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Prepared by

Steve A. Mizell, Greg McCurdy, Kevin Heintz, and Julianne J. Miller

Submitted to

U.S. Department of Energy
Environmental Management Nevada Program
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EXECUTIVE SUMMARY

Desert Research Institute (DRI) is conducting a field assessment of the potential for contaminated soil to be transported from the Smoky Site Contamination Area (CA) as a result of storm runoff. This activity supports U.S. Department of Energy (DOE) Environmental Management Nevada Program (EM NV) efforts to establish post-closure monitoring plans for the Smoky Site Soils Corrective Action Unit (CAU) 550. The work is intended to confirm the likely mechanism of transport and determine the meteorological conditions that might cause the movement of contaminated soils, as well as determine the particle size fraction that is most closely associated with transported radionuclide-contaminated soils. These data will facilitate the design of the appropriate post-closure monitoring program.

In 2011, DRI installed a meteorological monitoring station on the west side of the Smoky Site CA and a hydrologic (runoff) monitoring station within the CA, near the east side. The meteorological station collects air temperature, wind speed, wind direction, relative humidity, precipitation, solar radiation, barometric pressure, soil temperature, and soil water content data. The maximum, minimum, and average or total values (as appropriate) for each of these parameters are recorded for each 10-minute interval. The maximum, minimum, and average water depth in the flume installed at the hydrologic station are also recorded for each 10-minute interval. This report presents the data collected from these stations during fiscal year (FY) 2018.

During the FY2018 reporting period, the warmest months were June, July, and August and the coldest were December through March. Solar radiation showed the same seasonal trend. Monthly mean wind speeds were highest in the spring (March through May) and early summer (June). Winds were generally from the west during the summer and from the north throughout the fall and winter. The monthly average relative humidity ranged from the mid-teens to approximately 50 percent. Humidity was lowest in the fall and highest in the winter. Monthly total precipitation ranged from 0 in October, December, and June to approximately 1.38 inches (in) (35.05 millimeters [mm]) in July. Total precipitation for FY2018 was 3.86 in (98.04 mm).

During the reporting period, two runoff events were recorded at the flume. One occurred on July 14, 2018, in response to precipitation earlier the same day. This event produced a peak water depth of 11.26 in (28.60 centimeters [cm]) in the flume, which is equivalent to a discharge of 1.86 cubic feet per second (cfs) (0.05 cubic meters per second [cm/s]) and a velocity of 3.97 feet per second (fps) (1.21 meters per second [m/s]) through the flume. Applying the flume hydraulic measurements to the channel geometry at the nearest surveyed cross-section it was determined that the velocity through the channel was 1.29 fps (0.39 m/s), which is sufficient to transport silts and fine sands. The second flow event occurred in response to earlier precipitation on September 4, 2018. This event produced a peak water depth of 0.78 in (1.98 cm) in the flume, which is equivalent to a discharge of 0.03 cfs (0.001 cm/s) and a velocity of 1.17 fps (0.36 m/s) through the flume. Applying the flume hydraulic measurements to the channel geometry at the nearest surveyed cross-section it was determined that the velocity through the channel was 0.03 fps (0.01 m/s). Although neither runoff event produced sufficient flow velocities through the natural channel to cause local erosion and transport of coarser bedload materials, the velocity of the first runoff event was sufficient to transport silts and fine sands, which have been shown to be preferentially associated with radionuclide contaminants. Therefore, a sampling event was planned after the first flow event in conjunction with a periodic maintenance inspection.

As no suspended load sampling is available at this location, bedload samples were collected from the vicinity of the flume on August 7, 2018. The collected sediment was separated into three particle size fractions and each fraction was analyzed for americium-241 (Am-241), plutonium-238 (Pu-238), and plutonium-239/240 (Pu-239/240) by alpha spectrometry. The two smaller particle size fractions had higher concentrations of all three radionuclides than the largest particle size fraction. Additionally, Pu-239/240 had the highest concentration and Pu-238 had the lowest concentration in all samples. The same relationship between the concentrations of Pu-238 and Pu-239/240 was seen in samples reported in FY2013 and FY2014.

Observation of meteorological and environmental conditions that lead to storm runoff will help identify parameters and threshold conditions that should be incorporated into post-closure monitoring plans for this and similar sites as well as aid in determining appropriate closure strategies for other Soils CAUs.

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LIST OF ACRONYMS, SYMBOLS, AND ABBREVIATIONS

Am-241	americium-241
CA	Contamination Area
CAU	Corrective Action Unit
cfs	cubic feet per second
cps	counts per second
cm	centimeters
cm/s	cubic meters per second
DOE	Department of Energy
DRI	Desert Research Institute
EM NV	Environmental Management Nevada Program
fps	feet per second

FY	fiscal year
GOES	Geostationary Operational Environmental Satellite (GOES)
in	inch
LIDAR	light detection and ranging
MDL	method detection limit
m/s	meters per second
µm	micrometer
mm	millimeter
min	minutes
NDEP	Nevada Division of Environmental Protection
NNSA	National Nuclear Security Administration
NNSS	Nevada National Security Site
pCi/g	picocuries/gram
Pu-238	plutonium-238
Pu-239/240	plutonium-239/240
SwRI	Southwest Research Institute
TDR	time-domain reflectometry
VWC	volumetric water content
WRCC	Western Regional Climate Center

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INTRODUCTION

Desert Research Institute (DRI) has been authorized to conduct field assessments to evaluate the potential for transport of radionuclide-contaminated soils during precipitation runoff events. Aerial surveys of radionuclide activity on the ground surface in Areas 3, 8, 11, 18, and 25 of the Nevada National Security Site (NNSS) suggest that radionuclide-contaminated soils may be migrating along ephemeral channels (Colton, 1999). The U.S. Department of Energy (DOE), Environmental Management Nevada Program (EM NV) Soils Activity has authorized and funded an assessment of runoff transport.

The Smoky Site Contamination Area (CA) (Corrective Action Unit [CAU] 550) in Area 8 was selected for this investigation because radionuclide-contaminated sediment deposits have been documented on Circle Road, where ephemeral channels that drain the CA intersect the road (Bechtel Nevada, 2000; J. Traynor, NSTec, personal communication, 2011). Figure 1 shows a low-elevation aerial survey for americium-241 (Am-241) that delineates the Smoky contamination as an elongate zone trending north-northwest to south-southeast (Colton, 1999). This trend is approximately parallel to ephemeral drainages emanating from the Smoky Hills to the north, as evidenced by the unnamed mapped drainage that lies along the west side of the contamination zone. The narrow lobe in the 1,500 to 3,200 counts per second (cps) contour that extends toward the south-southeast may also indicate transport along a drainage channel.

Closure of CAU 550, the Smoky Site, was approved by the Nevada Division of Environmental Protection on March 2, 2015 (C.D. Andres, NDEP Bureau of Federal Facilities, letter to R.F. Boehlecke, NNSA, Environmental Management Operations, March 2, 2015). The assessment of potential transport of radionuclide-contaminated soil material by storm runoff was undertaken to determine what meteorological conditions result in the movement of contaminated soils and what particle size fractions are associated with transported contamination. Understanding the controls on radionuclide-contamination transported by runoff will facilitate the appropriate design of post-closure monitoring plans and procedures.

BACKGROUND

The Smoky Site CA is located in the northwest quadrant of Yucca Flat, in southeastern Nye County, Nevada. In addition to the namesake test, Smoky—which was an aboveground nuclear device test detonated in 1957—four additional tests were conducted in the area. These included three safety tests (Oberon, Ceres, and Titania) conducted in 1958 and a weapon effects test (Mudpack) conducted in 1964 (Colton, 1999). Figure 1 shows the resultant elongated area of surface contamination trending in a northwest-southeast direction (Colton, 1999). This area of surface contamination encompasses the Smoky, Oberon, Ceres, and Mudpack test locations. Near the southern extent and slightly to the southwest of this CA, there is a triangular area of surface contamination associated with the Titania test. A low-level aerial survey (Figure 1) reported more than 7,000 cps of Am-241 at the center of the two areas of elevated americium (Colton, 1999).

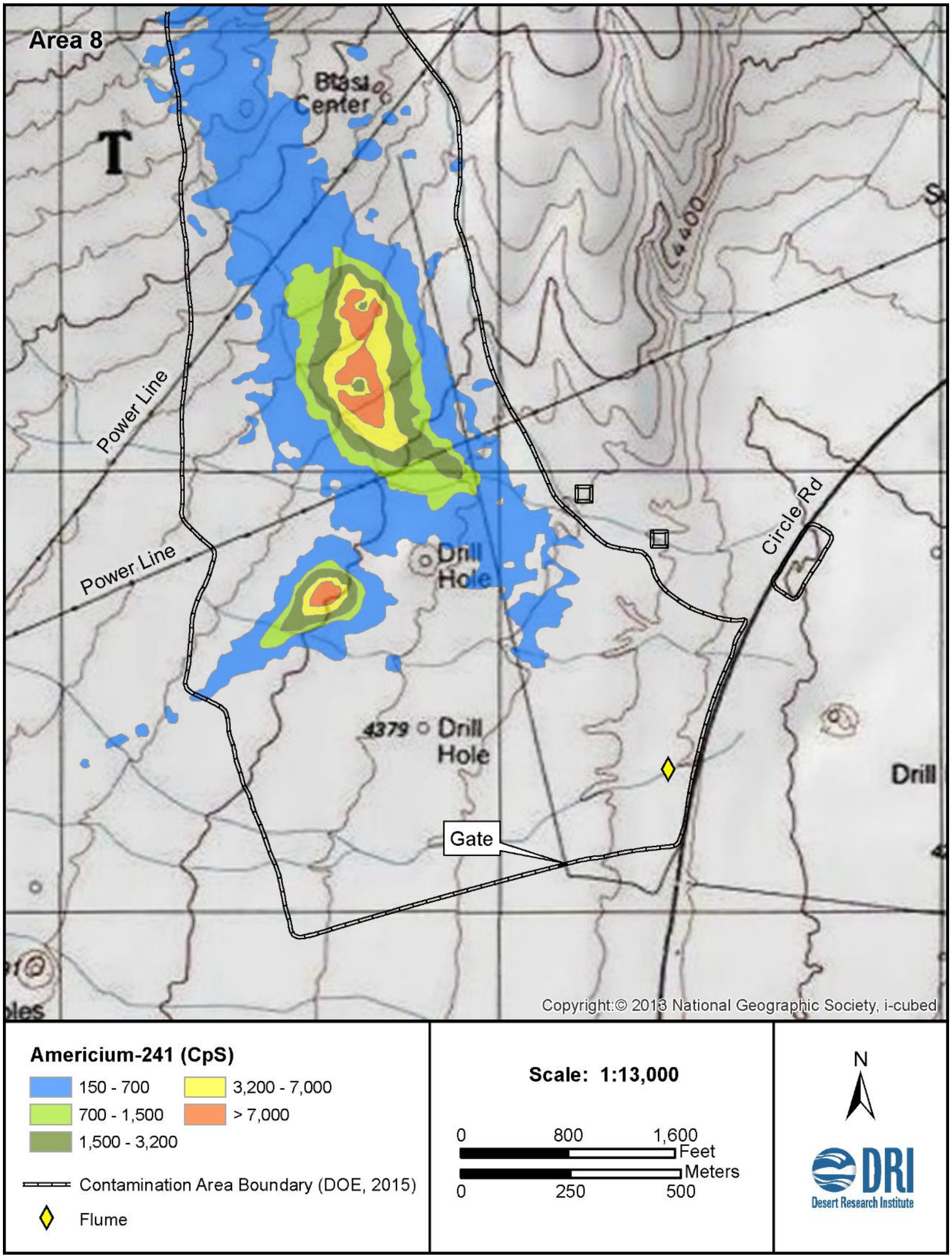

Figure 1. Americium-241 concentrations determined by aerial survey (Colton, 1999), CA boundary (DOE, 2015), and flume shown on a topographic map (USGS, 1986) of the Smoky Site area.

