Southwest Florida Water Management District

Technical Memorandum

To: File

From: M. Heyl, Chief Environmental Scientist, Springs and Environmental Flows

Date: February 29, 2012 (Updated April 6 and October 24, 2012)

RE: Impact of flow on NO_3+NO_2-N concentration in seven Florida spring discharges.

The relationship between water quality, particularly nitrite and nitrate nitrogen, and minimum flows and levels (MFLs) was raised by Dr. R. Knight at the October 26, 2011 Springs Coast Stake-Holder's meeting[1]. Increases in nitrate (NO_3-N) plus nitrite (NO_2-N) nitrogen concentrations in spring systems within the St. Johns River Water Management District and the Southwest Florida Water Management District (District) have been documented and the source attributed mostly to inorganic fertilizer application (Phelps 2004. Jones et al. 1997). In addition to increases in nitrate+nitrite nitrogen (NO_X-N) concentrations, the discharge of many Florida spring systems have been declining since the 1960s. The initial [2]evaluation was undertaken to determine if there is a relationship between spring flow and NO_X-N concentrations in the Chassahowitzka River, Homosassa River and Silver River systems. The primary source of water for these three systems is groundwater discharging from the Upper Floridan aquifer, which is at, or near land surface over much of the respective groundwater basins. Nutrients introduced at land surface can percolate directly into the aquifer and become entrained in groundwater movement relatively unimpeded. The Chassahowitzka and Homosassa are in the Coastal Springs Groundwater Basin (Knochenmus and Yobbi 2001) while Silver Springs is in a separate groundwater basin. In addition, this technical memorandum responds to several other flow related issues.

Flow

Spring flow in these three systems is directly related to potentiometric difference with the Floridan aquifer. The discharge estimates reported by the United States Geologic Survey (USGS) for many of the spring systems along the west coast of Florida are derived from Upper Floridan water level (potentiometric surface) measured at the Weeki Wachee Well (USGS 28320108231561). Water level in the Upper Floridan aquifer is directly related to rainfall. Figure 1 illustrates the cumulative annual departure from the long-term (1910-2007) rainfall average (56.3 inches) at the Chinsegut Hill National Oceanographic Atmospheric Administration weather station at Brooksville. Compared to the long-term average, the cumulative annual rainfall has been gradually declining at this station since the 1960s. Annual springflow for the three systems and the Weeki Wachee River, another area spring-dominated system, was normalized (divided

---

[1] http://www.swfwmd.state.fl.us/files/database/site_file_sets/2053/BKnight_-_Spring_MFLs_Workshop_Slides_26oct2011[1].pdf

[2] Weeki Wachee, Gum Springs, Southeast Fork Homosassa and Rainbow were subsequently added.

by respective1967-2007 averages) and superimposed on the rainfall departure and presented as Figure 2. This plot indicates that the spring discharge patterns very closely mirrors the rainfall departure. Declines in flow during 1967-2007 were statistically significant for all systems shown (p values for linear declines: Chassahowitzka = 0.008, Weeki Wachee = 0.004, Rainfall – 0.009 and Silver river = 0.000).

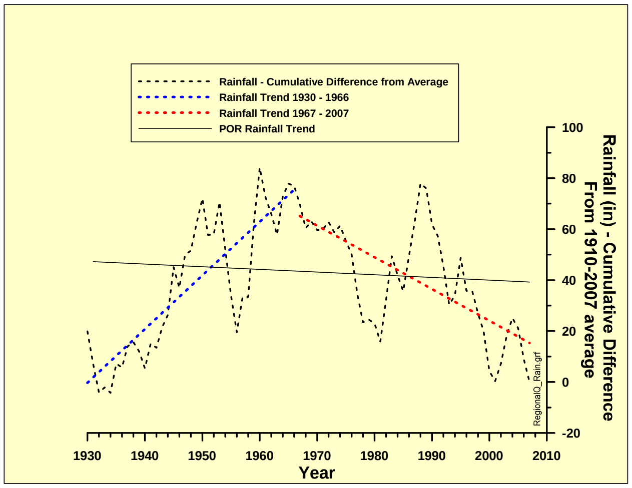

Figure 1. Annual rainfall – cumulative departure from long-term average. Trends shown: 1930 – 1966 and 1967 – 2010.

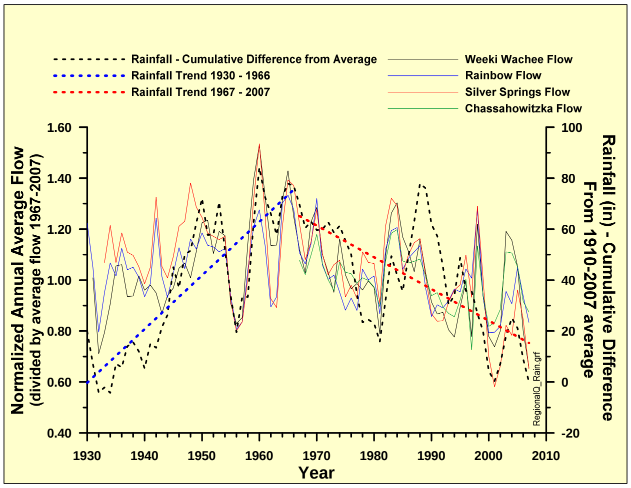

Figure 2. Normalized springflows and cumulative rainfall departure.

