dissolved solids most frequently occurred during Block 1 under baseline flow conditions (Figure 4). Stations HCSW-3 and HCSW-4 showed similar trends in their data (as shown by individual sample dots in Figure 4). This appears to reflect seasonal influence with more exceedances occurring during the typical dry season of April – June in both systems. Figure 5 demonstrates the influence of season on the probability of threshold exceedance using station HCSW-4 as an example.

During Block 1, the GLMM model predicts that 59% of samples (38 of 64 tested samples) would exceed the 0.5 probability threshold for total dissolved solids at station HCSW-4 and 47% samples (16 of 34 tested samples) would exceed this threshold at station 24049 under baseline flow conditions. With the proposed minimum flows, a low flow threshold is recommended for Block 1, with no allowable reduction in flows.

During Block 2, the GLMM model predicts that 5% of samples (3 of 57 tested samples) at HCSW-4 would surpass the 0.5 probability threshold for exceedance under baseline flow conditions. There is no change to this prediction under minimum flow conditions (a 12% flow reduction during Block 2). During Block 3a Block 3b, and Block 3c the probability threshold exceedances are not predicted to surpass 0.5 under baseline or minimum flow conditions.

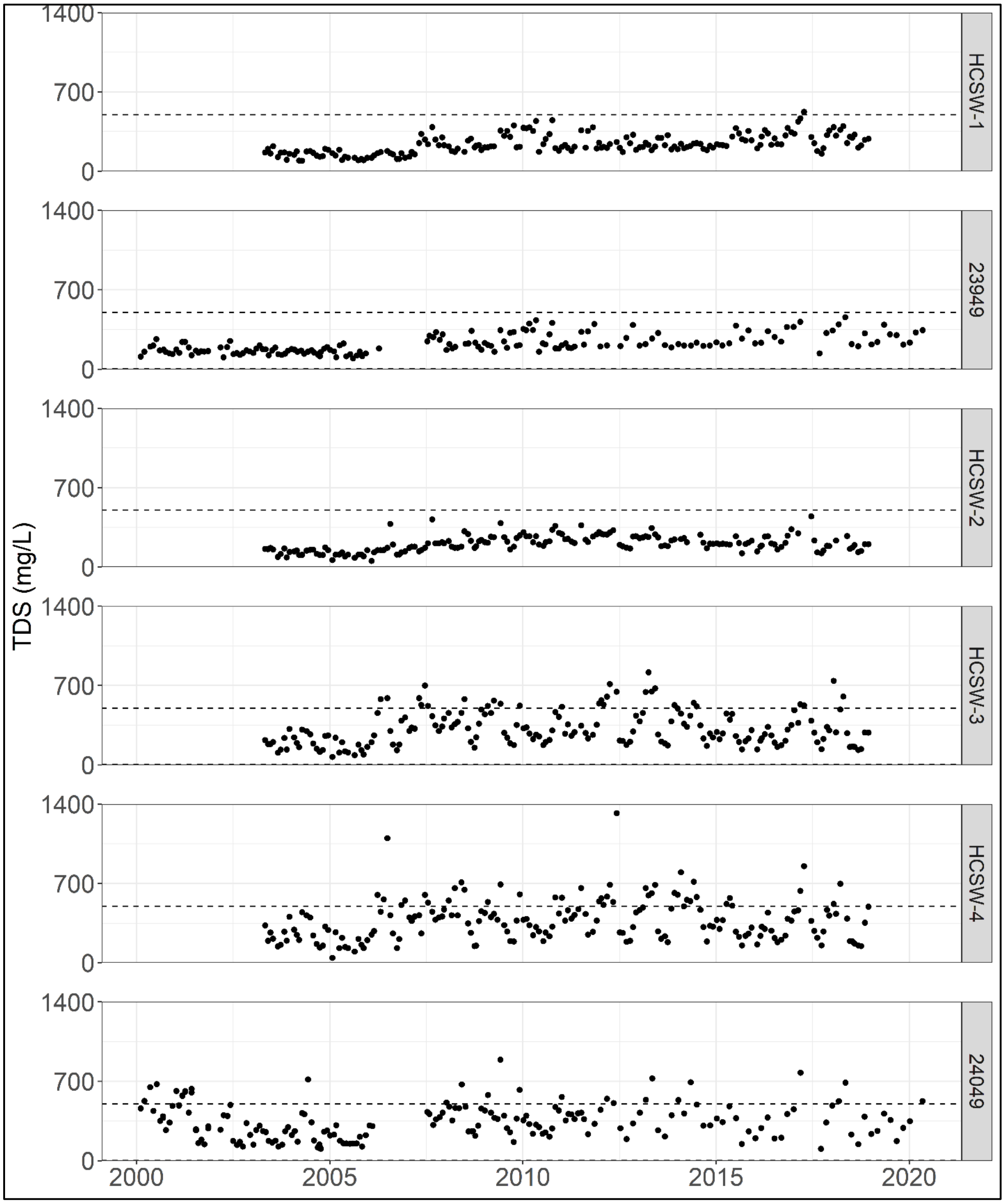

Figure 3. Sample distribution for total dissolved solids (TDS) at HCSP (HCSW-1 through -4) and SWFWMD (23949 and 24049) stations, listed from upstream to downstream. The dashed line indicates the State water quality threshold for Class I waterbodies (>500 mg/L). Note this threshold is for the annual geometric mean rather than for individual samples.

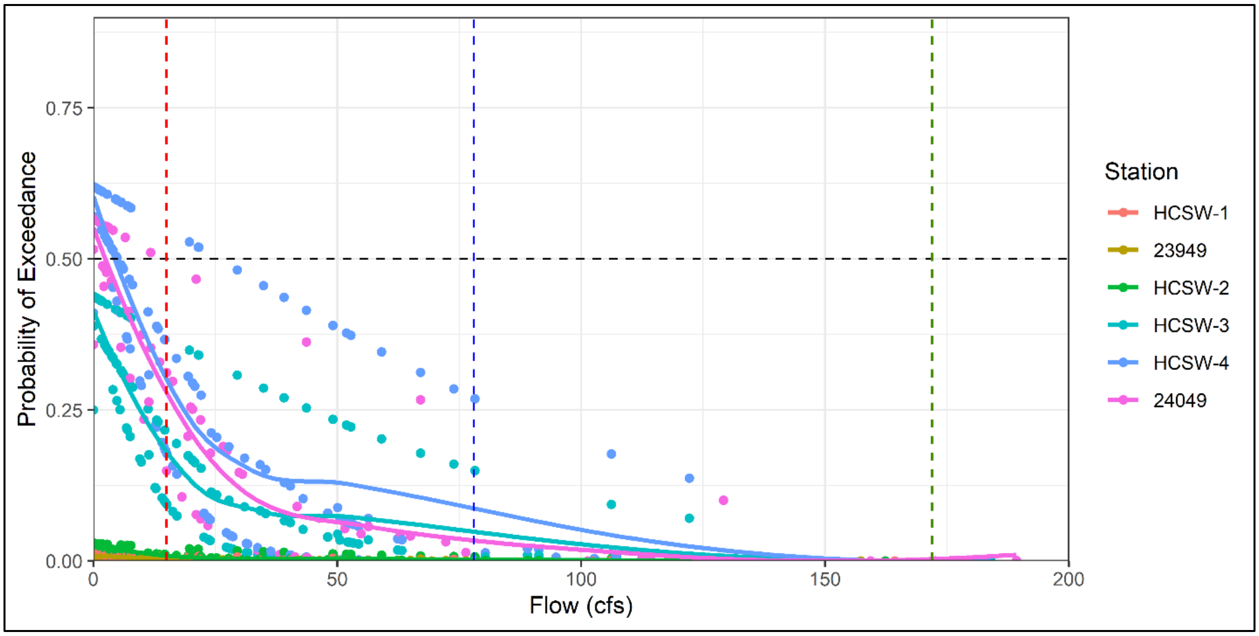

Figure 4: Predicted probability of exceedance of the State water quality threshold for total dissolved solids in Class I waters (>500 mg/L) compared to baseline flow at the USGS Horse Creek at SR72 near Arcadia, FL gage (No. 02297310). The dashed black line indicates the 0.5 probability of exceedance threshold. The dashed red line indicates the border of Block 1 and Block 2 (15 cfs), the dashed blue line delineates the border between Block 2 and Block 3a (78 cfs), and the dashed green line shows the border between Block 3a and Block 3b (172 cfs). Data for Block 3c are not shown since the probability for exceedance declines rapidly in Block 3a. Dots show predicted probabilities for individual samples under baseline flow conditions and locally estimated scatterplot smoothing (LOESS) polylines are provided for each station. Stations are listed in the key from upstream to downstream.