The Smoky Site CA is situated on a dissected alluvial fan approximately 0.6 mile (1,000 meters) south of the Smoky Hills. The mapped drainages shown on the topographic map of Oak Spring, Nevada (U.S. Geological Survey 1:24,000 scale), trend south-southeast from the Smoky Hills, and then easterly toward the center of Yucca Flat. The larger of the two areas of elevated americium in the Smoky Site CA is bounded on the east, west, and south by mapped channels. The western corner of the smaller contaminated area surrounding the Titania test site is drained by a mapped channel trending west to east. Elevation contours in the immediate vicinity of these contaminated areas suggest that unmapped channels may convey runoff from the areas of highest contamination into the mapped drainages.

RESEARCH APPROACH

The presence of Am-241 to the north (Figure 1) is believed to have resulted from the original event plumes in response to meteorological conditions at the time the experiments were executed and the presence of Am-241 to the south is believed to be the result of runoff erosion and migration down washes draining the area (Bechtel Nevada, 2000). The presence of radionuclide-contaminated soils in channels that traverse and convey runoff from the Smoky Site CA suggests that radionuclide-contaminated soil was transported by rainfall-generated runoff subsequent to the various experimental tests. However, there are insufficient data to determine if the observed contamination is the result of an ongoing process or if the transport was limited to a period of higher hydraulic energy resulting from the reduced ground cover that immediately followed the Smoky Site tests.

Desert Research Institute proposed performing a field-scale assessment of meteorological and hydrologic conditions that could potentially lead to the transport of radionuclide-contaminated soil from the Smoky Site CA. The research plan includes measuring local meteorological parameters, measuring the runoff resulting from local rainfall, and collecting bulk channel bed samples (i.e., bedload) for laboratory analysis after flow events. Meteorological observations are collected at a station established outside the western boundary of the Smoky Site CA (Figure 2). Storm runoff measurements are collected at a flume installed in the channel that exits the east side of the Smoky Site CA (Figure 2) and discharges across Circle Road. The precipitation and runoff data are used to establish threshold conditions that could lead to the transport of soil particles, including radionuclide-contaminated soils. These thresholds will help establish the conditions that would require monitoring drainage channel transport pathways under a post-closure monitoring strategy.

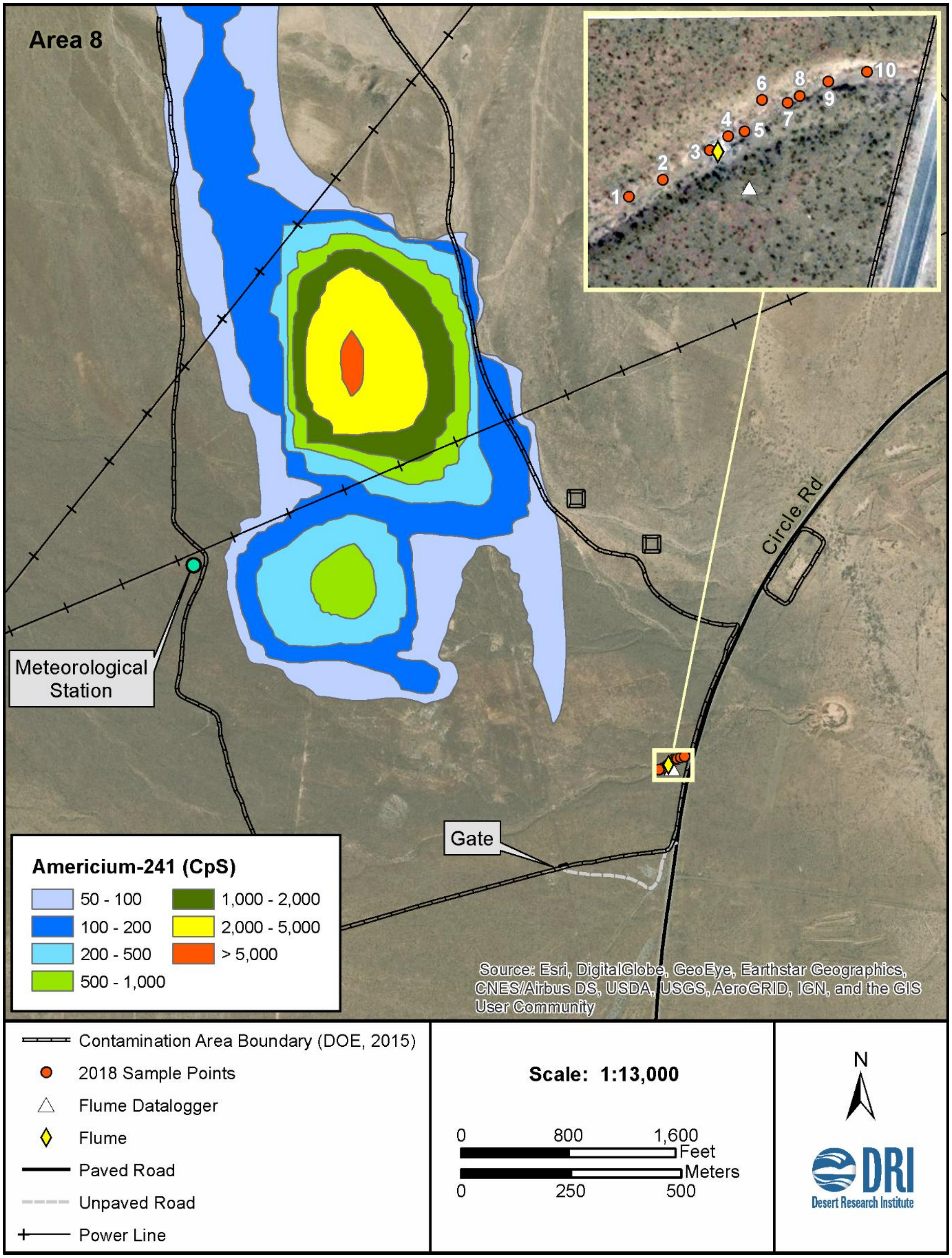

Figure 2. Americium-241 concentrations determined by a pedestrian survey (Bechtel Nevada, 2000), CA boundary (DOE, 2015), and flume and meteorological data collection sites, as well as August 7, 2018, channel bed sample collection sites.

The meteorological station (Figure 3)—which has instrumentation to measure temperature, relative humidity, wind speed, wind direction, soil volumetric water content, soil temperature, solar radiation, barometric pressure, and precipitation—was installed in an uncontaminated area adjacent to the Smoky Site CA on July 14 and 15, 2011. The meteorological station also includes Geostationary Operational Environmental Satellite (GOES) communication equipment. Table 1 lists the coordinates of the monitoring stations.

A Parshall flume with a 6-inch (in) (15.24-centimeter [cm]) throat was installed to measure channelized runoff. The channel near the south boundary of the Smoky CA was selected for the flume installation because flow through this channel was known to have deposited radionuclide-contaminated sediments outside of the CA on Circle Road on repeated occasions (Bechtel Nevada, 2000; J. Traynor, NSTec, personal communication, 2011). There is also an extensive headcut emanating from the subsidence crater on the south side of Circle Road, which is evidence of extensive erosional flow through this channel.

The original location of the flume was to be between the Smoky Site CA boundary and the adjacent road (Figure 2). However, because there was not sufficient space on the shoulder of Circle Road and an assessment by Radiological Control determined that it was not possible to downgrade contamination controls on the study channel, the flume (Figure 4) was placed inside the Smoky Site CA. Table 1 lists the flume coordinates. The flume installation includes a pressure transducer for measuring the depth of flow through the flume. The pressure transducer is installed in a stilling well connected to the flume. A radio frequency transmitter/receiver (Figure 5) allows pressure data to be sent to and recorded on the datalogger at the meteorological station.

Meteorological observations are collected every three seconds and water depth in the flume is collected every five seconds. Maximum, minimum, and average or total observations are evaluated for every 10-minute time interval and stored on the meteorological station datalogger. The 10-minute data are retrieved manually each quarter, unless the data download is coordinated with a non-routine maintenance visit. The 10-minute summary data are further reduced to an hourly summary for transmission to the Western Regional Climate Center (WRCC) at DRI in Reno, Nevada. These transmissions are made each hour via the GOES communication system and are uploaded to a restricted-access internet webpage that is available to project personnel. The hourly data are replaced by the 10-minute data when the data become available. Meteorological and flume data collection at the Smoky Site CA began in July 2011. Output from the monitoring equipment has been reported approximately annually since the equipment was installed (Miller *et al.*, 2012a,b; Mizell *et al.*, 2017a,b).

Table 1. Coordinates* of monitoring equipment installed at the Smoky Site.

Equipment	Latitude	Longitude
Meteorological Station	37.177584	-116.073694
Flume	37.173446	-116.061581
Flume datalogger	37.173366	-116.061496

* Coordinates are updated based on GPS survey performed on August 7, 2018.

Figure 3. The Smoky Site CA meteorological station was installed to measure precipitation, wind, and other climate parameters. A radio communication system is used to exchange information with the flume datalogger and the Geostationary Operational Environmental Satellite (GOES) communication system allows regular data transmission to the Western Regional Climate Center (WRCC) in Reno.

Figure 4. A Parshall flume was installed to measure runoff from the southern portion of the Smoky Site CA. The initial installation (top) was reinstalled and reinforced (bottom) after the flume was washed out in July 2013. The conduit laying on the hillside connects the water presure sensor to the datalogger.

Figure 5. Runoff conditions in the flume are detected by the pressure transducer and transmitted to the datalogger (inside the white enclosure) via the yellow cable, recorded in the datalogger, and relayed by radio (black antenna) to the meteorological station. (Since this photo was taken, the pressure transducer cable was placed in a conduit to protect it from damage by animals.)

FISCAL YEAR 2018 OBSERVATIONS

Data collection at the Smoky Site meteorological station began on July 14, 2011, and at the flume on July 20, 2011 (Miller *et al.*, 2012a). Measurements of air temperature, relative humidity, wind speed and direction, soil volumetric water content, soil temperature, solar radiation, barometric pressure, and precipitation are collected every three seconds. Water depth in the flume is collected every five seconds. Maximum, minimum, and average or total values are recorded on the datalogger for every 10-minute interval and every hour. The hourly values are transmitted via GOES to the WRCC, where the data are reviewed to confirm collection and identify irregularities. After review, the hourly values are uploaded to the restricted-access project website. The 10-minute data are retained on the datalogger and downloaded during quarterly site visits. When data quality is confirmed, the 10-minute data are uploaded to the website and hourly data for the same time period are deleted. Table 2 lists the significant events associated with data collection at the Smoky Site and the datalogger download exercises accomplished during fiscal year (FY) 2018. No instrumentation or connection cables were damaged by animals during FY2018. Placing the pressure transducer cable in the conduit between the flume stilling well and the flume datalogger last fiscal year (January 2017) appears to have been a successful tactic for preventing animal damage.

