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Open File Report 2018–1014

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By W. Scott McBride and Dorothy F. Sifuentes

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.092903	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch per month (in/mo)	304.8	millimeter per year (mm/yr)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

Datum

Vertical coordinate information is referenced to either the National Geodetic Vertical Datum of 1929 (NGVD 29) or the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to either the North American Datum of 1927 (NAD 27) or the North American Datum of 1983 (NAD 83).

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

BCSIR	Big Cypress Seminole Indian Reservation
bgl	below ground level
EAA	Everglades Agricultural Area
EPA	U.S. Environmental Protection Agency
ER	eastern reservation
FDEP	Florida Department of Environmental Protection
OP	orthophosphorus
P	phosphorus
ppb	parts per billion
SFWMD	South Florida Water Management District
STA	stormwater treatment area
STORET	Storage and Retrieval (EPA Water-Quality Data Management System)
TP	total phosphorus
USGS	U.S. Geological Survey
WCA	water conservation area
WR	western reservation

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By W. Scott McBride and Dorothy F. Sifuentes

Abstract

The Seminole Tribe of Florida (the Tribe) is partnering with the U.S. Environmental Protection Agency to develop a numeric phosphorus criterion for the 52,000-acre Big Cypress Seminole Indian Reservation (BCSIR), which is located downgradient of the Everglades Agricultural Area, and of other public and private lands, in southeastern Hendry County and northwestern Broward County in southern Florida. The U.S. Geological Survey (USGS), in cooperation with the Tribe, used water-quality data collected between October 2014 and September 2016 by the Tribe and the South Florida Water Management District (SFWMD), along with data from rainfall gages, surface-water stage and discharge gages, and groundwater monitoring wells, to (1) examine the relations between local hydrology and measured total phosphorus (TP) and orthophosphorus (OP) concentrations and (2) identify explanatory variables for TP concentrations. Of particular concern were conditions when TP exceeded 10 parts per billion (ppb) (0.01 milligram per liter [mg/L]) given that the State of Florida and the Miccosukee Tribe of Indians Alligator Alley Reservation (located downstream of the BCSIR) have adopted a 10-ppb maximum TP criterion for surface waters.

From October 2014 to September 2016, the Tribe collected 47–52 samples at each of nine water-quality sites for analysis of TP and OP, except at one site where 28 samples were collected. For all sites sampled, concentrations of TP (as phosphorus [P]) ranged from less than 0.002 mg/L (2 ppb) to a maximum of nearly 0.50 mg/L (500 ppb), whereas concentrations of OP (as P), the reactive form of inorganic phosphorus readily absorbed by plants and (or) abiotically absorbed, ranged from less than 0.003 mg/L (3 ppb) to a maximum of 0.24 mg/L (240 ppb). The median and interquartile ranges of concentrations of TP and OP in the samples collected in 2014–16 by the Tribe were similar to the median and interquartile ranges of concentrations in samples collected by the SFWMD at nearby sites during the same period. Differences in concentrations can likely be explained by differences in sample collection methods, sampling locations, sample collection time, and the hydrology during sampling or by the number of samples collected. A major limitation of this study was the short duration of sample collection, which covers a limited range of hydrologic conditions within the BCSIR.

The effect of surface-water and groundwater hydrologic conditions on TP and OP concentrations was assessed by using rainfall data and surface-water stage and discharge records. The highest TP and OP concentrations occurred during peak surface-water flows in the canals following long dry periods. Concentrations of TP and OP increased internal to the BCSIR in the western half of the BCSIR during wet periods, but increased concentrations tended to lag behind rainfall events, likely because control structures upstream of sampling sites do not release flows until the water levels in the canals reach predetermined levels. This pattern may indicate that bed sediments in the canals contain high concentrations of phosphorus that becomes resuspended during high flows or that phosphorus salts that had accumulated on dry land during dry periods are carried into the canals by runoff. The largest TP spikes usually occurred at the beginning of high-flow events, but then quickly tapered off even when flows remained high.

Groundwater flows were assessed in the BCSIR by using groundwater level observations from two preexisting USGS monitoring well clusters, each characterized by a shallow well installed in the surficial aquifer system and a deeper well installed in the intermediate aquifer system. Groundwater levels were evaluated with respect to surface-water levels and discharge in the BCSIR during the period of surface-water

sampling. During dry conditions water levels in canals were often higher than groundwater levels in the surficial aquifer, indicating the potential for surface water to recharge the surficial aquifer. During wetter conditions, this trend reversed, and there was potential for shallow groundwater discharge into the canals.

From October 2014 to September 2016, concentrations of TP tended to decrease as surface-water inflows moved across the BCSIR from north to south. In both the western and eastern halves of the reservation, the mean concentration of TP was lower in the surface-water outflows from the BCSIR than in the inflows. The mean concentration of TP in the inflows to the western reservation was 0.04 mg/L (40 ppb), whereas the mean concentration of TP in the outflows was 0.03 mg/L (30 ppb). In the eastern reservation, the mean concentration of TP in the inflows was 0.07 mg/L (70 ppb), whereas the mean concentration of TP in the outflows was 0.04 mg/L (40 ppb).

TP and OP concentrations were evaluated relative to other water-quality parameters, including turbidity, suspended solids, nitrate plus nitrite, dissolved oxygen, pH, and specific conductance, to determine if any relations existed between TP and other variables. Weak relations were indicated for turbidity and suspended solids at two sites, which indicates that there may be a relation of increased TP to mobilization of sediment.

Introduction

The native ecosystem of The Everglades in south Florida originally evolved primarily as an oligotrophic (nutrient poor) environment (Noe and Childers, 2007), which resulted in endemic plant species that are adapted to very low nutrient conditions, such as the monoculture of *Cladium jamaicense* (sawgrass) that originally dominated much of the area. The Everglades is unique in that large changes in habitat can result from even slight increases in nutrients, especially phosphorus (P), which creates substantial challenges for managing nonpoint sources of nutrients (U.S Environmental Protection Agency [EPA], 2000). Although oligotrophic ecosystems require macronutrients such as nitrogen (N), P, and potassium (K), excessive nutrient concentrations, whether from natural or anthropogenic sources, can be toxic to aquatic life and can also affect surface-water quality through eutrophication (Coupe, 2002). Anthropogenic sources of nutrients, such as N-, P-, and K-based fertilizers, and substantive changes to the hydrology, including the construction of canals and control structures, have resulted in increased nutrient concentrations in The Everglades. P enrichment is one of the most damaging anthropogenic affects to The Everglades (Noe and others, 2001). High levels of P have resulted in excessive growth of nuisance plant species including algae, duckweed, and cattails (McCormick and O’Dell, 1996; Miao and DeBusk, 1999), which are not desirable wildlife habitat.

In the aquatic environment, dissolved inorganic P (as salts) or as oxidized phosphate from fertilizers, animal wastes, and natural sources is taken up (immobilized) by plants and converted to organic P (EPA, 2017a). The organic P is then available to animals that eat plant tissues. When plants or animals excrete wastes or die, the organic P becomes available to bacteria that mineralize it back to the inorganic form (EPA, 2017a). Some of the converted inorganic P remains dissolved (and readily available), and some is attached to particles. The cycle starts again when the mineralized inorganic P is taken up by plants (EPA, 2017a).

The Seminole Tribe of Florida, hereinafter referred to as the “Tribe,” has collected water-quality data within the Big Cypress Seminole Indian Reservation (BCSIR) since the 1980s. The Tribe was granted status similar to that of a State in 1994 for the purpose of administering the Clean Water Act as delegated by the EPA (EPA, 2017b). The EPA first approved the Tribe’s water-quality standards in 1997. The Tribe is currently (2018) working with the EPA to develop a numeric P criterion for waters entering and exiting the BCSIR in the central part of The Everglades (figs. 1 and 2). In cooperation with the Tribe, the U.S. Geological Survey (USGS) examined existing water-quality data to (1) explore the relations between local hydrology and measured total phosphorus (TP) and orthophosphorus (OP) concentrations and (2) identify explanatory variables for TP concentrations. In particular, conditions were identified when TP levels in the BCSIR were 10 parts per billion (ppb) or greater. Research has shown that flora and fauna in The Everglades are affected by P when concentrations in the soil and water exceed about 10 ppb (Rizzardi, 2001). The State of Florida and the Miccosukee Tribe of Indians Alligator Alley Reservation (fig. 2) downstream of the BCSIR have adopted 10 ppb as the criterion for P in water in The Everglades, but the State of Florida bases compliance with the criterion on a complex four-part statistical test that averages P concentrations across multiple sites and time spans (Florida Department of State, 2017). Failure of any one part of the four-part test results in noncompliance with the criterion. The Miccosukee Tribe uses a simpler criterion whereby surface-water flows shall never exceed 10 ppb of TP at any time or under any conditions of flow (Miccosukee Tribe of Indians of Florida, 2010).

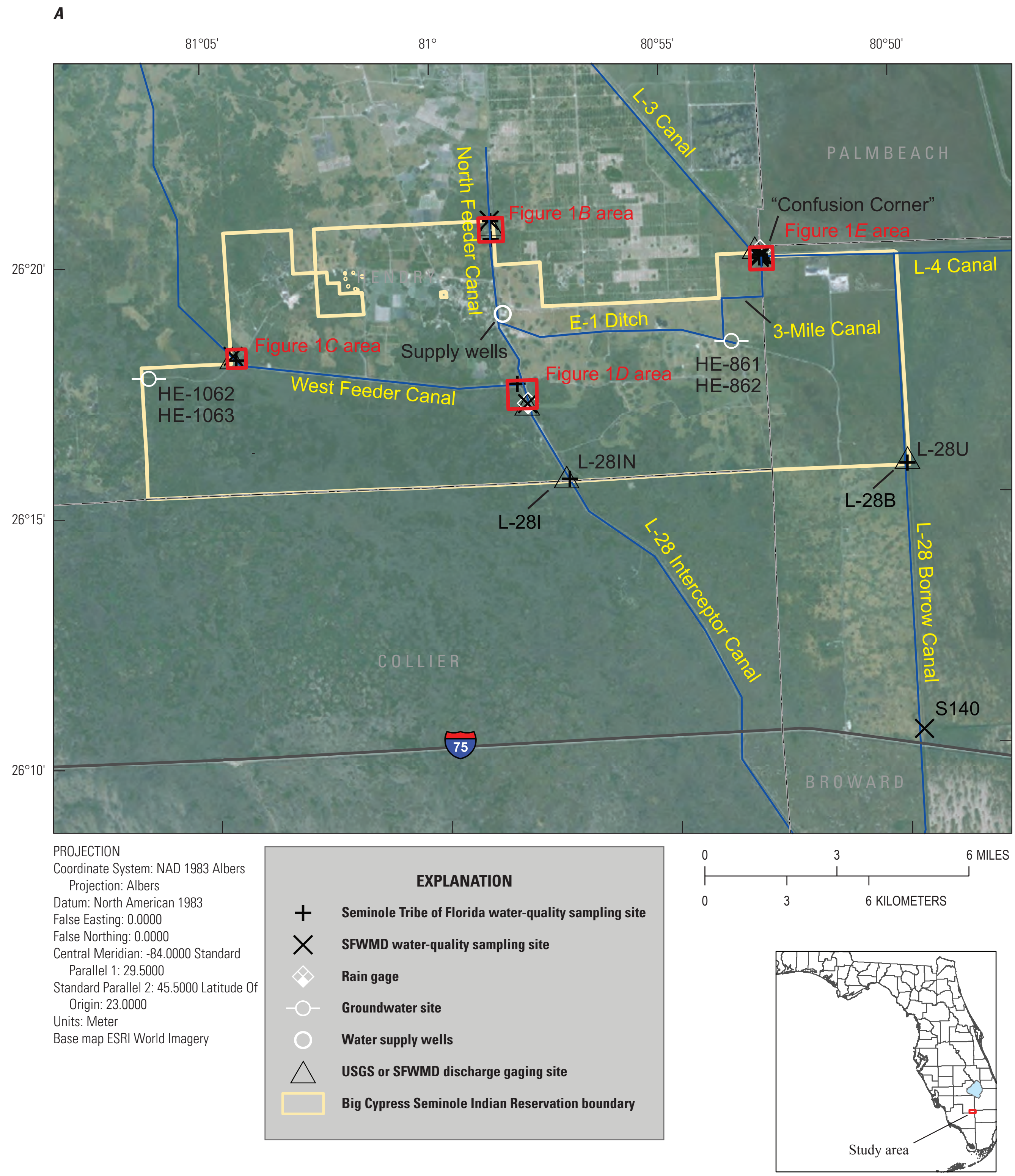

Figure 1. Locations of water-quality sampling sites in the *A*, Big Cypress Seminole Indian Reservation (BCSIR), Florida; *B*, area around the BCS04 sampling site; *C*, area around the BCS06 sampling site; *D*, area around the BCS08 sampling site; and *E*, area around the BCS01, BCS02, and BCS03 sampling sites, 2014–16. Site location information available in table 1. [SFWMD, South Florida Water Management District; USGS, U.S. Geological Survey]

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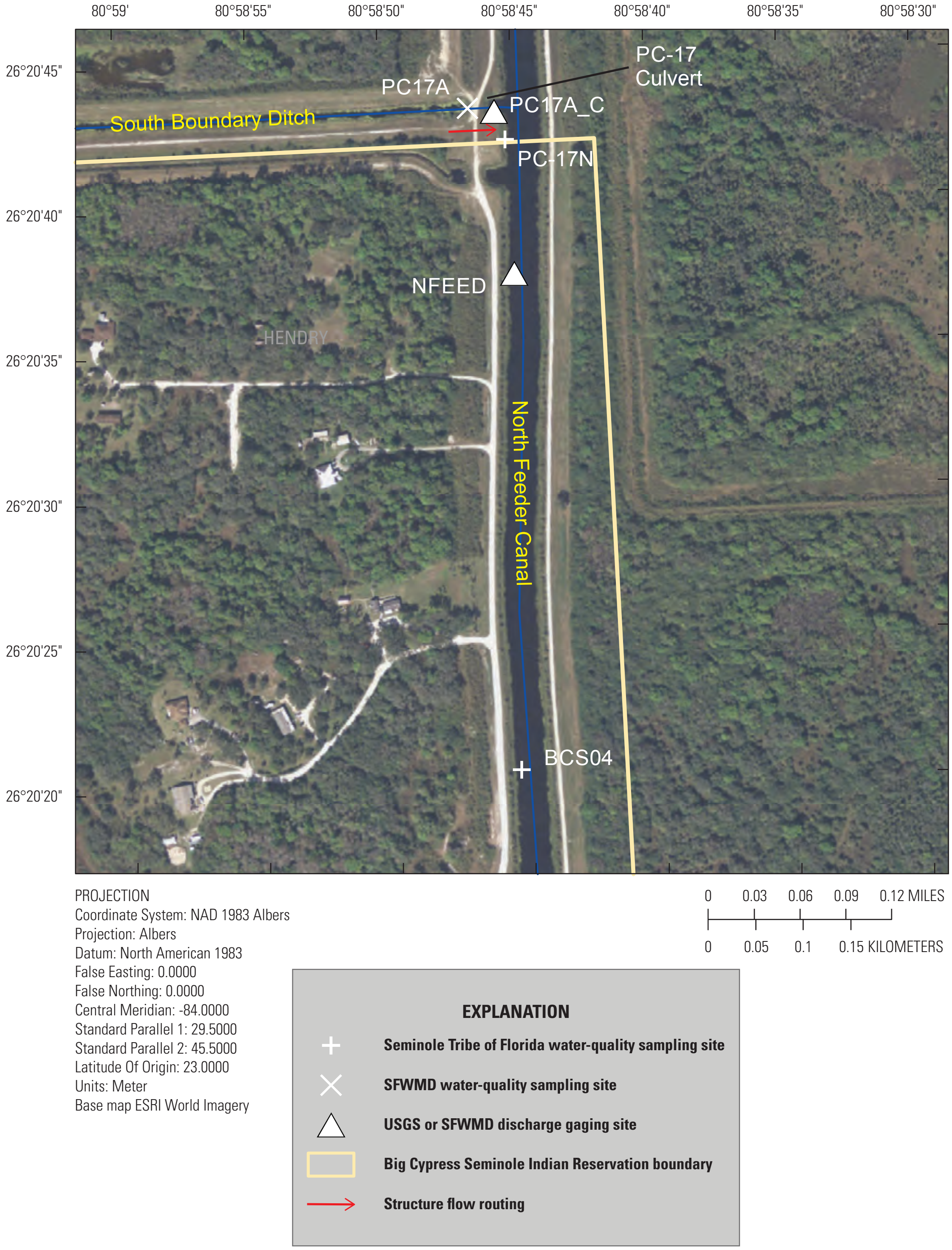

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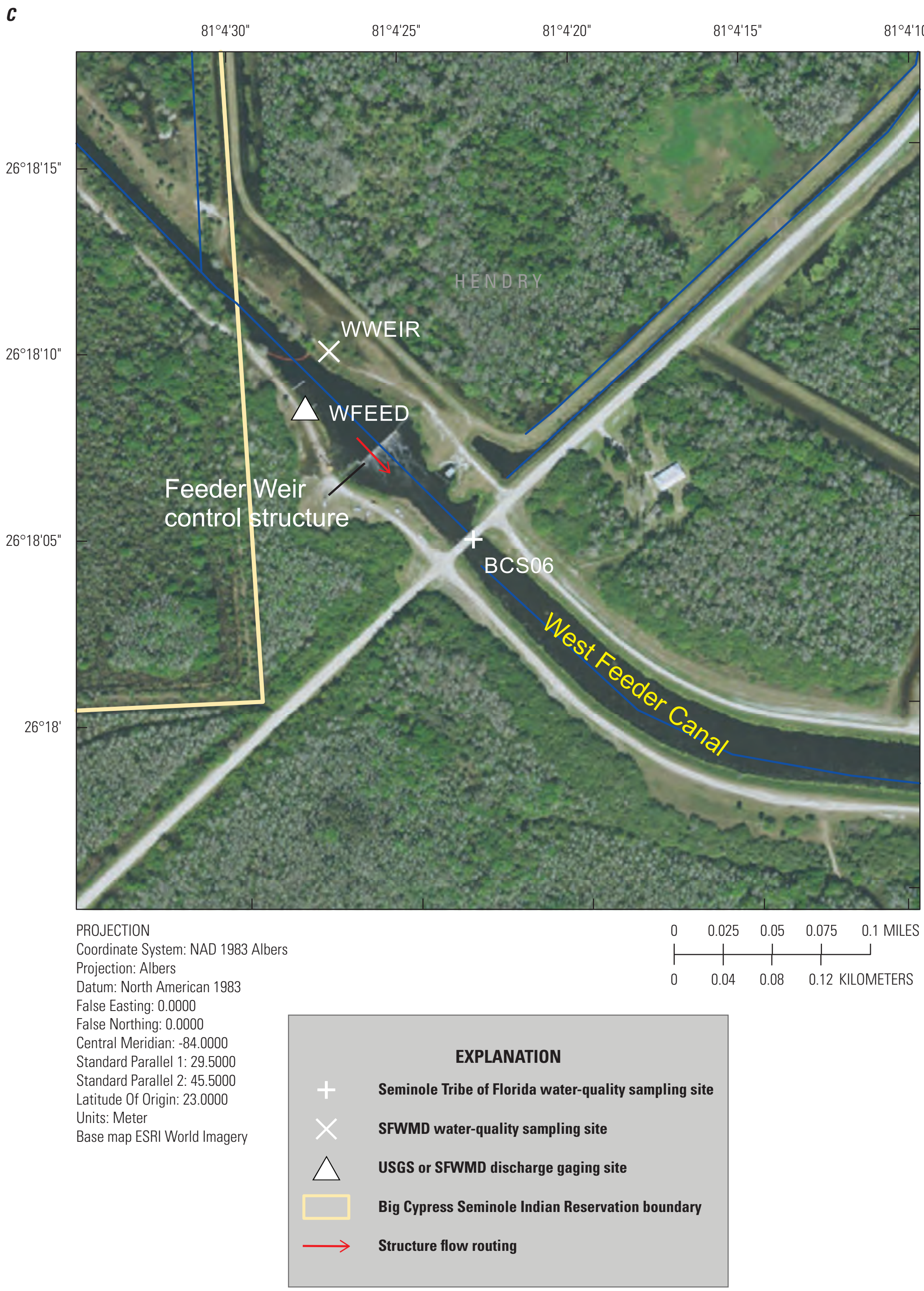

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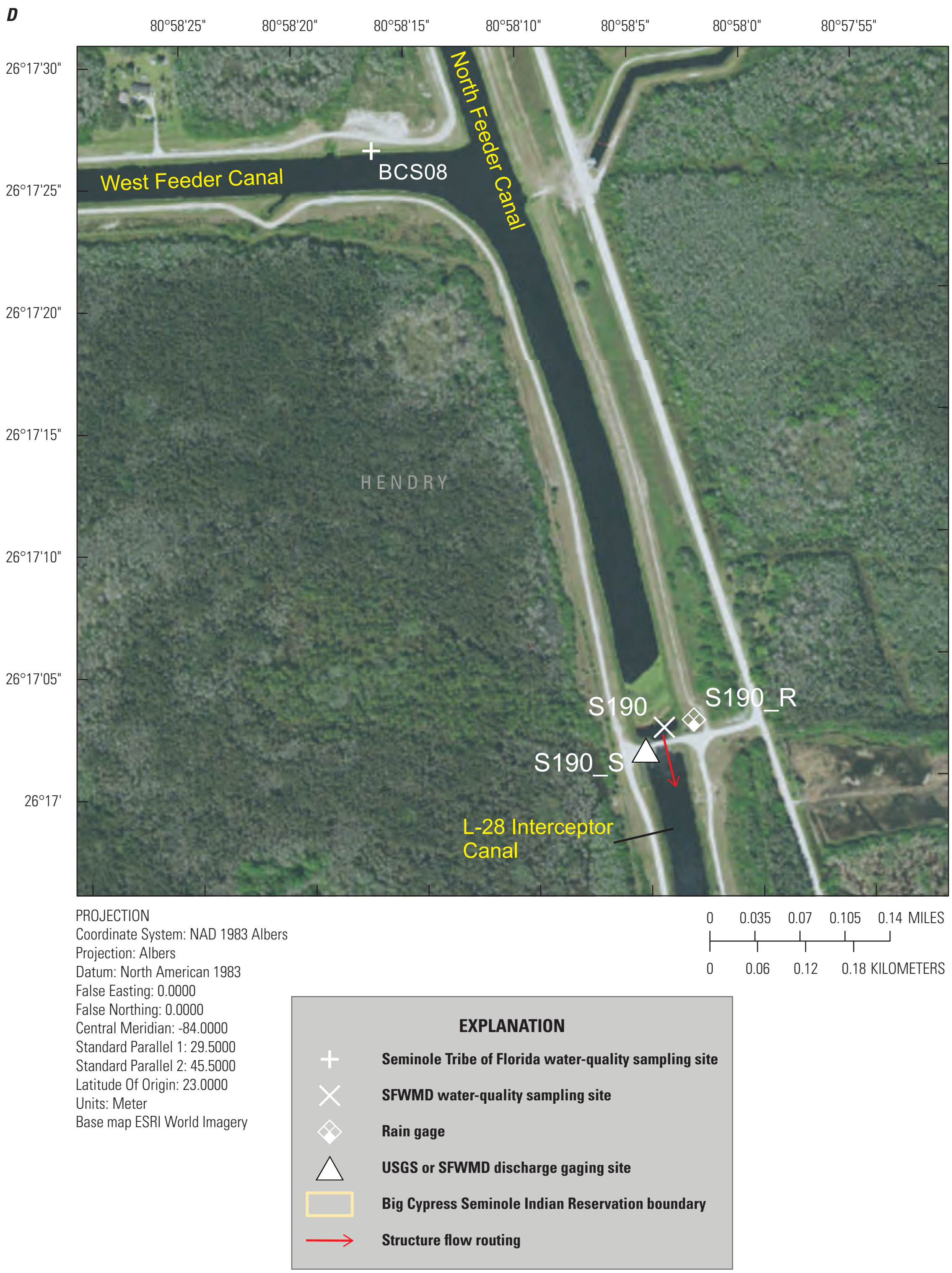

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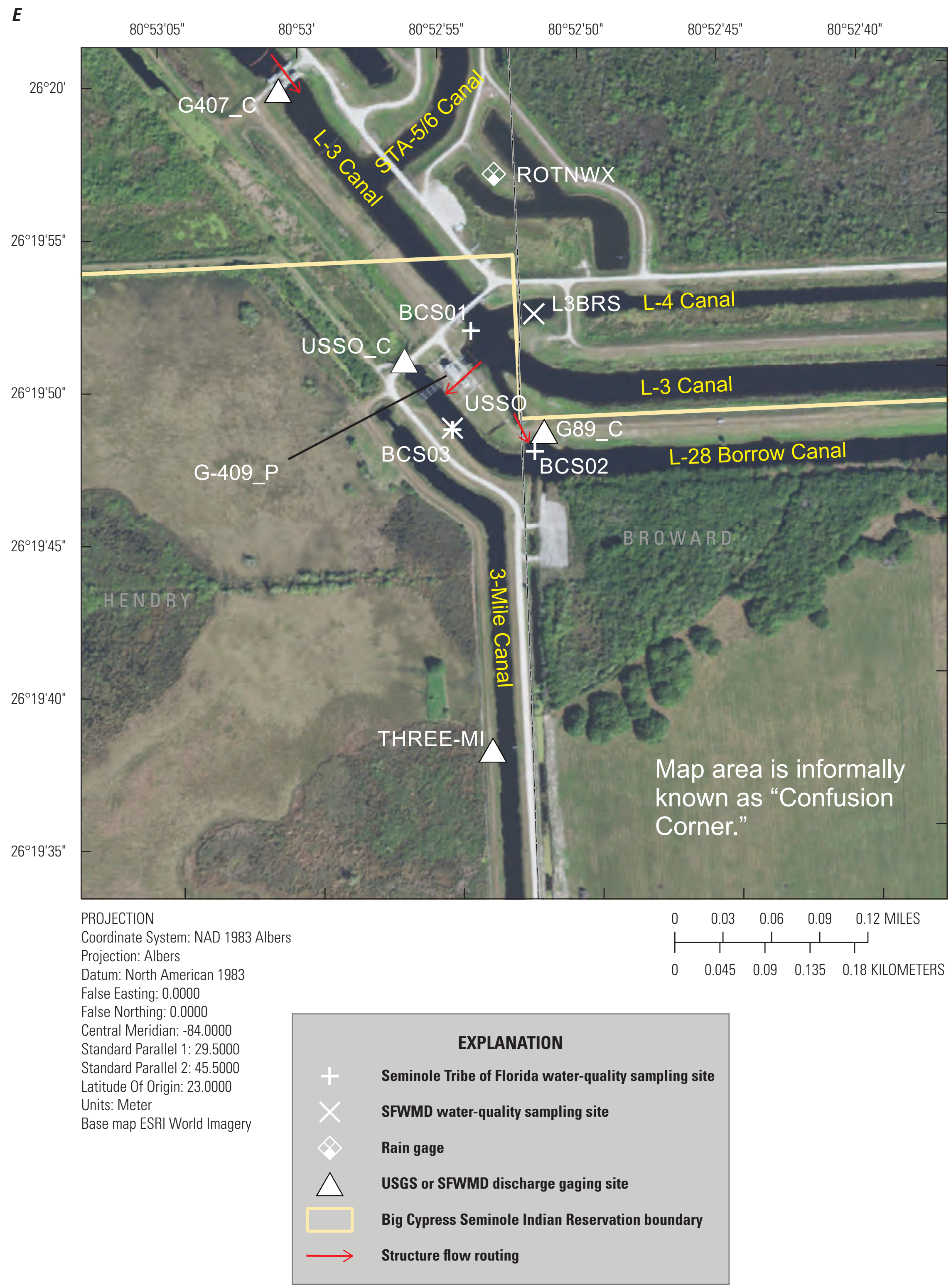

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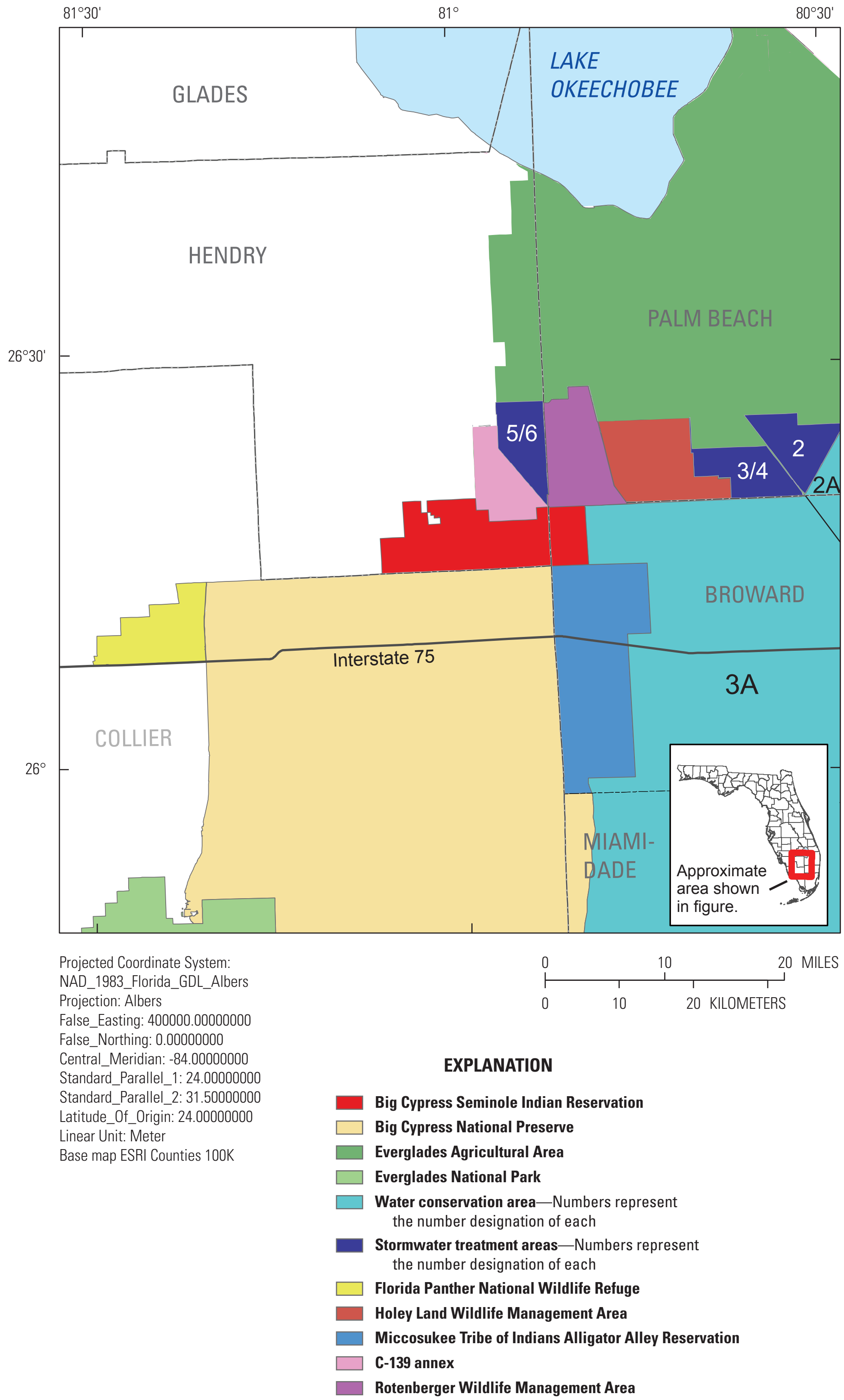

Figure 2. Location of the Everglades Agricultural Area, stormwater treatment areas, water conservation areas, and other natural areas near the Big Cypress Seminole Indian Reservation, Florida (modified from Florida Natural Areas Inventory, 2017).

Purpose and Scope

The purpose of this report is to (1) describe the relations between the local hydrology and measured TP and OP concentrations and (2) identify explanatory variables for TP and OP concentrations. The data examined were collected from October 2014 to September 2016 by the Tribe at nine surface-water sites (fig. 1 and table 1) within the BCSIR (data from site PC17N were used in only some of the analyses because P contributions from this site are also measured at downstream site BCS04). Water-quality data collected by the South Florida Water Management District (SFWMD) from January 2014 to December 2016 also were examined.

