



Real-time Monitoring Report

Roger Williams Park
Providence, RI

Prepared for the Southeast
New England Program (SNEP) Network

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Background

Roger Williams Park is a 435-acre park in Providence, Rhode Island. Created in 1871, the park includes an extensive system of ponds most of which were artificially created by dredging and damming Mashapaug Brook in the late 19th century (Horsley Witten et al., 2013). Over the years, increasing development and urbanization in the watershed surrounding the park ponds has impaired the ponds' water quality, resulting in frequent algae blooms in warmer months. In addition to impacting the pond ecology these blooms sometimes produce cyanotoxins, a health hazard for recreational boaters and other park users. In 2007, the Rhode Island Department of Environmental Management (RIDEM) included the Roger Williams Park (RWP) ponds in a Total Maximum Daily Load (TMDL) analysis of nine ponds in Rhode Island impaired for phosphorus (RIDEM, 2007).

In 2013 a group of consultants led by Horsley Witten with the guidance of a Technical Steering Committee completed an in-depth report on the RWP pond water quality issues and made recommendations for improvements (Horsley Witten et al., 2013). The report concluded that the major source of phosphorus, a key nutrient linked to algae blooms, was untreated stormwater runoff on impervious surfaces in the watershed, but that other significant sources include internal loading from sediments in the pond and the park's overly abundant goose population (Horsley Witten et al., 2013). Recommendations included diverting stormwater runoff to treatment BMPs, removing curbs and reducing pavement, increased catch basin cleaning and street sweeping, planting shoreline buffers and stabilizing slopes, public outreach to increase awareness of the impacts of runoff from the surrounding watershed, and taking measures to reduce the goose population (Horsley Witten et al., 2013).

Starting in 2017 as part of a consent decree between RIDEM and the City of Providence to address ongoing phosphorus pollution problems in the park, 35 structural and non-structural BMPs were installed in the park (PSIC, 2021). The structural BMPs included infiltration basins, swales, rain gardens and sand filters, while the nonstructural BMPs included pavement removal, shoreline buffer plantings, and goose control. These measures were designed primarily to treat stormwater runoff and pollutant loading coming from within the park, and collectively reduce phosphorus loading to the ponds by approximately 30-60 pounds per year (Table 1). However, the implementation in the park did not directly address the largest portion of the phosphorus load (an estimated 360 pounds per year), which comes into the park from the upper watershed (Horsley Witten et al., 2013). Efforts to address phosphorus loading from the upper watershed are ongoing.

Roger Williams Park BMP Phosphorus Reduction	
EPA Performance Curve Method	Sum of all
BMPs Watershed (ac)	34.72
Calculated WQV (cf)	119731.92
P reduction (lb/yr)	62.10
N reduction (lb/yr)	489.55
TSS reduction (lb/yr)	15242.08
Volume Reduction (cf/year)	5031039.49
From Wood Environmental	Sum of all BMPs
P reduction s (lb/yr)	30.88

In 2020 the Providence Stormwater Innovation Center (PSIC), a collaboration between the City of Providence Parks Department, the University of Rhode Island, Restore America's Estuaries, the Rhode Island Department of Transportation, the Southeast New England Program Network, the Robbins-de Beaumont Foundation and the University of New Hampshire Stormwater Center was formed to take advantage of the abundance of BMPs in the park and the experience gained from their installation and maintenance to advance stormwater treatment in the region. In 2020 and 2021 the PSIC also undertook several monitoring efforts to determine whether some of the installed BMPs were working as designed, as well as to get a sense of the current water quality in the park ponds.

Historic Conditions

The park ponds were created in the late 19th and early 20th century by dredging and damming Mashapaug Brook, which flows from nearby Mashapaug pond. The ponds are quite shallow (the deepest is an average of 4.3 feet deep) and have grown shallower over time from sedimentation (Horsley Witten et al., 2013). Dredging was last done in the 1980s in an attempt to address water quality problems and increase depth. The flushing rate is estimated to be approximately 9 times per year (Horsely Witten Group, 2013).

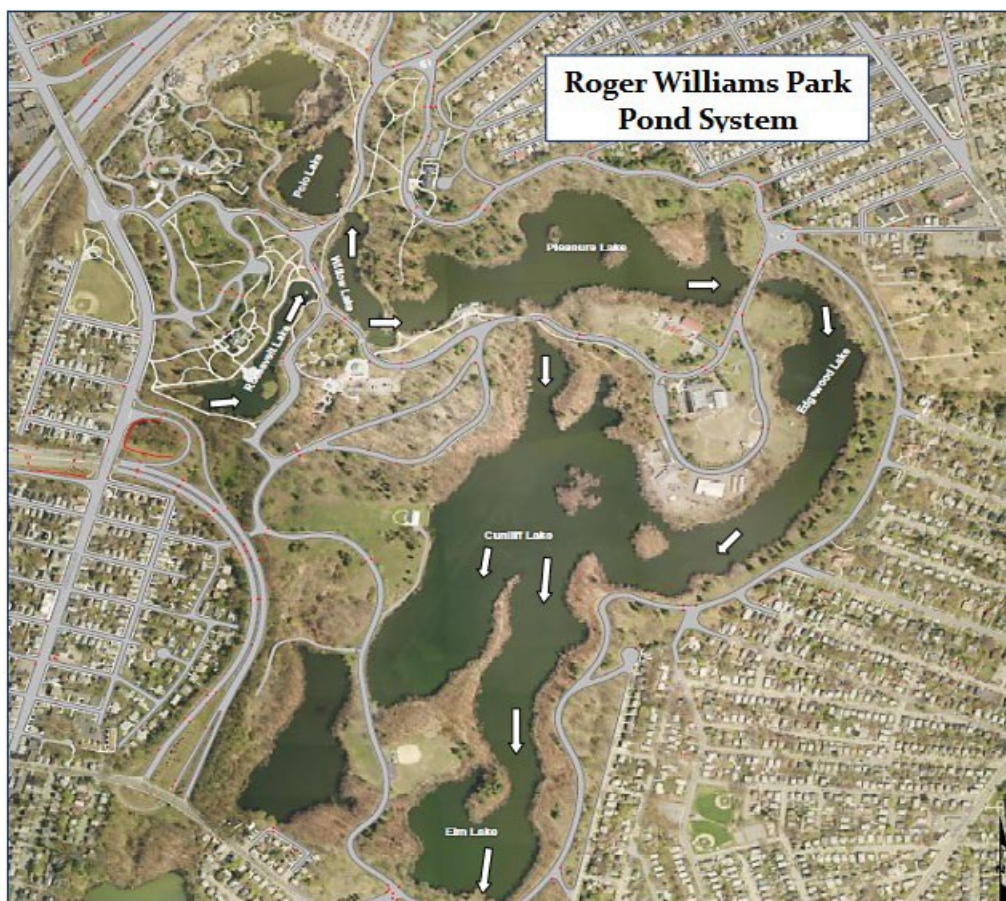


Figure 1: Arial overview of the Roger Williams Park Pond System (Horsley Witten et al, 2013)
 Table 2: Roger Williams Park Pond characteristics (Horsley Witten et al, 2013)

Roger Williams Park Ponds Characteristics			
Pond	Average Depth (feet)	Area (Acres)	Direction of Flow
Roosevelt	1.3	3.8	West to East then North to South
Willow	2.0	3.4	South to North and North to South
Polo	2.3	3.6	South to North
Pleasure	2.6	18.6	West to East
Edgewood	3.0	19.3	North to South
Cunliff	4.3	32.3	North to South
Elm	4.3	21.7	North to South

The Roger Williams Park pond watershed consists of two parts: an upper watershed that feeds Tongue, Spectacle, and Mashapaug ponds, which are the source of Mashapaug brook which flows into the park ponds, and a lower watershed around the ponds themselves. Both the upper and lower watersheds are highly developed and over 80% of the watershed classified high density residential, commercial, industrial, or mixed commercial/industrial and less than 20% forest, wetland, or water (RIDEM, 2007).

Impervious surface covers half of the total watershed area (Horsely Witten Group, 2013).

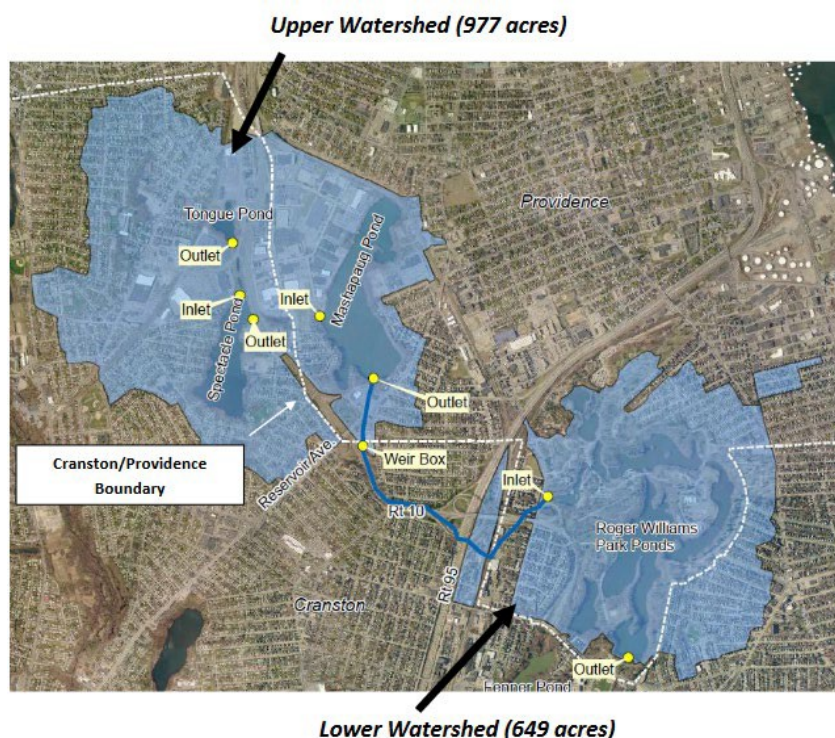


Figure 2: Roger Williams Park pond subwatershed areas (Horsley Witten et al, 2013)

Untreated runoff and dense development in the watershed have negatively impacted the water quality of the park's ponds over the years and led to high nutrient levels and historical concentrations of phosphorus increased significantly in the 1980s and averaged 85 ug/L in the summer at the inlet (Roosevelt Lake), 56 ug/L in the spring and 55 ug/l in the fall. Outlet concentrations (Cunliff Lake) have historically measured higher averaging 104, 76, and 61 ug/L in the summer, spring and fall respectively (table 3). It should be noted that while historically inlet concentrations of TP trended lower than outlet concentrations the sampling was never paired making any conclusions of the sampling difficult. The nutrient levels have in recent years led to highly eutrophic conditions and frequent algal blooms. The park has attempted to manage the algal blooms with copper sulfate treatment, and more recently, stormwater best management practices (BMPs) such as infiltration basins, shoreline restoration, and goose population control.

Table 3: Historical total Phosphorus monitoring results from various sources

Roger Williams Park Ponds Historical Total Phosphorus Monitoring Results (ug/L)					
Source	Date	Roosevelt Lake	Cunliff Lake	Elm Lake	Elm Lake outlet
Lee Pare and Associates	December 1979	15			22
Lee Pare and Associates	June 1980	115			301
URIWW	1993	65			
RIDEM TMDL	summer 1993	85			
RIDEM TMDL	fall 1993	44			
RIDEM TMDL	spring 1994	56			
RIDEM TMDL	summer 1994	85			
RIDEM TMDL	fall 1994	65			
URIWW	1994	69			
RIDEM TMDL	spring 2001		70		
RIDEM TMDL	summer 2001		78		
RIDEM TMDL	fall 2001		81		
RIDEM TMDL	spring 2002		31		
RIDEM TMDL	summer 2002		122		
RIDEM TMDL	fall 2002		40		
RIDEM TMDL	spring 2003		127		
RIDEM TMDL	summer 2003		113		
URIWW	2003		120		
URIWW	2005			97	
URIWW	2012		87	82	

Sampling/Monitoring Methods:

The objective in this study was to attain real-time water quality information and hydraulic data over an extended range of time. A new monitoring plan and instrumentation installation were implemented to obtain hydraulic performance. Existing flumes were used at influent (Seal House) and effluent locations (Cunliff Dam) as a flow monitoring and sampling locations (figure 3). For the inlet location: Water was pumped from an intake location just below the dam weir in Roosevelt Pond into the Seal House and through a flow cell containing a UV-Vis spectrometer (spectro::lyser V3). A similar installation was used at the outlet location just below the Cunliff lake outfall. The influent location was also instrumented with a rain gage. The full instrumentation setup is shown in figure 4.

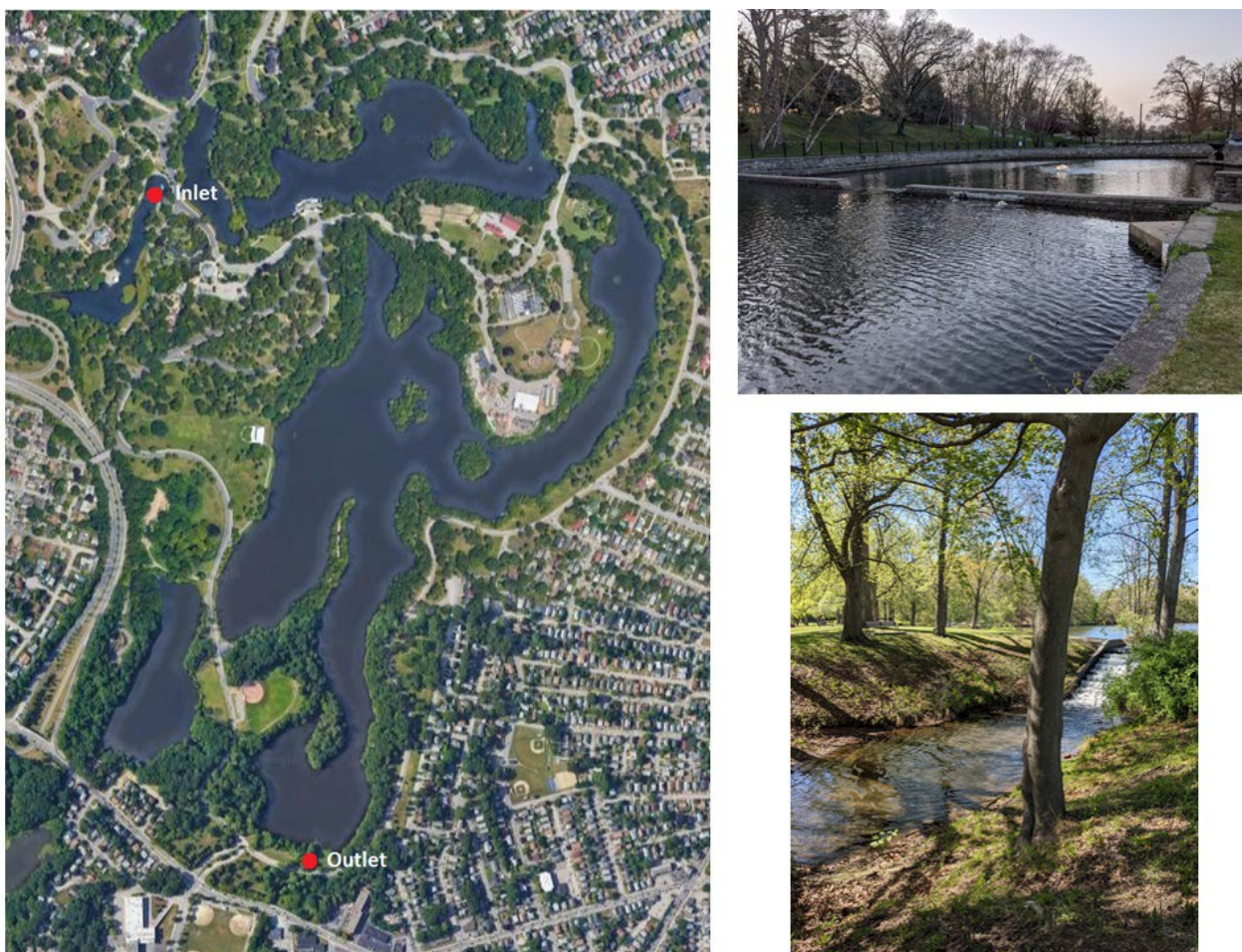


Figure 3: Clockwise from left: The Roger Williams Park ponds with inlet and outlet monitoring locations marked, the inlet weir, spillway at park pond outlet.

The spectrometers recorded measurements at 1-hour intervals through the duration of the study. In addition, we collected grab samples at the influent (table 1) and effluent (table 2) locations.

Grab samples were collected by hand directly into appropriately prepared bottles at the same sites as the continuous sampling water intakes. These samples were later analyzed for nitrates, phosphates, ammonium, total nitrogen, and total phosphorus by the University of Rhode Island Watershed Watch laboratory in accordance with the URI WW Analytical Laboratory QAPP.



Figure 4: Outlet instrumentation

Water levels at the inlet and outlet were measured using an Onset HOB0 U20L Data Loggers. At the inlet the logger was mounted in a stilling well attached to the sidewall slightly upstream of the dam in Roosevelt pond. We took regular measurements to establish a relationship between HOB0 logger water level and water depth over the dam weir. Flow was then calculated using depth of water over the weir and the weir geometry. At the outlet the logger was mounted in a stilling well attached to the channel side just above the pond outfall. Since the outlet geometry was unconventional, regular flow measurements were taken with a Pygmy current meter and counter. These flow measurements along with the corresponding water levels measured with the ONSET HOB0 U20L Data Loggers were used to build a stage/discharge curve for the outlet and calculate flow.

Water level was recorded at 5-minute intervals and coupled with periodic flow measurements to calibrate influent and effluent modeling results.

Partial Least Squares Regression

Partial least squares regression (PLSR) is a multivariate statistical method suited for determining the linear regression of a data set with limited observed values (lab results) paired with a high number of predictor values (absorbance data). The resulting regression equation is in the form of an ordinary linear equation or a first-degree polynomial with all 205 spectral predictor variables rather than one in the case of an ordinary linear equation. Equation 1 shows the general linear form of the PLSR. The sum of the products for all absorbance spectra from $I = 1$ to n of the linear coefficients (b) and the absorbance values (x) plus the y-intercept (a) is the predicted response (y).

$$y = a + \sum_{i=1}^n b_i x_i \quad (\text{Eqn. 1})$$

Calibration:

We used accredited laboratory derived analyte concentration results from the periodic grab samples taken to further calibrate the spectrometer results (tables 4 and 5).

Below is a list of grab sample calibration data used to adjust s-can fingerprint data

Table 4: influent calibration samples

Upstream - Roosevelt Lake outlet at Seal House						
	ppb NO3-N	ppb Amm-N	ppb TN	ppb PO4-P	ppb TP	
5/26 1200	50	167	959	15	7	fair
5/28 2000	55	84	955	17	42	storm
5/28 2100	56	79	1125	21	52	storm
5/29 1800	130	166	744	16	51	storm
5/29 1900	142	156	711	17	55	storm
5/30 1500	108	169	657	10	22	storm
7/2 1300	12	118	580	6	52	fair
7/9 1100	77	151	842	17	93	storm
7/9 1200	97	134	731	15	83	storm
7/9 1400	99	142	659	23	86	storm
7/13 1900	62	84	637	4	45	fair
7/27 1600	18	52	672	5	47	fair

Table 5: effluent calibration samples

RWP outflow stream at bridge						
	ppb NO3-N	ppb Amm-N	ppb TN	ppb PO4-P	ppb TP	
5/26 1300	below detection	53	757	15	32	fair
5/28 2000	below detection	57	842	16	29	storm
5/28 2100	below detection	81	744	19	28	storm
5/29 1800	below detection	54	723	17	42	storm
5/29 1900	below detection	84	737	15	28	storm
5/30 1500	below detection	NA	761	15	30	storm
7/2 1300	18	22	1040	6	64	fair
7/9 1100	26	NA	932	50	65	storm
7/9 1200	20	19	864	7	56	storm
7/9 1400	16	19	879	6	63	storm
7/13 1900	15	54	1028	4	85	fair
7/27 1600	15	16	1110	6	47	fair

Results

There was a 6-month period of reliable monitoring results, with a few gaps resulting from monitoring system failures such as clogged sampling lines. We evaluated the influent and effluent locations for a range of parameters including rainfall, flow, and concentrations of TSS, TP, TN and DOC (figure 5). We also calculated flux (mass) of each pollutant at both locations using the concentration and flow data (figure 6). Vertical pink lines denote instrument cleaning and calibration events, and vertical drops in data lines likely denote fouling of the optical lens which resulted in measurements outside of the calibrated bounds of the instrument. After cleaning and calibration events the measurements return to common trendline values.

Long term hyetograph, pollutograph and mass flux results.

The flow data showed a trend of greater outflow than inflow in the months of June-July, fairly balanced flows in August, and the reverse trend of greater inflow than outflow in September. This could indicate groundwater contributions to the pond system early in the year, and infiltration to groundwater later in the year. Rainfall was much more predictive of influent flows (with high rainfall periods leading to high influent flows) than it was of effluent flows. Since there are multiple ponds for water to flow through between the influent and the effluent attenuation of spikes in inflow at the outlet was expected.

However, even considering the attenuation effluent flows did not correlate well with influent flows or rain events, indicating that sources of water other than the influent, such as groundwater, likely contribute to the system.

Generally, particularly in sewerred watersheds such as this one, groundwater would be expected dilute nutrient concentrations, and not be a source of phosphorus loading.

Pollutant concentration data (figure 5) showed influent concentrations of phosphorus trended higher than effluent concentrations whereas the opposite trend occurred for nitrogen (figure 5).

Long term pollutant mass data (figure 6) show initial influent fluxes of phosphorus and nitrogen were observed during the early summer rainfall period (June). Effluent mass flux remained higher than influent mass flux for much of the monitoring period. The overall trend of phosphorus concentrations at the outlet was similar to the inlet (although inlet concentrations were much more variable) so the increase in mass flux is likely due to the greater flow volume. Since phosphorus inputs from groundwater are unusual, the consistency in phosphorus concentrations at the outlet could be an indication of internal loading driven by anoxic sediments releasing phosphorus into the water column.

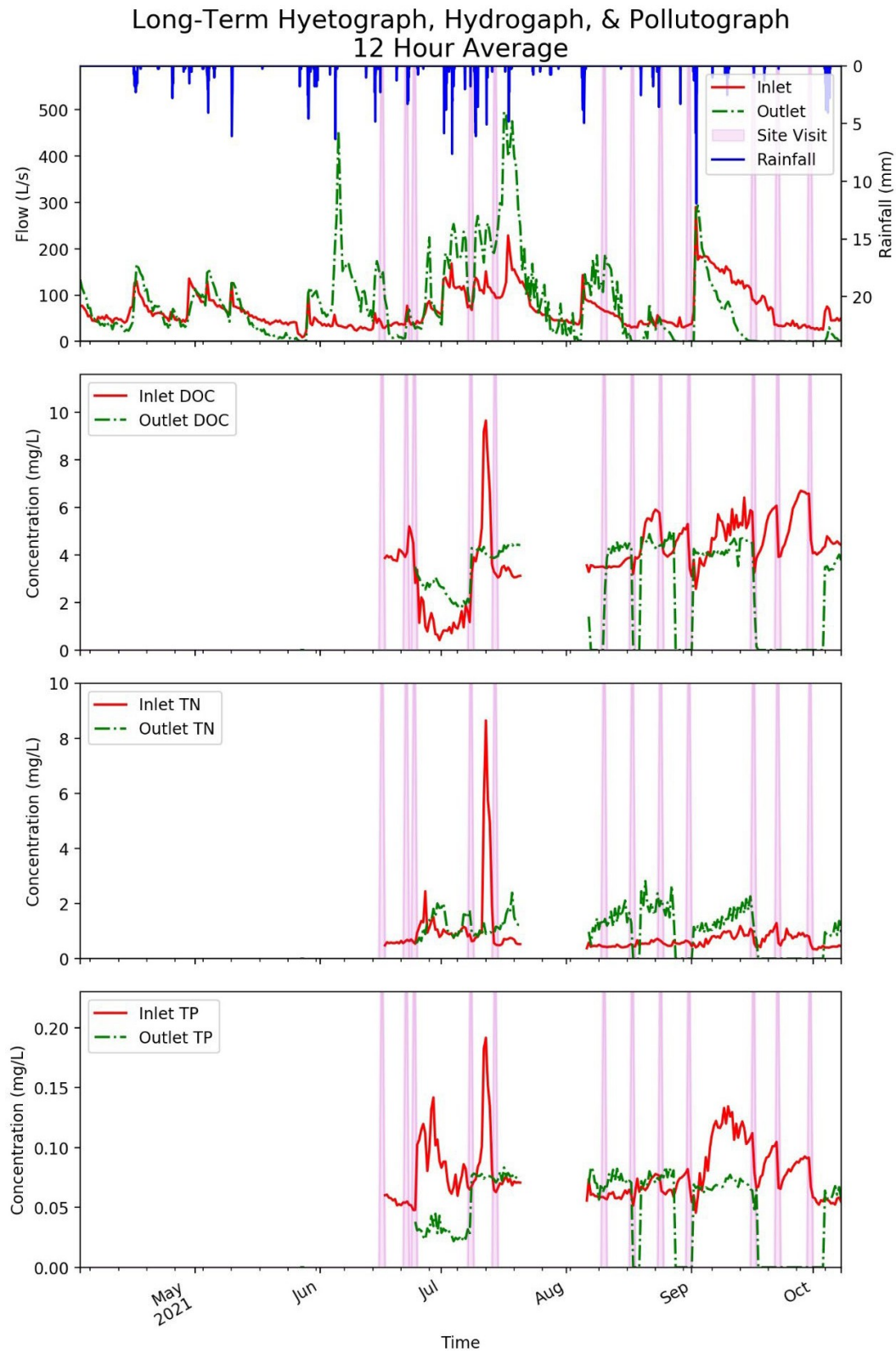


Figure 5: real-time concentration data for the period of monitoring.

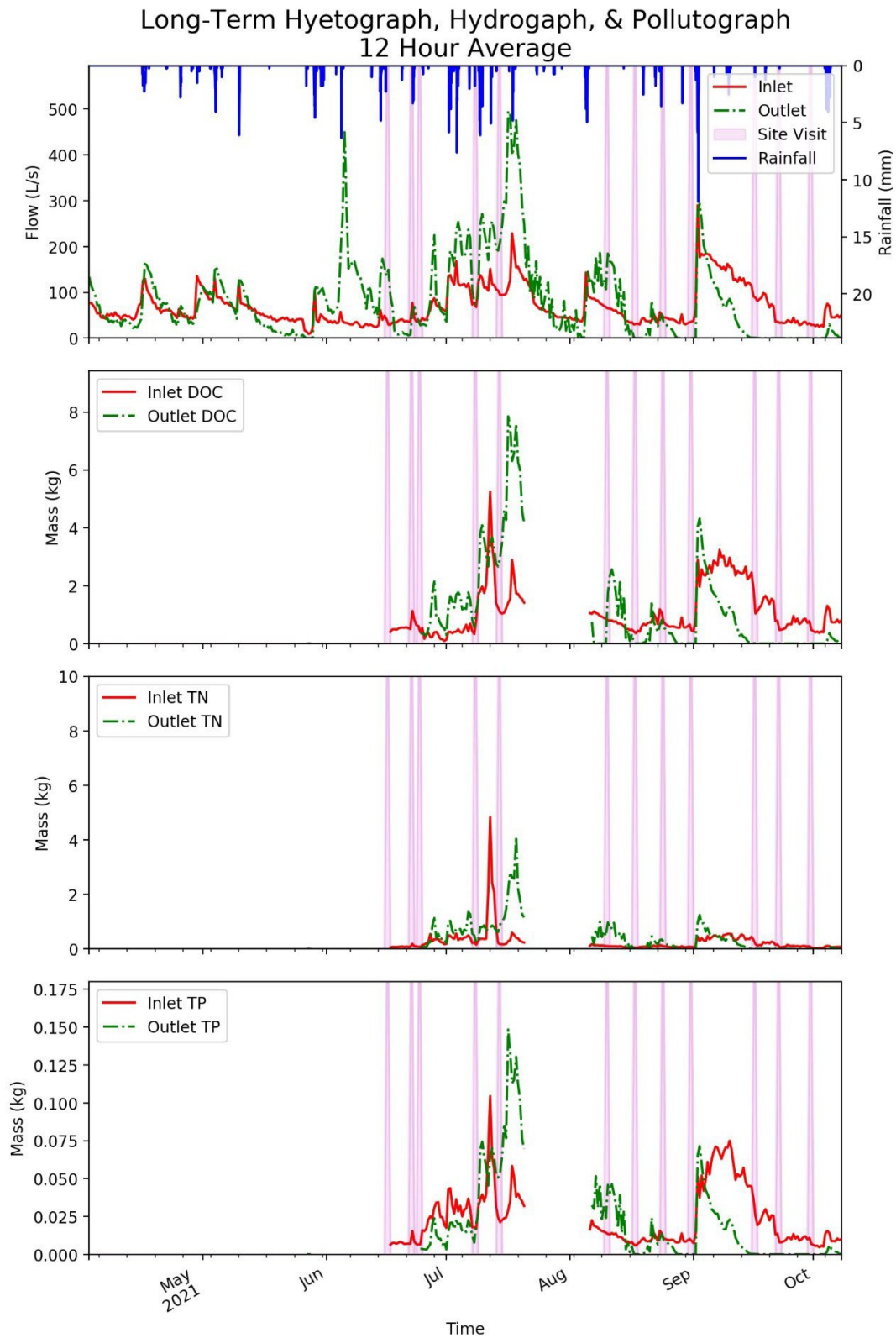


Figure 6: real-time mass data for the period of monitoring

Monthly hyetograph, pollutograph and mass flux results.

July concentrations results (Figure 7) showed a runoff induced spike in concentration of DOC, TN and TP. There was a subsequent flux for the same parameters (Figure 8) however mass fluxes may show artificial mass due to large groundwater contributions that would typically be lower in pollutant concentrations but add mass based on increased effluent flows during dry times toward the end of July.

July was followed by a period of little rain throughout the month of August (2.02 in) (Figure 9) and baseline concentrations of TN and TP in the influent monitoring location of around 0.52 mg/L TN and

0.07 mg/L for TP. Interestingly later storms were either too small or did not mobilize a significant enough load to alter baseline conditions. There were large diurnal fluctuations in flow and associated nitrogen concentrations with little change in TP between 8/7 and 8/17 that kept TN concentrations in the effluent location consistently above concentrations in the influent. See weekly results for further analysis (appendix C).

High levels of DOC concentrations suggest algal/cyanobacteria growth, diurnal patterns of TN concentration suggest possible nitrogen fixation, higher or consistent concentrations of TP suggest internal loading due to stratification or anoxic conditions that release internally sorbed phosphorus from the benthic sediments.

September concentration results (figure 11) recorded a larger number of rain events (2.52 in), and a higher input of baseline concentration of TN and TP (0.78 mg/L and 0.09 mg/L respectively). Again, there was diurnal cycling of TN and TP in the influent locations possibly indicating daytime consumption and nighttime senescence of nutrient uptake (figure 15). This could also be an effect of variations in cyanobacteria being discharged at the outlet as they move up and down in the water column in response to light levels and nutrient availability (Ganf and Oliver, 1982)). Where effluent concentrations of TN were higher than influent concentrations, influent TP and DOC were higher than effluent concentrations. Flows for both influent and effluent locations stabilized and exhibited a 2-week lag time suggesting evidence of an internal time of concentration. The flow monitoring in September showed predictable rainfall response patterns and did not exhibit any of the possible groundwater contributions documented at the outlet in the previous month. Mass flux values did not show any noteworthy results and are not shown but can be found along with all long term monthly data in the appendices to this report.

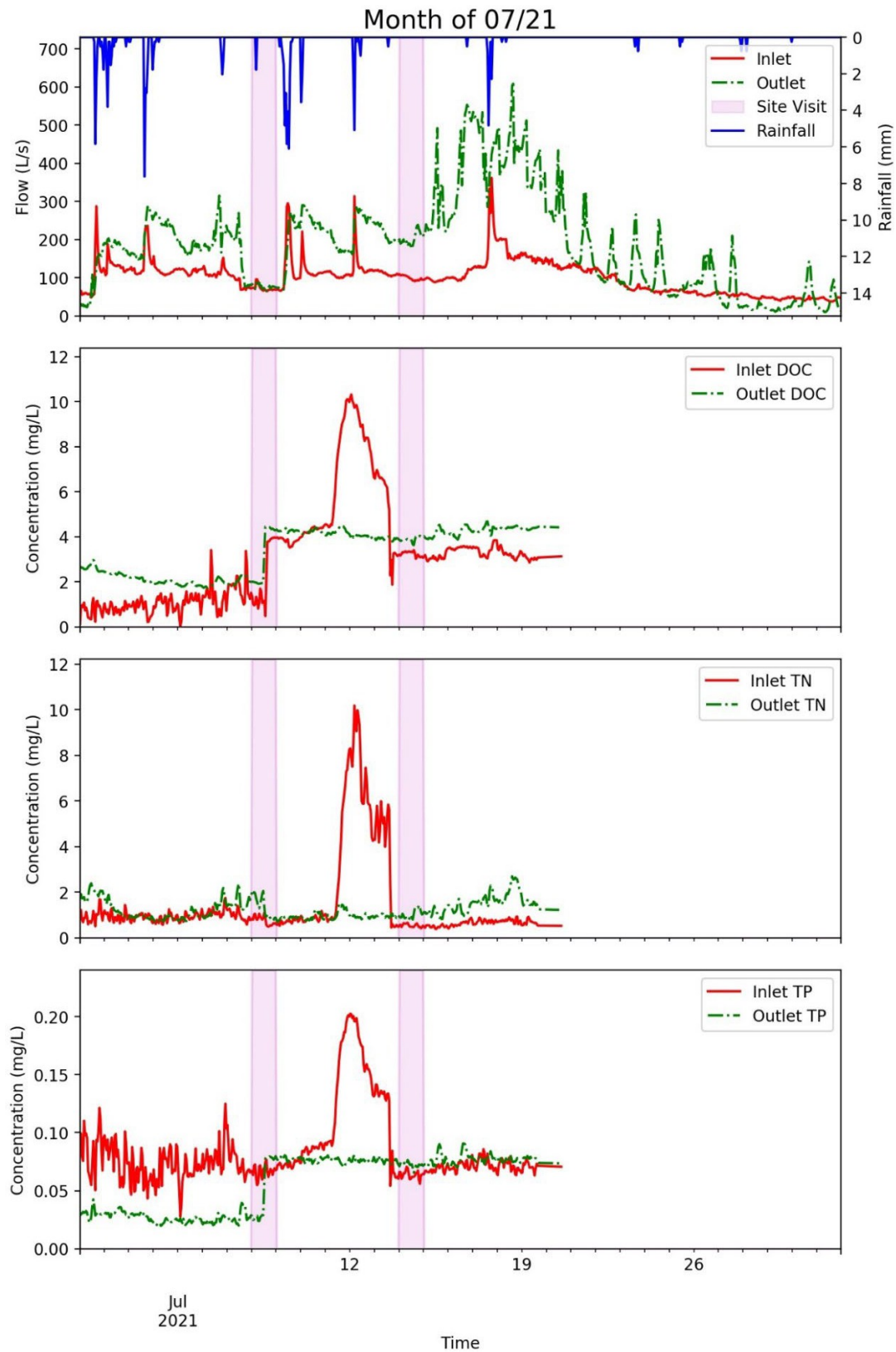


Figure 7: Monthly summary of real-time concentration data for targeted events.

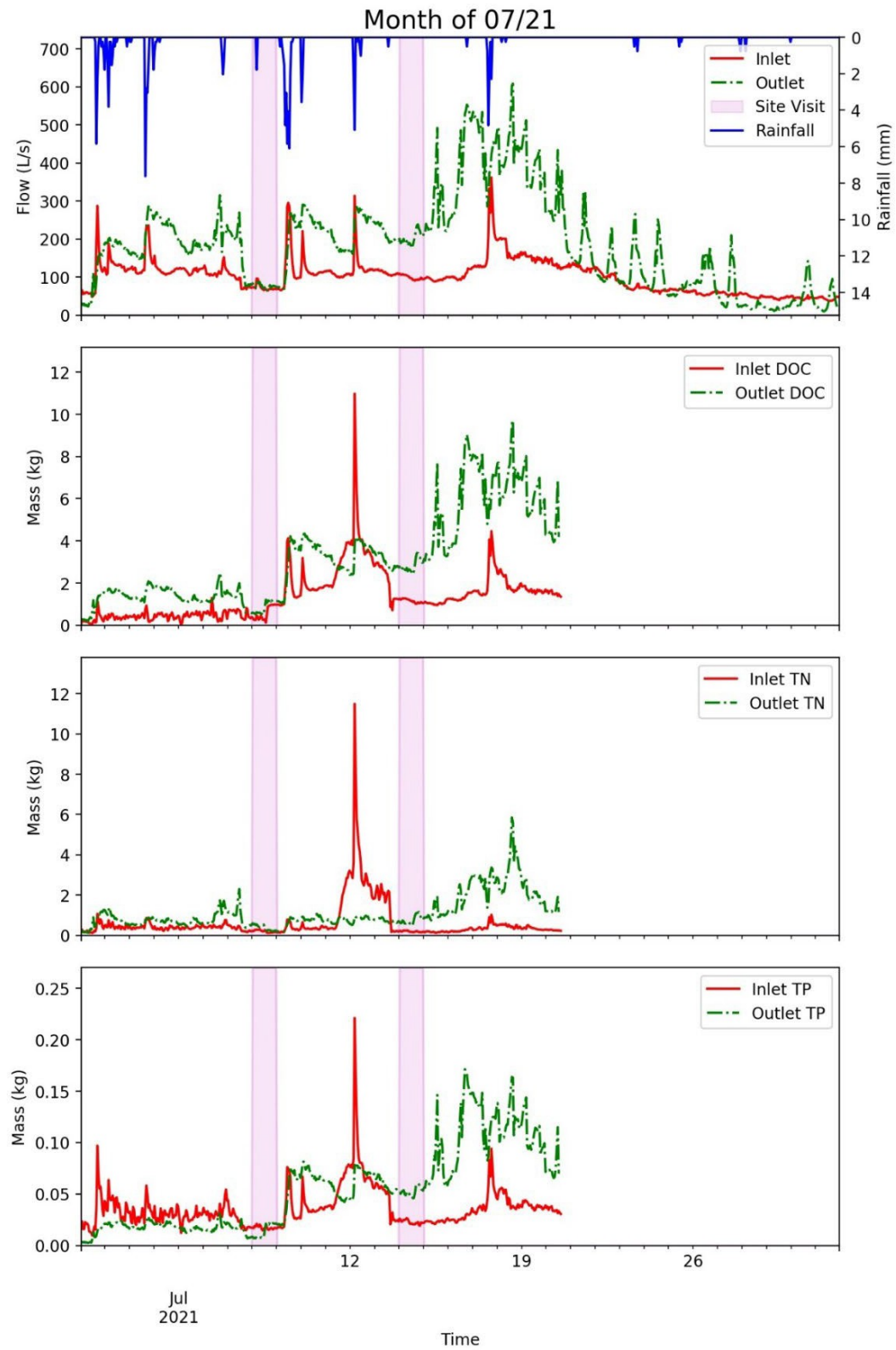


Figure 8: Monthly summary of real-time mass data for targeted events.

