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Prepared in cooperation with the Village of Ruidoso, New Mexico

Geomorphic Survey of North Fork Eagle Creek, New Mexico, 2017

Open-File Report 2018–1187

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

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DAVID BERNHARDT, Acting Secretary

U.S. Geological Survey
James F. Reilly II, Director

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Conversion Factors

U.S. customary units to International System of Units

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)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88), except in some cases to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

Geomorphic Survey of North Fork Eagle Creek, New Mexico, 2017

By Alexander P. Graziano

Abstract

About one-quarter of the water supply for the Village of Ruidoso, New Mexico, is derived from groundwater pumping along North Fork Eagle Creek in the Eagle Creek Basin near Alto, New Mexico. Because of concerns regarding the effects of groundwater pumping on surface-water hydrology in the Eagle Creek Basin and the effects of the 2012 Little Bear Fire, which resulted in substantial losses of vegetation in the basin, the monitoring of North Fork Eagle Creek for short-term geomorphic change has been required by the U.S. Department of Agriculture Forest Service, Lincoln National Forest, as part of the permitting decision that allows for the continued pumping of the production wells. The monitoring of short-term geomorphic change in North Fork Eagle Creek began in June 2017 with a geomorphic survey of the stream reach located between the North Fork Eagle Creek near Alto, New Mexico, streamflow-gaging station (USGS site 08387550) and the Eagle Creek below South Fork near Alto, New Mexico, streamflow-gaging station (USGS site 08387600). The 2017 geomorphic survey was conducted by the U.S. Geological Survey (USGS), in cooperation with the Village of Ruidoso, and was the first in a planned series of five annual geomorphic surveys. The results of the 2017 geomorphic survey are summarized and interpreted in this report and are provided in their entirety in its companion data release.

The study reach is 1.86 miles long, and large sections of the reach are characterized by intermittent streamflow. Where water is normally present (including at the upper and lower portions of the reach near the streamflow-gaging stations), the discharge typically remains below 2 cubic feet per second throughout the year. Therefore, if geomorphic change is to occur, it will likely be driven by seasonal high-flow events. Discharge records from streamflow-gaging stations in the Eagle Creek Basin indicated that high-flow events in the basin (with peaks above 50 cubic feet per second) typically occurred during the North American monsoon months of July, August, and September. Additionally, the records appear to indicate that, as expected, overland runoff and “flashy” responses to rainfall have increased in the 5 years since the 2012 Little Bear Fire.

For the 2017 geomorphic survey of North Fork Eagle Creek, cross sections were established and surveyed at 14 locations along the study reach. Cross-section survey results indicated that channel characteristics (including channel width and area) varied widely along the study reach. Also, as part of the survey, woody debris accumulations and pools in the channel of the study reach were identified, cataloged, photographed, and surveyed for location. There were 58 woody debris accumulations and 14 pools found in the study reach. On the basis that debris jams could be a driver of geomorphic change in North Fork Eagle Creek, woody debris accumulations were classified according to their debris jam potential. The burn marks found on some woody debris indicated that the 2012 Little Bear Fire may be a contributing factor to the volume of debris in North Fork Eagle Creek. However, the woody debris present at the time of the survey did not appear to have substantially affected the geomorphic state of the study reach. Further, the structure and composition of the woody debris accumulations indicated that, under high-flow conditions, most woody debris would likely be transported downstream and out of the study reach without causing substantial geomorphic change through further jamming.

Introduction

Water supply for the Village of Ruidoso, New Mexico, is derived from surface-water and groundwater resources of the Eagle Creek and Rio Ruidoso Basins (U.S. Department of Agriculture Forest Service, 2015), which are both located within the Upper Rio Hondo Basin in south-central New Mexico (fig. 1). On average, 24–29 percent of the annual water supply for the village is directly contributed from three active (of four in total) municipal production wells (hereafter referred to as “North Fork wells”) located along North Fork Eagle Creek in the Lincoln National Forest (U.S. Department of Agriculture Forest Service, 2016) (fig. 2). The North Fork Eagle Creek Basin is one of two basins (the other is the South Fork Eagle Creek Basin) that make up nearly all of the portion of the Eagle Creek Basin located upstream from the U.S. Geological Survey (USGS) streamflow-gaging station Eagle Creek below South Fork near Alto, New Mexico (USGS site 08387600; hereafter referred to as the “Eagle Creek gaging station”) (fig. 2).

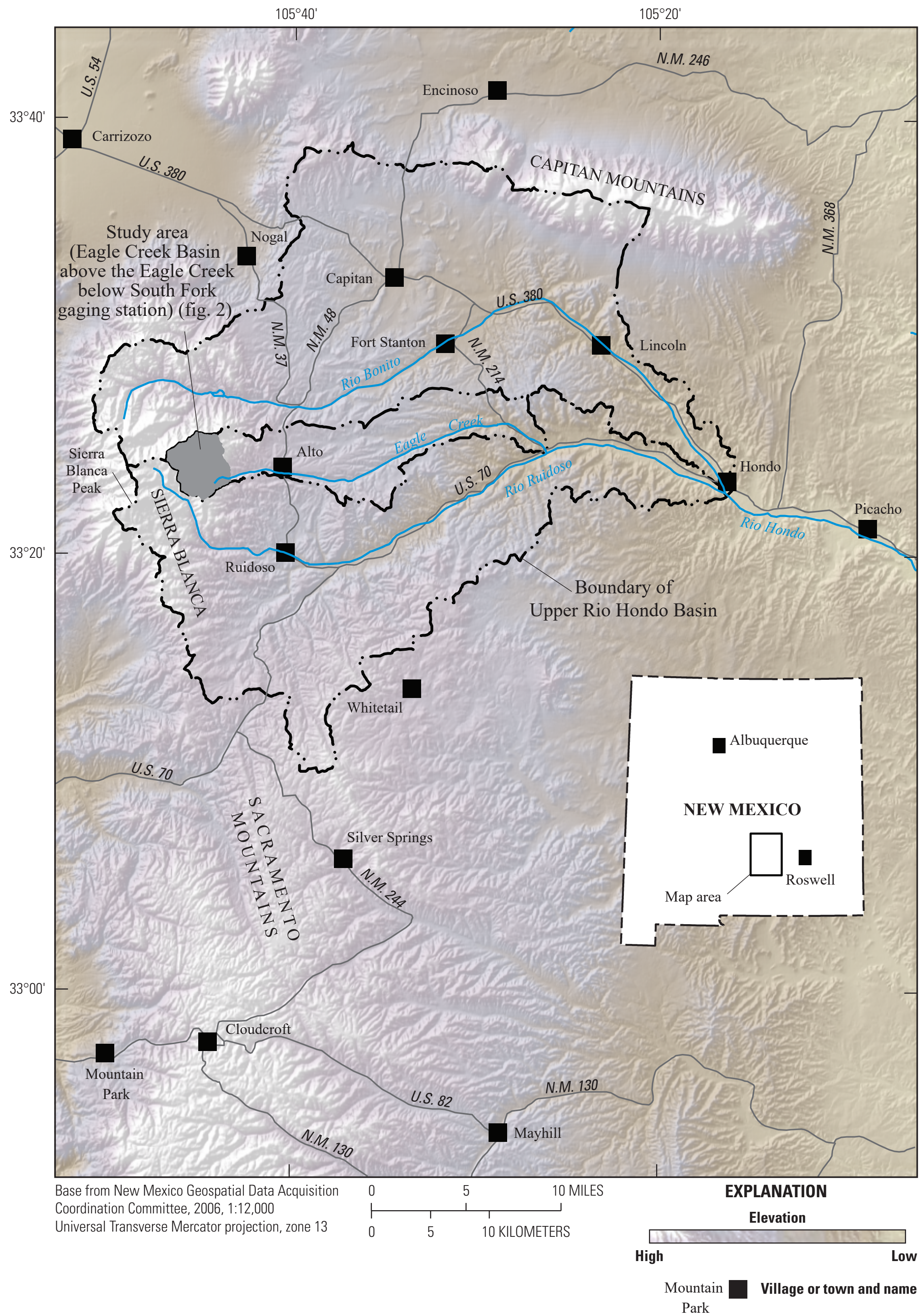

Figure 1. Location of study area and geographic features in south-central New Mexico (modified from Matherne and others, 2010).

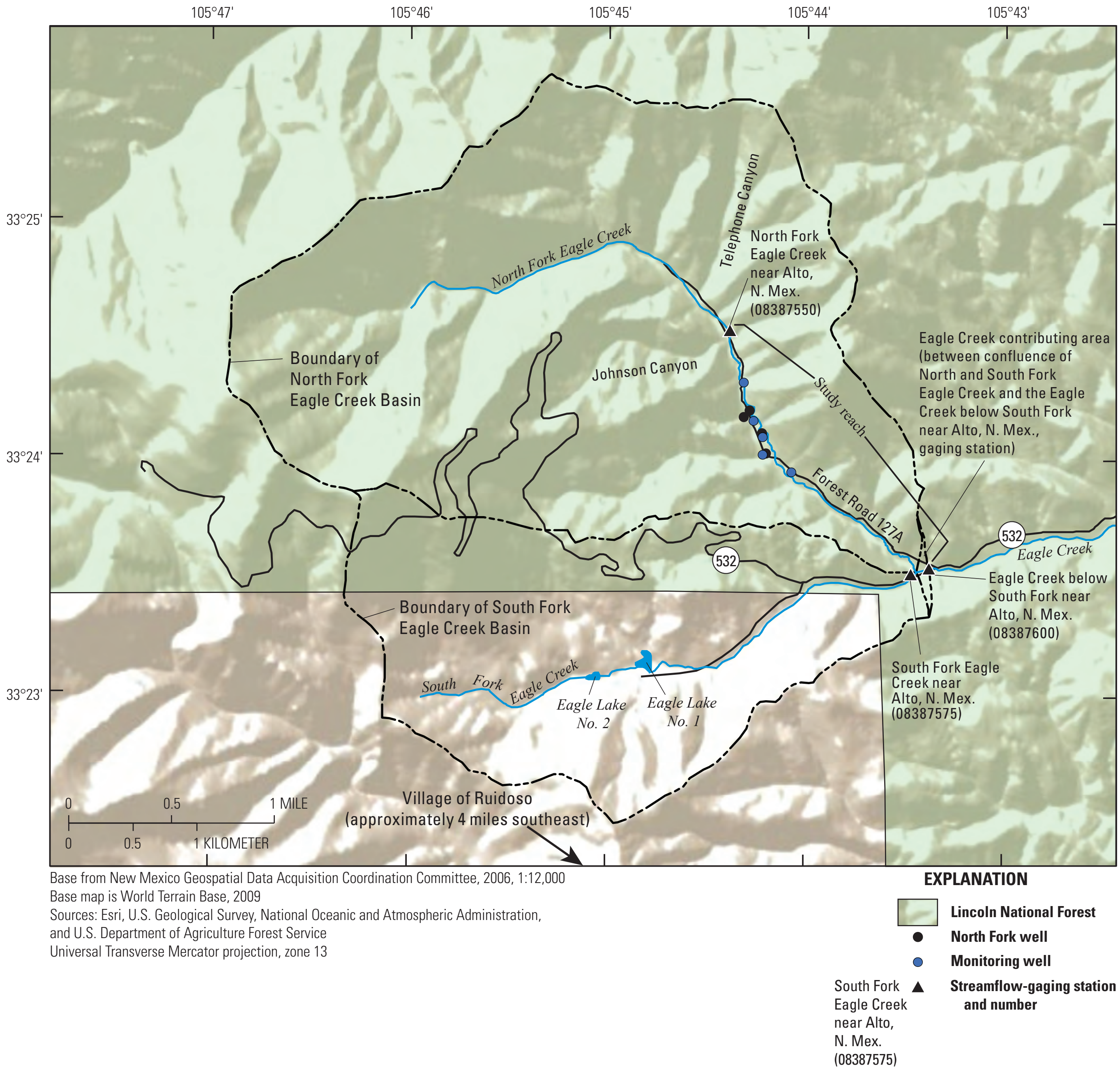

Figure 2. Location of the study reach, North and South Fork Eagle Creek Basins, Eagle Creek Basin contributing area, Lincoln National Forest boundaries, streamflow-gaging stations, and wells in the study area of the Eagle Creek Basin, south-central New Mexico (modified from Matherne and others, 2010).

The North Fork wells began production in 1988, and the special use permit for operation of the wells (granted by the U.S. Department of Agriculture Forest Service, Lincoln National Forest) expired in 1995 (U.S. Department of Agriculture Forest Service, 2015). At that time, discussions began regarding special use permit renewal (U.S. Department of Agriculture Forest Service, 2015). A concern by some parties in the discussions was the potential effect of well operations on streamflow in Eagle Creek (U.S. Department of Agriculture Forest Service, 2015). Resulting from these discussions, the USGS, in cooperation with the Village of Ruidoso, conducted a study of North Fork Eagle Creek from 2007 to 2009 to characterize the hydrology of the Eagle Creek Basin upstream from the Eagle Creek gaging station and the effects of groundwater pumping on streamflow (Matherne and others, 2010).