Table 2. Significant events associated with meteorological and hydrologic observations at the Smoky Site for shallow ephemeral channel transport monitoring.

FY2018	
Date	**Description**
October 6, 2017	Quarterly datalogger download and routine maintenance at meteorological station.
January 5, 2018	Quarterly datalogger download and routine maintenance at meteorological station.
March 20, 2018	Quarterly datalogger download and routine maintenance at meteorological station.
May 1, 2018	Datalogger download and routine maintenance at meteorological station. (Work performed early to coordinate with other activities.)
July 6, 2018	Quarterly datalogger download and routine maintenance at meteorological station.
August 7, 2018	Sample collection, datalogger download, equipment service, equipment location confirmation survey, and routine maintenance in the CA and at the meteorological station following the July flow event.
October 5, 2018	Quarterly datalogger download and routine maintenance at meteorological station.

Meteorological Observations

Appendix A summarizes the daily average values of the meteorological parameters for October 1, 2017, through September 30, 2018. Appendix B contains plots of daily meteorological and other environmental observations. The monthly summary data indicate that:

1) Average daily maximum temperatures were highest in June, July, and August. The coldest months were December through March.
2) June, July, and August recorded the highest monthly solar radiation (sunshine). November through January had the lowest solar radiation.
3) Monthly mean wind speeds were highest in March, April, and June. Winds were predominantly from the west in March and May through September and from the north in October through February and April.
4) Monthly average relative humidity ranged from the mid-teens to approximately 50 percent.
5) Monthly precipitation ranged from 0.00 in (0.00 mm) to approximately 1.38 in (35.05 mm). The highest monthly rainfall occurred in July, followed by January. Total rainfall in FY2018 was 3.86 in (98.04 mm).

Precipitation Observations

Precipitation was recorded at the Smoky Site rain gage during each of nine months in FY2018. No precipitation was recorded in October 2017, December 2017, or June 2018 (Appendix A and Figure B-2). Less than approximately 0.40 percent of the 10-minute observation periods (199 of 52,560) reported precipitation of any amount. Fifty-two 10-minute observations periods reported more than 0.01 in (0.25 mm), but only seven reported more than 0.10 in (2.54 mm). Most precipitation events were short duration and low intensity.

Soil Moisture Observations

Soil moisture is measured over approximately the top 4 in (10.16 cm) of the soil column using factory-calibrated time-domain reflectometry (TDR) sensors installed adjacent to the meteorological station. The TDR sensor readings have not been compared with laboratory-determined soil moisture content, and therefore may not reflect actual moisture content. However, the TDRs are expected to give accurate indications of changes in soil moisture content that result from meteorological conditions.

The observed volumetric water content (VWC) of the soil ranged between 0.07 (6.9 percent) and 0.28 (27.8 percent) during FY2018 (Figure 6). The minimum soil water content values occurred in late September 2018. Other periods of low soil moisture content occurred in early January 2018 and early July 2018. The fall/winter low soil moisture conditions occurred after the summer thunderstorm season and prior to the winter frontal storm season. The highest reported water content in FY2018 was recorded on January 9, 2018, in association with an eight-hour precipitation event that produced 10-minute intensities of up to 0.04 in (1.02 mm). The January 9th precipitation event was preceded by approximately 24 hours of intermittent light precipitation with 10-minute intensities of 0.02 in (0.51 mm) or less. The magnitude of the soil water content response to individual precipitation events appeared to depend on the intensity and duration of the precipitation and the antecedent soil water conditions.

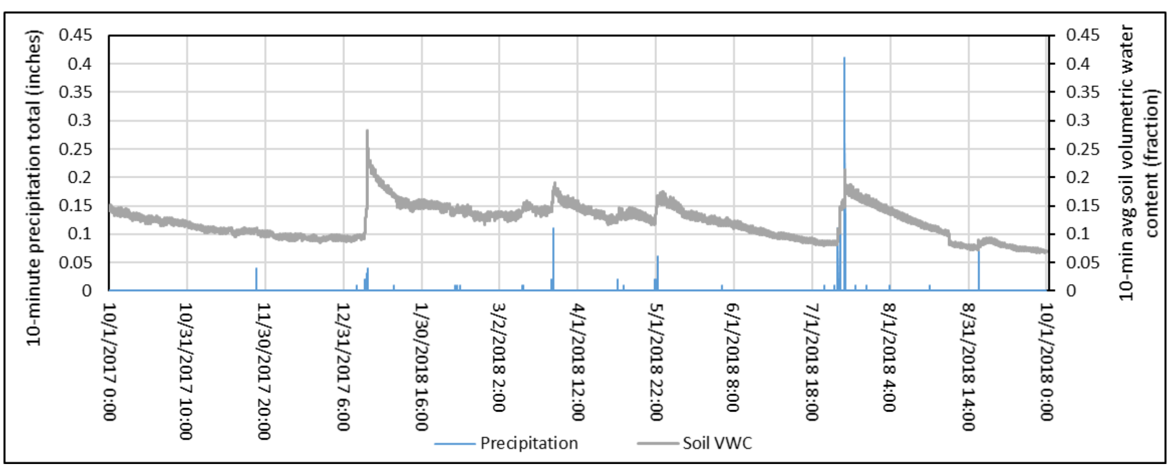

Figure 6. FY2018 precipitation and soil water content observed at the Smoky Site meteorological station.

Channel Runoff Observations

The water depth hydrograph recorded by the pressure transducer at the flume indicated two flow events during FY2018 (Figure 7). Table 3 provides details of the flow and associated precipitation events recorded on July 14, 2018, and September 4, 2018. Appendix C presents hydrographs of the individual flow events in greater detail.

The precipitation event that resulted in the July 14, 2018, flow was preceded by precipitation on July 11th and 12th; 0.17 in (4.32 mm) fell on the 11th and 0.31 in (7.87 mm) fell on the 12th (Figure 7). Precipitation on July 14th began at 11:00 and lasted approximately one hour (Figure C-1). (All times are Pacific Standard Time [PST] and are based on a 24-hour clock.) A total of 0.82 in (20.83 mm) of precipitation fell during that hour. The peak 10-minute intensity, 0.41 in (10.41 mm), occurred at 11:20 and was the highest intensity observed during the year.

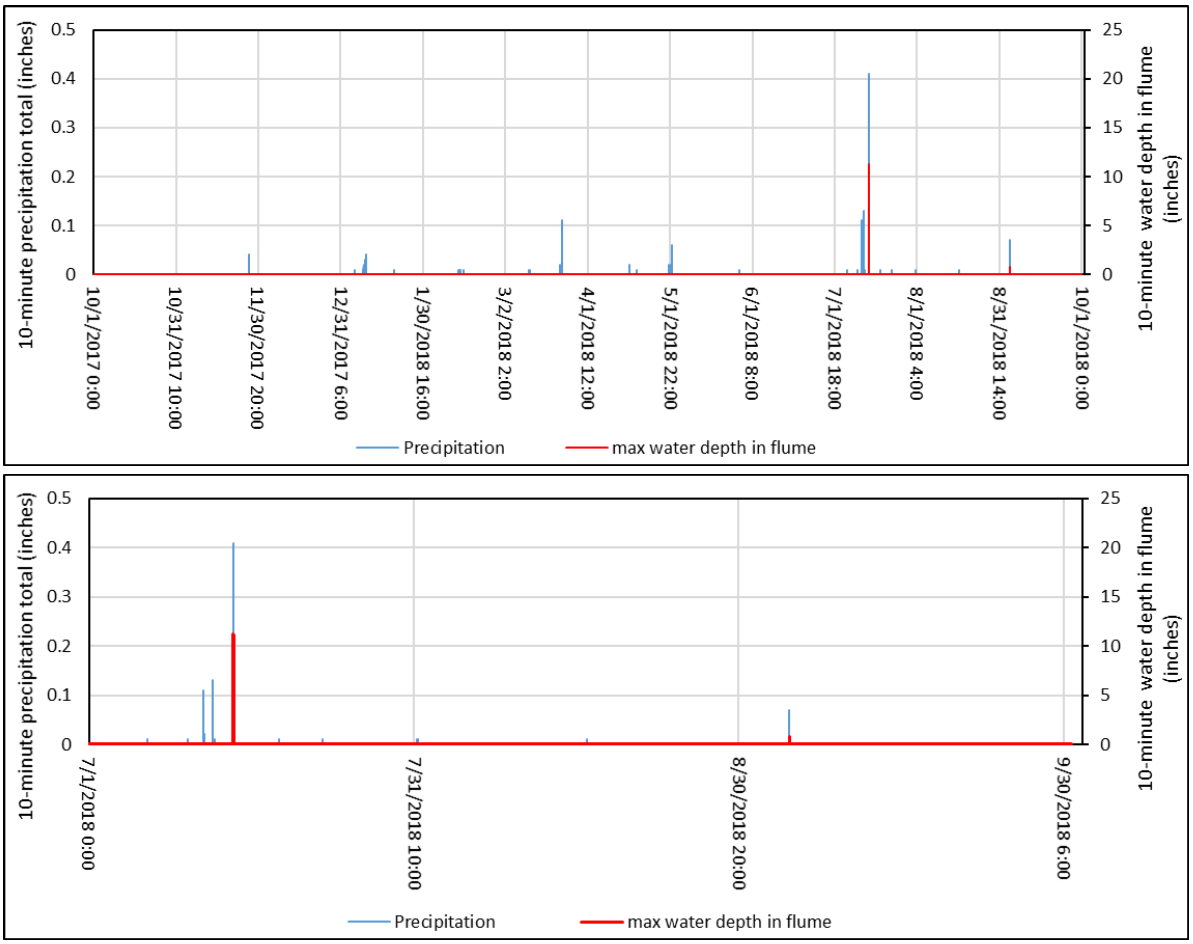

Figure 7. Depth of water in the flume and precipitation events recorded during FY2018. The top graph is for the entire year. The bottom graph focuses on July through September, when two separate flow events were recorded.

Table 3. Precipitation, soil moisture, and flow characteristics associated with runoff events recorded in the Smoky Site flume during FY2018. Times shown are based on the 24-hour clock and are shown in hh:mm format.

