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Post Cerro Grande Fire Stream Channel Morphology In Lower Pueblo Canyon, Reach P-4 East

Los Alamos County, New Mexico

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2905 Rodeo Park Drive East
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FOREWORD

The mission of the New Mexico Environment Department DOE Oversight Bureau is to assure that activities at DOE facilities are protective of the public health and safety and the environment. The Bureau's activities are funded through a grant from the U.S. Department of Energy in accordance with the provisions set forth in the *Agreement-in-Principle between the State of New Mexico and the U.S. Department of Energy*. One of the primary objectives of the agreement is the development and implementation of a program of independent monitoring and oversight.

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Abstract

The May 2000 Cerro Grande fire severely burned the upper portion of the Pueblo Canyon watershed. As a result, storm water flows through the canyon have increased in frequency and magnitude, resulting in increased erosion and channel adjustments to the increased flow regime. In November of 2001, the New Mexico Environment Department began a study in Pueblo Canyon to (1) establish a baseline for monitoring changes in stream morphology, (2) demonstrate a method for evaluation and monitoring of changes in Pueblo stream channel morphology, and (3) compare current stream morphology to pre-fire geomorphic mapping of contaminant (plutonium 239/240) distribution in Pueblo Canyon sediments. We found that areas of the lowest contaminant inventory and concentration in lower Pueblo Canyon (stream reach P-4 East) are severely impacted by the increased frequency and magnitude of storm water discharges. However, as the channel continues to adjust, accelerated erosion is encroaching into the upper half of this reach, where higher concentrations and inventories of contaminants exist. We found that pre-fire stream channel classifications, based on the Dave Rosgen stream classification system, were generally E6 types and were transitioning to B, C, or F stream types. Reach P-4 East is a relatively small area within the lower portion of the Pueblo Canyon system and measurements of the type described in this report are being extended into upstream reaches in Pueblo Canyon.

Introduction

In November and December 2001, the Department of Energy Oversight Bureau of the New Mexico Environment Department measured stream dimensions, pattern, channel profile, and bed features in lower Pueblo Canyon, reach P-4 East. This stream reach is approximately six miles downstream of the upper watershed area burned during the Cerro Grande fire, and contains legacy contaminants from Los Alamos National Laboratory (LANL) operations. This study established 13 cross sections along approximately 3,700 feet of lower Pueblo Canyon. Oversight Bureau investigators measured stream dimensions at each cross section, slope and bed features along a longitudinal profile, and the sinuosity of the stream channel. These features were used to characterize geomorphic conditions of this reach, and establish benchmarks for monitoring future stream adjustments. See Plate 1 for a map view of the study area. The geomorphologic assessment and observations were then compared to LANL evaluations of plutonium contamination in Pueblo Canyon found in Reneau et al. (1998).

The May 2000, Cerro Grande fire significantly affected the upper Pueblo Canyon watershed. Nearly one hundred percent of the upper watershed was burned, of which eighty percent underwent a high intensity burn, resulting in complete loss of vegetative cover (overstory, understory and ground cover) and produced hydrophobic soil conditions in much of the upper watershed (BAER 2000). These hydrophobic soils repel moisture, resulting in

decreased infiltration and increased runoff. The elimination of vegetative cover resulted in increased soil movement from rain splash and accelerated erosion due to increased runoff from exposed, unprotected slopes. Despite some successful watershed rehabilitation, stream flows (frequency of bankfull flows and total discharge) have increased significantly and sediment yield has increased. This is consistent with results after the 1977 La Mesa fire and the 1996 Dome fire. Veenhuis (2002), found that peak discharge increased over 100 times in the first two years compared to pre-fire conditions, and decreased rapidly after that to 3-5 times pre-fire flows. Before the Cerro Grande fire, lower Pueblo Canyon geomorphic characteristics were the result of the adjustment of its boundaries to the existing flow and sediment regime. Pre-fire historic aggradation-degradation cycles have been well documented and are discussed in Reneau and McDonald (1996) and Reneau et al. (1996, 1998, 2003). Since the fire, the canyon is again changing to compensate for increases in discharge and sediment yield. This study is intended to collect the basic geomorphic data needed to support the characterization of the current status and condition of lower Pueblo Canyon, provide direction for further studies of Pueblo Canyon and other streams draining the Pajarito Plateau, and assemble the empirical basis to support future mitigation efforts.

Description of Plate 1 Plan View of P-4 East Study Area

Plate 1 shows the entire P-4 East study area, all cross sections described in this report, and incorporates units of stream channel and floodplain deposits described by the LANL Environmental Restoration, Canyons Focus Area investigations. These investigations have detailed the nature and extent of plutonium contamination within post-1942 alluvial sediments in four reaches of Pueblo Canyon in Reneau et al. (1998). Reach P-4 East is the furthest downstream reach of Pueblo Canyon and the subject of this study. The green and dark brown features on Plate 1 represent the active channel area incised into pre-1942 deposits, several stages of post-1942 deposits, and the Puye formation; the light brown and mustard tones reflect overbank deposits on flood plain terraces; and the white areas show the confining canyon wall colluvium. Road fill materials from construction of State Road 502 are labeled as fill. Detailed unit descriptions can be found in Reneau et al. (1998). The greatest average contaminant concentrations are contained in the older post-1942 fine-grained sediment deposits in c3 and f1 units. In many places the c3 units comprise the banks or confining terraces of the stream.

Site and Parameter Selection Rationale

Pueblo Canyon was chosen for this study for the following reasons:

- The Cerro Grande fire significantly impacted the upper Pueblo Canyon watershed on the Pajarito Plateau in 2000.
- There has been a significant increase in the frequency and magnitude of storm water discharges in the canyon since the Cerro Grande fire.
- There were significant increases in offsite plutonium transport from Pueblo Canyon in 2001 based on Oversight Bureau storm water monitoring data.

- In 1998, the Los Alamos National Laboratory Environmental Restoration Project Canyons Focus Area published "Evaluation of Sediment Contamination in Pueblo Canyon" report (LA-UR-98-3224) describing extensive investigations and their evaluations of Pueblo Canyon (Reneau, et al., 1998).
- The Canyons Focus Area had previously installed a number of permanent cross sections in the canyon.
- Lower Pueblo Canyon has a gage station maintained by RRES-WQH and has fair records for recent past (1992 – 1999) and current flows.
- The Pajarito Plateau Watershed Partnership considers lower Pueblo Canyon a priority for studies that enhance understanding of fluvial and contaminant transport.

The reach of Pueblo Canyon we studied corresponds with that described by the Environmental Restoration Project in their reach report as P-4 East. We divided this reach into two sub reaches, P-4 East (A) and P-4 East (B) due to major erosion changes and subsequent differences in geomorphic parameters.

Methodology

Hydrological Data

Available hydrological data (discharge volumes and frequency) was gathered for the LANL E060 gage located in lower Pueblo Canyon. LANL RRES-WQH division installed the E060 gage in lower Pueblo Canyon in 1992 (Shaull, et. al., 2001). E060 is located at the State Highway department's maintenance yard 4.2 miles east of Los Alamos, in reach P-4 East (A) between cross sections ER-2 and ER-3. Daily flow is maintained in this reach by effluent from the Los Alamos County Bayo wastewater treatment plant. During the three years before the Cerro Grande fire, only two flow events in lower Pueblo canyon were 10 cubic feet per second (cfs) or greater (peak flow of 11 cfs). After the fire, in 2000, 2001, and 2002, there were a total of 36 flow events that were 10 cfs or greater with an average flow of 102 cfs and a peak flow of 1440 cfs (Shaull, et. al., 2003). There were six flow events in 2000, seventeen in 2001, and thirteen in 2002 that were 10 cfs or greater.

Field Collection of Data

A Laser Beacon®, Model 3900 (LB-1), was used to measure the elevations of channel features along each cross section and the longitudinal profile. Five cross sections were placed in stream riffles in reach P-4 East (A), four of which were over previously installed ER cross sections. Eight new cross sections were placed in riffles in reach P-4 East (B). All cross sections were placed perpendicular to corresponding channels. At each cross section, depositional features, terraces, vegetation, and other features were noted. Longitudinal profiles of 1177 ft. and 2515 ft. were measured through reach P-4 East (A) and P-4 East (B) respectively. The longitudinal profile included measurements of both the thalweg (the deepest part of the channel) and when present, the water surface. The surveys were tied into existing reference benchmarks at the E060 Gage in reach P-4 East (A) and a highway department benchmark in reach P-4 East (B). The Wolman Pebble Count Method (SWQB

QUAP, 2001) was used to characterize bed and bank materials on each longitudinal profile and locally at all P-4 East (B) cross sections.

Treatment of Data

Field collected data were entered into a Microsoft Excel spreadsheet developed by Dan Mecklenburg (Copyright © 1999 River4m, Ltd) which generated the cross section, longitudinal profile, and particle size distribution figures. We used this spreadsheet model to calculate the fluvial geomorphic parameters listed throughout the report and which are summarized in Appendix B.

Determination of Bankfull Discharge

Bankfull discharge is associated with a momentary maximum flow which, on the average, has a recurrence interval of 1.5 years as determined using a flood frequency analysis (Dunne and Leopold, 1978; in Rosgen, 1996). Bankfull discharge represents the upper level of the range of channel-forming flows, which transport the bulk of the available sediment over time (Wolman and Miller 1960, in Rosgen, 1996). Northern Arizona University (NAU) conducted a systematic study on the geomorphology of 75 reaches of streams and rivers in New Mexico. Their data showed a very strong correlation between watershed size and bankfull channel cross sectional area for the state as a whole (Knight et al., 1999). The area of Pueblo Canyon watershed upstream from reach P-4 East is approximately 8 mi^2. According to the NAU study, the bankfull cross sectional area for streams of 8 mi^2 watershed size ranged from 7 ft^2 to 30 ft^2, based on New Mexico regional curves.

The pre-fire flow record was inadequate to determine a pre-fire bankfull discharge based on a flood frequency recurrence interval of 1.5 years. Prior to the Cerro Grande fire an effective channel forming flow of 5 cfs to 6 cfs was maintained nearly daily by the Bayo wastewater treatment plant. This resulted in stable, wetland conditions with single or multiple narrow channels throughout most of P-4 East. Post-fire bankfull discharge determinations were complicated by the multiple storm water flow events that occurred after the Cerro Grande fire. Twenty-three flow events had occurred during 2000 and 2001 since the fire ranging from 11 cfs to 1440 cfs (average 121 cfs), which altered or obscured many pre-fire bankfull indicators. In many cases, the stream channel had changed dramatically from pre-fire conditions before we began this study. Post-fire discharge is highly variable and we can only estimate effective bankfull discharge at this time. Linear and elevation measurements were made of all depositional and erosional features found at each cross section. These measurements were plotted and the measurement of a bankfull indicator was selected which resulted in a cross sectional area near the high end of the regional curves. Initial estimates of bankfull discharge, based on a cross sectional average of 26.3 ft^2, average slope of the reach, and a reach based particle-size-based roughness coefficient resulted in an average bankfull discharge of 172 cfs and high variability (104 cfs – 267 cfs) between cross sections. Reviewers of an earlier draft commented that these discharges appeared too high and showed too much variability. One reviewer suggested that cross section specific slopes and roughness coefficients might produce more realistic and less variable results.

We collected additional cross section specific slopes and roughness coefficients, and chose channel features as bankfull heights that produced a discharge between 50 and 60 cfs. We used this range of discharges because when we subtracted the highest flow from 2001, the average discharge of the remaining 35 flow events (from 2000 – 2003) was 63 cfs and additionally, when we subtracted the highest flow from 2002; the average discharge of the remaining 34 flows was 48 cfs. Using this range of bankfull or effective discharge reduced the variability and allowed the Mecklenburg model to adjust predicted channel dimensions based on consistent range of discharge. This resulted in a reduction in the cross sectional area average to 22.7 ft^2 in P-4 East (A) where wetland conditions prevail. In addition, the cross sectional area dropped to an average of 12.3 ft^2 as the stream channel transitioned from relatively stable wetland conditions of P-4 East (A) to the actively eroding section of P-4 East (B).

The five cross sections located in the upstream portion of the study area, P-4 East (A) reach (ER1-ER4, and NMED1) were used as a basis for estimating the post-fire bankfull cross sectional area and discharge rate at bankfull. These cross sections were chosen because they showed the least amount of channel adjustment due to post-fire floods and they are located both upstream and downstream from a rated gage station. Treated effluent discharges maintain a wetland condition in the active channel deposits consisting of lush, chest-high grasses and forbs. Initial assessments of channel type, using a 50 cfs - 60 cfs flow, indicated this reach consisted mostly of B6 (Rosgen stream classification) type channels. The vegetative cover allowed us to use the same roughness coefficient of 0.044 as determined for B6 type streams (Rosgen 1994) for all five cross sections. We used site-specific slopes for each cross section, which were measured 10 feet upstream and 10 feet downstream at the water's edge at each location. The P-4 East (A) cross sectional area estimates averaged 22.7 3 ft^2 (18.5 ft^2 – 25.9 ft^2) and remained near the upper range for New Mexico streams with an 8 mi^2 watershed area. This resulted in an estimated bankfull discharge range of 51.6 cfs to 62.3 cfs (average 57.7 cfs) for those five cross sections. Of the 36-storm water flow events in lower Pueblo Canyon in 2000, 2001, and 2002, 11 were greater than and 25 were less than this average discharge.

Cross sections downstream from P-4 East (A) were grouped together as P-4 East (B) (NMED 2 - NMED 9) in response to significant differences in geomorphic parameters due to channel adjustments to the increased flow regime. In this reach both roughness coefficients (based on pebble counts) and slopes used were cross section specific. The cross sections were plotted and the measurement of a bankfull indicator was selected which resulted in discharges near the range calculated for P-4 East (A). It was assumed that the discharge should be nearly constant throughout both sub-reaches due to the relative shortness of the entire reach and the lack of tributaries. Bankfull cross sectional areas were calculated using cross section specific slopes and roughness coefficients and choosing bankfull indicators that generated discharges approximating those calculated in reach P-4 (A). This resulted in the cross sectional area varying between cross sections in response to changes in channel morphology, slope and roughness coefficients.

Global Positioning System (GPS) Use

We used a Trimble ™ Explorer III hand-held Global Positioning System (GPS) unit to determine the coordinates of the two end stakes at each cross section. The GPS unit was held while walking in the thalweg to determine the pattern of the thalweg. We used the same procedure to determine the location of the terrace banks. All coordinates were overlaid on Geographic Information System (GIS) coverage maps provided by the LANL Facility Information Management Analysis and Display. Reneau et al. (1998) previously mapped the geomorphic units. This places the current stream banks and cross sections into context with the geomorphic units described by LANL and provide insight on which units are stable, threatened with erosion, or have eroded and may no longer be present.

Stream Classification System

We used the measured channel dimensions, longitudinal profile of the valley and stream, and the mapped plan view of the channel in lower Pueblo Canyon to classify the P-4 reach. We used a stream classification system, described by Rosgen (1996, 1994), to classify the channel at each cross section, predict changes in the reach, and establish references for future monitoring of stream conditions in lower Pueblo Canyon. The system uses measurable morphological features to provide consistent and reproducible descriptions and assessments.

This system uses unitless ratios of basic morphological measurements to classify stream courses into eight basic morphological stream types (A, B, C, D, DA, E, F, or G). These measurements and ratios are listed below and classification criteria are shown in Table 1.

- Entrenchment Ratio (W fpa / W bkf) = Flood Prone Area Width / Bankfull Area Width
- Width / Depth Ratio (W bkf / d bkf) = Bankfull Area Width / Bankfull Mean Depth
- Sinuosity = Stream Length / Valley Distance
- Slope = Stream Elevation Change / Stream Length

Table 1. Classification Key for streams (Rosgen 1996)

Stream Type	Entrenchment Ratio	W / D Ratio	Sinuosity	Slope
A	<1.4	<12	1.0 to 1.2	0.04 to 0.10
B	1.4 to 2.2	>12	1.0 to 1.2	0.02 to 0.039
C	>2.2	>12	>1.2	<0.02
D	N/A	>40	N/A	<0.04
DA	>2.2	Highly variable	Highly variable	<0.005
E	>2.2	<12	>1.5	<0.02
F	<1.4	>12	>1.2	<0.02
G	<1.4	<12	<1.2	0.02 to 0.039

Values of Entrenchment and Sinuosity ratios can vary by +/- 0.2 units, while Width/Depth ratios can vary by +/- 2.0 units (Rosgen, 1996). When application of these variances resulted in a possible change of classification, we noted that the Rosgen classification could be one or

the other. Only one station, NMED 6, did not fit any classification well and was noted with a question mark after the classification.

Once classified into a basic morphological group, channel slope and channel bed materials further modify the stream classification. The dominant bed material class determines this modification: silt-clay (6), sand (5), gravel (4), cobble (3) boulder (2), or bedrock (1). For example, a B type stream with silt/clay dominated bed material would be a “B6” stream type. Some classifications can be further modified by the slope such as a “B6” stream type with a slope of < 0.02 would be a “B6c” stream.

The pre-fire stream channel classifications were generally E6 types based on channel measurements at six of the least altered cross sections and using a pre-fire bank full estimate of 10 cubic feet per second. These type channels are slightly entrenched with very low width/depth ratios. Using a post-fire bankfull discharge estimate of 50 cfs to 60 cfs, we found the pre-fire E6 stream type was transitioning to B, C, or F types. Table 2 lists the parameters used to determine the stream classification of each cross section in this study.

Table 2. Rosgen Stream Classification Summary of P-4 East

	ER 1	ER 2	ER 3	ER 4	NMED1	NMED2	NMED3
Distance Along Profile	128	347	686	905	1047	1246	1517
Width/Depth Ratio	126.44	52.6	56.34	58.36	58.90	34.74	18.7
Entrenchment Ratio	1.63	1.81	1.21	1.55	2.05	1.14	8.90
Sinuosity	1.19	1.19	1.19	1.19	1.19	1.1	1.1
Slope	0.0135	0.0077	0.011	0.0232	0.0118	0.0108	0.0089
Channel Materials	Silt/Clay	Silt/Clay	Silt/Clay	Silt/Clay	Silt/Clay	Bedrock	Fine gravel
Rosgen Classification	B6c	B6c	F6 or B6c	B6	B6c or C6	F1	C4

	NMED 4	NMED 5	NMED 6	NMED 7	NMED 8	NMED 9
Distance Along Profile	1791	2198	2516	2782	3081	3512
Width/Depth Ratio	20.1	36.5	7.9	86.8	36.9	45.4
Entrenchment Ratio	3.11	1.87	2.84	2.31	1.59	7.28
Sinuosity	1.1	1.1	1.1	1.1	1.1	1.1
Slope	0.015	0.0087	0.01275	0.0045	0.024	0.026
Channel Materials	Fine Gravel	Fine Gravel	Coarse Sand	Medium Gravel	Fine Gravel	Very Coarse Sand
Rosgen Classification	C4	B4c	E5?	C4 or B4c	F4b or B4	C5b

Results and Discussion

The following section describes in detail our measurements and findings for each of the thirteen cross sections, two longitudinal profiles and multiple channel material measurements. Cross sections are named from west to east (upstream to downstream) beginning with ER-1 to NMED-9. ER-1 through ER-4 represent cross sections previously established by the ER Project and re-measured in this study. Cross sections NMED-1 through NMED-9 are new cross sections established in this study. Reach P-4 East was sub-divided into two separate reaches. P-4 East (A) includes cross sections ER-1 through NMED-1 and P-4 East (B) includes cross sections NMED-2 through NMED-9. Longitudinal profiles and channel material assessments were performed separately on each of these sub reaches.

P-4 East (A) ER-1 Cross Section

Cross section ER-1 is the western most, upstream cross section in Pueblo Canyon, reach P-4 East (A). The endpoints are labeled A and A', measured 139 feet from north to south. This cross section extends across bank-forming abandoned channel deposits, sandbar deposits from 1991 floods, and the active channel. The reference map (Figure 1) illustrated the plan view of cross section ER-1, the active thalweg, terrace banks, and LANL Environmental Restoration (ER) geomorphic units.

The geomorphic units shown here and throughout the report are described in the LANL Environmental Restoration Project report "Evaluation of Sediment Contamination in Pueblo Canyon: reaches P-1, P-2, P-3, and P-4" (Reneau, et al., 1998). The c and f units are post 1942 channel and floodplain units, and the Q units on map include bedrock, pre-1942 stream terraces, and side-slope fans, as well as colluvium. Mapping was aided by examination of sequential aerial photographs dating back to 1935 and extensive field checking, as well as by 1991 orthophotographs (Steve Reneau, 2003, personal communication).

The following unit descriptions apply to all location maps used in this report. The geomorphic unit, c1a, highlighted by light green, was the active channel area in 1991. C1b units are sandbars deposited during 1991 floods, which are confined within a channel incised into c3 geomorphic units. C2 units are pre-1991 channel areas that were active in the 1980s, incised into an earlier post-1942 channel (c3, previously aggrading channel that was abandoned by incision between 1981 and 1986) (Reneau, et al., 1998). Pre-1942 units on the flood plain are covered by the post-1942 flood deposits and labeled with an f prefix. Unit c3 is a filled channel abandoned after 1942 that is higher in elevation than the existing channel area. These c3 and f1units have the highest average concentrations of plutonium in P-4 East (Reneau, et al., 1998).

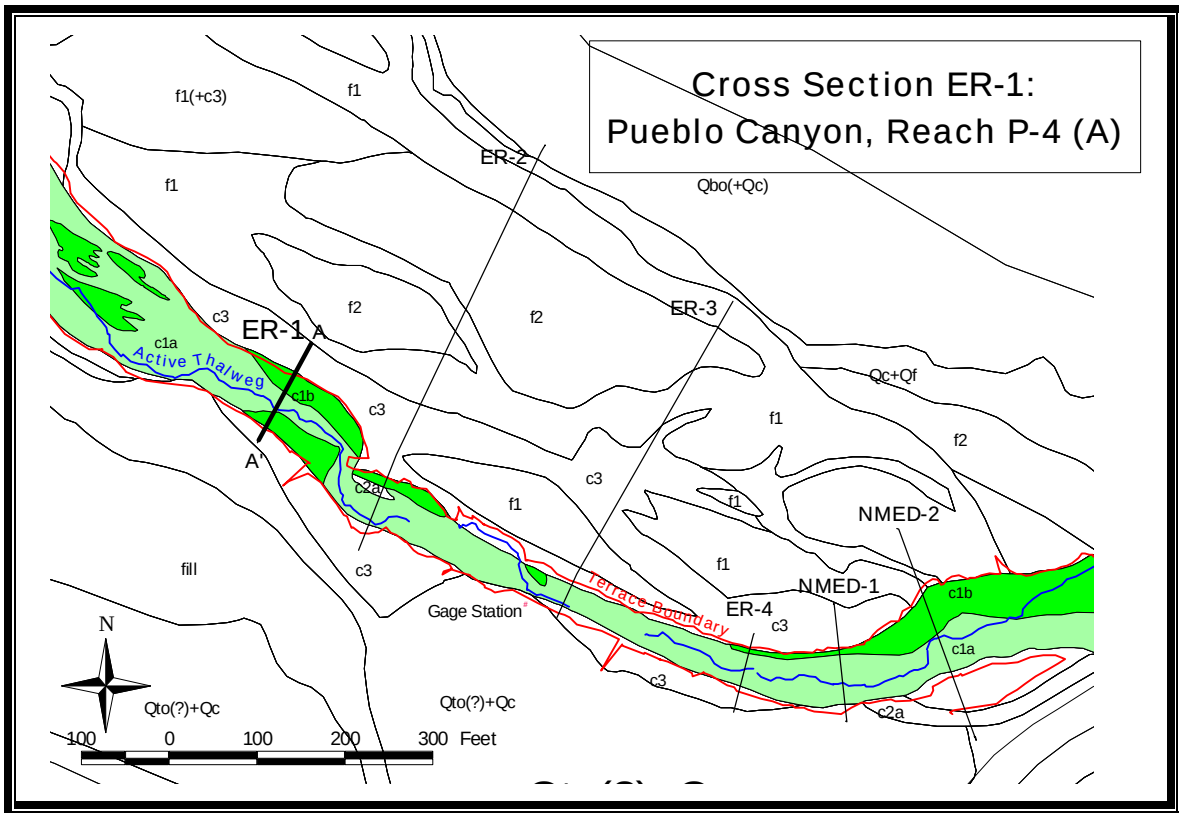


Figure 1. Location of P-4 East (A) ER-1 cross section (A-A', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

The blue line marks the thalweg, the deepest point in a channel. It is the most consistently water filled part of the channel, but during effluent release from the Bayo wastewater treatment plant, water follows a braided stream pattern in many areas along this reach. The red line outlines the edge of the confining terraces and conforms to the boundary between the active channel and the bank forming c3 unit delineated by LANL ER geomorphic report.

The cross section (Figure 2) demonstrates the stream dimensions and characteristics at this location. The c3 units, which form the 2 to 3 foot confining terraces, are present from 0 to 40 feet and 120 feet to the end of this cross section. Except at 110 feet, little evidence remains of c1b sandbar units originally delineated between 41 to 70, and 96 to 120 feet. The active channel appears to be between 50 to 110 feet, different from LANL geomorphic delineation of the active channel from 70 to 96 feet. Several small channels, within the active channel area, are water filled during higher water stages resulting from Bayo water treatment discharge. The channel at 115 feet is abandoned. In November of 2001, at ER-1, the width of the channel at the flood prone stage was 89 feet. The channel is 3.6 feet deep from the deepest part of the channel (thalweg) to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 1.9 feet. Other stream dimensions reflected by cross section ER-1 are listed in Table 3. At bankfull stage, the cross sectional area is approximately 24 square feet. The average depth of the channel is 0.43 foot and the wetted perimeter is 56 feet.

Table 3. Stream dimensions at P4 East (A) ER-1 cross section

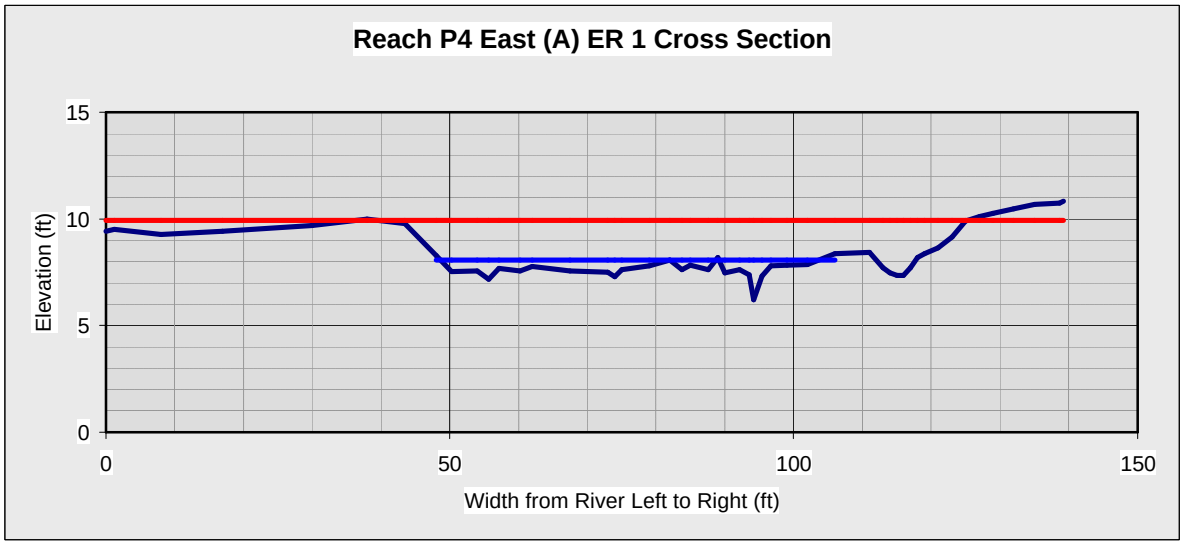
Stream Dimensions	
23.53	Cross section area at bankfull stage (ft sq)
54.55	Width at bankfull stage
1.86	Maximum depth at bankfull
3.57	Bank height
89	Width flood prone area (at 2 x max depth)
0.43	Mean depth
56.46	Wetted Perimeter
0.42	Hydraulic radius
126.44	Width / depth ratio
1.63	Entrenchment ratio
0.0135	Slope
1.19	Sinuosity

A width to depth ratio of 126.4, entrenchment value of 1.63, and a sinuosity of 1.19 suggest the stream at this area is a "B" type stream (Rosgen classification). The predominance of the silt-clay fraction in the channel bed material and a slope <0.02 refines the classification to a "B6c" type. A B6 stream type is moderately sensitive to stream flow and sediment increases, contributes moderate sediment supplies, and has a low stream bank erosion potential (Rosgen, 1994). Additional stream hydraulic and physical parameters are listed in Table 4.