Following the USGS study, the U.S. Department of Agriculture Forest Service, Lincoln National Forest, issued the “North Fork Eagle Creek Wells Special Use Authorization Project Draft Environmental Impact Statement” in May 2012, shortly before the start of the Little Bear Fire, which, in June 2012, burned approximately 3,380 acres of the 3,400-acre North Fork Eagle Creek Basin (U.S. Department of Agriculture Forest Service, 2015) (fig. 3). Burn severities in the basin ranged from high to very low or unburned. Specifically, it was determined that 26 percent of the basin burned at high severity, 26 percent burned at moderate severity, 27 percent burned at low severity, and 21 percent either burned at very low severity or remained unburned (U.S. Department of Agriculture Forest Service, 2015) (fig. 3). Notably, the North Fork Eagle Creek riparian corridor (defined as the area extending 200 feet [ft] out on either side of the channel) primarily burned at or below low severity, and there was little loss of vegetation (U.S. Department of Agriculture Forest Service, 2015).

Following the Little Bear Fire, changes in some aspects of the hydrology of North Fork Eagle Creek were expected, including increased overland runoff and reduced infiltration, temporary increases in “flashy” responses to rainfall and snowmelt, increased sediment and debris yields, and changes

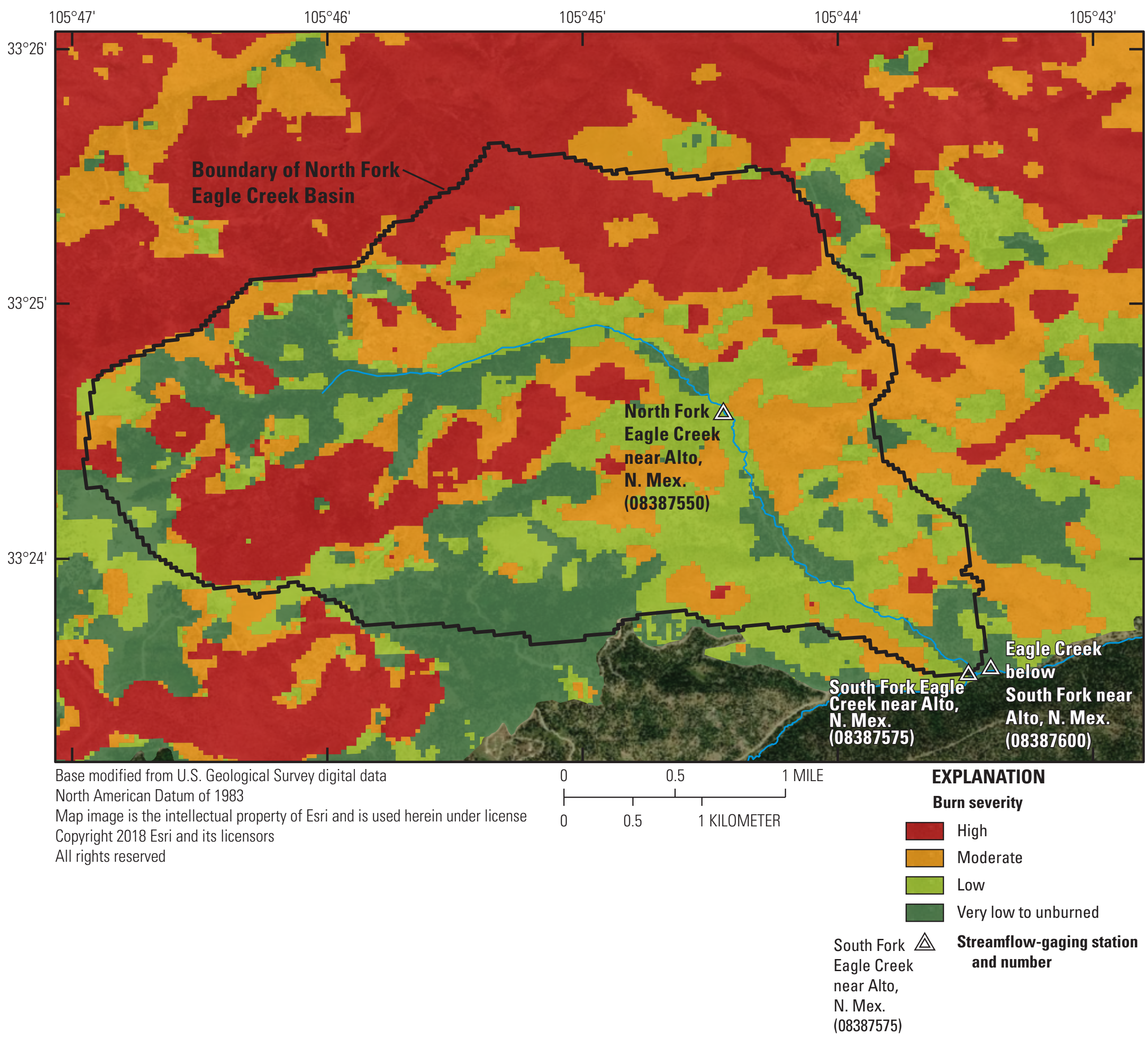

Figure 3. Little Bear Fire burn severity in the North Fork Eagle Creek Basin, south-central New Mexico, as established by the Burned Area Emergency Response (BAER) Team, June 28, 2012. Modified from data supplied by the U.S. Department of Agriculture Forest Service, Little Bear Fire BAER Team (U.S. Department of Agriculture Forest Service, written commun., 2012).

to vegetation as a result of flooding (U.S. Department of Agriculture Forest Service, 2016). On the basis of the altered postwildfire watershed conditions, a supplemental draft environmental impact statement was released by the U.S. Department of Agriculture Forest Service, Lincoln National Forest, in 2014 (U.S. Department of Agriculture Forest Service, 2015). In February 2016, the U.S. Department of Agriculture Forest Service, Lincoln National Forest, released the “Record of Decision North Fork Eagle Creek Wells Special Use Authorization,” which established new monitoring and mitigation requirements but allowed the Village of Ruidoso to continue to operate the North Fork wells (U.S. Department of Agriculture Forest Service, 2016).

The “Record of Decision North Fork Eagle Creek Wells Special Use Authorization” established the one alternative, among those considered in the final environmental impact statement, that was to be implemented (U.S. Department of Agriculture Forest Service, 2016). It also stipulated the terms and conditions of a new special use permit. Included in the decision were multiple monitoring measures designed to help determine direct or indirect effects of pumping on the quantity and quality of both surface water and groundwater. The Village of Ruidoso entered into a cooperative agreement for the USGS to assist in one of these monitoring efforts, which involves periodic geomorphic surveys of a portion of North Fork Eagle Creek.

The objective of this study is to use repeat surveys to define the geomorphic characteristics of North Fork Eagle Creek over the stream reach between the North Fork Eagle Creek near Alto, New Mexico, streamflow-gaging station (USGS site 08387550; hereafter referred to as the “North Fork gaging station”) and the Eagle Creek gaging station (fig. 2) to address the requirements of the record of decision. Specifically, the plan is to conduct annual geomorphic surveys for 5 years, from 2017 to 2021, and based on the results of the surveys, publish annual reports that summarize the geomorphic state of the reach and changes from previous surveys. Additionally, all quality-assured data collected for the study are planned for publication in a series of companion data releases. The results presented and discussed in this report are from the 2017 geomorphic survey, the first of the five planned surveys, and the survey data used for this report are published in its companion data release (Graziano, 2018).

Study Area

The study area is the portion of the Eagle Creek Basin located upstream from the Eagle Creek gaging station (area of 8.1 square miles [mi^2]) (figs. 1 and 2). The study area is located on the eastern flank of the Sierra Blanca within the Upper Rio Hondo Basin, about 4 miles (mi) northwest of the Village of Ruidoso, New Mexico and about 2.5 mi west of Alto, New Mexico (fig. 1). Included in the study area are the North Fork Eagle Creek Basin (area of 5.3 mi^2), the South Fork Eagle Creek Basin (area of 2.8 mi^2), and a small contributing area from the Eagle Creek Basin (area of less than 0.1 mi^2) (fig. 2). The study area is a forested mountain watershed, where the dominant tree species are *Pinus ponderosa* (ponderosa pine) and mixed conifers (Matherne and others, 2010).

The basin most significant to the study is the North Fork Eagle Creek Basin, which, as previously discussed, was substantially burned by the 2012 Little Bear Fire (fig. 3). It is a mostly undeveloped basin, where the major exceptions are the wells and their associated infrastructure and a group of 22 cabins, which are mostly located upstream from the North Fork gaging station (Matherne and others, 2010). The basin is defined by narrow, steep drainage, with the head of drainage for North Fork Eagle Creek lying at about 10,500 ft, while 4.5 mi downstream, the Eagle Creek gaging station (320 ft downstream from the mouth of North Fork Eagle Creek) lies at about 7,600 ft, giving North Fork Eagle Creek an average gradient of 640 feet per mile (ft/mi) (Matherne and others, 2010).

The study reach is defined as the reach beginning about 100 ft upstream of the North Fork gaging station and ending at the Eagle Creek gaging station (fig. 2). The reach begins as North Fork Eagle Creek and runs for 1.80 mi before converging with South Fork Eagle Creek, where it becomes Eagle Creek and runs for just 320 ft before reaching the Eagle Creek gaging station (fig. 2). In total, the study reach is 1.86 mi long. Large sections of the study reach are characterized by intermittent streamflow, and streamflow levels in the study reach have likely been affected by the three active North Fork wells that pump from the bedrock aquifer to supply water to the Village of Ruidoso (Matherne and others, 2010). Specifically, Matherne and others (2010) found that, for the study period before the North Fork wells were drilled (from 1970 to 1980), groundwater flow out of the basin represented about 33 percent of basin yield, and for the study period after the North Fork wells were drilled and put into service (from 1988 to 2000), Matherne and others (2010) estimated that groundwater flow out of the basin represented about 16 percent of basin yield and mean annual groundwater pumping represented about 17 percent of basin yield. Further, Matherne and others (2010) approximated that, beginning about 1,600 ft downstream from the North Fork gaging station, water is transmitted into the bedrock aquifer at a rate of about 0.7–1 cubic foot per second (ft^3/s), and if it is assumed that the bedrock aquifer would be saturated if groundwater pumping had never occurred, then water being transmitted to the aquifer would instead be flowing continuously to Eagle Creek or saturating the alluvium. However, Matherne and others (2010) concluded that streamflow in some part of the stream channel between the North Fork and Eagle Creek gaging stations was likely discontinuous during parts of both the study period before the North Fork wells were drilled and the study period after they were drilled.

Streamflow-Gaging Stations in the Eagle Creek Basin

Surface-water discharge is measured by the USGS at three streamflow-gaging stations in the Eagle Creek Basin study area (fig. 2; table 1). These streamflow-gaging stations include the previously mentioned North Fork and Eagle Creek gaging stations in addition to the South Fork Eagle Creek near Alto, New Mexico, streamflow-gaging station (USGS site 08387575; hereafter referred to as the “South Fork gaging station”).

Table 1. Streamflow-gaging stations in the study area of the Eagle Creek Basin, south-central New Mexico.

[mi^2, square mile; NGVD 29, National Geodetic Vertical Datum of 1929]

Site name	Site number	Period of record	Drainage area (mi^2)	Elevation (feet above NGVD 29)
Eagle Creek below South Fork near Alto, New Mexico	08387600	1969–80; 1988–2017	8.14	7,600
North Fork Eagle Creek near Alto, New Mexico	08387550	2007–17	3.16	7,900
South Fork Eagle Creek near Alto, New Mexico	08387575	2007–17	2.79	7,630

The Eagle Creek gaging station is located 320 ft downstream from the confluence of North Fork Eagle Creek and South Fork Eagle Creek, 1.84 mi downstream from the North Fork gaging station, and 460 ft downstream from the South Fork gaging station (fig. 2). Daily mean discharge at the Eagle Creek gaging station, from the record period starting the year North Fork well production began and ending with water year 2017 (April 28, 1988, to September 30, 2017; a water year is the 12-month period October 1 through September 30 designated by the calendar year in which it ends), ranged from values of 0.00 ft^3/s, which occurred on multiple days in 1989, 1990, 1996, 2000–4, 2006–9, and 2011–14, to a value of 186 ft^3/s, which occurred on July 27, 2008 (U.S. Geological Survey, 2018a) (figs. 4 and 5*A*). The number of zero discharge days and the duration of sustained periods of zero discharge have increased over the last 28 years. There were 460 days of zero discharge in the first 14 years of the period (with only 85 of those days occurring in the first 10 years, between 1989 and 1999) and 1,741 days of zero discharge in the second 14 years of the period (U.S. Geological Survey, 2018a). The longest periods of sustained zero discharge occurred between March 2011 and June 2013 (U.S. Geological Survey, 2018a), during which the 2012 Little Bear Fire occurred.

