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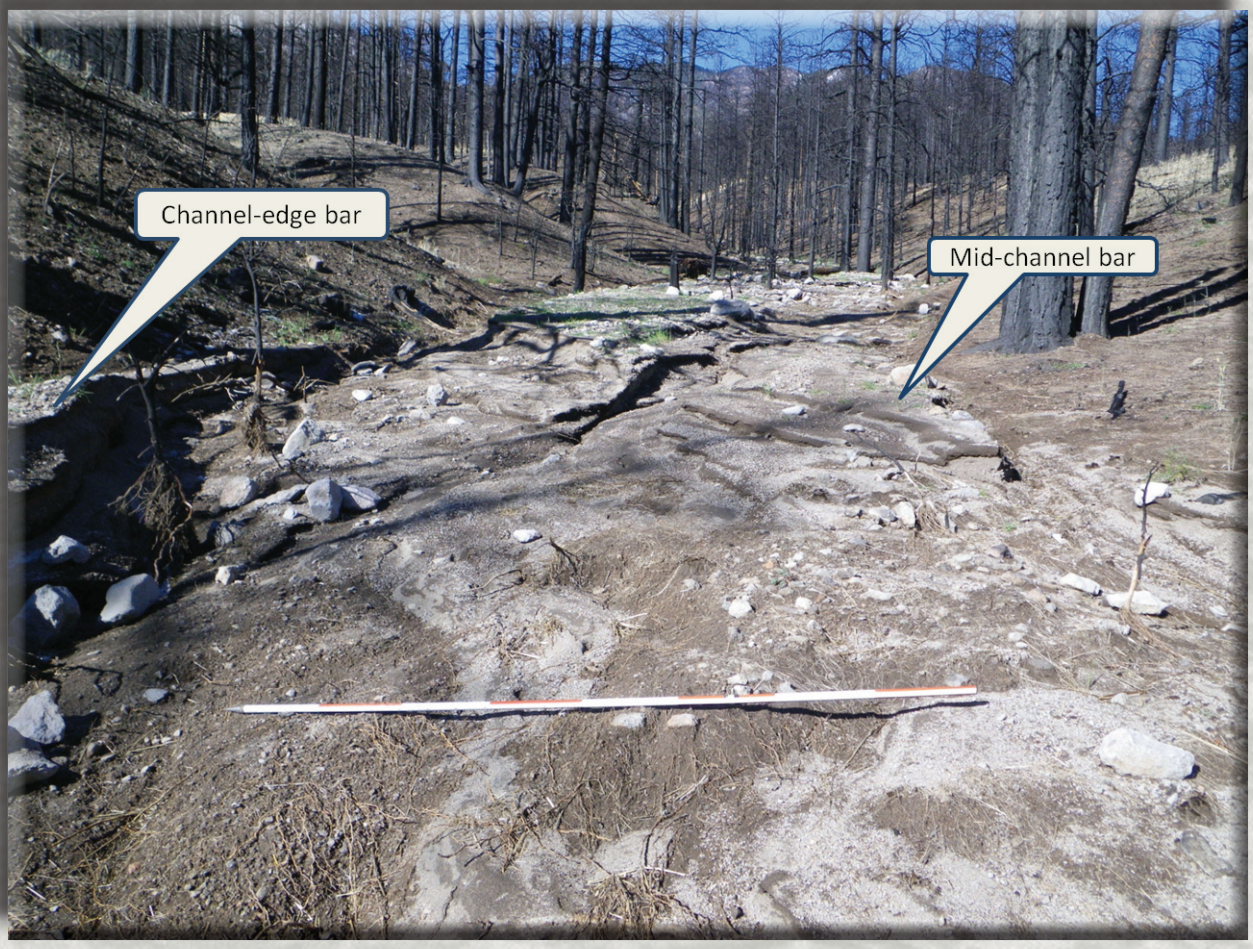

Movement of Channel-Borne Sediments in the 2010 Schultz Fire Burn Area

June 2011

Michael D. Carroll

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MOVEMENT

OF CHANNEL-BORNE SEDIMENTS

IN THE 2010 SCHULTZ FIRE BURN AREA

BY MICHAEL D. CARROLL

A Thesis

Submitted in Partial Fulfillment

Of the Requirements for the Degree of

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ABSTRACT

MOVEMENT OF CHANNEL-BORNE SEDIMENTS IN THE 2010 SCHULTZ FIRE BURN AREA

MICHAEL D. CARROLL

The 2010 Schultz Fire burned 6,091 hectares (15,051 acres) of Ponderosa Pine and mixed conifer forest, four kilometers (two and a half miles) north of Flagstaff, Arizona between June 20 and 30, 2010. Sixty-seven percent of the affected area burned at moderate to high intensity, destroying much of the vegetation and organic duff layer that previously covered the forest floor. The intensity of the fire, granular soils, and steep slopes made the burn area highly susceptible to the generation of debris flows and hyperconcentrated flows by runoff from intense summer monsoon storms common in the area. The first storm to generate such flows from the burn area occurred on July 16, with the largest occurring on July 20, exactly one month after ignition of the fire. On July 20, a 10-yr Average Recurrence Interval (ARI) storm dropped up to 92 mm (3.6 in) of rain on the area. The resulting flows damaged houses and infrastructure in the communities immediately downstream of the burn area. This thesis presents the results of a study undertaken to gain an understanding of the type and amount of sediments located in the burn area channels, and available for mobilization and transport by future storm flows.

The U. S. D. A. Forest Service, Burned Area Emergency Response (BAER) team divided the burn area into 11 sub-watersheds. This study focused on watershed 7, the Rope-Arabian-Campbell watershed (named for directly-affected streets at the

wildland-urban interface), because of the intensity of the July 20 flows and the likelihood of runoff and flows from it having direct impacts on downstream communities during future storm events.

Field investigations took place in the fall and early winter of 2010, after the summer monsoon storms and before heavy winter snow. A 15" latitude and longitude grid was overlain on a map of the area and channel cross sections were developed at each channel-grid intersection. This resulted in 42 study sites, with additional investigation throughout the subject watershed. Channel cross section development included measuring; the channel bed profile, post-fire sediment thickness, channel slope, and conducting grain size analysis on post-fire sediments using either, sieve analysis or pebble counts as necessary based on maximum particle size.

The study revealed that the channel network changed substantially during the summer monsoon storms following the fire. Reaches with slopes greater than 40% tend to be scoured two to three meters unless scour stopped at bedrock. Post-fire debris-flow and hyperconcentrated-flow deposits left by larger storms were, and continue to be, reworked by lesser storms. There is over 15,500 m^3 (20,273 yd^3) of post-fire sediment available to be transported downstream through the burn area. The main factors in determining the amount of sediment that will be transported out of the burn area appear to be the volumetric flow rate / velocity and the duration of runoff that the channels experience. An increased understanding of the sediment transport processes occurring in the burn area is needed, as it is important when planning measures to mitigate downstream damages from the

sediment that will be transported within and from the burn area over the next ten to twenty years.

Acknowledgments

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Flagstaff, AZ
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I. Introduction

A. The Schultz Fire

As detailed on the multi agency Incident Information System web site "http://inciweb.org/incident/1996/", the Schultz Fire originated from an abandoned campfire at approximately 11 am June 20, 2010, four kilometers (two and a half miles) north of Flagstaff, Arizona (see Figure 1). High winds quickly spread the fire through dense Ponderosa Pine and mixed conifer forest burning 6,091 hectares (15,051 acres) before being declared 100% contained on June 30, 2010. The fire burned across terrain with slopes ranging from 5 to 25 % in the piedmont and up to 100 % in the mountain highlands. Sixty seven percent of the burn area experienced moderate to high burn severity, a categorization indicative of nearly complete destruction of all tree and vegetative cover as well as much of the organic material covering the forest floor and comprising the upper portion of the soil profile (USDA Forest Service, 2010). Removal of the forest floor organic duff and litter exposed the underlying mineral soils to severe erosion by intense monsoon thunderstorms. The burn severity in the watersheds created conditions favorable for the formation of debris flows and hyperconcentrated flows. It is likely that while the magnitude of floods from a given amount of precipitation will diminish as time passes, the conditions favorable to flood formation will persist in the watershed for the next ten to twenty years (Haessig, 2010; Meyer et al, 2001).

Figure 1: Location of 2010 Schultz Fire within Arizona. (Google Maps 2010)

B. Description of the burned area

1. Topography

The burned area, outlined in red on Figure 2, is located near the southern edge of the Colorado Plateau on the eastern flanks of the San Francisco Peaks. The area includes piedmont from 2,200 m (7,218 ft) elevation to mountain peaks reaching to 3,368 m (11,050 ft) elevation. Soils in the area range from bare volcanic rock or soil a few centimeters thick on the higher mountain slopes to granular colluvial soils tens of meters thick covering the lower piedmont areas. The area was

extensively logged in the early 1900's leaving a network of unmaintained natural surface roads, which were eroded during post-fire runoff. In early 2011, the Coconino National Forest took measures to minimize this erosion.

The drainage channels leading from the mountain slopes of the burned watersheds spill out onto a land form known in the southwestern U.S. as a bajada, which is a moderately-sloping alluvial plain formed by the coalescing of adjacent alluvial fans (Parker, 1997). The bajada forms part of the piedmont region lying between the mountain slopes and the relatively flat valley floor. Beyond and downstream of the eastern edge of the burn area, the land surface has been modified by human activity, including several decades of agricultural use and more recent subdivision development with associated homes, roads, and utility infrastructure.

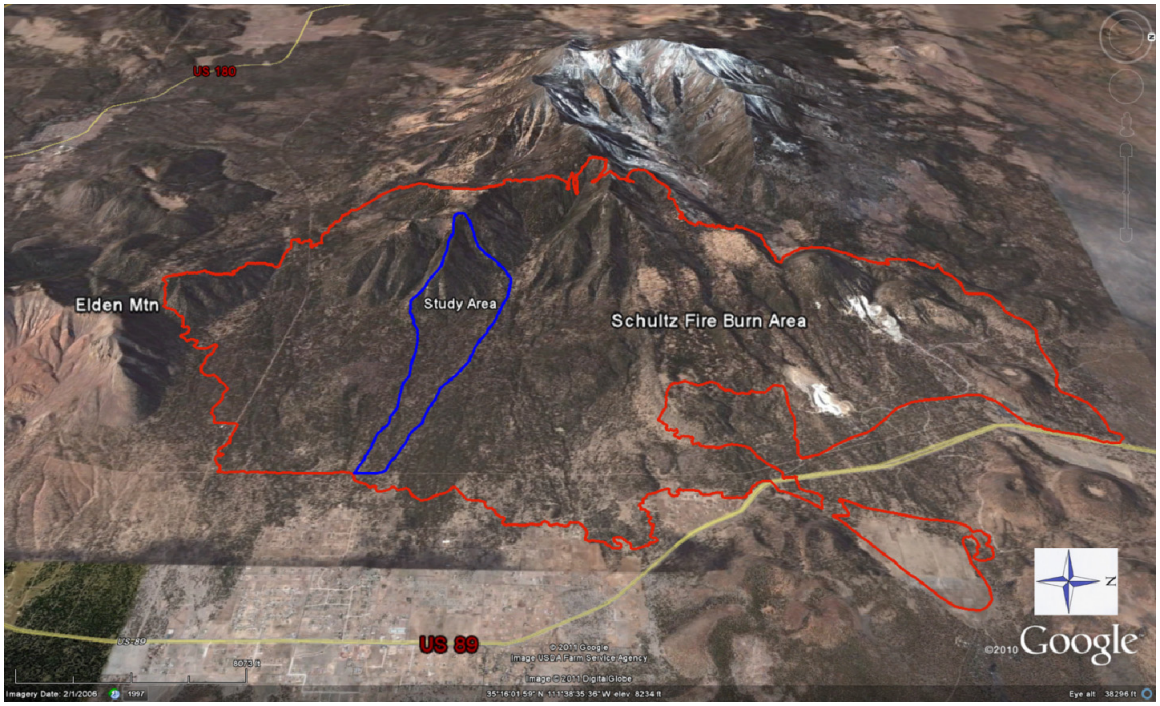


Figure 2: Looking west, Schultz Burn boundary in red and study watershed boundary in blue (Google Earth 2011)

C. Purpose of this study

Watershed hydrologic processes are highly-altered in the post-wildfire environment. Understanding how these changes are manifested at the local channel level and on a watershed scale will help provide information necessary to mitigate anticipated impacts from debris, hyperconcentrated, and flood flows. Investigation into post-wildfire watershed-level channel processes is needed to understand the dynamics of these processes occurring within the burn area. The knowledge gained can then be used to enhance comprehension of the landscape-scale processes occurring in the wildfire-influenced system (Cannon, 2001b; Neary et al., 2006).

Data and observations gained from detailed channel-level studies is invaluable for quantifying post-fire sedimentation following wildfire. The high degree of variability in natural drainage systems, both within a single channel and between nearby channels, requires field verification to determine which findings from one locality can be applied to another location in the same region. The body of knowledge so built will help scientists, engineers, and community leaders plan for and implement mitigation measures to minimize wildfire impacts. This knowledge can also be utilized in future developments and improvements to existing infrastructure by informing and guiding regional risk assessments of potential hazards from post-fire sedimentation. In an effort to contribute to this body of knowledge, this study focused on sediment transport processes in the Rope-Arabian-Campbell watershed (also referred to as sub-basin 7) of the 2010 Schultz Fire burn area (see Figure 13 and Maps in Appendix A). The main question to

answer is how much post-fire sediment is present that can be readily mobilized and moved downstream by future runoff. To estimate this sediment volume one must first understand the processes at work within the watershed that transport and stabilize sediments.

D. Limitation of the study

Several factors limited this study. First, the short time period available to conduct field surveys limited the amount of data that could be collected. Fieldwork began as soon as access to the burn area was granted. Surveys were conducted from late October thru December 2010, following the end of the monsoon precipitation events that resulted in debris, hyperconcentrated, and flood flows. Second, evidence of the effect each flow had on the previous flow's deposits was obscured and very difficult to decipher. Additionally, there were no detailed data available on channel morphology and conditions prior to the fire, nor subsequent floods in the study-area channel system. Lastly, fieldwork was limited to the portion of the watershed below the Waterline Road, (see Map 1 in Appendix A). A reconnaissance of the area revealed that it was not safe to do detailed study above the Waterline Road because of the dangerous footing created by slopes nearing 100% that were covered with straw mulch aerially placed a few days prior to access being granted. This last restriction had minimal adverse impact on the study as the major portion of the channels on these steep upper slopes had been scoured to bedrock. Thus, while high-velocity, sediment-starved water emanating from channels near the Waterline Road had an impact on sediment transport processes below the road, there was

little sediment remaining in the channels above the roads poised to move downstream.

II. Literature review

One of the challenges of investigating sediment transport processes in burned areas is the difficulty in making direct observations. Burn area channels are dangerous during storms, and the timing and location of flows are unpredictable. Normally, investigators arrive after an event and at best have fresh sediment deposits to examine. What actually happened during runoff events is open to interpretation. More puzzling questions arise if investigators are not able to examine the deposits until after several runoff events have occurred. Such was the situation with this study. In the three months following the fire, there were at least five storms resulting in debris, hyperconcentrated, and flood flows passing thru the study area. The largest of these events occurred on July 20 and August 16, 2010.

The process of sediment transport occupies a continuum, from clear water stream flow, through stream flow with solid transport and hyperconcentrated flow, to debris flow. Clearly-defined boundaries between flow types probably do not exist and a definition based on a single easily measurable criterion is not feasible (Coussot and Meunier, 1996; Pierson, 2005). There are characteristics of these flows that are recognizable and can be used to give a general idea of the flow type. These characteristics will are addressed in the following sections. For the purpose of this post-fire sediment transport study, flows are classified as flood flow, hyperconcentrated flow, or debris flow.

A. Properties of flows

1. Flood flow

Flood flow is flowing water in which the sediment concentration is small enough that it does not affect flow behavior, i.e. it is essentially a Newtonian fluid. John Costa (1988) states that flood flows can contain up to 40% by weight (20% by volume) solid material. However, Pierson (2005) states that sediment concentration alone should not be used to define flows. Flood flow can transport a considerable amount of sediment of varying particle size depending on flow volume and velocity. In flood flow, sediment and water form two distinct phases, one in the upper portion of the flow, the other near the channel bed. Sediment is suspended in the flowing water, or it is rolled or saltated along the channel bed by the force of the flowing water. This results in the two phases moving at different speeds. Flood flow can scour and aggrade channels, though not as dramatically as a debris flow (Costa, 1988; Coussot and Meunier, 1996).

2. Hyperconcentrated flows

The next step up the flow regime is hyperconcentrated flow. These flows are described as two-phase fluids in which the larger particles move along the lower portion of the flow with velocities less than the much more fluid upper portion of the flow (Coussot and Meunier, 1996). Hyperconcentrated flows are flowing mixtures of water and sediment that possess measurable yield strength (i.e. they are non-Newtonian fluids) but still look like stream flow, with one notable exception.

Hyperconcentrated flows display a distinct dampening of turbulence (Pierson and Costa, 1987) and contain sediment concentrations in the 40 to 70% by weight (20 to 47% by volume) range (Costa, 1988; Coussot and Meunier, 1996). The yield strength these flows possess is a function of the suspended sediment present in the flow with the concentration of fine sediment (less than 0.075 mm (0.003 in) a key parameter. Water carrying sand and gravel at concentrations as high as 35%, by volume, can move as a flood flow. However, the addition of as little as 10%, by volume, clay can transform the material into a hyperconcentrated flow.

The erosive or depositional power of hyperconcentrated flows varies with the concentration of suspended sediments. These flows can rapidly scour a channel tens of meters deep or just as rapidly fill a channel with sediment (Pierson, 2005). Hyperconcentrated flows are similar to flood flows in their response to changes in watershed hydrologic conditions (Pierson and Costa, 1987) e.g. flow volume is controlled by watershed time of concentration and rainfall duration and intensity.

3. Debris flows

As the percentage of sediment entrained in the flow increases, a threshold is reached where there is a rapid increase in shear strength. Pierson and Costa (1987) used this increase in shear strength to delineate the lower boundary for debris flows. They describe this type of flow as a mixture of sediment and water with high enough yield strength to possess plastic flow behavior (Pierson and Costa, 1987). Debris flows observed in the field and those in experimental flumes display a very similar characteristic flow behavior. In both situations, the flows form steep surge

fronts of coarse-grained material that is highly resistant to moving downstream. These surge fronts do not contain measurable pore-fluid pressure, and are pushed along by relatively fine-grained and water-rich debris-flow tails that have a wide range of pore-fluid pressures, with some being twice as high as hydrostatic (Iverson, 1997; Pierson and Costa, 1987). Debris flows may leave lateral levees composed of coarse material from the lobate surge front. The flow behavior enables debris flows to carry gravel and larger particles in suspension while becoming partially liquefied as they are remolded while moving down slope. Particles that exceed the flow's suspension capability, such as large boulders, are often rolled down the channel by the mass of the flow (McCoy et al., 2010; Pierson and Costa, 1987).

A key characteristic of a debris flow is the strong transient nature of sediment entrainment. This can form periodic surges of heavily debris-laden slurry (often greater than 60 % solids by volume) with intervening periods of relatively low or no flow (Coussot and Meunier, 1996) once a debris flow has stopped moving it can leave deposits with a characteristic lack of grain size sorting in their vertical profile. However, there is often a higher concentration of large boulders in the surge-front deposits (Iverson, 1997; Coussot and Meunier, 1996). The central part of a debris flow resembles a hyperconcentrated flow, which pushes the lobate surge front forward and generally contains 40% to 60% solid material by volume. This concentration is less than that in the flow's frontal lobe, which may contain more than 60% solid material, by volume (Coussot and Meunier, 1996). Debris flows essentially move as a single-phase viscous fluid in which the water and solid portions move downstream at the same speed.

Since they rarely observe debris flows in the field, researchers normally rely on detailed inspection of channel scour characteristics and sediment deposits to interpret these events. While this method has its limitations, considerable information can be gleaned from such deposits. While hyperconcentrated flow deposits display grain-size sorting similar to flood flow deposits, debris flow deposits do not show this vertical sorting (Iverson, 1997). There is, however, a tendency for the concentration of large boulders to be greater in a debris-flow surge front than the center or tail of the debris flow (Coussot, 1996, Iverson, 1997). This is a function of the way debris flows move and form deposits. In addition to these characteristics, an interpretation of flow deposits must consider that it is likely that more than one process operated within the channel during the same event (Cannon, 2001); i.e., initial debris flows may be followed by hyperconcentrated flows and flood flows during the same storm.

As discussed above, debris flows and hyperconcentrated flows have very different characteristics, with debris flows being the less common but much more energetic type of flow capable of rapidly scouring channels and destroying structures. Debris flows often occur with the first major runoff event from a burned area with most, but not all, subsequent runoff consisting of hyperconcentrated flows or flood flow (Cannon et al., 2001b). There is a tendency for debris flows to reoccur three to ten years after a fire when roots from trees killed in the fire decay to the point that they no longer provide deep soil stabilization (Haessig, 2010; Meyer et al., 2001). These soil failures consist of slabs of soil often a meter or thicker breaking loose from steep slopes adjacent to channels as the holding capacity of the tree roots

degrades over time, resulting in a recharge of sediment to channels by colluvial slope processes. This process is separate from the surface erosion that grasses and small shrubs can help reduce. During rain events such slope failures may trigger larger landslides and potentially supply sediments to debris flows. On the other hand, hyperconcentrated flows may continue to occur for tens of years after a fire (Meyer et al., 2001).

B. Channel sedimentation processes from burn areas

When wildfire affects a mountainous area, it changes the dynamics of sediment transport both within the channel and across the landscape. The movement of sediment into channels and its further transportation downstream through the drainage network occurs in a stochastic process controlled by local weather, climatic, topographic, geologic, and biotic controls that vary from region to region (Benda and Dunne, 1997). The influence each of these variables has will likely change as climate changes. A manifestation of this is revealed in the convergence of changes in weather patterns, increased forest stand density (usually the result of the last hundred years of timber management practices), and increased fuel loads from the historic practice of total wildfire suppression. Historically, the immediate effects from wildfire were generally limited to the burn area and immediate downstream locations. However, as climate changes and the frequency, size, and severity of wildfires continues to increase, the extent of these affected areas may also increase (Neary et al. 2006; Moody et al. 2008; Youberg, 2008).

In a study of sediment, yields after wildfire in the western United States Moody and Martin (2009) determined that the sediment yield from channels in burned areas were greater than the sediment yield from adjacent hill slopes. They also determined that while the nature of post fire sedimentation is localized and episodic, sediment yields did not significantly correlate with slope or hill-slope soil erodibility. This indicates that sediment availability may be more important than slope or soil erodibility in estimating post fire sediment yields. The sporadic nature of sediment yield processes indicates that sediments may accumulate in channels for tens to hundreds of years before being mobilized by high-intensity runoff events. The magnitude, duration, and recurrence of these events are controlled by the specific topographic, geologic, and climatic characteristics of the watershed (Benda and Dunne, 1997).

1. Watershed response to wildfire

One response to wildfire in watersheds is a change in the shape of the storm-runoff hydrograph for a given precipitation event. Post-fire peak storm flows tend to be dramatically higher magnitude than pre-fire hydrographs while maintaining nearly the same duration of pre-fire stormwater runoff (Earles et al. 2004: Nelson, Woodruff, and Dixon, 1999). Following the 1996 Chino Well Fire in SE New Mexico fire, the Mud Canyon Basin produced a 100-year runoff event in response to a 5-year storm (Nelson, Woodruff, and Dixon, 1999). This phenomenon was again demonstrated following the 2000 Cerro Grande Fire in north central New Mexico. Following that fire, the HEC-1 hydrology computer program was used to develope a

calibrated model that was used to simulate pre-fire and post-fire storm flow for the Pueblo Canyon watershed (Earles et al., 2004). The resulting hydrographs, shown in Figure 3, show a 663% increase in peak flow and 336% increase in total runoff from the watershed after the fire, without increase in the duration of stormwater runoff. This magnification phenomenon tends to lessen as the number of years since the fire increases.

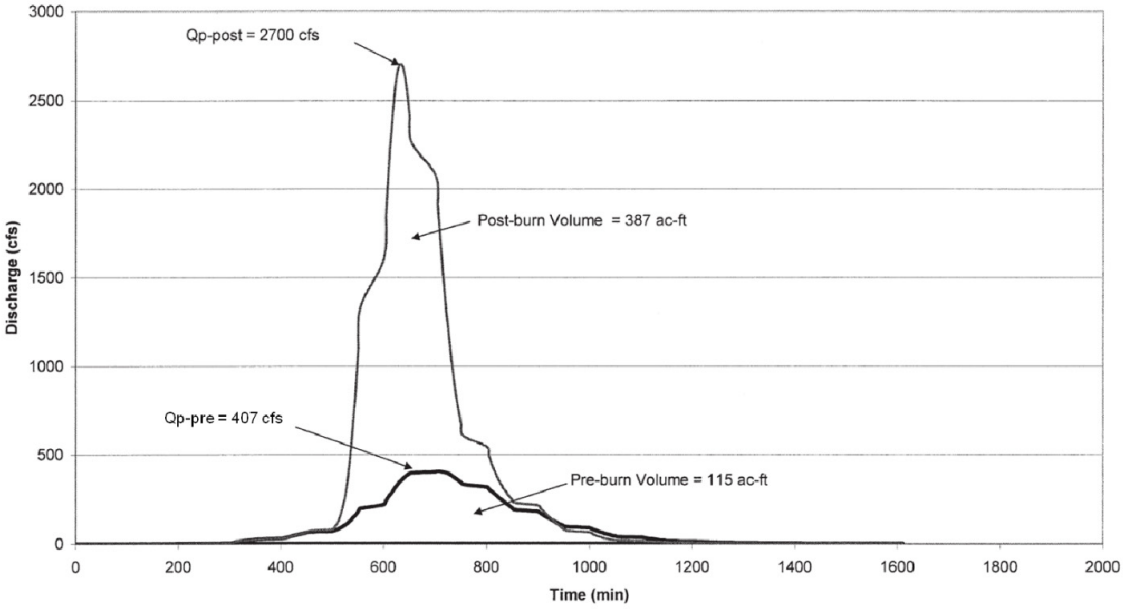


Figure 3: Modeled pre- and post-fire hydrographs for Pueblo Canyon, NM, following The 2000 Cerro Grande wildfire. (Earles et al., 2004)

One of the greatest problems with predicting debris flows is the uncertainty over which events will combine to produce a flow. Seemingly similar circumstances will result in sediment movement by hyperconcentrated flow in one instance and by debris flow in another (Keller, Valentine, and Gibbs, 1997). The inability to accurately predict what type of flow will occur is indicative of insufficient

understanding of the interaction between the underlying factors of; precipitation intensity, burn severity, and watershed geomorphology that influence how watersheds respond to wildfire. Even within a single channel, the characteristics of flows moving material may change substantially within a single event, ranging across the continuum from debris flow through hyperconcentrated flow to sediment-laden stream flow (Wondzell and King, 2003).

A watershed characteristic that is particularly relevant to Arizona is the likelihood that channel systems will be transport-limited much of the time. As summer monsoon storms deliver intense short duration precipitation, much of the material eroded from hill slopes and mobilized from channels will be transported only a short distance downstream before coming to rest in the channel. This material will remain there, temporarily stored until a larger event flushes it further down the channel. This process can cause major changes in channel morphology both in the burned area and in downstream areas. Debris flows and hyperconcentrated flows may transport large volumes of sediment out of the burn area, causing downstream damage. Additionally, the buildup of sediments can raise channel beds resulting in overbank flooding (Keller, Valentine, and Gibbs, 1997; Neary et al. 2006; Wondzell, and King, 2003).

A somewhat less-prominent process that delivers sediment to channels is dry ravel. Material moves down steep slopes (generally greater than 60%) without the assistance of flowing water by this process. The material builds up in channels and is stored, ready to be moved downstream by the next significant runoff event (Wondzell and King, 2003).

2. Long term processes

As the number of years since a fire increases, the watershed generally passes from a transport-limited system to a sediment-limited system. The driving force behind this transition involves a combination of the reduction in the volume of sediment transported to the channels and the continued downstream movement of post-fire sediment already present in the channels. As a watershed recovers from wildfire the re-growth of herbaceous vegetation, reformation of the organic duff layer, and the reduction of fire-induced soil water-repellency combine to reduce the volume of sediment entering the channels. At the same time, the continued downstream movement of sediment present in the channels reduces the amount available for transport, resulting in a sediment-limited system (Meyer, 2001). As discussed previously this pattern may be interrupted between three to ten years post-fire with a temporary increase in sediment yield due to landslides and debris flows.

III. Study area

A. Overview

The study area consists of the 406-hectare (1003-acre) Rope-Arabian-Campbell watershed located within the Schultz Fire burn area on the eastern flank of Schultz Peak of the San Francisco Peaks. The watershed forms an elongated oval 5.5 km (3.4 mi) long in the east west direction and 1 km (0.6 mi) wide near its mid-

section, with altitudes in the area ranging from 2,200 m (7,218 ft) at the lower end of the watershed to 3,046 m (9,976 ft) near the summit of Schultz Peak. As depicted in Figure 4 and Appendix A, the area is bounded on the east by the power line near the wildland urban interface (WUI) at the boundary between National Forest and private land, and runs westerly to near the summit of Schultz Peak. The central channel of the watershed is 5.9 km (3.7 mi) long with an 890 m (2920 ft) elevation change creating an overall slope of 15%. Local channel slopes range from a low of 5% to a high of 73%.

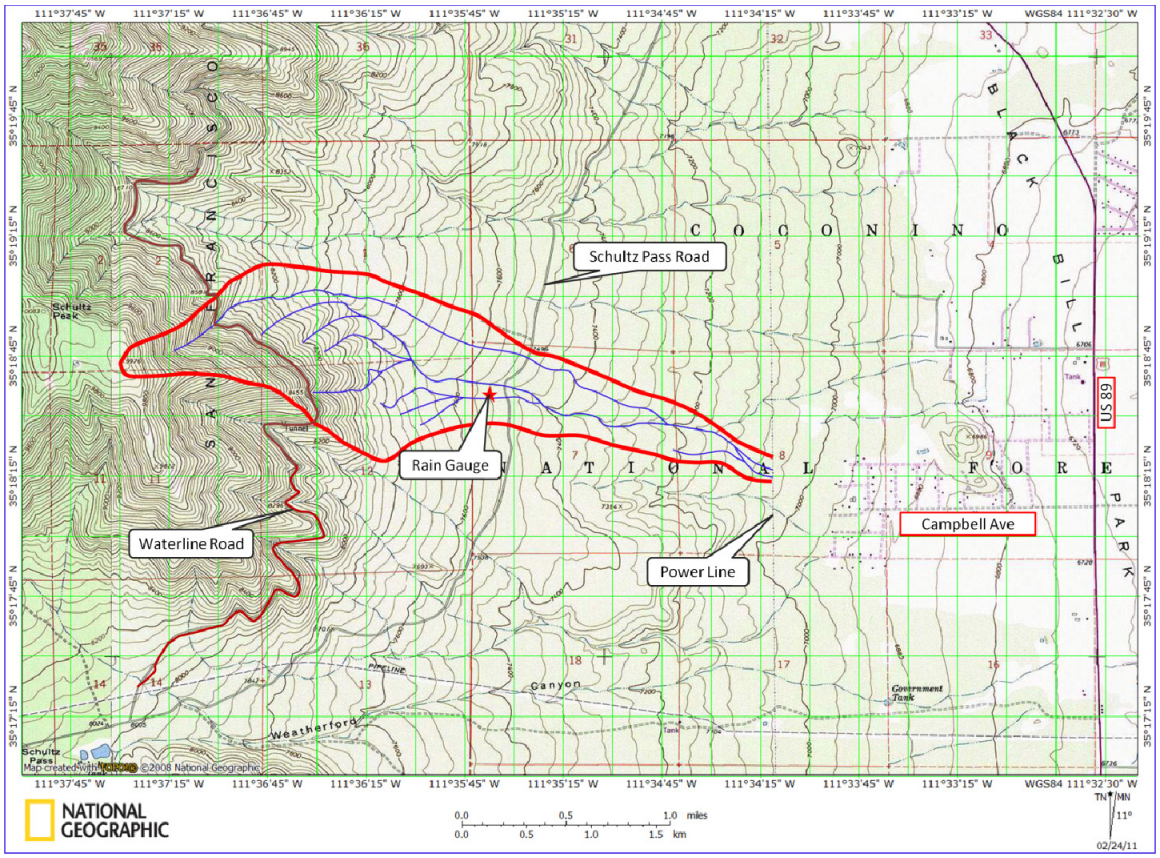


Figure 4: Study watershed outlined in red with main channels indicated in blue. Note that the channel paths do not always agree with those printed on the original USGS topographic map.

The area is comprised of volcanic bedrock overlain by highly erodible granular soils with low amounts of clay. These soils are classified as sandy loams, loamy skeletal, and deep cobbley sandy loams with 15 to 35% rock fragments in the 2.5 to 25 cm (1 to 9.8 in) size range exposed on the surface (Haessig, 2010). Soils at higher elevations are often less than ¼ m (4/5 ft) thick and generally thicken in the lower piedmont such that there are very-limited exposures of bedrock below 2,500 m (8,200 ft) elevation within the study area.

Prior to the fire, the area was covered with Ponderosa Pine forest on the lower elevations and mixed-conifer and aspen forest at elevations generally above 2,400 m (7,874 ft). The stands of trees were a mix of young dog-hair thickets interspaced among mid-age to mature trees. There was little shrubby vegetation whose roots could survive the fire and grow back providing root support to the soil in the near future. The exception is in some locations on slopes above 2,400 m (7,874 ft) where Aspen shoots sprouted after the summer 2010 rains.

The lower part of the study area consists of mainly Holocene to middle-Pliocene volcanic material and Quaternary surface deposits with a small amount of Paleozoic sedimentary rocks (Haessig, 2010). The surface deposits are mixtures of course to fine material and poorly sorted alluvial fan deposits. Higher up in the watershed, above 2,400 m (7,874 ft) elevation, bedrock exposures show highly fractured volcanic rock. There is no written record of debris flow activity in the area prior to July 2010. However, subsequent investigation of the area reveals evidence of multiple debris flows in the past several hundred years. The presence of large trees in the channels and on flow deposits indicates that the responsible flows

occurred more than 80 years ago (Haessig, 2010). However, specific study such as tree coring was not done to date the flows. In the BAER Team Report, geologist Polly Haessig states that some flows may have occurred after the area was logged in the early 1900's (Haessig, 2010). Debris flow and fluvial deposits laid down prior to 2010 have been incised by recent post-fire erosion.

Details of the severity of burn the watershed suffered are given in Table 1. All of the unburned and low burn severity areas occurred in the lower piedmont section of the study area. These areas have slopes less than 10%.

Table 1: Burn severity of Rope-Arabian-Campbell watershed (Higginson, 2010)

Burn severity	Area (hectares)	% of watershed
Unburned	23	6
Low	19	5
Moderate	74	18
High	290	71

B. Weather conditions summer and fall 2010

The 2010 monsoon season proved to be the fourth wettest on record for the Flagstaff Area. In the three months following the fire there were at least six storms that produced enough rain to create runoff from the burned area. The first of these occurred on July 16 and produced ash and sediment-laden flows, but at low enough

volume and intensity to do little damage outside the burned area (National Weather Service, 2010).

The largest storm in spatial coverage and intensity occurred on July 20. During that storm the burned area received 25 to 75 mm (1 to 3 in) of rain, with 45 mm (1.8 inch) falling in less than one hour. Rain gauges in the burned area indicated that the first 25 mm (1 in) of rain fell in less than 15 minutes, which corresponds to an hourly rate of 100 mm/hr (3.9 inches/hr). This event produced multiple debris flows and hyperconcentrated flows from the burn area (National Weather Service, 2010). Rainfall intensities from NOAA Atlas 14 (see Table 2) suggest that the storm had an average return interval (ARI) of nearly 10 years (NOAA Atlas 14, 2010).

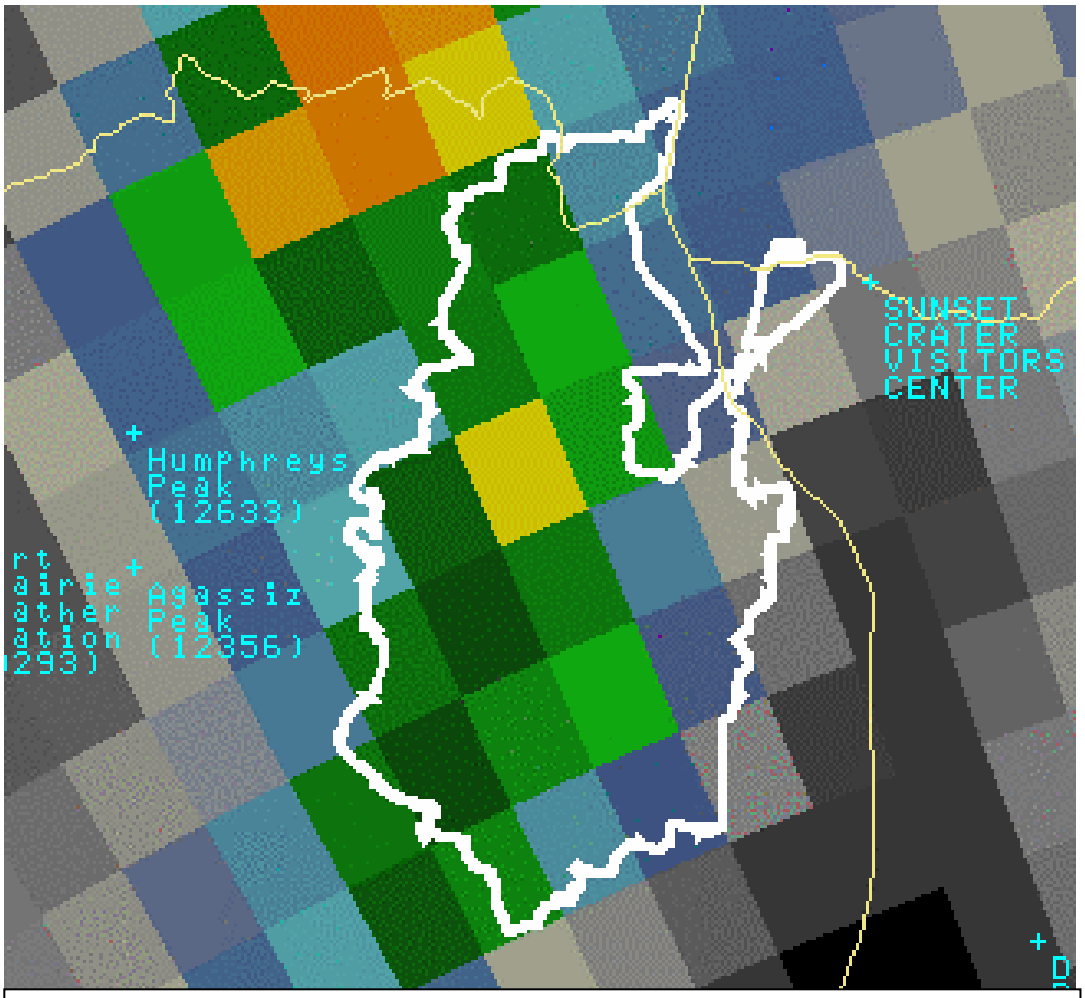
Table 2: NOAA estimates of expected rainfall intensities near the Yavapai County Alert sensor number 3460 (35.30917 N 111.5925 W), used to measure the rainfall data detailed below (NOAA Atlas 14, 2010)

Average Recurance Interval (years)	Precipitation Frequency Estimates (mm)						Average Recurance Interval (years)	Precipitation Intensity Estimates (mm/hr)				
	5 min	10 min	15 min	30 min	60 min			5 min	10 min	15 min	30 min	60 min
1	6	9	11	15	18		1	69	53	44	29	18
2	7	11	14	19	24		2	90	68	57	38	24
5	10	15	19	26	32		5	121	92	76	51	32
10	12	19	23	31	39		10	147	112	93	62	39
25	15	23	29	39	48		25	184	141	116	78	48
50	18	27	34	46	56		50	215	164	135	91	56
100	21	32	39	53	65		100	249	189	157	105	65
200	24	36	45	60	75		200	286	217	180	121	75
500	28	43	53	72	89		500	339	258	213	144	89
1000	32	49	61	82	101		1000	386	293	243	163	101
* These precipitation frequency estimates are based on a partial duration series.												

