SAR Post-Fire Monitoring Report for the 2018 Holy Fire

November 14, 2019

RIVERSIDE COUNTY
WATERSHED PROTECTION

P8/228175

SAR Post-Fire Monitoring Report for the 2018 Holy Fire

November 14, 2019

Prepared for:

Riverside County Flood Control and Water Conservation District

Prepared by:

Alta Environmental an NV5 Company

Alta Environmental an NV5 Company
1155 Sportfisher Drive, Suite 202
Oceanside, CA 92054

P8/228175

Executive Summary

The Holy Fire burned approximately 23,000 acres of the Cleveland National Forest in August 2018. The altered landscape stability of the steep forested lands and the potential for mud and debris flows created an immediate concern for not only the safety of the community, but the potential for water quality impacts to downstream waterbodies of Lake Elsinore and Temescal Creek. Lake Elsinore is a natural freshwater lake "impaired" for nutrients and increased storm flows and sediment runoff following wildfires has been associated with increased nutrient loads. Although there is no regional agency responsible for conducting post-fire water quality monitoring, the Riverside County Flood Control and Water Conservation District (District) undertook the development and implementation of the following post-fire water quality monitoring study to assess the effects of the Holy Fire on the hydrologic response, sediment loads, and contribution of pollutant loads from post-fire runoff.

The monitoring design was based on the guidance included in the Post-Fire Water Quality Monitoring Plan prepared by the California Stormwater Monitoring Coalition, which was developed as a response plan that could be quickly implemented following a fire. The goal of the study was to assess a key management question: "How does post-fire runoff affect contaminant flux?". Contaminant flux calculations were used to compare the relative mass contributions of contaminants from the burned catchments vs. the unburned natural areas. In general, the contaminant flux of the continents analyzed in this study (e.g., metals, nutrients, and organic contaminants) were higher from the burned catchments compared to the unburned natural area. Mean total phosphorus and total nitrogen flux were between 69- and 98-fold higher from burned catchments and the total copper, lead, and zinc flux were between 659- and 11,169-fold higher compared to unburned natural areas. The contaminant flux results characterized the potential water quality impacts to downstream waterbodies and provided stormwater managers and stakeholders with data to evaluate the post-fire contribution of nutrient loads in context with other sources within the watersheds. Understanding of the effects of the Holy Fire on contaminant flux provides information that can inform management actions, including existing strategies to comply with requirements for the impairments in Lake Elsinore.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

GLOSSARY OF ACRONYMS, ABBREVIATIONS, AND TERMS

Alta	Alta Environmental
CFS	Cubic Feet Per Second (Flow Measurement)
CMP	Consolidated Monitoring Plan
District	Riverside County Flood Control and Water Conservation District
EVMWD	Elsinore Valley Municipal Water District
GPM	Gallons Per Minute (Flow Measurement)
in./hr.	Inches Per Hour (Rainfall Measurement)
MS4	Municipal Separate Storm Sewer System
NWS	National Weather Service
NPDES	National Pollutant Discharge Elimination System
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project
SARWQCB	Santa Ana Regional Water Quality Control Board
SCCWRP	Southern California Coastal Water Research Project
SMC	Southern California Stormwater Monitoring Coalition
SWAMP	Surface Water Ambient Monitoring
SWRCB	State Water Resources Control Board
TMDL	Lake Total Maximum Daily Load
USEPA	United States Environmental Protection Agency
USDA	United States Department of Agriculture
USGS	United State Geological Survey

1.0 INTRODUCTION

The Holy Fire burned approximately 23,000 acres of the Cleveland National Forest in August 2018. The Riverside County Flood Control and Water Conservation District (District) undertook the coordination and oversight of the post-fire preparation and response, including development and implementation of a post-fire water quality monitoring study at District facilities near the Holy Fire. The District serves as the Principal Permittee in the Santa Ana River Region as regulated by the municipal separate storm sewer system (MS4) National Pollutant Discharge Elimination System (NPDES) Permits and conducted the post-fire monitoring on behalf of the Permittees within the Santa Ana River Region of Riverside County. In coordination with Alta Environmental (Alta), with feedback from the Regional Board staff, and the Lake Elsinore and Canyon Lake Total Maximum Daily Load (TMDL) Task Force, the District developed a post-fire monitoring study to assess the potential water quality impacts of the Holy Fire. The monitoring plan was developed based on the guidance included in the Post-Fire Water Quality Monitoring Plan prepared by the Southern California Coastal Water Research Project (SCCWRP) and Southern California Stormwater Monitoring Coalition (SMC) titled "Effects of Post-fire Runoff on Surface Water Quality: Development of a Southern California Regional Monitoring Program with Management Questions and Implementation Recommendations" (Stein and Brown, 2009).

The goal of this study is to assess contaminant concentration and flux by sampling stormwater runoff from the terminal end of burned catchments and comparing the data to reference sites, and to assess the effects of the Holy Fire on the hydrologic response, sediment loads, and contribution of pollutant loads (metals, nutrients, and organic contaminants) from post-fire runoff.

1.1 Background

Wildfires generate geological hazards due to the removal of vegetation that keeps drainages intact, changes in the erodibility of affected soil, and altered landscape stability (Schwartz, 2018). Wildfires can create the potential for high debris flows in watersheds with steep slopes and high-to-moderate soil burn severity. Exacerbated debris flows usually occur within 1-3 years of the fire event. Intense rainfall can trigger destructive, fast-moving debris flows; a dangerous post-fire hazard (Schwartz). These increased storm flows often contain high loads of nutrients, metals, and organic pollutants. A key factor that influences post-fire erosion and increased runoff flow is fire-induced soil water repellency which increases after the soil is burned and can reduce watershed infiltration rates after a wildfire (Nicita, 2018). Consumption of the rainfall-intercepting canopy and of the soil-mantling litter and duff, intensive drying of the soil, combustion of soil-binding organic matter, and the enhancement of formation of water-repellant soils can result in decreased rainfall infiltration into the soil, thereby significantly increasing overland flow and runoff in channels (Cannon et al., 2003).

Waterbodies that receive storm runoff from wildfire impacted watersheds are often waterbodies that have an "impaired" designation under Section 303(d) of the Clean Water Act. Often in southern California watersheds, the elevated contaminants in post-fire runoff are the same contaminants elevated in the receiving waterbody (Stein and Brown, 2009). Research has identified that ammonium or phosphorous based compounds used to fight fires may contribute to elevated nutrient concentrations in stormwater (Pappa et al., 2006). The PHOS-CHEK® fire retardants were used to help slow the spread of the Holy Fire, which are qualified by the United States Department of Agriculture (USDA) Forest Service. However, the exact concentrations of the chemical ingredients of PHOS-CHEK® are withheld due to trade secrets. Coordinated post-fire monitoring is essential to provide information that can be used to manage, repair, and protect sensitive waterbodies from the effects of post-fire runoff. Monitoring techniques measure and analyze post-storm flow levels, pollutant increase, and the resulting loads to receiving waterbodies (Stein and Brown, 2009).

1.2 Holy Fire Area Description

The Holy Fire began on August 6, 2018, roughly one quarter mile east-northeast from the confluence of the Trabuco Canyon and the Holy Jim Canyon. The Holy Fire burned approximately 23,000 acres in the Cleveland National Forest, including parts of Orange and Riverside counties. Approximately 18,000 acres burned on National Forest lands, 2,500 acres burned on non-Forest Service lands inside the congressional boundary of the Cleveland National Forest, and 2,500 acres burned outside of the Cleveland National Forest. Approximately 14% of the burned acres had a high soil burn severity (3,290 acres), 71% had a moderate soil burn severity (16,250 acres), and 15% had a low soil burn severity (1,780 acres), and 7% were very low soil burn severity or unburned (1,780 acres) (Schwartz). **Figure 1** displays the United States Geological Survey (USGS) estimates of the likelihood of debris flow from the individual stream segments, based upon a design storm with a peak 15-minute rainfall intensity of 0.94 inches per hour (in./hr.). The stream segments from the burn area depicted in **Figure 1** are ephemeral and will likely only have temporary and intermittent flow in response to significant precipitation.

The two largest waterbodies downstream of the burn area are Lake Elsinore and Temescal Creek. Lake Elsinore is a natural freshwater lake impaired for nutrients. Due to the local climate and watershed hydrology, the level of Lake Elsinore historically and currently fluctuates with alternate periods of a dry lakebed and extreme flooding. Since 2007, the Elsinore Valley Municipal Water District (EVMWD) has discharged large volumes of treated recycled water to Lake Elsinore in order to offset natural evaporation and maintain the lake elevation. In 1994, Lake Elsinore was listed by the Santa Ana Regional Water Quality Control Board (SARWQCB) on its Clean Water Act 303(d) list of impaired waters due to excessive levels of algae, nutrient enrichment and low dissolved oxygen. In December 2004, the SARWQCB adopted amendments to the Water Quality Control Plan for the Santa Ana River Basin to incorporate TMDLs for nutrients in Lake Elsinore. The SARWQCB adopted Resolution No. R8-2004-0037 in December of 2004, and it was subsequently approved by the U.S. Environmental Protection Agency (USEPA) on September 30, 2005.

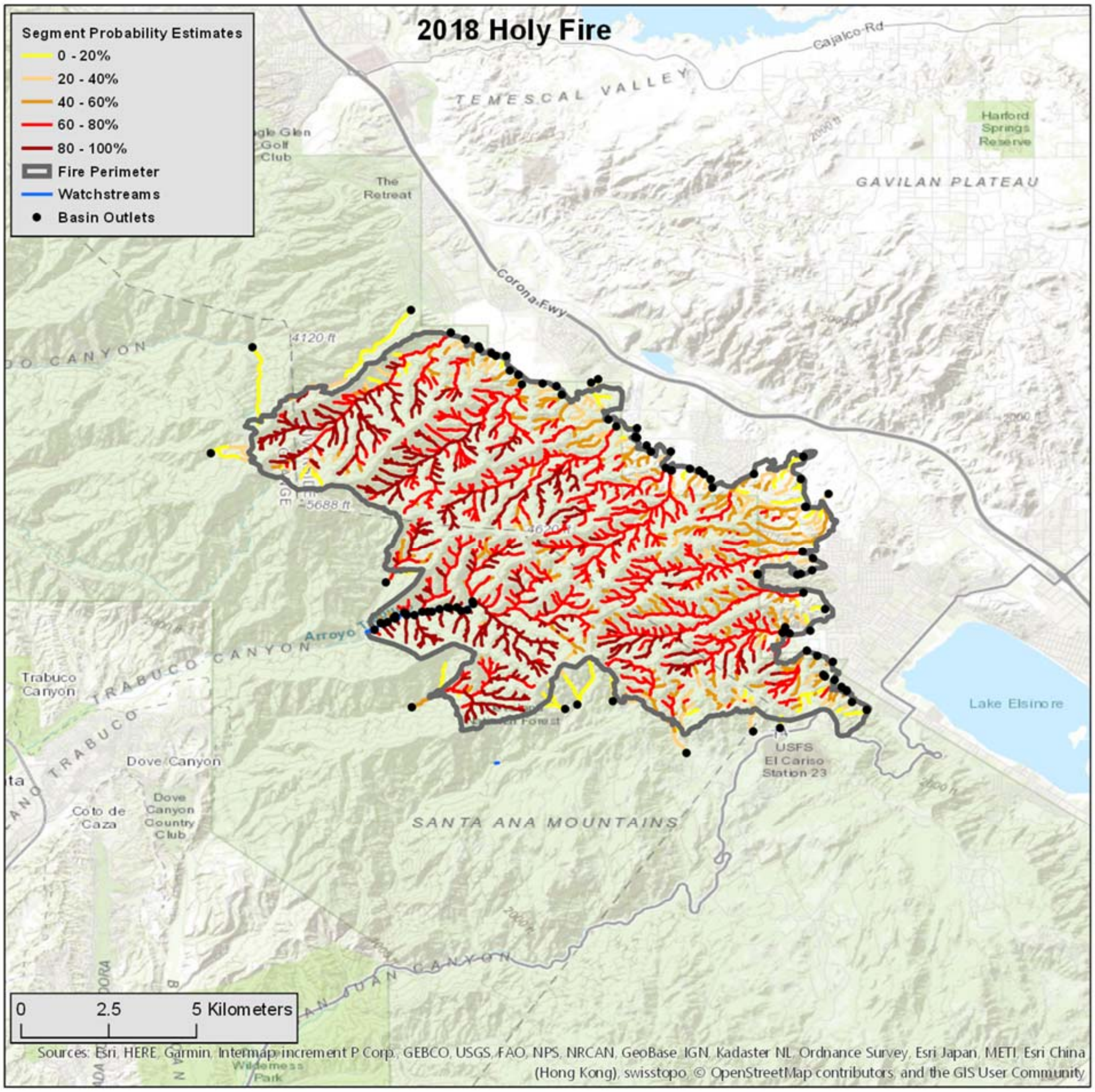


Figure 1. Holy Fire Perimeter and Likelihood of Debris Flow by Stream Segment (USGS).

2.0 METHODOLOGY

The monitoring design was based on the SMC Post-Fire Water Quality Monitoring Plan (Stein and Brown, 2009). Due to the timing of the Holy Fire and the limited time to implement the study prior to the first rain event of the 2018-2019 wet season, a simple monitoring plan was incorporated into the scope of work. The sampling methodology is summarized below and followed the general sampling protocols in the District's Consolidated Monitoring Plan (CMP), Quality Assurance Project Plan (QAPP) Volume II.

2.1 Post-Fire Monitoring Locations

The post-fire monitoring study included ten monitoring locations, as described in **Table 1** and shown in **Figures 2 and 3**. The two primary sampling locations were Horsethief Canyon and McVicker Debris Basin, which are located at the terminal end of burned catchments. The Horsethief Canyon was chosen to evaluate runoff potentially discharging downstream to Temescal Creek and the McVicker Debris Basin was chosen to evaluate runoff potentially discharging downstream to Lake Elsinore. The study was designed to compare stormwater runoff from the terminal end of burned catchments (Horsethief and McVicker) and comparing the data to reference data from an unburned catchment of similar size and land cover through two storm events. The most appropriate reference sampling location was identified at the historical reference monitoring location on Adobe Creek. The Adobe Creek site, at an elevation of 1,614 feet, is in an open and relatively undisturbed area with little development in its upper watershed. The total drainage area tributary to the Adobe Creek station is approximately 394 acres, all of which resides within Riverside County, located within the Santa Rosa Plateau, and approximately 14.5 miles from the McVicker Debris Basin. Other reference or control sites were evaluated, however, many of the adjacent locations in the Santa Ana Region were either burned from previous fires or potentially impacted from ash fallout from the 2018 Holy Fire. In addition to the sampling locations, visual observations and photographs were collected at seven locations. A map of the monitoring locations within the Santa Ana Region is provided in **Figure 2** and an overview map including the reference sampling location on Adobe Creek is provided in **Figure 3**. The site photographs are provided in **Appendix A**.

Table 1. Post-Fire Monitoring Locations.

