APPENDIX E —WATER RESOURCE VALUES (WRVS) ASSESSMENT

Water Resource Values (WRVs) Assessment

The minimum flows and levels section of the State Water Resources Implementation Rule (Rule 62-40.473, *Florida Administrative Code* [*F.A.C.*]) requires that "consideration shall be given to…environmental values associated with coastal, estuarine, riverine, spring, aquatic, and wetlands ecology." The environmental values described by the rule include:

1. Recreation in and on the water;
2. Fish and wildlife habitats and the passage of fish;
3. Estuarine resources;
4. Transfer of detrital material;
5. Maintenance of freshwater storage and supply;
6. Aesthetic and scenic attributes;
7. Filtration and absorption of nutrients and other pollutants;
8. Sediment loads;
9. Water quality; and
10. Navigation.

Consideration of these environmental values, referred to here as water resource values (WRVs), is meant to ensure that recommended MFLs condition for the Wekiva River basin protects the full range of water-related functions that provide beneficial use to humans and ecological communities. The recommended MFLs condition equals the flow necessary to meet the most downstream MFL (i.e., State Road [SR 46]) and thus is equal to the current-pumping condition for each Wekiva River basin water body (Tables 29 and 30 in main report).

All 10 WRVs are typically not applicable to a specific priority water body because of site-specific differences, including varying hydrologic characteristics (e.g., riverine vs. lake systems or the presence/absence of tidal influence). Two of the environmental values listed above (estuarine resources and navigation) are not applicable and thus were not considered as part of this assessment. Protection of boat passage within the Wekiva River basin was not assessed as part of Navigation, but as part of Recreation in and on the water.

Also, WRV #5 (Maintenance of freshwater storage and supply) was not explicitly evaluated. The purpose of this environmental value is to protect an adequate amount of freshwater for non-consumptive uses and environmental values associated with coastal, estuarine, riverine, spring, aquatic, and wetlands ecology. This environmental value encompasses all other environmental values identified in Rule *62-40.473 F.A.C*. Because the overall purpose of the MFL is to protect environmental resources and other non-consumptive beneficial uses while also providing for consumptive uses, this environmental value is considered protected if the remaining relevant values are protected. Numerous metrics, in addition to the primary criteria described in the *MFLs Determination* section in the Main Report, were evaluated to ensure all relevant environmental values are protected. These metrics were assessed to determine if the recommended basin-wide MFLs condition (equal to the current-pumping condition for all water bodies) will protect all relevant environmental values in the basin.

Several of the following analyses were conducted and provided to St. Johns River Water Management District (SJRWMD) by Janicki Environmental, Inc. and ATM, a Geosyntec Company, as part of work done under Contract # 32928.

WRV 1. Recreation in and on the water

Recreation is an extremely important environmental value within the Wekiva River basin, especially at the two largest springs (Wekiwa Springs and Rock Springs) and their spring runs, but also at numerous locations along the length of the Wekiva River. The basin includes numerous clear springs, long spring runs, dark water rivers, and vast undeveloped uplands. This environmental value was assessed to ensure protection of the active use of these water resources and associated natural systems. Recreational activities within the Wekiva River basin typically include, but are not limited to swimming, wading, scuba diving, paddling (i.e., use of canoes, kayaks and paddle boards), boating (use of motorboats), fishing, and other pursuits.

These environments combine to make this area a unique and extremely popular resource. As an indicator of this popularity, during fiscal year 2021-2022, attendance at Wekiwa Springs alone was greater than 400,000. This high use was associated with an economic impact of Wekiwa Springs of over fifty million dollars (FDEP 2021).The majority of visitors within the Wekiva River basin are daily visitors that come to picnic, swim, or rent a kayak, canoe or paddleboard for a couple of hours (ECFRPC 2021). Based on kayak and canoe rental data from 2003 - 2017, average boat rentals during this period is about 1,150 per month. Swimming typically occurs at larger springs (e.g., Wekiwa, Rock, and Sanlando Springs) and at Wekiva Island. However, these activities are limited elsewhere on the Wekiva River due to the lack of large easily accessible beaches or other public access within shallow reaches. Access is also impeded by aquatic vegetation in many locations. Numerous hiking, biking, and horseback riding trails exist on the extensive public land tracts adjacent to the Wekiva River, yet none of the trails traverse significant distances along the river's edge due to the extent of inundated floodplain. Despite these large public land holdings, the Wekiva River floodplain characteristics limit access to the river to relatively small public landings, private docks, and boat launches. These access points include the following locations:

- Wekiwa Spring State Park – canoe and kayak launch with boat rental
- Wekiva Island – private marina with boat ramp; swimming from the perimeter dock, canoe, kayak, and paddleboard rentals
- Buffalo Tram backcountry campsite on the Wekiva River in Rock Springs Run State Reserve

- Hammock House on the Wekiva River within Rock Springs Run State Reserve
- Seminole Wekiva Trail spur which ends at the Wekiva River at the historic railroad crossing
- Wekiva Falls RV Park – private park with small boat ramp; canoe and kayak rentals
- Wilson Landing Park – Seminole County park with boardwalk, canoe, and kayak launch
- Lower Wekiva River Preserve State Park at Katie's Landing - canoe and kayak launch
- Wekiva River Haven - private marina downstream of Katie's Landing. This facility is currently closed. Historically, this facility rented small motorboats.

The magnitude of recreational use within the Wekiva River basin (Wekiwa Springs, Rock Springs, Rock Springs Run, Wekiva River, and smaller springs) is usually related to temperature, with an increase in activity during warmer months (peaking in June/July) and a decline during cooler months (lowest in December/January) (WSI 2007a, WSI 2021) (Figures E-1 and E-2).

Additional Wekiva River recreation information is available in numerous documents, including:

- Wekiva Aquatic Preserve Management Plan [Florida Department of Environmental Protection (FDEP) 2014]
- Wekiva Wild and Scenic River System Management Plan (Wekiva Wild and Scenic River System Advisory Management Committee 2012)
- Wekiva River Basin State Parks Multi Unit Management Plan Amendment (FDEP 2012)
- Wekiva River Buffer Conservation Area Management Plan [St. Johns River Water Management District (SJRWMD) 2012]
- Wekiwa Springs State Park web page (http://www.floridastateparks.org/wekiwasprings/), (http://www.floridastateparks.org/rockspringsrun/default.cfm)
- Lower Wekiva River Preserve State Park (https://www.floridastateparks.org/park/Lower-Wekiva-River)
- Friends of the Wekiva River web page (https://www.friendsofwekiva.org/)
- Wekiva River Aquatic Preserve web page (https://floridadep.gov/rcp/aquatic-preserve/locations/wekiva-river-aquatic-preserve)
- The Economic Impact of the Wekiva River Area [East Central Florida Regional Planning Council (ECFRPC) 2021]

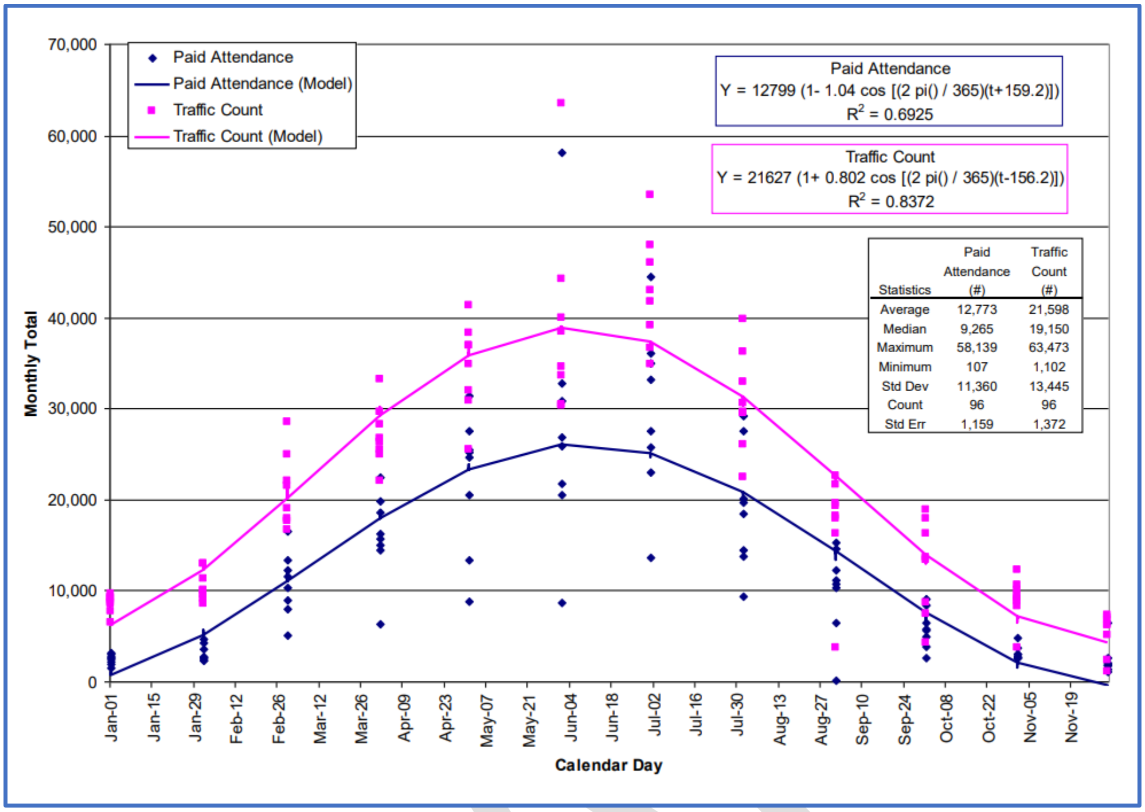

Figure E-1. Kelly Park monthly attendance (1998 – 2005); source: WSI 2007a

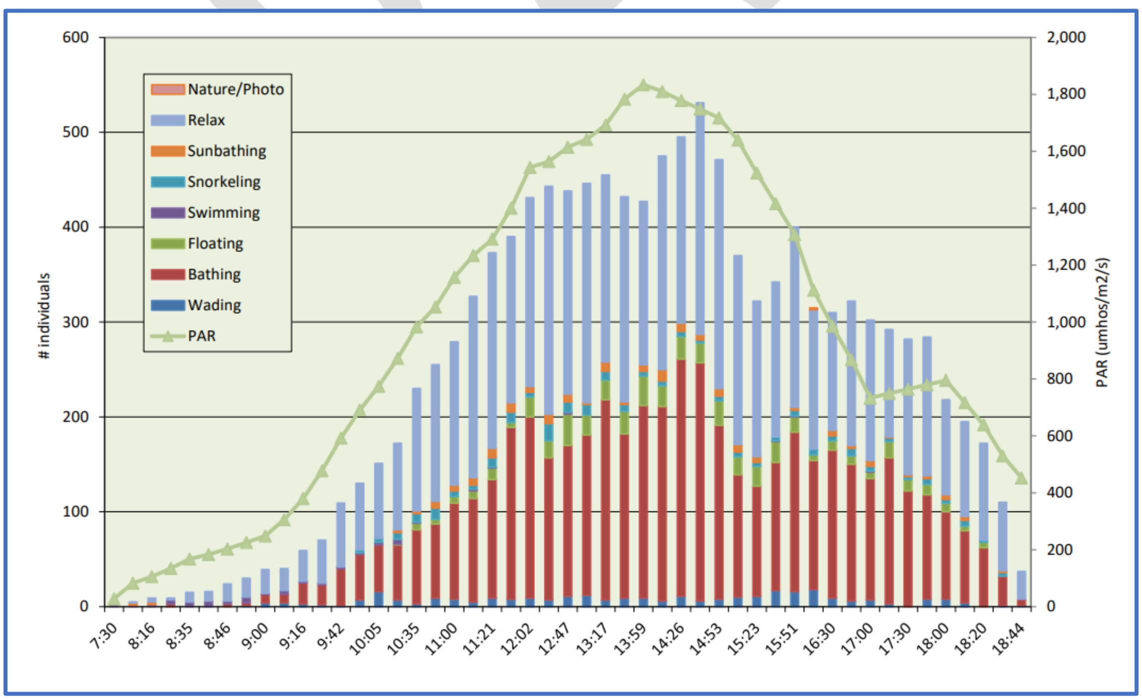

Figure E-2. Wekiwa Springs Park attendance vs light level (PAR [photosynthetically active radiation]; positively related to temperature); source: WSI 2021

Paddling Depth

Protection of recreational functions and values within the Wekiva River basin is dependent on adequate water depths during low-flow conditions (Figure E-3). To protect various types of paddling activities, a protective water depth of 20 inches was defined in 1990 by the Florida Department of Natural Resources (FDNR 1990). This depth was the primary criterion for original (i.e., current) adopted Minimum Frequent Low for the Wekiva River (Hupalo et al 1994). The adequacy of the 20-inch paddling water depth criterion was reconfirmed in 2019 (*personal communication*; Deborah Shelley, Manager of the Wekiva / Middle St. Johns / Tomoka Marsh Aquatic Preserves).

In addition to a recommended minimum depth of 20 inches, the paddling depth metric also has a recommended width of 9 feet (ft), which will allow for the passage of two kayaks with approximately 1 ft of buffer between them. The paddling depth metric is as follows:

Paddling depth exceedance metric:

- Critical elevation: water level elevation that provides a water depth of at least 20 inches across a minimum of 9 feet of the river channel, at a given transect.

Impact Threshold:

- Allow no more than a 15% reduction in exceedance of the critical elevation, relative to a no-pumping condition.

<u>Rock Springs Run</u>

The 14,000-acre Rock Springs Run State Reserve (RSRSR) encompasses parts of both Rock Springs Run and the Wekiva River. While the RSRSR does not have a public boat launch, boaters can travel through it after accessing either Rock Springs Run or the Wekiva River at a designated launch site upstream or downstream of the reserve. Primitive camping opportunities within the reserve include two canoe camping areas (Indian Mound Camp on Rock Springs Run and Buffalo Tram Camp on the Wekiva River). The Florida Park Service also recently contracted with a concessionaire to operate a Wekiva River launch access in the reserve.

Kings Landing is a private canoe livery located on the western end of Rock Springs Run, just downstream from Kelly Park, a 237-acre park maintained by the Orange County Parks and Recreation Department. The business currently rents approximately 100 canoes per month, with an anticipation of increased use in the future. Canoe renters from Kings Landing have an 8-mile run down Rock Springs Run to Wekiva Island at the upper reach of the Wekiva River. The Wekiva Island operator provides a takeout ramp and space for vehicle parking and canoe storage for Kings Landing customers. Access to Rock Springs Run is generally limited to the following locations: Wekiwa Spring State Park, Kelly Park, Kings Landing and Camp Joy.

Figure E-3. Left: Kayaking on Rock Springs Run; Right: Canoe launch site at Wekiwa Springs State Park.

At the shallowest cross-section in Rock Springs Run, downstream of Kelly Park (350.27; Figure E-4), the critical water surface elevation is 21.1 ft NAVD 88. The paddling depth metric (depth ≥ 20 inches across ≥ 9 feet of river channel) was met at ROK5 and thus all cross-sections meet the criterion for all flows under the no-pumping condition.

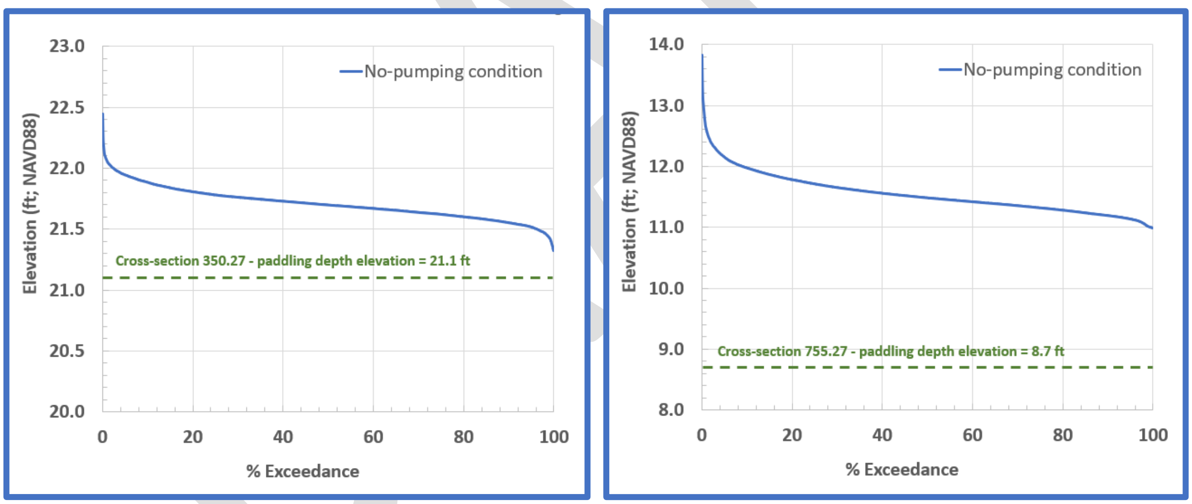

Figure E-4. No-pumping condition water levels at Rock Springs Run at limiting cross-section 350.27 (left) and Wekiwa Springs at limiting cross-section 755.27 (right). Dashed lines depict critical paddling elevation with a minimum depth of 20 inches and a minimum width of 9 feet.

<u>Wekiwa Springs</u>

At the shallowest cross-section in the run downstream of Wekiwa Springs (755.27; E-4), the critical water surface elevation is 8.7 ft NAVD 88. The paddling depth metric (depth ≥ 20 inches across ≥ 9 feet of river channel) was met at 755.27 and thus all cross-sections meet the criterion for all flows under the no-pumping condition.

Little Wekiva River

Based on a review of all surveyed and HEC-RAS cross-sections, channel morphology resulting in water depths greater than an average of 20 inches occurs for most of the lower Little Wekiva River (LWR) (downstream of Springs Landing Boulevard), even when the river is at low stage. However, review of data from immediately downstream of Springs Landing Boulevard and sections upstream of this location indicate that passage can be restricted in these areas during low water periods. On the lower LWR, obstructions due to tree fall are generally a bigger issue than low water levels throughout the river channels in the Wekiva basin (*personal communication*: Robert Brooks, Wekiwa Springs State Park manager, 2017).

The paddling depth metric was met at all cross-sections below Springs Landing Boulevard Bridge for all flows under the no-pumping condition. The critical paddling depth was not met under the no-pumping condition for cross-sections upstream of Springs Landing Boulevard.

Wekiva River

The critical paddling depth (depth ≥ 20 inches across ≥ 9 feet of river channel) was met at all cross-sections for the middle and lower Wekiva River under the no-pumping condition. Further, a more constraining boat passage metric (depth ≥ 20 inches across ≥ 20 feet of river channel) was evaluated for these portions of the river (see below).

Assessment

The critical water depth was met at all cross-sections in the Wekiva River, Wekiwa Springs Run and Rock Springs Run under both the no-pumping and current-pumping conditions. The paddling depth metric was met at all cross-sections below Springs Landing Boulevard Bridge for all flows under the no-pumping condition. However, the exceedance of the critical paddling elevation (17.3 ft) at a single cross-section (245.69) was reduced by approximately 1.6% under the current-pumping condition (Figure E-5). The critical paddling depth was not met under the no-pumping condition for cross-sections upstream of Springs Landing Boulevard, and thus not evaluated for those cross-sections under current-pumping conditions.

Given the very small response to paddling depth by the reduction in flow under the current-pumping condition, this metric is considered protected by the recommended MFLs condition for the Wekiva River basin.

Boat Passage

In addition to using canoes, kayaks and paddle boards, another popular recreational activity, especially along portions of the lower Wekiva River, is the use of motorized boats. As such, a boat passage metric was evaluated for the middle and lower river sections, below river mile (RM)10. The upper section of the river, above the confluence with the Little Wekiva River

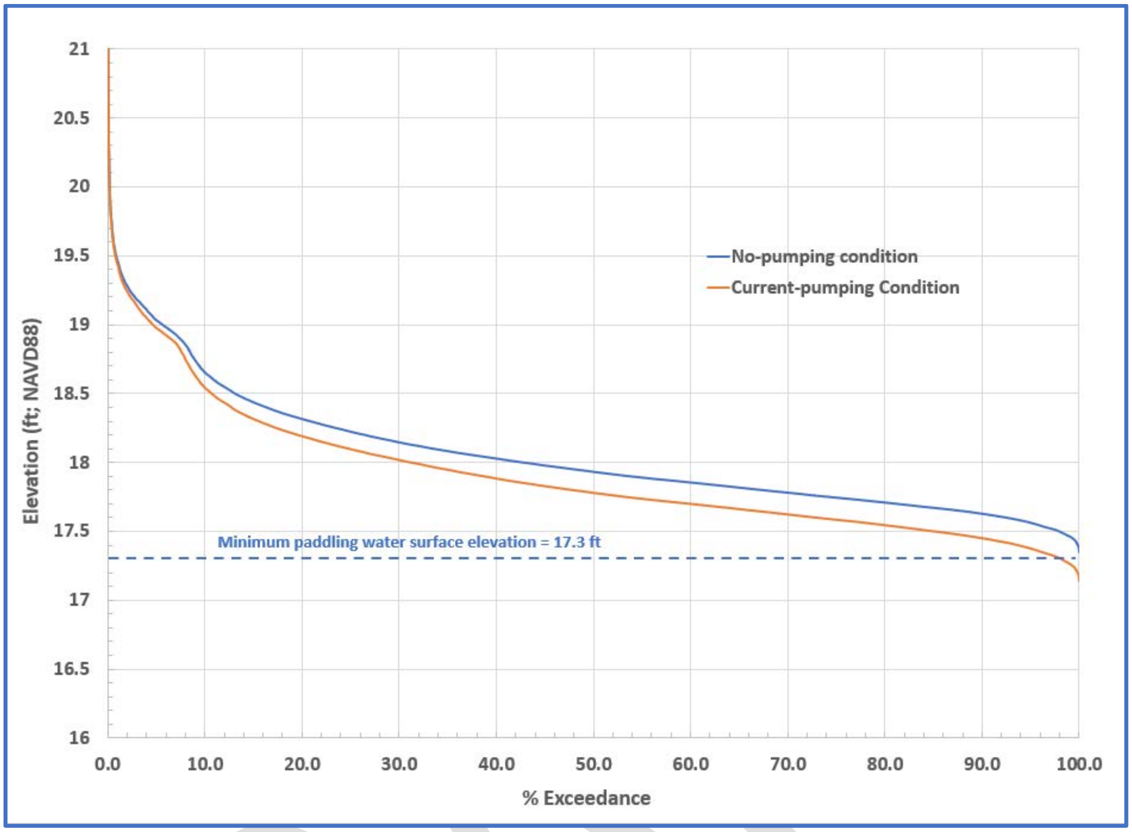

Figure E-5. No-pumping and current-pumping condition water levels for the Little Wekiva River at Springs Landing Blvd at limiting cross-section 245.69. Dashed line depicts critical paddling elevation with a minimum depth of 20 inches and a minimum width of 9 feet.

(from RM 10 to 14) is best suited to canoes and kayaks although some smaller powerboats (25 hp and smaller) will traverse this reach and launch from the Wekiva Island boat ramp. The last 5 miles of the river are in the Wekiva Aquatic Preserve, which is largely unspoiled wilderness. There is more powerboat traffic on this lower stretch of the Wekiva River as boaters travel from the St. Johns River. Guided pontoon boat cruises on the lower section provide wildlife viewing opportunities (https://floridadep.gov/rcp/aquatic-preserve/locations/wekiva-river-aquatic-preserve).

Motorized boats on the Wekiva River are typically 16- to 20-foot long and draw around 15 inches (HSW 2008, Leslie and Sherwood 2009, Skeeter 2019). These boats will have a typical maximum width of 8 ft. Safe motorboat operation also includes adequate propeller clearance of typical vessels on the river. Typical small motorboat propeller shaft lengths run from 20 to 25 inches (Iboats 2019). This length includes the boat transom height above the water, which means propeller clearance below the hull would be considerably less. As a result, a 20-inch water depth for small outboard motor clearance (depending on motor size, shaft length, boat size, and boat displacement) between the bottom of these vessels and the channel bottom is adequate for preventing permanent damage to submerged aquatic vegetation (SAV) by prop scarring the SAV substrate, and physical damage to boat motors.

Average channel depths in the majority of the Wekiva River are greater than 20 inches, even when the river is at low stage. One area that is an exception to this general condition is the river reach known as “The Flats” near State Road (SR) 46 (Figure E-6). Markedly shallow water depths occur in this reach compared to all other reaches of the Wekiva River. This area is a potential constraint to boat passage and is one of the focal points of the boat passage evaluation.

A typical boat passage metric includes a minimum depth (e.g., 20 inches) and minimum width. MFLs for other systems have used a 50-ft width, which is based on providing for two-way boat traffic (i.e., for two 10-ft wide pontoon boats), while also allowing adequate buffer to limit collisions with other boats and, potentially, banks and shallow areas. Although a boat passage criterion wide enough to allow for two boats is sometimes used, aquatic vegetation (e.g., *Vallisneria* and *Nuphar*) currently limits access to one-boat width in many places in the Wekiva River channel. This is especially true directly upstream of SR 46 in The Flats (Figure E-6).

In light of the heavily vegetated conditions that persist in The Flats, the recommended minimum width for boat passage equals 20 feet. This minimum width will allow passage for an 8-ft-wide motorboat with 6 ft of buffer on both sides for protection of sensitive shallow areas. Because of the luxuriant vegetation in portions of the Wekiva River, particularly in the Flats area upstream of SR 46, boat traffic proceeds cautiously. There are several areas where only one boat can pass, irrespective of flows and stages, because of excessive vegetation. The boat passage metric is as follows:

Boat passage exceedance metric:

- Critical elevation: water level elevation that provides a water depth of at least 20 inches across a minimum of 20 feet of the river channel, at a given transect.

Impact Threshold:

- Allow no more than a 15% reduction in exceedance of the critical elevation, relative to a no-pumping condition.

The boat passage / paddling depth metric was assessed for all transects in the middle and lower Wekiva River, but results are provided below for only the most limiting (constraining) cross-sections. The most limiting cross-sections evaluated using this metric were located within “The Flats”, RS 332.58 with a critical water surface elevation of 5.7 ft, and RS 344.64, with a critical water surface elevation of 5.1 ft (Figures E-7 and E-8). The boat passage metric was met at both cross-sections for all flows under the no-pumping condition.

<u>Assessment</u>

The boat passage metric (depth ≥ 20 inches across ≥ 20 feet of river channel) was met under the no-pumping condition in the two most constraining locations on the lower and middle Wekiva River (see above for details). This metric was also met at these, and all other, cross-sections under the current-pumping condition (Figure E-8).

Figure E-6. View upstream (top) and downstream (bottom) from “The Flats” on the Wekiva River

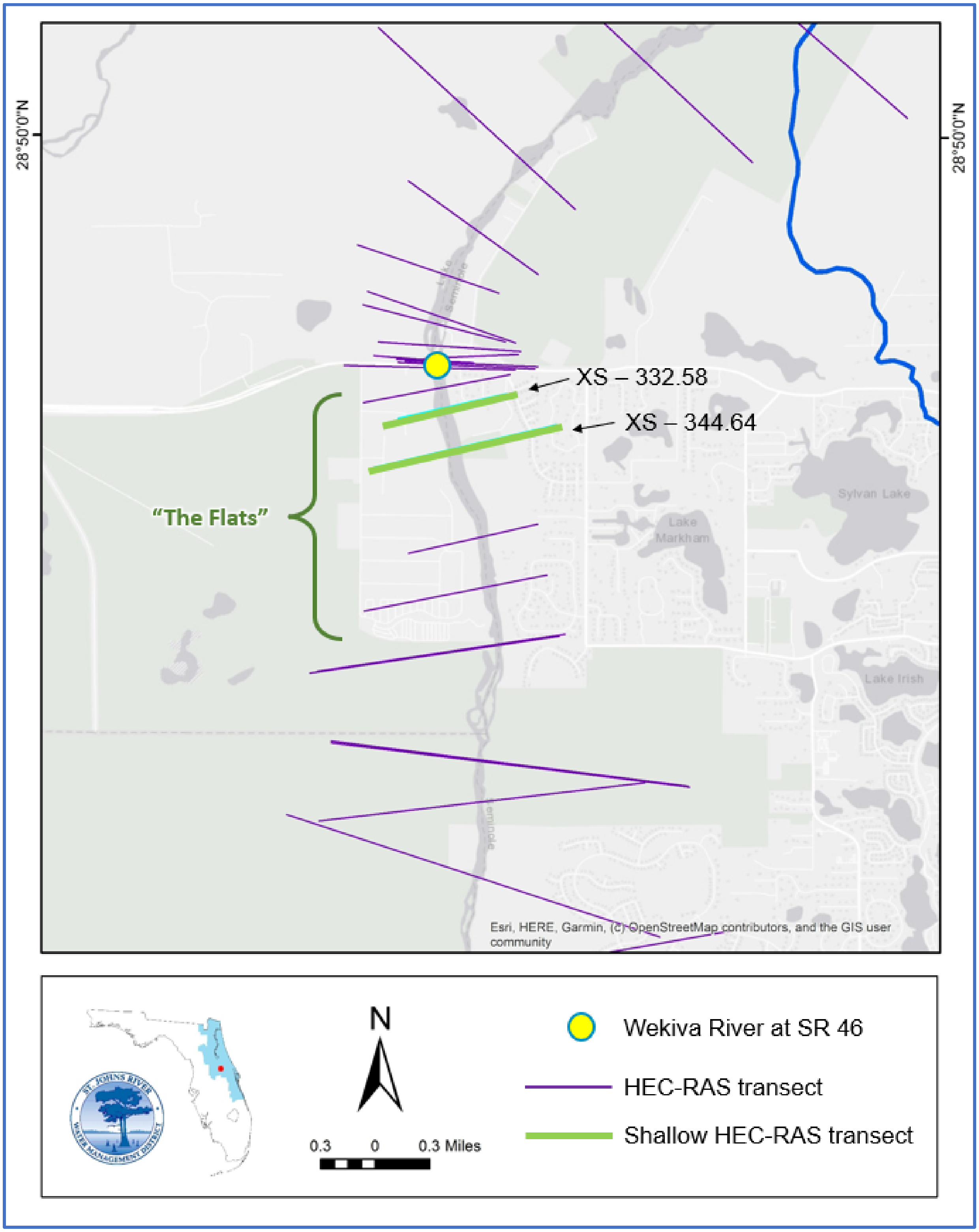

Figure E-7. HEC-RAS transect locations near the Wekiva River at SR 46, including limiting (shallow) transects in the area upstream of SR 46 known as "The Flats".

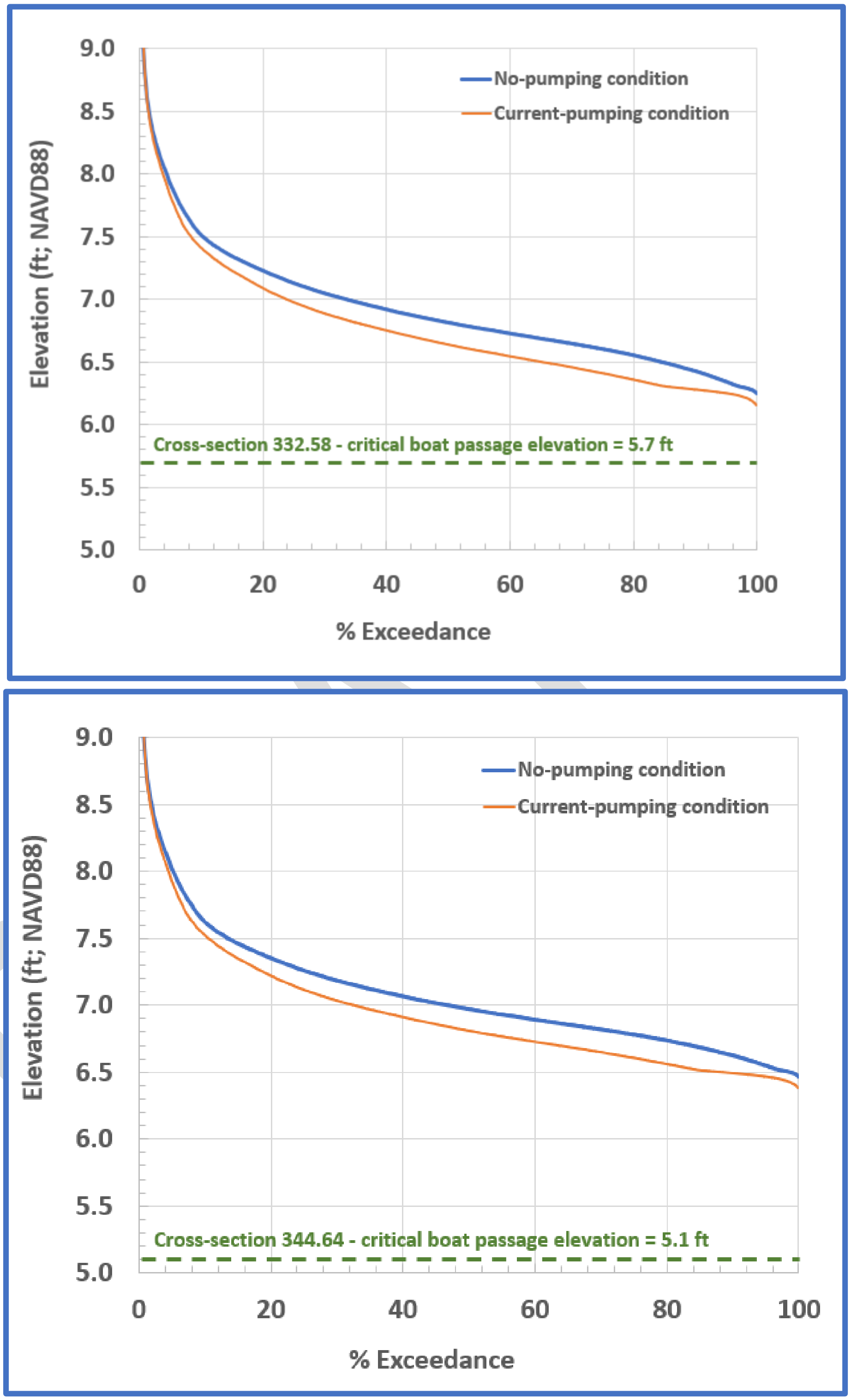

Figure E-8. No-pumping and current-pumping condition water levels at the two most constraining (i.e., shallowest) Wekiva River cross-sections: 332.58 and 344.64. Dashed line depicts boat passage elevation with a minimum depth of 20 inches and a minimum width of 20 feet.

Boat Ramp Usage

In addition to boat passage and paddling depth constraints, recreational activities in and on the Wekiva River are also potentially affected by the impact of low water conditions on boat ramp usage (Figure E-9). This is especially true for small motorboats. Important boat ramps in the Wekiva River basin include Wekiva Falls RV Park, Wekiva Island, Katie's Landing, and Wilson's Landing. Canoes and kayaks were not considered to be subject to this constraint, and so the canoe launch site at King's Landing was not evaluated using this metric. The specific indicator of protection for boat ramp access is based on maintaining a minimum 20-inch boat draft (boat ramp minimum elevation plus 20 inches) to ensure that small motorboats can utilize boat ramps. The boat ramp metric is as follows:

Boat ramp exceedance metric:

- Critical elevation: water level elevation that provides a water depth of at least 20 inches above the minimum boat ramp depth.

Impact Threshold:

- Allow no more than a 15% reduction in exceedance of the critical boat ramp elevation, relative to a no-pumping condition.

Figure E-9. Boat ramp at Wekiva Island.

The boat ramp metric was assessed for all boat ramps and launches for which data were available. All elevations were transferred to the closest compliance gage using the HEC-RAS model. Critical elevations, no-pumping, MFLs (15% reduction in no-pumping), and current-pumping conditions are presented in Table E-1. The exceedance of all critical elevations is higher under the current-pumping condition than under the MFLs condition. As such, access to all boat ramps is protected under the current-pumping condition.

Table E-1. Critical elevations (minimum boat ramp elevation plus 20-inch draft) and MFLs condition (NP-15%) and current-pumping condition exceedances for key boat ramps and launches in the Wekiva River basin.

Boat Ramp	Critical elevation (ft; NAVD 88)	NP Condition Exceedance (%)	MFLs Condition Exceedance (%)	CP Condition Exceedance (%)
Wekiva Island	10.9	98.6	83.8	88.0
Wekiva Falls	8.2	99.4	84.5	91.6
Wilson's Landing	7.1	100	85.0	99.8
Katie's Landing	5.1	99.5	84.6	93.3

Tubing depth

One of the most important recreational activities at Rock Springs (Kelly Park) is tubing along the 0.5 mile of spring run that extends from the headspring to the takeout (Figure E-10). This upper portion of the spring run is solely used for swimming, wading, and tubing. Canoeing, kayaking, and paddle boarding are prohibited in this part of the park.

The Rock Springs headspring and a small reach of the spring run are within Kelly Park, a 237-acre parcel managed by Orange County and adjacent to the Wekiwa Springs State Park. Rock Springs is an extremely popular second magnitude spring with a long-term average flow of 56 cfs. This Outstanding Florida Spring (OFS) attracts thousands of people each year (Figure E-11), with an average of 1,350 visitors using the park each day (Orange County Parks 2019; www.ocfl.net).

A minimum depth of 1.05 feet is used for the tubing depth metric and is based on a critical depth threshold used for the recent Ichetucknee River MFLs (SRWMD 2021). This depth threshold was developed to ensure that there was 1.05 ft above submerged aquatic vegetation (SAV) in the Ichetucknee River. A width criterion of 5 feet (i.e., a cross-sectional area of 1.05 feet deep by 5 feet wide) is recommended to ensure adequate room for tubers to navigate safely while also minimizing SAV and emergent vegetation impacts.

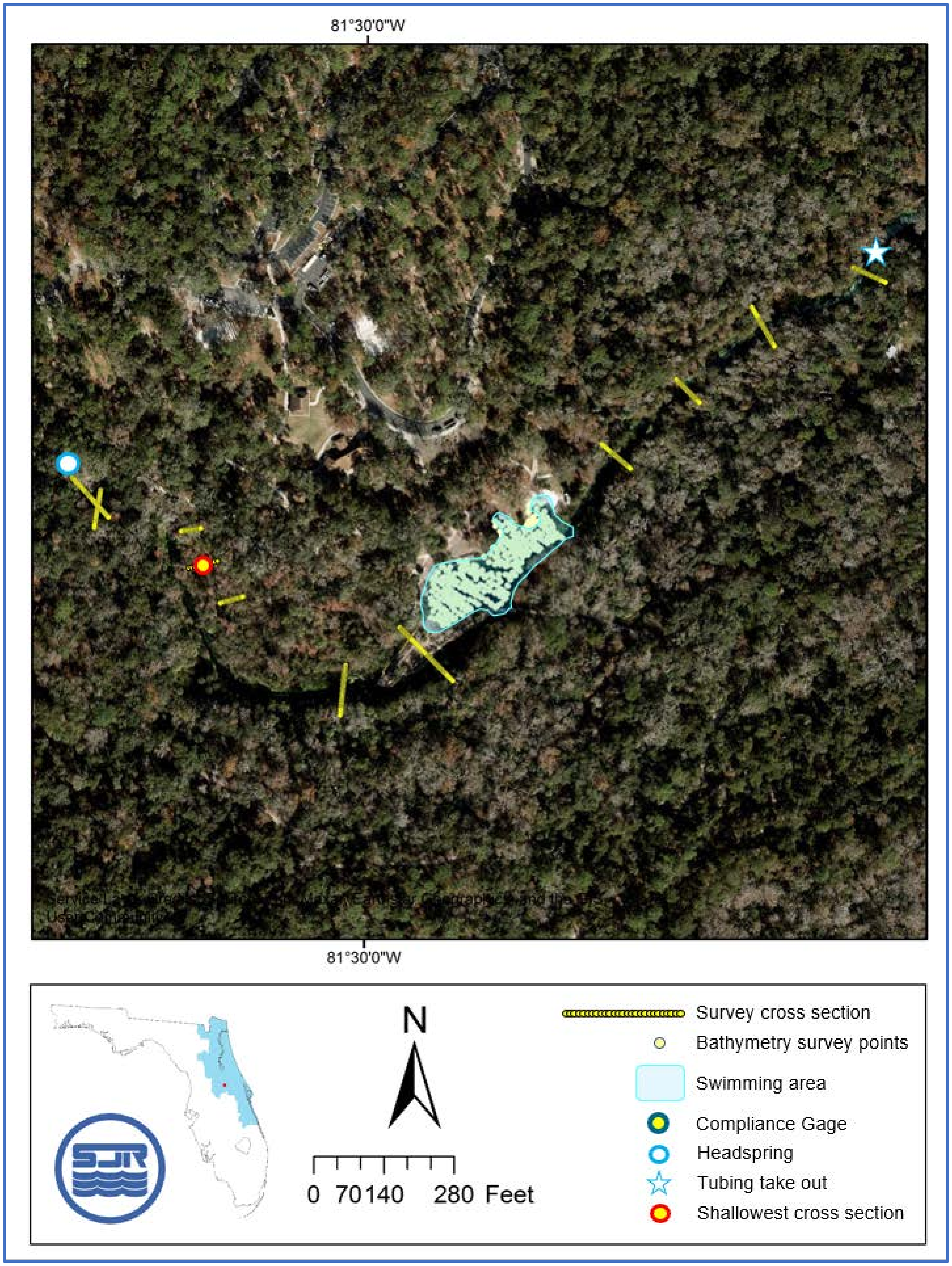

Figure E-10. Location of headspring, shallowest cross section, swimming area and tubing take out at Kelly Park, Orange County.

Figure E-11. Swimmers and tubers at headspring of Rock Springs.

The Rock Springs tubing metric was assessed by evaluating the exceedance of the critical tubing elevation (i.e., the elevation that affords minimum depth and width, described above) at the shallowest cross-section in Rock Springs Run (Figure E-12) under the current-pumping condition. The current-pumping condition was compared to the MFLs condition (a 15% reduction in exceedance of this critical elevation relative to the no-pumping condition).

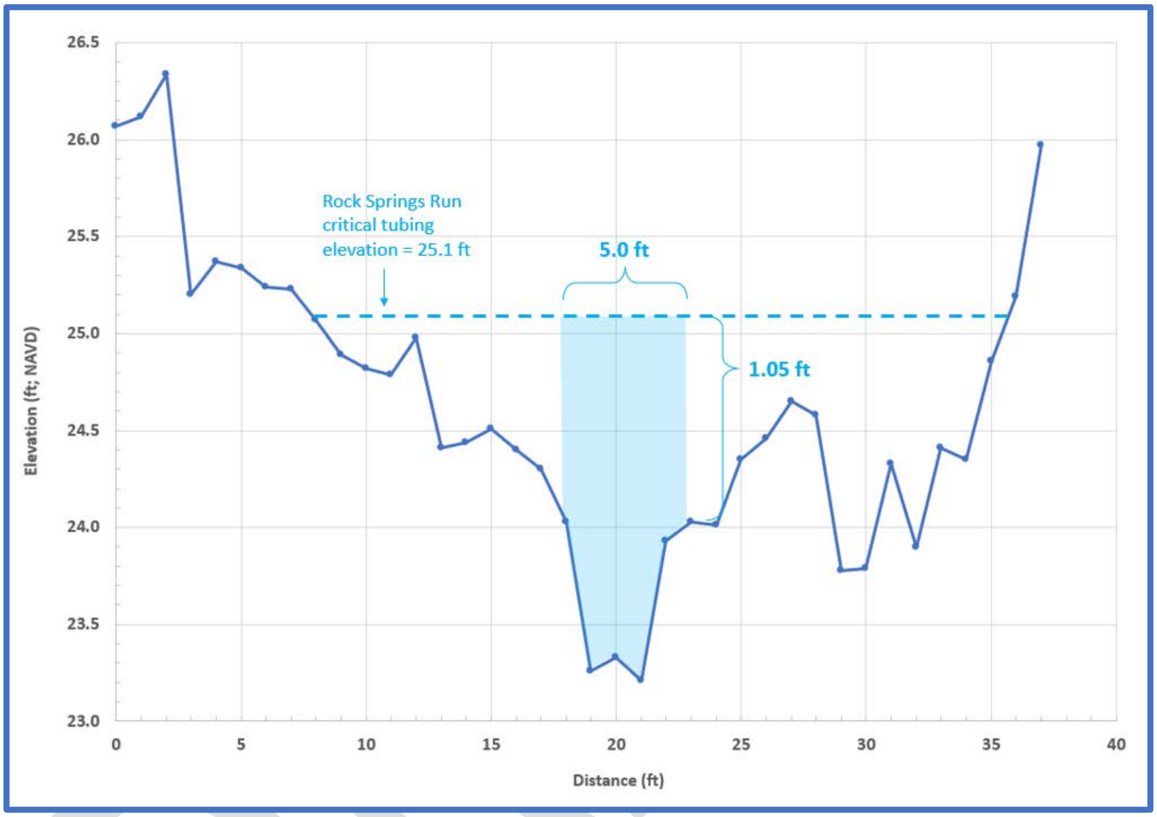

Figure E-12. Critical (minimum) elevation at shallowest cross-section in Rock Springs Run; this elevation affords minimum tubing area (width = 5 feet and depth = 1.05 feet).

Because the center of the shallowest reach of Rock Springs Run contains primarily limestone bedrock and does not contain SAV, no offset was applied to the spring run bottom elevation, in contrast to other MFLs set using this metric (i.e., 1.05 ft was added to the bottom elevation, not to the top of SAV).

The elevation at the shallowest cross-section that meets the critical depth and width equals 25.1 ft NAVD 88 (Figures E-12 and E-13). There is a 0.37 ft drop in water surface elevation between this cross-section and the Rock Springs gage. So, the elevation for which the exceedance analysis was performed was 24.7 ft NAVD 88 at the Rock Springs gage.

The exceedance of the shallowest tubing elevation translated to the Rock Springs gage (24.7 ft NAVD 88) under the no-pumping condition is 100% and therefore the MFLs condition exceedance equals 85.0%. Under the current-pumping condition, the critical tubing elevation

Figure E-13. Shallowest reach of Rock Springs Run, 0.2 miles downstream of headsprings.

is exceeded for 25,932 days, which is only one day less than under the no-pumping condition (25,933). This rounds to 100% exceedance and as such this metric is considered protected under the current-pumping condition.

Swimming and wading depth

Swimming and wading in spring pools and runs is very popular at several locations in the Wekiva basin. The effects of water level reductions (relative to the no-pumping condition) on elevations important for swimming and wading were evaluated for swimming areas at Rock Springs Run (Kelly Park) and Wekiwa Spring (headspring pool at Wekiwa Springs State Park). In addition to these two large public swimming areas, the feasibility of developing a swimming/wading metric was also explored for three private springs in the basin: Palm Springs (historical spring-fed swimming pool within "The Springs" neighborhood), Sanlando Springs (swimming area with beach in "The Springs" neighborhood) and Starbuck Springs (spring pool at private residence).

Rock Springs – Kelly Park

The swimming area at Kelly Park is approximately 0.4 miles downstream of the headspring within the run. Rock Springs Run is a stable system with very small water level fluctuations. The difference between the P10 and P90 (typically used to describe water level range) is only 0.3 feet under the no-pumping condition. Because of this very small water level range, it was deemed not appropriate to use a temporal exceedance metric to assess withdrawal effects on swimming at Rock Springs. A 15% change in temporal exceedance would cause a very

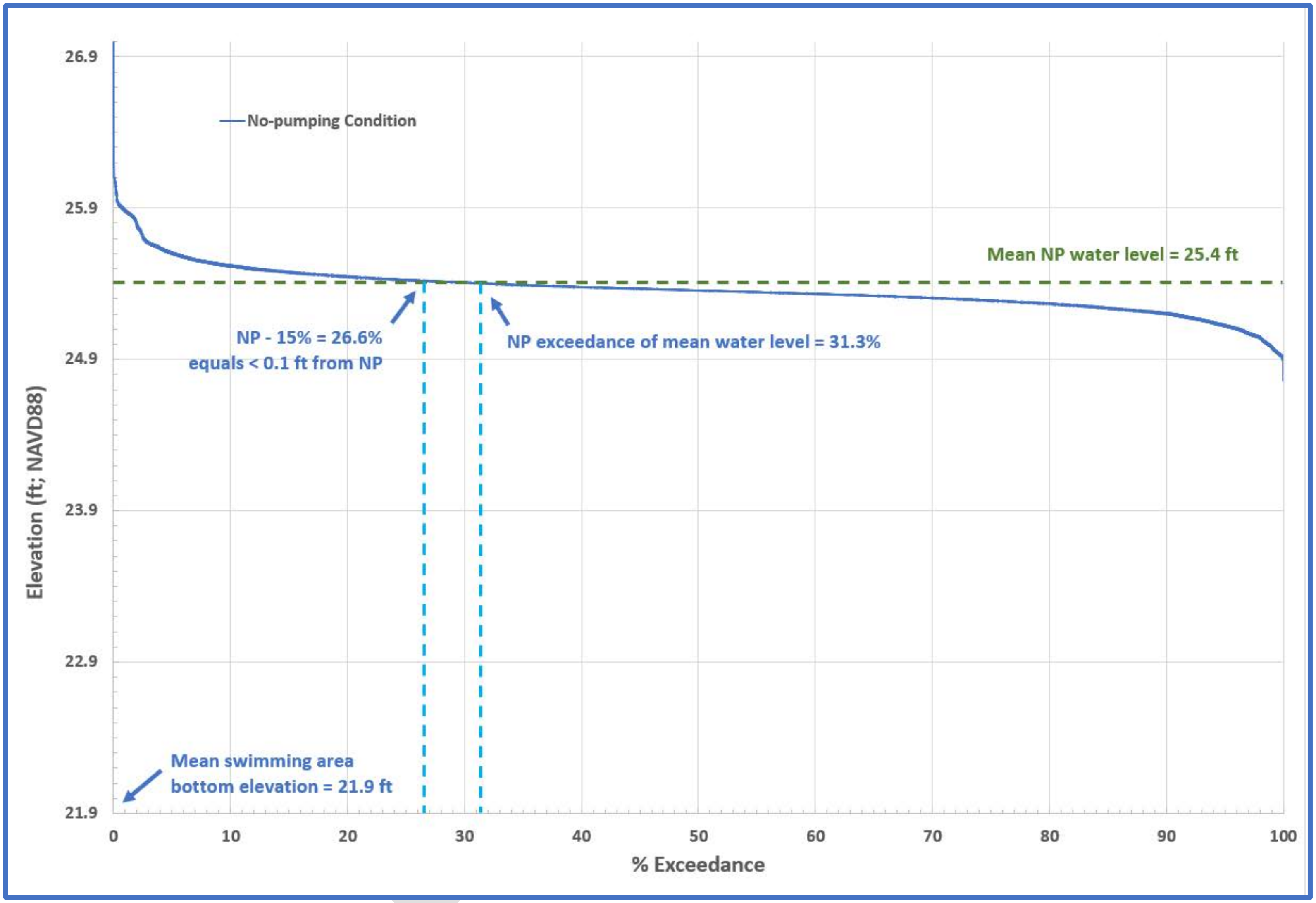

Figure E-14. Graph depicts a 15% reduction in temporal exceedance from no-pumping average water level at Rock Springs (Kelly Park) swimming area; this would equate to an allowable reduction in depth of < 0.1 ft.

small shift (only 0.02 ft) from the no- pumping elevation of 25.40 ft to 25.38 ft (Figure E-14). This would *not* be considered the limit beyond which significant harm would occur to recreation in the Kelly Park swimming area. As such, a temporal exceedance metric was not used for assessing the impact of withdrawal to swimming depth at Rock Springs.

Instead, swimming depth at the Kelly Park swimming area was evaluated as the change in average depth relative to the no-pumping condition. Bathymetric survey data (> 290 soundings) were collected and used to estimate the average bottom elevation of the spring pool, which was then used to determine average pool depth under different flow conditions (Figure E-15). Based on the bathymetric survey, the average bottom elevation is 21.9 ft NAVD 88 in the swimming area. The no-pumping condition average and median water levels (i.e., over the POR) in the Kelly Park swimming area are the same and equal 25.4 ft NAVD 88. Based on the average bottom elevation of 21.9 ft, this yields an average water depth of 3.5 feet under the no-pumping condition within the Kelly Park swimming area. The swimming depth metric at Rock Springs (Kelly Park) was assessed by comparing the average depth under the current-pumping condition with the MFLs condition, which is defined as a 15% reduction in average depth under the no-pumping condition (Figure E-16).

The MFLs condition average swimming depth equals 3.0 ft, which is a 0.5 ft (15%) reduction relative to the no-pumping condition depth of 3.5 ft. The MFLs condition for swimming depth is within the range considered suitable for wading (2 to 4 feet). Note that the no-pumping condition average depth (3.5 ft) is less than that found to be suitable for swimming (≥ 4 feet) based on a recent study on recreational functions and values for Florida springs (Wetland Solutions, Inc. 2021).

<u>Wekiwa Springs State Park</u>

Wekiwa Springs is a very popular swimming and wading area, locally and regionally (Figure E-17). This second magnitude OFS has a long-term average flow of 63 cfs, attracts on average 1,300 visitors per day (*personal communication*: Robert Brooks at Wekiwa Springs State Park), and has a recreational carrying capacity of 3,220 users per day (FDEP 2017). Similar to Rock Springs, Wekiwa Springs is a stable system with very small water level fluctuations; the difference between the P10 and P90 (typically used to describe water level range) is only 0.6 feet under the no-pumping condition. As with Rock Springs this small water level range (i.e., flat exceedance curve) results in a very constraining temporal exceedance metric. A 15% change in exceedance would shift from the no-pumping elevation of 12.20 ft to 12.24 ft (a change of 0.04 ft). Therefore, as with Kelly Park, the swimming at Wekiwa Springs was assessed by evaluating the change in average depth relative to the no-pumping condition.

Bathymetric survey data were collected and used to determine the average bottom elevation of the spring pool, which was then used to determine average pool depth under different flow

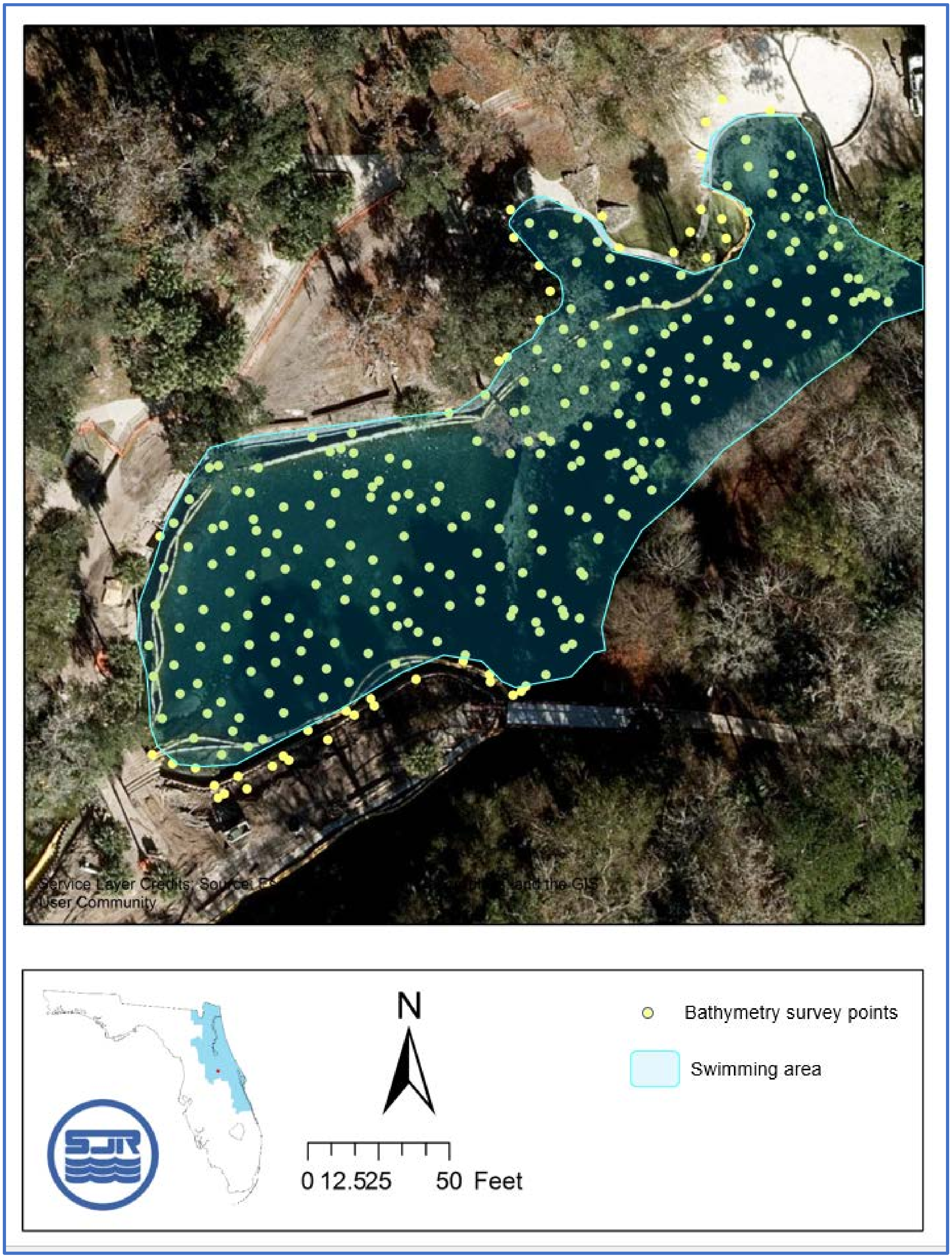

Figure E-15. Location of > 290 bathymetric soundings surveyed within the swimming area at Rock Springs (Kelly Park) in 2022.

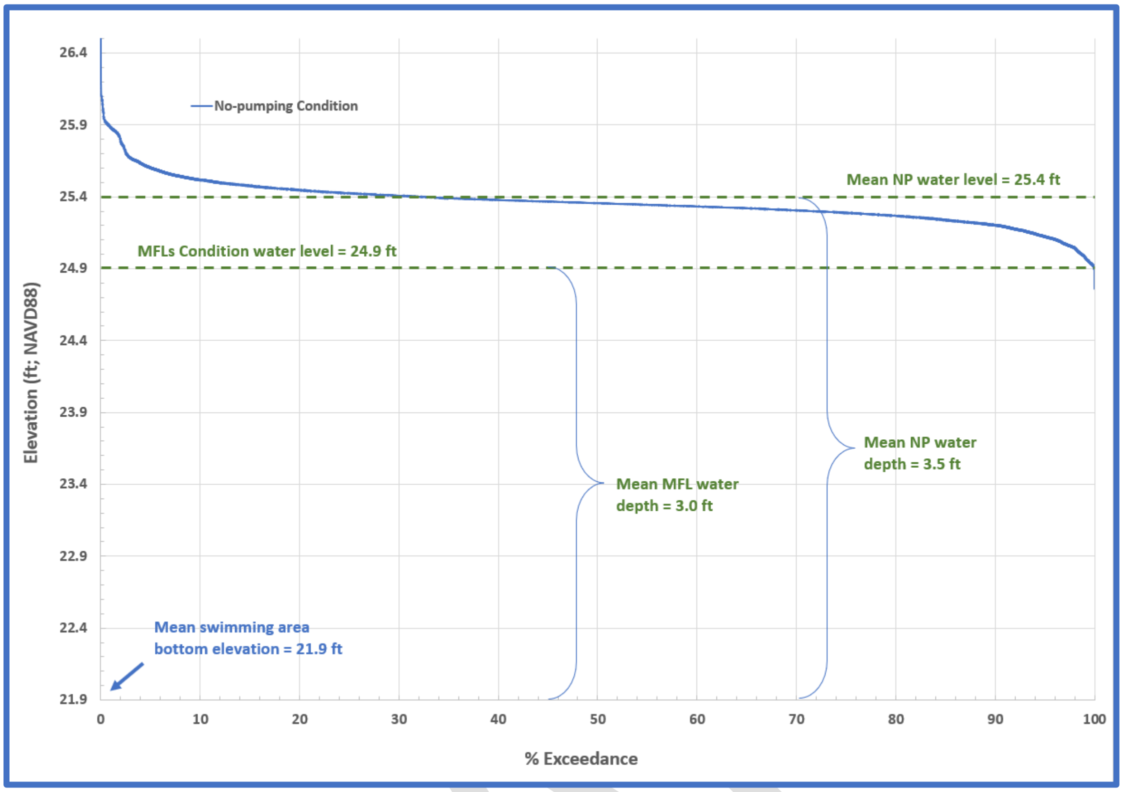

Figure E-16. No-pumping (NP) average depth and MFLs condition swimming depth (15% reduction from NP) at Rock Springs (Kelly Park) swimming area.

Figure E-17. Swimming area in Wekiwa Springs headspring pool at Wekiwa Springs State Park.

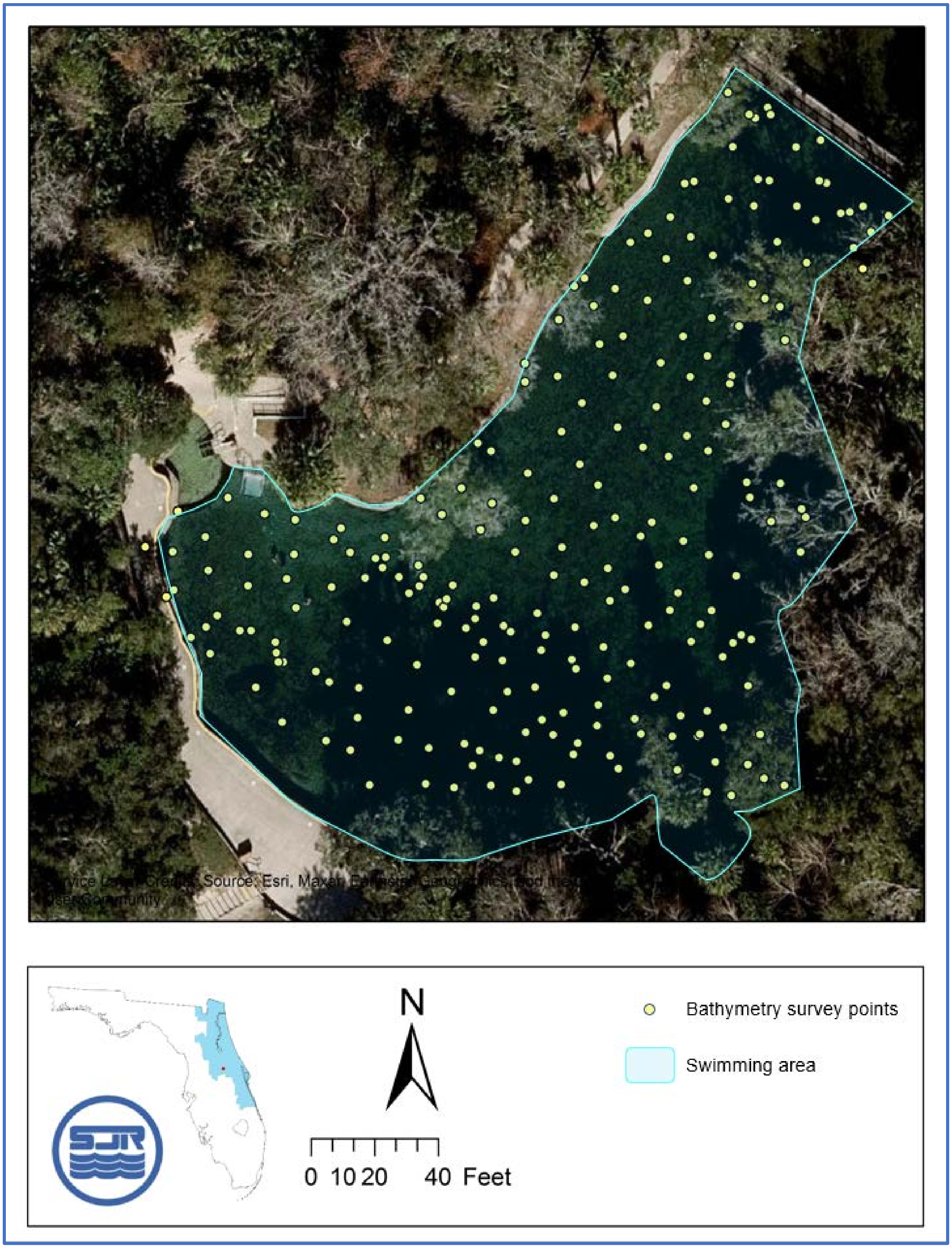

Figure E-18. Location of > 230 bathymetric soundings surveyed within the swimming area at Wekiwa Springs State Park in 2022.

conditions (Figure E-18). The no-pumping condition average water level (i.e., over the POR) in the Wekiwa Springs State Park swimming area (main spring pool) equals 12.2 ft NAVD 88 (median water level equals 12.1 ft). Based on the bathymetric survey, with over 230 survey points, the average bottom elevation is 7.5 ft NAVD 88 in the swimming area, yielding an average water depth of 4.7 feet over the POR under the no-pumping condition.

The swimming depth metric at Wekiwa Springs was assessed by comparing the average depth under the current-pumping condition with the MFLs condition, which is defined as a 15% reduction in average depth under the no-pumping condition (Figure E-19). The MFLs condition average swimming depth equals 4.0 ft, which is a 0.7 ft (15%) reduction relative to the no-pumping condition depth of 4.7 ft. The MFLs condition for swimming depth is within the range considered suitable for wading (2 to 4 feet) and swimming (≥ 4 feet) based on a recent study on recreational functions and values for Florida springs (Wetland Solutions, Inc., 2021). It is also within the range commonly recommended and designed for recreational and lap pools (3.25 to 5 feet).

The protection of swimming and wading at Wekiwa Springs State Park and Kelly Park was evaluated by assessing the effect of withdrawal on the average no-pumping condition depth

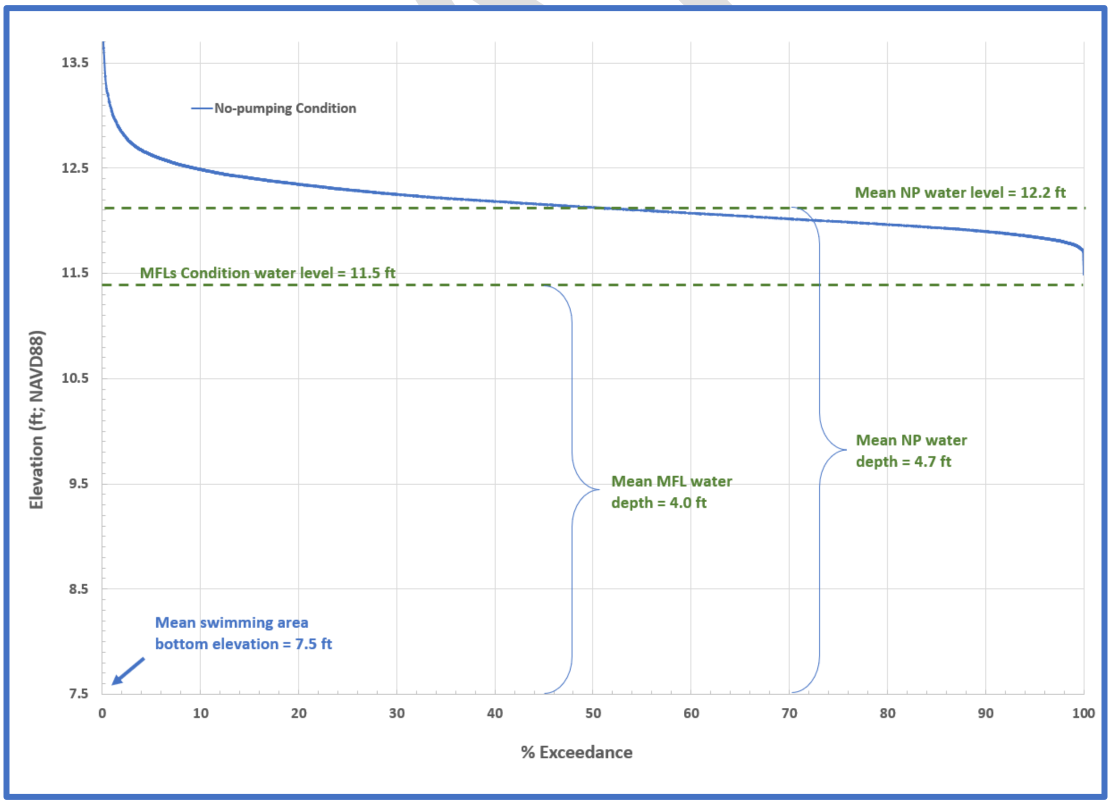

Figure E-19. No-pumping (NP) average depth and MFLs condition swimming depth (15% reduction from NP) at Wekiwa Springs swimming area.

in the swimming areas of these two parks. The MFLs condition average swimming depth at the Kelly Park swimming area equals 3.0 ft, which is a 0.5 ft (15%) reduction relative to the no-pumping condition depth of 3.5 ft (Table E-2). The MFLs condition average swimming depth at the Wekiva State Park swimming area equals 4.0 ft, which is a 0.7 ft (15%) reduction relative to the no-pumping condition depth of 4.7 ft. The average depth of the swimming areas under current-pumping conditions is reduced 0.2 ft (from 4.7 to 4.5 ft) at Wekiwa Springs State Park and 0.3 ft (from 3.5 ft to 3.2 ft) at Kelly Park (Table E-2). Both represent less than a 15% reduction from the no-pumping condition (i.e., have greater depth than under the MFLs condition). As such, swimming depths are considered protected under the current-pumping condition for both sites.

Table E-2. Average depth under no-pumping (NP), MFLs (NP – 15%) and current-pumping (CP) conditions for Wekiwa Springs State Park swimming area and Kelly Park (Rock Springs) swimming area.

Swimming Area	NP average depth (ft)	MFLs average depth (ft)	CP average depth (ft)
Wekiwa Springs State Park	4.7	4.0	4.5
Kelly Park	3.5	3.0	3.2

Little Wekiva River Springs – Sanlando, Starbuck and Palm Springs

A swimming depth metric was also investigated for three springs in the Little Wekiva River basin: Sanlando Springs, Starbuck Springs and Palm Springs. These small springs were part of the original 1996 Wekiva River basin MFLs determination. Sanlando and Starbuck Springs are second magnitude springs with long-term average flows of approximately 20 cfs and 12 cfs, respectively. Palm Springs is a third magnitude spring with a long-term average flow of approximately 5 cfs. All three springs are within the gated neighborhood called "The Springs" and are primarily used for recreation (swimming and wading) by local residents.

Bathymetric surveys were conducted to determine average elevation of the spring pool bottom at all three springs (Table E-3). Bottom elevations were compared to average water level data to estimate average pool depth under different flow conditions.

All three of these Little Wekiva River springs are highly altered and have walls, weirs or control structures that affect flow rate and pool stage (Figure E-20). Because of these structural alterations, the relationship between flow and water level was analyzed at each spring. This was important because the lack of a strong relationship would preclude the ability to develop a meaningful swimming or wading metric (based on level or depth) that would be sensitive to changes in flow.

Table E-3. Average water level and spring pool depth for observed POR (1985 to present) for Palm, Sanlando and Starbuck Springs.

System	Average water level for observed POR (ft; NAVD 88)	Pool bottom elevation (ft; NAVD 88)	Average spring pool depth for observed POR (ft; NAVD 88)
Palm Springs	21.2	17.8	3.4
Sanlando Springs	25.6	21.3	4.3
Starbuck Springs	19.9	16.3	3.6

Figure E-20. Outlet structure at Sanlando Springs.

Palm Springs

Palm Springs (Figure E-21) flow fluctuates from less than 3 cfs to almost 9 cfs over the observed POR (1985 to present; Figure E-22). During this period, water levels fluctuate approximately 6 feet from approximately 20 ft to just under 27 ft NAVD 88. A comparison of flow versus level at Palm Springs demonstrates a stark lack of relationship between these two parameters ($r^2 = 0.04$; Figure E-23). This is likely due to the fact that the "run" between the Palm Springs pool outlet structure and the Little Wekiva River is very short and the former is highly influenced by a backwater effect from the latter. There is also evidence for local swimmers adding and removing weir boards at Palm Springs, which occasionally and randomly raises and lowers the water level.

Figure E-21. Palm Springs, Seminole County.