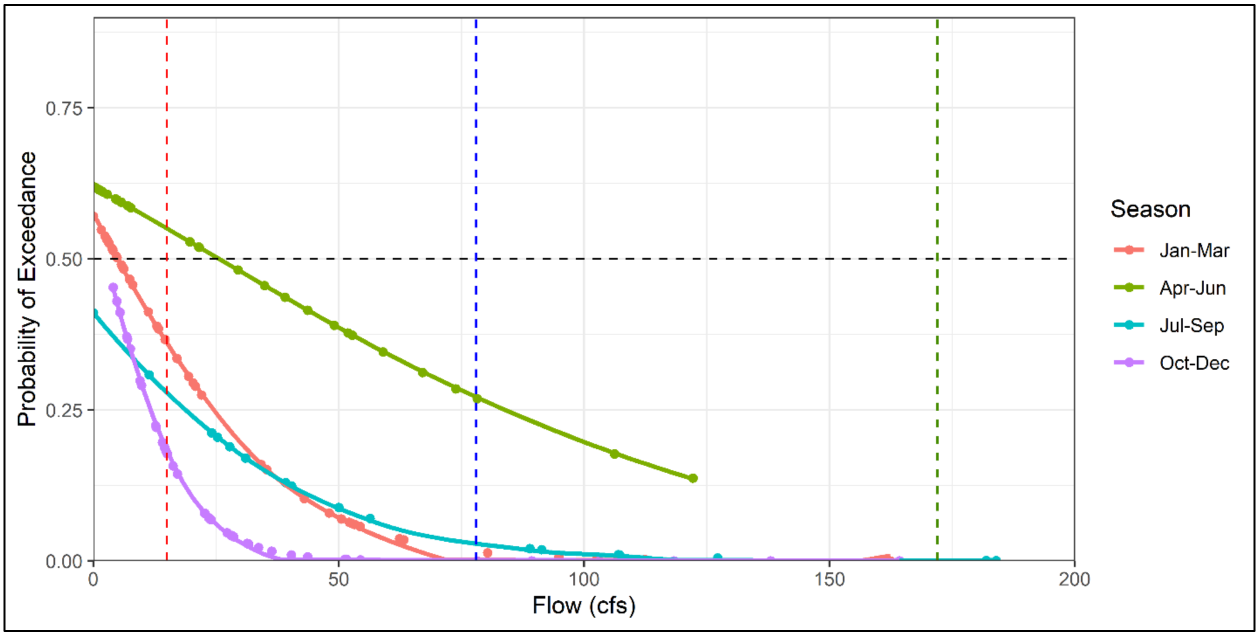

Figure 5: Predicted probability of exceedance of the State water quality threshold for total dissolved solids in Class I waters (>500 mg/L) compared to baseline flow at the USGS Horse Creek at SR72 near Arcadia, FL gage (No. 02297310) for station HCSW-4, by season. The dashed black line indicates the 0.5 probability of exceedance threshold. The dashed red line indicates the border of Block 1 and Block 2 (15 cfs), the dashed blue line delineates the border between Block 2 and Block 3a (78 cfs), and the dashed green line shows the border between Block 3a and Block 3b (172 cfs). Data for Block 3c are not shown since the probability for exceedance declines rapidly in Block 3a. Dots represent predicted probabilities for individual samples under baseline flow conditions and locally estimated scatterplot smoothing (LOESS) polylines are shown for each season.

Dissolved Calcium

Data from HCSP stations HCSW-1 through HCSW-4 and SWFWMD stations 23949 and 24049 were utilized in the creation of GLMMs for dissolved calcium. A time series of data from each station is shown in Figure 6. Exceedance of the State Class I water quality threshold of 100 mg/L for dissolved calcium was utilized as the binary response.

The GLMM model with the lowest AIC (227.3) considered the log transformed baseline flow, river kilometer, and the interaction between log transformed baseline flow and river kilometer. When all data were visualized, the predicted probability of exceedance was below the 0.5 probability threshold during all flow blocks at each station under baseline flow conditions (Figure 7). The recommended minimum flows did not change this result.

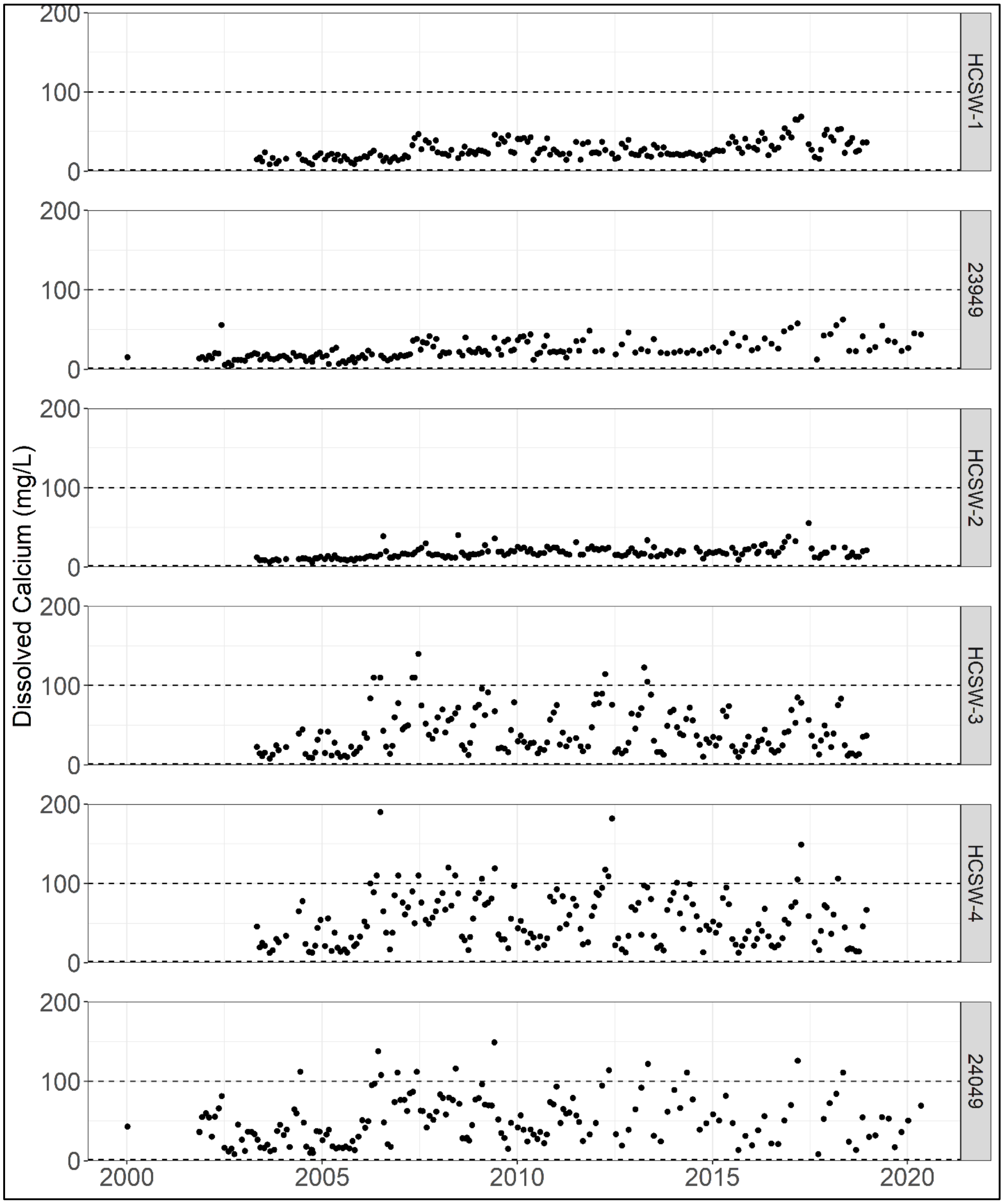

Figure 6. Sample distribution for dissolved calcium at HCSP (HCSW-1 through -4) and SWFWMD (23949 and 24049) stations, listed from upstream to downstream. The dashed line indicates the State water quality threshold for Class I waterbodies (>100 mg/L). Note this threshold is for the annual geometric mean rather than for individual samples.

