Horse Creek Water Quality Assessment

Hardee & DeSoto Counties, Florida

For

Southwest Florida Water Management District

June 2, 2021

By

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Cover art is a derivative, abstract artistic rendering of an aerial photograph of Horse Creek at State Road 72 in DeSoto County.

The SWFWMD tasked Applied Technology & Management, Inc. with this assessment under Task Work Assignment 20TW0002927. Janicki Environmental, Inc. assisted Applied Technology & Management, Inc. with the assessment.

Suggested reference:

Applied Technology & Management, Inc. and Janicki Environmental, Inc., 2021. Horse Creek water quality assessment: Southwest Florida Water Management District task work assignment 20TW0002927 report, Brooksville, Florida, 40 pp.

List of Abbreviations and Acronyms

ATM	Applied Technology & Management, Inc.
BMAP	basin management action plan
C	degrees Celsius
cfs	cubic feet per second
color	colored dissolved organic matter
COD	chemical oxygen demand
DEP	Florida Department of Environmental Protection
DO	dissolved oxygen (without regard to specific measurement)
DO_C	dissolved oxygen analyzed as concentration
DO_{SAT}	dissolved oxygen analyzed as percent saturation
F^-	fluoride
F.A.C.	Florida Administrative Code
Fe^{2+}	iron
HARD	hardness
HCSP	Horse Creek Stewardship Program
IWR	Impaired Waters Rule
MFLs	minimum flows and levels
mg/L	milligram per liter
mL	milliliter
MK	Mann Kendall
NAVD88	North American Vertical Datum of 1988
NH_4^+	ammonium
No.	number
NO_3^-	nitrate
NO_2^-	nitrite
$NO_3^-+NO_2^-$	sum of nitrate and nitrite
NTU	Nephelometric turbidity unit
p	probability value
pCi/L	picocurie per liter
PCU	platinum-cobalt unit
pH	quantitative measure of the acidity or basicity of a solution based on the concentration of the hydrogen ion
PO_4^{3-}	orthophosphate
R^2	coefficient of determination
SMK	Seasonal Mann Kendall
SRP	soluble reactive phosphorus
SFWMD	South Florida Water Management District
SJRWMD	St. Johns River Water Management District
SRWMD	Suwannee River Water Management District
SWFWMD	Southwest Florida Water Management District
SU	standard units
TEMP	temperature
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
TOC	total organic carbon
TN	total nitrogen
TP	total phosphorus
TURB	turbidity
TSS	total suspended solids
USGS	U.S. Geological Survey
µg/l	microgram per liter
µmho/cm	micromho per centimeter
WBID	waterbody identification
>	threshold exceedance

Executive Summary

The Southwest Florida Water Management District assessed the quality of water in Horse Creek, from the confluence of Horse Creek with the Peace River to the northern side of Florida State Road 62. The assessment was based on regression and time series trend analyses. Southwest Florida Water Management District contracted Applied Technology & Management to conduct this water quality assessment. Applied Technology & Management collaborated with Janicki Environmental on the assessment.

Assessment results support the Southwest Florida Water Management District's consideration of relationships between water quality constituents and flow as an environmental value.

Statistical analyses were used to develop relationships between river flow and the following primary classes of water quality constituents: nutrients and water clarity. (Other constituent classes were also assessed but not described in this executive summary.)

Thirty-four percent of **nutrient** concentration relationships with flow were positively correlated, such that increases in flow correlated with increases in concentration. Twenty-two percent of these concentration relationships with flow were negatively correlated, and forty-four percent did not exhibit a statistically significant correlation. Forty-three percent of chlorophyll *a* concentration relationships with flow were negatively correlated, such that increases in flow correlated with decreases in chlorophyll *a* concentration. Twenty-nine percent of flow-chlorophyll *a* concentration relationships were seasonal, based on regression of chlorophyll *a* concentration on monthly flows.

Seventy-two percent of water **clarity** relationships with flow were positive, such that increases in flow correlated with increase in water clarity. Seventy-nine percent of flow-water clarity correlations were statistically significant.

1.0 Introduction

The Southwest Florida Water Management District (SWFWMD) assessed water quality trends in Horse Creek, in the Peace River watershed (Figure 1).

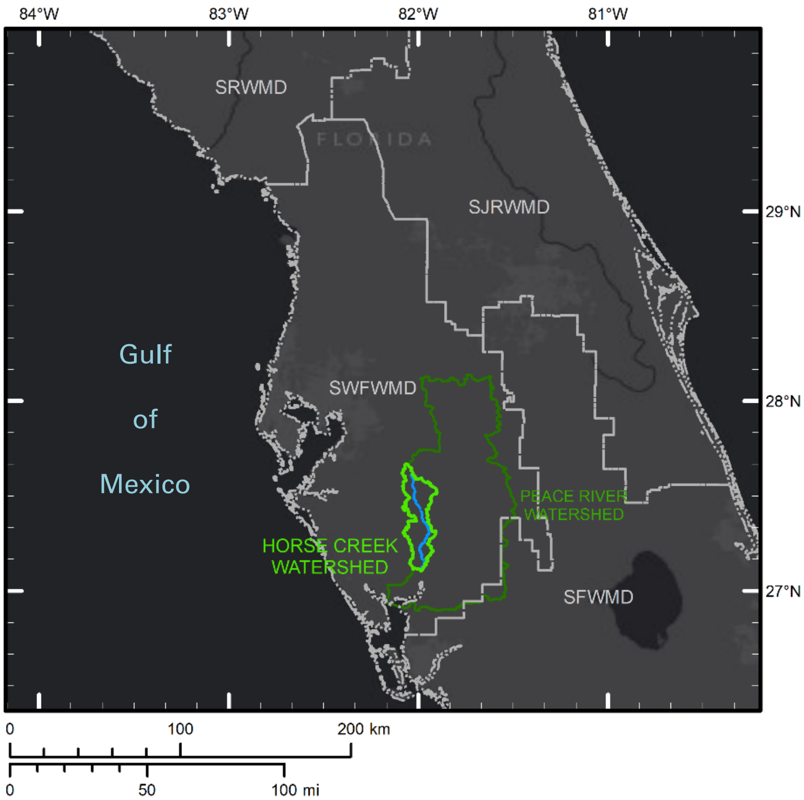

Figure 1. *General, regional location map of Horse Creek (blue polyline) and Horse Creek watershed (bright green polygon) in the Peace River watershed (dark green polygon) of the Southwest Florida Water Management District (SWFWMD). Also shown: South Florida Water Management District (SFWMD), St. Johns River Water Management District (SJRWMD), and Suwannee River Water Management District (SRWMD).*

Water quality is an environmental value when determining Minimum Flows and Levels (MFLs) [Water Resource Implementation Rule, rule 62–40.473, Florida Administrative Code (F.A.C.)]. This report describes relationships between water quality constituent concentrations and flows in Horse Creek. This report presents water quality trends and relationships between water quality constituent concentrations and flows in Horse Creek.

In this introduction, the assessed reach is defined (Section 1.1) and assessment objectives are presented (Section 1.2). The organization of the remainder of this report is described in Section 1.3, including a brief description of subsequent sections.

1.1 Assessed Reach

Horse Creek flows 87 kilometers (54 miles) from the northern side of Florida State Road 62 east of Duette to the confluence of Horse Creek with the Peace River southwest of Arcadia (Figure 2). Horse Creek flows through Hardee and DeSoto Counties, and drains parts of Hillsborough, Polk, Manatee, Hardee, and DeSoto Counties. Horse Creek flows under Florida State Road 62, Florida State Road 64 west of Zolfo Springs, Goose Pond Road, Hardee County Road 661, Hardee County Road 663, Florida State Road 70 northwest of Arcadia, Florida State

Road 72 southwest of Arcadia, and DeSoto County Road 761 (Figure 3). In general, Florida State Road 70 is referred to as Oak Street and Magnolia Street in Arcadia. We reference State Road 70 exclusively, throughout this report.

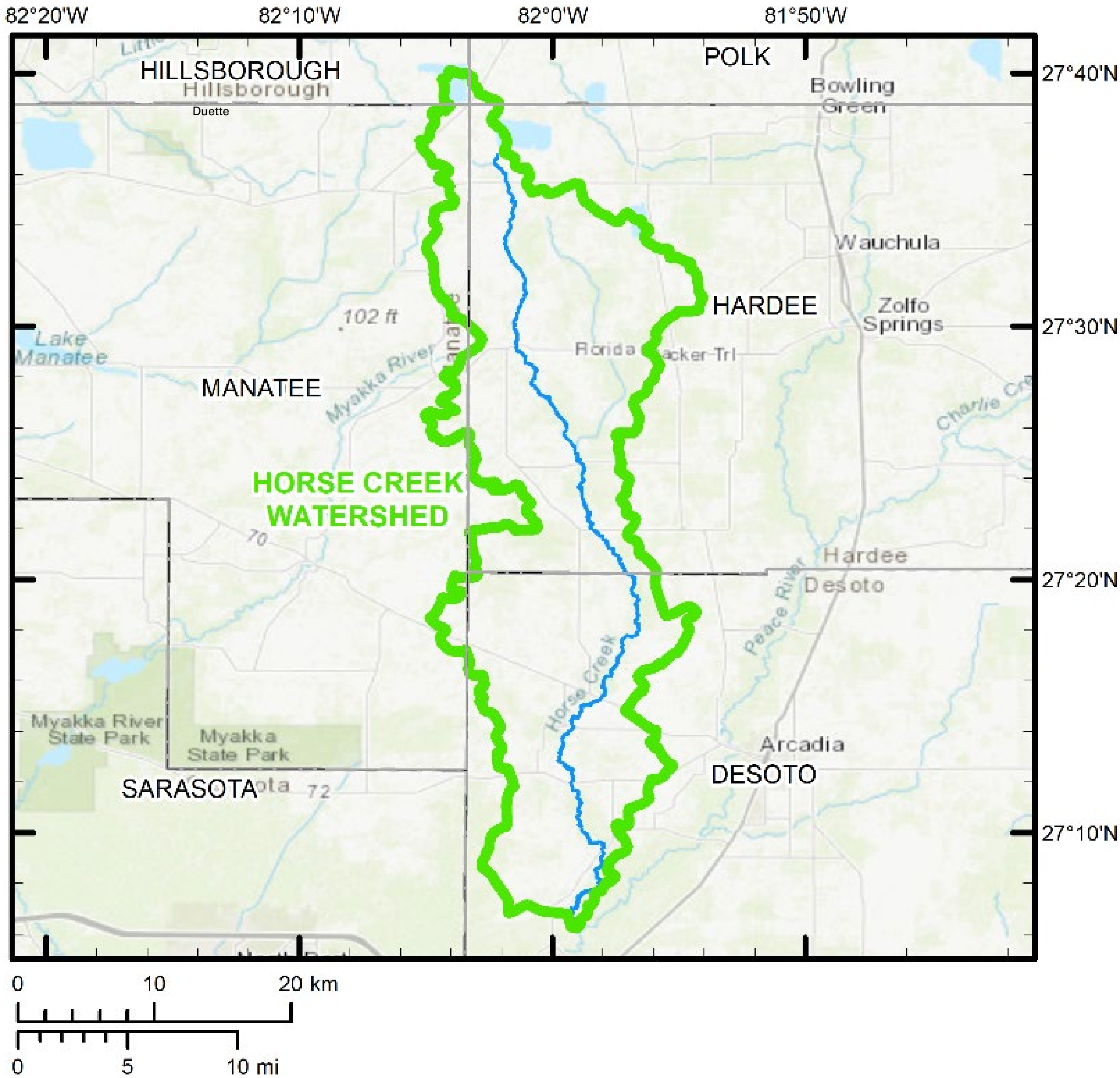

Figure 2. Horse Creek watershed in Hillsborough, Polk, Manatee, Hardee, and DeSoto Counties.

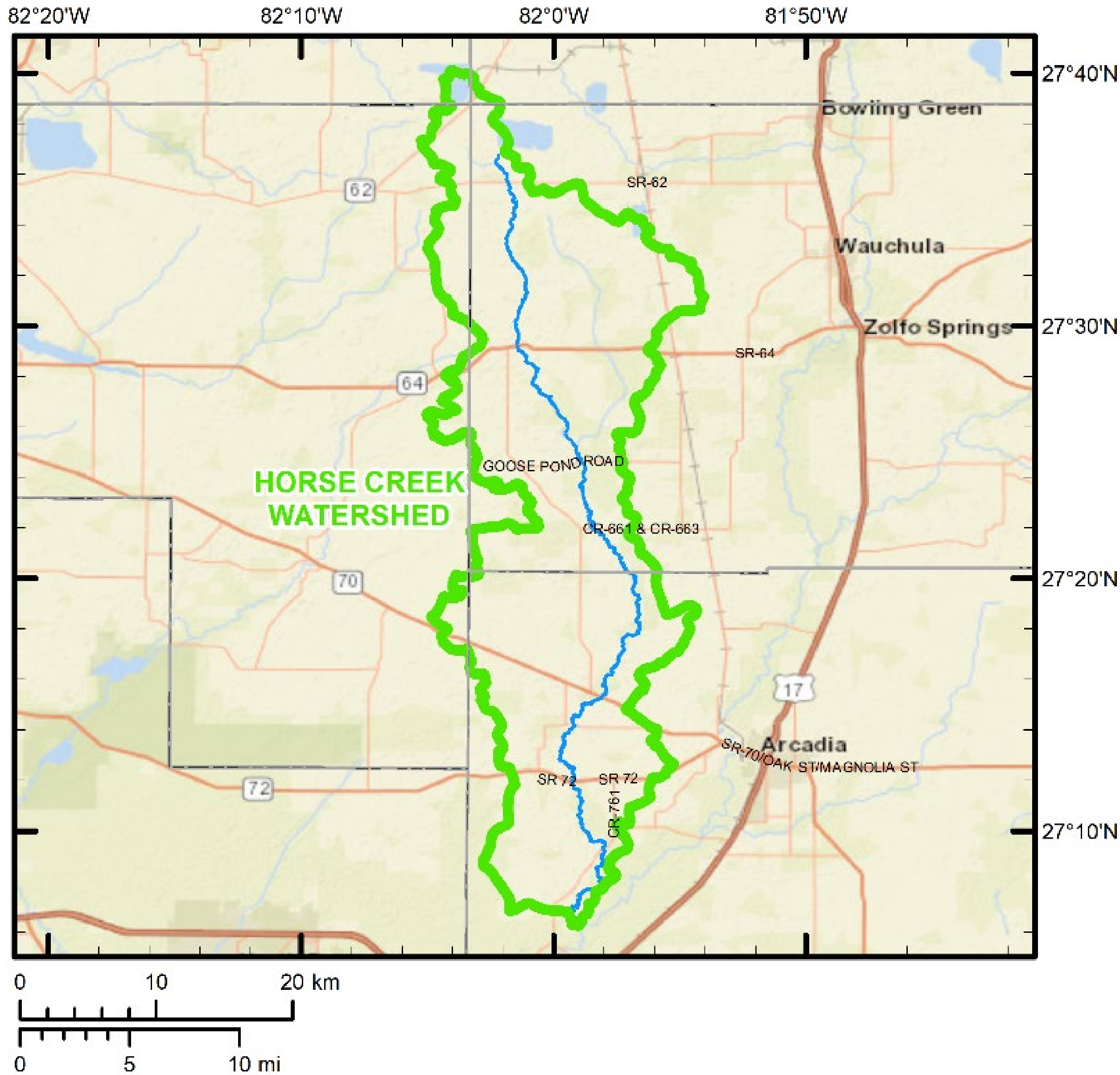

Figure 3. Horse Creek road crossings.

Several major tributaries drain to Horse Creek (Figure 4). Buzzard Roost Branch and Brandy Branch drain to Horse Creek in DeSoto County. Osborn Branch, Brushy Creek, Elder Branch, and the West Fork Horse Creek drain to Horse Creek in Hardee County. Lettis Creek drains to Brushy Branch in Hardee County. Oak Creek drains to a prairie in Hardee County; the prairie eventually drains to Brushy Creek.

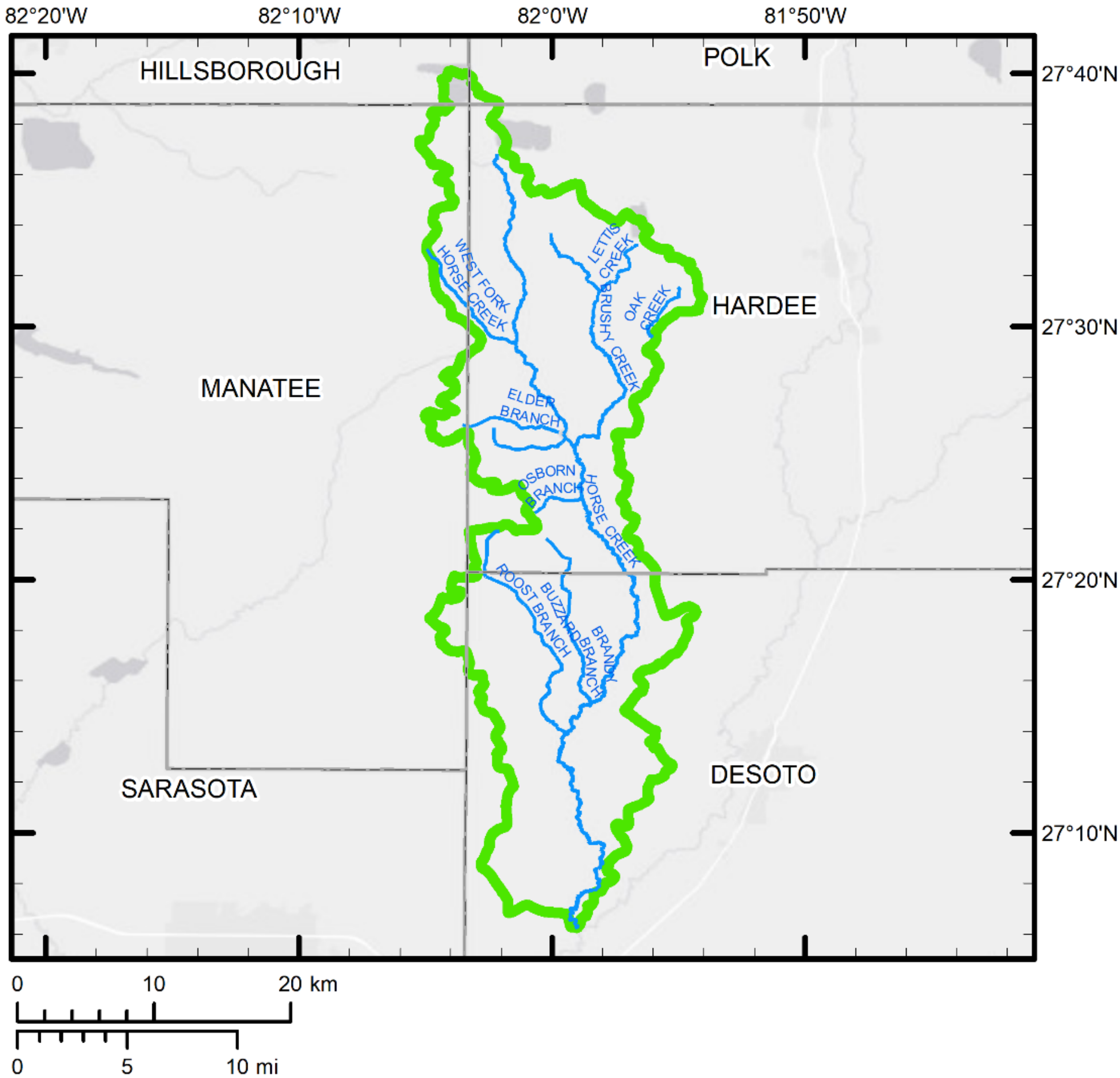

Figure 4. Selected, major Horse Creek tributaries.