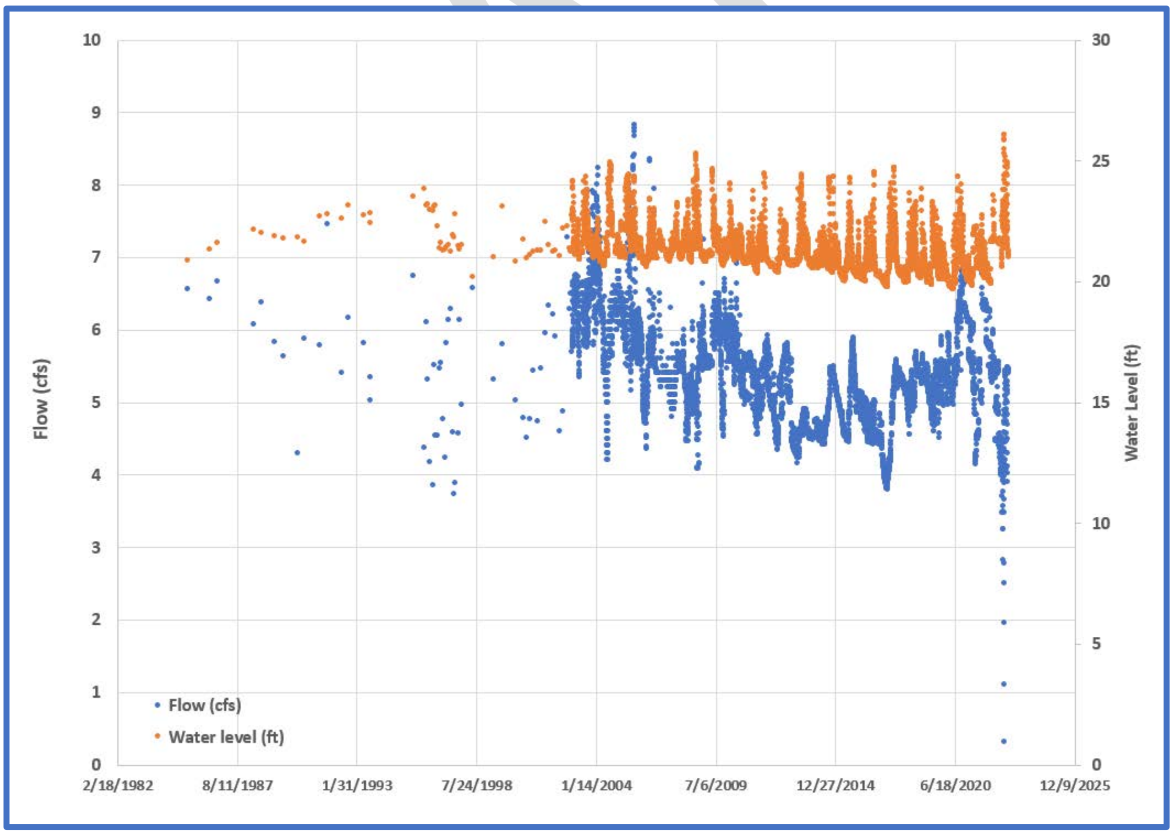

Figure E-22. Spring flow (cfs) and spring pool water level (ft) at Palm Springs.

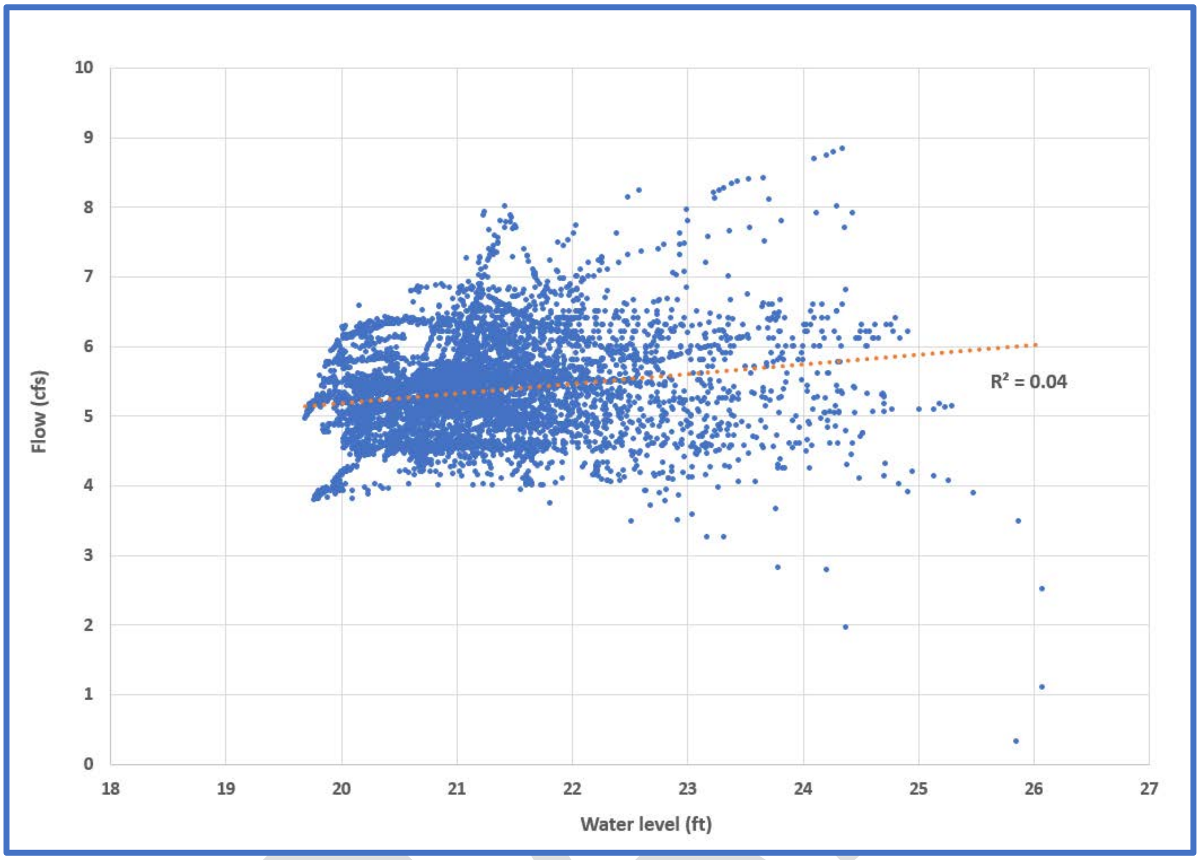

Figure E-23. Spring flow (cfs) versus spring pool water level (ft) at Palm Springs.

Sanlando Springs

Sanlando Springs (Figure E-24) flow exhibits a large (10 – 35 cfs) fluctuation over the POR. However, during this same period water levels remain fairly stable (Figure E-25). Similar to Palm Springs, a comparison of flow and level at Sanlando Springs demonstrates a very weak relationship between these two parameters (r^2 = 0.08; Figure E-26). The lack of relationship is likely due to the fact that weir boards at Sanlando Springs are removed and the spring pool drawn down every week or two to facilitate cleaning algae from the beach area.

Figure E-24. Sanlando Springs, Seminole County.

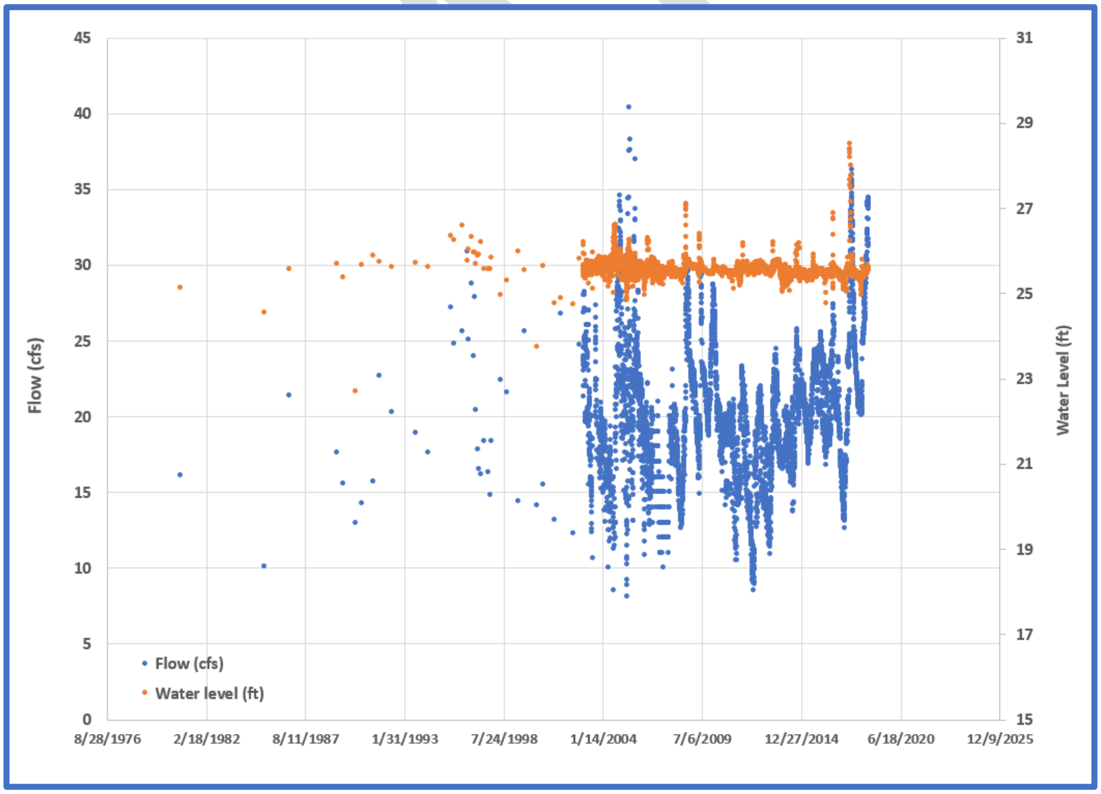

Figure E-25. Spring flow (cfs) and spring pool water level (ft) at Sanlando Springs.

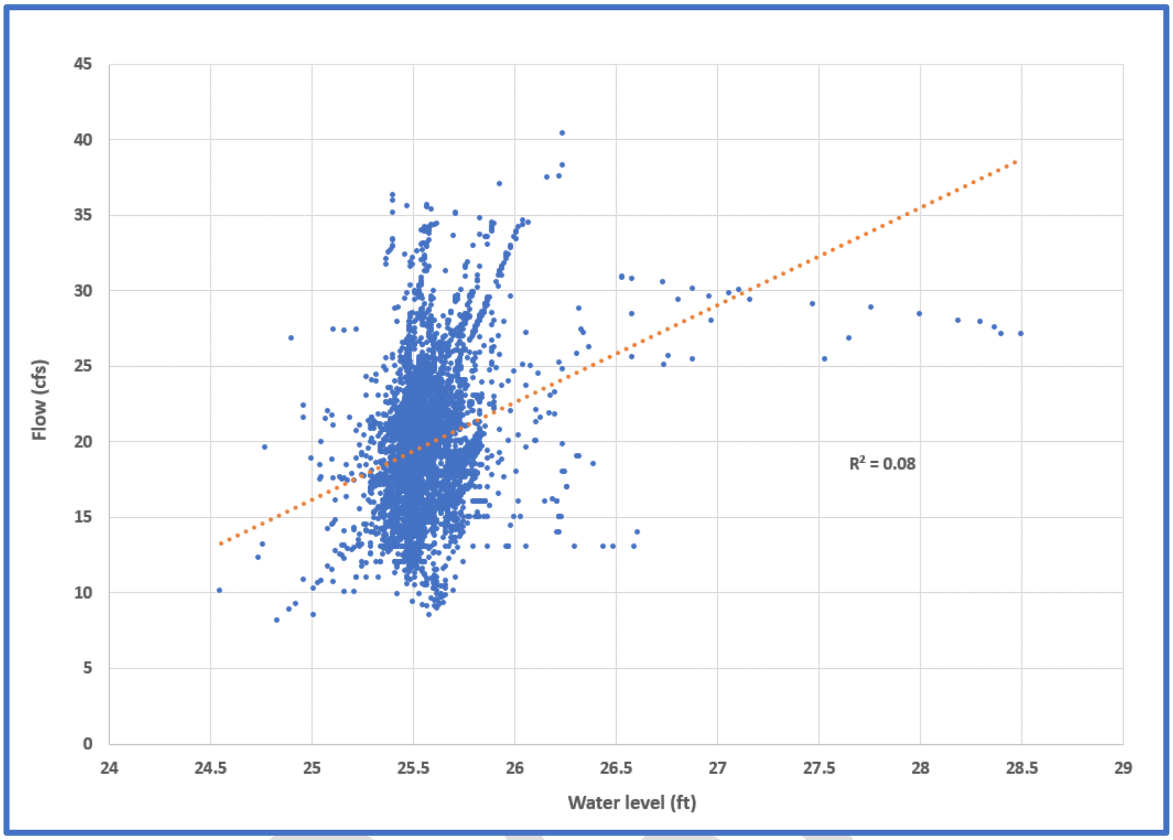

Figure E-26. Spring flow (cfs) versus spring pool water level (ft) at Sanlando Springs.

<u>Starbuck Springs</u>

The flow at Starbuck Springs (Figure E-27) increases from a low of approximately 6 cfs to a high of nearly 23 cfs over the POR (1985 – present; Figure E-28). During this period water levels are much more stable, fluctuating from 19 ft to approximately 23.5 ft (NAVD 88). Similar to the other two LWR springs, flow versus water level at Starbuck Springs are not related ($r^2 = 0.002$; Figure E-29).

There is a lack of relationship between flow and water level at Palm, Sanlando and Starbuck Springs (Figures E-23, E-26, and E-29). There are several reasons for the lack of relationship between flow and water level at these three springs. The primary reason at all three springs is likely due to backwater effects from the flooding of the LWR. The spring runs for all three springs are relatively short and water backs up frequently from the river into these spring pools. Another reason for the lack of relationship between flow and level at two of the springs (Palm and Sanlando Springs) is that weir boards are removed frequently.

Because of the lack of relationship between flow and water level, it was deemed inappropriate to develop a water-level-based swimming or wading metric at these three

Figure E-27. Starbuck Springs, Seminole County.

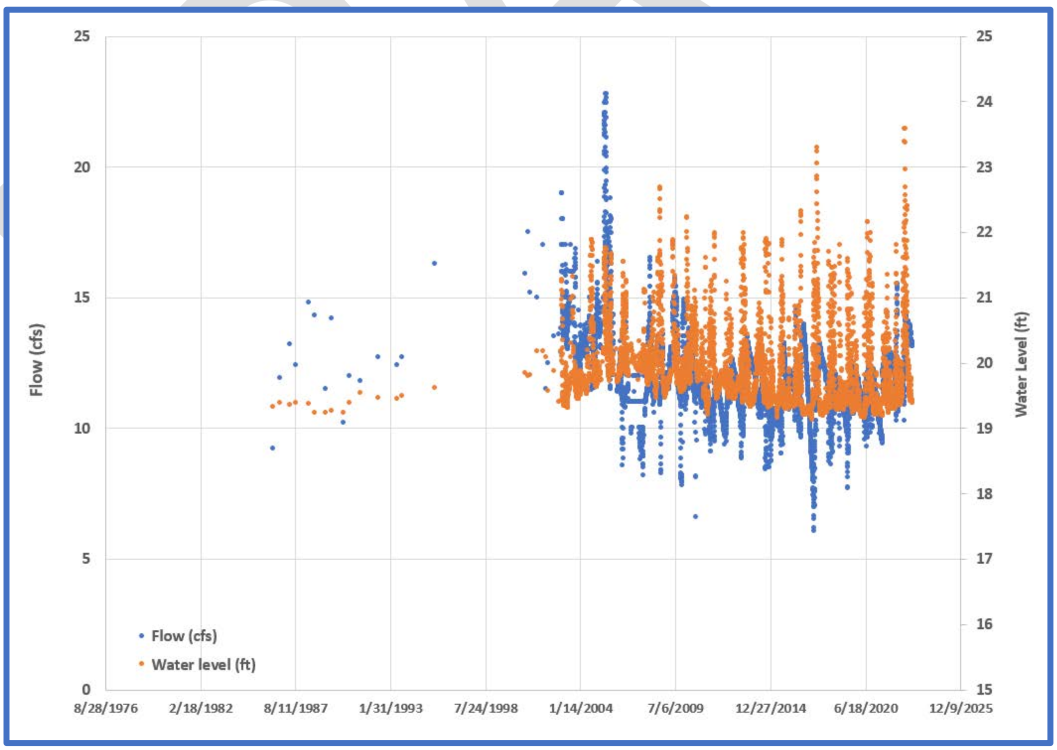

Figure E-28. Spring flow (cfs) and spring pool water level (ft) at Starbuck Springs.

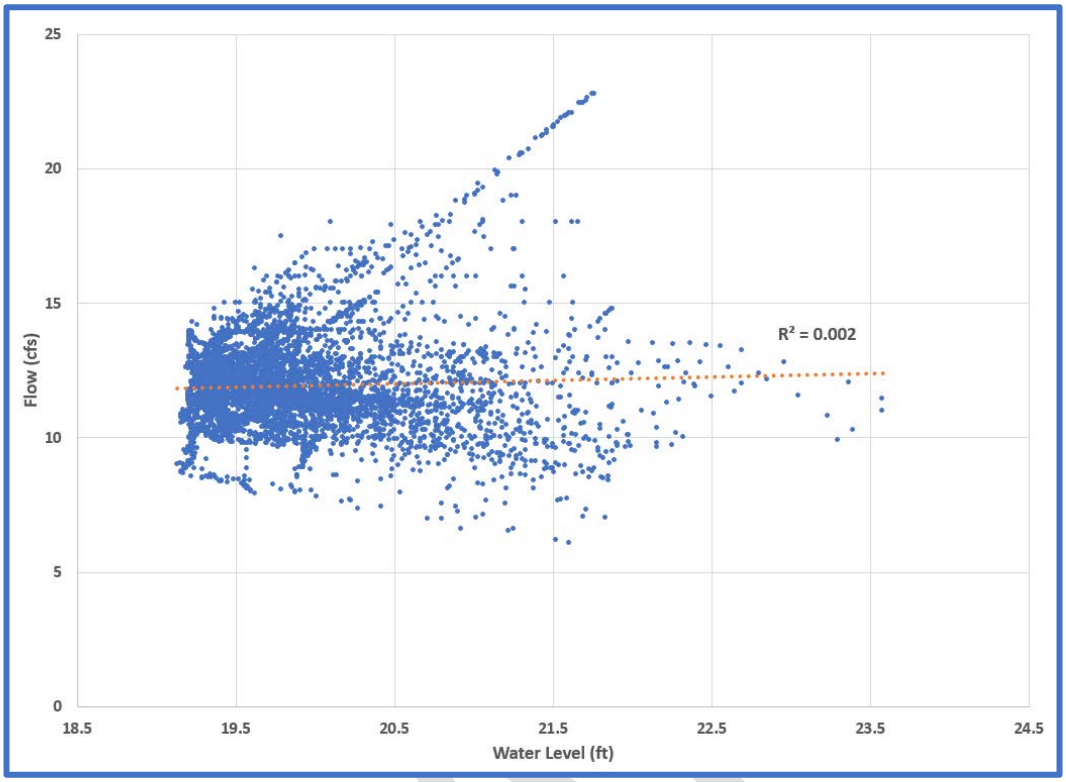

Figure E-29. Spring flow (cfs) versus spring pool water level (ft) at Starbuck Springs.

springs. Average water level, average depth or a depth threshold (e.g., 4 feet per WSI 2021) would all be very insensitive metrics. Flow could be reduced by a large amount before a significant change in water level would occur. For example, flow ranges from 10 to 35 cfs when water levels equal 25.5 ft at Sanlando Springs (Figure E-25). Much of this range is likely due to backwater from the Little Wekiva River.

The insensitivity of elevation-based metrics mean that they are not useful for assessing the effects of withdrawal on pool depth at these three small springs. The development of a minimum flow for these small springs is based instead on the flow required to meet downstream MFLs (see below for details).

WRV 2. Fish and Wildlife Habitat and Passage of Fish

The Wekiva River system includes many miles of in-channel habitats, diverse floodplains and associated terrestrial communities, all of which provide important habitat for numerous fish and wildlife populations. These habitats harbor rare and/or endangered species, such as the gopher tortoise, wood stork, bald eagle, Audubon's crested caracara, roseate spoonbill, sandhill crane, manatee, bluenose shiner and American shad. Twenty-three species found in the Wekiva River basin are officially listed by the state or federal government as in danger (or possible danger) of going extinct (FDEP 2014).

Numerous fish, insect, amphibians, reptiles, mammals, birds and plant species living in or adjacent to the Wekiva River were documented in the Wekiva River Basin BioBlitz 2012 organized by the Friends of the Wekiva River. Many additional sources of Wekiva basin fauna information exist, including Warren (2000), Walsh and Kroening (2007), Walsh et. al. (2009), on-going turtle research by the Central Florida Freshwater Turtle Research Group, annual bird surveys (FDEP 2014), on-going snail and mussel studies (FWC unpublished data 2020), macroinvertebrate sampling efforts in Wekiva basin springs (Mattson et al. 2022) and various Florida Fish and Wildlife Conservation Commission (FWC) fish and wildlife research efforts.

Primary Metrics

WRV 2 is meant to ensure the consideration and protection of aquatic and wetland environments required by fish and wildlife, including endangered, endemic, listed, regionally rare, recreationally or commercially important, or keystone species. One of the purposes of the primary metrics evaluated for the Wekiva River basin systems is the protection of wetland environments that provide critical foraging, reproductive and resting habitat for myriad fish and wildlife species. The event-base FH (at SR 46 and Wekiwa Springs) and the MA (at SR 46) resulted in an allowable impact in the basin equal to the current-pumping condition (see Appendix D and *MFLs Assessment* section in main report). In so doing, these metrics will protect the structure and function of floodplain and in-channel habitats necessary to maintain the long-term viability of fish and wildlife populations in the basin.

In addition to the primary metrics described in the *MFLs Determination* section in the Main Report, several other analyses were performed to ensure that key fish and wildlife functions and values are considered. These are presented below. The status of these metrics was evaluated using the basin-wide flow freeboard which is equal to the current-pumping condition.

Fish Passage

A fish passage metric was developed to ensure provision of adequate passage for large-bodied fish species within the main reaches of the river system (i.e., the mainstem Wekiva River, Rock Springs Run and Little Wekiva River). This will ensure the protection of movement necessary for foraging, migration and other life history requirements. Guidelines for fish passage are typically based on body dimension measurements for multiple fish species (Hupalo et al. 1994). Few studies have documented minimum water depths required to maintain fish passage, and it is unknown how many shallow obstructions can be navigated by fish before health and vitality are compromised (Hupalo et al. 1994). However, given the recognized importance of this environmental value, minimum fish passage depths have been established for numerous priority water bodies.

Minimum water depths of at least 0.6 feet have been used previously in Florida (SRWMD 2007; SWFWMD 2002). The SJRWMD has previously used a depth of 0.8 feet over 25% of the channel width as the criterion for fish passage (Hall and Borah 1998; Mace 2007; SJRWMD 2012) (Figure E-30). This depth is based on work conducted in cold-water streams and rivers to protect large-bodied salmonids (i.e., salmon and trout) (Thompson 1972; Everest et al. 1985). The relative size of these fishes is comparable to larger fish in the Wekiva River (e.g., largemouth bass and gar). It is assumed that protection of fish passage for larger species will also protect passage for the numerous small-bodied species that inhabit the Wekiva River. See Attachment 1 to this appendix for Wekiva River basin fish community data. An evaluation of the potential sensitivity of American shad (and other alosid species) to flow reduction is provided below. The fish passage metric is as follows:

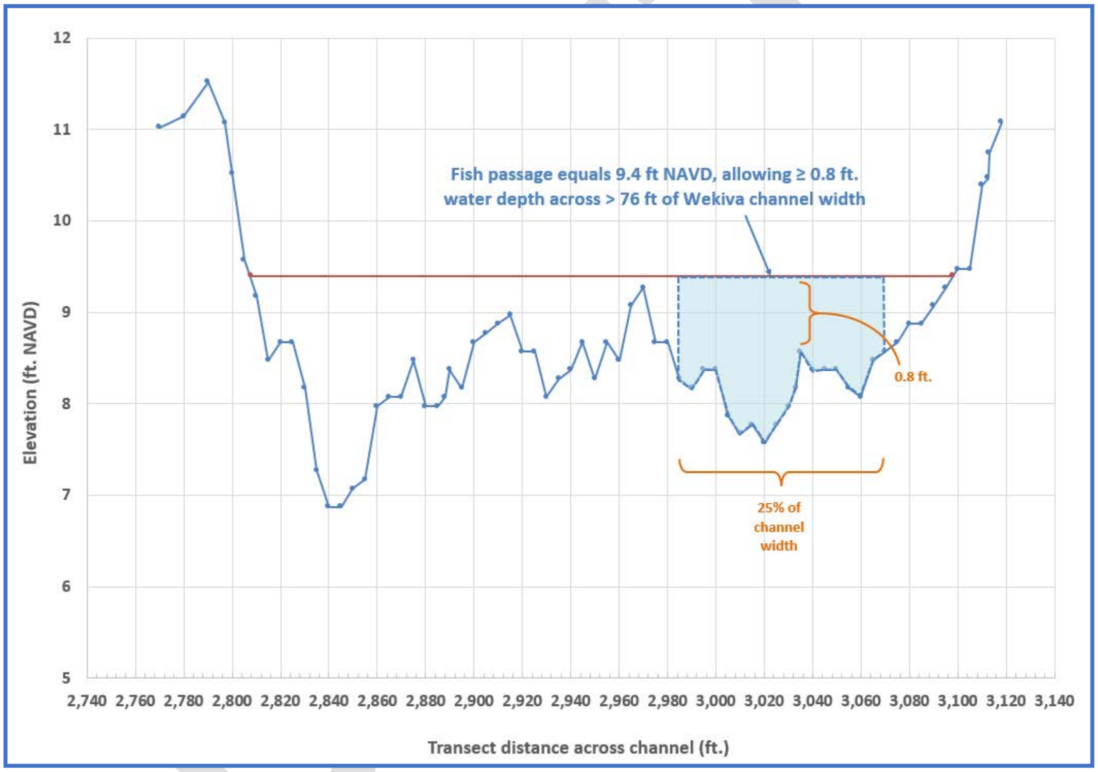

Figure E-30. Example fish passage elevation and depth at The Swamp transect in the Wekiva River.

Fish passage exceedance metric:

- Critical elevation: water level elevation that provides a water depth of at least 0.8 feet across at least 25% of the river channel (Figure E-30).

Impact Threshold:

- Allow no more than a 15% reduction in exceedance of the critical fish passage elevation, relative to a no-pumping condition.

The fish passage metric was evaluated for all transects in the Wekiva River basin HEC-RAS model. The HEC-RAS model was used to develop relationships between river flow and water surface elevation (stage), at each of the model's transects. For each HEC-RAS cross-section, the depth of water over the channel bottom is estimated for a given flow.

A graphical tool (data plot) was used to aid in the identification of cross-sections and flows that do not allow for passage of fish (Figure E-31). For each cross-section, the depth of water over the channel bottom is estimated for a given flow. The difference between this depth and the depth required to maintain fish passage (i.e., ≥ 0.8 feet over ≥ 25% of the cross-section) is represented by the value 'Z' in the plot (Figure E-31).

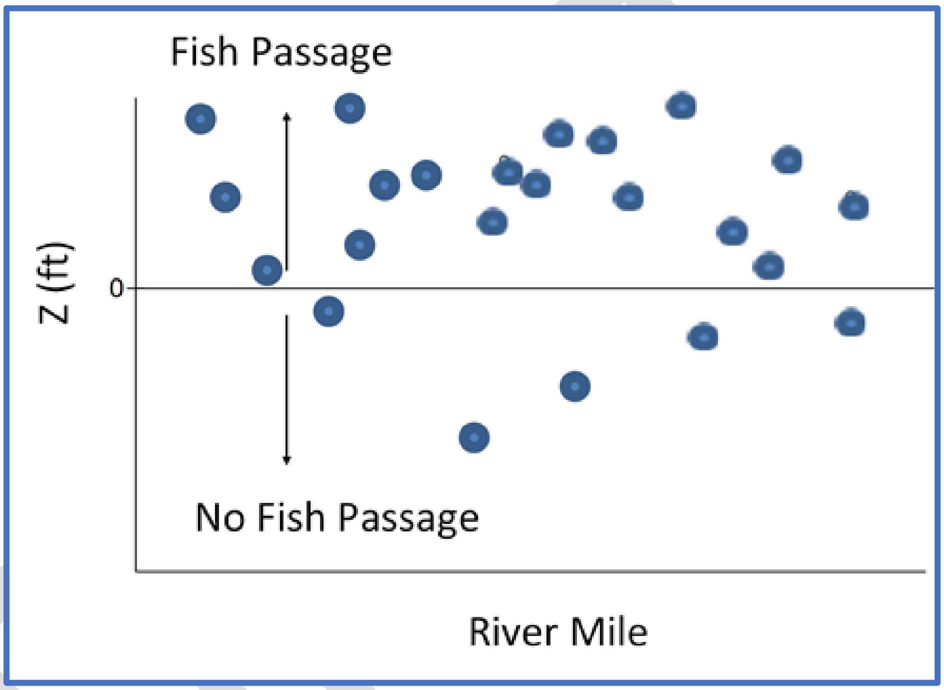

Figure E-31. Conceptual diagram of fish passage exceedance for a given flow; Z is defined as the maximum simulated depth at a cross-section minus the critical depth necessary for fish passage. When Z > 0, fish passage is allowed at flow condition X. When Z < 0, fish passage is precluded at flow condition X.

<u>Assessment</u>

As described above, the fish passage metric was assessed for all transects in the HEC-RAS model. At all four sites and at all transects evaluated, the critical fish passage depth (≥ 0.8 feet over ≥ 25% of the cross-section) was achieved at each flow under the no-pumping condition and current-pumping condition (Figure E-32).

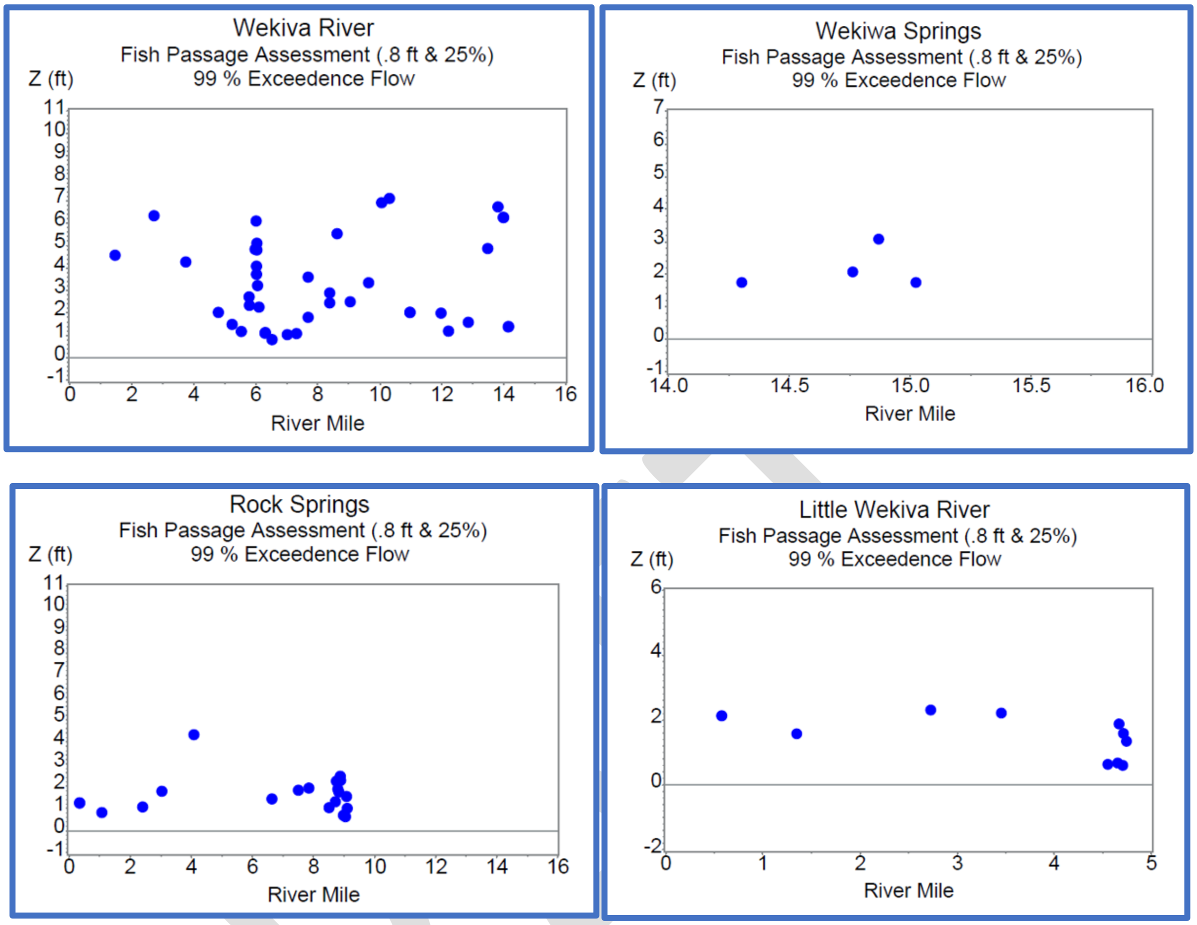

Figure E-32. Fish passage results for the Wekiva River at SR46, Wekiwa Springs, Rock Springs and the Little Wekiva River cross-sections under the current-pumping condition.

Manatee Passage

Another passage metric was evaluated to ensure protection of adequate depths for movement of the West Indian manatee (*Trichechus manatus*), a federally threatened species that uses lower portions of the Wekiva River (primarily downstream of SR 46). Sustainability of Florida's manatee population depends on the availability of warm-water refuges during winter months. Manatees begin to seek warmer waters when the temperature of the river drops below the high 60s Fahrenheit (°F), typically between November and March.

While neither Rock Springs nor Wekiwa Springs are recognized as primary or secondary warm-water refugia for manatees, evidence suggests that two named springs (Island Spring and Nova Springs) have the potential to provide refugia for manatee in the Wekiva River downstream of SR 46 (Figure E-33). Additionally, the lower one-mile reach of the Wekiva River is designated a slow speed zone due to the regular presence of manatees in lower portions of the river.

Portions of the Wekiva River have “high potential” for providing suitable habitat for manatee, however, they are thought by experts to be restricted by shallow depths in the section of the Wekiva River upstream of the SR 46 bridge known as “The Flats” (*personal communication*: Teresa Calleson of FWC) (Figure E-6). The Wekiva River provides a significant food source for manatees, especially in the river just downstream of SR 46, ensuring assessment of an area known to provide manatees with forage habitat and possible warm water refuge (Nova and Island Springs) (Figure E-33). For this reason, manatee passage was only evaluated for the Wekiva River below SR 46.

The assessment of the relationship between Wekiva River flow and manatee passage was similar to the evaluation used for fish passage. The HEC-RAS model was used to estimate water depth as a function of river flow at each of the transects below RM 6 (Figure E-33).

The specific indicator of protection for manatee passage is based on maintaining a minimum depth of 3 feet at the most limiting HEC-RAS transect (Figure E-34). This depth threshold was chosen based on lower limit of preferred manatee depths documented at Blue Springs (Volusia County, Florida) (Worthy 2003). This depth has been used as a manatee passage threshold by SWFWMD and SRWMD.

The manatee passage metric is as follows:

Manatee passage exceedance metric:

- Critical elevation: water level elevation that provides a water depth of at least 3 feet above the highest elevation (shallowest point) of a given transect.

Impact Threshold:

- Allow no more than a 15% reduction in exceedance of the critical manatee passage elevation, relative to a no-pumping condition.

<u>Assessment</u>

Manatee passage was evaluated for cross-sections in the HEC-RAS model downstream of SR 46 using the same approach as for the fish passage metric. Of the twelve cross-sections evaluated, only one (cross-section 292.23) did not meet the critical depth criterion under the no-pumping condition (E-35). Under the current-pumping condition, no new cross-sections

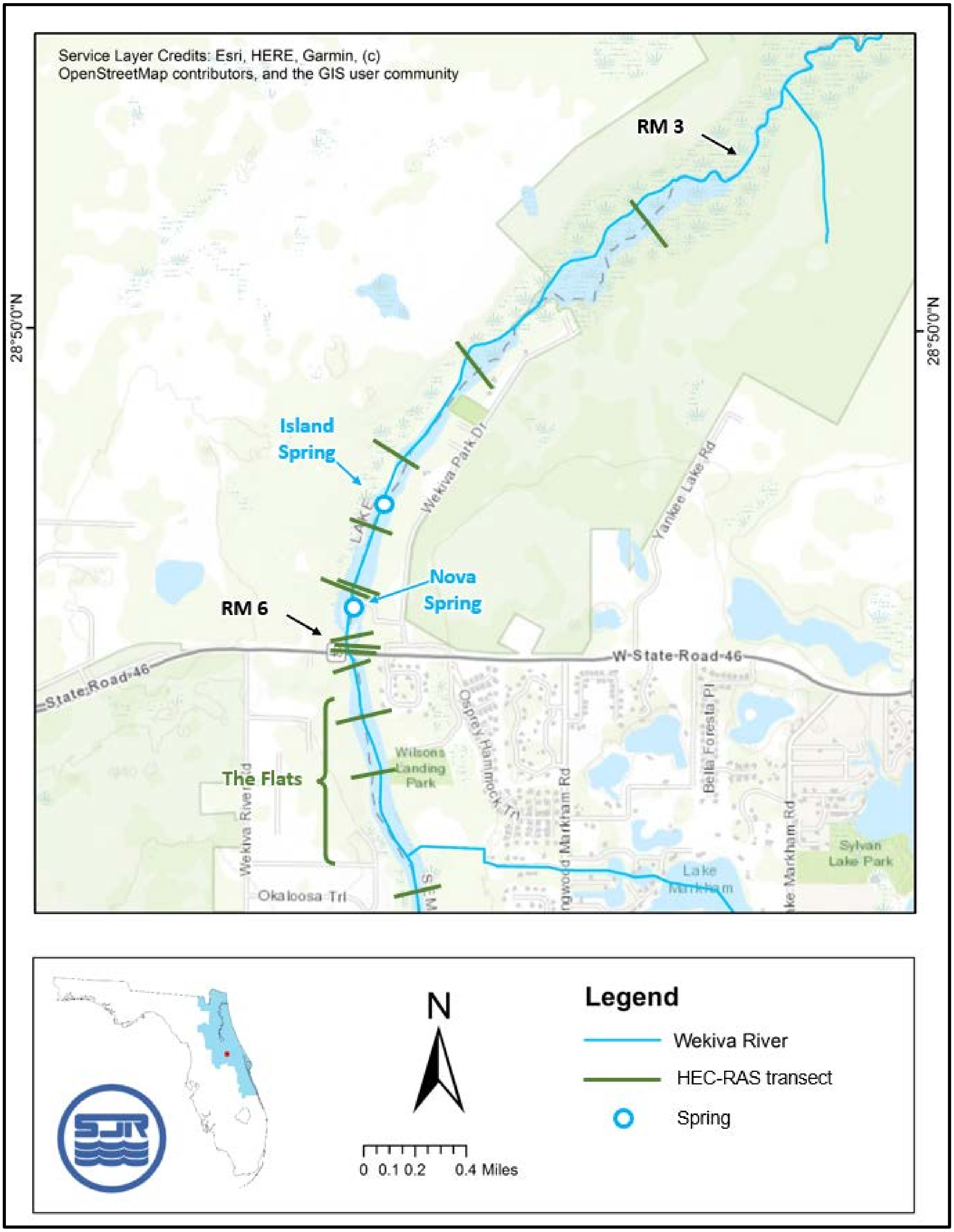

Figure E-33. Location of two potential manatee warm water refuge sites (Nova Spring and Island Spring) downstream of the SR 46 bridge on the Wekiva River

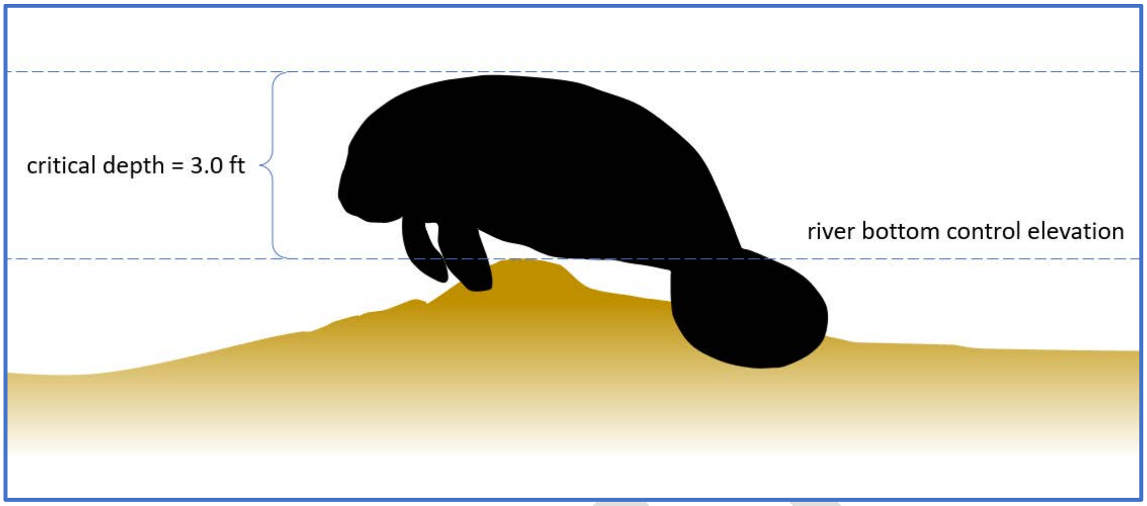

Figure E-34. Illustration of manatee passage elevation that provides adequate depth (3.0 ft) for movement (i.e., provides clearance over highest river bottom elevation).

failed to achieve meeting the critical depth threshold (i.e., the only cross-section failing to meet the threshold also failed under the no-pumping condition). Therefore, manatee passage in the Lower Wekiva River is considered protected by the current-pumping condition.

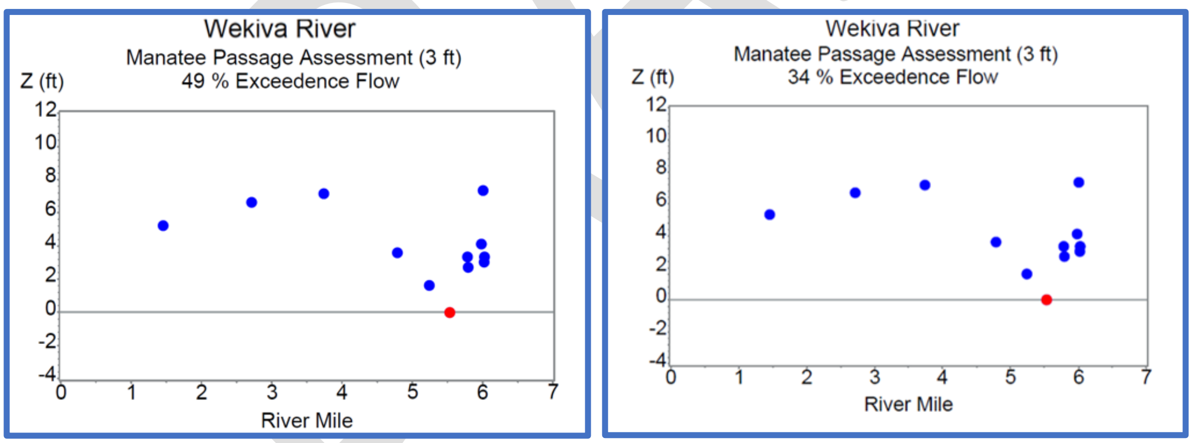

Figure E-35. Manatee passage results for the Wekiva River at SR 46 under the no-pumping condition (left graph) and current-pumping condition (right graph).

Shad Spawning Habitat

American shad (*Alosa sapidissima*) is one of three species of anadromous river herrings that spawn in the St. Johns River and its tributaries, including the Wekiva River (Williams et al. 1972; McBride 2000; Harris and McBride 2004; Harris et al. 2007). Blueback Herring (*Alosa aestivalis*) and Hickory Shad (*Alosa mediocris*) are the other two species found in the St. Johns and Wekiva Rivers. None of these species are listed, but their harvest and recreational fisheries are regulated by the Atlantic States Marine Fisheries Commission. Currently stocks of American shad are considered severely depleted and restoration efforts are now underway to rebuild populations of all three species of riverine herrings (ASMFC 1999; ASMFC 2009a; ASMFC 2009b). Adequate water flow and water quality at American shad spawning grounds may be the primary factors limiting shad abundance and recovery in Florida (McBride 2000). Therefore, it is important to consider the spawning habitat requirements of these species during the development of MFLs for the Wekiva River.

Of the three anadromous herrings found in the St. Johns and Wekiva Rivers, American shad is most abundant and most studied (Walburg and Nichols 1967; Williams et al. 1972; McBride 2000; Holder et al. 2008). Hickory shad are much less abundant than American shad but are frequently found occupying similar habitats (McBride 2000; Harris et al. 2007; McBride and Holder 2008). Blueback herring are the most rare and are the least studied of the three species (Williams et al. 1972; McBride 2000; McBride et al. 2010). Evidence suggests that three species of river herrings spawn in the lower Wekiva River between the mouth of Blackwater Creek and the St. Johns River (pers. comm. R. Hyle, FWC). All three species ascend the St. Johns River and its tributaries (including the Wekiva River) to spawn in the late winter and early spring (December– April). Spawning by all three species has been indirectly confirmed in the Wekiva River by the capture of females having fresh post-ovulatory follicles and of ripe males. The relative abundance of river herrings in the Wekiva River is low to moderate (depending on the year) and described as patchy, compared to the relative abundance within other known spawning areas along the St. Johns River (Miller and Mace 2019).

<u>Field assessment</u>

A field assessment was conducted to quantify the general availability of depths and velocities that support river herring spawning in Wekiva River. This field assessment occurred at 26 sites within the Wekiva River, extending from the headwaters near the confluence of Rock Springs Run to the Wekiva River mouth (Miller and Mace 2019) (Figure E-36).

Potential spawning habitat availability was estimated using field measurements of flow, depth, and substrate type (Miller and Mace 2019). Field measurements were taken at river discharges of 189 cfs and 173 cfs, which are approximately the 90th and 97th exceedance flows under the current-pumping condition. Twenty two (85%) of the sites sampled were characterized by surface water velocity (> 0.7 ft s-1) and water depths (> 1.5 ft) sufficient to provide suitable

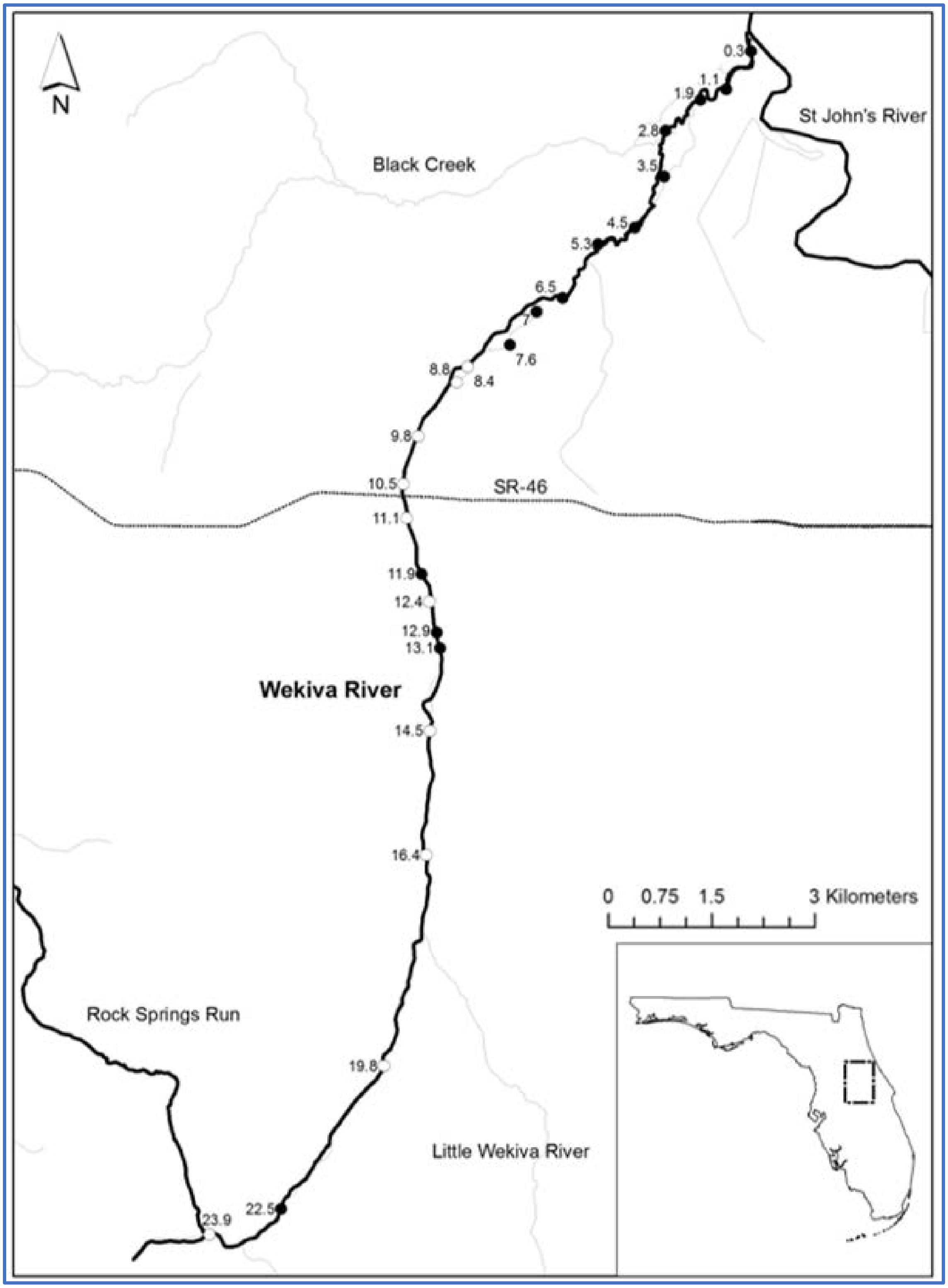

Figure E-36. River herring habitat suitability assessment sites in the Wekiva River (modified from Miller and Mace 2019) spawning habitat for American shad. Further, 100% of the sites had surface velocities and depths considered optimal for Hickory shad and Blueback herring spawning.

Findings from this field study suggest that, even at historically low flows that would be experienced less than 10% of the time under the current-pumping condition, velocities and depths were suitable along almost the entire Wekiva River to support spawning by all three species. Therefore, it is likely that frequent low discharges are not a factor regulating alosid reproduction in the Wekiva River (Miller and Mace 2019), and that the recommended MFLs for the basin (i.e., current-pumping condition) are sufficient to prevent significant harm to these anadromous herring species.

Bluenose shiner

The bluenose shiner (*Pteronotropis welaka*) is listed as state Threatened on Florida's Endangered and Threatened Species List. The bluenose shiner typically occurs in the western panhandle of Florida and several other southeastern states, but there is a disjunct population within the St. Johns River. The primary threats to this species, listed by the FWC, are habitat loss / degradation due to reductions in water quality and quantity, river impoundments, and channel dredging, among others (FWC 2016). The state Imperiled Species Management Plan recommends protection for the bluenose shiner by maintaining or improving existing water quality and quantity and habitat characteristics within priority sub-watersheds (including St. Johns River tributaries). The entire St. Johns River upper tributaries bluenose shiner population is believed to be in decline, possibly due to habitat loss and exploitation for the aquarium trade (Hipes et al 2001).

Bluenose shiners were collected in the Wekiva River in 1997 (Warren et al. 2000), as well as during the 2012 Wekiva River Bioblitz in Rock Springs Run and the Wekiva River (Travis Tuten, Fisheries Biologist, FWC, *personal communication*, May 30, 2012). Most recently, bluenose shiners were collected during 2019 and 2020 FWC fish surveys (unpublished data 2020). During this latest field assessment, FWC staff collected bluenose shiners from both Rock Springs Run and the Wekiva River. During the summer 2019 sampling, one individual was collected just below the confluence where Rock Springs Run meets the Wekiva River. None were collected during the winter 2019 Wekiva River sampling event. On Rock Springs Run, bluenose shiners were collected during both sample seasons. FWC staff collected 13 individuals during the summer 2019 sample and 18 individuals during the winter 2019 sample. This suggests that the species has populations that are still persisting in areas where they have been historically documented. Habitats favored by bluenose shiners are common throughout both the Wekiva River and Rock Springs Run, but FWC recommends further research to better understand relative abundances and population trends of this sensitive species. Further research is also underway to better define bluenose shiner habitat characteristics and preferences. This is part of an effort by FWC to update the current habitat suitability index (HSI) for this species for use in future SEFA or other habitat simulation modeling. The SEFA modeling results presented in the *MFLs Determination* and the *MFLs Assessment* sections in the Main Report (see also Appendix D) suggest a very minor effect of the current-pumping condition on bluenose shiner habitat suitability (i.e., AWS) (Table D-4 in Appendix D).

In addition to the bluenose shiner, numerous other species of fish were collected by the Florida Fish and Wildlife Research Institute (FWRI) during 2019 and 2020; these collections demonstrate the large and diverse fish community that exists in the Wekiva River (see Attachment 1 to this appendix for summary of FWRI fish sampling effort).

Basin Wetland Inundation Analysis

Another way that WRV#2 was evaluated was by assessing the effect of the MFLs condition (i.e., the current-pumping condition) on long-term basin-wide wetland inundation. This analysis was an effort to translate the most constraining metric (the event-based MA for the Wekiva River at SR 46, and the minimum Frequent High for the Wekiva River at SR 46 and Wekiwa Springs) into spatial context. This spatial assessment is to determine whether a minimum hydroperiod meant to maintain floodplain wetlands provides adequate protection for aerial extent of wetlands when calculated as percent reduction of wetland area (acres) inundated in the basin over the long-term (i.e., over the 71-year simulated POR) as a result of pumping impact.

This analysis involved various steps and procedures. First, cross-section data from the Wekiva River basin HEC-RAS model were merged with Light Detection and Ranging (LiDAR) data to yield floodplain and channel terrain data for the entire basin. Next, these data were imported into HEC-RAS Mapper, which was then used to export a series of raster (TIF) files that represent area (acres) of the basin inundated under two scenarios, the no-pumping condition and the current-pumping condition.

Floodplain maps (TIFs) were generated for only integer percentile flows (i.e., 1 - 100th flow percentiles) to maintain manageable file sizes and computation times. Daily observed flows for the Wekiva River at SR 46 (USGS gage 02235000; cross section 319.75 in HEC-RAS model) were ranked and percentiles were calculated. One day was selected and mapped in HEC-RAS for each percentile. This generated 100 TIF files for each of the two flow scenarios. The TIF files were processed by counting cells with water depth greater than zero in each map, then calculating the inundated area given the cell area. Area inundated under an average flooding condition (P25), the no-pumping condition, and the current-pumping condition is depicted below for illustration (Figure E-37). Each percentile is represented by a single date in the POR.

For each percentile, under each of the two pumping scenarios, the generated floodplain map was converted to a polygon so that it could be compared with mapped wetland area in ArcGIS. Areas within the mapped vegetation wetland polygons were classified as wetlands and those falling outside of the wetland polygons were classified as uplands.

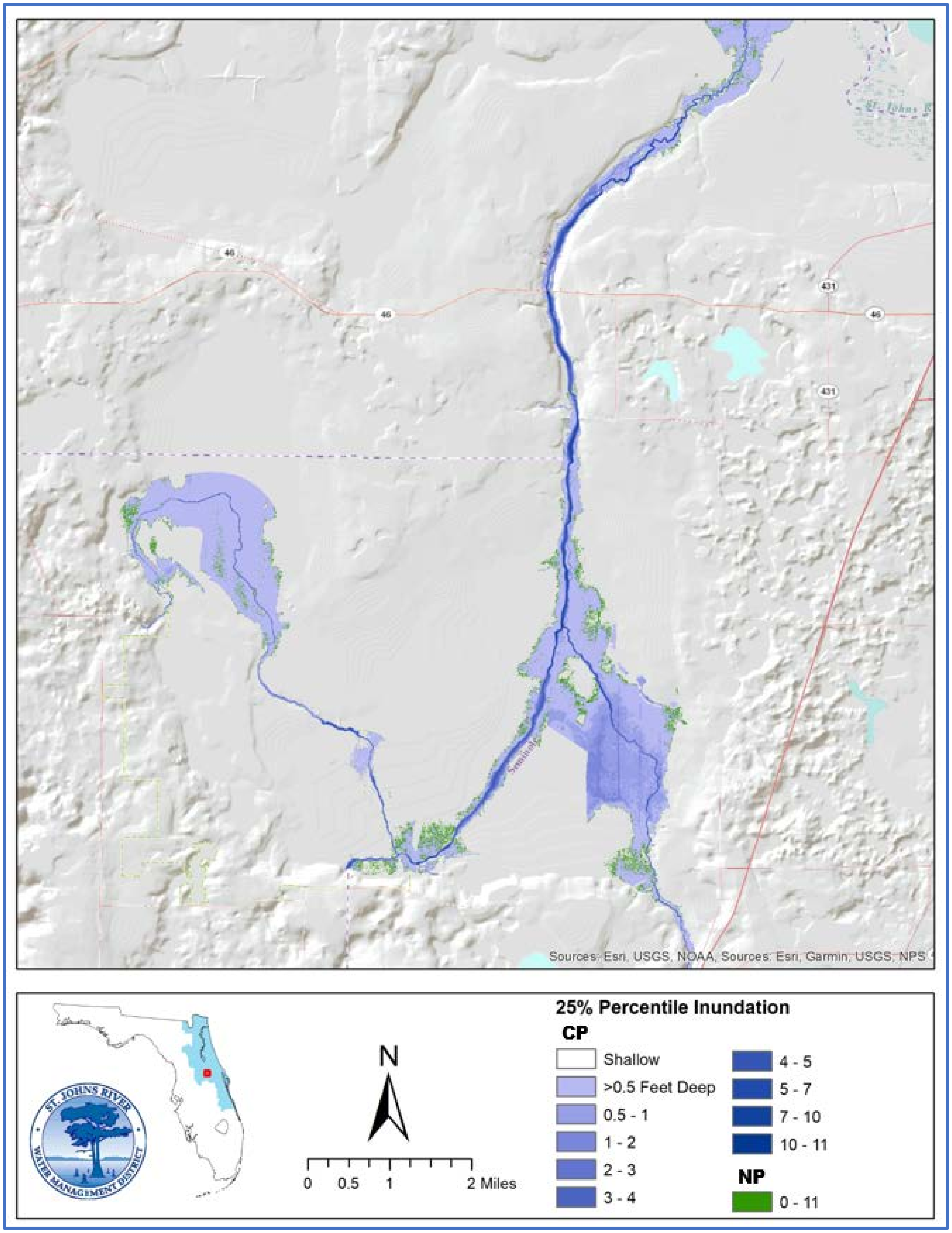

Figure E-37. Wetland inundation in the Wekiva River basin under the no-pumping (green) and current-pumping (blue) conditions, at the 25th percentile flow condition.

Wetland area (acres) inundated was then averaged across all 100 percentiles (i.e., representing the entire POR) for each of the two pumping scenarios. Average wetland area inundated was then compared between the no-pumping and current-pumping conditions to estimate the percent reduction in wetland inundation caused by the basin-wide MFLs condition (i.e., the current-pumping condition).

The total wetland area inundated under the no-pumping condition is approximately 2,166 acres. Under the MFLs (i.e., current-pumping) condition, the area of wetlands inundated equals approximately 1,828 acres (Figure E-38). This constitutes a 15.6% reduction in area of wetlands inundated under the recommended MFLs condition relative to the no-pumping condition.

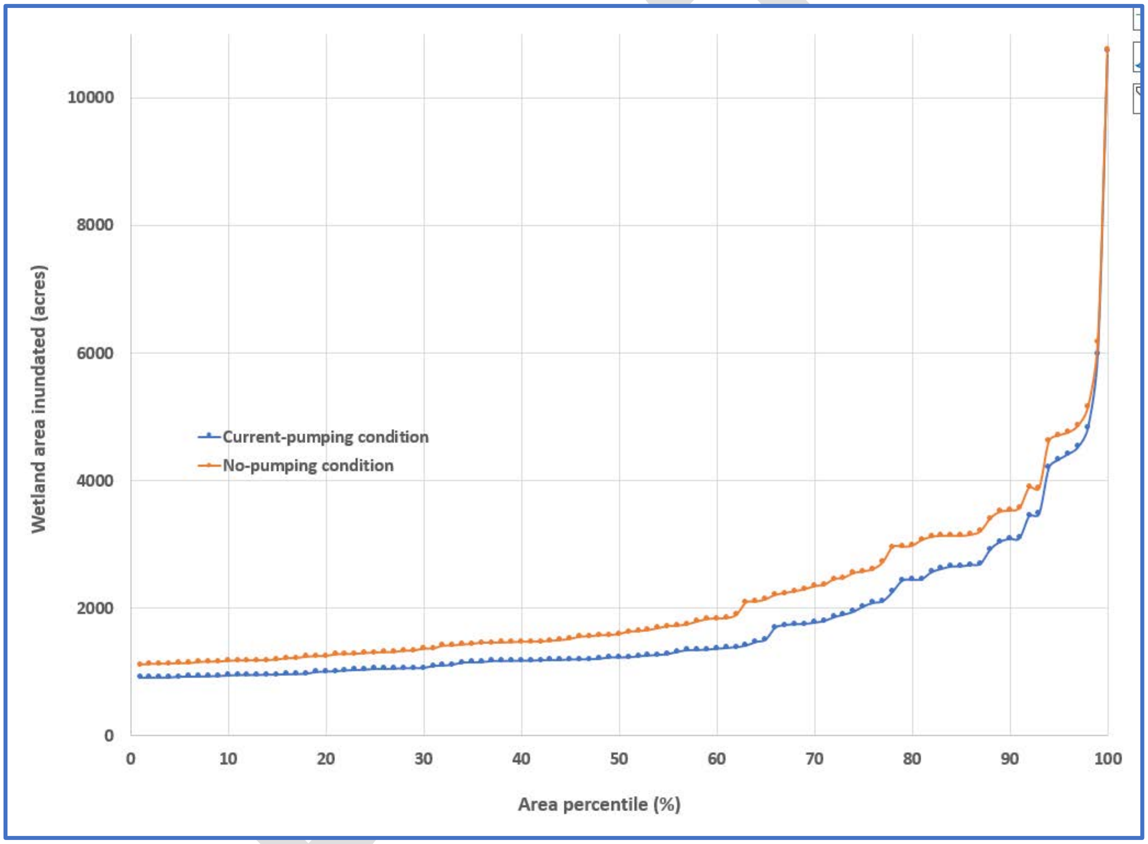

Figure E-38. Wekiva River basin wetland area (acres) inundated under the NP and CP conditions; average area difference equals 15.6%; percentiles based on total inundated area

Others have used a similar floodplain wetland inundation criterion as the primary metric for MFLs determination (e.g., Minimum Flow for the Rainbow River System) (Holzwart et al., 2017). The reduction in Wekiva River basin wetland inundation from the NP and CP conditions (i.e., 15.6%) is very similar to the wetland inundation area reduction (15%) allowed by the Rainbow River MFLs. This is especially true given the sources of uncertainty in Wekiva River analysis, which includes LiDAR terrain data in areas with forested wetlands (i.e., determination of true ground level where vegetation is thick), the limited spatial resolution of the HEC-RAS model due to limited surveyed cross-sections, wetland boundary data that varies in resolution, and spatial interpolation between bathymetry data and LiDAR captured over dry land.

For these reasons, the basin wetland inundation results are best used as a high-level check on the MFLs condition; this analysis puts the assessment based on other metrics into a spatial context. The wetland inundation analysis indicates that the MFLs condition is not overly constraining. However, these results do show that a moderate amount of change is occurring to wetland inundation dynamics under the current-pumping condition. This, along with other results presented here, and the IHA analysis (Appendix F) provide a weight of evidence that it is prudent to limit withdrawal impact to the current-pumping condition for a system with high ecological and human-use value.

WRV 4. Transfer of Detrital Material

Consideration of this WRV is meant to ensure the maintenance of flow sufficient to transport detrital material to and from floodplain environments. Detrital material is defined as loose organic material and debris as well as associated decomposing biota. A significant portion of detrital transfer occurs during high-water events, when accumulated detrital materials in floodplain wetlands are moved to the aquatic system.

Detrital material is an important component of the food web in aquatic ecosystems (Mitsch and Gosselink 2015). Detrital material transport is an important ecological function in many riverine systems (Wetzel 2001) including spring runs (Odum 1957). This detrital material forms the basis for a detritus food web, in which microbes and aquatic insects utilize the reduced carbon in the dead plant material from an upstream ecosystem to promote their own growth and metabolism. These organisms, in turn, are food for fish and wildlife in downstream segments.

Two processes important to the transfer of detrital material are inundation of the floodplain, as that is the primary source of detritus that is mobilized by the inundation, and transfer of the material from the floodplain to the main channel, where it is transported to other locations.

Particulate export was measured periodically during the Pollutant Load Reduction Goal (PLRG) Analysis for the Wekiva River and Rock Springs Run (WSI 2007b) in an effort to quantify particulate organic carbon outputs to the Wekiva River system. During the study, community export of particulate suspended matter was quantified in each stream segment studied using a plankton net suspended in the current at mid-depth. The mesh size on the plankton net was 153 µm. Three replicate plankton net samples were collected at the upstream and downstream end of each segment. Samples collected by the plankton net at a known stream velocity and for a known time were rinsed into a sample bottle and returned to the laboratory for wet, dry, and ash-free dry weight analyses. Samples were ashed at an oven temperature of 450°C. Net production of fine particulate export in each segment was calculated as the difference between the upstream and downstream export rates. For the Wekiva River Segment between Wekiva Falls and SR 46, the particulate organic matter export rate for the 2005-2007 monitoring was -0.10 g/m2/day. Export was negative for all seasons sampled.

Detritus consists of all nonliving organic matter, in both dissolved and particulate forms. In aquatic ecosystems in general, nearly all the organic matter consists of dissolved organic carbon compounds (DOC) and particulate organic carbon compounds (POC) (Wetzel 2001). The water quality (WRV 9) section below provides information on the relationship between flow and total organic carbon (TOC). Analysis of the data indicates a positive relationship between flow and TOC. This is not unexpected given that most of the TOC and, by inference, detritus will be transported in response to storm events that inundate the river floodplain for sufficient time. In the graph, TOC is used as a surrogate for detritus.

Inundation of floodplain is the critical function that must be maintained to protect this WRV. The minimum FH, which is the constraint for the Wekiva River and Wekiwa Springs, is based on providing a sufficient number of high-water (flooding) events to protect floodplain wetlands and associated wildlife habitat values. Maintaining sufficient high-water events will also ensure that detrital material that has accumulated during drier periods is transported to aquatic habitats downslope.

Compliance with the recommended FH should provide for the protection of flooding events necessary for the transfer of detrital material throughout the Wekiva River system. Therefore, the recommended minimum flows for each Wekiva River basin system, which are based on the current-pumping condition, are considered to be protective of this WRV.

Algal scour

Water velocity exerts hydrodynamic control over physical, chemical and biological characteristics of streams and rivers (Poff et al. 1997; Poff et al. 2009; Reaver et al. 2019). Maintaining velocities adequate to scour or slough algae from SAV and other surfaces is important in spring-fed rivers (Reaver et al. 2019). The algae that is detached becomes a source of detritus for consumption and processing by downstream microbial and higher level food webs. Studies of Florida springs document the relationship between reduced velocity and the proliferation of algae and suggest that this relationship may influence how algal communities respond to nutrient increases (Stevenson et al. 2007). The Collaborative Research Initiative on Sustainability and Protection of Springs (CRISPS) evaluated the significance of velocity in Silver Springs and the Silver River and compared those findings to previous studies of Florida Springs. Velocity and shear stress data from this and other Florida studies suggest an algal scour critical velocity threshold of 0.22 m/s (95% CI: 0.16 - 0.27

m/s; Figure E-39) which equates to 0.71 ft/s (95% CI: 0.53 - 0.89 ft/s). As described below, this algal scour threshold was used to evaluate the effect of water withdrawal on critical velocities at all four Wekiva basin sites.

Wekiva River

Flow velocity evaluations using the HEC-RAS model indicate that critical velocities adequate to promote algal scour are uncommon on the Wekiva River. Of the 43 cross-sections in the HEC-RAS model, only four had no-pumping condition velocities at or above the algal scour critical threshold (0.71 ft/s) for greater than 5% of the time (an additional 12 cross-sections had exceedances between 1% and 5% of the time), and only one was at or above the critical threshold for greater than 10% of the time (Figure E-40; Table E-4). These four cross-sections constitute approximately 16.6% of the Wekiva River, from the confluence of the Little Wekiva River to the confluence of the St. Johns River. One cross-section is located upstream of SR 46 and the other three are located downstream of SR 46 (Figure E-40). At the majority (39 of 43) of cross-sections, the critical velocity was either never met under the NP condition or always met under both the NP and CP conditions.

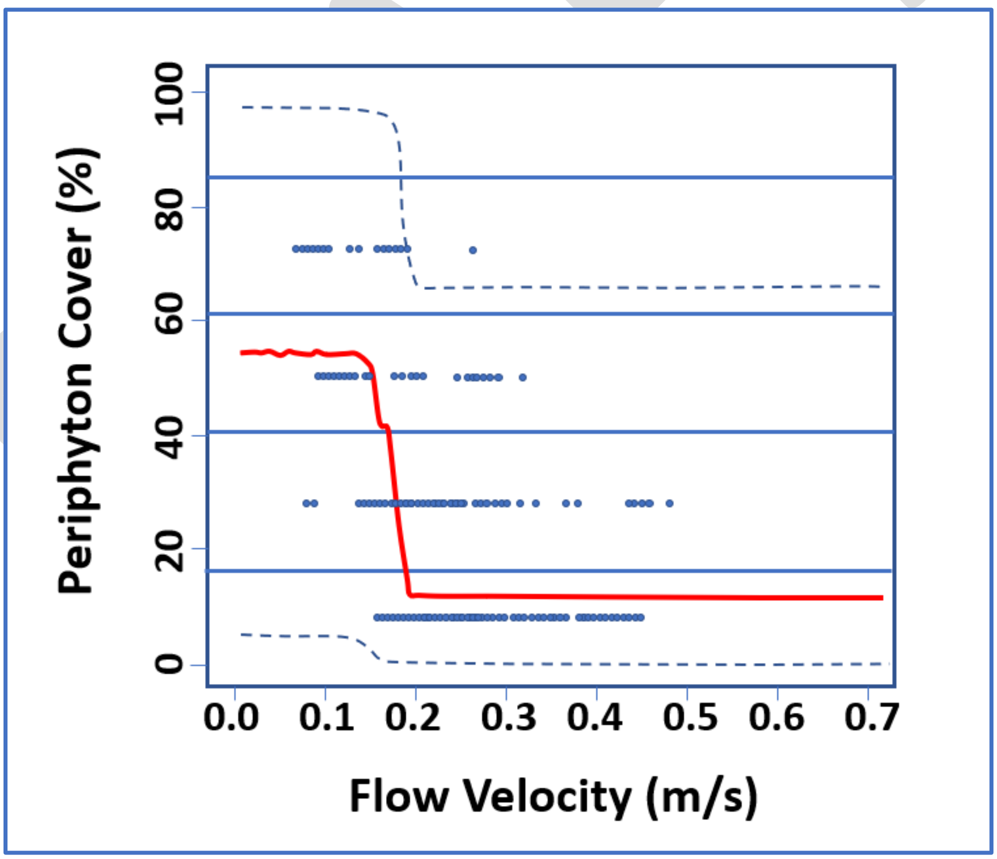

Figure E-39. Relationship between velocity and algal cover, showing 0.22 m s^{-1} critical threshold (breakpoint in red line); *adapted from Reaver et al. 2019*.