Table 4. Additional parameters determined from stream dimensions at P4 East (A) ER-1

Stream hydraulics	
2.19	Velocity (ft/sec)
51.57	Discharge rate, Q (cfs)
0.35	Shear stress (lbs/ft sq)
0.43	Shear velocity (ft/sec)
0.80	Unit stream power (lbs/ft/sec)
0.35	Froude number
5.15	Friction factor u/u*
20.72	Threshold grain size (mm)
Channel material	
11	Measured D84 (mm)
11.95	Relative roughness
0.0253	Manning's "n" from channel material

The cross section (Figure 2) displays the profile view, bankfull height, and flood prone area. The area under the horizontal blue line represents the cross section area at bankfull stage and the horizontal red line depicts the flood prone area height. The flood prone height is approximately twice the maximum depth in a riffle or straight stream section. It generally includes the active flood plain and low terraces, and in most streams is associated with a < 50 year return interval flood rather than with a very rare flood.



A A'

Figure 2. P-4 East (A) ER-1 cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height.

Figure 3 is a downstream view of reach P-4 East (A) channel at cross section ER-1. The photo is oriented so that cross section starts at A, left or north in this photo, and continues south to A'.

A A'

Figure 3. View of P4 East (A) ER-1 cross section looking downstream

Our researcher is standing on the cross section with stadia rod in the thalweg. The 1.9 -foot deep thalweg is in the right foreground of this photo. The channel floodplain is grass covered, maintained by effluent water from the Bayo wastewater treatment plant, and is currently stable. At the left and right side of the photo, the 2 to 3 foot banks (c3 units) are evident. Note that at ER-1 cross section, the flood prone area extends beyond the northern terrace, over the left bank. This over bank flow produces widespread depositional areas on the flood plain, collects again and enters the mainstream between NMED2 and NMED 3,

where it is causing significant bank erosion. From 1981 to 2001, these flood plains had been isolated from the incised active channel. These were flooded in 2001 and again in 2003.

P-4 East (A) ER-2 Cross Section

Cross section ER-2 is the second western most cross section in Pueblo Canyon, reach P-4 East (A), measured during this study. It is approximately 180 feet downstream from cross section ER-1. The endpoints are labeled B and B', measured 542 feet from north to south. This cross section extends up to the steep valley walls covered by Quaternary colluvium in Pueblo Canyon, and across terraces, that from 1981 to 2001 had been isolated from the active channel. The cross section extends across abandoned channel deposits that form confining banks to the active channel, and across sandbar deposits and younger abandoned channel deposits within the active channel. The reference map (Figure 4) illustrates the plan view of cross section ER-2, the active thalweg, terrace banks, and LANL ER geomorphic units. The cross section, profile, bankfull area, and predicted flood prone levels are shown in Figure 5.

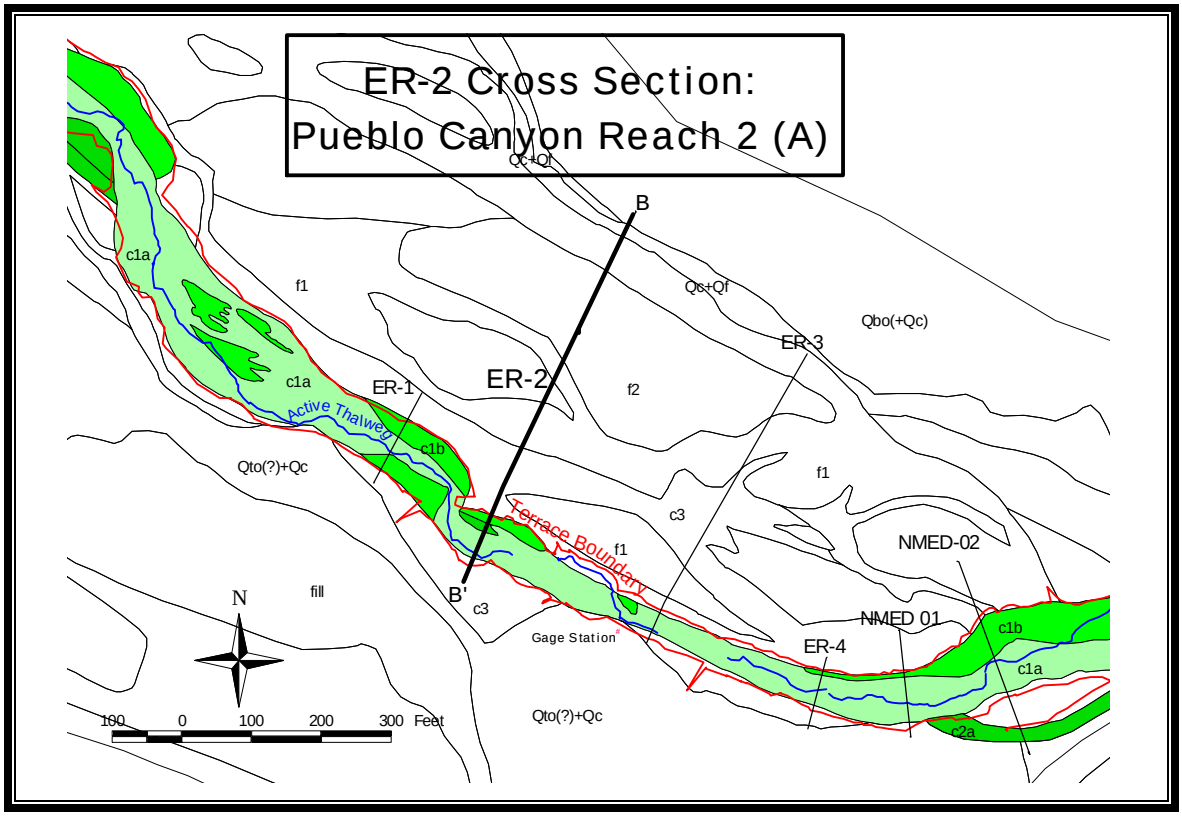


Figure 4. Location of P-4 East (A) ER-2 cross section (B-B', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

Pre-1942 and post-1942 units on the flood plain are covered by post-1942 flood deposits and labeled with an f prefix. Unit c3 is an earlier post-1942 abandoned channel higher in elevation than the existing channel that has formed confining banks to the area.

The blue line marks the thalweg. Effluent from the Bayo wastewater treatment plant supplies water that fills the channel on an almost daily frequency. In this area, the stream is confined within a single channel, although it follows a braided pattern in other areas along this reach. The red line outlines the edge of the confining banks, but does not conform to the unit boundaries delineated by the LANL ER. These are minor departures from previously mapped features. Foot traffic is affecting the south bank at the cross section.

Figure 5 demonstrates the dimensions and characteristics at this location, measured along the entire extent of the NMED cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height. The water flow is confined within a single channel. The flood prone area is confined within the terrace banks due to vertical incision of the channel.

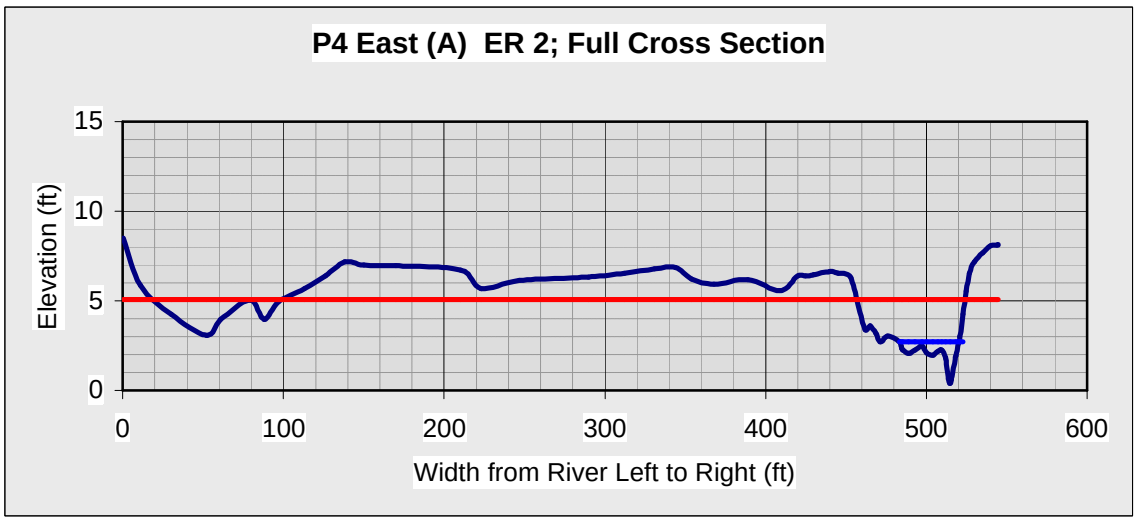


Figure 5. Full extent of P4 East (A) ER-2 cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height.

Quaternary colluvium is found from 0 to 40 feet at this cross section. Old and recent flood plain deposits extend from 40 to 370 feet. The bank forming c3 abandoned channel-deposits are found on both sides of the active channel at 370 to 460 feet, and 520 feet to the end of the cross section. Evidence of sandbar deposits from a 1991 flood, abandoned channel deposits, as well as recent flood debris exists in the channel from 460 to 485 feet. The thalweg is at 518 feet.

In November of 2001, at ER-2, the width of the channel at the flood prone stage was 67 feet. The channel is 5.9 feet deep from the thalweg to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 2.3 feet. Other stream dimensions reflected by cross section ER-1 are listed in Table 5. At bankfull stage, the cross sectional area is approximately 25.9 square feet. The average depth of the channel is 0.7 foot and the wetted perimeter is 37.9 feet.

Table 5. Stream dimensions at P-4 East (A) ER-2 cross section

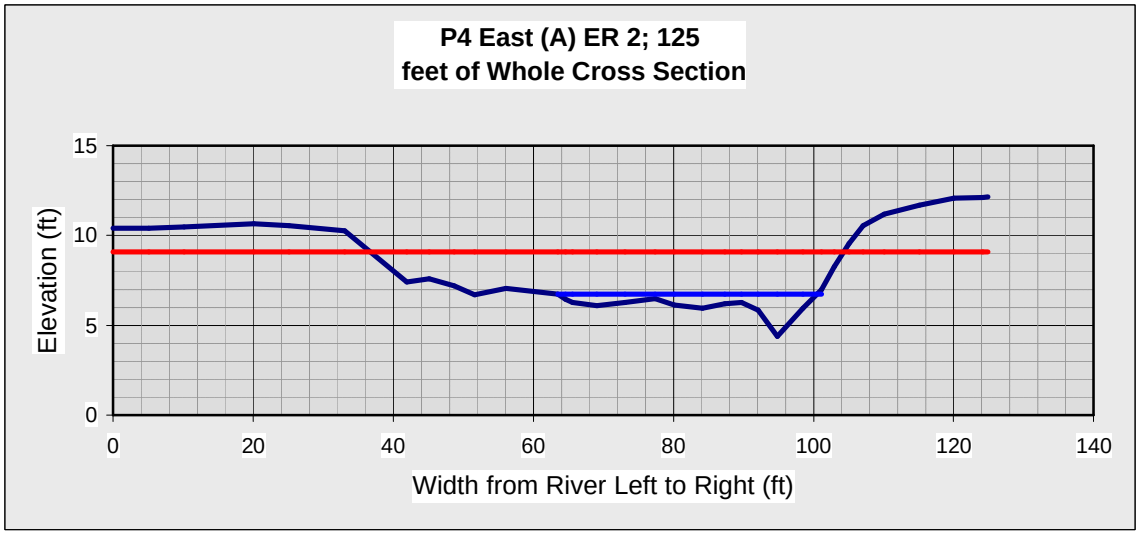
Stream dimensions	
25.9	Cross section area at bankfull stage (ft sq)
36.9	Width at bankfull stage
2.3	Maximum depth at bankfull
5.9	Bank height
67.0	Width flood prone area (at 2 x max depth)
0.70	Mean depth
37.9	Wetted Perimeter
0.68	Hydraulic radius
52.6	Width / depth ratio
1.81	Entrenchment ratio
0.0077	Slope
1.19	Sinuosity

A width to depth ratio of 52.6 and entrenchment value of 1.8 and sinuosity of 1.19 suggest the stream at this area is a "B" type stream (Rosgen classification). The predominance of the silt-clay fraction in the channel bed material and a slope of <0.02 refines the classification to a "B6c" type. A B6 stream type is moderately sensitive to stream flow and sediment increases, contributes moderate sediment supplies, and has a low stream bank erosion potential (Rosgen, 1994). Additional stream hydraulic and physical parameters are listed in the Table 6.

Table 6. Additional parameters determined from stream dimensions at ER-2

Stream hydraulics	
2.3	Velocity (ft/sec)
59.5	Discharge rate, Q (cfs)
0.33	Shear stress (lbs/ft sq)
0.41	Shear velocity (ft/sec)
0.769	Unit stream power (lbs/ft/sec)
0.23	Froude number
5.6	Friction factor u/u*
19.1	Threshold grain size (mm)
Channel material	
11.0	Measured D84 (mm)
19.4	Relative roughness
0.0242	Manning's "n" from channel material

Figure 6 displays 125 feet of the cross section that correlates with an earlier cross section measured by the LANL Environmental Restoration Project.



B B'

Figure 6. Portion of P4 East (A) ER-2 cross section corresponding with previous LANL ER cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height.

Figure 7 is a downstream view of the P-4 East (A) reach at Cross section ER-2. The photo is oriented so that cross section starts at B, left or north in this photo, and continues south to B'.

B B'

Figure 7. View of P4 East (A) ER-2 cross section looking downstream

Our researcher is standing on the cross section with stadia rod in the thalweg. The 2.3-foot deep thalweg is within a single channel and is in the right foreground of this photo. The channel bottom is grass covered, maintained by effluent water from the Bayo wastewater treatment plant. Recent flood debris is evident on the tree trunk in the middle of the photo. The bank at the right in this photo is approximately 8 feet high and has been affected by recent foot traffic. The left bank is approximately 6 feet high.

P-4 East (A) ER-3 Cross Section

Cross section ER-3 is the third western most cross section in Pueblo Canyon, reach P-4 East (A), measured during this study. It is approximately 270 feet downstream from cross section ER-2, and 45 feet downstream of LANL E060 gage station. The endpoints are labeled C and C', measured 460 feet from north to south. This cross section extends up to the steep valley walls covered by Quaternary colluvium, and across terraces, that from 1981 to 2001 had been isolated from the active channel. The cross section extends across the active channel, and abandoned bank-forming channel deposits. The reference map (Figure 8) illustrates the plan view of cross section ER-1, the active thalweg, terrace banks, and LANL ER geomorphic units.

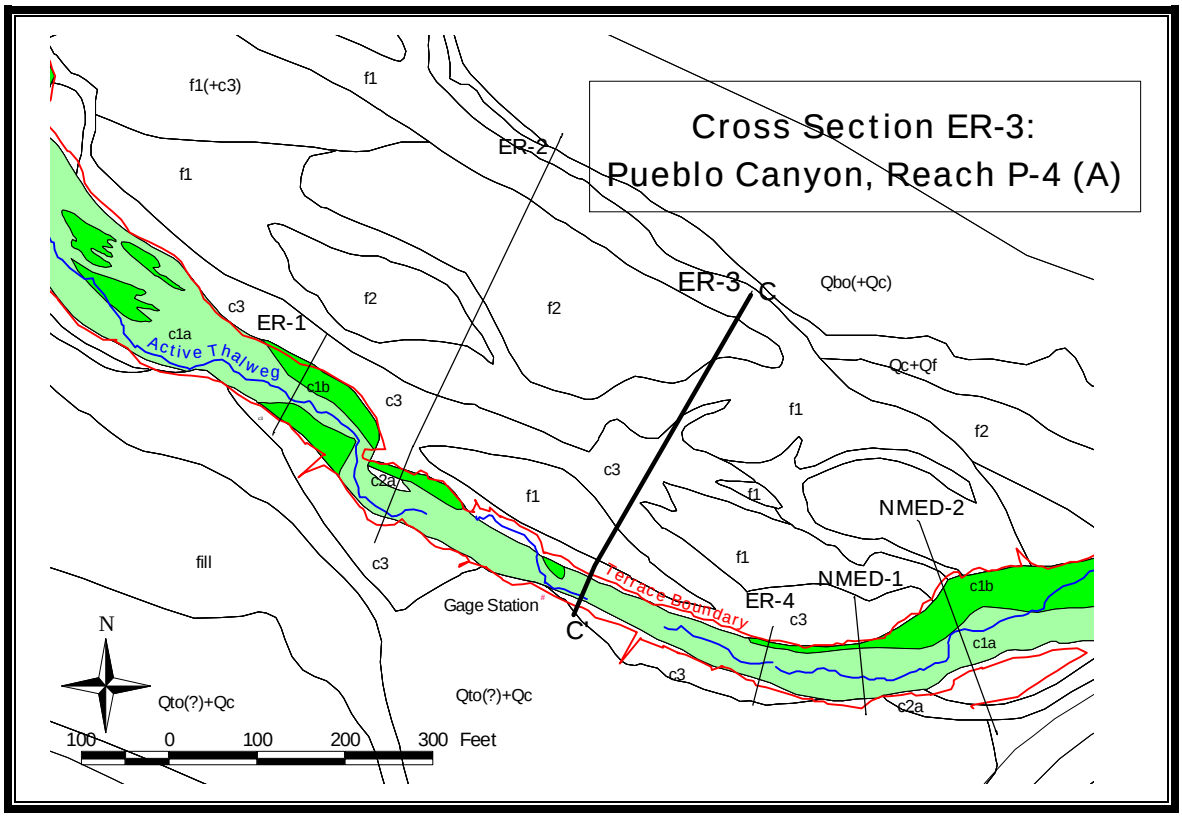


Figure 8. Location of P-4 East (A) ER-3 cross section (C-C', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

The geomorphic unit, c1a, highlighted by light green, was the active channel area in 1991. Unit c1a, the active channel, is incised into c3 geomorphic units. The pre-1942 units and post-1942 units on the upper terrace flood plain are covered by the post-1942 flood deposits and labeled with an f prefix. Recent flood activity in 2001 has added fresh deposits. The c3 units are post-1942 deposits and contain greater contaminant concentrations and inventory than c1a units and they comprise the bank forming terrace unit.

The blue line marks the thalweg. Effluent from the Bayo wastewater treatment plant supplies water that fills a braided stream pattern in this area almost daily. The red line outlines the edge of the confining terraces marked on the map by the f and c3 units. The red line does not conform to the boundary between the active channel and the bank forming c3 unit delineated by LANL ER geomorphic report. Note the lateral movement of the thalweg and terrace boundary on the north bank 70 to 170 feet west of cross section ER-3. This movement suggests erosion may have removed up to 15 feet of the bank.

Figure 9 demonstrates the dimensions and characteristics at this location, measured along the entire extent of the NMED cross section. The cross section begins at the left on the flood plain from 0 to 190 feet. Lobes of channel deposits from the c3 abandoned channel system occur from 190 to 340 feet, followed by additional flood plain deposits to 390 feet. It appears that the channel could be up to 15 feet wider than delineated by the LANL ER geomorphology maps. Parts of the bank-forming c3 abandoned channel deposits, found at both sides of this channel (from 389 to 400 and 445 to 455 feet), are less than that delineated by LANL ER. The thalweg is broader and more shallow than found in the preceding channels. It is found between 410 to 445 feet. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height. The present active flood prone area is confined within the banks of this active channel.

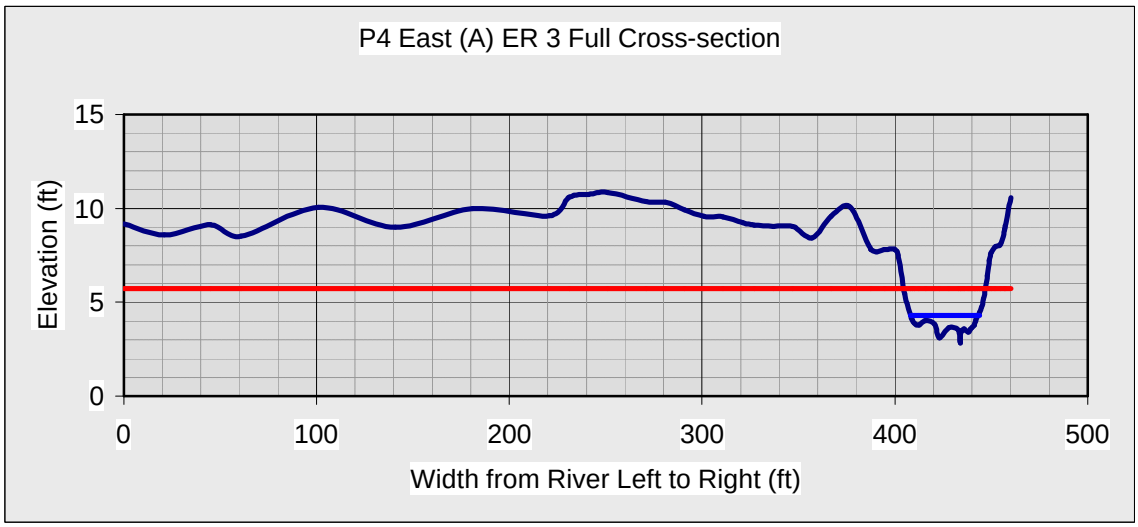


Figure 9. Entire view of P-4 East (A) ER-3 cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height.

In November of 2001, at ER-3, the width of the channel at the flood prone stage was 42 feet. The channel is 4.9 feet deep from the thalweg to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 1.5 feet. At bankfull stage, the cross sectional area is approximately 21.5 square feet. The average depth of the channel is 0.6 foot and the wetted perimeter is 36 feet. Other stream dimensions reflected by cross section ER-3 are listed in Table 7.

Table 7. Stream dimensions at P-4 East (A) ER-3 cross section

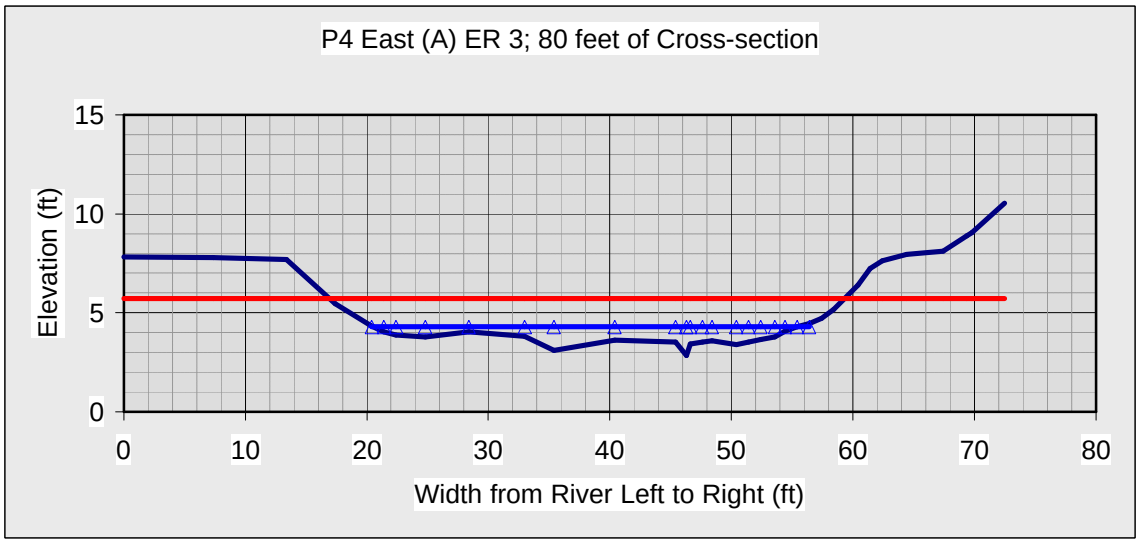
	Stream dimensions
21.52	Cross section area at bankfull stage (ft sq)
34.82	Width at bankfull stage
1.45	Maximum depth at bankfull
4.85	Bank height
42	Width flood prone area (at 2 x max depth)
0.62	Mean depth
35.73	Wetted Perimeter
0.60	Hydraulic radius
56.34	Width / depth ratio
1.21	Entrenchment ratio
0.011	Slope
1.19	Sinuosity

A width to depth ratio of 56.3, entrenchment value of 1.2, and a sinuosity of 1.19 suggest the stream at this area is an "F" type stream (Rosgen classification). The predominance of the silt-clay fraction in the channel bed material and a slope of <0.02 refines the classification to a "F6" type. An F6 stream type has very high sensitivity to increases in stream flow magnitude and timing and/or sediment increases, contributes high sediment supplies, and has a very high stream bank erosion potential (Rosgen, 1994). Additional stream hydraulics calculated from stream dimensions and physical parameters are listed in Table 8.

Table 8. Additional parameters determined from stream dimensions at P-4 East (A) ER-3

	Stream hydraulics
2.53	Velocity (ft/sec)
54.40	Discharge rate, Q (cfs)
0.41	Shear stress (lbs/ft sq)
0.46	Shear velocity (ft/sec)
1.07	Unit stream power (lbs/ft/sec)
0.32	Froude number
5.48	Friction factor u/u*
24.83	Threshold grain size (mm)
	Channel material
11.0	Measured D84 (mm)
17.12	Relative roughness
0.0244	Manning's "n" from channel material

Figure 10 displays 80 feet of the entire cross section that correlates with an earlier cross section measured by the LANL ER Project.



C C'

Figure 10. Portion of P-4 East (A) ER-3 cross section corresponding with previous LANL ER cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height.

Figure 11 is a downstream view of the P-4 East (A) channel at cross section ER-3. The photo is oriented so that cross section starts at C, left or north in this photo, and continues to C'.

C C'

Figure 11. View of P-4 East (A) ER-3 cross section looking (downstream)

Our researcher is standing on the cross section with stadia rod in the thalweg. The 1.5-foot deep thalweg is in the south half of the channel. Notice the broad channel and developing braided pattern of the stream. The floodplain is grass covered and maintained by effluent water from the Bayo wastewater treatment plant. The banks are approximately 5 feet high at the right and left in this photo.

P-4 East (A) ER-4 Cross Section

Cross section ER-4 is the fourth western most cross section in Pueblo Canyon, reach P-4 East (A), measured during this study. It is approximately 250 feet downstream from cross section ER-3. The endpoints are labeled D and D', measured 110 feet from north to south. This cross section extends up to colluvium covered valley wall to the south, across the active channel, and onto bank forming abandoned channel deposits to the north. Figure 12 illustrates the plan view of cross section ER-4, the active thalweg, terrace banks, and LANL ER geomorphic units.

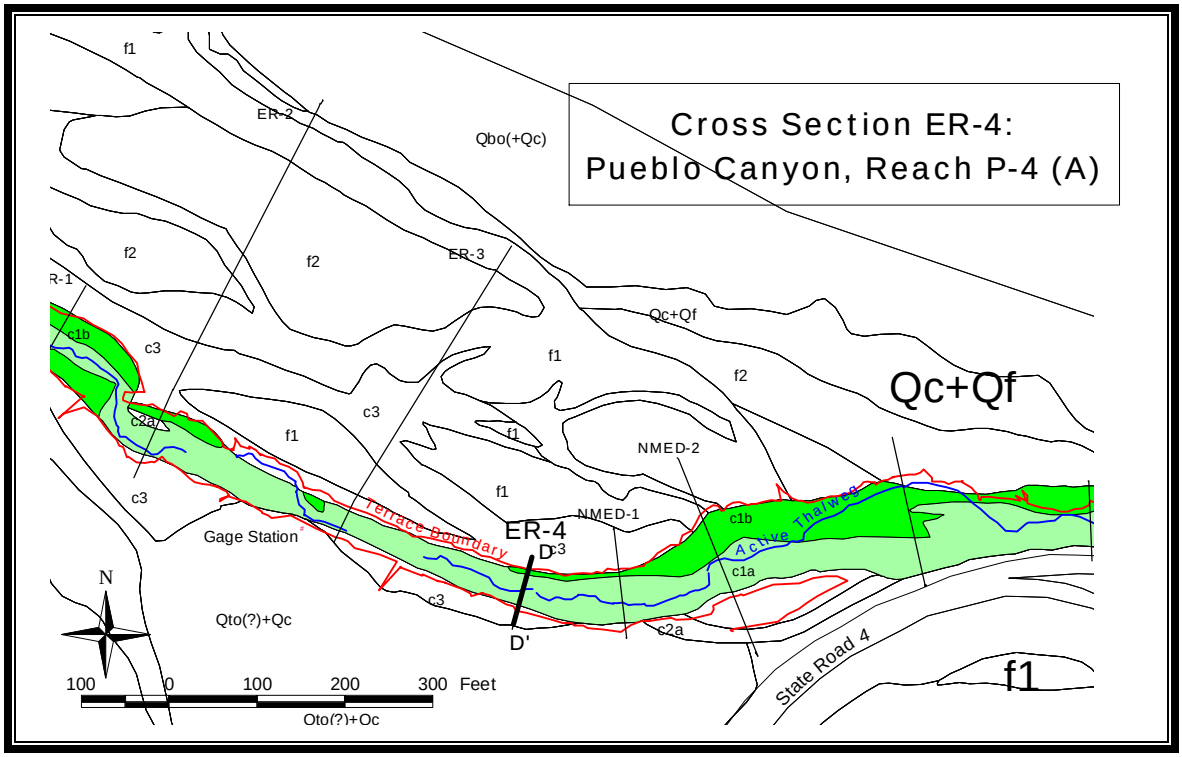


Figure 12. Location of P-4 East (A) ER-4 cross section (D-D', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

The geomorphic unit, c1a, highlighted by light green, was the active channel area in 1991. The active channel is incised into c3 geomorphic units. Unit c1b is adjacent sandbar deposits from 1991 floods found within the active channel. Unit c3 is an earlier abandoned channel higher in elevation than the active channel, and forms the confining banks in this area. Steep, Quaternary colluvium covered slopes are found at the southern end of the cross section. The blue line marks a deepening thalweg. Effluent from the Bayo wastewater treatment plant no longer fills the single channel in this area. The thalweg is incised and substantially deeper than the preceding channels. The red line outlines the edge of the confining terraces marked on the map by the c3 units.