P concentrations were examined, and relations between TP and OP concentrations and other geochemical and hydrologic variables were explored for the Tribe sampling sites. In particular, conditions were identified when TP levels in the BCSIR were 10 ppb or greater. The four-part test used to determine compliance with the State of Florida's 10-ppb TP criterion was not calculated (the Tribe is not subject to the State of Florida's TP criterion). Mean and median concentrations of TP were examined on a site-by-site basis. Quality-assurance data were also examined as a check of data integrity. Additional analyses that may be useful to further refine understanding and achieve the expressed goal of developing numeric nutrient criterion for P are described. Limitations of this analysis are also presented.

Description of Study Area

The BCSIR is located in southeastern Hendry County and northwestern Broward County in south Florida (fig. 2). The Big Cypress National Preserve is located along the southern boundary of the BCSIR, and Lake Okeechobee is located approximately 30 miles (mi) to the north. South and southeast of Lake Okeechobee is the 700,000-acre Everglades Agricultural Area (EAA), of which about 500,000 acres are used for sugar farming. Additional private agricultural land (not shown in fig. 2), a series of stormwater treatment areas (STAs), wildlife management areas, and the C-139 Annex are located between the EAA and the BCSIR. The STAs are constructed wetlands designed to reduce nutrients from agricultural runoff waters of the EAA prior to release to the State's water conversation areas (WCAs) (SFWMD, 2017c). The WCAs are vast tracks of remnant Everglades sawgrass marsh that serve multiple purposes, including flood control, storage for water supply, and protected habitat for plant and animal communities (SFWMD, 2015). The C-139 Annex is located north of the BCSIR. This land has historically been used primarily for agricultural purposes, but the SFWMD purchased this property from private interests in 2010 with the intention of restoring the property to a more natural state to help reduce P concentrations to lands downgradient.

The BCSIR includes approximately 52,000 acres and consists mostly of wetlands, forest, and agricultural lands with smaller areas used as rangeland and urban-residential (fig. 3). The western half of the BCSIR (hereafter called the western reservation [WR]) is primarily wetlands and forest, whereas the eastern half of the BCSIR (hereafter called the eastern reservation [ER]) is primarily wetlands and agricultural land, which is used as pasture and for citrus groves. In 2010, the population of the BCSIR was 591 persons (U.S. Census Bureau, 2017). Most of the population lives in the north-central section of the BCSIR in the Tribe community area (fig. 3).

Surface-Water Flow Routing in BCSIR

Surface water is routed through the BCSIR by a series of inflow and outflow canals and ditches and flow-control structures (figs. 1*A*–1*E*). Major drainages include the West Feeder, North Feeder, and L-3 Canals, which convey flow into the BCSIR, and the L-28 Interceptor and L-28 Borrow Canals, which convey flow out of the BCSIR. Flow-control structures largely control flow directions and discharge rates in the canals and ditches; some, such as pumps or gated spillways and culverts, are actively managed to control flow, and some, such as fixed weirs or culverts, passively control flow. Some flow-control structures that affect flow into and out of the BCSIR are outside of the reservation. During the wet season or for wet periods and specific rainfall events, flow-control structures are frequently managed to promote drainage, whereas during the dry season or dry periods, flow-control structures are managed to prevent drainage.

Western Reservation Inflows and Outflows

The L-28 Interceptor drainage system is located in the WR and consists of the L-28 Interceptor Canal, the North Feeder Canal, and the West Feeder Canal (fig. 1*A*). The North Feeder and West Feeder Canals convey water southward and southeastward. These canals converge upstream of the S190_S structure (fig. 1*D*), which conveys water southward into the L-28 Interceptor Canal. The L-28 Interceptor Canal routes flow southeastward through the south-central part of the BCSIR, into Big Cypress National Preserve, and ultimately terminates in the Miccosukee Tribe of Indians Alligator Alley Reservation (fig. 2) southeast of the BCSIR.

Eastern Reservation Inflows and Outflows

Flows are conveyed into the ER from the L-3 Canal into the SFWMD USSO_C structure (fig. 1*E*), which routes flow into the L-28 Borrow Canal (figs. 1*A* and 1*E*) at what is locally known as "Confusion Corner." At Confusion Corner (figs. 1*A* and 1*E*), other flows either are routed east along the L-3 or L-4 Canals or are pumped through the G409_P pump structure into the 3-Mile Canal (fig. 1*E*). The L-28 Borrow Canal also routes flows eastward along the border of the BCSIR, and the canal turns sharply to the south about 3 mi east of Confusion Corner and forms the eastern boundary of the BCSIR. Irrigation water allotted to the Tribe enters the BCSIR by way of G409_P pump station into the Tribe's 3-Mile Canal (figs. 1*A* and 1*E*).

Table 1. Big Cypress Seminole Tribe of Florida water-quality sites used in the phosphorus concentrations analysis, and companion U.S. Geological Survey and South Florida Water Management District water-quality, surface-water gaging, and rainfall sites, 2014–16.

[WQ, water quality; SFWMD, South Florida Water Management District; USGS, U.S. Geological Survey; NAD 83, North American Datum of 1983; —, not applicable]

Tribe WQ site	Latitude	Longitude	Horizontal datum	Companion SFWMD WQ site	Latitude	Longitude	Horizontal datum	USGS or SFWMD gaging station (S=SFWMD and U=USGS)*	Informal USGS gage name	SFWMD rainfall site
Western reservation										
BCS06	26° 18' 05"	-81°04' 23"	NAD 83	WWEIR	26° 18' 10"	-81°04' 27"	NAD 83	261808081042800 (U)	WFEED	S-190R
BCS04	26° 20' 20"	-80° 58' 45"	NAD 83	—	—	—	—	262038080584600 (U)	NFEED	S-190R
PC-17N	26° 20' 42"	-80° 58' 45"	NAD 83	PC17A	26° 20' 43"	-80° 58' 47"	NAD 83	PC17A_C (S)	—	S-190R
BCS08	26° 17' 26"	-80° 58' 17"	NAD 83	S190	26° 17' 02"	-80° 58' 04"	NAD 83	S190_S (S)	—	S-190R
L-28IN	26° 15' 30"	-80° 57' 12"	NAD 83	—	—	—	—	261533080571600 (U)	L-28I	S-190R
Eastern reservation										
BCS01	26° 19' 52"	-80° 52' 54"	NAD 83	L3BRS	26° 19' 52"	-80° 52' 52"	NAD 83	G407_C (S)	—	S-190R
BCS02	26° 19' 47"	-80° 52' 52"	NAD 83	—	—	—	—	G89_C (S)	—	S-190R
BCS03	26° 19' 48"	-80° 52' 55"	NAD 83	USSO	26° 19' 48"	-80° 52' 55"	NAD 83	USSO_C (S)	—	S-190R
L-28U	26° 15' 37"	-80° 49' 50"	NAD 83	S140	26° 10' 18"	-80° 49' 39"	NAD 83	261543080495000 (U)	L-28B	S-190R

*Locations of gaging stations are available in table 2.

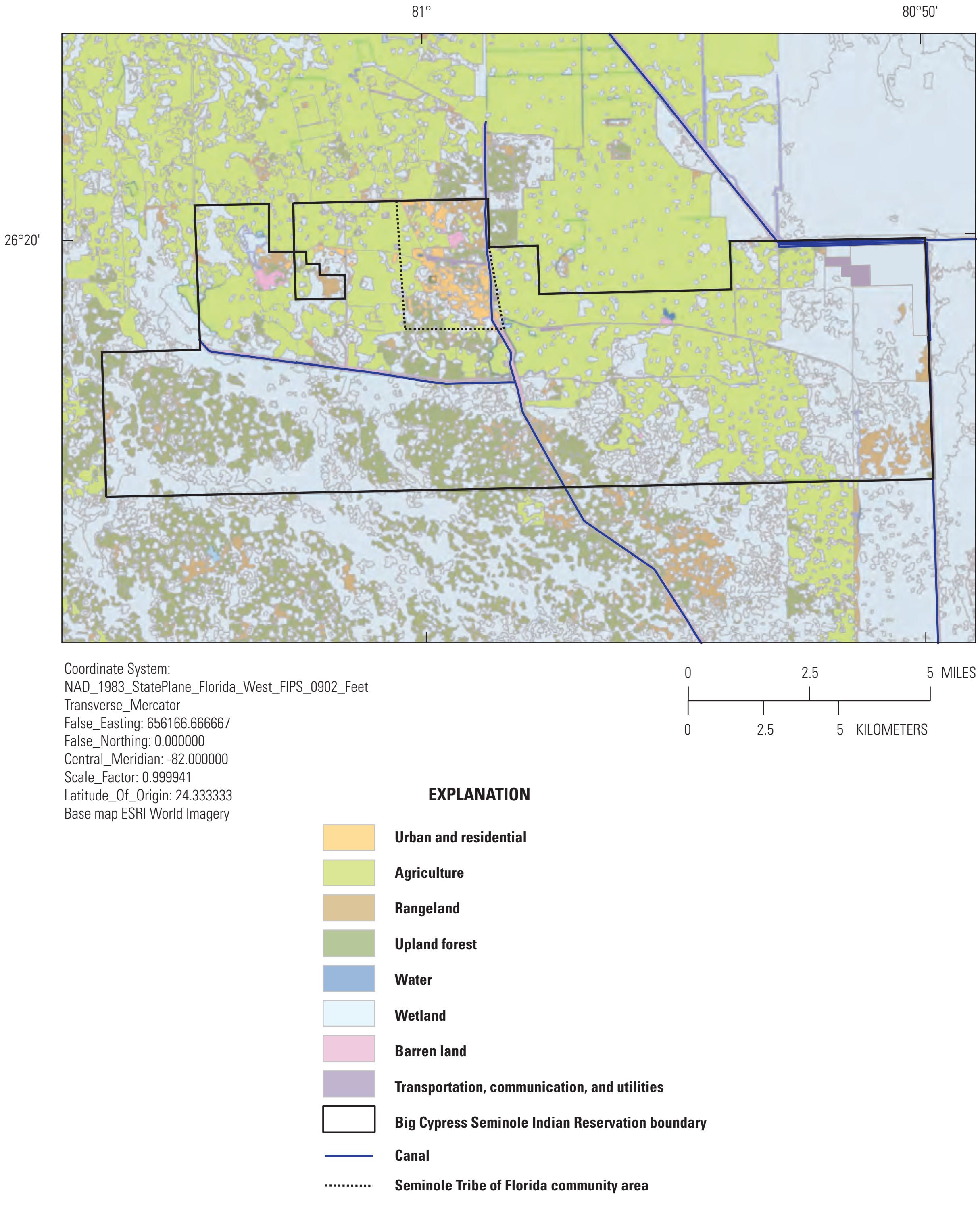

Figure 3. Land use in the Big Cypress Seminole Indian Reservation, Florida (modified from Florida Department of Environmental Protection, 2017a).

The 3-Mile Canal is designed to route water pumped by the G409_P structure southward into the E-1 Ditch (fig. 1*A*), where flows can be distributed over agricultural lands in the BCSIR through a series of ditches for irrigation purposes.

Analysis of Total Phosphorus and Orthophosphorus Data

The TP and OP data were examined temporally and spatially and evaluated with respect to surface-water discharge and rainfall rates. The Tribe collected water-quality samples from nine surface-water sites in the BCSIR from 2014 to 2016. Five of the sites were in the WR, and four were in the ER, though data from one of the WR sites were used in only some of the analyses. The TP and OP concentration data were paired with surface-water stage and discharge data from sites that best represented the hydrologic conditions at each water-quality site. In addition, some water-quality data samples were collected by the SFWMD at sampling sites near sites where the Tribe collected data. These are henceforth referred to as “companion” sites. The companion sites are identified in table 1.

Discharge values reported for the USGS sites represent the monthly mean flow rates across a cross section of the canal at the location of the monitoring station and were obtained from the U.S. Geological Survey National Water Information System (U.S. Geological Survey, 2017). Daily discharge values reported by the SFWMD sites used in this report (South Florida Water Management District, 2017b) were averaged on a monthly basis, and the monthly means are presented here. The discharge values from the USGS and SFWMD are not directly comparable because the USGS values are measured across a canal cross section and the SFWMD values are measured through a control structure. Because of these differences, period of record analysis of the structure flows is provided only for the USGS data, and not for the SFWMD data.

Rainfall data from two sites were examined. One rainfall site was central to the BCSIR, whereas the other site was located outside but near the northern border of the BCSIR.

Groundwater was not sampled for TP and OP, and groundwater levels and gradients are not assumed to be directly related to TP and OP concentrations measured in surface water in the BCSIR. Shallow groundwater and surface water are strongly interconnected, so groundwater flow directions and groundwater/surface-water flow interactions are qualitatively evaluated to provide more complete information on the hydrologic environment. Groundwater flow conditions in the BCSIR were examined by using groundwater level data collected at two sites. Each groundwater site, one in the WR and another in the ER, consists of two wells with one well installed in the surficial aquifer system and another installed in the intermediate aquifer system. Detailed information regarding the hydrogeology in the region of the BCSIR can be found in Reese and Cunningham (2000).

Western Reservation Water-Quality and Surface-Water Sites

Tribe sampling sites BCS06 and BCS04 are on the West Feeder and North Feeder Canals, respectively, where surface water flows into Tribe lands (figs. 1*A*–1*C* and table 1). The TP and OP concentration data from the nearby SFWMD site WWEIR (fig. 1*C*) were compared with concentration data collected at the BCS06 sampling site. A SFWMD companion site is not available for the North Feeder Canal; however, water samples collected at SFWMD site PC17A, on the South Boundary Ditch, contain private landowner agricultural runoff prior to discharge into the North Feeder Canal (fig. 1*B*). Site BCS04 reflects flows in the North Feeder Canal downstream of PC17A, plus inflow from Tribe culvert PC-17 (fig. 1*B*). Tribe site PC-17N (fig. 1*B* and table 1) is just above Tribe culvert PC-17, and downstream of PC17A, in the North Feeder Canal. Site BCS08 (fig. 1*D* and table 1) is downstream of BCS06 and BCS04 on the West Feeder Canal just above where the North Feeder and West Feeder Canals merge to become the L-28 Interceptor Canal (fig. 1*D*). This site is unique in that it is the only site located within the central part of the BCSIR and is not near a boundary. The SFWMD site at S190 is located about 0.5 mi downstream of BCS08 and was considered its companion site (fig. 1*D*). The L-28 Interceptor Canal exits the BCSIR approximately 2.5 mi south-southeast of BCS08. Tribe sampling site L-28IN (fig. 1*A* and table 1) is near the canal’s point of egress from the BCSIR, and there is no companion SFWMD water-quality site in the area. The SFWMD data from S190 were collected approximately 2 mi upstream of L-28IN in a closed channel.

Surface-water discharge and stage data from USGS gages located in the WR were collected from the following sites: WFEED (USGS 261808081042800 West Feeder Canal abv West Weir nr Clewiston FL) (fig. 1*C*), NFEED (USGS 262038080584600 North Feeder Canal blw PC-17A nr Clewiston, FL) (fig. 1*B*), and L-28I (USGS 261533080571600 L-28 Interceptor Canal blw S-190 near Clewiston, FL) (fig. 1*A*) (USGS, 2017). Surface-water discharge and stage data from SFWMD gages in the ER were collected from the following sites: G89_C (culvert), G407_C (culvert), and USSO_C (culvert) (SFWMD, 2017b) (fig. 1*E*). Table 1 lists the pairings of Tribe water-quality sites with USGS and SFWMD gaging sites, and table 2 lists the locations of all of the gaging sites.

Table 2. U.S. Geological Survey and South Florida Water Management District surface-water gaging stations used in the Big Cypress Seminole Indian Reservation phosphorus concentrations analysis, 2014–16.

[Data from U.S. Geological Survey (2017) and South Florida Water Management District (2017b). USGS, U.S. Geological Survey; abv, above; nr, near; FL, Florida; NAD 83, North American Datum of 1983; blw, below; SFWMD, South Florida Water Management District; —, not applicable; NAD 27, North American Datum of 1927]

Informal site name	Station name	Station owner	USGS number	Latitude	Longitude	Horizontal datum
			Western reservation			
WFEED	West Feeder Canal abv West Weir nr Clewiston FL	USGS	261808081042800	26°18'08"	-81°04'28"	NAD 83
NFEED	North Feeder Canal blw PC17A nr Clewiston, FL	USGS	262038080584600	26°20'38"	-80°58'46"	NAD 83
—	PC17A_C	SFWMD	—	26°20'43"	-80°58'46"	NAD 83
—	S190_S	SFWMD	—	26°17'02"	-80°58'04"	NAD 83
L-28I	L-28 Interceptor Canal blw S-190 near Clewiston, FL	USGS	261533080571600	26°15'33"	-80°57'16"	NAD 27
			Eastern reservation			
—	G407_C	SFWMD	—	26°20'00"	-80°53'01"	NAD 83
—	USSO_C	SFWMD	—	26°19'51"	-80°52'56"	NAD 83
—	G89_C	SFWMD	—	26°19'48"	-80°52'52"	NAD 83
THREE-MI	Three Mile Canal below G409 near Clewiston, FL	USGS	02289035	26°19'38"	-80°52'54"	NAD 83
L-28B	L-28 Canal above S-140 near Clewiston, FL	USGS	261543080495000	26°15'43"	-80°49'50"	NAD 27

Eastern Reservation Water-Quality and Surface-Water Sites

Tribe sampling sites BCS01, BCS02, and BCS03 (fig. 1*E* and table 1) are at Confusion Corner (figs. 1*A* and 1*E*), where the L-3, L-4, L-28 Borrow, and 3-Mile Canals intersect (figs. 1*A* and 1*E*). Sites BCS01, BCS02, and BCS03 are less than 0.1 mi from one another, but each site represents a potentially different mixture of water sources depending on structure operations, such as pumps or culverts. Site BCS01 is the most upstream site at Confusion Corner and is located on the L-3 Canal upstream of the G409_C pump structure (fig. 1*E*). Water-quality data collected at BCS01 are used to characterize the Tribe's entitlement source waters, and its companion SFWMD site is L3BRS (fig. 1*E* and table 1). Site BCS02 is on the L-28 Borrow Canal at a gated culvert where flow from the L-3 Canal can be diverted into the L-28 Borrow Canal. There is no companion SFWMD site to BCS02. Site BCS03 is upstream of BCS02 on the L-28 Borrow Canal and downstream of the SFWMD USSO_C structure. The SFWMD USSO (fig. 1*E* and table 1) water-quality sampling site was companion with BCS03. Flows from the L-3 Canal can enter the L-28 Borrow Canal from the gated culvert at BCS02. The primary outflow in the ER is the L-28 Borrow Canal. Tribe sampling site L-28U (fig. 1*A* and table 1) is near the southeastern corner of the BCSIR, where the L-28 Borrow Canal exits the BCSIR. Tribe water-quality data collected at L-28U were paired with SFWMD water-quality data collected at S140 (fig. 1*A* and table 1); though S140 is approximately 6 mi downstream (south) of L-28U, S140 was paired with L-28U because S140 is the only SFWMD water-quality site on the L-28 Borrow Canal downstream of the BCSIR.

Surface-water discharge and stage data used in the analysis of water-quality and groundwater data in the ER were collected from USGS gages THREE-MI (USGS 02289035 Three Mile Canal below G-409 near Clewiston, FL) (fig. 1*E*) and L-28B (USGS 261543080495000 L-28 Canal above S-140 near Clewiston, FL) (fig. 1*A*) (USGS, 2017). The SFWMD structures for which flow data are used in this report include PC17A_C (culvert) and S190_S (structure) (fig. 1*B* and 1*D* and tables 1 and 2).

Groundwater Sites

Two USGS groundwater monitoring well clusters are located in the BCSIR; cluster HE -1062 and HE -1063 (fig. 1*A* and table 3) are in the WR, and cluster HE - 861 and HE - 862 (fig. 1*A* and table 3) are in the ER. Monitoring wells HE -1062 and HE -1063 are about 1.9 mi west-southwest of the WFEED gaging station (USGS station number 261808081042800; fig. 1*C* and table 2). The WFEED gaging site is about 220 feet (ft) upstream of the Feeder Weir control structure (fig. 1*C*). There are no groundwater pumping sites in the area where the West Feeder Canal enters the BCSIR, and there are no major surface-water bodies near the monitoring wells, so it is assumed that groundwater levels near WFEED are likely similar or possibly slightly higher than those at HE -1062 and HE -1063. The HE -1062 well is shallower than HE -1063, completed at a depth of about 10 ft below ground level (bgl), or at about 8.3 ft referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29), in the surficial aquifer system; HE -1063 is completed at a depth of about 123 ft bgl, or -104.7 ft referenced to NGVD 29, in the intermediate aquifer system (table 3) (USGS, 2017).

Monitoring well cluster HE - 861 and HE - 862 are about 1.8 mi south-southwest of the THREE-MI gaging site (USGS station number 02289035; figs. 1*A* and 1*E* and table 3) and adjacent to the E-1 Ditch (fig. 1*A*). The THREE-MI gaging site is downstream of the G409_P pump structure (fig. 1*E*), which routes water from the L-3 Canal to the 3-Mile Canal. The 3-Mile Canal intersects the E-1 Ditch approximately 2 mi south of Confusion Corner (fig. 1*A*). There are no control structures between THREE-MI and the E-1 Ditch where the groundwater monitoring wells HE - 861 and HE - 862 are located. It is therefore assumed that canal stage functions as a level pool and that canal stage near the groundwater monitoring wells is very close to the stage at THREE-MI. Monitoring well HE - 862 is shallow, completed at a depth of about 11 ft, or at about 4.1 ft referenced to NGVD 29, in the surficial aquifer system; well HE - 861 is deeper, completed at a depth of about 70 ft, or -55.1 ft referenced to NGVD 29, in the intermediate aquifer system (table 3).

Rainfall Sites

Rainfall data from two SFWMD rainfall gages located in and near the BCSIR were examined (table 4). Rainfall data recorded at S190_R (fig. 1*D* and table 1), which is centrally located in the BCSIR next to the L-28 Interceptor Canal (fig. 1*A*), were compared with rainfall data from ROTNWX (fig. 1*E* and table 1), which is located just outside of the BCSIR, north of where the STA-5/6 Canal meets the L-3, L-4, and L-28 Borrow Canals (fig. 1*E*) at Confusion Corner. Data from ROTNWX were used to validate the data from S190_R, but all subsequent analyses used rainfall data from S190_R because this site was central to all of the water-quality sites located in the BCSIR.

Methods of Water-Quality Data Collection and Analysis

The Tribe collects monthly water-quality samples at nine sites in the BCSIR along the major inflows and outflows to the BCSIR, though data from only eight of the sites were used in most of the analyses. Samples were analyzed by the Tribe in the field for pH, temperature, specific conductance, and dissolved oxygen by using calibrated meters. Laboratory analyses for the Tribe were provided by Florida Spectrum Environmental Services (www.flenviro.com), which is certified under the National Environmental Laboratory

Table 3. U.S. Geologcial Survey wells used in the analysis of groundwater levels in the Big Cypress Seminole Indian Reservation, 2014–16.

[Data from U.S. Geological Survey (2017). USGS, U.S. Geological Survey; ft, feet; NAD 27, North American Datum of 1927; NGVD 29, National Geodetic Vertical Datum of 1929; SAS, surficial aquifer system; IAS, intermediate aquifer system]

USGS site name	USGS site number	Latitude	Longitude	Horizontal datum	Land surface elevation, in ft	Vertical datum	Top of opening, in ft below land surface	Bottom of opening, in ft below land surface	Aquifer	Formation
Western reservation										
HE -1062	261746081061803	26°17'46"	-81°06'18"	NAD 27	18.3	NGVD 29	5	10	SAS	Non-artesian sand aquifer
HE -1063	261746081061804	26°17'46"	-81°06'18"	NAD 27	18.3	NGVD 29	78	123	IAS	Tamiami Formation
Eastern reservation										
HE - 862	261735080534002	26°18'09"	-80°53'35"	NAD 27	15.1	NGVD 29	7	11	SAS	Non-artesian sand aquifer
HE - 861	261735080534001	26°18'09"	-80°53'35"	NAD 27	14.9	NGVD 29	37	70	IAS	Tamiami Formation

Table 4. South Florida Water Manangement District rainfall gages used in the analysis of rainfall patterns in the Big Cypress Seminole Indian Reservation, 2014–16.

[Data from South Florida Water Management Distrct (2017b). SFWMD, South Florida Water Management District; NAD 83, North American Datum of 1983]

SFWMD rainfall site	Latitude	Longitude	Horizontal datum
S190_R	26°17'03"	-80°58'03"	NAD 83
ROTNWX	26°19'57"	-80°52'53"	NAD 83

Accreditation Program by the Florida Department of Health (Florida Department of Health, 2017), and included chloride, chlorophyll-a, color, enterococci, ammonium, nitrate and nitrite, total Kjeldahl nitrogen (TKN), TP, OP, total suspended solids (TSS), and turbidity, as well as additional analytes on a quarterly and biannual basis. Both TP and OP were analyzed by using EPA Method 365.1 (determination of P by semiautomated colorimetry). Samples analyzed for TP are unfiltered and contain all sources of P found in the water column, including particulates, whereas OP samples are filtered through a 0.45-micron (µ) syringe filter and contain only dissolved sources of P and colloidal material smaller than 0.45 µ. Analytical methods for the other analytes can be found at the Florida Spectrum Environmental Services web page (www.flenviro.com). After the end of each fiscal year, all Tribe water-quality and field data from the previous year were uploaded to the EPA Storage and Retrieval (STORET) database for permanent archive and were made publicly available (EPA, 2017b). Water-quality data collected by the SFWMD can be accessed through their DBHYDRO database (SFWMD, 2017b).

Water samples were analyzed by the Tribe or SFWMD for the concentration of both TP and OP. OP, or "reactive" P (PO_4^-), is the main ingredient in fertilizers and is the form of P that is most readily absorbed by plants (Domagalski and Johnson, 2012). Measurements of OP are a good estimator of the amount of P that is readily available for algae and plant growth and (or) abiotically absorbed (EPA, 2017c). TP is a measure of all forms of P in a water sample, and regulations limiting the concentration of TP in State waters are based on totals, so this report primarily examines concentrations of TP.

Water-quality data collected by the Tribe within the BCSIR were used to identify explanatory variables for aqueous P concentrations and describe the relations between local hydrology and measured TP and OP concentrations. Specifically, TP and OP were evaluated temporally with respect to surface-water discharge rates at nearest discharge gaging sites and rainfall rates.

For the P concentrations analysis, the Tribe and SFWMD water-quality data were matched with companion SFWMD or USGS discharge and stage data to determine whether TP concentrations are related to these variables (table 1). Similarly, TP and OP concentrations were compared to monthly cumulative rainfall data collected by the SFWMD (SFWMD, 2017b). All TP and OP concentration data were reported relative to P. Data from PC-17N (fig. 1*B*) were excluded from analysis, other than plotting TP and OP concentrations with discharge and rainfall, because TP contributions to the North Feeder Canal were measured at nearby downstream site BCS04. Discharge sites NFEED, S190_S, L-28I, and L-28B sometimes undergo negative flows. The negative flows, which were generally of low magnitude, were not plotted in the figures comparing discharge with TP and OP concentrations because the resulting figures would not have shown periods of positive flows with enough detail for the analysis.

The interquartile ranges of TP concentrations for the eight water-quality sampling sites are illustrated as box and whisker plots. Suspected outliers were arbitrarily defined as any concentrations that are greater than 1.5 times the length of the box and that plot above the box as individual data points along the vertical axis. It is likely that many of the outliers represent real concentrations, but extreme values skew the data and make site comparisons under normal conditions difficult.

Plots and correlation coefficients (Helsel and Hirsch, 2002) between TP concentrations and the concentrations of other water-quality parameters, including specific conductance, turbidity, discharge, suspended solids, pH, nitrate plus nitrite, and dissolved oxygen, were calculated to determine if any relations existed between TP and other variables that might be useful in helping our understanding of how P reacts in the BCSIR.

Quality Assurance

The Tribe checks and validates its water-quality data by using quality assurance/quality control methods that are incorporated into both the sampling and the analytical protocols. The Tribe established its own set of rigorous water-quality sampling protocols (Seminole Tribe of Florida, 2014a, 2014c, 2014d, 2014e, 2014f, 2014g, 2014h, 2014i, 2014j) based on Florida Department of Environmental Protection (FDEP) protocols (FDEP, 2017b). The Tribe protocols were reviewed and accepted by the EPA in 2014 (Seminole Tribe of Florida, 2016). Tribe water-quality technicians who are responsible for sample collection attend water-quality field method training courses conducted by the FDEP (Keith Morton, Seminole Tribe of Florida, oral commun., 2017). Samples are tracked from field to laboratory by using chain-of-custody forms. All of the methods used to analyze the Tribe's water-quality samples are documented in the Quality Assurance Project Plan (Seminole Tribe of Florida, 2014a).

Field quality-control procedures include the collection of field blanks, equipment blanks, and replicates (Seminole Tribe of Florida, 2014f). Field blanks are collected to characterize site conditions that might compromise samples, such as contamination from dust. Equipment blanks are collected during each sampling event, and the data are used to monitor the effectiveness of sampling equipment decontamination procedures. Replicates test the repeatability of sampling procedures and the variability of environmental conditions. Equipment and field blanks are collected at least once per sampling event, whereas replicates are collected monthly.

The analytical results from the field quality-control samples are used to evaluate sampling procedures and to validate the environmental data before they are permanently stored. Data validation includes checks of field quality assurance data, laboratory precision, percent recoveries, and verifications of data qualifier codes. From 2014 to 2016, it was necessary to reject less than 2 percent of all of the analytical results collected by the Tribe for failures to meet data quality acceptance criteria. Most rejections were the result of blank contamination (Seminole Tribe of Florida, 2014b, 2015, 2016). All cases of blank contamination were traced back to improperly cleaned sampling buckets. After the buckets were thoroughly cleaned or replaced, blank results once again met acceptance criteria.

Relations Between Total Phosphorus and Orthophosphorus Concentrations and Rainfall, Surface-Water Discharge, and Groundwater Levels

Rainfall, surface-water discharge, and groundwater level data collected during the study period provide information about the hydrologic conditions during that period. Summary statistics for TP and OP data are provided, and TP and OP data are examined spatially and temporally and within the context of local hydrologic conditions.

Rainfall

The periods of record and completeness of datasets differ at the S190_R and ROTNWX rainfall sites (figs. 4 and 5), but the monthly cumulative rainfall data from 1997 or 1998 through March 2017 were similar, with highest rainfall occurring during June–September [about 6–8 inches (in.) per month] and lowest rainfall occurring during November–April (generally less than 2.5 in. per month). Monthly totals during 2014–16 indicated notable temporal variability, with substantially greater rainfall in July 2014 than in July 2016 and substantially greater than average rainfall during December 2015–January 2016. Rainfall was also spatially variable, with higher rainfall totals during July 2014 and during June and August 2016 at ROTNWX than at S190_R. Rainfall data from S190_R were primarily used in the analysis of the water-quality data because ROTNWX and S190_R had similar rainfall trends and because S190_R was centrally located to all of the water-quality sites. Rainfall data from ROTNWX were used when analysis was local to the area of that site.

From 1998 to 2016, mean annual rainfall at the S190_R rainfall gage was 49.0 in. (fig. 6). The driest year in this period was 2006 with 34.2 in. of rainfall, whereas the wettest year was 2002 with 62.5 in. Rainfall totals for 2014, 2015, and 2016 (the study period) were 47.9, 58.6, and 57.4 in., respectively. In 2014, rainfall was about 2 percent below the long-term mean, whereas in 2015 and 2016 rainfall was about 16 and 15 percent, respectively, above the long-term mean. The 2 years preceding the study period (2012 and 2013) were also wet,with 54.0 and 58.8 in. of rainfall, respectively, which is about 10 and 20 percent greater than the long-term mean.

The winter of 2015–16 was unusually wet in south Florida (figs. 4 and 5) because of an intense El Niño event. El Niño events typically result in warmer and wetter conditions in the southeastern United States and are caused by warmer than normal tropical waters in the central and eastern Pacific Ocean that affect global weather patterns (National Oceanic and Atmospheric Administration, 2018). The mean monthly cumulative rainfall for December and January from 1998 to 2016 at the S190_R rainfall gage was 1.6 and 2.1 in., respectively, whereas in the winter of 2015–16 the rainfall totals for December and January were 6.0 and 10.1 in., respectively.