Parts of the following three active phosphate mines are located in the Horse Creek watershed: the Four Corners Lonesome phosphate mine, the Fort Green phosphate mine, South Pasture; and parts of the following three inactive phosphate mines are located in the Horse Creek watershed: South Pasture Extension phosphate mines, the Ona phosphate mine, and the DeSoto phosphate mine (Figure 5 and Table 1). All six mines are owned by Mosaic. The DEP has issued National Pollution Discharge Elimination System discharge permits to Mosaic, to potentially discharge water to Horse Creek (Figure 6).

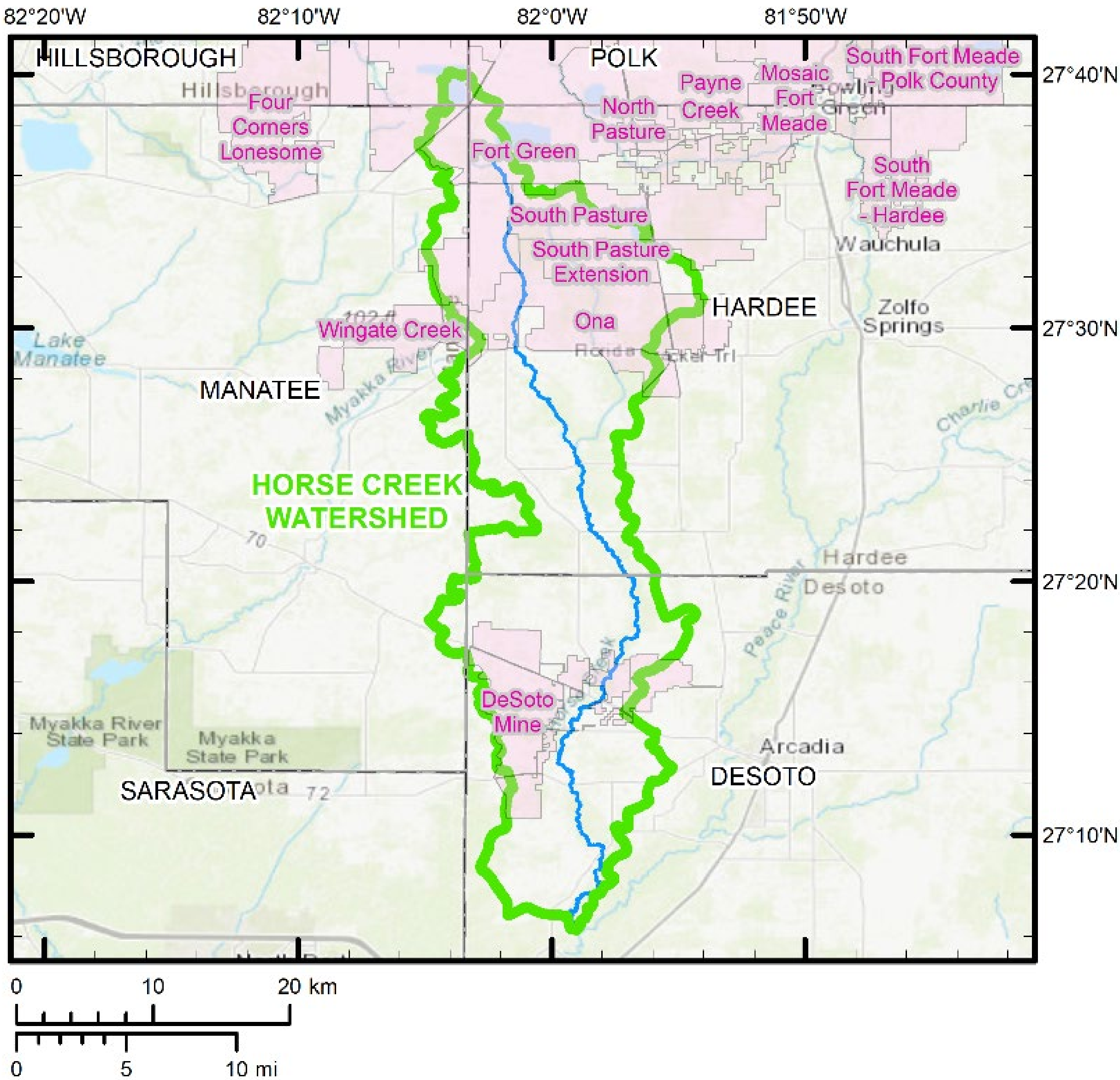

Figure 5. Phosphate mines near Horse Creek.

Table 1. Mines near Horse Creek, status, and year of mining operations commencement. All mines operated by Mosaic.

Mine Name	Status	Commencement of Operation
Fort Green	Active, Under Reclamation	1975
Four Corners Lonesome	Active, Under Reclamation	1985
South Pasture	Active, Under Reclamation	1995
South Pasture Extension	Inactive, not yet mined	---
Ona	Inactive, not yet mined	---
DeSoto Mine	Inactive, not yet mined	---

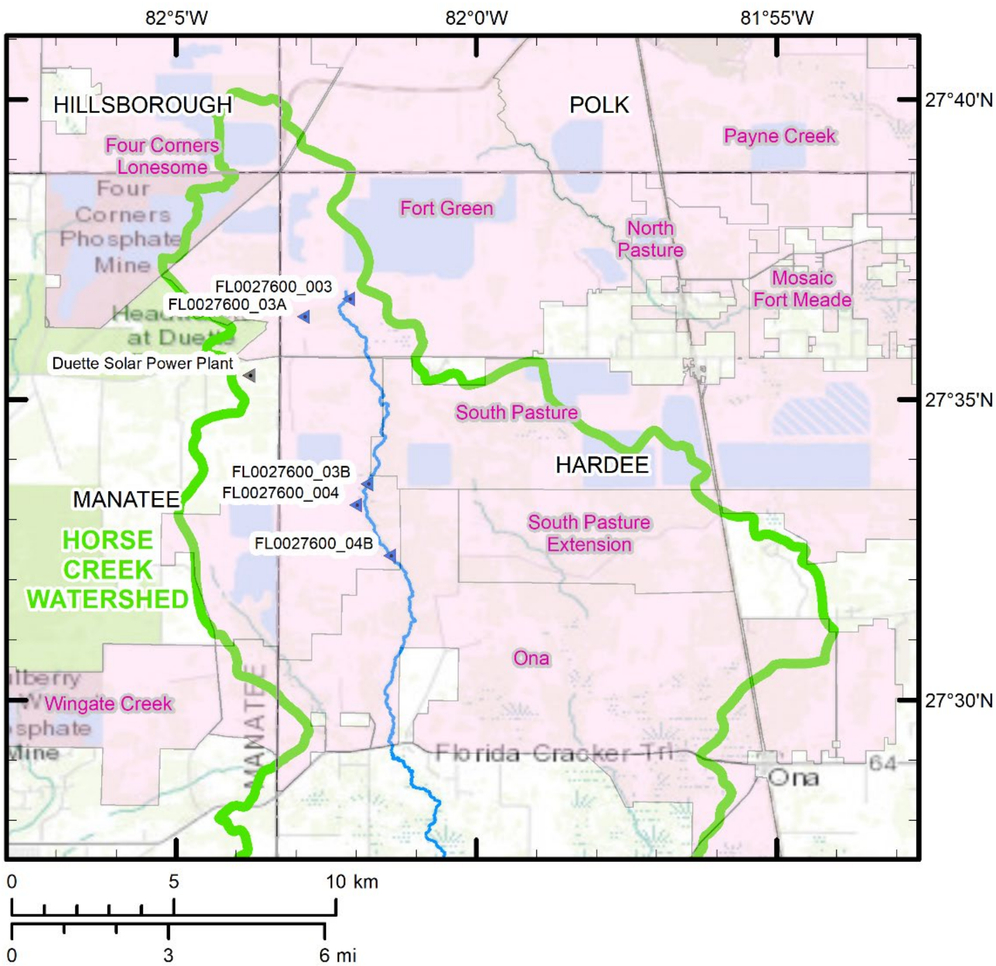

Figure 6. Permitted National Pollution Discharge Elimination System outfalls (triangular arrowhead) in the Horse Creek watershed. Mosaic phosphate mine discharges use the FL0027600 identification number prefix

1.2 Objectives

The objective of this assessment is to analyze water quality in Horse Creek. To achieve this objective, the following tasks were performed:

- Reviewed and summarized publications related to water quality in Horse Creek.
- Tabulated regulatory water quality criteria and impairment determinations, and ongoing restoration activities in Horse Creek and tributaries that drain to Horse Creek.
- Identified water quality constituents most important to Horse Creek health.
- Built a database of measured water quality constituents and calculated flows for Horse Creek.
- Described regression methods to relate water quality measurements to calculated flow.
- Developed and described water quality relationships with flow.
- Identified and described other important relationships to predict changes in water quality in assessed reaches.

1.3 Assessment Report Organization

Section 2 describes present water quality conditions in Horse Creek based on Florida Department of Environmental Protection (DEP) assessments. Section 3 describes data sources. Section 4 presents methods. Section 5 presents results. Section 6 summarizes findings.

The following statistical tools and supplemental material are presented in a separate appendix: descriptive plots and statistics by data source (appendix A), bivariate plots of flow and water quality (appendix B), linear (log-log) regression summary table and detailed statistical output (appendix C), logistic regression summary table and detailed statistical output (appendix D), Horse Creek Stewardship Program spatial distribution plots (appendix E), and a literature summary (appendix F).

2.0 Water Quality Criteria

This section includes detailed discussion of Horse Creek water quality criteria, historic and contemporary water quality conditions, and adopted water quality restoration initiatives. Water quality constituents that are most important to the health of Horse Creek are presented in Section 2.1. Impairment determinations from the DEP are summarized in Section 2.2. This assessment does not determine whether a waterbody is impaired or not impaired. This assessment also does not evaluate the accuracy or validity of FDEP determinations of impairment. Ongoing restoration programs in Horse Creek are reviewed in Section 2.3.

2.1 Water Quality Parameters Most Important to System Health

Nutrients are the most significant water quality constituents because nutrients influence the ecological health of the system. Waterbodies can become eutrophic when loaded with excess nutrients, which can cause algae to bloom, decrease dissolved oxygen (DO) concentrations, and degrade the ecosystem. Chlorophyll a concentration is a key indicator of eutrophication. Where nutrient concentrations exceed associated water quality criteria, chlorophyll a concentration may be greater than the associated water quality standard, and DO concentrations may be less than associated standard.

2.2 Summary of Designated Use, Criteria, and Florida Department of Environmental Protection Impairment Determinations

The Clean Water Act requires that States classify surface waters according to designated use. Florida (62–302.400, F.A.C.) classifies surface water into one of the following six classes associated with designated use:

- Class I—Potable water supplies: Includes impoundments and associated tributaries, certain lakes, rivers, or portions of rivers used as a source of potable water.
- Class II—Shellfish propagation or harvesting: Generally coastal waters where shellfish harvesting occurs.
- Class III—Fish consumption, recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife: The surface waters of the state are Class III unless described in rule 62–302.400, F.A.C.
- Class III-Limited—Fish consumption; recreation or limited recreation; and/or propagation and maintenance of a limited population of fish and wildlife: This classification is restricted to waters with human-induced physical or habitat conditions that, because of those conditions, have limited aquatic life support and habitat that prevent attainment of Class III uses.
- Class IV—Agricultural water supplies: generally located in agriculture areas around Lake Okeechobee.
- Class V—Navigation, utility, and industrial use.

With the exception of a potable part of Horse Creek (WBID 1787) upstream of the Peace River, all waterbodies in the Horse Creek watershed are class III. The potable part of Horse Creek is class I. The potable part of Horse Creek is from the Peace River to a point 16.2 kilometers (10 miles) upstream of the Peace River.

The DEP uses water quality data from several sources to assess Florida's waterbodies and determine whether waterbodies meet water quality criteria. The DEP must promulgate surface water quality criteria for water quality constituents per Rule 62–302, F.A.C. The DEP organizes Florida's waters with waterbody identification (WBID) numbers. Impaired waterbodies are characterized as "listed" because these waterbodies are on an adopted impairment list. An impaired waterbody is a waterbody with at least one water quality or biological constituent that does not meet associated criteria.

The DEP most recently adopted assessment lists for the Horse Creek watershed on October 21, 2016 (Cycle 3). Cycle 1 and Cycle 2 lists were adopted in June 2005 and on January 15, 2010, respectively. Waterbodies in the Horse Creek watershed are in assessment group 3, which will be re-assessed in summer 2021. The DEP is transitioning to a biennial assessment goal, in which all waterbodies in the State of Florida are assessed once every two years (DEP, 2021). The DEP identified Brandy Branch (WBID 1936) as the sole impaired waterbody in the Horse Creek watershed (Table 2, Figure 7). Brandy Branch is impaired for fecal coliform bacteria.

Table 2. *Impaired waterbody in the Horse Creek watershed.*

Waterbody WBID	Parameter Assessed Using IWR	Assessment Status	Assessment Period	Assessment Data	Criterion Concentration or Threshold Not Met
Brandy Branch WBID 1939	Fecal Coliform Bacteria	Impaired	January 1, 2008 through July 30, 2015	7 of 15 > 400 counts / 100 mL	≤ 400 Counts / 100 mL

Notes: WBID is waterbody identification
IWR is Impaired Waters Rule
≤ is less than or equal to
mL is milliliter

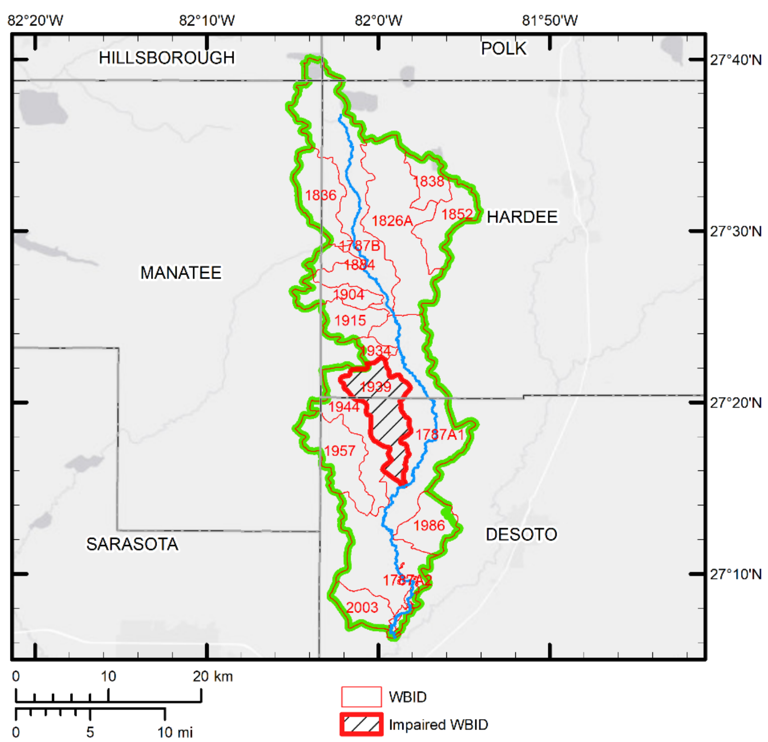

Figure 7. *Unimpaired and impaired waterbodies in the Horse Creek watershed (green polygon), and Florida Department of Environmental Protection Waterbody Identification (WBID) numbers.*

2.3 Actions to Restore Impaired Waterbodies

The DEP has not established total maximum daily loads (TMDLs) or basin management action plans (BMAPs) for any waterbodies in the Horse Creek watershed.

The DEP and Florida Department of Health manage bacteria impairment; consequently, the SWFWMD does not manage bacteria impairment. The DEP does not currently emphasize TMDL development for bacteria impairments, preferring to focus resources on nutrient TMDLs. The likelihood of DEP developing a TMDL for Brandy Branch bacteria impairment is low. The DEP performed a statewide mercury TMDL because atmospheric deposition is generally considered the mercury source. As mercury is not generally associated with changes in flows, mercury was not assessed, and waterbodies impaired for mercury are not described in this overview. The DEP and Florida Department of Health manage mercury impairment; consequently, the SWFWMD does not manage mercury impairment.

3.0 Data

Data were obtained for this assessment from county, state, and federal sources. This section describes water quantity parameters and data (Section 3.1) and water quality constituents and data (Section 3.2).

Water quantity data were obtained from the U.S. Geological Survey (USGS). Water quality data were obtained from the SWFWMD, the DEP, and the USGS. Applicable counties did not possess water quantity data or water quality data that are not also in State of Florida databases.