Site Name	Description	Latitude	Longitude	Monitoring Elements
801HCU650	Horsethief Canyon	33.718772	-117.431275	Sampling, field parameters, visual observations, photos
801HCD651	Horsethief Canyon Downstream	33.738739	-117.429458	Field parameters, visual observations, photos
802MBU652	McVicker Debris Basin	33.687497	-117.403408	Sampling, field parameters, visual observations, photos
802MBD653	McVicker Basin/Leach Canyon Downstream	33.671714	-117.374033	Field parameters, visual observations, photos
802WEU654	West Elsinore MDP Upstream	33.691631	-117.405758	Visual observations, photos
802WED655	West Elsinore MDP Downstream	33.676928	-117.366814	Visual observations, photos
802LSU656	Lime St Channel Upstream	33.658103	-117.387497	Visual observations, photos
802LSD657	Lime St Channel Downstream	33.663450	-117.379364	Visual observations, photos
802LCD658	Leach Canyon Dam	33.676589	-117.409558	Visual observations, photos
902ADB848	Adobe Creek Reference	33.513361	-117.267889	Sampling, field parameters, visual observations, photos (Event 1 only)
Holy Jim Canyon Rain Gauge	Located in upper watershed of the burned catchments (elevation 7,267 f.)	33.678361	-117.516611	Rainfall

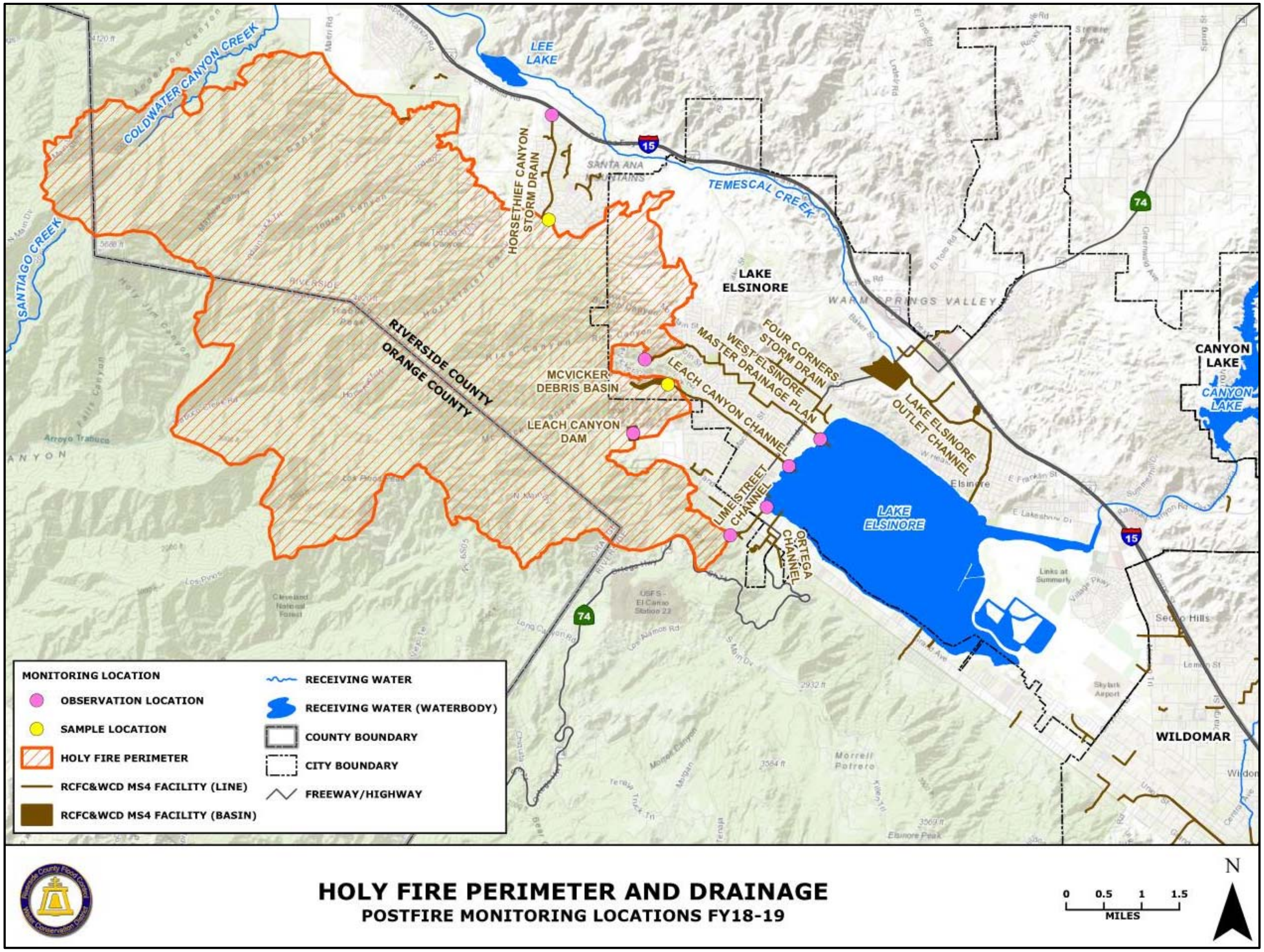


Figure 2. Post-Fire Monitoring Locations.

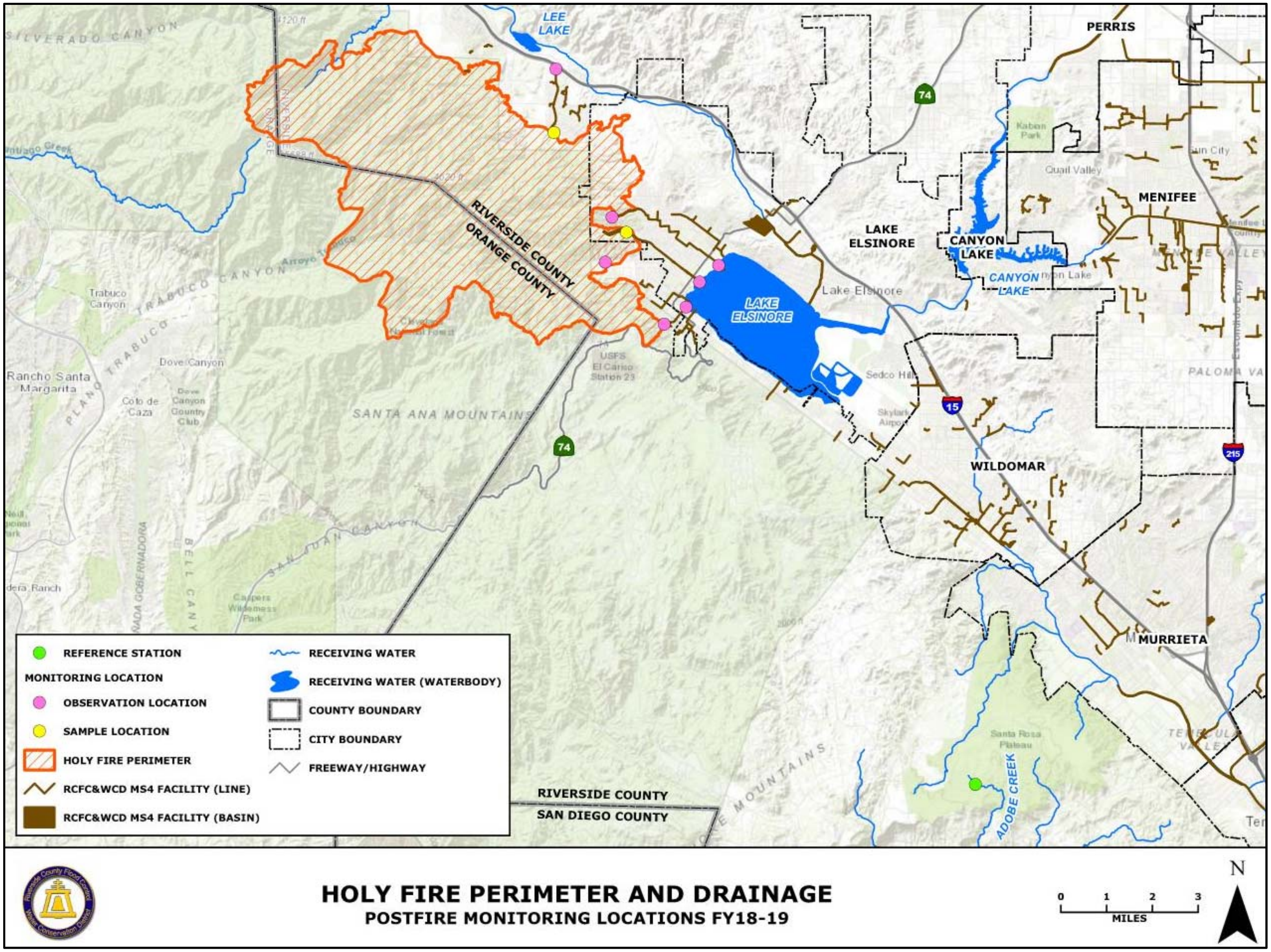


Figure 3. Overview of Post-Fire Monitoring Locations.

2.2 Wet Weather Monitoring Methodology

Wet weather monitoring was conducted during two storm events in the 2018-2019 monitoring season (October 1, 2018 through May 31, 2019). Water quality sampling and flow monitoring was conducted at three locations: Horsethief Canyon, McVicker Debris Basin, and Adobe Creek Reference (first event only). The water quality samples were analyzed for the constituents listed in the 'Holy Fire Post-Fire Water Quality Monitoring Constituents' column in **Table 2**. This list includes all constituents monitored for the Lake Elsinore and Canyon Lake TMDL Watershed-Wide Monitoring and those recommended in the SMC Post-Fire Water Quality Monitoring Plan (SCCWRP, 2009).

Due to the sediment and debris expected during storm flows at Horsethief Canyon and McVicker Debris Basin, time-weighed composite samples were collected using a sample pole. Automated sampling equipment could not be used due to the viscosity of the sediment laden discharge. Six individual sample aliquots were targeted over the course of the hydrograph and composited into a single sample for analysis. Some variation occurred depending on actual storm intensity, duration, and safety concerns for field staff due to debris flows and associated community evacuations. At a minimum, four time-weighted sample aliquots were collected. At the Adobe Reference monitoring location, automated flow-weighted composite samples were collected by taking sample aliquots across the entire hydrograph of the wet weather event. Grab samples were collected for parameters not amenable to composite sampling (Biochemical Oxygen Demand and Chemical Oxygen Demand). Grab samples were collected manually from representative flows using grab sampling techniques with certified clean sample containers. All samples were immediately placed on ice and transferred to the laboratory within the method specified holding time.

Flow rates were measured or estimated in accordance with the USEPA NPDES Storm Water Sampling Guidance Document (USEPA 833-B-92-001). Prior to the first monitoring event, flow meters with submerged pressure transducers were installed at each site as the primary level measuring device. However, modifications were required to estimate the flow rates. Immediately following the first monitoring event, the flow meter at the McVicker Debris Basin was damaged during channel cleaning activities. Prior to the second monitoring event, the pressure sensor was replaced with a downward looking ultrasonic sensor to avoid potential damage by debris flow and channel clearing activities. Due to constraints at the Horsethief Canyon monitoring location, flows were not sufficient to register on the flow meter installed downstream of the debris basin. Since the flow was free-flowing and falling over an obstruction (basin headwall), flow was estimated using the bucket add stopwatch method (USEPA 833-B-92-001). This procedure involves reading the time that each sample is taken, the time it takes for the container to be filled, and the volume of discharge collected, the flow rate is then calculated in gallons per minute (gpm).

Field measurements were taken with a water quality data Sonde (e.g., YSI 6600 Multiparameter Sonde). Field measurements followed guidelines from the State of California's Surface Water Ambient Monitoring Program (SWAMP) (MPSL-DFG 2014). Field parameters included; temperature, pH, specific conductance, turbidity, and dissolved oxygen. Field parameters were collected at the six sampling locations including; Horsethief Canyon, McVicker Debris Basin, Horsethief Canyon Downstream, McVicker Basin/Leach Canyon Downstream, and Adobe Reference. Photographs were collected during the storm event to document site conditions and drone aerial imagery of the area surrounding the sampling locations was collected pre- and post-storm. Field sample collection information, visual observations, and field parameters were recorded on field data sheets.

Table 2. Monitoring Constituents.

Parameters	Lake Elsinore and Canyon Lake Nutrient TMDL Monitoring Program[1]	Post-Fire Water Quality Monitoring Plan Suggested Constituents[2]	RCFCWCD Post-Fire Water Quality Monitoring Constituents
General			
Flow	x	Core	x
Rainfall	x	Core	x
Temperature	x	Core	x
pH	x	Core	x
Specific Conductance	x	Core	x
Turbidity	x	Not Listed	x
Dissolved Oxygen	x	Core	x
Biochemical Oxygen	x	Not Listed	x
Chemical Oxygen Demand	x	Not Listed	x
Total Dissolved Solids	x	Optional	x
Total Hardness	x	Core	x
Total Suspended Solids	x	Core	x
Dissolved Organic Matter		Core	x
Total Organic Carbon		Core	x
Nutrients			
Ammonia-Nitrogen	x	Core	x
Kjeldahl Nitrogen	x	Core	x
Nitrate as N	x	Core	x
Nitrite as N	x	Core	x
Organic Nitrogen	x	Not Listed	x
Total Nitrogen	x	Not Listed	x
Total Phosphorus	x	Core	x
Ortho-Phosphate	x	Core	x
Sulfate		Core	x
Metals (Total and Dissolved)			
Aluminum		Core	x
Iron		Core	x
Cadmium		Core	x
Copper		Core	x
Lead		Core	x
Manganese		Core	x
Nickel		Core	x
Zinc		Core	x

Quality assurance/quality control (QA/QC) for sampling processes included proper collection of the samples to minimize the possibility of contamination. Samples were collected in laboratory-

[1] Lake Elsinore and Canyon Lake TMDL Comprehensive Monitoring Work Plan (Haley & Aldrich, Inc., 2016)
[2] Stein and Brown, 2009. SMC Post-Fire Water Quality Monitoring Plan.

supplied, laboratory-certified, contaminant-free sample bottles. Field staff wore powder-free, nitrile gloves at all times during sample collection. Sample processing and handling for water chemistry was conducted in accordance with the District's CMP QAPP Volume II and with guidance developed in the QAPP for SWAMP (State Water Resources Control Board (SWRCB) 2008). Field staff ensured that sample holding temperatures were maintained from sample collection through delivery to the laboratory within required hold times. Field QA/QC samples were collected following SWAMP guidance and included field duplicates and field blanks (SWRCB 2008)[3]. All instruments were calibrated in accordance with manufacturer's specifications. Calibration of the flow monitoring and sampling equipment was conducted immediately prior to deployment or use, field verified during each sample event, and post-calibrated when the equipment was removed. All sampling personnel were trained in appropriate sampling techniques and followed the guidance in the District's CMP (QAPP Volume II).

[3] All results from the field blank were below laboratory reporting limits. With the exception of organic nitrogen, all duplicate results were within SWAMP recommended RPD limits when compared to the primary sample

3.0 WET WEATHER MONITORING EVENTS

Wet weather monitoring was conducted during two storm events in the 2018-2019 monitoring season (October 1, 2018 through May 31, 2019). Mobilization was based on the District's criteria described in the CMP and mobilization for monitoring was initiated when the National Weather Service (NWS) forecast predicted likely rainfall of 0.3 inch in six hours and/or 0.5 inch in 24 hours to allow for the greatest chance to sample a representative storm event. A rainfall event of approximately one inch occurred on October 13, 2018, however field teams confirmed that no post-fire runoff was observed at the monitoring locations. Since this event did not create runoff from the burn areas, the mobilization criteria were adapted to also consider the USGS rainfall rate thresholds for post-burn areas. High intensity, short duration rainfall rates are found to be the primary cause of debris flows and the USGS computes rainfall rate thresholds for burn areas less 2 years old based on statistical occurrences of debris flows.

The first wet weather monitoring event was conducted on November 29, 2018 and was the 'first flush' from the burned catchments of the 2018 Holy Fire with significant post-fire sediment and debris flows, and the second wet weather monitoring event was conducted during a series of storms from January 14-17, 2019, as shown in **Figure 4**. The following sections provide a brief narrative summary of the two wet weather monitoring events, including hydrographs and photographs. Detailed pre-storm, mid-storm, and post-storm photographs from all the monitoring locations for each monitoring event are provided in **Attachment A**. The field data sheets are provided in **Attachment B**, calibration logs are provided in **Attachment C**, completed chain of custody forms are provided in **Attachment D**, laboratory reports are provided in **Attachment E**, and the detailed flow data and composite sampling information is provided in Excel format in **Attachment F**. The results are discussed in **Section 4**.

