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Monitoring Potential Transport of Radioactive Contaminants in Shallow Ephemeral Channels: FY2013 and FY2014 (revised)

Prepared by

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

Submitted to

Nevada Field Office
National Nuclear Security Administration
U.S. Department of Energy
Las Vegas, Nevada

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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, which supports National 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.

The DRI 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. Temperature, wind speed, wind direction, relative humidity, precipitation, solar radiation, barometric pressure, and soil temperature 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 (revised) data collected from these stations during fiscal year (FY) 2013 and FY2014.

During this time frame, the warmest months were June and July and the coldest were December and January. Solar radiation reflects the same seasonal trend. Monthly mean wind speeds were highest in the late winter and spring (February through June). 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 low teens to greater than 40 percent. During storms, the relative humidity was approximately 100 percent. Monthly total precipitation ranged from zero to approximately three inches. The months with the highest precipitation amounts were July 2013 and August 2014. Total precipitation each year exceeded seven inches.

Two major rainfall events occurred during July 2013. The July 24, 2013, storm produced 1.01 inches of rainfall, with runoff to a depth of 10 inches measured in the flume, which correlates to an approximate maximum discharge of 1.55 cubic feet per second (cfs). The July 28, 2013, storm produced 1.38 inches of rainfall, with 21.88 inches of runoff measured in the flume, which correlates to an approximate maximum discharge of 4.01 cfs. Using surveyed channel geometry data, it is estimated that this event resulted in a flow velocity of approximately three 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. In this case, the second July runoff event excised the flume from the channel and washed it five to six feet downstream. It is likely that the runoff event velocity was enough to transport the sands from beneath the flume, undercutting the flume, which allowed the flume to become buoyant enough to be moved even at lower flow velocities. Although the flume was not operational until it was reinstalled on March 4, 2014, the pressure transducer, which remained buried in the channel bed, reported qualitative evidence of a third major runoff event in September 2013.

Diurnal and annual cycles evident in the flume water depth data prior to the flume washout led to a review of the equipment installation and datalogger processing program. It was determined that temperature data from the pressure transducer, which are used to measure water depth in the flume, were not being contemporaneously used to adjust the depth measurement. A temperature correction was applied to all pressure data collected prior to March 4, 2014, using the average transducer pressure and average ambient air temperature for each 10-minute interval in the data record. Between March 4 and July 15, 2014, the temperature correction was made using the average transducer pressure and temperature data for each 10-minute interval. After July 15, 2014, the temperature correction was applied before the sampled pressure data were summarized for the 10-minute intervals.

Major flows at the flume are associated with high-intensity, short-duration precipitation events (i.e., summer convective storms). Five major runoff events are evident in the flume water depth record during the two years reported in this document. All of these storms occurred in July, August, or September, during the summer precipitation period of convective storms.

Eight bulk channel bed samples (i.e., bedload) were collected during FY2013 and six additional samples were collected during FY2014, following runoff events. All samples were submitted for grain-size analysis, and then subsampled into three size fractions. On average, 3.8 percent of the sampled sediment was in the <63 µm size fraction, 8.5 percent was in the 63 µm to 250 µm fraction, and particles >250 µm represented 87.6 percent of the sampled material, consistent with channel bed materials.

The two smaller size fractions were submitted for laboratory analyses to determine the presence of Americium-241 (Am-241), Plutonium-238 (Pu-238), and Plutonium-239/240 (Pu-239/240), all of which were found. The radionuclide concentrations for the two size fractions were then compared using the nonparametric Kruskal-Wallis rank sum statistical test to determine if one of the smaller size fractions was more likely to have higher concentrations. Although the results are not consistent for all sample sets, this analysis suggests that these radionuclides are more likely to bind to the smaller particle size fraction than to the larger size fraction.

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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
K-W	Kruskal-Wallis
NNSA	National Nuclear Security Administration
NNSS	Nevada National Security Site
NFO	Nevada Field Office
Pu-238	Plutonium 238
Pu-239/240	Plutonium 239/240
TDR	Time domain reflectometry
USGS	U.S. Geological Survey
WRCC	Western Regional Climate Center

INTRODUCTION

The U.S. Department of Energy (DOE) National Nuclear Security Administration (NNSA), Nevada Field Office (NFO), Environmental Management's Soils Activity has authorized the Desert Research Institute (DRI) to conduct field assessments of 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 (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 weapons effects test conducted in 1964 (Mudpack [number 3]). This survey suggests radionuclide-contaminated soils may be migrating down the ephemeral channels that traverse CAU 550. This phenomenon is also suggested by the lobe of higher concentration that extends southeastward at the south end of the high-concentration area (labeled number 3 in Figure 1).

Corrective Action Unit 550 in Area 8 of the NNSS was selected for the study because the aerial survey indicates that a channel mapped on the U.S. Geological Survey (USGS) topographic map of the area traverses the south end of the area of surface contamination. This channel lies south of the point (number 3 in Figure 1) and anecdotal information indicates that sediment has been deposited on Circle Road, which borders the southeast boundary of the CAU from an adjacent channel (Traynor, personal communication, 2011). Because 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 transport of contaminated soils under ambient climatic conditions will facilitate an appropriate closure design and post closure monitoring program.

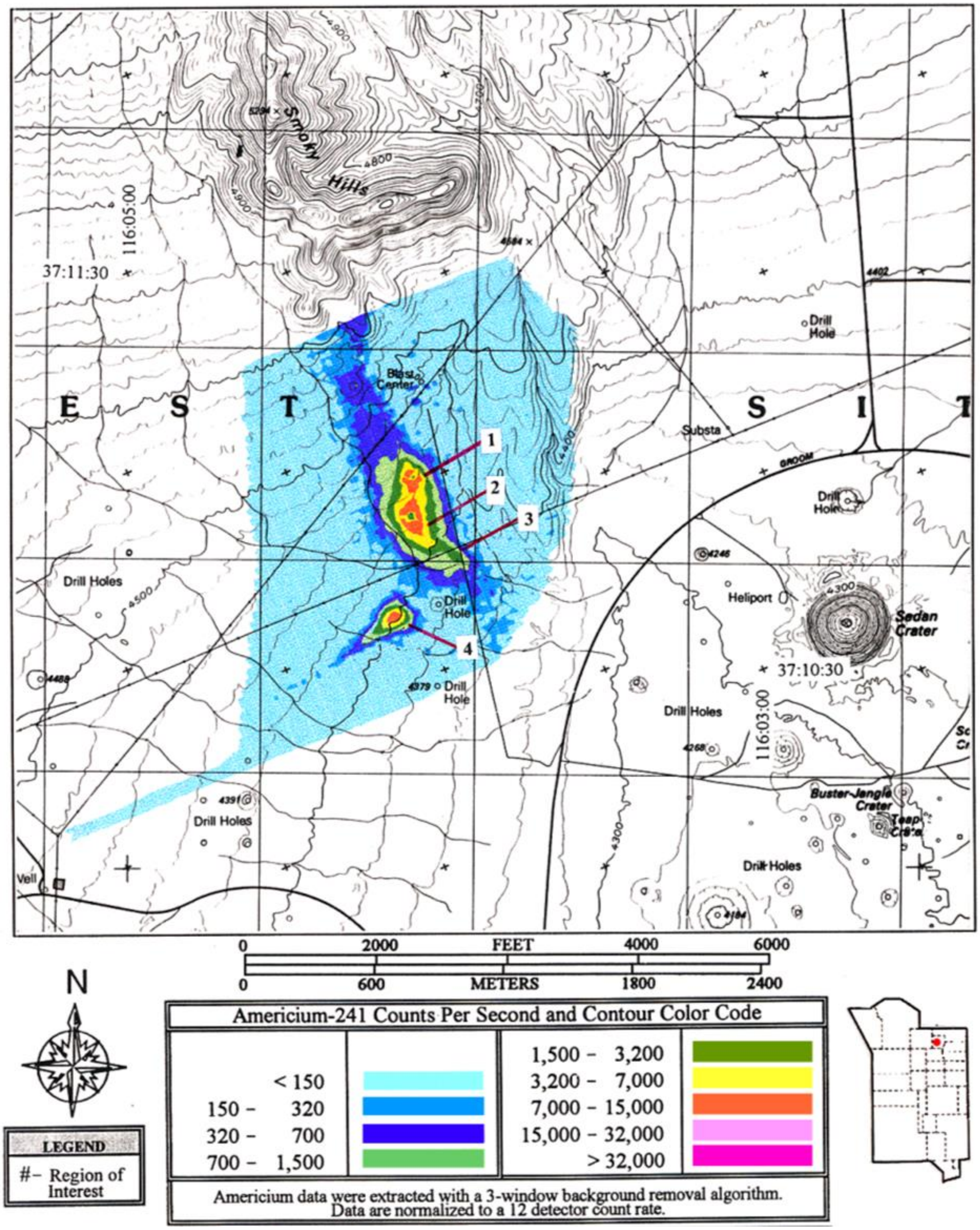


Figure 1. Americium-241 detections at the Smoky CA in northwest Yucca Flat, Nevada (Colton, 1999). Numbered markers identify ground zero for the three safety experiments Oberon (number 1), Ceres (number 2), and Titania (number 4) and the weapons test Mudpack (number 3).

BACKGROUND

The Smoky CA is located in Area 8 of the NNSS in the northern part of Yucca Flat, in southeastern Nye County, Nevada. In addition to the namesake test, Smoky, 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 weapons effect 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 shaped 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 Americium-241 (Am-241) at the center of the two surface contamination areas (Colton, 1999). Additionally, there has been measured contamination transported across Circle Road from an adjacent channel (Traynor, personal communication, 2011).

The Smoky CA is situated on the alluvial fan approximately 0.3 miles (1,000 m) south of the Smoky Hills. Mapped drainages shown on the Oak Spring, Nevada, topographic map (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 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 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 reduced ground cover immediately following the Smoky area tests.

The Desert Research Institute (DRI) proposed to perform a field scale assessment of meteorological and hydrologic conditions that would 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., bedload) for laboratory analysis after flow events. Measurements will be 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 would likely lead to the transport of soil particles, including radionuclide-contaminated soils. These thresholds will aid in establishing the conditions that would require monitoring of drainage channel transport pathways for development of a post-closure monitoring strategy.

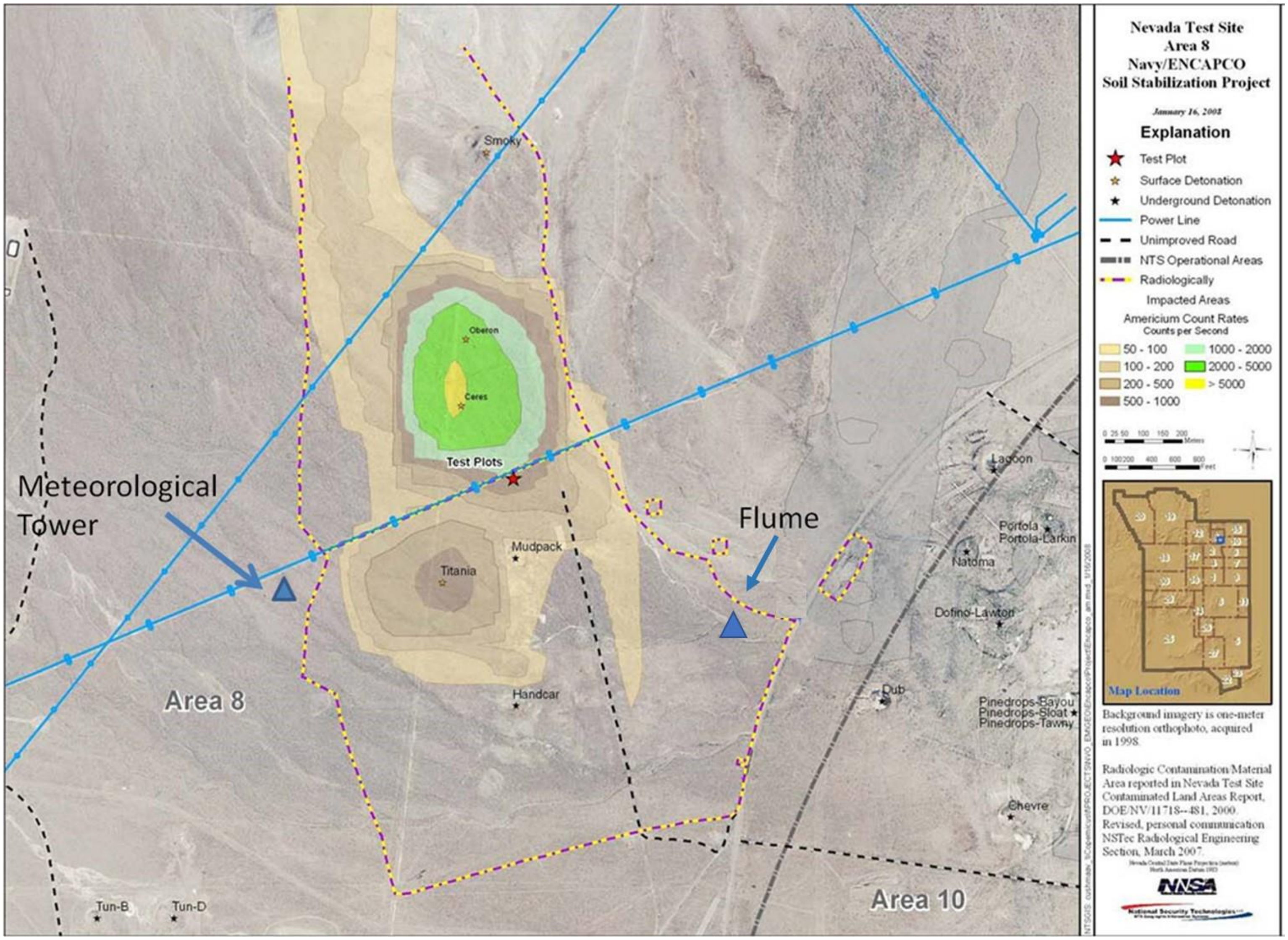


Figure 2. Approximate locations of the meteorological station and flume installations at the Smoky CA in Yucca Flat, Nevada National Security Site.

The meteorological station—including 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. Coordinates of the meteorological station are 37º 10’ 39.48” latitude and -116º 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. Smoky CA meteorological station was installed to measure precipitation, wind, and other climate parameters.

A flume to measure channelized runoff was originally to be installed between the Smoky CA boundary and the adjoining road (Figure 2). 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. Coordinates of the flume are 37º 10’ 37.13” latitude and -116º 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 permit 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 Western Regional Climate Center via GOES satellite.

FISCAL YEAR 2013 AND 2014 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 (Table 1). 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. Significant events in the data collection history at the Smoky Site and datalogger download exercises accomplished during fiscal year (FY) 2013 and FY2014 are listed in Table 1.

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

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 bedload 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

Notes: Bold black text indicates work activity accomplished on-site; bold red text indicates a critical modification to data collection procedures; bold blue text indicates flow event recorded in the flume.

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

Date FY2014	Description
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 (1010h through 1350h)	Sensor malfunction unknown cause
7/6/2014 (1850h through 2120h)	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.
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 (1450h) through 8/4/2014 (1850h)	Major flow event; flume mouth plugged, flume overtopped; sensor stilling well packed with sediment
8/4/2014 (1900h) to 8/20/2014 (1130h)	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 re-installed; Download datalogger at flume satellite station and at meteorological station; collected channel sediment samples

Notes: Bold black text indicates work activity accomplished on-site; bold red text indicates a critical modification to data collection procedures; bold blue text indicates flow event recorded in the flume.

Meteorological Observations

Ten-minute meteorological data for October 1, 2012, through September 30, 2014, have been summarized by month and year in Tables 2 and 3. Daily average values of the meteorological parameters are shown in time series plots presented in Appendices A and B. During the two-year reporting period, the monthly summary data indicate that:

1) The warmest months were June and July and the coldest were December and January. Solar radiation was highest in June and lowest in December.
2) Monthly mean wind speeds were highest in the late winter and spring (February through June). The winds were generally from the southwest during the summer and from the northwest throughout the remainder of the year.
3) Monthly average relative humidity ranged from the low teens to greater than 40 percent. Monthly precipitation ranged from zero inches to approximately three inches; the highest monthly rainfall amounts occurred in July 2013 and August 2014. Total rainfall each year exceeded seven inches.

Table 2. Monthly meteorological observations at the Smoky Site, NNSS, during FY2013.

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-12	13821	4.9	296	35.4	60.7	75.1	94	46.6	35	65.9	101	43	34	98	05	25.57	1.20
Nov-12	9127	4.9	274	36.9	49.6	63.7	78	36.8	21	52	79	31	43	98	07	25.63	0.14
Dec-12	7170	4.9	316	42.4	38.6	48.9	66	29.1	16	40.4	65	27	60	99	16	25.53	0.64
Jan-13	9045	5.7	322	53.3	35.1	50.5	65	22.7	03	36	57	16	48	100	09	25.66	0.59
Feb-13	11596	6.4	326	39.5	40.3	54.2	66	26.5	17	43.5	64	29	39	97	07	25.58	0.00
Mar-13	16133	6.5	295	48.8	53	66.9	81	38.8	27	57.4	86	36	32	99	02	25.55	0.28
Apr-13	18187	8.2	322	51.7	59.7	73.5	90	43.4	28	68.4	102	42	21	78	03	25.48	0.00
May-13	17593	7.4	307	34.7	66.2	79.6	92	50.6	40	75.9	104	51	23	94	02	25.5	0.41
Jun-13	21733	6.6	202	38.5	79.7	94.3	108	61.3	54	90	121	64	13	48	00	25.48	0.00
Jul-13	17357	6.3	230	40.9	82.3	96.6	107	66.4	57	90.2	125	63	31	93	02	25.55	2.97
Aug-13	19477	5.8	209	34.3	78.3	92.2	98	63.6	56	88.2	114	68	28	94	02	25.57	0.20
Sep-13	15826	5.9	285	45.5	69.9	83.2	95	56.6	39	77.7	107	50	37	94	04	25.51	0.69
FY2013	*177065*	*6.1*	*282*	*53.3*	*59.5*	*73.2*	*108*	*45.2*	*03*	*65.5*	*125*	*16*	*34*	*100*	*00*	*25.55*	*7.12*

Table 3. Monthly meteorological observations at the Smoky Site, NNSS, during FY2014.