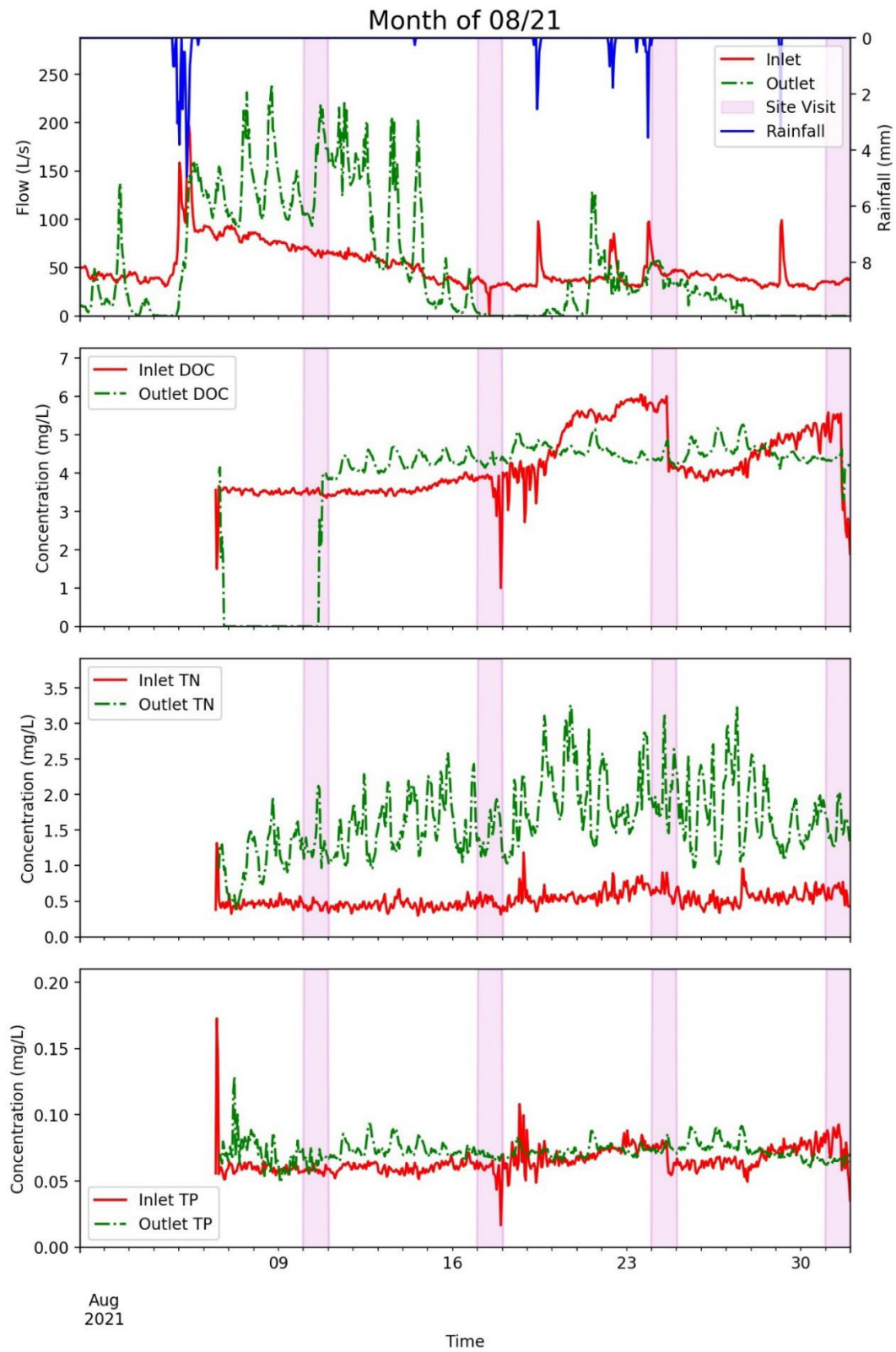


Figure 9 August concentration patterns

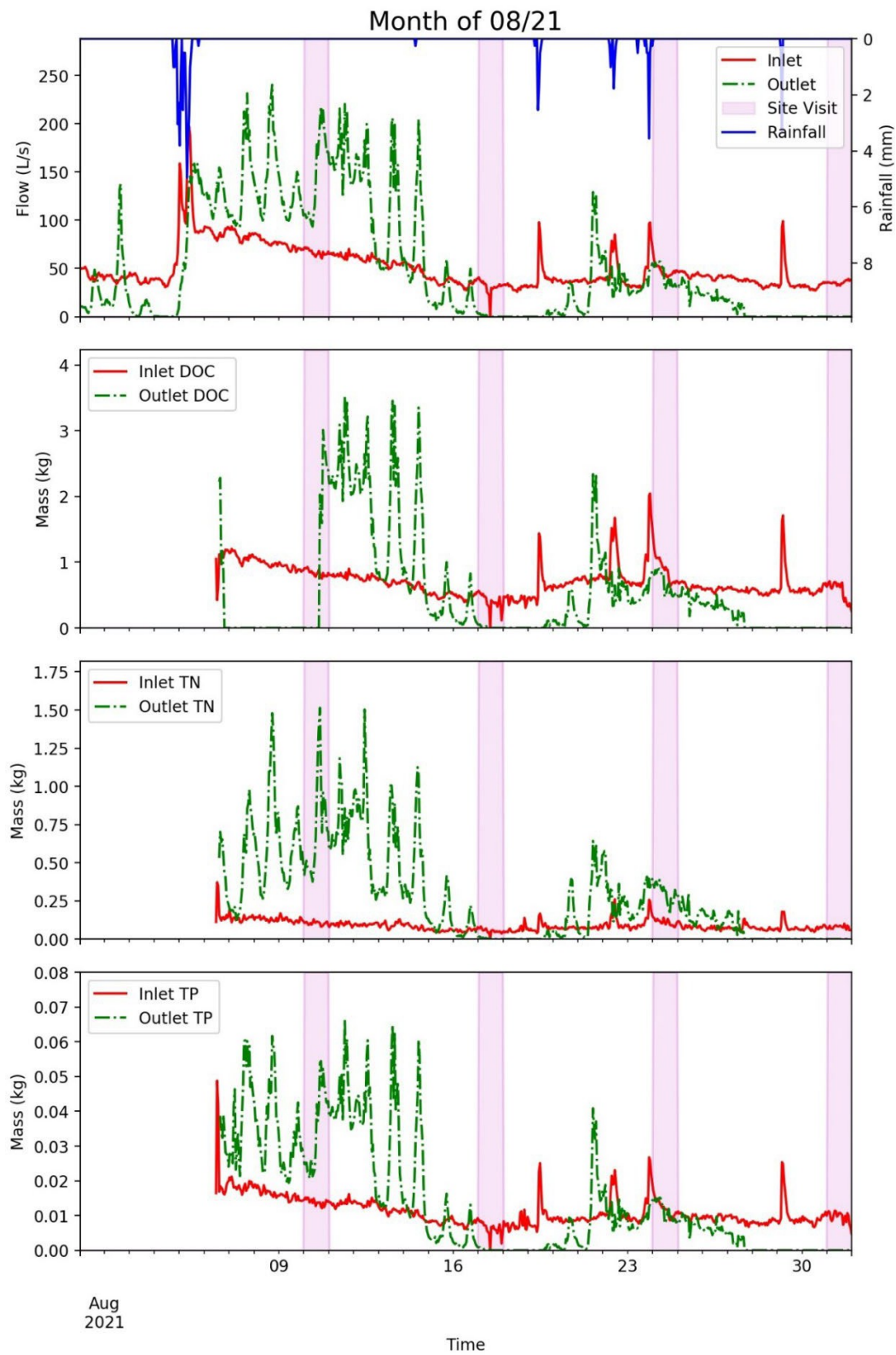


Figure 10: August mass flux patterns

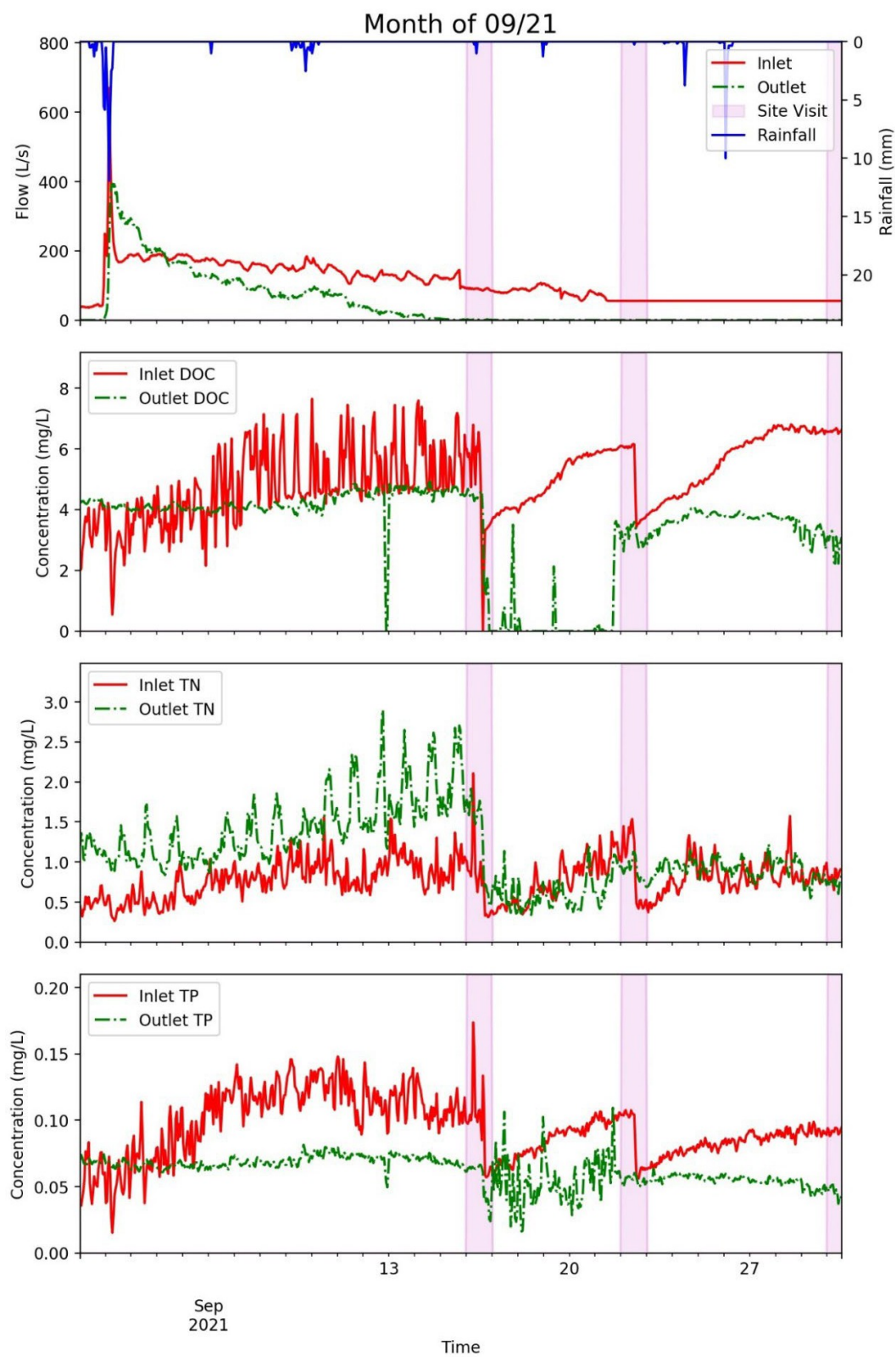


Figure 11: September concentration patterns

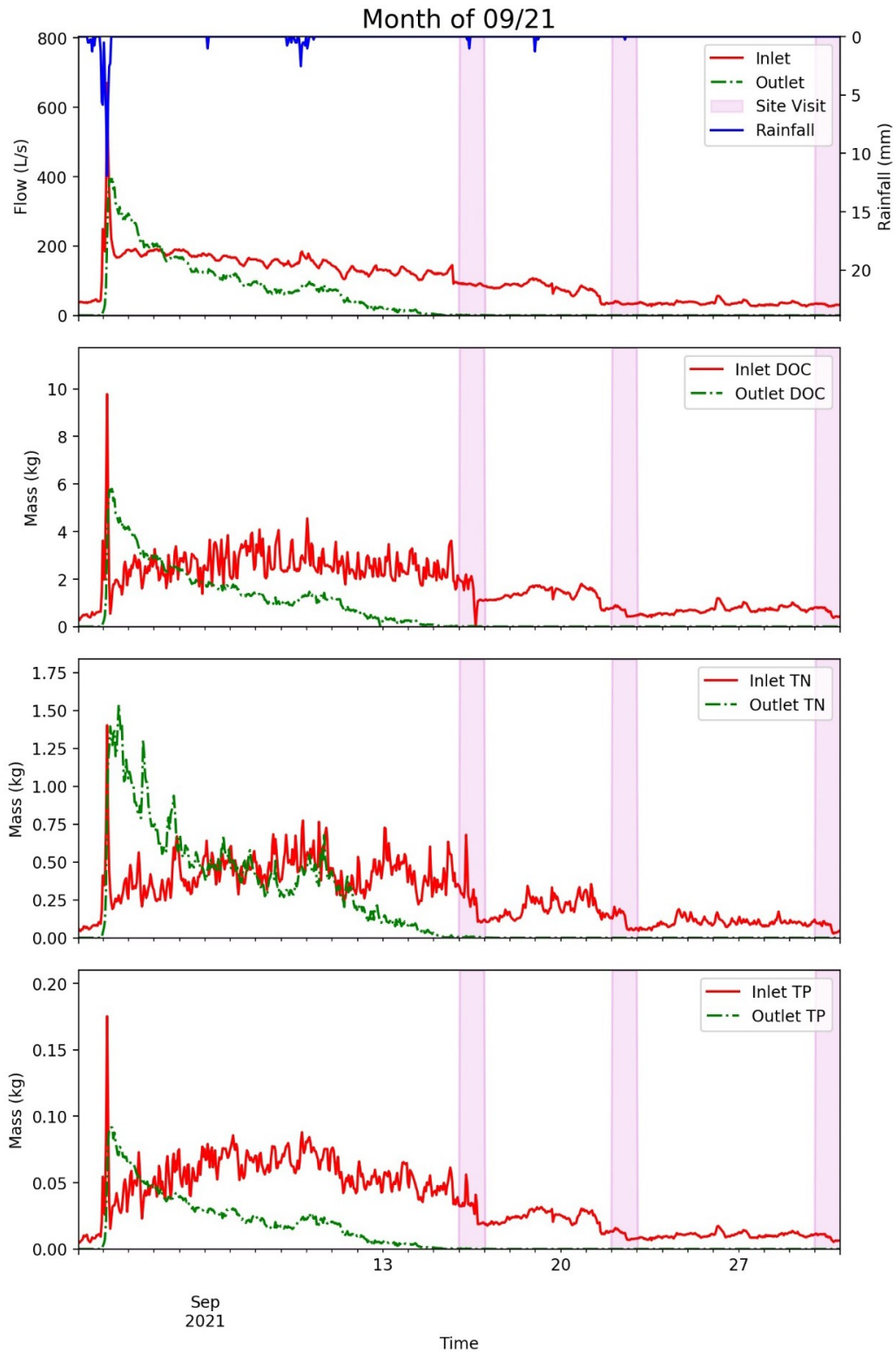


Figure 12: September mass flux patterns

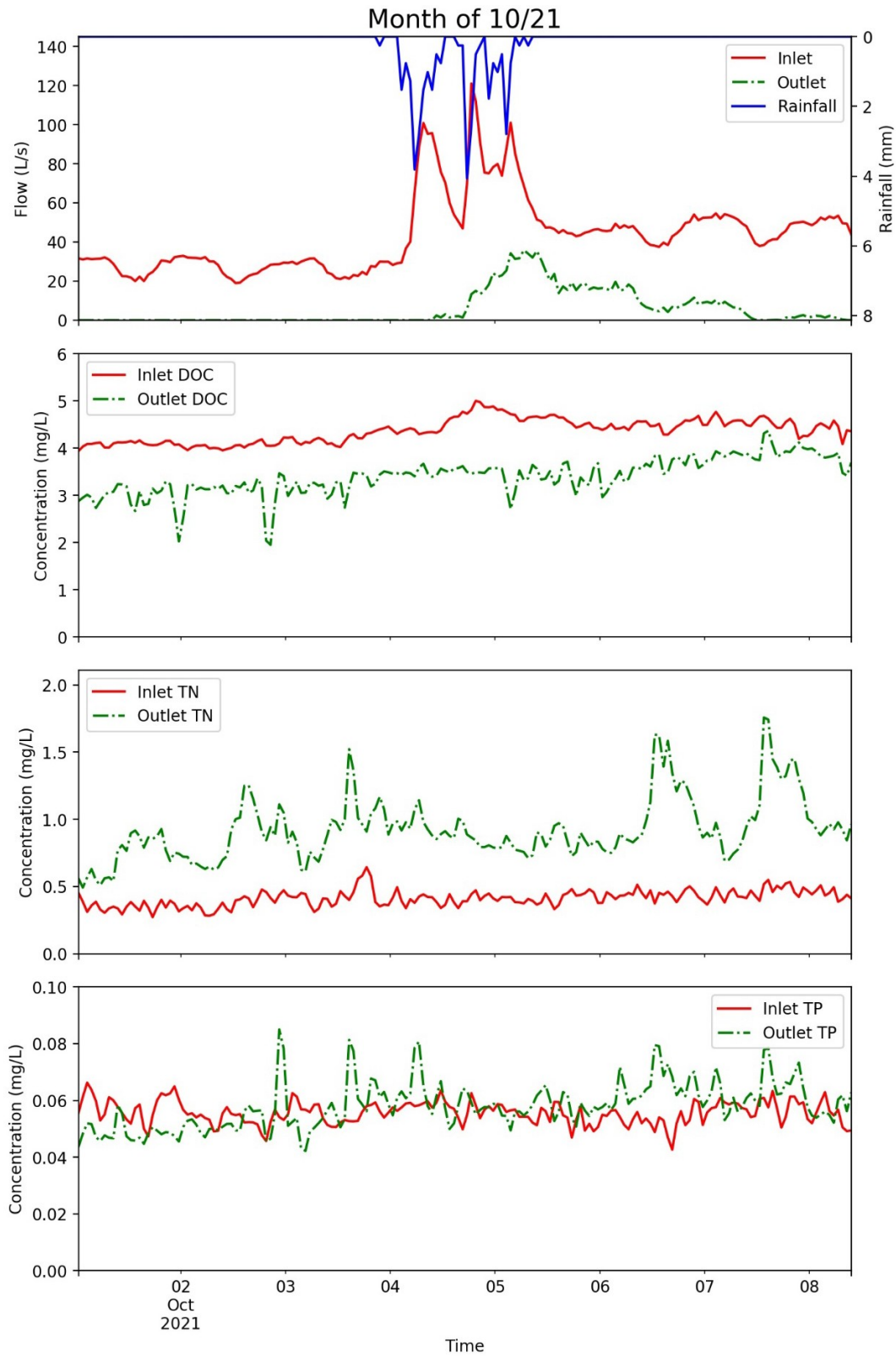


Figure 13: October concentration patterns

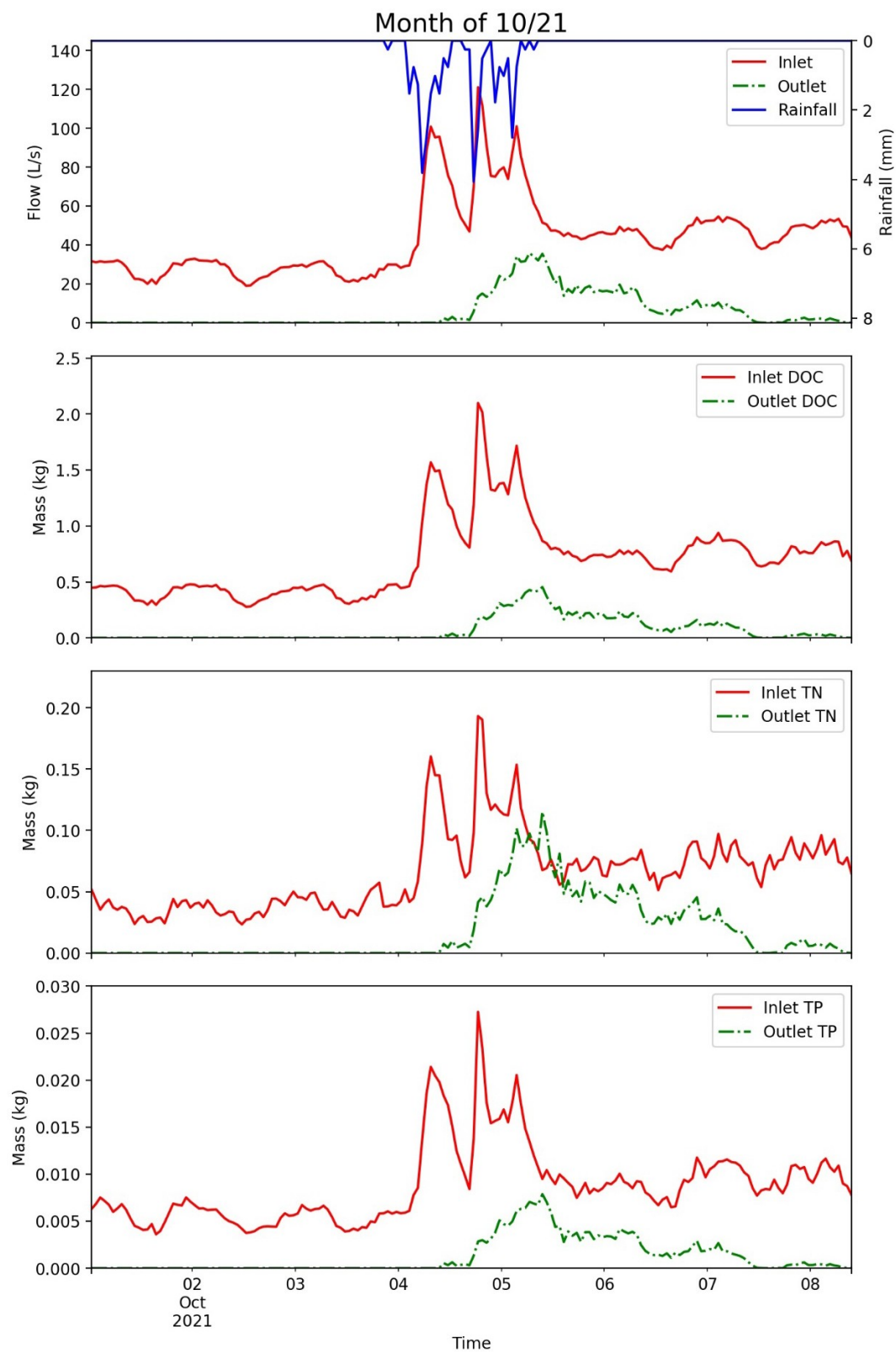


Figure 14: October mass flux patterns

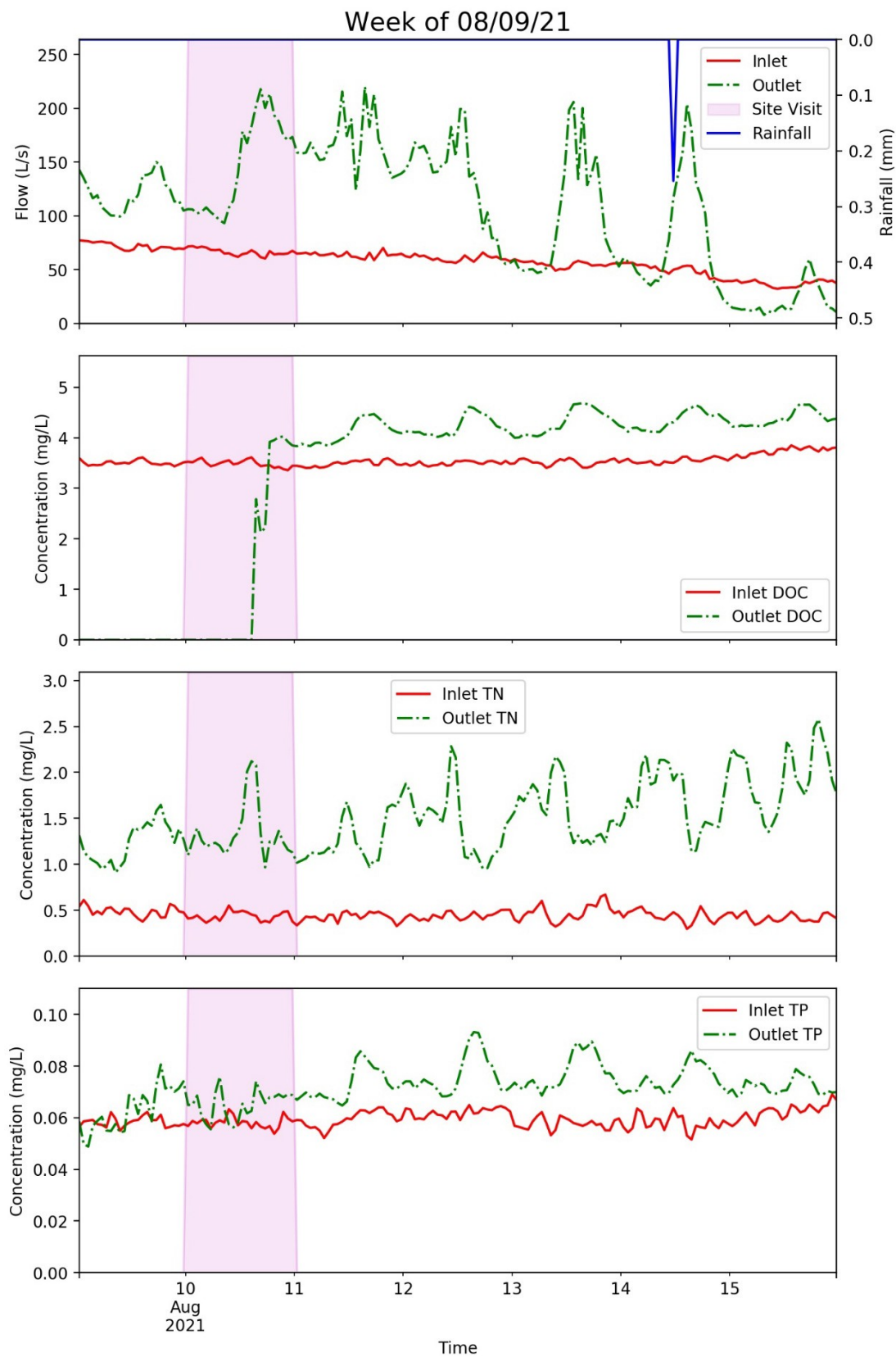


Figure 15: Week of 8/9/21 concentration patterns showing diurnal cycles.

Weekly (event-based) hyetograph, pollutograph and mass flux results.

There was a large concentration of TN and TP centered around the 7/12 rain event (Table 6). This represents an early runoff influenced source of nutrients that likely influenced future water chemistry.

Early summer rainfall events showed event-based inputs of higher pollutant concentrations (Table 6). Where inputs were higher, effluent concentrations remained relatively consistent.

Table 6: Event based influent and effluent concentrations

Event	Start Date	Total Rainfall (in)	Mean Inflow (gpm)	Mean Outflow (gpm)	Total Inflow (gal)	Total Outflow (gal)	Mean Inlet UV-Vis DOC (mg/L)	Mean Outlet UV-Vis DOC (mg/L)	Mean Inlet UV-Vis TN (mg/L)	Mean Outlet UV-Vis TN (mg/L)	Mean Inlet UV-Vis TP (mg/L)	Mean Outlet UV-Vis TP (mg/L)
16	2021-07-10 00:34:00	0.23	1,798	3,444	5,502,346	10,539,043	5.99	4.23	2.42	0.99	0.12	0.08
17	2021-07-12 03:34:00	0.35	2,055	3,933	4,192,785	8,023,851	7.84	3.98	6.28	0.94	0.15	0.08
18	2021-07-17 14:34:00	0.39	3,714	6,518	3,119,643	5,475,201	3.54	4.36	0.71	1.75	0.07	0.08
	Totals	0.97			12,814,774	24,038,095						

Overall concentrations varied throughout the study but consistently showed influent concentrations higher in phosphorus and lower in nitrogen (Table 7). Also of note, average concentrations in both influent and effluent locations exceeded the 0.025 mg/L total phosphorus limit established by the state (RIDEM, 1997) for any lake, pond, kettle hole, or reservoir. The 0.025 mg/L criterion was used as the target concentration for shallow ponds (5m< in depth) in the original total maximum daily load (TMDL) established for Roger Williams Park ponds (RIDEM, 2007).

Table 7: Influent and effluent monthly averages of pollutant concentrations throughout the study

	Total Rainfall (in)	Mean Inflow (gpm)	Mean Outflow (gpm)	Total Inflow (gal)	Total Outflow (gal)	Mean Inlet UV-Vis DOC (mg/L)	Mean Outlet UV-Vis DOC (mg/L)	Mean Inlet UV-Vis TN (mg/L)	Mean Outlet UV-Vis TN (mg/L)	Mean Inlet UV-Vis TP (mg/L)	Mean Outlet UV-Vis TP (mg/L)
Min	1.64	651	731	28,109,396	31,572,729	2.90	2.88	0.52	1.13	0.07	0.03
Max	4.21	1,608	2,932	71,778,966	130,889,827	5.01	3.76	1.37	1.64	0.09	0.07
Median	2.02	933	923	41,108,568	41,145,295	4.20	3.40	0.78	1.23	0.08	0.06
Average	2.36	1,040	1,141	42,068,773	49,495,508	3.91	3.35	0.79	1.23	0.08	0.06

While some temporal trends were observed, the event average concentrations and mass flux stayed consistent throughout the study (table 8). Influent concentrations of TP were generally higher (29%) with an average influent concentration of 0.08 mg/L and effluent concentration of 0.06 mg/L. Over the study period the total influent TP mass was generally higher than the effluent TP mass with average influent TP mass (4.19lbs) and average effluent TP mass (2.94 lbs). The trend was the opposite for TN with effluent concentrations of TN generally higher with an average influent concentration of 1.15mg/L and effluent concentration of 1.34 mg/L and average influent TN mass (52.53 lbs) and an average effluent TN mass of 60.78 lbs. Phosphorus reductions indicate increased algae growth and incorporation of TP into biomass and DOC and nitrogen generation may be an indication of nitrogen fixation by cyanobacteria.

Table 8: Overall influent and effluent statistics for concentrations and mass of monitored constituents

	Mean Inlet UV- Vis DOC (mg/L)	Mean Outlet UV-Vis DOC (mg/L)	Mean Inlet UV- Vis TN (mg/L)	Mean Outlet UV-Vis TN (mg/L)	Mean Inlet UV- Vis TP (mg/L)	Mean Outlet UV-Vis TP (mg/L)	Total Inlet UV- Vis DOC (lb)	Total Outlet UV-Vis DOC (lb)	Total Inlet UV- Vis TN (lb)	Total Outlet UV-Vis TN (lb)	Total Inlet UV- Vis TP (lb)	Total Outlet UV-Vis TP (lb)
Min	0.78	1.92	0.43	0.56	0.05	0.02	13.89	6.82	2.08	1.11	0.22	0.07
Max	7.84	4.67	6.28	2.14	0.15	0.08	942.54	648.20	231.64	174.17	20.70	10.52
Median	4.41	4.25	0.68	1.35	0.07	0.07	98.67	116.93	22.48	63.09	2.30	2.03
Average	4.11	3.82	1.15	1.34	0.08	0.06	197.04	177.55	52.53	60.78	4.19	2.94

Comparison of 2021 data to historic trends

Comparing 2021 real-time data summaries for influent and effluent locations (*Table 8*) to historic monitoring data used to develop the TMDL (*Table 3*), there has been a 50% reduction in the summer average TP concentrations at the outlet versus historic data. Average concentrations for the summer inlet and fall outlet locations appeared similar to historic trends whereas average fall inlet concentrations recorded a 27% increase from historic trends. It is difficult to compare grab sampling to continuous monitoring data, which is statistically more robust, however the 50% reduction in summer TP averages seems significant and is likely due to the major in-park installations of stormwater management controls.

Table 9: Monthly concentration summaries for the constituents monitored

Month	Total Rainfall (in)	Mean Inflow (gpm)	Mean Outflow (gpm)	Total Inflow (gal)	Total Outflow (gal)	Mean Inlet UV-Vis DOC (mg/L)	Mean Outlet UV-Vis DOC (mg/L)	Mean Inlet UV-Vis TN (mg/L)	Mean Outlet UV-Vis TN (mg/L)	Mean Inlet UV-Vis TP (mg/L)	Mean Outlet UV-Vis TP (mg/L)
4	1.64	1,005	1,006	41,108,568	41,145,295						
5	3.16	933	923	41,632,183	41,188,470						
6	1.72	651	1,486	28,109,396	64,192,258	2.90	2.88	0.88	1.24	0.08	0.03
7	4.21	1,608	2,932	71,778,966	130,889,827	3.08	3.40	1.37	1.23	0.08	0.06
8	2.02	797	817	35,558,830	36,490,664	4.20	3.76	0.52	1.64	0.07	0.07
9	2.52	1,596	731	68,928,412	31,572,729	5.01	3.32	0.78	1.13	0.09	0.06
10	1.25	690	93	7,365,055	989,313	4.37	3.40	0.41	0.92	0.06	0.06

Table 10: Comparison of 2021 data TP data to historic trends, historical results derived from Table 3.

	2021 (mg/L)		Historic (mg/L)	
	Inlet	Outlet	Inlet	Outlet
Spring	NA	NA	0.056	0.076
Summer	0.08	0.05	0.085	0.104
Fall	0.08	0.06	0.055	0.061

The phosphorus concentration showed some distinct spikes in response to large rain events, most noticeably at the inlet but also to some extent at the outlet. Between storms, while the inlet concentrations dropped the outlet concentrations sometimes remained higher, which could point to some internal loading from sediments in summer months, as noted in the TMDL (RIDEM, 2007)

Conclusions:

While it is difficult to compare continuous monitoring data to limited grab sample data, it does appear that total phosphorus concentrations at the outlet of the Roger Williams Park ponds have decreased in comparison to historical data. This could be an indication that the management measures taken so far by the park have had some beneficial effects. However, both phosphorus and nitrogen concentrations remain high. Very high pulses of TP during storm events are seen at the inlet and indicate periods of external contributions from the large subwatershed areas outside of the parks control. There are also elevated levels of DOC indicating biomass production within the park ponds that lead to a slight reduction in average TP concentrations between the inlet at the outlet monitoring locations.

The park installed an impressive number of bioretention systems and infiltration basins to treat the runoff generated from impervious surfaces and runoff within the park itself, however the park is a small fraction of the ponds' total watershed. To significantly improve water quality and reduce algal blooms the park will also need to address ongoing high nutrient concentrations in the inflow that feeds the ponds and internal sources such as sediments. Managing inflow and sediment phosphorus concentrations with a treatment such as alum injection to lock up and settle influent phosphorus out of the water column may be necessary until upper watershed nutrient loading can be controlled. There are innovative methods that have been developed in the region for phosphorus inactivation where aluminum (Al) compounds were added from a self-propelled barges with water column applications of alum binders used as maintenance treatments, applied when needed (. to strip P from the water column to minimize algae blooms (Wagner, 2017).

While internal loading appears to be present in the park indicated by elevated phosphorus concentrations and mass flux during non-storm events alum injection alone will not solve the TP and cyanobacteria problems in the ponds. Prior to significant investments internal treatments in the park the significant external load contributions at the inlet need to be controlled.

Future studies

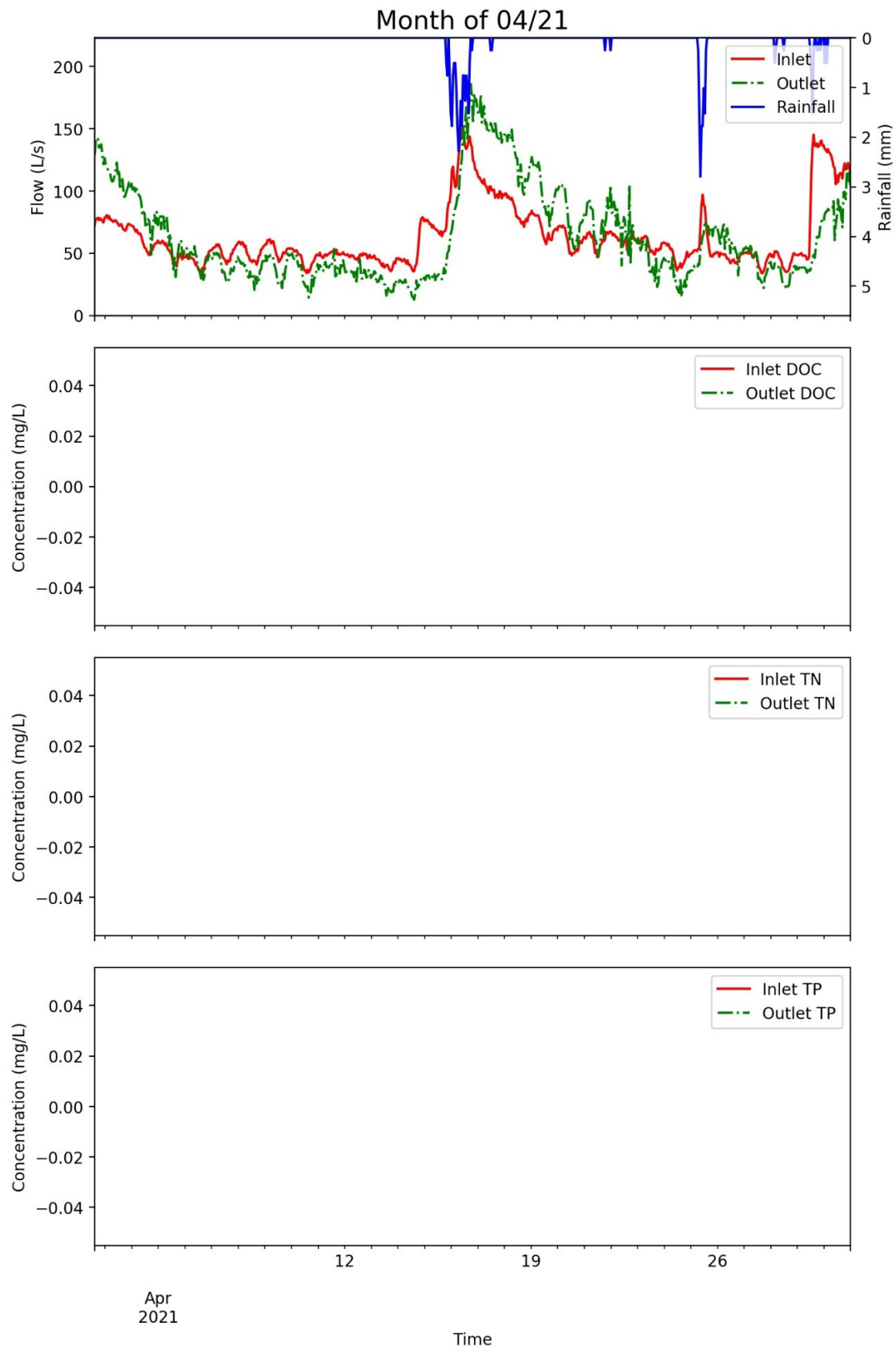
Due to the significant chemical treatment for algae (copper sulfate) the scrutiny or additional collection of real time data in response chemical treatments would be interesting to review.

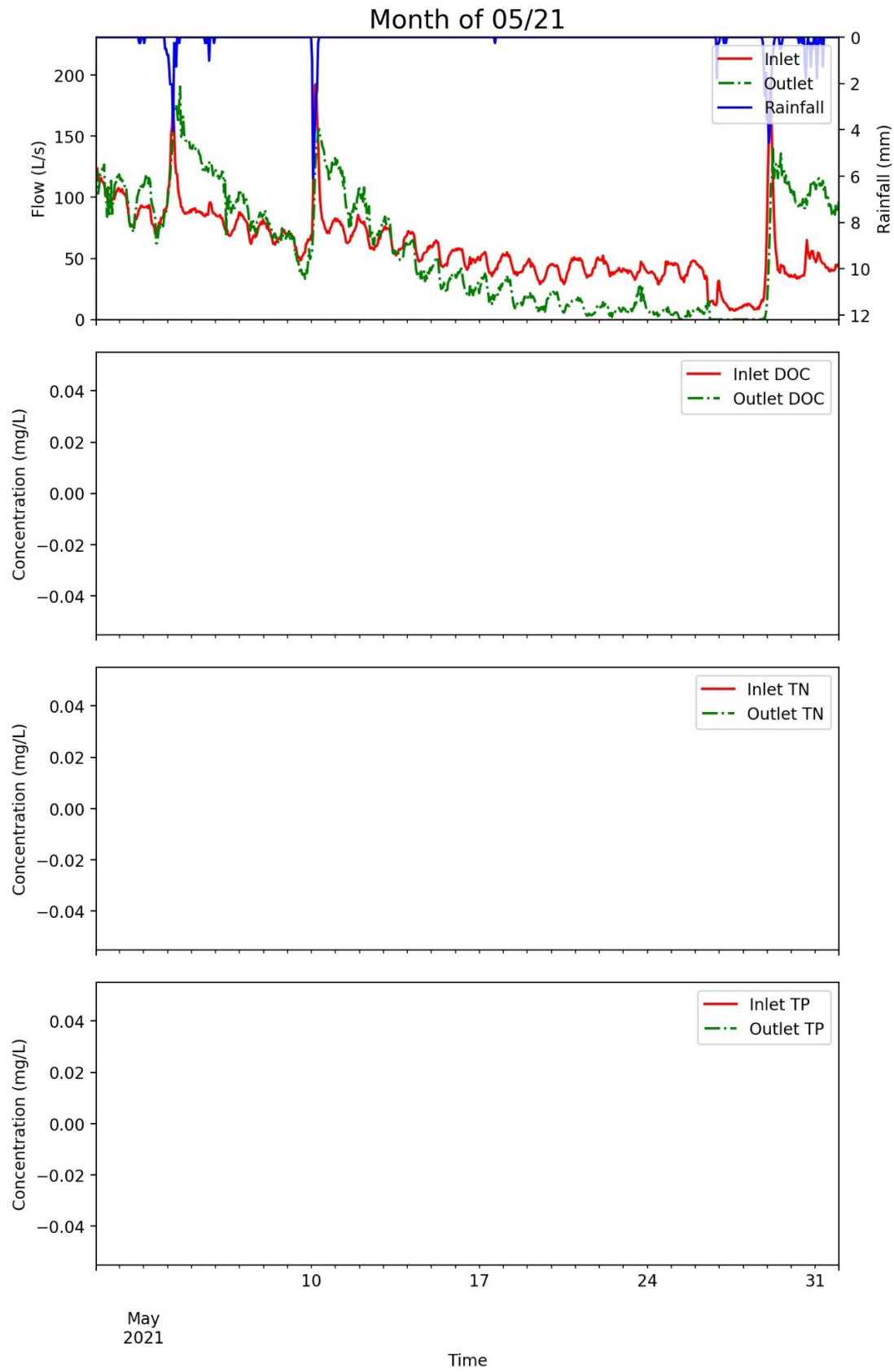
References

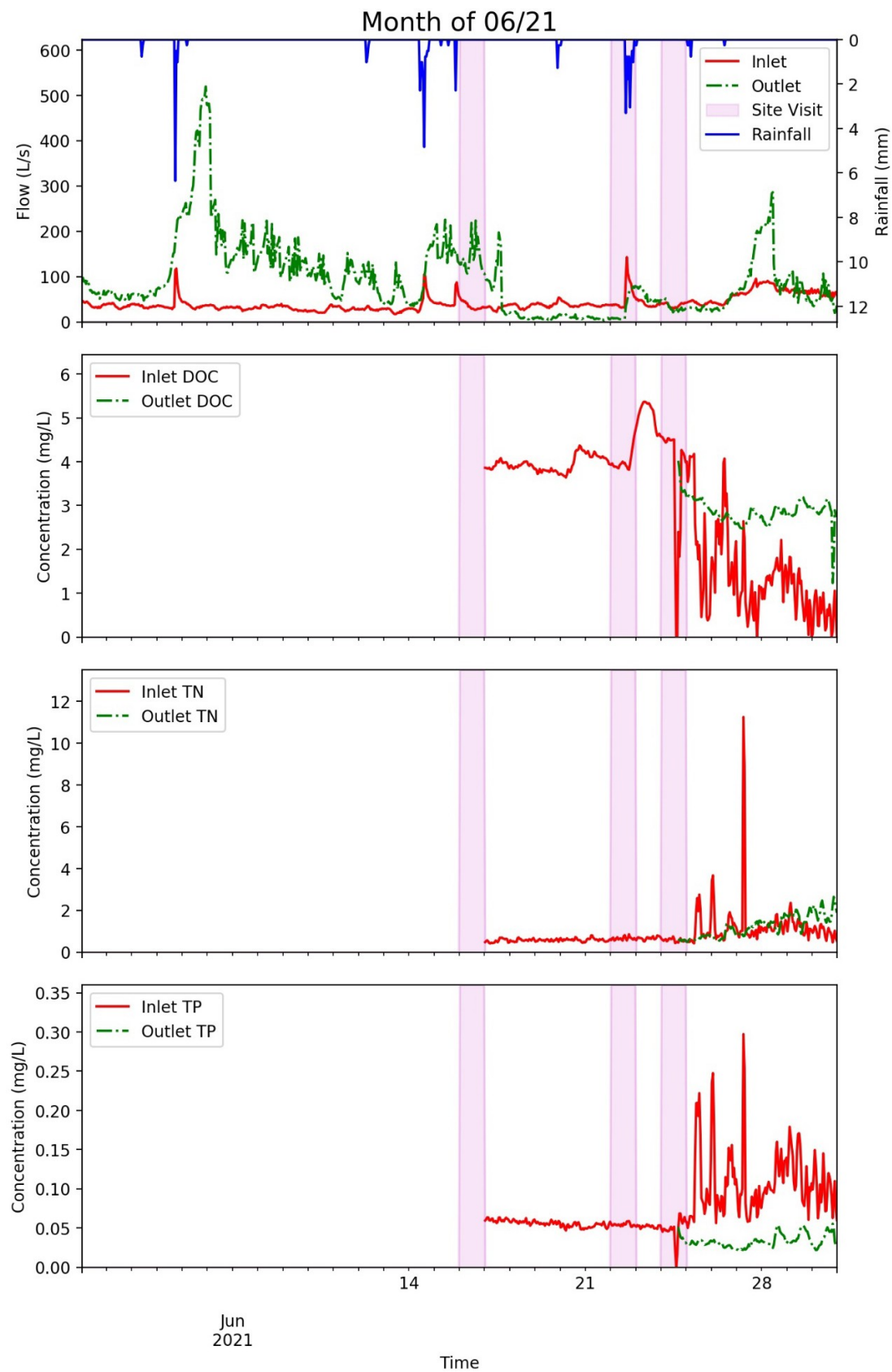
- Ganf, G. G. & Oliver, R. L. (1982). Vertical separation of light and available nutrients as a factor causing replacement of green algae by blue-green algae in the plankton of a stratified lake. *Journal of Ecology*, 70(3), 829-844. <https://doi-org.unh.idm.oclc.org/10.2307/2260107>
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- Providence Parks & Recreation. (2013). Restoring the ponds in Roger Williams Park: Executive Summary.
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- [RIDEM] Office of Water Resources. (2007). Total maximum daily loads for phosphorus to address 9 eutrophic ponds in Rhode Island. Rhode Island Department of Environmental Management. <http://www.dem.ri.gov/programs/benviron/water/quality/rest/pdfs/eutropnd.pdf>
- Kenneth J. Wagner (2017) Preface: Advances in phosphorus inactivation, Lake and Reservoir Management, 33:2, 103-107, DOI: 10.1080/10402381.2017.131606