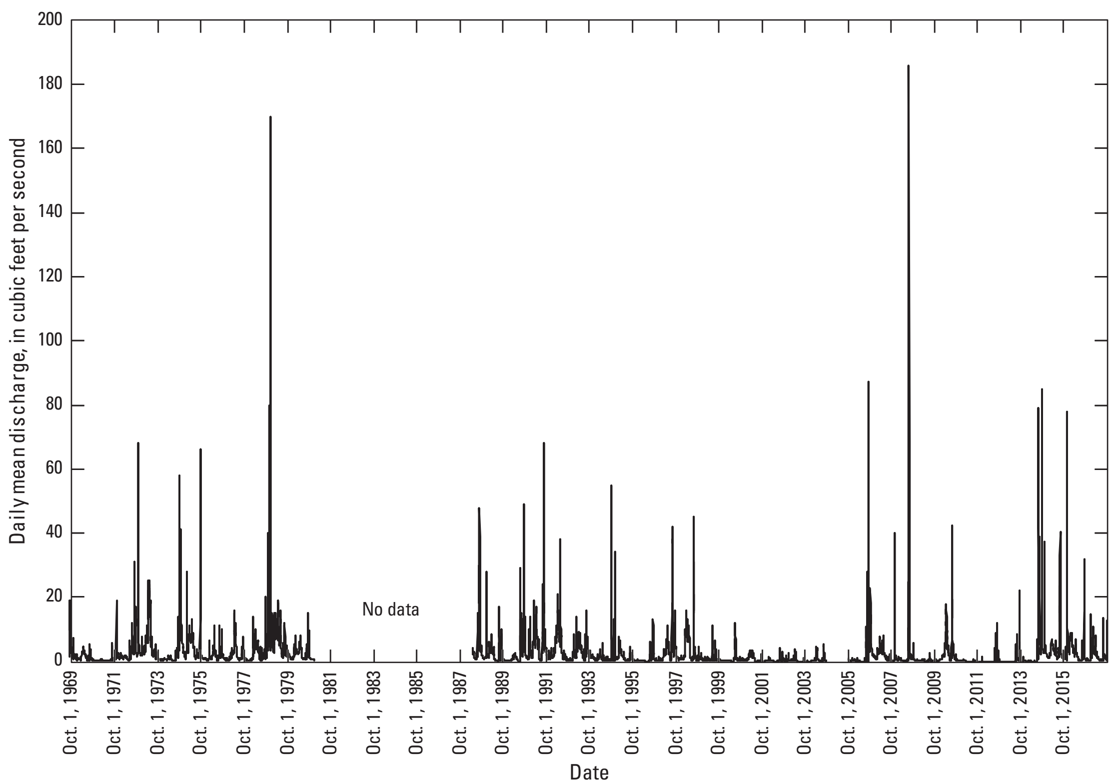

Figure 4. Daily mean discharge at the Eagle Creek below South Fork near Alto, New Mexico, streamflow-gaging station (U.S. Geological Survey site 08387600) in the Eagle Creek Basin, south-central New Mexico, for the period of record, 1969–80 and 1988–2017 (U.S. Geological Survey, 2018a).

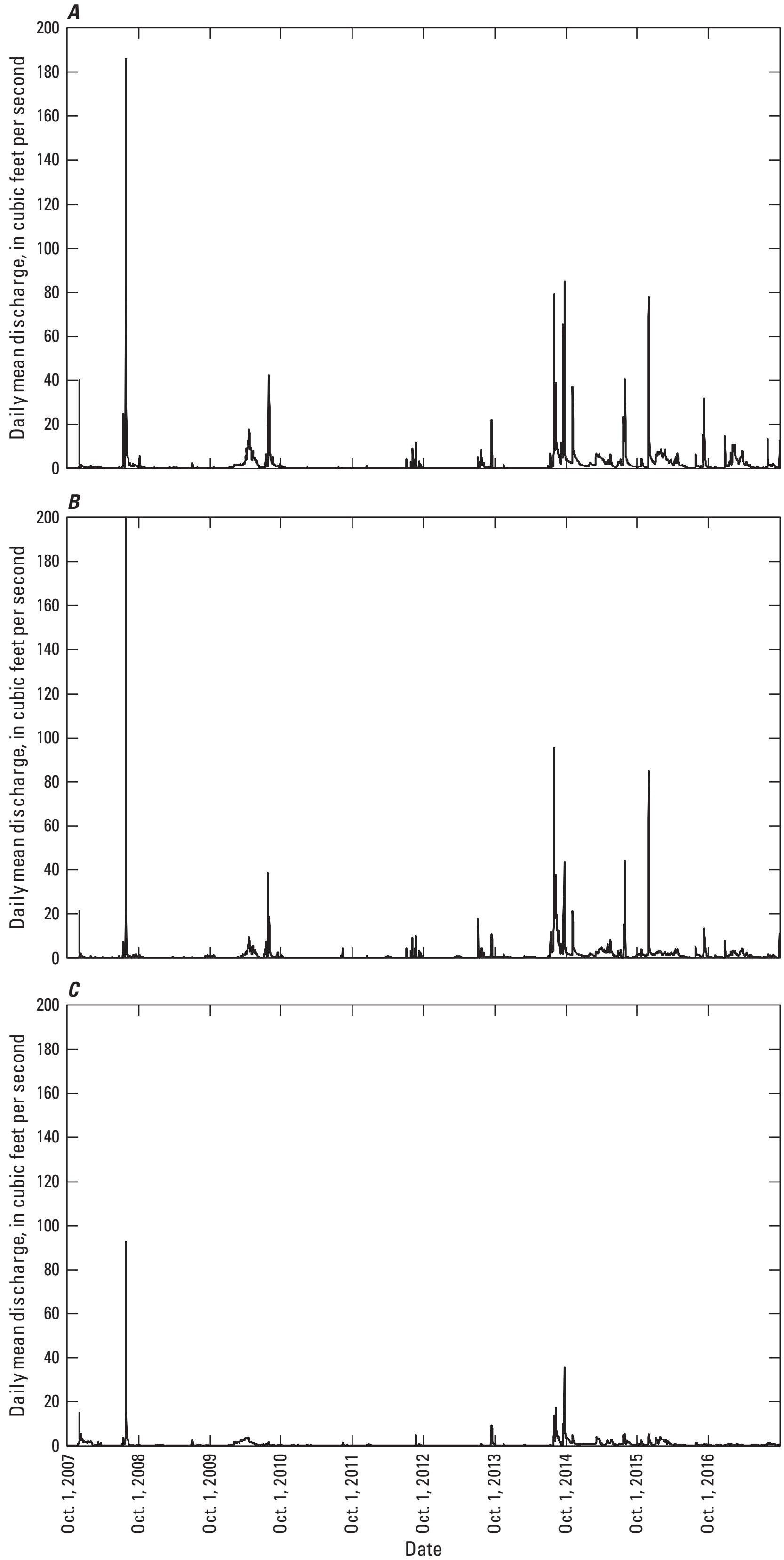

Figure 5. Daily mean discharge at the three streamflow-gaging stations in the Eagle Creek Basin, south-central New Mexico, October 1, 2007, to September 30, 2017. *A*, Eagle Creek below South Fork near Alto, New Mexico, streamflow-gaging station (U.S. Geological Survey [USGS] site 08387600) (U.S. Geological Survey, 2018a). *B*, North Fork Eagle Creek near Alto, New Mexico, streamflow-gaging station (USGS site 08387550) (U.S. Geological Survey, 2018b). *C*, South Fork Eagle Creek near Alto, New Mexico, streamflow-gaging station (USGS site 08387575) (U.S. Geological Survey, 2018c).

Daily mean discharge at the Eagle Creek gaging station, from the start of the period of record to the end of water year 2017 (August 27, 1969, to December 31, 1980, and April 28, 1988, to September 30, 2017), most often remained below 2.00 ft^3/s, with sustained periods of discharge above 2.00 ft^3/s typically resulting from snowmelt runoff in March, April, and May (U.S. Geological Survey, 2018a) (figs. 4 and 5*A*). Peak annual discharge at the Eagle Creek gaging station for water years 1970–80 (October 1, 1969, to September 30, 1980) and 1989–2017 (October 1, 1988, to September 30, 2017) exceeded 50 ft^3/s on 18 occasions and reached a maximum of 340 ft^3/s in July 2008 (U.S. Geological Survey, 2018a). In New Mexico, because of the summer convective storms of the North American monsoon (Adams and Comrie, 1997), it is common for rainfall-driven peak annual discharge to occur in the months of July through September. Of the 18 occasions in which peak annual discharge exceeded 50 ft^3/s, 12 were during the North American monsoon season (U.S. Geological Survey, 2018a). Additionally, two of the five highest peak annual discharges occurred after the Little Bear Fire (during a period of only 6 years) (U.S. Geological Survey, 2018a).

Though the Eagle Creek gaging station is below the confluence of North Fork Eagle Creek and South Fork Eagle Creek (fig. 2), the loss of discharge in the reach of North Fork Eagle Creek located below the North Fork gaging station typically results in the sum of discharges recorded at the South Fork and North Fork gaging stations being greater than the discharge recorded at the Eagle Creek gaging station (Matherne and others, 2010). If discharge were not lost to aquifer or alluvium infiltration then it would be expected that, because of their proximity, the sum of the discharges at the two upstream gaging stations would always be less than or equal to the discharge at the Eagle Creek gaging station.

The North Fork gaging station is located 1.78 mi upstream from the confluence of North Fork Eagle Creek and South Fork Eagle Creek (fig. 2). Daily mean discharge at the gaging station, from the start of the period of record to the end of water year 2017 (September 7, 2007, to September 30, 2017), ranged from values of 0.00 ft^3/s, which occurred on multiple days in 2011, 2012, and 2015, to an estimated value of 200 ft^3/s, which occurred on July 27, 2008 (the same day as the maximum daily mean discharge at the Eagle Creek gaging station for the period of record, through September 30, 2017) (U.S. Geological Survey, 2018a, b) (fig. 5*A* and *B*). Most often, though, daily mean discharge at the gaging station remained below 2.00 ft^3/s during the period of record (through September 30, 2017) and followed seasonal patterns similar to those seen at the Eagle Creek gaging station (U.S. Geological Survey, 2018a, b). At these discharge levels, it is common for water to be partially or completely lost to aquifer recharge or alluvium saturation before reaching Eagle Creek (Matherne and others, 2010).

Though discharge at the North Fork gaging station is most often below 2.00 ft^3/s (U.S. Geological Survey, 2018b) (fig. 5*B*) and though some sections of the reach only flow intermittently (Matherne and others, 2010), periods of heavy rainfall can cause significant increases in the discharge. Peak annual discharge for water years 2008–17 (October 1, 2007, to September 30, 2017) exceeded 50 ft^3/s on six occasions and reached an estimated maximum of 1,400 ft^3/s in July 2013 (the year following the Little Bear Fire) (U.S. Geological Survey, 2018b). Notably, the magnitude of this estimated maximum is questionable because it is unusually high and it was not verified by high-flow events at the other two gaging stations in the Eagle Creek Basin (U.S. Geological Survey, 2018a, b, c). However, field notes from regular station inspections at the North Fork, South Fork, and Eagle Creek gaging stations in July and August 2013 indicate that at least one more summer high-flow event occurred later in July 2013 and was significant enough to either bury or destroy gaging equipment, putting both the North Fork and Eagle Creek gaging stations out of service for a few months. Therefore, peak annual discharge for water year 2013 (October 1, 2012, to September 30, 2013) at the North Fork gaging station was still likely well above 50 ft^3/s (although it may not have been as high as 1,400 ft^3/s). Of the six occasions in which peak annual discharge exceeded 50 ft^3/s, five occurred in the month of July, during North American monsoon season, and one occurred in November (U.S. Geological Survey, 2018b). Additionally, four of the five highest peak annual discharges occurred after the 2012 Little Bear Fire (U.S. Geological Survey, 2018b).

The South Fork gaging station is located 140 ft upstream from the confluence of North Fork Eagle Creek and South Fork Eagle Creek and 460 ft upstream from the Eagle Creek gaging station (fig. 2). Daily mean discharge at the South Fork gaging station, from the start of the period of record to the end of water year 2017 (September 6, 2007, to September 30, 2017), ranged from values of 0.00 ft^3/s, which occurred on many days each year from 2008 to 2014, to a value of 92.6 ft^3/s, which occurred on July 27, 2008 (the same day as the maximum daily mean discharge at the North Fork gaging station for the period of record, through September 30, 2017, and the maximum daily mean discharge at the Eagle Creek gaging station for the period of record, through September 30, 2017) (U.S. Geological Survey, 2018a, b, c) (fig. 5*C*). The period of March 2011 to June 2013, during which the 2012 Little Bear Fire occurred, was primarily dry at the South Fork gaging station (U.S. Geological Survey, 2018c), and the timing of dry days largely correlated with what was seen at the Eagle Creek gaging station (U.S. Geological Survey, 2018a). Otherwise, daily mean discharge at the South Fork gaging station largely remained below 1.00 ft^3/s (U.S. Geological Survey, 2018c) and followed similar seasonal patterns to the daily mean discharges of the other two gaging stations (U.S. Geological Survey, 2018a, b). Peak annual discharge at the South Fork gaging station for water years 2008–17 (October 1, 2007, to September 30, 2017) exceeded 50 ft^3/s during 2 of the 10 water years, with one occurrence prior to the Little Bear Fire, in 2008, and the other occurrence after the Little Bear Fire, in 2014 (U.S. Geological Survey, 2018c).