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-13	13719	5.4	324	63	54.8	69.1	80	40.6	30	60	90	59	34	97	00	25.56	0.98
Nov-13	9106	5.2	334	52	47.8	61	76	35.6	29	50.5	75	33	43	93	07	25.61	0.22
Dec-13	8576	4.9	333	49.1	37.5	53	65	24.3	08	37.9	62	20	42	96	07	25.19	0.31
Jan-14	9386	5.2	327	39.2	45	60.7	68	31	22	44.6	65	29	30	98	05	25.29	0.03
Feb-14	10287	5	294	41.6	45.7	59.4	73	31.6	17	49	76	26	37	98	07	25.53	0.89
Mar-14	15421	7.2	320	47.9	51	63.7	74	37.4	27	56.2	84	36	34	97	52	25.81	0.16
Apr-14	17492	7.6	301	51.3	58.4	71.5	82	43.6	31	67.1	96	40	23	90	19	25.51	0.21
May-14	20373	7.5	244	44.3	66.9	80.3	95	50.5	40	76.7	111	47	19	97	02	25.5	0.20
Jun-14	21620	6.9	205	37	77.7	91.7	101	60	52	89.1	123	62	12	34	01	25.44	0.00
Jul-14	12334	6.1	189	43	82.7	96.2	104	68.2	63	92.2	122	71	28	91	03	25.59	0.93
Aug-14	17616	5.5	215	33.9	75.7	88.3	97	61.9	58	83.5	115	63	35	99	04	25.57	3.22
Sep-14	16509	5.3	229	38.1	73.2	87	95	58.4	44	81.2	108	56	32	90	05	25.52	0.32
FY2014	*172439*	*6.0*	*276*	*63.0*	*59.7*	*73.5*	*104*	*45.3*	*08*	*65.7*	*123*	*20*	*30.8*	*99*	*00*	*25.51*	*7.47*

Hydrologic Observations

The largest flow event during FY2013 and FY2014 occurred on July 28, 2013, and washed out the flume, which was reinstalled on March 4, 2014, the earliest date when equipment and radiological control technician support were both available. Figure 6 shows that the flume was overturned by this flow event and washed downstream five to six feet from its original position. The yellow cable in the lower right corner of Figure 6 connects the pressure transducer, used to measure water depth, to the electronic datalogger. Although the flume was excised from the channel and the pressure transducer stilling well was broken off of the flume, the pressure transducer remained in the channel bed and continued to function. Therefore, during the seven months when the flume was not operating, it was possible to detect the presence of water in the channel on select occassions. During this time, flow rate estimates were made using channel cross-section data that were surveyed at the beginning of the project. When the flume was reinstalled, it was strapped to rebar that had been driven into the channel bed and additional sand bags were placed immediately adjacent to the flume to further anchor it.

Figure 6. Flume moved downstream approximately five or six feet after the July 28, 2013, storm event.

Diurnal and annual cycles in the pressure transducer data recorded prior to March 4, 2014, led to a review of the equipment installation and datalogger processing program. During the March 4, 2014, equipment reinstallation, the pressure transducer was connected to the datalogger to collect the transducer temperature as well as pressure data.

The 10-minute maximum, minimum, and average values of these parameters were recorded in the long-term data archive. On July 15, 2014, the datalogger program was modified to apply the temperature correction, using the transducer temperature, as the pressure sensor is sampled. Because actual observations of pressure and temperature are not retained in the long-term data archive, it was necessary to apply a temperature correction to 10-minute average observations for all data prior to July 15, 2014. Therefore, the temperature correction applied to the 10-minute average pressure data collected between the original equipment installation on July 19, 2011, and March 4, 2014, used the 10-minute average panel temperature from the flume datalogger rather than the transducer temperature. Ten-minute average pressure data collected between March 4 and July 15, 2014, were corrected for temperature variations using the 10-minute average transducer temperature. After July 15, 2014, all pressure data have been adjusted using the simulataneously collected transducer temperature so that the 10-minute average pressure data are automatically reported as temperature-corrected pressure data. Precipitation and depth of water in the flume (calculated using the appropriate temperature corrections described above) are presented in Figures 7 and 8 for FY2013 and FY2014, respectively.

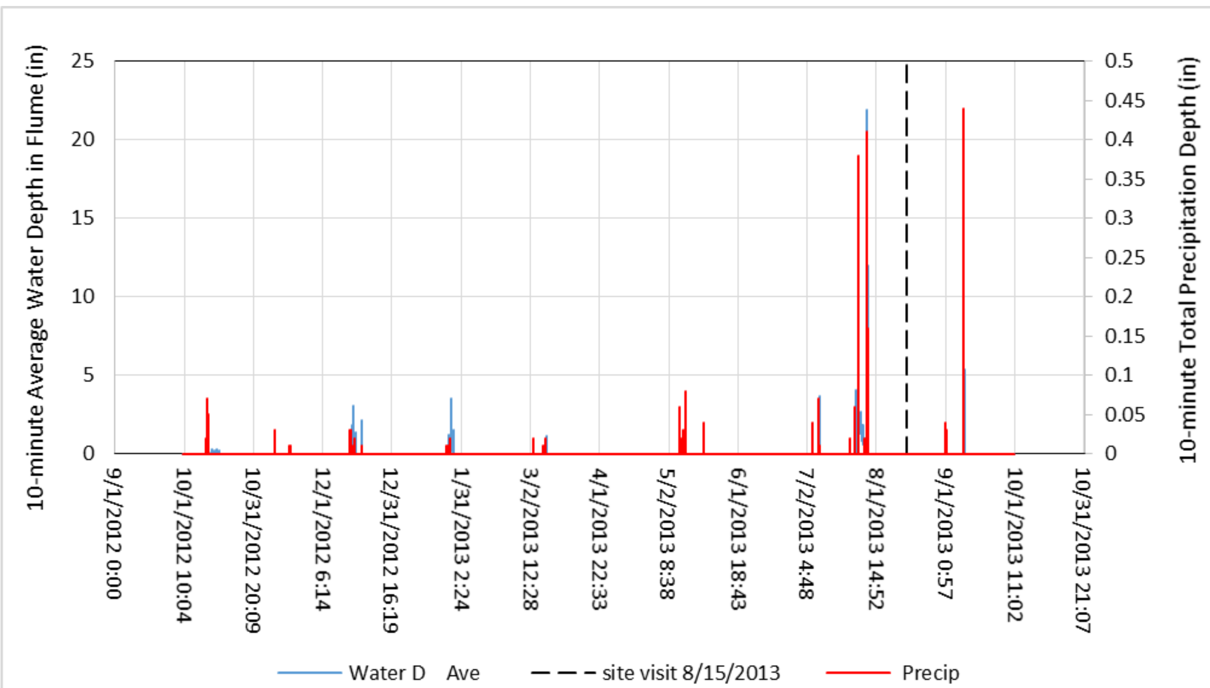


Figure 7. Ten-minute average depth of water in the Smoky Site flume and 10-minute total precipitation depth at the Smoky Site meteorological station for FY2013. Water depth in the flume is measured by the pressure transducer, which is corrected for temperature using the datalogger panel temperature at the meteorological station.

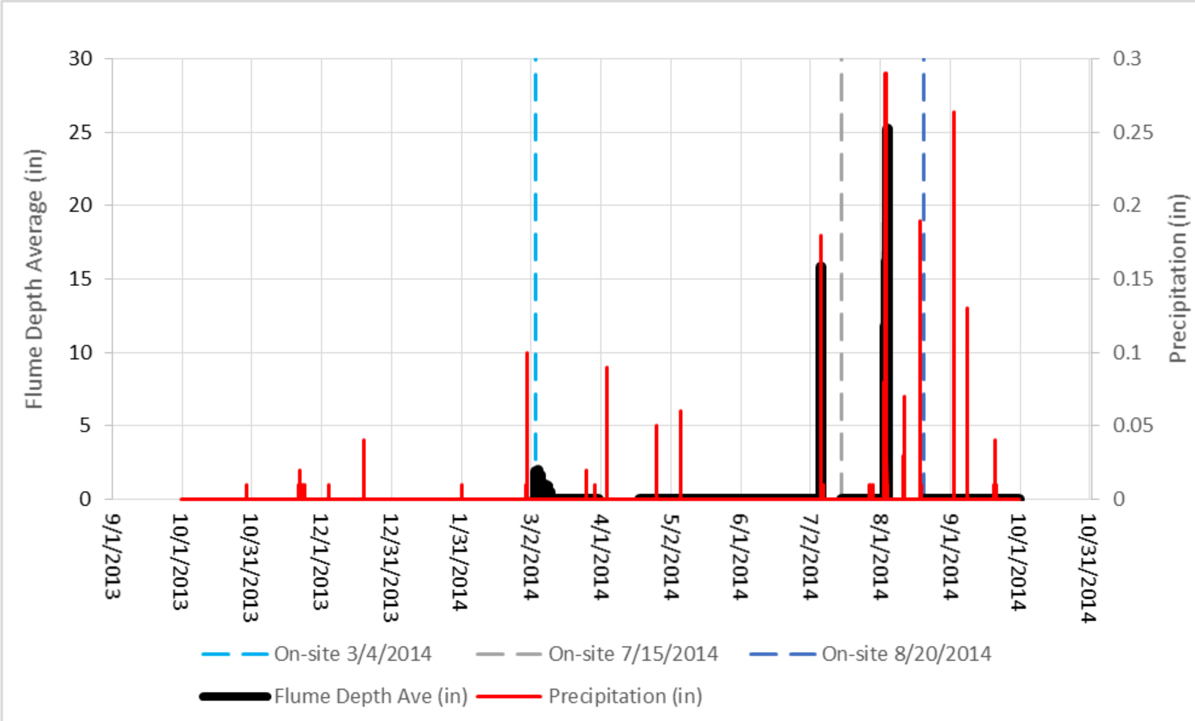


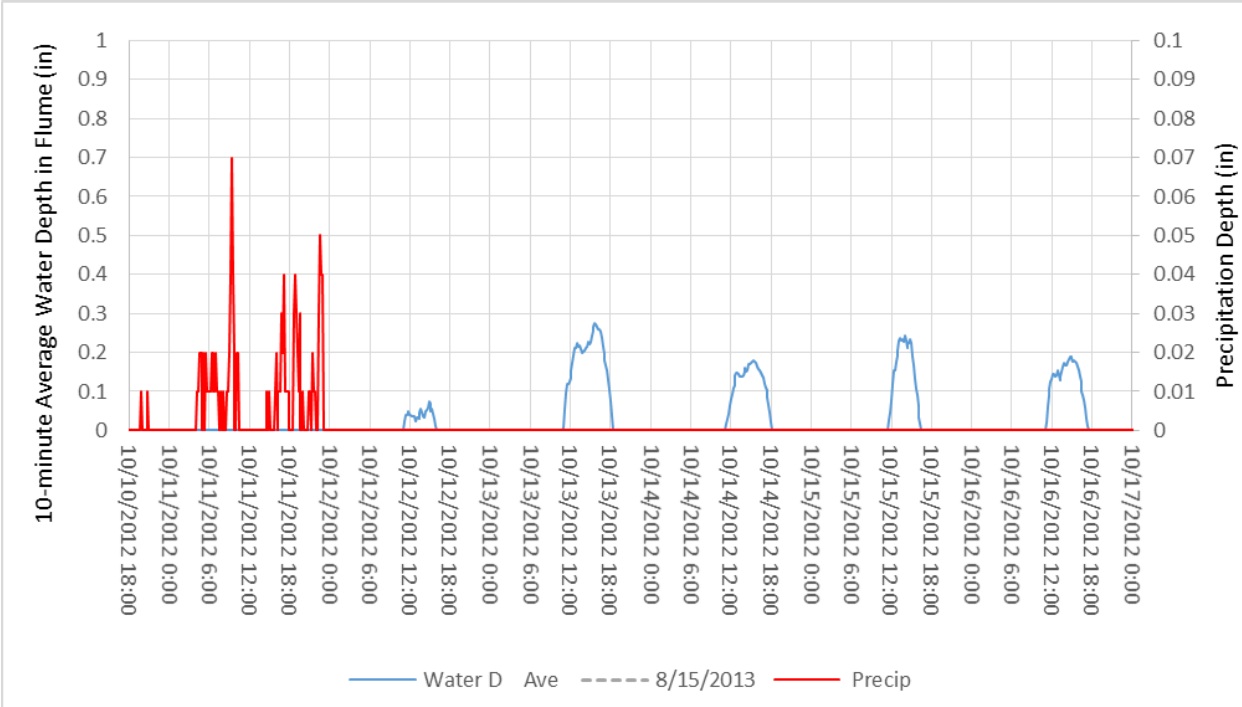
Figure 8. Ten-minute average water depth in the Smoky Site flume and 10-minute total precipitation depth at the Smoky Site meteorological station for FY2014. Water depth in the flume is measured by the pressure transducer. The 10-minute average pressure data from the transducer are corrected for temperature using the 10-minute average transducer temperature between March 4 and July 15, 2014. After July 15, 2014, the pressure data are corrected using the transducer temperature collected at the same time the pressure data are collected.

The pressure transducer indicated positive pressure measurements on fifteen occasions during FY2013 and three occasions during FY2014 (Table 4). However, only four of these events were determined to be actual flow events. A review of each of these events individually revealed that many occurred at approximately the same time of day, typically between 1200h and 1800h, and appeared to reflect a significant correlation with the diurnal 10-minute average air temperature. Although several of these events also were proceeded by a low-intensity, long-duration precipitation event, the majority of the precipitation events were not sufficient to produce measurable runoff.

Table 4. Occasions when output from the pressure transducer at the flume suggested possible flow at the Smoky Site during FY2013 and FY2014. However, only four instances were actual flow events.

Date	Depth of flow (in)	Precipitation 10-min max. (in)	Duration (hr)	Assessment
October 11-16, 2012	0.26	0.07	27.17	Artifact of temperature correction
December 13 and 14, 2012	3.00	0.03	19.67	Artifact of temperature correction
December 15, 2012	1.36	0.03	0.17	Artifact of temperature correction
December 18, 2012	2.03	0.01	6.67	Artifact of temperature correction
January 25 and 26, 2013	3.50	0.02	50.00	Artifact of temperature correction
March 9, 2013	1.01	0.02	21.83	Artifact of temperature correction
May 8, 2013	1.38	0.06	35.66	Artifact of temperature correction
July 7, 2013	3.59	0.07	4.83	Artifact of temperature correction
July 23, 2013	3.98	0.06	2.17	Artifact of temperature correction
July 24, 2013	10.08	0.38	1.00	Actual flow event
July 28, 2013	21.88	0.41	4.00	Actual flow event
September 8, 2013	8.37	0.44	2.83	Not quantifable, flume out of service
March 4, 2014	1.96	0.00	n/a	Artifact of temperature correction
July 6, 2014	15.79	0.18	1.00	Actual flow event
August 3 and 4, 2014	25.19	0.29	28.00	Actual flow event

Figure 9 clearly illustrates this type of event in October 2012. On this occasion, there was a rainfall event of approximately 27 hours duration during which only four 10-minute intervals produced 0.04 inches or more of precipitation. Total precipitation during the storm was 1.2 inches. This rainfall event was followed by five intervals over the next four days during which the pressure transducer indicated positive pressure for intervals of approximately six hours each. The first occurrence was approximately 12 hours after the last recorded precipitation and subsequent intervals of positive pressure were separated by approximately 18 hours of zero pressure. The lower graph in Figure 9 shows the strong visual relationship between the positive pressure events and the afternoon diurnal air temperature cycle. Linear regression of air temperature and pressure during the positive pressure interval resulted in correlation coefficients between 0.08 and 0.65, which indicate a weak to moderately strong correlation.