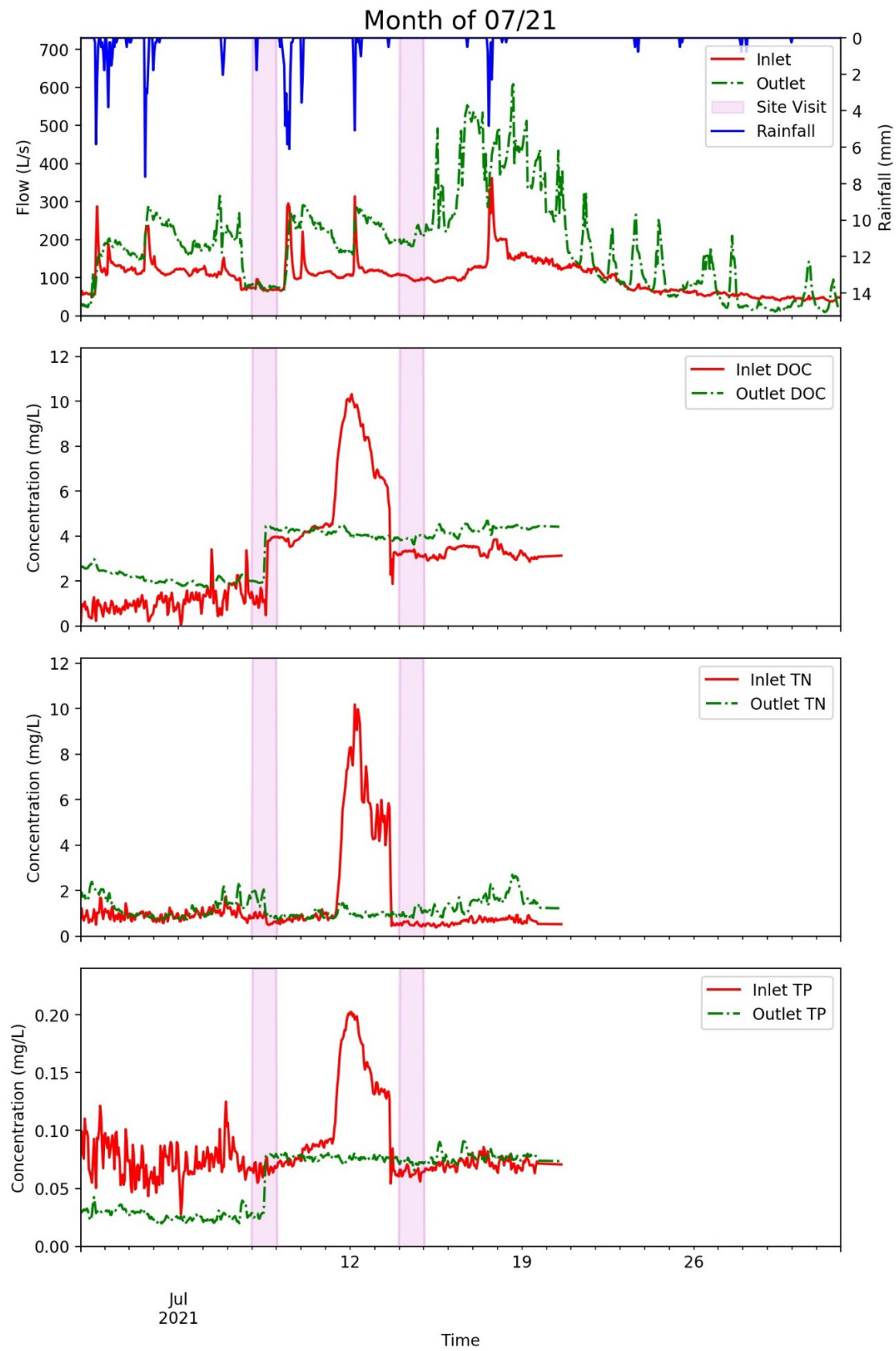
Appendix A: Monthly Concentration

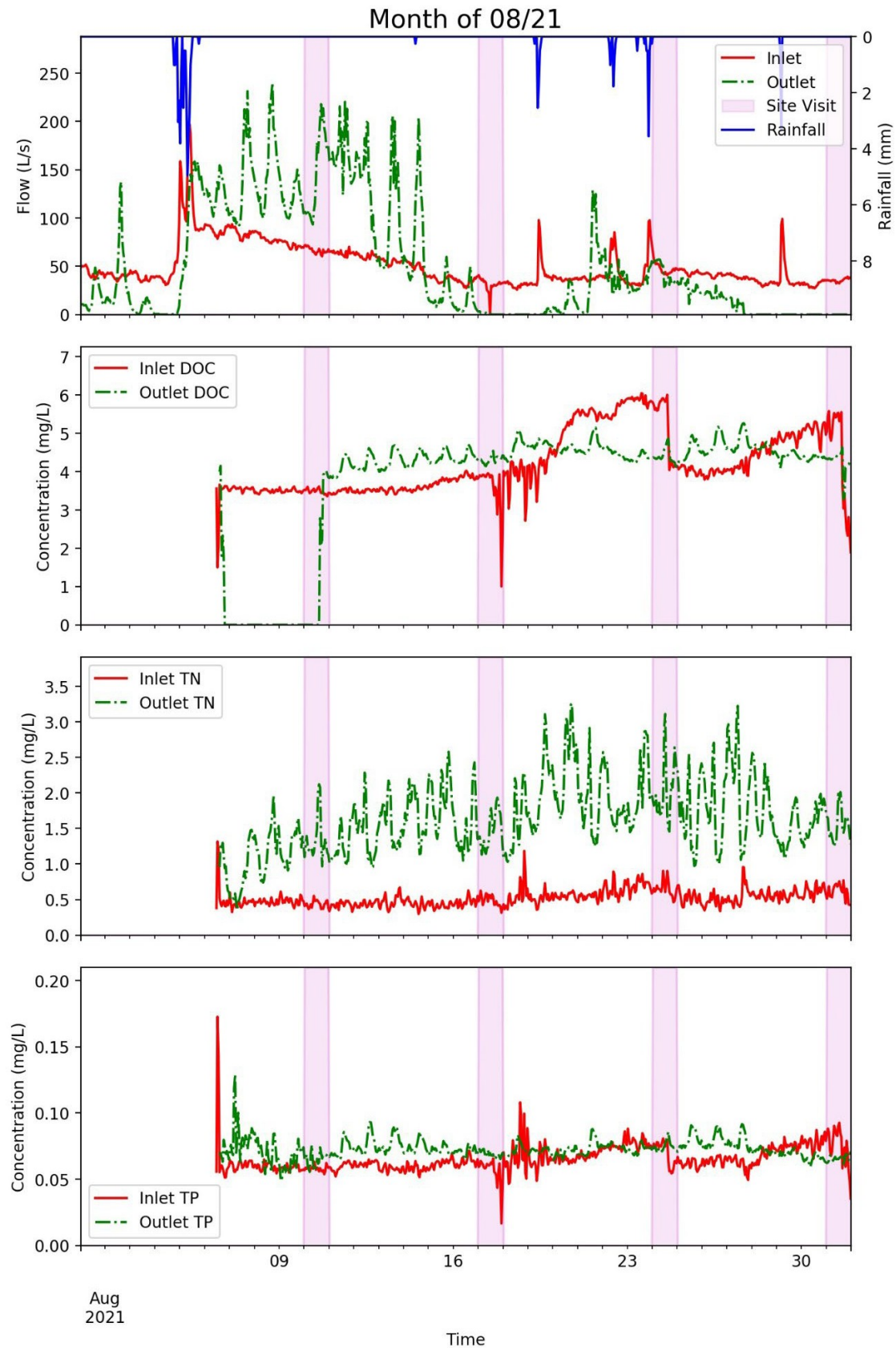
The real-time UV-visual concentrations of DOC, TN, and TP are shown in the graphs and summary tables in this appendix along with the rainfall, inflow, and outflow. Days where instrument maintenance are highlighted in magenta. Time with no data lines indicate either a system error (pump failure, etc.) and the associated data was either missing or did not pass quality control.

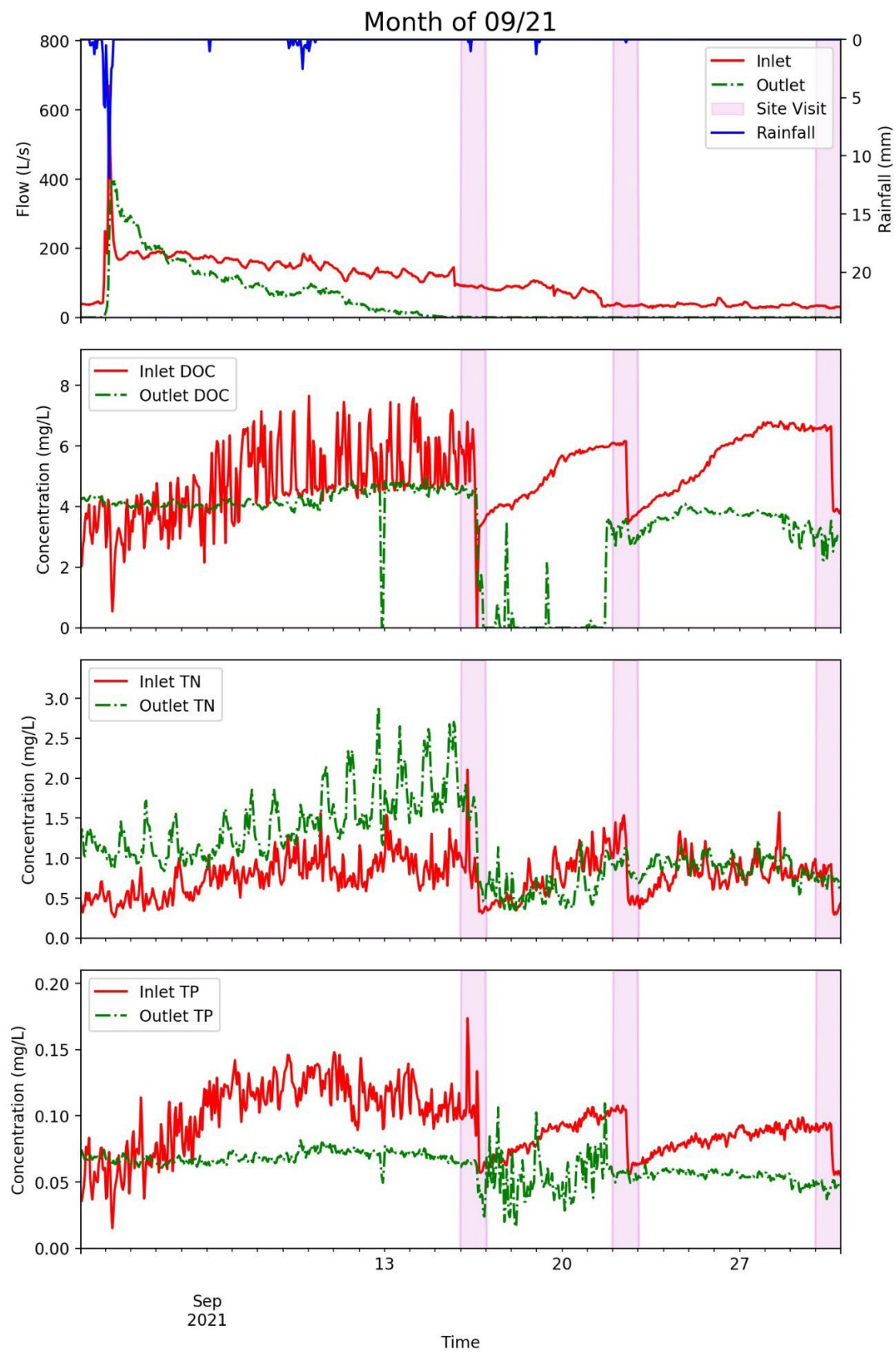


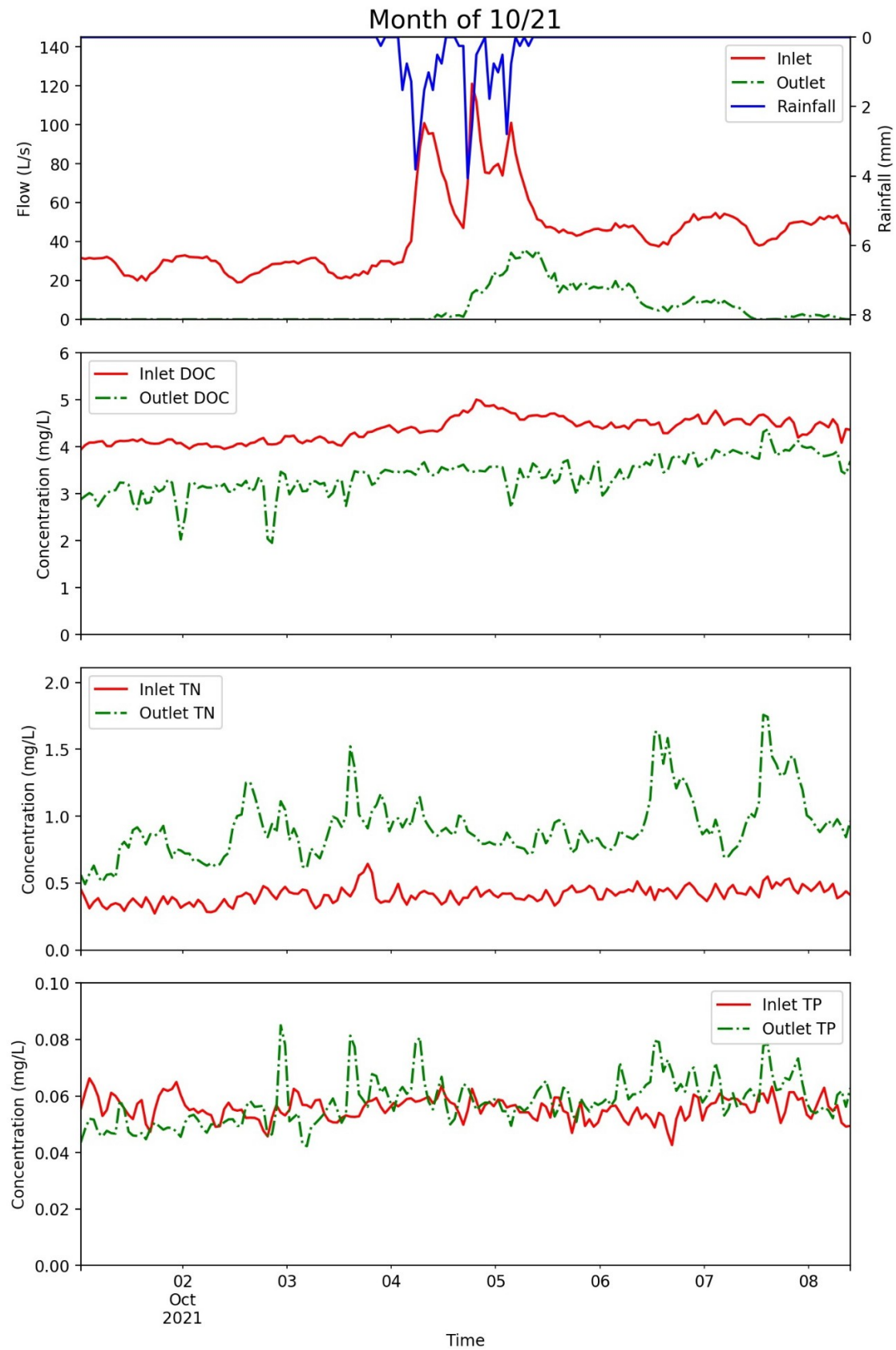








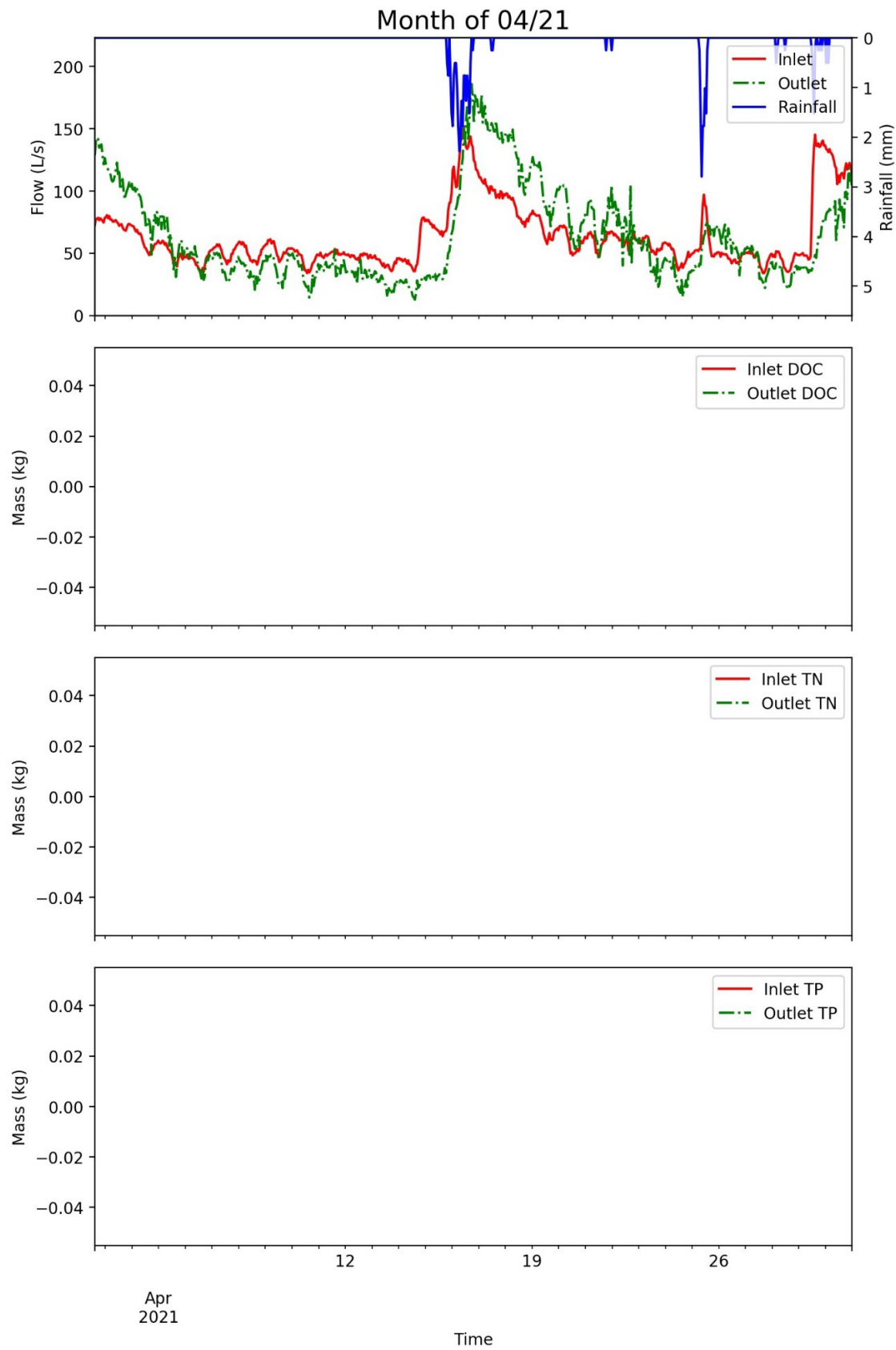


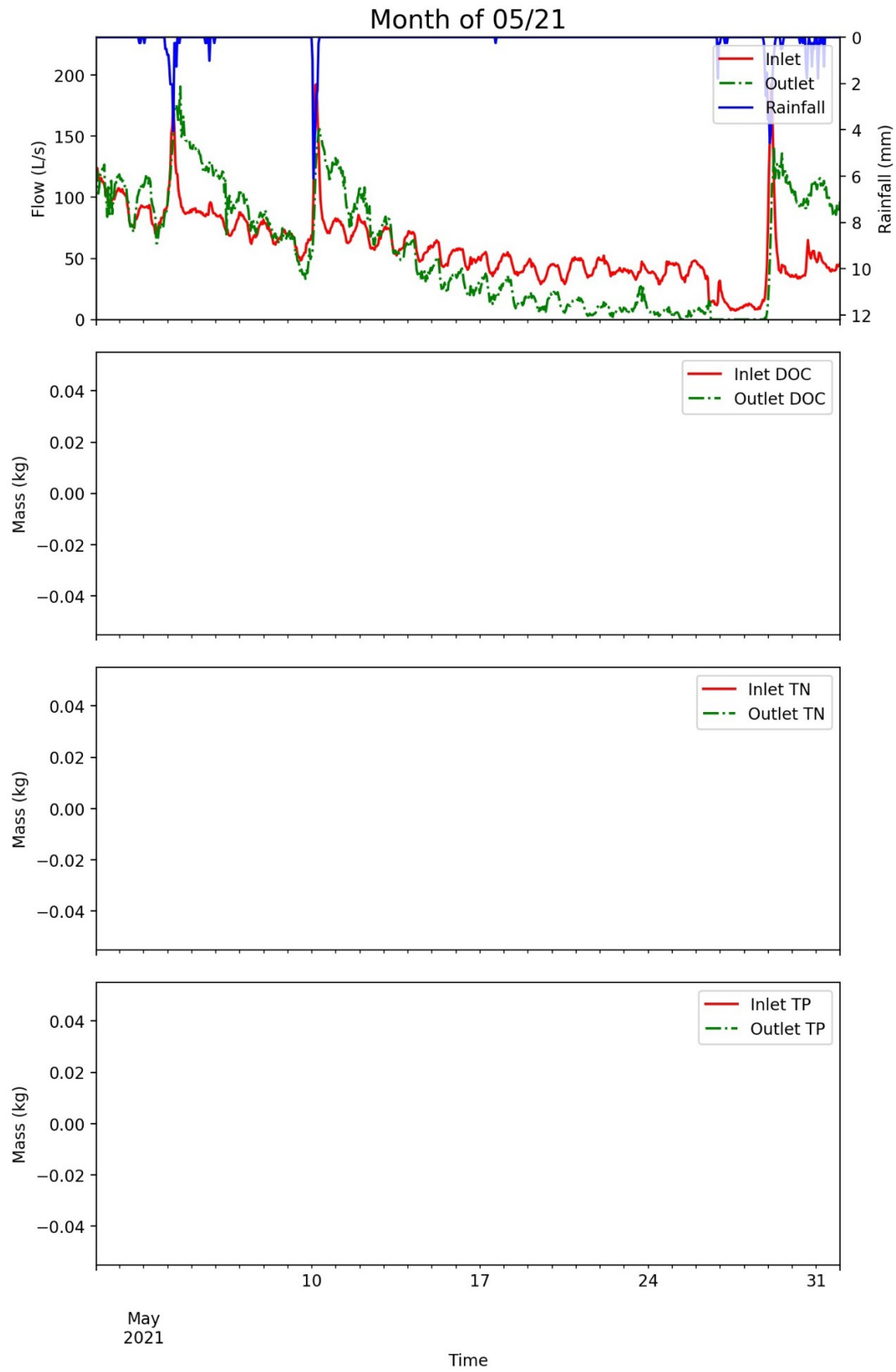


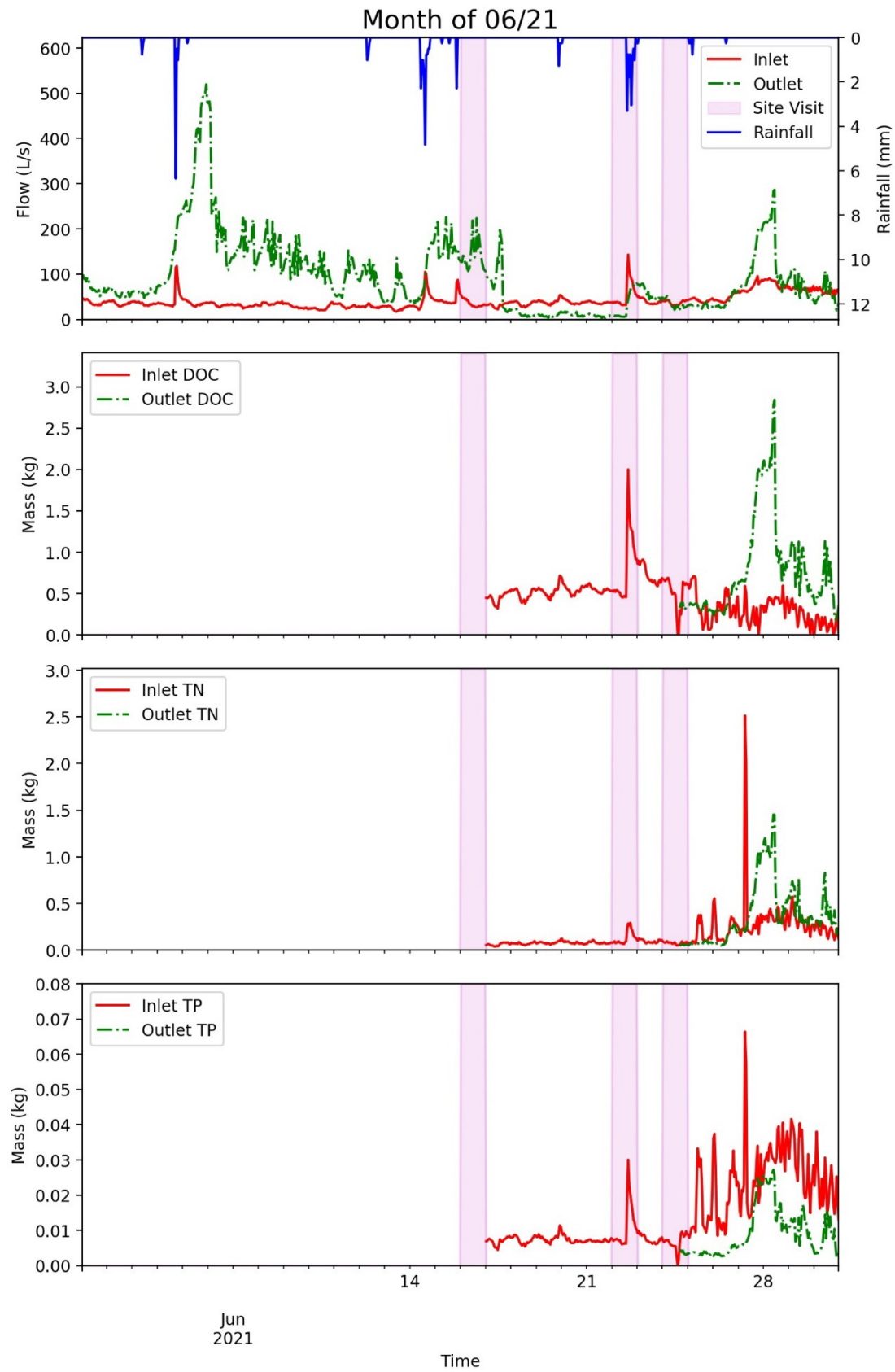
Month	Total Rainfall (in)	Mean Inflow (gpm)	Mean Outflow (gpm)	Total Inflow (gal)	Total Outflow (gal)	Mean Inlet UV- Vis DOC (mg/L)	Mean Outlet UV- Vis DOC (mg/L)	Mean Inlet UV- Vis TN (mg/L)	Mean Outlet UV- Vis TN (mg/L)	Mean Inlet UV- Vis TP (mg/L)	Mean Outlet UV- Vis TP (mg/L)
4	1.64	1,005	1,006	41,108,568	41,145,295	N/A	N/A	N/A	N/A	N/A	N/A
5	3.16	933	923	41,632,183	41,188,470	N/A	N/A	N/A	N/A	N/A	N/A
6	1.72	651	1,486	28,109,396	64,192,258	2.90	2.88	0.88	1.24	0.08	0.03
7	4.21	1,608	2,932	71,778,966	130,889,827	3.08	3.40	1.37	1.23	0.08	0.06
8	2.02	797	817	35,558,830	36,490,664	4.20	3.76	0.52	1.64	0.07	0.07
9	2.52	1,596	731	68,928,412	31,572,729	5.01	3.32	0.78	1.13	0.09	0.06
10	1.25	690	93	7,365,055	989,313	4.37	3.40	0.41	0.92	0.06	0.06
Min	1.64	651	731	28,109,396	31,572,729	2.90	2.88	0.52	1.13	0.07	0.03
Median	2.02	933	923	41,108,568	41,145,295	4.20	3.40	0.78	1.23	0.08	0.06
Average	2.36	1,040	1,141	42,068,773	49,495,508	3.91	3.35	0.79	1.23	0.08	0.06
Max	4.21	1,608	2,932	71,778,966	130,889,827	5.01	3.76	1.37	1.64	0.09	0.07
Total	16.52	7,278	7,987	294,481,410	346,468,556						

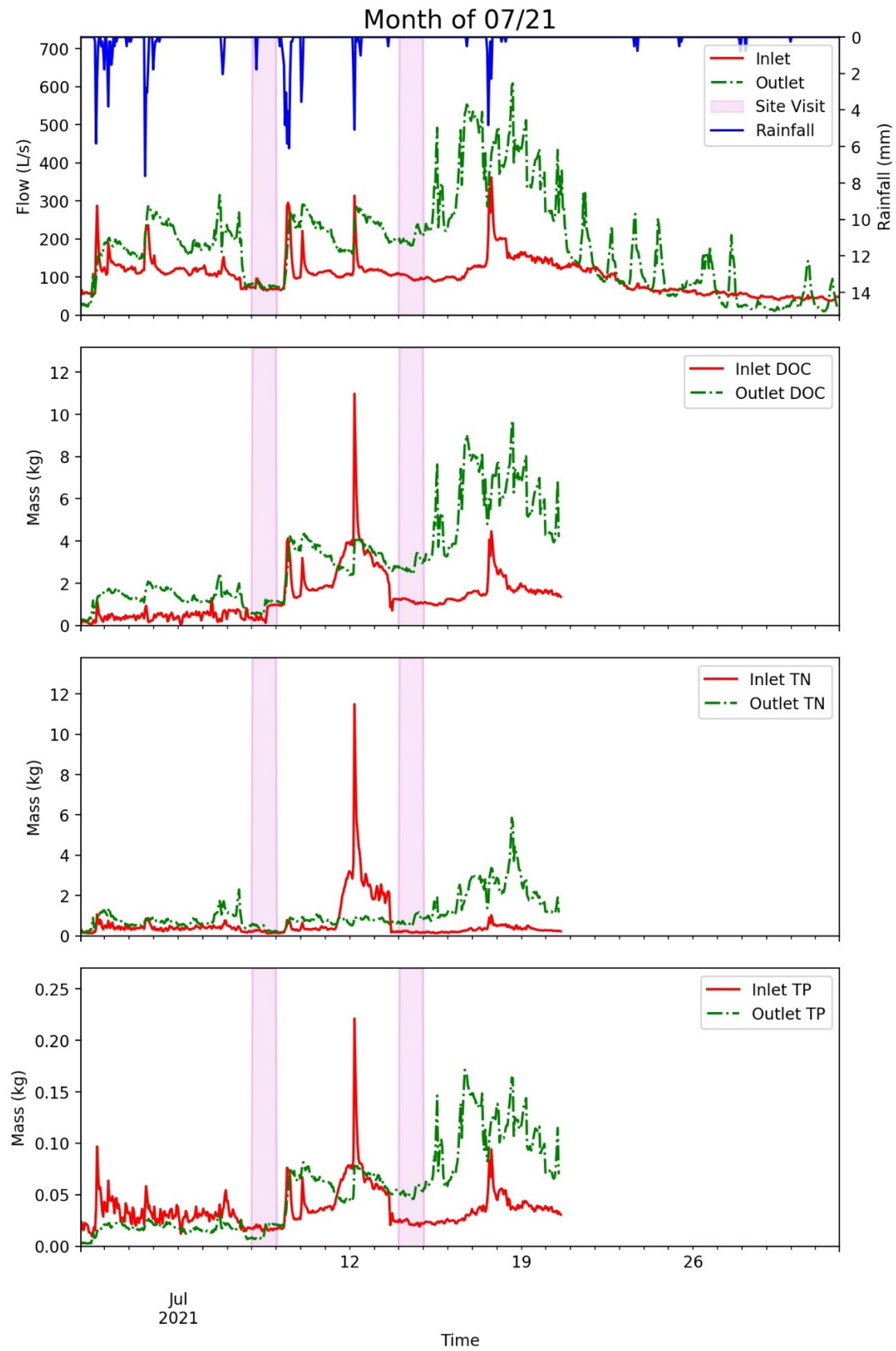
Appendix B: Monthly Mass Flux

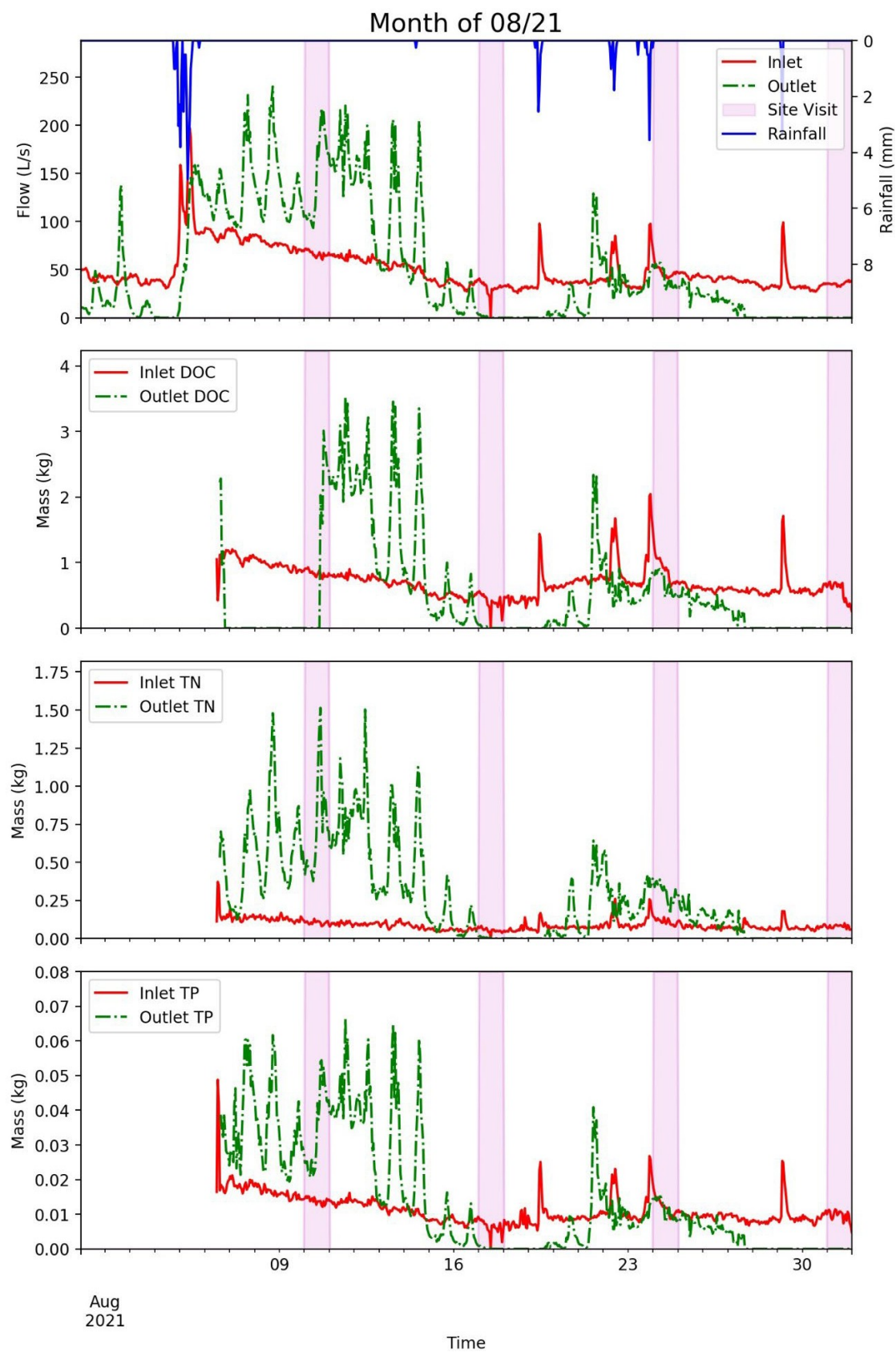
The real-time UV-visual mass flux of DOC, TN, and TP are shown in the graphs and summary tables in this appendix along with the rainfall, inflow, and outflow. Mass flux was calculated by multiplying the flow (converted to volume) by concentration. Days where instrument maintenance are highlighted in magenta. Time with no data lines indicate either a system error (pump failure, etc.) and the associated data was either missing or did not pass quality control.

