HYDRAULIC CHANNEL GEOMETRY & SCALING RELATIONS IN TRIBUTARIES OF BIG CREEK, VALLEY & IDAHO COUNTIES, CENTRAL IDAHO

by

Holly H. Young

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Acknowledgements

The process of researching and writing this senior thesis was made much less painful with the help and advice of my siblings. Steve provided valuable information on meeting self-set deadlines, Peter was a sympathetic ear when my stress levels rose to venting level, and May provided motivational texts when I needed to get my ass in gear. Thanks, guys.

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Abstract

While at a discrete point the form of a river may appear irregular and strongly influenced by local forcings such as a fallen tree or a blocky landslide, simple power functions often reveal robust scaling between channel form (width, depth, slope, etc.) and discharge over the length or a river. The often monotonic downstream change in these variables occurs as a result of progressively increasing stream flow. Though these functions were often developed in anthropogenically-influenced low-land, alluvial systems, landscape evolution models frequently assume that these scaling relationships can be applied to bedrock channels. The applicability of these relationships to bedrock channels has only recently begun to be investigated.

To assess the validity of applying these classic relationships to mountainous bedrock channels, a field study was conducted during the summer of 2013 in the Big Creek drainage (~1400 km^2), located in the Frank Church River of No Return Wilderness, Valley and Idaho Counties, Idaho. This drainage represents an ideal field area as it has experienced little anthropogenic disturbance and features bedrock channels incised into metasedimentary, igneous and metaigneous rock. Additionally, it provides an opportunity to build upon previous and ongoing stream ecology and geomorphology studies done within the Big Creek watershed. Using Taylor Wilderness Research Station as a base, measurements of bankfull width, stage, slope, and substrate grain size of four tributaries of Big Creek (Cabin, West Cave, East Crooked, and Pioneer) were collected at stations positioned along each stream. Multiple measurements of each variable were collected and averaged per station. Stations were placed so as to reflect logarithmic increases in drainage area, as determined using a USGS Digital Elevation Model (DEM) of the Big Creek drainage.

Analysis of field data suggests that the measured tributaries do not consistently follow predicted scaling relationships. Some variables which respond rapidly to flow conditions such as width and depth demonstrate more consistent scaling relations while other variables, such as slope or grain size, do not. Width, depth, and slope are correlated with drainage area, while median grain size is sometimes correlated with drainage area and sometimes with slope.

DEM-extracted channel data from 24 tributaries to Big Creek indicate that channel steepness is influenced by lithology and recent but currently inactive faults. Tributaries in less resistant rocks predominantly have lower steepness, and channels with high steepness have post-Eocene normal faults cutting through their basins. Channel steepness and concavity are somewhat correlated in the Big Creek basin. Longitudinal profiles of the streams display pronounced knickpoints related to lithologic changes, faults, glaciation, the Soldier Bar landslide, and possibly base level drop 2 – 4 Ma caused by capture of the upper Snake River.

These findings suggest the Big Creek basin is a landscape in transition, responding to large scale consistent external forcings, (e.g. climate), local conditions (e.g. lithologic variations and faulting), recent disturbances, (e.g. debris flows) and legacy effects (e.g. glaciation and base level fall). If well constrained scaling relations exist in bedrock rivers, they would be best observed where steady and uniform forcings have driven erosion into largely homogeneous substrate. Though Big Creek does not present these conditions, it does elucidate the source of deviations from scaling relations and which variables most rapidly reestablish good scaling relations following a perturbation.

Chapter 1. Introduction

1.1 Problem Statement

Research into hydraulic geometry relationships has historically been conducted in low-land alluvial channels, with little in-depth investigation into scaling relationships in bedrock channels. Recent field observations have prompted researchers to question the assumption made in many landscape evolution models that bedrock channels are comparable to those found in lower gradient alluvial environments. Contemporary research into bedrock channels suggests classic power-law relationships that operate in alluvial channels may also be present in mountainous bedrock channels; however, the degree of similarity between low-land relationships and those in bedrock channels has not yet been fully evaluated. Additionally, the consistency of those relationships across variable lithologies, geomorphic legacies, and climates remains in question. Further collection and analysis of field measurements are needed to evaluate if established hydraulic geometry relationships are valid and consistent in bedrock channels. This study has several objectives: 1) to determine what, if any, scaling relationships are present within individual bedrock tributaries to Big Creek in central Idaho; 2) to assess the consistency of scaling relationships within the Big Creek drainage basin; and 3) to add to the current data set of bedrock channel geometry field measurements from around the world.

1.2 Background

1.2.1 Scaling Relationships in Alluvial Rivers

Intuitively, as drainage area of a river increases so must river discharge. Leopold & Langbein (1962) posited that on average each unit of drainage area contributes approximately the same volume of water to runoff, concluding there is a one-to-one relationship between discharge and drainage area. This relationship is shown by:

$$Q=eA^{1.0} \quad [1]$$

where Q is bankfull discharge, A is drainage area, e is empirically determined, and the exponent is approximately unity (Dunne & Leopold, 1978; Galster, 2007). In the absence of flow data, this equation allows for the substitution of drainage area for bankfull discharge (Hack, 1957; Flint, 1974; Howard et al., 1994), as is done in this study.

Simple power-law functions also describe how observed channel characteristics adjust with discharge along the length of a river channel due to a progressive increase in stream flow in the downstream direction (Figure 1) (Leopold & Maddock, 1953). These functions are expressed as:

$$w=aQ^{b} \quad [2]$$

$$d=cQ^{f} \quad [3]$$

$$v=pQ^{j} \quad [4]$$

where w is bankfull width, d is average depth, v is depth-averaged velocity, Q is water discharge, and $a, b, c, f, p,$ and j are empirically derived constants. Average values for $b, f,$ and j are 0.26, 0.40, and 0.34, respectively, for the Midwestern United States (Leopold & Maddock, 1953) and 0.49, 0.38, and 0.13 for the Pacific Northwest (Castro & Jackson, 2001). Substitution of drainage area in place of discharge yields the following relationships:

$$w=aeA^{b} \quad [5]$$

$$d=ceA^{f} \quad [6]$$

$$v=peA^j \quad [7]$$

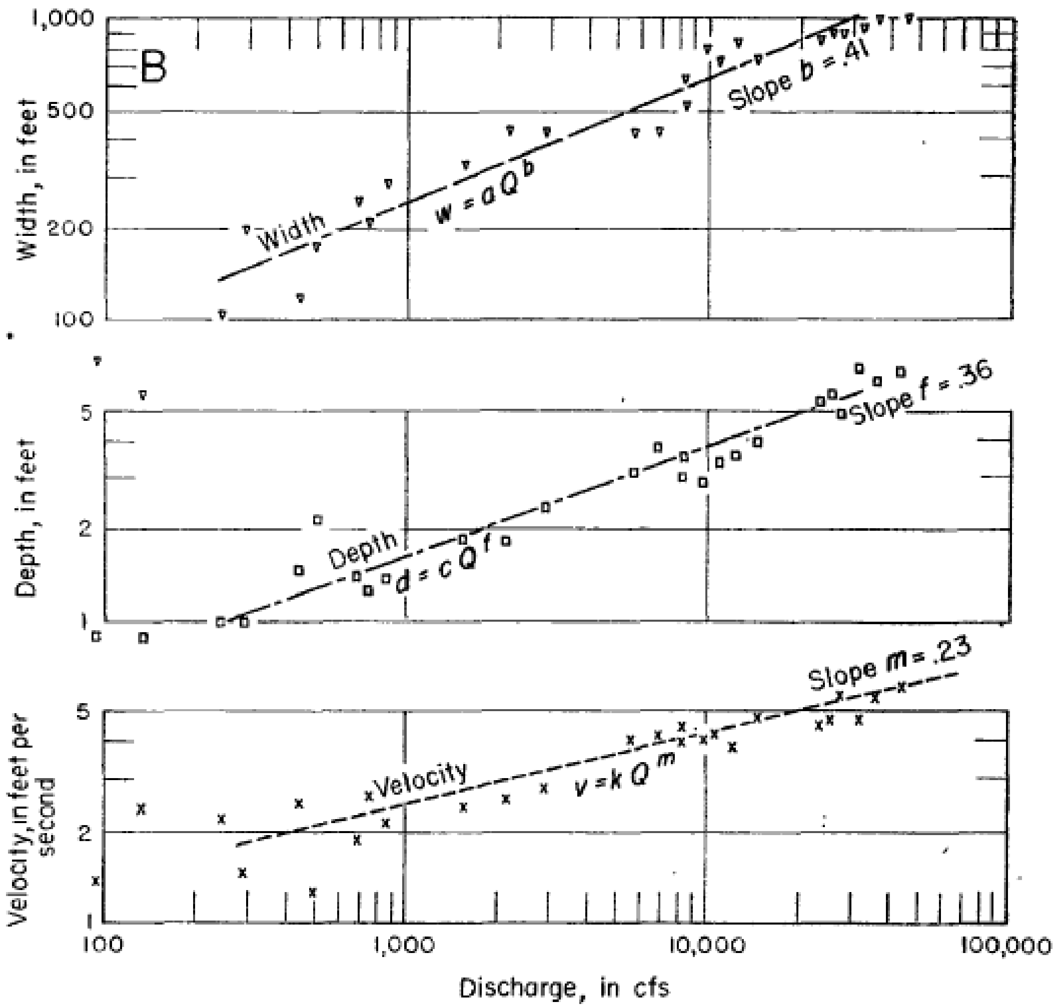


Figure 1. Typical relationships between width, depth, velocity, and discharge from a gaging station on the Cheyenne River near Eagle Butte, South Dakota. From Leopold & Maddock, 1953.

Because velocity measurements are time consuming, dangerous at high flow and require more cumbersome and technical equipment, it can be convenient to substitute slope in its place. Leopold & Maddock (1953) established that as depth and velocity increase in the downstream direction, slope overall decreases downstream, leading to the relation:

$$S=gA^z \quad [8]$$

where *S* is slope, *A* is drainage area, and g and z are empirically derived constants (Hack, 1957). Since water-surface slope approximates along-stream average slope and is easier to measure, it is often used as a proxy in hydraulic geometry equations (Simon & Castro, 2003). Because area (as a proxy for discharge) and slope are the primary driving forces in setting channel geometry and can easily be extracted from digital elevation models (DEMs), resisting variables in channel incision are commonly compared to them (Howard, 1994; Golden & Spinger, 2006; Wobus et al., 2006). Shifts in the interactions between energy expenditures and driving and resisting forces may be shown by variations in slope (Hack, 1957, 1973; Snyder et al., 2000; Snyder et al., 2003).

Taken together, equations 5, 6, 7, and 8 predict variations in reach-scale channel morphology, describing increases in width, depth, and velocity, synchronous with decreasing slope, as discharge increases. However, these relationships were developed in lowland alluvial systems (Wolman, 1953), and most subsequent field studies have also been conducted in low-land environments (Jarrett, 1990). Additionally, previous field study locales have recently been recognized as being strongly influenced by human land use (Walter & Merritts, 2008), leading to questions regarding how representative they are of undisturbed systems.

1.2.2 Scaling Relationships in Bedrock Rivers

Bedrock channels differ from alluvial channels in several significant ways. A bedrock channel is defined as meeting either or both of the following conditions: 1) sediment transport capacity (Q_c) exceeds bedload sediment supply (Q_s) over the long-term; or 2) the river is actively incising through in-place bedrock over long-term timescales (Gilbert, 1877; Howard et al., 1994; Whipple et al., 2013). Implications of these criteria are 1) thin, patchy, or temporary alluvium exists in the channel which is mobilized during high flow events (Montgomery et al., 1996), or persists despite active incision (Howard et al., 1994), and 2) bedrock is everywhere near the surface, even in cases of persistent apparent alluvial cover (Howard et al., 1994; Whipple et al., 2013). Given these parameters, it follows that bedrock rivers are dominant in regions of net erosion and include most steep, coarse bedded mountain rivers (Wohl & Merritt, 2008).

Landscape evolution models increasingly include the assumption that scaling relationships (Figure 2a and b) developed in alluvial channels can be applied to bedrock channels (e.g. Montgomery & Gran, 2001). Though recent work suggests that the relationships between hydraulic variables in bedrock channels are similar to those found in alluvial settings (Finnegan et al., 2005; Whipple et al., 2013), the applicability of these classic scaling relationships has not yet been thoroughly tested. Field studies of power-law relationships in bedrock channels have yielded width-area relationships with exponents ranging from 0.21 to 0.56 (Figures 2), and depth-area relations with exponents of ~0.3 (Montgomery & Gran, 2001; Snyder et al., 2003; Finnegan et al., 2005; Golden & Springer, 2006; Whittaker et al., 2007; Wohl & Merritt, 2008; Wohl & David, 2008). Slope-area relations typically have exponents between 0.3 – 1.2 (Sklar & Dietrich, 1998; Snyder et al., 2000).

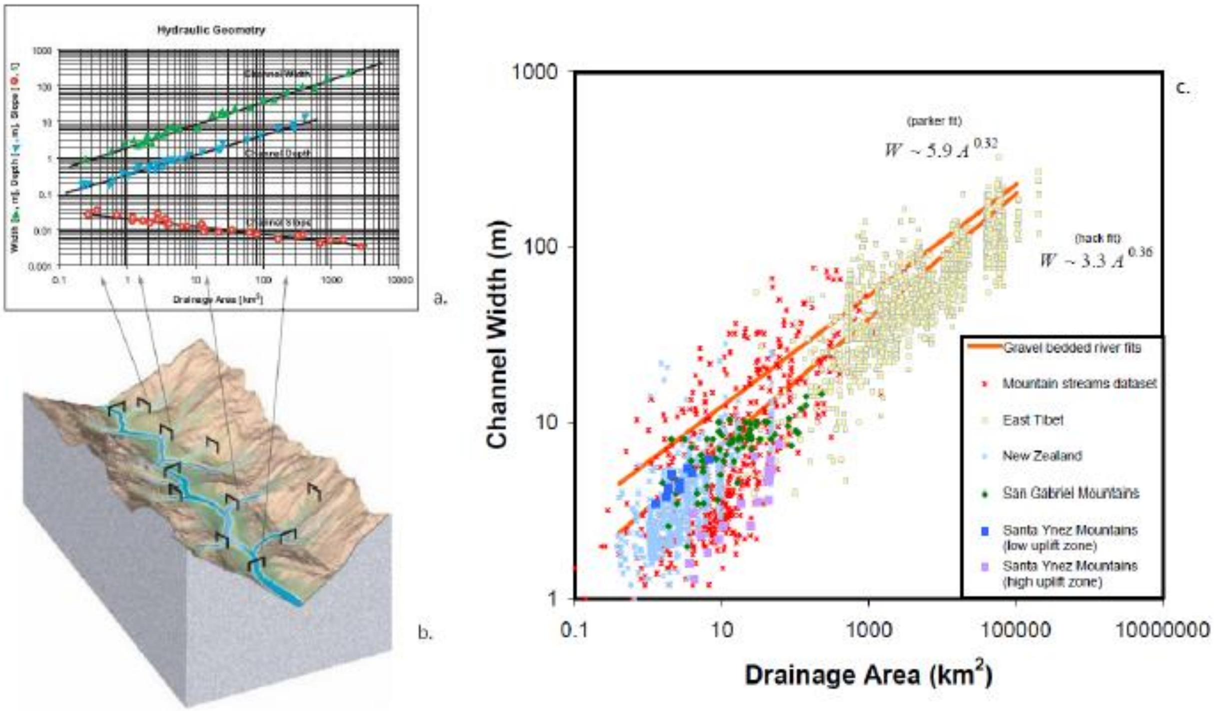


Figure 2. On log-log plots (a.), common geometric descriptors of channel form (from top to bottom: width, depth, and slope) show consistent trends with increasing drainage area. In a well-adjusted, equilibrium watershed (b.), measurements can be collected at any combination of points along the mainstem or in tributary streams (Figures a. and b. modified from Grotzinger et al., 2006). Under these conditions, all channels should exhibit the same scaling relationships. Recently compiled data from steep mountain channels around the world (c.) are considerably more variable though they are typically relatively consistent within a given locality. Reproduced from Whipple et al., 2013.

As discussed above, discharge in alluvial channels is related to drainage area by a power-law equation with an exponent approaching unity. However, in landscapes where precipitation (solid and liquid) and evapotranspiration are both spatially and temporally variable, such as mountainous terrains, average annual runoff may not have a linear relationship with drainage area, meaning the exponent associated with the discharge-drainage area relationship will likely be somewhat less than one (Galster, 2007; Dunne & Leopold, 1978). Thus, it is likely bedrock channels will possess discharge-area equations with exponents less than those present in low-land alluvial channels.

Within bedrock channels, median grain size (D_{50}) and lithology are two resisting variables that have garnered particular attention. Hack (1957) suggested slope increases in proportion to a function of grain size for a given drainage area. Previous work in alluvial settings has shown a general tendency for downstream-fining of D_{50} (Sternberg, 1875), attributed to numerous mechanisms (e.g. Gasparini et al., 2004). However, downstream trends in decreasing grain size can be disrupted by continuous mixing with adjacent hillslope sediment sources (Church, 2002) and glacier termini (Heller et al., 2001). Workers have shown a proclivity in mountainous headwater channels for episodic disturbance by debris flows to dominate sediment transport and routing (Benda, 1990).

The strength of both bedrock substrate and the clasts in transport can have a significant impact on incision rates (Sklar & Dietrich, 2004) and channel slope. Less resistant units are more easily eroded and produce wider channels with lower slopes, while more resistant units have a stronger resistance to erosion and result in steeper, narrower channel slopes (Wohl, 2000; Whipple, 2004, Lifton et al., 2009). For these reasons and those discussed above, we anticipate that spatial and temporal variability in the conditions that determine channel form can, in bedrock rivers, result in local deviations from expected power law relations (Figure 3)

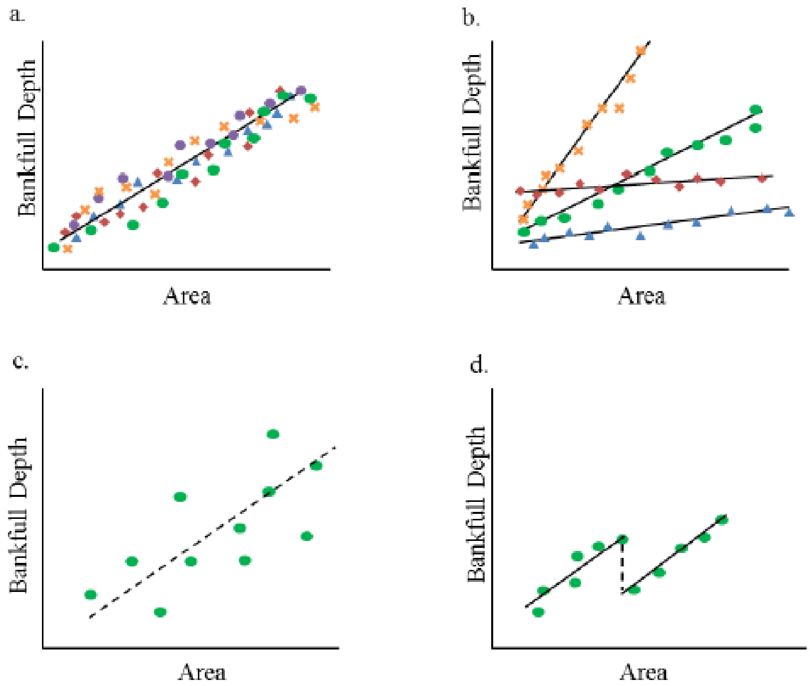


Figure 3. Theoretical log-log plots of bankfull depth vs. drainage area illustrating potential scaling relationships that might be found in bedrock channels: (a.) scaling relationships are well-defined and consistent across various tributaries as denoted by different symbols; (b.) individual tributaries have well-defined scaling but are inconsistent within the watershed; (c.) a tributary with extremely variable data, resulting in poor internal scaling; (d.) a tributary with a break in scaling, indicating a shift in dominant fluvial processes or environmental conditions.

1.2.3 Long Profile Development

Over long time scales, given consistent forcing, rivers develop steady state longitudinal profiles. Steady state refers to a long-term condition in which the river has fully adjusted to lithologic, tectonic, and climatic influences (Carson and Kirkby, 1972; Willgoose et al, 1991; Whipple et al., 2013). Hack (1957) first described the relationship between channel gradient and drainage area (eq. 8), a modified version of which has become known as Flint's law (Flint,1974):

$$S=k_sA^{\theta} \qquad [9]$$

where k_s is the channel steepness index and θ is the concavity index. It is important to note this slope-area scaling relation only holds downstream of a critical drainage area where fluvial processes dominate over hillslope processes (Sklar & Dietrich, 1998). It is also important to recognize that discrete channel reaches with distinct steepness and concavity indices may be present within a single longitudinal profile, separated by knickpoints or other discontinuities (Whipple, 2004).

The concavity index, θ, of bedrock channels varies widely, ranging from 0.3 – 1.2 (Sklar & Dietrich, 1998; Snyder et al., 2000). The concavity index is dominantly controlled by relative rates of river discharge and width increasing in the downstream direction (Tucker, 2004), but can be modified by downstream changes in frequency and amount of in-channel bedrock exposure (Sklar & Dietrich, 2004), rock uplift rate (Kirby & Whipple, 2001), runoff intensity (Craddock et al., 2007), and substrate characteristics (Moglen & Bras, 1995). Low concavities (<0.4) are linked to either short, steep drainages strongly effected by debris flows (Brocklehurst & Whipple, 2002) or to increases in incision rate or rock strength in the downstream direction (Kirby & Whipple, 2001). Moderate concavities (0.4-0.7) are linked to bedrock channels with homogeneous lithologies in areas of active and uniform rock uplift rates (Whipple, 2004). High concavities (0.7-1.0) are linked to transitions to dominantly alluvial channels, disequilibrium conditions caused by slowing rock uplift rates (Whipple, 2004), and decreases in rock strength in the downstream direction (Kirby & Whipple, 2001).

While the concavity index can be considered independent of climate, lithology, and tectonics (Wobus et al., 2006), the channel steepness index, k_s, is known to be a function of all of those parameters, and rock uplift in particular (Snyder et al., 2000; Kirby & Whipple, 2001). As such, channel steepness is an extremely useful measure of the influences these factors on landforms (Wobus et al., 2006; Whipple et al., 2013).

1.3 Approach

In order to evaluate fluvial scaling relationships in bedrock rivers, field measurements of channel width, depth, slope, and grain size were collected on four tributaries of Big Creek, located in central Idaho. Three to twelve measurement stations were established per stream to test the two hypotheses stated earlier. Field data were compiled and analyzed to determine if scaling relationships could be detected within individual tributaries and evaluate the consistency of any scaling relationships across tributaries (e.g. Figure 3). A DEM of the basin was used to extract and analyze channel slope and drainage areas in these and additional tributaries.

Chapter 2. Study Area

2.1 Regional Setting

2.1.1 Topography and Tectonics

Big Creek spans across Valley and Idaho Counties in central Idaho (Figure 4). The drainage basin lies within the Payette National Forest and the Frank Church-River of No Return Wilderness, the largest wilderness area in the contiguous United States. Steep, high-relief mountains cover a wide area of this region of Idaho, contrasting with the linear basins and ranges found in the southern and eastern parts of the state. The Big Creek basin is located within the Salmon River Mountains, whose boundaries are usually defined by the Salmon River and its larger tributaries. Big Creek flows east out of the Salmon River Mountains into the Middle Fork Salmon River, which in turn flows into Salmon River, the Snake River, and ultimately joins the Columbia River.

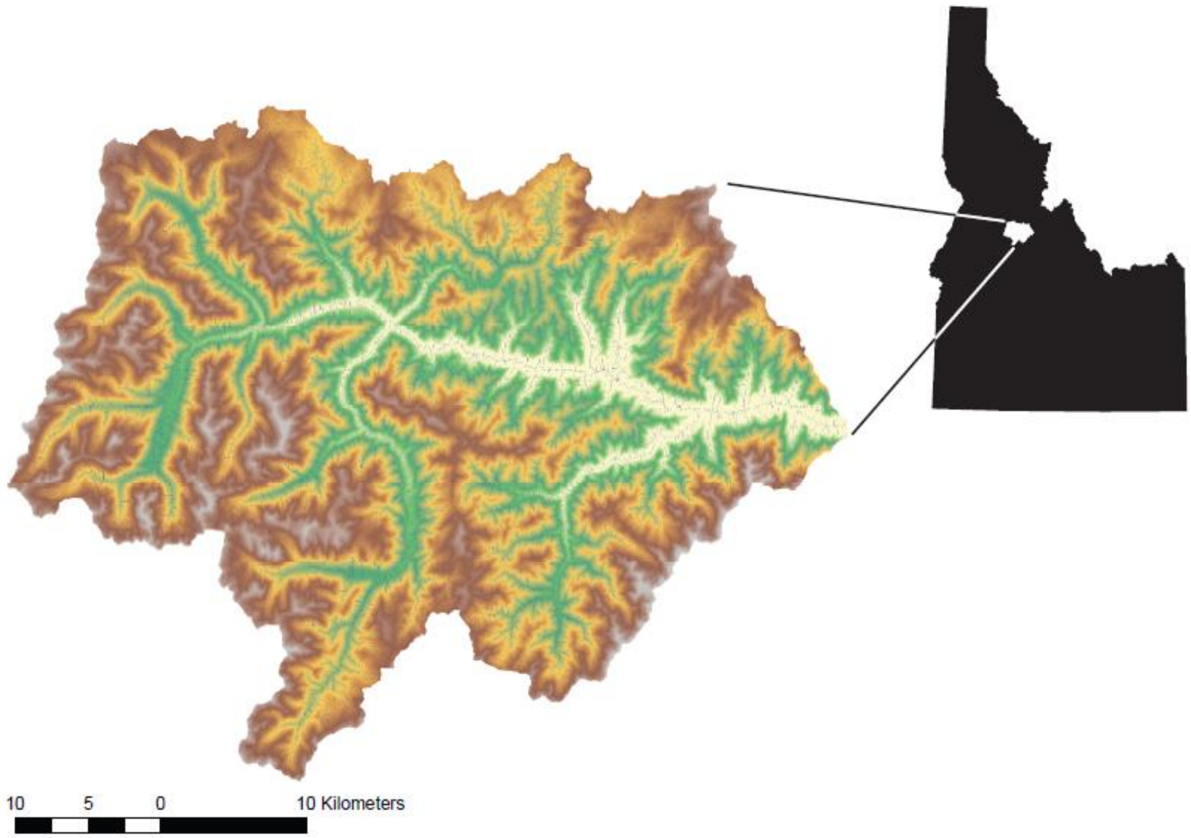


Figure 4. DEM of the Big Creek watershed, showing location in Idaho. Mainstem of Big Creek flows roughly east-west. Color ramp ranges between 1030 m and 2908 m above sea level.

This area experienced very minimal anthropogenic impact and is largely preserved in its natural state due to its remote location. Small mining camps operated within the basin in the late nineteenth and early twentieth centuries, including the Snowshoe Mine on Crooked Creek (Idaho State Historical Society, 1980). Two gold mines, the Dewey Mine and the Sunnyside Mine, located near the headwaters of Monumental Creek in the southern part of the basin, were actively mined from 1866 until the 1990s (Barker, 2013). The limited nature of human impacts within the Big Creek watershed enables us to study how stream geometry is determined by natural influences alone.

The uplift and incision history of central Idaho is poorly constrained. Fisher & Johnson (1995) state that uplift and exhumation occurred prior to Eocene volcanism. Dimitru et al. (2013) support this interpretation, stating that regional uplift occurred during emplacement of the Idaho batholith (98 – 53 Ma). Apatite zircon fission track thermochronology indicates the batholith was shallowly buried from 50 – 10 Ma (≤ 4 km) (Sweetkind & Blackwell, 1989), necessitating rapid uplift during 60 – 50 Ma, followed by slow uplift 50 – 10 Ma (as summarized in Lifton, 2005). Fossil leaf assemblages sampled in the Salmon River area suggest an elevation of 4 km in middle Eocene time, though uncertainty regarding the age of flora sampled makes this questionable, and lower elevation ranges are also suggested (Wolfe et al., 1998). Topography in the Salmon River Mountains is dominantly composed of high, subdued plateaus, studded with low relief glaciated horns. This planar surface is thought to represent slow erosion that occurred from 50 – 10 Ma (Sweetkind & Blackwell, 1989).

Regional incision into the Rocky Mountain orogenic plateau, which includes the Big Creek basin, began after 8 Ma and was well underway by 3 – 4 Ma (McMillan et al., 2006). This agrees with Sweetkind & Blackwell's (1989) interpretation of a second, rapid erosional phase occurring since 10 Ma, indicated by steep, deeply incised river canyons throughout the region. Cosmogenic ^{10}Be denudation measurements from the Salmon River are consistent with apatite fission track and weathering rind data, suggesting a denudation rate of ~1 mm/yr (Kirchner et al., 2001; Sweetkind & Blackwell, 1989). Erosion exhumed the Idaho Batholith and caused further isostatically-driven uplift of central Idaho (Jordan, 1994; Meyer & Leidecker, 1999).

Capture of the upper Snake River by the lower Snake River occurred 2 – 4 Ma (Malde, 1994; Othberg, 1994; Repenning et al., 1994; Wood, 1994; Wood & Clemens, 2004), significantly increasing the drainage area and incision rate of the lower Snake River and causing a drop in the base level of the Salmon River (Meyer & Leidecker, 1999). This drop in base level at the outlet of the Salmon River is believed to have initiated rapid incision that propagated up the drainage, generating the high relief topography we see today.

2.2 Big Creek Drainage Basin

2.2.1 Basin Characteristics

The Big Creek basin (1540 km^2) mainstem is approximately 67.2 km long, stretching from southwest of Edwardsburg, Idaho east to the Middle Fork Salmon River. Elevations range between 1030 and 2908 m. Basin relief is 1876 m. Mean elevation is 2101 m. Average hillslope gradient is 35 degrees, inhibiting soil development in the basin and causing hillslope erosion to occur principally by rock fall, landslides, and debris flows. Average gradient for mainstem Big Creek is 1.1% (Figure 5). Leopold & Skibitzke (1967) found an exponent of 0.74 for the bankfull discharge – drainage area relationship (eq. 1) of the Middle Fork Salmon River and its tributaries.

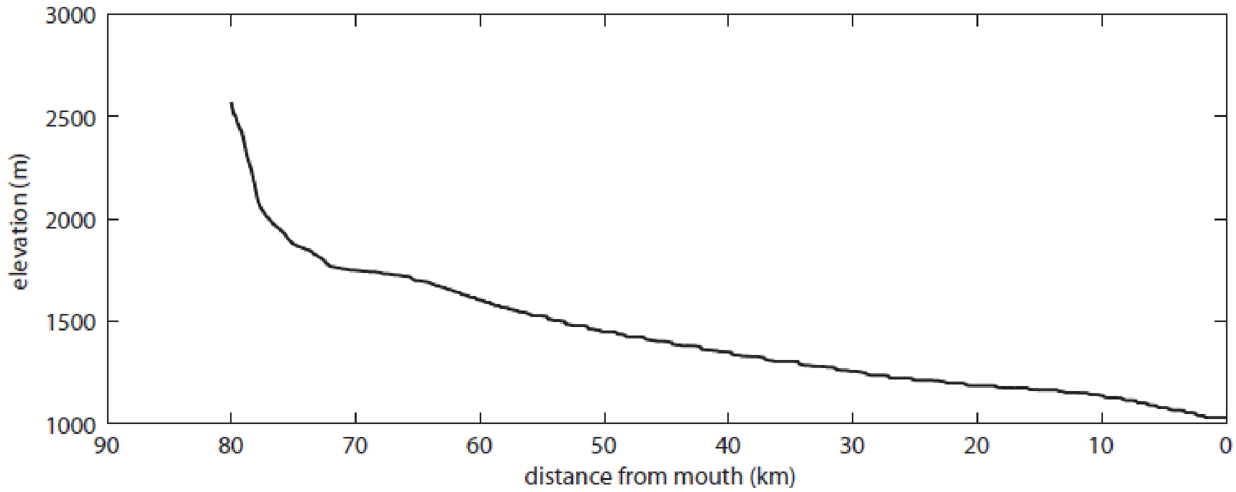


Figure 5. Longitudinal profile of Big Creek showing two pronounced knickpoints, one at approximately 10 km upstream, and another at approximately 65 km upstream.

2.2.2 Geologic and Natural History of Big Creek

2.2.2.1 Lithologies

The rocks of the Big Creek basin can be divided into five groups: 1) Meso- and Neoproterozoic metasedimentary and metavolcanic units found mainly in the northwestern basin and along the lower mainstem (Yy & Zsm); 2) Neoproterozoic intrusions found in patches along the mainstem of Big Creek (Zdi); 3) Cretaceous granite and granodiorite intrusions exclusive to the western-most portion of the basin; 4) Eocene intrusions concentrated in the northeastern basin with dikes located throughout the drainage (Tdp, Tg, Tgd) ; and 5) Eocene Challis volcanics centered in the southern half of the basin (Tdq, Tat) (Stewart et al., 2013) (Figure 6). Units in parentheses only represent the lithologies found in studied tributaries and are not a complete list.

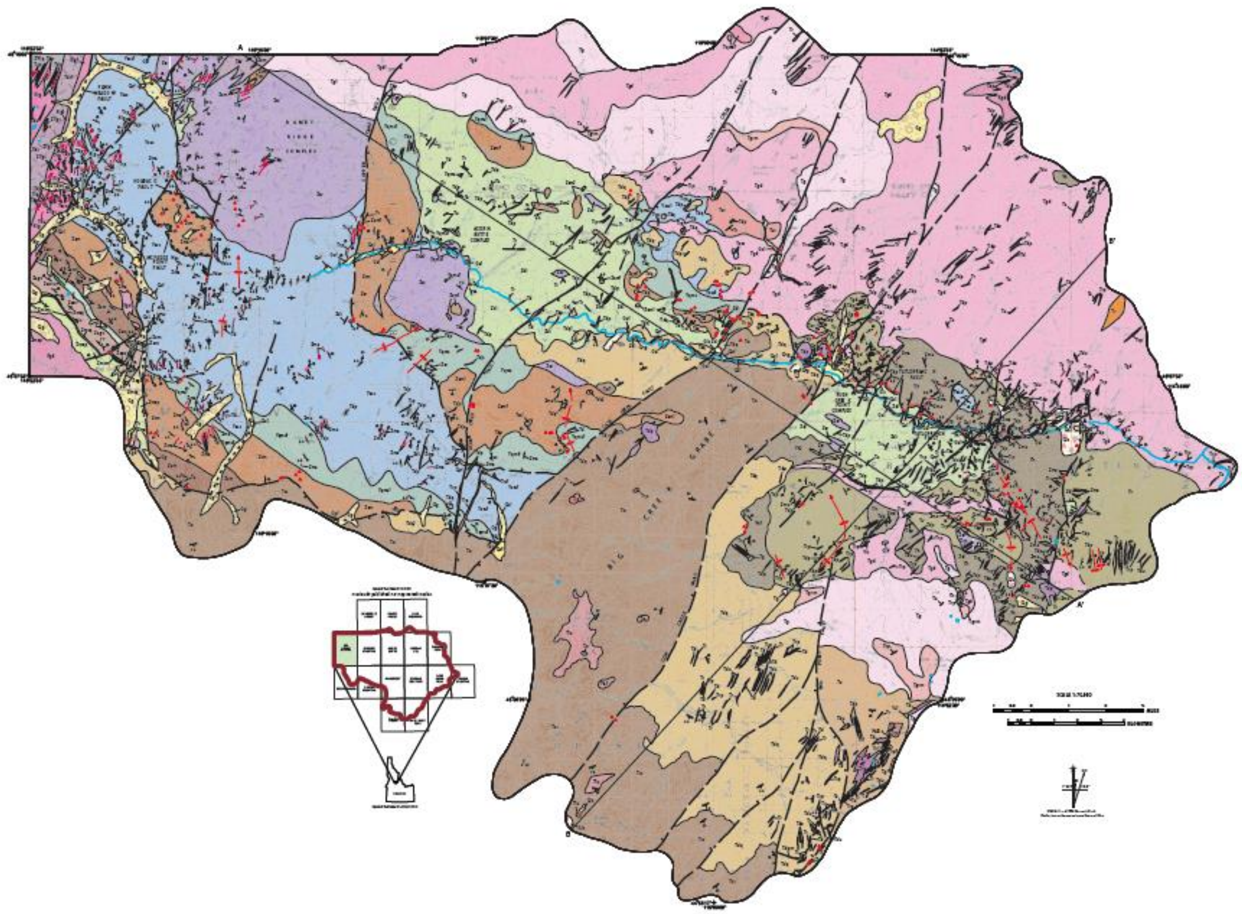


Figure 6. Geologic map of most of the Big Creek basin. Blues, olive green, tans, and yellow greens are Meso- and Neoproterozoic metasedimentary and metavolcanic rocks, purple and light green are Neoproterozoic intrusives, bright pinks in the western-most part of the basin are Cretaceous intrusives, lighter pinks in the northeastern area are Eocene intrusives, and browns around the southern basin margin are Eocene Challis volcanics. Reproduced from Stewart et al., 2013.

2.2.2.2 Faulting

The Big Creek drainage is cut by nine major faults, as mapped by Stewart et al. 2013, ranging in age from Neoproterozoic to post-Eocene. These faults affect the topographic character of the basin as they affect both rock erodability and surface deformation.

The Taylor Ranch fault is a mylonitic shear zone located in the eastern portion of the Big Creek drainage. It can be traced from Pioneer Creek northwest along Big Creek until it is truncated by the Cow Creek fault in the northwest. Gently east-dipping mylonitic lineation suggests strike-slip displacement. Neoproterozoic plutons aligned in a north-west direction paralleling the fault suggest it may also be Neoproterozoic in age.

The Hogback fault is a north-south trending, initially right-lateral and subsequently normal (east-dipping) fault found in the western portion of the Big Creek drainage. Strike-slip movement is thought to have occurred in the Precambrian, displacing the Neoproterozoic section by 4,000 m. Post-Cretaceous reactivation as a normal fault is indicated by Cretaceous granodiorite intrusions in contact with Mesoproterozoic section showing no signs of contact metamorphism.

The McFadden Point fault is a low angle normal fault located in the northwest part of the drainage, near McFadden Point. It appears to be cut by the Hogback fault, suggesting it pre-dates post-Cretaceous movement along that fault.

The Acorn Creek, Cave Creek, Cow Creek, and Two Point faults are northeast-trending normal faults associated with the eruption of the Eocene Challis volcanics and subsequent collapse of the Thunder Mountain cauldron complex, creating three fault-bound blocks. The Acorn Creek and Cave Creek faults are parallel, east-dipping faults cutting across the entire eastern portion of the basin. Block one is bound by the Acorn Creek fault on the west and the Cave Creek fault to the east. Collapse primarily occurred in the southern part of the block, near Marble and Center Mountains. The Cow Creek fault dips to the west, and is located east of Cave Creek fault. Together with the Cave Creek fault, it creates the Big Creek graben (block two). The graben terminates at an undulating south-dipping normal fault just north of Big Creek. Volcanic outcrop patterns on this block suggest tilting only occurred north of Big Creek. Two Point fault forms the eastern edge of block three. In the south it is joined by three subsidiary faults which share its sense of displacement. Tuff outcrop patterns suggest the block tilted to the south.

In the western portion of the basin, the Fawn Meadow fault strikes roughly north-south and may have experienced two episodes of movement. Extensive alteration and mineralization are common along the fault, much of which is thought to have occurred prior to Eocene dike emplacement. Mylonite with gently north-plunging lineations indicates early strike-slip displacement, likely left-lateral. Brecciated Eocene dikes indicate post-Eocene, down-to-the-east normal faulting.

The Copper Camp fault is an east-dipping, roughly north-south striking normal fault located in the western basin. It drops Neoproterozoic quartzite into contact with Neoproterozoic syenite. Post-Eocene movement is demonstrated by displacement of Eocene granodiorite and granite.

2.2.2.3 Glaciation

The higher elevation peaks within the Big Creek drainage show signs of glacial erosion. West of Beaver Creek, approximately three-quarters up the drainage from the confluence with the Middle Fork Salmon, glacial landforms are common in the mountains bounding Big Creek and its tributaries. No work has been done to date or map these landforms, but inferences can be drawn using other glaciated Idaho terrains. A study near McCall, Idaho (~100 km west of Big Creek) dated moraines to the Pinedale (~14-20 ka), Bull Lake (~140-150 ka) and intermediate ages (Colman & Pierce, 1984). Glacial deposits in the Sawtooth Mountains (~130 km south of Big Creek) are thought to be of both Pinedale and Bull Lake ages (Borgert et al., 1999), with some deposits post-dating the Last Glacial Maximum (~16-17 ka) (Thackray et al., 2004). It seems likely that the glacial features in Big Creek derive from either or both glacial periods represented by these other glacially-eroded Idaho mountains. Past glaciation affects contemporary channel forms in Big Creek (valley slope, valley width, grainsize, etc) both due to local effects of glacial sculpting as well as downstream alterations in sediment and water fluxes.

2.2.2.4 Rock Hardness and Valley Morphometry

The degree of influence that bedrock strength exerts on valley morphometry is not well understood. Lifton (2005) investigated the relationships between rock strength, valley floor width, hillslope gradient, stream gradient, and aspect along the mainstem of Big Creek. His findings suggested that while valley floor width is strongly correlated with rock strength of weaker southern-facing valley walls, there is only a moderate correlation between rock strength and hillslope gradient, and no correlation between bedrock strength and stream gradient (Lifton, 2005; Lifton et al, 2009). This suggests one or more other variables affect channel slope within Big Creek streams.

2.2.2.5 Big Creek Lake

The Soldier Bar landslide deposit is located near the confluence of Goat Creek with Big Creek in the lower basin. The slide dammed both Big and Goat Creeks, and subsequent impoundment of water created Big Creek Lake (Eversole, 2008; Link et al., 2014). Minimum age for the landslide is indicated by lacustrine deposits at Cave Creek dated with optically stimulated luminescence (OSL) to 17.5 ± 1.5 ka, suggesting that lake elevation was already higher than 1268 meters by that time (Eversole, 2008). Overflow at the deposit carved four downstream-sloping spillway terraces. The impoundment also drove deltaic deposition in the upper basin that can be traced up to the Monumental Bar area (Eversole, 2008) (Figure 7). Another OSL age from a terrace at Taylor Ranch indicates the lake had dropped to at least as low as 1257 meters by 11.3 ± 0.8 ka (Eversole, 2008). Currently, Big Creek has incised back to its approximate elevation prior to the Soldier Bar landslide, evidenced by incision of Big Creek through landslide related deposits back down to bedrock, and incision from the Middle Fork Salmon River has begun propagating upstream of the landslide deposit (Link et al., 2014).

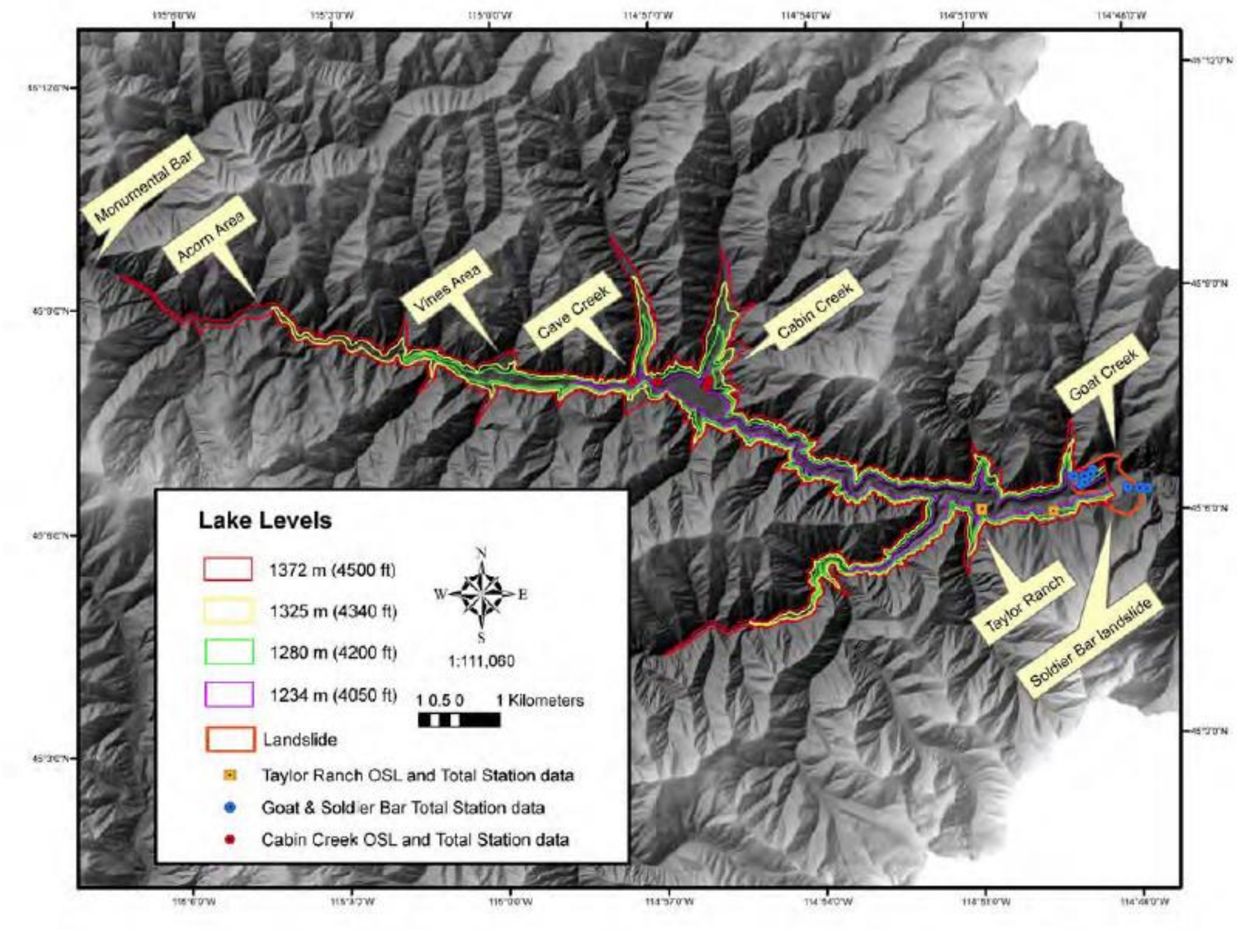


Figure 7. DEM with the four lake levels of Big Creek Lake shown (red, yellow, green, and purple lines with respective elevations shown in inset). The Soldier Bar landslide is outlined in orange at the far right of the figure. OSL sampling sites and total station scan locations indicated by orange, blue, and red dots. From Eversole, 2008.

2.2.2.6 Fire History

The Big Creek basin has experienced numerous wildfires in ancient times as well as in recent decades. The largest fire in recent history was the Diamond Point Complex in 2000, which burned over 600 km^2, including some of the original structures at Taylor Wilderness Research Station (TWRS) and the surrounding area. Since 1970, more than 980 km^2 (~64%) of the basin has burned (Figure 8). The prevalence of fires has greatly contributed to the amount of wood in stream channels (Malison & Baxter, 2010) throughout the basin and has likely had both local and reach-scale effects on channel morphologies.