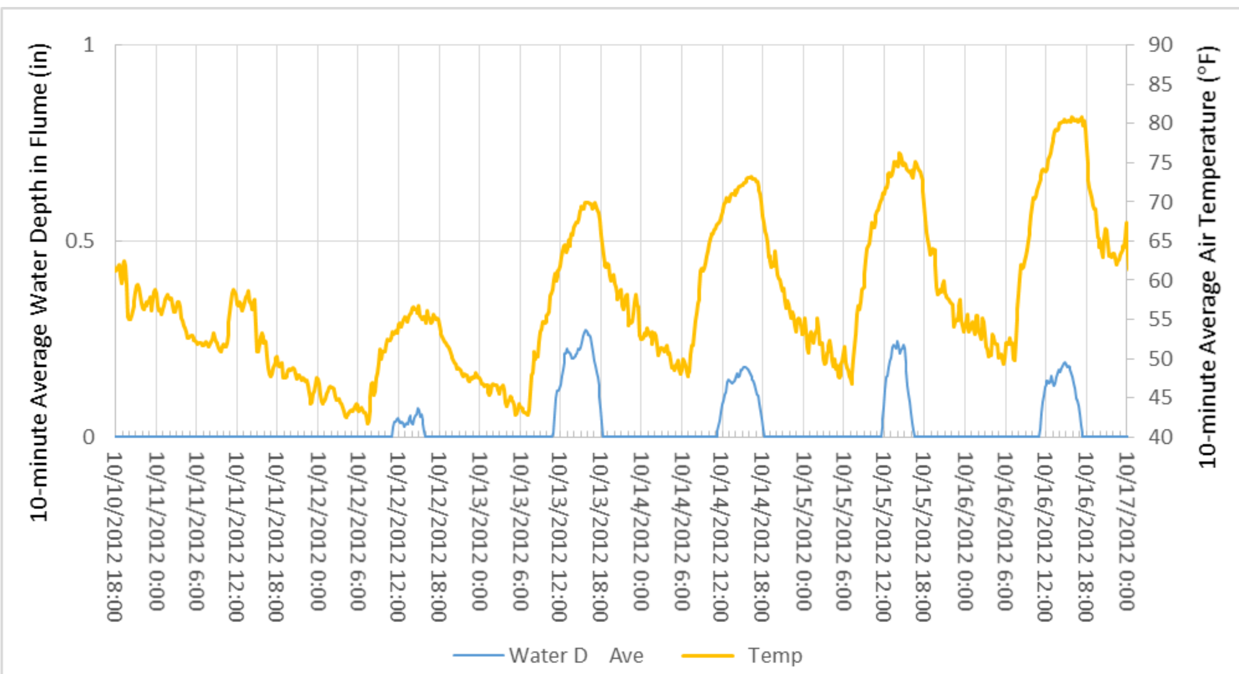
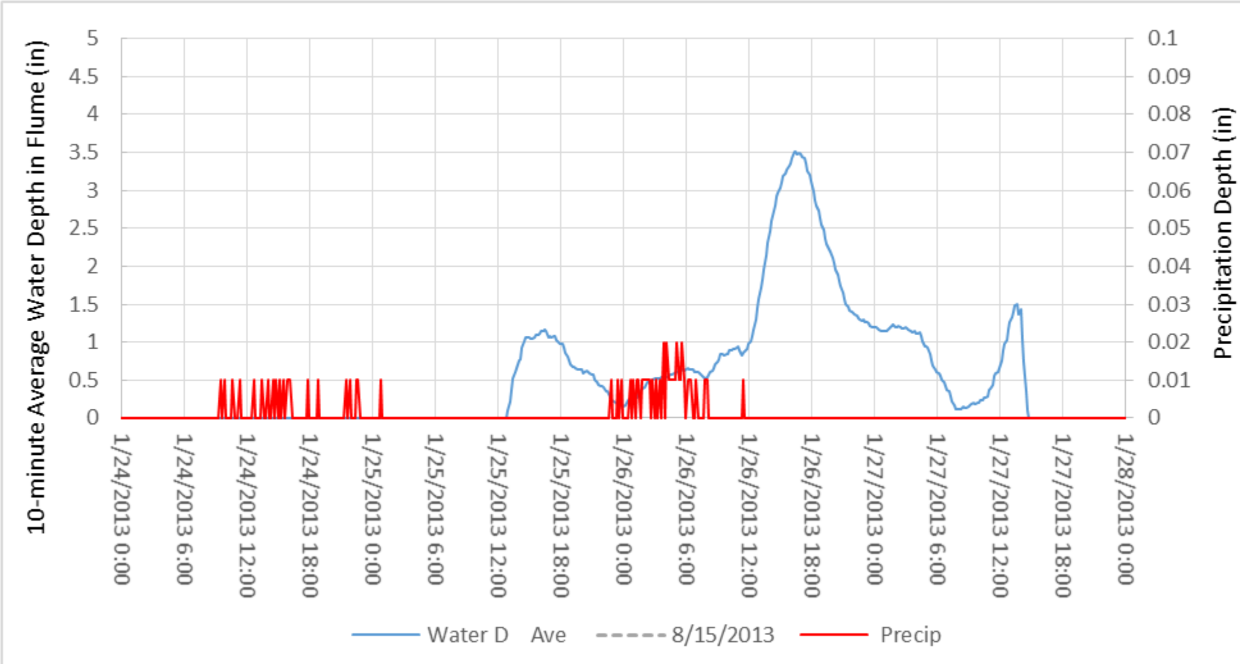


Figure 9. Signals from the pressure transducer following the October 11, 2012, precipitation event (upper graph) appear to have a significant correlation with the 10-minute average air temperature (lower graph). These afternoon pressure events are thought to be a residual effect of the temperature correction, which was based on the 10-minute average pressure and temperature.

Figure 10 shows the same phenomena but is complicated by the occurrence of two rainfall events. The first of these events began at approximately 0930h on January 24, 2013, and lasted until approximately 0100h on January 25, 2013, (storm duration of 3.34 hours) and produced a total of 0.21 inches of precipitation. However, this storm never produced more than 0.01 inches of rain during any 10-minute interval. The second rainfall event started at approximately 2250h on January 25, 2013, and lasted until 1130h January 26, 2013, (storm duration of 12.67 hours), producing a total of 0.38 inches of rainfall but never more than 0.02 inches during any 10-minute interval. The first positive pressure event began at approximately 1300h on January 25, 2013, which was approximately 12 hours after the end of the first precipitation event. The second rainfall event began just as the first positive pressure event was ending. The increasing positive pressure during the second precipitation event may be partially the result of rainfall-runoff, but the total rainfall was inadequate to produce a hydrograph with a peak of 3.5 inches and duration of 30 hours (midnight January 26, 2013, to 0800 January 27, 2013). A third positive pressure peak occurred between 0800h and 1500h on January 27, 2013. A comparison of the average 10-minute air temperature to the transducer pressure again suggests a strong correlation. Linear regression of air temperature and pressure during the positive pressure interval resulted in correlation coefficients between 0.04 and 0.69, which indicate a weak to moderately strong correlation.

It is highly improbable that the cyclic pattern of positive pressure shown in Figure 9 is indicative of water flow through the flume because there are no precipitation events coincident with the pressure events. Additionally, although the regression analyses do not indicate a perfect correlation, the regular recurrence of the positive pressure events during the afternoon hours when the diurnal air temperature is also peaking suggests a correlation with air temperature, especially as there were no corresponding precipitation events. It is likely that these events are an artifact of the process by which the temperature correction was applied to the pressure data or to a combination of damp soil or high humidity in conjunction with the temperature correction. As mentioned above, similar afternoon peaks occur in the pressure data for January 25 through 27, 2013, during and just after precipitation events. Therefore, it is difficult to separate the artifacts of the temperature correction process from actual flow events that may be associated with e low-intensity, long-duration storms. Therefore, these types of pressure events are not considered in the following discussion of the flow events that are more clearly delineated. More graphs illustrating these observations are presented in Appendix C.

In contrast to the transducer (flume) events defined by afternoon positive pressure values, there are five events in the two-year record that are characterized by short-duration flows that have a maximum flow depth in excess of 10 inches in the flume. The first two of these occurred in July 2013 (Figures 7 and 11). Between July 23 and 28, 2013, the diurnal fluctuation in pressure values is evident. However, there are two spikes in the pressure values associated with high-intensity, short-duration precipitation events that suggest runoff is passing through the flume.



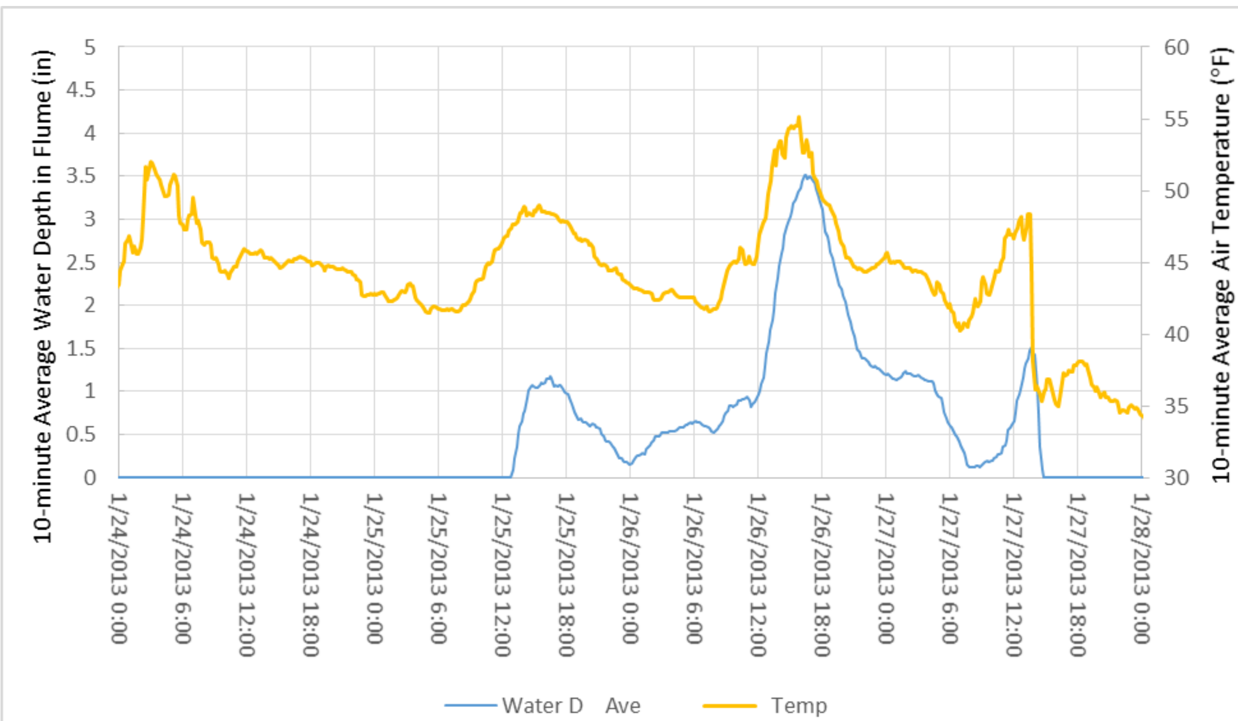


Figure 10. Signals from the pressure transducer following the precipitation events on January 24 and 26 (upper graph) appear to have a significant correlation with the 10-minute average air temperature (lower graph). These afternoon pressure events are thought to be a residual effect of the temperature correction, which was based on 10-minute average pressure and temperature.

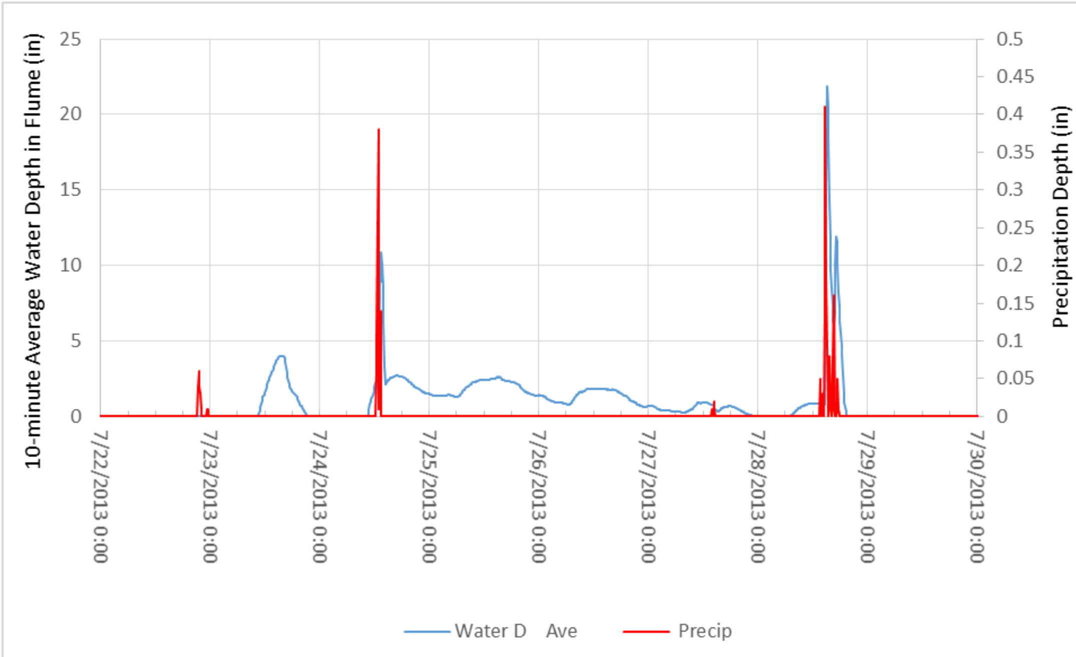
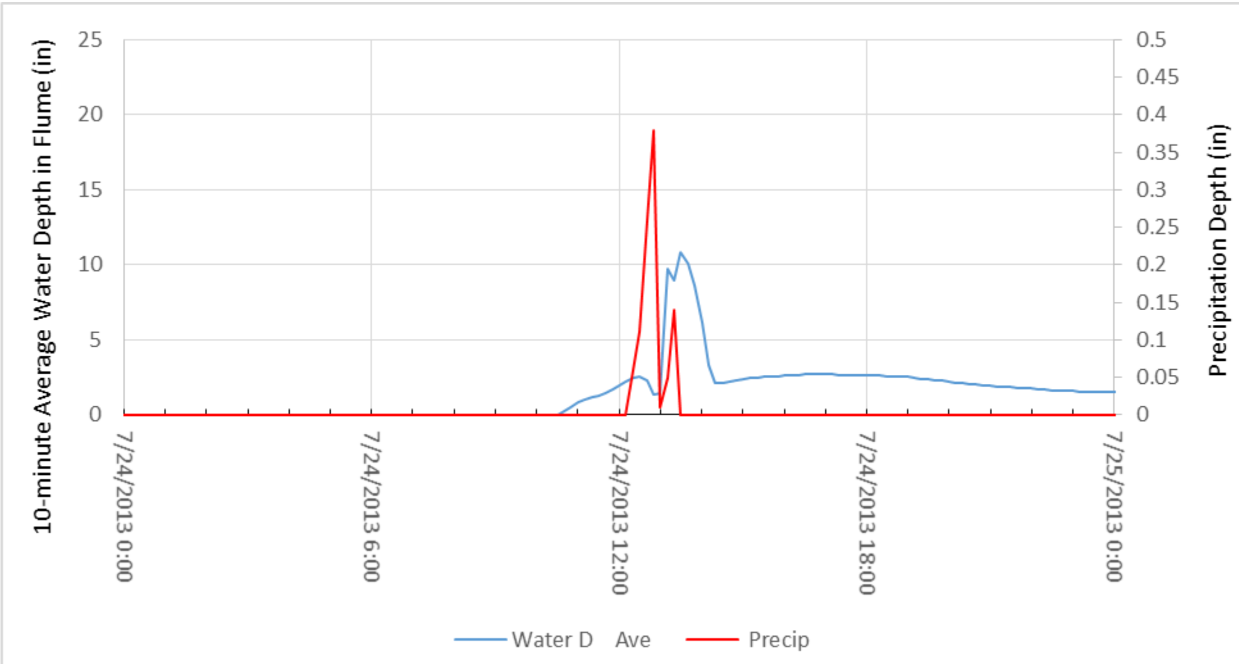


Figure 11. This portion of the Smoky flume hydrograph exhibits the afternoon diurnal peak pressure pattern. However, there are also two high-intensity, short-duration rainfall events and associated high-peak, short-duration flow events superimposed on the diurnal fluctuations.

Precipitation on July 24, 2013, lasted approximately one hour and produced a total of 1.01 inches of rain (Figure 12). Three of the 10-minute intervals during the hour produced in excess of 0.1 inches of rain; the peak 10-minute interval was 0.38 inches of rain. The resulting runoff event appears to have begun approximately 50 minutes after the precipitation event started, during the 10-minute interval following the peak intensity 10-minute precipitation interval. The runoff event lasted 1.34 hours. Six of the eight 10-minute intervals during the runoff event indicated a depth of more than six inches of water in the flume, which correlates to an approximate maximum discharge of 0.69 cfs. This entire runoff event is superimposed on the afternoon diurnal positive pressure behavior. The positive correlation, as seen in the earlier examples, is suggested except during the time when flow was actually occurring. During the flow event the suggested correlation between temperature and flow depth is negative (Figure 12).

