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Effects on Lower St. Johns River Nutrient Supply and TMDL Target Compliance from the Restoration of a Free-Flowing Ocklawaha River

by

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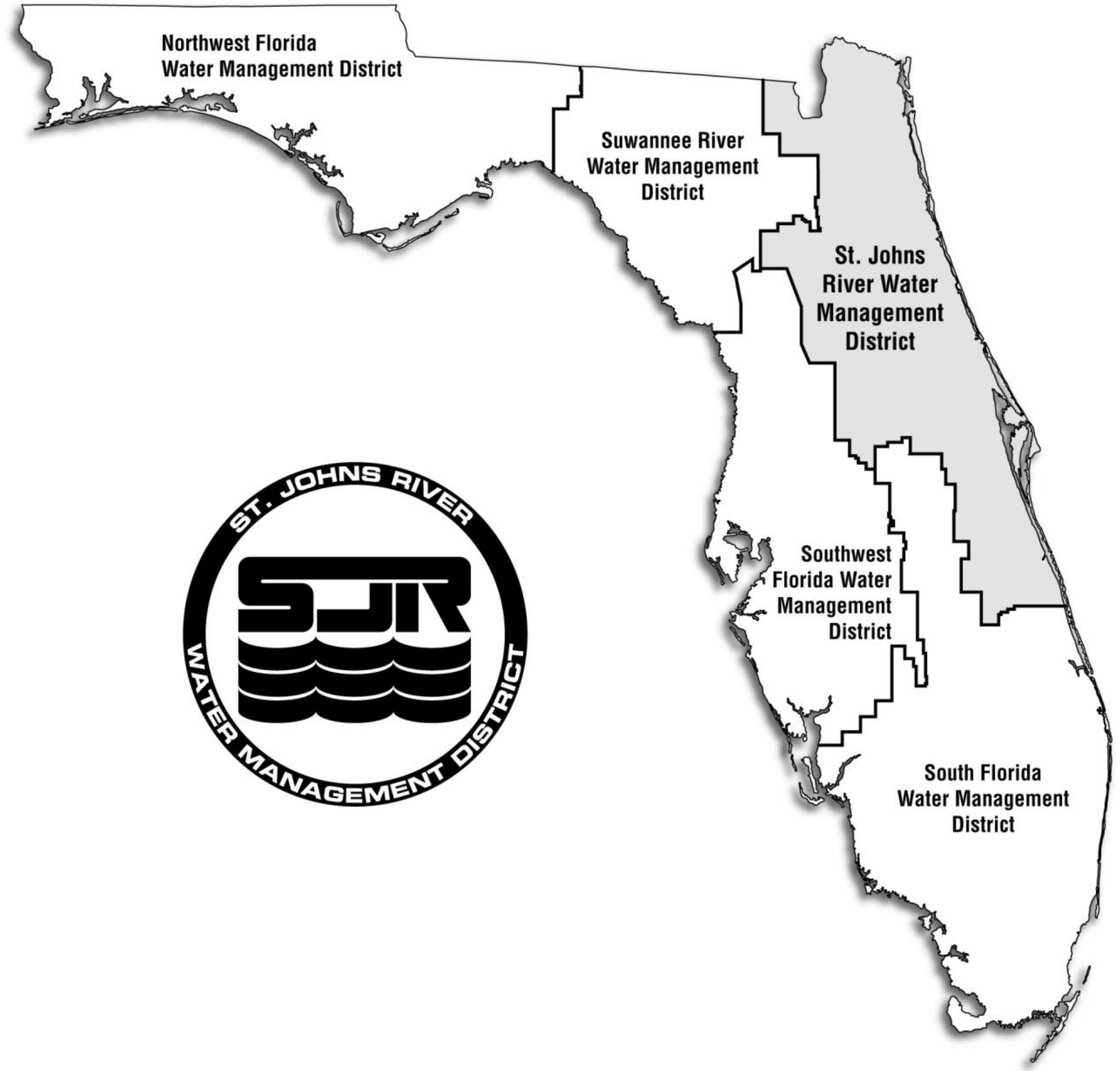
St. Johns River Water Management District
Palatka, Florida

2016



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EXECUTIVE SUMMARY

This report details the results of analyses performed by the St. Johns River Water Management District about the possible downstream effects of restoring of the lower Ocklawaha River to a free-flowing condition by removing the Rodman Reservoir. The analysis represents the most comprehensive reassessment to date focusing on the changes in nitrogen and phosphorus export from a free-flowing Ocklawaha River. The original assessment, conducted in 1994 as part of the Environmental Studies Concerning Four Alternatives for Rodman Reservoir and the Lower Ocklawaha River (ECT, 1994) predicted that the removal of Rodman Reservoir would significantly increase nutrients, in particular, nitrate-nitrogen, delivered to the lower St. Johns River Estuary. With the application of additional data and improved modeling capabilities, this report yields more accurate findings intended to inform interested parties about likely outcomes of restoration.

New information about the role of nitrogen in worsening eutrophication in the lower St. Johns River that was not known at the time of the restoration permit submittal has greatly influenced the findings of this study. Monitoring data indicate that the availability of nitrogen alone (i.e., without the addition of phosphorus) does not encourage algal bloom growth in the freshwater reach of the lower St. Johns River and therefore does not constitute an adverse environmental impact from restoration. In addition, while phosphorus remains the controlling nutrient for algal blooms in this reach, this analysis suggests that on average just eight additional tons of phosphorus would be added annually from restoration efforts. While phosphorus reduction elsewhere would presumably be necessary to mitigate the effects of that increase, the offset of a load of this magnitude should be attainable through the use of current technology in several nearby water bodies, including the middle St. Johns River, Lake George, or the freshwater portion of the lower St. Johns.

Final recommendations concerning approval or denial of the Florida Department of Environmental Protection permit application have not been finalized as a result of this analysis.

BACKGROUND

Rodman Reservoir was originally created as the eastern entry pool for the Cross-Florida Barge Canal project. The reservoir was first filled in 1968, flooding 24 miles of the lower Ocklawaha valley from County Road 316 at Eureka to Riverside Landing, the location of the Rodman, now Kirkpatrick, Dam.

In 1991, federal de-authorization of the Cross Florida Barge Canal Project resulted in the transfer of canal lands to the state of Florida. An ad hoc Canal Lands Advisory Committee (CLAC) was formed to provide recommendations to the Governor and Cabinet on the disposition of the barge canal lands and structures. After deliberating on the recommendations of the CLAC, the 1993 Legislature passed Chapter 92-213, Laws of Florida, which directed the Department of Natural Resources (now the Florida Department of Environmental Protection [FDEP]) to " . . . study the efficacy, both environmental and economic, of complete restoration of the Ocklawaha River, partial restoration of the river, total retention of Rodman Reservoir, and partial retention of the reservoir . . .." Funds were provided for the St. Johns River Water Management District

(SJRWMD) to undertake the study of these four alternatives. As part of the comprehensive assessment performed by SJRWMD, Volume 11 of the Environmental Studies Concerning Four Alternatives for Rodman Reservoir and the Lower Ocklawaha River, Surface Water Quality and Alternatives Analysis for Rodman Reservoir (ECT, 1994) predicted a post-restoration increase in nitrogen (in the form of nitrate+nitrite-N) and phosphorus (as orthophosphate) loads of 878 and 30 metric tons/yr to the LSJR.

Despite the predicted increase in downstream nutrient load, the positive aspects related to the restoration of floodplain functions, increased unique habitat and migratory fish passage appeared to provide overall net environmental gain. At the directive of then-Gov. Lawton Chiles and the Florida Cabinet, FDEP in 1997 submitted a permit application to SJRWMD for the removal of Rodman Reservoir to restore a free-flowing lower Ocklawaha River.

But in 1999, once the permit application package was complete, the case for the restoration was deemed insufficient to meet the environmental resource permit (ERP) and consumptive use permit (CUP) public interest tests, and SJRWMD staff informed FDEP that they could not recommend approval to their Governing Board. The most prominent concern contributing to the recommendation of denial centered on the potential adverse impacts of increased nutrient load to the lower St. Johns River. Adding to this concern was the fact that the lower St. Johns at the time was one of the most prominent water bodies included on the 1999 consent decree between the U.S. Environmental Protection Agency and Earthjustice to establish Total Maximum Daily Loads (TMDLs) for impaired Florida waters. FDEP requested that SJRWMD not take agency action and to hold the permit in abeyance indefinitely, a status which has continued until this day.

Scientific staff at both SJRWMD and FDEP recognized that the Alternatives Analysis report's (ECT, 1994) water quality effects assessment was based on very limited data and contained significant shortcomings. To address these shortcomings, the agencies established a monitoring program and developed computational tools to better characterize the expected changes in downstream nutrient loads and their expected eutrophication effects on the lower St. Johns River. In the interim, the lower St. Johns River TMDL analysis established the targets for the attainment of river water quality, and the process and precedent for nutrient pollution credit trading, through which additional nutrient loads may be offset. In 2012, SJRWMD and FDEP jointly developed a study plan that would employ these new data and analytical tools to reevaluate restoration alternatives. This report is intended to provide a general reassessment of the magnitude and eutrophication effects of the expected post-restoration nutrient loads to the lower St. Johns River by including recent data and utilizing more sophisticated empirical and statistical models.

In both the Upper Ocklawaha and Lower St. Johns River basins, lake restoration projects and removal and improved treatment of point and nonpoint sources of nutrient pollution has resulted in reductions in phosphorus concentrations and significant amelioration of eutrophication of the affected aquatic ecosystems (Ceric and Winkler, 2014; Fulton, 2014; FDEP, 2014). This assessment of the free-flowing Ocklawaha River nutrient load to the lower St. Johns River is based on models developed on the conditions that existed from the mid-1990s through 2012, incorporating historic data from a time when the loading rates were greater, hence overestimate the nutrient loads and receiving water body conditions that exist presently and in the future. This fact, along with the conservative assumptions built into the downstream delivery calculations, would lead one to expect that the downstream algal biomass increases under a free-flowing Ocklawaha River will be less than portrayed based on conservative mixing load and concentration increases.

This analysis estimates that a free-flowing Ocklawaha River will increase the average TP load to the lower St. Johns River by 11.5 metric tons (MT)/yr in reservoir-full years, and by 0.1 MT/yr in drawdown years. If drawdowns are conducted once every three years (the 2012 and upcoming 2015 drawdowns were both postponed a year hence will have been conducted on 4-year cycles), then the long-term median discharge condition phosphorus load increase under a free-flowing Ocklawaha River will be 7.7 MT/yr. To put this load in context, the allocated domestic wastewater phosphorus load to the freshwater lower St. Johns River is 12.4 MT/yr, and the annual load from the Georgia Pacific Palatka Mill was estimated in 2011 to be 11.5 MT/yr (LSJR BMAP, 2011). The Tri-County Agricultural Area (TCAA) delivers an average annual estimated phosphorus load of 84 MT/yr (FDEP, 2008). Two of the SJRWMD-designed and built regional stormwater treatment systems in the TCAA together removed an annual average of 4.5 MT/yr (2009–2014; Livingston-Way, 2014 Draft BMAP). And, since 2012, SJRWMD has conducted a gizzard shad harvest program on Lake George which has annually removed approximately 4.6 MT/yr. So the predicted phosphorus load increase from a free-flowing lower Ocklawaha, while not insignificant, is in the range of other permitted phosphorus loads to the LSJR, and within the realm of reduction achieved by projects currently functioning elsewhere in the basin. Should FDEP choose to pursue this restoration, and if a mitigation were deemed appropriate to offset potential harm based on the predicted phosphorus load increase, it would likely be achievable through a combination of treatment project options directed elsewhere in the middle St. Johns, Lake George, or the freshwater LSJR. This fact, combined with the understanding of adverse impacts that accompany reservoir drawdowns, a necessary management action for the maintenance of the reservoir (Hendrickson et al., 2016), appears sufficient such that a recommendation of denial, on the grounds of the detrimental impacts to downstream water quality, is no longer a certainty for this restoration permit.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance and efforts of the following: Joe Stewart, Tim Cera, Faye Baird and Ed Carter for providing essential documentation of groundwater attributes and reservoir water budget data; Frank Nearhoof for providing FDEP reservoir water quality data and coordination in field sampling audits; Robert Burks, Tiffany Trent and Tanya Stevens for SJRWMD sampling efforts; Chou Fang, Lisa Grant, Kris Davis and Tom Mayton for background context on the restoration permit-related issues; Ed Lowe for recommendations on the approach for this analysis; and the reviewers, Lawrence Keenan, Wayne Magley, and Rob Mattson.

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ACRONYMS

CDOM – Colored Dissolved Organic Matter

CFBC – Cross Florida Barge Canal

DON – Dissolved Organic Nitrogen

EFDC – Environmental Fluid Dynamics Code

ERP – Environmental Resource Permit

FDEP – Florida Department of Environmental Protection

FFR – Free-Flowing River

HSPF – Hydrologic Simulation Program Fortran

LOR – Lower Ocklawaha River

LSJR – Lower St. Johns River

MSJR – Middle St. Johns River

MT – Metric Tons (2,204.6 lbs)

NGVD – National Geodetic Vertical Datum

NOx – Nitrate + Nitrite Nitrogen

PO4 – Orthophosphate Phosphorus

PON – Particulate Organic Nitrogen

PP – Particulate Phosphorus

SJRWMD – St. Johns River Water Management District

TKN – Total Kjeldahl Nitrogen

TMDL – Total Maximum Daily Load

TN – Total Nitrogen

TP – Total Phosphorus

USGS – U.S. Geological Survey

HYDROLOGIC ANALYSIS

GENERAL HYDROLOGIC SETTING

A combination of directly measured flows and available simulated discharge for the remaining ungauged watershed contributing area (Cera et al., 2012) were combined to develop the water budget for the Rodman Reservoir reach of the LOR. Directly measured surface inflows included the Ocklawaha River at Eureka (USGS #02240500), Orange Creek (USGS #02243000), and Orange Springs (SJRWMD station #10362775). Reservoir reach outflow was calculated as the sum of discharge at Rodman Dam (USGS #02243960) and volume releases during lock-throughs at Buckman Lock. Direct precipitation volume was determined from an overlay of the NEXRAD gridded rainfall (Vieux and Associates, Inc. (2007), and evaporation determined by an overlay of gridded estimates of incoming solar radiation by Geostationary Operational Environmental Satellites (Jacobs et al., 2008; USGS, 2015). Changes in storage were determined from the reservoir hypsographic curve, based on changes in reservoir stage at Orange Springs (USGS #02243959). Details of the water budget development are described in greater detail in Appendix A.

The major flows into Rodman Reservoir can be subdivided into three general categories based on chemical characteristics and the prevailing hydrologic setting that controls their relative contributions. The prominent hydrologic features of the headwaters of the Ocklawaha River are large, eutrophic, karst prairie lakes (Figure 1). Levels in most of these lakes are maintained by a variety of stage control structures, hence they only provide a significant outflow to the lower Ocklawaha after substantial, prolonged rainfall accumulation. The drainage area of these karst lakes regions, defined here as the areas above the Moss Bluff (USGS #02238500) and Orange Creek (USGS #02243000) discharge stations, is 1,348 square miles (excludes Paynes Prairie). Although this is 64 percent of the total drainage area, discharge exiting these lake regions is equivalent to only 14 percent of the mean monthly discharge at Kirkpatrick Dam (USGS, 2015) (Figure 2). A greater volume is provided by the 36 percent of surface water basin area adjacent to the river channel between Moss Bluff and Rodman Dam, a portion of which is reflected in the discharge measured at the USGS gauging site at Eureka (USGS #02240500). This surface water basin area adjacent area runoff is equivalent to 20 percent of dam discharge. The greatest contributor to the LOR is artesian spring flow, primarily from Silver River, equivalent to 66 percent of the water volume at the dam median discharge condition, and 75 percent of the time constitutes more than half of the discharge volume.

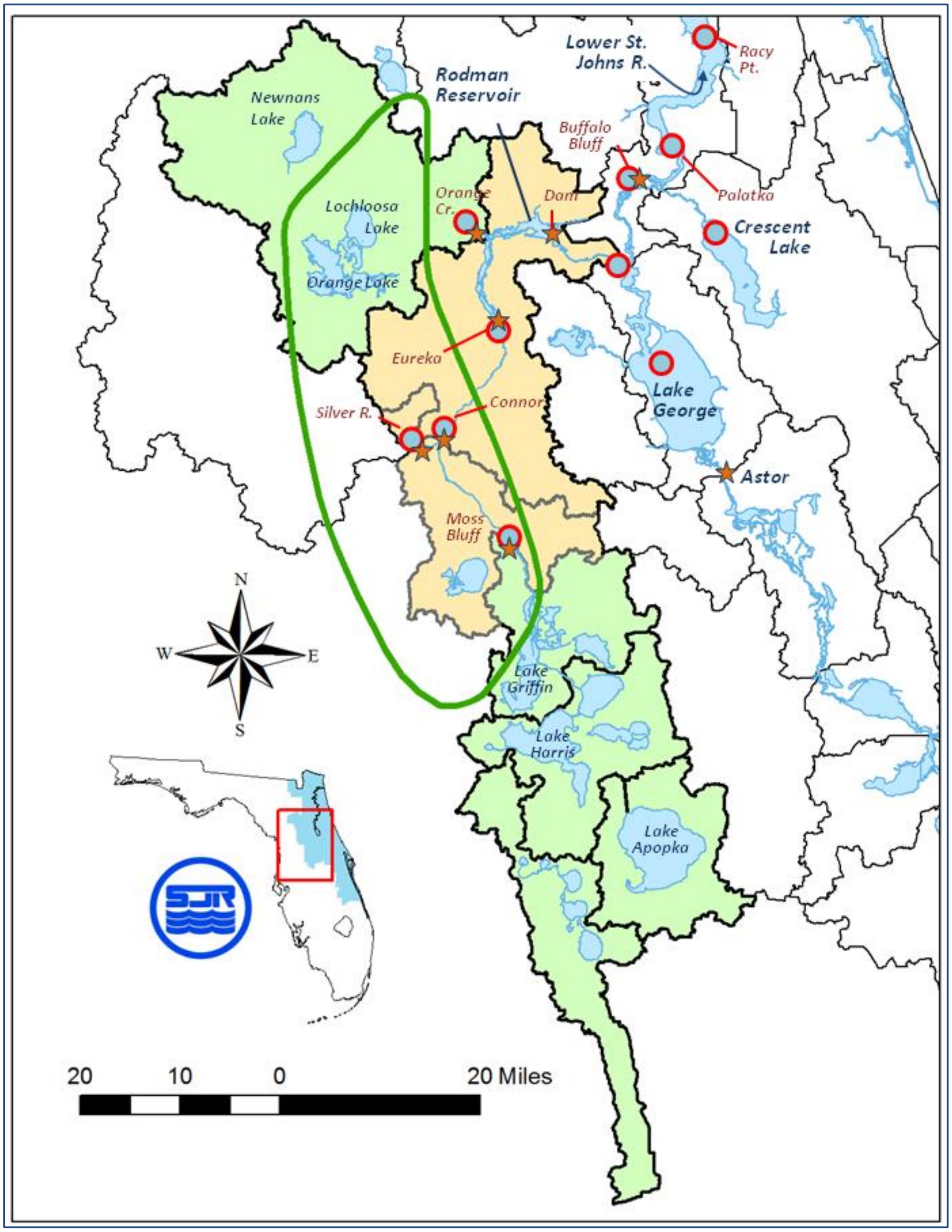

Figure 1. The Ocklawaha River Basin and Rodman Reservoir. Green areas indicate the karst lake regions of the upper Ocklawaha and Orange Creek. Tan areas indicate the adjacent tributary basins. The green line identifies the border of the Silver Springs springshed. Long-term ambient water quality monitoring stations are shown in red circles; discharge gauging sites are shown as red stars.

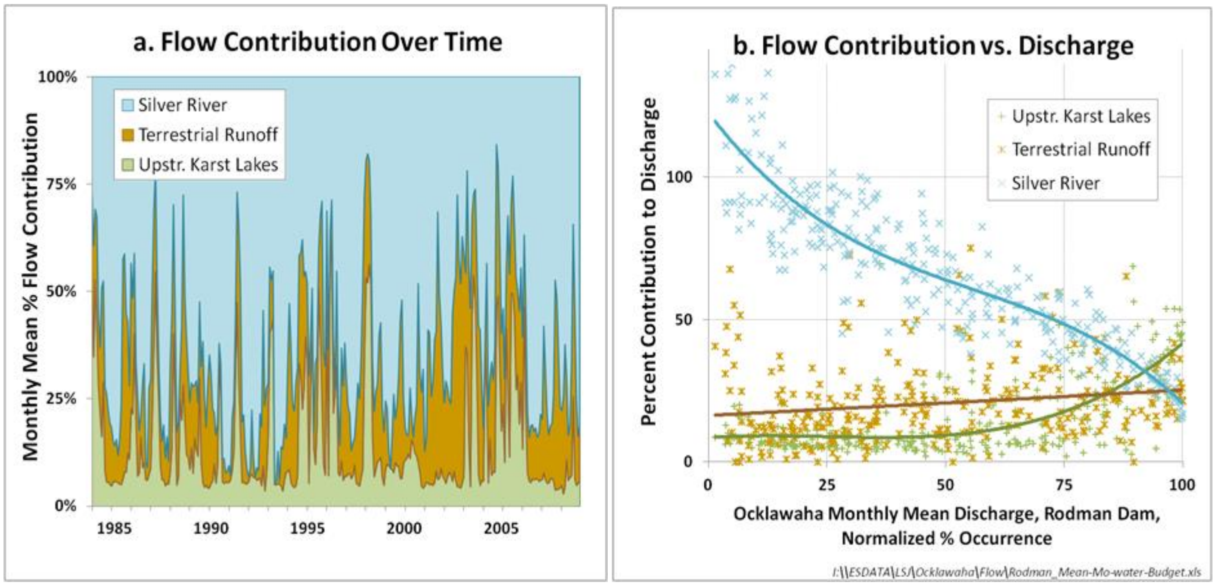

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Figure 2, Monthly Mean Percent Contribution of the Three Major Flow Categories to Lower Ocklawaha River Discharge (a) Over Time from 1984–2008, and (b) As a Function of River Discharge Occurrence. Percent occurrence calculated as the normalized distribution of the monthly mean of the log-normalized discharge, with higher values indicating higher discharge. Monthly mean percent contribution more than or less than 100 percent occur due to evaporation loss, changes in storage during drawdowns, and groundwater exchange.

RESERVOIR MANAGEMENT PHASES

Reservoir drawdown phases are used in this analysis as the temporal components, as these have been shown to exert a strong influence over the water quality exiting Rodman Reservoir (Hendrickson et al., 2016), as well as corresponding to the seasonality of phytoplankton productivity in the LSJR. The drawdown phases of the reservoir management cycle are shown in Figure 3, using the 1999 drawdown year as an example. Drawdown phases correspond roughly to the following time intervals: October 1–November 19 (antecedent), November 20–January 15 (drawdown), January 16–March 10 (low pool), and March 11–May 31 (refill). Mean inflow and outflow values were also calculated for June–July and August–September to complete the annual cycle with similar length temporal steps for all years. To relate the discharge conditions in nutrient mixing analysis for the Ocklawaha River to the expected co-occurring conditions for the LSJR, corresponding 20-year (10/1/1993–9/30/2013) discharge occurrence frequencies were calculated based on the observed discharge means, for time blocks matching the phases of Rodman Reservoir drawdowns.

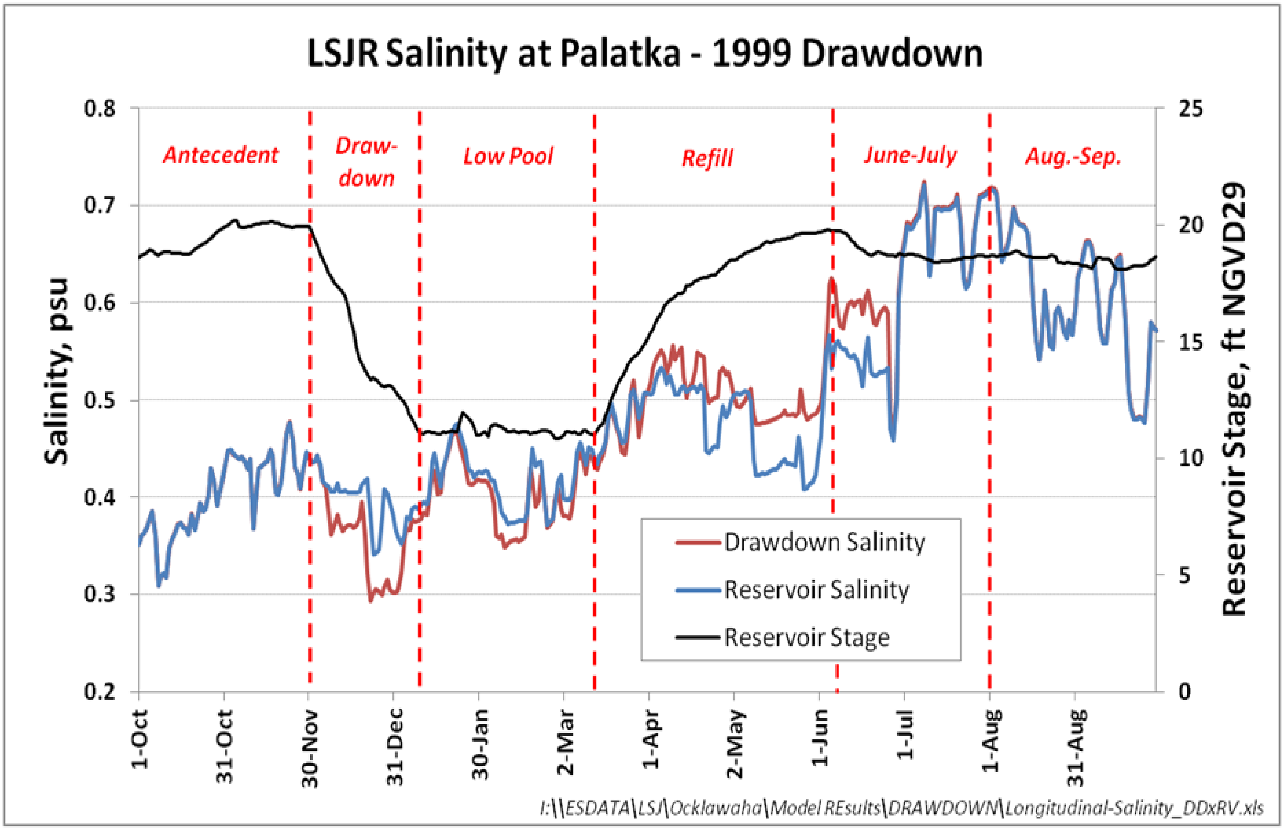

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Figure 3. Rodman Reservoir Drawdown Phases Used as Temporal Steps in the LSJR Mixing Analysis. Blue and red lines plot the scenario salinities in the LSJR at Palatka, based on simulations with the EFDC hydrodynamic model. Because salinity (converted from specific conductance) of the LOR is only 40 percent of that of the SJR, the departures in salinity identify the timing of pulses or reductions in Ocklawaha River water. During the drawdown phase, the addition of released reservoir storage lowers Palatka salinity, relative to the reservoir condition. During the refill phase, the curtailment of normal Ocklawaha River flow to replenish reservoir storage increases salinity relative to the reservoir-full condition. During the refill phase, the resumption of reservoir condition salinity lags the timing of the reservoir-full condition stage by three weeks, providing some indication of travel time of Ocklawaha River water.

RESERVOIR REACH INFLOW AND DISCHARGE

The compiled surface inflow and outflow time series for the LOR Rodman Reservoir reach from 1994–2013 is shown in Figure 4. Inflow and outflow are similar at high discharge, though at low discharge, variations in reservoir storage lead to oscillations of outflow discharge above and below the inflow. These storage oscillations are evident in reservoir drawdown years, when drawdown outflow exceeds inflow, and subsequent refill phase inflow exceeds outflow. For the subsequent analysis of nutrient load changes, the Rodman Reservoir reach total inflow is used to represent the free-flowing river condition discharge.

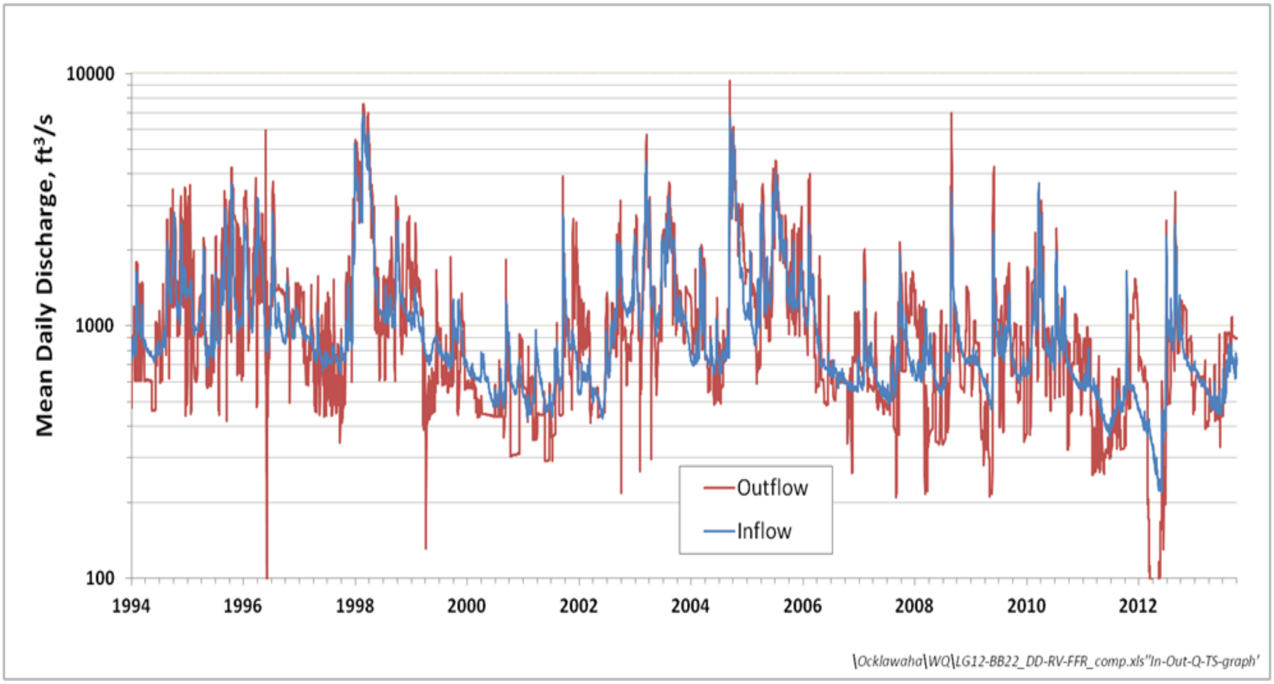

Figure 4. Daily Discharge Time Series for Combined Inflow (blue) and Outflow (red) in and out of the Rodman Reservoir Reach of the Lower Ocklawaha, 1994–2013

During the low pool phase of reservoir drawdowns, discharge at Rodman Dam is substantially greater than the sum of the inflow to the reservoir reach (Hendrickson et al., 2016), presumably due in large part to the release of head pressure over as many as 20 springs submerged in the reservoir (Abbott, 1971; Mirti, unpublished data). Using a watershed yield approach, Wycoff (2010) calculated a mean of 412 ft^3/s in excess of inflow at the pre-reservoir Ocklawaha Riverside location (using data from 1943–1952), which he partly attributed to artesian spring discharge, though he also indicated a suspicion of an over-prediction of the Riverside gauging data. Tibbals (1989) provided an estimate of about 150 ft^3/s for this submerged spring flow, based on a regional groundwater model that predicted the pre-development potentiometric surface in the LOR. The influent and effluent nature of the reservoir reach is evident in the differences in the inflow and outflow water budget as a function of the differences in reservoir stage and surficial and upper Floridan aquifer water levels. These mean monthly differences are plotted in Figure 5, and indicate that when aquifer level is high relative to the reservoir stage, outflow tends to exceed inflow. When aquifer head level is low relative to reservoir stage, the opposite is true, and outflow tends to be less than inflow.

The presumptive presence of this connection has lead to the working hypothesis, for the purpose of this analysis, that discharge increases by artesian springs submerged in Rodman Reservoir reach will be offset by decreases in artesian discharge elsewhere. It is further presumed, based on the similarity in ion composition between the reservoir springs and the St. Johns River springs in the region, that the decreases will occur in this group, hence this reallocation of artesian discharge would result in no net nutrient load change from artesian springs to the St. Johns.

Based on this presumption, the nutrient load associated with submerged springs is not included in the free-flowing river load estimate.

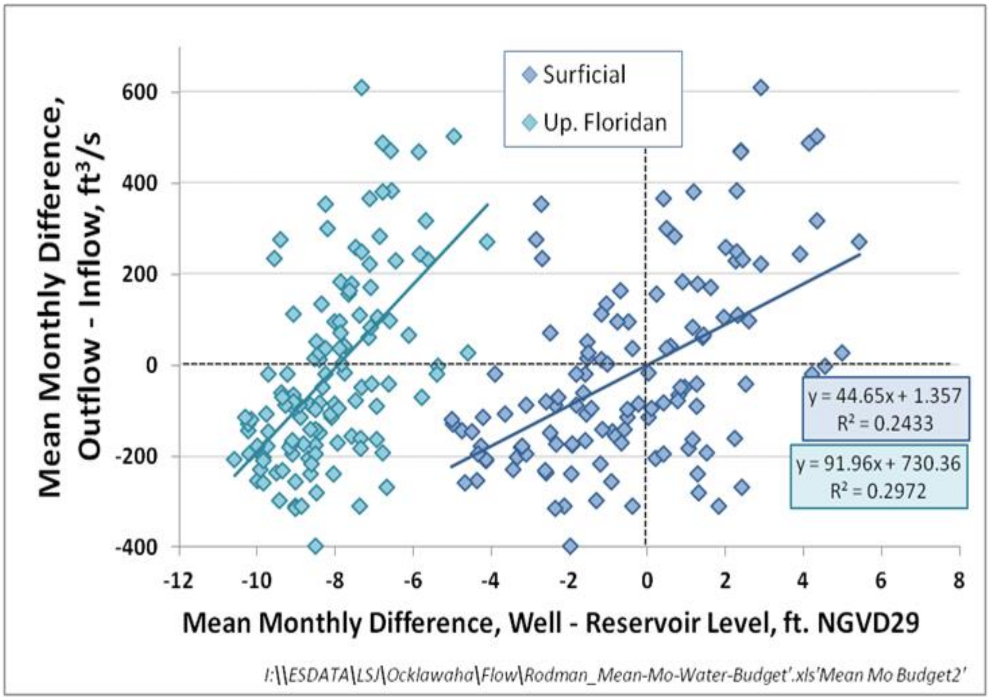

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Figure 5. Relationship for the Monthly Mean Difference Between Rodman Reservoir Outflow – Inflow and Monthly Mean Difference Between Groundwater (Surficial in dark blue, and Upper Floridan in light blue) and Reservoir Stage. This water budget does not account for changes in storage other than that which occurs from direct precipitation (added to inflow) and potential evaporation (added to outflow).