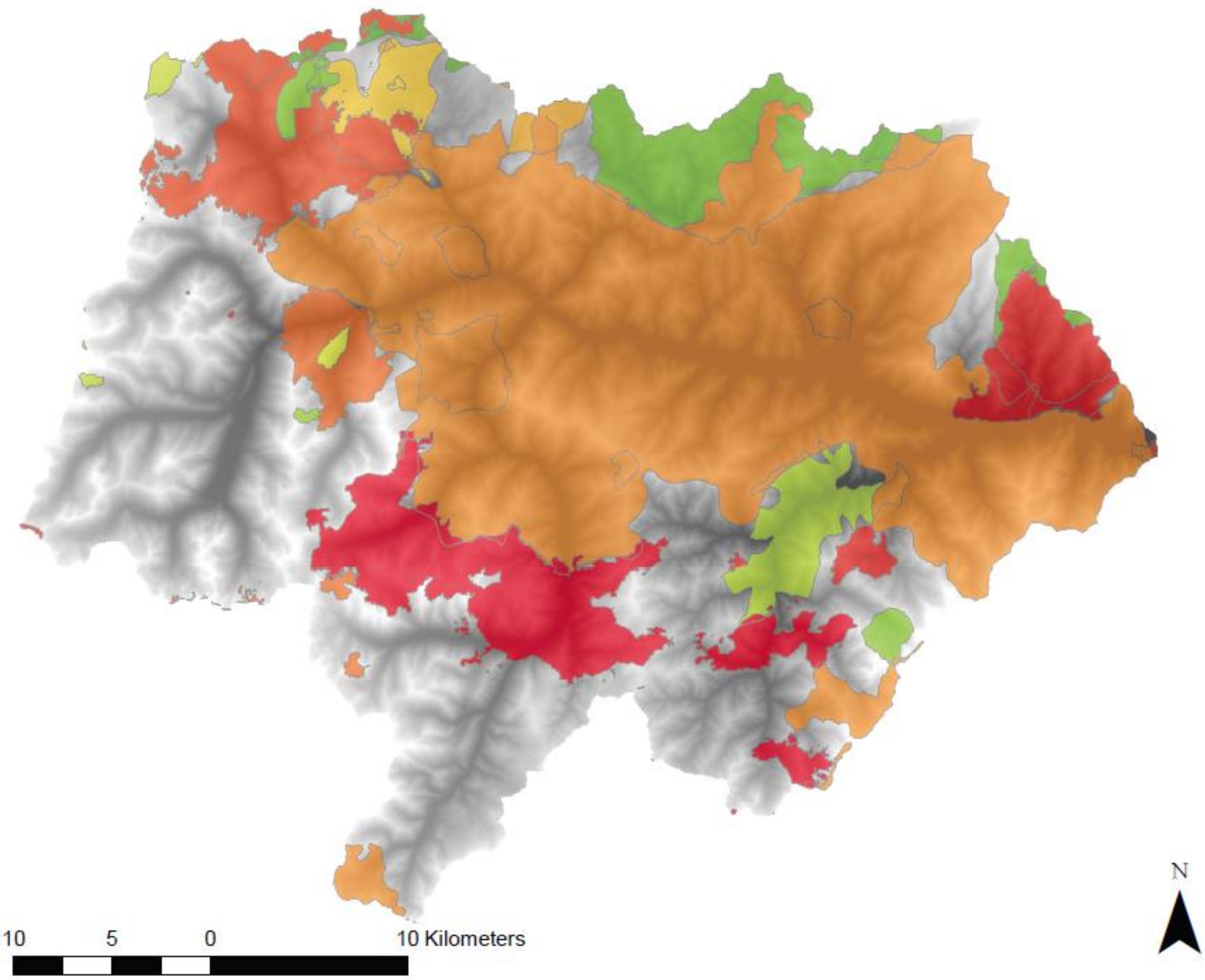


Figure 8. DEM of basin with fire extents shown. Greens are older fires (beginning with 1970), reds are from 2006 and 2007. Large orange area covering most of basin is the extent of the Diamond Point Complex which burned in 2000. Burn area data from the United States Forest Service.

2.2.2.7 Stream Ecology and Fire Recovery

Since 1993, annual sampling and habitat measurements by Idaho State University (ISU) Department of Biological Sciences Stream Ecology Center faculty and students have been taking place on six tributaries of Big Creek: Cave, Cliff, Cougar, Goat, Pioneer, and Rush. All sampled tributaries are located in the lower part of the Big Creek basin. Each August, periphyton and macroinvertebrates are sampled, and stream width and depth, streambed substrate, solar radiation, aspect, temperature, and riparian vegetation are measured at five transects spread over 200 meters. These data have facilitated numerous studies on the aquatic ecosystem's response to wildfire and climate changes (Davis et al., 2013; Malison & Baxter, 2010 Rugenski & Minshall, 2014; Schenk, personal comm.). The long-term data set was initiated by Dr. Minshall and thus we use his name to describe this group of locations (The Minshall Sites).

2.3 Tributary and Reach Descriptions

Channel measurements were made in four major tributaries of Big Creek. Between three and twelve discontinuous reaches were established on each stream (Figure 9). Reaches were identified using the first three letters of the tributary name and a three digit number. Numbers increase with proximity to the Big Creek confluence. Reach lengths range between 133.5 and 562 meters. Below are descriptions of the measured tributaries and reaches located on each stream. Descriptions include bedrock lithology, percent of bedrock in channel and banks, channel morphology (following the nomenclature of Montgomery & Buffington, 1997), presence of floodplains and/or landslide deposits, and an approximate number of large woody debris in the channel (Table 1). Note that three of the four streams are on the north side of Big Creek where the mainstem trail provides safe access. Though we had intended to sample more streams at a higher density, the summer field season or 2013 was significantly shortened by a mandatory evacuation due to wildfires.

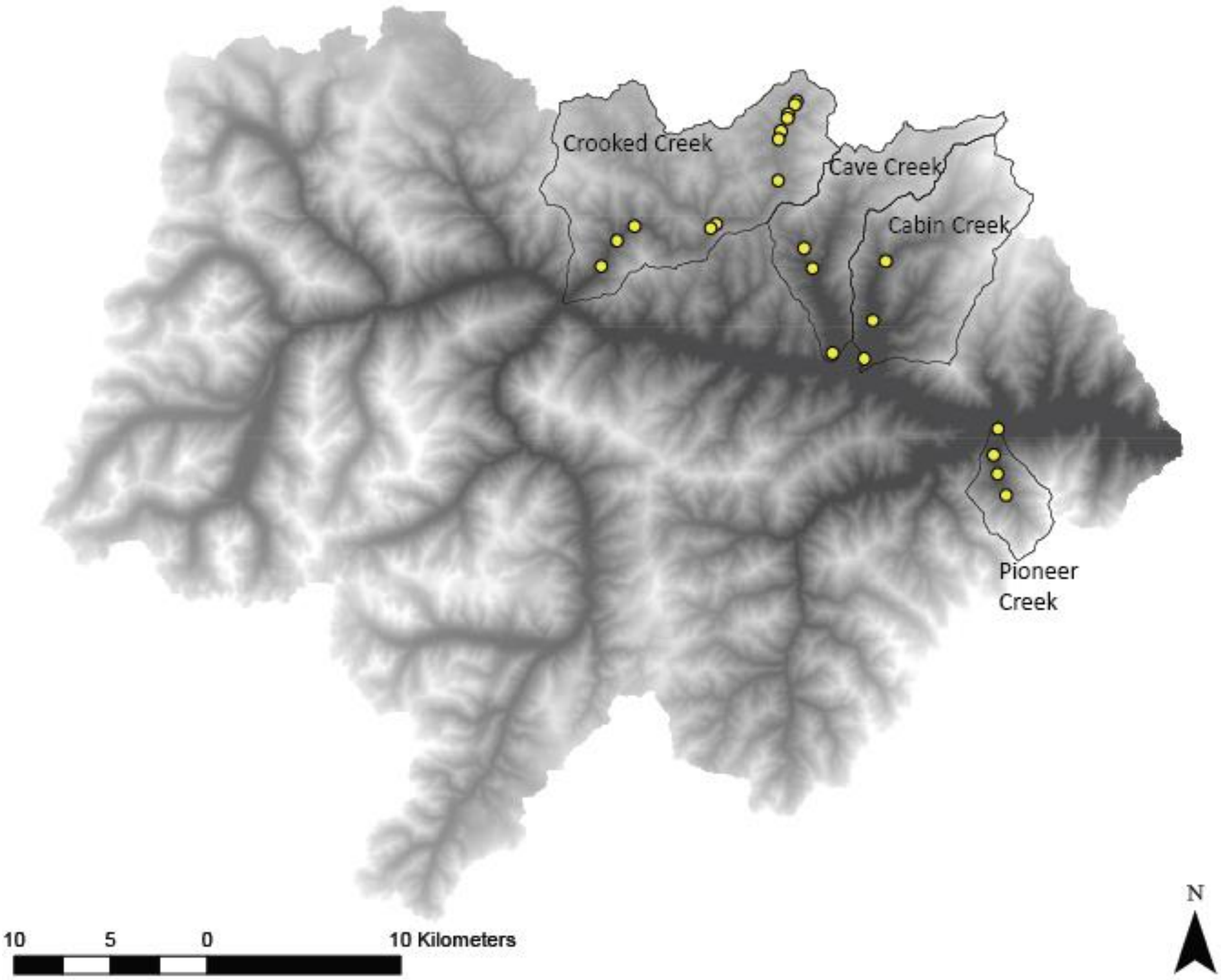


Figure 9. DEM of basin showing locations of field measurement stations (yellow dots). Tributaries are labeled and their watershed boundaries are outlined in black.

Stream	Site ID	Reach Length (m)	Channel Morphology	Large Woody Debris	Lithology	Percent Bedrock in Channel	Percent Bedrock in Banks	Flood-plain or landslide deposits
Cabin	Cab004	396	riffle & run	18+	Tgd	0	0	-
	Cab005	508	riffle + run & pools	33+	Yy & Tat (Q)	0	0	alluvium
	Cab006	562	riffle & pool	13	Yy & Tdq(Q)	0	0	terrace gravel & alluvium
West Cave	WCave004	140	riffle & run	0	Tat	0	0	-
	WCav005	291	run & pools	3	Tgd (Q)	0	0	alluvium
	WCav006	451	riffle & pools	11	Yy & Tdp (Q)	0	0	alluvium
Crooked	Cro001	150	riffle & run	24	Tg	0	0	-
	Cro003	165	riffle & run	32+	Tg	0	0	-
	Cro004	175	riffle & run	39+	Tg	0	0	-
	Cro006	241	riffle & run	37+	Tg	0	0	-
	Cro008	157	riffle & run	35+	Tg	0	0	-
	Cro009	270	run & pool	49+	Tg	0	0	-
	Cro010	403	riffle & run	100+	Tgd	0	0	small debris flow?
	Cro011	400	riffle & run	100+	Tgd	0	0	-
	Cro012	394	riffle & run	100+	Tgd	0	2	-
	Cro013	405	riffle & run	60+	Zdi	-	2	talus slopes
	Cro014	313	run & pool	5+	Zdi & Zsm	0	0	talus slopes
	Cro015	530	riffle & run	18+	Zdi	0	<1	talus slopes
Pioneer	Pio009	133.5	step pool	6	Yy	0	0	-
	Pio011	192	step pool	10	Yy & Tgd	0	0	-
	Pio012	205	step pool	14	Zdi	0	0	-
	Pio013	220.5	step pool	12	Zdi	0	0	-

Table 1. Table of quantitative and qualitative descriptors for field reaches. Reaches in an individual stream are ordered from downstream to upstream. Large woody debris were counted if greater 30 cm in length and 10 cm in diameter. Geologic formation codes are provided in section 2.2.2.1.

2.3.1 Cabin Creek

Cabin Creek is located in the lower Big Creek drainage. ~15.3 km long, it flows south through Eocene granodiorite and andesitic tuff, Mesoproterozoic metasediments and quartzite, and Quaternary terraces and alluvium. It has a drainage area of ~64.4 km^2. A landing strip is located on the Quaternary deposits ~1.5 km from the Big Creek confluence. Cow Creek, a large tributary of Cabin, joins with Cabin ~0.5 km upstream from the landing strip. Cabin parallels the west-dipping Cow Creek fault in its upper reaches and near the Big Creek confluence, but is dominantly in the hanging wall of the fault. Three measurement stations were established on Cabin Creek (Figures 10 &11).

Figure 10. Looking upstream at site Cab006.

Figure 11. Overview photo of site Cab006. Arrow in photo points north.

2.3.2 West Cave Creek

Cave Creek is also in the lower portion of Big Creek drainage. It is ~20 km long, flowing south, and drains ~46.9 km^2. The West Fork Cave Creek splits from the mainstem ~4.6 km upstream of the Big Creek confluence. It continues 10 km to its own headwaters (14.6 km from these headwaters to Big Creek confluence). We focused on the West Fork rather than the mainstem of Cave due to time constraints and better trail access. It flows through Eocene granodiorite, granite, and andesitic tuff, and Mesoproterozoic metasediments. The mainstem of Cave Creek flows parallel to the east-dipping Cave Creek fault in its middle section. The headwaters and lower reaches are located in the hanging wall of the fault. West Fork Cave Creek crosses the Cave Creek fault just above the confluence with the mainstem. Three measurement stations were established on this stream (Figures 12 & 13).

Figure 12. Photo looking upstream at site WCav006.

Figure 13. Overview photo of site WCav006.

2.3.3 East Crooked Creek

Crooked Creek is located near the center of the Big Creek basin. It flows generally south, though as its name implies, it winds a tortuous path toward Big Creek. It is approximately 21 km long and drains an area of ~102.6 km^2. Crooked splits ~11 km upstream of the confluence with Big Creek to form two forks, East Crooked and West Crooked. Due to better trail access, East Crooked Creek was selected. It cuts through Eocene granite and granodiorite, Neoproterozoic diorite, syneite, and quartzite, and Mesoproterozoic quartzite. It flows parallel to the east-dipping Acorn creek fault in the headwaters, crosses into the hanging wall, and parallels the fault again before returning to the footwall. Twelve measurement stations were established on Crooked Creek (Figures, 14, 15, 16, & 17).

Figure 14. Photo looking downstream at site Cro010.

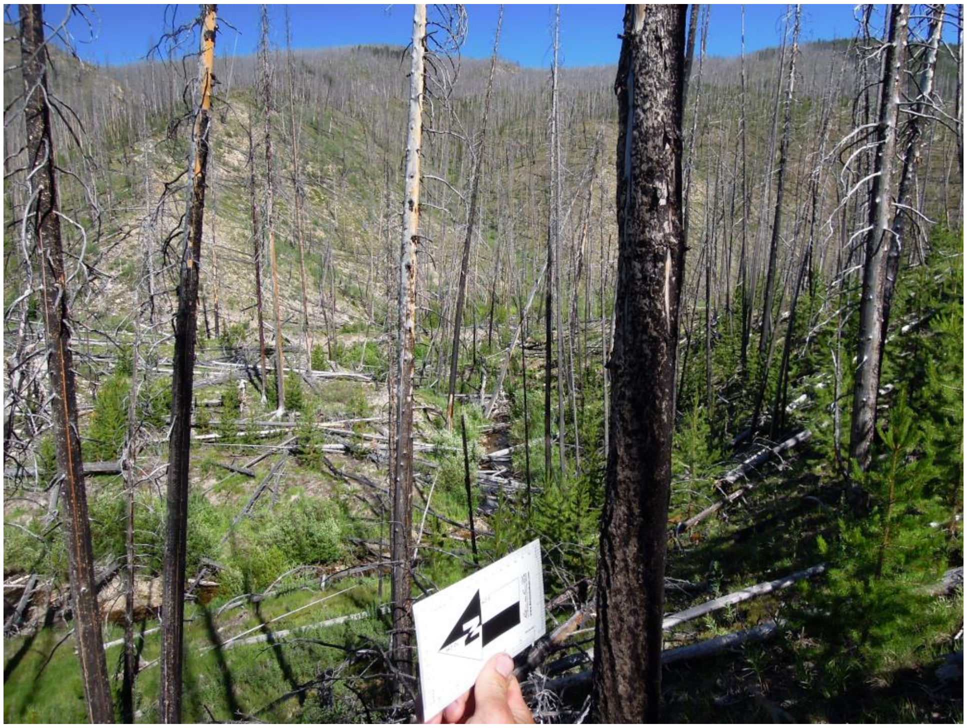


Figure 15. Overview photo of site Cro010.

Figure 16. Photo looking upstream at site Cro013.

Figure 17. Overview photo of site Cro013.

2.3.4 Pioneer Creek

Pioneer was the eastern-most tributary measured. It is north-flowing, ~7.3 km long and drains 15.9 km^2. It has incised into Mesoproterozoic metasediments and quartzites, Eocene granodiorite, and Neoproterozoic diorite. It has deposited an alluvial fan at the Big Creek confluence, on which TWRS is located. Pioneer parallels an east-dipping normal fault for much of its length. Four measurement stations were established on this stream (Figures 18 & 19).

Figure 18. Photo looking upstream at site Pio012.

Figure 19. Overview photo of site Pio009.

Chapter 3. Methods

3.1 Introduction

Three types of field data were collected in this study. First, we measured channel characteristics (width, depth, slope, and grain size). Second, we made qualitative descriptions of field sites, including lithology and channel morphology. Third, we conducted an approximate count of large woody debris (LWDs). Additional data were supplied by other researchers or extracted from a digital elevation model (DEM) of the basin, allowing for further slope analyses and comparisons of channel profiles.

3.2 Field Surveys

Field measurements of channel width, depth, slope, and grain size were taken on four tributaries of Big Creek during July and August of 2013 using TWRS as a base (Appendix A). Site locations for each stream were chosen based on logarithmic increases in upstream drainage area as determined using GIS software (ArcGIS, v10.1) and a USGS digital elevation model (USGS, 2010) of the Big Creek basin. As such, sites were more closely spaced in the headwaters of streams, where increases in drainage area occur more rapidly, and spaced farther apart when approaching Big Creek. To avoid capturing non-bedrock channel characteristics, sites were selected upstream of the alluvial fans often found at confluences.

Sites were located using a GPS device, and their suitability assessed on site. Sites with obvious, local disruptions to the channel (beaver dams, split channels, recent landslides) were re-located or discarded. Exact GPS coordinates of final site locations were taken in the field, at both the beginning and end of each reach. Site measurements were conducted in the downstream direction, beginning at the top of each reach and working down. Measurements were taken on multi-day backpacking trips for all streams, and all field data was entered into water-proof field notebooks.

Upon arriving at the beginning of each reach, bankfull stage was assessed using scour lines, perennial vegetation boundaries, changes in bank slope, changes in bank substrate size, and lichen and mineral-stain lines as indicators. Bankfull width was measured using a weather-resistant metric tape, to the 0.01 meter, aligned perpendicular to streamflow at bankfull stage. Bankfull depth was measured from the streambed to bankfull stage within the thalweg to the 0.01 meter using a folding metric ruler stick. Bankfull width was then multiplied by 30 to determine a suitable reach length.

The reach was then measured out using the metric tape, staying as close to the stream as allowed by vegetation and topography. Three to four site stations were placed within each reach at the top, bottom, and at mid-points. Upstream-facing, downstream-facing, and overview photos were taken at the top station of each reach, and additional photos were taken throughout the reach if deemed appropriate. Bankfull width and depth were measured for each station using the method described above.

Two to three measurements of channel slope were taken at each station, using the water surface to approximate the average slope of the channel bed. A handheld inclinometer was used to measure slope, to the 0.5%. The distance over which slope was measured was as long as possible, but varied depending on the visibility allowed by vegetation along channel banks and the sinuosity of the channel. Slope measurements attempted to span over a variety of channel morphologies (e.g. multiple steps and pools or riffles and runs) and the type associated with each measurement was noted.

A pebble count was performed for each reach. A total of 100 grains per reach were measured along their intermediate axis, following the technique developed by Wolman (1954), to the 0.1 centimeter using a folding metric ruler stick. The measurements were distributed over the stations. Gravel bars were preferentially used where available and grains were taken from the active channel when no bars were present. Grains were chosen randomly by zig-zagging back and forth and lowering a pencil while looking away, then measuring the first grain touched by the pencil tip.

Lithology and percent bedrock in the channel and banks were noted throughout each reach. An estimate of the number of large woody debris (LWDs) was made by counting all wood greater than 30 cm in length and 10 cm in diameter and keeping a running tally as progress was made along the reach. If more than 100 LWDs were noted in the channel, 100+ was noted. Dominant channel morphology was qualitatively noted using the methodology developed by Montgomery and Buffington (1997), and field sketches of each reach were made.

3.3 Minshall Sites

As mentioned above, annual site measurements and sampling has taken place on six tributaries of Big Creek and the mainstem since 1993. These August measurements have been conducted by the ISU Department of Biological Sciences Stream Ecology Center and collaborators. The sites were originally established in 1988 by Dr. Wayne Minshall of ISU. In 1993, a measurement protocol was set and annual sampling and measurements have been completed for the last ~20 years. As geomorphic parameters can have a strong influence on a stream ecosystem, a data set of long-term channel variables has been compiled for the seven sampling locales to test hypotheses regarding ecosystem response to fire and climate change. Due to their antiquity, these sites may be located in alluvial fan deposits associated with the Big

Creek confluence, therefore representing alluvial rather than bedrock characteristics. This data and the associated methods were graciously provided by the Stream Ecology Center at ISU.

Single-point measurements were taken on six tributaries of Big Creek and the mainstem during August of 2013 at established site locations (Appendix B). Site reaches are 200 meters in length, broken into five equal transects (1 transect every 50 meters). Exact GPS coordinates of site locations were taken in the field, at both the beginning and end of each reach. Work was conducted in the upstream direction. Wetted edge was measured to the 0.1 meter for each transect using a metric tape stretched across the stream, and an estimate of bankfull was made where possible. Two to three channel slope measurements per reach were taken to the 0.5% using a handheld inclinometer and the water surface to approximate the average slope of the channel bed. One 100 count substrate heterogeneity survey was done per reach, using a random number table to determine distance from right bank. All measurements were taken from particles within the channel. The B-axis was measured to the 1 cm using a gravelometer, and water depth was measured to the 1 cm using a metric ruler. Embeddedness was qualitatively estimated. When encountered, wood was treated as a particle and measured. All data was entered into water-proof field notebooks.

3.4 DEM Analysis

Longitudinal profiles and slope data for 34 streams, including field measured streams, were extracted from a USGS DEM with 10m postings using GIS software, and Stream Profiler, a tool developed to extract longitudinal profiles and analyze the steepness and concavity of stream channels from DEMs using Arc GIS and MATLAB software (Stream Profiler, 2013) (Appendix C).

3.5 Data Analysis

Reach-average measurements of field survey data were calculated in Excel using the multiple measurements taken for each channel variable. Median grain size (D_{50}) was calculated. Log-log plots comparing bankfull width vs. drainage area, bankfull depth vs. drainage area, slope vs. drainage area, and grain size vs. drainage area were generated for each stream. Additional log-log plots comparing the variables across streams were also made, as well as plots comparing grain size to slope. Trendlines were added and prefactors and exponents calculated.

Minshall site field data was entered into Excel spreadsheets, and reach average measurements of bankfull and slope were calculated. Median substrate size was calculated. Wood measurements were excluded from average particle size measurements. Drainage area for each reach was found using an accumulation area grid derived from the 10m DEM in Arc GIS. Composite log-log plots comparing bankfull vs. drainage area, particle size vs. drainage area, and slope vs. drainage area, as well as a plot comparing substrate size to slope, were generated. Trendlines were added and exponents calculated.

Extracted longitudinal profiles were overlain in Adobe Illustrator to evaluate similarities in channel profiles between channels. Channels were grouped into families, representing different levels of channel steepness and inferred erosional histories.

Slope data from field measured streams were extracted from the USGS DEM and log-log plots of the extracted slopes vs. drainage area were generated. Comparisons between field and DEM measurements of slope were made.

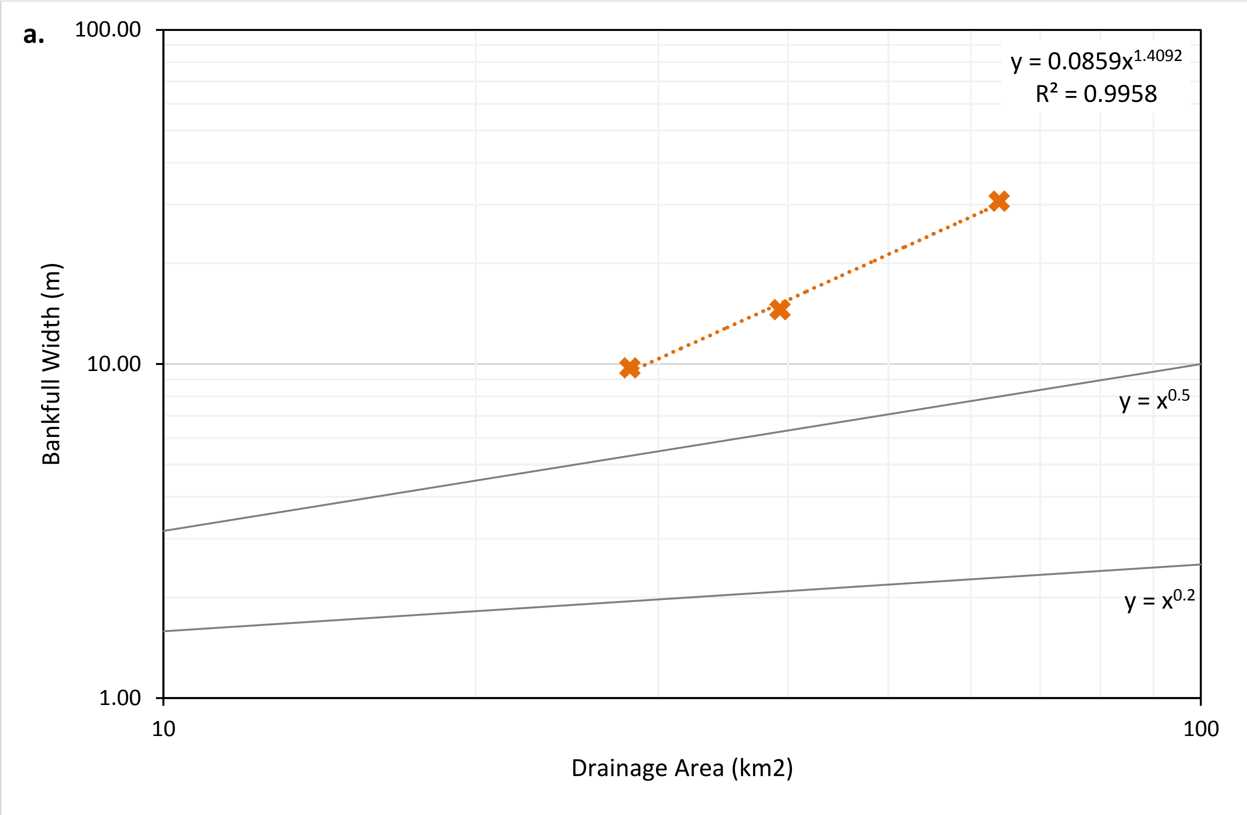
Chapter 4. Results

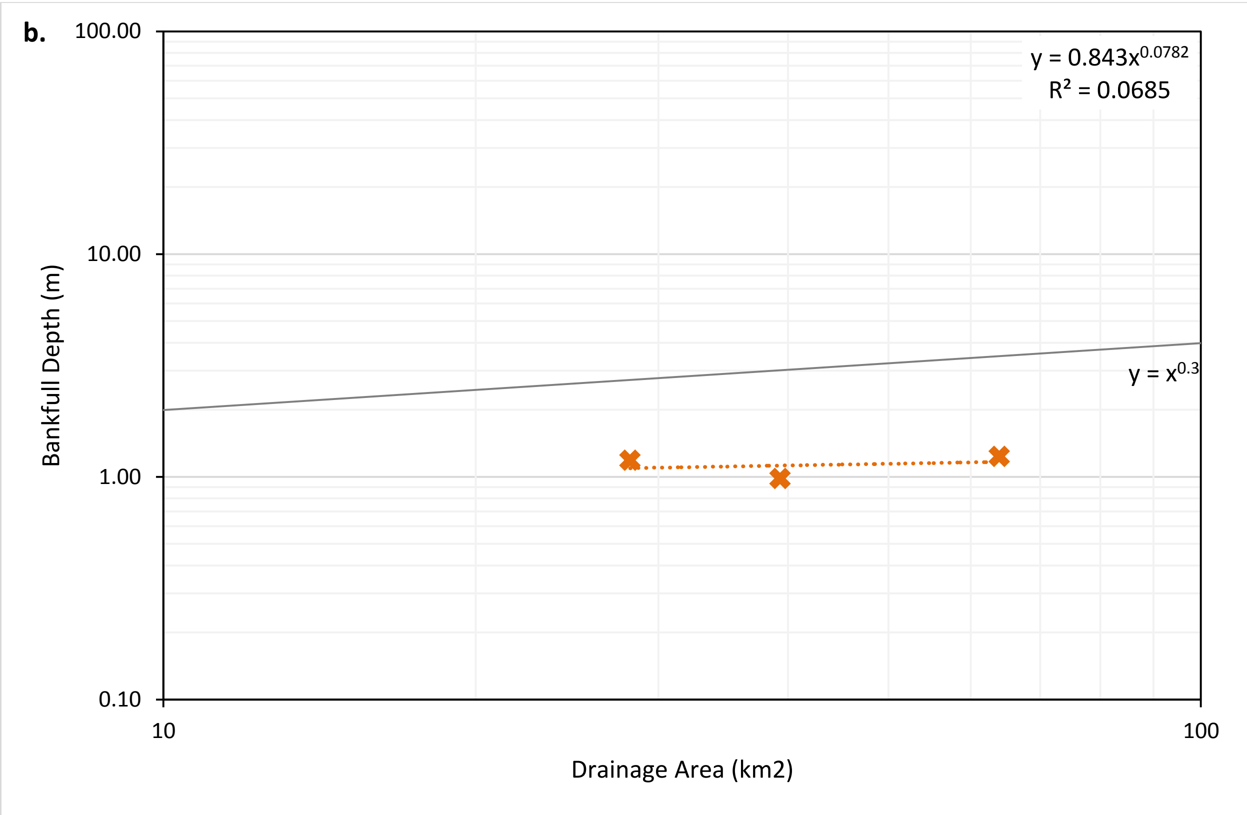
4.1 Field Measurements

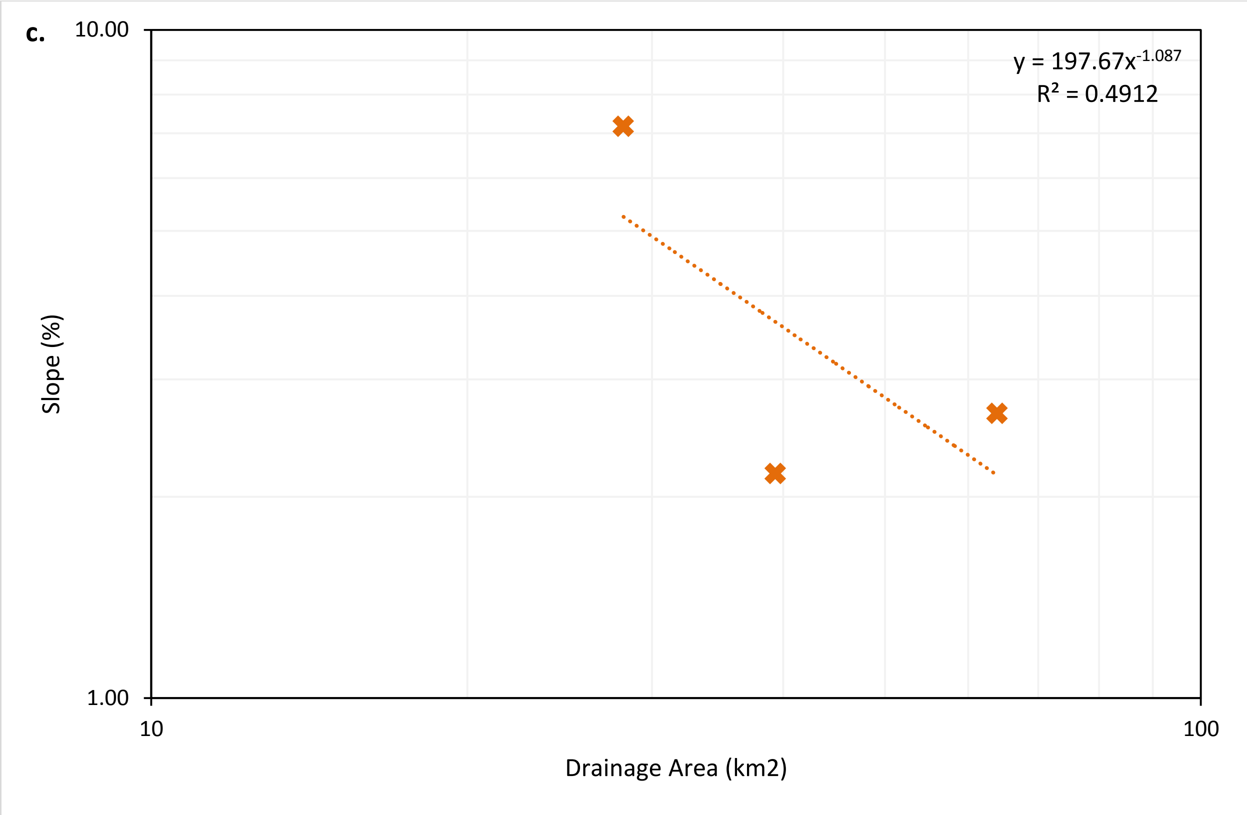
4.1.1 Cabin Creek

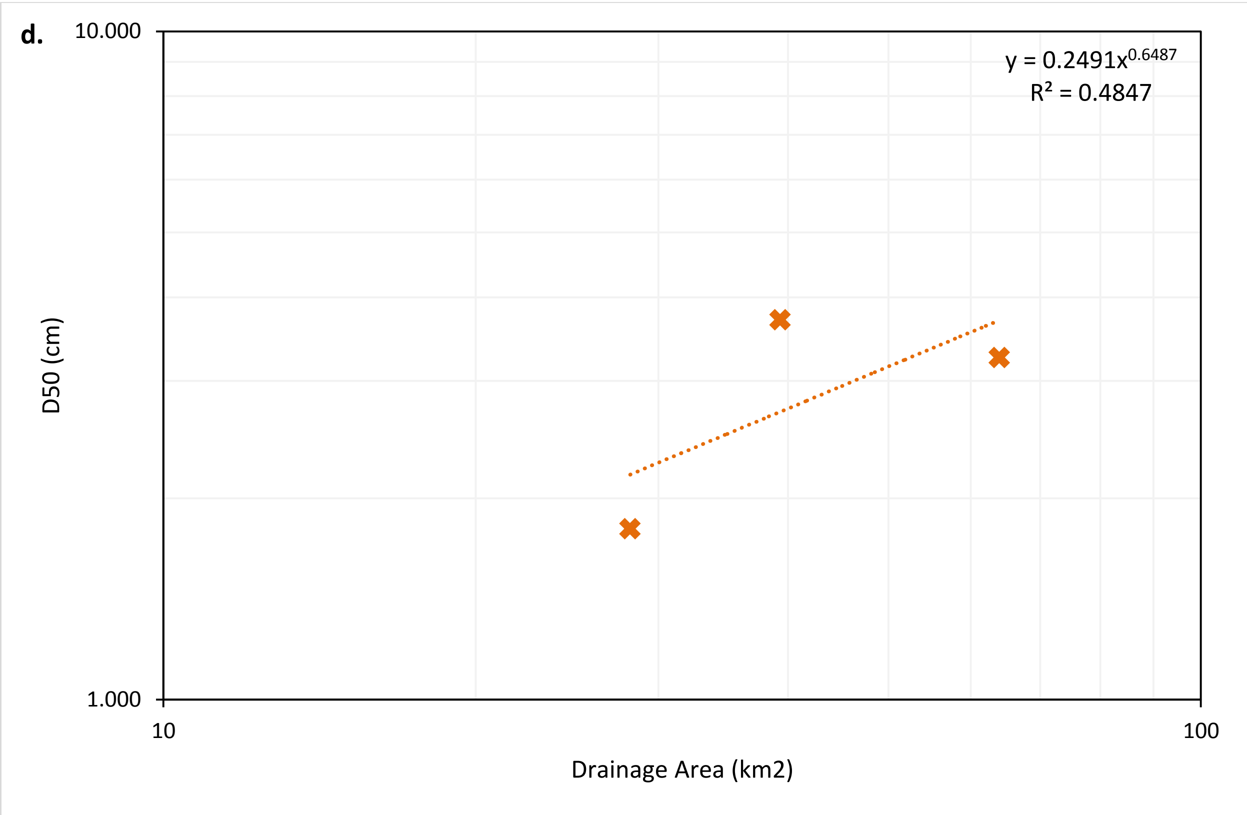
Cabin Creek displays scaling relationships between drainage area and some channel geometry variables, while others show poor correlations with drainage area. Note that only three points were available for this channel and the inferences described here are not well supported.

- Width and drainage area shows a strong positive correlation with an exponent greater than those found in previous bedrock or alluvial channel studies discussed above (Figure 20a).
- Depth and drainage area shows a very weak positive correlation with an exponent less than those found in previous studies discussed above (Figure 20b).
- Slope and drainage area shows a poor negative correlation (Figure 20c).
- Median grain size and drainage area shows a poor positive correlation (Figure 20d).
- Median grain size and slope shows a very strong negative correlation (Figure 20e).


a.
100.00
10.00
1.00
Bankfull Width (m)
y = 0.0859x^1.4092
R² = 0.9958
y = x^0.5
y = x^0.2
10
100
Drainage Area (km2)


b.
100.00
10.00
1.00
0.10
Bankfull Depth (m)
y = 0.843x^0.0782
R² = 0.0685
y = x^0.3
10
100
Drainage Area (km2)


c.
10.00
1.00
10
100
Slope (%)
Drainage Area (km2)
y = 197.67x^-1.087
R² = 0.4912


d.
10.000
1.000
10
100
D50 (cm)
Drainage Area (km2)
y = 0.2491x^0.6487
R² = 0.4847

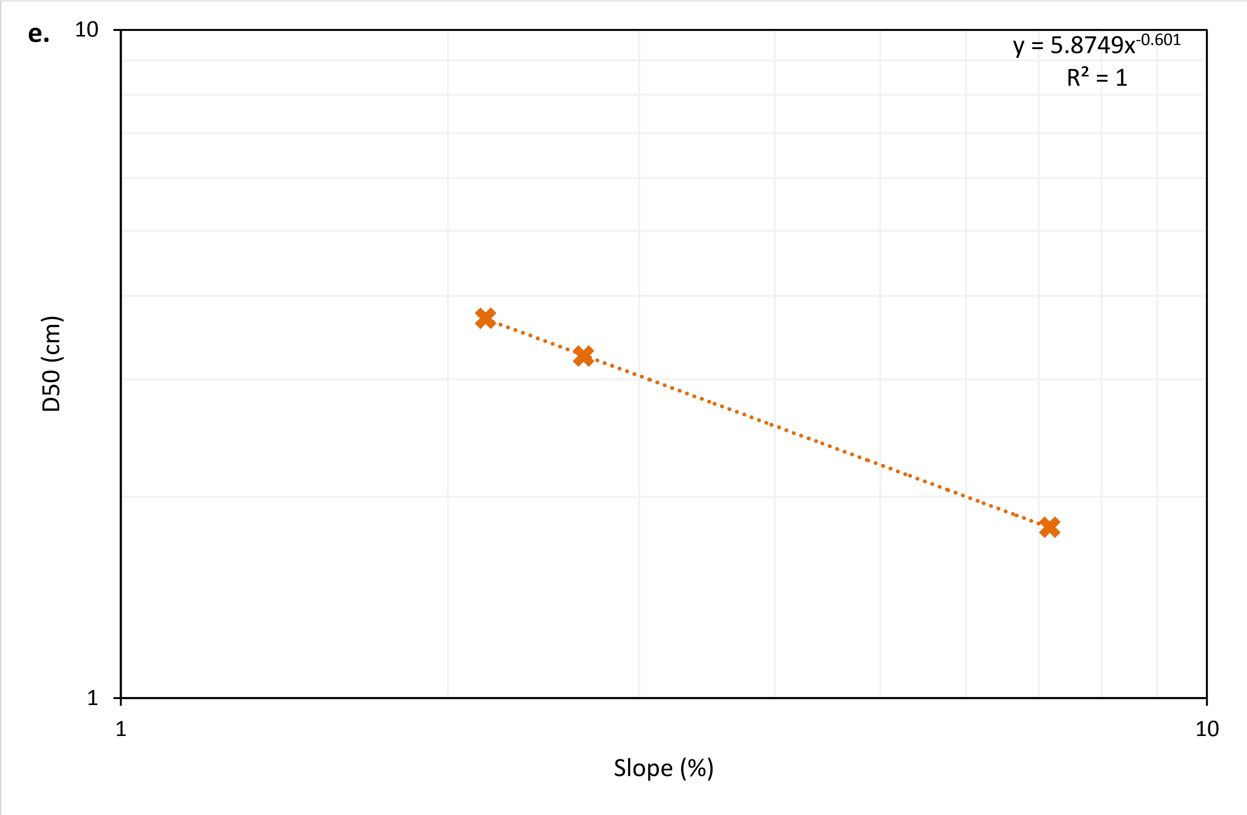


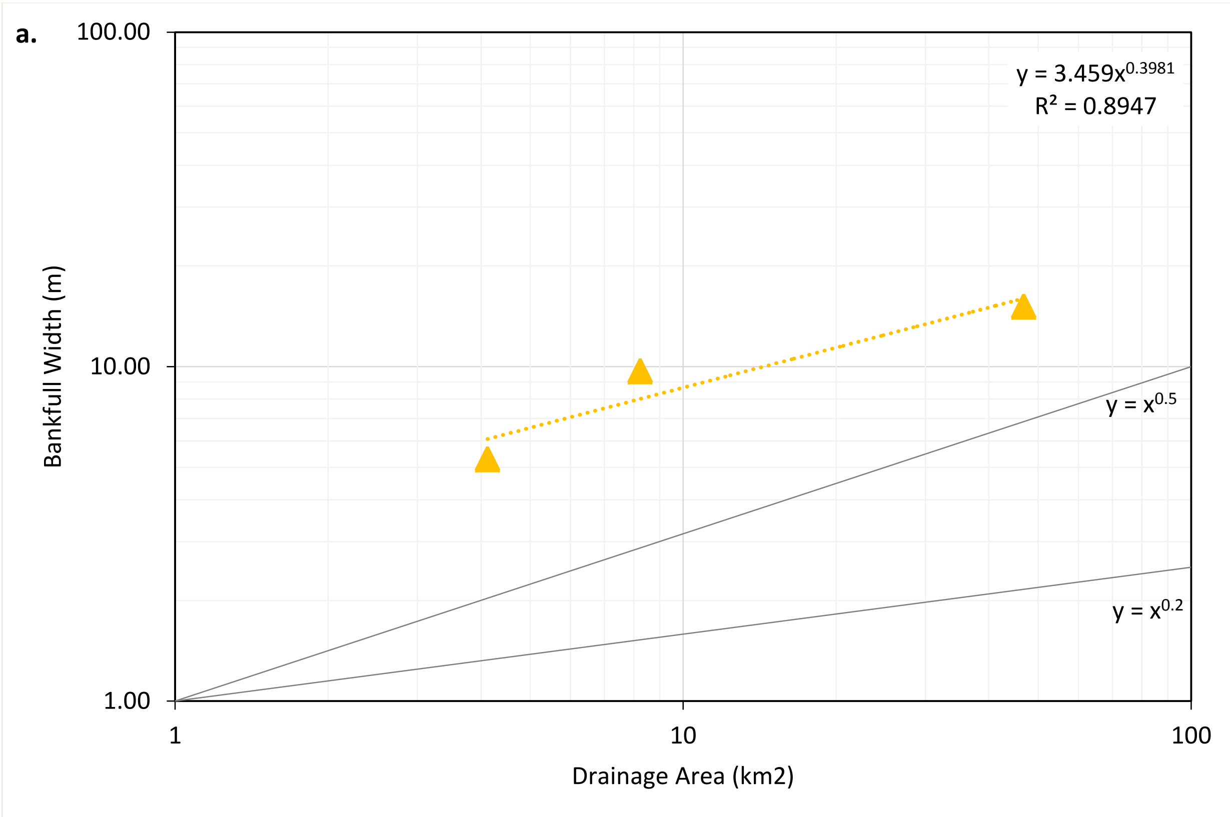
Figure 20. Log-log plots of Cabin Creek response and driving variables with descriptive equations and R^2 shown. (a.) Bankfull width compared to drainage area, showing strong internal scaling. Low and high values of W – A relation slope found by previous studies are shown by grey lines with equation indicating exponent of respective lines; (b.) bankfull depth compared to drainage area, showing poor internal scaling; D – A relation slope found by previous studies shown by grey line with equation indicating exponent; (c.) slope compared to drainage are, showing weak internal scaling; (d.) median grain size (D50) compared to drainage area, showing weak internal scaling; and (e.) median grain size compared to slope, showing very strong internal scaling.