In the weeks and months following the fire, a cooperative effort between the Coconino National Forest, the National Weather Service, and Coconino and Yavapai Counties resulted in seven rain gauges being installed in the burn area. One of those, gauge number 3460, is located in the study area near the point that Schultz Pass Road crosses the main channel (see Figure 13 or Map 1 appendix A). This gauge was activated on July 11, 2010 and recorded rainfall in the study area for all the major rainstorms after the fire. Rain data for sensor 3460 can be obtained from the Yavapai County Alert page (http://hydrolynx.co.yavapai.az.us/histdata.html?FN=rain) (Note: as of 2011, this site requires the use of Internet Explorer web browser.) The last large monsoon storm of the season occurred on August 16. This storm delivered 27 mm (1.1 in) of rain in 45 minutes, giving it a 5 yr ARI, and initiated debris flows and hyperconcentrated flows from several sub-watersheds in the burn area (National Weather Service, 2010).

The National Weather Service used Doppler radar information to measure storm rainfall totals over the burn area and determined that rainfall intensities could vary widely within the burn area (see Figure 5). Typically, higher elevations receive more total rainfall and at higher intensity than locations only a kilometer or two distant, lower in the piedmont (National Weather Service, 2010). Total rainfall estimations using Doppler radar for the July 20 storm show the western portion (higher elevations) of the Schultz Fire burn area received as much as twice the rainfall as the eastern portion (lower elevations) of the burn area. This contrast is relevant, because the rainfall data used in this study were gathered by alert sensor

3460, located near the center of the Rope-Arabian-Campbell watershed (see Figure 13 or Map 1 Appendix A). Since this sensor is located in the piedmont zone, presumably it did not record the most intense rainfall of the July 20 storm, which was indicated by the Doppler Radar data. Thus, the flows passing through the study area channels would have been greater than the rainfall data suggest. However, the sensor 3460-rainfall data do capture the relationship between rainfall intensity and total daily rainfall, as well as the clustering of storms.



Doppler radar estimation of total rainfall for July 20, 2010 storm
Schultz Fire Burn outlined in white
Pixel color indicates rainfall in inches
Orange = 4 – 5 Yellow = 3 – 4 Green = 2 – 3

Figure 5: NWS Doppler Radar image from July 20, 2010 storm over burn area. (NWS 2010)

As depicted in Figure 6 and Figure 7, the study area experienced several intense rainfall events in the months following the fire. The events of July 20 and August 16 were by far the most intense, with both producing debris flows and hyperconcentrated flows that inundated portions of the community immediately downstream of the burned area. Another aspect of the rainfall that should be

considered is the clustering of less-intense storm events that occurred close together in time, causing a high antecedent moisture condition in channel bed and bank materials. This possibly could have led to greater runoff and greater amounts of sediment mobilized in subsequent runoff events.

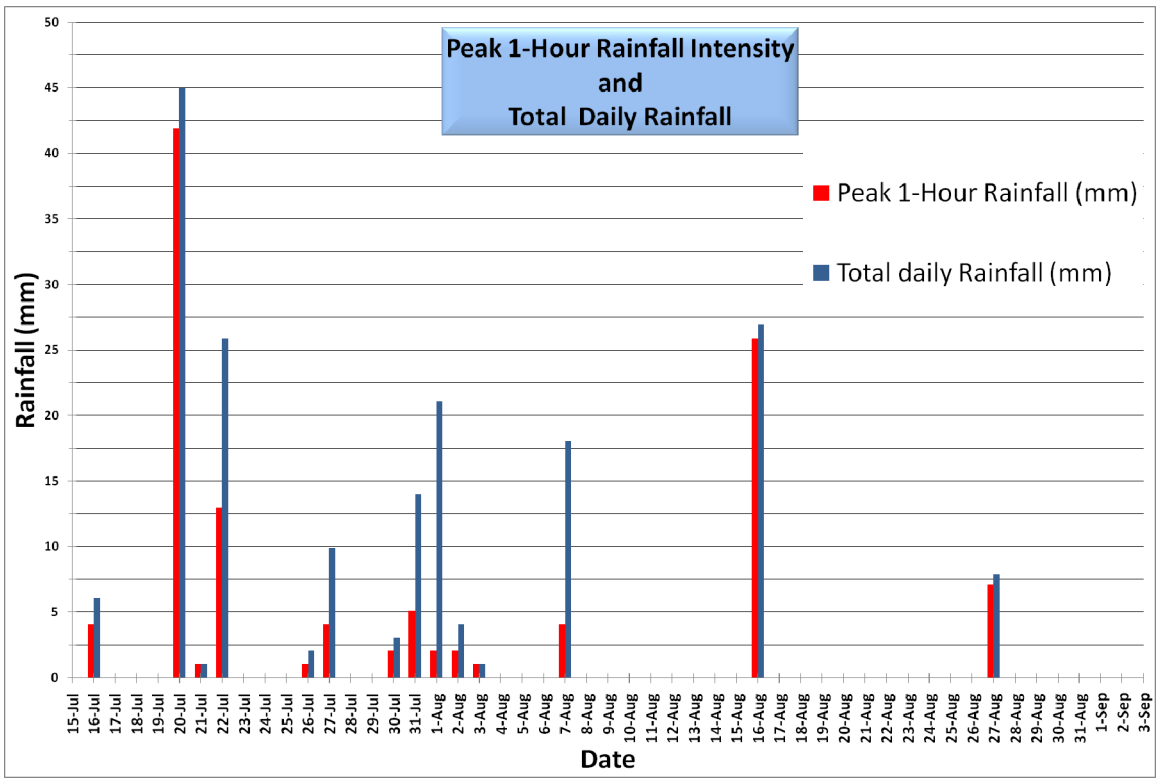


Figure 6: Rainfall for Jul 15 thru Sept 3, 2010. Rainfall data from Yavapai County Alert page for sensor 3460.

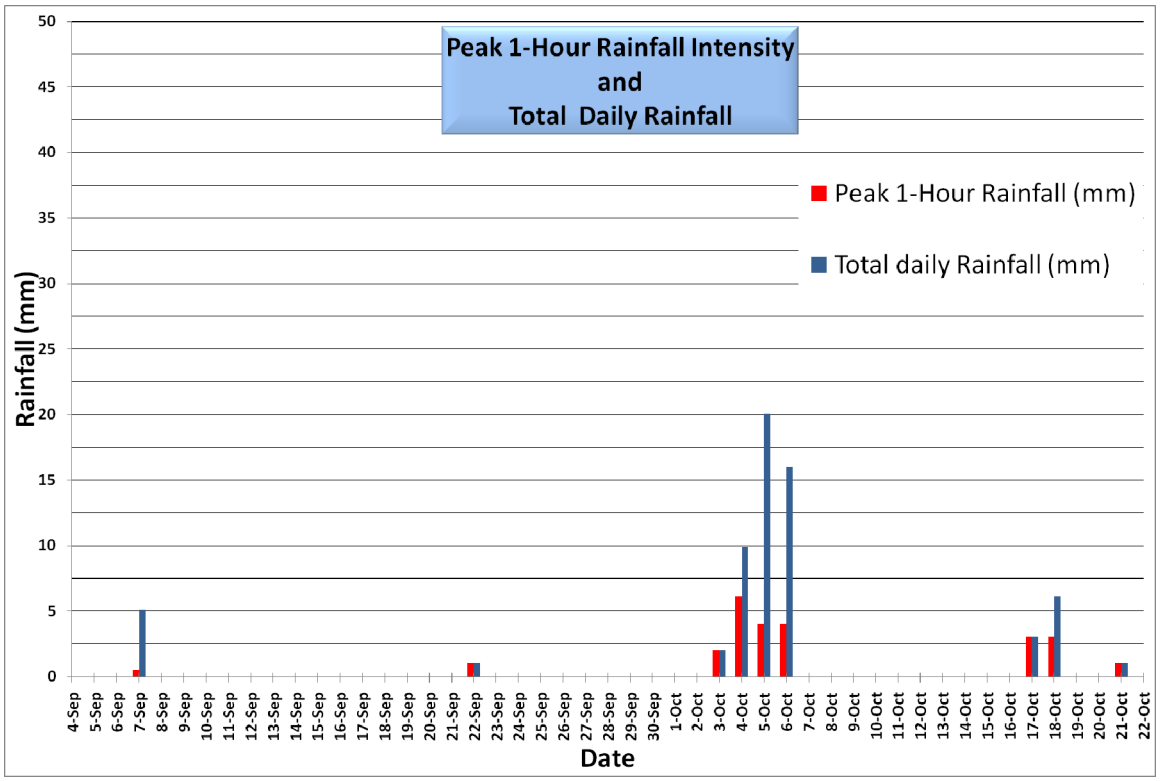


Figure 7: Rainfall for Sept 4 thru October 22, 2010. Rainfall data from Yavapai County Alert page for sensor 3460.

As part of the BAER team assessment Hydrologist Brad Higginson (2010) used the WILDCAT4 computer model to predict pre- and post-fire runoff from the Schultz Fire burn area. This model is used to form a macro-level view of hazard areas and does not consider all aspects of the watershed, such as channel routing. Even with this limitation, comparing the pre and post-fire flows is useful in understanding the magnitude of flow that can be expected from the burn area. From the simulation results, post-fire peak flows from the Rope-Arabian-Campbell-Watershed were expected to be nearly 11 times greater than pre-fire flows (see Table 3).

Table 3: Results of WILDCAT4 model run for the 10-yr, 1-hr, NOAA Atlas 14 Storm (Higginson, 2010).

	Total Runoff	Peak Flow
Pre-Fire	1480 m^3 (1.2 acre ft)	0.57 m^3/s (20 ft^3/s)
Post-Fire	20846 m^3 (16.9 acre ft)	6.14 m^3/s (217 ft^3/s)

IV. Methodology

A. Selecting the study area

The study area was chosen with guidance from Dr. Dan Neary of the USDA Rocky Mountain Research Station and Ann Youberg of the Arizona Geological Survey. The Rope-Arabian-Campbell watershed, referred to as sub-basin 7 in the Schultz Fire BAER Report (USDA Forest Service, Coconino National Forest. 2010), was chosen because there was post-flooding evidence of multiple debris flows in the upper watershed, and flow in the main watershed channel has direct impacts on homes, infrastructure, and businesses immediately downstream of the study area. Additionally, this watershed was instrumented by a cooperative effort between Coconino County, The U.S. Forest Service, and Yavapai County post-fire with two of seven total rain gauge alert stations. Of the two gauges installed in the Rope-Arabian-Campbell watershed, only the lower elevation gauge was installed in time to record most of the season's summer monsoon rainfall. The lower gauge (sensor 3460) is located at the intersection of the main channel and Schultz Pass Road at an elevation of 2,290 m (7,510 ft). The other (sensor 3462) is along the Waterline Road near the head of the North Channel at an elevation of 2,600 m (8,530 ft).

Lastly, this watershed was selected for study because it is large enough to give meaningful information that can be extrapolated to other watersheds of the burned area, but small enough to be studied in the limited time available.

B. Cross section selection

To determine where to develop cross-sectional measurements and observations of the watershed's channels, The National Geographic Society's 'Topo!' mapping program (version 4.5.0) was used to develop a 15-second grid of latitude and longitude for the study area, with the grid lines approximately 377 m (1,238 ft) apart. At points where the channels crossed a grid longitude line, the corresponding Latitude-Longitude coordinates were transferred to a GPS unit, which was used to locate the points in the field. This provided a base of channel locations to examine in the field. As fieldwork progressed, additional locations were added as identified and judged necessary. Overall, 42 specific locations were investigated (see Map 2 Appendix A).

C. Field procedures

1. Cross section location and measurement

In the field, a Garmin GPS Map60 unit was used to locate each of the predetermined cross section locations. A reference point was established on one channel bank for each cross section location. These points were marked by driving a 60d (15 cm, 6 in) nail into the base of a tree, or a 60 cm (24 in) spike into the soil if

no tree was conveniently located. A level line was then run across the channel perpendicular to the thalweg. The channel cross-section was developed by means of elevation measurement at a 1-m (3.3 ft) interval using a level rod. The 1-m (3.3 ft) interval was supplemented with closer measurements if distinctive features, such as slope breaks, the edges of mid-channel bars, logs, or large boulders fell within the interval.

To measure channel slope, a range pole with eye height marked on it was placed 50 m (164 ft) downstream of the cross section location. Then from the same distance upstream of the cross section, the slope was measured using a handheld clinometer. One hundred meters (328 feet) along the channel was the minimum desired distance to obtain slope data, however longer distances were used when conditions allowed. In locations where 50 m (164 ft) could not be sighted shorter sight distances were used.

Observations at each cross section location and at other locations of interest in the channel were made in order to document channel morphology that included:

a) Evidence of channel scour or aggradation. (Evidence consisted of the depth of post-fire sediments in the channel, exposure of tree base flairs and roots, difference of surface elevation from fire marks left on large stationary boulders)
b) Bed and bank material
c) Obstructions (tree roots, trees, rocks, etc.) and abrupt changes in channel morphology

d) Degree of sinuosity (estimated by comparing thalweg distance to direct line distance between points half way between cross-section locations)

e) Debris flow deposits adjacent to the channel

f) Location, shape, and volume of sediment deposits

g) Evidence documenting deposits from either single- or multiple-flow events

h) Evidence of material entering the sides of the channel via sheet flow or debris flow

i) Determination of the elevation of material above the lowest part of the channel, the amount and type of flow obstructions immediately downstream of the deposit, and rough size estimate of the majority of material in the deposit. This data will be used to assess the likelihood of material stabilizing in place in the channels until moved by large flood flows.

2. Sediment sampling and sieve analysis

Where the level line crossed the thalweg, the sediments were excavated to determine the thickness of post-fire sediment. This was determined by the presence of intact small tree roots (< 1 mm (0.04 in) diameter) in the undisturbed pre-fire sediments. The surface defined by the tops of these roots proved to be a reliable indicator of the border between pre-fire and post-fire sediments. Once the depth of the post-fire sediment layer was determined, a sediment sample was taken from the entire vertical profile of the post-fire sediment.

Sediment samples were collected using a square edged trowel 3 cm (1.2 in) wide with 3 cm (1.2 in) length marked on the blade. Working downward from the channel bed surface to the pre-fire sediment surface removing layers approximately 2.5 cm (1 in) at a time a 3 by 3 cm (1.2 by 1.2 in) sample was collected along the vertical thickness of the post-fire sediment. During collection care was taken to prevent sediments from the channel surface from falling in the sample being collected. Samples were immediately placed in labeled plastic bags. Samples so gathered were later analyzed using standard sieve analysis procedures in EM 1110-2-1906 Laboratory Soils Testing manual (US Army Corps of Engineers, 1970). Results of this analysis are discussed in section V.C.1 on page 45 of this thesis.

3. Sediment grain size analysis by pebble count

Pebble counts were conducted on debris flow deposits, where the presence of large particles would have required very large sample sizes. For example, per EM 1110-2-1906 (US Army Corps of Engineers, 1970) sediment with a maximum particle size of 76.2 mm (3 inches) requires a minimum sample size of 64 kg (141 lb). Since collecting such large samples was impractical, the pebble count method was employed.

The pebble count method involves randomly selecting at least 100 particles from along the surface of the channel cross section. The median axis of each particle is measured and the particle classified into one of fourteen size categories, which range from less than 1 mm (0.04 in) to greater than 256 mm (10.2 in) (Kondolf, 1997). This method is commonly used in surveys of active streambeds and is effective, yet can be time consuming. In this study, the amount of time available for

fieldwork was extremely limited and only nine pebble counts were completed prior to the end of this field season.

For this study, a modified pebble count method was adopted. As shown in Figure 8, a 30-m (98.4 ft) cloth tape with 1-cm (0.4 in) divisions was laid out along the cross section, directly on the ground, with as much ground contact as possible. Photos were taken of the entire tape in 1-m (3.3 ft) segments. Later the photos were analyzed to estimate the size of the particles directly below the top of the tape at each 10 cm (4 in) increment. This method does not allow for precise measuring of each particle along its intermediate axis. However, the categorizing of particles into size classes per Kondolf (1997) combined with an estimation of the intermediate axis measurement minimized the impact of this modification.

Figure 8: Example of pebble count by tape method (Photo by Mike Carroll).

4. Sediment Volume Calculations

The volume of post-fire sediment in the channels was estimated by breaking the channel down into reaches. Each reach was centered on a cross section location and extended upstream and downstream half way to the adjacent cross section locations. Sediment deposits such as mid-channel bars (see Figure 9) tend to form wedge shaped deposits with the thickest portion on the downstream end. Therefore, estimates of sediment volume were made while traversing up the channel to make the presence of these types of deposits more easily identifiable.

Measurements of sediment deposits along the length of the channel were made using pace counts. Measurements of sediment deposits laterally across the channel and of sediment deposit thickness were made with either a loose cloth tape or a cloth tape permanently affixed to a range pole. Near the upper end of mid-channel bars, or where bed sediments appeared different, a small pit was dug to verify the sediment thickness. Typically, this was done where boulders or large tree roots affected flow in the channel. Sediment volume was calculated at approximate intervals of 30 m (98 ft) , then the procedure was repeated until sediment volumes for the entire reach was estimated.

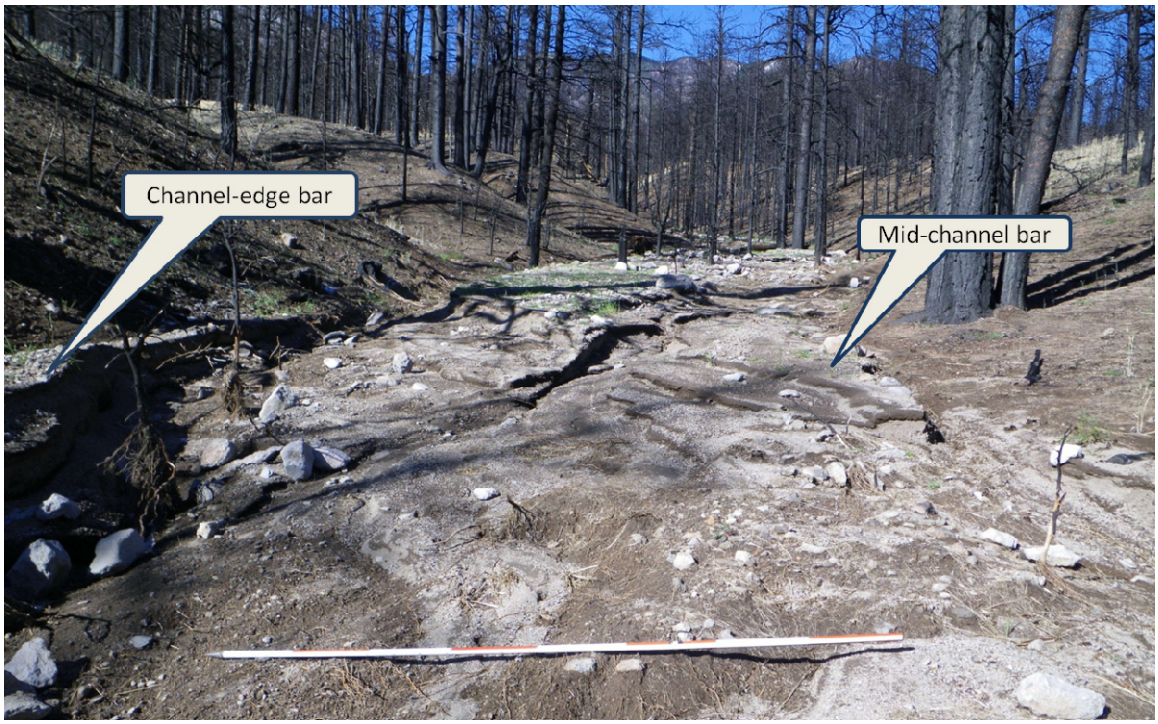


Figure 9: Edge and mid channel bars (photo by Mike Carroll).

The use of this method required the assumption that, except for the visible edges of mid-channel bars, deposits along the banks, and those at boulders and large tree roots, the thickness of sediments lessened evenly in the upstream direction. It also required the assumption that there is minimal variation in channel geometry hidden by the sediment deposits. This method cannot account for boulders mixed in with the finer sediments. However, those boulders will only be mobilized by very large storm or debris flows.

V. Discussion of findings

A. Watershed divisions

The study area can be divided into three basic elevation zones. Moving from high to low elevation, these are; mountain slope, intermediate mountain slope, and piedmont. The elevations referenced in this study as zonal boundaries are only applicable to the Rope-Arabian-Campbell watershed. The boundary between the mountain slope and piedmont is physiographic only loosely connected to elevation. The elevations used represent the approximate location of an abrupt change in watershed slope. For example, the mountain slope – intermediate mountain slope border lies roughly along the line where slopes change from 20 to 45% within a few hundred meters. The location of zone boundaries can be seen in Map 1 Appendix A. Channel profiles are discussed in section V.B. of this paper.

1. Mountain slopes

Mountain slopes cover the higher elevations of the study area from near the summit of Schultz Peak, elevation 3,073 m (10,083 ft) down to an elevation of approximately 2,560 m (8,400 ft). In this area, channel slopes generally exceed 60% with the steepest channel measured at 73%. The channels are 1 to 5 meters (3.3 to 16.4 feet) wide and incised 1 to 2 meters (3.3 to 6.6 feet) deep to bedrock, as can be seen in Figure 10. These steep channels cut to rock, resulting in concentrated runoff attaining high velocities with relatively little entrained sediment. Flow in these channels has excess sediment transport capacity and thus erodes deeply when it reaches channel deposits in the lower portion of the downstream mountain slope

zone. The bedrock in the area of the northern-most channel has few fractures. However, the bedrock in the area of southern channels is highly fractured. High velocity post-fire flows moving down the steep channels in the area were able to mobilize some material from the fractured bedrock channel beds and move that material toward the piedmont.

The entire mountain slope zone of the study area suffered moderate and high burn severity. As the tree roots killed by the fire decompose, there will likely be an upsurge in the volume of sediments moving down the channels. Countering this, to some extent, will be the stabilizing effect provided by aspen trees that are sprouting from roots systems that survived the fire.

Figure 10: North Channel as it crosses the Waterline. Note channel is scoured to bedrock. Channel slope is 53% (photo by Mike Carroll).

2. Intermediate mountain zone

The intermediate mountain zone extends from the lower edge of the mountain zone at approximately 2,560 m (8,400 ft) down to the upper edge of the piedmont zone at approximately 2,377 m (7,800 ft) elevation. Channels in this zone are typically ½ to 2 m (1.6 to 6.6 ft) wide and incised 1 to 3 m (3.3 to 9.8 ft). However, soils in the intermediate mountain zone are much thicker than on the higher mountain slopes and the channels area are generally not scoured to bedrock.

In this area, channels D and E (see Figure 13 for channel locations) are incised through soils consisting of unsorted deposits of granular material with clasts between 15 and 30 cm (6 and 12 in) supported in a matrix of particles less than 1 cm (0.4 in). This material possesses strength similar to very weak concrete (the matrix of fine material was hard to penetrate with a geologist's pick) when dry, but it loses much of that strength when moist. This indicates that antecedent moisture conditions have a large effect on how much erosion occurs with each runoff event. These channel deposits have been in place for at least a hundred years as indicated by the large trees that grew on them.

Channel C (see Figure 13 for location), is scoured to bedrock at its upper end in the mountain slope zone, then transitions into a debris flow deposit, and then the channel splits in two, with each channel branch scoured 1/2 to 2 meters (1.6 to 6.6 ft) deep for 50 to 100 meters (164 to 328 feet) downstream (see Figure 11 and Figure 12). This is caused by a short bench in the overall mountain slope as it nears the piedmont. The gullies run downhill until the channel slope lessens in the piedmont transition and the channel aggrades until it joins the main channel.

As with the higher mountain slopes all of the intermediate mountain slopes in the study area suffered moderate or high burn severity. While the density of trees adjacent to the channels of the intermediate mountain zone is less than that on the mountain slopes the trees present are two to four times larger. Also, there are no aspen trees growing in the intermediate mountain zone.

At the lower end of the intermediate mountain slope, the channels undergo a distinct lessening of slope as they enter the piedmont zone.

Figure 11: Debris-flow deposit immediately upstream of scour in Fig 12. Location L33 (photo by Mike Carroll).

Figure 12: Channel below location L33. (Photo by Lynn Carroll).

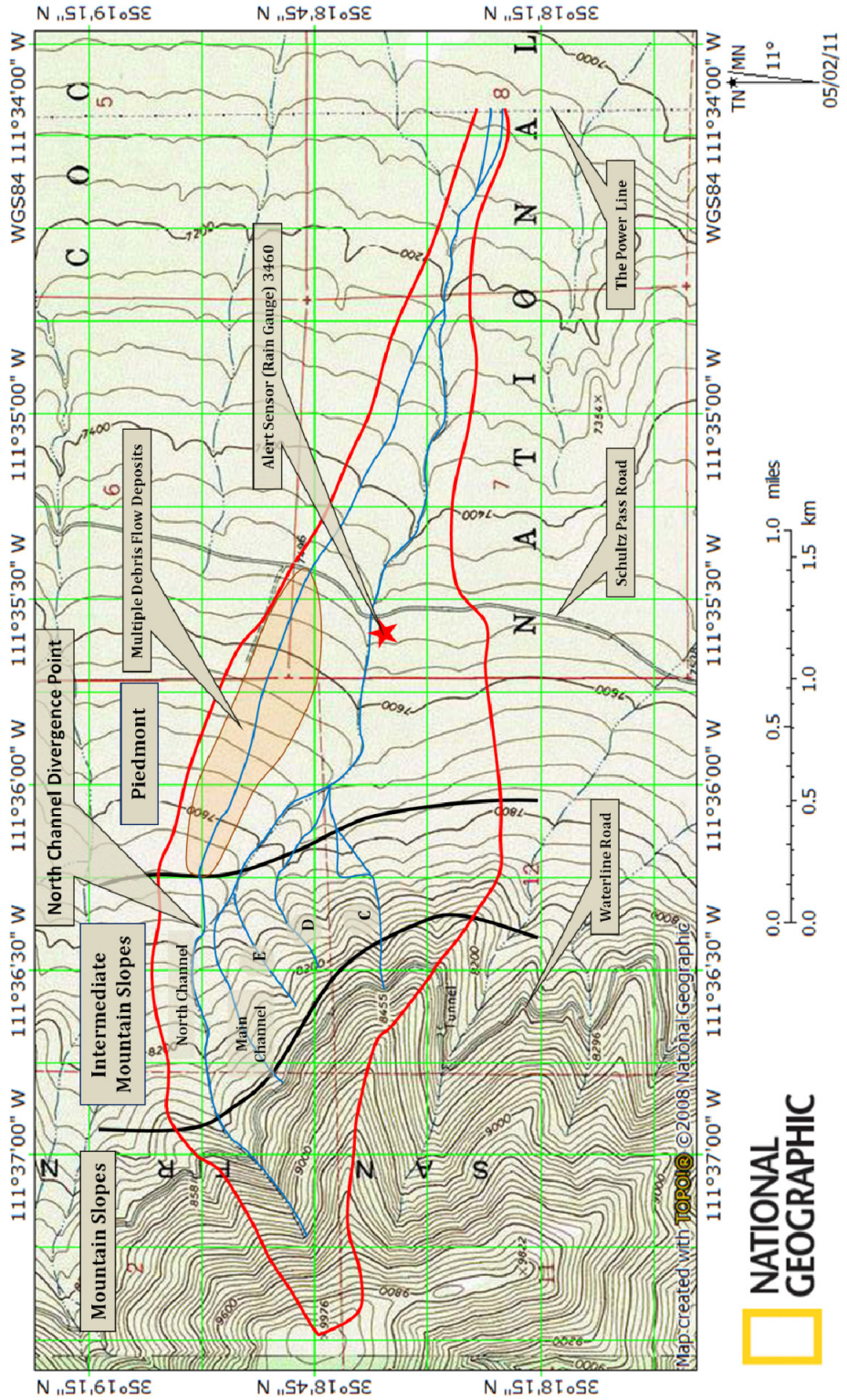


Figure 13: Map of study area showing main channels, location of large debris flow deposits, and topographic divisions. A larger version of this map is included in Appendix A.

3. The piedmont

Moving down slope, the piedmont zone extends from the terminus of the intermediate mountain slopes, elevation approximately 2,377 m (7,800 ft), to the terminus of the study area at the power line, elevation 2,146 m (7,040 ft). Initially the channels were incised between 0.3 and 1 m (1 and 3.3 ft). While much of this scour may have occurred during the July 20 event, which was the highest intensity storm of the season over the burn area, scour may also have occurred during the July 22 event, when soils likely had higher antecedent moisture content. After this initial incision, sediments were deposited in the channels raising the pre-fire channel thalweg by up to a meter.

In several locations, deposits of post-fire sediments are located outside of pre-fire channels and above the current channel bed elevation. During subsequent storms (or possibly during later stages of the July 20 storm) flows began eroding fine material from these debris flow deposits and refilling scoured channel reaches. The July 20 and subsequent flows transported sediments out of the burn area. Thus, overall, the channel reaches in the piedmont are aggrading. At the same time, some sediment deposits are being eroded with the end effect of smoothing the overall channel bed profiles.

In channels located in the lower portion of the piedmont zone, post-fire sediments have raised the pre-fire channel bed elevation. Infilling of the channel in this manner is consistent with typical alluvial fan and bajada formation (Blair, 1994).

B. The main channels

The locations of the main channels in the study area can be seen on Figure 13 with elevation profiles of the north channel, the main channel, and channel C shown respectively in Figures 14 thru 16. Note the distinct change in channel slope at the transition between the piedmont and mountain slopes in both the North and main channels. On channel C, note the bench structure that allowed debris flow deposits to accumulate (see Figure 16).

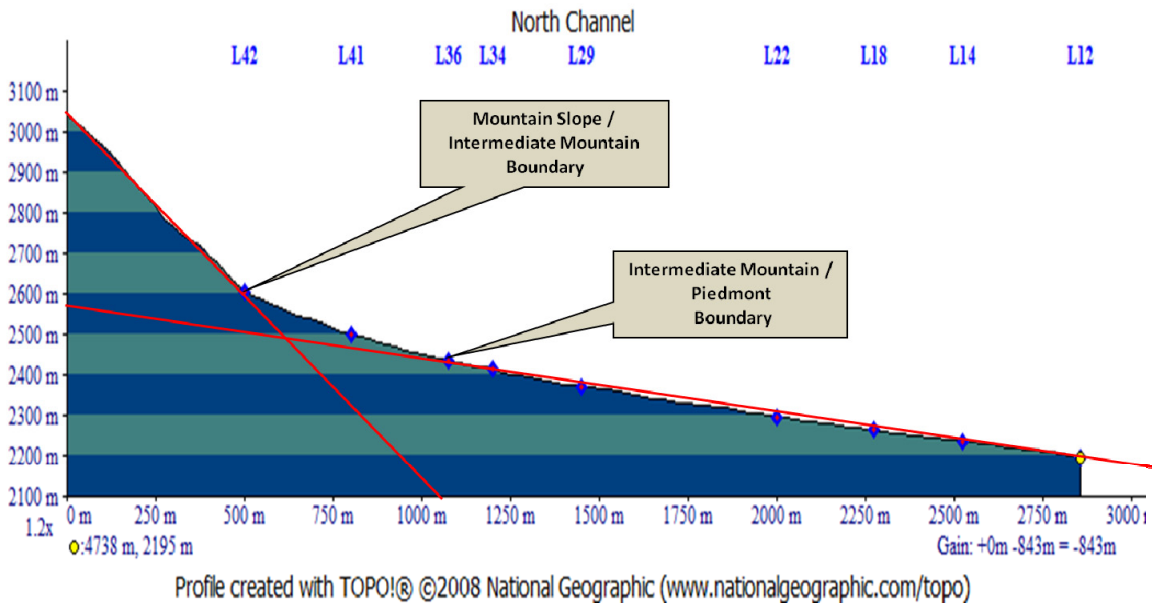


Figure 14: Elevation profile for the north channel. The red lines indicate the average slope of the piedmont and mountain slope portions of the channel.

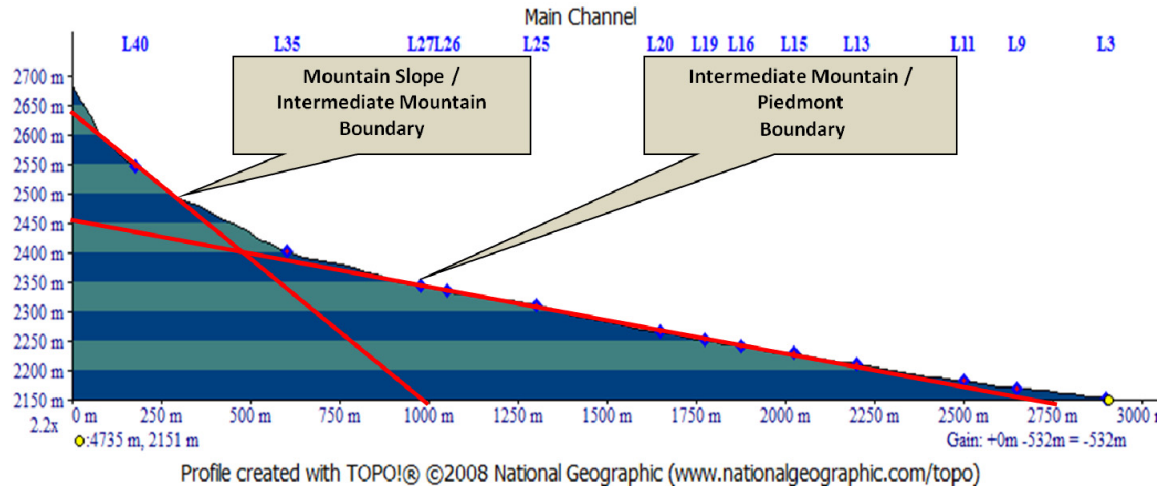


Figure 15: Elevation profile for the main channel. The red lines indicate the average slopes of the piedmont and mountain slope portions of the channel.

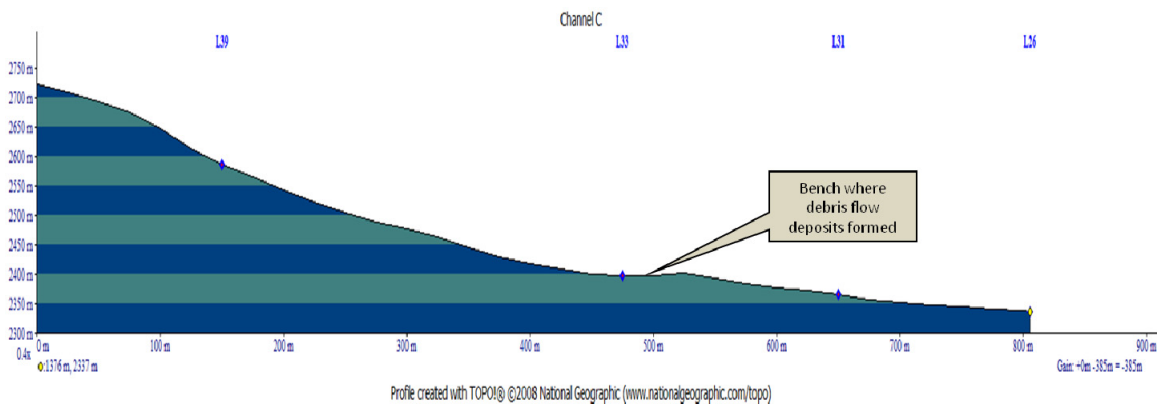


Figure 16: Elevation profile for channel C

Approximately 100 m (328 ft) north of the main channel, the north channel follows a path running nearly parallel to the main channel (see Figure 17). At some point in the past the north channel diverged from the main channel just downstream of L36 (see Map 2 in Appendix A for location) and followed the current north channel route. The presence of fine-grained mineral soil, similar to that

covering most of the land outside the study area channels, indicates that this divergence occurred prior to the high volume flows of July 2010. The presence of recent sediment greater than 10 cm diameter in the cutoff channel (see Figure 17 for location) indicates that after the Schultz Fire, at least part of a debris flow lobe spilled over into the main channel at this location (identified as L36.) Material less than gravel size (2.5 cm or 1 in) and any woody debris that may have been

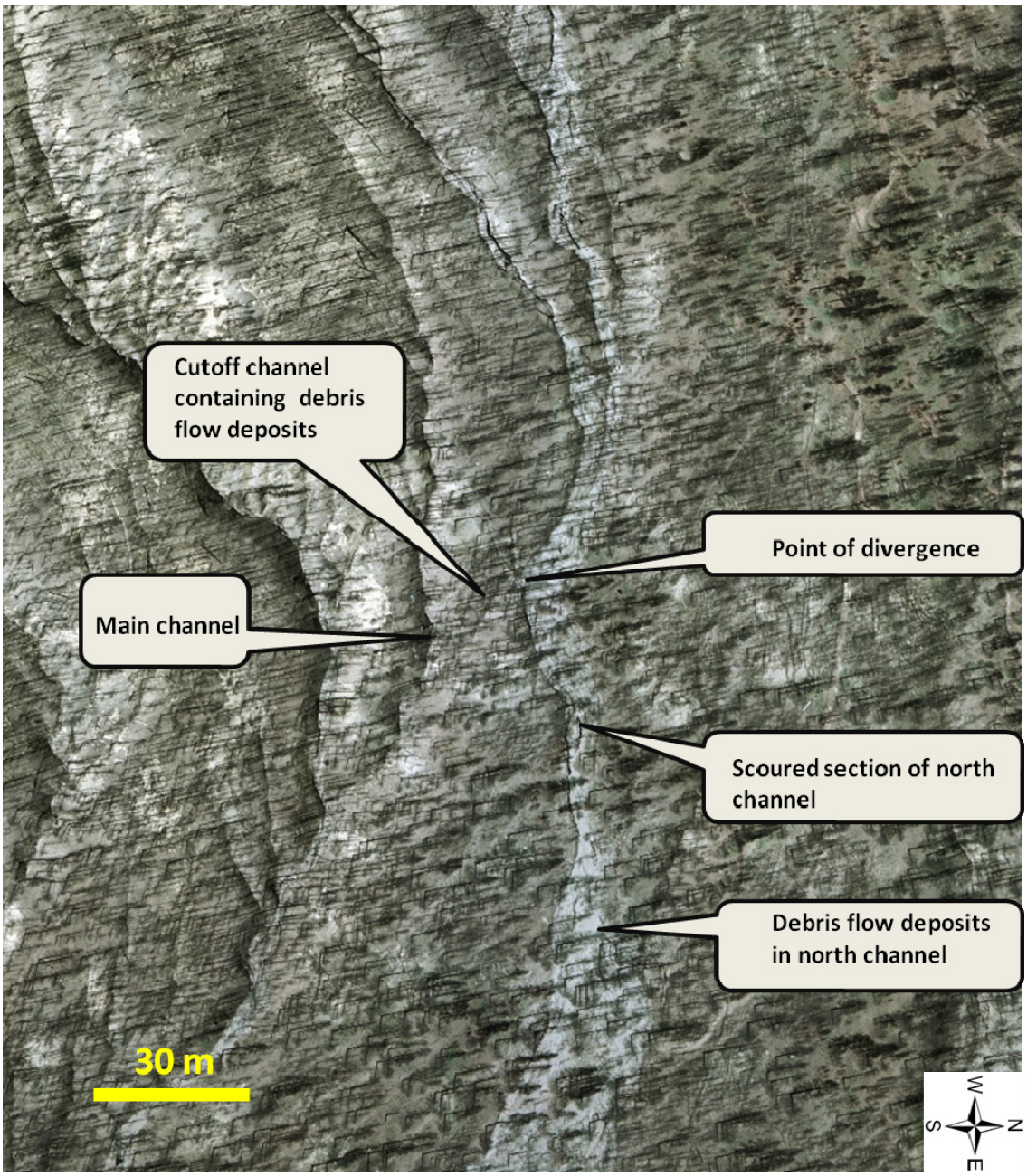


Figure 17: Location of North Channel divergence from the main channel (Photo from Rocky Mountain Research Station, Flagstaff Office)

part of this flow have been removed by subsequent runoff. The connection between the two channels is not scoured and all the flow from the section of channel to the west, and higher elevation, flows down the north channel.

It is not clear if the northern route had a defined channel prior to the July 20 storm. If it did, the flows must have been such that the flow did not cut through the upper layer of vegetation and organic soil. There are indications (small roots, dog-hair thickets of small pines) that preclude the presence of a cut channel prior to the July 20 event. Analysis of pre-fire aerial photos reveals indicators that there was dispersed flow down the path but no clear evidence of a cut channel. This type of condition appears to be the typical pre-fire morphology across the mountain slopes of the burn area.

