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Prepared by

Steve A. Mizell, Julianne J. Miller, Greg McCurdy, and
Scott A. Campbell

Submitted to

U.S. Department of Energy
Environmental Management Nevada Program
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Nevada System of Higher Education

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EXECUTIVE SUMMARY

The Desert Research Institute (DRI) is conducting a field assessment of the potential for contaminated soil to be transported from the Smoky Contamination Area (CA) as a result of storm runoff. This activity supports Nevada Nuclear Security Administration (NNSA) efforts to complete regulatory closure of the Soils Corrective Action Unit (CAU) contamination areas. The work is intended to confirm the likely mechanism of transport and determine the meteorological conditions that might cause 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 appropriate closure design and post-closure monitoring program.

Desert Research Institute installed a meteorological monitoring station on the west side of the Smoky CA and a hydrologic (runoff) monitoring station within the CA, near the east side, in 2011. Air temperature, wind speed, wind direction, relative humidity, precipitation, solar radiation, barometric pressure, soil temperature, and soil water content are collected at the meteorological station. 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 hydrology station are also recorded for every 10-minute interval. This report presents data collected from these stations during fiscal year (FY) 2015 and FY2016.

During the FY2015 and FY2016 reporting period, the warmest months were June, July, and August and the coldest were December and January. Solar radiation reflects the same seasonal trend. Monthly mean wind speeds were highest in the spring (April and May). Winds were generally from the southwest during the summer and from the northwest throughout the remainder of the year. Monthly average relative humidity ranged from the teens to greater than 60 percent. During storms, the relative humidity was approximately 100 percent. Monthly total precipitation ranged from zero to approximately 4.46 inches. The months with the highest precipitation amounts were August and October of 2015. Total precipitation was 5.14 inches in FY2015 and 8.90 inches in FY2016, which shows the temporal variability of precipitation in the southwestern United States.

Seven major rainfall events occurred: July 2 and 3, 2015; August 1, 2015; October 4 and 18, 2015; and January 4 and 31, 2016. The pressure transducer measuring water depth in the flume was not operating during the October storms and no runoff observations are available for these storms. The July and August storms were relatively high-intensity, short-duration storms that are typical of the summer thunderstorm season and the January storms were lower-intensity, longer-duration storms that are typical of winter frontally driven precipitation events.

The August 1, 2015, storm produced a maximum precipitation intensity of 0.52 inch in a 10-minute interval. This storm produced runoff that overtopped the flume with an estimated peak discharge of approximately six cubic feet per second (cfs). Precipitation intensities for the other major storms were between approximately 0.1 inch and 0.3 inch in 10 minutes. Using surveyed channel geometry and estimated flume discharge, it is estimated that the August 1, 2015, storm resulted in a flow velocity in excess of four feet per second (fps). Transport of unconsolidated desert sediments typically begins when flow velocities reach 3 to 4 fps (up to and including sand-sized particles at these velocities), with greater

velocities capable of transporting larger and heavier materials. No bed-load samples were collected from the Smoky Site channel during FY2015 and FY2016. Review of the data collected during FY2015 and FY2016 led to the following principal observations and conclusions:

1) Five runoff events were recorded at the flume during FY2015 and FY2016. Only the August 1, 2015, storm produced runoff with sufficient velocity to cause erosion.

2) Short-duration, high-intensity precipitation events (i.e., summer convective storms) produced rapid runoff events during which significant water depths were recorded in the flume.

3) The runoff event on January 5, 2016, shows that the lower-intensity, longer-duration precipitation events associated with winter frontal storms may produce runoff. However, neither the January 5, 2016, runoff event nor the January 31, 2016, runoff event had sufficient velocity to cause erosion and transport sediment.

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LIST OF ACRONYMS

Am-241	americium-241
CA	Contamination Area
CAS	Corrective Action Site
CAU	Corrective Action Unit
cfs	cubic feet per second
DOE	Department of Energy
DRI	Desert Research institute
fps	feet per second
FY	fiscal year
GOES	Geostationary Operational Environmental Satellite
NNSA	National Nuclear Security Administration
NNSS	Nevada National Security Site
NFO	Nevada Field Office
TDR	time domain reflectometry
USGS	U.S. Geological Survey
WRCC	Western Regional Climate Center

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INTRODUCTION

The U.S. Department of Energy (DOE), National Nuclear Security Administration (NNSA), Nevada Field Office (NFO), Environmental Management's Soils Activity has authorized Desert Research Institute (DRI) to conduct field assessments of the potential transport of radionuclide-contaminated soils from Corrective Action Unit (CAU) 550, Smoky Contamination Area (CA) during precipitation runoff events. Corrective Action Unit 550 includes Corrective Action Sites (CASs) 08-23-03, 08-23-04, 08-23-06, and 08-23-07. These CASs are associated with the tests designated Ceres, Smoky, Oberon, and Titania, respectively. Aerial surveys at this location, as well as at other locations on the Nevada National Security Site (NNSS), suggest that radionuclide-contaminated soils may be migrating along ephemeral channels in Areas 3, 8, 11, 18, and 25 (Colton, 1999).

Figure 1 shows the results of a low-elevation aerial survey for americium-241 (Am-241) (Colton, 1999) in Area 8. The numbered markers in Figure 1 identify ground zero for three safety experiments conducted in 1958 (Oberon [number 1], Ceres [number 2], and Titania [number 4]) and a weapon effects test conducted in 1964 (Mudpack [number 3]). The survey identified a northwest-southeast elongated zone of higher contamination that is approximately parallel to ephemeral drainages emanating from the Smoky Hills north of the test locations. An unnamed mapped drainage lies along the west side of the elongate contamination zone and discharges into a drainage that conveys runoff to the southeast toward Circle Road. Additionally, a lobe on the south edge of the contamination zone, just below label number 3 (Figure 1), may indicate transport along a drainage channel. Anecdotal information also indicates that runoff in an adjacent channel has deposited sediment on Circle Road, which is on the southeast border of the CAU (J. Traynor, personal communication, 2011). These observations led to the selection of the Smoky Site as the location for an investigation of the potential for radionuclide migration by water-driven sediment transport during storm runoff events.

Because the contamination is particularly close to the boundary of CAU 550, Smoky CA, it is important to know if radionuclide-contaminated soils are moving, what meteorological conditions result in the movement of contaminated soils, and what particle size fractions associated with contamination are involved.

Closure plans are being developed for the CAUs on the NNSS. The closure plans may include post-closure monitoring for the possible release of radioactive contaminants. Determining the potential for the transport of contaminated soils under ambient climatic conditions will facilitate an appropriate closure design and post-closure monitoring program.

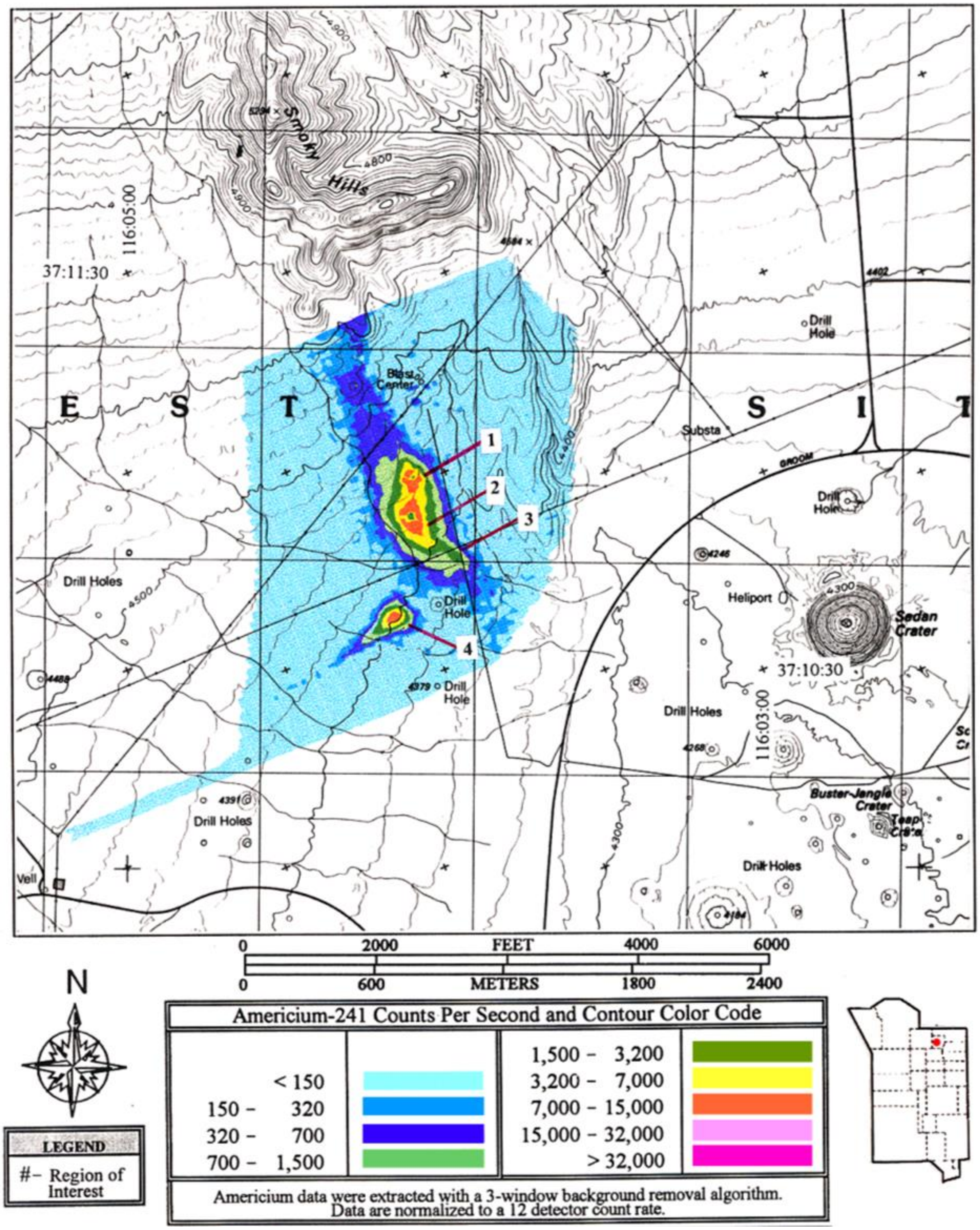


Figure 1. Americium-241 detections at the Smoky CA in northwest Yucca Flat, Nevada (Colton, 1999). Numbered markers identify ground zero for the three safety experiments Oberon (number 1), Ceres (number 2), and Titania (number 4) and the weapons test Mudpack (number 3).

BACKGROUND

The Smoky CA is located in Area 8 of the NNSS in the northern part of Yucca Flat, which is 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 tests included three safety tests (Oberon, Ceres, and Titania) conducted in 1958 and a weapon effects test (Mudpack) conducted in 1964 (Colton, 1999). As a result of these tests, there is an 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 contamination area is a triangular area of surface contamination associated with the Titania test. A low-level aerial survey of the area (Figure 1) reported up to 15,000 counts per second of Am-241 at the center of the two surface contamination areas (Colton, 1999). Additionally, transported contamination has been measured across Circle Road from an adjacent channel (J. Traynor, personal communication, 2011).

The Smoky CA is situated on the alluvial fan approximately 0.6 mile (1,000 m) south of the Smoky Hills. Mapped drainages shown on the topographic map of Oak Spring, Nevada, (USGS 1:24000 scale) trend south-southeast from the Smoky Hills, and then easterly toward the center of Yucca Flat. The larger of the two contaminated areas in the Smoky CA is bounded on the east, west, and south by mapped channels. The western corner of the smaller contamination area surrounding the Titania test site is drained by a mapped channel trending west to east. Elevation contours in the immediate vicinity of these contamination areas suggest that unmapped channels may convey runoff from the areas of highest contamination into the mapped drainages.

RESEARCH APPROACH

The presence of radionuclide-contaminated soils in channels that traverse and convey runoff from the Smoky CA suggests that contaminated soil has been transported by rainfall-generated runoff. 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 immediately following the Smoky area 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 CA. The research plan includes measuring local meteorological parameters, measuring the resulting runoff from local rainfall, and collecting bulk channel bed samples (i.e., bed load) for laboratory analysis after flow events. Measurements are made at locations in and adjacent to the Smoky CA (Figure 2). The precipitation and runoff data will be 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 the drainage channel transport pathways to develop a post-closure monitoring strategy.