OVERVIEW OF LOWER OCKLAWAHA NUTRIENT CONCENTRATIONS

GENERAL WATER QUALITY SETTING

Chemical quality of the three major source categories that comprise the Rodman Reservoir reach inflow is summarized in Table 1. Inflow from the upper Ocklawaha, as sampled at the Moss Bluff lock and dam and downstream of Lake Griffin, is high in organic nutrients, with NOx and PO_4 representing relatively small proportions of TN and TP. Particulate organic nitrogen (PON) and particulate phosphorus (PP) are strongly correlated with chlorophyll-*a*, suggesting that most of the available nutrients are incorporated into phytoplankton biomass or detritus. The 2003–2012 mean TP concentration at Moss Bluff is 0.042 mg/L. This concentration is markedly lower than that occurring in the late 1990's, when the concentration average was 0.074 mg/L, and declining TP concentration at the Moss Bluff sampling site has been documented in recent trends assessments (Winkler and Ceric, 2014; Fulton, 2014). The mean total nutrient concentrations for sampling dates occurring in the upper quartile of discharge, when the upper Ocklawaha is a relatively large contributor (inflow mean for sampling dates = 38% of Rodman Dam discharge), are only slightly elevated when compared to the overall mean.

Orange Creek is the largest tributary to the Rodman Reservoir reach of the LOR. SJRWMD monitors water quality in Orange Creek at Hwy. 21, upstream of Orange Springs and the confluence of Little Orange Creek and Cabbage Creek, which flows from the City of Interlachen to the north (Figure 6). NOx for this site is elevated and exhibits a significant inverse relationship between flow and concentration, suggesting that a relatively constant discharge source in the watershed may be responsible for the observed elevated levels. The mean NOx concentration for the lower quartile flow dates mean is 0.67 mg/L, with the maximum concentration at 1.3 mg/L (sample date 5/9/2011). As with the upper Ocklawaha, a large component of the total nutrient composition emanating from the Orange Lake basin is in the organic form, though likely in colored dissolved organic matter (CDOM) and macrophyte detritus, as chlorophyll-*a* is much lower. The mean organic nutrient concentration for sampling dates in the upper quartile discharge is more than double the overall mean, and both TKN and TP are significantly correlated with discharge. These elevated concentrations at high-flow suggest the mobilization of nutrients as soils and/or exposed sediments are re-flooded after extended drought periods, and spikes in both organic and inorganic nutrient concentrations following increases in stage are evident in time series data.

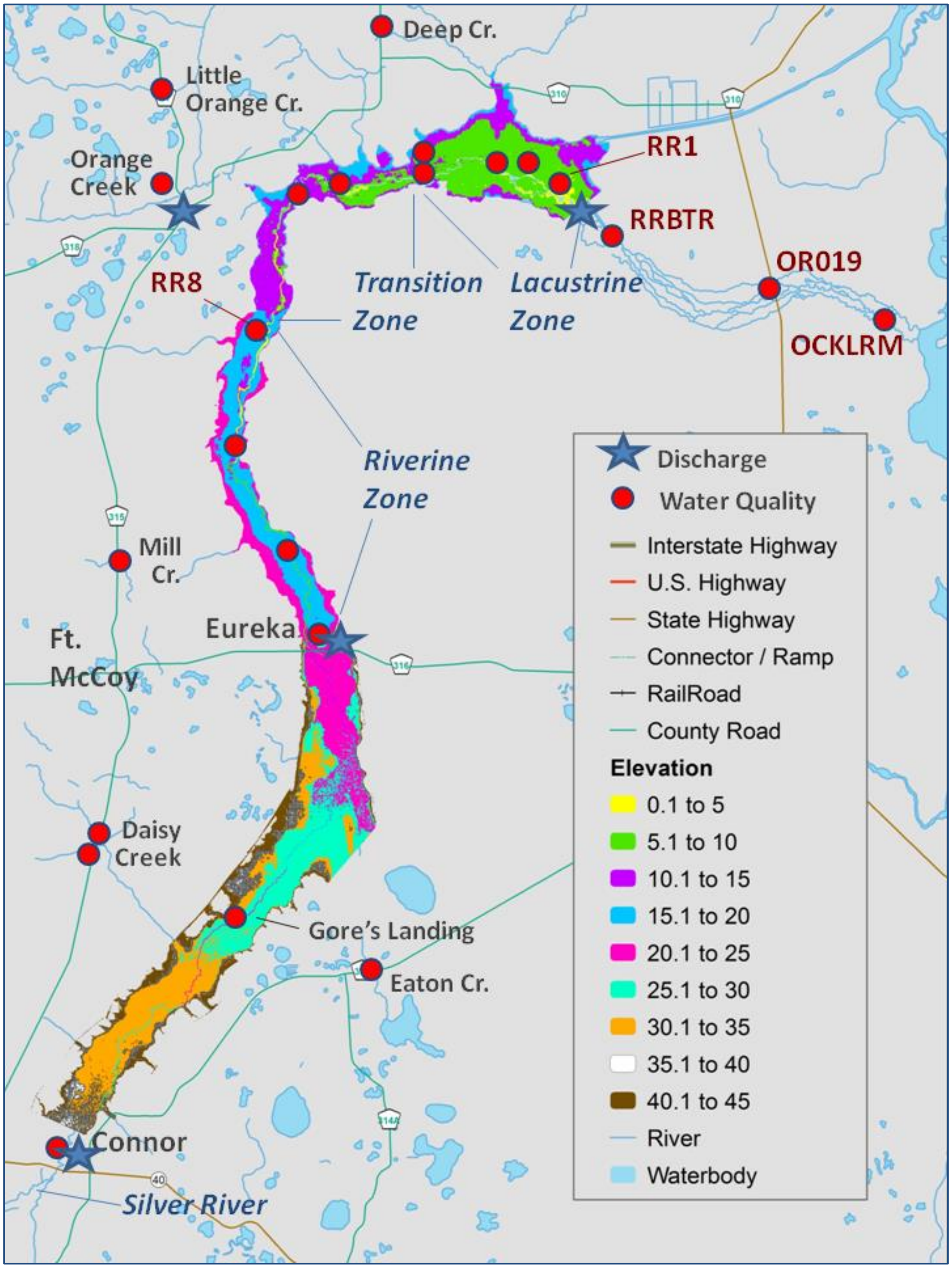

Figure 6. Rodman Reservoir Zones and Discharge and Water Quality Monitoring Sites. Elevations in NGVD29, determined from bathymetry and interpolation from cross-section survey transects.

SJRWMD and FDEP recently established water quality monitoring sites at several of these smaller tributaries flowing into the reservoir reach, including Little Orange Creek, Mill Creek and Deep Creek. In data collected in 2013–2014, the Little Orange Creek branch of Orange Creek had mean TN and TP concentrations of 1.06 and 0.076 mg/L, slightly elevated above typical natural background for streams draining undeveloped watersheds, but still below the State numeric nutrient criteria thresholds of 1.54 and 0.12 mg/L. Data from Mill Creek at its most downstream location show elevated concentrations of TN (2013-14 mean = 1.68 mg/L), but low TP concentrations (0.045 mg/L). Data from the upstream Mill Creek site at County Road 315 indicate elevated ammonium-N, strongly correlated with TN, suggesting potential fertilizer or livestock waste inputs to this branch. Upstream of the reservoir reach, data from the north branch of Daisy Creek exhibit elevated TP and TN concentrations, as well elevated turbidity and biochemical oxygen demand. In contrast, data from Deep Creek, the most downstream tributary of the reservoir reach, exhibit extraordinarily low TN concentrations, relatively low color, and high alkalinity and pH, suggesting substantial groundwater inputs to this tributary. These exceptions aside, historic and recent data indicate that as a group, the tributaries which feed the reservoir reach exhibit chemistry typical of blackwater streams draining minimally-developed, natural landscapes, with moderate TN, most of which is in is refractory CDOM, and low TP concentrations, and low pH (Table 1).

Table 1. Summary of Nutrient Water Quality for Source Categories Contributing to the Lower Ocklawaha River.

	POR	Discharge Category	Sample Day Mean % Rodman Inflow	No. of Samples	Chl-a, Pheo-Corr., µg/L	Color, Pt-Co Units	NOx, mg/L	PON, mg/L	TKN, mg/L	TN, mg/L	PO4, mg/L	PP, mg/L	TP, mg/L	TSS, mg/L	pH, Standard Units
KARST LAKE INFLOWS															
Ocklawaha R. at Moss Bluff	2003-12	Overall	8.7	109	21.2	64	0.014	0.440[a]	2.036	2.071	0.005	0.031[b]	0.042	6.7	7.3
		Top Quartile	38.3	14	29.2	47	0.013	0.682[a]	2.368	2.410	0.012	0.033[b]	0.045	10.4	7.6
Orange Cr. abv. Orange Sp.	2003-12	Overall	2.8	120	0.6	193	0.214	0.342[c]	0.925	1.469	0.087	-	0.093	4.0	6.6
		Top Quartile	8.6	26	0.9	360	0.044	1.119[c]	1.915	1.974	0.154	-	0.199	4.2	6.1
TRIBUTARIES															
Daisy Cr. at NW 105 Rd.	1994	Overall	-	8	0.5	336	0.015	0.171	1.432	1.452	0.174	0.054	0.378	7.6	6.1
Daisy Cr. at CR 315	2012	Overall	-	4	-	604	0.028	0.043	1.617	1.649	0.012	0.013	0.062	-	5.1
L. Orange Cr. blw. Cabbage Cr.	2013-14	Overall	-	22	0.3	365	0.050	0.073	1.012	1.061	0.044	0.017	0.076	-	6.0
Mill Cr. at CR 315	1993-94	Overall	-	11	0.4	330	0.002	0.111	1.289	1.305	0.004	0.013	0.016	3.0	4.1
Mill Cr. at CR 315	2013-14	Overall	-	8	1.1	522	0.029	0.177	2.003	2.032	0.017	0.014	0.046	-	4.5
Mill Cr. NE 148th Terr.	2013-14	Overall		24	0.0	517	0.037	0.125	1.645	1.682	0.014	0.013	0.045	-	5.3
Sweetwater Cr. nr. Hollister	1993-94	Overall	-	10	0.3	353	0.008	0.040	0.920	0.929	0.061	0.008	0.091	1.5	3.7
Alligator Cr. SE of Hardesty L.	1993-94	Overall	-	10	0.3	460	0.014	0.100	1.095	1.113	0.041	0.012	0.074	2.0	5.0
Poley Br. SE of Hardesty Lake	1993-94	Overall	-	10	0.4	561	0.010	0.123	1.365	1.377	0.007	0.023	0.044	3.0	6.2
Deep Cr. at CR 315	1993-94	Overall	-	11	0.2	61	0.012	0.130	0.331	0.351	0.008	0.006	0.015	3.1	6.8
Deep Cr. CR 315 (FDEP)	2010-12	Overall		35	-	-	0.021	-	0.206	0.231	-	-	0.020	-	-
Deep Cr. CR 315 (SJRWMD)	2013-14	Overall		24	0.6	100	0.035	0.073	0.334	0.368	0.016	0.008	0.028	-	7.3
Brunt Bridge Cr. at CR 315	1993-94	Overall	-	12	0.3	487	0.008	0.070	1.044	1.059	0.007	0.011	0.020	4.5	4.7
Tributary Median					**0.3**	**413**	**0.015**	**0.106**	**1.095**	**1.113**	**0.015**	**0.013**	**0.045**	**3.0**	**5.2**
ARTESIAN SPRINGS															
Silver River	2002-12	Overall		124	1.2	10	0.990	0.011	0.129	1.254	0.029	0.003	0.044	1.8	7.6
Orange Springs	2004-12	Overall		39	-	2	0.011	-	0.17	0.177	0.086	-	0.089	-	7.9

a. PON for dates w/out TKN-D estimated by (TKN-T - TKN-D) = Turbidity*0.1005 - 0.0003; $R^2 = 0.94$

b. PP for dates w/out TP-D estimated by PP = 0.798*TP-T - 0.0024; $R^2 = 0.71$

c. DON to calculate PON estimated by relationship between DOC and color, with assumed 35:1 OC:ON ratio in CDOM.
d. Station located near the mouth of Silver R., so reflects occasional floodplain inputs
All means calculated as geometric means, unless negative values are present, in which case the median is substituted

The nutrient chemistry of Silver River is considerably different than the upstream inflow and adjacent tributaries. Silver River is low in organic and particulate nutrients, high in NOx, and PO_4 constitutes a large proportion of the TP concentration. It is essentially absent of CDOM except at high flow, when near-stream source areas and some tributaries contribute to the spring run.

These contrasting water quality types affect the chemical profile of the LOR from Moss Bluff to the mouth (Figure 7). Nutrient and organic carbon concentrations drop significantly after the inflow of the Silver River. Downstream of this inflow, nitrogen partitioning shifts from organic N to NOx, with total N continuing to decline from the loss of this bio-available N form through denitrification and assimilation. Downstream of Highway 40, organic carbon concentrations increase moderately from the input of the adjacent blackwater streams.

By extrapolating the water quality monitoring data for the adjacent basin tributaries to the un-sampled contributing area between Eureka and the dam, a phase mean water quality time series was created to combine with observed monitoring data from the Ocklawaha at Eureka and Orange Creek. These three contributing sources were summed based on their flow-proportional contribution, to create a composite phase mean water quality time series to the reservoir reach of the LOR. This phase mean series is used in this analysis to represent the FFR condition. The time series of phase means for this summed reservoir reach inflow, and for the long-term monitoring station below the dam, are shown in Figure 8.

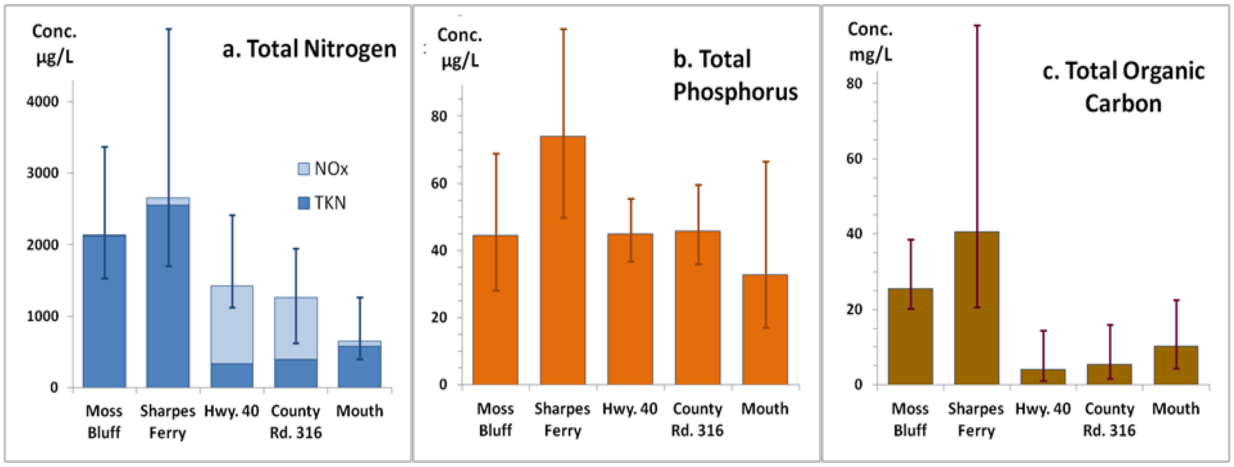

Figure 7. Longitudinal Patterns in Median (a) Total Nitrogen, (b) Total Phosphorus, and (c) Total Organic Carbon in the Ocklawaha River below Moss Bluff. Data Are from the SJRWMD 2015 Status and Trends Assessment (Winkler and Ceric, 2014).

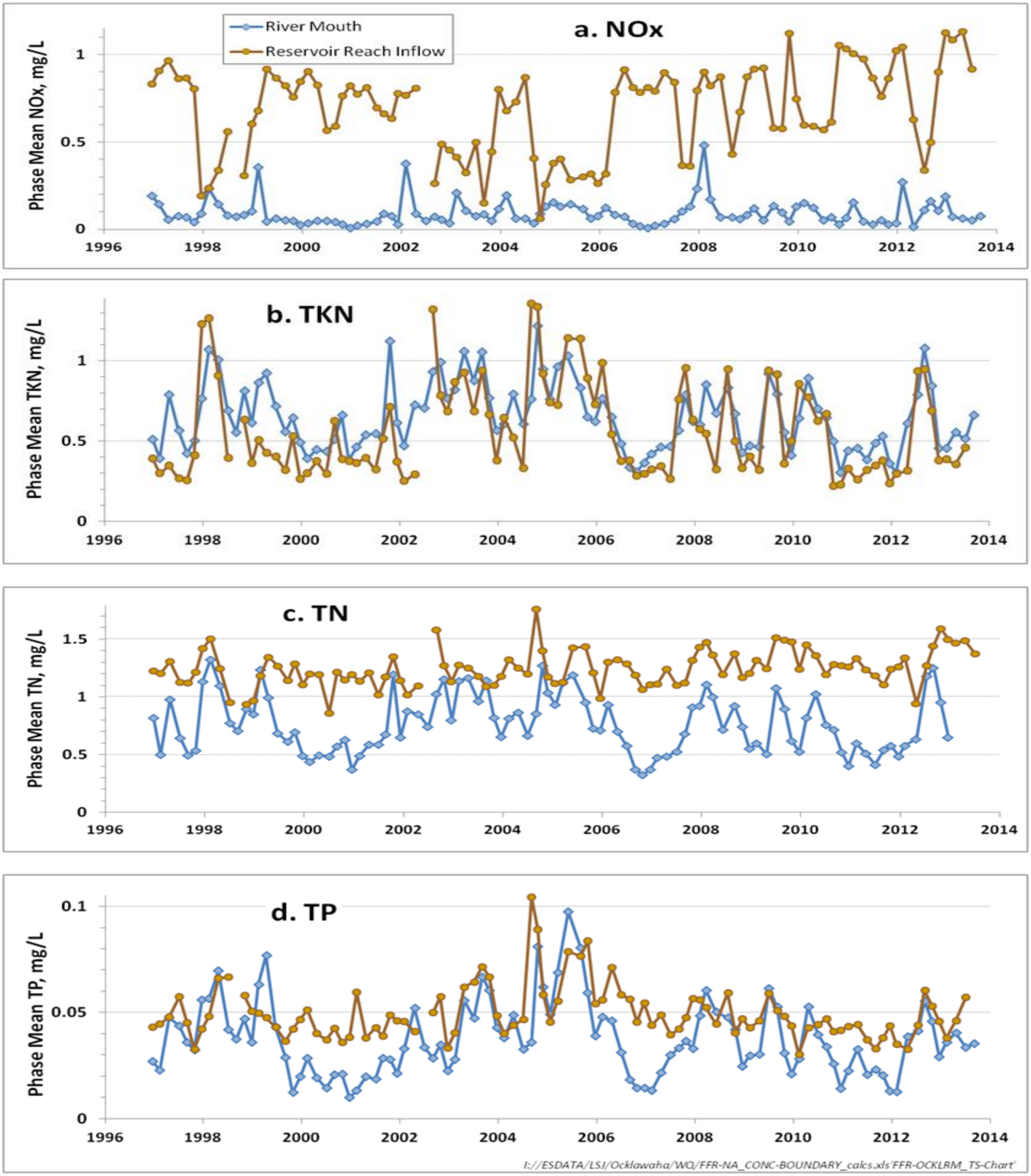

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Figure 8. Time Series of Phase Mean NOx, TKN, TN, and TP for the Observed Data Collected at the Ocklawaha River Mouth (blue) and Composite, Calculated Flow-Weighted Inflow to the Rodman Reservoir Reach (tan), 1997–2013.

CHANGES IN LSJR NUTRIENT CONCENTRATIONS WITH A FREE-FLOWING RIVER

APPROACH

Nutrient enrichment of the LSJR from industrial and domestic wastewater discharges, and runoff from agricultural and urban development, has led to nearly annual blooms of cyanobacteria, with the highest density occurring in the broad, shallow freshwater reach just downstream of Palatka, between Rice Creek and Riverdale (Hendrickson et al., 2002). In 2008, FDEP and EPA adopted Total Maximum Daily Loads for N and P entering the LSJR to address water quality impairments associated with this excessive nutrient enrichment and its associated cultural eutrophication (Magley and Joyner, 2008).

While elevated concentrations of N and P are the underlying cause of nuisance cyanobacteria blooms, in dynamic river estuaries such as the LSJR, the prevailing river discharge, water temperature, inputs of natural color from dissolved organic matter, wind mixing, tidal currents and zooplankton grazing will exert substantial control over the potential for nutrients to fully translate into phytoplankton biomass. Based on the C:P ratio that is typically considered to represent nutrient-balanced growth in phytoplankton biomass (Redfield, 1958), annual maximum bloom density in the freshwater LSJR reaches the point of theoretical phosphorus limitation (i.e., the point at which all available external P has been incorporated into phytoplankton, and the bloom cannot expand unless additional P is provided) in only 4 out of 10 years, demonstrating the importance of other controlling factors.

ESTIMATED CHANGES IN LOR AND LSJR N AND P CONCENTRATIONS

This analysis employs a conservative mixing approach that assumes 1) under the free-flowing river condition, the nutrient load exported to the LSJR is equivalent to the load imported to the Rodman reach of the LOR; and 2) that the entire exported nutrient load is delivered downstream and assimilated into phytoplankton biomass. Neither of these conditions would be expected to actually occur in the free-flowing river condition, hence this analysis is expected to characterize the most extreme theoretical outcome. The analysis utilizes a coupled continuously-stirred tank reactor (CSTR) concept (Chapra, 1997) that calculates a downstream nutrient concentration based on the proportional load contributions of the three major inputs that make up the LSJR: the middle St. Johns River, the Ocklawaha River, and Dunns Creek, which drains the Crescent Lake Basin. To calculate the representative contributing loads from the Middle SJR and Crescent Lake Basin, the discharge and nutrient concentration means were calculated for the temporal steps corresponding to drawdown phase, in the same manner as was done for the LOR inflow sum and reservoir scenarios (Appendix A). These three major source loads were summed and then divided by the discharge to derive concentrations at Palatka. Palatka was selected at the location to express that composite concentration, as it is the location of a long-term water quality monitoring site, and is the inlet to the zone of maximum phytoplankton productivity for the LSJR freshwater reach.

Three LOR scenarios were calculated: the existing condition with Rodman Reservoir at normal operating stage (18–20 ft NGVD29); the existing condition during a reservoir drawdown-year (11 ft NGVD29); and a FFR condition. For each of these scenarios, a set of linear regression models were developed relating the discharge occurrence frequencies of the reservoir reach phase mean total inflow (independent variable) to the observed or calculated phase mean nutrient concentrations (dependent variable). Observed data for the long-term Ocklawaha river mouth monitoring station were used to calculate nutrient concentration phase means for the drawdown and reservoir-full scenarios. The reservoir reach inflow volume-weighted phase mean nutrient concentrations described in the General Water Quality section were used to represent the FFR condition.

The reservoir management phase discharge versus concentration models are shown in Figures 9, 10, and 11. Because of the contrasting chemical characteristics of the three predominant inflow categories to the reservoir reach, and the strong control that hydrology exerts on their proportional contributions, discharge is significantly correlated with concentration for all but three of the total of 46 models. Those three exceptions are for the two FFR (i.e., inflow) TP models under the drawdown and low pool condition, and for the drawdown condition NOx model during the low pool phase. Sixteen of the models produced coefficients of determination (R2) greater than 0.7, with the FFR NOx models, and all of the TKN models, generally highly significant.

Analogous phase mean discharge versus nutrient concentration models were created for the Middle St. Johns and Crescent Lake Basin, and these relationships are shown in Appendix B. Discharge condition is not as strong a driver of phase-mean concentration for the middle St. Johns and Dunns Creek, hence fewer of these analogous discharge versus concentration models were significant or highly significant. In general, the St. Johns River and Dunns Creek phase mean TP concentrations are significantly correlated with discharge, but the TKN and NOx relationships are less significant, largely because inter-annual patterns in phytoplankton productivity exert substantial control over nitrogen partitioning, through assimilation and nitrogen fixation.

From these three sets of models, the downstream loads and concentrations are determined for the 25th percentile (low flow that is exceeded 75 percent of the time), median, and 75th percentile (high flow that is exceeded only 25 percent of the time) phase-mean discharge conditions. Downstream loads were calculated by summing the three mass load contributions, with the individual source loads determine by the product of the predicted phase mean concentration and discharge volume for the duration of the phase. The calculation is made under the premise that all three major inflows are at the same discharge occurrence frequency, a condition that is generally true.

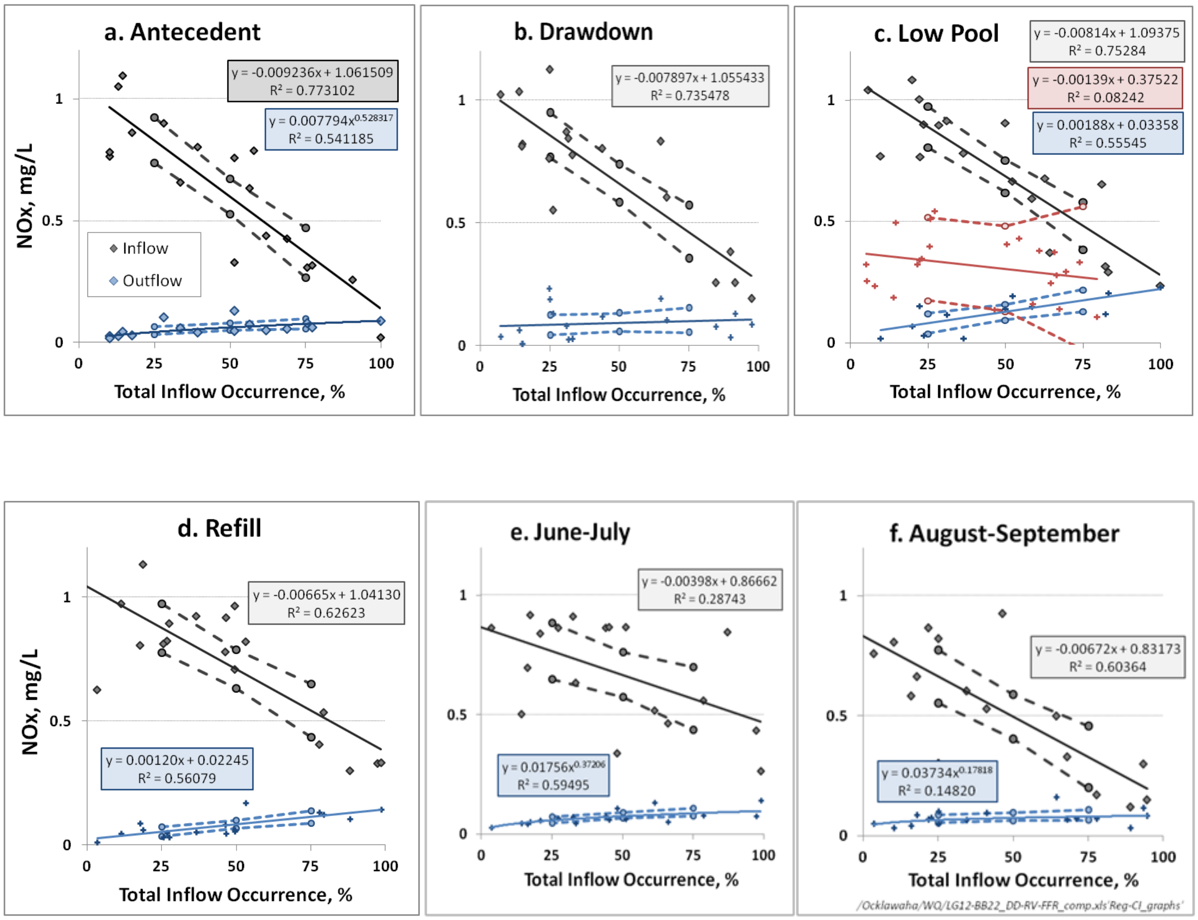

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Figure 9. Relationships Between Lower Ocklawaha River Mean Nitrate+Nitrite (NOx) Concentration and Discharge Occurrence for the Rodman Reservoir Management Phases. Grey symbols and lines are the flow-proportional inflow concentrations used to indicate the FFR condition. Blue lines and symbols indicate the reservoir-full condition, while red lines and symbols indicate the drawdown condition. Dashed lines indicate the 95 percent confidence interval of the regression slope.

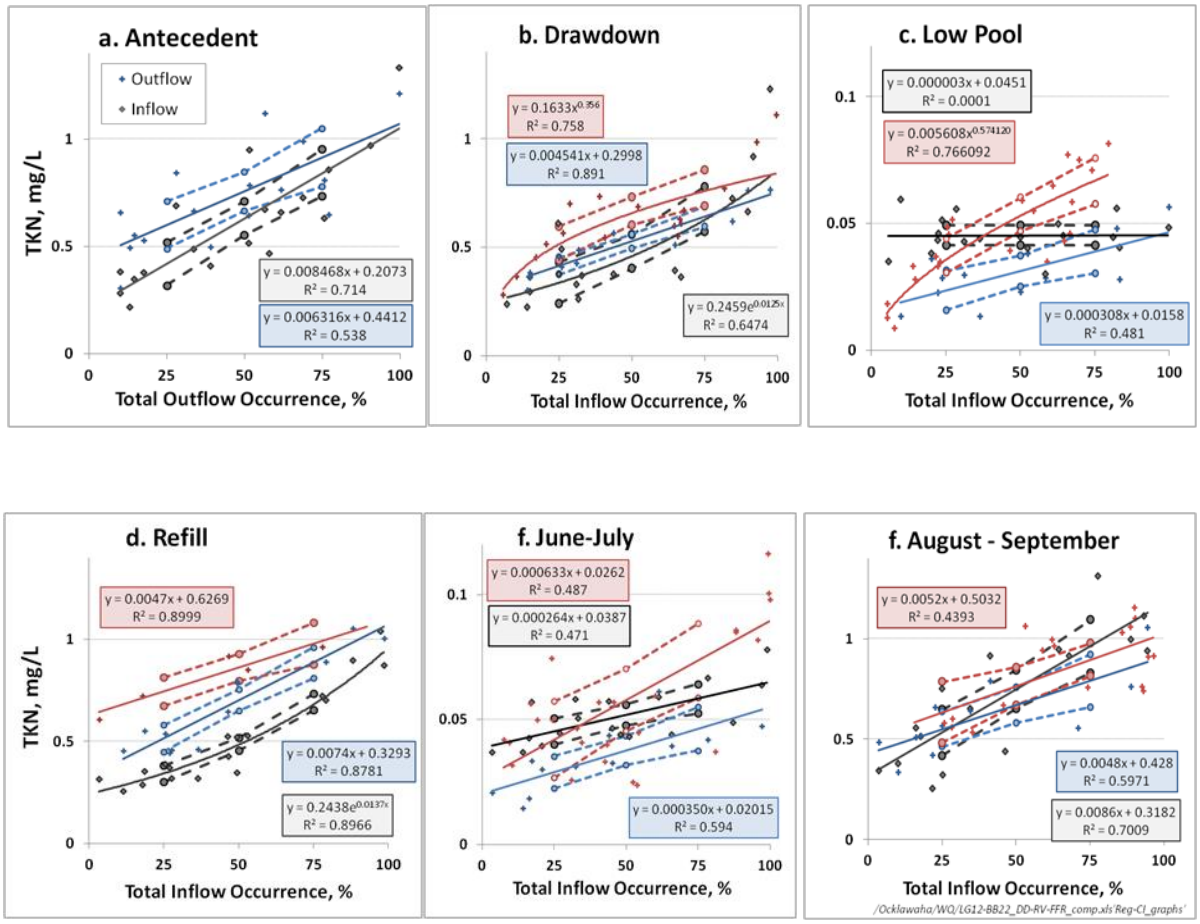

Figure 10. Relationships Between Lower Ocklawaha River Mean Total Kjeldahl Nitrogen Concentration and Discharge Occurrence for the Rodman Reservoir Management Phases. Grey symbols and lines are the flow-proportional inflow concentrations used to indicate the FFR condition. Blue lines and symbols indicate the reservoir-full condition, while red lines and symbols indicate the drawdown condition. Dashed lines indicate the 95 percent confidence interval of the regression slope.

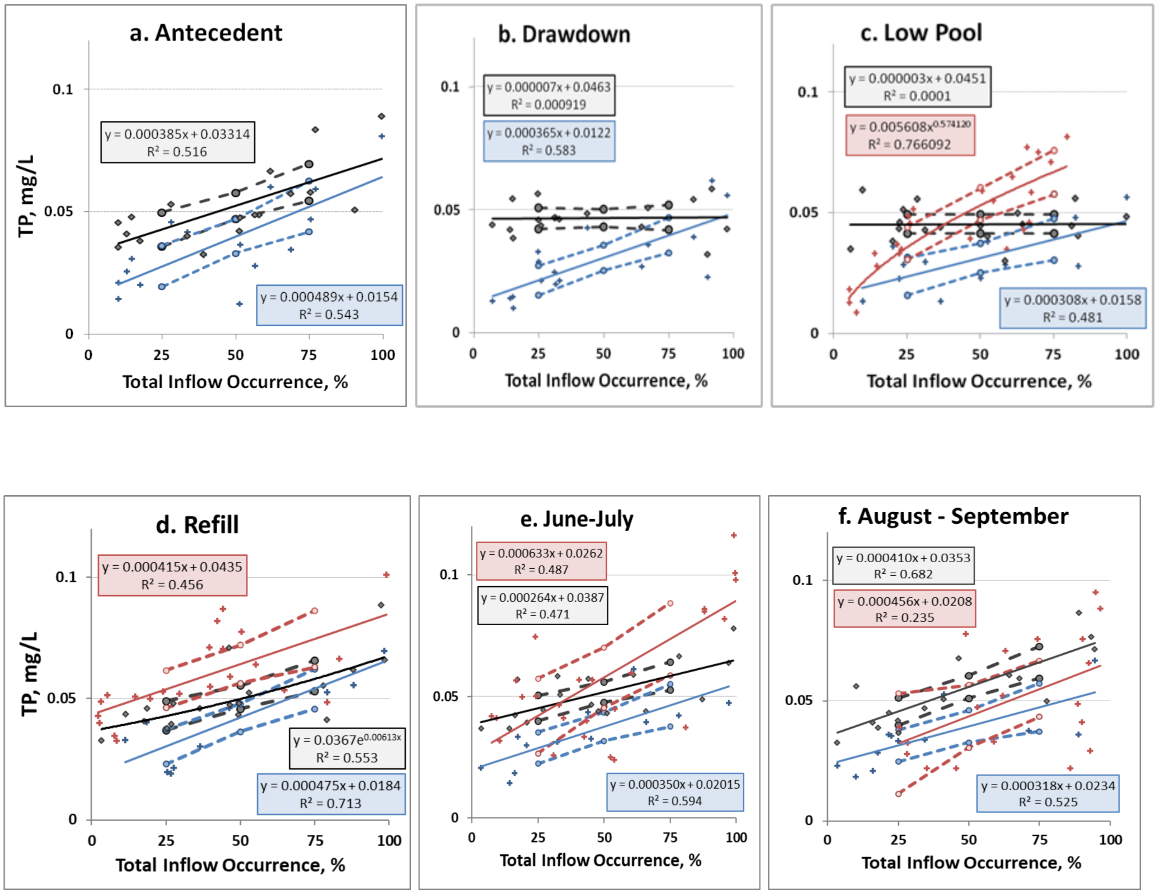

Figure 11. Relationships Between Lower Ocklawaha River Mean Total Phosphorus Concentration and Discharge Occurrence for the Rodman Reservoir Management Phases. Grey symbols and lines are the flow-proportional inflow concentrations used to indicate the FFR condition. Blue lines and symbols indicate the reservoir-full condition, while red lines and symbols indicate the drawdown condition. Dashed lines indicate the 95 percent confidence interval of the regression slope.