3.1 Water Quantity Parameters and Data

3.1.1 Water Quantity Parameters

Four primary constituents are used to describe the quantity of water in Horse Creek: water surface elevation, water depth, gage height, and flow. The following discusses each constituent.

3.1.1.1 Water Surface Elevation

Water surface elevation is the height of the air-water interface in a waterbody above or below a datum. Typically, elevation in the United States is referenced to NAVD88. Water surface elevation is measured in linear units, such as meters or feet.

3.1.1.2 Water Depth

Water depth is the distance from the bed or bottom of a waterbody to the air-water interface of a waterbody. Water depth is measured in linear units, such as meters or feet.

3.1.1.3 Gage Height

Gage height is the vertical distance of the air-water interface in a waterbody above or below a datum. Gage height is also referred to as gauge height, stage, water level, or level. Typically, gage height is measured above an arbitrary point in a river; gage height is not always referenced to NAVD88. Gage height is measured in linear units, such as meters or feet.

3.1.1.4 Flow

Flow in a river is the volume of water moving through a cross section of the river, over a duration of time. Flow is measured in volume per time, such as cubic meters per second, cubic feet per second, or million gallons per day. Flow is typically calculated from water level, using a relationship between flow and water level called a “rating curve.” The rating curve is built from coincident measurements of flow and water level. Water level is typically measured at a frequency of once every 5 to 60 minutes. Instantaneous flow is calculated using the rating curve from measured water level. These instantaneous calculations are then averaged over longer periods, such as daily, monthly, or yearly, prior to publication. Peak flow typically is also calculated and published. Peak flow is sometimes measured directly, during a peak-flow event. The type of flow data used in an analysis is a function of the use of the data; for example, an analysis of seasonality may rely on monthly average flows, while an analysis of floods may rely on peak flows. Daily average flows were used in building regression relationships while monthly median flows were used for testing monthly trends in flows over time.

3.1.2 Daily Flow Statistics

Two USGS water quantity monitoring stations monitor discharge in Horse Creek. A time series plot of the discharge record for these gages is provided in Figure 8. The upstream USGS Horse Creek gage near Myakka Head (No. 02297155) has been monitored since 1977 the USGS estimates flow at this gage with a rating-curve relationship between water-surface elevation and flow. The downstream USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310) has been monitored since 1950; the USGS also estimates flow at this gage with a rating curve. USGS Horse Creek gage near Limestone (No. 02297251) reports gage height since 2019.

Across stations, minimum daily flow ranged from zero to 10,700 cfs at the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310) and zero to 2,240 cfs at USGS Horse Creek gage near Myakka Head (No. 02297155) (Table 3). At both sites, the period of record was sufficient for the analyses. A data gap between September 30th, 2002 and September 30th, 2003 exists in the Arcadia gage period of record while a data gap for the USGS Horse Creek gage near Myakka Head (No. 02297155) gage exists between December 7th, 2016 and January 19th, 2017. No gap filling was conducted as there were sufficient observations for regression analysis without estimating flows for these missing periods of record. Regression of flow on water quality in this assessment exclusively use flow data; water quality data were not regressed on water surface elevation, water depth or gage height.

Table 3*. Horse Creek water quantity measurement sites with associated summary statistic information including daily minimum, maximum, and interquartile statistics.*

				Daily Flow				
USGS gage	Location	Period	Length	Min	25th	50th	75th	Max
			[years]	[cfs]	[cfs]	[cfs]	[cfs]	[cfs]
02297155	near Myakka Head	1977-2020	43	0	1.9	7.16	32	2240
02297310	at State Road 72 near Arcadia	1950-2020	70	0	11	44	182	10700

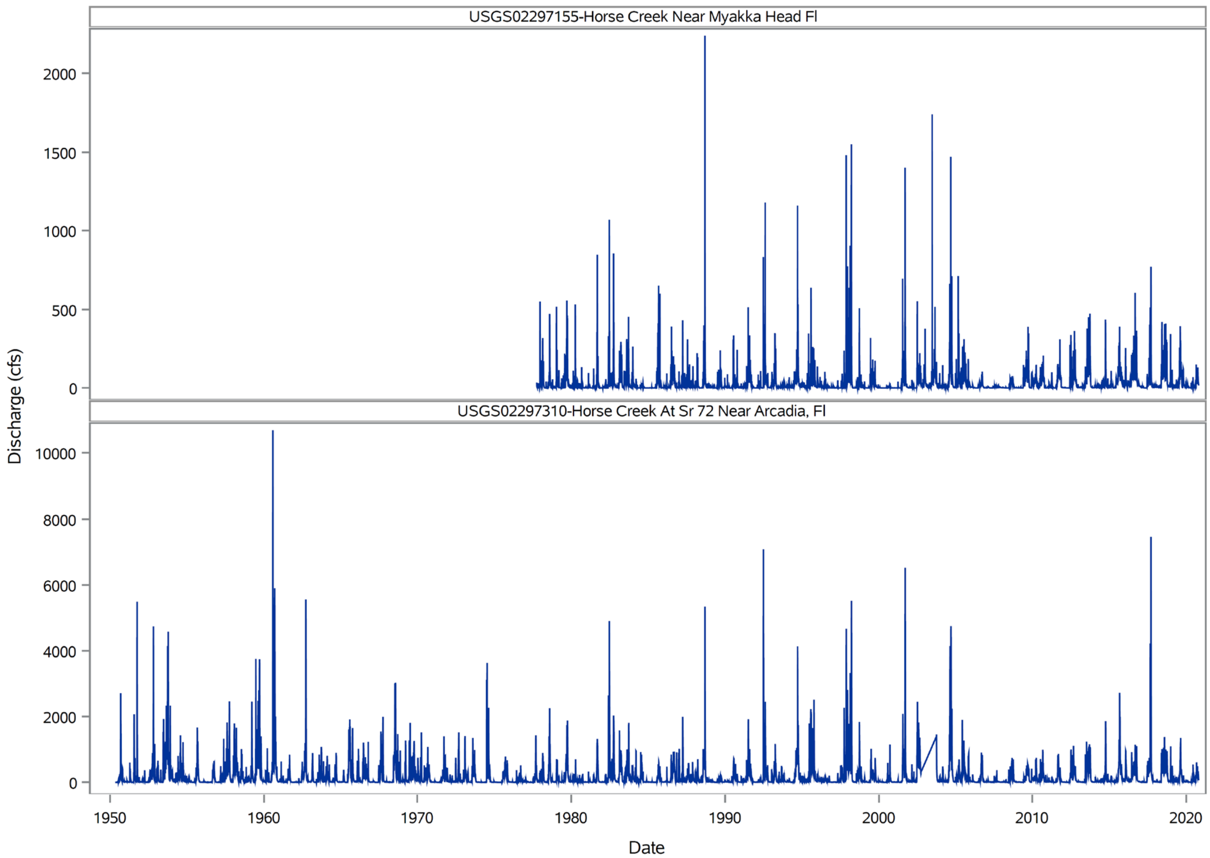

Figure 8. Timeseries plots for discharge (flow) in cubic feet per second (cfs) for the two USGS Horse Creek gages. Note Y axis scale difference between USGS Horse Creek gage near Myakka Head (No. 02297155) (top) and USGS Horse Creek gage at State Road 72 (No. 02297310) (bottom).

3.2 Water Quality Constituents and Data

3.2.1 Water Quality Constituents

Water quality constituents of interest were identified in consultation with District staff and grouped for analysis based on their relevance to each other and their impact on water quality (Table 4). The constituent groups included Nitrogen, Phosphorus, Chlorophyll *a*, Physio-Chemical, and Minerals and Metals. Constituents of these groups are summarized in the sub-sections below.

3.2.1.1 Nitrogen

Nitrogen is an essential nutrient for all plants including algae. However, an overabundance of nitrogen can harm aquatic ecosystems by causing an imbalance of algae and other nuisance plants that can disrupt ecosystem function .Total nitrogen (TN) is the sum of inorganic and organic nitrogen. Nitrogen species include nitrate (NO_3^-), nitrite (NO_2^-), Total Kjeldahl nitrogen (TKN), and ammonium (NH_4^+). NO_3^- and NO_2^- are assessed as a sum (NO_3^-+NO_2^-). TKN is the sum of organic nitrogen and NH_4^+. Ammonium NH_4^+ typically occurs in very low concentrations, and is often below the laboratory detection limits. When the method detection limit concentration is reported, the actual NH_4^+ concentration is less than the minimum NH_4^+ concentration that the instrument is capable of measuring. When NH_4^+ data are available, organic nitrogen is calculated as the difference between TKN and NH_4^+: organic nitrogen = TKN - NH_4^+.

3.2.1.2 Phosphorus

Total phosphorus in water exists in two forms, dissolved (soluble) and particulate (attached to particles). Dissolved phosphorus can be further subdivided into soluble reactive phosphorus (SRP) and soluble nonreactive phosphorus. Orthophosphorus (PO_4^{3-}) is a component of soluble reactive phosphorus (SRP) and is the most common dissolved form. Orthophosphorus is readily available to aquatic vegetation including algae and in elevated concentrations can contribute to algae blooms. Like nitrogen, phosphorus is an essential nutrient for all plants including algae. However, an overabundance of phosphorus can harm aquatic ecosystems by causing an imbalance of algae and other nuisance plants that can disrupt ecosystem function.

3.2.1.3 Chlorophyll a

Chlorophyll *a* is a light receptor and primary electron donor during photosynthesis. Chlorophyll *a* concentration is used as a proxy for algal abundance. Pheophytin is a natural chlorophyll *a* degradation product with a light absorption peak in the same spectrum as chlorophyll *a*. Chlorophyll reported as "uncorrected" includes pheophytin while "corrected" chlorophyll *a* measures chlorophyll concentration after removing the pheophytin. The DEP has archived corrected chlorophyll *a* concentration since 2001. Prior to 2001, uncorrected chlorophyll *a* concentration was more common. Data archived for this project included uncorrected chlorophyll *a* concentration and data provided by HCSP which was simply reported as chlorophyll *a*.

3.2.1.4 Physio-Chemical Constituents

The physio-chemical constituent group includes dissolved oxygen, pH, temperature, and conductivity. Dissolved oxygen (DO) is expressed in terms of concentration and as percent saturation. (In this assessment, DO is a generic acronym that references dissolved oxygen, DO_C is a specific acronym that references dissolved oxygen concentration, and DO_{SAT} is a specific acronym that references percent dissolved oxygen saturation. The percent saturation calculation attempts to account for water's ability to hold oxygen molecules as a function of temperature (and salinity in estuarine systems). Dissolved oxygen can be added to water through physical processes, interactions with the atmosphere, and photosynthesis. Dissolved oxygen is removed from water by aquatic animals and decomposition. Dissolved oxygen is an important indicator of aquatic ecosystem vitality because it is necessary in many biological processes. The constituent pH is a scaled representation of hydrogen ion concentration. It is a measure of alkalinity or acidity in water. The range for pH is from 0 to 14, where pH 7 is neutral, pH < 7 is acidic, and pH > 7 is alkaline. At different pH levels, different chemical species become soluble and bioavailable, which can benefit or harm aquatic plants and animals. Conductivity is a measure of the ability of water to pass an electrical current and measured in micromhos per centimeter (µmhos/cm) or microsiemens per centimeter (µs/cm). Water temperature is a physical property expressing the average thermal energy of a substance.

3.2.1.5 Minerals and Metals

Minerals and metals include major anions and cations calcium, chloride, fluoride, iron, magnesium, and sulfate. These charged particles affect the conductivity of the water and the presence of these constituents is typically reflective of the geology of the area through which a stream or river flows, or the bedrock through which groundwater flows. Hardness, total dissolved solids, and radium were also included in this group. Hardness is the concentration of dissolved minerals, particularly calcium and magnesium, in water while radium is naturally-occurring radionuclides, and in the Horse Creek basin, presents in the presence of phosphate rock.

3.2.1.6 Indicators of Water Clarity

The following constituents were included as indicators of water clarity: color, turbidity, total (and dissolved) suspended solids and total organic carbon. Color is a measure of water clarity which, in southwest Florida, is particularly affected by the presence of tannins from decomposition of organic material. Color is typically measured using a spectrophotometer and reported in platinum cobalt units (pcu). True color is measured after filtering suspended substances (*e.g.*, those contributing to turbidity) while apparent color represents the color one sees with the naked eye and therefore includes the effects of suspended particles. The water quality data for Horse Creek includes measures of both true color and apparent color, the latter of which is reported by the HCSP. Turbidity is an estimate of the amount of suspended material in the water column. At elevated levels turbidity can cause water to appear cloudy or hazy. Water can be made turbid by sediments, inorganic and organic matter, algae, colored dissolved organic matter, plankton, and other microscopic organisms. Turbidity can increase during rain events due to runoff from surrounding lands, as well as from high flows when greater flow velocities and volumes suspend material from the stream bed. Similarly, suspended solids are particles that are larger than 2 microns found in the water column. Most suspended solids are made up of inorganic materials though bacteria and algae can also contribute to the total solids concentration. Total suspended solids affect water clarity; the more solids present in the water, the less clear the water will be. Some suspended solids can settle to the bottom of a water body particularly during periods of low or no water flow, potentially smothering benthic organisms. Higher concentrations of suspended solids can also serve as carriers of toxics, which cling to suspended particles. Total solids measurements can be useful as an indicator of the effects of runoff and concentrations often increase during rainfall while total dissolved solids can be an indicator of groundwater contributions to streamflow which tend to increase water clarity. Total Organic Carbon (TOC) is a measure of the total amount of carbon in organic compounds found in the water sample. While not specifically a measure of water clarity, it can represent contribution of both anthropogenic and natural sources of carbon inputs into the streambed that affect water clarity.

Table 4. *Water quality constituents measured in field or analyzed in lab along with associated measurement units. Constituent groups were assigned for presentation of results.*

Constituent Group	Field Constituent	Units
Physio-chemical	Conductivity	Micromho per centimeter
Physio-chemical	Dissolved Oxygen	Milligram per liter and Percent Saturation
Physio-chemical	pH	Standard Unit
Physio-chemical	Temperature	Degree Celsius
Constituent Group	**Lab Constituent**	**Units**
Nitrogen	Ammonia	Milligram per liter
Nitrogen	Ammonium	Milligram per liter
Physio-chemical	Biological Oxygen Demand	Milligram per liter
Physio-chemical	Chemical Oxygen Demand	Milligram per liter
Minerals and Metals	Calcium	Milligram per liter
Minerals and Metals	Chloride	Milligram per liter
Chlorophyll	Chlorophyll *a*	Microgram per liter
Water Clarity	Color	Platinum-cobalt unit
Phosphorus	Dissolved Orthophosphate	Milligram per liter
Minerals and Metals	Fluoride	Milligram per liter
Physio-chemical	Hardness	Milligram per liter
Minerals and Metals	Iron	Microgram per liter
Minerals and Metals	Magnesium	Milligram per liter
Nitrogen	Nitrate	Milligram per liter
Nitrogen	Nitrate-Nitrite	Milligram per liter
Nitrogen	Nitrite	Milligram per liter
Nitrogen	Organic Nitrogen	Milligram per liter
Phosphorus	Ortho Phosphate as PO_4^{3-}	Milligram per liter
Phosphorus	Phosphorus in Total Orthophosphate as P	Milligram per liter
Minerals and Metals	Radium 226	Picocurie per liter
Minerals and Metals	Radium 228	Picocurie per liter
Minerals and Metals	Radium Total	Picocurie per liter
Minerals and Metals	Sulfate	Milligram per liter
Water Clarity	Total Dissolved Solids	Milligram per liter
Nitrogen	Total Kjeldahl Nitrogen	Milligram per liter
Nitrogen	Total Nitrogen	Milligram per liter
Water Clarity	Total Organic Carbon	Milligram per liter
Phosphorus	Total Phosphorus	Milligram per liter
Water Clarity	Total Suspended Solids	Milligram per liter
Water Clarity	Turbidity	Milligram per liter
Nitrogen	Unionized Ammonium	Milligram per liter

3.2.2 Water Quality Data

Water quality data were obtained from the SWFWMD (including from the Horse Creek Stewardship Program, HCSP), the DEP, and the USGS. For data obtained from the DEP, this assessment used IWR run 59 (dated July 10, 2020). This database contains data collected by the DEP, the SWFWMD, and USGS. Where data are replicated in both IWR run 59 and original data source, the original source data were analyzed.

Once constituents were selected from the datasets, the following data processing steps were used as data screening procedures prior to analysis:

1. Stations meeting minimum sample size requirements of 30 observations were selected, as agreed upon by the SWFWMD.
2. Observations with one or more of the following fatal DEP qualifier codes: (?, V, N, O, Y, H, J, K, Q) were removed though J codes were retained in the Horse Creek Stewardship Program (HCSP) database after review of data.
3. Formatted data into an analytical format
4. Performed outlier analysis to identify potential influential or erroneous observations
5. Output analytical dataset with outliers identified (not removed)
6. Described data with plots and statistics

Descriptive plots and statistics, including results of outlier analysis, are delivered as Appendix B provided as part of the Supplemental Materials document associated with this task assignment. The Appendix contains:

1. A table listing each station meeting inclusion criteria with number of observations and period of record for each constituent as well as the percent of observations identified as potential outliers by each method.
2. A univariate histogram for each constituent at each site including distributional statistics and curves based on normal and log normal distributions.
3. Temporal box plots of the data distribution for each station/constituent combination.
4. Timeseries plots with outliers identified for each station/constituent combination.

The water quality sites in Horse Creek are shown in Figure 9 and listed in Table 5, along with each station's period of record and sample size for field and lab-measured constituents.

