Lake Okeechobee Watershed Tributary Nutrient Loading Trends WY2006-WY2015

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South Florida Water Management District

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A correction was made on July 5, 2016, to figures 4 through 8 to correct the x-axis label 2008 that was shown twice.

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Table 1. Conversion factors and acronyms.

Multiply	By	To Obtain
	Length	
inch (in)	2.54	centimeter (cm)
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	640.0	Acre
	Volume	
cubic foot (ft^3)	0.2832	cubic meter (m^3)
acre-foot	1233.48	cubic meter (m^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	1233.046	cubic meter per year (m^3/yr)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per day (ft^3/d)	0.2832	cubic meter per day (m^3/d)
cubic foot per second (cfs)	0.6463	million gallon per day (mgd)
cubic foot per second (cfs)	448.83	gallon per minute (gpm)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)

CERP	Comprehensive Everglades Restoration Plan
FDACS	Florida Department of Agriculture and Consumer Services
FDEP	Florida Department of Environmental Protection
KREA	Kissimmee River Eutrophication Abatement
LOWA	Lake Okeechobee Watershed Assessment
LOWP	Lake Okeechobee Watershed Project
TCNS	Taylor Creek and Nubbin Slough
SFWMD	South Florida Water Management District
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

1. Abstract

In April 2003, the U.S. Army Corps of Engineers (USACE), Florida Department of Agriculture and Consumer Services (FDACS), South Florida Water Management District (SFWMD or District), and U.S. Geological Survey (USGS) entered into a cooperative agreement for the design, installation, operation, and maintenance of a tributary-scale monitoring system located within the Lake Okeechobee Comprehensive Everglades Restoration Plan (CERP) area. This long-term tributary monitoring program was established to monitor changes resulting from restoration activities implemented throughout this area. Both flow and water quality data were collected. To assess the success or deficiencies of restoration efforts, many years of continued evaluation of these tributary loading stations for statistically significant trends were performed. Specifically, this study conducted statistical and trend analysis for the 14 tributary loading stations (12 USGS and two District stations) and made recommendations for continuation of this monitoring network.

The study period was from water year (WY- May 1 to April 30) 2006 through WY2015. Summary statistics included mean, median, minimum, maximum, and standard deviation. Monthly mean values were used for all statistical analyses. Trends of five parameters: mean monthly flow, total phosphorus (TP) load, flow-weighted mean TP concentration, total nitrogen (TN) load, and flow-weighted mean TN concentration for the 14 tributary loading stations in the Lake Okeechobee Watershed were analyzed with a Seasonal Kendall Tau test. Six of the 14 stations analyzed revealed significant increasing trends for one or more of the five parameters and the remaining eight stations had no trend for any parameters. Three stations showed a significant increasing trend in TP load or/and the TP flow-weighted mean concentration. These three stations, however, did not have an increasing trend in flow. A statistically significant increasing trend in flow at two stations did not result in significant increases of either TP or TN loads. There was a significant increasing trend for flow, TP and TN loads, at one station but no significant trend of flow-weighted TP or TN concentrations were found at that station. Since there were no sites with decreasing trends in any parameters, the continuation of all 12 USGS monitoring sites is recommended. In addition, 10 years of data may not be enough time to demonstrate statistically significant reductions from the watershed activities due to legacy phosphorus and various project implementation schedules in these monitored basins. Continued monitoring also will provide additional data to evaluate the effectiveness of nutrient reduction projects implemented through the state's newly developed Basin Management Action Plan (BMAP).

2. Introduction

As required by the Northern Everglades and Estuaries Protection Program (NEEPP), the SFWMD monitors the water quality of inflows to and outflows from Lake Okeechobee control structures and maintains a long-term water quality monitoring network within the Lake Okeechobee Watershed (**Figure 1**). This network is continuously reviewed for efficiency and to ensure all data objectives associated with legislatively mandated and permit-required monitoring are being met. This informs stakeholders and the public on the progress of federally and state-funded restoration efforts. In addition, the District coordinates monitoring efforts with the FDACS, the Florida Department of Environmental Protection (FDEP), and USGS to leverage monitoring sites and reduce duplication of efforts. This information also is used for FDEP's Lake Okeechobee Watershed BMAP (FDEP et al., 2014).

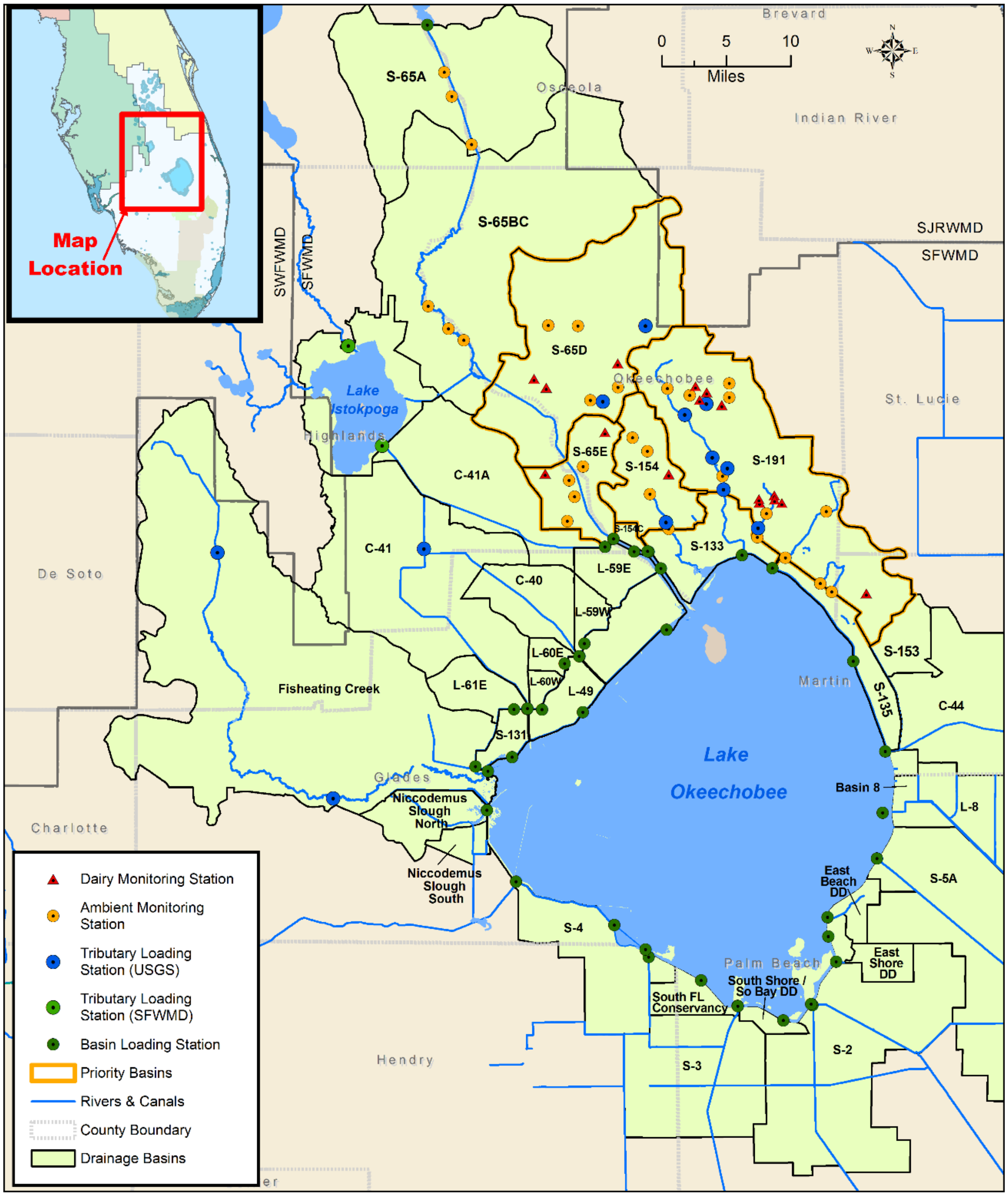

Figure 1. Locations of Water Year 2015 (WY2015) (May 1, 2014–April 30, 2015) water quality sampling stations under the ambient, tributary, and basin loading projects in the Lake Okeechobee Watershed.

