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Hydrologic and Sediment Data Collected From Selected Basins at the Fort Leonard Wood Military Reservation, Missouri—2010–11

Scientific Investigations Report 2012–5268

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photographs from various locations at the Fort Leonard Wood Military Reservation.

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KEN SALAZAR, Secretary

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Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton per day (ton/d)	0.9072	metric ton per day
ton per day (ton/d)	0.9072	megagram per day (Mg/d)
ton per square mile (ton/mi^2)	0.3503	megagram per square kilometer (Mg/km^2)
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)
ton per year (ton/yr)	0.9072	metric ton per year
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)
pound per cubic foot (lb/ft^3)	0.01602	gram per cubic centimeter (g/cm^3)
ton per cubic foot (ton/ft^3)	0.02569	metric ton per cubic meter

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Hydrologic and Sediment Data Collected From Selected Basins at the Fort Leonard Wood Military Reservation, Missouri—2010–11

By Joseph M. Richards, Paul H. Rydlund, and Miya N. Barr

Abstract

Commercial and residential development within a basin often increases the amount of impervious area, which changes the natural hydrologic response to storm events by increasing runoff. Land development and disturbance combined with increased runoff from impervious areas potentially can increase sediment transport. At the Fort Leonard Wood Military Reservation in Missouri, there has been an increase in population and construction activities in the recent past, which has initiated an assessment of the hydrology in selected basins. From April 2010 to December 2011, the U.S. Geological Survey, in cooperation with the U.S. Army Maneuver Support Center at the Fort Leonard Wood Military Reservation, collected hydrologic and suspended-sediment concentration data in six basins at Fort Leonard Wood.

Storm-sediment concentration, load, and yield varied from basin to basin and from storm to storm. In general, storm-sediment yield, in pounds per square mile per minute, was greatest from Ballard Hollow tributary (06928410) and Dry Creek (06930250), and monthly storm-sediment yield, in tons per square mile, estimates were largest in Ballard Hollow tributary (06928410), East Gate Hollow tributary (06930058), and Dry Creek (06930250).

Sediment samples, collected at nine sites, primarily were collected using automatic samplers and augmented with equal-width-increment cross-sectional samples and manually collected samples when necessary. Storm-sediment load and yield were computed from discharge and suspended-sediment concentration data. Monthly storm-sediment yields also were estimated from the total storm discharge and the mean suspended-sediment concentration at each given site.

Introduction

Commercial and residential development within a basin often increases the amount of impervious area, which changes the natural hydrologic response to storm events by increasing runoff. Increases in runoff lead to stream deformation, down-cutting, and bank erosion, which results in excess sediment, a leading cause of water quality impairment throughout the United States. From 2000 to 2010, population has increased more than 10 percent at the Fort Leonard Wood Military Reservation (FLWMR) in Missouri (U.S. Census Bureau, 2011). This population growth and an increase in construction activities within the cantonment area of the FLWMR prompted an investigation of hydrologic changes and potential stream impairment. The U.S. Geological Survey (USGS), in cooperation with the U.S. Army Maneuver Support Center (MANSCEN) at FLWMR, began a study in April 2010 to collect hydrologic and suspended-sediment concentration (SSC) data in selected basins within the FLWMR. The FLWMR is under the regulation of the Missouri Clean Water Law and Federal Clean Water Act and the data collected by this study will help satisfy some requirements for a Municipal Separate Storm Sewer System (MS4) permit required by the Missouri Department of Natural Resources (Shannon Kelly, Fort Leonard Wood, oral commun., 2012).

Previous Studies

Several previous studies relating to issues of surface-water and groundwater quantity and quality have been completed at the FLWMR, many of which are described in Imes and others (1996). Imes and others (1996) reported the results of a study designed to characterize the regional surface-water and groundwater quantity and quality in the vicinity of the FLWMR relating to environmental contamination that may have resulted from historic operational practices. Harrison and others (1996) mapped the geology, characterized bedrock structures potentially affecting groundwater flow, and mapped many karst features at the FLWMR and adjacent areas. Kleeschulte and Imes (1997) described the regional groundwater flow system and how the karst terrane that underlies the FLWMR affects the local and regional flow system.

Purpose and Scope

The report describes the methods used to collect local-scale, surface-water hydrologic and sediment data during storm events in selected basins at the FLWMR. The report also presents the data that were collected from April 2010 to December 2011 and the associated storm-sediment yield.

Description of Study Area

FLWMR is located in the southern part of Pulaski County, Missouri (fig. 1) and lies within the Salem Plateau of the Ozark Plateaus Physiographic Province (Fenneman, 1938). The FLWMR is approximately 64,000 acres in size and is bounded to the east by the Big Piney River, to the west by Roubidoux Creek, to the north by Interstate 44, and to the south by publicly and privately owned hardwood forest land (fig. 1; Kleeschulte and Imes, 1997). The mean annual precipitation in the area is approximately 42 inches (Imes and others, 1996). The rocks exposed in the area are Ordovician age and are dominantly carbonate composition. Soils in most of the area consist of silty and sandy loam to very cherty silty loam derived from locally weathered bedrock (Harrison and others, 1996). Some loess deposits of wind-blown silty loam, colluvial material on the steep hillsides, and recent alluvial fill along larger streams also are present in lesser amounts (Harrison and others, 1996). Karst features such as springs, sinkholes, caves, and losing streams are common at the FLWMR and can affect groundwater and surface-water flow (Imes and others, 1996; Kleeschulte and Imes, 1997).

Data Collection Equipment and Methods

For this study, streamgages were installed and streamflow and SSC data were collected at six basins designated by MANSCEN within the FLWMR boundary (table 1; fig. 2). Each basin had one co-located streamgage and sediment sampling site except for the Quarry Hollow Tributary Basin. The Quarry Hollow Tributary Basin had three co-located streamgage and sediment sampling sites designed to evaluate the sediment contribution from the open gravel quarry located near the basin outlet. An additional sediment sampling site (South ditch, USGS station number 374313092042401) within the Quarry Hollow Tributary Basin was not co-located with a streamgage. This site was sampled manually for sediment six times during four storms to determine the sediment contribution to the Quarry Hollow Tributary Basin from this site (table 1; fig. 2).

Various equipment and methods were used to collect hydrologic and SSC data for this study. Because the basins monitored in this study were small, many of the basins had no flow for much of the study. The study was designed to collect hydrologic data primarily during storm events; therefore, in some basins that did have a small base flow component, streamgage equipment was not always set up to record this base flow. Because of the emphasis on storm events, few low-flow discharge measurements were made for this study. Storm events generally produced hydrographs that rose rapidly to the peak discharge and receded almost as quickly to pre-storm discharge values. The storm-event hydrographs generally were short in duration and sediment samples only were collected during storm events (fig. 3).

Hydrologic Data

The equipment used to collect stage data at each site consisted of a pressure transducer that measured the stage in the stream and a data logger that stored the stage data at 5-minute intervals (Buchanan and Somers, 1974). Continuous stage data collected by the data logger at each site were stored in the USGS National Water Information System (NWIS) database (Sauer, 2002) and were used to determine the peak stage and the hydrograph of stage versus time for any given storm event. Discharge measurements were made using hydroacoustic equipment according to the methods outlined in Mueller and Wagner (2009) and Turnipseed and Sauer (2010). USGS personnel used the discharge measurements to establish the stage-discharge relation for each site (Kennedy, 1984; Kennedy, 1989).

Precipitation data were collected by an existing National Weather Service rain gage, number 03938 (not shown on a figure), located at the FLWMR Forney Army Airport (fig. 1; National Oceanic and Atmospheric Administration, n.d.), and augmented with precipitation data collected using tipping bucket rain gages installed at select sites (table 1). Data from these rain gages were stored in the streamgage data logger.

The stage and precipitation data were transmitted by satellite to a USGS computer and served on the internet in near real time. After collection, all hydrologic data were quality assured and stored in the NWIS database.

Sediment Data

Sediment samples were collected primarily with an automatic sampler (Sigma 900MAX) that was housed inside the streamgage and connected to the data logger. Sediment samples were collected from one fixed point in the water column, and the sampler orifice location generally was positioned on the bank near the streamgage. The streamgage data logger was programmed to collect stage, compute discharge, and compute the volume of water that passed the monitoring site during 5-minute increments. The stage data and volume computations were used to initiate sampling by the automatic sampler, which collected a flow-weighted sediment sample during each sampled storm event. A SSC was analyzed from sample water that was pumped into sample collection bottles by a 12-volt peristaltic pump housed in the automatic sampler. As a result