Runoff Event	**July 14, 2018**	**September 4, 2018**
Precipitation		
Total antecedent (48-hour) precipitation (in)	0.31	0.00
Storm duration (min)	60 (11:00 to 12:00)	50 (13:30 to 14:20)
Total precipitation (in)	0.82	0.12
Time of peak 10-minute intensity	11:20	13:50
Peak 10-minunte intensity (in)	0.41	0.07
Soil moisture content		
Average soil VWC during 48 hours prior to precipitation (fraction)	0.15	0.07
Time of peak 10-minute soil VWC	11:50	14:00
Peak 10-minute soil VWC (fraction)	0.21	0.09
Average soil VWC during 48 hours following precipitation (fraction)	0.17	0.09
Recorded runoff event		
Duration (min)	70 (11:40 to 12:50)	100 (14:00 to 15:40)
Time of peak 10-minute runoff depth	12:10	14:30
Peak 10-minute runoff depth (in)	11.26	0.78
Peak 10-minute discharge (cfs)	1.86	0.03
Peak 10-minute flow velocity (fps) in the flume	3.97	1.17
Peak 10-minute flow velocity (fps) in the channel	1.29	0.03
Time between peak precipitation and peak runoff depth (min)	50	40

VWC = volumetric water content; cfs = cubic feet per second; fps = feet per second; min = minute.

The July 14, 2018, precipitation event produced flow through the flume beginning between 11:40 and 11:50, which was 20 minutes to 30 minutes after the peak precipitation intensity. The flow lasted a little more than one hour (11:40 to 12:50; Figure C-1). The maximum 10-minute flow depth of 11.26 in (28.60 cm) occurred between 12:00 and 12:10, approximately 20 minutes to 30 minutes after flow began. The maximum flow depth is equivalent to a discharge of 1.86 cubic feet per second (cfs) (0.05 cubic meters per second [cm/s]) (Appendix D). It is likely that the high antecedent soil moisture resulting from precipitation on July 11th and 12th, and the high-intensity precipitation on July 14th, were contributing factors in the runoff event.

The precipitation event that resulted in the September 4, 2018, flow lasted approximately 50 minutes (13:30 to 14:20) and produced a total of 0.12 in (3.05 mm) (Figure C-2). The peak 10-minute intensity, 0.07 in (1.78 mm), occurred between 13:40 and 13:50. Flow in the flume began between 14:00 and 14:10, which was 10 minutes to 20 minutes after the peak precipitation intensity. Peak flow depth through the flume, 0.78 in (1.98 cm), occurred between 14:20 and 14:30. The peak flow depth was estimated to be equivalent to a discharge of approximately 0.03 cfs (0.0008 cm/s) (Appendix D).

Flow velocities are reported in Table 3 as peak 10-minute flow velocities (fps) in both the flume and within the channel. The channel velocity was calculated by applying the flume hydraulic measurements to the channel geometry at the nearest surveyed cross-section. Although neither runoff event produced sufficient flow velocities through the natural channel to cause local erosion and transport of coarser (coarse sand and gravel) bedload materials, the velocity of the July 2018 runoff event was sufficient to transport silts and fine sands (Garcia [Ed.], 2008), which have been shown to be preferentially associated with radionuclide contaminants (Mizell *et al.*, 2017a). Therefore, a sampling event was planned in conjunction with a periodic maintenance inspection visit after the July 14, 2018, flow event.

Channel Bed Samples

Because no suspended load sampling was available to collect fine-grained materials within the flow itself, 10 channel bed samples were collected from the Smoky Site on August 7, 2018, to evaluate the radiological characteristics of sediments in the vicinity of the flume. Sample locations were selected to represent sites likely to experience deposition of finer grained materials as a result of recent flow in the channel. Figure 2 shows the location of the sample sites relative to the flume. Table E-1 lists the coordinates of the sample sites. Samples were collected using a handheld plastic scoop and were placed in a one-liter plastic bottle.

Navarro managed the sample analysis through an existing contract with Southwest Research Institute (SwRI) in San Antonio, Texas. As in previous years, the collected materials were separated into two particle size fractions: less than 63 micrometers (µm) and greater than 63 µm but less than 250 µm. For the FY2018 samples, the greater than 250 µm size fraction was also analyzed. Each particle size fraction for each sample was analyzed for Am-241, plutonium-238 (Pu-238), and plutonium-239/240 (Pu-239/240) using alpha spectrometry.

Between 1,310 grams (g) and 1,480 g of sediment were collected in each sample (Table E-2). The size fraction greater than 250 µm accounted for more than 80 percent of the mass of each sample. The size fraction greater than 63 µm but less than 250 µm accounted for between 3 percent and 15 percent of the mass of each sample, and the size fraction less than 63 µm accounted for 0.20 percent to 3 percent of the mass of each sample.

The highest reported concentrations for Am-241, Pu-238, and Pu-239/240 of 57.5 picocuries per gram (pCi/g), 5.98 pCi/g, and 351 pCi/g, respectively, were associated with Sample 4. Sample 4 was collected from a shallow terrace near the flume on the north side of the main channel.

Generally, the size fraction greater than 250 µm returned the lowest concentrations for all three radionuclides (Table 4, Figure 8, Table E-2). The size fraction less than 63 µm produced the highest concentrations of Am-241 for six of the samples and the highest concentration of Pu-239/240 for seven of the samples (Figure 8, Table E-2). The size fraction greater than 63 µm but less than 250 µm produced the highest concentrations of Am-241 and Pu-239/240 in the remaining samples (Figure 8, Table E-2). The highest concentrations of Pu-238 in the samples were produced by the size fraction greater than 63 µm but less than 250 µm, except for Sample 4 for which the size fraction less than 63 µm produced the highest concentration. Statistical analysis determined that both the less than 63 µm and the greater than 63 µm but less than 250 µm size fractions had concentrations that were statistically different from the greater than 250 µm size fraction. However, analysis indicated no statistical difference between the less than 63 µm and greater than 63 µm but less than 250 µm size fractions.

The FY2013 and FY2014 Smoky monitoring report (Mizell *et al.*, 2017a) presents alpha spectrometry results for two size fractions: less than 63 µm and greater than 63 µm but less than 250 µm. The size fraction greater than 250 µm was not analyzed for the samples reported in the FY2013 and FY2014 report. No flow events sufficient to transport sediment occurred during FY2015, FY2016, or FY2017 and no samples were collected during those years.

The FY2018 sample analysis results were compared with analysis results for the FY2013 and FY2014 samples. All three sample sets exhibited similar patterns for Am-241 and Pu-239/240, with the highest concentrations occurring in the less than 63 µm size fraction for most samples. The Pu-238 concentrations were highest in the less than 63 µm size fraction for the FY2013 samples and in the greater than 63 µm but less than 250 µm size fractions for the FY2014 and FY2018 samples.

Table 4. Summary of alpha spectrometry results (pCi/g) for the ten FY2018 Smoky Site channel bed samples.

	Am-241			**Pu-238**			**Pu-239/240**		
Particle size fraction	**<63**	**>63 <250**	**>250**	**<63**	**>63 <250**	**>250**	**<63**	**>63 <250**	**>250**
Count[1]	10	10	8	10	10	4	10	10	10
Average (pCi/g)	11.46	5.92	1.80	2.33	2.79	1.08	60.76	22.02	5.37
Maximum (pCi/g)	57.5	8.73	5.57	5.98	4.48	2.46	351	31.4	20.3
Minimum (pCi/g)	4.33	3.77	0.46	1.39	1.77	0.39	14.8	14	0.48
Standard deviation (pCi/g)	16.48	1.91	1.71	1.32	0.78	0.93	103.74	6.82	5.95

[1] The number of results greater than the method detection limit (MDL).

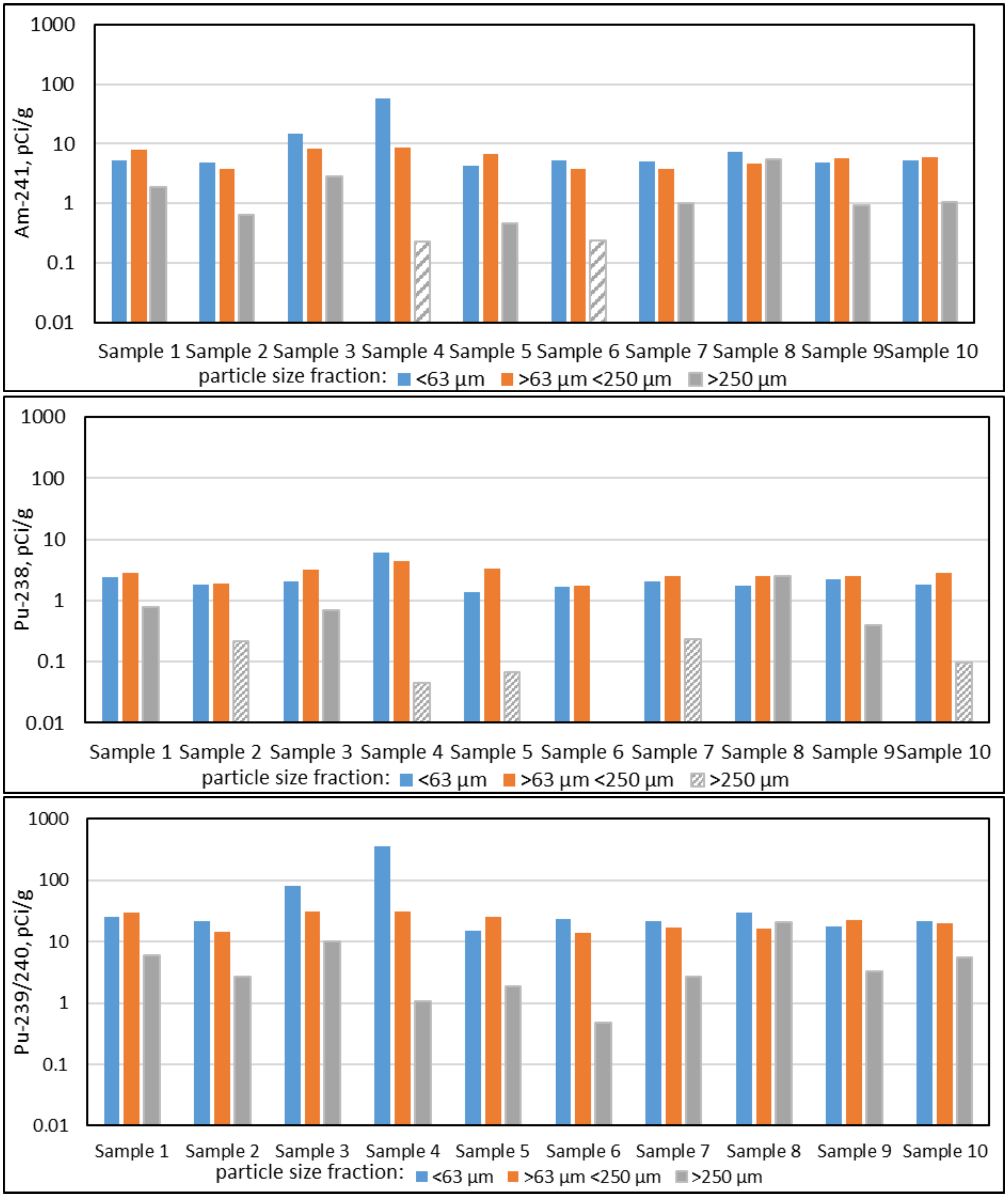

Figure 8. Americium-241 (top), plutonium-238 (middle), and plutonium-239/240 (bottom) concentrations (picocuries per gram [pCi/g]) in channel bed sediment samples collected from the Smoky channel monitoring site in FY2018. The hachured pattern indicates reported concentrations below the method detection limit (MDL). The Pu-238 result for Sample 6 was reported as a negative value and is plotted above as zero.