LOR SCENARIO CHANGES IN LOADS AND CONCENTRATIONS TO THE LSJR

Nitrogen

The results of the conservative mixing calculation for NOx and TKN are shown in Appendices C and D, and include the discharge and concentration values for the three Ocklawaha scenarios (reservoir-full, drawdown, and free-flowing), the corresponding middle St. Johns River and Dunns Creek concentrations, and the calculated loads and concentrations for the LSJR at Buffalo Bluff (just below the mouth of the Ocklawaha but above Dunns Creek) and Palatka.

Conservative mixing calculations predict that under the Ocklawaha FFR condition, TN concentration at Palatka will increase (Figure 12), though only under one scenario (refill phase low flow) does the TN increase exceed the 95th percentile confidence bounds of the regression. The relative increase is small during high flow, but increases as discharge decreases. When compared to the reservoir-full condition, the free-flowing river condition produces the greatest relative increases during the low pool and refill phases (January–May), at 9 percent for the median discharge condition, and 21 percent for the 25th percentile low flow. Because of the increase in nutrient export from the LOR in drawdown years, the relative increase of the free-flowing river condition is less. The greatest relative increase occurs during the drawdown phase, due to dilution resulting from the release of the pool volume, which has a low concentration relative to the St. Johns. After the drawdown phase, the greatest relative increase is calculated for the low pool phase, at 13 percent under the low flow condition, and 6 percent for the median flow condition.

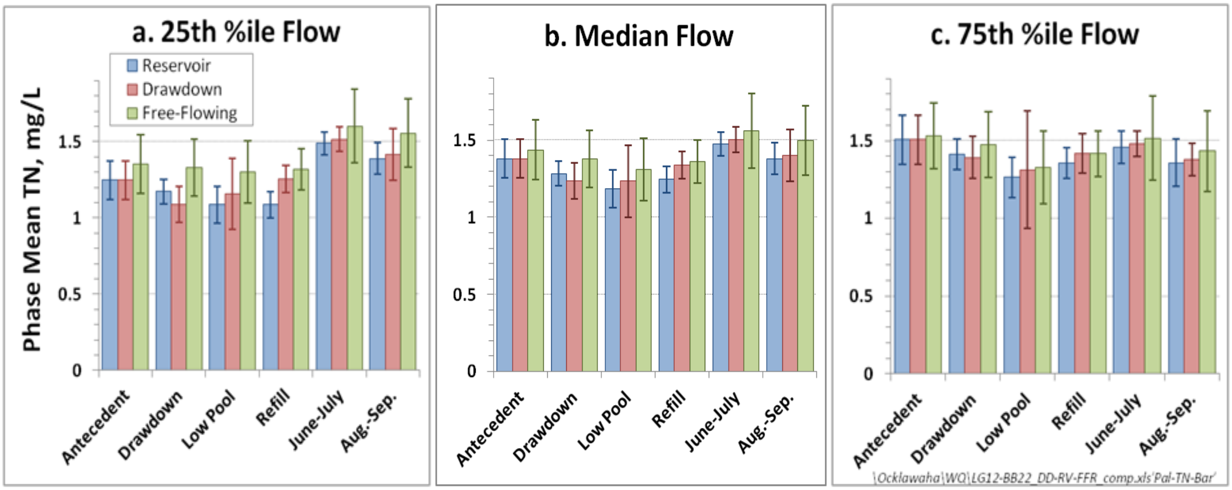

Figure 12. Calculated Phase-Mean TN Concentrations for the Lower St. Johns River at Palatka, for the (a) 25th (b) Median, and (c) 75th Percentile Flow Conditions, for the Three Lower Ocklawaha Scenarios. Error bars represent the 95th percentile confidence interval of the regression relationship between LOR discharge and concentration.

When the calculated changes in predicted Palatka nitrogen concentration are separated into the component nitrogen forms TKN and NOx, significant differences begin to emerge between scenarios. All of the increase in TN under the FFR condition is predicted to occur in the form of NOx, while TKN concentration is predicted to decrease relative to the reservoir and drawdown conditions. Under the low flow condition, FFR NOx is predicted to significantly increase for all phases except the low pool phase (Figure 13 (a)). Under the median discharge condition, Palatka NOx concentration is predicted to be significantly greater during the refill and June–July phases (Figure 13(b)). Under the FFR scenario, TKN concentration is predicted to be significantly lower during the refill phase for the low and median flow condition.

For the 25th, median and 75th percentile discharge occurrences, the calculated FFR total annual increase in TN load to the LSJR over the reservoir-full condition is 375, 382, and 344 MT/yr, occurring through a combination of an increase in NOx, and a decrease in TKN loads. Under the reservoir drawdown condition, the calculated FFR TN increases are 238, 168, and 99 MT/yr. By comparison, the mean annual observed TN load at Palatka (2004–2013) is 4,410 MT (Lowe et al., 2015).

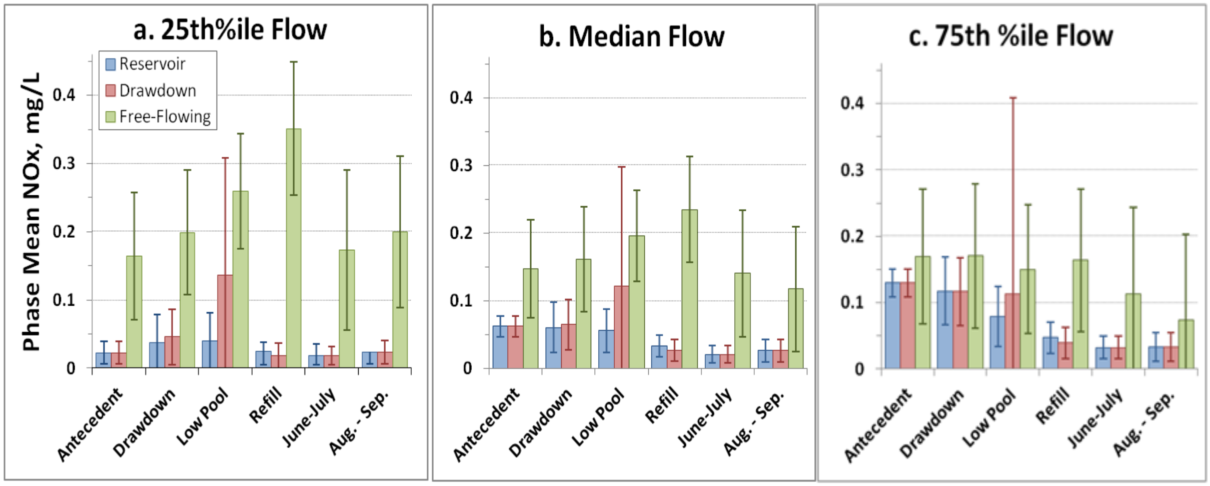

Figure 13. Calculated Phase-Mean NOx Concentrations for the Lower St. Johns River at Palatka, for the (a) 25th , (b) Median, and (c) 75th Percentile Flow Conditions, for the Three Lower Ocklawaha Scenarios. Error bars represent the 95th percentile confidence interval of the regression relationship between LOR discharge and concentration.

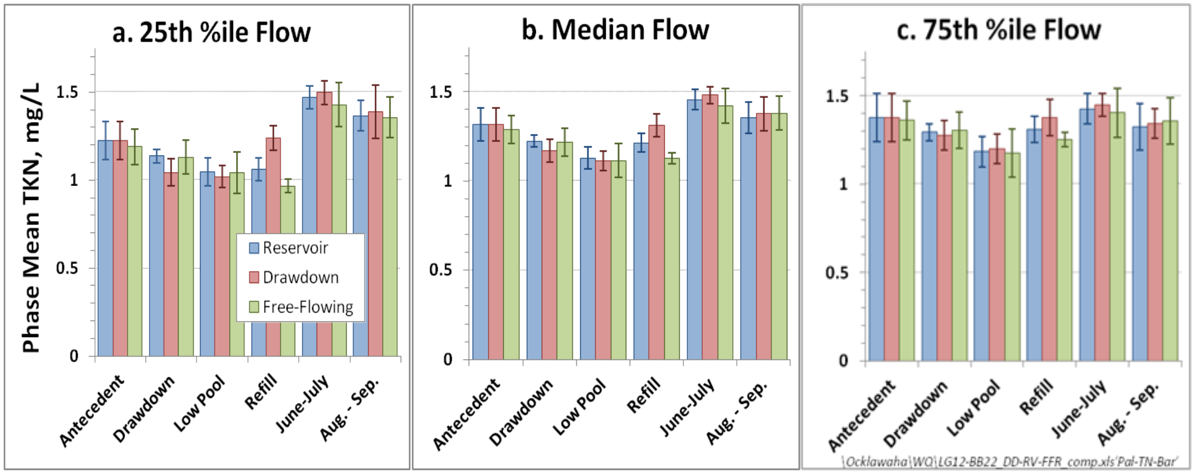

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Figure 14. Calculated Phase-Mean TKN Concentrations for the Lower St. Johns River at Palatka, for the (a) 25th , (b) Median, and (c) 75th Percentile Flow Conditions, for the Three Lower Ocklawaha Scenarios. Error bars represent the 95th percentile confidence interval of the regression relationship between LOR discharge and concentration.

To evaluate the accuracy of the mixing calculations, the reservoir-full and drawdown condition concentration predictions for NOx, TKN and TN were compared to the observed phase means for the long-term monitoring station at Palatka, and this comparison is shown in Figures 15, 16 and 17. The FFR condition calculated concentrations are also shown in these figures for reference. For most phases, the pattern in observed concentrations appears to follow the calculated Palatka NOx concentrations for the respective discharge condition. Large differences in calculated NOx between the reservoir and drawdown condition during the low pool phase are also apparent in the Palatka monitoring data (Figure 15(c)). For three of the drawdown years (2002, 2005, and 2012), the observed Palatka concentrations exceed the predicted concentrations by a considerable amount, reflecting the large inter-annual variability in winter NOx in the St. Johns. Calculated TKN concentrations also appear to match the observed Palatka concentration versus discharge pattern for the antecedent, drawdown and low pool phases. Predicted TKN concentrations agreement with observed means begins to degrade during the refill phase, and predictions appear to overestimate observed concentrations from June through September (Figure 16 (e and f)). These discrepancies in NOx and TKN can most likely be attributed to losses in transit from processes not included in the conservative mixing analysis. Two of the upstream sources that were summed to create the Palatka concentration estimate, Lake George and Crescent Lake, have a large amount of their water column N during spring and summer in phytoplankton biomass or detritus. As waters transit the riverine segments from these lakes to Palatka, phytoplankton growth is generally net negative, and conditions are conducive for decomposition, remineralization of organic N and subsequent denitrification, which will lead to nitrogen decline.

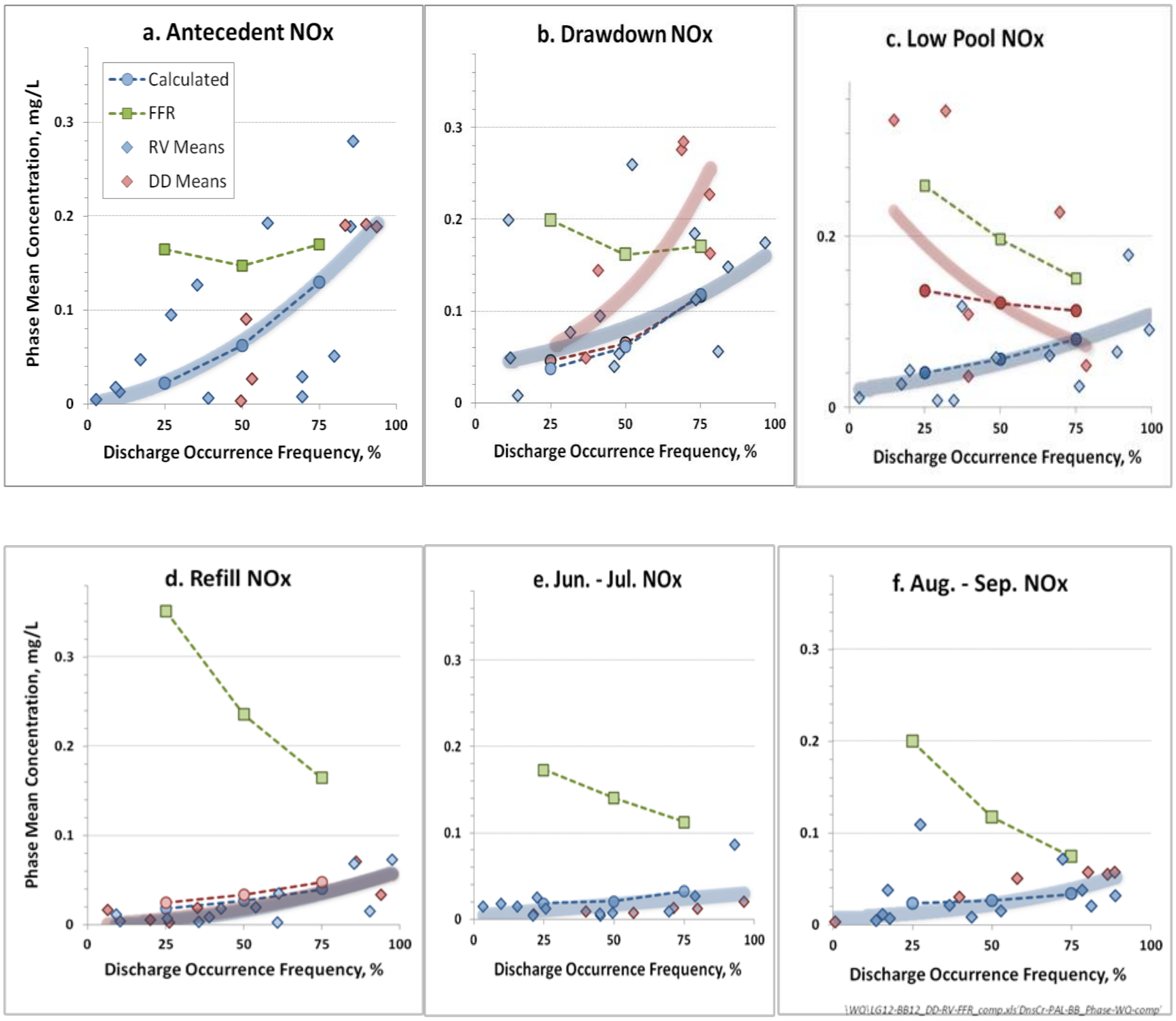

Figure 15. Comparison Between Conservative Mixing-Calculated Phase-Mean NOx (blue (reservoir) or red (drawdown) circles and dashed lines) and the Observed Phase Mean Concentrations (blue and red diamonds) Based on Discharge Occurrence Frequency for the St. Johns River at Palatka. Circles identify the 25th, Median, and 75th Percentile Flow Conditions. Wide, semi-transparent regression lines identify the relationship between discharge and the observed means. Solitary blue dashed lines are shown when there is no difference between reservoir and drawdown conditions. Green squares indicate the predicted FFR concentration.

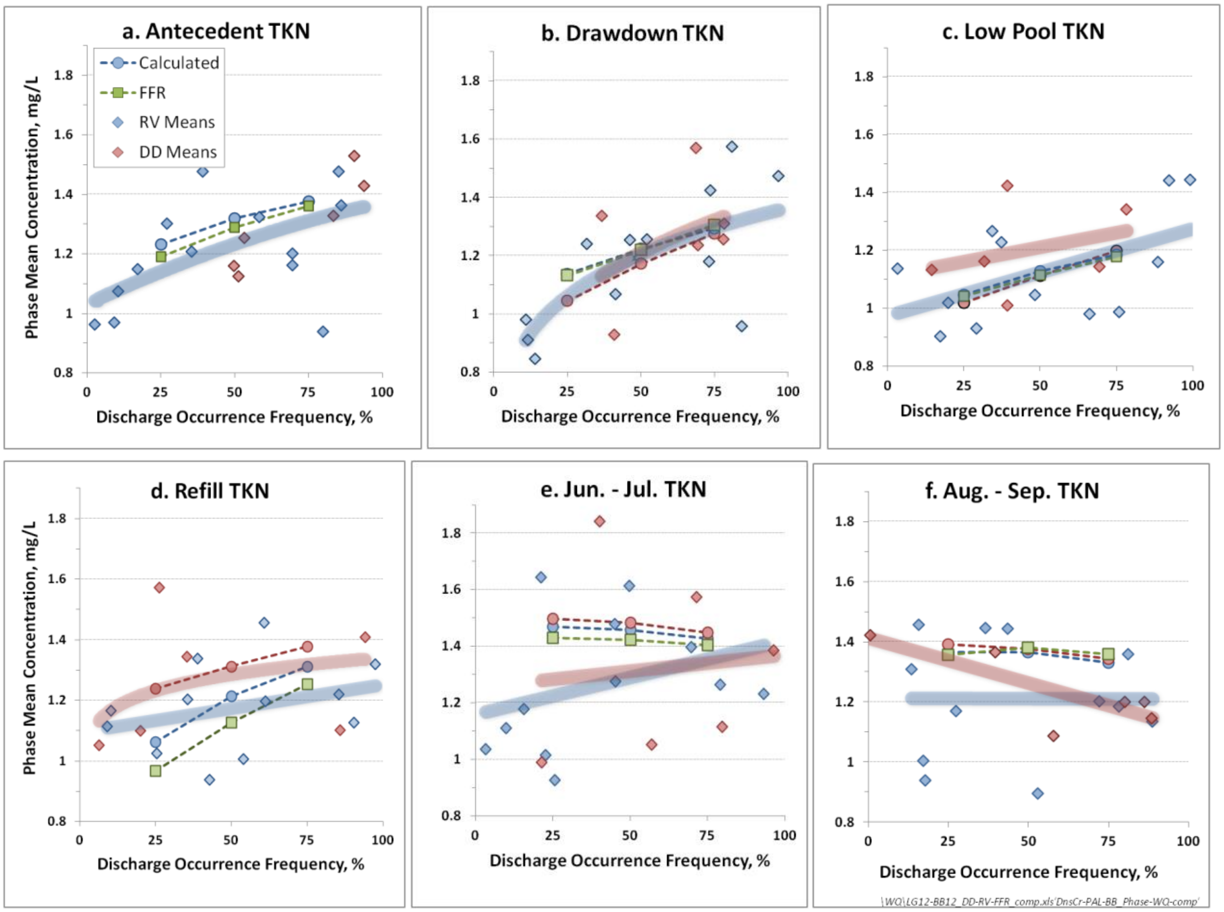

Figure 16. Comparison Between Conservative Mixing-Calculated Phase-Mean TKN (blue (reservoir) or red (drawdown) circles and dashed lines) and the Observed Phase Mean Concentrations (blue and red diamonds) Based on Discharge Occurrence Frequency for the St. Johns River at Palatka. Circles identify the calculated 25th, Median, and 75th Percentile Flow Conditions. Wide, semi-transparent regression lines identify the relationship between discharge and the observed means. Solitary blue dashed lines are shown when there is no difference between reservoir and drawdown conditions. Green squares indicate the predicted FFR concentration.

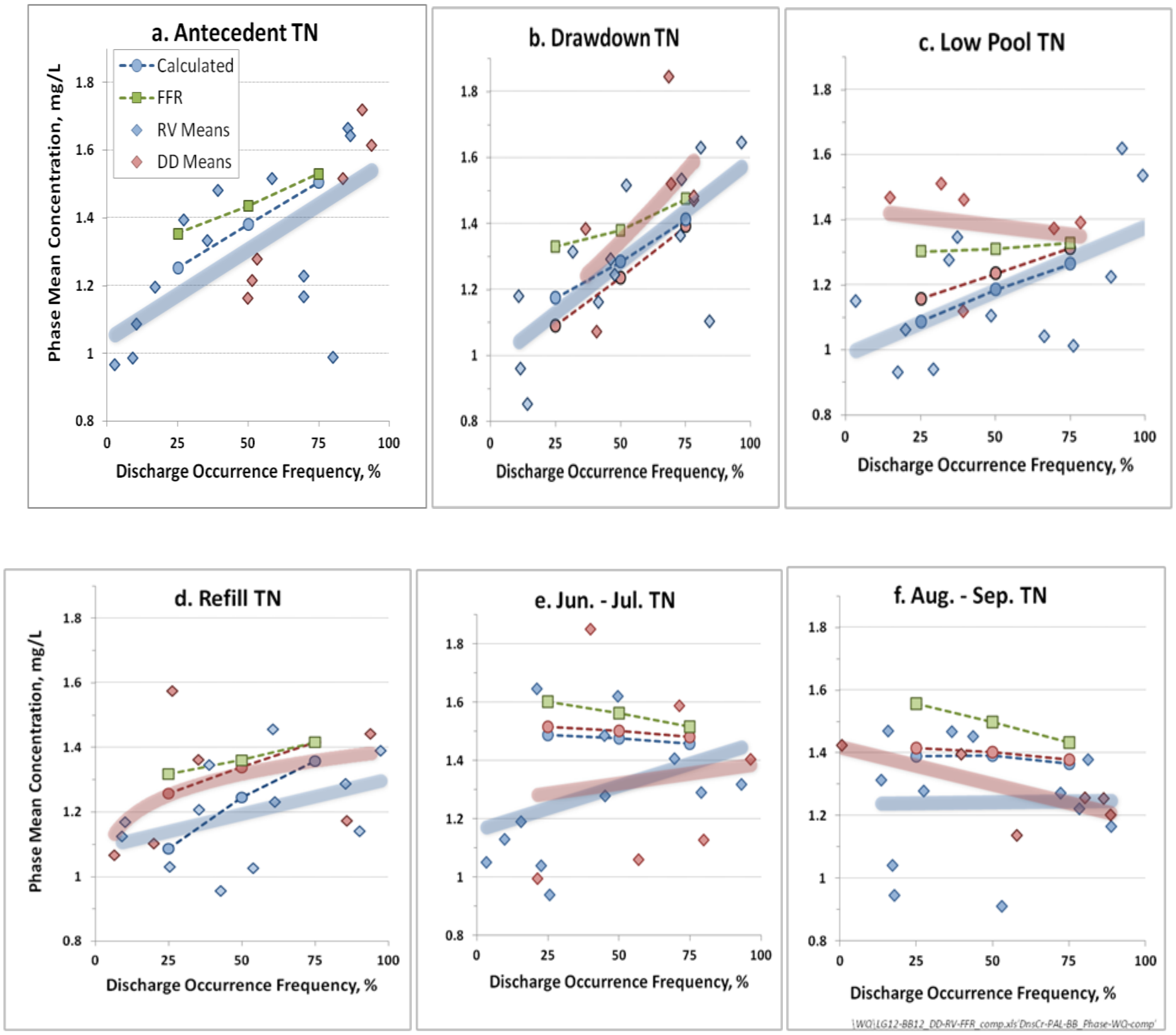

Figure 17. Comparison Between Conservative Mixing-Calculated Phase-Mean TN (blue (reservoir) or red (drawdown) circles and dashed lines) and the Observed Phase Mean Concentrations (blue and red diamonds) Based on Discharge Occurrence Frequency for the St. Johns River at Palatka. Circles identify the calculated 25th, Median, and 75th Percentile Flow Conditions. Wide, semi-transparent regression lines identify the relationship between discharge and the observed means. Solitary blue dashed lines are shown when there is no difference between reservoir and drawdown conditions. Green squares indicate the predicted FFR concentration.

Phosphorus

The conservative mixing calculation results estimating LOR and downstream LSJR TP concentrations are shown in Appendix E. With the exception of drawdown-year, refill-phase concentrations, LOR TP concentrations under the current and FFR condition tend to be less than those observed in the St. Johns River exiting Lake George. Because of this, the LOR inflow in almost all cases lowers the TP concentration of the LSJR below the mouth of the Ocklawaha. This results in the paradox in drawdown years, whereby drawdown phase TP load to the LSJR is increased by 2 to 3 MT over the reservoir condition, but the resulting concentration at Buffalo Bluff is lowered, due to the delivery of this load with released reservoir storage that is at a lower concentration than that of the LSJR. Conversely, during reservoir refill, TP load difference between the reservoir and drawdown condition are negligible, as the increase in refill phase TP tends to offset the reduction in mass load delivery due to reduced LOR discharge. However, the concomitant reduction in dilution leads to a substantial increase in calculated TP concentration in the LSJR (10–20 percent) over the reservoir-full condition.

The calculated changes in TP concentration in the St. Johns River at Palatka are shown in the Figure 18 bar chart. The conservative mixing calculation indicates that the FFR condition (green bars) would increase downstream TP over the reservoir-full scenario (blue bars) for all management phases and flow conditions, though none of the increases are great enough such that the bounds of the 95 percent confidence intervals no longer overlap. The greatest increase is calculated for low flow conditions, particularly during the low pool phase (mid-January through mid-March), increasing the TP at Palatka from 0.049 mg/L to 0.056 mg/L (13 percent). Under the median discharge condition, Palatka TP increases are calculated to be between 3 and 6 percent, while under high flow, the TP increase is between 1 to 4 percent. In drawdown years (red bars), FFR scenario TP is initially high relative to the drawdown phase calculated concentration, due primarily to the dilution induced by the release of reservoir storage. This pattern is reversed during the refill and post-refill (June–July) phases, and mixing calculations indicate that the FFR condition would result in a 6 to 9 percent decrease in drawdown-year TP during the refill phase, with smaller decreases predicted for the low pool and post-refill phases under median and high flow conditions. Again, though, these drawdown year increases are not significantly greater than the predicted reservoir and FFR conditions based on these models.

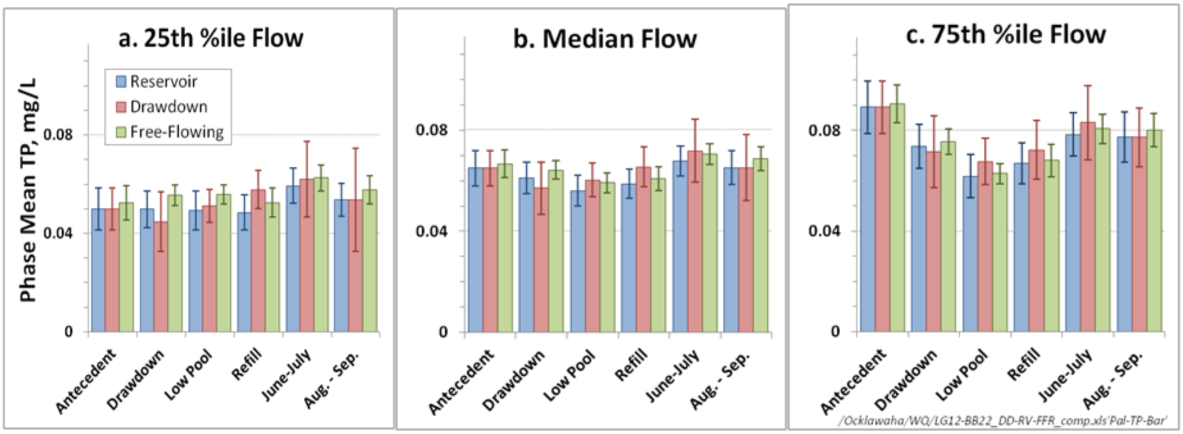

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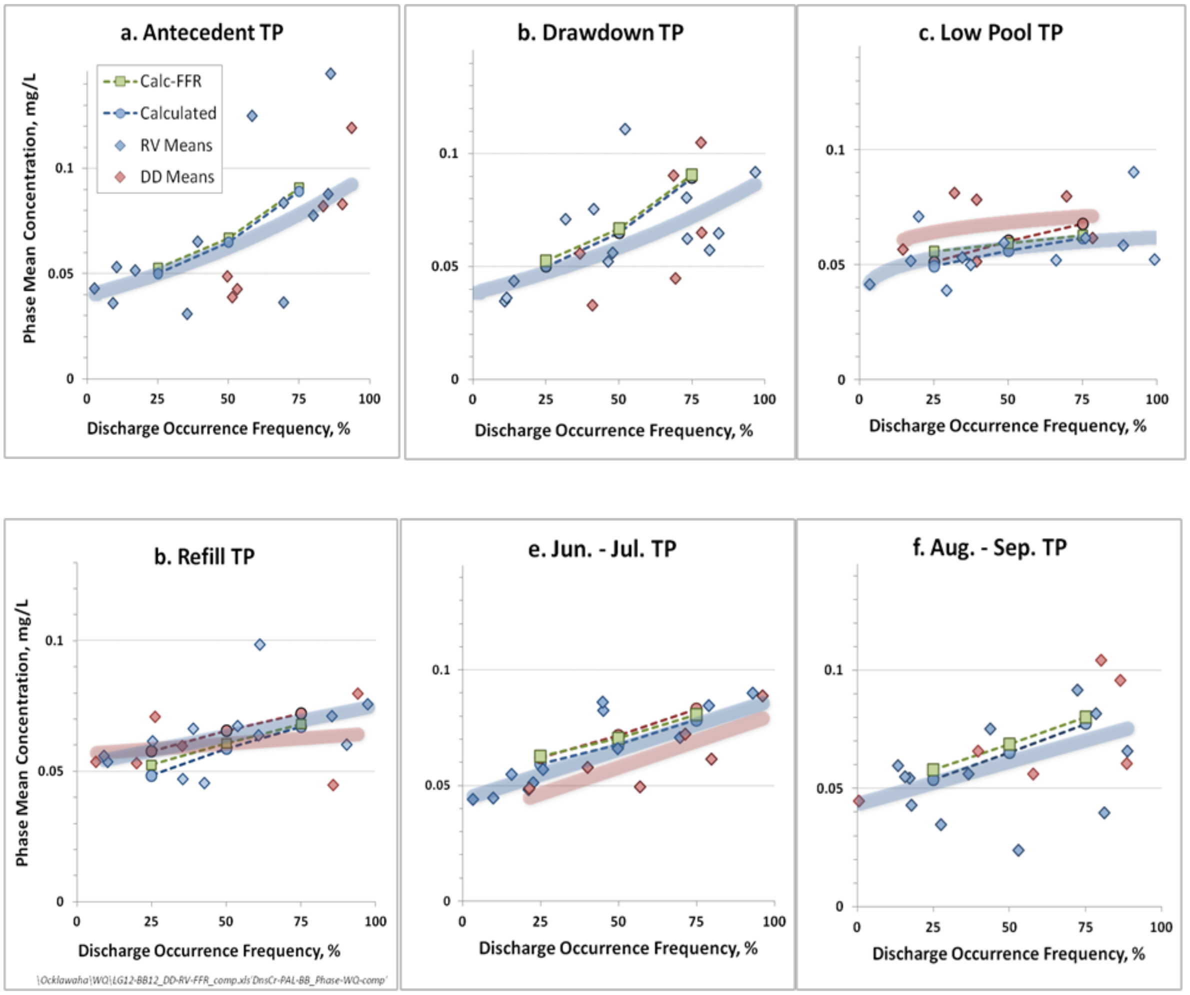
Figure 18. Calculated Phase-Mean TP Concentrations for the Lower St. Johns River at Palatka, for the (a) 25th, (b) Median, and (c) 75th Percentile Flow Conditions, for the Three Lower Ocklawaha Scenarios. Error bars represent the 95th percentile confidence interval of the regression relationship between LOR discharge and concentration.

Under the 25th, median, and 75th percentile discharge conditions, the FFR scenario is calculated to increase the annual TP load to the LSJR by 10.5, 11.5, and 11.1 MT above that delivered under the reservoir scenario. In drawdown years, the annual median discharge condition TP load attenuation falls to essentially zero, with the FFR total annual loads for the 25th percentile and median discharge conditions exceeding the drawdown load by only by 5.3 and 0.1 MT, while under the 75th percentile discharge condition, the drawdown load exceeds the FFR by 8.3 MT.

Figure 19 compares the actual Palatka phase mean TP concentrations to the calculated values. As was the case for nitrogen, though there is spread in concentrations of the monitoring means, the predicted concentrations appear to lie near the central tendency of the ambient data, and match the pattern with respect to discharge. Elevated concentrations in low pool TP predicted by the mixing calculations are discernible in the observed means (figure frame c), though the predicted increase during the refill phase is not apparent (figure frame d), largely due to an anomalously low phase mean at Palatka in 2005 of 0.045 mg/L. Coincident means for this relatively short, high flow refill phase (2/28–3/26) for the upstream inputs at the outlet of Lake George, the Ocklawaha mouth, Buffalo Bluff and Dunns Creek were 0.086, 0.072, 0.071, and 0.093 mg/L, contradict this low mean concentration at Palatka.

In the prior drawdown effects examination (Hendrickson et al., 2016), drawdown years were simulated with the dynamic river water quality model, CE-QUAL-ICM, with an Ocklawaha River flow and water quality time series matching the reservoir-full condition. These reservoir condition results were compared to the drawdown (i.e., actual) condition results to derive a scenario difference. The refill phase mean daily drawdown scenario TP percent increases at Palatka for the 1999, 2002 and 2005 drawdowns (which in relative terms were dry, average and wet years) was 14.4, 10.4 and 8.7 percent (Figure 20), relative increases that are comparable to the 25th, median and 75th percentile mixing analysis increases of 19.3, 11.4 and 7.8 percent.


a. Antecedent TP

b. Drawdown TP

c. Low Pool TP

b. Refill TP

e. Jun. - Jul. TP

f. Aug. - Sep. TP

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Figure 19. Comparison Between Conservative Mixing-Calculated Phase-Mean TP (blue (reservoir) or red (drawdown) circles and dashed lines) and the Observed Phase Mean Concentrations (blue and red diamonds) Based on Discharge Occurrence Frequency for the St. Johns River at Palatka. Circles identify the calculated 25th, Median, and 75th Percentile Flow Conditions. Wide, semi-transparent regression lines identify the relationship between discharge and the observed means. Solitary blue dashed lines are shown when there is no difference between reservoir and drawdown conditions. Green squares indicate the predicted FFR concentration.