The District's current monitoring network includes sample locations at three hydrologic levels within the Lake Okeechobee Watershed: (1) sub-watershed and drainage basin level (basin loading stations), (2) sub-basin level (tributary and ambient stations), and (3) project/parcel/farm level (dairy stations). Load monitoring is conducted only for stations at the sub-watershed and drainage basin level (basin loading stations). Basin loading stations are monitored for TP, TN, and flow. The Lake Okeechobee Operating Permit issued by the FDEP requires additional Class I water quality parameters be collected from 34 control structures with direct discharges into Lake Okeechobee. Data from all these monitoring efforts reside in the District's hydrometeorologic database (DBHYDRO).

The focus of this analysis is at the second tier monitoring (sub-basin level). Sub-basin concentration monitoring is conducted at ambient monitoring stations and tributary stations under four different projects. The ambient long-term trend projects include the Kissimmee River Eutrophication Abatement (KREA) and Taylor Creek Nubbin Slough (TCNS) projects and the sub-basin loading project (OKUSGS) located within the Lake Okeechobee Watershed CERP area. The Lake Okeechobee Watershed Assessment (LOWA) Project also monitors TP at the tributary level and is used to support the Works of the District Regulatory Program, Chapter 40E-61, F.A.C. Data from the 14 tributary OKUSGS monitoring sites are included in this analysis (**Figure 2**). The District collects and analyzes water quality from these 14 sites and flow at two sites; the USGS, under contract from FDACS, maintains flow data from 12 of these sites. Water quality samples were collected on a biweekly, flow only basis. Flow readings were triggered every fifteen minutes and were summed for total monthly discharge in load calculations. The OKUSGS project loading stations provide a unique data set in that these are the only upper tributary level monitoring sites where both nutrient concentrations and hydrologic flow are monitored, which allows for the calculation of loading at the upper tributary level.

To assess the success or deficiencies of restoration efforts in the Lake Okeechobee Watershed, many years of continued monitoring of these basins and sub-watersheds to evaluate for statistically significant trends are critical. The highly variable nature of the environmental processes reflected in the data from these tributaries and the influence of storm events on the water quality make continuous monitoring necessary. Evaluations that show no significant trends over several years also are useful to determine if the system has stabilized there may be a need to implement additional measures in the watershed if the lake does not meet water quality goals. The continued efforts of FDACS, FDEP, and the District to implement programmatic improvements and construct water quality restoration projects in the northern Lake Okeechobee Watershed warrant the maintenance of a robust monitoring network. The ability to track trends and seasonal signals in flow and nutrient concentrations at the basin and sub-watershed levels remains a critical component to the Northern Everglades monitoring complex and BMAP.

2.1 OKUSGS Project History

In April 2003, the U.S. Army Corps of Engineers (USACE) and USGS entered into a cooperative agreement for the design, installation, operation, and maintenance of a tributary scale monitoring system located within the Lake Okeechobee CERP area (USACE, 2003). This long-term monitoring program was established to monitor changes resulting from restoration activities implemented throughout the area. Both flow and water quality data were collected. Five objectives of this monitoring program were defined in the scope of work (USACE, 2003):

- Compute loads for phosphorus, nitrogen, and total suspended solids in selected tributaries with no current load monitoring.
- Characterize spatial distribution of loads across the Lake Okeechobee CERP area.
- Establish baseline water quality and streamflow information at the tributary level.
- Provide data to cooperators for planning management measures for restoration of Lake Okeechobee.
- Provide data for evaluating changes in the watershed, particularly the cumulative effect of restoration management measures at the tributary level.

The monitoring network was originally composed of 16 monitoring stations for water quality and streamflow with emphasis on the four priority basins of S-191, S-154, S-65D, and S-65E (**Figure 2**). The site construction and installation were completed by the end of 2004. Flow monitoring was initiated for most sites in May 2005 and the water quality monitoring began in July 2005. Due to reduced funding of CERP in the USACE FY2006 (October 1, 2005 to September 30, 2006) budget, the SFWMD and FDACS secured additional funds to augment the CERP budget in an effort to continue with some beneficial level of monitoring and the network was optimized to the current 14 station design. Further budget reductions in 2008 led the SFWMD to leverage this monitoring with other District water quality sites, and the District assumed collection and analysis of all water quality samples. The USGS continues monitoring for flow at 12 stations under contract with FDACS (**Figure 2** and **Table 2**). Two historic OKUSGS stations also are analyzed in this report but the District funds the flow data for these two particular sites (02270500/ARBUCK and 02273198/S-68).

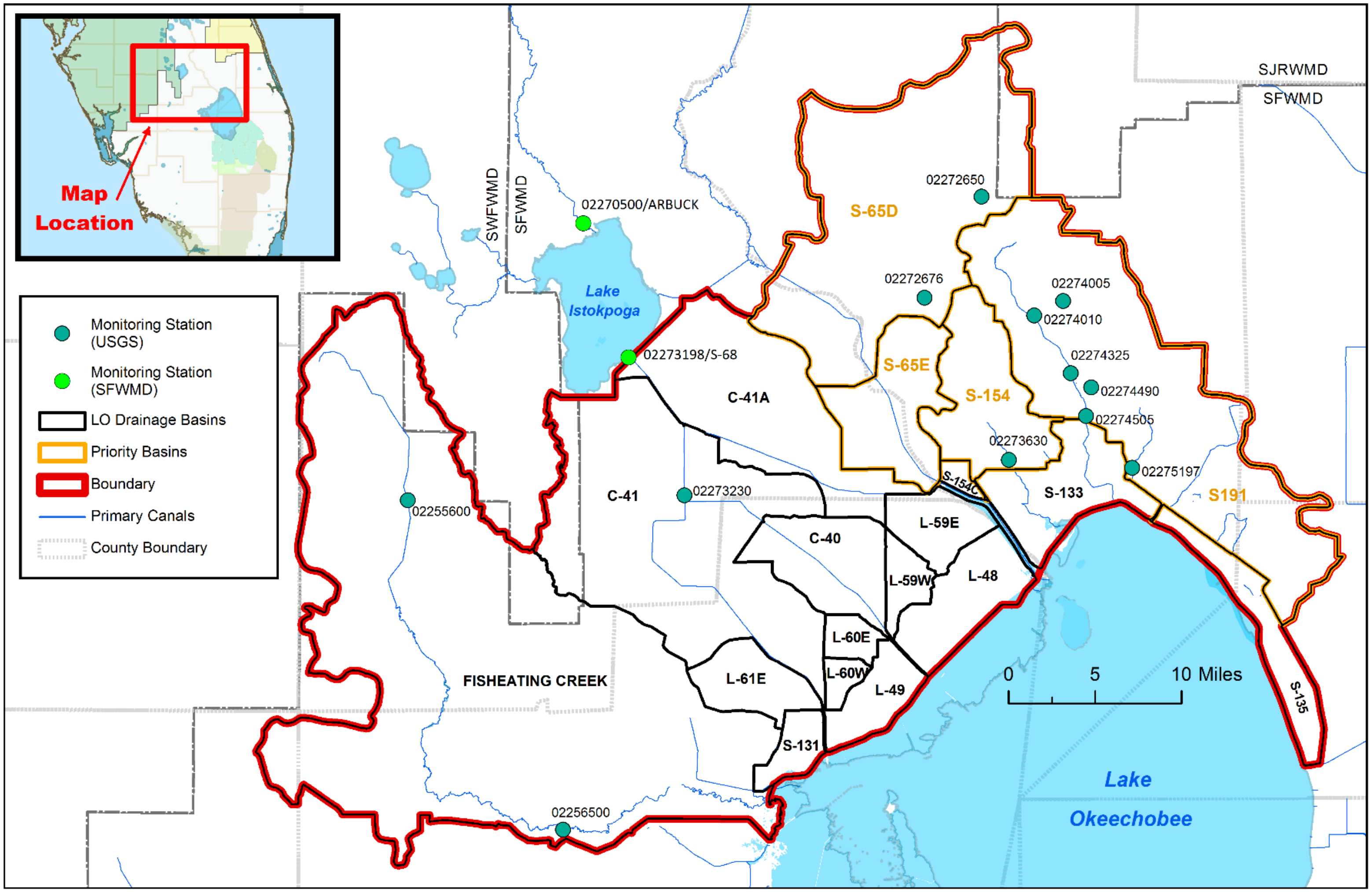

Figure 2. Current OKUSGS project tributary loading stations in the Lake Okeechobee Watershed.