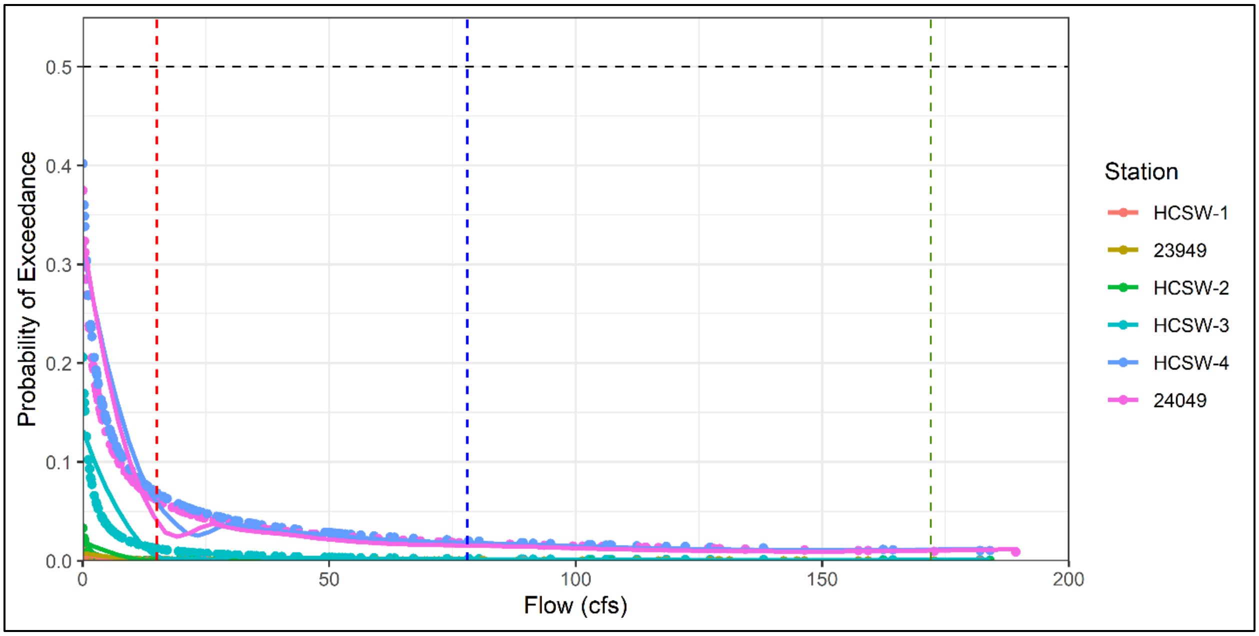

Figure 7: Predicted probability of exceedance of the State water quality threshold for dissolved calcium in Class I waters (>100 mg/L) compared to baseline flow at the USGS Horse Creek at SR72 near Arcadia, FL gage (No. 02297310). The dashed black line indicates the 0.5 probability of exceedance threshold. The dashed red line indicates the border of Block 1 and Block 2 (15 cfs), the dashed blue line delineates the border between Block 2 and Block 3 (78 cfs) and the dashed green line shows the border between Block 3a and Block 3b (172 cfs). Data for Block 3c are not shown since the probability for exceedance declines rapidly in Block 3a. Dots represent predicted probabilities for individual samples under baseline flow conditions and locally estimated scatterplot smoothing (LOESS) polylines are shown for each station. Stations are listed in the key from upstream to downstream.

Dissolved Sulfate

Data from HCSP stations HCSW-1 through HCSW-4 and SWFWMD stations 23949 and 24049 were utilized in the creation of GLMMs for dissolved sulfate. A time series of data from each station is shown in Figure 8. Exceedance of the State Class I water quality threshold of 250 mg/L for dissolved sulfate was utilized as the binary response.

The GLMM with the lowest AIC (358.1) considered baseline flow, season, river kilometer, and the interaction between baseline flow and season. When all data were visualized, the predicted probability of exceedance was below the 0.5 probability threshold during all flow blocks at most stations under baseline flow conditions, the exception being a sample crossing the threshold at station HCSW-4 during Block 1 (Figure 9). All flows during Block 1 are protected under the proposed minimum flows. The recommended minimum flows did not change the results for any block or station.

Stations HCSW-3, HCSW-4, and 24049 showed a similar trend in their data, visible in the dots on the plot (Figure 9), which were driven by seasonal impacts, illustrated using station HCSW-4 as an example (Figure 10). For these stations, the spring dry season (April-June) tends to have relatively higher likelihoods of 0.5

probability threshold exceedance, and the probability of threshold exceedance is highest at low flows from January-March (Figure 10).

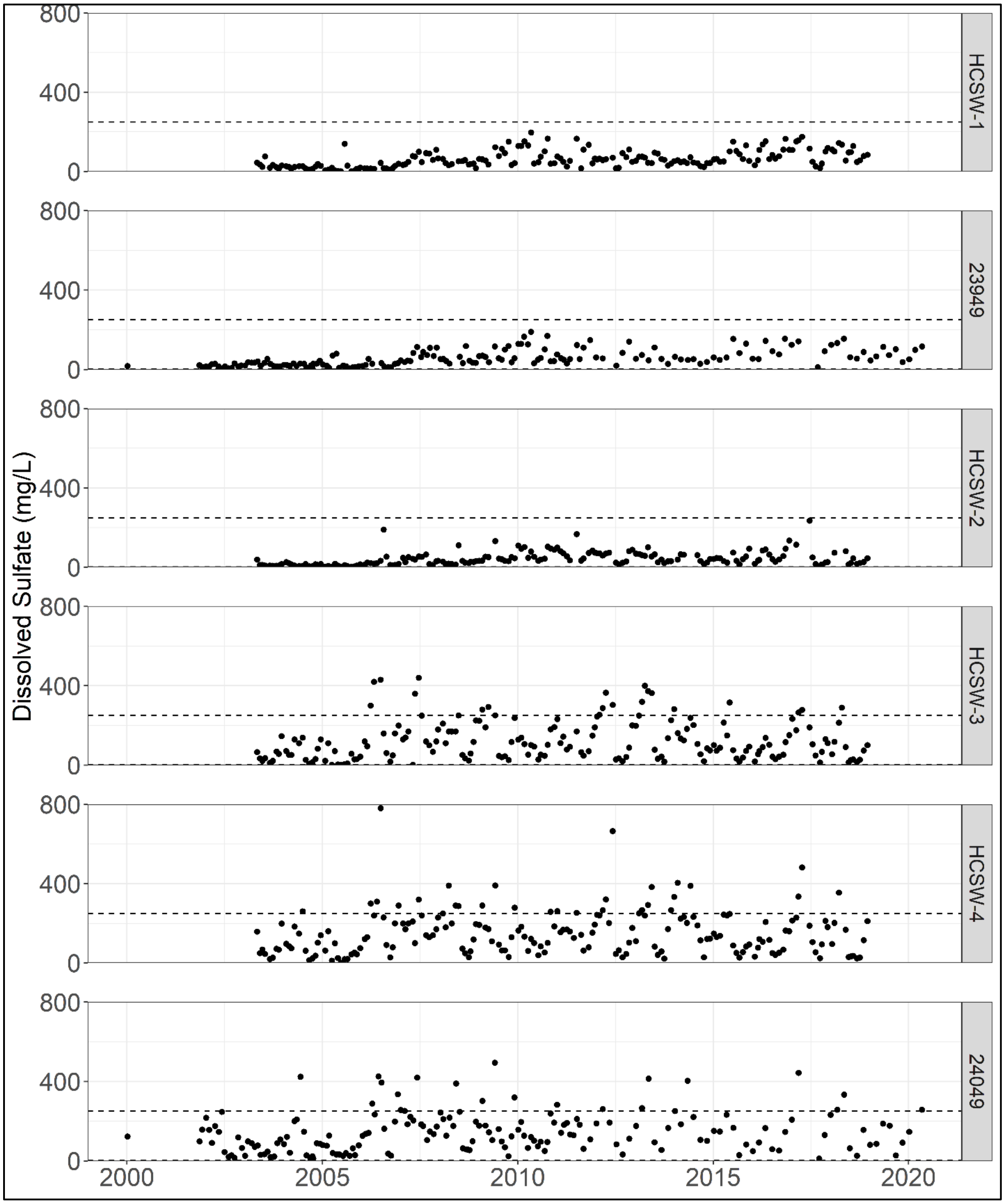

Figure 8. Sample distribution for dissolved calcium at HCSP (HCSW-1 through -4) and SWFWMD (23949 and 24049) stations, listed from upstream to downstream. The dashed line indicates the State water quality threshold for Class I waterbodies (>250 mg/L). Note this threshold is for the annual geometric mean rather than for individual samples.