The dimensions measured at this location and characteristics along the P-4 East (A) ER-4 cross section are illustrated in Figure 13. The c3 bank-forming abandoned channel deposits extend from 0 to 27 feet. The 1991 c1b sandbar, from 27 to 33 feet, is eroded away or buried by the adjacent bank. The active channel is found between 33 and 70 feet, and the thalweg at 48 feet. The south bank, at 78 feet, is formed from the c3 unit (78 to 101 feet). The steep slope at 101 feet to the end of the cross section is Quaternary colluvium. Cross section ER-4 correlates with an earlier cross section measured by the LANL ER Project.

In November of 2001, at ER-4, the width of the flood prone area was 51 feet. The channel is 6.5 feet deep from the thalweg to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 2.5 feet. At bankfull stage, the cross sectional area is approximately 18.5 square feet. The average depth of the channel is 0.56 foot and the wetted perimeter is 36.2 feet. Other stream dimensions measured at cross section ER-4 are listed in the Table 9.

Table 9. Stream dimensions at P4 East (A) ER-4 cross section

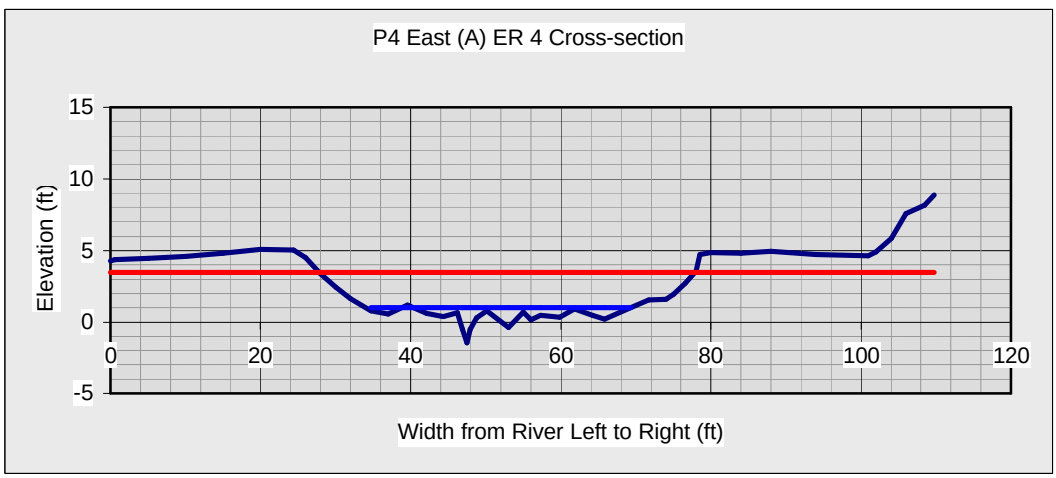
Stream dimensions	
18.49	Cross section area at bankfull stage (ft sq)
32.85	Width at bankfull stage
2.47	Maximum depth at bankfull
6.50	Bank height
51	Width flood prone area (at 2 x max depth)
0.56	Mean depth
36.15	Wetted Perimeter
0.51	Hydraulic radius
58.36	Width / depth ratio
1.55	Entrenchment ratio
0.0232	Slope
1.19	Sinuosity

A width to depth ratio of 58.4, entrenchment value of 1.55, and sinuosity of 1.19 suggest the stream at this area is a “B” type stream (Rosgen classification). The predominance of the silt-clay fraction in the channel bed material and a slope of 0.02 – 0.039 refines the classification to a “B6” type. A B6 stream type is moderately sensitive to stream flow and sediment increases, contributes moderate sediment supplies, and has a low stream bank erosion potential (Rosgen, 1994). Additional stream hydraulic and physical parameters are listed in the following Table 10.

Table 10. Additional parameters determined from stream dimensions at P-4 East (A) ER-4

Stream hydraulics	
3.29	Velocity (ft/sec)
60.88	Discharge rate, Q (cfs)
0.74	Shear stress (lbs/ft sq)
0.62	Shear velocity (ft/sec)
2.68	Unit stream power (lbs/ft/sec)
0.60	Froude number
5.33	Friction factor u/u*
47.42	Threshold grain size (mm)
Channel material	
11	Measured D84 (mm)
15.60	Relative roughness
0.0239	Manning's "n" from channel material

In Figure 13, the area under the horizontal blue line represents the cross section area at bankfull stage. The red line depicts the flood prone area confined within the channel banks.



D D'

Figure 13. P-4 East (A) ER-4 cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height.

Figure 14 is a downstream view of the P 4 East (A) channel at Cross section ER-4. The photo is oriented so that cross section starts at D, left or north in this photo, and continues to D'.

D D'

Figure 14. View of P-4 East (A) ER-4 cross section looking downstream

Our researcher is standing on the cross section with stadia rod in the thalweg. The 2.5-foot incised thalweg is in the center of the channel. The channel depth is continuing to increase downstream. The flood plain is grass covered, maintained by effluent water from the Bayo wastewater treatment plant. The banks are approximately 6 feet high at the right and left in this photo.

P-4 East (A) NMED-1 Cross Section

Cross section NMED-1 is the fifth western most, and last cross section measured in reach P-4 East (A), during this study. Eight additional cross sections are located in reach P-4 East (B). It is approximately 130 feet downstream from cross section ER-4. The endpoints are labeled E and E', measured 142 feet from north to south. This cross section extends south to the colluvium-covered slope, across the active cannel, and onto the terrace to the north. The reference map (Figure 15) illustrates the plan view, terrace banks, active thalweg, and LANL ER geomorphic units. Figure 16 illustrates the profile view of cross section NMED-1, bankfull area, and predicted flood prone level.

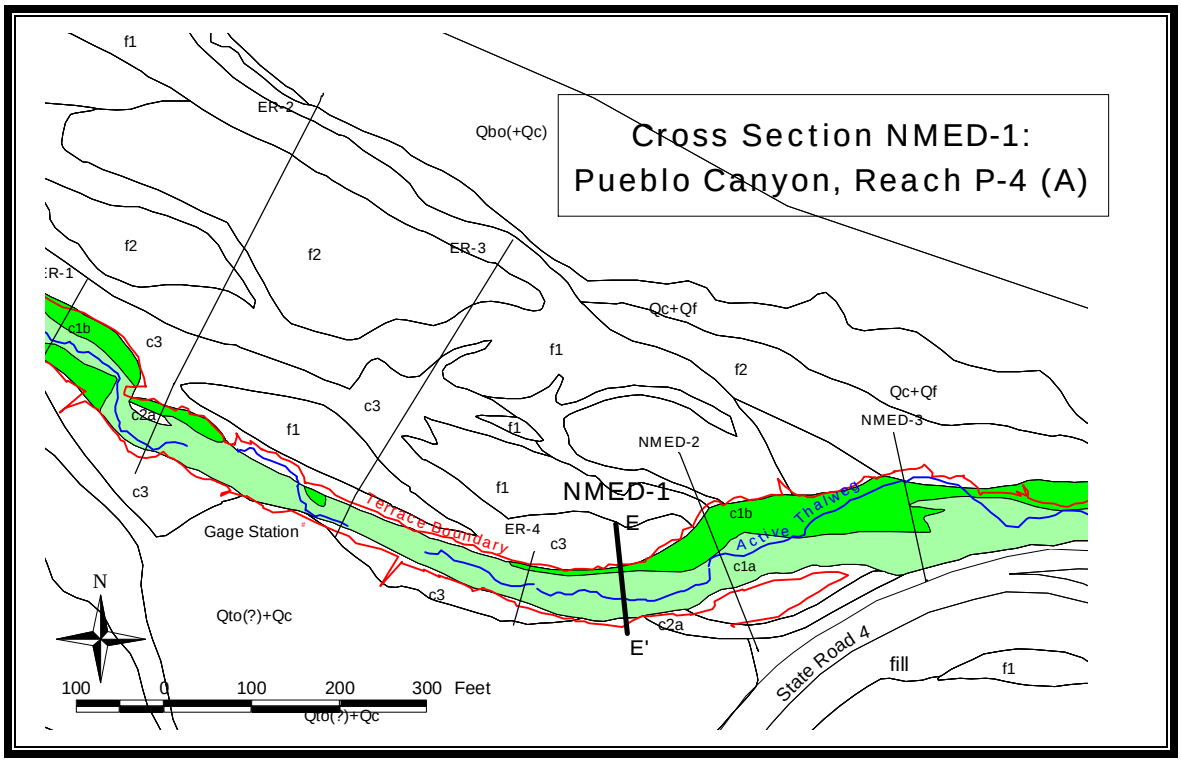


Figure 15. Location of P-4 East (A) NMED-1 cross section (E-E', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

The c1a geomorphic unit, highlighted by light green, is presently the active channel, and was the active channel area in 1991. The channel is incised into the colluvium Quaternary unit on the south and c3 units on the north. The unit c1b is a sandbar deposit from 1991 floods, forming 1 to 2 foot thick banks. Unit c3 is an earlier abandoned channel higher in elevation than the active channel area. In this area the c3 units form the confining channel banks. Cross section NMED-1 is measured north up to an f1 floodplain unit deposited onto pre-1942 geomorphic units. The blue line in Figure 15 marks a deepening thalweg. The red line outlines the edge of the confining terraces marked on the map by the c3 unit to the north, and the colluvium Quaternary unit to the south. The line does not conform to the boundaries outlined by LANL ER geomorphic maps. The disparity is small and affected on the south bank, west of NMED-1, by a side drainage joining the main channel.

Figure 16 demonstrates the measured dimensions at this location and characteristics along the entire extent of the NMED-1 cross section. The c3 bank-forming abandoned channel deposits are seen from 0 to 55 feet. The active channel is between 61 and 123 feet, and the thalweg is at 93 feet. The adjacent c1b sandbar unit deposited in 1991 has been eroded away or buried by sloughing bank materials. The south bank is comprised of Quaternary colluvium and forms a steep slope above the bank at 130 feet. Cross section NMED-1, and the remaining sections measured to the east of this location, does not correlate with LANL ER Project cross sections. This 142-foot length provides a consistent scale between all the cross sections measured during this study. The horizontal blue line characterizes the bankfull

area. The thalweg continues to deepen to the east. In Figure 16, the red line depicts the flood prone area height. Flood heights at this level are barely confined by the north bank.

In November of 2001, at NMED-1, the width of the channel at the flood prone stage was 77 feet. The channel is 6.8 feet deep from the thalweg to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 2.95 feet. At bankfull stage, the cross sectional area is approximately 23.9 square feet. The average depth of the channel is 0.64 foot and the wetted perimeter is 39.8 feet. Other stream dimensions reflected by cross section NMED-1 are listed in Table 11.

Table 11. Stream dimensions at P-4 East (A) NMED-1 cross section

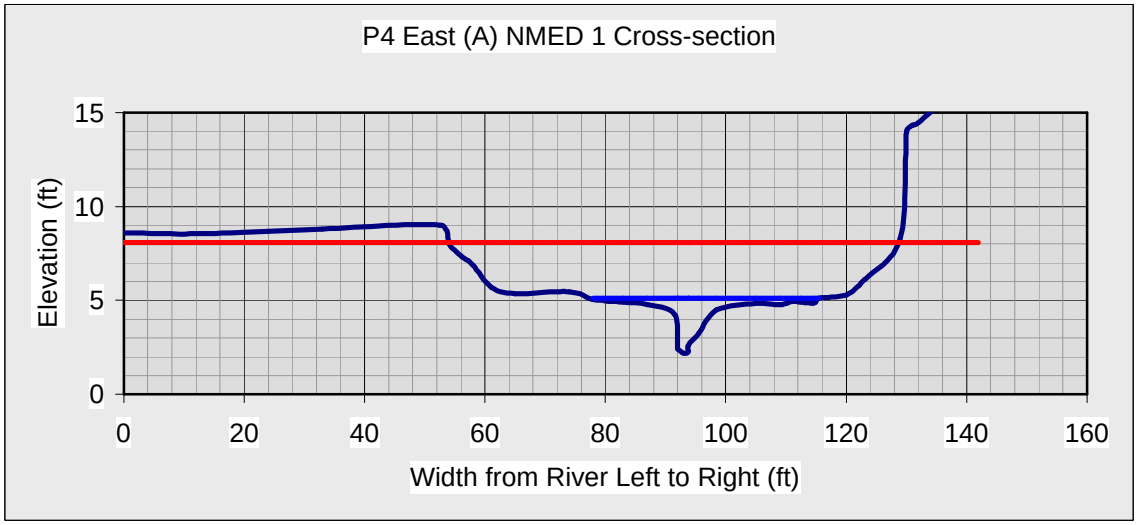
Stream dimensions	
23.88	Cross section area at bankfull stage (ft sq)
37.50	Width at bankfull stage
2.95	Maximum depth at bankfull
6.83	Bank height
77	Width flood prone area (at 2 x max depth)
0.64	Mean depth
39.76	Wetted Perimeter
0.60	Hydraulic radius
58.90	Width / depth ratio
2.05	Entrenchment ratio
0.0118	Slope
1.19	Sinuosity

A width to depth ratio of 58.9, entrenchment value of 2.05, and a sinuosity of 1.19 suggest the stream at this area is a “B” type stream (Rosgen classification). The predominance of the silt-clay fraction in the channel bed material and a slope <0.02 refines the classification to a “B6c” type. A B6 stream type is moderately sensitive to stream flow and sediment increases, contributes moderate sediment supplies, and has a low stream bank erosion potential (Rosgen, 1994). Additional stream hydraulic and physical parameters are listed in Table 12.

Table 12. Additional parameters determined from stream dimensions at P-4 East (A) NMED-1

Stream hydraulics	
2.61	Velocity (ft/sec)
62.26	Discharge rate, Q (cfs)
0.44	Shear stress (lbs/ft sq)
0.48	Shear velocity (ft/sec)
1.22	Unit stream power (lbs/ft/sec)
0.33	Froude number
5.47	Friction factor u/u*
26.63	Threshold grain size (mm)
Channel material	
11.0	Measured D84 (mm)
17.64	Relative roughness
0.024	Manning’s “n” from channel material

The area under the blue line in Figure 16 represents the cross section area at bankfull stage and the red line marks the flood-prone area.



E E'

Figure 16. P-4 East (A) NMED-1 cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height.

Figure 17 is a downstream view of the P-4 East (A) channel at cross section NMED-1. The photo is oriented so that cross section starts at E, left or north in this photo, and continues to E'.

E E'

Figure 17. View of P-4 East (A) NMED-1 cross section looking downstream

Our researcher is standing on the cross section with stadia rod in the thalweg. The 2.95-foot incised thalweg is in the center of the channel. The flood plain is grass covered, maintained by effluent water from the Bayo wastewater treatment plant. The banks are approximately 4 feet high at the left and 9 feet at the right in this photo. The 9-foot right bank is eroding.

P-4 East (B) NMED-2 Cross Section

Cross section NMED-2 is the western most cross section measured in reach P-4 East (B). It is approximately 140 feet downstream from cross section NMED-1 in reach P-4 East (A). The endpoints are labeled F and F', measured 279 feet from north to south. This cross section extends over an abandoned terrace, the active channel and associated sandbar and abandoned channel deposits, and road fill materials at the south edge of the cross section. The reference map (Figure 18) illustrates the plan view cross section NMED-2, the active thalweg, terrace banks, and LANL ER geomorphic units. Figure 19 illustrates the profile view, bankfull area, and predicted flood prone level at NMED-2 cross section.

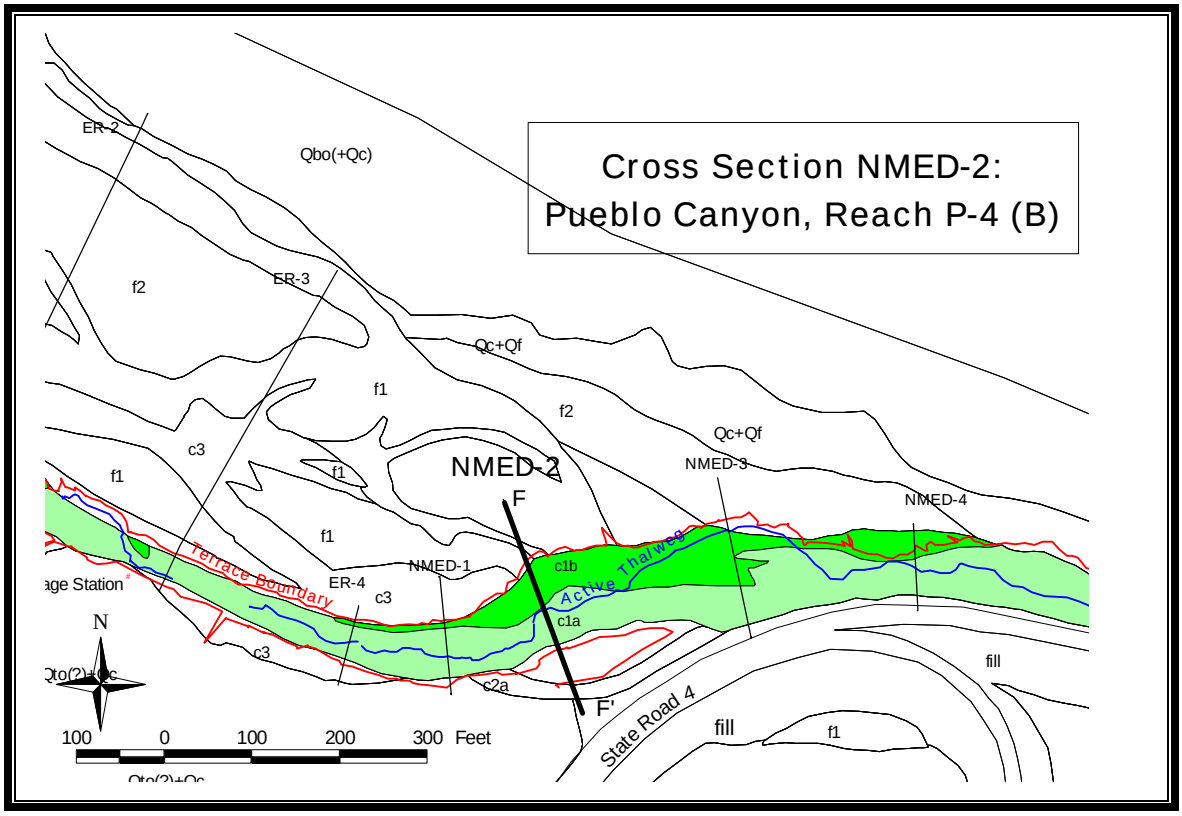


Figure 18. Location of P-4 East (B) NMED-2 cross section (F-F', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

The geomorphic unit, c1a, highlighted by light green, was the active channel area in 1991, and remains so. The active channel is incised into c3 and f1 geomorphic units. Unit c1b is sandbar deposits from 1991 floods, and the c2a unit is from abandoned channel deposits. The c2a channels were active during the 1980s and are incised into a c3 unit that was abandoned by incision between 1981 and 1986. Unit c3 is an earlier abandoned channel higher in elevation than the active channel area. The fill material at the south edge of the cross section is the road construction base for State Road 4.

The blue line marks the thalweg. It has incised down to Puye Formation bedrock and is becoming wider and shallower. The bedrock unit forms a grade control and is forcing accelerated widening of the channel in this area. Effluent from the Bayo wastewater treatment plant supplies water that partially fills the single channel in this area almost daily. The red line outlines the edge of the confining terraces marked on the map by the flood plain units to the north and south. There is a slight disparity between the line and LANL geomorphic maps, suggesting moderate bank erosion where overbank floodwaters spilled over c3-f1 bank while re-entering channel.

Figure 19 demonstrates the dimensions at this location measured along the entire 279-foot extent of the NMED cross section. Cross section NMED-2, along with the following cross sections (NMED 3-9), does not correlate with a previously measured LANL ER Project cross section. Flood deposits (f1 units) are found from the beginning of the cross section to 80 feet, with abandoned c3 lobes present within that section. Terrace banks are marked at 80 and 195 feet, confining the (c1a) active channel and adjacent (c1b) 1991 sandbar deposits. The widening thalweg is at 145 feet. At this location, the thalweg has migrated north of its original, now abandoned course. The original thalweg channel is not evident in the cross section, but channel-plugging materials could be found at 175 feet. More f1 flood plain units are found between 195 and 240 feet, and abandoned channel deposits (c2a) are found between 240 and 260 feet. Fill material used for the base of State Road 4 exist from 262 feet to the end of the cross section.

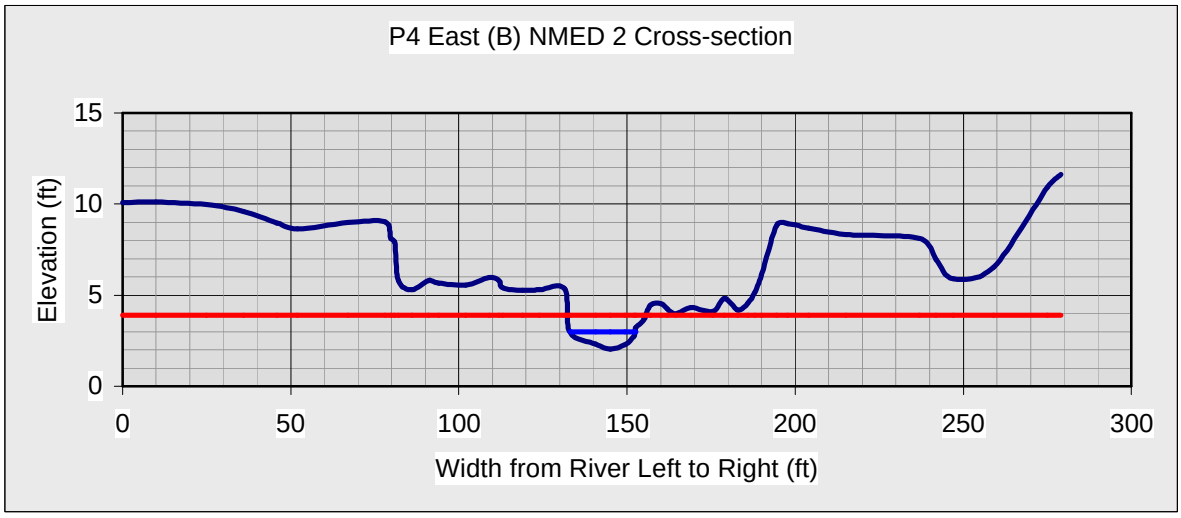


Figure 19. P-4 East (B) NMED-2 cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height.

In November of 2001, at NMED-2, the width of the channel at the flood prone stage was 22 feet. The channel is 7.0 feet deep from the thalweg to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 0.9 feet. At bankfull stage, the cross sectional area is approximately 10.8 square feet. The average depth of the channel is 0.6 feet and the wetted perimeter is 19.5 feet. Other stream dimensions reflected by P-4 East (B) NMED-1 cross section are listed in Table 13.

Table 13. Stream dimensions at P-4 East (B) NMED-2 cross section

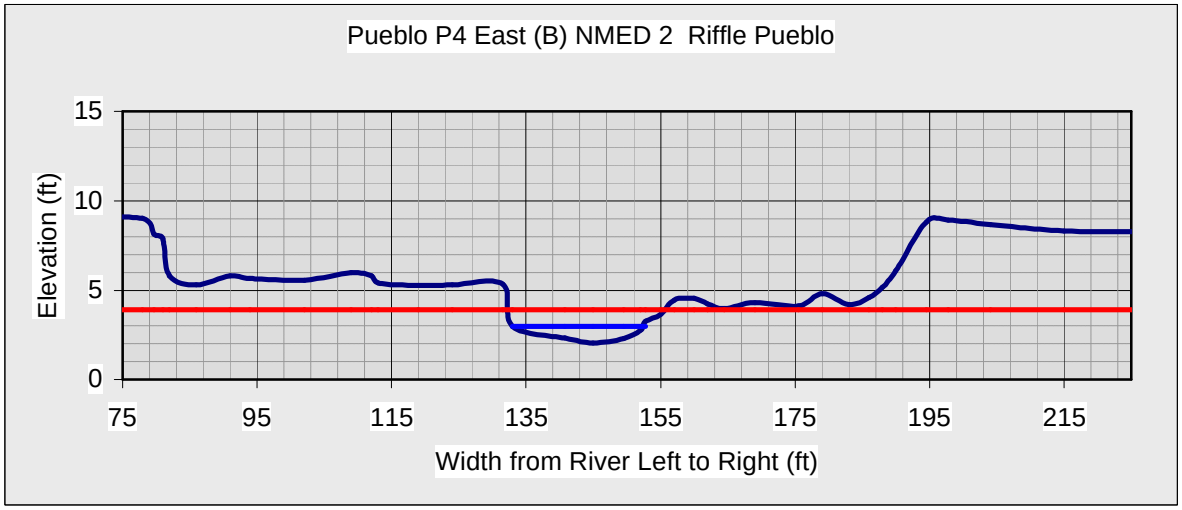
Stream dimensions	
10.77	Cross section area at bankfull stage (ft sq)
19.35	Width at bankfull stage
0.93	Maximum depth at bankfull
6.97	Bank height
22	Width flood prone area (at 2 x max depth)
0.56	Mean depth
19.50	Wetted Perimeter
0.55	Hydraulic radius
34.74	Width / depth ratio
1.14	Entrenchment ratio
0.0108	Slope
1.1	Sinuosity

A width to depth ratio of 34.7, entrenchment value of 1.14, and a sinuosity of 1.1 suggest the stream at this area is an "F" type stream (Rosgen classification). The presence of bedrock as the dominant bed material refines this to a "F1" stream channel at NMED 2. A F1 stream type has low sensitivity to increases in stream flow magnitude and timing and/or sediment increases, contributes low sediment supplies, and has a moderate stream bank erosion potential (Rosgen, 1994). Additional stream hydraulic and physical parameters for P-4 East (B) NMED 2 are listed in Table 14.

Table 14. Additional parameters determined from stream dimensions at P-4 East (B) NMED-2

Stream hydraulics	
6.94	Velocity (ft/sec)
74.71	Discharge rate, Q (cfs)
0.37	Shear stress (lbs/ft sq)
0.44	Shear velocity (ft/sec)
2.60	Unit stream power (lbs/ft/sec)
2.68	Froude number
15.83	Friction factor u/u*
22.10	Threshold grain size (mm)
Channel material	
0 "bedrock"	Measured D84 (mm)
	Relative roughness
	Manning's "n" from channel material

Figure 20 displays 150 feet of the cross section. This figure more plainly shows the c1b sandbar unit at 80 to 130 feet. The area below the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the height of the flood prone area.



F F'

Figure 20. 150-foot view of P-4 East (B) NMED-2 cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height.

Figure 21 is a downstream view of the channel at P-4 East (B) NMED-2 in Pueblo Canyon, reach P-4 East (B). The photo is oriented so that cross section starts at F, left or north in this photo, and continues south to F'.

F F'

Figure 21. View of P-4 East (B) NMED-2 cross section looking downstream.

Our researcher is standing on the cross section with stadia rod in the thalweg. The shallow, 0.93-foot, widening thalweg has abandoned its original course, located within the grass-covered banks to the right of the person in the photo. The channel bottom is bedrock, and the areas around the thalweg are greatly disturbed. State Road 4 fill materials can be seen at the far right, as well as the Pueblo canyon walls covered by Quaternary colluvium at the top of the photo.