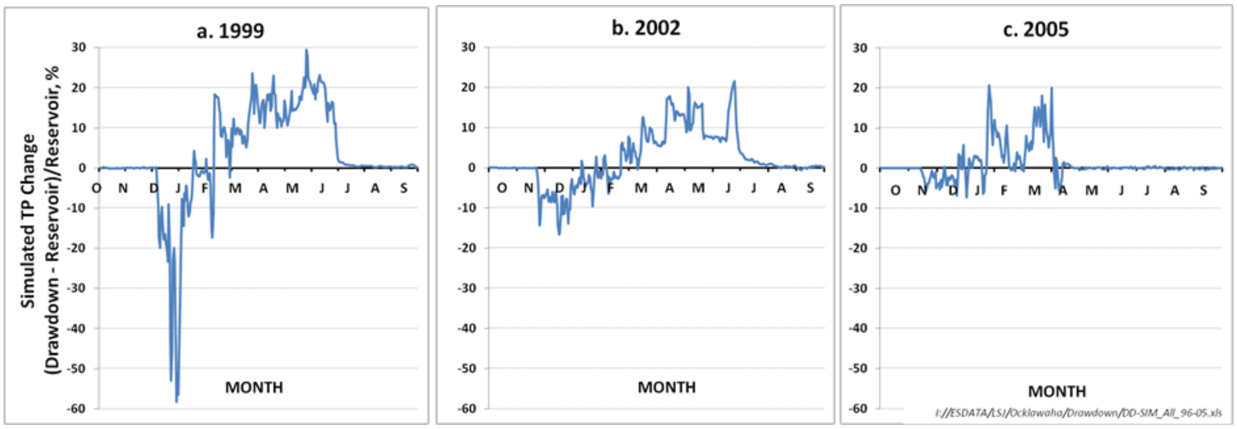

Figure 20. Daily TP Percent Change in the LSJR at Palatka for the 1999, 2002 and 2005 Drawdowns Simulated with the St. Johns River Estuary Model Application of CE-QUAL-ICM. Drawdown years were simulated as reservoir full years based on models relating Ocklawaha Mouth concentrations to the discharge condition at Eureka. Negative values indicate the drawdown phase, when the release of pool storage lowers downstream concentrations. Positive values indicate the relative increase in downstream concentrations due to reduced dilution and higher LOR TP concentrations.

FRESHWATER REACH POTENTIAL ALGAL BIOMASS CHANGES

A free-flowing LOR will change the timing and amounts of nitrogen and phosphorus supplied to the LSJR, potentially affecting the density and duration of phytoplankton blooms in this eutrophic river estuary. The change in nutrient supply would occur in the freshwater reach of the estuary, where phytoplankton blooms have historically been the most severe, and diminish downstream. These blooms typically undergo succession in composition until ultimately dominated by the nitrogen fixing cyanobacteria species *Anabaena circinalis*, *Cylindrospermopsis raciborskii, or Aphanizomenon flos-aquae*, which thrive in the low N and high P conditions of the freshwater reach. The LSJR freshwater reach TMDL water quality target limits the duration of a blooms, with a “bloom” defined as a chlorophyll-a concentration of 40 µg/L or greater, to a maximum of 40 days. This target was designed to counteract the adverse effects of cyanobacteria blooms on the abundance of beneficial zooplankton, and to promote the maintenance of healthy pelagic food chains (Hendrickson et al., 2003).

To estimate the potential algal biomass that could be generated by the FFR condition NOx and TP concentration changes, the conservative mixing results at Palatka were extrapolated downstream to the freshwater LSJR zone of maximum bloom severity, located between river mile (RM) 75 to RM 60. This zone encompasses the FDEP water body segmentation system IDs 2213 K and L, the “worst-case WBIDs” in the LSJR TMDL process. The long-term monitoring station within this reach at Racy Point has been used as the benchmark for water quality targets compliance for post-TMDL assessments. The scenario-specific Palatka NOx and TP load increases were added to the observed loads at Racy Point, and then divided by the Racy Point discharge, to express scenario loads as a phase mean concentration increases. Phase mean discharge volume flux at Racy Point was estimated with output from EFDC hydrodynamic model simulations (Sucsy et al., 2011), using a simple expansion based on the relationship between the mean monthly discharge at Palatka and Racy Point (Appendix A). The difference between the scenario-specific and actual observed NOx and TP concentrations were then converted to algal biomass as chlorophyll-*a*, using Redfield (1958) nutrient ratios (106:16:1

C:N:P molar ratio) and assuming a 50:1 algal carbon to chlorophyll-*a* ratio, and then added to the existing time series chlorophyll-*a* data. The combined effect of the FFR addition of NOx and TP was determined following the decision tree depicted in Figure 21. In this decision tree, the scenario TP, converted to chlorophyll-a concentration, was added to the existing chlorophyll-*a* (unless algal C:TP after TP addition > 106 molar) to create a TP-driven biomass increase. Then, if NOx was at a low concentration indicative of limiting conditions (here considered below 0.02 mg/L), the chlorophyll-*a*-equivalent of this added NOx was added to the existing concentration, up to the theoretical maximum algal C:TP ratio, to provide a NOx-driven biomass increase. The TP and NOx biomass increases were compared, and the greater (up to the theoretical algal C:TP maximum) was selected as the final scenario combined TP and NOx biomass increase.

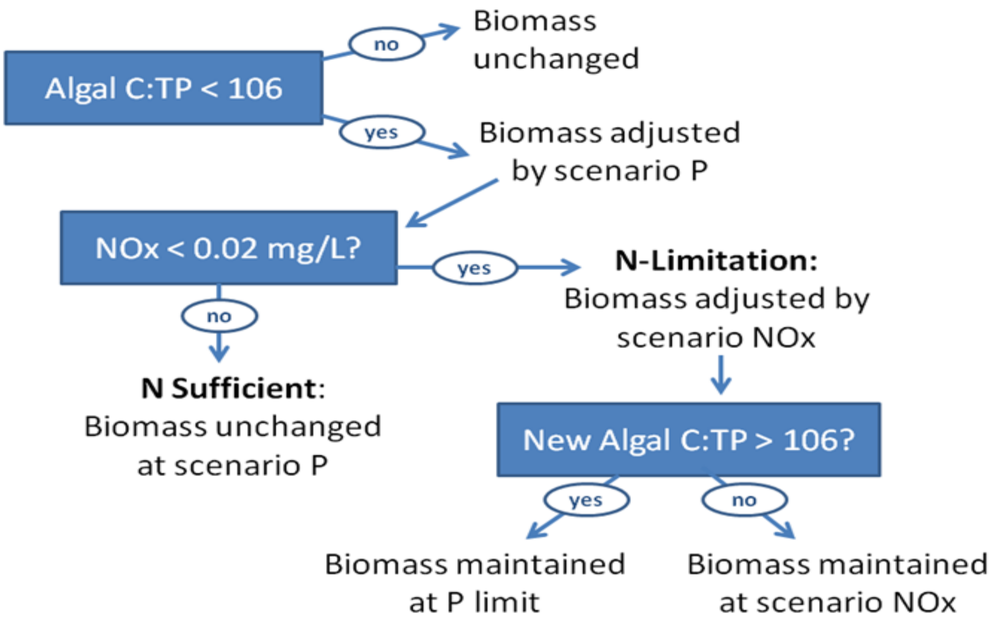

Figure 21. Decision Tree for the Determination of the Changes in Chlorophyll-*a* Arising from the Extrapolated Load of NOx and TP Load to the Center of the LSJR Freshwater Reach at Racy Pt. The Algal C:TP threshold is the Redfield (1958) molar ratio of the calculated algal carbon to total phosphorus ratio.

From this chlorophyll-*a* time series, bloom (chlorophyll-*a* greater than 40 µg/L) duration was calculated for three scenarios: the LOR in perpetual reservoir condition, the LOR in perpetual drawdown condition, and the FFR, for the 12 reservoir-full years between 1995 and 2011. Drawdown years are excluded, as theoretically they are affected by the changes in residence time and TP supply that occurs during drawdowns. This load and algal biomass extrapolation has two conservative assumptions built in: it assumes that there is no NOx or TP lost by assimilation, denitrification or sedimentation from the LOR to the worst-case WBIDs, and that all added NOx and TP are incorporated into phytoplankton biomass.

Table 2 lists the normalized occurrence frequency distributions for the durations of Racy Pt. (LSJR WBID 2213K) chlorophyll-*a* greater than 40 µg/L, as defined by the twelve reservoir-full years from 1995–2011, for the calculated TP-driven and combined biomass increases. Over this time span, observed bloom duration (representing the reservoir-full condition) exceeded 40 days in 7 of the 12 years, and interpolating for the exceedance percentile corresponding to 40 days produces a rate of exceedance of 62.4 percent. The additional phosphorus added during drawdown years, based on the assumptions of complete delivery and assimilation, would lead to a normalized exceedance rate of 71.8 percent, and, for the 1995–2011 period, calculated bloom durations exceeded 40 days in 8 of the 12 years. Under the FFR condition, the TP-driven criteria exceedance rate is 65.1 percent, with 7 of the 12 years calculated to exceed 40 days. For these 12 reservoir condition years, the median, annual maximum chlorophyll-*a* is 67.7 µg/L. With the drawdown year TP additions, median annual maximum chlorophyll-*a* would be 75.4 µg/L. Under the FFR scenario, the median, annual maximum chlorophyll-*a* would be 69.2 µg/L.

Table 2. Mean Duration and Frequency of Exceedance of the Freshwater LSJR TMDL Threshold for the Reservoir-Full, Drawdown and Free-Flowing River Conditions, for TP Load Additions Only, and for the Combined Calculated effect of NOx and TP. Estimates based on monitoring from 1995 – 2011, excluding reservoir drawdown years.

Scenario	Mean Duration of Chlorophyll-a > 40 µg/L (days)		Criteria Exceedance Frequency (%)	
	Total P Only	Combined TP and NOx	Total P Only	Combined TP and NOx
Reservoir (Base Case)	52	52	62.4	62.4
Drawdown	63	67	71.8	75.1
Free-Flowing	55	129	65.1	87.7

Under the assumption of complete downstream delivery and incorporation of NOx, scenario bloom durations and exceedance rates increase. Under the perpetual drawdown condition, mean bloom duration increases from 52 days to 67 days, an increase of 4 days over the TP-driven-only increase. For the FFR scenario, mean calculated bloom duration increases to 129 days, more than twice the duration of the TP-driven-only increase. The drawdown scenario rate of criteria exceedance increased to 75.1 percent, compared to TP-only rate of 71.8. The FFR scenario rate of exceedance rises to 87.7 percent, compared to the TP-only rate of 65.1 percent. In nine of the twelve years, the additional NOx was calculated to be sufficient to drive phytoplankton biomass to the point of phosphorus limitation at some point in the bloom cycle. In comparison, theoretical P limitation occurred in five of the 12 years in the reservoir-year ambient data.

DISCUSSION

Since the emergence of the concern of increased nutrient supply to the LSJR resulting from the restoration of the LOR, SJRWMD has worked with FDEP to compile a baseline data set and develop empirical and mechanistic modeling tools to better quantify the magnitude of the restoration's impact. This analysis represents the initial component of the phased study plan to apply these data and models to quantify the restoration's water quality impacts, intended to provide a generalized assessment of the upper limit of expected effects, and to identify the elements that should be included in a second phase mechanistic modeling assessment.

The water budget for this nutrient load assessment is based on available measured and simulated discharge, precipitation and evaporation data. The water budget calculations indicate that discharge exiting the LOR will increase, due to the resumption of flow from as many as 20 submerged springs, a finding that is supported by previous modeling studies (Wycoff, 2010; Tibbals, 2010). This analysis presumes that reduced artesian discharge elsewhere will offset the LOR spring flow increase, resulting in no net increase in load to the St. Johns. This is a conservative assumption in the analysis, as the inclusion of this load would produce lower downstream calculated concentrations through dilution with this lower concentration groundwater.

This analysis of effect on the LSJR is referenced to river discharge occurrence frequency, as discharge condition exerts significant control upon phytoplankton productivity in this river estuary. Flow determines the timing, location and magnitude of maximum phytoplankton density, the import of CDOM, which controls the underwater light environment, and the import of nutrients, which control ultimate standing stock (Phlips et al, 2007). The use of discharge occurrence versus concentration models also facilitates the incorporation of flow-dependent concentration changes that are highly significant in the LOR and that would not be accounted for if load were merely calculated as the product of average flow and average concentration. The 25th through 75th percentile discharge occurrences were selected to bracket this initial analysis because they are for the most part within the range of the observed data, strengthening the predictions. Statistical confidence of the downstream concentration predictions is based only on the discharge occurrence frequency versus concentration regression model confidence intervals of the LOR models, and does not include the statistical variance of the Dunns Creek and Middle St. Johns (i.e., Lake George outlet) models. As the inter-annual variation in St. Johns River nutrient is peripheral to the subject of this analysis, the results should remain valid in a relative sense.

The analysis assumes the total downstream export and incorporation by phytoplankton of the FFR nutrient load. This approach was adopted in part to convey the maximum downstream nutrient load, with the intention to project a "worst-case" condition for the LSJR. Though an in-depth analysis of longitudinal changes in nutrient concentrations was beyond the scope of this analysis, Appendix B contains a partial analysis of available data based on long-term paired monitoring, and recent intensive monitoring by FDEP. Longitudinal changes in NOx concentrations in the Ocklawaha indicate that at most times there will be a net loss under a FFR condition, from assimilative and dissimilative biological processing. While a net overall loss of TP is also expected, the hydrological characteristics mediating short-term gain or loss during longitudinal transport are presently less well understood. It is expected that a free-flowing lower Ocklawaha will exhibit characteristics similar to other natural rivers in northeast Florida, in which there is generally a net loss of TP in spring and summer from assimilation and sedimentation, followed by a net increase in fall and winter due to primary producer senescence and organic matter decomposition, and floodplain inundation, TP mobilization and export. These processes will be important to quantify in a subsequent phase of modeling, in order to refine the estimates derived here.

Conservative mixing calculations indicate that a free-flowing LOR will increase downstream TP concentrations when compared to the reservoir-full operational state (Figure 22 (a)). The greatest relative increases occur under low-flow conditions because 1) the Ocklawaha is a proportionally larger contributor to the St. Johns under low flow; 2) reservoir residence time and assimilation are greater, maximizing the difference between the current condition and the FFR condition; and 3) St. Johns River TP concentration is lower at low flow. At median discharge, the FFR is calculated to increase the annual average TP concentration at Palatka by 4.4 percent over the reservoir-full condition, and by 1.6 percent over the drawdown condition. The FFR condition leads to a large (though not significant) increase in TP specifically during the drawdown phase of drawdown years, due to the dilution of LSJR water from released reservoir storage (Figure 22 (b)). However, during the low pool, refill, and post-refill phases, the FFR is calculated to result in lower TP (though again not significant) than the drawdown condition. The timing of this increase in drawdown TP delivery occurs coincident with the exponential growth phase of the LSJR freshwater reach spring cyanobacteria bloom, hence its potential effect on algal growth is greater. By extrapolating the increase in TP load to the zone of maximum phytoplankton growth, and assuming that all of this load is converted to phytoplankton biomass, the FFR condition is calculated to increase the frequency of TMDL criteria exceedance from 62 percent of the time, to 65 percent, based on conditions existing from 1995–2011. However, again due to the timing of TP load delivery, the drawdown condition is calculated to increase the incidence of TMDL criteria exceedance to 72 percent. Because reservoir drawdowns are conducted approximately every three years, the calculated increase in potentially detrimental TP load during drawdowns cancels out the lower incidence of TMDL criteria exceedance under the reservoir condition, and the long-term net effect of increased P load from the FFR, particularly given the confidence of the models used in this analysis, is essentially zero.

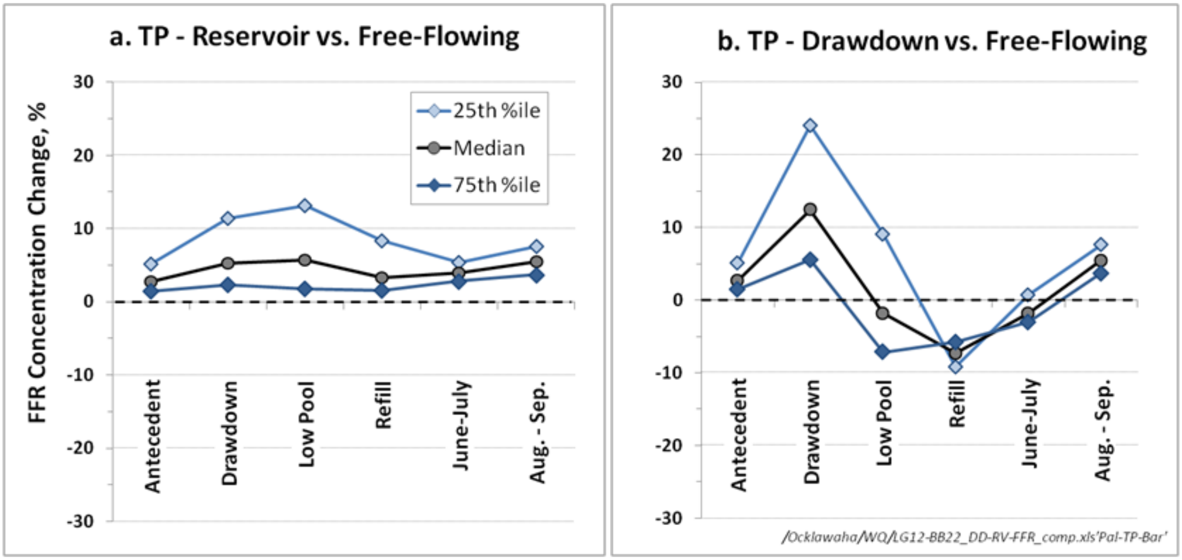

Figure 22. Percent Change in Total Phosphorus Concentration at Palatka Under the Free-Flowing River Condition Relative to the Reservoir Condition (a) and Drawdown Condition (b).

Applying the same assumptions of complete export and zero decay leads to larger relative increases in the projected N concentrations (Figure 23). At Palatka, the annual average percent increase in TN over the reservoir-full condition is projected to be 8 percent under at the median discharge, and 14 percent at low flow (Figure 23 (a)). When compared to the drawdown scenario, the same discharge conditions are projected to increase TN by 6 and 11 percent (Figure 23 (b)). If one assumes that all of the total additional N is delivered to Racy Point, and is fully incorporated into phytoplankton, then the projected duration of blooms increases substantially. So the effect of a free-flowing LOR on the worsening of eutrophication in the LSJR depends largely on the actual delivery of NOx, and its effect on phytoplankton growth and community composition.

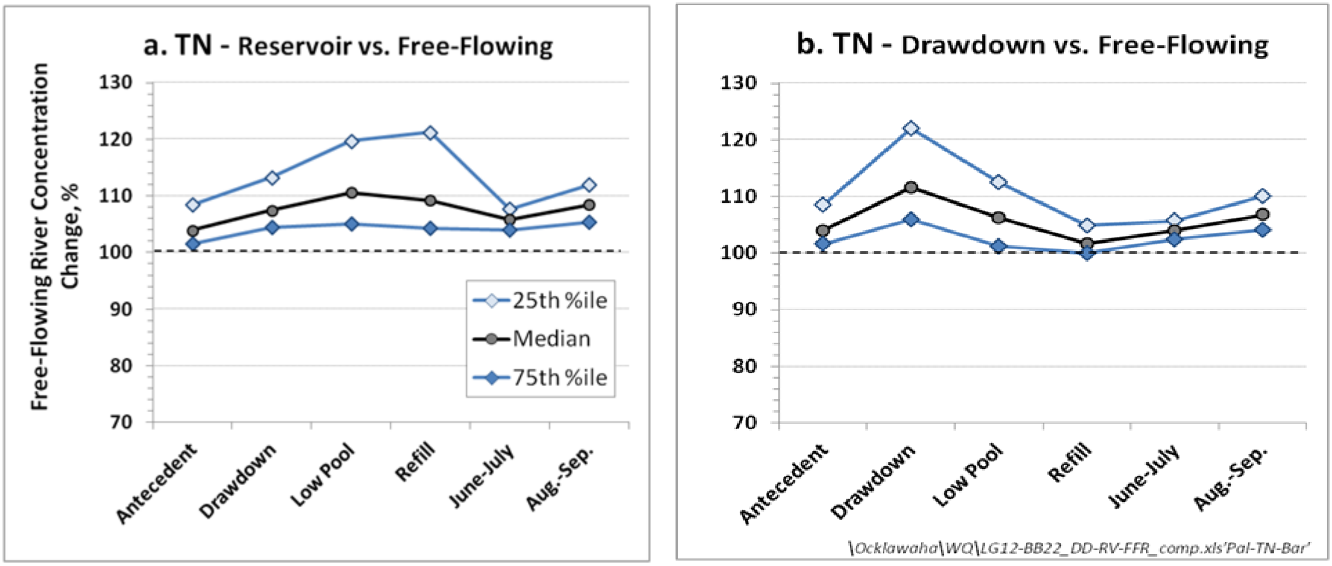

Figure 23. Percent Change in Total Nitrogen Concentration at Palatka Under the Free-Flowing River Condition Relative to the Reservoir Condition (a) and Drawdown Condition (b).

Due to the general condition of P over-enrichment that has existed until recently in the LSJR, nutrient enrichment assays conducted on LSJR phytoplankton have demonstrated the greater tendency for N additions to stimulate algal growth (Schelske and Aldridge, 1995; Paerl et al, 2003; Paerl et al., 2005). Schindler et al. (2008) have argued that the short-term limitation of N in nutrient enrichment assays is not a reliable indicator of the need for N control to reverse eutrophication. Conley et al. (2009) have countered the P-only reduction philosophy for the freshwater reaches of river estuaries may lead to the downstream delivery to nitrogen sensitive marine systems. To better relate these general positions regarding the role of N enrichment to the specific conditions of the freshwater LSJR, it is worth examining how inter-annual patterns in N supply have historically affected the biomass and composition of the phytoplankton.

The flux and processing of N in the LSJR is complex, largely due to the prominence of N-fixation and denitrification, which affect not only the partitioning but also the magnitude of the total N pool. Phytoplankton exert a dominant effect on N partitioning, as expanding blooms discernibly draw down the external supply of NOx, and spikes in particulate organic N (PON) and ammonium (NH_4) act as strong indicators of spatial-temporal bloom expansion or decline. Patterns in NOx are of particular interest here, as this N form is expected to be appreciably elevated in water delivered by a free-flowing LOR.

Fall and winter peaks in NOx, followed by a sharp decline in early spring, are a prominent, reoccurring signal in the St. Johns River (Figure 24 (a)). Along the St. Johns River, NOx concentrations are the greatest at the outlet of Lake Poinsett, below the middle St. Johns River Lakes at Deland, and within the oligohaline reach of the lower St. Johns in south Jacksonville (Figure 24 (b)). High concentration spikes of NOx occur in most winters (Figure 25), and are likely the result of a combination of factors, including external load inputs, decline in primary producer assimilation, decline in denitrifer activity, and the senescence of phytoplankton standing stock and re-mineralization of organic N to NOx. The finer scale temporal and spatial characteristics of these nearly annual NOx spikes in Lake George and the LSJR are shown in Figure 26 for four typical high concentration years. Two of these years exhibited low flow conditions (2002 and 2012), and three of the years coincide with reservoir drawdowns (2002, 2005 and 2012). These winter NOx peaks occur downstream into the river's marine reach, with the highest concentrations tending to occur at the fresh-oligohaline interface, Hibernia Point and Piney Pt. (RKM 69–47). There is an apparent longitudinal shift in the concentration spikes, with higher downstream values peaking later. This pattern suggests advection of a water mass high in organic N in which N is undergoing remineralization to NOx, perhaps also combined with greater water depth, which separates NOx from the zone of active denitrification at the sediment-water interface. Lagging water temperatures may also favor a south to north biological activity pattern.

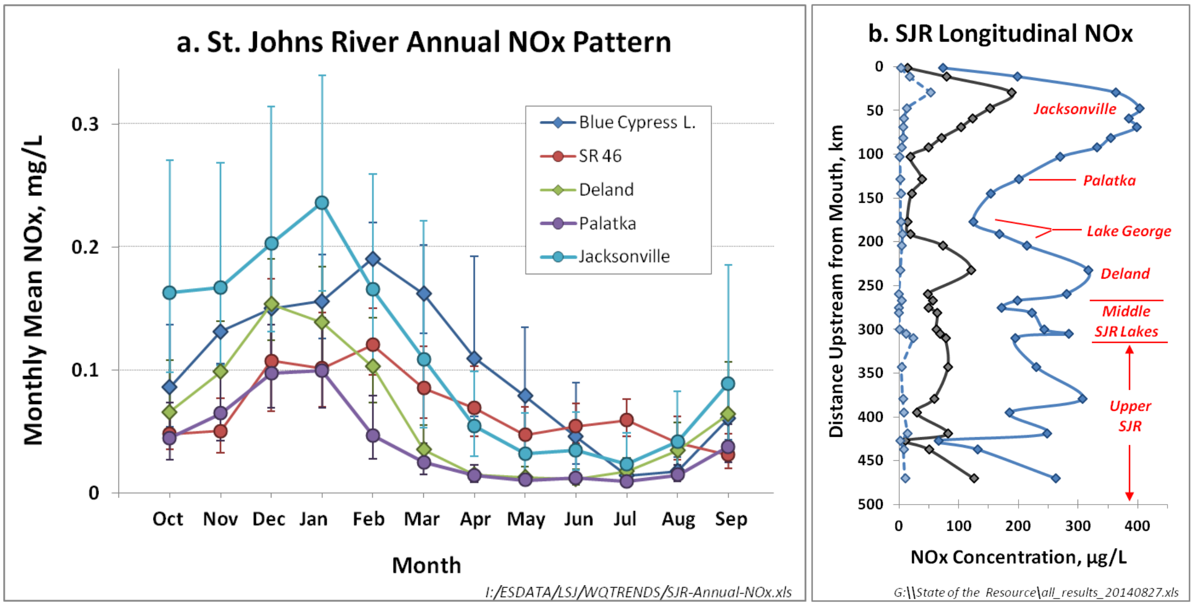

Figure 24. Mean Annual and Longitudinal Patterns in NOx Concentrations in the St. Johns River. (a) Monthly Mean NOx Concentration for Selected St. Johns River Long-Term Water Quality Monitoring Locations, 1995–2012. Error bars bound the 95 percent confidence interval of the mean. (b) Long-term median (black), 10th percentile (blue dashed line), and 90th percentile (solid blue line) NOx concentrations in the St. Johns from headwaters to mouth.

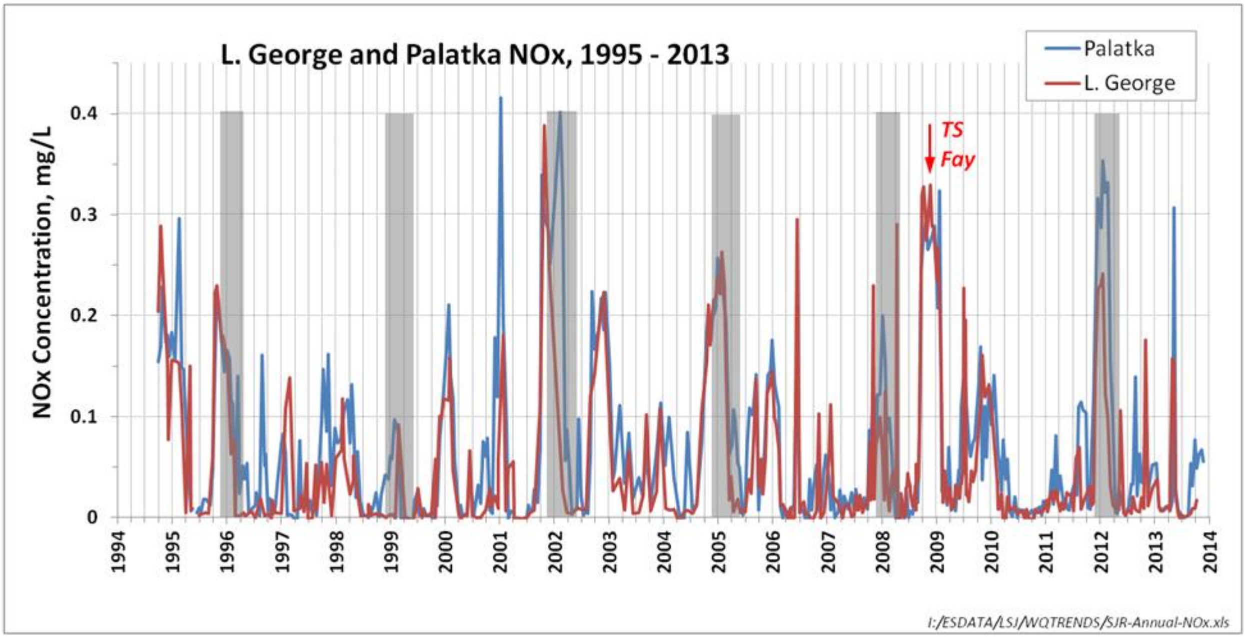

Figure 25. Time Series of NOx Concentration for the Long-Term Monitoring Station in the LSJR at the Outlet of Lake George and Palatka, Located Above and Below the Ocklawaha River Mouth. Grey bars highlight reservoir drawdowns.

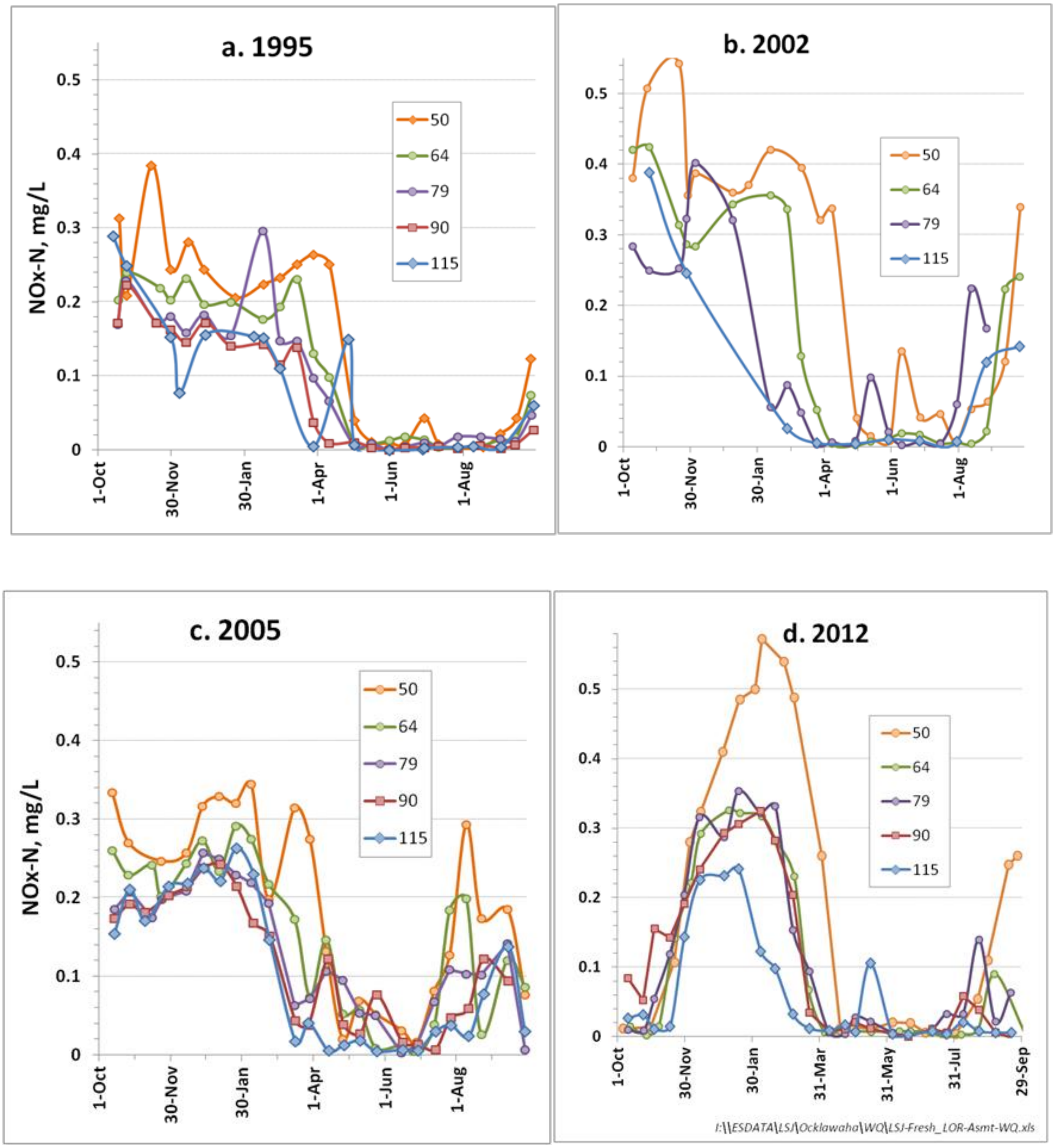

Figure 26. Typical Annual Patterns in NOx for Lake George and the LSJR Freshwater Reach. Stations identified by river mile location, with numbers increasing upstream. RM 115 = North Lake George; RM 90 = Buffalo Bluff; RM 79 = Palatka; RM 64 = Racy Pt.; and RM 50 = Shands Bridge.

The disappearance of NOx in spring is not concomitant with chlorophyll-*a* increase, and when chlorophyll-*a* increases, the rates of biomass increase suggest that assimilation is only partly responsible for NOx decline. In most years, phytoplankton biomass (as chlorophyll-*a*) does not begin to increase until NOx concentration has declined to a low level. While a simple comparison of gain and loss in river concentrations does not account for the flux of N from other sources, primarily that of external load sources, it suggests that only a portion of NOx is utilized in phytoplankton primary production.

One striking feature of the annual pattern is the consistency with which diminishing concentrations of NOx, and also dissolved silica (SiO_2), are associated with the increase in the relative abundance of N-fixing cyanobacteria. Silica is also a fundamental regulator of phytoplankton community structure in the Lake George and the LSJR, as it is an essential growth element for diatom algae, the natural dominant group for a lacustrine blackwater river such as the St. Johns. For these same four NOx-spike years (as well as other years not shown), N-fixing cyanobacteria appear in the phytoplankton community shortly after NOx and dissolved SiO2 are very low and essentially depleted (Figure 27). Phytoplankton biomass continues to increase after the depletion of these nutrients, with N-fixing cyanobacteria the beneficiary of the niche created by the depletion of inorganic N and silica.

In 12 of the 19 years from 1995–2013, the fall and winter NOx concentration exceeded 0.2 mg/L, and these are referred to in this analysis as high-NOx years. The median chlorophyll-*a* at the point of the NOx depletion and associated N-fixing cyanobacteria appearance for these 12 high-NOx years is 25 µg/L. Converting this to phytoplankton biomass N, using the standard phytoplankton nutrient ratios (Redfield, 1958), translates to approximately 0.22 mg/L of water column N incorporated in phytoplankton biomass. The median TN concentration in the freshwater LSJR in late winter, prior to appreciable N-fixation, is 1.30 mg/L (1995–2012), hence it would appear that readily bio-available N is much lower than the chemically measured TN. While the usual TN:TP ratio in the LSJR suggests that phytoplankton primary production is phosphorus limited, or N and P co-limited, nutrient enrichment assay experiments (studies in which individual nutrients are added to river water samples in order to identify the nutrient that stimulates algal growth) have demonstrated in the overwhelming tendency for nitrogen to be the primary limiting macronutrient (Schelske and Aldridge, 1996; Paerl et al. 2004).