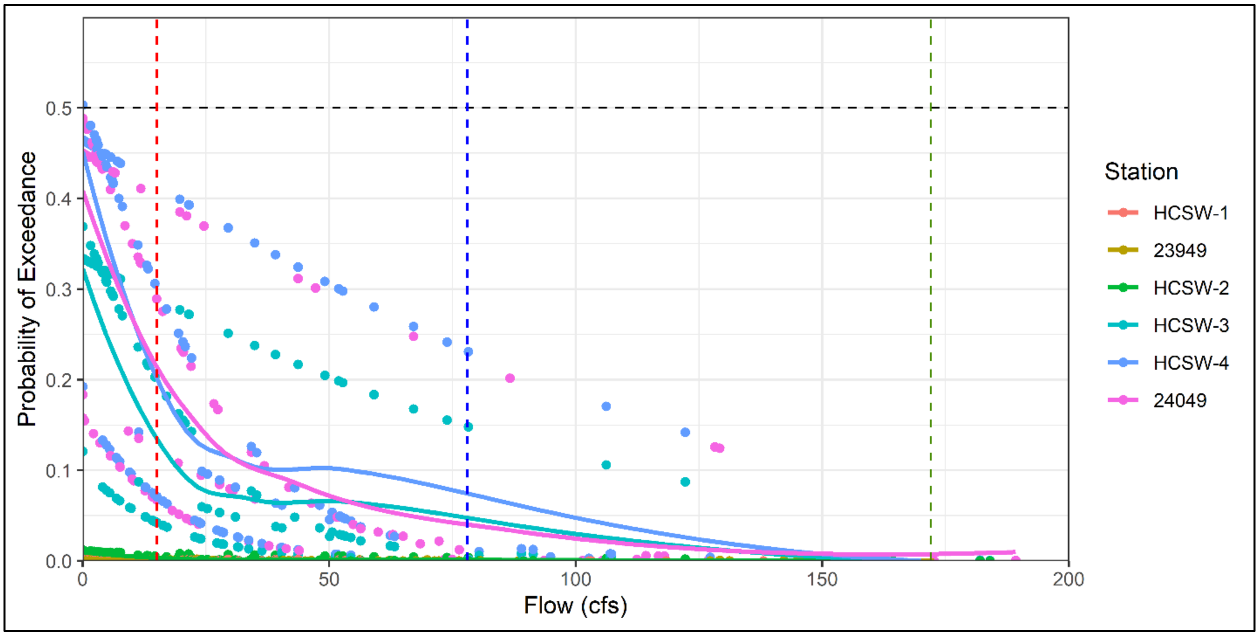

Figure 9: Predicted probability of exceedance of the State water quality threshold for dissolved sulfate in Class I waters (>250 mg/L) compared to baseline flow at the USGS Horse Creek at SR72 near Arcadia gage (No. 02297310). The dashed black line indicates a 0.5 probability of exceedance threshold. The dashed red line indicates the border of Block 1 and Block 2 (15 cfs), the dashed blue line delineates the border between Block 2 and Block 3a (78 cfs), and the dashed green line shows the border between Block 3a and Block 3b (172 cfs). Data for Block 3c are not shown since the probability for exceedance declines rapidly in Block 3a. Dots represent predicted probabilities for individual samples under baseline flow conditions and locally estimated scatterplot smoothing (LOESS) polylines are shown for each station. Stations are listed in the key from upstream to downstream.

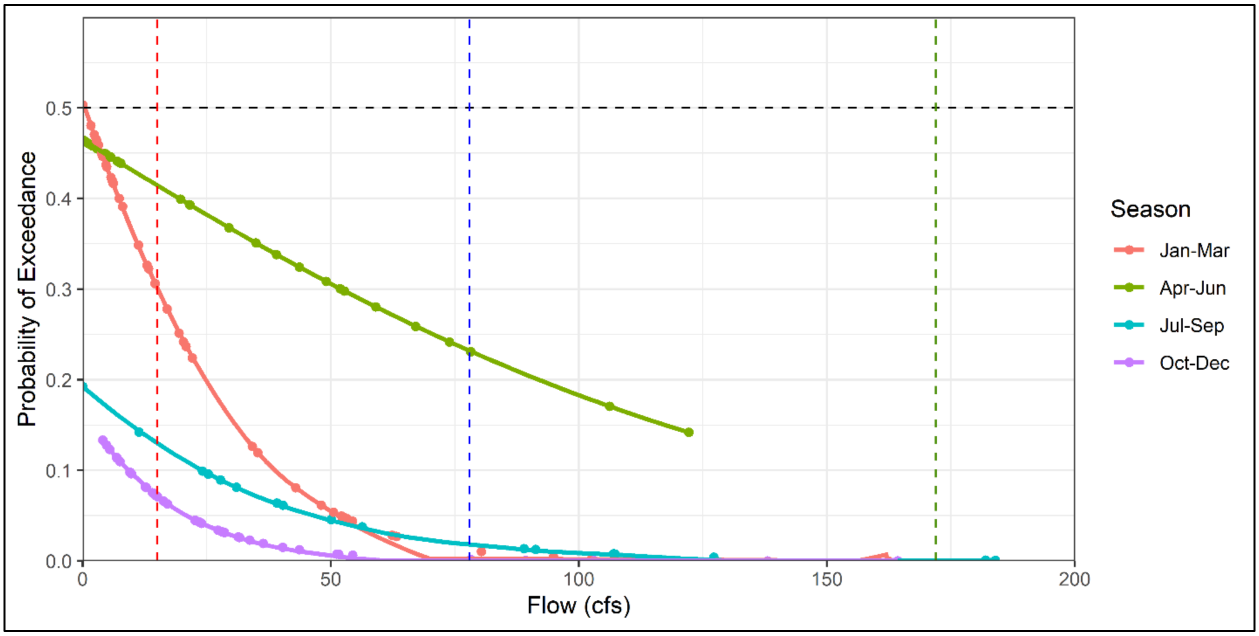

Figure 10: Predicted probability of exceedance of the State water quality threshold for dissolved sulfate in Class I waters (>250 mg/L) compared to baseline flow at the USGS Horse Creek at SR72 near Arcadia, FL gage (No. 02297310) for station HCSW-4, by season. The dashed black line indicates the 0.5 probability of exceedance threshold. The dashed red line indicates the border of Block 1 and Block 2 (15 cfs), the dashed blue line delineates the border between Block 2 and Block 3a (78 cfs), and the dashed green line shows the border between Block 3a and Block 3b (172 cfs). Data for Block 3c are not shown since the probability for exceedance declines rapidly in Block 3a. Dots represent predicted probabilities for individual samples under baseline flow conditions and locally estimated scatterplot smoothing (LOESS) polylines are shown for each season.

Total Nitrogen

Data from HCSP stations HCSW-1 through HCSW-4 and SWFWMD stations 23949 and 24049 were utilized in the creation of GLMMs for total nitrogen. A time series of data from each station is shown in Figure 11. Exceedance of the State Class III water quality threshold of 1.65 mg/L for total nitrogen was utilized as the binary response.

The GLMM with the lowest AIC (959.6) incorporated log transformed baseline flow, season, river kilometer, and the interaction between log transformed baseline flow and season. When results were visualized, the predicted probability of exceedance was below the 0.5 probability threshold within each block under baseline flow conditions (Figure 12). The proposed minimum flows did not change these results.

Similar trends were observed in the predicted response of individual samples by season for all stations. An example of the trends, using data from station HCSW-4 is shown in Figure 13. The probability of threshold exceedance is greatest during the wet summer season (July – September) and lowest from January through March (Figure 13).