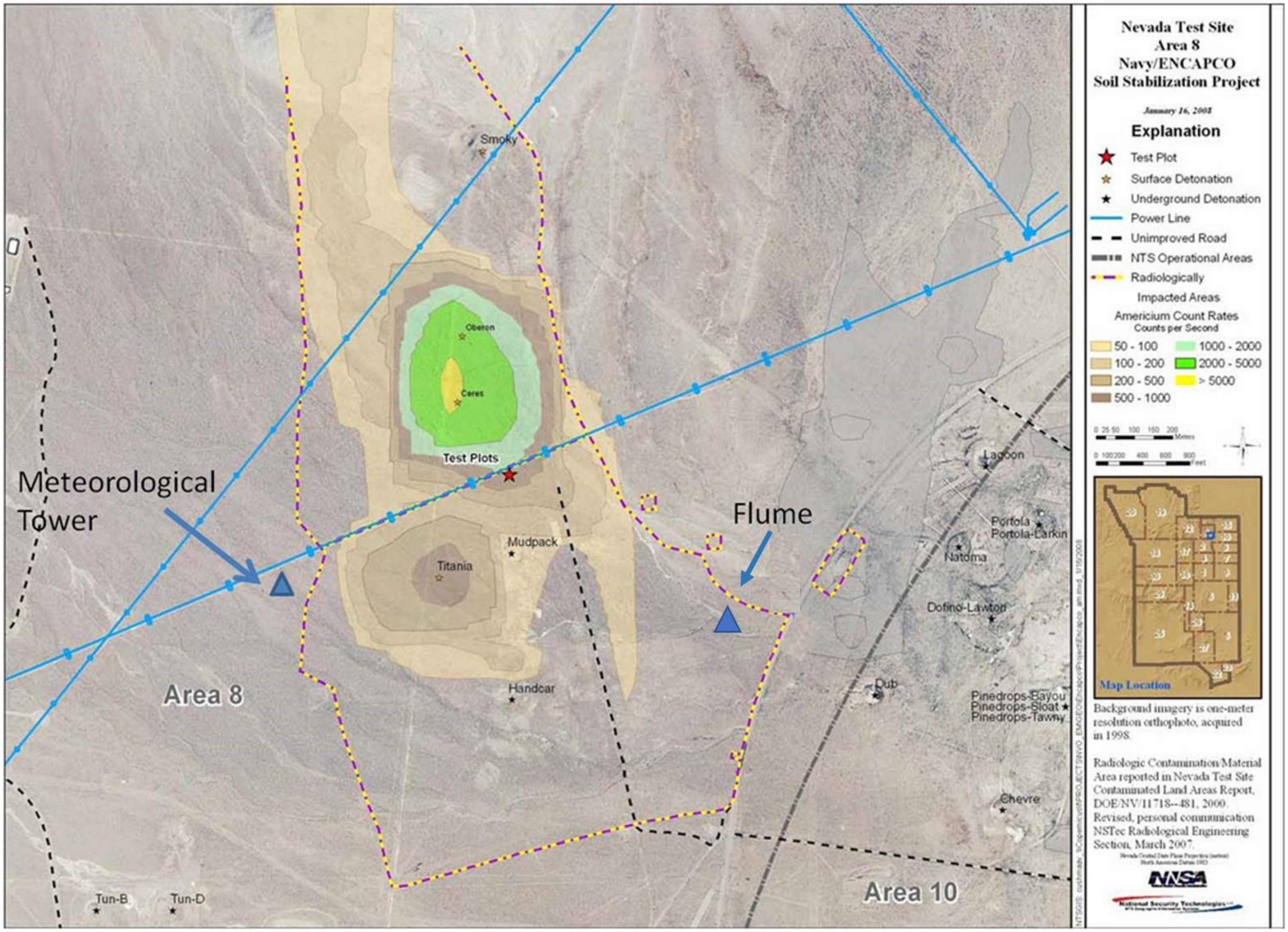


Figure 2. Approximate locations of the meteorological station and flume installations at the Smoky CA in Yucca Flat, Nevada National Security Site.

The meteorological station—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 CA (Figure 3) on July 14 and 15, 2011. The coordinates of the meteorological station are 37^{o} 10’ 39.48” latitude and -116^{o} 4’ 25.59” longitude. The meteorological station also includes Geostationary Operational Environmental Satellite (GOES) transmission equipment and equipment to receive radio frequency data transmissions from the flume instrumentation station (Figure 2). The accumulated meteorological data are transmitted daily to the Western Regional Climate Center (WRCC) at the DRI offices in Reno via GOES. At the WRCC, the data are uploaded to a restricted-access internet webpage that is available to project personnel.

Figure 3. The Smoky CA meteorological station was installed to measure precipitation, wind, and other climate parameters.

Installation of a 6-inch Parshall flume between the Smoky CA boundary and the adjoining road to measure channelized runoff (Figure 2) was originally intended. However, because there was not sufficient space on the shoulder of the road and Radiological Control determined that it was not possible to downgrade contamination controls on the study channel to be instrumented, the flume (Figure 4) was placed inside the Smoky CA. The flume was installed on July 19, 2011, at a location approximately 50 feet (15 meters) upstream of the position indicated in Figure 2. The coordinates of the flume are 37^{o} 10’ 37.13” latitude and -116^{o} 3’ 34.85” longitude. The flume installation includes a pressure transducer for measuring flow depth through the flume and a radio frequency transmitter/receiver to allow communication with the meteorological station (Figure 5). Meteorological and flume data transmissions from the Smoky CA were received beginning July 20, 2011.

Figure 4. View looking downstream through the flume installed to measure runoff from the Smoky CA (prior to washout in July 2013).

Figure 5. Runoff conditions in the flume are detected by the pressure transducer (yellow cable), recorded in the datalogger (white box), and relayed by radio (black antenna) to the meteorological station for transmission to the WRCC via the GOES.

FISCAL YEAR 2015 AND 2016 OBSERVATIONS

Data collection from the electronic sensors placed at the meteorological station at the Smoky study site began on July 14, 2011. Data collection at the flume site began July 20, 2011 (Appendix C). 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 daily via GOES to the WRCC, where the data are reviewed to identify collection or transmission irregularities, and then 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 1 lists the significant events in the data collection history at the Smoky Site and the datalogger download exercises accomplished during fiscal year (FY) 2015 and FY2016.

Table 1. History of significant events associated with meteorological and hydrological observations at the Smoky Site for shallow ephemeral channel transport monitoring.

Date	Description
FY2015	
January 16, 2015	Download datalogger at meteorological station.
Week of March 29, 2015	Download datalogger at meteorological station.
May 15, 2015	New batteries were installed at the meteorological station.
July 1, 2015	0.2 in precipitation at met station; 18.27 in water depth at flume.
July 2-3, 2015	0.18 in precipitation at met station; 15.96 in water depth at flume.
August 1, 2015	0.52 in precipitation at met station; 35.7 in water depth at flume.
Week of August 9, 2015	Download datalogger at meteorological station.
August 23, 2015	Water depth pressure sensor failed; failure because of animal damage discovered.
September 24, 2015	Battery at flume datalogger appears to be failing.
FY2016	
October 1, 2015	Download datalogger at meteorological station.
November 30, 2015	Repair Geokon water depth pressure sensor and solar power. Flume reinforced with sandbags.
January 5, 2016	0.02 in precipitation at met station; 10.34 in water depth at flume.
January 16, 2016	Download datalogger at meteorological station.
January 23, 2016	0.04 in precipitation at met station; 9.89 in water depth at flume.
January 31, 2016	0.04 in precipitation at met station; 12.39 in water depth at flume.
April 3, 2016	Download datalogger at meteorological station.
May 15, 2016	Batteries preemptively replaced at meteorological station; no data were lost.
June 7, 2016	Download datalogger at meteorological station.
July 14, 2016	Download datalogger at meteorological station.
August 17, 2016	Geokon pressure sensor failed because of animal damage, repaired on January 24, 2017.

Meteorological Observations

Tables 2 and 3 summarize the 10-minute meteorological data for October 1, 2014, through September 30, 2016, by month and fiscal year. The daily average values of the meteorological parameters are shown in time series plots in Appendices A and B. During the two-year reporting period, the monthly summary data indicate that:

1) Average daily temperatures were highest in June and August. July and September were only slightly cooler (by four to six degrees Fahrenheit).
2) June and July recorded the highest monthly solar radiation. August, April, and May had the next highest solar radiation (sunshine).
3) The coldest months were December and January. These were also the months with the lowest solar radiation.
4) Monthly mean wind speeds were highest in May, but the April winds were just one mile per hour slower. Winds were generally from the southwest in May through September and from the northwest in October through April.
5) Monthly average relative humidity ranged from the upper teens to greater than 60 percent. Monthly precipitation ranged from 0 to approximately 1.57 inches; the highest monthly rainfall occurred in January 2016. Total rainfall exceeded five inches in FY2015 and eight inches in FY2016.

Table 2. Monthly meteorological observations at the Smoky Site, NNSS, during FY2015.

Date	**Total Solar Radiation**	**Mean Wind Speed**	**Mean Wind Direction (vector ave.)**	**Max. Wind Gust**	**Ave. Air Temp.**	**Ave. Daily Max. Temp.**	**Max. Temp.**	**Ave. 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-14	13836	5.0	297	35.3	63.3	77.5	86.3	48.2	39.2	69.1	96.9	47.0	24.5	55.9	7.0	25.59	0.00
Nov-14	9856	5.0	306	39.7	49.0	63.5	77.2	35.3	23.5	52.7	80.6	32.0	30.8	92.7	5.5	25.63	0.04
Dec-14	6794	4.8	328	55.0	40.4	50.0	64.6	32.1	19.8	42.0	64.1	27.5	65.3	100.0	16.3	25.60	0.91
Jan-15	8322	4.7	330	31.4	44.5	57.4	68.7	32.3	19.1	44.2	62.3	27.8	48.1	99.1	7.0	25.70	0.80
Feb-15	10892	5.5	326	34.9	50.3	63.4	74.5	37.5	30.0	52.2	74.4	34.2	39.2	96.0	6.7	25.60	0.24
Mar-15	15887	5.8	317	45.4	54.8	68.2	80.6	40.2	23.0	59.0	91.7	32.5	33.7	99.9	5.8	25.62	0.31
Apr-15	18756	7.6	309	53.8	56.1	68.7	81.8	81.8	27.7	66.1	95.8	43.1	24.0	91.7	7.1	25.49	0.07
May-15	18339	6.6	207	45.5	53.2	73.7	91.3	48.6	39.0	72.0	104.5	48.6	36.3	91.4	7.1	25.50	0.56
Jun-15	20604	6.2	211	38.8	79.6	92.4	102.7	62.9	50.4	89.4	121.1	63.8	18.0	95.4	1.4	25.50	0.06
Jul-15	19986	6.3	201	39.0	78.0	89.7	99.1	64.1	56.4	87.7	120.3	65.3	28.7	95.4	4.4	25.60	1.04
Aug-15	19077	6.0	221	39.4	80.8	93.7	100.9	66.2	55.7	88.7	112	67.8	26.4	95.0	4.2	25.60	1.11
Sep-15	17028	5.9	221	36.2	74.7	87.7	96.5	60.1	49.5	82.4	110.5	59.6	24.3	70.4	5.7	25.50	0.00
FY2015	*179377*	*5.8*	*272.8*	*55.0*	*60.4*	*73.8*	*102.7*	*50.8*	*19.1*	*67.1*	*121.1*	*27.5*	*33.3*	*100.0*	*1.4*	*25.6*	*5.14*

Table 3. Monthly meteorological observations at the Smoky Site, NNSS, during FY2016.

Date	Total Solar Radiation	Mean Wind Speed	Mean Wind Direction (vector ave.)	Max. Wind Gust	Ave. Air Temp.	Ave. Daily Max. Temp.	Max. Temp.	Ave. 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-15	11388	5.3	330	38.0	61.6	72.6	86.8	51.5	42.1	64.8	94.2	48.1	50.6	98.0	11.5	25.58	4.46
Nov-15	9850	6.5	318	53.6	42.8	54.5	71.5	31	18.2	46.3	71.5	26.5	41.1	94.0	7.2	25.56	0.05
Dec-15	7782	5.3	318	42.1	36.2	47.2	64.9	26	13.7	37.6	57.4	25.1	49.6	96.6	9.0	25.55	0.24
Jan-16	7466	4.5	330	33.0	37.6	48.5	60.9	28.6	19.8	37.8	56.7	26.4	61.9	100.0	9.8	25.59	1.57
Feb-16	11973	5.4	328	47.6	44.3	59.1	72.9	30.6	10.9	45.3	71.1	27.1	49.5	98.3	10.3	25.70	0.34
Mar-16	15258	6.8	285	45.9	50.4	62.9	73.5	35.7	26.3	55.6	77.1	34.5	39.7	97.4	6.6	25.51	0.29
Apr-16	16640	7.8	318	45.2	56.7	68.2	79.6	43.2	35.3	64.0	87.9	43.6	38.2	98.1	4.4	25.52	0.87
May-16	19267	7.0	307	42.7	63.4	74.6	88.7	49.4	39.7	72.4	102.7	47.5	32.5	95.1	6.0	25.47	0.17
Jun-16	21983	6.8	201	36.4	80.3	93.2	102.2	63.8	50.9	88.4	112.3	64.9	19.4	94.9	3.5	25.54	0.63
Jul-16	22358	6.9	211	44.1	82.5	95.5	103.8	66.3	58.9	91.5	114.7	67.7	18.5	87.9	2.6	25.55	0.25
Aug-16	20109	6.1	225	36.3	79.8	93.1	98.3	63.9	54.5	89.1	110.9	68.1	20.5	79.7	1.5	25.55	0.01
Sep-16	16862	6.6	265	44.9	70.4	83.8	93	54.6	45.0	78.5	102	55.6	22.8	82.5	4.1	25.57	0.02
FY2016	*180936*	*6.3*	*286.3*	*53.6*	*58.8*	*71.1*	*103.8*	*45.4*	*10.9*	*64.3*	*114.7*	*25.1*	*37.0*	*100.0*	*1.5*	*25.56*	*8.90*

Hydrologic Observations

Figure 6 shows the total amount of precipitation and the average water depth in the flume for 10-minute observation periods during FY2015 and FY2016. Precipitation events were recorded at the Smoky rain gage each month during the two year period except for October 2014 and September 2015. Storms that produce approximatley 0.05 inch of precipitation during at least one 10-minute sampling interval have produced flow in the flume. However, precipitation intensity must approach 0.1 inch in 10 minutes to consistently result in measurable flow.