Precipitation on July 28, 2013, lasted approximately four hours and produced a total of 1.38 inches of rainfall (Figure 13). The maximum 10-minute rainfall amount was 0.41 inches and three additional 10-minute intervals exceeded 0.1 inches. The resulting runoff event appears to have begun at approximately the same time as the peak intensity 10-minute precipitation. This event lasted 4.67 hours and peaked at a depth of 21.88 inches in the flume, which correlates to an approximate maximum discharge of 4.01 cfs. Using surveyed channel geometry, it is estimated that flow velocities exceeded 3 fps, which is enough to begin sediment transport within a channel. Water depth in the flume was greater than 6.0 inches for approximately 64 percent of the flow event. The air temperature dropped



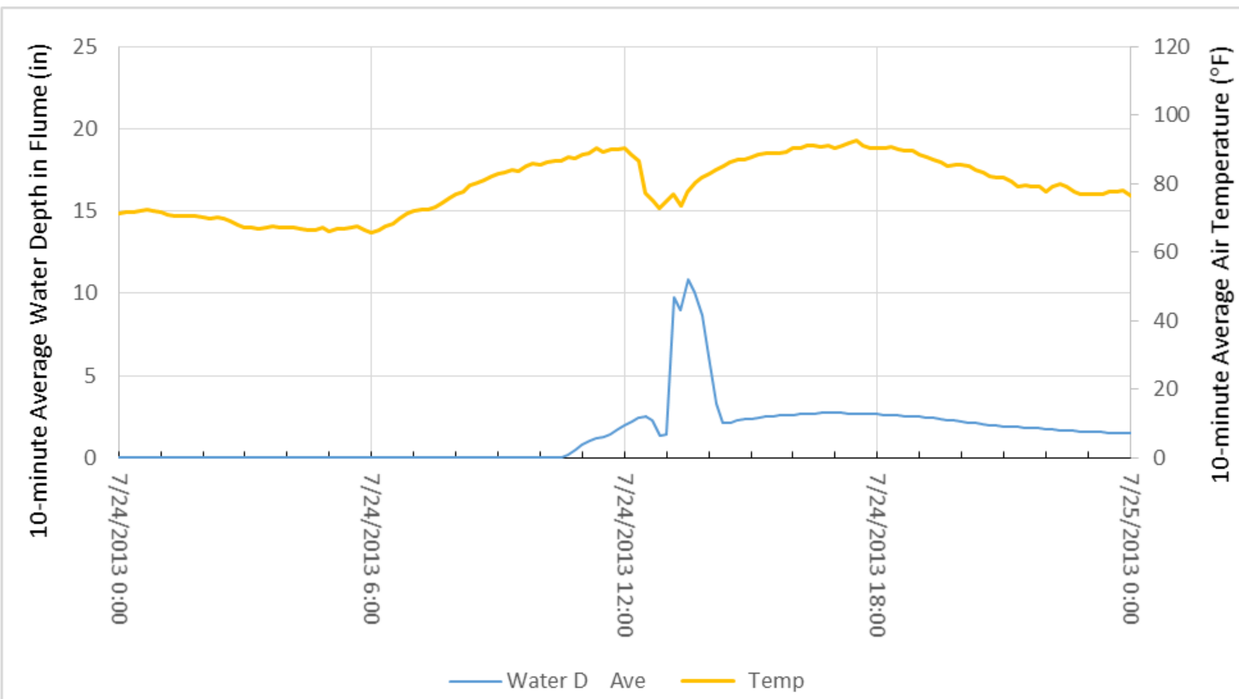
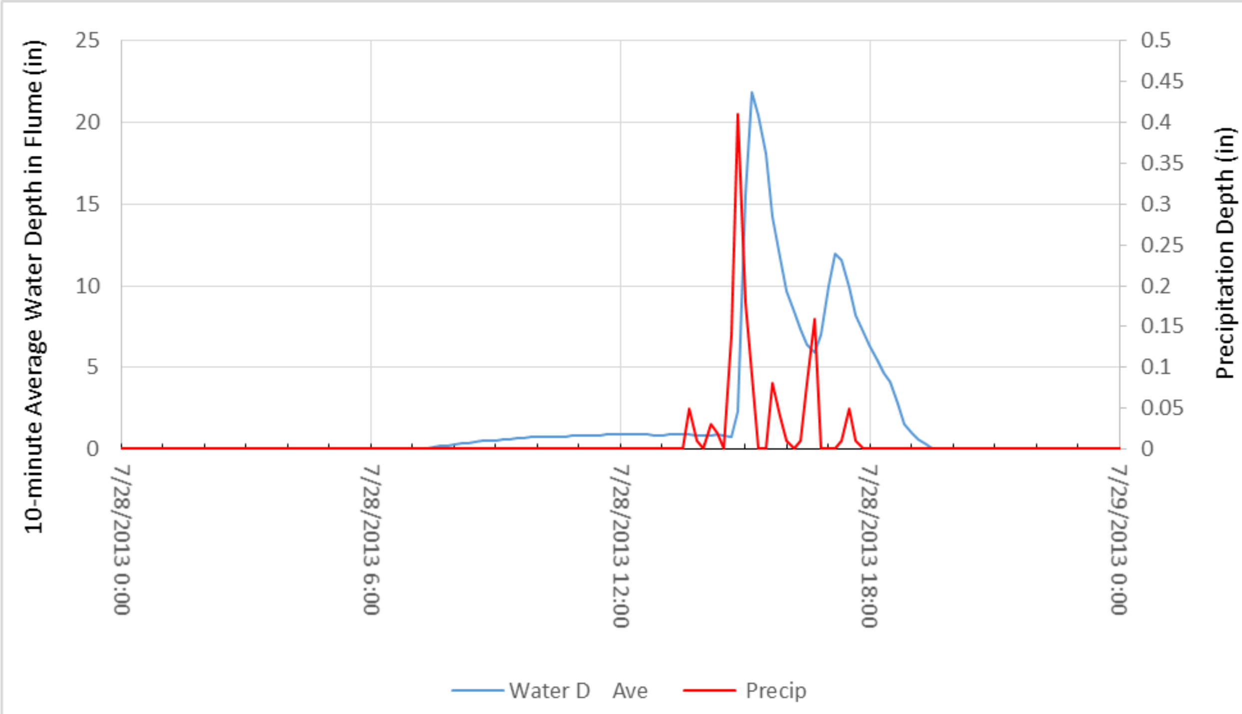


Figure 12. The flow event on July 24, 2013, began approximately 50 minutes after the associated precipitation event (upper graph). Visual comparison of flow with air temperature (lower graph) indicates likely positive correlation between temperature and flow depth except during the actual flow event when the correlation appears to be negative.



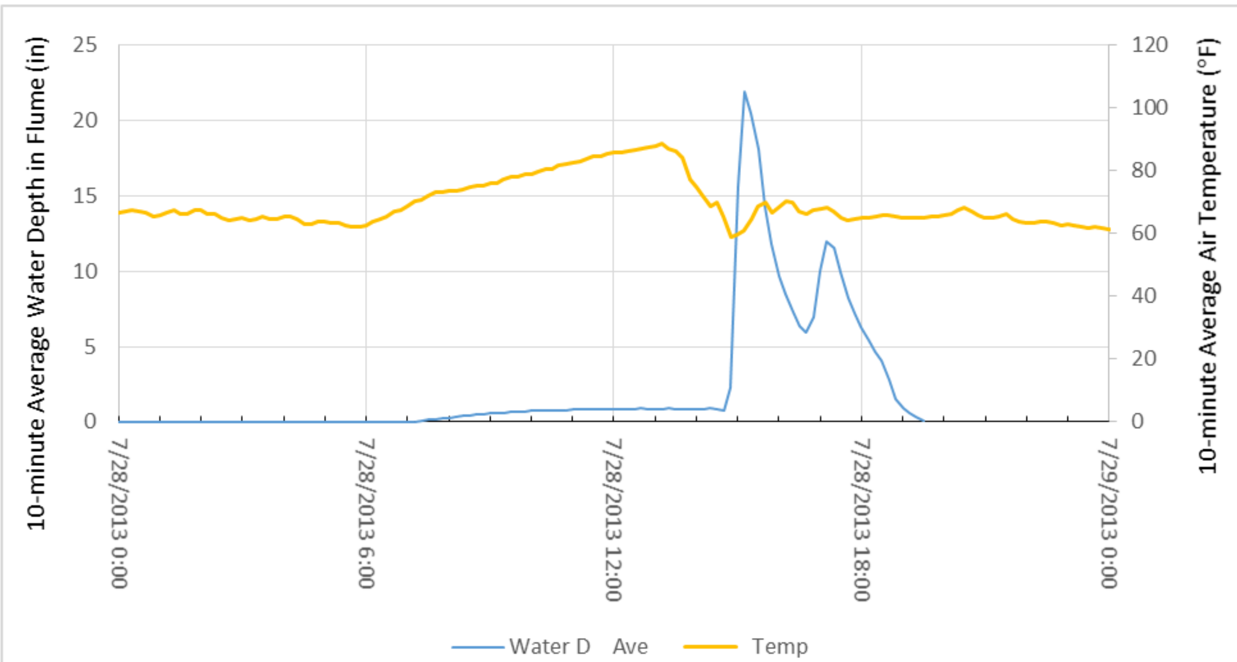


Figure 13. The first and second runoff peaks during the July 28, 2013, flow event occurred approximately 20 and 30 minutes, respectively, after the immediately preceding maximum precipitation intensities (upper graph). Again, air temperature declined during the precipitation and flow events despite an apparent positive correlation between temperature and water depth during the six hours preceding the flow event (lower graph).

as the precipitation event began and it remained low throughout the flow event. As the flow event came to a close, the transducer begin to transmit unreliable values. Although destruction of the flume was not visually confirmed until August 15, 2013, it is believed that the July 28, 2013, flow event broke the transducer stilling well off of the flume and pushed the flume downstream.

Light precipitation events that produced less than 0.05 inches of rainfall during any 10-minute interval are recorded in the data record (Figures 7 and 8) between the likely time the flume became inoperable (July 28, 2013) and the time it was rebuilt (March 4, 2014). The transducer recorded a few positive pressure events during this time as well. With the exception of an event in September 2013, the positive pressure events were small, possibly indicating a depth of less than 0.5 inches of water in the channel at the location of the pressure transducer. These events were removed from the data record because the flume was not operational and it was unlikely that these were actual flow events as there was no precipitation recorded at the adjacent meteorological station. However, the pressure event on September 8, 2013, (Figure 14) was retained because it is associated with a high-intensity, short-duration precipitation event. This precipitation event lasted 2.83 hours and produced a total of 0.65 inches of rainfall. The peak intensity 10-minute rainfall was 0.44 inches. This was the only interval during which rainfall depth exceeded 0.10 inches during this storm. The transducer data indicate that the maximum water depth in the channel following this precipitation event was 8.48 inches. However, this is suspect as the transducer was buried in the channel bed sediments. Therefore, it is not possible to evaluate this runoff event.

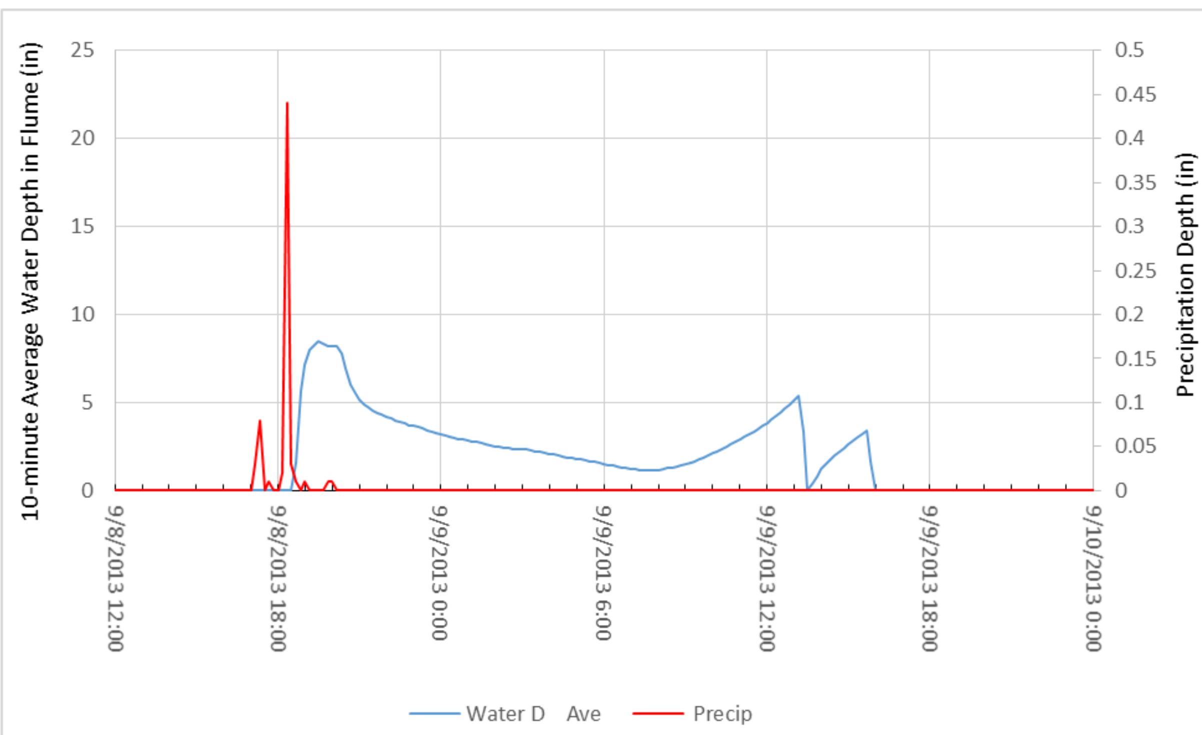


Figure 14. An intense, short-duration precipitation event appears to have caused flow in the channel on September 8, 2013, after the flume had been washed out. The pressure transducer recorded up to 8.37 inches of water in the channel.

A precipitation event that began at approximately 1950h on July 6, 2014, lasted approximately one hour and produced a peak rainfall of 0.18 inches in a 10-minute interval (Figure 15). The accompanying runoff event also lasted approximately one hour. It produced a maximum 10-minute average flow depth of 16 inches in the flume, which correlates to a discharge of 3.25 cfs. Initiation of the flow event lagged the start of precipitation by approximately 20 minutes and the peak flow lagged the peak precipitation by approximately 30 minutes. The pressure transducer began giving out-of-range values before flow in the flume ceased.

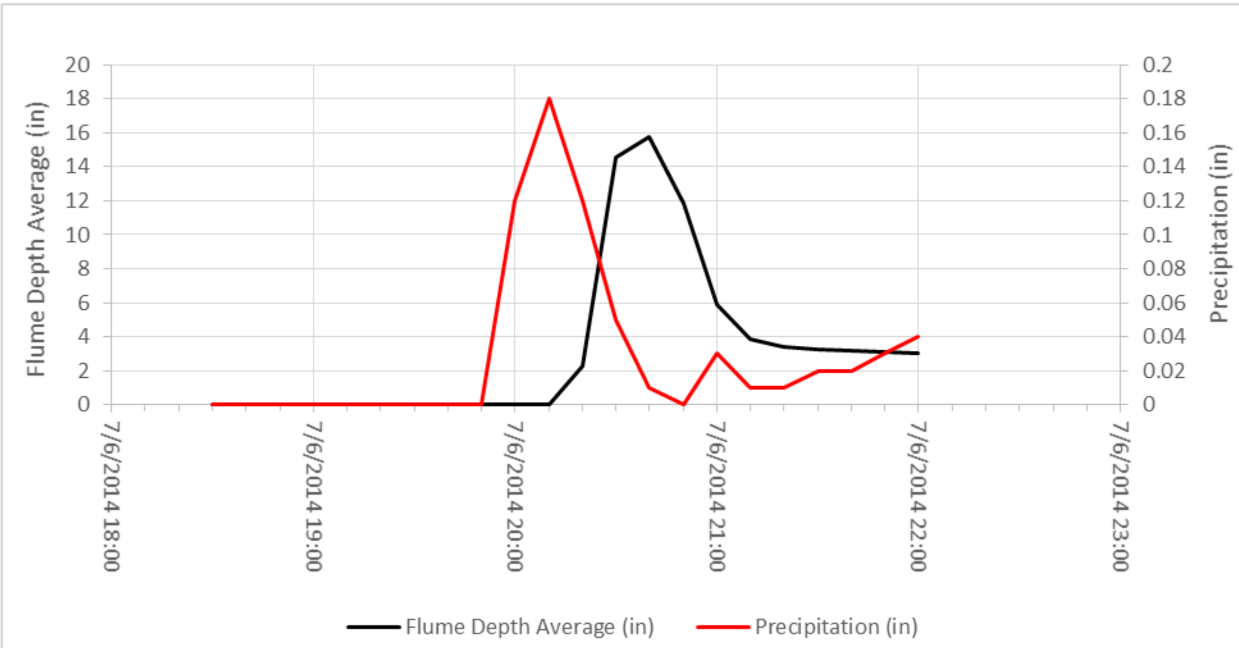


Figure 15. The precipitation event on July 6, 2014, produced a maximum of 0.18 inches of rainfall in 10 minutes and resulted in a flow event that had a maximum flow of 16 inches through the flume.

Figure 16 shows that a series of storm cells passed across the Smoky Site between 1400h on August 3, 2014, and 1300h on August 4, 2014. These storm cells generated six 10-minute peaks in the precipitation record that ranged from 0.10 to 0.29 inches. The resulting flume flow event 10-minute peaks ranged from an average depth of 4.14 to 25.19 inches (discharge of 0.38 to 4.83 cfs). The runoff peaks lagged from 30 to 60 minutes after the precipitation peaks (Table 5). The higher runoff peak intervals appear to be characterized by higher precipitation peak intervals and increased antecedent moisture conditions. Once again, the pressure transducer began transmitting out-of-range values, but this time the out-of-range values started at the same time the runoff ceased.

Table 5. Peak characteristics of rainfall and runoff events on August 3 and 4, 2014.

Date	Precipitation		Runoff Flow		Lag between peak rainfall and runoff depths
	Peak Time (h)	**Peak Rainfall (inches)**	**Peak Time (h)**	**Peak Depth (inches)**	
03 August 2014	1440	0.29	1520	11.62	40 min
04 August 2014	0240	0.19	0310	16.21	30 min
	0400	0.10	0500	9.30	60 min
	0540	0.06	0630	4.14	50 min
	0910	0.13	1000	10.81	50 min
	1200	0.29	1230	25.19	30 min

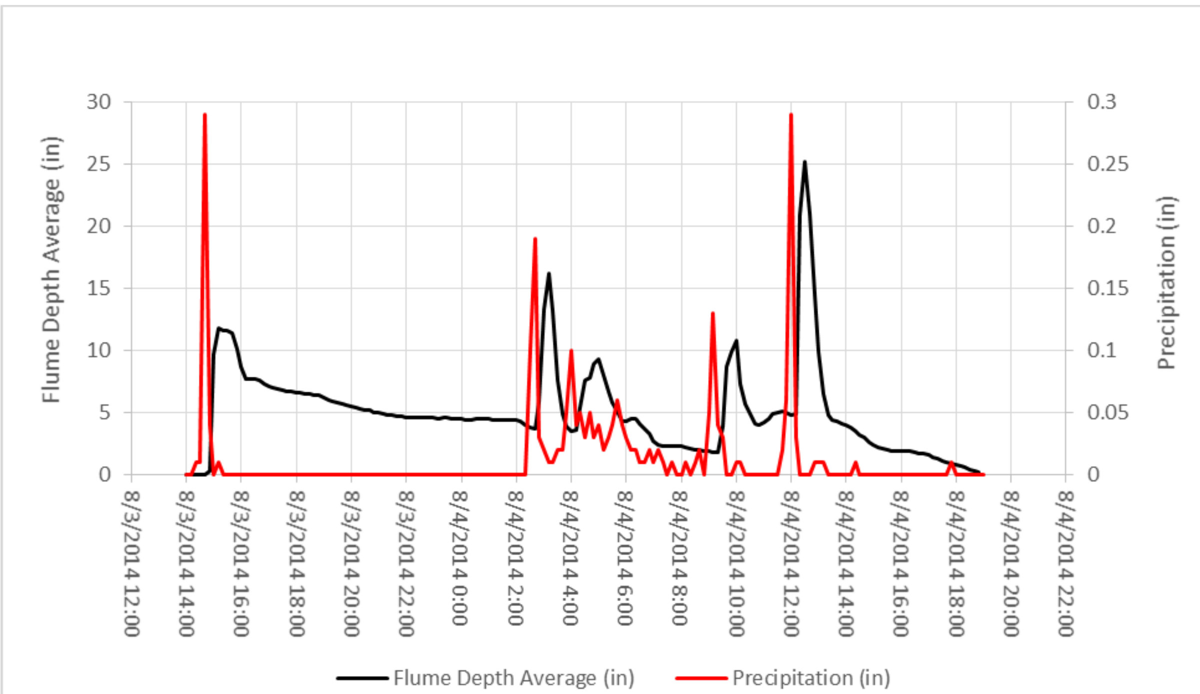


Figure 16. Precipitation on August 3 and 4, 2014, produced six peak rainfall periods that ranged from 0.06 inches in 10 minutes to 0.29 inches in 10 minutes. Each spike in precipitation was followed by a spike inflow through the flume.