Methods

The field survey was conducted during the week of June 19–23, 2017, when continuous discharge (recorded at 15-minute intervals) at the North Fork gaging station ranged from 0.24 to 0.57 ft^3/s (U.S. Geological Survey, 2018b), and substantial portions of the study reach were observed to be dry at the surface. During the week of the field campaign, 14 cross-section locations were established and surveyed. All accumulations of woody debris and all pools located in the reach were identified, cataloged, photographed, and surveyed for location. All points surveyed were referenced to the North American Datum of 1983 (NAD 83) and the North American Vertical Datum of 1988 (NAVD 88) by using survey-grade real-time kinematic global navigation satellite systems (RTK GNSS). Points were surveyed in accordance with standard USGS protocols for use of RTK GNSS (Rydlund and Densmore, 2012) and were referenced to a single survey mark. However, survey points were not referenced to an established bench mark; therefore, all surveyed points have an approximate relative horizontal and vertical accuracy of ±0.1 ft, but the accuracy relative to NAD 83 and NAVD 88 is unknown.

Cross-Section Surveys

Reference marks for future surveys were monumented in concrete at 14 cross-section locations on both banks of North Fork Eagle Creek (fig. 6). Cross sections were surveyed from the left to the right from the perspective looking downstream and included points in both the channel and the adjacent flood plains. The initial cross-section locations were chosen on the basis of equal distance estimations, with one cross section established approximately every 1,500 ft, from 100 ft upstream from the North Fork gaging station to 380 ft upstream from the confluence with South Fork Eagle Creek. Additional cross-section locations were established on the basis of tributary locations, road crossings, and alluvial fan formations, with cross sections being established directly downstream from tributaries and road crossings and in the middle of alluvial fan formations. Cross sections were surveyed in accordance with USGS standard protocols (Benson and Dalrymple, 1967), whereby individual surveyed points were selected on the basis of where substantial changes in slope occurred and where the points of lowest elevation in each cross section were also surveyed to obtain a thalweg point.

Cross-Section Profiles and Characteristics

Cross-section profiles were developed by using the slope-area computation graphical user interface (SACGUI) application (Bradley, 2012). SACGUI utilizes version 7 of the slope-area computation (SAC) program, which is described in Fulford (1994). SAC was developed based on the standard USGS slope-area measurement technique presented in Dalrymple and Benson (1967) and is regularly used within the USGS. SACGUI includes a method for the development of cross-section profiles by using x-y-z coordinates. For this study, SACGUI was used to convert x-y coordinates to “distance from left bank” values. Additionally, on the basis of bankfull stage estimates, other cross-section characteristics were either calculated in SACGUI or were derived from SACGUI output files.

Bankfull stage is the water level of bankfull discharge, which has been defined as the amount of discharge that completely fills the channel (Knighton, 1998). Estimates of bankfull stage were based on field observations of bank locations, photographs of the cross sections, and cross-section profile plots. The primary features used to determine bankfull stage were the abrupt decreases in slope that are typically associated with the zone of transition between the channel and the flood plain. These determinations were then secondarily verified by changes in terrain and vegetation. However, because there were large sections of the stream that were dry, and because the slope changes of some banks were poorly defined, making estimates of bankfull stage was difficult at some cross-section locations. Additionally, determination of bankfull stage is characteristically subjective (Johnson and Heil, 1996). Therefore, because it was important to retain consistency in the methods used to determine bankfull stage, a few additional rules, based on field observations, were established for estimating bankfull stage at North Fork Eagle Creek.

First, since the tops of the left and right banks were not often at the same elevation, the bankfull stage was always set at the lower of the two banks. Second, at the locations where banks were well defined, the channel appeared to be between 1 and 3 ft deep; therefore, it was determined that, unless banks were well defined outside of that range, bankfull stage should be found and set in that range. Third, if it was found that the initial choice for bankfull stage was at a stage which could hypothetically result in water flowing or pooling in a smaller side channel, then to reduce uncertainty in channel characteristic determinations, bankfull stage was lowered to a stage just below the base of the smaller side channel, where, at that stage, it could be assumed that flow would only be occurring in the main channel.

Estimates of bankfull stage were then used to calculate cross-section characteristics of maximum depth at bankfull stage, area, width, bank height, and slope. Maximum depth at bankfull stage, area, and width were calculated in SACGUI, and bank height and slope were calculated from interpretations of SACGUI results. Bank heights were specifically calculated by defining top of bank as the point where bankfull stage met the left or right bank and by defining bottom of bank as the point on the left or right side of the channel where an abrupt increase in slope began. The distance and elevation of the points used for bank height were then used to calculate bank slope.

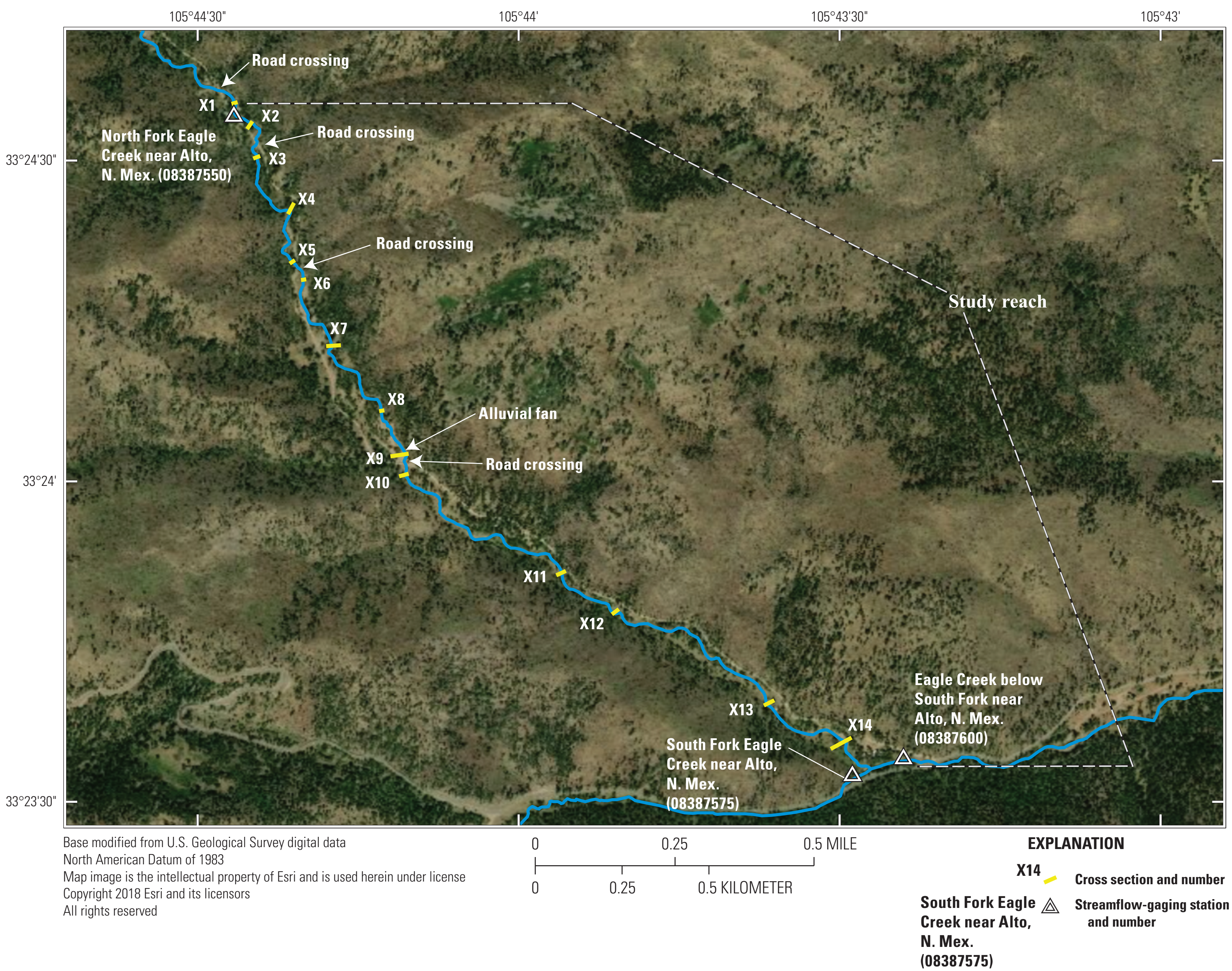

Figure 6. Study reach with locations of streamflow-gaging stations, locations and extents of cross sections, and locations of other features in the Eagle Creek Basin, south-central New Mexico, 2017.

Woody Debris

Woody debris is an important component of forested watersheds that can substantially affect the hydrology, geomorphology, and ecology of streams (Wallace and others, 1995; Abbe and Montgomery, 1996). Geomorphic studies of woody debris often focus on large woody debris (LWD), typically defined as logs and branches greater than 0.3 ft in diameter and 5 ft in length (Heimann, 2017), a definition which is also used for this study. Importantly, LWD can serve as the “key member” of a debris jam (Abbe and Montgomery, 1996), meaning it can serve as the foundation of a debris jam. Debris jams can control pool and bar formation (Abbe and Montgomery, 1996), pool spacing (Montgomery and others, 1995), sediment storage, channel width, and stream gradient (Nakamura and Swanson, 1993), in addition to other geomorphic channel characteristics.

All woody debris accumulations in the channel of the study reach of North Fork Eagle Creek were identified, cataloged, photographed, and surveyed for location by using RTK GNSS. Woody debris accumulations were found by walking the study reach of the channel from upstream to downstream. Generally, woody debris accumulations of any size were cataloged, including individually scattered pieces of LWD and small piles of twigs and sticks. However, individually scattered twigs and sticks were not cataloged, as this type of debris likely fell directly into the channel from nearby trees instead of being deposited by streamflow. Additionally, the potential geomorphic effects of this type of debris were presumed to be insignificant. From the photographs, all identified accumulations of woody debris were later classified on the basis of whether they were debris deposits, potential debris jams, or active debris jams.

Debris deposits are defined here as areas containing pieces of woody debris that appear to have been transported downstream during periods when streamflow increased and deposited in a largely random fashion when streamflow receded. Debris deposits could include scattered LWD or accumulations of smaller woody debris. As debris deposits were not identified as woody debris jams, they were not characterized by a pileup of debris and they did not contain key members. Further, the LWD found in debris deposits did not typically retain any limbs, and therefore, the likelihood that this debris could later snag, anchor, and form a key member was presumed to be low. Pieces from debris deposits could, however, later add to the volume of debris jams farther downstream.

Potential debris jams are defined here as areas containing pieces of LWD that have the potential to later serve as key members in debris jams. The LWD found in potential debris jams could be trees that naturally fell into or across the channel (and may still be anchored to the bank), logs that were placed across the channel by people (for recreational purposes), or logs that were carried downstream by high flows (which settled perpendicular or oblique to flow direction and were long enough to span most, if not all, of the channel in their settled locations). The likelihood that the LWD found in these areas could become key members in debris jams, either in their surveyed locations or farther downstream, was presumed to be higher than that of the woody debris accumulations defined as debris deposits.

Active debris jams are defined here as areas where woody debris jams have already formed. They were identified by the presence of a pileup of woody debris and possibly other debris (including grass, pinecones, pine needles, and sediment) against one or more key members of woody debris. The key members were typically LWD, but because of the relatively small size of the channel in some locations, they could be smaller than the LWD definition used for this study. Active debris jams were presumed to be the most likely woody debris accumulations that could serve as drivers of geomorphic change.

Pools

Pools, which are important components of stream ecosystems, provide habitat for various aquatic species (Wallace and others, 1995) and contribute to hydraulic complexity, which supports habitat diversity (Buffington and others, 2002). Pool dimensions and frequency can be affected by woody debris (Montgomery and others, 1995; Abbe and Montgomery, 1996), sediment load (Madej and Ozaki, 1996), and other watershed disturbances (Lisle, 1982).

During the 2017 geomorphic survey, pools in the channel of the study reach of North Fork Eagle Creek were identified, cataloged, photographed, and surveyed for location by using RTK GNSS. They were not measured or classified by size, but metrics such as “residual depths” (Lisle, 1987), the difference in depth or bed elevation between a pool and the downstream riffle crest, can be used for pool monitoring in future surveys. In areas where water was present, pools were identified as locations where velocities decreased and water depths increased. They were verified by the presence of downstream riffle crests or artificial weirs, which were at higher elevations than the channel thalweg and controlled the stage. In areas that were dry, pools were primarily identified as locations where the thalweg of the channel appeared to be longitudinally concave and, in the presence of water, would presumably adopt the features previously mentioned.

Geomorphic Survey of North Fork Eagle Creek in 2017

The results of the 2017 geomorphic survey, presented in the following sections, have been derived from the data published in the companion data release (Graziano, 2018). The data release contains the full set of survey point identifiers, locations, elevations, cross-section bank distances, woody debris classifications, and point descriptions.

Channel Profile

A channel profile of North Fork Eagle Creek, from cross section 1 to 14, was developed on the basis of the cross-section thalweg points (fig. 7; table 2). Between cross sections 1 and 14 there was 266.6 ft of fall over 9,146 ft (1.73 mi), which amounts to an average gradient of 154 ft/mi. Calculations of stream gradient from cross section to cross section yield results that range from 121 ft/mi, for the reach segment between cross sections 11 and 12, and 239 ft/mi, for the reach segment between cross sections 9 and 10. The gradient for all other cross-section-defined reach segments fell between 125 ft/mi and 200 ft/mi.