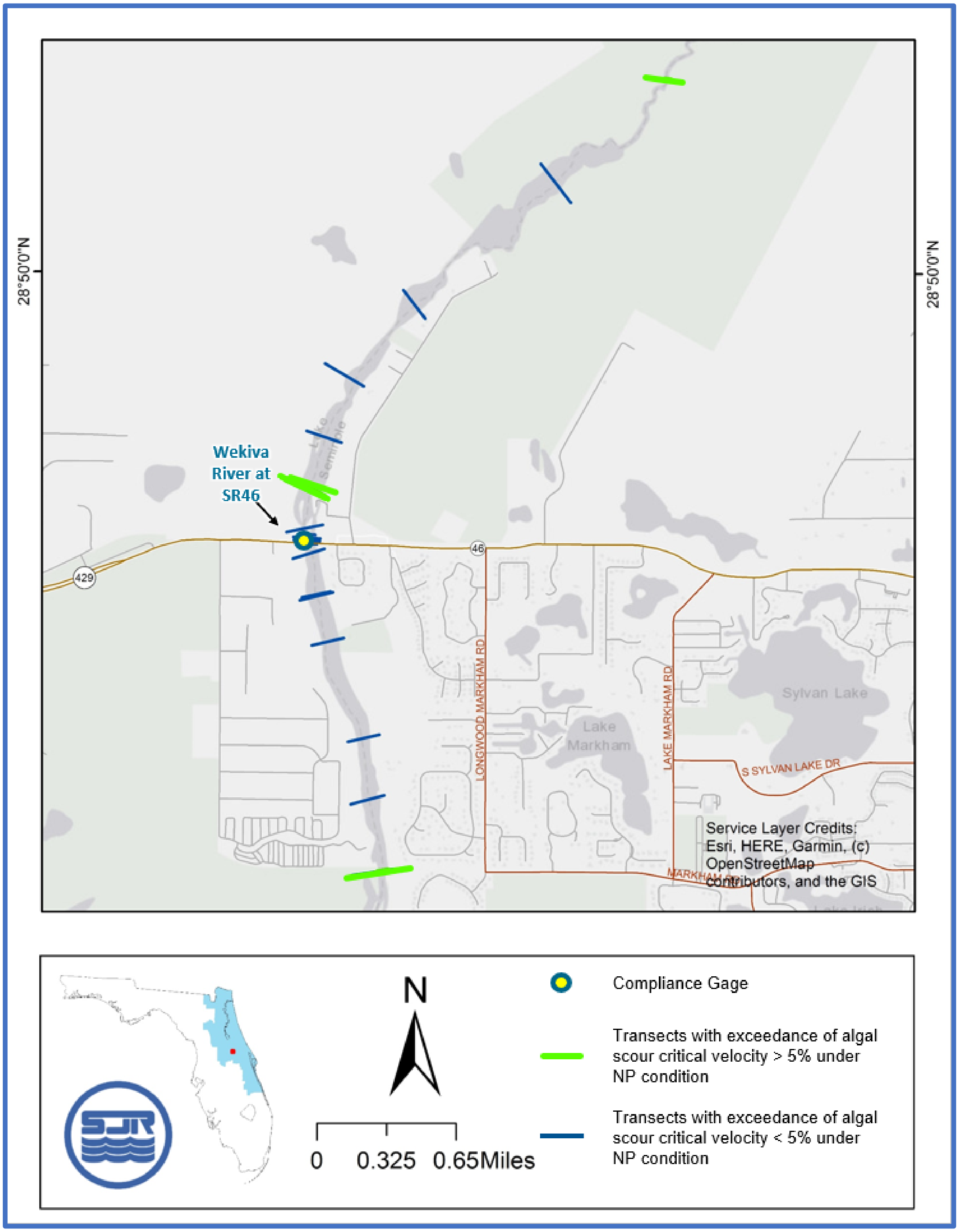

Figure E-40. Wekiva River cross-sections that exceed algal scour threshold > 5% of the time under the no-pumping (NP) condition. These four locations represent 16.6% of the Wekiva River, from the confluence of the Little Wekiva River to where it joins the St. Johns River.

At the four cross-sections tested, all experienced a greater than 15% change in exceedance under the current-pumping condition (Table E-4). However, in each case the reduction in velocity (i.e., NP minus CP velocity) was very small; reduction ranged from 0.02 to 0.03 ft/s (Table E-4). Because of the very few cross-sections applicable (that constitute < 17% of the river length) and the very small reduction in velocity, algal scour velocities are considered protected under the current-pumping condition; note that the current-pumping condition is equal to the MFLs condition for the Wekiva River at SR46, based on the minimum FH and MA, and for Wekiwa Springs, based on the minimum FH (see Appendix D and *MFLs Determination* section in main report for details).

Table E-4. Percent of time critical algae scour velocity threshold is met or exceeded under the no-pumping (NP) for the 4 Wekiva River and 3 LWR cross-sections that had NP exceedance above the velocity threshold greater than 5% of the time; reduction in exceedance (%) of critical threshold relative to NP, and reduction in velocity from NP to CP are also presented.

Cross-section ID	No-pumping condition velocity (ft/s)		Percent of time met or exceeded under NP (%)	Threshold exceedance reduction from NP to CP (%)	Velocity reduction from NP to CP (ft/s)
	Min	Max			
Wekiva River					
405.90	0.35	2.07	8.1	18.5	0.03
305.84	0.51	1.34	23.3	29.6	0.02
305.54	0.45	1.27	9.1	20.9	0.02
143.23	0.37	1.36	8.1	19.8	0.03
Little Wekiva River					
31214	0.46	3.67	88.2	89.0	NA
25047	0.003	2.36	11.4	12.1	NA
18249	0.50	1.56	67.5	47.0	0.04

<u>Little Wekiva River (LWR)</u>

Like the mainstem of the Wekiva River, critical velocities adequate to promote algal scour are also rare on the LWR. Of the nine LWR cross-sections in the HEC-RAS model, only three had no-pumping condition velocities at or above the algal scour critical threshold for greater than 5% of the time (Table E-4). At two of these, the critical velocity exceedance increased under the current-pumping condition, and at a single cross-section where the increase was greater than 15%, the absolute change in velocity was only 0.04 ft/s (Table E-4). As such, algal scour velocities are considered protected under the current-pumping condition for the Little Wekiva River.

Wekiwa Springs Run and Rock Springs Run

None of the three Wekiwa Springs Run cross-sections and none of the nineteen Rock Springs Run cross-sections in the HEC-RAS model had no-pumping condition velocities at or above the algal scour critical threshold for greater than 5% of the time. Because the threshold is reached very rarely, even under the no-pumping condition, current-pumping condition reductions in flow were not considered to significantly harm algal scour velocities at these two sites.

WRV 6. Aesthetic and Scenic Attributes

The Wekiva River system has rare ecological, recreational and aesthetic attributes that have led to its designation as an Outstanding Florida Water (OFW) under Rule 62-302.700, F.A.C., a National Wild and Scenic River, and a Florida Aquatic Preserve under Section 258.39, Florida Statutes. The aesthetic and scenic attributes of the Wekiva River and its major springs and tributaries contribute to its significant regional economic importance, including, but not limited to, recreational outfitters, ecotourism, and natural attractions.

The typical working definition for Aesthetic and Scenic Attributes in SJRWMD MFLs is as follows: Those features of a waterscape usually associated with passive uses such as bird watching, sightseeing, hiking, photography, contemplation, and painting, plus other forms of relaxation that usually result in human emotional responses of well-being and contentment.

The Wekiva Wild and Scenic River System Management Plan (Wekiva Wild and Scenic River System Advisory Management Committee 2012) discusses a number of scenic attributes for the Wekiva River system. Many segments have natural communities that are in near pristine condition. The clear water in the spring runs and tannic dark water add to the uniqueness of this system.

The scenic attributes noted by the management plan include the many natural communities present in the floodplain and in the river channel, wildlife viewing, clear water in the spring runs, and clear, tannic water in the river channel. These attributes are protected by other WRVs. For example, protection of WRV-2 (Fish and Wildlife Habitat and the Passage of Fish) will help to maintain aquatic and wetland environments required by fish and wildlife. This includes both floodplain and in-stream habitats. Protection of WRV-2 will protect the scenic attributes related to viewing of natural communities and wildlife throughout the Wekiva River basin.

Clear water in the spring runs and clear, tannic water in the river channel were also noted in the management plan as scenic attributes. The issue of water clarity would be addressed in WRV-9 (Water Quality). Examination of WRV-9 includes rigorous statistical analyses of available flow and water quality data to determine if flow-related water quality conditions exist in the Wekiva River that need protection. Water clarity could also be affected by nutrient filtration and absorption processes. These processes are evaluated under WRV-7 (Filtration and Absorption of Nutrients and other Pollutants). Protection of the processes contained in WRV-7 will help to protect this aspect of water clarity from negative effects due to water withdrawal. It is important to note that poor water quality related to nutrient loading from groundwater sources are not protected by this (or any other) MFL; these loading issues are addressed by nutrient pollutant reduction goals.

As access to the Wekiva River is primarily by kayak or boat, several of these passive uses contained in the definition of Aesthetics and Scenic Attributes, e.g., bird watching, photography, or contemplation, would be integrated with the recreational boating criteria in WRV-1. This would involve maintaining sufficient water depths in river channel to accommodate recreational and commercial (ecotourism and outfitters) watercraft (i.e., canoes, kayaks, and motorized vessels up to 26 ft [Class 1]) access for scenic and wildlife viewing.

Based on the relationship of WRV-6 (Aesthetics and Scenic Attributes) to other WRVs including WRV-1 (Recreation in and on the Water), WRV-2 (Fish and Wildlife Habitat and the Passage of Fish), WRV-7 (Filtration and Absorption of Nutrients and other Pollutants) and WRV-9 (Water Quality), it is anticipated that the development of MFLs to protect these other WRVs will also protect WRV-6, Aesthetics and Scenic Attributes.

WRV 7. Filtration and Absorption of Nutrients and Other Pollutants

Filtration consists of physical, chemical and biological processes that occur as water flows through media such as soil, sediment, and vegetation. Absorption is a chemical process that occurs during filtration. In natural environments, filtration and absorption can take place at many points throughout the hydrologic cycle. Therefore, understanding where these processes occur is important in evaluating whether the MFLs condition will protect this WRV.

The biogeochemical processing of dissolved constituents is controlled by complex interactions between the rate at which water flows through surface and subsurface flow paths and the rate at which dissolved constituents are processed by such processes as adsorption to sediments or uptake by microorganisms and vegetation (Hamilton and Helsel 1995). This processing of dissolved constituents typically occurs in the floodplains of streams and water bodies. Floodplain soils and sediments that comprise the boundaries of streams support abundant microorganisms and vegetation as well as low redox environments and/or steep redox gradients that are essential for numerous biogeochemical processes (Ponnamperuma 1972). Consequently, floodplain soils and sediments that comprise the boundaries of streams are areas in which a large proportion of the biogeochemical processing of dissolved constituents typically occurs (Hill et al. 1998; Hill and Lymburner 1998).

Wetland Solutions, Inc. (WSI) performed a nutrient mass balance for two segments of the Wekiva River as part of a WRVs assessment (WSI 2007a). Their analyses were focused on two segments in the Wekiva River: segment 1 corresponded to the Wekiwa Springs run and segment 2 corresponded to the reach between Wekiva Falls and SR 46; segment 2 is most relevant to this evaluation. Estimated removals for total nitrogen in segment 2 were positive during the fall and summer seasons (4.31 and 0.76 kg/ha/d) and negative during the winter and spring seasons (-1.32 and -0.40 kg/ha/d). Total organic nitrogen estimated mass removals were positive in the fall season (4.62 kg/ha/d) and negative the other three seasons (-4.66 to -0.24 kg/ha/d). Estimated mass removals for total inorganic nitrogen were generally positive at 0.19 to 1.79 kg/ha/d, except for the summer season (-0.43 kg/ha/d). The estimated mass removal for total phosphorus was generally negative in this segment (- 0.44 to -0.09 kg/ha/d), except for the fall season (0.25 kg/ha/d). The estimated mass removal for soluble reactive phosphorus was positive during the fall and winter seasons (0.06 and 0.03 kg/ha/d) and negative during the spring and summer seasons (-0.19 kg/ha/d) for each. Overall, estimated mass removals/additions for the 2,550 ft Segment 2 were low and are as follows:

- Total Phosphorus: -3.0%
- Soluble Reactive Phosphorus: -1.5%
- Total Nitrogen: 2.6%
- Total Organic Nitrogen: -2.2%
- Total Inorganic Nitrogen: 2.4%

Gross Primary Productivity (GPP)

Cohen et al. (2011) investigated nitrogen removal mechanisms on a number of spring-fed rivers. One conclusion was that significant nitrogen removal occurs in spring run streams and that denitrification was the dominant process across almost all the systems. They found that denitrification is strongly coupled to gross primary productivity (GPP) as is presented in Figure E-41. GPP is one measure of ecosystem metabolism that provides insights into the overall function of an aquatic ecosystem.

The two outliers removed to yield the dashed line fit are both for upper river sites (Silver River and Rainbow River), which may not achieve the same level of denitrification as the rest of the river because of stronger hydraulic gradients (precluding water entering the sediments from the river) or because of reduced labile carbon availability.

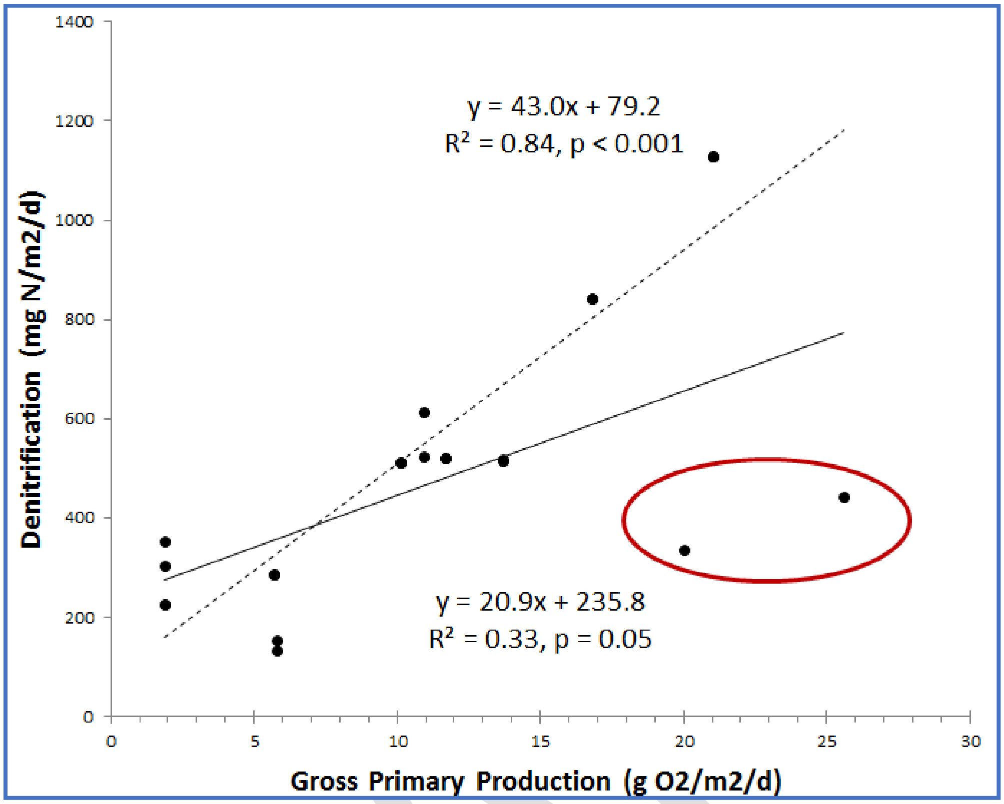

Figure E-41. Relationship between denitrification and gross primary production for river systems. Source: Cohen et al. (2011)

WSI measured GPP of 6.4 g O2/m2/day at Wekiva River segment 2 during the 2006-2007 monitoring period. During the 2005-2006 monitoring period, GPP was 4.11 g O2/m2/day. WSI also measured GPP at 12 Florida springs as part of a broad springs ecosystem metabolism study (WSI 2010). The consumption and production of oxygen by all spring flora and fauna are included in their GPP measurements. As part of this assessment, WSI examined the relationship between GPP and spring velocity and discharge. They found that at velocities up to approximately 0.82 ft/sec, GPP increased, whereas at velocities greater than this, GPP declined (WSI 2010). The decline in GPP above this velocity is likely related to physical conditions that reduce habitat suitability for SAV, which is a key component in primary production in spring ecosystems (WSI 2010).

Wekiva River

GPP evaluations, based on velocity simulations using the Wekiva River basin HEC-RAS model, indicate that average in-channel velocities are typically below the 0.82 ft per second threshold within the Wekiva River. There are locations within some cross-sections where velocities do exceed this threshold, but these are localized and do not reflect a general characteristic of the Wekiva River. Similar to the algal scour velocity results, of the 43 cross-sections evaluated, only three had no-pumping condition velocities at or above the GPP threshold (Table E-5). At these three cross-sections, the change in exceedance under current-pumping conditions was slightly more than 15% relative to the no-pumping condition. However, the absolute change in velocities was very small (0.01 – 0.03 ft/s). Because only a few cross-sections exceeded the MFLs threshold and because the velocities reductions are

Table E-5. Percent of time critical GPP velocity threshold is met or exceeded under the no-pumping (NP) for the 3 cross-sections that had NP exceedance above the velocity threshold; reduction in exceedance (%) of critical threshold relative to NP, and reduction in velocity from NP to CP are also presented.

Cross-section ID	No-pumping condition velocity (ft/s)		Percent of time met or exceeded under NP (%)	Threshold exceedance reduction from NP to CP (%)	Velocity reduction from NP to CP (ft/s)
	Min	Max			
405.90	0.35	2.07	4.5	15.6	0.03
305.84	0.51	1.34	4.9	16.3	0.01
143.23	0.37	1.36	2.5	16.0	0.02

very small, velocities necessary to promote high GPP are not considered to be significantly harmed by the MFLs condition (i.e., the basin-wide current-pumping condition).

Previous studies have found that denitrification in spring runs is an important nutrient reduction pathway and is related to gross primary production (GPP). Given the relative insensitivity in average in-channel velocities with flow rate and the small changes to velocities at or near the GPP threshold (0.82 ft/s), nitrogen removal due to denitrification in the Wekiva River is not anticipated to change significantly due to the MFLs condition (i.e., the current-pumping condition).

Numerous studies describe alluvial floodplains as efficient nitrogen (N) and phosphorus (P) removers and as pollutant sinks (Kitchens et al. 1975; Wharton and Brinson 1979). Due to the Wekiva River and its tributaries being designated as an Outstanding Florida Waterway, a National Wild and Scenic River, a Florida Scenic and Wild River, a State Canoe Trail, and Regionally Significant by the East Central Florida Regional Planning Council, protection of the nutrient removal functions of floodplain wetlands is an important consideration in the development of MFLs.

The major factor that would be affected by any flow reductions would be the reduction in the frequency of physical contact of water with riparian or floodplain vegetation. The degree of nutrient release and assimilation in the wetlands, as well as the decomposition of the vegetation communities, depends to a large extent on the frequency and duration of inundation, because the process of filtration and absorption requires both wet and dry periods. Inundation of floodplain is the critical function that must be maintained to protect this WRV. The minimum FH, which is the constraint for the Wekiva River and Wekiwa Springs, is based on providing a sufficient number of high-water (flooding) events to protect floodplain wetlands and associated wildlife habitat values. Maintaining sufficient high-water events will also ensure that the ability of floodplains within the Wekiva River basin continue to provide the important functions associated with filtration of nutrients and other pollutants . Therefore, the recommended minimum flows for each Wekiva River basin system, which are based on the current-pumping condition, are considered to be protective of this WRV.

WRV 8. Sediment Loads

The purpose of evaluating this environmental value is to ensure sufficient flows and velocities to maintain naturally occurring sediment entrainment and transport. Entrainment and transport of inorganic materials often depends on the volume and velocity of the water. The primary purpose of this metric is to determine whether the long-term transport of sediment will be negatively influenced by withdrawals and the MFLs condition for the basin (i.e., the current-pumping condition). Major changes in the sediment transport regime could cause net erosion or deposition of sediment in the channel, thereby changing the natural sediment regime and affecting habitat quality and quantity and recreational uses.

Sediment grain size used in these analyses was estimated based on the SCS Soil Survey for Seminole (1990) and Orange (1989) Counties. Soils surrounding the Wekiva River are dominated by well- to moderately well-sorted medium to fine sand over a majority of its length. Based on the Unified Soil Classification System (USCS), fine to medium sand would have a median grain size diameter (D50) of approximately 0.5 millimeter (mm), with most particles being less than 2.0 mm in size. Based on this, for sediment transport purposes, bed material was analyzed as non-cohesive inorganic fine sediment with a median grain size diameter (D50) of 0.50 mm. The initiation of motion of these particles is primarily a function of bed shear stress and particle size (Yang, 2006). Bed shear stress (τ) is computed as:

$$\boldsymbol{\tau = \gamma\ RS}$$

where

γ = specific weight of water

R = hydraulic radius (cross-sectional flow area over wetted perimeter)

S = the slope of the energy grade line (which can be approximated by the bottom slope of the channel for uniform or gradually varied flow conditions).

A commonly accepted measure of the initiation of motion for uniform non-cohesive sediments can be determined using the Shields diagram (Shields, 1936). The Shields curve divides a region of motion from a region of no motion. By determining the dimensionless Shields parameter and dimensionless grain Reynolds number, a prediction of sediment motion is obtained. For D50 sediment grain sizes of approximately 0.50 mm (i.e., size of fine to medium sand found in Wekiva basin systems), the critical bed shear for motion is about 0.006 pound per square foot (lb/ft^2).

HEC-RAS model results were utilized to evaluate bed shear across the range of flows and along the river reach. Based on the HEC-RAS results, Shields parameters were calculated for a range of flows to determine if the bed is mobilized and sediment transported across the entire range of flows and cross-sections per the Shields incipient motion diagram. It was determined that sediment motion occurs for all flows and cross-sections evaluated.

Critical sediment transport velocities were estimated based on the work of Hjulstrom (1935). Hjulstrom curves depict a wide range of uniform sediment size and flow conditions and indicate ranges of velocity necessary for erosion (entrainment), transport, and deposition (sedimentation). Based on this work, sediment of a diameter of 0.5 mm would be suspended and remain transported at velocities of between 3.7 centimeters per second (0.1 ft/sec) and 19 cm/sec (0.6 ft/sec), respectively. HEC-RAS model data were evaluated to determine whether significant changes in the frequency of critical velocities/critical shear stress for D50 particles occurs under current pumping relative to the no-pumping condition. The sediment transport metric involved evaluating two velocities: those necessary for entrainment and transport. The sediment transport metric is as follows:

Sediment transport metric:

- Critical velocities: 0.1 ft/sec equals the critical velocity for sediment entrainment; 0.6 ft/sec equals the critical velocity for sediment transport

Impact Threshold:

- Allow no more than a 15% reduction in exceedance of critical sediment transport velocities (both for entrainment and transport), relative to a no-pumping condition.

Wekiwa Springs

None of the three Wekiwa Springs Run cross-sections exceed either sediment velocity threshold (0.1 ft/s or 0.6 ft/s) under the no-pumping condition. Therefore, they were not evaluated under the current-pumping condition.

Rock Springs Run

All 19 cross-sections at Rock Springs Run exceed the sediment *entrainment* velocity threshold under both the no-pumping and current-pumping conditions. Of the six (of 19) cross-sections with no-pumping condition velocities at or above the sediment *transport* critical threshold for greater than 5% of the time, only three exhibited a greater than 15% reduction under current pumping (Table E-6). At four cross-sections, this threshold is exceeded less than 5% of the time, and at nine cross-sections, it is never exceeded under the no-pumping condition. Because all cross-sections exhibited no change for sediment entrainment velocities and 16 of 19 exhibited no change for sediment transport velocities, this metric is considered protected under the current-pumping condition.

Table E-6. Percent of time critical sediment transport velocity (0.6 ft/s) is met or exceeded under the no-pumping (NP) and current-pumping (CP) conditions for 6 (out of 19) Rock Springs Run stations that had NP exceedance above 5%.

Cross-section ID	No-pumping condition velocity (ft/s)		Percent of time 0.6 ft/s met or exceeded under NP (%)	Percent of time 0.6 ft/s met or exceeded under CP (%)
	Min	Max		
479.28	1.14	1.42	100	100
477.83	1.20	1.37	100	100
466.21	0.57	0.77	99.3	54.3
462.31	0.83	1.12	100	100
459.92	0.58	0.76	99.6	64.0
1817	0.25	0.79	60.8	24.2

Little Wekiva River

Under the no-pumping condition, the critical sediment *entrainment* velocity (0.1 ft/s) is always equaled or exceeded at eight of the nine LWR cross-sections (Table E-7). Under the no-pumping condition, the critical sediment *transport* velocity (0.6 ft/s) is always equaled or exceeded at three of the nine LWR cross-sections, and almost always at another one cross-section (Table E-8). At three cross-sections this threshold is never exceeded under the no-pumping condition (Table E-8).

There was almost no change to the sediment transport velocity (0.6 ft/s) under the current-pumping condition relative to the no-pumping condition (Table E-8). At two cross-sections, there was a small (5.7 to 10.1%) reduction in exceedance, and at another two cross-sections, exceedance increased (Table E-8). Overall, the effect was minimal and sediment transport velocities are considered protected under the current-pumping condition.

Table E-7. Percent of time critical sediment entrainment velocity (0.1 ft/s) and sediment transport velocity (0.6 ft/s) is met or exceeded under the no-pumping condition (NP) for Little Wekiva River stations.

Cross-section ID	No-pumping condition velocity (ft/s)		Percent of time met or exceeded under NP (%)	
	Min	Max	0.1 ft/s	0.6 ft/s
31214	0.46	3.67	100.0	94.9
25047	0.00	2.36	74.0	15.5
24851	0.72	1.86	100.0	100.0
24569	1.05	1.88	100.0	100.0
18249	0.50	1.56	100.0	100.0
14398	0.14	0.92	100.0	0.1
10758	0.10	0.39	100.0	0.0
7113	0.22	1.27	100.0	0.3
3050	0.23	2.16	100.0	11.8

Table E-8 Percent of time critical sediment transport velocity (0.6 ft/s) is met or exceeded under the no-pumping (NP) and current-pumping (CP) conditions for Little Wekiva River cross-sections.

Cross-section ID	No-pumping condition velocity (ft/s)		Percent of time 0.6 ft/s is met or exceeded (%)	
	Min	Max	NP	CP
31214	0.46	3.67	94.9	95.1
25047	0.00	2.36	15.5	16.6
24851	0.72	1.86	100.0	100.0
24569	1.05	1.88	100.0	100.0
18249	0.50	1.56	100.0	94.3
14398	0.14	0.92	0.1	0.1
10758	0.10	0.39	0.0	0.0
7113	0.22	1.27	0.3	0.3
3050	0.23	2.16	11.8	10.6

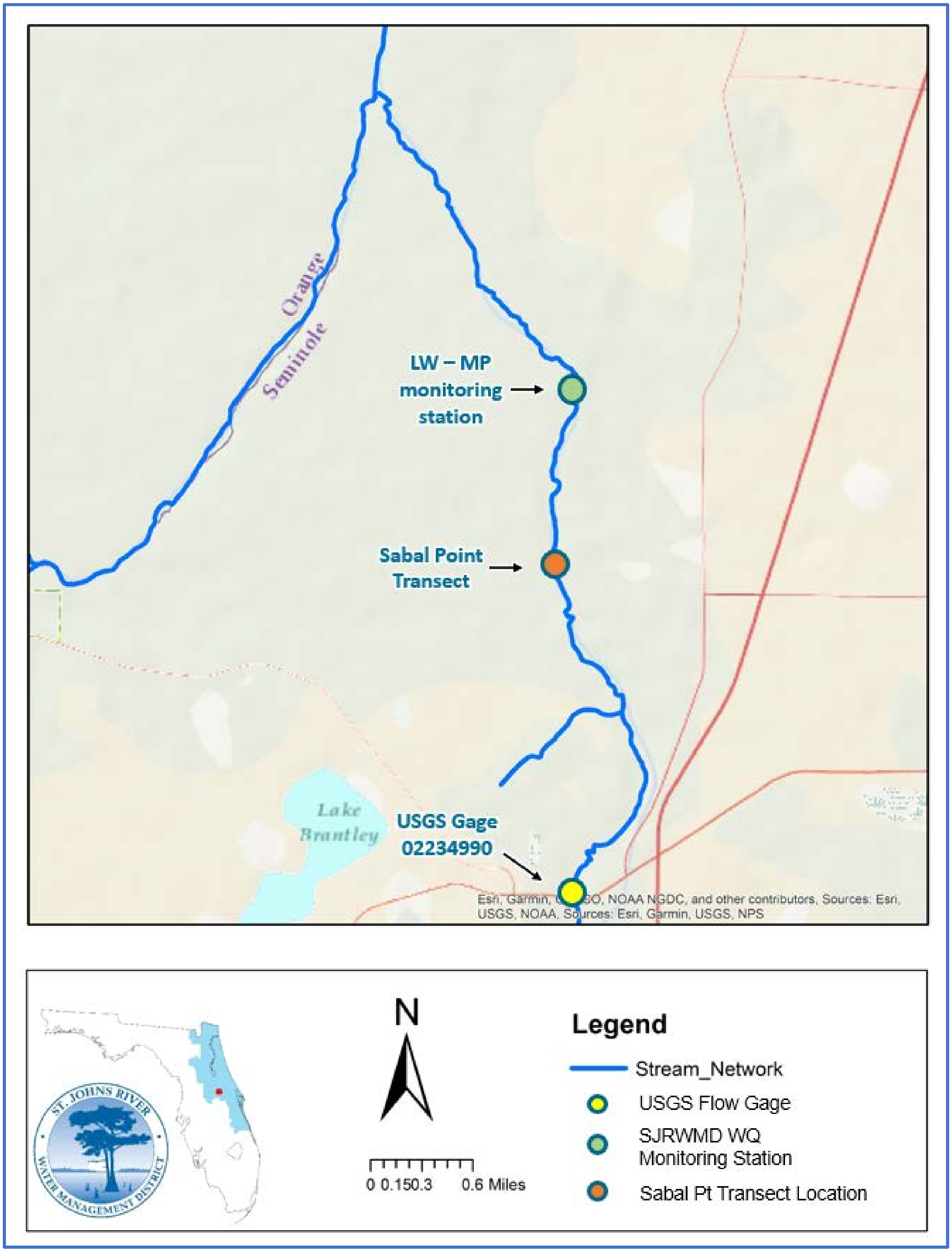

Figure E-42. SJRWMD water quality monitoring station LW-MP, USGS flow gage and Sabal Point ecological transect located on the Little Wekiva River.

Excessive Sedimentation in the LWR

Excessive erosion and sedimentation in the LWR watershed is a well-documented problem (CDM 2005; SJRWMD 2021). Previous sediment monitoring by the SJRWMD (2001 - 2017; data not presented here) indicates that excessive sedimentation in the LWR watershed is largely due to storm-driven erosion processes that are exacerbated by increased impervious surface cover due to watershed development. Analysis of total suspended solids (TSS) data collected at SJRWMD monitoring station LW-MP (Figure E-42) shows a slight positive relationship between TSS and flow, but the relationship is very weak (R^2 = 0.11) (Figure E-43).

Over the past several decades there have been numerous efforts to mitigate excessive erosion in the upper portions of the watershed. These have included bank stabilization projects, regional detention/retention projects, in-channel armoring, and the placement of in-channel weirs to reduce hydraulic gradients (FDEP 2004). However, armoring efforts likely have transferred the erosive power of the LWR downstream and as a consequence may have also transferred the erosion and sedimentation problems to downstream, more rural reaches (SJRWMD 2021). This may be contributing to increased sediment deposition that is occurring in downstream reaches of the LWR. Increased sedimentation has been documented downstream of Springs Landing Boulevard. Because of this, Seminole County has proposed

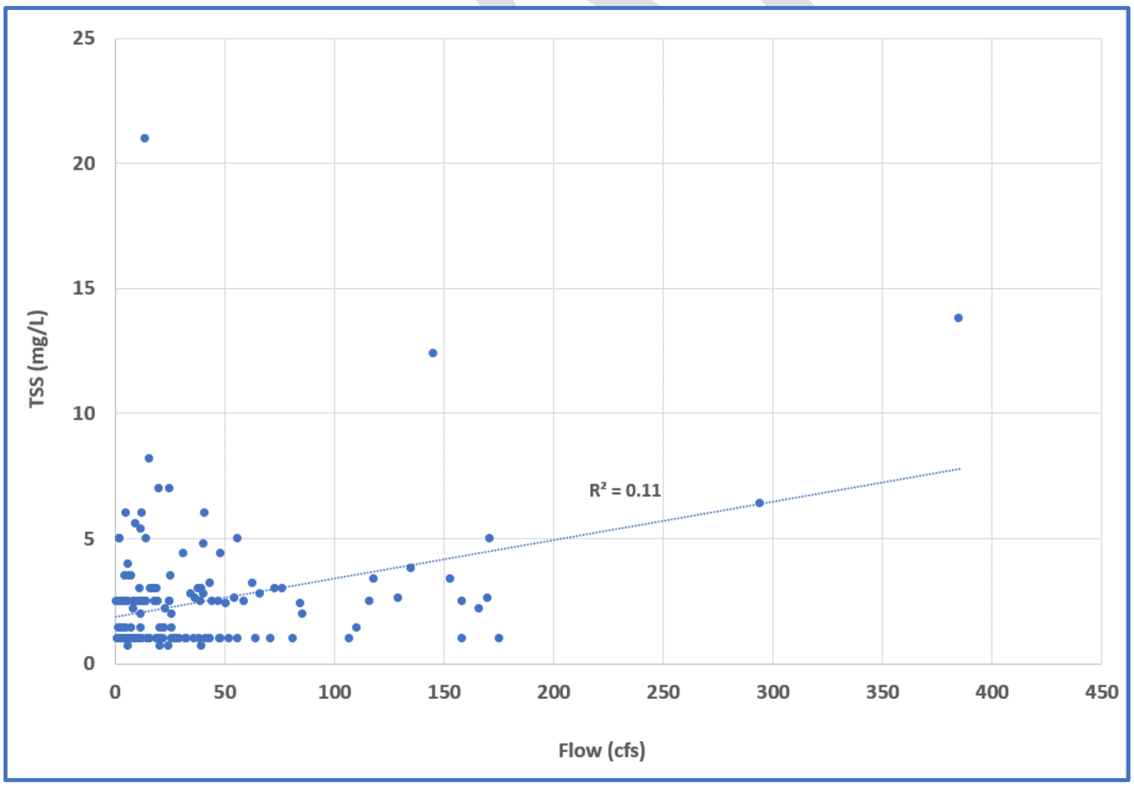

Figure E-43. TSS concentration (mg/L) versus flow (cfs) in the LWR (source: SJRWMD water quality data from monitoring site LW-MP and flow data from USGS gage 02234990) a remediation project to remove this large influx of sediment as well as invasive plants that have filled portions of the river channel in this area.

In contrast to the large amount of deposited sediment in lower reaches of the LWR, TSS concentrations at the LW-MP monitoring station appear to be decreasing slightly over time (Figure E-44). This decrease is likely in response to the structural improvements that have been implemented in the Little Wekiva River watershed and river channel. This small reduction in suspended sediment is occurring despite the movement of deposited sediment (bedload) from upstream to downstream reaches.

As part of the MFLs determination, an effort was made to ensure that excessive sedimentation in the LWR did not negatively influence the ecological data or HEC-RAS modeling used for the environmental analyses. When it was apparent that one of the ecological transects (Sabal Point) (See Figure 41 in Main Report) was being negatively affected by sedimentation, this transect was dropped and replaced with another transect further upstream near the Springs Landing Boulevard gage. The sedimentation was also accounted for in the HEC-RAS model, including representing the infilling of the Sabal Point cross-section in the model. Further, a cross-section located at the compliance gage (Springs Landing Boulevard) was re-surveyed to determine whether sedimentation was occurring and could influence the rating at

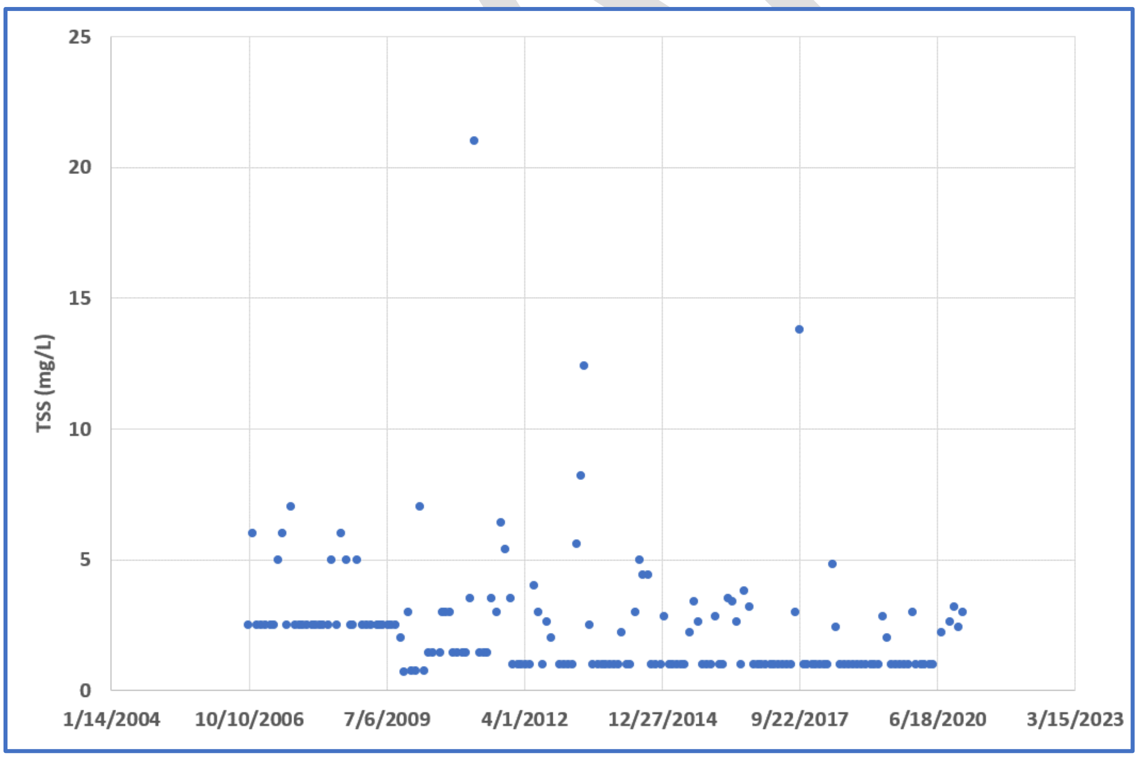

Figure E-44. TSS concentration (mg/L) over time in the LWR; (source: SJRWMD data from monitoring site LW-MP, located downstream of SLB) this site. The amount of accrual over the four years between surveys (from 2017 to 2021) was small (Figure E-45).

Sediment monitoring data and critical velocity analyses using the HEC-RAS model (described above) both suggest that excessive sedimentation in the LWR is due to excessive loading and not due to insufficient flows or velocities. Further, these analyses demonstrate that the current-pumping condition will not reduce critical sediment entrainment or transport velocities, relative to the no-pumping condition.

Wekiva River

Under the no-pumping condition, the critical sediment *entrainment* velocity (0.1 ft/s) is equaled or exceeded at 39 of 43 Wekiva River cross-sections. The remaining four cross-sections exceed this critical entrainment threshold less than 1% of the time. Under the no-pumping condition, the critical sediment *transport* velocity (0.6 ft/s) is equaled or exceeded greater than 1% of the time at 12 of 43 Wekiva River cross-sections and greater than 5% of the time at only four cross-sections (Table E-9). Note that these are the same four areas that exceeded the algal scour velocity threshold and constitute only 16.6% of the Wekiva River, from the confluence of the Little Wekiva River to the confluence of the St. Johns River

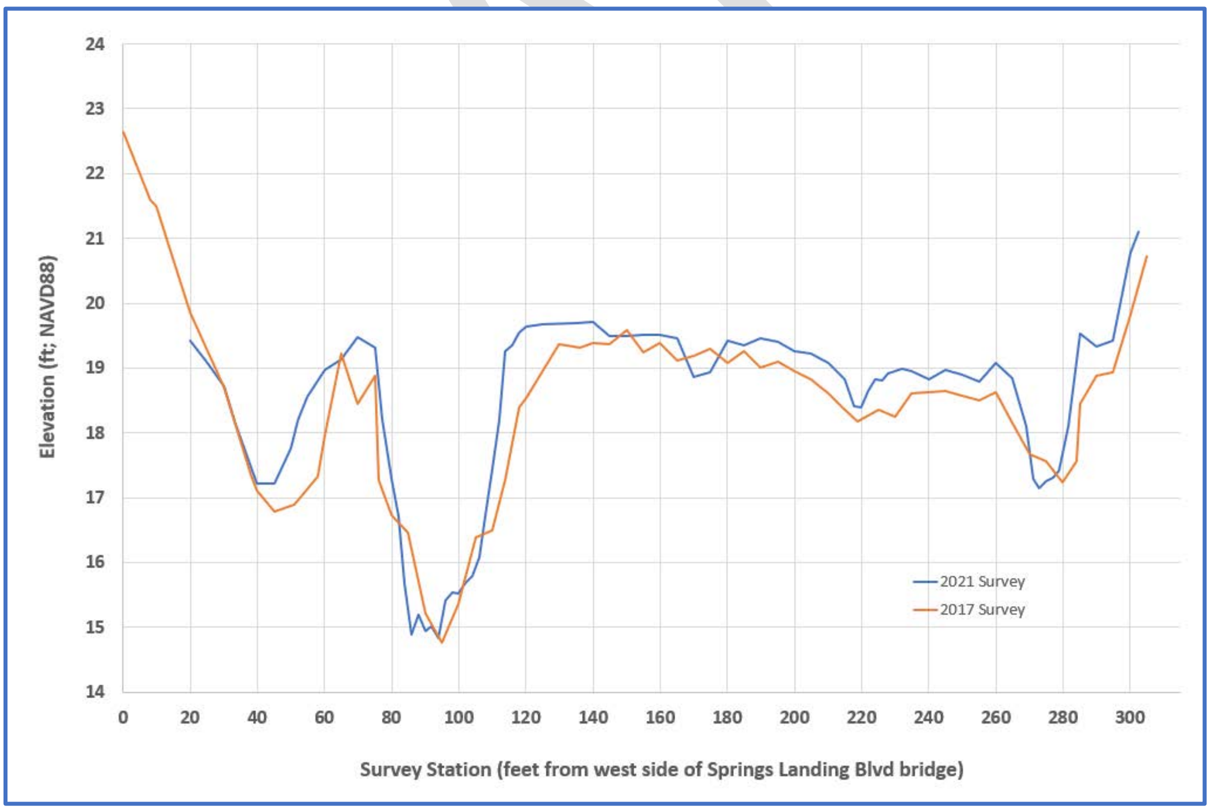

Figure E-45. LWR surveyed cross-section at the Springs Landing Boulevard bridge; the location of the compliance gage for the LWR MFLs. Survey data from 2017 and 2021 are depicted.

Table E-9. Percent of time critical sediment transport velocity is met or exceeded under the no-pumping (NP) and current-pumping (CP) condition for the four mainstem Wekiva River cross-sections with NP exceedance above 5%.

Cross-section ID	**No-pumping condition velocity (ft/s)**		**Percent of time met or exceeded under NP (%)**	**Velocity reduction from NP to CP (%)**	**Velocity reduction from NP to CP (ft/s)**
	Min	**Max**			
405.90	0.35	2.07	19.0	26.8	0.03
305.84	0.51	1.34	88.0	21.0	0.05
305.54	0.45	1.27	38.2	24.0	0.03
143.23	0.37	1.36	23.8	31.5	0.03

(Figure E-40). At only a single cross section is exceedance of the sediment transport threshold greater than 50% of the time (Table E-9). At 20 cross-sections, the transport threshold is never exceeded under the no-pumping condition. In short, velocities in the Wekiva River under the no-pumping condition are less than the sediment transport threshold for most locations and for most of the time.

Under the current-pumping condition, the critical sediment entrainment velocity (0.1 ft/s) is always exceeded at cross-sections where it was exceeded under the no-pumping condition. Similar to algal scour velocities, the sediment transport velocity (0.6 ft/s) was reduced by a very small amount (0.03 to 0.05 ft/s) for the four cross-sections that exceeded the threshold for greater than 5% of the time under the no-pumping condition (i.e., for the four cross-sections evaluated; Table E-9). As with the algal scour threshold, very few cross-sections exhibited effects of withdrawal on sediment transport velocities and these reductions in velocity were very small (Table E-9). As such, sediment transport velocities in the Wekiva River are considered protected under the current-pumping condition; the current-pumping condition is equal to the MFLs condition for the Wekiva River at SR46, based on the minimum FH and MA metrics, and for Wekiwa Springs, based on the minimum FH (see Appendix D and *MFLs Determination* section in Main Report for details).

WRV 9. Water Quality

Water quality is a critical environmental value, important in the assessment of riverine MFLs. The relationship between flow and various water quality parameters were assessed for each of the four primary Wekiva River basin MFLs systems. Water quality data were also evaluated to determine whether any temporal trends are evident.

Water quality data used in the following analyses were derived from the Florida Department of Environmental Protection (FDEP) Impaired Waters database (Run 60) and the SJRWMD water quality data base. Flow data used in these analyses were obtained from SJRWMD and USGS gages (see *Hydrology* section in Main Report for details regarding flow data).

A suite of parameters that are important to riverine ecosystems and that have consistent sampling over time were chosen for analysis. These include nutrients (ammonium, nitrate-nitrite, total Kjeldahl nitrogen [TKN], total nitrogen [TN], orthophosphate [PO_4], and total phosphorus [TP]), total organic carbon, chlorophyll, conductivity, dissolved oxygen, oxygen percent saturation, total dissolved solids, total suspended solids, alkalinity, turbidity, and color. The relationship between various water quality parameters relative to flow and time are presented as a series of graphs in Attachment 2 of this appendix. Conclusions drawn from these comparisons are summarized below for most parameters.

Wekiwa Springs

The primary water quality monitoring location utilized for Wekiwa Springs was the SJRWMD station 73688 located downstream of the spring boil (Figure E-46). See Attachment 2 for graphs of water quality parameters versus flow and over time. Water quality data for Wekiwa Springs span a period from 1931 to 2020; however, sampling was infrequent prior to 1968 and semi-monthly to monthly from 1968 to 1997. More regular sampling began in late 1998.

Nitrate+nitrite (NOx) concentrations appear to have decreased in Wekiwa Springs since the 1990s but have leveled off in the last decade or so (Figures 53 and 55 in Attachment 2). Both dissolved and total NOx exhibit a positive relationship with flow (Figures 54 and 56 in Attachment 2). TKN has varied within a relatively narrow range over the past decade in Wekiwa Springs, with no overall trend over time (Figure 57 in Attachment 2). Total nitrogen is calculated as the sum of NOx and TKN. As the values of NOx are of greater magnitude than TKN, the patterns illustrated by TN more closely match the former and demonstrate a slight increase over time and a positive relationship with flow (Figures 59 and 60 in Attachment 2). Rule 62-302.531, F.A.C., defines applicable numeric interpretations of narrative nutrient criteria (NNC). For spring vents, the applicable numeric interpretation of the NNC is 0.35 mg/L of nitrate-nitrite as an annual geometric mean (AGM), not to be exceeded more than once in any three calendar year period. At Wekiwa Springs the NNC for NOx has been exceeded every year in the period-of-record (Figure E-47).

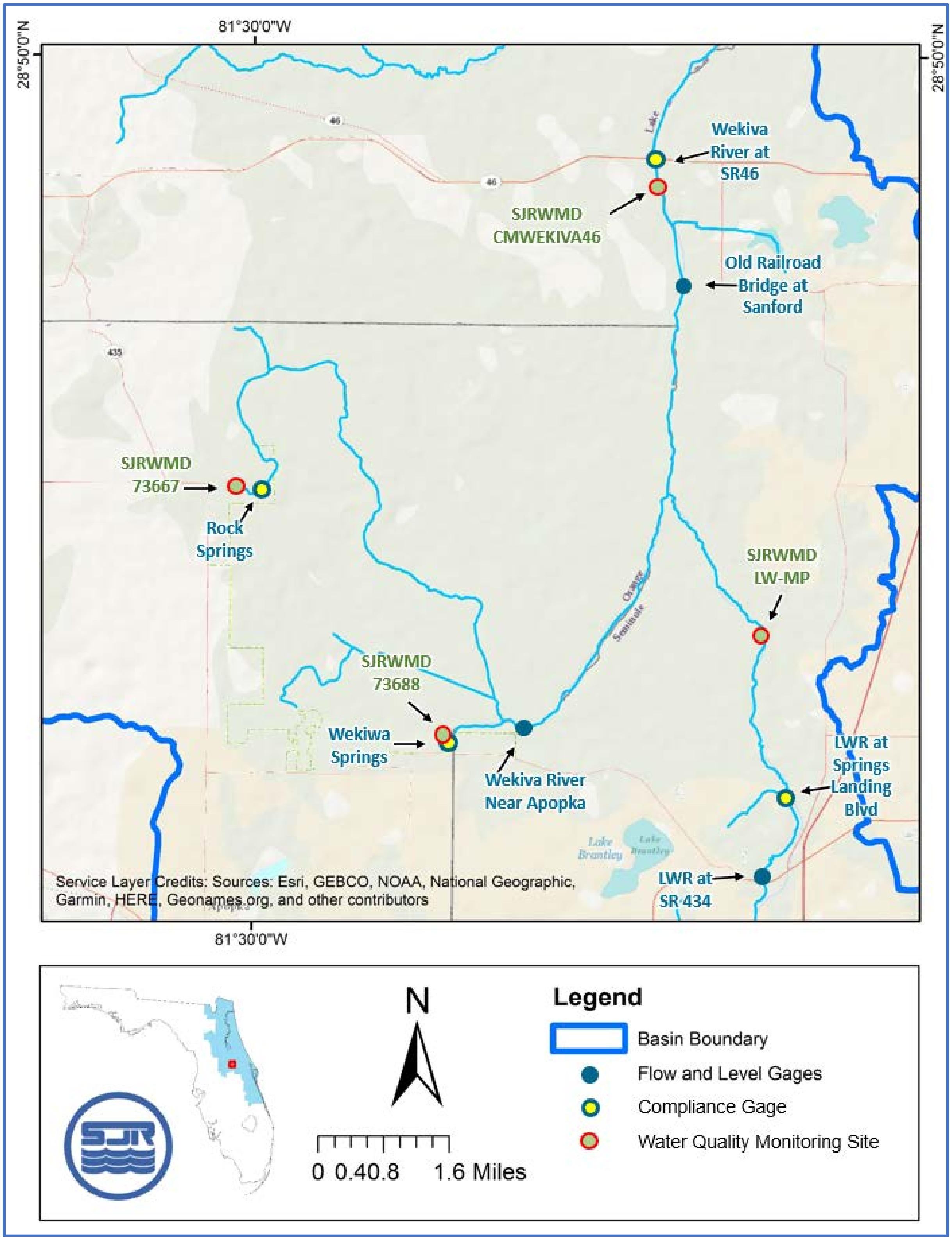

Figure E-46. SJRWMD water quality monitoring sites (names in green) used for Wekiva River basin water quality analyses.

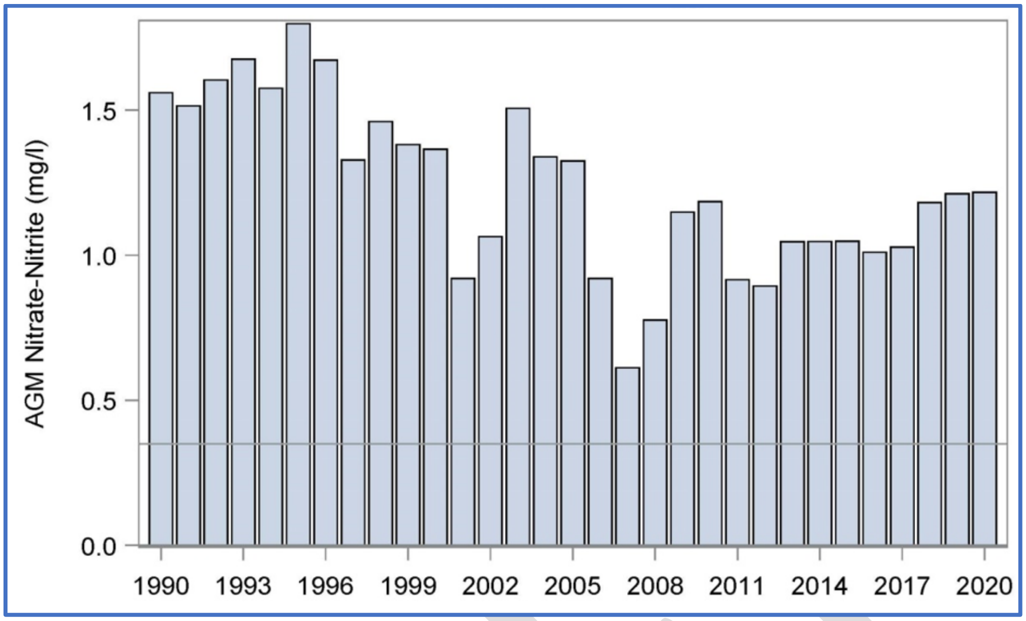

Figure E-47. Wekiwa Springs annual geometric mean for NOx; grey line represents the NNC (0.35 mg/L) for NO_3+NO_2

The AGM values for nitrate-nitrite were regressed against annual average discharge to test for a flow-concentration relationship. A clear positive relationship (increasing concentration with increasing discharge) is evident from this comparison (Figure E-48). TN also exhibited a strong positive relationship with annual average flow.

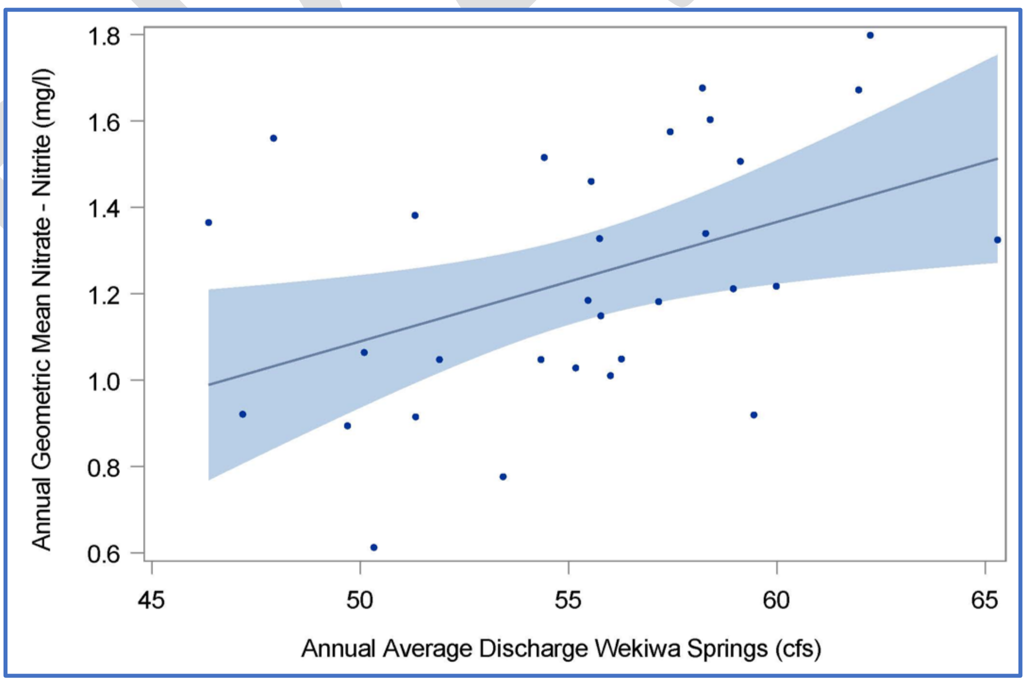

Figure E-48. Annual geometric mean for NOx versus annual average flow at Wekiwa Springs; shaded area represents the 95% confidence interval

Orthophosphate values have also been reported as both dissolved and total. Both forms appear to vary over a very narrow range of values and have a slight positive relationship with flow (Figures 62 and 64 in Attachment 2). Total phosphorus appears to have slightly increased over time in Wekiwa Springs, however the change in magnitude is small (Figure 65 in Attachment 2). There is no discernable relationship between total phosphorus and flow (Figure 66 in Attachment 2).

The POR for chlorophyll data in Wekiwa Springs is relatively short and no pattern is evident based on this brief time series (Figure 67 in Attachment 2). There is also no discernable relationship with flow (Figure 68 in Attachment 2).

While remaining low, conductivity values exhibited an increasing trend over time (Figure 69 in Attachment 2). Conductivity has a negative relationship with flow beyond a certain threshold (Figure 70 in Attachment 2). Dissolved oxygen (dO) data suggest a slight increase over time, but values remain low (< 2.0 mg/L) (Figure 71 in Attachment 2). Low dO is expected near a spring vent given the groundwater source. There was no discernable relationship between dO and flow (Figure 72 in Attachment 2).

Nutrient concentration data suggest that elevated nitrogen is related to loading, not reduced flows in Wekiwa Springs. The remaining parameters for Wekiwa Springs had nearly flat regression slopes and wide confidence intervals, indicating a weak or nonexistent relationship with flow. Therefore, this environmental value is considered protected under the recommended basin-wide MFLs condition (i.e. the current-pumping condition).

Rock Springs

The primary water quality monitoring location utilized for Rock Springs was the SJRWMD station 73667 located near the spring vent (Figure E-46). See Attachment 2 for graphs of water quality parameters versus flow and over time. Water quality data for Rock Springs span a period from 1932 to 2020; however, sampling was infrequent prior to 1968 and semi-monthly to monthly from 1968 to 2001. More regular sampling began in late 2002.

Nitrate-nitrite (NOx) values have been reported as both total and dissolved. Similar to Wekiwa Springs, NOx levels appear to have decreased slightly since the 1990s, but with reduced variability in the last decade or so (Figures 87 and 89 in Attachment 2). Also similar to Wekiwa Springs, both dissolved and total NOx exhibit a positive relationship with flow at Rock Springs (Figures 88 and 90 in Attachment 2).

As described above for Wekiwa Springs, the applicable interpretation of the NNC for NOx for spring vents is 0.35 mg/L, expressed as an AGM which is not to be exceeded more than once in any three calendar year period. At Rock Springs, AGMs for NOx exceeded the NNC every year in the period-of-record (Figure E-49). NOx AGM values were regressed against annual average discharge for Rock Springs to test for a flow-concentration relationship. Similar to Wekiwa Springs, a clear positive relationship (increasing concentration with increasing discharge) is evident from this comparison (Figure E-50). TN also exhibited a strong positive relationship with annual average flow.

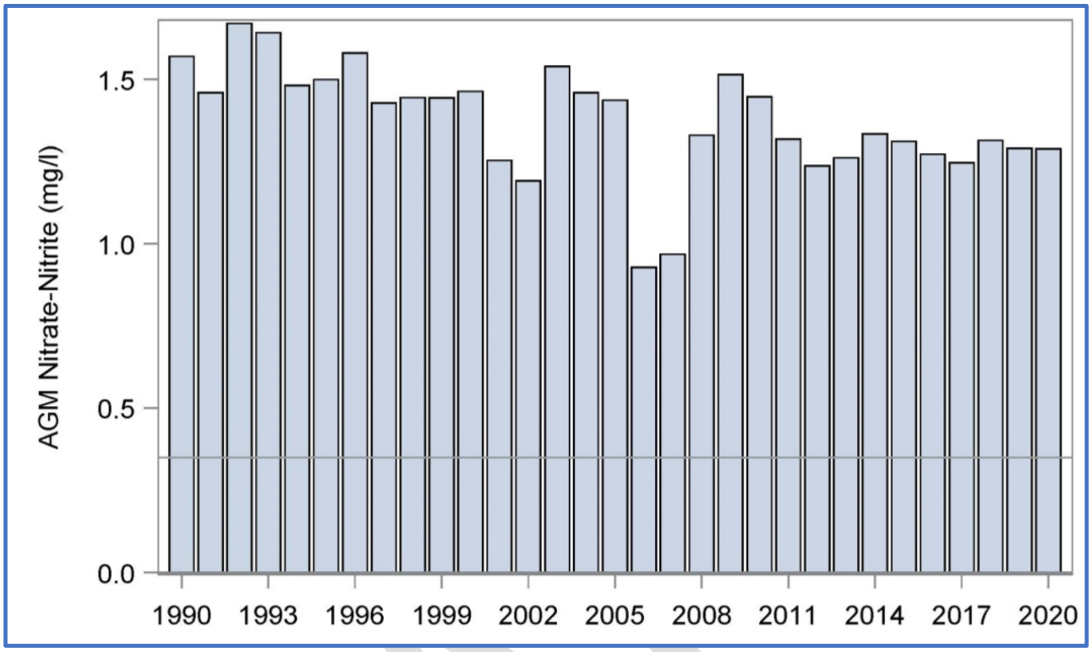

Figure E-49. Rock Springs annual geometric mean for NOx; grey line represents the NNC (0.35 mg/L) for NO_3+NO_2

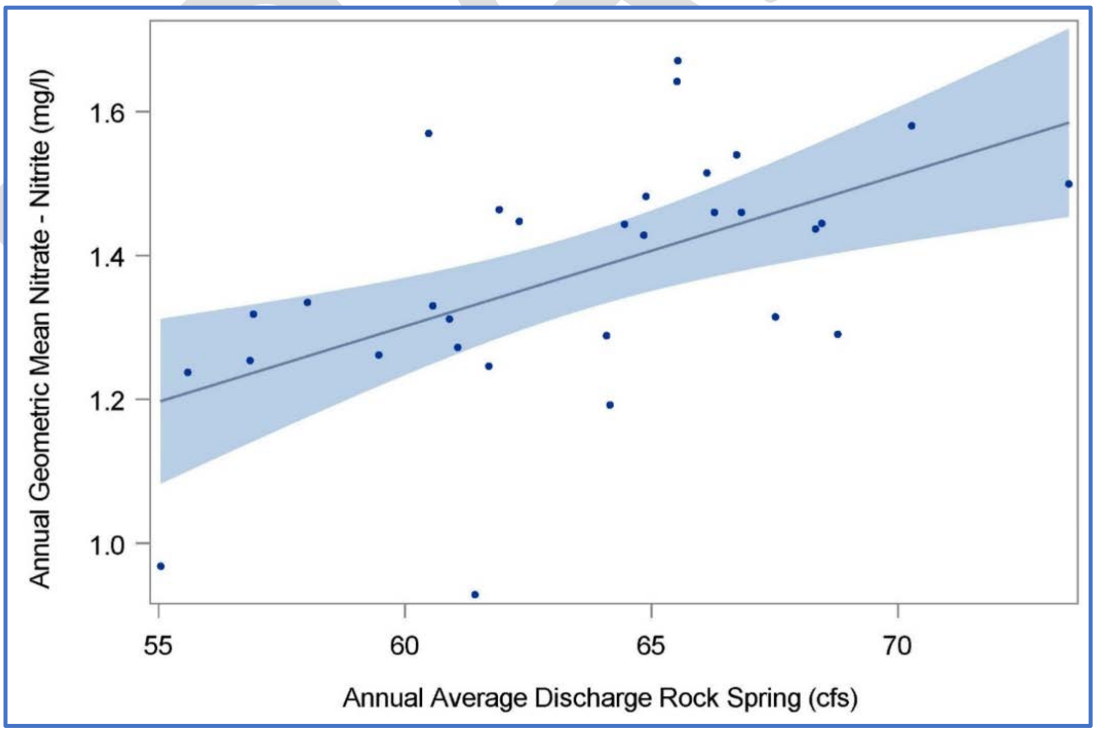

Figure E-50. Annual geometric mean for NOx versus annual average flow at Rock Springs; shaded area represents the 95% confidence interval

Orthophosphate values have also been reported as both dissolved and total. Both forms exhibit a slight positive relationship with flow at Rock Springs (Figures 92 and 94 in Attachment 2). Total phosphorus appears to have increased very slightly over time at Rock Springs, however, the change in magnitude is small (Figure 95 in Attachment 2). There is no discernable relationship between total phosphorus and flow (Figure 96 in Attachment 2).

While remaining low, conductivity values at Rock Springs exhibit an increasing trend over time (Figure 97 in Attachment 2). Conductivity values exhibit a slight negative relationship with flow; however, the change in magnitude is small (Figure 98 in Attachment 2). Rock Springs has been characterized by declining flows over the period-of-record, which may account for the increase in conductivity over the same timeframe.

There is no discernible pattern in dO over time and values are consistently low (Figure 99 in Attachment 2). There is a positive relationship between dO and flow, but this is driven by relatively few values (Figure 100 in Attachment 2). Low dO is expected near a spring vent given the groundwater source.

Total dissolved solids appear to have increased slightly over time at Rock Springs and TDS has a negative relationship with flow (Figures 101 and 102 in Attachment 2).

As with Wekiwa Springs, nitrogen concentrations in Rock Springs exhibit an increasing concentration with increasing discharge (i.e., is related to loading, not reduced flows). Also, the remaining parameters for Rock Springs have nearly flat regression slopes and wide confidence intervals, indicating a weak or nonexistent relationship with flow. Therefore, this environmental value is considered protected under the recommended basin-wide MFLs condition (i.e. the current-pumping condition).

Little Wekiva River

The primary water quality monitoring location utilized for the LWR analyses was the SJRWMD station LW-MP, located downstream of Springs Landing Boulevard (Figure E-46). See Attachment 2 for graphs of water quality parameters versus flow and over time.

Dissolved ammonia values in the LWR did not exhibit a temporal trend over the POR, remaining fairly consistent but with inter- and intra-annual variability (Figure 111 in Attachment 2). Ammonia concentration also did not exhibit a relationship with flow (Figure 112 in Attachment 2). Dissolved NOx concentration reflects a decline over the POR and a slight negative relationship with flow (Figures 113 and 114 in Attachment 2). TKN has increased over time and exhibits a positive relationship with flow (Figures 115 and 116 in Attachment 2). TN did not exhibit a temporal trend or a strong relationship with flow (Figures 117 and 118 in Attachment 2).

The LWR is in the Peninsular Nutrient Watershed Region and therefore has a total phosphorus NNC threshold of 0.12 mg/L and a total nitrogen threshold of 1.54 mg/L. These values are AGM concentrations not to be exceeded more than once in a three-year period (i.e., three calendar years). The TP threshold was exceeded in the LWR each year in the POR (Figure E-51). In contrast, the TN threshold was never exceeded for the LWR (Figure E-52).

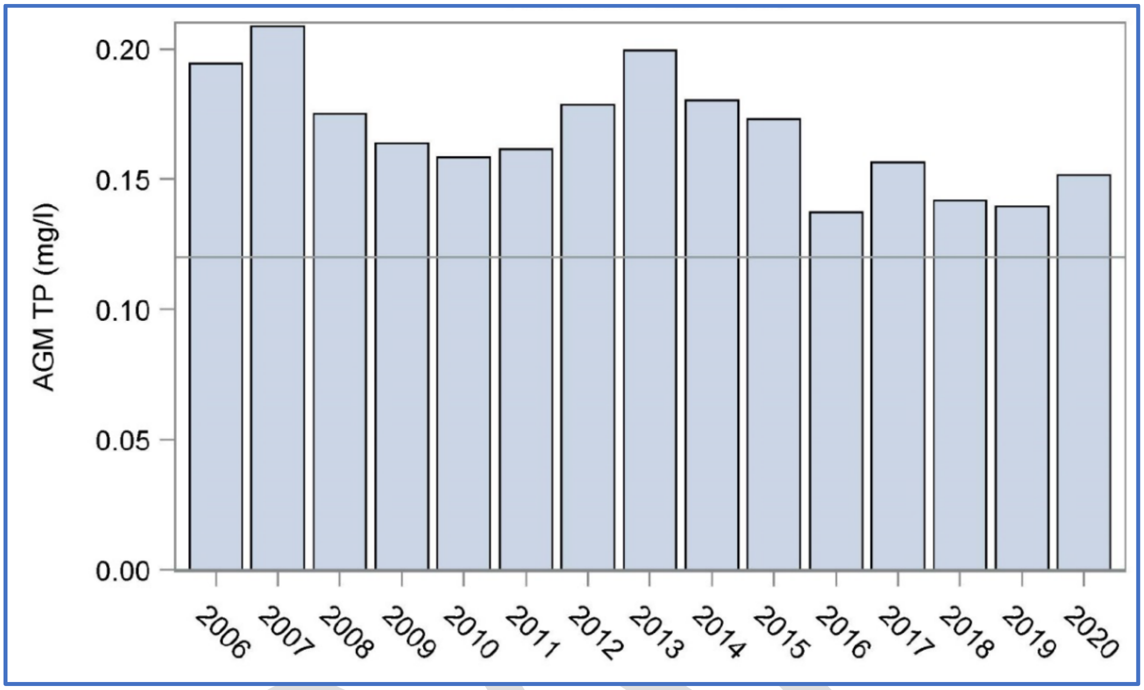

Figure E-51. LWR AGM for TP; the grey line represents the NNC (0.12 mg/L) for total phosphorus

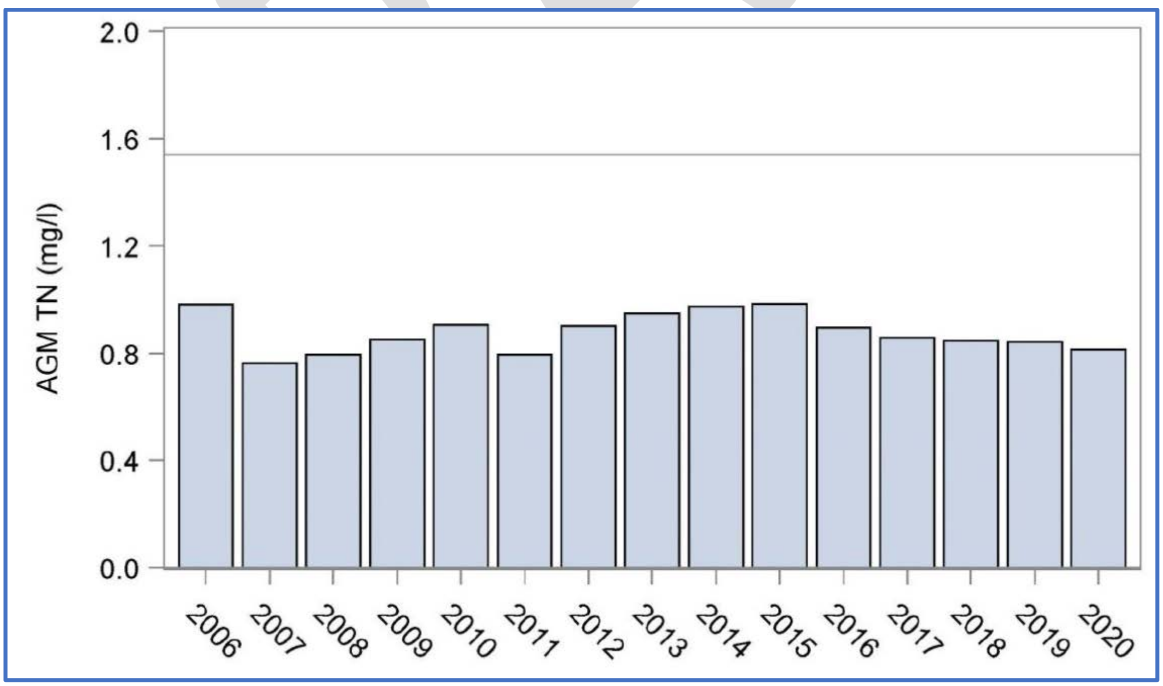

Figure E-52. LWR AGM for TN; the grey line represents the NNC (1.54 mg/L) for total nitrogen

Dissolved orthophosphate concentration exhibits a declining trend over the POR (Figure 119 in Attachment 2). A wider range of orthophosphate values is observed at flows greater than 30 cfs than below 30 cfs. There is a decline in dissolved orthophosphate with increasing flow (Figure 120 in Attachment 2). Similar to dissolved orthophosphate, total phosphorus exhibits a slight decline over the POR, but is not related to flow (Figures 121 and 122 in Attachment 2).