Related Hydrologic Data

Soil moisture is measured in the top four inches of 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 precipitation events. The observed volumetric soil moisture content ranged between 8.6 percent in June 2013 and 27 percent following a significant precipitation event in the second week of October 2013 (Figure 7). The largest precipitation event of the year in the later part of July 2013 also showed a pronounced increased value for the soil moisture content (25 percent), but because this was a higher intensity storm, much of the precipitation resulted in direct runoff (Figure 7). July 2013 showed the largest gain in soil moisture content, with values that ranged from 8.5 to 24.7 percent. Generally, moisture content rose following precipitation events that exceeded 0.02 inches. Rainfall of lesser magnitude did not produce a notable change in the measured moisture content. However, antecedent soil moisture conditions also played a role because small precipitation events falling on already damp soil produced a noticeable change in soil moisture content.

SOIL PARTICLE SIZE DISTRIBUTION AND RADIONUCLIDE ANALYSIS

Eight bulk soil samples were collected along the channel bed downstream of the Smoky flume on August 15, 2013, when it was discovered that the flume had been washed downstream. An additional six samples were collected on August 20, 2014. Both sets of samples were submitted to the Southwest Research Institute laboratory for particle size analysis. After analysis, the samples were grouped into three size fractions: <63 µm, 63 µm to 250 µm, and >250 µm. The subsample groups that represented the two smaller size fractions were submitted to GEL Laboratories to determine the concentrations of Amercium-241 (Am-241), Plutonium-238 (Pu-238), and Plutonium 239/240 (Pu-239/240).

Tables 6A and 6B present the results for the FY2013 and FY2014 samples, respectively. For the 14 samples, the smaller size fraction (<63µm) was associated with higher levels of radioactivity in the majority of cases (specifically, all but three of the Am-241 analyses, eight of the Pu-238 analyses, and two of the Pu-239/240 analyses).

Table 6A. Particle size and radionuclide analysis results for bedload samples collected in FY2013.

Sample	Particle Size Percentages			<63 µm (pCi/g)			63 µm to 250 µm (pCi/g)		
	<63 µm (%)	63 to 250 µm (%)	>250 µm (%)	Am-241	Pu-238	Pu-239/240	Am-241	Pu-238	Pu-239/240
SMK01	3.8	12.0	84.2	1.02	0.21	5.87	0.35	0.23	2.14
SMK02	1.9	6.6	91.5	1.96	0.28	9.87	0.33	0.11	1.20
SMK03	1.4	1.6	97.0	1.48	0.25	13.30	0.70	0.09	1.42
SMK04	17.4	23.9	58.7	1.07	0.53	24.80	0.59	0.24	3.65
SMK05	1.6	6.3	92.1	0.92	0.37	7.00	0.28	0.28	1.41
SKM06	6.7	11.9	81.4	2.29	0.37	8.37	0.39	0.09	1.84
SMK07	1.5	1.5	97.0	0.84	0.23	4.03	0.99	0.22	5.75
SMK08	6.5	18.4	75.1	1.67	0.24	7.40	0.46	0.13	1.83

Table 6B. Particle size and radionuclide analysis results for bedload samples collected in FY2014.

Sample	Particle Size Percentages			<63 µm (pCi/g)			63 µm to 250 µm (pCi/g)		
	<63 µm (%)	63 to 250 µm (%)	>250 µm (%)	Am-241	Pu-238	Pu-239/240	Am-241	Pu-238	Pu-239/240
SMK09	1.7	3.6	94.7	2.25	1.30	24.20	1.11	1.51	10.50
SMK10	1.4	3.6	95.0	2.10	0.91	21.10	1.28	1.89	9.97
SMK11	2.8	7.4	89.8	3.45	1.23	35.70	2.36	2.29	15.80
SMK12	1.3	4.5	94.2	1.51	1.06	11.70	1.54	1.56	10.50
SMK13	2.0	7.2	90.8	1.53	1.05	15.10	0.87	0.86	5.77
SMK14	3.7	11.0	85.3	0.85	0.85	7.43	1.64	1.76	10.60

The nonparametric Kruskal-Wallis (K-W) statistical test was run to determine if the radionuclides were preferentially binding to either the <63 µm or the 63 µm to 250 µm size fractions. The null hypothesis for this test states that the values of the two data sets are drawn from the same population, and therefore are not distinctive. In this application the null hypothesis means that there is no preference for radionuclide binding to either of the two size fractions. The K-W test assigns a rank to all of the values in the compared data sets in ascending order. The sum of the ranks for each data set are used to calculate the test parameter (H), which is compared to a critical value (H-critical). At a probability of 0.05 (95 percent confidence interval), the H-critical value is 3.8 for the tests reported in this study. If H-calculated is greater than H-critical, the null hypothesis is rejected and the alternate hypothesis that the size fractions represent different radionuclide populations is accepted.

Tables 7A, 7B, and 7C show the results of the K-W test for the FY2013, FY2014, and combined data sets, respectively. The H-calculated value is greater than the H-critical value for all three radionuclides in the FY2013 samples, for Pu-238 in the FY2014 samples, and for Am-241 and Pu-239/240 when all the samples are tested together. Additionally, the mean concentration and the rank sum parameter for radionuclide concentrations for the <63 µm size fraction are larger than the concentrations for the 63 to 250 µm fraction, with two exceptions. The mean and rank sum parameter for the 63 to 250 µm are larger than for the <63 µm fraction for Pu-238 in FY2014. The mean of the <63 µm fraction for Pu-238 in the combined data set is larger but the rank sum parameter is smaller than for the 63 to 250 µm fraction. Although statistical assessment of the sample radionuclide analyses are not consistent for all sample sets, the results suggest that these radionuclides are more likely to bind to the smaller (<63 µm) particle size fraction than to the larger (63 to 250 µm) particle size fraction.

Previous work with radionuclide-contaminated soils in Plutonium Valley and other sites on the NNSS (Tamura, 1985; Friesen, 1992; Murarik *et al.*, 1992; Misra *et al*., 1993) have indicated that the highest activity levels of Plutonium tend to be found in the fine sands, silts, or clays (Friesen, 1992; Misra *et al*., 1993; Murarik *et al.*, 1992; Papelis *et al*., 1996; Hoeffner *et al*., 2002, Tamura, 1985). Therefore, the most likely particle sizes to be transported during flow events are also preferentially associated with radionuclide activity.

Table 7A. Analysis of variance results for radionuclide determinations for the FY2013 samples.

Radionuclide	<63 µm			63 to 250 µm			Compare	
	µ	σ	Rank sum	µ	σ	Rank sum	H-critical	H-calculated
Am-241	1.4	0.5	98	0.5	0.2	38	3.8	9.9
Pu-238	0.3	0.1	92	0.2	0.1	44	3.8	5.6
Pu-239/240	10.1	6.6	99	2.4	1.6	37	3.8	10.6

Table 7B. Analysis of variance results for radionuclide determinations for the FY2014 samples.

Radionuclide	<63 µm			63 to 250 µm			Compare	
	µ	σ	Rank sum	µ	σ	Rank sum	H-critical	H-calculated
Am-241	1.9	0.9	43	1.5	0.5	35	3.8	0.4
Pu-238	1.1	0.2	26	1.6	0.5	52	3.8	4.3
Pu-239/240	19.2	10.1	50	10.5	3.2	28	3.8	3.1

Table 7C. Analysis of variance results for radionuclide determinations for the FY2013 and FY2014 samples.

Radionuclide	<63 µm			63 to 250 µm			Compare	
	µ	σ	Rank sum	µ	σ	Rank sum	H-critical	H-calculated
Am-241	1.6	0.7	257	0.9	0.6	149	3.8	6.2
Pu-238	0.6	0.4	211	0.8	0.8	195	3.8	0.2
Pu-239/240	14.0	9.2	261	5.9	4.8	145	3.8	7.1

CONCLUSIONS

1) Probably because of the way temperature corrections had to be applied to pressure data from the transducer at the flume prior to July 15, 2013, there are several occasions when a positive correlation between the diurnal air temperature variations and the pressure data is evident. This relationship is especially notable when a low-intensity, long-duration precipitation event has brought moisture to the area. No such event is seen in the transducer record after the datalogger was programmed to apply the temperature correction as the pressure data are collected.

2) Short-duration, high-intensity precipitation events produced short-duration runoff events during which significant water depth was reported at the flume. One such event washed the flume out. Two of these events occurred in July 2013 before the flume was washed out and two more occurred in July and August 2014 after the flume was reinstalled.

3) Determination of Am-241, Pu-238, and Pu-239/240 on channel sediments collected downstream of the flume indicate that higher radionuclide concentrations are associated with the <63 µm sediment size fraction than with the 63 to 250 µm size fraction. This smallest size fraction is the first to be transported during flow events, and is typically transported as suspended sediment entrained within the flow. Therefore, it can be transported for significant distances.

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 inches [0.5 centimeters]) 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 aid in the identification of meteorological conditions that may require monitoring and sampling of channel runoff migration pathways under a closure plan. Requirements for monitoring meteorological conditions and for sampling runoff pathways can then be appropriately incorporated in 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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APPENDIX A: FY2013 TEN-MINUTE METEOROLOGICAL OBSERVATIONS FOR THE SMOKY SITE

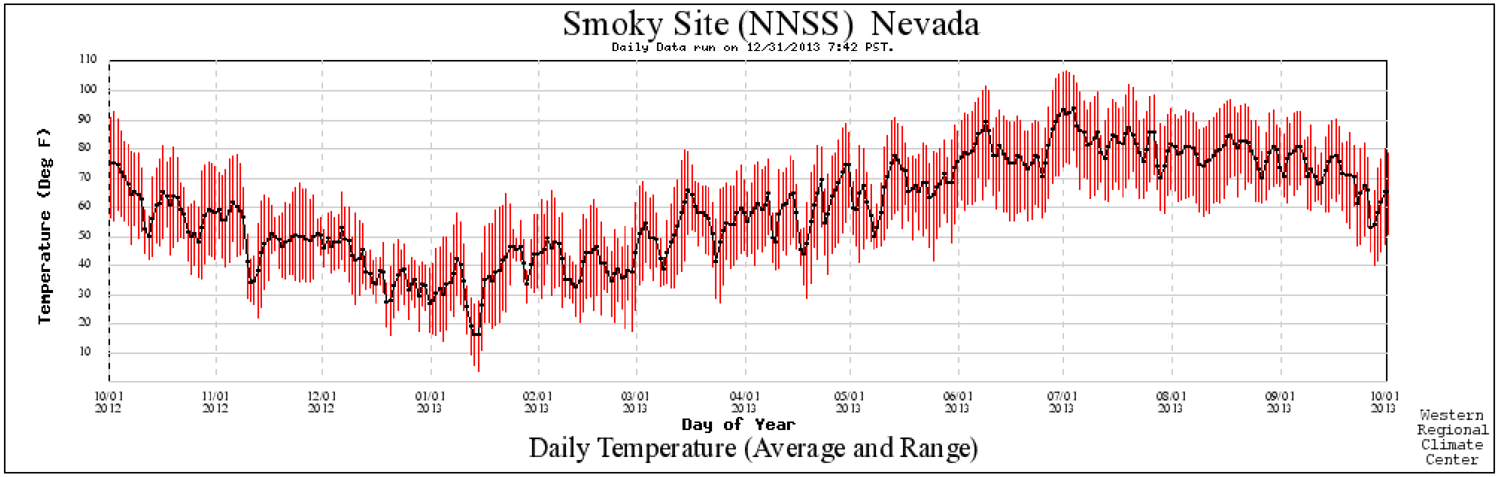


Figure A-1. Daily average, maximum, and minimum air temperature observed at the Smoky Site meteorological station during FY2014. Data depict short-term variations superimposed on the expected seasonal trend.

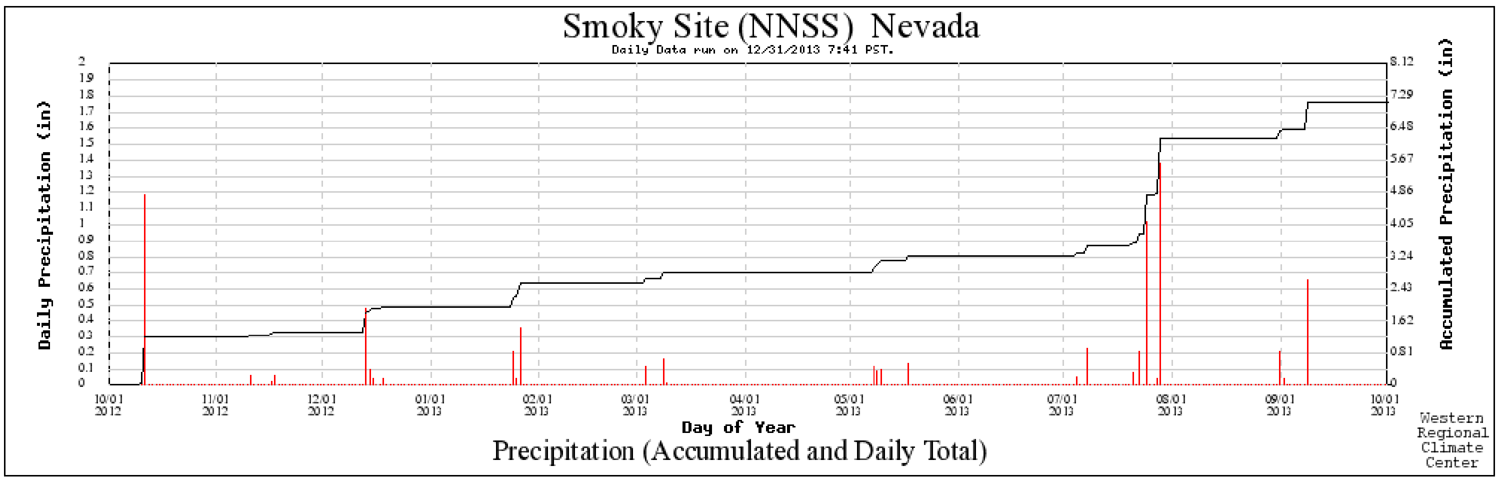


Figure A-2. Daily and cumulative precipitation measured at the Smoky Site meteorological station during FY2013. Daily precipitation equaled or exceeded 0.1 inches on sixteen days. The total FY2013 accumulation was approximately 7.12 inches.

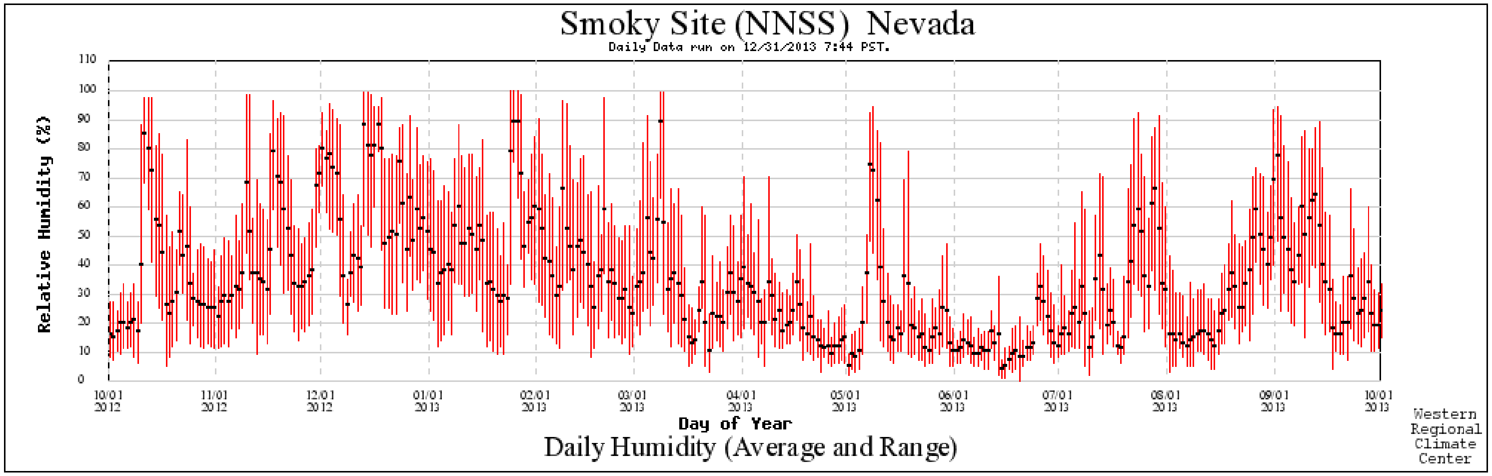


Figure A-3. Daily average, maximum, and minimum relative humidity at the Smoky Site meteorological stations during FY2013. The daily average relative humidity equaled or exceeded 80 percent on ten days. The period of high humidity (<90percent) in early December 2013 is not associated with a precipitation event.