Surface-Water Discharge

Although the USGS surface-water gaging stations do not have identical periods of record, with station records for L-28B and L-28I more than a decade longer than those for NFEED, THREE-MI and WFEED, all show generally higher mean monthly discharge beginning in June or July and ending in October, with the highest discharge in September and generally lower discharge during November–May (fig. 7). Discharge trends are similar to seasonal rainfall trends, with highest discharge and rainfall occurring during June through September (figs. 4 and 5). During the wet season, mean monthly discharge is substantially higher at L-28I and L-28B than at the other sites (fig. 7). Discharge at L-28I essentially represents downstream outflows, and discharge at L-28B represents flows routed through the ER. Mean monthly discharge at WFEED and NFEED, which represent upstream inflows to the BCSIR, combines to contribute to flow measured at S190_S, which represents outflows from the BCSIR. Mean monthly discharge at the THREE-MI gaging station is generally very low compared to other stations and represents flows routed into the BCSIR.

Station WFEED is upstream of a weir structure, and NFEED is downstream of a culvert that discharges into the North Feeder Canal. During 2014–16, discharge at WFEED and NFEED had similar trends and timing of peaks of mean monthly discharge (figs. 8 and 9). Highest monthly mean discharge in August and September 2014 followed a peak in monthly rainfall in July 2014; similarly, the highest monthly mean discharge in September 2015 followed a monthly rainfall peak in August 2015, and highest monthly mean discharge during August through October 2016 followed monthly rainfall peaks during May, June, and August 2016 (figs. 4 and 5). A high monthly mean discharge at both sites in February 2016 followed high rainfall during December 2015 and January 2016 (figs. 4 and 5).

Station PC17A_C is a structure that routes flow from the South Boundary Ditch into the North Feeder Canal, approximately 600 ft north, or upstream, of the NFEED gaging station (fig. 1*B*). The flow measured through the culvert at PC17A_C during the 2014 and 2015 wet seasons (fig. 10) is generally about 20 cubic feet per second (ft^3/s) lower than flows measured at the NFEED (fig. 9), indicating that flow from the South Boundary Ditch into the North Feeder Canal contributes substantially to flow in the canal during the wet season; for example, as much as 86 percent in September 2016.

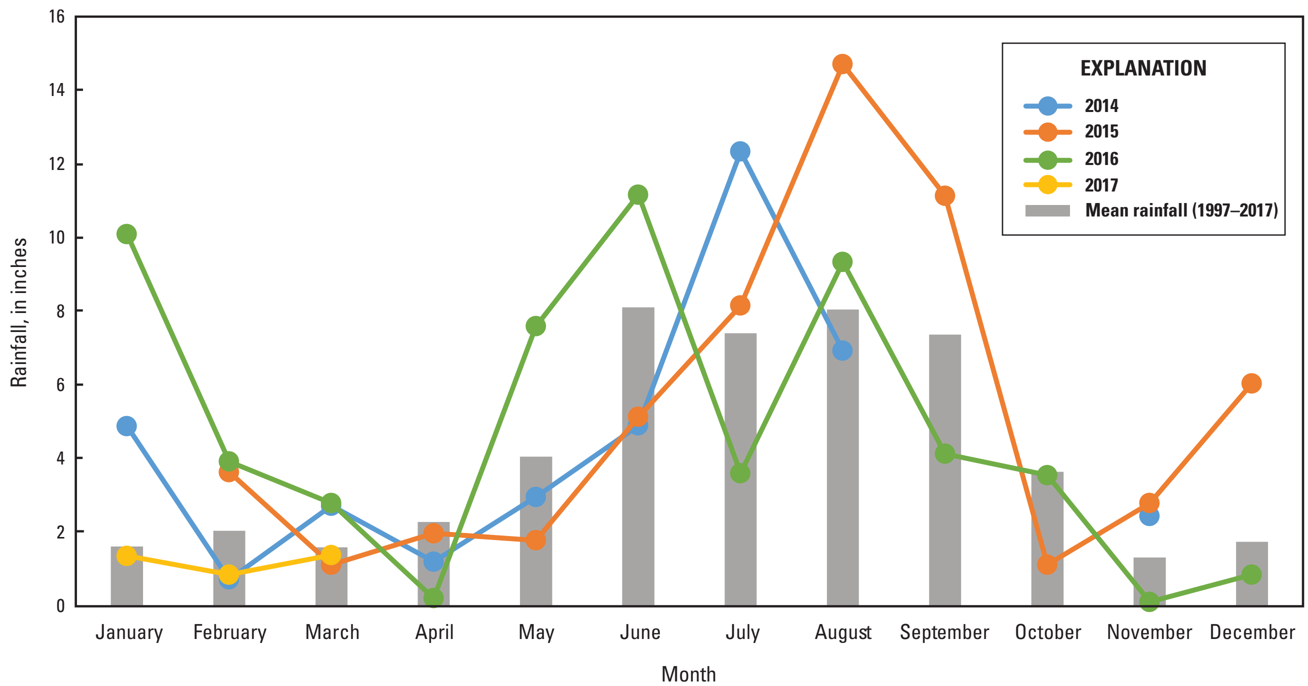

Figure 4. Monthly mean rainfall from March 1997 to March 2017 and monthly rainfall from January 2014 to March 2017 at S190_R, Big Cypress Seminole Indian Reservation, Florida (South Florida Water Management District, 2017b). See figure 1D for site location.

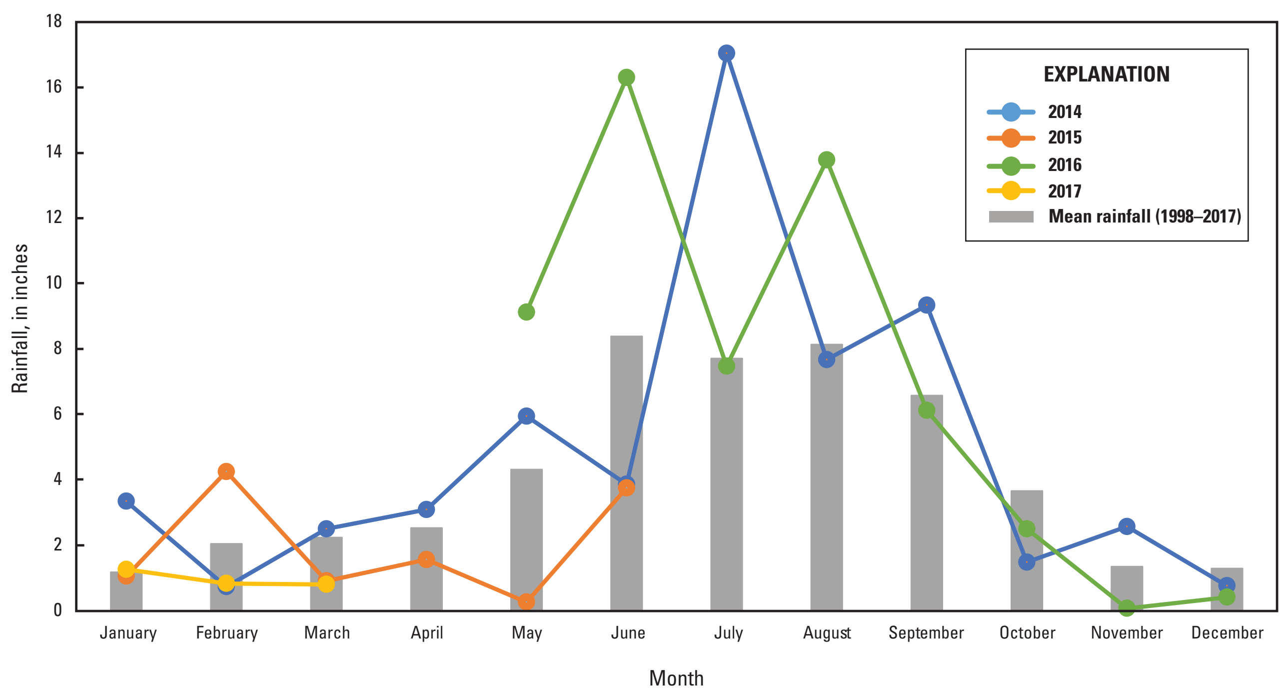

Figure 5. Monthly mean rainfall from January 1998 to March 2017 and monthly total rainfall from January 2014 to March 2017 at ROTNWX, Big Cypress Seminole Indian Reservation, Florida (South Florida Water Management District, 2017b). See figure 1E for site location.

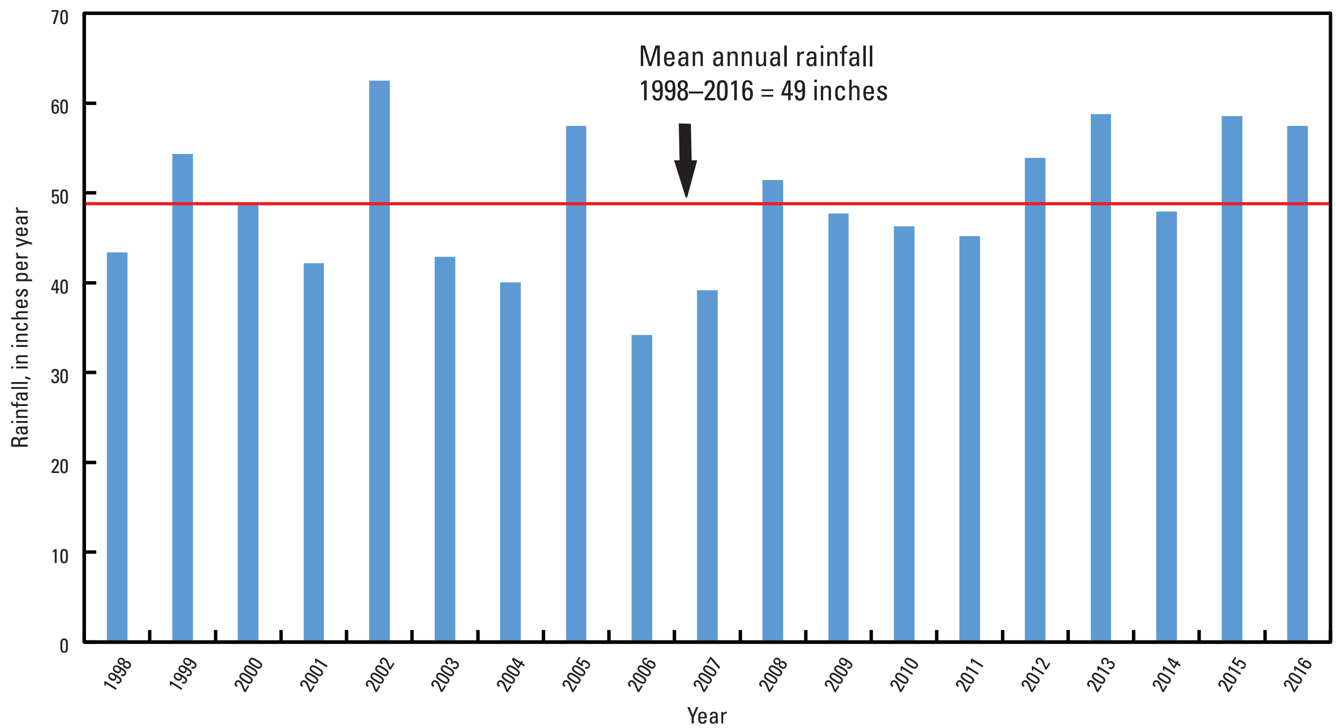

Figure 6. Total annual rainfall from 1998 to 2016 at the S190_R rainfall gage in the Big Cypress Seminole Indian Reservation, Florida (South Florida Water Management District, 2017b). See figure 1*D* for site location.

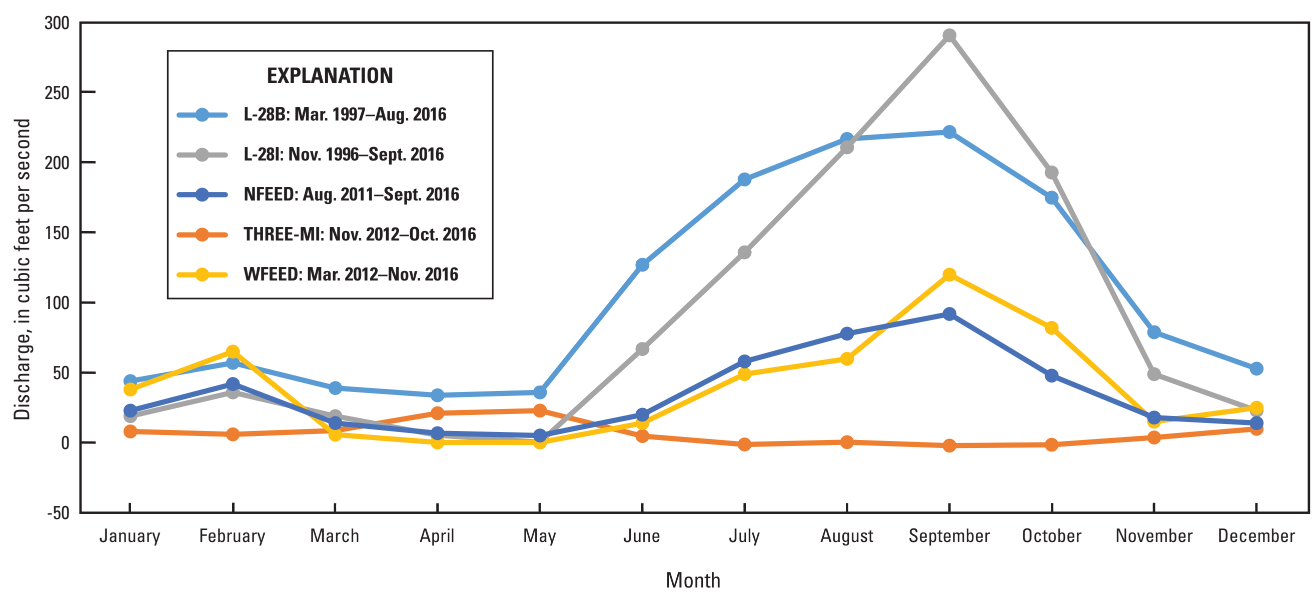

Figure 7. Mean monthly discharge for periods of record for U.S. Geological Survey (USGS) surface-water gaging stations WFEED (USGS 261808081042800 West Feeder Canal abv West Weir nr Clewiston FL), NFEED (USGS 262038080584600 North Feeder Canal blw PC-17A nr Clewiston, FL), L-28I (USGS 261533080571600 L-28 Interceptor Canal blw S-190 near Clewiston, FL), THREE-MI (USGS 02289035 Three Mile Canal below G-409 near Clewiston, FL), and L-28B (USGS 261543080495000 L-28 Canal above S-140 near Clewiston, FL), Big Cypress Seminole Indian Reservation, Florida (U.S. Geological Survey, 2017). Periods of record differ.

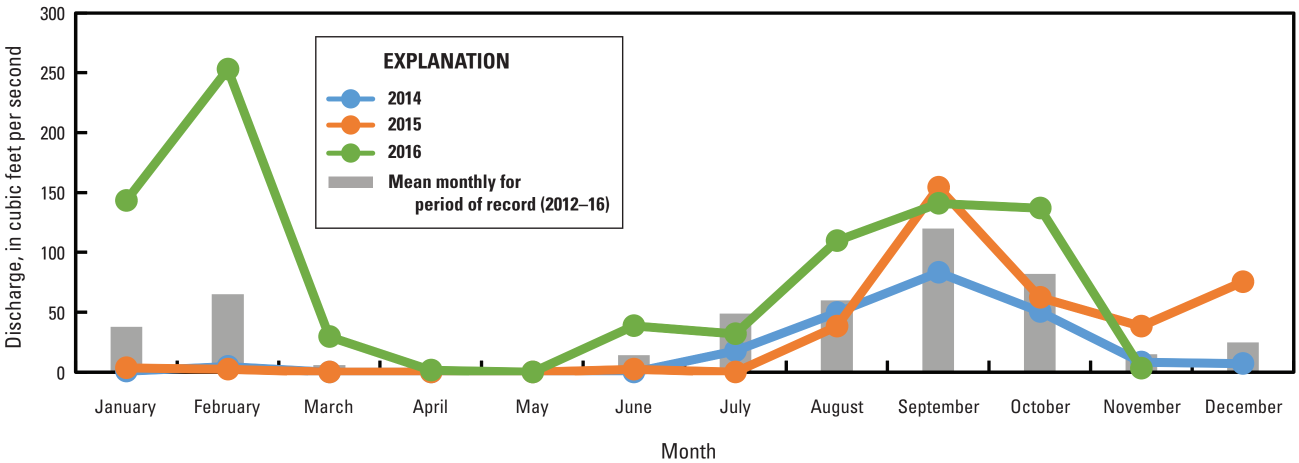

Figure 8. Monthly mean discharge rates during 2014–16 and mean monthly discharge for period of record (Mar. 2012–Nov. 2016) at U.S. Geological Survey (USGS) surface-water gaging station WFEED (USGS 261808081042800 West Feeder Canal abv West Weir nr Clewiston FL), Big Cypress Seminole Indian Reservation, Florida (U.S. Geological Survey, 2017).

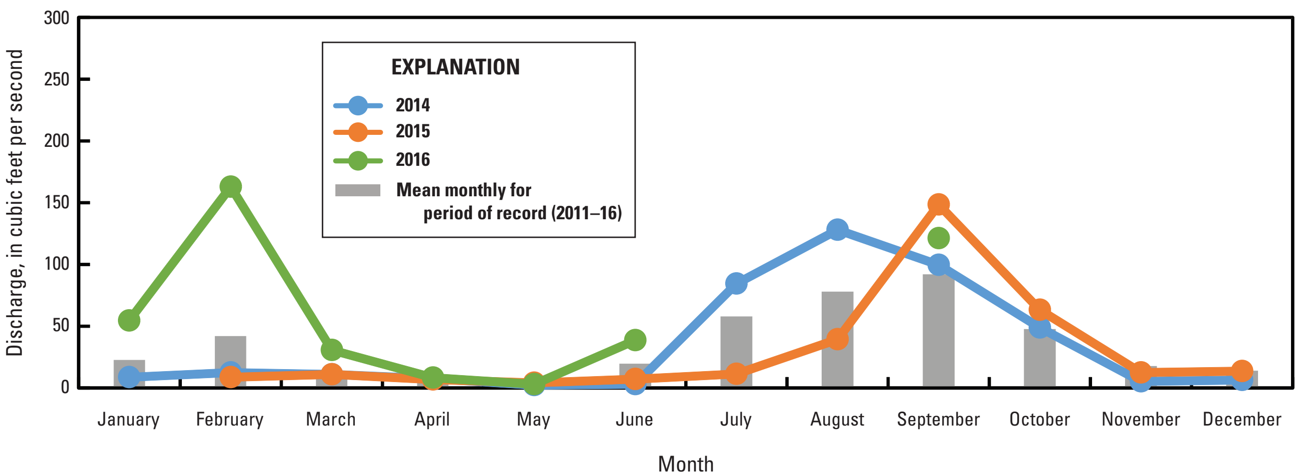

Figure 9. Monthly mean discharge rates during 2014–16 and mean monthly discharge for period of record (Aug. 2011–Sept. 2016) at U.S. Geological Survey (USGS) surface-water gaging station NFEED (USGS 262038080584600 North Feeder Canal blw PC-17A nr Clewiston, FL), Big Cypress Seminole Indian Reservation, Florida (U.S. Geological Survey, 2017).

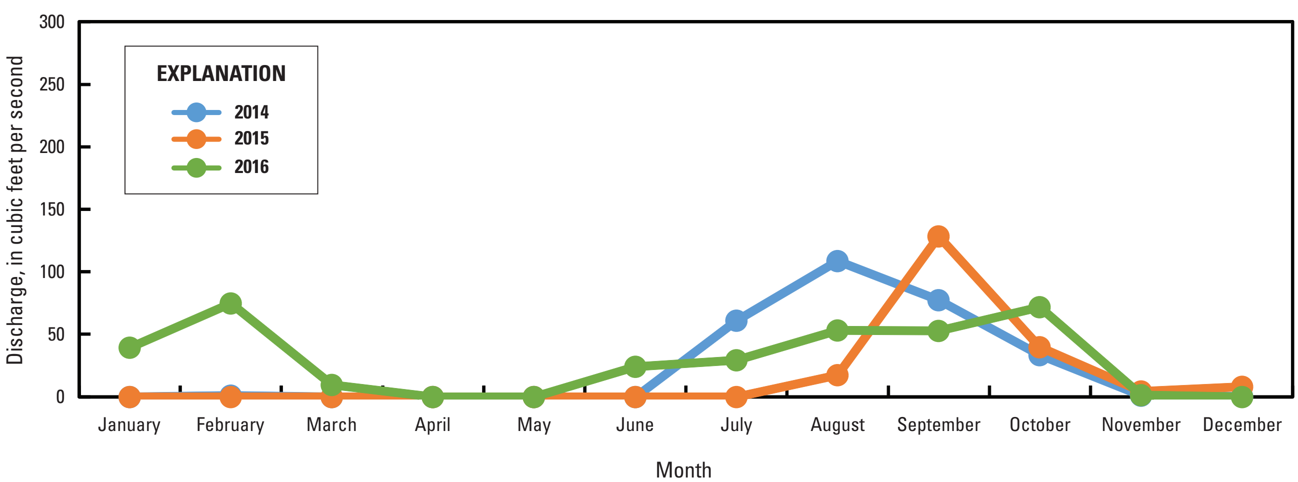

Figure 10. Monthly mean discharge rates at South Florida Water Management District surface-water gaging station PC17A_C during 2014–16, Big Cypress Seminole Indian Reservation, Florida (South Florida Water Management District, 2017b).

Flow through the PC17A_C was about 80 ft^3/s lower during February 2016 and about 60 ft^3/s lower during September 2016 than flows measured in the NFEED, representing only about half of the flow measured in the canal.

The L-28 Interceptor Canal receives discharge from the West Feeder and North Feeder Canals, as well as any overland flow or groundwater discharge from within the L-28 drainage area. The S190_S spillway structure on the L-28 Interceptor Canal is downstream of the confluence of the North Feeder and West Feeder canals (fig. 1*D*). Flow measured at S190_S (fig. 11) represents the sum of the flows from the North Feeder and West Feeder Canals (figs. 7 and 8), plus or minus any flow added or lost between the stations. Generally the flow values measured at the S190_S structure are approximately equal to or greater than the sum of flow values measured at NFEED and WFEED.

Discharge is also measured on the L-28 Interceptor Canal about 1.9 mi downstream of the S190_S structure at the L-28I open-channel discharge gaging site (figs. 1*A* and 12). Discharge at L-28I represents most of the surface-water flow out of the WR. Although flow rates measured at the S190_S structure and at L-28I are not directly comparable and the stations are not near each other, the monthly flow rate values are of similar magnitude during the wet season and wet months January and February 2016 (figs. 11 and 12). There are no major surface-water discharges into or out of the L-28 Interceptor Canal between the S190_S structure and the L-28I gage (figs. 1*A* and 1*D*).

Flow structures USSO_C, G407_C, and G89_C are located in the Confusion Corner area (fig. 1*E*). Discharge values at G407_C represent flow in the L3 Canal and indicate only rare flow through the structure, and any infrequent flows are generally of short duration and of a magnitude of about 10 ft^3/s or less; therefore, no graphical plot of monthly mean flows during 2014–16 are provided herein for this gaging station. Station G89_C is a culvert structure connecting the L-3 and L-28 Borrow Canals, and during 2014–16 no flow was recorded. Station USSO_C is a culvert structure that directs flow from an unnamed canal or ditch parallel and west of the L-3 Canal into the L-28 Borrow Canal. During the 2014–16 study period, about 1 year of data was missing, from August 2015 through July 2016 (fig. 13).

The L-28 Borrow Canal routes discharges from the USSO_C structure in Confusion Corner, around the northeastern and eastern side of the BCSIR, and may receive discharge from the eastern side of the BCSIR and the western side of the Water Conservation Area 3A drainage area. Discharge measured at the L-28B open-channel discharge gaging site (fig. 1*A*) would reflect these cumulative flows (fig. 14). Station L-28B is about 14 mi downstream of the USSO_C structure. Because of the gap in discharge records at the USSO_C structure from August 2015 through July 2016, which included major rainfall events during fall 2015 and winter 2016, comparisons between discharge measured at USSO_C and L-28B are limited (figs. 13 and 14). Discharge patterns for 2014 and the latter part of 2016 show similar patterns at USSO_C and L-28B, with substantially larger flows measured at the downstream station L-28B, indicating substantial discharge contributions between USSO_C and L-28B.

The 3-Mile Canal flows southward from Confusion Corner into the BCSIR. Discharge measured at the THREE-MI gaging station (fig. 1*E*) during 2014–16 was substantially smaller and showed different temporal trends than at the other sites that route surface water into the BCSIR (fig. 15). Mean monthly discharge during the study period (2014–16) ranged from about -3 ft^3/s to about 55 ft^3/s. Mean monthly discharge for the full period of record (2012–16) was highest in April and May and lowest in September and October, and monthly means during the study period generally follow this temporal trend. This trend is the opposite of the discharge trends at the other stations because the THREE-MI gaging station is downstream of the G409_P pump structure, which routes water from the L-3 Canal into the 3-Mile Canal on an as-needed basis to meet water supply entitlements to the Tribe, typically during the dry season. During the wet season, it is unnecessary to route water into the 3-Mile Canal, so discharge is very low and may be negative. Negative values are likely the result of wind-driven flow, or flow reversal as a result of overland flow or groundwater discharge to parts of the canal system downstream of the THREE-MI gaging station.

Groundwater Levels

The altitude and trends of groundwater levels at well cluster HE -1062 and HE -1063 are similar (fig. 16). Groundwater levels rise during wet periods in response to major rainfall events and fall during drier conditions. During drier periods, as groundwater levels decline, groundwater levels at the deeper HE -1063 well are generally higher than at the shallow HE -1062 well, indicating upward groundwater-flow potential. During wetter periods, groundwater levels at the deep and shallow wells are similar. Surface-water stage trends at WFEED are similar to groundwater level trends at wells HE -1062 and HE -1063, rising during wet periods and falling during dry periods. During dry periods, canal stages are higher than groundwater levels, indicating potential downward leakage of water from the canal to groundwater. During wet periods, groundwater levels are higher than canal stages, indicating that groundwater is potentially flowing into the canal.

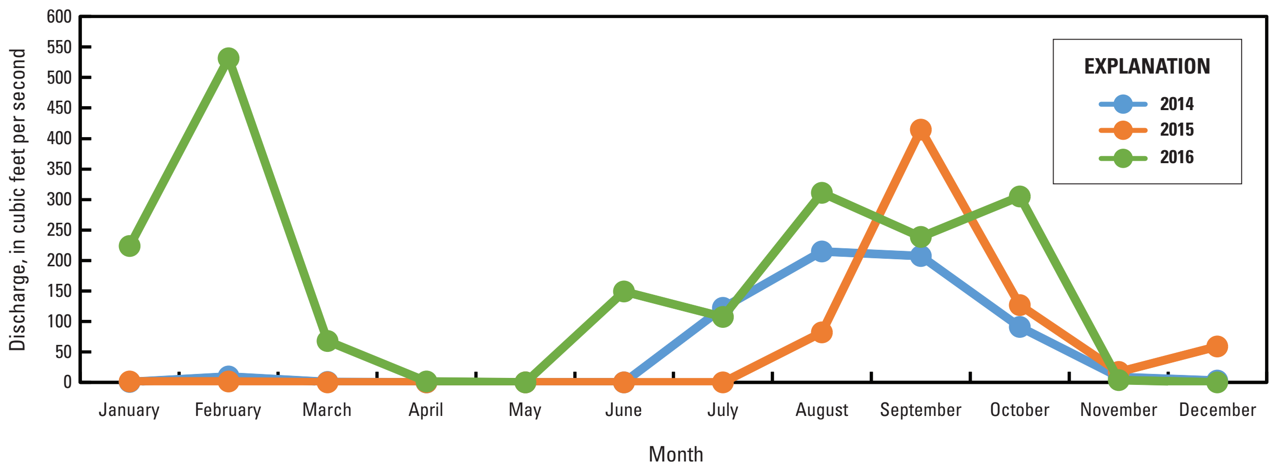

Figure 11. Monthly mean discharge rates at South Florida Water Management District surface-water gaging station S190_S during 2014–16, Big Cypress Seminole Indian Reservation, Florida (South Florida Water Management District, 2017b).

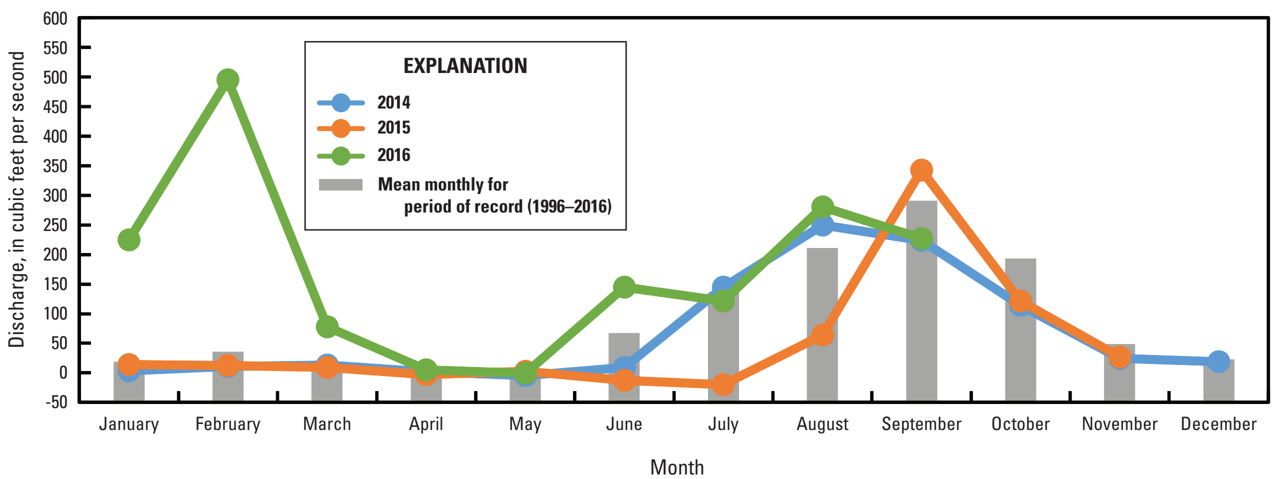

Figure 12. Monthly mean discharge rates during 2014–16 and mean monthly discharge for period of record (Nov. 1996–Sept. 2016) at U.S. Geological Survey (USGS) surface-water gaging station L-28I (USGS 261533080571600 L-28 Interceptor Canal blw S-190 near Clewiston, FL), Big Cypress Seminole Indian Reservation, Florida (U.S. Geological Survey, 2017).

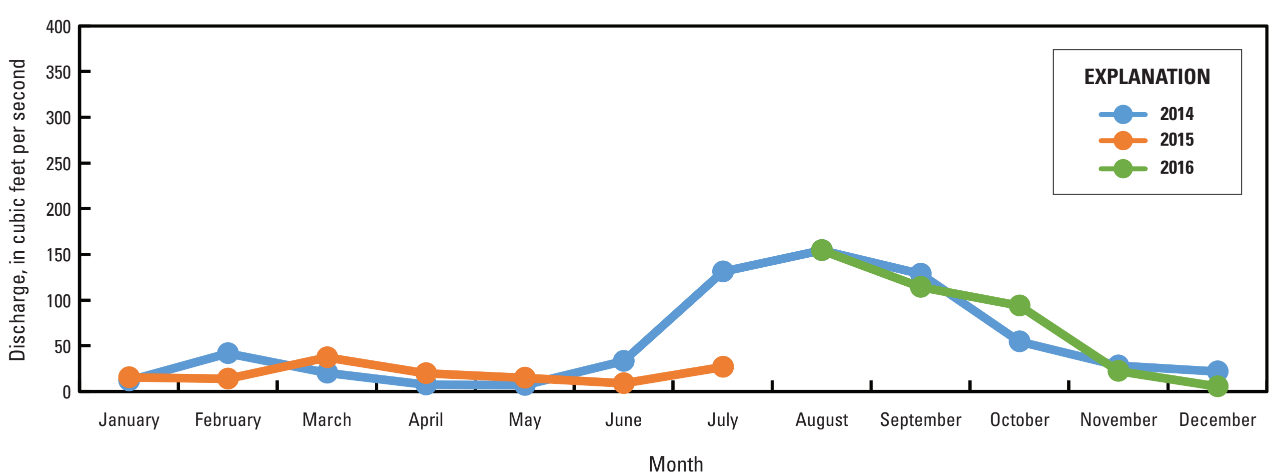

Figure 13. Monthly mean discharge rates at South Florida Water Management District surface-water gaging station USSO_C during 2014–16, Big Cypress Seminole Indian Reservation, Florida (South Florida Water Management District, 2017b).