Just below the point where the north channel diverges from the main channel, it is deeply scoured. The scoured reach is 0.5 to 1.5 m (1.6 to 5 ft) deep, up to 10 m (33 ft) wide, 100 m (328 ft) long, and with a slope of 8%. At the end of this scour section, the flow opened to a wide area with 5% slope and spread out across the landscape depositing multiple lobes of debris flow material (depicted as the orange area on Figure 13). In this part of the watershed, there are at least six individual debris-flow deposits that remain largely intact. Additionally, there are several more, which have been eroded by subsequent flood flows. These 2010 deposits spread throughout the area with frontal lobes generally angled outward and downstream from the channel thalweg with evidence of debris flow deposits reaching back to the channel line. The majority of the fine material has eroded out of these deposits, probably during flood flows after the July 20 storm and those that followed. Near Schultz Pass Road (Forest System Road 420), the flow coalesces back to a well-defined channel (terminus of orange area on Figure 13). From this point downstream, there are no indications of debris flows. At the time of the fieldwork,

the channel was scoured in most places with a few sections aggrading between the road and the junction of the North Channel with the main channel, location L13 on Map 2 in Appendix A.

C. Sediment analysis

1. Grain size

Grain size analyses were completed for 29 locations within the study area. Twenty-one samples were analyzed using standard sieve analyses procedures, sediment at eight locations was analyzed using the pebble count procedure described earlier, and sieve analysis completed for two samples from pre-fire sediments collected from below the post-fire deposition and post-fire channel scour. Grain-size-analysis data are provided in Appendix B.

As shown in Figure 18, sieve analyses revealed the granular nature of the sediments, as they are composed of greater than 95% sand and gravel.

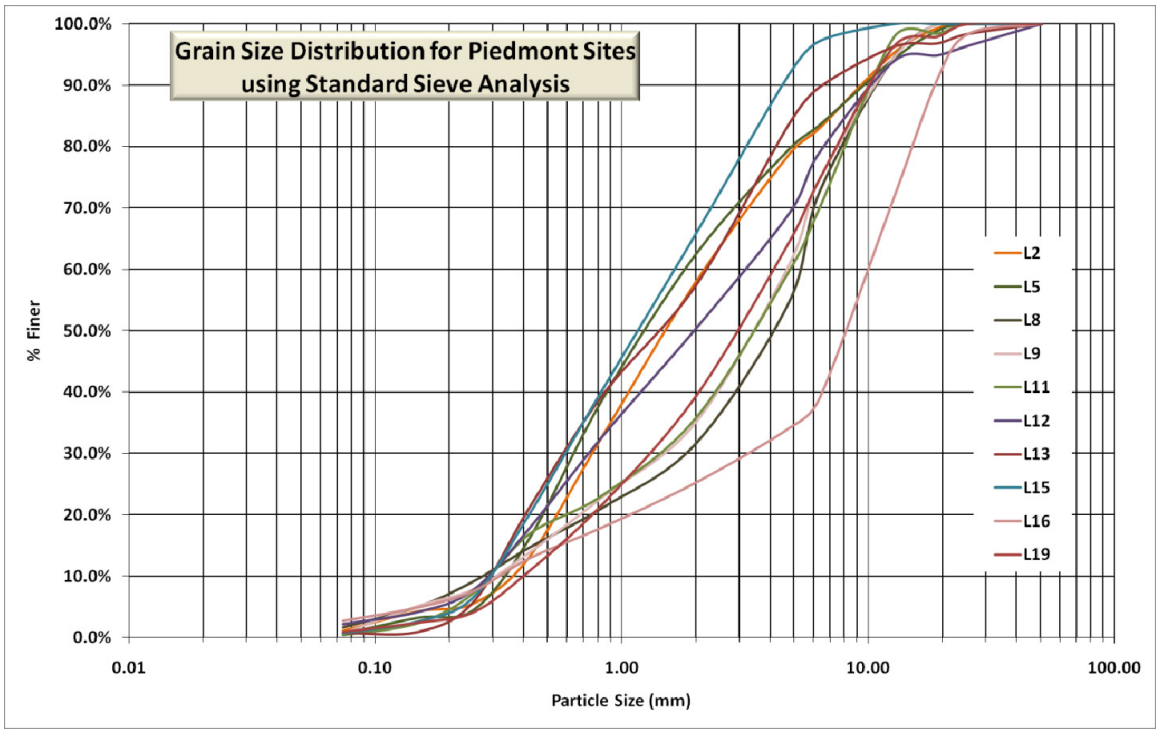


Figure 18: Grain size distribution for piedmont zone. Grain size categories per ASTM Standard D2487-06.

Grain-size distributions determined using the pebble count method (see Figure 19) show that while these sediments are still granular, there are 10 to 25% cobbles and boulders present.

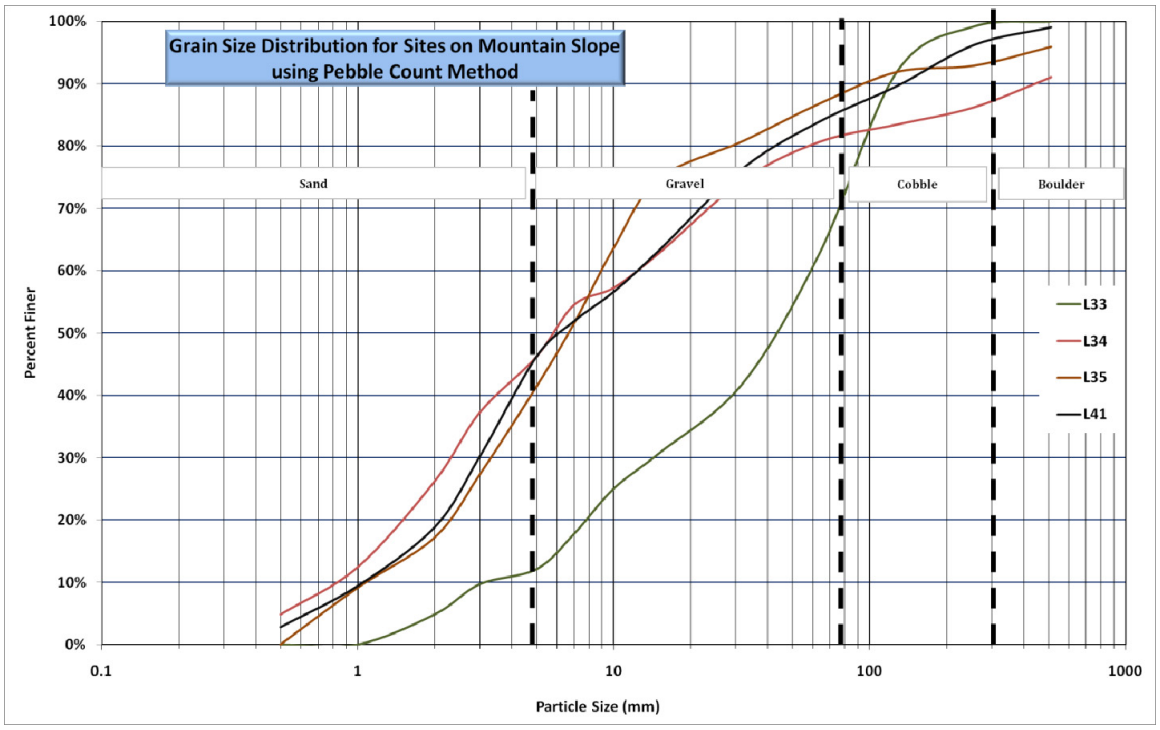


Figure 19: Grain size distribution for the mountain slope zone. Grain size categories per ASTM Standard D2487-06.

At locations L7 and L26 (Map 2 in Appendix A) pre-fire channel sediments and post-fire sediments directly above them were sampled separately. As seen in Figure 20, pre-fire channel bed sediments have a higher percentage of fine material than the post-fire sediments. This is indicative of years of stability in the channel bed where fine material filtered down through the upper sediments.

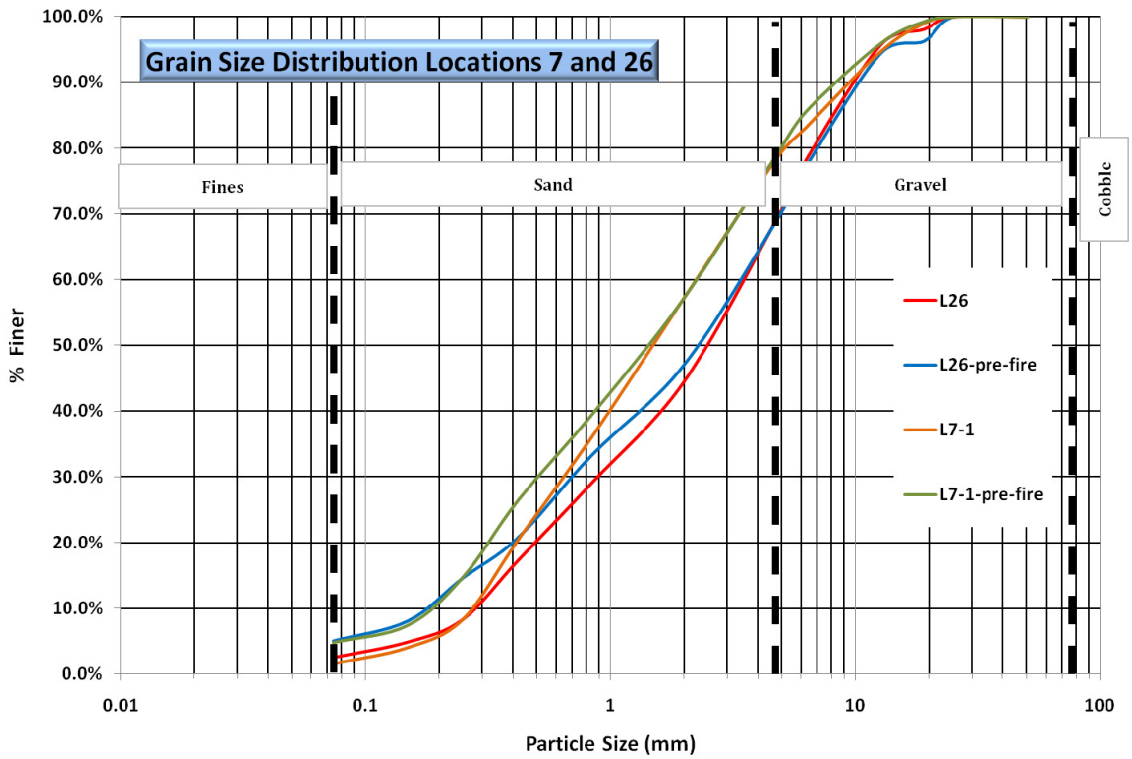


Figure 20: Comparison of pre and post-fire sediment grain size. Grain size categories per ASTM Standard D2487-06.

2. Estimate of sediment volume

Using cross-section data and field observations, an estimate of the volume of post-fire sediment remaining in the channels and readily available for movement downstream by flood flows was made. The consistent shape of the channels through the piedmont and easily discernable mid-channel bars made these estimates possible. Results of this volume estimate are shown in Table 4.

The volume estimation was completed by first breaking the channel down into reaches. Each reach was centered on a cross section location and extended half way to the adjacent cross sections. Moving up the channel, volumes for mid-channel

bars, remnant deposits along the banks, and the volume of sediment on channel bed were calculated separately and then summed for each 30- m (100-ft) section of channel reach. It was assumed that the thickness of sediments varied evenly both along the channel length and that there was minimal variation in channel geometry hidden by sediments. These assumptions introduce limitations, e.g.; the method cannot account for buried boulders mixed in with the finer sediments.

The post-fire sediment residing in the channels is not the only material that could be easily transported by future hyperconcentrated or flood flows. The materials comprising the channel bed below that which was disturbed in summer, 2010 is essentially the same granular material as the post-fire sediments. This material has very little cohesive strength and thus is readily available for transport by future flows. The cohesive strength of the channel bed and banks is likely to diminish as roots from trees and shrubs killed in the fire begin to decompose lessening the stabilizing effect they have on the soil (Neary et al. 2006, Meyer et al. 2001). This system is transport-limited in that the volume and intensity of runoff control how much sediment will be moved.

Specific study was not done to determine the amount of cohesion the post-fire sediments displayed when moist or saturated. However, it was evident from field observations that they did display some cohesion when moist, however, flow with a depth of 1 cm (0.4 in) could transport sediment downstream.

Table 4: Estimations of channel bed elevation changes and readily transportable post-fire sediment.

Zone	Location #	Initial bed elevation change (m)	Current bed elevation change (m)	Channel slope (%)	Available post-fire sediment (m^3)
Piedmont	**1**	-1.5	-1.2	5	100
	5	-1.5	-0.5	5	250
	7	-0.3	-0.6	5	100
	8	-1.0	-0.3	5	850
	9	-1.0	-0.6	5	2700
	10	-0.3	+0.2	6	600
	11	-0.3	+0.2	8	3000
	12	-0.2	+0.1	8	400
	13	-0.1	+0.1	4	50
	15	-0.2	-0.1	7	100
	17	-0.5	+0.1	8	1000
	19	-0.3	-0.1	8	250
	20	-0.5	+0.75	8	2000
	25	+0.5	-0.1	8	1000
	27	0	+0.4	10	3000
	35	+1.5	+0.75	9	100
Intermediate Mountain	**40**	?	-1.5	44	0
				TOTAL	**15500**

Location # corresponds to L# listed on Map 2 in Appendix A

Initial bed elevation change are an estimation of the amount of scour (-) or aggradation (+) that occurred during the 2010 summer monsoon runoff events.

Current bed elevation change is an estimation of the difference in elevation of the channel bed during October – December 2010 compared to the pre-fire bed elevation. This was estimated using burn marks on large boulders, large trees, and the location of large tree roots, as well as projecting the shape of the channel from remnants of the pre-fire channel banks remaining in places sheltered from scouring flows.

Channel slope is the average slope of the current bed surface measured along the thalweg.

Available post-fire sediment is the volume of sediment present in channel bed deposits and in mid-channel bars. This is interpreted to be the most readily transportable sediment.

As indicated in Table 4 there are approximately 15,500 m^3 (20,273 yd^3) of post-fire sediments present in the studied Rope-Arabian-Campbell watershed channels. All of these sediment deposits are located in the piedmont zone of the watershed. The 100-m^3 (131- yd^3) deposit at location L35 is included in this number. The juncture between mountain slope and piedmont is not a well-defined line, but a transition. Location L35 is in this transitional area. The distribution of sediments by channel slope is displayed in Table 5. In this table, it can be seen that the majority of channels in the piedmont have slopes of either 5% or 8% and that 75% of the post-fire sediments reside in those channel reaches.

Table 5: Sediment quantities arranged by channel slope

Channel slope	Number of channels in slope range	Volume of sediment present (m^3)	Percentage of total
4%	1	50	0.3
5%	5	4000	25.8
6%	1	600	3.9
7%	1	100	0.6
8%	6	7650	49.4
9%	1	100	0.6
10%	1	3000	19.4

VI. Summary and Conclusions

The Schultz fire burned 6,091 hectares (15,051 acres) of mixed conifer forest with 67% of the area-experiencing moderate to high burn severity. The severity of the burn, the granular nature of the soils, channel slopes ranging from 5% to 73%, and the depth-intensity characteristics and timing of monsoon storms set the stage for massive sediment transport events. During the three months immediately following the fire there were several monsoon storms that triggered debris flows and hyperconcentrated flows from the burn area. These flows damaged more than twenty homes and damaged infrastructure in communities downstream of the burn. For a given storm, the post fire watershed produced runoff much greater than under the pre-fire conditions.

Since attempting to study the entire Schultz Fire burn area in the limited amount of time available was impractical, one sub watershed was selected for study. The Rope-Arabian-Campbell watershed was selected because it is directly impacts the downstream community and it is representative of the remainder of the burn area. Thus, focused study of the sediment transport processes occurring in the Rope-Arabian-Campbell watershed would reveal what could be expected from other watersheds within the burn area.

This study was conducted to gain an understanding of the sediment transport processes occurring in a watershed typical of those in the burn area. The understanding thus gained was used to estimate the amount of post-fire sediments present in the channels and that could be readily mobilized by future storms. To

estimate the sediment volume, channel cross sections were studied at 42 locations within the Rope-Arabian-Campbell watershed.

The fire's removal of grasses and the duff layer revealed the presence of debris-flow deposits that pre-date the 2010 events. Field study reveals that the sediment transport processes visible in the watershed at the time fieldwork was conducted have been operating in this area for a very long time. The presence of debris-flow or hyperconcentrated-flow deposits on which large trees have grown indicates that the responsible flows occurred nearly one hundred years ago, probably after logging operations cleared most of the large trees from the land.

Analysis of field data indicates that (as of December 2010) there is 15,500 m^3 (20,273 yd^3) of post-fire sediment in the channels of the watershed, primarily on the piedmont. This material is granular, with very little cohesion, making it readily available to be transported downstream. Additionally, the channel bed and banks are made up of similar granular material that could erode, adding to the sediment moved though the channels.

The channel-bed sediments and underlying soils appear to be able to absorb a large amount of water. Much of the runoff from smaller short-duration monsoon storms on the upper slopes could be absorbed into the channel bed sediments of the piedmont prior to exiting the basin. Runoff from short-duration or low-intensity rainfall may transport channel sediments from higher elevations down to the piedmont where they will be stored until the next large runoff transports them further down the system.

For a given storm, i.e.: the 10-yr ARI storm, post-wildfire runoff events can produce flows ten or more times greater than those under pre-fire conditions do. This results in the movement of large volumes of sediment by debris, hyperconcentrated, and flood flows. The occurrence of another storm of similar magnitude or greater than the 10-yr ARI storm of July 20, 2010 could rapidly transport a large fraction of the sediment which has temporarily resided in the channels, to points out beyond the piedmont. Actual transport and volume transported will be dependent on storm intensity and duration, vegetation recovery, antecedent moisture condition, and root strength.

As the Rope-Arabian-Campbell watershed evolves in the aftermath of the fire, several key factors will influence sediment transport. These include soil moisture, vegetation recovery, root decay, and precipitation. Recovery of vegetation will help stabilize channel deposits. Soil moisture conditions favorable for plant growth will help vegetation re-colonize the area. The roots of these plants will help increase soil resistance to erosion by all but the higher flood flows. The antecedent moisture conditions in the channel beds and banks of the upper watershed will have an impact on channel scour and migration. The beds of the upper channels are cut through material that is more resistant to erosion when dry, but lose much of that resistance when wet. Thus, a period of wet weather or snowmelt preceding a heavy rain could promote rapid erosion of sediment from this area.

One aspect that must be considered when dealing with the aftermath of the Schultz Fire is that in the past hundred years the local environment has been altered by anthropogenic activities. Wildfire is now understood to be a natural part of the

southwest's forest ecosystem. However, the exclusion of natural wildfire for the greater part of the 20th century and past timber management practices have changed forest structure, hydrologic response of watershed runoff, and sediment transport characteristics. Although past timber management practices and the belief that all fire is bad are no longer accepted, many forests have high stand densities and low average tree size and age. These conditions exist as we enter a period of climate change that may change local weather patterns. Periods of hotter dryer weather set the stage for large intense wildfires cause by human activities as well as lightning from thunderstorms. This coupled with snowmelt runoff, and the high-intensity rainfall associated with monsoon storms could result in increased flooding and sediment transport from areas affected by wildfire.

The overall interpretation of the events of the summer of 2010 is that the runoff from the July 20 storm created multiple debris flows along the Rope-Arabian-Campbell watershed channel network, leaving deposits in some areas and scouring the channels in others. Flows from subsequent events, and possibly from later portions of the July 20 event, have eroded the gravel and finer sediments out of the debris flow deposits and moved much of them into the main channel. Runoff from subsequent storms is now moving that sediment down the north channel between the Schultz Pass Road and its intersection with the main channel (see Figure 13).

The main channel through the piedmont section of the watershed is experiencing a period of equalization. There are sediment deposits left by debris and hyperconcentrated flows that are up to a meter above the level of the current channel bed. The gravel and finer material (generally <2.5 cm (1 in)) is being

eroded, by smaller (less than 5-yr ARI) storms and snowmelt runoff, and moved into the channel where they refill areas scoured during the summer 2010 events. In effect, the processes now at work are smoothing out the body of sediment lying in the channel network of the piedmont region. As time progresses it is likely that much of this sediment will stabilize in the channel until another large event, like the storm of July 20 or August 16, mobilizes and moves it further downstream. In the meantime summer monsoon storms and winter rainfall will continue to move sediment but at a lesser rate.

It is expected that substantial amounts of sediment will continue to be transported from the Schultz fire burn area for ten or more years post fire. The movement of this sediment will occur, but in pulses separated by periods in which little sediment moves.

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VIII. Appendices

A. Maps of Study Area

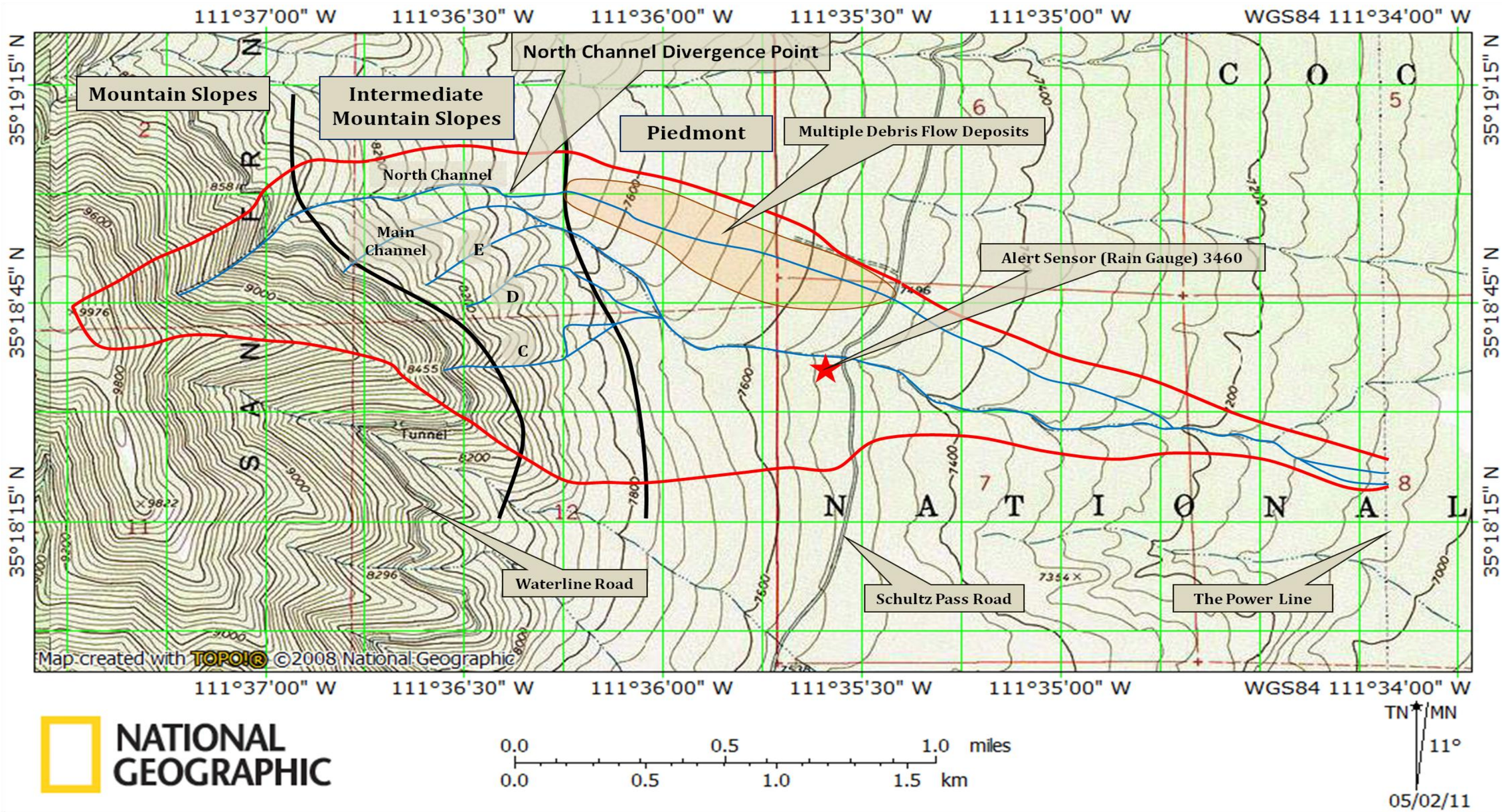
B. Appendix B: Grain Size Analysis

C. Appendix C: Cross Section Data

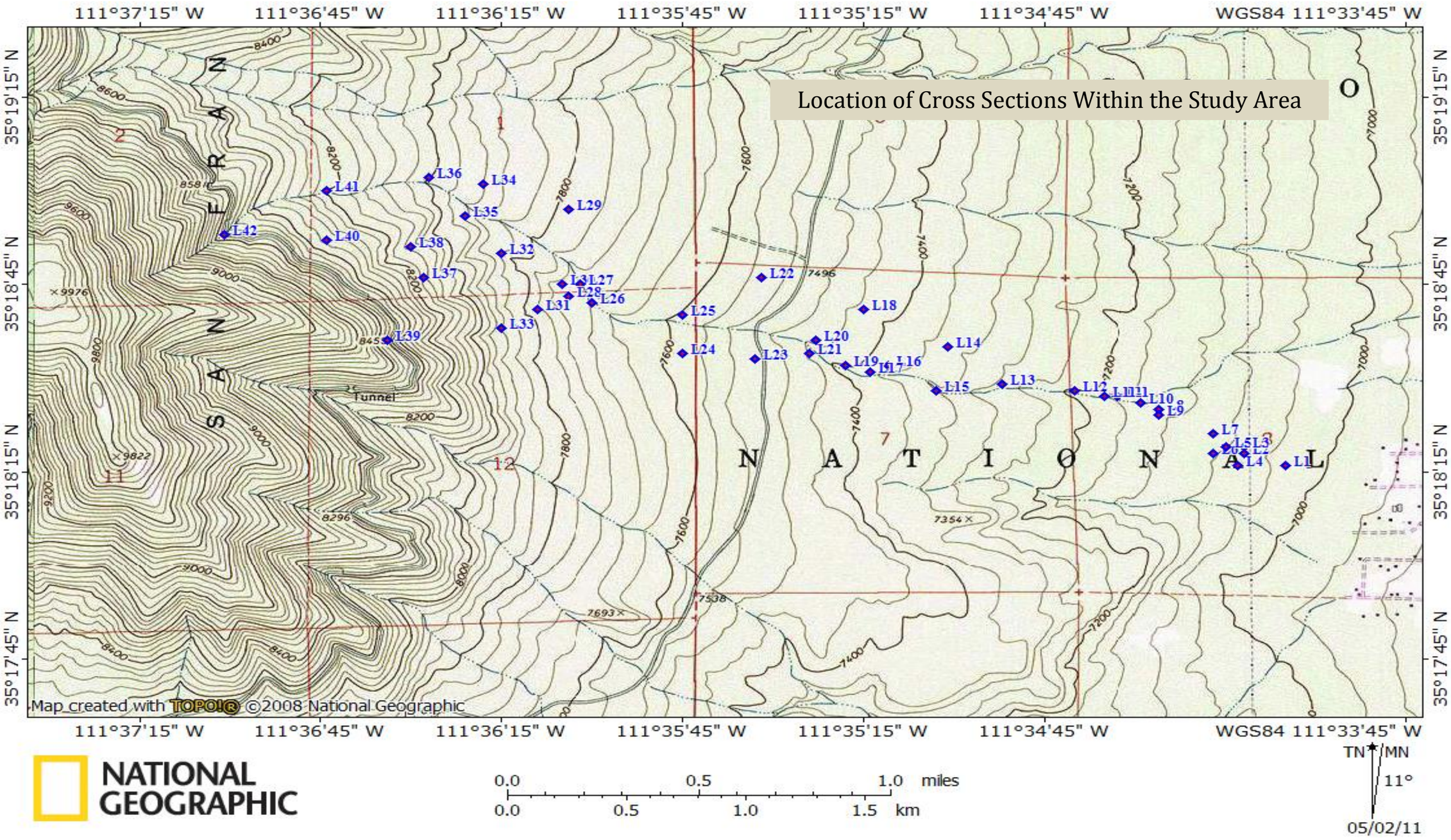
D. Appendix D: Definitions

Appendix A

Map of Study Area



Map: 1: The Rope-Arabian-Campbell Watershed



Map: 2: Cross sections within the study area

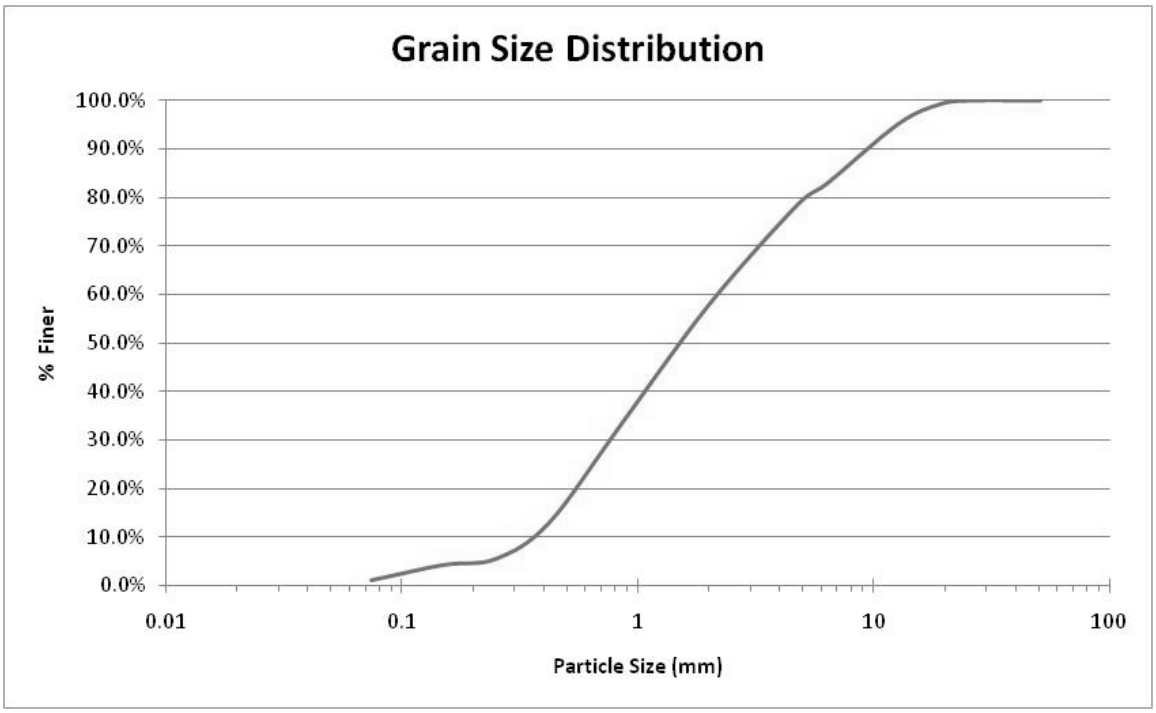
Appendix B

Grain Size Analysis

Note: The sample numbers listed in each chart of this appendix, correspond to the locations for each sample in appendix C.

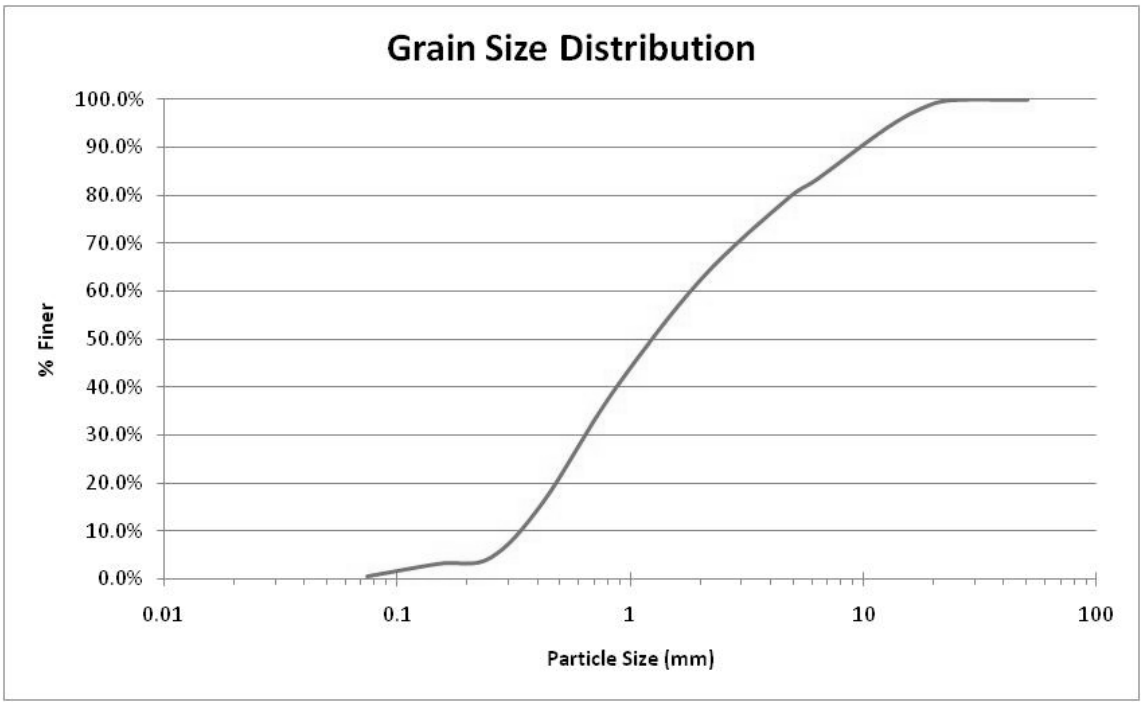
Appendix B: Grain Size Analysis

Sample	L2		Note				Percent of sample	
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer		
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			5.68	0.7%	99.3%		
1/2"	12.700			32.49	4.1%	95.2%		
1/4"	6.350	381.2	479.25	98.05	12.2%	83.0%		
4	4.760	351.8	386.54	34.74	4.3%	78.7%	21.3%	
10	2.000	432.58	598.23	165.65	20.7%	58.0%		Sand
20	0.840	400.28	600.25	199.97	25.0%	33.0%		
40	0.420	399.23	559.36	160.13	20.0%	13.1%		
60	0.250	367.75	427.58	59.83	7.5%	5.6%		
100	0.149	356.25	366.55	10.30	1.3%	4.3%		
200	0.074	323.45	348.59	25.14	3.1%	1.2%	77.5%	
Pan	0.000	349.79	359.23	9.44	1.2%	0.0%	1.2%	Fines
Totals				801.42	100.0%		100.0%	



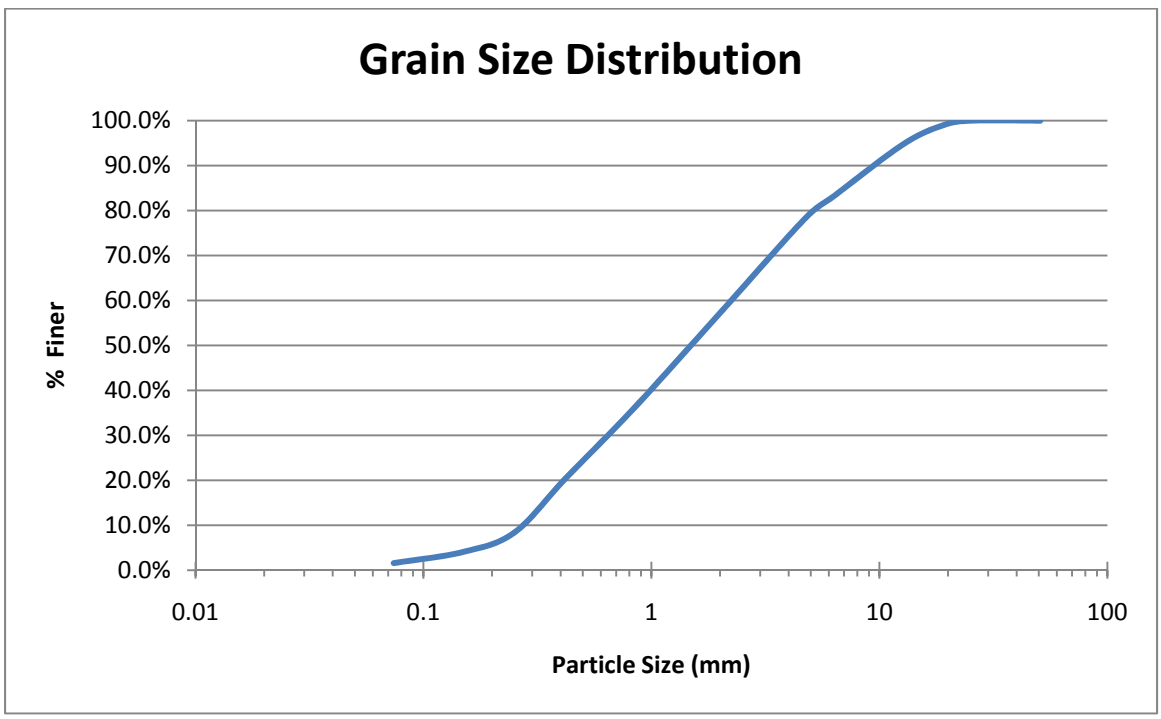
Appendix B: Grain Size Analysis

Sample	L5		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			9.84	1.2%	98.8%		
1/2"	12.700			38.88	4.6%	94.2%		
1/4"	6.350	372.80	463.34	90.54	10.7%	83.5%		
4	4.760	371.34	405.02	33.68	4.0%	79.5%	20.5%	
10	2.000	444.72	588.22	143.50	17.0%	62.5%		Sand
20	0.840	415.76	613.59	197.83	23.5%	39.0%		
40	0.420	395.60	589.43	193.83	23.0%	16.0%		
60	0.250	377.90	475.20	97.30	11.5%	4.4%		
100	0.149	358.97	369.52	10.55	1.3%	3.2%		
200	0.074	324.20	346.26	22.06	2.6%	0.6%	78.9%	
Pan	0.000	358.12	362.93	4.81	0.6%	0.0%	0.6%	Fines
Totals				842.82	100.0%		100.0%	



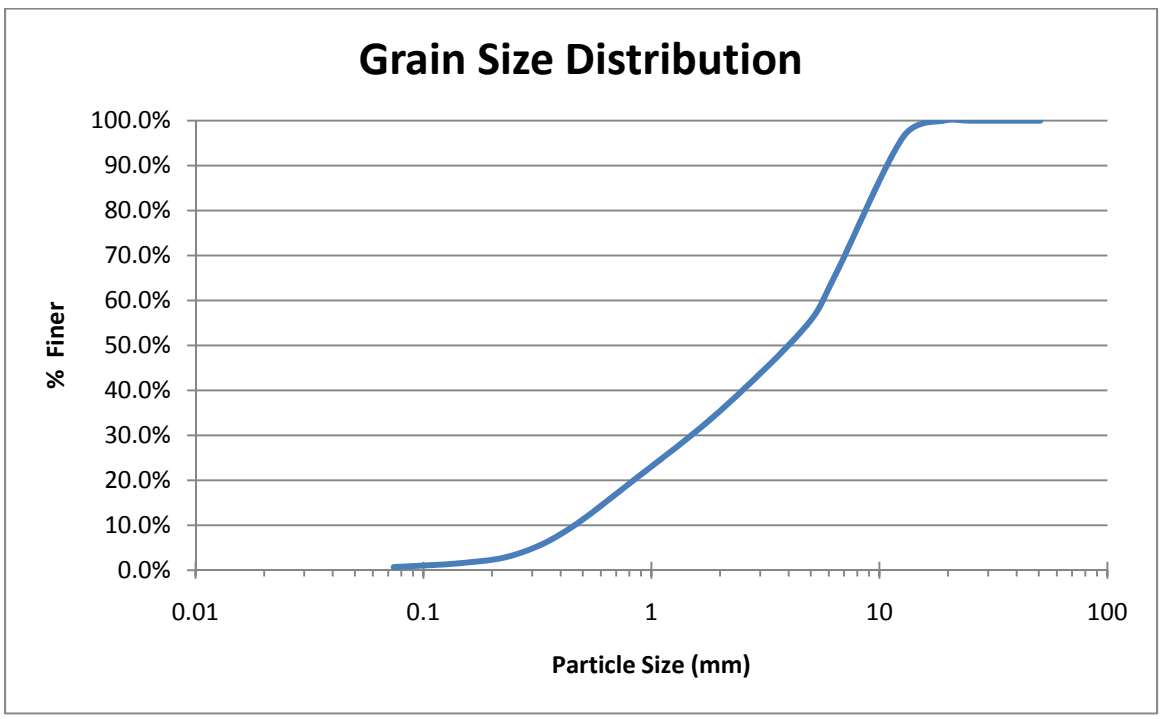
Appendix B: Grain Size Analysis

Sample	L7-1		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			8.84	1.0%	99.0%		
1/2"	12.700			38.08	4.3%	94.7%		
1/4"	6.350	371.80	473.34	101.54	11.4%	83.3%		
4	4.760	371.77	415.02	43.25	4.9%	78.4%	21.6%	
10	2.000	439.72	628.22	188.50	21.2%	57.2%		Sand
20	0.840	405.76	593.66	187.90	21.1%	36.1%		
40	0.420	395.60	534.81	139.21	15.7%	20.4%		
60	0.250	367.90	475.20	107.30	12.1%	8.3%		
100	0.149	358.97	397.15	38.18	4.3%	4.0%		
200	0.074	324.20	346.26	22.06	2.5%	1.6%	76.9%	
Pan	0.000	368.02	381.82	13.80	1.6%	0.0%	1.6%	Fines
Totals				888.66	100.0%		100.0%	