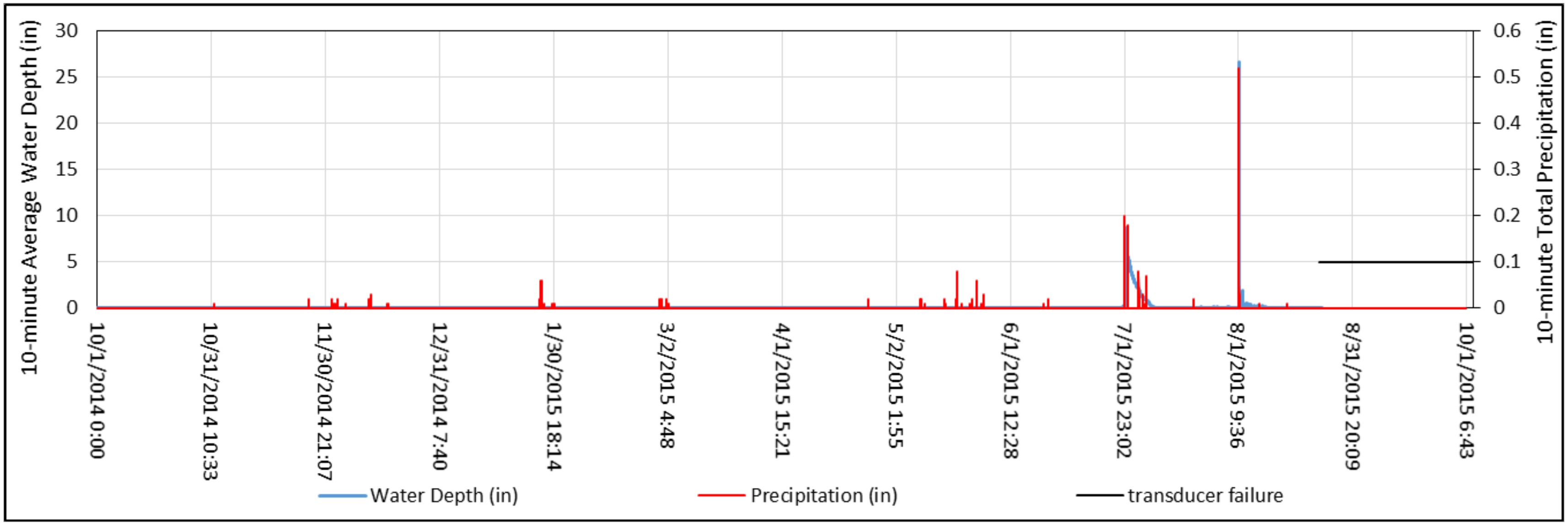
Precipitation exceeded 0.1 inch in 10 minutes on five occasions during this reporting period: July 1, 2015; August 1, 2015; October 5, 2015; October 18, 2015; and June 11, 2016. The PHS rain gage, which is approximately 1.7 miles east-northeast of the Smoky rain gage, generally recorded precipitation on the same days as the Smoky gage (Table 4). Precipitation at gages in the area surrounding the Smoky study area suggests that the precipitation records at the Smoky gage are records of real precipitation events, and therefore potential indicators of runoff down the channel. There were two occasions in July 2015 when the Smoky gage recorded precipitation but the PHS gage did not, which likely reflect thunderstorms that frequently are localized events.

Flow through the flume was observed in association with precipitation events in July 2015, August 2015, and January 2016. No flow was recorded in association with the two precipitation events in October 2015 because the pressure transducer installed to record water depth in the flume failed on August 23, 2015 (Table 1, Figure 6). It was repaired on November 30, 2015, but failed again on August 17, 2016. The pressure transducer was replaced in January 2017. No other significant precipitation events occurred while the flume pressure transducer was inoperable.

Table 4. Daily precipitation totals (inches) for the Smoky site gage and another nearby gage during major precipitation events. Flow is reported as inches of water in the flume.

Date	Smoky Rain Gage	Smoky Flume Flow	PHS Rain Gage
7/1/2015	0.35	8.81	0.00
7/2/2015	0.2	6.55	0.00
8/1/2015	1.07	26.63	1.16
10/5/2015	1.07	*	0.54
10/18/2015	2.44	*	2.11
1/5/2016	0.78	0.34	0.88
1/31/2016	0.53	2.49	0.03
6/11/2016	0.51	None	Not available

* Pressure transducer was not operating.



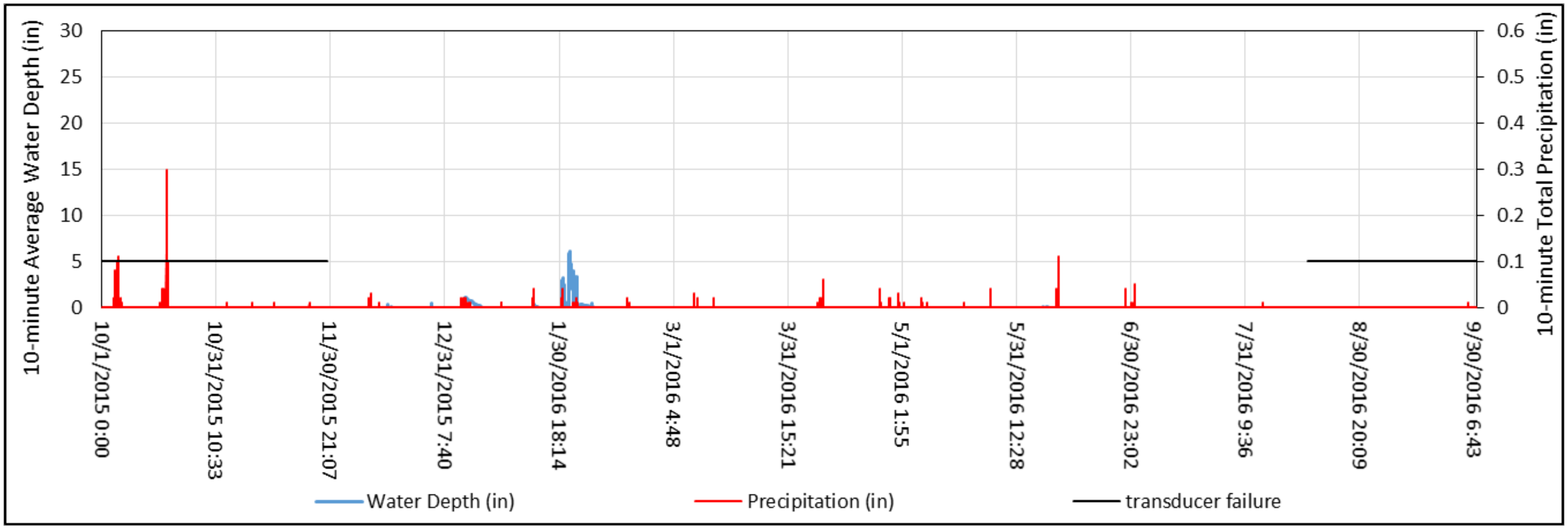


Figure 6. Total precipitation and average water depth in the flume for 10-minute measurement periods for FY2015 (top) and FY2016 (bottom).

Flow in the flume was observed in conjunction with precipitation events that recorded more than 0.1 inch during at least one 10-minute observation period in July and August of 2015 (Figure 6). Flow depth on January 23, 2016, was recorded to be approximately 0.8 inch in the flume, but the volume of runoff through the flume was considered excessive compared with the associated precipitation. Flows through the flume on January 5, 2016, and again on January 31, 2016, exceeded a one-inch depth. Although these flows occurred in response to smaller precipitation events, the precipitation events were longer lasting and the water volumes conveyed appeared reasonable when compared with the precipitation record. The pressure transducer in the flume was not operational during precipitation events in October 2015 and no flow through the flume was recorded during the precipitation event on June 11, 2016, even though precipitation exceeded 0.1 inch. Each flow event reported to produce water depths at the flume in excess of one inch is examined individually in the following pages. The range of values on the plot axes has been selected to highlight features in the individual flow and precipitation events.

Precipitation was recorded during five of the first 10 days of July 2015 (Figures 6 and 7). Precipitation intensity exceeded 0.1 inch in 10 minutes on July 1 and 2, 2015. The intensity of the other precipitation events during this period was less than 0.08 inch in 10 minutes (Table 5 and Figure 7). Figure 7 shows the original data indicating flow through the flume during the early July 2015 time period. The top graph suggests a seven- to eight-day flow recession, which seems to be an unreasonable response when compared with the amount of precipitation recorded. Additionally, the dirunal variations in water depth are not in response to precipitation events. Rather, they mimic diurnal patterns seen in the FY2013 and FY2014 records (Mizell *et al.*, 2017). Historically, these diurnal patterns have been correlated with diurnal temperature fluctuations when there has been light precipitation but no flow through the flume (as indicated by zero values during the overnight and morning hours). Although the diurnal variations in the water depth record in early July 2015 are superimposed on a declining, non-zero trend in water depth, the diurnal pattern is believed to indicate false water depth values. The pressure sensor in the Geokon transducer is several inches from the temperature sensor, and therefore it is likely that the diurnal pattern observed in the July record occured because the temperature sensor is above the water level and is measuring variations in air temperature and not water temperature.

Table 5. Precipitation and flow characteristics in early July 2015.

Date	Time (PST)	Total Precipitation (in)	Precipitation Duration (hrs)	Maximum 10-minute Intensity
July 1, 2015	2300	0.35	0.33	0.20
July 2, 2015	2200	0.20	0.50	0.18
July 5, 2015	1210	0.03	0.33	0.02
July 5, 2015	1830	0.24	1.16	0.08
July 6, 2015	2120	0.05	0.50	0.03
July 7, 2015	1240	0.02	0.33	0.10
July 7, 2015	1700	0.07	0.17	0.07

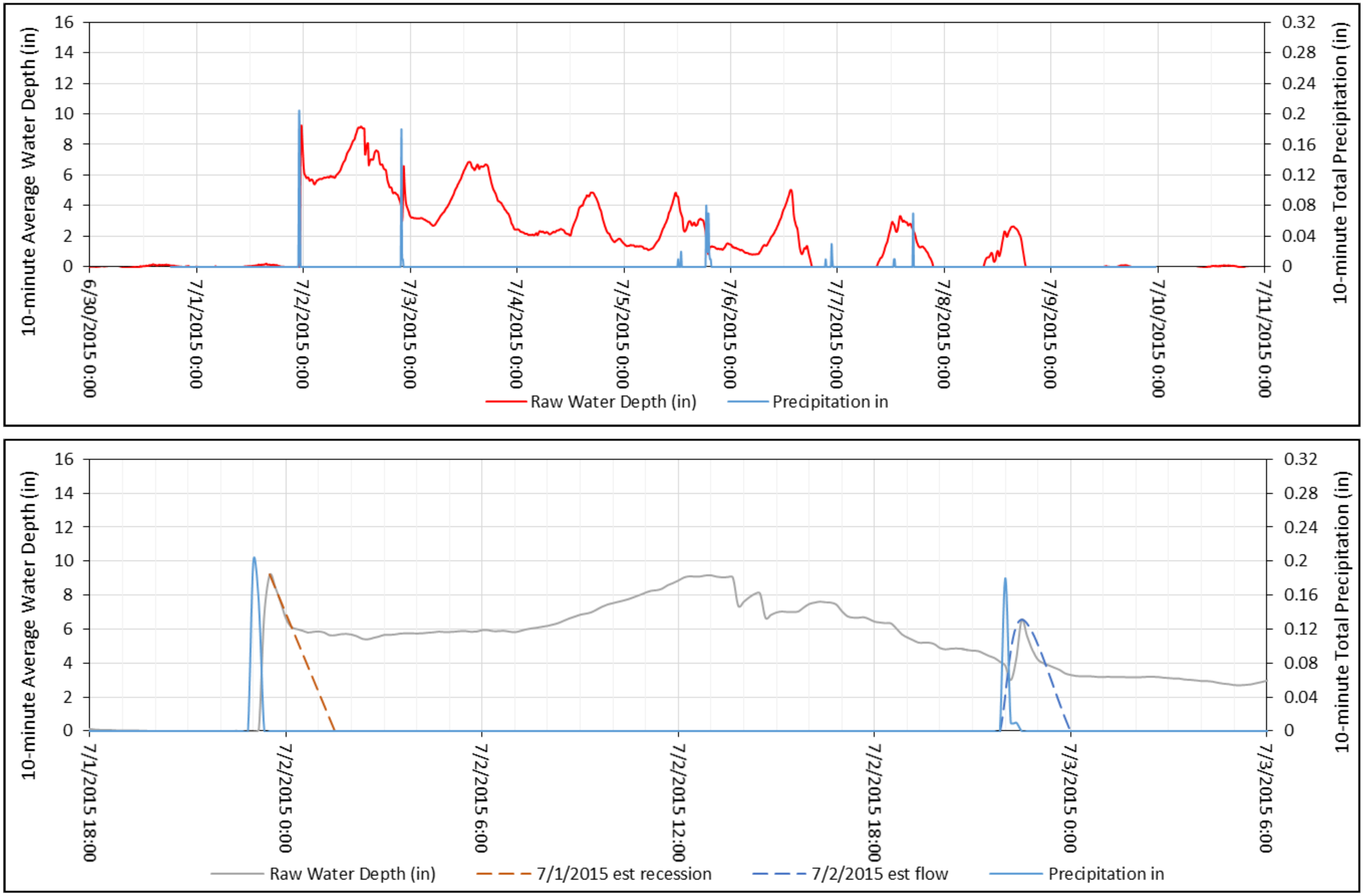


Figure 7. Total precipitation and average water depth in the flume for 10-minute measurement periods of precipitation and flume flow recorded July 1 through July 10, 2015, (upper graph) and the significant precipitation events of July 1 and 2, 2015 (lower graph).

Two precipitation events—July 1 and 2, 2015—appear to have caused a response in the flume water depth (Figure 7). The water depth observations indicated a response to these precipitation events, but the complete hydrograph is obscured by the apparent long-duration recession curve. Estimates of the hydrographs resulting from these precipitation events were approximated using the recorded hydrograph peaks and professional judgement. The July 1, 2015, precipitation event produced a flow that peaked at 8.81 inches (1.25 cubic feet per second [cfs]) approximately 30 minutes after the first precipitation was recorded. The extension of the initial period of recession following this peak suggests that this flow event was approximately 2.5 hours long and that it was likely to have produced significant runoff. Precipitation on July 2, 2015, resulted in a water depth that peaked at 6.55 inches (0.79 cfs) approximately 30 minutes after precipitation began. The extension of both the rising and falling limbs of this peak suggests that the flow event lasted approximately six hours. Eight other precipitation events occurred during this eight-day "recession" in the reported water depth (July 2 at 2200h, July 5 at 1210h and 1250h, July 5 at 1830h through 1930h, July 6 at 2120h and 2240h, and July 7 at 1240h and 1700h). These subsequent precipitation events did not produce any spikes in water depth in the flume. The preciptation intensities were less than 0.1 inch in 10 minutes, which has been determined to be the threshold for generating flow at the flume.