Conductivity values varied over a relatively narrow range (~ 200 microsiemens per centimeter [µS/cm]) over the POR in the Little Wekiva River, with a shallow declining trend suggested over this timeframe (Figure 125 in Attachment 2). There is a negative relationship with flow (Figure 126 in Attachment 2). However, the absolute change in conductivity is small and it is consistently below 400 µS/cm.

Dissolved oxygen concentration does not exhibit a trend over time, but there is a slight negative relationship with flow (Figures 127 and 128 in Attachment 2). Values were typically greater than 4 mg/L.

As mentioned above (see Sediment Loads WRV), total suspended solids appear to decline slightly over the POR (Figure 133 in Attachment 2). TSS is also slightly positively related to flow (Figure 134 in Attachment 2). However, the frequency of samples collected at flow rates greater than 25 cfs is low compared to the frequency of samples at lower flow rates; there are also many outliers over the range of flows.

Dissolved organic carbon (DOC) concentrations indicate an increasing trend over the POR (Figure 139 in Attachment 2). There is also a positive relationship between DOC and flow suggesting that dissolved carbon is largely influenced by land-based inputs added via runoff in the wet season (Figure 140 in Attachment 2).

Annual geometric mean values for TP, TN, NO3, and chlorophyll were regressed against annual average discharge at SR46. TN exhibited a strong positive relationship (increasing concentration with increasing flow) with annual average flow. The remaining parameters had nearly flat slopes to the regression line, and wider confidence intervals, indicating a weak or nonexistent relationship with flow. Therefore, this environmental value is considered protected under the current-pumping condition.

Wekiva River at SR 46

The primary station utilized for Wekiva River water quality analyses was the SJRWMD station CMWEKIVA46 located just upstream of SR 46 (Figure E-46). See Attachment 2 for graphs of water quality parameters versus flow and over time.

Ammonium was reported initially as total ammonium and was later reported as dissolved ammonium. This change made it difficult to assess temporal pattern, but total ammonium does not appear to have a trend over time (Figure 11 in Attachment 2). Total ammonium does appear to have a positive relationship with flow, but this relationship may be driven by a small number of values at larger flow rates (Figure 12 in Attachment 2). Dissolved ammonium appears to decline since 2010 (Figure 13 in Attachment 2). Nitrate-nitrite was also reported initially as total nitrate-nitrate, switching to dissolved nitrate-nitrite after 2010. These data indicate a declining trend in nitrate-nitrite over time (Figure 15 in Attachment 2). Nitrate-nitrite concentrations do not appear to be related to flow at lower flows (i.e., groundwater driven base flows), but upon reaching a certain threshold (approximately 300 cfs) exhibit a negative relationship with flow (Figure 16 in Attachment 2). TKN did not exhibit a distinct trend over time but there was a positive relationship between TKN and flow (Figures 17 and 18 in Attachment 2). TN showed a slight decreasing trend over time and a positive relationship with flow (Figures 19 and 20 in Attachment 2).

As with the Little Wekiva River, nutrient data for the Wekiva River were compared to thresholds for the Peninsular Nutrient Watershed Region (0.12 mg/L for TP and 1.54 mg/L for TN). The criterion for chlorophyll *a* is an AGM of 20 µg/L. In addition, a Total Maximum Daily Load (TMDL) has been established for nitrogen and phosphorus in the Wekiva River. As part of the TMDL, target average monthly nitrate-nitrite (0.286 mg/L) and total phosphorus (0.065 mg/L) concentrations have been established.

AGMs were calculated for chlorophyll *a* and nutrient data collected at SR46. The AGM for TP occasionally exceeded the NNC and have been very near the NNC in the last several years (Figure E-53); the values have exceeded the TMDL target every year except 1995. Total nitrogen AGMs have not exceeded the NNC in the 23-year period (Figure E-54). However, nitrate-nitrite (components of total nitrogen) values have frequently exceeded the TMDL target value for nitrate. Annual geometric means for chlorophyll *a* have been consistently below the NNC for the POR.

Orthophosphate was originally reported as total orthophosphate and in the mid-2000s switched to being reported as dissolved orthophosphate. Dissolved orthophosphate suggests a decline over the past decade (Figure 23 in Attachment 2) and the relationship between orthophosphate (both total and dissolved) and flow was negative (Figures 22 and 24 in Attachment 2). TP did not exhibit a discernable trend over time or a strong relationship with flow (Figures 25 and 26 in Attachment 2).

Total organic carbon did not exhibit a trend over time but was positively related to flow (Figures 27 and 28 in Attachment 2). Chlorophyll (corrected for pheophytin) concentrations were consistently lower than 5 µg/L, with the exception of several outliers, and a slight increase in concentration over time was apparent (Figure 29 in Attachment 2). A slight negative relationship between chlorophyll concentration and flow was observed (Figure 30 in Attachment 2).

Conductivity and dissolved oxygen (concentration and percent saturation) exhibited a slight decline over the POR (Figures 31, 33, and 35 in Attachment 2) and a negative relationship with flow (Figures 32, 34, and 36 in Attachment 2). Total dissolved solids also slightly decreased over time (Figure 37 in Attachment 2). Total suspended solids illustrated a declining pattern over time, though high outliers occurred throughout the period of record (Figure 39 in Attachment 2). TSS exhibited a positive relationship with flow (Figure 40 in Attachment 2).

AGM values for TP, TN, nitrate-nitrite (NOx), and chlorophyll were regressed against annual average flow for the Wekiva River. TN exhibited a strong positive relationship (increasing concentration with increasing flow) with annual average flow, suggesting that increased nitrogen is from high loading, not decreased flow (Figure E-55).

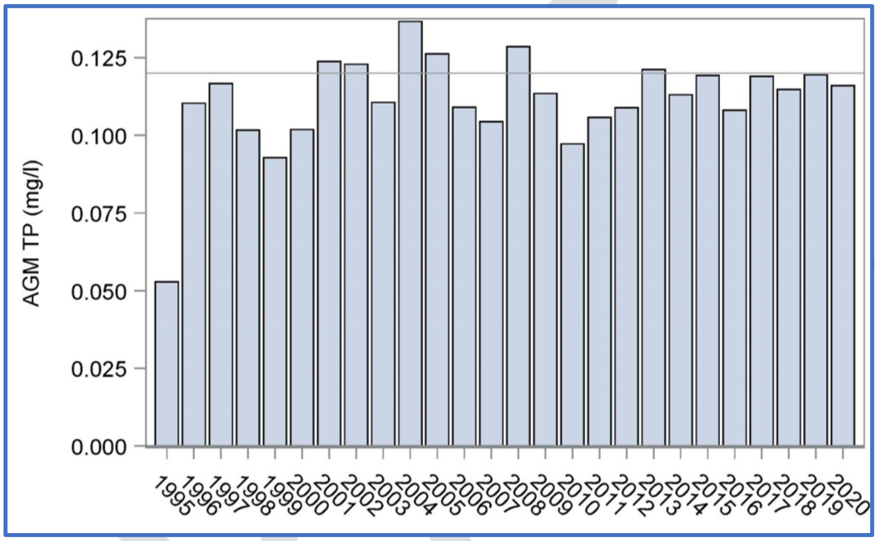

Figure E-53. Wekiva River AGM for TP; the grey line represents the NNC (0.12 mg/L) for total phosphorus

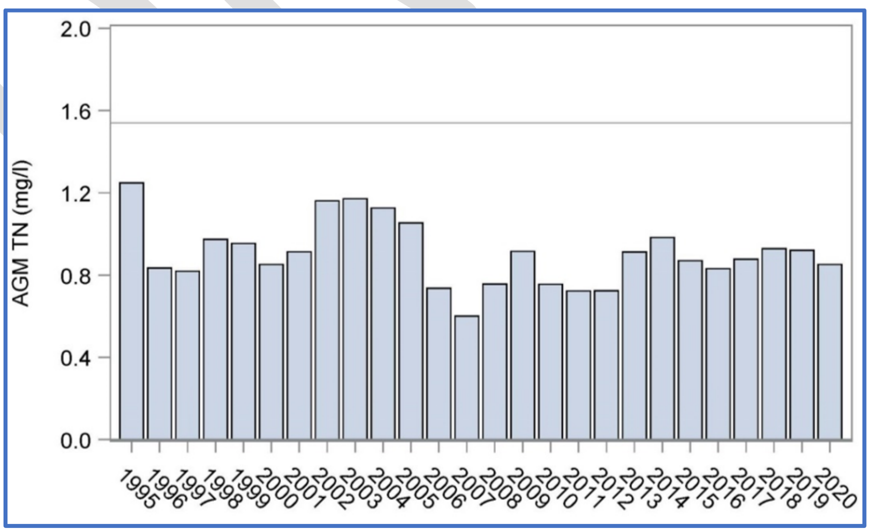

Figure E-54. Wekiva River AGM for TN; the grey line represents the NNC (1.54 mg/L) for total nitrogen

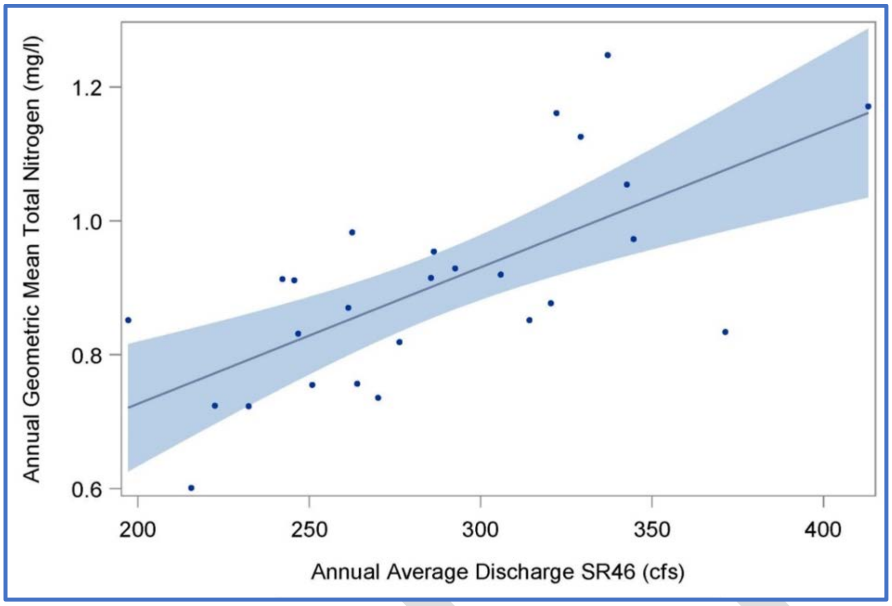

Figure E-55. AGM for TN versus annual average flow for the Wekiva River; shaded area represents the 95% confidence interval

Summary

Based on the analyses described above, excessive nitrogen in Wekiwa Springs, Rock Springs and the Wekiva River is related to loading from the landscape and not reduced flow. In fact, nitrogen concentrations increase with increased flow. Water quality within the Wekiva River basin will not be improved with a constraining minimum flow, but instead is dependent on the chemical mass balances within the springshed (Munch et al. 2007). Nitrogen and phosphorus that is added to the landscape does not fully assimilate and much makes its way to surficial and deeper groundwater. Nitrate and nitrite are very mobile and have dramatically increased in groundwater in recent decades (Osburn et al. 2006; Phelps 2006). The positive relationship of nutrients and flow is consistent with observations made for other springs and spring-fed rivers. Heyl (2012) examined the relationship between spring flow and NOx concentrations in the Chassahowitzka River, Homosassa River, Silver Springs, Pumphouse and Trotter springs, Gum Springs, and Rainbow Springs systems. NOx concentrations had markedly increased in all of these springs. Heyl evaluated the relationship between flow and NOx concentration in each system with standard statistical techniques. In all six systems, the increase in NOx concentration was determined to be independent of flow, but strongly dependent on time (i.e., date).

Regarding their research on springs in the Suwannee River Water Management District, Upchurch et al. (2007) state: “The clear conclusion from this analysis is that minimum flows and levels (MFLs) cannot be utilized to mitigate NOx discharging from the springs by promoting high flow.” Upchurch et al. (2007) further stated, “In order to maintain an optimal pattern of flow from the springs through the use of minimum discharge and levels, discharge of high NOx concentrations in spring water is likely to result unless NOx sources are reduced."

In addition to nutrients being related to loading and not flow, the remaining parameters had nearly flat regression slopes and wide confidence intervals (see Attachment 2), indicating a weak or nonexistent relationship with flow. Therefore, water quality within the Wekiva River basin is not significantly related to flow reduction and is considered protected under the recommended basin-wide MFLs condition (i.e. the current-pumping condition).

WRVs Assessment Summary

A large suite of criteria were evaluated to ensure that the recommended MFLs condition (basin-wide current-pumping condition) is protective of important, relevant environmental functions and values. The WRVs assessment included evaluating numerous recreational metrics, fish and wildlife metrics (in addition to primary criteria), critical velocity thresholds and water quality analyses. The WRVs assessment results above indicate that the eight WRVs relevant to the Wekiva River basin systems are protected by the recommended MFLs (Table E-10).

The recommended minimum flow for the mainstem of the Wekiva River (i.e., assessed at SR 46) equates to an allowable reduction in flow, relative to the no-pumping condition, of 8.5%. This is within the range of allowable change (10% reduction from natural baseline condition) deemed protective for large river systems with outstanding biological / ecological attributes (Acreman and Ferguson 2010; Richter et al. 2011). The allowable change for the Wekiva River is also within the range (3.0 – 19.0%) and similar to the average (7.6%) allowable flow reduction based on adopted MFLs for spring-fed rivers in Florida (Table E-11).

Table E-10. Chapter 62-40.473, *F.A.C.*, criteria evaluated to determine protection of environmental values by the recommended MFLs condition for each Wekiva River basin system.

WRV	Environmental Criteria Evaluated	Protected by the MFLs Condition?
Recreation in and on the water	Paddling depth; boat passage; boat ramp usage; tubing depth, swimming/wading depth	Yes
Fish and wildlife habitats and the passage of fish	FH, MA, organic drying metric, floodplain inundation metric, SEFA, fish passage, manatee passage, shad spawning habitat, basin-wide wetland inundation	Yes
Estuarine resources	NA	NA
Transfer of detrital material	Primary floodplain metrics; algal scour	Yes
Maintenance of freshwater storage and supply	Other relevant WRVs are protected by the MFLs condition, thereby providing balance between consumptive and non-consumptive uses.	Yes
Aesthetic and scenic attributes	Protection of fish and wildlife, recreation and water quality metrics	Yes
Filtration and absorption of nutrients and other pollutants	Primary floodplain metrics; GPP	Yes
Sediment loads	Sediment entrainment and transport velocities; relationship between TSS and flow	Yes
Water quality	Nutrients (Nox, TN and TP) and other parameters; comparisons with flow and temporal trends	Yes
Navigation	NA	NA

Table E-11. Allowable reduction in average flow based on adopted MFLs for Florida spring-fed river systems; average allowable reduction is 7.6%.

Spring-fed River System	Adopted MFL allowable reduction to average flow (%)
Chassahowitzka River System	3.0
Homosassa River System	3.0
Rainbow River	5.0
Wacissa River	5.1
Ichetucknee River	5.8
Aucilla River	6.5
Silver River	6.5
Peace River at Zolfo Spring	8.0
Lower Santa Fe River	8.0
Weeki Wachee River System	10.0
Crystal River System and Kings Bay Springs	11.0
Lower Alafia River	19.0
Average	**7.6**

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WRVs Assessment Attachment 1 – FWRI Fish Survey Summary for the Wekiva River and Rock Springs Run

Florida Fish and Wildlife Conservation Commission – Fish and Wildlife Research Institute Summary of Fish Community Survey of Rock Springs Run and the Wekiva River

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General Sampling Protocols

Rock Springs Run and the Wekiva River were sampled using pulsed DC boat-mounted electrofishing equipment to describe community fish assemblages. To the extent possible, sampling was done as close to the recommended FWC standard protocols for sampling community fish assemblages in lotic waterbodies. Electrofishing sampling was conducted using either a standard electrofishing boat configuration with an outboard motor, an airboat electrofisher, usually accompanied by an additional airboat with fish work-up equipment and crew, or a modified “mini-shocker” using a small 5-horsepower tiller-motor that is more maneuverable in a narrow stream. We used only one dipper instead of the standard two on the front of the boat for netting and collecting fish. This measure reduced the amount of manpower needed for sampling and maintained consistency across the three electrofishing gears. Also, in some areas of tight cover and overhanging branches, having two dippers on the front of the boat would be difficult and cumbersome. An airboat electrofisher was used in areas on both spring runs that we termed “meadows”, identified by dense beds of aquatic macrophytes, typically eelgrass, that often extended to the surface of the water. The use of airboats prevented unwanted damage to critical habitat that a standard outboard motor would have on aquatic vegetation.

Transect points were spaced at 100-meter intervals throughout the center of each spring run for its entirety. Upon arrival at the appropriate centerline point selected, the left or right bank was randomly selected for sampling and the starting GPS coordinates were recorded. For the regular and mini-shocker gears, a 100-m transect was sampled in an upstream manner along the shore or vegetation line and, upon completion, the ending GPS coordinates were recorded. Shocking was done against the current because boat operation and maneuverability were more controlled. Boat operation in shallow water also disturbed the bottom substrate and this would cloud the water, so we did not want increased turbidity to impede the dipper from seeing or collecting fish. The airboat shocked in a diagonal pattern back and forth from the bank to the center channel over the course of 100-meters due to the presence of submersed vegetation throughout the entire transect. All fish were collected, measured, weighed, and released. If further identification was needed, fish were transported back to the laboratory for work up.

Wekiva River Sampling Results

A total of 125 sites were sampled on the Wekiva River over the two sampling seasons. Sixty-six sites were sampled in the summer 2019 season, 56 sites using standard electroshocker boats and

10 sites using the airboat electrofisher. The winter 2020 sample consisted of 59 sites with 46 using standard electrofishing boats and 13 sites using the airboat electrofisher.

Fifty-two different species were collected over both rounds of sampling, with 48 species collected in the summer sample while 43 species were collected during the winter (Table 1). Nine species were only collected during the summer 2019 sample: Gizzard Shad, Bluespotted Sunfish, Walking Catfish, Snail Bullhead, Dimerus Cichlid (also known as the Chanchita), Flagfish, Swamp Darter, Speckled Madtom, and Bluenose Shiner. White Mullet, Chain Pickerel, Hickory Shad, and Hogchoker were only collected during the winter 2020 sample.

A total of 10,274 individual fish were collected during the summer 2019 sample and 5,081 fish during the winter 2020 sample. The five most abundant fish species in the summer sample were Redbreast Sunfish, Spotted Sunfish, Coastal Shiners, Bluegill, and Eastern Mosquitofish (Table 1). As far as biomass for the summer sample, the five highest contributors were Bowfin Largemouth Bass, White Catfish, Florida Gar, and Redbreast Sunfish (Table 1)). Even though approximately half as many fish were collected in the winter sample, the percentages of the total catch were similar for the five most abundant species, with the most abundant species again being Redbreast Sunfish, followed by Coastal Shiners, Eastern Mosquitofish, Spotted Sunfish, and Bluegill (Table 1). The five highest contributors to the total weight of the winter 2020 sample were Bowfin, Largemouth Bass, Florida Gar, Lake Chubsucker, and Redbreast Sunfish (Table 1). As one can see, biomass results were similar with the exception of White Catfish. Catfish species almost disappeared in our winter sample. The reason for this absence is unknown, but may be attributed to seasonal movement by catfish species or that the very lowest portion of the Wekiva River, where catfish were more abundant, was not included in the winter 2020 sample as we focused our effort on sections of the river more characteristic of a spring run.

Rock Springs Run Results

A total of 68 sites were sampled on Rock Springs Run over the course of this project. The mini-shocker was used for 56 sites and the airboat electrofisher accounted for the remaining 12 sites. Each sample season consisted of 28 mini-shocker transects. The summer 2019 sample had 5 airboat sites while the winter 2020 sample had 7 airboat sites.

Thirty-two different species were collected each sampling season, with two species being collected only in the summer sample (Swamp Darter and Taillight Shiner) and another two species being collected only during the winter sample (Black Crappie and Dimerus Cichlid). A total of 3,640 individual fish were collected during the summer 2019 sample and 3,467 fish in the winter 2020 sample.

The five most abundant fish species in the summer sample were Eastern Mosquitofish, Spotted Sunfish, Redbreast Sunfish, Metallic Shiners, and Coastal Shiners (Table 2). As far as biomass for the summer sample, the five highest contributors were Largemouth Bass, Bowfin, Lake Chubsucker, Redbreast Sunfish, and Spotted Sunfish (Table 2). Results were similar for the winter sample, with the most abundant fish species being Eastern Mosquitofish, followed by Coastal Shiners, Metallic Shiners, Redbreast Sunfish, and Spotted Sunfish (Table 2). Biomass results were also similar, with Largemouth Bass representing over one-third of the total biomass catch, followed by Bowfin, Lake Chubsucker, Redbreast Sunfish, and Spotted Sunfish (Table 2).

Bluenose Shiner

The state listed Bluenose Shiner was collected from both Rock Springs Run and the Wekiva River. During our summer 2019 sampling on the Wekiva River, we collected one individual just below the confluence where Rock Springs Run meets the Wekiva River. We did not collect any during our Winter 2019 sample of the Wekiva River. On Rock Springs Run, we collected Bluenose Shiners during both sample seasons. We collected 13 individuals during the summer 2019 sample and 18 individuals during the winter 2019 sample. These are positive signs that this species has populations persisting in areas where they have been historically documented. Habitats favored by Bluenose Shiners are common throughout these waterbodies, but further research is needed to better understand relative abundances and population trends of this sensitive species.

Exotic Fish Species

Five species of exotic fish were collected on the Wekiva River: Blue Tilapia, Brown Hoplo, Dimerus Cichlid, Vermiculated Sailfin Catfish, and Walking Catfish. These same species were also collected on Rock Springs Run, minus Blue Tilapia. Although we did not capture any Blue Tilapia during our sampling of Rock Springs Run, they were observed swimming away from the boat during both seasons. Standard sampling protocols do not target these species of fish effectively; therefore, relative abundances are biased towards the extreme low end of the spectrum of actual fish present. Vermiculated Sailfin Catfish were the most numerous exotic species collected, followed by Brown Hoplo and Blue Tilapia, while both the Dimerus Cichlid and Walking Catfish were the least captured exotic species (Table 3). Although we expected more fish would move into the spring runs during the winter to take advantage of the warmer water emitting from the spring compared to the main-stem St. Johns River and lakes, seasonal shifts in the relative abundances or presence/absence of species was not reflected in our samples. Investigating other methods for capturing these fish in spring runs, particularly Blue Tilapia and Vermiculated Sailfin Catfish, is currently ongoing.

Table 1. Wekiva River total count, percent composition of total count, and percent composition of total biomass for Summer 2019 and Winter 2020 electrofishing sampling.

Species	Count 2019	% Count 2019	% Biomass 2019	Count 2020	% Count 2020	% Biomass 2020
American Eel	29	0.28%	0.78%	19	0.37%	1.03%
Black Crappie	22	0.21%	0.73%	6	0.12%	0.29%
Blackbanded Darter	100	0.97%	0.03%	91	1.79%	0.05%
Blue Tilapia	5	0.05%	0.73%	5	0.10%	1.94%
Bluefin Killifish	109	1.06%	0.01%	63	1.24%	0.00%
Bluegill	780	7.59%	4.37%	321	6.32%	4.17%
Bluenose Shiner	1	0.01%	0.00%	-	-	-
Bluespotted Sunfish	4	0.04%	0.00%	-	-	-
Bowfin	118	1.15%	16.65%	92	1.81%	29.33%
Brook Silverside	34	0.33%	0.01%	114	2.24%	0.04%
Brown Bullhead	7	0.07%	0.33%	2	0.04%	0.26%
Brown Hoplo	3	0.03%	0.07%	2	0.04%	0.10%
Chain Pickerel	-	-	-	2	0.04%	0.29%
Channel Catfish	7	0.07%	0.97%	2	0.04%	0.99%
Coastal Shiner	1298	12.63%	0.20%	802	15.78%	0.21%
Dimerus Cichlid	2	0.02%	0.01%	-	-	-
Dollar Sunfish	182	1.77%	0.11%	19	0.37%	0.02%
Eastern Mosquitofish	588	5.72%	0.03%	535	10.53%	0.04%
Flagfish	2	0.02%	0.00%	-	-	-
Florida Gar	275	2.68%	11.62%	104	2.05%	11.57%
Gizzard Shad	10	0.10%	0.65%	-	-	-
Golden Shiner	72	0.70%	0.57%	55	1.08%	1.14%
Golden Topminnow	4	0.04%	0.00%	1	0.02%	0.00%
Hickory Shad	-	-	-	1	0.02%	0.16%
Hogchoker	-	-	-	1	0.02%	0.00%
Lake Chubsucker	241	2.35%	4.94%	166	3.27%	8.02%
Largemouth Bass	563	5.48%	16.38%	278	5.47%	21.90%
Least Killifish	124	1.21%	0.00%	50	0.98%	0.00%
Longnose Gar	46	0.45%	1.70%	11	0.22%	0.64%
Marsh Killifish	3	0.03%	0.00%	1	0.02%	0.00%
Metallic Shiner	126	1.23%	0.01%	162	3.19%	0.01%
Pirate Perch	25	0.24%	0.01%	2	0.04%	0.00%
Pugnose Minnow	163	1.59%	0.02%	63	1.24%	0.01%
Rainwater Killifish	3	0.03%	0.00%	9	0.18%	0.00%
Redbreast Sunfish	1933	18.81%	7.11%	918	18.07%	5.79%
Redear Sunfish	128	1.25%	1.27%	41	0.81%	1.21%
Sailfin Molly	533	5.19%	0.13%	206	4.05%	0.06%
Seminole Killifish	360	3.50%	0.55%	283	5.57%	0.59%
Snail Bullhead	2	0.02%	0.04%	-	-	-
Speckled Madtom	1	0.01%	0.00%	-	-	-
Spotted Sunfish	1652	16.08%	4.63%	510	10.04%	3.21%
Striped Mullet	77	0.75%	6.08%	7	0.14%	1.13%
Sunshine Bass	6	0.06%	0.53%	5	0.10%	0.38%
Swamp Darter	2	0.02%	0.00%	-	-	-
Tadpole Madtom	2	0.02%	0.00%	2	0.04%	0.00%
Taillight Shiner	40	0.39%	0.01%	17	0.33%	0.00%
Vermic. Sailfin Catfish	17	0.17%	1.20%	10	0.20%	2.20%
Walking Catfish	2	0.02%	0.06%	-	-	-
Warmouth	386	3.76%	2.72%	82	1.61%	1.91%
White Catfish	128	1.25%	13.11%	3	0.06%	0.21%
White Mullet	-	-	-	5	0.10%	0.39%
Yellow Bullhead	59	0.57%	1.64%	13	0.26%	0.68%
Grand Total	**10274**	**100.00%**	**100.00%**	**5081**	**100.00%**	**100.00%**

Table 2. Rock Springs Run total count, percent composition of total count, and percent composition of total biomass for Summer 2019 and Winter 2020 electrofishing sampling.

Species	Count 2019	% Count 2019	% Biomass 2019	Count 2020	% Count 2020	% Biomass 2020
American Eel	3	0.08%	0.43%	3	0.09%	0.84%
Black Crappie	-	-	-	2	0.06%	0.28%
Blackbanded Darter	82	2.25%	0.11%	71	2.05%	0.08%
Bluefin Killifish	19	0.52%	0.01%	30	0.87%	0.01%
Bluegill	47	1.29%	1.44%	25	0.72%	1.01%
Bluenose Shiner	13	0.36%	0.01%	18	0.52%	0.01%
Bowfin	42	1.15%	20.25%	40	1.15%	33.11%
Brook Silverside	3	0.08%	0.00%	7	0.20%	0.01%
Brown Bullhead	6	0.16%	0.41%	4	0.12%	0.27%
Brown Hoplo	1	0.03%	0.01%	7	0.20%	0.82%
Coastal Shiner	388	10.66%	0.39%	544	15.69%	0.44%
Dimerus Cichlid	-	-	-	2	0.06%	0.01%
Dollar Sunfish	21	0.58%	0.12%	6	0.17%	0.03%
Eastern Mosquitofish	584	16.04%	0.18%	892	25.73%	0.23%
Florida Gar	21	0.58%	5.65%	13	0.37%	3.75%
Golden Shiner	25	0.69%	0.50%	10	0.29%	0.62%
Lake Chubsucker	212	5.82%	11.90%	99	2.86%	8.62%
Largemouth Bass	148	4.07%	29.94%	142	4.10%	34.72%
Least Killifish	45	1.24%	0.00%	32	0.92%	0.00%
Marsh Killifish	3	0.08%	0.00%	1	0.03%	0.00%
Metallic Shiner	406	11.15%	0.11%	420	12.11%	0.11%
Pirate Perch	3	0.08%	0.01%	3	0.09%	0.01%
Pugnose Minnow	22	0.60%	0.02%	43	1.24%	0.03%
Redbreast Sunfish	516	14.18%	9.25%	381	10.99%	4.72%
Redear Sunfish	9	0.25%	0.94%	8	0.23%	0.87%
Sailfin Molly	256	7.03%	0.23%	239	6.89%	0.21%
Seminole Killifish	51	1.40%	0.44%	53	1.53%	0.35%
Spotted Sunfish	543	14.92%	8.81%	307	8.85%	4.45%
Swamp Darter	20	0.55%	0.01%	-	-	-
Taillight Shiner	1	0.03%	0.00%	-	-	-
Vermic. Sailfin Catfish	5	0.14%	4.07%	2	0.06%	1.38%
Walking Catfish	1	0.03%	0.22%	1	0.03%	0.01%
Warmouth	130	3.57%	3.32%	48	1.38%	1.35%
Yellow Bullhead	14	0.38%	1.20%	14	0.40%	1.64%
Grand Total	**3640**	**100.00%**	**100.00%**	**3467**	**100.00%**	**100.00%**

Table 3. Total count of exotic species collected during Summer 2019 and Winter 2020 electrofishing sampling on Rock Springs Run and the Wekiva River.

	Summer 2019		Winter 2020		
Species	Rock Springs Run	Wekiva River	Rock Springs Run	Wekiva River	Grand Total
Blue Tilapia		5		5	10
Brown Hoplo	1	3	7	2	13
Dimerus Cichlid		2	2		4
Vermic. Sailfin Catfish	5	17	2	10	34
Walking Catfish	1	2	1		4
Grand Total	**7**	**29**	**12**	**17**	**65**

WRVs Assessment Attachment 2 - Janicki Environmental, Inc. Water Quality Graphs

Water Quality Graphs

The following water quality graphs and analyses were created and provided to SJRWMD by Janicki Environmental, Inc. (JEI) in 2021, as part of work done under Contract # 32928.

Summaries of water quality data relative to patterns over time and with flow are presented as a series of graphics and provide a pair of figures for each analyzed parameter. One graph provides a time-series plot over the period of record (which varies by site and parameter). In addition, quadratic and linear regression lines are overlaid on each time-series. Triangle symbols represent regression outliers. The second graph in each pair provides a plot of each parameter versus flow (cfs). As with the time-series plots, the flow relationship plots include quadratic and linear regression lines, and outliers.

Wekiva River at SR 46

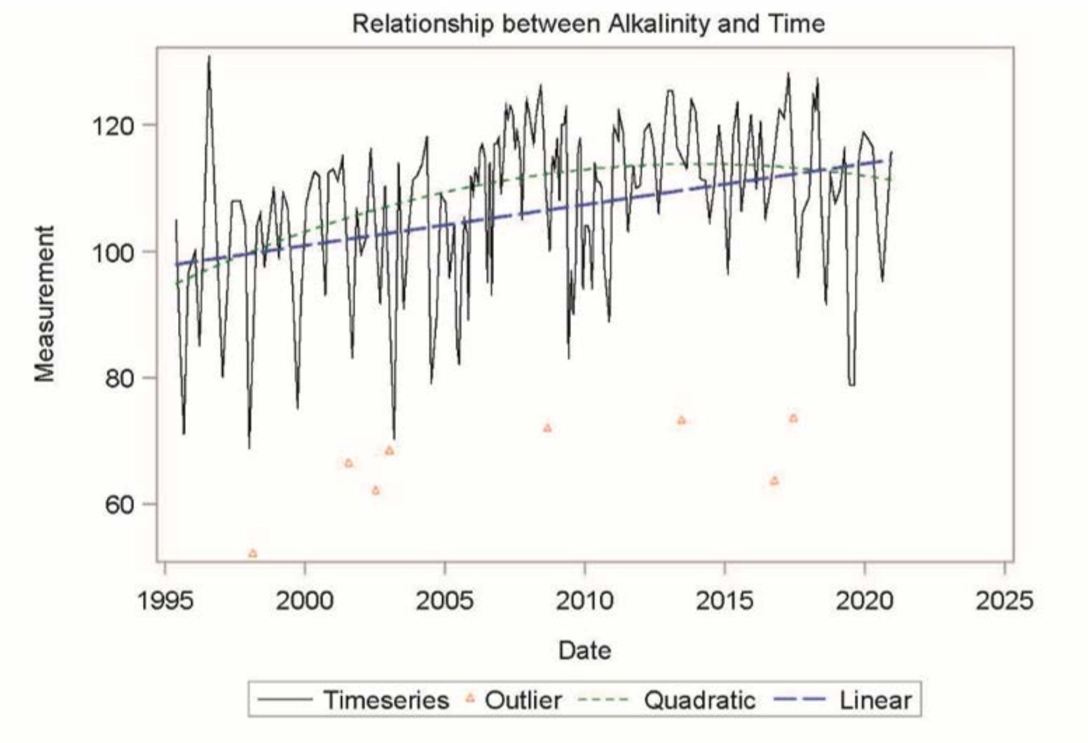
The data used for the Wekiva River at SR 46 analyses were derived from the Florida Department of Environmental Protection Impaired Waters database (Run 60) and the St. Johns River Water Management District water quality data base. The flow data used in these analyses were obtained from District staff and originated with the US Geological Survey at their gauging station on the Wekiva River at SR 46 (02235000). The primary station utilized for water quality analyses was CMWEKIVA46 (Figure E-46).

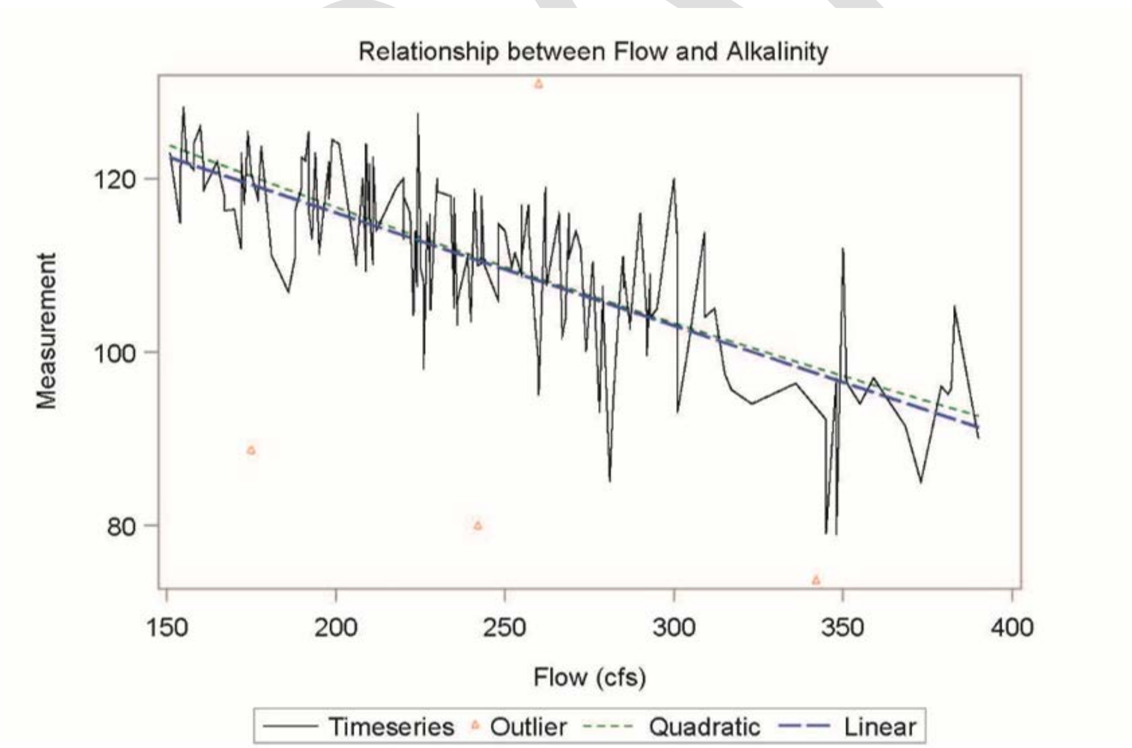
Gaged flows ranged to greater than 1,000 cfs but the majority of recorded flows associated with the water quality parameters were less than 400 cfs. Thus, the flow relationship plots have been restricted to the range zero to 400 cfs.

Alkalinity (Figures 1 and 2) exhibited a cyclical up and down pattern over time, but with an overall increasing trend indicated by the positive slope of the linear regression line. Alkalinity overall decreased with increasing flow values. The cyclical pattern over time may therefore be related to seasonal patterns in flow. Calcium (Figures 3 and 4) exhibited similar patterns to alkalinity, with a slight overall increase over time, but illustrating a negative relationship with flow. Chloride values displayed intra- and inter-annual variation, but overall appeared to be declining over time (Figures 5 and 6). The chloride-flow regression line has a positive slope suggesting an increasing level of chloride with increasing flow.

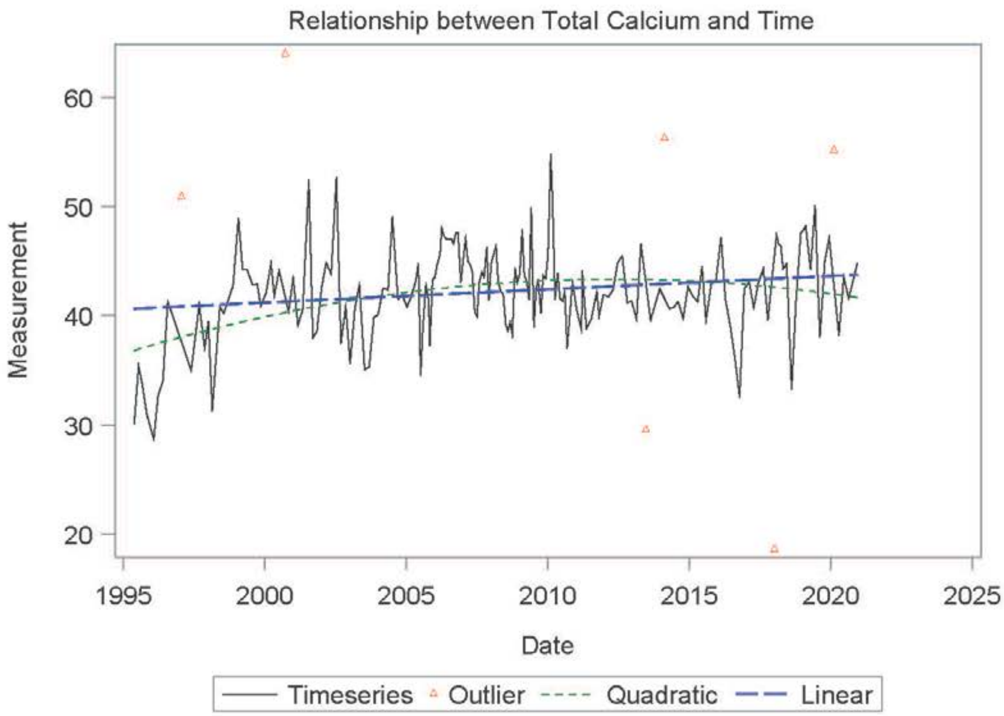
Sulfate values also suggested a declining pattern over time given the negative slope of the regression line (Figures 7 and 8). The relationship with flow exhibited an opposite slope, suggesting a positive relationship between sulfate and flow. The greater outlier values also occurred at the higher (and less frequent) flow values. Observed magnesium values (Figures 9 and 10) indicated a very small decline over the period of record. Additionally, a negative relationship with flow was apparent.

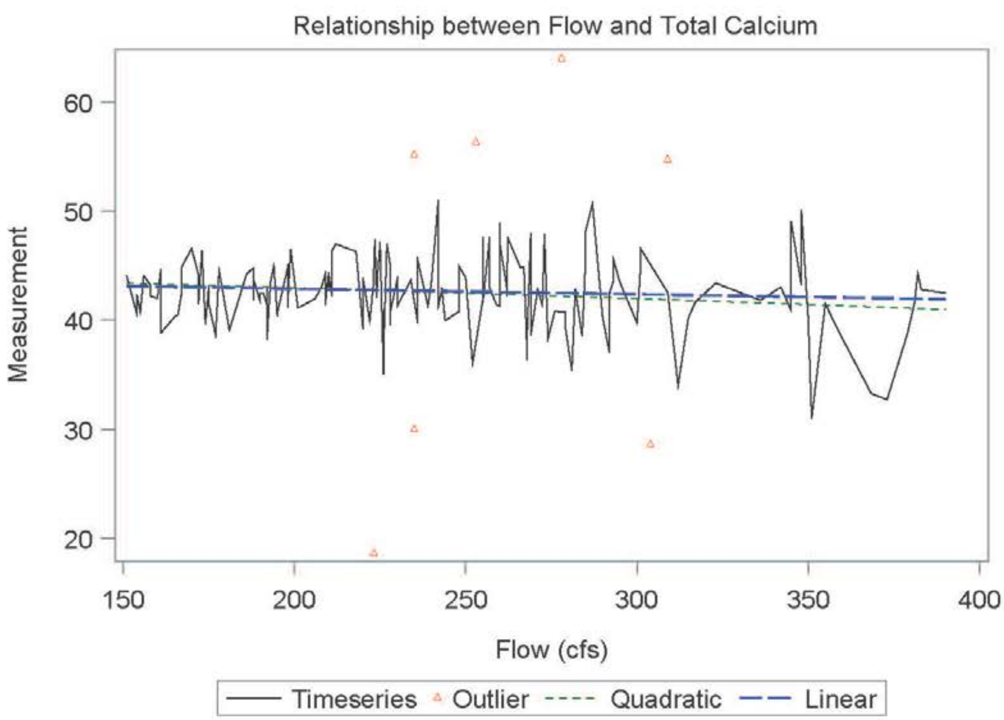
Nutrient parameters exhibited variable responses over time and flow range. Ammonium was reported initially as total ammonium (Figures 11 and 12) and was later reported as dissolved ammonium (Figures 13 and 14). Given the switch, it is difficult to assess patterns over time, but total ammonium does not appear to have a trend over time; however total ammonium did appear to have a positive relationship with flow, but this relationship may be driven by a small number of values at larger flow rates. Dissolved ammonium illustrates a decline since 2010 (Figures 13 and 14).



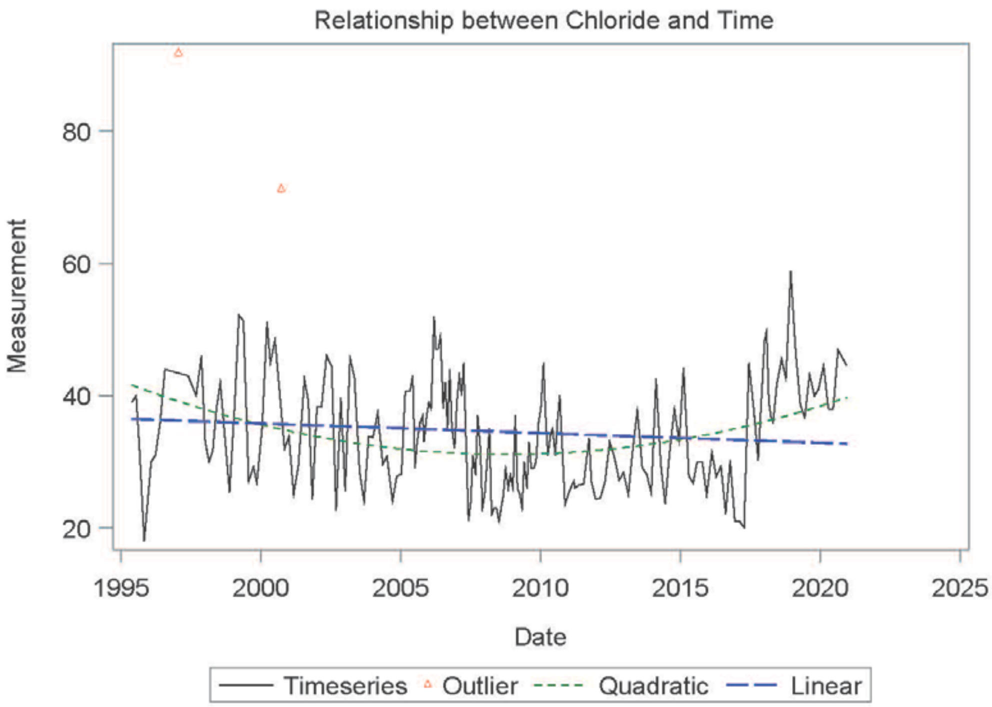


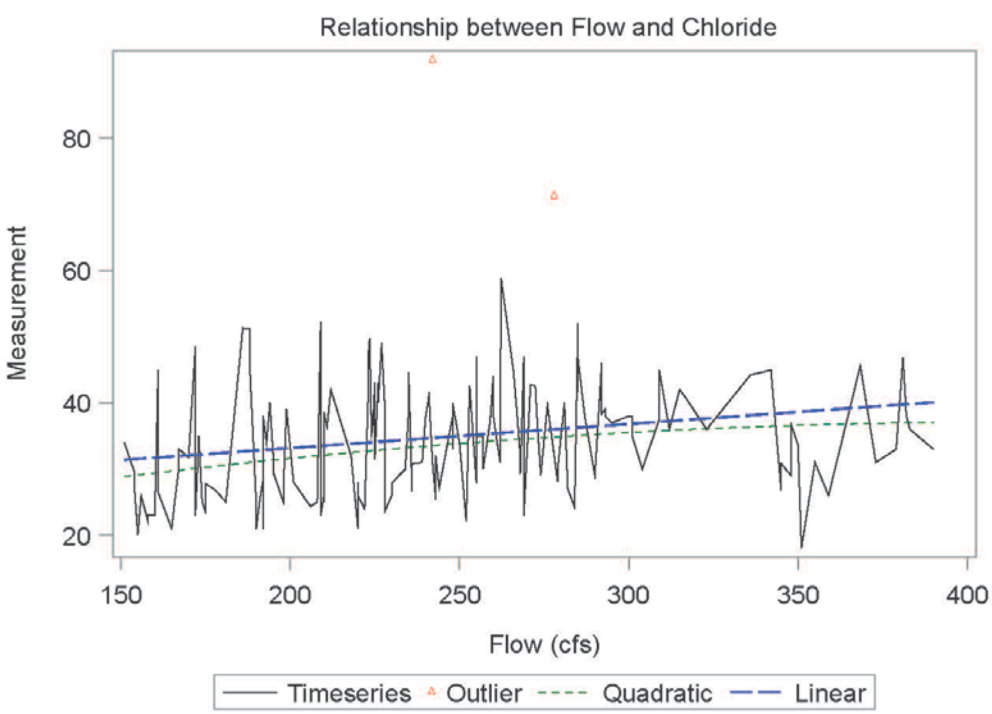
Figures 1 and 2. Time-Series of Alkalinity (top), and Relationship between Alkalinity and Flow (bottom)



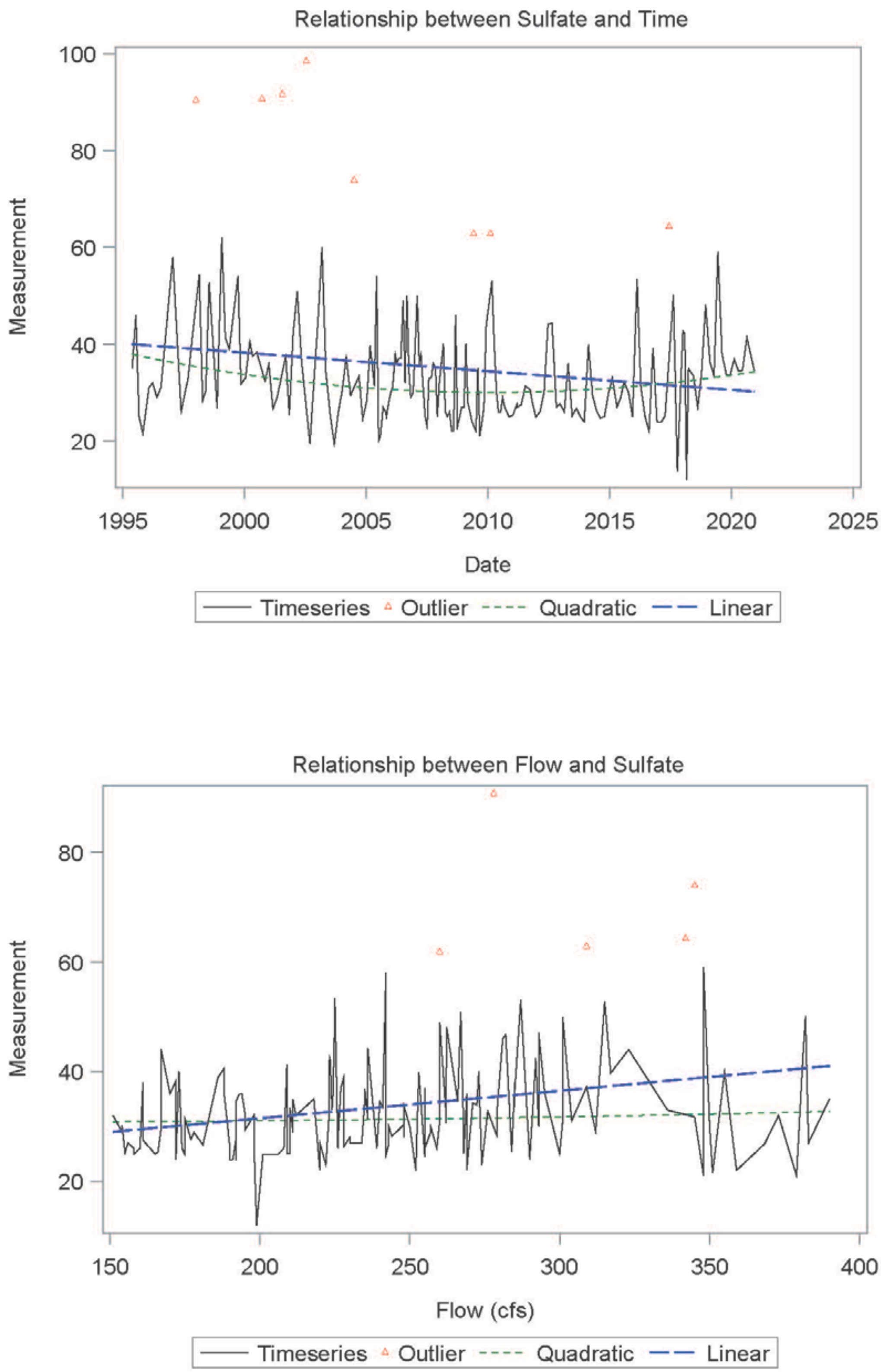


Figures 3 and 4. Time-Series of Calcium (top), and its Relationship with Flow (bottom)

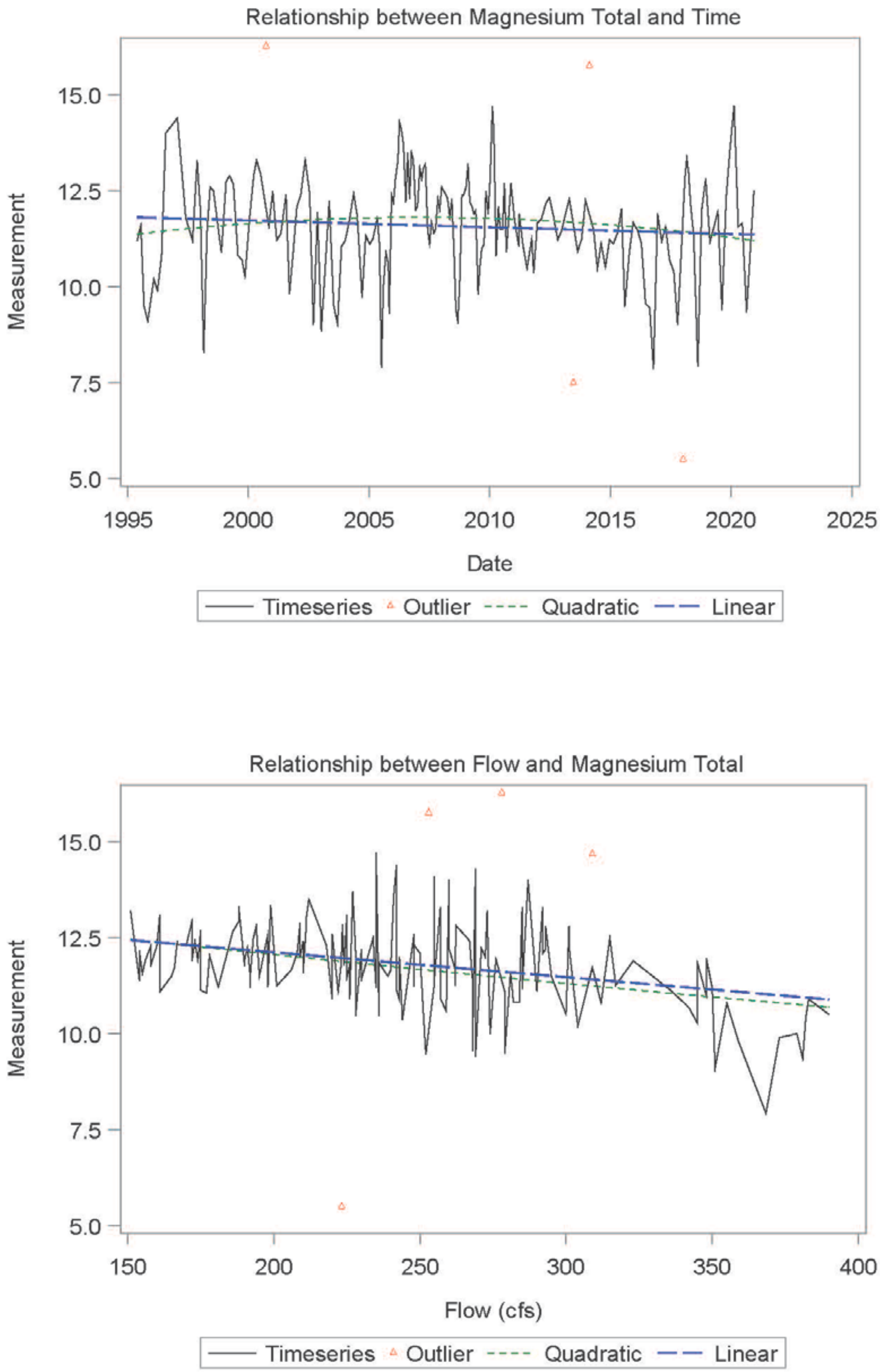




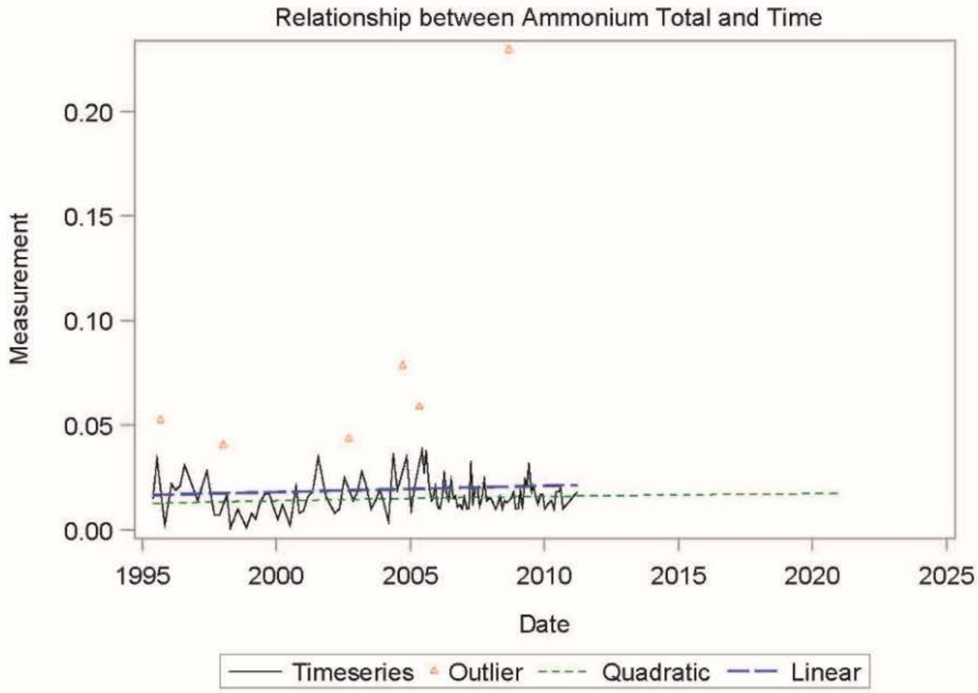
Figures 5 and 6. Time-Series of Chloride (top), and its Relationship with Flow (bottom)

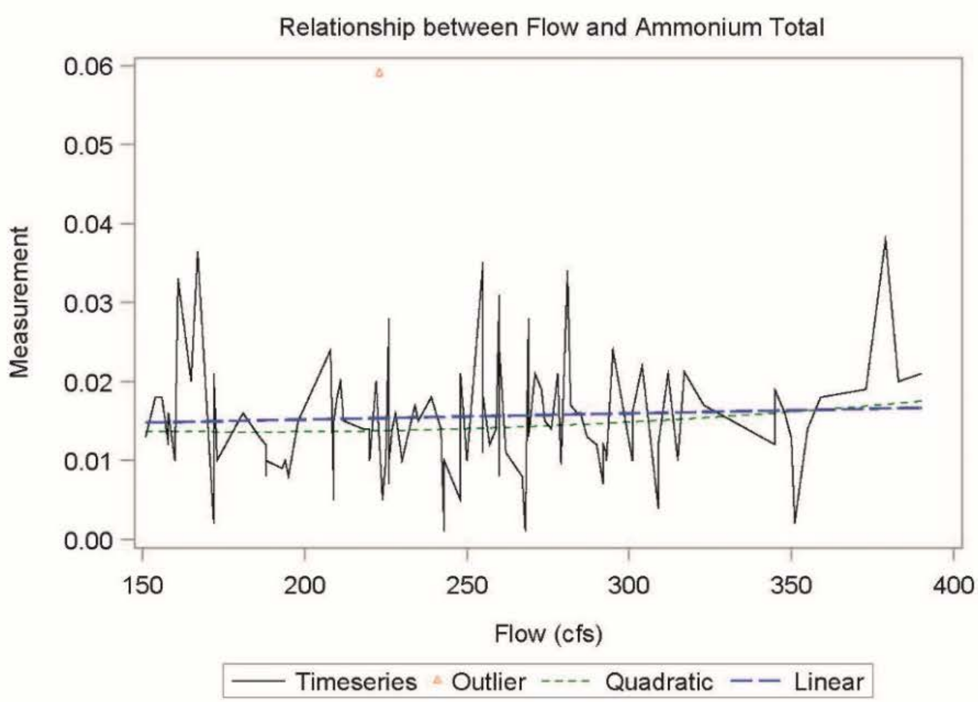


Figures 7 and 8. Time-Series of Sulfate (top), and its Relationship with Flow (bottom)

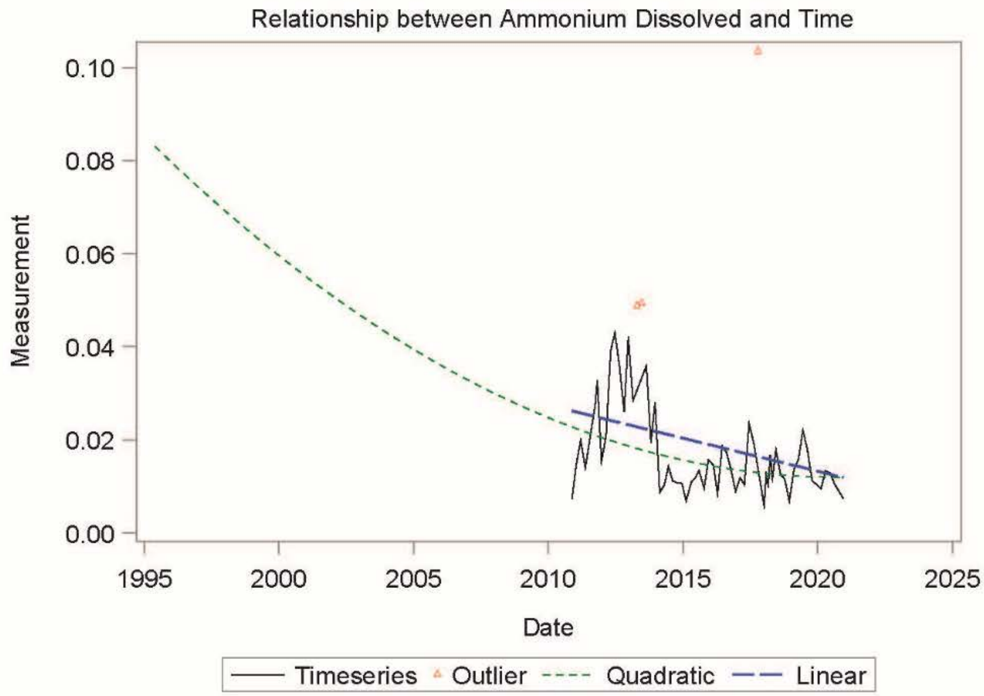


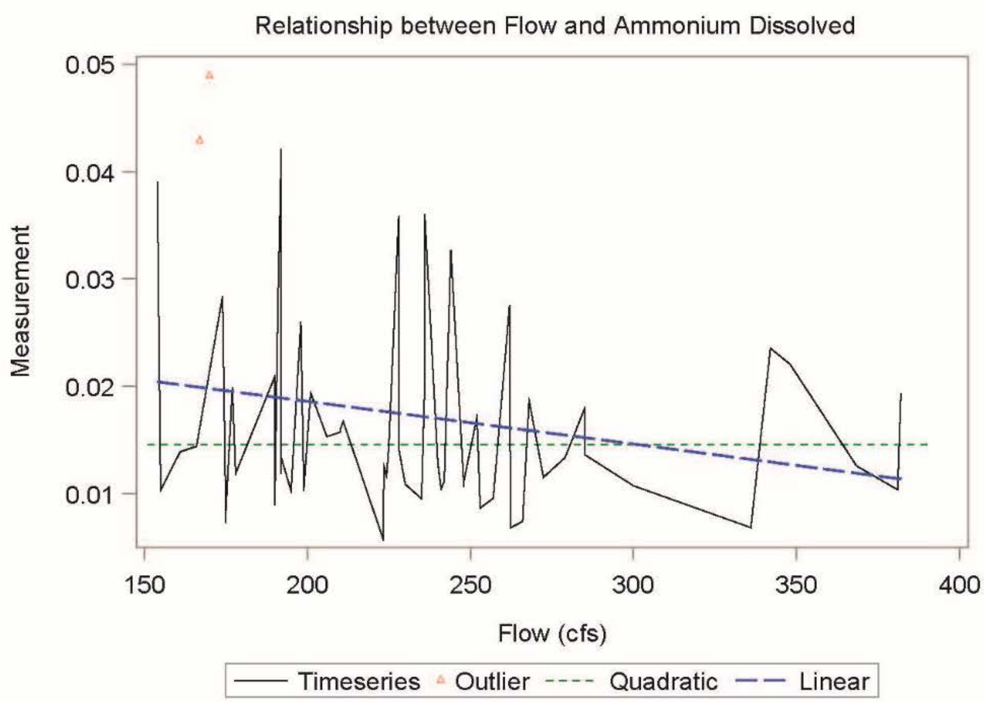
Figures 9 and 10. Time-Series of Magnesium (top), and its Relationship with Flow (bottom)





Figures 11 and 12. Time-Series of Total Ammonium (top), and its Relationship with Flow (bottom)





Figures 13 and 14. Time-Series of Dissolved Ammonium (top), and its Relationship with Flow (bottom)

Nitrate-nitrite was also reported initially as total nitrate-nitrate, switching to dissolved nitrate-nitrite after 2010. Figures 15 and 16 depict combined total and dissolved (after 2010) nitrate-nitrite and indicate a declining trend in nitrate-nitrite over time. The relationship with flow suggests that concentrations hold fairly uniform at lower range of flow, but upon reaching a certain threshold exhibit a negative relationship with flow (as exhibited by the quadratic regression).

Total Kjeldahl nitrogen (TKN) exhibited inter-annual variation, but a distinct trend over time was not indicated by the slope of the regression line (Figures 17 and 18). A visible positive relationship between TKN and flow was observed.

Total nitrogen is the sum of TKN and nitrate-nitrite. A shallow decreasing trend over time is suggested in Figures 19 and 20. As with TKN, total nitrogen exhibited a positive relationship with flow.

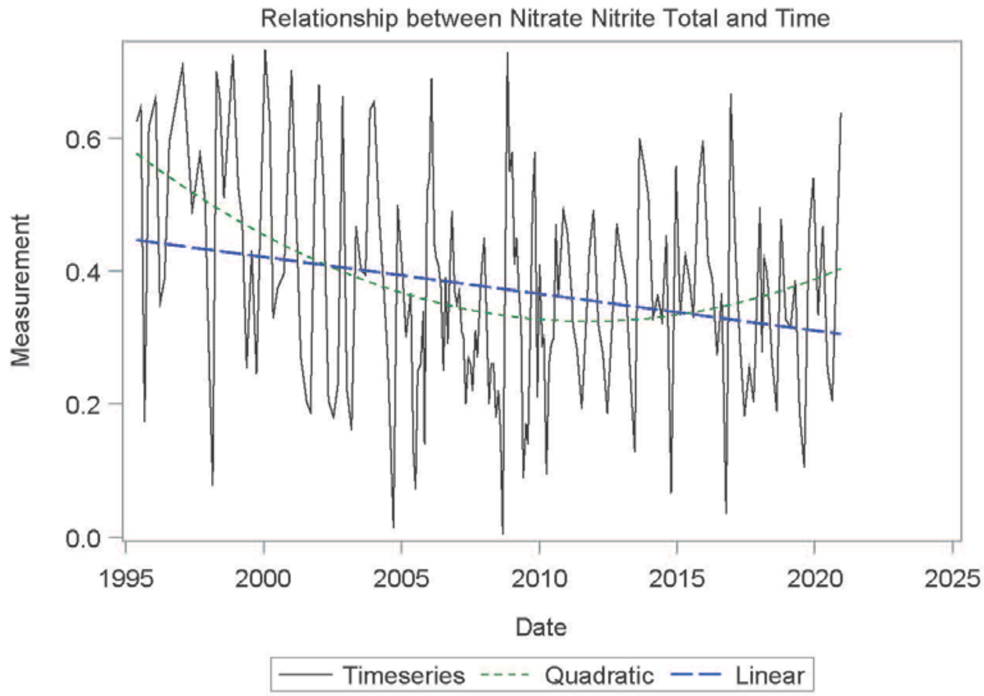
Orthophosphate was originally reported as total orthophosphate (Figures 21 and 22) and in the mid-2000s switched to being reported as dissolved orthophosphate (Figures 23 and 24). The time-series suggest that a decline in total orthophosphate may have occurred over time, but more recent measurements negate this pattern. However, the timeseries of dissolve orthophosphate suggests a decline over the past decade. The relationship of orthophosphate (both total and dissolved) with flow was negative.

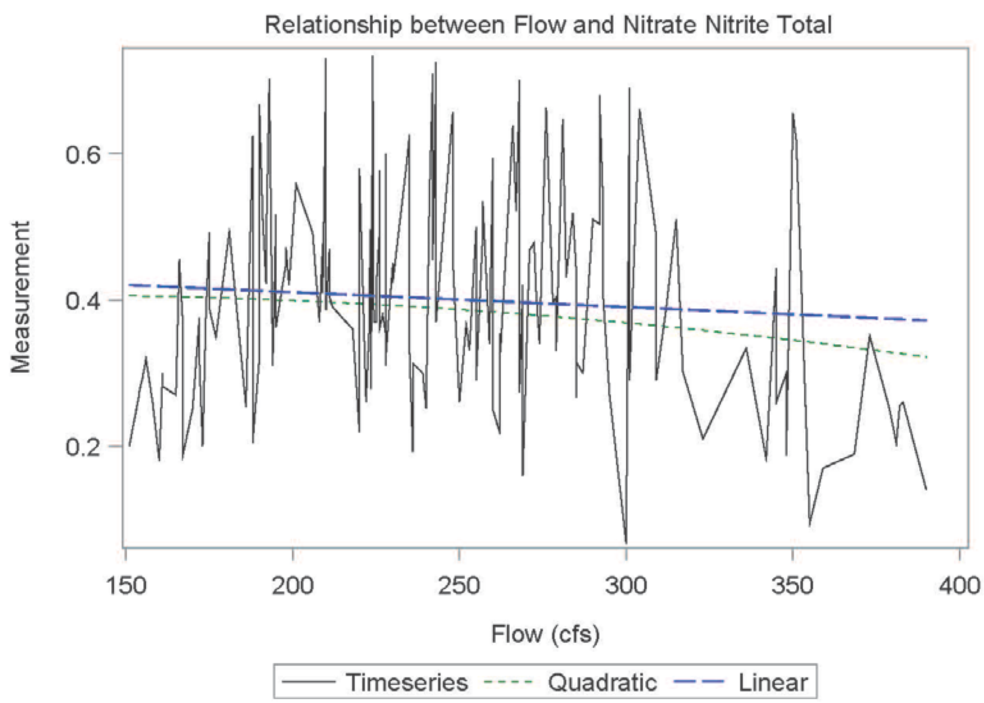
Total phosphorus values (Figures 25 and 26) did not exhibit a discernable pattern over time. A strong relationship with flow was also not apparent.

Total organic carbon values illustrated variability over the period of record, but did not exhibit a strong trend pattern over time (Figures 27 and 28). The relationship between total organic carbon and flow, however, exhibited an evident positive slope.

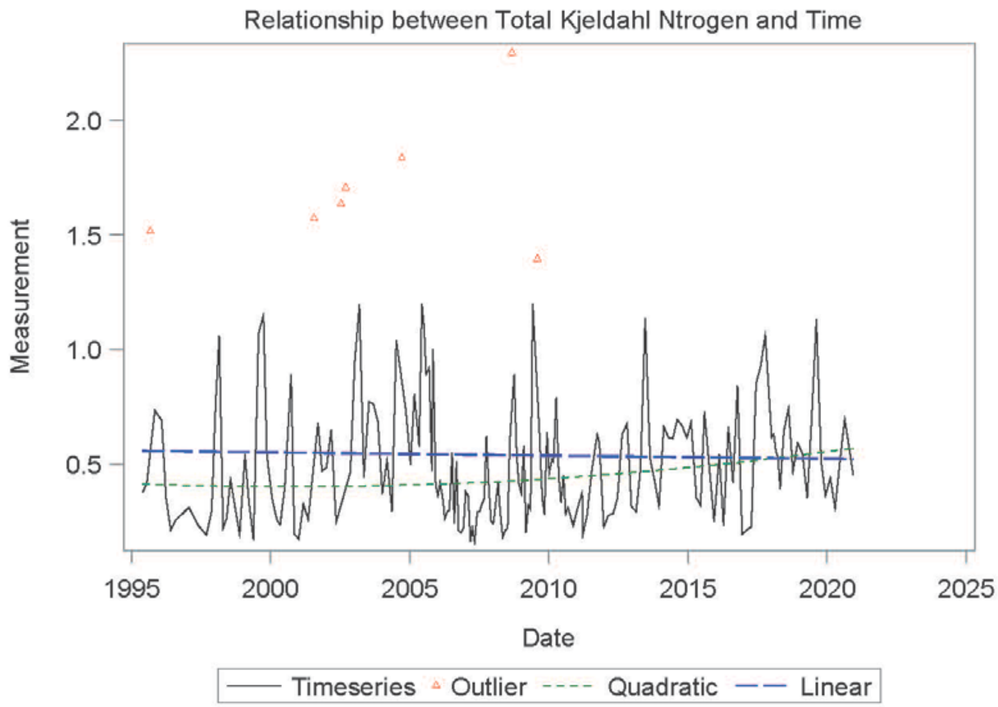
Chlorophyll (corrected for pheophytin) values were consistently lower than 5 µg/L with the exception of several outliers (Figures 29 and 30); a slight increase in concentration over time was apparent. A slight negative slope was observed in the relationship between chlorophyll concentration and flow, and the highest outliers did occur near the lower end of the flow range. However, outlier values were observed across the range of flow.