P-4 East (B) NMED-3 Cross Section

Cross section NMED-3 is the second western most cross section measured in reach P-4 East (B). It is approximately 250 feet downstream from cross section NMED-2. The endpoints are labeled G and G', measured 203 feet from north to south. This cross section extends over a terrace, the active channel, the floodplain and associated sandbars, to a concrete road apron at the south end of the cross section. The reference map (Figure 22) illustrates the plan view of P-4 East (B) NMED-3 cross section, the active thalweg, terrace banks, and LANL ER geomorphic units. Figure 23 displays the NMED 3 cross section profile, bankfull area, and predicted flood prone level.

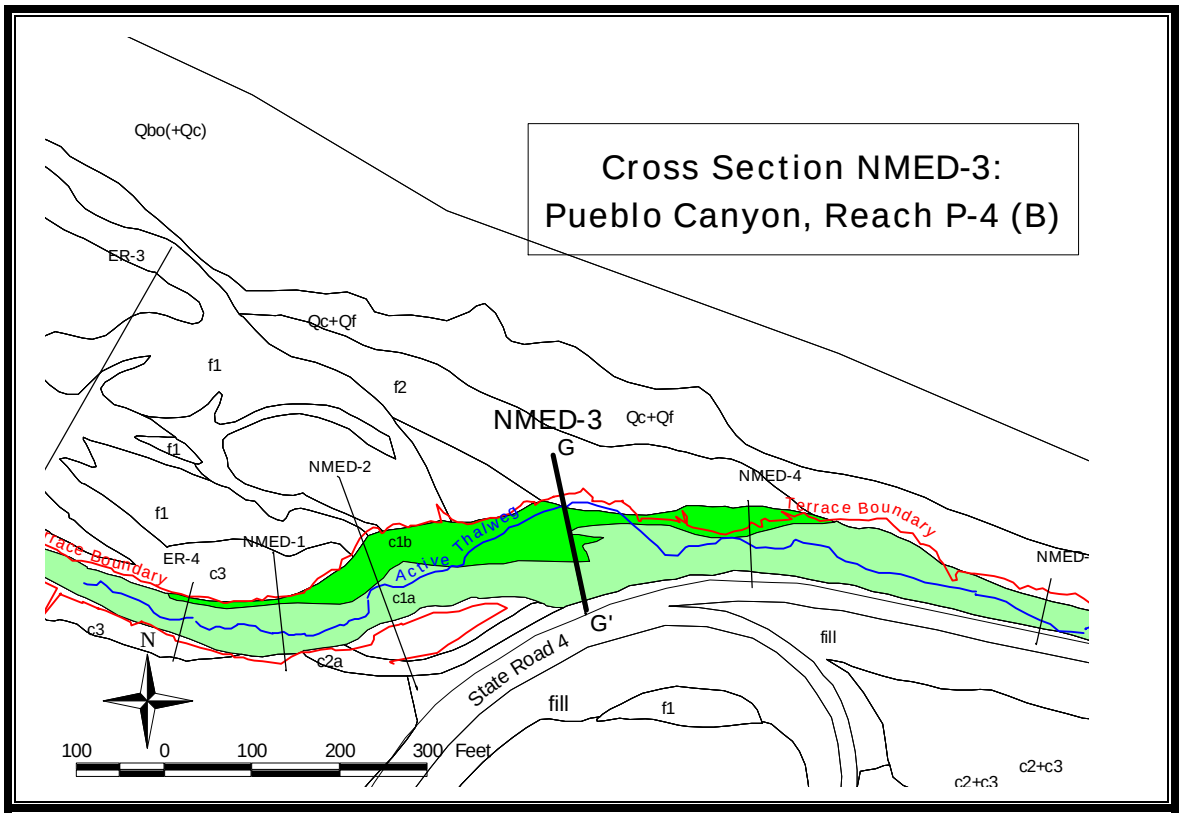


Figure 22. Location of P-4 East (B) NMED-3 cross section (G-G', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

The geomorphic unit, c1a, highlighted by light green, was the active channel area in 1991, and remains so. The active channel is incised into pre-1942 geomorphic units, covered by f2 flood plain units. Unit c1b is a sandbar deposit from 1991 floods. The fill designation at State Road 4 includes an 8-foot wide concrete road apron.

The blue line marks the thalweg, which has abandoned its original channel and has scoured down to the Puye Formation bedrock base. The active channel is widening, and eroding the c1b sandbar and the northern terrace bank. Effluent from the Bayo wastewater treatment

plant supplies water to this area almost daily. The red line outlines the edge of the confining terraces and no longer conforms to the unit boundaries outlined by the LANL ER geomorphic maps. The banks appear to have receded by as much as 25 feet.

Figure 23 demonstrates the dimensions at this location measured along most of the 203-foot extent of the NMED cross section. The first 50 feet of the cross section demonstrated little elevation variability and was not included thereby maintaining a consistent horizontal scale with the other cross sections. Cross section NMED-3 does not correlate with a LANL ER Project cross section. The f2 flood plain unit extends from the beginning of the cross section to 48 feet. The existing channel is at 70 feet. Remnants of the c1b sandbar unit exist between the new and old thalweg, from 82 to 147 feet. The original thalweg, now abandoned, is at 157 feet. The c1a channel features exist from here to 190 feet. From this point to the end of the cross section is a concrete apron for State Road 4. By measuring the difference from the existing bank edge to the LANL ER geomorphic unit boundaries, it appears that at least 15 feet of the terrace bank has been eroded.

In November of 2001, at NMED-3, the width of the channel at the flood prone stage was 136 feet. The channel is 8.4 feet deep from the thalweg to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 1.8 feet. At bankfull stage, the cross sectional area is approximately 12.5 square feet. The average depth of the channel is 0.82 feet and the wetted perimeter is 15.7 feet. Other stream dimensions reflected by NMED-3 cross- section are listed in the Table 15.

Table 15. Stream dimensions at P-4 East (B) NMED-3 cross section

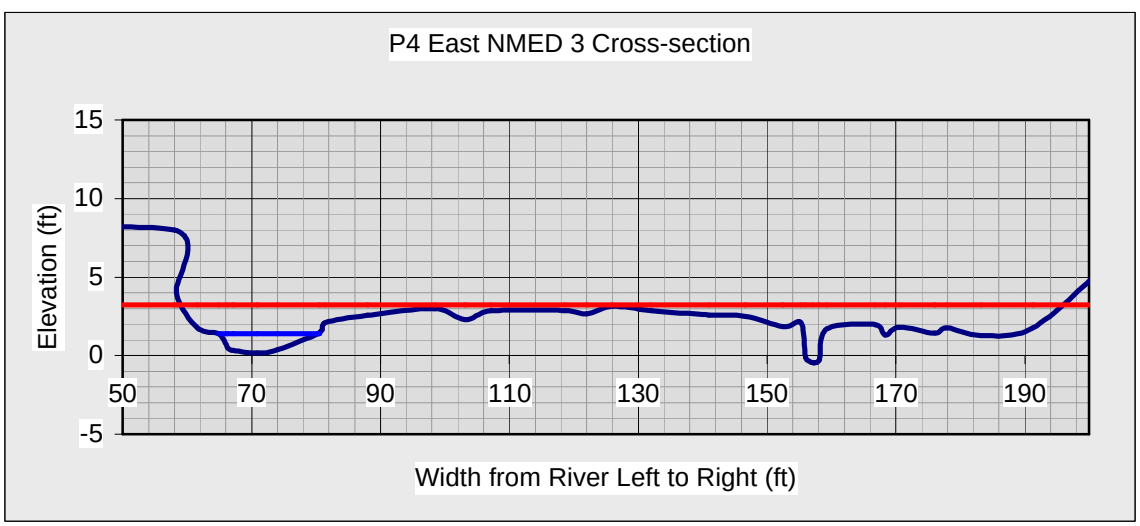
Stream dimensions	
12.5	Cross section area at bankfull stage (ft sq)
15.3	Width at bankfull stage
1.8	Maximum depth at bankfull
8.4	Bank height
136.0	Width flood prone area (at 2 x max depth)
0.82	Mean depth
15.65	Wetted Perimeter
0.80	Hydraulic radius
18.7	Width / depth ratio
8.90	Entrenchment ratio
0.00885	Slope
1.1	Sinuosity

A width to depth ratio of 18.7, entrenchment value of 8.9, and a sinuosity of 1.1 suggest the stream at this area is a "C" type stream (Rosgen classification). The predominance of fine gravel bed materials and a slope of 0.0089 refine the classification to a "C4" stream type. A C4 stream type is very highly sensitive to stream flow and sediment increases, contributes very high sediment supplies, and has a very high stream bank erosion potential (Rosgen, 1994). Additional stream hydraulic and physical parameters are listed in the Table 16.

Table 16. Additional parameters determined from stream dimensions at P-4 East (B) NMED-3

Stream hydraulics	
4.3	Velocity (ft/sec)
53.4	Discharge rate, Q (cfs)
0.44	Shear stress (lbs/ft sq)
0.48	Shear velocity (ft/sec)
1.931	Unit stream power (lbs/ft/sec)
0.70	Froude number
9.0	Friction factor u/u*
26.6	Threshold grain size (mm)
Channel material	
20.0	Measured D84 (mm)
12.4	Relative roughness
0.028	Manning's "n" from channel material

In figure 23, the area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height.



G G'

Figure 23. P-4 East (B) NMED-3 cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height.

Figure 24 is a downstream view of the channel at Cross section NMED-3 in Pueblo Canyon, reach P-4 East (B). The photo is oriented so that cross section starts at G, left or north in this photo, and continues south to G'.

G G'

Figure 24. View of P-4 East (B) NMED-3 cross section looking downstream.

Our researcher is standing on the cross section with a stadia rod in the thalweg. The channel bottom is bedrock, the active channel is widening, and the areas around the thalweg are greatly disturbed. Substantial amounts of bank and channel materials are being removed as well as new flood materials being deposited on the flood plain.

P-4 East (B) NMED-4 Cross Section

Cross section NMED-4 is the third western most cross section measured in reach P-4 East (B). It is approximately 230 feet downstream from cross section NMED-3. The endpoints are labeled H and H', measured 101 feet from north to south. This cross section, similar to cross section NMED-3, extends over a terrace, the active channel, the flood plain and a concrete road apron to the south. The reference map (Figure 25) illustrates the plan view of P-4 East (B) NMED-4 cross section, the active thalweg, terrace banks, and LANL ER geomorphic units. Figure 26 displays the NMED 4 cross section profile, bankfull area, and predicted flood prone level.

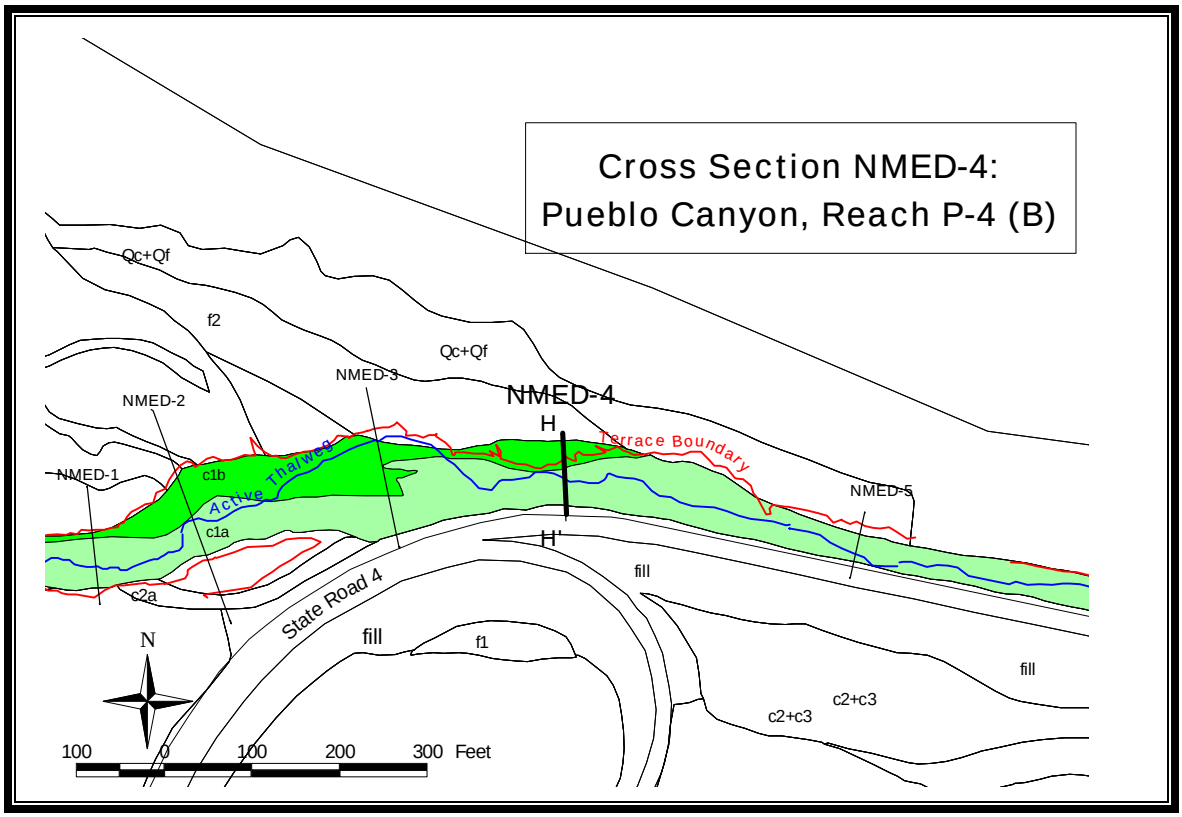


Figure 25. Location of P-4 East (B) NMED-4 cross section (H-H', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

The geomorphic unit, c1a, highlighted by light green, was the active channel area in 1991. It remains the active channel although it is in an area of great disturbance. The channel is incised into pre-1942 geomorphic units, which were covered by post 1942 flood plain deposits. The fill designation along State Road 4 includes an 8-foot wide concrete road apron.

The blue line marks the thalweg, which has abandoned its original course and is eroding the northern terrace bank. It has also scoured to a bedrock bottom and the channel is widening. Effluent from the Bayo wastewater treatment plant supplies water to this area almost daily. The red line outlines the edge of the confining terraces and no longer conforms to the unit boundaries outlined by the LANL ER geomorphic maps.

None of the measured stream channel characteristics would provide a bankfull measurement that would generate flows within the 50 to 60 cfs range chosen for this analysis. An artificial measurement was inserted which generated a 54 cfs flow. It is believed that high flow events have scoured away evidence of other flows at this station.

At NMED-4, the existing thalweg is at 53 feet. The old channel may have been along the concrete road apron starting at 87 feet. The c1a channel area is between the old and new thalweg. By measuring the difference in distance between the existing bank edge and LANL

ER geomorphic unit boundaries, it appears that 10 to 15 feet of the terrace bank has been eroded away.

In November of 2001, at NMED-4, the width of the flood prone area was 46 feet. The channel is 7.4 feet deep from the lowest point in the channel (thalweg) to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 1.2 feet. At bankfull stage, the cross sectional area is approximately 10.9 square feet. The average depth of the channel is 0.74 feet and the wetted perimeter is 15.2 feet. Other stream dimensions reflected by NMED-4 cross section are listed in Table 17.

Table 17. Stream dimensions at P-4 East (B) NMED-4 cross section

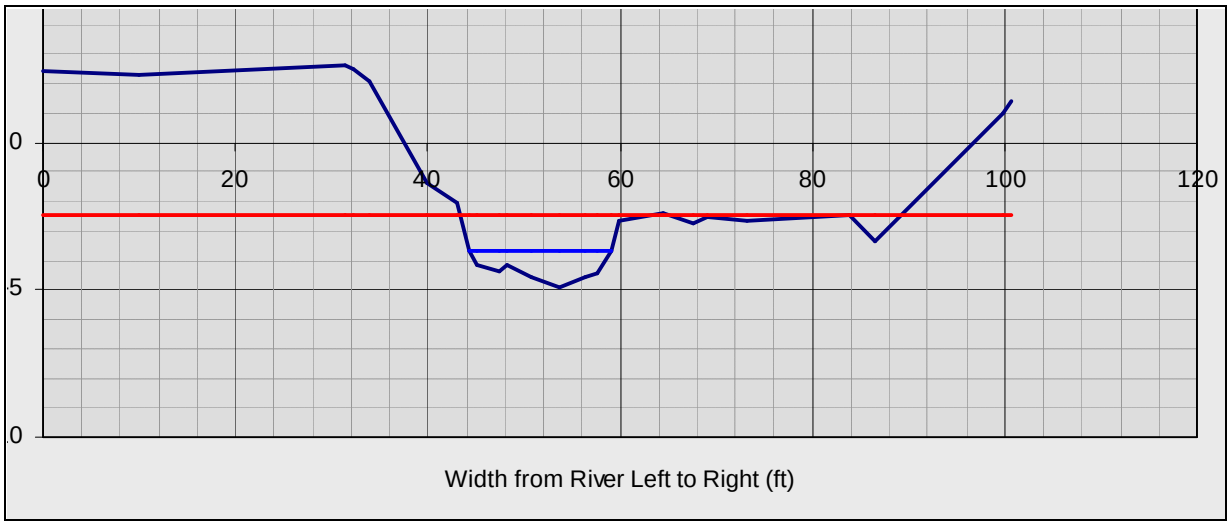
Stream dimensions	
10.9	Cross section area at bankfull stage (ft sq)
14.8	Width at bankfull stage
1.2	Maximum depth at bankfull
7.4	Bank height
46.0	Width flood prone area (at 2 x max depth)
0.74	Mean depth
15.23	Wetted Perimeter
0.72	Hydraulic radius
20.1	Width / depth ratio
3.11	Entrenchment ratio
0.015	Slope
1.1	Sinuosity

A width to depth ratio of 20.1 and entrenchment value of 3.11 suggest the stream at this area is a “C” type stream (Rosgen classification). The predominance of fine gravel material refines the classification to a “C4” stream type. A C4 stream type is very highly sensitive to stream flow and sediment increases, contributes high sediment supplies, and has a very high stream bank erosion potential (Rosgen, 1994). Additional stream hydraulic and physical parameters are listed in the Table 18.

Table 18. Additional parameters determined from stream dimensions at P-4 East (B) NMED-4

Stream hydraulics	
5.0	Velocity (ft/sec)
54.8	Discharge rate, Q (cfs)
0.67	Shear stress (lbs/ft sq)
0.59	Shear velocity (ft/sec)
3.5	Unit stream power (lbs/ft/sec)
1.06	Froude number
8.5	Friction factor u/u*
42.4	Threshold grain size (mm)
Channel material	
22	Measured D84 (mm)
10.2	Relative roughness
0.029	Manning’s “n” from channel material

Figure 26 demonstrates the dimensions measured at this location and characteristics along the entire 101-foot extent of the NMED cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the widening of the thalweg. The red line depicts the height flood prone area confined within the terrace banks and SR 4 highway embankment.



H H'

Figure 26. P-4 East (B) NMED-4 cross section

Figure 27 is a downstream view of the channel at cross section NMED-4 in Pueblo Canyon, reach P-4 East (B). The photo is oriented so that cross section starts at H, left or north in this photo, and continues south to H'. The white steel fence-post (near H) marks a New Mexico Highway Department benchmark (included in cross section).

H H'

Figure 27. View of NMED-4 cross section looking downstream

Our researcher is standing on the cross section with a stadia rod in the thalweg. The channel bottom is bedrock, and the areas around the thalweg are greatly disturbed. Substantial amounts of bank and channel materials are being removed as well as new flood materials being deposited.

P-4 East (B) NMED-5 Cross Section

NMED-5 cross section is the fourth western most cross section measured in reach P-4 East (B). It is approximately 390 feet downstream from cross section NMED-4. The endpoints are labeled I and I', measured 74 feet from north to south. This cross section extends from steep, colluvium covered slopes, through the active channel, to a concrete road apron to the south. The reference map (Figure 28) illustrates the plan view of P-4 East (B) NMED-5 cross section, the active thalweg, terrace banks, and LANL ER geomorphic units. Figure 29 displays the NMED 5 cross section profile, bankfull area, and predicted flood prone level. The geomorphic units shown here are described in Reneau, et al., 1998.

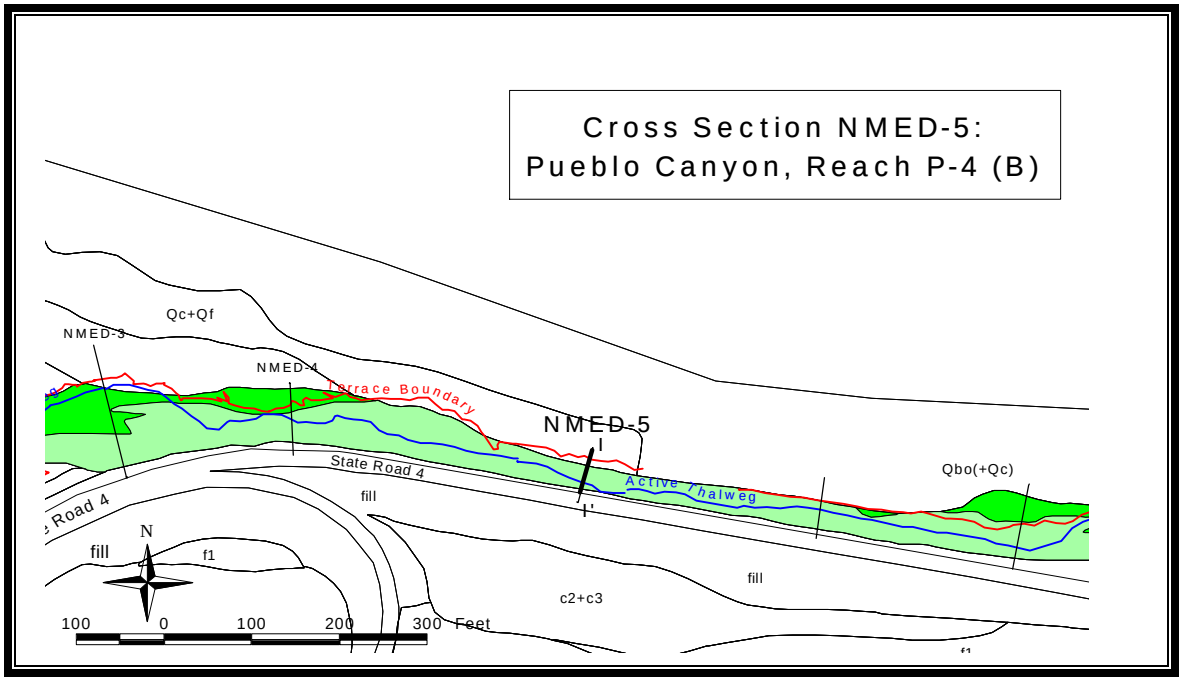
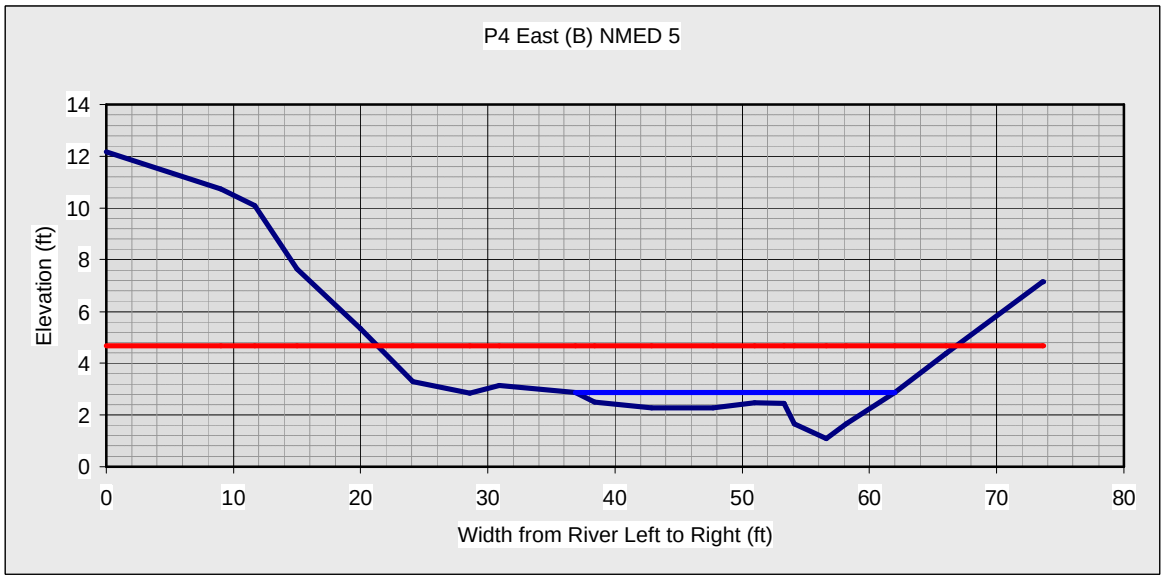


Figure 28. Location of P-4 East (B) NMED-5 cross section (I-I', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

In this area, the Quaternary colluvium covered slopes and State Road 4 are confining the channel. The geomorphic unit, c1a, highlighted by light green, is the present channel, and was the active channel area in 1991. It is incised into pre-1942 geomorphic units. The fill designation along State Road 4 includes an 8-foot wide concrete road apron.

The blue line marks the thalweg, and is back in its original 1991 channel. Downstream, 55 feet east of this section, head cutting is occurring, creating a 3 to 4 foot waterfall. The red line outlines the bank edge of the confining terraces and no longer conforms to the unit boundaries outlined by the LANL ER geomorphic maps. The difference measured between the bank edge and LANL ER geomorphic unit suggest up to 10 feet of the bank has been eroded away.

Figure 29 demonstrates the measured dimensions at this location and characteristics along the entire 74-foot extent of the NMED cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the height of the flood prone area. It is confined between the steep colluvium slopes along the north wall of Pueblo canyon, and State Road 4.



I I'

Figure 29. P-4 East (B) NMED-5 cross section

At NMED-5, the existing thalweg is located along the base of the concrete apron at State Road 4. The bank edge at the colluvium slope was measured at 12 feet. The steepness and length of the slope may have contributed to the disparity between the mapped bank edge and the unit boundaries outlined by the LANL ER geomorphic maps.

In November of 2001, at NMED-5, the width of the channel at the flood prone stage was 47 feet. The channel is at least 9 feet deep from the thalweg to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 1.8 feet. At bankfull stage, the cross sectional area is approximately 17.2 square feet. The average depth of the channel is 0.7 feet and the wetted perimeter is 25.8 feet. Other stream dimensions reflected by NMED-5 cross section are listed in Table 19.

Table 19. Stream dimensions at P-4 East (B) NMED-5 cross section

Stream dimensions	
17.2	Cross section area at bankfull stage (ft sq)
25.1	Width at bankfull stage
1.8	Maximum depth at bankfull
9.0	Bank height
47.0	Width flood prone area (at 2 x max depth)
0.69	Mean depth
25.83	Wetted Perimeter
0.67	Hydraulic radius
36.5	Width / depth ratio
1.87	Entrenchment ratio
0.00865	Slope
1.1	Sinuosity

A width to depth ratio of 36.5 and entrenchment value of 1.9 suggest the stream at this area is a "B" type stream (Rosgen classification). The predominance of fine gravel bed materials refines the classification to a "B5" stream type. The site specific slope of <0.02 slope further refines the classification to a "B5c" stream type. A B5 stream type is moderately sensitive to stream flow and sediment increases, contributes moderate sediment supplies, and has a moderate stream bank erosion potential (Rosgen, 1994). Additional stream hydraulic and physical parameters are listed in Table 20.

Table 20. Additional parameters determined from stream dimensions at P-4 East (B) NMED-5

Stream hydraulics	
3.5	Velocity (ft/sec)
60.7	Discharge rate, Q (cfs)
0.36	Shear stress (lbs/ft sq)
0.43	Shear velocity (ft/sec)
1.3	Unit stream power (lbs/ft/sec)
0.56	Froude number
8.2	Friction factor u/u*
21.3	Threshold grain size (mm)
Channel material	
23	Measured D84 (mm)
9.1	Relative roughness
0.030	Manning's "n" from channel material

Figure 30 is an upstream view of the channel at P-4 East (B) NMED-5 cross section. The photo is oriented so that cross section starts at I, right or north in this photo, and continues south to I'. This view is different than all preceding photos in that it is an upstream view rather than downstream. It is presented to show the erosion that has produced the head-cut that is forming downstream from NMED-5.

I' I

Figure 30. View of P-4 East (B) NMED-5 cross section looking upstream

Our researcher is standing on the cross section with a stadia rod in the thalweg. The road concrete apron extends along the channel above and below this cross section for approximately one fourth of a mile. A 3 to 4 foot head cut is evident in the foreground as well as the slumping deposits from the previous active channel. In November 2001, this head cut was approximately 55 feet downstream of cross section P-4 East (B) NMED 5. In November 2002, this head cut had advanced into P4 East (B) NMED-5 and by November 2003, it had advanced over 400 feet upstream to P-4 East (B) NMED-4.