An explanation for the long recession curve is not immedately clear. Perhaps the flume became plugged early in the flow event and water ponded in front of the flume, and then drained slowly through the plug. Alternatively, the pressure transducer in the flume may have been impacted in wet mud during the initial flow through the flume and dried out slowly, independent of the presence of water in the flume.

The precipitation event on August 1, 2015, peaked at 1250h with a maximum intensity of 0.52 inch in 10 minutes (Figure 8). The peak intensity was immediately preceeded by a rain fall intensity of 0.07 inch reported at 1240h and followed by an intensity of 0.14 inch at 1300h. The initial 10-minute precipitation amount and all precipitation measurements beginning 20 minutes after the peak intensity were less than 0.1 inch and consistently diminished through the last four hours of the storm. The associated peak water depth in the flume, 26.63 inches, occurred at 1320h, which was 30 minutes after the precipitation peak. The rising limb lasted approximately 1 hour and 20 minutes. The recession limb lasted approximately 3 hours and 40 minutes, although most of the flow had passed through the flume by 1500h (1 hour and 40 minutes after the peak). The peak water depth overtopped the flume, and therefore an estimate of the discharge cannot be made. At the maximum depth of flow (18.0 inches) for this flume, the discharge is 3.9 cfs. Therefore, discharge during this overtopping flow is likely to have approached 6 cfs to 7 cfs.

A winter storm front passed through the area on January 4, 5, 6, and 7, 2016. Winter precipitation on the NNSS is associated with low-intensity, long-duration frontal storms. Rain was recorded beginning at 1200h on January 4, 2016, and continued intermittently until 0050h on January 7, 2016 (Figure 9). The longest period of continuous precipitation lasted from 1350h until 1800h on January 5, 2016, and produced 0.38 inch. However, no 10-minute measurement interval produced more than 0.02 inch of precipitation. The highest intensity

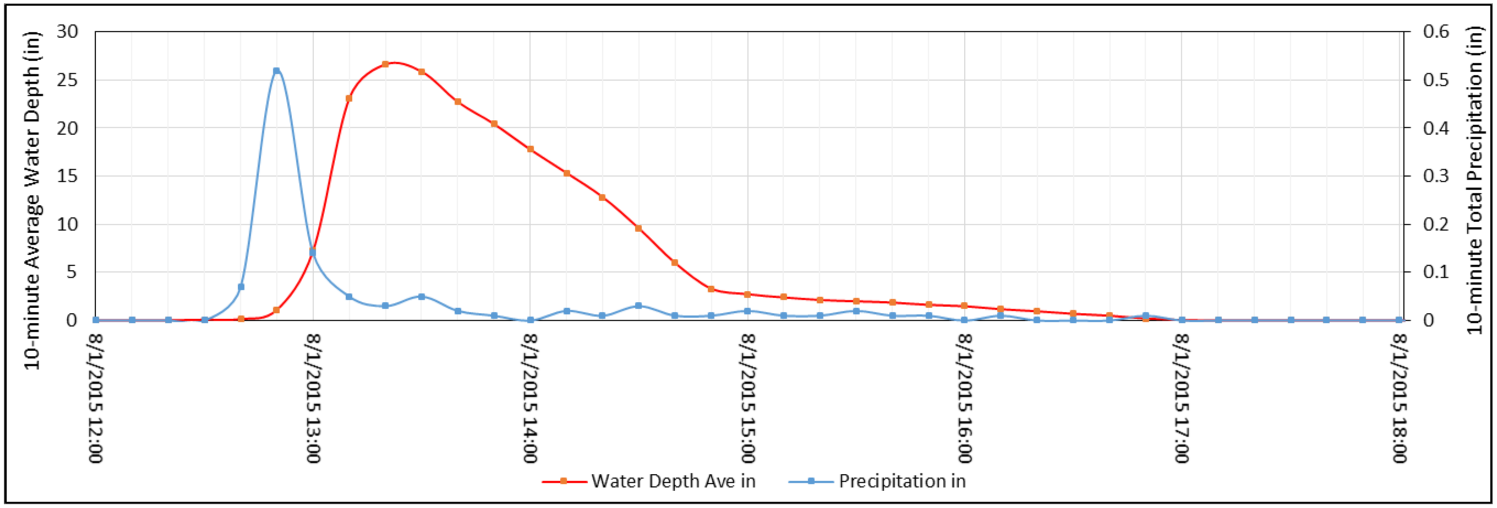


Figure 8. Total precipitation and average water depth in the flume for 10-minute measurement periods for the precipitation and flume flow recorded August 1, 2015.

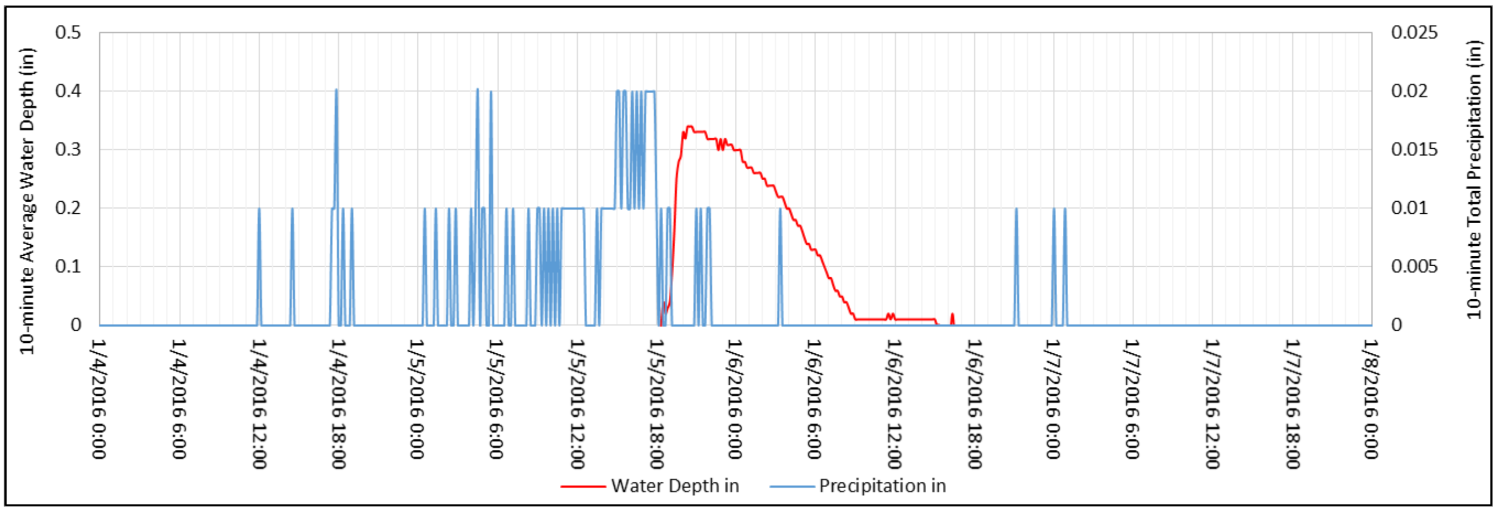


Figure 9. Total precipitation and average water depth in the flume for 10-minute measurement periods for the precipitation and flume flow recorded January 5 through 6, 2016.

precipitation occurred between 1400h and 1800h on January 5, 2016. Flow through the flume began at 1830h and peaked with a water depth of 0.34 inch at 2020h on January 5, 2016. The peak flow in the flume occurred approximately two hours after the long period of light precipitation. The recession limb of this hydrograph dropped consistently to a depth of approximately 0.01 inch at 0900h on January 6, 2016. A consistent flow depth (0.01 inch) was reported throughout the next nine hours, and then dropped to zero. This plateau in the hydrograph is believed to be the result of the accumulation of wet sediment packed around the pressure transducer inside the stilling well rather than flow through the flume. The actual flow event appears to have lasted approximately 14.5 hours. The shallow water level during this flow event is below the low value for the flume discharge rating table but suggests a discharge value of approximately 0.015 cfs.

Another winter storm passed through the area on January 31, 2016. The storm produced a total of 0.53 inch of precipitation over a seven hour period that lasted from 1100h to 1810h. Maximum 10-minute precipitation intensity was approximately 0.04 inch at 1520h and again at approximately 1650h (Figure 10). Flow through the flume was first indicated approximately 20 minutes after the first recorded precipitation, when the average 10-minute water depth in the flume increased to approximately 0.1 inch. Flow increased continuously at a rate of approximately 0.36 inch per hour to a peak of 2.49 inches (0.17 cfs) for the 10-minute period ending at 1710h. Flow decreased at an irregular rate from the peak (averaging approximately 0.13 inch per hour) until it reached a depth of 1.73 inches at approximately 1740h. Flow depth then declined continuously at approximately 0.3 inch per hour until 0510h on February 1, 2016, when flow returned to zero. The flow through the flume lasted approximately 17 hours and 50 minutes: 5 hours 40 minutes for the rising limb and 12 hours for the recession limb.

Table 6 shows that flow through the flume typically peaks approximately 30 minutes after the maximum 10-minute precipitation has occurred. The exception is the January 5, 2016, flow event that peaked almost three hours after the peak rainfall. This precipitation event consisted of more than 30 hours of sporadic, low-intensity rainfall. Four hours on the afternoon of January 5, 2016, was the only period of continuous precipitation.

Flow velocities in excess of three feet per second (fps) cause erosion in natural channels. The velocity of flow during the runoff events observed during FY2015 and FY2016 was estimated using the indicated discharge and the surveyed channel geometry (Table 6). Only the event of August 1, 2015—during which the flume was overtopped—had a velocity in excess of 3 fps. Therefore, it was the only runoff event during these two years when channel sediment might have been moved downstream.

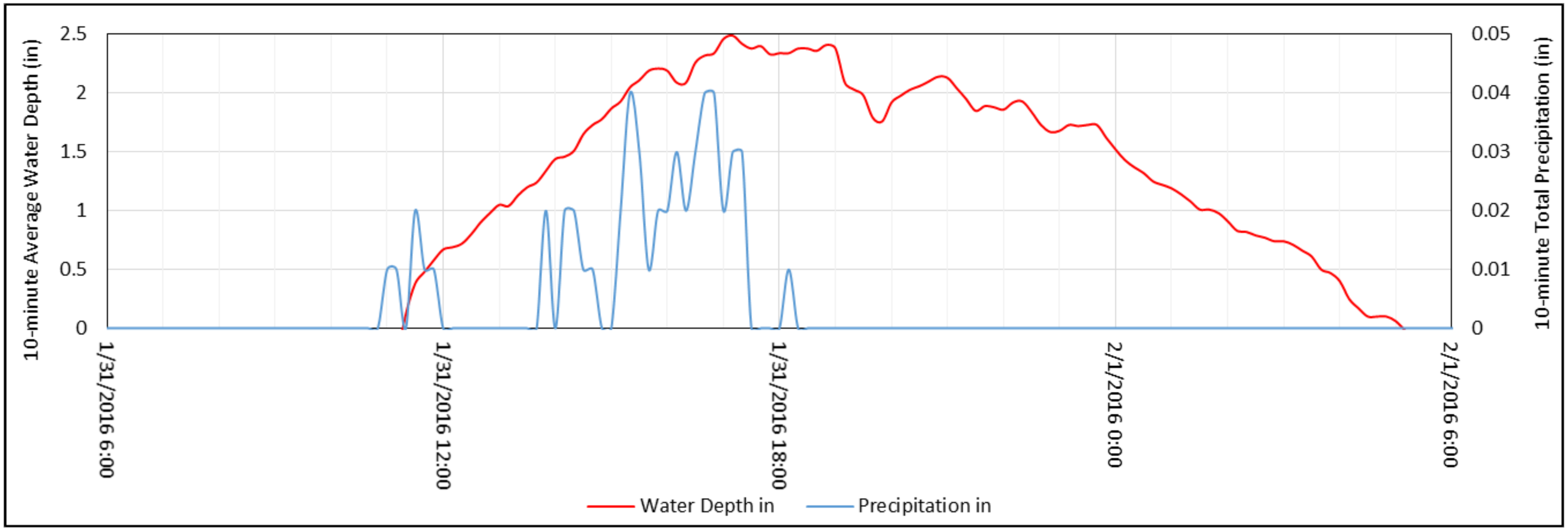


Figure 10. Total precipitation and average water depth in the flume for 10-minute measurement periods for the precipitation and flume flow recorded January 31 through February 1, 2016.

Table 6. Peak precipitation and runoff characteristics for FY2015 and FY2016.

Precipitation			**Flow**				**Time between Peak precipitation and Runoff Depth**
Peak Time	**Peak Precipitation**	**Total Precipitation**	**Peak Time**	**Peak Depth (inches)**	**Peak Discharge (cfs)**	**Estimated Flow Velocity (fps)**	
July 1, 2015 2300	0.2	0.35	July 1, 2015 1130	8.81	1.25	0.9	30 min
July 2, 2015 2200	0.18	0.2	July 2, 2015 1030	6.55	0.79	0.6	30 min
August 1, 2015 1250	0.52	1.07	August 1, 2015 1320	26.63	6*	4.5	30 min
January 5, 2016 1730	0.02	0.78	January 5, 2016 2020	0.34	0.015*	0.01	2 hr 50 min
January 31, 2016 1640	0.04	0.53	January 31, 2016 1710	2.49	0.17	0.1	30 min

* These values are estimated because the observed water level was outside the range of the flume discharge rating table.