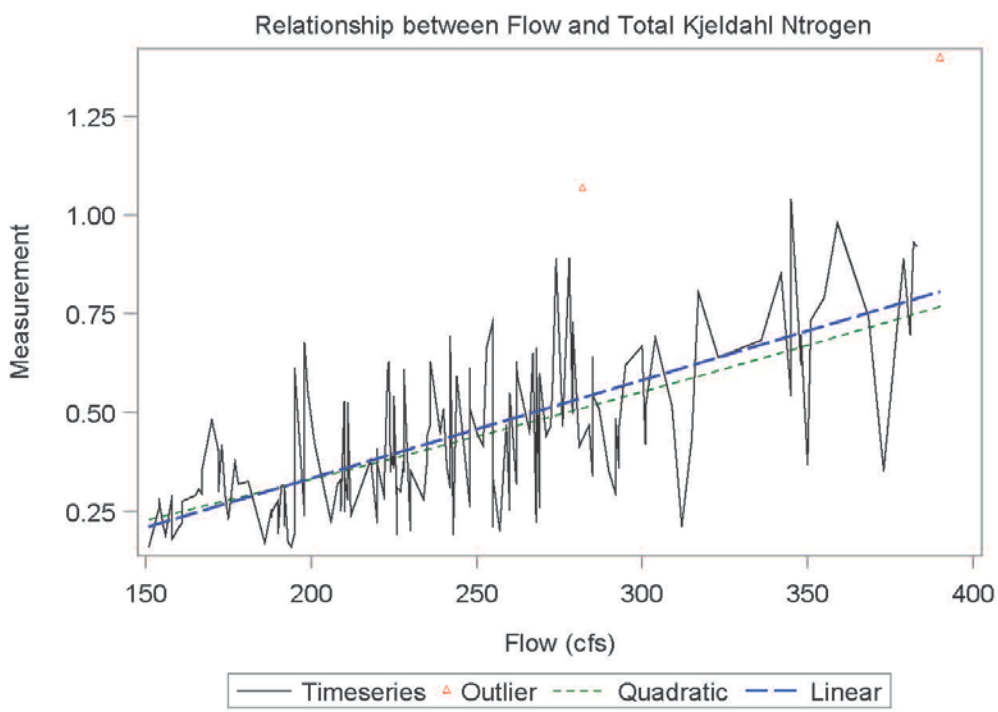
Conductivity displayed both inter- and intra-annual variability over time (Figures 31 and 32). Overall, conductivity appeared to illustrate a slight decreasing trend over the period of record. A narrower range of values were observed between 2008 and 2012. Conductivity displayed a negative relationship with flow.



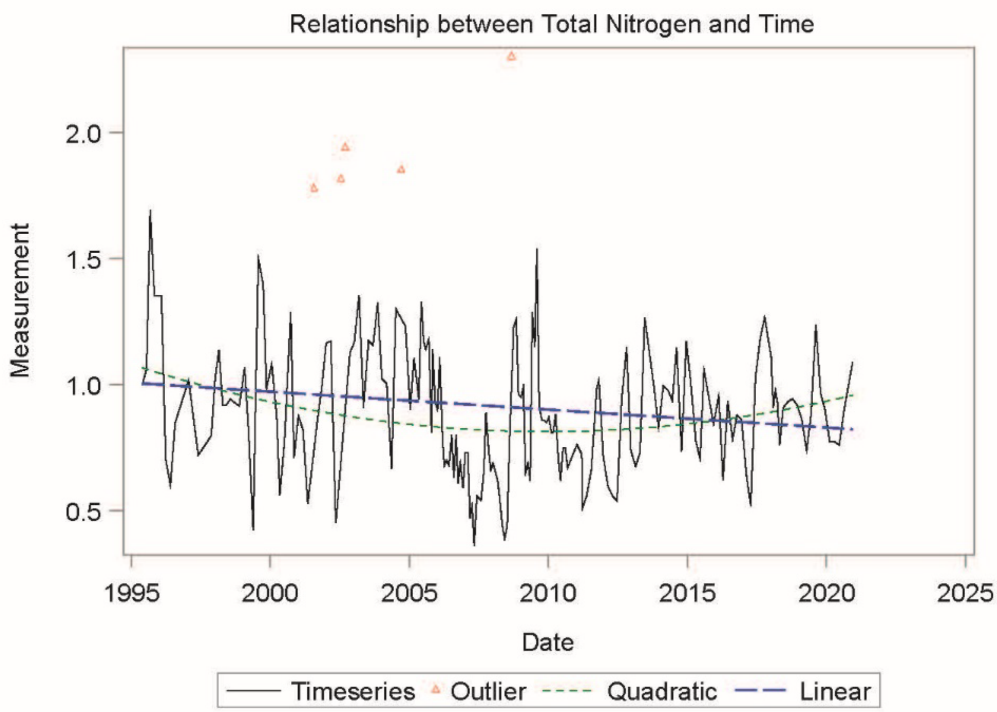


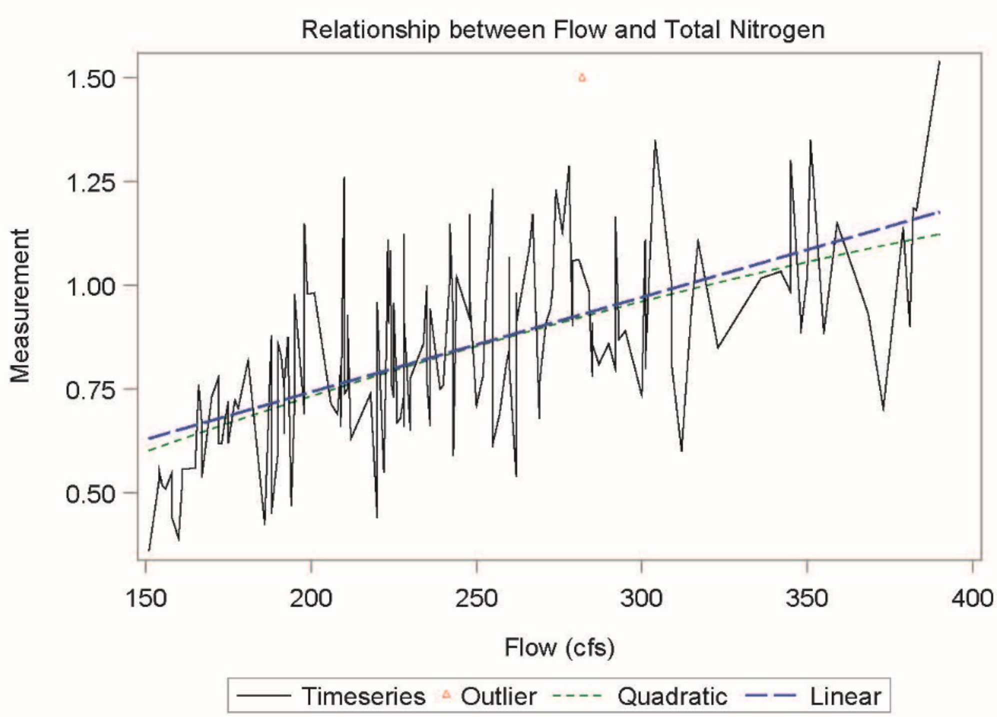
Figures 15 and 16. Time-Series of Nitrate-Nitrite (top), and its Relationship with Flow (bottom)



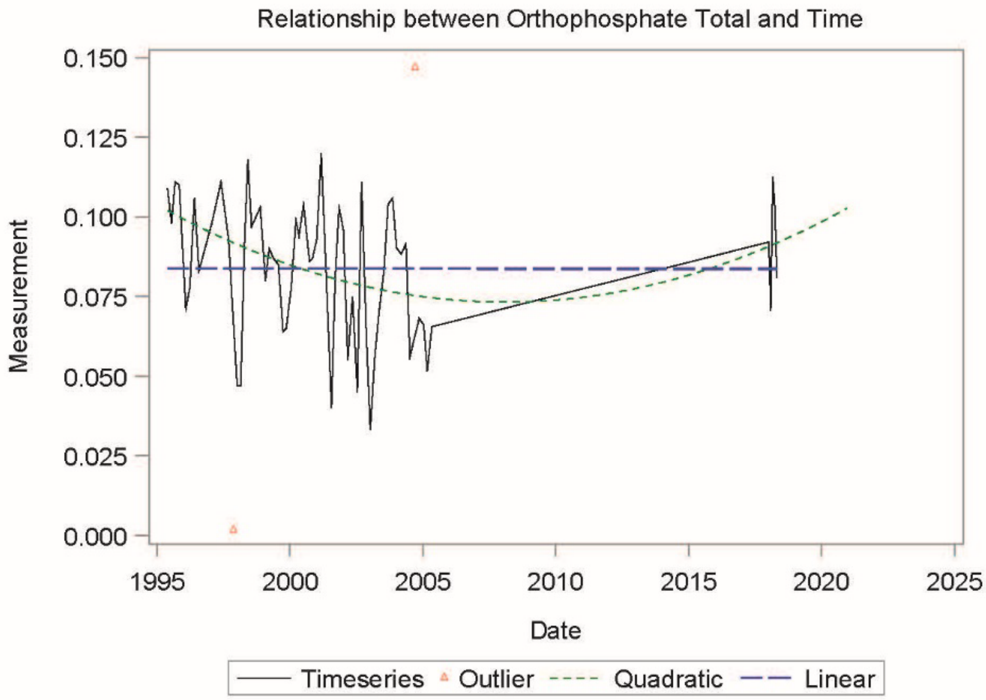


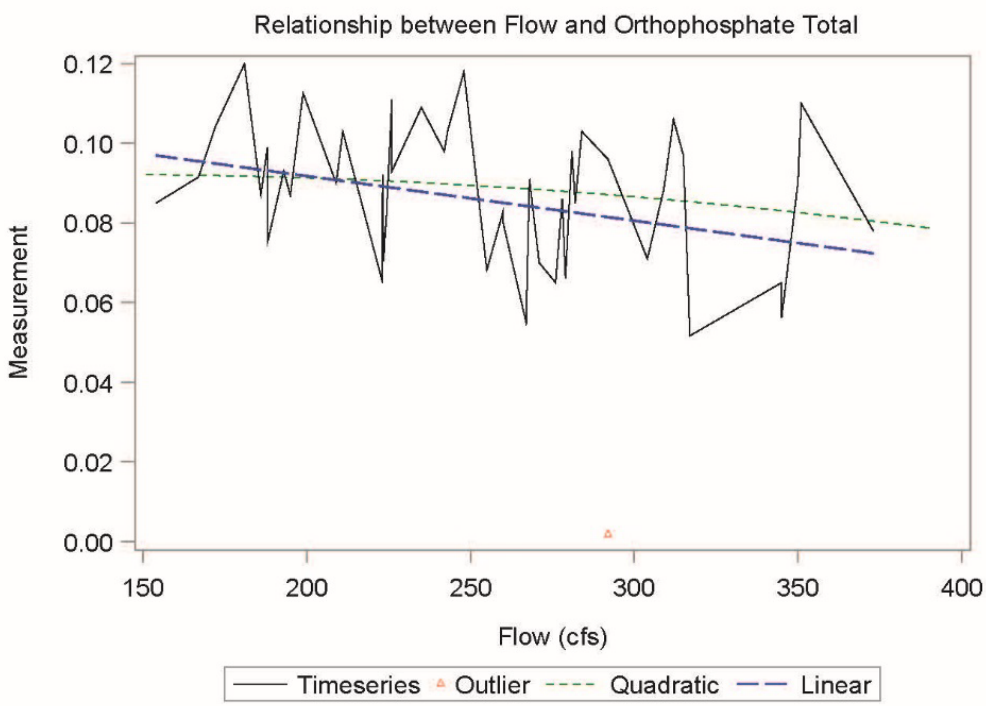
Figures 17 and 18. Time-Series of TKN (top), and its Relationship with Flow (bottom)



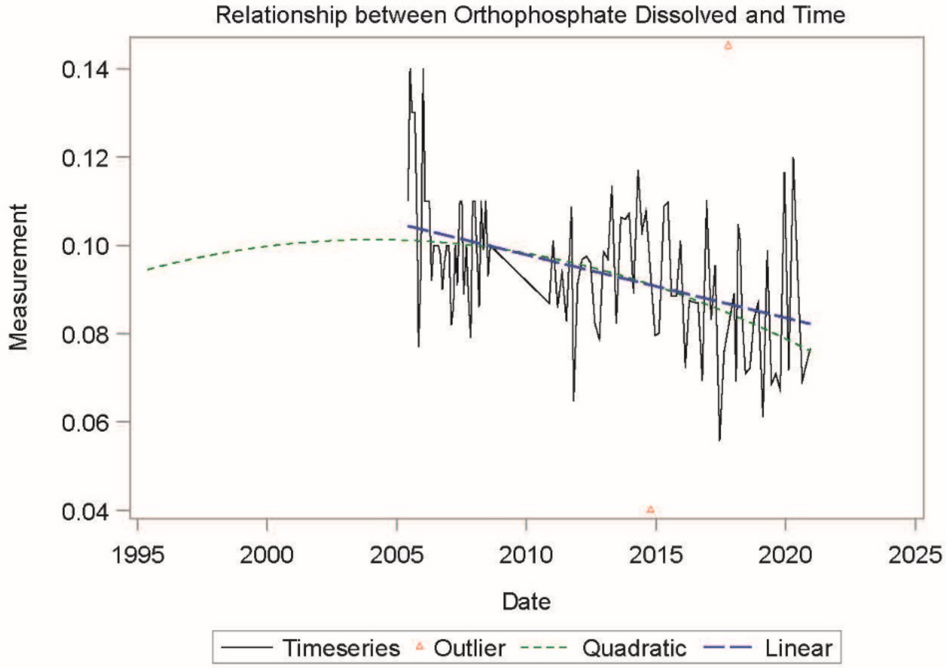


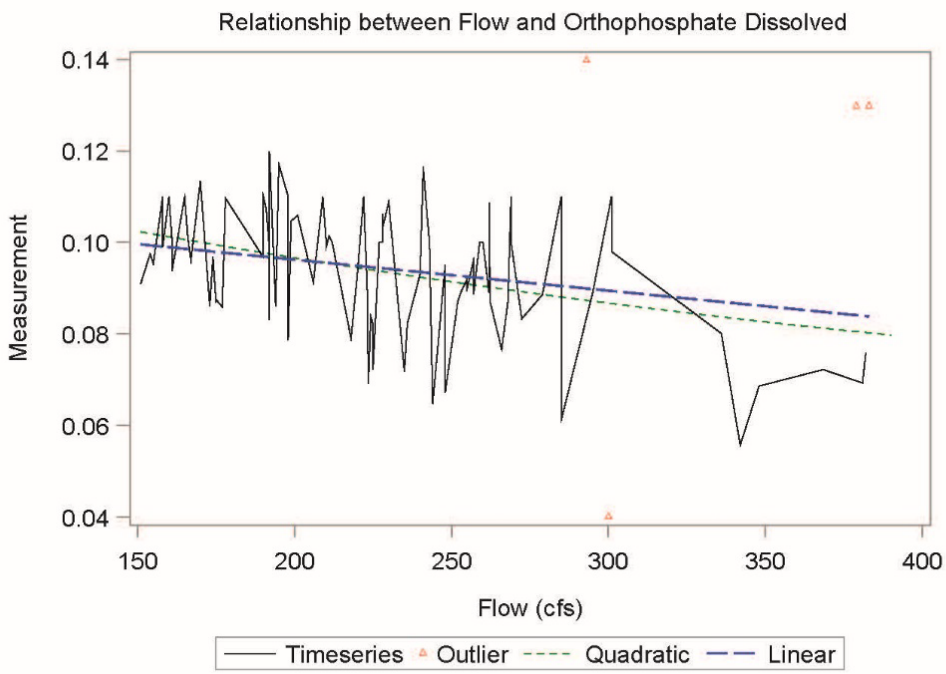
Figures 19 and 20. Time-Series of TN (top), and its Relationship with Flow (bottom)



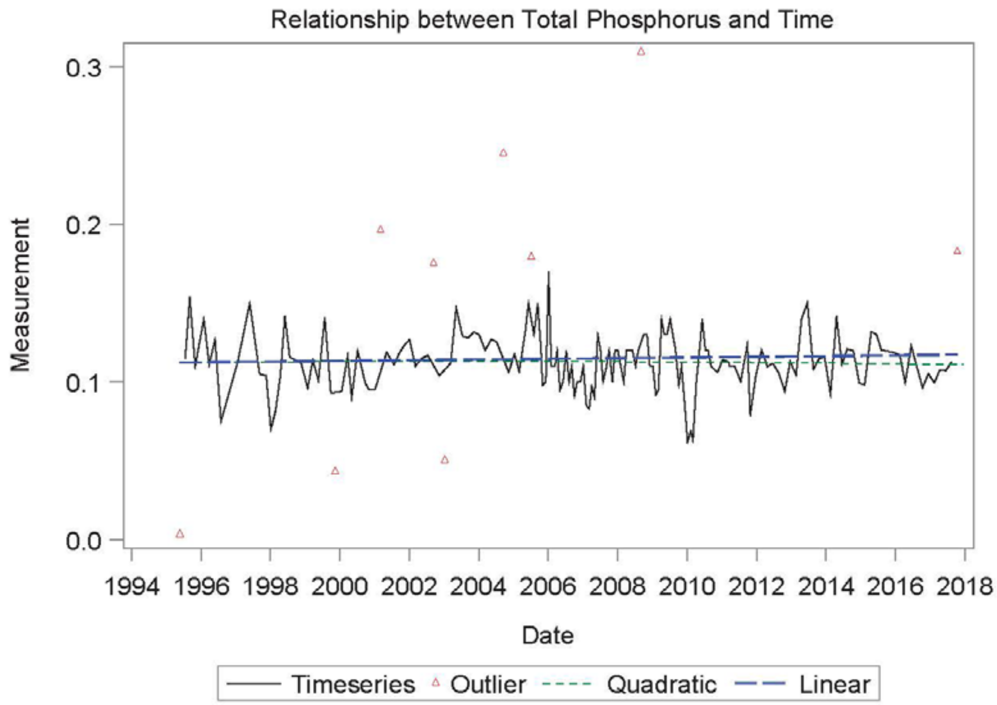


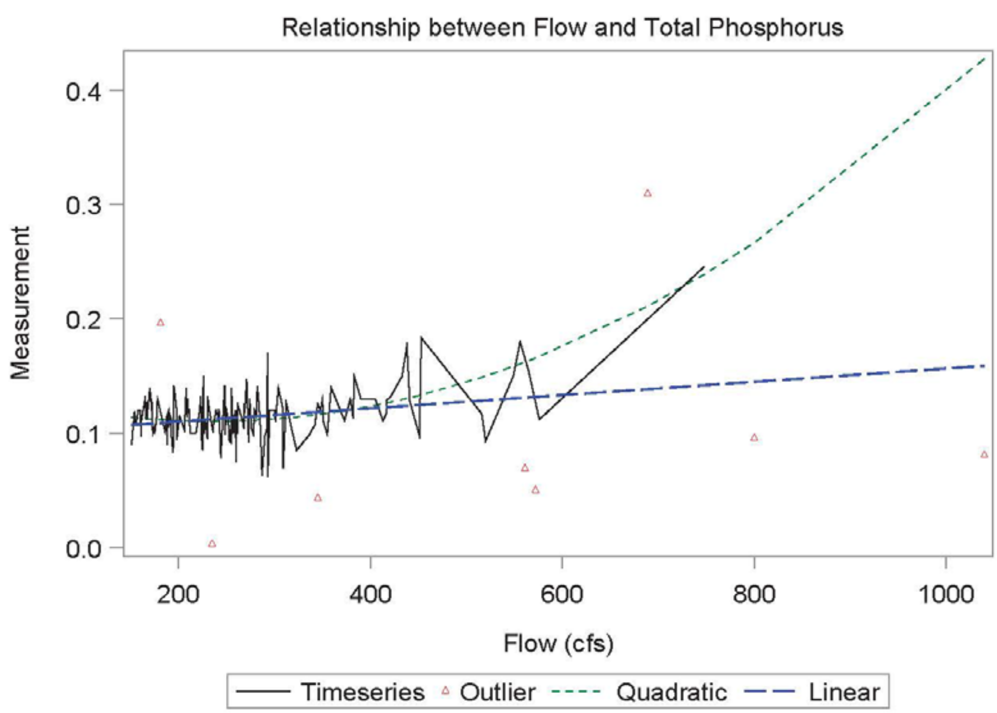
Figures 21 and 22. Time-Series of Total Orthophosphate (top), and its Relationship with Flow (bottom)



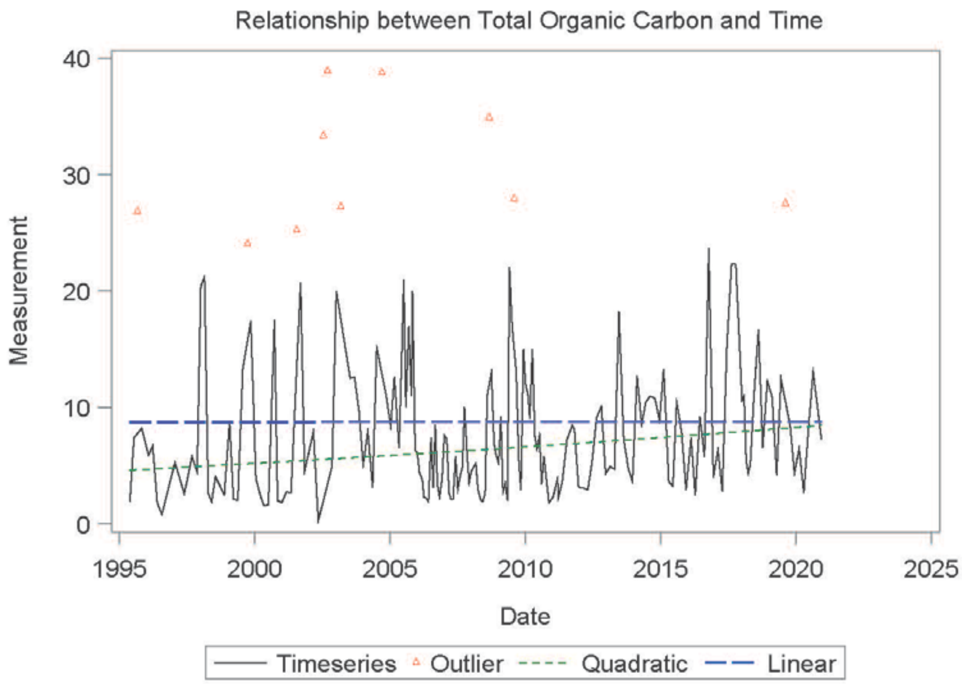


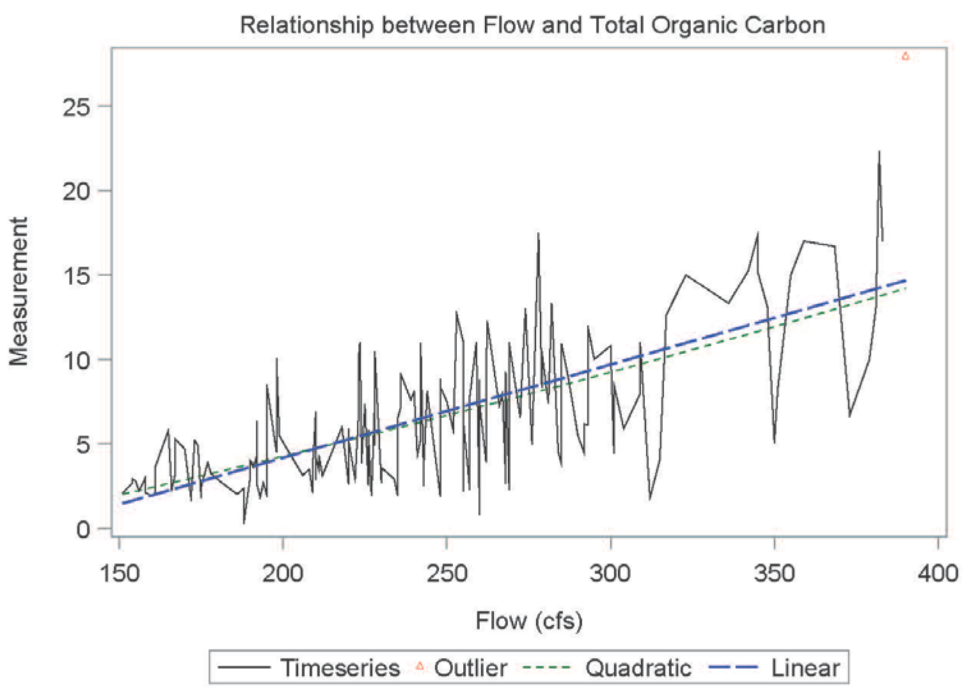
Figures 23 and 24. Time-Series of Dissolved Orthophosphate (top), and its Relationship with Flow (bottom)



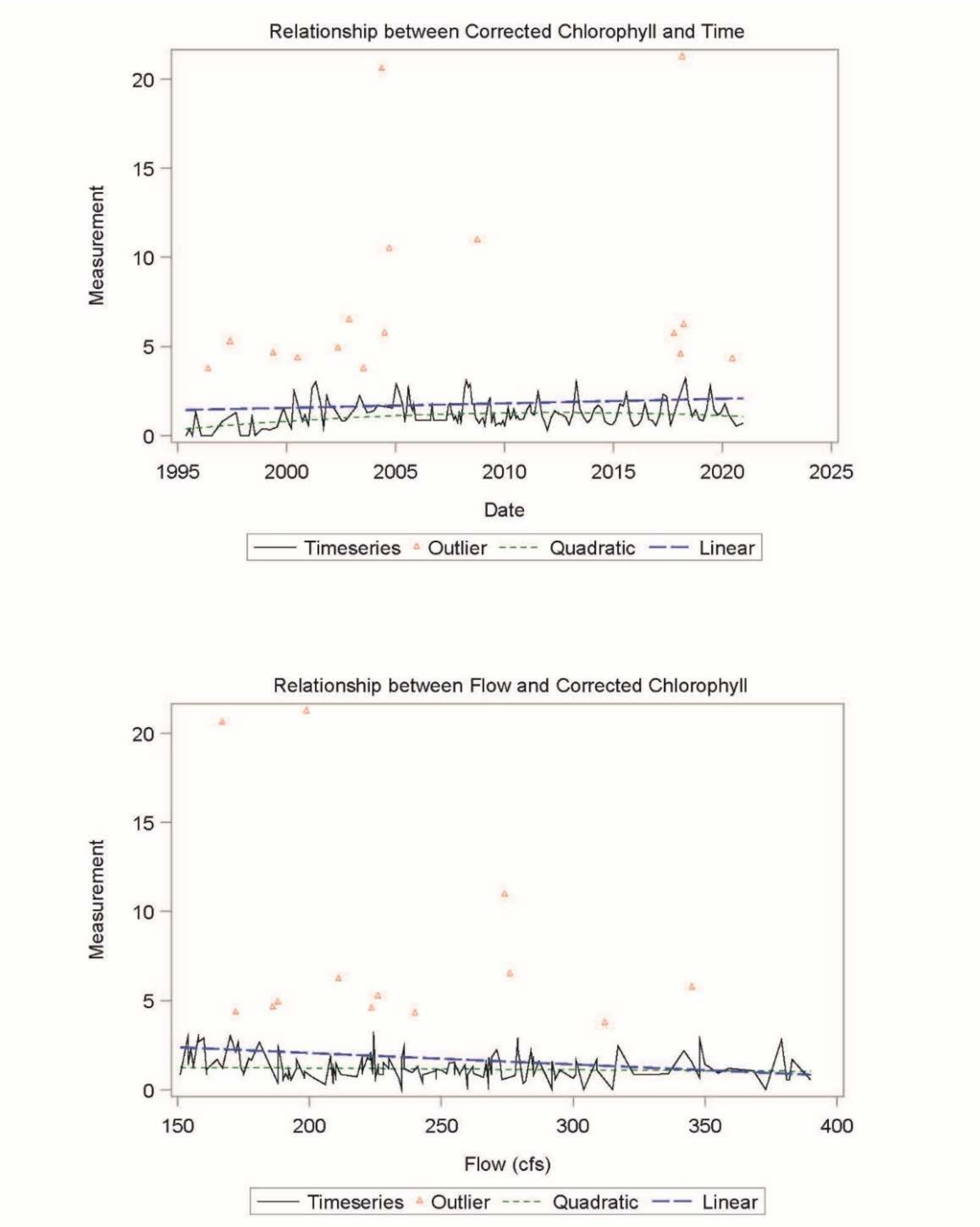


Figures 25 and 26. Time-Series of Total Phosphorus (top), and its Relationship with Flow (bottom)

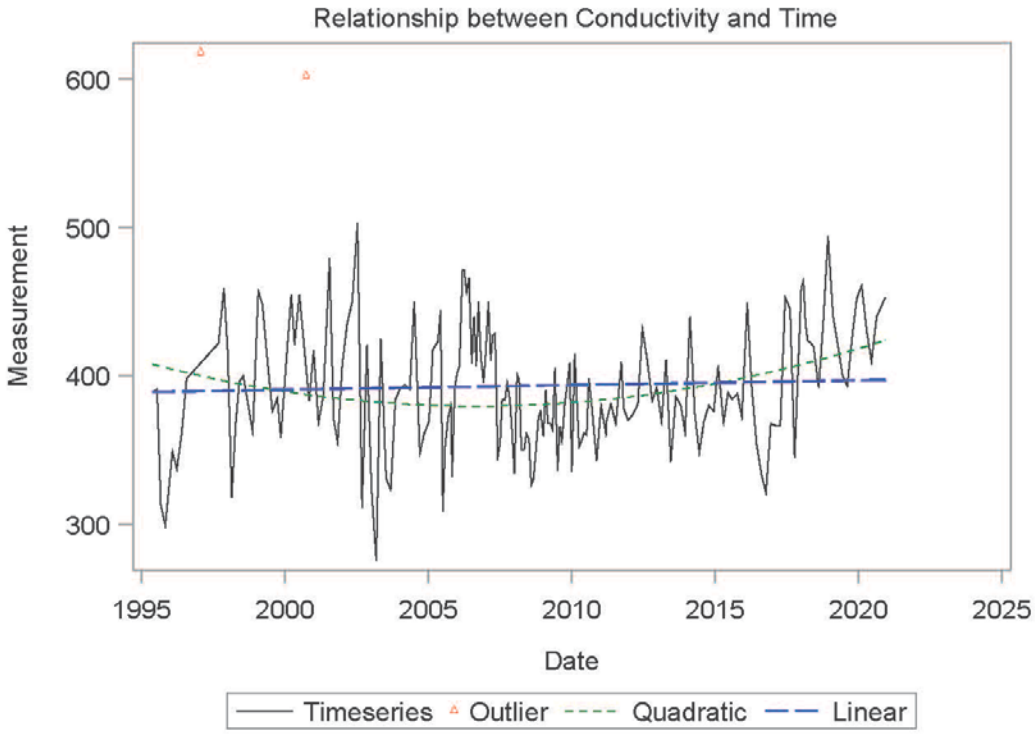


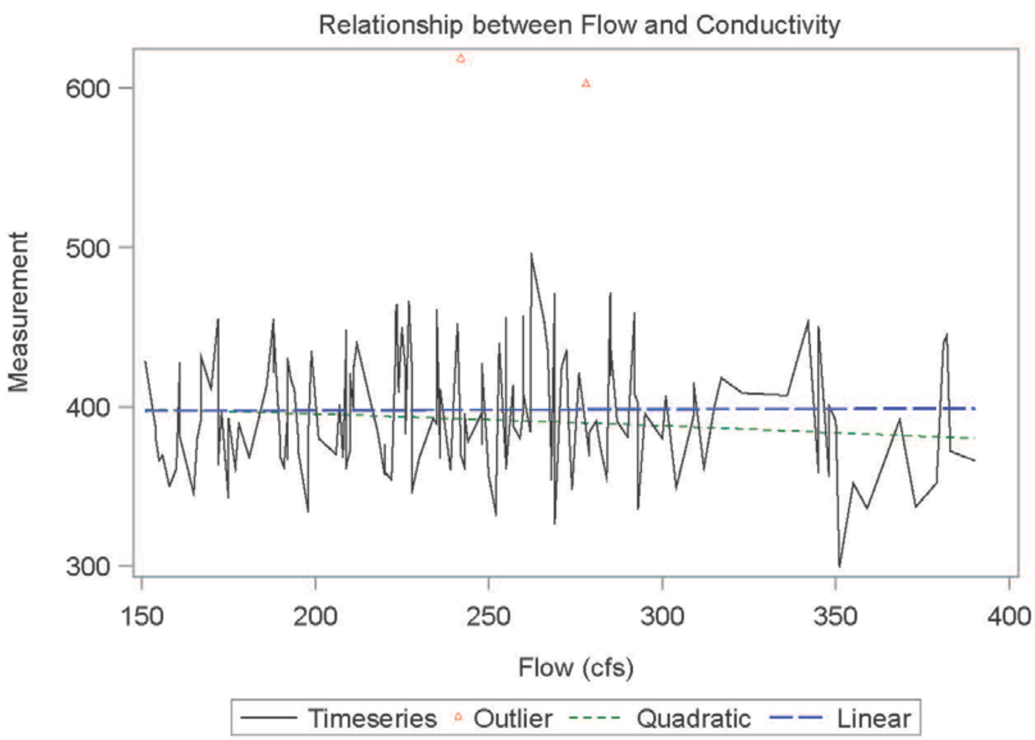


Figures 27 and 28. Time-Series of Total Organic Carbon (top), and its Relationship with Flow (bottom)



Figures 29 and 30. Time-Series of Corrected Chlorophyll (top), and its Relationship with Flow (bottom)





Figures 31 and 32. Time-Series of Conductivity (top), and its Relationship with Flow (bottom)

Dissolved oxygen, both in terms of concentration (Figures 33 and 34) and percent saturation (Figures 35 and 36) exhibited intra-annual variation, but overall a declining trend over time was observed. A negative relationship with flow was also apparent.

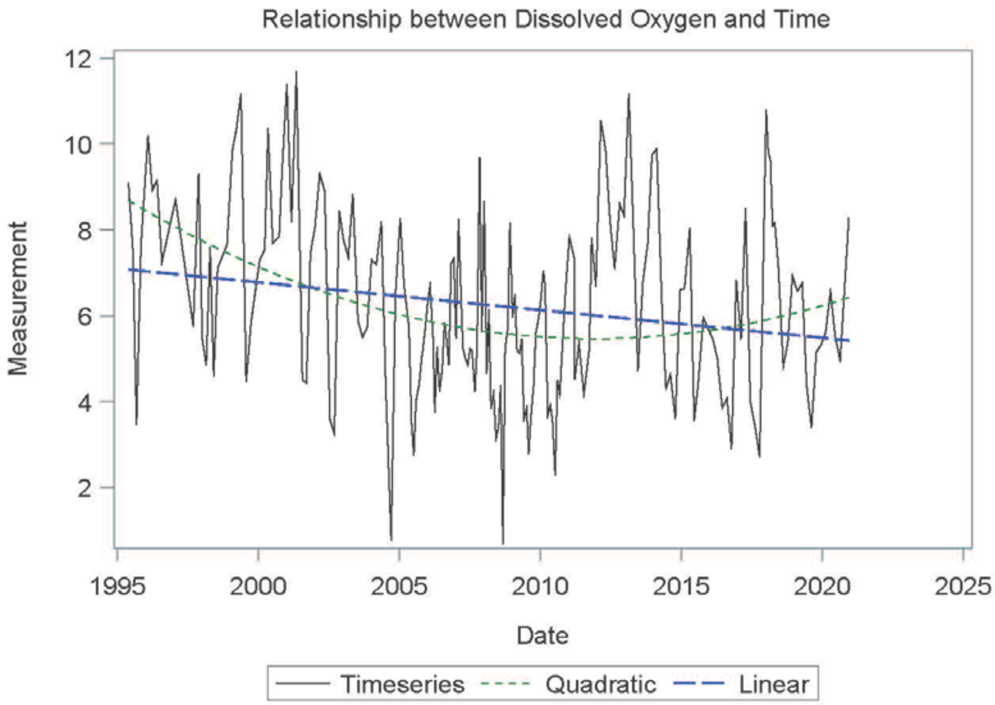
Total dissolved solids (TDS) values were no longer recorded after 2011 (Figures 37 and 38). The time-series plot suggested a slight declining pattern over time. An investigation of the relationship between TDS and flow suggested that at the range of flows plotted there is a positive relationship, Values for flows greater than roughly 350 cfs, however, appear to be lower and suggest that flows greater than 350 cfs might be correlated with lower TDS.

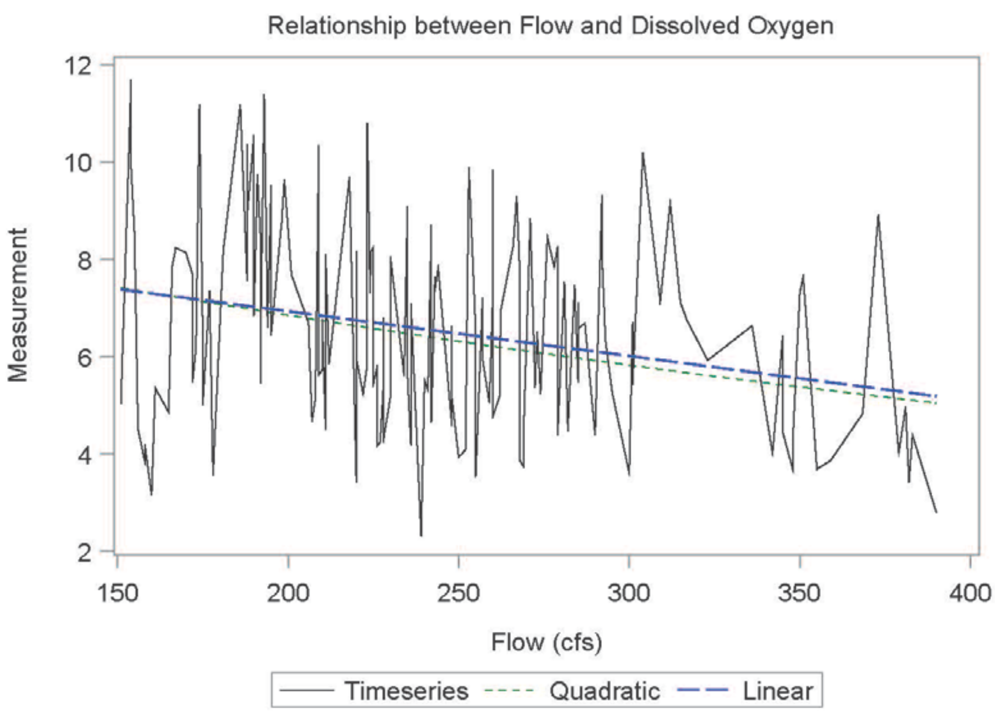
Total suspended solids illustrated a declining pattern over time, though high outlier values occurred over the period of record (Figures 39 and 40). A positive relationship with flow was suggested by the regression.

Turbidity values (Figures 41 and 42) also illustrated a declining pattern over the period of record. Additionally, both the quadratic and linear regressions indicated a positive relationship with flow.

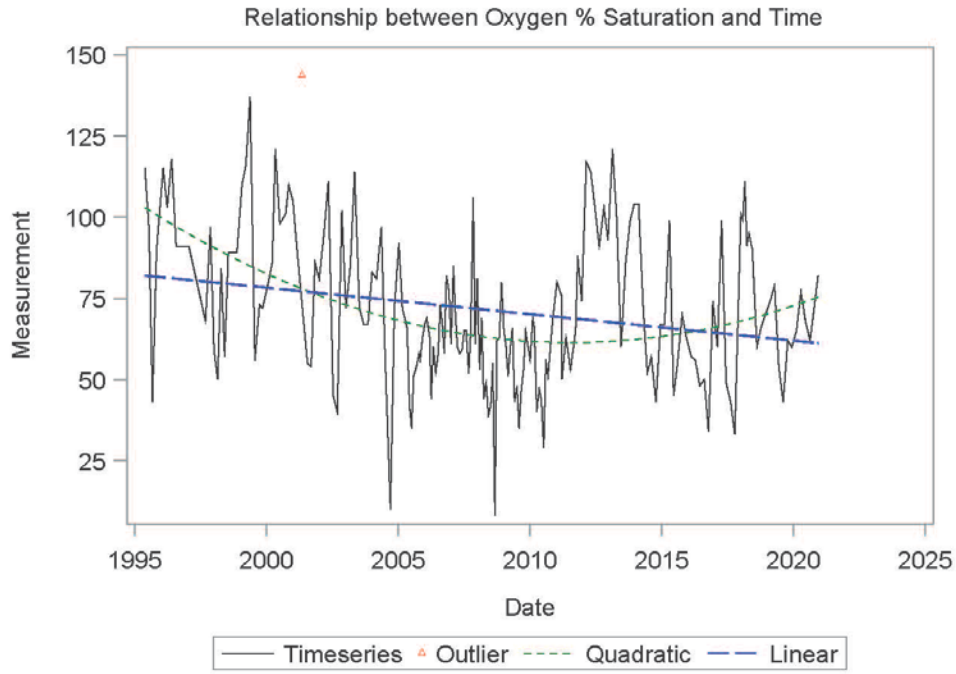
Color values (Figures 43 and 44) showed a slight decrease over time, and the larger outlier values appeared prior to 2005. There was a gap in available data between 2006 and 2011. The flow plot illustrates a positive relationship between color and flow.

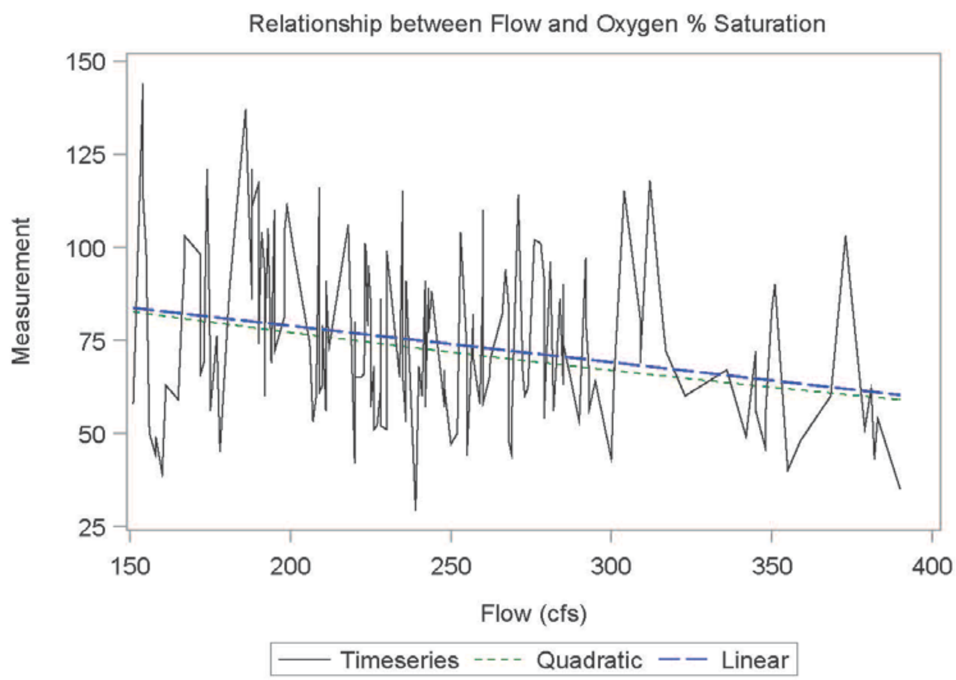
Secchi depth values indicated a decreasing linear trend over time (Figures 45 and 46); the quadratic regression suggests that Secchi values initially increased over time until values started to even out and then decline. A negative relationship with flow was suggested. This is not surprising as other parameters affecting water clarity (color, total suspended solids, turbidity, etc.) had positive relationships with flow indicating lesser visibility with increasing flow.



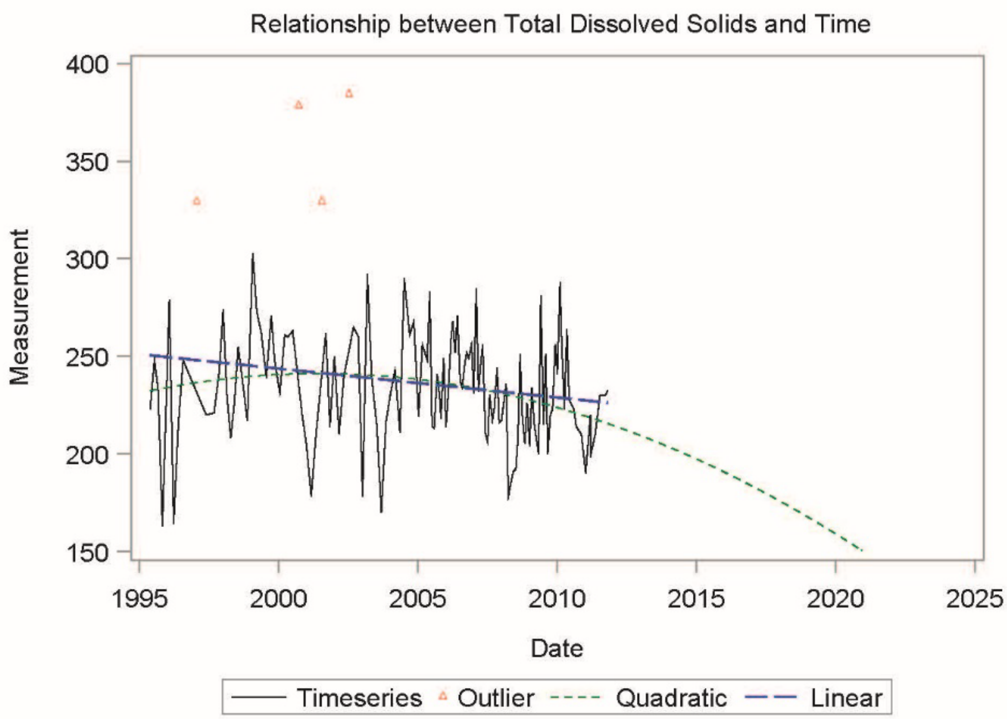


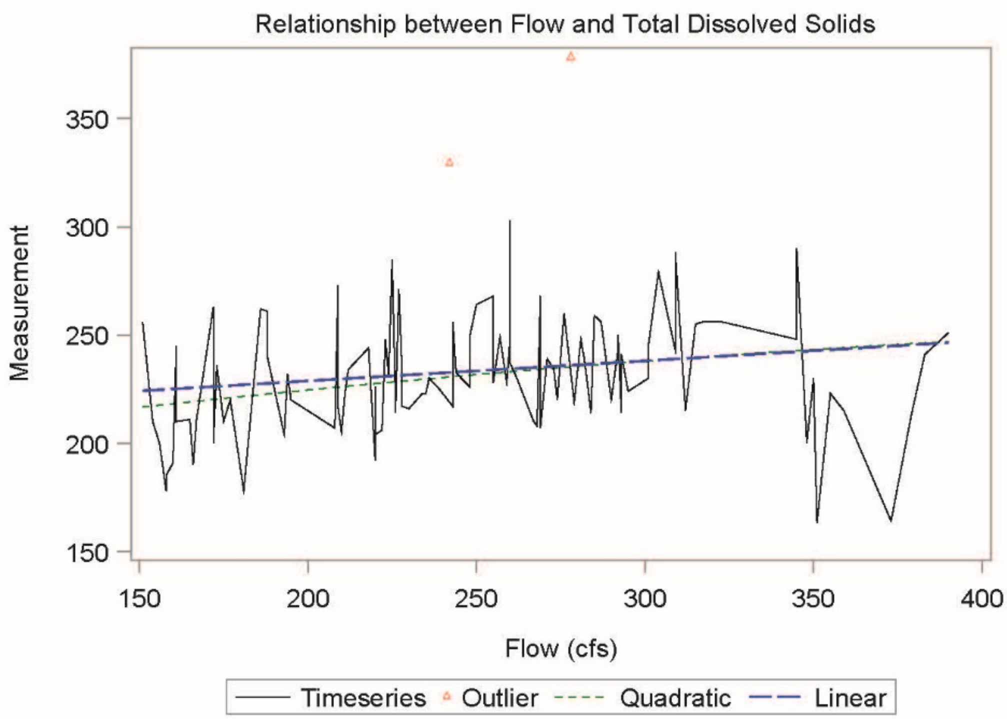
Figures 33 and 34. Time-Series of dO Concentration (top), and its Relationship with Flow (bottom)



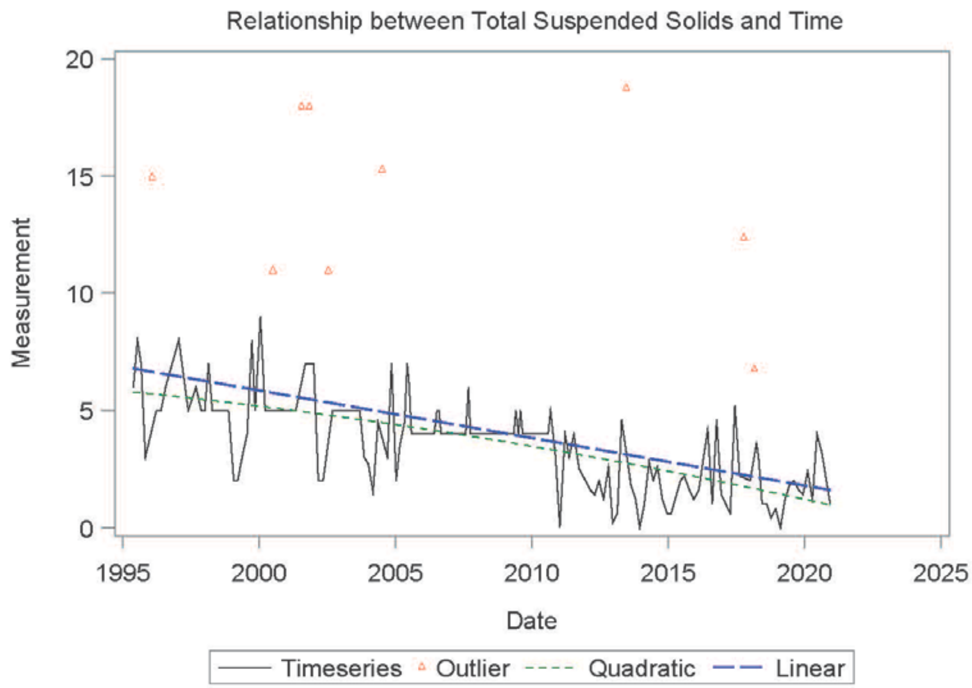


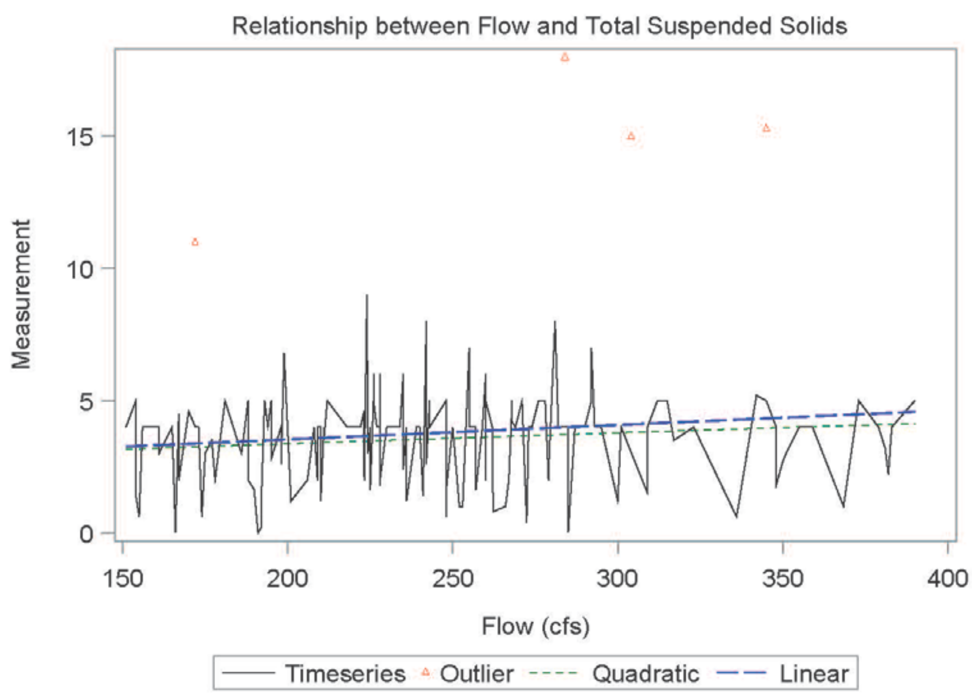
Figures 35 and 36. Time-Series of dO Percent Saturation (top), and its Relationship with Flow (bottom)



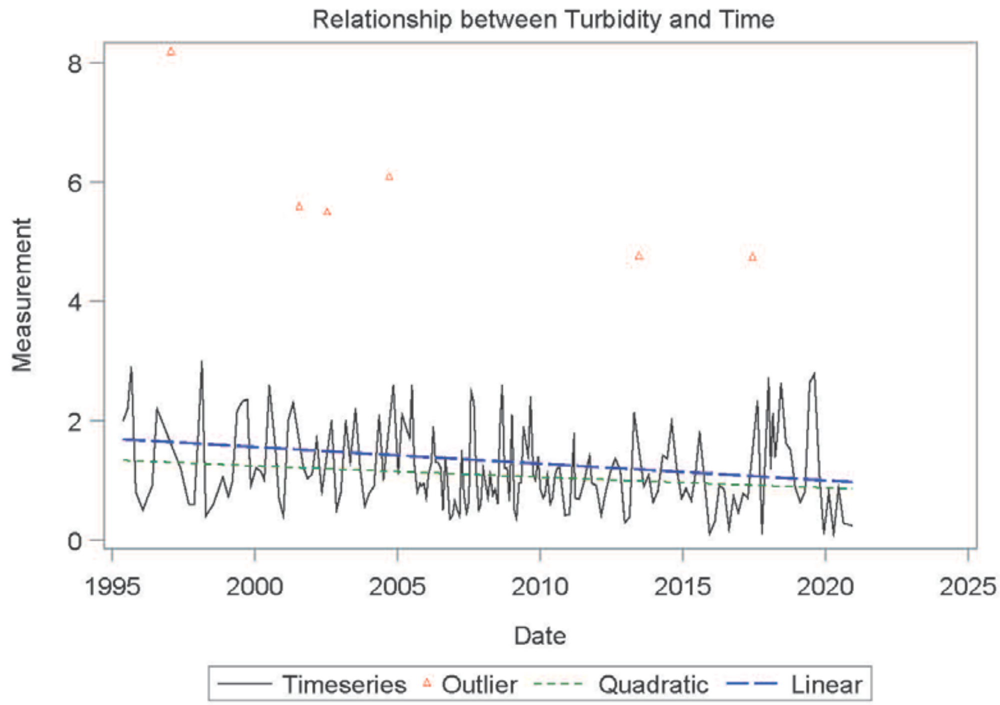


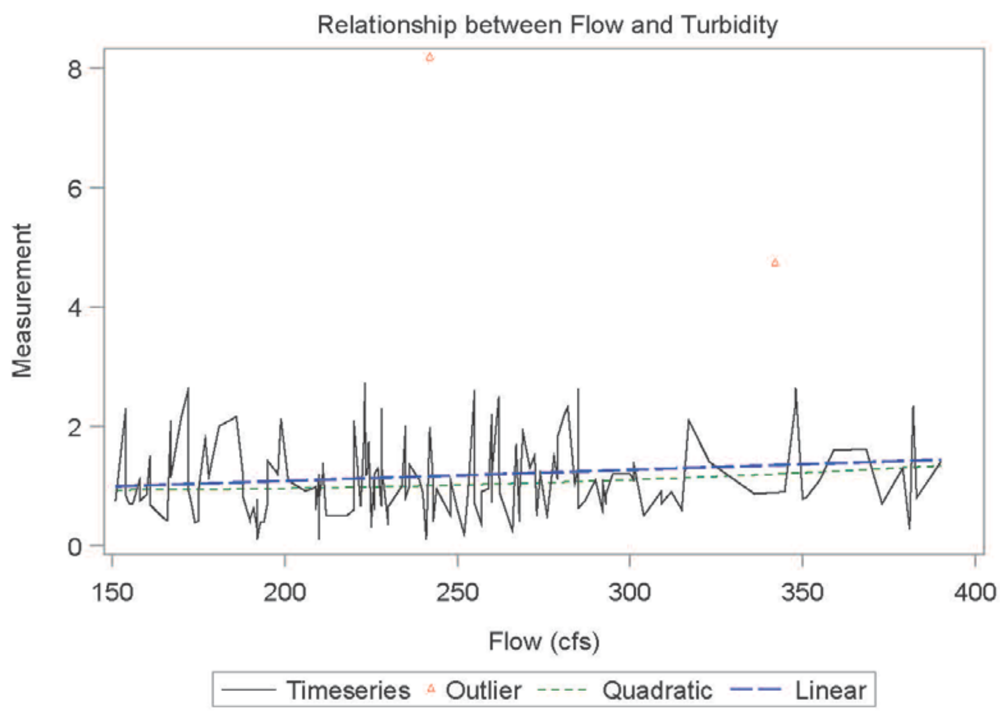
Figures 37 and 38. Time-Series of TDS (top), and its Relationship with Flow (bottom)



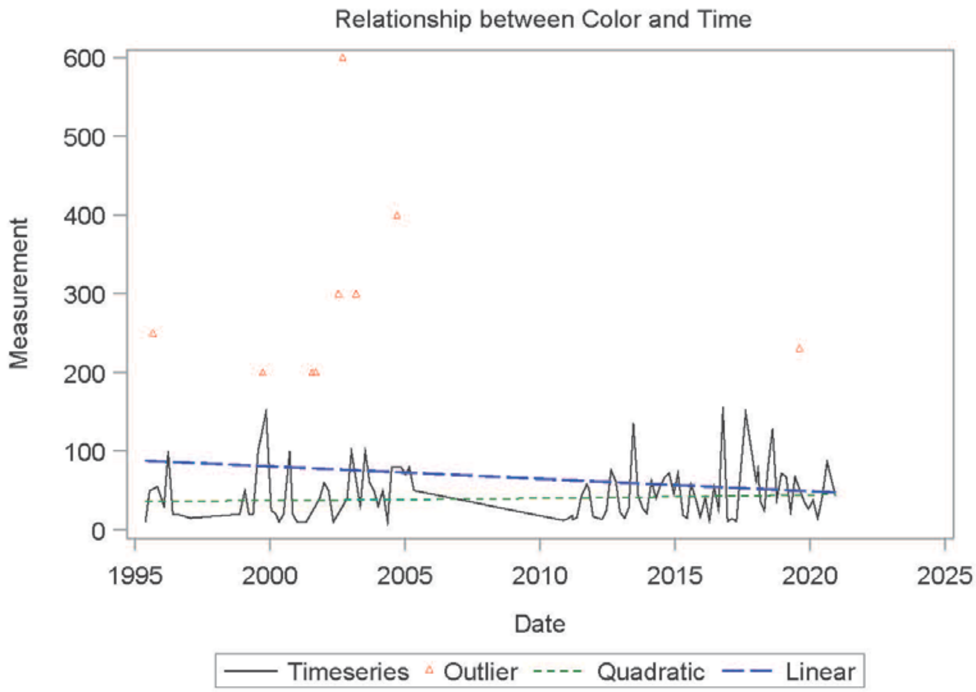


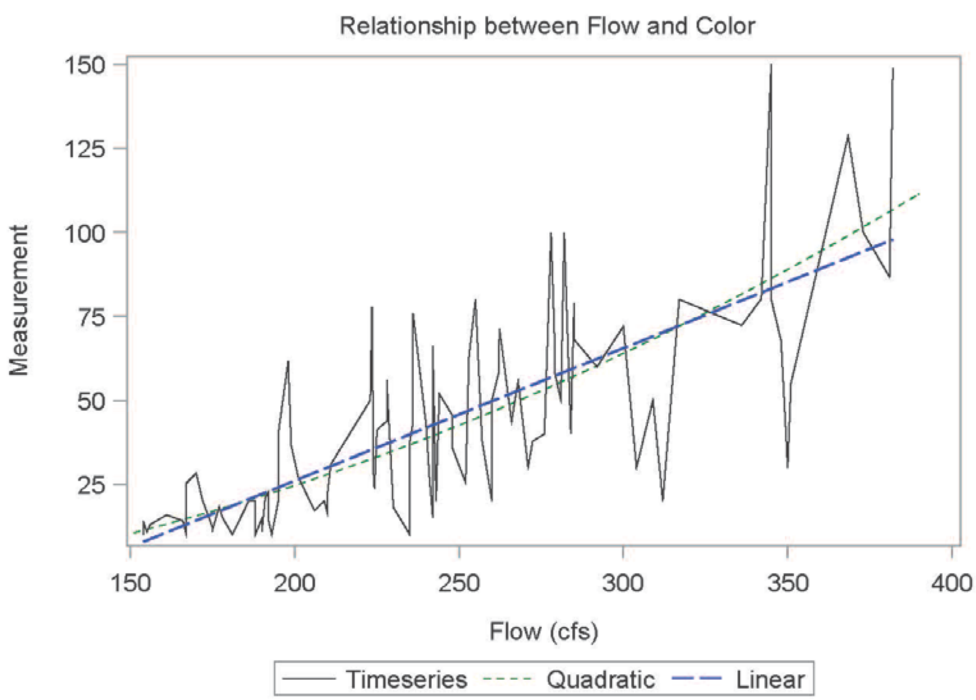
Figures 39 and 40. Time-Series of TSS (top), and its Relationship with Flow (bottom)



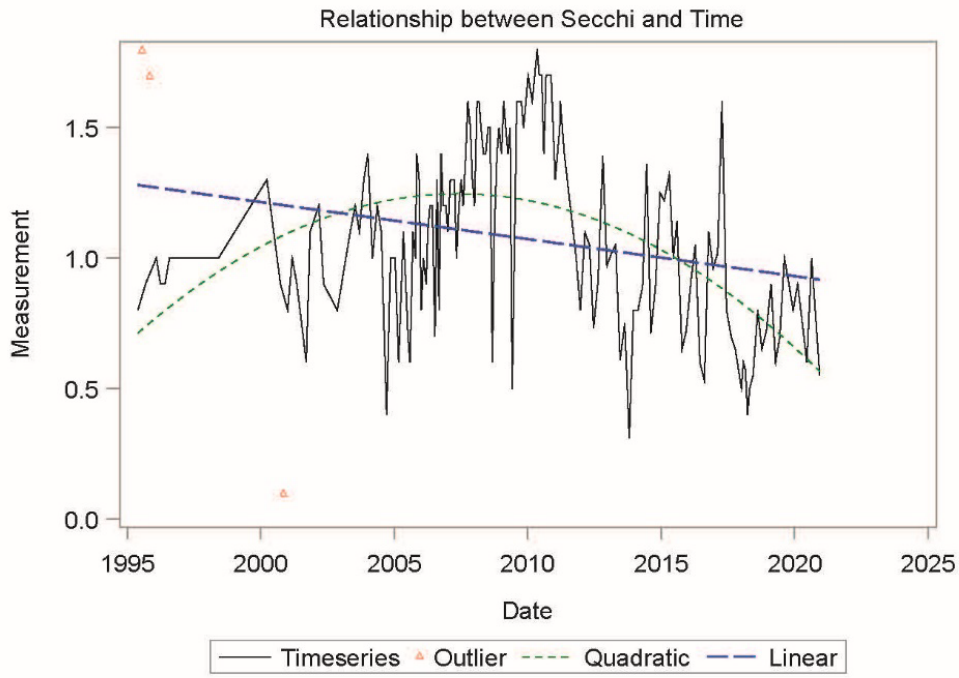


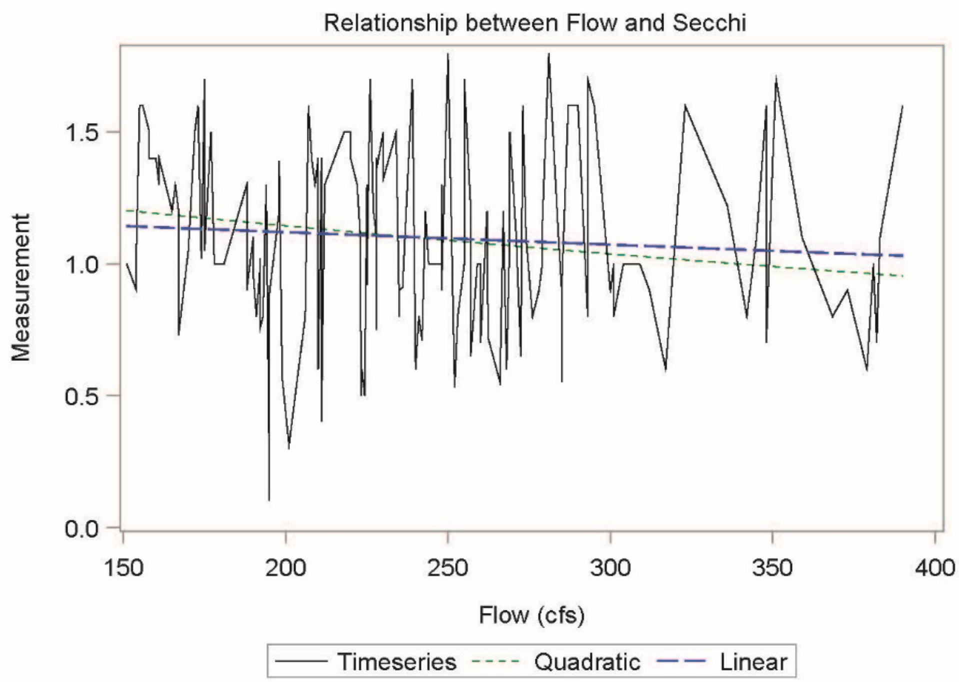
Figures 41 and 42. Time-Series of Turbidity (top), and its Relationship with Flow (bottom)





Figures 43 and 44. Time-Series of Color (top), and its Relationship with Flow (bottom)





Figures 45 and 46. Time-Series of Secchi Depth (top), and its Relationship with Flow (bottom)

Wekiwa Springs

The data used for the Wekiwa Springs analyses were obtained from the Wekiwa Springs gage 00371831 (Wekiwa Springs at Altamonte Springs). Data for Wekiwa Springs span a period from 1931 to 2020; however, sampling was infrequent prior to 1968 and semi-monthly to monthly from 1968 to 1997. More regular sampling began in late 1998. The top figure in each pair provides a time series plot over the possible 1956-2020 time period (note, the period-of-record differs amongst parameters).

Alkalinity (Figures 47 and 48) exhibited a cyclical up and down pattern over time, but with an overall increasing trend indicated by the positive slope of the linear regression line. Alkalinity overall decreased with increasing flow values. The cyclical pattern over time may therefore be related to seasonal patterns in flow.

Chloride values displayed intra- and inter-annual variation, but overall increased over time (Figures 49 and 50), with a doubling in magnitude from the 1950s to 2020. At higher levels of flow (greater than 65 cfs), chloride levels declined with increasing flow. Most of the data were collected in 1990 and later, a period when flows were largely less than or equal to 65 to 70 cfs.

Similar to chloride, sulfate values also increased over time and exhibited a declining pattern at higher flows (Figures 51 and 52). Additionally, as with chloride, sulfate values doubled over the period-of-record. The increase in sulfate and chloride over the period-of-record is concurrent with a declining pattern in flows over a similar period.

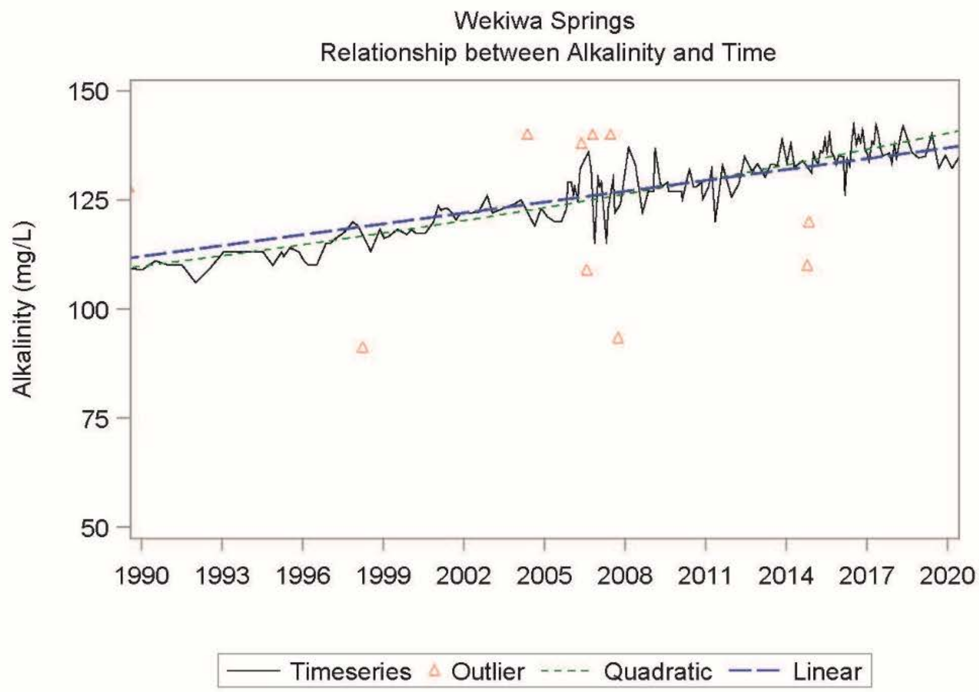
Nitrate-nitrite values have been reported as both total and dissolved. These are plotted separately in Figures 53 and 54 and Figures 55 and 56, respectively. Nitrate+nitrite levels appear to have decreased since the 1990s, but the time series indicate a leveling off in the last decade or so. Both dissolved and total nitrate+nitrite exhibit a positive relationship with flow. Flows have also been relatively consistent for the past decade after having decreased earlier in the period-of-record.

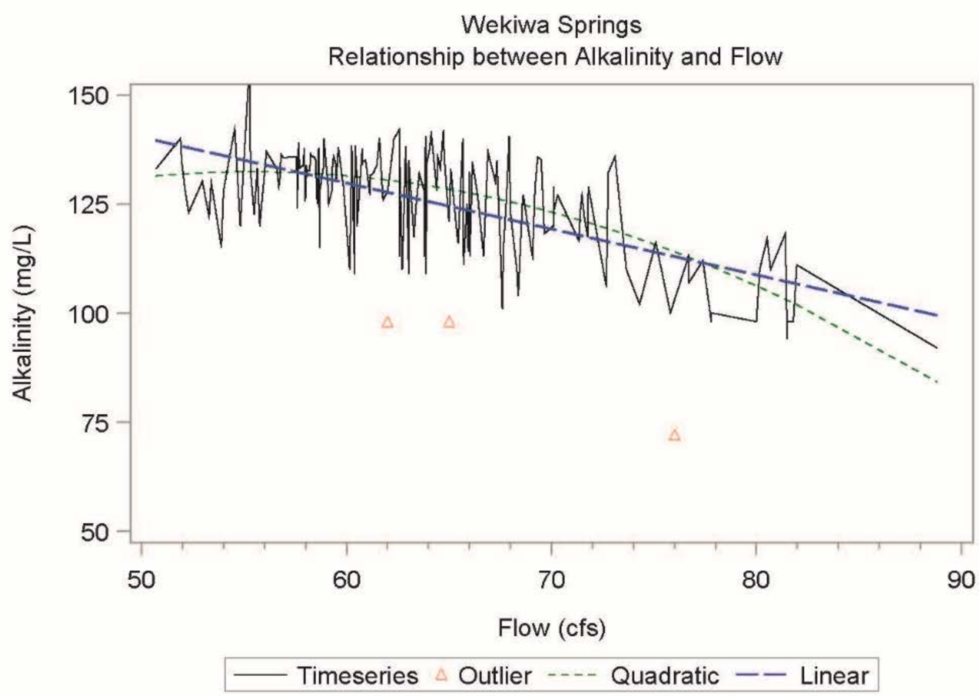
Total Kjeldahl nitrogen (TKN) has varied within a relatively narrow range over the past decade in Wekiwa Springs, with no overall trend over time (Figures 57 and 58). Conversely to NO2NO3, TKN exhibited a slight negative relationship with flow, but the slope of the line is shallow. The slope is weighed by relatively few points in the higher range of flows, which have been infrequent in the past decade.