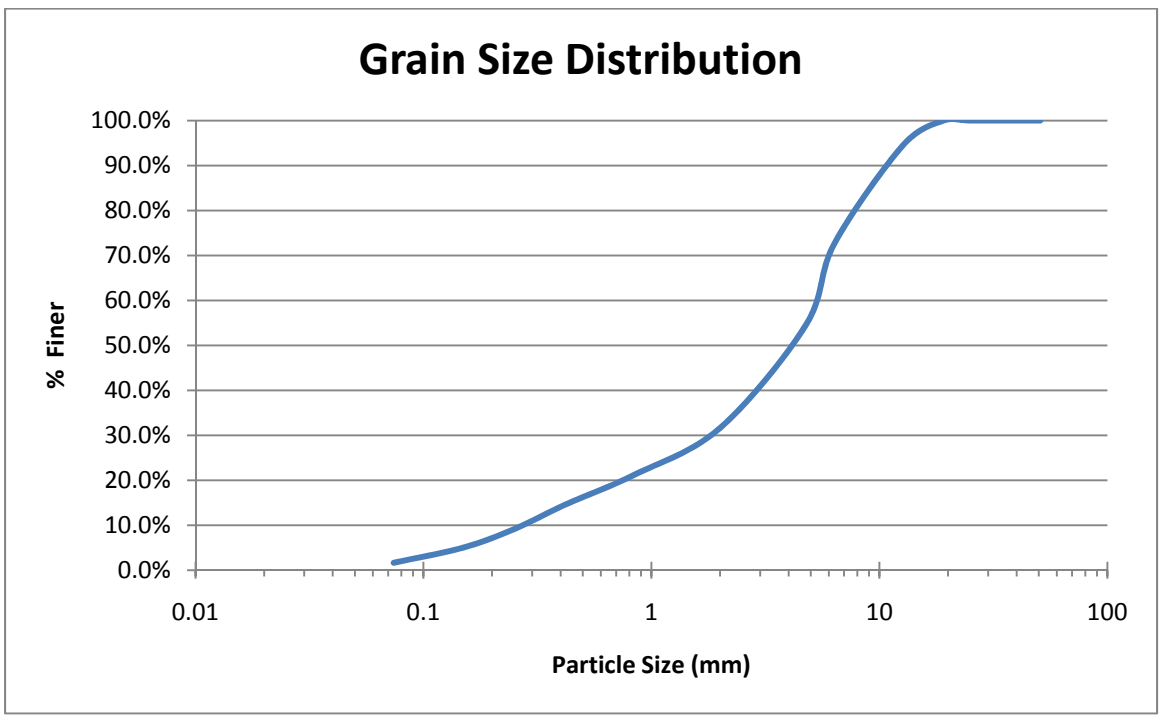
Appendix B: Grain Size Analysis

Sample	L7-2		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			0.00	0.0%	100.0%		
1/2"	12.700			45.89	3.7%	96.3%		
1/4"	6.350	371.81	762.40	390.59	31.1%	65.2%		
4	4.760	371.80	509.79	137.99	11.0%	54.3%	45.7%	
10	2.000	446.53	683.21	236.68	18.8%	35.4%		Sand
20	0.840	395.32	587.84	192.52	15.3%	20.1%		
40	0.420	399.64	543.21	143.57	11.4%	8.7%		
60	0.250	365.62	431.96	66.34	5.3%	3.4%		
100	0.149	352.04	374.47	22.43	1.8%	1.6%		
200	0.074	341.67	353.37	11.70	0.9%	0.7%	53.6%	
Pan	0.000	368.51	376.84	8.33	0.7%	0.0%	0.7%	Fines
Totals				1256.04	100.0%		100.0%	



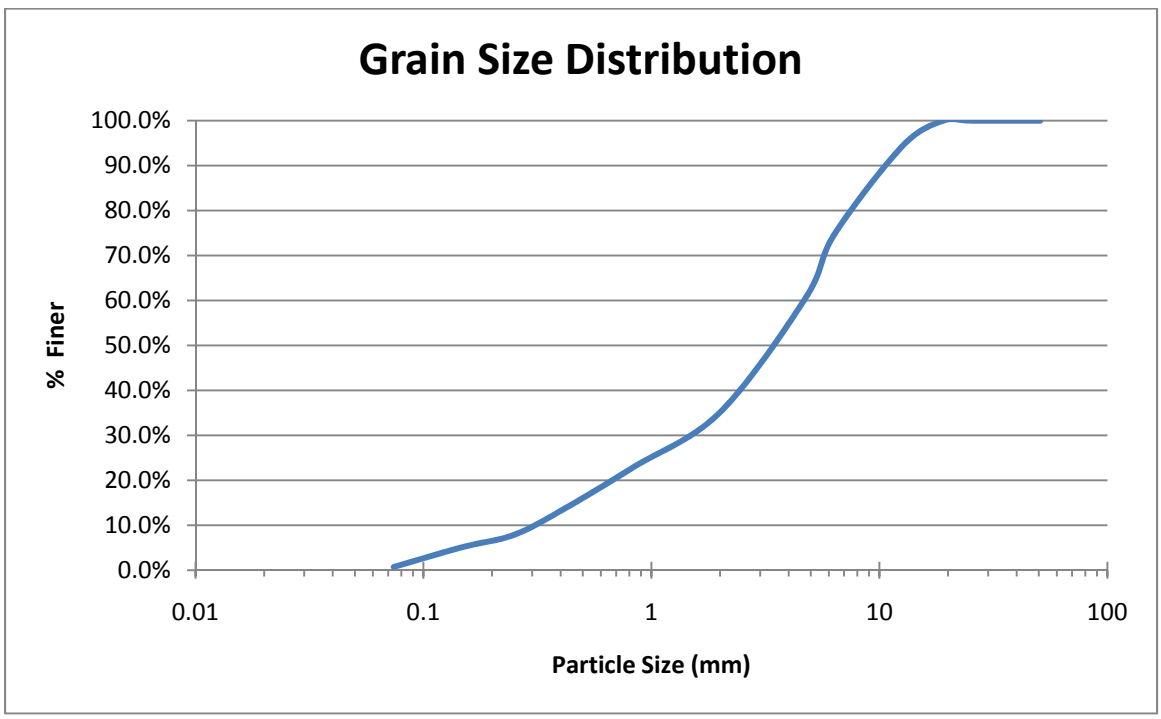
Appendix B: Grain Size Analysis

Sample	L8		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			0.00	0.0%	100.0%		
1/2"	12.700			32.88	5.5%	94.5%		
1/4"	6.350	349.50	480.91	131.41	21.9%	72.7%		
4	4.760	359.68	468.56	108.88	18.1%	54.6%	45.4%	
10	2.000	419.74	557.56	137.82	22.9%	31.6%		Sand
20	0.840	356.89	419.56	62.67	10.4%	21.2%		
40	0.420	375.56	415.19	39.63	6.6%	14.6%		
60	0.250	343.68	376.59	32.91	5.5%	9.1%		
100	0.149	330.92	355.76	24.84	4.1%	5.0%		
200	0.074	321.17	341.39	20.22	3.4%	1.6%	52.9%	
Pan	0.000	346.45	356.25	9.80	1.6%	0.0%	1.6%	Fines
Totals				601.06	100.0%		100.0%	



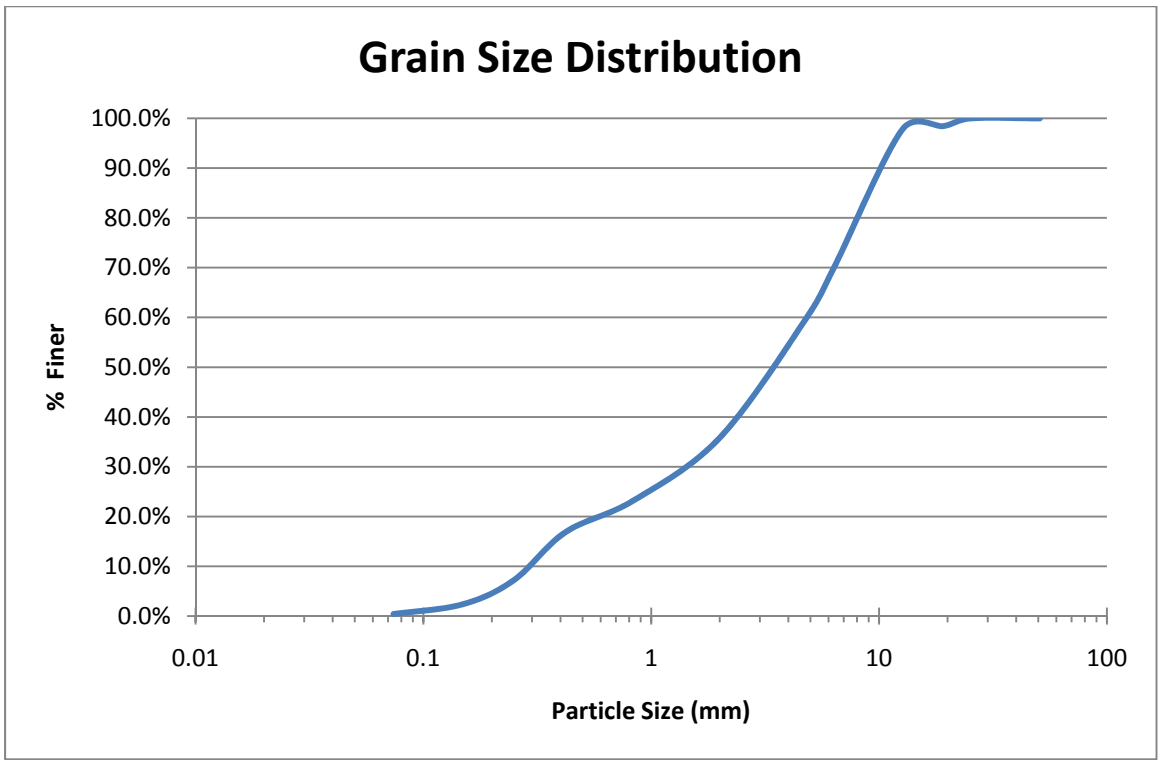
Appendix B: Grain Size Analysis

Sample	L9		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			0.00	0.0%	100.0%		
1/2"	12.700			29.88	5.5%	94.5%		
1/4"	6.350	349.50	456.58	107.08	19.8%	74.7%		
4	4.760	359.68	435.89	76.21	14.1%	60.7%	39.3%	
10	2.000	419.74	558.25	138.51	25.6%	35.1%		Sand
20	0.840	356.89	422.56	65.67	12.1%	23.0%		
40	0.420	375.56	425.36	49.80	9.2%	13.8%		
60	0.250	343.68	375.89	32.21	5.9%	7.9%		
100	0.149	330.92	345.69	14.77	2.7%	5.1%		
200	0.074	321.17	345.21	24.04	4.4%	0.7%	60.0%	
Pan	0.000	346.45	350.26	3.81	0.7%	0.0%	0.7%	Fines
Totals				541.98	100.0%		100.0%	

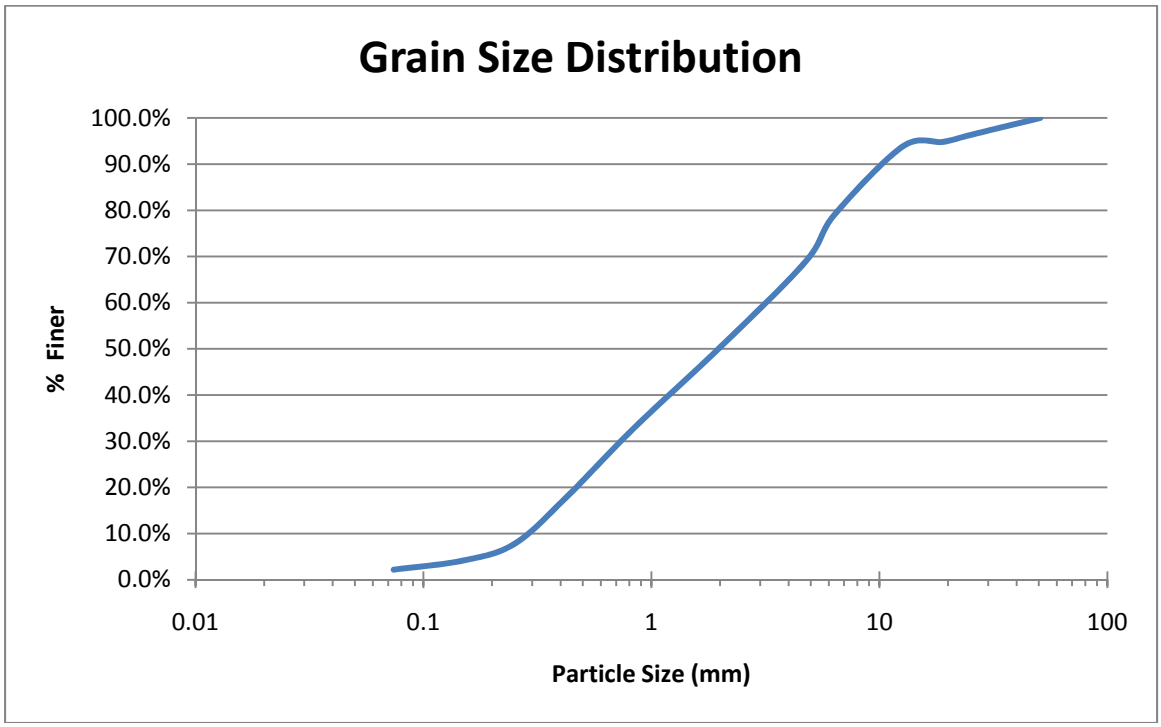


Appendix B: Grain Size Analysis

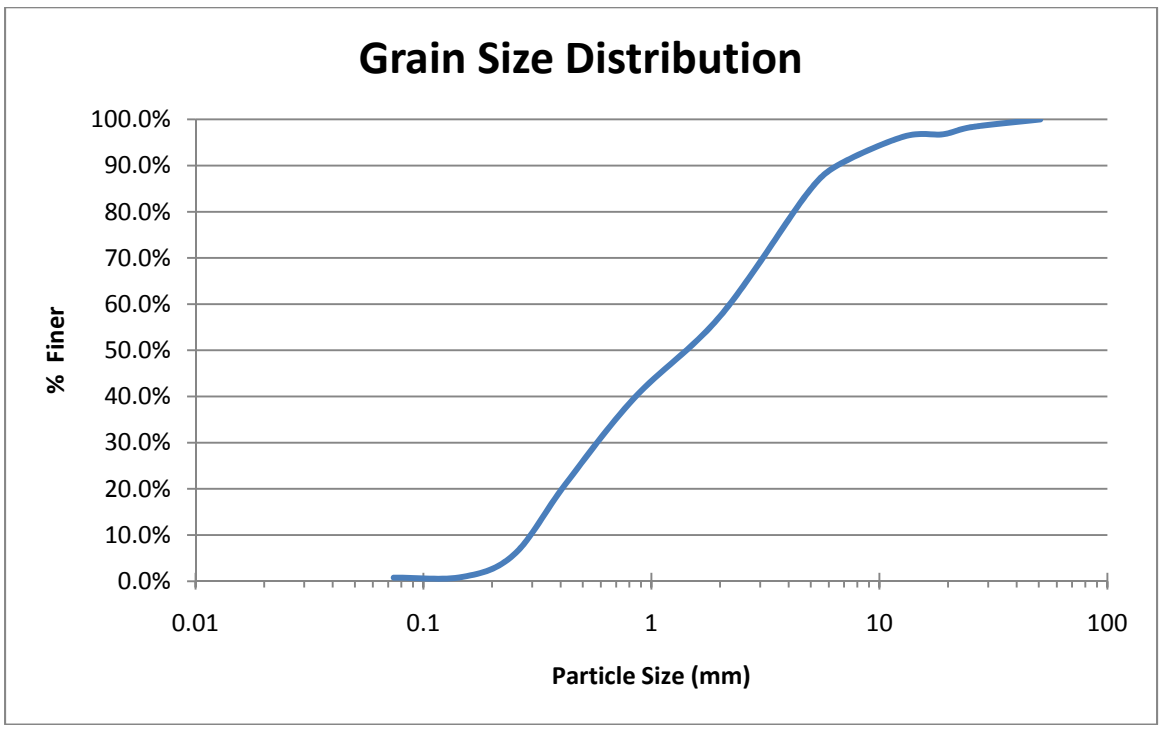
Sample	L11		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			23.96	1.6%	98.4%		
1/2"	12.700	371.77	530.76	9.11	0.6%	97.8%		
1/4"	6.350	371.81	796.44	424.63	27.8%	70.0%		
4	4.760	511.22	670.45	159.23	10.4%	59.6%	40.4%	
10	2.000	440.26	803.97	363.71	23.8%	35.8%		Sand
20	0.840	406.09	597.91	191.82	12.6%	23.3%		
40	0.420	395.73	494.08	98.35	6.4%	16.8%		
60	0.250	368.06	514.54	146.48	9.6%	7.3%		
100	0.149	359.06	433.53	74.47	4.9%	2.4%		
200	0.074	324.28	354.39	30.11	2.0%	0.4%	59.2%	
Pan	0.000	368.04	374.27	6.23	0.4%	0.0%	0.4%	Fines
Totals				1528.10	100.0%		100.0%	



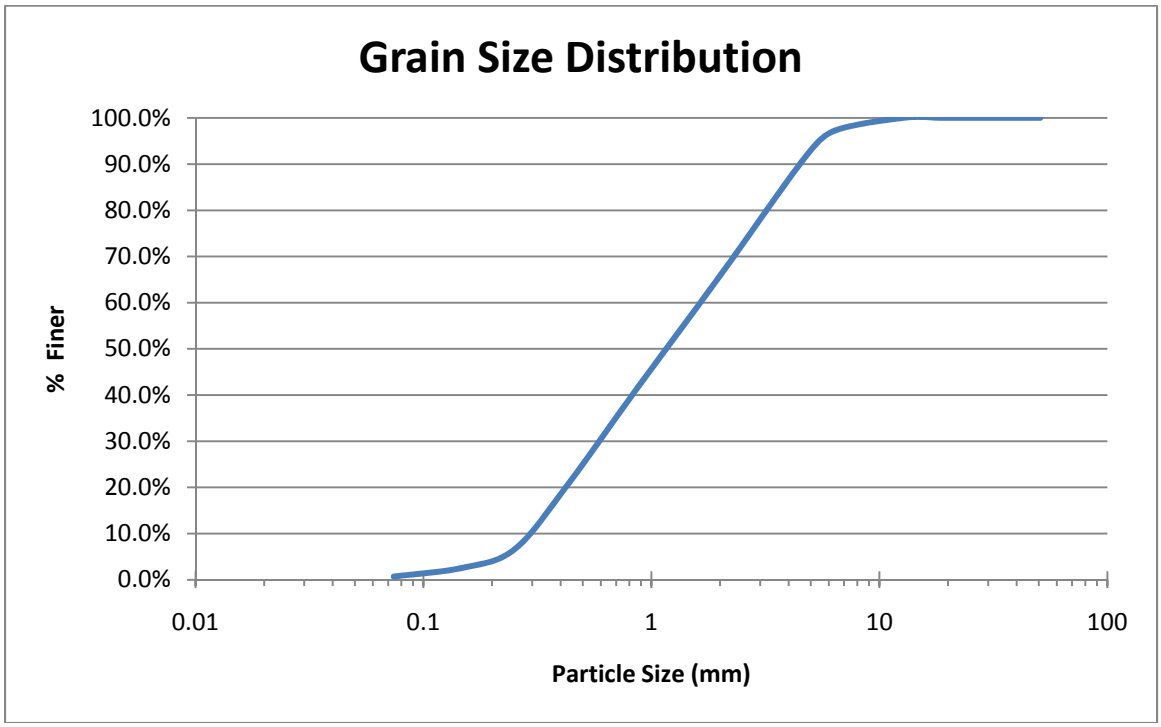
Sample	L12		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			34.61	3.6%	96.4%		
3/4"	19.100			14.99	1.6%	94.8%		
1/2"	12.700			9.11	0.9%	93.9%		
1/4"	6.350	371.81	514.18	142.37	14.8%	79.0%		
4	4.760	371.81	468.31	96.50	10.1%	69.0%	31.0%	
10	2.000	430.94	609.95	179.01	18.7%	50.3%		Sand
20	0.840	406.06	573.38	167.32	17.4%	32.9%		
40	0.420	395.73	541.63	145.90	15.2%	17.7%		
60	0.250	367.97	463.50	95.53	10.0%	7.7%		
100	0.149	359.05	393.48	34.43	3.6%	4.2%		
200	0.074	324.34	343.27	18.93	2.0%	2.2%	66.8%	
Pan	0.000	367.97	388.94	20.97	2.2%	0.0%	2.2%	Fines
Totals				959.67	100.0%		100.0%	



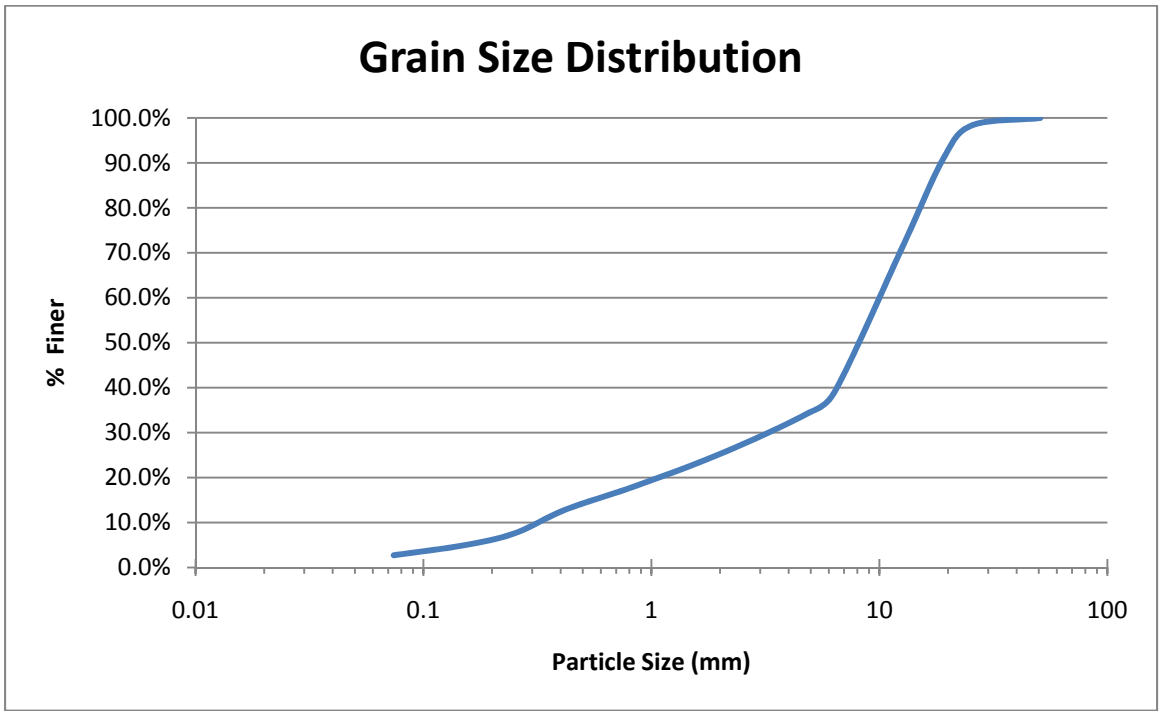
Sample	L13		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		
1"	25.400			13.58	1.7%	98.3%		Gravel
3/4"	19.100			12.58	1.5%	96.8%		
1/2"	12.700			4.58	0.6%	96.2%		
1/4"	6.350	371.89	425.69	53.80	6.6%	89.7%		
4	4.760	511.58	561.25	49.67	6.1%	83.6%		
10	2.000	430.94	645.28	214.34	26.2%	57.4%	41.0%	
20	0.840	406.06	550.99	144.93	17.7%	39.7%		Sand
40	0.420	395.73	547.89	152.16	18.6%	21.0%		
60	0.250	367.97	492.51	124.54	15.2%	5.8%		
100	0.149	359.05	398.89	39.84	4.9%	0.9%		
200	0.074	324.34	325.78	1.44	0.2%	0.8%		
Pan	0.000	367.97	374.25	6.28	0.8%	0.0%	57.4%	
Totals				817.74	100.0%		100.0%	Fines



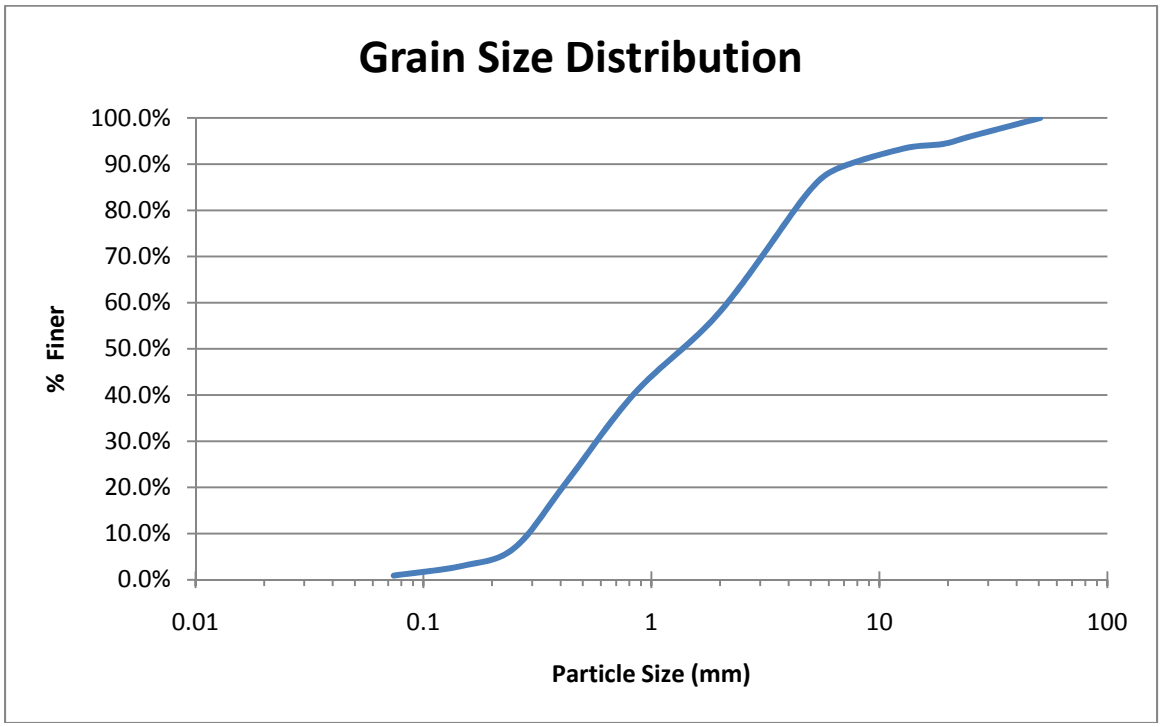
Sample	L15		Date				Percentage of sample	
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer		
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			0.00	0.0%	100.0%		
1/2"	12.700			0.00	0.0%	100.0%		
1/4"	6.350	371.79	396.02	24.23	2.8%	97.2%		
4	4.760	511.50	559.45	47.95	5.5%	91.7%	8.3%	
10	2.000	440.17	665.05	224.88	25.9%	65.8%		Sand
20	0.840	406.10	625.80	219.70	25.3%	40.6%		
40	0.420	395.83	575.07	179.24	20.6%	20.0%		
60	0.250	368.04	484.77	116.73	13.4%	6.5%		
100	0.149	359.03	393.28	34.25	3.9%	2.6%		
200	0.074	324.25	340.83	16.58	1.9%	0.7%	91.0%	
Pan	0.000	368.09	374.13	6.04	0.7%	0.0%	0.7%	Fines
Totals				869.60	100.0%		100.0%	



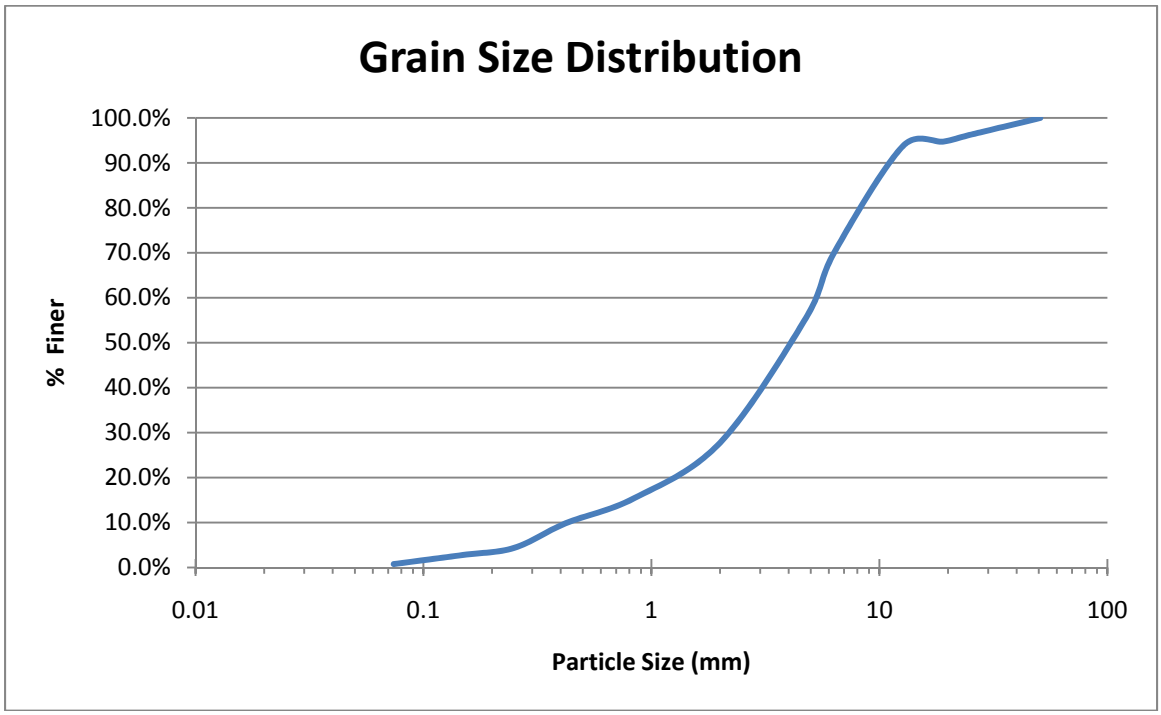
Sample	L16		Note				Percentage of sample	
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer		
2"	50.8					100.0%		Gravel
1"	25.400			15.57	1.7%	98.3%		
3/4"	19.100			67.84	7.3%	91.0%		
1/2"	12.700	371.75	551.89	180.14	19.4%	71.6%		
1/4"	6.350	371.75	674.05	302.30	32.6%	39.0%		
4	4.760	371.78	417.47	45.69	4.9%	34.1%	65.9%	
10	2.000	436.00	517.88	81.88	8.8%	25.3%		Sand
20	0.840	404.00	471.04	67.04	7.2%	18.0%		
40	0.420	396.00	443.82	47.82	5.2%	12.9%		
60	0.250	368.00	417.18	49.18	5.3%	7.6%		
100	0.149	360.00	384.71	24.71	2.7%	4.9%		
200	0.074	324.00	344.33	20.33	2.2%	2.7%	31.4%	
Pan	0.000	368.00	393.25	25.25	2.7%	0.0%	2.7%	Fines
Totals				927.75	100.0%		100.0%	



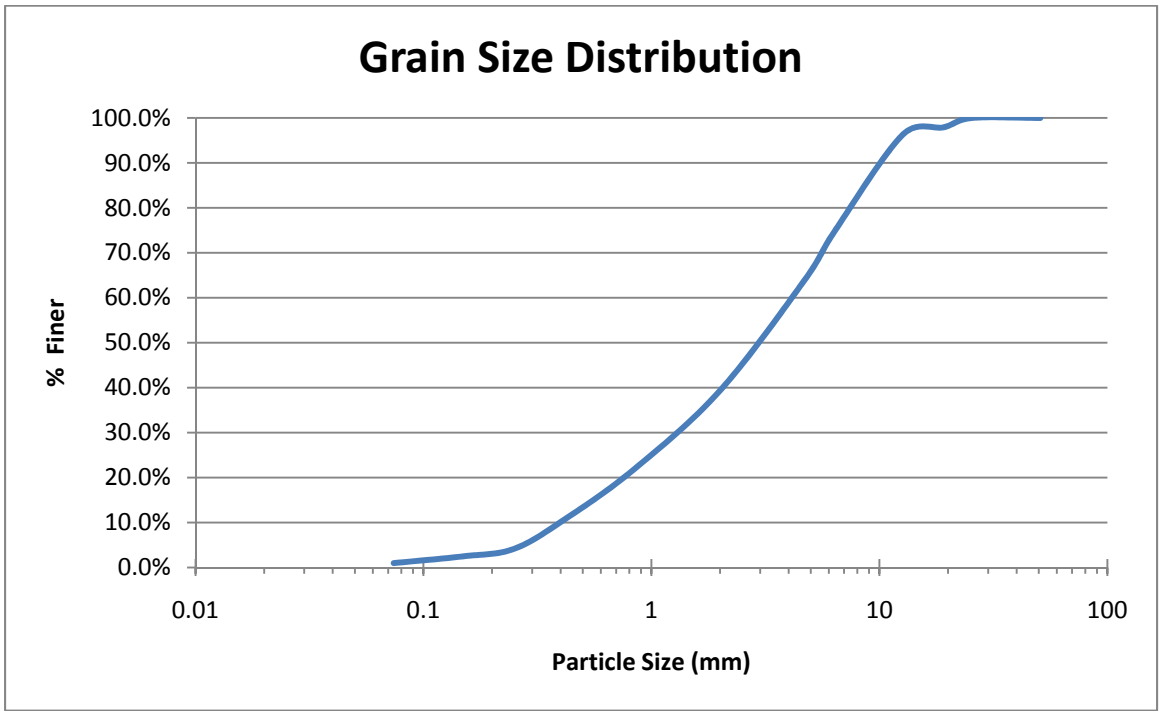
Sample	L17-1		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			34.61	3.9%	96.1%		
3/4"	19.100			14.99	1.7%	94.4%		
1/2"	12.700			9.11	1.0%	93.4%		
1/4"	6.350	371.89	412.66	40.77	4.6%	88.7%		
4	4.760	511.58	559.61	48.03	5.4%	83.3%	16.7%	
10	2.000	430.94	653.99	223.05	25.2%	58.1%		Sand
20	0.840	406.06	563.09	157.03	17.8%	40.3%		
40	0.420	395.73	567.27	171.54	19.4%	20.9%		
60	0.250	367.97	491.80	123.83	14.0%	6.8%		
100	0.149	359.05	392.77	33.72	3.8%	3.0%		
200	0.074	324.34	343.22	18.88	2.1%	0.9%	82.4%	
Pan	0.000	367.97	375.83	7.86	0.9%	0.0%	0.9%	Fines
Totals				883.42	100.0%		100.0%	



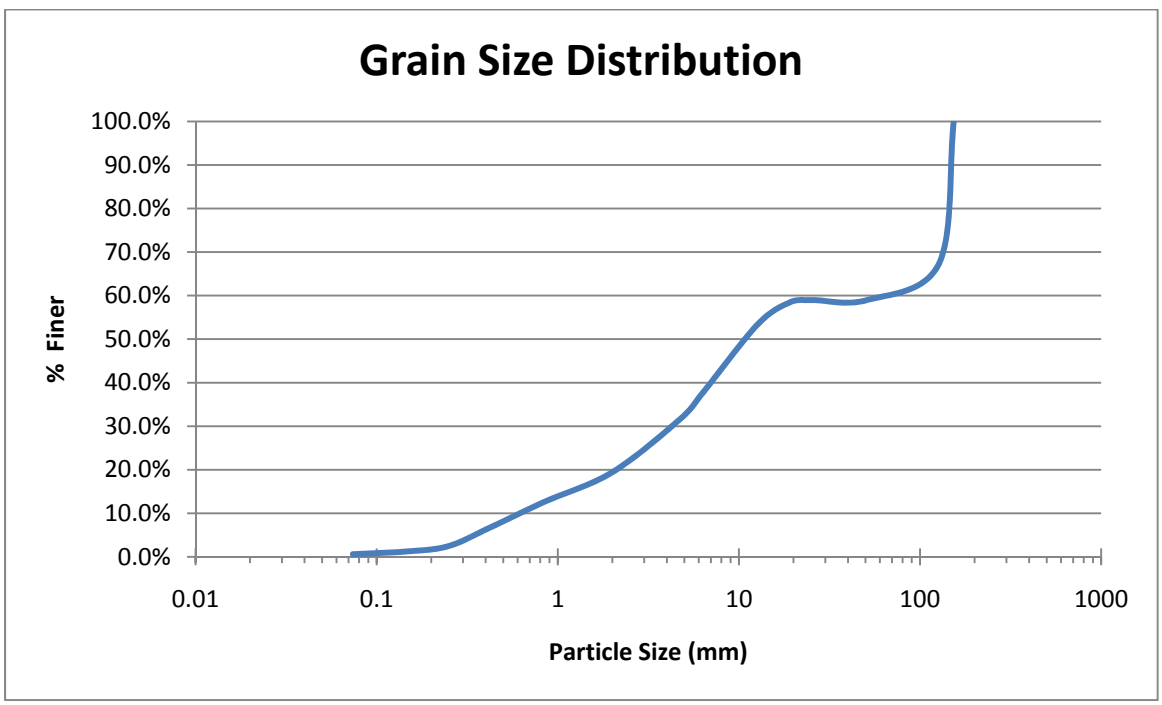
Sample	L17-2		Note				Percentage of sample	
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer		
2"	50.8					100.0%		Gravel
1"	25.400			34.61	3.7%	96.3%		
3/4"	19.100			14.99	1.6%	94.7%		
1/2"	12.700			9.11	1.0%	93.8%		
1/4"	6.350	371.78	594.95	223.17	23.6%	70.1%		
4	4.760	511.58	649.90	138.32	14.6%	55.5%	44.5%	
10	2.000	430.94	693.14	262.20	27.8%	27.7%		Sand
20	0.840	406.06	522.62	116.56	12.3%	15.4%		
40	0.420	395.73	448.40	52.67	5.6%	9.8%		
60	0.250	367.97	419.53	51.56	5.5%	4.4%		
100	0.149	359.05	374.05	15.00	1.6%	2.8%		
200	0.074	324.34	343.46	19.12	2.0%	0.7%	54.8%	
Pan	0.000	367.97	374.96	6.99	0.7%	0.0%	0.7%	Fines
Totals				944.30	100.0%		100.0%	