Related Hydrologic Data

Soil moisture is measured over the top four inches 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 soil moisture content ranged between 0.089 (8.9 percent) and 0.276 (27.6 percent) during FY2015 and between 0.074 (7.4 percent) and 0.308 (30.8 percent) during FY2016 (Figure 11). The minimum soil water content values occurred in late November of 2015 and in late September of 2016. The fall season low soil moisture conditions occur after the summer thunderstorm season and prior to the winter frontal storm season. The highest reported water content in FY2015 was recorded on January 27, 2015, which can be associated with a storm of a maximum precipitation intensity of approximately 0.06 inch in 10 minutes. The low-intensity storm lasted a total of approximately 18 hours, but most of the soil water change occurred during the last hour of the storm. The maximum soil water content in FY2016 occurred in October 2015 in association with a precipitation event that recorded an intensity of 0.3 inch in 10 minutes. The magnitude of the soil water content response to individual precipitation events appears to be dependent on the intensity and duration of the precipitation and the antecedent soil water conditions.

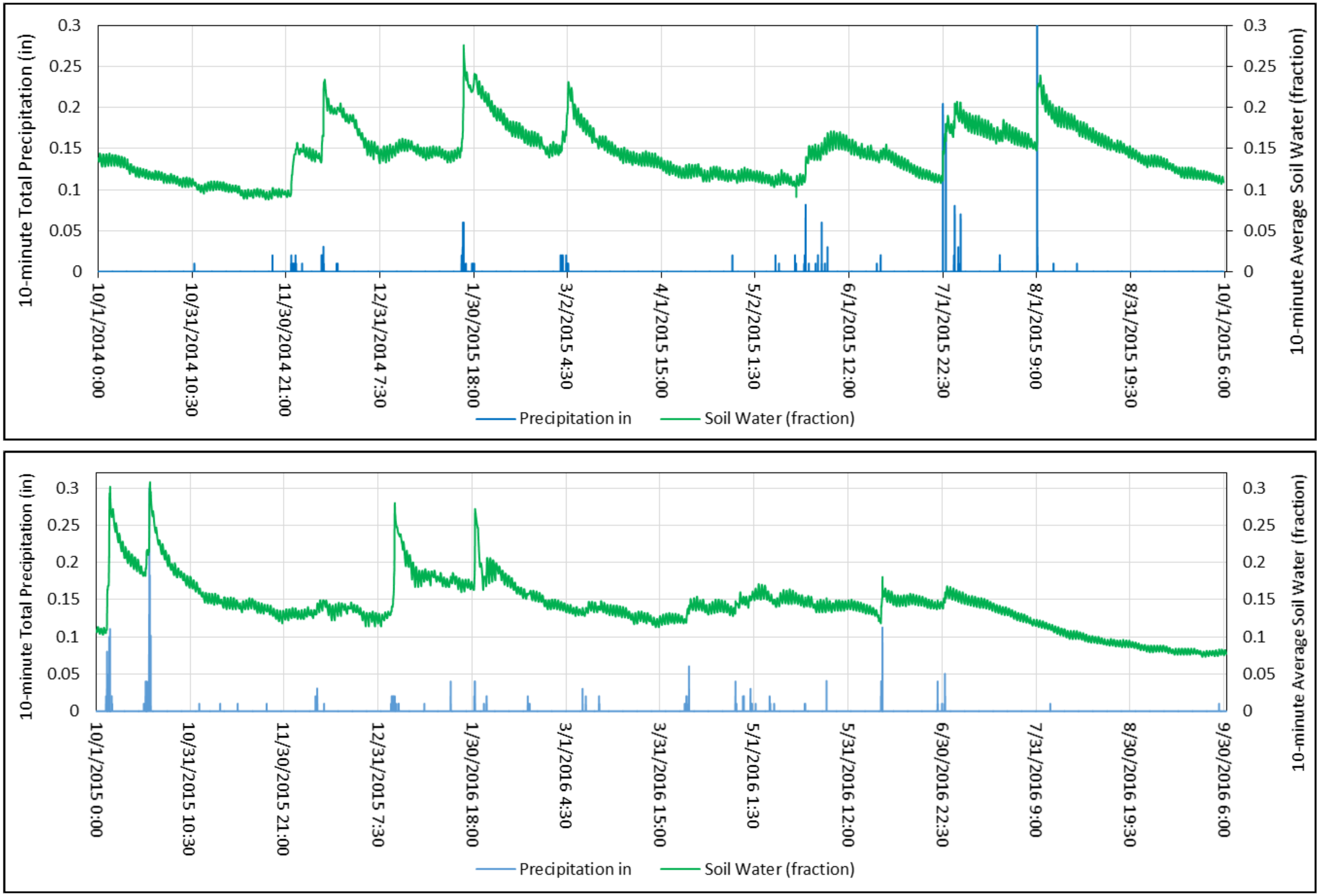


Figure 11. Soil water content over the upper four inches of soil responded to most precipitation events during FY2015 and FY2016.

Soil Particle Size Distribution and Radionuclide Analysis

No bed-load samples were collected for radionuclide analysis during FY2015 or FY2016.

CONCLUSIONS

1) In July 2015, the reported water depth in the flume exhibited positive correlation with air temperature, which is anomalous. This phenomenon had been observed previously and had been addressed by using the transducer temperature measure to adjust the water depth values under the assumption that the pressure and temperature sensors are inundated at the same time. Observation of this behavior in July 2015 is likely the result of the temperature sensor in the transducer being exposed to the air while the pressure sensor remained submerged, and therefore an additional correction was required. The Geokon transducers used during this time period were replaced with Campbell Scientific transducers in January 2017, after the reporting period for this report. It is expected that the design of the Campbell transducers will eliminate this diurnal temperature response by the pressure transducer under specific soil moisture conditions.
2) Short-duration, high-intensity precipitation events produced short-duration runoff events during which significant water depth was reported in the flume. These events occurred in July 2015, August 2015, October 2015, and June 2016. Flow in the flume was recorded following the July and August 2015 events. The transducer installed to detect water depth in the flume was not operational during October 2015. Although precipitation intensity exceeded 0.1 inch per 10-minute interval in June 2016, the precipitation was not enough to cause flow through the flume.
3) The runoff event on January 5, 2016, shows that the lower-intensity, longer-duration precipitation events associated with winter frontal storms can produce runoff. However, neither the January 5, 2016, nor the January 31, 2016, runoff events had sufficient velocity to cause erosion and transport sediment.

RECOMMENDATIONS

The August 1, 2015, storm/runoff event overtopped the flume. Although this flow did not damage or destroy the flume, which happened in FY2013, it gives further evidence that the six-inch Parshall flume is not large enough to convey the runoff that is commonly occurring in the instrumented watershed. It is recommended that the six-inch flume be replaced with a larger flume or a weir. To facilitate the collection of bed-load samples following runoff events, sediment traps should be constructed and installed to ensure that samples are collected from consistent locations in the channel.

FUTURE WORK

Data transmitted from the Smoky CA instrumentation will be reviewed monthly by project personnel to identify precipitation events that exceed the specified rainfall threshold (~0.2 inch [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 characterize the meteorological conditions that produced the runoff. This analysis will help delineate threshold conditions that are likely to result in sediment transport and radionuclide migration in conjunction with the sediment. Establishment of these thresholds will help identify meteorological conditions that may require monitoring and sampling of channel runoff migration pathways under a closure plan. Requirements for monitoring meteorological conditions and sampling runoff pathways can then be appropriately incorporated into closure plans. Because they are located inside the CA, any service work on the flume or datalogger and communication equipment associated with the flume will require the support of a radiological control technician.

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Colton, D., 1999. A series of low-altitude aerial radiological surveys of selected regions within areas 3, 5, 8, 9, 11, 18, and 25 at the Nevada Test Site. DOE/NV/11718-362, prepared for the U.S. Department of Energy, Nevada Operations Office by Bechtel Nevada.

Mizell, S.A., J.J. Miller, G.D. McCurdy, and S.A. Campbell, 2017. Monitoring Potential Transport of Radioactive Contaminants in Shallow Ephemeral Channels: FY2013 and FY2014 (revised). DOE/NV/0000939-42, prepared for the U.S. Department of Energy, Nevada Field Office. Las Vegas, Nevada.

Traynor, J., personal communication, 2011.

APPENDIX A: FY2015 10-MINUTE METEOROLOGICAL OBSERVATIONS FOR THE SMOKY SITE

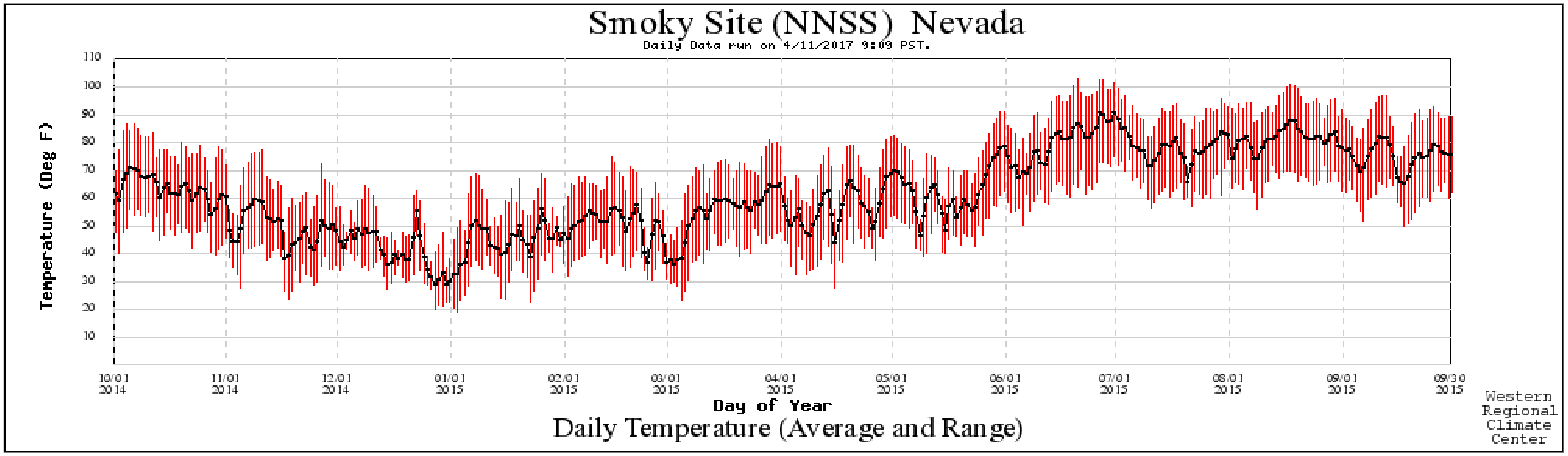

Figure A-1. Daily average, maximum, and minimum air temperature observed at the Smoky Site meteorological station during FY2015. Data depict short-term variations superimposed on the expected seasonal trend.

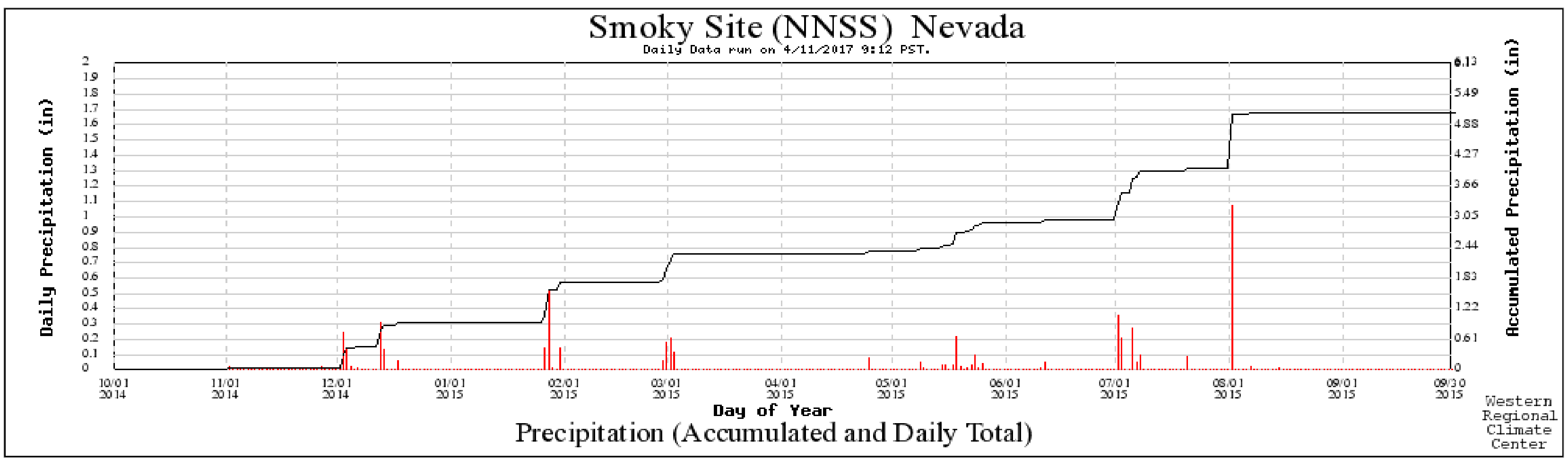

Figure A-2. Daily and cumulative precipitation measured at the Smoky Site meteorological station during FY2015. Daily precipitation equaled or exceeded 0.1 inch on fifteen days. The total FY2015 accumulation was approximately 5.14 inches.