P-4 East (B) NMED-6 Cross Section

Cross section NMED-6 is the fifth western most cross section measured in reach P-4 East (B). It is approximately 310 feet downstream from cross section NMED-5. The endpoints are labeled J and J', measured 90 feet from north to south. As with cross- section NMED-5, it extends from steep colluvium covered slopes, through the active channel, to a concrete road apron to the south. The reference map (Figure 31) illustrates the plan view of P-4 East (B) NMED-6 cross section, the active thalweg, terrace banks, and LANL ER geomorphic units. Figure 32 displays the NMED 6 cross section profile, bankfull area, and predicted flood prone level.

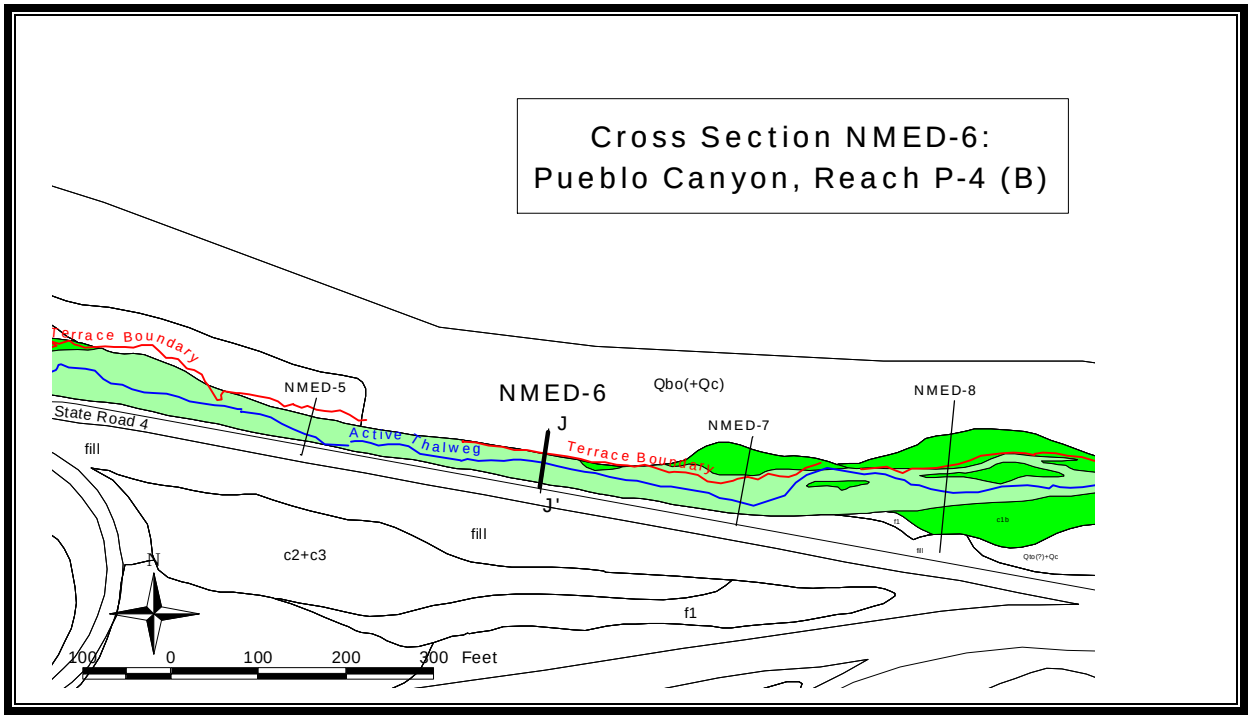


Figure 31. Location of P-4 East (B) NMED-6 cross section (J-J', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

The geomorphic units shown here are described in Reneau, et al., 1998. In this area, the canyon walls and State Road 4 are confining the channel. The geomorphic unit, c1a, highlighted by light green, was the active channel area in 1991, and remains the case. It is incised into pre-1942 geomorphic units. The fill designation along State Road 4 includes an 8-foot wide concrete road apron.

The blue line marks the thalweg, and is the center of the increased down cutting that is occurring. The channel has scoured through the previous active channel deposits to bedrock as well as alternatively depositing fresh sand material. The red line outlines the edge of the confining terraces and conforms to LANL ER geomorphic unit boundaries.

In November of 2001, at NMED-6, the width of the channel at the flood prone stage was 25 feet. The channel is 5.3 feet deep from the thalweg to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 1.4 feet. At bankfull stage, the cross sectional area is approximately 9.8 square feet. The average depth of the channel is 1.1 feet and the wetted perimeter is 9.9 feet. Other stream dimensions reflected by cross section NMED-6 are listed in Table 21.

Table 21. Stream dimensions at P-4 East (B) NMED-6 cross section

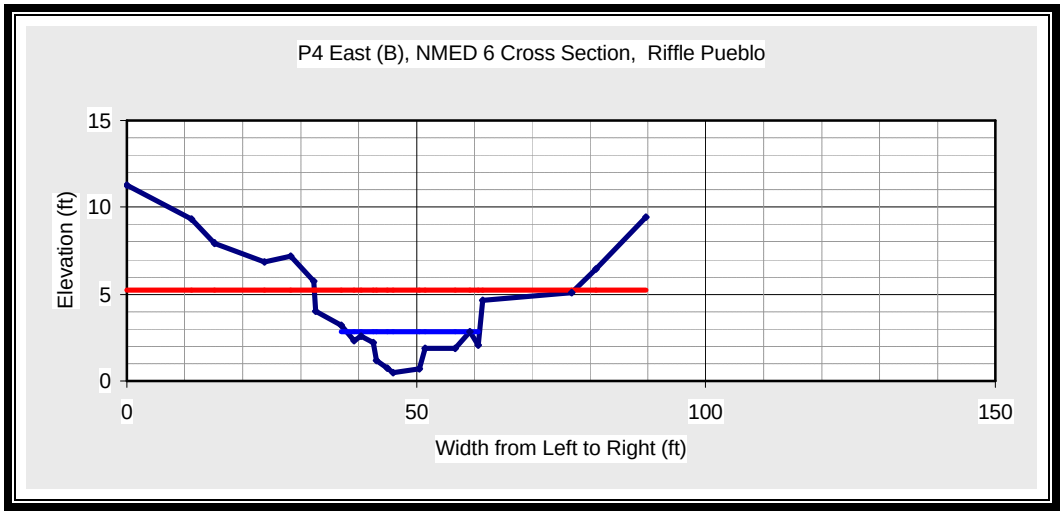
Stream dimensions	
9.8	Cross section area at bankfull stage (ft sq)
8.8	Width at bankfull stage
1.4	Maximum depth at bankfull
5.3	Bank height
25.0	Width flood prone area (at 2 x max depth)
1.11	Mean depth
9.88	Wetted Perimeter
0.99	Hydraulic radius
7.9	Width / depth ratio
2.84	Entrenchment ratio
0.01275	Slope
1.1	Sinuosity

A width to depth ratio of 7.9 and entrenchment ratio of 2.8 suggest the stream at this area is an “E” type stream (Rosgen classification). The predominance of coarse sand bed materials refines the classification to an “E5” stream type. The sinuosity of “E” type streams is usually high or greater than 1.5 while the sinuosity of this reach is near 1. This cross section does not fit any Rosgen class well. An E5 stream type has a very high sensitivity to stream flow and sediment increases, contributes moderate sediment supplies, and has a high stream bank erosion potential (Rosgen, 1994). Additional stream hydraulic and physical parameters are listed in Table 22.

Table 22. Additional parameters determined from stream dimensions at P-4 East (B) NMED-6

Stream hydraulics	
6.2	Velocity (ft/sec)
60.6	Discharge rate, Q (cfs)
0.79	Shear stress (lbs/ft sq)
0.64	Shear velocity (ft/sec)
5.5	Unit stream power (lbs/ft/sec)
1.07	Froude number
9.7	Friction factor u/u*
50.9	Threshold grain size (mm)
Channel material	
22	Measured D84 (mm)
15.4	Relative roughness
0.027	Manning’s “n” from channel material

Figure 32 demonstrates the measured dimensions at this location and characteristics along the entire 90-foot extent of the NMED-6 cross section. The 3-foot bank at 60 feet demonstrates the vertical scouring. The thalweg occurs at 45 feet, and the bank edge was delineated at 33 feet. The concrete apron for the road starts at 78 feet. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the height of the flood prone area, confined between State Road 4 and the colluvium-covered slopes.



J J'

Figure 32. P-4 East (B) NMED-6 cross section

Figure 33 is a downstream view of the channel at cross section NMED-6 in Pueblo Canyon, reach P-4 East (B). The photo is oriented so that cross section starts at J, left or north in this photo, and continues south to J'.

J J'

Figure 33. View of P-4 East (B) NMED-6 looking downstream

Bedrock is exposed in the left foreground of this photo as well as fresh sand and cobble material in the right foreground. The vertical channel incision has abandoned the previous active channel area demonstrated by the grass-covered banks in the right half of this photo.

P-4 East (B) NMED-7 Cross Section

NMED-7 is the sixth western most cross section measured in reach P-4 East (B). It is approximately 260 feet downstream from cross section NMED-6. The endpoints are labeled K and K', measured 125 feet from north to south. This cross section extends from steep colluvium covered slopes, across 1991 sandbar deposits, through the active channel, to fill materials used for the base of State Road 4. The concrete apron ends just upstream from this cross section. The reference map (Figure 34) illustrates the plan view of P-4 East (B) NMED-7 cross section, the active thalweg, terrace banks, and LANL ER geomorphic units. Figure 35 displays the NMED-7 cross section profile, bankfull area, and predicted flood prone level.

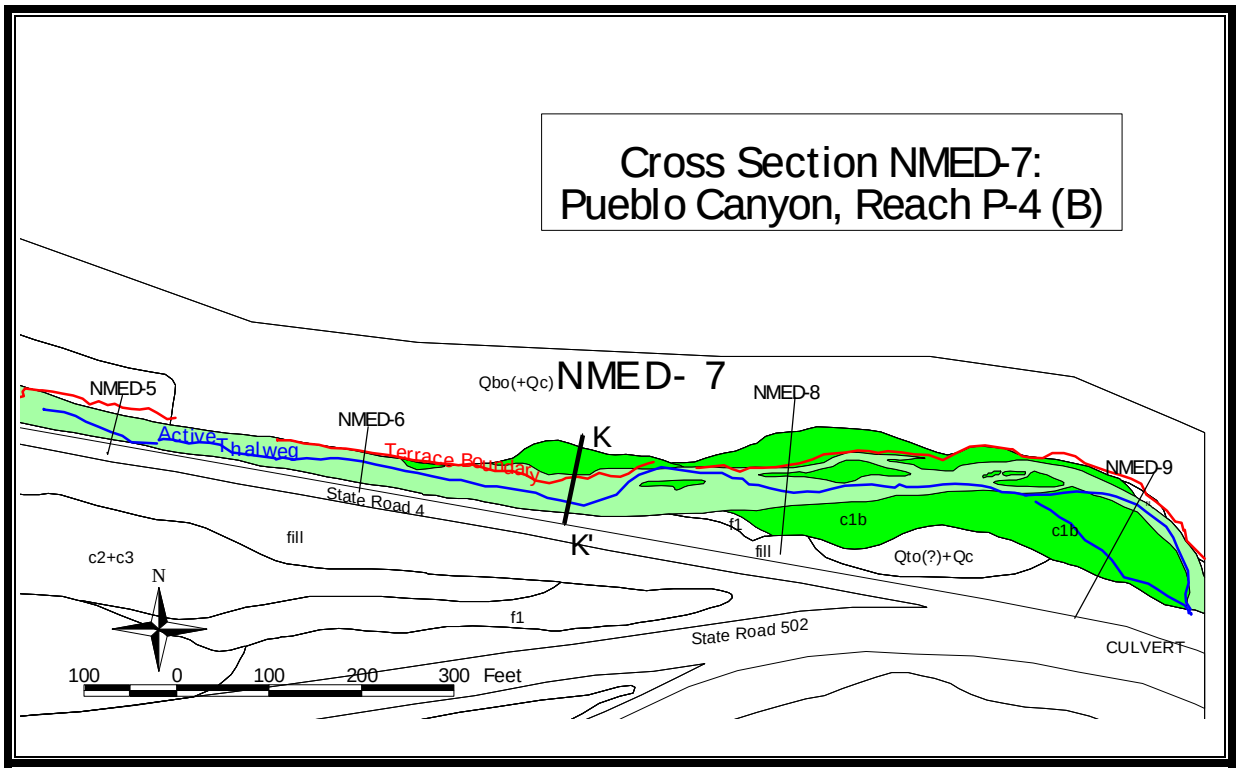


Figure 34. Location of P-4 East (B) NMED-7 cross section (K-K', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

The geomorphic units shown here are described in Reneau, et al., 1998. In this area, the canyon walls and State Road 4 are becoming less confining to the channel, and new flood deposits over the entire channel area are common. The geomorphic unit, c1a, highlighted by light green, was the active channel area in 1991, and remains so. It is incised into pre-1942 geomorphic units. The c1b unit consists of coarse-grained sandbar deposits resulting from floods in 1991. The fill label designates road base material along State Road 4. The blue line marks the thalweg. Effluent from the Bayo wastewater treatment plant supplies water that partially fills a single incised channel in this area almost daily. The red line conforms to

the edge of the LANL ER geomorphic c1b unit in this area. Alternate deposition and scouring is occurring through this area. In November of 2001, at NMED-7, the width of the channel at the flood prone stage was 106 feet. The channel is 3.5 feet deep from the lowest point in the channel (thalweg) to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 1.5 feet. At bankfull stage, the cross sectional area is approximately 24.2 square feet. The average depth of the channel is 0.5 feet and the wetted perimeter is 47 feet. Other stream dimensions reflected by cross section NMED-7 are listed in the Table 23.

Table 23. Stream dimensions at P-4 East NMED-7 cross section

Stream dimensions	
24.2	Cross section area at bankfull stage (ft sq)
45.8	Width at bankfull stage
1.5	Maximum depth at bankfull
3.5	Bank height
106	Width flood prone area (at 2 x max depth)
0.5	Mean depth
47	Wetted Perimeter
0.5	Hydraulic radius
86.8	Width / depth ratio
2.3	Entrenchment ratio
0.0045	Slope
1.1	Sinuosity

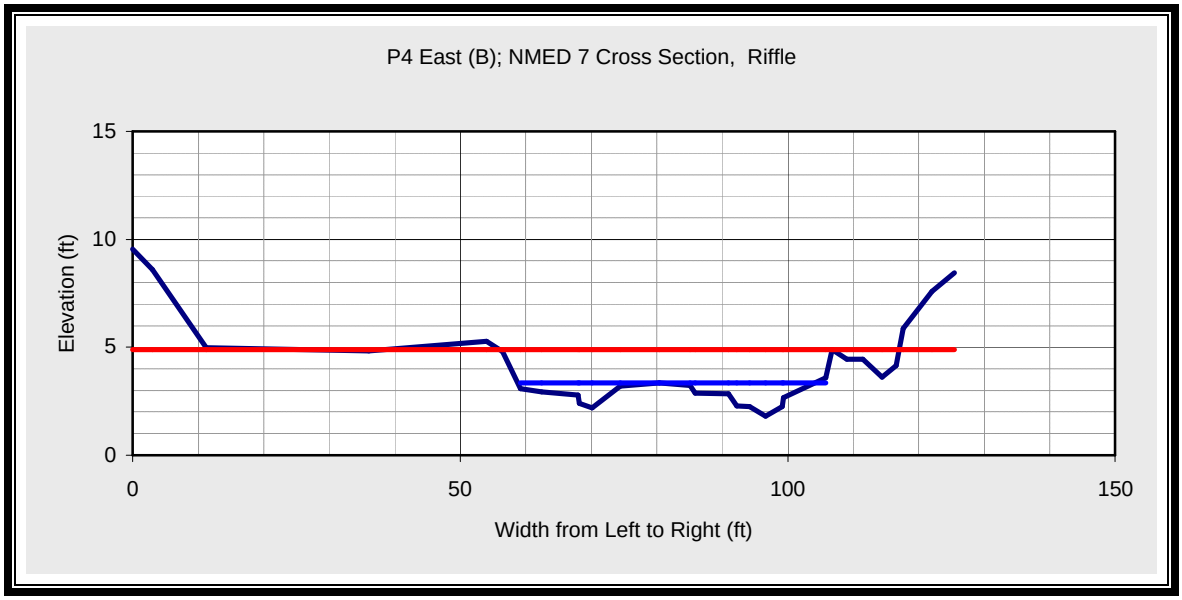
A width to depth ratio of 86.8 and entrenchment value of 2.3 suggest the stream at this area is a "C" type stream (Rosgen classification). The predominance of medium gravel bed materials refines the classification to a "C4" stream type. A C4 stream type is very highly sensitive to stream flow and sediment increases, contributes high sediment supplies, and has a very high stream bank erosion potential (Rosgen, 1994). Additional stream hydraulic and physical parameters are listed in Table 24.

Table 24. Additional parameters determined from stream dimensions at P-4 East (B) NMED-7

Stream hydraulics	
2.0	Velocity (ft/sec)
48.5	Discharge rate, Q (cfs)
0.15	Shear stress (lbs/ft sq)
0.27	Shear velocity (ft/sec)
0.3	Unit stream power (lbs/ft/sec)
0.24	Froude number
7.3	Friction factor u/u*
8.9	Threshold grain size (mm)
Channel material	
26	Measured D84 (mm)
6.2	Relative roughness
0.032	Manning's "n" from channel material

Figure 35 demonstrates the measured dimensions at this location and characteristics along the entire 125-foot extent of the NMED cross section. The steep colluvium-covered slope ends

at 6 feet, and the c1b unit extends from here to 55 feet. The channel has demonstrated alternate down cutting and deposition along the active channel, from 55 to 110 feet. Materials from 105 to the 117 feet appear to be original c1a channel deposits, abandoned from the active channel area by previous down cutting. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts the flood prone area height. The flood prone area extends over the bank forming c1b sandbar unit, and is confined by the colluvium-covered slope and road fill along State Road 4.



K K'

Figure 35. P-4 East (B) NMED-7 cross section

Figure 36 is a downstream view of the channel at P-4 East (B) NMED-7 cross section. The photo is oriented so that cross section starts at K, left or north in this photo, and continues south to K'.

K K'

Figure 36. View of P-4 East (B) NMED-7 cross section looking downstream

Our researcher is standing on the cross section with a stadia rod in the thalweg. The c1b sandbar unit is located under the chamisa-covered area (yellow bushes in the left portion of this photo). The steep colluvium-covered slope is left and behind the c1b unit. The channel in the foreground demonstrates the alternate alluvial fill and down cutting.

P-4 East (B) NMED-8 Cross Section

Cross section NMED-8 is the sixth western most cross section measured in reach P-4 East (B). It is approximately 265 feet downstream from cross section NMED-7. The endpoints are labeled L and L', measured 215 feet from north to south. This cross section extends from colluvium-covered steep slopes, across 1991 sandbar deposits, through the active channel, to the fill materials for the road base. The channel area broadens substantially in this area. The reference map (Figure 37) illustrates the plan view of P-4 East (B) NMED-8 cross section, the active thalweg, terrace banks, and LANL ER geomorphic units. Figure 38 displays the entire NMED-8 cross section profile, bankfull area, and predicted flood prone level.

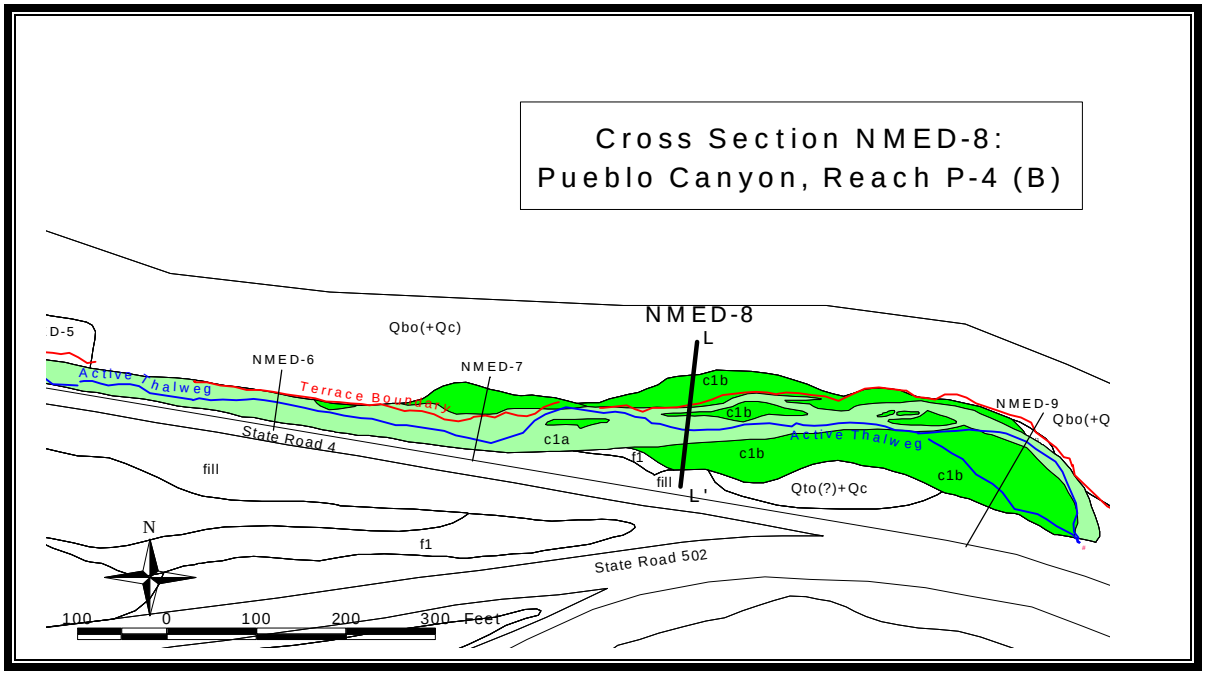


Figure 37. Location of P-4 East (B) NMED-8 cross section (L-L', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

The geomorphic units shown here are described in Reneau, et al., 1998. In this area, the canyon walls and State Road 4 are becoming less confining to the channel, and flood deposits of new materials over the entire channel area are common. The geomorphic unit, c1a, highlighted by light green, was the active channel area in 1991, and remains so. It is incised into pre-1942 geomorphic units. The c1b unit consists of coarse-grained sandbar deposits resulting from floods in 1991. The fill label designates road base material.

The blue line marks the thalweg. Effluent from the Bayo wastewater treatment plant supplies water to this area almost daily. The red line, or north terrace, conforms to the edge of the c1b unit in this area. Alternate deposition and scouring is occurring through this area.

Figure 38 demonstrates the measured dimensions at this location and characteristics along the entire 215-foot extent of the NMED cross section. The steep colluvium-covered slope ends at 45 feet, and the c1b unit extends from here to 105 feet, and from 145 to 185 feet. The channel has demonstrated alternate down cutting and deposition within the active channel area between 105 and 145 feet. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts height of the flood prone area.

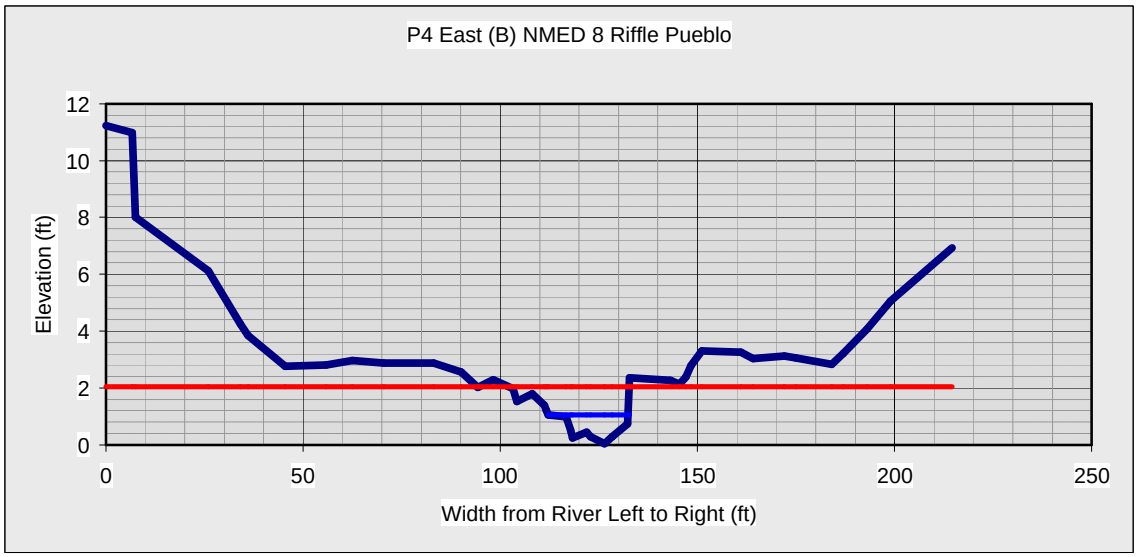


Figure 38. Entire cross section view at P-4 East (B) NMED-8

In November of 2001, at NMED-8, the width of the channel at the flood prone stage was 32 feet. The channel is 3.3 feet deep from the lowest point in the channel (thalweg) to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 1.0 feet. At bankfull stage, the cross sectional area is approximately 11 square feet. The average depth of the channel is 0.55 foot and the wetted perimeter is 20.6 feet. Other stream dimensions reflected by cross section NMED-8 are listed in Table 25.

Table 25. Stream dimensions at P-4 East (B) NMED-8 cross section

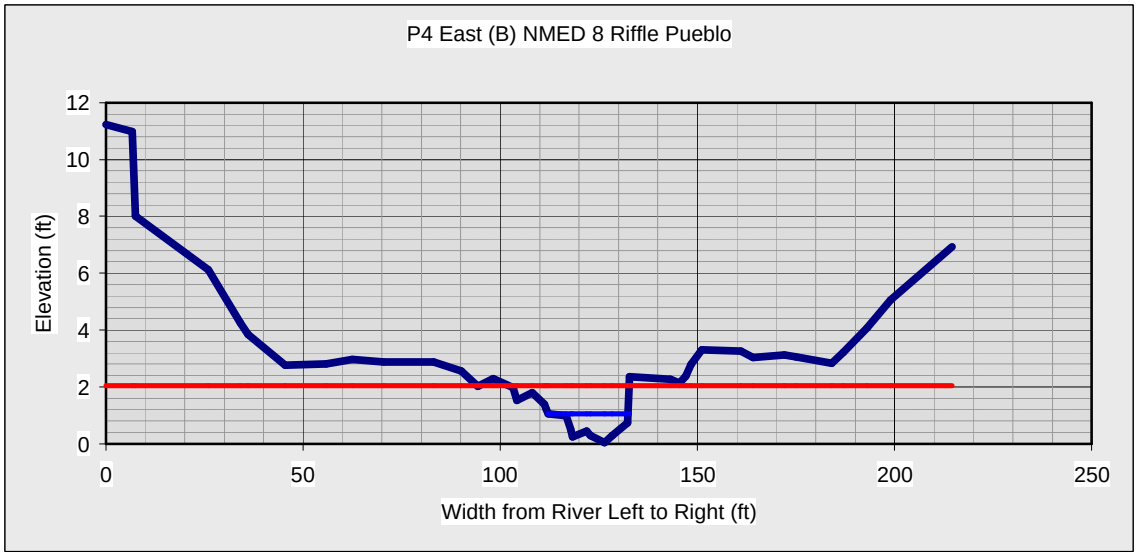
Stream dimensions	
11.0	Cross section area at bankfull stage (ft sq)
20.1	Width at bankfull stage
1.0	Maximum depth at bankfull
3.3	Bank height
32.0	Width flood prone area (at 2 x max depth)
0.55	Mean depth
20.56	Wetted Perimeter
0.53	Hydraulic radius
36.9	Width / depth ratio
1.59	Entrenchment ratio
0.02385	Slope
1.1	Sinuosity

A width to depth ratio of 36.9 and entrenchment value of 1.6 suggest the stream at this area is an "F" type stream (Rosgen classification). The predominance of fine gravel bed materials refines the classification to an "F4" stream type. A slope of 0.02 – 0.039 further refines the classification to an "F4b" stream type. An F4 stream type is extremely sensitive to stream flow and sediment increases, contributes very high sediment supplies, and has a very high stream bank erosion potential (Rosgen, 1994). Additional stream hydraulic and physical parameters are listed in the Table 26.

Table 26. Additional parameters determined from stream dimensions at P-4 East (B) NMED-8

Stream hydraulics	
4.6	Velocity (ft/sec)
50.2	Discharge rate, Q (cfs)
0.79	Shear stress (lbs/ft sq)
0.64	Shear velocity (ft/sec)
3.716	Unit stream power (lbs/ft/sec)
1.19	Froude number
7.2	Friction factor u/u*
51.3	Threshold grain size (mm)
Channel material	
29	Measured D84 (mm)
5.7	Relative roughness
0.033	Manning's "n" from channel material

At this cross section, remnants of the c1b sandbar units, as well as fresh flood deposits, appears on the right and left sides of Figure 38, from 50 to 105 feet and 145 to 185 feet.