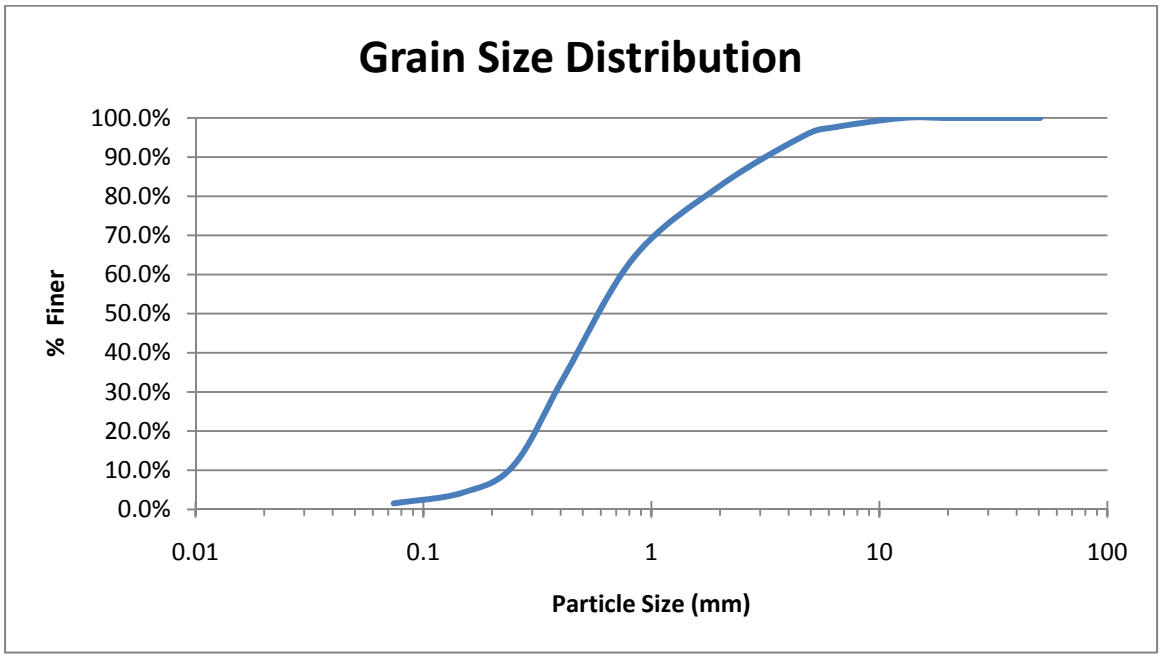
Sample	L19		Note				Percentage of sample	
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer		
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			19.11	2.1%	97.9%		
1/2"	12.700			14.25	1.6%	96.3%		
1/4"	6.350	371.85	569.12	197.27	21.6%	74.7%		
4	4.760	511.27	605.94	94.67	10.4%	64.3%	35.7%	
10	2.000	440.01	668.05	228.04	25.0%	39.3%		Sand
20	0.840	405.84	565.48	159.64	17.5%	21.8%		
40	0.420	395.86	496.54	100.68	11.0%	10.8%		
60	0.250	368.27	429.21	60.94	6.7%	4.1%		
100	0.149	359.16	374.50	15.34	1.7%	2.5%		
200	0.074	324.51	338.23	13.72	1.5%	0.9%	63.4%	
Pan	0.000	368.10	376.76	8.66	0.9%	0.0%	0.9%	Fines
Totals				912.32	100.0%		100.0%	



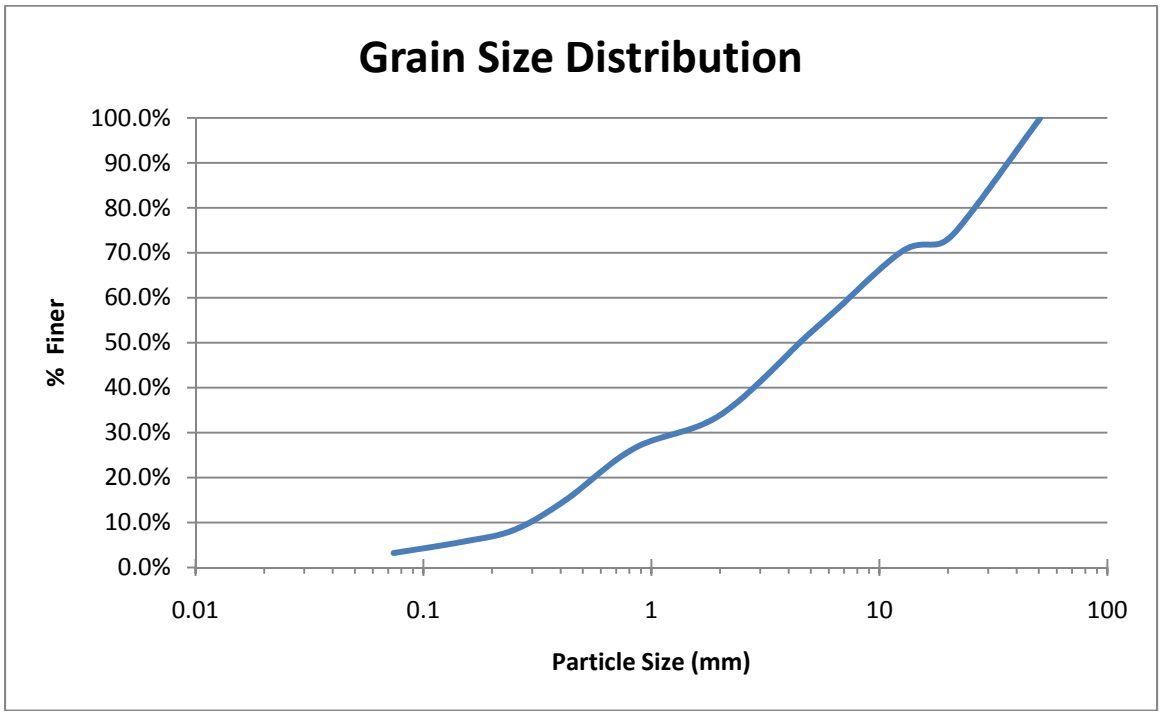
Sample	L20-1		Note				Percentage of sample	
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer		
	153.4					100.0%		Cobble
5"	127			590	32.7%	67.3%	32.7%	
2"	50.8			150	8.3%	59.0%		Gravel
1"	25.400			0.00	0.0%	59.0%		
3/4"	19.100			9.43	0.5%	58.5%		
1/2"	12.700			90.97	5.0%	53.4%		
1/4"	6.350	371.80	653.63	281.83	15.6%	37.8%		
4	4.760	371.77	481.18	109.41	6.1%	31.7%	35.6%	
10	2.000	440.10	661.90	221.80	12.3%	19.4%		Sand
20	0.840	405.96	529.36	123.40	6.8%	12.6%		
40	0.420	395.79	502.68	106.89	5.9%	6.7%		
60	0.250	367.94	443.49	75.55	4.2%	2.5%		
100	0.149	358.97	381.06	22.09	1.2%	1.3%		
200	0.074	324.22	335.93	11.71	0.6%	0.6%	31.1%	
Pan	0.000	368.03	378.91	10.88	0.6%	0.0%	0.6%	Fines
Totals				1803.96	100.0%		100.0%	



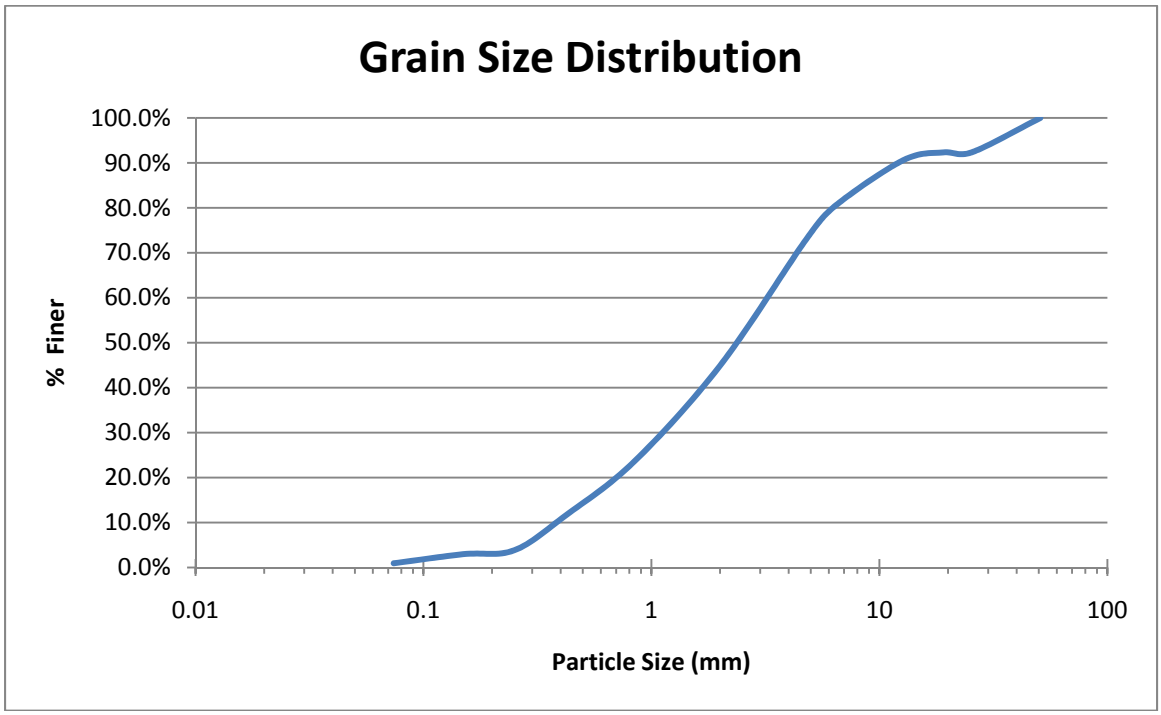
Sample	L20-2		Note				Percentage of sample	
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer		
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			0.00	0.0%	100.0%		
1/2"	12.700			0.00	0.0%	100.0%		
1/4"	6.350	371.85	391.67	19.82	2.4%	97.6%		
4	4.760	511.46	527.64	16.18	1.9%	95.7%	4.3%	
10	2.000	439.82	548.91	109.09	13.0%	82.7%		Sand
20	0.840	405.96	558.37	152.41	18.2%	64.5%		
40	0.420	396.01	646.36	250.35	29.9%	34.6%		
60	0.250	368.24	562.08	193.84	23.2%	11.4%		
100	0.149	359.08	418.81	59.73	7.1%	4.3%		
200	0.074	324.38	347.61	23.23	2.8%	1.5%	94.2%	
Pan	0.000	368.11	380.65	12.54	1.5%	0.0%	1.5%	Fines
Totals				837.19	100.0%		100.0%	



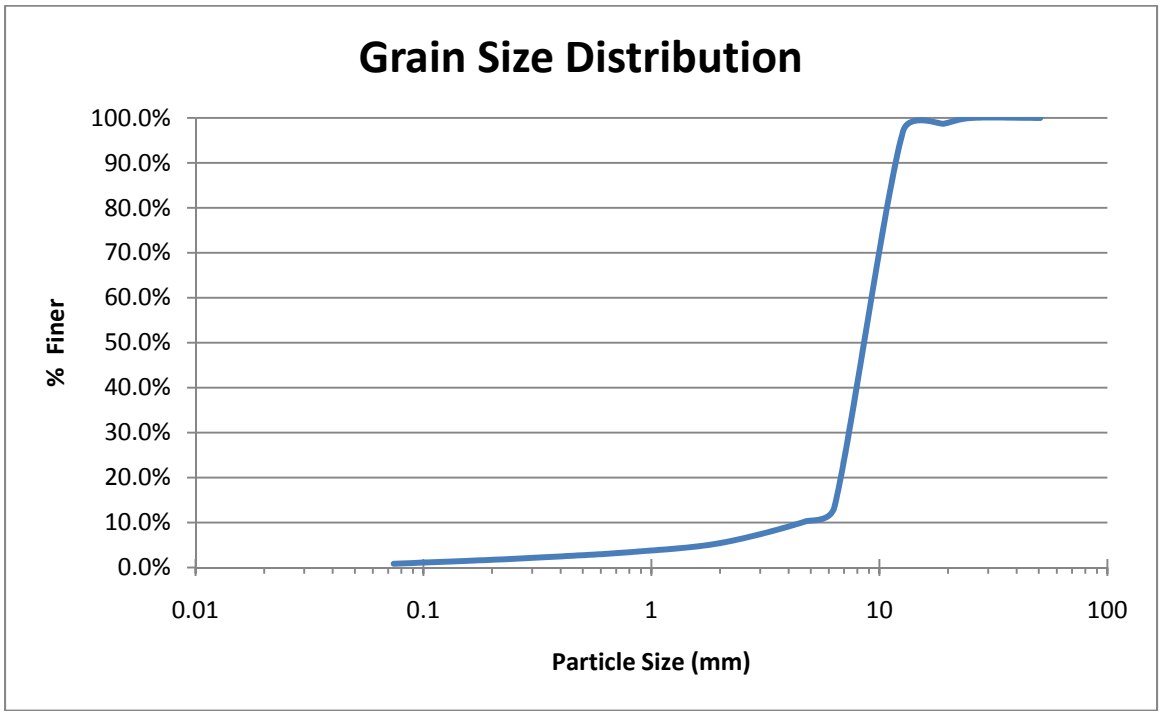
Sample	L20-3		Note				Percentage of sample	
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer		
2"	50.8					100.0%		Gravel
1"	25.400			167.20	20.9%	79.1%		
3/4"	19.100			53.97	6.7%	72.4%		
1/2"	12.700			15.41	1.9%	70.5%		
1/4"	6.350	371.79	480.21	108.42	13.5%	56.9%		
4	4.760	511.29	556.49	45.20	5.6%	51.3%	48.7%	
10	2.000	439.80	579.20	139.40	17.4%	33.9%		Sand
20	0.840	405.98	465.11	59.13	7.4%	26.5%		
40	0.420	395.81	488.04	92.23	11.5%	15.0%		
60	0.250	367.95	420.99	53.04	6.6%	8.4%		
100	0.149	359.05	380.15	21.10	2.6%	5.7%		
200	0.074	324.26	344.45	20.19	2.5%	3.2%	48.1%	
Pan	0.000	368.05	393.89	25.84	3.2%	0.0%	3.2%	Fines
Totals				801.13	100.0%		100.0%	



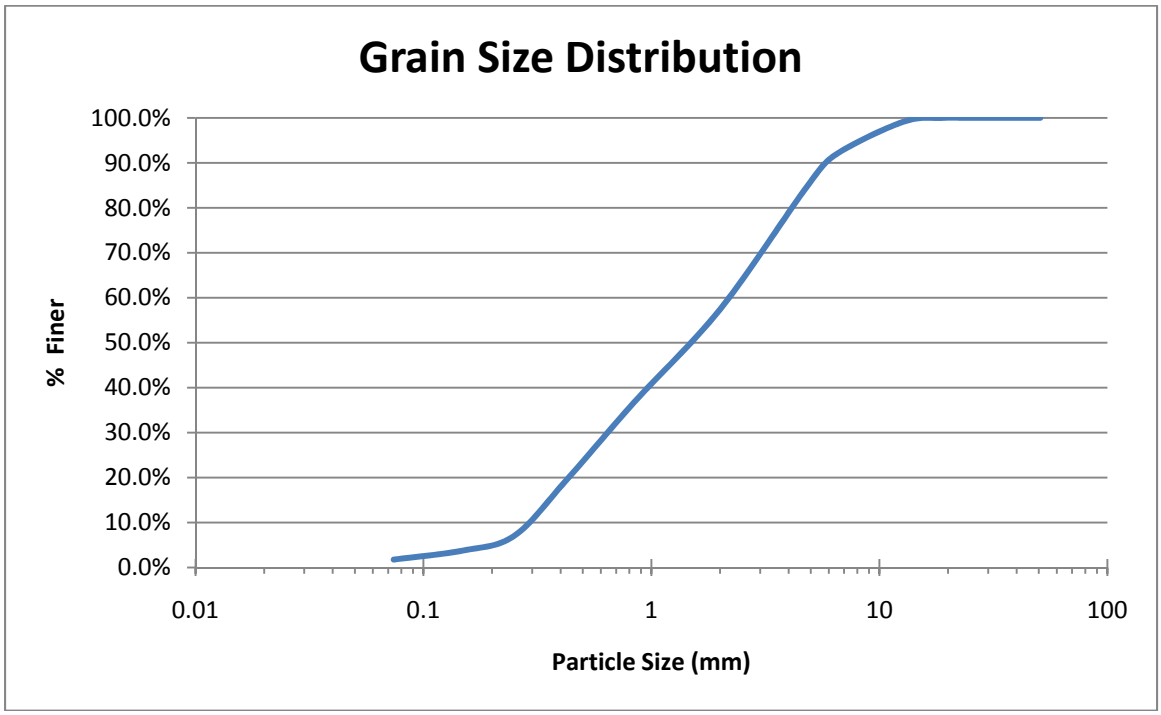
Sample	L21-1		Note				Percentage of sample	
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer		
2"	50.8					100.0%		Gravel
1"	25.400			76.52	7.6%	92.4%		
3/4"	19.100			0.00	0.0%	92.4%		
1/2"	12.700			17.75	1.8%	90.6%		
1/4"	6.350	371.77	474.62	102.85	10.3%	80.3%		
4	4.760	371.77	445.82	74.05	7.4%	72.9%	27.1%	
10	2.000	439.72	719.96	280.24	28.0%	44.9%		Sand
20	0.840	405.76	619.41	213.65	21.3%	23.6%		
40	0.420	395.60	515.80	120.20	12.0%	11.6%		
60	0.250	367.90	445.34	77.44	7.7%	3.8%		
100	0.149	358.97	367.69	8.72	0.9%	2.9%		
200	0.074	324.20	344.39	20.19	2.0%	0.9%	72.0%	
Pan	0.000	368.02	377.27	9.25	0.9%	0.0%	0.9%	Fines
Totals				1000.86	100.0%		100.0%	



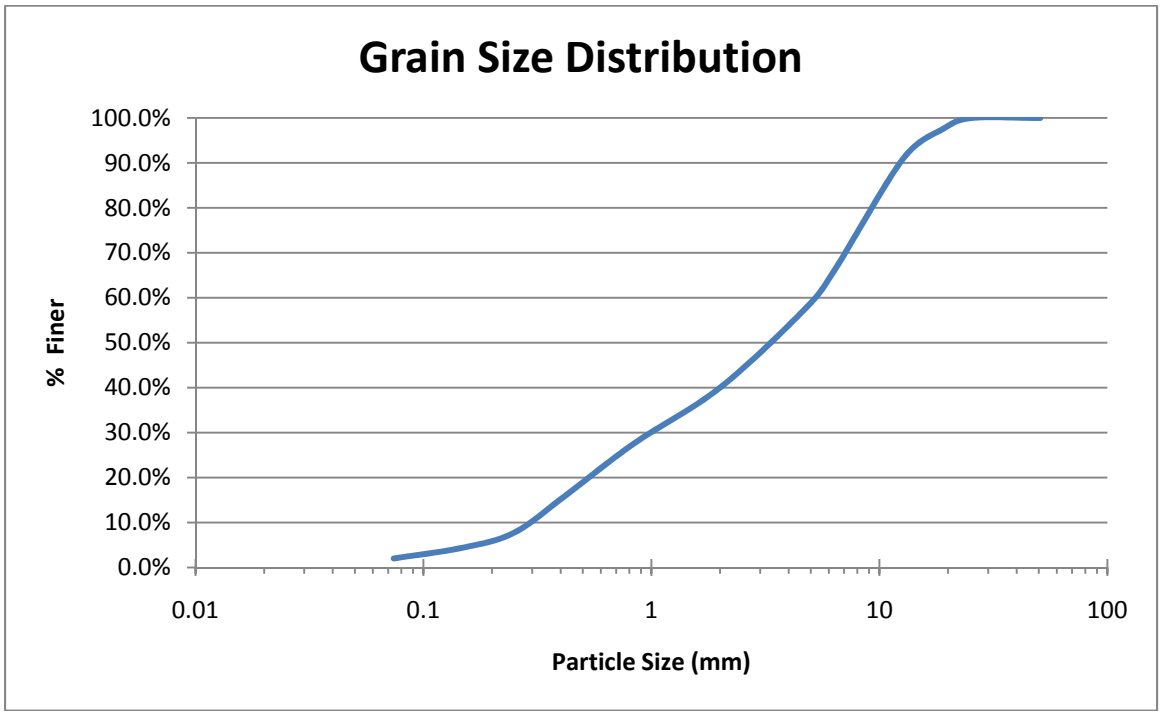
Sample	L21-2		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			6.53	1.3%	98.7%		
1/2"	12.700			8.42	1.7%	97.0%		
1/4"	6.350	371.76	790.12	418.36	83.5%	13.5%		
4	4.760	371.81	387.77	15.96	3.2%	10.3%	89.7%	
10	2.000	446.53	470.83	24.30	4.9%	5.4%		Sand
20	0.840	395.32	405.04	9.72	1.9%	3.5%		
40	0.420	399.64	404.41	4.77	1.0%	2.5%		
60	0.250	365.62	368.60	2.98	0.6%	1.9%		
100	0.149	352.04	354.51	2.47	0.5%	1.4%		
200	0.074	341.67	344.73	3.06	0.6%	0.8%	9.4%	
Pan	0.000	368.51	372.71	4.20	0.8%	0.0%	0.8%	Fines
Totals				500.77	100.0%		100.0%	



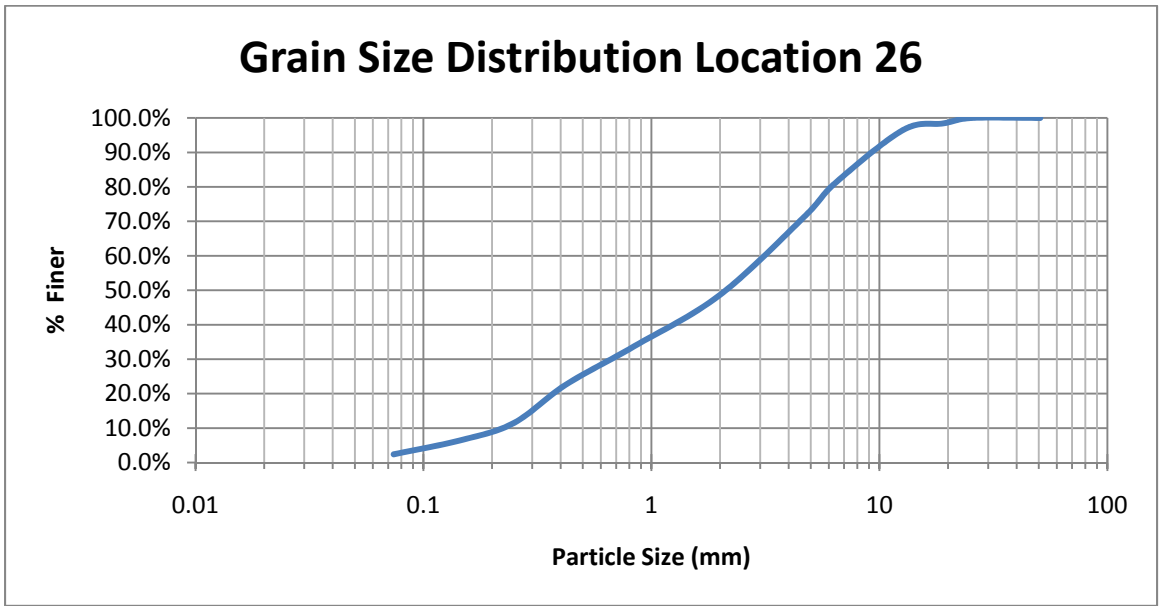
Sample	L24-1		Note				Percentage of sample	
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer		
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			0.00	0.0%	100.0%		
1/2"	12.700			32.33	0.9%	99.1%		
1/4"	6.350	371.85	647.08	275.23	7.5%	91.6%		
4	4.760	511.30	777.95	266.65	7.2%	84.4%	15.6%	
10	2.000	439.75	1432.39	992.64	27.0%	57.4%		Sand
20	0.840	405.87	1166.78	760.91	20.7%	36.7%		
40	0.420	395.71	1041.20	645.49	17.5%	19.2%		
60	0.250	368.31	816.70	448.39	12.2%	7.0%		
100	0.149	359.07	479.43	120.36	3.3%	3.8%		
200	0.074	324.32	398.51	74.19	2.0%	1.7%	82.7%	
Pan	0.000	368.13	432.07	63.94	1.7%	0.0%	1.7%	Fines
Totals				3680.13	100.0%		100.0%	



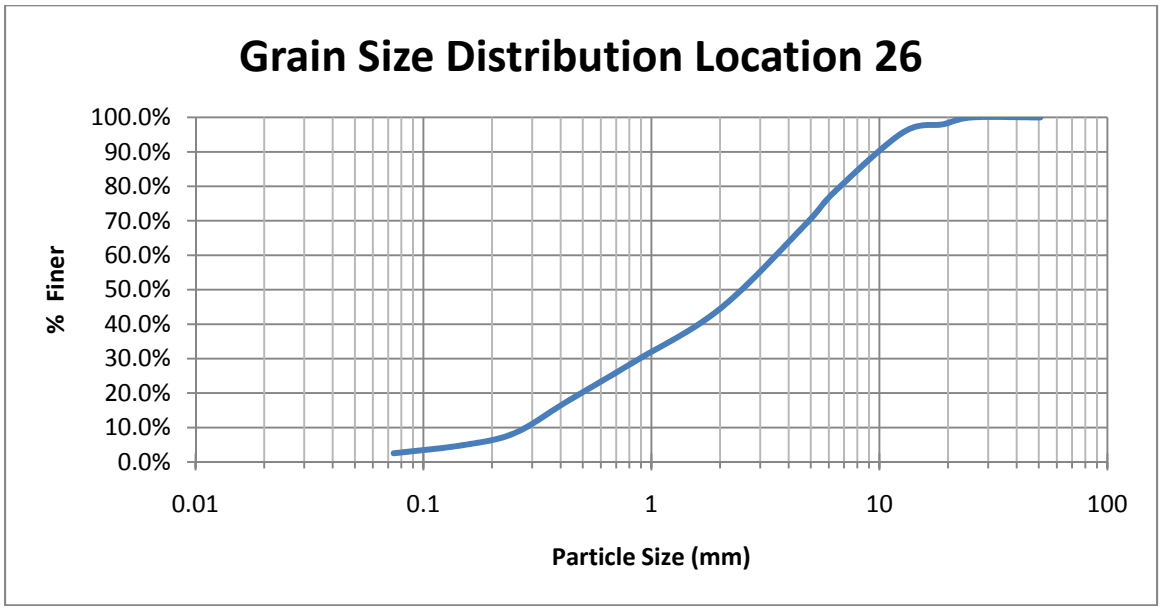
Sample	L24-2		Note				Percentage of sample	
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer		
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			26.69	2.4%	97.6%		
1/2"	12.700	371.79	447.32	75.53	6.7%	90.9%		
1/4"	6.350	371.81	651.30	279.49	24.8%	66.1%		
4	4.760	511.28	605.66	94.38	8.4%	57.7%	42.3%	
10	2.000	439.88	639.44	199.56	17.7%	40.0%		Sand
20	0.840	405.82	545.46	139.64	12.4%	27.6%		
40	0.420	395.83	526.41	130.58	11.6%	16.0%		
60	0.250	368.13	461.29	93.16	8.3%	7.7%		
100	0.149	359.04	396.57	37.53	3.3%	4.4%		
200	0.074	324.25	351.45	27.20	2.4%	2.0%	55.7%	
Pan	0.000	368.17	390.54	22.37	2.0%	0.0%	2.0%	Fines
Totals				1126.13	100.0%		100.0%	



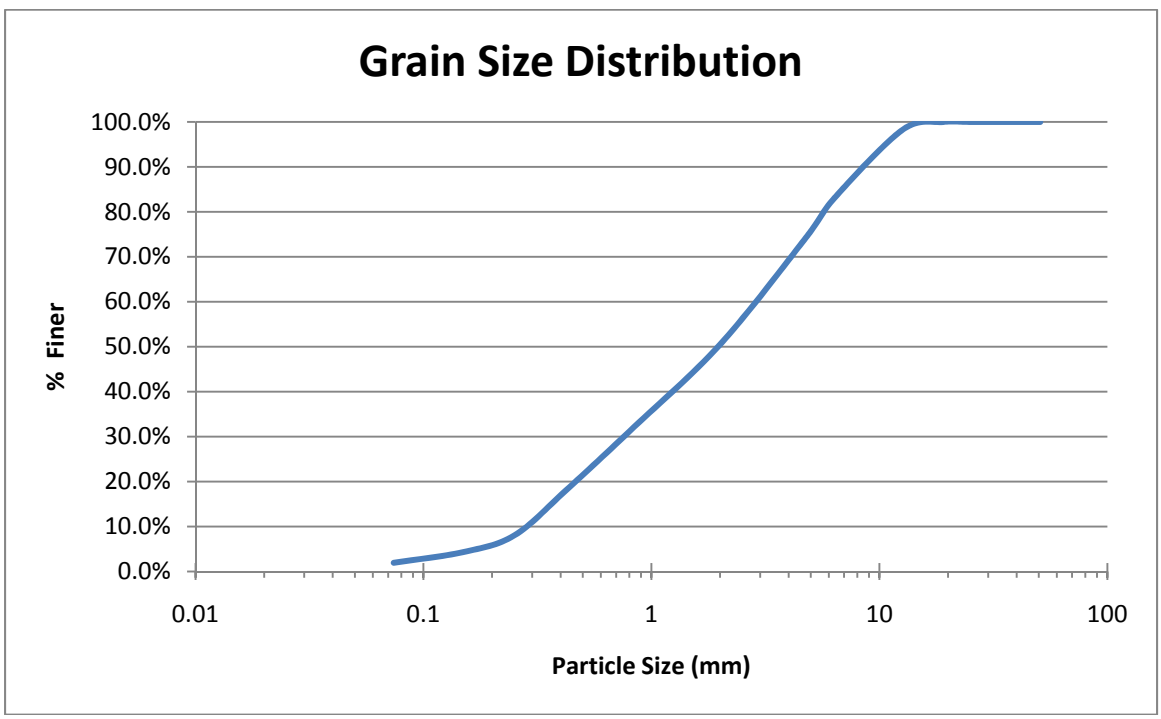
Sample	L25		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			12.64	1.6%	98.4%		
1/2"	12.700			15.46	1.9%	96.5%		
1/4"	6.350	371.81	496.58	124.77	15.6%	80.9%		
4	4.760	511.22	584.23	73.01	9.1%	71.8%	28.2%	
10	2.000	440.26	625.30	185.04	23.1%	48.7%		Sand
20	0.840	406.09	525.69	119.60	14.9%	33.7%		
40	0.420	395.73	485.26	89.53	11.2%	22.6%		
60	0.250	368.06	456.23	88.17	11.0%	11.5%		
100	0.149	359.06	398.36	39.30	4.9%	6.6%		
200	0.074	324.28	358.23	33.95	4.2%	2.4%	69.4%	
Pan	0.000	368.04	387.25	19.21	2.4%	0.0%	2.4%	Fines
Totals				800.68	100.0%		100.0%	



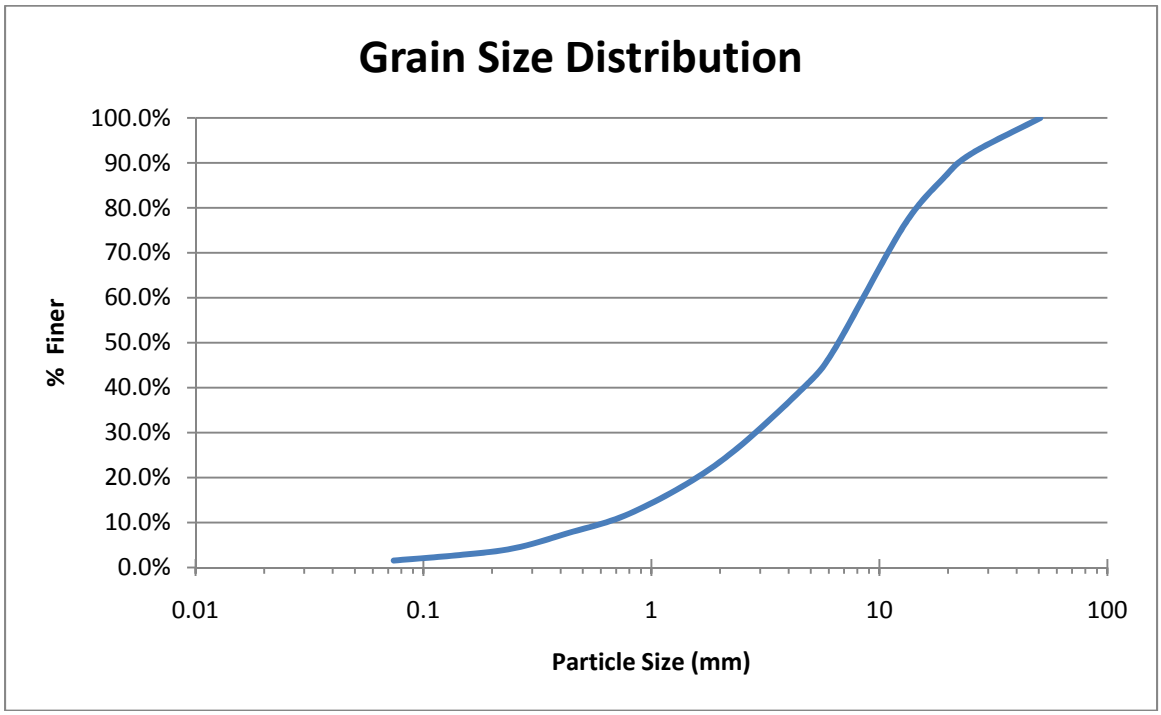
Sample	L26		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			12.64	2.0%	98.0%		
1/2"	12.700			15.46	2.4%	95.7%		
1/4"	6.350	371.81	483.60	111.79	17.3%	78.4%		
4	4.760	511.22	571.35	60.13	9.3%	69.1%	30.9%	
10	2.000	440.26	599.60	159.34	24.6%	44.5%		Sand
20	0.840	406.09	505.59	99.50	15.4%	29.1%		
40	0.420	395.73	471.95	76.22	11.8%	17.3%		
60	0.250	368.06	426.04	57.98	9.0%	8.4%		
100	0.149	359.06	381.34	22.28	3.4%	4.9%		
200	0.074	324.28	339.56	15.28	2.4%	2.6%	66.5%	
Pan	0.000	368.04	384.59	16.55	2.6%	0.0%	2.6%	Fines
Totals				647.17	100.0%		100.0%	



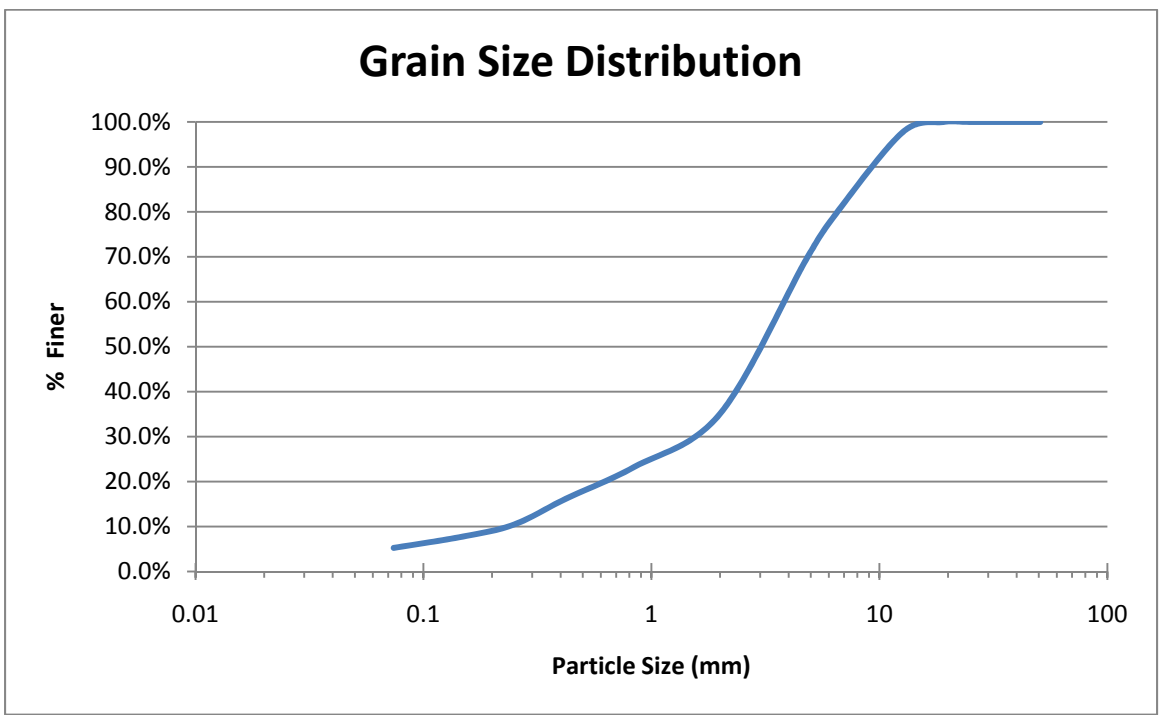
Sample	L27-1		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			0.00	0.0%	100.0%		
1/2"	12.700			14.05	1.7%	98.3%		
1/4"	6.350	371.87	500.52	128.65	15.3%	83.1%		
4	4.760	511.32	585.65	74.33	8.8%	74.3%	25.7%	
10	2.000	440.27	640.52	200.25	23.8%	50.5%		Sand
20	0.840	405.96	560.40	154.44	18.3%	32.2%		
40	0.420	395.89	515.57	119.68	14.2%	18.0%		
60	0.250	368.06	452.03	83.97	10.0%	8.0%		
100	0.149	359.08	390.27	31.19	3.7%	4.3%		
200	0.074	324.24	344.26	20.02	2.4%	1.9%	72.3%	
Pan	0.000	368.18	384.53	16.35	1.9%	0.0%	1.9%	Fines
Totals				842.93	100.0%		100.0%	



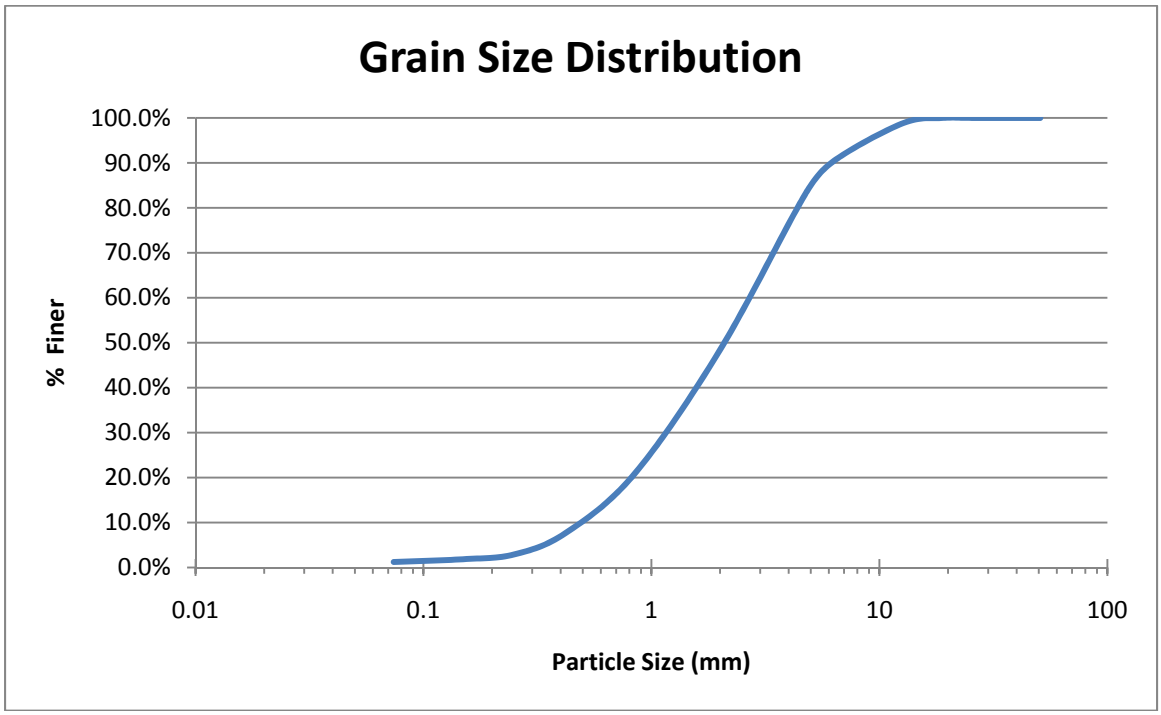
Sample	L27-2		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			85.62	7.9%	92.1%		
3/4"	19.100			59.58	5.5%	86.6%		
1/2"	12.700	371.83	489.34	117.51	10.8%	75.8%		
1/4"	6.350	371.86	667.06	295.20	27.2%	48.5%		
4	4.760	511.29	598.10	86.81	8.0%	40.5%	59.5%	
10	2.000	439.89	624.25	184.36	17.0%	23.5%		Sand
20	0.840	405.92	525.84	119.92	11.1%	12.5%		
40	0.420	395.85	449.68	53.83	5.0%	7.5%		
60	0.250	368.14	402.80	34.66	3.2%	4.3%		
100	0.149	359.06	374.71	15.65	1.4%	2.9%		
200	0.074	324.27	338.38	14.11	1.3%	1.6%	39.0%	
Pan	0.000	368.19	385.01	16.82	1.6%	0.0%	1.6%	Fines
Totals				1084.07	100.0%		100.0%	