Table 2. Description of the USGS tributary loading stations in the Lake Okeechobee Watershed.

OKUSGS Station No./DBHYDRO Flow	Station Description	Flow Site Name	DBKEY	Water Quality Site Name (s)	POR for both Flow and Concentration
02255600	Fisheating Creek @ Lake Placid	02255600	88210	02255600	July 2005 - Present
02256500/FISHP	Fisheating Creek @ Palmdale	FISHP	00090	02256500	July 2005 - Present
02270500/ARBUCK*	Arbuckle Creek inflow to Lake Istokpoga	ARBUCK	00210	02270500	July 2005 - Present
02272650	Fish Slough @ Basinger	02272650	88212	02272650/ KREA 01	July 2005 - Present[1]
02272676	Cypress Slough @ Basinger	02272676	88214	02272676	July 2005 - Present
02273198/S68*	Lake Istokpoga at S-68	S68_S	15955	02273198	July 2005 - Present
02273230	C-41 @ Brighton	02273230	88216	02273230	July 2005 - Present
02273630	Popash Slough, Okeechobee	02273630	88218	02273630/ KREA 30A	July 2005 - Present[2]
02274005	Otter Creek, Okeechobee	02274005	88220	02274005/ TCNS 209	July 2005 - Present[2]
02274010	Taylor Creek @ Cypress Quarters	02274010	88223	02274010/ TCNS 213	July 2005 - Present[2]
02274325	Taylor Creek Grassy Island	02274325	88225	02274325/ S390	July 2005 - Present
02274490	Williamson Ditch, Okeechobee	02274490	88227	02274505/ TCNS 214	July 2005 - Present[2]
02274505	Wolff Creek, Okeechobee	02274505	88229	02274505/ TCNS 217	July 2005 - Present[2]
02275197	Mosquito Creek, Okeechobee	02275197	88231	02275197	July 2005 - Present

[1]Water Quality monitoring since 1986 under KREA/TCNS/TCSTA; flow monitoring since 2005.

[2]Water Quality monitoring since 1988 under KREA/TCNS/TCSTA; flow monitoring since 2005.

*The district monitors both flow and water quality at these two stations which are not part of the OKUSGS network. The District monitors water quality and USGS, under a contract from FDACS, monitors flow at the remaining 12 stations which are part of the OKUSGS network.

3. Report Objectives

The objectives of this report are to (1) conduct statistical and trend analysis for the 14 OKUSGS project tributary loading stations through water year 2015, (2) compare the statistics and trends at these locations;, and (3) provide summarized results and make recommendations for continuation of this monitoring network. The statistical evaluation of the OKUSGS project loading stations provides a unique opportunity to assess the majority of remaining sites in the northern Lake Okeechobee Watershed where both nutrient concentrations and hydrologic flow are available at tributary locations upstream of direct inflows to Lake Okeechobee.

4. Methods

The study period is from WY 2006 through WY2015. Summary statistics included mean, median, minimum, maximum, and standard deviation. Monthly mean values were used for all other statistical analyses. Trends of five parameters: mean monthly flow (acre-feet [ac-ft]), TP load in metric tons (mt), flow-weighted mean TP concentration in µg/L, TN load in mt, and flow-weighted mean TN concentration in mg/L from WY2006 to WY2015 for the 14 tributary loading stations in the Lake Okeechobee Watershed were analyzed with a Seasonal Kendall Tau test. The Seasonal Kendall Tau test was used to verify the statistical significance of the trends in the time series of TP and TN concentrations for the study period. The Seasonal Kendall Tau is a non-parametric test frequently used to detect trends for water quality time series data. It is a rank-order statistic that can be applied to time series data exhibiting seasonal cycles, missing and censored data, and indications of non-normality (Yu and Zou, 1993). Non-parametric tests perform analyses based on the ranks of the data and therefore are not influenced by outliers or skewed data that may have been present within the 2005 to 2007 data period (due to the occurrence of four hurricanes impacting the study area during this period and drought conditions in 2008 and 2009.

When data are collected over time, significant autocorrelation may exist between data values. The Seasonal Kendall Tau provides an adjusted p-value for data that exhibit a significant level of dependence (Reckhow et al., 1992). For the purpose of determining statistical significance, an alpha (α) level of 0.05 was selected. Results of the Seasonal Kendall Tau test indicate if a statistically significant increase or decrease in concentrations or other values is present at the station level. The test also produces a Sen slope value, which is an estimate of the amount of change in the measured value (e.g., mt, mg/L, or µg/L) per year. This methodology and approach had been used in a previous water quality trend analysis by Zhang et al. (2011), as well as the sub-watershed level trend analysis included in the 2011 Lake Okeechobee Watershed Protection Plan Update (SFWMD et al., 2011).

5. Results and Discussion

5.1 Summary Statistics

A total of 14 tributary monitoring stations within the Lake Okeechobee Watershed Project area in the Lake Okeechobee Watershed were studied: two stations located at the inflow and outflow of Lake Istokpoga and 12 stations mainly located in the four priority basins (S-154, S-191, S-65D, and S-65E). Summary statistics of five parameters: flow, TP load, TP flow-weighted mean concentration (FWMC), TN load, and TN FWMC data collected from the 14 tributary monitoring stations from WY2006 to 2015 were determined.

TP and TN Concentrations. The highest TP FWMC of 697 µg/L was recorded at station 02273630, which is located at Popash Slough in the S-154 basin (**Table 3**). The lowest TP FWMC of 75 µg/L was recorded at station 02273198, which is located at outflow structure S-68 from Lake Istokpoga. The highest TN FWMC of 2.83 mg/L was recorded at station 02255600, which is located along Fisheating Creek in Lake Placid, within the Fisheating Creek Sub-watershed. The lowest TN FWMC of 1.33 ppm was recorded at Arbuckle Creek inflow station 02270550 to Lake Istokpoga.

Comparing the Lake Istokpoga inflow (measured at station 02270500) to the outflow (02273198) over the 10 year period of record, the mean TP concentration was reduced 43% (from 132 µg/L to 75 µg/L) Based on this difference, one might conclude that Lake Istokpoga provided an assimilative function for TP. However, for the same period, the lake did not show an assimilation capacity for TN (1.33 mg/L at inflow versus 1.45 mg/L at outflow).

TP and TN Loads. A review of the TP loading statistics reveals much of the higher loading rates to be a function of flow volume. The highest TP load (43 mt) was recorded at C-41 Canal at Brighton (02273230), followed by Fisheating Creek at Palmdale (37 mt) (02256500), Arbuckle Creek (30 mt) (02270500), and Lake Istokpoga at S-68 (26 mt) (02273198) (**Table 3**). These sites had relatively high flow volumes but relatively low TP concentrations. Other sites exhibited higher TP loads when compared to the amount of flow generated from the drainage areas due to the higher flow-weighted mean TP concentrations [Popash Slough (02273630), Taylor Creek at Cypress Quarters (02274010), Taylor Creek at Grassy Island (02274325), Williamson Ditch (02274490) and Mosquito Creek (02275197)].

The highest TN load (462 mt) occurred at the S-68 outflow structure for Lake Istokpoga (02273198) (**Table 3**). This site also had the largest mean flow volume (249,000 ac-ft), but a relatively low flow-weighted mean TN concentration (1.45 mg/L), the second lowest of the 14 sites. The site along the C-41 canal (02273230) had the second highest TN load (361 mt) and the second highest flow-weighted TN concentration (2.41 mg/L). The highest flow-weighted TN concentration (2.83 mg/L) was recorded at Fisheating Creek at Lake Placid (02255600), followed by C-41 canal at Brighton (2.41 mg/L) (02273230), and Taylor Creek at Cypress Quarters (2.26 mg/L) (02274010).