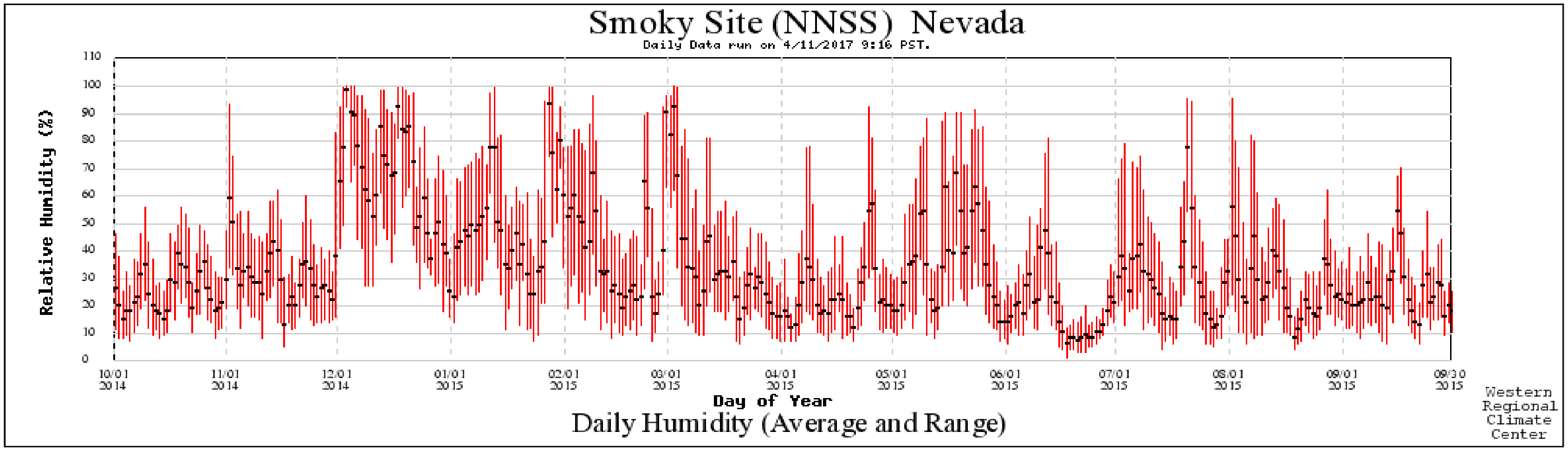

Figure A-3. Daily average, maximum, and minimum relative humidity at the Smoky Site during FY2015. The high humidity (<90 percent) in early December 2014 is associated with a series of low-intensity precipitation events.

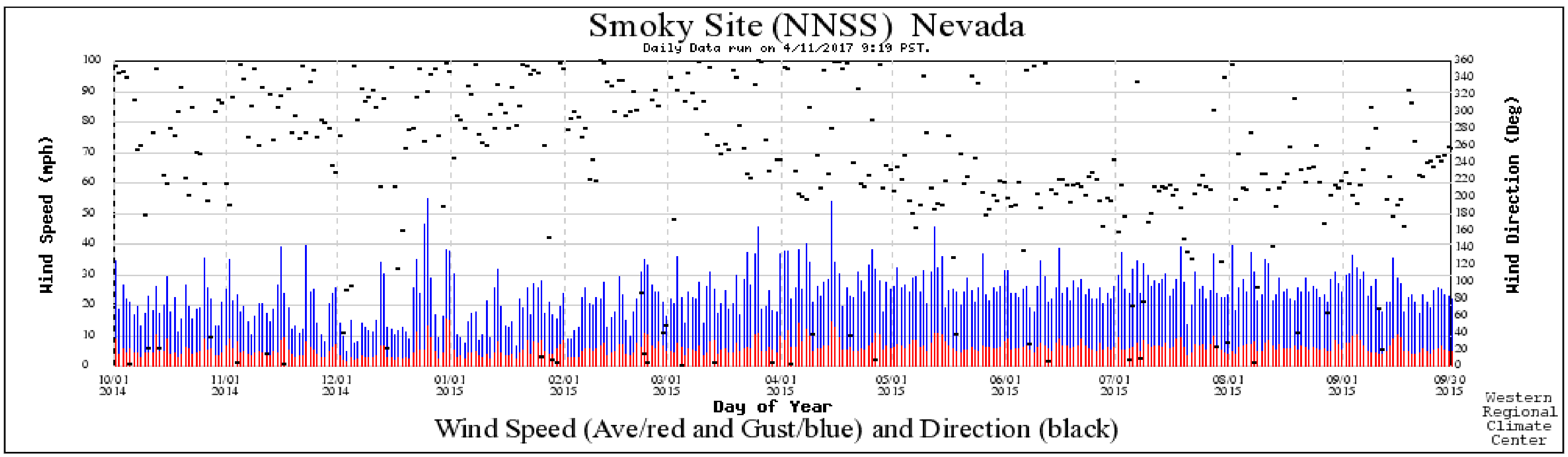

Figure A-4. Daily average and peak wind speeds and daily average wind direction at the Smoky Site during FY2015. Peak wind speed exceeded 50 mph in late December and mid-April. Generally, the wind direction tends to be from the southwest between April and September and from the northwest between October and March.

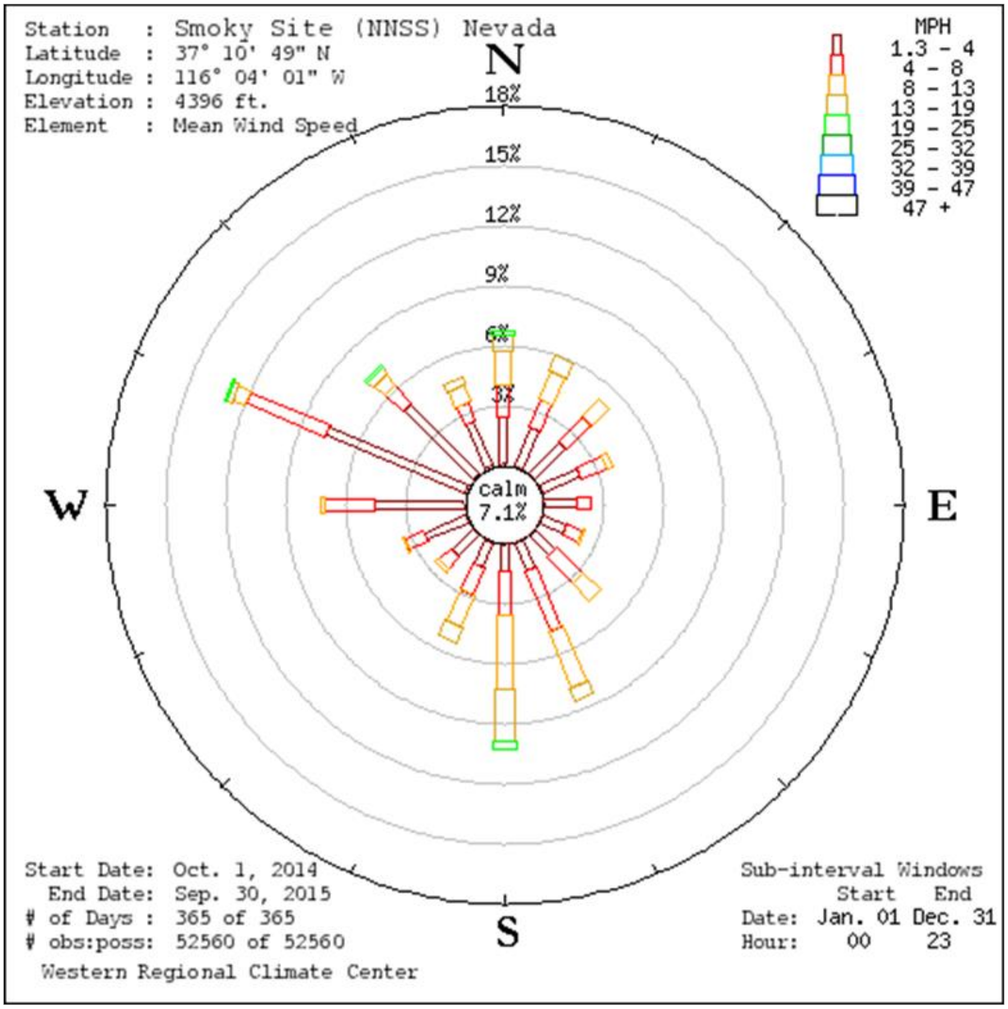

Figure A-5. The FY2015 wind rose for the Smoky Site meteorological station shows stronger winds tend to come from the northwest quadrant and from the south. Winds from these directions dominate the wind pattern at the site.

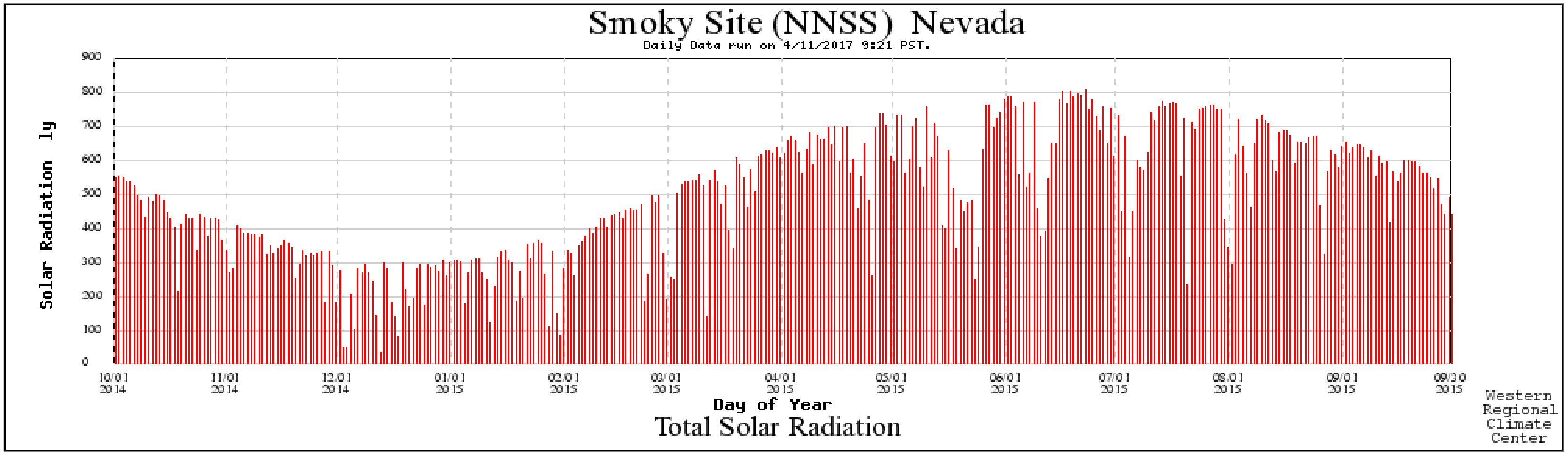

Figure A-6. Total daily solar radiation at the Smoky Site during FY2015 exhibit the expected annual trend with the greatest radiation occurring in the late spring and summer and the lowest radiation occurring in the late fall and winter. Occasions of unseasonably low solar radiation suggest cloud cover, which may be indicative of storm conditions and may occur at any time throughout the year.

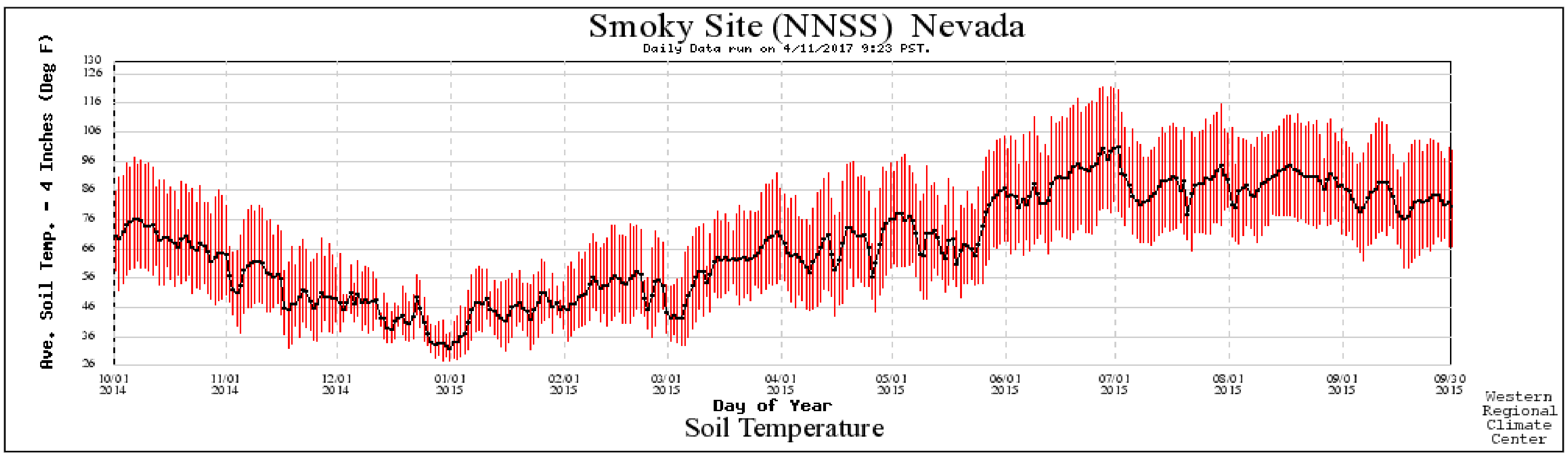

Figure A-7. Daily average, maximum, and minimum soil temperature measured at a depth of four inches at the Smoky Site meteorological station reflect a seasonal pattern similar to the air temperature. Soil temperature reflects a seasonal pattern similar to air temperature.