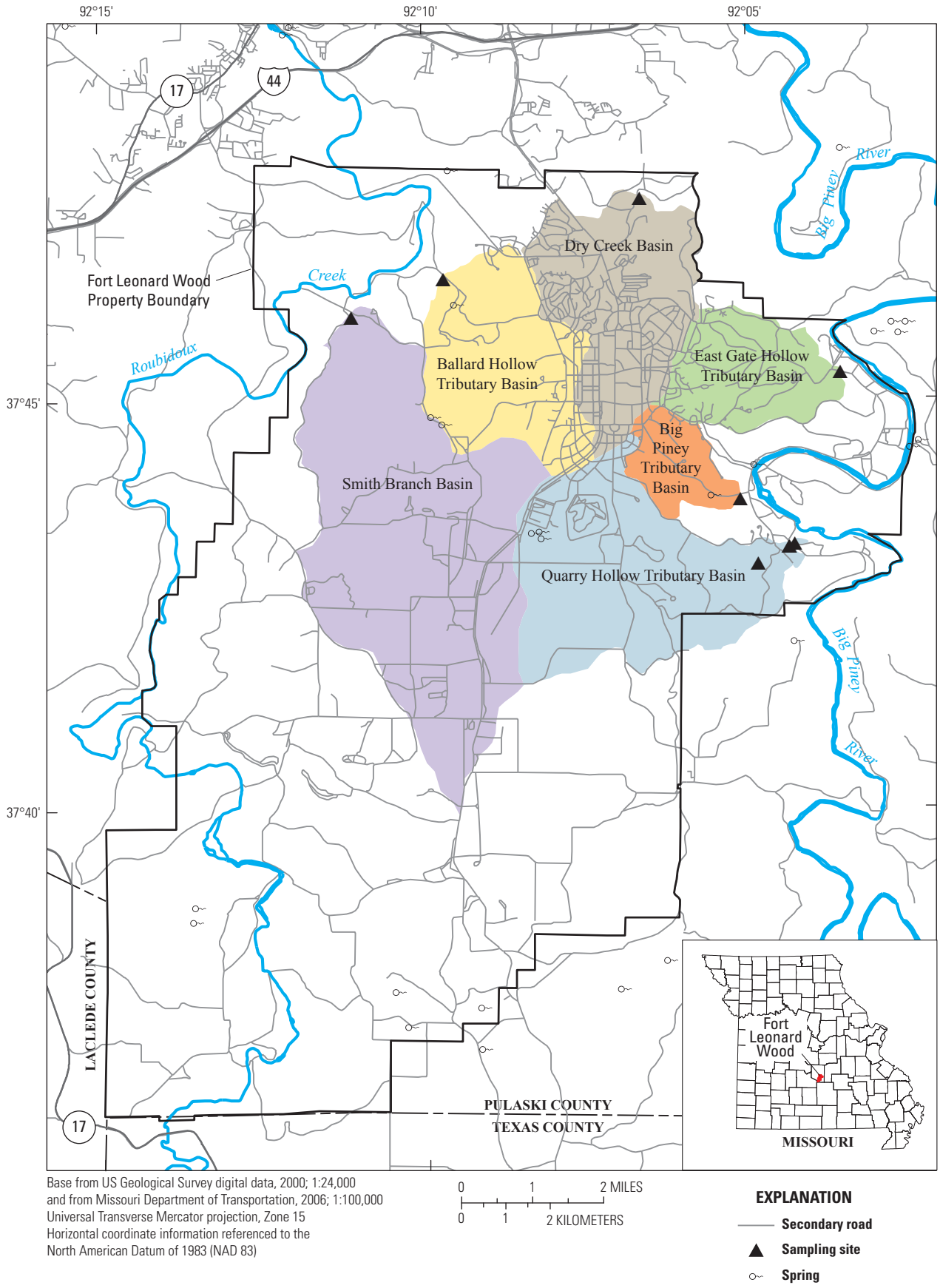

Figure 1. Location of study area.

Table 1. Hydrologic and sediment data collection sites at the Fort Leonard Wood Military Reservation, Missouri.

[mi², square miles; Y, yes; N, No; --, no period of record]

Site number	Site name	Drainage area (mi²)	Drainage area (acres)	Period of record		Precipitation data	Events sampled
				From	To		
06928400	Smith Branch	13.8	8,812	6/10/2010	12/28/2011	Y	4
06928410	Ballard Hollow tributary	5.31	3,401	4/16/2010	12/28/2011	Y	13
06930025	Big Piney tributary	1.54	984	6/2/2010	12/3/2010	N	14
06930023	Quarry Hollow tributary	7.44	4,765	4/16/2010	12/28/2011	Y	11
374313092042401	South ditch	0.05	29	--	--	N	4
06930027	Quarry Hollow tributary below quarry	8.01	5,128	1/26/2011	12/23/2011	Y	7
06930028	Quarry Hollow tributary below quarry catchment	8.03	5,139	5/13/2010	12/27/2011	N	3
06930058	East Gate Hollow tributary	3.18	2,033	4/23/2010	12/27/2011	Y	15
06930250	Dry Creek	5.63	3,605	4/16/2010	12/28/2011	N	15

of short hydrograph duration times and event-driven protocol, sediment point samples from the automatic samplers were not calibrated to equal-width-increment (EWI) cross-sectional sediment samples.

The sites were visited after each storm to verify peak stage values and to retrieve sample collection bottles from the automatic samplers. Early in the project, while the stage-discharge relation was being developed, a mean SSC was computed from individual samples that were collected at specific points on the discharge hydrograph. Later in the project, samples collected throughout the discharge hydrograph were composited into a single bottle and SSC was determined from the composited sample. In addition, sediment samples occasionally were collected by hand, and when stream conditions were suitable for wading, sediment samples were collected manually using a DH-81 sampler and the EWI method (Edwards and Glysson, 1999; Lane and others, 2003). These samples were collected to augment the automatically collected samples, to provide quality assurance/quality control data for the automatically collected samples, to provide opportunistic samples at additional sites, or to provide a sample when the automatic sampler failed to operate correctly.

Sediment samples were transported to and analyzed by the USGS Missouri Water Science Center sediment laboratory. Laboratory analysis for SSC was performed in accordance to the filtration methods described in Guy (1969).

Sample Site Descriptions and Storm-Sediment Load

Every precipitation event has the potential of eroding and moving sediment from the land surface. Factors affecting the amount and type of sediment eroded from the landscape and washed into receiving streams include soil type, land use, land cover, land slope, precipitation intensity, precipitation volume, antecedent moisture conditions, and physical stream channel characteristics. Thus, differences in SSC and sediment load in a given stream can have many causes. Sediment load is the mass of sediment material moved by stream water past a fixed point in space and consists of two components: bed sediment load and suspended-sediment load. Bed sediment moves by rolling, sliding, or bouncing along the bed of the stream, and suspended sediment moves by being carried along in suspension in the water column (Sturm, 2001). Sediment sampled in this study was the suspended-sediment part of the sediment load.

For this study, the event-mean SSC and the sampled runoff volume were used to compute a sediment load associated with the sampled storm at each sampling site (table 2). The event-mean SSC was computed from the arithmetic mean of the individual SSC samples collected throughout the hydrograph or was the laboratory-determined composite SSC. The sampled runoff volume was the sum of the incremental discharge (5-minute intervals) of water that passed the streamgage between the time the first and last samples were collected (fig. 3). For most of the storm events, the stage rose rapidly and thus most of the sediment sample collection was on the peak and falling limb of the hydrograph (fig. 3). The load represents the sediment mass passing the streamgage

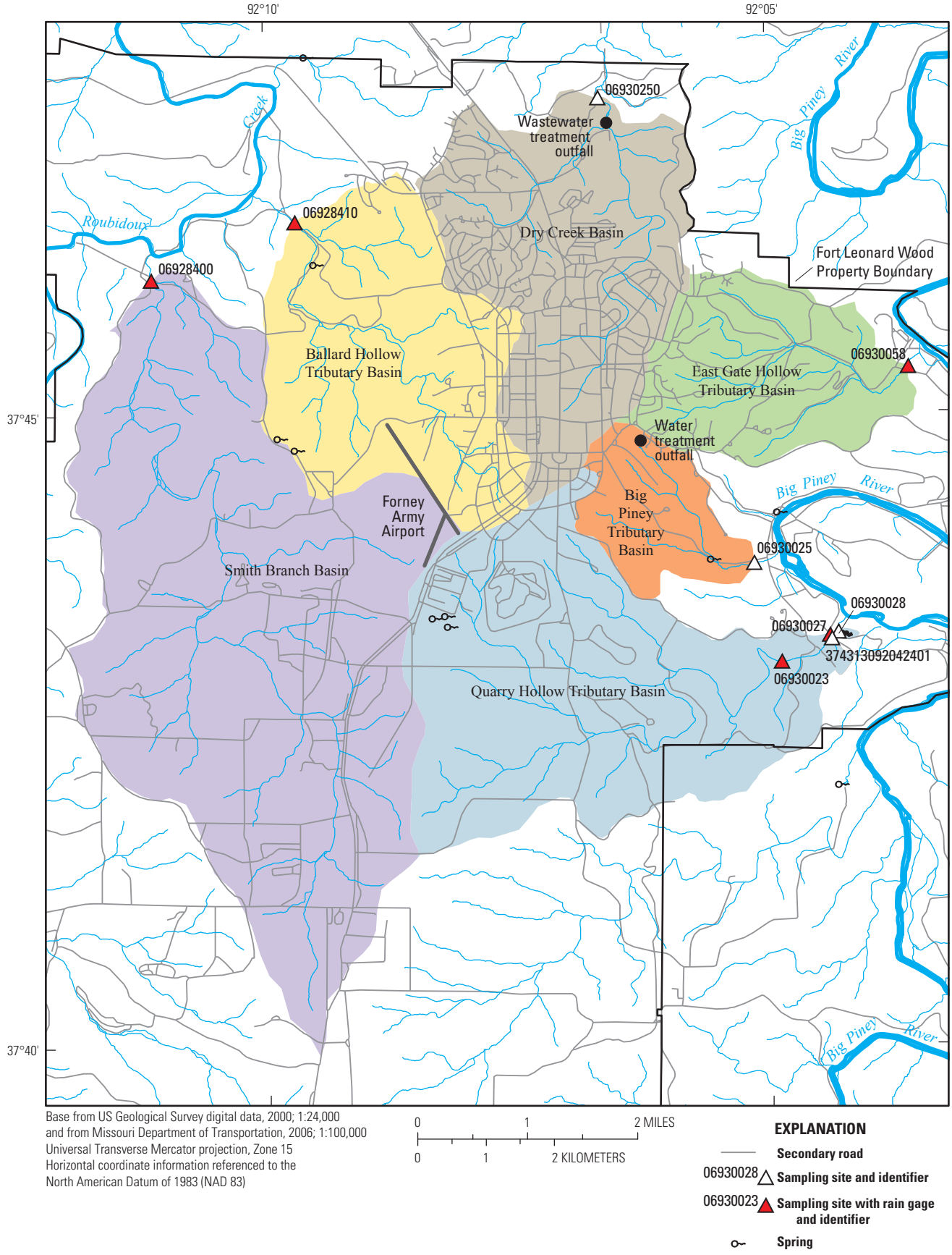

Figure 2. Location of data collection sites.