It should be noted that rainfall departures from average are not linearly related to discharge departures from average. Recently it has been suggested that the difference is due to withdrawals. In a report to the Florida Fish and Wildlife Conservation Commission on Gum Slough Springs Wetland Solutions, Inc. (2011) notes:

> *“. . . since the installation of the USGS gauge, flows in Gum Slough have experienced a more than 50% decline. To further examine these changes in flow the long-term rainfall since installation of this gauge was evaluated. . . . Base on LOESS smoothed monthly rainfall, decrease in rainfall have been approximately 15% over the same period. The spring appears to respond quickly to rainfall events with increased spring flows evident within one to two months after a large rainfall event. However, the difference between the estimated decline in rainfall and flow indicates that groundwater withdrawals have contributed to reductions in flow in Gum Slough during the existing period-of-record”. (*page 16)

This line of reasoning ignores a major hydrologic component, namely evapotranspiration. In 1994, Leopold wrote about the importance of evapotranspiration when discussing the impact of declining rainfall on streamflow:

> *"Suppose the rainfall in a certain year is 40 inches, which would be typical for a location such as Washington, D.C. Evaporation and transpiration might take 20 inches during the year, leaving 20 inches to be carried off by streamflow. Suppose that in the following year the precipitation is 30 inches, 25 percent less than in the previous year. If evaporation and transpiration are the same, which is quite possible, streamflow would be only 10 inches, or 50 percent of that which occurred in the year previous. Thus, a 25 percent change in precipitation becomes a 50 percent change in runoff – a demonstration of the sensitivity of streamflow to changes in rainfall."*
> (page 96)

In Leopold's first example, runoff (and/or recharge) accounts for 50% of the rainfall. For comparison, annual rainfall in the spring coast is approximately 55 inches and evapotranspiration is approximately 34 inches per year, making the runoff component an even smaller fraction (38%) of the rainfall. Thus, the decline in runoff (or recharge) is even more sensitive to declines in rainfall.

Flows in the Chassahowitzka, Homosassa and Silver River systems have been declining since the 1960s and the Homosassa and Silver River system flows declined over the period for which NO_X-N data is available. On the other hand, flow in the Chassahowitzka since NO_X-N monitoring began in 1993 has been cyclic but with a slight overall positive trend. Figure 3 compares the long-term flow with the flow on dates corresponding to NO_X-N sampling near the main spring vent in the Chassahowitzka River.

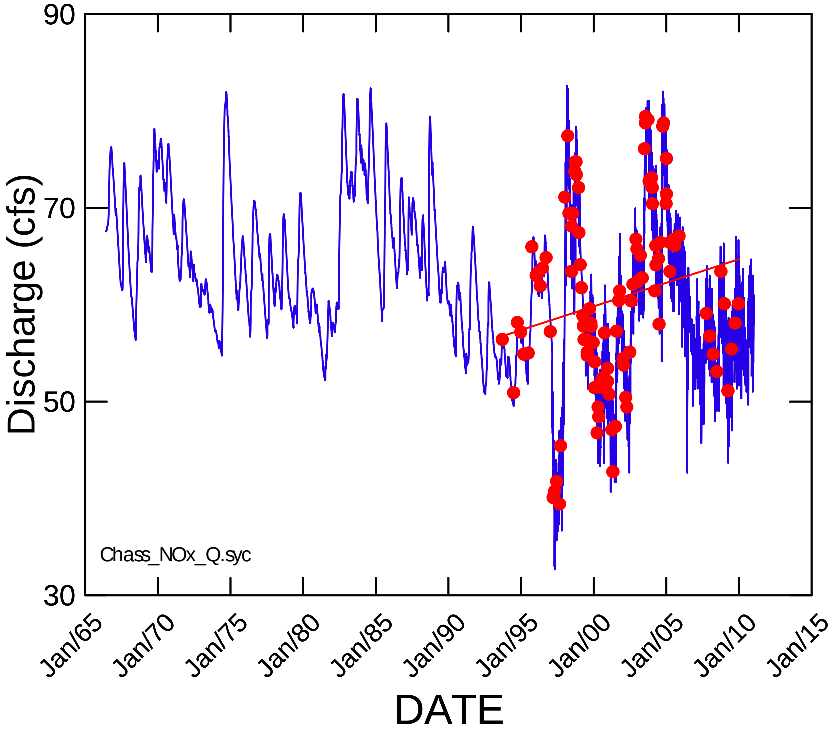

Figure 3. Chassahowitzka discharge (cfs). Red dots indicate NO_X-N sample dates and red line is flow trend for these dates. [Three day moving average applied from 1997 – 2012 to reduce noise.]

Data Sources

Flows for present evaluation were taken from USGS reported values for the Chassahowitzka River (02310650), and the Homosassa River (02310678). Annual flow values for Silver River were taken directly from a Microsoft Excel spreadsheet prepared by Wetland Solutions Inc. (WSI) and electronically transmitted by R. Clarke to Dr. Sonny Hall of the St. John's River Water Management District on February 8, 2012.

Nitrate-nitrite concentrations for the Homossassa River were obtained from the District's Water Management Information System (WMIS[3]) and represent data collected and analyzed by the District. Results were limited to samples collected from within spring vents. The Homosassa results represent samples taken from the following vents Homossassa 1, Homosassa 2, and Homosassa 3 spring vent. Six Homosassa results (1% of total samples) marked as "*Estimated value, value not accurate*.' were excluded from the evaluation. The following analytes were combined without modification a) nitrite+nitrate –N (total), b) nitrite+nitrate – N (dissolved), c) nitrate-N (total), and d) nitrate-N (dissolved). Three hundred and thirty three results were analyzed.

Annual average concentrations for the Silver River evaluation were taken without modification from the WSI spreadsheet previously identified. Fifty-four annual average values were analyzed.

The results for the Chassahowitzka River were obtained from a variety of sources including a) Mote Marine Laboratory, b) University of Florida (T. Frazer) and c) WMIS. All samples were collected in the Main vent, or immediately downstream. All reported results were above the reporting limit for the respective laboratories. The University of Florida collected three samples from right bank to left bank across the river and these were averaged by transect prior to use. One hundred and fifty four results were analyzed.