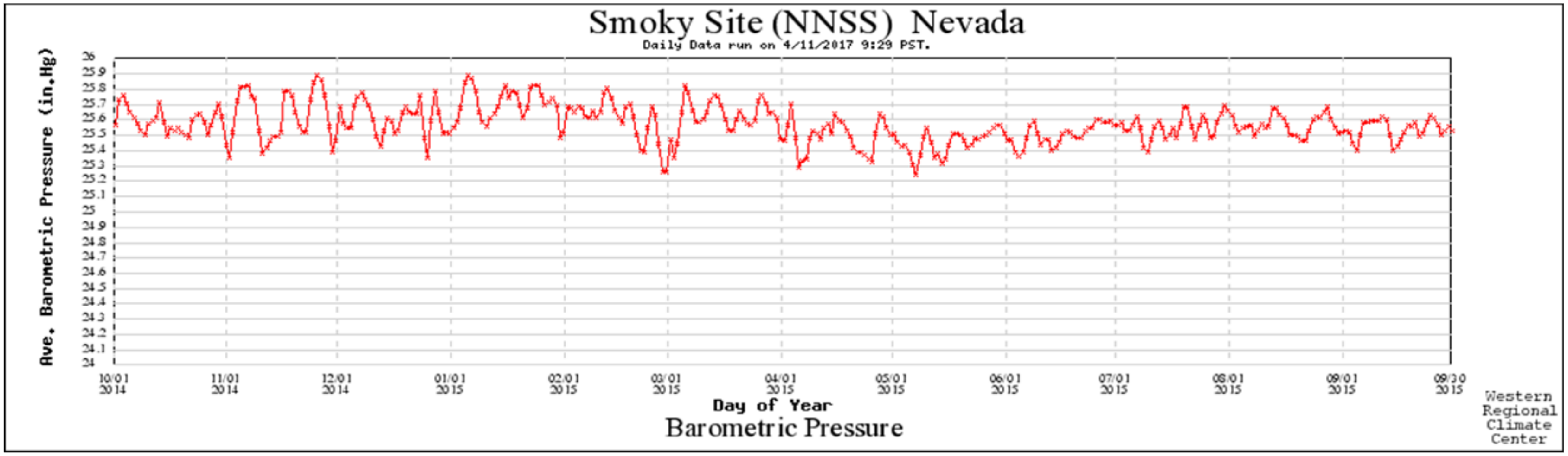

Figure A-8. Barometric pressure recorded at the Smoky Site meteorological station during FY2015 fluctuated between 25.2 and 25.9 inches of mercury.

APPENDIX B: FY2016 10-MINUTE METEOROLOGICAL OBSERVATIONS FOR THE SMOKY SITE

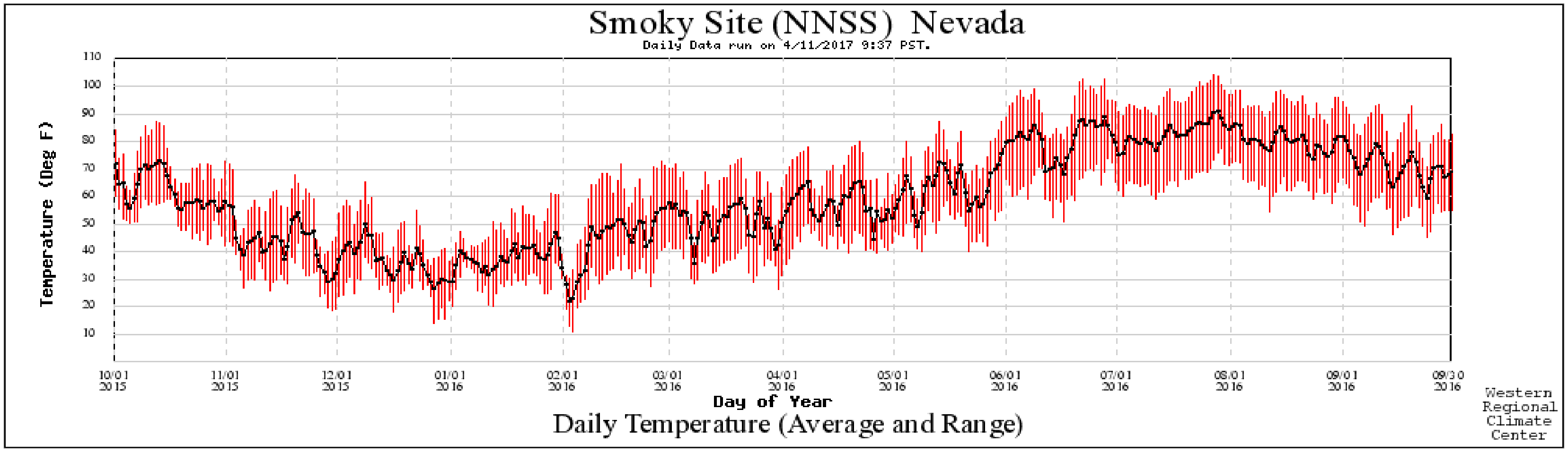

Figure B-1. Daily average, maximum, and minimum air temperature observed at the Smoky Site meteorological station during FY2016. Data depict short-term variations superimposed on the expected seasonal trend.

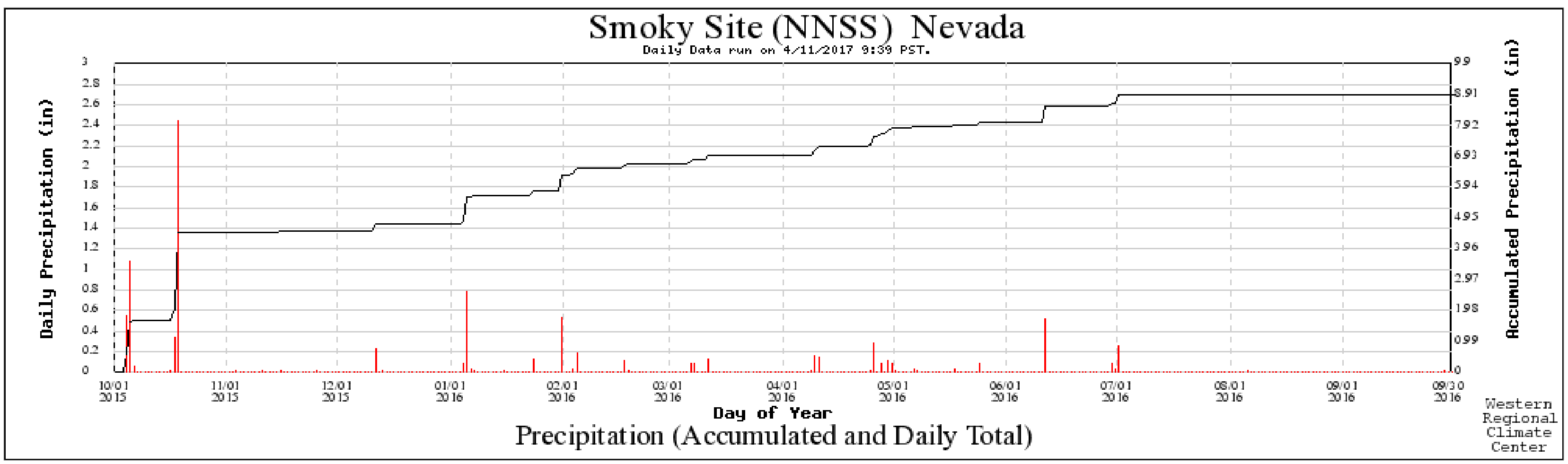

Figure B-2. Daily and cumulative precipitation measured at the Smoky Site meteorological station during FY2016. Daily precipitation equaled or exceeded 0.1 inch on 17 days. The total FY2016 accumulation was approximately 8.90 inches.

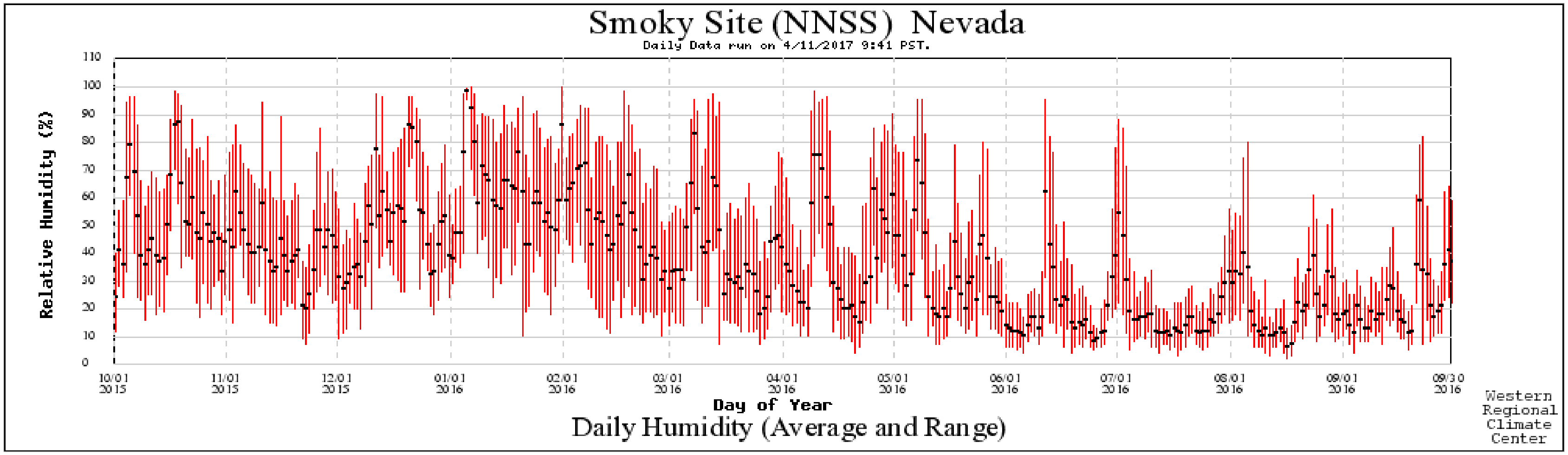

Figure B-3. Daily average, maximum, and minimum relative humidity at the Smoky Site meteorological station during FY2016. The daily average relative humidity equaled or exceeded 90 percent on 39 days.

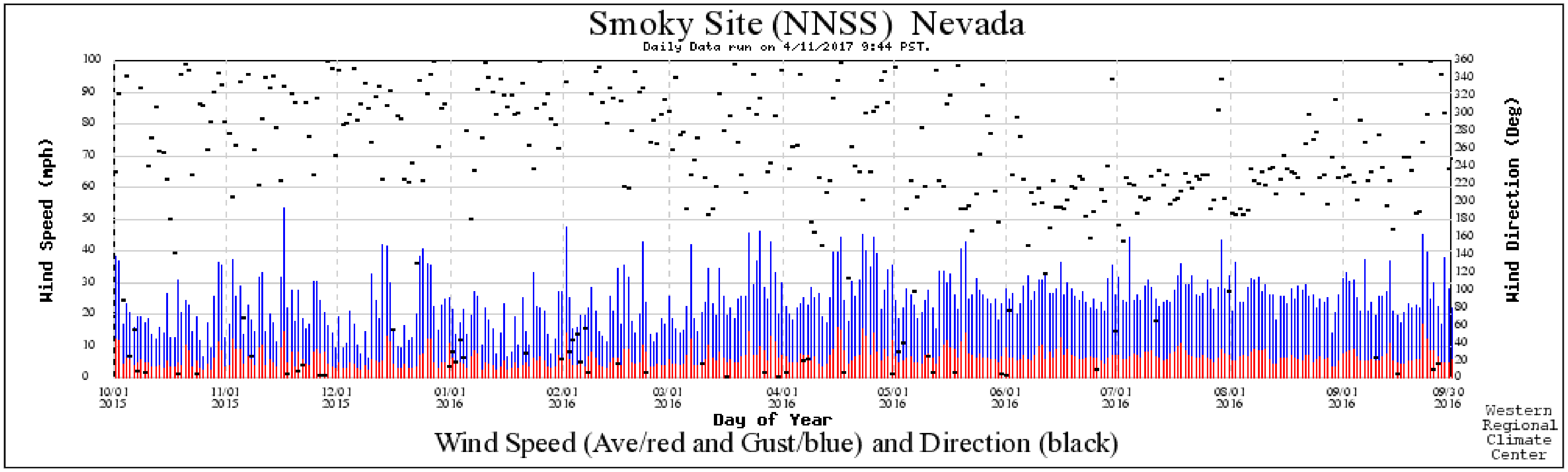

Figure B-4. Daily average and peak-gust wind speeds and daily average wind direction observed at the Smoky Site meteorological station during FY2016. Peak wind speed exceeded 50 mph once in November 2015. Wind direction tended to be from the south to southwest in June and July and from the northwest between October and March.

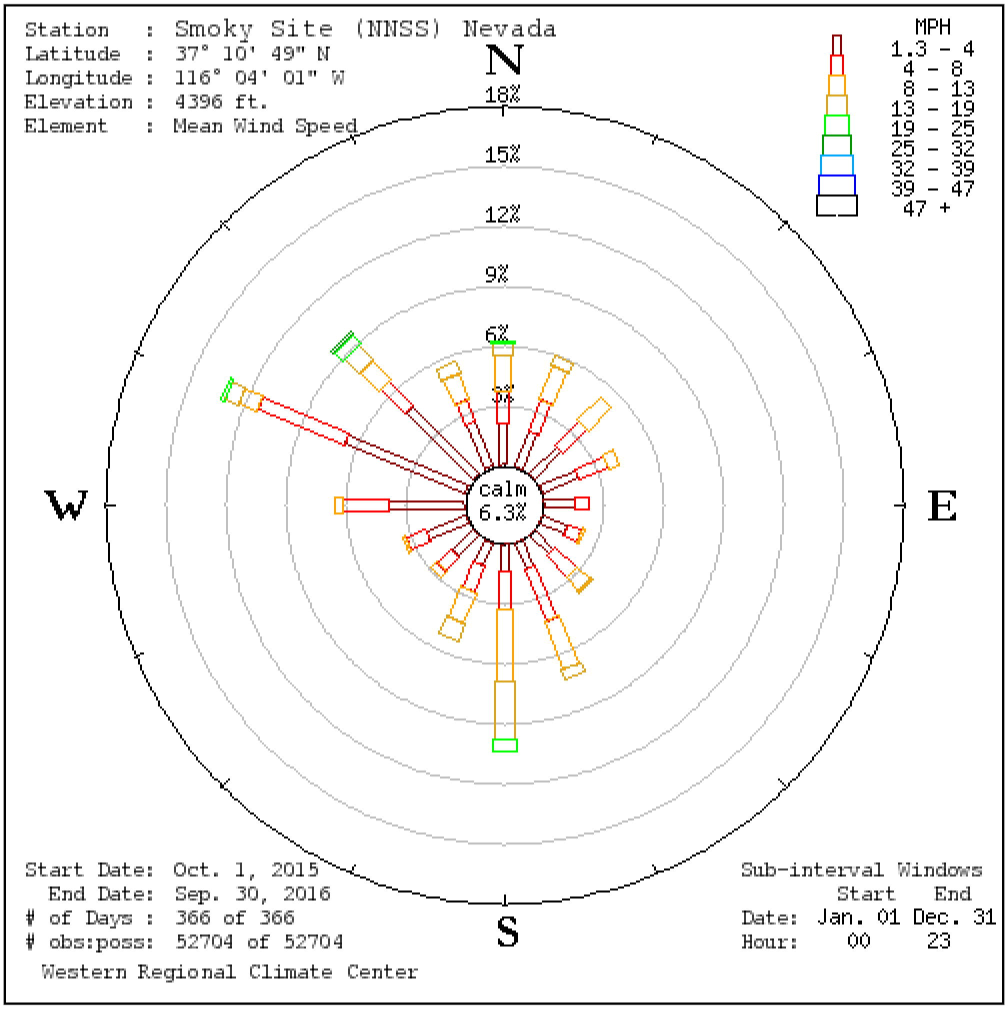

Figure B-5. The FY2016 wind rose for the Smoky Site meteorological station shows stronger winds tend to come from the northwest quadrant, and from the south. Winds from these directions dominate the wind pattern at the site.