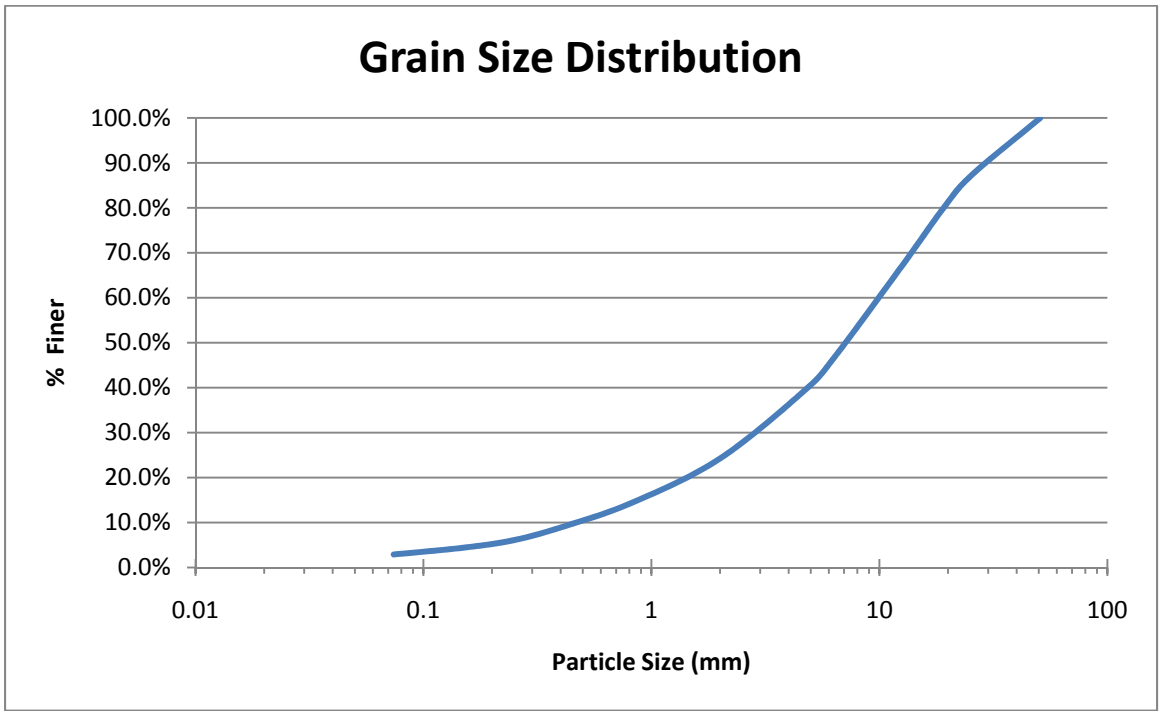
Sample	L30		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			0.00	0.0%	100.0%		
1/2"	12.700			9.38	2.2%	97.8%		
1/4"	6.350	371.81	451.18	79.37	18.7%	79.1%		
4	4.760	511.29	553.00	41.71	9.8%	69.3%	30.7%	
10	2.000	439.95	585.39	145.44	34.2%	35.1%		Sand
20	0.840	405.76	456.05	50.29	11.8%	23.2%		
40	0.420	395.79	425.98	30.19	7.1%	16.1%		
60	0.250	368.03	392.19	24.16	5.7%	10.4%		
100	0.149	359.05	370.46	11.41	2.7%	7.8%		
200	0.074	324.39	335.15	10.76	2.5%	5.2%	64.1%	
Pan	0.000	368.13	390.34	22.21	5.2%	0.0%	5.2%	Fines
Totals				424.92	100.0%		100.0%	



Sample	L32		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			0.00	0.0%	100.0%		
3/4"	19.100			0.00	0.0%	100.0%		
1/2"	12.700			4.12	1.2%	98.8%		
1/4"	6.350	371.91	401.17	29.26	8.3%	90.5%		
4	4.760	511.45	536.92	25.47	7.2%	83.3%	16.7%	
10	2.000	439.84	562.60	122.76	34.9%	48.4%		Sand
20	0.840	405.97	503.32	97.35	27.7%	20.7%		
40	0.420	395.98	442.02	46.04	13.1%	7.6%		
60	0.250	368.25	384.99	16.74	4.8%	2.9%		
100	0.149	359.12	362.87	3.75	1.1%	1.8%		
200	0.074	324.39	326.57	2.18	0.6%	1.2%	82.1%	
Pan	0.000	368.18	372.42	4.24	1.2%	0.0%	1.2%	Fines
Totals				351.91	100.0%		100.0%	



Sample	L41		Note					
Sieve #	Sieve Opening (mm)	Mass of Empty Sieve (g)	Mass of Sieve + Sample (g)	Mass of Sample Retained (g)	Percent Retained	Percent Finer	Percentage of sample	
2"	50.8					100.0%		Gravel
1"	25.400			105.51	12.7%	87.3%		
3/4"	19.100			60.72	7.3%	80.0%		
1/2"	12.700	371.80	475.87	104.07	12.5%	67.4%		
1/4"	6.350	371.81	543.16	171.35	20.7%	46.8%		
4	4.760	511.27	570.43	59.16	7.1%	39.6%	60.4%	
10	2.000	439.99	567.65	127.66	15.4%	24.2%		Sand
20	0.840	405.84	485.86	80.02	9.6%	14.6%		
40	0.420	395.85	440.38	44.53	5.4%	9.2%		
60	0.250	368.26	394.35	26.09	3.1%	6.1%		
100	0.149	359.17	373.35	14.18	1.7%	4.4%		
200	0.074	324.51	336.92	12.41	1.5%	2.9%	36.8%	
Pan	0.000	368.09	391.93	23.84	2.9%	0.0%	2.9%	Fines
Totals				829.54	100.0%		100.0%	



Appendix C

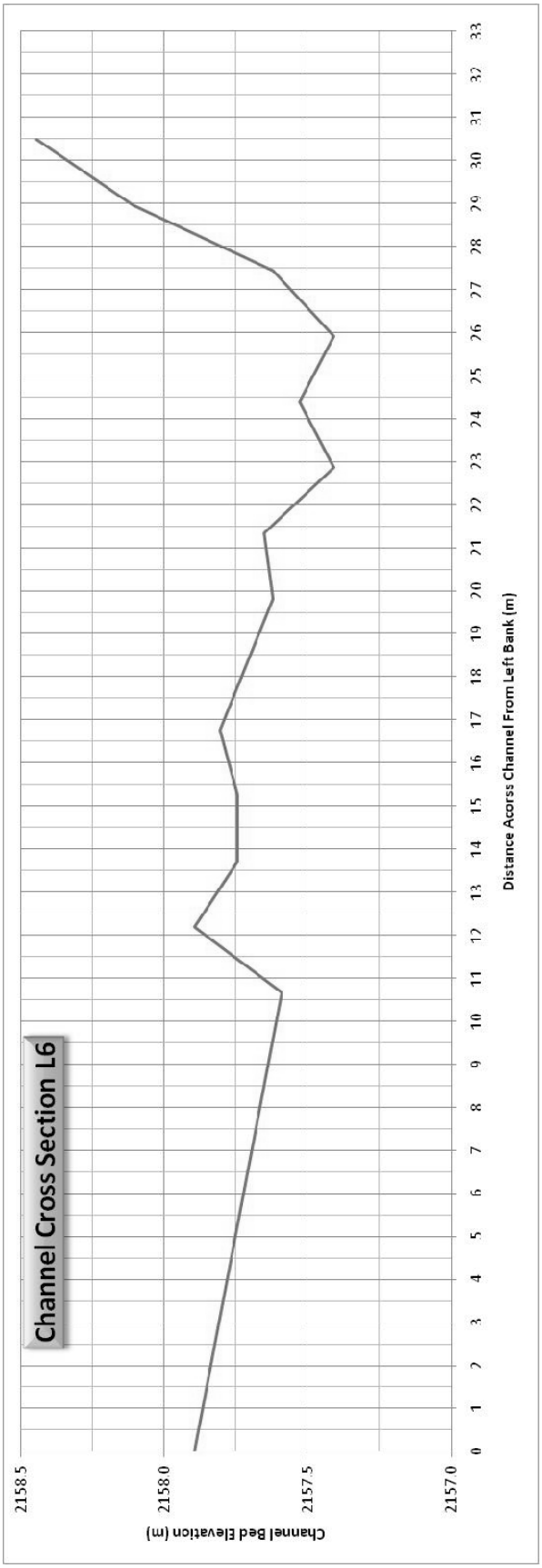
Cross Section Data

Note:

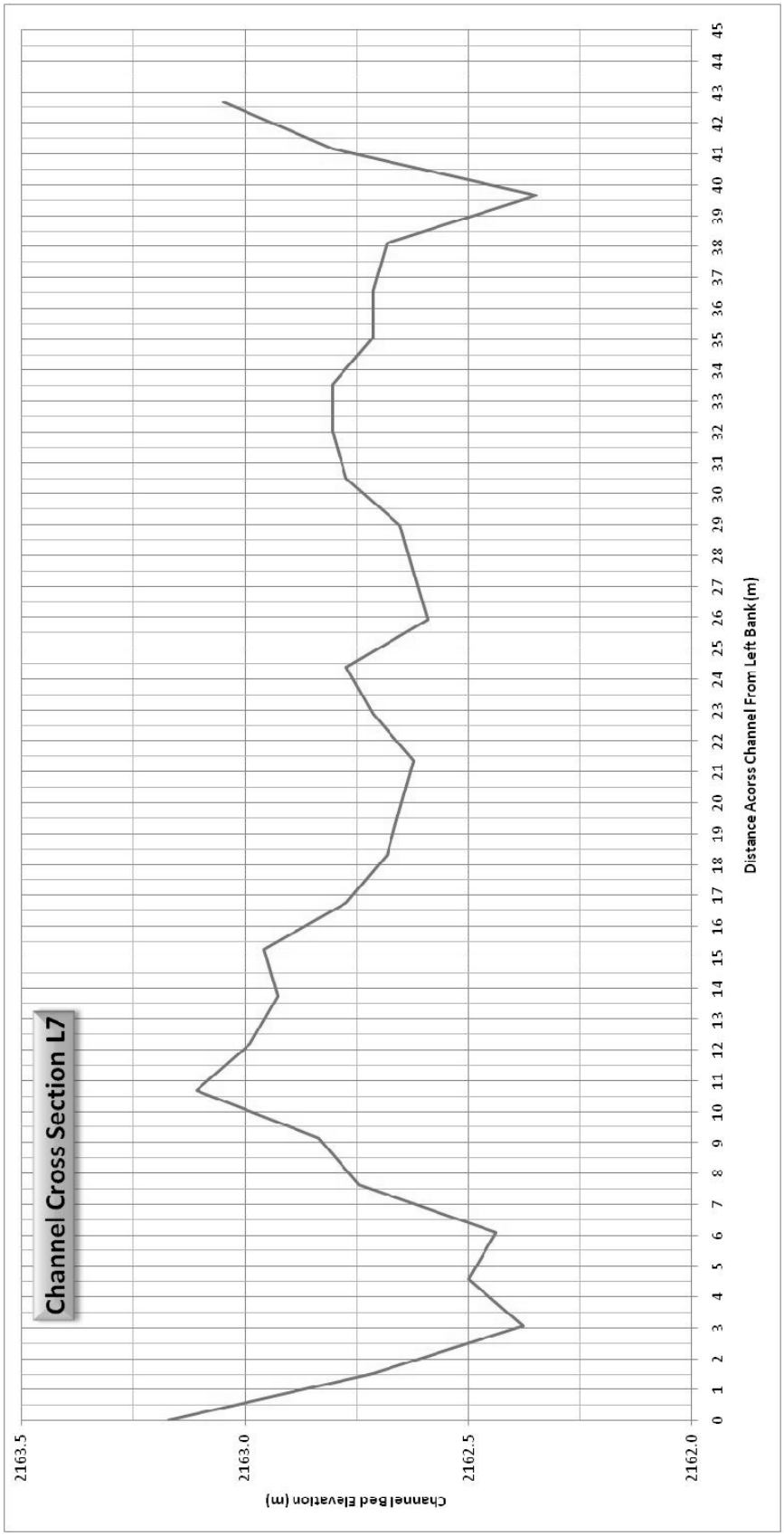
Elevation datum for all points is North American Vertical Datum 1929

All cross sections are viewed looking downstream

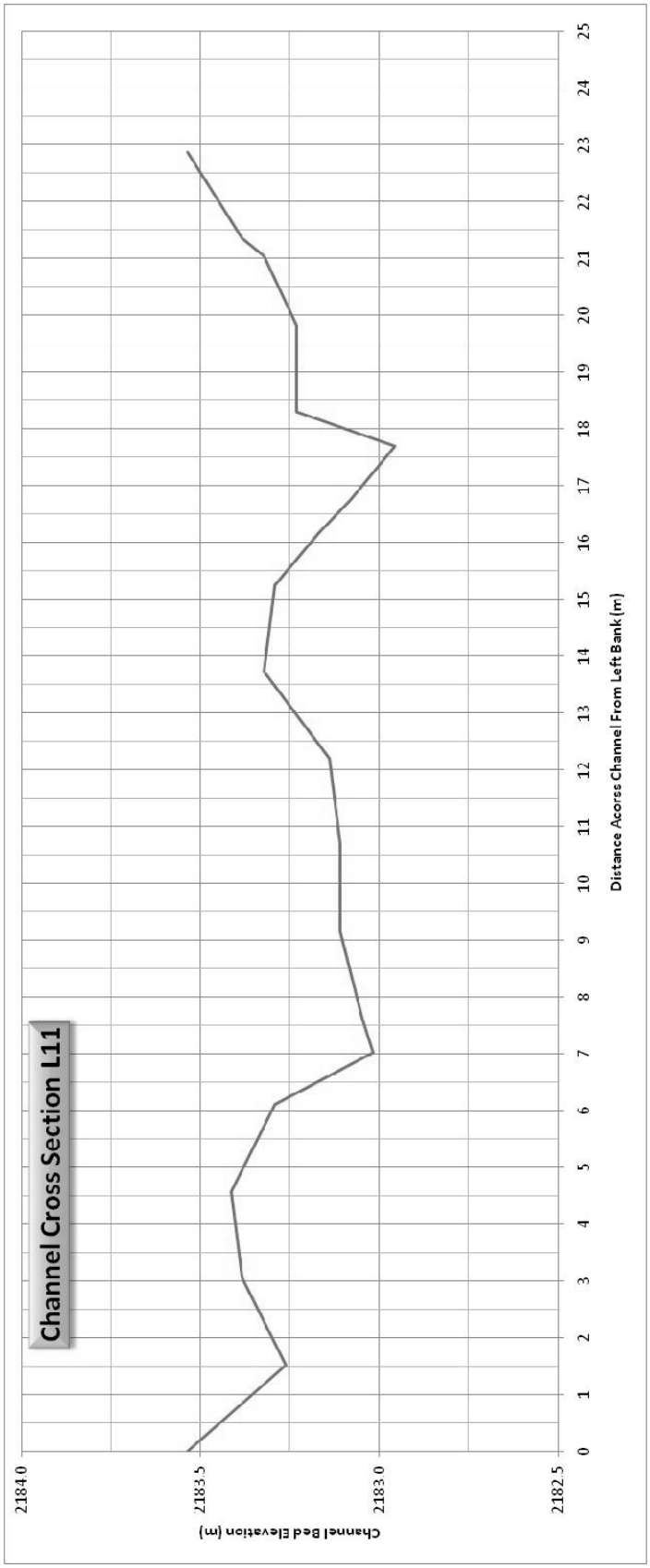
L6						*Notes*
Reference point = nail at base of tree on left bank						
Reference point elevation =				feet	meters	
				7080.0	2158.5	
Distance from level line to reference point				2.2	0.6	
Distance from left bank		Distance from surface to level line		Surface Elevation		
feet	meters	feet	meters	feet	meters	
0.00	0.00	4.00	1.22	7078.20	2157.90	Evenly graded bed slope. 50/50 gravel and sand
35.00	10.67	5.00	1.52	7077.20	2157.59	
40.00	12.20	4.00	1.22	7078.20	2157.90	Boulders 7 to 45 cm
45.00	13.72	4.50	1.37	7077.70	2157.74	
50.00	15.24	4.50	1.37	7077.70	2157.74	
55.00	16.77	4.30	1.31	7077.90	2157.80	
60.00	18.29	4.60	1.40	7077.60	2157.71	
65.00	19.82	4.90	1.49	7077.30	2157.62	
70.00	21.34	4.80	1.46	7077.40	2157.65	
75.00	22.87	5.60	1.71	7076.60	2157.41	
80.00	24.39	5.20	1.59	7077.00	2157.53	
85.00	25.91	5.60	1.71	7076.60	2157.41	
90.00	27.44	4.90	1.49	7077.30	2157.62	
95.00	28.96	3.30	1.01	7078.90	2158.11	
100.00	30.49	2.20	0.67	7080.00	2158.44	


Channel Cross Section L6
Channel Bed Elevation (m)
2158.5
2158.0
2157.5
2157.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
Distance Acorss Channel From Left Bank (m)

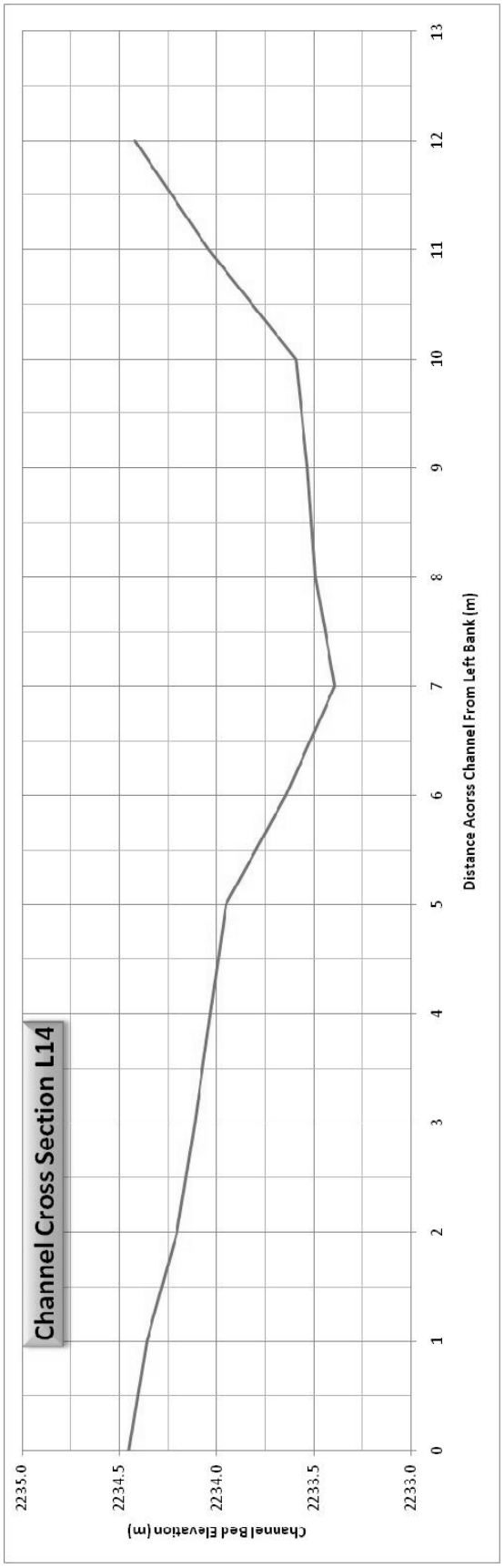
L7						Notes
Reference point = large rock on Right Bank at base of marked						
				feet	meters	
Reference point elevation =				7094.0	2162.8	
Distance from level line to reference point				3.3	0.9	
Distance from left bank		Distance from surface to level line		Surface Elevation		
feet	meters	feet	meters	feet	meters	
0.00	0.00	2.10	0.64	7095.20	2163.17	
5.00	1.52	3.60	1.10	7093.70	2162.71	
10.00	3.05	4.70	1.43	7092.60	2162.38	
15.00	4.57	4.30	1.31	7093.00	2162.50	Split of main flow channel
20.00	6.10	4.50	1.37	7092.80	2162.44	
25.00	7.62	3.50	1.07	7093.80	2162.74	
30.00	9.15	3.20	0.98	7094.10	2162.84	Boulder Pile
35.00	10.67	2.30	0.70	7095.00	2163.11	
40.00	12.20	2.70	0.82	7094.60	2162.99	
45.00	13.72	2.90	0.88	7094.40	2162.93	cobbles in bed
50.00	15.24	2.80	0.85	7094.50	2162.96	
55.00	16.77	3.40	1.04	7093.90	2162.77	
60.00	18.29	3.70	1.13	7093.60	2162.68	
65.00	19.82	3.80	1.16	7093.50	2162.65	
70.00	21.34	3.90	1.19	7093.40	2162.62	
75.00	22.87	3.60	1.10	7093.70	2162.71	
80.00	24.39	3.40	1.04	7093.90	2162.77	
85.00	25.91	4.00	1.22	7093.30	2162.59	
90.00	27.44	3.90	1.19	7093.40	2162.62	
95.00	28.96	3.80	1.16	7093.50	2162.65	edge of current flow channel
100.00	30.49	3.40	1.04	7093.90	2162.77	
105.00	32.01	3.30	1.01	7094.00	2162.80	sand & boulder bed (no gravel)
110.00	33.54	3.30	1.01	7094.00	2162.80	
115.00	35.06	3.60	1.10	7093.70	2162.71	sand bed with braids in channel
120.00	36.59	3.60	1.10	7093.70	2162.71	
125.00	38.11	3.70	1.13	7093.60	2162.68	
130.00	39.63	4.80	1.46	7092.50	2162.35	
135.00	41.16	3.30	1.01	7094.00	2162.80	
140.00	42.68	2.50	0.76	7094.80	2163.05	


Channel Cross Section L7
Channel Bed Elevation (m)
2163.5
2163.0
2162.5
2162.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45
Distance Acorss Channel From Left Bank (m)

L11						Notes
Reference point = nail at base of tree on left bank						
Reference point elevation =				feet	meters	
				7162.0	2183.5	
Distance from level line to reference point				0.0	0.0	
Distance from left bank		Distance from surface to level line		Surface Elevation		
feet	meters	feet	meters	feet	meters	
0.00	0.00	0.00	0.00	7162.00	2183.54	
5.00	1.52	0.90	0.27	7161.10	2183.26	
10.00	3.05	0.50	0.15	7161.50	2183.38	
15.00	4.57	0.40	0.12	7161.60	2183.41	Long established grass evident
20.00	6.10	0.80	0.24	7161.20	2183.29	
23.00	7.01	1.70	0.52	7160.30	2183.02	
25.00	7.62	1.60	0.49	7160.40	2183.05	
30.00	9.15	1.40	0.43	7160.60	2183.11	
35.00	10.67	1.40	0.43	7160.60	2183.11	
40.00	12.20	1.30	0.40	7160.70	2183.14	
45.00	13.72	0.70	0.21	7161.30	2183.32	
50.00	15.24	0.80	0.24	7161.20	2183.29	
53.00	16.16	1.20	0.37	7160.80	2183.17	
55.00	16.77	1.50	0.46	7160.50	2183.08	
58.00	17.68	1.90	0.58	7160.10	2182.96	
60.00	18.29	1.00	0.30	7161.00	2183.23	
65.00	19.82	1.00	0.30	7161.00	2183.23	
69.00	21.04	0.70	0.21	7161.30	2183.32	
70.00	21.34	0.50	0.15	7161.50	2183.38	
75.00	22.87	0.00	0.00	7162.00	2183.54	

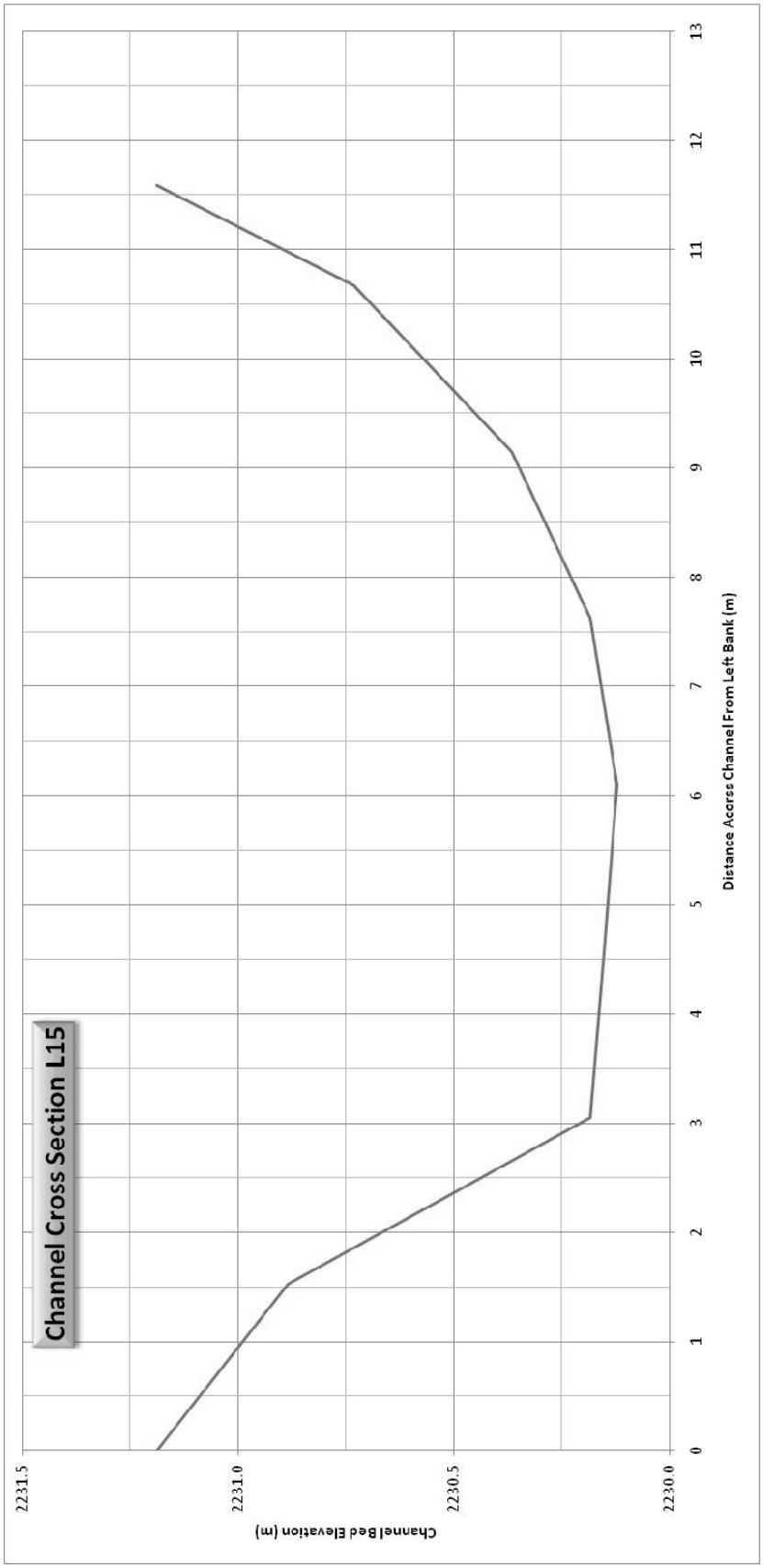

Channel Cross Section L11
Channel Bed Elevation (m)
2184.0
2183.5
2183.0
2182.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
Distance Across Channel From Left Bank (m)

L14					
Reference point = spike in ground on right bank					
Reference point elevation =				feet	meters
				7329.0	2234.5
Distance from level line to reference point				0.0	0.0
Distance from left bank		Distance from surface to level line		Surface Elevation	
	meters		meters		meters
	0		0.00		2234.45
	1		0.09		2234.36
	2		0.25		2234.20
	3		0.34		2234.11
	4		0.42		2234.03
	5		0.50		2233.95
	6		0.81		2233.64
	7		1.06		2233.39
	8		0.96		2233.49
	9		0.92		2233.53
	10		0.86		2233.59
	11		0.41		2234.04
	12		0.03		2234.42


Channel Cross Section L14
Channel Bed Elevation (m)
2235.0
2234.5
2234.0
2233.5
2233.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Distance Acorss Channel From Left Bank (m)

Location L15

Reference point = nail at base of tree on left bank					
Reference point elevation =				feet	meters
				7315.0	2230.2
Distance from level line to reference point				3.3	0.9
feet	meters	feet	meters	feet	meters
0.00	0.00	0.00	0.00	7318.30	2231.19
5.00	1.52	1.00	0.30	7317.30	2230.88
10.00	3.05	3.30	1.01	7315.00	2230.18
15.00	4.57	3.40	1.04	7314.90	2230.15
20.00	6.10	3.50	1.07	7314.80	2230.12
25.00	7.62	3.30	1.01	7315.00	2230.18
30.00	9.15	2.70	0.82	7315.60	2230.37
35.00	10.67	1.50	0.46	7316.80	2230.73
38.00	11.59	0.00	0.00	7318.30	2231.19

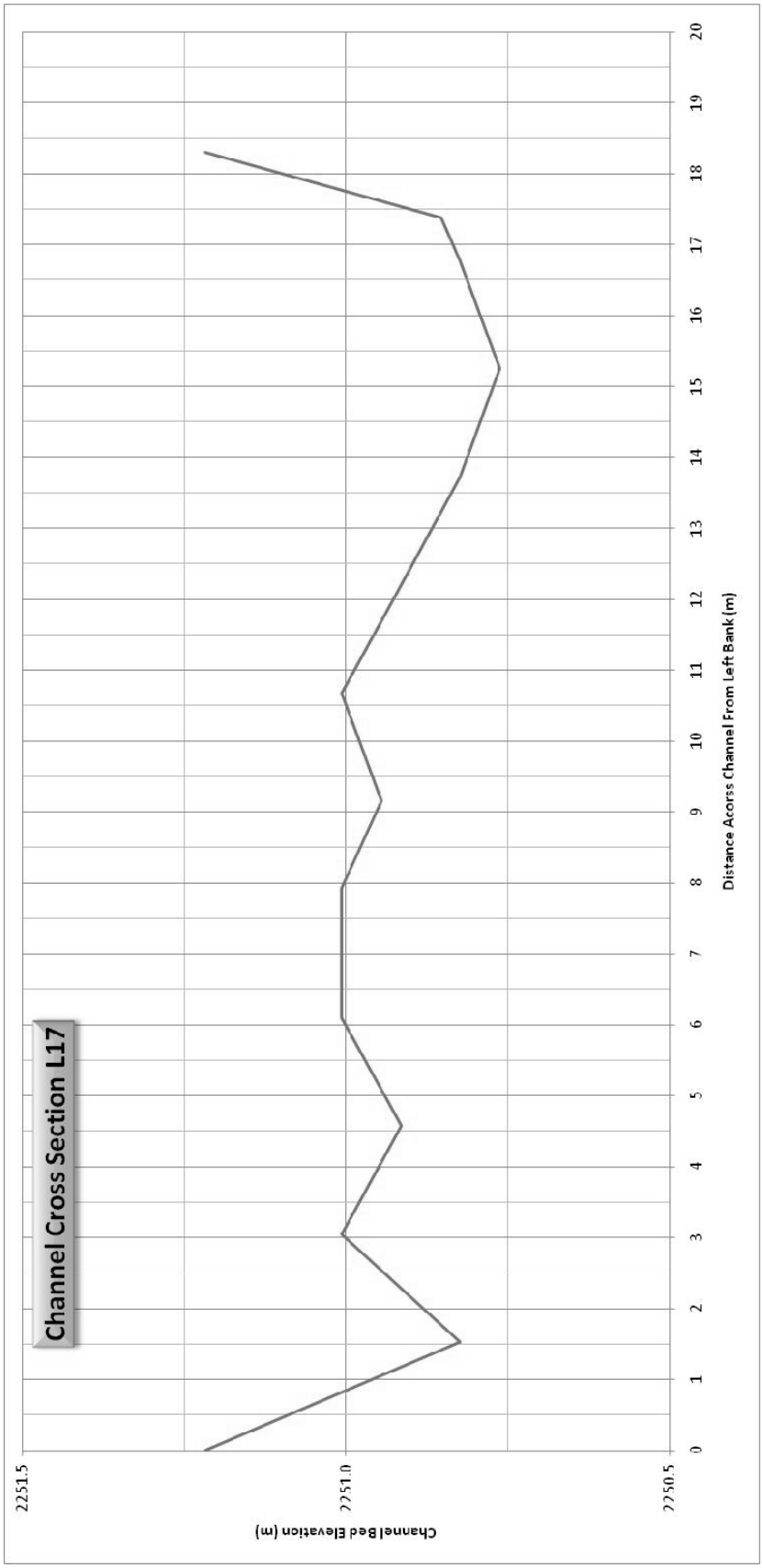

Channel Cross Section L15
Channel Bed Elevation (m)
2231.5
2231.0
2230.5
2230.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Distance Acorss Channel From Left Bank (m)

Location L17

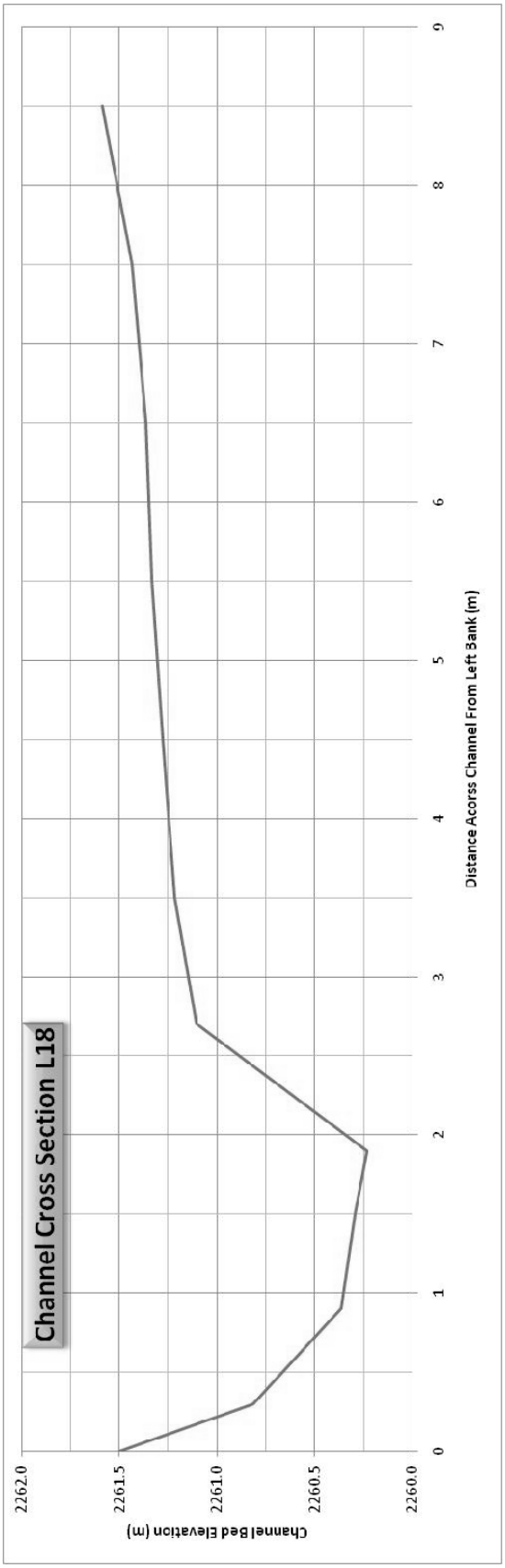
Reference point = nail at base of tree on right bank

	feet	meters
Reference point elevation =	7384.0	2251.2
Distance from level line to reference point	0.0	0.0

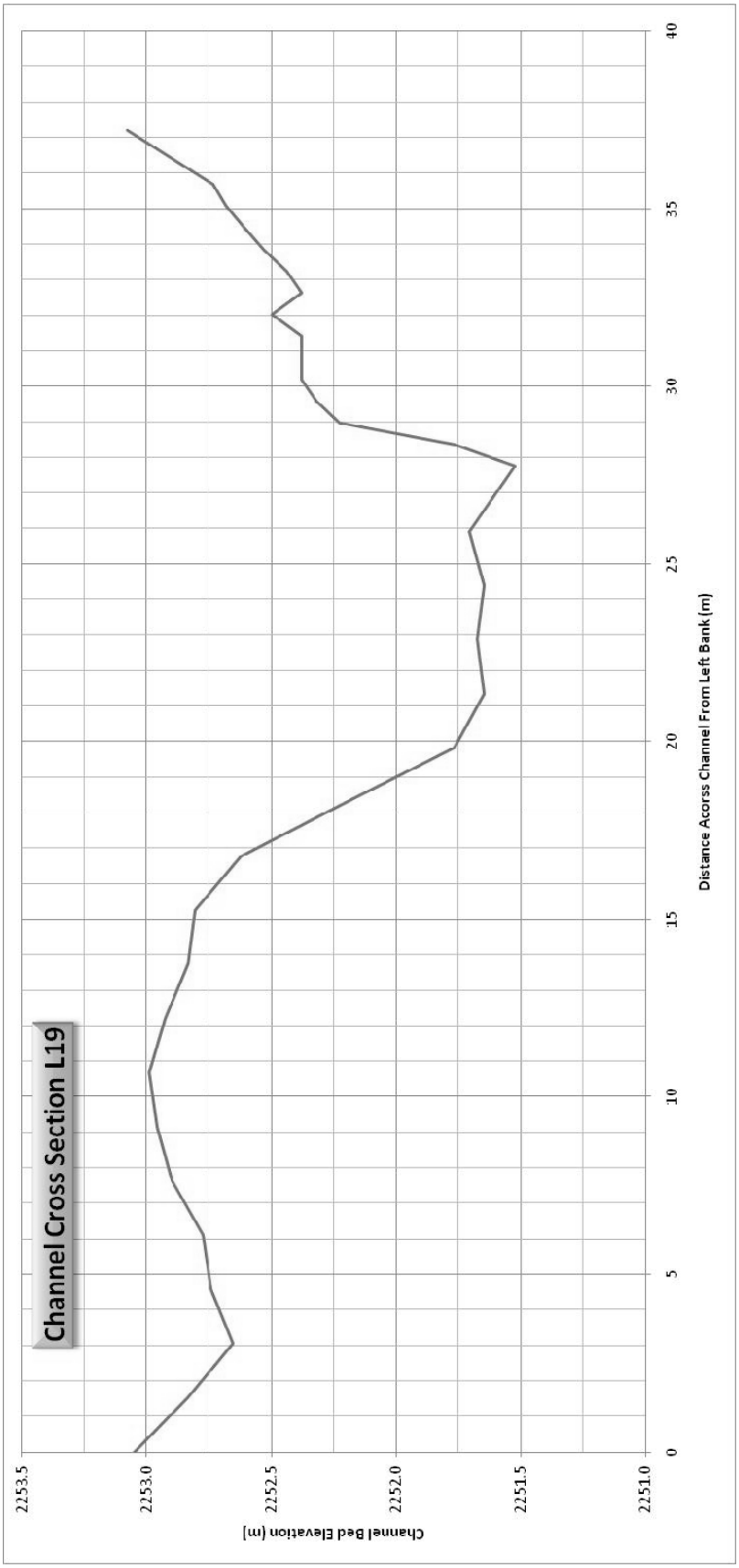
feet	meters	feet	meters	feet	meters
0.00	0.00	0.00	0.00	7384.00	2251.22
5.00	1.52	1.30	0.40	7382.70	2250.82
10.00	3.05	0.70	0.21	7383.30	2251.01
15.00	4.57	1.00	0.30	7383.00	2250.91
20.00	6.10	0.70	0.21	7383.30	2251.01
25.00	7.62	0.70	0.21	7383.30	2251.01
26.00	7.93	0.70	0.21	7383.30	2251.01
30.00	9.15	0.90	0.27	7383.10	2250.95
35.00	10.67	0.70	0.21	7383.30	2251.01
40.00	12.20	1.00	0.30	7383.00	2250.91
45.00	13.72	1.30	0.40	7382.70	2250.82
50.00	15.24	1.50	0.46	7382.50	2250.76
55.00	16.77	1.30	0.40	7382.70	2250.82
57.00	17.38	1.20	0.37	7382.80	2250.85
60.00	18.29	0.00	0.00	7384.00	2251.22


Channel Cross Section L17
Channel Bed Elevation (m)
2251.5
2251.0
2250.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Distance Acorss Channel From Left Bank (m)