Methods

In addition to the significant flow trends in each system, the NO_X-N concentrations are also increasing in each system. Consequently, in order to fully evaluate the observed changes, each trend must be evaluated in the context of the other. The question is whether the change in NO_X-N (response variable) is the result of a change in flow or time (both candidate predictor variables). Thus, it is necessary to systematically remove the influence of one predictor variable before testing the other predictor variable.

Figure 4 illustrates the relationship of discharge and NO_X-N concentration during the NO_X-N sampling period for the Chassahowitzka River. NO_X-N was specified as the response variable,

---

[3] http://www18.swfwmd.state.fl.us/ResData/Search/ExtDefault.aspx

discharge was selected as the predictor variable and a LOWESS (Helsel and Hirsch 1992) smooth calculated. The output includes the observed NO_X-N values, the predicted NO_X-N values and the difference termed ‘residuals’. The residuals represent the concentration of NO_X-N that cannot be explained by flow. In essence, the ‘effect’ of flow was removed from the time series of NO_X-N values. The residuals were then plotted against time (Figure 5, left panel). A statistically significant trend (Spearman’s rho = 0.500, p=0.0000 and Tau-b =0.342, p = 0.0000) resulted indicating that the NO_X-N concentration that cannot be explained by flow is statistically increasing with time.

Time was then selected as the predictor variable and the evaluation repeated. In this case, the variation in NO_X-N that can be explained by time was removed and the residuals tested for a

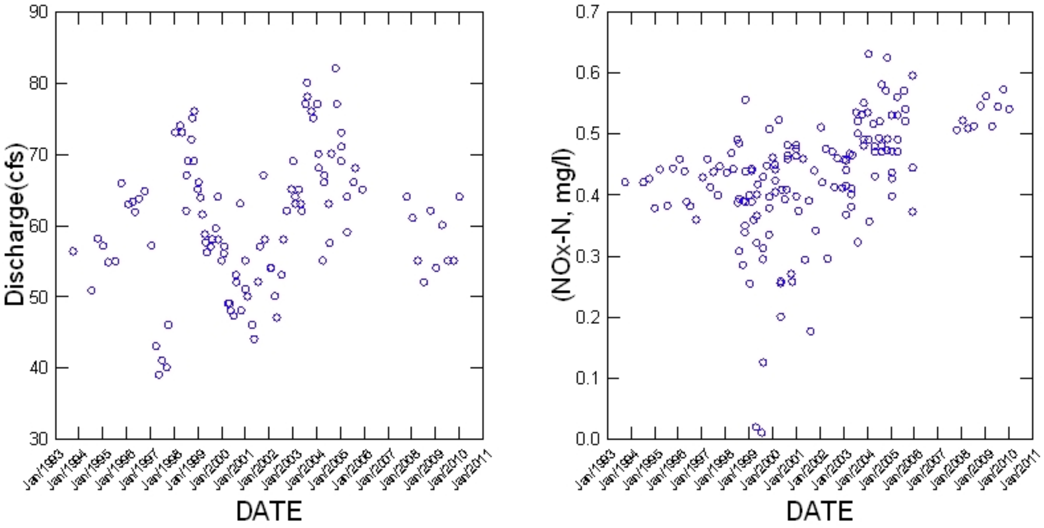

Figure 4. Chassahowitzka River discharge (left panel) and NOx-N (right panel) as function of date.

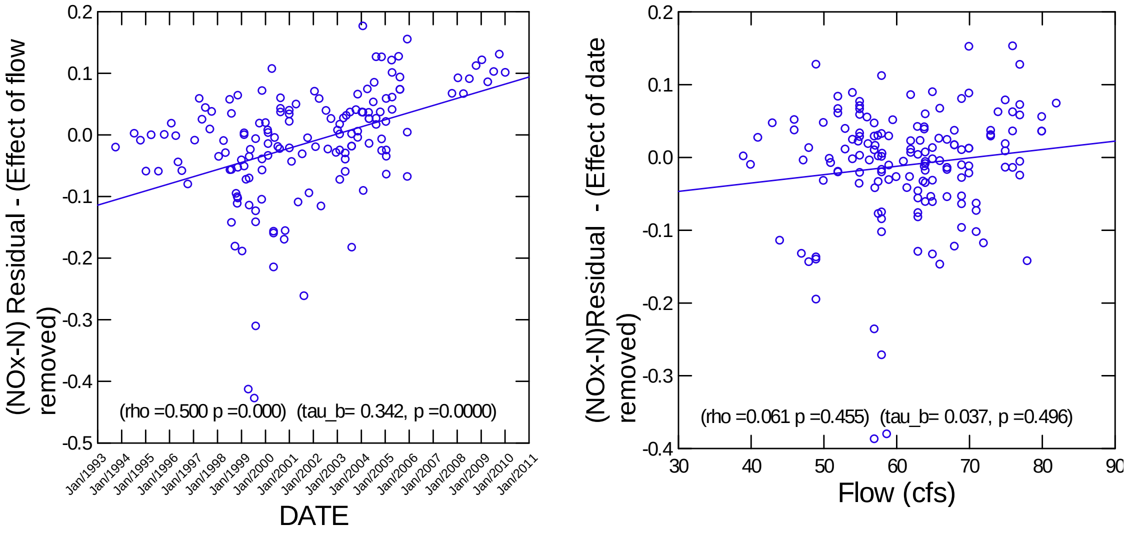

Figure 5. Chassahowitzka residual plots. Concentration unaccounted for by flow is significantly related to date (left panel) while concentration unaccounted for by date is not significantly related to flow (right panel).

significant relationship with flow. The results (Figure 5, right panel) indicate that once the time effect has been removed from concentration, the relationship with flow is not significant (p = 0.455 for Spearman test, p = 0.496 for Tau-b test).