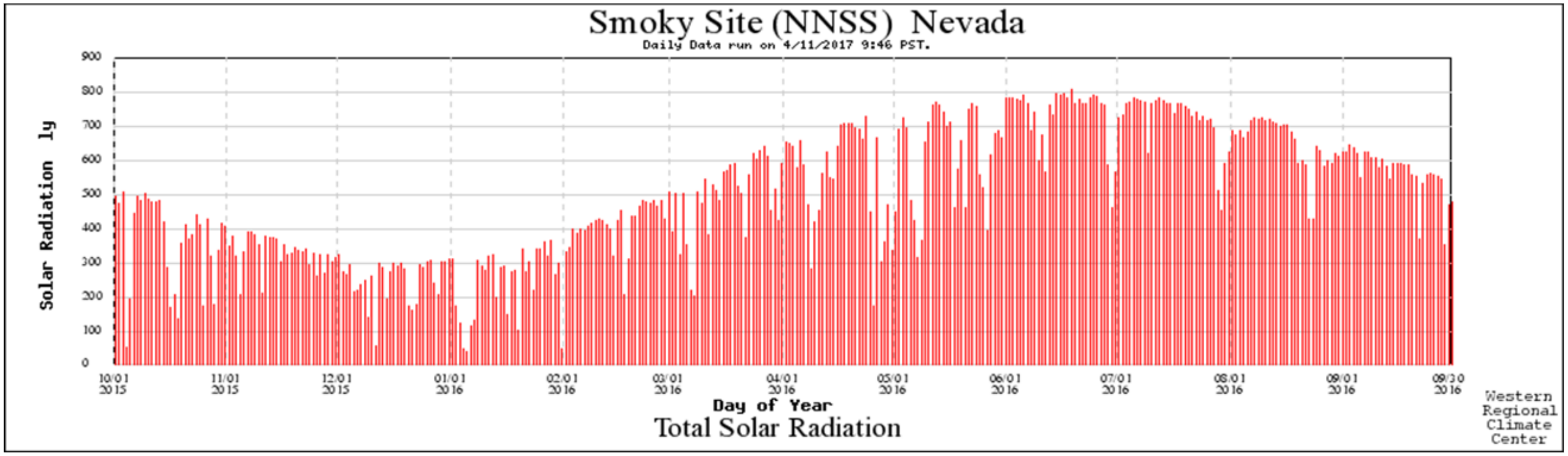

Figure B-6. Total daily solar radiation at the Smoky Site during FY2016 exhibit the expected annual trend with the greatest radiation occurring in the late spring and summer and the lowest radiation occurring in the late fall and winter. Occasions of unseasonably low solar radiation suggest cloud cover, which may be indicative of storm conditions and may occur at any time throughout the year.

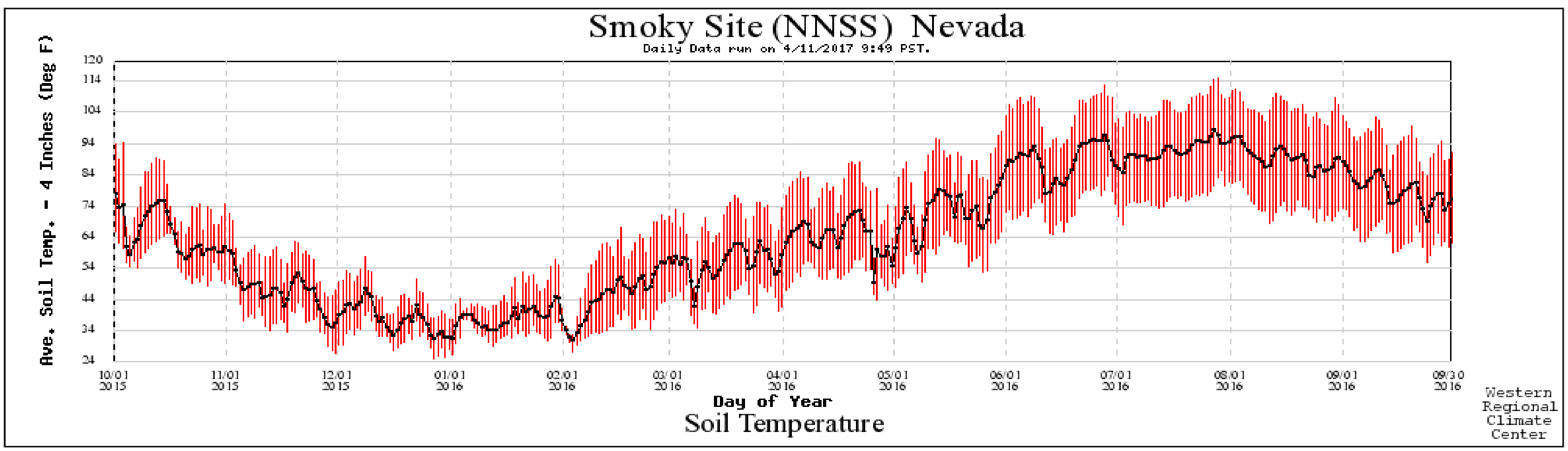

Figure B-7. Daily average, maximum, and minimum soil temperature measured at a depth of four inches at the Smoky Site meteorological station reflect a seasonal pattern similar to the air temperature.

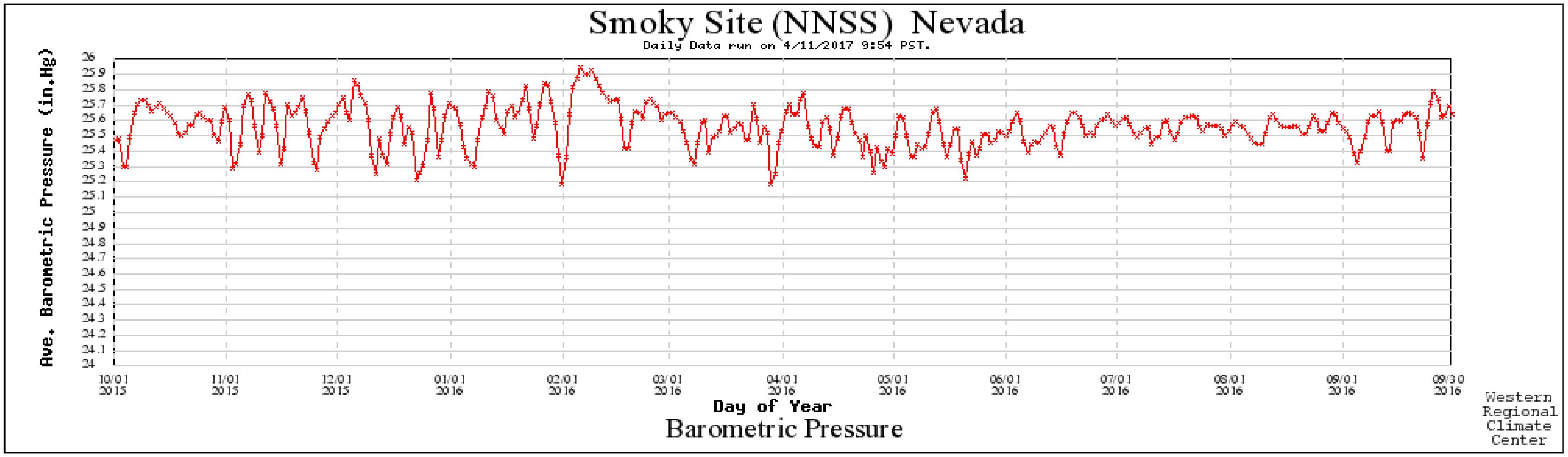

Figure B-8. Barometric pressure recorded at the Smoky Site meteorological station during FY2016 fluctuated between 25.2 and 26 inches of mercury.

APPENDIX C: HISTORY OF MONITORING ACTIVITIES AND METEOROLOGICAL AND HYDROLOGICAL OBSERVATIONS AT THE SMOKY SITE, JULY 2011 TO PRESENT

Table C-1. Smoky Site monitoring activities and meteorilogical and hydrological observations, July 2011 to present.

Date	Description
FY2011	
7/14 and 15/2011	**Meteorological station** installed with datalogger and GOES transmitter adjacent to the Smoky Site CA
7/14/2011	**Data collection initiated**
7/19/2011	**Flume installed** with satellite datalogger and radio communication to meteorological datalogger; **data collection initiated 7/20/2011**
FY2012	
7/26/2012	Download datalogger at meteorological station
7/30/2012	**Download datalogger at flume satellite station**; single bed-load sample collected below flume
8/23/2012	Download datalogger at meteorological station
9/19/2012	Download datalogger at meteorological station
FY2013	
4/19/2013	Download datalogger at meteorological station
7/26/2013	Download datalogger at meteorological station
7/28/2013	**Flume washed out** by high flow event; precipitation events recorded on 7/24 and 7/28
8/15/2013	**Download datalogger at flume satellite station;** Field personnel noted flume was moved from point of installation; collect sediment samples from channel in CA
FY2014	
10/9/2013	Download datalogger at meteorological station
1/24/2014	Download datalogger at meteorological station
3/4/2014	**Flume reinstalled**; **datalogger program revised** to record temperature at pressure transducer and perform temperature compensation using meteorological-station datalogger panel temperature; pressure sensor field tested; **flume was NOT functional 7/28/2013 through 3/4/2014**
4/1/2014 (2130) to 4/18/, 2014 (1920)	Datalogger recorded “out of range” (-9999) values, bad sensor data probably because of dry zero drift
4/4/2014	Download datalogger at meteorological station
4/19, 2014 (1010 through 1350)	Sensor malfunction unknown cause
7/6/2014 (1850 through 2120)	**Flow event**; flume mouth plugged, **flume overtopped**; sensor stilling well packed with sediment
7/6/2014 (2130) to 7/15/2014 (1200)	Datalogger recorded “out of range” values, **flume plugged at throat** causing malfunction of sensor reading

Table C-1. Smoky Site monitoring activities and meteorilogical and hydrological observations, July 2011 to present (continued).

Date	Description
FY2014	
7/15/2014	Download datalogger at flume satellite station AND at meteorological station
7/15/2014	**Second datalogger program** modification installed to apply temperature compensation to the pressure sensor output using pressure sensor temperature; stilling well cleaned, sensor tested, and reinstalled
8/3 (1450) through 8/4/2014 (1850)	**Major flow event**; flume mouth plugged, **flume overtopped**; sensor stilling well packed with sediment
8/4/2014 (1900) to 8/20, 2014 (1130)	Datalogger recorded "out of range" values; **flume plugged at throat** causing malfunction of sensor reading
8/20/2014	**Flume rebuilt**, stabilized; transducer stilling well cleaned and reinstalled; download datalogger at flume satellite station AND at meteorological station; collected channel sediment samples
FY2015	
January 16, 2015	Download datalogger at meteorological station
Week of March 29, 2015	Download datalogger at meteorological station
May 15, 2015	New batteries were installed at the meteorological station
July 1, 2015	0.2 in precipitation at met station; 18.27 in water depth at flume
July 2-3, 2015	0.18 in precipitation at met station; 15.96 in water depth at flume
August 1, 2015	0.52 in precipitation at met station; 35.7 in water depth at flume
Week of August 9, 2015	Download datalogger at meteorological station
August 23, 2015	**Water depth pressure sensor failed**; failure because of animal damage discovered XX/XX/.XXX
September 24, 2015	Battery at flume datalogger appears to be failing
FY2016	
October 1, 2015	Download datalogger at meteorological station
November 30, 2015	**Repair Geokon water depth pressure sensor** and solar power Flume reinforced with sandbags
January 5, 2016	0.02 in precipitation at met station; 10.34 in water depth at flume
January 16, 2016	Download datalogger at meteorological station
January 23, 2016	0.04 in precipitation at met station; 9.89 in water depth at flume
January 31, 2016	0.04 in precipitation at met station; 12.39 in water depth at flume
April 3, 2016	Download datalogger at meteorological station
May 15, 2016	Batteries preemptively replaced at meteorological station; no data were lost
June 7, 2016	Download datalogger at meteorological station
July 14, 2016	Download datalogger at meteorological station
August 17, 2016	**Geokon pressure sensor failed** because of animal damage, **repaired on January 24, 2017**

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