Total nitrogen is calculated as the sum of NO2NO3 and TKN. As the values of NO2NO3 are of greater magnitude than TKN, the patterns illustrated by TN more closely match those of nitrate+nitrite. A slight increase over time is suggested, and a positive relationship with flow is apparent (Figures 59 and 60).

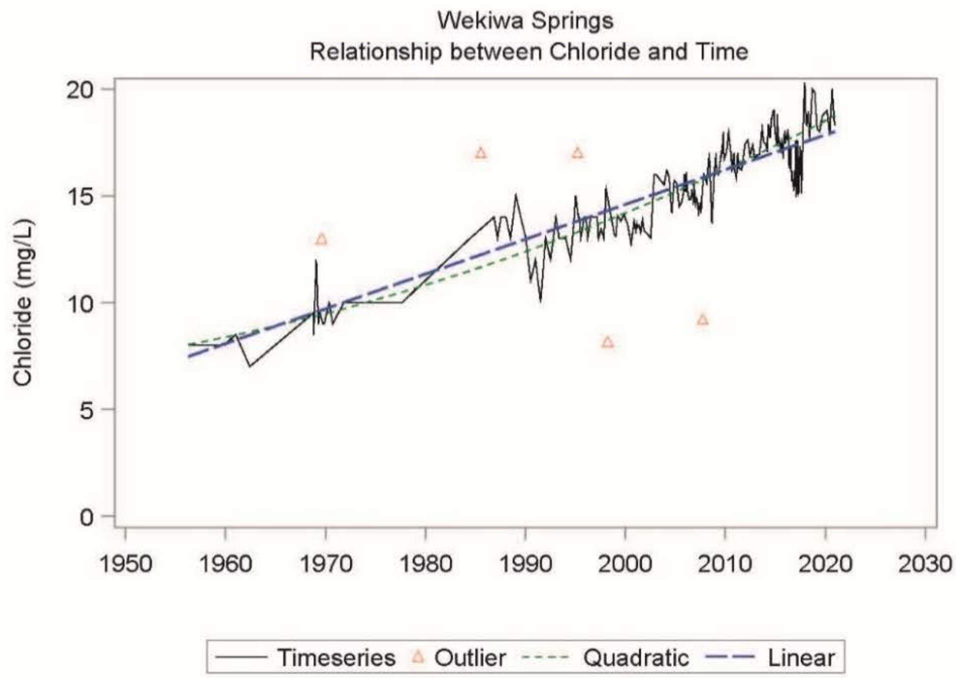
Orthophosphate values have also been reported as both dissolved (Figures 61 and 62) and total (Figures 63 and 64). Both forms appear to vary over a very narrow range of values, with a low-slope positive relationship to flow. Flows for the last decade have been relatively consistent and thus may indicate why there has been little variability in orthophosphate over the last decade.

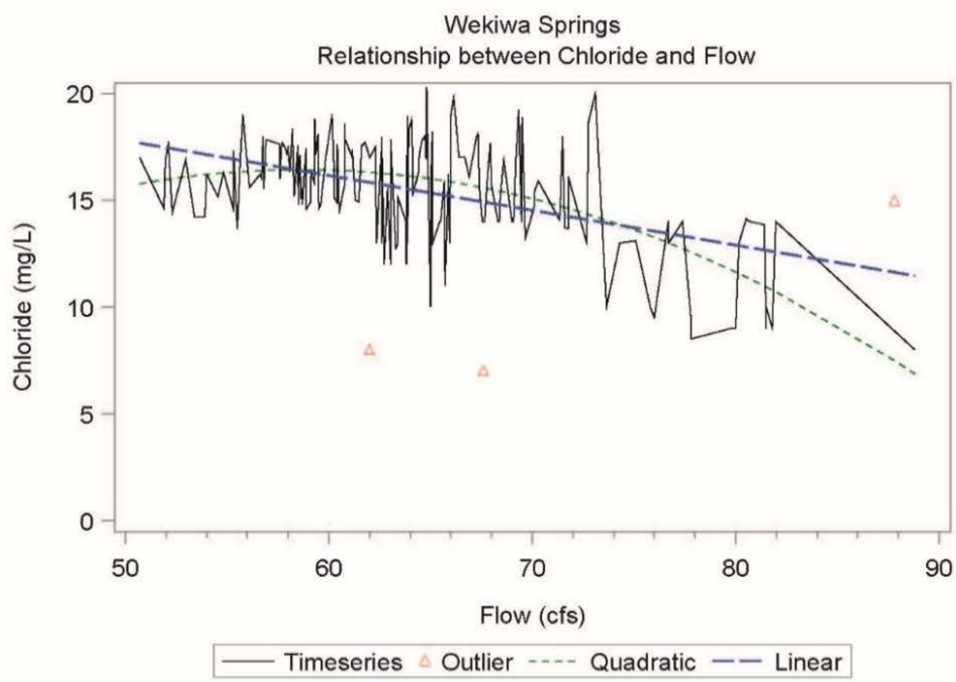
Total phosphorus appears to have slightly increased over time in Wekiwa Springs, however the change in magnitude is small (Figures 65 and 66). There is no discernable pattern in total phosphorus relative to flow.



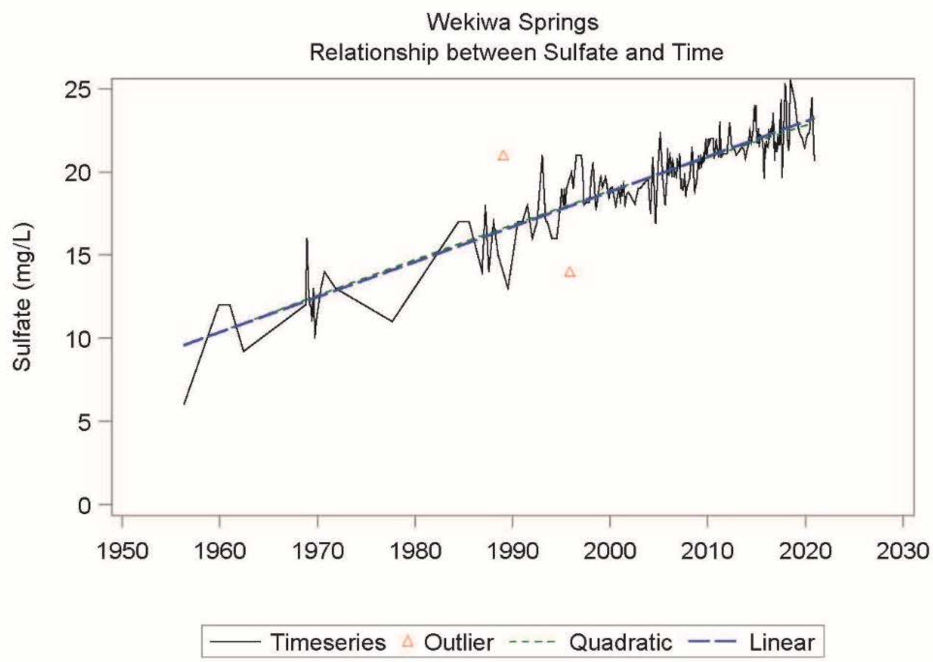


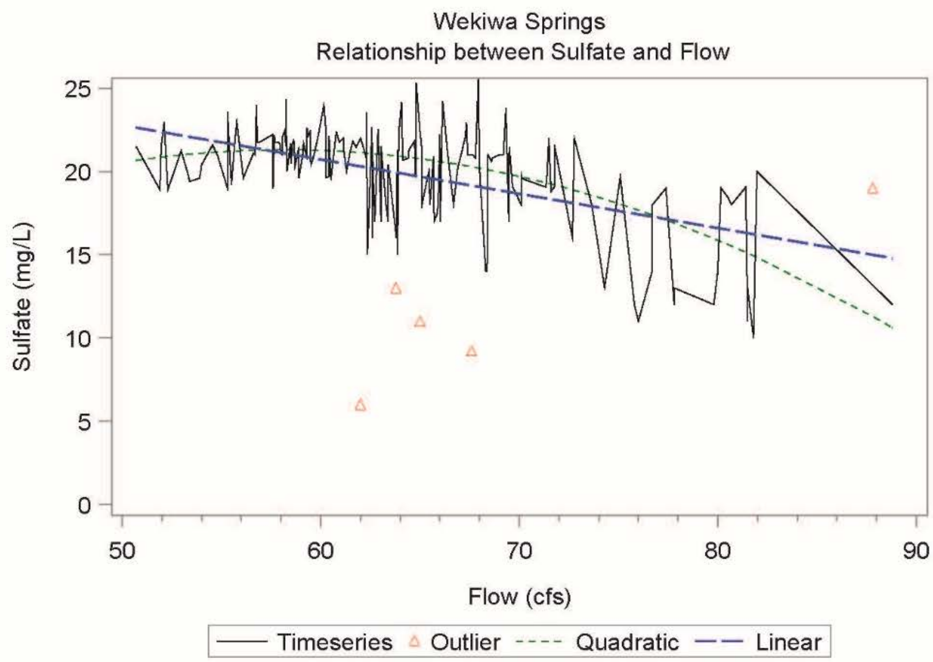
Figures 47 and 48. Time-Series of Alkalinity (top), and its Relationship with Flow (bottom)



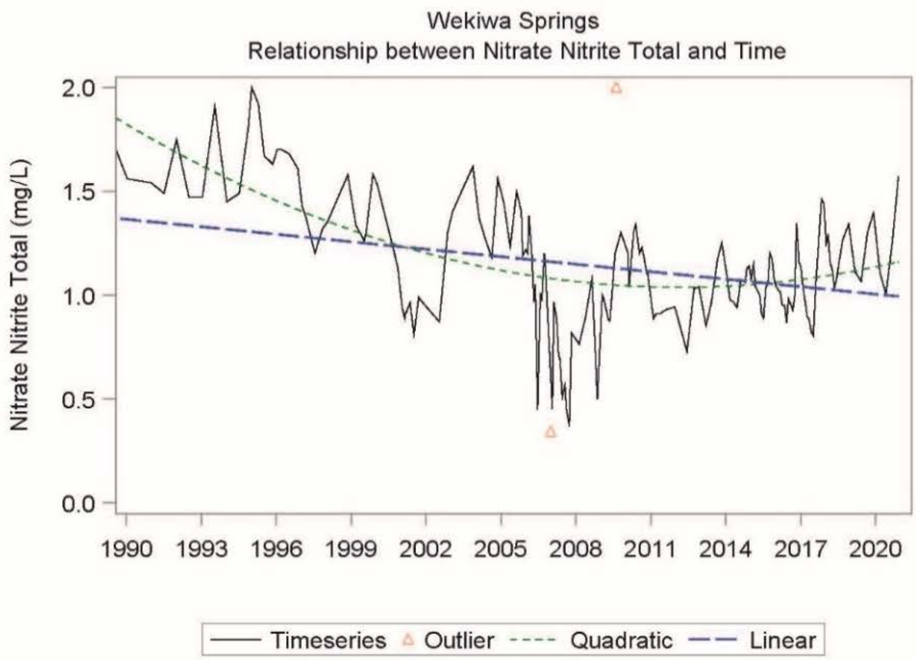


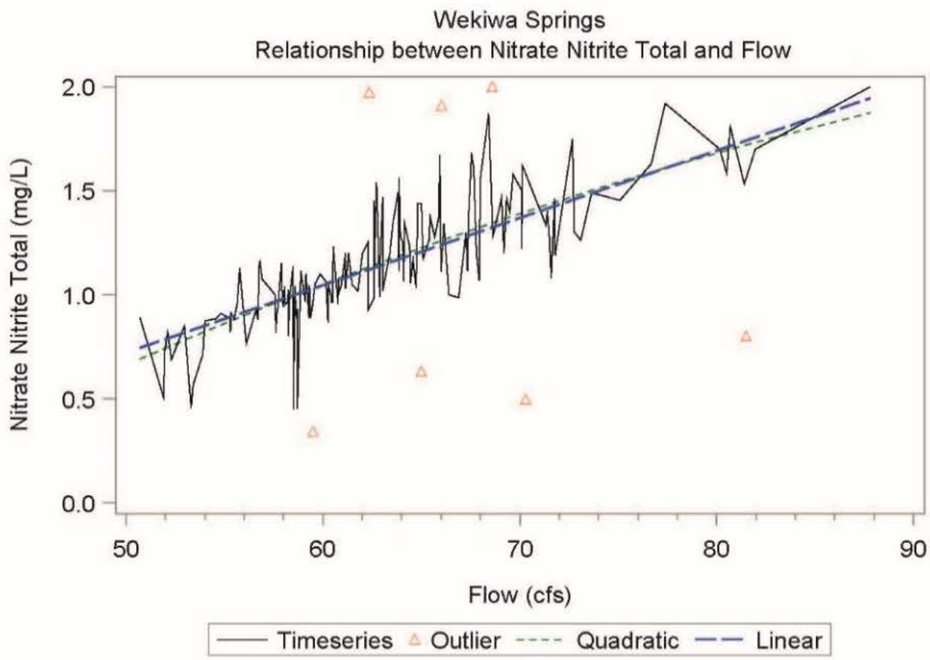
Figures 49 and 50. Time-Series of Chloride (top), and its Relationship with Flow (bottom)



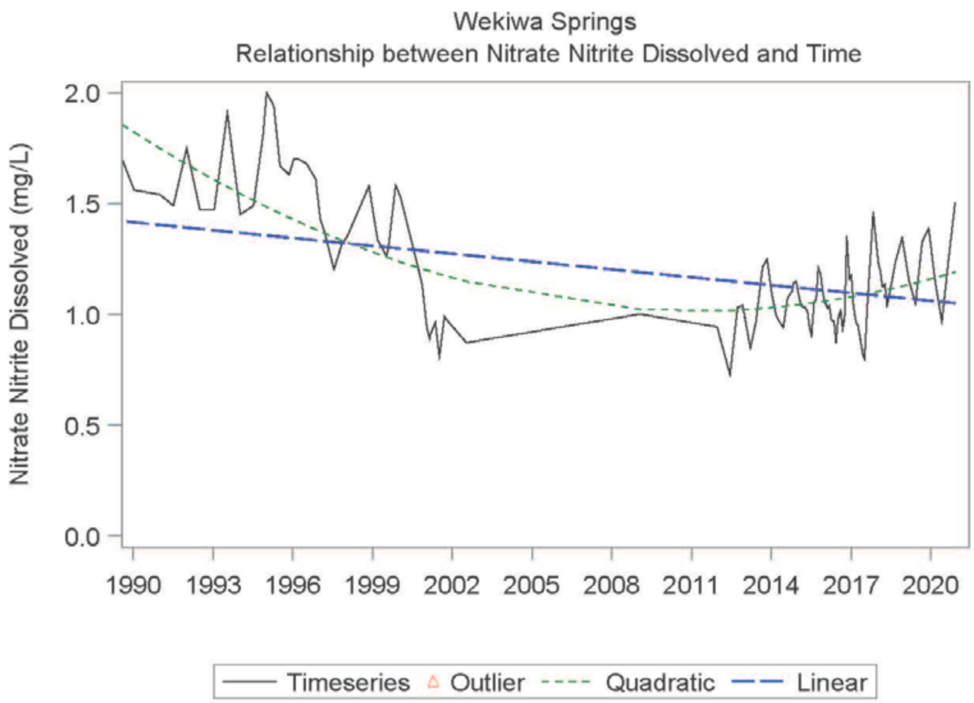


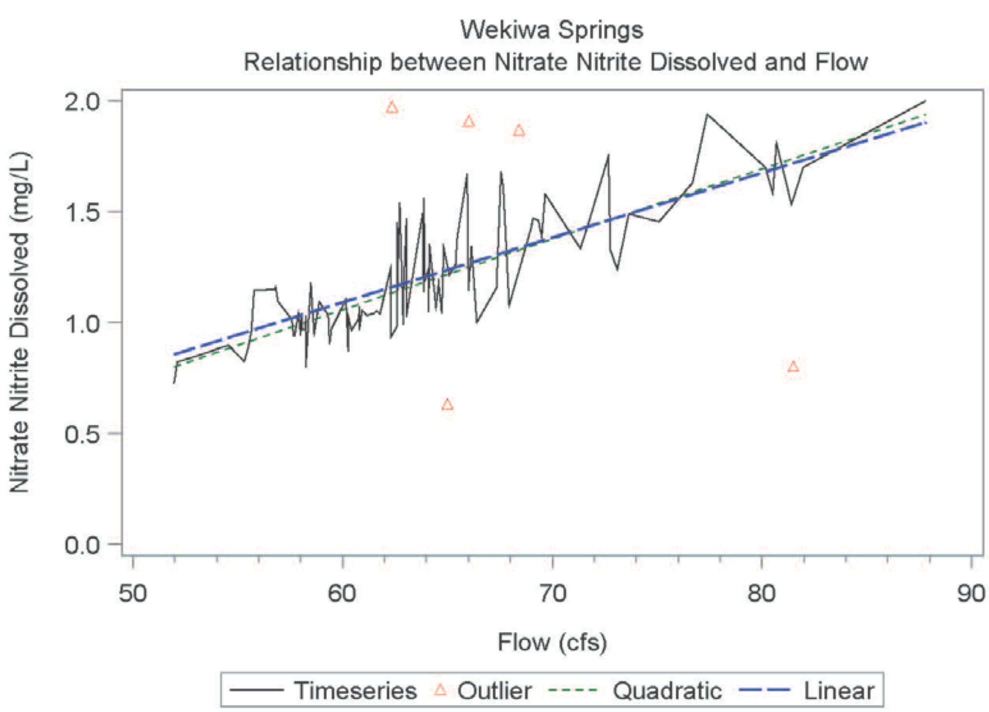
Figures 51 and 52. Time-Series of Sulfate (top), and its Relationship with Flow (bottom)



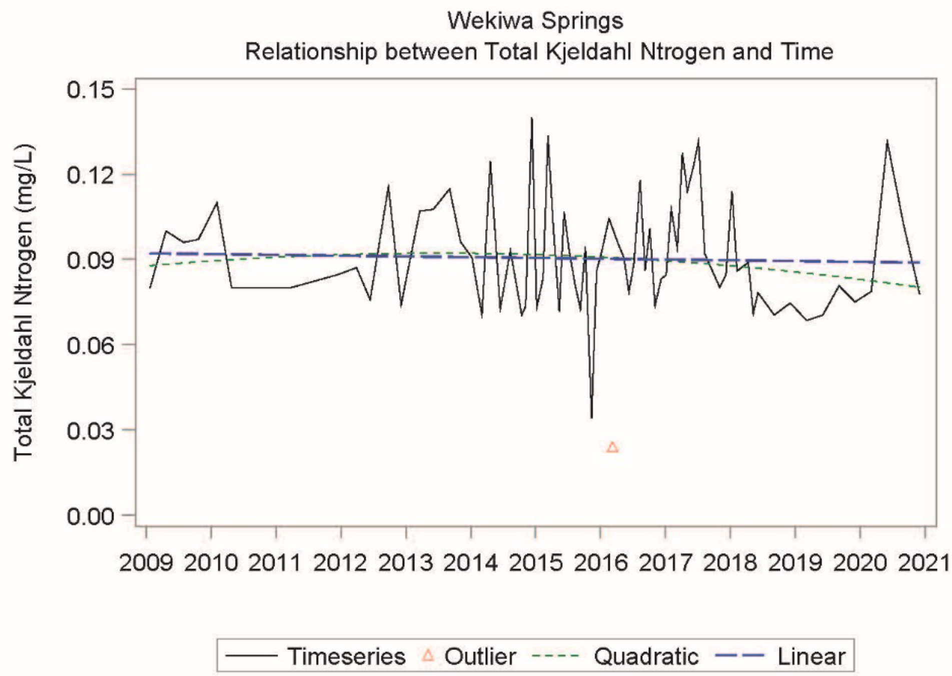


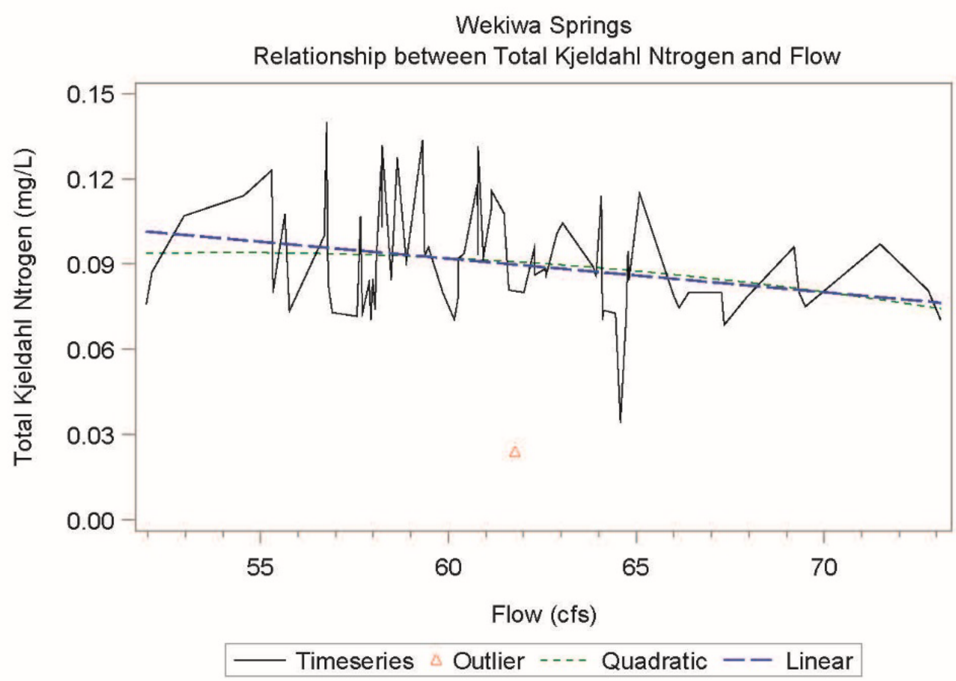
Figures 53 and 54. Time-Series of Nitrate-Nitrite Total (top), and its Relationship with Flow (bottom)



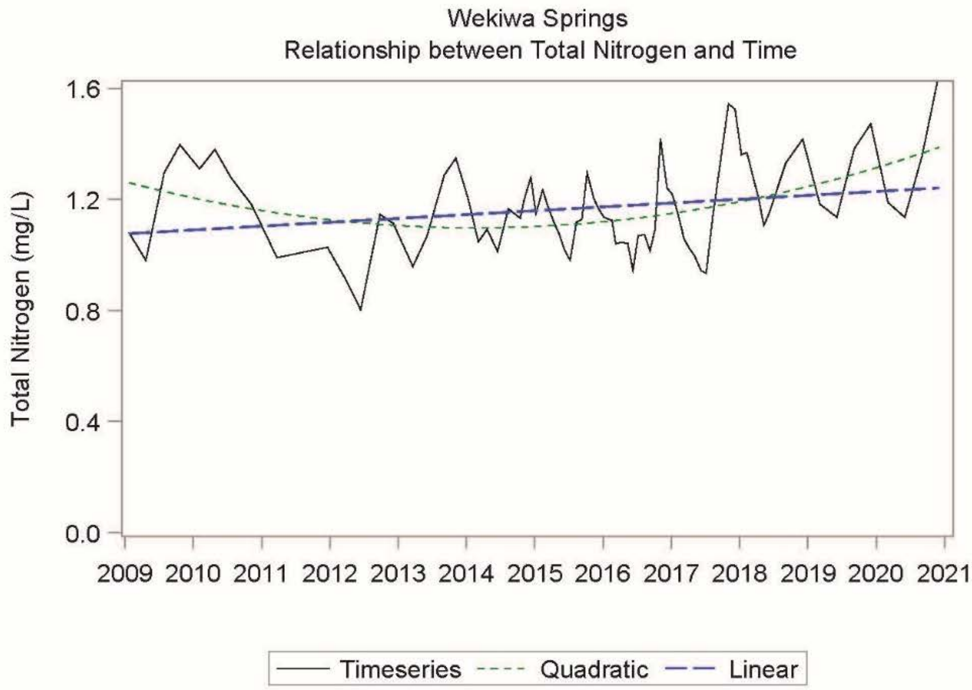


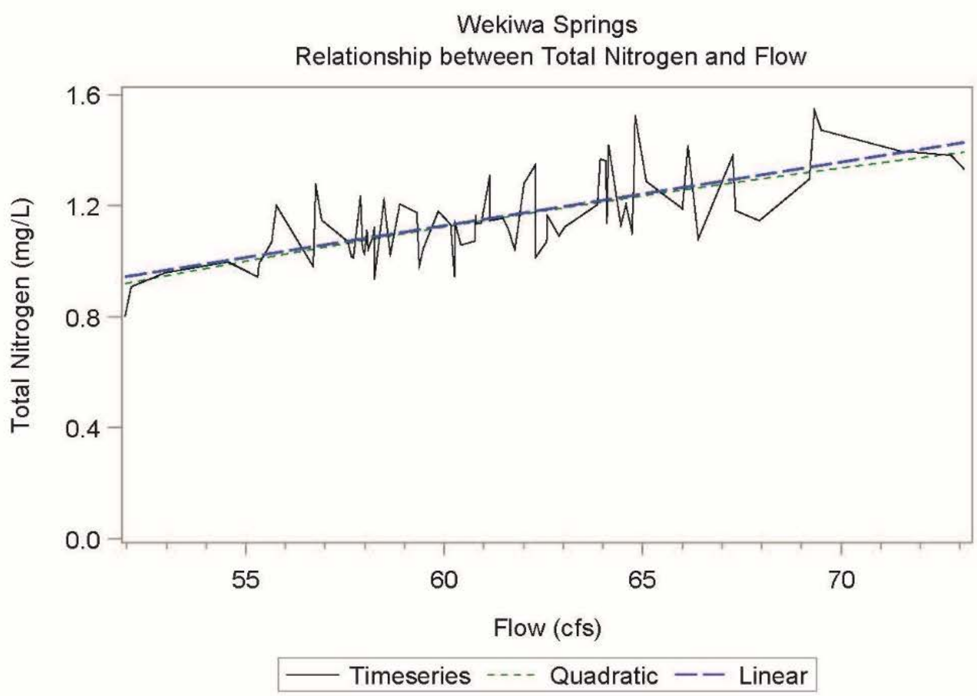
Figures 55 and 56. Time-Series of Nitrate-Nitrite Dissolved (top), and its Relationship with Flow (bottom)



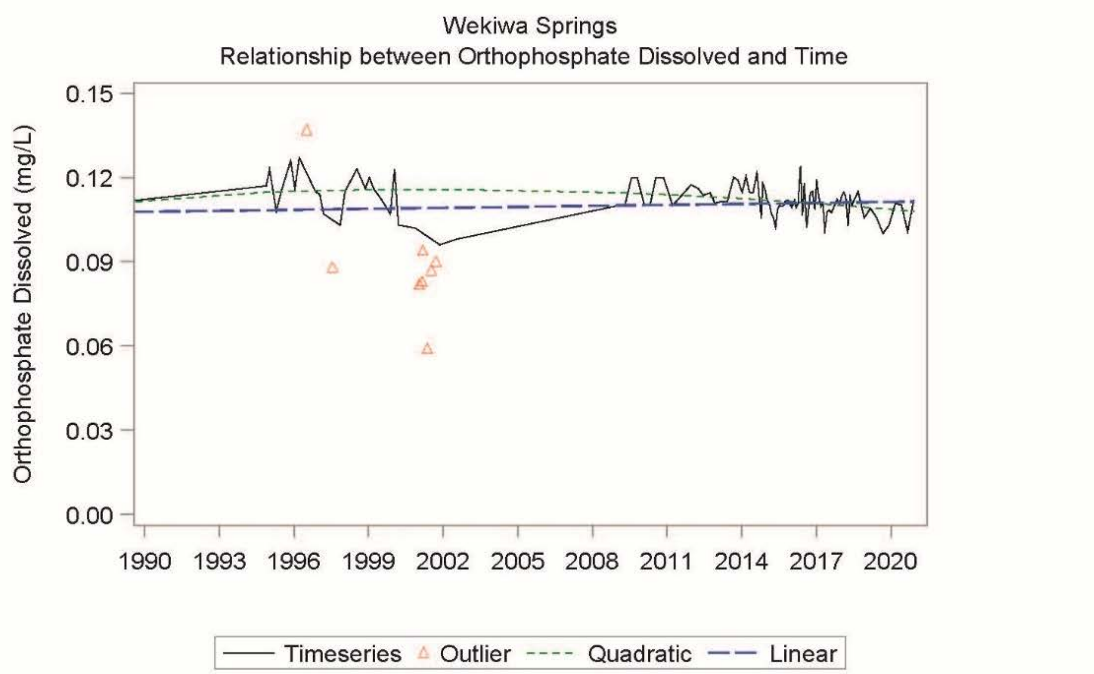


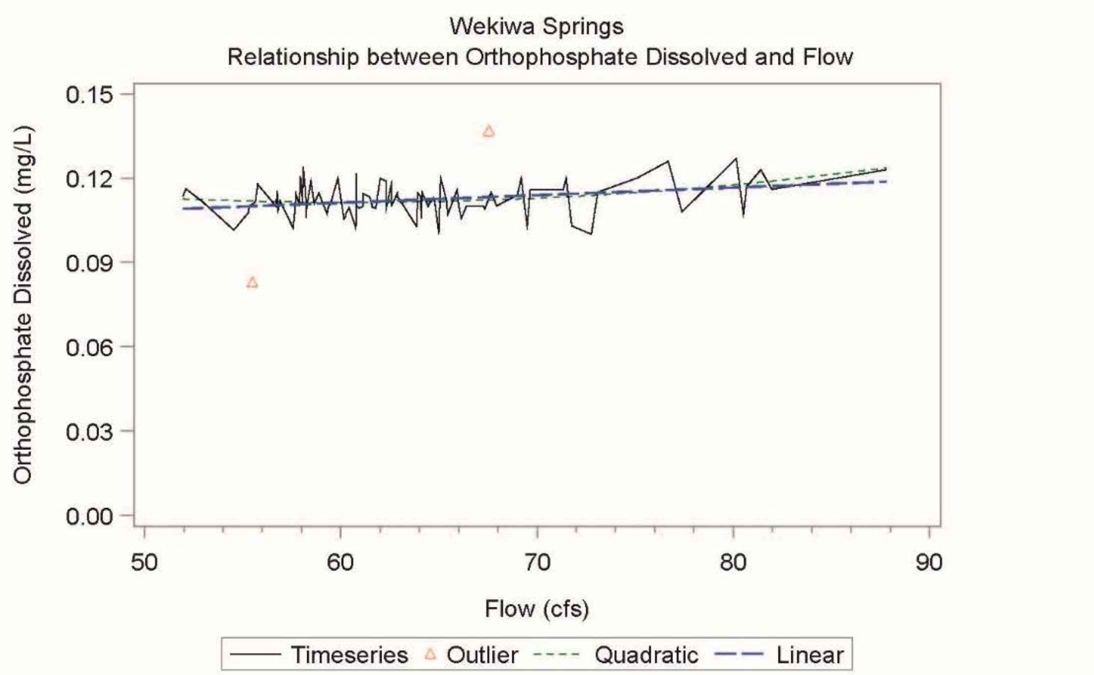
Figures 57 and 58. Time-Series of TKN (top), and its Relationship with Flow (bottom)



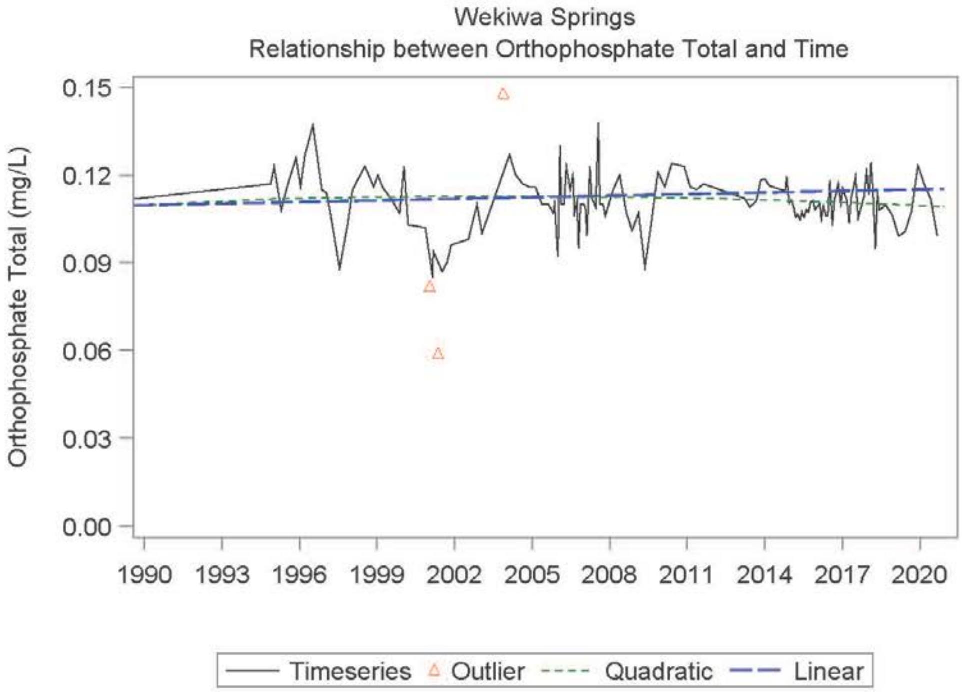


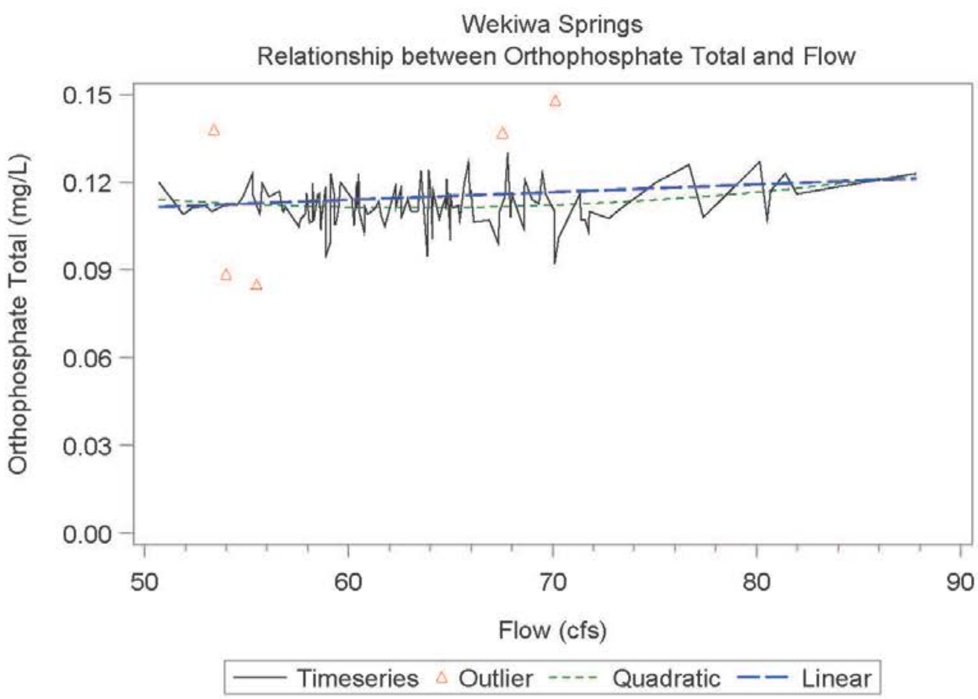
Figures 59 and 60. Time-Series of TN (top), and its Relationship with Flow (bottom)



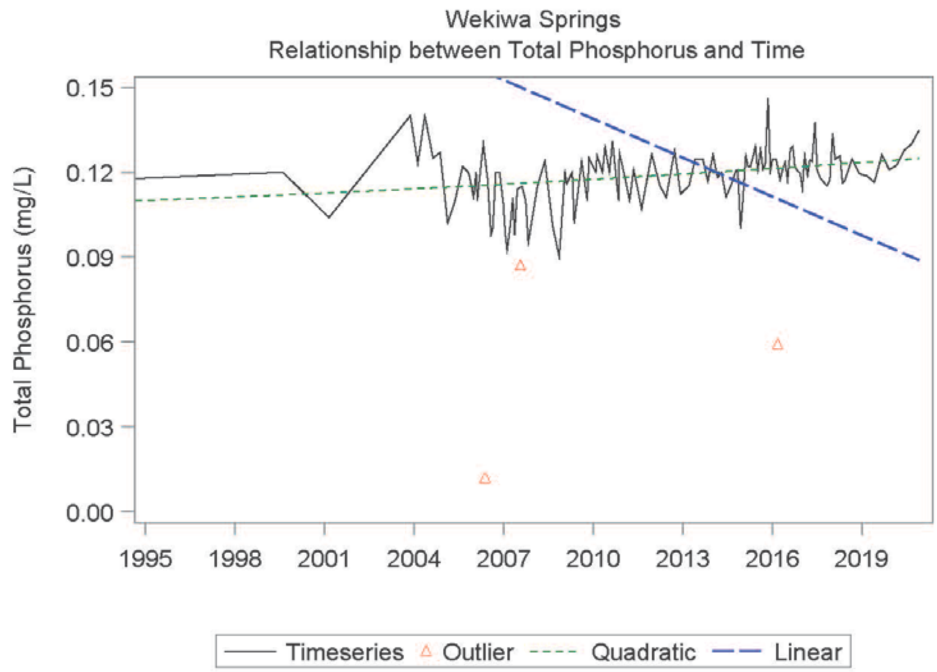


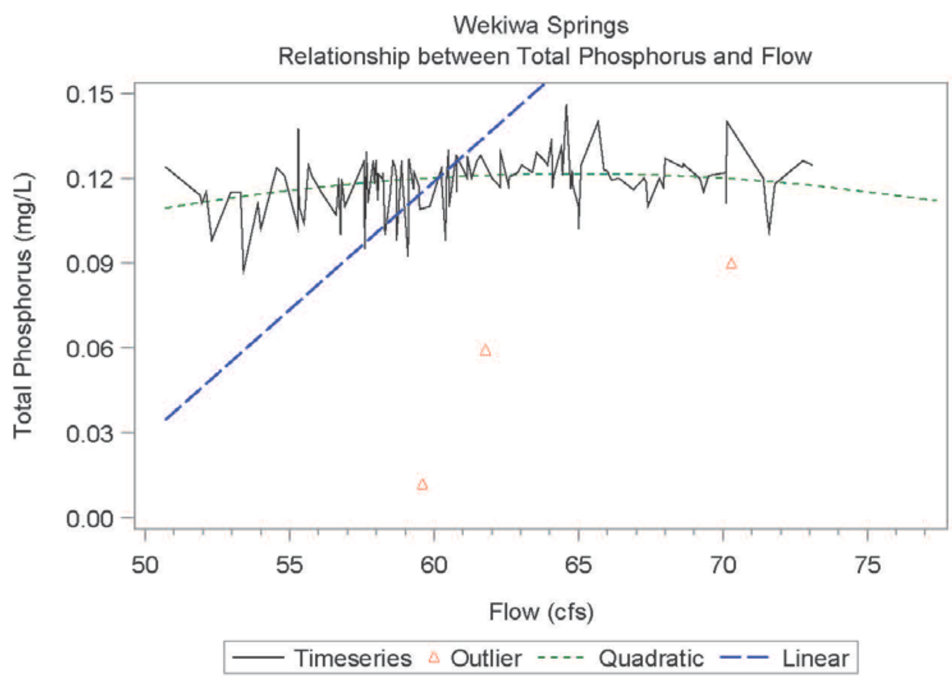
Figures 61 and 62. Time-Series of Orthophosphate Dissolved (top), and its Relationship with Flow (bottom)





Figures 63 and 64. Time-Series of Orthophosphate Total (top), and its Relationship with Flow (bottom)





Figures 65 and 66. Time-Series of TP (top), and its Relationship with Flow (bottom)

The period-of-record for chlorophyll data in Wekiwa Springs is relatively short and no pattern is evident in the brief time series; values are consistently low [less than 1.0 micrograms per liter (µg/L); Figures 67 and 68]. Additionally, no relationship with flow is apparent.

While remaining low, conductivity values exhibited an increasing trend over time (Figures 69 and 70). Conductivity values in Wekiwa Springs appear to decrease with increasing flow beyond a certain threshold. Over the period-of-record, flows exhibit a decreasing trend, which thus correlates with the increasing conductivity values over the same time period.

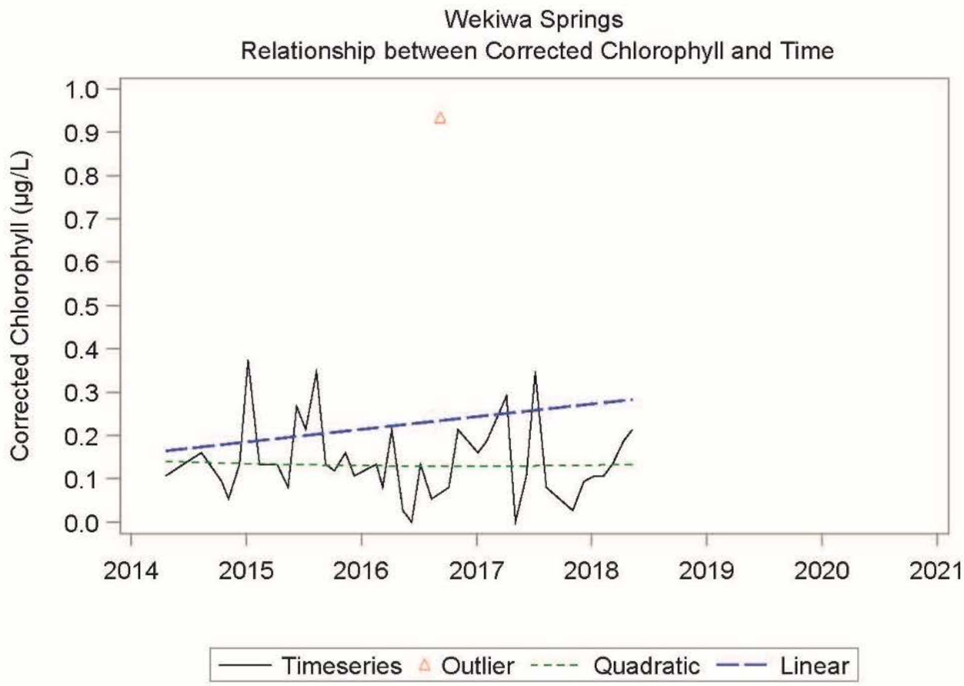
Dissolved oxygen concentrations in Wekiwa Springs are illustrated in Figures 71 and 72. The quadratic regression of the time series suggests a slight increase in dO over time, but values remain under 2.0 milligrams per liter (mg/L). It is not unexpected for spring vents to have low dO, due to the length of time the water has been underground. Reaeration and photosynthesis typically increase dO as the water flows down the spring run. There was no discernable relationship with flow.

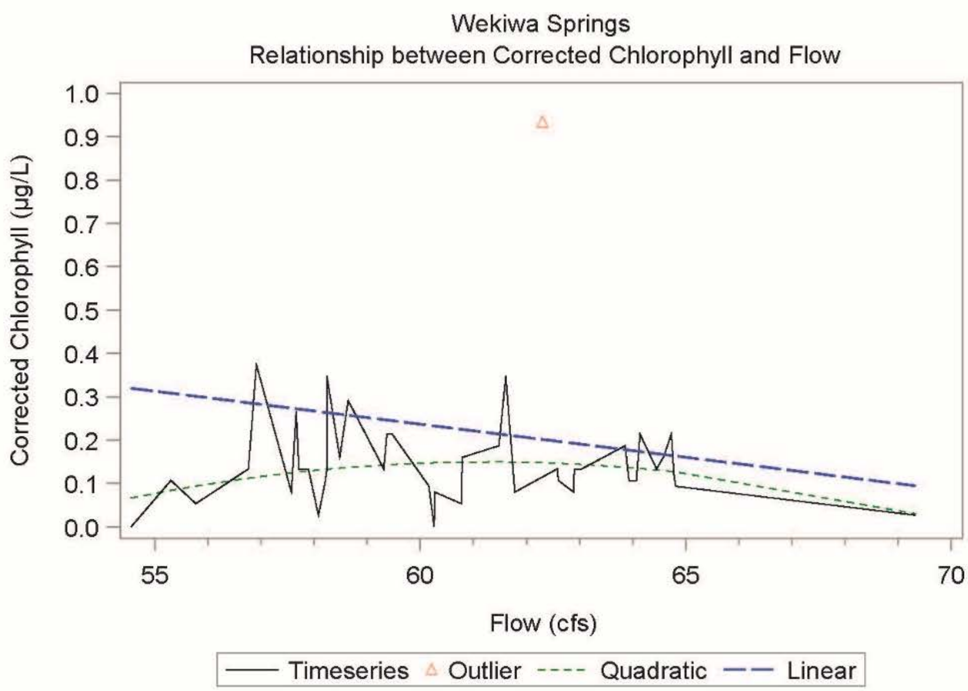
The period-of-record for TSS data in Wekiwa Springs is relatively short. No discernable pattern over time, or in relationship to flow, was apparent in this short time-series (Figures 73 and 74).

The time series of water color data in Wekiwa Springs suggests a slight decline over the last decade (Figures 75 and 76), although values were relatively low throughout this period. A slight negative relationship with flow was indicated.

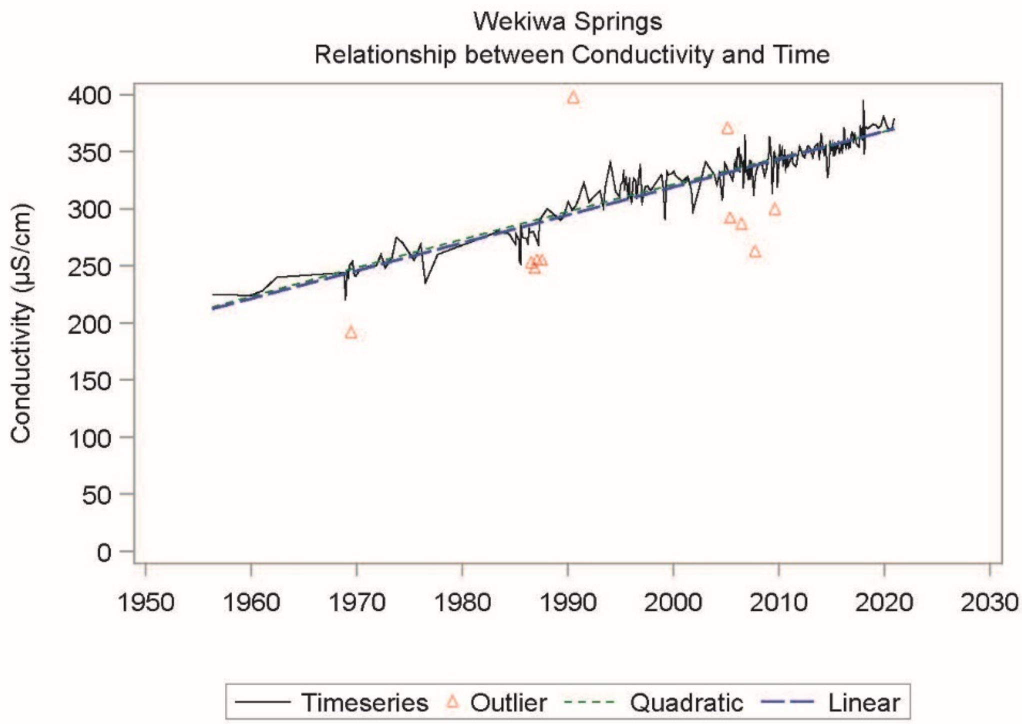
Groundwater flowing into a spring tends to have a buffering capacity, stabilizing pH. This is illustrated in the data for pH reported at Wekiwa Springs (Figures 77 and 78). No discernable pattern over time, or relative to flow, was apparent.

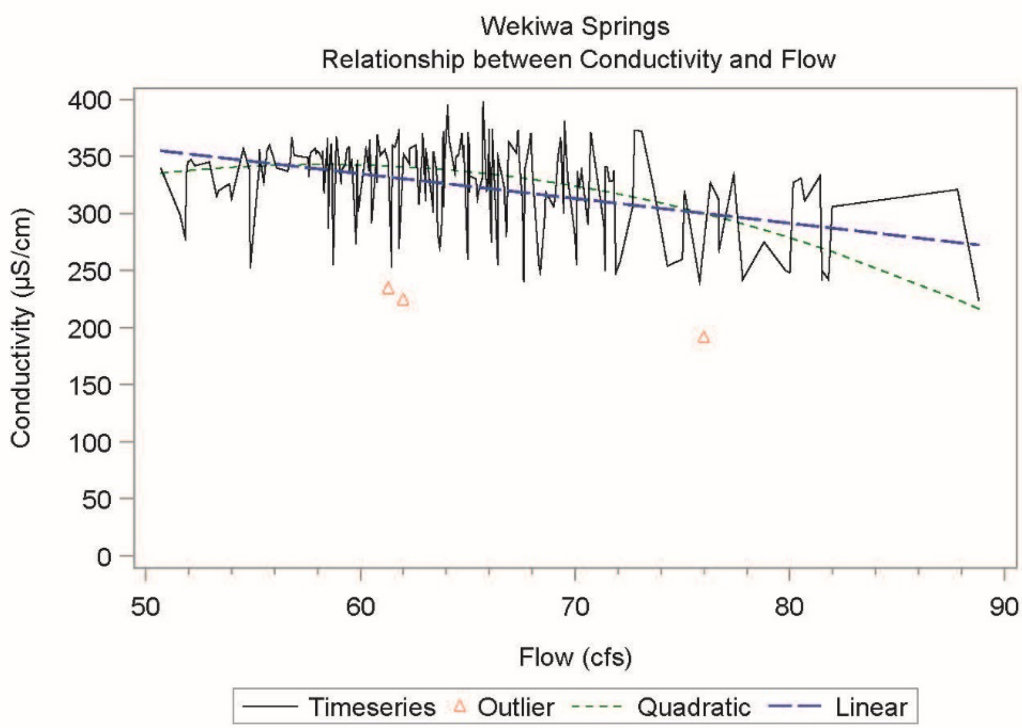
Given that the flow in a spring is derived from ground water, water temperature in a spring is expected to be relatively constant. This is supported by both the time series and the relationship with flow (Figures 79 and 80). While a slight increase in water temperature is suggested in the time series, the magnitude of this change is extremely small over a 50-year period.



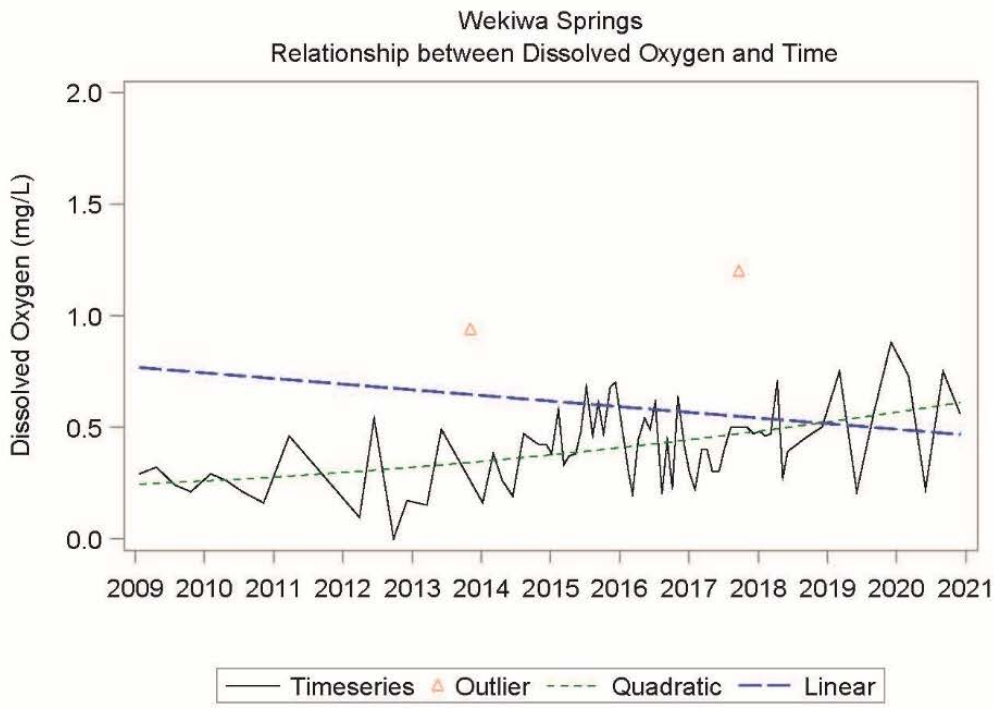


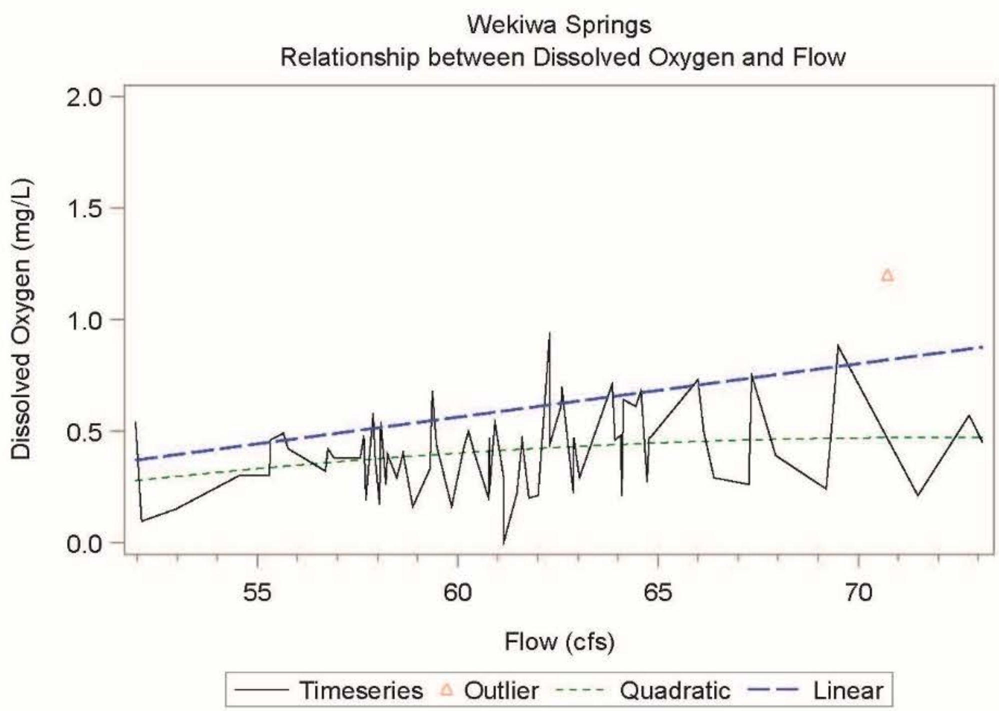
Figures 67 and 68. Time-Series of Corrected Chlorophyll (top), and its Relationship with Flow (bottom)



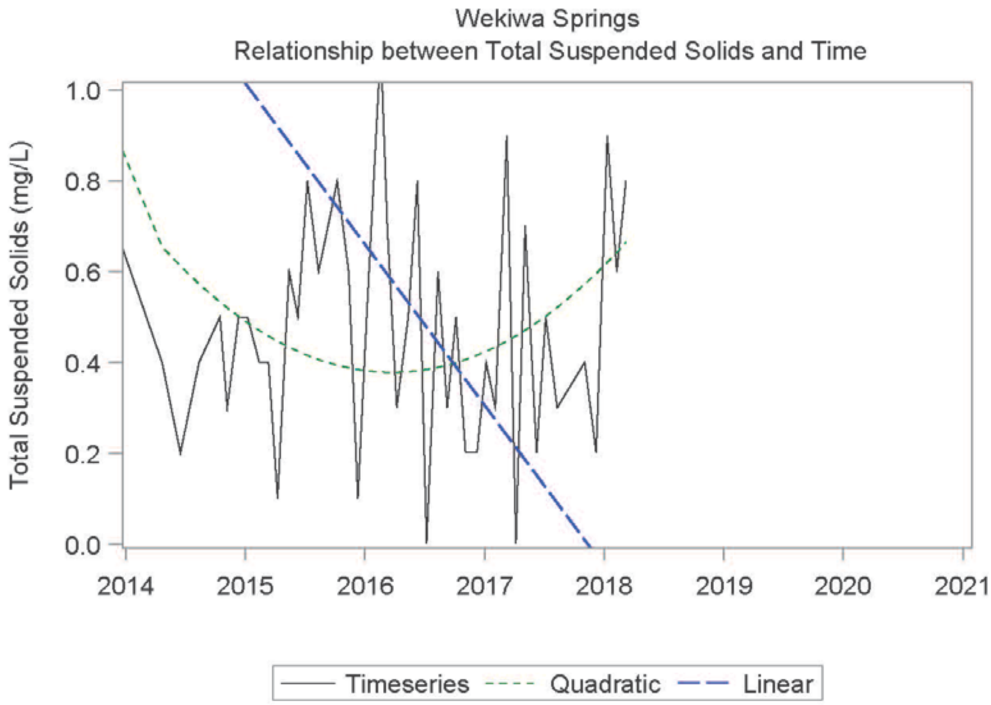


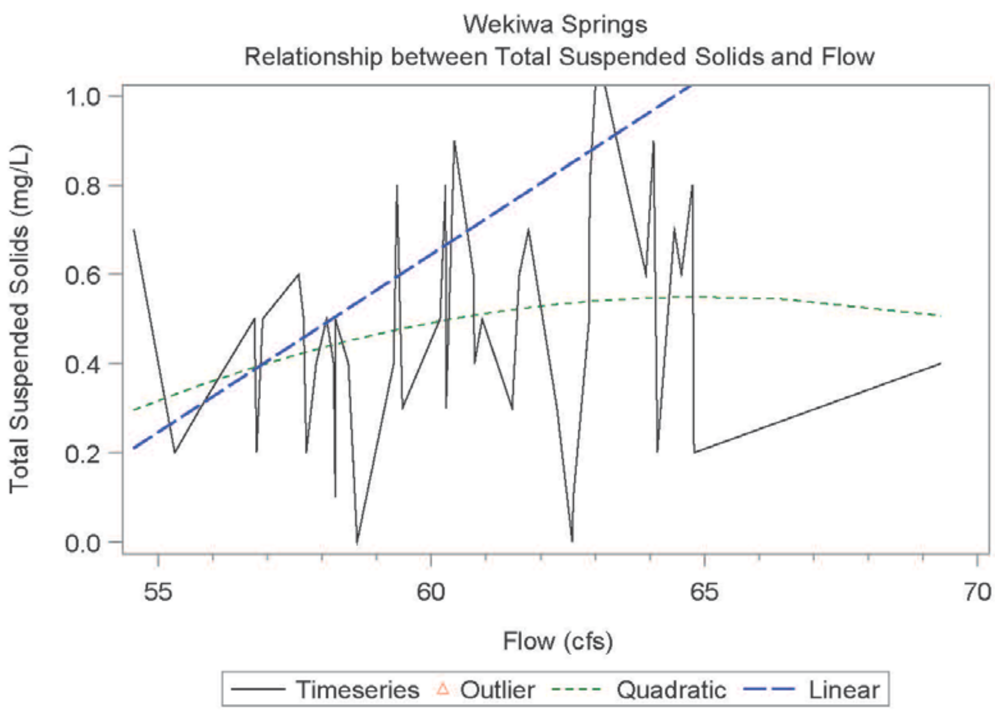
Figures 69 and 70. Time-Series of Conductivity (top), and its Relationship with Flow (bottom)



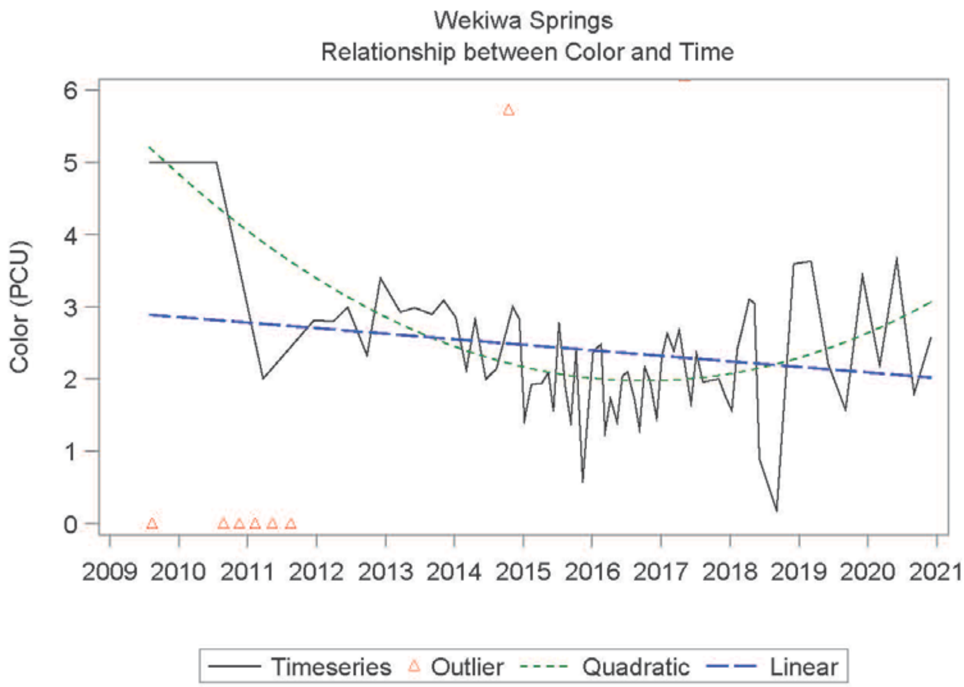


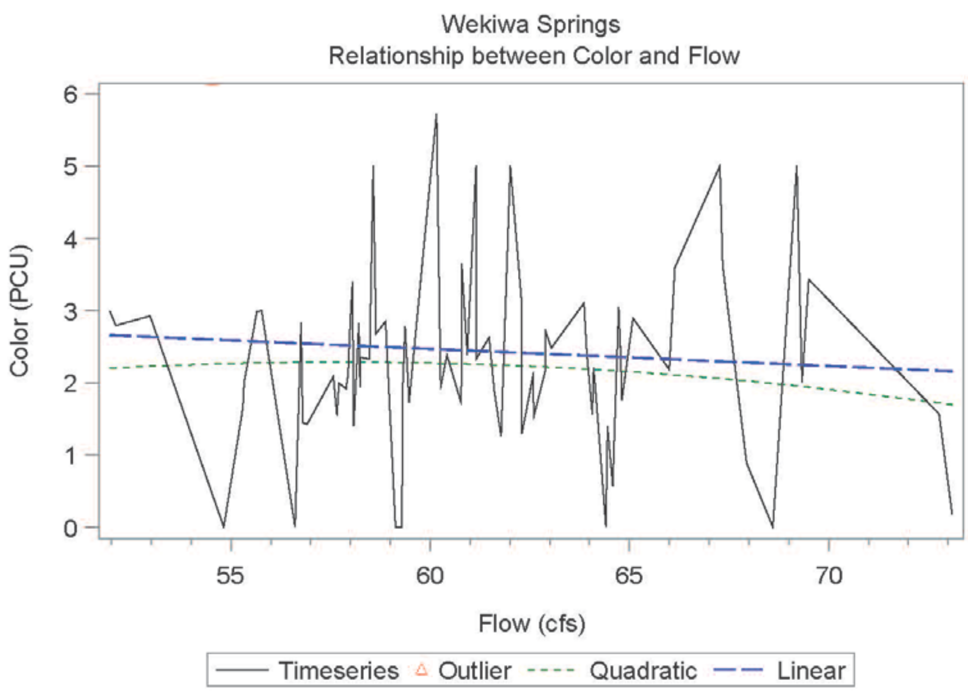
Figures 71 and 72. Time-Series of Dissolved Oxygen (top), and its Relationship with Flow (bottom)



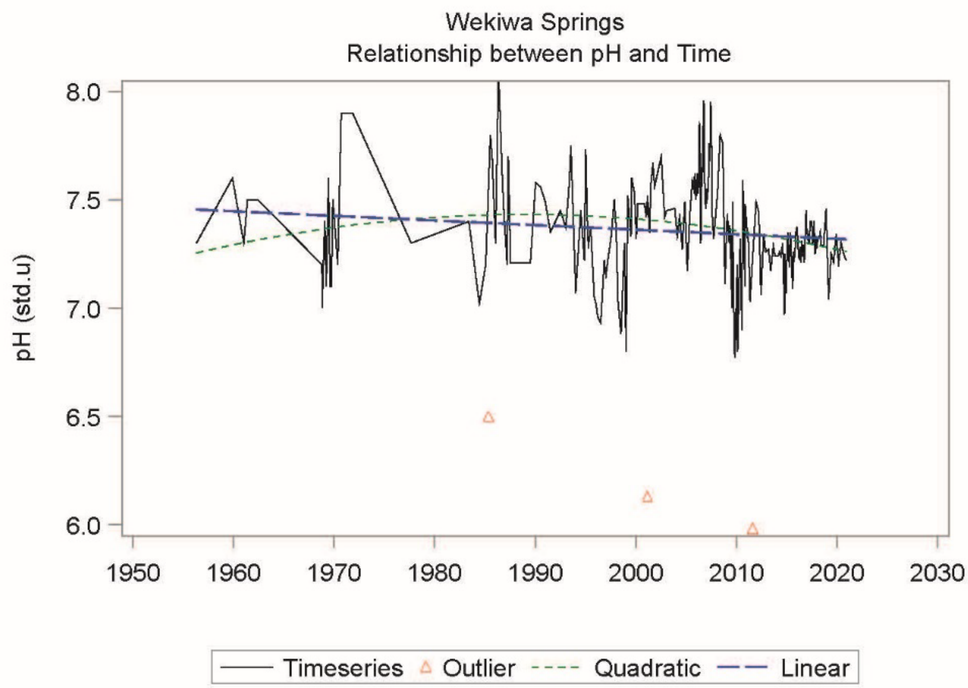


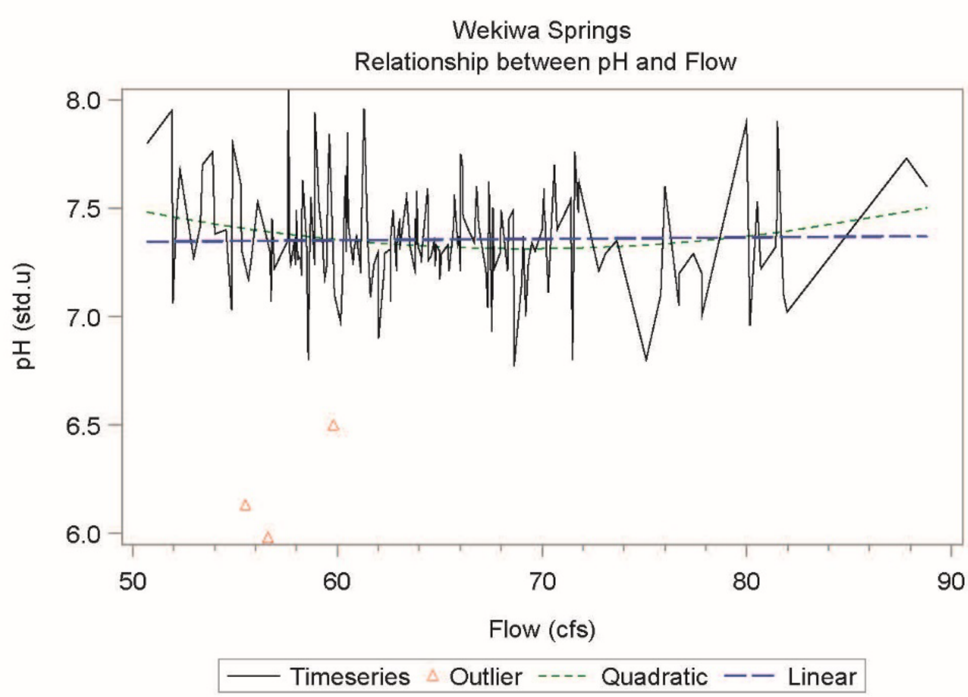
Figures 73 and 74. Time-Series of TSS (top), and its Relationship with Flow (bottom)



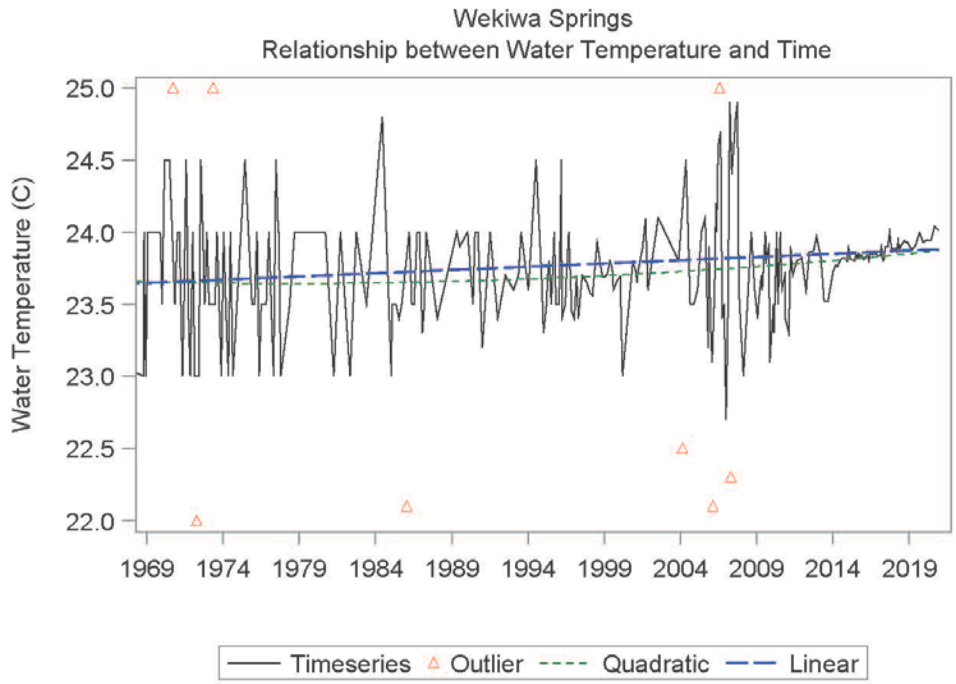


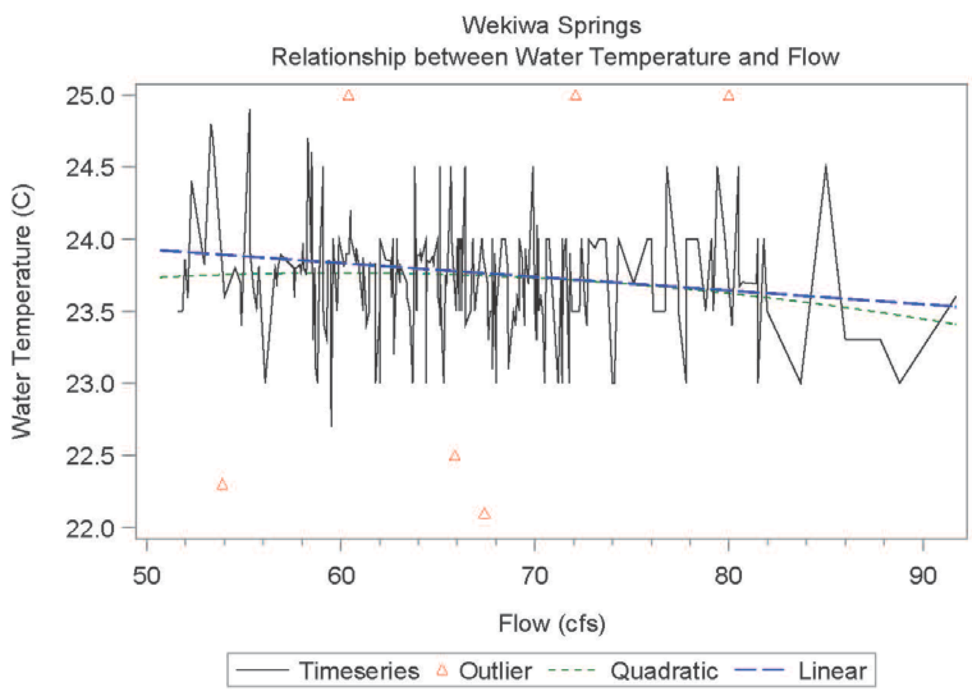
Figures 75 and 76. Time-Series of Color (top), and its Relationship with Flow (bottom)





Figures 77 and 78. Time-Series of pH (top), and its Relationship with Flow (bottom)





Figures 79 and 80. Time-Series of Temperature (top), and its Relationship with Flow (bottom)

Rock Springs

The data used for the Rock Springs analyses were obtained from the SJRWMD gage 00330830 (Rock Springs at Apopka Discharge). Data for Rock Springs span a period from 1932 to 2020; however, sampling was infrequent prior to 1968 and semi-monthly to monthly from 1968 to 2001. More regular sampling began in late 2002. The top graph in each pair provides a time series plot over the 1956-2020 time period (note, the period-of-record differs amongst parameters).