Table 3. Summary of flow, total phosphorus, and total nitrogen data collected from WY2006 to WY2015.

OKUSGS No./Site Name	Station Description	Parameter	Annual Summary Statistics				
			Mean	Standard Deviation	Minimum	Median	Maximum
02255600	Fisheating Creek at Lake Placid	Flow (ac-ft x 10^3)	32	21	5	36	64
		TP Load (mt)	9	7	1	9	20
		TP fwmc (µg/L)	205	95	103	199	404
		TN Loads (mt)	107	65	17	105	191
		TN fwmc (mg/L)	2.83	0.98	2.04	2.54	5.34
02256500	Fisheating Creek at Palmdale	Flow (ac-ft x 10^3)	149	91	32	152	295
		TP Load (mt)	37	29	4	32	80
		TP fwmc (µg/L)	177	65	72	177	297
		TN Loads (mt)	322	200	66	306	689
		TN fwmc (mg/L)	1.75	0.16	1.55	1.71	2.08
02270500	Arbuckle Creek infow to Lake Istokpoga	Flow (ac-ft x 10^3)	184	98	64	171	342
		TP Load (mt)	30	16	5	33	52
		TP fwmc (µg/L)	132	36	60	131	192
		TN Loads (mt)	285	116	116	300	460
		TN fwmc (mg/L)	1.33	0.22	0.98	1.32	1.69
02272650 /KREA01	Fish Slough at Basinger	Flow (ac-ft x 10^3)	19	12	2	21	36
		TP Load (mt)	9	6	1	9	18
		TP fwmc (µg/L)	373	105	212	395	550
		TN Loads (mt)	44	25	5	47	76
		TN fwmc (mg/L)	1.90	0.19	1.58	1.92	2.17
02272676	Cypress Slough at Basinger	Flow (ac-ft x 10^3)	27	17	2	29	51
		TP Load (mt)	15	10	0	18	28
		TP fwmc (µg/L)	415	142	64	431	608
		TN Loads (mt)	50	31	3	55	94
		TN fwmc (mg/L)	1.51	0.17	1.17	1.51	1.72
02273198	Lake Istokpoga at S-68	Flow (ac-ft x 10^3)	249	159	31	254	528
		TP Load (mt)	26	21	2	25	71
		TP fwmc (µg/L)	75	21	45	77	108
		TN Loads (mt)	462	288	39	477	883
		TN fwmc (mg/L)	1.45	0.28	1.02	1.44	1.94
02273230	C-41 at Brighton	Flow (ac-ft x 10^3)	129	83	42	105	276
		TP Load (mt)	43	26	12	39	92
		TP fwmc (µg/L)	287	110	168	229	455
		TN Loads (mt)	361	214	128	306	814
		TN fwmc (mg/L)	2.41	0.63	1.56	2.29	3.57

Note: The use of µg/L for TP and mg/L for TN is a result of lab reporting detection limits for each and the number of decimal places for which each parameter can be analyzed.

Table 3. Summary of flow, total phosphorus, and total nitrogen data collected from WY2006 to WY2015 (Continued).

OKUSGS No./Site Name	Station Description	Parameter	Annual Summary Statistics				
			Mean	Standard Deviation	Minimum	Median	Maximum
02273630 /KREA30A	Popash Slough at Okeechobee	Flow (ac-ft x 10^3)	11	10	0	9	25
		TP Load (mt)	10	10	0	7	32
		TP fwmc (µg/L)	697	180	466	668	1,029
		TN Loads (mt)	29	25	0	25	70
		TN fwmc (mg/L)	2.15	0.21	1.80	2.17	2.48
02274005 /TCNS209	Otter Creek at Okeechobee	Flow (ac-ft x 10^3)	2	1	1	3	4
		TP Load (mt)	2	1	0	1	3
		TP fwmc (µg/L)	495	166	193	504	743
		TN Loads (mt)	7	5	1	7	16
		TN fwmc (mg/L)	2.17	0.54	1.46	2.12	3.21
02274010 /TCNS213	Taylor Creek at Cypress Quarters	Flow (ac-ft x 10^3)	24	12	6	25	45
		TP Load (mt)	18	10	2	18	34
		TP fwmc (µg/L)	592	174	269	591	874
		TN Loads (mt)	68	37	15	61	133
		TN fwmc (mg/L)	2.26	0.32	1.76	2.26	2.73
02274325 /S390	Taylor Creek at Grassy Island	Flow (ac-ft x 10^3)	32	15	7	32	54
		TP Load (mt)	22	14	2	19	50
		TP fwmc (µg/L)	531	175	250	536	937
		TN Loads (mt)	83	42	14	84	131
		TN fwmc (mg/L)	2.07	0.27	1.61	2.12	2.46
02274490 /TCNS214	Williamson Ditch at Okeechobee	Flow (ac-ft x 10^3)	16	6	6	15	28
		TP Load (mt)	10	5	2	12	16
		TP fwmc (µg/L)	471	165	171	507	693
		TN Loads (mt)	38	16	15	37	63
		TN fwmc (mg/L)	1.84	0.19	1.60	1.84	2.23
02274505 /TCNS217	Wolff Creek at Okeechobee	Flow (ac-ft x 10^3)	3	2	0	3	6
		TP Load (mt)	1	1	0	1	3
		TP fwmc (µg/L)	322	86	135	321	435
		TN Loads (mt)	7	5	0	8	14
		TN fwmc (mg/L)	1.83	0.21	1.42	1.87	2.09
02275197	Mosquito Creek at Okeechobee	Flow (ac-ft x 10^3)	8	6	2	8	22
		TP Load (mt)	5	4	1	5	16
		TP fwmc (µg/L)	469	110	259	485	637
		TN Loads (mt)	22	20	4	22	73
		TN fwmc (mg/L)	2.13	0.32	1.59	2.15	2.68

Note: The use of µg/L for TP and mg/L for TN is a result of lab reporting detection limits for each and the number of decimal places for which each parameter can be analyzed.

5.2 Tributary Nutrient Loading Trends

Significant trends were found at six of the 14 stations for one or more of the five parameters (**Figure 3 and Table 4).** The remaining eight stations had no trend for any parameters **(Table 5).** No increasing trends in TN FWMC were found and significant increase in TP FWMC was found only at one site, 02272650 (Fish Slough at Basinger). A significant increasing trend in TP load or/and the TP FWMC that was not related to flow was found at three stations, 02272650 (Fish Slough at Basinger), 02272676 (Cypress Slough at Basinger), and 02274490 (Williamson Ditch at Okeechobee) (**Figure 3 and Table 4**). Despite a statistically significant increasing trend in flow at two stations 02274005 (Otter Creek at Okeechobee) and 02274325 (Taylor Creek at Grassy Island), significant increases of TP and TN loads and concentrations were not found (**Table 4**). Station 02274505 (Wolff Creek at Okeechobee) is the only station with a significant increasing trend for flow, TP and TN loads, but it does not show a significant TP or TN concentration trend (**Table 4**). This area of the watershed should be further investigated for upstream land use or hydrological changes that have affected all three indicators of impacts to water quality. The statistical trend in flow is most likely driving the increasing trend in TN and TP loads at this site. This may be a function of localized rainfall, but analysis of basin-wide rainfall data was not specific to this report and should be considered in future analyses.

5.3 Discussion

The study provided the basic statistics and trend analysis results using data collected at the 14 tributary loading stations. Focus on future analysis of the six stations exhibiting significant increasing trends (**Figures 4** through **8**) is recommended. The contributing areas should be defined and further investigated for upstream land use or hydrological changes that have affected all three indicators (flow, load, and concentration) of impacts to water quality. Furthermore, analysis of basin-wide and site specific rainfall should be investigated as a potential cause of the significantly increased flow exhibited at three of the fourteen sites. Additionally, further analysis of basin-level trends at the structures and direct inflows to Lake Okeechobee should be compared with the upstream tributary loading network. This will provide valuable information to assess the success of FDEP, FDACS, and SFWMD basin restoration projects. Many of the sites analyzed in this report are located in areas scientifically relevant to these initiatives, including the Istokpoga Marsh Project, the Taylor Creek STA, the Hybrid Wetland Treatment Technology (HWTT) along Taylor Creek, and the Kissimmee River Restoration Project.