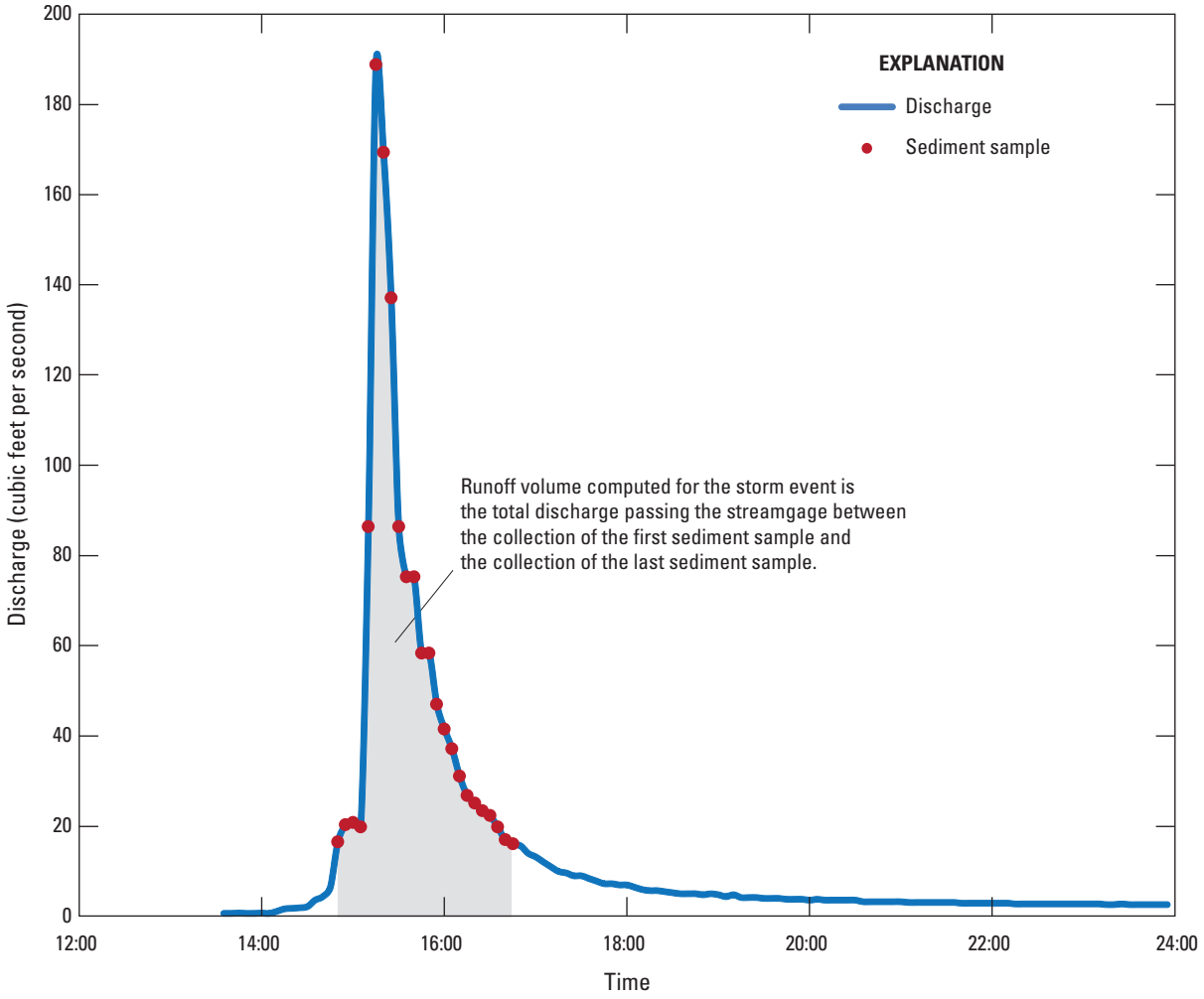

Figure 3. Example storm-event hydrograph and sediment sample collection plot at East Gate Hollow tributary (06930058) for the July 30, 2011, storm event.

during the sampling period and may not accurately represent the mass of sediment passing the streamgage for the entire storm event. In some cases, the sediment sampling period coincided very well with the storm runoff period; however, in other cases, few samples were collected throughout the hydrograph and thus the sediment sampling period does not coincide with the storm runoff period.

Sediment load for a given sampling event (i) was computed using the following equation:

$$LOAD_i = EMC_i \times RV_i \times \left(6.245 \times 10^{-5}\right) \quad (1)$$

where

$LOAD_i$ is sediment load (in pounds) for event i,

EMC_i is event-mean suspended-sediment concentration (in milligrams per liter) for event i,

RV_i is runoff volume (in cubic feet) for event i, and

6.245×10^{-5} is the conversion from milligrams per liter to pounds per cubic foot.

Smith Branch Basin

The Smith Branch sampling site (06928400; fig. 2) was located approximately 0.29 miles upstream from the confluence of Smith Branch with Roubidoux Creek. The drainage area at the streamgage was 13.8 square miles (mi^2; table 1), and the channel at the streamgage was narrow and steep sided with a bedrock bottom. Imes and others (1996) did not measure this stream during a low-base flow seepage run on Roubidoux Creek. During the period of this study, Smith Branch did not flow except during, and shortly after, storm events (fig. 4).

Storm events were successfully sampled at this site four times (table 1; fig. 4). The SSC for all storms sampled ranged from 222 to 1,210 milligrams per liter (mg/L) and had a mean of 481 mg/L (table 2). The sediment load ranged from 76.8 to 383,000 pounds (table 2). A precipitation hyetograph for this site is shown in figure 4, and monthly precipitation totals are presented in table 3.

Table 2. Sampled runoff volume, event-mean suspended-sediment concentration, sediment load, and sediment yield for selected basins at the Fort Leonard Wood Military Reservation, Missouri.

[ft^3, cubic foot; mg/L, milligrams per liter; lb, pound; $(lb/mi^2)/min$, pounds per square mile per minute; --, no data

Storm event date	Sampled runoff volume (ft^3)	Event-mean suspended-sediment concentration (mg/L)	Sediment load (lb)	Sediment yield [$(lb/mi^2)/min$]
Smith Branch (06928400)				
07/09/2010	5,490	224	76.8	1.12
07/26/2010	5,070,000	1,210	383,000	232
11/25/2010	1,990,000	269	33,400	14.3
02/24/2011	767,000	222	10,600	19.2
Ballard Hollow tributary (06928410)				
07/08/2010	858,000	1,480	79,300	119
09/01/2010	175,000	1,550	16,900	127
11/25/2010	214,000	855	11,400	61.3
04/15/2011	1,510,000	1,050	99,000	117
04/23/2011	1,280,000	642	51,300	55.2
04/25/2011	624,000	482	18,800	20.8
05/12/2011	1,030,000	465	29,900	32.2
05/19/2011	811,000	512	25,900	39.0
05/20/2011	760,000	253	12,000	15.1
05/28/2011	265,000	617	10,200	34.9
08/04/2011	901,000	863	48,600	67.8
08/20/2011	335,000	363	7,590	20.4
09/18/2011	346,000	452	9,770	28.3
Big Piney tributary (06930025)				
[1]06/20/2010	14,700	313	287	--
[1]06/26/2010	22,700	365	517	--
[1]06/27/2010	21,400	286	382	--
[1]07/03/2010	20,800	263	342	--
[1]07/05/2010	17,900	190	212	--
[1]07/07/2010	35,900	198	444	--
[1]08/08/2010	20,200	281	354	--
[1]08/13/2010	11,200	228	159	--
[1]08/14/2010	12,500	250	195	--
[1]08/16/2010	31,500	183	360	--
[1]08/18/2010	32,700	180	368	--
[1]08/20/2010	3,450	736	159	--
[1]08/21/2010	22,500	268	377	--
[1]08/22/2010	20,700	138	178	--
Quarry Hollow tributary (06930023)				
02/24/2011	249,000	512	7,960	7.38
02/27/2011	186,000	2,630	30,500	41.0
03/14/2011	833,000	545	28,400	11.4
04/15/2011	229,000	906	13,000	15.9
04/22/2011	165,000	332	3,420	3.41

Table 2. Sampled runoff volume, event-mean suspended-sediment concentration, sediment load, and sediment yield for selected basins at the Fort Leonard Wood Military Reservation, Missouri.—Continued

[ft^3, cubic foot; mg/L, milligrams per liter; lb, pound; $(lb/mi^2)/min$, pounds per square mile per minute; --, no data

Storm event date	Sampled runoff volume (ft^3)	Event-mean suspended-sediment concentration (mg/L)	Sediment load (lb)	Sediment yield [$(lb/mi^2)/min$]
Quarry Hollow tributary (06930023)—Continued				
04/23/2011	990,000	1,250	77,300	16.4
[2]04/25/2011a	187,000	49.0	572	0.405
[2]04/25/2011b	2,170,000	668	90,500	36.3
05/28/2011	187,000	1,930	22,500	31.8
08/04/2011	249,000	1,570	24,400	32.8
09/18/2011	4,470	2,600	726	19.5
South ditch (374313092042401)				
[2]02/24/2011a	226	308	4.35	87.0
[2]02/24/2011b	23.6	94.0	0.139	2.78
03/14/2011a	45.7	6,520	18.6	372
03/14/2011b	22.6	240	0.339	6.78
04/15/2011	7.50	25.0	0.012	0.240
05/23/2011	30.0	91.0	0.170	3.40
Quarry Hollow tributary below quarry (06930027)				
04/15/2011	623,000	676	26,300	12.2
04/22/2011	319,000	357	7,110	5.22
04/23/2011	1,300,000	1,020	82,800	26.5
05/19/2011	98,400	627	3,850	9.61
05/20/2011	72,900	204	929	2.32
08/04/2011	99,000	235	1,450	0.584
08/20/2011	118,000	294	2,170	0.903
Quarry Hollow tributary below quarry catchment (06930028)				
05/26/2011	2,080,000	29.0	3,770	1.24
08/04/2011	561,000	467	16,400	7.43
08/22/2011	55,100	367	1,260	2.85
East Gate Hollow tributary (06930058)				
07/08/2010	10,900	900	613	19.3
09/01/2010	307,000	26.0	498	0.167
09/02/2010	69,200	6.00	25.9	0.096
09/03/2010	21,900	292	399	1.67
11/24/2010	432,000	21.0	567	0.585
04/15/2011	493,000	419	12,900	16.6
04/22/2011	154,000	80.0	769	1.93
04/23/2011	924,000	279	16,100	11.6
05/19/2011	565,000	346	12,200	10.8
05/20/2011	720,000	43.0	1,930	1.26
05/28/2011	211,000	357	4,700	10.6
07/30/2011	396,000	2,200	54,400	143
08/04/2011	224,000	365	5,110	13.4
08/20/2011	14,900	129	120	2.52
09/19/2011	38,300	347	830	6.53

Table 2. Sampled runoff volume, event-mean suspended-sediment concentration, sediment load, and sediment yield for selected basins at the Fort Leonard Wood Military Reservation, Missouri.—Continued

[ft^3, cubic foot; mg/L, milligrams per liter; lb, pound; $(lb/mi^2)/min$, pounds per square mile per minute; --, no data

Storm event date	Sampled runoff volume (ft^3)	Event-mean suspended-sediment concentration (mg/L)	Sediment load (lb)	Sediment yield [$(lb/mi^2)/min$]
06/15/2010	48,300	449	1,350	16.0
07/08/2010	2,090,000	681	88,900	126
07/26/2010	895,000	394	22,000	20.6
08/21/2010	256,000	572	9,140	7.06
09/01/2010	1,490,000	868	80,800	169
11/24/2010	2,340,000	353	51,600	55.5
04/15/2011	3,160,000	1,070	211,000	341
04/23/2011	2,060,000	667	85,800	92.4
04/25/2011	4,370,000	510	139,000	165
05/12/2011	1,050,000	385	25,200	63.9
05/19/2011	1,970,000	543	66,800	148
05/20/2011	323,000	213	4,300	38.2
07/30/2011	888,000	1,290	71,500	317
08/04/2011	2,150,000	780	105,000	219
09/17/2011	82,300	637	3,270	10.6

[1]Samples affected by release of water from water-treatment sediment-settling ponds upstream from the gage and data not representative of storm events in the basin.