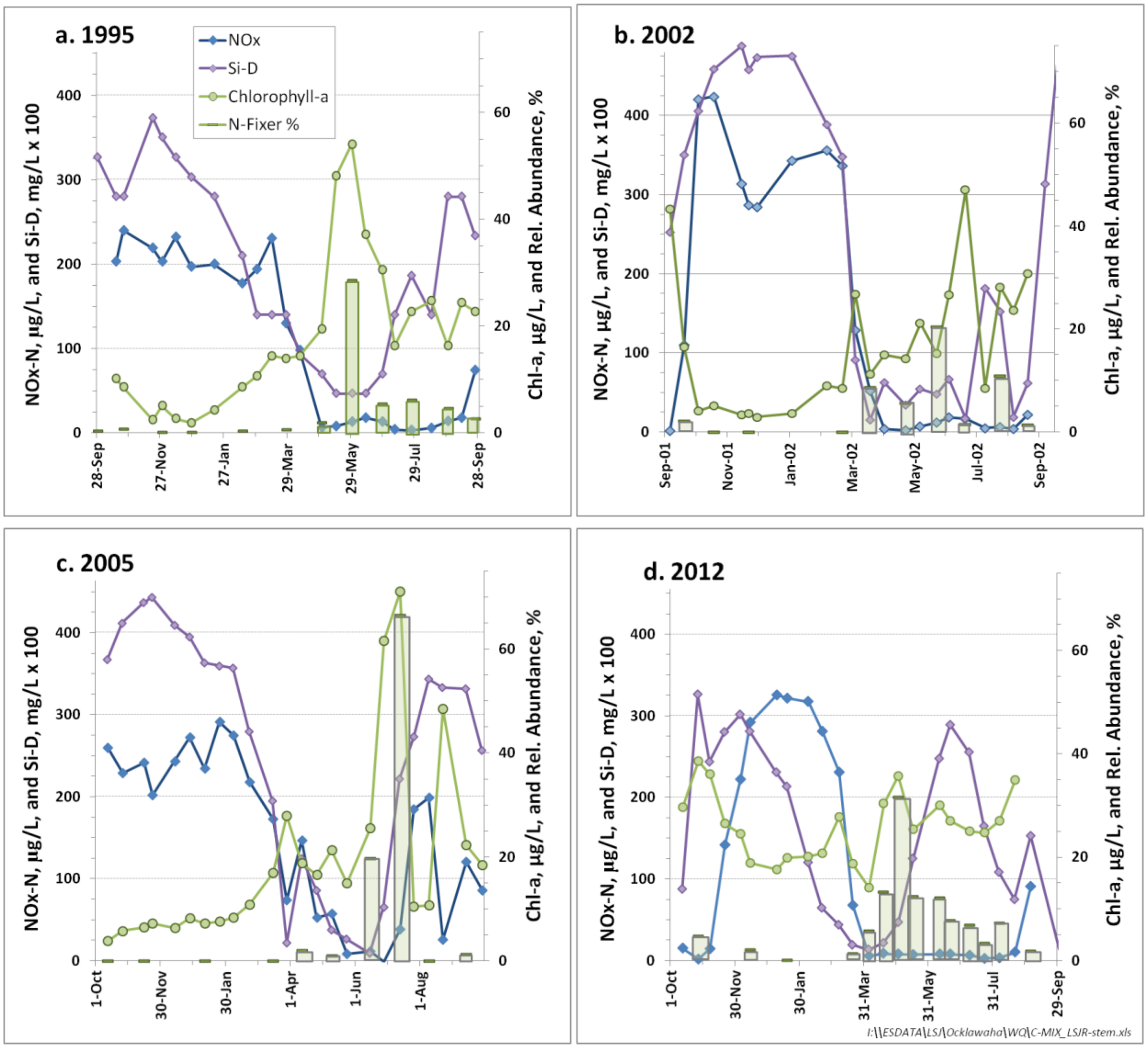

Figure 27. Time Series Patterns in NOx (blue diamonds), Dissolved Silicon (purple diamonds), and Chlorophyll-a (green circles) concentration, and the Percent Relative Abundance of N-Fixing Cyanobacteria (green bars), for Four Typical Water Years (October–September) for the LSJR Freshwater Reach Long-Term Monitoring Station at Racy Pt.

If 0.22 mg/L can be construed as representative of background, readily bio-available N pool, based on coincident NOx depletion and N-fixing cyanobacteria exponential growth, then it follows that, aside from the fact that a large amount of the TN in the freshwater LSJR is recalcitrant, the N available for phytoplankton growth is in relatively short supply relative to P, a hypothesis that is consistent with nutrient enrichment assay results. Conservative mixing calculations indicate that if no LOR NOx is lost in transit, the concentration of NOx entering the freshwater LSJR at Palatka will increase from between 0.08 to 0.21 mg/L under the median discharge condition, and by as much as 0.35 mg/L during the spring (refill phase) in low flow years. This NOx concentration will augment a limited bio-available N pool, with much of it assimilated by phytoplankton.

In the LSJR, N deficiency of the expanding bloom is circumvented by atmospheric N-fixation as the phytoplankton community undergoes succession to N-fixing cyanobacteria. The activity of N-fixing cyanobacteria has been established and quantified in river sample assays, with Paerl et al. (2005) measuring mean gross daily N-fixation of 0.028 µg N/µg chl-a/hr. This translates to a gross daily N acquisition of 0.027 mg/L for a bloom with a chlorophyll-*a* concentration of 40 µg/L. The observed median daily TN increase during expanding blooms at Racy Point, which could be considered more representative of a net rate, is 0.011 mg/L. The low flow (when calculated increase is the greatest), refill phase mean daily calculated increase in NOx at Palatka for the FFR condition is 0.0054 mg/L, hence the current rate of N-addition through N-fixation appears to be twice the FFR calculated increase. Thus it would appear that additions of NOx to the LSJR from a FFR would not increase, but would only supplant, N added through N-fixation.

The likely ineffectuality of additional NOx supply to increase phytoplankton standing stock is supported by observed chlorophyll-*a* concentrations in drawdown years, when despite a 1.4 to 3.4-fold (calculated) increase in NOx concentration at Palatka (Appendix C), with the exception of 1999, drawdown years do not exhibit higher spring and summer phytoplankton biomass (Figure 28). In fact, in 1999, the drawdown year with the largest bloom (freshwater reach bloom peak biomass reached 156 µg/L as chlorophyll-*a*), is absent a NOx spike, while the four subsequent drawdown years with high refill-phase NOx concentrations exhibit lower than normal phytoplankton biomass. (ranked between the 5th to 36th percentile of the normalized distribution of the seasonal means).

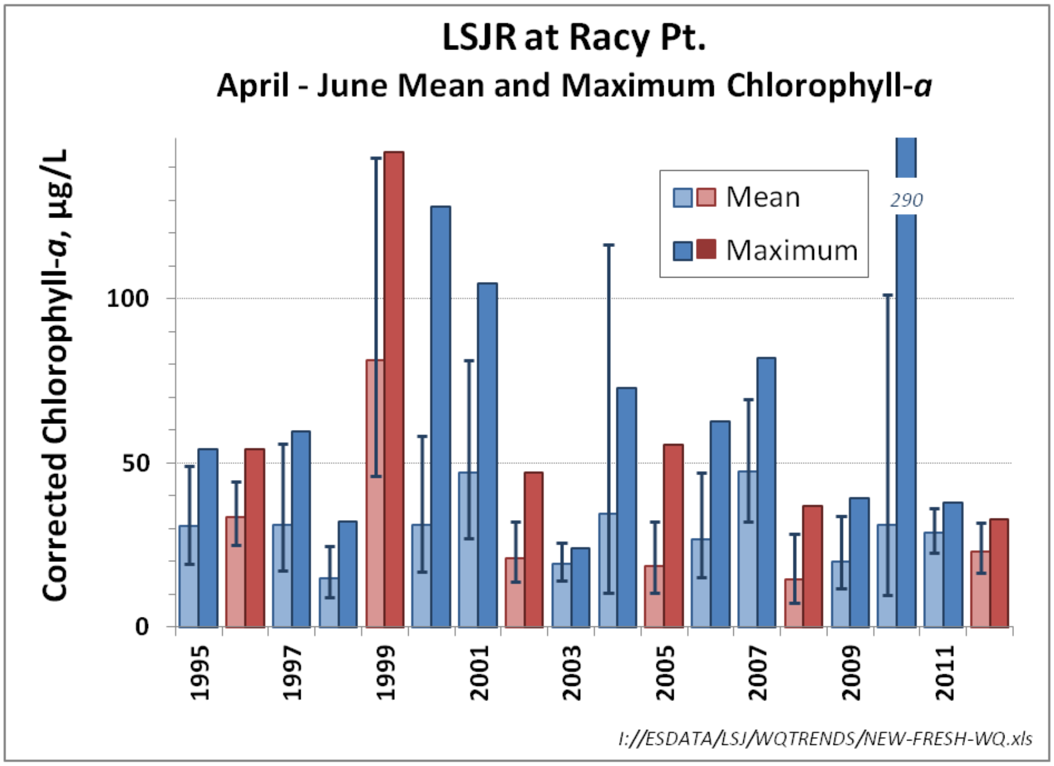

Figure 28. Spring Mean (light toned) and Maximum (dark toned) Chlorophyll-a at the Long-Term LSJR Freshwater Reach Station at Racy Point, 1995 – 2012. Reservoir-full years are shown in blue, while drawdown years are shown in red. Error bars represent the 95 percent confidence interval of the log-normalized corrected chlorophyll-a concentration.

While data presented here clearly show the capability of Rodman Reservoir to retain nitrogen, during times of the year it appears also to be a significant sink for dissolved silica. Comparison of above and below-reservoir monthly mean SiO_2-D concentration indicates that from December through June, while the reservoir is full, SiO_2-D concentrations at the head of the reservoir are significantly greater than those at the mouth (Figure 29). In drawdown years, SiO_2-D at the mouth greatly exceeds the reservoir condition, and even appears greater than the inflowing concentrations, indicating the possible mobilization of reservoir or floodplain stored SiO_2.

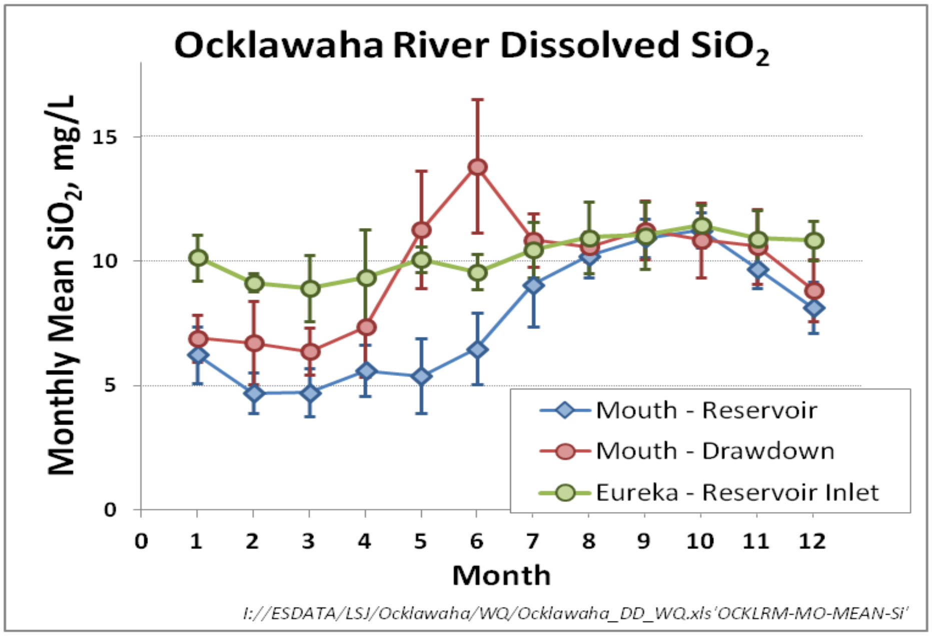

Figure 29. Monthly Mean Dissolved SiO_2 Concentrations Above (At Eureka, green symbols) and Below (at the river mouth, blue (reservoir-full) and red (drawdown) symbols) Rodman reservoir. Monthly means for ambient monitoring data collected between 1996–2014. Error bars represent the 95% confidence interval of the mean.

These observed data suggest that additions of NOx of the magnitude expected from the restoration of the LOR will not increase LSJR freshwater reach phytoplankton standing stock. Reduction of nitrogen alone has been shown to be ineffectual to control eutrophication in freshwater lakes (Schindler et al., 2008; Havens et al., 2002), and it has been hypothesized that the retention of silica in reservoirs has contributed to the dominance of cyanobacteria in downstream waters (Koszelnik and Tomaszek, 2008; Ittekkot et al., 2000). The addition of NOx and dissolved SiO_2 may instead have the effect of delaying the community succession from the late winter community of eukaryotic algae, primarily composed of diatoms, to N-fixing cyanobacteria, and patterns in the phytoplankton community composition in the LSJR and Lake George tend to support this. For phytoplankton community composition data collected at the long-term freshwater monitoring sites in Lake George and the freshwater LSJR, the mean January–March (coincident with drawdown-year low pool phase) NOx concentration is inversely correlated with spring bloom cyanobacteria biomass (Figure 30). These relationships suggest that the increased supply of NOx, and possibly also SiO_2, associated with a FFR scenario would not result in increased downstream phytoplankton biomass, and may actually improve the quality of the LSJR pelagic food chain, by counteracting the adaptive advantage of N-fixing cyanobacteria and encouraging the growth of beneficial eukaryotic algae in the phytoplankton.

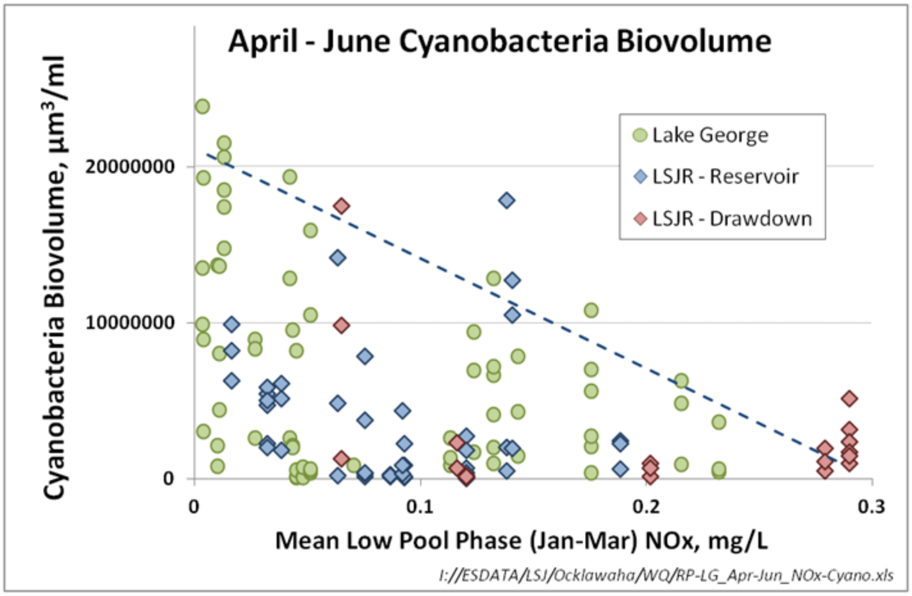

Figure 30. Relationship Between Cyanobacteria Biovolume and the Mean January–March NOx Concentration, 1994–2012. Each symbol represents an individual sample. The blue dashed linear regression line is the relationship through the 90th percentile of the 9-sample rolling mean for NOx-concentration-sorted samples, and is intended to represent cyanobacteria biomass potential as a function of preceding season NOx supply.

CONCLUSIONS AND RECOMMENDATIONS

In both the Upper Ocklawaha and Lower St. Johns River basins, lake restoration projects and removal and improved treatment of point and nonpoint sources of nutrient pollution has resulted in reductions in TP concentration and significant amelioration of eutrophication of the affected aquatic ecosystems (Ceric and Winkler, 2014; Fulton, 2014; FDEP, 2014). This assessment of FFR nutrient load to the lower St. Johns River is based on models developed on the conditions that existed from the mid 1990s through 2012, incorporating historic data from a time when loading rate was much greater, hence the models may overestimate the nutrient loads and receiving water body conditions that exist presently and in the future. This fact, along with the conservative assumptions built into the downstream delivery calculations, would lead one to expect that the downstream algal biomass increases under a free-flowing Ocklawaha River will be less than portrayed based on conservative mixing load and concentration increases.

This analysis estimates that a FFR will increase the TP load to the LSJR by 11.5 MT/yr in reservoir-full years, and by 0.1 MT/yr in drawdown years. If drawdowns are conducted once every three years (the 2012 and upcoming 2015 drawdowns were both postponed a year hence will have been conducted on 4-year cycles), then the long-term median discharge condition TP load increase under a FFR will be 7.7 MT/yr. To place this in context with other TP loads, the allocated domestic wastewater TP load to the freshwater LSJR is 12.4 MT/yr, and the annual load from the Georgia Pacific Palatka Mill was estimated in 2011 to be 11.5 MT/yr (LSJR BMAP, 2011). The Tri-County Agricultural Area (TCAA) delivers an average annual estimated TP load of 84 MT/yr (FDEP, 2008). Two of the SJRWMD-designed and built regional stormwater treatment systems in the TCAA together removed an annual average of 4.5 MT/yr (2009–2014; Livingston-Way, 2014 Draft BMAP), while the rough fish harvesting project conducted in Lake George in 2015 removed 5 MT of TP in the form of fish biomass. So the predicted TP load increase from a free-flowing lower Ocklawaha, while not insignificant, is in the range of other permitted TP loads to the LSJR, and within the realm of reduction achieved by projects currently functioning elsewhere in the basin. Should FDEP choose to pursue this restoration, and if a mitigation were deemed appropriate to offset potential harm based on the predicted TP load increase, it would likely be achievable through a combination of treatment project options directed elsewhere in the middle St. Johns, Lake George, or the freshwater LSJR. This fact, combined with the understanding of other adverse impacts that occur as a result of reservoir drawdowns, a necessary management action for the maintenance of the reservoir, appears sufficient such that a recommendation of denial, on the grounds of the detrimental impacts to downstream water quality, is no longer a certainty for this restoration permit.

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APPENDIX A—WATER BUDGET FOR THE LOWER OCKLAWAHA RESERVOIR REACH

Discharge statistics for this nutrient loading analysis were developed for the Rodman Reservoir reach of the Lower Ocklawaha River (LOR), and for the freshwater reach of the Lower St. Johns River (LSJR). A 20-year baseline period of record from October 1993–September 2013 of observed and simulated daily mean discharge were used in the analysis, as this corresponds to the available discharge record for the LSJR. The total reservoir reach inflow was calculated as the sum of the measured discharge data for Eureka (USGS #02240500, at County Highway 316, approximately 26 miles above the Ocklawaha Mouth), Orange Creek (USGS #02243000 on Hwy. 21 in Orange Springs), and Orange Springs (SJRWMD station #10362775), with simulated discharge used to estimate flow from ungauged areas. Outflow was calculated as Rodman Dam plus the volume exiting during boat lock-throughs at the Buckman Lock. One Buckman lock-through at a reservoir stage of 20’ is equivalent to 1.008 million cubic ft, or, 11.67 cubic feet/sec per day per lock-through, which is roughly equivalent to one percent of the dam mean daily discharge per lock-through. Lock-through discharge data are available from 1995 – 2004, with the subsequent time period estimated from recent reports from September 2009 to the present, which indicate a range of 34 to 72 lockages per month.

The contributing basin area above Eureka is 1,367 mi2 (from USGS), equivalent to 65 percent of the total Ocklawaha contributing (excludes Paynes Prairie) drainage basin area of 2,097 mi2 to Rodman Dam, while 407 mi2 of the remaining 730 mi2 contributing drainage area between Eureka and Rodman Dam (56 percent of the Rodman reservoir reach) is upstream of the Orange Springs gauging station (Table 3). These two discharge monitoring stations gauge inflows from 85 percent of the total Ocklawaha watershed contributing area to the Rodman Dam location.

The remaining ungauged area flow was estimated from a subset of the simulated runoff developed with an application of Hydrologic Simulation Program Fortran (HSPF) for the Water Supply Impact Study (Cera, 2012). The simulated runoff data from six representative drainage basins (Table A-1) were summed and multiplied by 2 (the ratio of reference HSPF area to total ungauged contributing area) to extrapolate the total runoff volume for the total ungauged area. As these basins covered in the extrapolation are not karstic and are dominated by predictable rainfall-driven surface water runoff, this extrapolation is not expected to introduce bias in the estimate. Because the HSPF simulated data series ends in 2008, it was necessary to estimate the ungauged area discharge beyond the available simulated data. This was done with a simple empirical model based on rainfall and season, based on the simulated data from a 1990 – 2006 subset of the HSPF simulated runoff data. This model related discharge to the monthly mean rainfall for three long-term NOAA rainfall stations (Palatka, Ocala and Gainesville). Monthly mean runoff with this empirical rainfall-runoff model compared to the monthly mean HSPF simulated produced an R^2 of 0.67 with a slope is very close to one, suggesting little bias (Figure A-1). The agreement is not as good when compared to the observed Orange Creek measured monthly means, which is not unexpected owing to the karst nature of the headwaters of this basin and the long-term pattern in intermittent contribution of outflow from Orange Lake. Based on this empirical model, the median monthly mean discharge from the ungauged portion of the Ocklawaha River Basin, from 1990–2006, was 39.2 ft^3/s, compared to 42.0 ft^3/s for the HSPF-simulated data. The median of monthly mean ungauged area discharge, from 1993–2013, is 4.3 percent of the median monthly mean discharge from the reservoir, so error incorporated in the ungauged area estimate should have a relatively minor effect on the overall reservoir reach water budget.

Table A-1. Summary of Contributing Areas to Rodman Reservoir.

Contributing Area	Source	Area (mi2)
Ocklawaha R. Basin to Rodman Dam Excluding Paynes Prairie	USGS	2097.00
Lower Ocklawaha Basin Eureka to Rodman Dam Excl. Paynes Prairie	USGS	730.00
Orange Cr. Area above GS Gauge Excluding Paynes Prairie	USGS	469.00
USGS Ungauged Area Below Eureka		261.00
Non-Contributing Areas (CFBC and SE Jeep Trails)		45.68
Calculated Contributing Area Eureka - Dam Excl. Orange Cr.		215.32
HSPF Reference Ungauged Basins Below Eureka:		
Sweetwater Cr.	SJRWMD	31.44
Gum Cr.	SJRWMD	23.58
Bruntbridge Br.	SJRWMD	5.70
Island Lake Drain	SJRWMD	6.84
Un. Slough	SJRWMD	4.34
Mill Cr.	SJRWMD	35.44
Sum of Reference HSPF Land Area		107.34
Ratio of Total Ungauged Area Blw. Eureka to Reference HSPF Simulated Area	107.3/215.3 = 2.0	

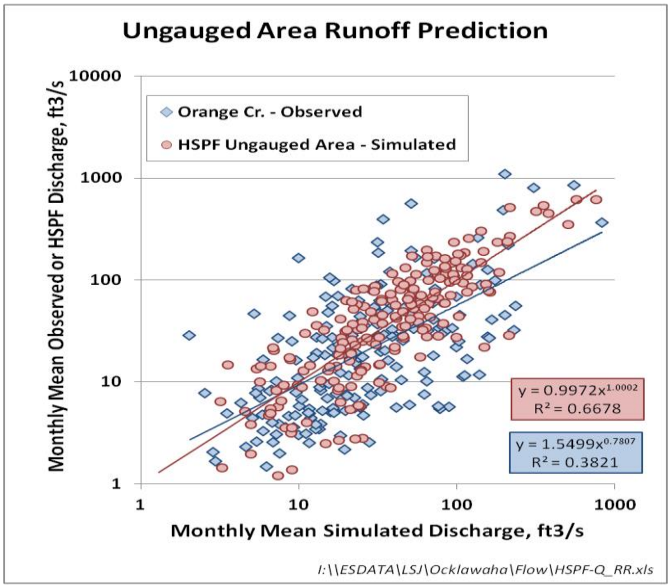


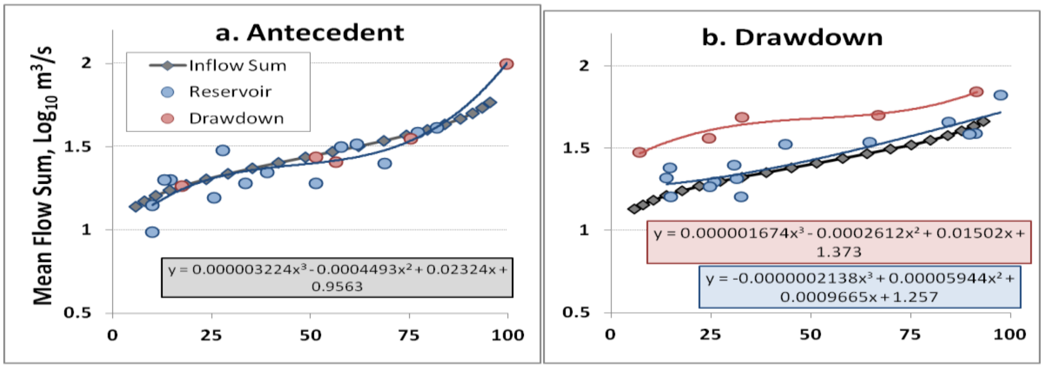
Figure A-1. Comparison between mean monthly predicted and observed or HSPF-simulated discharge for the cumulative rainfall-runoff model. The rainfall-runoff model uses the mean cumulative rainfall for four long-term nearby NOAA rainfall stations, where the cumulative rainfall is calculated as the current and previous rain totals, plus the 2nd previous month/2, plus the 3rd previous month/4, plus the 4th previous month/8. Blue symbols are for Orange Creek simulated vs. observed discharge. The relatively poor fit is presumed to be due to the effect of Orange Lake, which is frequently non-contributing and is partly drained by a sinkhole. Red symbols compare HSPF-simulated discharge to model-predicted. Model calibration data are from 1990–2006.

From the October 1993–September 2013 daily reservoir reach inflow and outflow, means were calculated corresponding to the phases of the normal reservoir management cycle. Means were based on the log10 discharge values to normalize the distribution of phase flows. For reservoir drawdown years, the phase averaging time interval corresponded to the dates listed in Table A-2. For reservoir-full years, the phase discharge means were calculated for intervals corresponding to October 1–November 19 (antecedent), November 20–January 15 (drawdown), January 16–March 10 (low pool), and March 11–May 31 (refill). Mean inflow and outflow values were also calculated for June–July and August–September to complete the annual cycle for all years. The flow occurrence frequencies for the 20-year phase mean log10-normalized inflow sums were developed using the Microsoft Excel NORMDIST function. These phase-specific occurrence frequency values of the total inflow were then used as the independent variable in third-order polynomial models with total outflow as the dependent variable (Figure A-2). Statistics were compiled for outflow under the reservoir full condition, and outflow under the drawdown condition, corresponding to the 25th, median and 75th percentile phase mean inflows. Predictions based on these hydrologic models were limited to this occurrence frequency range from the 25th to 75th percentile range to minimize bias that may be introduced due to data insufficiency and increased variance at the limits of the discharge range. In a similar fashion, phase mean discharge occurrence frequencies were also developed the 20-year daily flow time series interval from October 1993 – September 2013 for the St. Johns River exiting Lake George (Figure A-3; calculated as Buffalo Bluff (USGS #02244040, located 5 miles downstream of the

Ocklawaha mouth) – Rodman Dam discharge) and the LSJR at Palatka (calculated as the sum of Buffalo Bluff discharge and Dunns Creek (USGS #02244440) exiting the Crescent Lake Basin (Figure A-4)). These occurrence frequencies for Lake George and Palatka were expressed also as 3rd-order polynomial models in order to facilitate the calculation of discharge for a variety of occurrence frequencies. Because of occasional occurrences of phase-mean net-negative discharge from the Crescent Lake Basin, discharge corresponding to the 25th, median, and 75th percentile occurrences were determined with the Excel PERCENTILE function based on the non-log-transformed phase mean values.

Table A-2. Rodman Drawdown Phases Start and End Dates and Durations. Reservoir drawdown is considered initiated at the dam gate opening and beginning of high flow. Reservoir refill was considered to be from the reduction of dam discharge for pool replenishment to the point of the attainment of reservoir stage equivalent to the long-term mean operating elevation of 18.95 ft

	DRAWDOWN			LOW POOL			REFILL		
	START	END	Days	START	END	Days	START	END	Days
1999	12/1/98	1/11/99	41	1/12/99	3/14/99	61	3/15/99	5/8/99	55
2002	11/20/01	12/27/01	38	12/28/01	3/7/02	69	3/8/02	5/27/02	82
2005	11/8/04	12/15/04	38	12/16/04	2/27/05	74	2/28/05	3/26/05	27
2008	11/16/07	1/9/08	55	1/10/08	2/29/08	51	3/1/08	4/8/08	39
2012	11/20/11	1/15/12	57	1/16/12	2/26/12	42	2/27/12	6/24/12	119
Avg.			46			59			64



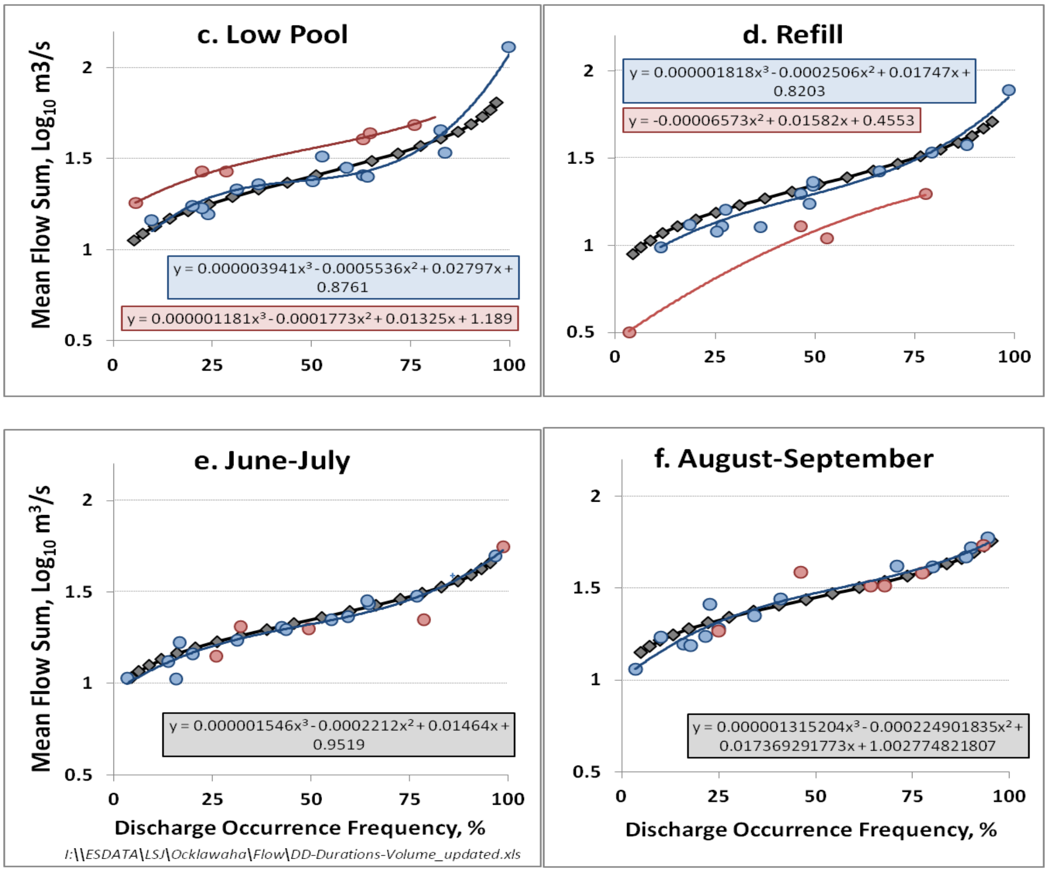


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Figure A-2. Rodman Reservoir Outflow as a Function of Reservoir Inflow Percent Occurrence, October 1993 - September 2013. Reservoir inflow (grey diamonds) calculated as the sum of surface runoff/inflow and precipitation, minus reservoir evaporation. Reservoir discharge calculated as the sum of dam discharge and Buckman Lock-throughs. Blue circles represent corresponding total outflow in reservoir-full years, while red circles represent outflow in drawdown years. The 1995-96 drawdown to 13 feet is omitted from the models, with the exception to the low pool model, for which an outflow adjusted to 11 feet was substituted in order to provide a value above the 75th percentile discharge to enhance model development. The 2002 phase mean was omitted from the refill model, as a significant portion of the outflow was estimated due to instrument failure, and outflow was anomalously greater than inflow.

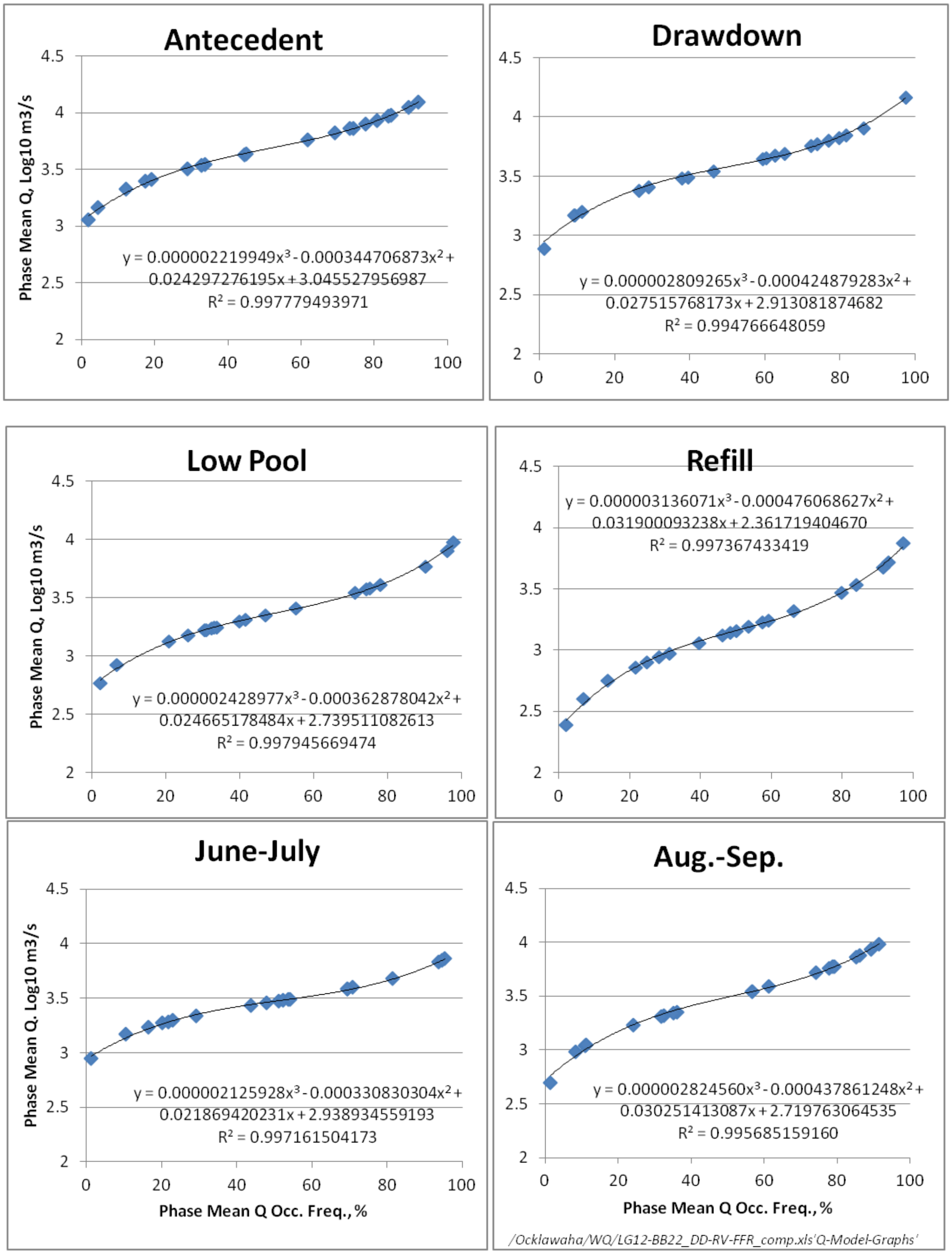

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Figure A-3. Phase Mean Discharge Occurrence Frequencies for The St. Johns River Above the Ocklawaha River Mouth.