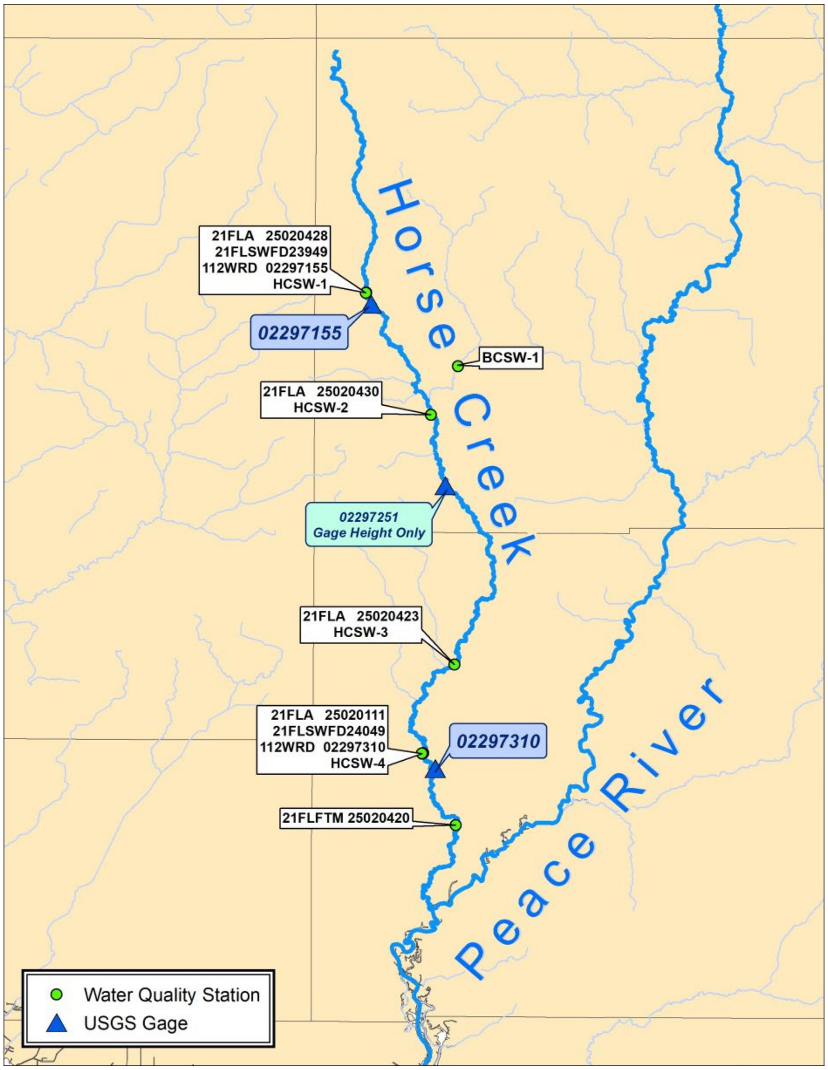

Figure 9. *Water quality and U.S. Geological Survey (USGS) gage stations in Horse Creek.*

Table 5. Sample stations (meeting criterion of at least 30 observations), associated data source and general period of record for water quality data in Horse Creek.

Data Source	Station	Station Name	First Date	Most Recent Date
USGS	USGS 02297155	Horse Creek near Myakka Head	10/26/1978	09/28/1999
USGS	USGS 02297310	Horse Creek near Arcadia	06/13/1962	09/29/1999
IWR Run 59	21FLA 25020111	Horse Creek State Road 72 bridge	05/15/1972	04/13/1998
IWR Run 59	21FLA 25020423	Horse Creek at State Road 70	05/15/1972	08/21/1991
IWR Run 59	21FLA 25020428	Horse Creek at State Road 64 bridge	05/15/1972	07/10/1990
IWR Run 59	21FLA 25020430	Horse Creek at State Road 663 bridge	12/12/1972	07/05/1990
IWR Run 59	21FLFTM 25020420	Horse Creek at Kings Highway	10/09/2001	01/17/2018
SWFWMD	23949	Horse Creek near Myakka Head	08/04/1997	05/06/2020
SWFWMD	24049	Horse Creek near Arcadia	08/05/1997	05/06/2020
HCSP	HCSW-1	Horse Creek at State Road 64	04/30/2003	12/12/2018
HCSP	HCSW-2	Horse Creek at Goose Pond Road	04/30/2003	12/12/2018
HCSP	HCSW-3	Horse Creek at State Road 70	04/30/2003	12/12/2018
HCSP	HCSW-4	Horse Creek at State Road 72	04/30/2003	12/12/2018

Notes: USGS is United States Geological Survey
IWR is Impaired Waters Rule
SWFWMD is Southwest Florida Water Management District
HCSP is Horse Creek Stewardship Program

4.0 Methods

4.1 Matching Flows and Water Quality Stations

Each water quality station was assigned a discharge record for developing relationships between water quality and flow. All water quality sites located at or upstream of site HCSW-3 (Figure 9) were assigned the Horse Creek near Myakka Head (No. 02297155) flow record. All stations downstream of this site were assigned the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310) flow record. No antecedent flow conditions were evaluated due to the proximity of the water quality stations to the discharge gages.

4.2 Analytical Methods

4.2.1 Trend Tests

Evaluating trends in water quality over time can provide important context to consider in assessing the relationships between water quality and flows. Two iterations of the non-parametric Mann Kendall test for trend (Mann 1945; Kendall 1975) were used for this evaluation. Monthly median flows were evaluated to determine if flows in any month were trending over the entire period of record for each gage. That is, a Mann Kendall (MK) trend test was performed for each month based on the monthly median flow value. Second, the Seasonal Mann Kendall (SMK) with correction for serial dependence (Hirsch and Slack 1984) was used to evaluate if water quality data were consistently trending over time across months to provide general assessments of trends in water quality over the time period of data collection. Inclusion criteria for these tests included having data collected in a recent time period (*i.e.*, since 2017) and, for the SMK test, at least 5 years of data and 60 observations. Results of the SMK were adjusted for multiple comparisons using the False Discovery Rate method (Benjamini and Hochberg 1993). Importantly, these methods describe trends but do not account for the effects of other potential explanatory factors affecting observed trends and therefore do not explain why a trend might be observed. Adjustments for serial correlation and multiple comparisons were included to be conservative in declaring the presence of a trend. Both serial correlation and multiple comparisons can lead to increased false positive rates and these methods attempt to minimize that artifact in the data analysis. Trend test results are reported for each site and constituent meeting criteria defined above and reported with number of observations (n), the p value of the statistical test, a column identifying whether or not serial correlations was present in the timeseries (which can affect the p value associated with the statistical test), the trend direction, and the Theil-Sen slope estimate (*i.e.*, the median of all pairwise slope estimates: Hirsch and Slack 1984).

4.2.2 Linear Regression

Linear regression is a common statistical method relating a predictor variable (*e.g.*, flow) to a response variable (*e.g.*, water quality constituent concentration) under a specific set of assumptions; principally that the relationship is linear. Additional assumptions include that the data are normally distributed, independent, and homoscedastic. These attributes are not typical properties of either flows or most common water quality constituents and to comply with those assumptions, natural log transformations were applied to both the predictor and response variables for useful relationships. To test for seasonal differences in the mean response to flow, a seasonal classification term was added to the model using dummy variables to evaluate how different months changed the average response between flows and water quality constituent concentrations. When seasonality was not detected, the results of univariate regressions with flow are presented. The coefficients of determination describe variance in water quality constituents attributable to both flow and season when both are significant (α= 0.05). Due to limited data availability for most sites, interaction terms were not considered for these models. To evaluate the model fit and potential utility in assessing these water quality relationships, the sign of the slope statistic (*i.e.*, positive or negative), the p value indicating the statistical significance of the slope statistic, and the coefficient of determination (R^2) defining the proportion of variation explained by the model were reported to aid in evaluating the resultant linear regression relationships. The following equation depicts the form of the linear regression that was applied.

$$Ln(Y_{ij}) = \beta_0 + \beta_1 * Ln(flow_i) + \beta_2 * season_j + e_{ij}$$

where:
Y = water quality response
β_0= intercept
β_1= slope estimate for the rate of change in Ln(Y)
per unit change in Ln(flow)
β_2 = effect of seasonal covariate defined by month

and the null hypothesis being evaluated is Ho: $\beta_1 = 0$.

Linear regression models were used to evaluate relationships between flow and water quality constituents to facilitate the SWFWMD's consideration of water quality as an environmental value in Horse Creek. The assessment was conducted to identify those constituents where variations in flow describe a significant proportion of the variation in a water quality constituent of interest. The modeling effort explicitly acknowledges that the results do not imply causation. Establishing causality is an extremely challenging endeavor and no one study can establish causality, particularly from observational data. Hill (1965) established 10 criteria for establishing causality, which include the strength of association, consistency among multiple studies, and experimental evidence. Therefore, establishing causality is beyond the scope of this effort.

Results of linear regression analyses are reported for "primary sites" which are defined as those with at least 100 observations for the constituent of interest, and "secondary sites" defined as those with fewer than 100 observations for the constituent of interest. The same location could be reported as a primary site for one constituent and a secondary site for another constituent. This separation was performed because many sampling locations had fewer than 100 observations, and it was determined to include these sites in the results but to isolate them from interpretation with those sites with a more robust sample set. Linear regression analyses are presented for those sites with smaller sample sizes but should be interpreted with caution.

4.2.3 Logistic Regression

Logistic regression is an alternative to natural-log transformation of both predictor and response variables (Hosmer and Lemeshow, 2000). Logistic regression relies on fewer assumptions than linear regression to model response relationships of the exponential family and relies on a relatively large sample size for estimation. Logistic regression is based on a binary transformation of the response variable to be either greater than or less than a specified a priori determined threshold value. DEP criteria were used for TN, TP, chlorophyll *a*, and DO (percent saturation) as ecologically relevant threshold values to classify exceedance or non-exceedance with the understanding that these models do not relate to determination of impairment, classification, or listing of a waterbody according to state water quality criteria. The general model structure was defined as:

$$g(y) = \ln\left[\frac{p(y)}{1-p(y)}\right] = \beta_0 + \beta_1 x_1 + \beta_2 x_2$$

where:

$p(y)$ = the probability of exceedance as a function of x;

$g(y)$ = the logit transformation of the odds of exceedance;

x_1 = the flow condition; and

x_2 = the covariate such as month used as a dummy variable; and β_0, β_1, and β_2 are regression coefficients.

Evaluation of the logistic regression model fits included calculating a generalized R^2 and evaluating the predictive capacity of the model with receiver operator curves (SAS Institute Inc., 2018). The computation of R^2 was derived by comparing the maximum likelihood estimate of the intercept-only model to the maximum likelihood estimate for the specified model:

$$R^2 = 1 - \left[\frac{L(O)}{L(\beta)}\right]^{2/n}$$

where:

L(O) = the maximum likelihood estimate under the intercept-only model;

L(β) = the maximum likelihood estimate under specified model; and

n = the sample size.

The generalized R^2 statistic was then rescaled to conform to the typical inference regarding R^2, in which the maximum value is 1.

The intent of using logistic regression in addition to linear regression was to investigate the relationship between flows and the probability of exceeding ecologically relevant water quality thresholds for a subset of water quality constituents (*i.e.*, TN, TP, corrected chlorophyll *a*, and dissolved oxygen). While linear regression estimates the change in a water quality constituent for a unit change in flows, logistic regression estimates the change in probability of exceeding a threshold value for a water quality constituent as a function of flows. Thereby, logistic regression was a complimentary assessment to evaluate if variations in flows resulted in an increased or decreased probability of exceeding ecologically relevant thresholds where those thresholds have been established. Threshold values associated with state water quality standards were used. Those threshold values include the maximum TN concentration for freshwater streams (1.65 mg/l), the maximum chlorophyll *a* corrected concentration for freshwater streams (20 µg/l), a maximum TP concentration for freshwater streams (0.49 mg/L), and minimum DO_{SAT} criteria of 38% saturation. The purpose of using these threshold values is that, at some temporal scale, they represent an ecologically relevant threshold value and that if the findings suggest that reductions in flows are associated with an increased probability of exceeding those thresholds, that finding may be worthy of further investigation. However, the state standards were derived as annual statistics and this assessment explicitly warns that the results of this analysis should not in any way be used to suggest that variations in flows would lead to impairments according to state standards. Logistic regression analysis was restricted to those stations and constituents with 100 or more observations as well as more than 10% of the observations showing exceedances of the thresholds.

5.0 Results of Statistical Analyses

This section presents the results of the statistical analyses described above.

5.1 Trend Test Results

5.1.1 Flow Trend Tests

A plot of the monthly median flow time series for each gage is presented in Figure 10. Results of the MK trend test suggest that monthly median flows were increasing over the period of record in June, August, September, and October at the USGS Horse Creek gage near Myakka Head (No. 02297155) between 1977 and 2020. No trend over time was observed in other months at the USGS Horse Creek gage near Myakka Head (No. 02297155) and no monthly trends were observed over the 70-year period of record at the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310). September flows at the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310) gage were highly variable relative to other months over time and likely influenced by hurricane activity.

A)

B)

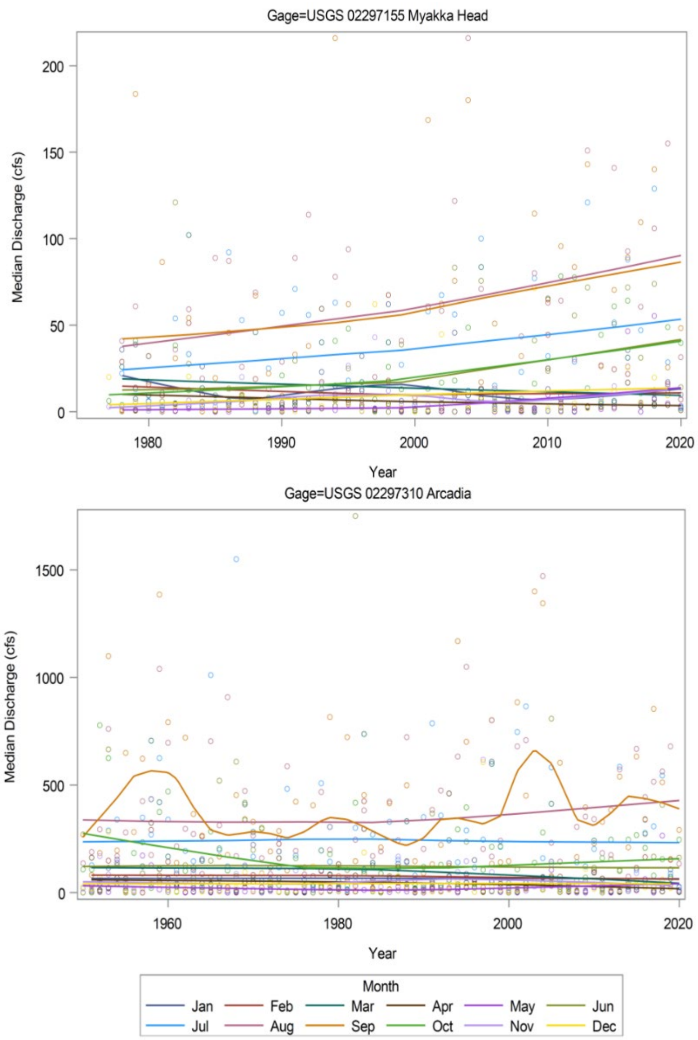

Figure 10. *Monthly median flow time series (points) and locally-estimated scatterplot smoothing (LOESS) polylines for (A) USGS Horse Creek gage near Myakka Head (No. 02297155) and (B) USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310).*

5.1.2 Water Quality Trend Tests

Water quality trend tests were conducted using the SMK test. Six stations met the requirements (*i.e.,* having recent data and at least 60 observations) for analysis and 129 constituent/station combinations were evaluated. Forty-three trend tests results were statistically significant. The results for statistically significant results are presented by constituent group in the sub sections below. Note that for ease of presenting the more limited results, chlorophyll *a* and nutrients constituent groups have been combined into one sub-section for presenting trend test results below.

5.1.2.1 Chlorophyll a and Nutrients

Chlorophyll *a* trends were decreasing over time at two of six sites (HCSW-1 and HCSW-4), orthophosphate as PO_4^{3-} trends increased at two of six sites while ammonia and nitrate-nitrite decreased at one site each (Table 6). Total nitrogen trends decreased over time at site 24049 (which has a period for record dating back to 1997) but increased over time at HCSW-3 between 2003 and 2019. No chlorophyll *a* or nutrient constituent was observed to be consistently trending at more than two sites.

Table 6. *Results of Seasonal Mann Kendall test for trend for those constituent-station combinations in the chlorophyll* a *and nutrients constituent group with statistically significant ($p<0.05$) results.*

Station	Constituent	N	Serial Correlation	Adjusted P Value	Theil Sen Slope (Change /Year)	Trend Direction
HCSW-1	Chlorophyll *a* (µg/l)	179	No	0.00050	-0.0420	Decreasing
HCSW-4	Chlorophyll *a* (µg/l)	183	No	0.00113	-0.0500	Decreasing
HCSW-1	Ammonia (mg/l)	175	No	0.00675	-0.0013	Decreasing
HCSW-2	Nitrate-Nitrite (mg/l)	167	No	0.00857	-0.0020	Decreasing
HCSW-2	Orthophosphate as PO_4^{3-} (mg/l)	171	Yes	0.03475	0.0070	Increasing
HCSW-3	Orthophosphate as PO_4^{3-} (mg/l)	179	No	0.04654	0.0047	Increasing
24049	Total Nitrogen (mg/l)	160	Yes	0.01662	-0.0209	Decreasing
HCSW-3	Total Nitrogen (mg/l)	183	No	0.03966	0.0160	Increasing

Notes: N is sample size; µg/L is microgram per liter; $p < 0.05$ is significant $p \geq 0.05$ is not significant; mg/L is milligram per liter

5.1.2.2 Physio-Chemical Constituents

Physio-chemical constituents were increasing when a statistically significant trend was observed (Table 7). pH increased at five of six stations. Alkalinity increased at four of six stations and conductivity increased at three of six stations.