[2]Two samples collected in the same day.

Ballard Hollow Tributary Basin

The Ballard Hollow tributary sampling site (06928410; fig. 2) was located approximately 0.47 miles upstream from the confluence of Ballard Hollow tributary with Roubidoux Creek. The drainage area at the streamgage was 5.31 mi^2 (table 1). The channel at the streamgage was narrow and steep sided with a gravel and cobble bottom. Imes and others (1996) measured 0.18 cubic foot per second (ft^3/s) at this stream during a low-base flow seepage run on Roubidoux Creek. The streamgage orifice elevation at this site was set such that flow less than approximately 12.2 ft^3/s was not recorded by the streamgage.

Storm events were successfully sampled at this site thirteen times (table 1; fig. 5). The SSC for all storms sampled ranged from 253 to 1,550 mg/L and had a mean of 737 mg/L (table 2). The sediment load ranged from 7,590 to 99,000 pounds (table 2). A precipitation hyetograph for this site is shown in figure 5, and monthly precipitation totals are presented in table 3.

Big Piney Tributary Basin

The Big Piney tributary sampling site (06930025) was located approximately 0.33 miles upstream from the confluence of the Big Piney tributary with the Big Piney River. The drainage area at the streamgage was 1.54 mi^2 (table 1). A small amount of base flow is maintained by a spring that discharges to the tributary approximately 0.42 mi upstream from the streamgage. Imes and others (1996) did not measure this stream during a low-base flow seepage run on the Big Piney River. The streamgage orifice elevation at this site was set such that flow less than approximately 0.55 ft^3/s was not recorded by the streamgage.

The outfall for the water-treatment sediment-settling ponds for the drinking water intake from the Big Piney River is located near the basin divide (Shannon Kelly, Fort Leonard Wood, oral commun., 2012; fig. 2). The settling ponds are periodically (once a day or once every other day) drained to the headwaters of the Big Piney tributary. The presence of the settling ponds and periodic water release was not known to the USGS at the time of the installation and operation of the streamgage and subsequent sediment sampling; therefore, the gage was relocated to the Quarry Hollow Tributary Basin in early 2011. It is unclear if any of the sediment samples that were collected from this basin were associated with a storm event. It is believed most, if not all, of the sediment samples collected in this basin were collected from the water that was released from the settling pond.

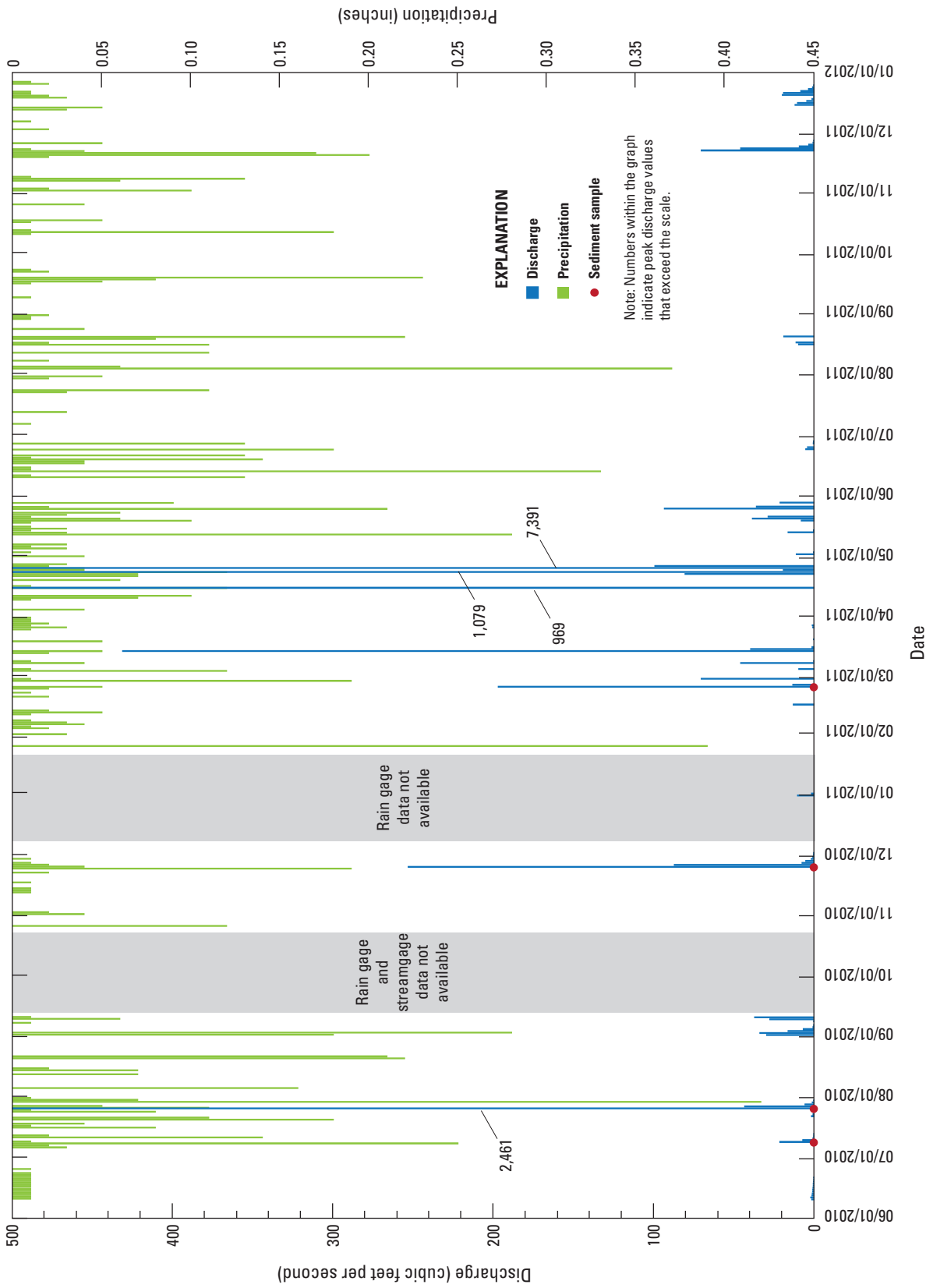

Figure 4. Smith Branch (06928400) discharge hydrograph, hyetograph, and sediment sample collection dates.

Table 3. Total monthly precipitation (inches) in selected basins at the Fort Leonard Wood Military Reservation, Missouri.

[--, no data]

Date (month year)	Precipitation (inches)					
	Forney Army Airport	Smith Branch (06928400)	Ballard Hollow tributary (06928410)	Quarry Hollow tributary (06930023)	Quarry Hollow tributary below quarry (06930027)	East Gate Hollow tributary (06930058)
April 2010	2.08	--	[1]2.19	[1]1.70	--	[1]1.49
May 2010	6.00	--	6.44	6.59	--	6.52
June 2010	4.61	[1]0.24	4.81	3.92	--	4.97
July 2010	4.83	7.00	7.57	5.87	--	6.25
August 2010	2.00	2.70	2.91	2.22	--	1.95
September 2010	7.72	[1]5.98	8.66	[1]5.34	--	7.77
October 2010	0.36	[1]0.17	[1]0.01	--	--	0.34
November 2010	4.02	4.45	3.67	--	--	3.84
December 2010	0.64	[1]0	1.86	1.05	--	1.12
January 2011	0.27	[1]0.59	0.28	0.43	[1]0	0.39
February 2011	3.16	6.53	3.89	3.91	2.55	3.63
March 2011	5.27	5.61	5.73	5.22	5.19	5.27
April 2011	6.98	8.25	7.90	8.79	7.90	8.43
May 2011	7.05	7.77	7.34	7.11	5.79	7.54
June 2011	4.14	4.33	3.93	5.43	5.05	3.76
July 2011	1.16	0.86	0.68	3.22	3.50	3.43
August 2011	6.05	5.95	5.55	6.02	6.81	5.02
September 2011	2.79	2.23	2.41	3.14	3.21	2.51
October 2011	2.21	2.23	1.86	2.57	2.43	2.34
November 2011	3.85	5.81	5.23	4.46	4.24	3.65
December 2011	2.57	2.84	2.68	2.79	2.20	2.83

[1]Values based on partial month record.

SSCs from this site were not considered to be representative of storm-sediment transport in this basin and therefore rainfall data were not included on figure 6. Nevertheless, fourteen samples were successfully collected at this site (table 1; fig. 6). The SSC for all samples ranged from 138 to 736 mg/L and had a mean of 277 mg/L (table 2). The sediment load ranged from 159 to 517 pounds (table 2).

Quarry Hollow Tributary Basin

The Quarry Hollow Tributary Basin was more intensively studied because of an active gravel quarry operation for an onsite asphalt plant. Imes and others (1996) estimated base flow of 0.07 ft^3/s in this basin during a low-base flow seepage run on the Big Piney River. The streamgage orifice elevation at the furthest upstream site, Quarry Hollow tributary (06930023; fig. 2), was set such that flow less than approximately 5.27 ft^3/s was not recorded by the streamgage (fig. 7).

Quarry Hollow Tributary

The Quarry Hollow tributary sampling site (06930023; fig. 2) was located approximately 0.97 miles upstream from the confluence of the Quarry Hollow tributary with the Big Piney River. The channel at the streamgage was narrow and had a gravel and cobble bottom, and was located adjacent to the asphalt plant and upstream from the quarry. The drainage area at the streamgage was 7.44 mi^2 (table 1).

Storm events were successfully sampled at this site eleven times (table 1; fig. 7). The SSC for all storms sampled ranged from 49.0 to 2,630 mg/L and had a mean of 1,181 mg/L (table 2). The sediment load ranged from 572 to 90,500 pounds (table 2). A precipitation hyetograph for this site is shown in figure 7, and monthly precipitation totals are presented in table 3.