Artesian springs will likely add to the total discharge of the lower Ocklawaha under a FFR scenario following the removal of reservoir head pressure (Wycoff, 2010; Tibbals, 1989). In a watershed yield analysis based on pre-reservoir (1943–1952) discharge data, Wycoff (2010) calculated an average of 412 ft^3/s of unaccounted discharge at Riverside Landing, the historic USGS gauging station (USGS # 02244000) located near the present location of Rodman Dam. A number changes have occurred in the Ocklawaha basin since these data were collected, including structural modifications in the Upper Ocklawaha (Tibbals et al., 2004), and the opening of a sinkhole in Orange Lake in 1957 (Kindinger et al., 1999) that have modified the water yield of the basin. For example, Wycoff (2010) reported a mean water yield (runoff volume /rainfall volume over watershed) for Orange Creek from 1943 to 1952 of 0.106; in comparison, the mean monthly water yield from 1990 through 2006 was 0.023.

In his groundwater modeling analysis, Tibbals (1989) predicted that the impoundment of Rodman Reservoir elevated the regional Florida aquifer potentiometric surface by up to 2 ft, extending a distance of 10 – 15 miles, and increased regional artesian spring discharge by 14 ft^3/s. If this is the case, then conversely, one might expect that removal of the reservoir would result in a reduction in the discharge of artesian springs in the region. Such a regional groundwater change would likely have some bearing on the free-flowing river effects on the LSJR, as it indicates that increased LOR flow (and load) would be compensated to some degree by artesian spring discharge reduction in other St. Johns River springs. Examination of the local upper Floridan monitoring well water level data during reservoir drawdowns suggests that changes in reservoir stage are communicated to the regional potentiometric surface through the changes in head pressure over the submerged springs. Abrupt reductions in the upper Floridan water level in the Forest Road No. 77 well, located adjacent and just to the south of the reservoir, can be seen coincident with reservoir drawdowns (Figure A-4). Delayed and less abrupt reductions in water level in the Frontier Dance Hall well, located 9.3 miles southeast of the reservoir are also discernible during reservoir drawdowns. Temporary reductions in artesian spring discharge are also apparent in the discharge time series for Silver Glen Springs, and in the intermittent discharge measurements made for Salt Springs and Croaker Hole. These transient changes in Florida Aquifer water level and artesian spring discharge could also occur from normal seasonal changes in aquifer recharge.

The relationship between reservoir stage, upper Floridan aquifer water level and artesian spring discharge are not well known as of this writing, and will need to be verified with additional data collection, analysis and groundwater modeling. For the purpose of this analysis, an operational presumption is followed such that any increases in discharge contributed by artesian springs submerged in Rodman Reservoir will be offset by decreases in artesian spring discharge elsewhere to the St. Johns River. As Rodman Reservoir submerged springs, based on limited sampling data, exhibit chemical constituent makeup similar to that of the St. Johns River springs group, the presumption in this analysis is that the reallocation of artesian spring would result in no net nutrient load change to the St. Johns. Hence, the submerged spring load is omitted from the free-flowing river load estimate. This presumption is incorporated in part because it imparts another conservative assumption into the analysis, as the omission of low concentration artesian spring flows increases downstream concentrations by omitting their dilution effect.

Predicted LSJR Discharge at Racy Pt. Through Extrapolation of EFDC Simulated Data

To calculate alternative scenario nutrient and chlorophyll-*a* concentrations for the benchmark TMDL water quality monitoring site at Racy Point (RM 64), it was necessary to estimate the monthly mean discharge for this location. For the Water Supply Impact Study, Sucsy et al. (2011) simulated river discharge from 1996–2005 with the dynamic, 3-D time-varying hydrodynamic model EFDC (Hamrick, 1996). In order to develop estimates of discharge at the freshwater reach station at Racy Point, 15 miles downstream of Palatka, these simulated data were used to develop a simple model to extrapolate discharge at Palatka (calculated as the sum of the upstream flows measured at Dunns Creek and Buffalo Bluff) to Racy Pt. Distance downstream was used to predict the slopes of the zero intercept regressions between Buffalo Bluff discharge, which were then used to predict the ratios of discharge between Palatka and Racy pt. This discharge multiplier was 1.046.

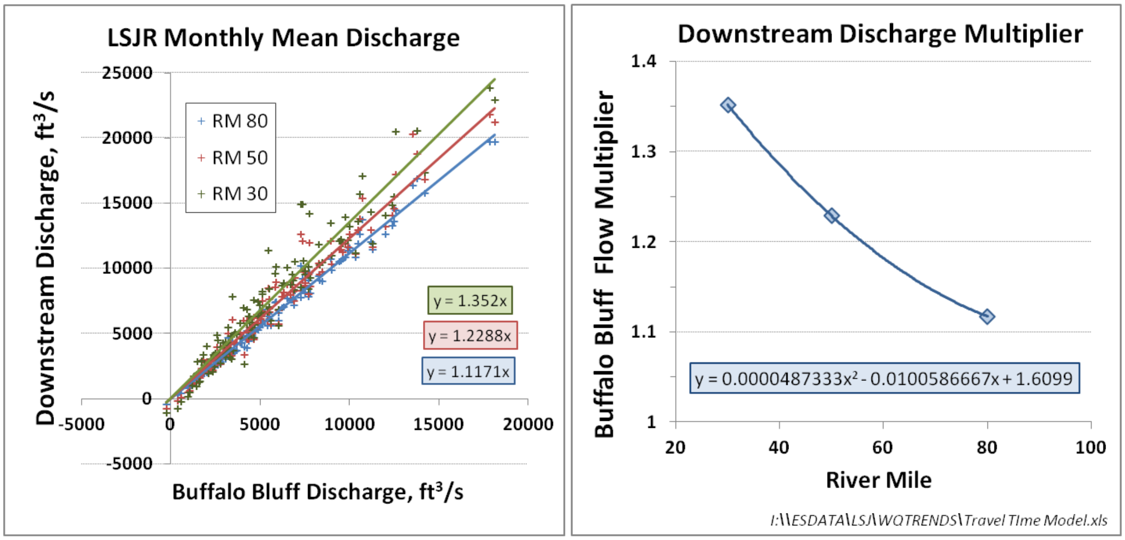

Figure A-6. LSJR Simulated Multipliers Used to Predict Discharge at Racy Pt.

APPENDIX B — LONGITUDINAL NUTRIENT PATTERNS IN THE LOWER OCKLAWAHA RIVER AND RODMAN RESERVOIR

Several phases of work have examined the longitudinal patterns in N and P forms in the Ocklawaha below the Silver River mouth. FDEP and SJRWMD staff (Magley, 2000; Hendrickson, 2000) examined the factors leading to the attenuation of NOx-N in the above-reservoir, free-flowing river reach between Connor and Eureka (Figure LOR-Map), and found that the NOx-N loss rate was strongly positively correlated with increasing river stage. Subsequent synchronized water quality collected at these two locations has shown that river stage is a strong predictor of the aggregate processes that modify downstream NOx delivery. Hydrologic processes associated with high river stage that increase the rate of longitudinal NOx decay include dilution, and increased assimilation and denitrification associated with greater cross-sectional area, decreased velocity and enhanced floodplain connectivity. Denitrification is believed to be the dominant process, and longitudinal NOx decline increases substantially when Highway 40 river stage is greater than 36 ft msl (NGVD29), an elevation corresponding to significant floodplain inundation (Figure NOx-stage (a)). A similar level of loss in NOx is observed for the 5.4 mile reach downstream of the dam to Highway 19, with the highest rate of loss appearing to occur when below-dam stage is greater than 4.5 ft (Figure NOx-stage (b)). In this reach, it appears that very low discharge conditions that occur during reservoir refill are conducive to the nitrification of organic and ammonia N, leading to a longitudinal increase in NOx. These processes could account for some of the low dissolved oxygen observed to occur in this reach during reservoir refills.

Utilizing the paired data collected between Connor and Eureka to parameterize the first-order decay model of Mulholland et al. (1992) led to a revised extrapolation of the FFR NOx load of approximately 300 MT/y, a substantial decrease from the alternatives analysis estimate of 878 MT/yr (ECT, 1994).

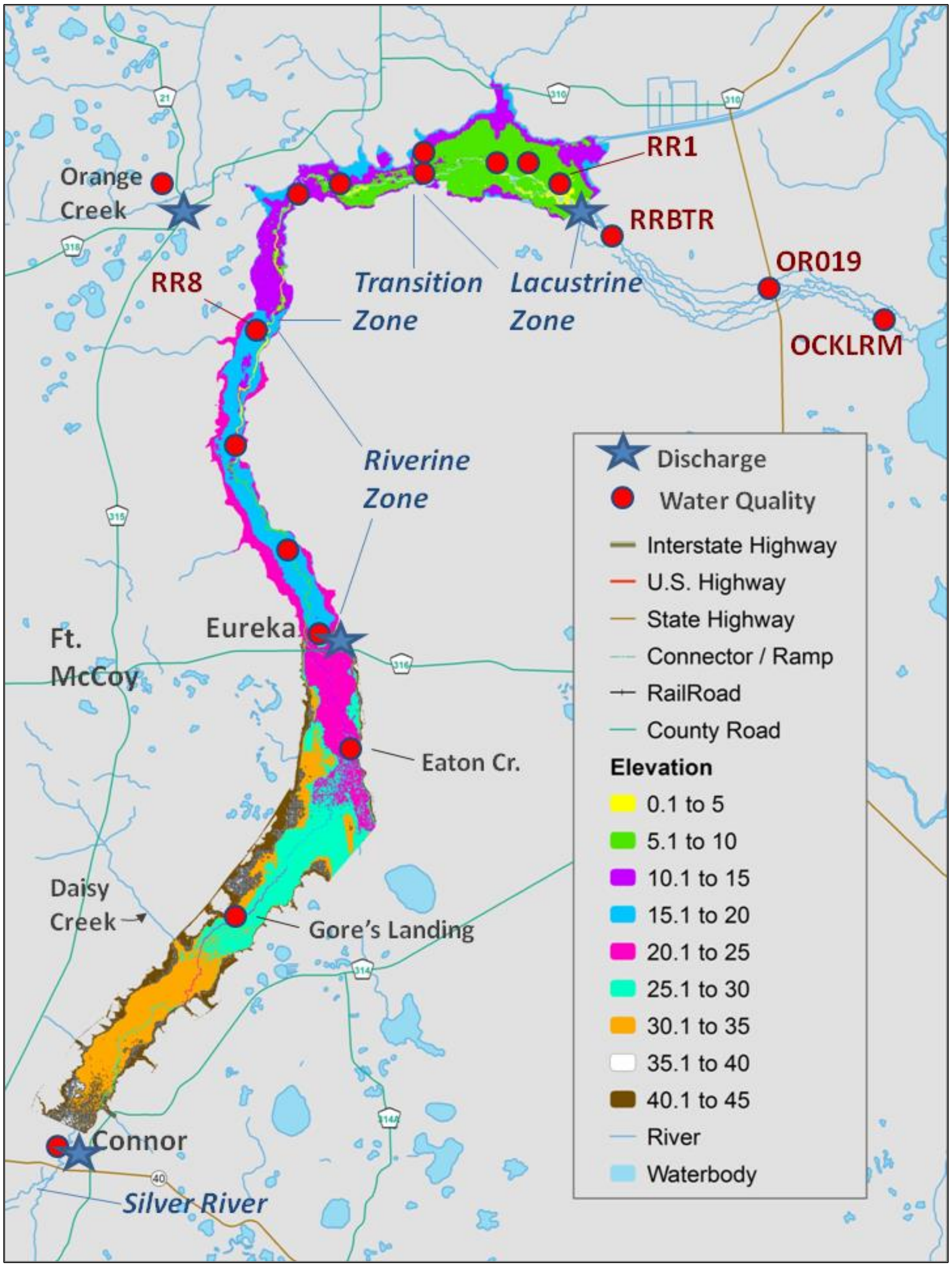

Figure LOR-Map. Rodman Reservoir Zones and Discharge and Water Quality Monitoring Sites. Elevations in NGVD29, determined from bathymetry and interpolation from cross-section survey transects.

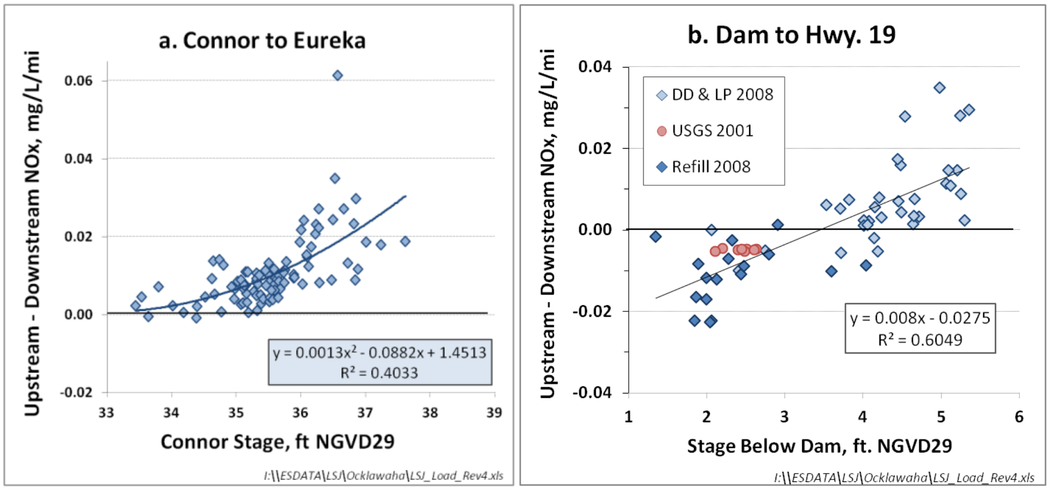

Figure NOx-Stage. Longitudinal Change in NOx between (a) Highway 40 (Connor) and County Rd. 316 (Eureka), and between (b) the Dam and Highway 19, as a function of stage. For (a), relationship developed from 64 paired sampling dates between 1994 and 2011, with transient flow outliers and dates with reservoir backwater effects omitted. For (b), relationship developed from the drawdown and low-pool phases of the 2008 drawdown.

Orthophosphate, and to a lesser degree TP, also exhibit positive correlations between stage and longitudinal concentration change. Recent monitoring by FDEP in the reach upstream of Rodman Reservoir for a segment relatively unaffected by external flow inputs (ascertaining the in-stream processing changes in TP from the longer-term record from Connor to Eureka is complicated by the inflow of elevated concentrations of TP from some tributaries) indicates that concentration change is weakly correlated with stage. The longitudinal change relationship is facultative whereby TP appears to increase in the downstream direction as stage falls below the critical floodplain inundation elevation, and decrease when stage is greater (Figure PxSTAGE-a). A similar pattern is observed in the reach below the dam, based on data collected during the 2008 reservoir drawdown, with TP and PO4 both decreasing longitudinally with stage increase above approximately 4 ft (NGVD29). As stage falls below this level, concentrations increase from upstream to downstream. This relationship is weak for TP, but relatively strong for PO4.

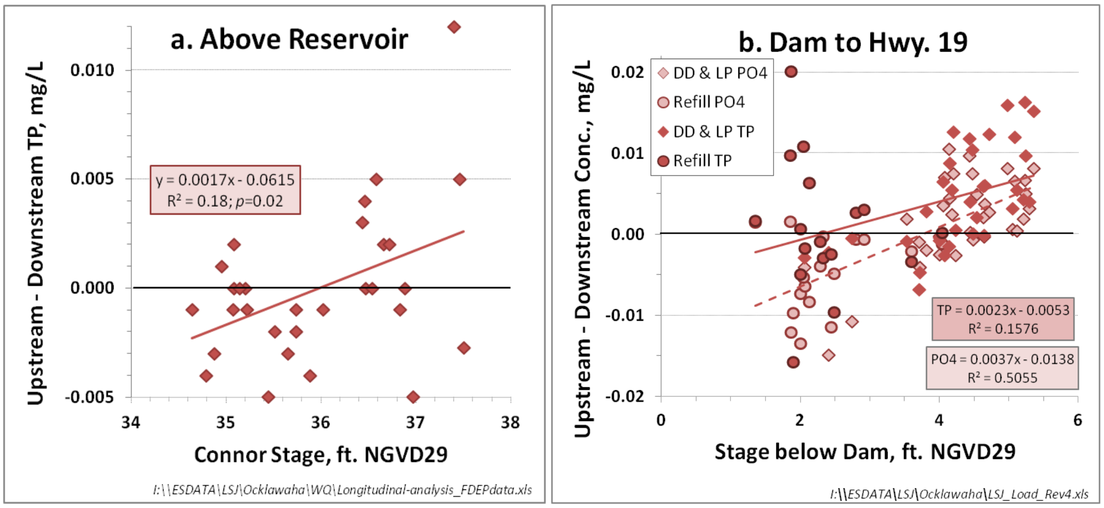

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Figure PxSTAGE. Longitudinal Change in Phosphorus Forms between (a) Gore's Landing and Eaton Creek, and between (b) the Dam and Highway 19, as a function of stage. For (a), relationship developed from 30 paired sampling dates between Dec. 2009 and Oct. 2012. For (b), relationship developed from the drawdown, low-pool and refill phases of the 2008 drawdown.

While longitudinal NOx decline (percent/mi) is low at low stage when flow is channel-bound, it is under these conditions that assimilation by aquatic primary producers appears to be relatively large. Evidence of this can be seen in the pattern of the relationship between NOx loss and incorporated N and P gain from Connor to Eureka. Channel-bound NOx loss is significantly correlated with Total Kjeldahl Nitrogen (TKN) increase, with approximately half of the NOx-N loss accounted for by TKN gain (Figure NOXtoORGNUT(a)). When river stage is sufficient to induce floodplain inundation, NOx loss and TKN increase from Connor to Eureka are uncorrelated. A similar pattern is evident for the relationship between NOx loss and non-PO4-P (TP – PO4) increase, though the level of significance for in-channel flow sampling events (p=0.06) is lower than that for nitrogen (p=0.0003) (NOXtoORGNUT(b)).

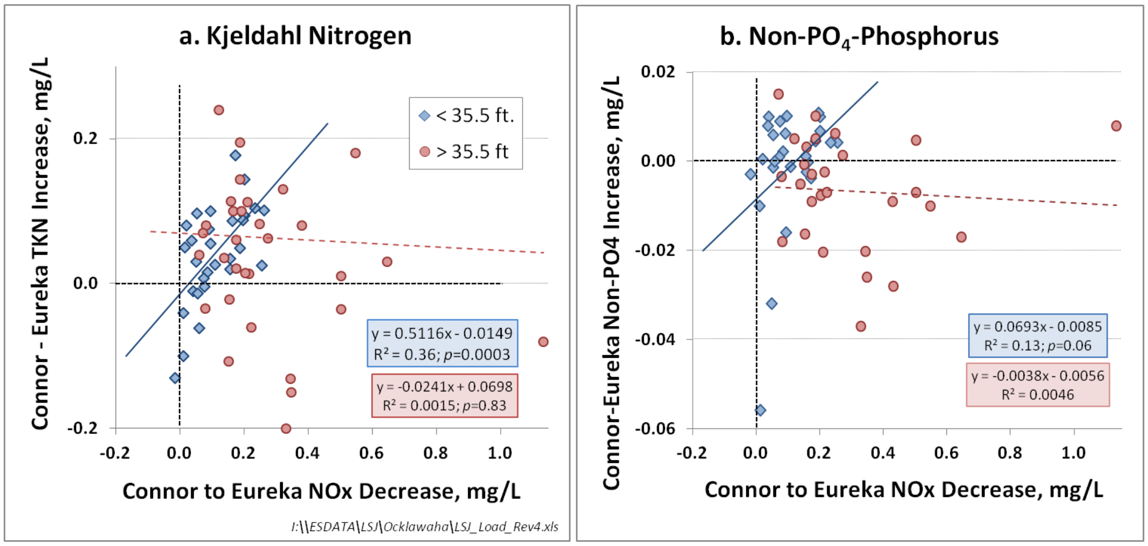

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Figure NOXtoORGNUT. Increase in Total Kjeldahl N (a) and Non-Orthophosphate-P (b) per Unit Loss in NOx-N in the Free-Flowing River Reach Between Connor and Eureka. Data are for 64 paired sampling events between 1994 and 2011. Events when transitional discharge conditions (discharge spike occurring at one location but not another) or Rodman Reservoir backwater influenced the Eureka sample were omitted.

Under the reservoir-full condition, NOx concentrations decline rapidly downstream of Eureka (Figure FDEP-data(a)). For sampling performed by the FDEP through 2010 – 2011when the reservoir was full, the relative loss in incoming NOx between Eureka and monitoring station RR8, located just above Orange Creek (a reach with no tributary inflow, hence most nutrient transformations can be attributed to floodplain and in-stream processes), averaged 54 percent (mean decrease = 0.59 mg/L) for samples collected from October–March, and 89 percent (mean decrease = 0.82 mg/L) for samples collected from April–September. The percent loss per mile, at 4.5 percent, was seven times greater than the channel-bound 0.6 percent per mile event mean loss between Connor and Eureka. Over this same reach, mean TKN increased by 43 percent (0.13 mg/L) from October – March, and by 25 percent (0.09 mg/L) from April – September. The lower rate of spring and summer TKN increase may be due to the increased fixed (i.e., rooted macrophytes or periphyton) incorporation, which would theoretically be sloughed as detritus in the fall and winter, accounting for the greater TKN gain during the October–March senescence and dormancy season. Overall mean annual average TKN gain at station RR8 for 2010 and 2011 was 0.11 mg/L, equivalent to 16 percent of the mean annual 0.69 mg/L loss in NOx.

Total phosphorus also declined longitudinally through the reservoir (Figure FDEP-Data(b)), with the mean decrease through the riverine reach to just above Orange Creek equivalent to 17 percent of the Eureka inflow concentration from October–March (0.007 mg/L), and 35 percent (0.015 mg/L) from April–September. From October–March, the mean differences between Eureka and downstream points within the reservoir were not significantly different from zero, while for the April–September season, differences were significant after the RR8 sampling location. Similar to that observed for NOx, the higher rate of TP decline from April–September suggests increased assimilation associated with higher fixed primary production. For many sampling events, the below-dam TP concentration was greater than that of the most downstream reservoir lacustrine reach station, suggesting that there may be floodplain inputs of TP in the tidal swamp below the reservoir. The mean difference in TP between the lacustrine reservoir station RR1 and the Ocklawaha mouth station OCKLRM was 0.008 mg/L, and was significantly greater than zero. The tendency for below-dam TP to increase downstream is also exhibited between the tailrace station and the mouth, with 34 of the 45 reservoir-full paired differences higher at the mouth. Exceptions to this downstream increase tend to occur most frequently in winter, and TP increase is weakly, positively correlated with water temperature (R2 = 0.21; p = 0.003). The increase was the greatest from April–June, corresponding with the time when floodplain waters would likely be receding, possibly leading to a net migration of shallow interstitial water from floodplain to river (Bowes et al., 2005).

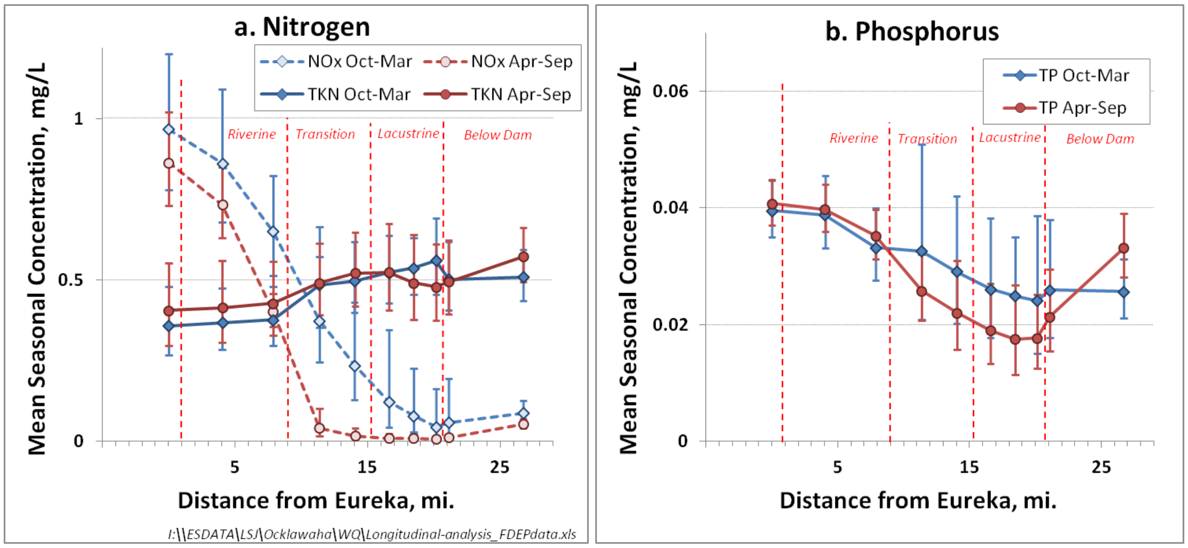
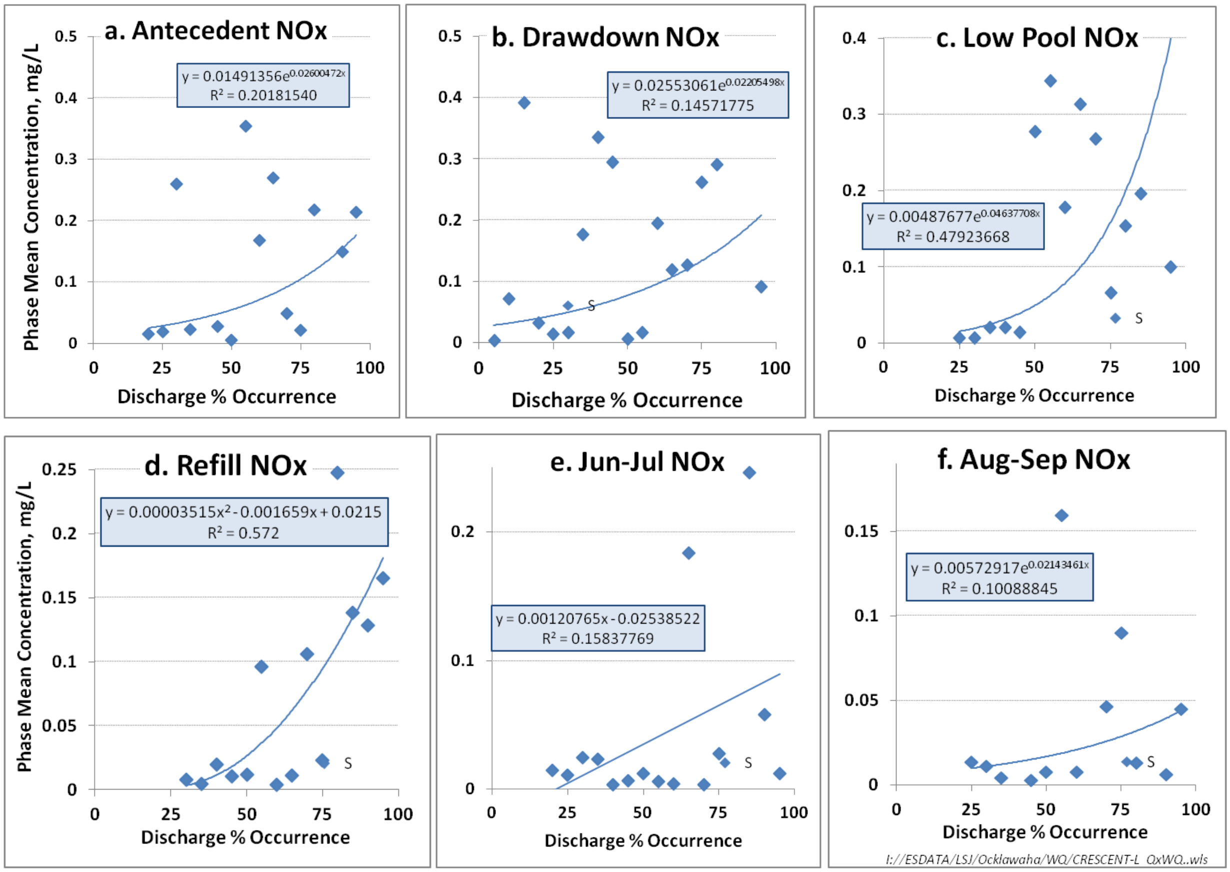


Figure FDEP-data. Mean Longitudinal Changes in (a) NOx and TKN and (b) TP in Rodman Reservoir for Reservoir Condition Sampling, 2010–2011. Data are divided into growing (April–September, red) and senescent/dormant seasons (October–March, blue).

APPENDIX C — LOWER OCKLAWAHA, DUNNS CREEK AND MIDDLE ST. JOHNS DISCHARGE VERSUS NUTRIENT CONCENTRATION MODELS

DUNNS CREEK

Nirate + Nitrite-N



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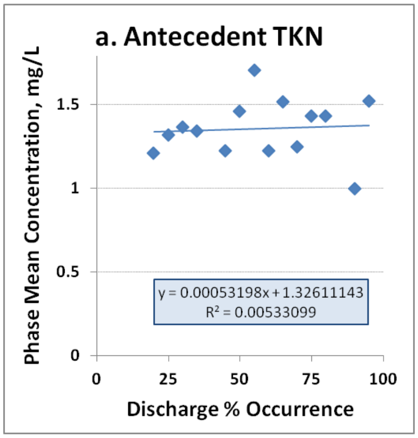
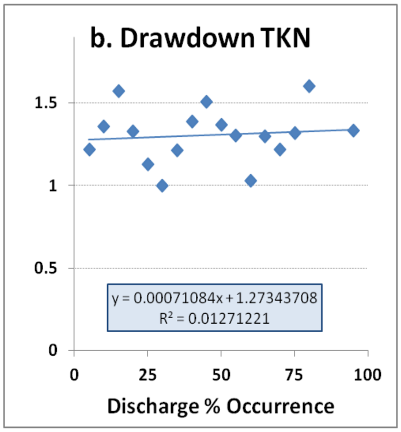
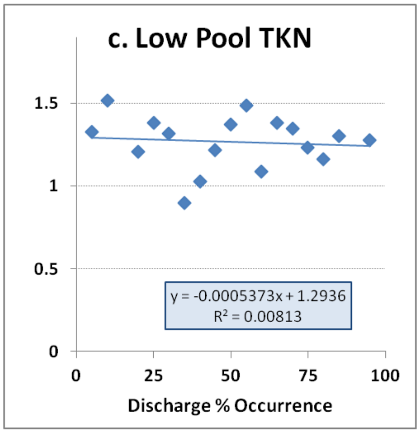
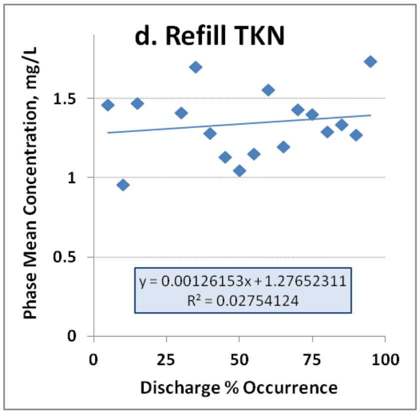
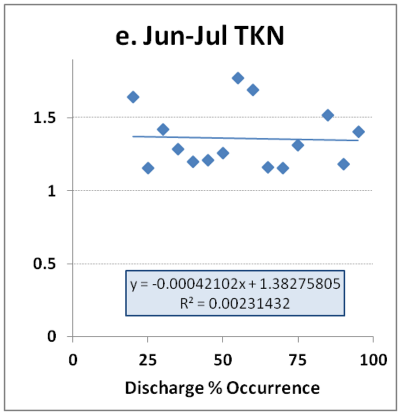
Total Kjeldahl-N