Alkalinity (Figures 81 and 82) exhibited a cyclical up and down pattern over time, but with an overall increasing trend indicated by the positive slope of the linear regression line. Alkalinity overall decreased with increasing flow values. The flow time series indicates a decreasing pattern over the period-of-record for alkalinity data and may account for the increasing alkalinity over time.

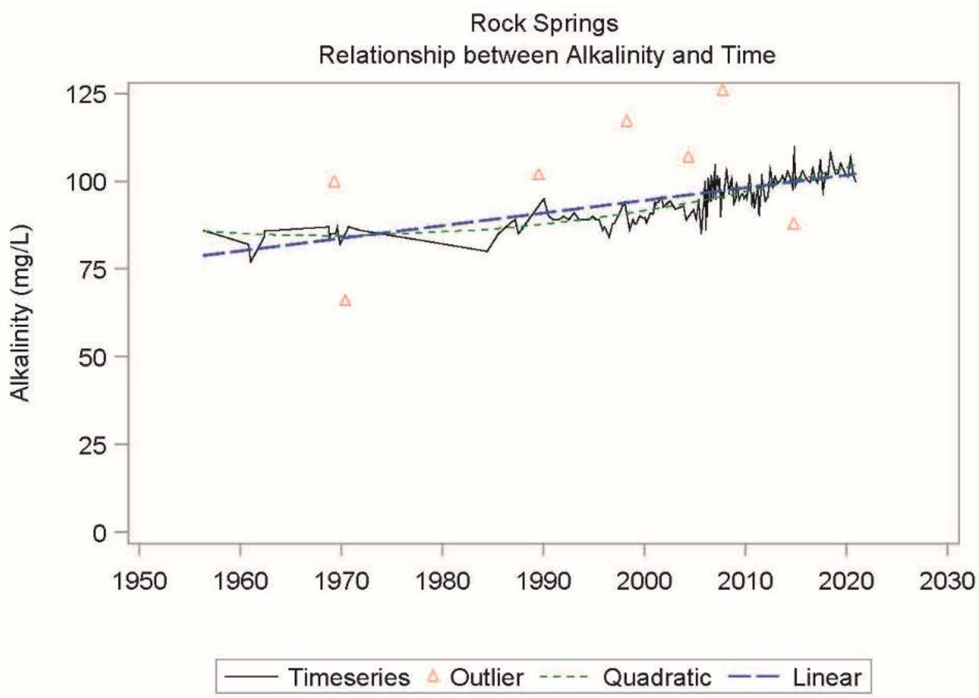
Chloride values displayed intra- and inter-annual variation, but overall, increased over time (Figures 83 and 84), with a doubling in magnitude from the 1950s to 2020. The linear regression line suggests chloride levels decline with increasing flow. As flows have generally declined since the late 1950s, this may explain the increasing chloride values over the same timeframe. Similar to chloride, sulfate values also increased over time; however, the slope of the line is not very steep (Figures 85 and 86). The flow-sulfate relationship appears to be negative, but with a shallow slope as well. The period-of-record for increasing sulfate values corresponds with the period of decreasing flows from Rock Springs.

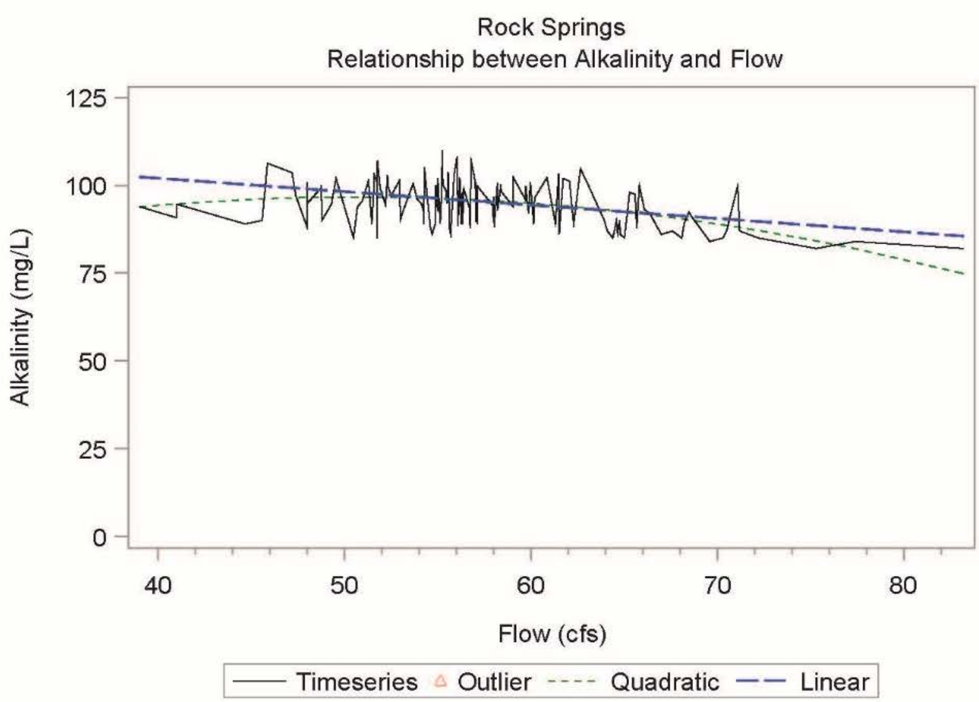
Nitrate-nitrite values have been reported as both total and dissolved. These are plotted separately in Figures 87 and 88 and Figures 89 and 90, respectively. Nitrate+nitrite levels appear to have decreased since the 1990s, but with reduced variability in the last decade or so. Both dissolved and total NO3+NO2 exhibit a positive relationship with flow.

Orthophosphate values have also been reported as both dissolved (Figures 91 and 92) and total (Figures 93 and 94). Both forms appear to vary over a narrow range of values, with a low-slope positive relationship to flow. The record for total orthophosphate is more complete and suggests a possible shallow-sloped increase in values over time. The lowest orthophosphate values occurred during the period of lowest flow on record (early 2000s).

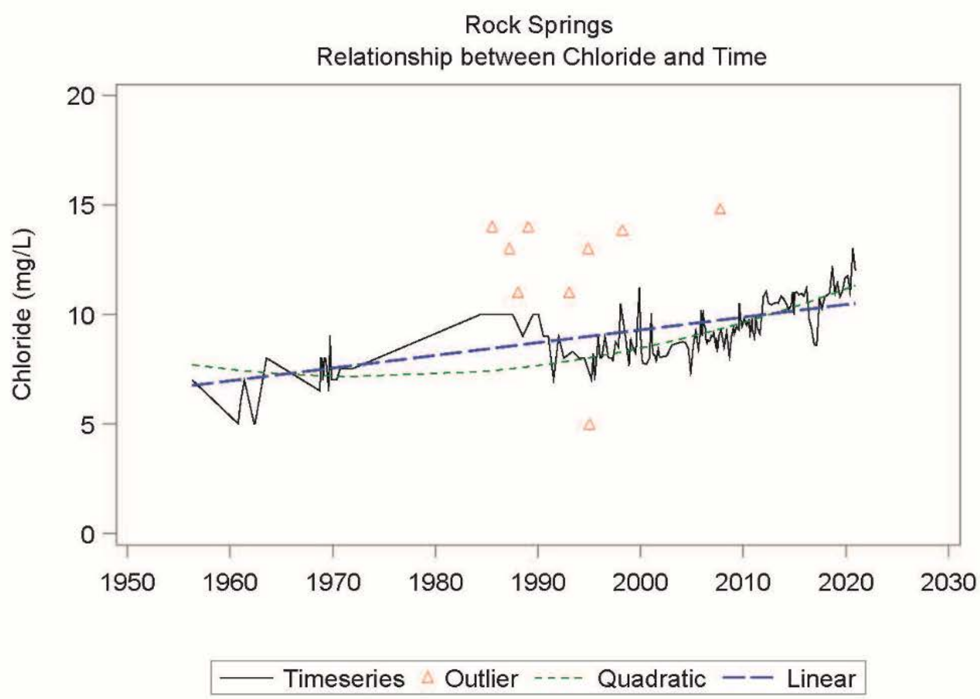
Total phosphorus appears to have increased very slightly over time in Rock Springs, however, the change in magnitude is small (Figures 95 and 96). There is no discernable pattern in total phosphorus relative to flow. The period-of-record for total phosphorus corresponds to a period of time where flows from the spring were relatively stable.

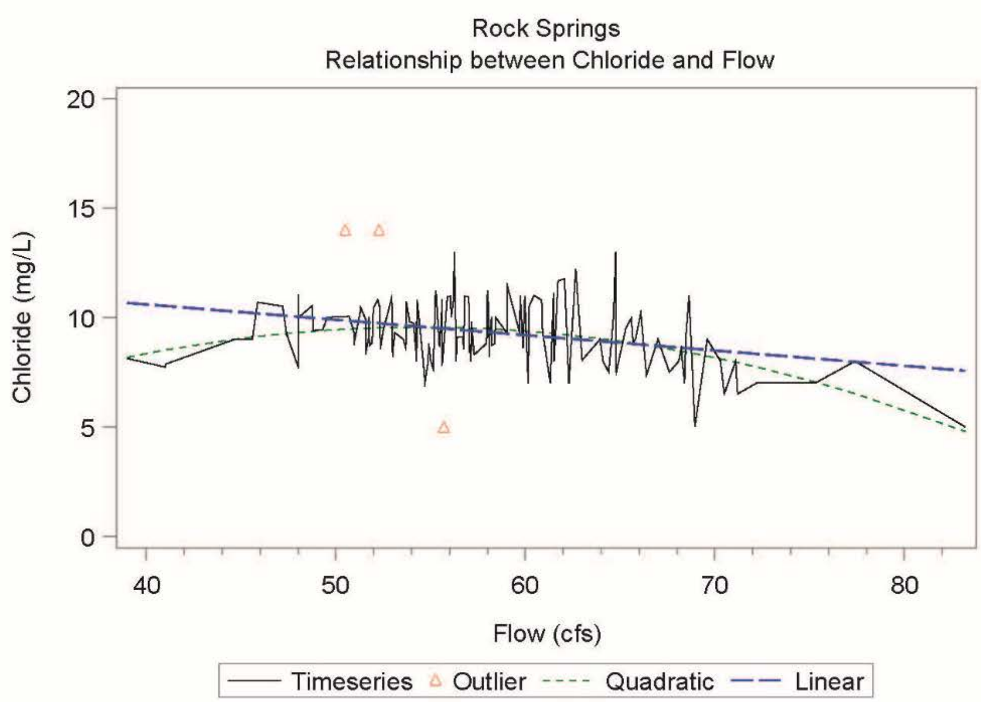
While remaining low, conductivity values exhibit an increasing trend over time (Figures 97 and 98). Conductivity values in Rocks Springs appear to decrease slightly with increasing flow; however, the change in magnitude of conductivity is small. Rock Springs has been characterized by declining flows over the period-of-record, which may account for the increase in conductivity over the same timeframe.



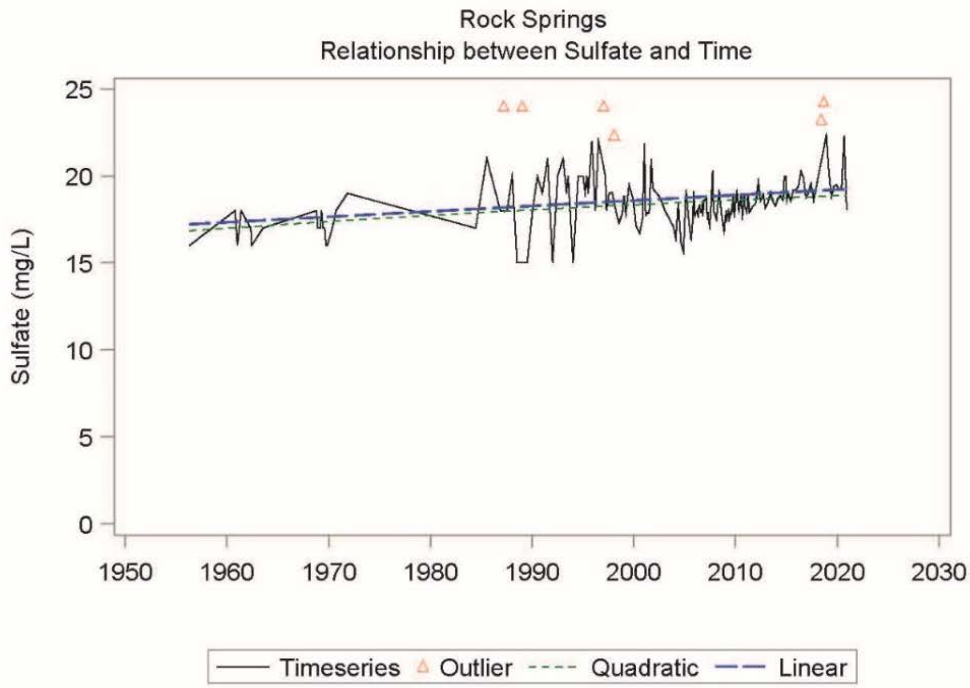


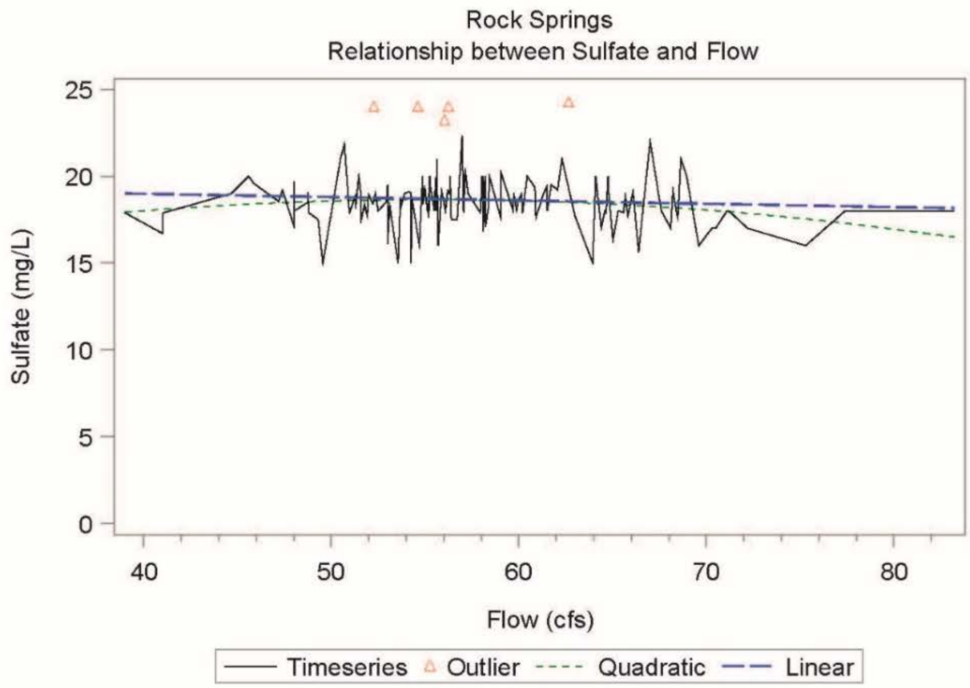
Figures 81 and 82. Time-Series of Alkalinity (top), and its Relationship with Flow (bottom)



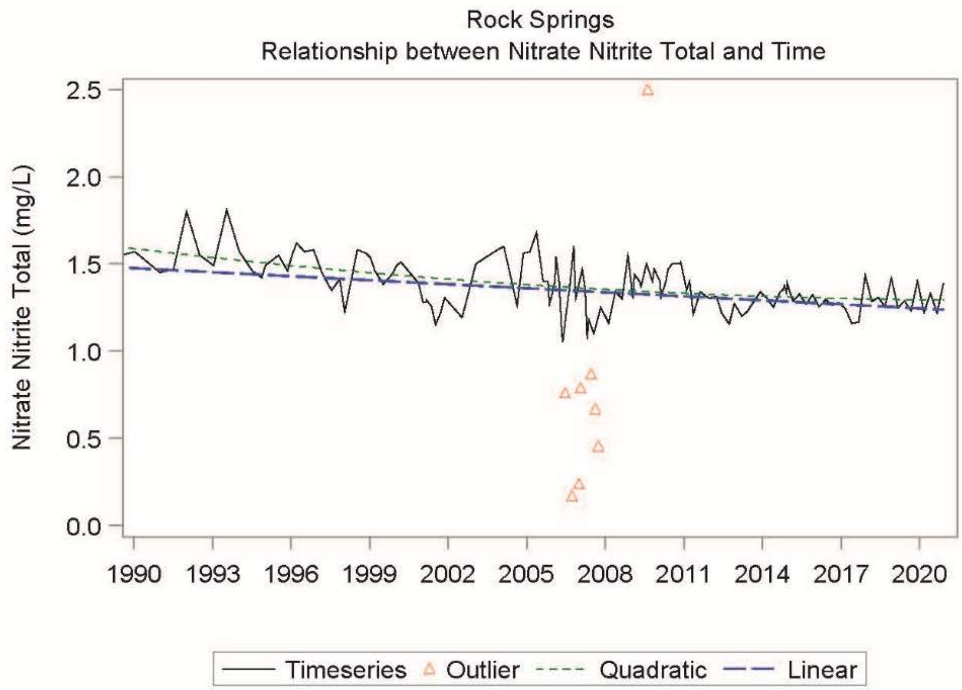


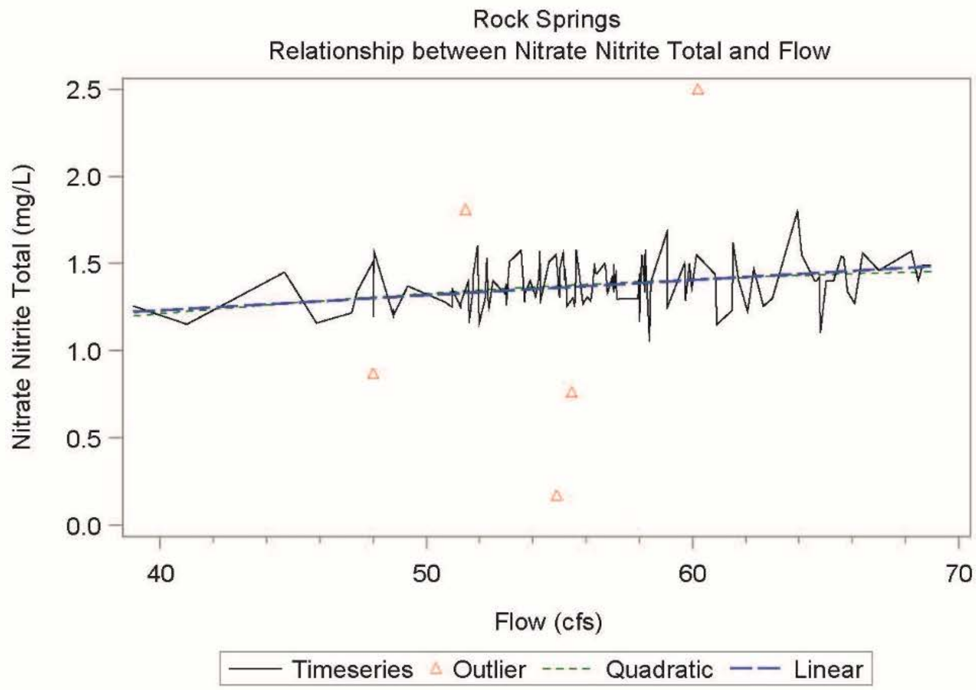
Figures 83 and 84. Time-Series of Chloride (top), and its Relationship with Flow (bottom)



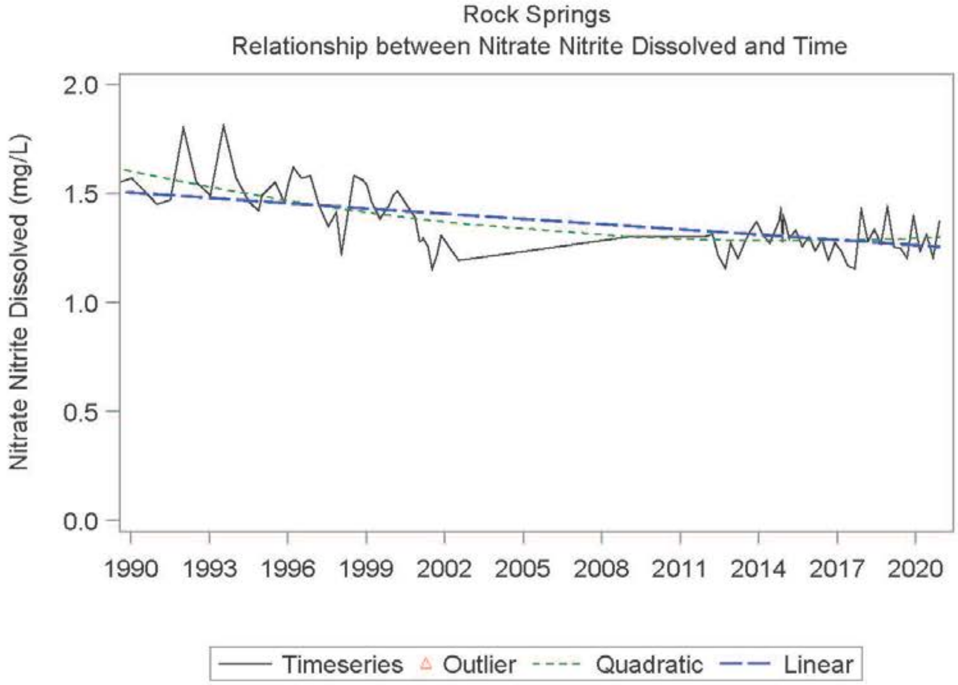


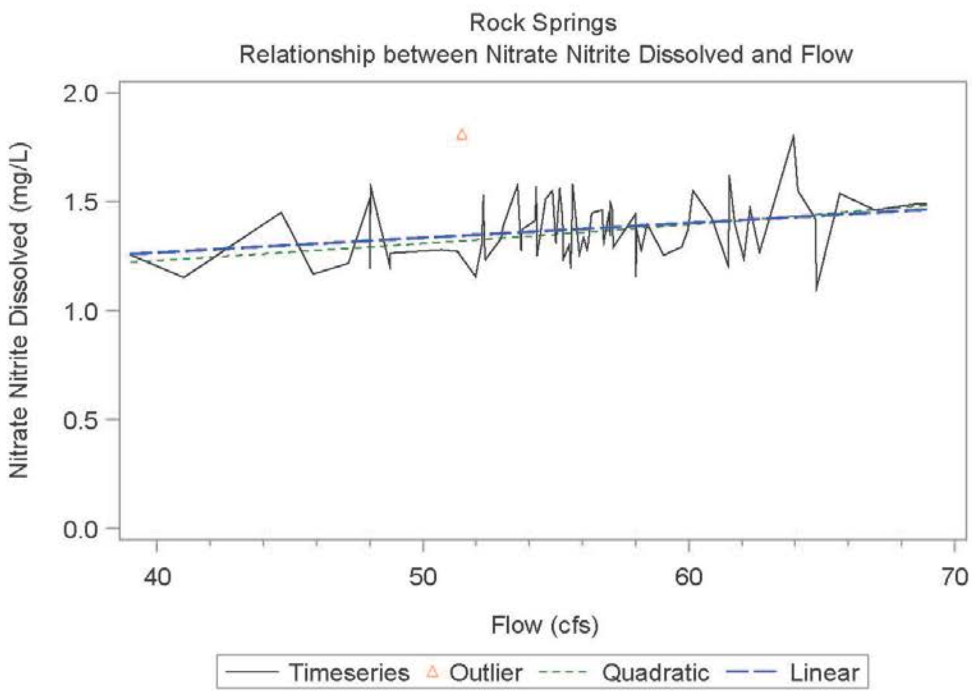
Figures 85 and 86. Time-Series of Sulfate (top), and its Relationship with Flow (bottom)



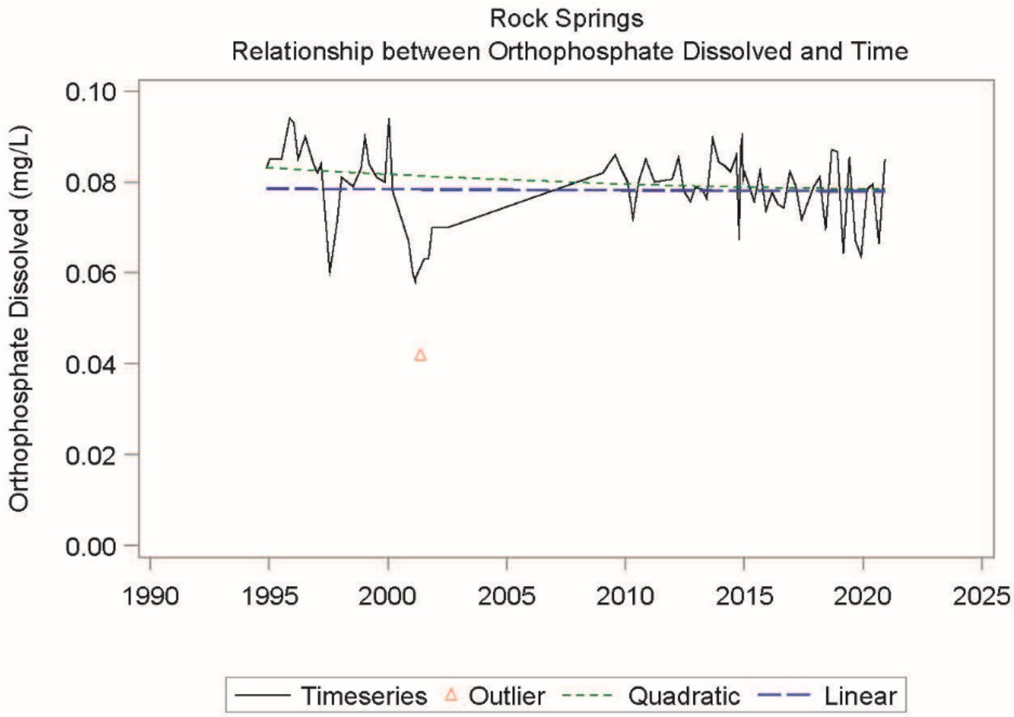


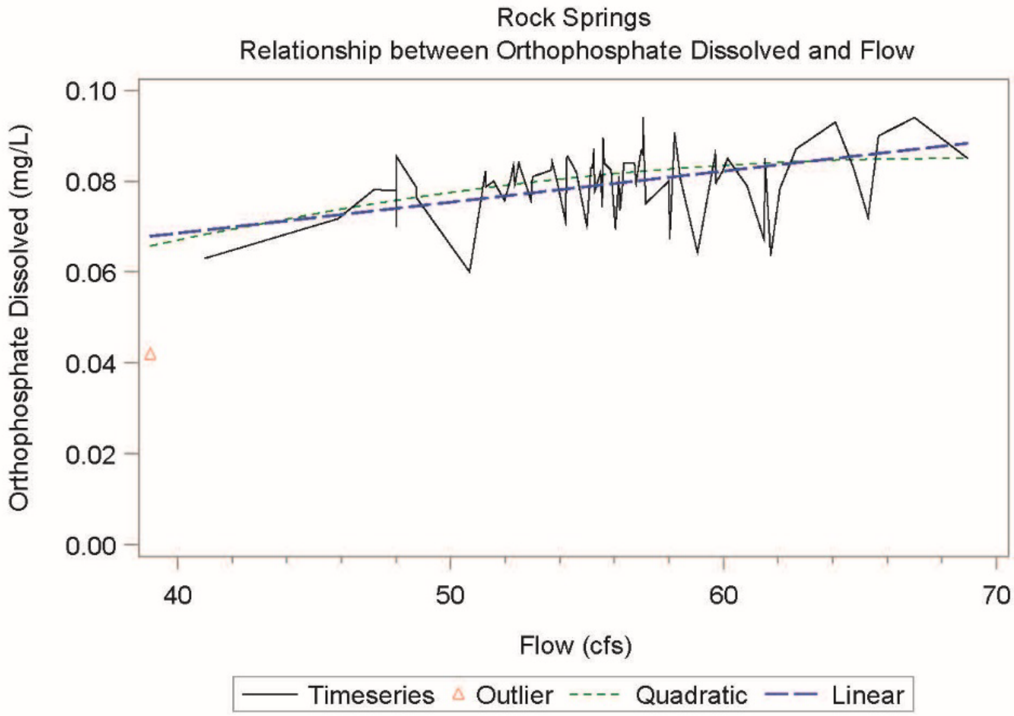
Figures 87 and 88. Time-Series of Nitrate-Nitrite Total (top), and its Relationship with Flow (bottom)



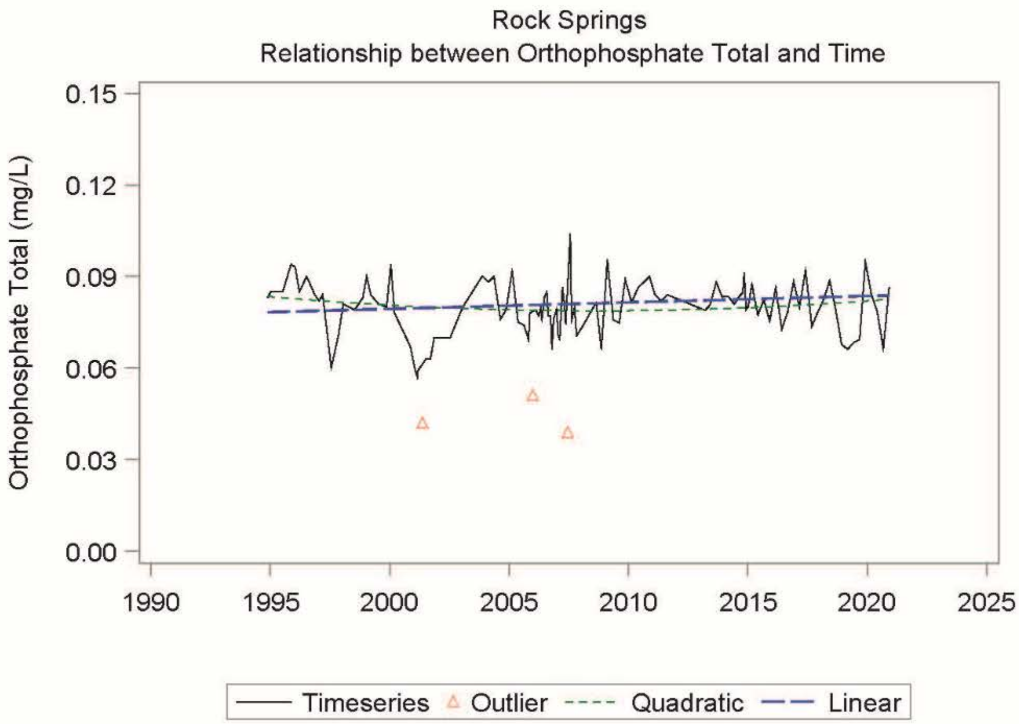


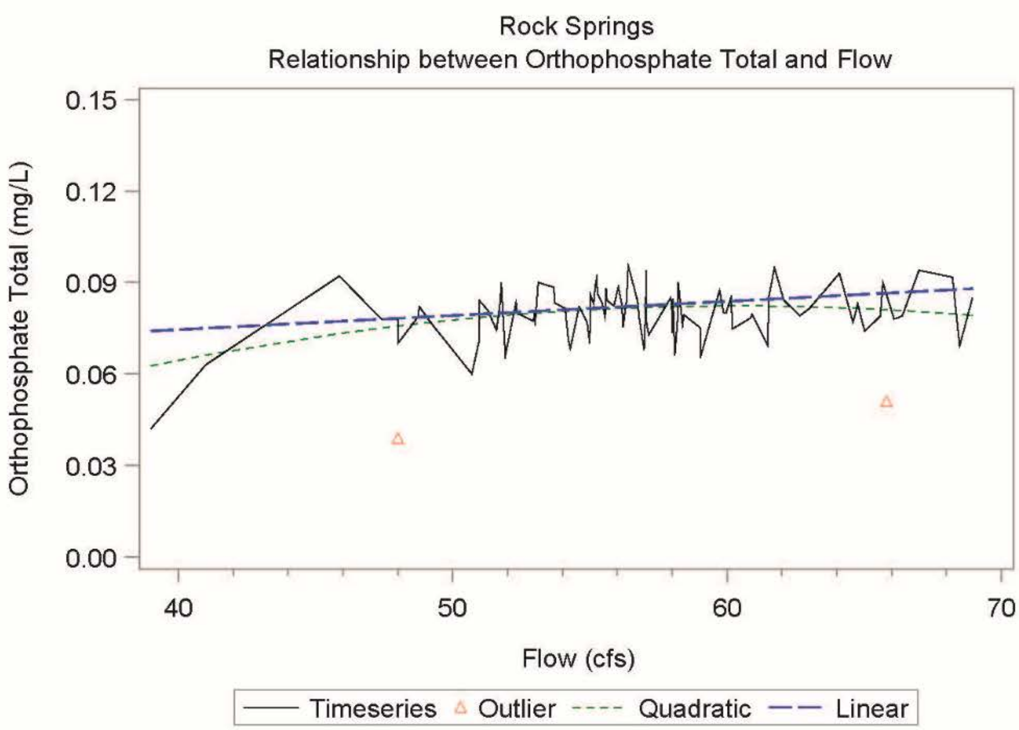
Figures 89 and 90. Time-Series of Nitrate-Nitrite Dissolved (top), and its Relationship with Flow (bottom)



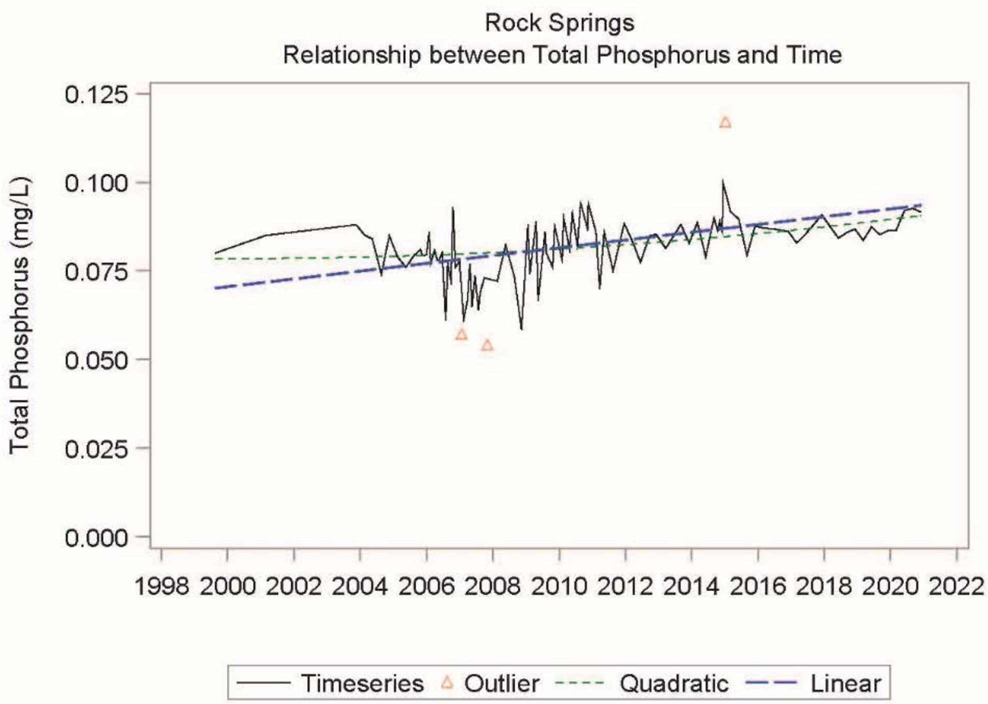


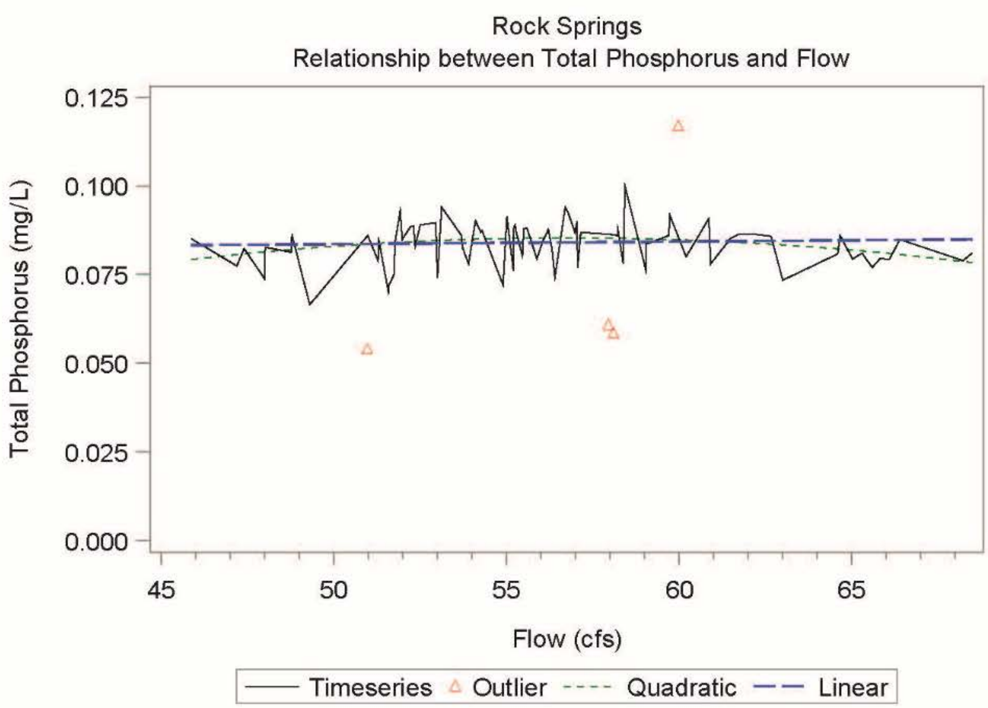
Figures 91 and 92. Time-Series of Orthophosphate Dissolved (top), and its Relationship with Flow (bottom)



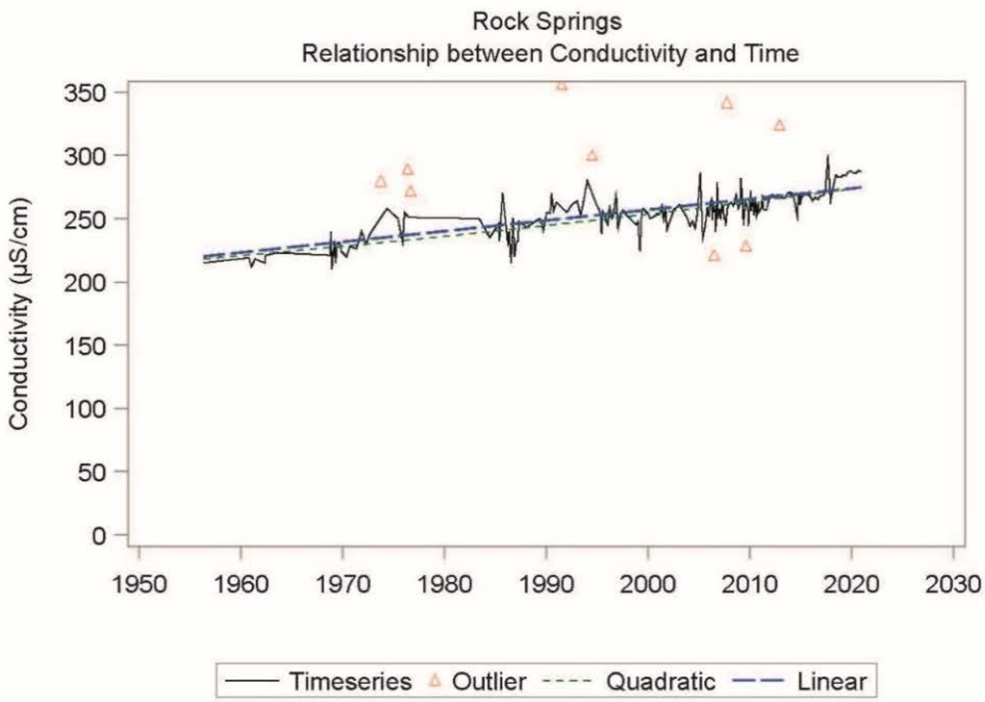


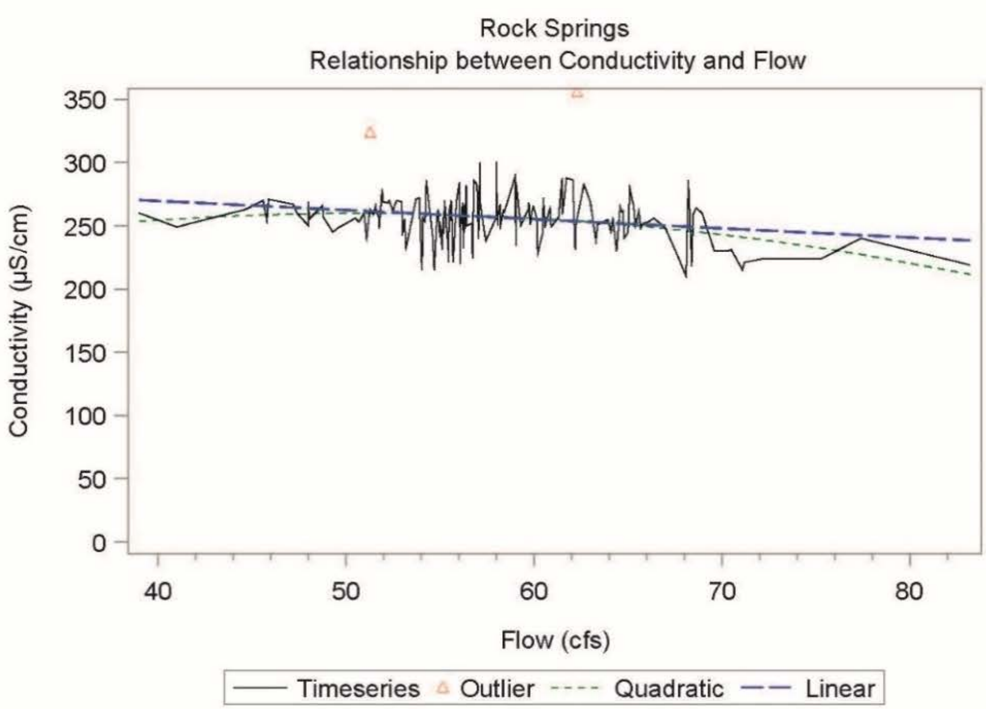
Figures 93 and 94. Time-Series of Orthophosphate Total (top), and its Relationship with Flow (bottom)





Figures 95 and 96. Time-Series of TP (top), and its Relationship with Flow (bottom)





Figures 97 and 98. Time-Series of Conductivity (top), and its Relationship with Flow (bottom)

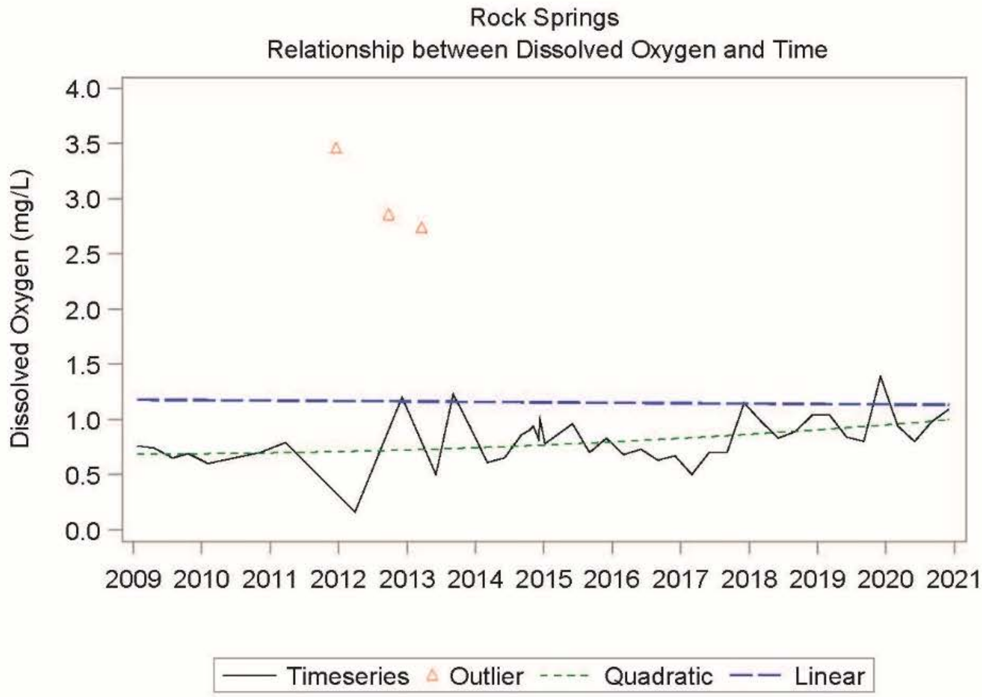
Dissolved oxygen concentrations in Rock Springs are illustrated in Figures 99 and 100. There is no discernible pattern in dO over time and dO values are consistently low. The linear regression suggests a positive relationship with flow, but this appears to be driven by relatively few values; the quadratic regression indicates no relationship of dO with flow. Low dO is not unexpected near a spring vent, given the groundwater source.

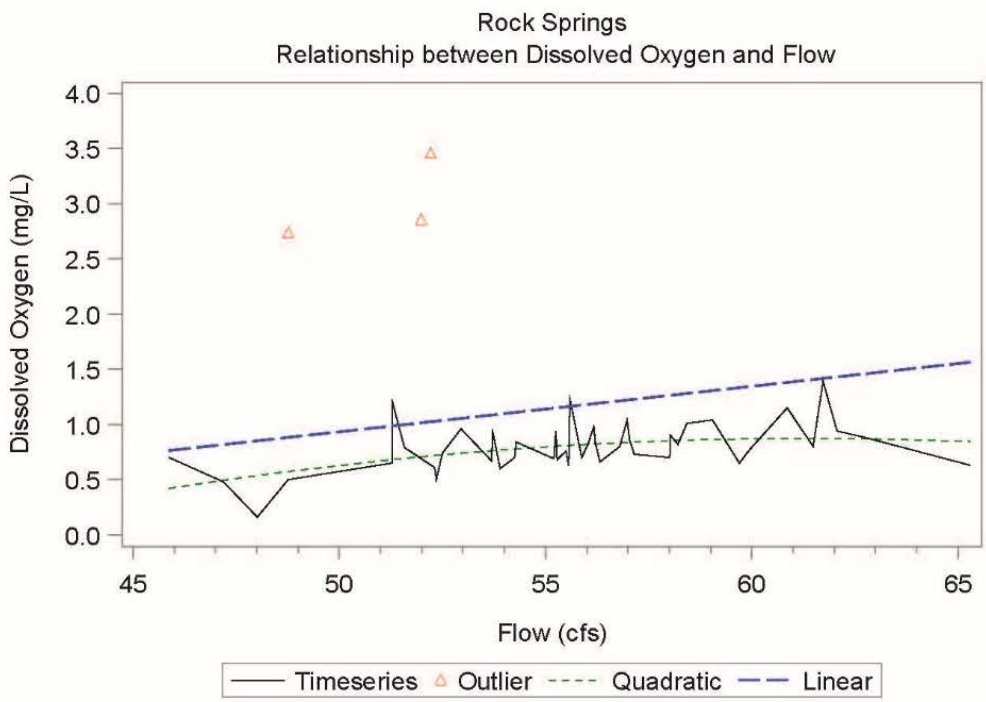
Total dissolved solids appear to have increased slightly over time in Rock Springs (Figures 101 and 102). When plotted against flow, a negative relationship is suggested. Thus, the slight increase in total dissolved solids over time may be due to the overall decline in flows over the period-of-record for Rock Springs.

Turbidity data from Rock Springs were limited but suggest a possible decline over the last decade (Figures 103 and 104). No relationship with flow was apparent.

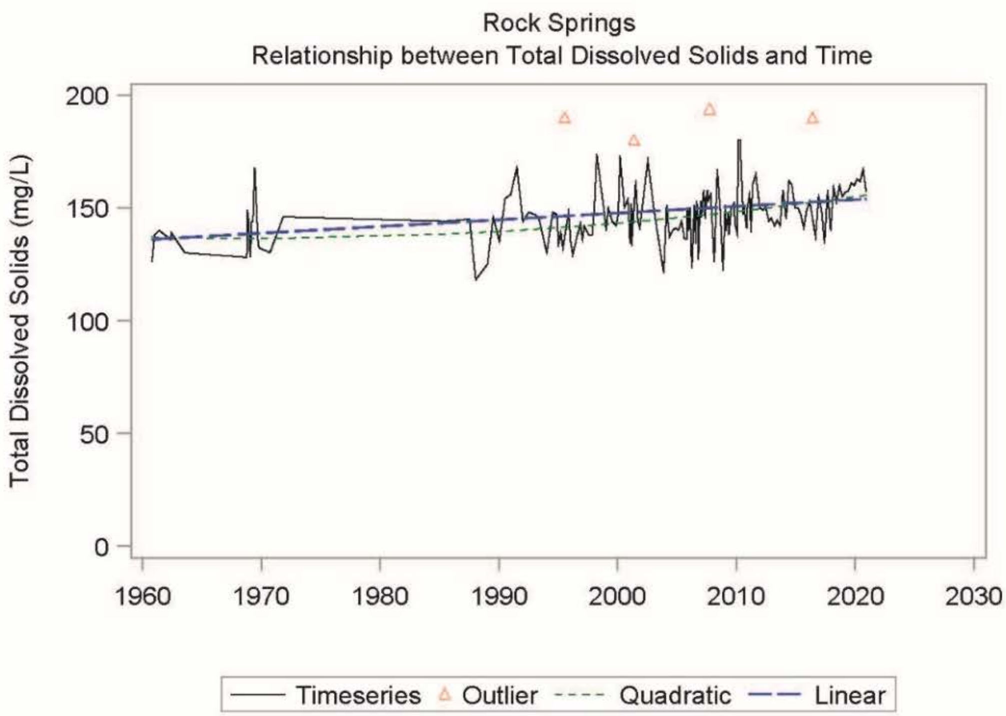
The data for pH reported at Rock Springs is provided in (Figures 105 and 106). No discernable pattern over time, or relative to flow, was apparent. This is not unexpected, given that groundwater flowing into a spring tends to have a buffering capacity, stabilizing pH.

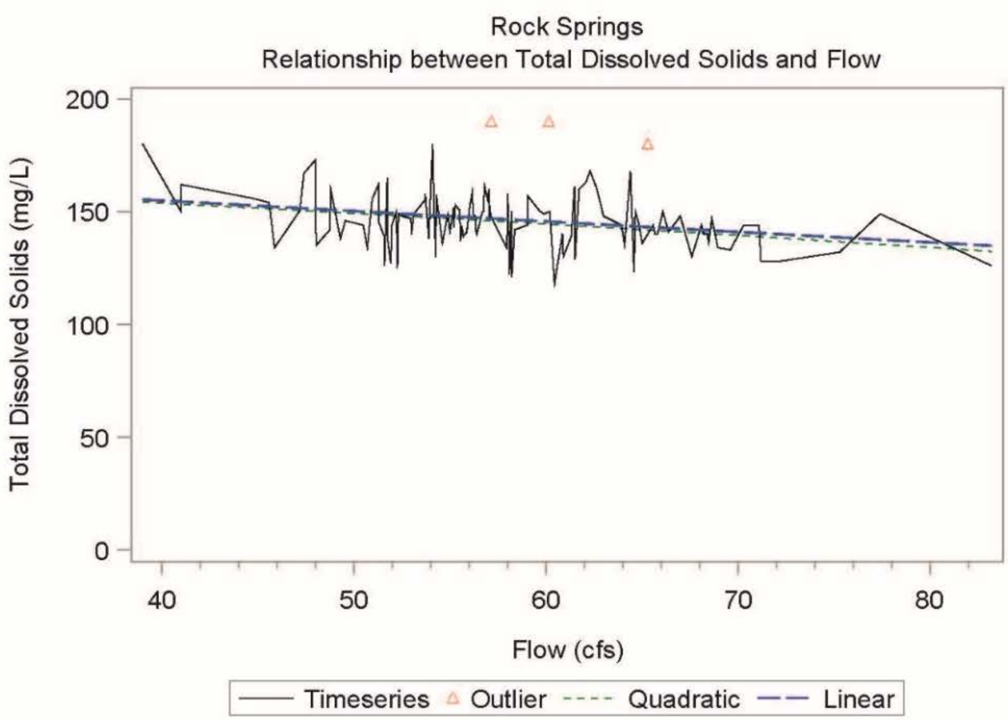
Water temperature in a spring is expected to be relatively constant. This is supported by both the time series and the relationship with flow in Figures 107 and 108. While a slight decrease in water temperature is suggested in the time series, the magnitude of this change is extremely small over a 50-year period.



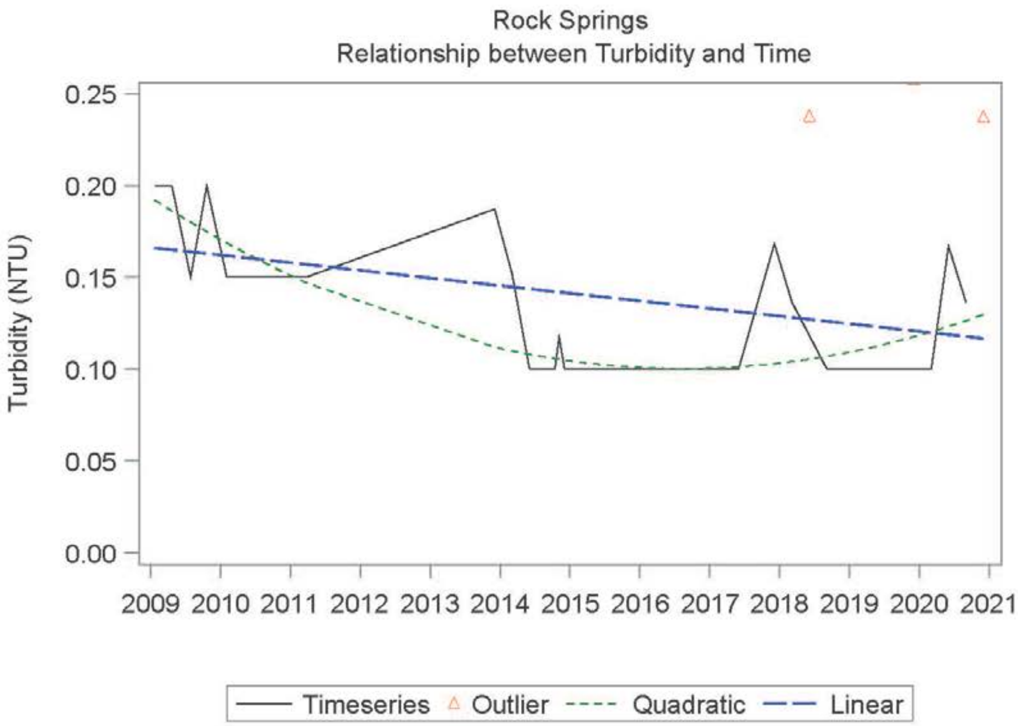


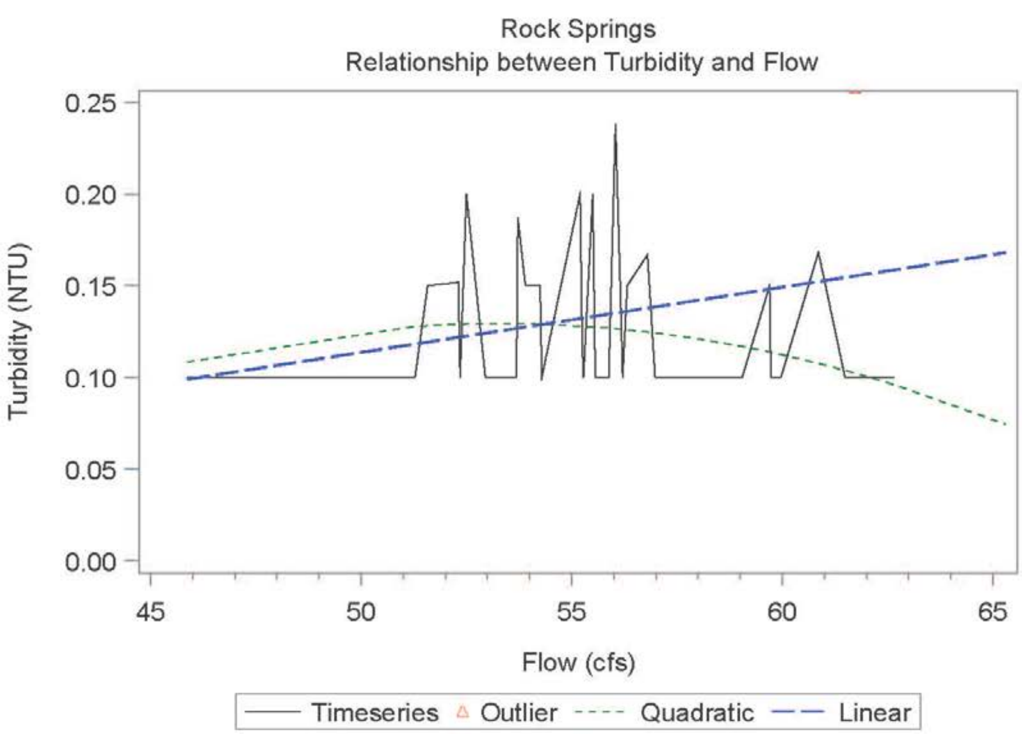
Figures 99 and 100. Time-Series of dO (top), and its Relationship with Flow (bottom)



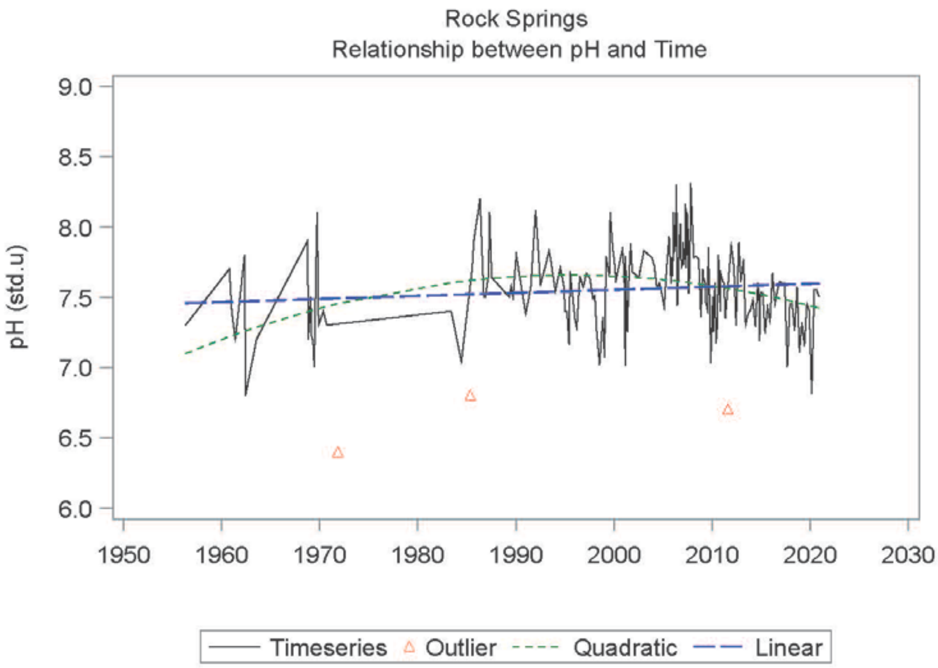


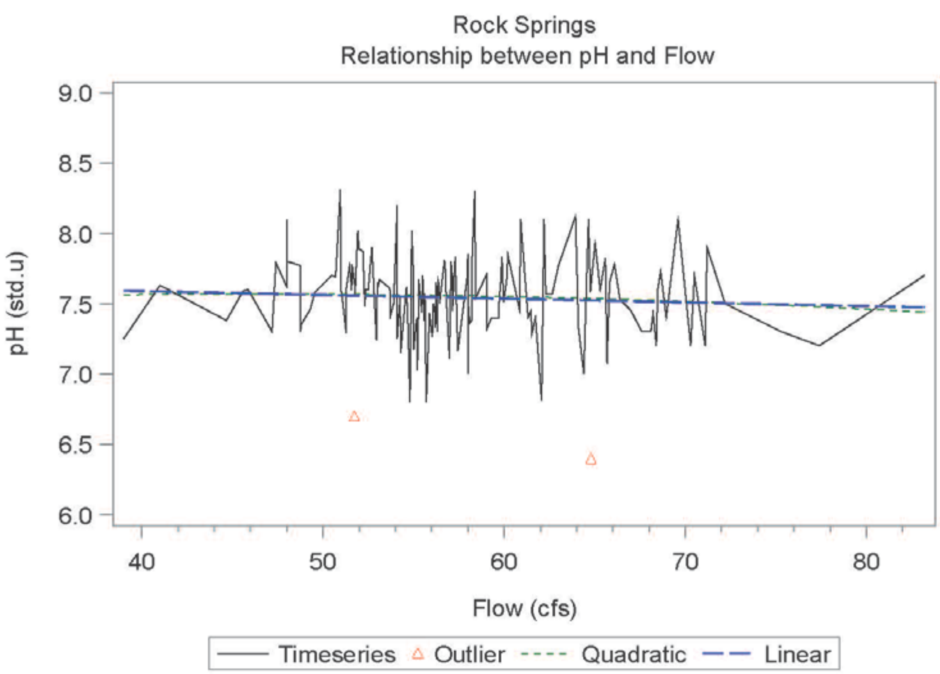
Figures 101 and 102. Time-Series of TDS (top), and its Relationship with Flow (bottom)



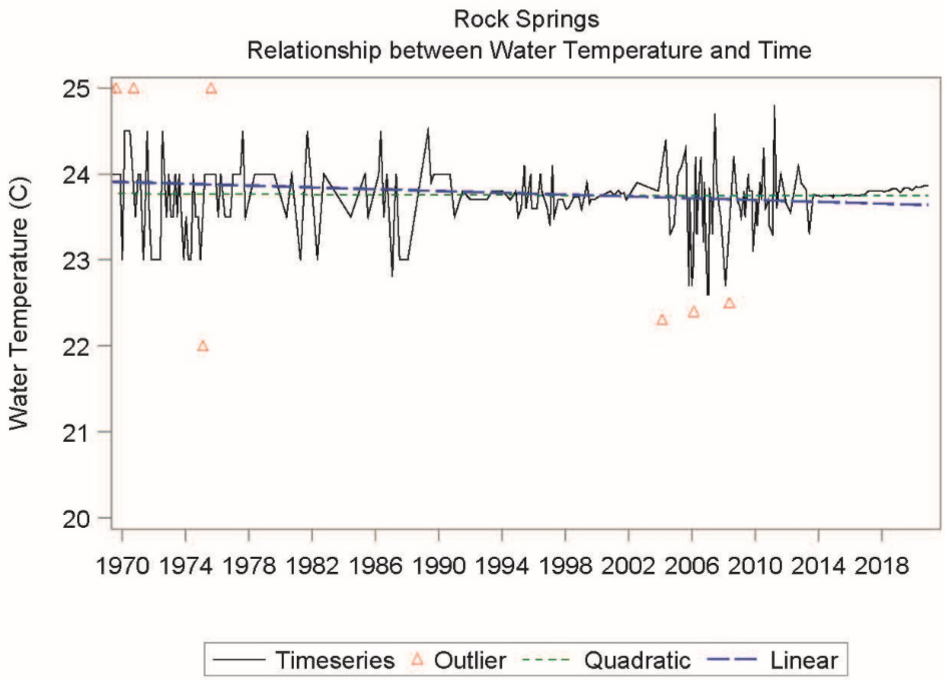


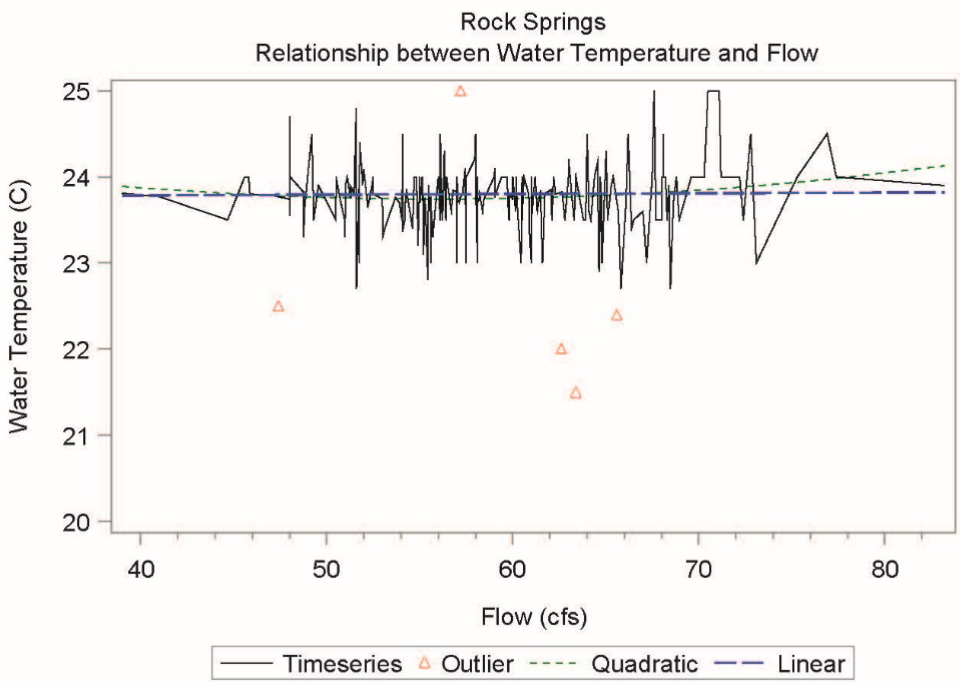
Figures 103 and 104. Time-Series of Turbidity (top), and its Relationship with Flow (bottom)





Figures 105 and 106. Time-Series of pH (top), and its Relationship with Flow (bottom)





Figures 107 and 108. Time-Series of Temperature (top), and its Relationship with Flow (bottom)

Little Wekiva river

The data used for the Little Wekiva River analyses were obtained from the SJRWMD gage LW-MP (see Figure E-46 in Main Report). Discharge data were obtained from the USGS station 02234990 (Little Wekiva River near Altamonte Springs, FL). The top graph in each pair provides a time series plot over the 2006-2020 time period (note, period-of-record may vary by parameter).

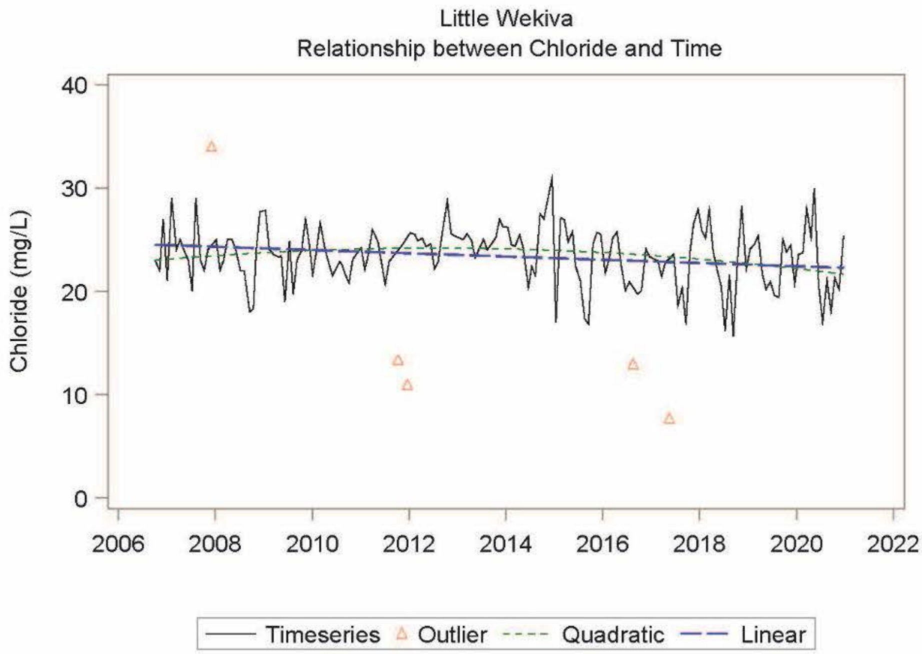
Chloride values (Figures 109 and 110) in the Little Wekiva River displayed intra- and inter-annual variation but overall decreased only slightly over the 2006-2020 period-of-record. As flow values increase, chloride values show a slight decline.

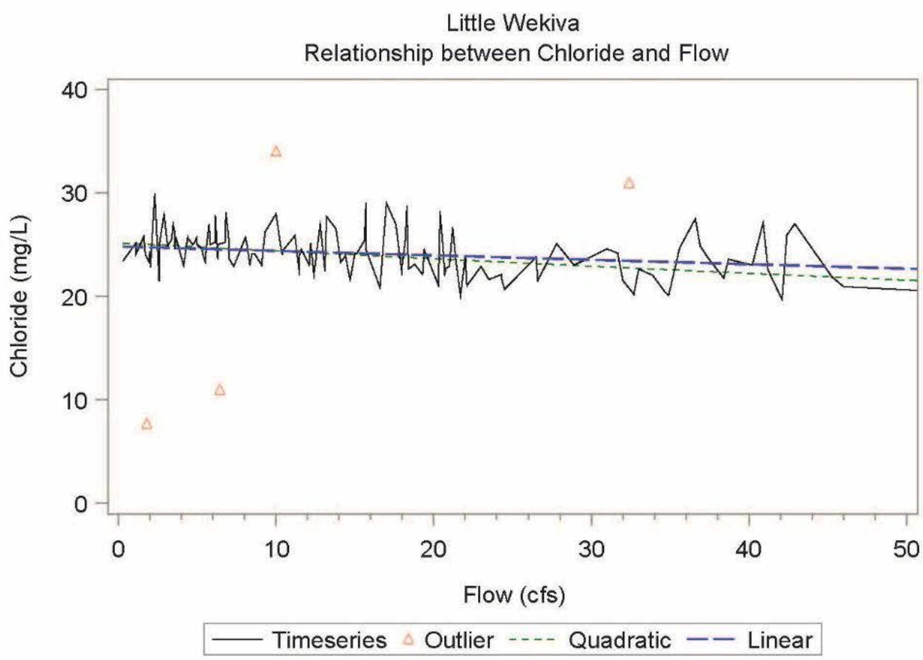
Dissolved ammonia values in the Little Wekiva River did not exhibit a temporal trend over the period-of-record (Figures 111 and 112), remaining fairly consistent but with inter- and intra-annual variability. Examination of the relationship of ammonia concentrations with discharge also did not indicate any trends in the data. Nitrate-nitrite values (dissolved; Figures 113 and 114), while exhibiting inter-annual variation, overall reflect a decline over the period-of-record. Regressions of nitrate-nitrite values with flow suggest a shallow-sloped inverse relationship, with slightly lowered nitrate-nitrite values at higher flows.