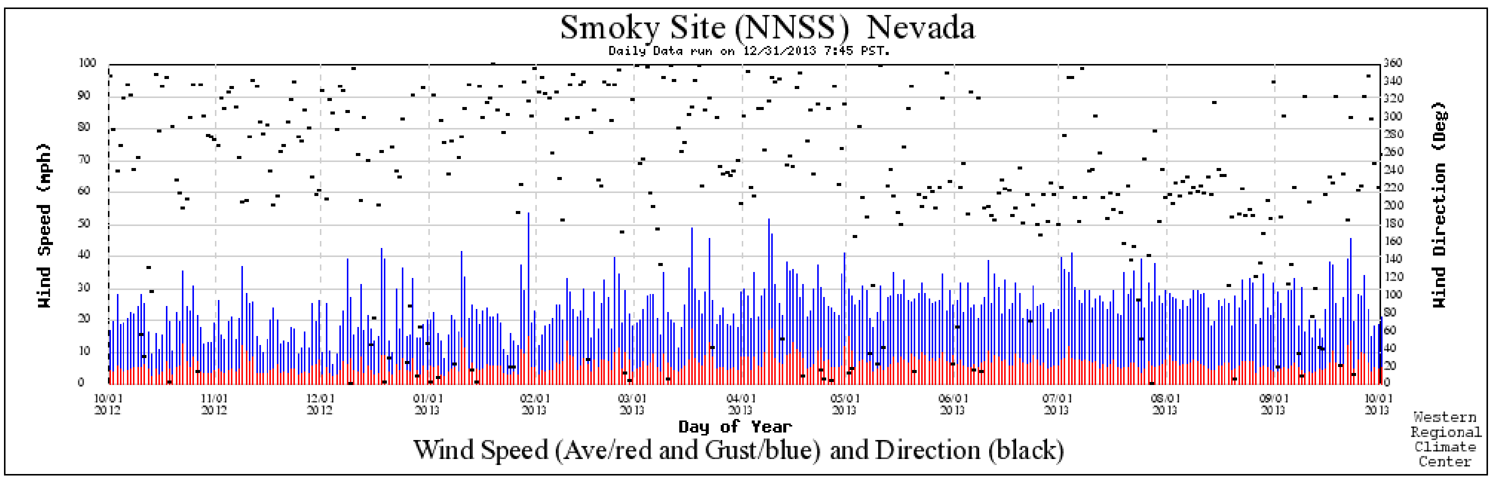


Figure A-4. Daily average and peak-gust wind speeds and daily average wind direction observed at the Smoky Site meteorological station during FY2013. The peak wind velocity exceeded 50 mph in late January and early April. Wind direction tended to be from the southwest between April and September and from the northwest between October and March.

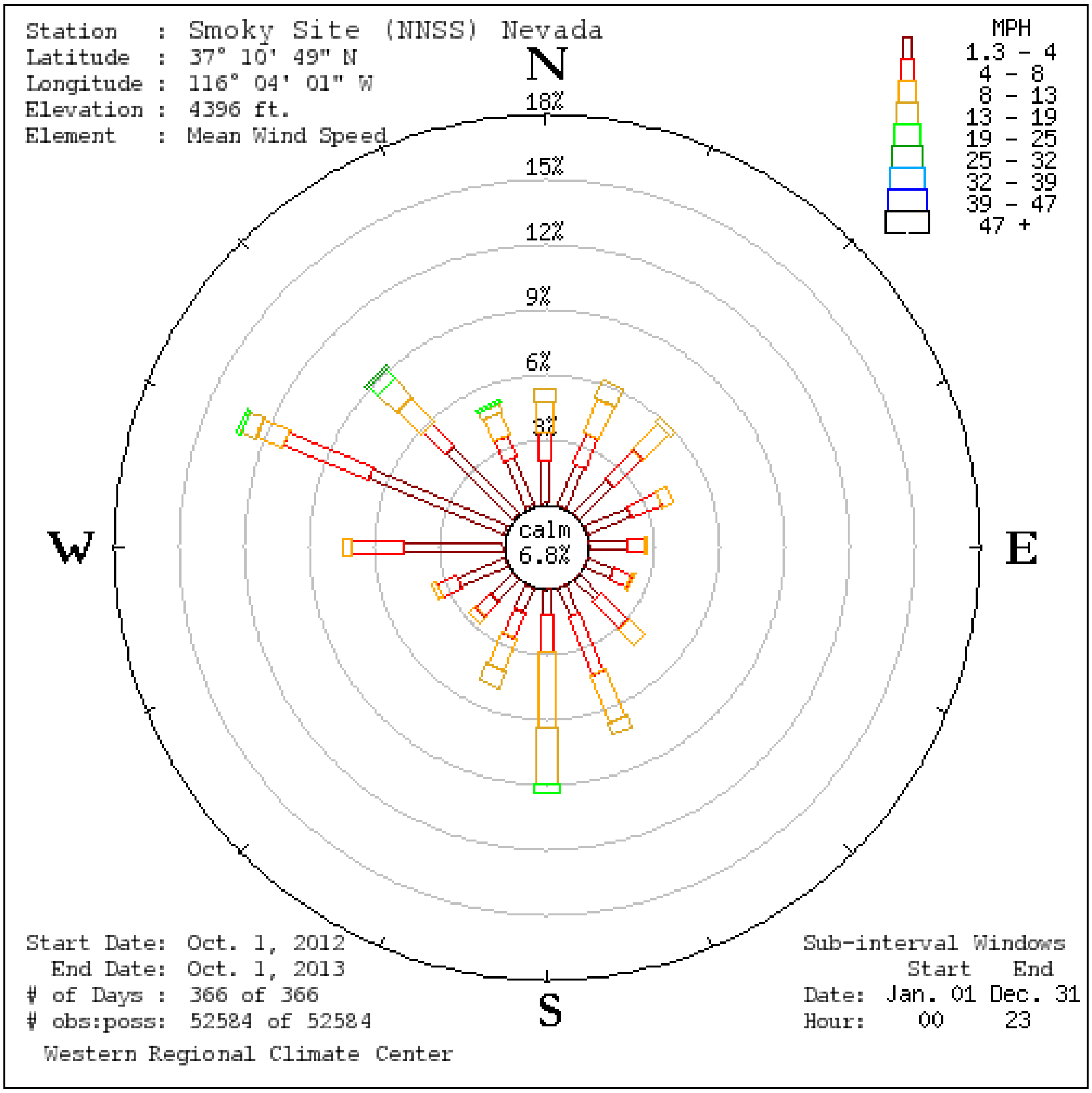


Figure A-5. The FY2013 wind rose for the Smoky Site meteorological station shows stronger winds tend to come from the northwest quadrant and from the south. Winds from these directions dominate the wind pattern at the site.

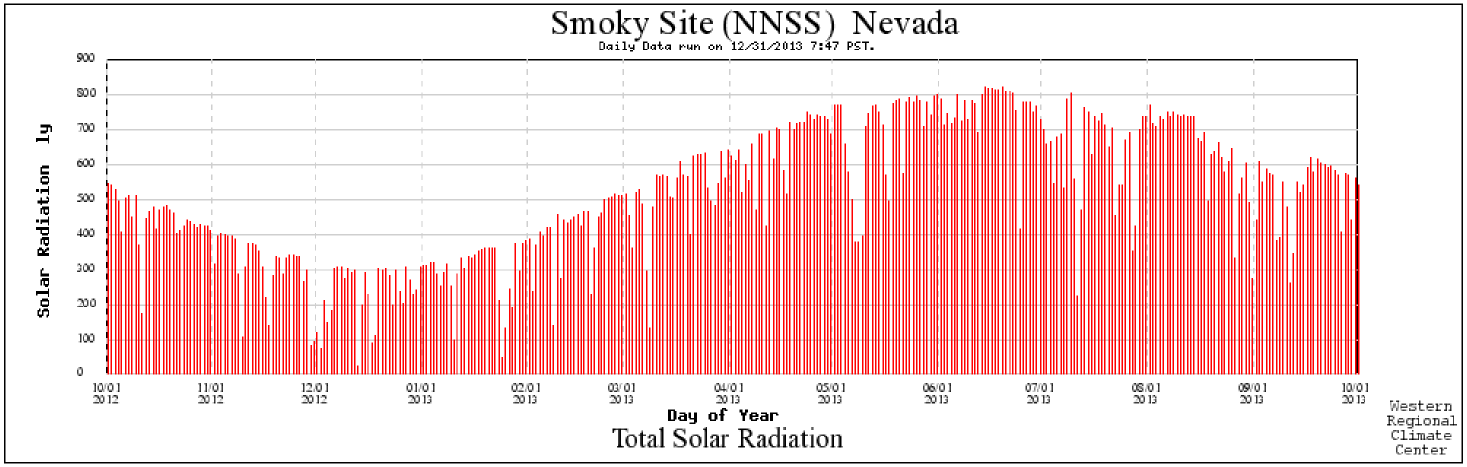


Figure A-6. Total daily solar radiation at the Smoky Site during FY2014 exhibit the expected annual trend with the greatest radiation occurring in the late spring and summer and the lowest radiation occurring in the late fall and winter. Occasions of unseasonably low solar radiation suggest cloud cover, which may be indicative of storm conditions and may occur at any time throughout the year.

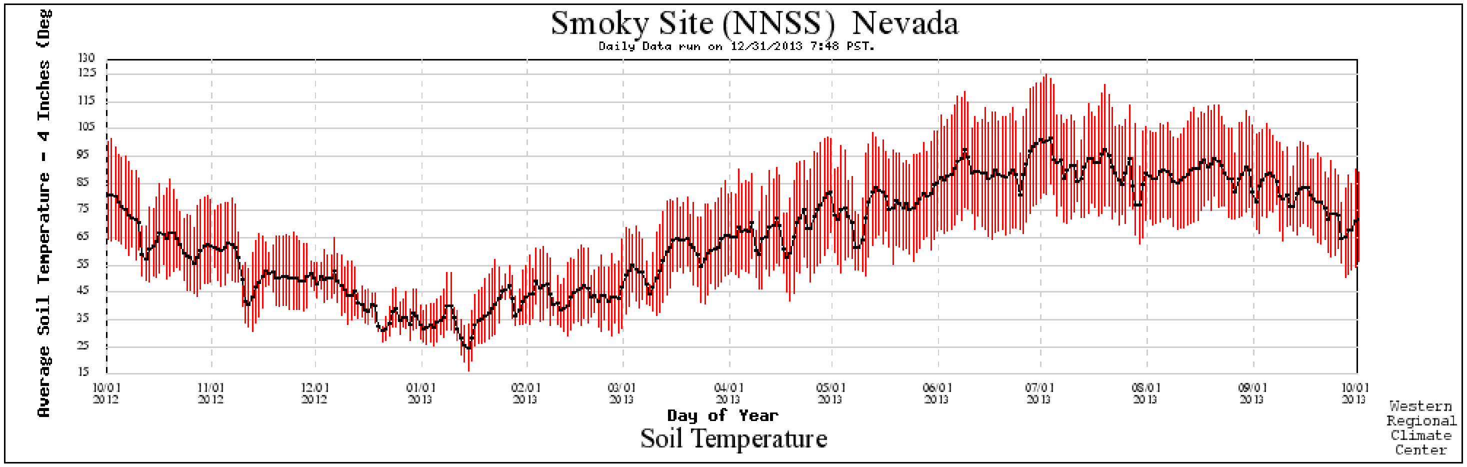


Figure A-7. Daily average, maximum, and minimum soil temperature measured at a depth of four inches at the Smoky Site meteorological station reflect a seasonal pattern similar to the air temperature. Soil temperature reflects a seasonal pattern similar to air temperature.

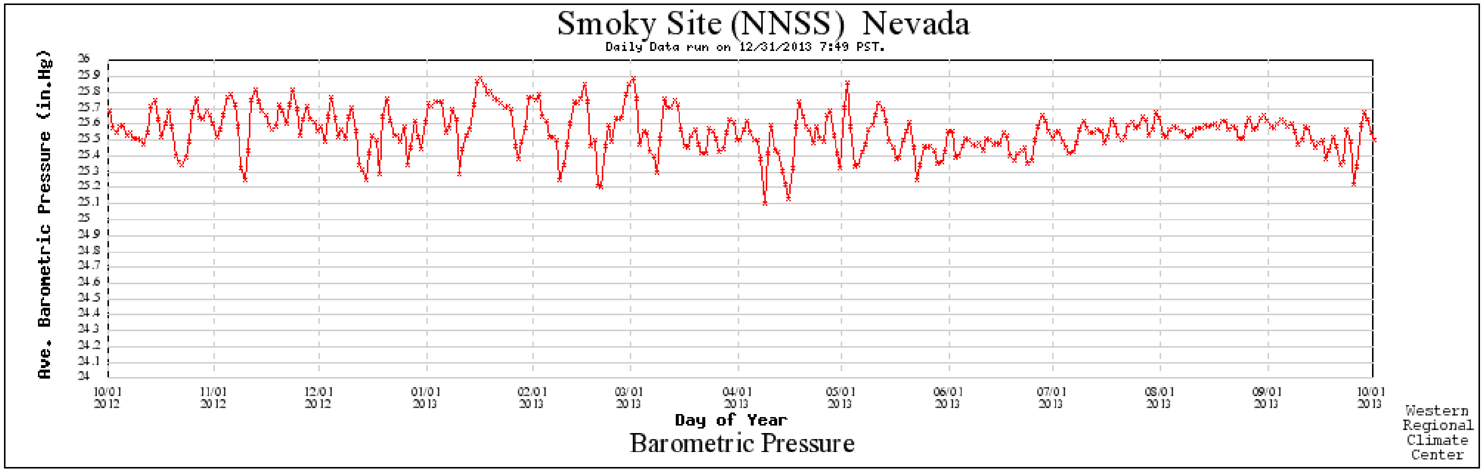


Figure A-8. Barometric pressure recorded at the Smoky Site meteorological station during FY2013 fluctuated between 25.1 and 25.9 inches of mercury.

APPENDIX B: FY2014 TEN-MINUTE METEOROLOGICAL OBSERVATIONS FOR THE SMOKY SITE

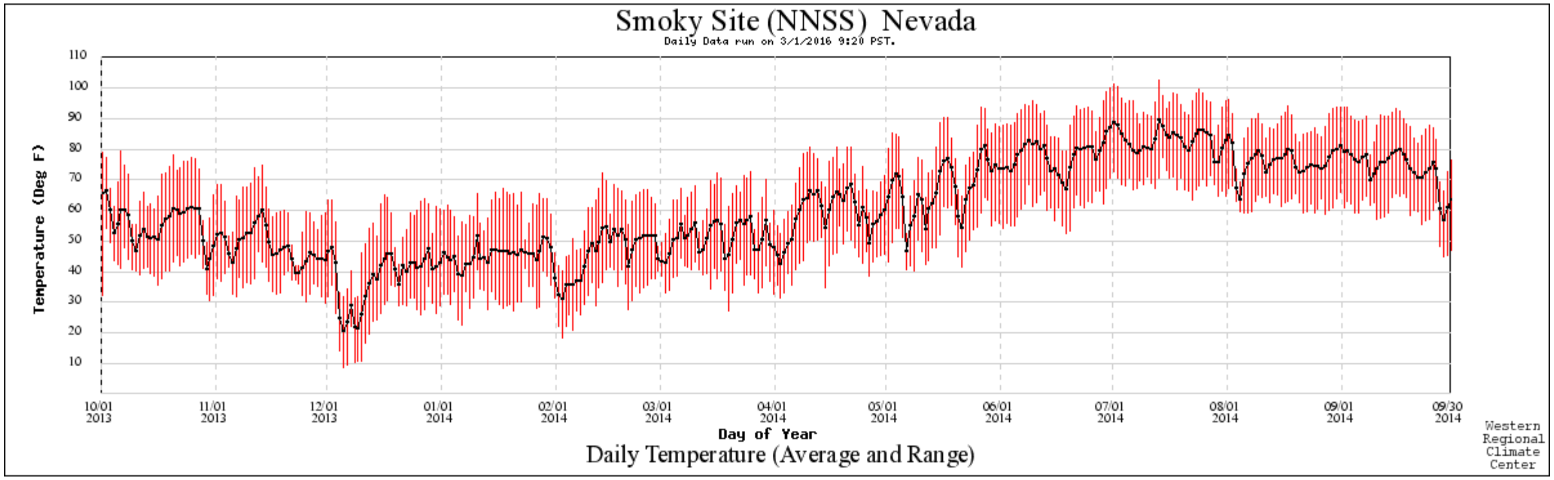


Figure B-1. Daily average, maximum, and minimum air temperature observed at the Smoky Site meteorological station during FY2014. Data depict short-term variations superimposed on the expected seasonal trend.

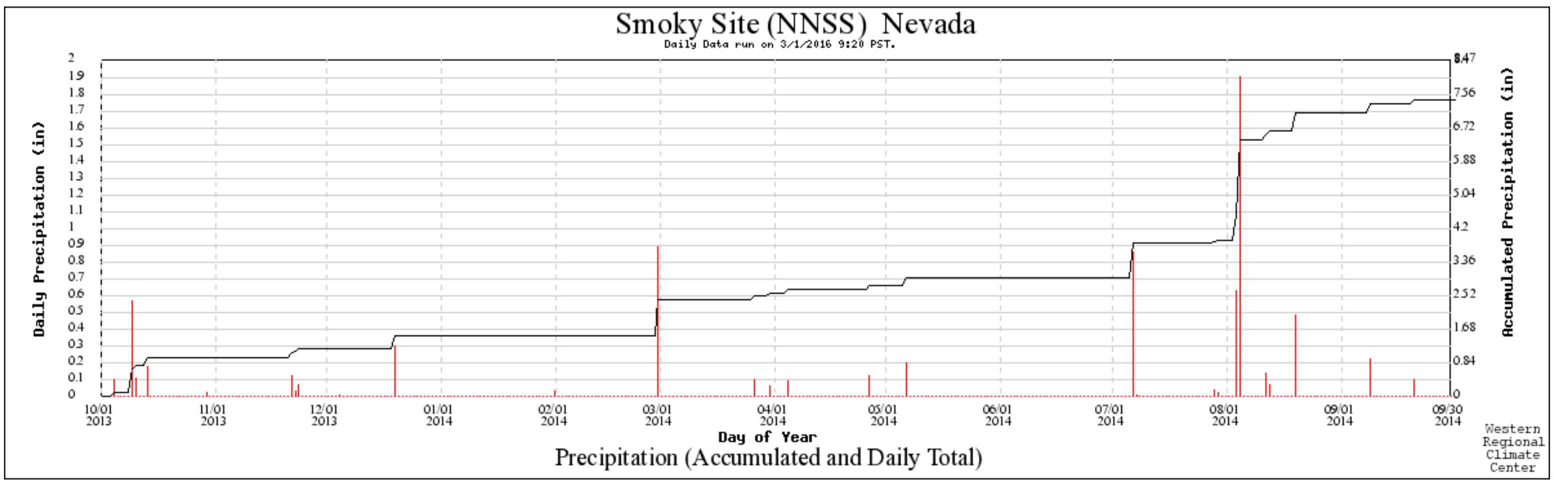


Figure B-2. Daily and cumulative precipitation measured at the Smoky Site meteorological station during FY2014. Daily precipitation equaled or exceeded 0.1 inches on 17 days. The total FY2014 accumulation was approximately 7.47 inches.