The series of tests were repeated using the Homosassa River data, beginning with the relationship of NO_X-N to flow and time (Figure 6). When the effect of flow was removed, the concentration residuals were significantly (p=0.000 for Spearman test, p = 0.000 for Tau-b test) related to time, but when the effect of time was removed first there was no significant

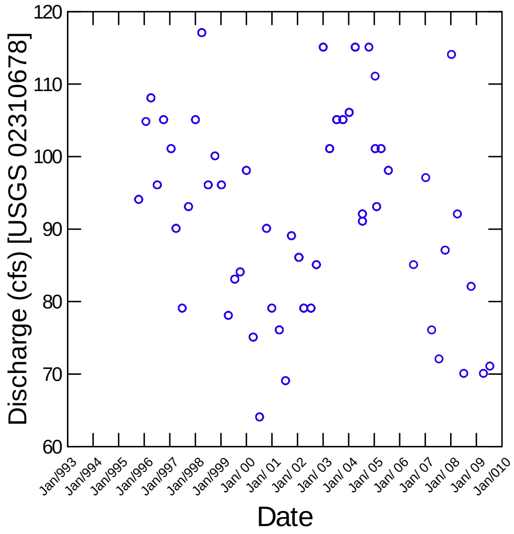

Figure 6. Homosassa Spring discharge (left panel) and NOx-N (right panel) as a function of date.

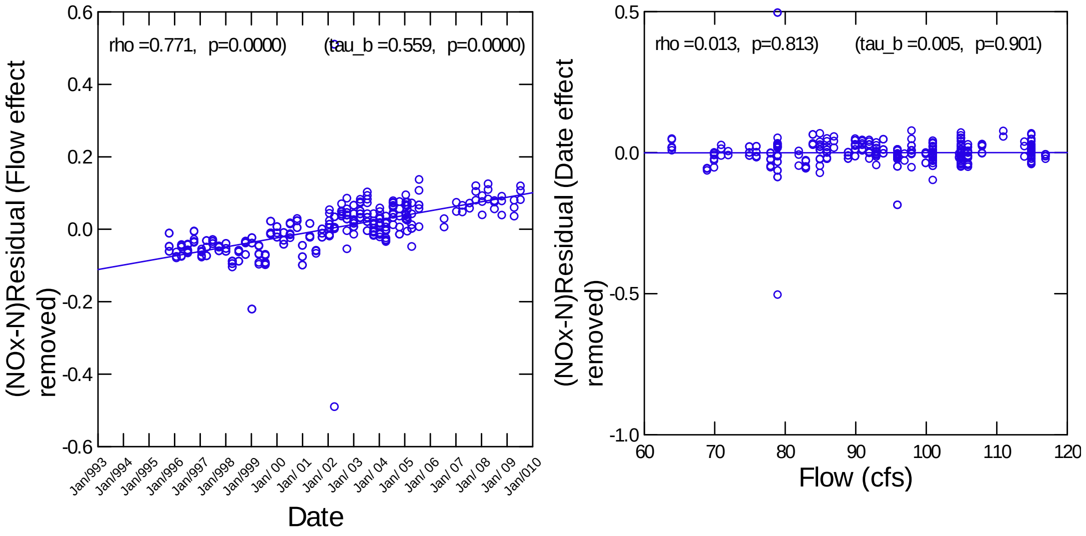

Figure 7. Homosassa residual plots. Concentration unaccounted for by flow is significantly related to date (left panel), while concentration unaccounted for by date is not significantly related to flow (right panel).

relationship of concentration with flow (p = 0.813 for Spearman test, p= 0.901 for Tau-b test). Figure 7 illustrates these relationships.

Lastly, the series of tests were repeated using the Silver Springs data. Exploratory relationships are shown in Figure 8. When the effect of flow was removed, the concentration residuals were

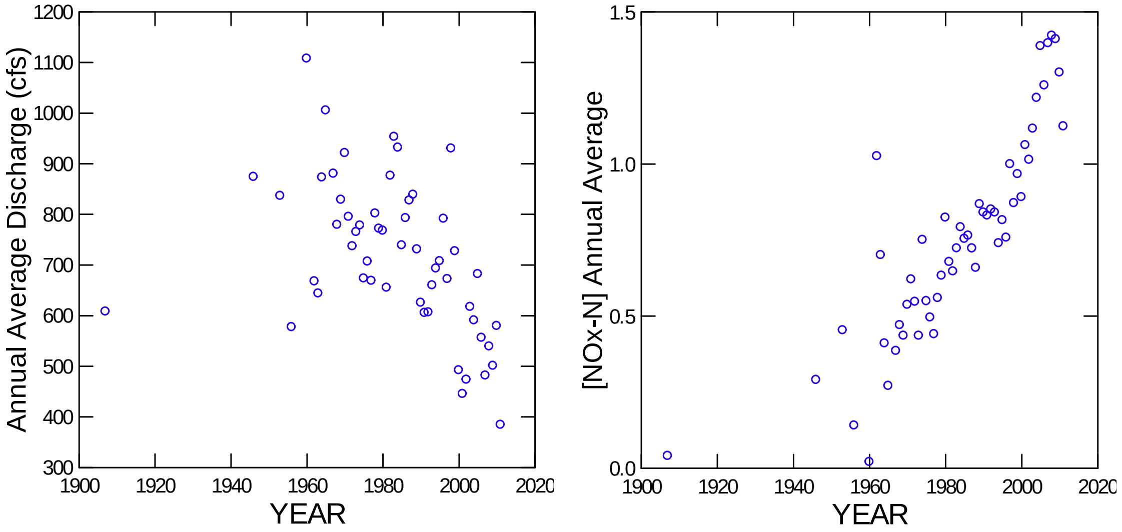

Figure 8. Silver Springs discharge (left panel) and NO_X-N (right panel) as a function of date.