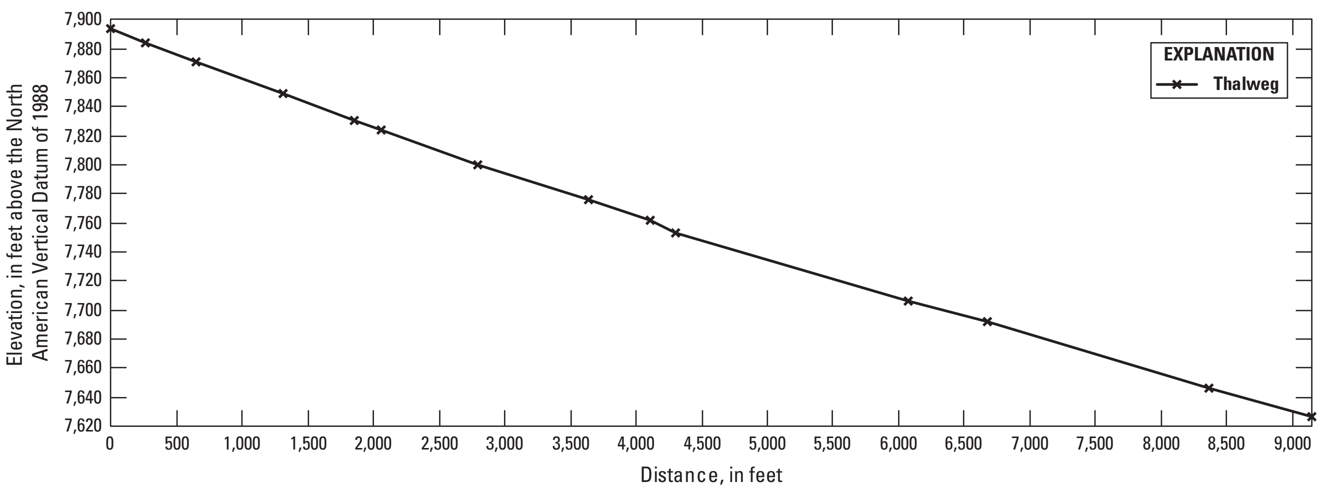

Figure 7. Channel profile from cross section 1 to 14 of North Fork Eagle Creek, south-central New Mexico, 2017.

Table 2. Channel profile data from cross sections of North Fork Eagle Creek, south-central New Mexico, 2017.

[Distances are based on creek trace in fig. 6; ft, foot; NAVD 88, North American Vertical Datum of 1988]

Cross section number	Distance downstream (ft)	Thalweg elevation (ft above NAVD 88)
1	0	7,893.5
2	267	7,883.4
3	648	7,871.1
4	1,308	7,848.7
5	1,857	7,830.4
6	2,053	7,823.8
7	2,794	7,800.0
8	3,634	7,775.7
9	4,107	7,761.8
10	4,305	7,752.8
11	6,070	7,705.8
12	6,676	7,691.9
13	8,359	7,645.9
14	9,146	7,626.9

Cross-Section Profiles and Characteristics

Cross-section profiles (fig. 8), created from the data published in the companion data release (Graziano, 2018), and cross-section characteristics (table 3) indicated that channel dimensions throughout the study reach were widely varied. Cross-section maximum depth at bankfull stage ranged from 1.4 to 5.0 ft, channel width ranged from 15.5 to 106.8 ft, and channel area ranged from 16.4 to 292.5 square feet (ft^2) (table 3). Notably, the upper end of this range is largely skewed by cross section 14, where bankfull stage was especially difficult to estimate. The banks in cross section 14 were not well defined, as there appeared to be a widening or fanning of the channel at this location. However, if cross section 14 is removed from consideration, the results are still quite varied, with the maximum depth at bankfull stage remaining at a range of 1.4 to 5.0 ft, channel width changing to a range of 15.5 to 38.0 ft, and channel area changing to a range of 16.4 to 111.5 ft^2. Accounting for all cross-section locations, bank heights ranged from 0.4 to 4.9 ft, and bank slopes ranged from 0.1 to 1.3 (dimensionless, ft/ft). The variation in these characteristics was consistent with qualitative field observations made during the survey and with the cross-section photographs. Further, it was noted that North Fork Eagle Creek was dry in some locations, including at some cross-section locations. However, where discharge was present, it likely remained below 0.60 ft^3/s during the week of the survey on the basis of the range of continuous discharge at the Eagle Creek gaging station being 0.10 to 0.39 ft^3/s (U.S. Geological Survey, 2018a) and the range of continuous discharge at the North Fork gaging station being 0.24 to 0.57 ft^3/s (U.S. Geological Survey, 2018b).

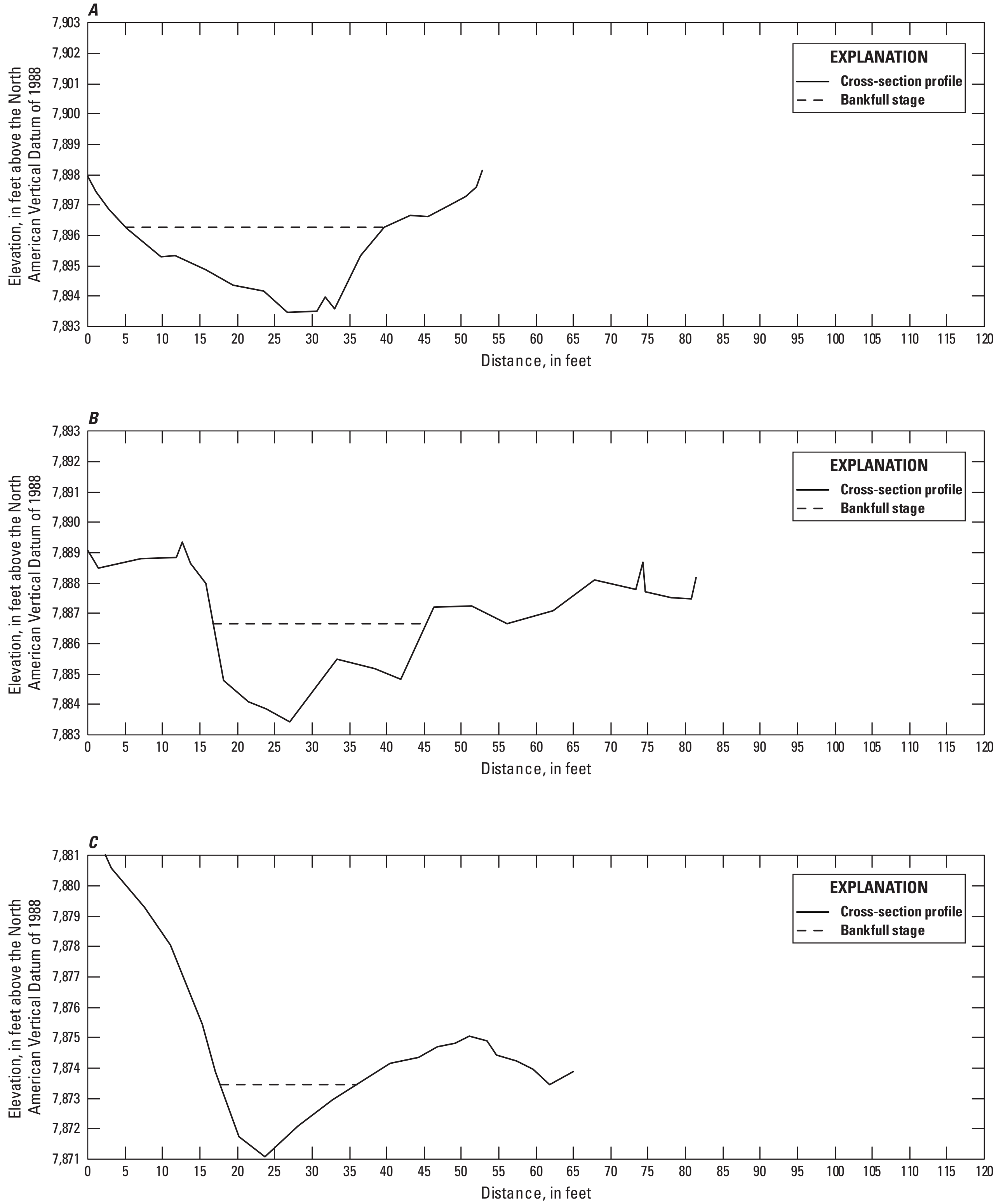

Figure 8. Cross-section profiles plotted with estimates of bankfull stage for North Fork Eagle Creek, south-central New Mexico, 2017. *A*, Cross section 1. *B*, Cross section 2. *C*, Cross section 3. *D*, Cross section 4. *E*, Cross section 5. *F*, Cross section 6. *G*, Cross section 7. *H*, Cross section 8. *I*, Cross section 9. *J*, Cross section 10. *K*, Cross section 11. *L*, Cross section 12. *M*, Cross section 13. *N*, Cross section 14.

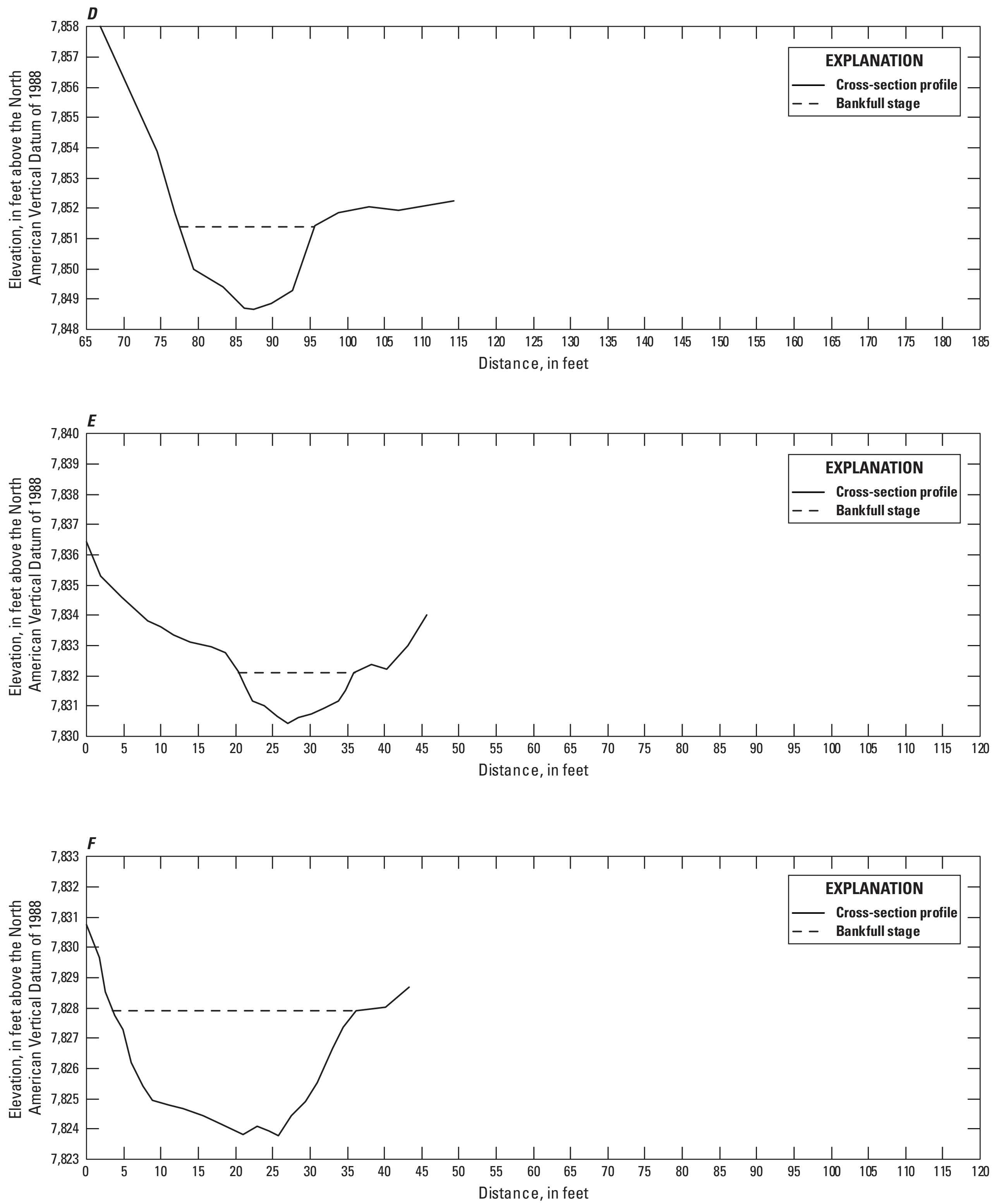

Figure 8. Cross-section profiles plotted with estimates of bankfull stage for North Fork Eagle Creek, south-central New Mexico, 2017. *A*, Cross section 1. *B*, Cross section 2. *C*, Cross section 3. *D*, Cross section 4. *E*, Cross section 5. *F*, Cross section 6. *G*, Cross section 7. *H*, Cross section 8. *I*, Cross section 9. *J*, Cross section 10. *K*, Cross section 11. *L*, Cross section 12. *M*, Cross section 13. *N*, Cross section 14.—Continued