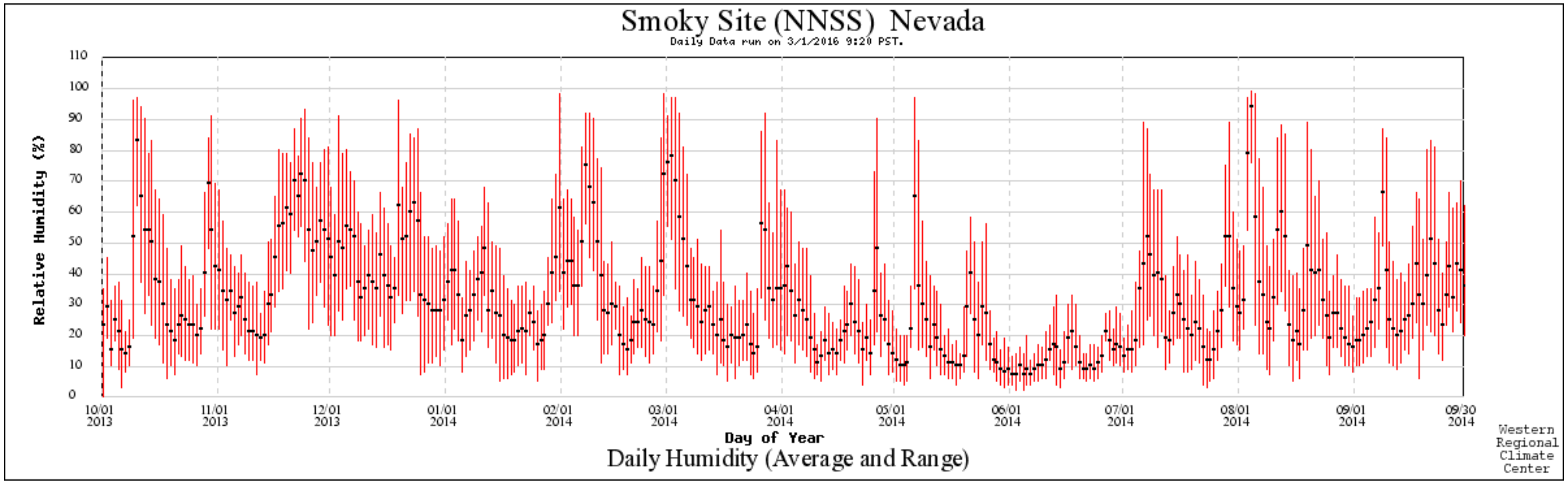


Figure B-3. Daily average, maximum, and minimum relative humidity at the Smoky Site meteorological station during FY2014. The daily average relative humidity equaled or exceeded 80 percent on three days.

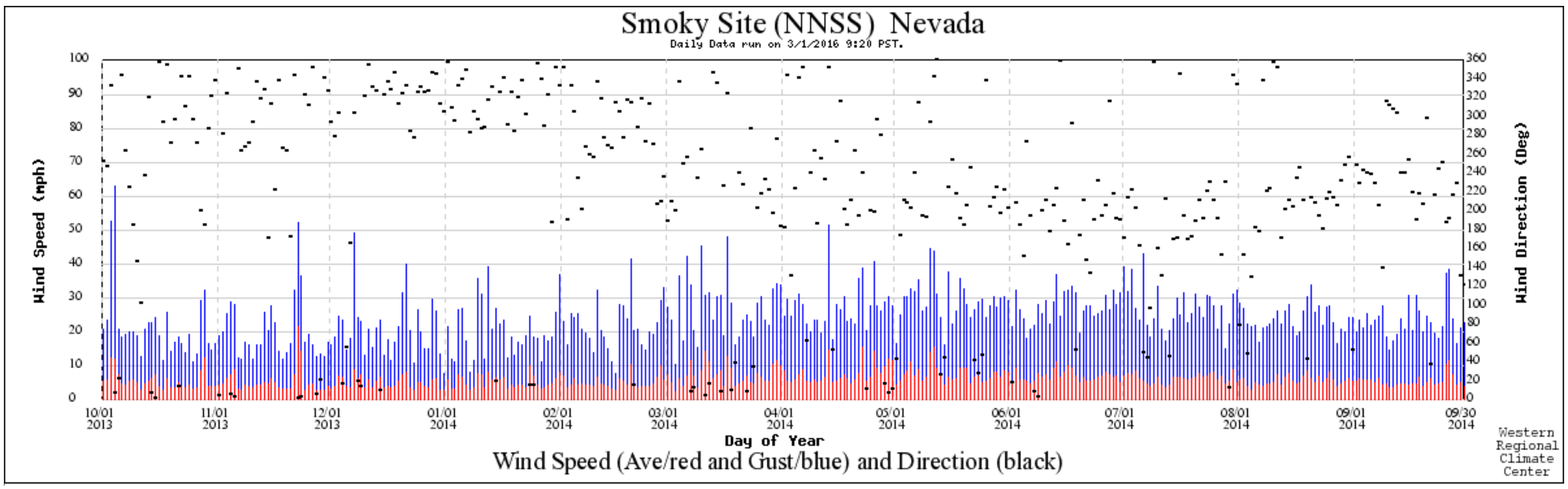
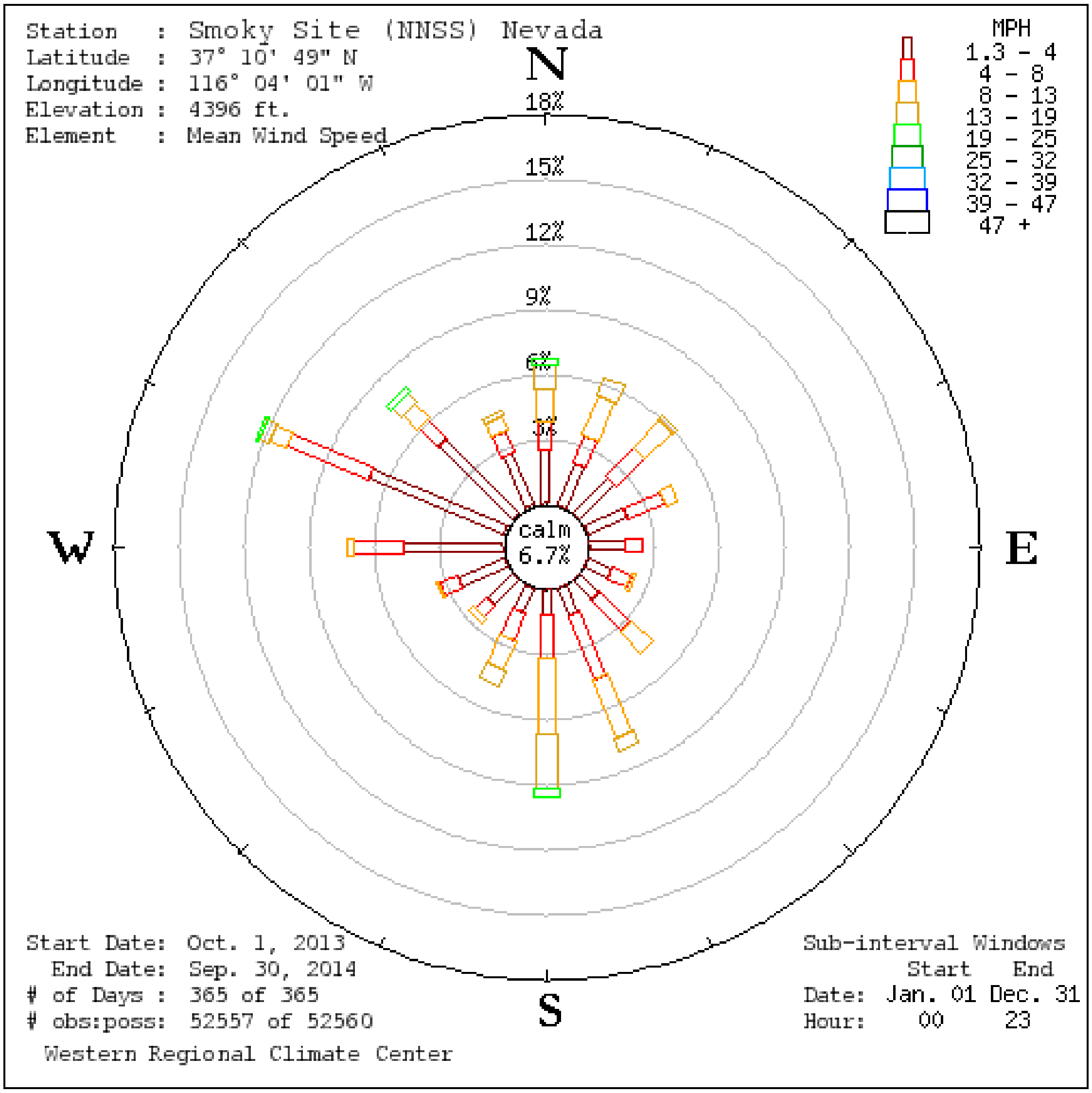


Figure B-4. Daily average and peak-gust wind speeds and daily average wind direction observed at the Smoky Site meteorological station during FY2014. Peak wind speed exceeded 60 mph once in October 2013. Wind direction tended to be from the south to southwest between April and September and from the northwest between October and March.



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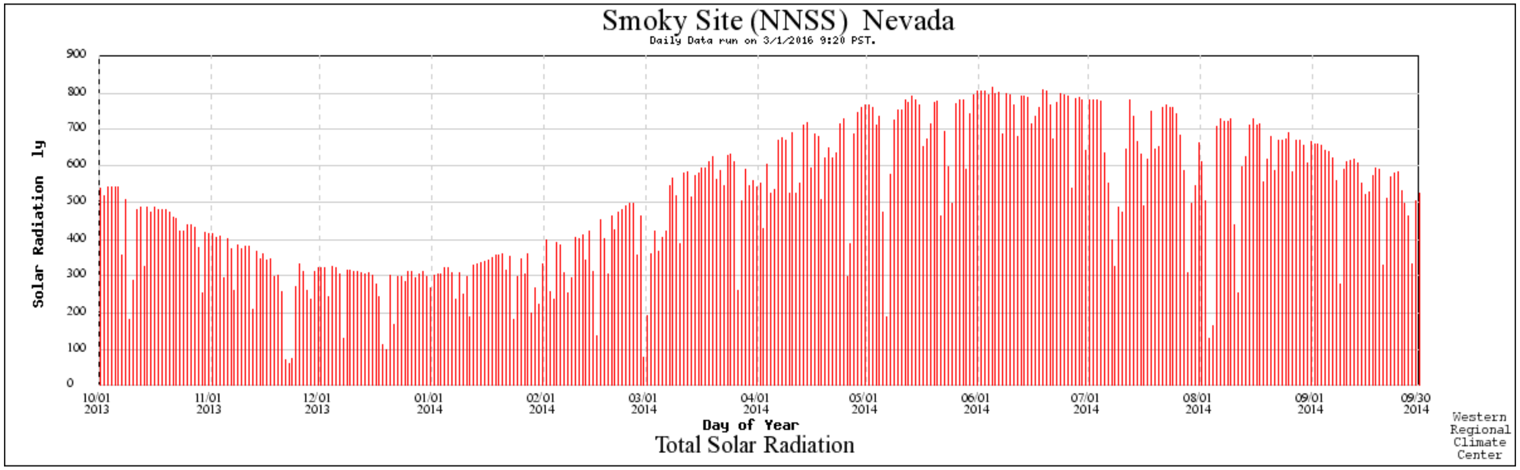

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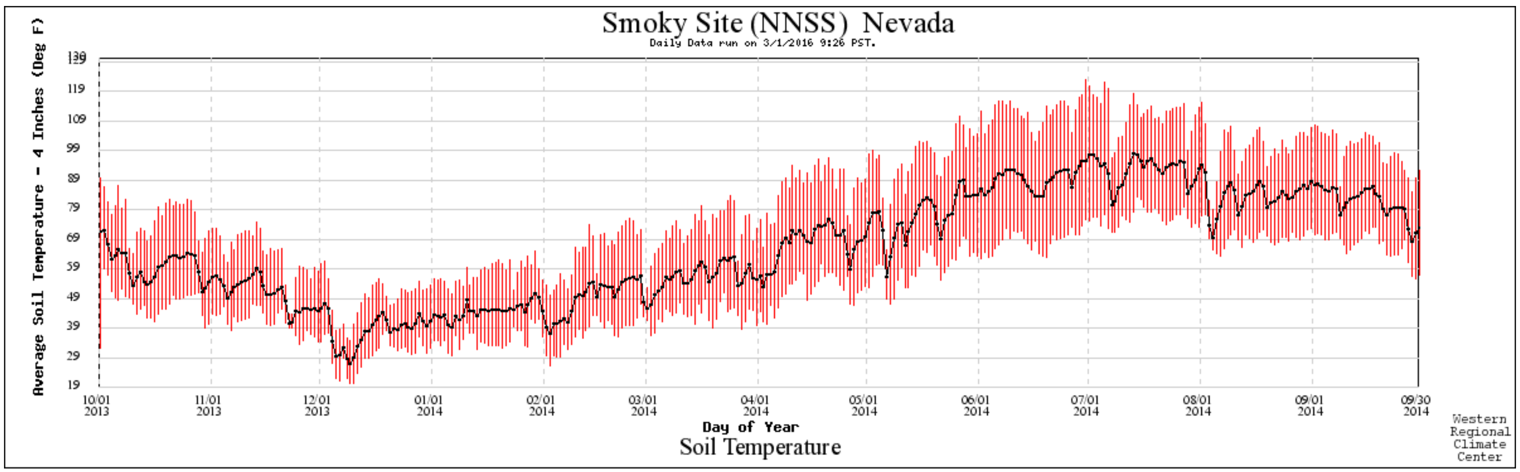

Figure B-7. Daily average, maximum, and minimum soil temperature measured at a depth of four inches at the Smoky Site meteorological station reflect a seasonal pattern similar to the air temperature.

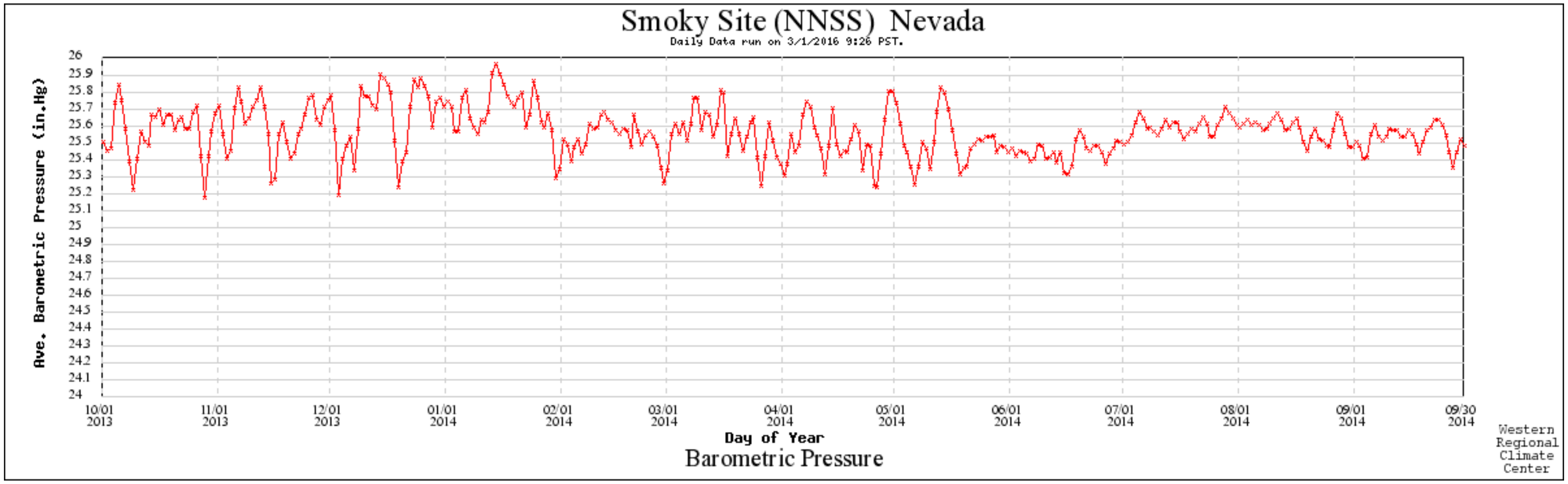

Figure B-8. Barometric pressure recorded at the Smoky Site meteorological station during FY2014 fluctuated between 25.2 and 26 inches of mercury.