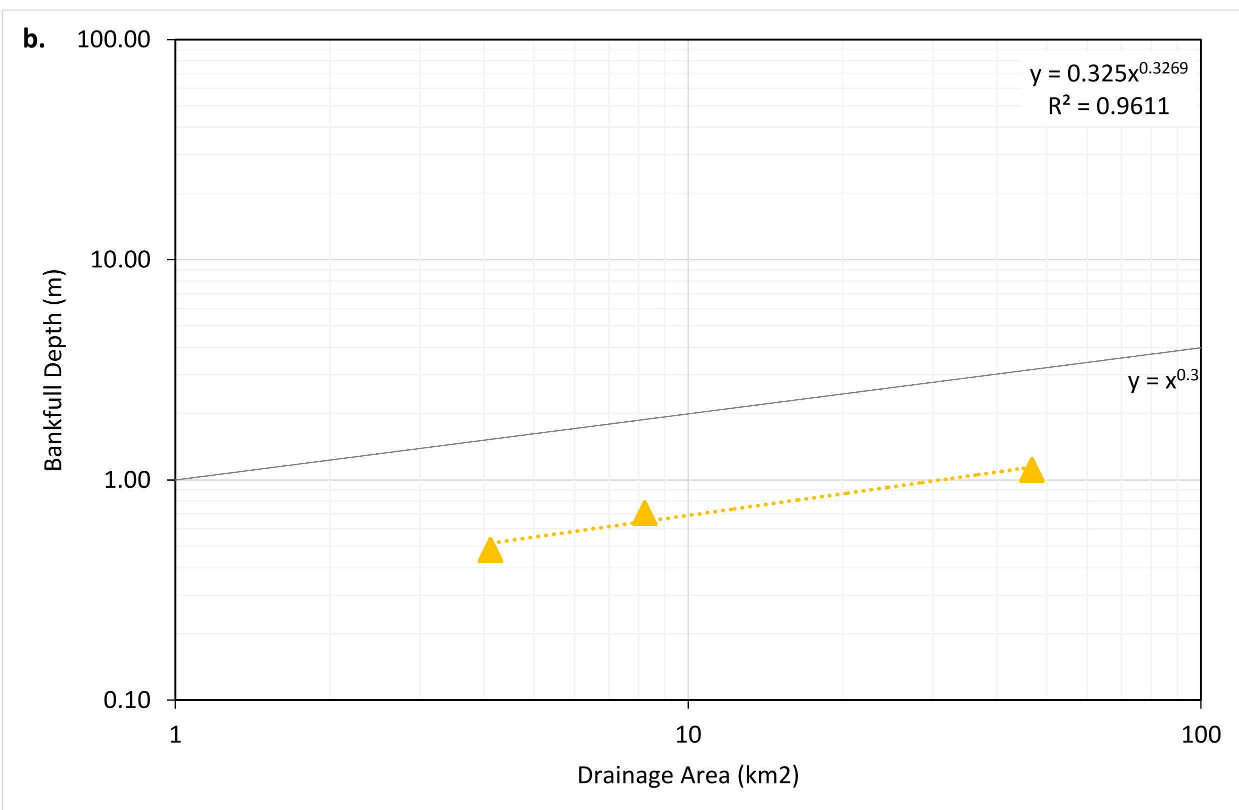
4.1.2 West Cave Creek

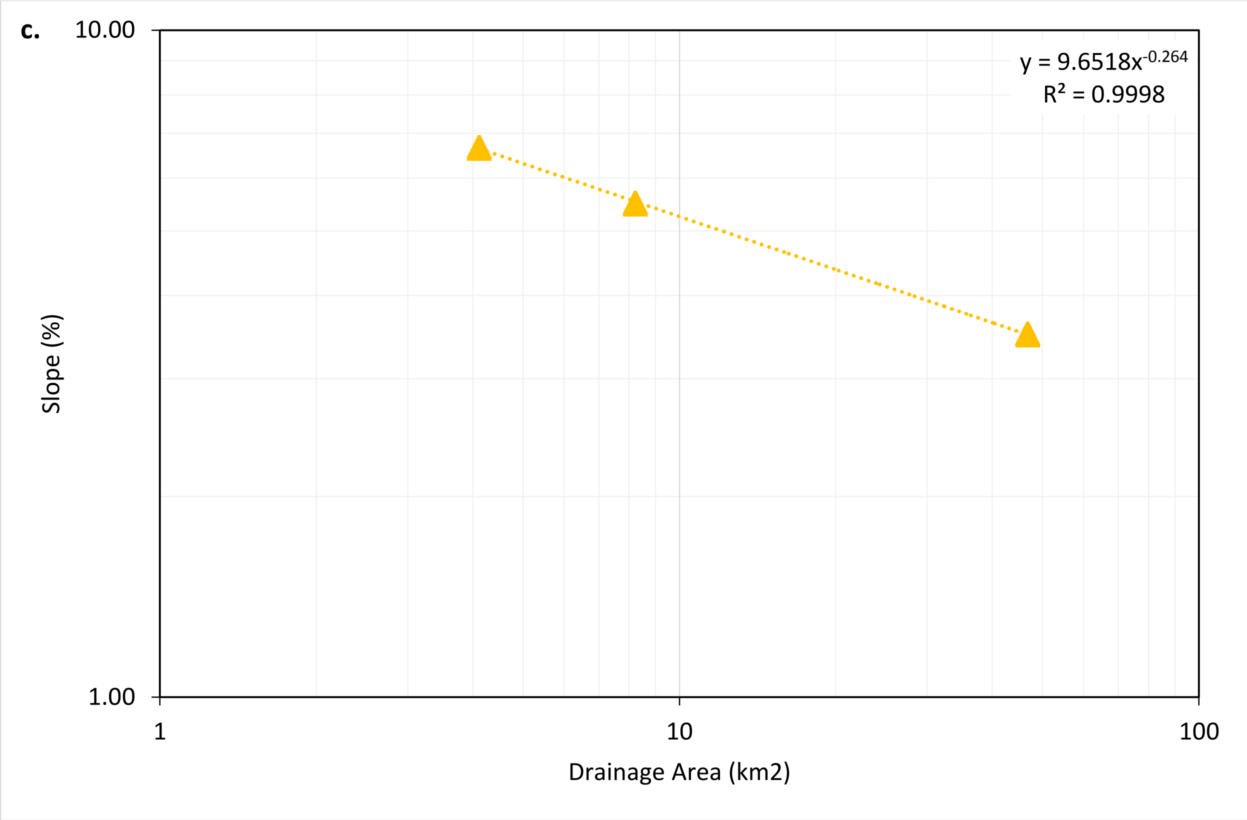
Overall, West Cave Creek shows much stronger correlation between hydraulic variables and drainage area compared to Cabin Creek. Like Cabin Creek these correlations are only based on data from three reaches.

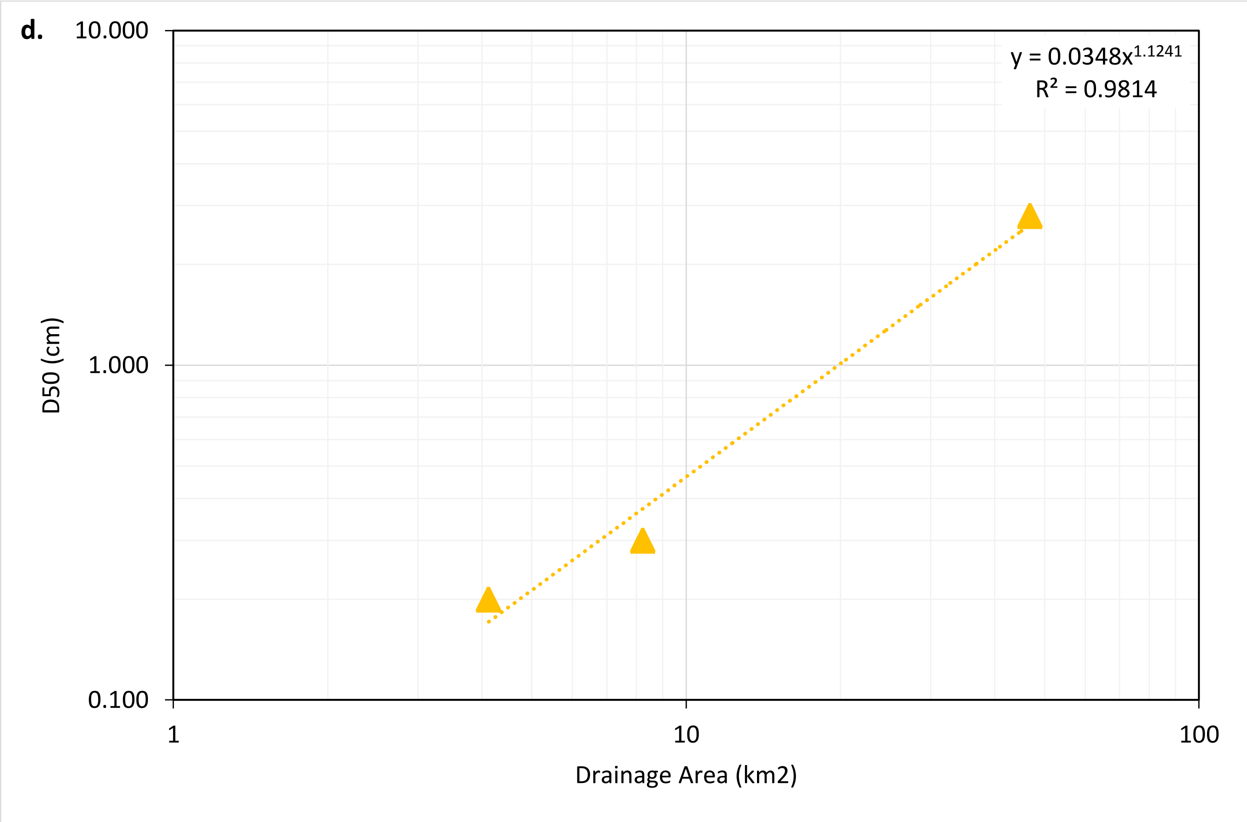
- Width and drainage area shows a strong positive correlation with an exponent within the range found in previous studies discussed above (Figure 21a).

- Depth and drainage area show a very strong positive correlation with an exponent very similar to those found in previous studies discussed above (Figure 21b).
- Slope and drainage area shows a very strong negative correlation (Figure 21c).
- Median grain size and drainage area shows a very strong positive correlation (Figure 21d).
- Median grain size and slope shows a very strong negative correlation (Figure 21e).


a.
100.00
10.00
1.00
Bankfull Width (m)
y = 3.459x0.3981
R² = 0.8947
y = x0.5
y = x0.2
1
10
100
Drainage Area (km2)


b.
100.00
10.00
1.00
0.10
Bankfull Depth (m)
y = 0.325x0.3269
R² = 0.9611
y = x0.3
1
10
100
Drainage Area (km2)


c.
10.00
1.00
1
10
100
Slope (%)
Drainage Area (km2)
y = 9.6518x^-0.264
R² = 0.9998


d.
10.000
1.000
0.100
1
10
100
D50 (cm)
Drainage Area (km2)
y = 0.0348x^1.1241
R² = 0.9814

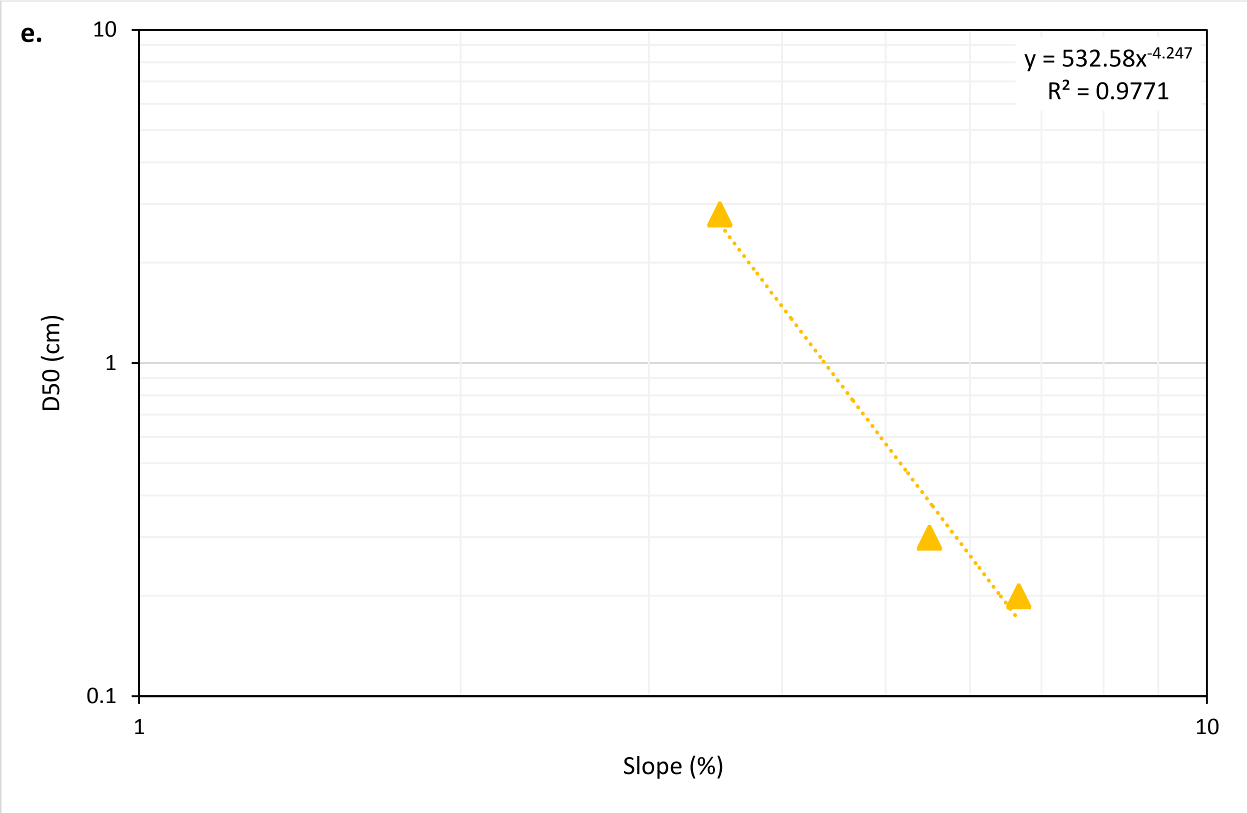


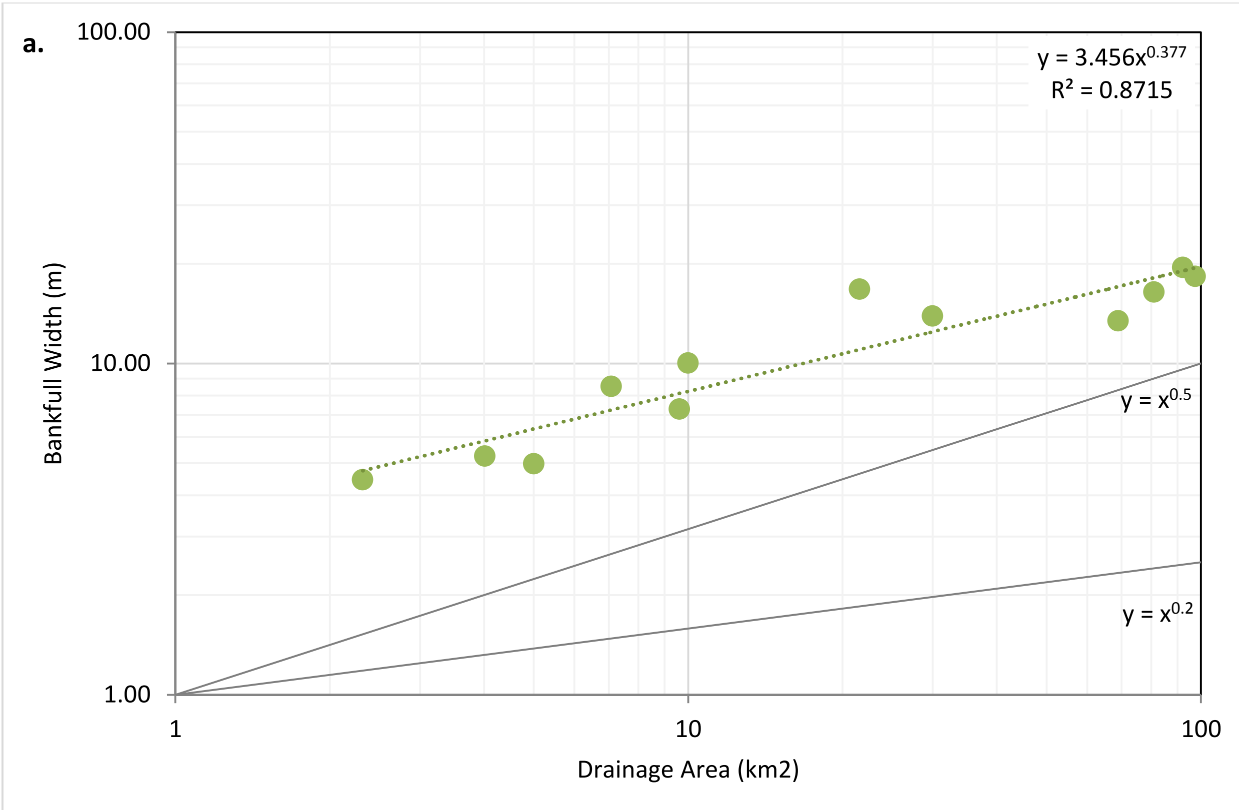
Figure 21. Log-log plots of West Cave Creek response and driving variables with descriptive equations and R^2 shown. (a.) Bankfull width compared to drainage area, showing strong internal scaling. Low and high values of W – A relation slope found by previous studies are shown by grey lines with equation indicating exponent of respective lines; (b.) bankfull depth compared to drainage area, showing strong internal scaling; D – A relation slope found by previous studies shown by grey line with equation indicating exponent; (c.) slope compared to drainage area, showing strong internal scaling; (d.) median grain size (D50) compared to drainage area, showing strong internal scaling; and (e.) median grain size compared to slope, showing strong internal scaling.

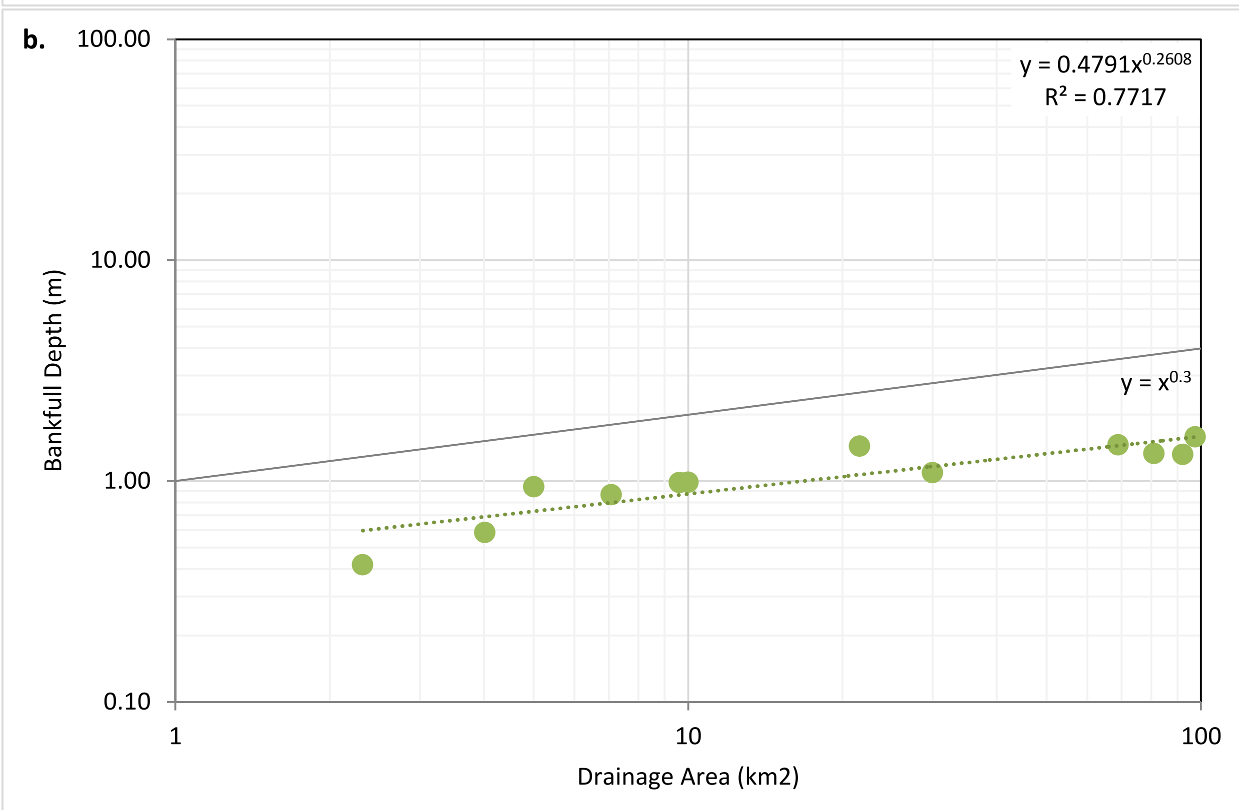
4.1.3 East Crooked Creek

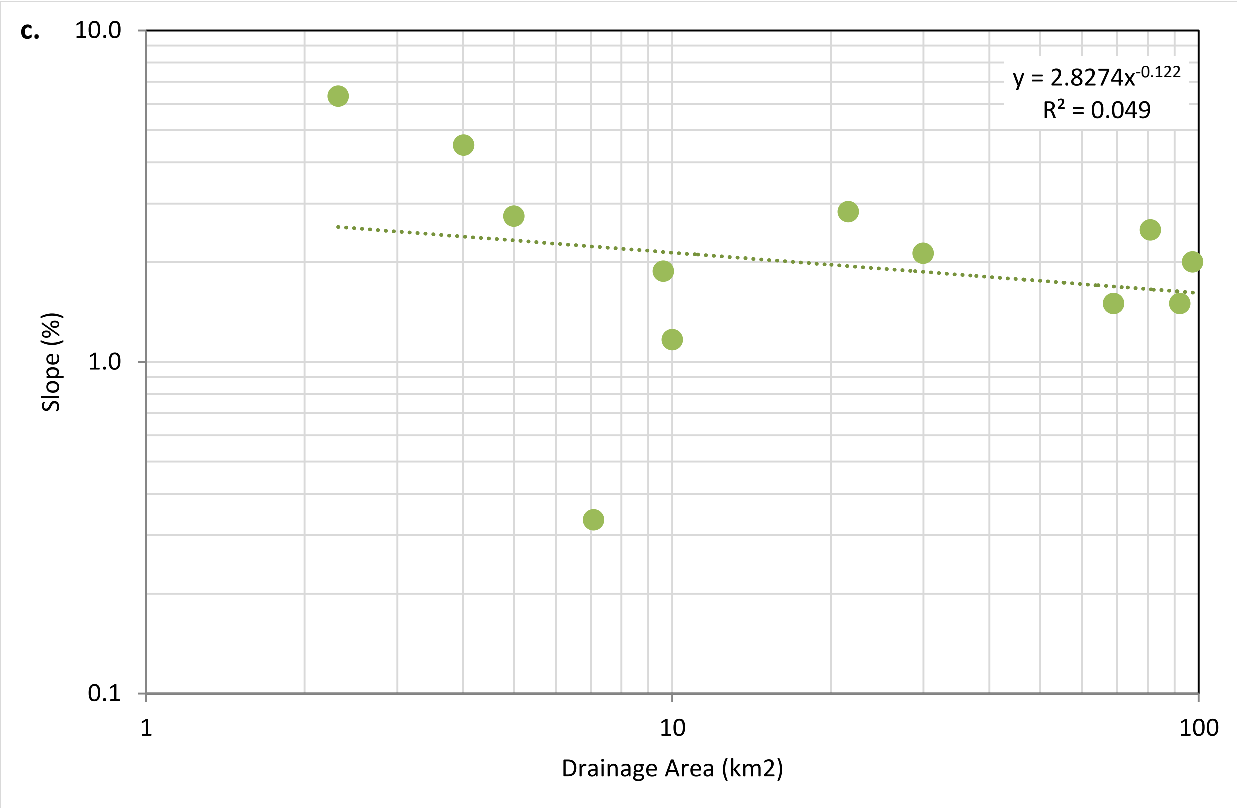
Like Cabin Creek, East Crooked Creek shows strong correlations between some hydraulic variables but not all. This creek has 12 observation reaches and thus the observed correlations are better supported.

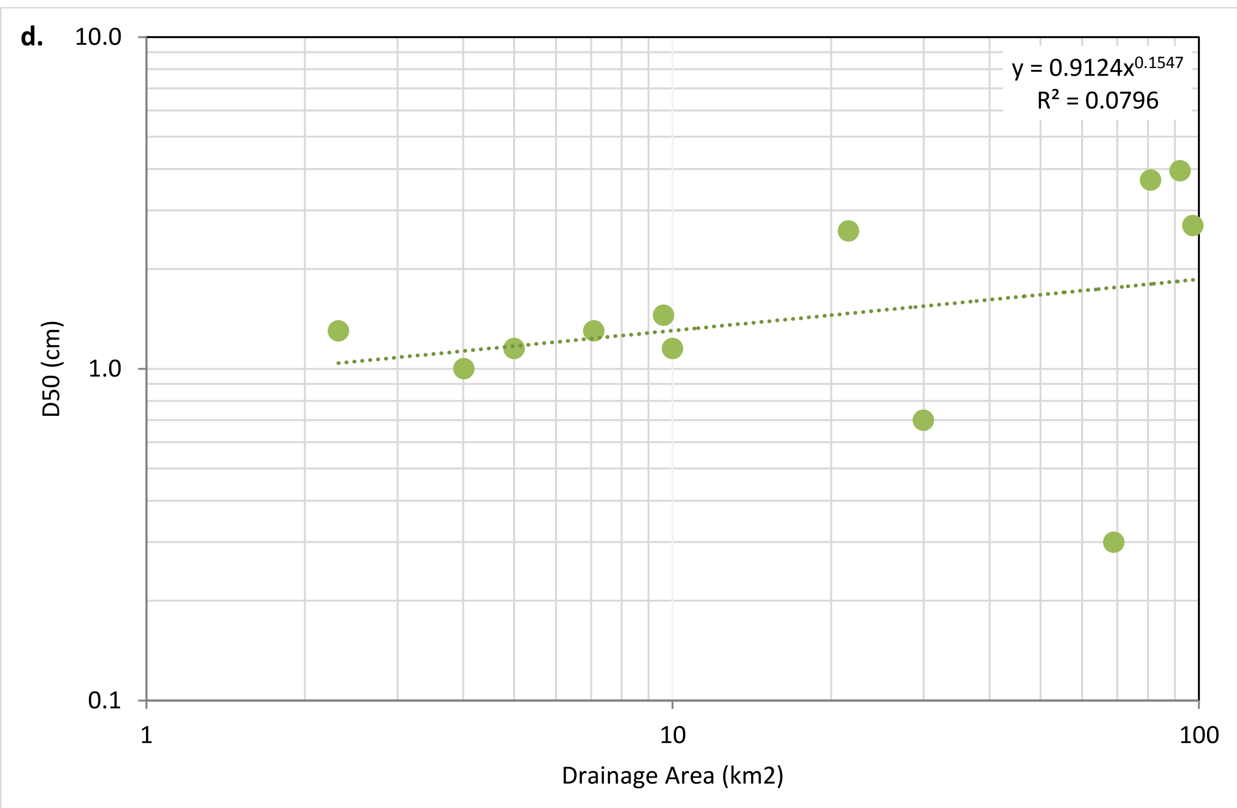
- Width and drainage area shows a strong positive correlation with and exponent within the range found by previous studies (Figure 22a).

- Depth and drainage area shows a strong positive correlation with and exponent very similar to that found in previous (Figure 22b).
- Slope and drainage area shows a very weak negative correlation (Figure 22c).
- Median grain size and drainage area shows a very weak positive correlation (Figure 22d).
- Median grain size and slope shows no correlation (Figure 22e).


a.
y = 3.456x0.377
R² = 0.8715
y = x0.5
y = x0.2
100.00
10.00
1.00
1
10
100
Bankfull Width (m)
Drainage Area (km2)


b.
y = 0.4791x0.2608
R² = 0.7717
y = x0.3
100.00
10.00
1.00
0.10
1
10
100
Bankfull Depth (m)
Drainage Area (km2)


c.
10.0
1.0
0.1
Slope (%)
y = 2.8274x^-0.122
R² = 0.049
1
10
100
Drainage Area (km2)


d.
10.0
1.0
0.1
D50 (cm)
y = 0.9124x^0.1547
R² = 0.0796
1
10
100
Drainage Area (km2)

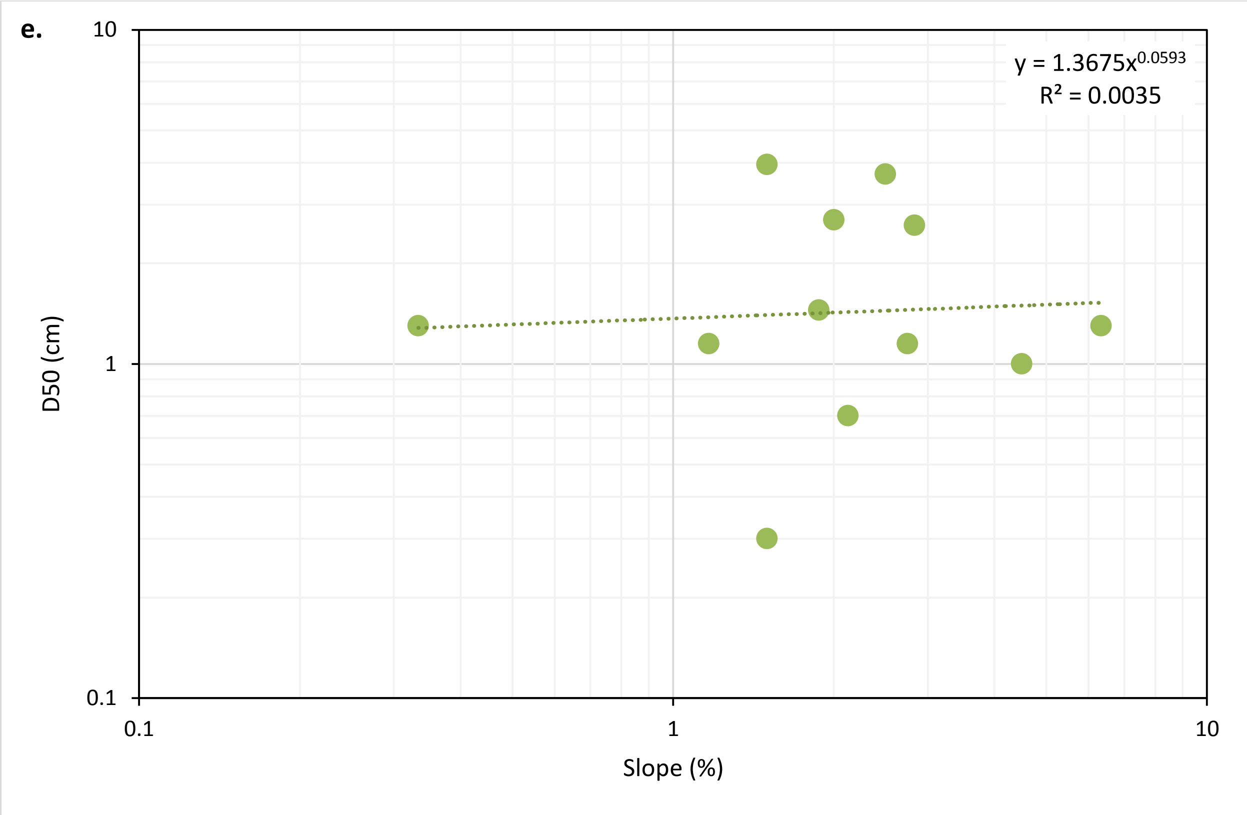


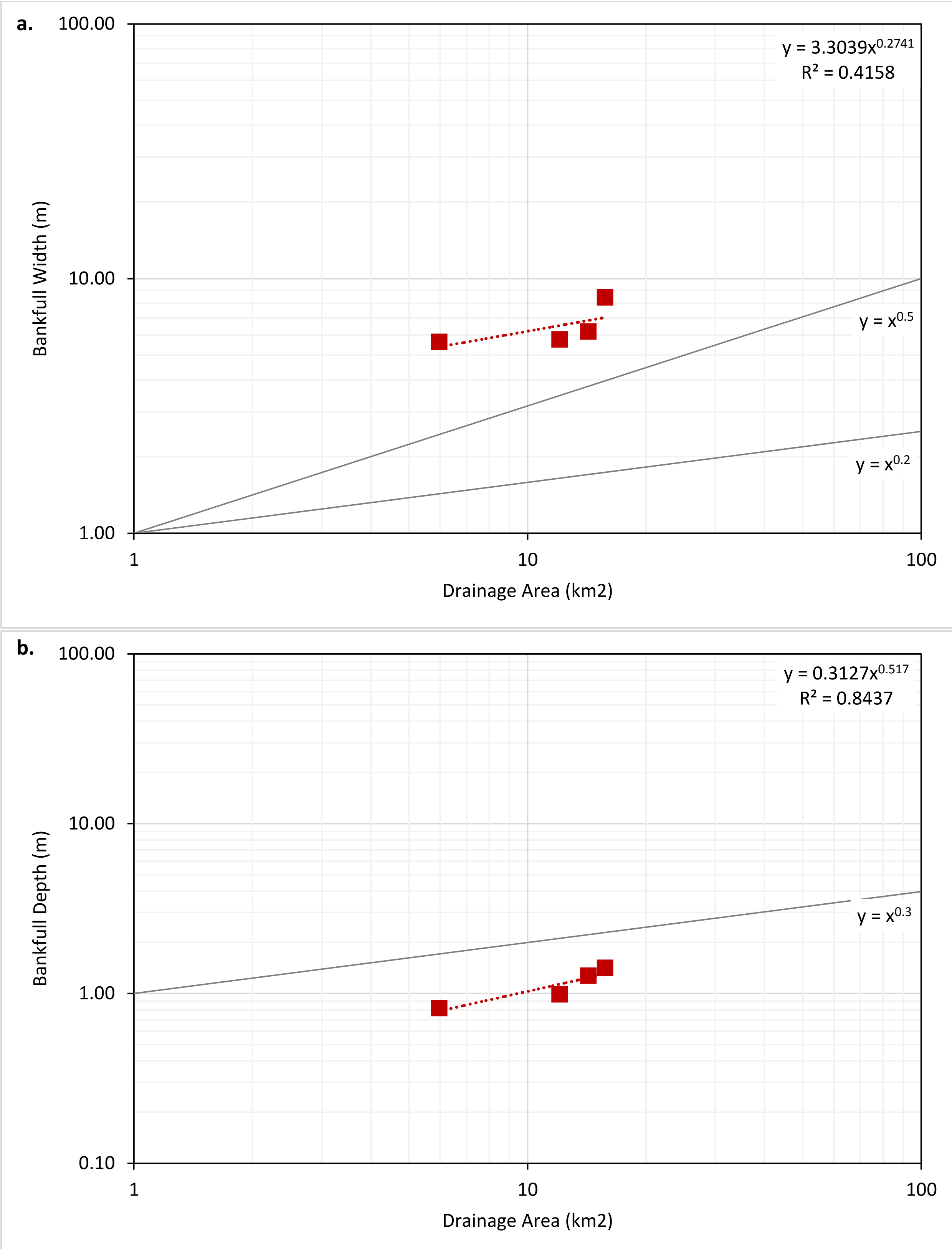
Figure 22. Log-log plots of East Crooked Creek response and driving variables with descriptive equations and R^2 shown. (a.) Bankfull width compared to drainage area, showing strong internal scaling. Low and high values of W – A relation slope found by previous studies are shown by grey lines with equation indicating exponent of respective lines; (b.) bankfull depth compared to drainage area, showing strong internal scaling; D – A relation slope found by previous studies shown by grey line with equation indicating exponent; (c.) slope compared to drainage are, showing weak internal scaling; (d.) median grain size (D50) compared to drainage area, showing very weak internal scaling; and (e.) median grain size compared to slope, showing no internal scaling.

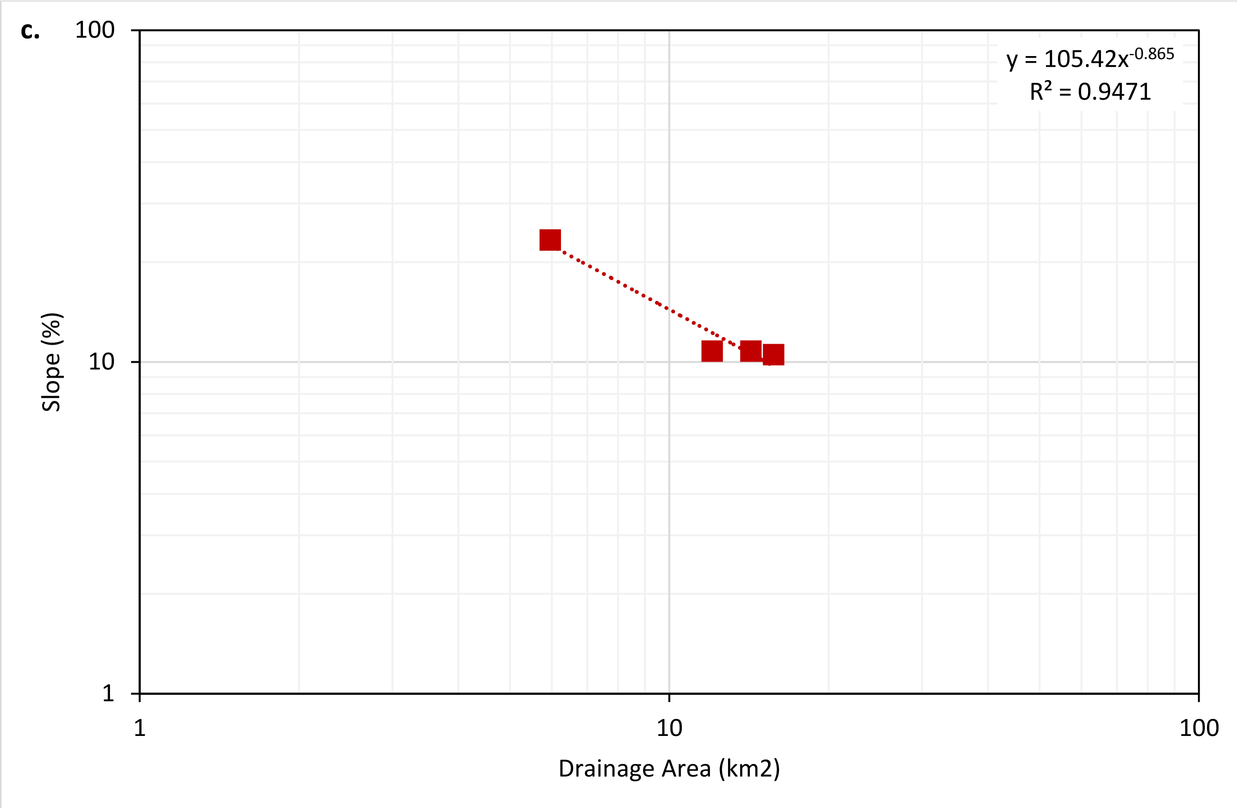
4.1.4 Pioneer Creek

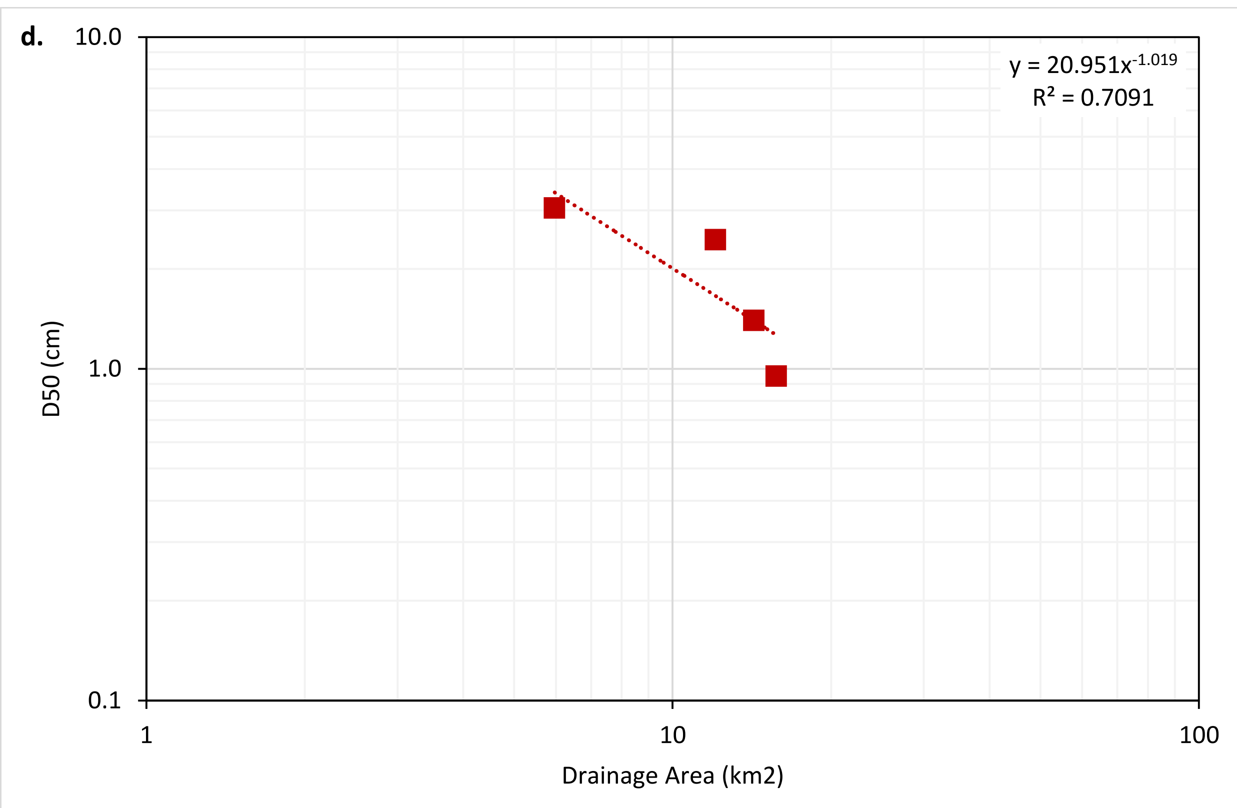
Similar to Cabin and East Crooked Creeks, Pioneer Creek shows strong correlations between some channel variables and drainage area but poor correlations with others. Only four reaches were investigated and of these, three were in the lower basin and one was much higher in the watershed. This affects the strength of our inference based on these data.

- Width and drainage area shows a poor positive correlation with an exponent within the range found by previous (Figure 23a).

- Depth and drainage area shows a strong positive correlation with an exponent greater than that found by previous studies (Figure 23b).
- Slope and drainage area shows a strong negative correlation (Figure 23c).
- Median grain size and drainage area shows a strong negative correlation (Figure 23d).
- Median grain size and slope shows a poor positive correlation (Figure 23e).


a.
100.00
10.00
1.00
Bankfull Width (m)
y = 3.3039x^0.2741
R² = 0.4158
y = x^0.5
y = x^0.2
1
10
100
Drainage Area (km2)
b.
100.00
10.00
1.00
0.10
Bankfull Depth (m)
y = 0.3127x^0.517
R² = 0.8437
y = x^0.3
1
10
100
Drainage Area (km2)


c.
y = 105.42x-0.865
R² = 0.9471
Slope (%)
100
10
1
1
10
100
Drainage Area (km2)


d.
y = 20.951x-1.019
R² = 0.7091
D50 (cm)
10.0
1.0
0.1
1
10
100
Drainage Area (km2)

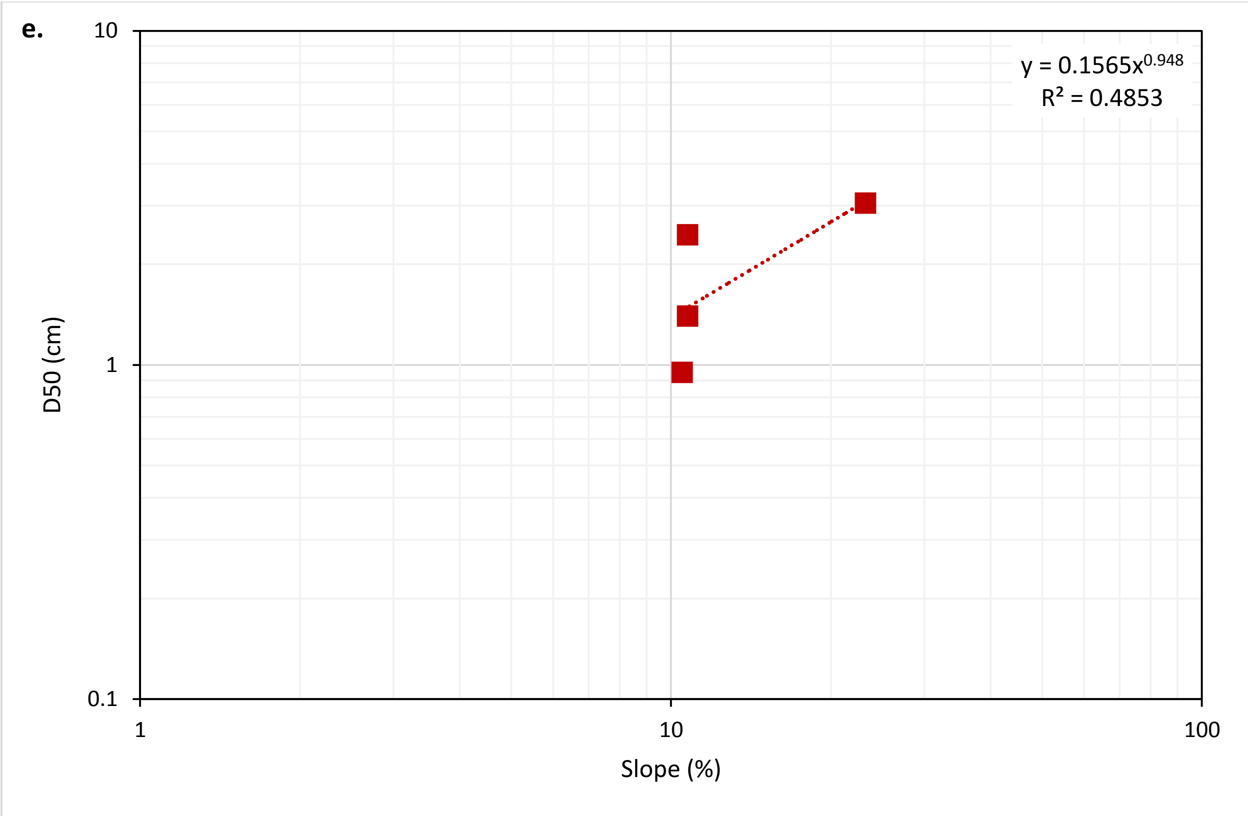


Figure 23. Log-log plots of Pioneer Creek response and driving variables with descriptive equations and R^2 shown. (a.) Bankfull width compared to drainage area, showing poor internal scaling. Low and high values of W – A relation slope found by previous studies are shown by grey lines with equation indicating exponent of respective lines; (b.) bankfull depth compared to drainage area, showing strong internal scaling; D – A relation slope found by previous studies shown by grey line with equation indicating exponent; (c.) slope compared to drainage are, showing strong internal scaling; (d.) median grain size (D50) compared to drainage area, showing strong internal scaling; and (e.) median grain size compared to slope, showing poor internal scaling.

4.1.5 Comparisons across Field Sites

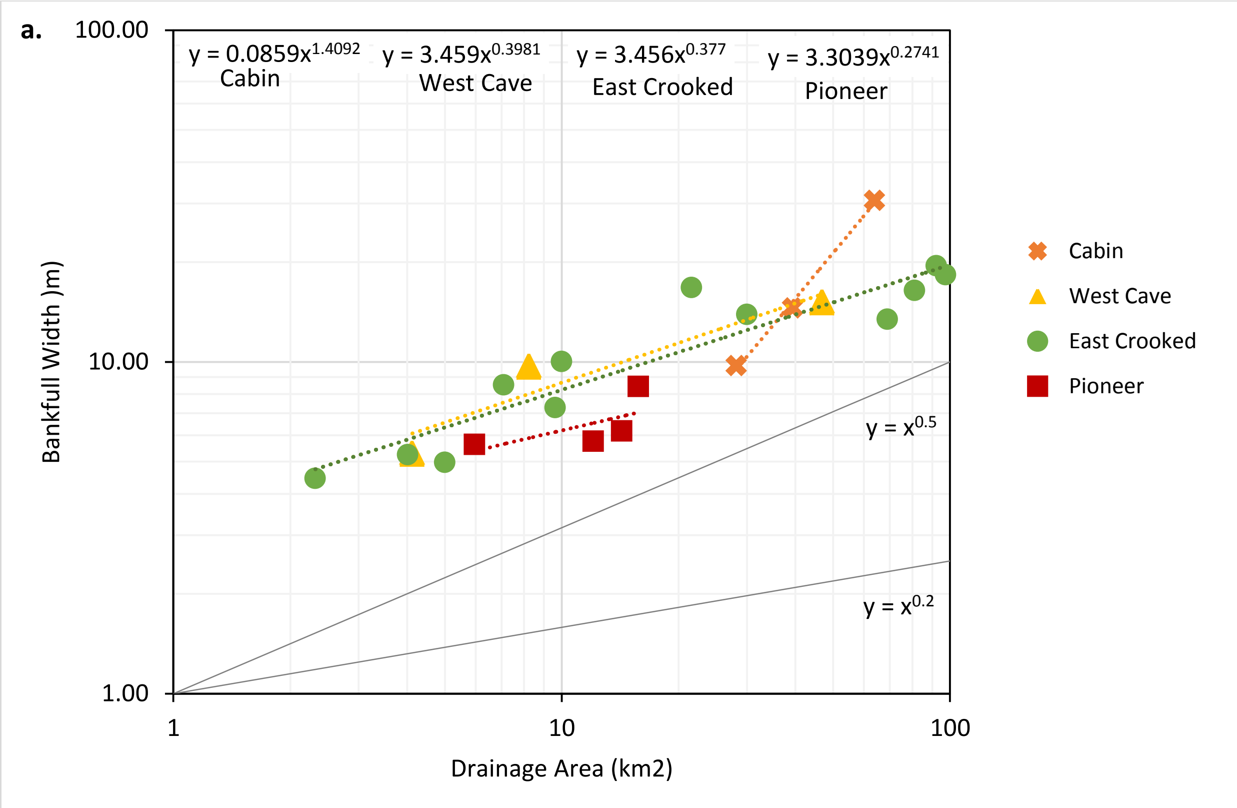
The consistency of scaling relationships between field measured tributaries of Big Creek varies by hydraulic variable.