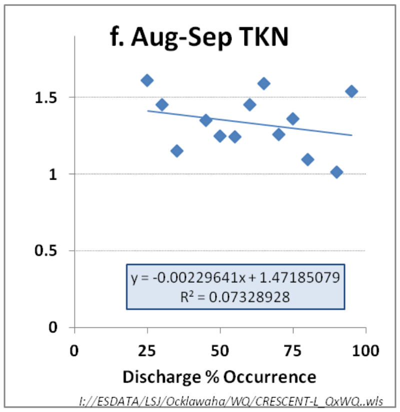

a. Antecedent TKN


b. Drawdown TKN

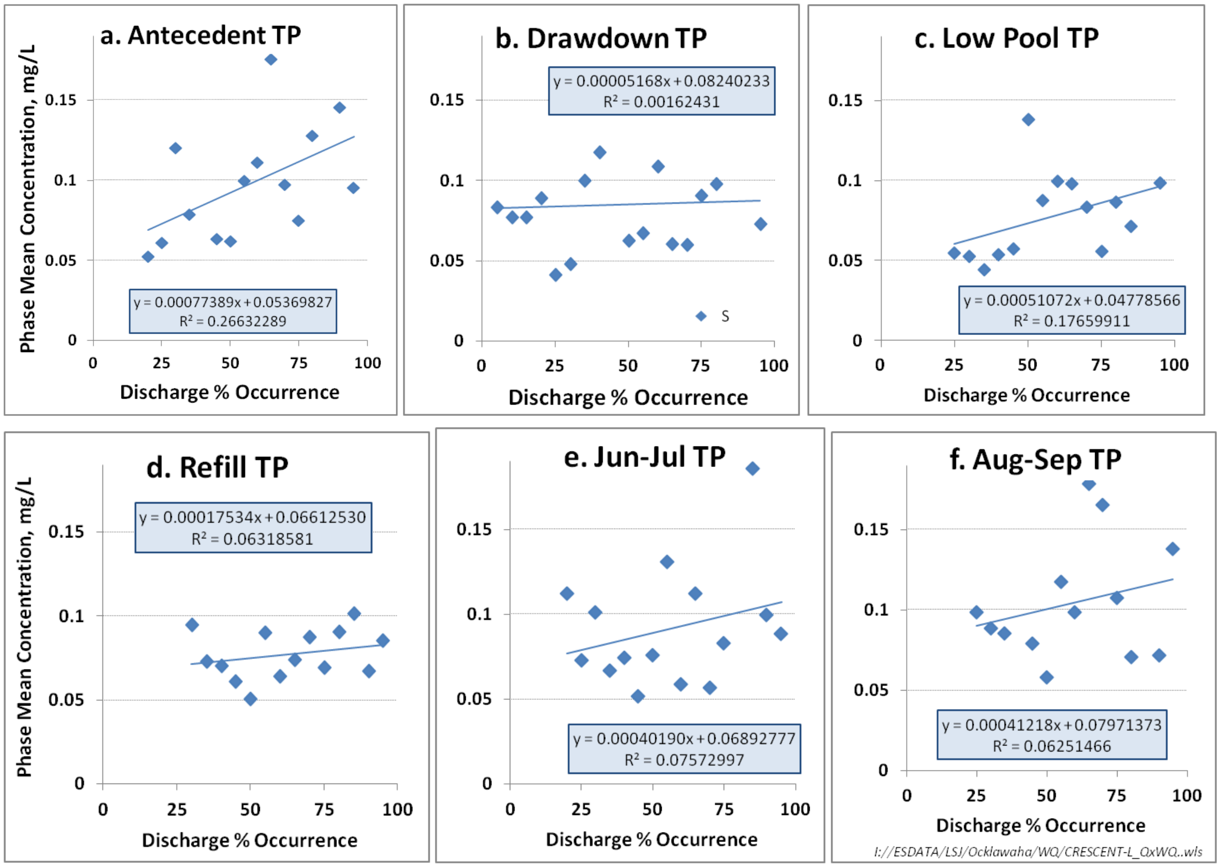

c. Low Pool TKN


d. Refill TKN


e. Jun-Jul TKN

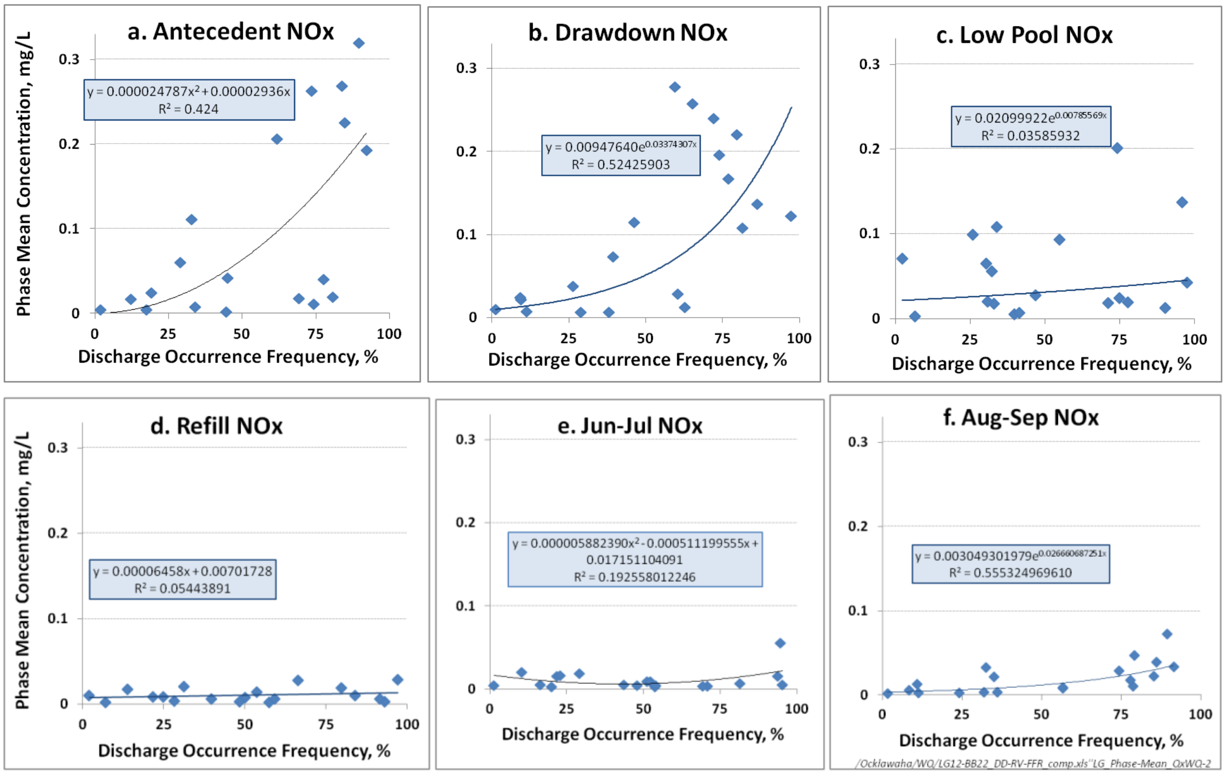

f. Aug-Sep TKN

Total Phosphorus



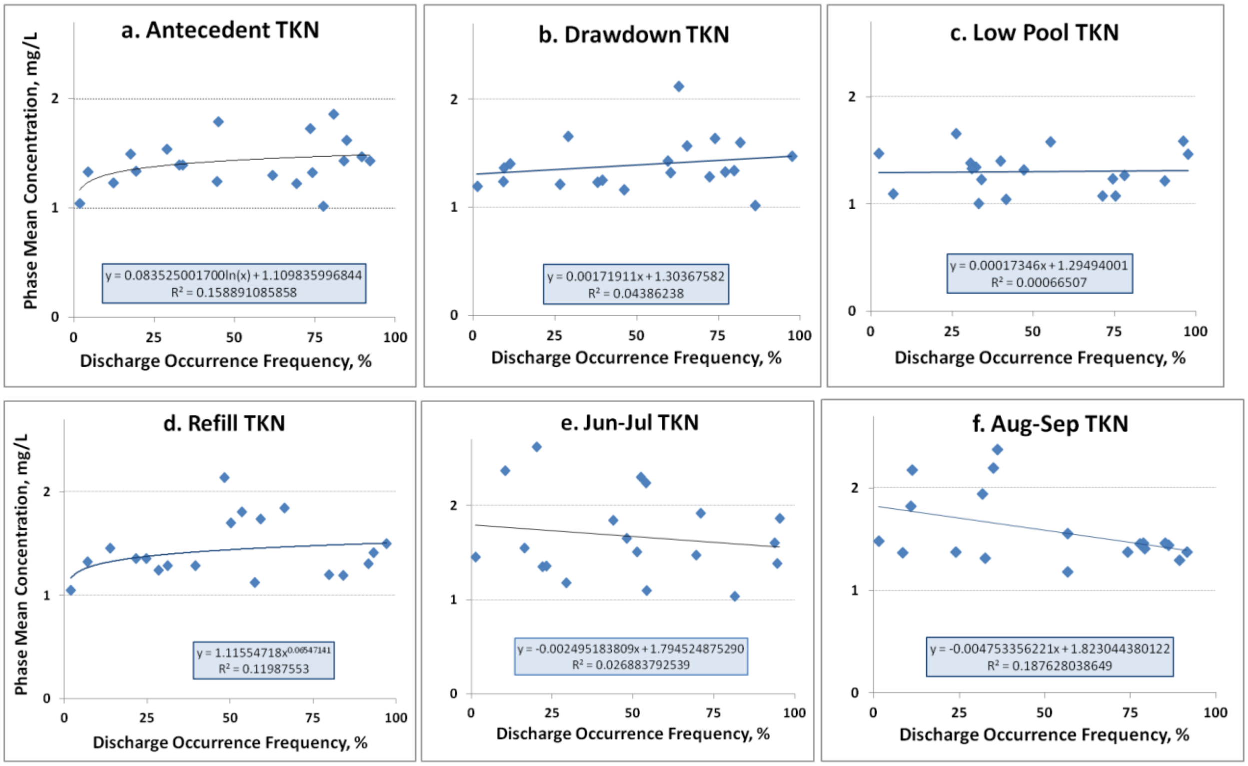
MIDDLE ST. JOHNS (LAKE GEORGE OUTLET)

Nitrate+Nitrite-N

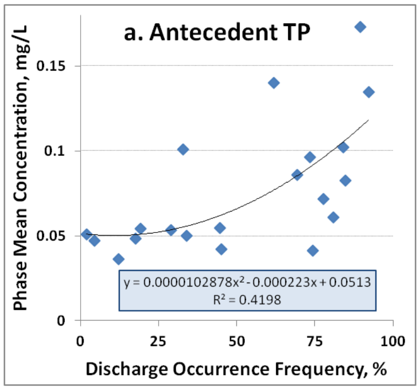


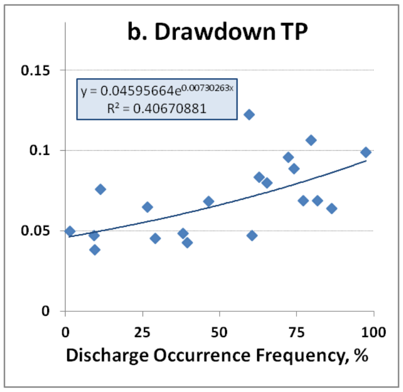
/Ocklawaha/WQ/LG12-BB22_DD-RV-FFR_comp.xls''LG_Phase-Mean_OxWQ-2

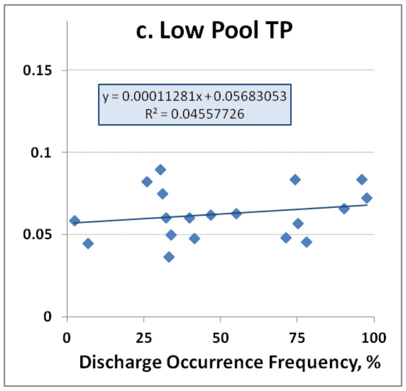
Total Kjeldahl N

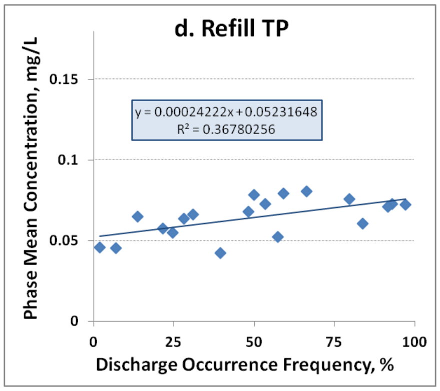


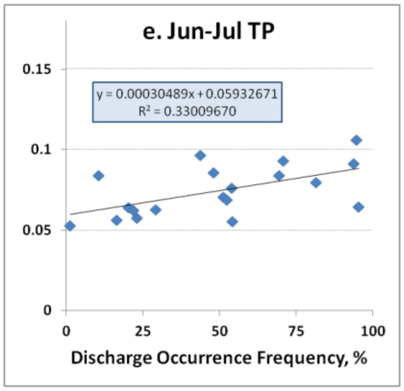
Total Phosphorus

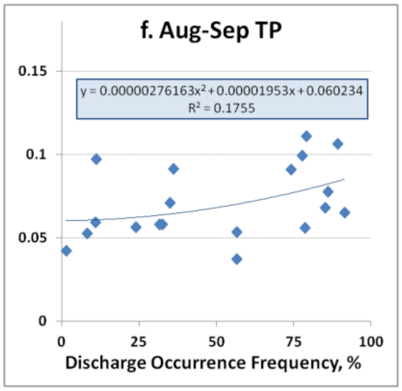












APPENDIX D — RESULTS OF CONSERVATIVE MIXING CALCULATIONS OF NOX LOADS AND CONCENTRATIONS IN THE LSJR AT BUFFALO BLUFF AND PALATKA AT THE 25TH, MEDIAN AND 75TH PERCENTILE RODMAN RESERVOIR MANAGEMENT PHASE MEAN OCCURRENCE DISCHARGE.

	RESERVOIR			**DRAWDOWN**			**Free-Flowing River**		
Antecedent	**25**	**50**	**75**	**25**	**50**	**75**	**25**	**50**	**75**
Lake George NOx mg/L	0.006	0.054	0.145	0.006	0.054	0.145	0.006	0.054	0.145
Lake George Q m3/s	84.0	134.3	207.7	84.0	134.3	207.7	84.0	134.3	207.7
Ocklawaha NOx mg/L	0.043	0.062	0.076	0.043	0.062	0.076	0.831	0.600	0.369
Ocklawaha Q m3/s	20.3	25.0	34.0	20.3	25.0	34.0	20.7	27.8	37.4
Ocklawaha Q% at SJR-BB	19.4	15.7	14.1	19.4	15.7	14.1	19.7	17.1	15.3
Duration (days)	50	50	50	50	50	50	50	50	50
L. George NOx Load, MT	2.15	31.54	130.33	2.15	31.54	130.33	2.15	31.54	130.33
Ocklawaha NOx Load, MT	3.74	6.65	11.21	3.74	6.65	11.21	74.11	71.96	59.60
Sum: SJR-BB Load MT	5.89	38.19	141.54	5.89	38.19	141.54	76.26	103.50	189.93
SJR BB Calc Conc NOx	0.0131	0.0555	0.1355	0.0131	0.0555	0.1355	0.1687	0.1478	0.1794
Dunns Cr. NOx mg/L	0.0286	0.0547	0.1049	0.0286	0.0547	0.1049	0.0286	0.0547	0.1049
Dunns Cr. Q m3/s	11.4	18.1	26.5	11.4	18.1	26.5	11.4	18.1	26.5
Dunns Q % at Palatka	9.9	10.2	9.9	9.9	10.2	9.9	9.8	10.0	9.8
Dunns Cr. Load NOx, MT	1.41	4.27	12.02	1.41	4.27	12.02	1.41	4.27	12.02
SJR Palatka Load Sum, MT	7.30	42.46	153.56	7.30	42.46	153.56	77.67	107.78	201.96
SJR Palatka Calc Conc	0.0146	0.0554	0.1325	0.0146	0.0554	0.1325	0.1549	0.1385	0.1721
Drawdown	**25**	**50**	**75**	**25**	**50**	**75**	**25**	**50**	**75**
Lake George NOx mg/L	0.022	0.051	0.119	0.022	0.051	0.119	0.022	0.051	0.119
Lake George Q m3/s	67.8	107.1	167.5	67.8	107.1	167.5	67.8	107.1	167.5
Ocklawaha NOx mg/L	0.084	0.092	0.100	0.084	0.092	0.100	0.858	0.661	0.463
Ocklawaha Q m3/s	20.6	26.7	37.5	40.8	47.8	54.4	19.3	25.3	33.2
Ocklawaha Q% at SJR-BB	23.3	20.0	18.3	37.6	30.9	24.5	22.2	19.1	16.5
Duration (days)	57	57	57	57	57	57	57	57	57
L. George NOx Load, MT	7.36	27.02	98.22	7.36	27.02	98.22	7.36	27.02	98.22
Ocklawaha NOx Load, MT	8.56	12.14	18.48	16.94	21.72	26.84	81.56	82.28	75.62
Sum: SJR-BB Load MT	15.92	39.16	116.69	24.30	48.74	125.06	88.92	109.30	173.84
SJR BB Calc Conc NOx	0.037	0.059	0.116	0.045	0.064	0.114	0.207	0.168	0.176
Dunns Cr. NOx mg/L	0.044	0.077	0.133	0.044	0.077	0.133	0.044	0.077	0.133
Dunns Cr. Q m3/s	6.8	11.0	25.8	6.8	11.0	25.8	6.8	11.0	25.8
Dunns Q % at Palatka	7.2	7.6	11.2	5.9	6.6	10.4	7.3	7.6	11.4
Dunns Cr. Load NOx, MT	1.49	4.15	16.95	1.49	4.15	16.95	1.49	4.15	16.95
SJR Palatka Load Sum, MT	17.41	43.31	133.65	25.79	52.89	142.02	90.41	113.46	190.79
SJR Palatka Calc Conc NOx	0.0371	0.0607	0.1176	0.0453	0.0647	0.1164	0.1953	0.1607	0.1711
Low Pool	**25**	**50**	**75**	**25**	**50**	**75**	**25**	**50**	**75**
Lake George NOx mg/L	0.026	0.031	0.038	0.026	0.031	0.038	0.026	0.031	0.038
Lake George Q m3/s	41.6	66.3	105.9	41.6	66.3	105.9	41.6	66.3	105.9
Ocklawaha NOx mg/L	0.081	0.128	0.175	0.340	0.306	0.271	0.890	0.687	0.483
Ocklawaha Q m3/s	19.6	24.3	33.6	26.8	36.8	46.3	18.1	25.5	35.9
Ocklawaha Q% at SJR-BB	32.0	26.8	24.1	39.2	35.7	30.4	30.3	27.8	25.3
Duration (days)	55	55	55	55	55	55	55	55	55
L. George NOx Load, MT	5.06	9.79	19.05	5.06	9.79	19.05	5.06	9.79	19.05
Ocklawaha NOx Load, MT	7.49	14.72	27.90	43.35	53.47	59.67	76.42	83.08	82.39
Sum: SJR-BB Load MT	12.54	24.51	46.95	48.40	63.27	78.72	81.47	92.87	101.44
SJR BB Calc Conc NOx	0.043	0.057	0.071	0.149	0.129	0.109	0.287	0.213	0.151
Dunns Cr. NOx mg/L	0.016	0.050	0.158	0.016	0.050	0.158	0.016	0.050	0.158
Dunns Cr. Q m3/s	6.7	9.6	16.0	6.7	9.6	16.0	6.7	9.6	16.0
Dunns Q % at Palatka	9.8	9.6	10.3	8.9	8.6	9.5	10.0	9.5	10.1
Dunns Cr. Load NOx, MT	0.49	2.27	12.00	0.49	2.27	12.00	0.49	2.27	12.00
SJR Palatka Load Sum, MT	13.03	26.78	58.95	48.89	65.54	90.72	81.96	95.14	113.44
SJR Palatka Calc Conc NOx	0.0404	0.0563	0.0798	0.1370	0.1224	0.1135	0.2600	0.1975	0.1513

APPENDIX D. (Cont.)

	RESERVOIR			DRAWDOWN			Free-Flowing River		
Refill	**25**	**50**	**75**	**25**	**50**	**75**	**25**	**50**	**75**
Lake George NOx mg/L	0.009	0.010	0.012	0.009	0.010	0.012	0.009	0.010	0.012
Lake George Q m3/s	23.1	40.8	71.0	23.1	40.8	71.0	23.1	40.8	71.0
Ocklawaha NOx mg/L	0.053	0.083	0.113	0.053	0.083	0.113	0.875	0.709	0.543
Ocklawaha Q m3/s	13.46	19.71	30.77	6.45	12.08	18.71	15.43	22.07	31.56
Ocklawaha Q% at SJR-BB	36.9	32.6	30.2	21.9	22.8	20.8	40.1	35.1	30.8
Duration (days)	75	46	28	75	46	28	60	60	60
L. George NOx Load, MT	1.29	1.66	2.04	1.29	1.66	2.04	1.03	2.17	4.37
Ocklawaha NOx Load, MT	4.59	6.45	8.40	2.20	3.95	5.10	69.98	81.09	88.78
Sum: SJR-BB Load MT	5.88	8.11	10.44	3.49	5.61	7.15	71.02	83.26	93.15
SJR BB Calc Conc NOx	0.025	0.034	0.042	0.018	0.027	0.033	0.356	0.255	0.175
Dunns Cr. NOx mg/L	0.002	0.026	0.095	0.002	0.026	0.095	0.002	0.026	0.095
Dunns Cr. Q m3/s	0.9	6.2	12.0	0.9	6.2	12.0	0.9	6.2	12.0
Dunns Q % at Palatka	2.4	9.3	10.5	3.0	10.5	11.8	2.3	8.9	10.5
Dunns Cr. Load NOx, MT	0.01	0.65	2.75	0.01	0.65	2.75	0.01	0.84	5.89
SJR Palatka Load Sum, MT	5.89	8.76	13.19	3.50	6.26	9.90	71.02	84.11	99.03
SJR Palatka Calc Conc NOx	0.024	0.033	0.048	0.018	0.027	0.040	0.348	0.235	0.167
June - July	**25**	**50**	**75**	**25**	**50**	**75**	**25**	**50**	**75**
Lake George NOx mg/L	0.008	0.006	0.012	0.008	0.006	0.012	0.008	0.006	0.012
Lake George Q m3/s	58.1	83.8	116.7	58.1	83.8	116.7	58.1	83.8	116.7
Ocklawaha NOx mg/L	0.058	0.075	0.088	0.058	0.075	0.088	0.767	0.668	0.568
Ocklawaha Q m3/s	15.5	21.2	30.0	15.5	21.2	30.0	16.5	21.8	29.0
Ocklawaha Q% at SJR-BB	21.1	20.2	20.4	21.1	20.2	20.4	22.1	20.7	19.9
Duration (days)	67	96	114	67	96	114	82	82	82
L. George NOx Load, MT	2.70	4.38	13.68	2.70	4.38	13.68	3.31	3.74	9.84
Ocklawaha NOx Load, MT	5.22	13.23	25.86	5.22	13.23	25.86	89.41	103.34	116.78
Sum: SJR-BB Load MT	7.92	17.61	39.53	7.92	17.61	39.53	92.72	107.08	126.62
SJR BB Calc Conc NOx	0.019	0.020	0.027	0.019	0.020	0.027	0.176	0.143	0.123
Dunns Cr. NOx mg/L	0.005	0.035	0.065	0.005	0.035	0.065	0.005	0.035	0.065
Dunns Cr. Q m3/s	1.9	4.0	24.8	1.9	4.0	24.8	1.9	4.0	24.8
Dunns Q % at Palatka	2.5	3.6	14.5	2.5	3.6	14.5	2.5	3.6	14.6
Dunns Cr. Load NOx, MT	0.05	1.15	15.95	0.05	1.15	15.95	0.06	0.98	11.48
SJR Palatka Load Sum, MT	7.97	18.76	55.48	7.97	18.76	55.48	92.79	108.06	138.10
SJR Palatka Calc Conc NOx	0.0183	0.0207	0.0328	0.0183	0.0207	0.0328	0.1713	0.1392	0.1143
August - September	**25**	**50**	**75**	**25**	**50**	**75**	**25**	**50**	**75**
Lake George NOx mg/L	0.006	0.012	0.023	0.006	0.012	0.023	0.006	0.012	0.023
Lake George Q m3/s	50.0	87.7	147.7	50.0	87.7	147.7	50.0	87.7	147.7
Ocklawaha NOx mg/L	0.066	0.075	0.081	0.066	0.075	0.081	0.664	0.496	0.328
Ocklawaha Q m3/s	20.7	29.7	39.4	20.7	29.7	39.4	21.2	28.2	37.4
Ocklawaha Q% at SJR-BB	29.3	25.3	21.0	29.3	25.3	21.0	29.8	24.3	20.2
Duration (days)	61	61	61	61	61	61	61	61	61
L. George NOx Load, MT	1.56	5.34	17.53	1.56	5.34	17.53	1.56	5.34	17.53
Ocklawaha NOx Load, MT	7.25	11.75	16.73	7.25	11.75	16.73	74.17	73.57	64.58
Sum: SJR-BB Load MT	8.81	17.10	34.26	8.81	17.10	34.26	75.73	78.91	82.11
SJR BB Calc Conc NOx	0.024	0.028	0.035	0.024	0.028	0.035	0.202	0.129	0.084
Dunns Cr. NOx mg/L	0.010	0.017	0.029	0.010	0.017	0.029	0.010	0.017	0.029
Dunns Cr. Q m3/s	0.8	13.1	32.5	0.8	13.1	32.5	0.8	13.1	32.5
Dunns Q % at Palatka	1.1	10.1	14.8	1.1	10.1	14.8	1.1	10.2	14.9
Dunns Cr. Load NOx, MT	0.04	1.16	4.90	0.04	1.16	4.90	0.04	1.16	4.90
SJR Palatka Load Sum, MT	8.85	18.25	39.15	8.85	18.25	39.15	75.77	80.07	87.01
SJR Palatka Calc Conc NOx	0.023	0.027	0.034	0.023	0.027	0.034	0.200	0.118	0.076

APPENDIX E — RESULTS OF CONSERVATIVE MIXING CALCULATIONS OF TKN LOADS AND CONCENTRATIONS IN THE LSJR AT BUFFALO BLUFF AND PALATKA AT THE 25TH, MEDIAN AND 75TH PERCENTILE RODMAN RESERVOIR MANAGEMENT PHASE MEAN OCCURRENCE DISCHARGE.

	RESERVOIR				DRAWDOWN				Free-Flowing River		
Antecedent	**25**	**50**	**75**		**25**	**50**	**75**		**25**	**50**	**75**
Lake George TKN mg/L	1.38	1.44	1.47		1.38	1.44	1.47		1.38	1.44	1.47
Lake George Q m3/s	84.0	134.3	207.7		84.0	134.3	207.7		84.0	134.3	207.7
Ocklawaha TKN mg/L	0.599	0.757	0.915		0.599	0.757	0.915		0.419	0.631	0.842
Ocklawaha Q m3/s	20.3	25.0	34.0		20.3	25.0	34.0		20.7	27.8	37.4
Ocklawaha Q% at SJR-BB	19.4	15.7	14.1		19.4	15.7	14.1		19.7	17.1	15.3
Duration (days)	50	50	50		50	50	50		50	50	50
L. George TKN Load, MT	500.9	832.9	1316.6		500.9	832.9	1316.6		500.9	832.9	1316.6
Ocklawaha TKN Load, MT	52.5	81.7	134.5		52.5	81.7	134.5		37.4	75.7	136.1
Sum: SJR@BB TKN Load MT	553.4	914.6	1451.0		553.4	914.6	1451.0		538.3	908.6	1452.7
SJR BB Calc Conc TKN	1.23	1.33	1.39		1.23	1.33	1.39		1.19	1.30	1.37
Dunns Cr. TKN mg/L	1.34	1.35	1.37		1.34	1.35	1.37		1.34	1.35	1.37
Dunns Cr. Q m3/s	11.4	18.1	26.5		11.4	18.1	26.5		11.4	18.1	26.5
Dunns Q % at Palatka	9.9	10.2	9.9		9.9	10.2	9.9		9.8	10.0	9.8
Dunns Cr. Load TKN, MT	65.95	105.54	156.62		65.95	105.54	156.62		65.95	105.54	156.62
SJR Palatka TKN Sum, MT	619.32	1020.16	1607.64		619.32	1020.16	1607.64		604.25	1014.11	1609.33
SJR Palatka Calc. TKN Conc	1.239	1.331	1.387		1.239	1.331	1.387		1.205	1.303	1.371
Drawdown	**25**	**50**	**75**		**25**	**50**	**75**		**25**	**50**	**75**
Lake George TKN mg/L	1.347	1.390	1.433		1.347	1.390	1.433		1.347	1.390	1.433
Lake George Q m3/s	67.8	107.1	167.5		67.8	107.1	167.5		67.8	107.1	167.5
Ocklawaha TKN mg/L	0.413	0.527	0.640		0.514	0.657	0.759		0.336	0.459	0.628
Ocklawaha Q m3/s	20.6	26.7	37.5		40.8	47.8	54.4		19.3	25.3	33.2
Ocklawaha Q% at SJR-BB	23.3	20.0	18.3		37.6	30.9	24.5		22.2	19.1	16.5
Duration (days)	57	57	57		57	57	57		57	57	57
L. George TKN Load, MT	449.85	733.20	1181.94		449.85	733.20	1181.94		449.85	733.20	1181.94
Ocklawaha TKN Load, MT	42.02	69.35	118.11		103.30	154.84	203.45		31.95	57.22	102.52
Sum: SJR@BB TKN Load MT	491.87	802.55	1300.05		553.15	888.04	1385.39		481.80	790.42	1284.46
SJR BB Calc Conc TKN	1.129	1.217	1.288		1.034	1.164	1.268		1.123	1.212	1.300
Dunns Cr. TKN mg/L	1.291	1.309	1.327		1.291	1.309	1.327		1.291	1.309	1.327
Dunns Cr. Q m3/s	6.8	11.0	25.8		6.8	11.0	25.8		6.8	11.0	25.8
Dunns Q % at Palatka	7.2	7.6	11.2		5.9	6.6	10.4		7.3	7.6	11.4
Dunns Cr. Load TKN, MT	43.56	70.67	168.51		43.56	70.67	168.51		43.56	70.67	168.51
SJR Palatka TKN Sum, MT	535.42	873.22	1468.56		596.71	958.71	1553.90		525.36	861.10	1452.97
SJR Palatka Calc. TKN Conc	1.141	1.224	1.292		1.049	1.173	1.274		1.135	1.219	1.303
Low Pool	**25**	**50**	**75**		**25**	**50**	**75**		**25**	**50**	**75**
Lake George TKN mg/L	1.299	1.304	1.308		1.299	1.304	1.308		1.299	1.304	1.308
Lake George Q m3/s	41.6	66.3	105.9		41.6	66.3	105.9		41.6	66.3	105.9
Ocklawaha TKN mg/L	0.427	0.593	0.758		0.519	0.725	0.930		0.361	0.559	0.757
Ocklawaha Q m3/s	19.6	24.3	33.6		26.8	36.8	46.3		18.1	25.5	35.9
Ocklawaha Q% at SJR-BB	32.0	26.8	24.1		39.2	35.7	30.4		30.3	27.8	25.3
Duration (days)	55	55	55		55	55	55		55	55	55
L. George TKN Load, MT	257.02	410.51	658.42		257.02	410.51	658.42		257.02	410.51	658.42
Ocklawaha TKN Load, MT	39.72	68.38	121.15		66.12	126.79	204.90		30.99	67.61	129.02
Sum: SJR@BB TKN Load MT	296.74	478.90	779.57		323.15	537.30	863.32		288.01	478.12	787.44
SJR BB Calc Conc TKN	1.021	1.113	1.175		0.994	1.097	1.193		1.015	1.097	1.169
Dunns Cr. TKN mg/L	1.280	1.267	1.253		1.280	1.267	1.253		1.280	1.267	1.253
Dunns Cr. Q m3/s	6.7	9.6	16.0		6.7	9.6	16.0		6.7	9.6	16.0
Dunns Q % at Palatka	9.8	9.6	10.3		8.9	8.6	9.5		10.0	9.5	10.1
Dunns Cr. Load TKN, MT	40.51	58.01	95.16		40.51	58.01	95.16		40.51	58.01	95.16
SJR Palatka TKN Sum, MT	337.25	536.91	874.73		363.66	595.31	958.48		328.52	536.13	882.60
SJR Palatka Calc. TKN Conc	1.046	1.128	1.183		1.019	1.111	1.199		1.042	1.113	1.177

APPENDIX E (Cont.)

	RESERVOIR			DRAWDOWN			Free-Flowing River		
Refill	**25**	**50**	**75**	**25**	**50**	**75**	**25**	**50**	**75**
Lake George TKN mg/L	1.377	1.441	1.480	1.377	1.441	1.480	1.377	1.441	1.480
Lake George Q m3/s	23.1	40.8	71.0	23.1	40.8	71.0	23.1	40.8	71.0
Ocklawaha TKN mg/L	0.515	0.701	0.887	0.745	0.862	0.980	0.343	0.484	0.681
Ocklawaha Q m3/s	13.46	19.71	30.77	6.45	12.08	18.71	15.43	22.07	31.56
Ocklawaha Q% at SJR-BB	36.9	32.6	30.2	21.9	22.8	20.8	40.1	35.1	30.8
Duration (days)	75	46	28	75	46	28	60	60	60
L. George TKN Load, MT	206.09	233.18	254.74	206.09	233.18	254.74	164.61	304.82	544.99
Ocklawaha TKN Load, MT	44.99	54.80	66.13	31.18	41.29	44.42	27.46	55.33	111.46
Sum: SJR@BB TKN Load MT	251.08	287.99	320.87	237.27	274.48	299.16	192.07	360.16	656.45
SJR BB Calc Conc TKN	1.060	1.200	1.301	1.239	1.309	1.376	0.963	1.105	1.234
Dunns Cr. TKN mg/L	1.308	1.340	1.371	1.308	1.340	1.371	1.308	1.340	1.371
Dunns Cr. Q m3/s	0.9	6.2	12.0	0.9	6.2	12.0	0.9	6.2	12.0
Dunns Q % at Palatka	2.4	9.3	10.5	3.0	10.5	11.8	2.3	8.9	10.5
Dunns Cr. Load TKN, MT	7.63	32.83	39.84	7.63	32.83	39.84	6.09	42.92	85.23
SJR Palatka TKN Sum, MT	258.71	320.82	360.71	244.90	307.31	339.00	198.17	403.07	741.69
SJR Palatka Calc. TKN Conc	1.066	1.213	1.308	1.241	1.312	1.375	0.971	1.126	1.249
June - July	**25**	**50**	**75**	**25**	**50**	**75**	**25**	**50**	**75**
Lake George TKN mg/L	1.732	1.670	1.607	1.732	1.670	1.607	1.732	1.670	1.607
Lake George Q m3/s	58.1	83.8	116.7	58.1	83.8	116.7	58.1	83.8	116.7
Ocklawaha TKN mg/L	0.514	0.641	0.767	0.648	0.773	0.898	0.381	0.498	0.614
Ocklawaha Q m3/s	15.5	21.2	30.0	15.5	21.2	30.0	16.5	21.8	29.0
Ocklawaha Q% at SJR-BB	21.1	20.2	20.4	21.1	20.2	20.4	22.1	20.7	19.9
Duration (days)	67	96	114	67	96	114	82	82	82
L. George TKN Load, MT	581.61	1161.64	1847.42	581.61	1161.64	1847.42	713.07	991.19	1329.37
Ocklawaha TKN Load, MT	46.14	112.64	226.57	58.14	135.95	265.34	44.44	77.04	126.23
Sum: SJR@BB TKN Load MT	627.74	1274.28	2073.99	639.75	1297.59	2112.76	757.52	1068.23	1455.61
SJR BB Calc Conc TKN	1.475	1.462	1.436	1.504	1.489	1.462	1.434	1.427	1.410
Dunns Cr. TKN mg/L	1.372	1.362	1.351	1.372	1.362	1.351	1.372	1.362	1.351
Dunns Cr. Q m3/s	1.9	4.0	24.8	1.9	4.0	24.8	1.9	4.0	24.8
Dunns Q % at Palatka	2.5	3.6	14.5	2.5	3.6	14.5	2.5	3.6	14.6
Dunns Cr. Load TKN, MT	15.08	44.69	330.54	15.08	44.69	330.54	18.49	38.14	237.85
SJR Palatka TKN Sum, MT	642.82	1318.98	2404.53	654.83	1342.28	2443.30	776.00	1106.36	1693.46
SJR Palatka Calc. TKN Conc	1.473	1.459	1.423	1.500	1.484	1.446	1.433	1.425	1.401
August - September	**25**	**50**	**75**	**25**	**50**	**75**	**25**	**50**	**75**
Lake George TKN mg/L	1.704	1.585	1.467	1.704	1.585	1.467	1.704	1.585	1.467
Lake George Q m3/s	50.0	87.7	147.7	50.0	87.7	147.7	50.0	87.7	147.7
Ocklawaha TKN mg/L	0.549	0.670	0.790	0.634	0.764	0.895	0.533	0.747	0.962
Ocklawaha Q m3/s	20.7	29.7	39.4	20.7	29.7	39.4	21.2	28.2	37.4
Ocklawaha Q% at SJR-BB	29.3	25.3	21.0	29.3	25.3	21.0	29.8	24.3	20.2
Duration (days)	61	61	61	61	61	61	61	61	61
L. George TKN Load, MT	448.73	732.54	1141.57	448.73	732.54	1141.57	448.73	732.54	1141.57
Ocklawaha TKN Load, MT	60.01	104.95	164.01	69.30	119.80	185.70	59.54	110.90	189.53
Sum: SJR@BB TKN Load MT	508.74	837.49	1305.58	518.03	852.34	1327.26	508.27	843.44	1331.10
SJR BB Calc Conc TKN	1.365	1.353	1.324	1.390	1.377	1.346	1.355	1.382	1.365
Dunns Cr. TKN mg/L	1.414	1.357	1.300	1.414	1.357	1.300	1.414	1.357	1.300
Dunns Cr. Q m3/s	0.8	13.1	32.5	0.8	13.1	32.5	0.8	13.1	32.5
Dunns Q % at Palatka	1.1	10.1	14.8	1.1	10.1	14.8	1.1	10.2	14.9
Dunns Cr. Load TKN, MT	5.68	93.98	222.58	5.68	93.98	222.58	5.68	93.98	222.58
SJR Palatka TKN Sum, MT	514.42	931.47	1528.16	523.71	946.32	1549.84	513.95	937.42	1553.68
SJR Palatka Calc. TKN Conc	1.366	1.354	1.321	1.390	1.375	1.339	1.356	1.379	1.355

APPENDIX F — RESULTS OF CONSERVATIVE MIXING CALCULATIONS OF TP LOADS AND CONCENTRATIONS IN THE LSJR AT BUFFALO BLUFF AND PALATKA AT THE 25TH, MEDIAN AND 75TH PERCENTILE RODMAN RESERVOIR MANAGEMENT PHASE MEAN OCCURRENCE DISCHARGE.