CONCLUSIONS

1) Numerous low-intensity precipitation events occurred during the reporting period. These had little impact on the soil moisture content and did not generate flow through the flume. Long-duration, low-intensity precipitation events and short-duration, high-intensity precipitation events produced noticeable increases in soil moisture.

2) Two flow events were recorded at the Smoky Site flume. These resulted from high-intensity precipitation events associated with relatively high soil moisture content conditions. Only the channel flow velocity of the July 14, 2018, storm was sufficient to transport silts and fine sands, which have been shown to be preferentially associated with radionuclide contaminants.

3) Bedload samples exhibited higher concentrations of Pu-239/240 than Pu-238 or Am-241. Additionally, radionuclide concentrations in the smallest and intermediate particle size fractions were not statistically different. However, both the smallest and intermediate size fractions had higher radionuclide concentrations than the largest size fraction.

RECOMMENDATIONS

Storm runoff through the flume has overtopped the flume on several occasions in the past (Mizell *et al.*, 2017a,b), although not during FY2018. These previous events indicate that the 6 in (15.24 cm) Parshall flume is not large enough to accommodate the amount of runoff that may be conveyed through the instrumented watershed. Replacing the 6 in (15.24 cm) flume with a larger flume or a weir is recommended.

Installing sediment traps to facilitate the collection of bedload samples following runoff events and to ensure that samples are collected from consistent locations in the channel is recommended. Installation of an ISCO sampler to collect suspended sediment during flow events, similar to the installation in Plutonium Valley (Nikolich *et al*., 2018), is also recommended.

Airborne or terrestrial light detection and ranging (LIDAR) or ground surveys, along with photography at established channel cross-sections should be considered as a technique for assessment of changes in channel geometry and sediment erosion/deposition following runoff events.

FUTURE WORK

Data transmitted from the Smoky Site CA instrumentation will be reviewed monthly by project personnel to identify precipitation events that exceed the specified rainfall threshold (~0.2 in [0.5 cm]) and to assess proper operation of the instrumentation and remote communication equipment. Field inspections will be scheduled to service instrumentation if necessary.

Meteorological data collected leading up to and during a detected runoff event will be analyzed to identify precipitation amounts and intensities, antecedent soil water conditions, and other factors that contributed to the observed runoff. This analysis will help delineate threshold conditions that are likely to result in sediment transport and possible radionuclide migration in conjunction with the sediment. Establishing these thresholds will help identify meteorological conditions that may require monitoring and sampling of channel runoff migration pathways under a post-closure monitoring plan. The requirements for monitoring meteorological conditions and sampling runoff pathways can then be appropriately incorporated into the post-closure monitoring plan for this and similar sites, as well as aid in determining appropriate closure strategies for other Soils CAUs.

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APPENDIX A. FY2018 METEOROLOGICAL OBSERVATIONS FOR THE SMOKY SITE SUMMARIZED BY MONTH

Table A-1. Summary of FY2018 monthly meteorological observations for the Smoky Site.

Date	Total Solar Radiation	Mean Wind Speed	Mean Wind Direction (vector avg)	Max. Wind Gust	Avg. Air Temp	Avg. Daily Max. Temp	Max. Temp	Avg. Daily Min. Temp	Min. Temp	Ave. Soil Temp. @ 4 inches	Max. Soil Temp. @ 4 inches	Min. Soil Temp. @ 4 inches	Ave. Relative Humidity	Max. Relative Humidity	Min. Relative Humidity	Ave. Barometric Pressure	Total Precip.
(mm-yy)	**(ly.)**	**(mph)**	**(Deg)**	**(mph)**	**(Deg F)**	**(Deg F)**	**(Deg F)**	**(Deg F)**	**(Deg F)**	**(Deg F)**	**(Deg F)**	**(Deg F)**	**(%)**	**(%)**	**(%)**	**(in Hg)**	**(in)**
Oct-17	14055	6.0	025	40.0	60.1	75.8	84.7	43.7	32.2	65.8	87.4	47.3	20.1	58.6	1.7	25.60	0.00
Nov-17	9256	4.8	324	40.2	50.7	65.7	76.6	37.2	24.0	54.5	75.8	34.4	38.5	83.7	6.5	25.60	0.06
Dec-17	8372	5.4	004	56.8	42.7	58.8	70.3	28.3	15.7	44.0	63.7	25.8	24.5	69.3	2.5	25.71	0.00
Jan-18	8284	4.3	009	42.5	44.4	57.8	71.5	31.9	22.6	45.0	65.6	30.6	48.0	99.8	6.8	25.68	1.07
Feb-18	10793	6.2	349	42.5	42.2	56	72.4	27.9	12.3	47.2	70.0	26.7	34.7	96.3	8.5	25.57	0.07
Mar-18	13907	7.3	290	44.4	47.0	58.8	74.8	34.7	19.4	52.2	79.5	30.7	42.1	95.3	4.3	25.53	0.56
Apr-18	18092	7.9	314	47.4	59.9	73.4	86.9	44.1	31.4	67.3	95.4	41.5	22.6	98.0	2.6	25.51	0.15
May-18	12731	6.5	284	38.8	66.2	79	92.5	51.4	40.9	75.8	104.5	47.6	30.4	94.1	3.7	25.47	0.44
Jun-18	23339	7.5	271	38.7	79.3	93.4	101.8	61.4	51.1	89.3	115.3	61.8	13.0	42.2	1.7	25.47	0.00
Jul-18	19188	5.9	259	34.3	84.6	98.4	104.7	69.6	62.7	93.0	113.8	69.6	29.4	93.6	2.7	25.61	1.38
Aug-18	19404	6.4	267	36.7	82.0	96.3	101.9	66.2	56.6	83.2	149.4	32.0	21.5	72.6	4.2	25.56	0.01
Sep-18	17149	6.1	279	37.3	74.1	89.2	96.9	57.2	48.9	32.0	32.0	32.0	17.8	64.4	2.7	25.53	0.12
FY2018	***174570***	***6.2***	***222.9***	***56.8***	***61.1***	***75.2***	***104.7***	***46.1***	***12.3***	***62.4***	***149.4***	***25.8***	***28.5***	***99.8***	***1.7***	***25.57***	***3.86***

APPENDIX B. PLOTS OF FY2018 DAILY METEOROLOGICAL OBSERVATIONS FOR THE SMOKY SITE

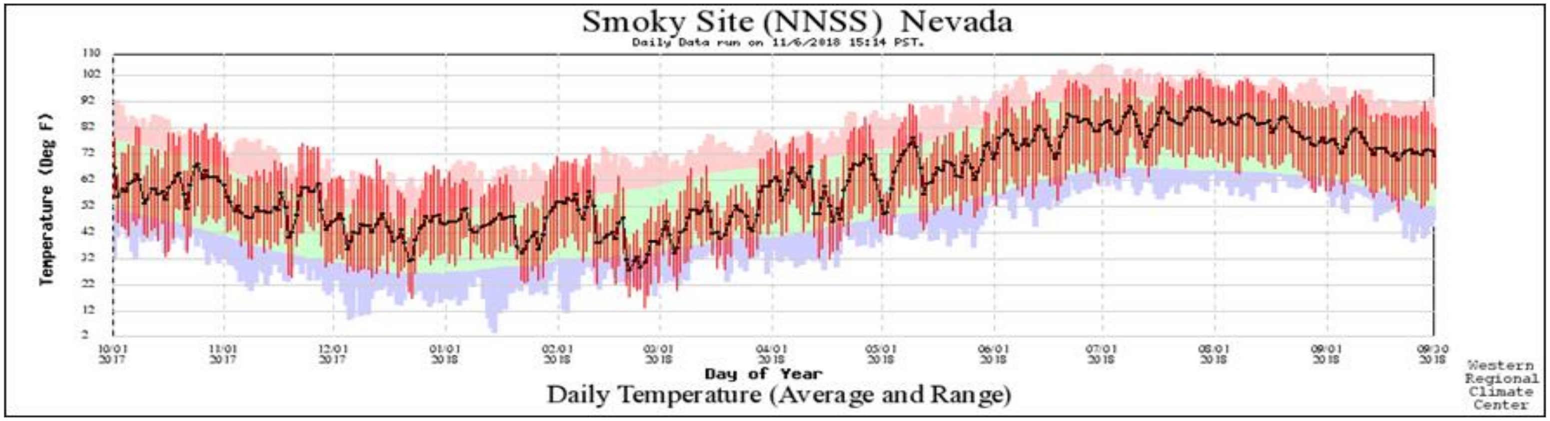

Figure B-1. Daily average (black ticks), maximum, and minimum (end points of vertical red bars) air temperature observed at the Smoky Site meteorological station during FY2018. Daily values are superimposed on long-term average (indicated by pastel green band) and extreme high-temperature (pastel red) and low-temperature (pastel blue) observations.

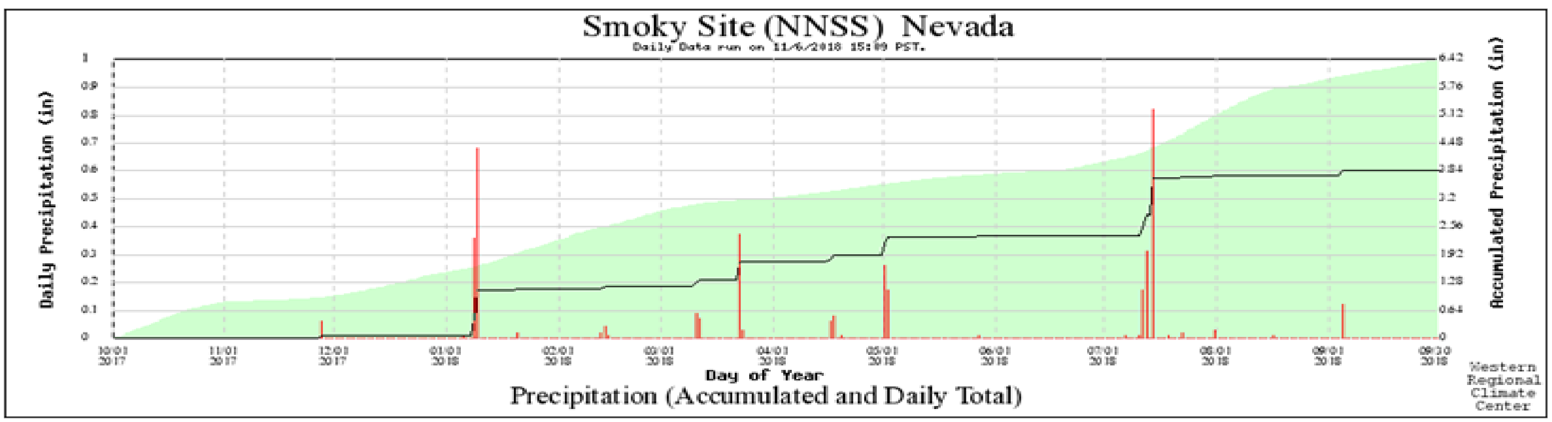

Figure B-2. Daily (red bars) and cumulative (black line) precipitation at the Smoky Site meteorological station during FY2018. FY2018 values are superimposed on the long-term (2011 to present) average daily cumulative precipitation (pale green background shading) for the Smoky Site.