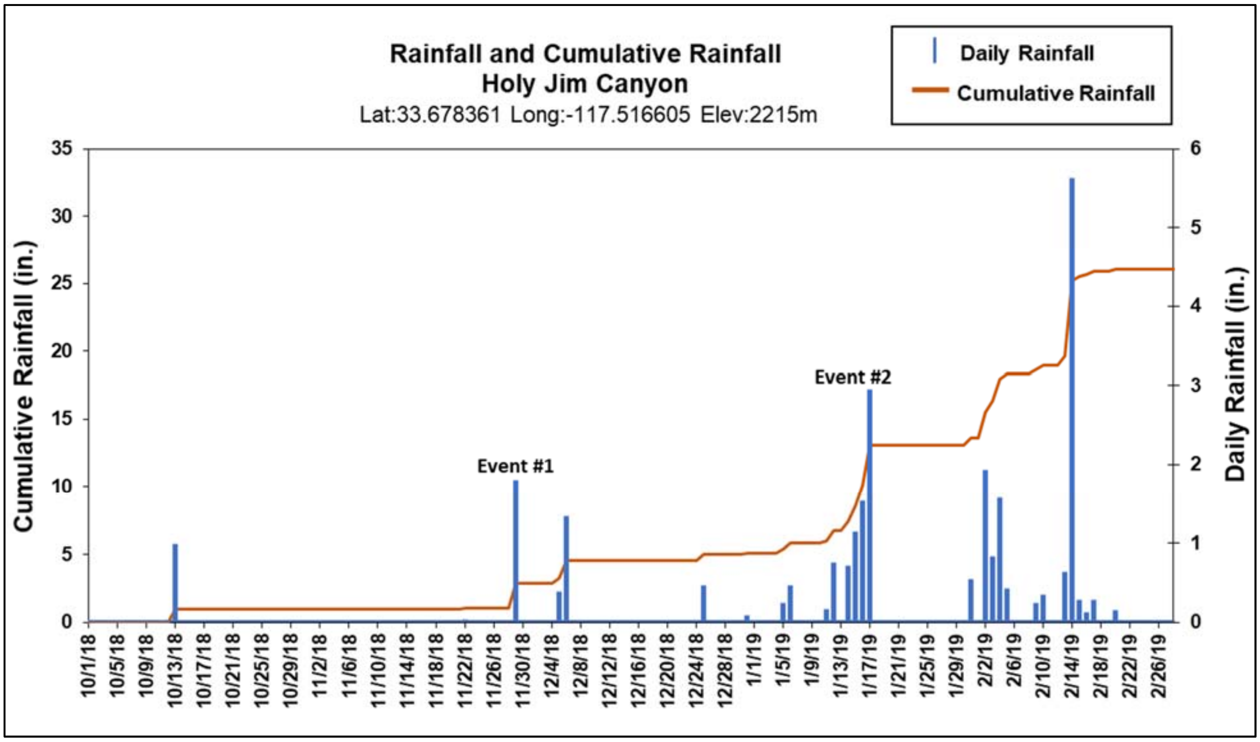


Figure 4. Event Rainfall.

3.1 Event 1

The first wet weather monitoring event was conducted on November 29, 2018. The event was the 'first flush' from the burned catchments of the 2018 Holy Fire and significant post-fire sediment and debris flows were observed. The total rainfall measured at the Holy Jim Canyon rain gauge was 1.80 inches, with a peak 15 minute rainfall rate of 0.15 inch, and a peak one hour rainfall rate of 0.48 inch (**Figure 5**). All monitoring elements for the ten monitoring locations were conducted and water quality samples were collected at the McVicker Debris Basin, Horsethief Canyon, and Adobe Creek Reference monitoring locations. Due to evacuation orders being issued for the areas surrounding the McVicker Debris Basin and Horsethief Canyon monitoring locations, composite sampling was ceased abruptly to protect the safety of field personnel.

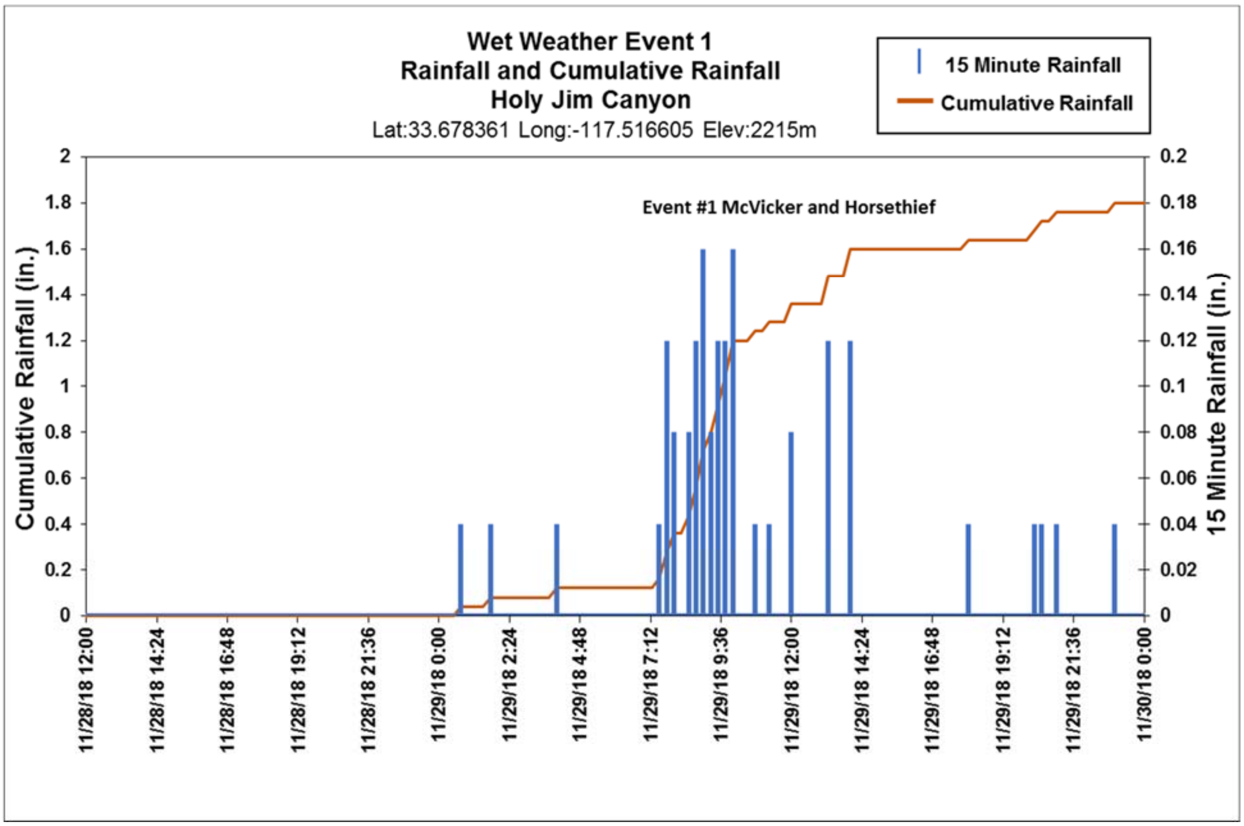


Figure 5. Event 1 Rainfall Summary.

Figure 6. View looking Downstream of the McVicker Debris Basin Sampling Location Mid-Storm (11/29/2018).

Prior to the first monitoring event, a flowmeter was installed in the main channel just downstream of the McVicker Debris Basin sampling location to estimate the flows discharging from the McVicker Debris Basin (**Figure 6**). However, the flowmeter was severely damaged due to the heavy debris flows and subsequently destroyed from a bulldozer clearing the channel of debris and sediment following the storm event. With the absence of continuous flow data, the flows discharging from the McVicker Debris Basin were estimated based on manual estimates of water level in the 36-inch storm drain that flows from the McVicker Debris Basin into the channel. The storm drain was flowing near full capacity during this sampling effort and the flow was estimated at approximately 67 cubic feet per second (cfs). A new flowmeter was installed in the 36-inch drain prior to the second wet weather monitoring event with a downward looking sensor mounted on the top of the storm drain to avoid potential damage by debris flow and channel clearing activities.

Figure 7. Horsethief Canyon Sampling Location Mid-Storm (11/29/2018).

During the Event 1 sampling effort, the only flows discharging from the Horsethief Basin (**Figure 7**) into the storm drain were through the small drainage holes drilled in the headwall and were not sufficient to register on the automated flowmeter. Using the bucket and stopwatch method described in **Section 2.2,** the flow was estimated at approximately 5 gallons per minute (0.01 cfs). While post-fire discharge from the Horsethief Canyon burn area was sampled, no significant sediment or debris flows were observed at the Horsethief Canyon monitoring location.

Flow weighted composite samples were collected from the Adobe Creek Reference monitoring location (**Figure 8**) using an automated sampler and a bubbler flow meter. Samples were collected during the rise, peak, and fall of the rainfall and discharge event (**Figure 9**). No unusual characteristics were noted in the stormwater discharge at this location.

Figure 8. Adobe Creek Reference Sampling Location During Storm (11/29/2018).

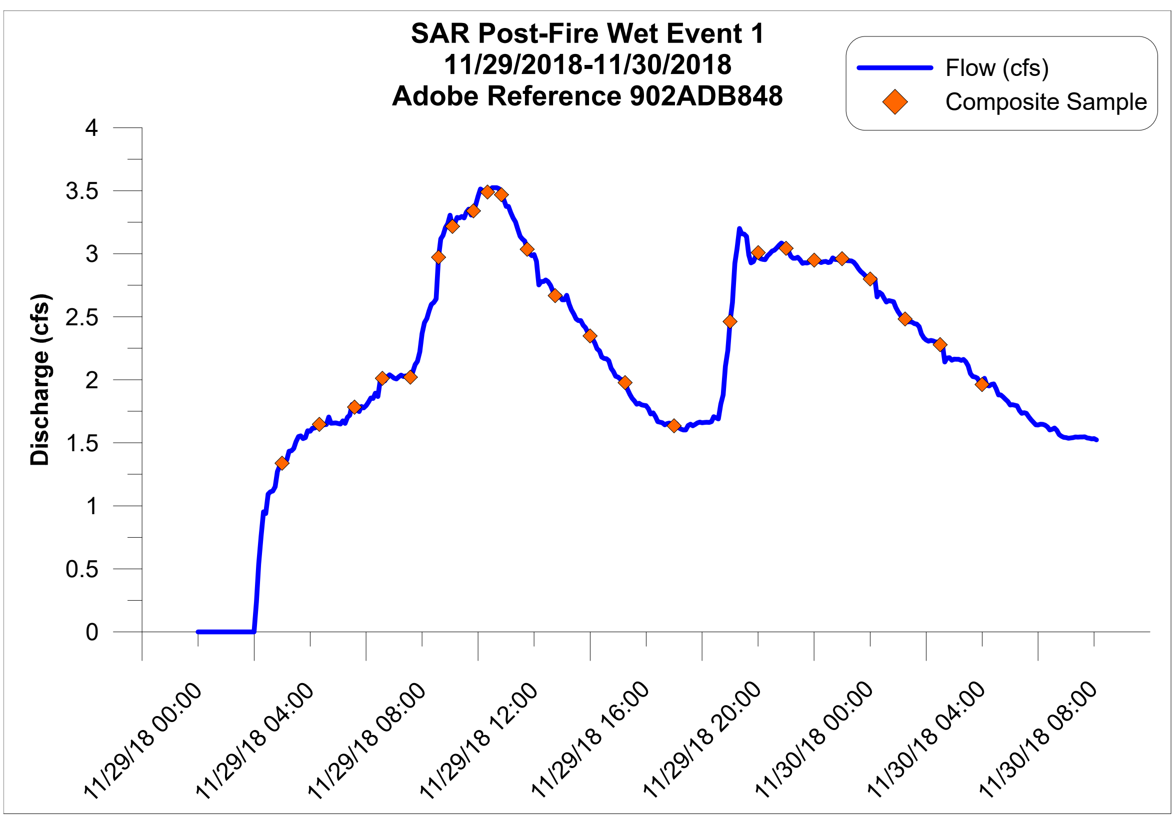


Figure 9. Adobe Creek Reference Event 1 Hydrograph.

3.2 Event 2

The second wet weather monitoring event was conducted during a series of storms from January 14-17, 2019. Water quality samples were collected at the McVicker Debris Basin on January 14, 2019 and the total rainfall measured at the Holy Jim Canyon rain gauge was 0.71 inch, with a peak 15 minute rainfall rate of 0.08 inch, and a peak one hour rainfall rate of 0.16 inch (**Figure 10**). The flowmeter installed in the 36-inch drain downstream of the McVicker Debris Basin prior to the second wet weather monitoring event, measured continuous flows during the event (**Figure 12**).

No flows were observed at the Horsethief Canyon monitoring location on January 14, 2019. Over the course of the next several days, a field team visited the Horsethief Canyon monitoring location. On January 17, 2019, the field team observed flow and collected water quality samples. The total rainfall measured at the Holy Jim Canyon rain gauge on January 17, 2019 was 2.95 inches, with a peak 15 minute rainfall rate of 0.16 inch, and a peak one hour rainfall rate of 0.51 inch (**Figure 10**).

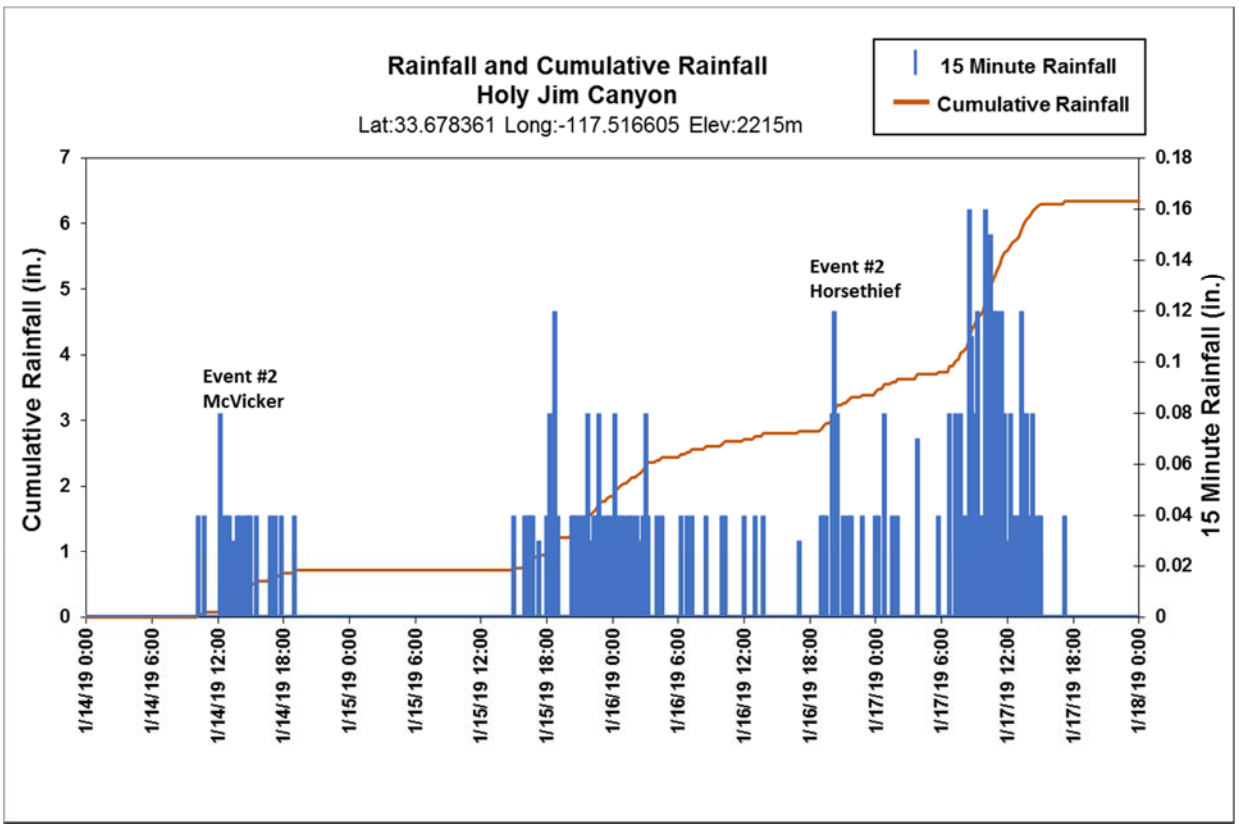


Figure 10. Event 2 Rainfall Summary.

Figure 11. McVicker Debris Basin Sampling Location Mid-Storm (1/14/2019).