Table 7. *Results of Seasonal Mann Kendall test for trend for those constituent-station combinations in the physio-chemical constituent group with statistically significant ($p<0.05$) results.*

Station	Constituent	N	Serial Correlation	Adjusted p Value	Theil Sen Slope (Change /Year)	Trend Direction
23949	Alkalinity (mg/l)	173	No	<0.0001	2.3150	Increasing
HCSW-1	Alkalinity (mg/l)	181	Yes	0.00534	2.0307	Increasing
HCSW-2	Alkalinity (mg/l)	173	No	<0.0001	1.7050	Increasing
HCSW-3	Alkalinity (mg/l)	182	Yes	0.01230	1.0929	Increasing
23949	Conductivity (µmho/cm)	206	No	<0.0001	13.4167	Increasing
HCSW-1	Conductivity (µmho/cm)	182	Yes	0.00586	12.2857	Increasing
HCSW-2	Conductivity (µmho/cm)	174	Yes	0.03803	9.0000	Increasing
23949	pH	206	No	<0.0001	0.0235	Increasing
HCSW-1	pH	182	No	<0.0001	0.0400	Increasing
HCSW-2	pH	174	No	0.00056	0.0255	Increasing
HCSW-3	pH	184	No	<0.0001	0.0371	Increasing
HCSW-4	pH	187	No	0.00113	0.0277	Increasing

Notes: N is sample size; µmho/cm is micromho per centimeter; $p < 0.05$ is significant $p \geq 0.05$ is not significant; mg/L is milligram per liter

5.1.2.3 Minerals and Metals

Seventeen station/constituent combinations in the minerals and metals group exhibited statistically significant trends over time (Table 8). Radium (both radium total and radium 228) decreased at four of six stations. Radium 226 was not found to be trending over time suggesting radium 228 was responsible for the decreasing trends in total radium over time as total radium is the sum of radium 226 and radium 228. Dissolved calcium and sulfate (total or dissolved) each increased at three of six stations. Both constituents increased in the upper portion of the system but not at the lower stations. Additional trends in minerals and metals were observed for only single stations, including fluoride (increasing), dissolved iron (decreasing) and magnesium (increasing).

Table 8*. Results of Seasonal Mann Kendall test for trend for those constituent-station combinations in the minerals and metals constituent group with statistically significant (p<0.05) results.*

Station	Constituent	N	Serial Correlation	Adjusted p Value	Theil Sen Slope (Change /Year)	Trend Direction
23949	Calcium Dissolved (mg/l)	159	No	<0.0001	1.1414	Increasing
HCSW-1	Calcium Dissolved (mg/l)	178	Yes	0.00575	1.1771	Increasing
HCSW-2	Calcium Dissolved (mg/l)	170	Yes	0.00968	0.7100	Increasing
23949	Fluoride (mg/l)	111	No	<0.0001	0.0120	Increasing
HCSW-2	Iron dissolved (mg/l)	169	Yes	0.00857	-0.0157	Decreasing
23949	Magnesium (mg/l)	147	No	<0.0001	0.4800	Increasing
HCSW-1	Radium Total (pCi/L)	172	No	0.00534	-0.0230	Decreasing
HCSW-2	Radium Total (pCi/L)	164	No	<0.0001	-0.0333	Decreasing
HCSW-3	Radium Total (pCi/L)	174	No	<0.0001	-0.0429	Decreasing
HCSW-4	Radium Total (pCi/L)	177	No	<0.0001	-0.0333	Decreasing
HCSW-1	Radium 228 (pCi/L)	173	No	<0.0001	-0.0100	Decreasing
HCSW-2	Radium 228 (pCi/L)	165	No	<0.0001	-0.0125	Decreasing
HCSW-3	Radium 228 (pCi/L)	175	No	<0.0001	-0.0121	Decreasing
HCSW-4	Radium 228 (pCi/L)	178	No	<0.0001	-0.0143	Decreasing
HCSW-1	Sulfate Total (mg/l)	182	No	<0.0001	4.5500	Increasing
HCSW-2	Sulfate Total (mg/l)	174	Yes	0.02543	2.5967	Increasing
23949	Sulfate Dissolved (mg/l)	157	No	<0.0001	3.9000	Increasing

Notes: N is sample size; pCi/L is picocurie per liter; $p < 0.05$ is significant $p \geq 0.05$ is not significant; mg/L is milligram per liter

5.1.2.4 Water Clarity

Turbidity increased over time at three of six stations (Table 9). The other water clarity constituents with statistically significant trends were color, TDS, and TOC at stations associated with the Myakka Head gage in the upper portion of the river.

Table 9*. Results of Seasonal Mann Kendall test for trend for those constituent-station combinations in the water clarity constituent group with statistically significant (p<0.05) results.*

Station	Constituent	N	Serial Correlation	Adjusted p Value	Theil Sen Slope (Change /Year)	Trend Direction
HCSW-1	Color (PCU)	181	Yes	0.04701	3.3333	Increasing
HCSW-1	Total Dissolved Solids (mg/l)	178	Yes	0.00534	9.8875	Increasing
23949	Total Organic Carbon (mg/l)	202	Yes	0.00334	0.3088	Increasing
HCSW-1	Turbidity (NTU)	182	No	0.04453	0.0467	Increasing
HCSW-3	Turbidity (NTU)	184	No	0.00175	0.0894	Increasing
HCSW-4	Turbidity (NTU)	187	No	0.00125	0.0918	Increasing

Notes: N is sample size; PCU is platinum-cobalt unit; NTU is Nephelometric turbidity unit; $p < 0.05$ is significant $p \geq 0.05$ is not significant; mg/L is milligram per liter; R^2 is the coefficient of determination

5.2 Linear Regression Results

This section presents the results of linear regression models; the results are presented by constituent group. Bivariate (*i.e.*, XY plots) plots of each constituent against flow followed by detailed statistical output for each regression performed are provided in Appendix B and C of the Supplemental Materials document, respectively.

In the regression tables below, regression statistics are reported where significant (p value less than 0.05) and an "ns" is reported where the p value was greater than or equal to 0.05. As described in the methods section, if the seasonal term was not significant in the model, the regression statistics reported for the intercept and flow terms represent the results from a univariate regression of the constituent against flow.

5.2.1 Nitrogen

Thirty-four analyses were performed on seven nitrogen constituents (ammonia, ammonium, unionized ammonium, nitrite, nitrate-nitrite, Total Kjeldahl nitrogen, and total nitrogen) at stations with samples sizes greater than or equal to 100 (Table 10). Fifteen of these relationships were found to be non-significant and seasonality was found to be significant for nine of these 15 non-significant relationships with flow. Positive relationships with flow were observed for TKN (5/6) and TN (6/7) with no significant negative relationships for those constituents. Four negative relationships were observed and were restricted to ammonia, unionized ammonium, nitrate, and nitrate-nitrite. Two of these results had R^2 values less than 0.10 and are denoted by an asterisk in Table 10 to suggest that, while statistically significant, very little of the variation in water quality is explained by the model.

***Table 10**. Linear regression for nitrogen constituents at primary water quality sites where sample size ≥ 100 in Horse Creek, on flows in cubic feet per second at either the USGS Horse Creek gage near Myakka Head (No.02297155) or the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310).*

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Myakka Head	Ammonia (mg/l)	23949	180	<0.001	ns	-0.032	0.26	0
Myakka Head	Ammonia (mg/l)	HCSW-1	174	ns	ns	-0.023	0.00	0
Myakka Head	Ammonia (mg/l)	HCSW-2	168	0.012	<0.001	-0.133	0.17	-1
Myakka Head	Ammonia (mg/l)	HCSW-3	175	ns	ns	-0.041	0.01	0
Arcadia	Ammonia (mg/l)	24049	176	0.001	ns	0.050	0.25	0
Arcadia	Ammonia (mg/l)	HCSW-4	174	ns	ns	-0.022	0.00	0
Arcadia	Ammonium (mg/l)	21FLA 25020111	113	0.038	ns	-0.067	0.18	0
Myakka Head	Nitrite (mg/l)	23949	158	<0.001	0.007	0.045	0.44	1
Arcadia	Nitrite (mg/l)	02297310	113	ns	ns	0.031	0.02	0
Arcadia	Nitrite (mg/l)	24049	154	<0.001	<0.001	0.094	0.49	1
Arcadia	Nitrate (mg/l)	02297310	113	0.045	ns	-0.127	0.22	0
Myakka Head	Nitrate-Nitrite (mg/l)	23949	209	<0.001	ns	0.049	0.20	0
Myakka Head	Nitrate-Nitrite (mg/l)	HCSW-1	176	0.003	0.047	0.102	0.21	1
Myakka Head	Nitrate-Nitrite (mg/l)	HCSW-2	166	ns	0.045	-0.085	0.02 *	-1
Myakka Head	Nitrate-Nitrite (mg/l)	HCSW-3	178	<0.001	ns	0.032	0.18	0
Arcadia	Nitrate-Nitrite (mg/l)	02297310	113	0.004	ns	-0.100	0.25	0
Arcadia	Nitrate-Nitrite (mg/l)	21FLA 25020111	104	ns	0.021	-0.147	0.05 *	-1
Arcadia	Nitrate-Nitrite (mg/l)	24049	202	<0.001	ns	-0.005	0.25	0
Arcadia	Nitrate-Nitrite (mg/l)	HCSW-4	177	<0.001	ns	-0.079	0.30	0
Arcadia	Organic Nitrogen (mg/l)	02297310	116	<0.001	<0.001	0.108	0.56	1
Myakka Head	TKN (mg/l)	HCSW-1	176	ns	<0.001	0.105	0.20	1
Myakka Head	TKN (mg/l)	HCSW-2	171	ns	ns	0.008	0.00	0
Myakka Head	TKN (mg/l)	HCSW-3	179	ns	<0.001	0.091	0.14	1
Arcadia	TKN (mg/l)	02297310	114	<0.001	<0.001	0.107	0.60	1
Arcadia	TKN (mg/l)	21FLA 25020111	141	ns	<0.001	0.130	0.37	1
Arcadia	TKN (mg/l)	HCSW-4	179	ns	<0.001	0.128	0.36	1
Myakka Head	Total Nitrogen (mg/l)	23949	162	<0.001	0.002	0.038	0.40	1
Myakka Head	Total Nitrogen (mg/l)	HCSW-1	179	ns	<0.001	0.104	0.23	1
Myakka Head	Total Nitrogen (mg/l)	HCSW-2	172	ns	ns	0.008	0.00	0
Myakka Head	Total Nitrogen (mg/l)	HCSW-3	181	ns	<0.001	0.067	0.08	1
Arcadia	Total Nitrogen (mg/l)	02297310	114	ns	0.006	0.059	0.07	1

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Arcadia	Total Nitrogen (mg/l)	24049	161	<0.001	0.007	0.042	0.30	1
Arcadia	Total Nitrogen (mg/l)	HCSW-4	179	ns	<0.001	0.069	0.12	1
Arcadia	Unionized Ammonium (mg/l)	21FLA 25020111	112	0.015	<0.001	-0.553	0.47	-1

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
cfs is cubic feet per second
N is sample size
TKN is Total Kjeldahl nitrogen
$p < 0.05$ is significant $p \geq 0.05$ is not significant
ns indicates p value is not significant
mg/L is milligram per liter
R^2 is the coefficient of determination
* indicates a low R^2 value

An additional 11 regressions were analyzed for six nitrogen constituents at stations with sample sizes less than 100 (Table 11). Five of these yielded significant relationships with flow including a single negative relationship (for nitrate which had a R^2 less than 0.10) and positive relationships for two organic nitrogen regressions, one total nitrogen and one TKN regression. Just one relationship indicated seasonality as significant (TKN at station 24049) but flow was not a significant factor for this station/constituent.

Table 11. Linear regression for nitrogen constituents at primary water quality sites where sample size < 100 in Horse Creek, on flows in cubic feet per second at either the USGS Horse Creek gage near Myakka Head (No.02297155) or the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310).

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Myakka Head	Nitrite (mg/l)	02297155	44	ns	ns	-0.009	0.01	0
Arcadia	Nitrite (mg/l)	21FLA 25020111	25	ns	ns	0.018	0.01	0
Myakka Head	Nitrate (mg/l)	02297155	44	ns	ns	-0.096	0.04	0
Arcadia	Nitrate (mg/l)	21FLA 25020111	85	ns	0.012	-0.110	0.07*	-1
Myakka Head	Nitrate-Nitrite (mg/l)	02297155	44	ns	ns	-0.049	0.01	0
Myakka Head	Organic Nitrogen (mg/l)	02297155	44	ns	<0.001	0.141	0.50	1
Arcadia	Organic Nitrogen (mg/l)	21FLA 25020111	82	ns	<0.001	0.104	0.16	1
Myakka Head	TKN (mg/l)	02297155	44	ns	<0.001	0.134	0.49	1
Myakka Head	TKN (mg/l)	23949	37	ns	ns	0.029	0.03	0
Arcadia	TKN (mg/l)	24049	37	0.031	ns	0.026	0.59	0
Myakka Head	Total Nitrogen (mg/l)	02297155	44	ns	<0.001	0.122	0.47	1

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
cfs is cubic feet per second
N is sample size
TKN is Total Kjeldahl nitrogen
$p < 0.05$ is significant $p \geq 0.05$ is not significant
ns indicates p value is not significant
mg/L is milligram per liter
R^2 is the coefficient of determination
* indicates a low R^2 value

When sample sizes were combined, 42% of nitrogen analyte relationships yielded positive relationships with flow (most frequently for TKN and TN), while 11% yielded negative flow relationships (for nitrate-nitrite, nitrate, unionized ammonium, and ammonia).

5.2.2 Phosphorus

Eleven analyses were performed on three phosphorus constituents (dissolved ortho P, orthophosphate as PO_4^{3-}, and total phosphorus) at stations with samples sizes greater than or equal to 100 (Table 12). Nine of these relationships were significant and all but one had negative slopes. Seasonality was significant for all but two of the 11 analyses.

Table 12. Linear regression for phosphorus constituents at primary water quality sites where sample size ≥ 100 in Horse Creek, on flows in cubic feet per second at either the USGS Horse Creek gage near Myakka Head (No.02297155) or the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310).

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Myakka Head	Dissolved Ortho P (mg/l)	23949	214	ns	<0.001	-0.055	0.11	-1
Arcadia	Dissolved Ortho P (mg/l)	24049	207	<0.001	0.004	-0.034	0.26	-1
Myakka Head	Orthophosphate as PO_4^{3-} (mg/l)	HCSW-1	175	ns	ns	-0.018	0.01	0
Myakka Head	Orthophosphate as PO_4^{3-} (mg/l)	HCSW-2	170	<0.001	<0.001	0.120	0.43	1
Myakka Head	Orthophosphate as PO_4^{3-} (mg/l)	HCSW-3	177	0.004	ns	0.022	0.20	0
Arcadia	Orthophosphate as PO_4^{3-} (mg/l)	02297310	123	0.015	0.027	-0.041	0.19	-1
Arcadia	Orthophosphate as PO_4^{3-} (mg/l)	HCSW-4	176	<0.001	0.043	-0.046	0.20	-1
Myakka Head	Total Phosphorus (mg/l)	23949	210	0.032	<0.001	-0.051	0.17	-1
Arcadia	Total Phosphorus (mg/l)	02297310	122	<0.001	0.029	-0.033	0.25	-1
Arcadia	Total Phosphorus (mg/l)	21FLA 25020111	172	0.014	0.021	-0.040	0.16	-1
Arcadia	Total Phosphorus (mg/l)	24049	204	<0.001	0.01	-0.030	0.32	-1

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
cfs is cubic feet per second
N is sample size
$p < 0.05$ is significant $p \geq 0.05$ is not significant
ns indicates p value is not significant
mg/l is milligram per liter
R^2 is the coefficient of determination
* indicates a low R^2 value

An additional three regressions were analyzed for three phosphorus analytes at stations with sample sizes less than 100 (Table 13). None of these yielded significant relationships with flow or indicated seasonality as significant.

Table 13. Linear regression for phosphorus constituents at primary water quality sites where sample size < 100 in Horse Creek, on flows in cubic feet per second at either the USGS Horse Creek gage near Myakka Head (No.02297155) or the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310).

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Myakka Head	Orthophosphate as PO_4^{3-} (mg/l)	02297155	44	ns	ns	-0.048	0.07	0
Arcadia	Total Orthophosphate P (mg/l)	21FLA 25020111	66	ns	ns	0.011	0.00	0
Myakka Head	Total Phosphorus (mg/l)	02297155	44	ns	ns	-0.036	0.05	0

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
cfs is cubic feet per second
N is sample size
$P < 0.05$ is significant $P \geq 0.05$ is not significant
ns indicates p value is not significant
mg/L is milligram per liter
R^2 is the coefficient of determination

When sample sizes were combined, 57% of phosphorus constituent regressions yielded negative relationships with flow, while 7% (one regression) yielded positive flow relationships with flow.

5.2.3 Chlorophyll *a*

Six regressions were performed for chlorophyll *a* at stations with samples sizes greater than or equal to 100 (Table 14). All but two (one at each flow gage location) exhibited significant relationships with flow; three were negative and one was positive. Seasonality was also indicated as significant for two of the significant flow relationships.

Table 14. Linear regression for uncorrected chlorophyll a at primary water quality sites where sample size ≥ 100 in Horse Creek, on flows in cubic feet per second at either the USGS Horse Creek gage near Myakka Head (No.02297155) or the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310).

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Myakka Head	Chlorophyll Uncorrected (µg/l)	23949	164	ns	0.003	-0.060	0.05*	-1
Myakka Head	Chlorophyll (µg/l)	HCSW-1	177	ns	0.026	0.075	0.03*	1
Myakka Head	Chlorophyll (µg/l)	HCSW-2	170	0.003	<0.001	-0.201	0.26	-1
Myakka Head	Chlorophyll (µg/l)	HCSW-3	178	ns	ns	0.026	0.01	0
Arcadia	Chlorophyll Uncorrected (µg/l)	24049	163	0.044	0.011	-0.070	0.16	-1
Arcadia	Chlorophyll (µg/l)	HCSW-4	177	ns	ns	0.024	0.00	0

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
cfs is cubic feet per second
N is sample size
$p < 0.05$ is significant $p \geq 0.05$ is not significant
ns indicates p value is not significant
mg/L is milligram per liter
R^2 is the coefficient of determination
* indicates a low R^2 value

An additional regression was analyzed for uncorrected chlorophyll *a* at a station with sample size less than 100 (Table 15). This relationship was not significant for either flow or seasonality.

Table 15. Linear regression for uncorrected chlorophyll a at a primary water quality site where sample size < 100 in Horse Creek, on flows in cubic feet per second at the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310).