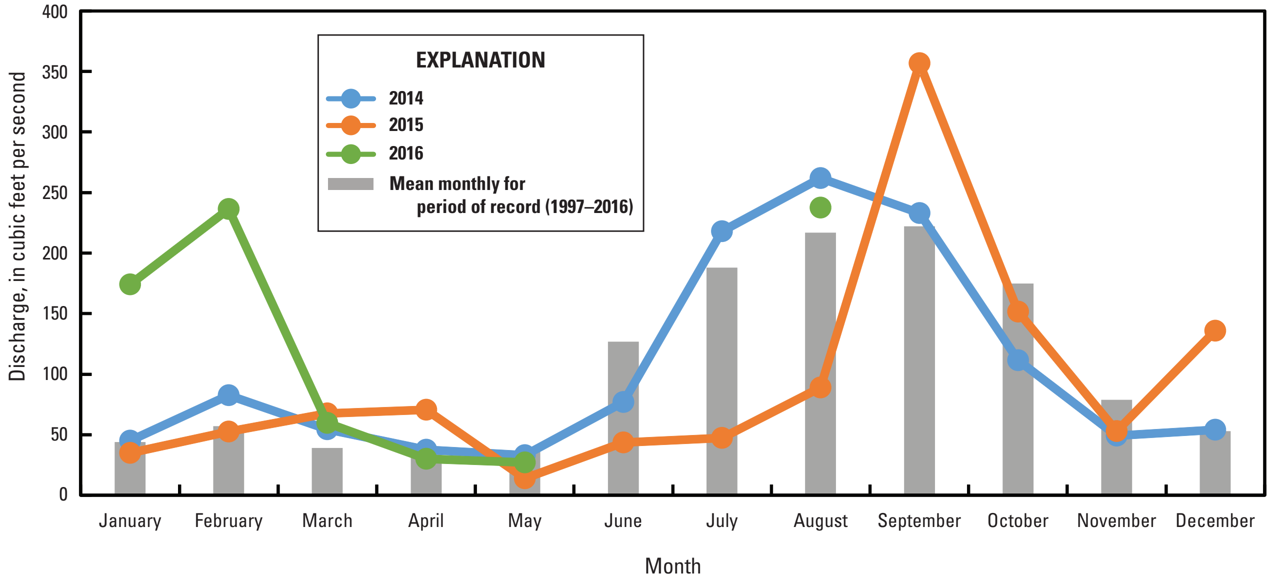

Figure 14. Monthly mean discharge rates during 2014–16 and mean monthly discharge for period of record (Mar. 1997–Aug. 2016) at U.S. Geological Survey (USGS) surface-water gaging station L-28B (USGS 261543080495000 L-28 Canal above S-140 near Clewiston, FL), Big Cypress Seminole Indian Reservation, Florida (U.S. Geological Survey, 2017).

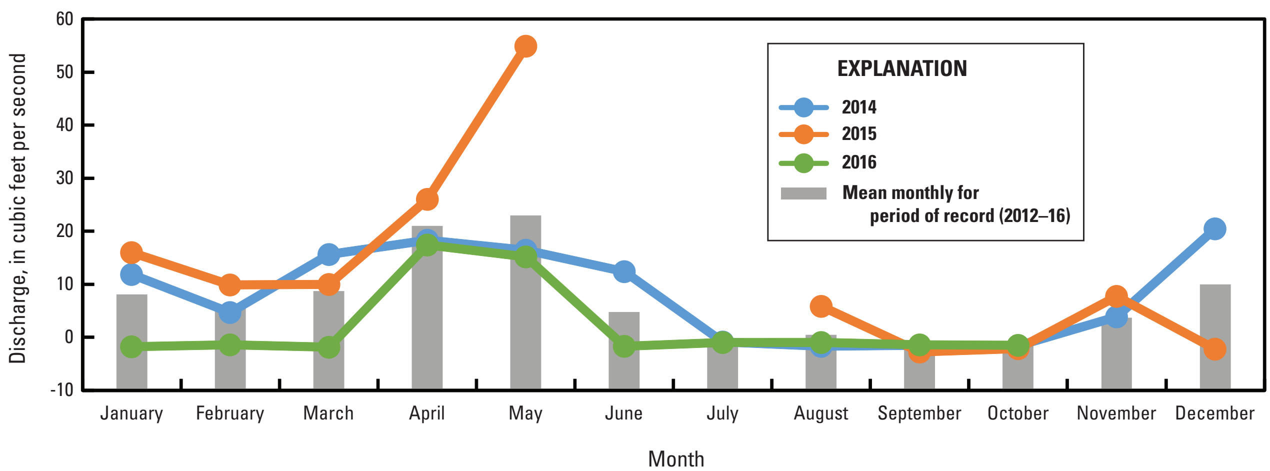

Figure 15. Monthly mean discharge rates during 2014–16 and mean monthly discharge for period of record (Nov. 2012–Oct. 2016) at U.S. Geological Survey (USGS) surface-water gaging station THREE-MI (USGS 02289035 Three Mile Canal below G-409 near Clewiston, FL), Big Cypress Seminole Indian Reservation, Florida (U.S. Geological Survey, 2017).

Figure 16. Daily groundwater levels at U.S. Geological Survey (USGS) wells HE -1062 and HE -1063, daily surface-water level at USGS surface-water gaging station WFEED, and daily rainfall at South Florida Water Management District rainfall site S190_R (South Florida Water Management District, 2017b; U.S. Geological Survey, 2017).

Altitudes and trends of groundwater levels at well cluster HE - 862 and HE - 861 differ for much of the study period (fig. 17). Groundwater levels at the deep well (HE - 861) correspond strongly to rainfall, declining during dry periods and rising during wet periods. Groundwater levels at the shallow well (HE - 862) correspond less strongly with rainfall and more strongly with surface-water levels at THREE-MI, remaining fairly constant at about 14 ft referenced to NGVD 29 during most dry periods and showing more variability during wet periods. Shallow groundwater levels are largely controlled by the surface-water levels, which are typically controlled by the surface-water control structures, actively or passively, to prevent discharges during dry periods and to drain during wet periods or before a major rainfall event. Groundwater levels in the deep well (HE - 861) are usually lower than in the shallow well (HE - 862), indicating downward flow potential. During some wet periods, the groundwater levels at HE - 861 and HE - 862 converge, showing similar trends and heights and indicating hydrostatic conditions; during brief intervals in 2016, groundwater levels in HE - 861 were slightly higher than in HE - 862, indicating upward flow potential. These trends indicate that during most of the study period, the canals likely recharged the aquifer in this area, and only during wet periods, when the groundwater gradient was upward, was the aquifer discharging into, or being drained by, the canal.

Groundwater levels at the well cluster in the WR (HE -1062 and HE -1063; fig. 16) range from about 12 ft bgl to 19 ft referenced to NGVD 29 and are generally higher and more variable than at the well cluster in the ER (HE - 862 and HE - 861; fig. 17), where groundwater levels range from less than 11 ft bgl to about 15 ft referenced to NGVD 29. The deep wells at each site (HE -1063 and HE - 861) show similar trends to each other in response to wet and dry periods and are probably more representative of ambient, regional groundwater conditions than the shallow wells.

Three public water supply wells are located in the north-central part of the BCSIR (fig. 1*A*). The BCSIR production wells produce an average of 0.17 million gallons per day of finished water (Lisa Meday, Seminole Tribe of Florida, written commun., 2017). It is not clear if pumping at these wells affects the groundwater levels in the monitoring wells, and it was not within the scope of this study to evaluate this relation.

Total Phosphorus and Orthophosphorus Concentrations

Concentrations of TP varied from less than the analytical detection limit (0.002 milligram per liter [mg/L]) (2 ppb) to a maximum of nearly 0.50 mg/L (500 ppb) (figs. 18 and 19). Concentrations of TP were typically less than 0.25 mg/L (250 ppb) at the nine Tribe water-quality sites, with 97 percent of the water samples collected containing 0.25 mg/L or less of TP. Most of the samples with concentrations of TP greater than 0.25 mg/L, about 64 percent, were collected at BCS02 (fig. 19) in the Confusion Corner area of the ER. All of the high concentrations, those greater than 0.25 mg/L, occurred from September 2015 to February 2016 (fig. 18). The high concentrations corresponded with very wet conditions in south Florida that resulted from tropical activity in late summer followed by a strong El Niño event over the winter (see “Rainfall” section above), resulting in very wet conditions in what is normally the dry season of south Florida. While the highest TP concentrations tended to occur in the wet season, TP concentrations typically remained high even in the dry season compared to the State of Florida’s 10-ppb (0.01-mg/L) criterion. The SFWMD reported in 2016 that 90 percent of The Everglades geographic area met the State of Florida’s four-part P criterion (SFWMD, 2017d). The WR and ER exhibited similar patterns in TP concentration from 2014 to 2016, though the WR had only 9 percent of the samples (1 sample) with high TP concentrations (greater than 0.25 mg/L) (figs. 18*A* and 18*B*).

Concentrations of OP at the nine Tribe water-quality sites varied from less than the analytical detection limit of 0.003 mg/L (3 ppb) to a maximum of 0.24 mg/L (240 ppb) (figs. 20 and 21). The number of samples collected at each site varied, but ranged from 12 to 46 samples per site from October 2014 to September 2016. Concentrations of OP were typically less than 0.15 mg/L (150 ppb) at the nine sites, with 97 percent of the samples containing less than 0.15 mg/L of OP. The relatively high concentrations all occurred from September 2015 to January 2016 at BCS02, BCS03, BCS04, PC-17N, L-28IN, and L-28U during the wet period described above. As would be expected, OP concentrations (fig. 20) were generally lower than TP concentrations (fig. 18), but exhibited a similar spatial pattern. Samples from the WR typically exhibited low concentrations of OP, less than about 0.05 mg/L (50 ppb) (fig. 20*A*), for the first half of the study period, but then concentrations spiked in September 2015 in correspondence with the beginning of the 2015–16 wet period and remained much more variable in concentration for the remainder of the study period. In the ER (fig. 20*B*), OP concentrations typically varied from about 0 to 0.10 mg/L (0 to 100 ppb) for the duration of the study period, with less of a response to the 2015–16 wet period than the WR.

Results of the TP and OP analyses for samples collected from 2014 to 2016 by the Tribe and SFWMD at the companion water-quality sites were generally similar. The median TP concentrations of the samples collected by the SFWMD tended to be slightly greater than those in samples collected by the Tribe (fig. 22). The slight positive bias in the SFWMD data might be explained by differences in sample collection methods, sampling locations, the hydrology during sampling, or the timing of sampling events. The SFWMD also collected a much larger number of samples (figs. 22 and 23); therefore, their data included a broader range of hydrologic conditions than did the data collected by the Tribe. The median OP concentrations (fig. 23) were nearly identical at the four sites where OP data were collected by both the Tribe and the SFWMD. The range of the 25th and 75th percentiles was slightly narrower at the SFWMD S140 site than at the Tribe L-28U site, but this discrepancy is likely explained by the distance between these sites; S140 is about 6 mi downstream of L-28U.

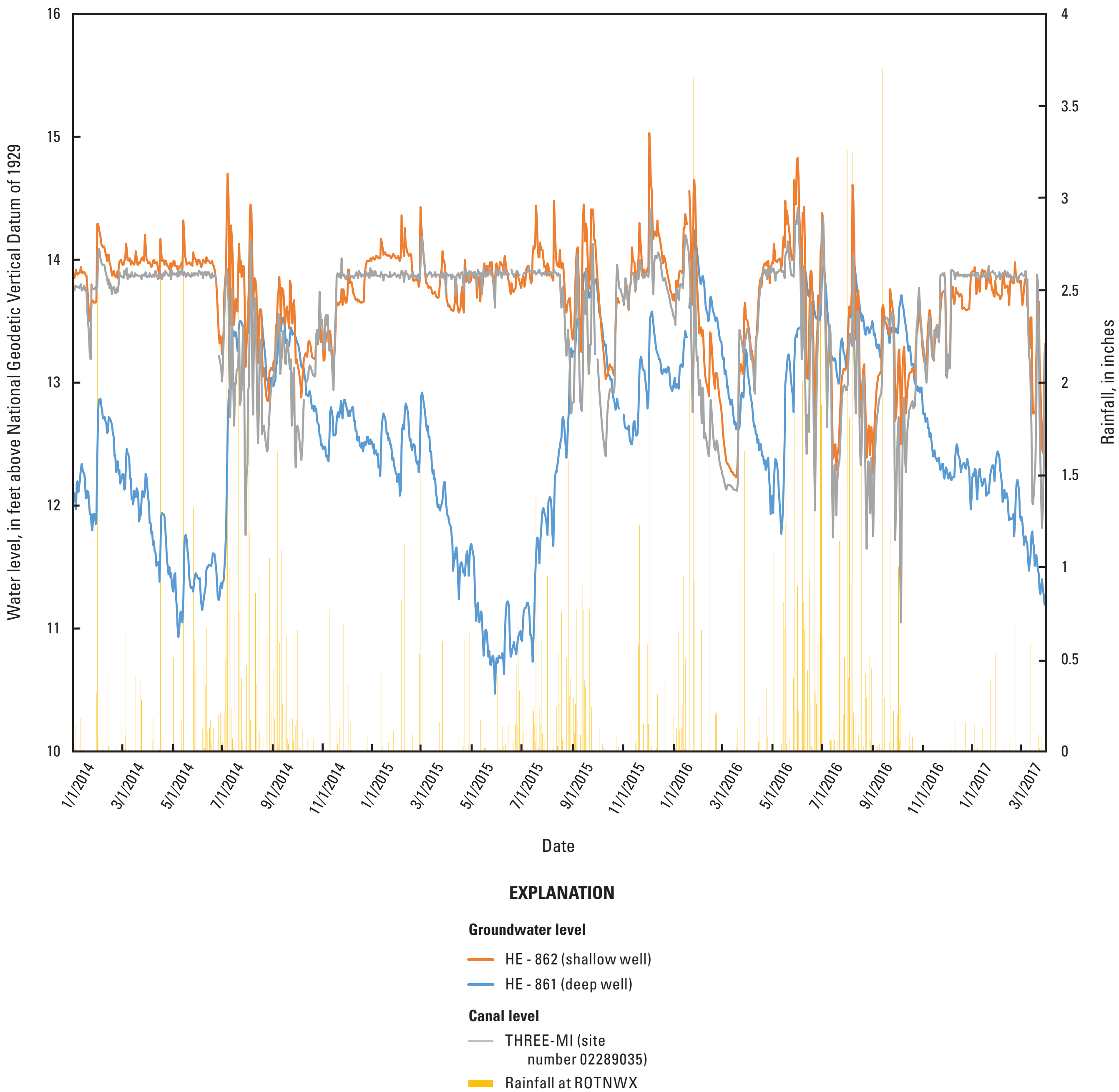

Figure 17. Groundwater levels at U.S. Geological Survey (USGS) wells HE - 862 and HE - 861, surface-water level at USGS surface-water gaging station THREE-MI, and rainfall at South Florida Water Management District rainfall site ROTNWX (South Florida Water Management District, 2017b; U.S. Geological Survey, 2017).

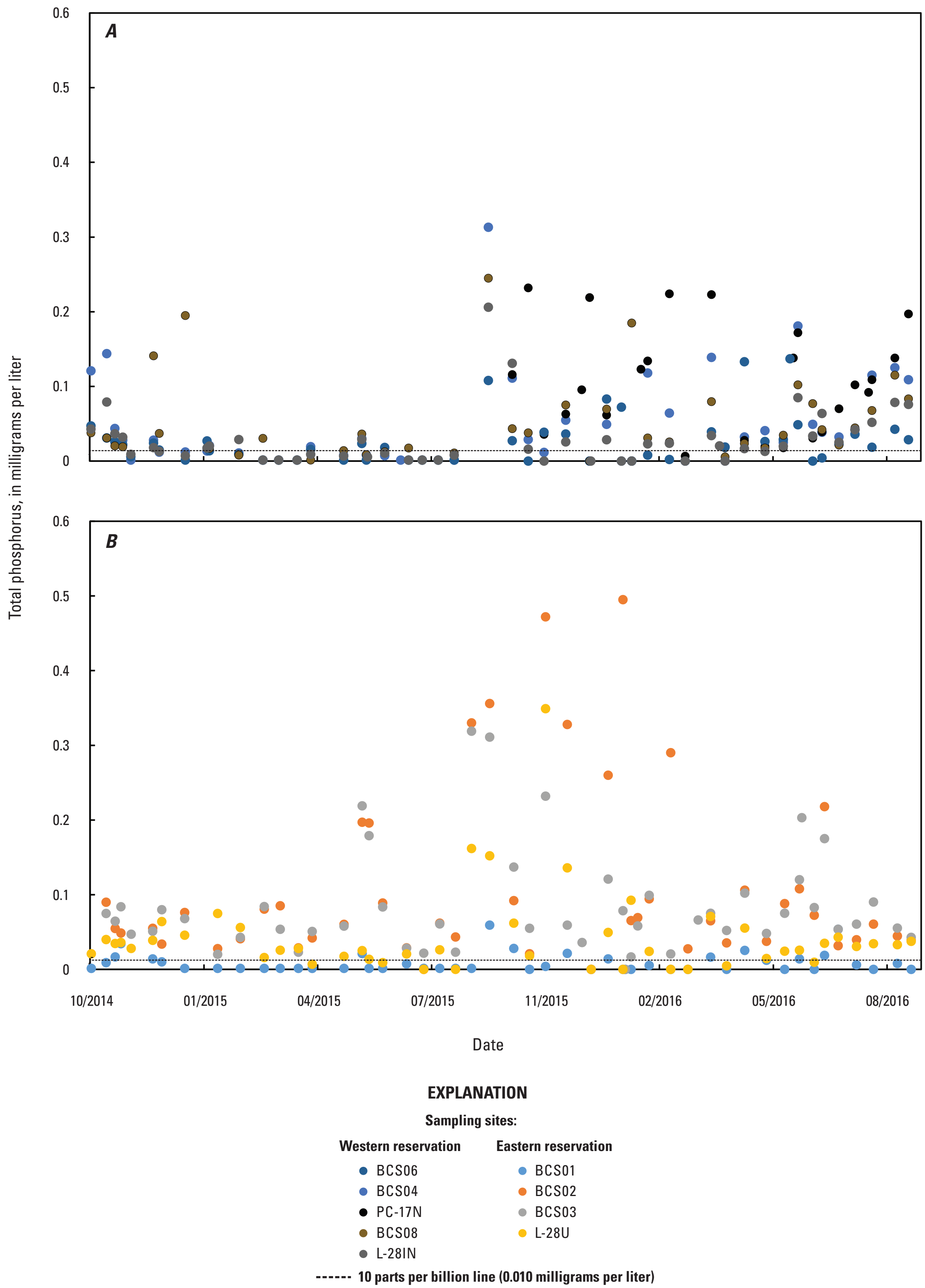

Figure 18. Total phosphorus concentrations at nine Seminole Tribe of Florida water-quality sampling sites in the *A*, western and *B*, eastern halves of the Big Cypress Seminole Indian Reservation, 2014–16 (U.S. Environmental Protection Agency, 2017b).

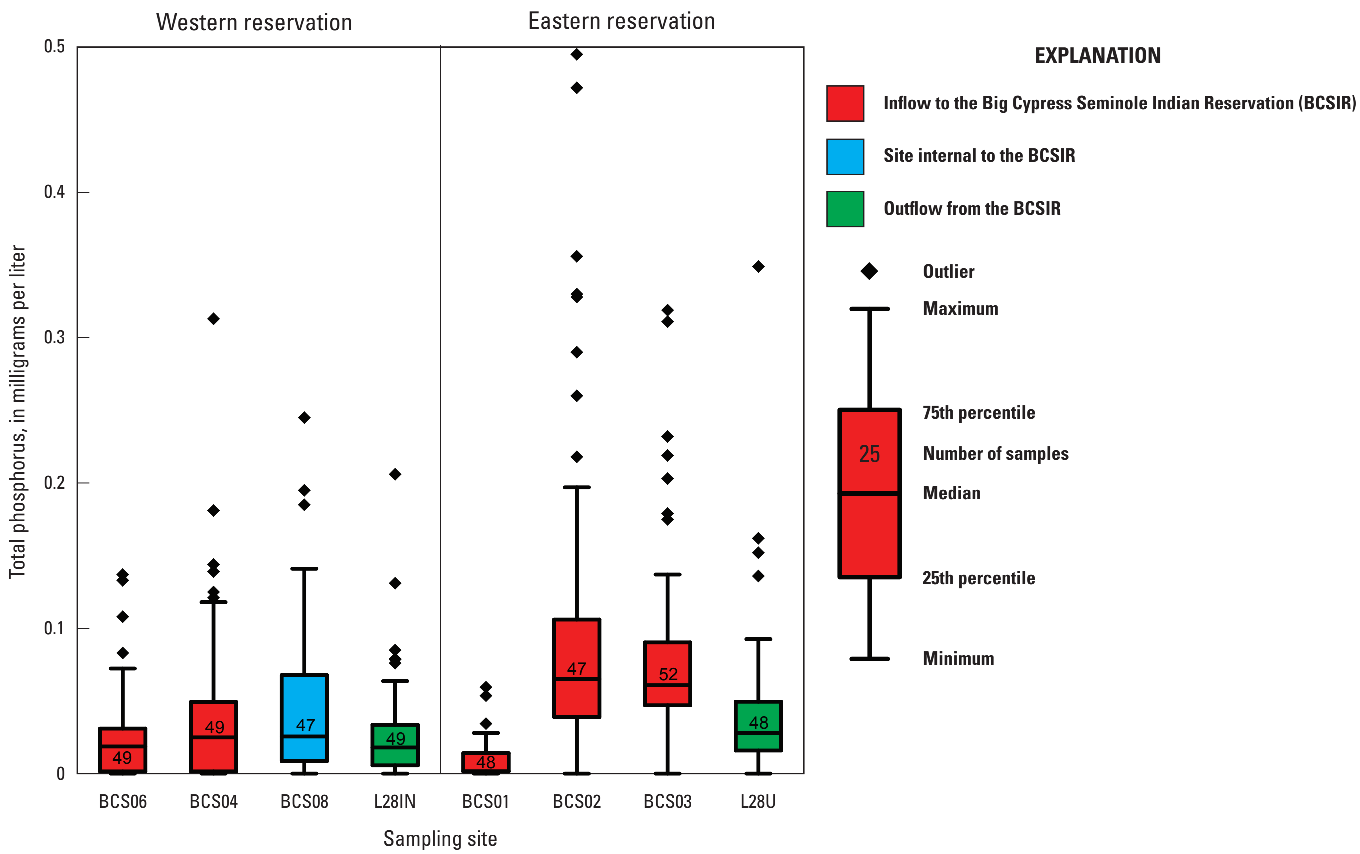

Figure 19. Minimum, maximum, median, and interquartile range of total phosphorus concentrations in the inflows to and outflows from the Big Cypress Seminole Indian Reservation, 2014–16 (U.S. Environmental Protection Agency, 2017b).

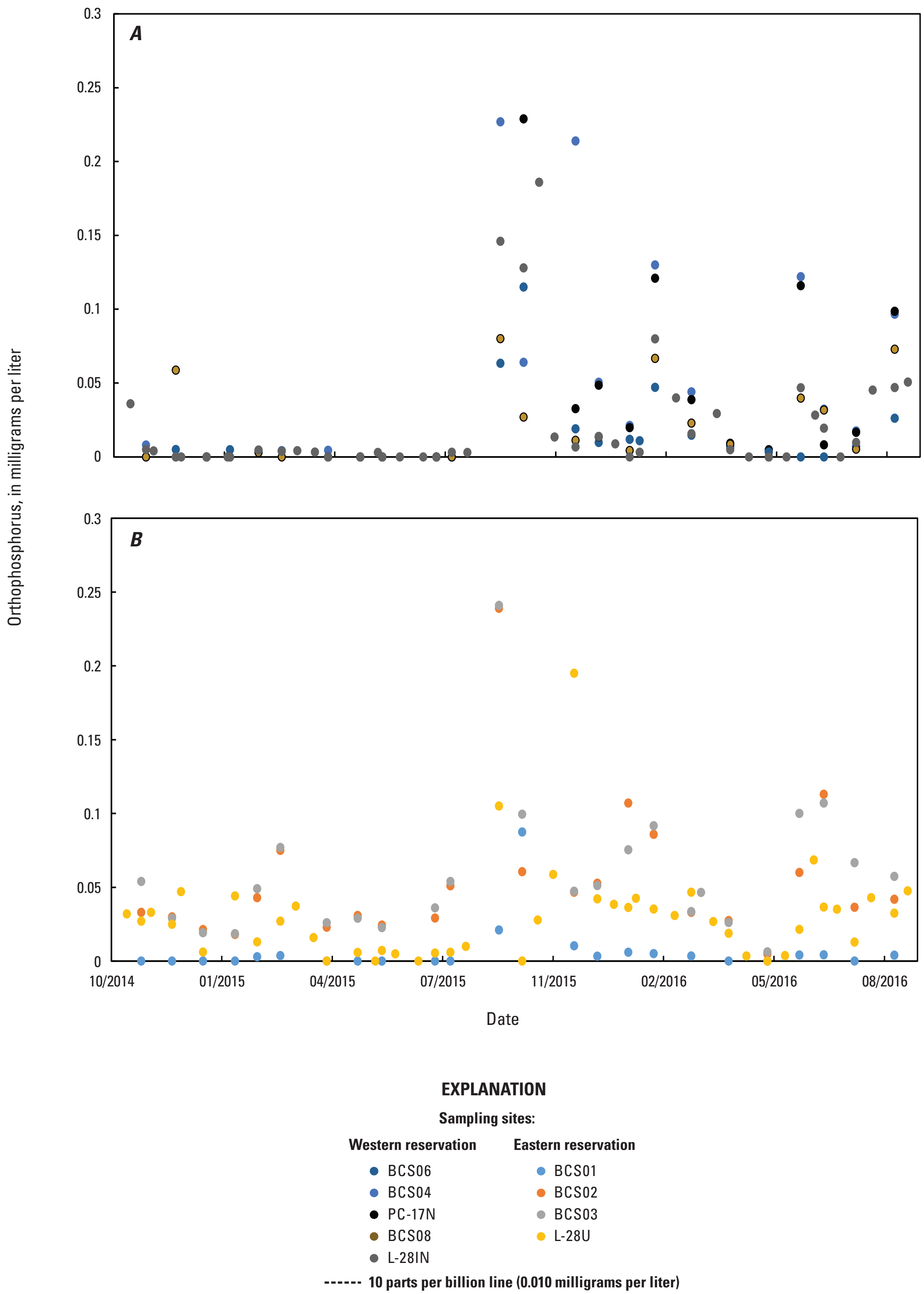

Figure 20. Orthophosphorus concentrations at nine Seminole Tribe of Florida water-quality sampling sites in the *A*, western and *B*, eastern halves of the Big Cypress Seminole Indian Reservation, Florida, 2014–16 (U.S. Environmental Protection Agency, 2017b).

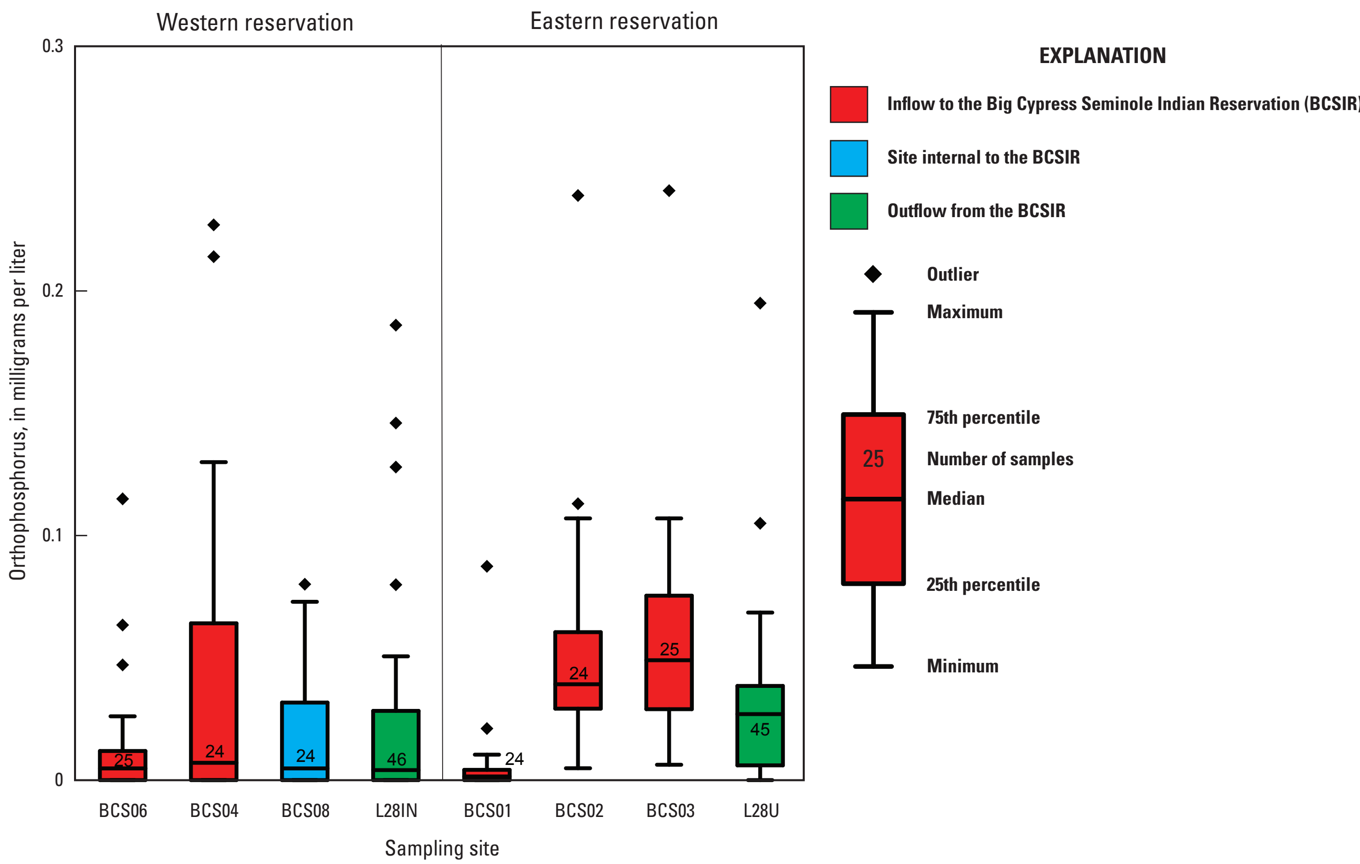

Figure 21. Minimum, maximum, median, and interquartile range of orthophosphorus concentrations in the inflows to and outflows from the Big Cypress Seminole Indian Reservation, Florida, 2014–16 (U.S. Environmental Protection Agency, 2017b).

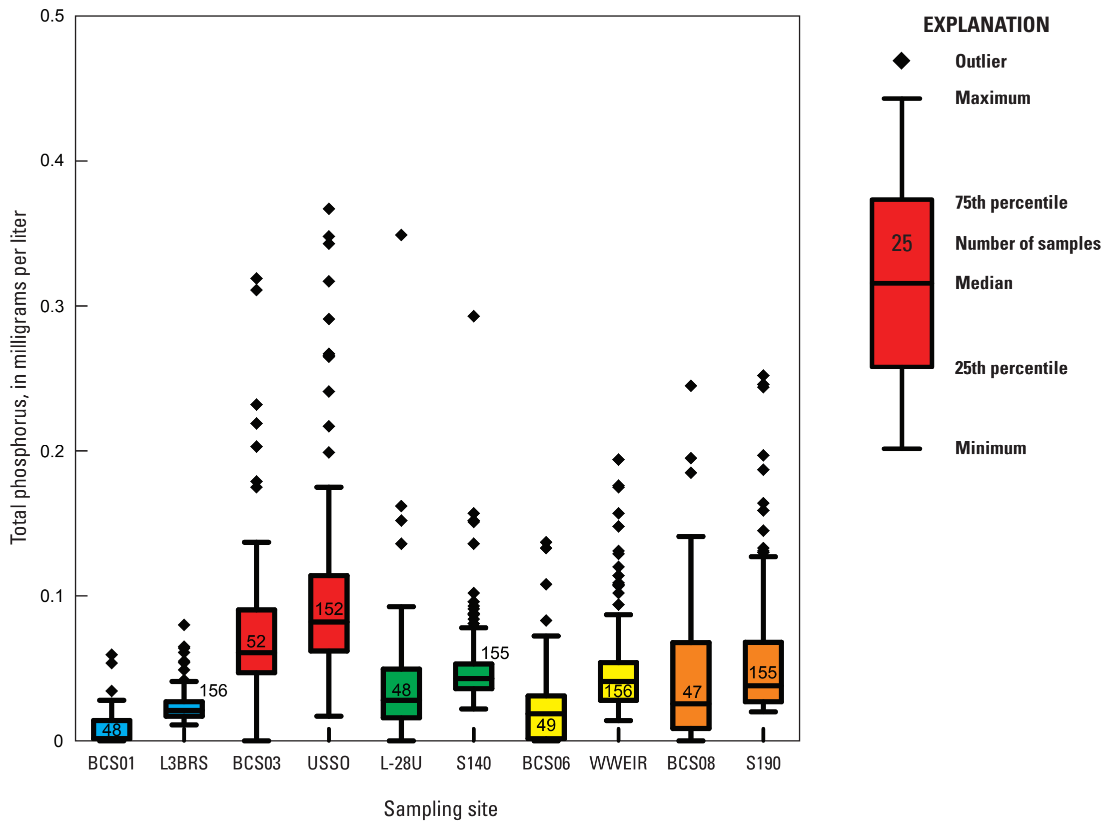

Figure 22. Comparison of the minimum, maximum, median, and interquartile range of the total phosphorus data collected by the Seminole Tribe of Florida and by the South Florida Water Management District (SFWMD) at similar locations in the Big Cypress Seminole Indian Reservation, Florida, 2014–16 (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b). Adjacent Tribe and SFWMD sites are paired by color, with the Tribe site listed first. Site location data are available in table 1.