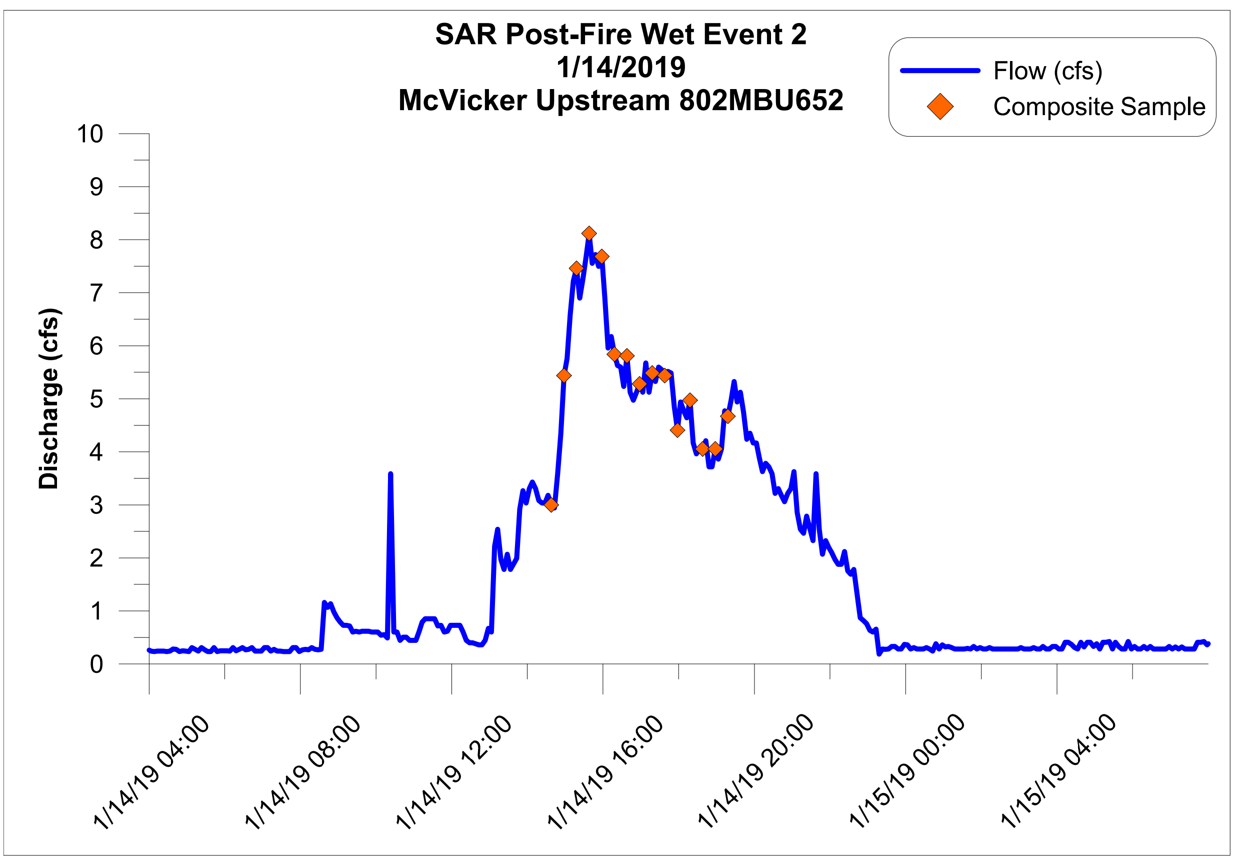


Figure 12. McVicker Debris Basin Event 2 Hydrograph.

Figure 13. Horsethief Canyon Sampling Location Mid-Storm (1/17/2019).

During the Event 2 sampling effort, the only flows discharging from the Horsethief Basin into the storm drain were from three drain holes in the headwall and the flows were not sufficient for the flowmeter to register flow (**Figure 13**). Based on manual estimates of flow using the bucket and stopwatch method described in **Section 2.2** the flow was estimated at approximately 80 gallons per minute (0.18 cfs) during each of the individual grab samples collected for the composite sample. While post-fire discharge from the Horsethief Canyon burn area was sampled, no significant sediment or debris flows were observed at the Horsethief Canyon monitoring location

Sampling was not conducted at the Adobe Creek Reference monitoring location on Event 2. One sample event was planned at the reference station during the monitoring plan development, which was deemed adequate to characterize normal, non-fire runoff conditions.

4.0 RESULTS

4.1 Hydrologic Response

A key factor that influences post-fire erosion and increased runoff flow is fire-induced soil water repellency which increases after the soil is burned and can reduce watershed infiltration rates after a wildfire (Nicita, 2018). Consumption of the rainfall-intercepting canopy and of the soil-mantling litter and duff, intensive drying of the soil, combustion of soil-binding organic matter, and the enhancement of formation of water-repellant soils can result in decreased rainfall infiltration into the soil, thereby significantly increasing overland flow and runoff in channels (Cannon et al., 2003). The high-to-moderate burn severity of the Holy Fire led to a loss of vegetation, created hydrophobic soils, changed the soil erosiveness of the steep forested lands, and created a risk of mass wasting. The aerial photographs in **Figure 14** show the spatial extent of the burn severity in the steep forested lands and provide visual evidence of post-fire related erosion of the channels within McVicker Canyon and Horsethief Canyon in December 2018. The above average rainfall with numerous high intensity rainfall events during the 2018-2019 winter storm season resulted in increased storm flows, channel erosion, and sediment runoff from the burned catchments throughout the 2018-2019 wet weather season.

Figure 14. Aerial photographs of McVicker Canyon (left) and Horsethief Canyon (right) in December 2018 following monitored events

4.2 Wet Weather Event Concentrations

The first wet weather monitoring event was conducted on November 29, 2018 and the second wet weather monitoring event was conducted during a series of storms from January 14-17, 2019. A summary of the wet weather event concentrations are provided in **Table 3** and graphs of the wet weather event concentrations are provided in **Figure 15** through **Figure 22**, which provide comparisons between the Adobe Creek Reference sites and the McVicker Debris Basin and Horsethief Canyon burned catchments.

Sample concentrations from the burned catchments were generally higher than the reference site. The concentrations from the burned catchments were lower than the first flush storm during the second wet weather monitoring event. The first wet weather monitoring event was the 'first flush' from the burned catchments of the 2018 Holy Fire and significant post-fire sediment and debris flows were observed. The first pulse of runoff following a fire usually contains the highest concentrations of contaminants (Bertrand-Krajewski et al. 1998). Dissolved metal concentrations are not available from the first event due to a laboratory error. The laboratory did not run the dissolved metals by error and the samples were disposed of by the laboratory before the error was identified. The dissolved metal concentrations for the second wet weather event were significantly lower than the total metal concentrations, indicating the metals were primarily in the particulate state, which is consistent with the high total suspended solids concentrations.

Table 3. Summary of Wet Weather Event Concentrations.

Parameter	Units	Event #1 11/29/2018			Event #2 1/14/2019	Event #2 1/17/2019
		Adobe	McVicker Debris Basin	Horsethief Canyon	McVicker Debris Basin	Horsethief Canyon
General						
Temperature	°C	11.6	13.6	14.3	10.5	12.6
pH	SU	7.51	7.44	7.23	7.79	7.96
Specific Conductance	mS/cm	0.470	0.680	0.557	0.238	0.127
Dissolved Oxygen	mg/L	8.12	8.58	8.65	9.78	8.25
Turbidity	NTU	0.8	OR (>4,000)	49.1	945.28	1940.06
Biochemical Oxygen Demand	mg/L	ND(<5.0)	<498	55	<50	ND(<10)
Chemical Oxygen Demand	mg/L	23	10,000	500	5,900	470
Total Dissolved Solids	mg/L	300	1,500	830	290	300
Total Hardness	mg/L	180	16,000	770	930	160
Total Suspended Solids	mg/L	ND(<2)	130,000	6,900	15,000	2,200
Total Organic Carbon	mg/L	7.7	780	100	43	15
Dissolved Organic Carbon	mg/L	6.9	330	77	15	8.1
Nutrients						
Ammonia-Nitrogen	mg/L	ND(<0.048)	8.9	3.8	0.81	0.14
Kjeldahl Nitrogen	mg/L	0.25	50	28	23	8.4

Parameter	Units	Event #1 11/29/2018			Event #2 1/14/2019	Event #2 1/17/2019
		Adobe	McVicker Debris Basin	Horsethief Canyon	McVicker Debris Basin	Horsethief Canyon
Nitrate as N	mg/L	ND(<0.055)	6.2	4.7	1.8	1.2
Nitrite as N	mg/L	ND(<0.0042)	1.2	0.11	0.053	0.027
Organic Nitrogen	mg/L	0.2	41	24	22	8.3
Total Nitrogen	mg/L	(0.25)J	58	33	25	9.6
Total Phosphorus	mg/L	0.12	7.3	16	16	4.6
Ortho Phosphate	mg/L	0.083	0.052	0.25	0.12	0.37
Sulfate	mg/L	51	170	53	28	2.8
Metals						
Aluminum, Total	ug/L	ND(<74)	3,400,000	97,000	320,000	67,000
Aluminum, Dissolved	ug/L	N/A[1]	N/A[1]	N/A[1]	ND(<37)	ND(<37)
Cadmium, Total	ug/L	ND(<0.12)	680	3.8	33	1.7
Cadmium, Dissolved	ug/L	N/A[1]	N/A[1]	N/A[1]	ND(<0.12)	ND(<0.12)
Copper, Total	ug/L	1.5	7,900	120	450	24
Copper, Dissolved	ug/L	N/A[1]	N/A[1]	N/A[1]	4.4	1.8
Iron, Total	ug/L	65	3,600,000	93,000	300,000	74,000
Iron, Dissolved	ug/L	N/A[1]	N/A[1]	N/A[1]	15	15
Lead, Total	ug/L	ND(<0.2)	5,100	200	210	64
Lead, Dissolved	ug/L	N/A[1]	N/A[1]	N/A[1]	ND(<0.2)	ND(<0.2)
Manganese, Total	ug/L	17	210,000	7,000	9,300	3,300
Manganese, Dissolved	ug/L	N/A[1]	N/A[1]	N/A[1]	96	ND(<5.0)
Nickel, Total	ug/L	1.9	5,700	45	300	13
Nickel, Dissolved	ug/L	N/A[1]	N/A[1]	N/A[1]	2.4	0.6
Zinc, Total	ug/L	6.2	39,000	730	1,700	200
Zinc, Dissolved	ug/L	N/A[1]	N/A[1]	N/A[1]	1.6	2.8

1. The analytical laboratory did not analyze dissolved metals from Event #1.

°C = degrees Celsius
mg/L = milligrams per liter
ug/L = micrograms per liter
mS/cm = milliSiemens per centimeter
NTU = nephelometric turbidity unit
N/A = not available
ND = not detected at the indicated detection limit (MDL)
J = Qualified with a "J" flag, results were evaluated to the MDL, reported concentration is > MDL and < reporting limit (RL).
OR = Out of range
SU = standard units (pH units)

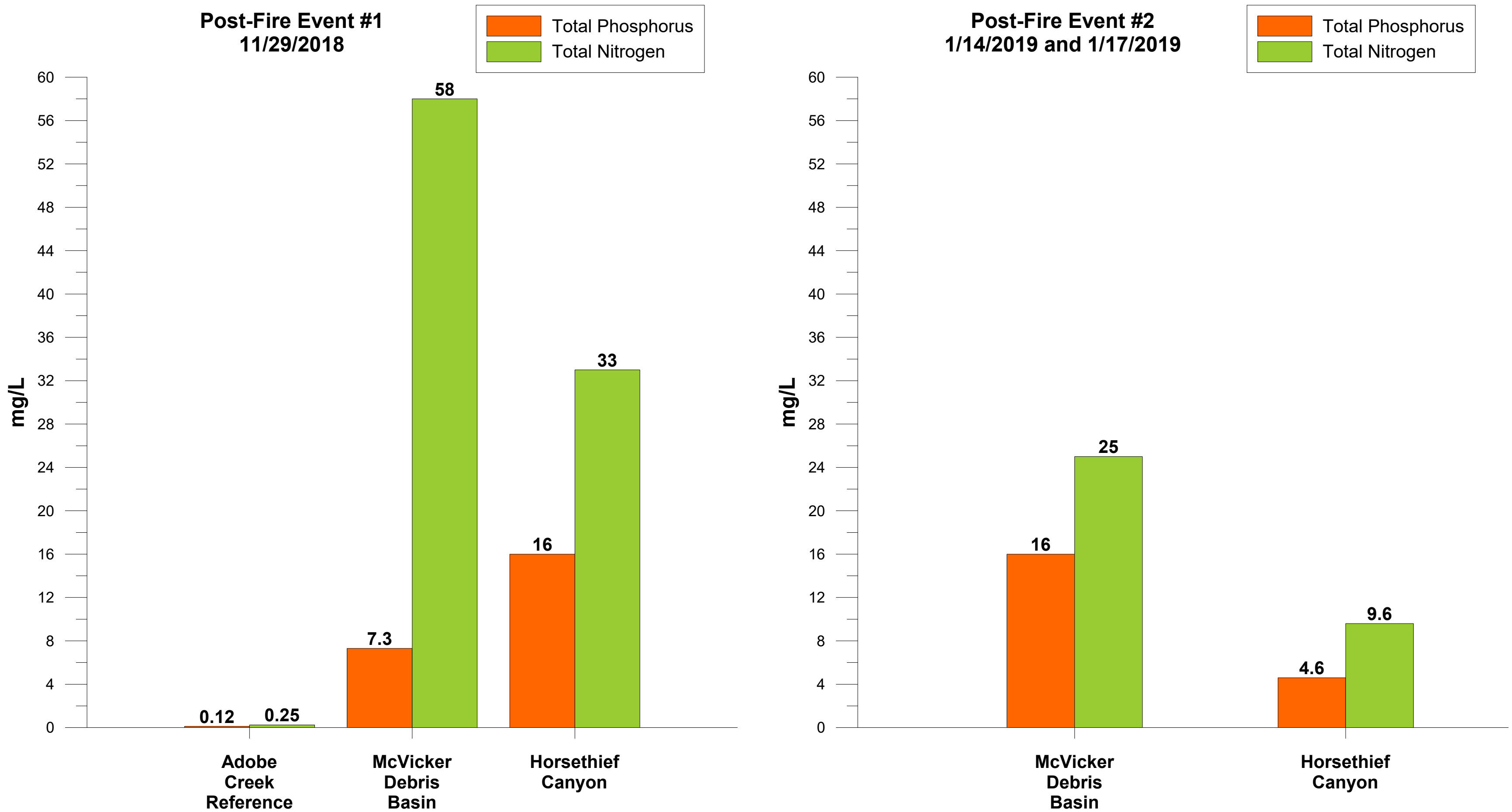


Figure 15. Total Phosphorus and Total Nitrogen (Event 1 and Event 2).