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Arcadia	Chlorophyll Uncorrected (µg/l)	21FLA 25020111	15	ns	ns	0.120	0.06	0

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
cfs is cubic feet per second
N is sample size
$p < 0.05$ is significant $p \geq 0.05$ is not significant
ns indicates p value is not significant
mg/L is milligram per liter
R^2 is the coefficient of determination

In total, 43% of chlorophyll *a* regressions yielded negative significant results, while 14% (one relationship) yielded a positive significant result.

5.2.4 Physio-Chemical Constituents

Thirty-nine analyses were performed on alkalinity, conductivity, pH, temperature, and dissolved oxygen (saturation and concentration) at stations with samples sizes greater than or equal to 100 (Table 16). Five of the six alkalinity regressions were significant and indicated negative relationships; seasonality was significant for five stations, including a station where flow was not significant. Seven of the nine conductivity analyses yielded significant relationship with flow, all of which were negative; seasonality was significant at five of these. All of the five relationships between conductivity and flow at Arcadia were significant, while only half of those at Myakka Head were significant. Seven of the nine pH regressions from stations with at least 100 samples were indicated to be significant with flow and characterized by negative slopes; three analyses indicated seasonality was significant for pH in Horse Creek. Nine relationships between dissolved oxygen concentration and flow were examined; four of these were against flow at Myakka Head while the remainder was flow at Arcadia. In addition, one analysis was completed comparing flow at Arcadia to dissolved oxygen saturation. All relationships indicated seasonality was significant which is not surprising given temperature effects on dissolved oxygen. Six of the concentration regressions with flow, as well as the saturation regression, were indicated to be significant; all but one (the most upstream station) were negative relationships. All five regressions for temperature were indicated to have significant seasonal effects. However, only one was characterized by a significant relationship with flow (negative).

Table 16. Linear regression for specified physio-chemical constituents at primary water quality sites where sample size ≥ 100 in Horse Creek, on flows in cubic feet per second at either the USGS Horse Creek gage near Myakka Head (No.02297155) or the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310).

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Myakka Head	Alkalinity (mg/l)	23949	179	0.012	<0.001	-0.066	0.23	-1
Myakka Head	Alkalinity (mg/l)	HCSW-1	179	ns	0.027	-0.036	*0.03	-1
Myakka Head	Alkalinity (mg/l)	HCSW-2	172	0.037	ns	0.010	0.12	0
Myakka Head	Alkalinity (mg/l)	HCSW-3	180	<0.001	0.047	-0.030	0.28	-1
Arcadia	Alkalinity (mg/l)	24049	175	0.002	<0.001	-0.198	0.75	-1
Arcadia	Alkalinity (mg/l)	HCSW-4	180	0.016	<0.001	-0.187	0.70	-1
Myakka Head	Conductivity (µmho/cm)	23949	216	ns	ns	-0.025	0.01	0
Myakka Head	Conductivity (µmho/cm)	HCSW-1	180	ns	ns	-0.005	0.00	0
Myakka Head	Conductivity (µmho/cm)	HCSW-2	173	ns	<0.001	-0.053	*0.08	-1
Myakka Head	Conductivity (µmho/cm)	HCSW-3	182	<0.001	<0.001	-0.158	0.47	-1
Arcadia	Conductivity (µmho/cm)	02297310	261	ns	<0.001	-0.242	0.59	-1
Arcadia	Conductivity (µmho/cm)	21FLA 25020111	208	0.002	<0.001	-0.227	0.68	-1
Arcadia	Conductivity (µmho/cm)	21FLFTM 25020420	227	<0.001	<0.001	-0.159	0.67	-1
Arcadia	Conductivity (µmho/cm)	24049	213	<0.001	<0.001	-0.193	0.69	-1
Arcadia	Conductivity (µmho/cm)	HCSW-4	181	<0.001	<0.001	-0.212	0.71	-1
Myakka Head	Dissolved Oxygen (mg/l)	23949	217	<0.001	0.021	0.010	0.56	1
Myakka Head	Dissolved Oxygen (mg/l)	HCSW-1	169	<0.001	ns	-0.001	0.56	0
Myakka Head	Dissolved Oxygen (mg/l)	HCSW-2	164	<0.001	0.01	-0.088	0.33	-1
Myakka Head	Dissolved Oxygen (mg/l)	HCSW-3	171	<0.001	ns	0.012	0.48	0
Arcadia	Dissolved Oxygen (mg/l)	02297310	183	<0.001	0.002	-0.030	0.37	-1
Arcadia	Dissolved Oxygen (mg/l)	21FLA 25020111	289	<0.001	<0.001	-0.059	0.50	-1
Arcadia	Dissolved Oxygen (mg/l)	21FLFTM 25020420	181	<0.001	ns	0.002	0.58	0
Arcadia	Dissolved Oxygen (mg/l)	24049	213	<0.001	<0.001	-0.035	0.60	-1
Arcadia	Dissolved Oxygen (mg/l)	HCSW-4	171	<0.001	<0.001	-0.083	0.62	-1
Arcadia	Dissolved Oxygen (%sat)	21FLA 25020111	282	<0.001	<0.001	-0.066	0.36	-1
Myakka Head	pH	23949	217	ns	<0.001	-0.010	0.16	-1
Myakka Head	pH	HCSW-1	180	ns	0.003	-0.008	*0.05	-1
Myakka Head	pH	HCSW-2	173	ns	0.005	-0.006	*0.05	-1
Myakka Head	pH	HCSW-3	182	0.01	ns	0.001	0.18	0
Arcadia	pH	02297310	209	ns	<0.001	-0.024	0.21	-1
Arcadia	pH	21FLA 25020111	281	ns	<0.001	-0.025	0.53	-1
Arcadia	pH	21FLFTM 25020420	193	0.021	ns	-0.004	0.22	0
Arcadia	pH	24049	212	<0.001	<0.001	-0.015	0.53	-1
Arcadia	pH	HCSW-4	181	ns	<0.001	-0.018	0.22	-1
Myakka Head	Temperature (C)	23949	217	<0.001	ns	0.005	0.72	0
Arcadia	Temperature (C)	02297310	209	<0.001	ns	-0.011	0.63	0
Arcadia	Temperature (C)	21FLA 25020111	287	<0.001	0.014	-0.017	0.54	-1
Arcadia	Temperature (C)	21FLFTM 25020420	193	<0.001	ns	-0.003	0.72	0
Arcadia	Temperature (C)	24049	213	<0.001	ns	0.006	0.76	0

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
cfs is cubic feet per second
N is sample size
mg/L is milligram per liter
$p < 0.05$ is significant $p \geq 0.05$ is not significant
ns indicates p value is not significant
R^2 is the coefficient of determination
C is degrees Celsius
* indicates a low R^2 value

An additional twenty-six regressions were analyzed for physio-chemical constituents at stations with sample sizes less than 100 (Table 17). Biological oxygen demand was analyzed from one station and found to have no significant relationship with flow. On the other hand, chemical oxygen demand (COD) exhibited a significant relationship with flow which was positive; no seasonality significance was indicated. In terms of conductivity, two regressions yielded negative significant relationships with flow at Myakka Head; one of these also indicated seasonality as significant. Four regressions for dissolved oxygen concentration and nine for dissolved oxygen saturation were analyzed. Six of these 13 total analyses were significant with flow and had negative slopes; seasonality was indicated as significant for only one and at a station where flow was not deemed significant. Temperature at stations with less than 100 samples was not found to be significantly related to flow, but all four regressions indicated seasonality was significant. pH at three stations exhibited significant negative relationships with flow at Myakka Head, while pH at one station was found to not vary significantly with flow at Arcadia. Seasonality was not a significant factor for pH at stations with fewer than 100 samples.

Table 17. *Linear regression for specified physio-chemical constituents at primary water quality sites where sample size < 100 in Horse Creek, on flows in cubic feet per second at either the USGS Horse Creek gage near Myakka Head (No.02297155) or the USGS Horse Creek gage at State Road 72 near Arcadia site (No. 02297310).*

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Arcadia	Biological Oxygen Demand (mg/l)	21FLA 25020111	34	ns	ns	0.050	0.04	0
Arcadia	Chemical Oxygen Demand (mg/l)	21FLA 25020111	39	ns	<0.001	0.181	0.57	1
Myakka Head	Conductivity (µmho/cm)	02297155	76	0.018	<0.001	-0.181	0.67	-1
Myakka Head	Conductivity (µmho/cm)	21FLA 25020428	29	ns	<0.001	-0.152	0.66	-1
Myakka Head	Dissolved Oxygen (mg/l)	02297155	76	ns	ns	-0.011	0.00	0
Myakka Head	Dissolved Oxygen (mg/l)	21FLA 25020423	39	ns	<0.001	-0.067	0.27	-1
Myakka Head	Dissolved Oxygen (mg/l)	21FLA 25020428	45	ns	ns	0.015	0.01	0
Arcadia	Dissolved Oxygen (mg/l)	21FLA 25020430	42	ns	ns	-0.133	0.05	0
Myakka Head	Dissolved Oxygen (%sat)	21FLA 25020423	39	ns	<0.001	-0.060	0.26	-1
Myakka Head	Dissolved Oxygen (%sat)	21FLA 25020428	44	ns	ns	0.023	0.03	0
Myakka Head	Dissolved Oxygen (%sat)	HCSW-1	64	ns	<0.001	-0.055	0.48	-1
Myakka Head	Dissolved Oxygen (%sat)	HCSW-2	55	ns	<0.001	-0.209	0.33	-1
Myakka Head	Dissolved Oxygen (%sat)	HCSW-3	65	ns	<0.001	-0.106	0.39	-1
Arcadia	Dissolved Oxygen (%sat)	02297310	38	ns	ns	-0.020	0.02	0
Arcadia	Dissolved Oxygen (%sat)	21FLA 25020430	42	ns	ns	-0.114	0.05	0
Arcadia	Dissolved Oxygen (%sat)	21FLFTM 25020420	63	0.007	ns	-0.029	0.56	0
Arcadia	Dissolved Oxygen (%sat)	HCSW-4	66	ns	<0.001	-0.087	0.56	-1
Arcadia	Hardness (mg/l)	21FLA 25020111	53	ns	<0.001	-0.293	0.61	-1
Myakka Head	pH	02297155	77	ns	<0.001	-0.022	0.17	-1
Myakka Head	pH	21FLA 25020423	35	ns	0.01	-0.013	0.18	-1
Myakka Head	pH	21FLA 25020428	42	ns	<0.001	-0.033	0.64	-1
Arcadia	pH	21FLA 25020430	44	ns	ns	-0.010	0.05	0
Myakka Head	Temperature (C)	02297155	76	<0.001	ns	0.008	0.69	0
Myakka Head	Temperature (C)	21FLA 25020423	39	<0.001	ns	-0.001	0.69	0
Myakka Head	Temperature (C)	21FLA 25020428	44	<0.001	ns	0.011	0.62	0
Arcadia	Temperature (C)	21FLA 25020430	45	<0.001	ns	0.004	0.71	0

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
cfs is cubic feet per second
N is sample size
mg/L is milligram per liter
R^2 is the coefficient of determination
$p < 0.05$ is significant $p \geq 0.05$ is not significant
ns indicates p value is not significant
C is degrees Celsius

When sample sizes were combined, 58% of relationships between flow and temperature, pH, dissolved oxygen, conductivity, and oxygen demand yielded negative relationships with flow, while 3% (two regressions) yielded positive flow relationships.

5.2.5 Minerals and Metals

Forty-two analyses were conducted to assess the relationship between flow and various minerals and metals from stations with samples sizes greater than or equal to 100 (Table 18). Four of the six regressions performed for both fluoride and calcium indicated significant relationships with flow, characterized by negative slopes. Seasonality was in no instance indicated as a significant factor for fluoride but was significant for three of the calcium analyses. All six chloride analyses yielded significant negative relationships with flow and seasonality was indicated as significant for all. Dissolved iron was indicated to vary significantly and positively with flow at three of the four stations with a minimum of 100 samples analyzed; seasonality was indicated to be significant for all four. Dissolved magnesium was assessed at two stations and found to have a significant negative relationship with flow and seasonality was significant for both. Total (n=4) and dissolved (n=2) sulfate was regressed against flow at both Myakka Head and Arcadia. Both relationships compared to flows at Arcadia were significant, while only one of the four regressions with Myakka Head flows was significant (the most downstream station). All significant results for sulfate were characterized by negative slopes. Seasonality was indicated to be significant for all sulfate regressions with the exception of two of the upstream stations that lacked significant relationships with flow at Myakka Head. The relationship between radium and flow includes radium 226, radium 228 and total radium. All four regressions for radium 226 indicated significant negative relationships with flow, while none of the radium 228 analyses resulted in significant findings. Total radium was characterized by significant negative relationships for three of the four stations analyzed. Seasonality was not significant for any analysis of radium.

Table 18. Linear regression for mineral and metal constituents at primary water quality sites where sample size ≥ 100 in Horse Creek, on flows in cubic feet per second at either the USGS Horse Creek gage near Myakka Head (No.02297155) or the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310).

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Myakka Head	Calcium Dissolved (mg/l)	23949	165	ns	0.012	-0.046	*0.04	-1
Myakka Head	Calcium Dissolved (mg/l)	HCSW-1	176	ns	ns	-0.008	0.00	0
Myakka Head	Calcium Dissolved (mg/l)	HCSW-2	169	ns	ns	-0.012	0.01	0
Myakka Head	Calcium Dissolved (mg/l)	HCSW-3	178	<0.001	<0.001	-0.211	0.62	-1
Arcadia	Calcium Dissolved (mg/l)	24049	160	<0.001	<0.001	-0.263	0.79	-1
Arcadia	Calcium Dissolved (mg/l)	HCSW-4	177	<0.001	<0.001	-0.268	0.69	-1
Myakka Head	Chloride (mg/l)	HCSW-1	179	<0.001	<0.001	-0.095	0.63	-1
Myakka Head	Chloride (mg/l)	HCSW-2	172	<0.001	<0.001	-0.101	0.60	-1
Myakka Head	Chloride (mg/l)	HCSW-3	181	<0.001	<0.001	-0.110	0.70	-1
Arcadia	Chloride (mg/l)	21FLA 25020111	147	0.004	<0.001	-0.129	0.53	-1
Arcadia	Chloride (mg/l)	21FLFTM 25020420	233	<0.001	<0.001	-0.143	0.69	-1
Arcadia	Chloride (mg/l)	HCSW-4	180	<0.001	<0.001	-0.155	0.77	-1
Myakka Head	Fluoride (mg/l)	23949	110	ns	ns	0.003	0.00	0
Myakka Head	Fluoride (mg/l)	HCSW-1	180	ns	ns	0.030	0.02	0
Myakka Head	Fluoride (mg/l)	HCSW-2	172	ns	0.002	-0.037	*0.06	-1
Myakka Head	Fluoride (mg/l)	HCSW-3	181	ns	<0.001	-0.135	0.25	-1
Arcadia	Fluoride (mg/l)	24049	100	ns	<0.001	-0.103	0.14	-1
Arcadia	Fluoride (mg/l)	HCSW-4	180	ns	<0.001	-0.160	0.33	-1
Myakka Head	Iron dissolved (mg/l)	HCSW-1	176	0.003	<0.001	0.132	0.38	1
Myakka Head	Iron dissolved (mg/l)	HCSW-2	168	<0.001	ns	-0.004	0.35	0
Myakka Head	Iron dissolved (mg/l)	HCSW-3	178	<0.001	<0.001	0.159	0.50	1
Arcadia	Iron dissolved (mg/l)	HCSW-4	177	<0.001	<0.001	0.309	0.67	1
Myakka Head	Magnesium dissolved (mg/l)	23949	153	0.041	0.007	-0.060	0.20	-1
Arcadia	Magnesium dissolved (mg/l)	24049	151	0.001	<0.001	-0.212	0.70	-1
Myakka Head	Radium 226 (pCi/L)	HCSW-1	171	ns	0.011	-0.052	*0.04	-1
Myakka Head	Radium 226 (pCi/L)	HCSW-2	164	ns	0.028	-0.054	*0.03	-1
Myakka Head	Radium 226 (pCi/L)	HCSW-3	173	ns	<0.001	-0.125	0.16	-1
Arcadia	Radium 226 (pCi/L)	HCSW-4	178	ns	<0.001	-0.113	0.14	-1
Myakka Head	Radium 228 (pCi/L)	HCSW-1	171	ns	ns	-0.009	0.01	0
Myakka Head	Radium 228 (pCi/L)	HCSW-2	164	ns	ns	0.000	0.00	0
Myakka Head	Radium 228 (pCi/L)	HCSW-3	173	ns	ns	-0.000	0.00	0
Arcadia	Radium 228 (pCi/L)	HCSW-4	178	ns	ns	0.006	0.00	0

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Myakka Head	Radium Total (pCi/L)	HCSW-1	170	ns	0.012	-0.029	*0.04	-1
Myakka Head	Radium Total (pCi/L)	HCSW-2	163	ns	ns	-0.014	0.01	0
Myakka Head	Radium Total (pCi/L)	HCSW-3	172	ns	<0.001	-0.054	0.10	-1
Arcadia	Radium Total (pCi/L)	HCSW-4	177	ns	<0.001	-0.042	*0.07	-1
Myakka Head	Sulfate Total (mg/l)	HCSW-1	180	ns	ns	0.045	0.01	0
Myakka Head	Sulfate Total (mg/l)	HCSW-2	173	ns	ns	-0.026	0.00	0
Myakka Head	Sulfate Total (mg/l)	HCSW-3	182	0.024	<0.001	-0.246	0.38	-1
Arcadia	Sulfate Total (mg/l)	HCSW-4	181	0.007	<0.001	-0.315	0.58	-1
Myakka Head	Sulfate Dissolved (mg/l)	23949	163	0.027	ns	0.075	0.13	0
Arcadia	Sulfate Dissolved (mg/l)	24049	160	<0.001	<0.001	-0.280	0.70	-1

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
cfs is cubic feet per second
N is sample size
R^2 is the coefficient of determination
$p < 0.05$ is significant $p \geq 0.05$ is not significant
ns indicates p value is not significant
mg/l is milligram per liter
pCi/L is picocurie per liter
* indicates a low R^2 value

An additional 14 regressions were analyzed for total calcium (n=4), chloride (n=1), fluoride (n=2), iron (n=1), magnesium (n=2) and total sulfate (n=4) at stations with sample sizes less than 100 (Table 19). With the exception of one non-significant result for total sulfate and one positive significant regression for iron, these analyses yielded significant negative relationships with flow. Seasonality was not indicated as a significant factor for any of these 14 analyses.