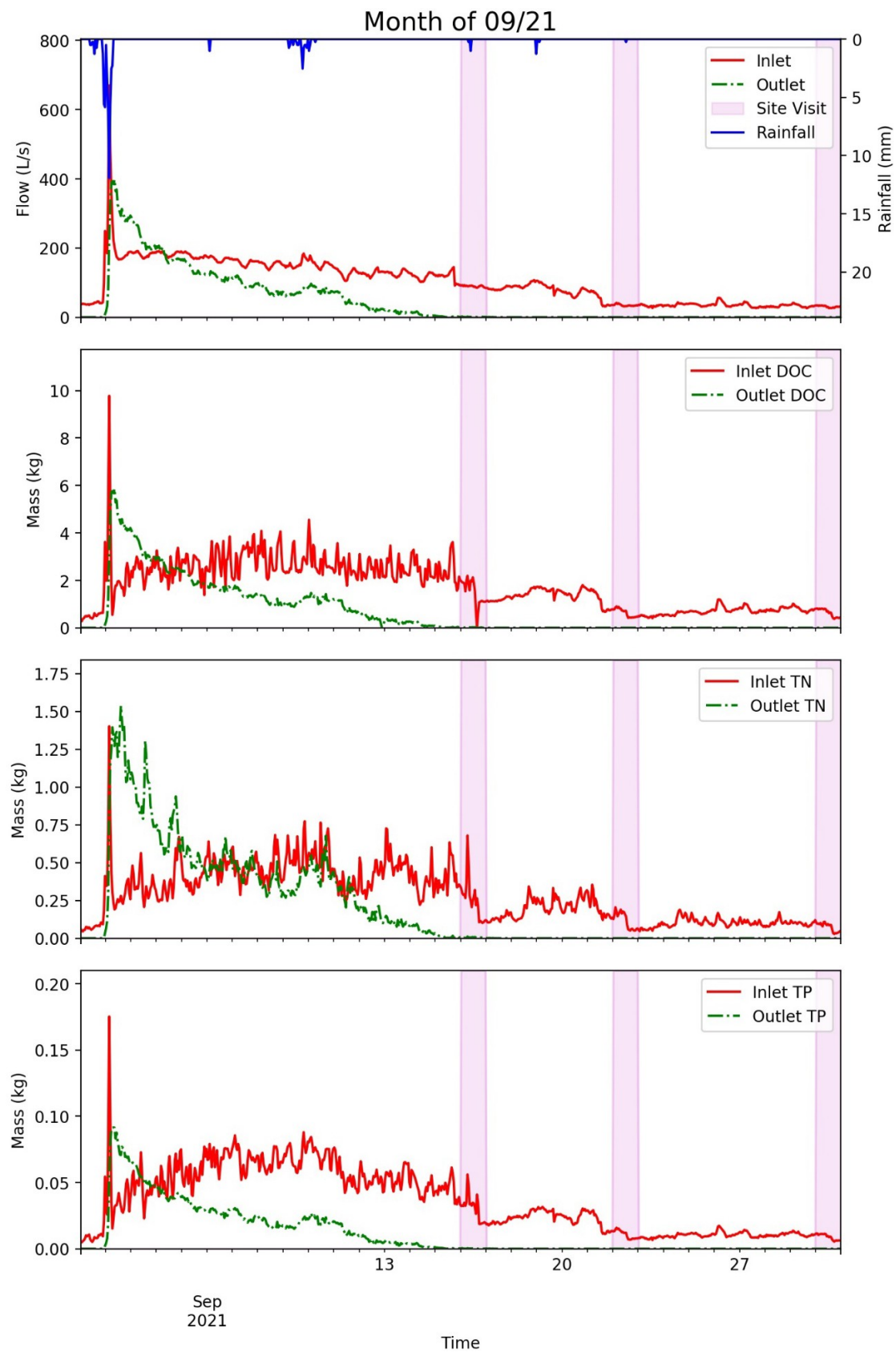


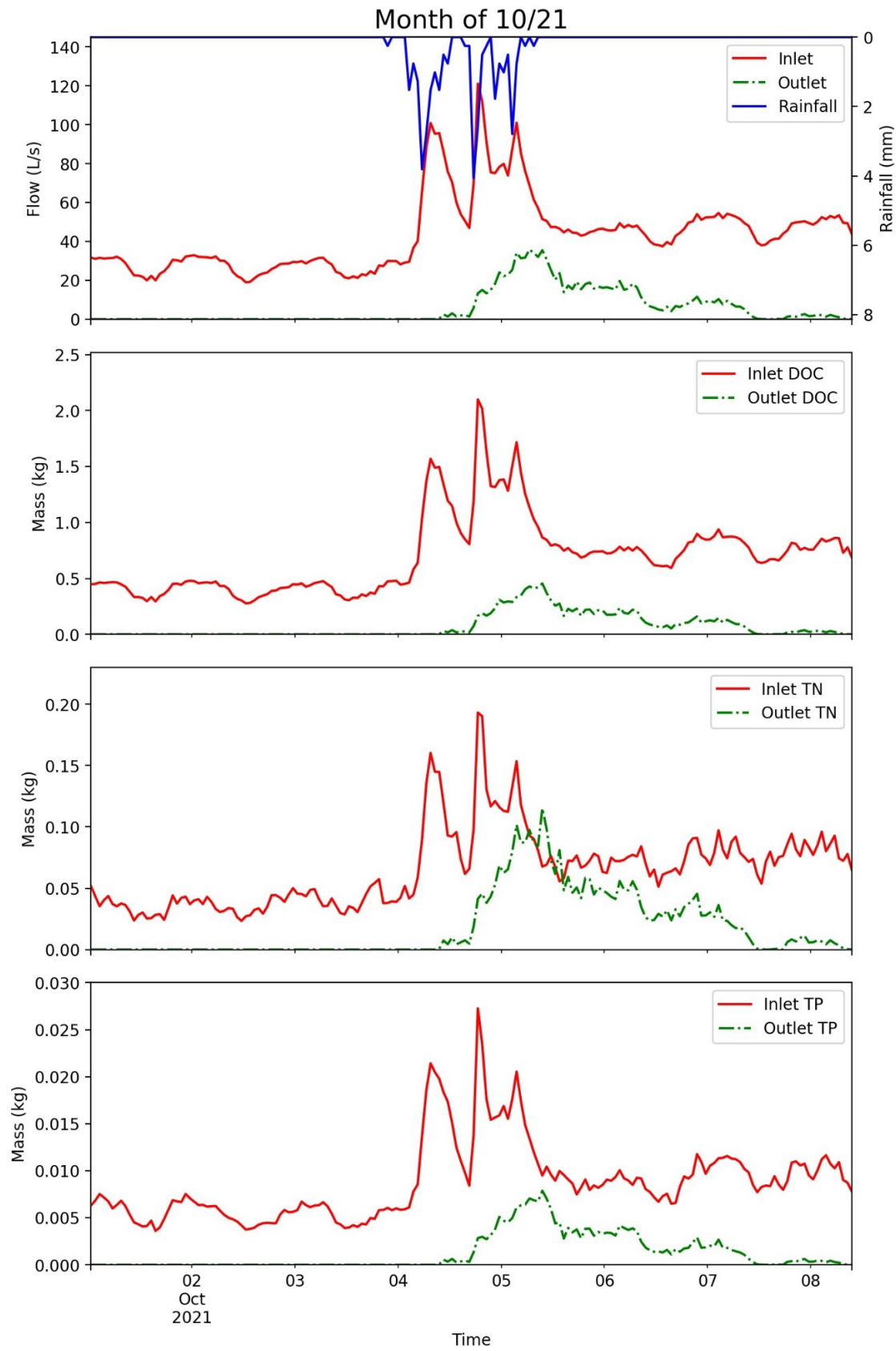








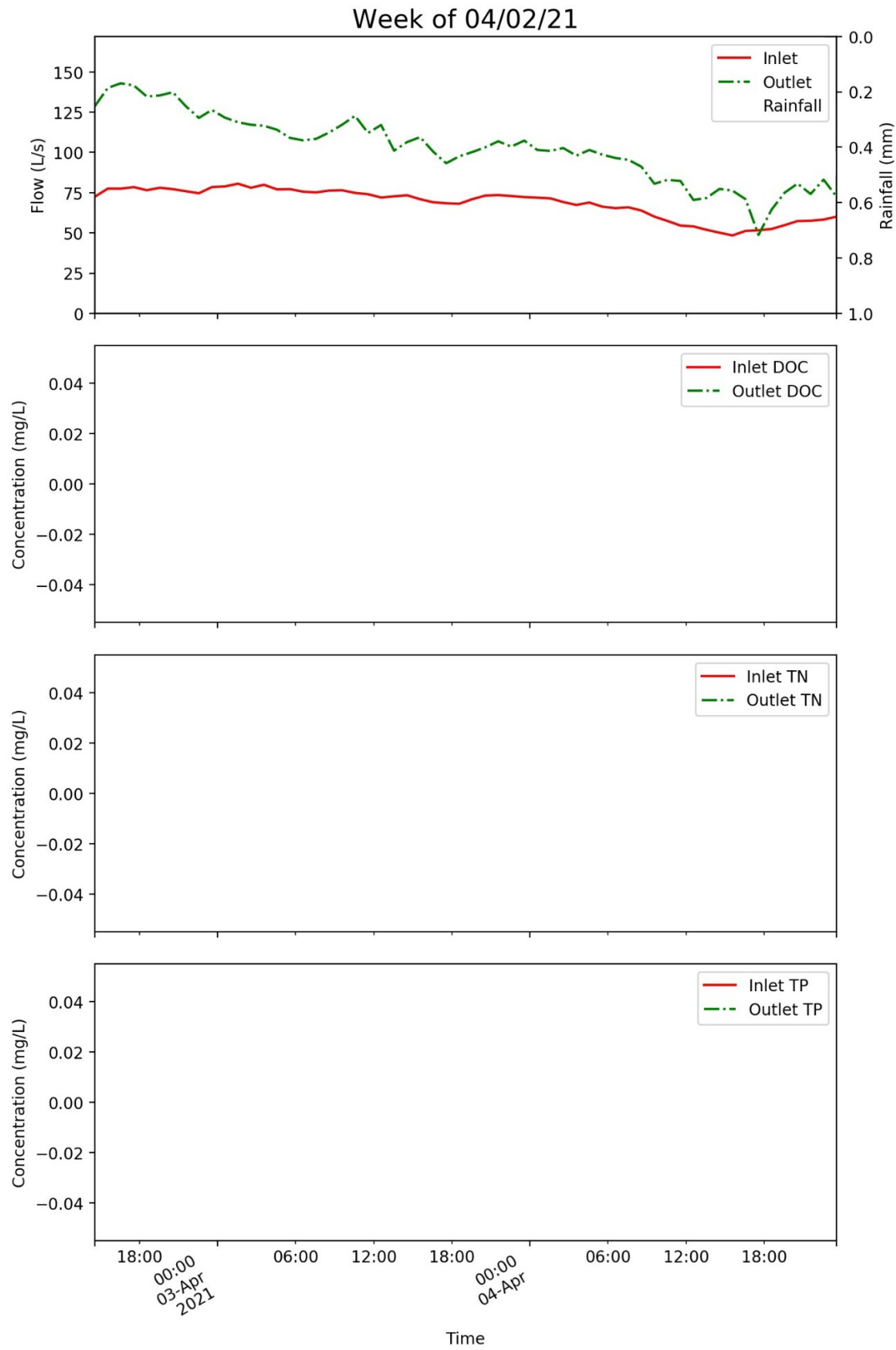




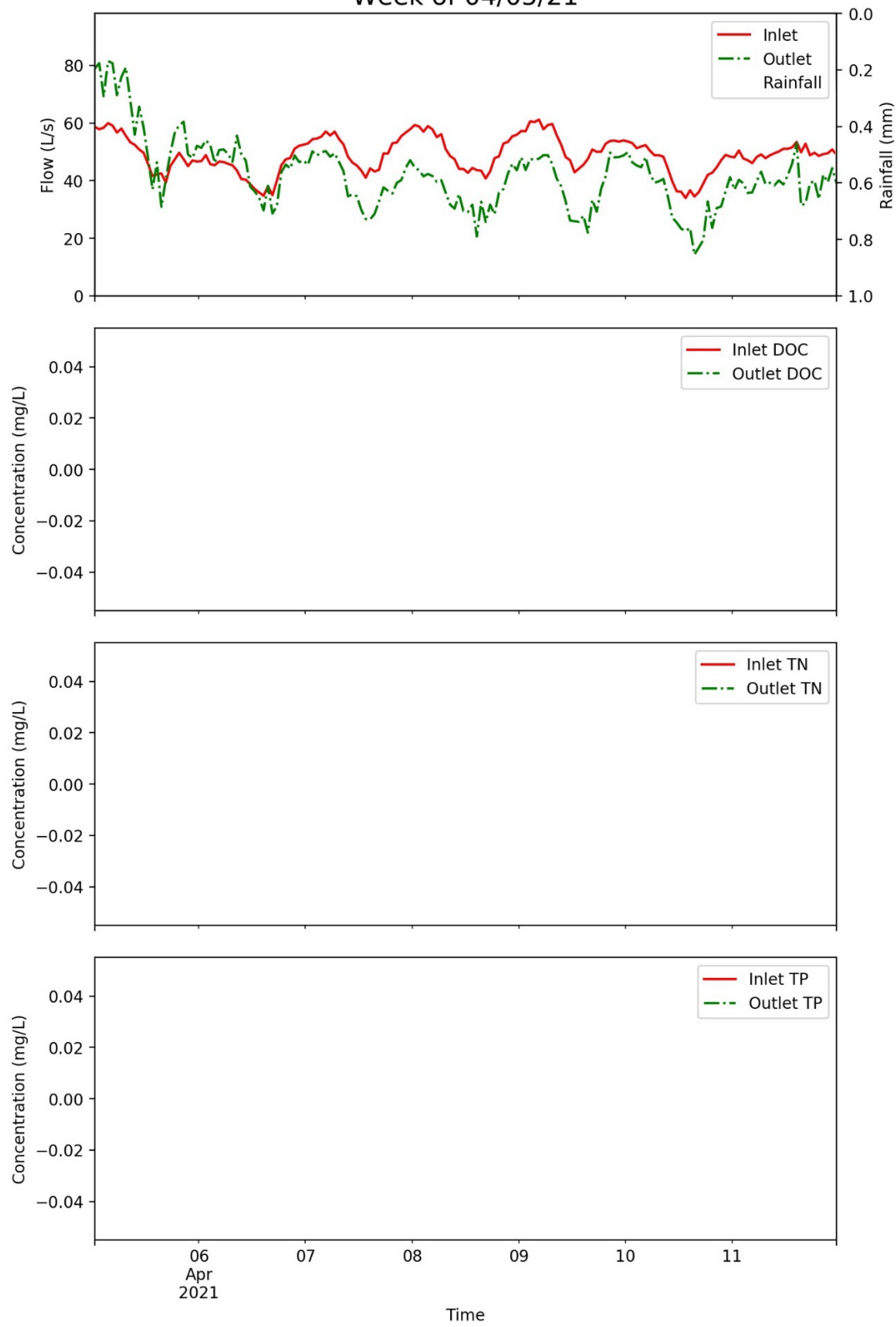
Month	Total Rainfall (in)	Mean Inflow (gpm)	Mean Outflow (gpm)	Total Inflow (gal)	Total Outflow (gal)	Total Inlet UV-Vis DOC (lb)	Total Outlet UV-Vis DOC (lb)	Total Inlet UV-Vis TN (lb)	Total Outlet UV-Vis TN (lb)	Total Inlet UV-Vis TP (lb)	Total Outlet UV-Vis TP (lb)
4	1.64	1,005	1,006	41,108,568	41,145,295	N/A	N/A	N/A	N/A	N/A	N/A
5	3.16	933	923	41,632,183	41,188,470	N/A	N/A	N/A	N/A	N/A	N/A
6	1.72	651	1,486	28,109,396	64,192,258	332.43	259.11	124.34	123.94	10.87	3.06
7	4.21	1,608	2,932	71,778,966	130,889,827	1,411.25	3,264.68	633.68	1,149.27	37.49	56.23
8	2.02	797	817	35,558,830	36,490,664	958.88	676.72	120.35	364.61	15.13	18.92
9	2.52	1,596	731	68,928,412	31,572,729	2,729.90	1,079.67	436.08	319.95	55.73	17.77
10	1.25	690	93	7,365,055	989,313	273.31	28.56	25.60	7.14	3.44	0.49
Min	1.64	651	731	28,109,396	31,572,729	332.43	259.11	120.35	123.94	10.87	3.06
Median	2.02	933	923	41,108,568	41,145,295	958.88	676.72	124.34	319.95	15.13	17.77
Average	2.36	1,040	1,141	42,068,773	49,495,508	1,141.15	1,061.75	268.01	392.98	24.53	19.29
Max	4.21	1,608	2,932	71,778,966	130,889,827	2,729.90	3,264.68	633.68	1,149.27	55.73	56.23
Total	16.52	7,278	7,987	294,481,410	346,468,556	5,705.77	5,308.74	1,340.05	1,964.91	122.66	96.47

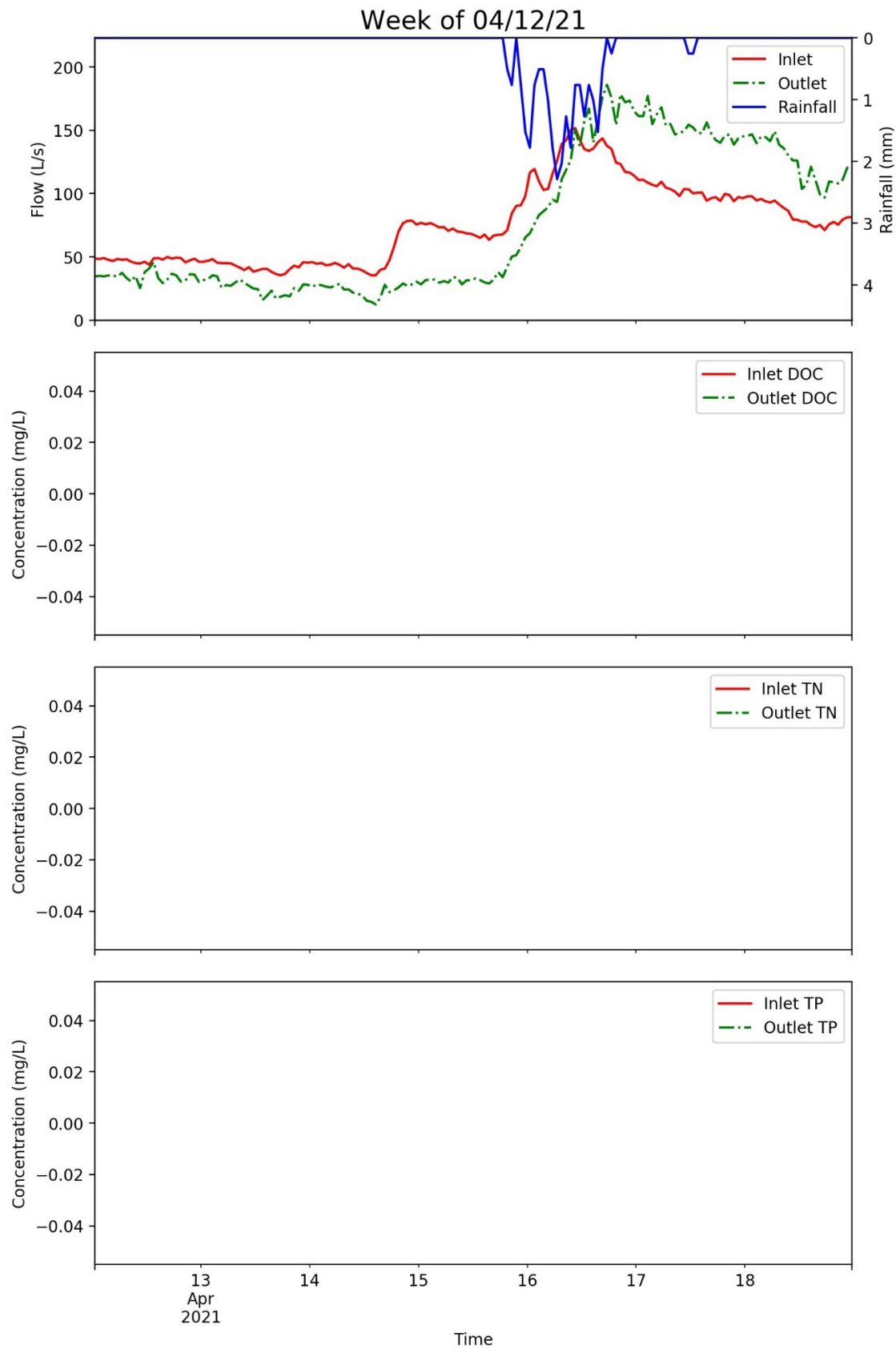
Appendix C: Weekly Concentration

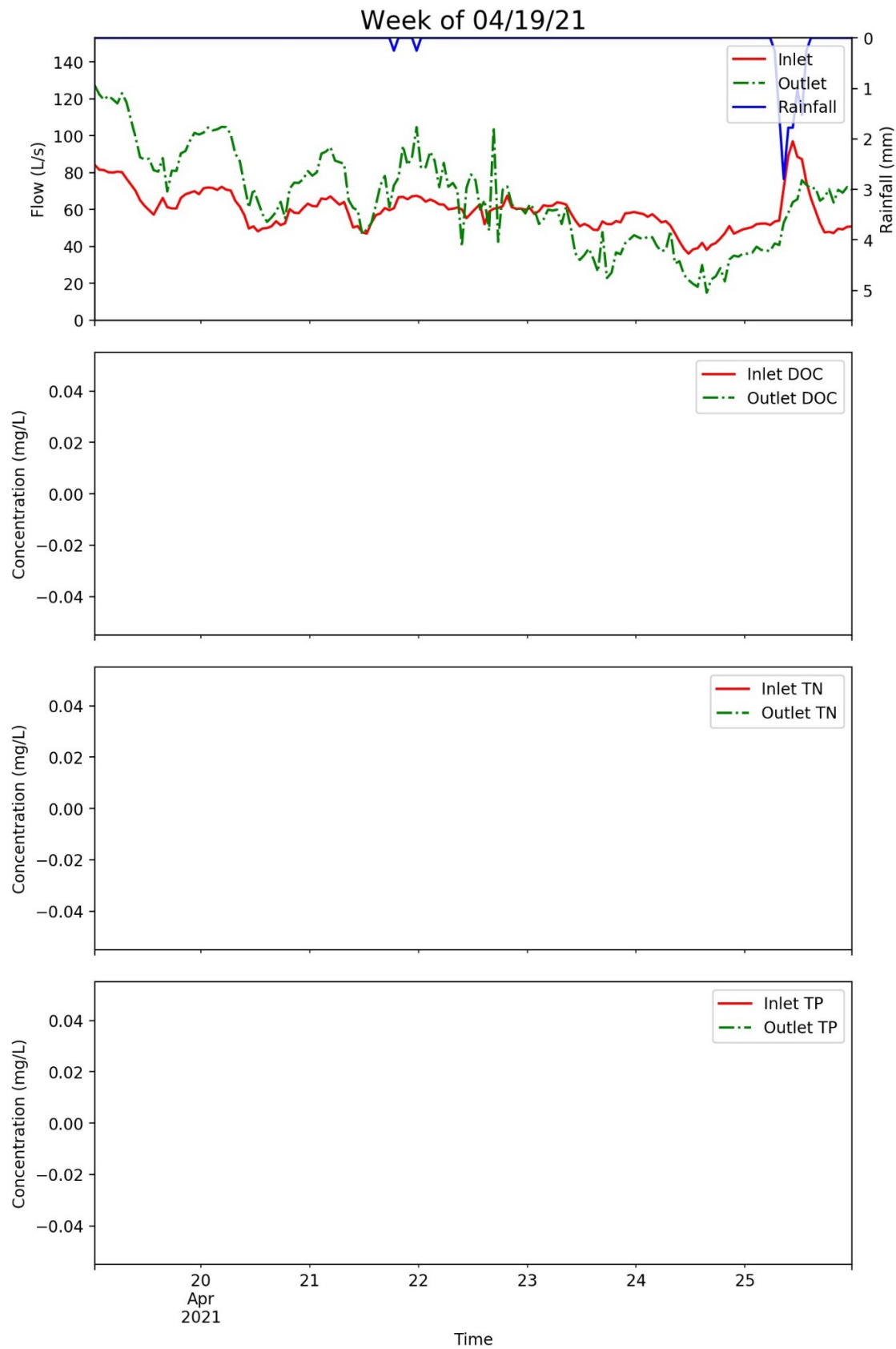
The real-time UV-visual concentrations of DOC, TN, and TP are shown in the graphs and summary tables in this appendix along with the rainfall, inflow, and outflow. Days where instrument maintenance are highlighted in magenta. Time with no data lines indicate either a system error (pump failure, etc.) and the associated data was either missing or did not pass quality control.