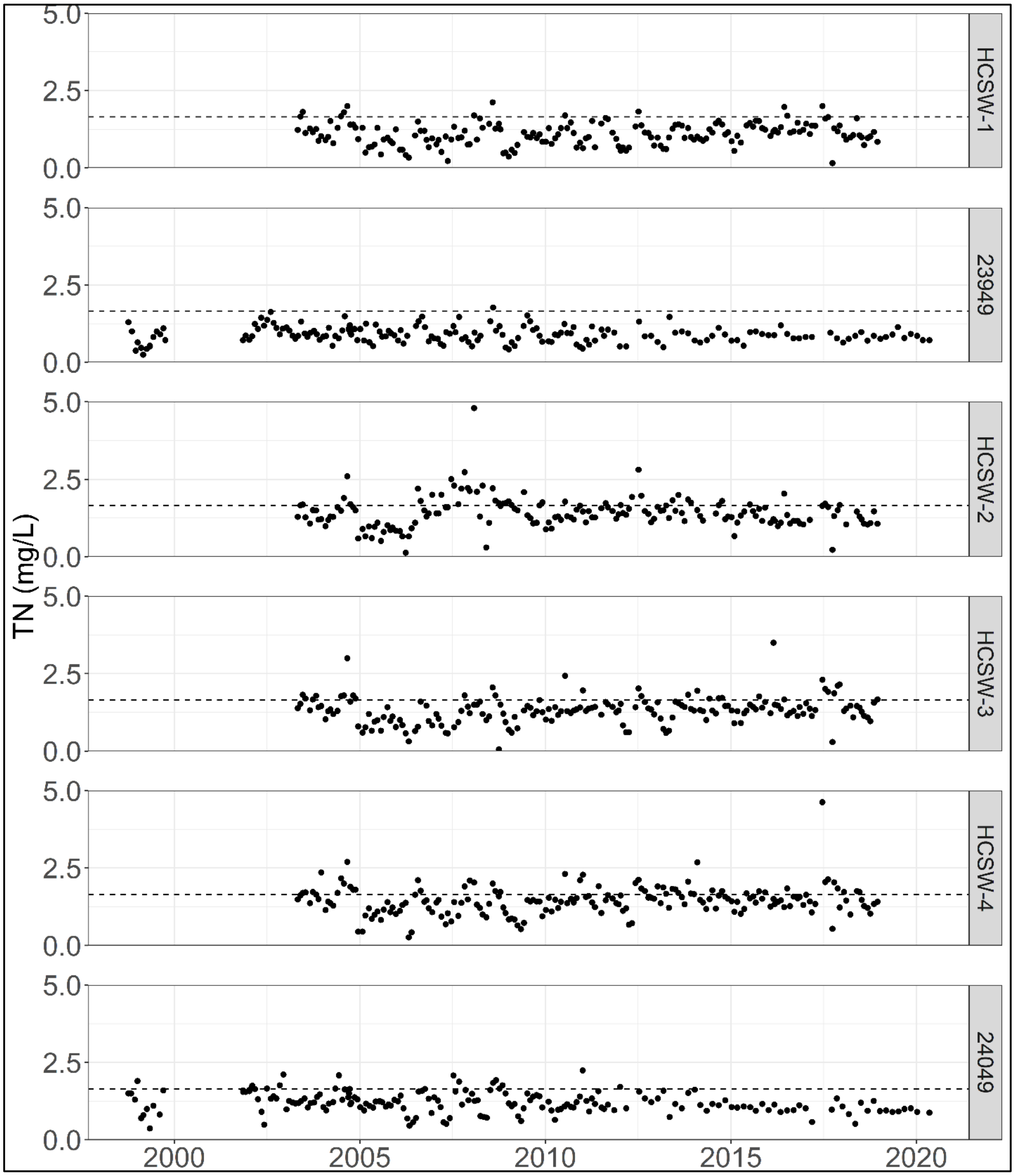

Figure 11. Sample distribution for total nitrogen (TN) at HCSP (HCSW-1 through -4) and SWFWMD (23949 and 24049) stations, listed from upstream to downstream. The dashed line indicates the State water quality threshold for Class III waterbodies (>1.65 mg/L). Note this threshold is for the annual geometric mean rather than for individual samples.

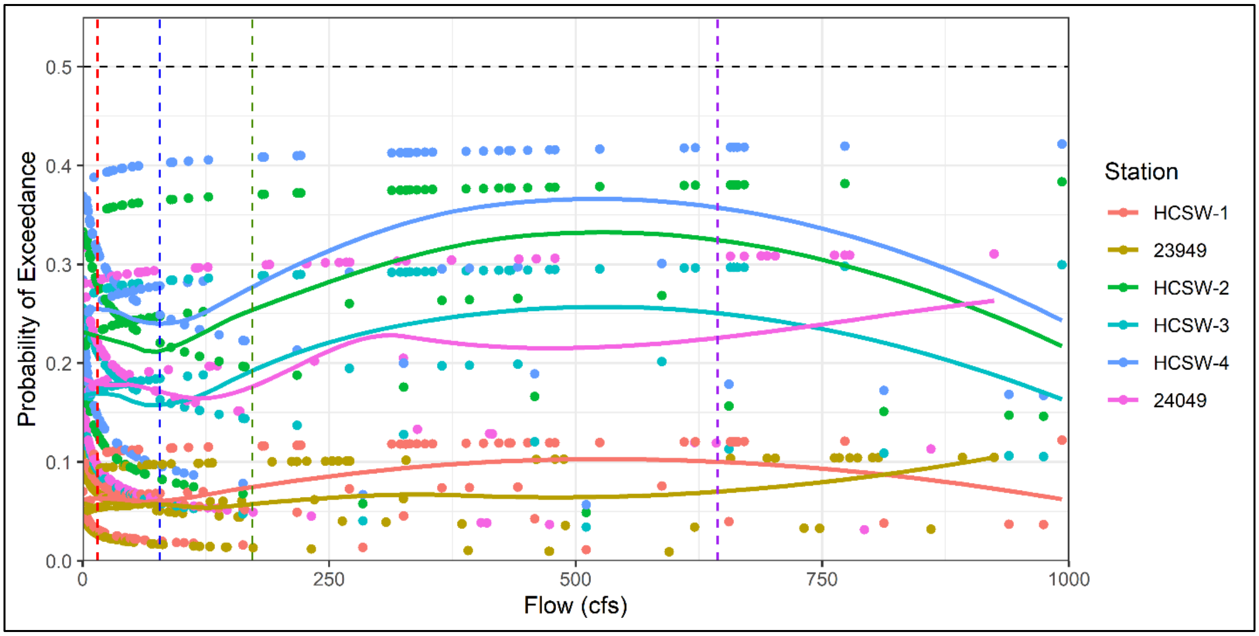

Figure 12: Predicted probability of exceedance of the State water quality threshold for total nitrogen in Class III waters (>1.65 mg/L) compared to baseline flow at the USGS Horse Creek at SR72 near Arcadia, FL gage (No. 02297310). The dashed black line indicates the 0.5 probability of exceedance threshold. The dashed red line indicates the border of Block 1 and Block 2 (15 cfs), the dashed blue line delineates the border between Block 2 and Block 3a (78 cfs), the dashed green line shows the border between Block 3a and Block 3b (172 cfs), and the dashed purple line shows the border between Block 3b and Block 3c (644 cfs). Dots represent predicted probabilities for individual samples under baseline flow conditions and locally estimated scatterplot smoothing (LOESS) polylines are shown for each station. Stations are listed in the key from upstream to downstream.

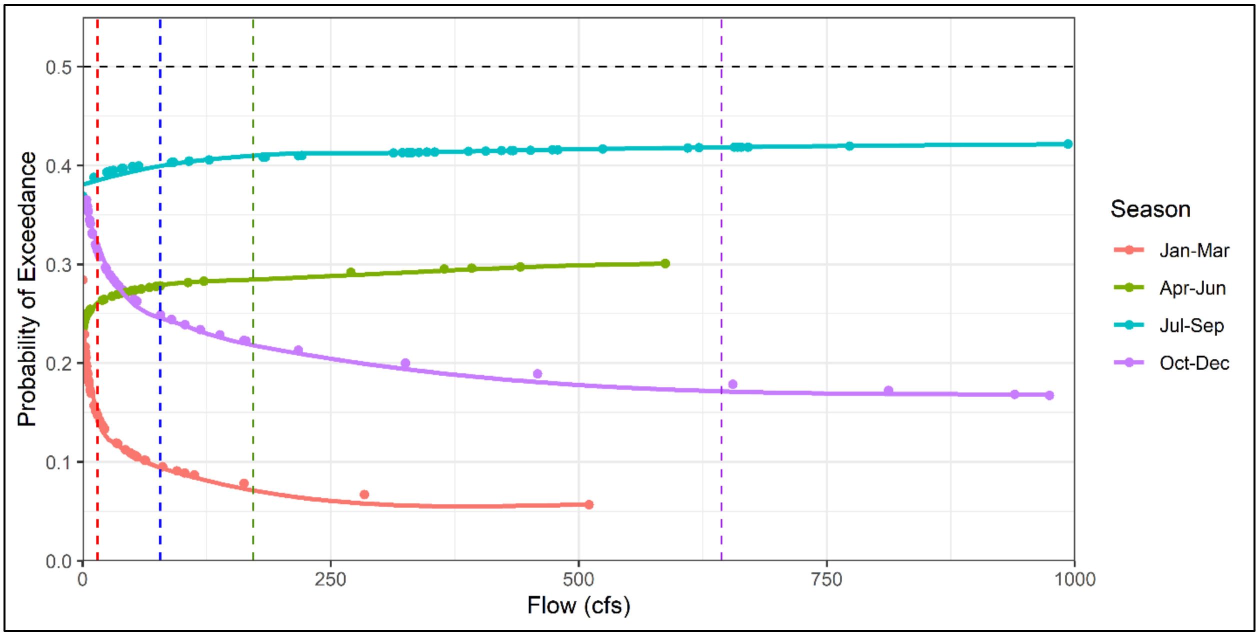

Figure 13: Predicted probability of exceedance of the State water quality threshold for total nitrogen in Class III waters (>1.65 mg/L) compared to baseline flow at the USGS Horse Creek at SR72 near Arcadia, FL gage (No. 02297310) at station HCSW-4, by season. The dashed black line indicates the 0.5 probability of exceedance threshold. The dashed red line indicates the border of Block 1 and Block 2 (15 cfs), the dashed blue line delineates the border between Block 2 and Block 3a (78 cfs), the dashed green line shows the border between Block 3a and Block 3b (172 cfs), and the dashed purple line shows the border between Block 3b and Block 3c (644 cfs). Dots represent predicted probabilities for individual samples under baseline flow conditions and locally estimated scatterplot smoothing (LOESS) polylines are shown for each season.

Total Phosphorus

Data from DEP station 21FLA 25020111, SWFWMD stations 23949 and 24049, and the USGS Horse Creek at SR72 near Arcadia, FL (No. 02297310) gage were utilized in the creation of GLMMs for total phosphorus. The HCSP program collects orthophosphate data, rather than total phosphorus, so their data were excluded from this analysis. A time series of data from each incorporated station is shown in Figure 14.