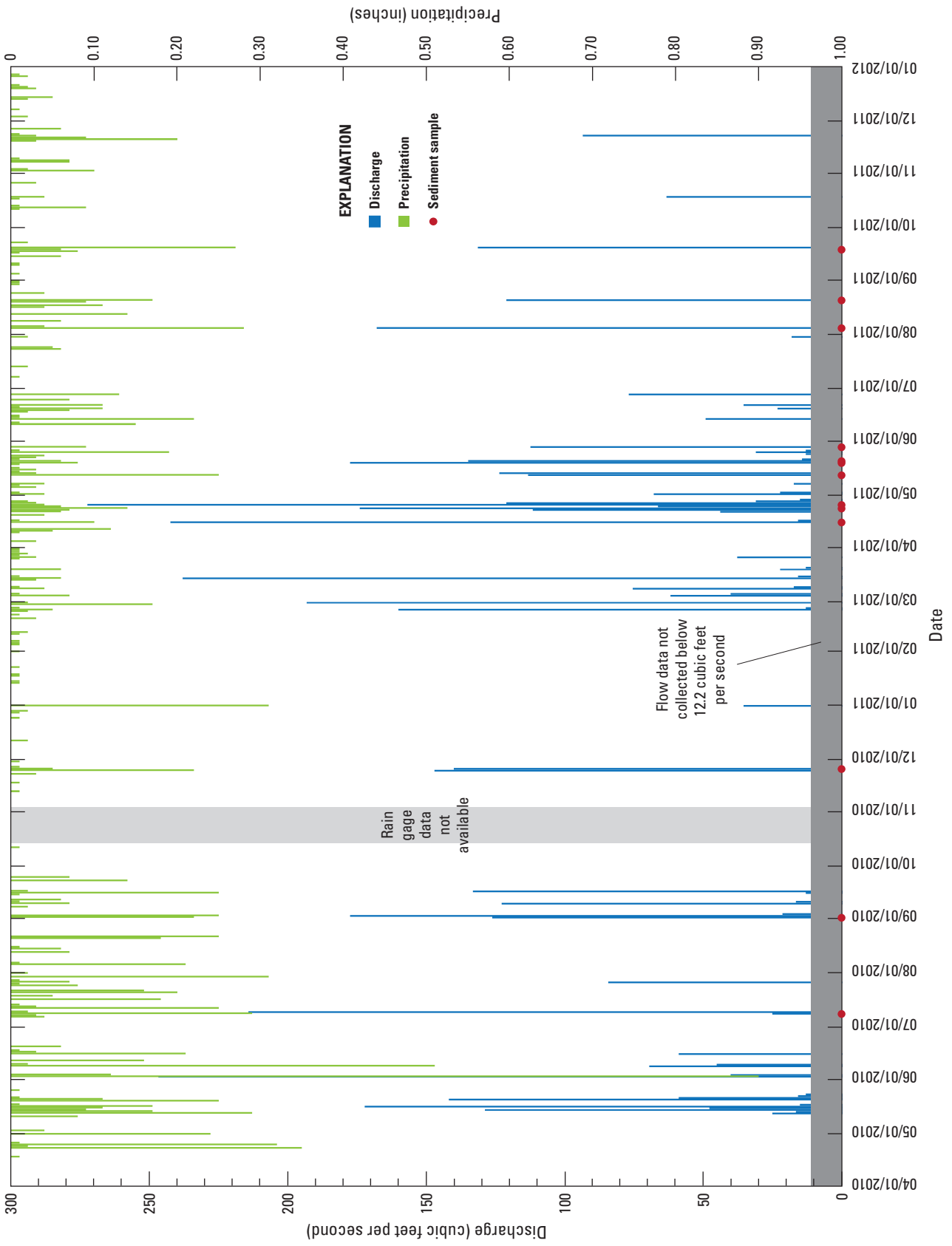

Figure 5. Ballard Hollow tributary (06928410) discharge hydrograph, hyetograph, and sediment sample collection dates.

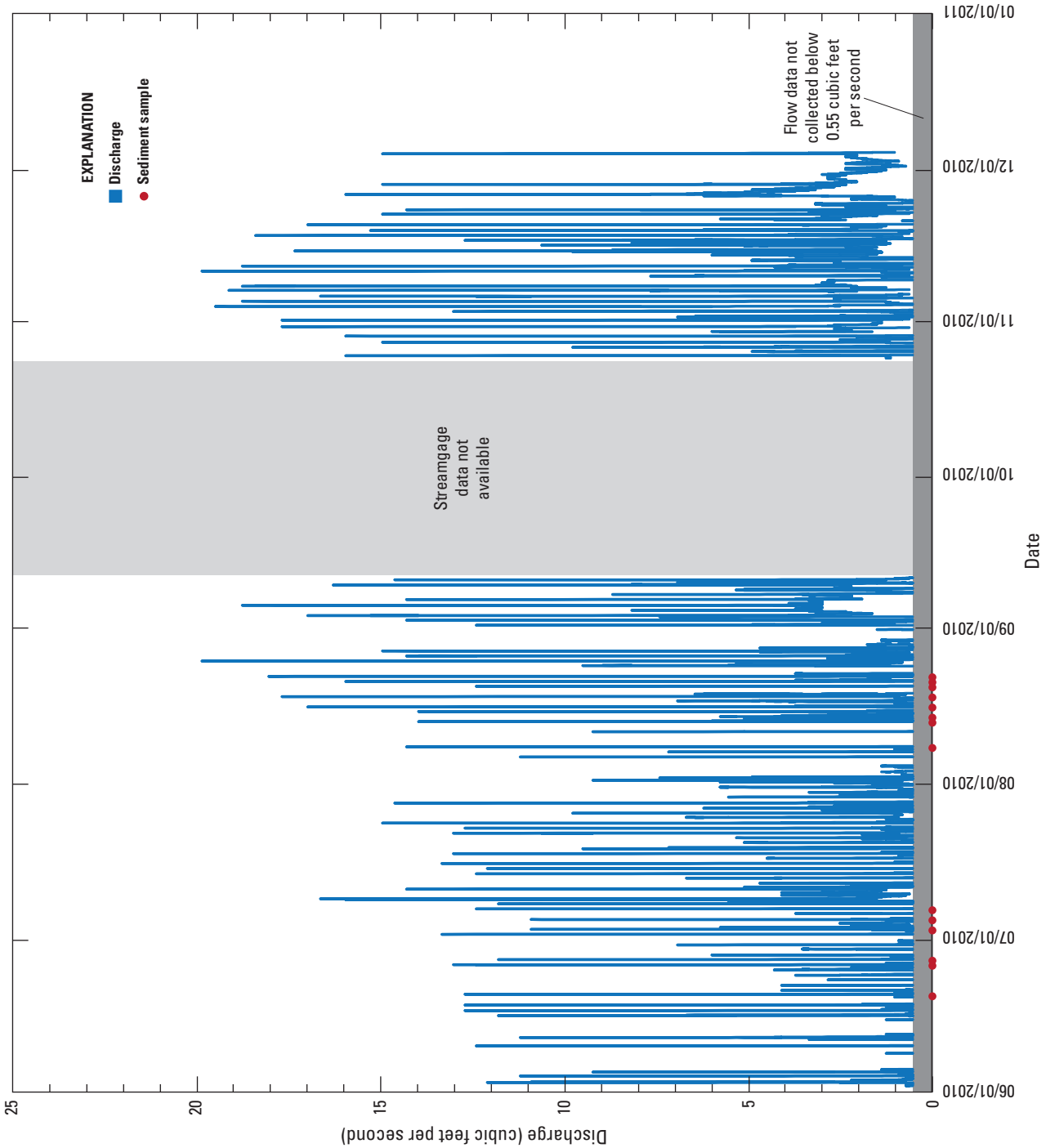

Figure 6. Big Piney tributary (06930025) discharge hydrograph and sediment sample collection dates.

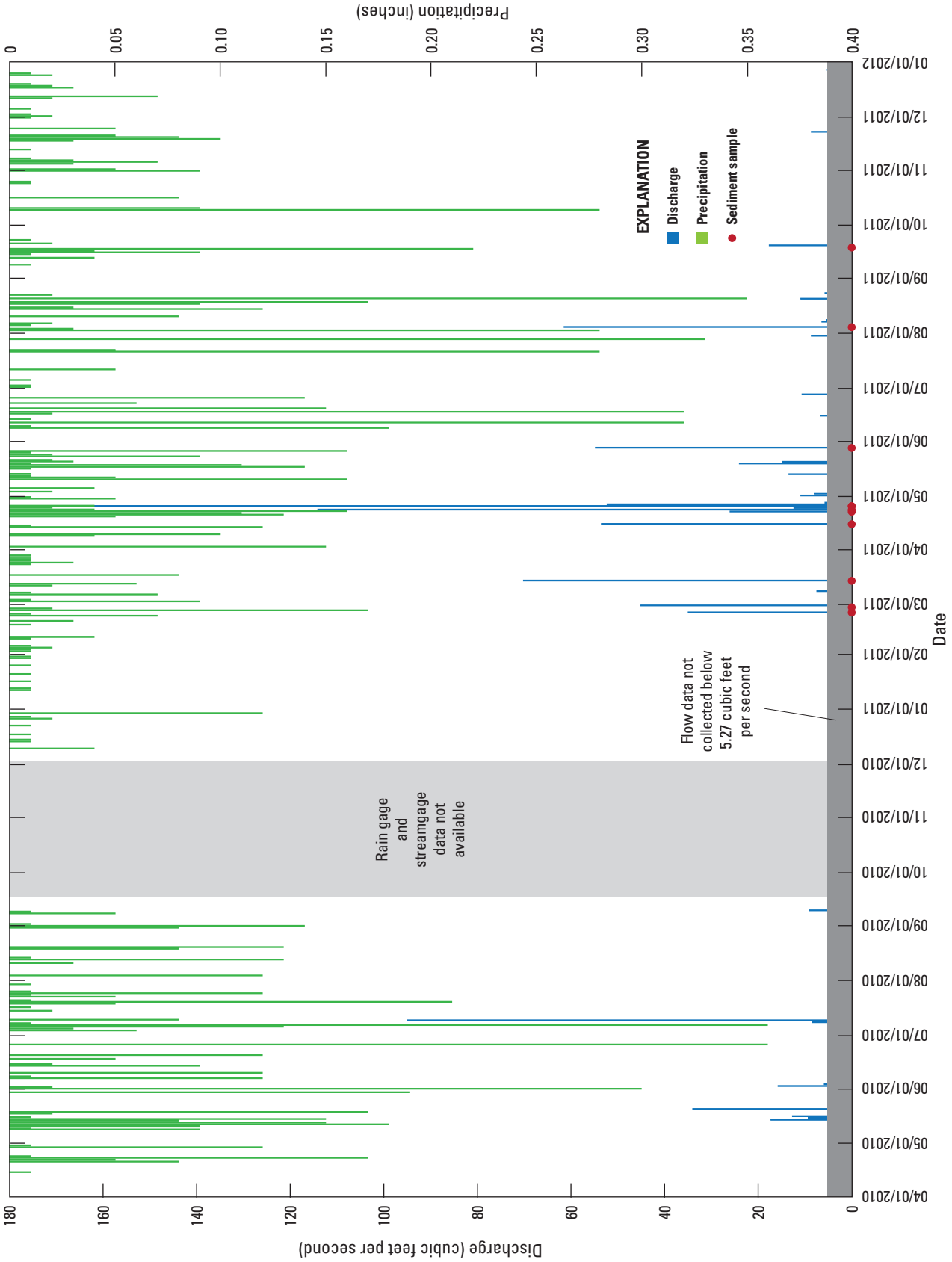

Figure 7. Quarry Hollow tributary (06930023) discharge hydrograph, hyetograph, and sediment sample collection dates.