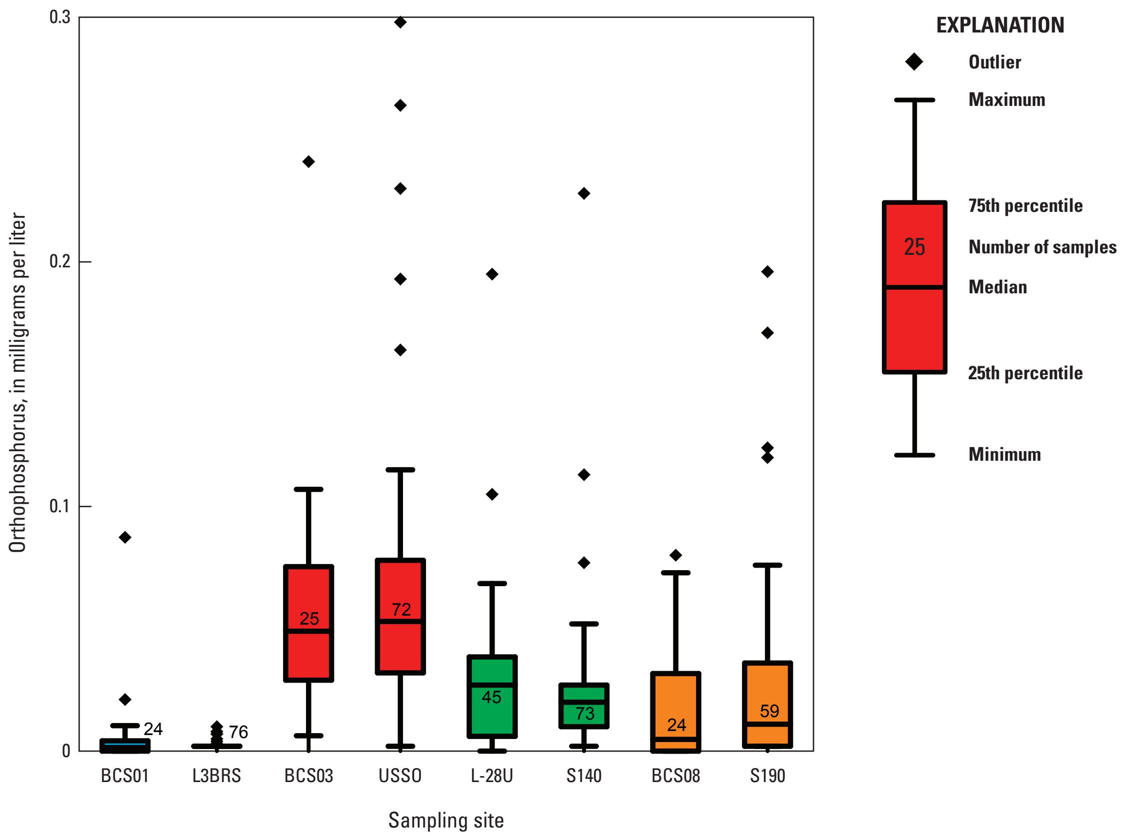

Figure 23. Comparison of the minimum, maximum, median, and interquartile range of the orthophosphorus data collected by the Seminole Tribe of Florida and by the South Florida Water Management District (SFWMD) at similar locations in the Big Cypress Seminole Indian Reservation, Florida, 2014–16 (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b). Adjacent Tribe and SFWMD sites are paired by color, with the Tribe site listed first. Site location data are available in table 1.

Inflows to the ER tended to have higher concentrations of TP and OP than those to the WR (figs. 18–21). The higher concentrations in the ER, measured at inflow sites BCS01, BCS02, and BCS03 (figs. 1*A* and 1*E*), likely resulted from agricultural practices upgradient of the BCSIR because flows into the ER emanate from the EAA (figs. 1 and 2). Inflows from the WR canals, where TP and OP are measured at BCS04 and BCS06 (figs. 1*A*, 1*B*, and 1*C*), also drain large areas of agricultural lands located north and west of the BCSIR, but some of the land to the north, the C-139 Annex (fig. 2), was purchased by SFWMD in 2010 with the intent of restoring citrus grove back into a functioning part of The Everglades ecosystem (SFWMD, 2017a). Restoration projects were underway on annex lands at the time of this writing (2018), but any benefits in P reduction were unclear at this time. Site BCS08 (fig. 1*D*) is unique in that it is the only water-quality sampling site internal to the BCSIR. Concentrations of TP for 2014–16 were higher at BCS08 than at either BCS06 or BCS04 (figs. 1*B*, 1*C*, and 23), which are both located upstream of site BCS08. The increases may come from TP contributions to the North Feeder Canal in the Seminole community area upstream of BCS08. Another possibility is that legacy TP in sediments from upstream sources is released into surface-water flows as they move across the BCSIR, especially during periods of higher flows.

From 2014 to 2016, concentrations of TP tended to decrease as flows moved across the BCSIR (figs. 18 and 22). In both the WR and ER, the mean and maximum concentrations of TP were lower in the outflows from BCSIR than in the inflows to it (table 5), whereas median concentrations remained the same for the inflows and outflows in the WR and decreased in those in the ER. For this analysis, the WR inflows included TP concentration data from BCS04 and BCS06, and the outflows were based on data from L-28IN (figs. 1*A*, 1*B*, and 1*C* and table 1). The ER inflows included TP concentration data from BCS01, BCS02, and BCS03, and the outflows were represented by data collected at L-28U (figs. 1*A* and 1*E* and table 1). From 2014 to 2016, the mean, median, and maximum concentrations of TP in the inflows to the WR were 0.04 mg/L (40 ppb), 0.02 mg/L (20 ppb), and 0.31 (310 ppb), respectively, whereas the mean, median, and maximum concentrations in the outflows were

Table 5. Mean, median, and maximum total phosphorus concentrations in surface-water inflows and outflows to the western and eastern Big Cypress Seminole Indian Reservation, 2014–16.

[TP, total phosphorus; conc., concentration; mg/L, milligrams per liter; max., maximum]

	TP, mean conc., mg/L	TP, median conc., mg/L	TP, max. conc., mg/L
Western reservation			
Inflows[1]	0.04	0.02	0.31
Outflows[2]	0.03	0.02	0.21
Eastern reservation			
Inflows[3]	0.07	0.04	0.5
Outflows[4]	0.04	0.03	0.35

[1]Inflows include TP concentrations from sites BCS04 and BCS06.

[2]Outflows include TP concentrations from site L-28IN.

[3]Inflows include TP concentrations from sites BCS01, BCS02, and BCS03.

[4]Outflows include TP concentrations from site L-28U.

Table 6. Percent exceedances for water-quality samples that exceeded 10 parts per billion of total phosphorus, October 2014 to September 2016, Big Cypress Seminole Indian Reservation, Florida.

[Data from U.S. Environmental Protection Agency (2017b). Site information available in figure 1 and table 1. ppb, parts per billion]

Tribe sampling site	Site type (inflow, outflow, or internal)	Total number of samples	Samples exceeding 10 ppb	Percent exceedance
Western reservation				
BCS06	Inflow	49	29	59
BCS04	Inflow	49	32	65
BCS08	Internal	47	35	74
L-28IN	Outflow	49	31	63
Eastern reservation				
BCS01	Inflow	48	14	29
BCS02	Inflow	47	45	96
BCS03	Inflow	52	49	94
L-28U	Outflow	48	38	79

0.03 mg/L (30 ppb), 0.02 mg/L (20 ppb), and 0.21 mg/L (210 ppb), respectively. In the ER inflows, the mean, median, and maximum concentrations of TP were 0.07 mg/L (70 ppb), 0.04 mg/L (40 ppb), and 0.50 mg/L (500 ppb), respectively, whereas the mean, median, and maximum concentrations in the outflows were 0.04 mg/L (40 ppb), 0.03 mg/L (30 ppb), and 0.35 mg/L (350 ppb), respectively. The TP concentration data indicate that the BCSIR did not contribute substantial TP to the canals that traverse its boundaries and that concentrations likely decreased during the study period. A longer period of record and more robust statistical analyses are needed to confirm the results of this initial analysis.

From 2014 to 2016, 59–65 percent of the samples collected at the WR inflows exceeded 10 ppb of TP, and 63 percent of the TP samples collected at the outflow exceeded 10 ppb (table 6). Samples from the internal BCS08 WR site exceeded 10 ppb of TP 74 percent of the time. At the ER inflows, 29 percent of the samples collected at BCS01 exceeded 10 ppb of TP, whereas samples from BCS02 and BCS03 exceeded 10 ppb of TP 96 and 94 percent of the time, respectively. Outflows in the ER at L-28U exceeded 10 ppb of TP 79 percent of the time.

Total Phosphorus and Orthophosphorus Concentrations and Surface-Water Flows

The highest TP and OP concentrations tended to occur during peaks in flows at most of the Tribe water-quality sites (figs. 24–32), but occasionally, high concentrations of TP occurred when flows were low, such as at BCS06 in May and June 2015 (fig. 24). There was no flow during this time period, although conditions were very wet (fig. 33), with some of the highest monthly rainfall averages of the study period. The rainfall might have caused overland flow or interflow in soils that might be related to the high TP concentrations. Similar high concentrations of TP occurred at BCS08 in November and December 2014 (fig. 27) when high flows were not occurring, but in this case conditions were dry (rainfall totals were about 2.5 in. in November and less than 1 in. in December). On the basis of the data that are available, it is unclear what caused these high concentrations of TP. Concentrations of TP and OP tended to increase in the BCSIR during wet periods, but the increases typically did not occur immediately following heavy rainfall (figs. 33–41). Increases in canal discharge tended to lag behind rainfall events (figs. 42–50), likely because control structures do not release flows until the canals reach predetermined stages. That higher concentrations of TP and OP do occur during wet conditions may indicate that sediments containing high concentrations of P become mobilized during high flows (Diaz and others, 2006). The highest concentrations of TP and OP usually occurred early in wet periods following long dry periods (figs. 33–41). During dry periods, sources of P, such as fertilizers, decaying plant matter, and organic wastes, likely accumulate on dry land and are flushed into the canal systems during wet periods (Daroub and others, 2005). When dry periods are prolonged, more P accumulates on land, resulting in higher concentrations of TP and OP during rainfall events that mark the end of dry periods.

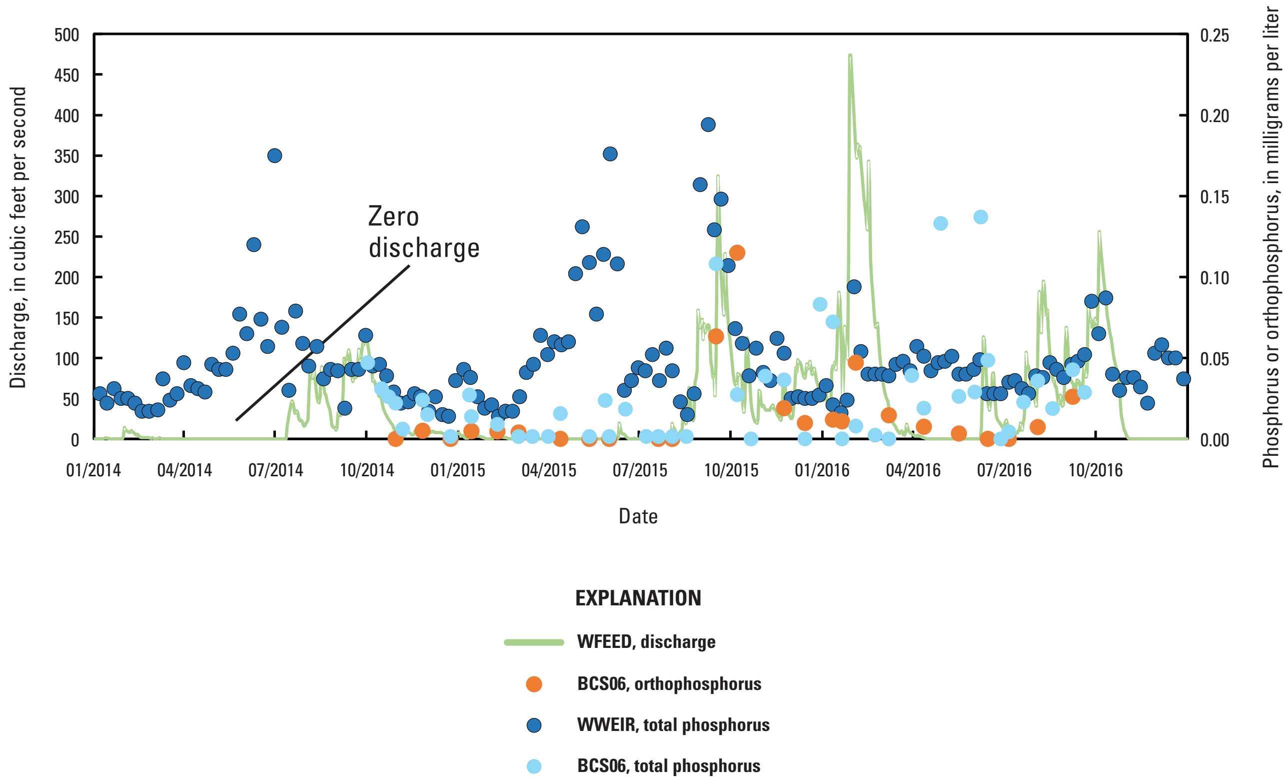

Figure 24. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida BCS06 and South Florida Water Management District WWEIR water-quality sites compared with discharge at the U.S. Geological Survey WFEED (261808081042800 West Feeder Canal abv West Weir nr Clewiston FL) surface-water gaging station (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b; U.S. Geological Survey, 2017).

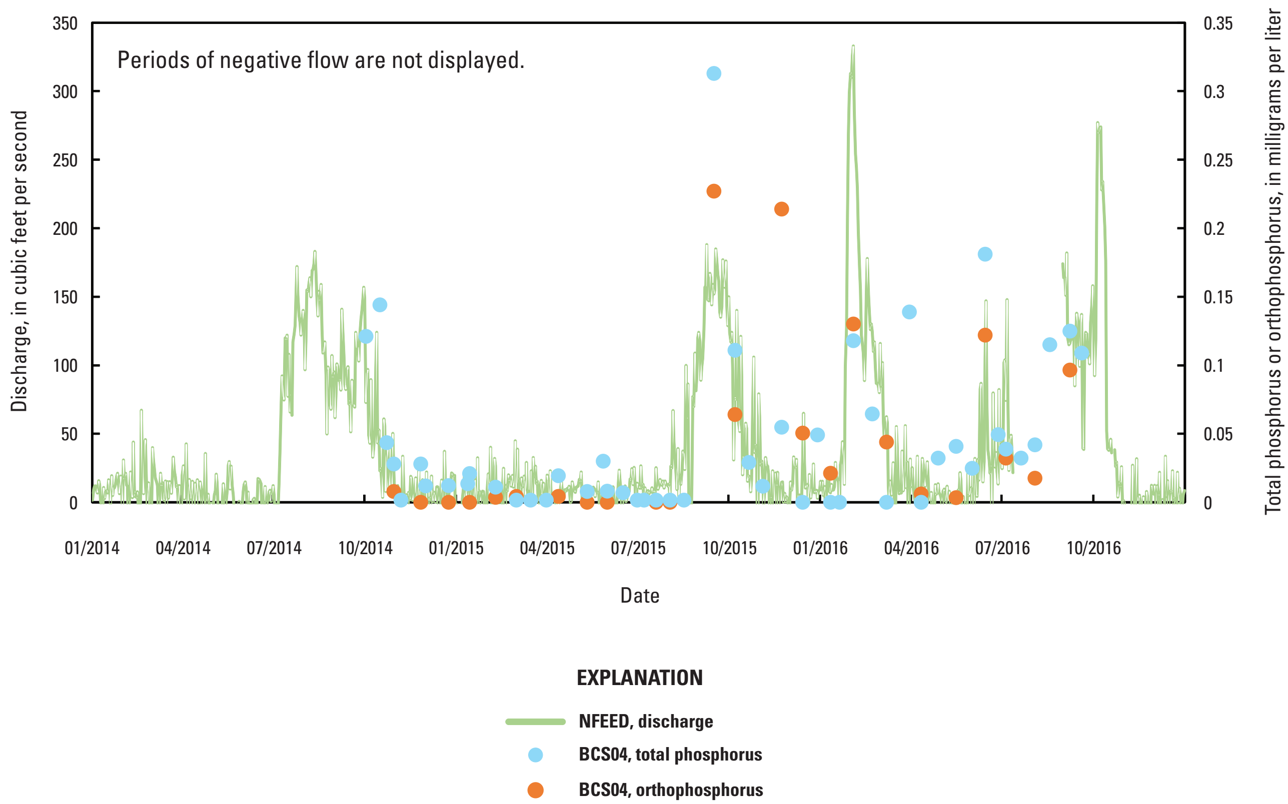

Figure 25. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida BCS04 water-quality site compared with discharge at the U.S. Geological Survey NFEED (262038080584600 North Feeder Canal blw PC-17A nr Clewiston, FL) surface-water gaging station (U.S. Environmental Protection Agency, 2017b; U.S. Geological Survey, 2017).

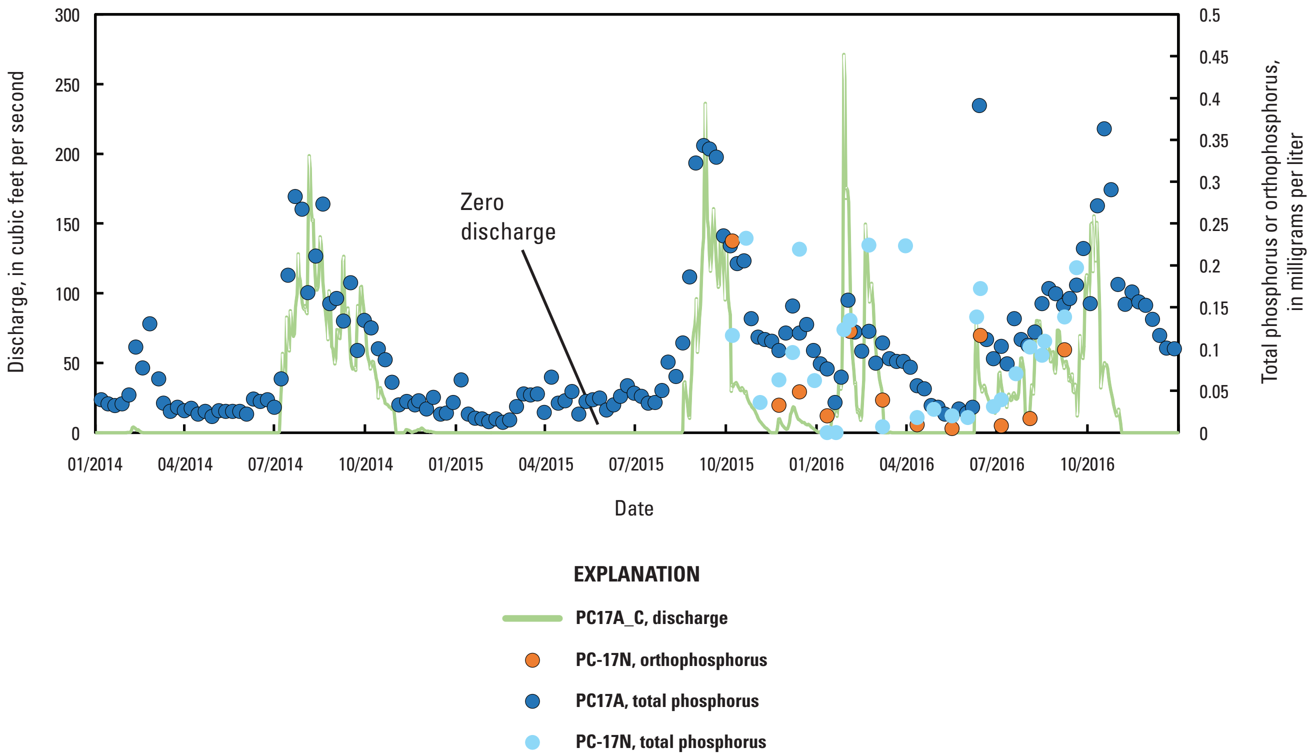

Figure 26. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida PC-17N and South Florida Water Management District (SFWMD) PC17A water-quality sites compared with discharge at the SFWMD PC-17A_C surface-water gaging station (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

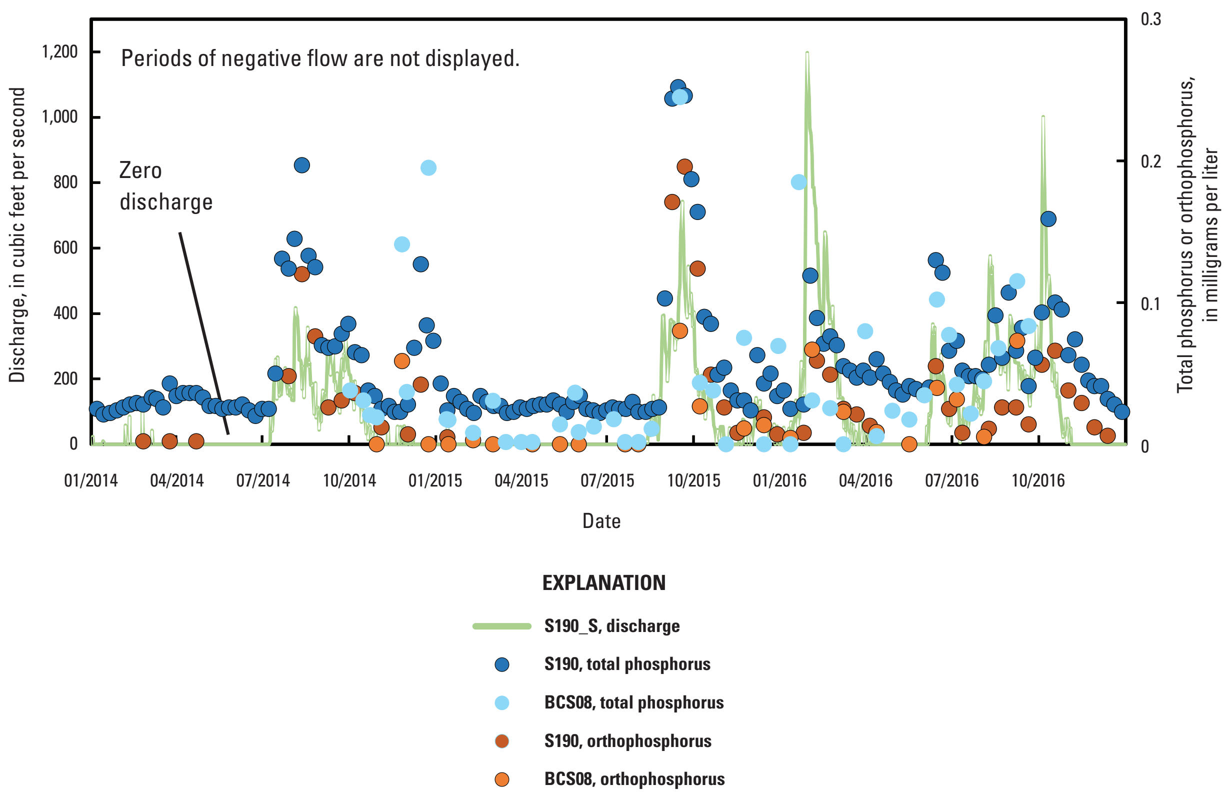

Figure 27. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida BCS08 and South Florida Water Management District (SFWMD) S190 water-quality sites compared with discharge at the SFWMD S190_S surface-water gaging station (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

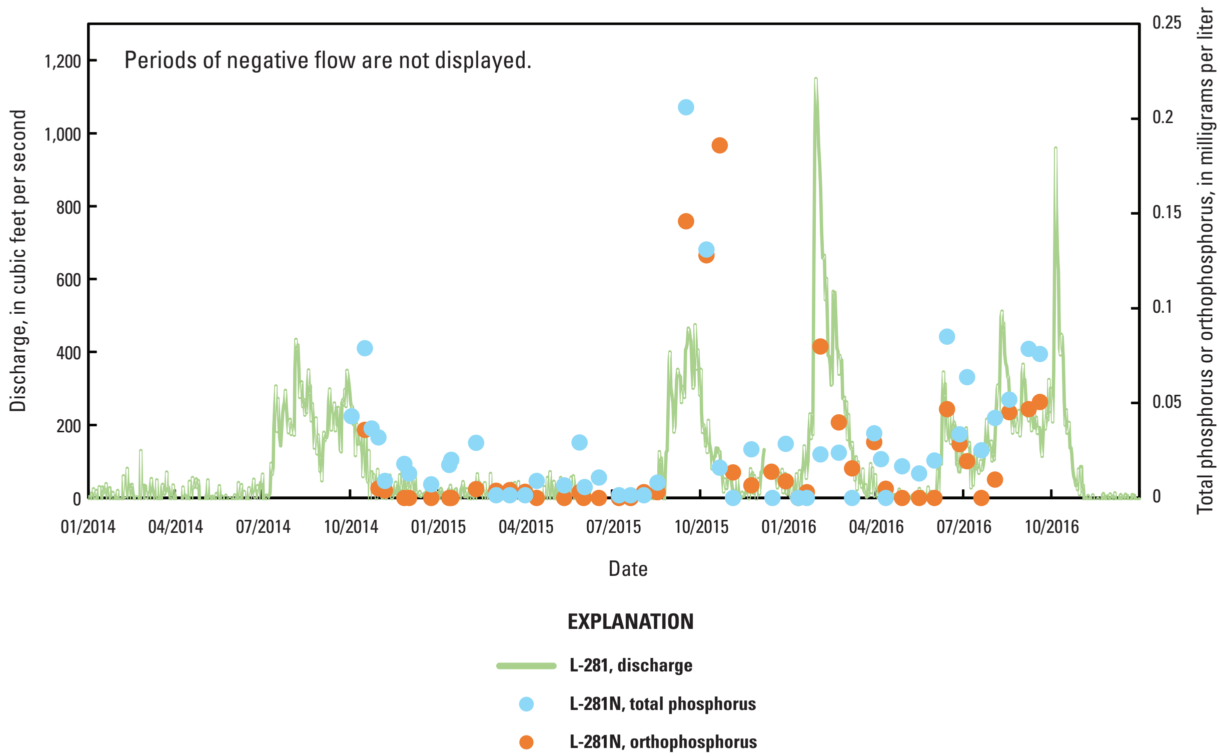

Figure 28. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida L-28IN water-quality site compared with discharge at the U.S. Geological Survey L-28I (261533080571600 L-28 Interceptor Canal blw S-190 near Clewiston, FL) surface-water gaging station (U.S. Environmental Protection Agency, 2017b; U.S. Geological Survey, 2017).