APPENDIX C: HYDROGRAPHS THAT REFLECT DIURNAL TEMPERATURE INFLUENCES ON PRESSURE TRANSDUCER DATA

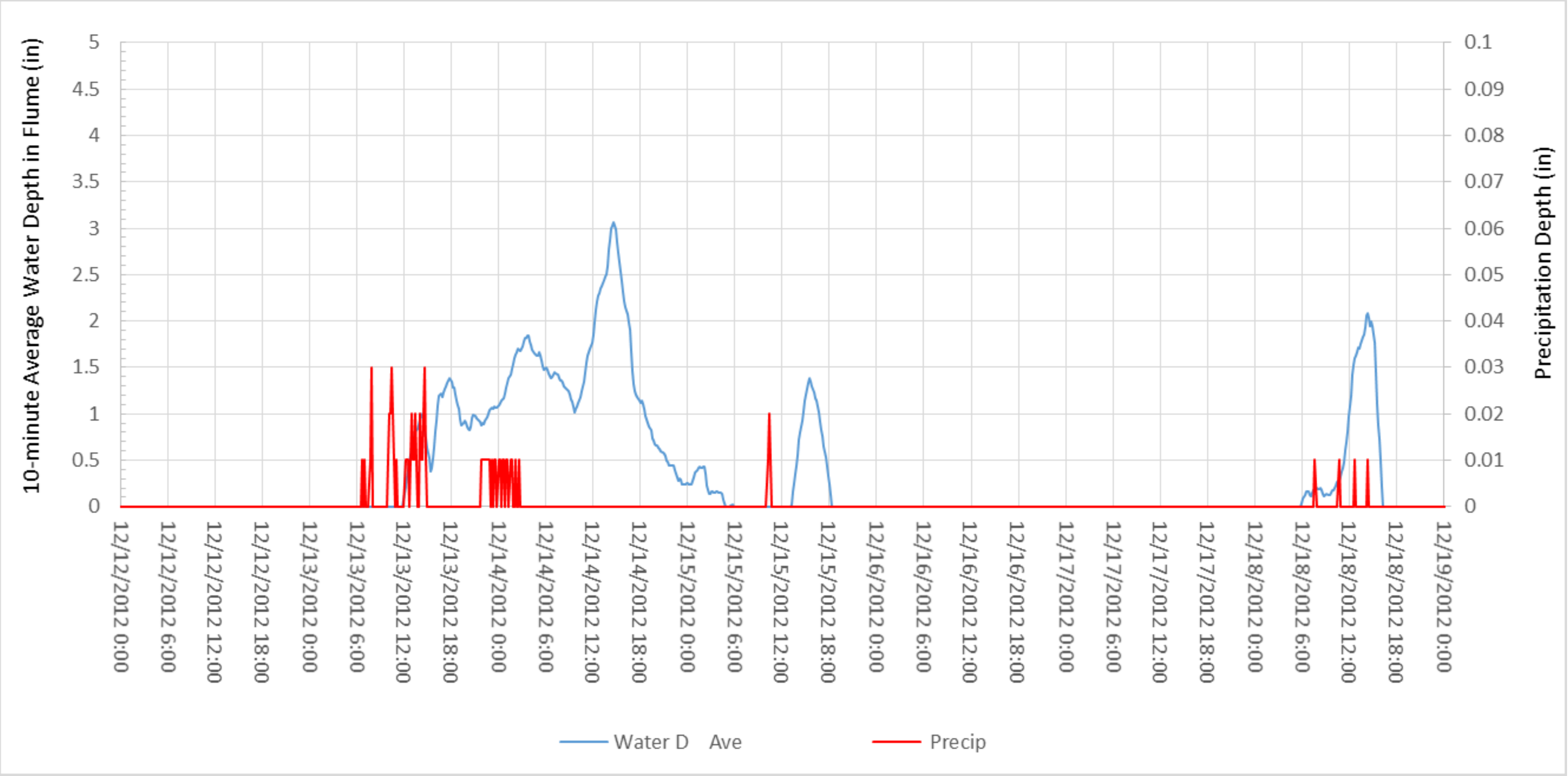

Figure C-1. Precipitation and transducer data for December 12-19, 2012.

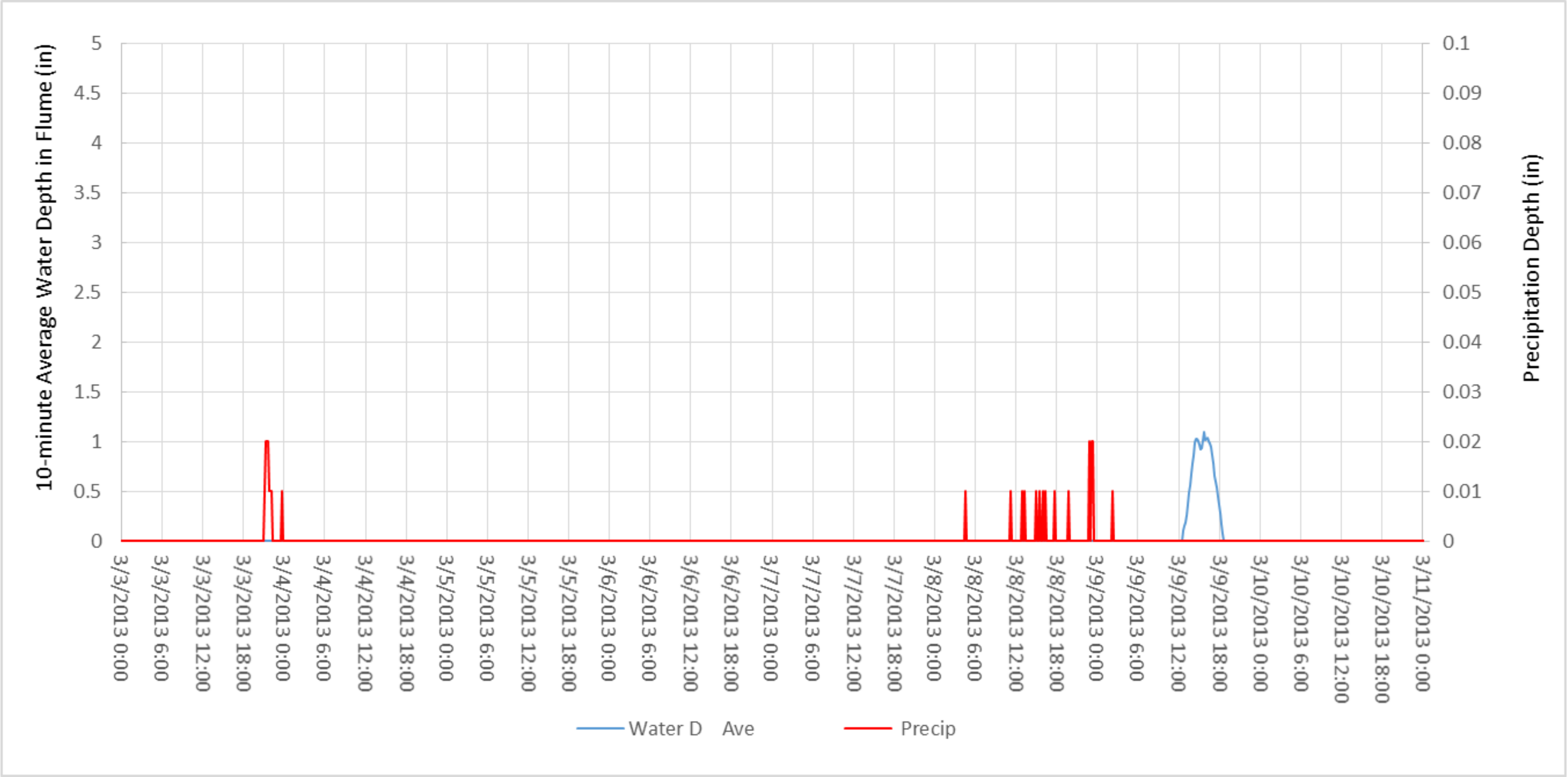

Figure C-2. Precipitation and transducer data for March 3-10, 2013.

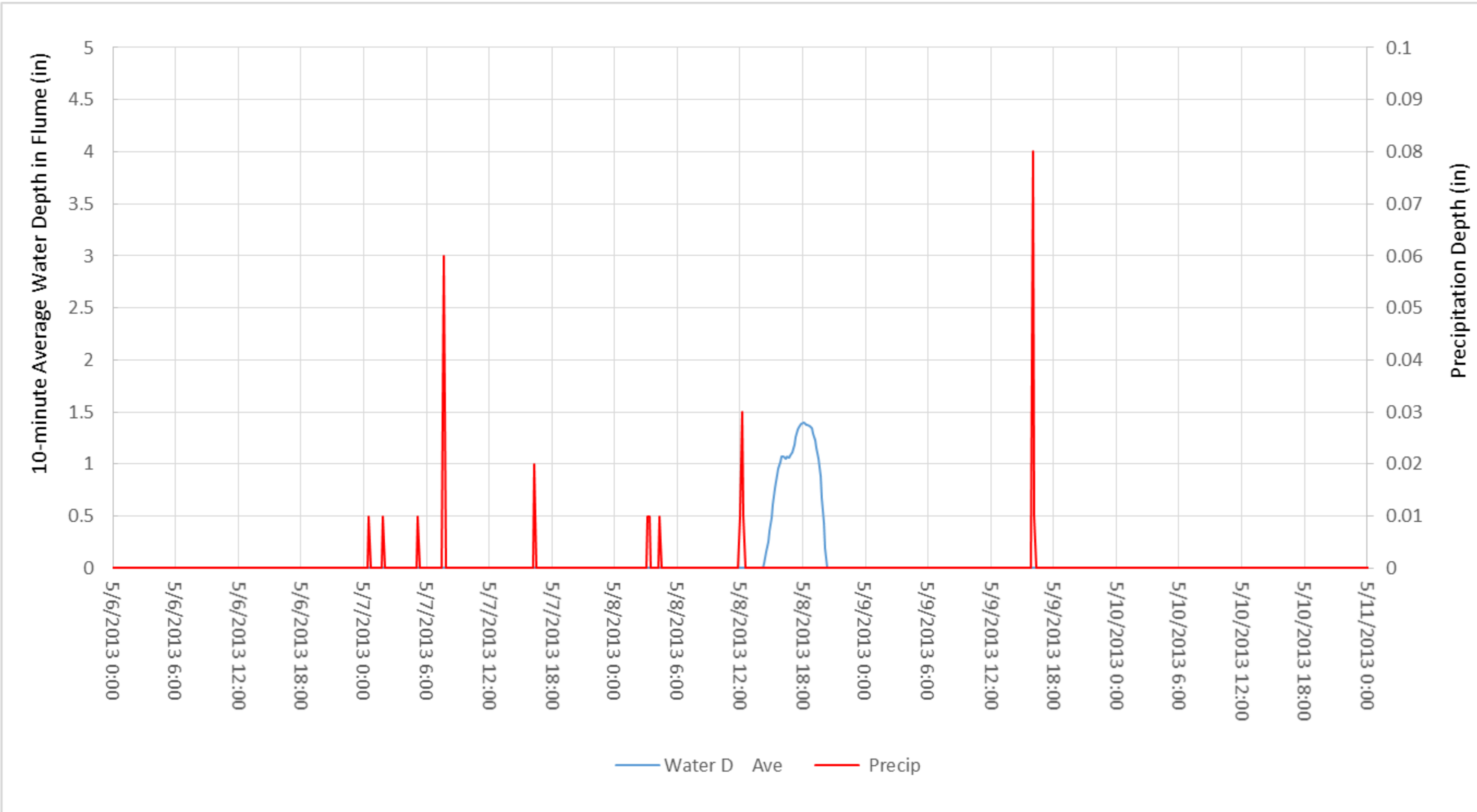

Figure C-3. Precipitation and pressure data for May 6-10, 2013.

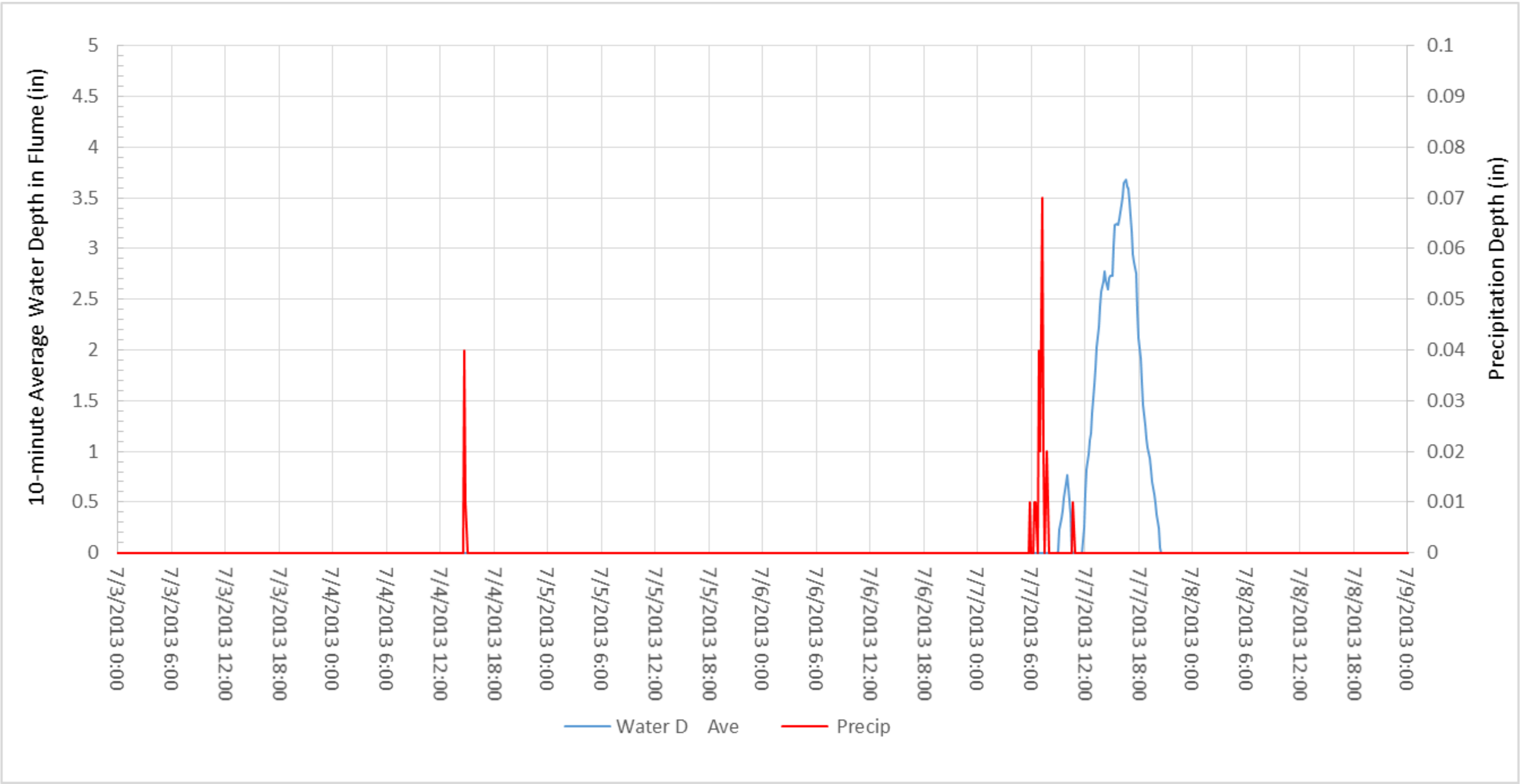

Figure C-4. Precipitation and pressure data for July 3-8, 2013.

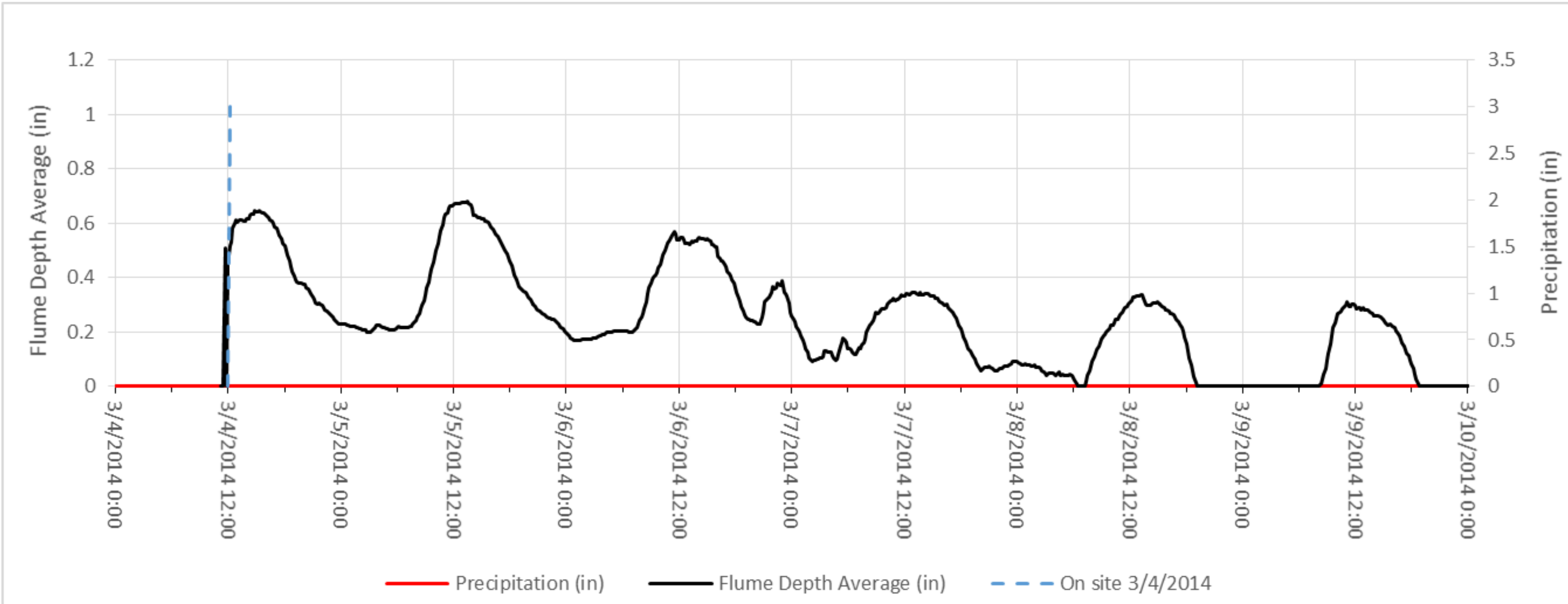

Figure C-5. Precipitation and pressure data for March 4-10, 2014.

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