The TP load to Lake Okeechobee in WY2016 was 296 mt over target as compared to the five-year rolling average TMDL target of 140 mt (Zhang et al., 2016). Since there were no sites with decreasing trends in any parameters, the continuation of all 12 OKUSGS monitoring sites is recommended. Continued monitoring will also provide additional data to evaluate the effectiveness of nutrient reduction projects implemented through BMAP efforts. Data collected from WY2006 to WY2013 may be used for baseline information when comparing with the post-BMAP data collected from WY2014 to future years.

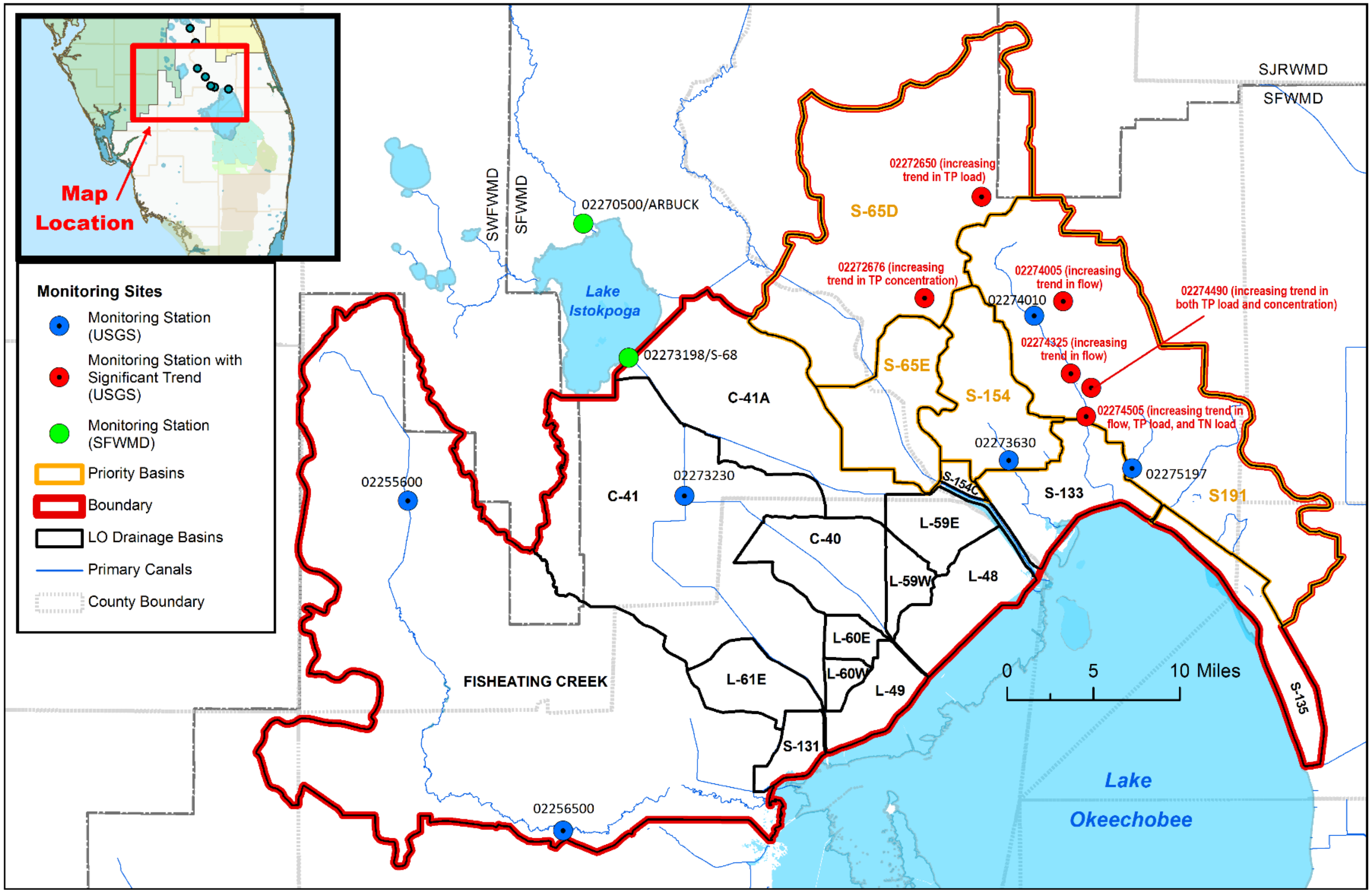

Figure 3. Current OKUSGS project tributary loading stations highlighting stations with significant trend in one or more parameters using Seasonal Kendall Tau trend analyses for Water Year 2006–2015.

Table 4. Seasonal Kendall Tau trend analyses of flow, TP load, TP flow-weighted mean concentration (FWMC), TN load, and TN FWMC for WY2006–2015 for stations with increasing trends in one or more parameters. **Bolded** parameters indicate significant changes. (Note: NA – not available)

Station	Parameter (unit)	Number of Month	Number of Month with NA	Kendall's Tau	Seasonal Sen Slope	Intercept	P Value
02272650	Flow (ac-ft x 10^3)	120	0	0.244	0.028	0.216	0.111
	TP Load (mt)	**120**	**0**	**0.259**	**0.011**	**0.072**	**0.000**
	TP FWMC (µg/L)	120	0	0.189	15.3	180.7	0.176
	TN Load (mt)	120	0	0.233	0.051	0.557	0.111
	TN FWMC (mg/L)	120	0	0.013	0.004	1.717	0.926
02272676	Flow (ac-ft x 10^3)	120	0	0.287	0.048	0.165	0.078
	TP Load (mt)	120	0	0.324	0.019	0.076	0.053
	TP FWMC (µg/L)	**120**	**19**	**0.292**	**20.2**	**256.7**	**0.039**
	TN Load (mt)	120	0	0.302	0.080	0.423	0.056
	TN FWMC (mg/L)	120	19	-0.079	-0.006	1.454	0.644
02274005	**Flow (ac-ft x 10^3)**	**120**	**0**	**0.146**	**0.004**	**0.075**	**0.044**
	TP Load (mt)	120	0	0.274	0.003	0.020	0.056
	TP FWMC (µg/L)	120	0	0.256	18.2	226.6	0.053
	TN Load (mt)	120	0	0.200	0.021	0.135	0.209
	TN FWMC (mg/L)	120	0	0.337	0.098	1.441	0.061
02274325	**Flow (ac-ft x 10^3)**	**120**	**0**	**0.144**	**0.047**	**0.604**	**0.047**
	TP Load (mt)	120	0	0.089	0.013	0.253	0.225
	TP FWMC (µg/L)	120	0	-0.041	-2.0	326.5	0.760
	TN Load (mt)	120	0	0.122	0.079	1.534	0.093
	TN FWMC (mg/L)	120	0	-0.026	-0.004	1.713	0.832
02274490	Flow (ac-ft x 10^3)	120	0	-0.063	-0.008	0.375	0.394
	TP Load (mt)	**120**	**0**	**0.144**	**0.006**	**0.135**	**0.047**
	TP FWMC (µg/L)	**120**	**0**	**0.389**	**31.2**	**212.6**	**0.031**
	TN Load (mt)	120	0	0.070	0.009	0.563	0.339
	TN FWMC (mg/L)	120	0	0.300	0.054	1.240	0.069
02274505	**Flow (ac-ft x 10^3)**	**120**	**0**	**0.235**	**0.004**	**0.021**	**0.001**
	TP Load (mt)	**120**	**0**	**0.276**	**0.001**	**0.006**	**0.000**
	TP FWMC (µg/L)	120	0	0.156	7.6	181.5	0.160
	TN Load (mt)	**120**	**0**	**0.207**	**0.004**	**0.036**	**0.004**
	TN FWMC (mg/L)	120	0	0.159	0.018	1.136	0.151

Table 5. Seasonal Kendall Tau trend analyses of flow, TP load, TP flow-weighted mean concentration (FWMC), TN load, and TN FWMC for WY2006–2015 for stations with no trend with any parameter. **(Note: NA – not available)**