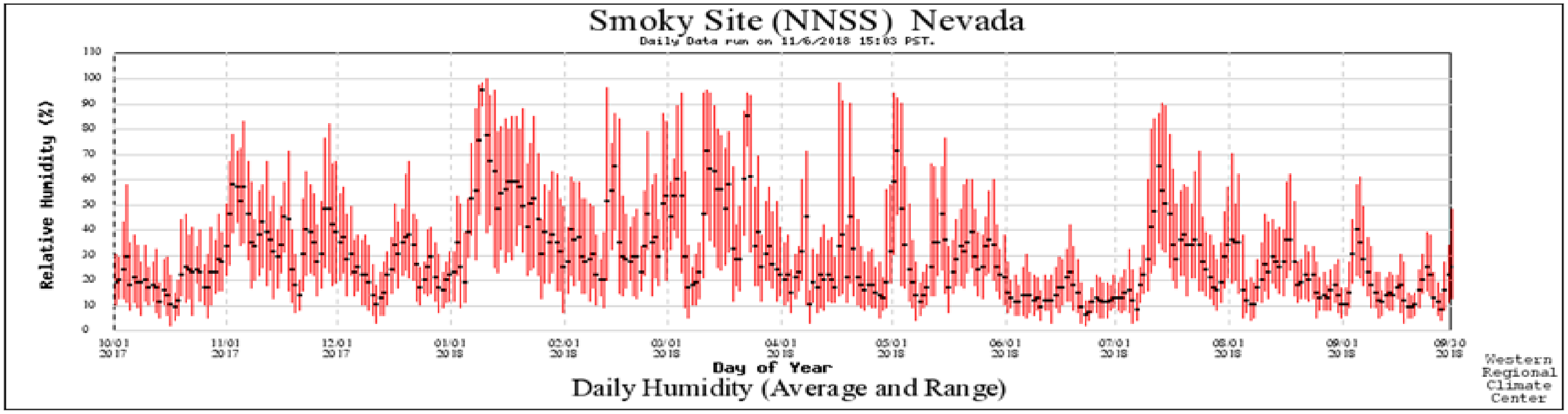

Figure B-3. Daily average (black ticks) and maximum and minimum (ends of vertical red bars) relative humidity at the Smoky Site during FY2018.

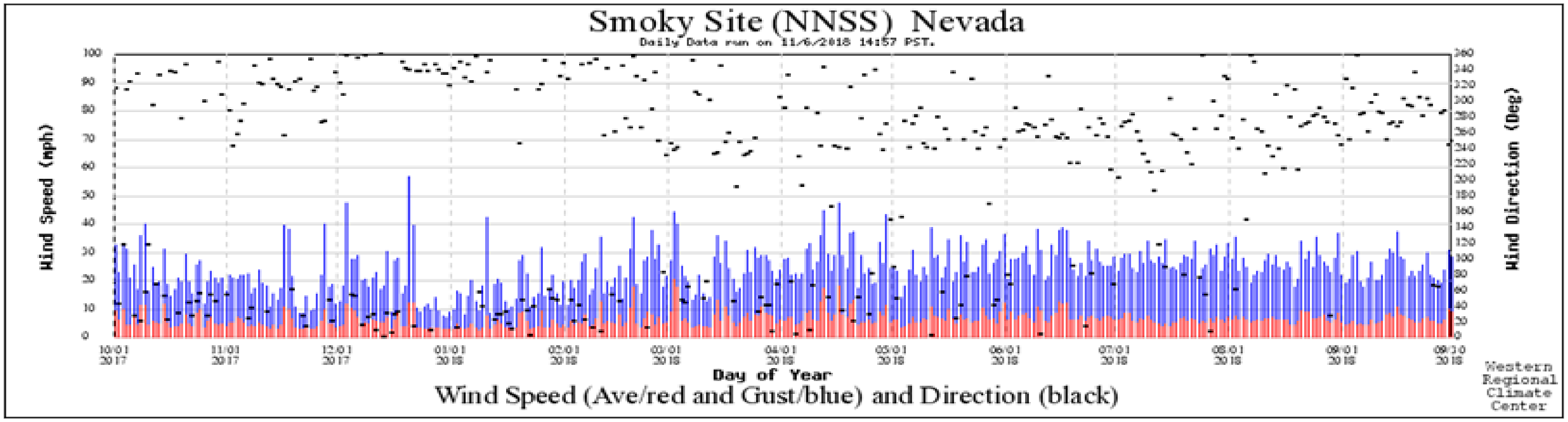

Figure B-4. Daily average (red bars) and peak (blue bars) wind speeds, and daily average (black ticks) wind direction at the Smoky Site during FY2018. Peak wind speed exceeded 54 mph (86.90 km/hr) on December 20, 2017. Generally, the wind direction tends to be from the north to northwest from October to February and from the west from March to September.

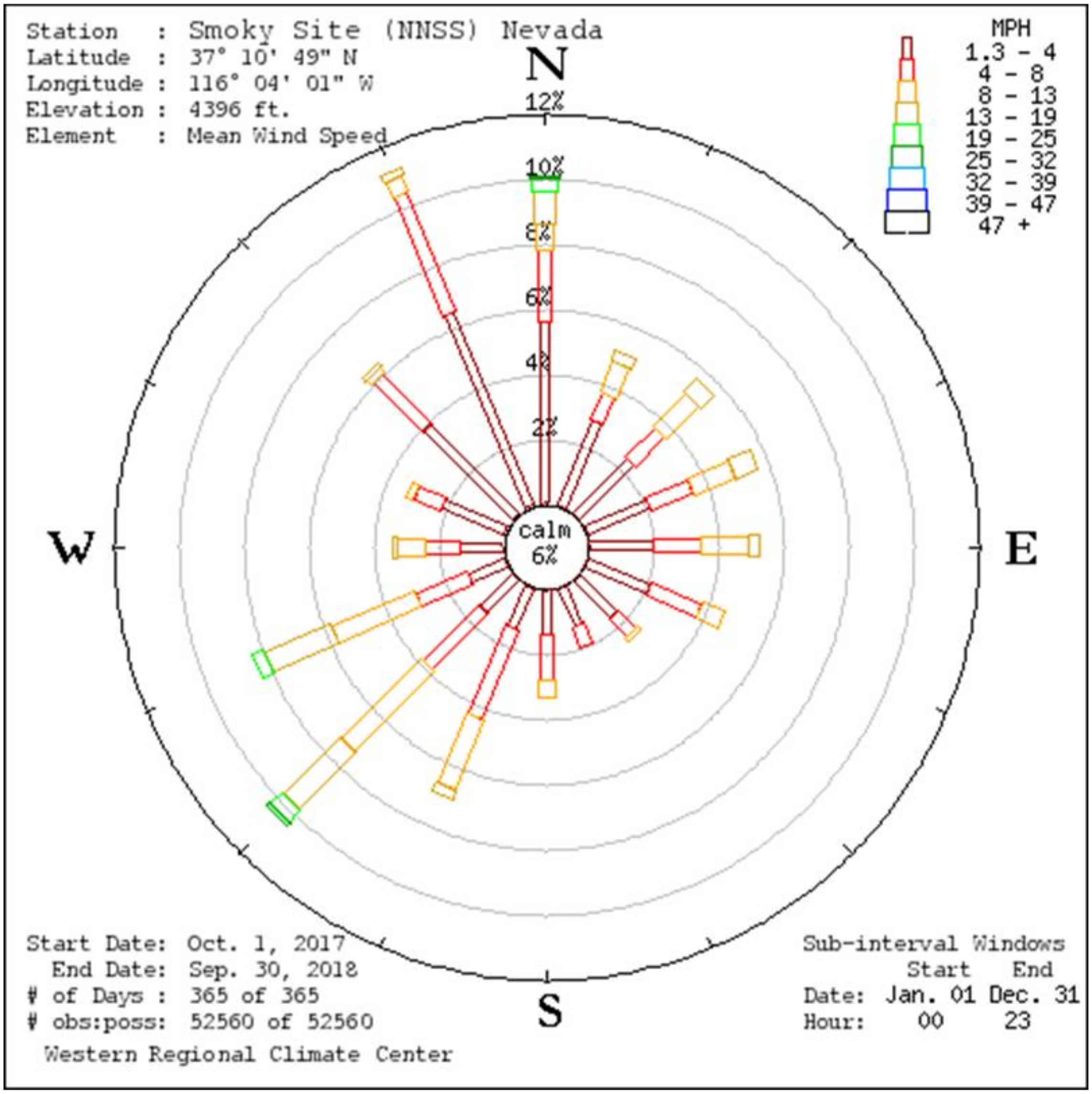

Figure B-5. The FY2018 wind rose for the Smoky Site meteorological station shows that stronger winds tend to come from the north and from the southwest quadrant. Winds from these directions are also among the most frequent.

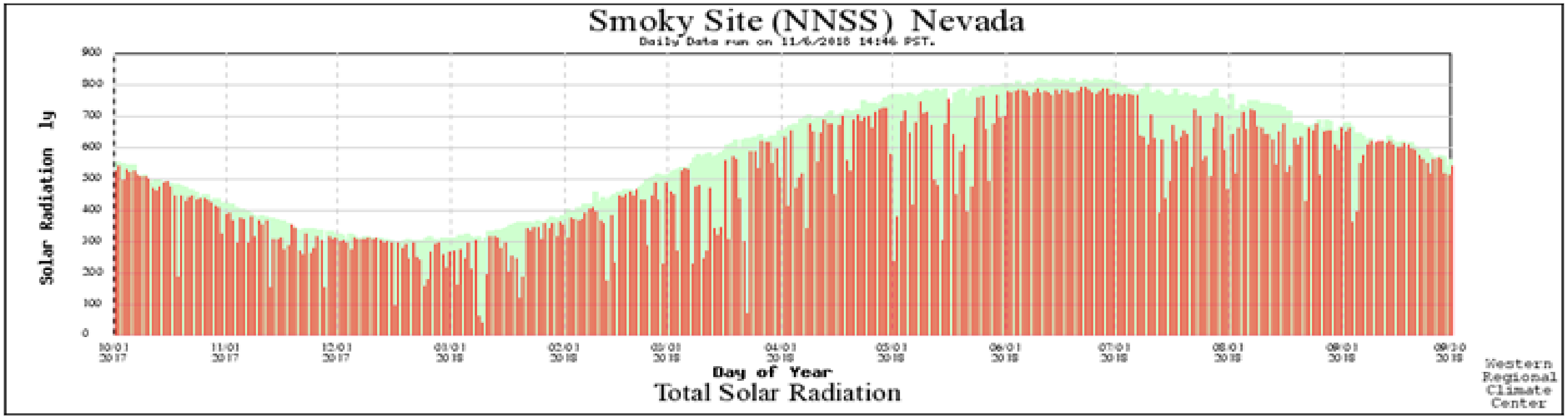

Figure B-6. Total daily solar radiation at the Smoky Site during FY2018 exhibits the expected annual trend with the greatest radiation occurring in the late spring and summer, and the lowest radiation occurring in the late fall and winter. The FY2018 solar radiation is superimposed on the long-term daily average solar radiation (pale green background shading). Occasions of unseasonably low solar radiation suggest cloud cover, which may be indicative of storm conditions and may occur at any time throughout the year.