South Ditch

The South ditch sampling site (374313092042401; fig. 2) was located approximately 50 feet upstream from the confluence of the South ditch with the Quarry Hollow tributary. The South ditch flows into the Quarry Hollow tributary approximately 50 feet upstream from the Quarry Hollow tributary below quarry (06930027; fig. 2) sampling site. This ditch flows northward and drains the southern part of the quarry. The drainage area of the ditch at the sampling point was 29 acres.

Manual EWI samples were collected at this site during four storm events to attempt to determine the sediment input from this ditch to the Quarry Hollow tributary. The SSC for all samples ranged from 25.0 to 6,520 mg/L, and sediment loads ranged from 0.012 pounds on April 15, 2011 to 18.6 pounds on March 14, 2011 (table 2). Measured flow at this site had a mean of 0.99 ft^3/s for the six samples collected.

Quarry Hollow Tributary Below Quarry

The Quarry Hollow tributary below quarry sampling site (06930027; fig. 2) was located approximately 0.41 miles upstream from the confluence of the Quarry Hollow tributary with the Big Piney River, and is approximately 50 feet downstream from the quarry. The drainage area at the streamgage was 8.01 mi^2 (table 1). The channel at the gage was narrow and partly filled with fine gravel that seemed to be partly derived from the quarry. Sediment transport and redistribution during storm events at this site frequently buried or occluded the orifice of the automatic sampler and made it difficult to obtain a representative sample.

Storm events were successfully sampled at this site seven times (table 1; fig. 8). The SSC for all storms sampled ranged from 204 to 1,020 mg/L and had a mean of 488 mg/L (table 2). The sediment load ranged from 929 to 82,800 pounds (table 2). A precipitation hyetograph for this site is shown in figure 8, and monthly precipitation totals are presented in table 3.

Quarry Hollow Tributary Below Quarry Catchment

The Quarry Hollow tributary below quarry catchment sampling site (06930028; fig. 2) was located approximately 0.21 miles upstream from the confluence of the Quarry Hollow tributary with the Big Piney River and had a drainage area of 8.03 mi^2 (table 1). This site was located approximately 260 feet downstream from a 2.3-acre sediment settlement basin designed to help mitigate the flow of sediment to the Big Piney River. Substantial amounts of organic detritus were observed in the water in the settlement basin and in flow exiting the settlement basin during storm events. This organic material frequently buried or occluded the orifice of the automatic sampler and made it difficult to get a representative sample at this site. This site also was susceptible to backwater effects from the Big Piney River. Because the point of zero flow was difficult to determine in the field at this site, a low flow extrapolation of the discharge rating was terminated at a streamgage height of 0.13 ft (0.45 ft^3/s). The resulting discharge record along with sampled runoff volume and storm-sediment load computations were not substantially affected by this rating definition for storm event analysis.

Storm events were successfully sampled at this site three times (table 1; fig. 9). The SSC for all storms sampled ranged from 29 to 467 mg/L and had a mean of 288 mg/L (table 2). The sediment load ranged from 1,260 to 16,400 pounds (table 2).

East Gate Hollow Tributary Basin

The East Gate Hollow tributary sampling site (06930058; fig. 2) was located approximately 0.17 mi upstream from the confluence of the East Gate Hollow tributary with the Big Piney River. The East Gate Hollow tributary maintained a small base flow throughout the study, presumably from spring discharge in the basin. The drainage area at the streamgage was 3.18 mi^2 (table 1). The channel at the streamgage was narrow, steep sided, and had a gravel bottom. Imes and others (1996) did not measure this stream during their low-base flow seepage run on the Big Piney River. This site had continuous flow throughout the period of study with a minimum recorded discharge of 0.11 ft^3/s.

Storm events were successfully sampled at this site fifteen times (table 1; fig. 10). The SSC for all storms sampled ranged from 6 to 2,200 mg/L and had a mean of 387 mg/L (table 2). The sediment load ranged from 25.9 to 54,400 pounds (table 2). A precipitation hyetograph for this site is shown in figure 10, and monthly precipitation totals are presented in table 3.

Dry Creek Basin

The Dry Creek sampling site (06930250; fig. 2) was located approximately 4.1 mi upstream from confluence of Dry Creek with the Big Piney River and approximately 0.3 mi downstream from the Fort Leonard Wood wastewater treatment plant. The drainage area was 5.63 mi^2 (table 1), and the channel at the streamgage was narrow and had a gravel and cobble bottom with exposed bedrock in many places. Dry Creek receives discharge from the wastewater treatment plant; however, the discharge is lost to the groundwater before the flow gets to the streamgage. Imes and others (1996) observed zero flow at its confluence with the Big Piney River during their low-base flow seepage run. During the period of this study, it is assumed that Dry Creek did not flow except during and shortly after storm events (fig. 11). Rainfall data from nearby rain gages was inconclusive for matching runoff with associated rainfall, probably because of the variable nature of runoff-producing rainfall in the study basin.

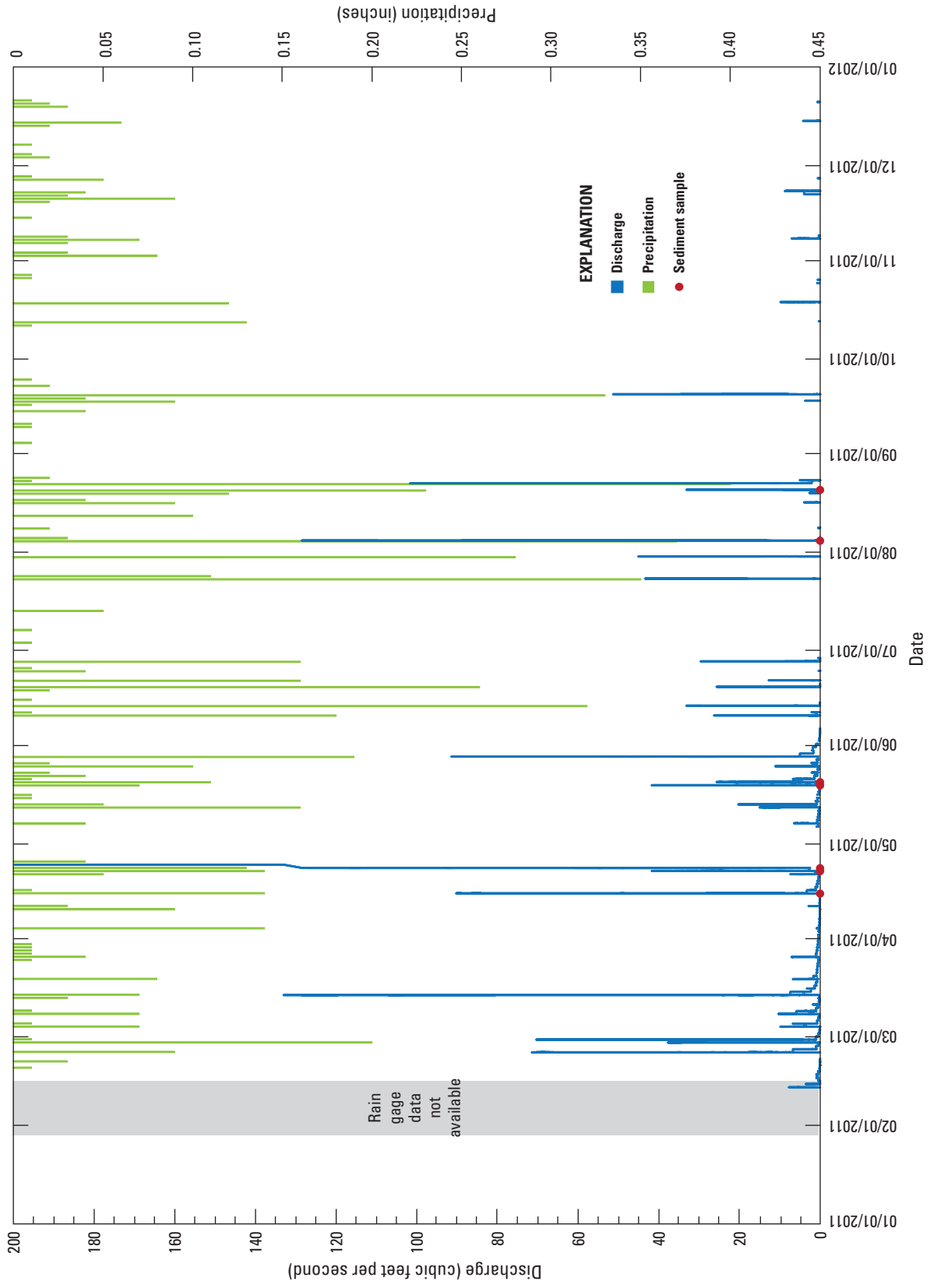

Figure 8. Quarry Hollow tributary below quarry (06930027) discharge hydrograph, hyetograph, and sediment sample collection dates.