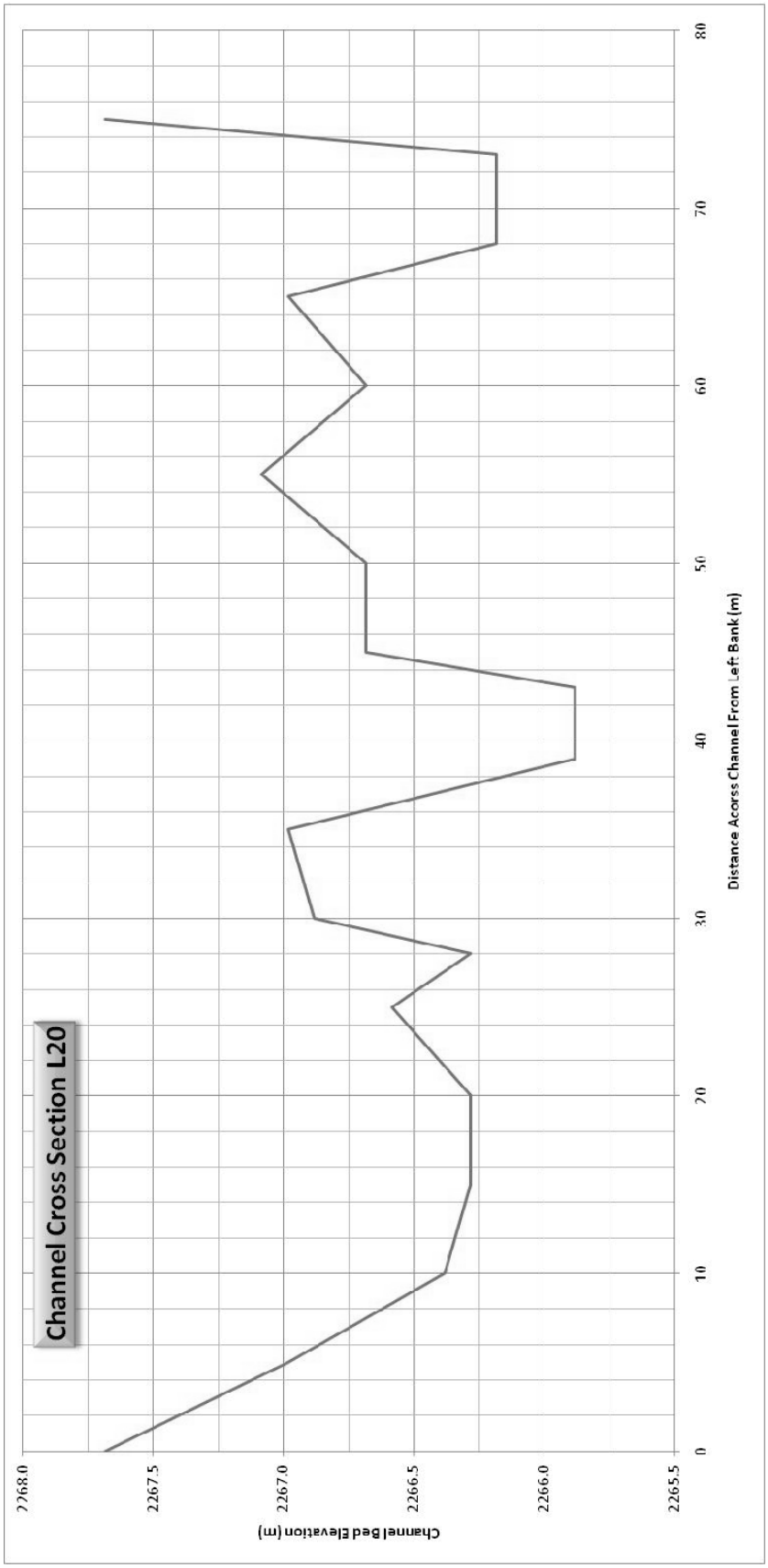
L18					
Reference point = Notch on large boulder on right bank					
Reference point elevation =				feet	meters
				7418.0	2261.6
Distance from level line to reference point				0.0	0.0
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0.00		0.09		2261.50
	0.30		0.77		2260.82
	0.90		1.22		2260.37
	1.50		1.29		2260.30
	1.90		1.35		2260.24
	2.70		0.48		2261.11
	3.50		0.37		2261.22
	4.50		0.31		2261.28
	5.50		0.25		2261.34
	6.50		0.22		2261.37
	7.50		0.15		2261.44
	8.50		0.00		2261.59


Channel Cross Section L18
Channel Bed Elevation (m)
2262.0
2261.5
2261.0
2260.5
2260.0
0
1
2
3
4
5
6
7
8
9
Distance Acorss Channel From Left Bank (m)

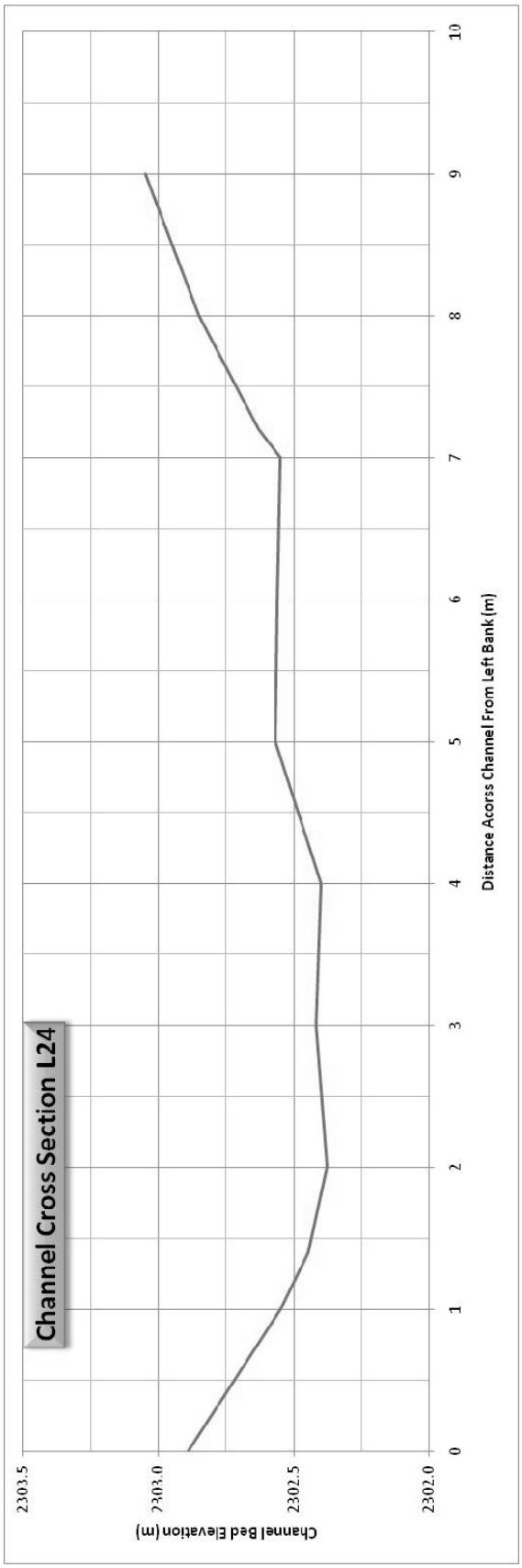
L19					
Reference point = nail at base of tree on left bank					
Reference point elevation =				feet	meters
				7390.0	2253.0
Distance from level line to reference point				2.2	0.6
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
0.00	0.00	2.20	0.67	7390.00	2253.05
5.00	1.52	2.90	0.88	7389.30	2252.84
10.00	3.05	3.50	1.07	7388.70	2252.65
15.00	4.57	3.20	0.98	7389.00	2252.74
20.00	6.10	3.10	0.95	7389.10	2252.77
25.00	7.62	2.70	0.82	7389.50	2252.90
30.00	9.15	2.50	0.76	7389.70	2252.96
35.00	10.67	2.40	0.73	7389.80	2252.99
40.00	12.20	2.60	0.79	7389.60	2252.93
45.00	13.72	2.90	0.88	7389.30	2252.84
50.00	15.24	3.00	0.91	7389.20	2252.80
55.00	16.77	3.60	1.10	7388.60	2252.62
60.00	18.29	5.00	1.52	7387.20	2252.20
65.00	19.82	6.40	1.95	7385.80	2251.77
70.00	21.34	6.80	2.07	7385.40	2251.65
75.00	22.87	6.70	2.04	7385.50	2251.68
80.00	24.39	6.80	2.07	7385.40	2251.65
85.00	25.91	6.60	2.01	7385.60	2251.71
91.00	27.74	7.20	2.20	7385.00	2251.52
93.00	28.35	6.40	1.95	7385.80	2251.77
95.00	28.96	4.90	1.49	7387.30	2252.23
97.00	29.57	4.60	1.40	7387.60	2252.32
99.00	30.18	4.40	1.34	7387.80	2252.38
101.00	30.79	4.40	1.34	7387.80	2252.38
103.00	31.40	4.40	1.34	7387.80	2252.38
105.00	32.01	4.00	1.22	7388.20	2252.50
107.00	32.62	4.40	1.34	7387.80	2252.38
109.00	33.23	4.20	1.28	7388.00	2252.44
111.00	33.84	3.90	1.19	7388.30	2252.53
113.00	34.45	3.65	1.11	7388.55	2252.61
115.00	35.06	3.40	1.04	7388.80	2252.68
117.00	35.67	3.23	0.98	7388.97	2252.73
122.00	37.20	2.10	0.64	7390.10	2253.08


Channel Cross Section L19
Channel Bed Elevation (m)
2253.5
2253.0
2252.5
2252.0
2251.5
2251.0
0
5
10
15
20
25
30
35
40
Distance Acorss Channel From Left Bank (m)

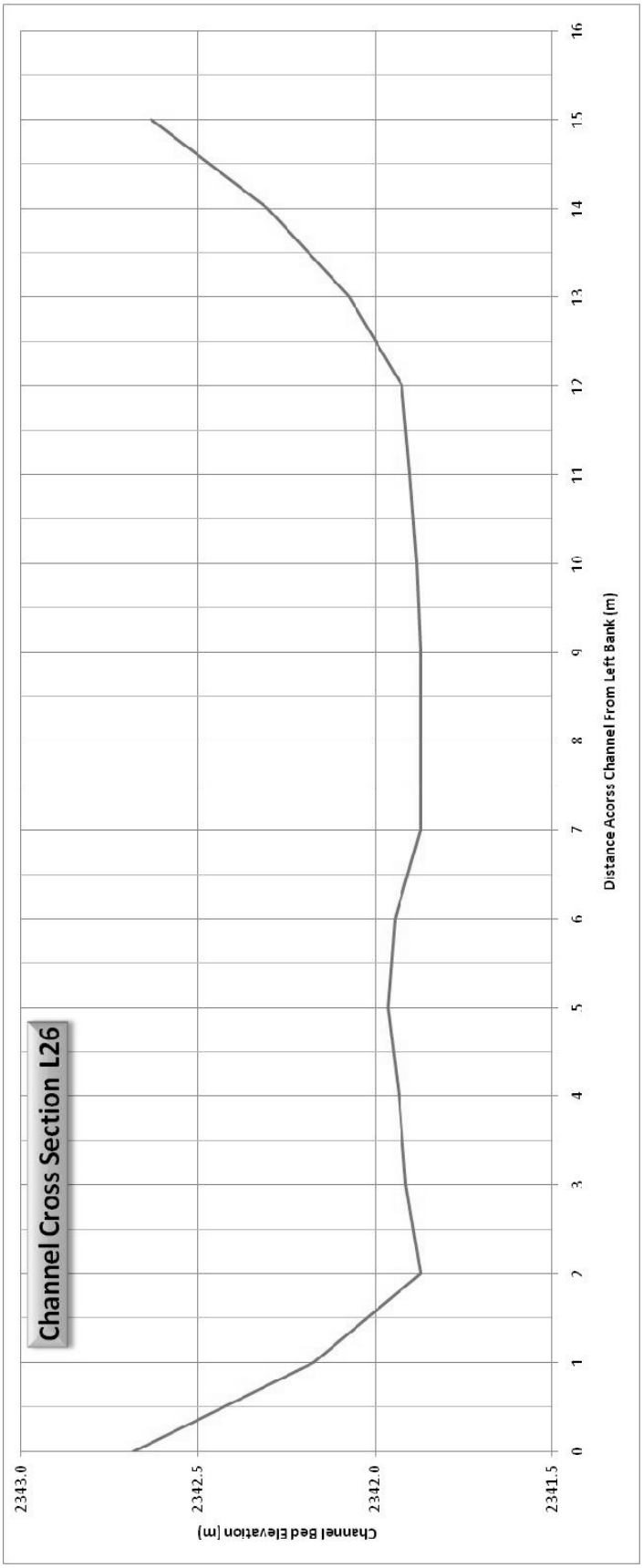
L20					
Reference point = Spike in ground on left bank near marked tree					
Reference point elevation =				feet	meters
				7438.0	2267.7
Distance from level line to reference point				0.0	0.0
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0.00		0.00		2267.68
	5.00		0.70		2266.98
	10.00		1.30		2266.38
	15.00		1.40		2266.28
	20.00		1.40		2266.28
	25.00		1.10		2266.58
	28.00		1.40		2266.28
	30.00		0.80		2266.88
	35.00		0.70		2266.98
	39.00		1.80		2265.88
	40.00		1.80		2265.88
	43.00		1.80		2265.88
	45.00		1.00		2266.68
	50.00		1.00		2266.68
	55.00		0.60		2267.08
	60.00		1.00		2266.68
	65.00		0.70		2266.98
	68.00		1.50		2266.18
	70.00		1.50		2266.18
	73.00		1.50		2266.18
	75.00		0.00		2267.68


Channel Cross Section L20
Channel Bed Elevation (m)
2268.0
2267.5
2267.0
2266.5
2266.0
2265.5
0
10
20
30
40
50
60
70
80
Distance Acorss Channel From Left Bank (m)

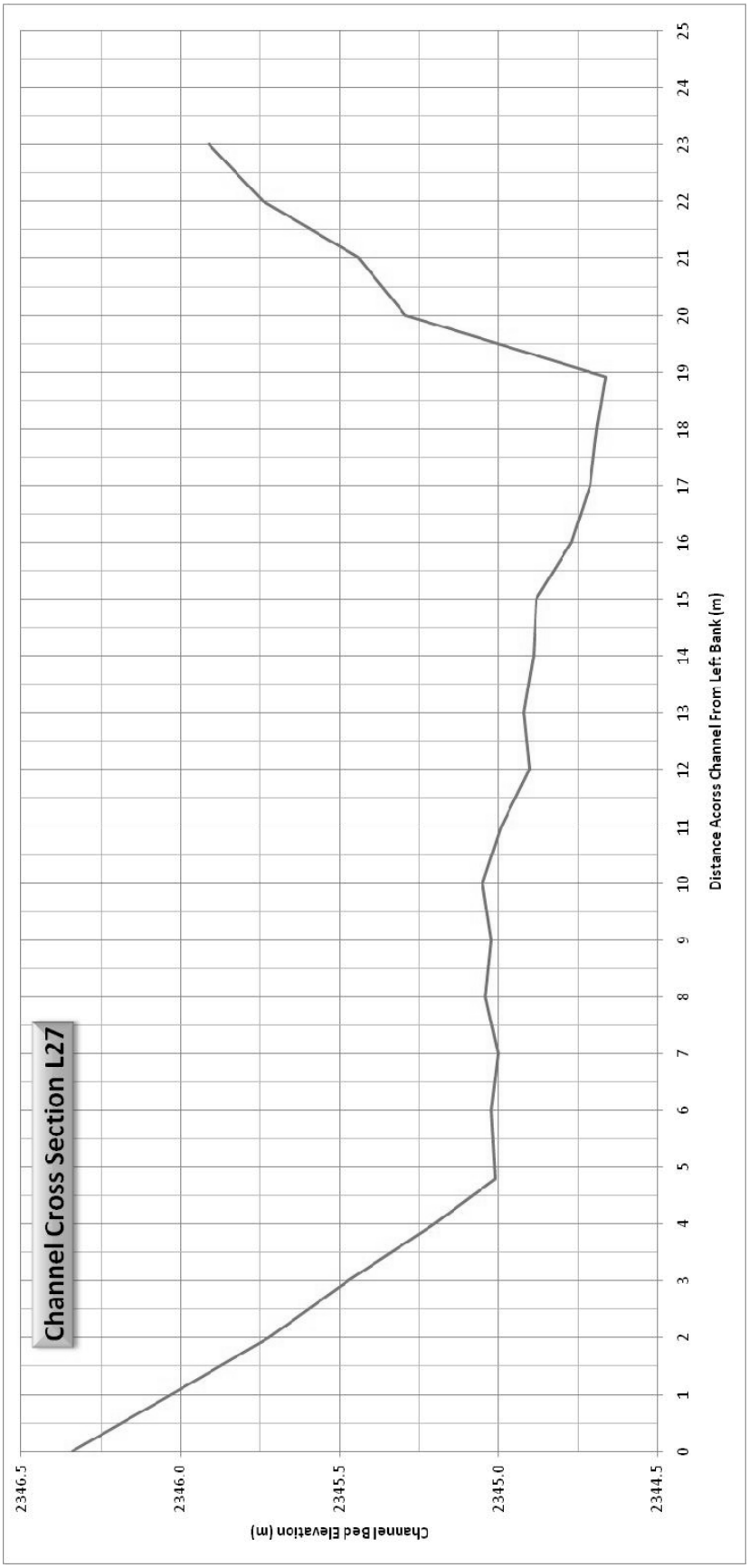
L24					
Reference point = nail at base of tree on right bank					
Reference point elevation =				feet	meters
				7554.0	2303.0
Distance from level line to reference point				0.0	0.0
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0.00		0.16		2302.89
	1.00		0.50		2302.55
	1.40		0.60		2302.45
	2.00		0.67		2302.38
	3.00		0.63		2302.42
	4.00		0.65		2302.40
	5.00		0.48		2302.57
	6.00		0.49		2302.56
	7.00		0.50		2302.55
	7.20		0.42		2302.63
	8.00		0.20		2302.85
	9.00		0.00		2303.05


Channel Cross Section L24
Channel Bed Elevation (m)
2303.5
2303.0
2302.5
2302.0
0
1
2
3
4
5
6
7
8
9
10
Distance Acorss Channel From Left Bank (m)

L26					
Reference point = nail in base of tree on left bank					
Reference point elevation =				feet	meters
				7684.0	2342.7
Distance from level line to reference point				0.0	0.0
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0.00		0.00		2342.68
	1.00		0.51		2342.17
	2.00		0.81		2341.87
	3.00		0.77		2341.91
	4.00		0.75		2341.93
	5.00		0.72		2341.96
	6.00		0.74		2341.94
	7.00		0.81		2341.87
	8.00		0.81		2341.87
	9.00		0.81		2341.87
	10.00		0.80		2341.88
	11.00		0.78		2341.90
	12.00		0.76		2341.92
	13.00		0.61		2342.07
	14.00		0.38		2342.30
	15.00		0.05		2342.63


Channel Cross Section L26
Channel Bed Elevation (m)
2343.0
2342.5
2342.0
2341.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Distance Acorss Channel From Left Bank (m)

L27					
Reference point = nail at base of tree on left bank					
Reference point elevation =				feet	meters
				7696.0	2346.3
Distance from level line to reference point				0.0	0.0
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0.00		0.00		2346.34
	1.00		0.31		2346.03
	2.00		0.62		2345.72
	3.00		0.87		2345.47
	4.00		1.14		2345.20
	4.80		1.33		2345.01
	6.00		1.32		2345.02
	7.00		1.34		2345.00
	8.00		1.30		2345.04
	9.00		1.32		2345.02
	10.00		1.29		2345.05
	11.00		1.35		2344.99
	12.00		1.44		2344.90
	13.00		1.42		2344.92
	14.00		1.45		2344.89
	15.00		1.46		2344.88
	16.00		1.57		2344.77
	17.00		1.63		2344.71
	18.00		1.65		2344.69
	18.90		1.68		2344.66
	20.00		1.05		2345.29
	21.00		0.90		2345.44
	22.00		0.60		2345.74
	23.00		0.43		2345.91

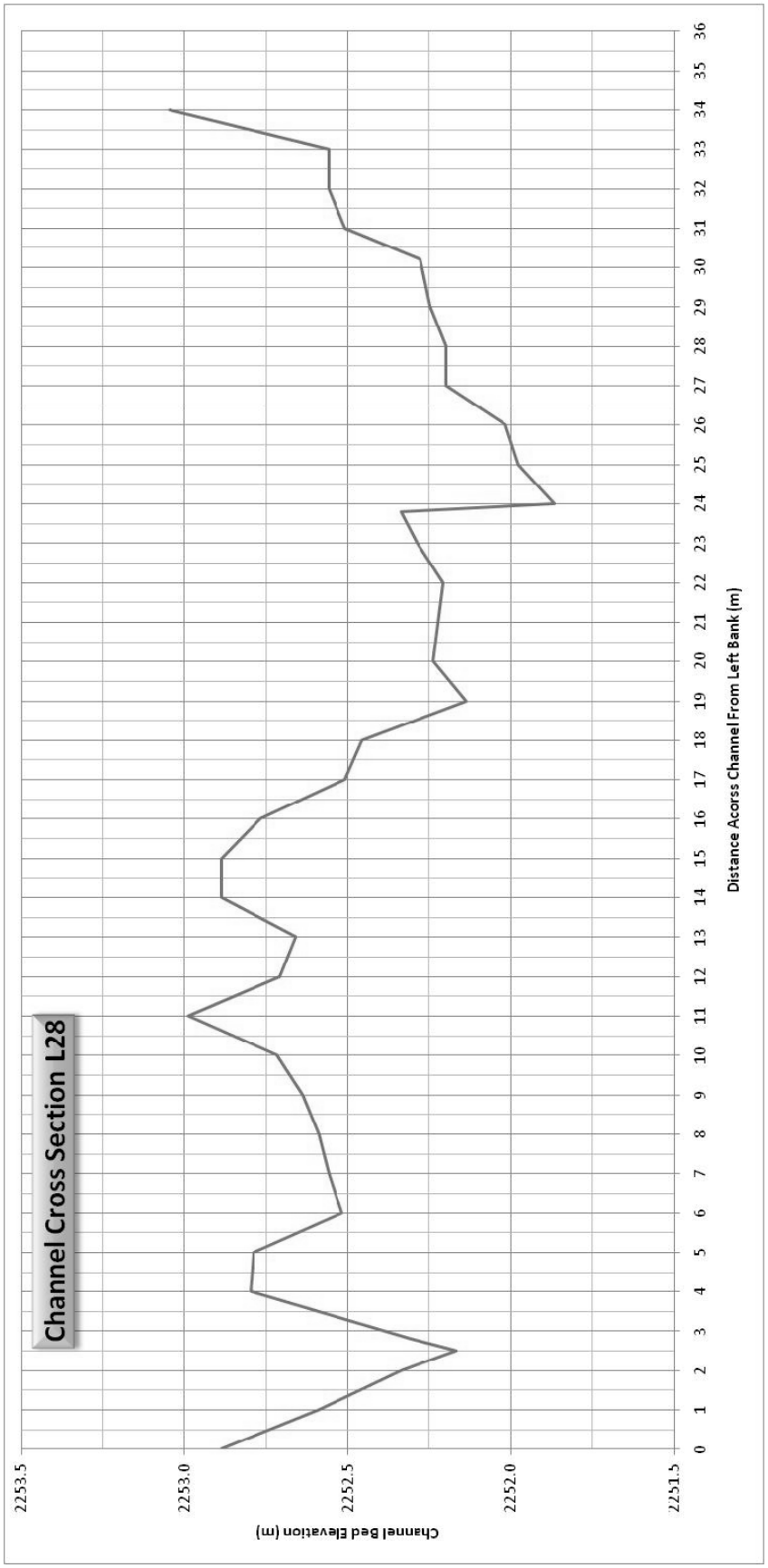

Channel Cross Section L27
Channel Bed Elevation (m)
2346.5
2346.0
2345.5
2345.0
2344.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
Distance Acorss Channel From Left Bank (m)

L28

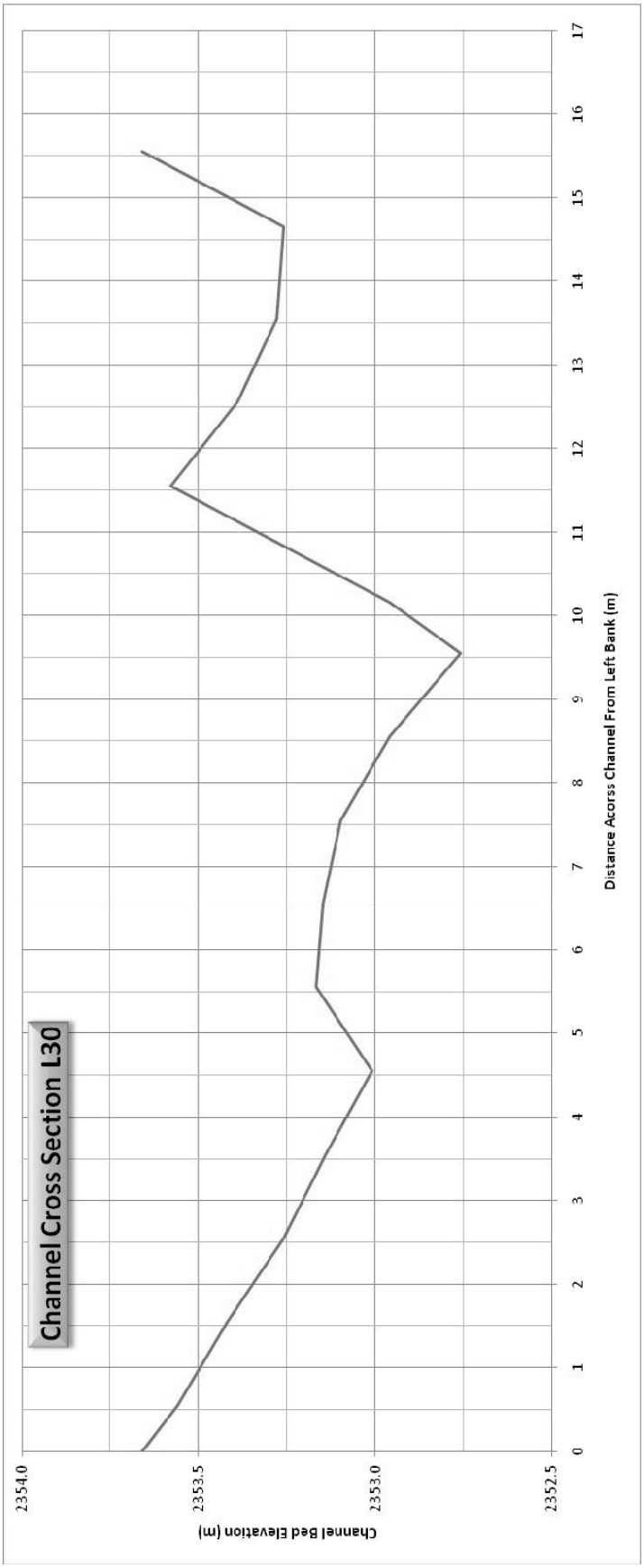
Reference point = nail at base of tree on right bank

Reference point elevation =	feet	meters
	7390.0	2253.0
Distance from level line to reference point		0.5

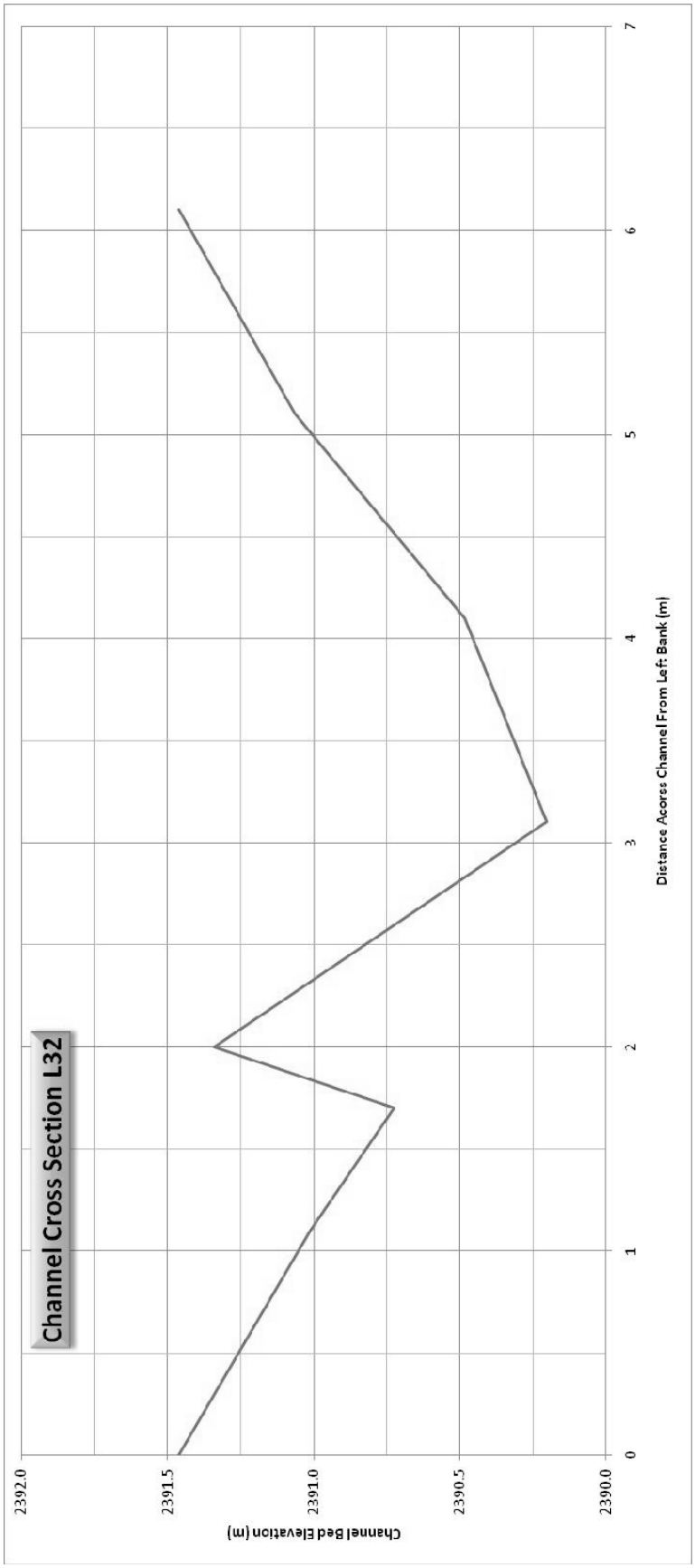
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0		0.65		2252.89
	1		0.95		2252.59
	2		1.2		2252.34
	2.5		1.37		2252.17
	2.8		1.23		2252.31
	4		0.74		2252.80
	5		0.75		2252.79
	6		1.02		2252.52
	7		0.98		2252.56
	8		0.95		2252.59
	9		0.9		2252.64
	10		0.82		2252.72
	11		0.55		2252.99
	12		0.83		2252.71
	13		0.88		2252.66
	14		0.65		2252.89
	15		0.65		2252.89
	16		0.77		2252.77
	17		1.03		2252.51
	18		1.08		2252.46
	19		1.4		2252.14
	20		1.3		2252.24
	22		1.33		2252.21
	23		1.25		2252.29
	23.8		1.2		2252.34
	24		1.67		2251.87
	25		1.56		2251.98
	26		1.52		2252.02
	27		1.34		2252.20
	28		1.34		2252.20
	29		1.29		2252.25
	30.2		1.26		2252.28
	31		1.03		2252.51
	32		0.98		2252.56
	33		0.98		2252.56
	34		0.49		2253.05


Channel Cross Section L28
Channel Bed Elevation (m)
2253.5
2253.0
2252.5
2252.0
2251.5
Distance Acorss Channel From Left Bank (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

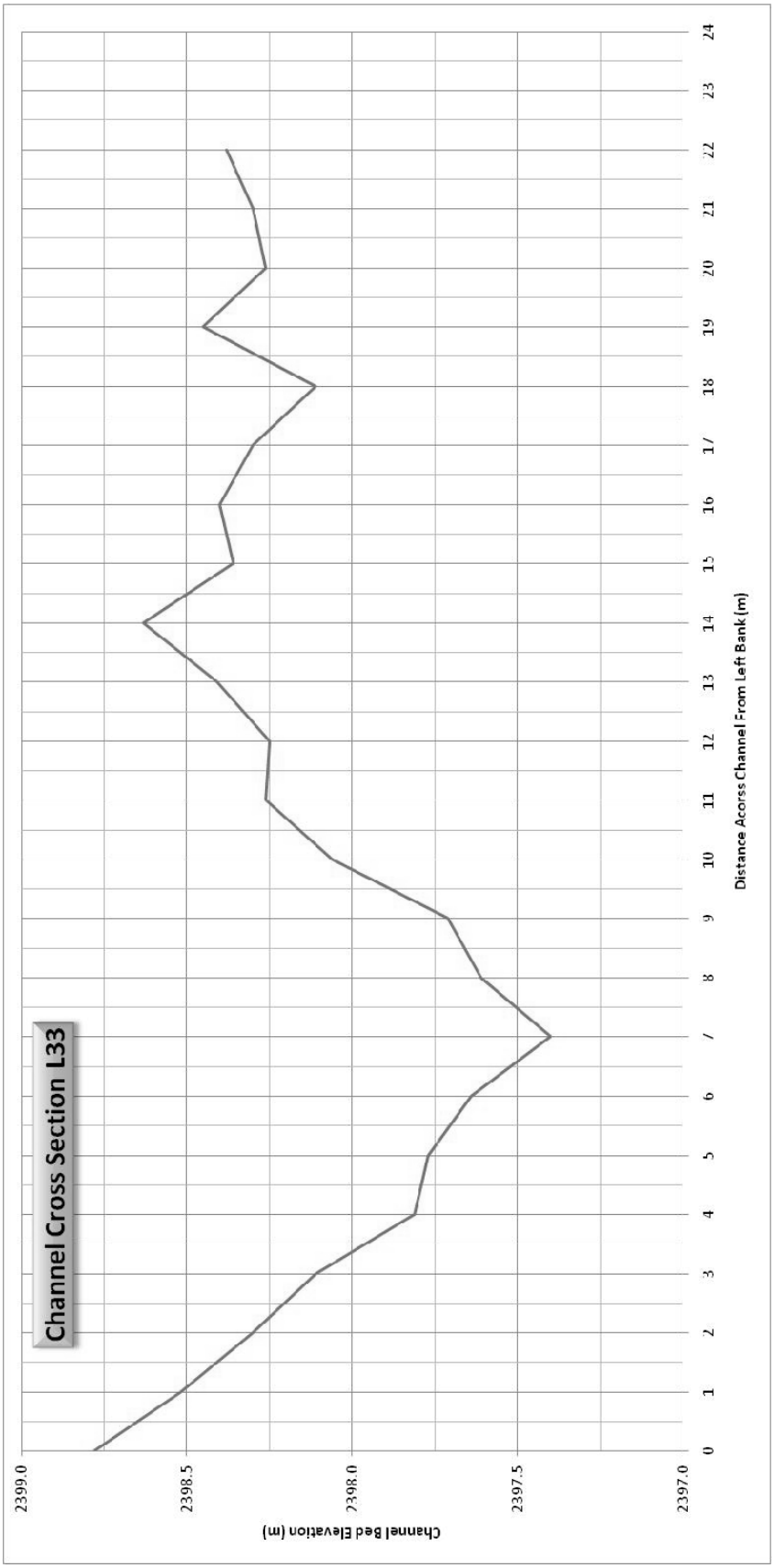
L30					
Reference point = nail at base of tree on left bank					
Reference point elevation =				feet	meters
				7720.0	2353.7
Distance from level line to reference point					0.0
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0		0		2353.66
	0.55		0.1		2353.56
	1.55		0.24		2353.42
	2.55		0.4		2353.26
	3.55		0.52		2353.14
	4.55		0.65		2353.01
	5.55		0.49		2353.17
	6.55		0.51		2353.15
	7.55		0.56		2353.10
	8.55		0.7		2352.96
	9.55		0.9		2352.76
	10.15		0.7		2352.96
	11.55		0.08		2353.58
	12.55		0.27		2353.39
	13.55		0.38		2353.28
	14.65		0.4		2353.26
	15.55		0		2353.66


Channel Cross Section L30
Channel Bed Elevation (m)
2354.0
2353.5
2353.0
2352.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Distance Acorss Channel From Left Bank (m)

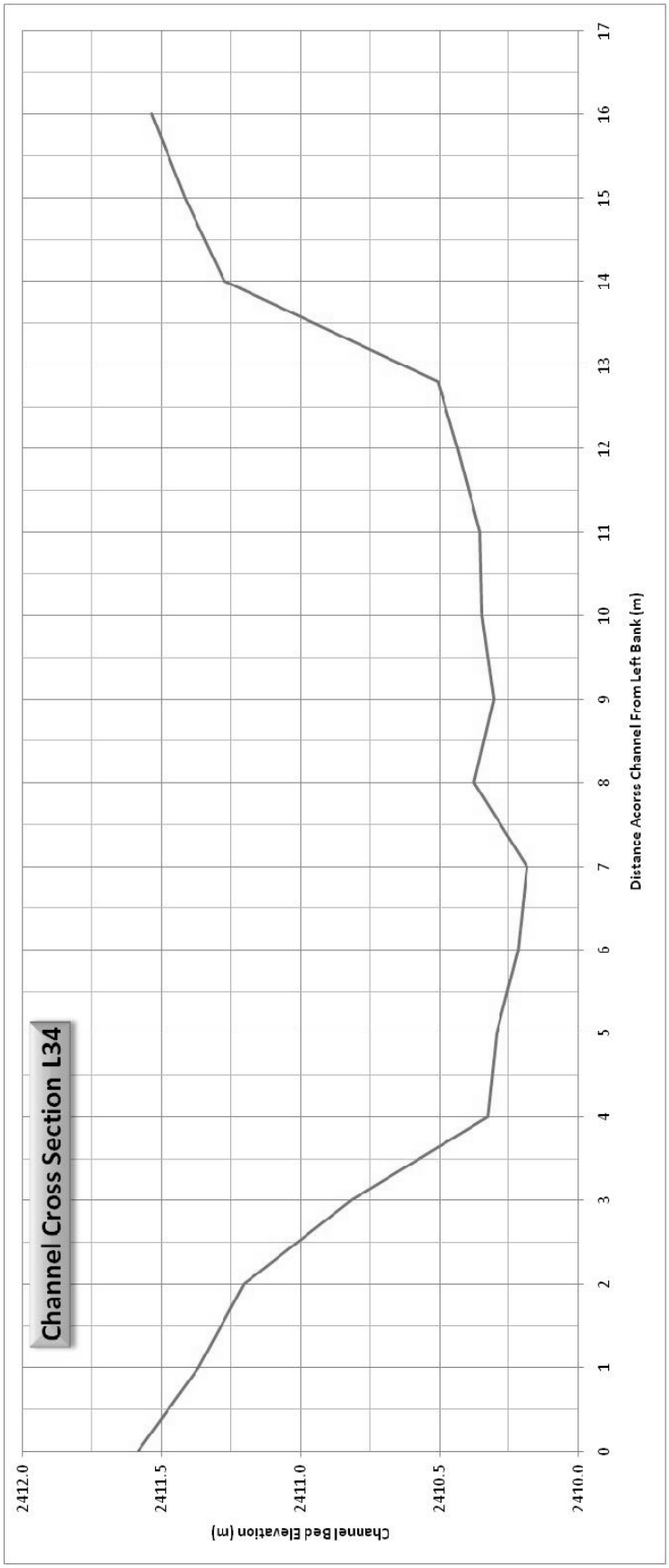
L32					
Reference point = nail at base of tree on right bank					
Reference point elevation =				feet	meters
				7844.0	2391.5
Distance from level line to reference point					0.0
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0.00		0.00		2391.46
	1.10		0.45		2391.01
	1.70		0.74		2390.72
	2.00		0.12		2391.34
	3.10		1.26		2390.20
	4.10		0.98		2390.48
	5.10		0.40		2391.06
	6.10		0.00		2391.46


Channel Cross Section L32
Channel Bed Elevation (m)
2392.0
2391.5
2391.0
2390.5
2390.0
0
1
2
3
4
5
6
7
Distance Acoss Channel From Left Bank (m)