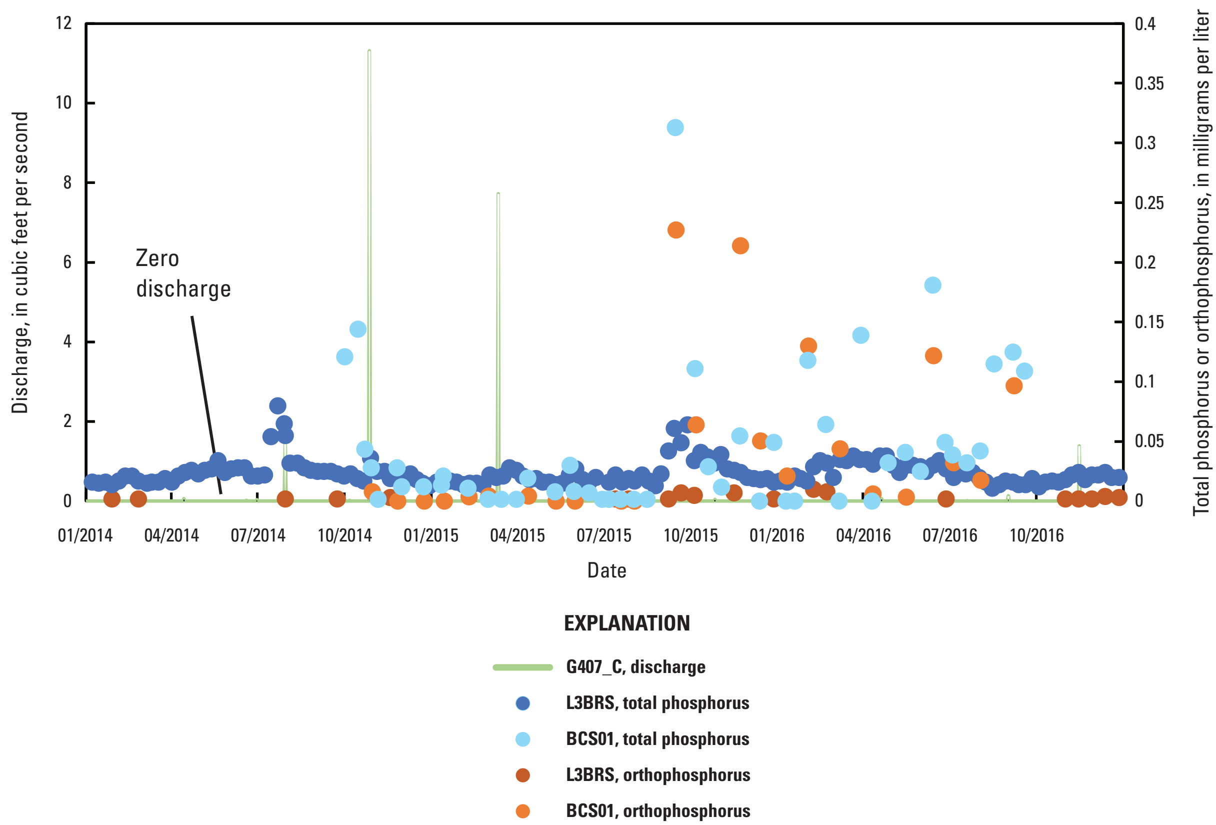

Figure 29. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida BCS01 and South Florida Water Management District (SFWMD) L3BRS water-quality sites compared with discharge at the SFWMD G407_C surface-water gaging station (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

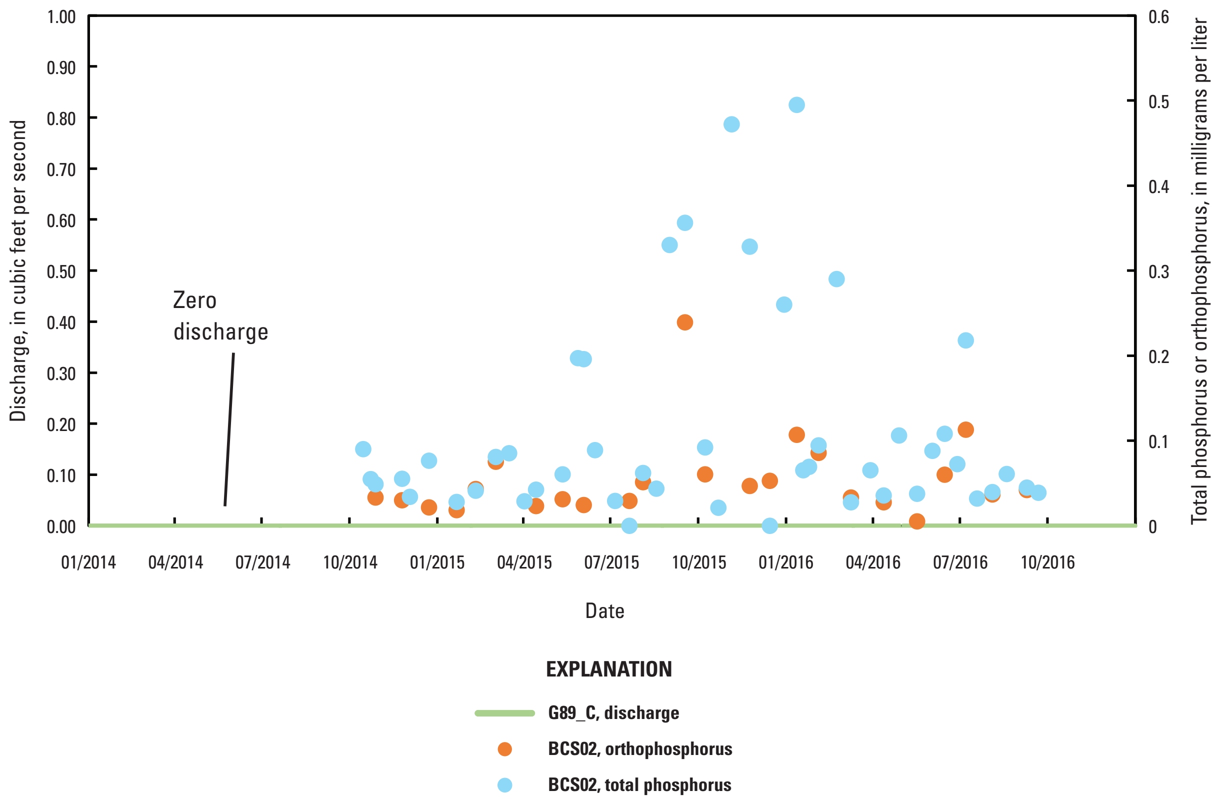

Figure 30. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida BCS02 water-quality site compared with discharge at the South Florida Water Management District G89_C surface-water gaging station (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

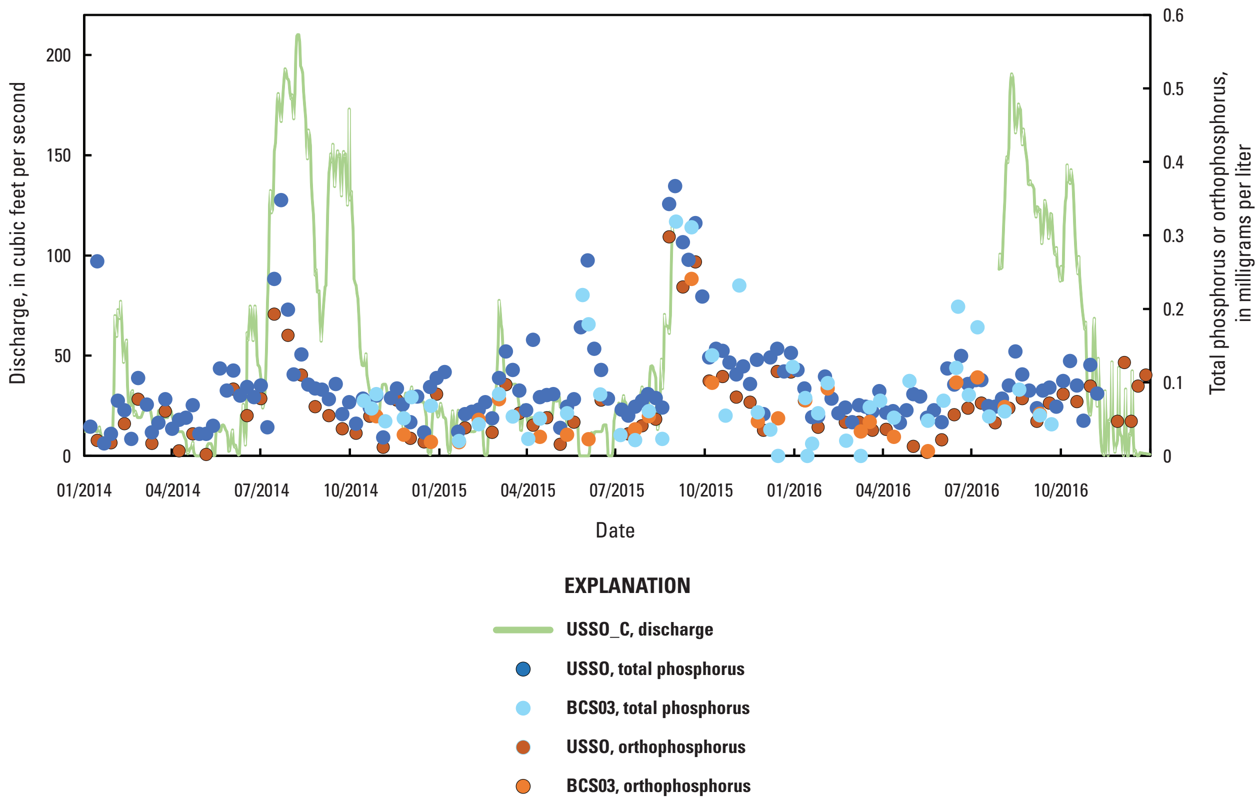

Figure 31. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida BCS03 and South Florida Water Management District (SFWMD) USSO water-quality sites compared with discharge at the SFWMD USSO_C surface-water gaging station (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

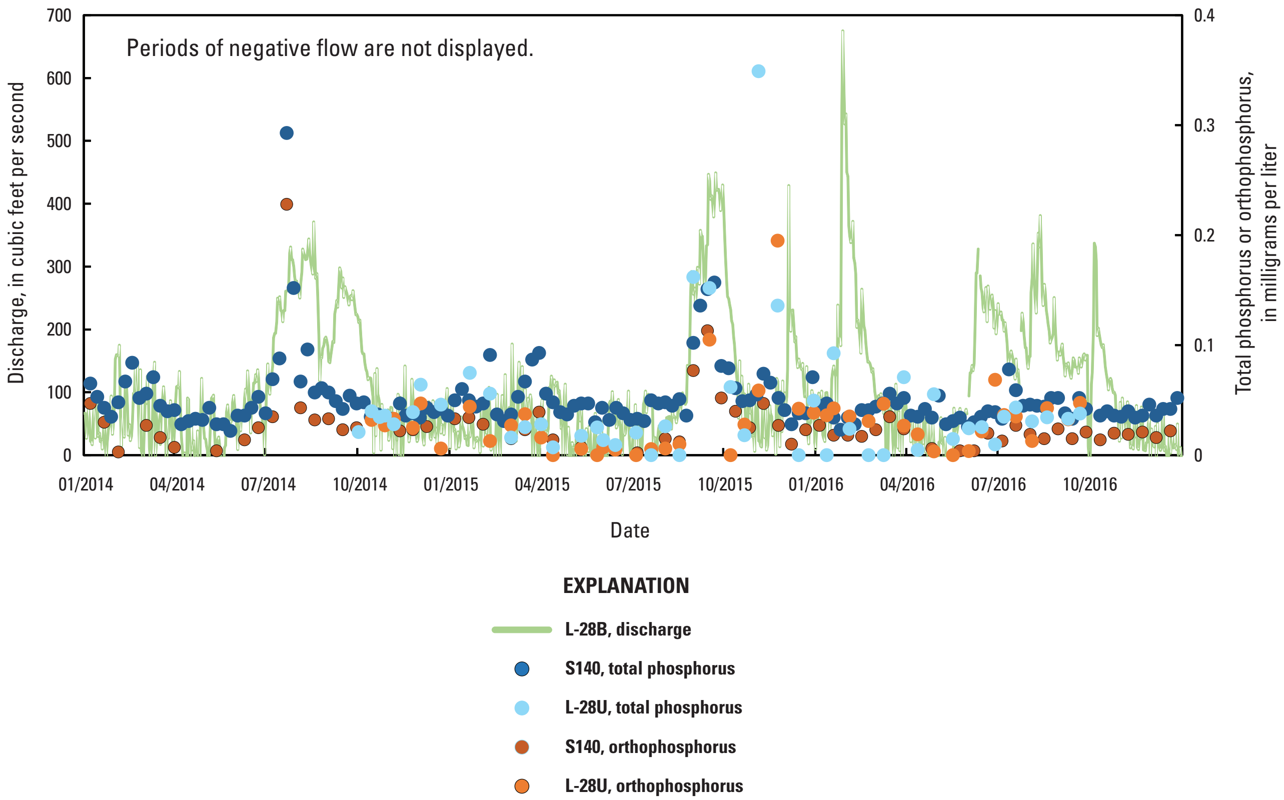

Figure 32. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida L-28U and South Florida Water Management District S140 water-quality sites compared with discharge at the U.S. Geological Survey L-28B (261543080495000 L-28 Canal above S-140 near Clewiston, FL) surface-water gaging station (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b; U.S. Geological Survey, 2017).

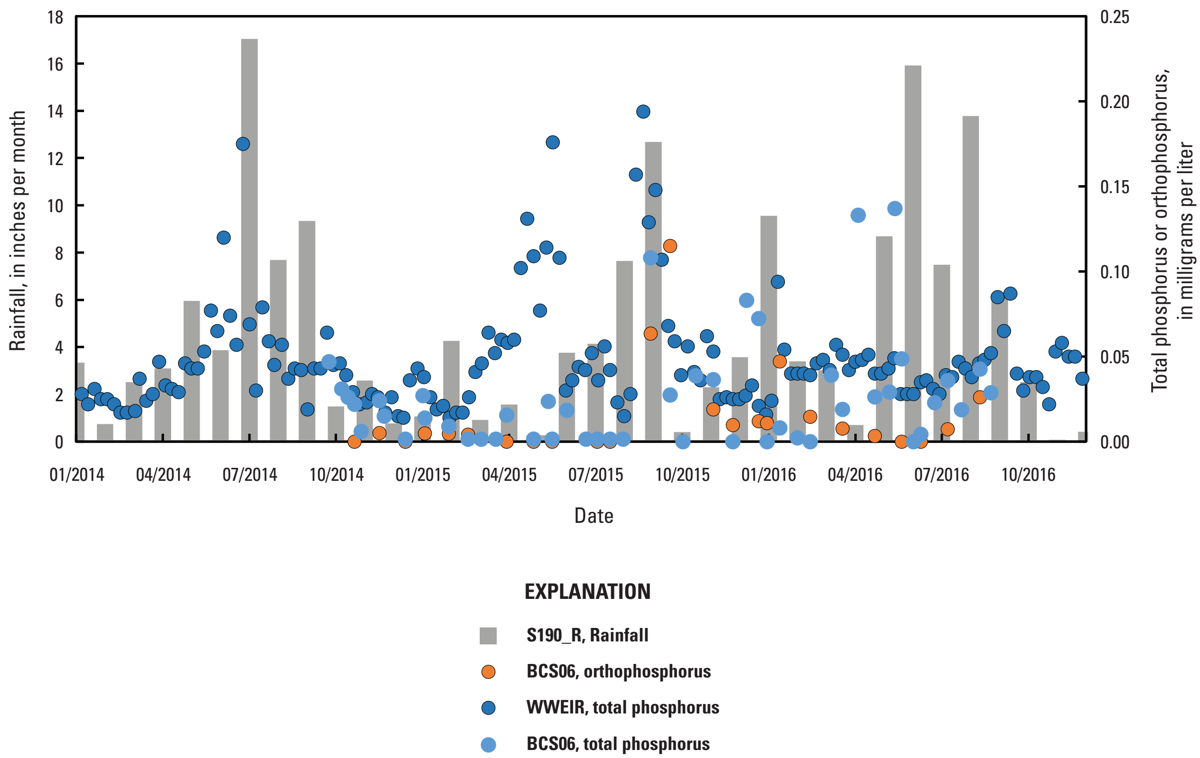

Figure 33. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida BCS06 and South Florida Water Management District (SFWMD) WWEIR water-quality sites compared with rainfall at the SFWMD S190_R rainfall gage (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

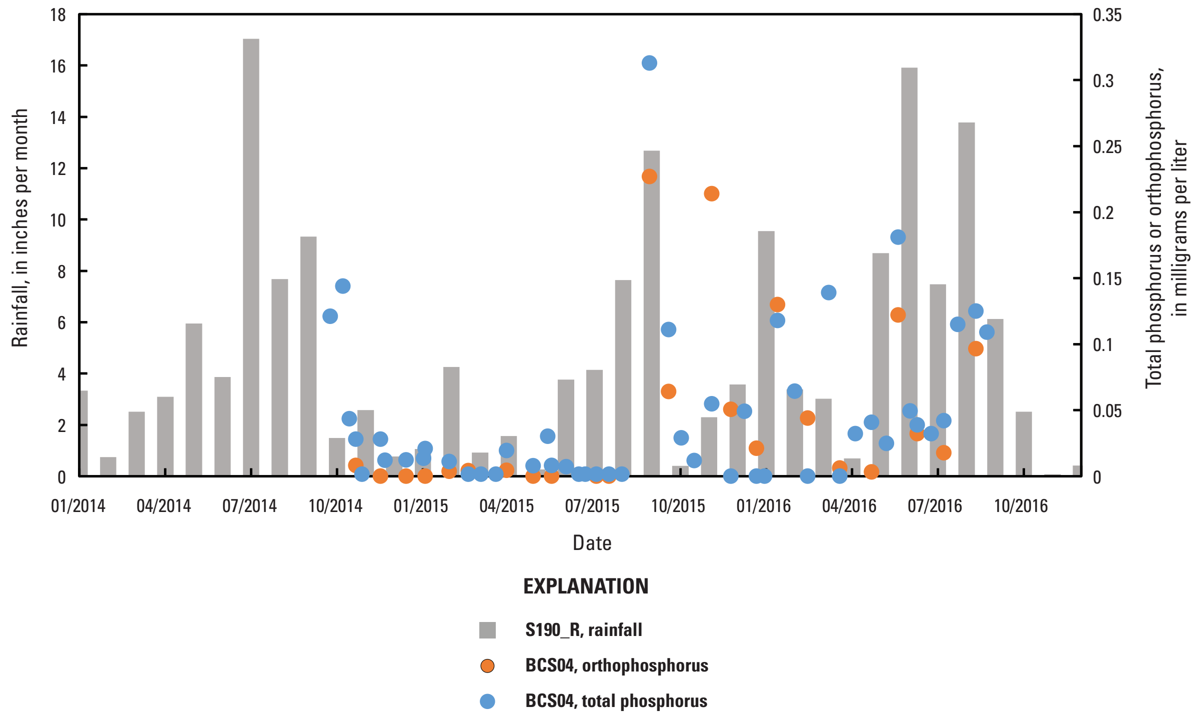

Figure 34. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida BCS04 water-quality site compared with rainfall at the South Florida Water Management District S190_R rainfall gage (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

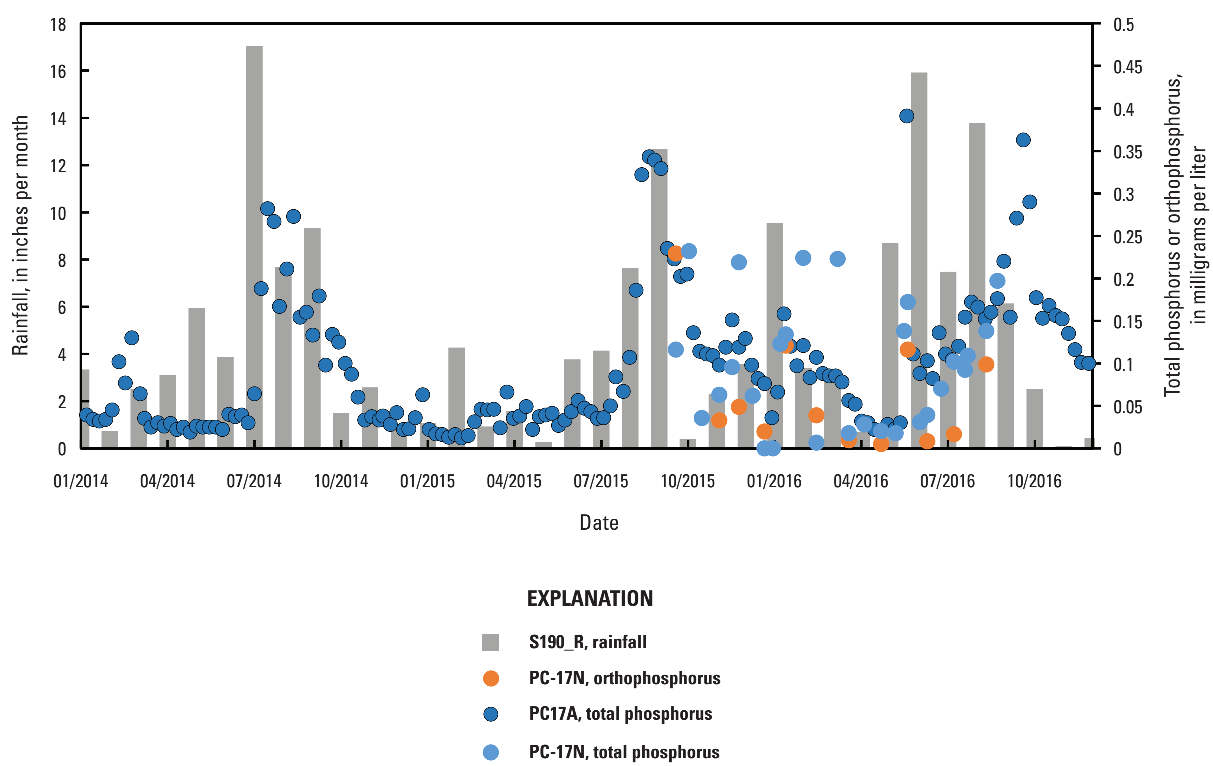

Figure 35. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida PC-17N and South Florida Water Management District (SFWMD) PC17A water-quality sites compared with rainfall at the SFWMD S190_R rainfall gage (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

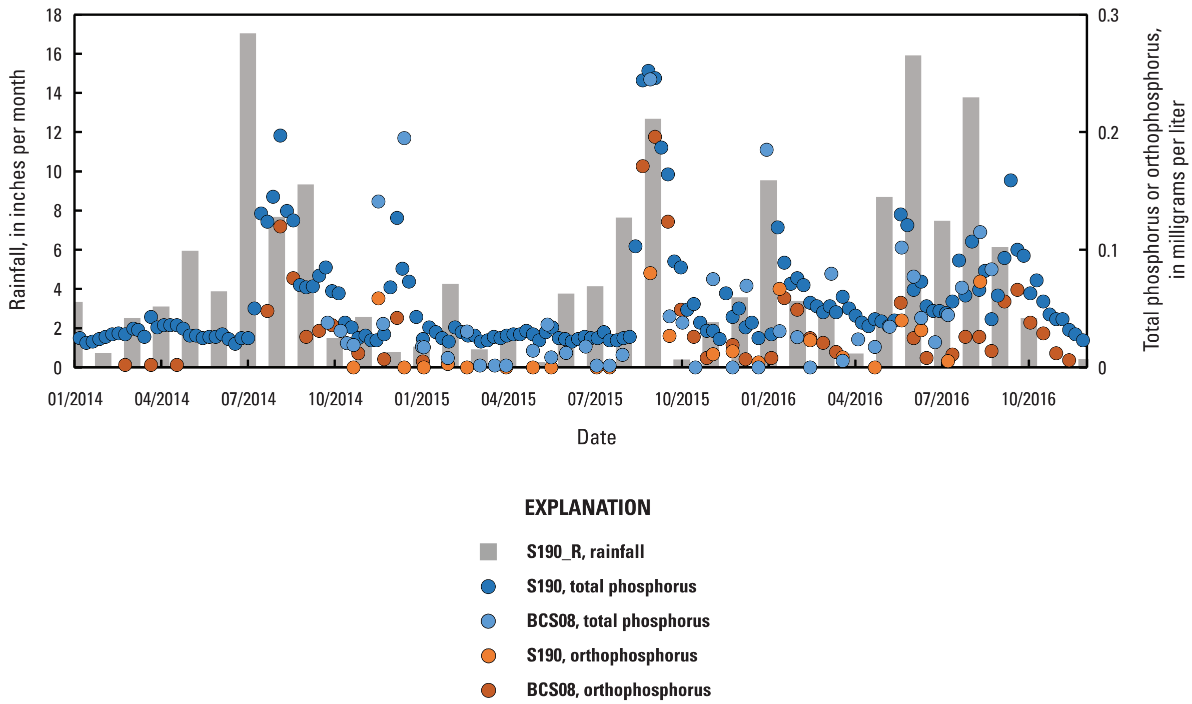

Figure 36. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida BCS08 and South Florida Water Management District (SFWMD) S190 water-quality sites compared with rainfall at the SFWMD S190_R rainfall gage (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

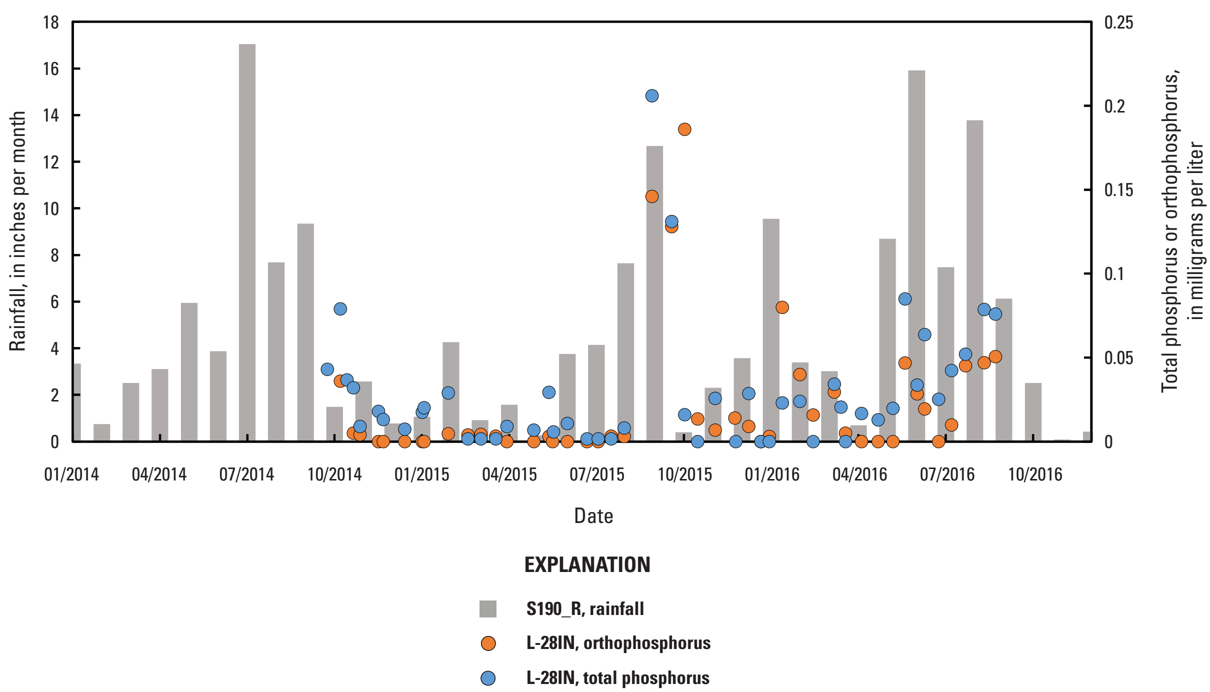

Figure 37. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida L-28IN water-quality site compared with rainfall at the South Florida Water Management District S190_R rainfall gage (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

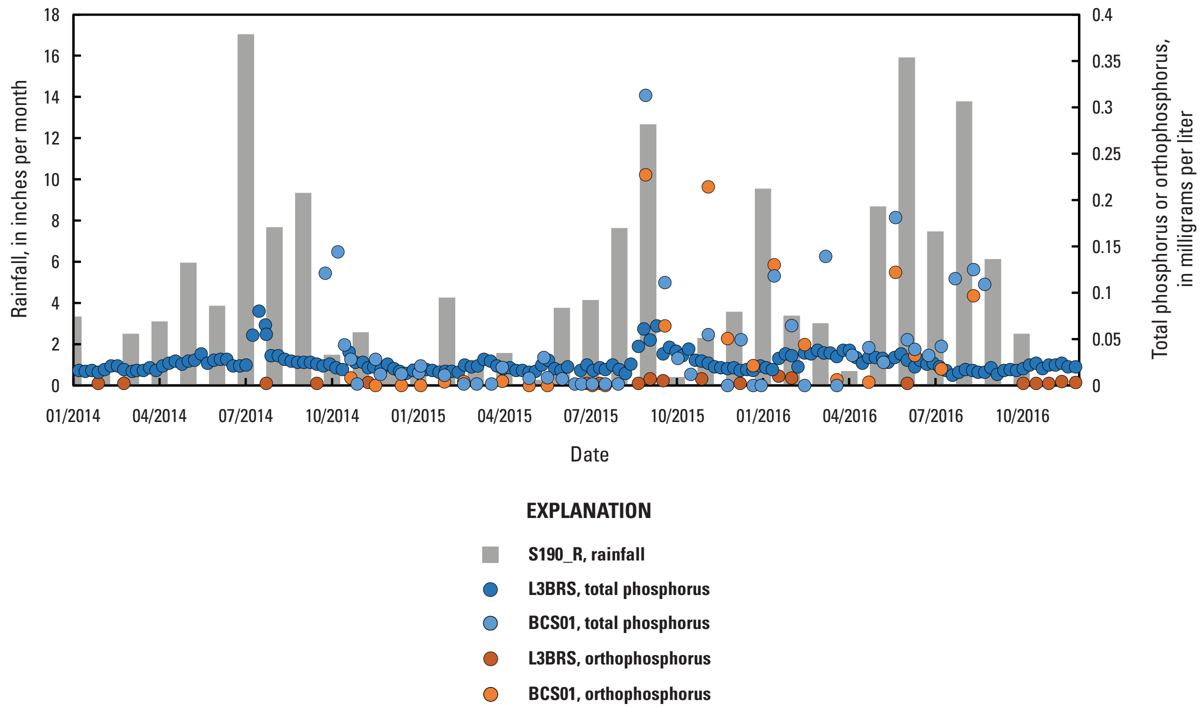

Figure 38. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida BCS01 and South Florida Water Management District (SFWMD) L3BRS water-quality sites compared with rainfall at the SFWMD S190_R rainfall gage (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

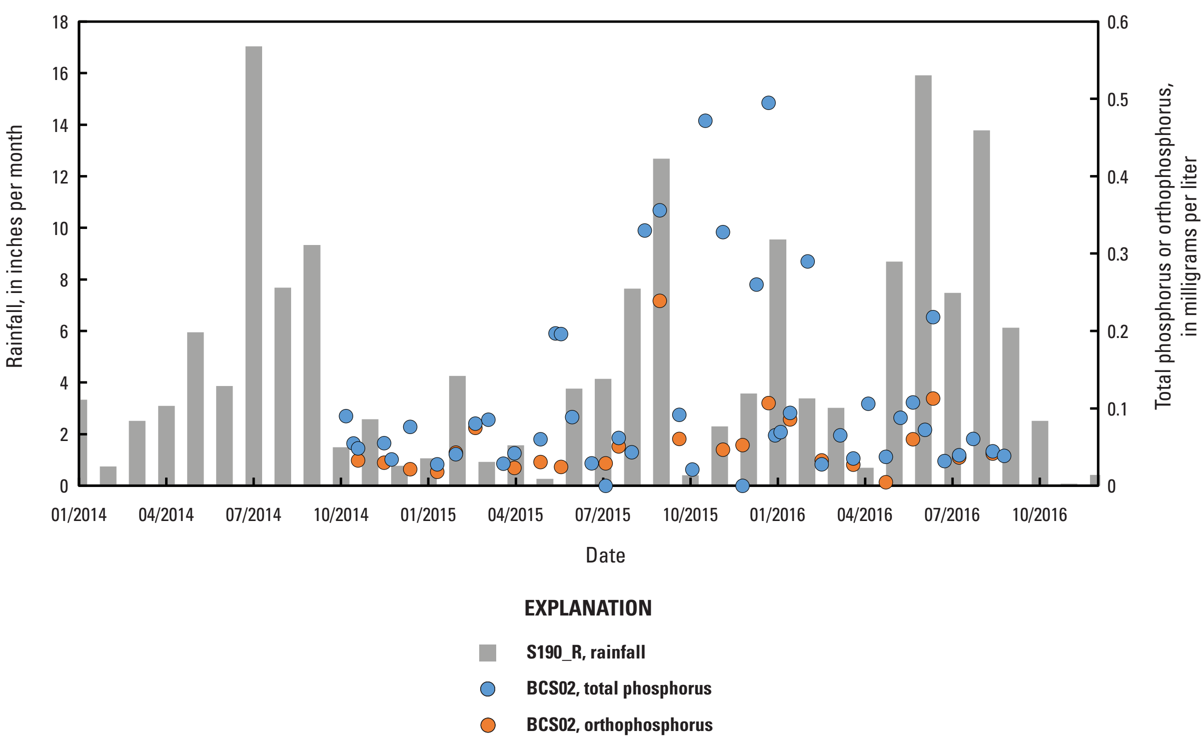

Figure 39. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida BCS02 water-quality site compared with rainfall at the South Florida Water Management District S190_R rainfall gage (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

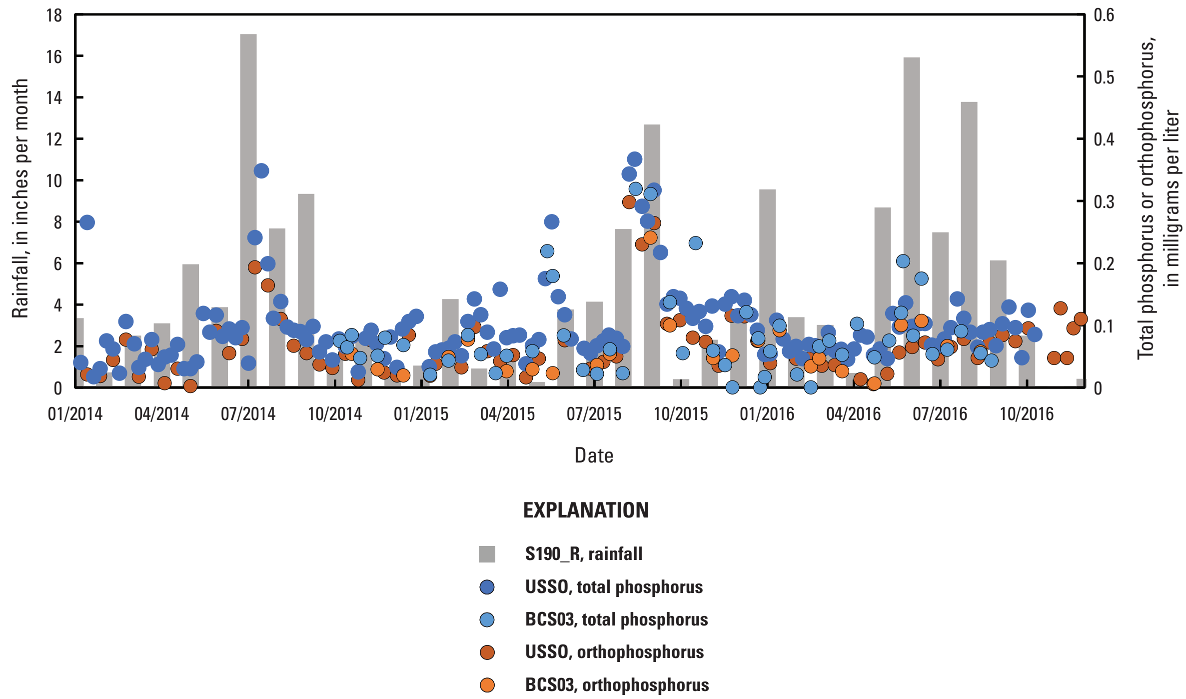

Figure 40. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida BCS03 and South Florida Water Management District (SFWMD) USSO water-quality sites compared with rainfall at the SFWMD S190_R rainfall gage (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

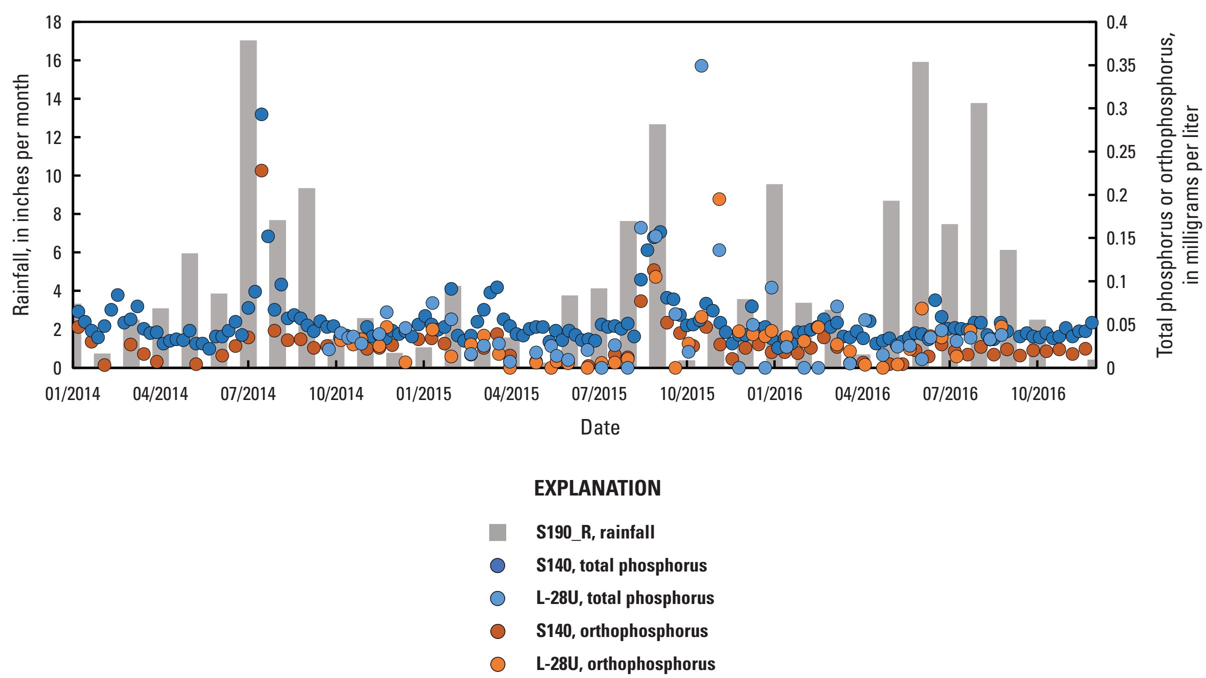

Figure 41. Total phosphorus and orthophosphorus data from the Seminole Tribe of Florida L-28U and South Florida Water Management District (SFWMD) S140 water-quality sites compared with rainfall at the SFWMD S190_R rainfall gage (U.S. Environmental Protection Agency, 2017b; South Florida Water Management District, 2017b).