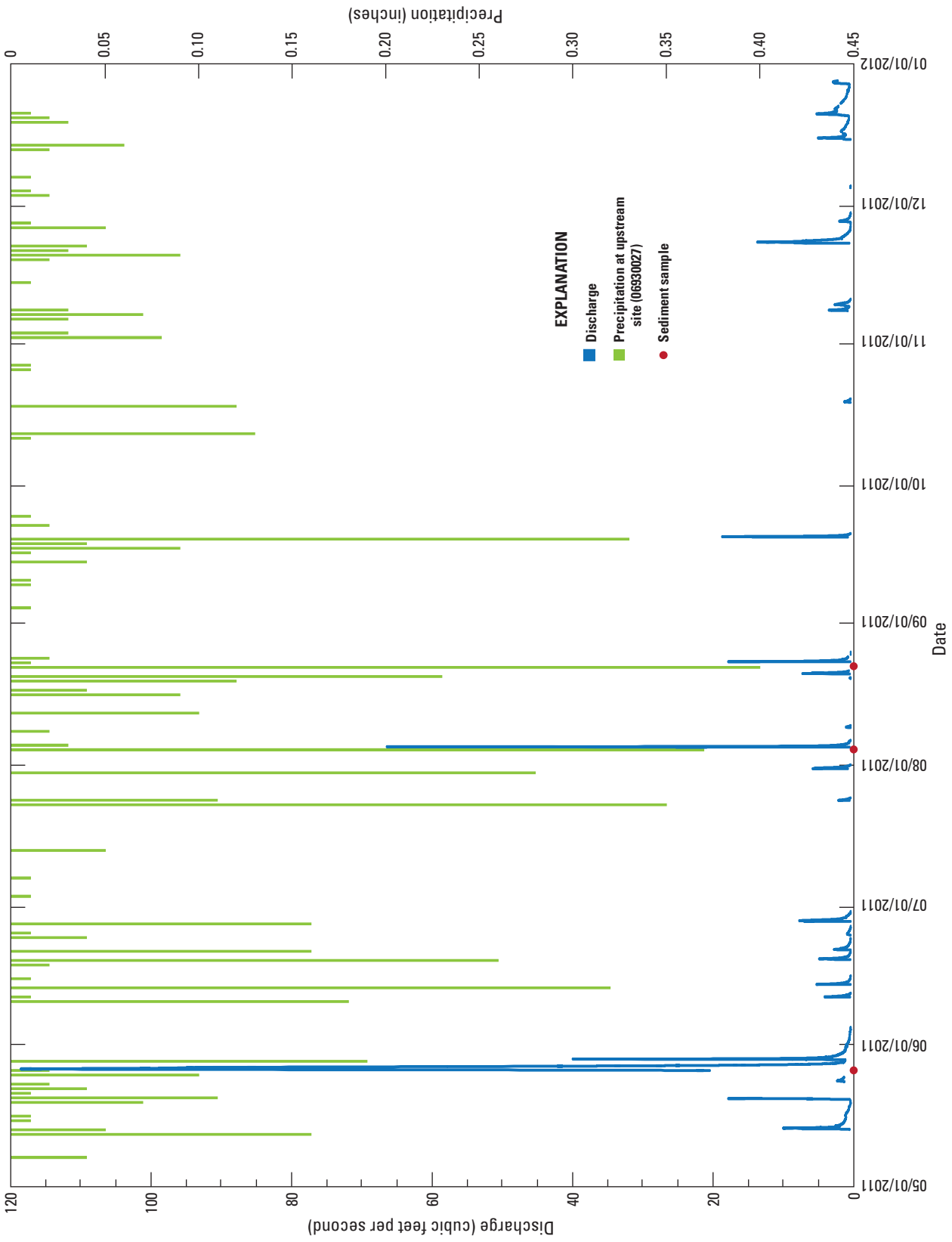

Figure 9. Quarry Hollow tributary below quarry catchment (06930028) discharge hydrograph and sediment sample collection dates.

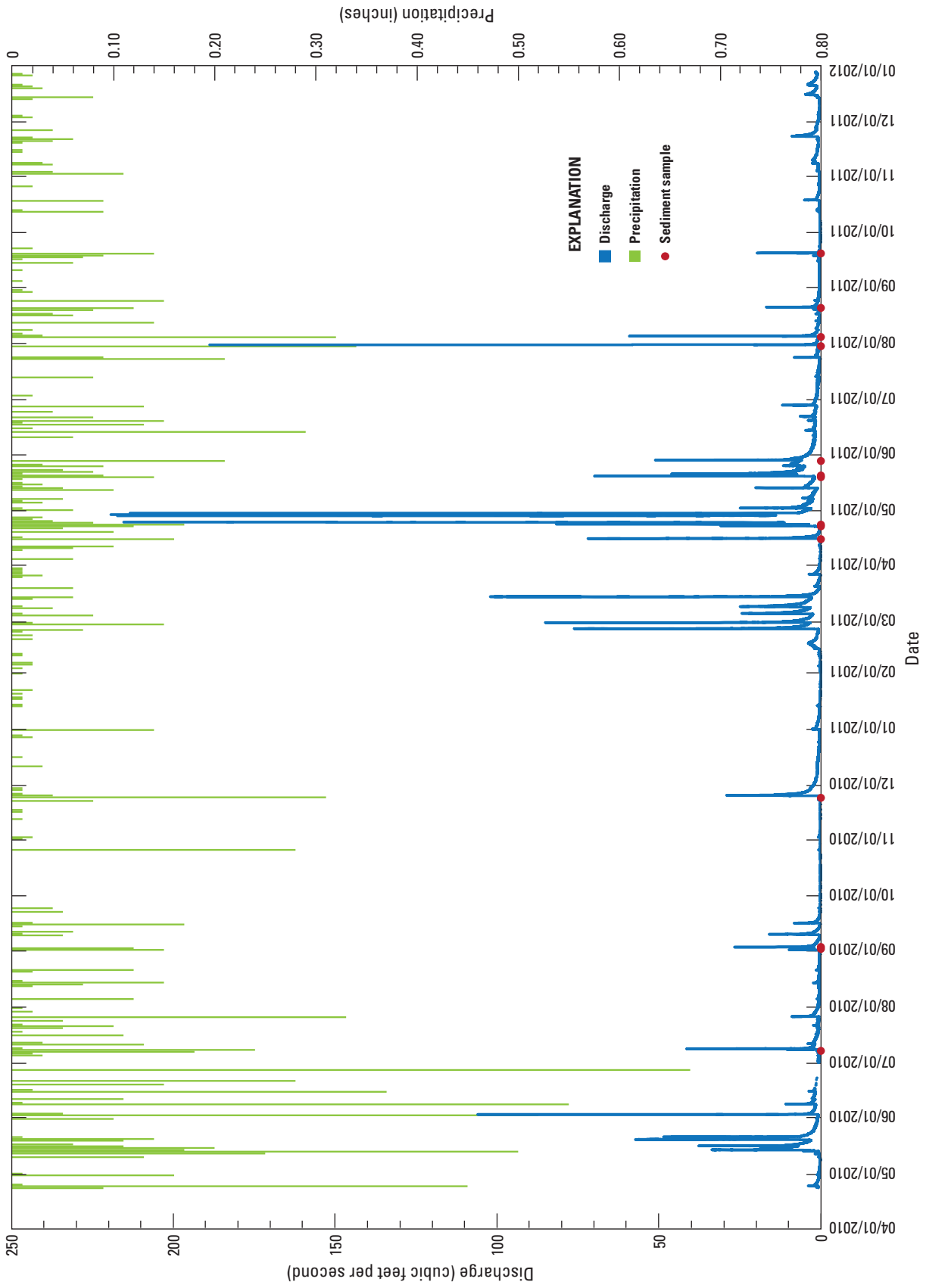

Figure 10. East Gate Hollow tributary (06930058) discharge hydrograph, hyetograph, and sediment sample collection dates.

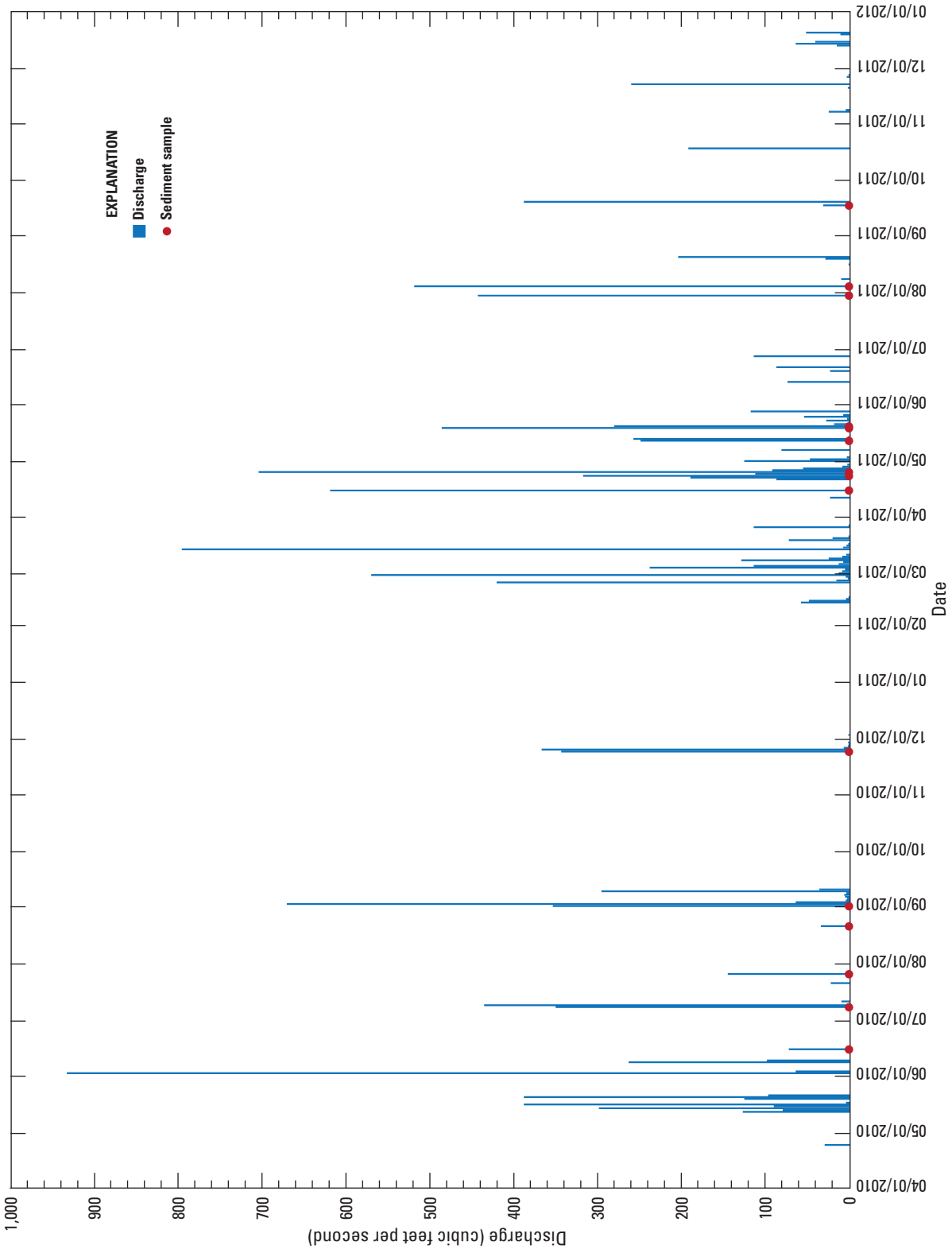

Figure 11. Dry Creek (06930250) discharge hydrograph and sediment sample collection dates.