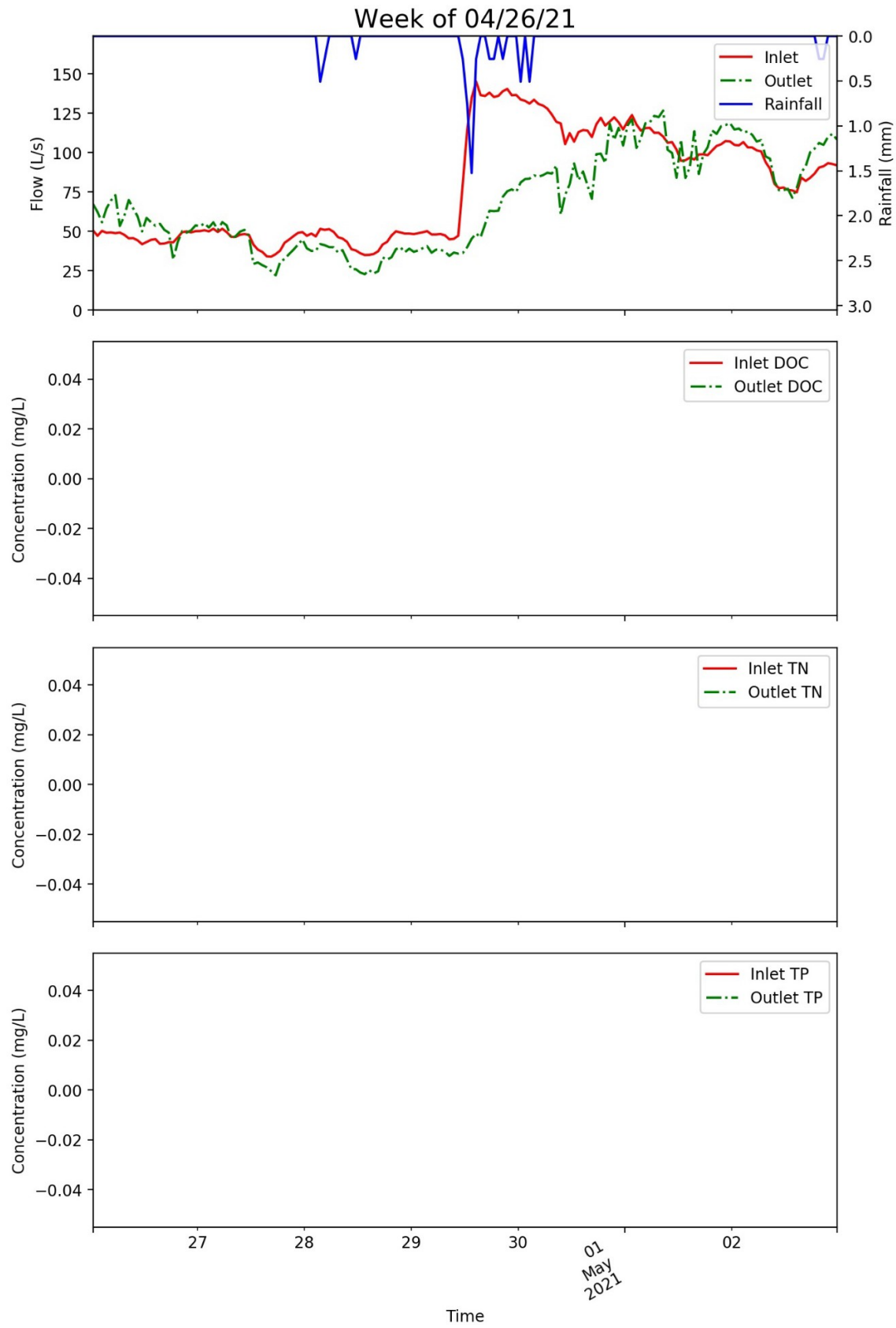


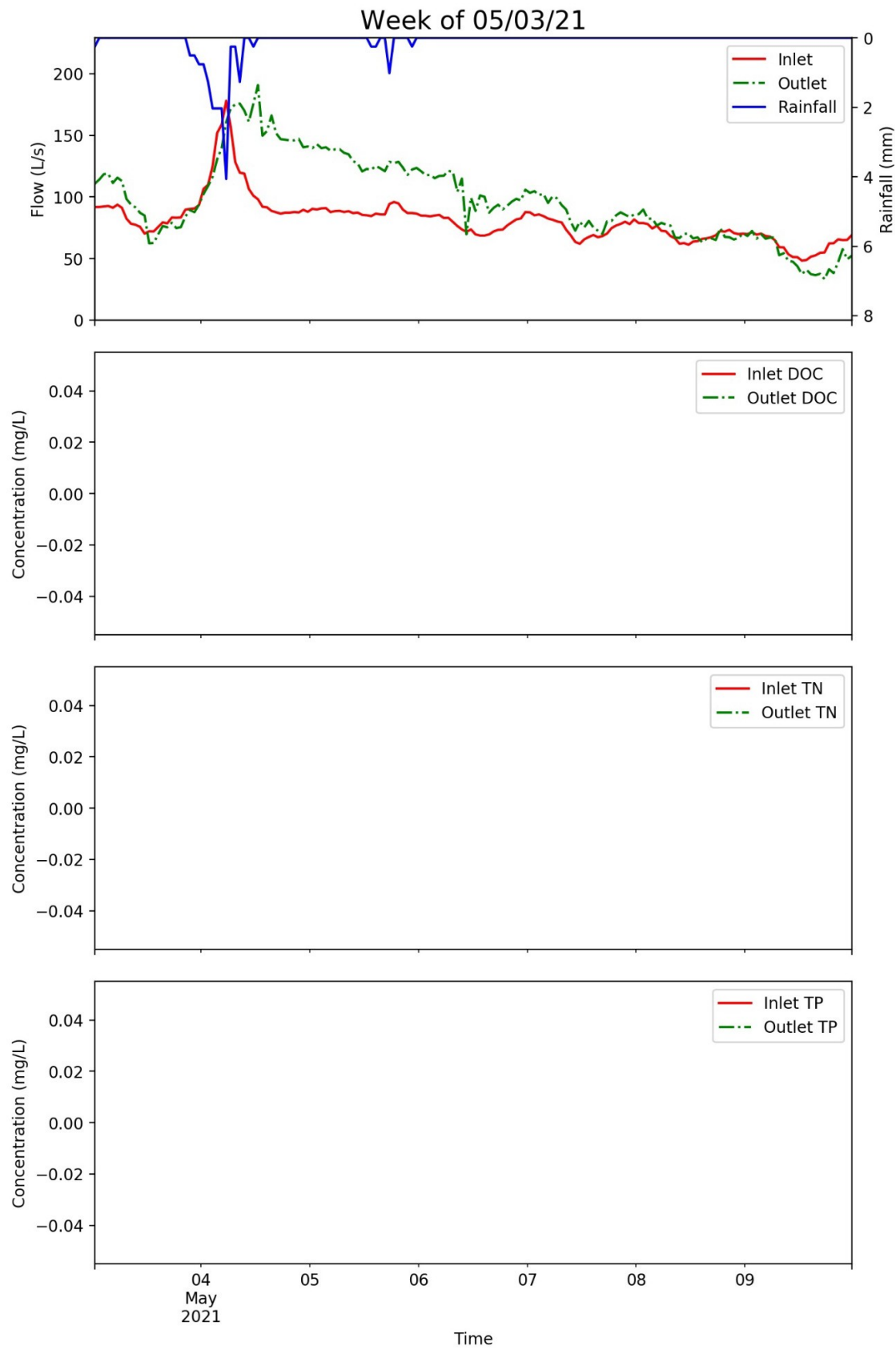
Week of 04/05/21

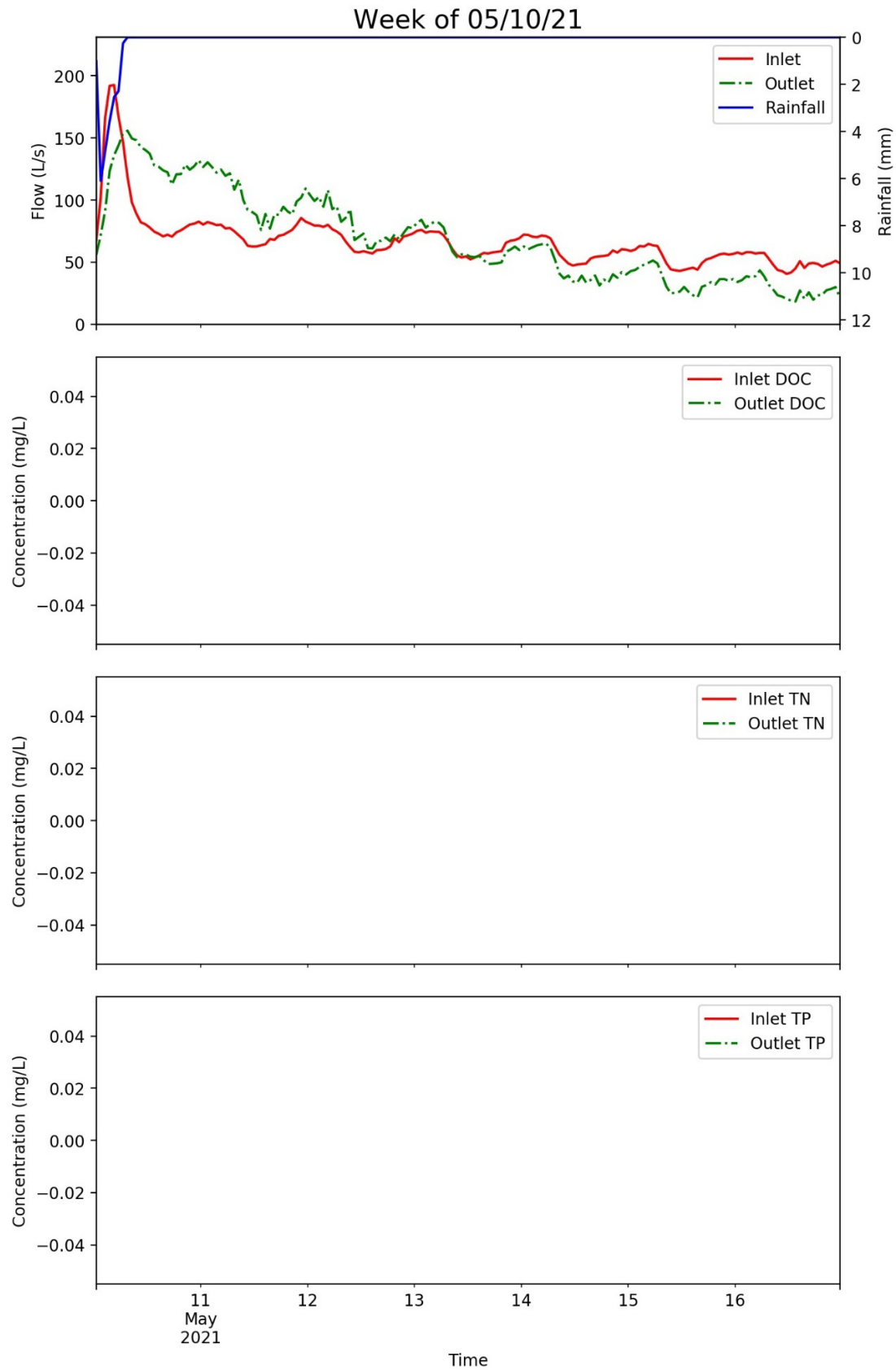


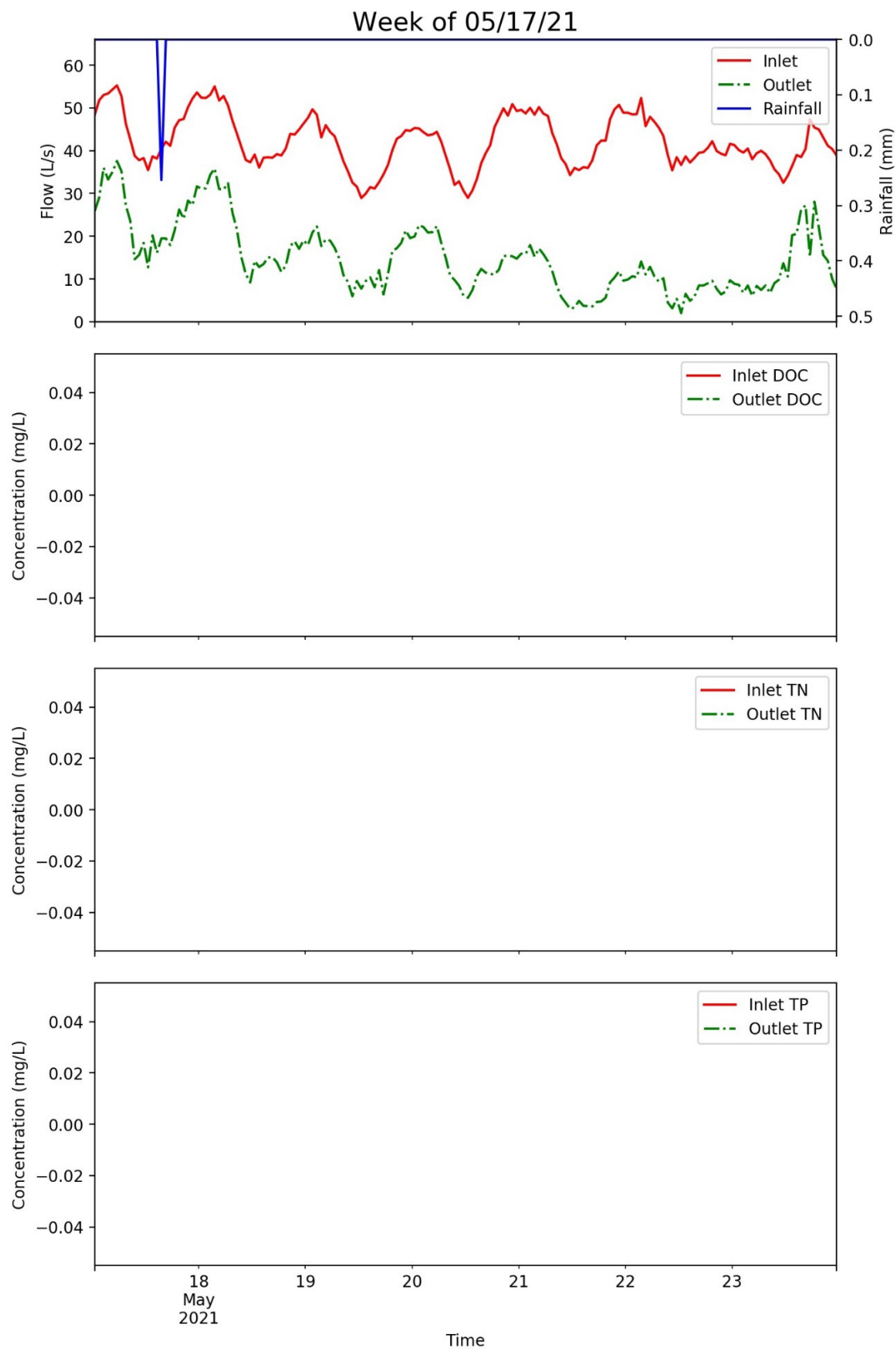


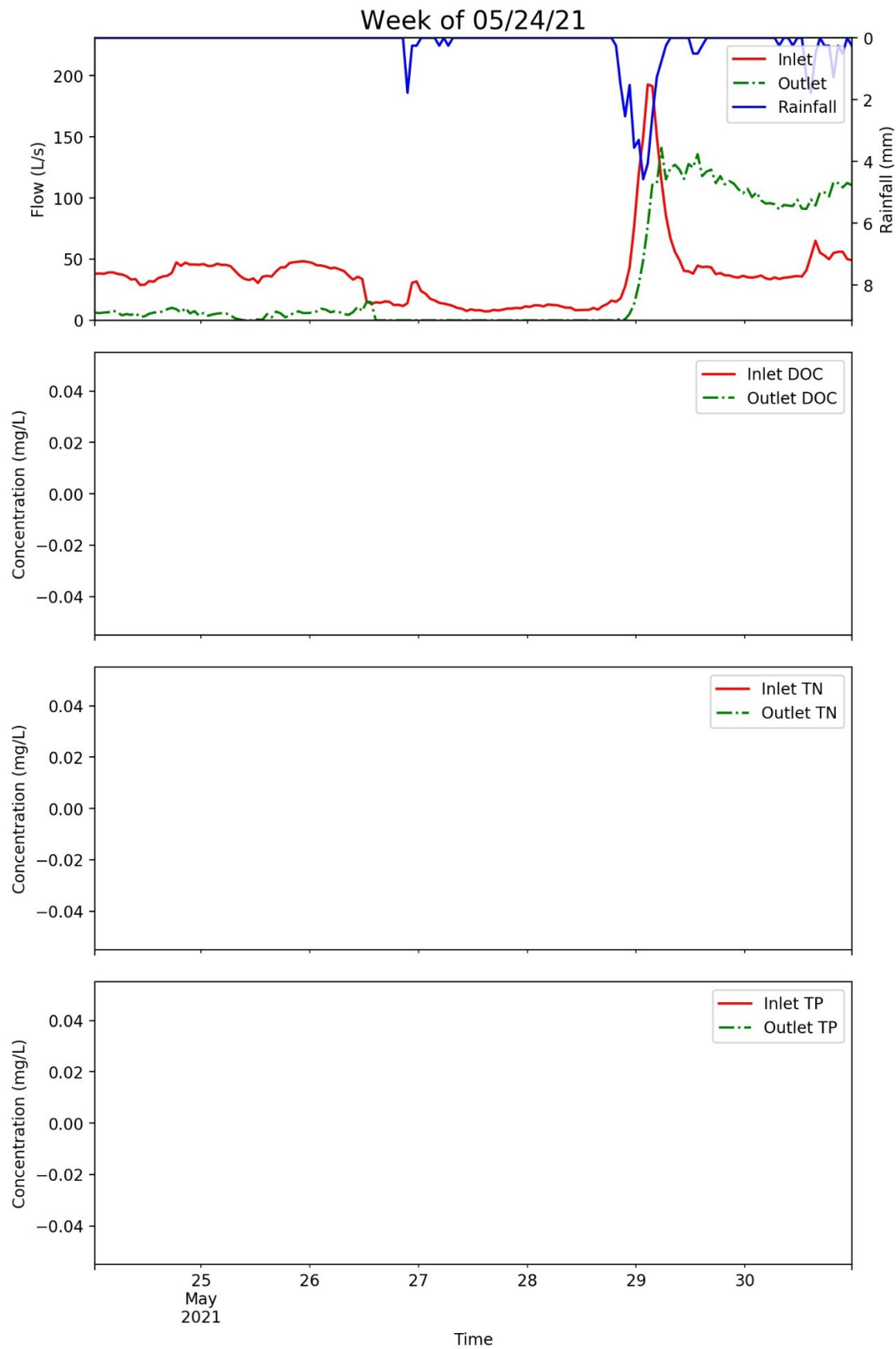


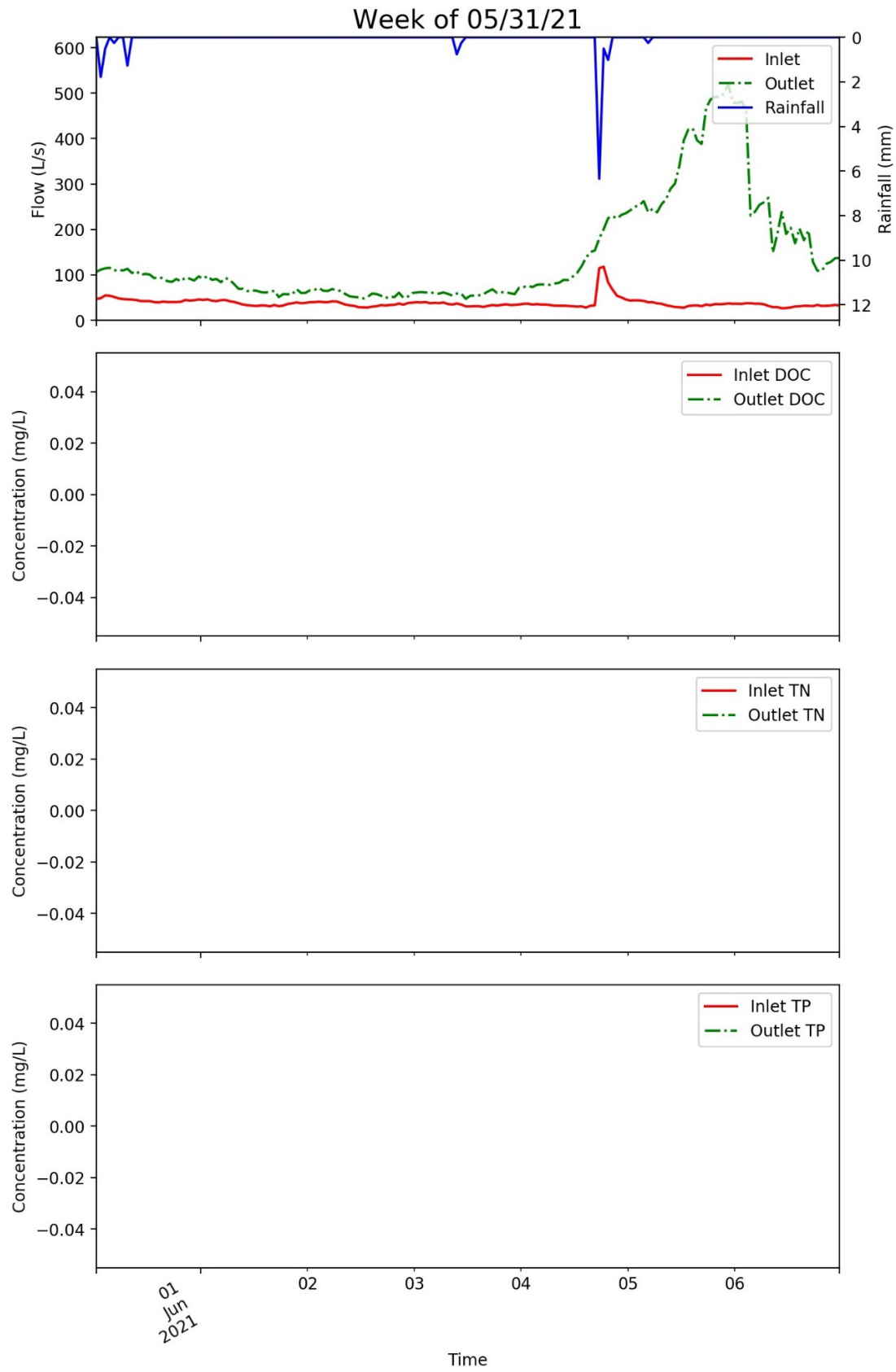


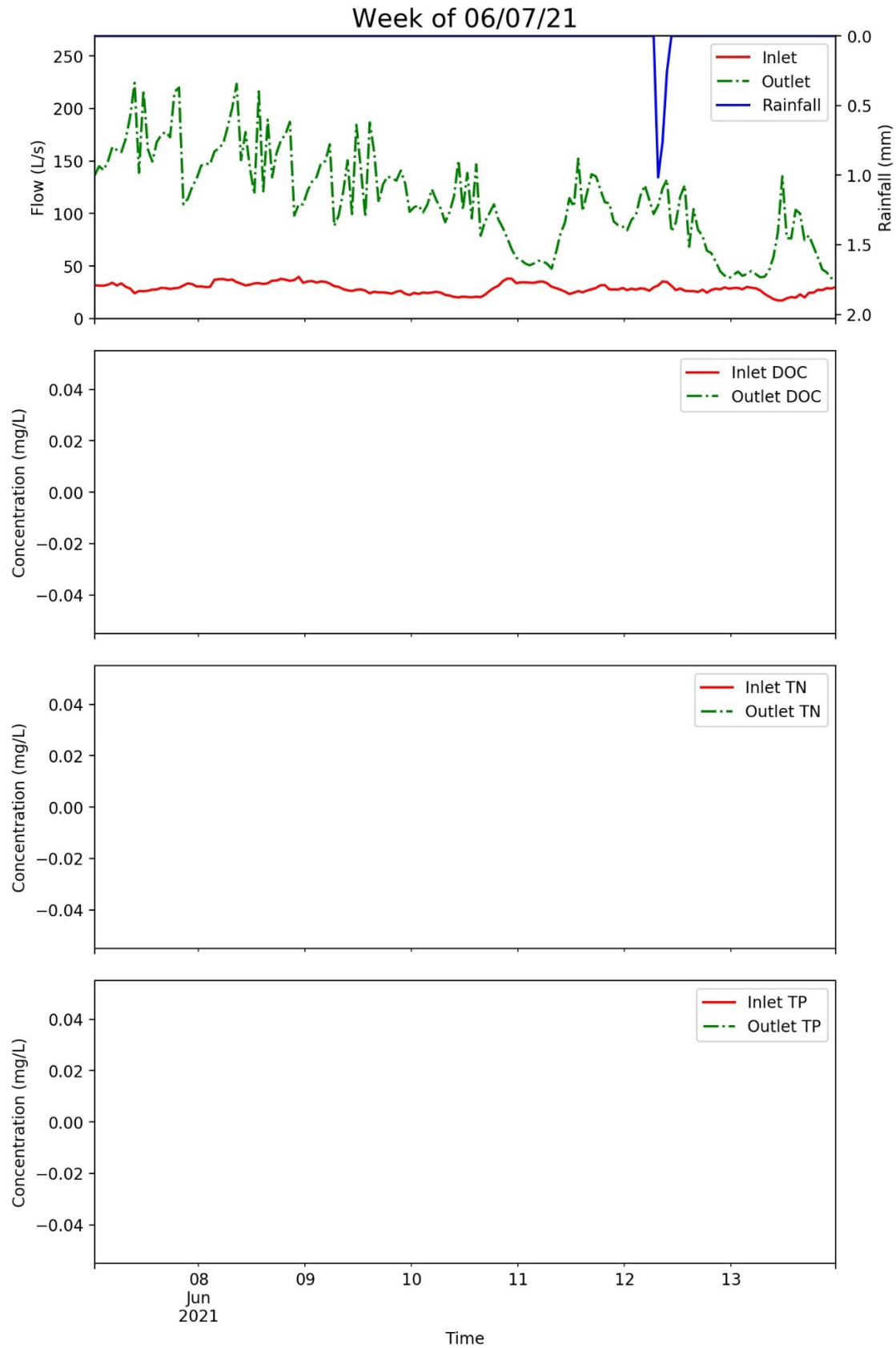


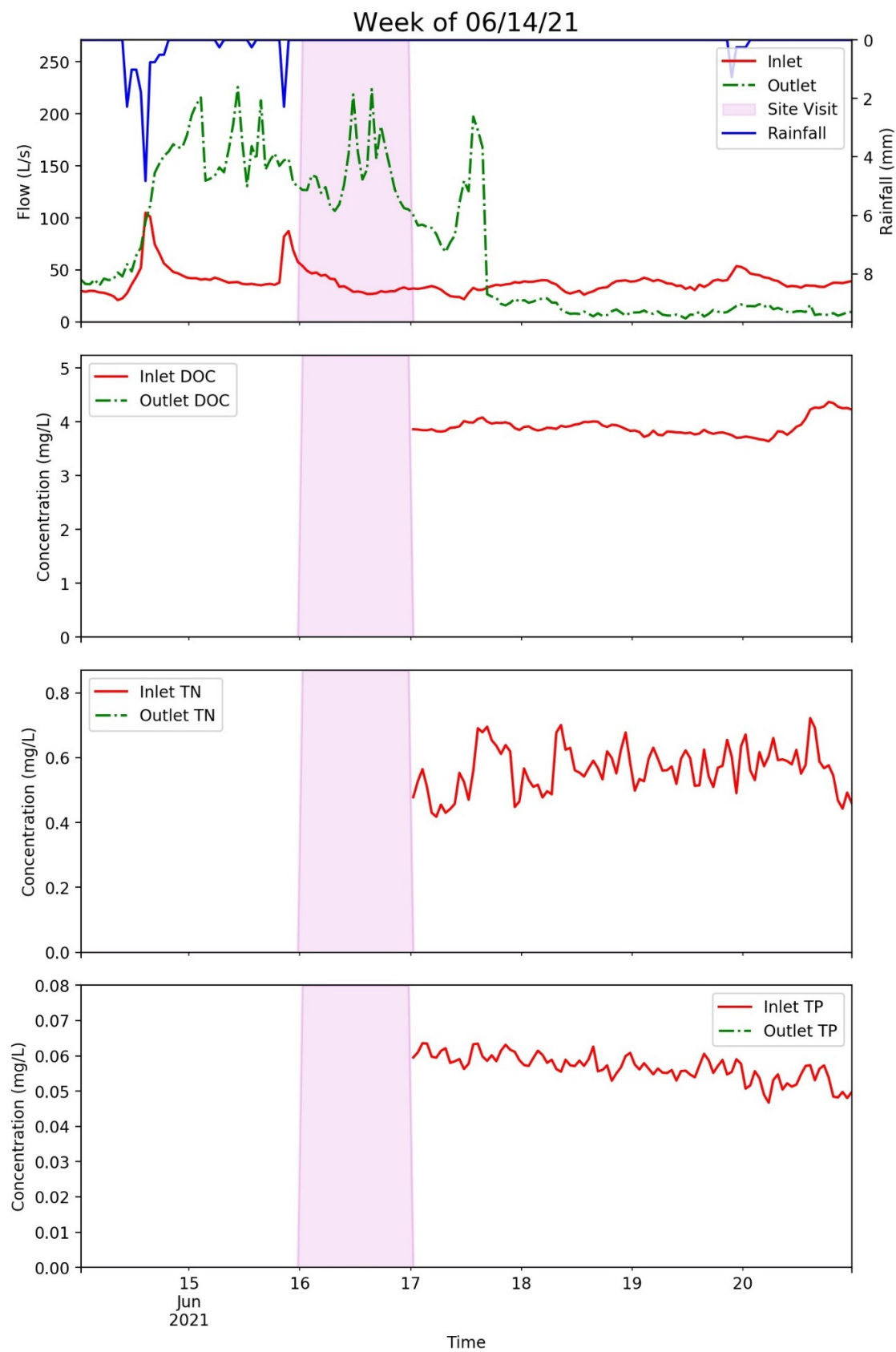


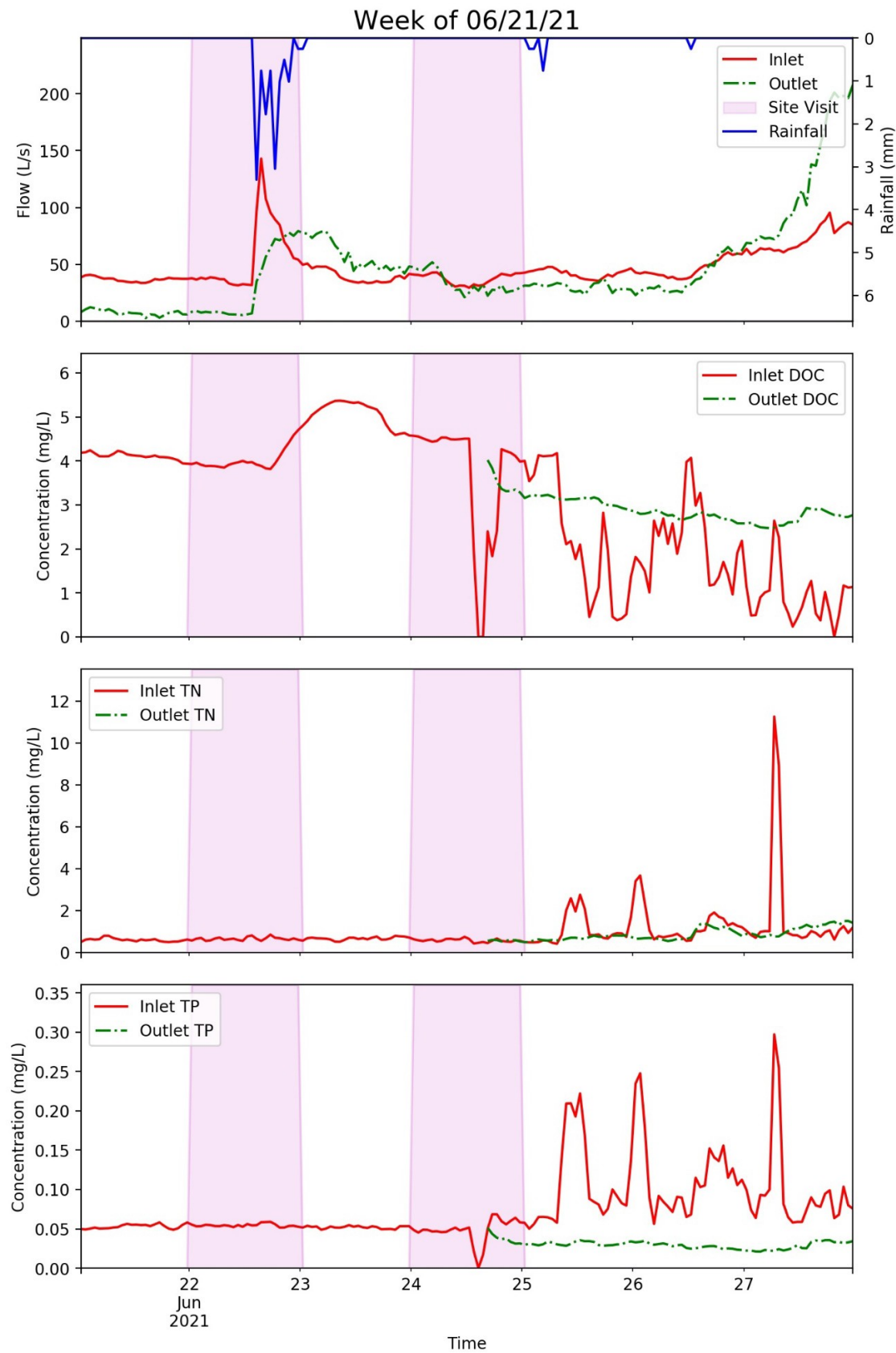


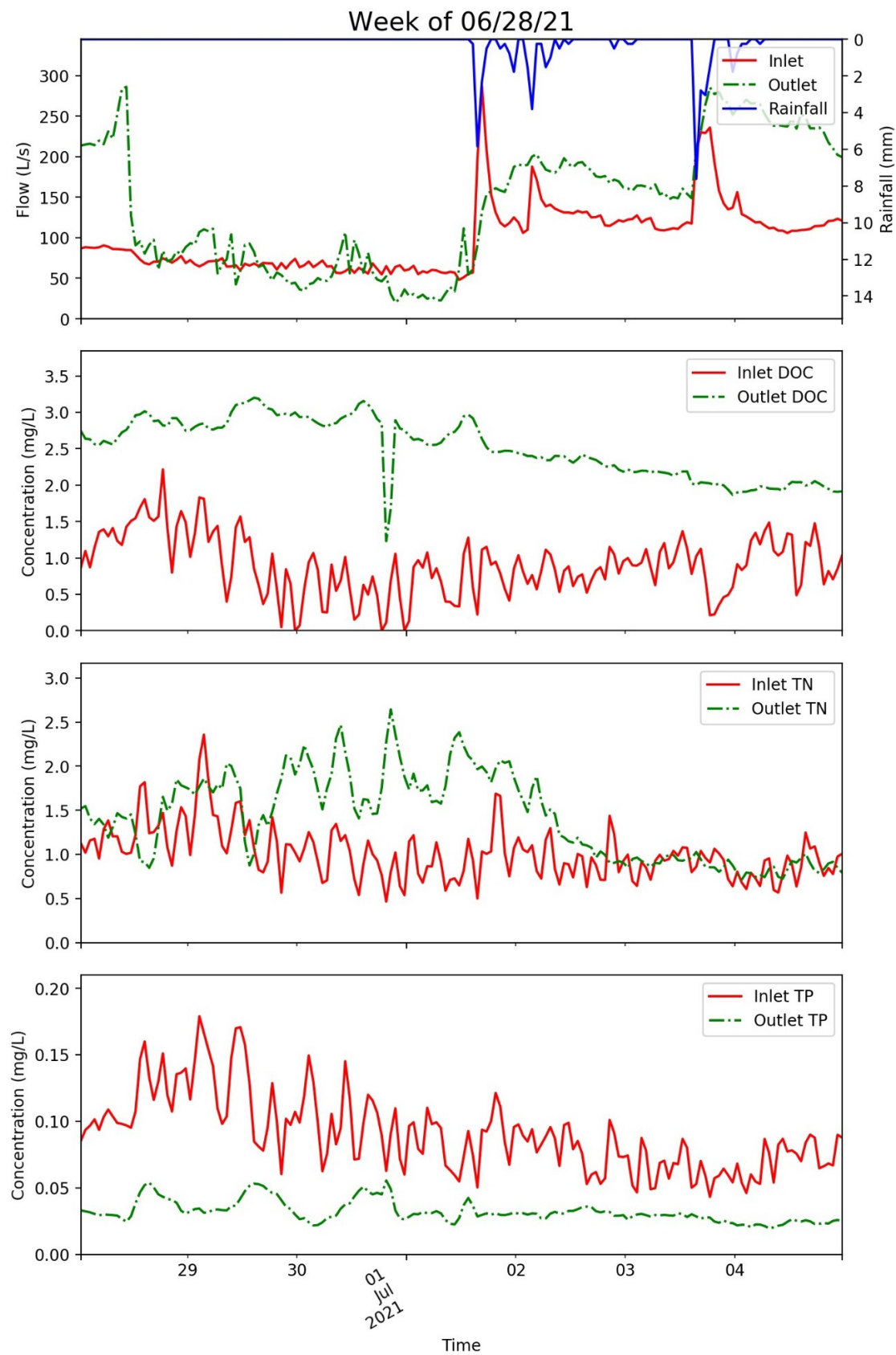


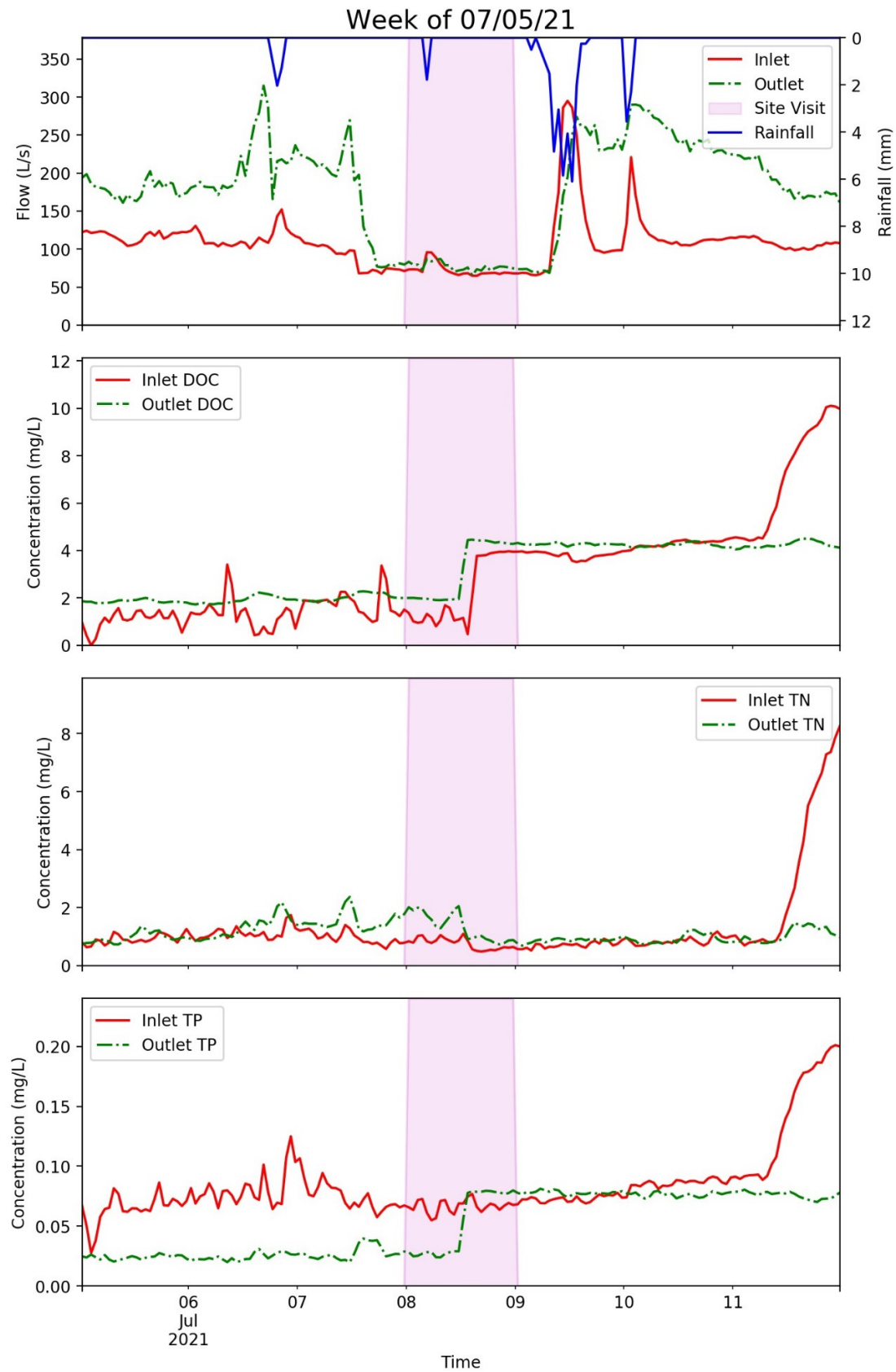


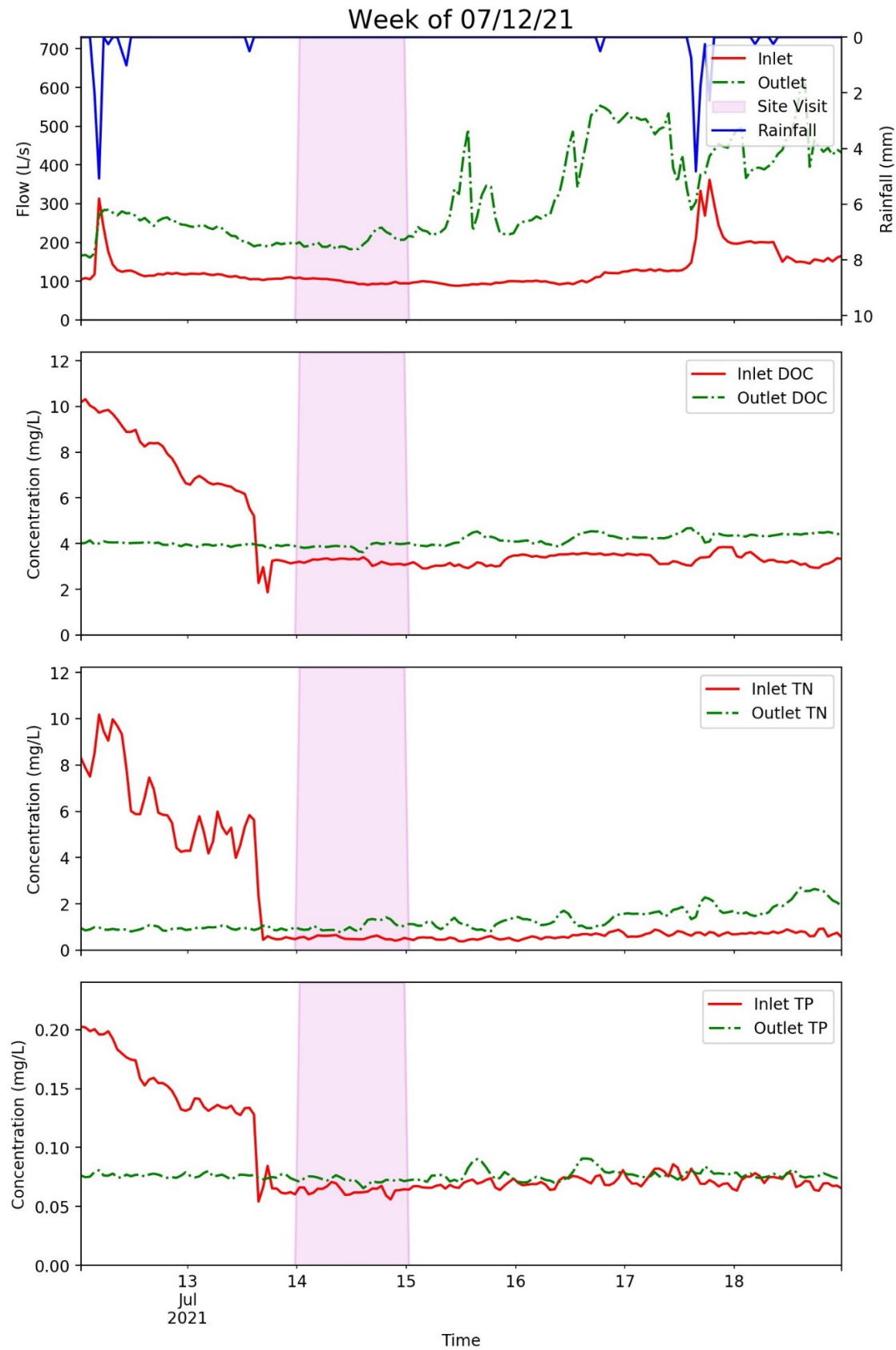


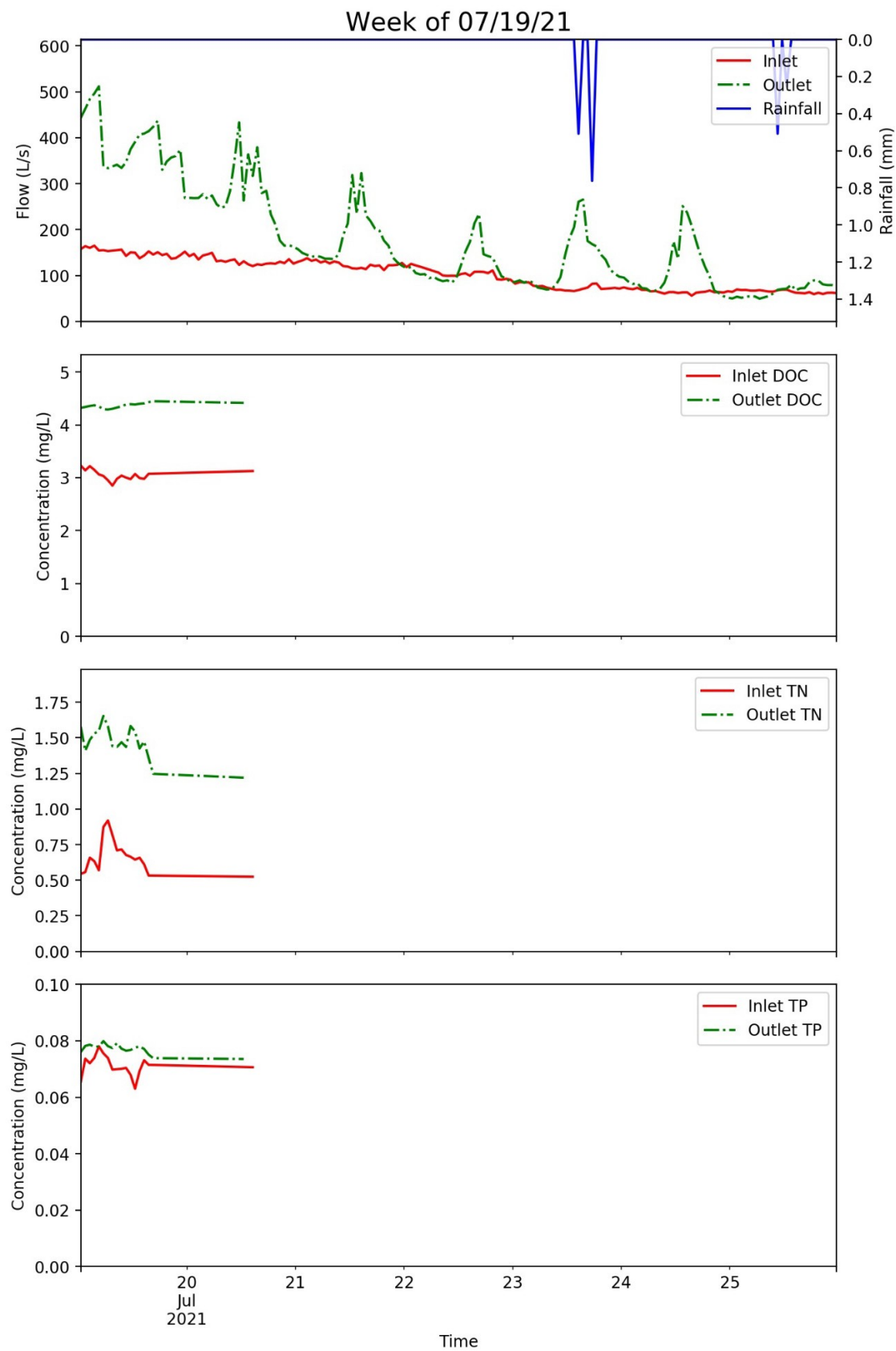


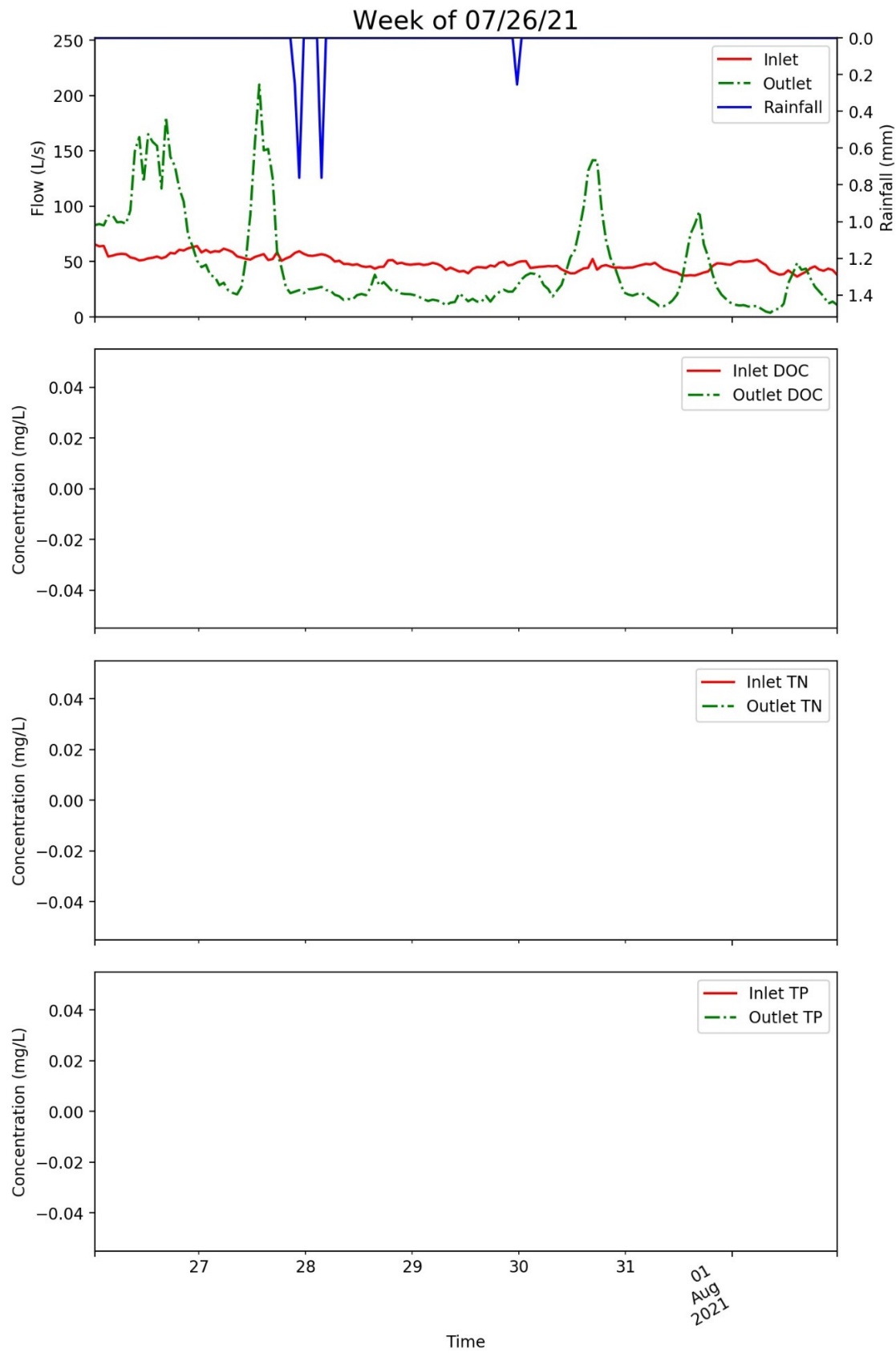


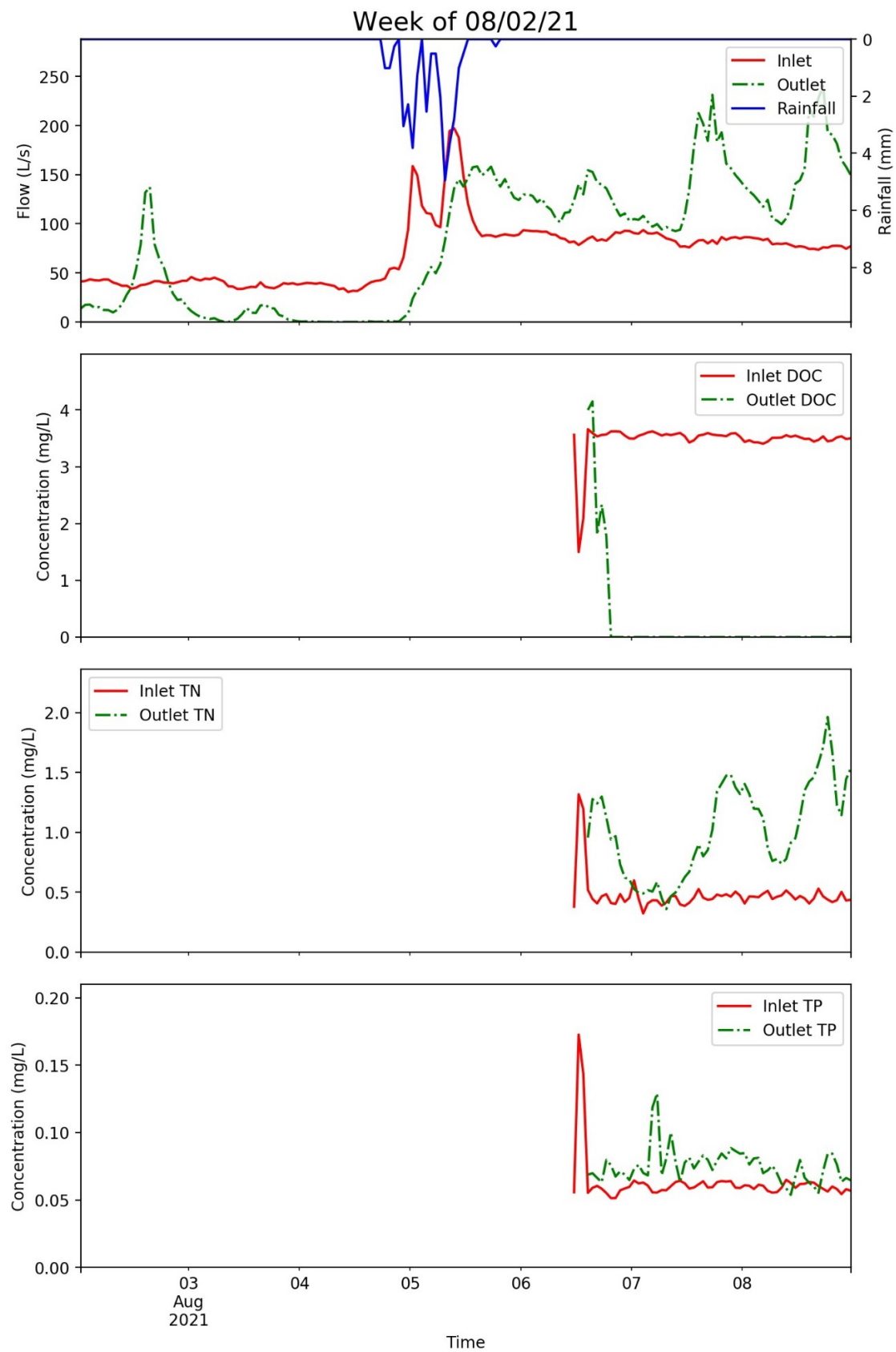




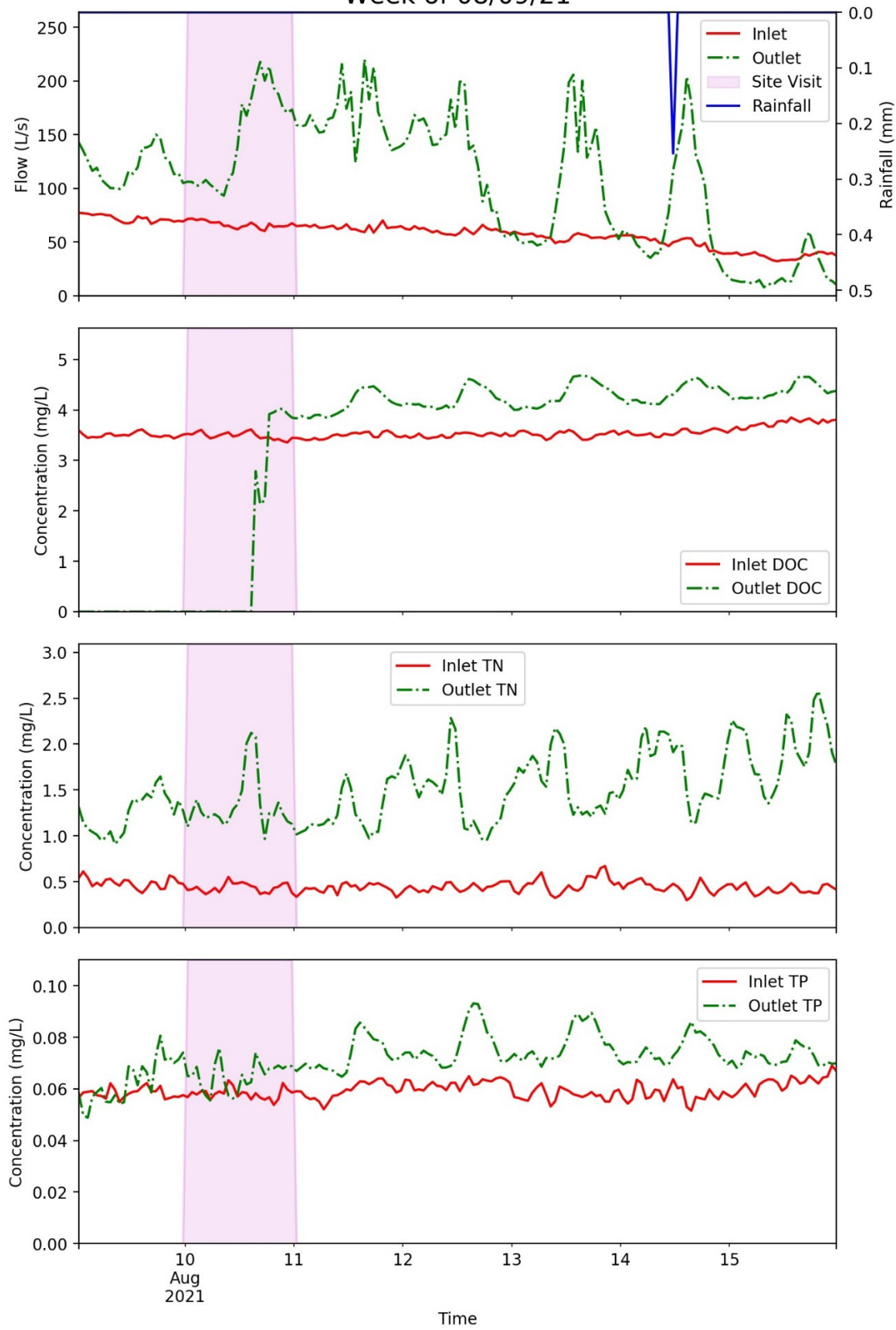


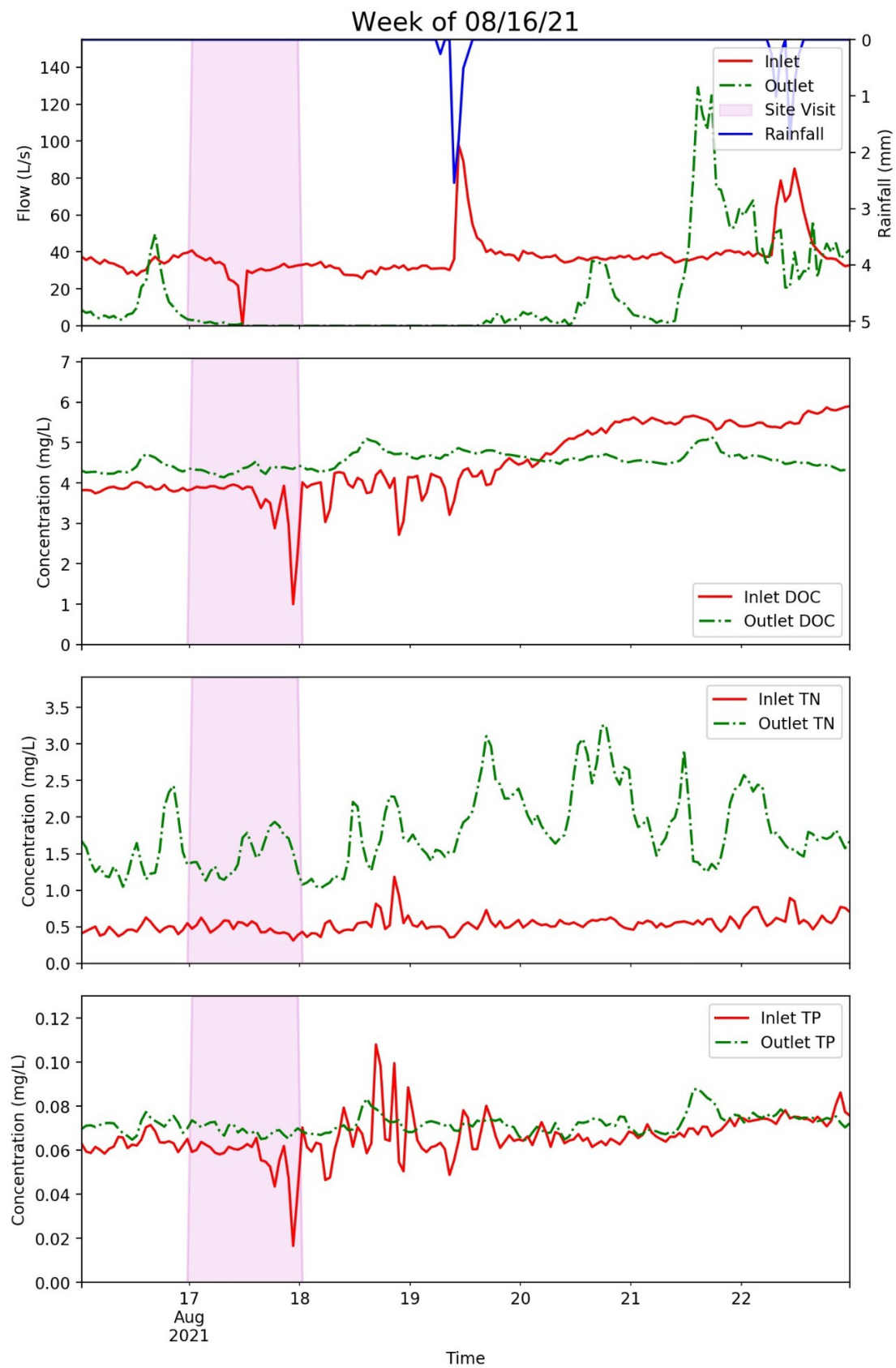


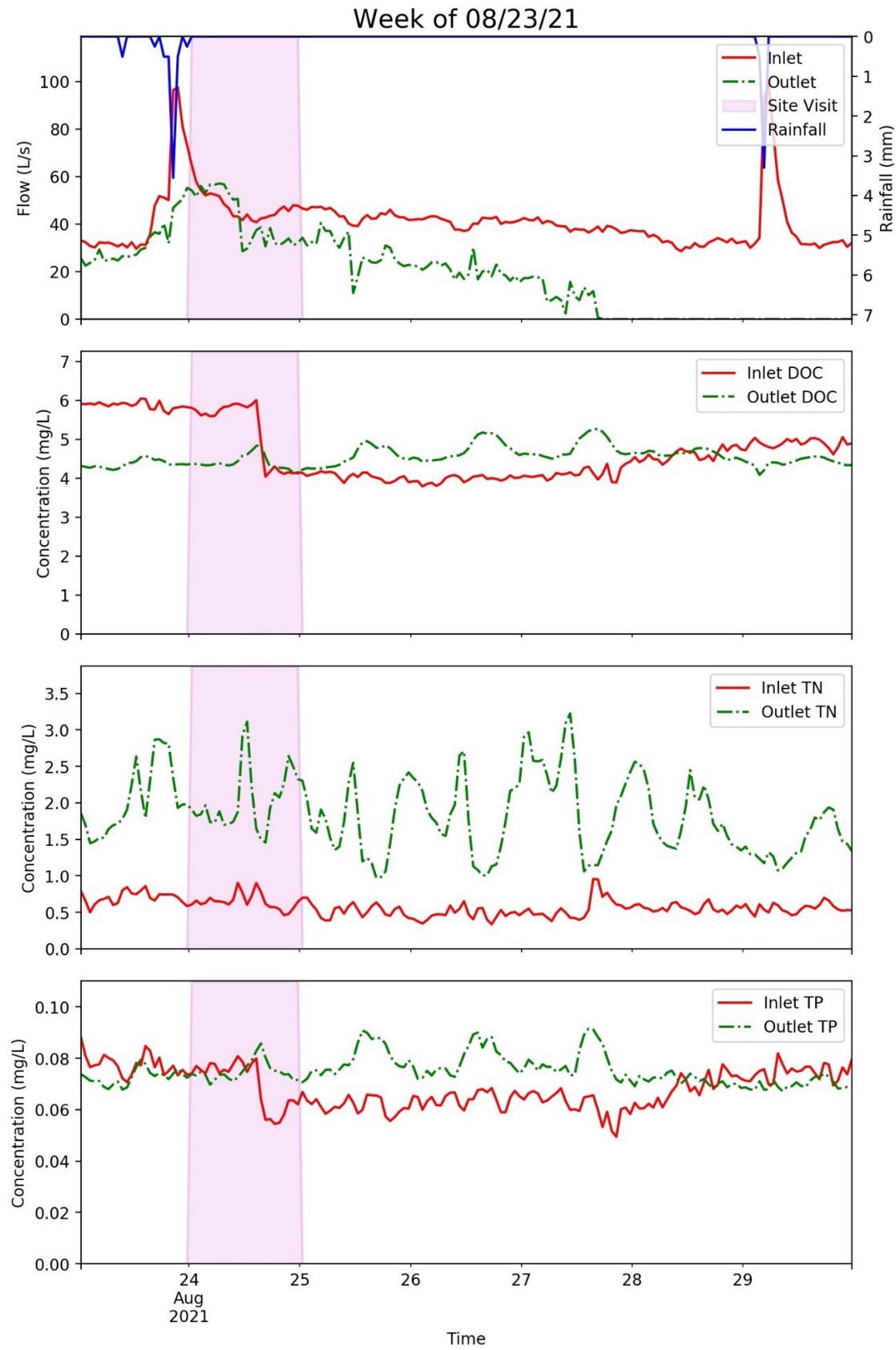


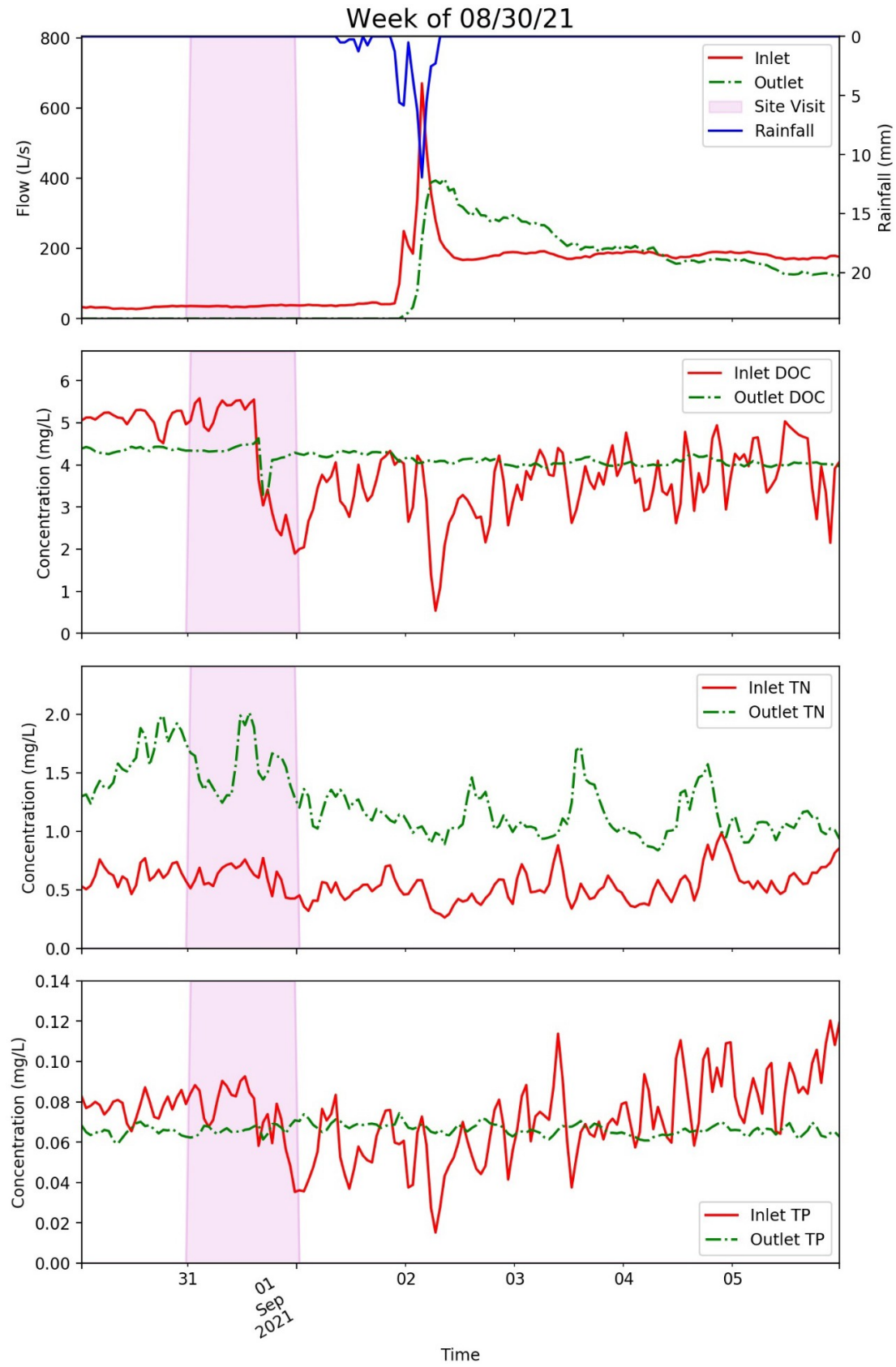


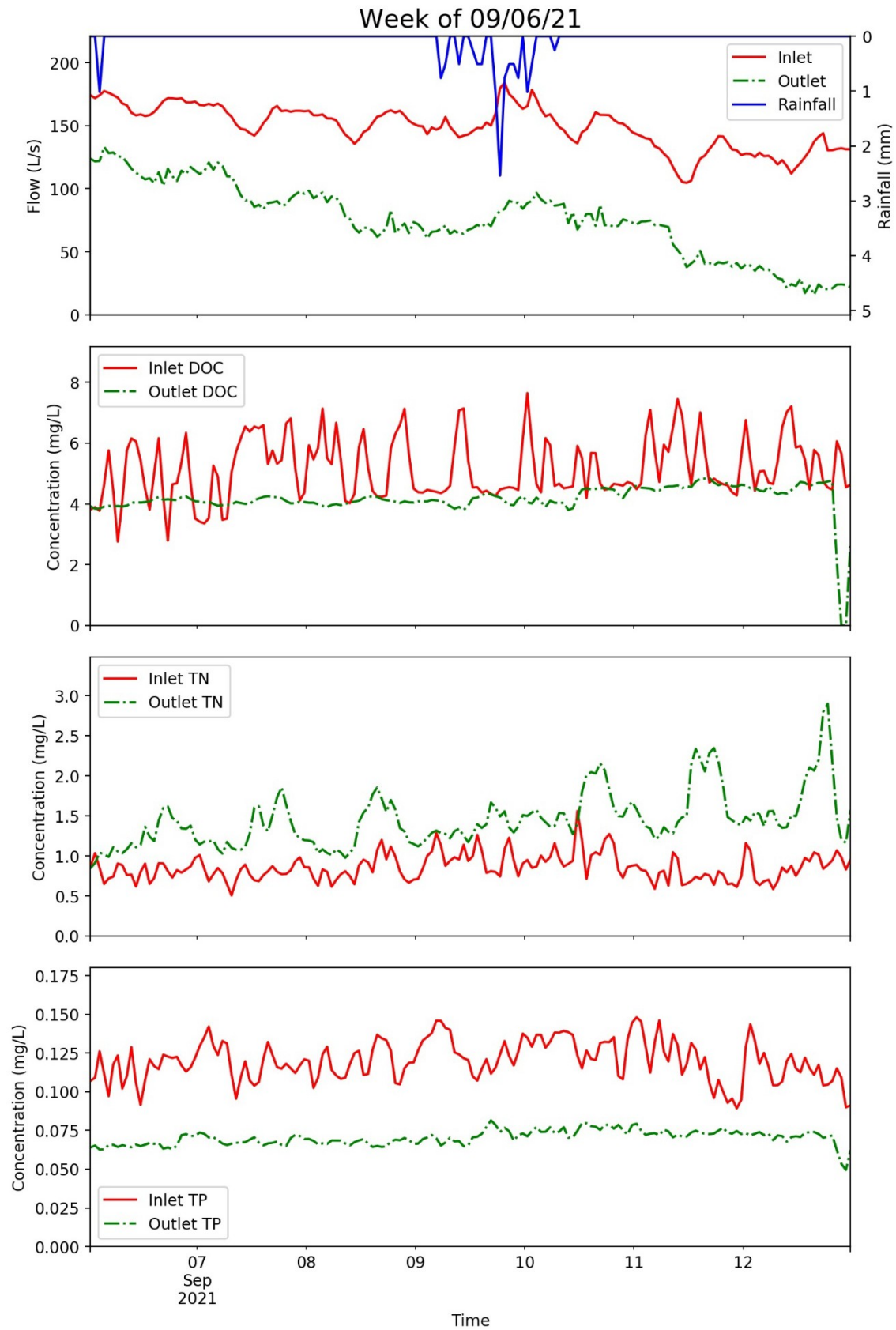
Week of 08/09/21

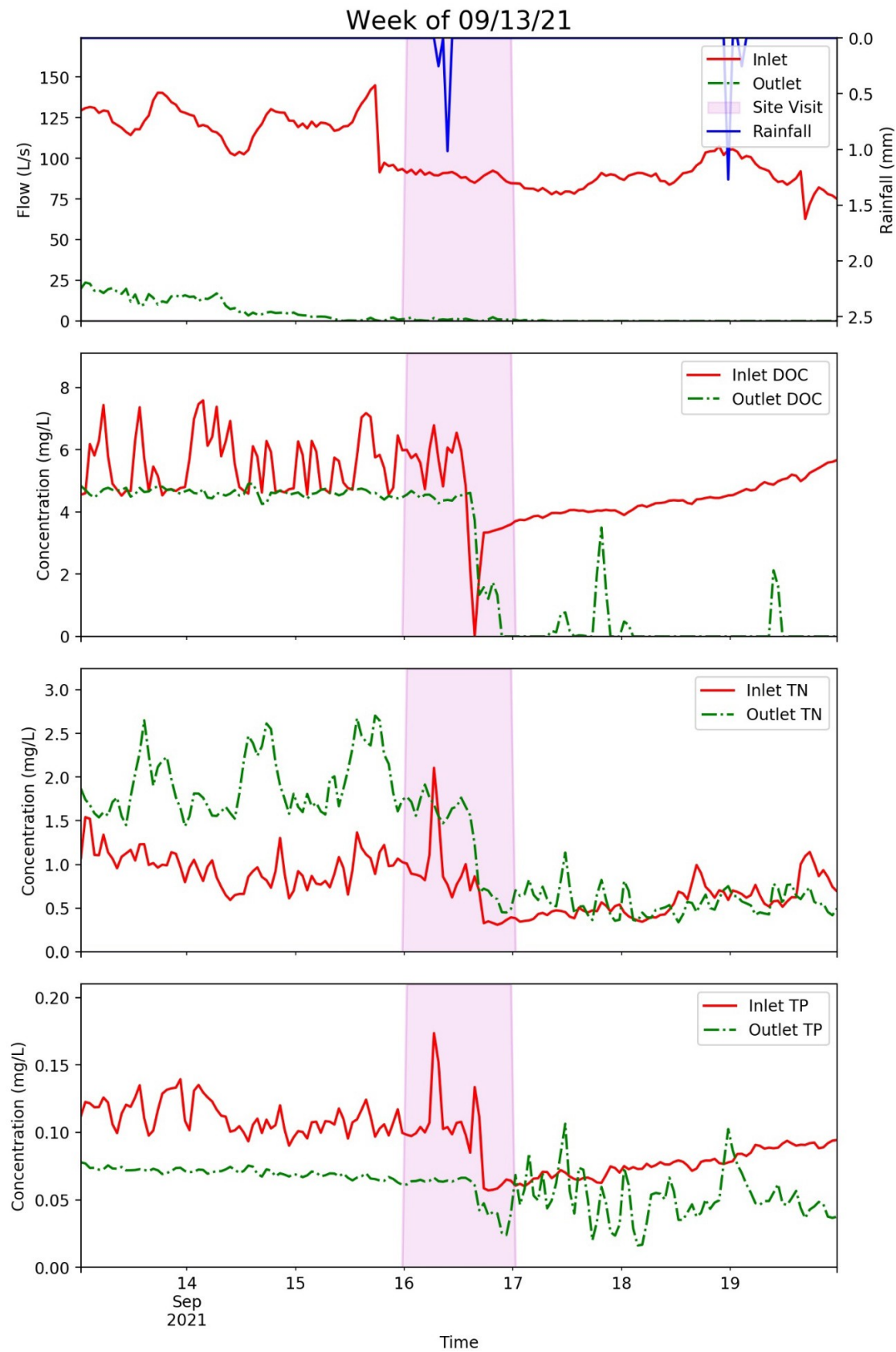


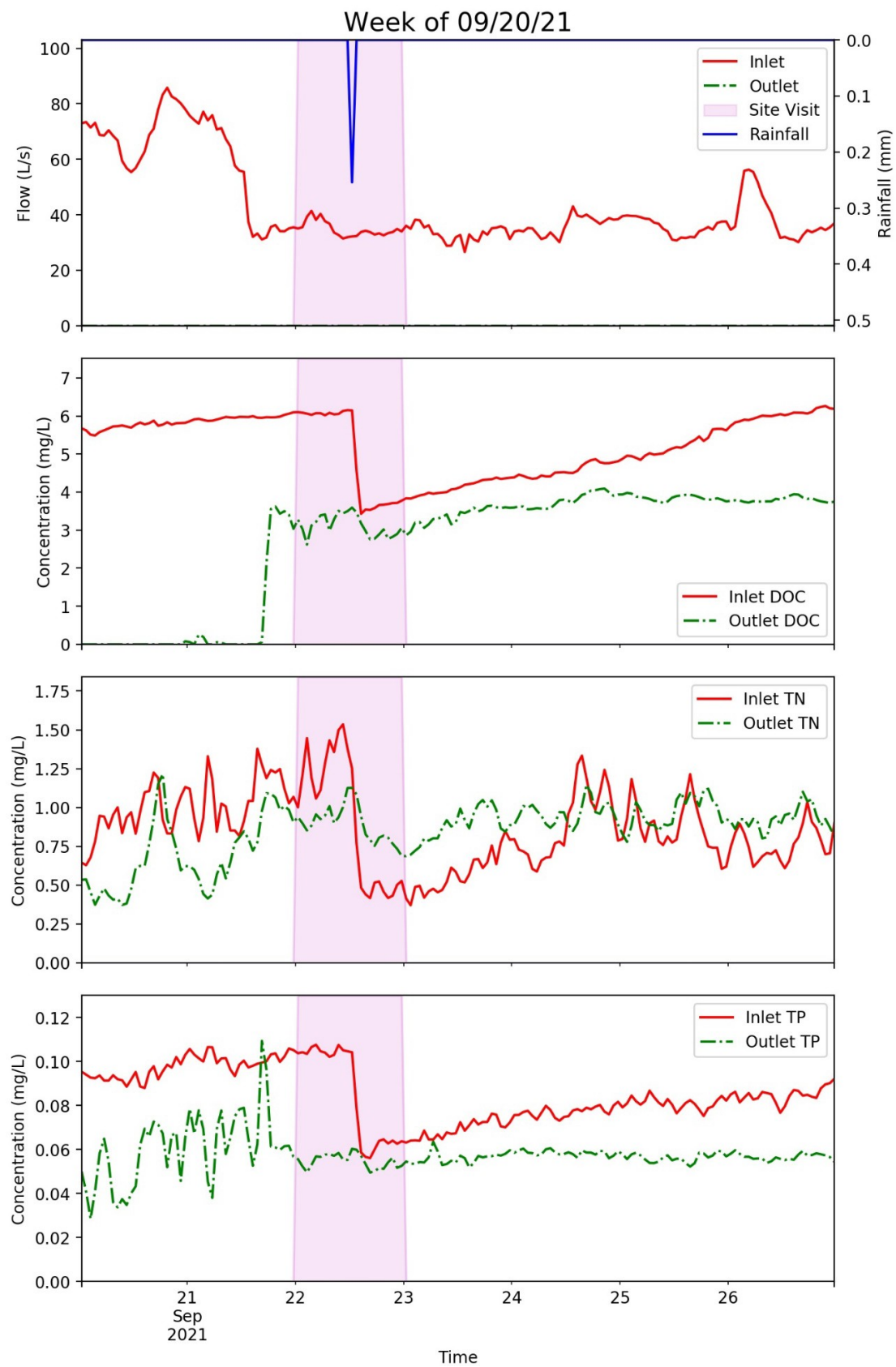


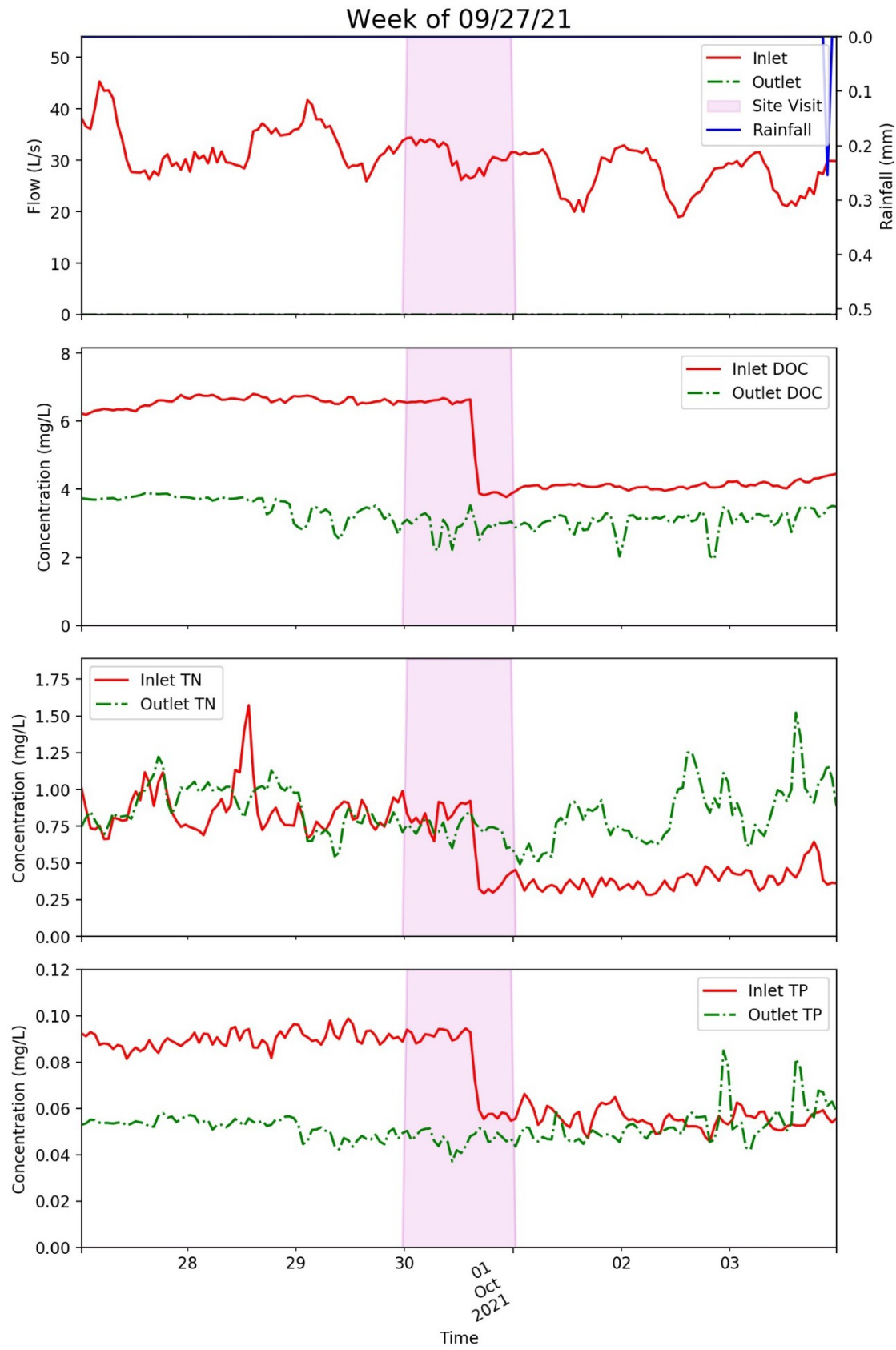


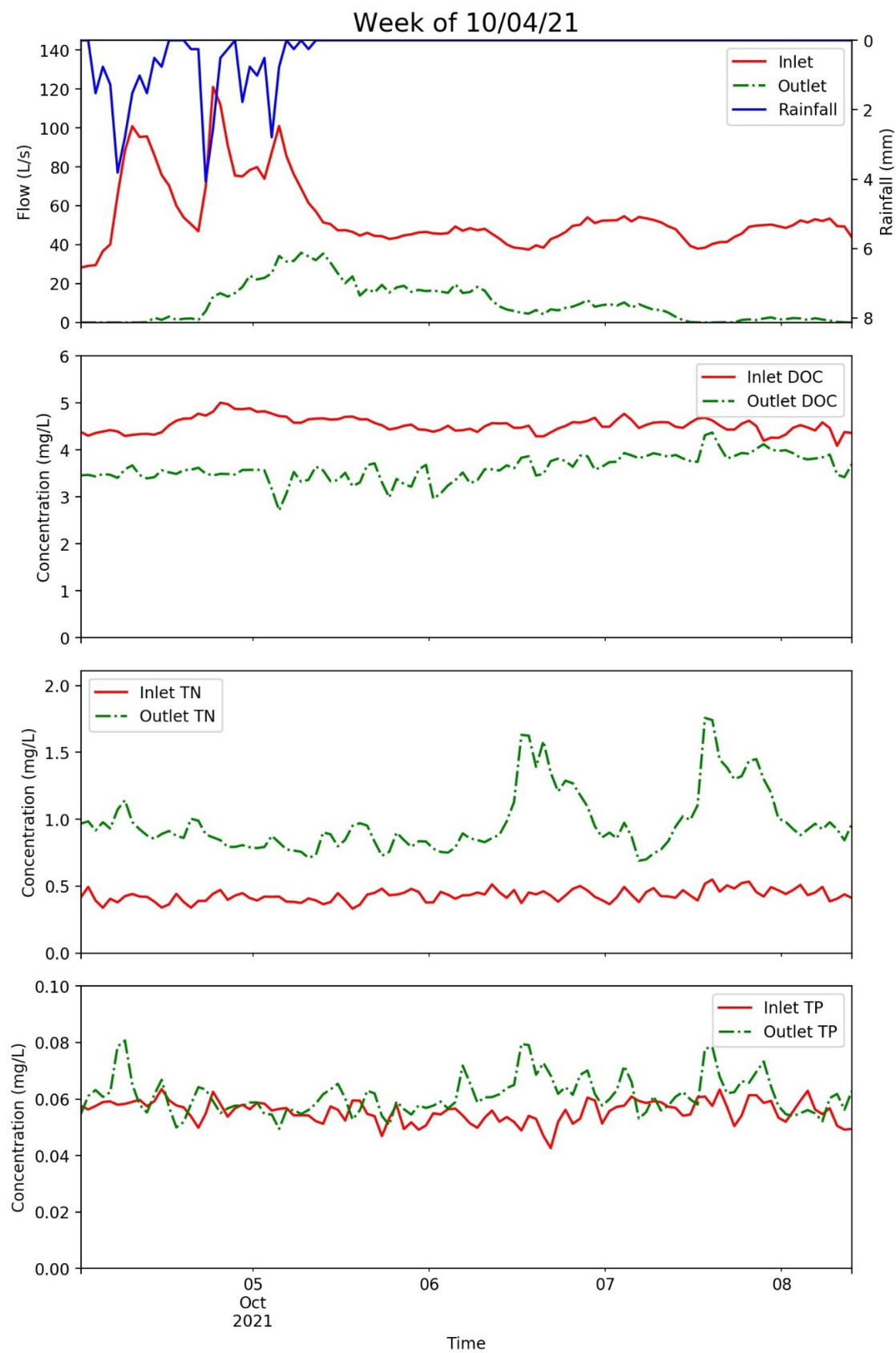










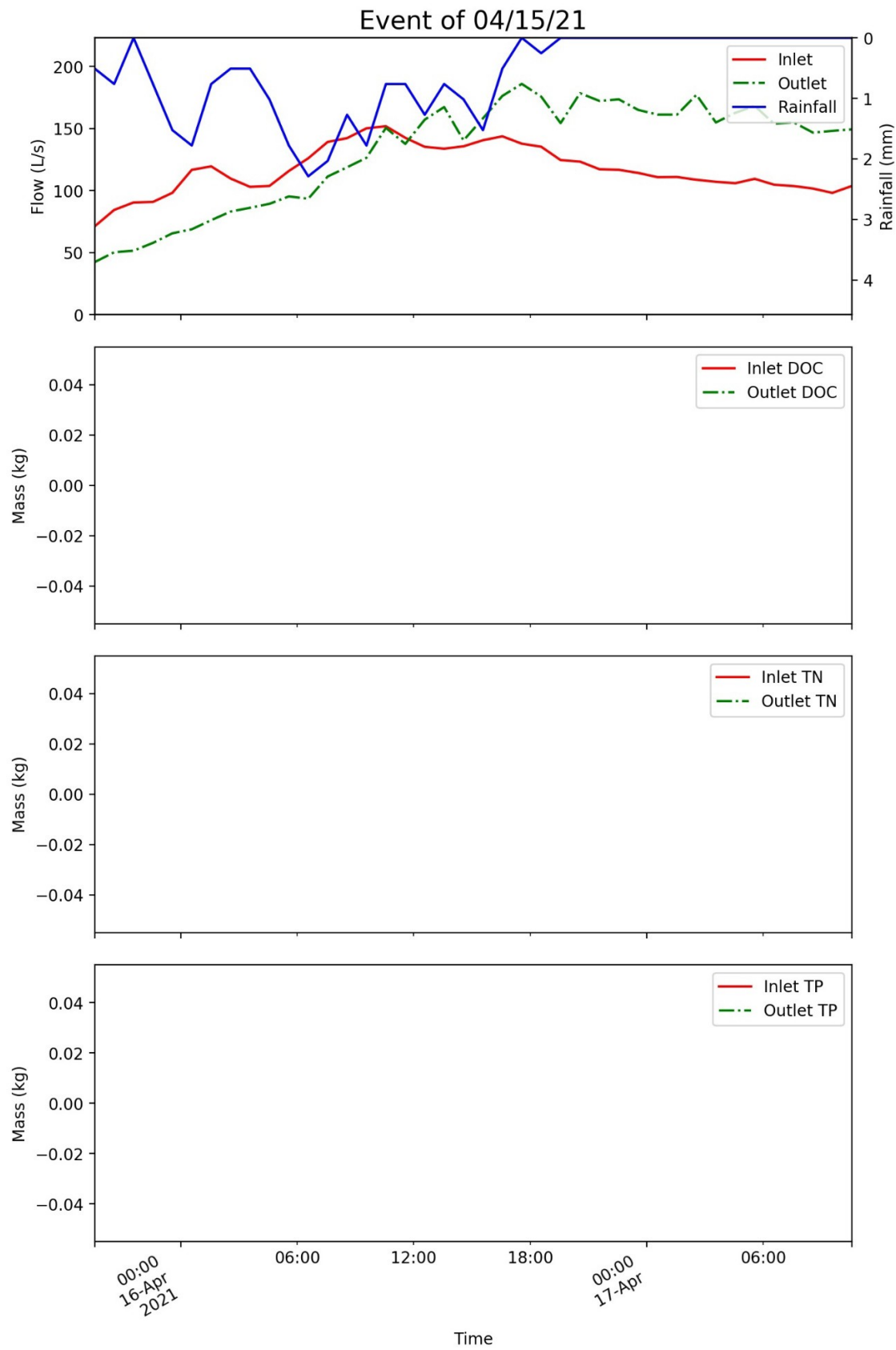


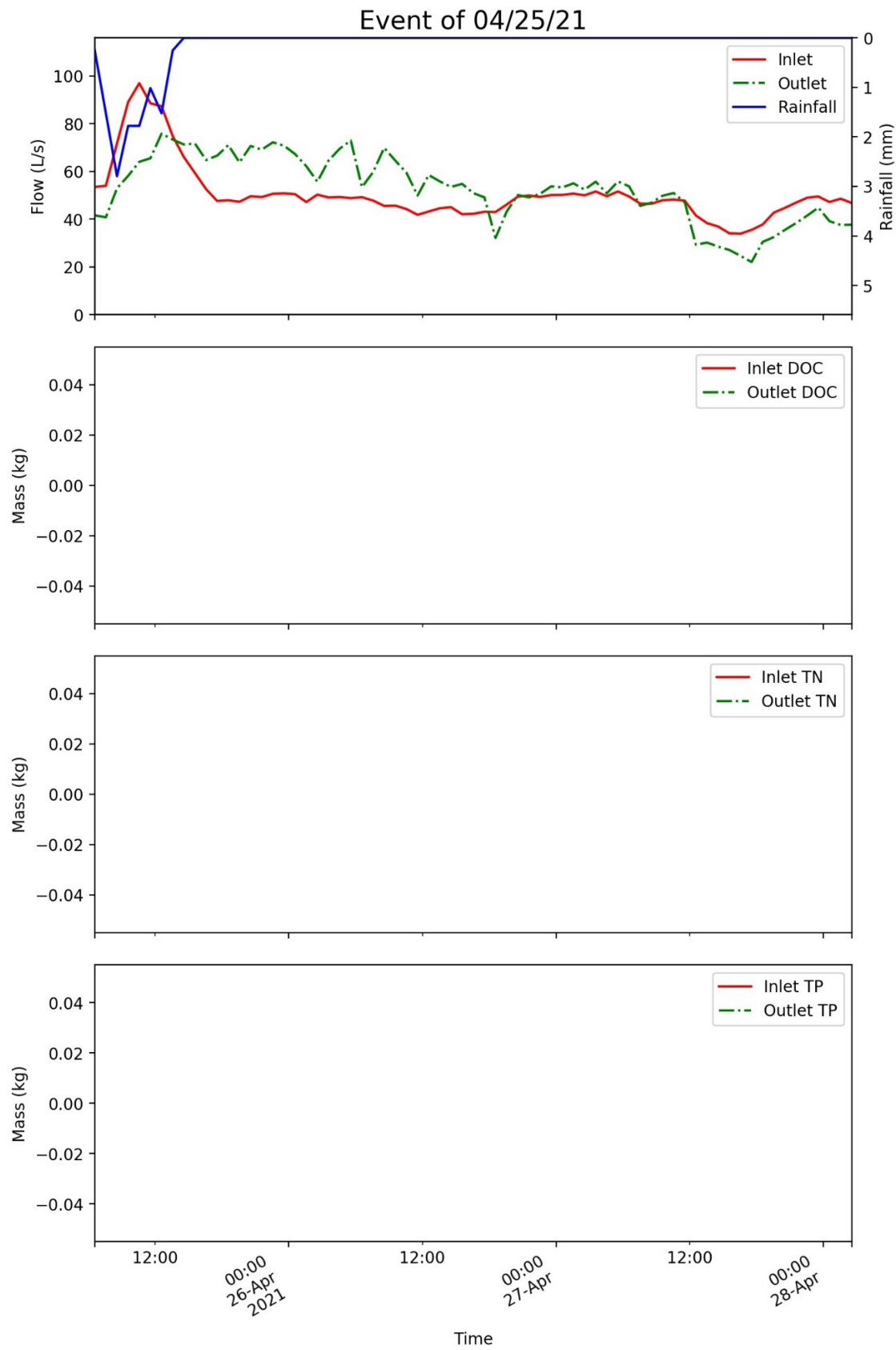
Week	Start Date	Total Rainfall (in)	Mean Inflow (gpm)	Mean Outflow (gpm)	Total Inflow (gal)	Total Outflow (gal)
13	4/2/21	0.00	1,087	1,628	3,782,223	5,665,615
14	4/5/21	0.00	776	663	7,824,963	6,681,510
15	4/12/21	0.97	1,193	1,205	12,029,862	12,145,519
16	4/19/21	0.45	942	1,042	9,492,345	10,502,083
17	4/26/21	0.24	1,238	1,079	12,475,765	10,876,294
18	5/3/21	0.71	1,282	1,550	12,917,897	15,624,516
19	5/10/21	0.81	1,063	1,090	10,714,339	10,984,526
20	5/17/21	0.01	669	237	6,744,166	2,386,382
21	5/24/21	1.46	569	514	5,737,209	5,180,698
22	5/31/21	0.51	603	2,265	6,075,671	22,828,912
23	6/7/21	0.08	456	1,804	4,594,476	18,182,244
24	6/14/21	0.72	608	1,155	6,127,018	11,645,333
25	6/21/21	0.56	749	733	7,552,921	7,389,890
26	6/28/21	1.60	1,577	2,231	15,898,474	22,484,633
27	7/5/21	1.65	1,697	2,813	17,107,899	28,357,615
28	7/12/21	0.80	2,023	5,034	20,396,369	50,738,273
29	7/19/21	0.08	1,624	2,858	16,371,972	28,809,163
30	7/26/21	0.08	772	730	7,785,607	7,358,427
31	8/2/21	1.24	1,112	1,298	11,208,549	13,082,267
32	8/9/21	0.01	916	1,728	9,236,299	17,416,230