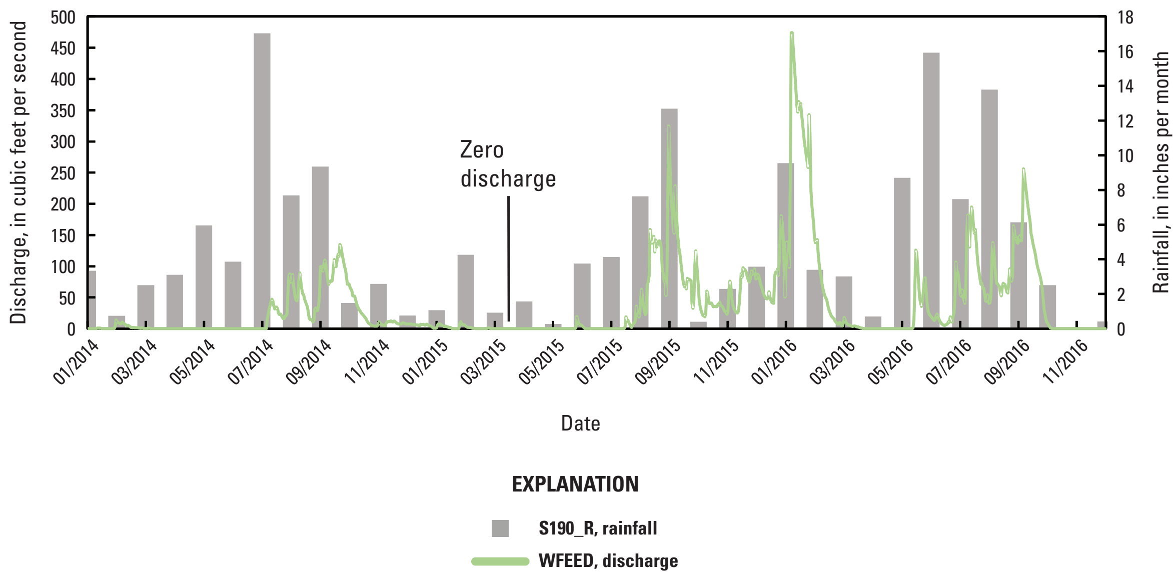

Figure 42. Discharge at the U.S. Geological Survey WFEED (261808081042800 West Feeder Canal abv West Weir nr Clewiston FL) surface-water gaging station compared with rainfall at the South Florida Water Management District S190_R rainfall gage (U.S. Geological Survey, 2017; South Florida Water Management District, 2017b).

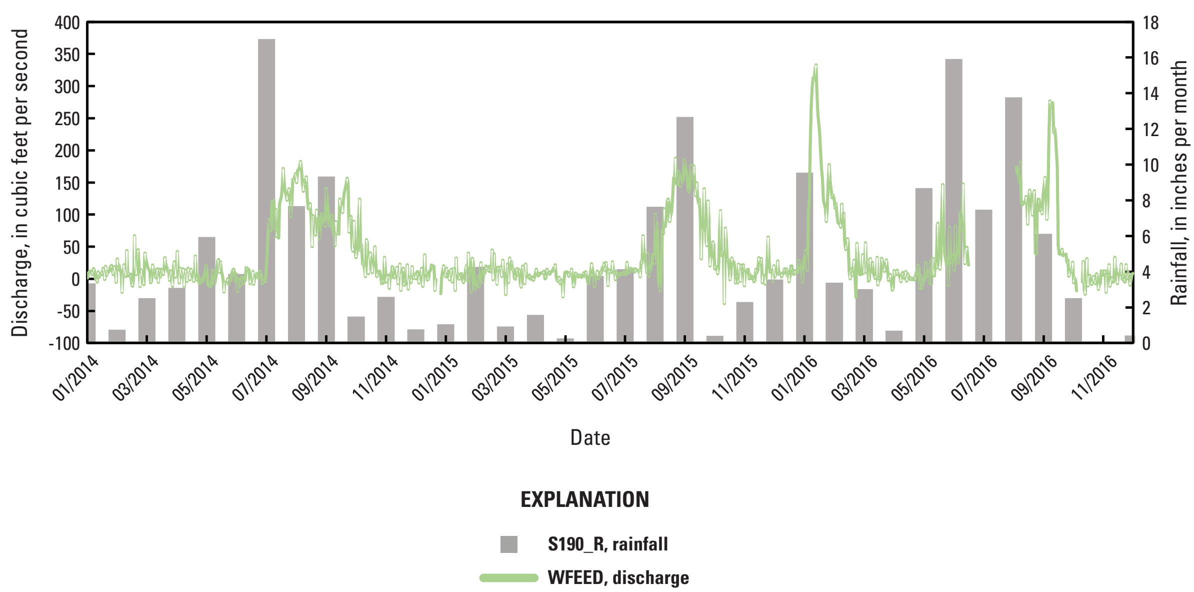

Figure 43. Discharge at the U.S. Geological Survey NFEED (262038080584600 North Feeder Canal blw PC17A nr Clewiston, FL) surface-water gaging station compared with rainfall at the South Florida Water Management District S190_R rainfall gage (U.S. Geological Survey, 2017; South Florida Water Management District, 2017b).

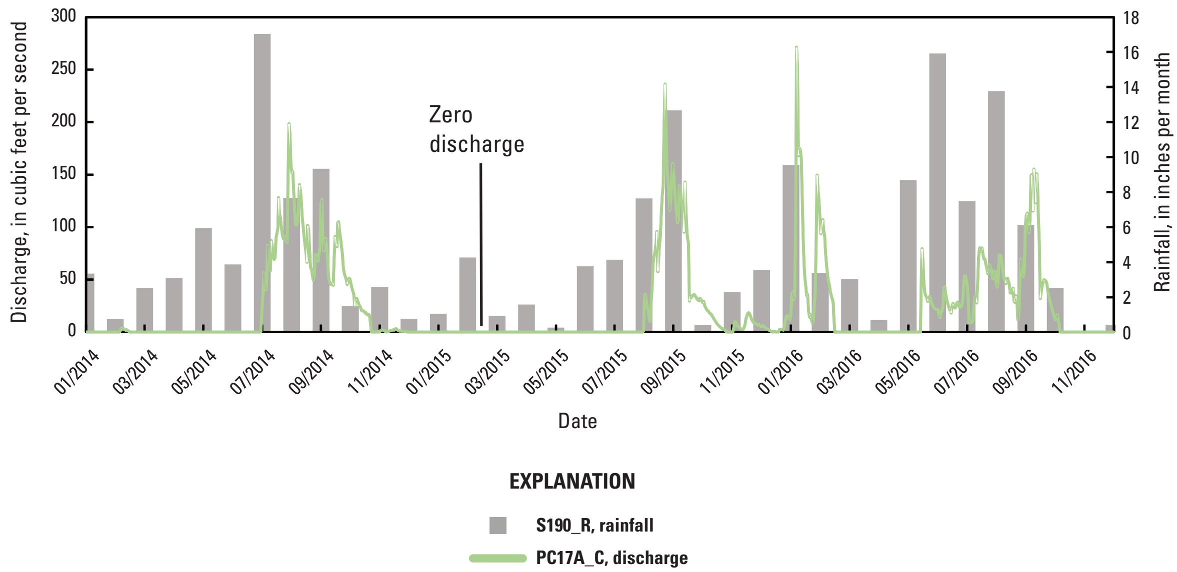

Figure 44. Discharge at the South Florida Water Management District PC17A_C surface-water gaging station compared with rainfall at the South Florida Water Management District S190_R rainfall gage (South Florida Water Management District, 2017b).

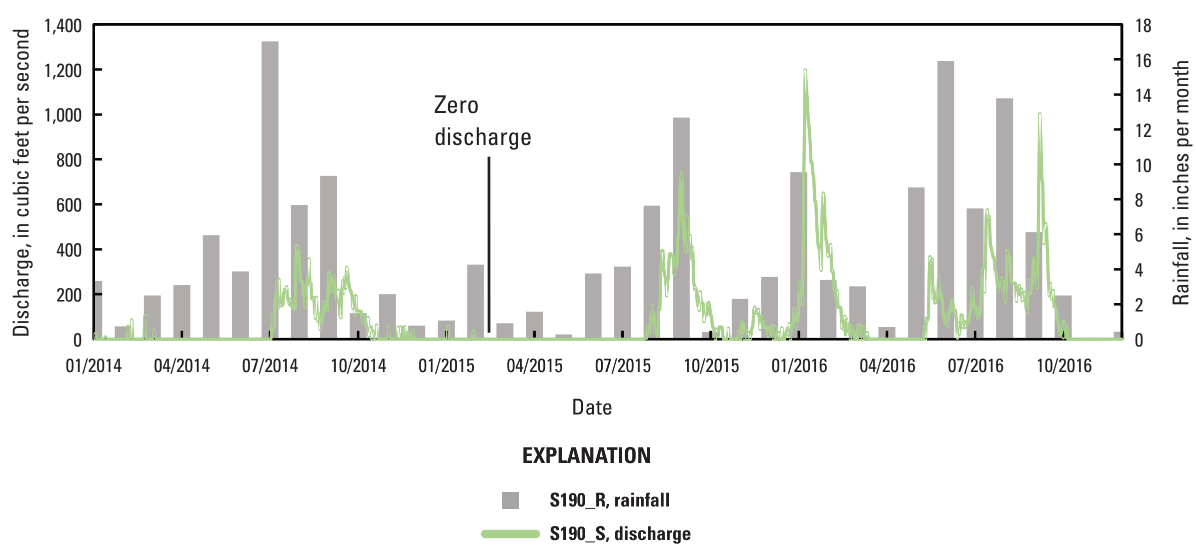

Figure 45. Discharge at the South Florida Water Management District S190_S surface-water gaging station compared with rainfall at the South Florida Water Management District S190_R rainfall gage (South Florida Water Management District, 2017b).

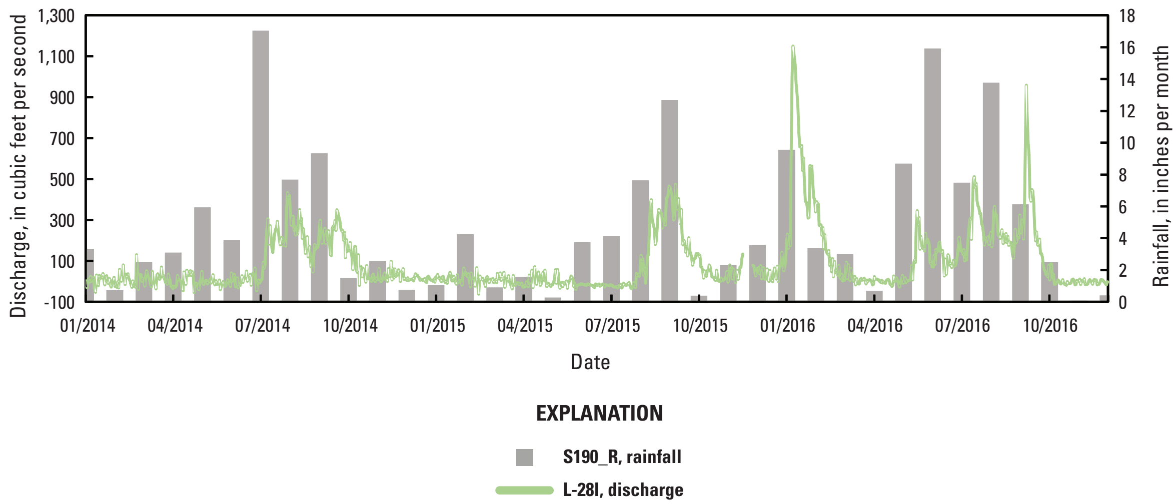

Figure 46. Discharge at the U.S. Geological Survey L-28I (261533080571600 L-28 Interceptor Canal blw S190 near Clewiston, FL) surface-water gaging station compared with rainfall at the South Florida Water Management District S190_R rainfall gage (U.S. Geological Survey, 2017; South Florida Water Management District, 2017b).

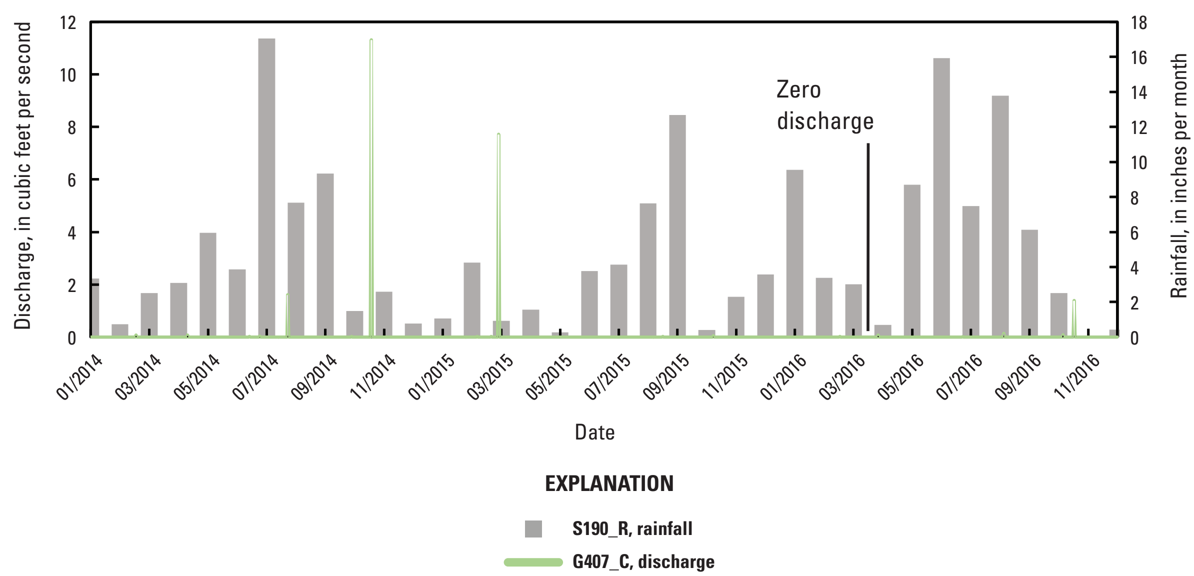

Figure 47. Discharge at the South Florida Water Management District G407_C surface-water gaging station compared with rainfall at the South Florida Water Management District S190_R rainfall gage (South Florida Water Management District, 2017b).

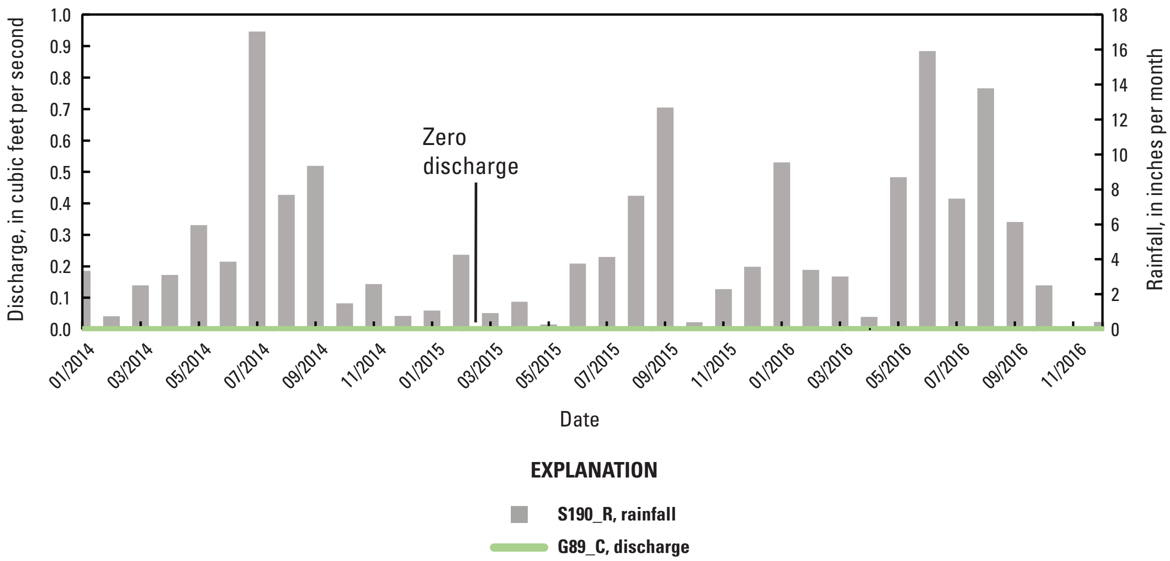

Figure 48. Discharge at the South Florida Water Management District G89_C surface-water gaging station compared with rainfall at the South Florida Water Management District S190_R rainfall gage (South Florida Water Management District, 2017b).

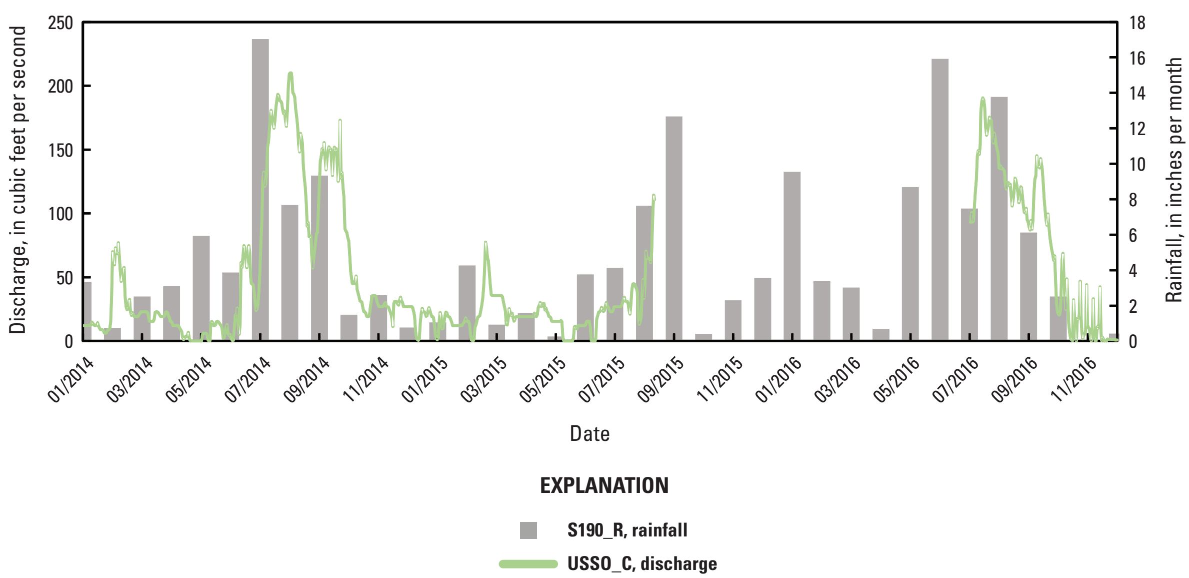

Figure 49. Discharge at the South Florida Water Management District USSO_C surface-water gaging station compared with rainfall at the South Florida Water Management District S190_R rainfall gage (South Florida Water Management District, 2017b).

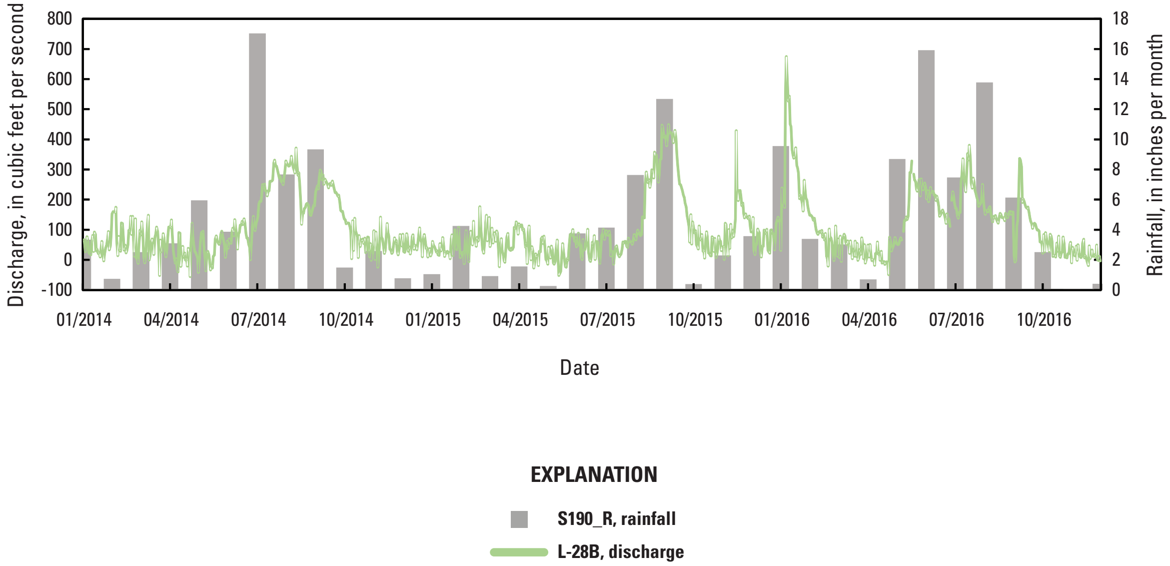

Figure 50. Discharge at the U.S. Geological Survey L-28B (261543080495000 L-28 Canal above S-140 near Clewiston, FL) surface-water gaging station compared with rainfall at the South Florida Water Management District S190_R rainfall gage (U.S. Geological Survey, 2017; South Florida Water Management District, 2017b).

Total Phosphorus and Water Quality Metrics

TP concentrations from eight water-quality sites in the BCSIR were plotted against other metrics of water quality, including specific conductance, turbidity, discharge, suspended solids, pH, nitrate plus nitrite, and dissolved oxygen (figs. 51–58). The purpose of this exploratory data analysis was to determine if any correlations existed between TP and other variables that might be useful in understanding how P reacts in the BCSIR. Weak relations (R-squared greater than 0.5) were indicated for TP and turbidity and for TP and suspended solids at BCS08 and BCS02 (table 7). These two sites had the highest values of turbidity and suspended solid concentration. This indicates that there may be a relation of increased TP and mobilization of sediment; however, zero discharge at BCS02 for the period of record makes interpretation problematic.

The lack of any strong relation with other constituents is likely because P is highly reactive in the environment and does not act as conservatively as do many of the constituents to which it was compared. It may be possible to develop relations between TP and OP and other constituents by using more sophisticated forms of statistical analysis, but these forms of data analysis were beyond the scope of this project.

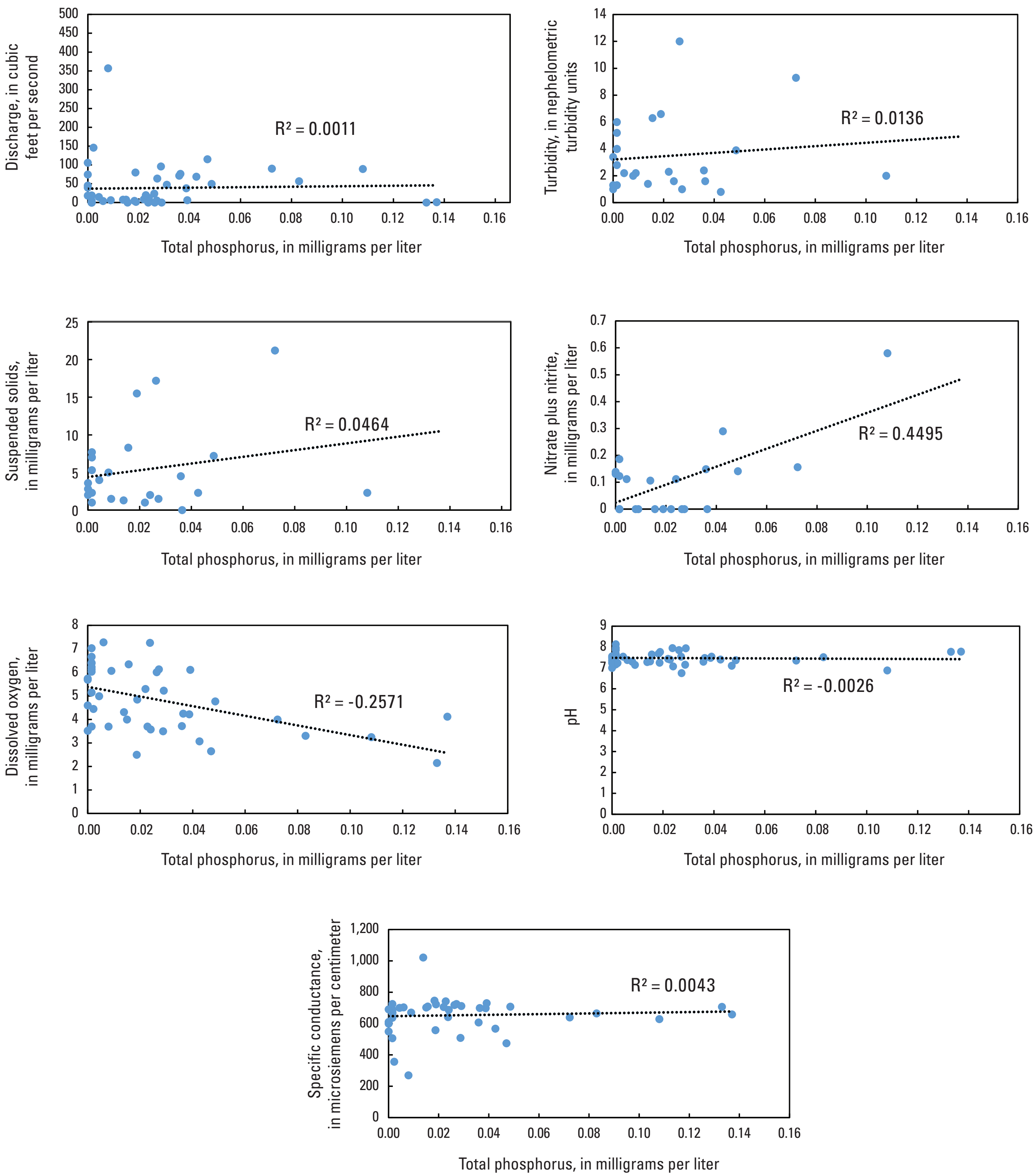

Figure 51. Total phosphorus concentrations at the Seminole Tribe of Florida BCS06 sampling site in the Big Cypress Seminole Indian Reservation, Florida, versus other water-quality and field parameters, 2014–16 (U.S. Environmental Protection Agency, 2017b).

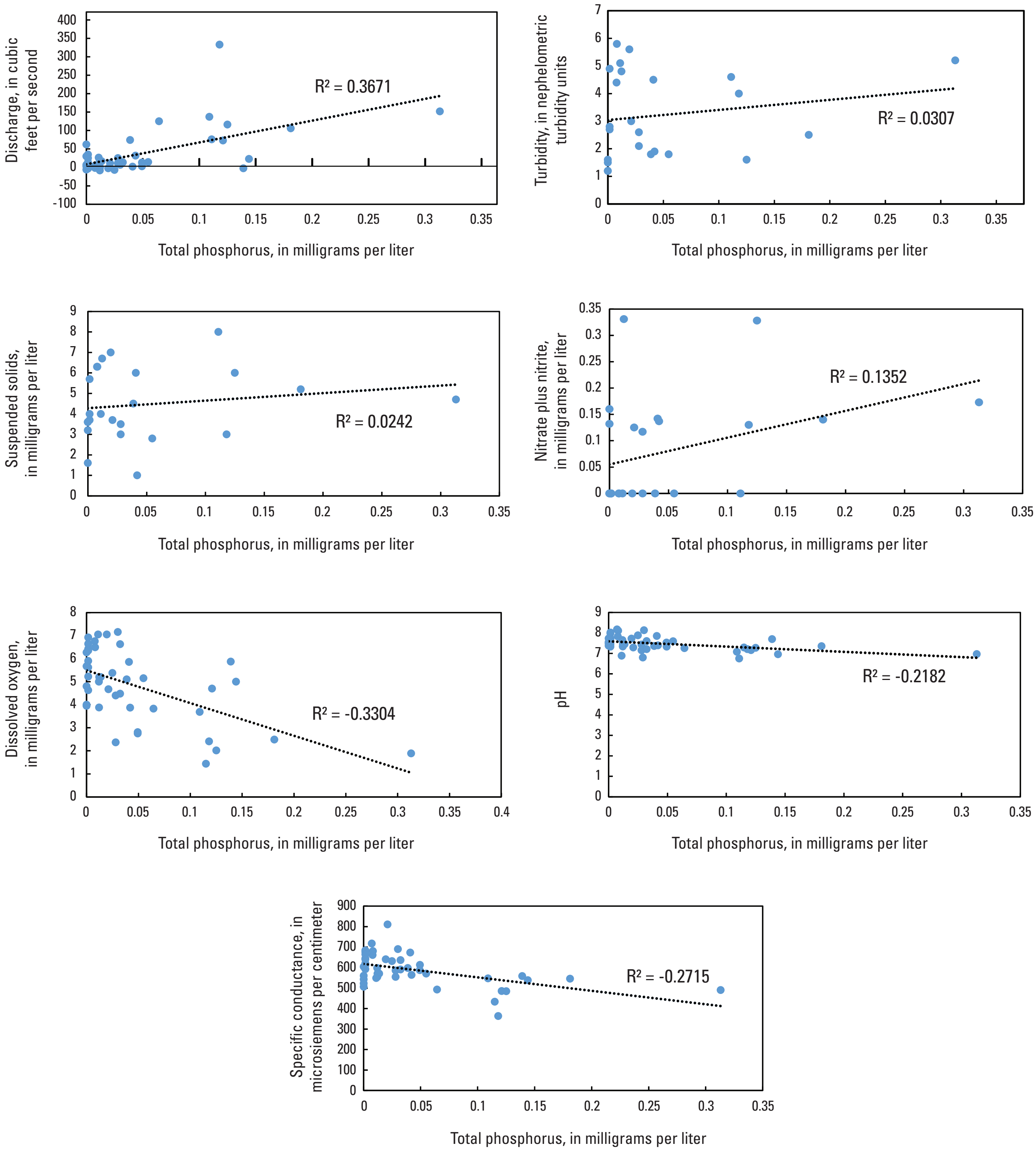

Figure 52. Total phosphorus concentrations at the Seminole Tribe of Florida BCS04 sampling site in the Big Cypress Seminole Indian Reservation, Florida, versus other water-quality and field parameters, 2014–16 (U.S. Environmental Protection Agency, 2017b).