Storm events were successfully sampled at this site fifteen times (table 1; fig. 11). The SSC for all storms sampled ranged from 213 to 1,290 mg/L and had a mean of 627 mg/L (table 2). The sediment load ranged from 1,350 to 211,000 pounds (table 2).

Sediment Yield Estimates

Sediment yield is the amount of material removed from the land surface by erosion in a given unit of time per unit area of the basin. Sediment yield is computed to normalize the sediment load by basin area and by time so that differences in basin size and sampling duration can be ignored when comparing the values between basins (table 2). Sediment yield is computed using the following equation:

$$YIELD_i = \frac{LOAD_i}{DA \times SAMPLE\ DURATION_i} \quad (2)$$

where

$YIELD_i$ is sediment yield (in (pounds per square mile) per minute) for event *i*,

$LOAD_i$ is constituent load (in pounds) for event *i*,

DA is the drainage area of the selected basin (in square miles), and

$SAMPLE\ DURATION_i$ is the sample collection duration (in minutes) for event *i*.

Yield was computed for each site for each sampled storm (storm-sediment yield) and estimated for each site for all storms by month (monthly storm-sediment yield). Because sediment samples were not collected for all storm events at any given site, monthly storm-sediment yield was computed to provide an estimate of the total basin sediment yield for all storms in the given month (table 4). To estimate monthly storm-sediment yield at a given site, the mean SSC for all sampled storms was multiplied by the monthly total storm runoff volume and divided by the basin area.

Storm-Sediment Yield

Storm-sediment yield values are presented in table 2. At Smith Branch (06928400), storm yields ranged from 1.12 to 232 pounds per square mile per minute [(lb/mi2)/min] with a median basin yield of 16.8 (lb/mi^2)/min. At Ballard Hollow tributary (06928410), storm yields ranged from 15.1 to 127 (lb/mi^2)/min with a median basin yield of 39.0 (lb/mi2)/min. Yields were not computed at Big Piney tributary (06930025) because SSCs were not believed to be representative of storm runoff, but more likely were the result of the release of water from the water-treatment sediment-settling ponds. At Quarry Hollow tributary (06930023), storm yields ranged from 0.405 to 41 (lb/mi^2)/min with a median basin yield of 16.4 (lb/mi^2)/min. At South ditch (374313092042401), the storm yields ranged from 0.240 to 372 (lb/mi^2)/min with a median basin yield of 5.09 (lb/mi2)/min. At Quarry Hollow tributary below quarry (06930027), the storm yields ranged from 0.584 to 26.5 (lb/mi^2)/min with a median basin yield of 5.22 (lb/mi^2)/min. At Quarry Hollow tributary below quarry catchment (06930028), storm yields ranged from 1.24 to 7.43 (lb/mi^2)/min with a median basin yield of 2.85 (lb/mi2)/min. At East Gate Hollow tributary (06930058), storm yields ranged from 0.096 to 143 (lb/mi^2)/min with a median basin yield of 6.5 (lb/mi^2)/min. At Dry Creek (06930250), storm yields ranged from 7.06 to 341 (lb/mi^2)/min with a median basin yield of 92.4 (lb/mi^2)/min.

The storm-sediment yield is highly variable because of many factors that were not quantified during this study. Based on the median storm-sediment yield, for the storms sampled, Ballard Hollow tributary (06928410) and Dry Creek (06930250) contributed the greatest sediment mass per square mile, whereas South ditch (374313092042401), Quarry Hollow tributary (06930023), Quarry Hollow tributary below quarry (06930027), Quarry Hollow tributary below quarry catchment (06930028), and East Gate Hollow tributary (06930058) contributed the least sediment mass per square mile. Smith Branch (06928400) contributed an intermediate amount of sediment mass per square mile based on median storm-sediment yield.

Monthly Storm-Sediment Yield

Estimates of monthly storm-sediment yield (table 4) were computed for each streamgaged site, except for the Big Piney tributary (06930025), using equation 2, where the sampling duration (SAMPLE DURATION in equation 2) was 1 month. LOAD in equation 2 was estimated by computing the total storm discharge for the given month and multiplying that value by the mean SSC (converted to tons per cubic foot by multiplying by 3.1225×10^{-8}) for all samples collected at the given site.

Base flow discharge was not included in the computation of monthly total storm discharge. Base flow was assumed to be zero at the Smith Branch (06928400) and Dry Creek (06930250) sites. At East Gate Hollow tributary (06930058), high base flow was assumed to be 3.0 ft^3/s and was applied from the middle of May to the beginning of August, 2010, and from the middle of February to the middle of July 2011. Low base flow at the East Gate Hollow tributary (06930058) site was assumed to be 0.60 ft^3/s and was applied during the remainder of the period of record. Discharges below these two values were not included in the monthly totals during the periods stated. Discharge values that were greater than approximately 0.50 ft^3/s at the Quarry Hollow tributary below quarry (06930027) and Quarry Hollow tributary below quarry catchment (06930028) sites would likely indicate discharge derived from storm runoff. Because flow data were not being collected below 5.27 ft^3/s at Quarry Hollow tributary (06930023), computation of monthly total storm discharge from the downstream sites, Quarry Hollow tributary below

Table 4. Estimated monthly storm-sediment yield (tons per square mile) in selected basins at the Fort Leonard Wood Military Reservation, Missouri.

[--, no data]

Date (month year)	Estimated Monthly Storm-Sediment Yield (tons per square mile)						
	Smith Branch (06928400)	Ballard Hollow tributary (06928410)	Quarry Hollow tributary (06930023)	Quarry Hollow tributary below quarry (06930027)	Quarry Hollow tributary below quarry catchment (06930028)	East Gate Hollow tributary (06930058)	Dry Creek (06930250)
April 2010	--	[1]0	[1]0	--	--	[1]27.3	[1]3.90
May 2010	--	556	66.0	--	--	349	663
June 2010	[1]6.99	101	2.58	--	--	32	236
July 2010	117	58.5	26.2	--	--	26	129
August 2010	0	0	0	--	--	29.7	11.3
September 2010	48.7	250	[1]5.16	--	--	102	493
October 2010	0	0	--	--	--	0.48	0
November 2010	142	146	--	--	--	115	293
December 2010	2.19	7.67	0	--	--	86.9	0
January 2011	0	0	0	[1]0	--	25.8	0
February 2011	26.2	150	36.0	31.2	--	213	378
March 2011	133	320	58.2	59.1	--	332	699
April 2011	1,048	1,170	344	104	--	448	1,083
May 2011	42.6	281	33.1	35.5	[1]91.4	505	479
June 2011	2.25	58.3	2.35	5.96	2.00	38	49.5
July 2011	0	9.88	1.25	3.66	0	51	58.2
August 2011	2.87	81.9	28.0	22.7	10.0	118	185
September 2011	0	22.8	3.18	5.08	2.67	21.6	76.9
October 2011	0	16.2	0	0.78	0	37.8	51.2
November 2011	53.0	31.7	1.59	1.43	4.66	145	125
December 2011	[1]39.8	[1]0	[1]0	[1]0.19	[1]0.04	[1]108	[1]49.9
Mean	87.6	155	32.0	22.5	13.9	134	241
Median	6.99	58.3	2.58	5.52	2.33	86.9	125

[1]Yield computed based on partial month discharge record.

quarry (06930027) and Quarry Hollow tributary below quarry catchment (06930028), did not include flow less than at 5.27 ft^3/s so the three sites could be compared. Because of the orifice elevation at the Ballard Hollow tributary (06928410) site, computation of monthly total storm discharge did not include flow less than 12.2 ft^3/s.

The mean and median monthly storm-sediment yield estimates are presented in table 4, and median yields were largest in Ballard Hollow tributary (06928410), East Gate Hollow tributary (06930058), and Dry Creek (06930250). The monthly storm-sediment yields at Ballard Hollow tributary (06928410), Quarry Hollow tributary (06930023), Quarry Hollow tributary below quarry (06930027), and Quarry Hollow tributary below quarry catchment (06930028) are likely being underestimated because the flow data less than 12.2 ft^3/s for site 06928410 and less than 5.27 ft^3/s for sites 06930023, 06930027, and 06930028 were not included in the calculations for those sites.

As would be expected, monthly yields tended to be larger during the wetter spring months and smaller during the drier summer months (table 4). For the period May to December 2011, when all streamgages were operating simultaneously, sediment yield from Ballard Hollow tributary (06928410), East Gate Hollow tributary (06930058), and Dry Creek (06930250) tended to have the largest estimated monthly yields.

Summary

Commercial and residential development within a basin often increases the amount of impervious area, which changes the natural hydrologic response to storm events by increasing runoff. Increases in runoff lead to stream deformation, downcutting, and bank erosion, which results in excess sediment, a leading cause of water quality impairment throughout the United States. An increase in construction activities, caused by a population increase of more than 10 percent from 2000 to 2010 at the Fort Leonard Wood Military Reservation in Missouri, has potentially led to hydrologic changes that could result in the greater likelihood of stream impairment because of excess sediment. From April 2010 to December 2011, the U.S. Geological Survey, in cooperation with the U.S. Army Maneuver Support Center, collected surface-water hydrologic data during storm events in selected basins at the Fort Leonard Wood Military Reservation.

Hydrologic and suspended-sediment concentration data were collected primarily during storm events in six basins within the Fort Leonard Wood Military Reservation boundary. Hydrologic data collection included continuous and discrete discharge measurement data collected at nine sites and precipitation data collected at five sites. Sediment samples, collected at nine sites, primarily were collected using automatic samplers and augmented with equal-width-increment channel cross-sectional samples and manually collected samples when necessary. Sediment samples were analyzed for suspended-sediment concentration at the U.S. Geological Survey Missouri Water Science Center sediment laboratory. Storm-sediment load and yield were computed from discharge and suspended-sediment concentration data. Monthly storm-sediment yields also were estimated from the total storm discharge and the mean suspended-sediment concentration at each given site.

Storm-sediment concentration, load, and yield varied from basin to basin and from storm to storm. In general, storm-sediment yield, in pounds per square mile per minute, was greatest from Ballard Hollow tributary (06928410) and Dry Creek (06930250), and monthly storm-sediment yield estimates, in tons per square mile, were largest in Ballard Hollow tributary (06928410), East Gate Hollow tributary (06930058), and Dry Creek (06930250).

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