Station	Parameter (unit)	Number of Month	Number of Month with NA	Kendall's Tau	Seasonal Sen Slope	Intercept	P Value
02255600	Flow (ac-ft x 10^3)	120	0	0.189	0.016	0.260	0.181
	TP Load (mt)	120	0	0.259	0.006	0.042	0.108
	TP FWMC (µg/L)	120	3	0.158	9.6	164.4	0.393
	TN Load (mt)	120	0	0.152	0.039	0.833	0.251
	TN FWMC (mg/L)	120	3	-0.277	-0.059	2.865	0.072
02256500	Flow (ac-ft x 10^3)	120	0	0.161	0.085	1.260	0.243
	TP Load (mt)	120	0	0.233	0.023	0.285	0.122
	TP FWMC (µg/L)	120	3	0.169	4.0	147.0	0.339
	TN Load (mt)	120	0	0.169	0.180	2.340	0.187
	TN FWMC (mg/L)	120	3	-0.119	-0.014	1.729	0.318
02270500	Flow (ac-ft x 10^3)	120	0	0.344	0.894	3.521	0.074
	TP Load (mt)	120	0	0.307	0.110	0.303	0.077
	TP FWMC (µg/L)	120	0	0.143	2.2	85.8	0.249
	TN Load (mt)	120	0	0.304	1.240	6.850	0.088
	TN FWMC (mg/L)	120	0	-0.267	-0.035	1.521	0.187
02273198	Flow (ac-ft x 10^3)	120	0	0.228	1.014	3.863	0.208
	TP Load (mt)	120	0	0.193	0.079	0.360	0.301
	TP FWMC (µg/L)	120	6	0.072	1.0	68.5	0.701
	TN Load (mt)	120	0	0.209	1.757	7.440	0.245
	TN FWMC (mg/L)	120	6	0.195	0.023	1.305	0.300
02273230	Flow (ac-ft x 10^3)	120	0	0.219	0.384	3.803	0.156
	TP Load (mt)	120	0	0.211	0.085	1.063	0.156
	TP FWMC (µg/L)	120	0	0.156	6.1	162.7	0.288
	TN Load (mt)	120	0	0.207	0.749	11.202	0.146
	TN FWMC (mg/L)	120	0	0.130	0.035	1.902	0.502
02273630	Flow (ac-ft x 10^3)	120	0	0.211	0.003	0.047	0.171
	TP Load (mt)	120	0	0.220	0.003	0.025	0.127
	TP FWMC (µg/L)	120	8	0.084	12.5	510.3	0.534
	TN Load (mt)	120	0	0.209	0.009	0.137	0.159
	TN FWMC (mg/L)	120	8	0.027	0.009	2.056	0.896
02274010	Flow (ac-ft x 10^3)	120	0	0.122	0.031	0.336	0.093
	TP Load (mt)	120	0	0.111	0.011	0.215	0.380
	TP FWMC (µg/L)	120	3	-0.105	-8.9	471.7	0.536
	TN Load (mt)	120	0	0.148	0.079	0.861	0.222
	TN FWMC (mg/L)	120	3	-0.012	-0.002	2.011	0.949
02275197	Flow (ac-ft x 10^3)	120	0	0.148	0.009	0.129	0.321
	TP Load (mt)	120	0	0.107	0.002	0.064	0.482
	TP FWMC (µg/L)	120	9	-0.135	-9.1	400.2	0.307
	TN Load (mt)	120	0	0.159	0.013	0.369	0.316
	TN FWMC (mg/L)	120	9	-0.127	-0.036	2.206	0.446

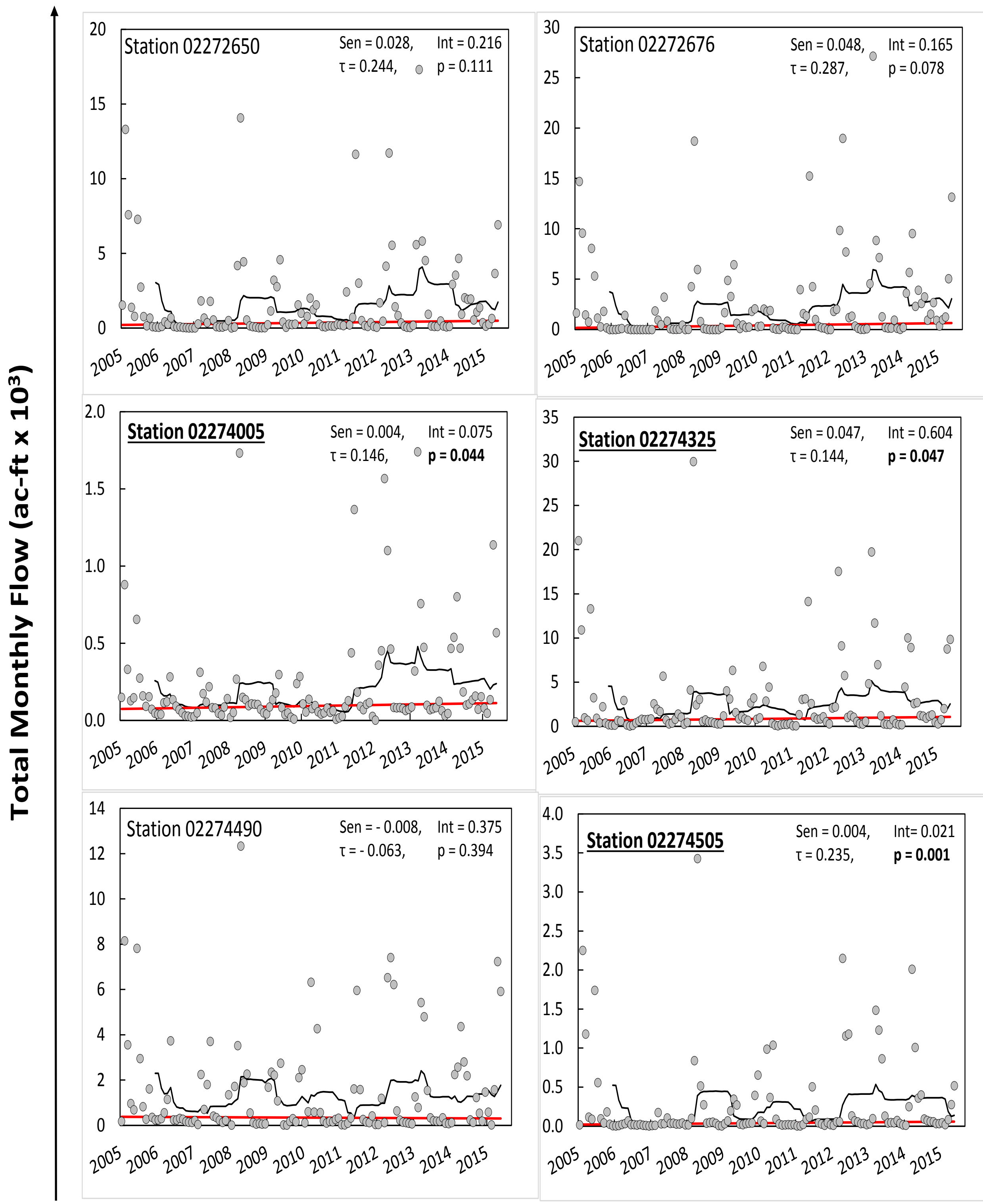

Figure 4. Monthly flows during WY2006–2015 for the six USGS tributary loading sites with significant trend for one or more parameters. Gray dots represent monthly values, black lines represent 12-month moving averages, and red lines represent Seasonal Kendall trend lines. Bold and underline station labels signify a significant relationship.