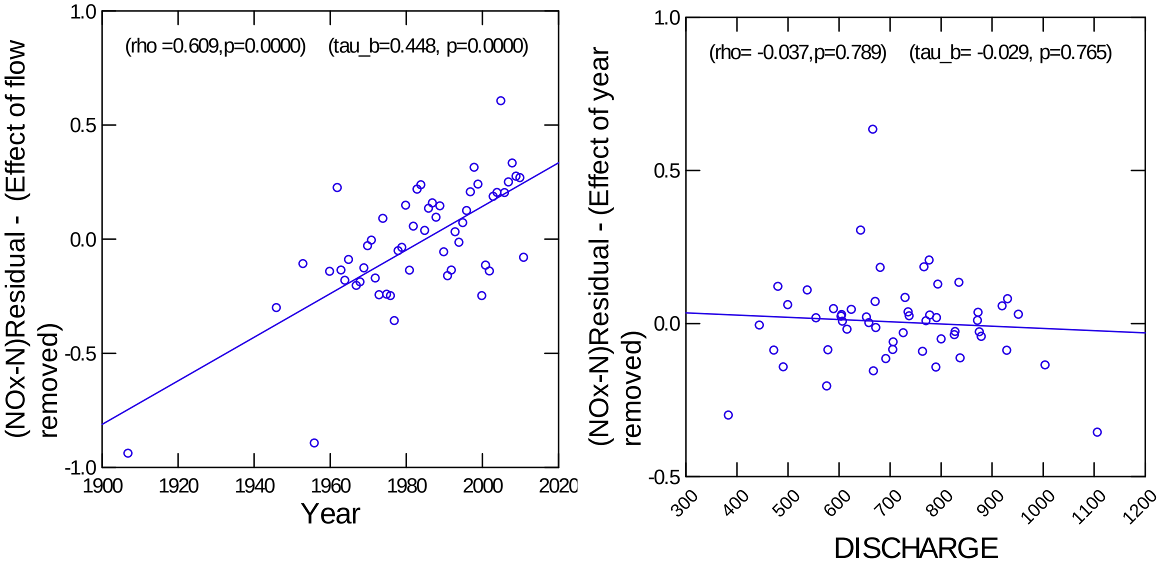

Figure 9. Silver Springs residual plots. Concentration unaccounted for by flow is significantly related to date (left panel) while concentration unaccounted for by date is not significantly related to flow (right panel).

significantly (p=0.000 for Spearman test, p = 0.000 for Tau-b test) related to time, but when the effect of time was removed first there was no remaining significant relationship of concentration with flow (p = 0.789 for Spearman test, p= 0.765 for Tau-b test). Figure 9 illustrates the relationships.

Discussion

Flow in the Chassahowitzka, Homosassa and Silver River systems has declined since the 1960s, closely following a pattern of declining rainfall. Rainfall deficits are not linearly related to discharge declines and small changes in rainfall translate into large declines in discharge.

NO_X-N concentration is increasing in the three systems investigated. The relationship between discharge and NO_X-N concentration in each of these systems was evaluated using standard statistical techniques. In all three systems, the increase in concentration was found to be independent of flow but strongly dependent on time.

Literature Cited

Helsel, D. R, and R.M.Hirsh. 1992. Statistical Methods in Water Resources. Elsevier Science Publishers.

Jones, G.W., S.B. Upchurch, K.M.Champion and D.J. Dewitt. 1997. Water-Quality and Hydrology of The Homosassa, Chassahowitzka, Weeki Wachee, and Aripeka Spring Complexes, Citrus and Hernando Counties, Florida. Origin of Increasing Nitrate Concentrations. Prepared by the Ambient Ground-Water Quality Monitoring Program. Southwest Florida Water Management District.

Knochenmus, L.A. and D.K. Yobbi. 2001. Hydrology of the Coastal Springs Ground-Water Basin and Adjacent Parts of Pasco, Hernando, and Citrus Counties, Florida. U.S. Geological Survey Water-Resources Investigation Report 01- 4230.

Leopold, L.B. 1994. A View of the River. Harvard University Press. Cambridge, Mass.

Phelps, G. G. 2004. Chemistry of Ground Water in the Silver Springs Basin, Florida, with an Emphasis on Nitrate: U.S. Geological Survey Scientific Investigation Report 2004-5144, 54 p.

Wetland Solutions, Inc. 2011. An Ecosystem-Level Study of Florida’s Springs – Part II – Gum Slough Springs Ecosystem Characterization. 104 p.

Updated April 6, 2012

Subsequent to release of this technical memorandum on February 29, 2012, similar analyses were conducted for springs (Pumphouse and Trotter) contributing to the Southeast Fork of the Homosassa, Gum Springs (vents 1, 2, 3, 4, Main and Gum Springs nr Holder) and Weeki Wachee. In all cases, the water quality data was obtained from the District's WMIS database and the discharge data was obtained directly from the USGS. The discharge stations used were 02310688, 02312764, and 02310525 respectively. The graphic results are presented on the following pages. The results of the springs contributing to the Southeast Fork and Gum Springs were consistent with the Chassahowitzka, Homosassa springs and Silver River. Weeki Wachee results were unusual, and indicate that NO_X is significantly related to both time and flow.