33	8/16/21	0.38	591	254	5,961,830	2,556,315
34	8/23/21	0.39	657	299	6,622,385	3,010,069
35	8/30/21	1.93	2,026	1,878	20,426,288	18,933,404
36	9/6/21	0.47	2,364	1,192	23,826,667	12,016,082
37	9/13/21	0.11	1,622	62	16,346,480	623,243
38	9/20/21	0.01	685	-	6,904,389	-
39	9/27/21	0.01	477	-	4,809,497	-
40	10/4/21	1.24	866	156	5,509,849	989,313

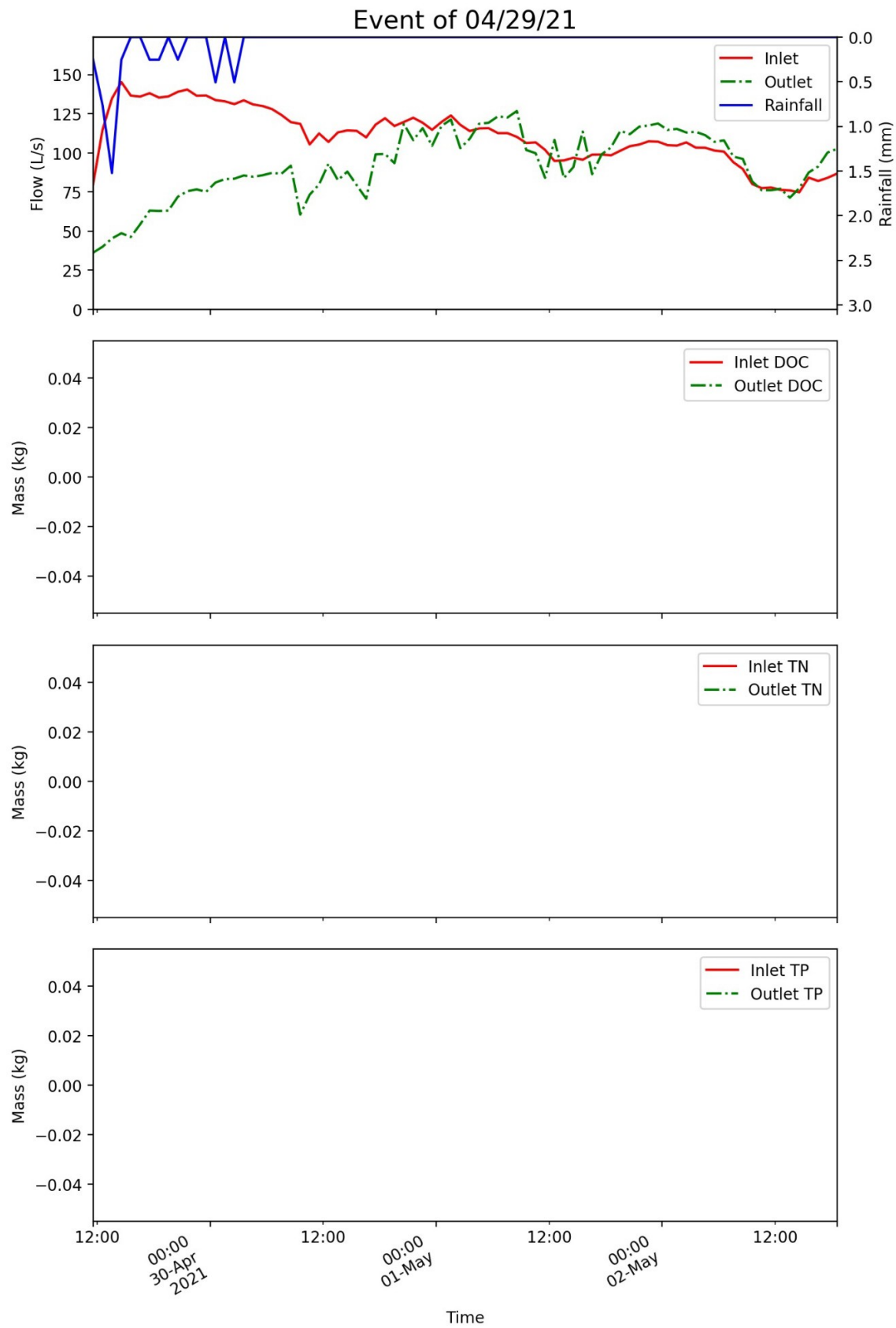
Week	Start Date	Mean Inlet UV- Vis DOC (mg/L)	Mean Outlet UV- Vis DOC (mg/L)	Mean Inlet UV- Vis TN (mg/L)	Mean Outlet UV- Vis TN (mg/L)	Mean Inlet UV- Vis TP (mg/L)	Mean Outlet UV-Vis TP (mg/L)
13	4/2/21	NaN	NaN	NaN	NaN	NaN	NaN
14	4/5/21	NaN	NaN	NaN	NaN	NaN	NaN
15	4/12/21	NaN	NaN	NaN	NaN	NaN	NaN
16	4/19/21	NaN	NaN	NaN	NaN	NaN	NaN
17	4/26/21	NaN	NaN	NaN	NaN	NaN	NaN
18	5/3/21	NaN	NaN	NaN	NaN	NaN	NaN
19	5/10/21	NaN	NaN	NaN	NaN	NaN	NaN
20	5/17/21	NaN	NaN	NaN	NaN	NaN	NaN
21	5/24/21	NaN	NaN	NaN	NaN	NaN	NaN
22	5/31/21	NaN	NaN	NaN	NaN	NaN	NaN
23	6/7/21	NaN	NaN	NaN	NaN	NaN	NaN
24	6/14/21	3.90	NaN	0.57	NaN	0.06	NaN
25	6/21/21	3.16	2.91	0.94	0.86	0.08	0.03
26	6/28/21	0.90	2.51	1.01	1.42	0.09	0.03
27	7/5/21	3.08	3.10	1.23	1.14	0.08	0.05
28	7/12/21	4.34	4.13	1.96	1.29	0.09	0.08
29	7/19/21	3.08	4.40	0.59	1.35	0.07	0.08
30	7/26/21	NaN	NaN	NaN	NaN	NaN	NaN
31	8/2/21	3.47	0.24	0.48	1.02	0.06	0.08
32	8/9/21	3.54	3.23	0.45	1.51	0.06	0.07
33	8/16/21	4.51	4.55	0.54	1.80	0.07	0.07
34	8/23/21	4.67	4.55	0.58	1.85	0.07	0.08
35	8/30/21	3.89	4.16	0.55	1.25	0.07	0.07
36	9/6/21	5.17	4.16	0.86	1.45	0.12	0.07
37	9/13/21	4.93	2.53	0.78	1.25	0.09	0.06
38	9/20/21	5.23	2.70	0.86	0.86	0.08	0.06
39	9/27/21	5.39	3.25	0.63	0.84	0.07	0.05
40	10/4/21	4.54	3.61	0.43	0.98	0.06	0.06

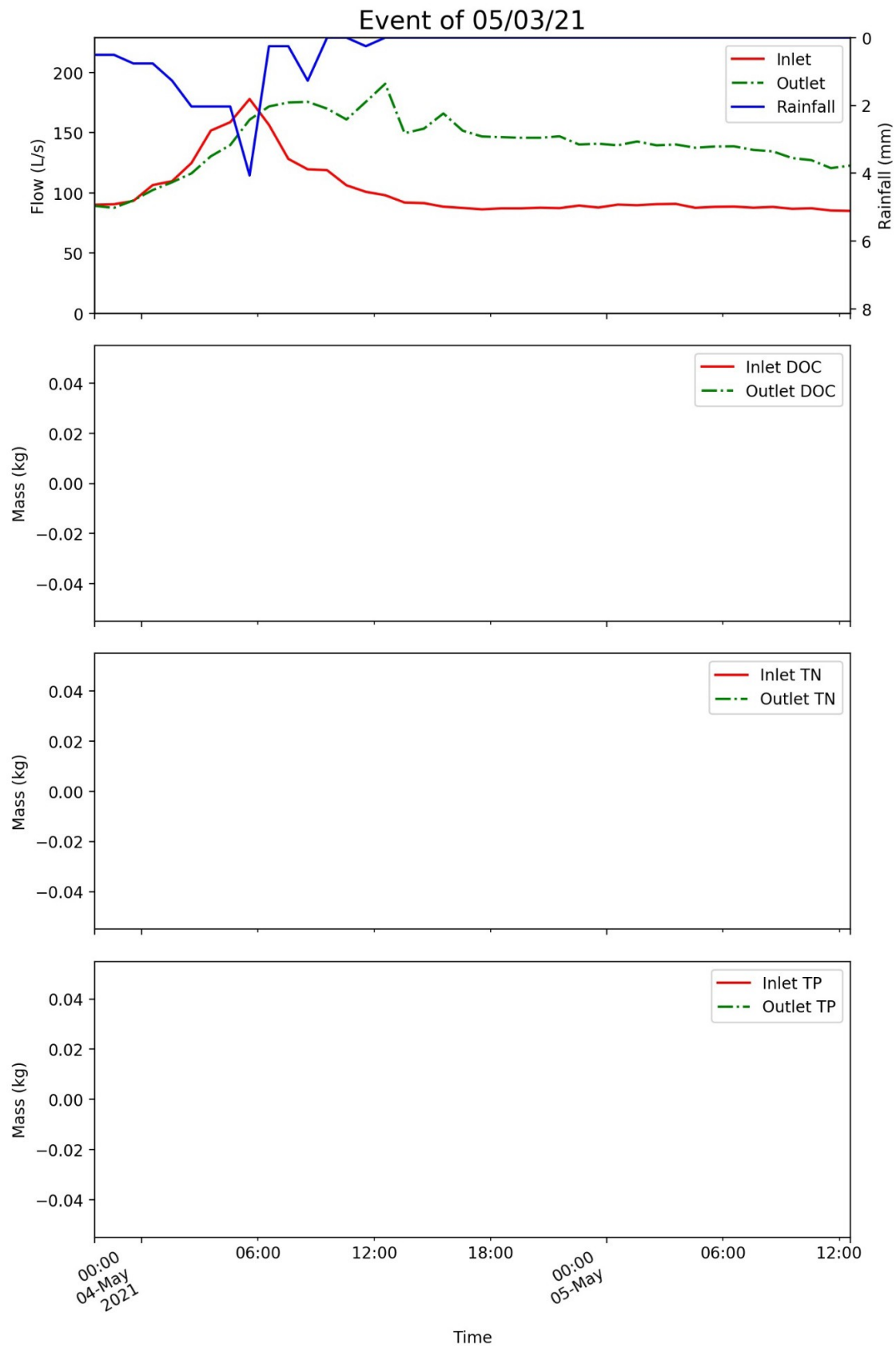
Appendix B: Weekly Mass Flux

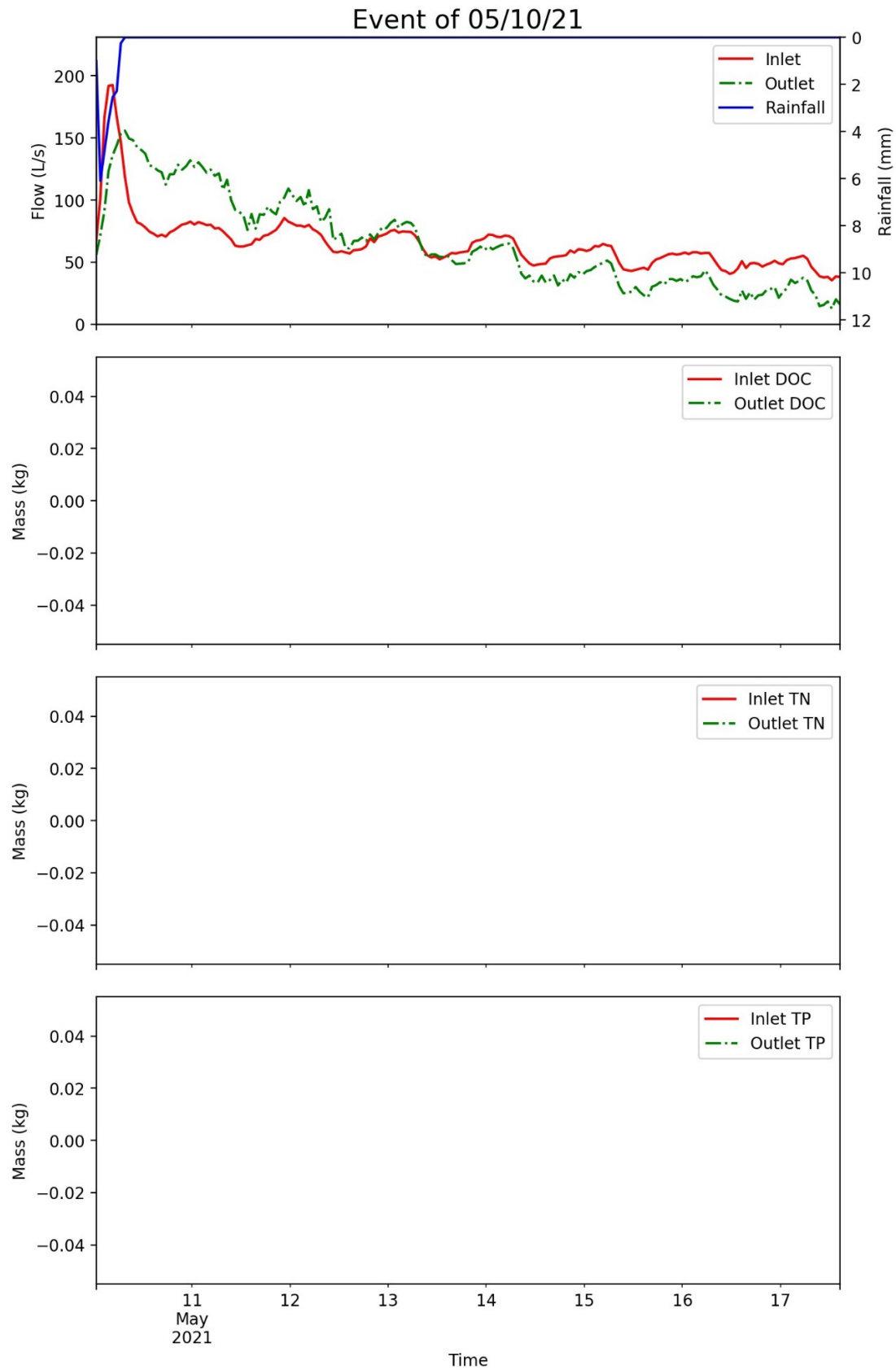
The real-time UV-visual mass flux of DOC, TN, and TP are shown in the graphs and summary tables in this appendix along with the rainfall, inflow, and outflow. Mass flux was calculated by multiplying the flow (converted to volume) by concentration. Days where instrument maintenance are highlighted in magenta. Time with no data lines indicate either a system error (pump failure, etc.) and the associated data was either missing or did not pass quality control.