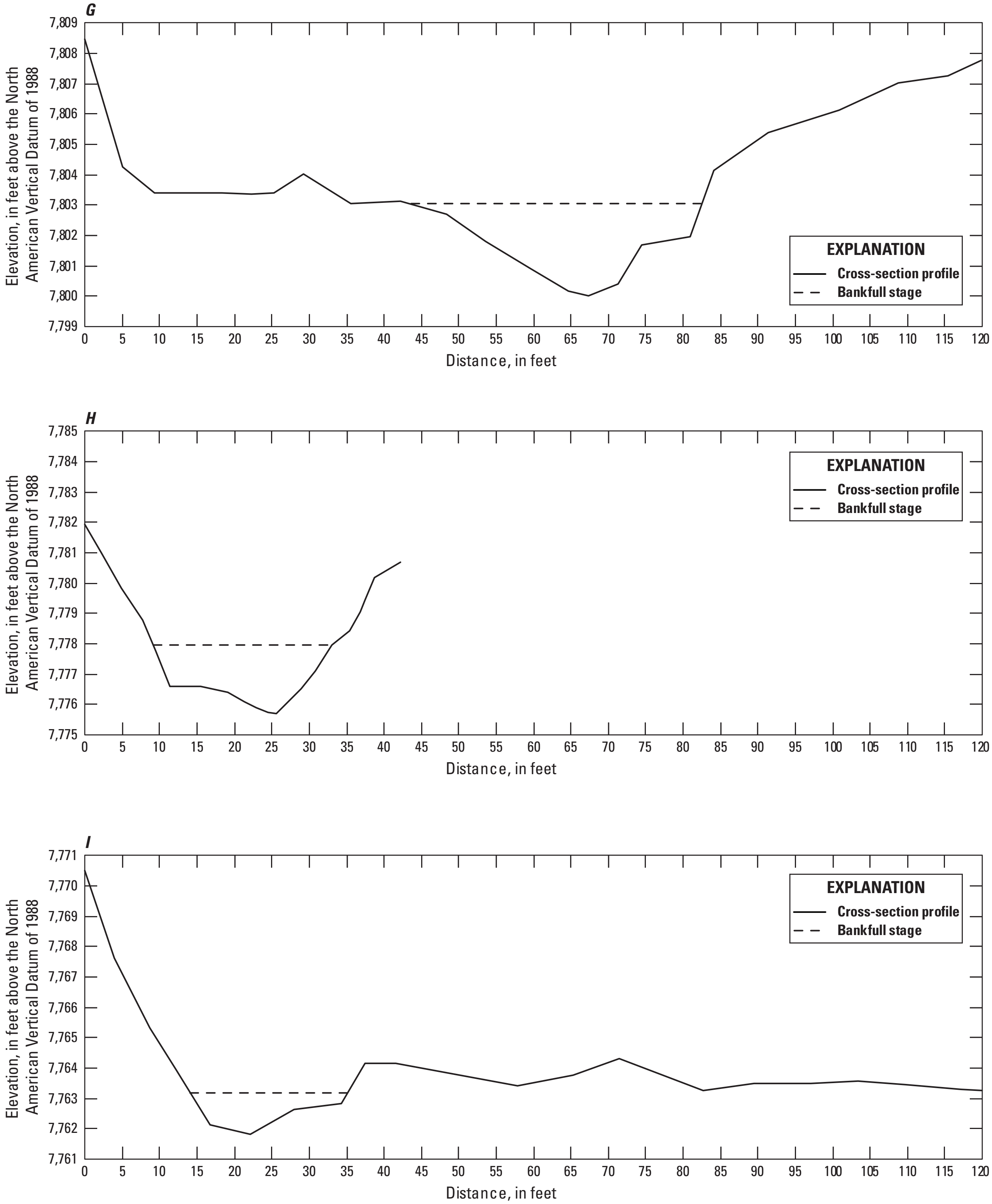

Figure 8. Cross-section profiles plotted with estimates of bankfull stage for North Fork Eagle Creek, south-central New Mexico, 2017. *A*, Cross section 1. *B*, Cross section 2. *C*, Cross section 3. *D*, Cross section 4. *E*, Cross section 5. *F*, Cross section 6. *G*, Cross section 7. *H*, Cross section 8. *I*, Cross section 9. *J*, Cross section 10. *K*, Cross section 11. *L*, Cross section 12. *M*, Cross section 13. *N*, Cross section 14.—Continued

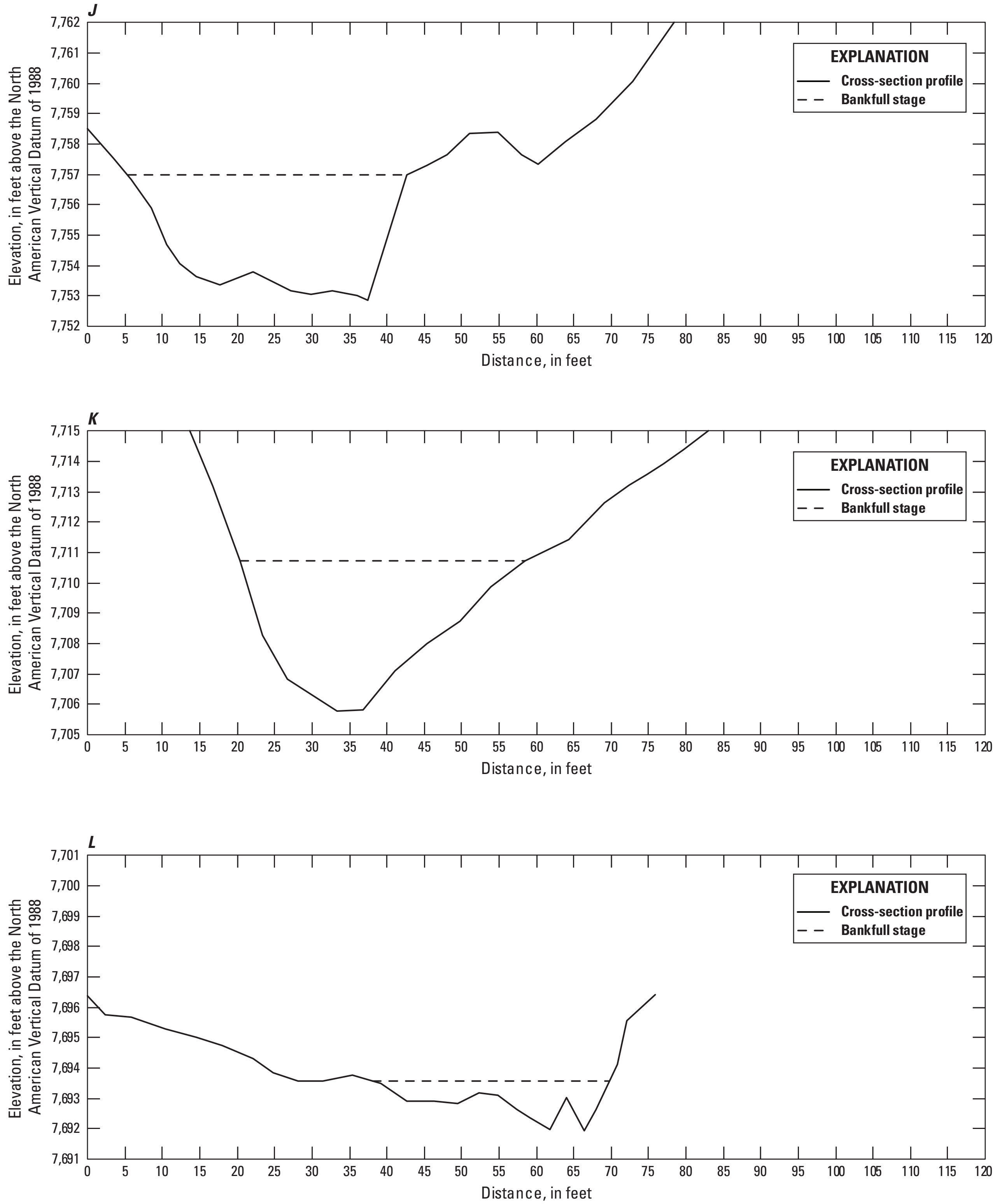

Figure 8. Cross-section profiles plotted with estimates of bankfull stage for North Fork Eagle Creek, south-central New Mexico, 2017. *A*, Cross section 1. *B*, Cross section 2. *C*, Cross section 3. *D*, Cross section 4. *E*, Cross section 5. *F*, Cross section 6. *G*, Cross section 7. *H*, Cross section 8. *I*, Cross section 9. *J*, Cross section 10. *K*, Cross section 11. *L*, Cross section 12. *M*, Cross section 13. *N*, Cross section 14.—Continued

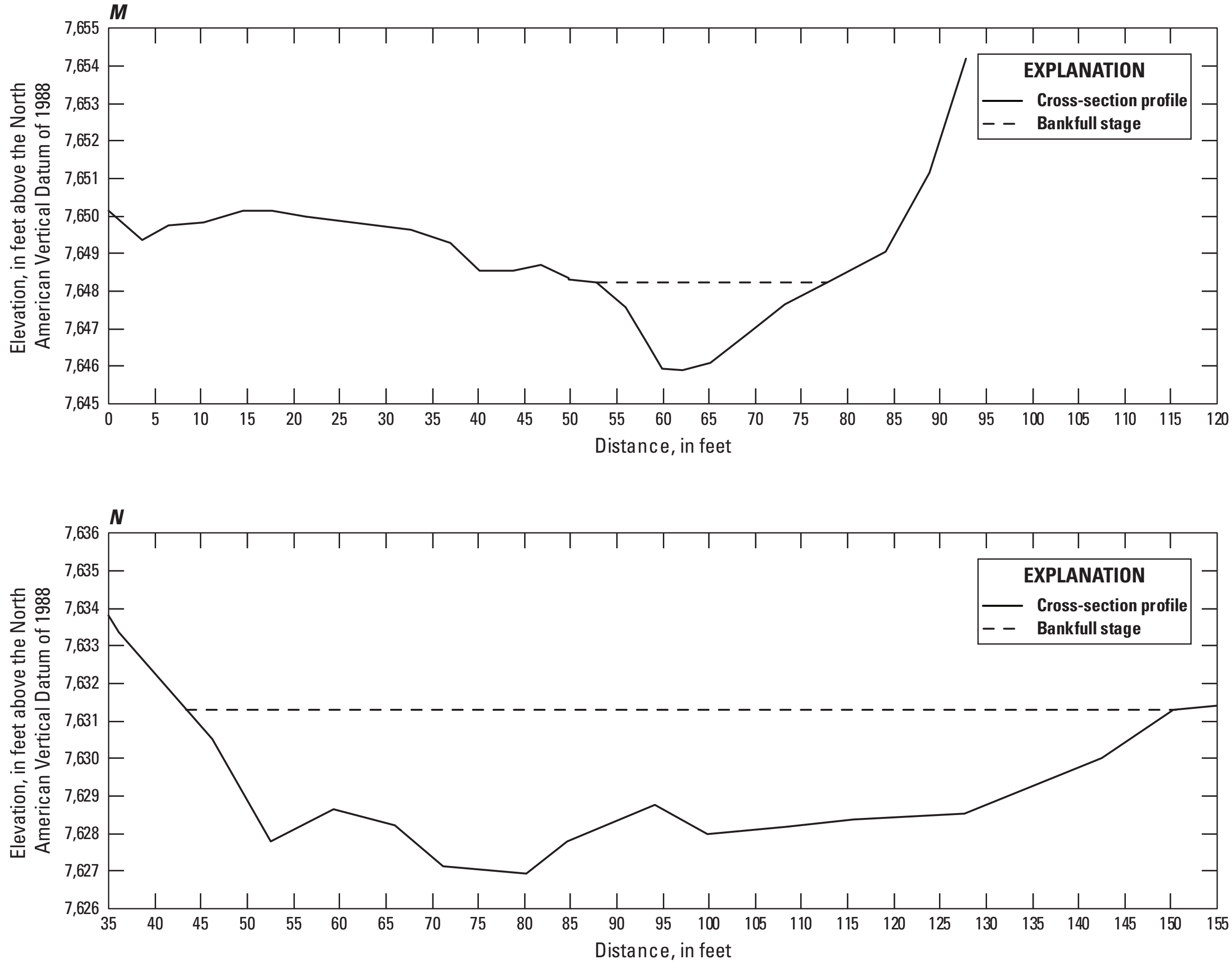

Figure 8. Cross-section profiles plotted with estimates of bankfull stage for North Fork Eagle Creek, south-central New Mexico, 2017. *A*, Cross section 1. *B*, Cross section 2. *C*, Cross section 3. *D*, Cross section 4. *E*, Cross section 5. *F*, Cross section 6. *G*, Cross section 7. *H*, Cross section 8. *I*, Cross section 9. *J*, Cross section 10. *K*, Cross section 11. *L*, Cross section 12. *M*, Cross section 13. *N*, Cross section 14.—Continued

Table 3. Cross-section characteristics of North Fork Eagle Creek, south-central New Mexico, 2017.