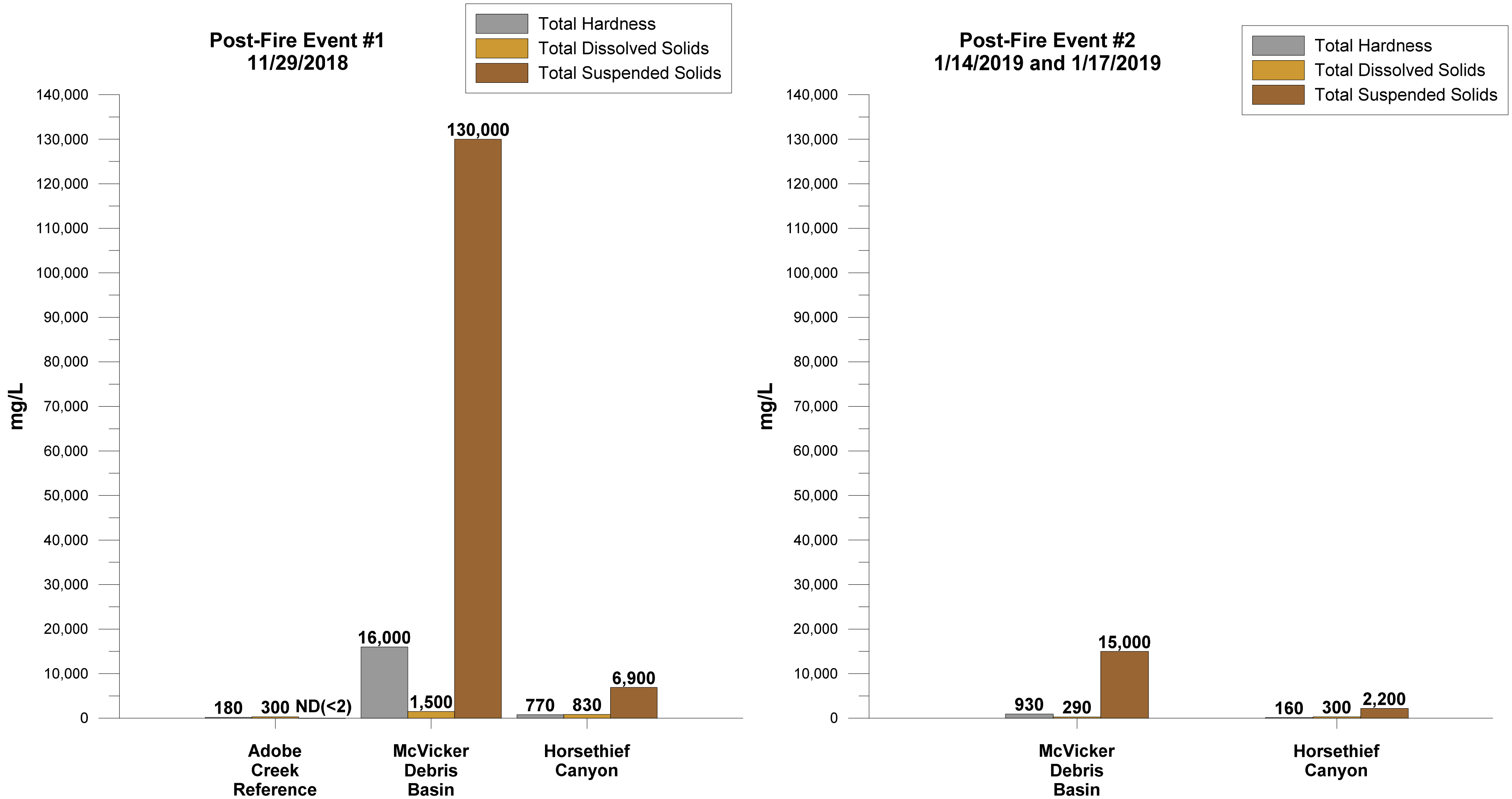


Figure 16. Total Hardness, Total Dissolved Solids, and Total Suspended Solids (Event 1 and Event 2).

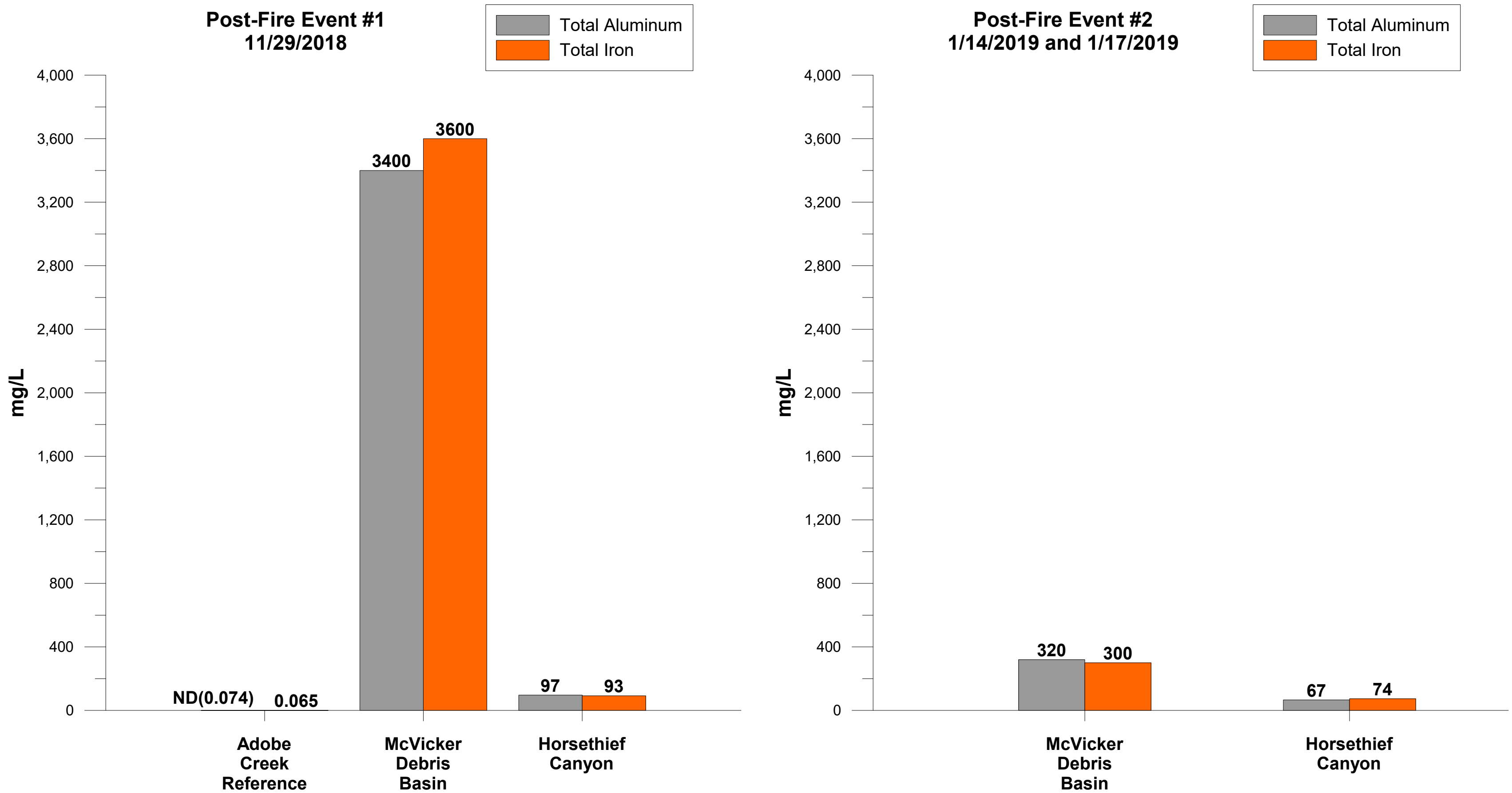


Figure 17. Total Aluminum and Total Iron (Event 1 and Event 2).

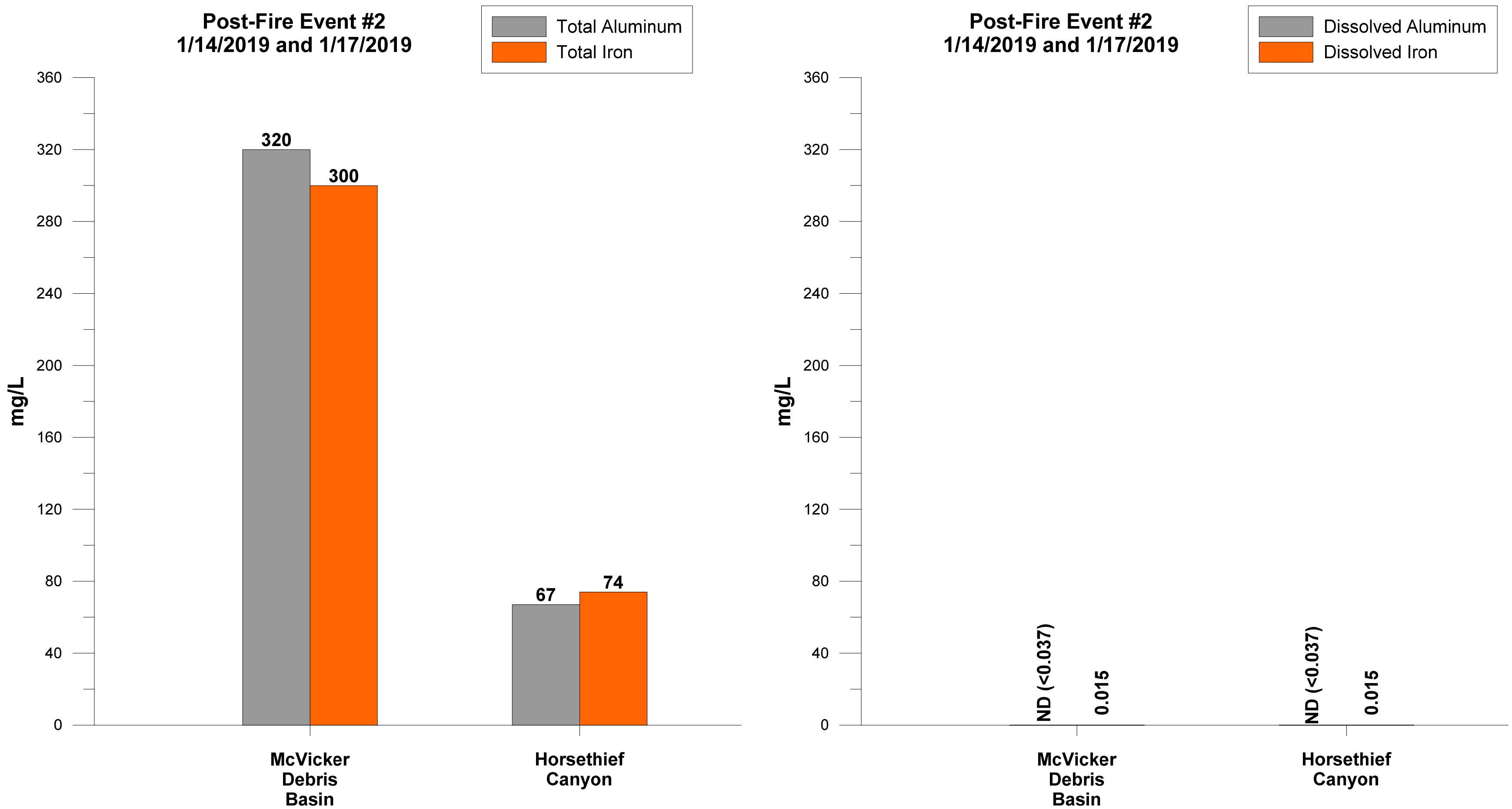


Figure 18. Total vs. Dissolved Aluminum and Iron (Event 2).

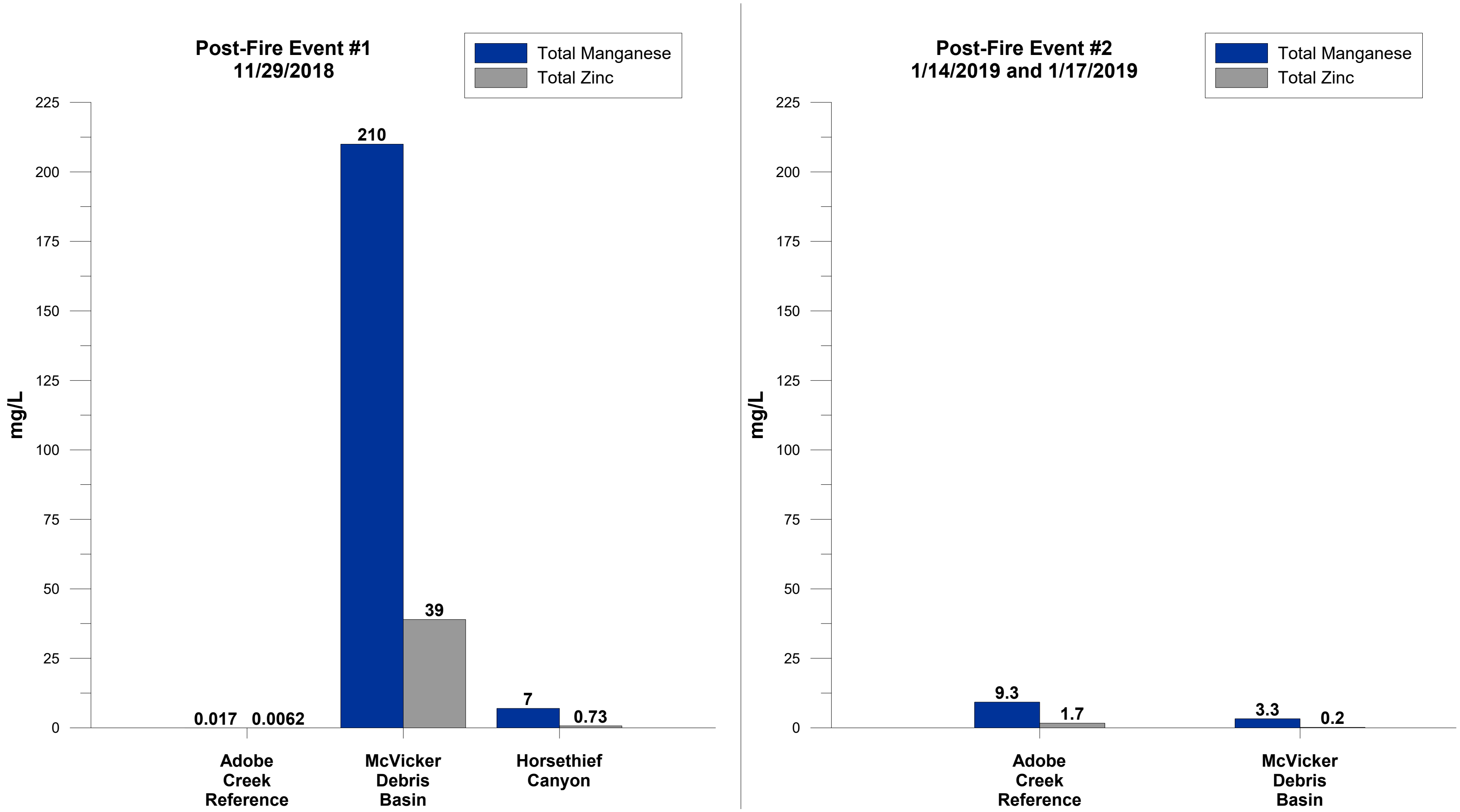


Figure 19. Total Manganese and Total Zinc (Event 1 and Event 2).

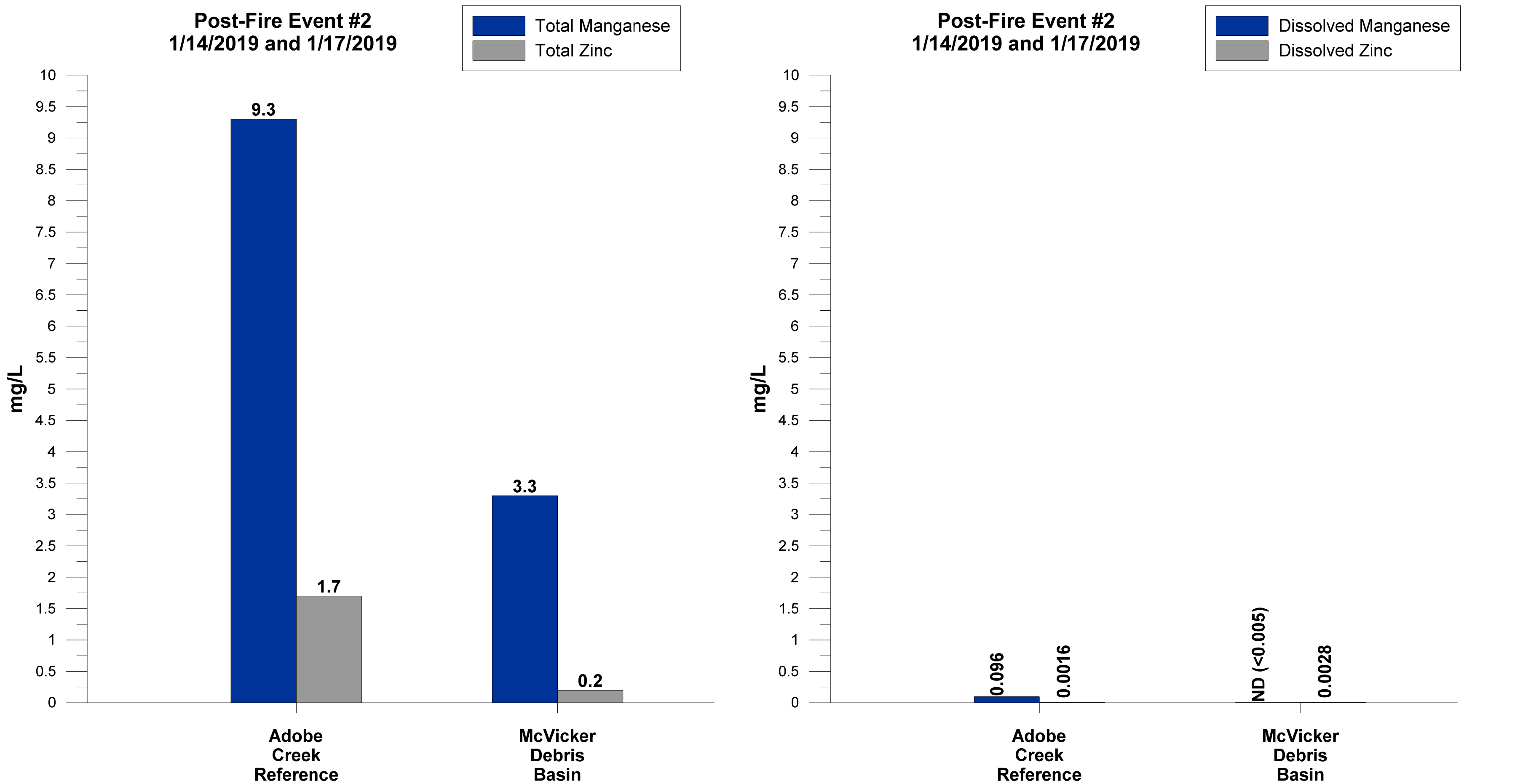


Figure 20. Total vs. Dissolved Manganese and Zinc (Event 2).