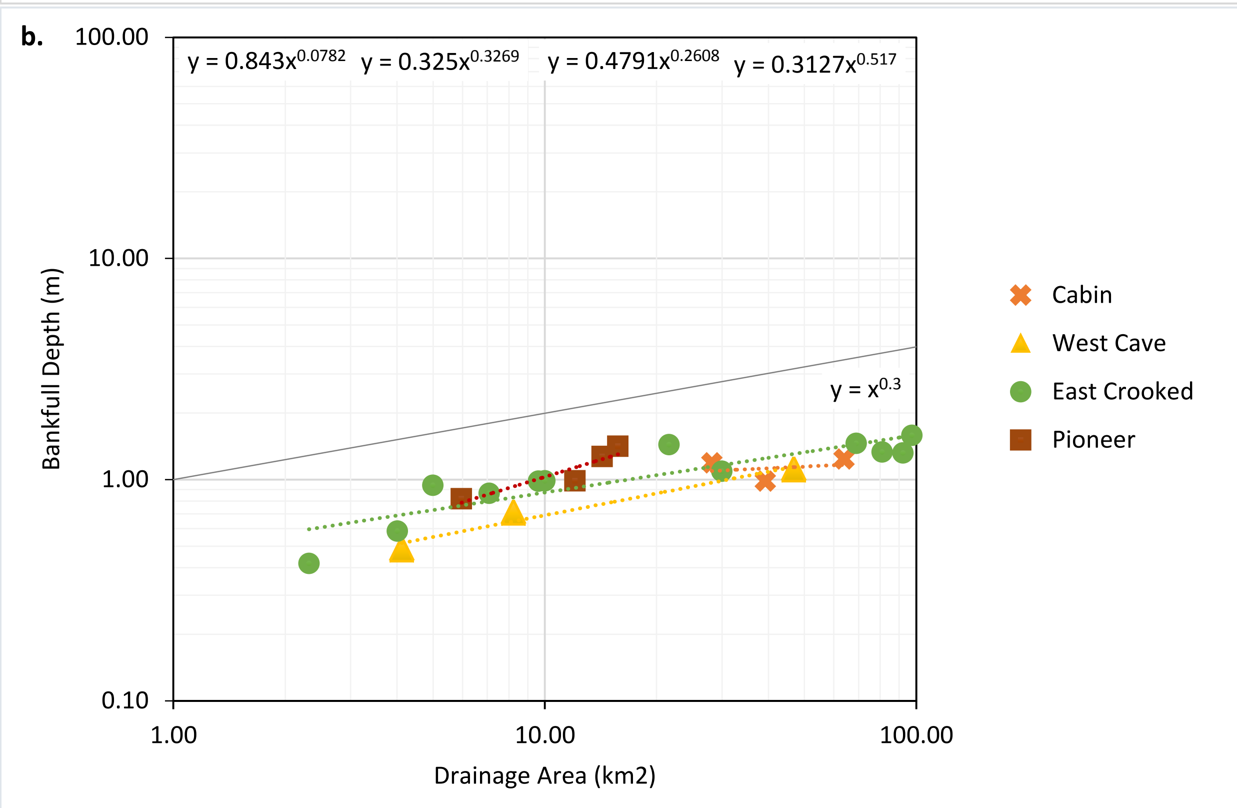
- Width and drainage area have consistent exponents in three of the four tributaries and all show the expected increase in width with drainage area. West Cave Creek, East Crooked Creek, and Pioneer Creek all have similar exponents (0.27 to 0.40) and prefactors (3.30 to 3.46) describing the slope of their width-area equations (Figure 24a). These exponents fall within the published ranges for bedrock channels (Montgomery & Gran, 2001; Snyder et al., 2003; Golden & Springer, 2006; Whittaker et al., 2007; Wohl & Merritt, 2008; Wohl & David, 2008). Cabin Creek deviates from the other streams significantly, with a much more rapid rate of change for its width-area relation (exponent of 1.41) and a much lower prefactor (0.09).

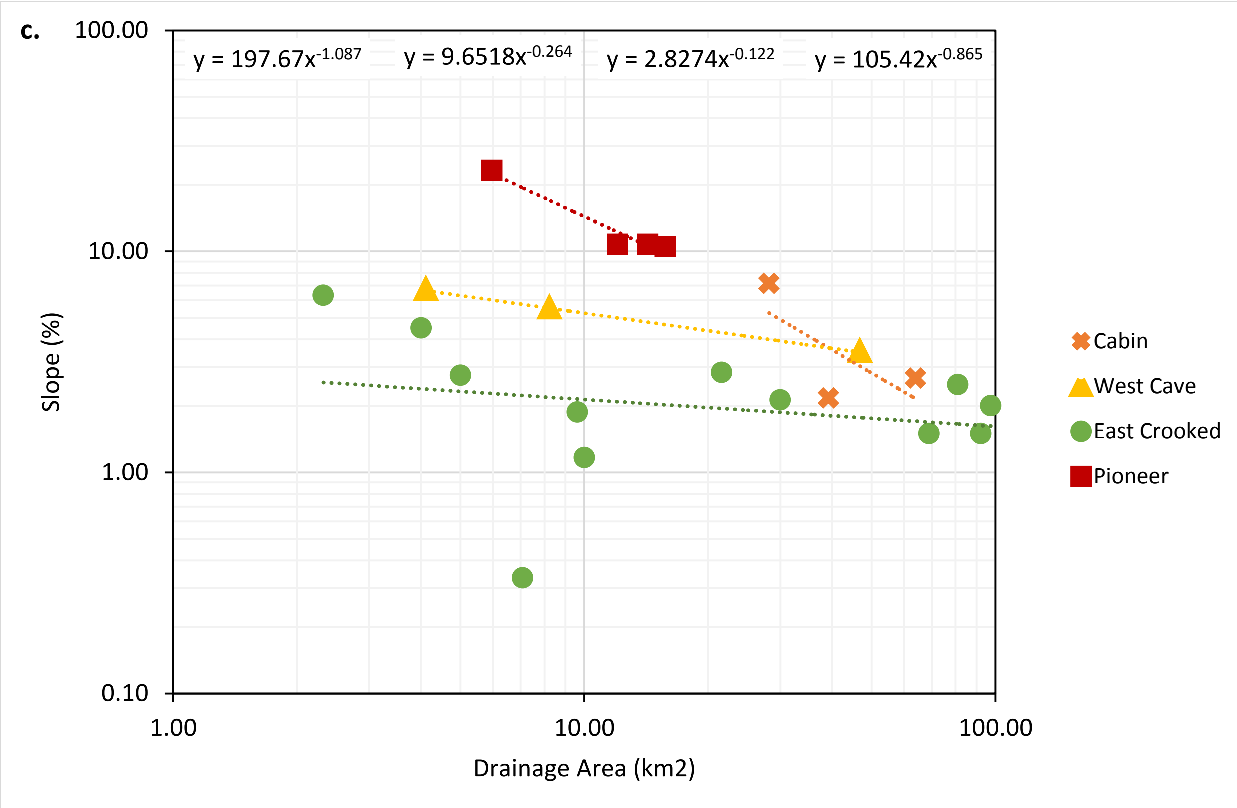
- Depth-drainage area relations are less consistent, though all also show an increase in depth with drainage area (Figure 24b). Cabin Creek and East Crooked Creek both have exponents (0.33 and 0.38, respectively) that are close to the published value for bedrock channels of 0.3 (Montgomery & Gran, 2001; Snyder et al., 2003; Golden & Springer, 2006; Whittaker et al., 2007; Wohl & Merritt, 2008; Wohl & David, 2008), indicating consistency between these two tributaries. Pioneer Creek has a somewhat higher exponent (0.52), while Cabin Creek has the lowest exponent (0.08). West Cave, East Crooked, and Pioneer Creeks have similar prefactors (0.3 – 0.5), and Cabin has a higher prefactor (0.8).
- Slope-drainage area relationships vary across the tributaries. All streams show a decrease in channel slope as drainage area increases, but at different rates (Figure 24c). East Crooked Creek has the smallest exponent (-0.12), while West Cave Creek has an exponent roughly twice that of Crooked (-0.26). Pioneer Creek has a graph slope approximately 3 times as steep as West Cave Creek (-0.87), and Cabin Creek's exponent is approximately four times that of West Cave (-1.09). Prefactors of streams vary widely (Cabin: 197.7; West Cave: 9.7; East Crooked: 2.8; Pioneer: 105.4).
- Median grain size is the most variable relationship. When compared with drainage area, Cabin Creek, West Cave Creek, and Crooked Creek all coarsen with increasing drainage

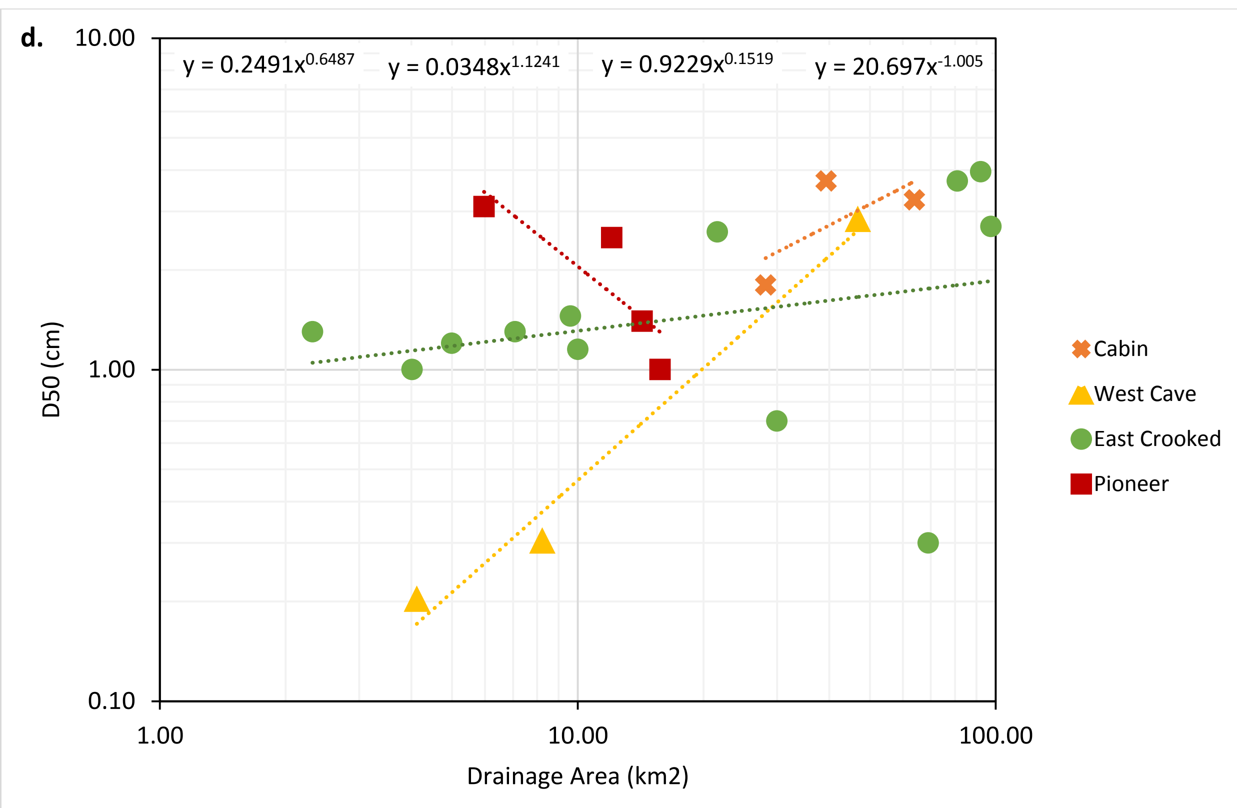
area, while Pioneer Creek fines with increasing drainage area (Figure 24d). The three streams that coarsen downstream all possess notably different exponents and prefactors for their power law equations.

- Grain size considered with slope yields similarly variable results (Figure 24e). Cabin Creek and West Cave Creek have negative correlations between median grain size and channel slope, and East Crooked Creek and Pioneer Creek have positive correlations. All tributaries have extremely different exponents and prefactors.


a.
y = 0.0859x^1.4092
Cabin
y = 3.459x^0.3981
West Cave
y = 3.456x^0.377
East Crooked
y = 3.3039x^0.2741
Pioneer
100.00
10.00
1.00
y = x^0.5
y = x^0.2
1
10
100
Bankfull Width)m)
Drainage Area (km2)
Cabin
West Cave
East Crooked
Pioneer


b.
y = 0.843x^0.0782
y = 0.325x^0.3269
y = 0.4791x^0.2608
y = 0.3127x^0.517
100.00
10.00
1.00
0.10
y = x^0.3
1.00
10.00
100.00
Bankfull Depth (m)
Drainage Area (km2)
Cabin
West Cave
East Crooked
Pioneer


c.
y = 197.67x^-1.087
y = 9.6518x^-0.264
y = 2.8274x^-0.122
y = 105.42x^-0.865
Slope (%)
Drainage Area (km2)
100.00
10.00
1.00
0.10
1.00
10.00
100.00
Cabin
West Cave
East Crooked
Pioneer


d.
y = 0.2491x^0.6487
y = 0.0348x^1.1241
y = 0.9229x^0.1519
y = 20.697x^-1.005
D50 (cm)
Drainage Area (km2)
10.00
1.00
0.10
1.00
10.00
100.00
Cabin
West Cave
East Crooked
Pioneer

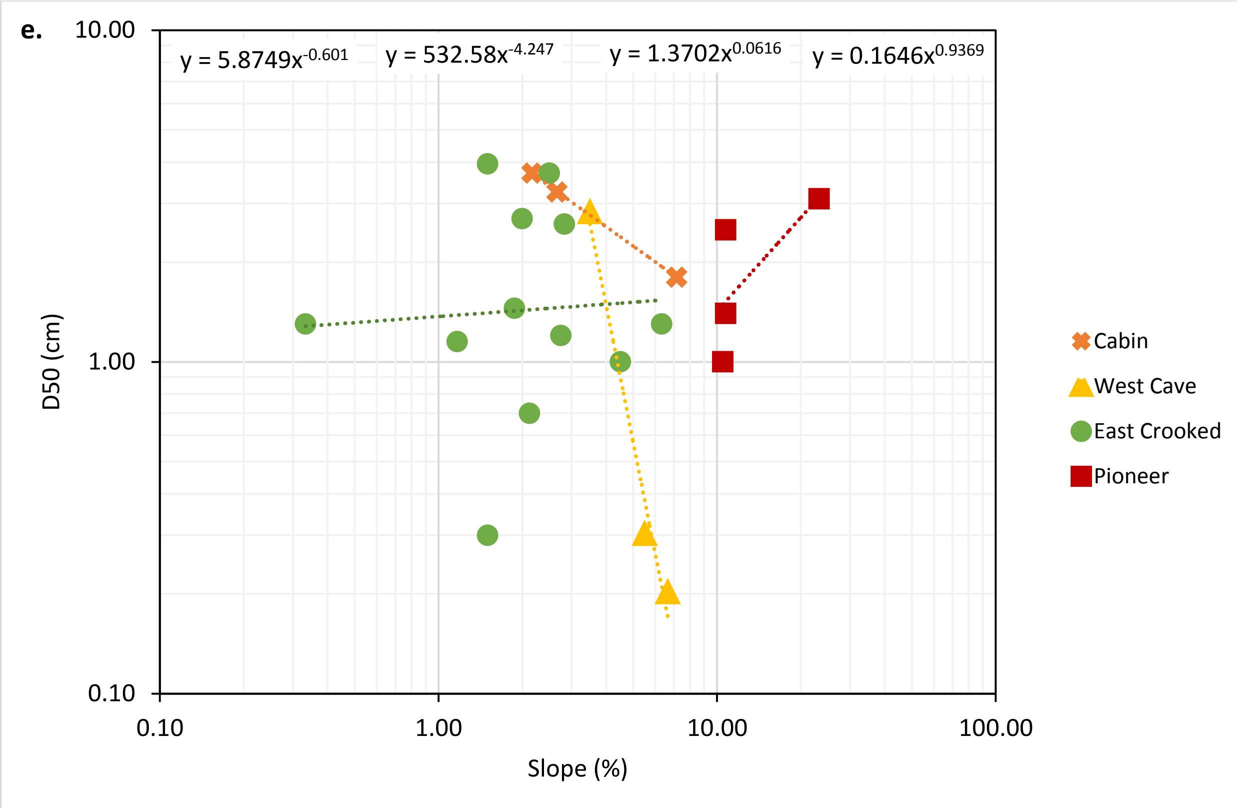
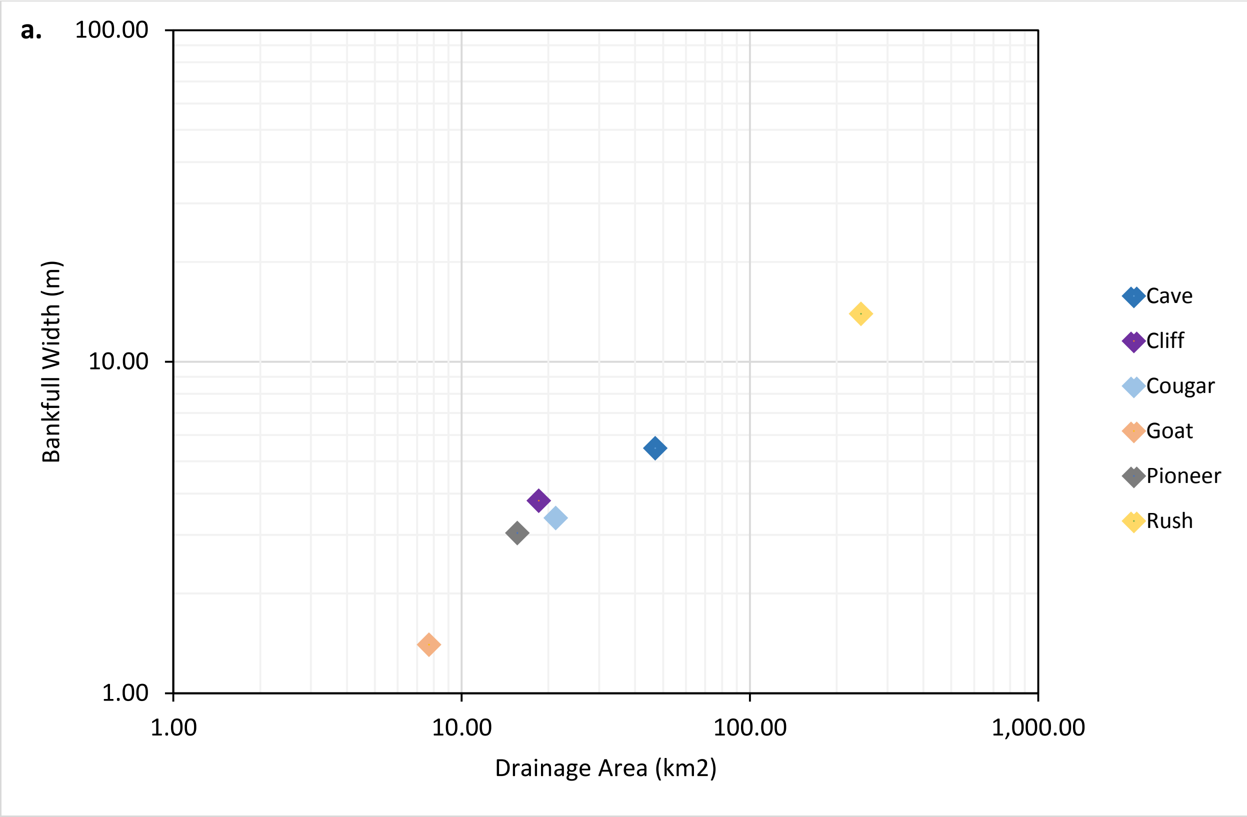


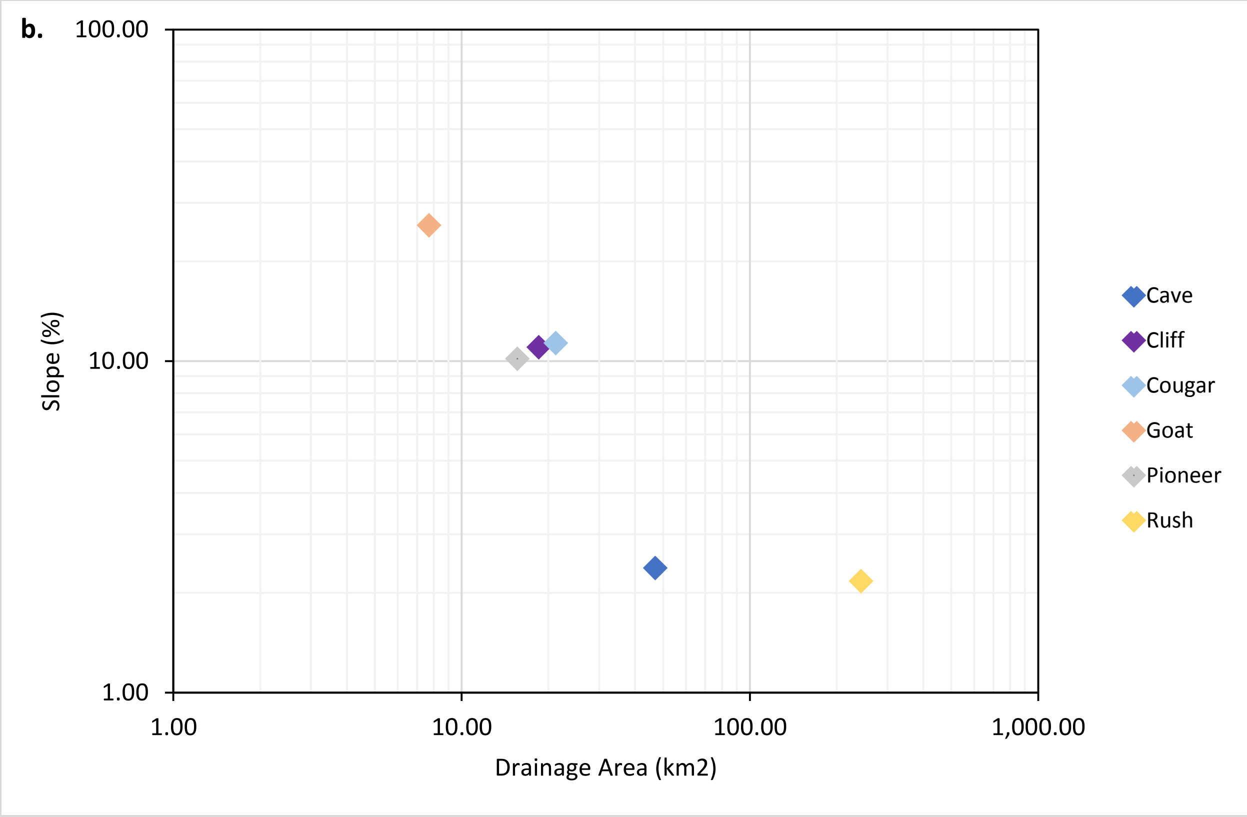
Figure 24. Log-log plots of all field measured tributaries comparing the consistency of scaling relationships across tributaries. Descriptive equations are shown across top of graphs (Cabin, West Cave, East Crooked, Pioneer left to right). (a.) Bankfull width compared to drainage area, showing consistent scaling between West Cave, East Crooked, and Pioneer Creeks matching that of previous studies and Cabin Creek deviating from the trend. Low and high values of W – A relation slope found by previous studies are shown by grey lines with equation indicating exponent of respective lines; (b.) bankfull depth compared to drainage area, showing relatively consistent scaling between West Cave, East Crooked, and Pioneer Creeks within the range of previous studies and Cabin again deviating; D – A relation slope found by previous studies shown by grey line with equation indicating exponent; (c.) slope compared to drainage area, showing no consistent scaling across tributaries, though all show a negative correlation; (d.) median grain size (D50) compared to drainage area, showing Cabin, West Cave, and East Crooked coarsening downstream but with no consistent scaling, and Pioneer fining downstream; (e.) median grain size compared to slope, showing Cabin and West Cave fining with increasing slope and East Crooked and Pioneer coarsening with increased slope. No consistency between tributaries.

4.2 Minshall Sites

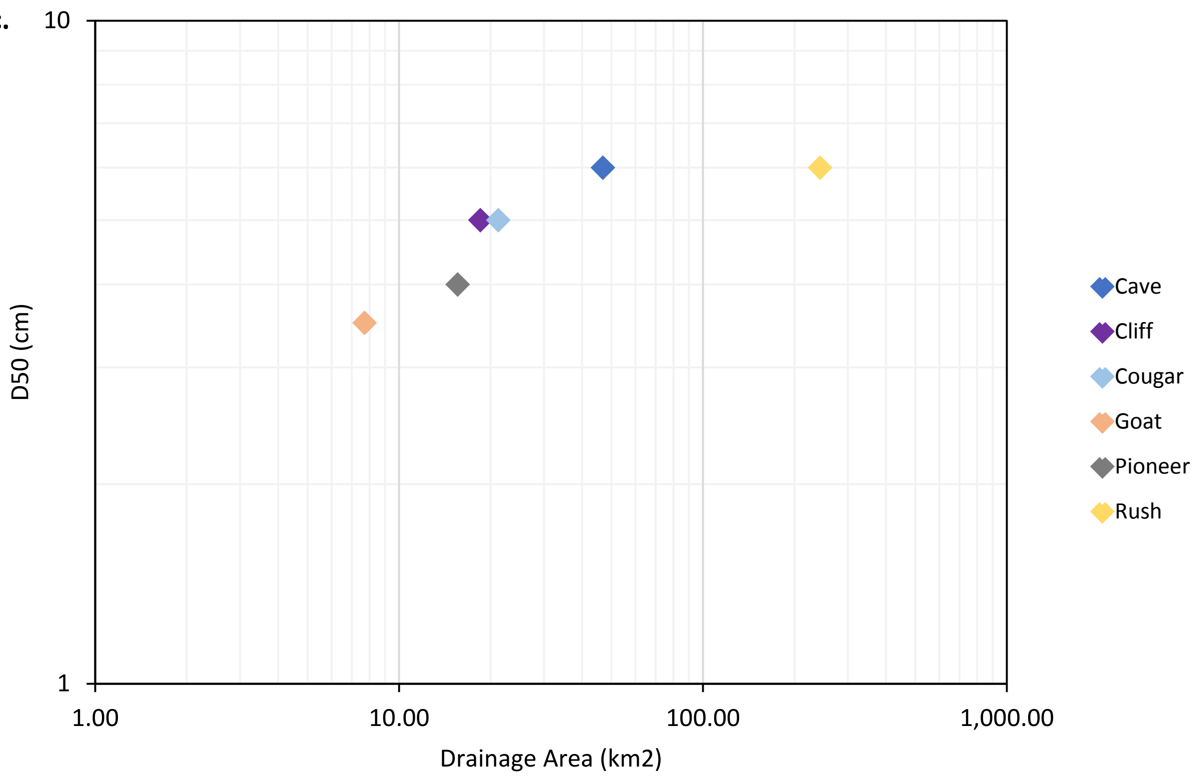
Annual sampling at the same locations on six tributaries of Big Creek has resulted in a long-term data set of stream ecology and channel morphology descriptors, of which the 2013 measurements were analyzed in this study. Because this data is limited to a single reach for each stream, only general trends can be inferred with respect to relative differences in drainage size and slope at each data point. Also note that many of these sites are located close to the confluence with Big Creek and are sometimes located on alluvial fans. This will have significant impact on all measured parameters relative to those measured in upstream, bedrock reaches.

- Bankfull width shows a progressive increase with drainage area, and appears to follow a fairly linear trend (Figure 25a).
- Channel slope shows a progressive decrease as drainage area increases (Figure 25b).
- Median grain size also tends to increase with drainage area (Figure 25c), appearing to closely mirror the slope-drainage area plot if reflected across the horizontal axis.
- Median grain size plotted with slope yields a more linear relationship with grain size decreasing as slope increases (Figure 25d).


a.
100.00
10.00
1.00
1.00
10.00
100.00
1,000.00
Bankfull Width (m)
Drainage Area (km2)
Cave
Cliff
Cougar
Goat
Pioneer
Rush


b.
100.00
10.00
1.00
1.00
10.00
100.00
1,000.00
Slope (%)
Drainage Area (km2)
Cave
Cliff
Cougar
Goat
Pioneer
Rush

c.


10
1
D50 (cm)
1.00
10.00
100.00
1,000.00
Drainage Area (km2)
Cave
Cliff
Cougar
Goat
Pioneer
Rush

d.

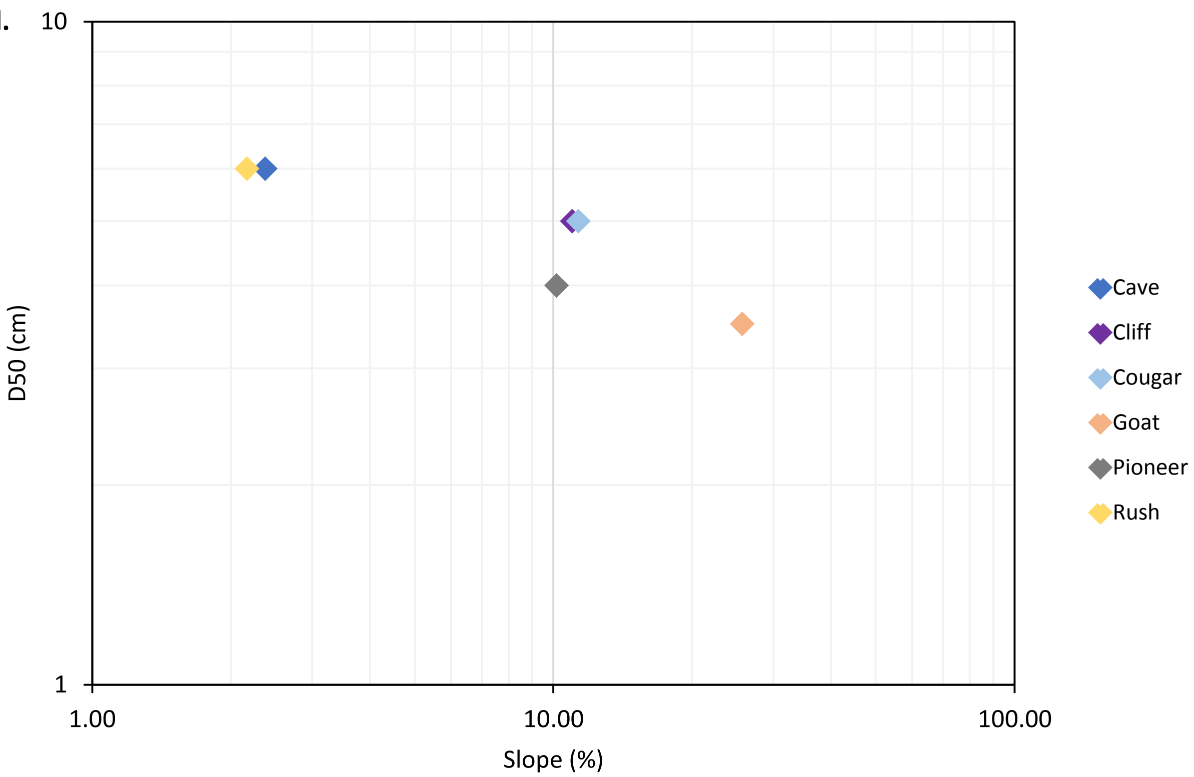

10
1
D50 (cm)
1.00
10.00
100.00
Slope (%)
Cave
Cliff
Cougar
Goat
Pioneer
Rush

Figure 25. Log-log plots of response and driving variables for Minshall site streams. (a.) Bankfull width compared to drainage area, showing a positive correlation; (b.) slope compared to drainage area, showing a negative correlation; (c.) median size (D50) compared to drainage area, showing a positive correlation; (d.) median grain size compared to slope, showing a negative correlation.

4.3 DEM Analysis

4.3.1 Channel Steepness & Concavity

Most tributaries of Big Creek can be separated into three distinct families based on their steepness values, after normalizing for a fixed concavity of 0.45 (k_{sn} values): high, moderate, and low (Figure 26). No fits or analyses were done for ten of the 35 streams (including Big Creek) due to inability to discern patterns or transitions to a fluvial regime. Watershed extent of the analyzed streams is shown in Figure 27. Individual slope-area plots are located in Appendix C.

- High steepness tributaries have k_{sn} values ranging between 123 and 246 and generally have higher concavity indices (seven of the ten have concavities above 0.7) (Table 2).
- Moderate steepness tributaries have k_{sn} values ranging between 85.7 and 108 and have concavity indices in the low (<0.4) and moderate (0.4 – 0.7) ranges (Table 2).
- Low steepness tributaries have k_{sn} values ranging between 47.6 and 79.5 and generally have concavity indices in the low (<0.4) and moderate ranges (0.4 – 0.7) (Table 2).
- Lithology appears to correlate somewhat with relative steepness. Streams with high steepness are found in diverse lithologies (five predominantly in softer Tertiary rocks, three in basins with a fairly even split between soft and hard lithologies, and two predominantly in harder Meso- and Neoproterozoic metasediments) (Figure 28). Tributaries with low and moderate steepness are predominantly in softer Tertiary rocks

(three of the six low steepness tributaries—two flow through significant reaches of Quaternary sediments, and four of the five moderate) (Figures 29 & 30).

- Most streams within the basin show a transition from hillslope to fluvial processes at a drainage area of ~10^5 m^2, but ten tributaries (Burnt, Pioneer, Rush, Cabin, Canyon, Cave, Buck, Monumental, Big Ramey, and Beaver) do not transition until a drainage area of 10^6 m^2 or greater. These streams all have post-Eocene faulting within their basins (Figure 31). Eight of these have high relative steepness, and two have low relative steepness.
- Three (Eagan, Bar, and East Crooked) of the ten streams not analyzed due to noisy slope-area data flow along post-Eocene fault traces for much of their lengths (Figure 31b).

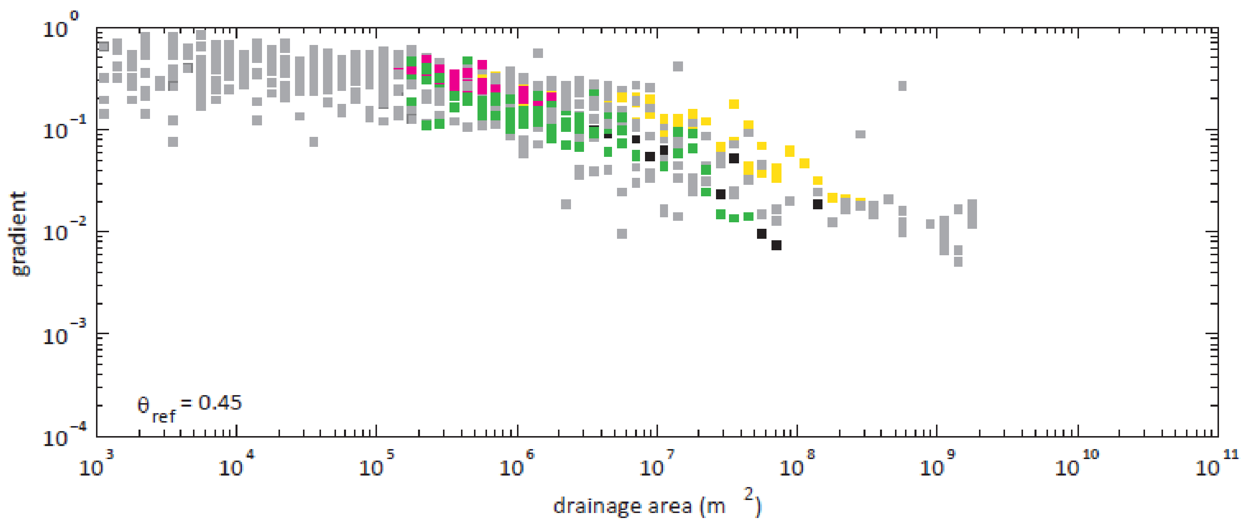


Figure 26. Log bin averages of slope-area data of 24 tributaries and Big Creek extracted from a DEM of the basin and grouped according to relative steepness. Only fluvial reaches were used to determine channel steepness and concavity, not entire channel lengths (individual plots showing fitted reaches are in Appendix C). For fitted reaches: green is low steepness, pink is moderate steepness, yellow is high steepness. Grey squares are sections of channels without fits, and black is Big Creek data.

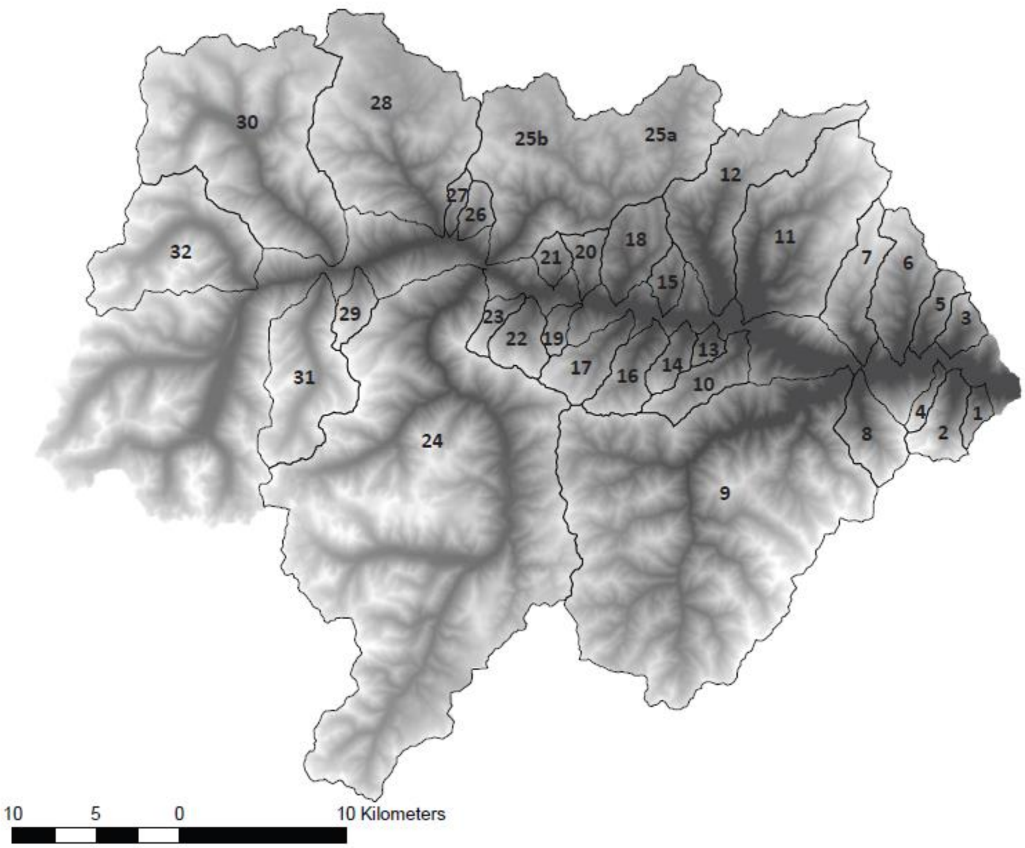


Figure 27. DEM of the basin showing tributary watersheds from which slope data was extracted. Numbers correspond to those in Table 2.

Relative Steepness	Map Number	Name	Drainage Area (km2)	K_{sn}	Concavity Index θ	Lithology	Aspect
High	2	Burnt	11.7	246	1.9	**Ym**, Ti	Northern
	3	Dunce	6.5	149	0.38	**Ti**	Southern
	8	Pioneer	15.9	195	0.7	Ym, **Ti**, **Ym**, **Zi**, Q	Northern
	9	Rush	243.4	123	1	**Tv**, **Ti**, **Tv**, **Ym**, **Ti**, **Zi**, **Q**	Northern
	10	Canyon	13.6	152	0.34	Tv, **Ym**, **Zi**, Tv	Northern
	11	Cabin	64.4	155	4.1	K, **Ti**, **Ym**, Q	Southern
	12	Cave	47.1	133	1.4	K, Ti, Q, **Ti**, **Q**, **Ti**, **Ym**, **Tv**	Southern
	16	Buck	13.5	141	1.2	Tv, **Zm**, **Tv**	Northern
	17	Fawn	14	130	0.27	Tv, **Zm**, **Tv**, Zi	Northern
	28	Big Ramey	86.8	138	1.3	**Ti**, **Zi**, **Zm**, Ym	Southern
Moderate	12a	West Cave		85.7	0.34	**Ti**, Q, Ti, Ym, Tv	Southern
	13	Coyote	3.2	94.4	0.4	**Tv**	Northern
	14	Doe	6.7	89.6	0.35	**Tv**	Northern
	19	Bull	4	108	0.5	Zm, Zi, **Tv**, Zm	Northern
	21	Acorn	4.7	95.1	0.4	**Zi**, Q	Southern
Low	5	Goat	7.9	71.4	0.59	**Ti**, Q	Southern
	15	Garden	5.6	71.5	0.36	Ti, **Tv**, **Ym**, Zi, Tv, Q	Southern
	18	Coxey	16.8	68.5	0.28	Ym, **Ti**, **Ym**, **Q**, **Zi**, **Ti**, Q	Southern
	25b	West Crooked	102.6	47.6	0.56	**Ti**, Ym, Zi	Southern
	24	Monumental	325.6	57.5	0.94	**Tv**, Ym, Zi, Q	Northern
	27	Whiskey	3.2	72.1	0.55	**Zi**, Ym	Southern
	30	Beaver	110.6	79.5	1.5	Ti, **Q**, **Zi**, **Ym**, Zi, Ym	Southern
	31	Little Marble	39.1	63.3	0.67	Tv, **Q**, Ym	Northern
	32	Smith	52.4	76	0.27	K, **Q**, Ym	Southern
	-	Big	1540	72.3	0.46	Zi, Ym, Tv, Ti, Q, Zm	East-West
No fits	1	Breeching	3.8	-	-	Ym, Ti	Northern
	4	Eagan	0.3	-	-	Ym, Zi, Ym, Ti	Northern
	6	Cougar	21.4	-	-	Ti, Ym	Southern
	7	Cliff	18.8	-	-	Ti, Ym	Southern
	20	Lime	6.2	-	-	Ym, Zm, Zi	Southern
	22	Routson	10.8	-	-	Zm, Ym, Tv, Zi	Northern
	23	Bar	5	-	-	Ym, Zi, Tv, Zi	Northern
	26	Little Ramey	4.9	-	-	Zi, Ym, Zi	Southern
	25a	East Crooked	102.6	-	-	Ti, Ym, Zi	Southern
	29	Gold	6.8	-	-	Ym	Northern

Table 2. Table with tributaries slope data was extracted for, numbered according to distance upstream of the Big Creek confluence. Crooked Creek (25a & b) and Cave Creek (12 & 12a) have two values for average K_{sn} and θ, corresponding to the different forks. Lithology is listed in downstream order with rock types of reach fits in bold (Ym: Mesoproterozoic metasedimentary; Zm: Neoproterozoic metasediments and volcanics; Zi: Neoproterozoic intrusives; Ti: Eocene intrusives; Tv: Eocene volcanics, Q: Quaternary sediments).

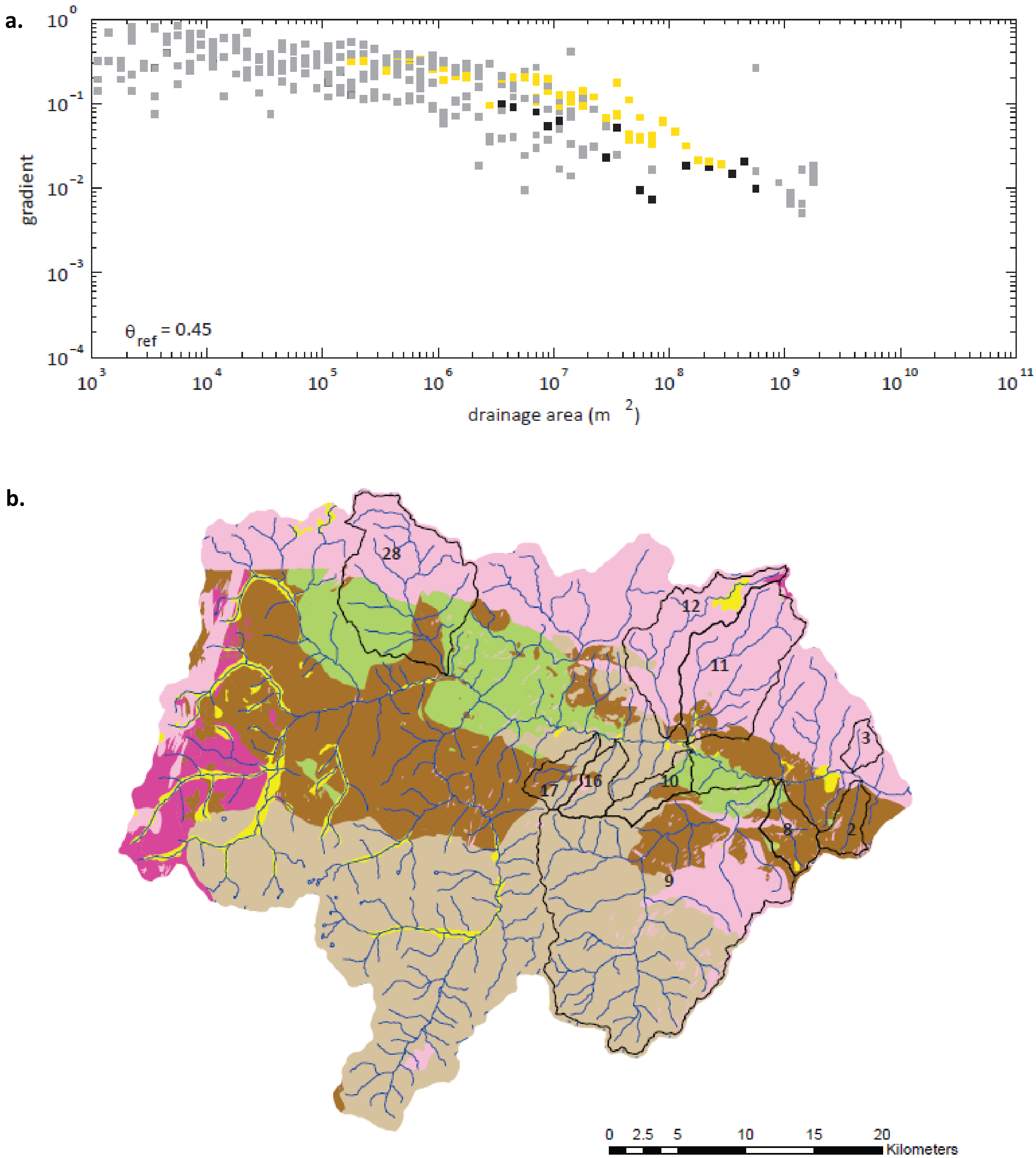
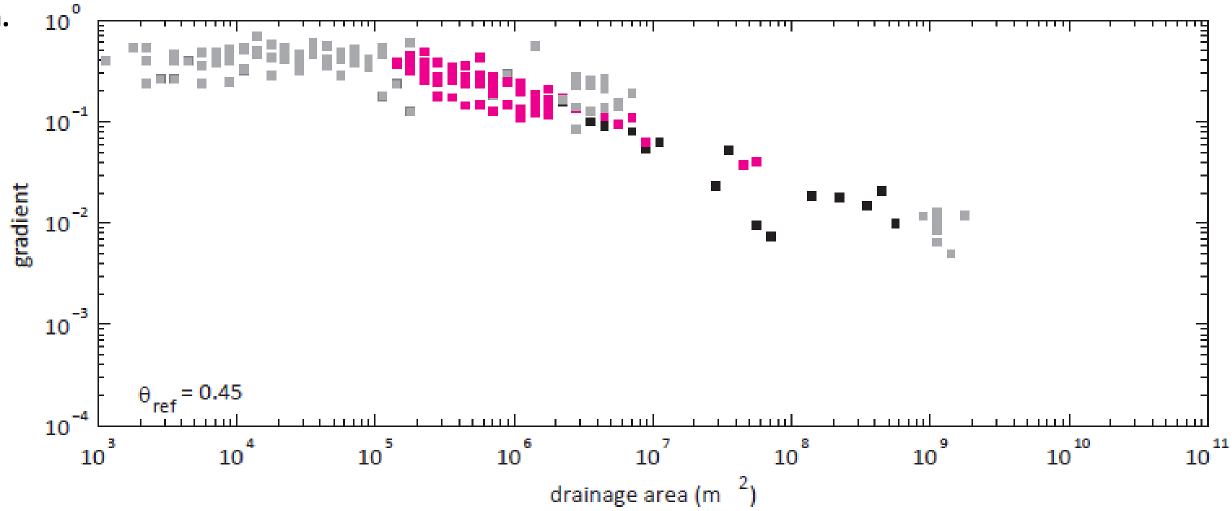


Figure 28. (a.) High steepness tributary slope - area data extracted from 10 m DEM of Big Creek basin; fitted reaches shown in yellow, reaches with no fits are in grey (squares are log-bin averages of slope – area data). Big Creek mainstem data shown in black. (b.) Merged Stewart et al., 2013 and Lund, et al., 2005 geologic maps of Big Creek basin with stream network shown. Steep tributaries are outlined in black and numbered after Table 2. Geology grouped according to hardness (after Lifton, 2005); in decreasing order of resistance: brown: Mesoproterozoic metasedimentary and Neoproterozoic metasediments and metavolcanics; light green: Neoproterozoic intrusives; bright pink: Cretaceous intrusives; light pink: Eocene intrusives; light tan: Eocene volcanics.

a.



b.