L L'

Figure 38. Entire cross section view at P-4 East (B) NMED-8

Figure 39 is a downstream view of the channel at P-4 East (B) NMED-8 cross section. The photo is oriented so that cross section starts at L, left or north in this photo, and continues south to L'.

L L'

Figure 39. View of NMED-8 cross section looking downstream

Our researcher is standing on the cross section with a stadia rod in the thalweg. The c1b sandbar unit is located under the grass-covered areas in the left and right portions of this photo. The steep colluvium-covered slope is at the far left, and background. The channel in the fore ground demonstrates the alternate aggradations and degradation.

P-4 East (B) NMED-9 Cross Section

Cross section NMED-9 is the eastern most cross section and last one measured in reach P-4 East (B). It is approximately 415 feet downstream from cross section NMED-8, and 140 west of the culvert at State Road 502. The Pueblo Canyon channel joins with the Los Alamos channel 150 feet downstream shortly after it passes below SR 502. The endpoints are labeled M and M', measured 220 feet from north to south. This cross section extends from a colluvium-covered steep slope, over a small area of flood plain deposits, the active channel, across 1991 sandbar deposits, to the fill materials used for the road base. The channel area is broader in this area than at previous cross sections NMED 4 through 6. The reference map (Figure 40) illustrates the plan view of P-4 East (B) NMED-9 cross section, the active thalweg, terrace banks, and LANL ER geomorphic units. Figure 41 displays the entire NMED-9 cross section profile, bankfull area, and predicted flood prone level.

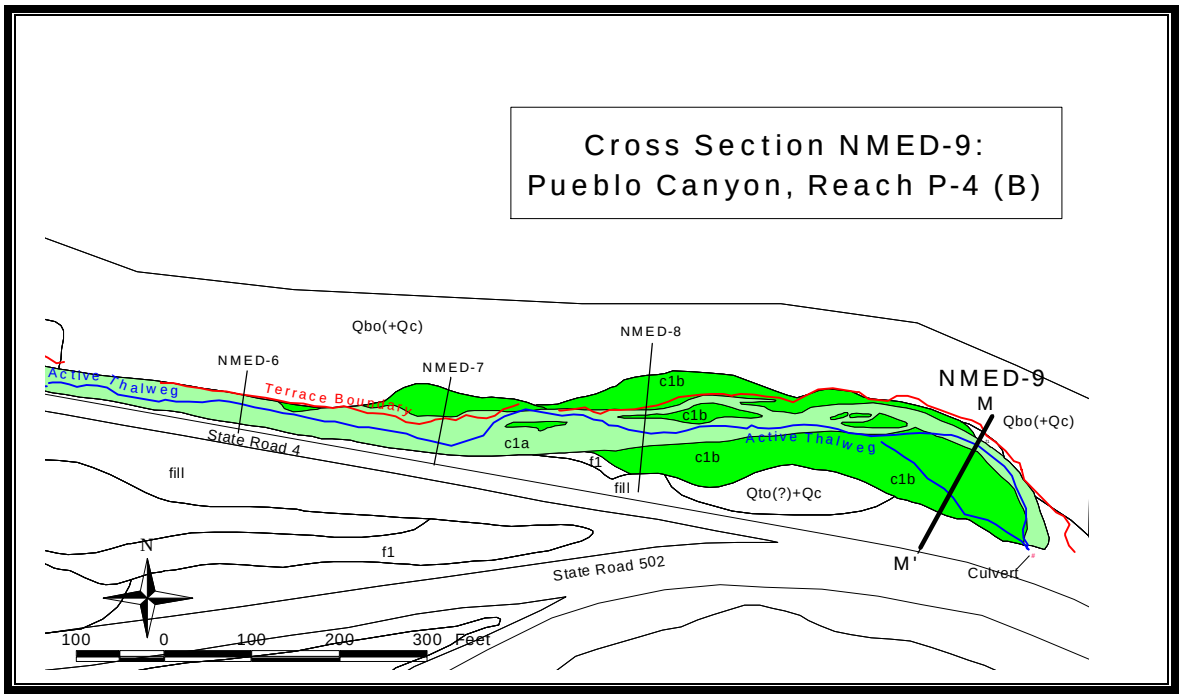


Figure 40. Location of P-4 East (B) NMED-9 cross section (M-M', bold line). Geomorphic units from Reneau et al. (1998). Post-1990 channel units (c1b and c1a) highlighted in green. Blue line indicates active thalweg and red lines indicate top of bank (terrace boundary) as surveyed in November 2001.

The geomorphic units shown here are described in Reneau, et al., 1998. In this area, the canyon walls and State Road 4 are becoming less confining to the channel, and new flood deposits are common over the entire area. The c1a geomorphic unit, highlighted by light green, was the active channel area in 1991 and remains so. The channel is incised into pre-1942 geomorphic units. The c1b unit consists of coarse-grained sandbar deposits resulting from floods in 1991. The fill label designates road base material along State Road 502.

The blue line marks the two thalwegs. The red line outlines the boundary between the base of the valley slope and the present active channel area. Alternate deposition and scouring is occurring through this area.

Figure 41 demonstrates the measured dimensions at this location and characteristics along the entire 220-foot extent of the NMED cross section. The area under the horizontal blue line represents the cross section area at bankfull stage and the red line depicts height of the flood prone area. A steep colluvium-covered slope ends at 28 feet; the remaining slope to the active channel is part of previous flood plain deposits. The c1a active channel unit extends from 40 to 60 feet, and the thalweg is at 45 feet. Remnants of the c1b sandbar unit, deposited in 1991, extend from 60 to 160 feet, with a second freshly cut thalweg at 135 feet. The broad floodplain that is present between the colluvium slope and State Road 502 is demonstrating alternate down cutting and deposition within this area.

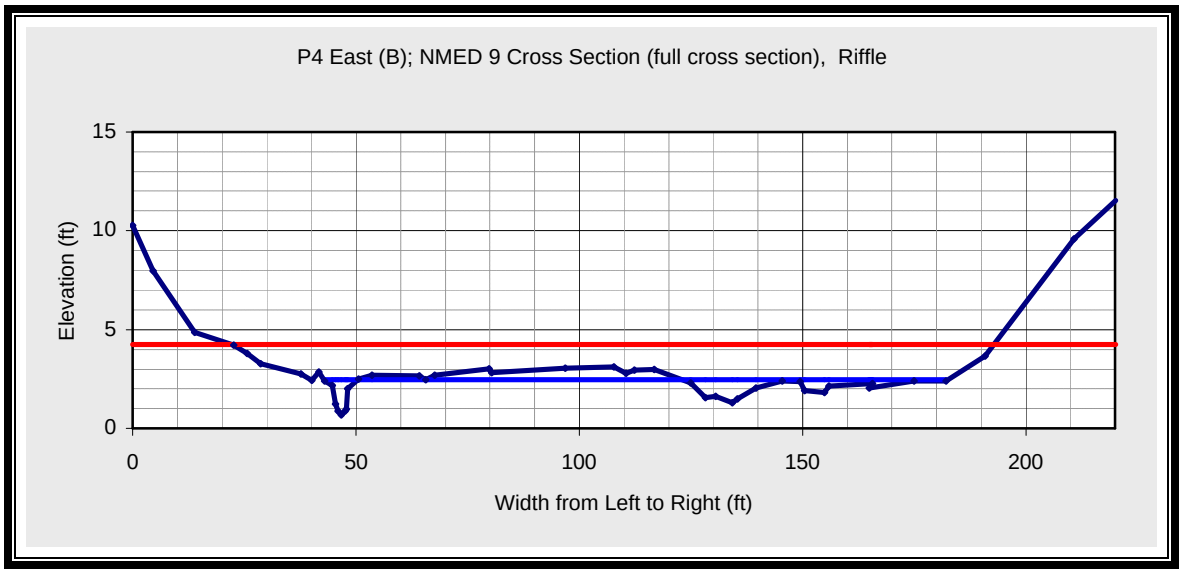


Figure 41. Full cross section view at P-4 East (B) NMED-9 cross section

In November of 2001, at NMED-9, the width of the channel at the flood prone stage was 166 feet. The channel is 3.5 feet deep from the lowest point in the channel (thalweg) to top of the lowest bank, and the depth of the thalweg (at bankfull stage) is 1.5 feet. At bankfull stage, the cross sectional area is approximately 11.5 square feet. The average depth of the channel is 0.5 foot and the wetted perimeter is 23.6 feet. Other stream dimensions reflected by cross section NMED-9 are listed in Table 27.

Table 27. Stream dimensions at P-4 East (B) NMED-9 cross section

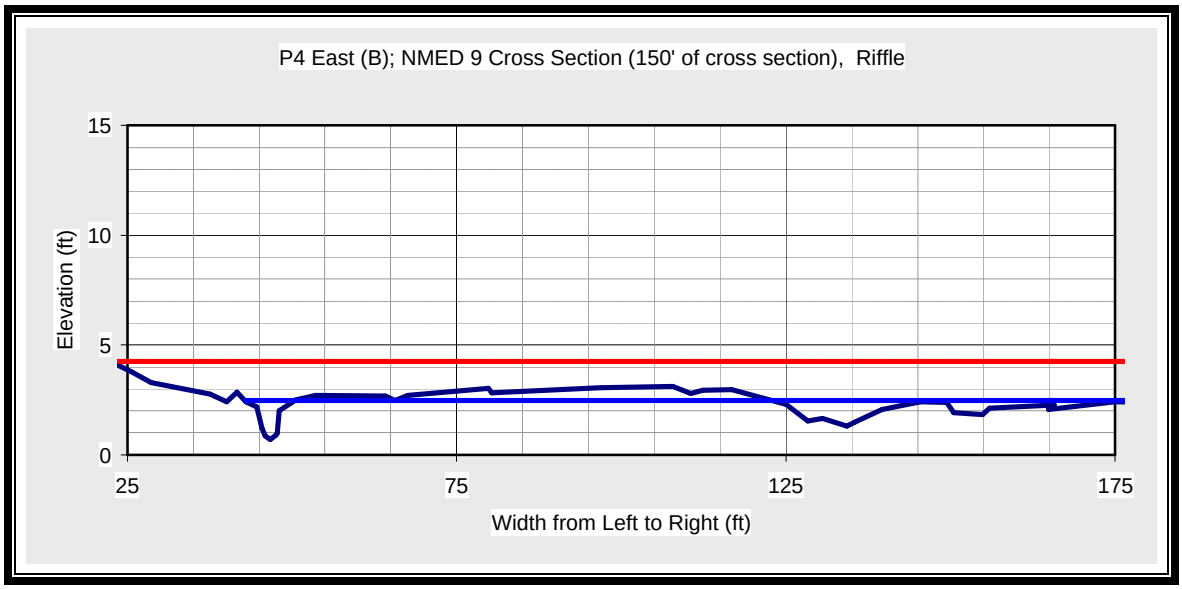
Stream dimensions	
11.5	Cross section area at bankfull stage (ft sq)
22.8	Width at bankfull stage
1.5	Maximum depth at bankfull
3.5	Bank height
166	Width flood prone area (at 2 x max depth)
0.5	Mean depth
23.6	Wetted Perimeter
0.5	Hydraulic radius
45.4	Width / depth ratio
7.3	Entrenchment ratio
0.026	Slope
1.1	Sinuosity

A width to depth ratio of 45.4 and entrenchment value of 7.3 suggest the stream at this area is a "C" type stream (Rosgen classification). The predominance of very coarse sand bed materials refine the classification to a "C5" stream type. The slope at this cross section of between 0.02 – 0.039 further refines the classification to a "C5b" stream type. A C5 stream type is very highly sensitive to stream flow and sediment increases, contributes very high sediment supplies, and has a very high stream bank erosion potential (Rosgen, 1994). Additional stream hydraulic and physical parameters are listed in Table 28.

Table 28. Additional parameters determined from the stream dimensions at P-4 East (B) NMED-9

Stream hydraulics	
5.1	Velocity (ft/sec)
58.7	Discharge rate, Q (cfs)
0.79	Shear stress (lbs/ft sq)
0.64	Shear velocity (ft/sec)
4.2	Unit stream power (lbs/ft/sec)
1.6	Froude number
8.0	Friction factor u/u*
50.8	Threshold grain size (mm)
Channel material	
18	Measured D84 (mm)
8.5	Relative roughness
0.029	Manning's "n" from channel material

Figure 42 displays 150 feet of the cross section, providing a consistent cross section scale between all the cross sections measured during this study. The two channels presently active are at 47 and 134 feet.



M M'

Figure 42. 150 -foot view of P-4 East (B) NMED-9 cross section

Figure 43 is a downstream view of the channel at P-4 East (B) NMED-9 cross section. The photo is oriented so that cross section starts at M, left or north in this photo, and continues south to M'

M M'

Figure 43. View of P-4 East (B) NMED-9 cross section looking downstream

Our researcher is standing on the cross section with a stadia rod in the northern thalweg. The southern channel is at the very far right of the photo. Remnants of the c1b sandbar unit as well as fresh flood deposits are located in the right of the photograph. The culvert under State Road 502 that carries water from Pueblo Canyon to Los Alamos Canyon is in the upper center of this photo. The steep colluvium covered-slope is in the left side of the photo.

Longitudinal Profiles Reach P-4 East (A) and P-4 East (B)

A longitudinal profile was measured through reach P-4 East (A) over 1177 feet beginning 128 feet upstream from ER-1 cross-section and continuing to 130 feet beyond NMED-1 cross-section. The longitudinal profile included measurements of the thalweg, bankfull estimates, and the water surface. The P-4 East (A) profile was tied into the top of the lower staff gage located at the LANL RRES-WQH, E060 gage station and is illustrated in Figure 44. The slope of reach P-4 East (A) was determined by dividing the elevation drop of 24.09 ft. along the 1177-foot reach by the length of the reach resulting in a slope of 2.047 percent. This is consistent with the range of slopes found in "B" stream types of 2 – 3.9 percent (Rosgen, 1996).

A longitudinal profile was measured through reach P-4 East (B) over 2515 feet beginning 69 feet upstream from NMED-2 cross-section and continuing to the culvert under SR 4, 180 feet beyond NMED-9 cross-section. The longitudinal profile included measurements of the thalweg and when present, the water surface. The P-4 East (A) profile is illustrated in Figure 45 and the entire reach [P-4 East (A) and (B)] is shown in Figure 46. The slope of reach P-4 East (B) was determined by dividing the elevation drop of 47.96 ft. along the 2515-foot reach by the length of the reach resulting in a slope of 1.907 percent. This is consistent with the typical slope found in "C" stream types of <2 percent (Rosgen, 1996).

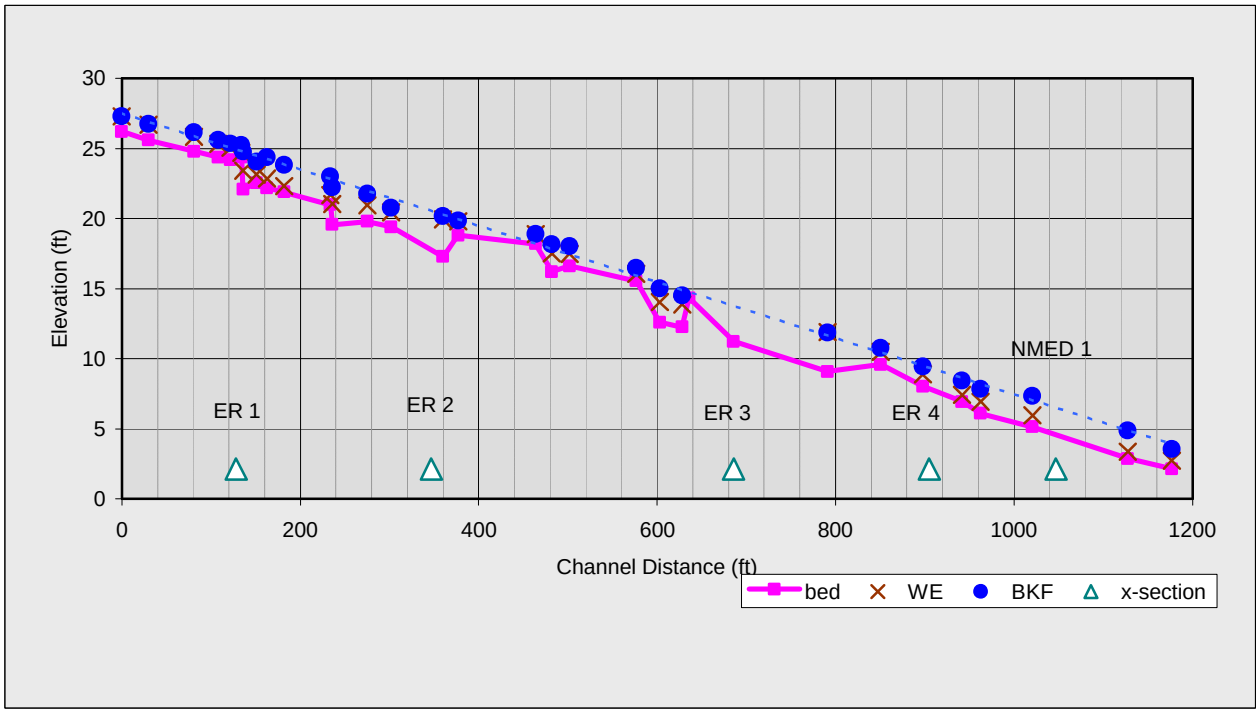


Figure 44. P-4 East (A) Longitudinal Profile

In Figure 44, the red line indicates the thalweg of the stream and the "x" indicates the water surface.

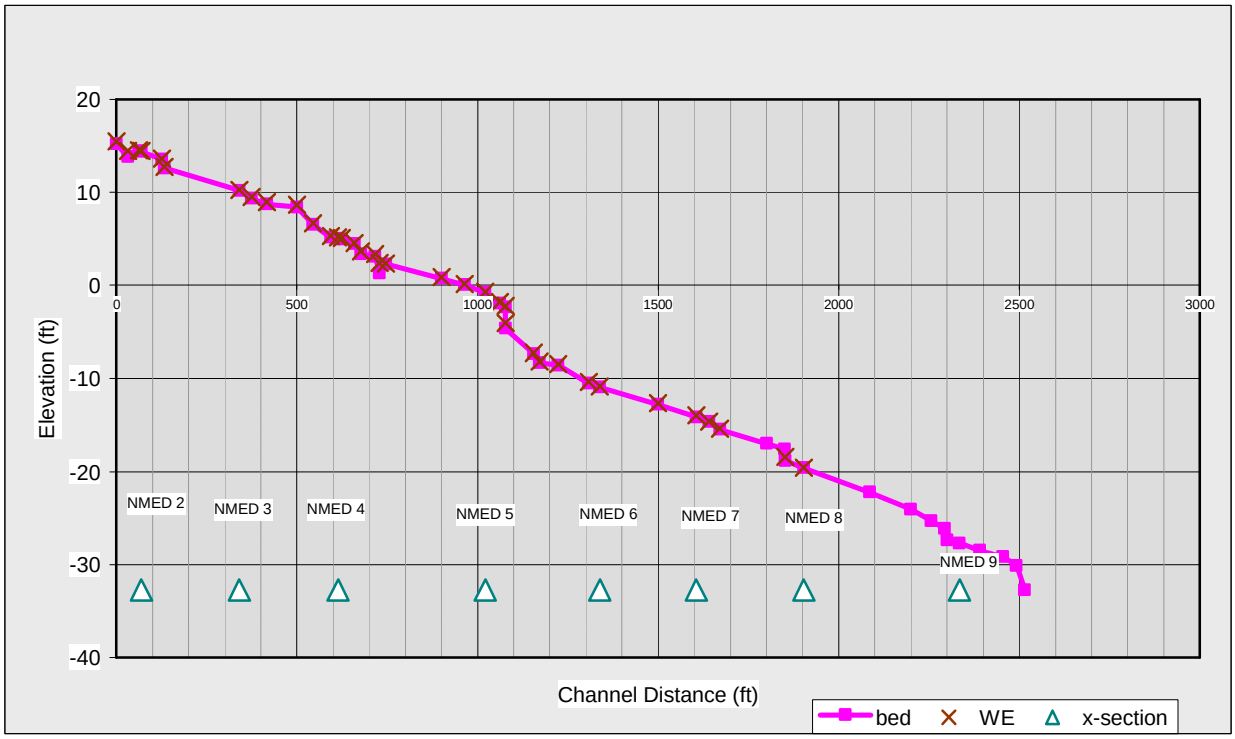


Figure 45. P-4 East (B) Longitudinal Profile

In Figure 45, the red line indicates the thalweg of the stream and the "x" indicates the water surface.

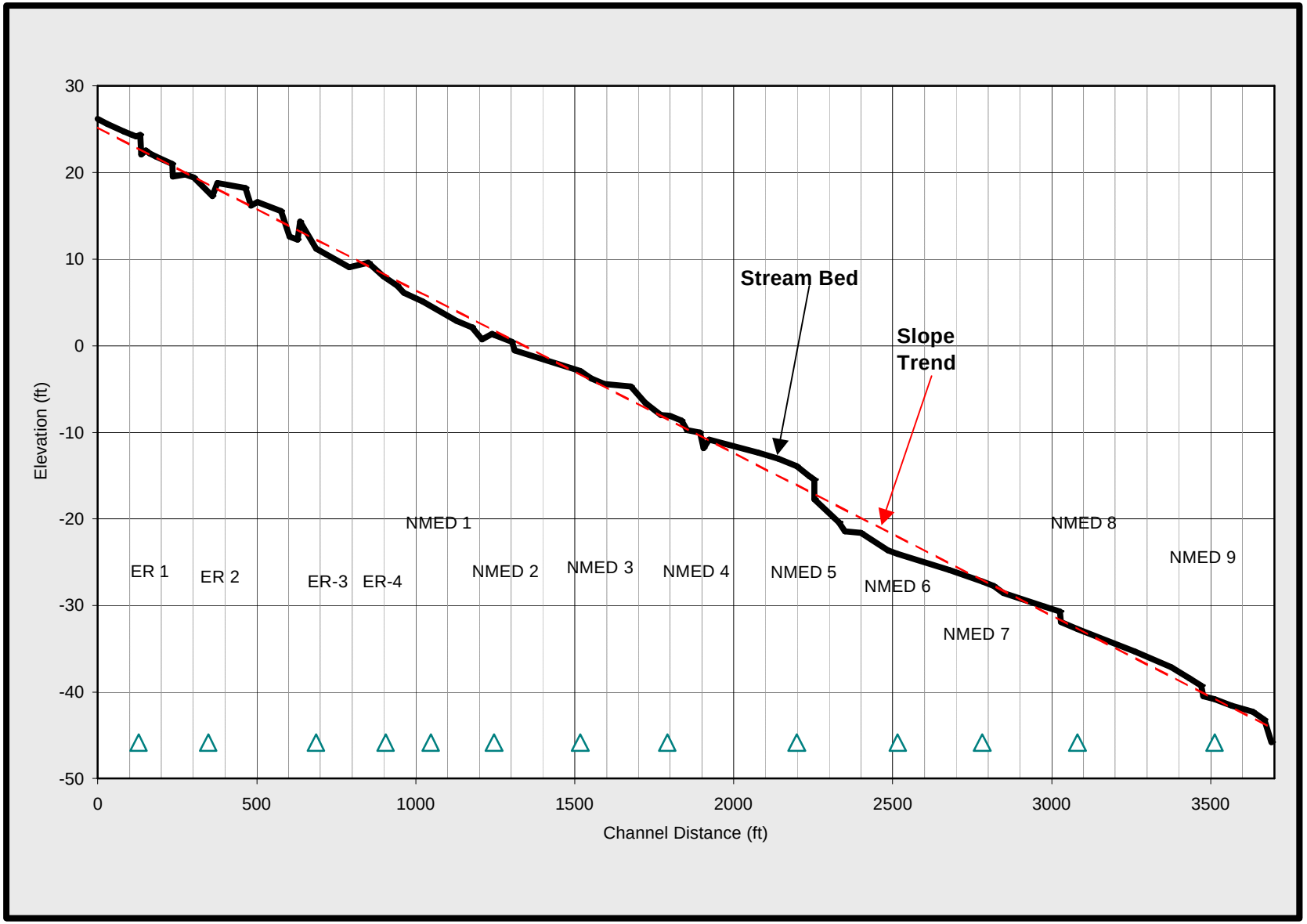


Figure 46. Reach P-4 East Entire Longitudinal Profile

Channel Materials Assessment Reach P-4 East (A) and P-4 East (B)

The Wolman Pebble Count Method (SWQB QUAP, 2001) was used to characterize bed and bank materials on each longitudinal profile. Each reach was divided into 10 equidistant transects and 10 pebbles were randomly chosen along each transect. Each pebble was measured using a ruler or in the case of silt/sand, a sand gage was utilized. Pebbles were collected and measured only from the bankfull width of the channel. P-4 East (A) channel materials are shown in Table 29 and P-4 East (B) channel materials are in Table 30. The channel material size in reach P-4 East (A) was smaller than that in reach P-4 East (B). This is indicated by an increase in the D84 (size of 84 percent of all particles) of 11 mm in reach P-4 East (A) to a D84 of 21.31 mm in reach P-4 East (B).

Table 29. P-4 East (A) bed materials

Material	Size Range (mm)		Count	% Of 100 Count	Cumulative %
Silt/clay	0	0.062	**72**	**0.72**	0.72
Very fine sand	0.062	0.125		0	0.72
Fine sand	0.125	0.25		0	0.72
Medium sand	0.25	0.5	3	0.03	0.75
Coarse sand	0.5	1	5	0.05	0.8
Very coarse sand	1	2		0	0.8
Very fine gravel	2	4		0	0.8
Fine gravel	4	6		0	0.8
Fine gravel	6	8	2	0.02	0.82
Medium gravel	8	11	2	0.02	0.84
Medium gravel	11	16	2	0.02	0.86
Coarse gravel	16	22	4	0.04	0.9
Coarse gravel	22	32	3	0.03	0.93
Very coarse gravel	32	45		0	0.93
Very coarse gravel	45	64	1	0.01	0.94
Small cobble	64	90	3	0.03	0.97
Medium cobble	90	128		0	0.97
Large cobble	128	180	3	0.03	1
Very large cobble	180	256		0	1
Small boulder	256	362		0	1
Small boulder	362	512		0	1
Medium boulder	512	1024		0	1
Large boulder	1024	2048		0	1
Very large boulder	2048	4096		0	1
Bedrock					
	Total Particle Count:		100		

Size percent less than (mm)

D16	D35	D50	D84	D95
N/A	N/A	N/A	11	71.7

Percent by substrate type

Silt/clay	Sand	Gravel	Cobble	Boulder	Bedrock
0.72	0.08	0.14	0.06	0	0

The percent of silt/clay decreased from P-4 East (A) from 72% to 5 % in reach P-4 East (B), percent sand increased from 8% in P-4 East (A) to 52 % in P-4 East (B) and percent gravel increased from 14 % in P-4 East (A) to 37 % in P-4 East (B). This is due to the destabilization of effluent maintained, vegetated B channels transitioning to a less stable C stream type.

Table 30. P-4 East (B) bed materials

Material	Size Range (mm)		Count	% of 100 Count	Cumulative %
Silt/clay	0	0.062	5	0.05	0.05
Very fine sand	0.062	0.125	2	0.02	0.07
Fine sand	0.125	0.25	1	0.01	0.08
Medium sand	0.25	0.5	5	0.05	0.13
Coarse sand	0.5	1	24	0.24	0.37
Very coarse sand	1	2	20	0.2	0.57
Very fine gravel	2	4		0	0.57
Fine gravel	4	6	2	0.02	0.59
Fine gravel	6	8	4	0.04	0.63
Medium gravel	8	11	3	0.03	0.66
Medium gravel	11	16	9	0.09	0.75
Coarse gravel	16	22	10	0.1	0.85
Coarse gravel	22	32	4	0.04	0.89
Very coarse gravel	32	45	3	0.03	0.92
Very coarse gravel	45	64	2	0.02	0.94
Small cobble	64	90	2	0.02	0.96
Medium cobble	90	128	3	0.03	0.99
Large cobble	128	180	1	0.01	1
Very large cobble	180	256		0	1
Small boulder	256	362		0	1
Small boulder	362	512		0	1
Medium boulder	512	1024		0	1
Large boulder	1024	2048		0	1
Very large boulder	2048	4096		0	1
Bedrock				0	
	Total Particle Count:		100		
		Size percent less than (mm)			
D16	D35	D50	D84	D95	
0.55	0.94	1.57	21.31	75.89	
		Percent by substrate type			
Silt/clay	Sand	Gravel	Cobble	Boulder	Bedrock
0.05	0.52	0.37	0.06	0.00	0.00

Site-specific material assessments were done on each P-4 East (B) cross section and are summarized in Table 31. The channel at NMED-2 is scoured to bedrock. Particle size tends to increase progressing downstream from a D84 of 20 mm at NMED-3 to a D84 of 29 mm at NMED 8. NMED-9 is a broad depositional area and the D84 decreases to 18 mm here.