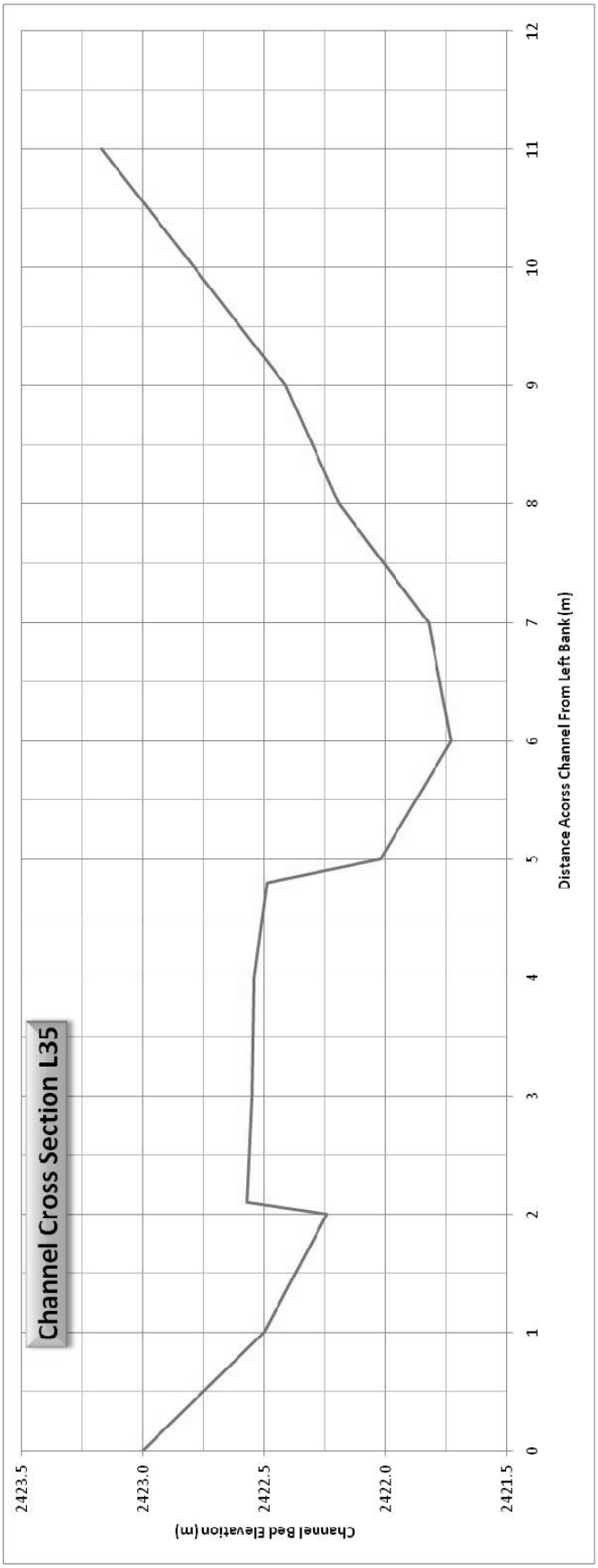
L33						Notes
Reference point = spike in ground near base of small tree on left bank						
Reference point elevation =				feet	meters	
				7868.0	2398.8	
Distance from level line to reference point					0.6	
Distance from left bank		Distance from surface to level line		Surface Elevation		
feet	meters	feet	meters	feet	meters	
	0.00		0.58		2398.78	
	1.00		0.84		2398.52	
	2.00		1.06		2398.30	
	3.00		1.25		2398.11	
	3.90		1.52		2397.84	
	4.00		1.55		2397.81	
	5.00		1.59		2397.77	
	6.00		1.72		2397.64	
	7.00		1.96		2397.40	
	8.00		1.75		2397.61	Debris Flow Deposits
	9.00		1.65		2397.71	
	10.00		1.30		2398.06	
	11.00		1.10		2398.26	
	12.00		1.11		2398.25	
	13.00		0.95		2398.41	
	14.00		0.73		2398.63	
	15.00		1.00		2398.36	
	16.00		0.96		2398.40	
	17.00		1.06		2398.30	
	18.00		1.25		2398.11	
	19.00		0.91		2398.45	Debris Flow Deposits
	20.00		1.10		2398.26	
	21.00		1.06		2398.30	Pre-fire Surface
	22.00		0.98		2398.38	


Channel Cross Section L33
Channel Bed Elevation (m)
2399.0
2398.5
2398.0
2397.5
2397.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Distance Acorss Channel From Left Bank (m)

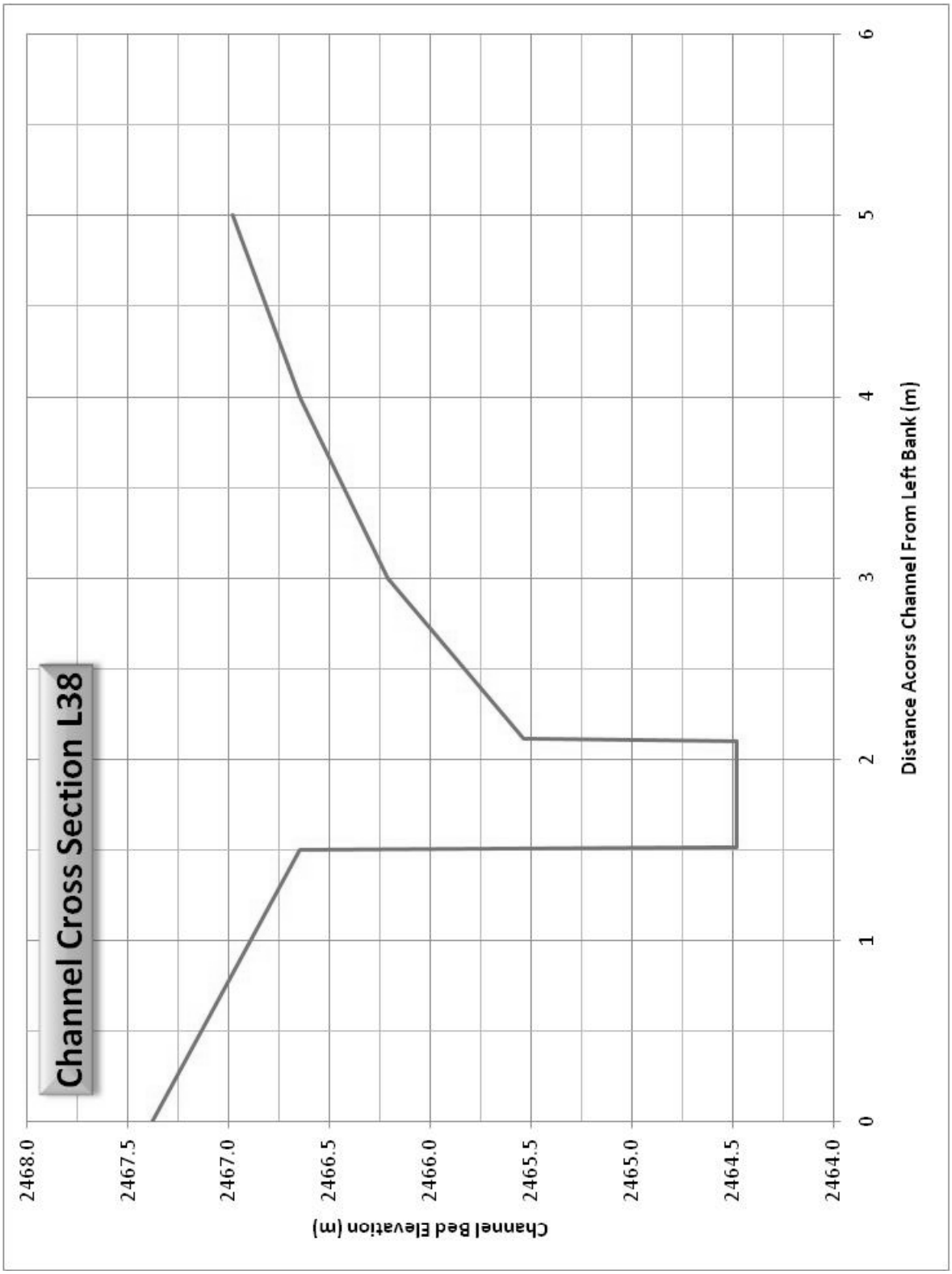
L34					
Reference point = nail at base of tree on left bank					
Reference point elevation =				feet	meters
				7910.0	2411.6
Distance from level line to reference point					0.61
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0.00		0.61		2411.59
	1.00		0.83		2411.37
	2.00		0.99		2411.21
	3.00		1.38		2410.82
	4.00		1.87		2410.33
	5.00		1.90		2410.30
	6.00		1.98		2410.22
	7.00		2.01		2410.19
	8.00		1.82		2410.38
	9.00		1.89		2410.31
	10.00		1.85		2410.35
	11.00		1.84		2410.36
	12.00		1.76		2410.44
	12.80		1.69		2410.51
	14.00		0.92		2411.28
	15.00		0.78		2411.42
	16.00		0.66		2411.54


Channel Cross Section L34
Channel Bed Elevation (m)
2412.0
2411.5
2411.0
2410.5
2410.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Distance Acorss Channel From Left Bank (m)

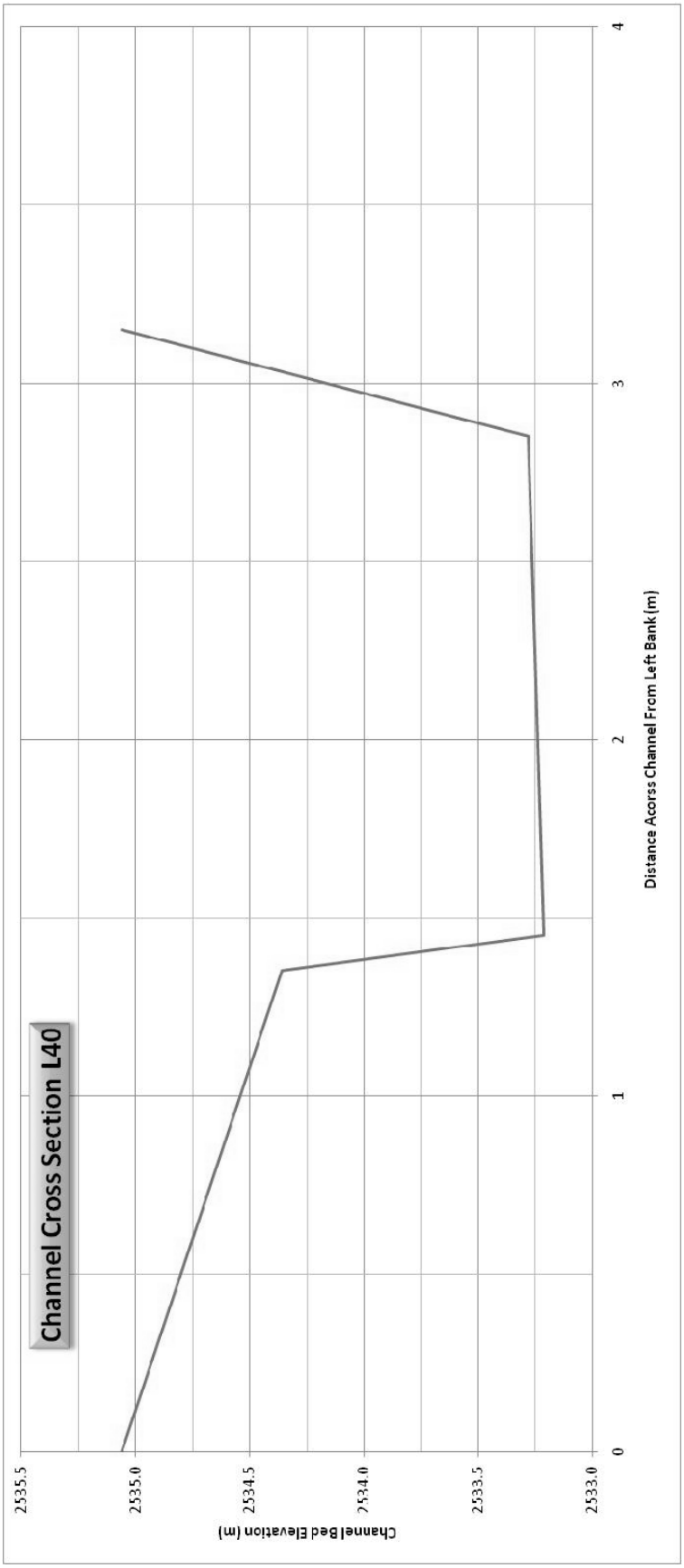
L35					
Reference point = Spike in ground on right bank					
Reference point elevation =			feet	meters	
			7948.0	2423.2	
Distance from level line to reference point				0.00	
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0		0.17		2423.00
	1		0.67		2422.50
	2		0.93		2422.24
	2.1		0.6		2422.57
	3		0.62		2422.55
	4		0.63		2422.54
	4.8		0.68		2422.49
	5		1.15		2422.02
	6		1.44		2421.73
	7		1.35		2421.82
	8		0.98		2422.19
	9		0.76		2422.41
	10		0.38		2422.79
	11		0		2423.17


Channel Cross Section L35
Channel Bed Elevation (m)
2423.5
2423.0
2422.5
2422.0
2421.5
0
1
2
3
4
5
6
7
8
9
10
11
12
Distance Acorss Channel From Left Bank (m)

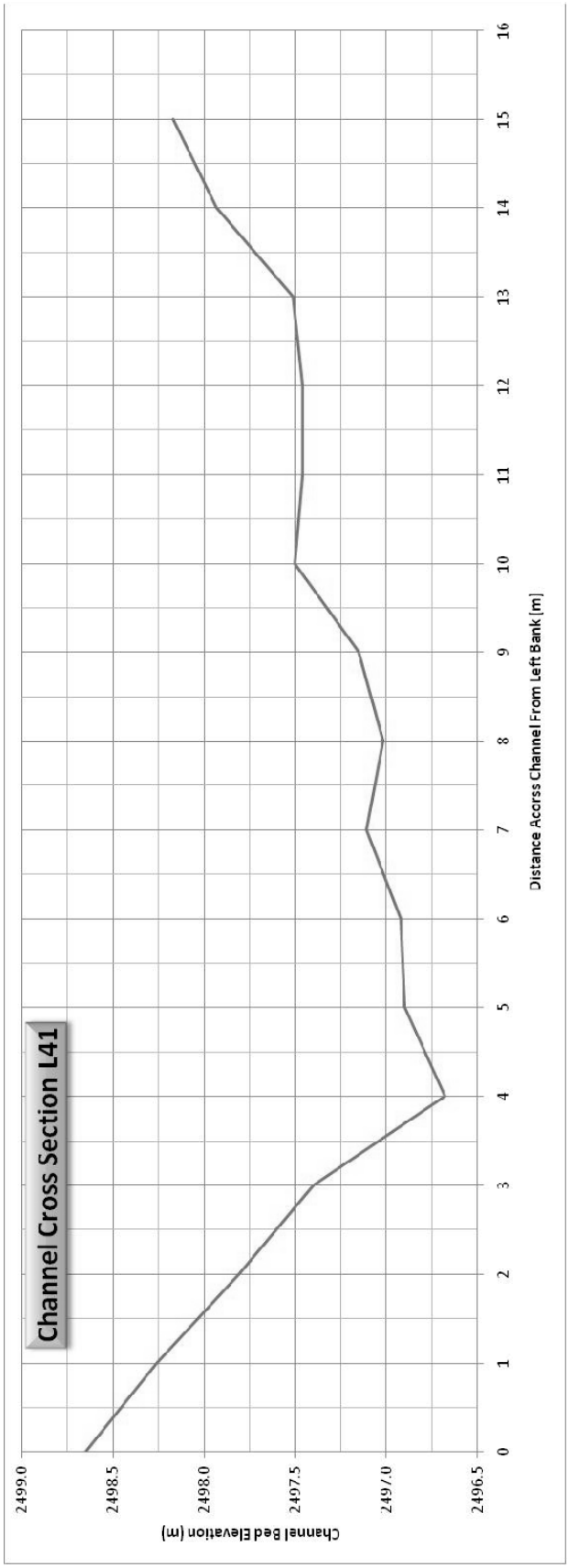
L38					
Reference point = nail at base of tree on left bank					
Reference point elevation =				feet	meters
				8093.0	2467.4
Distance from level line to reference point				0.0	0.0
Distance from left		Distance from		Surface Elevation	
	meters		meters		meters
	0.00		0.00		2467.38
	1.50		0.73		2466.65
	1.51		2.90		2464.48
	2.10		2.90		2464.48
	2.11		1.84		2465.54
	3.00		1.17		2466.21
	4.00		0.73		2466.65
	5.00		0.40		2466.98


Channel Cross Section L38
Channel Bed Elevation (m)
2468.0
2467.5
2467.0
2466.5
2466.0
2465.5
2465.0
2464.5
2464.0
0
1
2
3
4
5
6
Distance Acorss Channel From Left Bank (m)

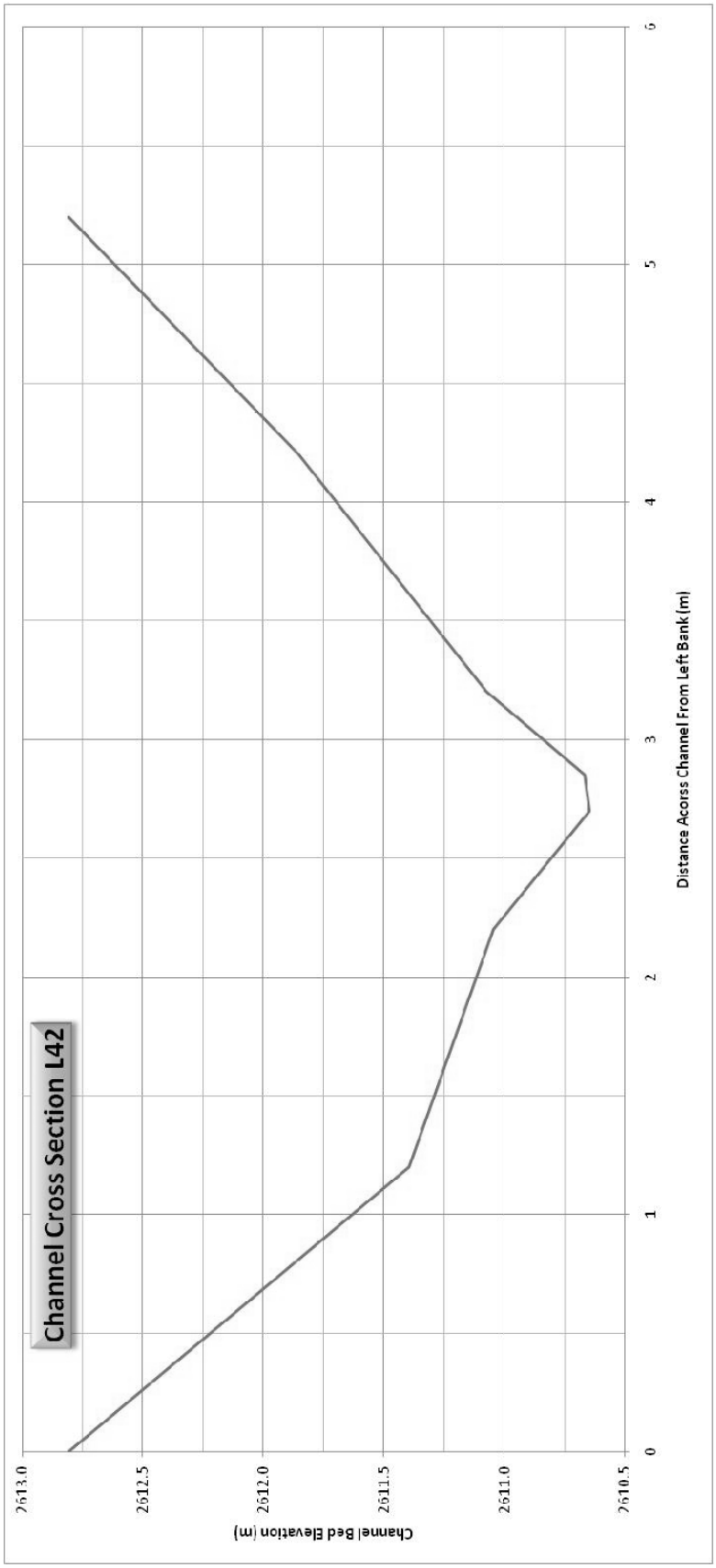
L40					
Reference point = spike in ground on right bank					
Reference point elevation =				feet	meters
				8315.0	2535.1
Distance from level line to reference point					0.00
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0.00		0.00		2535.06
	1.35		0.70		2534.36
	1.45		1.85		2533.21
	2.85		1.78		2533.28
	3.15		0.00		2535.06


Channel Cross Section L40
Channel Bed Elevation (m)
2535.5
2535.0
2534.5
2534.0
2533.5
2533.0
0
1
2
3
4
Distance Acorss Channel From Left Bank (m)

L41					
Reference point = nail at base of tree on right bank					
Reference point elevation =				feet	meters
				8194.0	2498.2
Distance from level line to reference point					0.48
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0.00		0.00		2498.65
	1.00		0.39		2498.26
	2.00		0.84		2497.81
	3.00		1.25		2497.40
	4.00		1.97		2496.68
	5.00		1.75		2496.90
	6.00		1.73		2496.92
	7.00		1.54		2497.11
	8.00		1.63		2497.02
	9.00		1.50		2497.15
	10.00		1.15		2497.50
	11.00		1.19		2497.46
	12.00		1.19		2497.46
	13.00		1.14		2497.51
	14.00		0.72		2497.93
	15.00		0.48		2498.17


Channel Cross Section L41
Channel Bed Elevation (m)
2499.0
2498.5
2498.0
2497.5
2497.0
2496.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Distance Accrss Channel From Left Bank (m)

L42					
Reference point =spike in ground in right bank					
Reference point elevation =				feet	meters
				8570.0	2612.8
Distance from level line to reference point					0.00
Distance from left bank		Distance from surface to level line		Surface Elevation	
feet	meters	feet	meters	feet	meters
	0.00		0.00		2612.80
	1.20		1.41		2611.39
	2.20		1.76		2611.04
	2.70		2.16		2610.64
	2.85		2.14		2610.66
	3.20		1.73		2611.07
	4.20		0.95		2611.85
	5.20		0.00		2612.80


Channel Cross Section L42
Channel Bed Elevation (m)
2613.0
2612.5
2612.0
2611.5
2611.0
2610.5
0
1
2
3
4
5
6
Distance Acorss Channel From Left Bank (m)

Location	Lattitude (DMS)				Longitude (DMS)			Elevation (FT)	Vertical GPS Percision (± Ft)	Channel Slope (%)	Channel Aggrading (+) or Degrading (-)	Bed elevation in relation to pre fire bed (m)	Bed Material (%) (divisions per ASTM D 2487-06)					Bed Characterization	Bank Characterization
													Method	Fines (<0.074 mm)	Sand (0.075 - 4.750 mm)	Gravel (4.751 - 75 mm)	Cobble (> 75 mm)		
L1	35	18	16		-111	34	5	7069	9	5	+	-1.2						Fluvial, Granular	prefire DF deposits
L2	35	18	18		-111	34	12	7037	18	5	+	-0.5	Sieve	17	78.7	4.3			
L3	35	18	19		-111	34	12	7045		5	+								
L4	35	18	16		-111	34	13	7061	32	5	+	0.2							
L5	35	18	19		-111	34	15	7051	9	5	+		Sieve	3.2	80.3	16.5		Granular >75% < 5cm	
L6	35	18	18		-111	34	17	7080	3	5	-	-0.5						75% sand, 20% gravel, 10% boulder	
L7	35	18	21		-111	34	17	7094	3	6	-	-0.5	Sieve	4	79.3	16.7		Braided with .3m high island deposits	
L7-2													Sieve	1.6	63.7	34.8			
L8	35	18	25		-111	34	26	7121	3	7	-	0.2	Sieve	5	67.7	27.3		Fine gravel and sand with large material along banks (DF Levees)	scattered 10 - 30 cm boulders from DF/HCFF lying on prefire surface
L9	35	18	24		-111	34	26	7130	15	5	+	-0.6	Sieve	5.1	69.6	25.3		Granular, DF/HCFF deposits now eroding, 50% < 2.5cm	Prefire surface intact,
L10	35	18	26		-111	34	29	7120	15	6	+	0.5						Channel braided, right channel 1m deeper than left. Material granular DF/HCFF deposits being reoworked, many boulders 10-50cm, bed 50% < 2.5cm	
L11	35	18	27		-111	34	33	7162	6	8	+	-0.5	Sieve	2.4	67.7	30		Granular, center portion of overall channel shows 20% >2.5cm	Fine, <2.5cm fluvial deposits, abundant tree roots, Many trees survived fire.
L 11-1	35	18	27		-111	34	35	7173	9	7	+	-0.6	Pebble Count	6	43	41	10	Flat granular surface	Prefire fluvial, many tree roots. Few trees survived fire
L12	35	18	28		-111	34	40	7258	9	8	-	-0.5	Sieve	4.2	74.9	21		Significant erosion occuring. Material < 2.5cm being washed from around larger material. Trees being undermined.	Eroding, tree roots exposed.
L13	35	18	29		-111	34	52	7265	15	4	+	0.1	Sieve	9	88.7	10.3		sand & gravel,	Left bank scouring as channel migrates. Abundant tree roots, some trees living
L14	35	18	35		-111	35	1	7329	9	5	+	-0.3						Large boulders in channel trapping sediment	
L15	35	18	28		-111	35	3	7315	6	7	+	-0.3	Sieve	2.6	94.6	2.8		Post Fire deposits 0.5m thick,	abundant tree roots. RB steep, LB flood plain
L16	35	18	32		-111	35	11	7370	5	13	-	-0.2	Sieve	4.9	34.1	61		pool and riffle type of system, sand & gravel pool beds with 3cm to 30cm boulders froming riffles. Pools 15m long. Post Fire sediments .2 m thick.	Very steep on both banks
L17	35	18	31		-111	35	14	7384	3	8	+	-0.2	Sieve	3	85.7	11.3		deposits filling initial scour.	Fine material with abundant tree roots (all trees dead) Area scoured to within a few cm of pre fire level
L17-2											-		Sieve	2.8	67.4	29.9			
L18	35	18	41		-111	35	15	7416	6	7	-	-0.2						Pre-fire colluvium,	Pre-fire colluvium with abundant tree roots, all trees dead
L19	35	18	32		-111	35	18	7390	3	5	+	-0.3	Sieve	2.5	72.3	25.3		granular, few very large boulders (>1m) buried in channel,	Abundant tree roots, on overbank pre-fire surface exposed, abundant grass roots

Location	Lattitude (DMS)				Longitude (DMS)			Elevation (FT)	Vertical GPS Percision (± Ft)	Channel Slope (%)	Channel Aggrading (+) or Degrading (-)	Bed elevation in relation to pre fire bed (m)	Bed Material (%) (divisions per ASTM D 2487-06)					Bed Characterization	Bank Characterization
													Method	Fines (<0.074 mm)	Sand (0.075 - 4.750 mm)	Gravel (4.751 - 75 mm)	Cobble (> 75 mm)		
L20	35	18	36		-111	35	23	7438	9	5	+	-0.6	Pebble Count	1.3	36.5	29.5	32.7	Braided DF/HDFF deposits now being eroded,. These deposits rise up to 1m above pre-fire bank elevation. Boulders (.5 to 1m) diverting low flows around in channel. Large boulders mix of dacite and basalt. Grass/small plants taking root in higher depostis.	Tree roots present, all trees dead. Flood flow signs up to 1m above present bed
L20-2													Sieve	4.3	93.4	2.4			
L20-3													Sieve	5.7	51.2	43.1			
L21	35	18	34		-111	35	24	7423	6	10	+	-0.4	Sieve	2.9	77.4	19.7		well sorted material in upper 5cm. More evenly graded below that.	abundant tree roots and boulders, all trees dead
L21-2													Sieve	1.4	12	86.5			
L22	35	18	46		-111	35	32	7560	14	7	-	0.1						DF depostis lying on pre-fire forest floor	Where channel is cut it exposes abundant tree and grass roots. All trees dead.
L23	35	18	33		-111	35	33	7517	7	5	+	0.1						Granular 75% <1.8cm	Low relief, barley abundant
L24	35	18	34		-111	35	45	7586	3	6	+	0.1	Sieve	3.8	87.9	8.4		Granular 75% <1.8cm	Low relief, barley abundant
L24-2													Sieve	4.4	61.7	33.9			
L25	35	18	40		-111	35	45	7572	12	7	-	-0.6	Sieve	6.6	74.3	19.1		many tree roots, braided, erroding beow pre fire bed	abundant tree roots, boulders, mix of DF and HCFF depostis now eroding
L26	35	18	42		-111	36	0	7680	5	19	-	-0.1	Sieve	4.9	73.5	21.6		Granular mainly <2.5cm, looks like fine material erroded from upsteram DF deposits.	steep slopes
L27	35	18	45		-111	36	2	7695	3	10	+	0.6	Sieve	4.3	78.8	16.9		granular material depositing as channel widens	steep slopes
L27-2													Sieve	2.9	45.7	51.5			
L27 P													Pebble Count	9	17	24	51		
L28	35	18	43		-111	36	4	7699	4	13	-	0.5	Pebble Count	9	20	25	46	Df deposits now being erroded.	not scoured, abundant barley, some areas are lower than top of floe deposits
L29	35	18	57		-111	36	4	7826	17	5	-	0.1	Pebble Count	14	47	16	23	DF depostis lying on pre-fire forest floor, some areas cutting into pre-fire layer a few cm. Downstream 2m deep gully forming.	Where channel is cut it exposes abundant tree and grass roots. All trees dead.
L30	35	18	45		-111	36	5	7720	10	6	-	0.0	Sieve	7.8	71.4	20.9		HCFF deposits now eroding back to pre-fire elevation. Small tree, vegatation, grass roots visible across pre-fire surface exposed in channel	steep slopes
L30 P														16	31	40	13		

Location	Lattitude (DMS)				Longitude (DMS)			Elevation (FT)	Vertical GPS Percision (± Ft)	Channel Slope (%)	Channel Aggrading (+) or Degrading (-)	Bed elevation in relation to pre fire bed (m)	Bed Material (%) (divisions per ASTM D 2487-06)					Bed Characterization	Bank Characterization
													Method	Fines (<0.074 mm)	Sand (0.075 - 4.750 mm)	Gravel (4.751 - 75 mm)	Cobble (> 75 mm)		
L31	35	18	41		-111	36	9	7796	10	16	-	-1.0						Large bounders, channel cut into pre-fire forest floor. Chanel probably did not exist prior to fire.	tree roots, colluvial soil
L32	35	18	50		-111	36	15	7844	15	20	-	-0.2	Sieve	1.8	88.7	9.5		boulders, fine dark sediments	boulders, tree roots
L33	35	18	38		-111	36	15	7867	5	30	-	0.5	Pebble Count	0	12	30	58	DF depostis	lower area cut through abundant tree roots
L34	35	19	1		-111	36	18	7909	3	10	-	-1.6	Pebble Count	5	41	28	26	material <30cm being deposited in gully cut during initial DF events.	Historic DF deposits. Abundant tree roots visible in cut areas.
L35	35	18	56		-111	36	21	7945	6	9	-	0.5	Pebble Count	0	41	39	19	Df deposits now being erroded.	steep slopes
L36	35	19	2		-111	36	27	8045	9	14	-	0.4						Df deposits now being erroded.	steep slopes, abundant tree roots
L37	35	18	46		-111	36	28	8113	15	44	o	0.0						abundant fine material	
L38	35	18	51		-111	36	30	8101	6	28	-	-2.0						Pre-fire hard colluvium	same as bed
L39	35	18	36		-111	36	34	8466	8	72	0 bedrock	-0.3						highly fractured bedrock, fractured pieces easily plucked from face, pieces average 40cm.	same as bed
L40	35	18	52		-111	36	44	8336	15	44	-	-1.5						channel cut through pre-fire colluvium with particles to 1m. When dry fine material is very hard, looses strenght when wet.	Same as bed, plus abundant tree roots in upper 0.3 m
L41	35	19	0		-111	36	44	8191	6	15	-		Sieve	4.4	42.4	53.2		fine material <3cm appears to be moving through area. Braiding evident.	steep slopes
L41 P													Pebble Count	3	43	30	24		
L42	35	18	53		-111	37	1	8571	3	53	o bedrock	-1.3						bedrock, soft and rounded, highly irregular surface	abundant tree roots in upper 0.6m, aspen shoots and vines actively growing

Location	Obstructions in flow channel	Obstructions in overbank	sinuosity	DF / HCFF deposits in channel	DF / HCFF deposits near channel	Sample	Pebble Count	XC Measure	Evidence of multiple flow events	Large volumes of material enter channel from overbank	Large vloume of material leave channel to overbank	Large Particle color	Large Partlcle Angularity	Remarks
		T = trees DF= Debris Flow Deposits HCFF	(L) = Low (M) = Medium (H) = High											
L1	N	T, DF	L	?	Y				Y	N	Y			
L2	trees	T, DF	L		Y				Y	N	Y			
L3														
L4														
L5		T, DF	M	N	Y					N	Y			
L6								Y						
L7	T, DF/HCFF	T	M	Y	N	YY		Y						
L7-2														
L8	trees, boulders < 1m	trees, boulders <1m	L	Y	Y				Y	N	Y			
L9	T,DF/HCFF	T, DF	L	Y	Y				Y	N	N			
L10	T, DF,HCFF	T, DF	L	Y	Y				Y	N	N			
L11	T(down)	T(many live)	M	Y	N	Y		Y	Y	N	Y			
L 11-1	N	T, DF/HCFF	M	N	Y		Y		Y	N	Y			
L12	T, DF and HCFF	T, DF	L	Y	Y	Y			Y	N	Y			
L13	T, Upstream large boulder pile	T, DF	H		DF				Y	N	Y			Boulder pile upstream has pushed channel to left bank. High flows will continue to errode bank.
L14	boulders	T	H					Y	Y	N	N			
L15	T, Boulders	T, boulders	M	N	N	Y		Y	N	N	N			
L16	T, Boulders	T	H	N	N	Y			N	N	N			narrowness of channel and steep banks contain all flow to same area effectively bluring evidence of multiple events.
L17	Standing and fallen trees, boulders	Trees, few very large boulders	M	Y	Y	YY		Y	Y	N	Some, not large volume			
L17-2														
L18	T	T	L	N	N			Y	Y	N	N			Looks like HSFF events. Probably multiple events, but most eveidence obscured by subsequent flows.
L19	T, Boulders	T, boulders	M	Y	Y	Y		Y	Y	N	N			

Location	Obstructions in flow channel	Obstructions in overbank	sinuosity	DF / HCFF deposits in channel	DF / HCFF deposits near channel	Sample	Pebble Count	XC Measure	Evidence of multiple flow events	Large volumes of material enter channel from overbank	Large vloume of material leave channel to overbank	Large Particle color	Large Partlcle Angularity	Remarks
		T = trees DF= Debris Flow Deposits HCFF	(L) = Low (M) = Medium (H) = High											
L20	T, Boulders	T,B	M	Y	N	YYY		Y	Y	N	N			Overbanks collonized by applied barley
L20-2														
L20-3														
L21	T,B	T,B, steep slope	H	N	N	YY			Y	N	N			side channel intering main channel. Sorting possibly part of backwater effect from main channel.
L21-2														Sample from lower portion of same site
L22	T, B, no distinct channel	same	?	Y	Y				Y	Y	Y			DF deposits spread over wide area, channels appera and dissapear. Multiple Df lobes in area.
L23	T	T	M	N	N				N	N	N			
L24	T	T	M	N	N	YY		Y	N	N	N			
L24-2														
L25	trees (standing and down), Boulders, Roots	Trees, Boulders	L	Y	Y				Y	Y	Y			Flood flow evidence to 1 m on banks above pre-fire channel
L26	Trees, boulders	Trees, Boulders, steep slopes	H	Y	N	Y		Y	Y	N	N			
L27	T,B	T,B, Steep slopes	H	Y	N	YY	Y	Y	Y	N	Y	light (dacite)	sub-roundded	Material depositing at this location. Channel triples in width from 50 m upstream, Hyperelevation flood flow evidence on bank outside bend. Upstream shows multiple island deposits that are erroding.
L27-2														
L27 P														
L28	trees (standing and down), Boulders	Trees	M	Y	N		Y	Y	Y	N	N	light (dacite)	Angular	Large particles avarage 40 - 60cm. Current flow channel is cutting into pre-fire bed in some places. Most of DF deposite will likely stabilize in place.
L29	Trees, DF	Trees (mature and dog hair thickets), Boulders	M	Y	Y		Y		Y	Y	Y	light (dacite)	Sub-angular	flow way is 100m wide with multiple DF lobes. Fine material now eroding out of DF lobes.
L30	Trees, HCFF deposits	very steep slopes	H	Y	N	Y	Y	Y	Y	N	N	light (dacite)	angular	Several island depostis left by HCFF now being erroded.
L30 P														

Location	Obstructions in flow channel	Obstructions in overbank	sinuosity	DF / HCFF deposits in channel	DF / HCFF deposits near channel	Sample	Pebble Count	XC Measure	Evidence of multiple flow events	Large volumes of material enter channel from overbank	Large vloume of material leave channel to overbank	Large Particle color	Large Partlcle Angularity	Remarks
		T = trees DF= Debris Flow Deposits HCFF	(L) = Low (M) = Medium (H) = High											
L31	boulders	trees, DF deposits	L	Y	N				Y	N	N	light (dacite)	Angular	likely that this channel was only active during large events (July20 & Aug 16) and will only flow in subsequent large events. Channel probably did not exist prior to fire
L32	boulders	very steep slopes	H	N	N	Y		Y	?	N	N	light (dacite)	Rounded	Channel appears to have stabilized. Upstream slopes increase to >40% within 100m
L33	DF deposit	Trees	M	Y	Y		Y	Y	Y	N	Y	light (dacite)	Angular	location in on bench between two sections of channel with slopes > 50%. DF depostis cover area. Upper channel scoured >1m with higher portion to bedrock. Below site flow split and cut >1 m slot channel through forest floor higher than pre-fire channel.
L34	DF deposit	Trees, DF deposits	L	Y	Y		Y	Y	Y	Y	Y	light (dacite)	Rounded	Gully likely formed in July 20 event (does not show on pre-fire map). Debris flow levees 20cm thick on banks. Channel banks appear to be pre-fire debris flow deposits.
L35	Trees, DF depostis	Steep Slopes	H	Y	N		Y	Y	Y	N	N	light (dacite)	Sub-angular	narrow deep channel, much of sediment will likely remain stable in all bu very high flows. Several more similar DF deposits upstream
L36	Trees (standing and fallen), Boulders	steep slopes, boulders, trees (standing and fallen0	H	Y	Y				Y	N	N	light (dacite)	Sub-angular	initial DF deposits are up to 1.5 m thick and now being erroded. Several short debris dams evident, none appear to have blocked entire channel.
L37	N	N	L	N	N				N	N	N	light (dacite)	Rounded	channel appears to be stable, rounded bottom shows little movement of abundant fine material.
L38	boulders	very steep with trees	H	N	N			Y	Y	N	N	light (dacite)	Angular	fine bank material that is dry is very hard (difficult to chip with geologist pick) it looses much of its strength when wet.
L39	downstream boulders	trees	L	N	N				?	Y	N	light (dacite)	Angular	above road channel diverges into multiple small drainages with no discernable channels. Total tributary area to this point is approx 3 hectares (or about 7 acres). Below road channel is cut to bedrock through 2 to 3 m thick colluvial deposits. With sideslope failure once tree roots decompose area could contribute up to 2800 m^3 sediment to channel.
L40	boulders	trees, steep slopes	H	N	N			Y	Y	N	N	light (dacite)	Angular	slot channel continuing to cut into historic debris flow deposits.
L41	trees, boulders	trees, boulders, steep slopes	M	Y	N	Y	Y	Y	Y	N	N	light (dacite)	Sub-angular	
L41 P														
L42	Pipeline	steep slopes, trees	L	N	N			Y	Y	N	N	light (dacite)		Bedrock is not fractured, but is soft and rounded. Bedrock surface was probably buried under soil and sediment prior to fire (no evidnece of burn in small hollows and sheltered areas of rock that wouldn't have been worn off). Slopes above channel are very steep >70% and have thick stands of aspen shoots growing.

Appendix D

Definitions

Appendix D: Definitions

Aggradation = The process by which a stream's gradient steepens due to increased deposition of sediment.

Alluvium = deposits of clay, silt, sand, gravel, or other particulate material that has been deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain.

ARI = Average Recurrence Interval

Bajada = a form of piedmont; a moderately sloping alluvial slope formed by the coalescing of adjacent alluvial fans.

Colluvium = material deposited by gravity as opposed to water movement. Particles are generally not well rounded and deposits are not sorted by particle size as seen in fluvial systems.

Dog hair thicket = a dense stand of small pine trees with average trees less than 15cm diameter. These stands choke the growth of trees and can act as ladder fuels increasing the likelihood of ground fire reaching tree crowns.

Duff = Loosely compacted organic material covering a forest floor. Typically composed of leaf litter and pine needles in varying stages of decay

Hydrostatic pressure= The pressure exerted by a fluid due to the force of gravity acting on it.

Mid-channel bar = a sediment deposit forming the higher portions of sediment in a braided channel.

Newtonian Fluid = A fluid possessing constant viscosity at a given temperature regardless of the rate of shear.

Piedmont = The transition region between mountain slopes and plain areas.

Appendix D: Definitions

Saltation = The process in which particles too large to be suspended in flowing water are bumped along the channel bed. The particles bounce along spending some time in the water stream and other time in contact with the channel bed.

Sediment Limited = runoff has enough energy to move more sediment than is available within the channel. This generally results in scouring of the channel

Thalweg = A line drawn along the deepest part of a channel.

Transport Limited = There is more sediment available for transport in the channel than the runoff has energy and volume to move. This generally results in an aggrading channel.

Wildland-Urban Interface (WUI) = The boundary between developed land and undeveloped land. This typically occurs at the boundary of government owned land such as National Forest, Parks, etc.