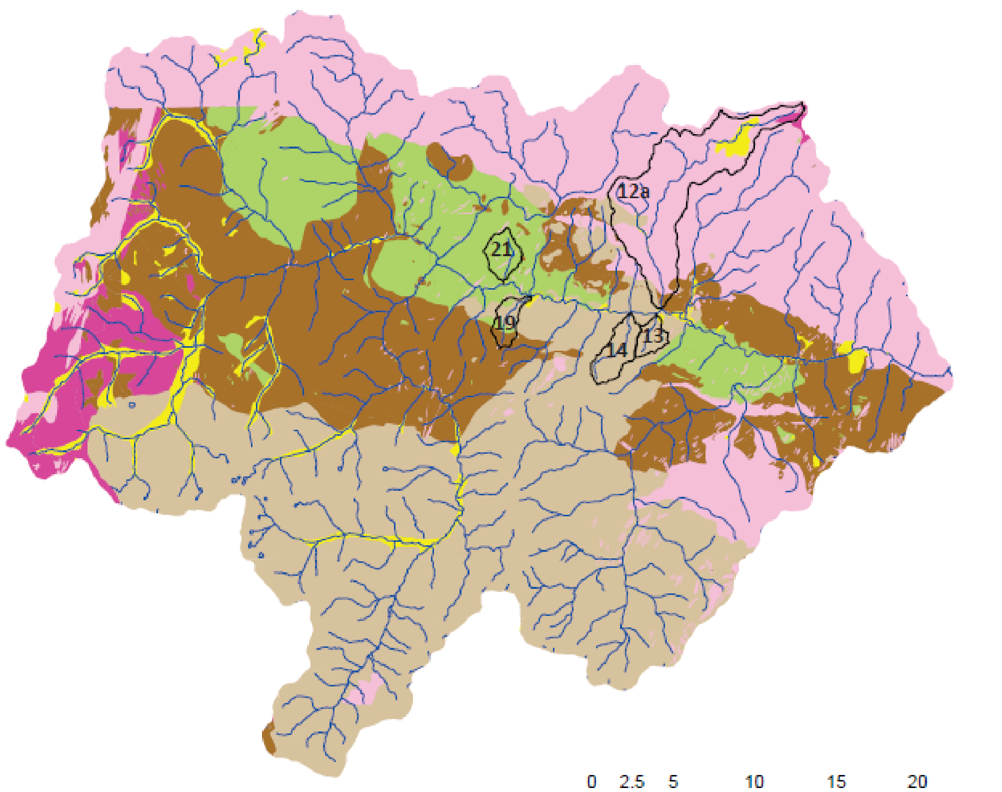
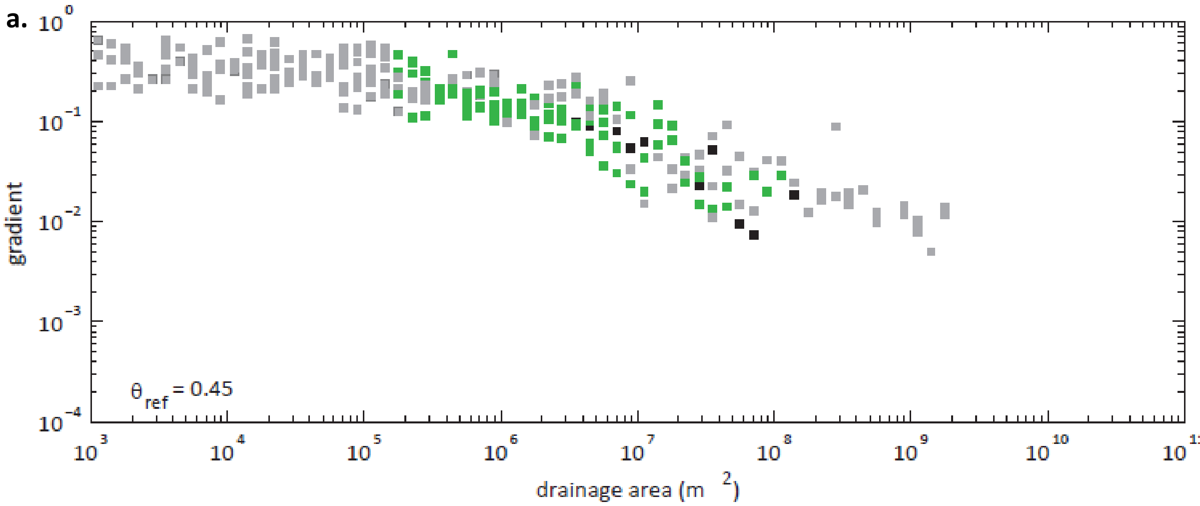


Figure 29. (a.) Moderate steepness tributary slope – area data extracted from 10 m DEM of Big Creek basin; fitted reaches shown in pink, no fit reaches are in grey (squares are log-bin averages of slope – area data). Big Creek mainstem data shown in black. (b.) Merged Stewart et al., 2013 and Lund, et al., 2005 geologic maps of Big Creek basin with stream network shown. Moderate steepness tributaries are outlined in black and numbered after Table 2. Geology grouped according to hardness (after Lifton, 2005); coloring same as Fig. 28.



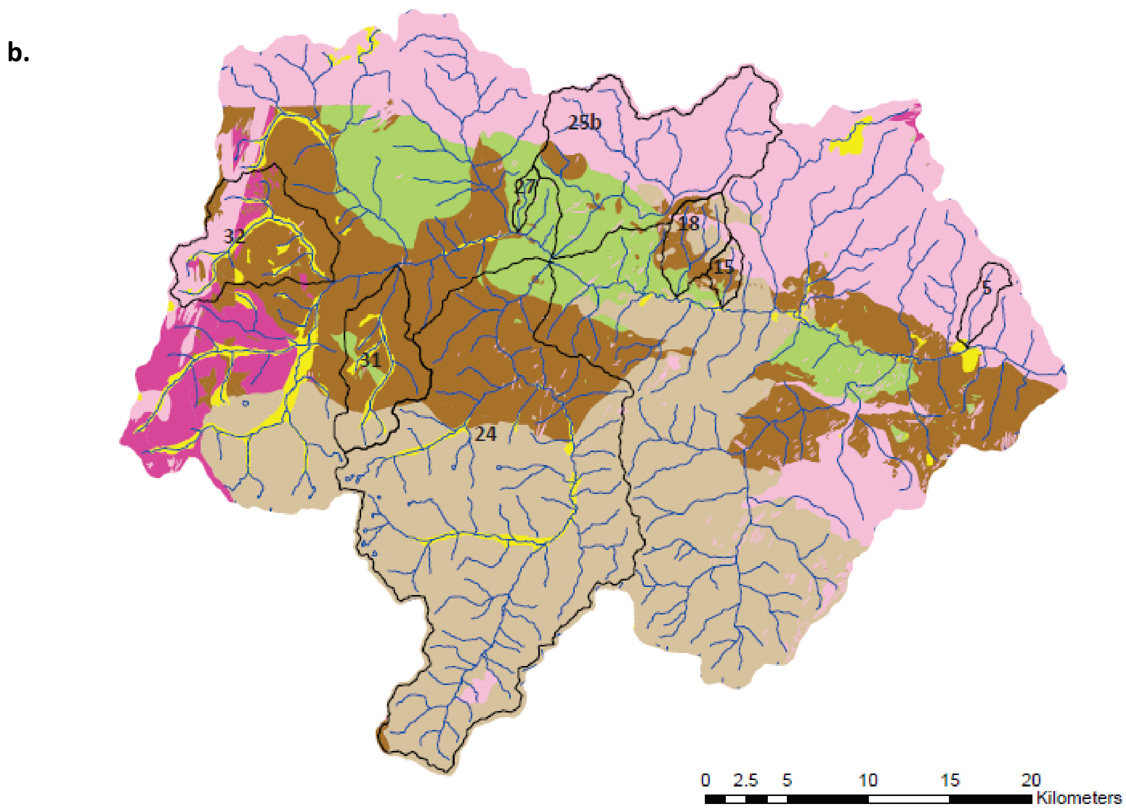
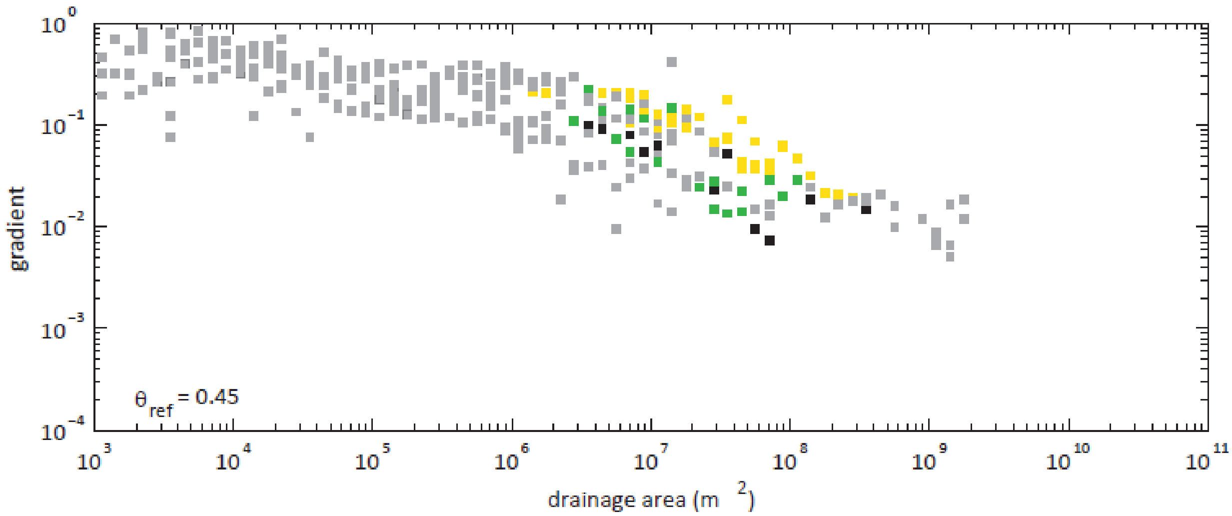


Figure 30. (a.) Low steepness tributary slope – area data extracted from 10 m DEM of Big Creek basin; fitted reaches shown in green, reaches with no fits are in grey (squares are log-bin averages of slope – area data). Big Creek mainstem data shown in black. (b.) Merged Stewart et al., 2013 and Lund, et al., 2005 geologic maps of Big Creek basin with stream network shown. Low slope tributaries are outlined in black and numbered after Table 2. Geology grouped according to hardness (after Lifton, 2005); coloring same as Fig. 28.

a.



b.

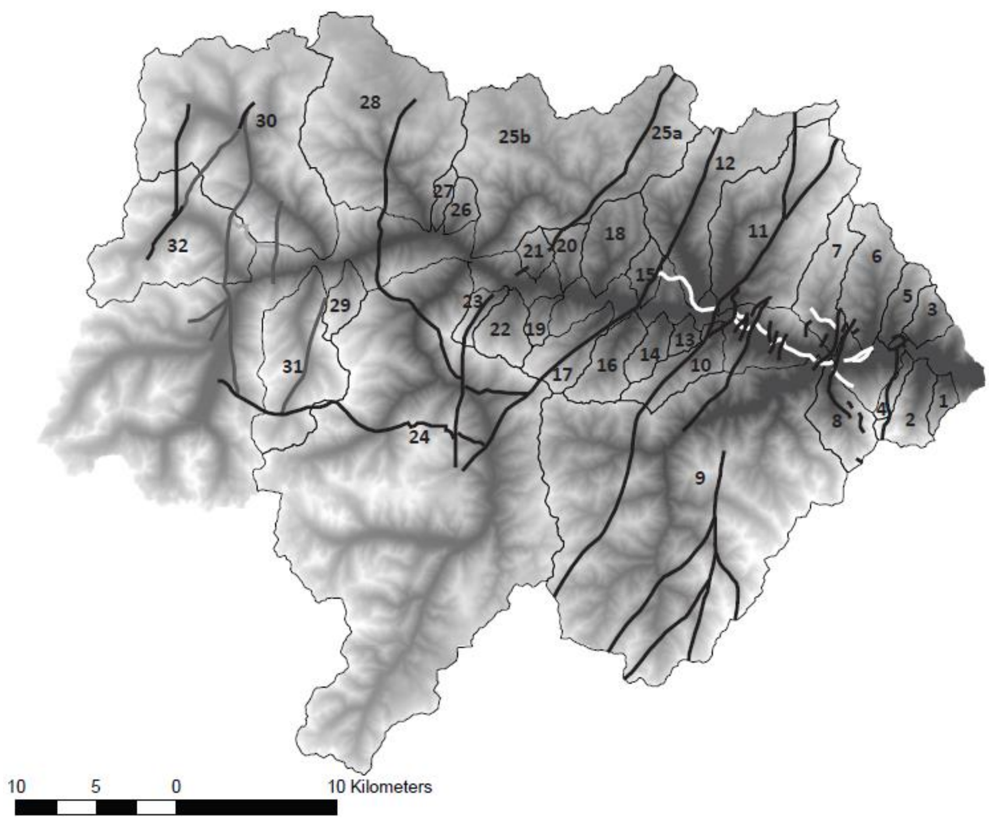


Figure 31. (a.) Slope – area data for streams within the Big Creek basin which transition from hillslope to fluvial processes at 10^6 m^2 drainage area or higher (squares are log bin averages of slope – area data). Green indicates low steepness streams [Monumental (24) and Beaver(30)], yellow high steepness [Burnt (4), Pioneer (8), Rush (9), Canyon (10), Cabin (11) Cave (12), Buck (16), and Big Ramey (28)]. Big Creek mainstem is in black. (b.) DEM of Big Creek basin with tributary drainages numbered according to Table 2 and fault traces colored according to age of most recent displacement (black: post-Eocene, dark gray: post-Cretaceous, light gray: pre-Cretaceous, white: Neoproterozoic). Notice that all streams which transition to fluvial regimes at higher drainage areas (with the exception of Buck, where a fault forms a drainage divide) have post-Eocene faulting within their individual basins.

4.3.2 Long Profiles

Many longitudinal profiles of channels in the Big Creek basin display significant deviations from the mature concave-up profile (Figure 32). Obvious knickpoints are observed in channels of all steepnesses (Figure 33), but several commonalities are observed in profiles with pronounced knickpoints.

- Tributaries in the lower 7 km of the drainage basin all display knickpoints in the lower section of their profiles (Figure 34).
- Knickpoints appear to be more pronounced in tributaries that cross faults with post-Eocene displacement, rather than flowing fault-parallel (Figure 35).
- Streams which flow fault-parallel predominantly have high steepness, while those which flow across faults are fairly evenly split between high and low steepness (Figure 35).
- Lithology changes from Eocene igneous rocks to Proterozoic metasedimentary or metaigneous rocks correspond to pronounced knickpoints in some channels, though others show no changes at points of similar lithology changes (Figure 36).

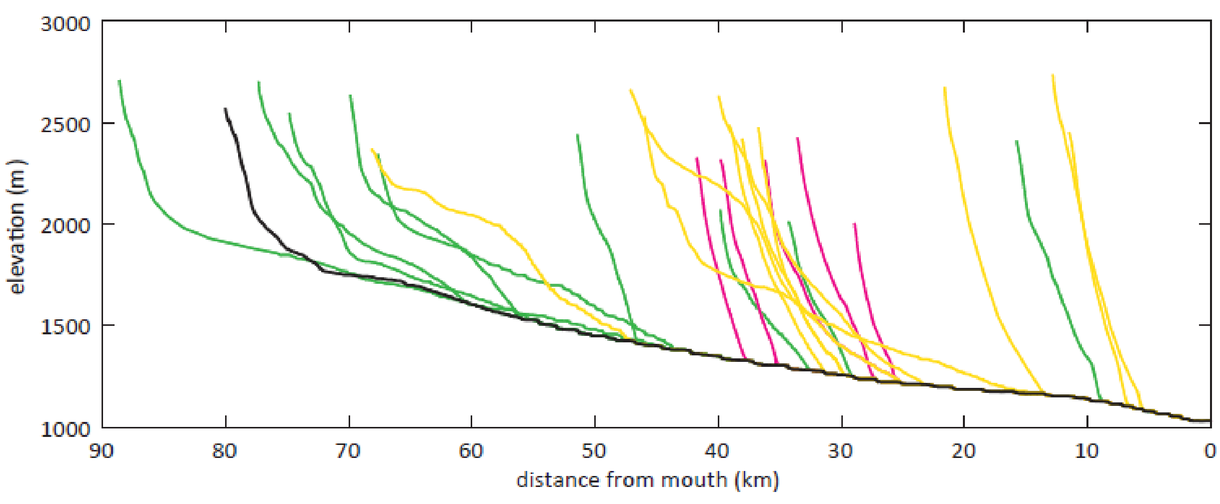
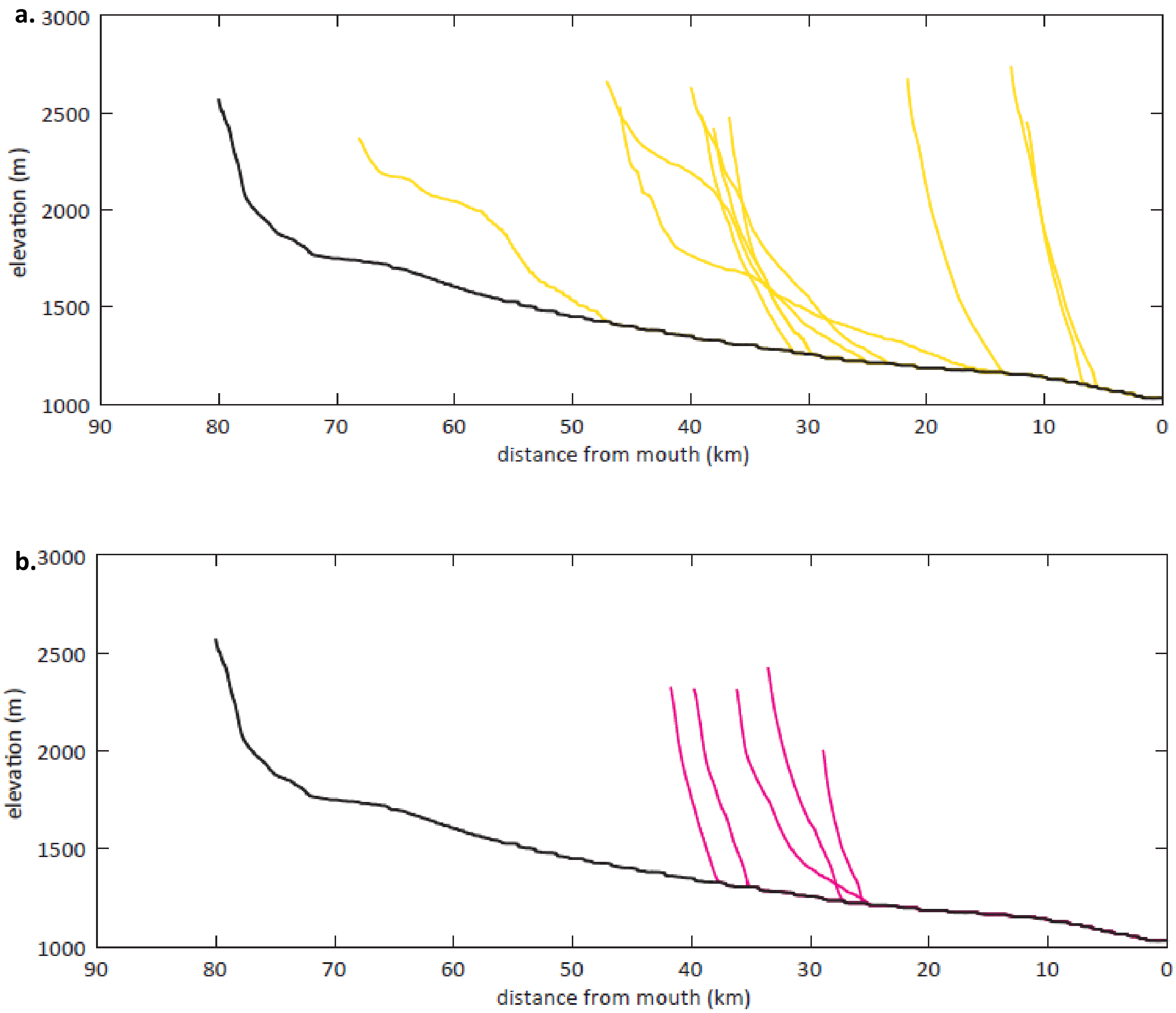


Figure 32. Longitudinal profiles of all tributaries for which slope data were extracted, colored according to relative steepness, as in Table 2. Big Creek is in black.


a.
b.
3000
2500
2000
1500
1000
elevation (m)
90
80
70
60
50
40
30
20
10
0
distance from mouth (km)

c.

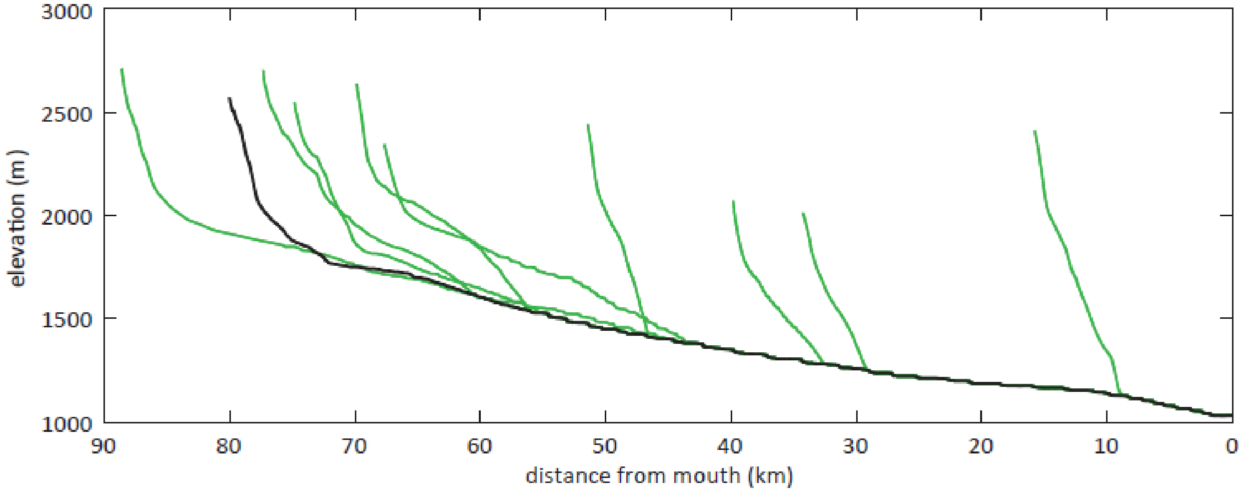


Figure 33. Longitudinal profiles separated according to relative steepness, with the Big Creek mainstem profile in black. (a.) Steep tributaries in yellow are predominantly located in the lower basin and are of varied length and drainage area. Several show pronounced convex-up sections. (b.) Moderate profiles are clustered around 30 km upstream of the Big Creek confluence, and all are of a similar length and drainage area. (c.) Low steepness tributaries are mostly found in the upper basin and are of varied length and drainage area. Several show obvious convex-up reaches and knickpoints.

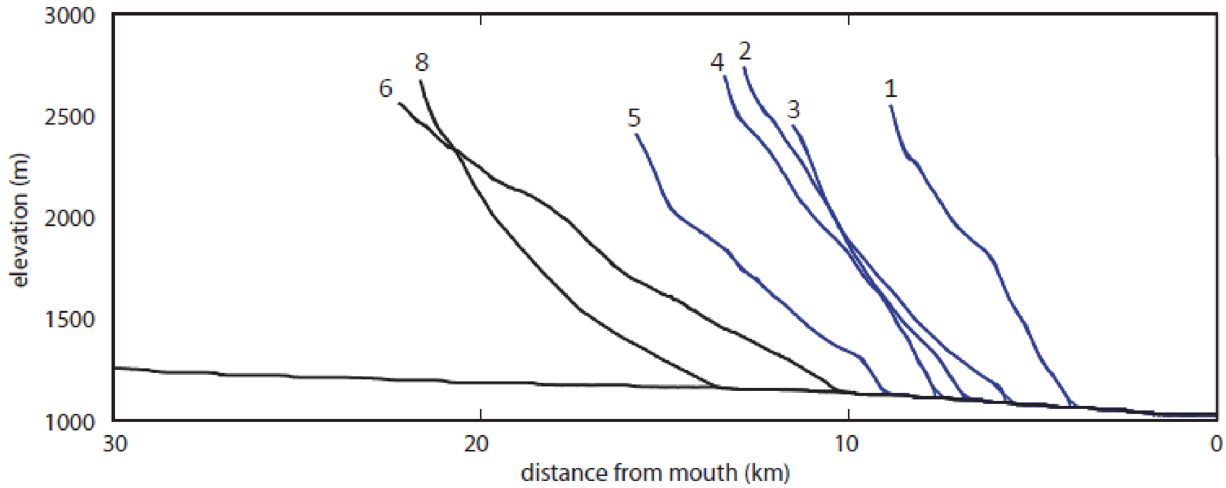
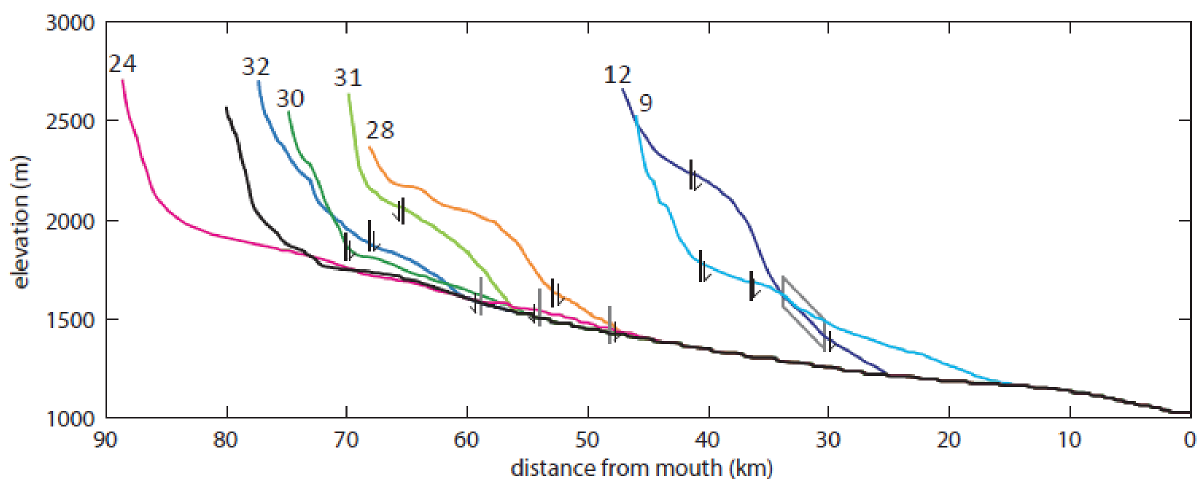


Figure 34. Longitudinal profiles of tributaries on the lower portion of Big Creek, numbers correspond to Table 2 and previous figures. Streams downstream of the Soldier Bar landslide are shown in blue, those above are in black. Knickpoints can be seen on the profiles of streams below the landslide at different distances upstream of their confluences with Big Creek, while profiles of streams located above the landslide do not have pronounced knickpoints in their lower reaches.

a.



b.

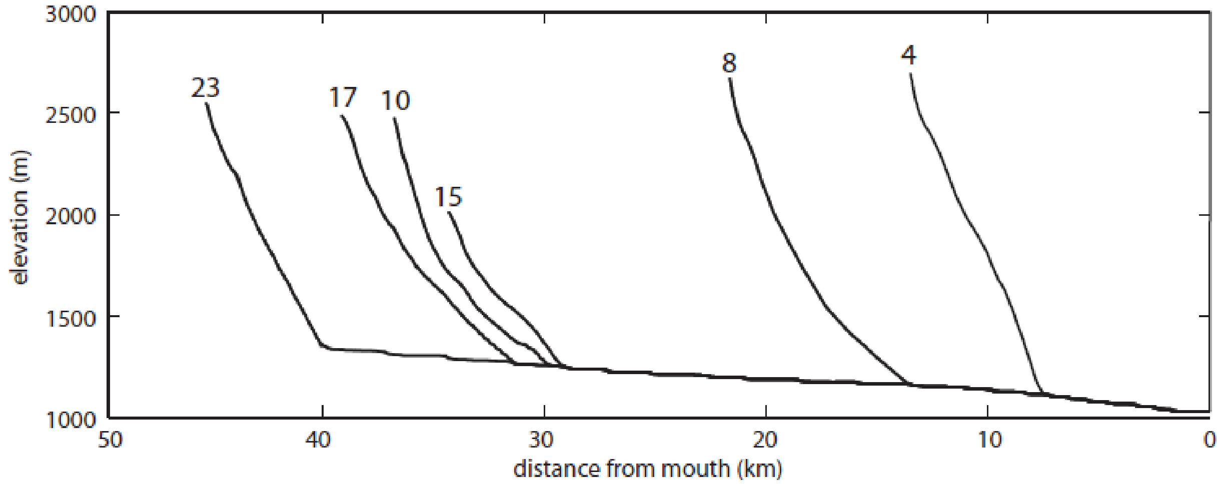


Figure 35. Tributaries are numbered according to Table 2. Refer to Figure 31 for DEM with fault traces. (a.) Longitudinal profiles of streams which cross faults with post-Eocene displacement. Black lines show approximate location of fault along profile and arrows show sense of displacement. Monumental (24) has faults shown in gray. Box on Cave (12) shows area where stream flows fault-parallel, with end of box marking location stream diverges from fault. Many areas of convexity in the profiles correspond to fault locations. (b.) Longitudinal profiles of streams which flow fault-parallel are shown. Streams tend to be steep and have minimal convexity.

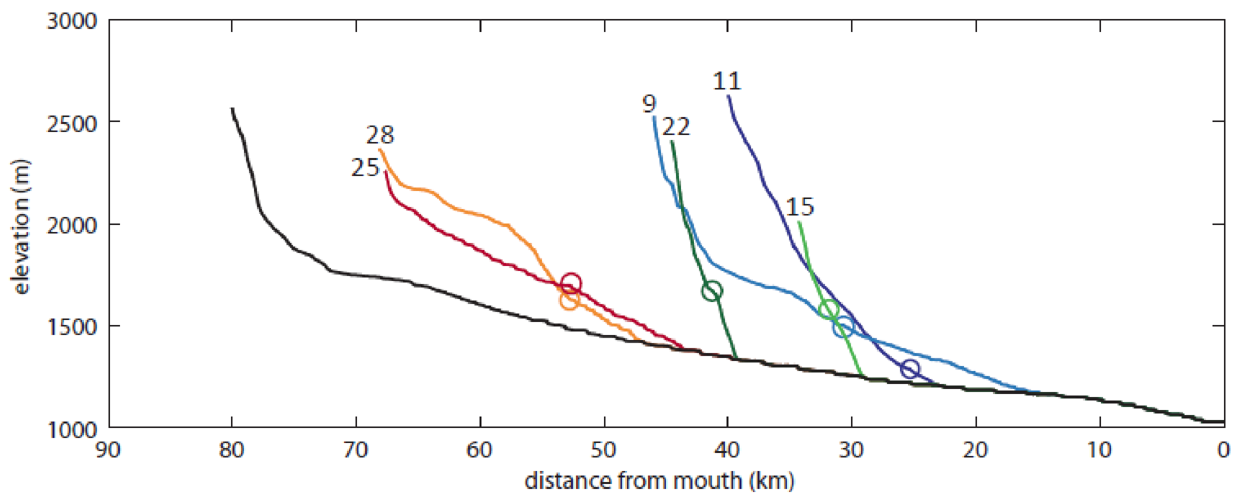


Figure 36. Longitudinal profiles of streams showing pronounced knickpoints (circled in same color as profile) which correspond to lithologic boundaries. Big Creek mainstem shown in black; numbers correspond to Table 2. Lithology changes at knickpoints are as follows (in order of downstream progression): Rush (9): Eocene volcanics to Mesoproterozoic metasediments; Cabin (11): Eocene intrusives to Quaternary sediments; Garden (15): Mesoproterozoic metasediments to Neoproterozoic intrusives; Routson (22): Mesoproterzoic metasediments to Eocene volcanics to Neoproterozoic intrusives (both transitions occur over a short distance); Crooked (25): Mesoproterozoic metasediments to Neoproterozoic intrusives; Big Ramey (28): Neoproterozoic intrusives to Neoproterozoic metasediments (change is due to fault).

Chapter 5. Discussion

5.1 Introduction

The following discussion is divided into six sections. The first three address scaling of hydraulic variables, while the fourth discusses longitudinal profiles within the Big Creek basin. Next, general conclusions are provided and ultimately suggestions are made for future work, both within the Big Creek basin and more generally in the field of bedrock channel geomorphology.

5.2 Width and Depth

Both width- and depth-area relationships are correlated within and across tributaries of Big Creek. The strong correlation of width vs. drainage area and depth vs. drainage area demonstrate that discharge is the dominant driving force of these response variables, supporting published work stating bedrock channels may behave analogously to alluvial channels with respect to these parameters (Wohl et al., 2004). Both along-channel and single point field measurements support this conclusion. Another point to consider is that bedrock was seldom observed in the bed and (more importantly) in the banks. This suggests that though these are steep mountain channels, their widths are not fixed by solid rock but rather by the transport capacity of the channel. For this reason, the scaling of width and depth will follow the form of other alluvial channels where form is determined by transport capacity during storms.

Exponents of the power-law relationships between drainage area/discharge and bankfull width/bankfull depth are consistent with previously published ranges for three of the four tributaries (Montgomery & Gran, 2001; Snyder et al., 2003; Golden & Springer, 2006; Whittaker et al., 2007; Wohl & Merritt, 2008; Wohl & David, 2008). Cabin Creek displays a noticeably higher slope (designated by the exponent) for its width-area equation and lower slope for its depth-area equation. Given the limited sampling of Cabin, and the placement of measurement sites, it is likely that these relationships are not representative of the channel as a whole. The sites with the largest and second largest drainage areas are both located in areas mapped as Quaternary alluvium (Stuart et al., 2013), meaning that only one site lies in the bedrock portion of the stream and the lower alluvial-dominated reaches are drastically over-represented for this stream. Additionally, only a small range of drainage areas were sampled (28 to 64 km^2) while a much broader range of drainage areas is represented in the other measurement sets, further calling into question the validity of these relationships.

5.3 Slope

Field measurements of channel slope support a negative correlation between drainage area and slope. Along-channel measurements of Pioneer and West Cave show a good correlation, and Cabin and Crooked Creeks also correlate, though not as well. This suggests field measurements were taken downstream of the transition from hillslope to fluvial processes. Single point measurements at confluences (the Minshall sites) also show a negative correlation between slope and area. Unlike width and depth, channel slope is much slower to adjust to flow events and thus the deviation from well-established scaling relationships provides a good indicator of legacy influences such as glaciers, landslides or lithological contrasts.

5.4 Grain Size

Plots of median grain size vs. drainage area show most tributaries coarsening downstream, suggesting that most streams are strongly coupled with adjacent hillslopes. Previous work has shown input from surrounding hillslopes can disrupt predicted downstream fining in mountainous streams (Church, 2002). In most Big Creek tributaries, hillslope relief increases downstream, potentially increasing the size of clasts found in the channel. Pioneer Creek, however, fines in the downstream direction, likely due to communition of in-channel grains. Single point measurements of multiple streams from reaches close to confluences also show a tendency for coarser median grain sizes in tributaries with larger drainage areas, indicating that hillslope-coupling may be the norm rather than exception in this landscape. Also, decreasing channel slopes may limit transport capacity, resulting in larger areas being more dominated by deposition. This would be true if the sediment source was either from mass movements such as debris flows or from fluvial events such as spring runoff.

Median grain size and channel slope correlate well in Cabin and West Cave Creeks, both showing fining with increasing slope. Pioneer correlates relatively well and displays coarsening with increasing slope. East Crooked Creek, though, shows extreme variability in median grain size when compared to channel slope. Point measurements demonstrate a propensity for median grain size to decrease with increased channel slope. It seems channel gradient may correlate most strongly with median grain size, but inputs from hillslopes may have obscured this relationship in some tributaries. More data are required to better evaluate these hypotheses.

5.5 Channel Steepness & Concavity

Channel steepness within the Big Creek basin is variable. Dividing the tributaries and mainstem into three separate steepness families allows for correlations with lithology, faulting, and concavity to be recognized.

Lifton (2005), using Schmidt hammer rebound measurements, found that within the Big Creek basin, Mesoproterozoic metasediments were the most resistant lithology, followed by

Neoproterozoic intrusives, Eocene intrusives, and Eocene volcanics in descending order of hardness. He also found the strength of all lithologies, with the exception of the Mesoproterozoic metasediments, varied greatly depending on aspect, with south-facing rocks being significantly softer and less resistant to erosion, which he inferred to be related to repetitive freeze-thaw cycles. Despite the variation in lithological resistance, he found no correlation between channel lithology and channel slope. This appears to be somewhat contradicted by the findings of this study. Steeper channels are found in various lithologies within the basin (two in predominantly hard lithologies, three have basins fairly evenly split between hard and soft rocks, and five in predominantly soft rocks). However, channels with moderate and low steepnesses are predominantly found in regions where softer Tertiary rocks dominate (four of the five moderate steepness and three of the six low steepness streams—excluding the two with significant reaches of Quaternary deposits). This may suggest stream steepness is responding to rock hardness in the Big Creek basin, as well as other factors, such as uplift. It is likely the use of a DEM within improved resolution (10 m compared to 30 m used by Lifton, 2005).

Post-Eocene faulting is also likely influencing channel steepness. Steeper streams are clustered near faults with displacement post-dating emplacement of the Eocene Challis volcanics. Eight of the ten streams with high relative steepness have post-Eocene normal faults cutting their basins, and an additional one has a divide formed by a fault trace. Fault-parallel channels may tend to be steeper than those which flow more directly across a fault. Of the six fault-parallel streams, slope-area data was analyzed for four, three of which are included in the high steepness category. Six streams which flow across faults were analyzed and are evenly split between the high and low steepness categories. As the majority of these streams flow through relatively soft Tertiary rocks or have basins with a relatively equal distribution of soft and hard rocks, it is inferred that relatively recent faulting has contributed more strongly than lithology to the steepness of these tributaries.

Another possible effect of post-Eocene faulting is shifting the hillslope-fluvial transition to a higher drainage area. Ten of the 24 tributaries from which slope-area data were analyzed have hillslope-fluvial transitions at 10^6 m^2 or greater, compared with the other 14 which transition at ~10^5 m^2. Of these ten streams, nine have post-Eocene faults mapped within their basins, and the remaining one has a fault mapped along its western drainage divide. Relatively recent faulting may have disrupted these channels, suppressing the roll-over from a hillslope to fluvial regime until a higher drainage area has been reached.

Steepness and concavity correlate somewhat in tributaries of Big Creek. Tributaries with high relative steepness predominantly have high concavities (seven of the ten have concavity indices above 0.7). High concavity is linked to decreases in rock strength in the downstream direction (Kirby & Whipple, 2001), slowing rock uplift rates in the downstream direction, and transitions to alluvial channels (Whipple, 2004). The lateral margins of the basin are predominantly Eocene igneous lithologies, while the central area is primarily Proterozoic units, meaning that many streams in the basin have stronger rocks in the lower reaches compared to upper reaches; therefore, the high concavities in these streams do not derive from downstream lithology changes. Three of these stream (Pioneer, Rush, and Cabin) have Quaternary deposits mapped at their confluences with Big Creek, suggesting a transition to an alluvial rather than bedrock channel may be contributing to their high concavities. As stated earlier, most of the high steepness streams have post-Eocene faults within their basins which are likely also contributing to the observed concavities.

Streams with low and moderate relative steepness generally have low (<0.4) and moderate concavities (0.4 – 0.7). The fitted reaches of channels with moderate concavities are contained within a single lithology (which varies from stream to stream) and do not cross any fault boundaries. Whipple (2004) linked channels in homogeneous lithologies in areas of active and uniform uplift rates to moderate concavities. It is inferred that channels with moderate concavities in the Big Creek basin are a reflection of this premise. Low concavities have been linked to short, steep drainages dominated by debris flows (Brocklehurst & Whipple, 2002) and increases in incision rate or rock strength in the downstream direction (Kirby & Whipple, 2001). Evidence of debris flow input can be seen on several channels, including West Cave Creek (θ = 0.34), in the form of debris flow chutes directed into the streams. This is supported by the inference of hillslope coupling seen in median grain sizes on this stream. Though incision rates have not been quantified on any tributaries of Big Creek, the lowering of base level following capture of the upper Snake would have increased incision rates and channel slopes along Big Creek and the tributaries along which the signal is already being transmitted. As stated earlier, many streams in the basin have stronger rocks in the lower reaches compared to upper reaches. It is likely that a combination of these factors are contributing to the low concavities of some tributaries of Big Creek, and unraveling which variable dominates in a particular channel may not be feasible.

5.6 Long Profiles

Knickpoints observed in long profiles of Big Creek tributaries generally correspond to post-Eocene faults or to lithologic contacts. Streams that flow approximately perpendicular to faults with post-Eocene displacement show greater influences from faulting than those which flow roughly fault-parallel. Channels display steeper sections where normal-fault headwalls have dropped relative to footwalls. Though none of these faults are mapped as currently active, their presence may result in lithologic contrasts that generate knickpoints. Other knickpoints correspond to lithologic boundaries as streams flow from Eocene igneous rocks on the periphery of the basin into terrain dominated by Proterozoic metasedimentary and metaigneous rocks in the center of the basin. Additional knickpoints are found in the lower reaches of streams located downstream of the Soldier Bar landslide. This mainstem knickpoint on lower Big Creek may be related to the landslide or the capture of the upper Snake River and subsequent base level drop 2 – 4 Ma (Malde, 1994; Othberg, 1994; Repenning et al., 1994; Wood, 1994; Wood & Clemens, 2004). As the knickpoint on Big Creek continues to propagate upstream, it is expected that knickpoint signal will in turn be propagated upstream in its tributaries. In these tributaries, the propagation of this signal will be stalled or 'hung-up' on lithologic contrasts at faults or contacts. The knickpoint on lower Goat Creek (shown in Figure 33) is more likely related to stream flow through Soldier Bar landslide deposits, rather to than base level fall.

Few of the tributaries of Big Creek display a mature concave-up, step-free longitudinal profile, indicating that most channels are relatively immature or have been heavily influenced by external forcings and heterogeneities. In the very upper basin, steps in channel form can also be attributed to the extent of downstream glacial erosion, especially in the far western, high elevation portion of the basin. For now, faults which juxtapose lithologies of varying strength and could have recent movement dominate lower elevation steps in the channel profile.

5.7 Conclusions

This study sought to determine if scaling relationships exist within tributaries of Big Creek and if relationships from individual tributaries were similar throughout the basin. The conclusions of this study are: 1) width and depth scale with drainage area in a similar manner in all studied tributaries; 2) channel slope is irregular and highly variable throughout the basin but is correlated with drainage area; and 3) median grain size is in some streams correlated with drainage area and in others with channel slope.

Overall, the Big Creek basin is a landscape in transition, adjusting to climatic, geomorphic, and tectonic forcings. Within the Big Creek basin, width and depth scale with drainage basin area, which is inferred to show a relationship between discharge and drainage basin area. These relationships are consistent within and across tributaries. Because width and depth are most strongly correlated with discharge, and discharge is strongly affected by changes in climate, width and depth may have shorter adjustment times relative to other channel variables and thus demonstrate a more robust correlation. Tributaries display a general tendency to coarsen downstream, inferred to indicate a strong coupling between channels and hillslopes throughout the basin. Median grain size likely correlates most strongly with channel slope, though hillslope input may obscure this relationship. Post-Eocene faults appear to strongly influence the overall steepness of channels cut by them. Channel steepness likely correlates with rock hardness, but a definitive relationship could not be elucidated due to the possibility of multiple driving factors and the inability to discern individual influences. Additionally, channel steepness correlates somewhat with concavity. Long profiles of channels show signs of disequilibrium and immaturity, including knickpoints caused by post-Eocene faulting, lithologic boundaries, and glaciation. Tributaries below the Soldier Bar landslide show signs of propagating knickpoints, inferred to be derived from base level fall following capture of the upper Snake during Neogene time.

5.8 Future Work

Future work in the Big Creek drainage should include a field based study of the effects of wood loading on channel morphology. The influences of wood on channel form have been documented in other locations, and Big Creek offers an unsurpassable field area to further understanding of these relationships. The large number of large woody debris in many channels throughout the basin, together with the minimal human impact, would allow workers to delineate the effect of wood loading at various scales. Woody debris can strongly influence local channel geometry (Abbe & Montgomery, 1996), but basin scale or mainstem consequences of impulsive wood loading are less clear. Studies investigating burn recovery of the basin, sediment loading after fires, and climatic changes should also be continued.

Further field studies into linkages between driving and resisting variables of bedrock channels should be undertaken in diverse settings, both within the Big Creek basin and worldwide. While this and other studies have yielded insights into processes occurring within bedrock channels, additional field studies are still needed to confirm or refute the partially consistent scaling relationships observed.