	Reservoir				Drawdown				Free-Flowing River		
Antecedent	**25**	**50**	**75**		**25**	**50**	**75**		**25**	**50**	**75**
Lake George TP mg/L	0.052	0.066	0.092		0.052	0.066	0.092		0.052	0.066	0.092
Lake George Q m3/s	84.0	134.3	207.7		84.0	134.3	207.7		84.0	134.3	207.7
Ocklawaha TP mg/L	0.028	0.040	0.052		0.028	0.040	0.052		0.042	0.054	0.065
Ocklawaha Q m3/s	20.3	25.0	34.0		20.3	25.0	34.0		20.7	27.8	37.4
Ocklawaha Q% at SJR-BB	19.4	15.7	14.1		19.4	15.7	14.1		19.7	17.1	15.3
Duration (days)	50	50	50		50	50	50		50	50	50
L. George TP Load, MT	18.93	38.23	82.96		18.93	38.23	82.96		18.93	38.23	82.96
Ocklawaha TP Load, MT	2.43	4.32	7.67		2.43	4.32	7.67		3.79	6.45	10.51
Sum: SJR-BB Load MT	21.36	42.55	90.63		21.36	42.55	90.63		22.71	44.68	93.47
SJR BB Calc Conc	0.047	0.062	0.087		0.047	0.062	0.087		0.050	0.064	0.088
Dunns Cr. TP mg/L	0.073	0.092	0.112		0.073	0.092	0.112		0.073	0.092	0.112
Dunns Cr. Q m3/s	11.4	18.1	26.5		11.4	18.1	26.5		11.4	18.1	26.5
Dunns Q % at Palatka	9.9	10.2	9.9		9.9	10.2	9.9		9.8	10.0	9.8
Dunns Cr. Load, MT	3.60	7.21	12.81		3.60	7.21	12.81		3.60	7.21	12.81
SJR Palatka Load Sum, MT	24.96	49.75	103.44		24.96	49.75	103.44		26.31	51.89	106.28
SJR Palatka Calc Conc	0.0499	0.0649	0.0892		0.0499	0.0649	0.0892		0.0525	0.0667	0.0906
Drawdown											
Lake George TP mg/L	0.055	0.066	0.079		0.055	0.066	0.079		0.055	0.066	0.079
Lake George Q m3/s	67.8	107.1	167.5		67.8	107.1	167.5		67.8	107.1	167.5
Ocklawaha TP mg/L	0.021	0.030	0.040		0.021	0.030	0.040		0.047	0.047	0.047
Ocklawaha Q m3/s	20.6	26.7	37.5		40.8	47.8	54.4		19.3	25.3	33.2
Ocklawaha Q% at SJR-BB	23.3	20.0	18.3		37.6	30.9	24.5		22.2	19.1	16.5
Duration (days)	57	57	57		57	57	57		57	57	57
L. George TP Load, MT	18.43	34.93	65.57		18.43	34.93	65.57		18.43	34.93	65.57
Ocklawaha TP Load, MT	2.17	4.01	7.30		4.30	7.18	10.61		4.42	5.81	7.65
Sum: SJR-BB Load MT	20.60	38.95	72.87		22.72	42.12	76.18		22.85	40.75	73.21
SJR BB Calc Conc	0.047	0.059	0.072		0.042	0.055	0.070		0.053	0.062	0.074
Dunns Cr. TP mg/L	0.084	0.085	0.086		0.084	0.085	0.086		0.084	0.085	0.086
Dunns Cr. Q m3/s	6.8	11.0	25.8		6.8	11.0	25.8		6.8	11.0	25.8
Dunns Q % at Palatka	7.2	7.6	11.2		5.9	6.6	10.4		7.3	7.6	11.4
Dunns Cr. Load, MT	2.82	4.59	10.96		2.82	4.59	10.96		2.82	4.59	10.96
SJR Palatka Load Sum, MT	23.42	43.54	83.83		25.55	46.70	87.14		25.67	45.34	84.17
SJR Palatka Calc Conc	0.050	0.061	0.074		0.045	0.057	0.071		0.055	0.064	0.075
Low Pool											
Lake George TP mg/L	0.060	0.062	0.065		0.060	0.062	0.065		0.060	0.062	0.065
Lake George Q m3/s	41.6	66.3	105.9		41.6	66.3	105.9		41.6	66.3	105.9
Ocklawaha TP mg/L	0.023	0.031	0.039		0.036	0.053	0.067		0.045	0.045	0.045
Ocklawaha Q m3/s	19.6	24.3	33.6		26.8	36.8	46.3		18.1	25.5	35.9
Ocklawaha Q% at SJR-BB	32.0	26.8	24.1		39.2	35.7	30.4		30.3	27.8	25.3
Duration (days)	55	55	55		55	55	55		55	55	55
L. George TP Load, MT	11.80	19.67	32.87		11.80	19.67	32.87		11.80	19.67	32.87
Ocklawaha TP Load, MT	2.18	3.60	6.21		4.53	9.27	14.73		3.88	5.47	7.71
Sum: SJR-BB Load MT	13.98	23.27	39.08		16.33	28.94	47.60		15.68	25.14	40.58
SJR BB Calc Conc	0.048	0.054	0.059		0.050	0.059	0.066		0.055	0.058	0.060
Dunns Cr. TP mg/L	0.061	0.073	0.086		0.061	0.073	0.086		0.061	0.073	0.086
Dunns Cr. Q m3/s	6.7	9.6	16.0		6.7	9.6	16.0		6.7	9.6	16.0
Dunns Q % at Palatka	9.8	9.6	10.3		8.9	8.6	9.5		10.0	9.5	10.1
Dunns Cr. Load, MT	1.92	3.36	6.54		1.92	3.36	6.54		1.92	3.36	6.54
SJR Palatka Load Sum, MT	15.90	26.63	45.62		18.25	32.30	54.13		17.60	28.50	47.12
SJR Palatka Calc Conc	0.0493	0.0559	0.0617		0.0511	0.0603	0.0677		0.0558	0.0592	0.0628

APPENDIX F (Cont.)

	Reservoir				**Drawdown**				**Free-Flowing River**		
Refill	**25**	**50**	**75**		**25**	**50**	**75**				
Lake George TP mg/L	0.058	0.064	0.070		0.058	0.064	0.070		0.058	0.064	0.070
Lake George Q m3/s	23.1	40.8	71.0		23.1	40.8	71.0		23.1	40.8	71.0
Ocklawaha TP mg/L	0.030	0.042	0.054		0.054	0.064	0.075		0.043	0.050	0.058
Ocklawaha Q m3/s	13.46	19.71	30.77		6.45	12.08	18.71		15.43	22.07	31.56
Ocklawaha Q% at SJR-BB	36.9	32.6	30.2		21.9	22.8	20.8		40.1	35.1	30.8
Duration (days)	79	66	26		79	66	26		60	60	60
L. George TP Load, MT	9.14	14.92	11.36		9.14	14.92	11.36		6.98	13.63	25.96
Ocklawaha TP Load, MT	2.76	4.71	3.77		2.36	4.40	3.17		3.42	5.71	9.51
Sum: SJR-BB Load MT	11.90	19.63	15.12		11.50	19.32	14.52		10.40	19.33	35.47
SJR BB Calc Conc	0.048	0.057	0.065		0.057	0.064	0.071		0.052	0.059	0.067
Dunns Cr. TP mg/L	0.071	0.075	0.079		0.071	0.075	0.079		0.071	0.075	0.079
Dunns Cr. Q m3/s	0.9	6.2	12.0		0.9	6.2	12.0		0.9	6.2	12.0
Dunns Q % at Palatka	2.4	9.3	10.5		3.0	10.5	11.8		2.3	8.9	10.5
Dunns Cr. Load, MT	0.43	2.63	2.16		0.43	2.63	2.16		0.33	2.40	4.93
SJR Palatka Load Sum, MT	12.33	22.25	17.28		11.93	21.95	16.68		10.73	21.73	40.40
SJR Palatka Calc Conc	0.0485	0.0588	0.0669		0.0578	0.0655	0.0723		0.0525	0.0607	0.0680
June-July											
Lake George TP mg/L	0.067	0.075	0.082		0.067	0.075	0.082		0.067	0.075	0.082
Lake George Q m3/s	58.1	83.8	116.7		58.1	83.8	116.7		58.1	83.8	116.7
Ocklawaha TP mg/L	0.029	0.038	0.046		0.042	0.058	0.074		0.045	0.052	0.058
Ocklawaha Q m3/s	15.5	21.2	30.0		15.5	21.2	30.0		16.5	21.8	29.0
Ocklawaha Q% at SJR-BB	21.1	20.2	20.4		21.1	20.2	20.4		22.1	20.7	19.9
Duration (days)	63	76	116		63	76	116		82	82	82
L. George TP Load, MT	21.30	41.20	95.95		21.30	41.20	95.95		27.56	44.27	67.98
Ocklawaha TP Load, MT	2.46	5.25	13.91		3.57	8.07	22.09		5.27	8.02	12.01
Sum: SJR-BB Load MT	23.76	46.46	109.87		24.87	49.27	118.04		32.83	52.29	79.99
SJR BB Calc Conc	0.059	0.067	0.075		0.062	0.071	0.080		0.062	0.070	0.077
Dunns Cr. TP mg/L	0.079	0.089	0.099		0.079	0.089	0.099		0.079	0.089	0.099
Dunns Cr. Q m3/s	1.9	4.0	24.8		1.9	4.0	24.8		1.9	4.0	24.8
Dunns Q % at Palatka	2.5	3.6	14.5		2.5	3.6	14.5		2.5	3.6	14.6
Dunns Cr. Load, MT	0.82	2.32	24.62		0.82	2.32	24.62		1.06	2.49	17.44
SJR Palatka Load Sum, MT	24.58	48.78	134.48		25.70	51.59	142.66		33.90	54.78	97.42
SJR Palatka Calc Conc	0.0594	0.0679	0.0784		0.0621	0.0718	0.0831		0.0626	0.0706	0.0806
August-September											
Lake George TP mg/L	0.062	0.068	0.077		0.062	0.068	0.077		0.062	0.068	0.077
Lake George Q m3/s	50.0	87.7	147.7		50.0	87.7	147.7		50.0	87.7	147.7
Ocklawaha TP mg/L	0.031	0.041	0.050		0.031	0.041	0.050		0.046	0.056	0.066
Ocklawaha Q m3/s	20.7	29.7	39.4		20.7	29.7	39.4		21.2	28.2	37.4
Ocklawaha Q% at SJR-BB	29.3	25.3	21.0		29.3	25.3	21.0		29.8	24.3	20.2
Duration (days)	61	61	61		61	61	61		61	61	61
L. George TP Load, MT	16.44	31.47	60.12		16.44	31.47	60.12		16.44	31.47	60.12
Ocklawaha TP Load, MT	3.41	6.38	10.42		3.41	6.38	10.42		5.09	8.27	13.01
Sum: SJR-BB Load MT	19.85	37.85	70.54		19.85	37.85	70.54		21.53	39.75	73.13
SJR BB Calc Conc	0.053	0.061	0.072		0.053	0.061	0.072		0.057	0.065	0.075
Dunns Cr. TP mg/L	0.090	0.100	0.111		0.090	0.100	0.111		0.090	0.100	0.111
Dunns Cr. Q m3/s	0.8	13.1	32.5		0.8	13.1	32.5		0.8	13.1	32.5
Dunns Q % at Palatka	1.1	10.1	14.8		1.1	10.1	14.8		1.1	10.2	14.9
Dunns Cr. Load, MT	0.36	6.95	18.95		0.36	6.95	18.95		0.36	6.95	18.95
SJR Palatka Load Sum, MT	20.21	44.80	89.49		20.21	44.80	89.49		21.89	46.70	92.07
SJR Palatka Calc Conc	0.0537	0.0651	0.0773		0.0537	0.0651	0.0773		0.0577	0.0687	0.0803

APPENDIX G — PROPOSED OCKLAWAHA RIVER RESTORATION NUTRIENT LOAD EFFECTS ASSESSMENT PLAN

Ocklawaha River Restoration Downstream Nutrient Load Effects Phased Assessment Plan

SJRWMD Division of Water Resources

May 31, 2012

Overview

The restoration of a free-flowing Lower Ocklawaha River (LOR) will change the hydrologic, chemical and biological characteristics of this aquatic ecosystem, and alter the magnitude and timing of fresh water flow and nutrient (nitrogen and phosphorus) loads to the St. Johns River Estuary (SJRE), the portion of the St. Johns River below the head of tide, from the inlet of Lake George to the mouth, and the downstream portion of which, the Lower St. Johns River (LSJR), has an established Total Maximum Daily Load (TMDL) for nutrients. This assessment plan proposes a methodology whereby existing computer models of the LOR and the SJRE would be applied in comparative scenario simulations to quantify the differences in hydrodynamics and water quality aspects related to eutrophication, for the existing LOR reservoir condition, and a free-flowing river condition. This quantification of water quality effects is needed to assess the viability of a proposed LOR restoration, and possible mitigation requirements to offset adverse effects. The aquatic ecosystem attributes to be assessed in this modeling study are: The changes in the spatial and temporal patterns of SJRE discharge, residence time and salinity associated with the restoration of a free-flowing LOR; The changes in the processing of nitrogen, phosphorus and carbon, associated with the transformation of the reservoir reach of the LOR from lacustrine to riverine, and the effect of this change on the delivery of nutrient mass loads to the SJRE; The changes in the algal productivity of the SJRE elicited by this change in nutrient load, dilution and residence time, particularly as it relates to the potential noncompliance of targets established for the TMDL for the freshwater LSJR, and the general worsening of eutrophication.

This outline describes a 3-stage analysis and modeling approach proposed by the SJRWMD Division of Water Resources for achieving the above goals. Stage 1 will provide an assessment of the upper limits of effects, and will be completed in a relatively short period of time for advanced planning purposes. It will use existing models to assess potential effects under the assumption that all of the nutrient assimilative capability of the restored reservoir reach will be lost. If results of this conservative assessment ("conservative" in the sense that its results should represent the strongest adverse effects, and hence decisions based upon it would be the most cautious) indicate that effects on the river are of the magnitude that can reasonably be mitigated, then work would proceed on stage 2 to refine models to predict the most probable effects.

In stage 2, the following two existing models of the LOR would be refined to assess the most probable effects:

1. A EFDC hydrodynamic model of the LOR would be recalibrated with historic, free-flowing river data, and applied to predict free-flowing river hydrologic characteristics;
2. A semi-empirical model of longitudinal nitrogen attenuation would be expanded to include the Rodman Reservoir reach, and enhanced to also include phosphorus, carbon and oxygen processing.

The EFDC hydrodynamic model of the LOR, after the additional stage 2 calibration, will be used to simulate the free-flowing river condition to (1) calculate area, duration, and depth of inundation of the LOR flood plain as inputs to the semi-empirical nutrient attenuation model (2 above), and (2) predict daily discharge and nutrient concentrations at the mouth of the Ocklawaha River as input to the Water Supply Impact Study (WSIS) versions of the SJRE hydrodynamic and water quality models. Scenarios with this input would represent the probable effects of a free-flowing LOR relative to a baseline condition, as the processes known to occur in the riverine environment, such as dilution, assimilation, and denitrification, would be included in this prediction.

The purpose of stages 1 and 2 is to assess the effects of nitrogen and phosphorus loads for a fully restored Ocklawaha River after a new steady-state, post-restoration free-flowing river condition is reached. A general approach to the assessment of transient effects occurring during the restoration is described in Stage 3.

Stage 1 Assessment – Effects With No LOR Nutrient Attenuation

WSIS CE-QUAL-ICM Water Quality Model

The WSIS CE-QUAL-ICM water quality model domain includes the entire SJRE from inlet of Lake George at Astor to the mouth of the St. Johns River and into the Atlantic Ocean inner shelf. The Ocklawaha River mouth is included in the SJRE model domain. Preparation of this model for this application will be performed by the Bureau of Engineering, in cooperation with the Bureau of Environmental Sciences, and will include:

1. Assessment of model goodness of fit, and limited recalibration to optimize the simulation of key parameters within the focus area of study;
2. Reformulation of inflow constituent loads at the model boundaries and contributing areas as concentrations, to create flexibility in scenarios creation;
3. Set-up of the TMDL nutrient input condition to serve as the scenarios baseline;
4. Create a concentration input boundary for the Ocklawaha River representing a “no nutrient attenuation” condition, based on the observed water quality data of the major inputs above and into Rodman Reservoir.

Two model scenario runs are proposed for this assessment of effects, as shown in Table 1, covering the time period from 1996–2008. This time period allows for the complete utilization of the available contributing watershed discharge time series (developed with the watershed model HSPF for the WSIS), and inclusion of the four, 11 foot Rodman Reservoir drawdowns from 1998–2008. HSPF simulated discharge will only be used where direct observed discharge data are unavailable. This time period also benefits from a more detailed chemistry time series for the upstream model boundary at the outlet of the middle St. Johns (MSJ) at Astor, where sampling was intensified to twice monthly in October 2004. Reformulation of the model input loads to concentrations (#2) is being done here to facilitate the application of different scenarios, and is merely an alternative method of model setup that has no effect on nutrient load delivery.

Recalibration will focus on model performance for Lake George, while the effects assessment will focus on the differences between LOR reservoir versus free-flowing river scenarios at Racy Pt. in the LSJR. Lake George is selected for calibration because of its detail of input chemistry data and stability in adjacent basin land development. Racy Pt. is selected to represent the alternative scenario effects, as it is downstream of the Ocklawaha and typically exhibits the maximum freshwater phytoplankton biomass. Model state variable kinetics parameters within CE-QUAL-ICM will be adjusted by comparison of simulated concentrations with in-river observed data. Calibration will be accomplished through the tuning of algal and bacterial productivity control parameters that control the partitioning of nutrients, organic carbon, and oxygen, within accepted bounds based on controlled studies, to optimize the fit between in-river observed and simulated data. Calibration will focus primarily on salinity, algal biomass organic carbon, total nitrogen, total phosphorus, and oxygen.

The free-flowing Ocklawaha River discharge to the SJR will be based on the historic 1943–1952 relationship between gauged inflow at Eureka and Orange Creek and discharge at Riverside, the USGS stream gauging station near the present Rodman Dam location prior to impoundment of Rodman Reservoir. The use of data from these downstream locations eliminates the effect of the reductions in discharge that have occurred over time above Moss Bluff and in Orange Creek. The approach to the development of this free-flowing river time series will undergo separate internal review prior to its application in the restoration scenarios.

Model scenario run results will be collated as statistics for relevant time periods, such as months or seasons, and as differences between scenarios, again focusing on the critical model variables salinity, algal biomass organic carbon, total nitrogen, total phosphorus, and oxygen.

These tasks will take about 60 hours of staff time, but must be spread out over four weeks to allow for lengthy computer run times.

Table 1. Stage 1 Modeling Scenarios

	Scenario	SJRE External Load Condition	LOR Condition
1	BASELINE: Rodman Reservoir and LSJR TMDL	LSJR TMDL-compliant nutrient load; Current condition MSJ WQ	Current reservoir-condition discharge measured at Rodman Dam including periodic drawdowns; biweekly chemistry data collected just above the Ocklawaha mouth (SJRWMD ambient monitoring station “OCKLRM” data)
2	Scenario 1. Free-flowing LOR, no reservoir-reach nutrient attenuation	LSJR TMDL-compliant nutrient load; Current condition	Observed chemistry data from Eureka, Deep Creek, Orange Creek, and submerged springs, calculated as flow-weighted composite without attenuation in the reservoir reach of the river;

	and LSJR TMDL	MSJ WQ	discharge estimated from pre-reservoir flow data relationships

Stage 2 – Effects With Nutrient Attenuation

EFDC Hydrodynamic Model of the LOR

A preliminary EFDC hydrodynamic model of the LOR was completed in 2010 under contract with Applied Technology & Management (ATM) and with funding from FDEP. This model application extends from the mouth of the Silver River (Connor) to Rodman Dam, with the model grid based on a topographic surface of the currently submerged portion of Rodman Reservoir reconstructed from best available survey transect and bathymetric data. Use of this model for the restoration scenarios application requires four additional steps:

1. Expansion of the model grid downstream from Rodman Dam to the confluence of the Ocklawaha River with the LSJR;
2. Calculation of increased artesian spring flow expected under a restored river condition;
3. Calibration of the EFDC hydrodynamic model using pre-dam stage-discharge relationships;
4. Simulation of the restored condition using meteorological conditions for the period from 1995 – 2011.

We recommend that ATM, the original developers of the model, perform this additional work. ATM can complete this work in 10 weeks at a cost of $27,000.

Nitrogen and Phosphorus Attenuation Model

Improved WQ monitoring instituted in 1999 shows that Ocklawaha River NOx-N concentration declines in the riverine reach between Silver River and Eureka, with the rate (i.e., loss per distance) of decline being an empirical function of river stage. Implicit in stage as the controlling variable of longitudinal change in NOx-N (and in other nutrient forms as well) are morphometric characteristics that control sedimentation, assimilation, and dissimilatory loss: stream velocity, segment volume, and the depth, areal extent and duration of interaction with the river floodplain. While this stage model can adequately predict NOx change in the free-flowing reach between the Silver River and Eureka, as it was developed and calibrated based on data for this reach, one can surmise that downstream of Eureka, the fundamental morphometric parameters relating stage to nutrient transformation will change, hence invalidating this simple Connor to Eureka stage model for downstream, free-flowing river scenario predictions. In addition, this model predicts only NOx change; for this effects assessment, it will be necessary to expand the model capabilities to include longitudinal phosphorus, organic carbon and oxygen (N, P, OC and O) patterns and processing.

To overcome these limitations, it is proposed to supplant the Silver River to Eureka model with a version based on the fundamental hydro-morphometric variables that exert process-based control of longitudinal N, P, OC and O transformation. A time-series of hydro-morphometric characteristics will be developed using the EFDC hydrodynamic model of the LOR (described above) for the period 1997 – 2011, to match the time period of available water quality data. The hydrodynamic model output will be condensed into a set of hydro-morphometric statistics for reaches of the river both above and below Eureka, with the free-flowing reach from Connor to Eureka used for model development and calibration. This improved nutrient assimilation and processing model will then be applied to reach below Eureka based on its free-flowing river hydro-morphometric statistics, also developed with the EFDC application. The outcome of this model simulation will be an estimate of the expected N, P, OC and O concentrations exiting the Ocklawaha River under the restored river condition.

TMDL Compliant Nutrient Load Inputs

It is proposed to construct two different nutrient concentration time series for the major boundaries at Astor (St. Johns River at SR 40) and Connor Ocklawaha River at SR 40) under this Stage 2 “Effects with Nutrient Attenuation” Ocklawaha restoration effects assessment:

1. A current condition water quality time series, based on actual observed data collected at these locations over the simulation time period;
2. A TMDL-compliant water quality time series that reflects the expected nutrient reductions under the MSJ TMDL, and a reduction of Silver River NOx to the proposed standard of 0.35 mg/ L.

Each of these water quality time series will be developed into model scenarios. The objective of the current condition scenario is to assess effects to the lower St. Johns River under the present upstream water quality condition. The TMDL compliant scenario objective is to assess the effects on the lower St. Johns that would be expected when TMDL nutrient conditions are achieved for both the middle St. Johns and the Ocklawaha.

WSIS CE-QUAL-ICM Water Quality Model

The WSIS CE-QUAL-ICM water quality model of the SJRE, as it was prepared in Stage 1 above for the baseline and alternative 1 scenarios, will be reapplied with Ocklawaha River discharge and nutrient concentrations developed in sections II.A and II.B and C substituted as model inputs. These scenarios will determine the most probable effects of free-flowing Ocklawaha River nutrient loads on the LSJR, under the condition with LSJR TMDLs in place, with and without upstream TMDLs. Analysis of model simulation results will again focus on the amounts, and changes in, salinity, algal biomass organic carbon, total nitrogen, total phosphorus, and oxygen. The scenarios planned for model simulations in Stage 2 are listed in Table 2.

Table 2. Stage 2 Modeling Scenarios

	Scenario	SJRE External Load Condition	LOR Condition
3	Scenario 2: Free-flowing LOR, Current condition WQ with In-stream Assimilation, LSJR	LSJR TMDL nutrient load; current condition MSJ WQ	Free-flowing river discharge estimated from pre-reservoir flow data relationships; Nitrogen and phosphorus attenuation of current condition WQ at LOR at Eureka, Orange Creek, Deep Creek, and submerged springs within the reservoir reach

	TMDL		
4	Scenario 3: Free-flowing LOR, TMDL-compliant WQ with In-stream Assimilation, LSJR TMDL	LSJR TMDL nutrient load; TMDL-compliant MSJ WQ	Free-flowing river discharge estimated from pre-reservoir flow data relationships; Nitrogen and phosphorus attenuation of TMDL-compliant WQ at the LOR at Eureka, Orange Creek, Deep Creek, and submerged springs within the reservoir reach

<u>Milestones and Schedule for Stages 1 and 2</u>

The following milestones and schedule follow the attached figure. Days to completion from the start of the project are provided in parentheses.

Stage 1 – LSJR Effects with No LOR Reservoir-Reach Nutrient Attenuation: Initial Assessment (30 days).

This milestone compares the baseline condition (Rodman Reservoir with LSJR TMDL-compliant nutrient loads) to a free-flowing LOR with no attenuation of nutrients in the restored reservoir reach, and is designed to provide an initial evaluation of the upper limit of potential effects associated the post-restoration LOR. The milestone is preceded by a calibration of model variables in the WSIS CE-QUAL-ICM water quality model.

Stage 2 – LSJR Effects with LOR Reservoir-Reach Nutrient Attenuation Under Upstream Current Condition and TMDL-Compliant Nutrient Concentrations (90 days after notice to proceed to ATM)

This milestone follows implementation of the EFDC hydrodynamic model of the LOR and estimation of nitrogen and phosphorus attenuation under the restored river condition. The EFDC-simulated discharge and attenuated nutrient concentration time-series for the mouth of the Ocklawaha River will be used to quantify the effect on the LSJR of increased nutrient loads due to a proposed Ocklawaha River restoration.

<u>Summary</u>

This assessment of the effects of altered nitrogen and phosphorus loads on the LSJR due to a restored Ocklawaha River is expected to take approximately four months total for both the initial and detailed assessment stages. Consulting work is additionally required at a cost of $27,000. In-house estimates of staff time are approximately 80 hours for the Bureau of Engineering and 200 hours for the Bureau of Environmental Sciences.

Stage 3. Assessment of Transient Restoration Construction Phase Effects

The preceding modeling investigation plan focuses on the changes in nutrient load and water quality effects on the LSJR for a post-LOR restoration state, when sufficient time has elapsed for the system to conform to a new steady-state. Transient WQ effects are expected to occur due the hydrologic manipulation and system perturbation associated with reservoir storage changes and earth-moving, and sediment resuspension during the restoration. Stage 3 modeling would assess these transient effects on the LSJR.

Effects on Lower St. Johns River Nutrient Supply and TMDL Target Compliance from the Restoration of a Free-Flowing Ocklawaha River

The original Ocklawaha River Restoration plan called for the restoration to be completed in four phases. Phase I of the restoration involves preparation and construction equipment placement, scour assessments, and other preliminary activities that have no bearing on downstream water quality. The three subsequent phases are summarized below:

<u>Phase II:</u>

- Pre-drawdown dredging to remove sediments from historic Ocklawaha River channel, 2000 feet upstream of dam; some work on west end of CFBC;
- Lower reservoir stage from 18 to 12 ft
- Plant vegetation strips on exposed upstream portions of floodplain.
- Install cribbing at select vulnerable sections of channel to prevent erosion.
- Clear side artesian spring channels of sediments and woody debris;
- Reconstruct historic cannels where intersected by CFBC.

<u>Phase III:</u>

- Second dredging of dam end of historic Ocklawaha River channel
- Lower reservoir stage from 12 ft to 6 ft
- Temporary boat portage system at Rodman Dam, and closure of Buckman Lock
- More vegetation strip planting and channel cribbing
- More clearing of artesian spring (Yazoo channels) runs
- Additional reconstruction of historic channels for Ocklawaha R., Deep Cr. And Camp Br.
- Close Buckman lock

<u>Phase IV</u>

- Third dredging of dam end of natural river channel
- Install sheet pile walls at both ends of Ocklawaha River channel above and below dam (upstream sheet pile dam will have riser boards) open dam embankment 2000 ft, dredge historic river channel; stabilize opening with vegetation, erosion control fabric
- Restore flow in the historic Ocklawaha R. channel by sequentially removing riser boards from sheet pile dam, slowly over a one month period;
- More streamside vegetation planting and channel stabilization
- Demolish Rodman Dam gate; partially fill dam tailrace.

The timeline for the original LOR restoration is summarized in Table 2.

Table 2. Timeline for Lower Ocklawaha River Restoration.

Phase	Year 1				Year 2				Year 3			
I	▨											
II	▨	▨	▨	▨	▨							
III					▨	▨	▨	▨	▨			
IV									▨	▨	▨	▨

In a draft revised restoration plan (FDEP, 2010), additional pre-construction phases have been proposed to moderate the transition of reservoir to river floodplain forest prior to construction, and to reduce the transient effects from oscillating wetting and drying cycles that accompany reservoir refills and storm-event related floodplain inundation and dewatering. This revised plan calls for successive reservoir drawdowns, separated by partial refills lasting for 18 to 20 months. The first drawdown to 11 feet would be initiated in October, with the first partial refill the following February to 16.5 ft This would be followed by another drawdown to 11 feet in 19 months, again to 11 feet, then a partial refill to 14.5 feet. A final drawdown would again be done in another 19 months to 9.5 feet, with the last refill to 11 feet. The restoration construction phase would begin after the stabilization at the 11 feet stage.

Because the details of the restoration may undergo revision, the nature and timing of drawdown and construction activities is presently uncertain. The effect of LOR restoration construction phase activities on the downstream SJRE will depend on various factors, such as the time of year that elements of the phased restoration plan occur, the discharge in the LOR relative to the St. Johns River, and events that occur during the restoration that affect LOR upstream discharge and exposed floodplain re-saturation. During the restoration, it will be necessary to apply adaptive management and to “design-build” in order to mitigate unpredictable and potentially adverse effects.

When the details of restoration phase have been established, we propose that the TMDL-condition SJRE WQ model be re-applied to guide the timing of restoration activities and mitigate of transient WQ effects. Alternative versions of the LOR EFDC application should be constructed to reflect the interim Ocklawaha Valley morphology for restoration phases, and re-applied to develop separate hydrologic statistics that can be reassessed through the nutrient attenuation model, in order to predict potential nutrient assimilation and export under a set of discharge conditions that may occur during restoration phases. This set of potential nutrient export scenarios should be tested with the SJRE WQ model to identify the optimal timing for restoration activities. A water quality monitoring program should also be implemented prior to and during the restoration, in order to evaluate model performance and undertake corrective actions.

FDEP Transmittal Correspondence. Fri 6/1/2012 10:57 AM

Frank and Wayne –

Thank you for your comments to the lower Ocklawaha restoration assessment plan, and your time on the teleconference Tuesday to explain the recommended revisions. I believe this attached revised version incorporates your recommendations, and is an improved plan with these changes. This version:

- Eliminates the 1995-99 condition set of scenarios, keeping only the LSJR TMDL condition. This was a good suggestion, as these would not be very relevant to the current condition, and as you indicated Frank, the impact on the TMDL condition of the LSJR is ultimately what the restoration effects will be judged against.
- Adds more detail on the extent of the model domain, the locations that will be relied upon for calibration and assessment of model scenario differences, and the statistics that will be developed;
- Adds detail on the proposed methods for developing the flow and chemistry inputs for scenarios.
- Adds an Ocklawaha and Middle St. Johns "TMDL compliant" nutrient load scenario.
- Incorporates into the stage 3 section of the plan the possibility of an alternative restoration timeline and approach, and the potential use of the modeling suite developed here in restoration activities timing and adaptive management.

Let me know if you see other modifications that you feel need to be included.

As for progress thus far, Pete has the full WSIS SJRE WQ model running for the complete simulation time period, and we are set to commence calibration. We also have a version of the free-flowing river discharge created and under review. So hopefully, we will have the stage 1 work done in less than the projected 30 days.

Jchend

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From: Nearhoof, Frank [mailto:Frank.Nearhoof@dep.state.fl.us]
Sent: Monday, May 21, 2012 2:32 PM
To: Ed Lowe; Bartlett, Drew
Cc: Casey Fitzgerald; Michael Cullum; Peter Sucsy; John Hendrickson; Vielhauer, Trina; Magley, Wayne
Subject: RE: Modeling work plan for Lower Ocklawaha

Ed: Wayne Magley and I have reviewed and discussed this and have the attached questions/comments (I should have consolidated these, but wanted to expedite getting them back so I apologize for the overlaps). It may be useful to have a quick teleconference to discuss. Look these over & if you want to do that give me some potentially available times on your end. Also, I make reference I my comments to the Restoration Plan itself & a potential alternative plan I created a while back. I'm attaching that also. FLN

Please take a few minutes to share your comments on the service you received from the department by clicking on this link DEP Customer Survey.

From: Ed Lowe [mailto:elowe@sjrwmd.com]
Sent: Wednesday, May 09, 2012 12:05 PM
To: Bartlett, Drew; Nearhoof, Frank
Cc: Casey Fitzgerald; Michael Cullum; Peter Sucsy; John Hendrickson
Subject: Modeling work plan for Lower Ocklawaha

Drew and Frank:

Attached is our proposed work plan for modeling of the effects of management options. We would need support for the contracting costs (approx. $27K).

Ed

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