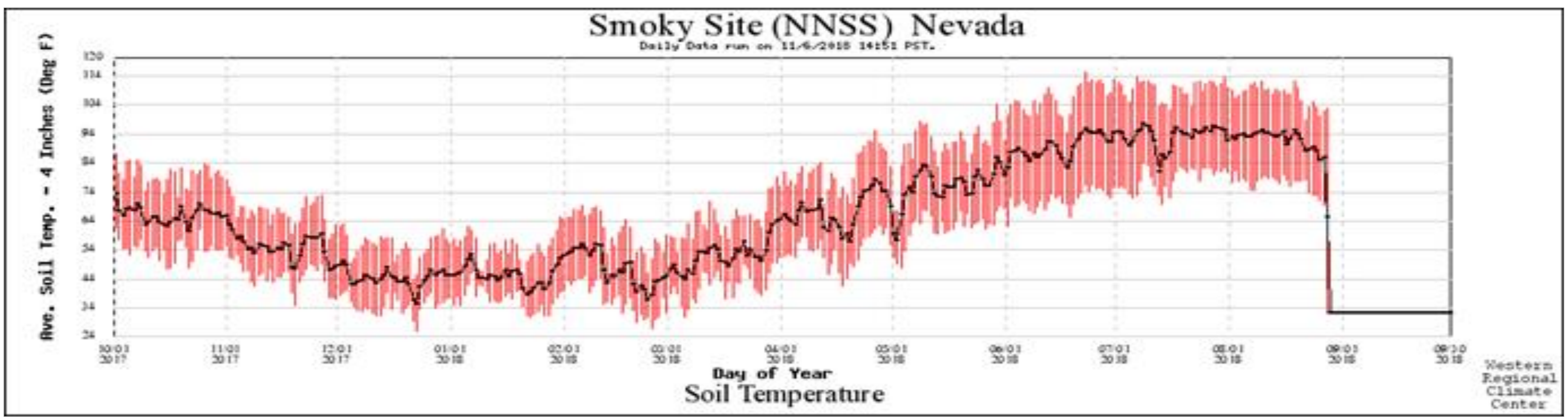

Figure B-7. Daily average (black ticks) and maximum and minimum (ends of vertical red bars) soil temperature measured at a depth of 4 in (10.16 cm) at the Smoky Site meteorological station reflect a similar seasonal pattern to the air temperature. The soil temperature sensor failed at approximately 15:50 on August 27, 2018; it was restored to service on October 5, 2018.

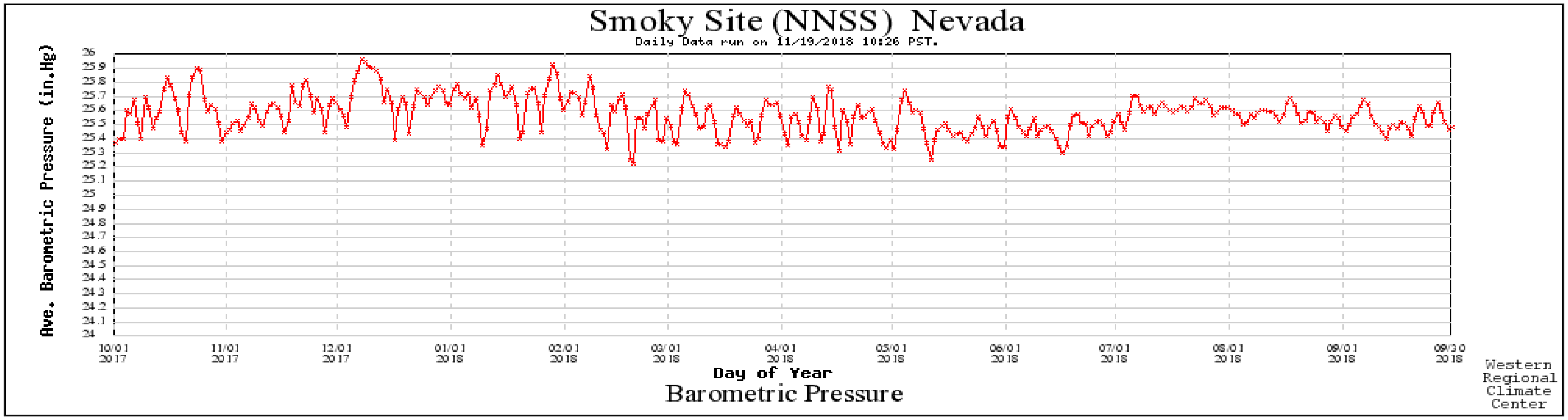

Figure B-8. Barometric pressure recorded at the Smoky Site meteorological station during FY2018 fluctuated between 25 and 26 in (63.5 and 66.04 cm) of mercury.

APPENDIX C. PLOTS OF FLOW EVENTS RECORDED AT THE SMOKY SITE FLUME DURING FY2018

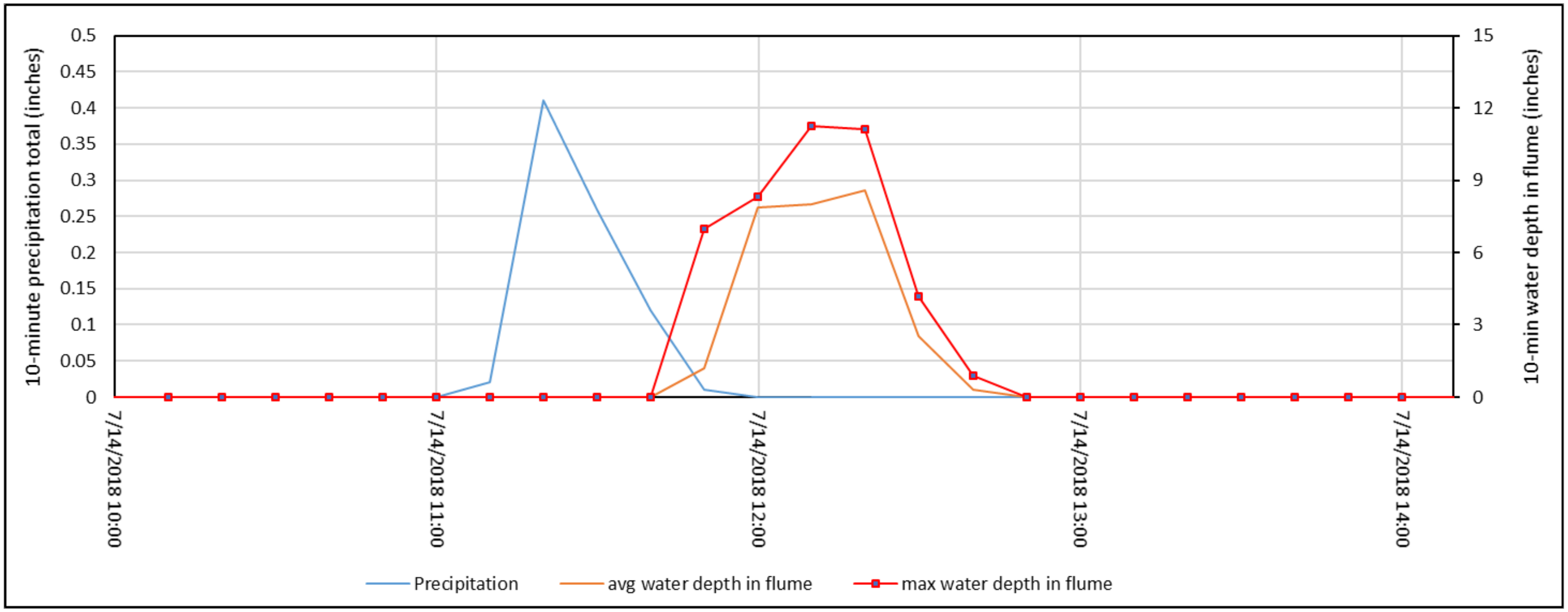

Figure C-1. Hyetograph of the July 14, 2018, precipitation event along with the associated runoff hydrograph at the Smoky Site flume. Nodes on the max water depth curve represent 10-minute observation periods.

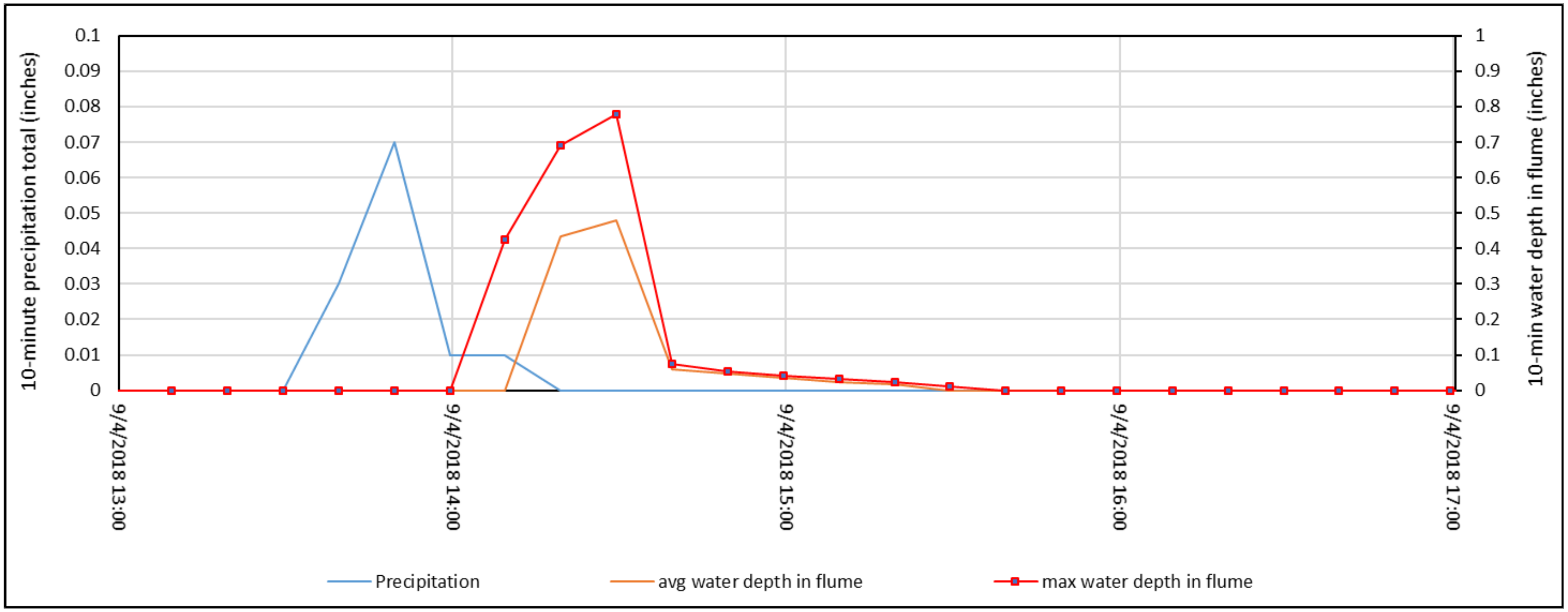

Figure C-2. Hyetograph of the September 4, 2018, precipitation event along with the associated runoff hydrograph at the Smoky Site flume. Nodes on the max water depth curve represent 10-minute observation periods.