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Appendix A: Longitudinal Field Measurements

Data contained in this appendix (in order):

- Width Data (site coordinates in UTM, bankfull width measurements for each site station, site average bankfull width, and drainage area of each site)
- Depth Data (site coordinates in UTM, bankfull depth measurements for each site station, site average bankfull depth, and drainage area of each site)
- Slope Data (site coordinates in UTM, approximate distance slope was measured over, slope for each site station, site average slope, and drainage area of each site)
- Grain Size Data (site coordinates in UTM, count of individual grain measurements, individual grain measurements for each site, site median grain size, and drainage area of each site)

Width Data							
Site ID	**Start**		**End**		**Widths (m)**	**Site Average Width (m)**	**Drainage Area (m2)**
	Easting	**Northing**	**Easting**	**Northing**			
Cab004A	0663428	5004754	0663178	5004647	13.20	9.73	28,171,675.44
Cab004B	0663428	5004754	0663178	5004647	7.40		
Cab004C	0663428	5004754	0663178	5004647	8.60		
Cab005A	0662795	5001765	0662743	5001528	16.95	14.53	39,312,893.39
Cab005B	0662795	5001765	0662743	5001528	10.95		
Cab005C	0662795	5001765	0662743	5001528	15.70		
Cab006A	0662348	4999833	0662308	4999471	18.75	30.65	63,943,619.80
Cab006B	0662348	4999833	0662308	4999471	35.10		
Cab006C	0662348	4999833	0662308	4999471	38.10		
WCav004A	0659302	5005416	0659264	5005295	4.65	5.3	4,121,581.46
WCav004B	0659302	5005416	0659264	5005295	6.80		
WCav004C	0659302	5005416	0659264	5005295	4.45		
WCav005A	0659733	5004404	0659830	5004135	9.70	9.7	8,236,253.31
WCav005B	0659733	5004404	0659830	5004135	9.70		
WCav006A	0660728	5000118	0660731	4999715	15.05	15.15	46,859,537.73
WCav006B	0660728	5000118	0660731	4999715	17.40		
WCav006C	0660728	5000118	0660731	4999715	13.00		
Cro001A	0658927	5012856	-	-	4.97	4.45	2,318,323.85
Cro001B	0658927	5012856	-	-	3.80		
Cro001C	0658927	5012856	-	-	4.59		
Cro003A	0658842	5012681	0658739	5012566	5.50	5.25	4,012,905.33
Cro003B	0658842	5012681	0658739	5012566	4.59		
Cro003C	0658842	5012681	0658739	5012566	5.67		
Cro004A	0658485	5012189	0658450	5012053	5.86	4.97	4,998,876.42
Cro004B	0658485	5012189	0658450	5012053	4.46		
Cro004C	0658485	5012189	0658450	5012053	4.60		
Cro006A	0658444	5011980	0658395	5011808	8.05	8.53	7,082,123.38
Cro006B	0658444	5011980	0658395	5011808	9.00		
Cro008A	0658134	5011350	0658096	5011256	5.25	7.28	9,613,218.11
Cro008B	0658134	5011350	0658096	5011256	7.14		
Cro008C	0658134	5011350	0658096	5011256	9.45		
Cro009A	0658023	5010924	0657938	5010727	9.00	10.03	10,000,907.23
Cro009B	0658023	5010924	0657938	5010727	11.05		
Cro010A	0657989	5008825	0657903	5008403	13.45	16.75	21,594,779.63
Cro010B	0657989	5008825	0657903	5008403	24.10		
Cro010C	0657989	5008825	0657903	5008403	12.70		
Cro011A	0654845	5006617	0654610	5006466	12.90	13.90	29,970,802.30
Cro011B	0654845	5006617	0654610	5006466	14.20		
Cro011C	0654845	5006617	0654610	5006466	13.40		
Cro011D	0654845	5006617	0654610	5006466	15.10		

Site ID	Start		End		Widths (m)	Site Average Width (m)	Drainage Area (m2)
	Easting	Northing	Easting	Northing			
Cro012A	0654577	5006415	0654458	5006080	13.15	13.45	68,980,574.17
Cro012B	0654577	5006415	0654458	5006080	13.05		
Cro012C	0654577	5006415	0654458	5006080	14.15		
Cro013A	0650728	5006514	0650396	5006406	13.50	16.41	81,008,400.03
Cro013B	0650728	5006514	0650396	5006406	17.50		
Cro013C	0650728	5006514	0650396	5006406	15.00		
Cro013D	0650728	5006514	0650396	5006406	19.65		
Cro014A	0649856	5005798	0649617	5005653	10.45	19.48	92,189,648.64
Cro014B	0649856	5005798	0649617	5005653	27.05		
Cro014C	0649856	5005798	0649617	5005653	20.95		
Cro015A	0649050	5004509	0648785	5004095	17.65	18.30	97,504,339.23
Cro015B	0649050	5004509	0648785	5004095	19.15		
Cro015C	0649050	5004509	0648785	5004095	18.10		
Pio009A	0669529	4992919	0669602	4992725	4.45	5.64	5,966,446.92
Pio009B	0669529	4992919	0669602	4992725	5.75		
Pio009C	0669529	4992919	0669602	4992725	6.71		
Pio011A	0669097	4993990	0669164	4993806	6.4	5.77	12,061,697.96
Pio011B	0669097	4993990	0669164	4993806	4.8		
Pio011C	0669097	4993990	0669164	4993806	6.1		
Pio012A	0668882	4994978	0668885	4994761	6.85	6.19	14,272,772.67
Pio012B	0668882	4994978	0668885	4994761	5.92		
Pio012C	0668882	4994978	0668885	4994761	5.8		
Pio013A	0669120	4996271	0669054	4996061	7.35	8.43	15,744,519.28
Pio013B	0669120	4996271	0669054	4996061	9.75		
Pio013C	0669120	4996271	0669054	4996061	8.2		

Depth Data							
Site ID	Start		End		Depths (m)	Site Average Depth (m)	Drainage Area (m2)
	Easting	Northing	Easting	Northing			
Cab004A	0663428	5004754	0663178	5004647	0.93	1.19	28,171,675.44
Cab004B	0663428	5004754	0663178	5004647	1.21		
Cab004C	0663428	5004754	0663178	5004647	1.42		
Cab005A	0662795	5001765	0662743	5001528	1.06	0.98	39,312,893.39
Cab005B	0662795	5001765	0662743	5001528	0.85		
Cab005C	0662795	5001765	0662743	5001528	1.03		
Cab006A	0662348	4999833	0662308	4999471	1.54	1.23	63,943,619.80
Cab006B	0662348	4999833	0662308	4999471	1.04		
Cab006C	0662348	4999833	0662308	4999471	1.12		
WCav004A	0659302	5005416	0659264	5005295	0.42	0.48	4,121,581.46
WCav004B	0659302	5005416	0659264	5005295	0.40		
WCav004C	0659302	5005416	0659264	5005295	0.63		
WCav005A	0659733	5004404	0659830	5004135	0.51	0.71	8,236,253.31
WCav005B	0659733	5004404	0659830	5004135	0.91		
WCav006A	0660728	5000118	0660731	4999715	1.25	1.11	46,859,537.73
WCav006B	0660728	5000118	0660731	4999715	1.18		
WCav006C	0660728	5000118	0660731	4999715	0.91		
Cro001A	0658927	5012856	-	-	0.49	0.42	2,318,323.85
Cro001B	0658927	5012856	-	-	0.44		
Cro001C	0658927	5012856	-	-	0.32		
Cro003A	0658842	5012681	0658739	5012566	0.51	0.58	4,012,905.33
Cro003B	0658842	5012681	0658739	5012566	0.63		
Cro003C	0658842	5012681	0658739	5012566	0.61		
Cro004A	0658485	5012189	0658450	5012053	0.91	0.94	4,998,876.42
Cro004B	0658485	5012189	0658450	5012053	0.98		
Cro004C	0658485	5012189	0658450	5012053	0.93		
Cro006A	0658444	5011980	0658395	5011808	0.72	0.87	7,082,123.38
Cro006B	0658444	5011980	0658395	5011808	1.01		
Cro008A	0658134	5011350	0658096	5011256	0.64	0.98	9,613,218.11
Cro008B	0658134	5011350	0658096	5011256	1.22		
Cro008C	0658134	5011350	0658096	5011256	1.08		
Cro009A	0658023	5010924	0657938	5010727	1.14	0.99	10,000,907.23
Cro009B	0658023	5010924	0657938	5010727	0.83		
Cro010A	0657989	5008825	0657903	5008403	1.78	1.44	21,594,779.63
Cro010B	0657989	5008825	0657903	5008403	1.00		
Cro010C	0657989	5008825	0657903	5008403	1.53		
Cro011A	0654845	5006617	0654610	5006466	0.80	1.09	29,970,802.30
Cro011B	0654845	5006617	0654610	5006466	1.16		
Cro011C	0654845	5006617	0654610	5006466	1.31		
Cro011D	0654845	5006617	0654610	5006466			
Cro012A	0654577	5006415	0654458	5006080	1.75	1.45	68,980,574.17
Cro012B	0654577	5006415	0654458	5006080	1.47		
Cro012C	0654577	5006415	0654458	5006080	1.14		
Cro013A	0650728	5006514	0650396	5006406	1.52	1.33	81,008,400.03

Site ID	Start		End		Depths (m)	Site Average Depth (m)	Drainage Area (m2)
	Easting	Northing	Easting	Northing			
Cro013B	0650728	5006514	0650396	5006406	1.46		
Cro013C	0650728	5006514	0650396	5006406	1.10		
Cro013D	0650728	5006514	0650396	5006406	1.24		
Cro014A	0649856	5005798	0649617	5005653	1.47	1.32	92,189,648.64
Cro014B	0649856	5005798	0649617	5005653	1.63		
Cro014C	0649856	5005798	0649617	5005653	0.85		
Cro015A	0649050	5004509	0648785	5004095	1.64	1.58	97,504,339.23
Cro015B	0649050	5004509	0648785	5004095	1.61		
Cro015C	0649050	5004509	0648785	5004095	1.50		
Pio009A	0669529	4992919	0669602	4992725	0.84	0.82	5,966,446.92
Pio009B	0669529	4992919	0669602	4992725	0.59		
Pio009C	0669529	4992919	0669602	4992725	1.02		
Pio011A	0669097	4993990	0669164	4993806	0.93	0.98	12,061,697.96
Pio011B	0669097	4993990	0669164	4993806	1.09		
Pio011C	0669097	4993990	0669164	4993806	0.93		
Pio012A	0668882	4994978	0668885	4994761	1.51	1.27	14,272,772.67
Pio012B	0668882	4994978	0668885	4994761	1.17		
Pio012C	0668882	4994978	0668885	4994761	1.12		
Pio013A	0669120	4996271	0669054	4996061	1.29	1.41	15,744,519.28
Pio013B	0669120	4996271	0669054	4996061	1.33		
Pio013C	0669120	4996271	0669054	4996061	1.61		

Slope Data								
Site ID	**Start**		**End**		**Approx. Distance (m)**	**Slopes (%)**	**Site Average Slope (%)**	**Drainage Area (m2)**
	Easting	**Northing**	**Easting**	**Northing**				
Cab004A	0663428	5004754	0663178	5004647	5	5.5	7.17	28,171,675.44
Cab004B	0663428	5004754	0663178	5004647	7	6.5		
Cab004C	0663428	5004754	0663178	5004647	4	9.5		
Cab005A	0662795	5001765	0662743	5001528	12	2.5	2.17	39,312,893.39
Cab005B	0662795	5001765	0662743	5001528	10	2		
Cab005C	0662795	5001765	0662743	5001528	8	2		
Cab006A	0662348	4999833	0662308	4999471	6	3	2.67	63,943,619.80
Cab006B	0662348	4999833	0662308	4999471	10	3.5		
Cab006C	0662348	4999833	0662308	4999471	8	1.5		
WCav004A	0659302	5005416	0659264	5005295	3	4.5	6.67	4,121,581.46
WCav004B	0659302	5005416	0659264	5005295	3	5.5		
WCav004C	0659302	5005416	0659264	5005295	1	10.0		
WCav005A	0659733	5004404	0659830	5004135	2	5.5	5.50	8,236,253.31
WCav005B	0659733	5004404	0659830	5004135	2	5.5		
WCav006A	0660728	5000118	0660731	4999715	4	3.0	3.50	46,859,537.73
WCav006B	0660728	5000118	0660731	4999715	4	4.5		
WCav006C	0660728	5000118	0660731	4999715	4	3.0		
Cro001A	0658927	5012856	-	-	4	5.0	6.3	2,318,323.85
Cro001B	0658927	5012856	-	-	5	9.5		
Cro001C	0658927	5012856	-	-	3	4.5		
Cro003A	0658842	5012681	0658739	5012566	4.5	5.5	4.5	4,012,905.33
Cro003B	0658842	5012681	0658739	5012566	5	3.5		
Cro003C	0658842	5012681	0658739	5012566	4	4.5		
Cro004A	0658485	5012189	0658450	5012053	4	5.5	2.8	4,998,876.42
Cro004B	0658485	5012189	0658450	5012053	4	2.5		
Cro004C	0658485	5012189	0658450	5012053	4	2.5		
Cro004D	0658485	5012189	0658450	5012053	4	0.5		
Cro006A	0658444	5011980	0658395	5011808	5	0.0	0.3	7,082,123.38
Cro006B	0658444	5011980	0658395	5011808	5	0.5		
Cro006C	0658444	5011980	0658395	5011808	4	0.5		
Cro008A	0658134	5011350	0658096	5011256	6	1.0	1.9	9,613,218.11
Cro008B	0658134	5011350	0658096	5011256	3	0.0		
Cro008C	0658134	5011350	0658096	5011256	3	4.5		
Cro008D	0658134	5011350	0658096	5011256	5	2.0		
Cro009A	0658023	5010924	0657938	5010727	4	1.0	1.2	10,000,907.23
Cro009B	0658023	5010924	0657938	5010727	6	1.0		
Cro009C	0658023	5010924	0657938	5010727	6	1.5		
Cro010A	0657989	5008825	0657903	5008403	7	2.5	2.8	21,594,779.63
Cro010B	0657989	5008825	0657903	5008403	7	5.0		
Cro010C	0657989	5008825	0657903	5008403	7	1.0		
Cro011A	0654845	5006617	0654610	5006466	8	0.5	2.1	29,970,802.30
Cro011B	0654845	5006617	0654610	5006466	7	2.5		
Cro011C	0654845	5006617	0654610	5006466	10	4.5		
Cro011D	0654845	5006617	0654610	5006466	7	1.0		

Site ID	Start		End		Approx. Distance (m)	Slopes (%)	Site Average Slope (%)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro012A	0654577	5006415	0654458	5006080	6	2.5	1.5	68,980,574.17
Cro012B	0654577	5006415	0654458	5006080	10	1.5		
Cro012C	0654577	5006415	0654458	5006080	10	1.5		
Cro012D	0654577	5006415	0654458	5006080	7	0.5		
Cro013A	0650728	5006514	0650396	5006406	10	2.5	2.5	81,008,400.03
Cro013B	0650728	5006514	0650396	5006406	10	2.0		
Cro013C	0650728	5006514	0650396	5006406	10	5.0		
Cro013D	0650728	5006514	0650396	5006406	8	0.5		
Cro014A	0649856	5005798	0649617	5005653	9	2.5	1.5	92,189,648.64
Cro014B	0649856	5005798	0649617	5005653	8	1.5		
Cro014C	0649856	5005798	0649617	5005653	7	0.5		
Cro015A	0649050	5004509	0648785	5004095	10	2.0	2.0	97,504,339.23
Cro015B	0649050	5004509	0648785	5004095	12	2.0		
Cro015C	0649050	5004509	0648785	5004095	12	1.0		
Cro015D	0649050	5004509	0648785	5004095	10	3.0		
Pio009A	0669529	4992919	0669602	4992725	4	31.5	23.25	5,966,446.92
Pio009B	0669529	4992919	0669602	4992725	4	17		
Pio009C	0669529	4992919	0669602	4992725	3	30.5		
Pio009D	0669529	4992919	0669602	4992725	3	14		
Pio011A	0669097	4993990	0669164	4993806	4	5	10.75	12,061,697.96
Pio011B	0669097	4993990	0669164	4993806	5	9.5		
Pio011C	0669097	4993990	0669164	4993806	4	2		
Pio011D	0669097	4993990	0669164	4993806	4	8.5		
Pio011E	0669097	4993990	0669164	4993806	5	18		
Pio011F	0669097	4993990	0669164	4993806	4	21.5		
Pio012A	0668882	4994978	0668885	4994761	4	12.5	10.75	14,272,772.67
Pio012B	0668882	4994978	0668885	4994761	5	16.5		
Pio012C	0668882	4994978	0668885	4994761	3	9.5		
Pio012D	0668882	4994978	0668885	4994761	6	4.5		
Pio013A	0669120	4996271	0669054	4996061	5	15	10.5	15,744,519.28
Pio013B	0669120	4996271	0669054	4996061	4	7.5		
Pio013C	0669120	4996271	0669054	4996061	3	11		
Pio013D	0669120	4996271	0669054	4996061	4	10.5		
Pio013E	0669120	4996271	0669054	4996061	3	9.5		
Pio013F	0669120	4996271	0669054	4996061	3	9.5		

Grain Size Data								
Site ID	**Start**		**End**		**Count**	**Grain Sizes (cm)**	**Site D50 (cm)**	**Drainage Area (m2)**
	Easting	**Northing**	**Easting**	**Northing**				
Cab004	0663428	5004754	0663178	5004647	49	57.800	1.800	28,171,675.44
					62	23.700		
					72	23.600		
					63	23.000		
					70	22.700		
					61	20.600		
					21	19.500		
					82	16.600		
					74	15.300		
					81	15.200		
					31	12.800		
					76	12.800		
					39	12.100		
					84	11.200		
					88	10.900		
					64	10.500		
					54	10.200		
					30	10.100		
					90	9.900		
					95	9.400		
					97	8.900		
					12	8.700		
					41	8.200		
					71	8.200		
					55	8.000		
					56	8.000		
					50	7.400		
					93	7.200		
					89	7.000		
					98	7.000		
					99	6.200		
					24	6.000		
					42	5.900		
					77	5.900		
					43	5.500		
					29	5.100		
					78	4.800		
					3	4.600		
					27	4.500		
					65	4.300		
					94	4.300		
					4	3.900		
					25	3.800		
					28	3.400		
					26	3.200		
					6	3.000		
					59	2.400		
					7	2.300		
					47	2.200		
					44	1.800		
					85	1.800		
					36	1.700		
					87	1.600		
					2	1.500		
					33	1.500		
					35	1.500		
					5	1.100		
					10	1.100		
					11	1.100		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	**Northing**	**Easting**	**Northing**				
Cab004	0663428	5004754	0663178	5004647	16	1.100		
					32	1.100		
					37	1.000		
					91	0.900		
					9	0.700		
					14	0.600		
					23	0.600		
					73	0.600		
					17	0.500		
					22	0.500		
					67	0.500		
					69	0.500		
					86	0.500		
					15	0.400		
					52	0.400		
					83	0.400		
					92	0.400		
					53	0.300		
					58	0.300		
					79	0.300		
					100	0.300		
					8	0.200		
					38	0.200		
					45	0.200		
					68	0.200		
					80	0.200		
					18	0.100		
					20	0.100		
					34	0.100		
					48	0.100		
					51	0.100		
					60	0.100		
					96	0.100		
					1	0.025		
					13	0.025		
					19	0.025		
					40	0.025		
					46	0.025		
					57	0.005		
					66	0.005		
					75	0.005		
Cab005	0662795	5001765	0662743	5001528	69	23.800	3.700	39,312,893.39
					10	21.400		
					96	19.300		
					65	17.100		
					72	16.700		
					51	16.000		
					53	14.800		
					98	14.300		
					52	13.400		
					14	13.300		
					55	12.700		
					85	12.400		
					18	12.200		
					38	11.700		
					62	11.200		
					32	11.000		
					16	10.800		
					58	9.800		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	**Northing**	**Easting**	**Northing**				
Cab005	0662795	5001765	0662743	5001528	22	9.700		
					47	9.500		
					30	9.300		
					36	7.900		
					88	7.800		
					90	7.800		
					33	7.500		
					81	7.200		
					50	7.000		
					57	7.000		
					31	6.900		
					39	6.900		
					68	6.900		
					1	6.400		
					49	6.300		
					9	6.200		
					19	6.100		
					35	5.800		
					76	5.800		
					63	5.600		
					73	5.600		
					42	5.100		
					6	5.000		
					26	5.000		
					54	5.000		
					60	4.700		
					94	4.600		
					37	4.500		
					20	4.100		
					44	4.100		
					25	4.000		
					95	3.800		
					7	3.600		
					27	3.600		
					75	3.100		
					71	2.800		
					29	2.700		
					43	2.600		
					61	2.500		
					80	2.100		
					83	1.900		
					11	1.800		
					70	1.700		
					59	1.600		
					67	1.600		
					34	1.400		
					8	1.300		
					3	1.000		
					99	0.800		
					5	0.700		
					21	0.600		
					78	0.600		
					24	0.400		
					4	0.300		
					41	0.300		
					45	0.300		
					74	0.300		
					77	0.300		
					82	0.300		
					97	0.300		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cab005	0662795	5001765	0662743	5001528	13	0.200		
					28	0.200		
					40	0.200		
					46	0.200		
					79	0.200		
					15	0.100		
					48	0.100		
					66	0.100		
					84	0.100		
					86	0.100		
					2	0.025		
					12	0.025		
					17	0.025		
					23	0.025		
					64	0.025		
					87	0.025		
					89	0.025		
					91	0.025		
					92	0.025		
					100	0.025		
					56	0.005		
					93	0.005		
Cab006	0662348	4999833	0662308	4999471	50	38.600	3.250	63,943,619.80
					49	34.100		
					46	32.500		
					77	28.000		
					93	21.400		
					73	20.700		
					34	20.100		
					60	16.200		
					44	15.100		
					57	14.600		
					53	12.400		
					59	11.500		
					100	11.300		
					26	11.200		
					88	10.600		
					85	10.500		
					43	10.200		
					98	9.500		
					45	9.100		
					15	8.900		
					7	8.700		
					99	7.400		
					29	7.200		
					52	7.100		
					11	7.000		
					92	6.800		
					58	6.500		
					76	6.400		
					95	6.300		
					39	6.200		
					14	6.100		
					78	6.100		
					87	6.100		
					27	6.000		
					40	5.800		
					55	5.400		
					68	5.400		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	**Northing**	**Easting**	**Northing**				
Cab006	0662348	4999833	0662308	4999471	84	5.400		
					62	5.300		
					28	5.100		
					54	5.100		
					2	4.800		
					18	4.200		
					71	4.200		
					56	4.100		
					20	4.000		
					36	3.900		
					30	3.700		
					79	3.700		
					9	3.400		
					13	3.100		
					25	3.100		
					94	3.100		
					19	3.000		
					37	3.000		
					5	2.900		
					74	2.700		
					72	2.600		
					23	2.400		
					67	2.200		
					75	2.200		
					51	2.000		
					61	2.000		
					32	1.700		
					3	1.500		
					33	1.500		
					41	1.500		
					42	1.500		
					90	1.500		
					10	1.400		
					24	1.300		
					16	1.200		
					1	1.100		
					64	1.100		
					17	1.000		
					31	0.800		
					63	0.700		
					21	0.600		
					65	0.300		
					12	0.200		
					80	0.200		
					6	0.100		
					8	0.100		
					47	0.100		
					48	0.100		
					4	0.025		
					22	0.025		
					35	0.025		
					38	0.025		
					66	0.025		
					69	0.025		
					70	0.025		
					81	0.025		
					82	0.025		
					83	0.025		
					86	0.025		
					89	0.025		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cab006	0662348	4999833	0662308	4999471	91	0.025		
					96	0.025		
					97	0.025		
WCav004	0659302	5005416	0659264	5005295	66	14.000	0.200	4,121,581.46
					36	9.500		
					46	7.100		
					44	3.600		
					26	2.600		
					42	2.400		
					3	2.100		
					24	1.600		
					15	1.400		
					25	1.300		
					33	1.300		
					53	1.300		
					17	1.200		
					98	1.100		
					21	0.900		
					39	0.900		
					65	0.900		
					2	0.800		
					18	0.800		
					45	0.800		
					54	0.700		
					92	0.700		
					99	0.600		
					8	0.500		
					27	0.500		
					29	0.500		
					31	0.500		
					51	0.500		
					97	0.500		
					100	0.500		
					1	0.400		
					9	0.400		
					57	0.400		
					61	0.400		
					68	0.400		
					81	0.400		
					86	0.400		
					5	0.300		
					6	0.300		
					14	0.300		
					37	0.300		
					40	0.300		
					60	0.300		
					62	0.300		
					73	0.300		
					74	0.300		
					75	0.300		
					80	0.300		
					90	0.300		
					4	0.200		
					22	0.200		
					32	0.200		
					41	0.200		
					52	0.200		
					91	0.200		
					7	0.100		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
WCav004	0659302	5005416	0659264	5005295	13	0.100		
					16	0.100		
					20	0.100		
					23	0.100		
					28	0.100		
					30	0.100		
					34	0.100		
					35	0.100		
					38	0.100		
					47	0.100		
					50	0.100		
					71	0.100		
					76	0.100		
					85	0.100		
					43	0.025		
					48	0.025		
					55	0.025		
					56	0.025		
					58	0.025		
					59	0.025		
					63	0.025		
					69	0.025		
					72	0.025		
					82	0.025		
					83	0.025		
					84	0.025		
					88	0.025		
					93	0.025		
					94	0.025		
					10	0.005		
					11	0.005		
					12	0.005		
					19	0.005		
					49	0.005		
					64	0.005		
					67	0.005		
					70	0.005		
					77	0.005		
					78	0.005		
					79	0.005		
					87	0.005		
					89	0.005		
					95	0.005		
					96	0.005		
WCav005	0659733	5004404	0659830	5004135	19	1.900	0.300	8,236,253.31
					12	1.800		
					16	1.800		
					69	1.600		
					47	1.500		
					87	1.500		
					99	1.500		
					2	1.400		
					14	1.400		
					66	1.400		
					77	1.300		
					85	1.300		
					10	1.200		
					30	1.200		
					33	1.200		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	**Northing**	**Easting**	**Northing**				
WCav005	0659733	5004404	0659830	5004135	86	1.200		
					100	1.200		
					24	1.100		
					74	1.100		
					92	1.100		
					76	1.000		
					67	0.900		
					88	0.900		
					93	0.800		
					15	0.700		
					18	0.700		
					65	0.700		
					75	0.700		
					11	0.600		
					45	0.600		
					48	0.500		
					64	0.500		
					97	0.500		
					34	0.400		
					36	0.400		
					43	0.400		
					80	0.400		
					83	0.400		
					89	0.400		
					94	0.400		
					95	0.400		
					1	0.300		
					13	0.300		
					17	0.300		
					26	0.300		
					29	0.300		
					42	0.300		
					44	0.300		
					61	0.300		
					63	0.300		
					78	0.300		
					79	0.300		
					82	0.300		
					90	0.300		
					91	0.300		
					5	0.200		
					8	0.200		
					21	0.200		
					32	0.200		
					46	0.200		
					54	0.200		
					57	0.200		
					59	0.200		
					62	0.200		
					72	0.200		
					73	0.200		
					81	0.200		
					84	0.200		
					96	0.200		
					98	0.200		
					3	0.100		
					6	0.100		
					7	0.100		
					9	0.100		
					20	0.100		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
WCav005	0659733	5004404	0659830	5004135	22	0.100		
					23	0.100		
					25	0.100		
					27	0.100		
					28	0.100		
					38	0.100		
					39	0.100		
					49	0.100		
					51	0.100		
					58	0.100		
					60	0.100		
					68	0.100		
					4	0.025		
					37	0.025		
					40	0.025		
					41	0.025		
					50	0.025		
					53	0.025		
					55	0.025		
					56	0.025		
					70	0.025		
					71	0.025		
					31	0.005		
					35	0.005		
					52	0.005		
WCav006	0660728	5000118	0660731	4999715	45	16.800	2.800	46,859,537.73
					44	13.500		
					24	13.300		
					5	13.000		
					55	13.000		
					62	12.800		
					56	11.400		
					30	11.200		
					89	10.900		
					27	10.600		
					84	10.400		
					90	10.400		
					70	9.900		
					91	9.700		
					83	9.500		
					63	9.300		
					49	9.200		
					16	8.700		
					41	8.500		
					88	8.100		
					19	7.700		
					53	7.700		
					33	7.600		
					10	7.400		
					75	7.000		
					17	6.800		
					93	6.800		
					64	6.500		
					78	6.400		
					8	6.300		
					31	6.100		
					51	5.700		
					60	5.600		
					7	5.500		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
WCav006	0660728	5000118	0660731	4999715	69	5.400		
					71	5.400		
					20	5.300		
					6	5.000		
					11	4.900		
					15	4.600		
					14	4.400		
					21	3.800		
					73	3.800		
					81	3.500		
					58	3.000		
					92	3.000		
					18	2.900		
					32	2.900		
					79	2.900		
					68	2.800		
					87	2.800		
					52	2.700		
					82	2.700		
					38	2.500		
					3	2.300		
					94	2.100		
					29	1.700		
					57	1.700		
					2	1.600		
					98	1.500		
					47	1.400		
					59	1.400		
					85	1.400		
					1	1.000		
					43	1.000		
					67	1.000		
					28	0.900		
					46	0.900		
					100	0.800		
					72	0.700		
					54	0.500		
					76	0.500		
					74	0.400		
					65	0.300		
					80	0.300		
					95	0.300		
					99	0.300		
					12	0.200		
					39	0.200		
					22	0.100		
					34	0.100		
					35	0.100		
					36	0.100		
					37	0.100		
					61	0.100		
					4	0.025		
					9	0.025		
					13	0.025		
					23	0.025		
					25	0.025		
					40	0.025		
					48	0.025		
					50	0.025		
					66	0.025		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	**Northing**	**Easting**	**Northing**				
WCav006	0660728	5000118	0660731	4999715	77	0.025		
					86	0.025		
					96	0.025		
					97	0.025		
					26	0.005		
					42	0.005		
Cro001	0658927	5012856	-	-	75	12.800	1.3	2,318,323.85
					99	12.300		
					37	11.700		
					67	10.300		
					98	9.700		
					31	9.500		
					40	8.600		
					68	7.900		
					74	7.600		
					69	7.000		
					71	6.700		
					47	6.600		
					14	6.500		
					93	6.400		
					73	5.700		
					13	5.500		
					15	5.300		
					96	5.200		
					89	5.100		
					42	4.900		
					81	4.900		
					32	4.800		
					16	4.400		
					55	4.400		
					62	4.100		
					56	3.900		
					65	3.800		
					36	3.600		
					84	3.500		
					94	3.500		
					27	3.400		
					64	3.200		
					60	3.000		
					53	2.800		
					92	2.800		
					30	2.600		
					70	2.500		
					85	2.500		
					90	2.500		
					78	2.400		
					12	2.300		
					66	2.100		
					76	2.100		
					29	2.000		
					23	1.900		
					26	1.900		
					34	1.900		
					97	1.900		
					35	1.800		
					18	1.300		
					45	1.300		
					91	1.300		
					11	1.000		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro001	0658927	5012856	-	-	49	1.000		
					51	1.000		
					20	0.900		
					48	0.900		
					82	0.900		
					88	0.900		
					9	0.800		
					4	0.700		
					39	0.700		
					2	0.600		
					10	0.600		
					50	0.600		
					57	0.600		
					63	0.600		
					83	0.600		
					86	0.600		
					87	0.600		
					95	0.600		
					100	0.600		
					1	0.500		
					3	0.500		
					5	0.500		
					7	0.500		
					28	0.500		
					21	0.400		
					22	0.400		
					58	0.400		
					17	0.300		
					25	0.300		
					46	0.300		
					77	0.300		
					8	0.200		
					19	0.200		
					24	0.200		
					43	0.200		
					59	0.200		
					6	0.100		
					33	0.100		
					38	0.100		
					41	0.100		
					44	0.100		
					52	0.100		
					54	0.100		
					61	0.100		
					72	0.100		
					79	0.100		
					80	0.100		
Cro003	0658842	5012681	0658739	5012566	12	21.500	1.0	4,012,905.33
					27	18.200		
					16	11.500		
					6	9.900		
					5	7.100		
					100	6.500		
					1	4.900		
					29	4.700		
					65	3.700		
					11	3.000		
					84	3.000		
					3	2.900		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro003	0658842	5012681	0658739	5012566	2	2.700		
					96	2.700		
					80	2.600		
					93	2.600		
					9	2.500		
					22	2.500		
					45	2.500		
					94	2.400		
					44	2.300		
					77	2.300		
					79	2.300		
					60	2.200		
					91	2.200		
					97	2.200		
					40	2.100		
					8	2.000		
					73	2.000		
					15	1.900		
					92	1.900		
					71	1.800		
					47	1.500		
					57	1.500		
					70	1.500		
					76	1.500		
					78	1.500		
					13	1.400		
					43	1.400		
					62	1.400		
					68	1.400		
					69	1.300		
					98	1.300		
					24	1.200		
					75	1.200		
					74	1.100		
					82	1.100		
					88	1.100		
					23	1.000		
					64	1.000		
					90	1.000		
					10	0.900		
					14	0.900		
					18	0.900		
					28	0.900		
					38	0.900		
					33	0.800		
					46	0.800		
					52	0.800		
					59	0.800		
					66	0.800		
					81	0.800		
					95	0.800		
					99	0.800		
					42	0.700		
					19	0.600		
					21	0.600		
					48	0.600		
					53	0.600		
					55	0.600		
					56	0.600		
					89	0.600		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	**Northing**	**Easting**	**Northing**				
Cro003	0658842	5012681	0658739	5012566	31	0.500		
					39	0.500		
					58	0.500		
					83	0.500		
					32	0.400		
					37	0.400		
					41	0.400		
					51	0.400		
					54	0.400		
					61	0.400		
					36	0.300		
					4	0.200		
					25	0.200		
					50	0.200		
					87	0.200		
					7	0.100		
					17	0.100		
					20	0.100		
					26	0.100		
					30	0.100		
					34	0.100		
					35	0.100		
					49	0.100		
					63	0.100		
					67	0.100		
					72	0.100		
					85	0.100		
					86	0.100		
Cro004	0658485	5012189	0658450	5012053	45	11.000	1.2	4,998,876.42
					10	9.400		
					36	9.200		
					65	9.200		
					67	8.800		
					81	8.400		
					41	7.500		
					99	7.200		
					49	7.000		
					48	6.900		
					53	6.500		
					85	6.500		
					6	6.000		
					17	6.000		
					42	5.800		
					44	5.600		
					11	5.500		
					18	5.400		
					9	5.300		
					82	5.100		
					92	5.100		
					15	5.000		
					83	5.000		
					77	4.500		
					46	4.400		
					96	4.000		
					16	3.900		
					71	3.500		
					52	3.200		
					51	2.800		
					20	2.600		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro004	0658485	5012189	0658450	5012053	26	2.600		
					35	2.600		
					39	2.600		
					69	2.600		
					97	2.600		
					8	2.400		
					78	2.400		
					86	2.400		
					56	2.200		
					87	2.100		
					72	1.900		
					88	1.900		
					94	1.800		
					66	1.700		
					89	1.700		
					74	1.600		
					7	1.300		
					70	1.300		
					73	1.300		
					91	1.000		
					68	0.900		
					76	0.900		
					95	0.900		
					13	0.800		
					55	0.800		
					61	0.800		
					23	0.700		
					60	0.700		
					93	0.700		
					28	0.600		
					30	0.600		
					31	0.600		
					43	0.600		
					58	0.600		
					75	0.600		
					29	0.500		
					33	0.500		
					79	0.500		
					5	0.400		
					24	0.400		
					40	0.400		
					59	0.400		
					64	0.300		
					12	0.200		
					14	0.200		
					19	0.200		
					32	0.200		
					34	0.200		
					57	0.200		
					100	0.200		
					1	0.100		
					2	0.100		
					3	0.100		
					4	0.100		
					21	0.100		
					22	0.100		
					25	0.100		
					27	0.100		
					37	0.100		
					38	0.100		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro004	0658485	5012189	0658450	5012053	47	0.100		
					50	0.100		
					54	0.100		
					62	0.100		
					63	0.100		
					80	0.100		
					84	0.100		
					90	0.100		
					98	0.100		
Cro006	0658444	5011980	0658395	5011808	53	9.200	1.3	7,082,123.38
					36	8.200		
					40	6.100		
					69	5.900		
					85	5.800		
					74	5.600		
					64	5.400		
					14	5.100		
					37	5.100		
					68	4.600		
					76	4.400		
					50	4.300		
					97	4.300		
					21	4.100		
					71	3.300		
					38	3.200		
					65	3.100		
					84	3.100		
					86	3.100		
					4	3.000		
					23	3.000		
					66	3.000		
					82	3.000		
					9	2.900		
					34	2.900		
					46	2.900		
					56	2.900		
					61	2.900		
					11	2.600		
					24	2.600		
					72	2.600		
					92	2.600		
					8	2.500		
					52	2.400		
					54	2.400		
					33	2.300		
					47	2.300		
					70	2.200		
					2	2.100		
					6	2.000		
					27	2.000		
					30	1.800		
					93	1.800		
					44	1.700		
					58	1.600		
					83	1.600		
					62	1.500		
					95	1.500		
					17	1.300		
					32	1.300		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro006	0658444	5011980	0658395	5011808	60	1.300		
					5	1.200		
					57	1.200		
					75	1.200		
					18	1.100		
					39	1.100		
					55	1.100		
					99	1.100		
					1	1.000		
					3	1.000		
					35	1.000		
					89	1.000		
					13	0.900		
					7	0.800		
					29	0.800		
					98	0.800		
					25	0.700		
					12	0.600		
					28	0.600		
					31	0.600		
					41	0.600		
					59	0.600		
					100	0.600		
					15	0.500		
					22	0.500		
					26	0.500		
					48	0.500		
					79	0.500		
					16	0.400		
					42	0.400		
					81	0.400		
					19	0.300		
					43	0.300		
					49	0.300		
					87	0.300		
					88	0.300		
					10	0.100		
					20	0.100		
					45	0.100		
					51	0.100		
					67	0.100		
					73	0.100		
					77	0.100		
					78	0.100		
					80	0.100		
					90	0.100		
					91	0.100		
					94	0.100		
					96	0.100		
					63	0.005		
Cro008	0658134	5011350	0658096	5011256	77	18.200	1.450	9,613,218.11
					29	16.500		
					25	14.500		
					13	14.200		
					36	13.300		
					9	12.000		
					28	9.500		
					40	7.800		
					88	7.400		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro008	0658134	5011350	0658096	5011256	51	7.100		
					58	7.100		
					87	6.800		
					100	6.400		
					82	6.200		
					66	5.800		
					86	5.600		
					8	5.300		
					59	4.400		
					7	4.000		
					57	3.800		
					34	3.600		
					90	3.600		
					33	3.500		
					35	3.400		
					96	3.400		
					41	3.200		
					2	3.000		
					15	3.000		
					6	2.800		
					27	2.500		
					53	2.500		
					16	2.400		
					21	2.400		
					44	2.300		
					73	2.300		
					98	2.300		
					24	2.200		
					30	2.100		
					48	2.100		
					14	1.900		
					67	1.900		
					22	1.800		
					95	1.800		
					39	1.700		
					91	1.700		
					97	1.700		
					4	1.600		
					72	1.600		
					1	1.500		
					47	1.500		
					3	1.400		
					46	1.400		
					69	1.400		
					89	1.300		
					45	1.200		
					84	1.200		
					85	1.200		
					52	1.100		
					70	1.100		
					5	1.000		
					75	1.000		
					93	1.000		
					94	1.000		
					18	0.900		
					49	0.900		
					80	0.900		
					92	0.900		
					17	0.800		
					56	0.800		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro008	0658134	5011350	0658096	5011256	79	0.800		
					60	0.700		
					74	0.700		
					81	0.700		
					65	0.600		
					63	0.500		
					99	0.500		
					12	0.400		
					26	0.400		
					43	0.400		
					68	0.400		
					78	0.400		
					10	0.300		
					11	0.300		
					50	0.300		
					54	0.300		
					64	0.300		
					32	0.200		
					20	0.100		
					23	0.100		
					31	0.100		
					38	0.100		
					55	0.100		
					61	0.100		
					71	0.100		
					83	0.100		
					19	0.025		
					42	0.025		
					62	0.025		
					76	0.025		
					37	0.005		
Cro009	0658023	5010924	0657938	5010727	96	10.900	1.150	10,000,907.23
					95	8.900		
					86	8.300		
					77	8.100		
					24	8.000		
					84	7.400		
					87	6.700		
					94	6.300		
					85	6.100		
					88	6.100		
					81	4.300		
					83	4.200		
					22	3.900		
					30	3.600		
					82	3.600		
					67	3.500		
					76	3.000		
					11	2.900		
					59	2.800		
					60	2.600		
					23	2.500		
					74	2.400		
					1	2.100		
					47	2.100		
					14	1.900		
					20	1.900		
					12	1.800		
					51	1.700		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	**Northing**	**Easting**	**Northing**				
Cro009	0658023	5010924	0657938	5010727	80	1.700		
					10	1.600		
					44	1.600		
					50	1.600		
					66	1.600		
					25	1.500		
					27	1.500		
					32	1.500		
					64	1.500		
					45	1.400		
					90	1.400		
					100	1.400		
					2	1.300		
					18	1.300		
					43	1.300		
					52	1.300		
					75	1.300		
					78	1.300		
					79	1.300		
					3	1.200		
					15	1.200		
					49	1.200		
					16	1.100		
					61	1.100		
					68	1.100		
					73	1.100		
					39	1.000		
					46	1.000		
					69	1.000		
					31	0.900		
					48	0.800		
					62	0.800		
					70	0.800		
					91	0.800		
					19	0.700		
					37	0.700		
					56	0.700		
					71	0.700		
					89	0.700		
					92	0.700		
					99	0.700		
					28	0.600		
					40	0.600		
					53	0.600		
					55	0.600		
					21	0.500		
					26	0.500		
					38	0.500		
					54	0.500		
					63	0.500		
					72	0.500		
					93	0.500		
					13	0.400		
					41	0.400		
					57	0.400		
					58	0.400		
					9	0.300		
					65	0.300		
					35	0.200		
					4	0.100		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	**Northing**	**Easting**	**Northing**				
Cro009	0658023	5010924	0657938	5010727	29	0.100		
					33	0.100		
					34	0.100		
					36	0.100		
					42	0.100		
					97	0.100		
					98	0.100		
					5	0.025		
					6	0.025		
					7	0.025		
					8	0.025		
					17	0.025		
Cro010	0657989	5008825	0657903	5008403	88	73.500	2.600	21,594,779.63
					98	30.400		
					99	20.900		
					92	20.300		
					37	17.400		
					69	16.800		
					72	15.900		
					64	14.100		
					79	13.200		
					52	12.500		
					26	11.300		
					76	11.100		
					58	10.900		
					86	10.700		
					47	9.100		
					36	8.800		
					28	8.700		
					89	8.200		
					67	7.400		
					16	7.300		
					60	7.200		
					68	7.000		
					61	6.300		
					42	6.200		
					44	6.100		
					59	6.000		
					74	5.600		
					15	5.500		
					97	5.500		
					71	5.400		
					10	5.200		
					62	5.000		
					2	4.900		
					8	4.700		
					18	4.700		
					35	4.600		
					66	4.600		
					84	4.400		
					39	4.300		
					41	4.200		
					7	3.800		
					70	3.800		
					90	3.700		
					93	3.600		
					94	3.500		
					13	3.400		
					32	3.200		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro010	0657989	5008825	0657903	5008403	57	3.000		
					17	2.600		
					38	2.600		
					55	2.600		
					91	2.500		
					87	2.300		
					23	2.200		
					75	2.100		
					96	2.000		
					51	1.900		
					46	1.700		
					12	1.600		
					31	1.600		
					82	1.500		
					14	1.300		
					40	1.300		
					49	1.200		
					50	1.100		
					100	1.100		
					30	1.000		
					73	1.000		
					25	0.900		
					29	0.900		
					45	0.900		
					53	0.900		
					77	0.800		
					33	0.700		
					1	0.600		
					6	0.600		
					9	0.600		
					22	0.600		
					56	0.600		
					81	0.500		
					21	0.400		
					65	0.400		
					4	0.300		
					5	0.300		
					27	0.300		
					78	0.300		
					63	0.200		
					85	0.200		
					3	0.100		
					11	0.100		
					19	0.100		
					24	0.100		
					34	0.100		
					43	0.100		
					54	0.100		
					80	0.100		
					83	0.100		
					95	0.100		
					20	0.025		
					48	0.025		
Cro011	0654845	5006617	0654610	5006466	81	12.300	0.700	29,970,802.30
					79	8.600		
					83	8.200		
					65	7.100		
					87	5.700		
					68	5.600		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro011	0654845	5006617	0654610	5006466	86	4.900		
					91	4.800		
					64	4.700		
					51	4.600		
					70	4.600		
					80	4.600		
					74	4.200		
					72	3.300		
					69	3.000		
					82	3.000		
					16	2.900		
					35	2.800		
					66	2.800		
					52	2.700		
					60	2.700		
					62	2.400		
					58	2.100		
					77	2.000		
					75	1.900		
					1	1.800		
					89	1.700		
					39	1.500		
					63	1.500		
					29	1.400		
					19	1.100		
					40	1.100		
					56	1.100		
					15	1.000		
					38	1.000		
					43	1.000		
					47	1.000		
					49	1.000		
					59	1.000		
					88	1.000		
					20	0.900		
					28	0.900		
					32	0.900		
					67	0.900		
					4	0.800		
					18	0.800		
					45	0.800		
					46	0.800		
					55	0.800		
					9	0.700		
					92	0.700		
					7	0.600		
					21	0.600		
					31	0.600		
					33	0.600		
					85	0.600		
					26	0.500		
					34	0.500		
					41	0.500		
					42	0.500		
					3	0.400		
					6	0.400		
					24	0.400		
					27	0.400		
					30	0.400		
					2	0.300		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro011	0654845	5006617	0654610	5006466	25	0.300		
					37	0.300		
					57	0.300		
					61	0.300		
					97	0.300		
					14	0.200		
					76	0.200		
					5	0.100		
					17	0.100		
					22	0.100		
					23	0.100		
					36	0.100		
					44	0.100		
					48	0.100		
					71	0.100		
					8	0.025		
					10	0.025		
					11	0.025		
					12	0.025		
					13	0.025		
					50	0.025		
					53	0.025		
					54	0.025		
					73	0.025		
					78	0.025		
					84	0.025		
					90	0.025		
					93	0.025		
					94	0.025		
					95	0.025		
					96	0.025		
					98	0.025		
					99	0.025		
					100	0.025		
Cro012	0654577	5006415	0654458	5006080	28	30.400	0.300	68,980,574.17
					61	15.400		
					26	14.000		
					27	12.100		
					59	9.300		
					62	8.900		
					56	7.700		
					53	7.600		
					55	6.600		
					22	6.400		
					86	6.300		
					64	5.900		
					67	4.700		
					96	4.500		
					98	4.200		
					23	3.500		
					81	3.300		
					66	2.900		
					78	2.900		
					39	2.600		
					9	2.500		
					21	2.200		
					60	2.200		
					92	2.000		
					19	1.800		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro012	0654577	5006415	0654458	5006080	25	1.700		
					12	1.600		
					70	1.600		
					91	1.500		
					51	1.400		
					89	1.400		
					68	1.300		
					58	1.200		
					65	1.200		
					34	1.100		
					17	1.000		
					63	1.000		
					18	0.900		
					79	0.900		
					75	0.600		
					100	0.600		
					20	0.500		
					35	0.500		
					52	0.400		
					71	0.400		
					77	0.400		
					80	0.400		
					7	0.300		
					15	0.300		
					24	0.300		
					40	0.300		
					54	0.300		
					88	0.300		
					4	0.200		
					6	0.200		
					8	0.200		
					14	0.200		
					16	0.200		
					33	0.200		
					37	0.200		
					47	0.200		
					48	0.200		
					1	0.100		
					2	0.100		
					3	0.100		
					5	0.100		
					10	0.100		
					11	0.100		
					13	0.100		
					29	0.100		
					30	0.100		
					31	0.100		
					32	0.100		
					36	0.100		
					38	0.100		
					41	0.100		
					42	0.100		
					43	0.100		
					44	0.100		
					45	0.100		
					46	0.100		
					49	0.100		
					50	0.100		
					57	0.100		
					69	0.100		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro012	0654577	5006415	0654458	5006080	72	0.100		
					74	0.100		
					76	0.100		
					87	0.100		
					95	0.100		
					97	0.100		
					99	0.100		
					73	0.025		
					82	0.025		
					83	0.025		
					84	0.025		
					85	0.025		
					90	0.025		
					93	0.025		
					94	0.025		
Cro013	0650728	5006514	0650396	5006406	15	57.500	3.700	81,008,400.03
					26	35.600		
					36	34.700		
					5	22.000		
					82	20.700		
					42	20.300		
					4	20.200		
					38	19.400		
					12	18.400		
					98	18.100		
					49	17.700		
					22	16.600		
					58	15.400		
					3	14.400		
					51	14.000		
					35	13.500		
					9	13.400		
					11	13.400		
					23	12.800		
					25	12.300		
					31	12.200		
					81	11.800		
					8	11.700		
					16	11.100		
					68	11.100		
					53	10.400		
					77	9.600		
					96	9.400		
					74	8.800		
					76	8.000		
					48	7.600		
					78	7.300		
					75	6.900		
					91	6.500		
					55	6.300		
					86	6.300		
					40	6.200		
					54	6.100		
					83	6.100		
					79	5.800		
					61	5.600		
					72	5.600		
					56	5.500		
					94	5.300		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro013	0650728	5006514	0650396	5006406	99	5.200		
					88	4.900		
					39	4.800		
					89	4.800		
					92	4.400		
					2	3.800		
					62	3.600		
					70	3.400		
					100	3.100		
					47	3.000		
					10	2.800		
					90	2.700		
					97	1.800		
					33	1.600		
					93	1.600		
					28	1.400		
					80	1.200		
					95	1.200		
					41	1.100		
					64	1.100		
					87	0.900		
					32	0.700		
					13	0.600		
					30	0.600		
					34	0.600		
					50	0.600		
					37	0.500		
					1	0.400		
					45	0.400		
					7	0.300		
					14	0.300		
					6	0.200		
					46	0.200		
					52	0.200		
					65	0.200		
					69	0.200		
					84	0.200		
					17	0.100		
					18	0.100		
					19	0.100		
					27	0.100		
					29	0.100		
					43	0.100		
					57	0.100		
					60	0.100		
					63	0.100		
					66	0.100		
					71	0.100		
					73	0.100		
					85	0.100		
					20	0.025		
					21	0.025		
					24	0.025		
					44	0.025		
					59	0.025		
					67	0.025		
Cro014	0649856	5005798	0649617	5005653	3	22.000	3.950	92,189,648.64
					32	22.000		
					6	21.800		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro014	0649856	5005798	0649617	5005653	29	19.400		
					11	18.000		
					17	16.900		
					20	15.200		
					24	14.400		
					10	13.700		
					8	12.400		
					100	12.200		
					27	11.600		
					42	11.500		
					65	11.500		
					9	11.300		
					39	11.300		
					61	11.000		
					41	10.300		
					40	10.200		
					56	9.600		
					57	9.000		
					64	8.600		
					93	8.600		
					46	8.300		
					79	7.900		
					44	7.600		
					49	7.600		
					25	7.300		
					62	7.100		
					66	7.100		
					89	6.900		
					48	6.800		
					54	6.700		
					53	6.000		
					71	5.900		
					16	5.800		
					72	5.400		
					78	5.400		
					36	5.200		
					1	5.100		
					4	5.100		
					15	5.000		
					21	5.000		
					63	4.900		
					13	4.700		
					14	4.700		
					5	4.600		
					12	4.400		
					59	4.400		
					43	4.200		
					45	3.700		
					55	3.700		
					30	3.600		
					50	3.600		
					18	3.400		
					33	3.300		
					74	3.000		
					34	2.900		
					2	2.800		
					26	2.800		
					70	2.800		
					77	2.700		
					80	2.600		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro014	0649856	5005798	0649617	5005653	51	2.500		
					60	2.400		
					84	2.400		
					35	2.300		
					91	2.100		
					99	1.900		
					31	1.800		
					69	1.700		
					92	1.600		
					75	1.400		
					38	1.100		
					90	1.100		
					98	1.100		
					28	1.000		
					37	1.000		
					88	0.900		
					7	0.800		
					47	0.700		
					76	0.700		
					85	0.700		
					23	0.600		
					52	0.600		
					87	0.600		
					22	0.500		
					73	0.400		
					58	0.300		
					82	0.200		
					19	0.100		
					81	0.100		
					86	0.100		
					94	0.100		
					67	0.025		
					68	0.025		
					83	0.025		
					95	0.025		
					96	0.025		
					97	0.025		
Cro015	0649050	5004509	0648785	5004095	28	28.800	2.700	97,504,339.23
					97	22.400		
					19	19.600		
					24	18.700		
					30	17.300		
					18	16.400		
					59	15.400		
					54	14.400		
					32	14.300		
					56	14.200		
					38	13.000		
					85	12.400		
					33	12.300		
					4	11.700		
					1	11.400		
					23	11.400		
					26	11.100		
					12	10.700		
					36	10.400		
					67	9.900		
					31	9.700		
					15	9.500		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Cro015	0649050	5004509	0648785	5004095	64	9.300		
					51	8.900		
					55	8.500		
					61	8.000		
					21	7.900		
					52	7.800		
					53	7.600		
					16	7.400		
					73	7.400		
					25	7.000		
					6	6.800		
					8	6.100		
					13	6.000		
					70	5.600		
					71	5.000		
					14	4.700		
					39	4.700		
					75	4.700		
					93	4.500		
					82	4.400		
					47	4.300		
					45	4.200		
					22	3.600		
					27	3.100		
					95	3.000		
					9	2.900		
					60	2.900		
					68	2.800		
					17	2.600		
					63	2.600		
					96	2.600		
					3	2.500		
					44	2.500		
					58	2.500		
					62	2.500		
					29	1.600		
					43	1.500		
					40	1.300		
					46	1.300		
					65	1.300		
					77	1.100		
					86	1.100		
					72	1.000		
					98	0.800		
					11	0.700		
					34	0.600		
					42	0.600		
					79	0.600		
					91	0.600		
					80	0.500		
					87	0.500		
					48	0.300		
					69	0.300		
					83	0.300		
					37	0.200		
					66	0.200		
					89	0.200		
					5	0.100		
					35	0.100		
					41	0.100		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	**Northing**	**Easting**	**Northing**				
Cro015	0649050	5004509	0648785	5004095	49	0.100		
					50	0.100		
					76	0.100		
					78	0.100		
					88	0.100		
					90	0.100		
					100	0.100		
					2	0.025		
					7	0.025		
					20	0.025		
					74	0.025		
					81	0.025		
					84	0.025		
					92	0.025		
					94	0.025		
					99	0.025		
					10	0.005		
					57	0.005		
Pio009	0669529	4992919	0669602	4992725	31	16.0	3.1	5,966,446.92
					72	14.8		
					94	14.6		
					32	14.0		
					70	13.8		
					77	13.6		
					92	11.2		
					24	10.4		
					68	9.9		
					96	9.9		
					88	8.9		
					79	8.8		
					15	8.5		
					91	7.6		
					100	7.6		
					7	7.2		
					16	7.2		
					90	7.2		
					5	7.1		
					30	7.0		
					43	6.7		
					62	6.7		
					8	6.5		
					69	6.4		
					49	6.2		
					3	6.0		
					20	6.0		
					21	5.8		
					46	5.8		
					18	5.6		
					87	5.4		
					33	5.2		
					56	5.1		
					76	4.8		
					85	4.7		
					28	4.5		
					48	4.4		
					71	4.4		
					17	4.2		
					99	4.1		
					23	4.0		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Pio009	0669529	4992919	0669602	4992725	25	4.0		
					34	4.0		
					52	3.9		
					61	3.7		
					98	3.7		
					89	3.6		
					75	3.5		
					40	3.1		
					95	3.1		
					9	3.0		
					35	3.0		
					4	2.9		
					2	2.8		
					37	2.8		
					82	2.8		
					57	2.7		
					80	2.7		
					6	2.6		
					50	2.6		
					66	2.6		
					74	2.6		
					11	2.5		
					38	2.5		
					67	2.5		
					27	2.4		
					86	2.3		
					45	2.2		
					10	2.1		
					78	1.9		
					29	1.8		
					58	1.8		
					59	1.8		
					39	1.7		
					73	1.7		
					26	1.5		
					51	1.5		
					63	1.5		
					13	1.3		
					55	1.3		
					12	1.2		
					14	1.2		
					22	1.2		
					36	1.2		
					64	1.2		
					83	1.1		
					93	0.9		
					19	0.7		
					42	0.7		
					81	0.6		
					54	0.5		
					60	0.5		
					65	0.5		
					44	0.4		
					84	0.4		
					97	0.4		
					1	0.1		
					41	0.1		
					47	0.1		
					53	0.1		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Pio011	0669097	4993990	0669164	4993806	13	26.7	2.5	12,061,697.96
					24	21.0		
					14	17.5		
					39	16.3		
					31	15.5		
					29	14.8		
					91	14.0		
					89	12.8		
					33	12.2		
					32	11.9		
					35	11.3		
					8	11.0		
					78	11.0		
					54	10.8		
					15	10.7		
					50	10.4		
					9	9.9		
					30	9.8		
					37	9.6		
					71	9.4		
					11	8.5		
					42	8.5		
					55	8.2		
					100	7.9		
					28	7.4		
					65	7.4		
					59	7.3		
					56	6.8		
					85	6.6		
					2	6.3		
					64	6.3		
					53	6.2		
					10	5.9		
					88	5.9		
					82	5.4		
					67	4.6		
					73	4.3		
					40	4.2		
					48	3.6		
					57	3.5		
					17	3.4		
					95	3.4		
					23	3.1		
					96	2.8		
					16	2.6		
					69	2.6		
					79	2.6		
					45	2.5		
					52	2.5		
					83	2.5		
					77	2.4		
					1	2.1		
					7	2.1		
					70	2.1		
					12	2.0		
					63	2.0		
					26	1.9		
					43	1.9		
					72	1.9		
					80	1.7		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Pio011	0669097	4993990	0669164	4993806	3	1.5		
					76	1.5		
					92	1.5		
					94	1.5		
					61	1.2		
					62	1.2		
					27	1.1		
					36	1.1		
					41	1.1		
					51	1.1		
					6	1.0		
					46	0.9		
					97	0.9		
					47	0.8		
					60	0.8		
					68	0.8		
					99	0.8		
					38	0.7		
					58	0.7		
					22	0.6		
					34	0.6		
					93	0.6		
					98	0.6		
					4	0.5		
					21	0.5		
					74	0.5		
					84	0.5		
					5	0.4		
					18	0.4		
					49	0.3		
					19	0.2		
					20	0.2		
					25	0.2		
					44	0.1		
					66	0.1		
					75	0.1		
					81	0.1		
					86	0.1		
					87	0.1		
					90	0.1		
Pio012	0668882	4994978	0668885	4994761	22	52.5	1.4	14,272,772.67
					31	18.5		
					93	14.6		
					38	14.4		
					32	10.5		
					42	9.8		
					76	8.8		
					26	8.7		
					24	7.6		
					75	7.2		
					54	6.7		
					33	6.1		
					94	5.6		
					97	4.9		
					29	4.8		
					69	4.7		
					7	4.4		
					47	4.2		
					89	4.2		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	**Northing**	**Easting**	**Northing**				
Pio012	0668882	4994978	0668885	4994761	78	4.1		
					10	3.6		
					49	3.6		
					37	3.5		
					30	3.4		
					40	3.2		
					27	2.9		
					77	2.7		
					23	2.6		
					28	2.6		
					43	2.6		
					36	2.5		
					82	2.5		
					39	2.4		
					71	2.4		
					35	2.1		
					34	2.0		
					100	2.0		
					9	1.9		
					13	1.9		
					60	1.9		
					96	1.9		
					99	1.9		
					11	1.8		
					15	1.8		
					20	1.8		
					70	1.8		
					63	1.7		
					91	1.6		
					44	1.4		
					48	1.4		
					65	1.4		
					57	1.3		
					67	1.3		
					80	1.3		
					92	1.2		
					14	1.1		
					41	1.1		
					2	0.9		
					52	0.9		
					56	0.9		
					72	0.9		
					84	0.9		
					83	0.8		
					87	0.8		
					98	0.8		
					4	0.7		
					6	0.7		
					18	0.7		
					45	0.7		
					58	0.7		
					17	0.6		
					46	0.6		
					68	0.6		
					81	0.6		
					1	0.5		
					21	0.5		
					53	0.5		
					59	0.5		
					62	0.5		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	**Northing**	**Easting**	**Northing**				
Pio012	0668882	4994978	0668885	4994761	95	0.5		
					12	0.4		
					51	0.4		
					61	0.4		
					64	0.4		
					85	0.4		
					3	0.3		
					8	0.3		
					19	0.3		
					25	0.3		
					74	0.3		
					16	0.2		
					5	0.1		
					50	0.1		
					55	0.1		
					66	0.1		
					73	0.1		
					79	0.1		
					86	0.1		
					88	0.1		
					90	0.1		
Pio013	0669120	4996271	0669054	4996061	75	38.2	1.0	15,744,519.28
					5	31.0		
					10	10.5		
					6	8.4		
					1	8.0		
					38	7.0		
					72	6.7		
					2	6.1		
					9	5.2		
					7	5.0		
					45	5.0		
					17	4.5		
					14	4.2		
					50	4.0		
					54	3.7		
					39	3.2		
					55	3.2		
					16	3.1		
					65	3.0		
					29	2.6		
					33	2.4		
					71	2.2		
					66	2.1		
					60	2.0		
					61	2.0		
					97	1.8		
					40	1.7		
					93	1.7		
					13	1.6		
					90	1.6		
					41	1.5		
					52	1.5		
					53	1.5		
					88	1.5		
					26	1.4		
					57	1.4		
					3	1.3		
					67	1.3		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Pio013	0669120	4996271	0669054	4996061	87	1.3		
					43	1.2		
					48	1.2		
					100	1.2		
					4	1.1		
					31	1.1		
					35	1.1		
					99	1.1		
					20	1.0		
					23	1.0		
					69	1.0		
					94	1.0		
					73	0.9		
					91	0.9		
					58	0.8		
					64	0.7		
					78	0.7		
					21	0.6		
					30	0.6		
					51	0.6		
					74	0.6		
					79	0.6		
					86	0.6		
					96	0.6		
					8	0.5		
					34	0.5		
					37	0.5		
					63	0.5		
					68	0.5		
					11	0.4		
					44	0.4		
					56	0.4		
					77	0.4		
					82	0.4		
					22	0.3		
					32	0.3		
					42	0.3		
					85	0.3		
					18	0.2		
					24	0.2		
					27	0.2		
					47	0.2		
					80	0.2		
					84	0.2		
					12	0.1		
					15	0.1		
					19	0.1		
					25	0.1		
					28	0.1		
					36	0.1		
					46	0.1		
					49	0.1		
					59	0.1		
					62	0.1		
					70	0.1		
					76	0.1		
					81	0.1		
					83	0.1		
					89	0.1		
					92	0.1		