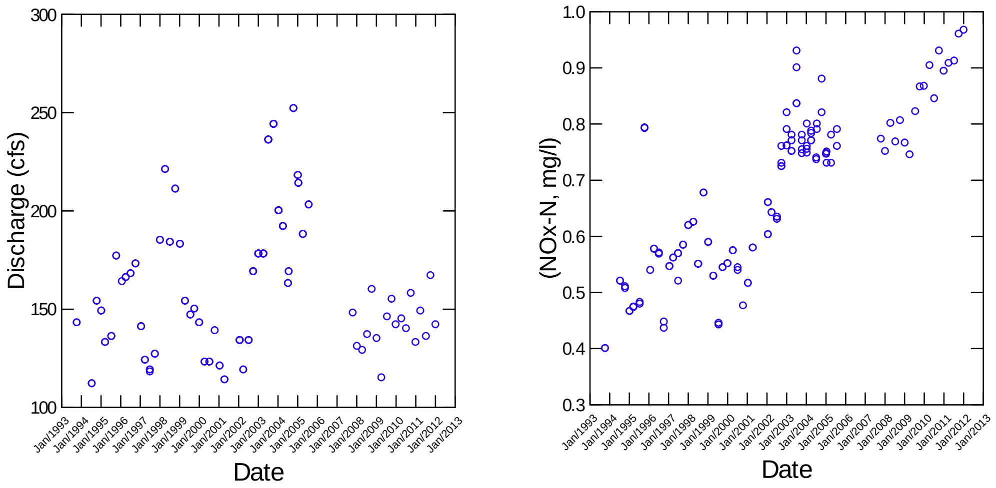

Figure 10. Weeki Wachee discharge (left panel) and NOx-N (right panel) as function of date.

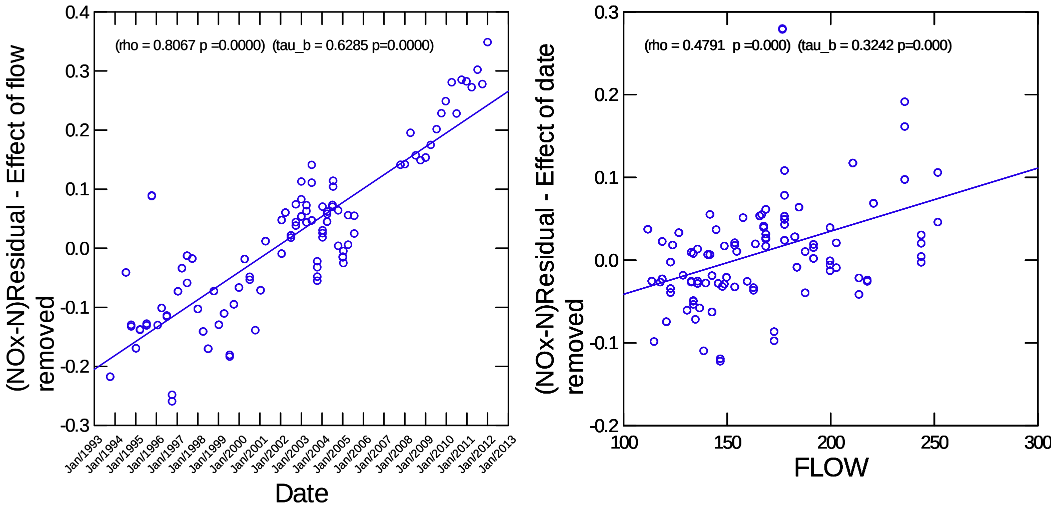

Figure 11. Weeki Wachee residual plots. Concentration unaccounted for by flow is significantly related to date (left panel) and concentration unaccounted for by date is also significantly related to flow (right panel).

Pump House and Trotter Springs vs. Southeast fork discharge.

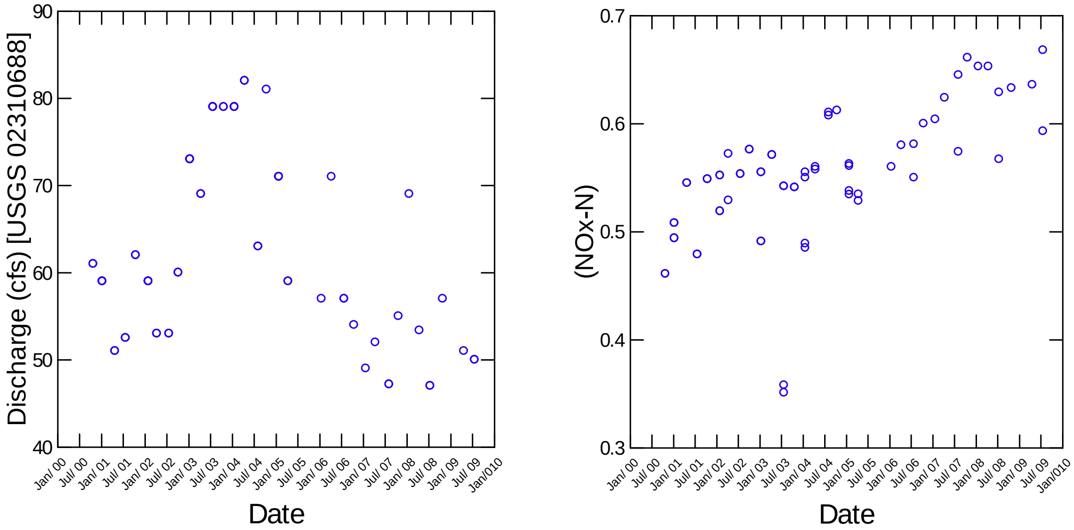

Figure 12. Southeast Fork discharge (left panel) and NO_X-N (right panel) as function of date.