Total Kjeldahl nitrogen (TKN) has varied over the period-of-record, but an increase over time is suggested (Figures 115 and 116). A positive relationship with flow is also indicated, particularly by the quadratic regression, despite some outlier values. Total nitrogen is calculated as the sum of nitrate+nitrite and TKN. As illustrated in Figures 113 and 114 and Figures 115 and 116, the patterns for nitrate-nitrite and TKN, while slight, are opposite of each other. While inter-annual variability is evident in the time series for total nitrogen (Figures 117 and 118), there is no detected trend in the total nitrogen data for the Little Wekiva River over the period-of-record. A strong relationship between total nitrogen and flow is also not evident.

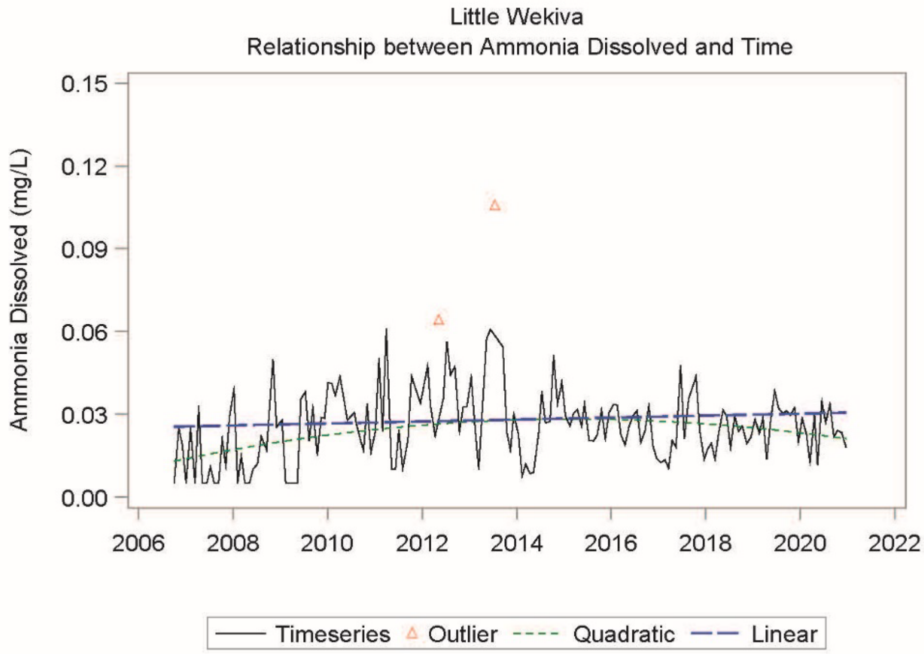
Dissolved orthophosphate values exhibit a declining trend over the period-of-record (Figures 119 and 120). A wider range of orthophosphate values is observed at flows greater than 30 cfs than below 30 cfs. The linear and quadratic regressions suggest a decline in concentrations with increasing flow values. Similar to dissolved orthophosphate, total phosphorus exhibits a low-slope decline over the period-of-record, but lacks an apparent relationship with flow (Figures 121 and 122. High concentration outlier values occur over the examined range of flows.

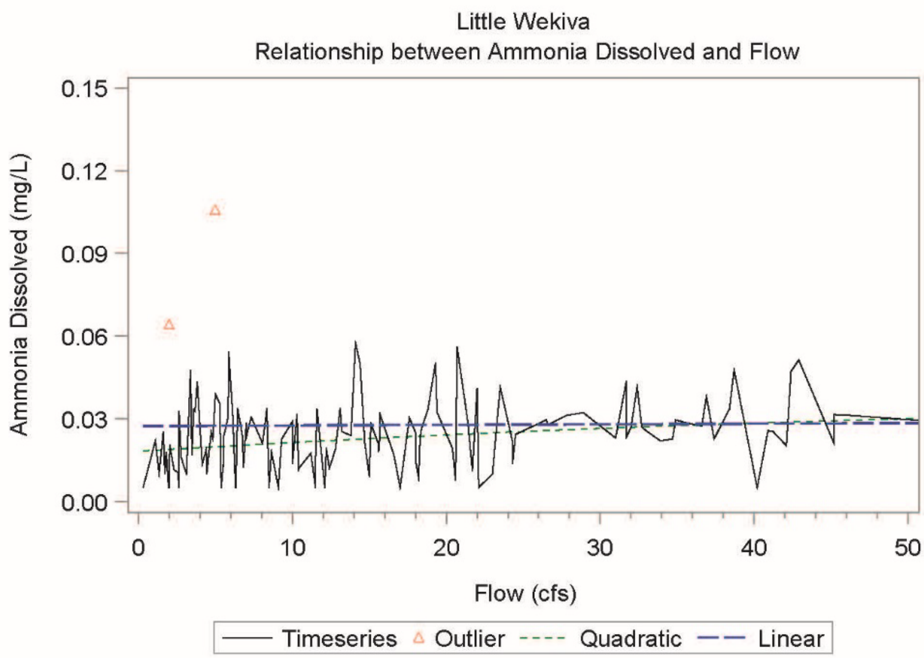
The period-of-record for chlorophyll (corrected for pheophytin) data in the Little Wekiva River is relatively short, and no pattern is evident in the time series; values never exceed 10 micrograms per liter (µg/L) (Figures 123 and 124). A positive relationship with flow is indicated by both the linear and quadratic regression lines, however high outlier values occur over the examined range of flows.



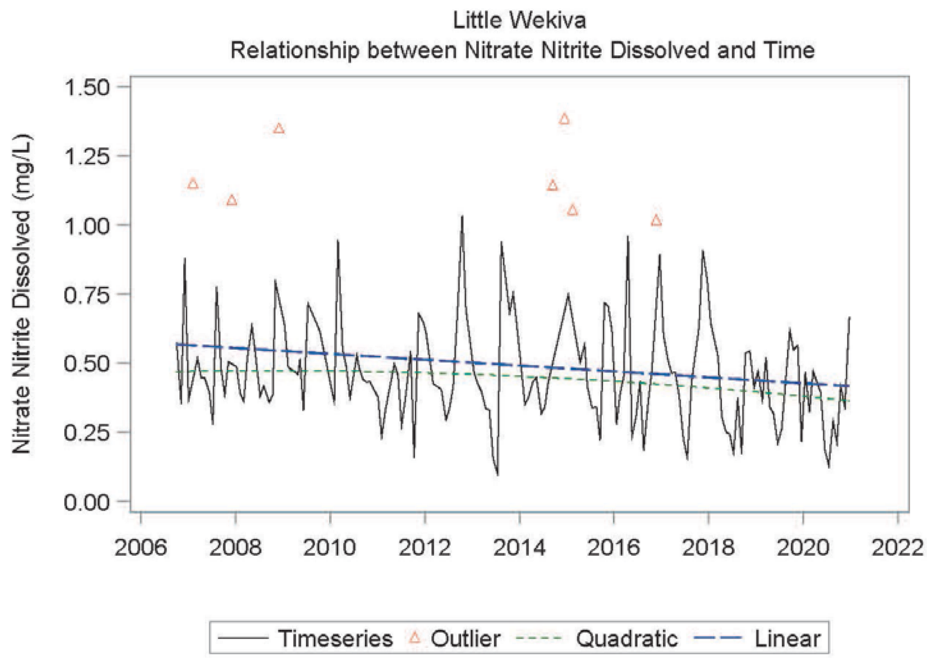


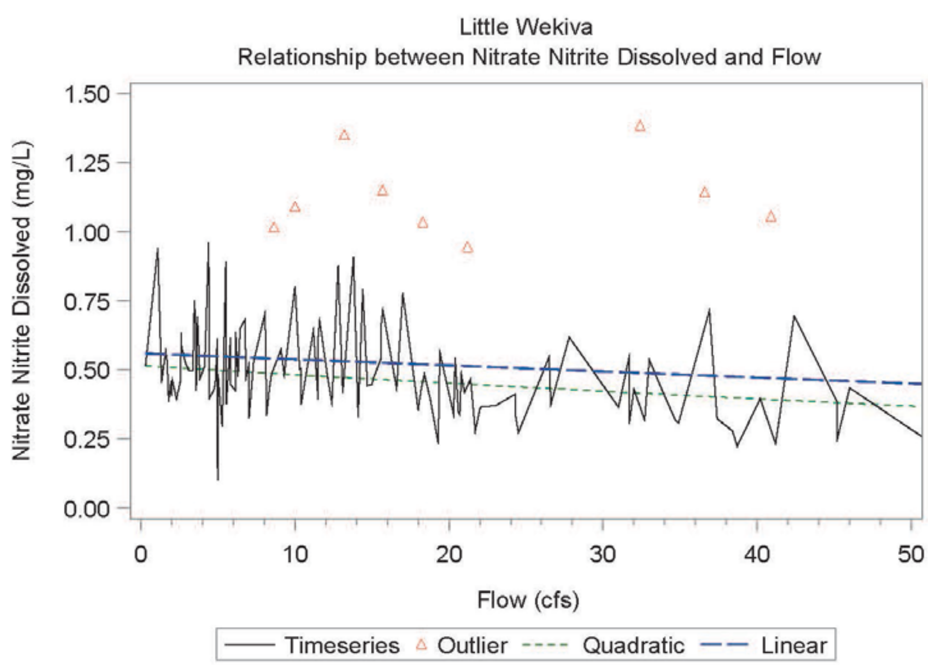
Figures 109 and 110. Time-Series of Chloride (top), and its Relationship with Flow (bottom)



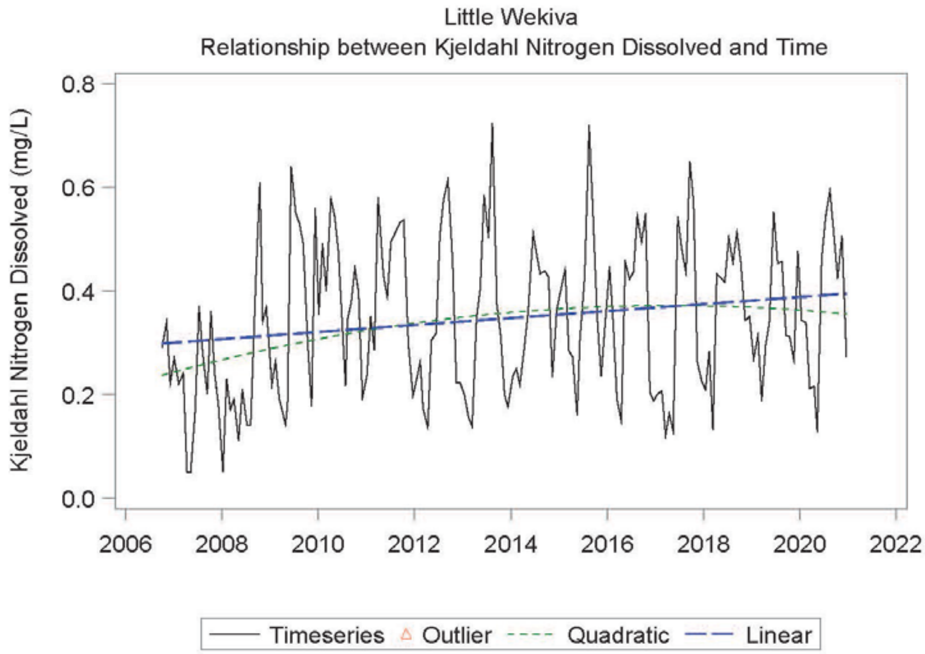


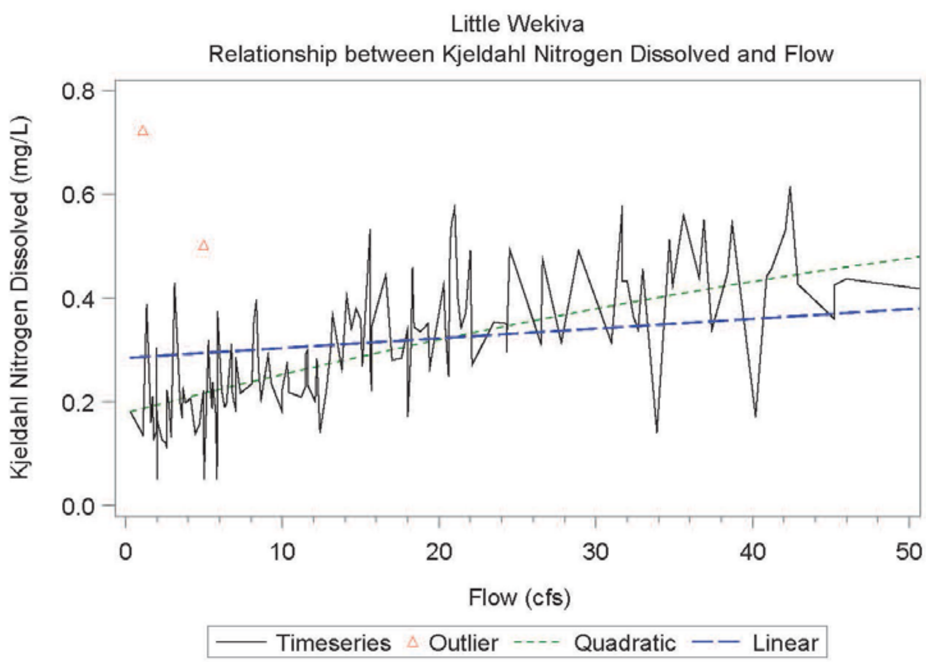
Figures 111 and 112. Time-Series of Ammonia Dissolved (top), and its Relationship with Flow (bottom)



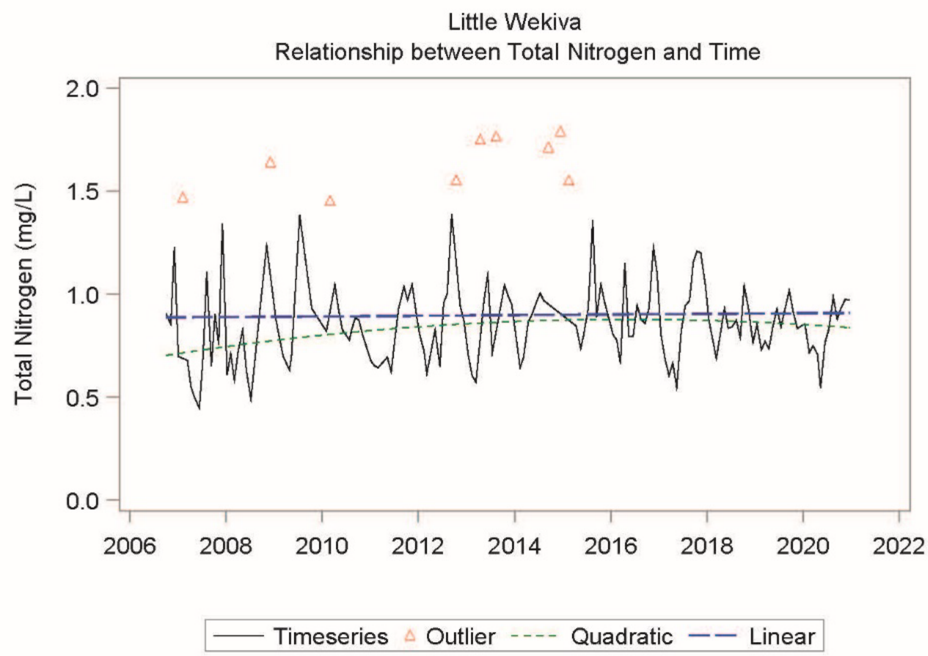


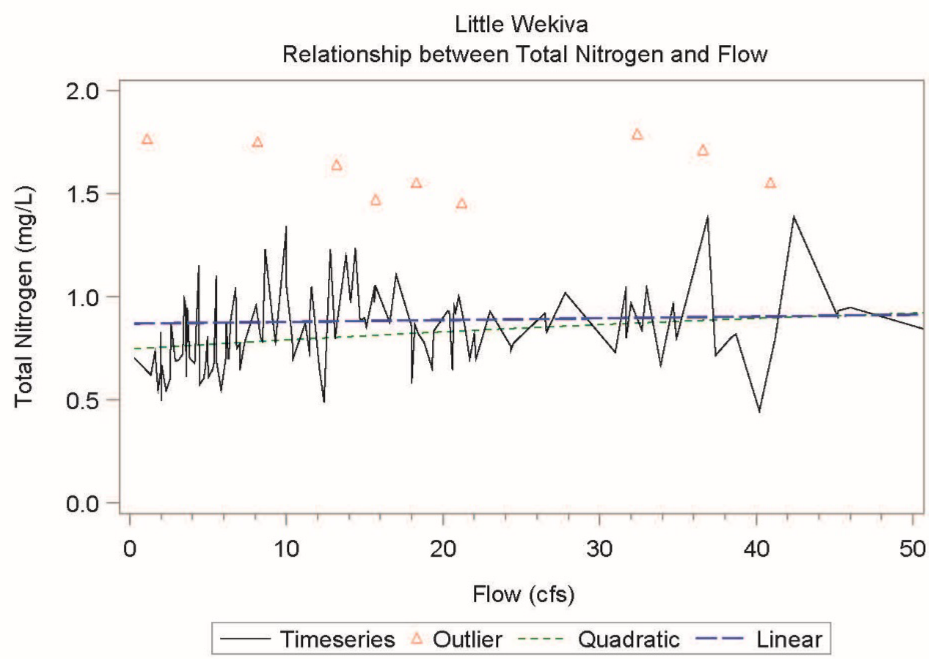
Figures 113 and 114. Time-Series of Nitrate-Nitrite Dissolved (top), and its Relationship with Flow (bottom)



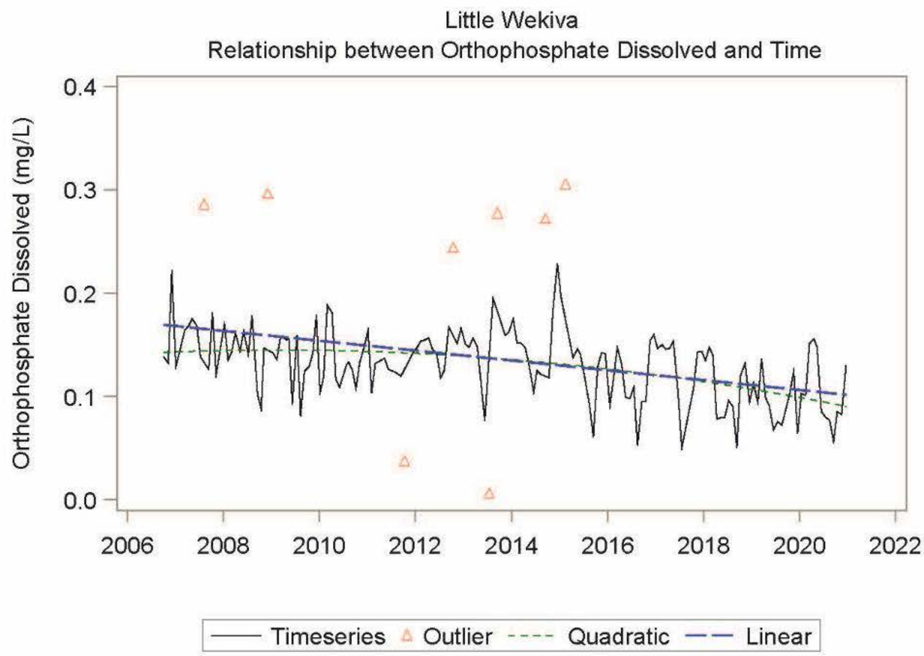


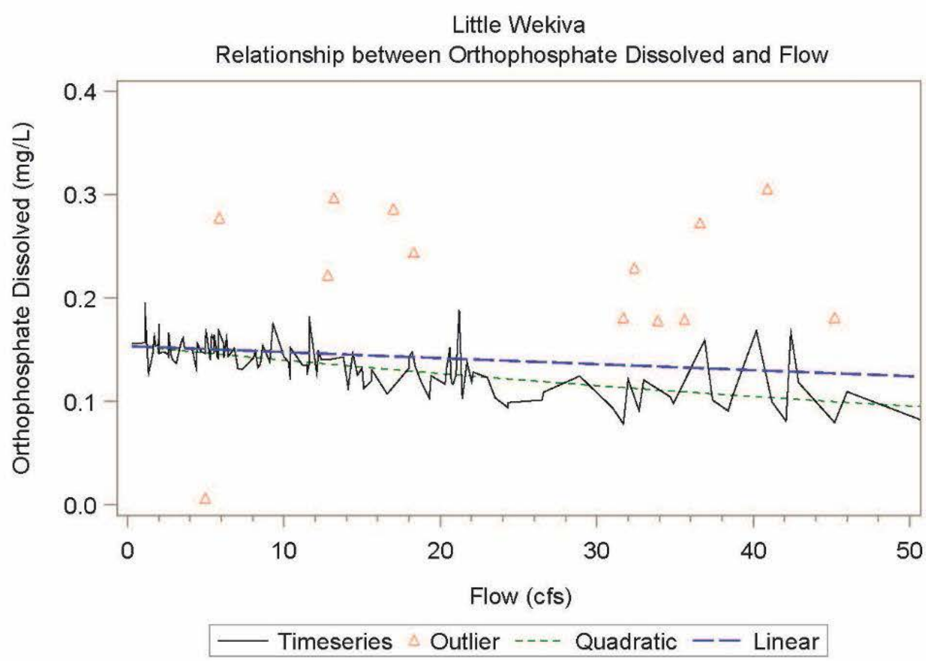
Figures 115 and 116. Time-Series of TKN (top), and its Relationship with Flow (bottom)



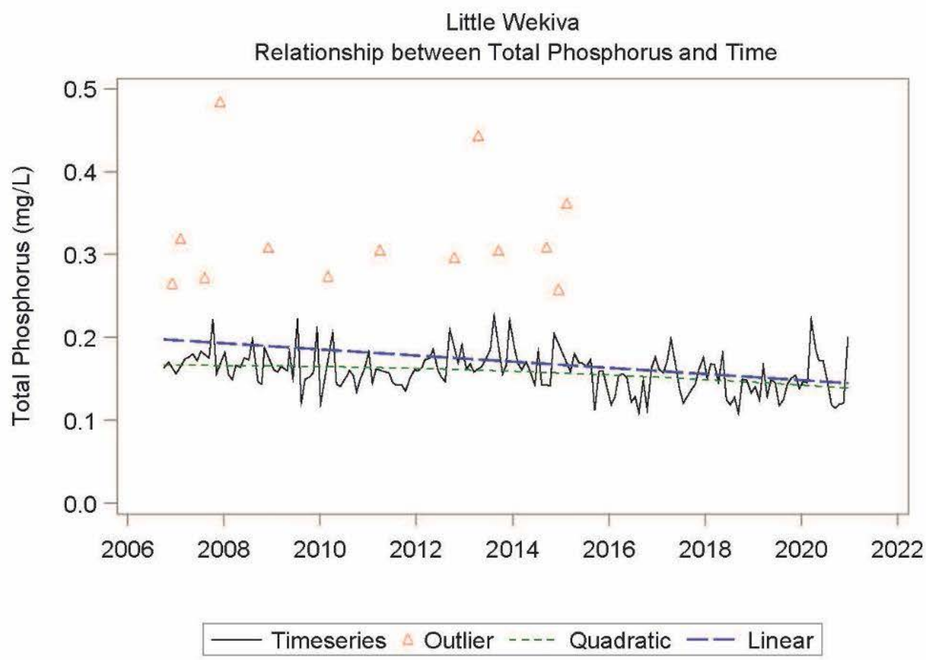


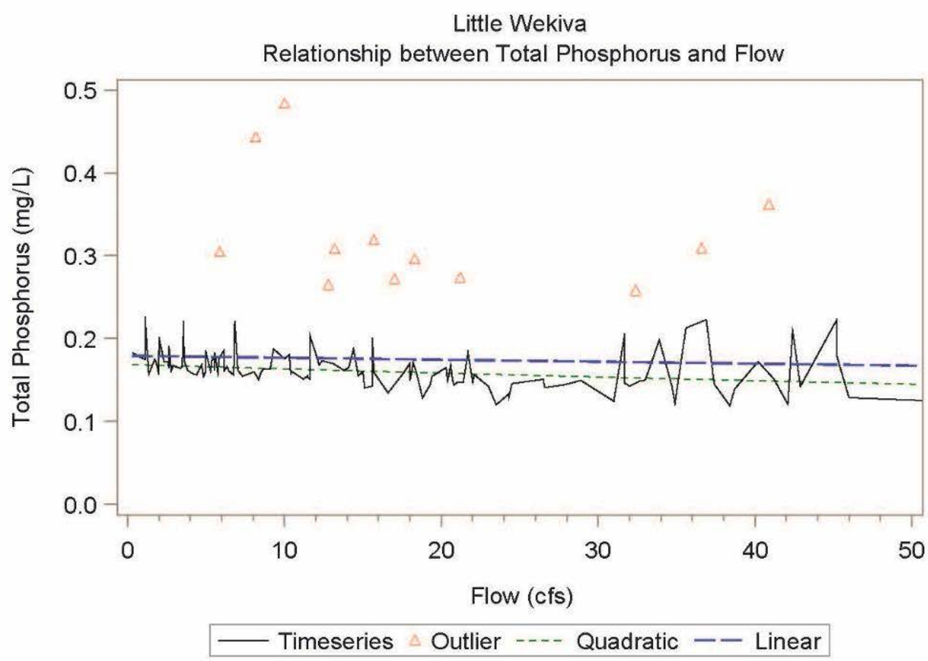
Figures 117 and 118. Time-Series of TN (top), and its Relationship with Flow (bottom)



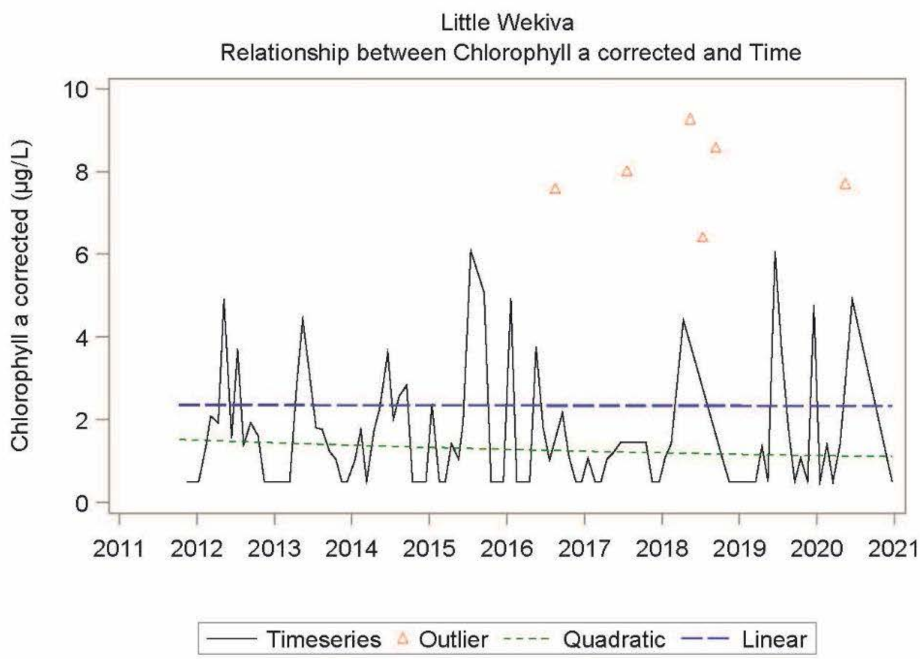


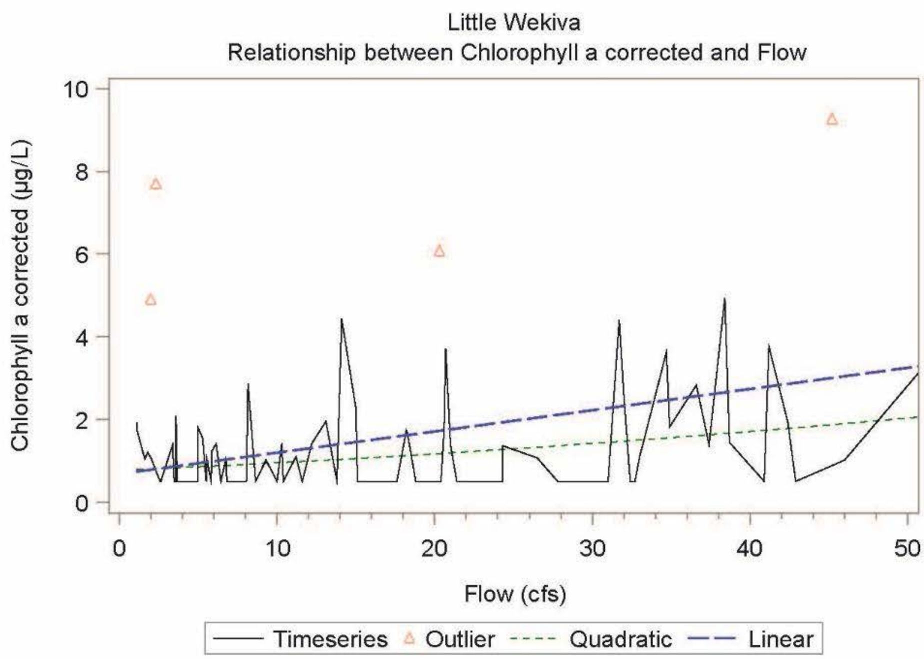
Figures 119 and 120. Time-Series of Orthophosphate Dissolved (top), and its Relationship with Flow (bottom)





Figures 121 and 122. Time-Series of TP (top), and its Relationship with Flow (bottom)





Figures 123 and 124. Time-Series of Chlorophyll a (top), and its Relationship with Flow (bottom)

Conductivity values varied over a relatively narrow range [within approximately 200 microSiemen per centimeter (µS/cm)] over the period-of-record in the Little Wekiva River, with a shallow declining trend suggested over this timeframe (Figures 125 and 126). A negative relationship with flow is indicated, particularly by the quadratic regression, though the absolute change in value is small, since conductivity is consistently below 400 µS/cm.

Dissolved oxygen concentrations over the period-of-record in the Little Wekiva River are illustrated in Figures 127 and 128. There is no indicated trend in concentration over the time series. Values were typically greater than 4 mg/L. A shallow-sloped negative relationship with flow is indicated, particularly by the quadratic regression.

Dissolved oxygen saturation values were contained in the SJRWMD database subsequent to late 2012. However, given that temperature and salinity data were reported earlier than that, dissolved oxygen saturation values were calculated for the available period-of-record (Figures 129 and 130). Unlike dissolved oxygen concentration (Figures 127 and 128), dissolved oxygen saturation levels appear to decline over the period-of-record. A shallow negative relationship with flow is suggested.

While total dissolved solids concentrations fluctuated over the period-of-record, there is an indication of a shallow-sloped negative trend in the time series (Figures 131 and 132). A shallow-sloped relationship between total dissolved solids and flow rate was suggested also by the regressions.

Linear regression of TSS indicates a shallow-sloped decline over the period-of-record (Figures 133 and 134). A shallow-sloped positive relationship is indicated with flow, however the frequency of sampled collected at flow rates greater than 25 cfs is much reduced compared to the frequency of samples at lower flow rates and outlier values occur over much of the range of flows.

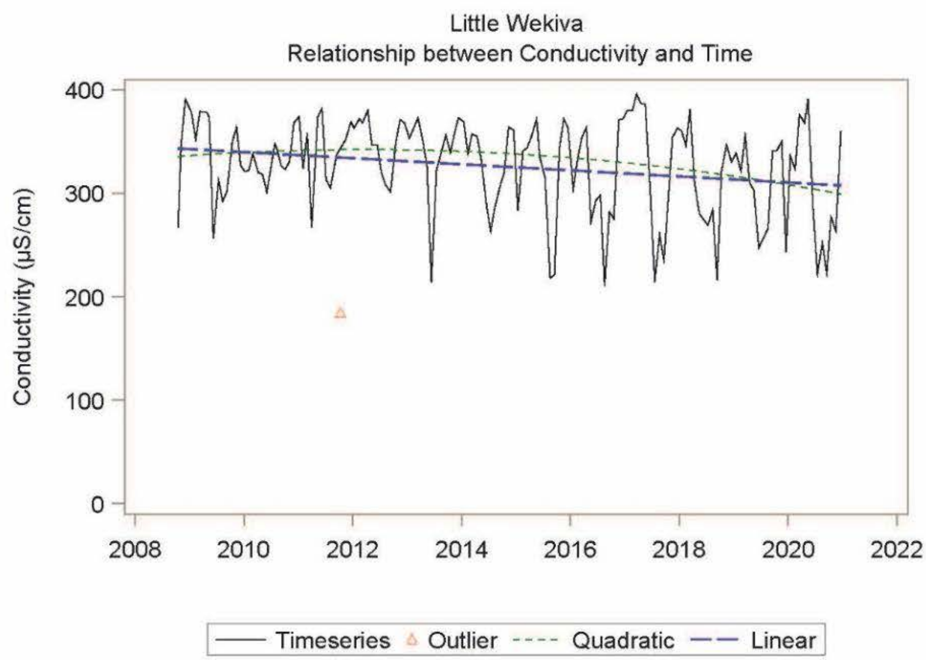
Color levels in the Little Wekiva River appear to have increased gradually over the 2006-2020 period-of-record (Figures 135 and 136), as evidenced by both the linear and quadratic regressions. Figure 135 also illustrates the level of intra-annual variability. An examination of the relationship of color with flow suggests a positive relationship. Thus, seasonal changes in flow may account for much of the intra-annual variability observed in the time series.

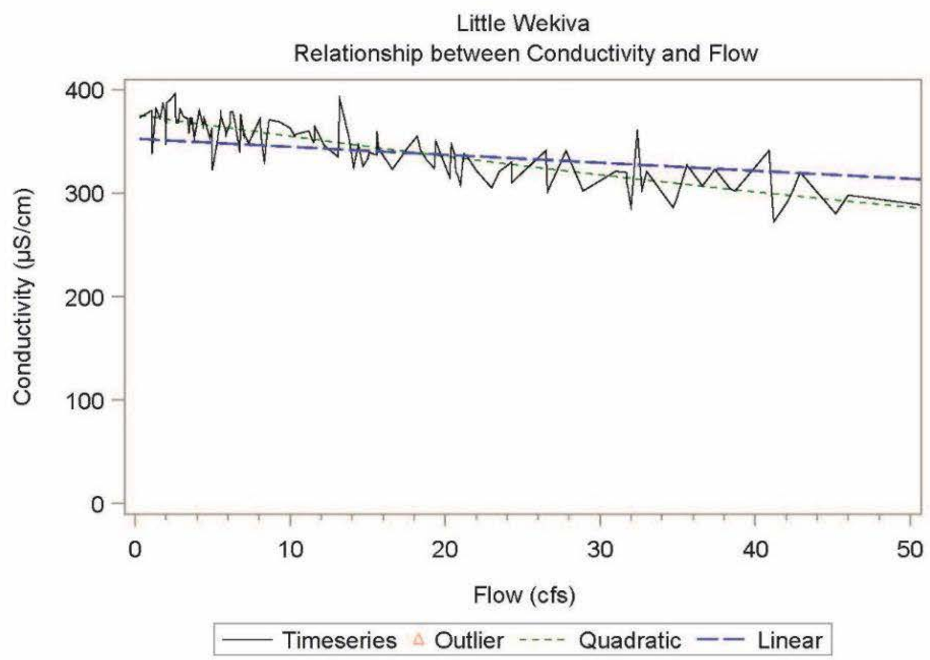
Along with gradual increases in color of the period-of-record, the clarity of the river appears to have been reduced as indicated by a reduction in Secchi depth over the same period (Figures 137 and 138). However, no relationship between Secchi depth and flow was indicated.

Dissolved organic carbon (DOC) levels indicate an increasing trend over the period-of-record (Figures 139 and 140). The time series also illustrates the intra-annual variability in DOC concentrations. Given the positive relationship with flow indicated by the quadratic regression, this intra-annual variation is probably largely influenced by land-based inputs added via runoff in the wet season.

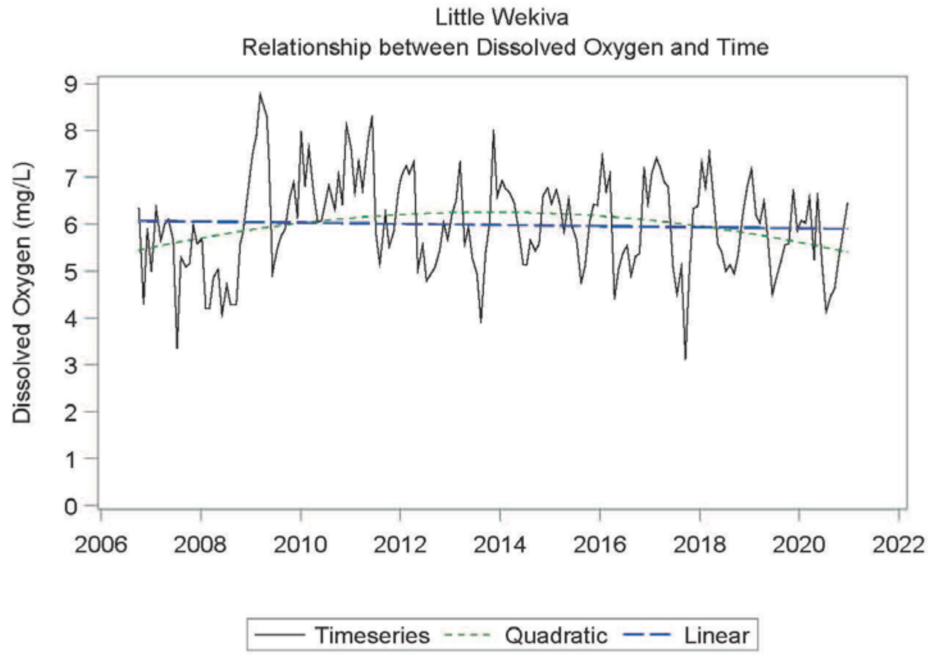
Figures 141 and 142 illustrate an oscillation of pH levels in the Little Wekiva River over the period-of-record, but no consistent directional trend. A slight negative relationship with flow is exhibited, however pH values do not exhibit a wide range of values and were collected at a lower frequency at higher flows than at lower flows.

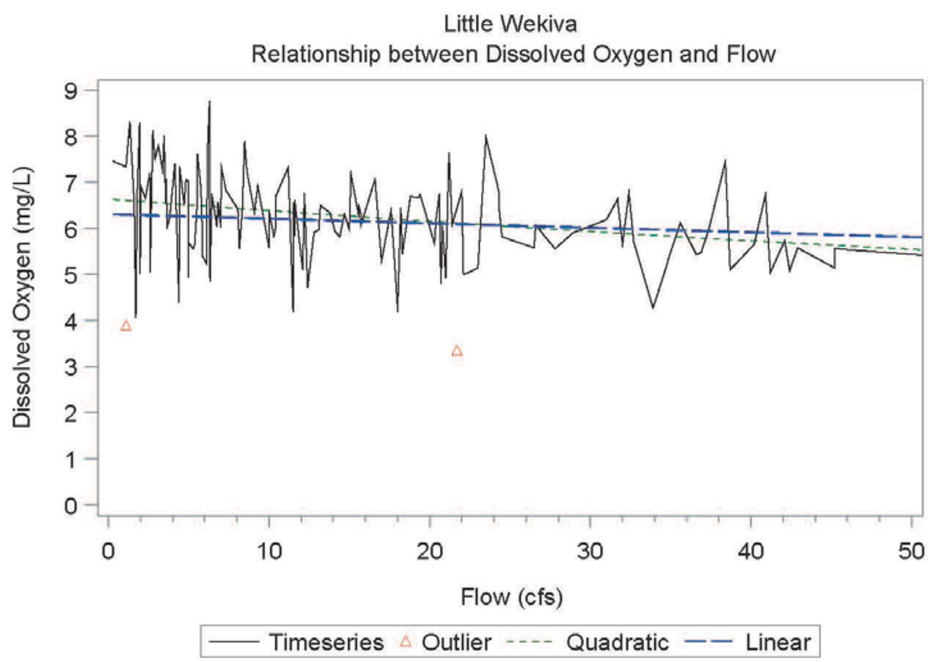
Water temperature values appear to have increased slightly over the period-of-record, while exhibiting seasonal patterns of variability (Figures 143 and 144). A shallow positive relationship with flow is also indicated. However, this could be correlated with seasonality as flow values may be greater during the warmer wet season months.



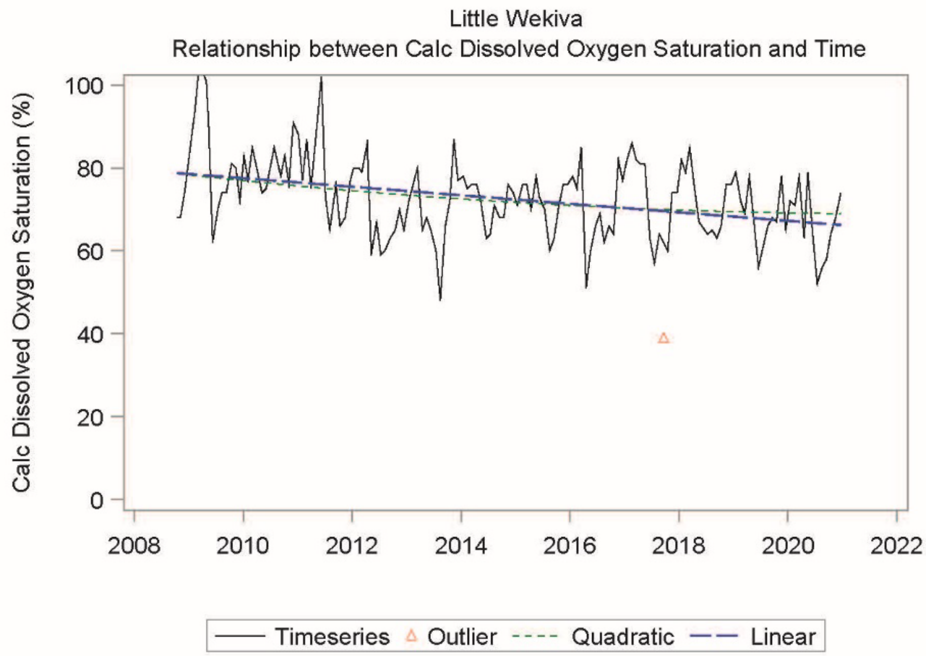


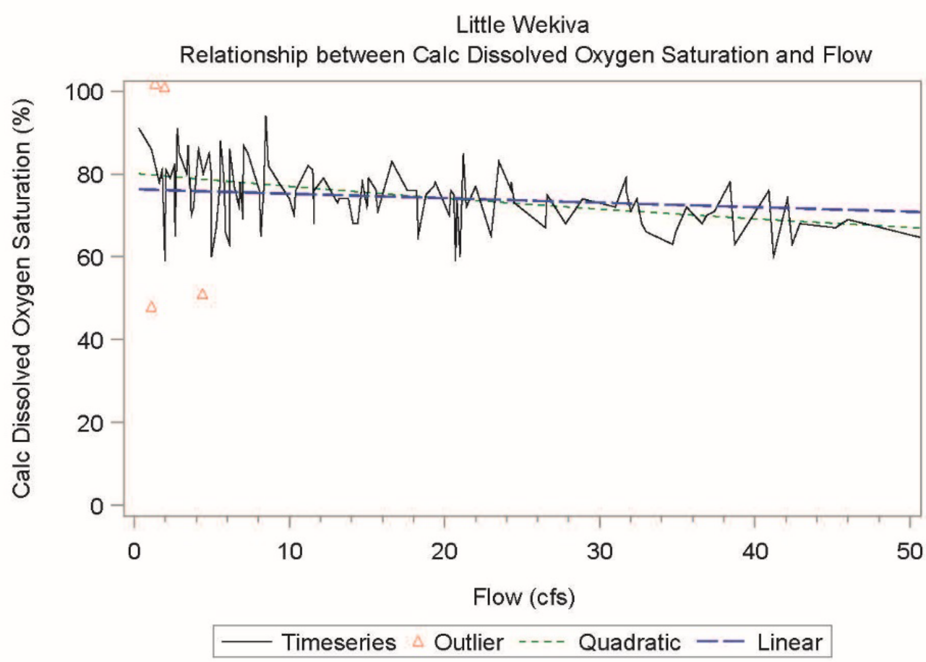
Figures 125 and 126. Time-Series of Conductivity (top), and its Relationship with Flow (bottom)



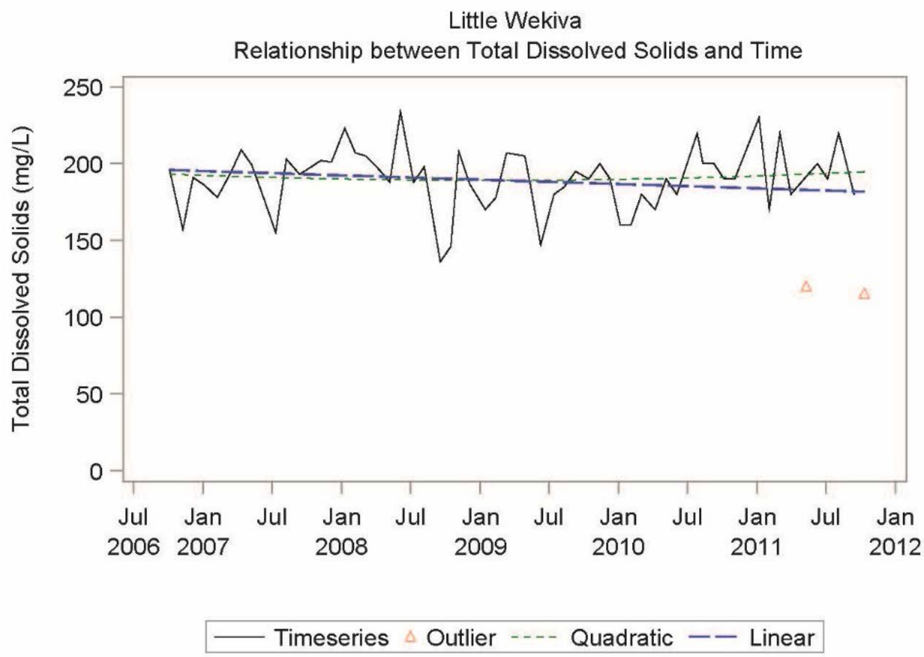


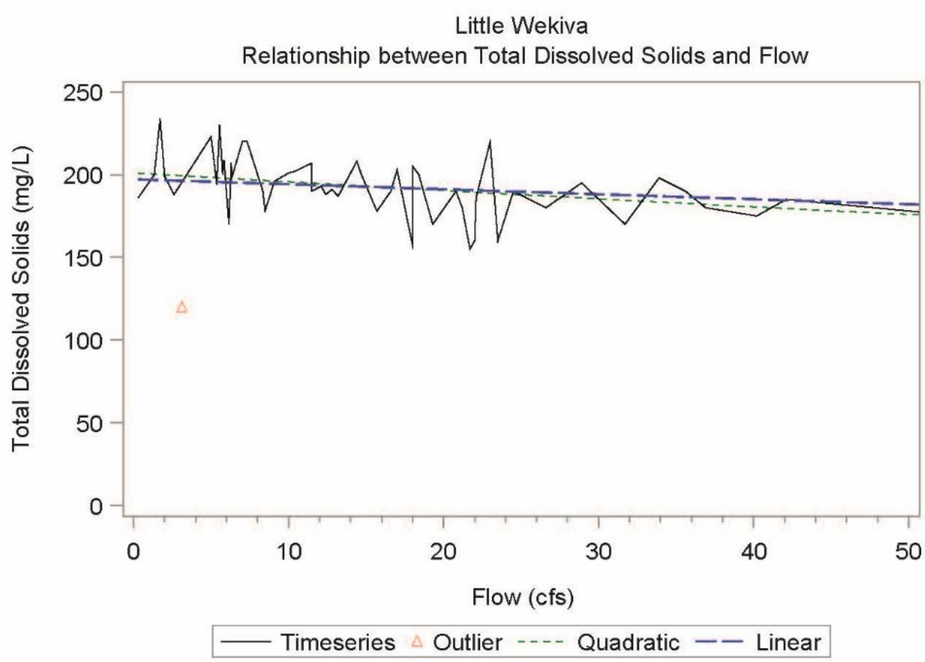
Figures 127 and 128. Time-Series of dO (top), and its Relationship with Flow (bottom)



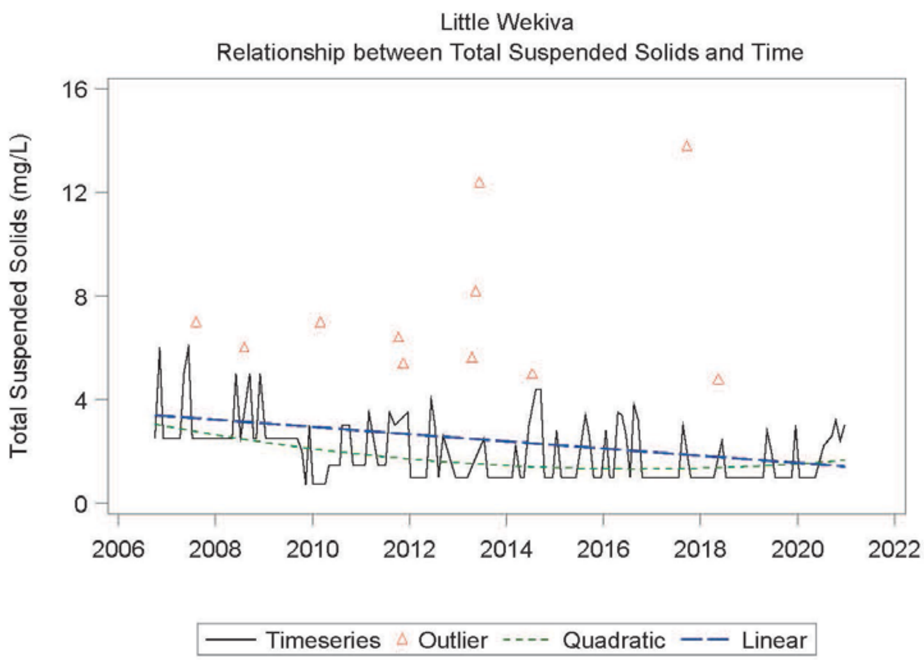


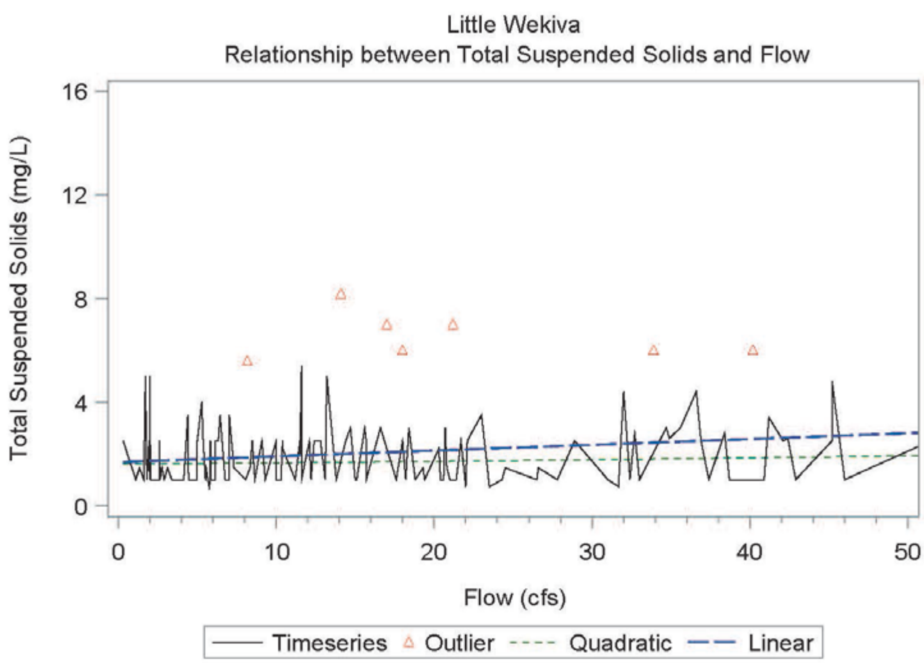
Figures 129 and 130. Time-Series of Calculated dO (top), and its Relationship with Flow (bottom)



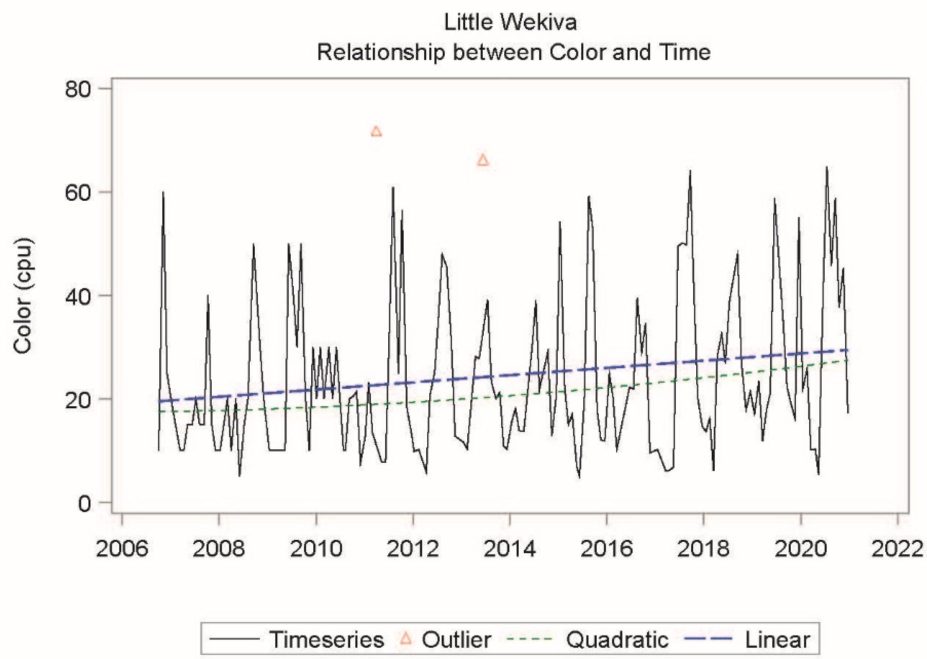


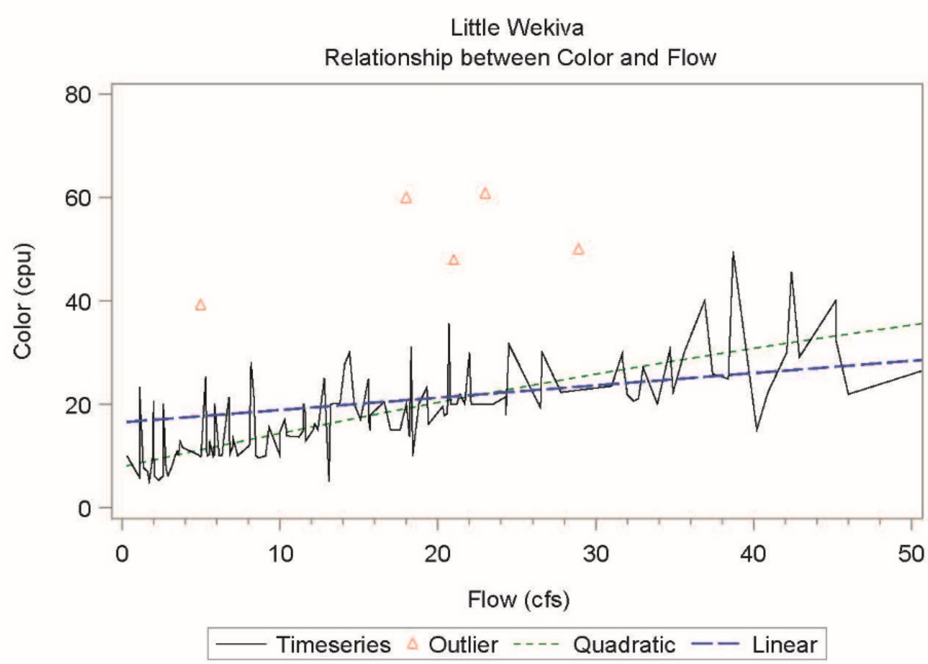
Figures 131 and 132. Time-Series of TDS (top), and its Relationship with Flow (bottom)



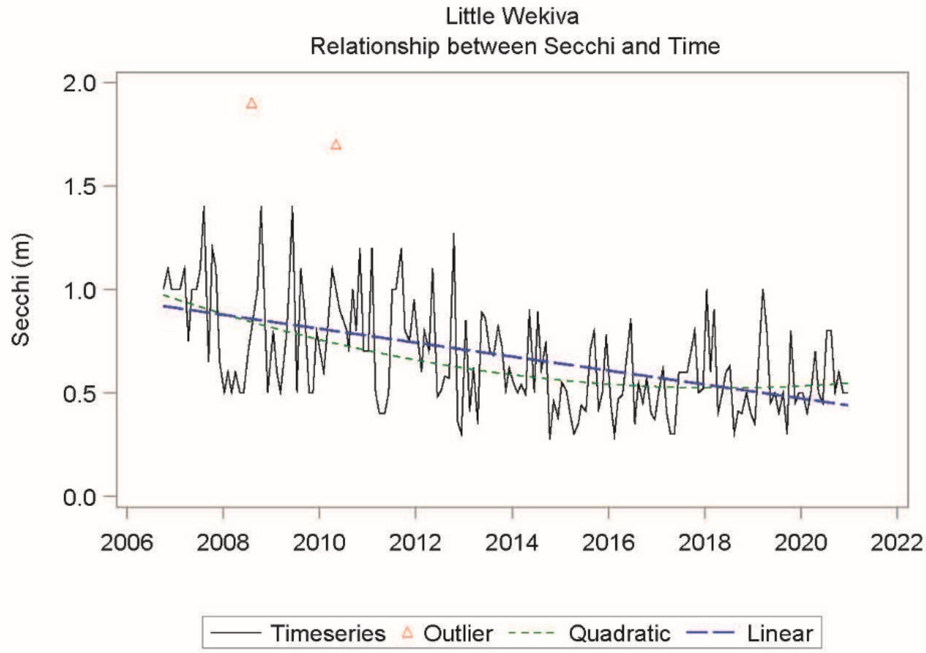


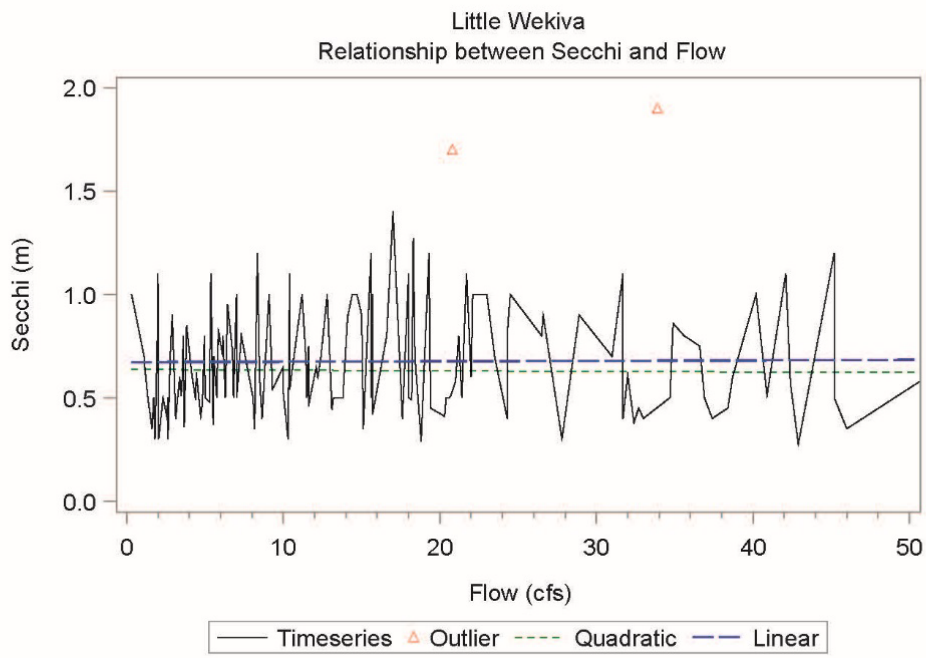
Figures 133 and 134. Time-Series of TSS (top), and its Relationship with Flow (bottom)



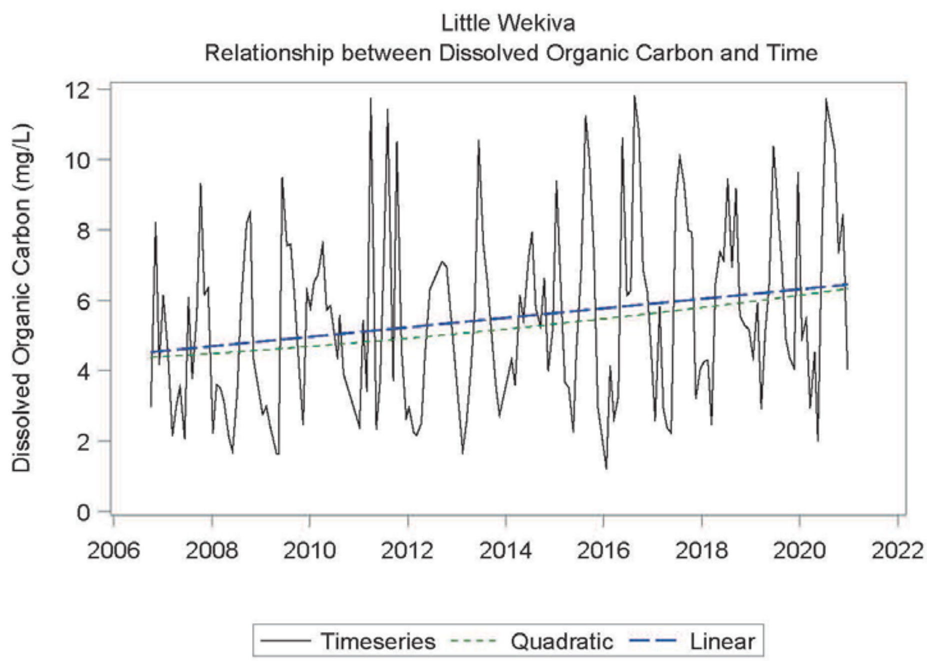


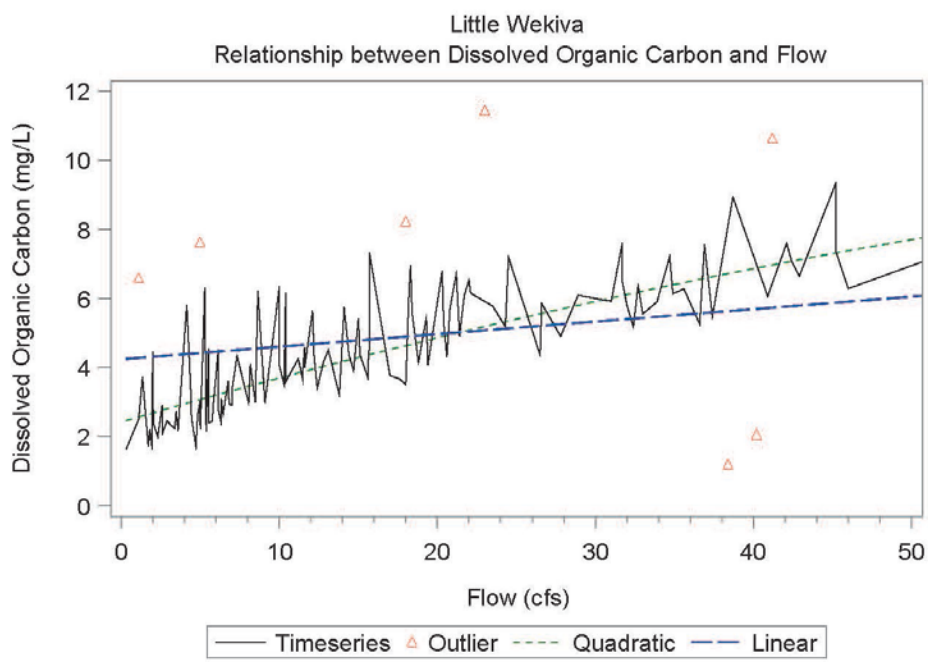
Figures 135 and 136. Time-Series of Color (top), and its Relationship with Flow (bottom)



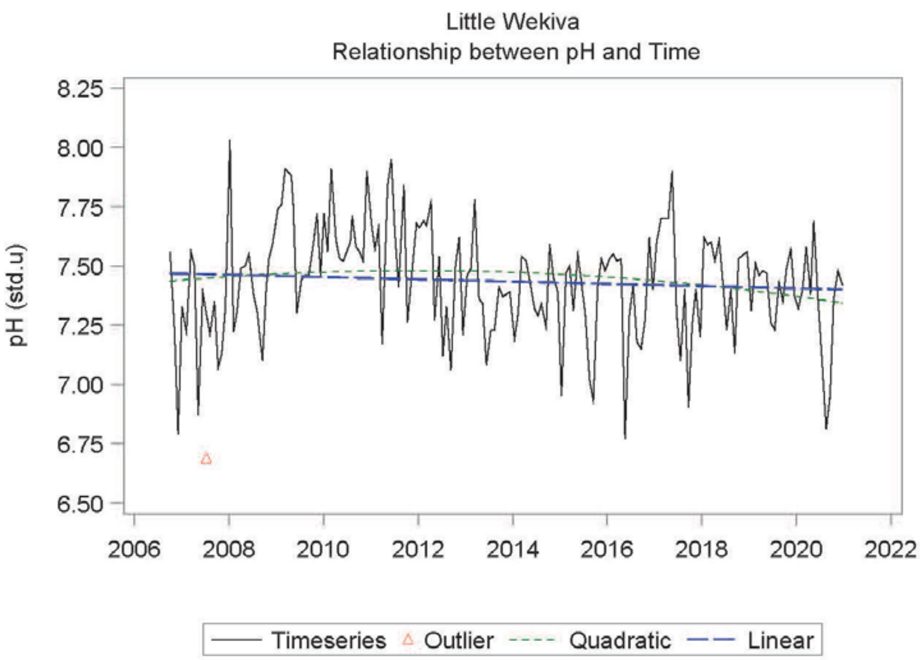


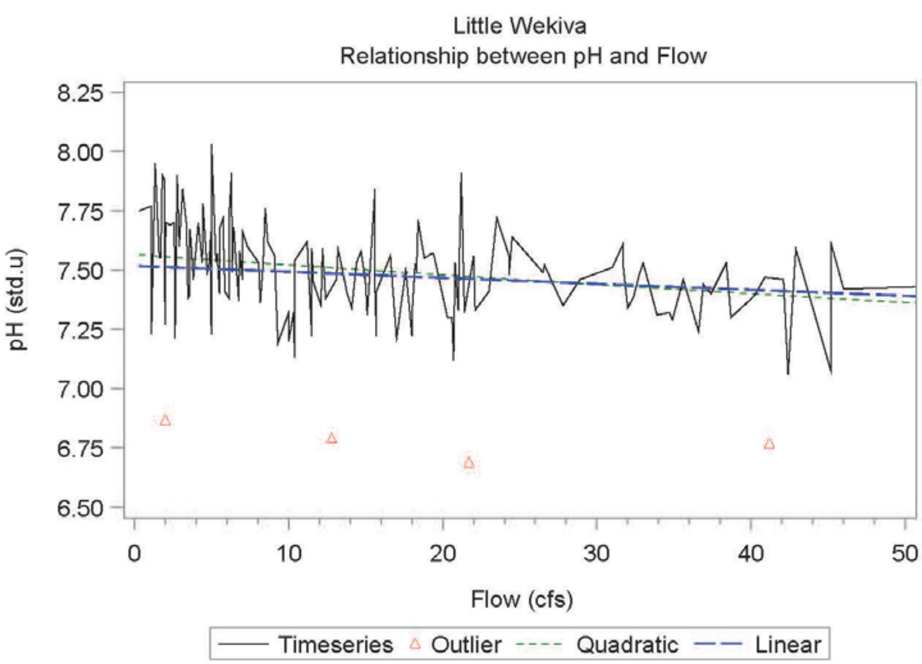
Figures 137 and 138. Time-Series of Secchi depth (top), and its Relationship with Flow (bottom)



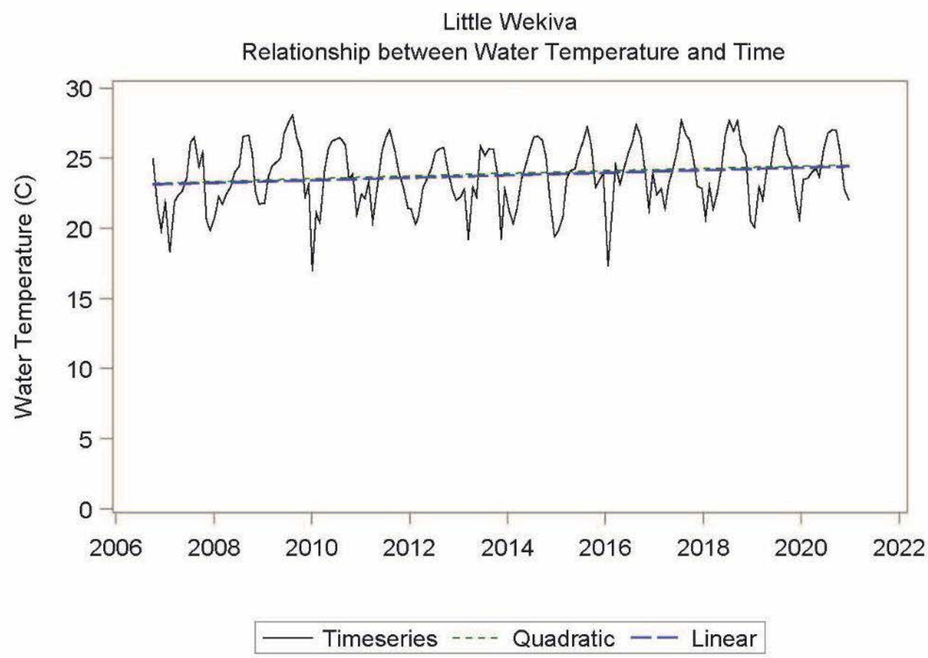


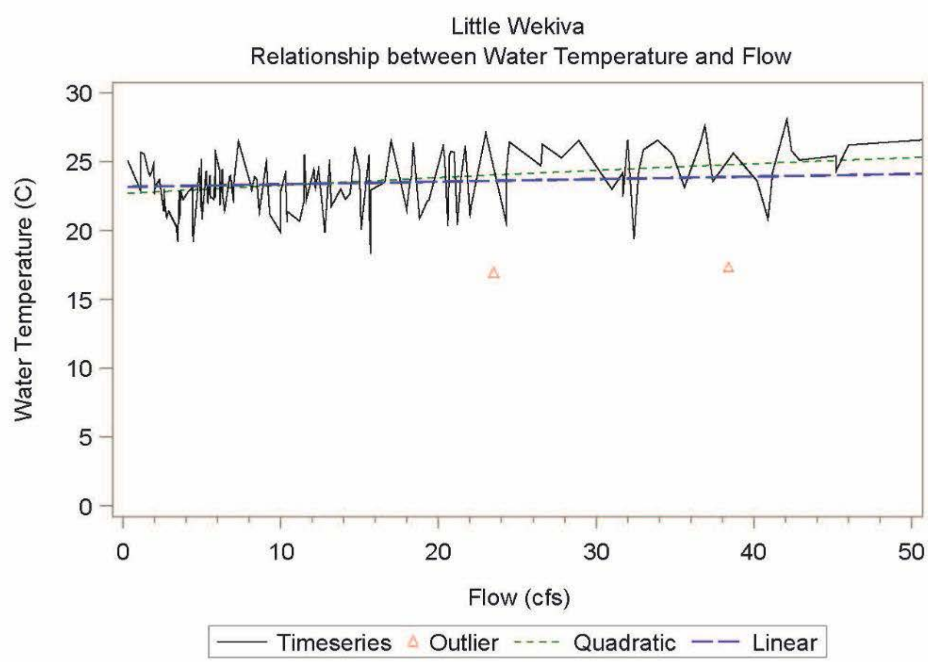
Figures 139 and 140. Time-Series of DOC (top), and its Relationship with Flow (bottom)





Figures 141 and 142. Time-Series of pH (top), and its Relationship with Flow (bottom)





Figures 143 and 144. Time-Series of Temperature (top), and its Relationship with Flow (bottom)