APPENDIX D. CALCULATION OF DISCHARGE AND FLOW VELOCITY

A rating table for the TRACOM 6 in Parshall flume is used to estimate the discharge in cubic feet per second (cfs) from the measured depth of water. Alternatively, the exponential equation fit to the values from the rating curve table can be used.

$$Q = 0.0406(D)^{1.5804}$$

Where:

D = depth of water in the flume in inches (in)

Q = discharge through the flume in cubic feet per second (cfs)

Table D-1. TRACOM discharge table for six-inch Parshall flume.

Depth (feet)	Depth (inches)	Discharge (cfs)	Depth (feet)	Depth (inches)	Discharge (cfs)
0.01	0.12	x	0.39	4.68	0.465
0.02	0.24	x	0.40	4.80	0.484
0.03	0.36	x	0.41	4.92	0.504
0.04	0.48	x	0.42	5.04	0.523
0.05	0.60	x	0.43	5.16	0.543
0.06	0.72	x	0.44	5.28	0.563
0.07	0.84	x	0.45	5.40	0.583
0.08	0.96	x	0.46	5.52	0.604
0.09	1.08	x	0.47	5.64	0.625
0.1	1.20	0.054	0.48	5.76	0.646
0.11	1.32	0.063	0.49	5.88	0.667
0.12	1.44	0.072	0.50	6.00	0.689
0.13	1.56	0.082	0.51	6.12	0.711
0.14	1.68	0.092	0.52	6.24	0.733
0.15	1.80	0.103	0.53	6.36	0.755
0.16	1.92	0.114	0.54	6.48	0.778
0.17	2.04	0.125	0.55	6.60	0.801
0.18	2.16	0.137	0.56	6.72	0.824
0.19	2.28	0.149	0.57	6.84	0.848
0.2	2.40	0.162	0.58	6.96	0.871
0.21	2.52	0.175	0.59	7.08	0.895
0.22	2.64	0.188	0.60	7.20	0.919
0.23	2.76	0.202	0.61	7.32	0.943
0.24	2.88	0.216	0.62	7.44	0.968
0.25	3.00	0.230	0.63	7.56	0.993
0.26	3.12	0.245	0.64	7.68	1.018
0.27	3.24	0.260	0.65	7.80	1.043
0.28	3.36	0.276	0.66	7.92	1.068
0.29	3.48	0.291	0.67	8.04	1.094
0.3	3.60	0.307	0.68	8.16	1.12
0.31	3.72	0.324	0.69	8.28	1.146
0.32	3.84	0.340	0.70	8.40	1.173
0.33	3.96	0.357	0.71	8.52	1.199
0.34	4.08	0.375	0.72	8.64	1.226
0.35	4.2	0.392	0.73	8.76	1.253
0.36	4.32	0.41	0.74	8.88	1.280
0.37	4.44	0.428	0.75	9.00	1.308
0.38	4.56	0.447	0.76	9.12	1.335

Table D-1. TRACOM discharge table for six-inch parshall flume (continued).

Depth (feet)	**Depth (inches)**	**Discharge (cfs)**	**Depth (feet)**	**Depth (inches)**	**Discharge (cfs)**
0.77	9.24	1.363	1.14	13.68	2.534
0.78	9.36	1.391	1.15	13.80	2.569
0.79	9.48	1.419	1.16	13.92	2.604
0.8	9.60	1.448	1.17	14.04	2.64
0.81	9.72	1.477	1.18	14.16	2.676
0.82	9.84	1.506	1.19	14.28	2.712
0.83	9.96	1.535	1.20	14.40	2.748
0.84	10.08	1.564	1.21	14.52	2.784
0.85	10.20	1.593	1.22	14.64	2.820
0.86	10.32	1.623	1.23	14.76	2.857
0.87	10.44	1.653	1.24	14.88	2.894
0.88	10.56	1.683	1.25	15.00	2.931
0.89	10.68	1.714	1.26	15.12	2.968
0.9	10.80	1.744	1.27	15.24	3.005
0.91	10.92	1.775	1.28	15.36	3.043
0.92	11.04	1.806	1.29	15.48	3.080
0.93	11.16	1.837	1.30	15.60	3.118
0.94	11.28	1.868	1.31	15.72	3.156
0.95	11.40	1.900	1.32	15.84	3.194
0.96	11.52	1.931	1.33	15.96	3.233
0.97	11.64	1.963	1.34	16.08	3.271
6.98	11.76	1.995	1.35	16.20	3.310
0.99	11.88	2.028	1.36	16.32	3.349
1.00	12.00	2.060	1.37	16.44	3.388
1.01	12.12	2.093	1.38	16.56	3.427
1.02	12.24	2.125	1.39	16.68	3.466
1.03	12.36	2.158	1.40	16.80	3.505
1.04	12.48	2.192	1.41	16.92	3.545
1.05	12.60	2.225	1.42	17.04	3.585
1.06	12.72	2.259	1.43	17.16	3.625
1.07	12.84	2.292	1.44	17.28	3.665
1.08	12.96	2.326	1.45	17.40	3.705
1.09	13.08	2.360	1.46	17.52	3.746
1.1	13.20	2.395	1.47	17.64	3.786
1.11	13.32	2.429	1.48	17.76	3.827
1.12	13.44	2.464	1.49	17.88	3.868
1.13	13.56	2.499	1.50	18.00	3.909

APPENDIX E. CHANNEL BED SAMPLE DATA

Table E-1. Coordinates of bedload samples collected from the instrumented channel at the Smoky Site in August 2018.

Sample #	Latitude (degrees)	Longitude (degrees)	Elevation (feet above sea level)	Sample site description
1	37.173349	-116.061828	1,314.0	No description recorded
2	37.173386	-116.061734	1,283.7	Composite of material in centerline of channel and pond south of active channel
3	37.17345	-116.061604	1,312.9	Flume inlet
4	37.17348	-116.061552	1,315.1	Terrace on north side of main channel
5	37.173491	-116.061507	1,314.8	Toe of channel side slope
6	37.17356	-116.061458	1,314.6	Immediately downstream at vegetation constriction in channel, near centerline
7	37.173553	-116.061387	1,313.8	Toe of channel side slope
8	37.173568	-116.061353	1,315.9	Channel centerline
9	37.173599	-116.061274	1,314.9	Channel centerline
10	37.173615	-116.061156	1,313.5	Channel centerline

Table E-2. Sample mass and alpha spectrometry results.

			Am-241			Pu-238			Pu-239/240			Sample Mass	
Location	**Date**	**Particle Size (µm)**	**Result (pCi/g)**	**Error (pCi/g)**	**DL (pCi/g)**	**Result (pCi/g)**	**Error (pCi/g)**	**DL (pCi/g)**	**Result (pCi/g)**	**Error (pCi/g)**	**DL (pCi/g)**	**Particle Size (g)**	**Total (g)**
Sample 1	8/7/2018	<63	5.34	1.3	0.375	2.45	0.759	0.36	25.3	4.01	0.36	33	1,399.08
		>63 <250	7.86	1.72	0.285	2.83	0.794	0.299	29.1	4.48	0.326	148.28	
		>250	1.87	0.614	0.26	0.778	0.374	0.28	5.94	1.26	0.305	1,217.8	
Sample 2	8/7/2018	<63	4.92	1.19	0.269	1.85	0.63	0.382	21.5	3.46	0.438	3.66	1,358.29
		>63 <250	3.77	1.04	0.4	1.86	0.681	0.508	14.6	2.6	0.358	47.44	
		>250	0.641	0.341	0.328	0.213	0.219	0.37	2.64	0.762	0.325	1,307.19	
Sample 3	8/7/2018	<63	15	2.93	0.428	2.04	0.714	0.589	81.1	11.5	0.375	6.38	1,310.64
		>63 <250	8.23	1.77	0.342	3.19	0.848	0.36	31.4	4.76	0.317	67.99	
		>250	2.86	0.882	0.55	0.697	0.437	0.656	10	1.93	0.368	1,236.27	
Sample 4	8/7/2018	<63	57.5	9.9	0.341	5.98	1.29	0.371	351	47.2	0.3	48.09	1,461.58
		>63 <250	8.73	1.92	0.619	4.48	1.13	0.494	31.2	4.84	0.379	200.91	
		>250	0.227	0.273	0.564	0.0443	0.14	0.385	1.06	0.464	0.338	1,212.58	
Sample 5	8/7/2018	<63	4.33	1.2	0.368	1.39	0.59	0.464	14.8	2.67	0.375	27.77	1,458.97
		>63 <250	6.63	1.51	0.278	3.39	0.863	0.276	25.1	3.91	0.391	232.73	
		>250	0.456	0.318	0.396	0.0666	0.133	0.312	1.86	0.632	0.339	1,198.47	
Sample 6	8/7/2018	<63	5.23	1.3	0.441	1.67	0.588	0.305	23.1	3.67	0.332	16.42	1,443.31
		>63 <250	3.85	1.03	0.364	1.77	0.624	0.394	14	2.48	0.452	116.95	
		>250	0.238	0.266	0.518	-0.0458	0.112	0.398	0.48	0.314	0.322	1,309.94	
Sample 7	8/7/2018	<63	5.03	1.28	0.405	2.09	0.704	0.422	21.4	3.5	0.371	15.83	1,397.85
		>63 <250	3.82	1.01	0.536	2.52	0.766	0.545	16.6	2.82	0.347	130.16	
		>250	1.02	0.452	0.354	0.23	0.211	0.294	2.67	0.764	0.32	1,251.86	
Sample 8	8/7/2018	<63	7.31	1.69	0.469	1.77	0.651	0.599	29.9	4.62	0.356	13.53	1,480.65
		>63 <250	4.57	1.15	0.546	2.53	0.743	0.367	16.3	2.73	0.296	98.63	
		>250	5.57	1.38	0.414	2.46	0.779	0.486	20.3	3.35	0.372	1,368.49	
Sample 9	8/7/2018	<63	4.77	1.22	0.451	2.24	0.718	0.594	17.9	2.95	0.305	15.11	1,480.51
		>63 <250	5.64	1.42	0.542	2.49	0.781	0.424	22.2	3.62	0.373	136.19	
		>250	0.915	0.462	0.419	0.393	0.305	0.368	3.27	0.942	0.368	1,329.21	
Sample 10	8/7/2018	<63	5.19	1.29	0.382	1.85	0.65	0.5	21.6	3.51	0.318	16.56	1,478.84
		>63 <250	6.08	1.48	5.25	2.84	0.859	0.441	19.7	3.32	0.356	66.46	
		>250	1.06	0.478	0.318	0.0957	0.166	0.366	5.48	1.26	0.477	1,395.82	

DL = detection limit

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