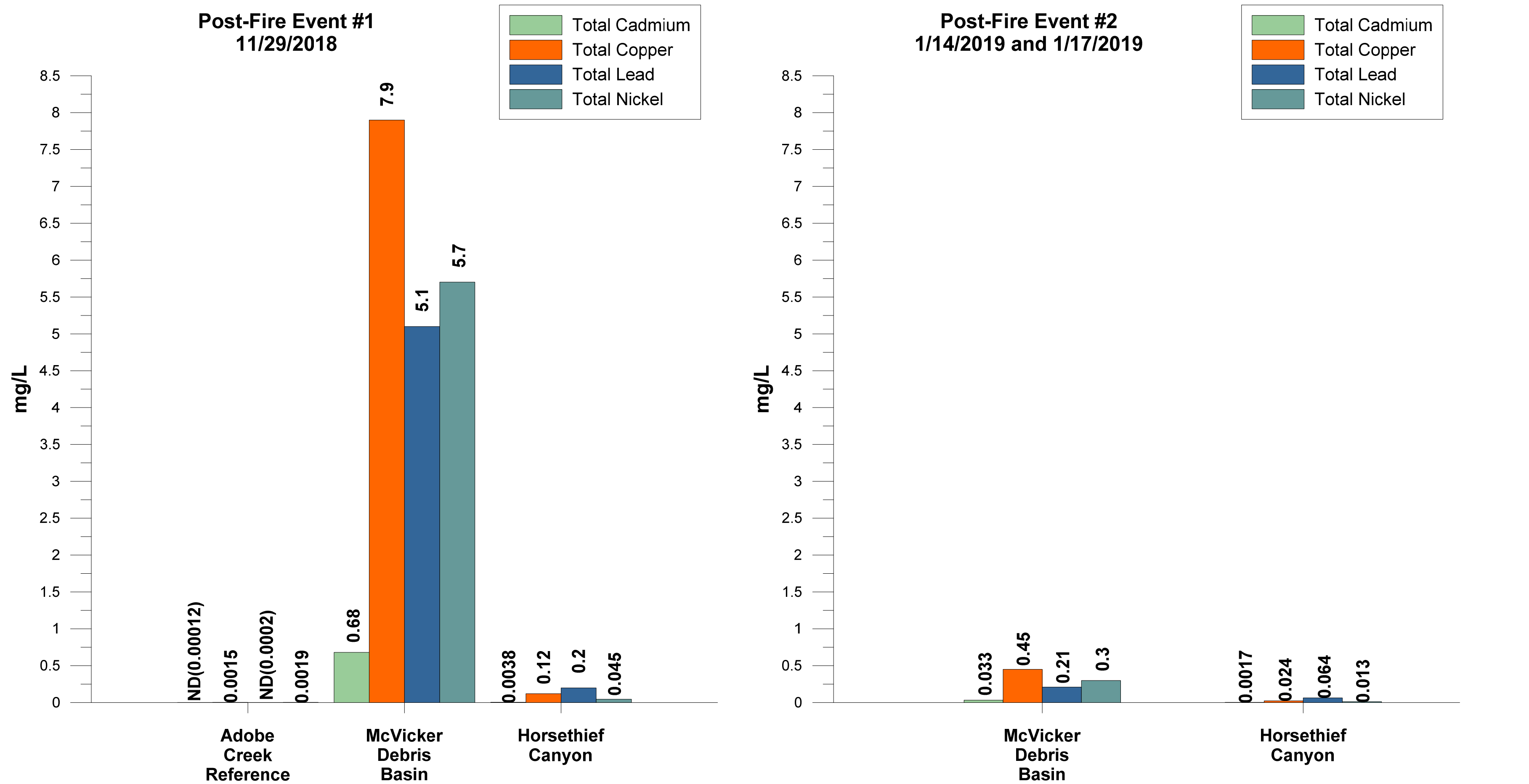


Figure 21. Total Cadmium, Total Copper, Total Lead, and Total Nickel (Event 1 and Event 2).

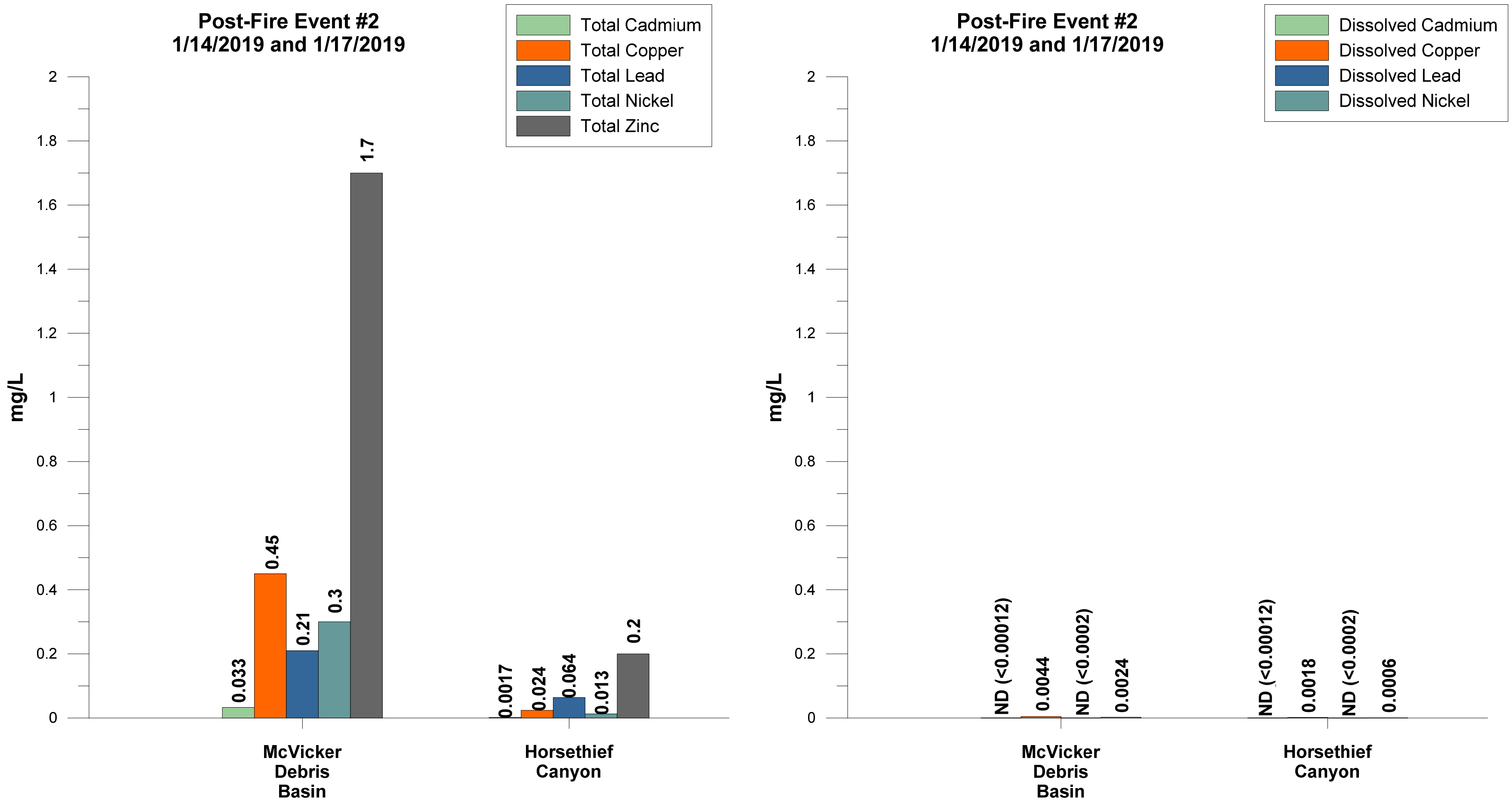


Figure 22. Total vs. Dissolved Cadmium, Copper, Lead, and Nickel (Event 2).

4.3 Assessment of Post-Fire Contaminant Flux

The study was designed to assess contaminant concentration and flux by sampling stormwater runoff from the terminal end of burned catchments and comparing the data to reference sites, and to assess the effects of the Holy Fire on the hydrologic response, sediment loads, and contribution of pollutant loads from post-fire runoff. Flux estimates were calculated to compare the data from burned catchments and reference sites of different sizes. Contaminant flux was calculated as the ratio of the mass loading in kilograms (kg) and the contributing catchment area in square kilometers (km^2) for each storm monitoring event (Stein et al., 2012).

The event mass contaminant loadings were calculated as the product of the individual event composite sample concentrations and measured or estimated individual storm event volume. When continuous flow measurements from in-situ flowmeters were available, those data were used to calculate storm volumes. When continuous in-situ flow measurements were not available, storm volumes were obtained from the Post-Fire Debris Flow Hazard Assessment conducted by the USGS. The USGS estimated the likelihood of debris flow of the individual stream segments and catchments from the Holy Fire, based upon a design storm with peak 15-minute rainfall intensities. **Figure 23** shows the burned catchments that were evaluated by the USGS, including McVicker Canyon and Horsethief Canyon. Estimates of storm event volumes in the recently burned catchment areas were estimated at the basin scale for a rainstorm with a 15-minute peak rainfall intensity of 0.47 in/hr. The 15-minute storm durations were selected because post-fire debris flows are most often triggered by high intensity, short-duration bursts of rain and, are likely to happen in most areas of the southwest. Differences in the USGS Hazard Assessment predictions and actual debris-flow occurrence may have occurred depending on actual storm duration, intensity and local conditions.

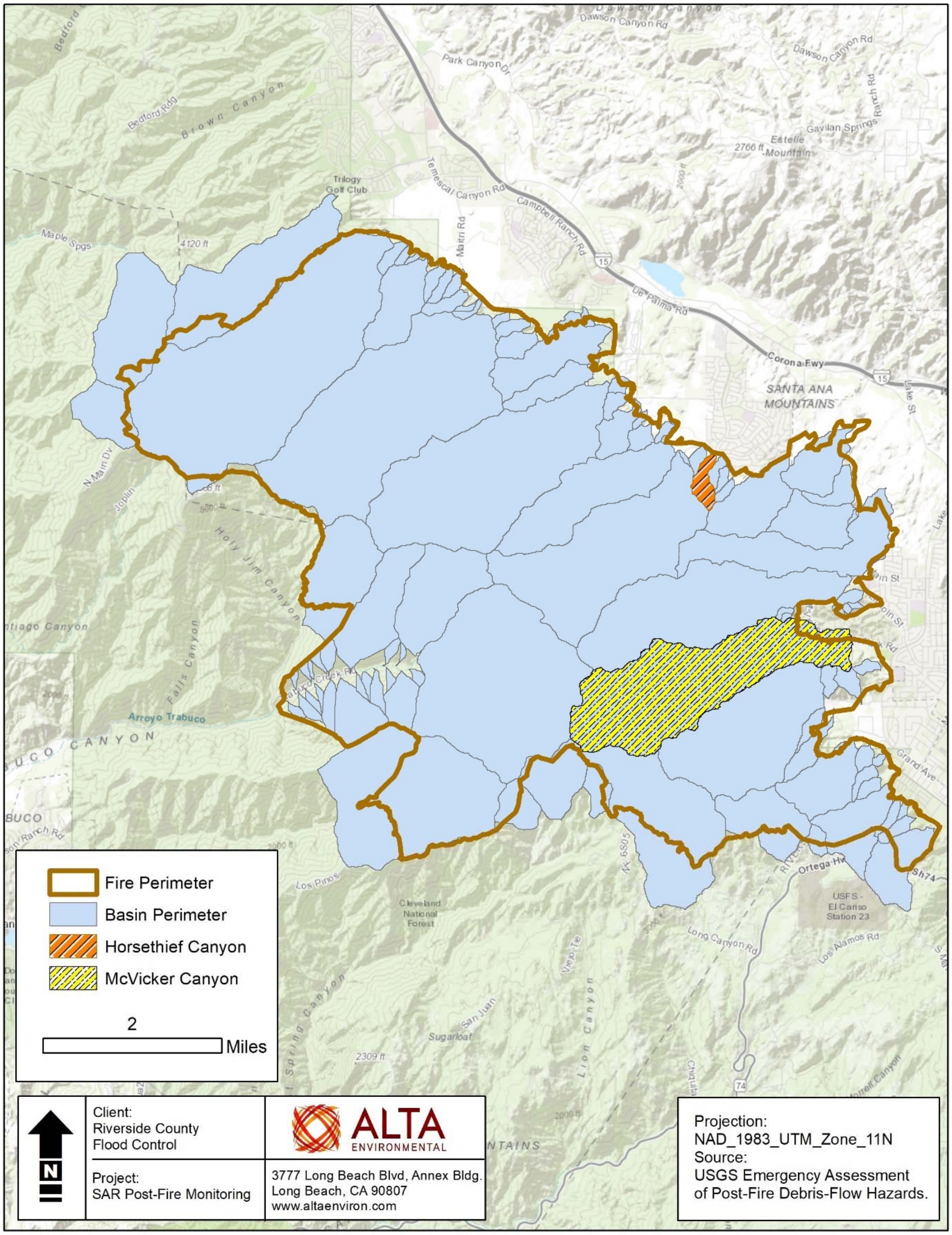


Figure 23. Estimated Burned Catchments from Holy Fire.

A summary of the contaminant flux estimates for the burned catchments monitored during this study (McVicker Debris Basin and Horsethief Canyon) compared to the Adobe Creek Reference site is provided in **Table 4**. Graphs of the contaminant flux are provided in **Figure 24** through **Figure 28**. The graphs provide contaminant flux comparisons between the Adobe Creek Reference and the burned catchments from McVicker Debris Basin and Horsethief Canyon. In general, the burned catchments had higher contaminant flux compared to the reference site and contaminant flux rates were lower during the second wet weather event. The first wet weather monitoring event was the 'first flush' from the burned catchments of the 2018 Holy Fire, which is also evident from the total and dissolved organic carbon, total suspended solids, and total metals results shown in **Figure 26**, **Figure 27**, and **Figure 28**, respectively.

Mean total phosphorus and total nitrogen flux (kg/km^2) were between 69- and 98-fold higher from burned catchments and total copper, lead, and zinc flux were between 659- and 11,169-fold higher compared to unburned natural areas. Mean total suspended solids flux were 27,177-fold higher from burned catchments compared to unburned natural areas. The contaminant flux from the burned catchments were lower during the second wet weather event in January 2019 compared to the 'first flush' event in November 2018, indicating the attenuation of contaminant concentrations and loads was observed as the 2018-2019 winter storm season experienced numerous high intensity rainfall events and above average total rainfall. For example, mean total phosphorus and total nitrogen flux (kg/km^2) were between 104- and 165-fold higher from burned catchments and total copper, lead, and zinc flux were between 1,295- and 27,713-fold higher compared to unburned natural areas during the 'first flush' event in November 2018.