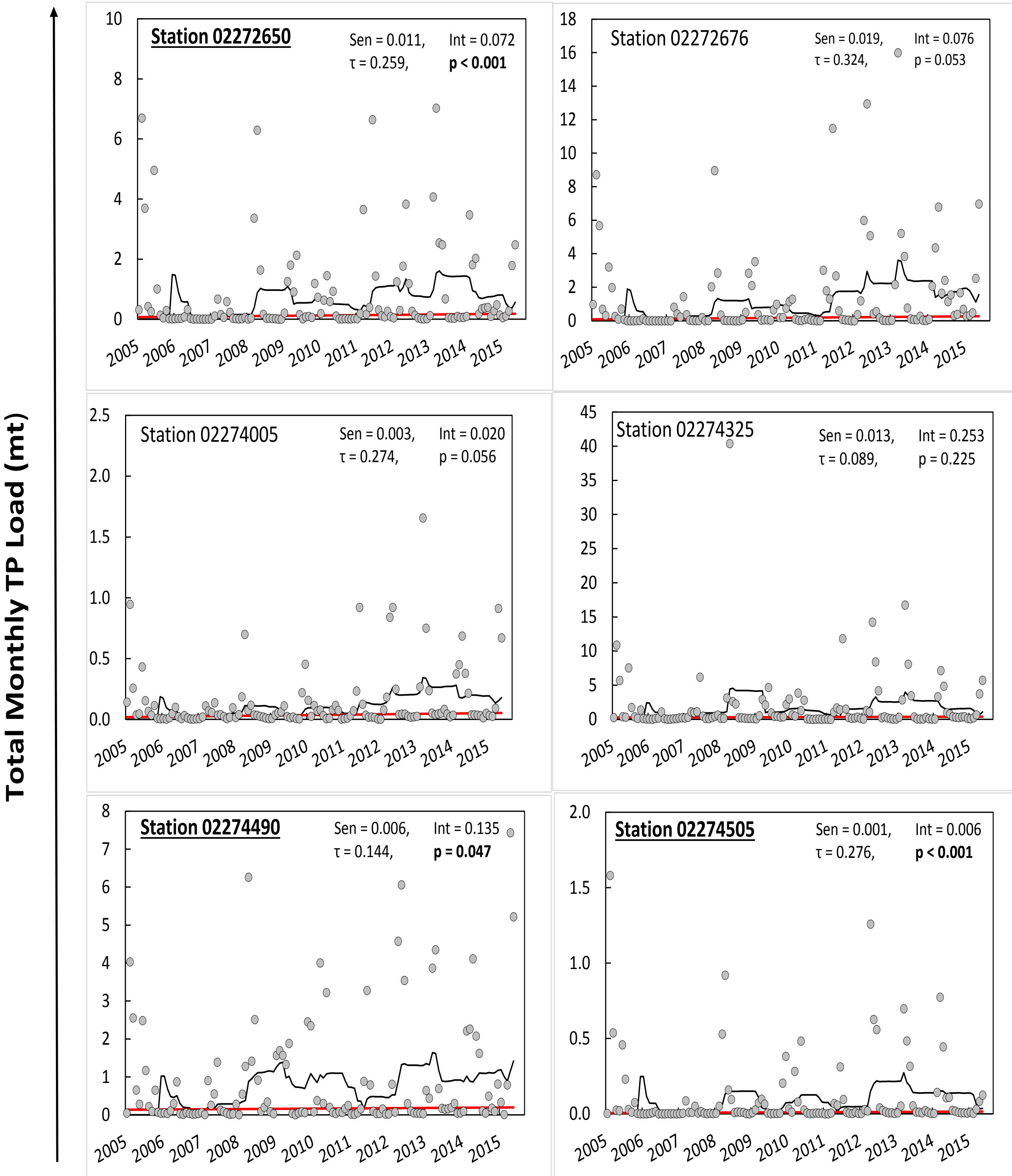

Figure 5. Monthly TP loads during WY2006–2015 for the six USGS tributary loading sites with significant trend for one or more parameters. Gray dots represent monthly values, black lines represent 12-month moving averages, and red lines represent Seasonal Kendall trend lines. Bold and underline station labels signify a significant relationship.

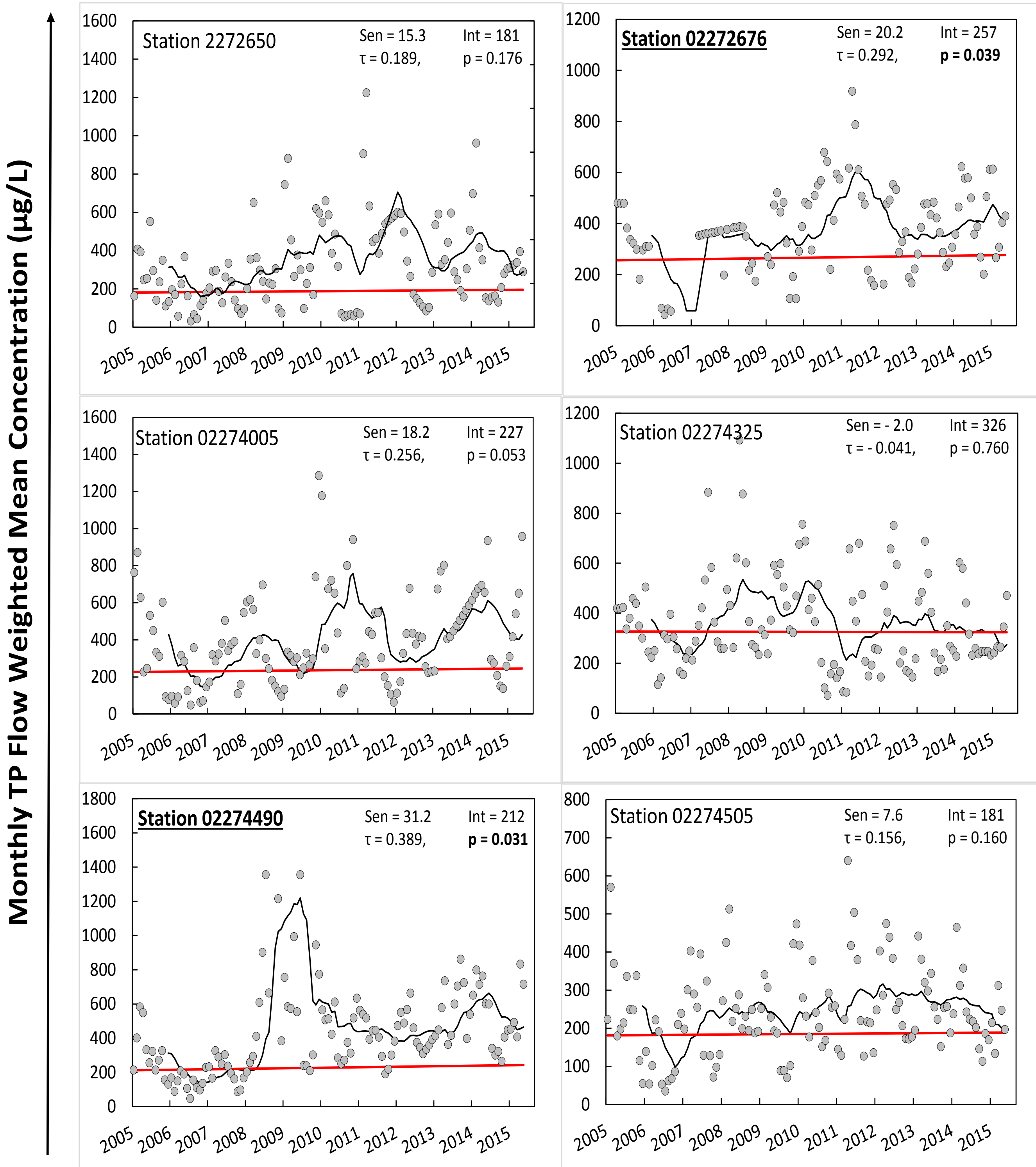

Figure 6. Monthly TP flow-weighted mean concentration (FWMC) during WY2006–2015 for the six USGS tributary loading sites with significant trend for one or more parameters. Gray dots represent monthly values, black lines represent 12-month moving averages, and red lines represent Seasonal Kendall trend lines. Bold and underline station labels signify a significant relationship.