[ft, foot; ft^2, square foot]

Cross section number	Bankfull stage (ft)	Maximum depth at bankfull stage (ft)	Cross-section channel width (ft)	Cross-section channel area (ft^2)	Left bank height (ft)	Left bank slope (dimensionless)	Right bank height (ft)	Right bank slope (dimensionless)
1	7,896.3	2.8	33.0	53.5	2.8	0.1	2.7	0.4
2	7,886.6	3.2	28.4	53.5	1.8	1.3	1.8	0.5
3	7,873.5	2.4	16.9	20.8	1.7	0.7	2.4	0.2
4	7,851.4	2.8	16.1	30.5	1.4	0.7	2.1	0.7
5	7,832.1	1.7	15.5	16.7	0.9	0.5	0.9	0.4
6	7,827.9	4.1	32.6	91.6	3.0	0.6	4.1	0.4
7	7,803.0	3.0	36.6	58.1	2.9	0.1	2.7	0.2
8	7,778.0	2.3	23.6	34.1	1.4	0.6	2.3	0.3
9	7,763.2	1.4	20.7	16.4	1.1	0.4	0.4	0.1
10	7,757.0	4.1	37.3	111.5	3.4	0.4	4.1	0.8
11	7,710.7	5.0	38.0	111.2	3.9	0.6	4.9	0.2
12	7,693.6	1.6	31.7	24.0	0.7	0.1	1.6	0.5
13	7,648.2	2.3	25.0	30.7	2.3	0.3	2.1	0.2
14	7,631.3	4.4	106.8	292.5	3.5	0.4	2.8	0.1

Woody Debris

There were 58 distinct accumulations of woody debris identified in the study reach (fig. 9*A*; table 4). The highest concentration of woody debris was identified in the upstream subreach, defined here as the reach segment between cross sections 1 and 10 (subreach length of 4,305 ft), where 37 accumulations of woody debris were identified (fig. 9*B*). In the downstream subreach, defined here as the reach segment between cross section 10 and the Eagle Creek gaging station (subreach length of 5,537 ft), only 21 accumulations of woody debris were identified (fig. 9*C*). Generally, within the upstream and downstream subreaches, woody debris accumulations were spread evenly. However, there was one major exception to this, which was seen in the reach segment between cross sections 8 and 11. That reach segment, which extends into both the upstream and downstream subreaches, has a length of 2,436 ft (approximately one-quarter of the study reach length), and only three distinct accumulations of woody debris were identified in it. Also notable is that just above this sparsely populated reach segment the cross-section-defined reach segment with the highest number of woody debris accumulations was found. Specifically, 10 woody debris accumulations were found in the reach segment between cross sections 7 and 8, which has a total length of 840 ft (less than one-tenth of the study reach length).

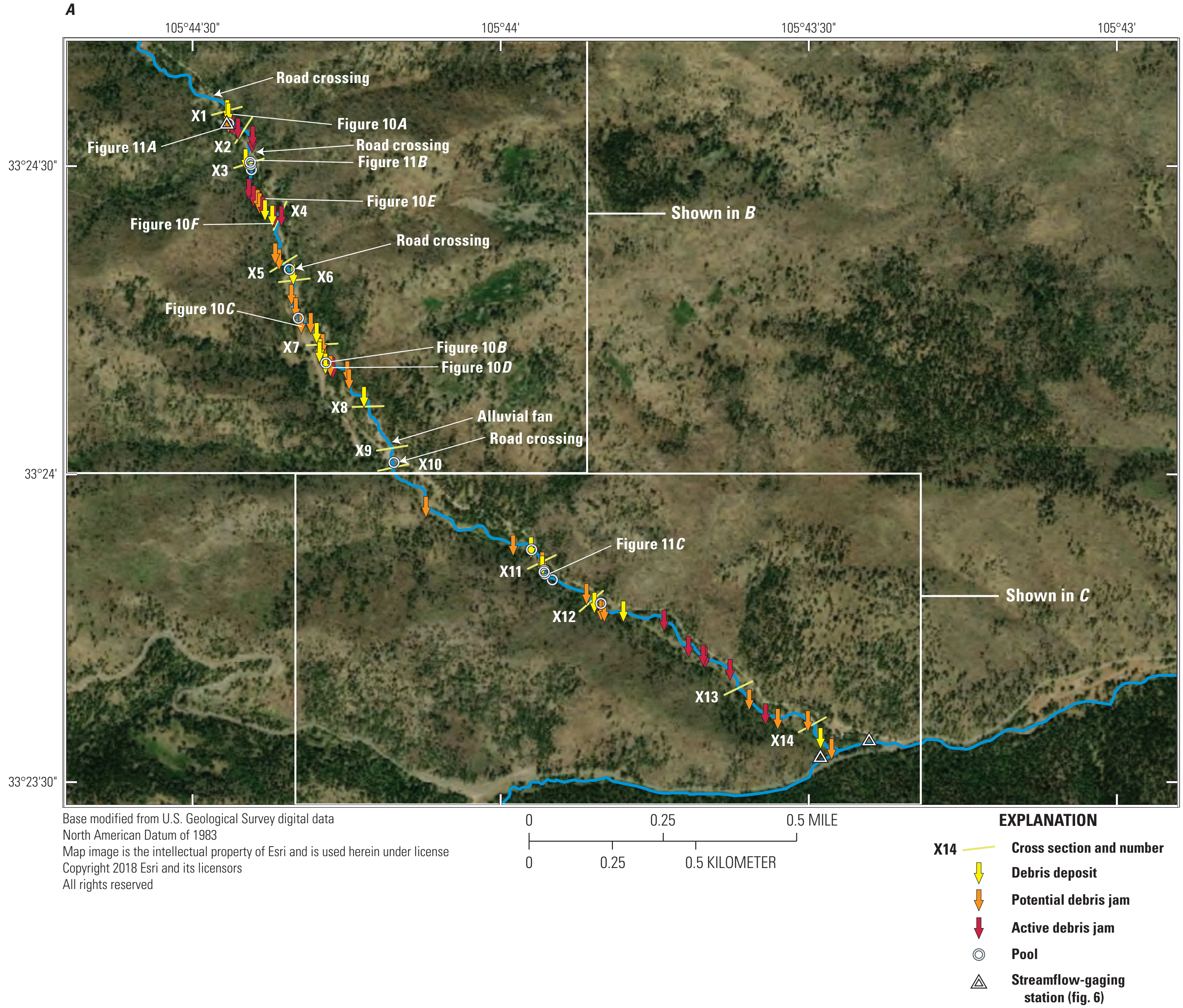

Figure 9. Study reach with locations of woody debris accumulations and pools relative to the locations of cross sections, streamflow-gaging stations, and other features in the Eagle Creek Basin, south-central New Mexico, 2017. Cross-section lengths are exaggerated for presentation purposes. *A*, Study reach. *B*, Upstream subreach. *C*, Downstream subreach.

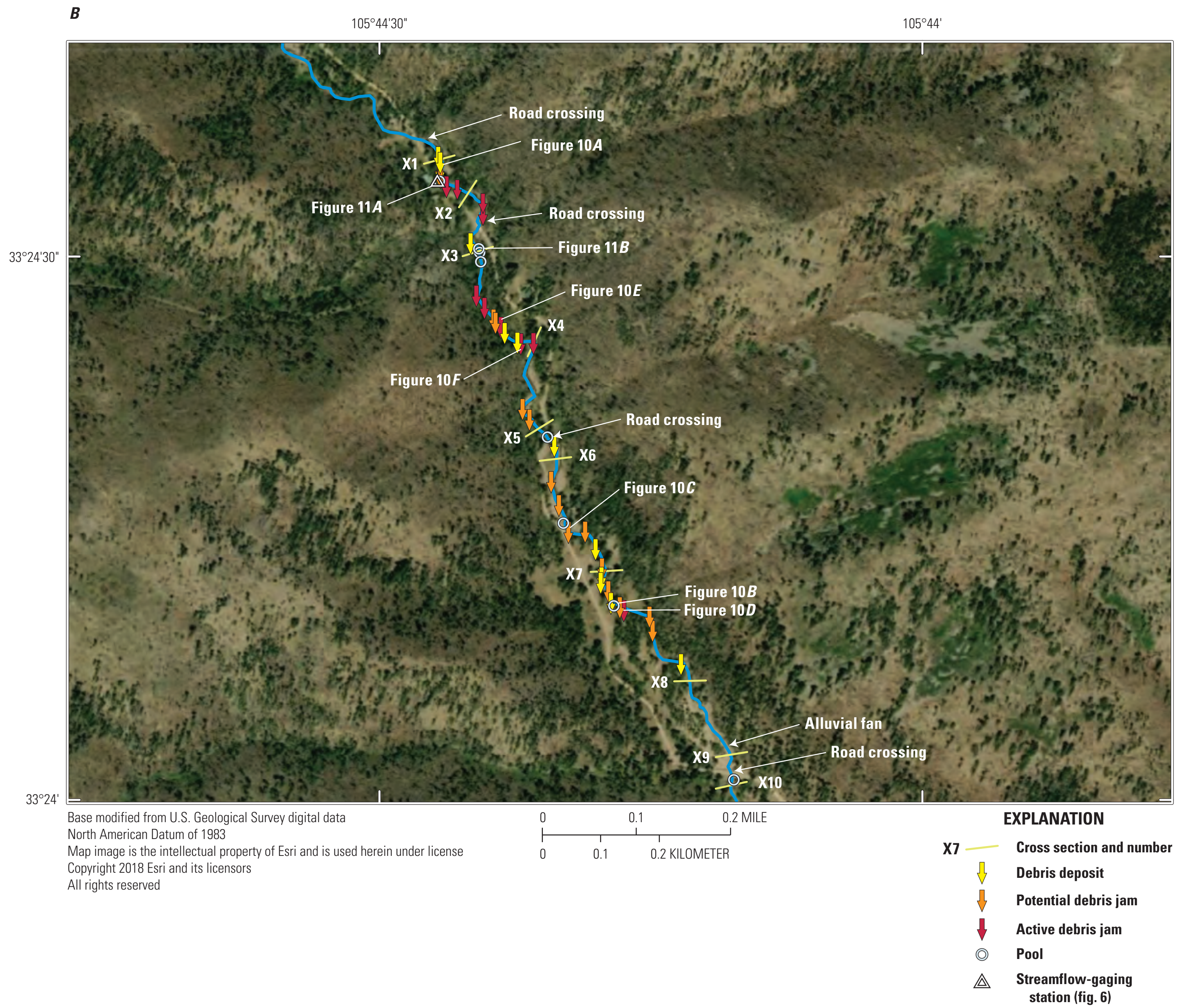

Figure 9. Study reach with locations of woody debris accumulations and pools relative to the locations of cross sections, streamflow-gaging stations, and other features in the Eagle Creek Basin, south-central New Mexico, 2017. Cross-section lengths are exaggerated for presentation purposes. *A*, Study reach. *B*, Upstream subreach. *C*, Downstream subreach.—Continued

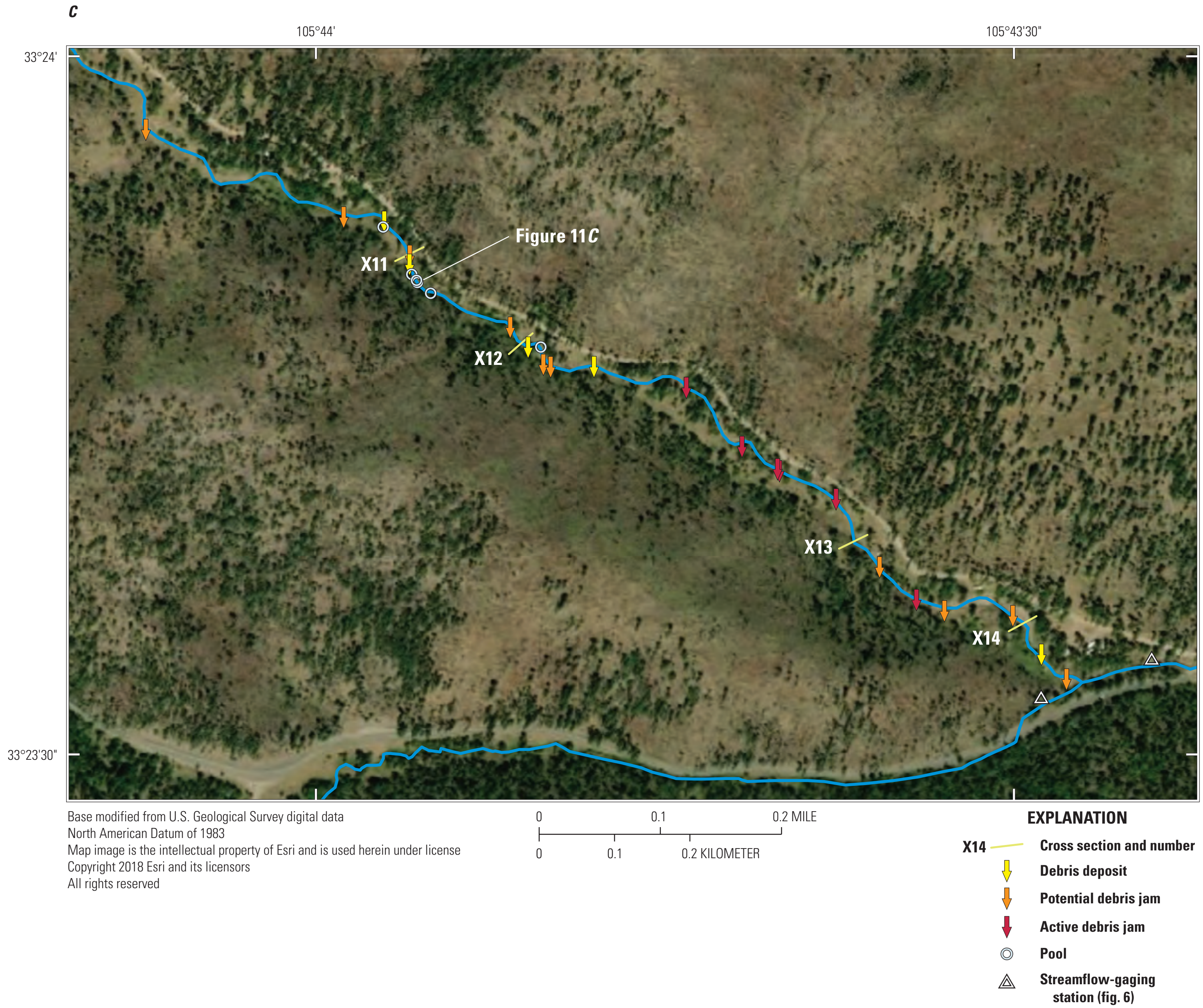

Figure 9. Study reach with locations of woody debris accumulations and pools relative to the locations of cross sections, streamflow-gaging stations, and other features in the Eagle Creek Basin, south-central New Mexico, 2017. Cross-section lengths are exaggerated for presentation purposes. *A*, Study reach. *B*, Upstream subreach. *C*, Downstream subreach.—Continued

Table 4. Woody debris locations and classifications in the study reach, Eagle Creek Basin, south-central New Mexico, 2017.