In a similar study to assess contaminant loading from wildfires in southern California, post-fire stormwater runoff was sampled from five wildfires that burned natural open space and compared to data from 16 unburned natural areas, mean copper, lead, and zinc flux were between 112- and 736-fold higher from burned catchments and total phosphorus was up to 921-fold higher compared to unburned natural areas (Stein et al., 2012). A key find of the study was that the attenuation of elevated flux values appeared to be driven mainly by rainfall magnitude and contaminant loading from burned landscapes has the potential to be a substantial contribution to the total annual load to downstream areas in the first several years following fires (Stein et al., 2012).

Table 4. Summary of Event Contaminant Flux (expressed as runoff load).

Parameter	Units	Event #1 11/29/2018			Event #2 1/14/2019	Event #2 1/17/2019
		Adobe Reference	McVicker Debris Basin	Horsethief Canyon	McVicker Debris Basin	Horsethief Canyon
Event Rainfall	in.	1.50	1.80	1.80	0.71	2.95
Peak Rainfall Intensity	in./hr.	N/A	0.48	0.48	0.16	0.51
Event Volume	cf	245,802.48[1]	666,340.64[2]	46,271.96[2]	156,418.39[1]	46,271.96[2]
Area	km^2	1.59	5.90	0.25	5.90	0.25
Total Suspended Solids	kg/km^2	4.37	415,742.53	36,440.50	11,260.66	11,618.71
Total Organic Carbon	kg/km^2	33.61	2,494.46	528.12	32.28	79.22
Dissolved Organic Carbon	kg/km^2	30.12	1,055.35	406.65	11.26	42.78
Ammonia-Nitrogen	kg/km^2	0.10	28.46	20.07	0.61	0.74
Kjeldahl Nitrogen	kg/km^2	1.09	159.90	147.87	17.27	44.36
Nitrate as N	kg/km^2	0.12	19.83	24.82	1.35	6.34
Nitrite as N	kg/km^2	0.01	3.84	0.58	0.04	0.14
Organic Nitrogen	kg/km^2	0.87	131.12	126.75	16.52	43.83
Total Nitrogen	kg/km^2	1.09	185.49	174.28	18.77	50.70
Total Phosphorus	kg/km^2	0.52	23.35	84.50	12.01	24.29
Ortho Phosphate	kg/km^2	0.36	0.17	1.32	0.09	1.95
Aluminum, Total	kg/km^2	0.16	10,873.27	512.28	240.23	353.84
Cadmium, Total	kg/km^2	0.0003	2.17	0.02	0.02	0.01
Copper, Total	kg/km^2	0.01	25.26	0.63	0.34	0.13
Iron, Total	kg/km^2	0.28	11,512.87	491.15	225.21	390.81
Lead, Total	kg/km^2	0.0004	16.31	1.06	0.16	0.34
Manganese, Total	kg/km^2	0.07	671.58	36.97	6.98	17.43
Nickel, Total	kg/km^2	0.01	18.23	0.24	0.23	0.07
Zinc, Total	kg/km^2	0.03	124.72	3.86	1.28	1.06

1. Event volume measured with flowmeter.
2. Event volume estimated using USGS data.

cf = cubic feet
hr. = hour
in. = inch
kg = kilogram
km^2 = square kilometers
kg/km^2 = flux (kilograms per square kilometers)
N/A = not available

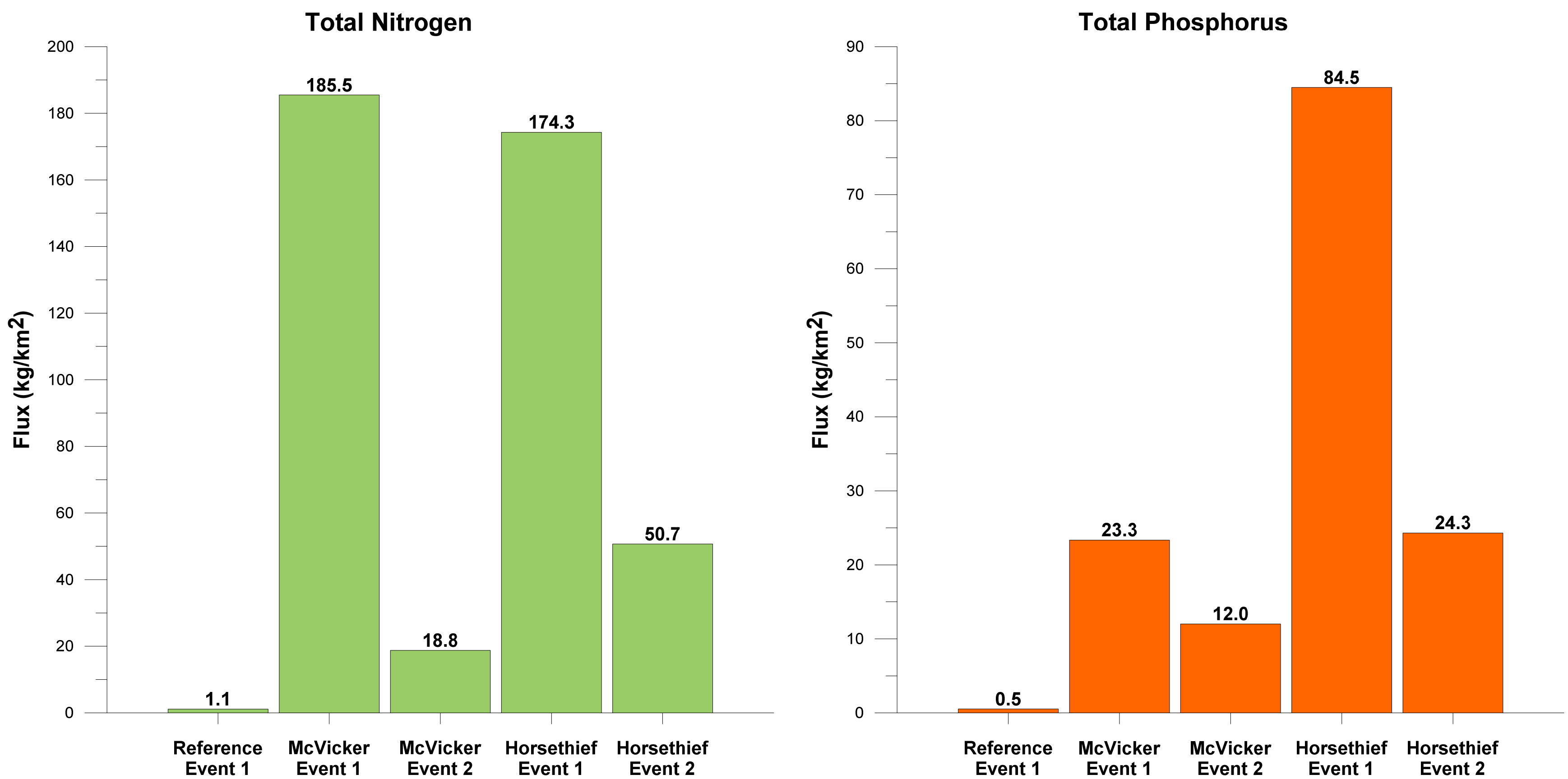


Figure 24. Total Phosphorus and Total Nitrogen Flux.

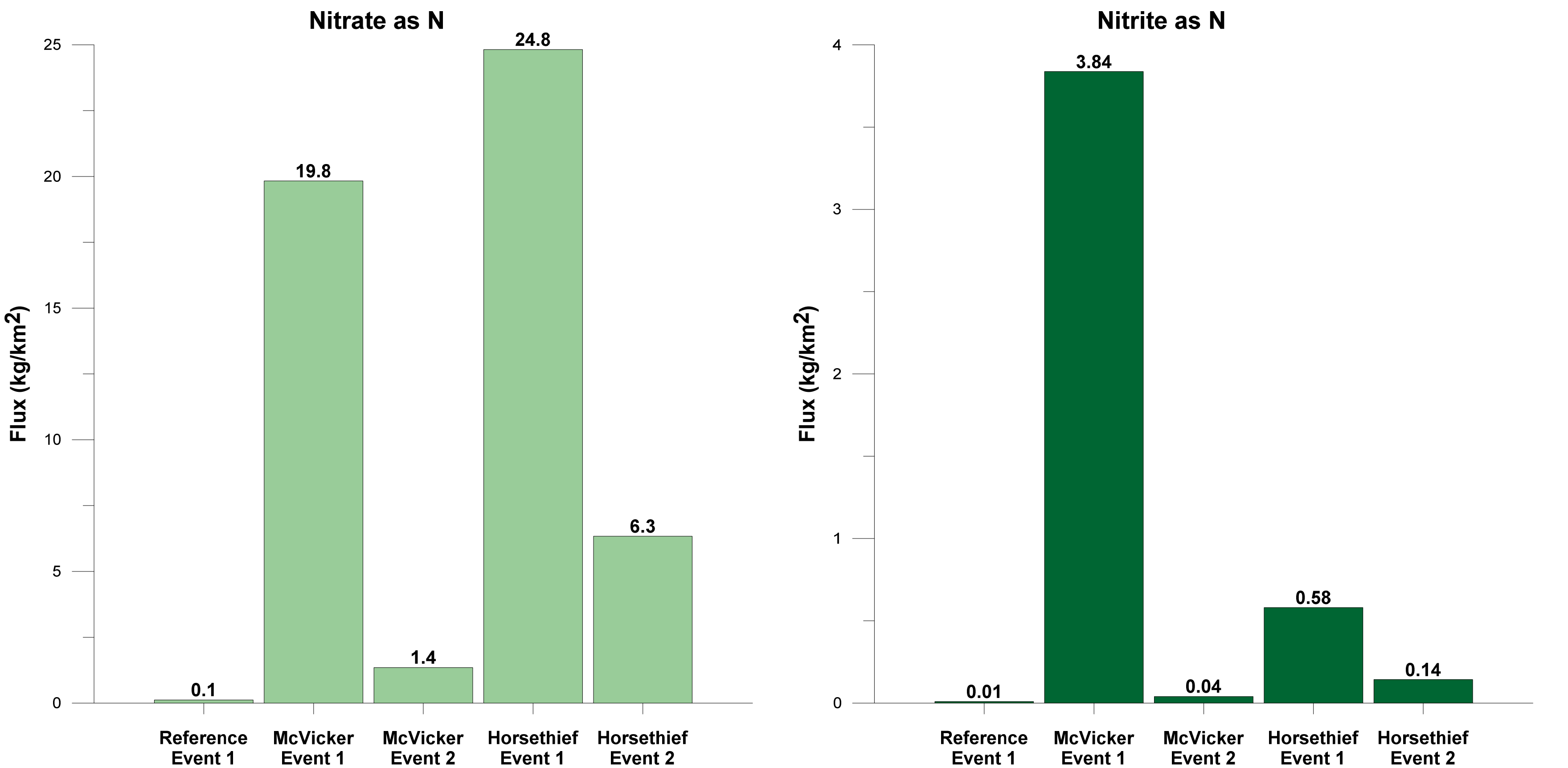


Figure 25. Nitrate as N and Nitrite as N Flux.

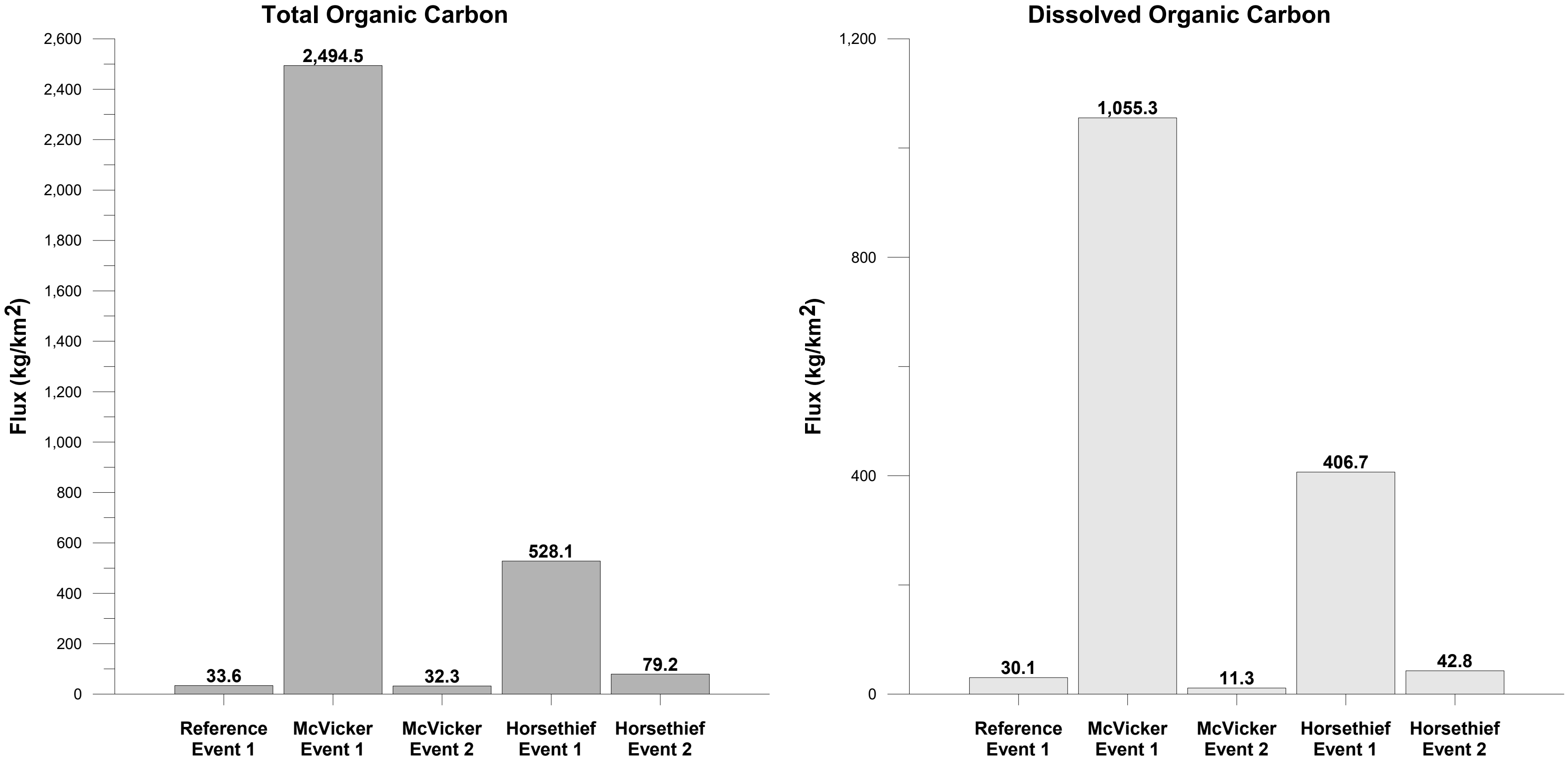


Figure 26. Total Organic Carbon and Dissolved Organic Carbon Flux.