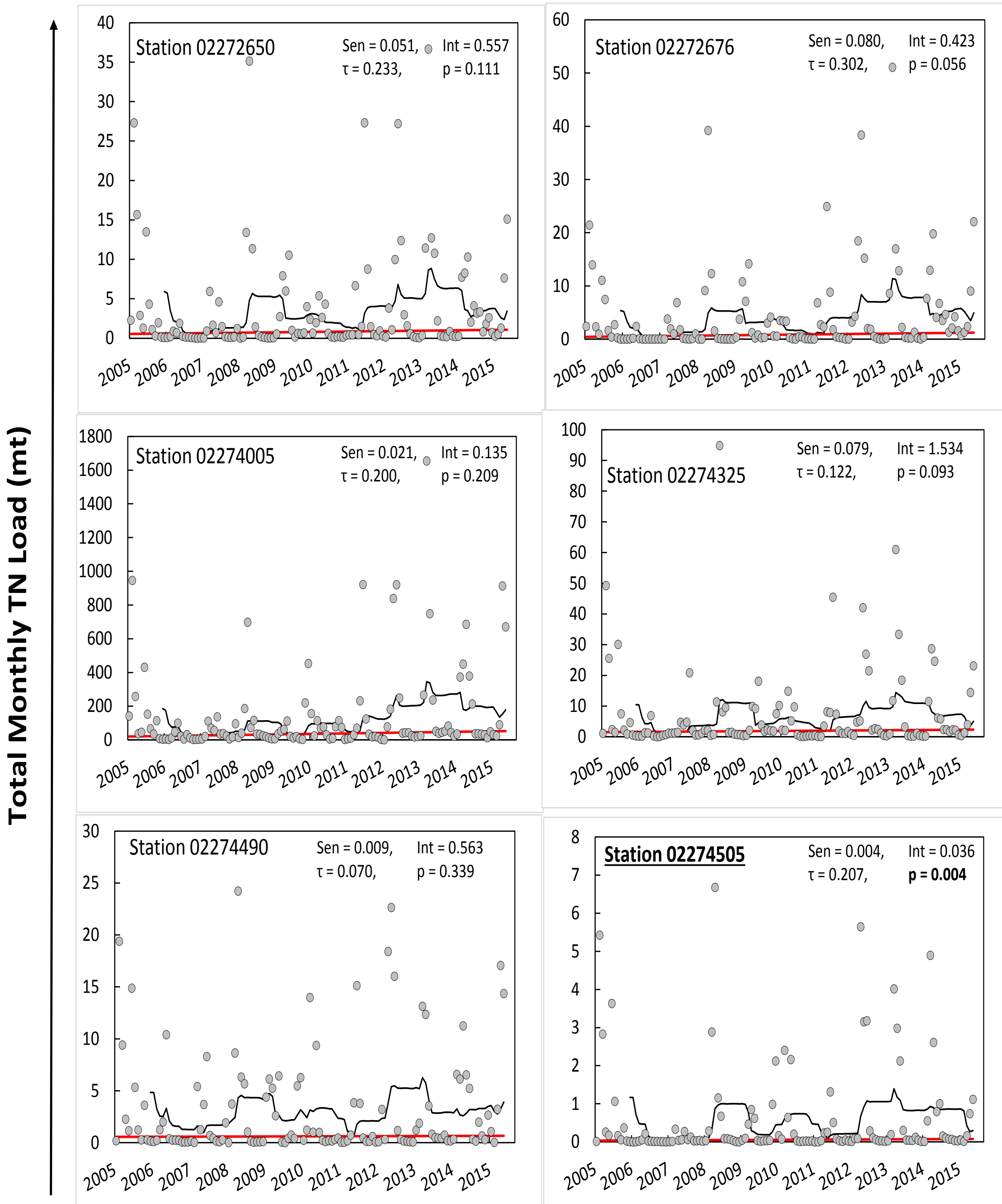

Figure 7. Monthly TN loads during WY2006–2015 for the six USGS tributary loading sites with significant trend for one or more parameters. Gray dots represent monthly values, black lines represent 12-month moving averages, and red lines represent Seasonal Kendall trend lines. Bold and underline station labels signify a significant relationship.

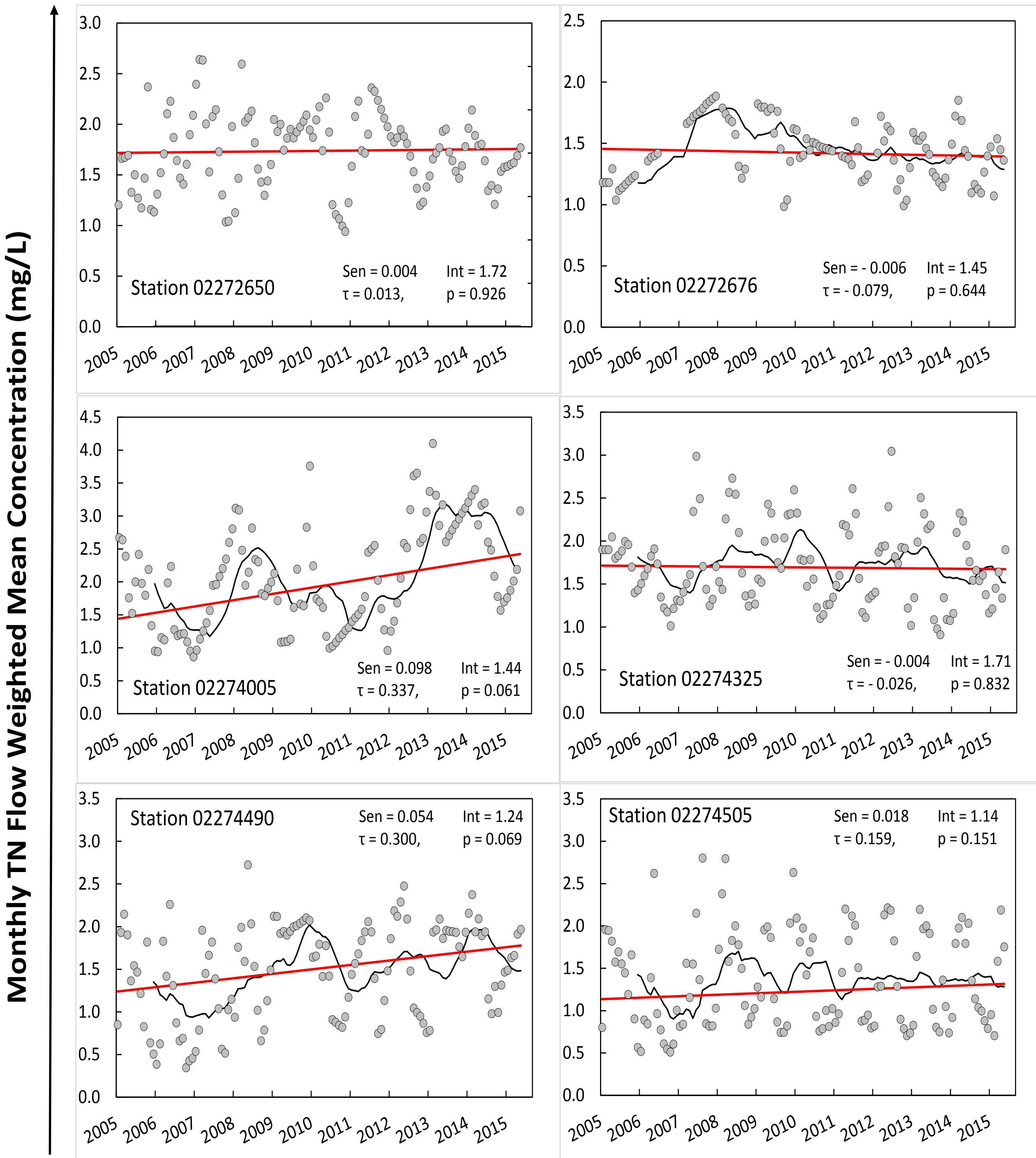

Figure 8. Monthly TN flow-weighted mean concentration (FWMC) during WY2006–2015 for the six USGS tributary loading sites with significant trend for one or more parameters. Gray dots represent monthly values, black lines represent 12-month moving averages, and red lines represent Seasonal Kendall trend lines. Bold and underline station labels signify a significant relationship.

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