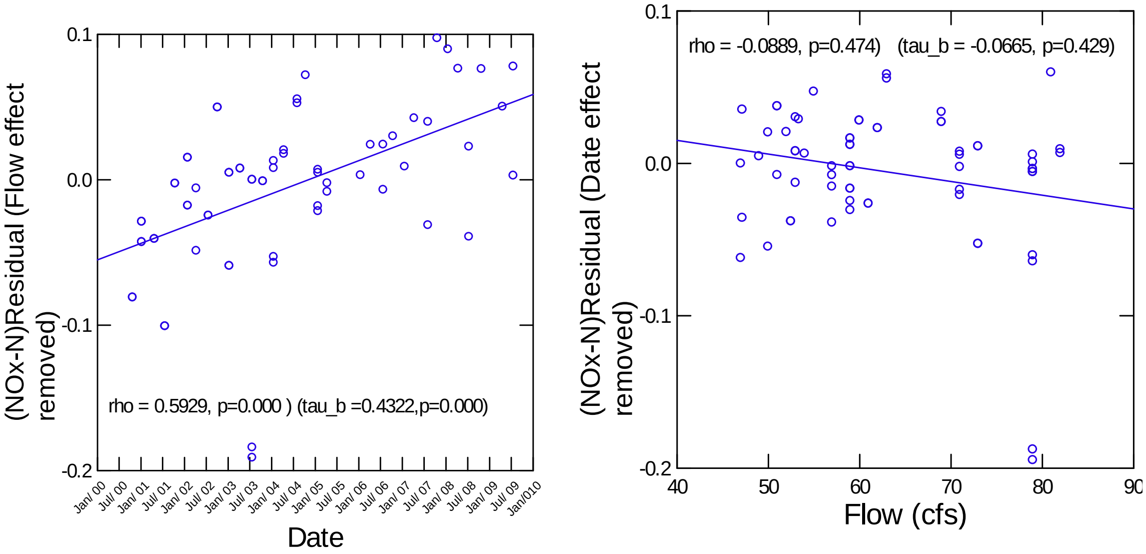

Figure 13. Southeast Fork residual plots. Concentration unaccounted for by flow is significantly related to date (left panel) while concentration unaccounted for by date is not significantly related to flow (right panel).

Gum Springs Main, #1, #2, #3, #4 and Gum Springs nr Holder.
(2003_10_16 through 2012_01_30) WMIS download 2012_03_07

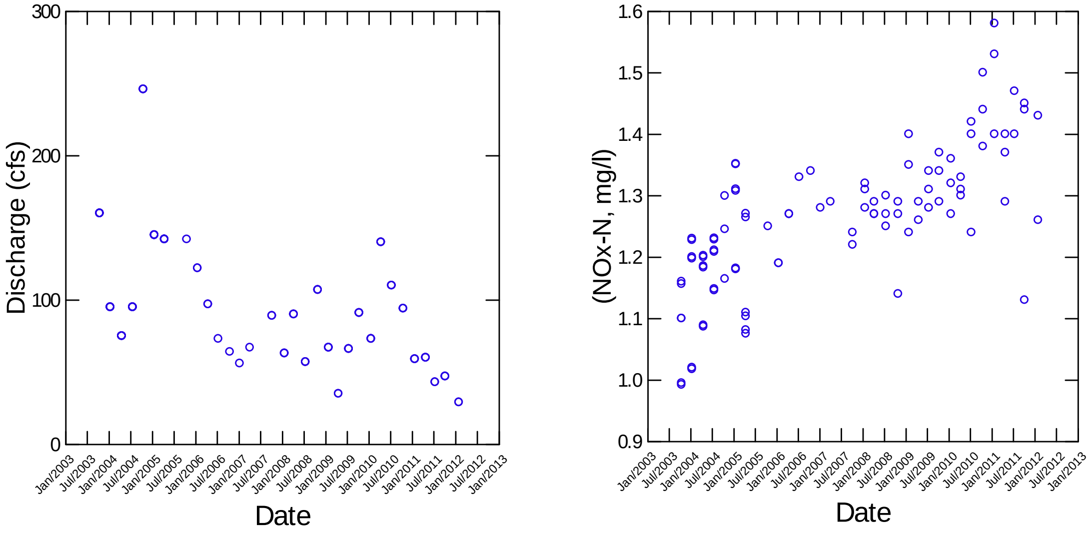

Figure 14. Gum Springs discharge (left panel) and NOx-N (right panel) as function of date.

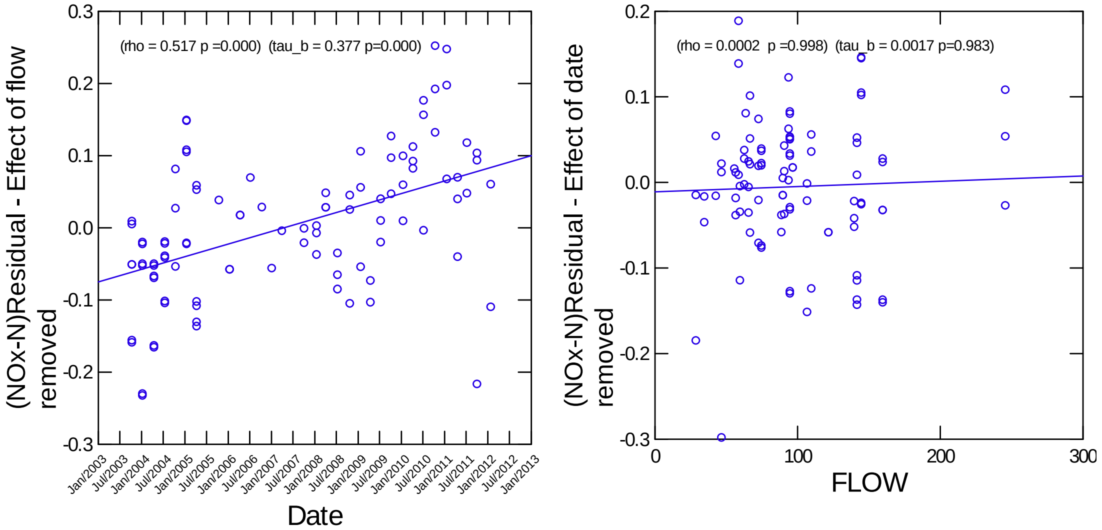

Figure 15. Gum Springs residual plots. Concentration unaccounted for by flow is significantly related to date (left panel) while concentration unaccounted for by date is not significantly related to flow (right panel).