Exceedance of the State Class III water quality threshold of 0.49 mg/L for total phosphorus was utilized as the binary response. The GLMM for total phosphorus with the lowest AIC (891.2) considered log transformed baseline flow, season, river kilometer, the interaction between log transformed baseline flow and river kilometer, and the interaction between log transformed baseline flow and season. When results were visualized, the likelihood of surpassing the 0.5 probability of threshold exceedance was greatest at station 25020111 under baseline flow conditions in all flow blocks (Figure 15). There were no observed changes to the number of samples predicted to surpass the 0.5 probability of exceedance threshold under minimum flow conditions in any block (Table 3).

Samples from station 02297310 exceeded the 0.5 probability threshold during all blocks under baseline flow conditions (Figure 15). The GLMM predicted that four out of 35 tested samples at station 02297310 would surpass the 0.5 probability for threshold exceedance under Block 2 minimum flow conditions, as opposed to three samples under baseline conditions. There were no changes to the number of samples predicted to surpass the 0.5 probability of exceedance threshold under minimum flow conditions under any other block (Table 3).

The same seasonal trends for the probability of total phosphorus threshold exceedance were observed at all stations, with the results for station 2502011 shown as an example (Figure 16). There were higher probabilities of threshold exceedance during the wet summer season (July-September) as you move though Blocks 2, Block 3a, and Block 3b. The other seasons featured a different pattern, with higher probabilities of exceedance during Block 1 flows and declines in the probability of exceedance as flows increase.

Results from modeling for this analyte should be interpreted with caution, as three of the stations occurred at the same geographic location, albeit over different periods of record, and sample collection frequencies.

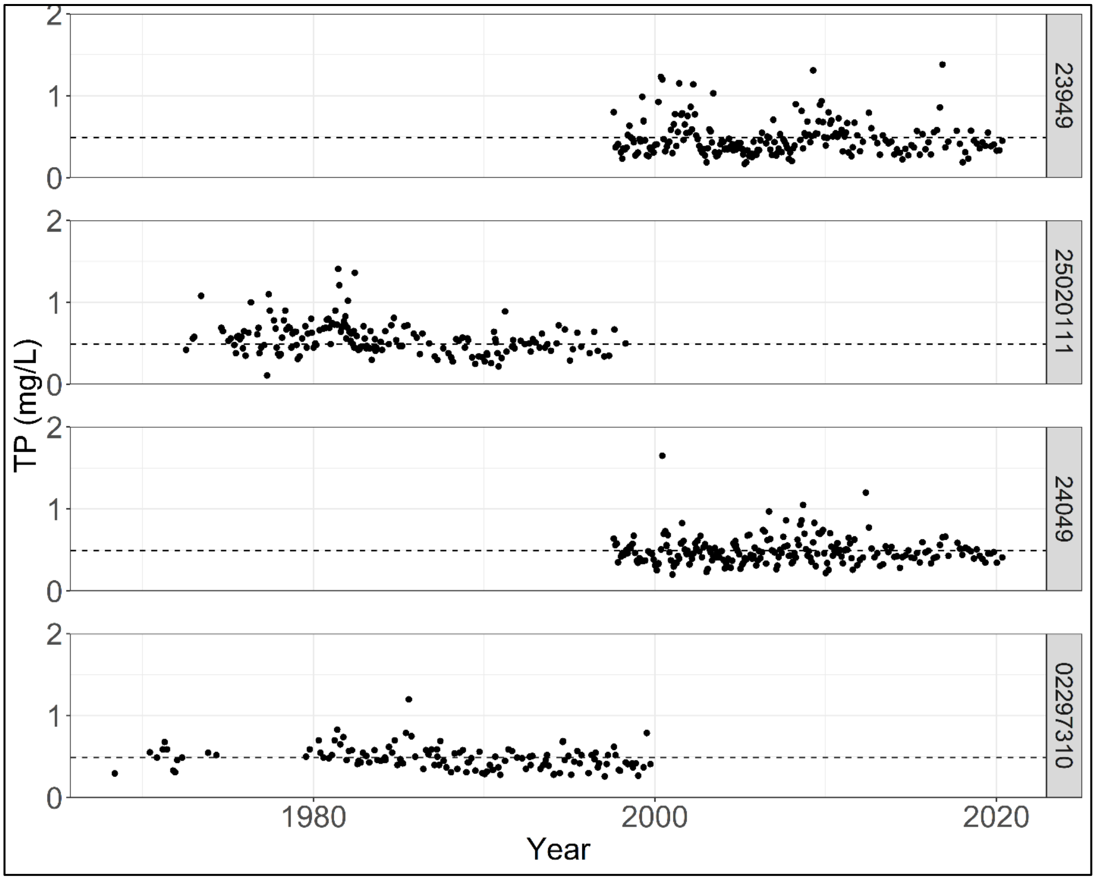

Figure 14. Sample distribution for total phosphorus (TP) at DEP (21FLA) 25020111), SWFWMD (23949 and 24049), and USGS (02297310) stations listed from upstream to downstream. The dashed line indicates the State water quality threshold for total phosphorus in Class III waterbodies (>0.49 mg/L). Note this threshold is for the annual geometric mean rather than for individual samples.

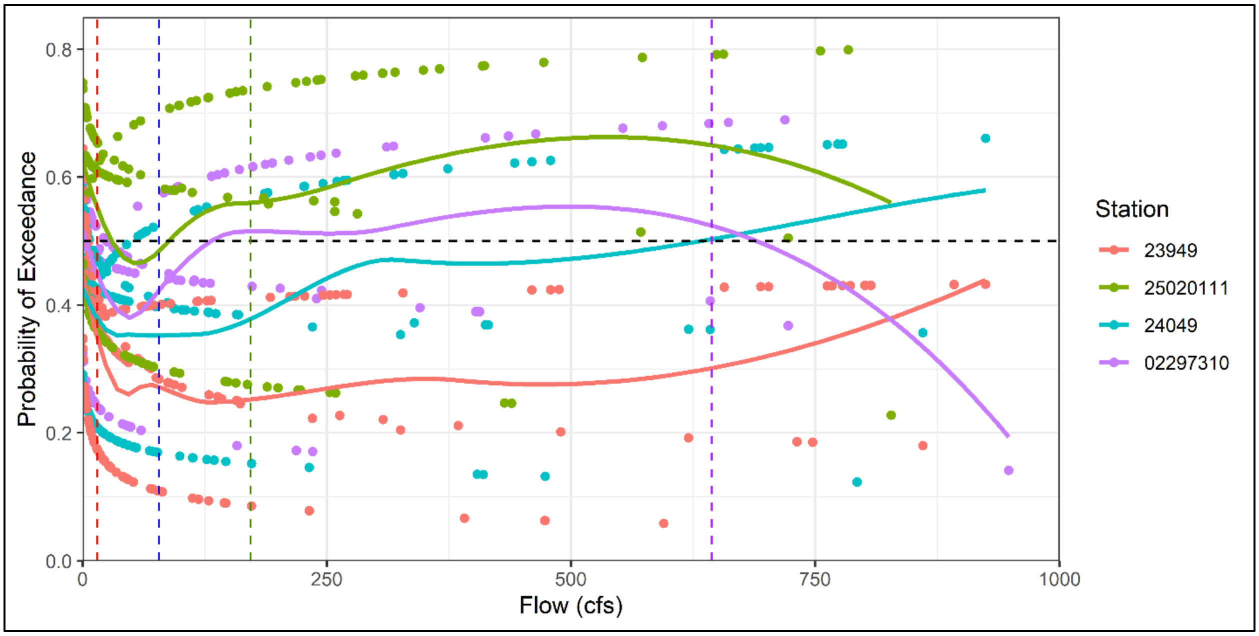

Figure 15: Predicted probability of exceedance of the State water quality threshold for total phosphorus in Class III waters (>0.49 mg/L) with baseline flow at the USGS Horse Creek at SR72 near Arcadia, FL gage (No. 02297310). The dashed black line indicates the 0.5 probability of exceedance threshold. The dashed red line indicates the border of Block 1 and Block 2 (15 cfs), the dashed blue line delineates the border between Block 2 and Block 3 (78 cfs), the dashed green line shows the border between Block 3a and Block 3b (172 cfs), and the dashed purple line shows the border between Block 3b and Block 3c (644 cfs). Dots represent predicted probabilities for individual samples under baseline flow conditions and locally estimated scatterplot smoothing (LOESS) polylines are shown for each station. Stations are listed in the key from upstream to downstream.

Table 3: The number of total phosphorus samples predicted to surpass the 0.5 probability threshold for State water quality criteria exceedance under baseline flow conditions and proposed minimum flows, as predicted using generalized linear mixed models. Stations and flow blocks where probabilities of exceedance were less than 0.5 are not shown.