Site ID	Start		End		#	Grain Sizes (cm)	Site D50 (cm)	Drainage Area (m2)
	Easting	Northing	Easting	Northing				
Pio013	0669120	4996271	0669054	4996061	95	0.1		
					98	0.1		

Appendix B: Minshall Site Data near Tributary Confluences

Data in this appendix were collected and provided by the Stream Ecology Center at Idaho State University during 2013 from the "Minshall sites," so named due to the establishment of annual sampling and measuring of stream ecology and hydraulic parameters by "Doc" Wayne Minshall, retired ISU Biology professor. Annual sampling and measurements have taken place on these streams since the late 1980s, with one interruption in the early 1990s due to wildfire.

Data contained in this appendix:

- Width Data (site, transect number, wetted edge width, estimate of bankfull width, average bankfull, and drainage area of site)
- Slope Data (site, individual slope measurements, average slope, and drainage area of site)
- Grain Size Data (site, count of individual measurements, individual grain size measurements, median grain size, and drainage area of site)

Width Data					
Stream	**Transect**	**Width of Wetted Edge (m)**	**Bankfull Estimate (m)**	**Average Bankfull (m)**	**Drainage Area (km^2)**
Cave	T1	3.9	5.4	5.48	46.95
	T2	3.3	4.6		
	T3	3.6	5.5		
	T4	3.05	5.7		
	T5	3.6	6.2		
Cougar	T1	1.15	3.4	3.375	18.53
	T2	1.7	*		
	T3	1.15	3.35		
	T4	4.6	*		
	T5	Missing!	*		
Cliff	T1	2.2	*	3.8	21.25
	T2	2.2	3.8		
	T3	3.15	*		
	T4	1.95	*		
	T5	2.8	*		
Goat	T1	0.8	1.2	1.4	7.71
	T2	0.6	*		
	T3	0.9	*		
	T4	0.05	0.9		
	T5	1.5	2.1		
Pioneer	T1	2.15	2.5	3.04	15.61
	T2	2.55	3.25		
	T3	2.6	2.8		
	T4	2.15	3.85		
	T5	1.8	2.8		
Rush	T1	8.4	*	13.925	243.18
	T2	3.15	10.7		
	T3	10.2	15.9		
	T4	8.7	13.5		
	T5	11.2	15.6		

Slope Data			
Stream	**Slopes (%)**	**Av. Slope (%)**	**Drainage Area (km^2)**
Cave	2.5	2.375	46.95
	2.25		
Cliff	9	11	18.53
	16		
	8		
Cougar	7	11.33333333	21.25
	6.5		
	20.5		
Goat	24	25.66666667	7.71
	22		
	31		
Pioneer	16	10.16666667	15.61
	12		
	2.5		
Rush	1.5	2.166666667	243.18
	2.5		
	2.5		

Grain Size Data								
Stream	**#**	**B axis (cm)**	**D50 (cm)**		**Stream**	**#**	**B axis (cm)**	**D50 (cm)**
Cave	1	7	6		Cliff	1	4	5
	2	7				2	10	
	3	23				3	1.5	
	4	6				4	3	
	5	2				5	1	
	6	1				6	2.5	
	7	7				7	0.01	
	8	4				8	0.01	
	9	5				9	8	
	10	0.1				10	12	
	11	18				11	15	
	12	0.1				12	0.01	
	13	8				13	6.5	
	14	3				14	4	
	15	1				15	2.5	
	16	1				16	2	
	17	8				17	6	
	18	9				18	9	
	19	3				19	13	
	20	6				20	12	
	21	1				21	5	
	22	4				22	4	
	23	0.1				23	1	
	24	0.1				24	4	
	25	3				25	1	
	26	12				26	9	
	27	0.1				27	2	
	28	14				28	2	
	29	7				29	4	
	30	17				30	10	
	31	0.1				31	2	
	32	15				32	3	
	33	8				33	4	
	34	2				34	3	
	35	2				35	2.5	
	36	10				36	8.5	
	37	5				37	19	
	38	2				38	0.01	
	39	2				39	7	
	40	1				40	18	
	41	0.1				41	4	
	42	19				42	1	
	43	8				43	12	
	44	8				44	1	
	45	7				45	5	
	46	0.1				46	0.01	
	47	5				47	5	
	48	2				48	14.5	
	49	0.1				49	11	
	50	23				50	14	
	51	0.1				51	11	
	52	26				52	2.5	
	53	2				53	5	
	54	13				54	5	
	55	7				55	0.01	
	56	0.1				56	0.01	
	57	12				57	19	
	58	8				58	0.01	
	59	6				59	16	
	60	20				60	40	
	61	3				61	0.01	

Stream	#	B axis (cm)	D50 (cm)		Stream	#	B axis (cm)	D50 (cm)
	62	7				62	17	
	63	5				63	2	
	64	14				64	33	
	65	0.1				65	13	
	66	1				66	30	
	67	6				67	9	
	68	9				68	7	
	69	16				69	1	
	70	6				70	4.5	
	71	13				71	2	
	72	5				72	8	
	73	0.1				73	21	
	74	20				74	19	
	75	8				75	2	
	76	5				76	15	
	77	7				77	2	
	78	6				78	6	
	79	0.1				79	6	
	80	11				80	9	
	81	6				81	2.5	
	82	30				82	3.5	
	83	0.1				83	1	
	84	1				84	5	
	85	0.1				85	19	
	86	34				86	11	
	87	0.1				87	4	
	88	8				88	3	
	89	16				89	14	
	90	3				90	20	
	91	0.1				91	3.5	
	92	10				92	1	
	93	0.1				93	6	
	94	21				94	14	
	95	11				95	15	
	96	11				96	10	
	97	2				97	3	
	98	8				98	40	
	99	6				99	46	
	100	3				100	1.5	
Cougar	1	8	5		Goat	1	6.5	3.5
	2	6				2	13	
	3	0.1				3	13	
	4	10				4	10	
	5	3				5	0.01	
	6	5				6	0.01	
	7	3				7	Wood	
	8	22				8	0.01	
	9	0.1				9	8	
	10	14				10	0.01	
	11	0.1				11	13	
	12	11				12	0.01	
	13	7				13	5	
	14	3				14	Wood	
	15	0.1				15	1	
	16	11				16	38	
	17	15				17	0.01	
	18	2				18	0.01	
	19	5				19	Wood	
	20	17				20	0.01	
	21	4				21	0.01	
	22	6				22	5.5	

Stream	#	B axis (cm)	D50 (cm)		Stream	#	B axis (cm)	D50 (cm)
	23	2				23	0.01	
	24	13				24	1	
	25	0.1				25	0.01	
	26	7				26	18	
	27	0.1				27	3	
	28	3				28	6	
	29	8				29	3.5	
	30	3				30	0.01	
	31	0.1				31	23	
	32	8				32	0.01	
	33	10				33	2	
	34	5				34	18	
	35	9				35	4	
	36	6				36	6	
	37	7				37	8.5	
	38	4				38	0.01	
	39	1.5				39	43	
	40	0.1				40	0.006	
	41	4				41	4	
	42	8				42	0.01	
	43	2				43	1.5	
	44	1				44	3	
	45	13				45	0.5	
	46	2				46	0.01	
	47	0.1				47	1.5	
	48	9				48	2.5	
	49	0.1				49	4.5	
	50	0.1				50	5	
	51	4				51	1	
	52	3				52	1.5	
	53	11				53	0.01	
	54	4				54	17	
	55	0.1				55	2	
	56	21				56	9	
	57	18				57	9	
	58	13				58	5	
	59	9				59	0.01	
	60	0.1				60	10	
	61	0.1				61	0.01	
	62	Bedrock				62	19	
	63	1.5				63	3.5	
	64	0.1				64	14	
	65	2				65	26	
	66	0.1				66	14	
	67	19				67	4	
	68	7				68	1.5	
	69	8				69	3.5	
	70	34				70	3.5	
	71	Bedrock				71	1.5	
	72	14				72	4	
	73	25				73	24	
	74	6				74	12	
	75	3				75	10	
	76	13				76	4	
	77	0.1				77	11	
	78	0.1				78	7.5	
	79	6				79	0.01	
	80	0.1				80	14	
	81	10				81	1	
	82	21				82	8	
	83	2				83	0.01	
	84	5				84	12	

Stream	#	B axis (cm)	D50 (cm)
	85	23	
	86	Bedrock	
	87	0.1	
	88	17	
	89	3	
	90	2	
	91	5	
	92	5	
	93	9	
	94	0.1	
	95	7	
	96	0.1	
	97	Bedrock	
	98	7	
	99	3	
	100	6	
Pioneer	1	5	4
	2	4	
	3	3	
	4	2	
	5	0.01	
	6	1	
	7	2	
	8	5	
	9	1	
	10	6	
	11	2	
	12	2	
	13	4	
	14	1	
	15	7	
	16	14	
	17	2	
	18	23	
	19	2	
	20	10	
	21	6	
	22	5	
	23	2	
	24	32	
	25	1	
	26	0.01	
	27	5	
	28	1	
	29	52	
	30	5	
	31	0.01	
	32	0.01	
	33	3	
	34	2	
	35	10	
	36	6	
	37	7	
	38	7	
	39	0.01	
	40	7	
	41	0.01	
	42	1	
	43	6	
	44	4	
	45	3	

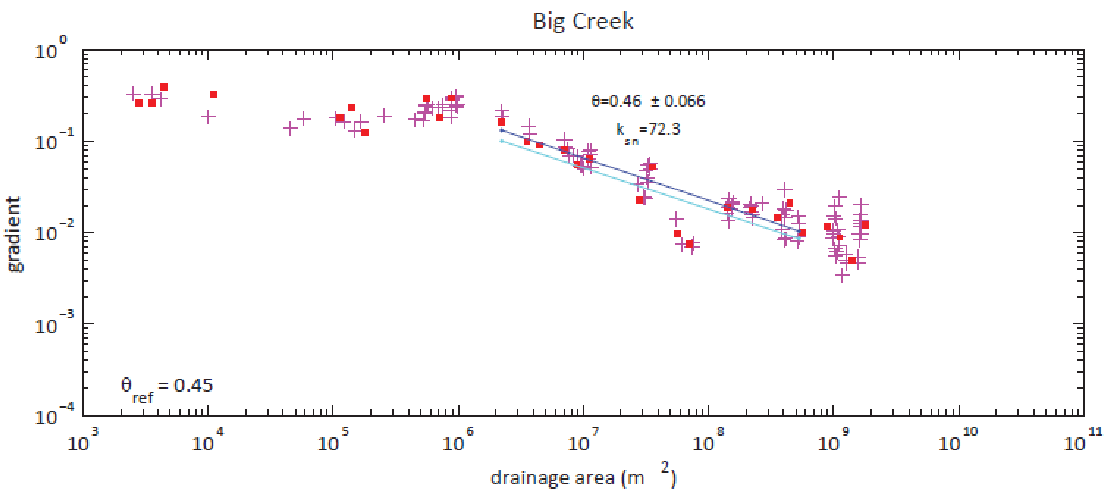
Stream	#	B axis (cm)	D50 (cm)
	85	0.01	
	86	2.5	
	87	19	
	88	7	
	89	0.01	
	90	7	
	91	7	
	92	0.01	
	93	2.5	
	94	0.01	
	95	7.5	
	96	32	
	97	6.5	
	98	0.006	
	99	5	
	100	0.01	
Rush	1	0.01	6
	2	9	
	3	11	
	4	8	
	5	6	
	6	10	
	7	5	
	8	6	
	9	7	
	10	17	
	11	11	
	12	3	
	13	7	
	14	3	
	15	1.5	
	16	3.5	
	17	5.5	
	18	4	
	19	11	
	20	3.5	
	21	1.5	
	22	2	
	23	18	
	24	6	
	25	1.5	
	26	8	
	27	10	
	28	3.5	
	29	12	
	30	1	
	31	2	
	32	5	
	33	1	
	34	9	
	35	7	
	36	12	
	37	3	
	38	4	
	39	14	
	40	5	
	41	1	
	42	22	
	43	7	
	44	19	
	45	4	

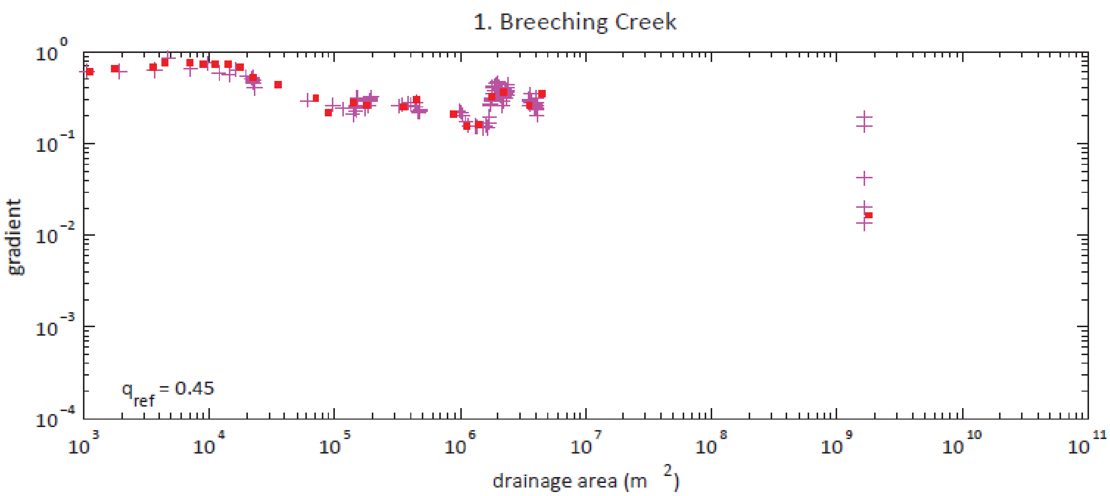
Stream	#	B axis (cm)	D50 (cm)		Stream	#	B axis (cm)	D50 (cm)
	46	4				46	5	
	47	75				47	3.5	
	48	8				48	1.5	
	49	2				49	16	
	50	13				50	6.5	
	51	7				51	10	
	52	4				52	7.5	
	53	10				53	5.5	
	54	5				54	1	
	55	5				55	7	
	56	5				56	17	
	57	3				57	4	
	58	3				58	15	
	59	6				59	5	
	60	1				60	34	
	61	8				61	3	
	62	0.01				62	3	
	63	3				63	7	
	64	7				64	11	
	65	0.01				65	1.5	
	66	9				66	6	
	67	18				67	14	
	68	3				68	6	
	69	10				69	3	
	70	13				70	7	
	71	4				71	9	
	72	7				72	52	
	73	5				73	8	
	74	8				74	3	
	75	2				75	3	
	76	5				76	5.5	
	77	2				77	0.006	
	78	3				78	6	
	79	3				79	14	
	80	6				80	3	
	81	10				81	1	
	82	2				82	16	
	83	1				83	27	
	84	0.01				84	0.01	
	85	4				85	5.5	
	86	2				86	5	
	87	1				87	26	
	88	0.01				88	2.5	
	89	7				89	27	
	90	6				90	12	
	91	22				91	9	
	92	1				92	22	
	93	4				93	2	
	94	4				94	88	
	95	8				95	6	
	96	7				96	2	
	97	11				97	2	
	98	1				98	0.01	
	99	11				99	3	
	100	3				100	17	

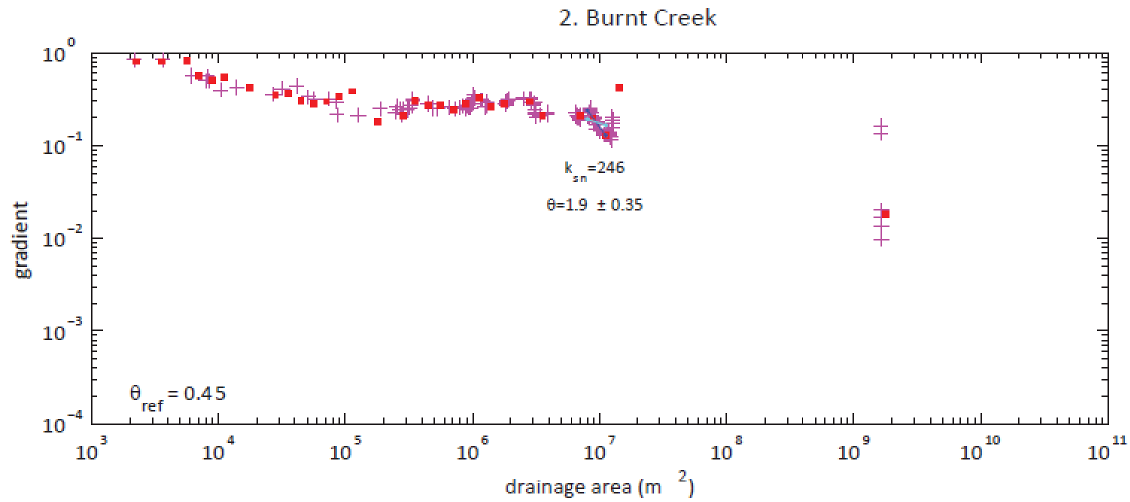
Appendix C: DEM-Derived Stream Profile Data

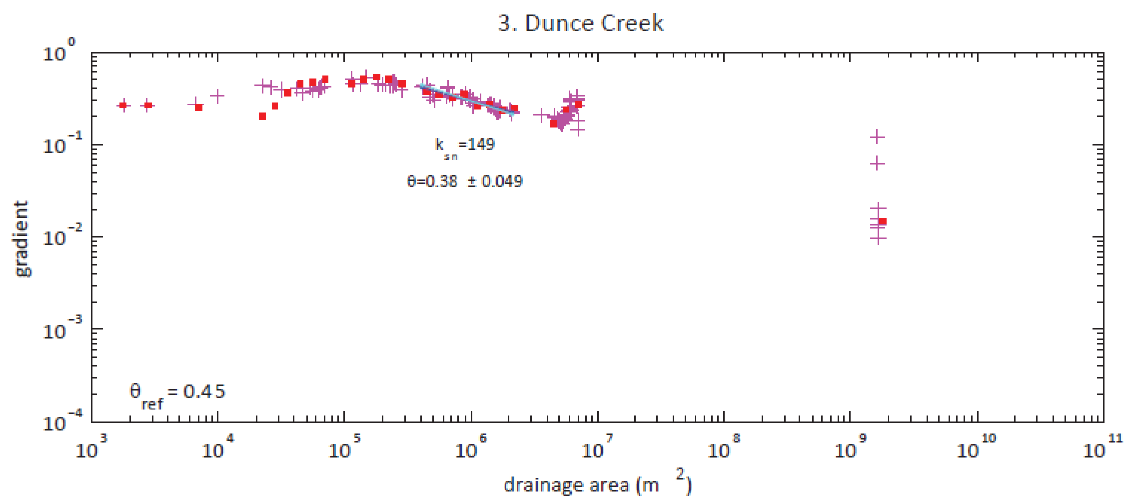
Data contained in this appendix:

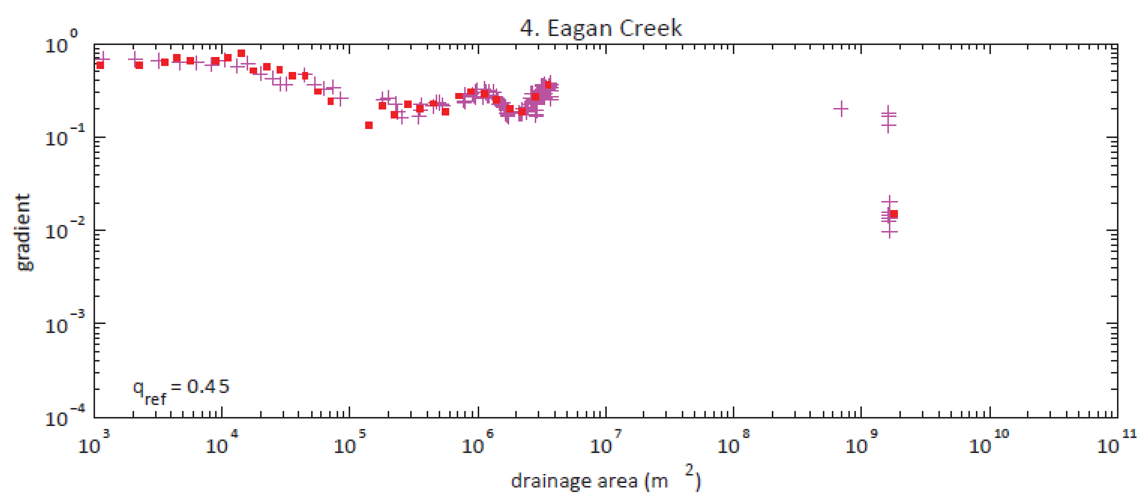
- Individual log-log slope-area plots of Big Creek and its tributaries. Plots are numbered as shown in Figure 27. Magenta plus symbols are raw slope area data equally spaced in the vertical direction along the profile. Red boxes are log-bin averages of the raw slope-area data. Dark blue lines are best fits to the selected data range while light blue lines show fits using a reference concavity of 0.45. The k_{sn} values discussed in the thesis are derived from these light blue lines. Channels without blue lines were not fit. Note that the data shown here include both the tributary data and the mainstem data downstream of the confluence. The mainstem Big Creek data can be distinguished as is follows a large increase in drainage area.
- Individual longitudinal profiles of Big Creek tributaries, each numbered as shown in Figure 27. Dark blue lines show modeled channel profiles using best fit concavities and steepnesses over the selected data range. Light blue lines show fits using a reference concavity of 0.5 and the measured k_{sn} value. The channel profiles show both the raw data (green) and a profile smoothed over a window of 500m (magenta)