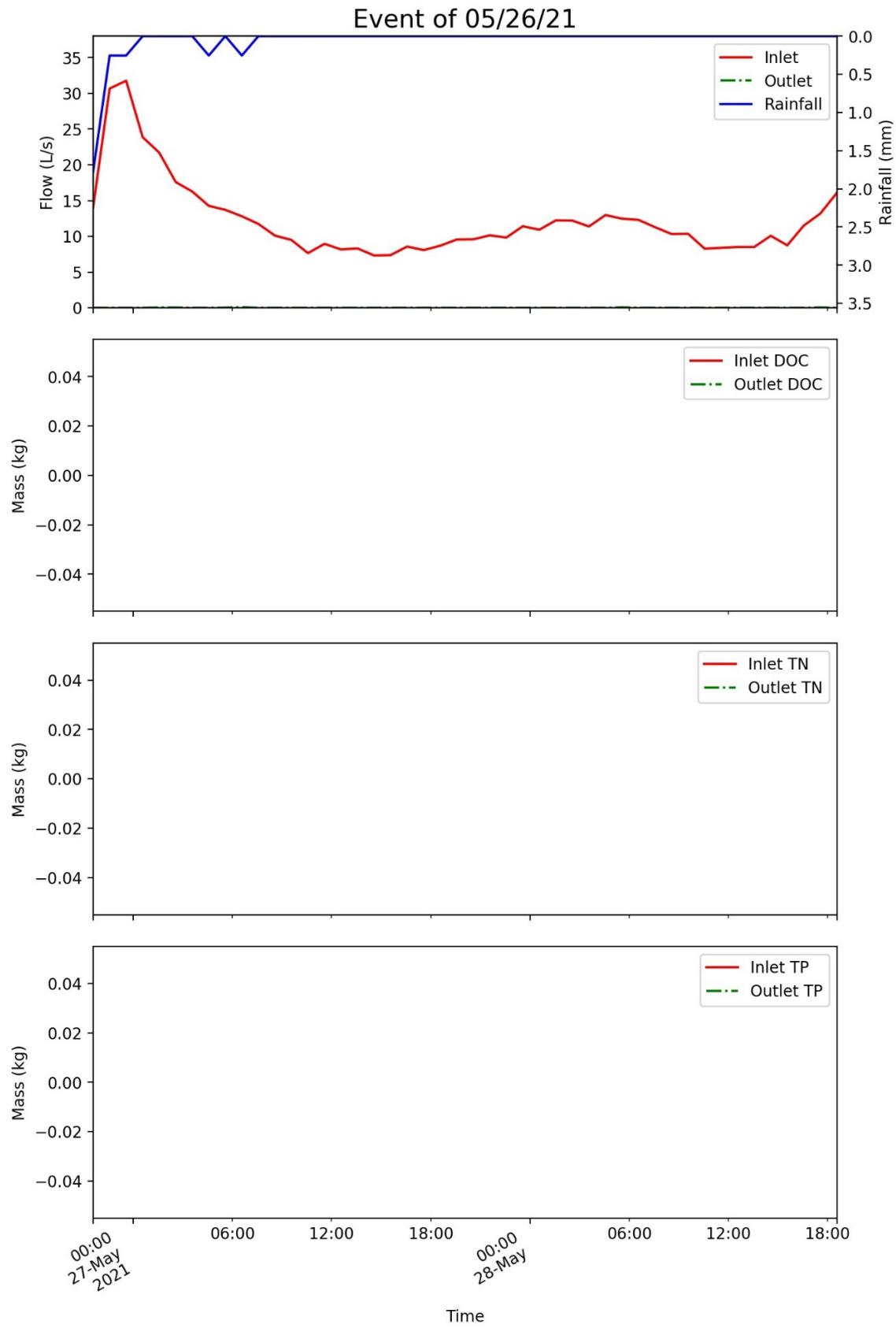


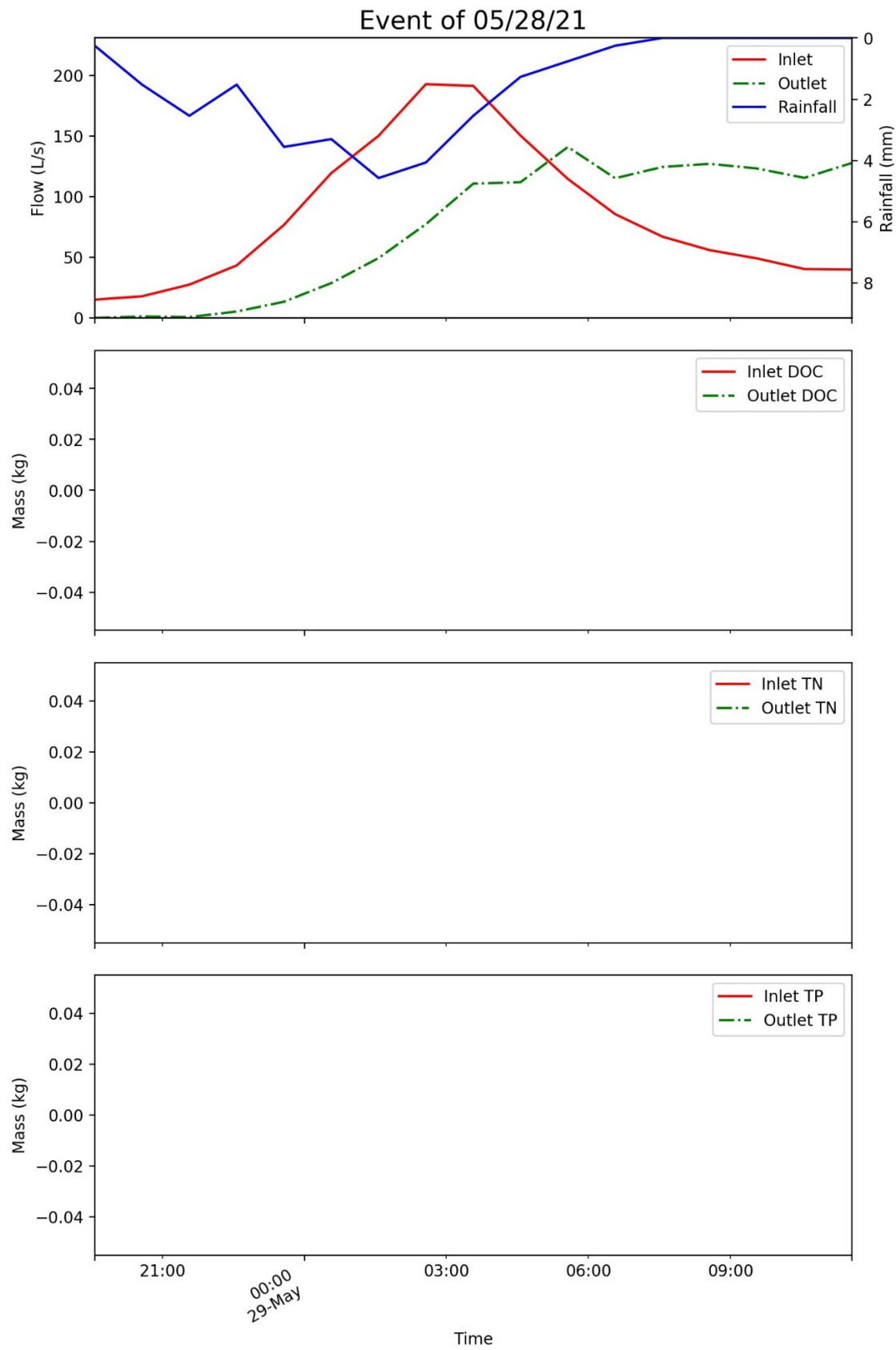


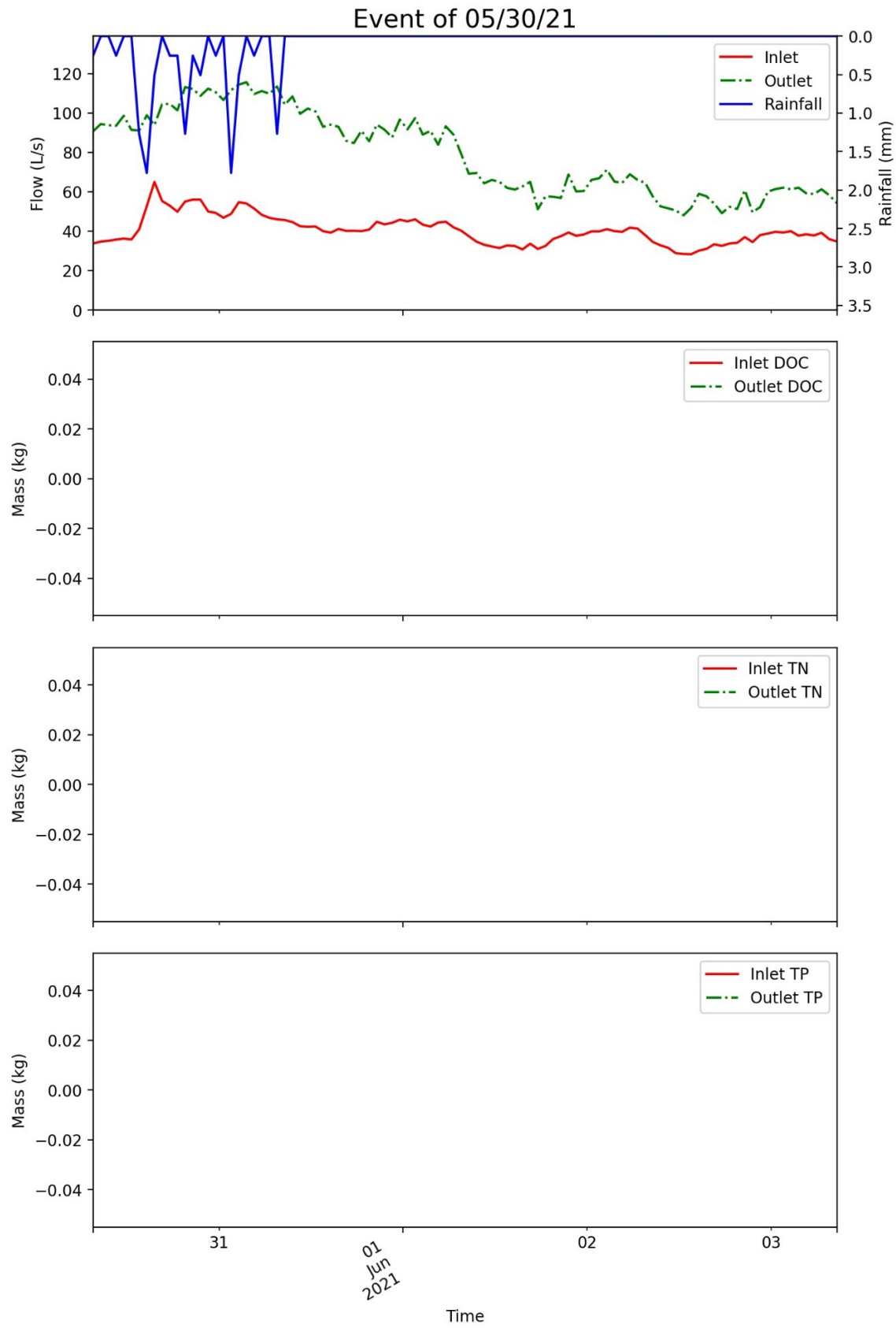


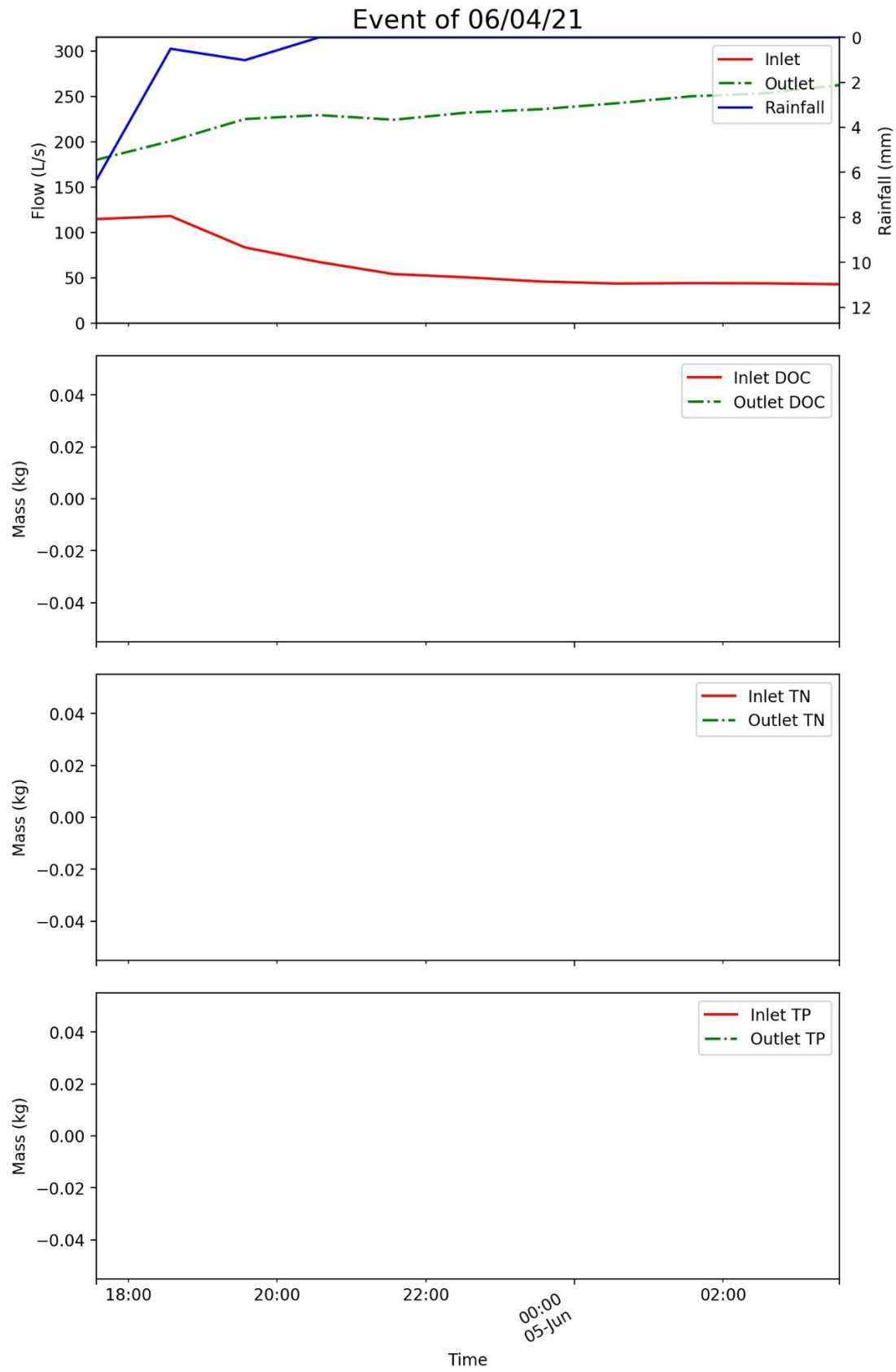


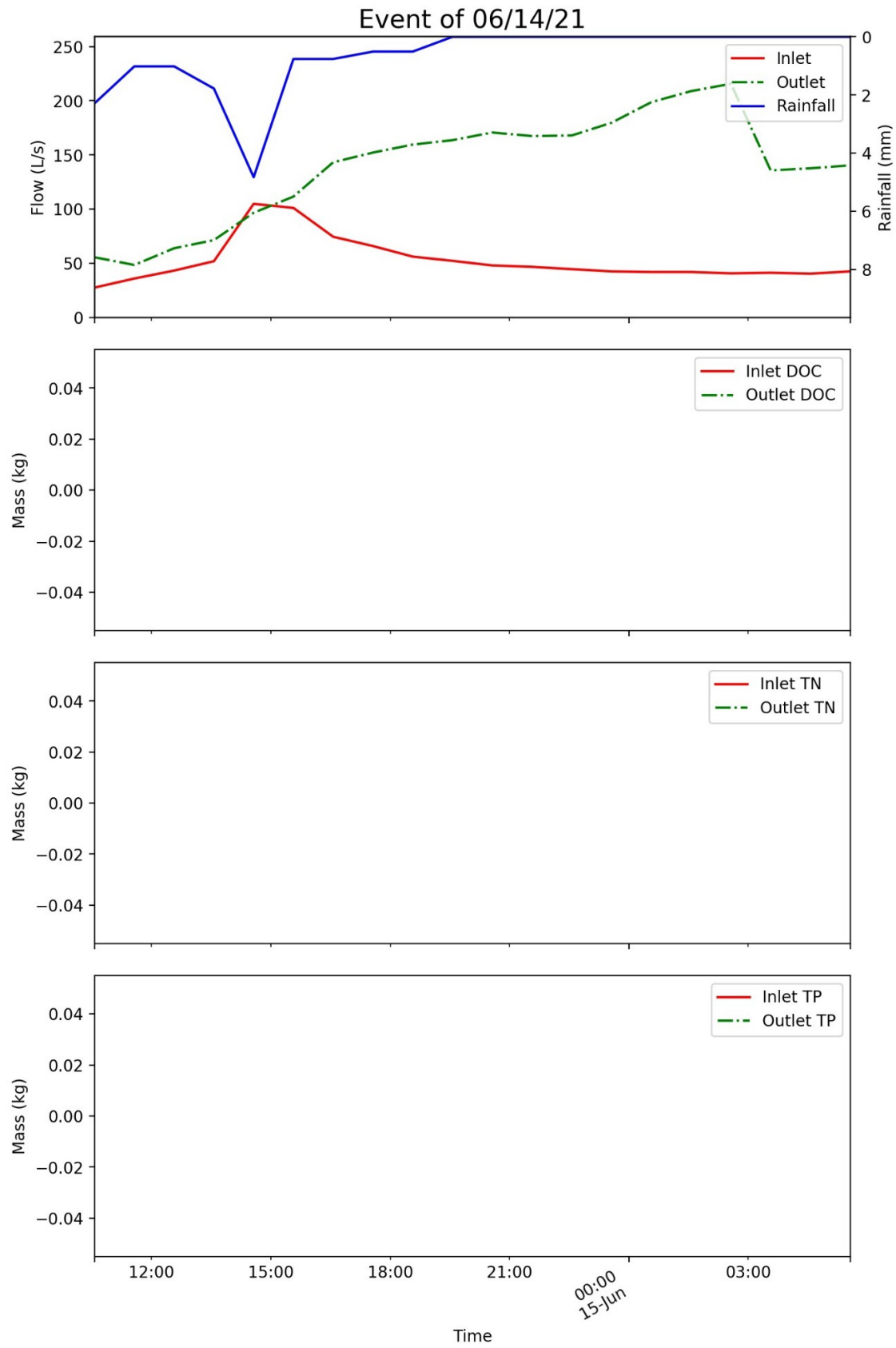




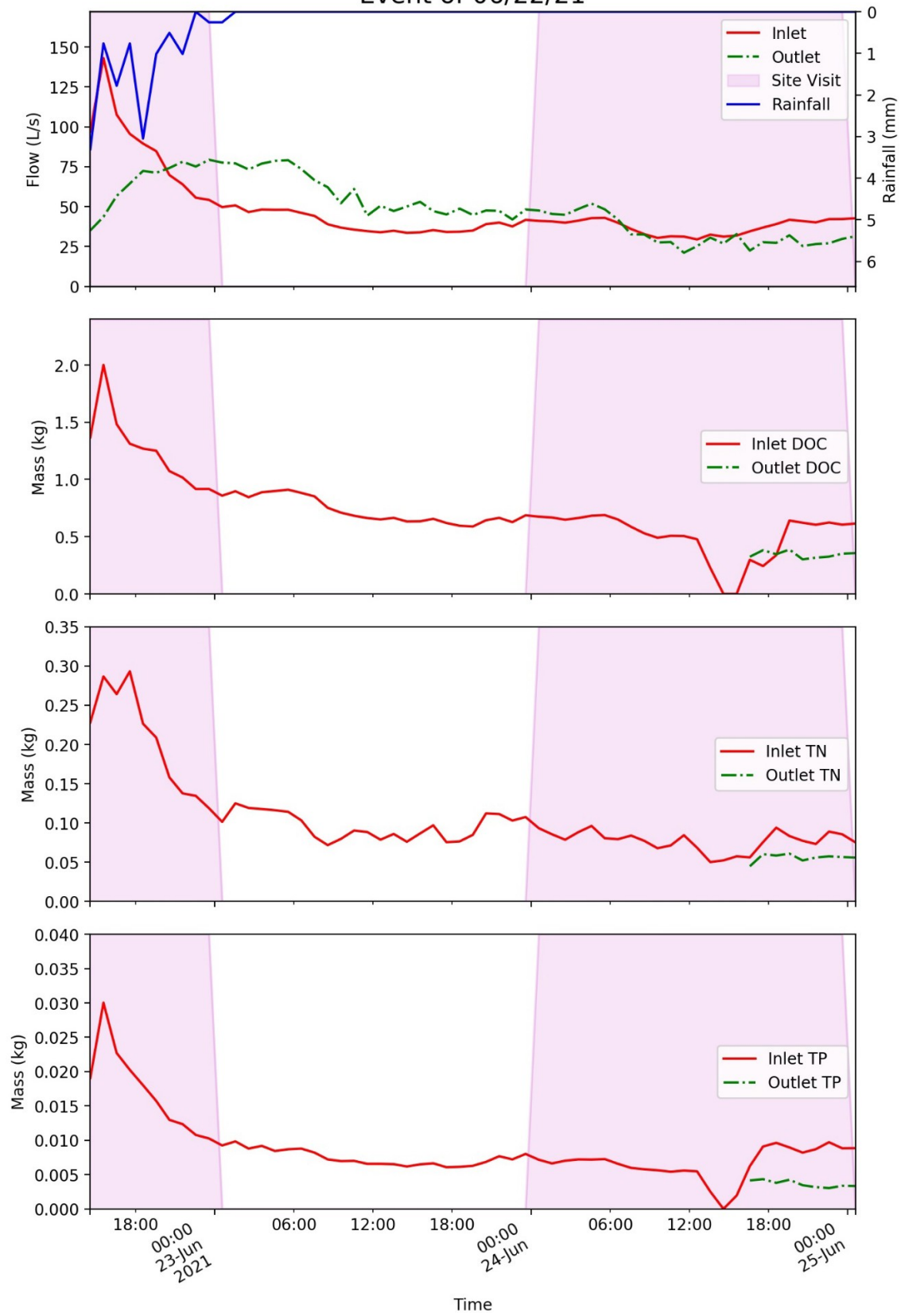


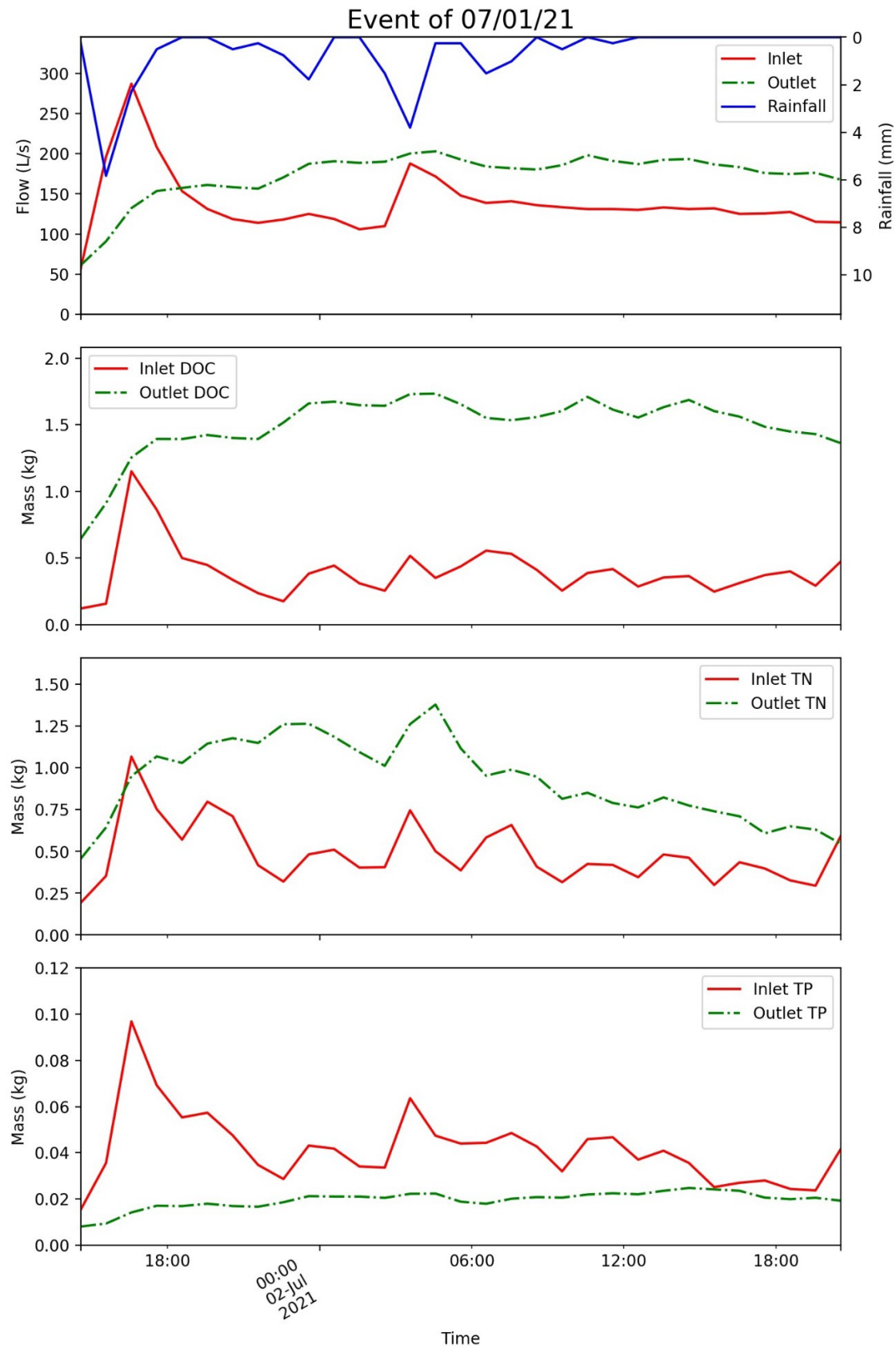


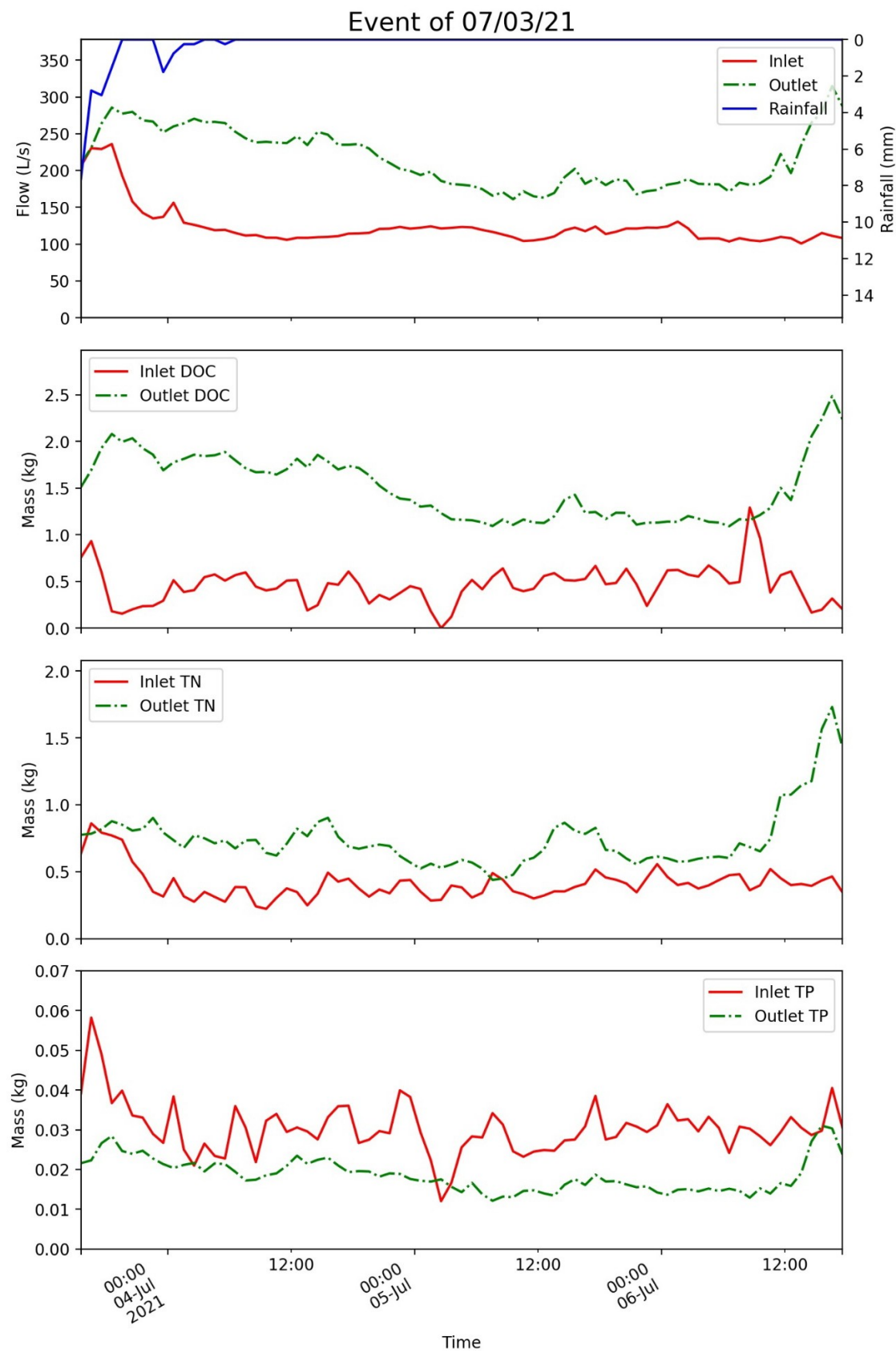


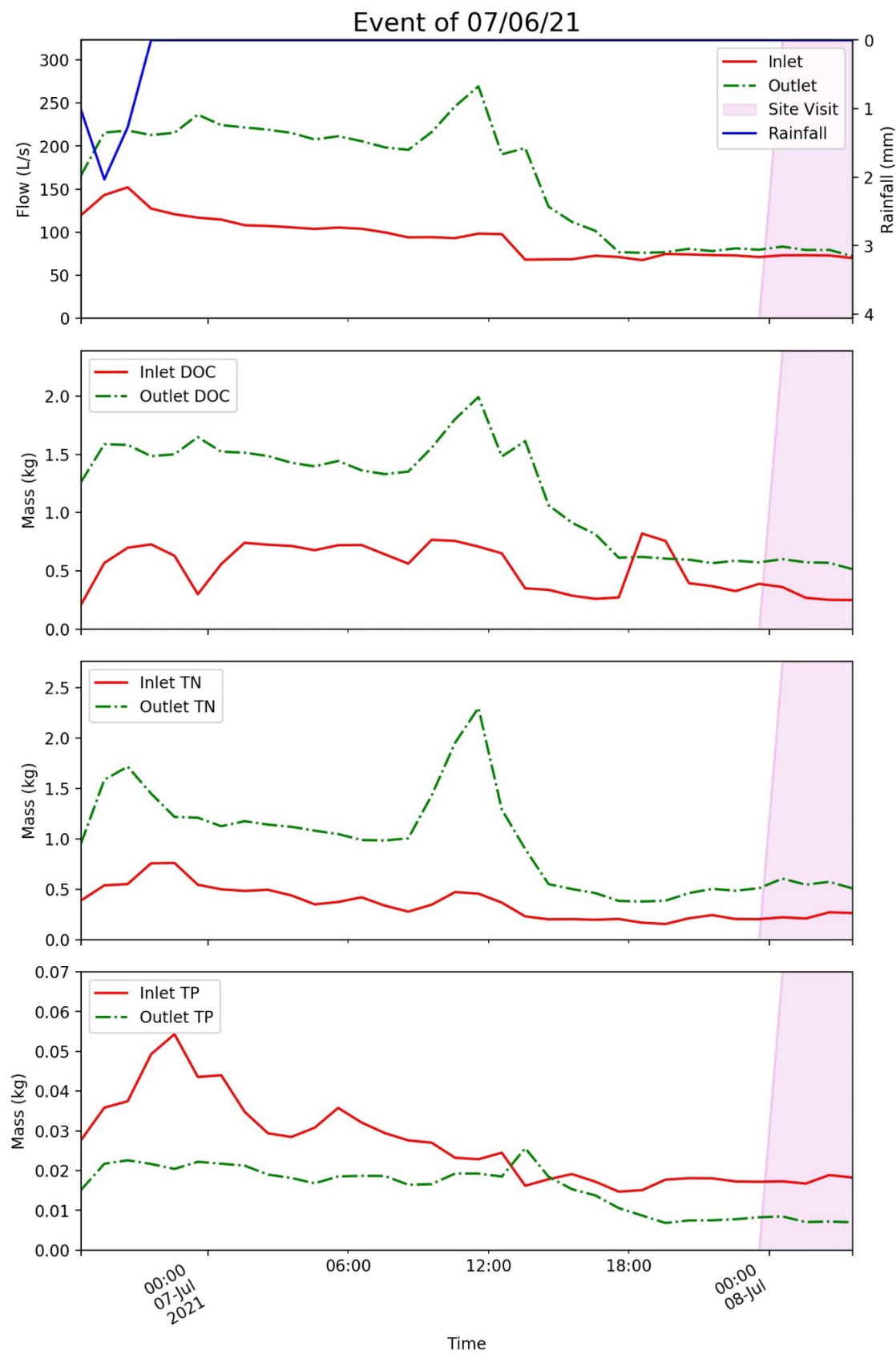


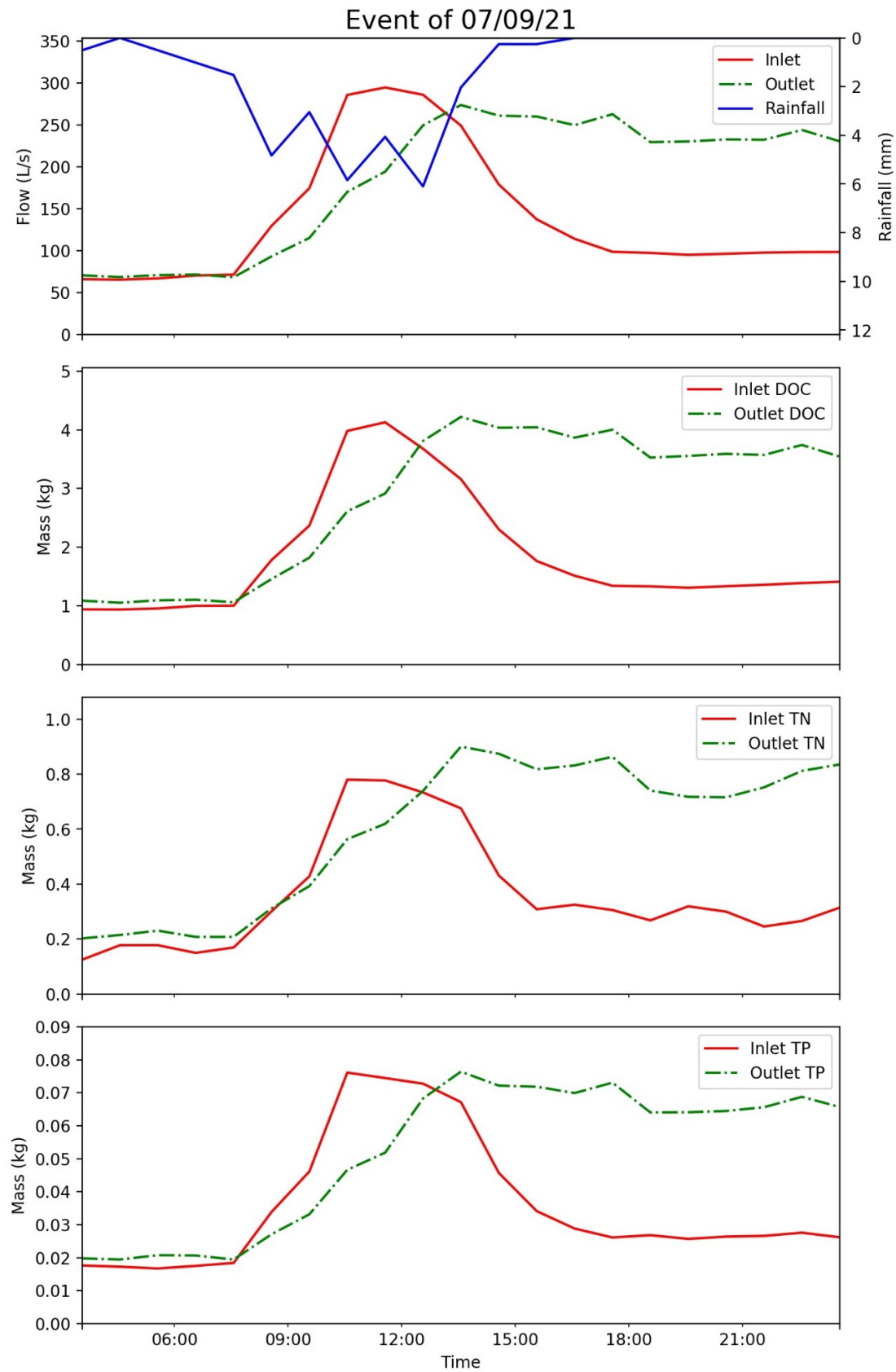
Event of 06/22/21

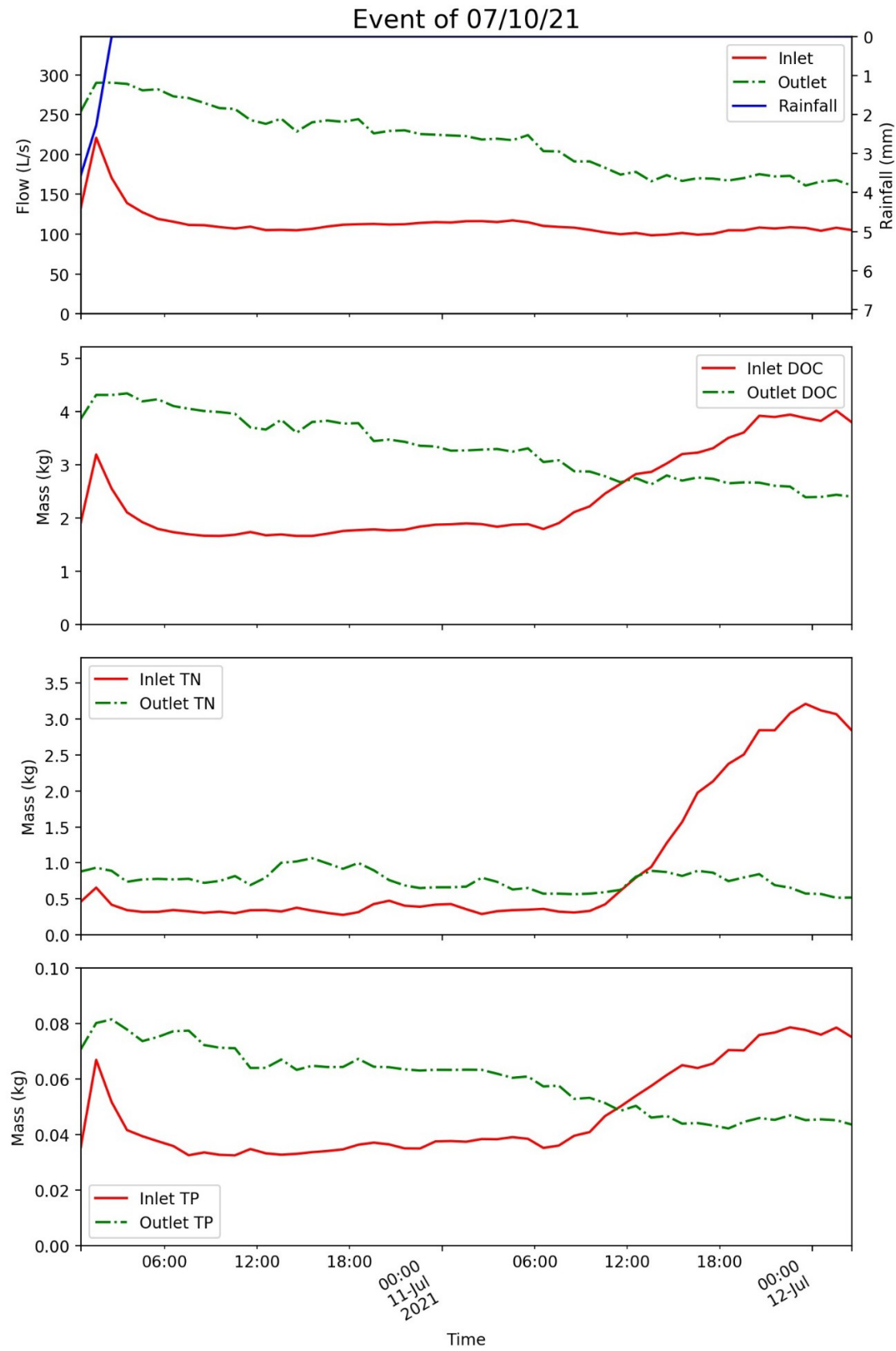


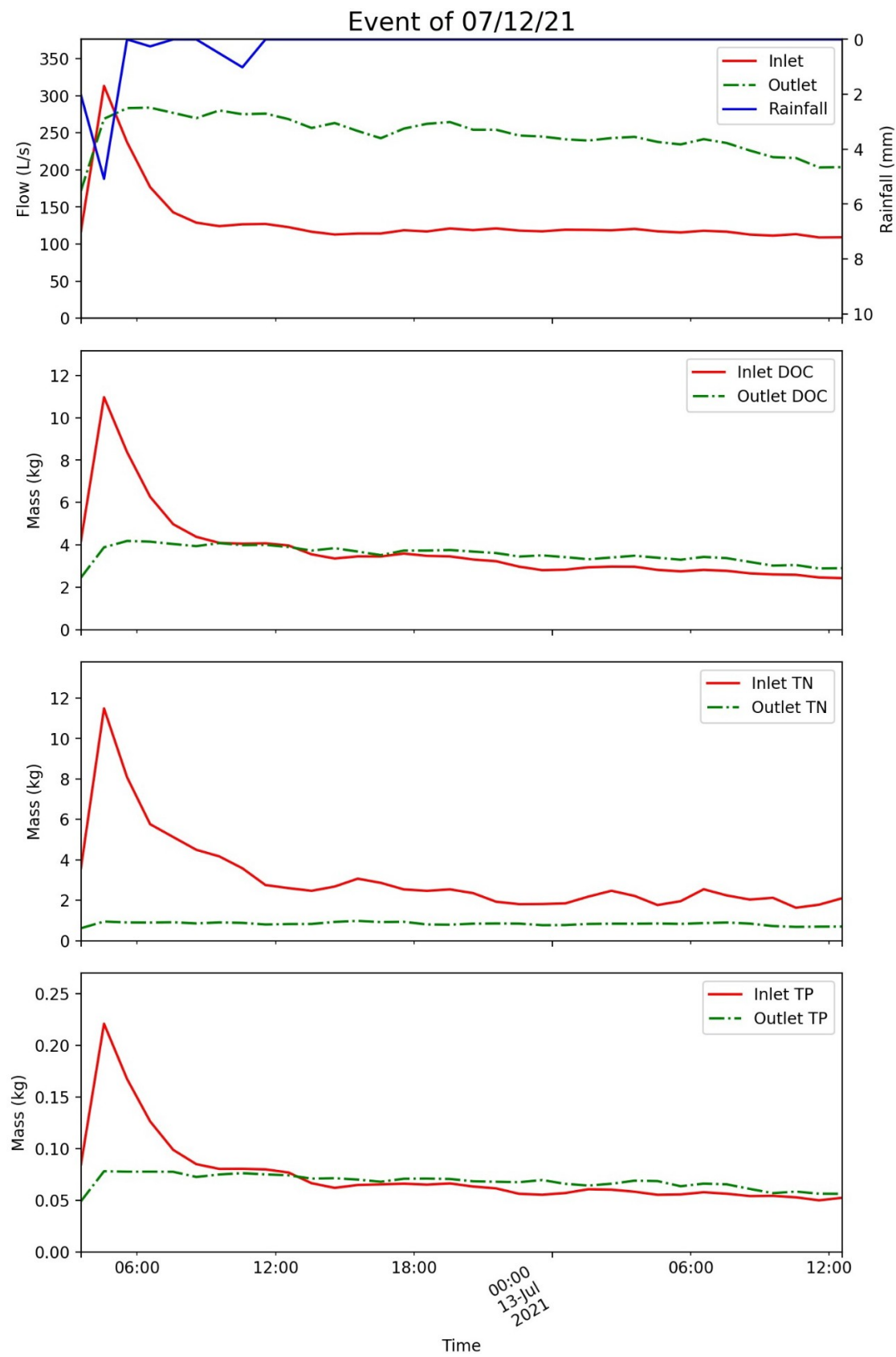


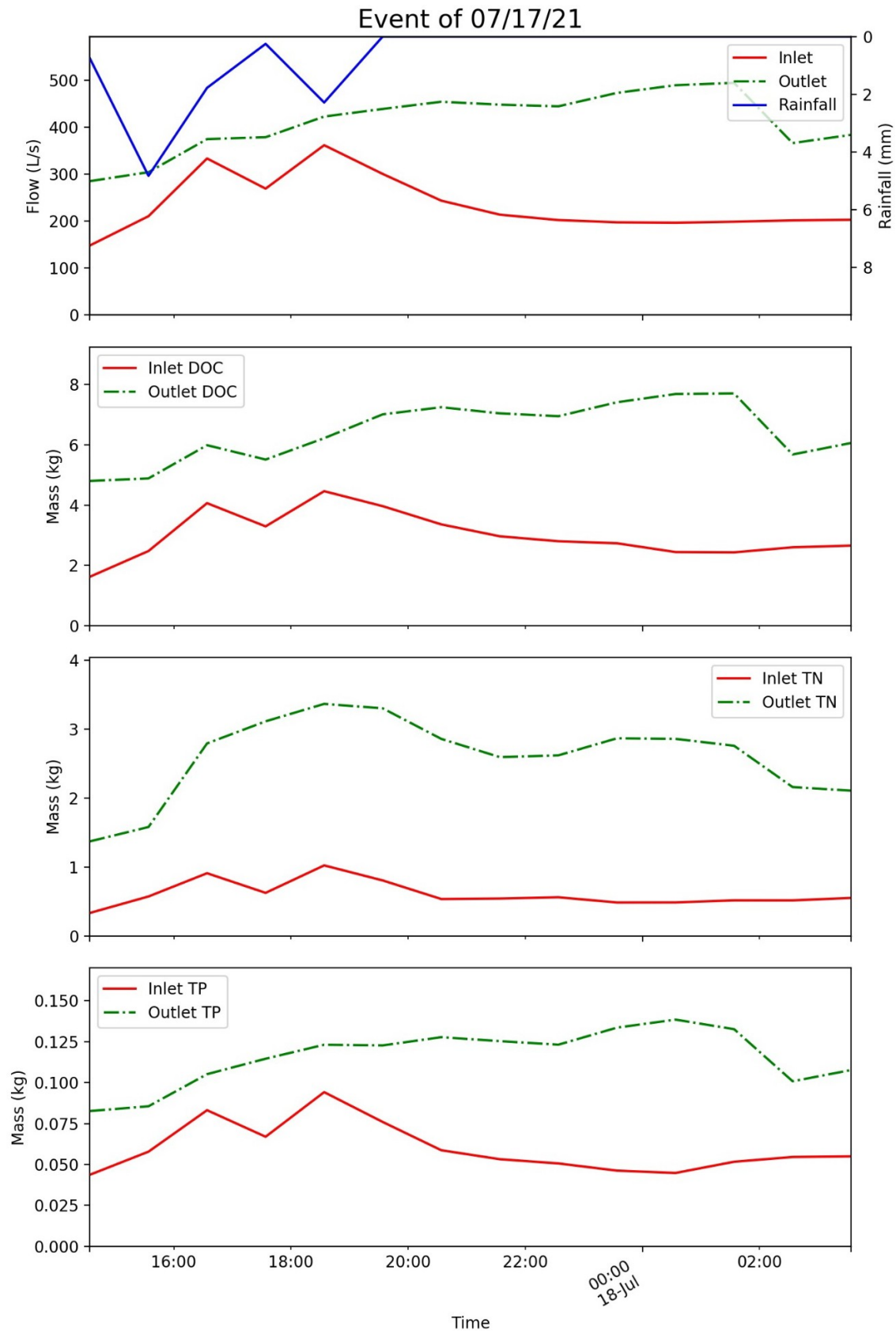


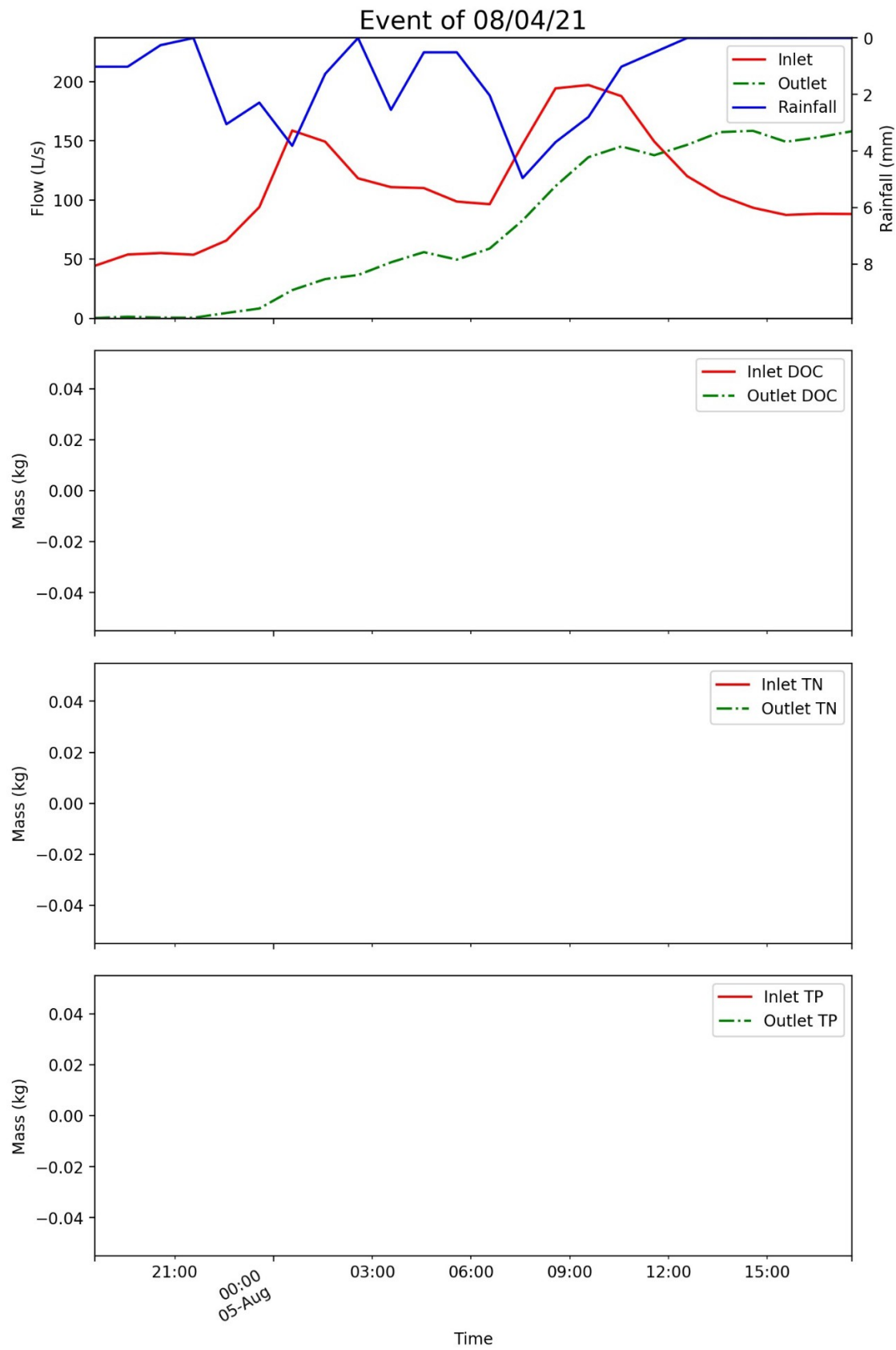




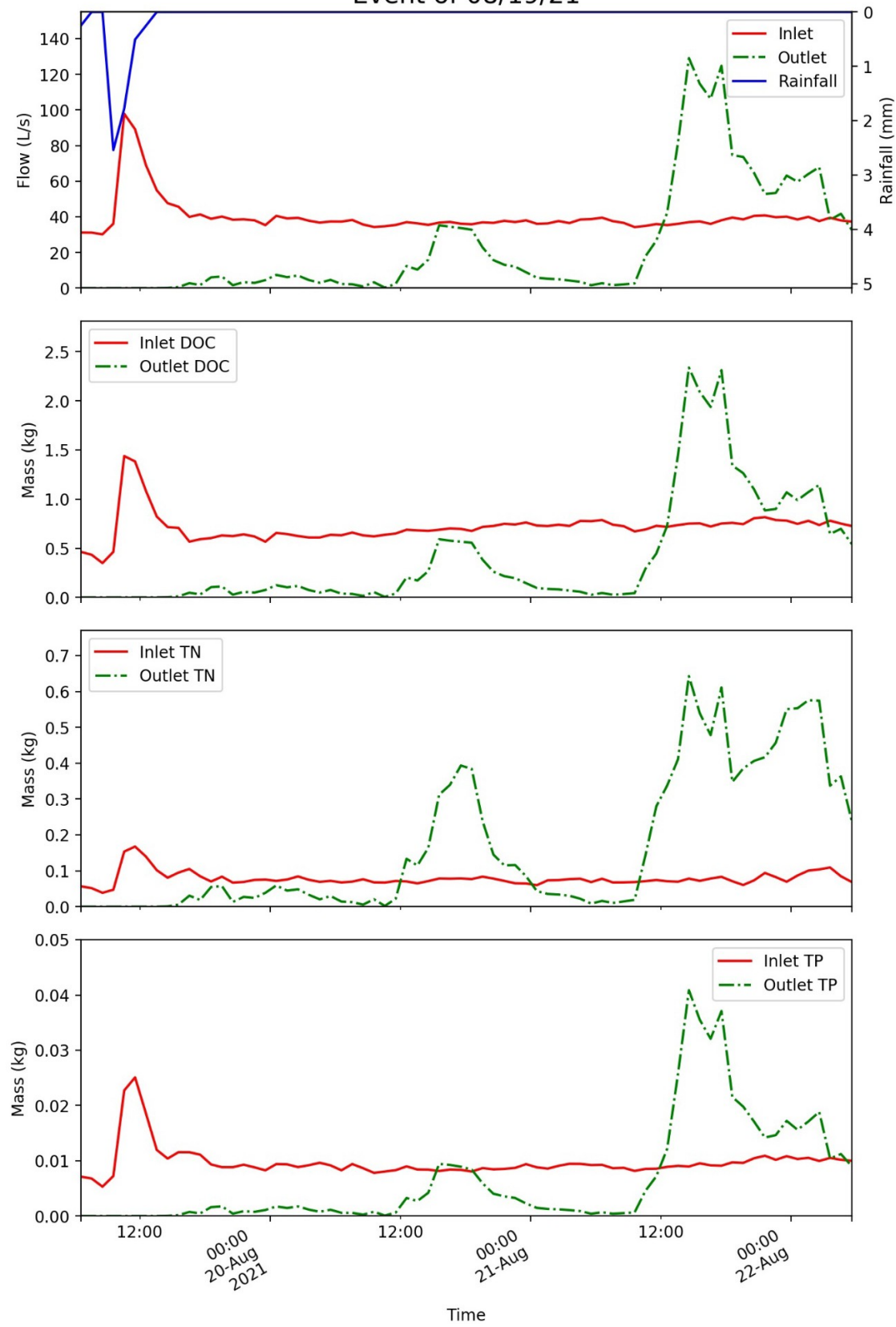


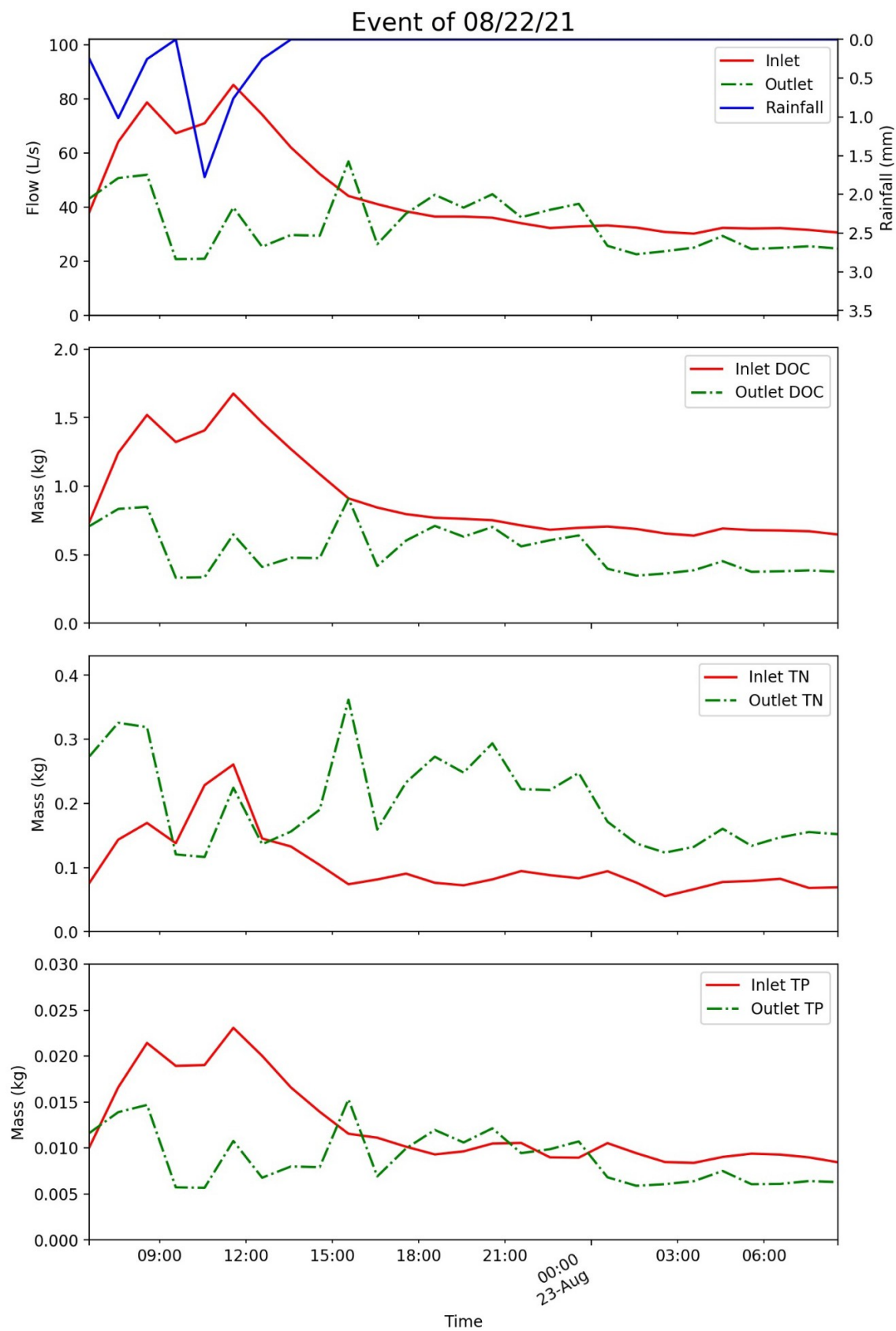




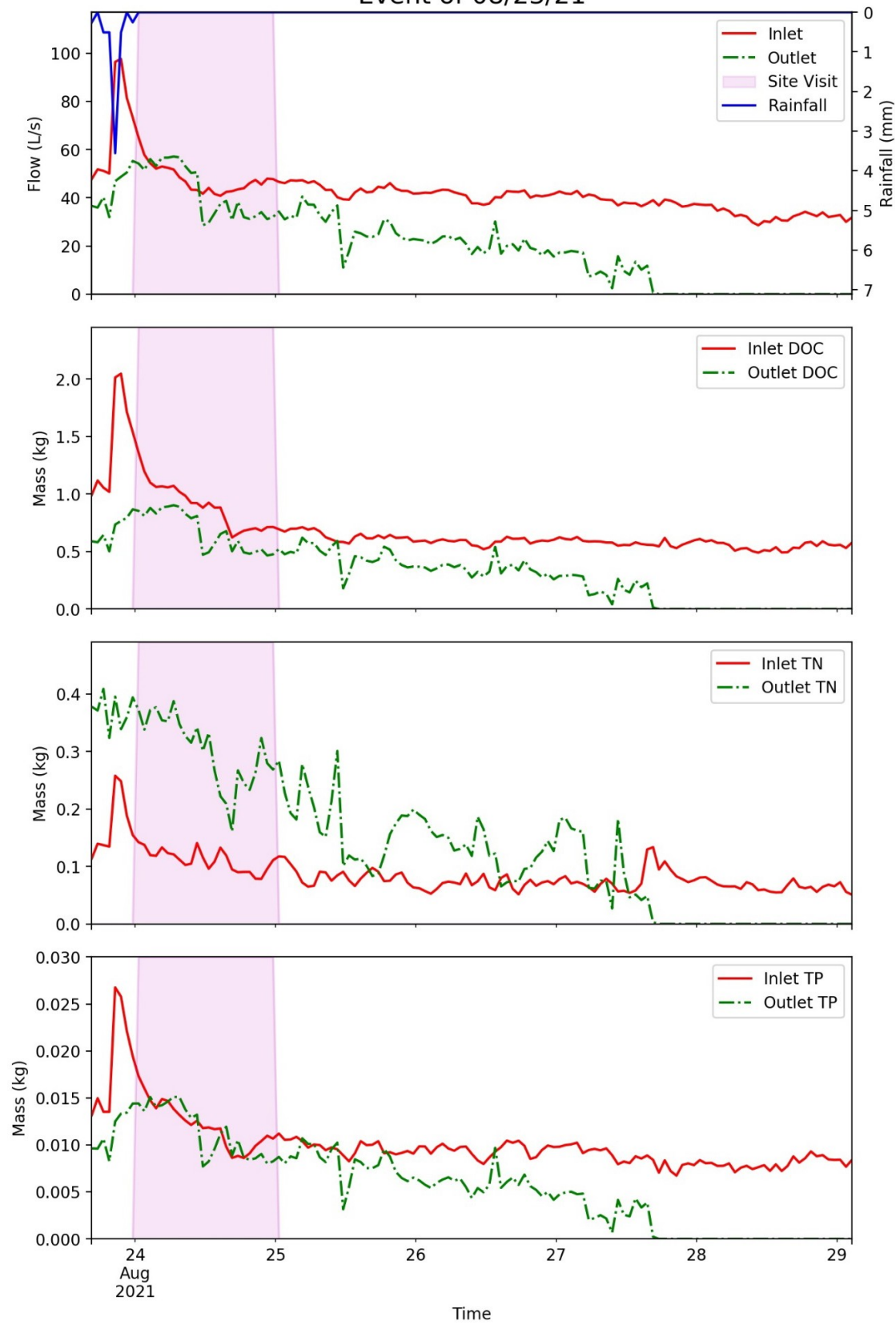


Event of 08/19/21

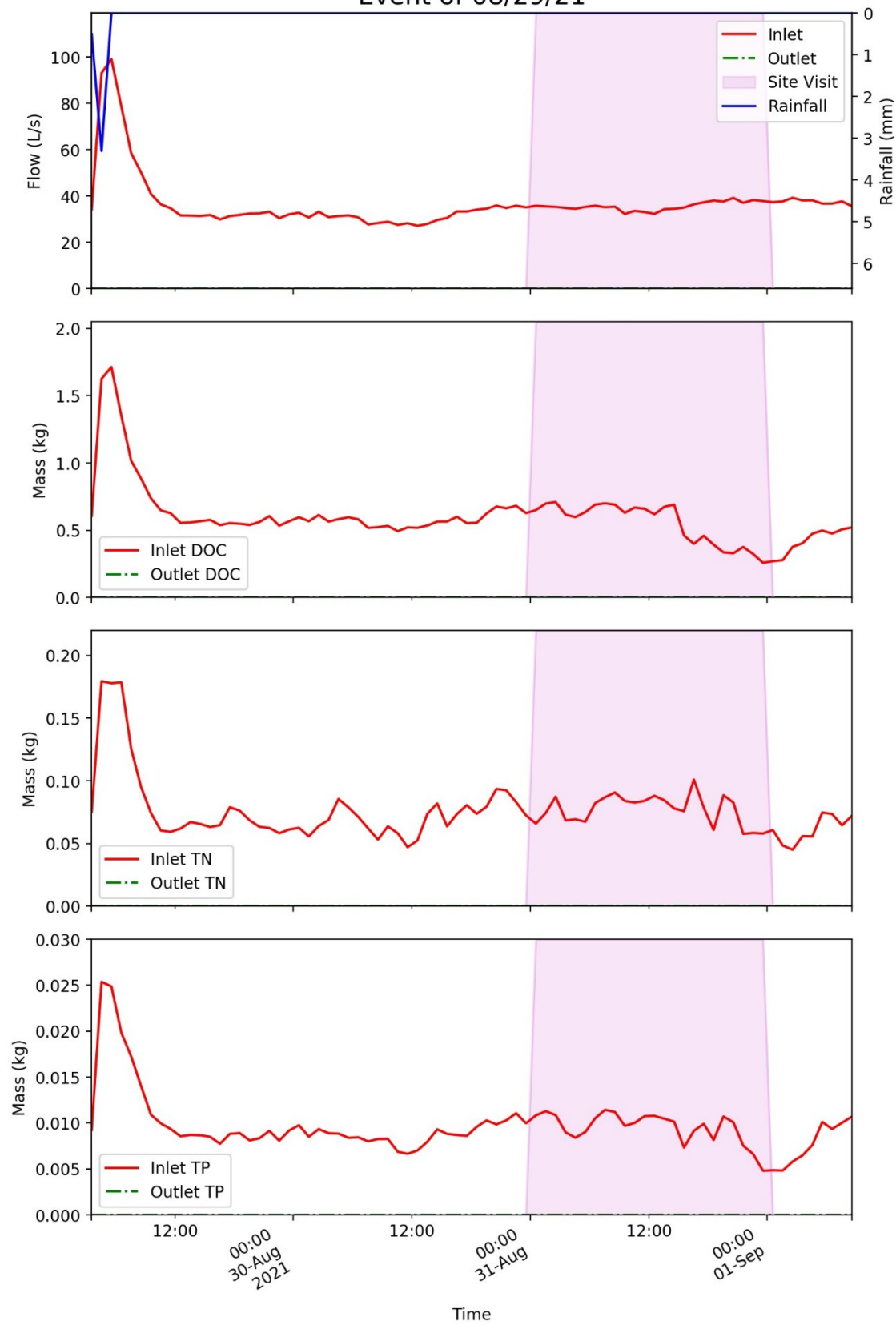


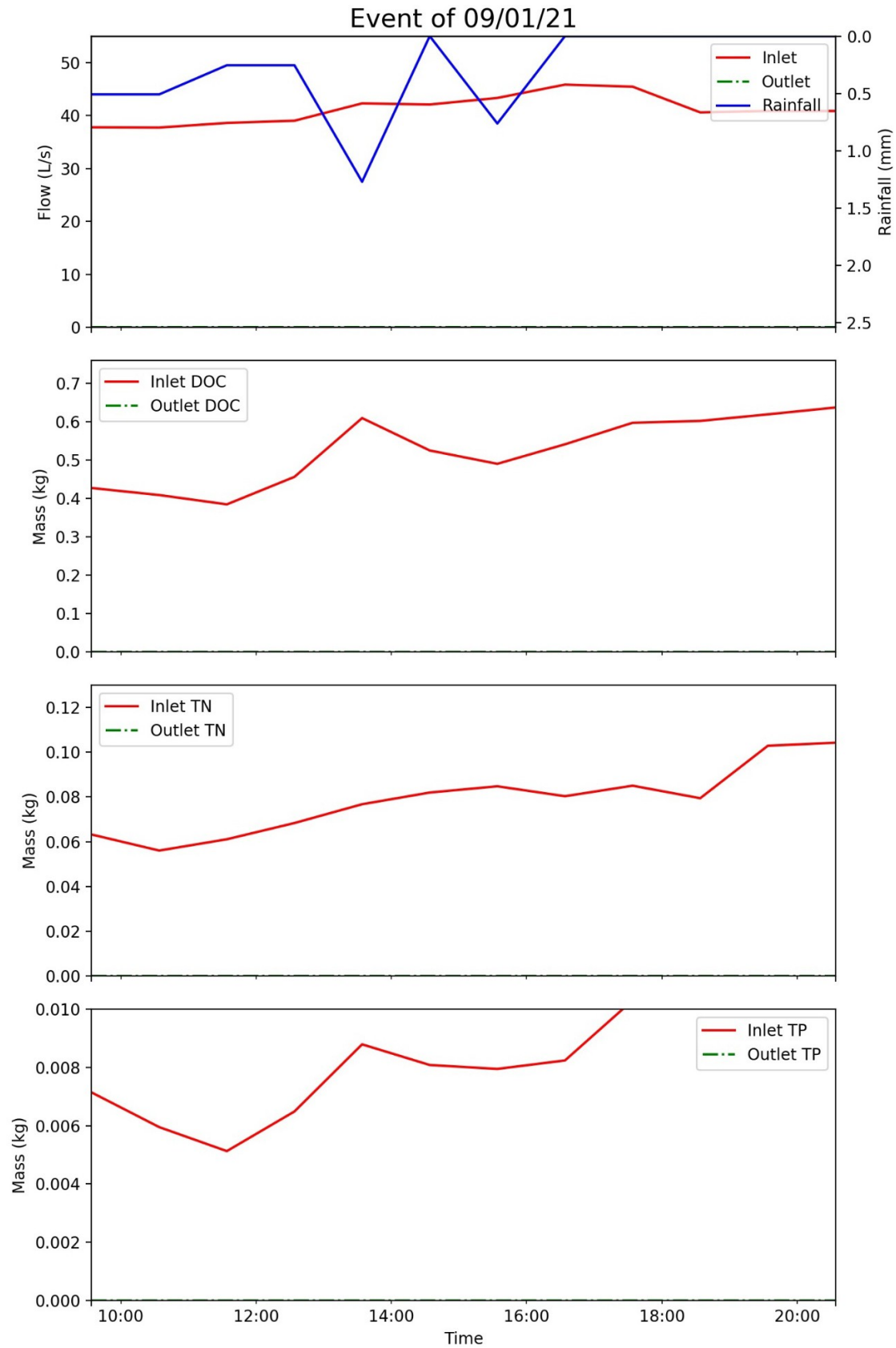


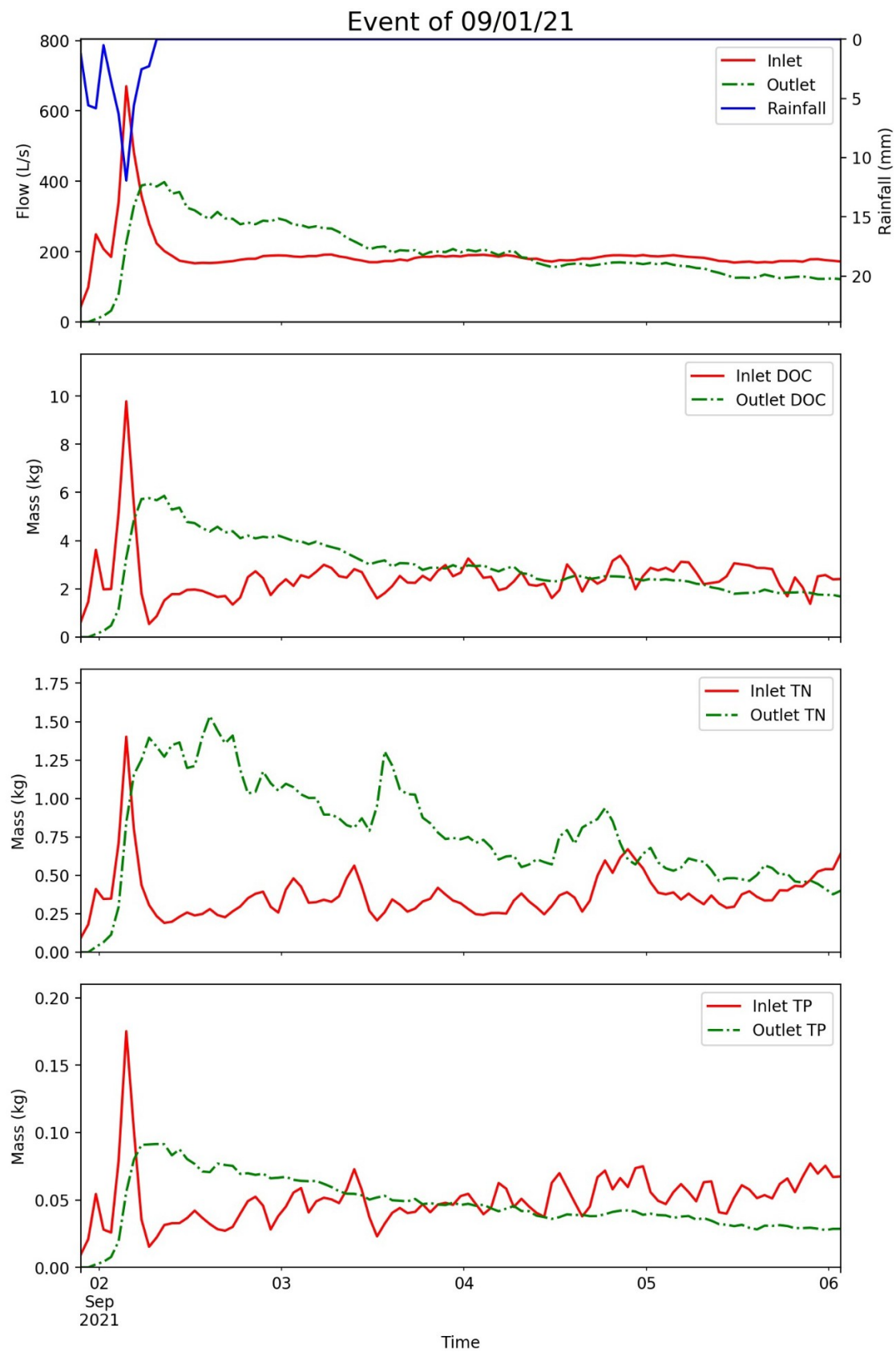
Event of 08/23/21

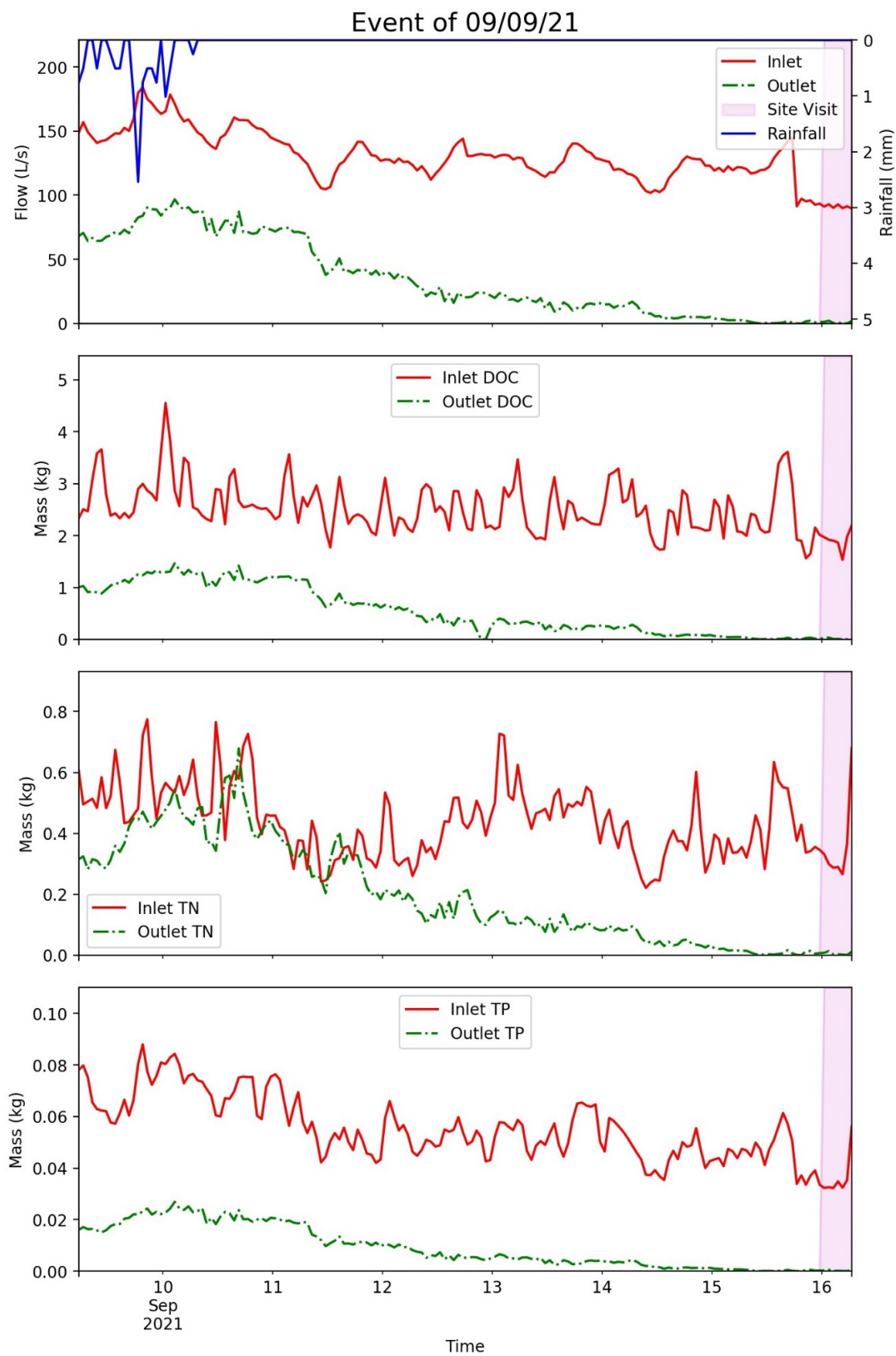


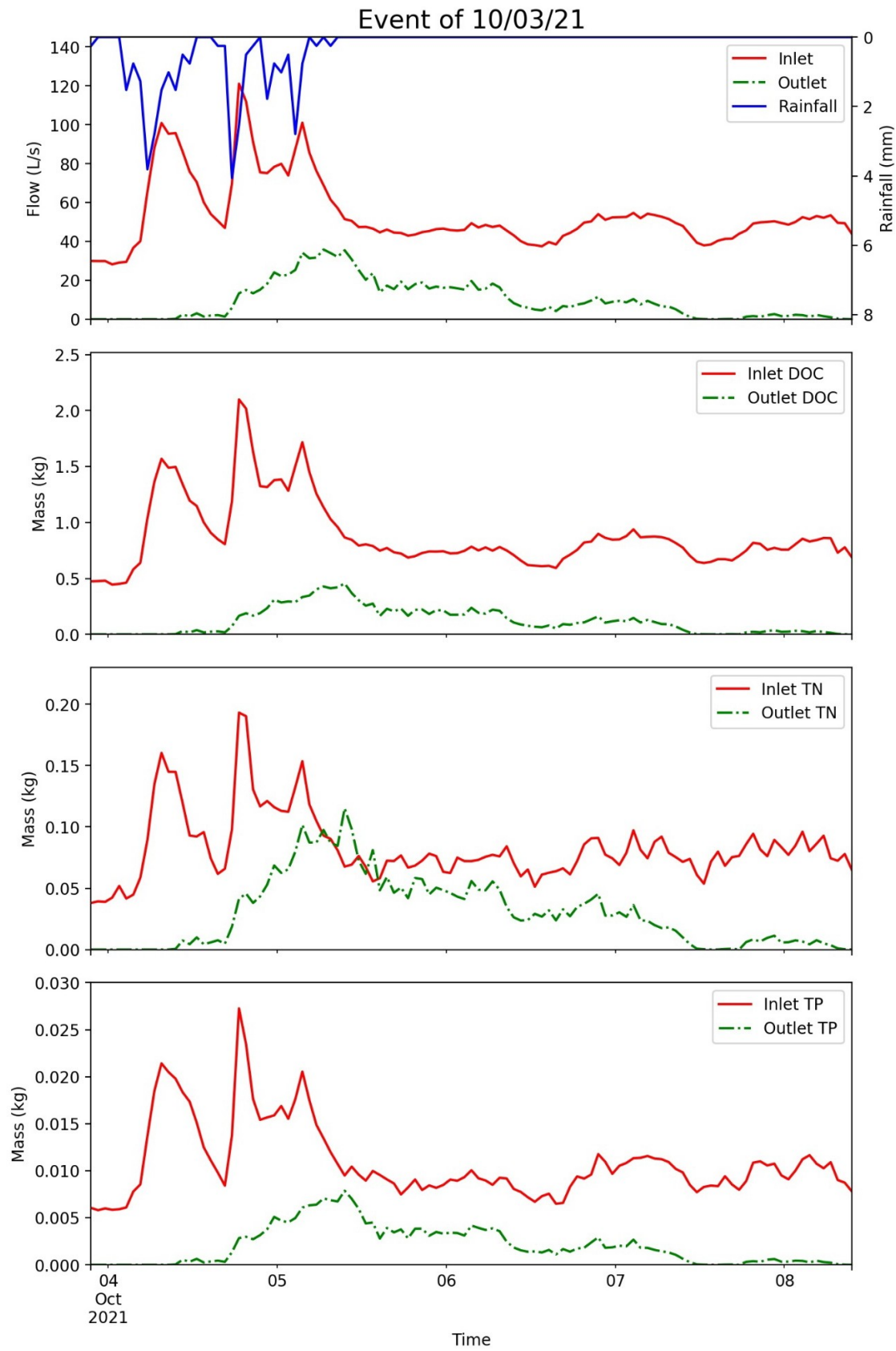
Event of 08/29/21











Week	Start Date	Total Inlet UV-Vis DOC (lb)	Total Outlet UV-Vis DOC (lb)	Total Inlet UV-Vis TN (lb)	Total Outlet UV-Vis TN (lb)	Total Inlet UV-Vis TP (lb)	Total Outlet UV-Vis TP (lb)