[X, cross section]

Location	Classifications			Total
	Deposit	Potential jam	Active jam	
Between X1 and X2	3	2	2	7
Between X2 and X3	1	0	2	3
Between X3 and X4	2	2	4	8
Between X4 and X5	0	2	1	3
Between X5 and X6	1	0	0	1
Between X6 and X7	1	4	0	5
Between X7 and X8	4	5	1	10
Between X8 and X9	0	0	0	0
Between X9 and X10	0	0	0	0
Between X10 and X11	1	2	0	3
Between X11 and X12	1	2	0	3
Between X12 and X13	2	2	5	9
Between X13 and X14	0	3	1	4
Between X14 and the Eagle Creek gaging station	1	1	0	2
Total	**17**	**25**	**16**	**58**

Of the 58 total woody debris accumulations, 17 were identified as debris deposits, 25 were identified as potential debris jams, and 16 were identified as active debris jams (fig. 9; table 4). Example photographs of the different classifications are presented in figure 10, and the locations of the examples are shown in figure 9. Figure 10*A* depicts a typical debris deposit, where woody debris appeared to have been transported downstream during a period when streamflow increased and deposited in a largely random fashion once streamflow receded. In figure 10*B*, which also depicts a debris deposit, evidence of fire can be seen in the charred wood (charred wood or burn-marked wood was also present in at least seven other woody debris accumulations). Figure 10*C*, which depicts the site of a potential debris jam, shows a large log that appears to have been cleanly cut and left in its location. The tree in figure 10*D*, which also depicts a potential debris jam, is assumed to have fallen across the channel naturally. Figures 10*E* and 10*F*, both depicting active debris jams, show the range in the size of the woody debris seen in active debris jams. Woody debris accumulation photographs indicated that, with one or two possible exceptions (including the woody debris accumulation depicted in fig. 10*F*), the woody debris present in North Fork Eagle Creek at the time of the survey likely had negligible effects on channel dimensions. Further, they did not appear to prevent any bed materials larger than sand from being transported downstream.

The distribution of debris deposits and potential debris jams largely correlated with the total distribution of woody debris, as there were 12 debris deposits identified in the upstream subreach and 5 identified in the downstream subreach, and there were 15 potential debris jams identified in the upstream subreach and 10 identified in the downstream subreach (fig. 9; table 4). Also, like in the total distribution, the highest numbers of both debris deposits (4) and potential debris jams (5) were found in the reach segment between cross sections 7 and 8.

The distribution of active debris jams was similar to the total distribution of woody debris, with some notable differences (fig. 9; table 4). Although there were more active jams found in the upstream subreach (10) than in the downstream subreach (6), they were largely concentrated within the smaller cross-section-defined reach segments. For example, 5 of the 6 active jams in the downstream subreach were found in the reach segment between cross sections 12 and 13, which has a length of 1,683 ft (approximately one-sixth of the study reach length); and 9 of the 10 active jams in the upstream subreach were found in the reach segment between cross sections 1 and 5, which has a length of 1,857 ft (approximately one-fifth of the study reach length). This meant that active debris jams were largely concentrated in reach segments that made up only a little over one-third of the total study reach length. Further, only one active debris jam was identified in the reach segment between cross sections 7 and 8, which was the reach segment where the highest number of woody debris accumulations were identified (10 in total).

Figure 10. Examples of woody debris accumulations found in North Fork Eagle Creek, south-central New Mexico, 2017 (photographs by S. Green, U.S. Geological Survey). Locations of examples are shown in figure 9. *A*, Debris deposit. *B*, Debris deposit. *C*, Potential debris jam. *D*, Potential debris jam. *E*, Active debris jam. *F*, Active debris jam.

Pools

Fourteen pools were identified in the study reach (fig. 9; table 5). Pools were not measured or classified. They were only identified in the upper two-thirds of the study reach (reach length of about 6,750 ft). In 9 of the 14 cross-section-defined reach segments, at least 1 pool was identified. There were two notably large clusters of pools around cross sections 3 and 11 with three pools being found around cross section 3 and four pools being found around cross section 11. Pool locations did not appear to have any correlation with the woody debris accumulations identified during the survey.

Example photographs presented in figure 11 depict the various characteristics of pools in the study reach (locations of the examples are shown in figure 9). Figure 11*A* depicts

Table 5. Pool locations in the study reach, Eagle Creek Basin, south-central New Mexico, 2017.

[X, cross section]

Location	Number of pools
Between X1 and X2	1
Between X2 and X3	0
Between X3 and X4	3
Between X4 and X5	0
Between X5 and X6	1
Between X6 and X7	1
Between X7 and X8	1
Between X8 and X9	0
Between X9 and X10	1
Between X10 and X11	1
Between X11 and X12	4
Between X12 and X13	1
Between X13 and X14	0
Between X14 and the Eagle Creek gaging station	0
Total	**14**

A B C

Figure 11. Examples of pools found in North Fork Eagle Creek, south-central New Mexico, 2017 (photographs by S. Green, U.S. Geological Survey). Locations of examples are shown in figure 9. *A*, Artificial weir of the North Fork Eagle Creek near Alto, New Mexico, streamflow-gaging station (U.S. Geological Survey site 08387550) and the pool that has formed upstream from it. *B*, Naturally occurring pool, which is representative of most of the pools that were found in the study reach. *C*, Dry area of the study reach that would likely form a pool during periods of continuous flow in the study reach.

the artificial weir of the North Fork gaging station and the pool that has formed upstream from it. It can be noted from the photograph that, because of the presence of the weir, fine sediment (which was not typically covering the streambed over much of the reach) has settled in the pool. Figure 11*B* depicts a naturally occurring pool, which is representative of most of the pools that were found in the study reach. However, figure 11*B* also depicts the only pool that was colocated with woody debris. Notably, the woody debris present in the photograph did not appear to cause the pool to form. Figure 11*C* depicts a dry area of the study reach that would likely form a pool during periods of continuous flow in the study reach. Photographs were taken of all but three of the pools, and of the photographed pools, all but one (fig. 11*C*) had water. Because large sections of the reach were dry, it is likely that pool identification was biased towards areas where water was present. Therefore, some pools present in the reach at the time of the survey may not have been identified. To mitigate this source of potential bias in the future, measurements of "residual depth" are planned for future surveys. Measurements of "residual depth" can be used to both classify pools and better define what qualifies as a pool in a dry section of the reach.

Potential for Geomorphic Change to North Fork Eagle Creek

The 2012 Little Bear Fire caused substantial loss of vegetation in the North Fork Eagle Creek Basin. The loss of vegetation and other potential fire effects were expected to cause hydrologic responses that included increased overland runoff and reduced infiltration, temporary increases in "flashy" responses to rainfall and snowmelt, increased sediment and debris yields, and changes to vegetation from flooding (U.S. Department of Agriculture Forest Service, 2016). The results presented in this report, from the first of five planned geomorphic surveys of North Fork Eagle Creek, are primarily intended to provide a baseline for future monitoring of these expected hydrologic responses (with the one exception being changes to vegetation from flooding). However, based on the data collected thus far, some conclusions can be drawn, and some inferences can be made.

The expected responses of increased overland runoff, reduced infiltration, and "flashy" responses to rainfall and snowmelt were analyzed by using the peak annual discharge records from the North Fork and Eagle Creek gaging stations (U.S. Geological Survey, 2018a, b). Though only 5 years of data have been collected since the Little Bear Fire (and with regards to the North Fork gaging station, only 5 years of data were collected before the Little Bear Fire), the peak annual discharge records appear to indicate that these expected hydrologic responses have started to occur. Notably, however, peak annual discharges of high magnitude (over 50 ft^3/s) have most commonly occurred during the North American monsoon season (U.S. Geological Survey, 2018a, b), indicating that most peak annual discharges have been caused by rainfall rather than snowmelt. Therefore, if observable geomorphic change occurs in the study reach during the 5 years planned for the study, there is a strong possibility that it will have been caused by rainfall during the months of the North American monsoon season (July, August, and September). However, long periods when discharge remained below 2 ft^3/s in the study reach (evidenced by daily mean discharge records for both the Eagle Creek and the North Fork gaging stations) (U.S. Geological Survey, 2018a, b) indicate that it is possible that neither rainfall nor snowmelt will be significant enough to cause observable geomorphic change in the study reach over the course of the study period.

The monitoring of other hydrologic responses to the 2012 Little Bear Fire, including expected increases in sediment and debris yields, began with the 2017 geomorphic survey of North Fork Eagle Creek. Data collected at 14 cross-section locations indicated that channel characteristics in the study reach were widely varied. However, cross-section results were not compared with each other in depth because same-location comparisons planned for future reports will have far more significance for the monitoring of geomorphic change. Specifically, these planned comparisons will be used to assess changes in channel dimensions (to include possible channel filling from increased sediment yields).

Regarding the expected increase in debris yields after the 2012 Little Bear Fire, the burn marks and charring on some woody debris indicated that the fire may be a contributing factor to the volume of debris in the channel. However, for the most part, the woody debris identified during the 2017 geomorphic survey did not appear to be affecting the geomorphic state of the study reach. Specifically, woody debris did not appear to be affecting the transport of sediment or the dimensions of the channel. Additionally, woody debris did not appear to be causing any channel adjustments (such as channel redirection or bifurcation). Generally, the most influential characteristic of the woody debris was that it had the capacity to prevent other woody debris or plant debris from being transported downstream. Further, at the typical discharge rates of less than 2 ft^3/s seen during the survey (U.S. Geological Survey 2018a, b), the flow direction and velocity were not being substantially affected by woody debris. Generally, either the channel was dry at locations containing woody debris, or the flow was low enough to simply trickle through the woody debris (that is, pools were not being formed by woody debris, and bank scour was not occurring). However, it should be noted that several high-flow events occurred in the intervening years between the 2012 Little Bear Fire and the 2017 geomorphic survey (U.S. Geological Survey 2018a, b) and those high-flow events may have caused substantial geomorphic changes to the study reach, to include changes caused by woody debris accumulations which were no longer present at the time of the 2017 geomorphic survey.

If geomorphic change driven by woody debris occurs during the study period, then on the basis of the locations of woody debris accumulations (and, more specifically, the locations of active debris jams), it appears to be less likely to occur in the center portion of the reach than it is in the uppermost or lowermost portions of the reach. However, because most woody debris accumulations in the study reach were not both large and well anchored, it is likely that most of the woody debris surveyed in 2017 will be transported downstream and out of the study reach during a high-flow event, rather than becoming or remaining jammed where it can cause substantial geomorphic change. If moderate discharges are sustained, however, such as in a period of sustained snowmelt runoff, the discharge levels may not be high enough to carry away some of the large active jams, but they could be high enough to result in some small local effects on channel dimensions (such as those related to bed scour, bed fill, and bank erosion).

During the 2017 geomorphic survey, only 14 pools were found in the study reach. Half of the identified pools were spread out along the reach, and half were clustered in two separate locations. Most likely, the identified pools will remain in place, with the same general size and structure, unless flow events of particularly high magnitude occur. However, because much of the study reach was dry during the 2017 geomorphic survey, it is possible for new pools to be identified in future years (even if geomorphic change does not occur). Improvements to the methods used for identifying pools in dry stream reaches are planned for implementation starting with the 2018 geomorphic survey.

Acknowledgments

Matthew Pedroza and Scott Green, USGS, conducted the field work.

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