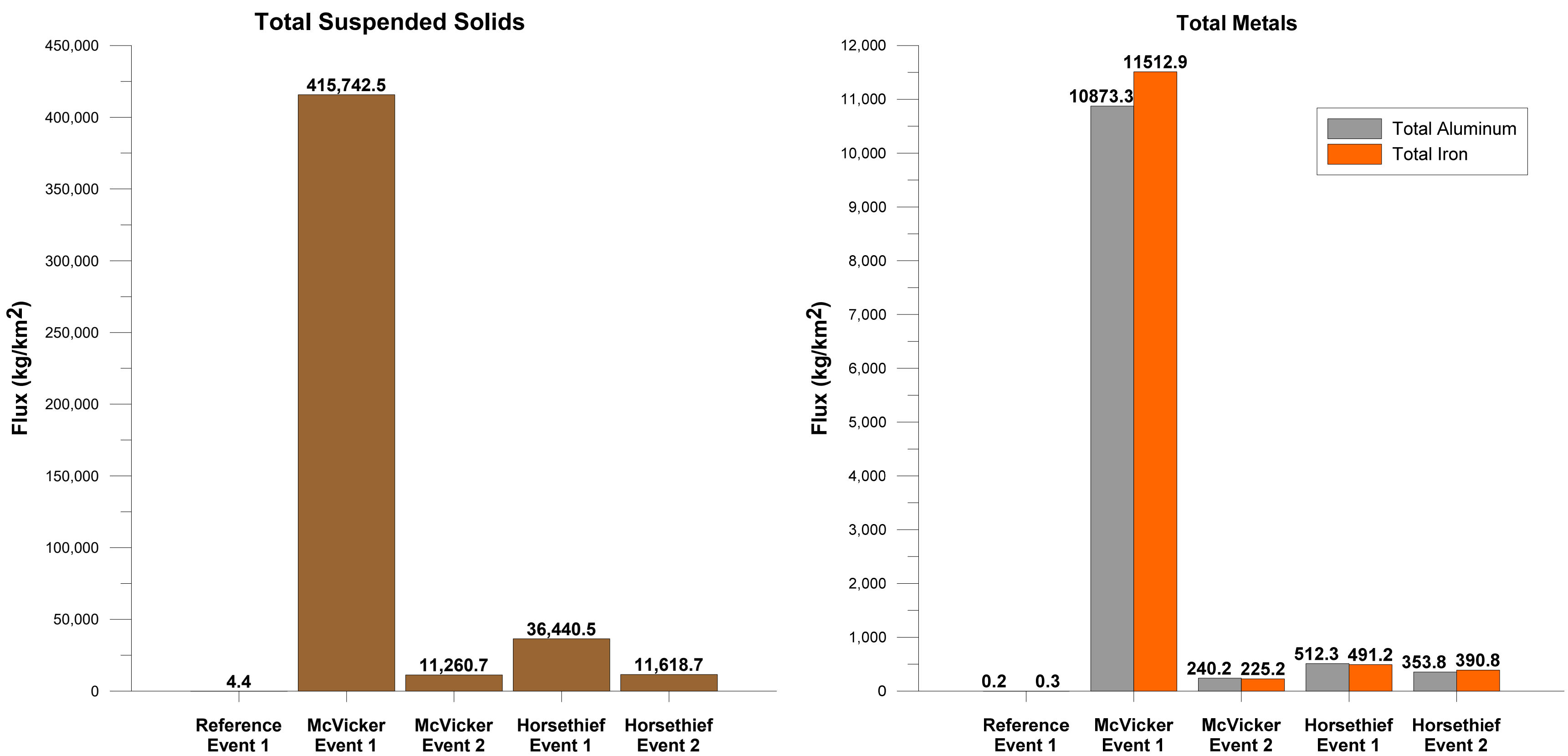
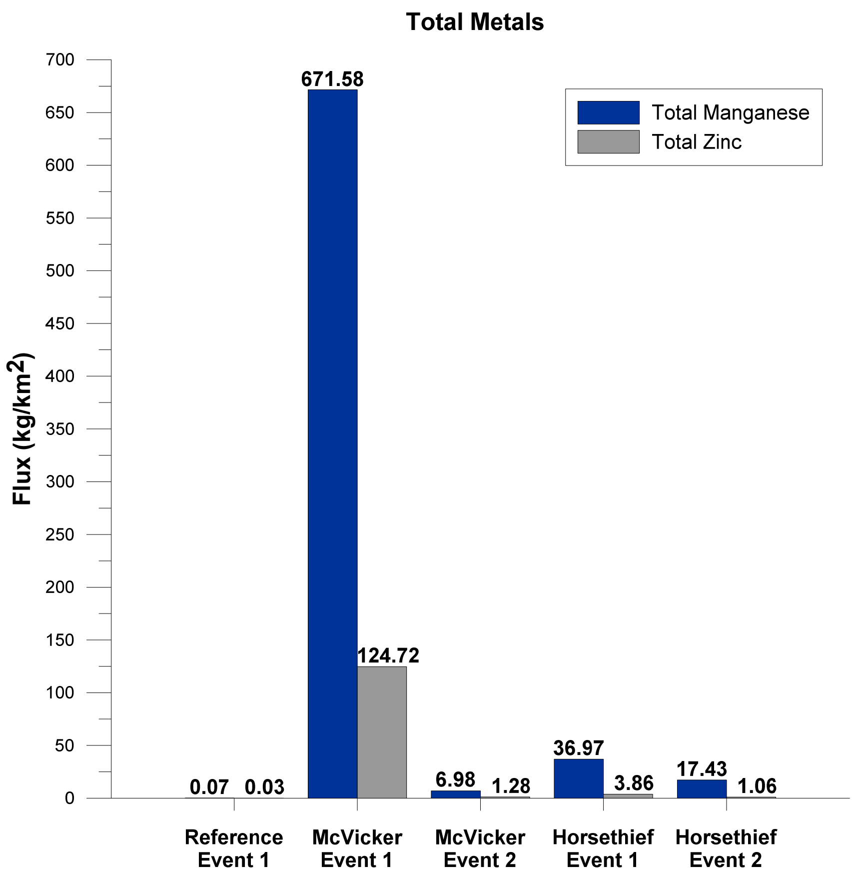


Figure 27. Total Suspended Solids, Total Aluminum, and Total Iron Flux.



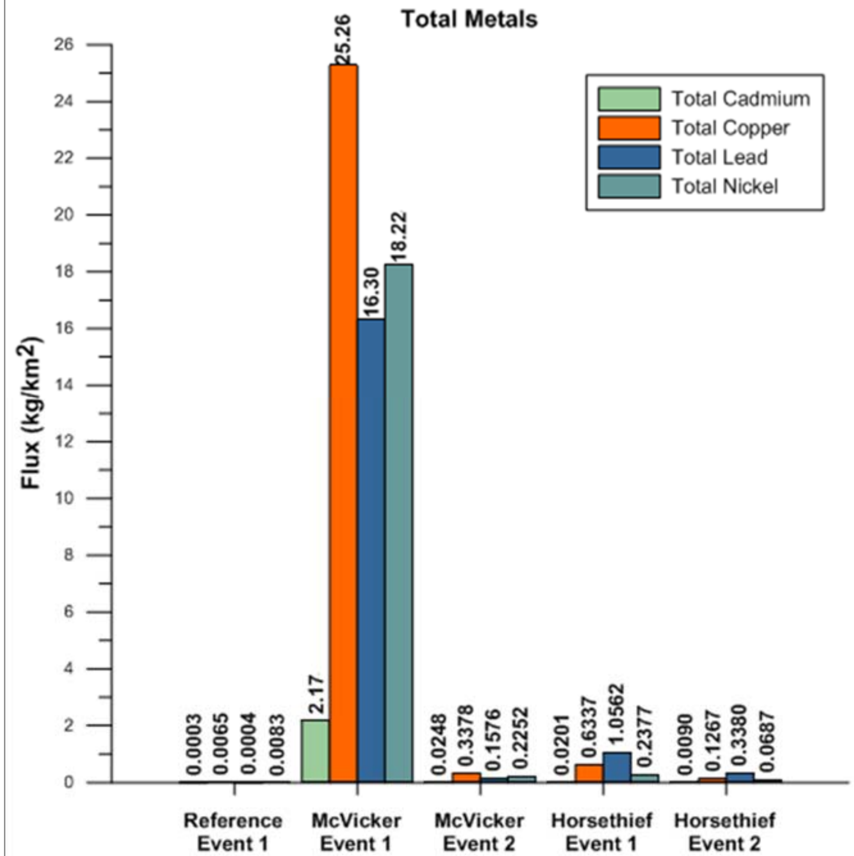


Figure 28. Total Cadmium, Copper, Lead, Manganese, Nickel, and Zinc Flux.

5.0 OTHER HOLY FIRE MONITORING EFFORTS

The following sections describe other special study monitoring efforts conducted in response to the 2018 Holy Fire.

5.1 Sediment Quality and Nutrient Load Reduction Study

In anticipation of the increased storm flows and sediment runoff following the Holy Fire, the District also implemented post-fire debris flow clean-up operations to improve and maintain overall debris basin capacity, capture eroding sediment mobilized by major rain events, protect downstream communities, and prevent further impacts to downstream receiving waters. The District's response protected the communities affected by the Holy Fire and water quality downstream by capturing approximately 178,904 cubic yards of sediment from District facilities and diverted the material to local landfills for disposal. As part of this effort, the District conducted a Sediment Quality and Nutrient Load Reduction Study to evaluate the nutrient loads removed from District basins, the full report is provided in **Appendix G**. From September 2018 through April 2019, the estimated amount of total nitrogen and total phosphorus removed from the Leach Canyon Dam and McVicker Debris Basin facilities was 7,527 tons and 120 tons, respectively. The District's effort prevented further impacts to water quality downstream by preventing these nutrient loads from entering Leach Canyon Channel, and ultimately into Lake Elsinore.

5.2 Lake Elsinore Post-Fire Monitoring Study: In-Lake Water Quality and Sediment Sampling

Additional monitoring within Lake Elsinore was subsequently conducted by local agencies to further assess the effect of post-fire runoff on downstream receiving waters. The goal of the sampling effort was to characterize the sediment plume deposited in Lake Elsinore as a result of post-fire runoff from Leach Canyon Channel, the largest conveyance of water and sediment from the area burned by the Holy Fire. The lateral extent of the sediment plume was defined by collecting a series of sediment cores along transects extending from the mouth of Leach Canyon Channel and the sampling locations included three stations within the sediment plume footprint, one station in the shallow beach area in between the Launch Pointe Recreation boat ramp and Leach Canyon Channel input, and one mid-lake reference station. Water and sediment samples were collected for physical parameters, analytical chemistry, and toxicity. The results of this sampling effort within Lake Elsinore are not a part of this report. The data will assist the local agencies and Regional Board staff in determining if mitigation of the sediment plume is necessary and whether post-fire runoff from the Holy Fire may have affected the progress of existing strategies to comply with requirements for the impairments in Lake Elsinore.

6.0 CONCLUSIONS

The Holy Fire burned approximately 23,000 acres of the Cleveland National Forest in August 2018. The high-to-moderate burn severity of the fire led to a loss of vegetation, created hydrophobic soils, and changed the soil erosiveness of the steep forested lands. The altered landscape stability and the potential for mud and debris flows created an immediate concern for not only the safety of the community, but the potential for water quality impacts to downstream waterbodies. The 2018-2019 winter storm season experienced above average rainfall with numerous high intensity rainfall events. Debris flows from the post-burn areas began in November 2018 and continued through the wet weather season. The District undertook the coordination and oversight of the post-fire preparation and response, including development and implementation of the post-fire water quality monitoring study to assess the effects of the Holy Fire on the hydrologic response, sediment loads, and contribution of pollutant loads from post-fire runoff.

The monitoring design focused on addressing one priority management question from the SMC Post-Fire Water Quality Monitoring Plan: "How does post-fire runoff affect contaminant flux?". Flux calculations were used to compare the relative mass contributions of contaminants from the burned catchments vs. the unburned natural areas. Mean total phosphorus and total nitrogen flux were between 69- and 98-fold higher from burned catchments and total copper, lead, and zinc flux were between 659- and 11,169-fold higher compared to unburned natural areas. Mean total suspended solids flux were 27,177-fold higher from burned catchments compared to unburned natural areas. The contaminant flux from the burned catchments were lower during the second wet weather event in January 2019 compared to the 'first flush' event in November 2018, indicating the attenuation of contaminant concentrations and loads decreased as the 2018-2019 winter storm season continued to experience numerous high intensity rainfall events and above average total rainfall. The mean total phosphorus and total nitrogen flux (kg/km^2) were between 104- and 165-fold higher from burned catchments and total copper, lead, and zinc flux were between 1,295- and 27,713-fold higher compared to unburned natural areas during the 'first flush' event in November 2018.

In a similar study to assess post-fire stormwater runoff from wildfires in southern California, mean copper, lead, and zinc flux were between 112- and 736-fold higher from burned catchments and total phosphorus was up to 921-fold higher compared to unburned natural areas. A key find of the study was that the attenuation of elevated flux values appeared to be driven mainly by rainfall magnitude and contaminant loading from burned landscapes has the potential to be a substantial contribution to the total annual load to downstream areas in the first several years following fires (Stein et al., 2012).

The contaminant flux results characterized the potential water quality impacts to downstream waterbodies of Lake Elsinore and Temescal Creek. This study provided stormwater managers and stakeholders with data to evaluate the post-fire contribution of nutrient loads in context with other sources within the watersheds. Understanding the effects of the Holy Fire on contaminant flux provides information that can inform management actions, including strategies used to comply with nutrient TMDLs.

Recommendations for Post-fire Monitoring Studies

Safety is a key consideration for monitoring at the terminal end of burned catchments. High intensity, short duration rainfall rates are the primary cause of debris flows and field teams may be mobilized within active evacuation zones during significant storm events. The unpredictable nature of the post-fire runoff from the Holy Fire and evolving site conditions required constant communication between District and project staff, accelerated techniques, and real-time modifications to successfully capture post-fire runoff while ensuring the safety of the field staff. Fortunately, the monitoring sites for this study were located downstream of the District's debris basins, which provided safe and accessible sampling locations during the debris flows. The following are key considerations when preparing for future post-fire monitoring efforts.

Study Design and Monitoring Logistics:

- Identifying a reference station from an unburned catchment of similar size and land cover not affected by historical fires or recent ash fall out can be challenging in short notice. Developing a list of potential reference sites in advance would be beneficial.
- Mobilization criteria should be developed on a site-specific basis and USGS debris flow thresholds for burned catchments may be a resource.
- Automated sampling equipment may not be feasible. Flexibility should be built into monitoring plans if real-time adjustments to monitoring approaches are needed.

Safety Considerations:

- Monitoring activities may be within zones subject to active evacuation procedures and field conditions are likely to be unpredictable. Multiple evacuation routes for field personnel provide an extra measure of safety if changes to access routes develop during monitoring activities.
- Communication is crucial for safety, which includes communication between field personnel, project staff, and emergency response agencies.

7.0 REFERENCES

Anderson, K.L. 2018. Burned Area Emergency Response: Holy Fire; Cleveland National Forest. Hydrology and Watershed Specialist Report.

Bertrand-Krajewski, J., G. Chebbo and A. Saget. 1998. Distribution of pollutant mass vs volume in stormwater discharges and the first flush phenomenon. Water Research 32:2341-2356.

Cannon, S.H., Gartner, J.E., Rupert, M.G. and Michael, J.A. 2003. Emergency Assessment of Debris-Flow Hazards from Basins Burned by the Piru, Simi, and Verdale Fires of 2003, Southern California. U.S. Geological Survey Open-File Report OF-03-481.

MPSL-DFW, 2014. SOP for Conducting Field Measurements and Field Collections of Water and Bed Sediment Samples with Associated Field Measurements and Physical Habitat in California. Version 1.1. March 2014.

Nicita, E. and E. Halverson. 2018. Holy Fire Burned Area Emergency Response; Soil Resource Report. USDA Forest Service.

Pappa, A., N. Tzamtzis and S. Koufopoulou. 2006. Effect of fire retardant application on phosphorus leaching from Mediterranean forest soil: short-term laboratory-scale study. International Journal of Wildland Fire 15:287-292.

Schwartz, J.Y., and T. Stempniewicz. 2018. Burned Area Emergency Response (BAER) Assessment: Geological Hazards. Cleveland National Forest, CA.

Stein, E.D., Brown, J.S., Hogue, T.S., Burke, M.P and A. Kinoshita. 2012. Stormwater Contaminant Loading Following Wildfires. University of California, Department of Civil and Environmental Engineering. Los Angeles, CA.

Stein, E.D. and J. Brown. 2009. Effects of Post-fire Runoff on Surface Water Quality: Development of a Southern California Regional Monitoring Program with Management Questions and Implementation Recommendations. SCCWRP. Technical Report 598. Costa Mesa, CA.

SWRCB (State Water Resources Control Board), 2008. SWRCB, Surface Water Ambient Monitoring Program Quality Assurance Program Plan (SWAMP). Final Technical Report Version 1. September 2008.

USEPA (U.S Environmental Protection Agency), 1992. NPDES Storm Water Sampling Guidance Document. EPA 833-B-92-001. Office of Water, USEPA, Washington, DC. July 1992.

Appendices