13	4/2/21	NaN	NaN	NaN	NaN	NaN	NaN
14	4/5/21	NaN	NaN	NaN	NaN	NaN	NaN
15	4/12/21	NaN	NaN	NaN	NaN	NaN	NaN
16	4/19/21	NaN	NaN	NaN	NaN	NaN	NaN
17	4/26/21	NaN	NaN	NaN	NaN	NaN	NaN
18	5/3/21	NaN	NaN	NaN	NaN	NaN	NaN
19	5/10/21	NaN	NaN	NaN	NaN	NaN	NaN
20	5/17/21	NaN	NaN	NaN	NaN	NaN	NaN
21	5/24/21	NaN	NaN	NaN	NaN	NaN	NaN
22	5/31/21	NaN	NaN	NaN	NaN	NaN	NaN
23	6/7/21	NaN	NaN	NaN	NaN	NaN	NaN
24	6/14/21	106.85	NaN	15.55	NaN	1.55	NaN
25	6/21/21	186.02	108.69	62.69	40.78	4.88	1.15
26	6/28/21	119.03	441.17	131.08	230.76	11.32	5.58
27	7/5/21	445.89	743.68	175.65	265.63	12	12.3
28	7/12/21	748.29	1775.53	346.59	594.96	15.43	32.43
29	7/19/21	137.6	454.71	26.46	141.09	3.18	7.83
30	7/26/21	NaN	NaN	NaN	NaN	NaN	NaN
31	8/2/21	139.23	16.48	19.13	71.91	2.51	4.91
32	8/9/21	271.74	447.71	34.52	204.98	4.56	10.46
33	8/16/21	228.59	99.82	27.01	39.35	3.32	1.63
34	8/23/21	259.6	112.71	31.87	48.38	3.78	1.91
35	8/30/21	619.3	640.64	91.8	172.46	12.32	10.4
36	9/6/21	1020.84	415.21	171.24	138.24	23.92	7
37	9/13/21	684.88	23.82	110.31	9.25	13.28	0.37
38	9/20/21	308	0	50.63	0	5.01	0
39	9/27/21	220.4	0	25.84	0	3.03	0
40	10/4/21	209.53	28.56	19.68	7.14	2.58	0.49