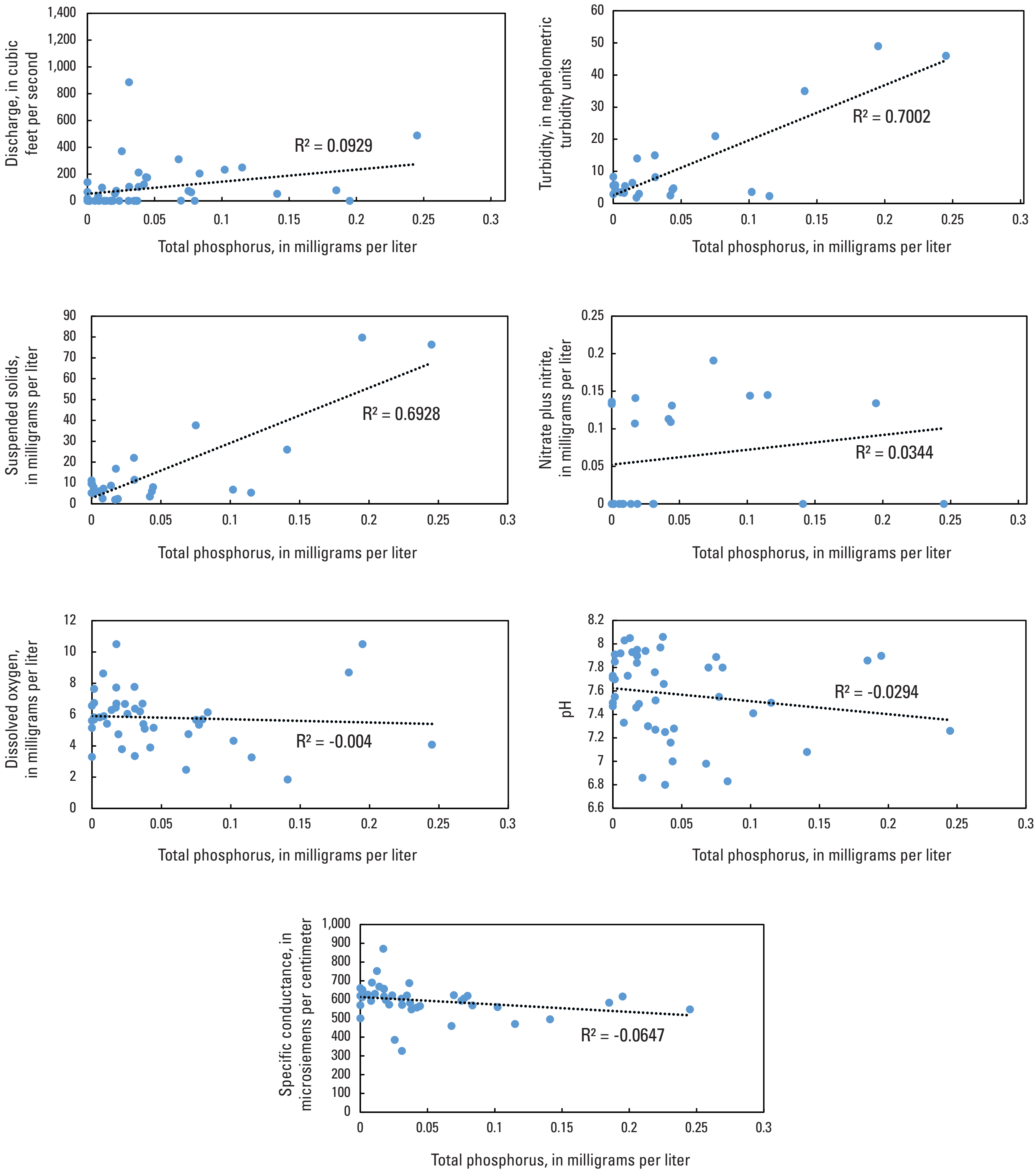

Figure 53. Total phosphorus concentrations at the Seminole Tribe of Florida BCS08 sampling site in the Big Cypress Seminole Indian Reservation, Florida, versus other water-quality and field parameters, 2014–16 (U.S. Environmental Protection Agency, 2017b).

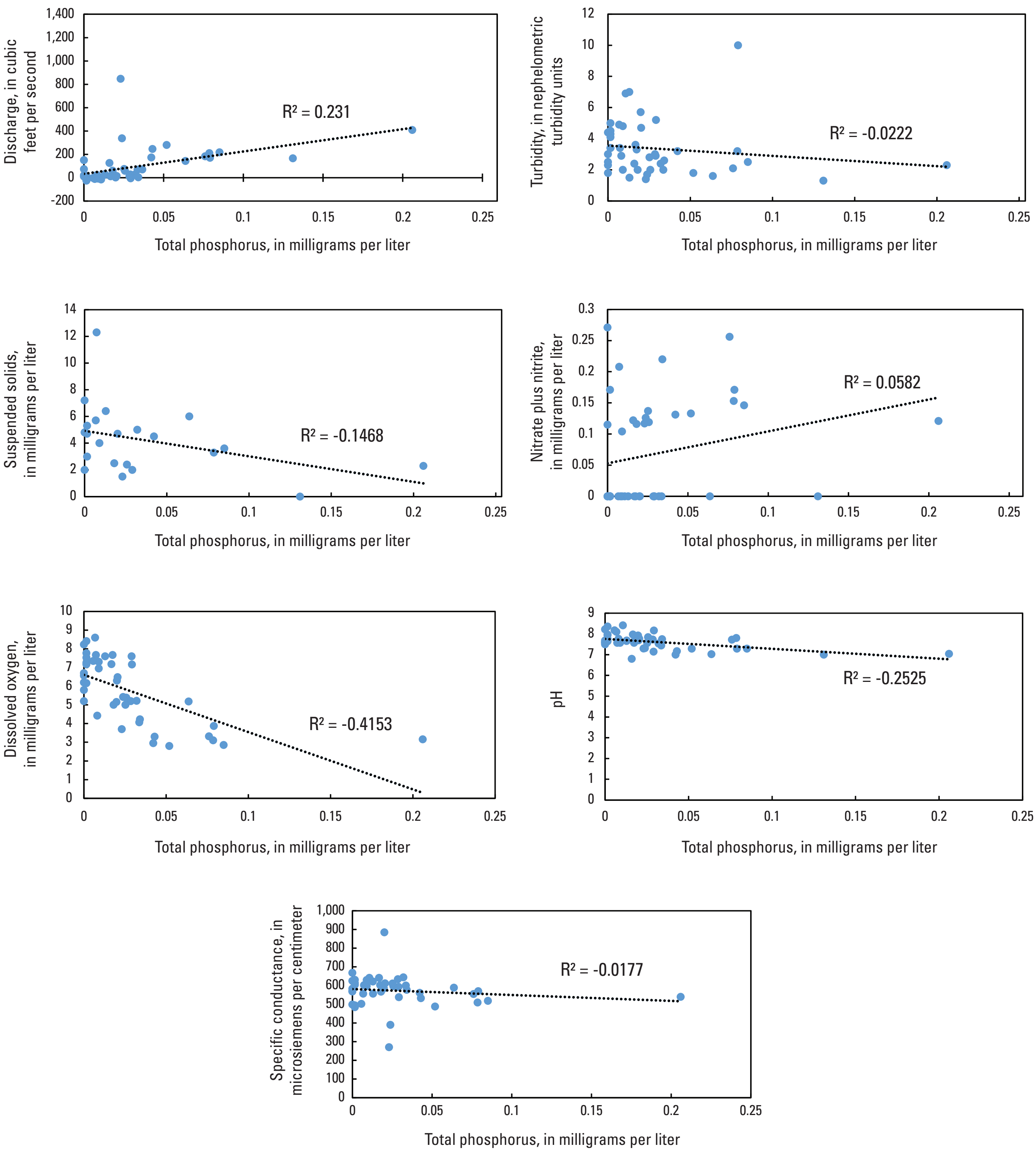

Figure 54. Total phosphorus concentrations at the Seminole Tribe of Florida L-28IN sampling site in the Big Cypress Seminole Indian Reservation, Florida, versus other water-quality and field parameters, 2014–16 (U.S. Environmental Protection Agency, 2017b).

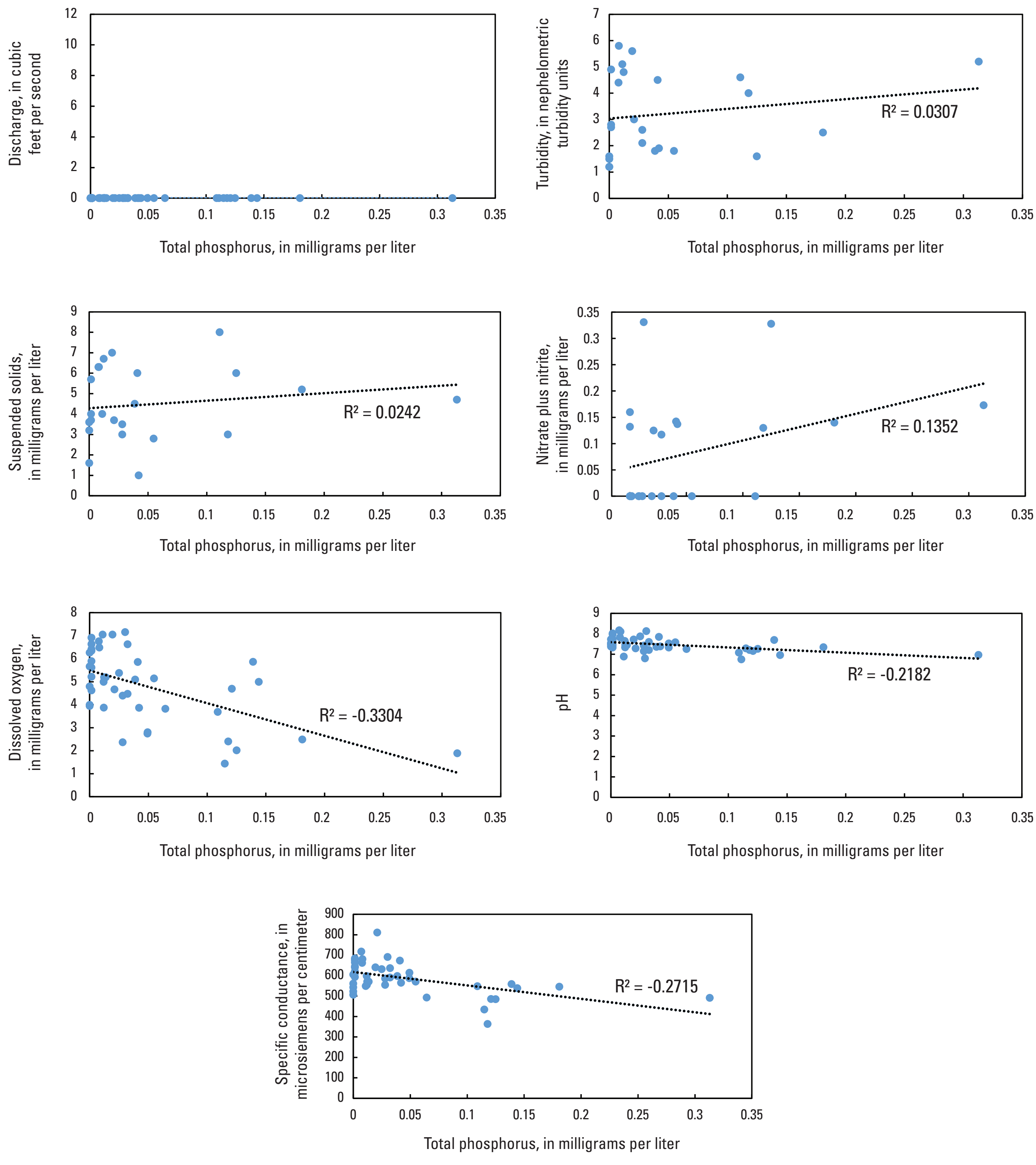

Figure 55. Total phosphorus concentrations at the Seminole Tribe of Florida BCS01 sampling site in the Big Cypress Seminole Indian Reservation, Florida, versus other water-quality and field parameters, 2014–16 (U.S. Environmental Protection Agency, 2017b).

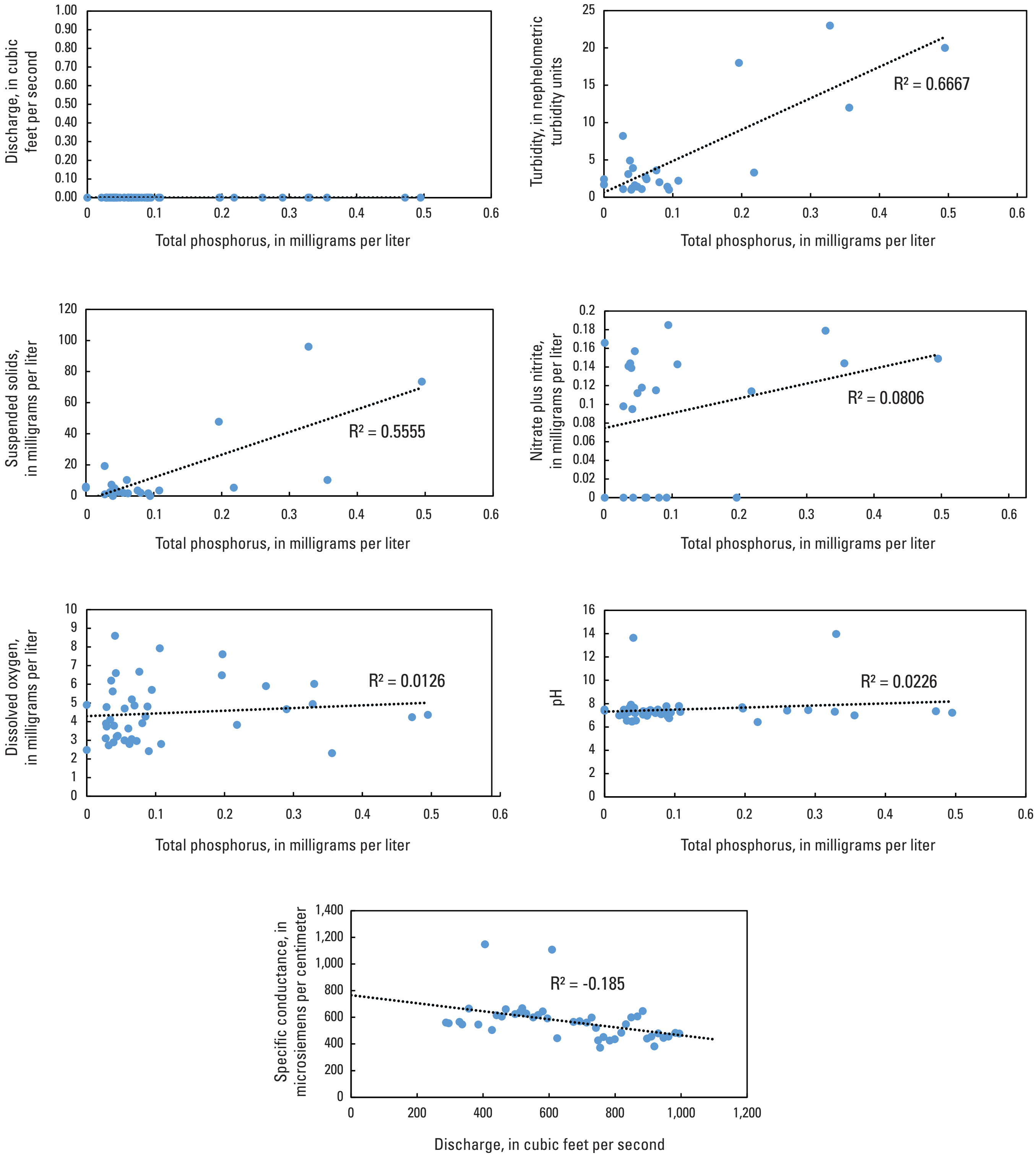

Figure 56. Total phosphorus concentrations at the Seminole Tribe of Florida BCS02 sampling site in the Big Cypress Seminole Indian Reservation, Florida, versus other water-quality and field parameters, 2014–16 (U.S. Environmental Protection Agency, 2017b).

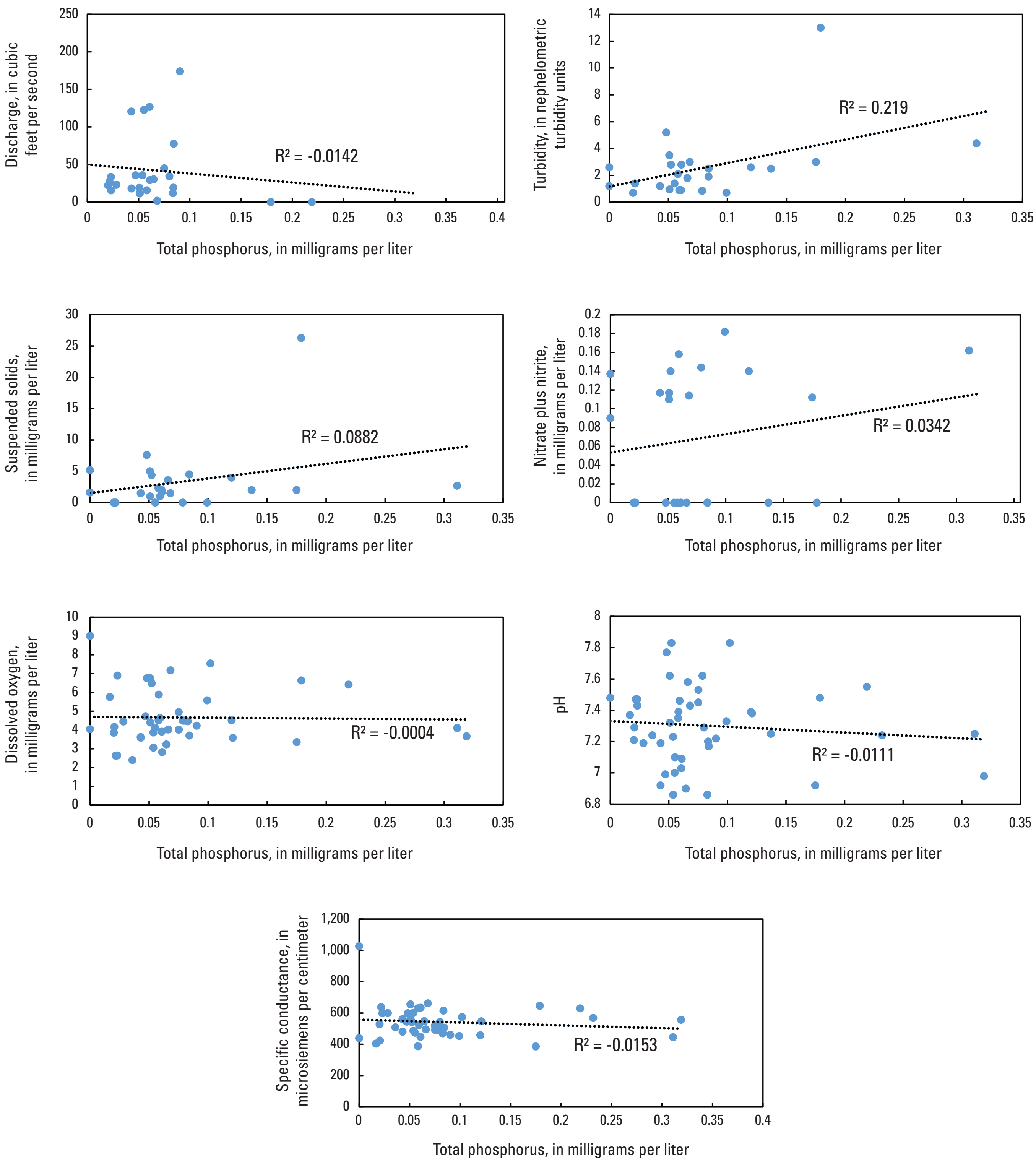

Figure 57. Total phosphorus concentrations at the Seminole Tribe of Florida BCS03 sampling site in the Big Cypress Seminole Indian Reservation, Florida, versus other water-quality and field parameters, 2014–16 (U.S. Environmental Protection Agency, 2017b).

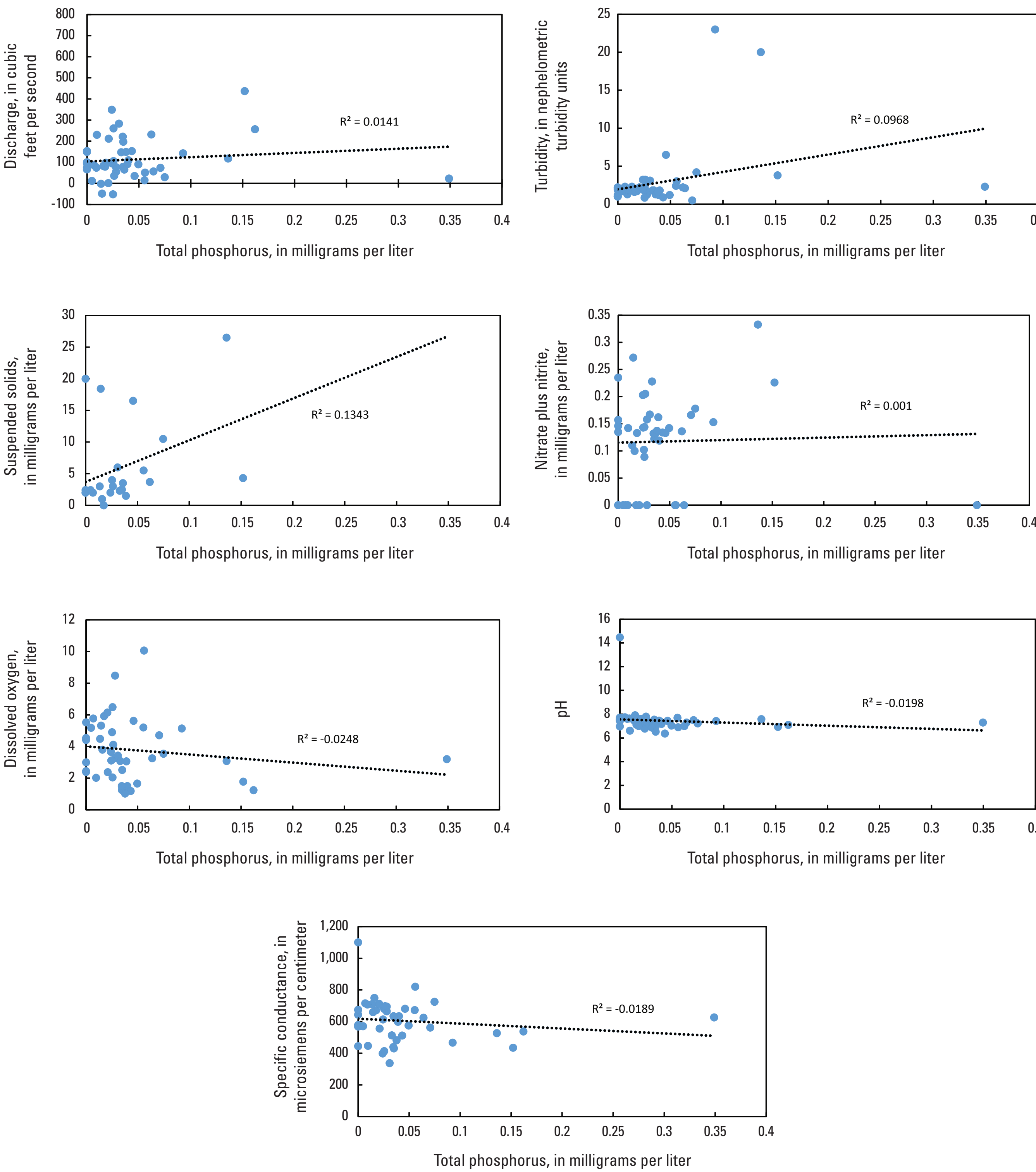

Figure 58. Total phosphorus concentrations at the Seminole Tribe of Florida L-28U sampling site in the Big Cypress Seminole Indian Reservation, Florida, versus other water-quality and field parameters, 2014–16 (U.S. Environmental Protection Agency, 2017b).

Table 7. Correlation coefficient of total phosphorous versus listed metrics.

[Values greater than 0.5 shown in bold font. —, not applicable or available]

Tribe sampling site	Discharge	Turbidity	Suspended solids	Nitrate plus nitrite	Dissolved oxygen	pH	Specific conductance
Western reservation							
BCS06	0.00	0.01	0.05	0.45	-0.26	-0.00	0.00
BCS04	0.37	0.03	0.02	0.14	-0.33	-0.22	-0.27
BCS08	0.09	**0.70**	**0.69**	0.03	-0.00	-0.03	-0.06
L-28IN	0.23	-0.02	-0.15	0.06	-0.42	-0.25	-0.02
Eastern reservation							
BCS01	—	0.03	0.02	0.14	-0.33	-0.22	-0.27
BCS02	—	**0.67**	**0.55**	0.08	0.01	0.02	-0.18
BCS03	-0.01	0.22	0.08	0.03	-0.00	-0.01	-0.02
L-28U	0.01	0.10	0.13	0.00	-0.02	-0.02	-0.02

Discussion

An increase in the number of water-quality monitoring sites in the BCSIR would aid any future efforts to study the hydrologic system. An increase in the number of internal water-quality sites would help in calculating nutrient loads and in understanding the fate of nutrients as they moved through the BCSIR. Collection of both filtered and unfiltered phosphorus samples would aid in understanding phosphorus transport processes. The collection of continuous water-quality data, such as specific conductance, pH, dissolved oxygen, temperature, and turbidity data, would likely help explain the phenomena that result in periodic high concentrations of TP. Currently (2018), little water-quality data are being collected north of the BCSIR border by the SFWMD, or by the Tribe at 3-Mile Canal, where the Tribe's water entitlements enter the BCSIR.

On the basis of the P data that are currently available, and on the limited scope of this analysis, it is not possible to determine the major sources of P in the BCSIR and the causes of occasional extreme peaks in P concentrations. A better understanding of sources, and the timing of inflow from those sources, would aid water managers in creating plans to reduce P loads in the BCSIR. It would likely be possible to determine P sources to the BCSIR by using the oxygen isotopes of P-containing ions or compounds. P transport processes could be defined by using a combination of dissolved and particulate P data, which would aid in designing remedial measures to reduce P in the inflows to the BCSIR. A detailed hydrologic and water-quality study of both the surface-water and groundwater system in the BCSIR would enhance our understanding of the flow system in the BCSIR and how it is being affected by outside sources of P and other chemical constituents. Combining traditional hydrologic study techniques, such as water budgets, with geochemical methods, such as isotopes and tracers, would provide detailed information on how the hydrology of the BCSIR functions. There is little information regarding the interactions of groundwater and surface water and the important role these interactions might have on surface-water flows and water quality in the BCSIR.

Summary

The Everglades, Florida, naturally evolved as an oligotrophic (nutrient-poor) environment, which resulted in endemic plant species that are adapted to very low nutrient conditions. Changes to the hydrology, plus new sources of phosphorus (P), have greatly increased the nutrient load reaching The Everglades ecosystem, thereby causing growth of undesirable plant species. The Seminole Tribe of Florida (Tribe) is working with the U.S. Environmental Protection Agency to develop a numeric P criterion for the Big Cypress Seminole Indian Reservation (BCSIR) and is currently (2018) using 10 parts per billion (ppb) (0.10 milligram per liter) of TP as a baseline. The U.S. Geological Survey (USGS), in cooperation with the Tribe, used water-quality data collected between October 2014 and September 2016 by the Tribe and the South Florida Water Management District (SFWMD), along with data from rainfall gages, surface-water stage and discharge gages, and groundwater monitoring wells, to (1) identify the effect of hydrologic conditions on concentrations of total phosphorus (TP) and orthophosphorus (OP) and (2) conduct data analysis to evaluate the relation between hydrologic variables and concentrations of TP and OP at surface-water monitoring sites located on canals that enter and exit the BCSIR.

The BCSIR is located in southeastern Hendry County and northwestern Broward County in southern Florida and consists mostly of wetlands, forest, and agricultural lands. North of the BCSIR is the Everglades Agricultural Area, which is primarily composed of sugar cane farms, and additional private agricultural lands, a series of stormwater treatment areas (constructed wetlands designed to reduce nutrients), and wildlife management areas.

Surface water is routed into the BCSIR through a series of inflow and outflow canals and ditches, which can be divided into those that enter into the western half of the reservation (hereafter called the western reservation [WR]) and those that enter into the eastern half of the reservation (hereafter called the eastern reservation [ER]). In the WR, the North Feeder Canal and West Feeder Canal convey water south and southeast. Near the center of the BCSIR, the North Feeder and West Feeder Canals merge to form the L-28 Interceptor Canal, which flows south through the Big Cypress National Preserve. In the ER, the L-3 Canal flows southeast and intersects with the L-28 Borrow Canal at "Confusion Corner" at the northern boundary of the BCSIR. The L-28 Borrow Canal forms the eastern border of the ER and is the primary source of outflow from the BCSIR in the ER.

From October 2014 to September 2016, the Tribe collected 47–52 samples at each of nine water-quality sites for analysis of TP, except at PC-17N, where 28 samples were collected. Concentrations of TP varied from less than the analytical detection limit [0.002 milligram per liter (mg/L)] to a maximum of nearly 0.50 mg/L. Concentrations of TP were typically less than about 0.25 mg/L at the nine water-quality sites, but there were occasional samples with greater concentrations.

Concentrations of OP, the reactive form of P that is readily absorbed by plants, varied from less than the analytical detection limit (0.003 mg/L) to a maximum of 0.24 mg/L. The number of samples collected at each site varied, but ranged from 12 to 46 samples from October 2014 to September 2016. Concentrations of OP were typically less than about 0.15 mg/L at the nine Tribe sites, but were occasionally higher. The highest concentrations all occurred from September 2015 to January 2016 at the BCS02, BCS03, BCS04, L-28IN, and L-28U sampling sites.

Results of the TP and OP analyses for samples collected from 2014 to 2016 by the Tribe and by the SFWMD at the companion water-quality sites were similar. The concentrations of TP in samples collected by the SFWMD tended to be slightly higher than those in samples collected by the Tribe at the six sites where both entities collected samples. Differences in concentration can likely be explained by differences in sample collection methods, sample collection time, sampling locations, the hydrology during sampling, or the number of samples collected by each entity. The concentrations of OP were nearly identical for the Tribe and SFWMD samples at the four sites where OP data were collected by both entities.

The highest TP and OP concentrations tended to occur in samples collected during peak flows in the canals. Concentrations of TP and OP tended to increase in the BCSIR during wet periods, but the increases typically did not occur immediately following heavy rainfall. This pattern may indicate that sediments containing high concentrations of P become mobilized during high flows. Increases in canal discharge tended to lag behind rainfall events, likely because control structures do not release flows until the canals reach predetermined stages. The highest concentrations of TP and OP usually occurred early in wet periods following long dry periods. During dry periods, sources of P, such as fertilizers, decaying plant matter, and organic wastes, likely accumulate on dry land and are flushed into the canal systems during the wet season. When dry periods are longer, more P accumulates on land, resulting in higher concentrations of TP and OP during events that mark the end of dry periods.

From 2014 to 2016, concentrations of TP tended to decrease as flows moved across the BCSIR. In both the WR and the ER, the mean and maximum concentrations of TP were lower in the outflows from the BCSIR than in the inflows. The TP concentration data indicate that the BCSIR did not contribute substantial TP to the canals that traverse its boundaries and that concentrations likely decreased during the study period. From 2014 to 2016, 59–65 percent of the samples collected at the inflow sites to the WR exceeded 10 ppb of TP, and 63 percent of the samples collected at the outflow sites exceeded 10 ppb of TP. At the ER inflow sites, 29 percent of the samples collected at BCS01 exceeded 10 ppb of TP, whereas samples from BCS02 and BCS03 exceeded 10 ppb of TP 96 and 94 percent of the time, respectively. Outflows from the ER at L-28U exceeded 10 ppb of TP 79 percent of the time.

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For more information about this publication, contact
Director
USGS Caribbean-Florida Water Science Center
4446 Pet Lane
Lutz FL 33559

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