Updated October 24, 2012

Subsequent to release of this technical memorandum on February 29, 2012 and updates on April 6, similar analyses were conducted for the Rainbow River using nitrogen data obtained from SWFWMD WMIS (downloaded 10/21/2012) and USGS flow data (0231300- Rainbow River at Dunnellon) downloaded from NWIS on 10/23/2012. Both approved and provisional flow data were used and the following Rainbow River stations were grouped for analysis.

Rainbow River Springs Included in Analysis.		
Rainbow 1, 2, 3, 4, 5, 7, 8.	Rainbow Bridge Seep North	Bubbling Spring
Rainbow East Seep Spring	Rainbow River at Dunnellon	Seep 1A Spring
Waterfall Spring		

The graphic results are presented on the following page. The results indicate that increase in nitrogen is unrelated to flow, but that the concentration is increasing with time. These findings are consistent with the other six springs evaluated and are partially in agreement with Weeki Wachee. Weeki Wachee results were unusual, and indicate that NO_X is significantly related to both time and flow... Results are summarized in the following table.

Summary of Flow, Date and NOx in Florida Springs		
System	**Effect of Flow Removed NOx Residuals vs. Date**	**Effect of Date Removed NOx Residuals vs. Flow**
Chassahowitzka	Significant	Not Significant
Homosassa	Significant	Not Significant
Pump House & Trotter	Significant	Not Significant
Silver Springs	Significant	Not Significant
Gum Springs 1, 2, 3 & 4	Significant	Not Significant
Weeki Wachee	Significant	Significant
Rainbow River	Significant	Not Significant

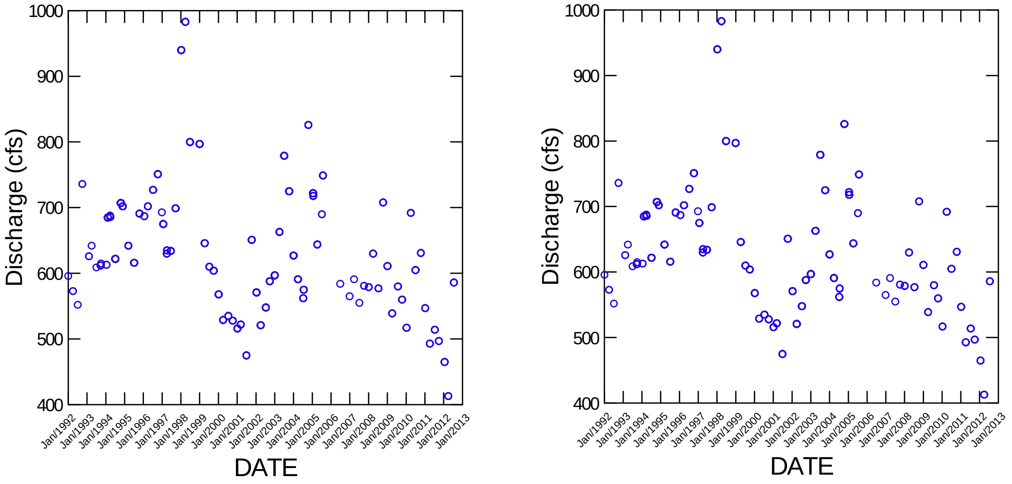

Figure 16 Rainbow River discharge (left panel) and NOx-N (right panel) as function of date.

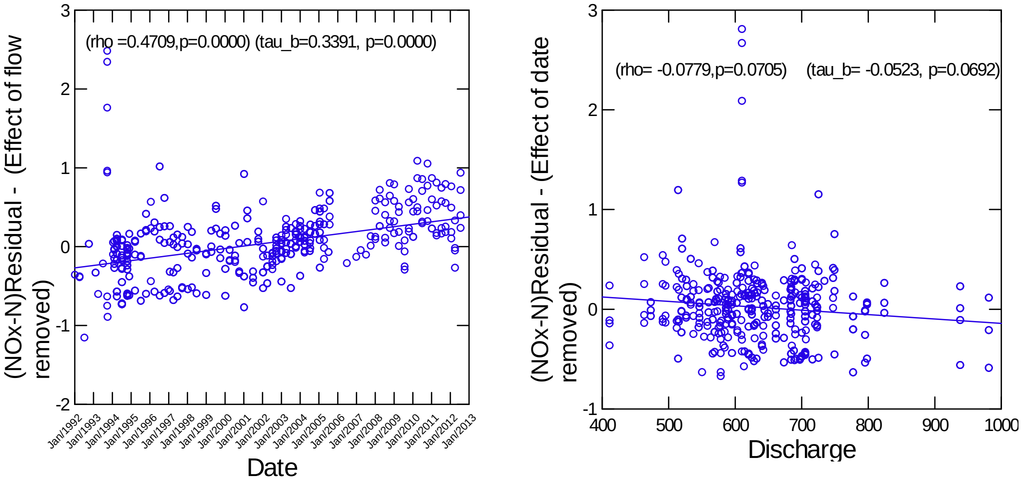

Figure 17. Rainbow River residual plots. Concentration unaccounted for by flow is significantly related to date (left panel) while concentration unaccounted for by date is not significantly related to flow (right panel).