Table 19*. Linear regression for mineral and metal constituents with <100 samples, on flows in cubic feet per second at either the USGS Horse Creek gage near Myakka Head (No.02297155) or the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310).*

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Myakka Head	Calcium Total (mg/l)	23949	30	ns	<0.001	-0.103	0.54	-1
Arcadia	Calcium Total (mg/l)	02297310	62	ns	<0.001	-0.338	0.71	-1
Arcadia	Calcium Total (mg/l)	21FLA 25020111	64	ns	<0.001	-0.310	0.62	-1
Arcadia	Calcium Total (mg/l)	24049	29	ns	<0.001	-0.183	0.64	-1
Arcadia	Chloride (mg/l)	02297310	75	ns	<0.001	-0.123	0.50	-1
Arcadia	Fluoride (mg/l)	02297310	73	ns	<0.001	-0.139	0.32	-1
Arcadia	Fluoride (mg/l)	21FLA 25020111	87	ns	<0.001	-0.174	0.74	-1
Arcadia	Iron (µg/l)	21FLA 25020111	51	ns	<0.001	0.224	0.53	1
Myakka Head	Magnesium (mg/l)	23949	32	ns	<0.001	-0.096	0.70	-1
Arcadia	Magnesium (mg/l)	24049	31	ns	<0.001	-0.153	0.48	-1
Myakka Head	Sulfate Total (mg/l)	23949	31	ns	ns	0.039	0.04	0
Arcadia	Sulfate Total (mg/l)	02297310	63	ns	<0.001	-0.369	0.45	-1
Arcadia	Sulfate Total (mg/l)	21FLA 25020111	91	ns	<0.001	-0.396	0.58	-1
Arcadia	Sulfate Total (mg/l)	24049	31	ns	<0.001	-0.192	0.39	-1

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
cfs is cubic feet per second
N is sample size
R^2 is the coefficient of determination
$p < 0.05$ is significant $p \geq 0.05$ is not significant
ns indicates p value is not significant
mg/l is milligram per liter

When sample sizes were combined, 68% of relationships between flow and minerals and metals yielded negative relationships with flow, while 7% yielded a positive flow relationship.

5.2.6 Indicators of Water Clarity

Twenty-two analyses were performed on indicators of water clarity (color, total organic carbon, total dissolved solids, total suspended solids, and turbidity) at stations with samples sizes greater than or equal to 100 (Table 20). All but four of these yielded significant relationships with flow (one color, two total dissolved solids and one turbidity). All significant relationships with flow were positive except TDS where two of three significant regressions had negative slopes. Total dissolved solids is typically an indication of groundwater inputs suggesting as flows increase groundwater becomes a lower contribution of the overall water clarity in the system. The one positive slope for TDS had an R^2 less than 0.10 suggesting little of the variation in TDS was explained by flow. Seasonality was found to be significant for all color, two total dissolved solids, both TOC regressions, and three of the turbidity regressions.

Table 20. Linear regression for indicator of water clarity constituents at primary water quality sites where sample size ≥ 100 in Horse Creek, on flows in cubic feet per second at either the USGS Horse Creek gage near Myakka Head (No.02297155) or the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310).

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Myakka Head	Color (PCU)	23949	213	<0.001	<0.001	0.130	0.57	1
Myakka Head	Color (PCU)	HCSW-1	179	0.011	<0.001	0.134	0.45	1
Myakka Head	Color (PCU)	HCSW-2	173	0.006	ns	0.011	0.20	0
Myakka Head	Color (PCU)	HCSW-3	181	<0.001	<0.001	0.155	0.49	1
Arcadia	Color (PCU)	21FLA 25020111	279	<0.001	<0.001	0.249	0.69	1
Arcadia	Color (PCU)	24049	206	<0.001	<0.001	0.228	0.76	1
Arcadia	Color (PCU)	HCSW-4	180	<0.001	<0.001	0.249	0.69	1
Myakka Head	Total Dissolved Solids (mg/l)	HCSW-1	176	ns	0.048	0.030	*0.02	1
Myakka Head	Total Dissolved Solids (mg/l)	HCSW-2	170	ns	ns	-0.016	0.01	0
Myakka Head	Total Dissolved Solids (mg/l)	HCSW-3	178	<0.001	<0.001	-0.132	0.47	-1
Arcadia	Total Dissolved Solids (mg/l)	02297310	122	ns	ns	-0.241	0.02	0
Arcadia	Total Dissolved Solids (mg/l)	HCSW-4	177	<0.001	<0.001	-0.184	0.56	-1
Myakka Head	Total Organic Carbon (mg/l)	23949	208	<0.001	<0.001	0.086	0.54	1
Arcadia	Total Organic Carbon (mg/l)	24049	202	<0.001	<0.001	0.101	0.66	1
Arcadia	Total Suspended Solids (mg/l)	21FLA 25020111	119	ns	<0.001	0.166	0.17	1
Myakka Head	Turbidity (NTU)	23949	212	0.002	<0.001	0.100	0.23	1
Myakka Head	Turbidity (NTU)	HCSW-1	180	ns	<0.001	0.184	0.35	1
Myakka Head	Turbidity (NTU)	HCSW-2	173	<0.001	ns	-0.024	0.33	0
Myakka Head	Turbidity (NTU)	HCSW-3	182	ns	<0.001	0.119	0.17	1
Arcadia	Turbidity (NTU)	21FLA 25020111	150	ns	<0.001	0.125	0.17	1
Arcadia	Turbidity (NTU)	24049	206	0.001	<0.001	0.172	0.32	1
Arcadia	Turbidity (NTU)	HCSW-4	181	ns	<0.001	0.187	0.31	1

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
cfs is cubic feet per second
N is sample size
R^2 is the coefficient of determination
$p < 0.05$ is significant $p \geq 0.05$ is not significant
ns indicates p value is not significant
mg/L is milligram per liter
PCU is platinum-cobalt unit
NTU is Nephelometric Turbidity Unit
* indicates a low R^2 value

An additional seven regressions (four color, two TOC and one turbidity) were analyzed at stations with sample sizes less than 100 (Table 21). Three of the four color relationships were significant and had positive slopes, both TOC regressions were significant with positive slopes and the turbidity regression was not significant with flow. Seasonality was only indicated as a significant factor for two of the four color regressions.

Table 21. Linear regression for indicator of water clarity constituents at primary water quality sites where sample size < 100 in Horse Creek, on flows in cubic feet per second at either the USGS Horse Creek gage near Myakka Head (No.02297155) or the USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310).

Gage	Constituent	Station	N	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Myakka Head	Color (PCU)	21FLA 25020423	37	0.004	0.01	0.078	0.75	1
Myakka Head	Color (PCU)	21FLA 25020428	42	ns	<0.001	0.133	0.38	1
Arcadia	Color (PCU)	02297310	62	0.004	<0.001	0.209	0.64	1
Arcadia	Color (PCU)	21FLA 25020430	42	ns	ns	0.031	0.04	0
Arcadia	Total Organic Carbon (mg/l)	02297310	39	ns	<0.001	0.147	0.33	1
Arcadia	Total Organic Carbon (mg/l)	21FLA 25020111	82	ns	<0.001	0.163	0.53	1
Myakka Head	Turbidity (NTU)	21FLA 25020428	32	ns	ns	0.051	0.04	0

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
cfs is cubic feet per second
N is sample size
R^2 is the coefficient of determination
$p < 0.05$ is significant $p \geq 0.05$ is not significant
ns indicates p value is not significant
mg/L is milligram per liter
PCU is platinum-cobalt units
NTU is Nephelometric Turbidity Units

When sample sizes were combined, 40% of relationships between flow and water clarity indicators yielded positive relationships with flow; 7% (two total dissolved solids regressions) yielded negative significant relationships.

5.3 Logistic Regression Results

Only TN and TP met criteria established above for logistic regression analysis. Dissolved oxygen percent saturation and chlorophyll a (uncorrected or corrected) either did not meet the sample size requirements or had an exceedance rate of less than 10% and were therefore disqualified from analysis. Total nitrogen at the Horse Creek Stewardship Program site HCSW-1 had an exceedance rate of 6.6% and was therefore disqualified. In addition, Horse Creek reported orthophosphate and not total phosphorus and therefore no logistic regression analysis was completed for those stations.

For station/constituent combinations that qualified for logistic regression (Table 22), the relationship between flow and the probability of exceeding the threshold values included both positive and negative relationships but the R^2 values were generally below 0.10 indicating little variation was explained by the model. For TN, HCSW-2, TN exceedances were negatively correlated with flows while for HCSW-3 and HCSW-4, the TN exceedance correlation with flow was positive. TN concentrations at site 24049 had less than 10% of the observations above the threshold value. With only an 8% exceedance rate, site 24049 did not even qualify for logistic regression analysis. Four sites met the requirements for TP logistic regression analysis. Total phosphorus exceedances were negatively correlated with flows at two of the sites and not correlated with flows at the other two sites but again, the R^2 values suggests flow is not a dominant driver of the probability of exceedance for these constituents.

Table 22. Results of logistic regression for constituents meeting the requirements of at least 100 observations and a 10% threshold exceedance rate. Thresholds were 1.65 mg/l (Total Nitrogen) and 0.49 mg/l (Total Phosphorus).

Constituent	Station	N	Below	Above	Month p Value	Flow p Value	Flow Slope	R^2	Slope Direction
Total Nitrogen (mg/l)	HCSW-3	181	148	33	ns	0.026	0.268	*0.05	1
Total Nitrogen (mg/l)	HCSW-4	179	131	48	ns	0.047	0.198	*0.03	1
Total Nitrogen (mg/l)	HCSW-2	172	126	46	0.043	0.002	-0.419	0.24	-1
Total Nitrogen (mg/l)	02297310	114	83	31	ns	0.96	0.006	0.00	0
Total Phosphorus (mg/l)	23949	210	137	73	ns	<0.001	-0.210	*0.08	-1
Total Phosphorus (mg/l)	24049	204	121	83	<0.001	ns	-0.089	0.35	0
Total Phosphorus (mg/l)	21FLA 25020111	172	73	99	ns	0.02	-0.203	*0.04	-1
Total Phosphorus (mg/l)	02297310	122	69	53	ns	ns	-0.012	0.00	0

Notes: Flow slope is the slope of the flow regression in ln(unit)/ln(cfs)
N is sample size
R^2 is the coefficient of determination
$p < 0.05$ is significant $p \geq 0.05$ is not significant
ns indicates p value is not significant
mg/L is milligram per liter
* indicates a low R^2 value

6.0 Summary of Results and Considerations

The analytical results descried above summarize an investigation into relationships with stream flow for a large group of water quality constituents. The results were presented to detail site-specific findings. The intent of the analysis was to provide the District with information that could be used to evaluate these relationships in consideration of water quality as an environmental value. To summarize the results across stations, Table 23 and Table 24 provide a summary of regression results by constituent across stations detailing the number of statistically positive, negative, and non-significant findings for primary and secondary evaluations, respectively. A total of 154 primary regressions were performed on 34 parameters from stations with a minimum of 100 samples (Table 23). Of these, 45% were negative and 24% were positive. For secondary regression results, 40% of the 62 regressions were negative and 18% were positive (Table 24). Regressions with consistently negative relationships with flow included chloride (7/7), conductivity (9/11), fluoride (6/8), total phosphorus (4/5), radium 226 (4/4) and pH (10/13). Consistently positive relationships with flow included turbidity (6/8), total nitrogen (7/8), total organic carbon (4/4) and color (9/11). Constituents with consistently non-significant relationships included ammonia (5/6), nitrate-nitrite (5/8), radium 228 (4/4) and temperature (4/5). Other regression results, such as for dissolved oxygen and chlorophyll *a*, were more site-specific and results were more variable.

It is important to note that the results described above are presented without regard to the strength of the association between flow and the constituent, expressed in this analysis by the R^2 statistic which quantifies the amount of variation in the response explained by the model. In some cases, the models were statistically significant but the R^2 values were low, suggesting the models explain less than 10% of the variability in water quality. These regressions were identified in the tables in the results section using an asterisk preceding the R^2 value. To evaluate the results across sites graphically in a similar manner to Table 23 and Table 24, summary plots were constructed to display the R^2 values for all significant regression by constituent. For clarity, regressions results with a negative slope against flow were plotted as negative R^2 values though technically R^2 is always a positive value. The resulting graphics are instructive to evaluate how strong the association between water quality and flow when significant. For example, when evaluating the results for regressions with at least 100 observations (Figure 11), chloride had a consistently negative relationship with flow and all R^2 values were 0.50 or higher indicating the majority of the variability in observed chloride concentrations could be explained by flow and season when seasonality was significant in the models. Calcium and color were other constituents with the majority of R^2 values above 0.50 while the radium, chlorophyll, nitrate-nitrite, and ammonia regressions were all below 0.30. There were fewer significant regressions for sites with less than 100 observations (Figure 12), but the results were generally similar to those regressions with at least 100 observations.

Table 23. Summary of linear regression results for each constituent analyzed; number of regressions resulting in negative, non-significant, or positive slopes; and the percentage of regressions with negative and positive slopes from all stations with greater than 100 samples.

	Slope Direction					
Constituent	Negative	Not Significant	Positive	Total	% Negative	% Positive
Alkalinity (mg/l)	5	1	0	6	83.3	0
Calcium Dissolved (mg/l)	4	2	0	6	66.7	0
Chlorophyll (µg/l)	3	2	1	6	50.0	16.7
Chloride (mg/l)	6	0	0	6	100.0	0
Color (PCU)	0	1	6	7	0	85.7
Conductivity (µmho/cm)	7	2	0	9	77.8	0
Dissolved Oxygen (mg/l)	5	3	1	9	55.6	11.1
Dissolved Oxygen (%sat)	1	0	0	1	100.0	0
Fluoride (mg/l)	4	2	0	6	66.7	0
Iron dissolved (mg/l)	0	1	3	4	0	75.0
Magnesium dissolved (mg/l)	2	0	0	2	100.0	0
Ammonia (mg/l)	1	5	0	6	16.7	0
Ammonium (mg/l)	0	1	0	1	0	0
Nitrite (mg/l)	0	1	2	3	0	66.7
Nitrate (mg/l)	0	1	0	1	0	0
Nitrate-Nitrite (mg/l)	2	5	1	8	25.0	12.5
Organic Nitrogen (mg/l)	0	0	1	1	0	100.0
PH (standard unit)	7	2	0	9	77.8	0
Dissolved Ortho P (mg/l)	2	0	0	2	100.0	0
Orthophosphate as PO_4^{3-} (mg/l)	2	2	1	5	40.0	20.0
Radium 226 (pCi/L)	4	0	0	4	100.0	0
Radium 228 (pCi/L)	0	4	0	4	0	0
Radium Total (pCi/L)	3	1	0	4	75.0	0
Sulfate Total (mg/l)	2	2	0	4	50.0	0
Sulfate Dissolved (mg/l)	1	1	0	2	50.0	0
Total Dissolved Solids (mg/l)	2	2	1	5	40.0	20.0
Temperature (C)	1	4	0	5	20.0	0
Total Kjeldahl Nitrogen (mg/l)	0	1	5	6	0	83.3
Total Nitrogen (mg/l)	0	1	6	7	0	85.7
Total Organic Carbon (mg/l)	0	0	2	2	0	100.0
Total Phosphorus (mg/l)	4	0	0	4	100.0	0
Total Suspended Solids (mg/l)	0	0	1	1	0	100.0
Turbidity (NTU)	0	1	6	7	0	85.7
Unionized Ammonium (mg/l)	1	0	0	1	100.0	0
All	69	48	37	154	44.8	24.0

Notes: mg/L is milligram per liter
µg/L is microgram per liter
PCU is platinum-cobalt unit
µmho/cm is micromho per centimeter
% sat is percent saturation
pCi/L is picocurie per liter
C is degrees Celsius

Table 24. Summary of linear regression results for each constituent analyzed; number of regressions resulting in negative , not significant, or positive slopes; and percentage of regressions with negative and positive slopes from all stations with 30 to 99 observations.