Table 31. P-4 East (B) NMED-2 through NMED-9 cross section specific particle size distribution summary

	Size percent less than (mm)					Percent by substrate type					
	D16	D35	D50	D84	D95	Silt/clay	Sand	Gravel	Cobble	Boulder	Bedrock
NMED-2	0.0	0.0	0.0	0	0	0%	0%	0%	0%	0%	100%
NMED-3	0.96	1.81	5.1	20	45	0%	38%	59%	3%	0%	0%
NMED-4	0.72	1.24	4.9	22	98	0%	48%	46%	6%	0%	0%
NMED-5	0.28	2.17	7.9	23	42	7%	28%	63%	2%	0%	0%
NMED-6	0.63	1.19	3.0	22	76	1%	43%	50%	6%	0%	0%
NMED-7	0.57	1.70	8.4	26	57	0%	37%	59%	4%	0%	0%
NMED-8	0.61	1.22	6.9	29	80	4%	42%	48%	7%	0%	0%
NMED-9	0.63	1.04	1.9	18	64	1%	50%	44%	4%	1%	0%

Summary

The Cerro Grande fire, in May 2000, burned almost 100 percent of the upper Pueblo Canyon Watershed. The fire reduced vegetation and decreased the ability of the soil to absorb moisture, resulting in increased frequency and magnitude of storm water discharges and associated sediment yields in the Pueblo Canyon watershed. These changes in fluvial processes have forced the stream to adjust its form to accommodate these increased yields. This is demonstrated by areas of accelerated alternating channel degradation and aggradation, accelerated bank erosion, vertical and lateral channel migration, and recent fine grained flood deposits on terraces as well as coarse grained deposits within the active channel areas.

In November and December 2001, the DOE Oversight Bureau of the New Mexico Environment Department measured stream dimensions, pattern, channel profile, and bed features in lower Pueblo Canyon, reach P-4 East. These measurements were used to characterize conditions of this reach, and establish benchmarks for monitoring future stream adjustments. This study establishes stream dimensions at 13 cross sections (4 that correlate to previous LANL ER cross sections), slope and bed features along a longitudinal profile, and the sinuosity pattern of the stream channel and valley in Pueblo Canyon, reach P-4 East.

Our evaluations indicate the stream is adjusting to the increased storm water discharges and sediment yields. The stream in reach P-4 East A, previously an E6 type channel is transitioning to a B6c or F type channel, which is moderately sensitive to stream flow and sediment increases, contributes moderate sediment supplies, and has a low stream bank erosion potential (Rosgen, 1994). Downstream from P-4 East A, in P-4 East B, the stream classification is transitioning from an E6 type to C and B type channels, demonstrating a very high sensitivity to stream flow and sediment increases, a very high sediment supply contribution, and a very high stream bank erosion potential (Rosgen, 1994). The P-4 East B sub reach is actively eroding. The stream has abandoned the old channel and has eroded the alluvial sediments to bedrock in many places. Deepening channels are resulting in localized lowering of the alluvial water table, stranding existing riparian vegetation, accelerating bank erosion and promoting the development of head cuts. A 3 to 4 foot head cut has developed in reach P-4 East B where sediments have eroded en masse and which advances further upstream each year. This head cut developed where the Pueblo Canyon flood plain is pinched by the highway right of way and valley colluvium forcing the stream to develop very high velocities during floods as it is confined along this reach.

LANL analytical measurements of samples from geomorphic units in Pueblo Canyon indicate contamination exists from post-1942 operations. LANL's preliminary risk assessment indicates the current concentrations pose acceptable risks. An inventory of 89.6-mCi plutonium 239/240 was estimated in reach P-4 East, of which 57% is stored in the coarse grain facies in c3 channel units, 10% in the coarse grain facies in c1a, b, and c2a, b, and c channel units. The remaining 30% is stored in overbank fine grain facies in c1, c1b, c2, c3, and f1 units.

The c3 unit, containing the highest percentage of plutonium in P-4 East, is exposed predominantly in reach P-4 East (A), where bank erosion potential is lower. Except at an area of accelerated erosion, along the north bank between cross sections ER-1 and ER-2, the c3 units comprising the banks in section A appear to be low-to-moderately eroded.

In reach P-4 East B, accelerated bank erosion is occurring, particularly at cross sections NMED-2, 3, and 4. Except for the thin overbank deposits on terraces in these areas, the banks are pre-1942 deposits. Vertical and lateral channel migration has resulted in accelerated down cutting and channel abandonment. Down cutting, or deepening of the thalweg, is becoming prominent at NMED-1. By NMED-2, channel incision has reached bedrock, abandoned its original stream course, and widened the active channel. Geomorphic units most affected are channel features that generally contain a smaller overall percentage of contaminants described by LANL though the older, post 1942, c3 units on the north bank are actively eroding between NMED-1 and NMED-2.

Between cross sections 4 and 6, the stream channel narrows as the north valley wall of Pueblo Canyon and State Road 502 confine it, producing extreme channel head cutting and erosion of previous active channel deposits. These c1a channel deposits, which have been removed by channel head cutting, have no available data characterizing contaminant levels. If these channel deposits are similar to upstream units, they should have had low concentrations and inventory of contaminants. As the valley widens again at cross section 7

to cross section 9, alternating erosion and deposition features are evident within the active channel area.

It appears that areas of the greatest post-1942 contamination in stream reach P-4 East in Pueblo Canyon are the least impacted by the increased frequency and magnitude of storm-water discharges. The exceptions to this are where overbank flood flows combine and return to the mainstream and are eroding post-1942, c3 bank-forming units. However, as the stream continues to adjust, the accelerated erosion encroaching into reach P-4 East section A and post-1942 abandoned (c3) channels which form the confining terrace banks may contribute greater levels of contaminants into the downstream Los Alamos channel system.

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Appendix A.

Cross section ER-1 through NMED-9 field measurements

section:	Reach P4 East (A) ER 1 Cross section only							
	Riffle							
stream:	Pueblo							
location:	Latitude: 35 52 17.047: Longitude: 106 13 05.502							
description:	Reach P4 East (A) ER 1 [furthest upstream x-s in P4 East (A)]							
height of instrument (ft):		15						
	distance	FS		FS	FS	W fpa	channel	Manning's
Notes	(ft)	(ft)	elevation	bankfull	top of bank	(ft)	slope (%)	"n" (Used)
L OB pin	0	5.57	9.43	6.93	5.22	89	1.35	0.044
L ER pin	1.2	5.49	9.51					
	8	5.74	9.26					
	17	5.58	9.42	dimensions				
	30	5.32	9.68	23.5	x-section area		0.4	d mean
	38	5.02	9.98	54.5	width		56.5	wet P
Top Left Bank	43.5	5.22	9.78	1.9	d max		0.4	hyd radi
	48	6.73	8.27	3.6	bank ht		126.4	w/d ratio
Bottom Left Bank	50.3	7.47	7.53	89.0	W flood prone area		1.6	ent ratio
Grass boundary	54	7.45	7.55					
Side channel	55.7	7.83	7.17	hydraulics				
	57.2	7.32	7.68	2.2	velocity (ft/sec)			
	60.2	7.43	7.57	51.6	discharge rate, Q (cfs)			
	62	7.24	7.76	0.4	shear stress ((lbs/ft sq)			
	67.5	7.43	7.57	0.4	shear velocity (ft/sec)			
	73	7.49	7.51	0.8	unit stream power (lbs/ft/sec)			
	74	7.72	7.28	0.3	Froude number			
Side channel	75	7.37	7.63	5.2	friction factor u/u*			
	79	7.2	7.8	20.7	threshold grain size (mm)			
BF	82	6.93	8.07					
	83.8	7.39	7.61	From channel material				
	85	7.16	7.84	11	measured D84 (mm)			
	87.6	7.37	7.63	11.953	relative roughness		9.0	fric. factor
	89	6.82	8.18	0.025	Manning's n from channel material			
	90	7.54	7.46					
L channel edge	92.1	7.38	7.62					
LWE	93.5	7.63	7.37					
TW	94.2	8.79	6.21					
RWE	95.4	7.69	7.31					
R channel edge	96.7	7.19	7.81					
	99	7.16	7.84					
	102	7.13	7.87					
grass boundary	106	6.63	8.37					
Side channel bank	111	6.58	8.42					
	113	7.28	7.72					
	114	7.54	7.46					
Recent scour	115	7.65	7.35					
	116	7.66	7.34					
	117	7.28	7.72					
Bank	118	6.81	8.19					
	119	6.62	8.38					
	121	6.36	8.64					
	123	5.84	9.16					
	125	5.09	9.91					
	127	4.88	10.12					
	129	4.75	10.25					
	132	4.53	10.47					
	135	4.32	10.68					
RB ER Pin	138.65	4.27	10.73					
RB NMED Pin	139.2	4.18	10.82					

section:	P4 East (A) ER 2; Full Cross section							
	Pool							
stream:	Pueblo							
location:	Latitude: 35 52 15.730; Longitude: 106 13 03.913 (upstream from E060 Gage)							
description:	219 feet downstream from ER 1; 339 feet upstream from ER 3							
height of instrument (ft):	11							
notes	distance (ft)	FS (ft)	elevation	FS bankfull	FS top of bank	W fpa (ft)	channel slope (%)	Manning's "n" (used)
NMED x-s Pin	0.25	2.48	8.52	8.27	4.72	67	0.765	0.044
	11	5.15	5.85					
	30	6.75	4.25					
A Channel bottom	52	7.91	3.09	dimensions				
Channel bank	61	7.04	3.96	25.9	x-section area		0.7	d mean
crest	79	5.95	5.05	36.9	width		37.9	wet P
B channel bottom	88	7.01	3.99	2.3	d max		0.7	hyd radi
	97	6.03	4.97	5.9	bank ht		52.6	w/d ratio
	113	5.32	5.68	67.0	W flood prone area		1.8	ent ratio
	126	4.6	6.4					
	138	3.82	7.18	hydraulics				
	150	4	7	2.3	velocity (ft/sec)			
	170	4.04	6.96	59.5	discharge rate, Q (cfs)			
crest	210	4.26	6.74	0.3	shear stress ((lbs/ft sq)			
C channel	223	5.31	5.69	0.4	shear velocity (ft/sec)			
	247	4.86	6.14	0.8	unit stream power (lbs/ft/sec)			
debris deposit	290	4.66	6.34	0.2	Froude number			
debris deposit	312	4.45	6.55	5.6	friction factor u/u*			
	331	4.22	6.78	19.1	threshold grain size (mm)			
	344	4.12	6.88					
D channel	354	4.77	6.23	From channel material				
	368	5.08	5.92	11	measured D84 (mm)			
	389	4.81	6.19	19.4	relative roughness		10.2	fric. factor
	409	5.43	5.57	0.024	Manning's n from channel material			
ER x-s Pin	419.9	4.6	6.4					
	425	4.6	6.4					
	430	4.53	6.47					
	440	4.36	6.64					
	445	4.45	6.55					
Top LT (erosion evident)	453	4.72	6.28					
Bottom LT	461.8	7.6	3.4					
	465	7.4	3.6					
	468.6	7.8	3.2					
	471.5	8.29	2.71					
	476	7.96	3.04					
BF	483.4	8.27	2.73					
	484.5	8.57	2.43					
wetland vegetation	485.5	8.73	2.27					
Channel bank	489	8.92	2.08					
R edge grass	493	8.73	2.27					
crest	497.3	8.52	2.48					
L edge grass	500	8.87	2.13					
	504	9.04	1.96					
	507.2	8.81	2.19					
L channel bank	509.6	8.73	2.27					
LWE	512	9.16	1.84					
TW	514.7	10.61	0.39					
	518.4	9.05	1.95					
R grass edge	521	8	3					
Trail erosion	522.9	6.75	4.25					
Trail erosion	525	5.45	5.55					
Top Right Terrace	527	4.46	6.54					
	530	3.82	7.18					
	535	3.31	7.69					
	540	2.93	8.07					
ER R x-s Pin	544.1	2.89	8.11					
NMED R x-s Pin	544.8	2.84	8.16					

section:	P4 East (A) ER 3 Full Cross section							
	Riffle							
stream:	Pueblo							
location:	Near E060 Gage							
description:	339 feet downstream from ER 2; 53 ft downstream from E060 Gage							
height of instrument (ft):	15							
notes	distance (ft)	FS (ft)	elevation	FS bankfull	FS top of bank	W fpa (ft)	channel slope (%)	Manning's "n"
L OB pin	0	5.83	9.17	10.71	7.31	43	1.1	0.044
	21	6.42	8.58					
	45	5.88	9.12					
	61	6.48	8.52	dimensions				
	101	4.95	10.05	21.5	x-section area		0.6	d mean
	141	6.01	8.99	34.8	width		35.7	wet P
A channel	181	5.03	9.97	1.5	d max		0.6	hyd radi
	221	5.39	9.61	4.9	bank ht		56.3	w/d ratio
	231	4.41	10.59	43.0	W flood prone area		1.2	ent ratio
	241	4.26	10.74					
	251	4.15	10.85	hydraulics				
	271	4.65	10.35	2.5	velocity (ft/sec)			
	281	4.68	10.32	54.4	discharge rate, Q (cfs)			
	291	5.07	9.93	0.4	shear stress ((lbs/ft sq)			
	301	5.43	9.57	0.5	shear velocity (ft/sec)			
	311	5.45	9.55	1.1	unit stream power (lbs/ft/sec)			
	321	5.77	9.23	0.3	Froude number			
	327	5.89	9.11	5.5	friction factor u/u*			
	337	5.96	9.04	24.8	threshold grain size (mm)			
	347	5.96	9.04					
	357	6.57	8.43	From channel material				
	367	5.42	9.58	11	measured D84 (mm)			
	377	4.94	10.06	17.1	relative roughness		9.9	fric. factor
L ER pin?	387.6	7.18	7.82	0.024	Manning's n from channel material			
	395	7.2	7.8					
Top of Terrace	401	7.31	7.69					
Midpoint of terrace	405	9.55	5.45					
Bottom of terrace	408	10.66	4.34					
	409	10.94	4.06					
	410	11.11	3.89					
	412.4	11.22	3.78					
	416	10.96	4.04					
	420.6	11.17	3.83					
	423	11.9	3.1					
	428	11.36	3.64					
	433	11.47	3.53					
TW	433.9	12.16	2.84					
LBWE	434.2	11.56	3.44					
RBWE	435.2	11.48	3.52					
	436	11.42	3.58					
	438	11.59	3.41					
	439	11.46	3.54					
	440	11.34	3.66					
	441.2	11.21	3.79					
	442	10.93	4.07					
BF	443	10.71	4.29					
	444	10.53	4.47					
	445	10.27	4.73					
	446	9.82	5.18					
Midpoint of terrace	448	8.6	6.4					
Top of terrace	449	7.76	7.24					
	450	7.36	7.64					
	452	7.05	7.95					
	455	6.9	8.1					
	457	6.11	8.89					
ER pin	457.4	5.95	9.05					
OB pin	460.1	4.45	10.55					

section:	Pueblo P4 East (A) ER 4							
	Riffle							
stream:	Pueblo							
location:	Latitude: 35 52 13.739 Longitude: 106 12 57.927							
description:	905 ft east on P4 East (A) longitudinal profile							
height of instrument (ft):	15							
notes	distance (ft)	FS (ft)	elevation	FS bankfull	FS top of bank	W fpa (ft)	channel slope (%)	Manning's "n" (Used)
L OB pin	0	10.71	4.29	14	9.97	51	2.32	0.044
L ER pin	0.6	10.61	4.39					
	5	10.56	4.44					
	10	10.4	4.6	dimensions				
	15	10.2	4.8	18.5	x-section area		0.6	d mean
	20	9.92	5.08	32.9	width		36.2	wet P
top LB	24.4	9.97	5.03	2.5	d max		0.5	hyd radi
	26	10.51	4.49	6.5	bank ht		58.4	w/d ratio
	28	11.62	3.38	51.0	W flood prone area		1.6	ent ratio
	30	12.56	2.44					
	32	13.38	1.62	hydraulics				
(grass boundary)	34.7	14.2	0.8	3.3	velocity (ft/sec)			
	37	14.44	0.56	60.9	discharge rate, Q (cfs)			
	39.6	13.79	1.21	0.7	shear stress ((lbs/ft sq)			
	42.2	14.39	0.61	0.6	shear velocity (ft/sec)			
	44.4	14.64	0.36	2.7	unit stream power (lbs/ft/sec)			
L top stream bank	46.3	14.34	0.66	0.6	Froude number			
LWE	46.9	15.52	-0.52	5.3	friction factor u/u*			
TW	47.5	16.47	-1.47	47.4	threshold grain size (mm)			
RWE	48	15.52	-0.52					
	48.8	14.73	0.27	From channel material				
	50.2	14.22	0.78	11	measured D84 (mm)			
	53	15.38	-0.38	15.6	relative roughness		9.6	fric. factor
	55	14.3	0.7	0.0244	Manning's n from channel material			
	56	14.84	0.16					
	57.3	14.51	0.49					
	59.8	14.65	0.35					
	61.8	14.07	0.93					
	64.2	14.51	0.49					
	65.8	14.79	0.21					
BF	69.3	14	1					
	71.7	13.45	1.55					
	74	13.4	1.6					
	75	13.04	1.96					
	76.6	12.28	2.72					
	78	11.45	3.55					
Top Right Bank	78.5	10.25	4.75					
	80	10.14	4.86					
	84	10.19	4.81					
	88	10.03	4.97					
	94	10.29	4.71					
	101	10.36	4.64					
	102	10.08	4.92					
Terrace base	104	9.16	5.84					
	106	7.44	7.56					
ER pin	108.5	6.88	8.12					
NMED pin	109.8	6.14	8.86					

section:	P4 East (A) NMED 1							
	Riffle							
stream:	Pueblo Canyon							
location:	Latitude: 35 52 13.624; Longitude: 106 12 56.138							
description:	142 ft downstream from ER4 x-section							
height of instrument (ft):	15							
	distance	FS		FS	FS	W fpa	channel	Manning's
notes	(ft)	(ft)	elevation	bankfull	top of bank	(ft)	slope (%)	"n" (Used)
Left Pin	0	6.41	8.59	9.87	5.99	77	1.175	0.044
	13	6.46	8.54					
	33	6.2	8.8					
Top HT	52.5	5.99	9.01	dimensions				
	54	6.99	8.01	23.9	x-section area		0.6	d mean
	56	7.63	7.37	37.5	width		39.8	wet P
	58	8.11	6.89	3.0	d max		0.6	hyd radi
Base of HT	61	9.3	5.7	6.8	bank ht		58.9	w/d ratio
	65	9.63	5.37	77.0	W flood prone area		2.1	ent ratio
	74	9.54	5.46					
	78	9.94	5.06	hydraulics				
	83	10.09	4.91	2.6	velocity (ft/sec)			
	87	10.22	4.78	62.3	discharge rate, Q (cfs)			
TLB	91.5	10.72	4.28	0.4	shear stress ((lbs/ft sq)			
LWE	92	12.41	2.59	0.5	shear velocity (ft/sec)			
Bottom LB	92	12.59	2.41	1.2	unit stream power (lbs/ft/sec)			
TW	93	12.82	2.18	0.3	Froude number			
Bottom RB	93.75	12.72	2.28	5.5	friction factor u/u*			
WE	93.75	12.39	2.61	26.6	threshold grain size (mm)			
	95.5	11.74	3.26					
Top RB	98.5	10.51	4.49	From channel material				
	105	10.16	4.84	11	measured D84 (mm)			
	109	10.24	4.76	17.6	relative roughness		9.9	fric. factor
	111	10.06	4.94	0.024	Manning's n from channel material			
	112.5	10.09	4.91					
	114.75	10.13	4.87					
BF	115.5	9.87	5.13					
	120	9.71	5.29					
	123	8.9	6.1					
	129	6.69	8.31					
TRB	130	1.05	13.95					
	131	0.68	14.32					
	132	0.57	14.43					
	137	-0.86	15.86					
Right Pin	142	-2.25	17.25					

section:	Pueblo P4 East (B) NMED 2							
	Riffle							
stream:	Pueblo							
location:	Lattitude: 35 52 13.401; Longitude: 106 12 54.069							
description:	Approximately 50 ft. downstream of head cut							
height of instrument (ft):	15							
notes	distance (ft)	FS (ft)	elevation	FS bankfull	FS top of bank	W fpa (ft)	channel slope (%)	Manning's "n" (Used)
L OB pin	0	4.91	10.09	12.02	5.98	22	1.08	0.015
Overbank deposition	10	4.89	10.11					
Overbank deposition	25	5.04	9.96					
Overbank deposition	36	5.4	9.6	dimensions				
Approximate Sample Point PU 10180	46	6.03	8.97	10.8	x-section area		0.6	d mean
	52	6.36	8.64	19.3	width		19.5	wet P
	67	6.01	8.99	0.9	d max		0.6	hyd radi
Top L Terrace	78	5.98	9.02	7.0	bank ht		34.7	w/d ratio
New Major Erosion	79.7	6.88	8.12	22.0	W flood prone area		1.1	ent ratio
	81	7.11	7.89					
	82	9.19	5.81	hydraulics				
	86	9.71	5.29	6.9	velocity (ft/sec)			
	91	9.19	5.81	74.7	discharge rate, Q (cfs)			
	94	9.34	5.66	0.4	shear stress ((lbs/ft sq)			
	102	9.43	5.57	0.4	shear velocity (ft/sec)			
	109	9.03	5.97	2.6	unit stream power (lbs/ft/sec)			
	112	9.19	5.81	2.7	Froude number			
	113	9.6	5.4	15.8	friction factor u/u*			
	119	9.74	5.26	22.1	threshold grain size (mm)			
	124	9.7	5.3					
Top LB	131.5	9.65	5.35	From channel material				
BF	133	12.02	2.98	0 (Bedrock)	measured D84 (mm)			
LWE	140.75	12.68	2.32	0	relative roughness		0	fric. factor
TW	145	12.95	2.05	0	Manning's n from channel material			
RWE	149.5	12.71	2.29					
	152	12.25	2.75					
	152.75	11.75	3.25					
	155	11.35	3.65					
	157	10.54	4.46					
	160	10.46	4.54					
	162	10.76	4.24					
Old TW filled in	164.5	11.02	3.98					
	169	10.68	4.32					
	175.5	10.89	4.11					
	179	10.18	4.82					
	183	10.8	4.2					
Old BF grass bound	186	10.42	4.58					
	188	9.85	5.15					
	190	8.9	6.1					
Top R Terrace	194.5	6.18	8.82					
	197.8	6.07	8.93					
	204	6.32	8.68					
	215	6.67	8.33					
Top Bank	237	6.9	8.1					
	242	8.06	6.94					
Channel bottom	247	9.1	5.9					
Bottom Road Armor	259	8.45	6.55					
Top Road Armor	275	4.09	10.91					
NMED Pin	279	3.39	11.61					

section:	P4 East (B) NMED 3							
	Riffle							
stream:	Pueblo							
location:	Right Bank Pin Latt: 35 52 14.320; Long:106 12 51.414							
description:	Reach P4 East (B) NMED 3 (271 ft downstream from NMED 2) Along SR4 Y							
height of instrument (ft):	15							
	distance	FS		FS	FS	W fpa	channel	Manning's
notes	(ft)	(ft)	elevation	bankfull	top of bank	(ft)	slope (%)	"n" (Used)
NMED Pin	0	7.08	7.92	13.61	7.01	136	0.885	0.028
	17	7.4	7.6					
Terrace	58	7.01	7.99					
	58.3	11	4	dimensions				
	61.6	13.26	1.74	12.5	x-section area		0.8	d mean
BF	64.9	13.61	1.39	15.3	width		15.7	wet P
	66.3	14.5	0.5	1.8	d max		0.8	hyd radi
LWE	67.2	14.67	0.33	8.4	bank ht		18.7	w/d ratio
TW	70.8	14.85	0.15	136.0	W flood prone area		8.9	ent ratio
	74	14.64	0.36					
Bottom RB	80.6	13.54	1.46	hydraulics				
	81.4	12.9	2.1	4.3	velocity (ft/sec)			
	88	12.43	2.57	53.4	discharge rate, Q (cfs)			
	98.5	12	3	0.4	shear stress ((lbs/ft sq)			
	103.1	12.72	2.28	0.5	shear velocity (ft/sec)			
	107.2	12.15	2.85	1.9	unit stream power (lbs/ft/sec)			
	118.6	12.13	2.87	0.7	Froude number			
Fence Line	122	12.35	2.65	9.0	friction factor u/u*			
	126	11.86	3.14	26.6	threshold grain size (mm)			
	132	12.13	2.87					
	141	12.42	2.58	From channel material				
	146.6	12.5	2.5	20	measured D84 (mm)			
Top LB (abandoned channel)	152.5	13.15	1.85	12.4	relative roughness		9.1	fric. factor
	155.3	12.92	2.08	0.028	Manning's n from channel material			
Bottom LB (abandoned channel)	156	15.11	-0.11					
TW (abandoned channel)	157.1	15.45	-0.45					
	158.1	15.32	-0.32					
Bottom RB (abandoned channel)	159.3	13.3	1.7					
Top RB (abandoned channel)	166.8	13.02	1.98					
	168.3	13.71	1.29					
	170.6	13.19	1.81					
	176	13.57	1.43					
	177.9	13.24	1.76					
	183.2	13.72	1.28					
Base of concrete armor	191.2	13.26	1.74					
Top of concrete armor	201.7	9.62	5.38					
NMED Pin	203	9.14	5.86					

section:	P4 East (B) NMED 4							
	Riffle							
stream:	Pueblo Canyon Latt:35 52 14.637; Long: 106 12 48.786							
location:	1 ft. East of NM Hyw. Dept Benchmark (LS 10213) POC 34 + 20.16							
description:	Lower Pueblo Canyon along SR4 Y							
height of instrument (ft):	15							
notes	distance (ft)	FS (ft)	elevation	FS bankfull	FS top of bank	W fpa (ft)	channel slope (%)	Manning's "n" (Used)
LB Pin	0	12.56	2.44	18.7	12.52	46	1.5	0.029
	10	12.74	2.26					
HWY. Dept Benchmark	31.4	12.39	2.61					
Fence Line	32.3	12.52	2.48	dimensions				
LB Terrace	34	12.95	2.05	10.9	x-section area		0.7	d mean
LB Bench	39.9	16.41	-1.41	14.8	width		15.2	wet P
Top LB	43	17.03	-2.03	1.2	d max		0.7	hyd radi
BF (inserted point)	44.2	18.7	-3.7	7.4	bank ht		20.1	w/d ratio
Bottom LB	45.2	19.16	-4.16	46.0	W flood prone area		3.1	ent ratio
	47.5	19.39	-4.39					
	48.2	19.14	-4.14	hydraulics				
LWE	50.8	19.56	-4.56	5.0	velocity (ft/sec)			
TW	53.6	19.91	-4.91	54.8	discharge rate, Q (cfs)			
RWE	56.4	19.54	-4.54	0.7	shear stress ((lbs/ft sq)			
Bottom RB	57.7	19.43	-4.43	0.6	shear velocity (ft/sec)			
(Inserted point)	59	18.7	-3.7	3.5	unit stream power (lbs/ft/sec)			
Top RB	59.9	17.66	-2.66	1.1	Froude number			
	64.5	17.42	-2.42	8.5	friction factor u/u*			
	67.5	17.73	-2.73	42.4	threshold grain size (mm)			
	69.1	17.52	-2.52					
	73.2	17.64	-2.64	From channel material				
	83.9	17.47	-2.47	22	measured D84 (mm)			
Base of Concrete Apron	86.6	18.37	-3.37	10.2	relative roughness		8.6	fric. factor
Top of Concrete Apron	99.8	13.98	1.02	0.029	Manning's n from channel material			
NMED RB Pin	100.6	13.61	1.39					