Station	Block	Samples (n)	Samples Surpassing 0.5 Probability of Threshold Exceedance (n)		Difference Between Baseline and MFL (n)
			Baseline	MFL	
25020111	2	45	26	26	0
	3a	25	19	19	0
	3b	33	24	24	0
	3c	11	10	10	0
02297310	2	35	3	4	1
	3a	17	8	8	0
	3b	35	15	15	0
	3c	10	8	8	0

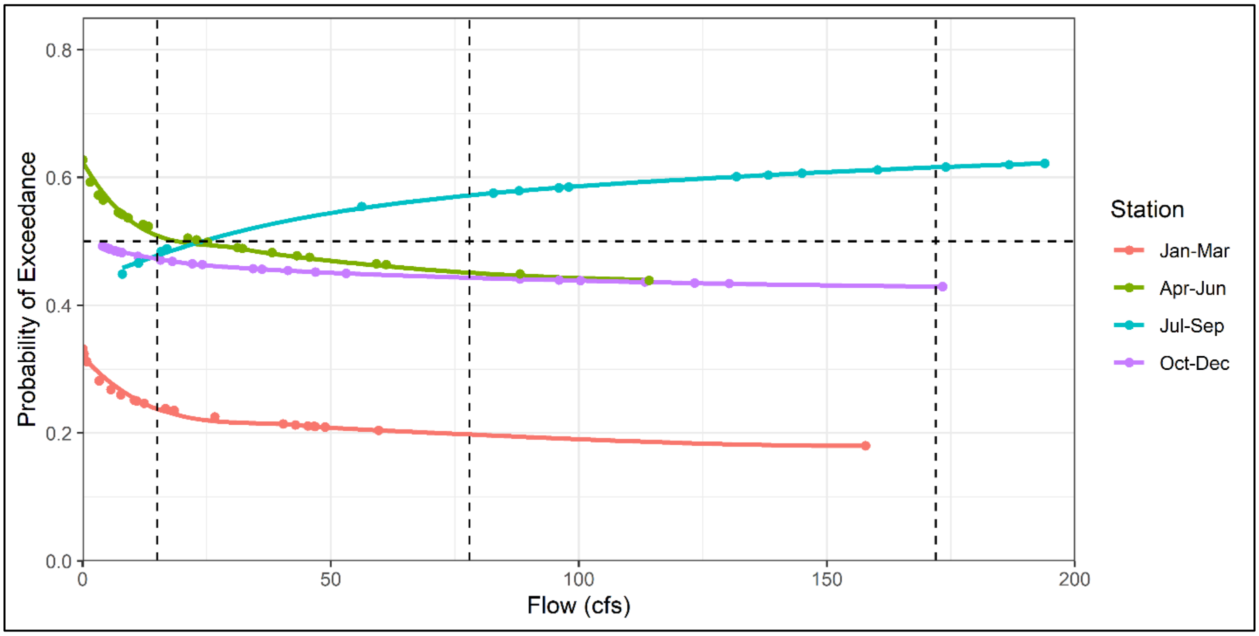

Figure 16: Predicted probability of exceedance of the State water quality threshold for total phosphorus in Class III waters (>0.49 mg/L) with baseline flow at the USGS Horse Creek at SR72 near Arcadia, FL gage (No. 02297310) at DEP station 2502111, by season. The dashed black line indicates the 0.5 probability of exceedance threshold. The dashed red line indicates the border of Block 1 and Block 2 (15 cfs), the dashed blue line delineates the border between Block 2 and Block 3 (78 cfs) and the dashed green line shows the border between Block 3a and Block 3b (172 cfs). Dots represent predicted probabilities for individual samples under baseline flow conditions and locally estimated scatterplot smoothing (LOESS) polylines are shown for each season.

Dissolved Oxygen Percent Saturation

Data from DEP stations (21FLA 25020428, 21FLA 25020430, 21FLA 25020423, 21FLA 25020111, and 21FLTM 25020420), HCSP stations (HCSW-1, -2, -3, and -4) and USGS Horse Creek at SR72 near Arcadia (No. 02297310) were utilized in the creation of GLMMs for dissolved oxygen percent saturation. A time series of data from each station is shown in Figure 17. Sample values below the State Class III water quality threshold of 38% for dissolved oxygen were utilized as the binary response.

The GLMM for dissolved oxygen percent saturation data with the lowest AIC (286.7) considered log transformed baseline flow, season, and station. When visualized, station HCSW-2 surpassed the 0.5 probability of exceedance threshold during Blocks 2, 3a, and 3b under baseline flow conditions. Exceedances occurred in all flow blocks for station 25020430 under baseline flow conditions (Figure 18).

The predicted number of samples exceeding the 0.5 probability threshold for station 02502430 did not change under the proposed minimum flows. During Block 3a, six of nine tested samples were predicted to surpass the 0.5 probability of threshold exceedance under proposed minimum flow conditions at station HCSW-2, as opposed to seven samples under baseline conditions (Table 4).

Both stations that experienced elevated probabilities of threshold exceedances also exhibited seasonal trends. The highest likelihood of threshold exceedance occurred during the spring dry season (April through June), with the lowest likelihood of threshold exceedances occurring during the winter season, January – March. An example of these trends is shown for station HCSW-2, which contained data for a wider range of flows than station 02502430 (Figure 19).

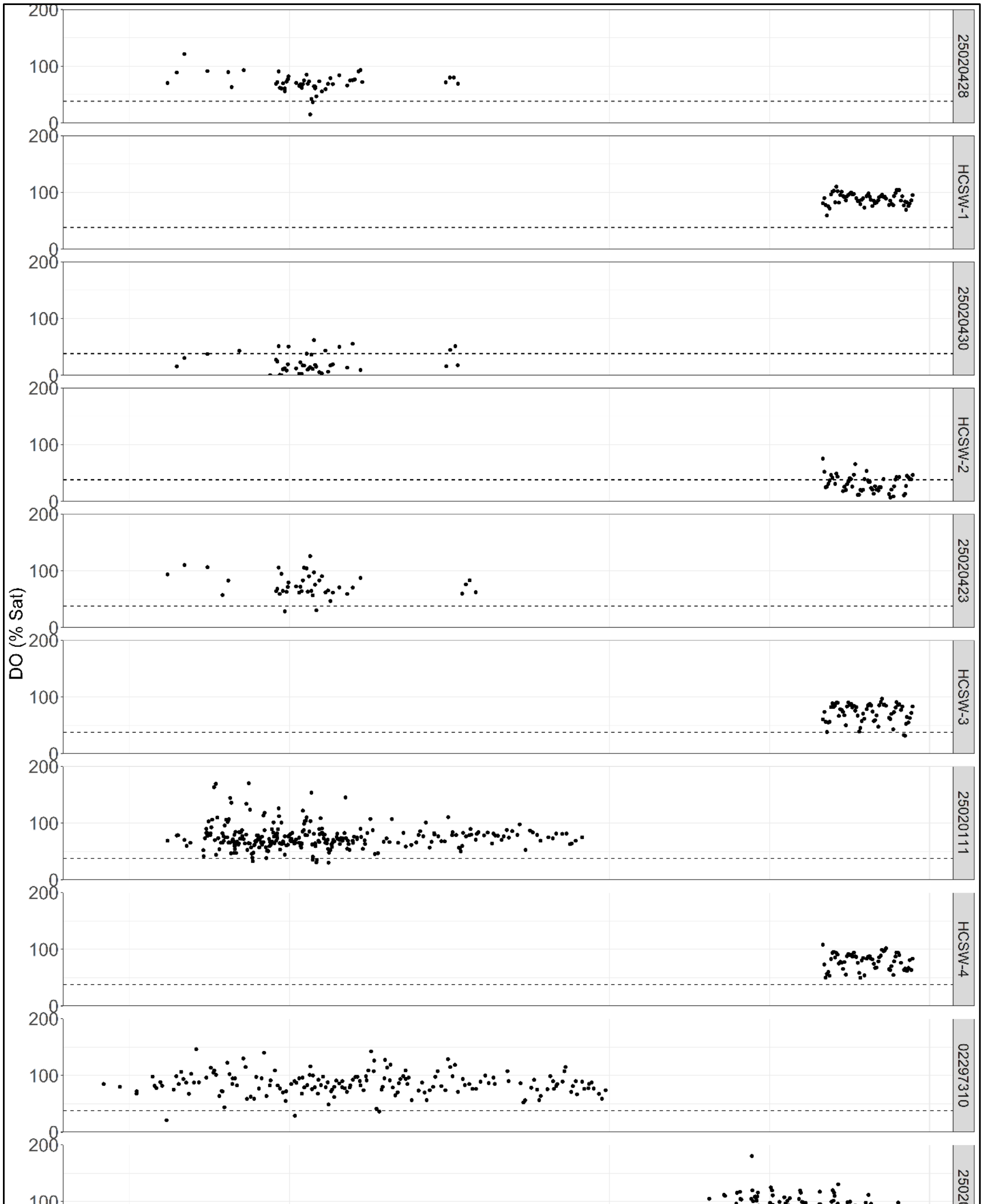

Figure 17. Sample distribution for dissolved oxygen percent saturation (DO % Sat) at DEP ((21FLA) 25020428, (21FLA) 25020430, (21FLA) 25020423, (21FLA) 25020111, and (21 FLTM) 25020420), HCSP (HCSW-1, -2, -3, and -4), and USGS (Gage No. 02297310) listed from upstream to downstream. The dashed line indicates the State water quality threshold for dissolved oxygen percent saturation (<38%).