	Slope Direction					
Constituent	Negative	Not Significant	Positive	Total	% Negative	% Positive
Biological Oxygen Demand (mg/l)	0	1	0	1	0.0	0.0
Calcium Total (mg/l)	4	0	0	4	100.0	0
Chlorophyll (µg/l)	0	1	0	1	0	0
Chloride (mg/l)	1	0	0	1	100.0	0
Chemical Oxygen Demand (mg/l)	0	0	1	1	0	100.0
Color (PCU)	0	1	3	4	0	75.0
Conductivity (µmho/cm)	2	0	0	2	100.0	0
Dissolved Oxygen (mg/l)	1	3	0	4	25.0	0
Dissolved Oxygen (%sat)	5	4	0	9	55.6	0
Fluoride (mg/l)	2	0	0	2	100.0	0
Iron (µg/l)	0	0	1	1	0	100.0
Hardness (mg/l)	1	0	0	1	100.0	0
Magnesium (mg/l)	2	0	0	2	100.0	0
Nitrite (mg/l)	0	2	0	2	0	0
Nitrate (mg/l)	1	1	0	2	50.0	0
Nitrate-Nitrite (mg/l)	0	1	0	1	0	0
Organic Nitrogen (mg/l)	0	0	2	2	0	100.0
PH (SU)	3	1	0	4	75.0	0
Orthophosphate as PO_4^{3-} (mg/l)	0	1	0	1	0	0
Sulfate Total (mg/l)	3	1	0	4	75.0	0
Temperature (C)	0	4	0	4	0	0
Total Kjeldahl Nitrogen (mg/l)	0	2	1	3	0	33.3
Total Nitrogen (mg/l)	0	0	1	1	0	100.0
Total Organic Carbon (mg/l)	0	0	2	2	0	100.0
Total Orthophosphate P (mg/l)	0	1	0	1	0	0
Total Phosphorus (mg/l)	0	1	0	1	0	0
Turbidity (NTU)	0	1	0	1	0	0
All	25	26	11	62	40.3	17.7

Notes: mg/L is milligram per liter
µg/L is microgram per liter
PCU is platinum-cobalt unit
µmho/cm is micromho per centimeter
% sat is percent saturation
pCi/L is picocurie per liter
C is degrees Celsius
NTU is Nephelometric turbidity unit

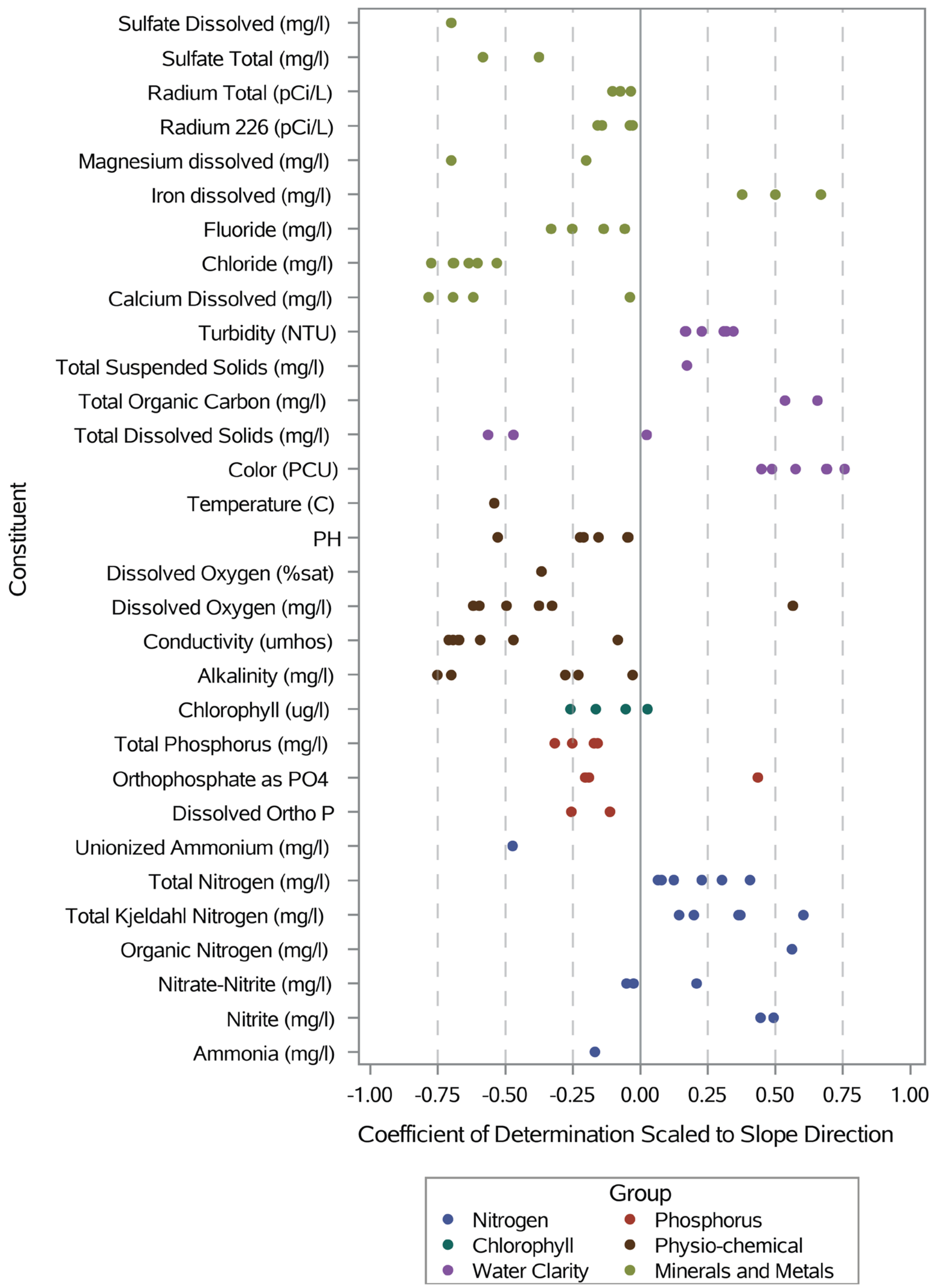

Figure 11. *Coefficient of determination (R^2) results for all significant regressions with at least 100 observations. The R^2 statistic is negative when the relationship with flow was negative. Color of filled circle indicates water quality group.*

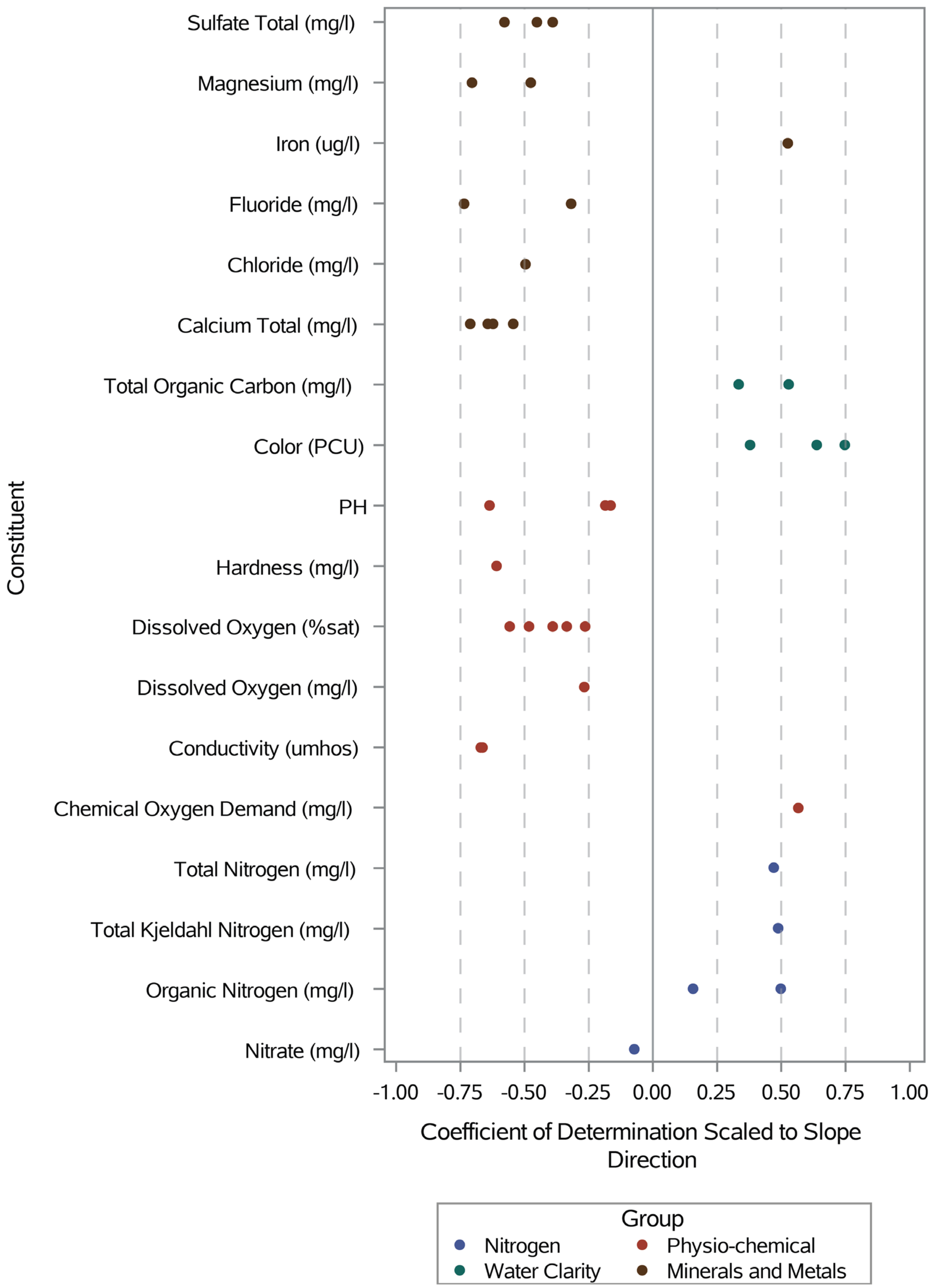

Figure 12. *Coefficient of determination (R^2) results for all significant regressions with less than 100 observations. The R^2 statistic is negative when the relationship with flow was negative. Color of filled circle indicates water quality group.*

Logistic regression results suggested the relationship between flow and the probability of exceeding the threshold values for TN included both negative and positive associations; however, the pseudo-R^2 results suggest a weak association between flow and the probability of a TN exceedance. Total phosphorus exceedances were negatively correlated with flows at two of the sites and not correlated with flows at the other two sites but again, the R^2 values suggest flow is not a dominant driver of the probability of exceedance for these constituents. The low R^2 and lack of consistency among results within a constituent suggests these results should be interpreted with caution. Dissolved oxygen percent saturation and chlorophyll *a* either did not meet the sample size requirements (DO_{SAT}) or had an exceedance rate of less than 10% (chlorophyll) and were therefore disqualified from analysis.

6.1 Ecological Patterns and Processes

Results of time series trend tests on monthly median flows suggested that flows during some summer months were increasing over time at the USGS gage near Myakka Head (No. 02297155) between 1977 and 2019. However, over the longer term period of record observed at the downstream USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310) gage (*i.e.*,1950's to present), no monthly time series trends were evident. The difference in period of record between the two sites did not explain this outcome based on results of testing the two gages over a common period of record (1978-2019). The cause of the increased trends over time at the USGS near Myakka Head (No. 02297155) gage and the lack of correspondence between that gage and USGS Horse Creek gage at State Road 72 near Arcadia (No. 02297310) are unknown at this time.

Water quality time series trend tests suggested that most (84/129) constituents were stable over the period of record evaluated. Exceptions were increasing trends in pH at five of six stations, increasing alkalinity at four of six stations and decreasing radium 228 and total radium at all four HCSP stations. Most other constituents were trending at fewer than 3 of the 6 stations evaluated which does not discount the findings but suggests more site-specific effects. Increasing relative contribution of groundwater may explain the observed trends in pH and alkalinity but that investigation was beyond the scope of this study. Radium trends may be the result of relatively high values in the beginning of the timeseries when there was a shift in the analytical laboratory as described in Flatwoods (2021).

The observed water quality relationships with flow were not unexpected for Florida rivers. For example, total nitrogen increases were correlated with increased flows though R^2 were typically less than 0.50. These findings are similar to results reported in similar water quality flow assessments conducted for the District in the Upper Withlacoochee River (Applied Technology & Management and Janicki Environmental, 2020) and Lower Withlacoochee River (Applied Technology & Management and Janicki Environmental, 2021) and generally result from increased flushing of organic rich wetland areas where decomposing organic matter and captured stormwater runoff contribute nitrogen to the system during the wet season. Indicators of water clarity suggest increasing flows reduce water clarity which also agrees with findings from other similar District studies. Minerals and metal concentrations were also typically negatively correlated with flows as the percent contribution from baseflow diminishes with increasing rainfall and flows. The exception was dissolved iron concentrations which were positively correlated with flows suggesting iron may be bonded with organic material contributed to the system during the wet season. Conductivity, dissolved oxygen, and pH also tended to be inversely correlated with flow as the contribution of runoff from the lands surface is typically lower in pH and conductivity than groundwater contributions. Physical factors such as residence time and velocity are largely driven by the variation in rainfall and flows. Residence time, or its converse, flushing rate, can significantly affect such water quality constituents as chlorophyll *a* and DO. Longer residence times can result in higher primary production and eventual algal abundance in planktonic and attached forms. In turn, DO concentrations depend upon the relative amounts of primary production and respiration. Elevated primary production can result in supersaturated DO conditions often seen in eutrophic systems. This excessive production can subsequently cause hypoxic or even anoxic conditions once productivity crashes, which influences organisms in higher trophic levels. However, Charlie Creek does not appear to be experiencing these symptoms.

One somewhat unexpected result of the linear regression analysis was the occurrence of negative correlations between flow and phosphorus constituents for slightly over half of the assessments, which is counter to findings from similar water quality flow assessments conducted for the District in the Upper Withlacoochee River (Applied Technology & Management and Janicki Environmental, 2020) and Lower Withlacoochee River (Applied Technology & Management and Janicki Environmental, 2021). However, the R^2 values for the Horse Creek phosphorus regressions were below 0.50 indicating the majority of variation in phosphorus constituents was left unexplained by these models. The Horse Creek watershed is complex with mining activity, reclamation of old mined lands, and substantial agricultural areas within the watershed and two nonpoint source discharge outfalls related to mining activities upstream of the Horse Creek Stewardship Program sites (Flatwoods 2021) which may contribute to the different responses to flow observed between these systems. In addition, there are several tributaries to Horse Creek including named streams (*e.g.*, Brushy Creek) and unnamed agricultural ditches that contribute to Horse Creek flows throughout the system. The degree to which these tributaries affect streamflow and water quality at the monitoring stations reported in this document was not an objective of this study

Flatwoods (2021) used analysis of variance to test for differences among the 4 sites in Horse Creek sampled by the HCSP. These sites have been consistently sampled since 2003 over the same time intervals allowing for valid comparisons. Significant differences among sites were reported for most constituents (Flatwoods 2021: Tables 6-2). We used distributional boxplots of water quality constituents (Appendix E of the supplemental document for this report) to visually evaluate longitudinal trends (*i.e.*, upstream to downstream) trends in water quality. Visual examination of differences between stations using the HCSP data suggests most constituents did not have a consistent longitudinal trend. Though chloride and calcium concentrations appeared to increase with movement downstream, the pattern among stations for other constituents examined was inconsistent from upstream to downstream suggesting site-specific responses instead of a consistent pattern of dilution or addition along the length of the creek.

6.2 Limitations, Uncertainties, and Assumptions

This report characterized relationships between flow and a large group of water quality constituents to support the District's consideration of water quality as a water resource value for Horse Creek. These relationships represent associations between flows and water quality concentrations and are not meant to be interpreted as directly causal.

Many factors can confound the relationship between flows and water quality. For example, seasonality in flows and water quality is common. The rainfall in this portion of the state follows the typical central Florida rainfall pattern with peaks in the summer months and particularly dry conditions in April and May. Seasonality in water quality represents the cumulative manifestation of a number of physical and biogeochemical drivers of ecological process in river systems that often co-vary with rainfall and flow temporal patterns. Physical factors such as residence time and velocity are largely driven by the variation in rainfall and flows. Residence time, or its converse flushing rate, can significantly affect such water quality constituents as chlorophyll *a* and DO. Longer residence times can result in higher primary production and eventual algal abundance in planktonic and attached forms. In turn, DO concentrations depend upon the relative amounts of primary production and respiration. Elevated primary production can result in supersaturated DO conditions often seen in eutrophic systems. This excessive production can subsequently cause hypoxic or even anoxic conditions once productivity crashes, which influences organisms in higher trophic levels, but this did not appear to be the case in Horse Creek. Low dissolved oxygen conditions were present at the HCSP site HCSW-2 with 62% of the values below the criterion value of 38% saturation; however, chlorophyll *a* concentrations at this site were only in exceedance to the state standard 9% of the time. This outcome supports observations in Flatwoods (2021) that site specific conditions may depress dissolved oxygen at this location.

We attempted to account for seasonality in evaluating the relationship between water quality and flow by including a term to account for differences in the monthly intercept of the linear regression relationship. Seasonality was identified in 99 of the 216 regressions. In only 14% of the regressions was seasonality identified as significant while flow was not significant. The potential for the relationship between a water quality constituent and flow to vary by season (*i.e.*, month) was not evaluated due to the limited sample sizes from which to assess this affect over the wide range of constituents evaluated. If seasonal blocks are defined in future

District efforts, the potential for this effect may be examined for a subset of constituents thought relevant to aid the District in evaluating water quality as an environmental value for its research needs.

In several cases the R^2 values were quite low indicating little of the overall variation in the water quality constituent was explained by the model. Clearly an R^2 less than 0.10, as was observed is several cases, would be of little utility in evaluating the effects of flow on water quality as it indicates the model explains less than 10% of the variation in flow; however, the R^2 alone is also not a sole means of judging the adequacy of the models. The results presented in this document are intended to provide information the District can use to identify potential relationships and pursue additional analyses as they determine would be beneficial for their research and management needs.

6.3 Recommendations for Future Monitoring

Four active phosphate mines are under reclamation near Horse Creek; three mines are presently not yet mined, but potentially will be mined in the future (Figure 5, Table 1). Part of Horse Creek from the Peace River to a point 16.2 kilometers (10 miles) upstream of the Peace River (WBID 1787) (Figure 7) is potable. Fluoride concentration may be a potable-water challenge in watersheds mined for phosphate. Both (1) mine activity alone, and (2) mine activity on lands upstream of a potable water supply may warrant additional monitoring to better differentiate from land with other uses, the relationship between mine land influence (A) on flow and water quality in Horse Creek and (B) on a water supply. For these purposes, we identify the following additional monitoring that SWFWMD may consider, to improve future analyses:

- Add flow and water quality measurement in Horse Creek at the southeastern corner of the Wingate Creek mine (Figure 5, Table 1)
- Measure benthic fluoride flux from the surficial aquifer at the southeastern corner of the Wingate Creek mine (Figure 5, Table 1)
- Add flow measurement at or near the USGS Horse Creek gage near Limestone (No. 02297251) (Figure 9)
- Add flow and water quality measurement at the upstream end of the potable part of Horse Creek, upstream of the Peace River (WBID 1787) (Figure 7)
- Measure benthic fluoride flux from the surficial aquifer at the upstream end of the potable part of Horse Creek, upstream of the Peace River (WBID 1787) (Figure 7)
- Add flow and water quality measurement in Horse Creek upstream of the confluence with Peace River (Figure 9)
- Measure fluoride concentration at all water quality gages

The HCSP and District water quality databases are important attributes to maintain future data collection within Horse Creek system.

7.0 References

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