section:	P4 East (B) NMED 5 11-01-01							
	Riffle							
stream:	Pueblo Canyon							
location:	55 ft. upstream from Headcut Latt: 35 52 13.958; Long: 106 12 44.288							
description:	Lower Pueblo Canyon along SR4 Y							
height of instrument (ft):	15							
notes	distance (ft)	FS (ft)	elevation	FS bankfull	FS top of bank	W fpa (ft)	channel slope (%)	Manning's "n" (Used)
LB Pin	0	2.82	12.18	12.12	4.9	47	0.865	0.03
Fence line	9	4.27	10.73	2.88	10.1			
LB Top of Terrace	11.7	4.9	10.1					
	15	7.37	7.63	dimensions				
	20	9.66	5.34	17.2	x-section area		0.7	d mean
Bottom of Left Bank	24.1	11.7	3.3	25.1	width		25.8	wet P
	28.6	12.15	2.85	1.8	d max		0.7	hyd radi
	30.9	11.87	3.13	9.0	bank ht		36.5	w/d ratio
BF	36.9	12.12	2.88	47.0	W flood prone area		1.9	ent ratio
	38.4	12.5	2.5					
LWE	42.9	12.72	2.28	hydraulics				
	47.7	12.72	2.28	3.5	velocity (ft/sec)			
	51	12.54	2.46	60.7	discharge rate, Q (cfs)			
Top of Bank	53.3	12.56	2.44	0.4	shear stress ((lbs/ft sq)			
LBWE (main channel)	54.1	13.35	1.65	0.4	shear velocity (ft/sec)			
TW (Concreet edge)	56.6	13.91	1.09	1.3	unit stream power (lbs/ft/sec)			
RWE	58.2	13.35	1.65	0.6	Froude number			
inserted point	62	12.12	2.88	8.2	friction factor u/u*			
Top of concreet apron	66	10.62	4.38	21.3	threshold grain size (mm)			
RB Pin	73.6	7.85	7.15					
RB Pin	73.6	7.85	7.15	From channel material				
				23	measured D84 (mm)			
				9.1	relative roughness		8.3	fric. factor
				0.030	Manning's n from channel material			

section:	P4 East (B) NMED 6							
	Riffle							
stream:	Pueblo							
location:	Right Bank Pin Latt:35 52 13.424; Long: 106 12 40.525							
description:	Reach P4 East (B) NMED 6 (317.5 ft downstream from NMED 5) Along SR4 Y							
height of instrument (ft):	16							
notes	distance (ft)	FS (ft)	elevation	FS bankfull	FS top of bank	W fpa (ft)	channel slope (%)	Manning's "n" (Used)
Left NMED Pin	0	4.73	11.27	14.1	10.23	25	1.275	0.027
	11.2	6.7	9.3					
	15.2	8.05	7.95					
Fence Line	23.7	9.12	6.88	dimensions				
	28.2	8.8	7.2	9.8	x-section area		1.1	d mean
Top of L Terrace	32.2	10.23	5.77	8.8	width		9.9	wet P
Bottom of L Terrace	32.6	11.98	4.02	1.4	d max		1.0	hyd radi
	37	12.8	3.2	5.3	bank ht		7.9	w/d ratio
	39.2	13.67	2.33	25.0	W flood prone area		2.8	ent ratio
	40.4	13.4	2.6					
	42.5	13.77	2.23	hydraulics				
Bottom of Bank	43.1	14.8	1.2	6.2	velocity (ft/sec)			
LWE	44.9	15.27	0.73	60.6	discharge rate, Q (cfs)			
TW	45.9	15.53	0.47	0.8	shear stress ((lbs/ft sq)			
RWE	50.5	15.31	0.69	0.6	shear velocity (ft/sec)			
BF	51.5	14.1	1.9	5.5	unit stream power (lbs/ft/sec)			
	56.7	14.1	1.9	1.1	Froude number			
	59.2	13.15	2.85	9.7	friction factor u/u*			
Base of "Old" Right Bank deposit	60.7	13.94	2.06	50.9	threshold grain size (mm)			
Top of "Old" Right Bank deposit	61.4	11.36	4.64					
Road Armor Base	76.8	10.91	5.09	From channel material				
Road Armor Top	81	9.55	6.45	22	measured D84 (mm)			
Right NMED Pin	89.7	6.57	9.43	15.4	relative roughness		9.6	fric. factor
				0.027	Manning's n from channel material			

section:	P4 East (B) NMED 7							
	Riffle							
stream:	Pueblo							
location:	Right Bank Pin Latt: 35 52 12.969; Long: 106 12 37.443							
description:	Reach P4 East (B) NMED 7 (266 ft downstream from NMED 6) Along SR4 Y							
height of instrument (ft):	15							
notes	distance (ft)	FS (ft)	elevation	FS bankfull	FS top of bank	W fpa (ft)	channel slope (%)	Manning's "n" (Used)
L NMED Pin	0	7.45	7.55	13.65	11.74	106	0.45	0.032
	3	8.4	6.6					
Toe of Coluvium	11.2	12.02	2.98					
	36	12.17	2.83	dimensions				
	54	11.74	3.26	24.2	x-section area		0.5	d mean
Top LB	56.5	12.2	2.8	45.8	width		46.8	wet P
Inserted value	58	13.65	1.35	1.5	d max		0.5	hyd radi
Bottom LB	59.2	13.92	1.08	3.5	bank ht		86.8	w/d ratio
Fence Line	62.4	14.07	0.93	106.0	W flood prone area		2.3	ent ratio
	68	14.22	0.78					
	68.2	14.59	0.41	hydraulics				
	70.1	14.81	0.19	2.0	velocity (ft/sec)			
	74.4	13.79	1.21	48.5	discharge rate, Q (cfs)			
BF	80.4	13.65	1.35	0.1	shear stress ((lbs/ft sq)			
	85.1	13.77	1.23	0.3	shear velocity (ft/sec)			
	85.9	14.13	0.87	0.3	unit stream power (lbs/ft/sec)			
	91	14.17	0.83	0.2	Froude number			
	92.2	14.71	0.29	7.3	friction factor u/u*			
LWE	94.2	14.74	0.26	8.9	threshold grain size (mm)			
TW	96.6	15.19	-0.19					
RWE	99.2	14.75	0.25	From channel material				
	99.4	14.34	0.66	26	measured D84 (mm)			
	103.8	13.79	1.21	6.2	relative roughness		7.3	fric. factor
Base of old Deposit	105.8	13.43	1.57	0.032	Manning's n from channel material			
Top of Old Deposit	106.8	12.12	2.88					
	109	12.56	2.44					
	111.5	12.57	2.43					
	114.4	13.4	1.6					
Base of Cut Bank	116.6	12.85	2.15					
Top of Cut Bank	117.6	11.14	3.86					
	122	9.41	5.59					
R NMED Pin	125.4	8.56	6.44					

section:	P4 East (B) NMED 8							
	Riffle							
stream:	Pueblo							
location:	Right Bank Pin Latt: 35 52 12.592; Long: 106 12 34.223							
description:	Reach P4 East (B) NMED 8 (298.5 ft downstream from NMED 7) Along SR4 Y							
height of instrument (ft):	15							
notes	distance (ft)	FS (ft)	elevation	FS bankfull	FS top of bank	W fpa (ft)	channel slope (%)	Manning's "n" (Used)
Left NMED Pin	0	3.78	11.22	13.95	11.7	32	2.385	0.033
Rock Ledge	6.75	4.03	10.97					
	7.45	6.98	8.02					
	26.05	8.89	6.11	dimensions				
Coluvium Slope	34.05	10.75	4.25	11.0	-section area		0.5	d mean
Toe (Flood Deposit)	36.05	11.15	3.85	20.1	width		20.6	wet P
	45.55	12.24	2.76	1.0	d max		0.5	hyd radi
	55.85	12.19	2.81	3.3	bank ht		36.9	w/d ratio
	62.55	12.03	2.97	32.0	ood prone area		1.6	ent ratio
	70.55	12.13	2.87					
	83.05	12.13	2.87	hydraulics				
	90.05	12.45	2.55	4.6	velocity (ft/sec)			
	94.25	12.99	2.01	50.2	discharge rate, Q (cfs)			
	98.15	12.71	2.29	0.8	shear stress ((lbs/ft sq)			
	103.25	13.02	1.98	0.6	shear velocity (ft/sec)			
	104.25	13.48	1.52	3.7	unit stream power (lbs/ft/sec)			
	108.05	13.21	1.79	1.2	Froude number			
	111.25	13.6	1.4	7.2	friction factor u/u*			
	111.75	13.78	1.22	51.3	threshold grain size (mm)			
BF	112.25	13.95	1.05					
Top LB	116.65	14.01	0.99	From channel material				
	117.85	14.48	0.52	29	measured D84 (mm)			
LWE (secondary Channel)	118.35	14.76	0.24	5.7	relative roughness		7.2	fric. factor
Sand Bar	121.95	14.56	0.44	0.033	Manning's n from channel material			
LWE	122.95	14.72	0.28					
TW	126.45	14.95	0.05					
RWE	128.35	14.72	0.28					
Bottom RB	132.25	14.26	0.74					
Top RB	132.85	12.64	2.36					
	143.25	12.73	2.27					
	145.45	12.86	2.14					
	147.05	12.62	2.38					
	148.35	12.21	2.79					
	151.05	11.7	3.3					
Fence Line	161.05	11.74	3.26					
	164.05	11.96	3.04					
	172.05	11.87	3.13					
	175.05	11.95	3.05					
Old Channel	184.05	12.17	2.83					
	187.05	11.79	3.21					
	193.05	10.94	4.06					
	199.05	9.95	5.05					
Right Pin	214.55	8.07	6.93					

section:	P4 East (B) NMED 9							
	Riffle							
stream:	Pueblo							
location:	Right Bank Pin Latt: 35 52 11.684; Long: 106 12 29.806							
description:	Reach P4 East (B) NMED 9 (421.5 ft downstream from NMED 8) Along SR4 Y							
height of instrument (ft):	18							
	distance	FS		FS	FS	W fpa	channel	Manning's
notes	(ft)	(ft)	elevation	bankfull	top of bank	(ft)	slope (%)	"n" (Used)
Left Pin	0	7.72	10.28	15.83	13.79	166	2.595	0.029
	4.6	10.04	7.96					
Toe of Coluvium	13.9	13.13	4.87					
	22.6	13.79	4.21	dimensions				
	25.6	14.21	3.79	11.5	x-section area		0.5	d mean
Valley Grass edge	28.6	14.72	3.28	22.8	width		23.6	wet P
	37.6	15.24	2.76	1.5	d max		0.5	hyd radi
	40.1	15.58	2.42	3.5	bank ht		45.4	w/d ratio
	41.6	15.14	2.86	166.0	W flood prone area		7.3	ent ratio
	43	15.6	2.4					
BF (Top of LB)	44.7	15.83	2.17	hydraulics				
Bottom of LB	45.4	16.77	1.23	5.1	velocity (ft/sec)			
LWE (secondary channel	45.9	17.12	0.88	58.7	discharge rate, Q (cfs)			
TW	46.7	17.31	0.69	0.8	shear stress ((lbs/ft sq)			
LWE (secondary channel	47.6	17.11	0.89	0.6	shear velocity (ft/sec)			
Bottom of RB	47.8	17.02	0.98	4.2	unit stream power (lbs/ft/sec)			
Top of RB	48.1	15.99	2.01	1.6	Froude number			
	50.6	15.49	2.51	8.0	friction factor u/u*			
	53.6	15.31	2.69	50.8	threshold grain size (mm)			
	64.2	15.33	2.67					
	65.6	15.53	2.47	From channel material				
	67.6	15.29	2.71	18	measured D84 (mm)			
	79.8	14.98	3.02	8.5	relative roughness		8.1	fric. factor
	80.3	15.19	2.81	0.029	Manning's n from channel material			
	96.8	14.94	3.06					
	107.8	14.9	3.1					
	110.5	15.22	2.78					
	112.4	15.06	2.94					
	116.8	15.02	2.98					
Top of LB (Main Channel)	125	15.7	2.3					
LWE (Main channel)	128.3	16.45	1.55					
Sand Bar	130.6	16.36	1.64					
TW	134.3	16.7	1.3					
RWE	135.4	16.51	1.49					
	139.6	15.94	2.06					
	145.4	15.6	2.4					
	149.4	15.63	2.37					
	150.5	16.09	1.91					
	154.9	16.17	1.83					
	155.9	15.87	2.13					
	165.7	15.74	2.26					
	164.9	15.95	2.05					
	175	15.59	2.41					
Toe of Road Bed	182.1	15.61	2.39					
	190.8	14.32	3.68					
	210.8	8.41	9.59					
Right Pin	220.1	6.48	11.52					

Coordinates of cross section end points

Cross section	North end point		South end point	
	dd mm ss.sss	ddd mm ss.sss	dd mm ss.sss	ddd mm ss.sss
ER-1	35 52 18.260	106 13 04.662	35 52 17.047	106 13 05.502
ER-2	35 52 20.705	106 13 00.942	35 52 15.730	106 13 03.913
ER-3	35 52 18.785	106 12 57.952	35 52 14.893	106 13 00.740
ER-4	35 52 11.609	106 12 57.609	35 52 13.739	106 12 57.927
NMED-1	35 52 15.066	106 12 56.332	35 52 13.624	106 12 56.138
NMED-2	35 52 15.984	106 12 55.311	35 52 13.401	106 12 54.069
NMED-3	35 52 16.263	106 12 51.944	35 52 14.320	106 12 51.414
NMED-4	35 52 15.691	106 12 48.847	35 52 14.637	106 12 48.786
NMED-5	35 52 14.737	106 12 44.065	35 52 13.958	106 12 44.288
NMED-6	35 52 14.305	106 12 40.399	35 52 13.424	106 12 40.525
NMED-7	35 52 14.203	106 12 37.176	35 52 12.969	106 12 37.443
NMED-8	35 52 14.687	106 12 33.992	35 52 12.592	106 12 34.223
NMED-9	35 52 13.660	106 12 28.610	35 52 11.684	106 12 29.806
Geographic Latitude/Longitude North American Datum 1983				

Appendix B.

Summary of Stream Dimensions and Hydraulic Parameters

Dimensions												
	x-section area	**width**	**d max**	**bank ht**	**W flood prone area**	**d mean**	**wet P**	**hyd radi**	**w/d ratio**	**ent ratio**	**slope**	**Sinuosity**
P4 East (A) ER 1	23.53	54.55	1.86	3.57	89	0.43	56.46	0.42	126.44	1.63	0.0135	1.19
P4 East (A) ER 2	25.9	36.9	2.3	5.9	67.0	0.70	37.90	0.68	52.6	1.81	0.0077	1.19
P4 East (A) ER 3	21.52	34.82	1.45	4.85	42	0.62	35.73	0.60	56.34	1.21	0.0110	1.19
P4 East (A) ER 4	18.49	32.85	2.47	6.50	51	0.56	36.15	0.51	58.36	1.55	0.0232	1.19
P4 East (A) NMED1	23.88	37.50	2.95	6.83	77	0.64	39.76	0.60	58.90	2.05	0.0118	1.19
P4 East (B) NMED 2	10.77	19.35	0.93	6.97	22	0.56	19.50	0.55	34.74	1.14	0.0108	1.10
P4 East (B) NMED 3	12.5	15.3	1.8	8.4	136.0	0.82	15.65	0.80	18.7	8.90	0.00885	1.10
P4 East (B) NMED 4	10.9	14.8	1.2	7.4	46.0	0.74	15.23	0.72	20.1	3.11	0.015	1.10
P4 East (B) NMED 5	17.2	25.1	1.8	9.0	47.0	0.69	25.83	0.67	36.5	1.87	0.00865	1.10
P4 East (B) NMED 6	9.8	8.8	1.4	5.3	25.0	1.11	9.88	0.99	7.9	2.84	0.01275	1.10
P4 East (B) NMED 7	24.2	45.8	1.5	3.5	106.0	0.53	46.75	0.52	86.8	2.31	0.0045	1.10
P4 East (B) NMED 8	11.0	20.1	1.0	3.3	32.0	0.55	20.56	0.53	36.9	1.59	0.02385	1.10
P4 East (B) NMED 9	11.5	22.8	1.5	3.5	166.0	0.5	23.6	0.5	45.4	7.3	0.026	1.10
Avg. ER1 - NMED1	22.7	39.3	2.2	5.5	65.2	0.6	41.2	0.6	70.5	1.7	0.0134	1.19
Avg. NMED2 - NMED9	13.5	21.5	1.4	5.9	72.5	0.7	22.1	0.7	35.9	3.6	0.0138	1.1
Hydraulics												
	velocity (ft/sec)	**discharge rate, Q (cfs)**	**shear stress (lbs/ft sq)**	**shear velocity (ft/sec)**	**unit stream power (lbs/ft/sec)**	**Froude number**	**friction factor u/u***	**threshold grain size (mm)**	**measured D84 (mm)**	**relative roughness**	**Manning's n used**	
P4 East (A) ER 1	2.19	51.57	0.35	0.43	0.80	0.35	5.15	20.72	11	11.95	0.044 ("n" for B6 channel)	
P4 East (A) ER 2	2.3	59.5	0.33	0.41	0.769	0.23	5.6	19.1	11	19.45	0.044 ("n" for B6 channel)	
P4 East (A) ER 3	2.53	54.40	0.41	0.46	1.07	0.32	5.48	24.83	11	17.12	0.044 ("n" for B6 channel)	
P4 East (A) ER 4	3.29	60.88	0.74	0.62	2.68	0.60	5.33	47.42	11	15.60	0.044 ("n" for B6 channel)	
P4 East (A) NMED1	2.61	62.26	0.44	0.48	1.22	0.33	5.47	26.63	11	17.64	0.044 ("n" for B6 channel)	
P4 East (B) NMED 2	6.94	74.71	0.37	0.44	2.60	2.68	15.83	22.10	0 (bedrock)		0.015 (float finish concrete)	
P4 East (B) NMED 3	4.3	53.4	0.44	0.48	1.931	0.70	9.0	26.6	20	12.4	0.028	
P4 East (B) NMED 4	5.0	54.8	0.67	0.59	3.464	1.06	8.5	42.4	22	10.2	0.029	
P4 East (B) NMED 5	3.5	60.7	0.36	0.43	1.305	0.56	8.2	21.3	23	9.1	0.030	
P4 East (B) NMED 6	6.2	60.6	0.79	0.64	5.476	1.07	9.7	50.9	22	15.4	0.027	
P4 East (B) NMED 7	2.0	48.5	0.15	0.27	0.297	0.24	7.3	8.9	26	6.2	0.032	
P4 East (B) NMED 8	4.6	50.2	0.79	0.64	3.716	1.19	7.2	51.3	29	5.7	0.033	
P4 East (B) NMED 9	5.1	58.7	0.79	0.64	4.164	1.61	8.0	50.8	18	8.5	0.029	
Avg. ER1- NMED1	2.6	57.7	0.5	0.5	1.3	0.4	5.4	27.7	11.0	16.4		
Avg. NMED2 - NMED9	4.7	57.7	0.5	0.5	2.9	1.1	9.2	34.3	22.9	9.7		

Description of Stream Dimensions and Variable Calculations

The dimensions of key features within a stream valley, their relationships, and variables for characterizing stream channels are outlined below. The ability to characterize and evaluate changes in stream channels can be useful as Los Alamos National Laboratory and the Bureau continue to monitor the effects of the Cerro Grande fire on Pajarito Plateau watersheds.

The method of characterizing stream channels consists of establishing permanent, benchmarked, measurements of stream dimensions (cross-sections and profiles) that can be used to document adjustments to changes in stream flow and sediment supply. These measurements are particularly useful in determining changes in stream stability and provide quantifiable information for determining whether the channels are down cutting, filling in, or eroding new channels. The following descriptions of parameters and calculations are from Dan Mecklenburg (Copyright © 1999 River4m, Ltd).

Stream Dimensions

- Cross-section
  - Bankfull Width (W_{bkf})
  - Bankfull Mean Depth (d_{bkf})
  - Bankfull Cross-section Area (A_{bkf})
  - Width / Depth Ratio (W_{bkf} / d_{bkf})
  - Maximum Bankfull Depth (d_{mbkf})
  - Width of Flood prone Area (W fpa)
  - Flood prone Height (2 x m_{bkf})
  - Entrenchment Ratio (W fpa / W bkf)
  - Thalweg

- Longitudinal Profile
  - Stream Length
  - Valley Length
  - Bankfull Height
  - Waters Edge Height
  - Thalweg Height
  - Terrace Height
  - Sinuosity (Stream Length / Valley Distance)
  - Water Surface Slope (Vertical Distance. Ft. / Linear Distance, Ft)

- Channel Materials
  - Wolman Pebble Count
  - Manning's Coefficient

Physical Location, GPS

- Cross-section End Points
- Thalweg
- Stream Bank Terrace

Descriptions of Stream-Channel Cross-Section Dimensions

Height of Instrument (HI) is the elevation of the survey level. It is found by adding the back sight rod reading to the elevation of a benchmark or turning point.

If the relative elevation is unknown, an arbitrary elevation can be entered. (i.e. 100 feet).

Distance (ft) of the cross-section is the measurement across the stream, from the endpoints of the cross-section.

By convention, distance is measured from left to right when facing down stream.

Foresight (FS) rod readings are vertical distances measured from the level to the ground.

Elevation is found by subtracting the foresight rod reading from the height of the instrument.

Foresight at Bankfull is the rod reading at bankfull stage. Bankfull elevation can then be calculated from this measurement.

Foresight at Top of Bank is the rod reading at the top of the channel banks, which may be a terrace and well above bankfull. Top of Bank elevation can then be calculated from this measurement.

Width of the Flood Prone Area (W fpa) is the flooded width at a stage twice the maximum depth for bankfull stage in a riffle or straight reach. This value is not valid in pool cross-sections.

Channel Slope (S) is the "rise over run" for a reach approximately 20 to 30 bankfull channel widths in length with the "riffle to riffle" surface slope representing the gradient at bankfull stage. Slope is determined from longitudinal profile data.

Manning's Roughness Coefficient value "n" is based on channel materials and stream hydraulic velocities.

Bankfull Cross-Section Area (A_{bkf}) is the area of the stream channel cross-section at bankfull stage in riffle sections of the stream.

Bankfull Width (W_{bkf}) is the width of the stream channel at bankfull stage in riffle sections of a stream.

Maximum Bankfull Depth (d_{mbkf}) is the maximum depth of flow at bankfull stage.

Flood Prone Height ($2 \times d_{mbkf}$) is flood stage height measured at twice the maximum depth in a riffle or straight stream section.

Bank Height is the height of the lowest bank, measured from the channel bed (thalweg) to the top of the bank.

Bank Height helps describe entrenchment. Over-bank flow begins at this stage defined by bank height.

Width of the flood prone area (W_{fpa}) is the flooded width at flood prone height.

It is used to define entrenchment and forms the entrenchment ratio when divided by the bankfull width.

Bankfull Mean Depth (d_{bkf}) = (A_{bkf}) / (W_{bkf})
(A_{bkf}) = cross-section area (square feet)
(W_{bkf}) = width at bankfull stage (feet)

This is the area of the stream channel cross-section at bankfull stage in a riffle cross-section.

Wetted Perimeter (P) (feet) is the perimeter of the channel cross-section formed by the bed and banks.

Hydraulic Radius (R) (feet) = (A_{bkf}) / P
(A_{bkf}) = cross-section area (ft2)
P = wetted perimeter (ft)

Width / Depth Ratio (W_{bkf} / d_{bkf}) is the channel width at bankfull stage divided by the mean depth.

Entrenchment Ratio (W_{fpa} / W_{bkf}) is the flood prone width divided by the bankfull width.

Hydraulic Calculation Formulas

Velocity (V) (ft / sec) = $(1.487 \times R^{2/3} \times (S / 100)^{1/2}) / n$
n = Manning's "n" coefficient

Discharge (Q) (cfs) = V (A_{bkf})

Shear Stress (pounds / ft^2) = 62.4 x R x S
62.4 = density of water (lbs / ft^3)

Shear Velocity = $(32.2 \times R \times S)^{1/2}$
32.2 = gravitational acceleration (ft / sec^2)

Unit Stream Velocity = power / unit area = $(62.4 \times Q \times S) / W_{bkf}$
Power = density of water x flow x slope

Froude number = V^2 / 32.2 x Maximum Bankfull Depth (d_{mbkf})

This is a dimensionless number expressing the ratio of inertial to gravitational forces. Values less than 1 are termed sub critical and are characteristic of relatively deep, slow stream flow. Values greater than 1 are termed supercritical and are characteristic of shallow fast streams.

Friction Factor = V/ shear velocity
Values vary from about 2 for rough streambeds to 16 for smooth.

Threshold grain size (mm) is the size particles predicted to be at "the threshold of motion" at the shear stress calculated. It is found from Shield's curve, which is a plot of particle size against the critical shear stress or the shear stress required to initiate movement.

Descriptions of Channel Material Measurements

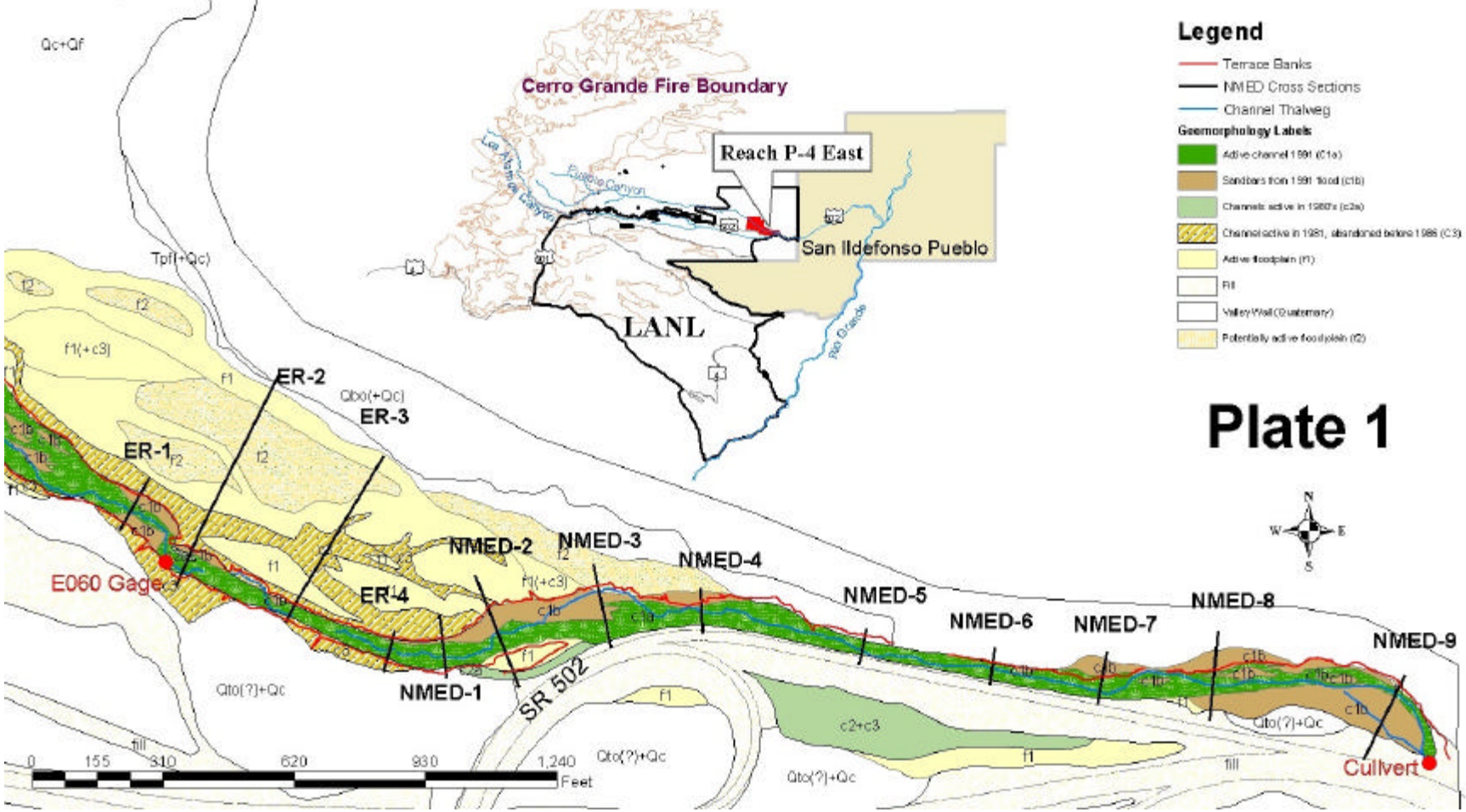
Measured D84 (mm), the particle size where 84% of the particles are this size or smaller.

Relative roughness = Maximum Bankfull Depth (d_{mbkf}) / D84

Friction Factor = 62.83 + 5.7 log (Maximum Bankfull Depth (d_{mbkf}) / D84)

Manning's "n" coefficient can be back calculated using velocities found from the relationships

Friction Factor = V / shear velocity
and
Friction Factor = (2.83 + 5.7 log (Maximum Bankfull Depth (d_{mbkf}) / D84))
so
Velocity = shear velocity x (2.83 + 5.7 log (Maximum Bankfull Depth (d_{mbkf}) / D84)

Manning's equation can be solved for "n" using this velocity and bed material size.

Pueblo Canyon, Reach P4 East: NMED Cross Section and Terrace Boundaries