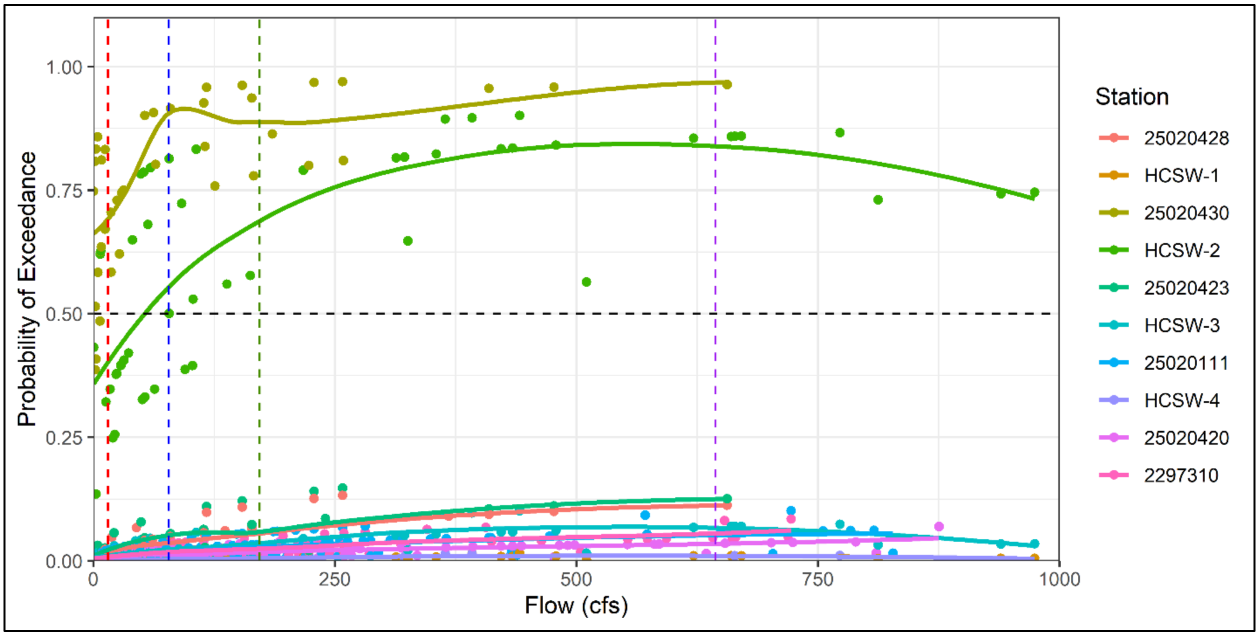

Figure 18: Predicted probability of exceedance of the State water quality threshold for dissolved oxygen percent saturation in Class III waters (<38%) with flow at the USGS Horse Creek at SR72 near Arcadia, FL gage (No. 02297310) compared to baseline flow. The dashed black line indicates the 0.5 probability of exceedance threshold. The dashed red line indicates the border of Block 1 and Block 2 (15 cfs), the dashed blue line delineates the border between Block 2 and Block 3a (78 cfs), the dashed green line shows the border between Block 3a and Block 3b (172 cfs), and the dashed purple line shows the border between Block 3b and Block 3c (644 cfs). Dots represent predicted probabilities for individual samples under baseline flow conditions and locally estimated scatterplot smoothing (LOESS) polylines are shown for each station. Stations are listed in the key from upstream to downstream.

Table 4: The number of dissolved oxygen percent saturation samples predicted to surpass the 0.5 probability threshold for State water quality criteria exceedance under baseline flow conditions and proposed minimum flows, as predicted using generalized linear mixed models. Stations and flow blocks where probabilities of exceedance were less than 0.5 are not shown.

Station	Block	Samples (n)	Samples Surpassing 0.5 Probability of Threshold Exceedance (n)		Difference Between Baseline and MFL (n)
			Baseline	MFL	
HCSW-2	2	20	5	5	0
	3a	9	7	6	-1
	3b	13	13	13	0
	3c	9	9	9	0
025020430	2	10	10	10	0
	3a	8	8	8	0
	3b	7	7	7	0
	3c	2	2	2	0

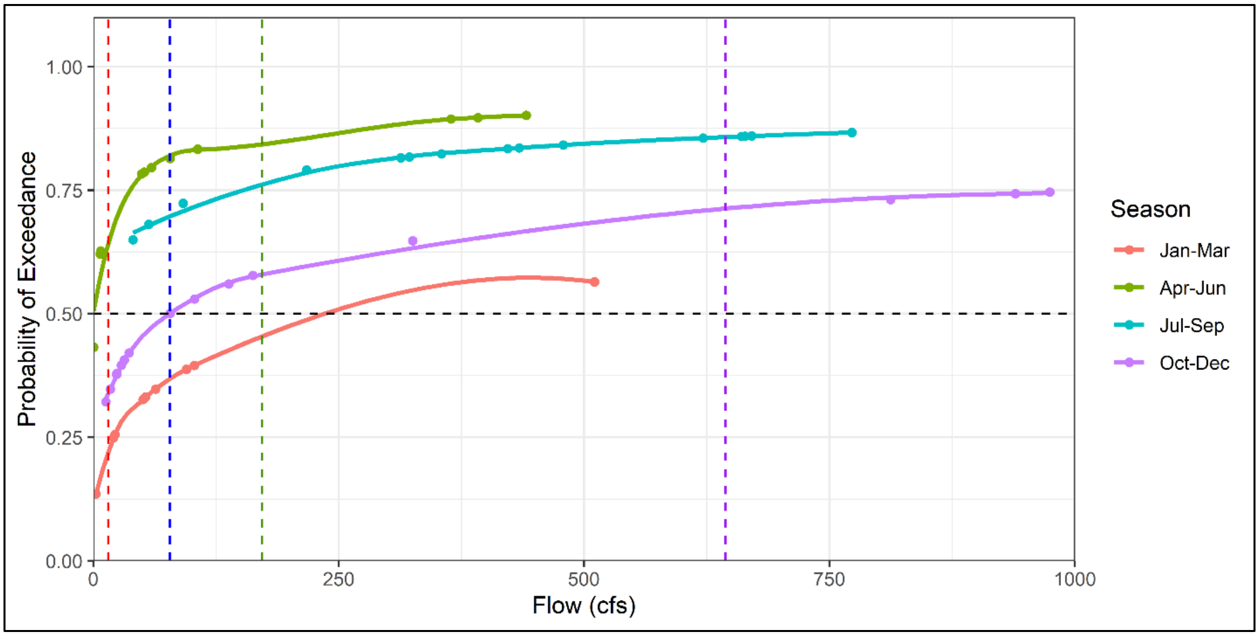

Figure 19: Predicted probability of exceedance of the State water quality threshold for dissolved oxygen percent saturation in Class III waters (<38%) compared to baseline flow at the USGS Horse Creek at SR72 near Arcadia, FL gage (No. 02297310) for station HCSW-2, by season. The dashed black line indicates the 0.5 probability of exceedance threshold. The dashed red line indicates the border of Block 1 and Block 2 (15 cfs), the dashed blue line delineates the border between Block 2 and Block 3a (78 cfs), the dashed green line shows the border between Block 3a and Block 3b (172 cfs), and the dashed purple line shows the border between Block 3b and Block 3c (644 cfs). Dots represent predicted probabilities for individual samples under baseline flow conditions and locally estimated scatterplot smoothing (LOESS) polylines are shown for each station.

Summary

All State water quality thresholds mentioned, apart from dissolved oxygen percent saturation, are based upon the annual geometric mean over a specified period. The State water quality threshold for dissolved oxygen percent saturation is exceeded if more than 10% of the daily average dissolved oxygen percent saturation values are below 38%. While the statistics calculated below are modeled off available sample data, and therefore, reflect the probability of exceedance on a per sample basis, it is assumed that if the number of samples exceeding the threshold is not substantially increased by flow reduction, the probability of exceeding the State water quality threshold once an annual geometric mean or 10% of daily averages is calculated would also not increase.

According to this analysis, the 0.5 probability threshold for exceeding the state water quality criteria for an analyte only increased at station 02297310 during Block 2 for total phosphorus. One additional sample was predicted to surpass the 0.5 probability threshold (Table 3). This is not expected to change the overall probability of the station exceeding the State water quality threshold for total phosphorus when annual geometric means are calculated.

The probability of threshold exceedance for dissolved oxygen percent saturation was predicted to decrease under the proposed minimum flow during block 3a at station HCSW-2. One fewer sample was expected to surpass the 0.5 probability threshold of exceedance under the proposed minimum flows as compared to baseline conditions.

Therefore, water quality constituents in Horse Creek are not expected to substantially change in response to flow reductions associated with implementation of the recommended minimum flows. The models are limited by the frequency of data collection at each site and varying periods of records for different stations and analytes.

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