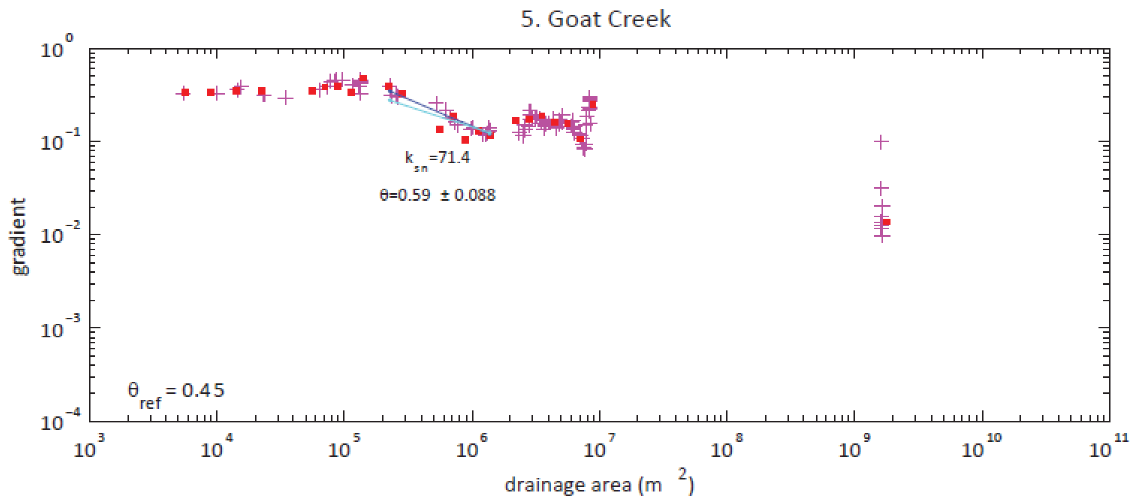

Big Creek
gradient
drainage area (m 2)
θ=0.46 ± 0.066
ksn=72.3
θref = 0.45

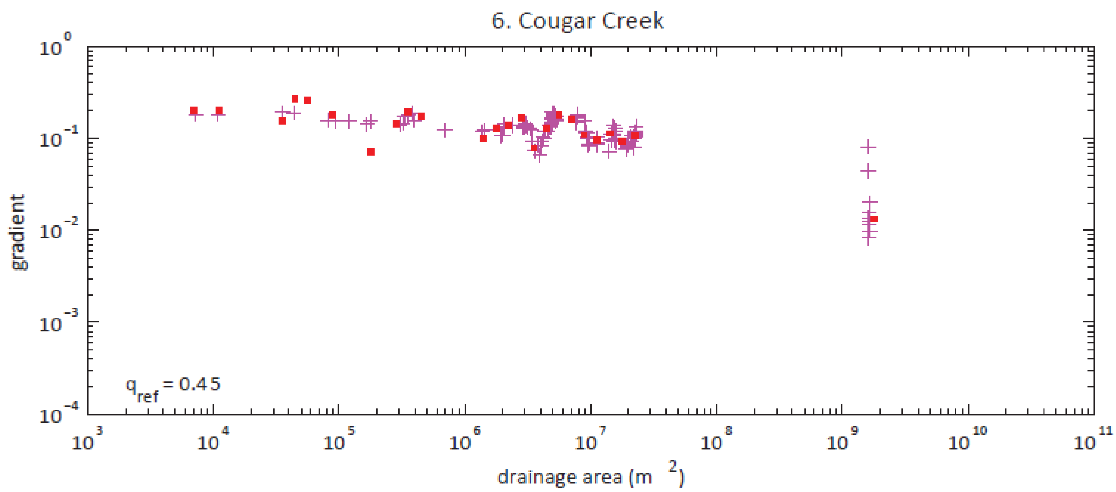

1. Breeching Creek
gradient
drainage area (m 2)
qref = 0.45

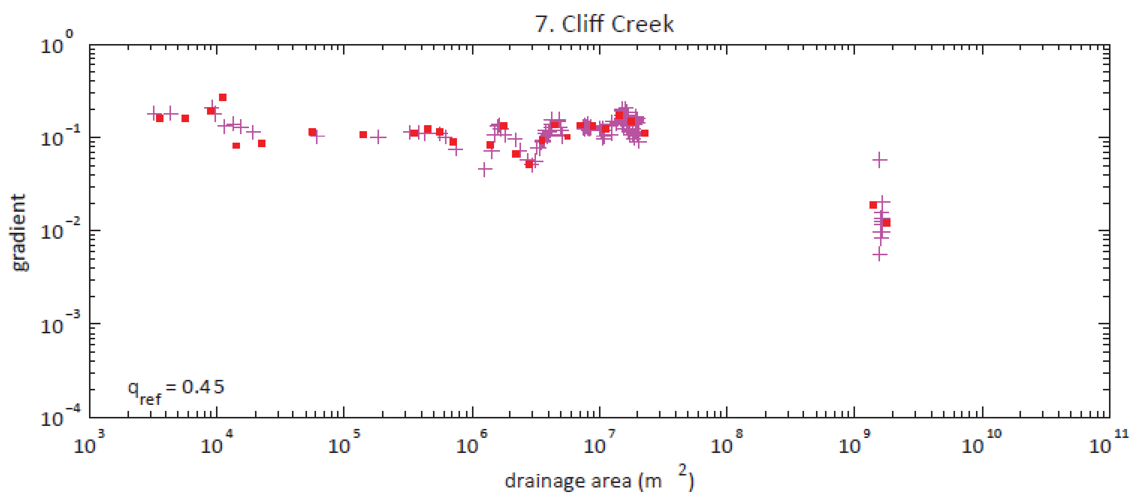

2. Burnt Creek
gradient
k_{sn}=246
θ=1.9 ± 0.35
$θ_{ref}$ = 0.45
drainage area (m ^{2})

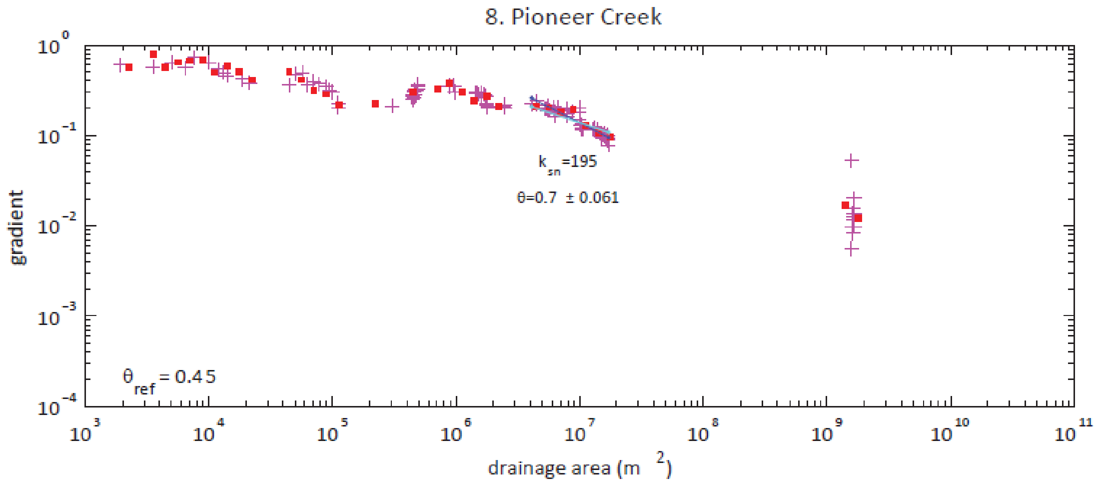

3. Dunce Creek
gradient
k_{sn}=149
θ=0.38 ± 0.049
$θ_{ref}$ = 0.45
drainage area (m ^{2})


4. Eagan Creek
gradient
q_{ref} = 0.45
drainage area (m ^{2})

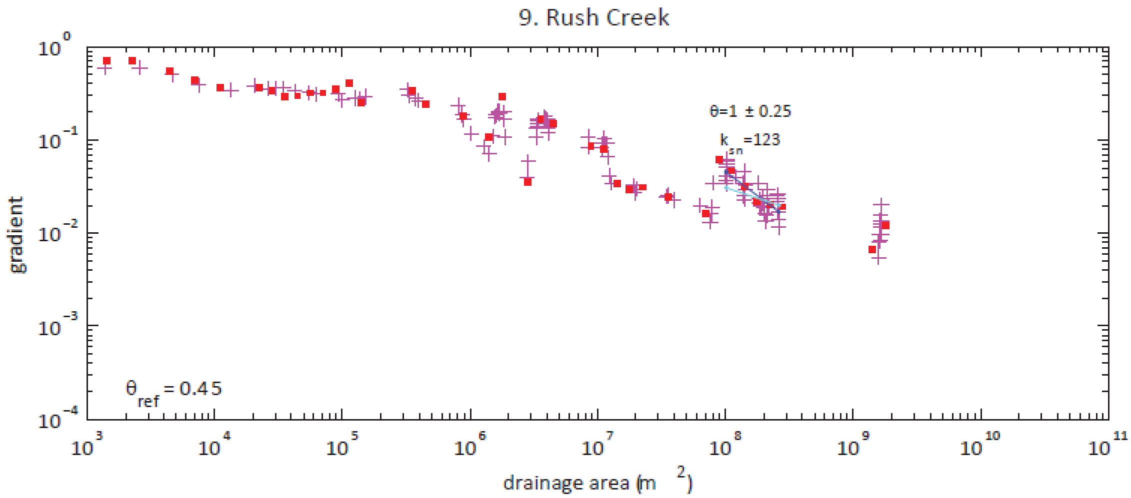

5. Goat Creek
gradient
drainage area (m 2)
k_{sn} =71.4
θ=0.59 ± 0.088
θ_{ref} = 0.45


6. Cougar Creek
gradient
drainage area (m 2)
q_{ref} = 0.45

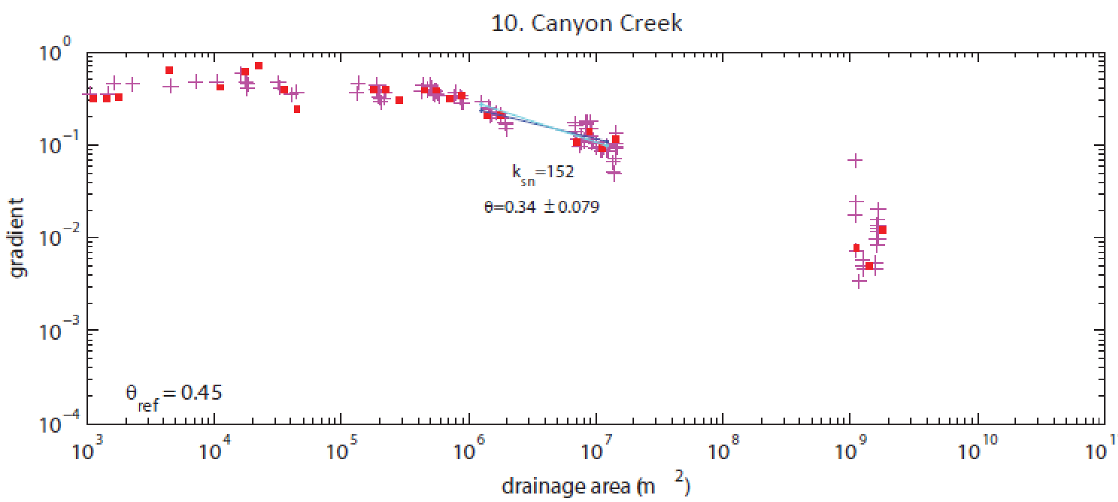

7. Cliff Creek
gradient
drainage area (m 2)
q_{ref} = 0.45



8. Pioneer Creek
gradient
drainage area (m 2)
k sn =195
θ=0.7 ± 0.061
θ ref = 0.45

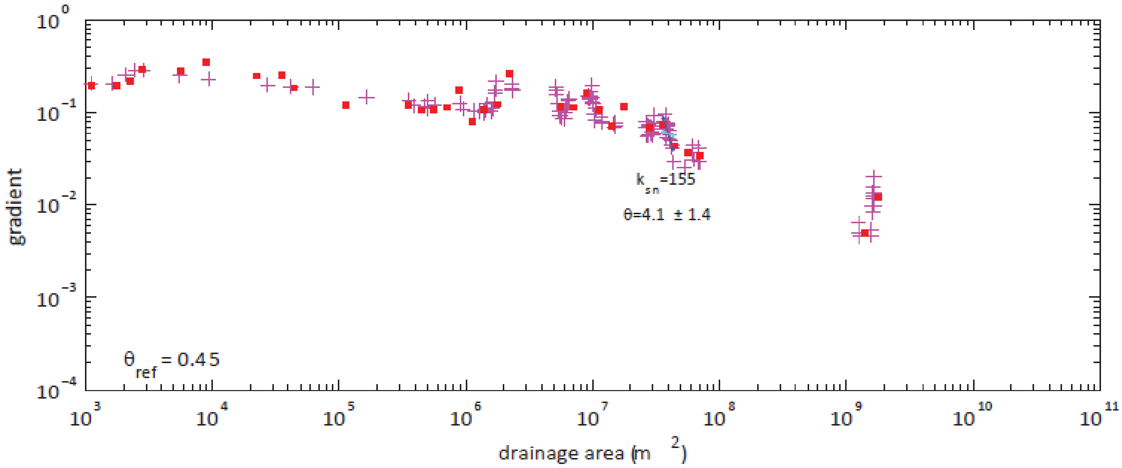


9. Rush Creek
gradient
drainage area (m 2)
θ=1 ± 0.25
k sn =123
θ ref = 0.45

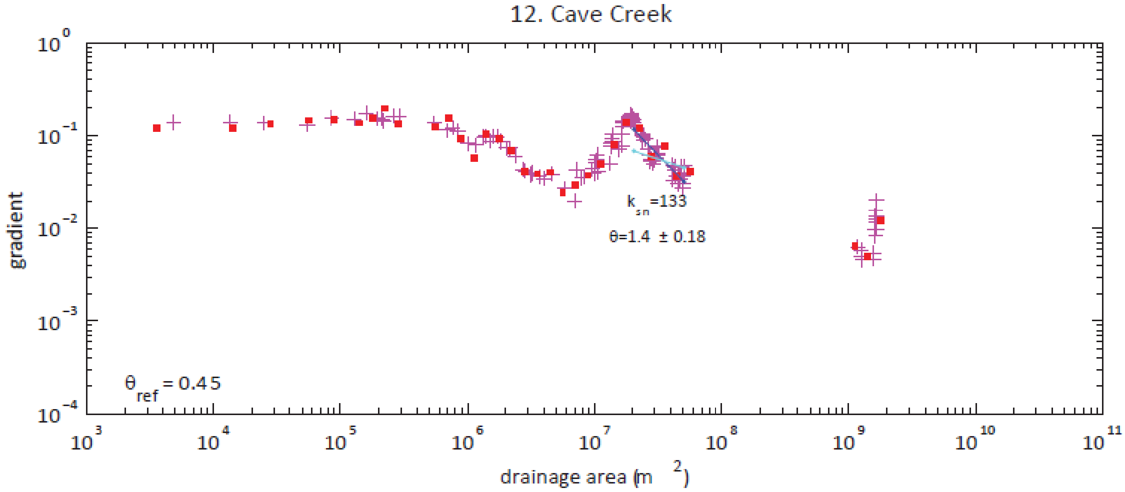


10. Canyon Creek
gradient
drainage area (m 2)
k sn =152
θ=0.34 ± 0.079
θ ref = 0.45

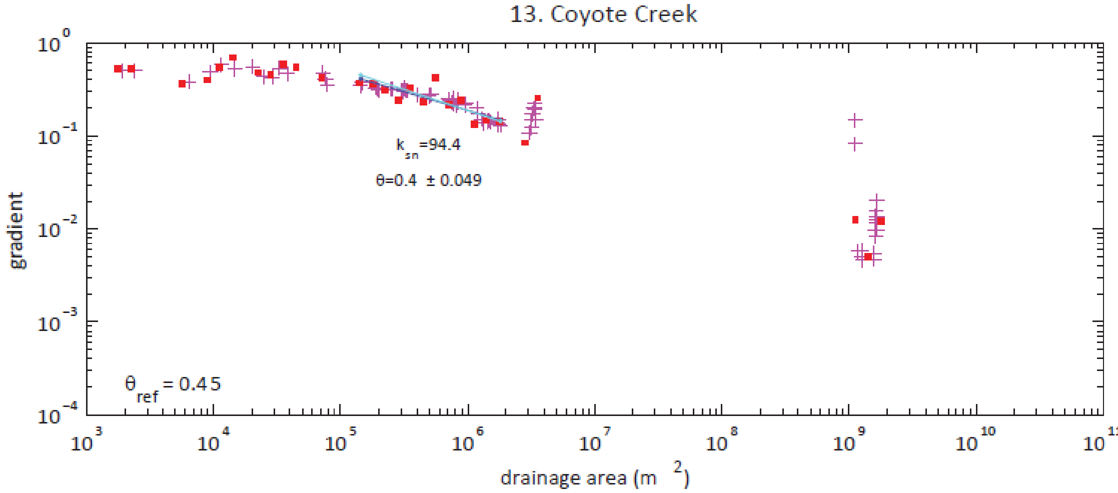
11. Cabin Creek

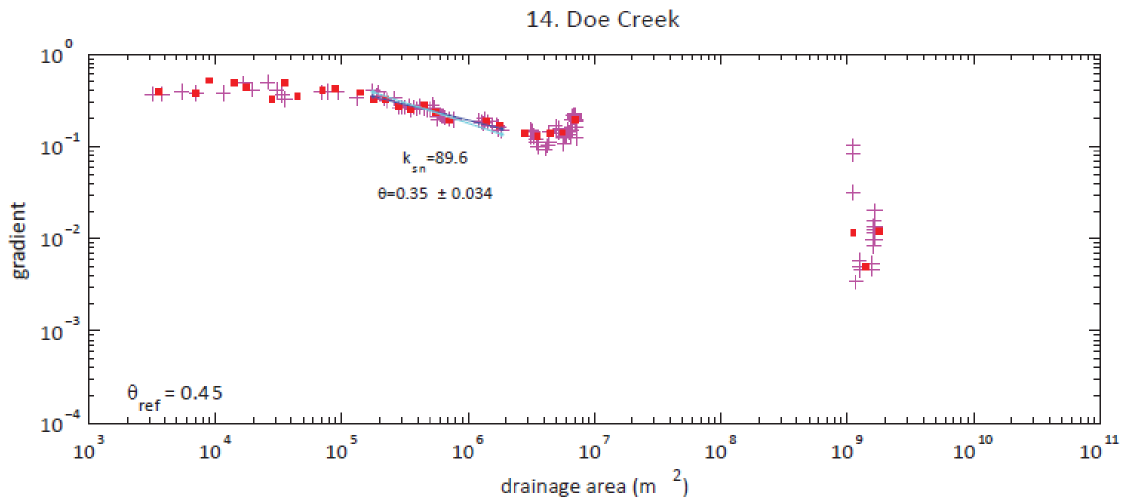


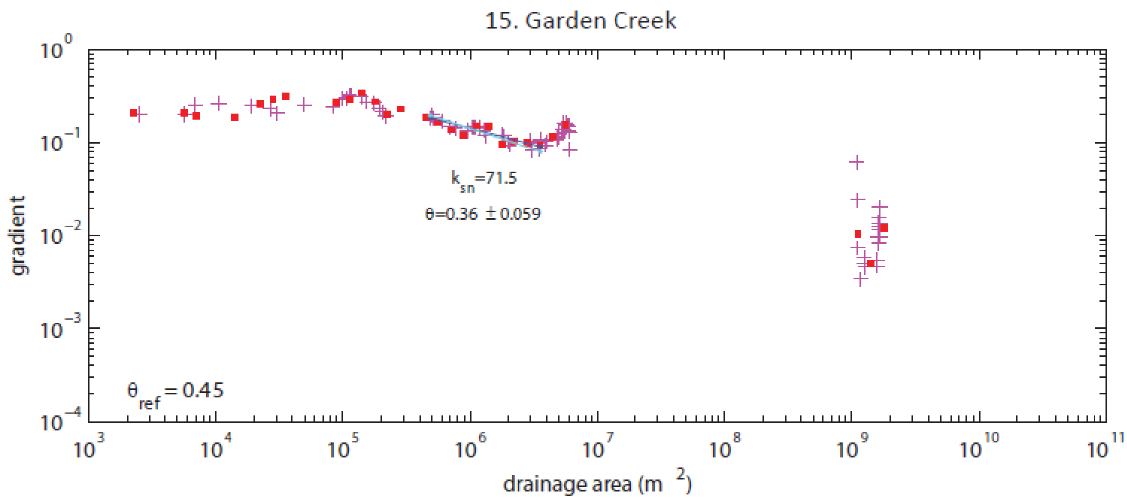
12. Cave Creek

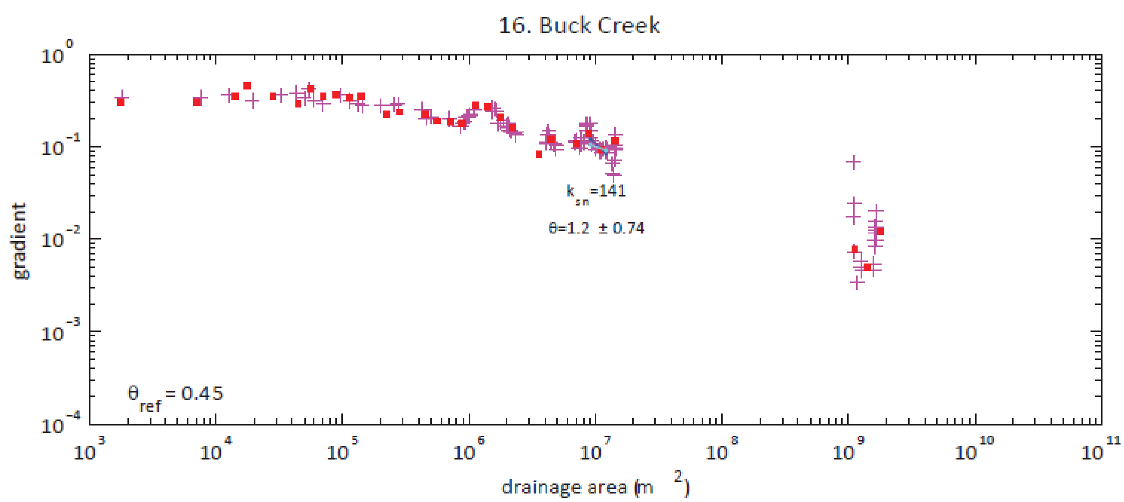


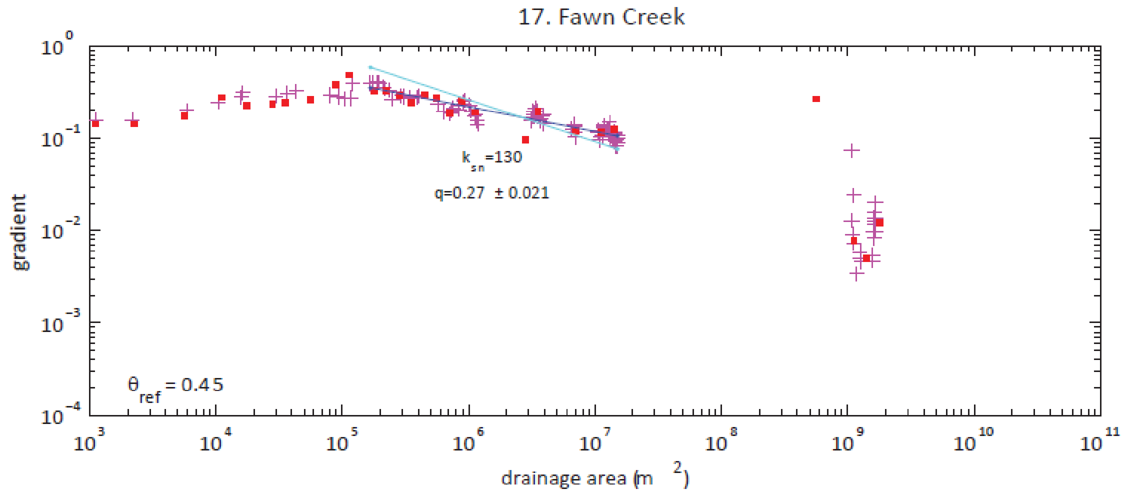
13. Coyote Creek

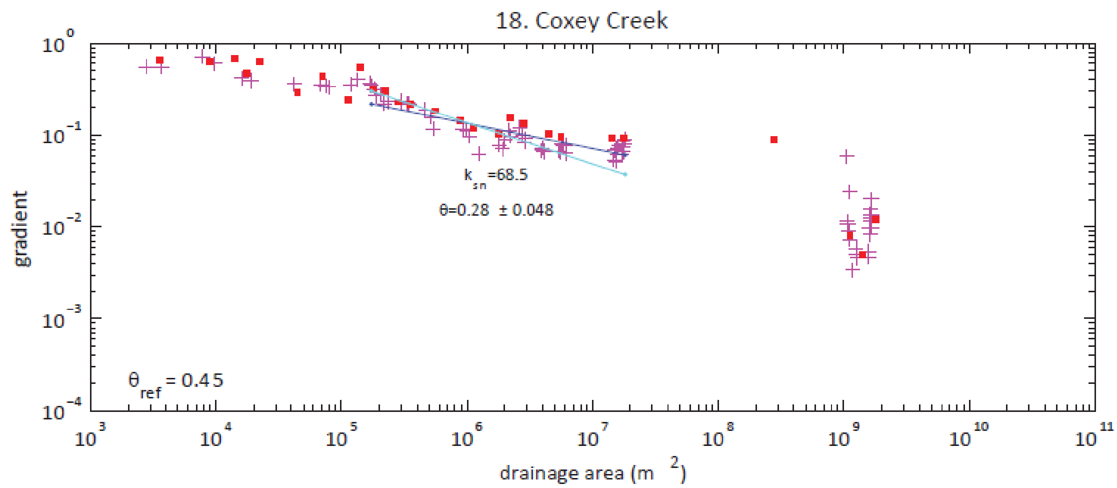


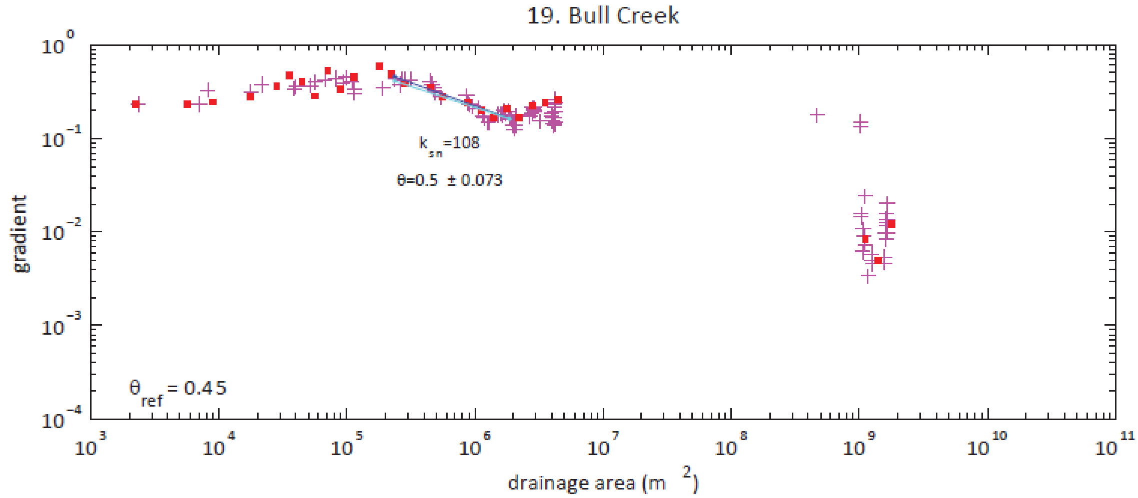

14. Doe Creek
gradient
drainage area (m 2)
k sn =89.6
θ=0.35 ± 0.034
θ ref = 0.45

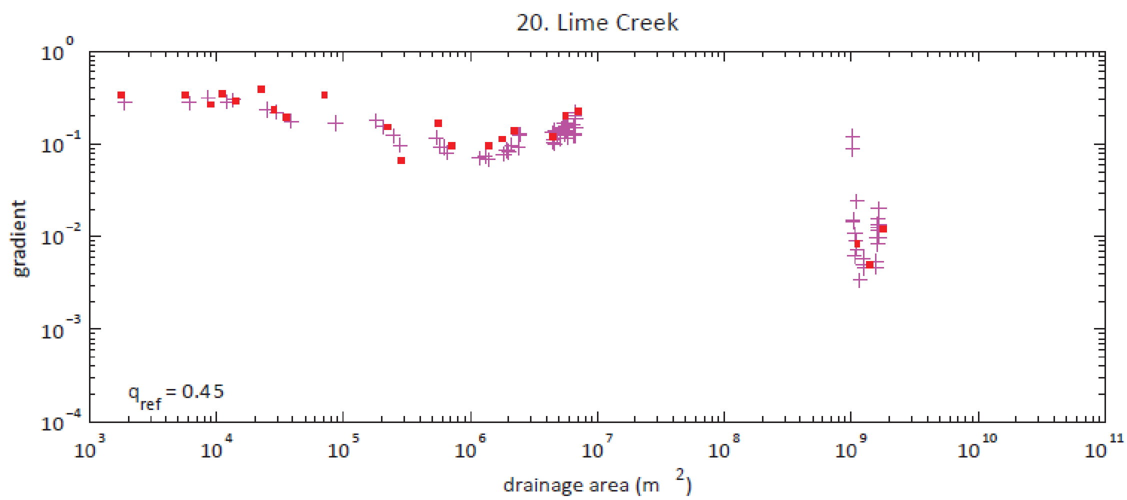

15. Garden Creek
gradient
drainage area (m 2)
k sn =71.5
θ=0.36 ± 0.059
θ ref = 0.45

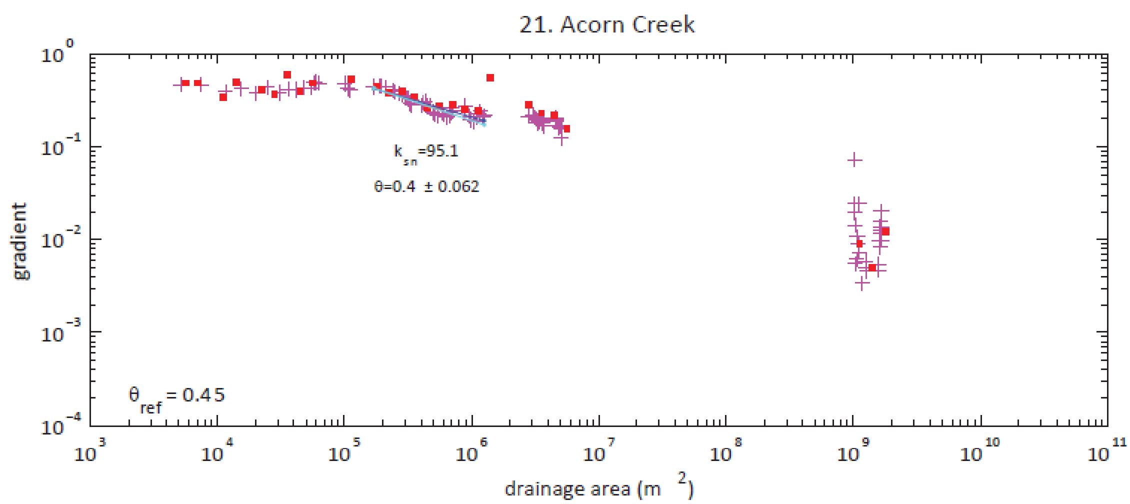

16. Buck Creek
gradient
drainage area (m 2)
k sn =141
θ=1.2 ± 0.74
θ ref = 0.45

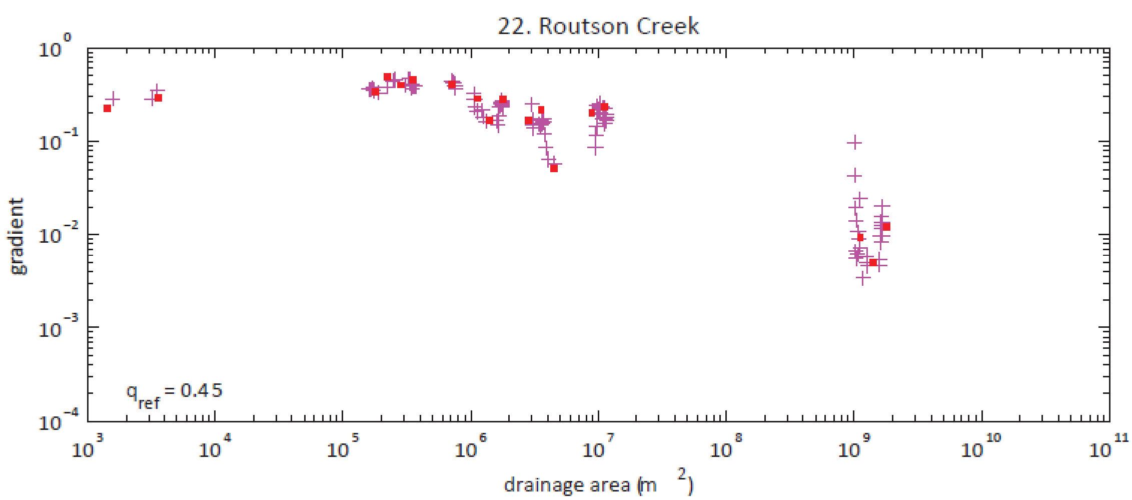

17. Fawn Creek
gradient
drainage area (m 2)
k sn =130
q=0.27 ± 0.021
θ ref = 0.45


18. Coxey Creek
gradient
drainage area (m 2)
k sn =68.5
θ=0.28 ± 0.048
θ ref = 0.45

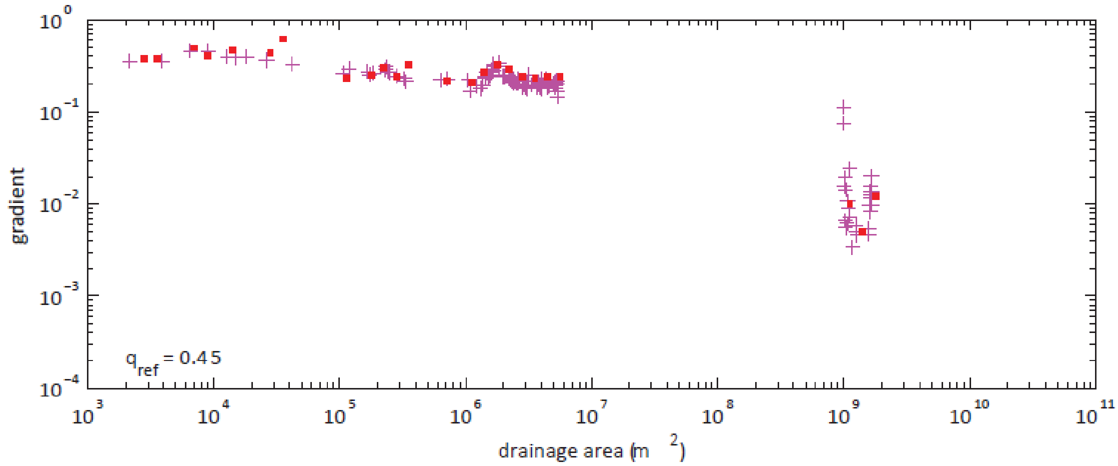

19. Bull Creek
gradient
drainage area (m 2)
k sn =108
θ=0.5 ± 0.073
θ ref = 0.45


20. Lime Creek
gradient
drainage area (m 2)
qref = 0.45

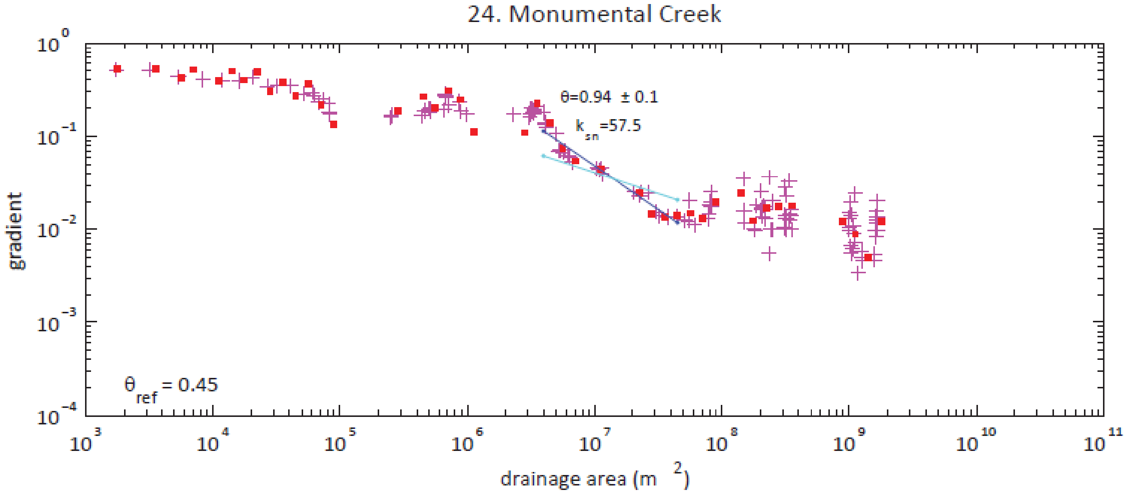

21. Acorn Creek
gradient
drainage area (m 2)
ksn=95.1
θ=0.4 ± 0.062
θref = 0.45


22. Routson Creek
gradient
drainage area (m 2)
qref = 0.45

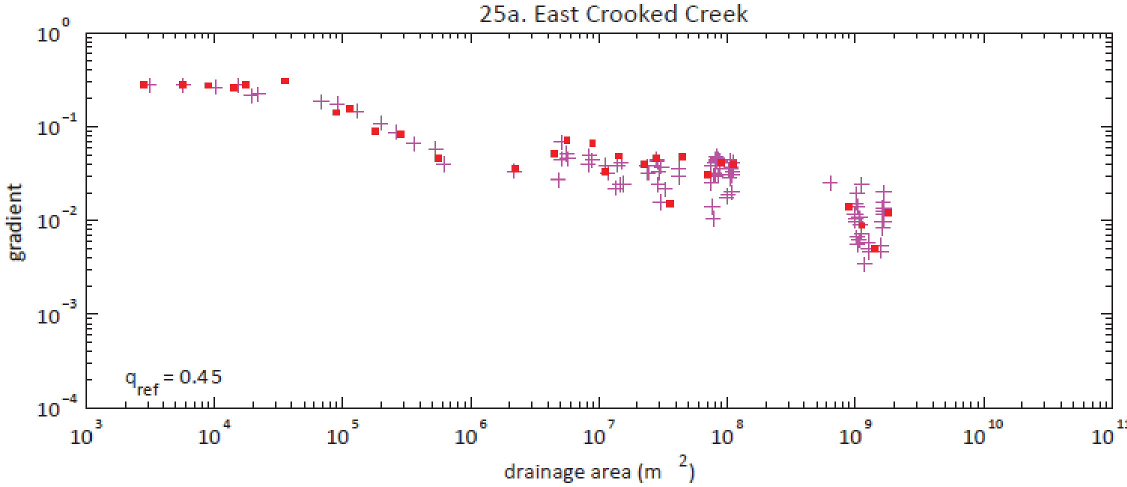
23. Bar Creek

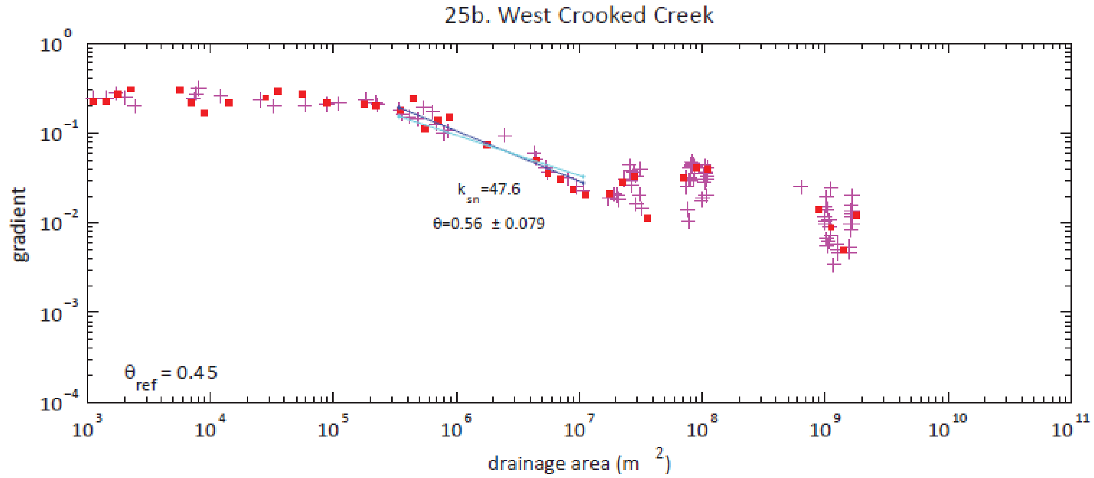


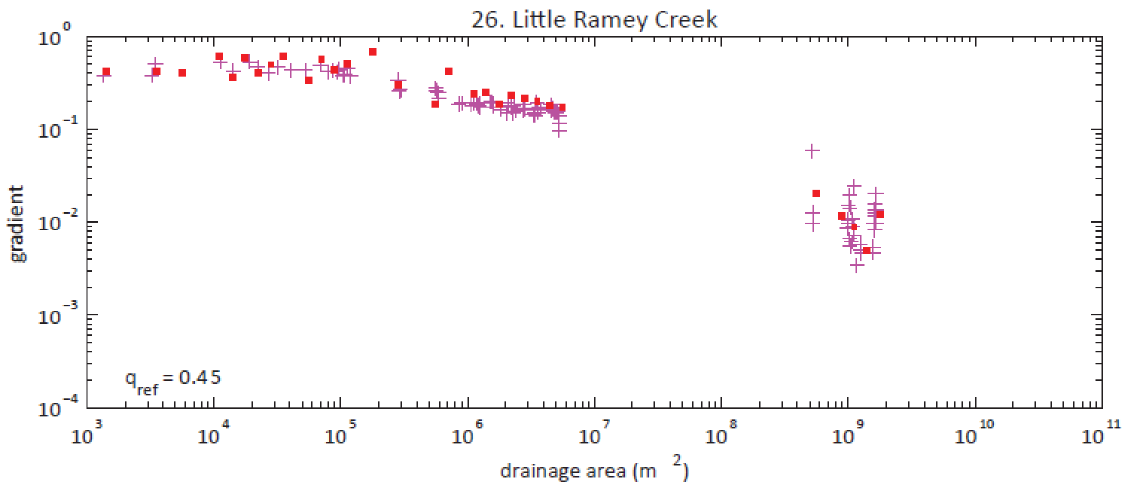
24. Monumental Creek

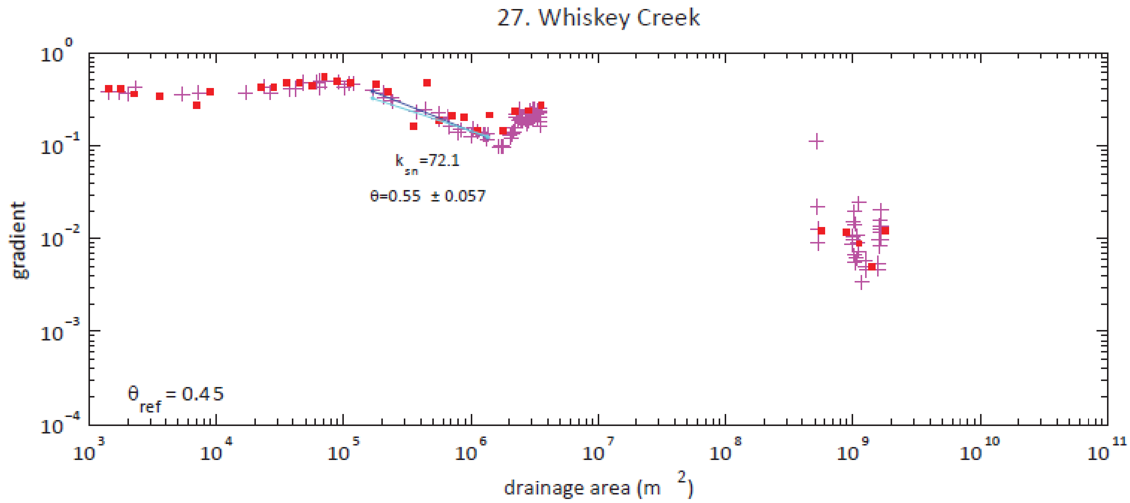


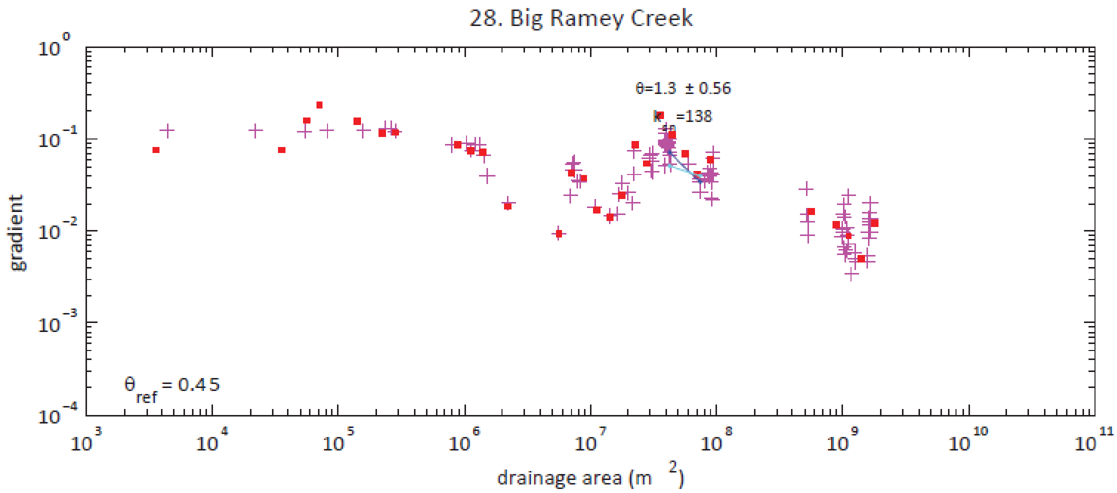
25a. East Crooked Creek

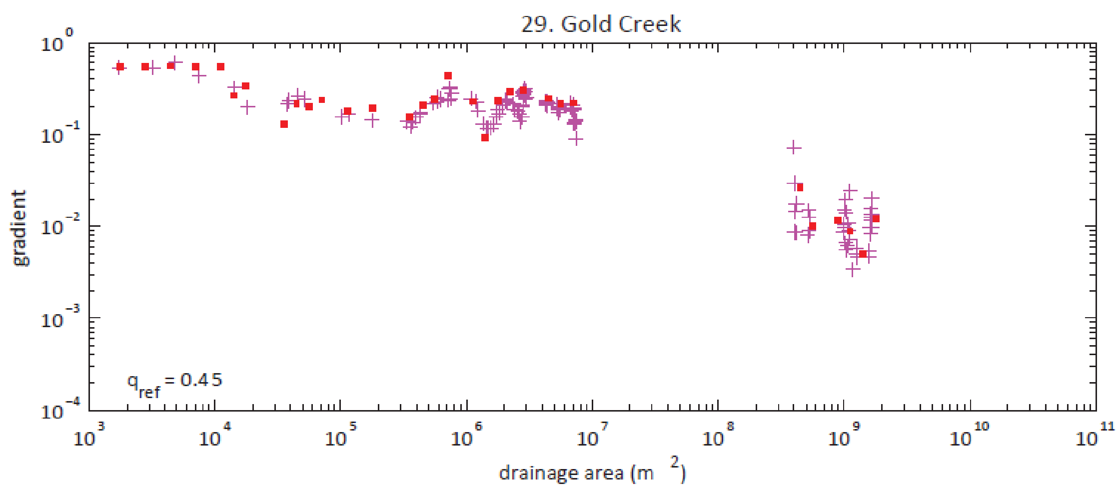


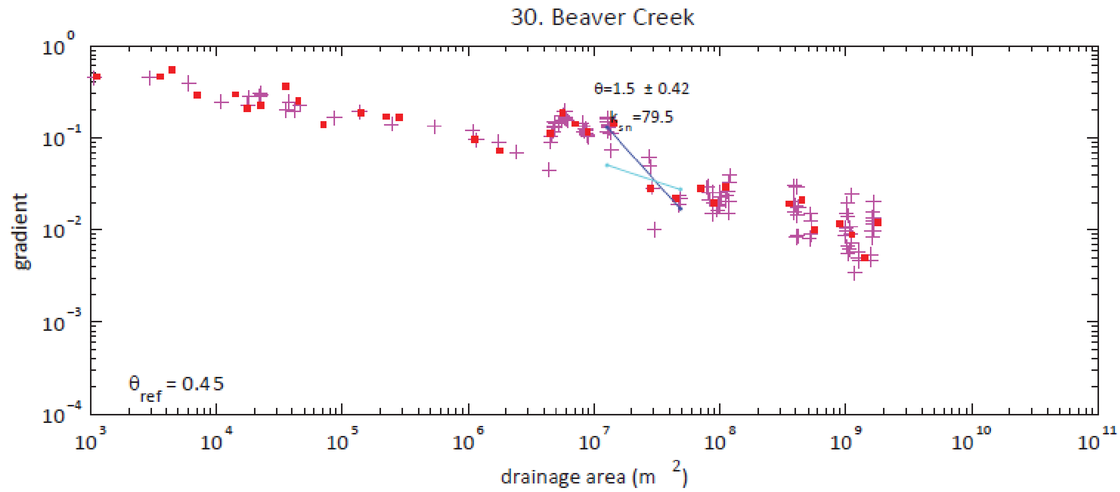

25b. West Crooked Creek
gradient
drainage area (m 2)
k sn =47.6
θ=0.56 ± 0.079
θ ref = 0.45

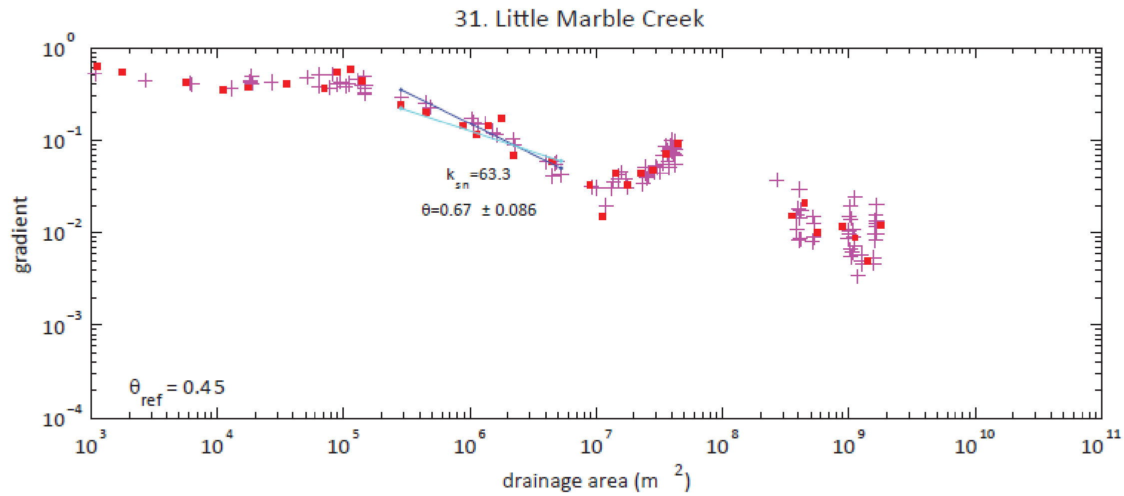

26. Little Ramey Creek
gradient
drainage area (m 2)
q ref = 0.45

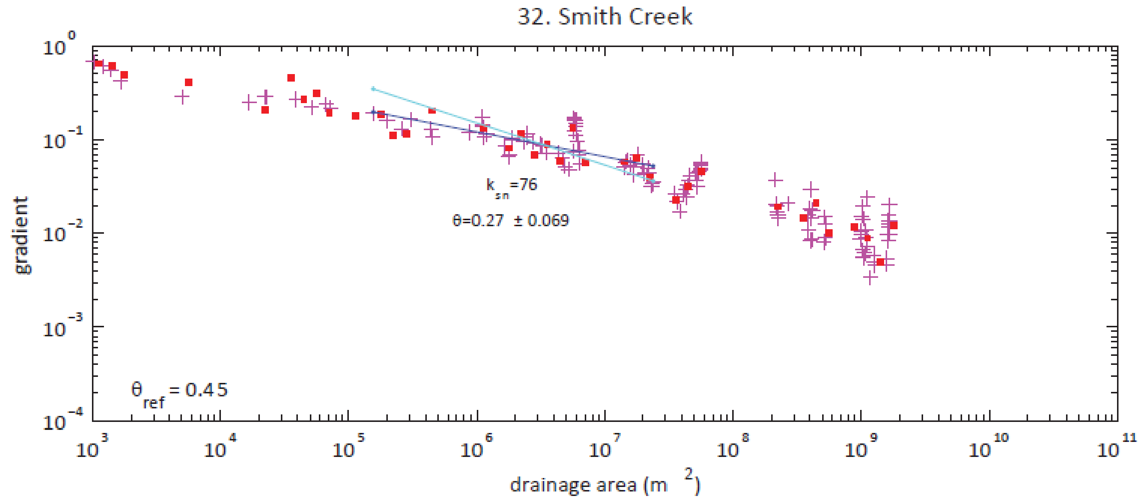

27. Whiskey Creek
gradient
drainage area (m 2)
k sn =72.1
θ=0.55 ± 0.057
θ ref = 0.45

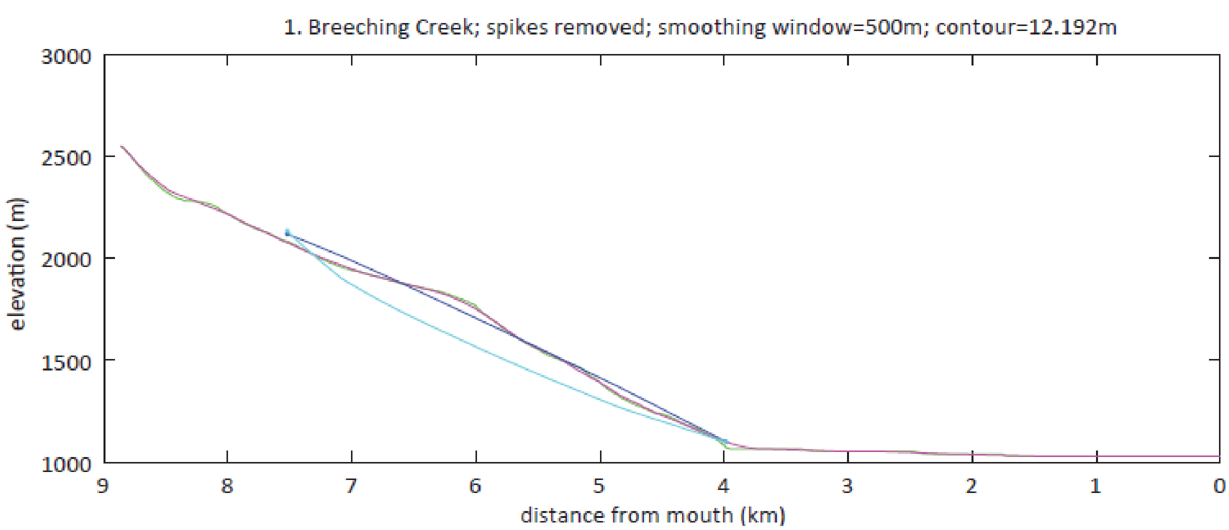

28. Big Ramey Creek
θ=1.3 ± 0.56
k_{sn}=138
$θ_{ref}$ = 0.45
gradient
drainage area (m^2)

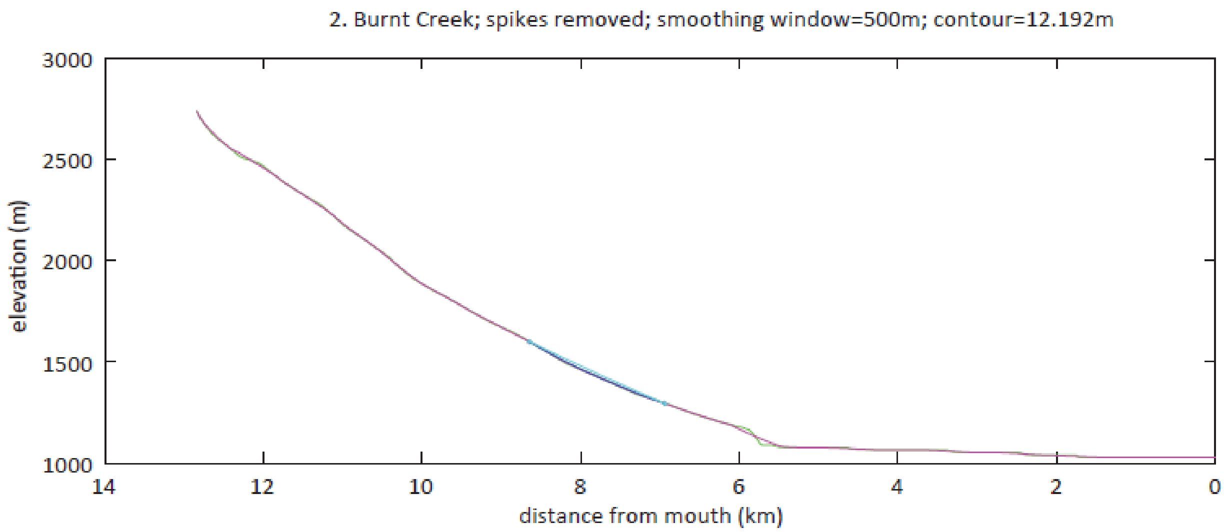

29. Gold Creek
q_{ref} = 0.45
gradient
drainage area (m^2)

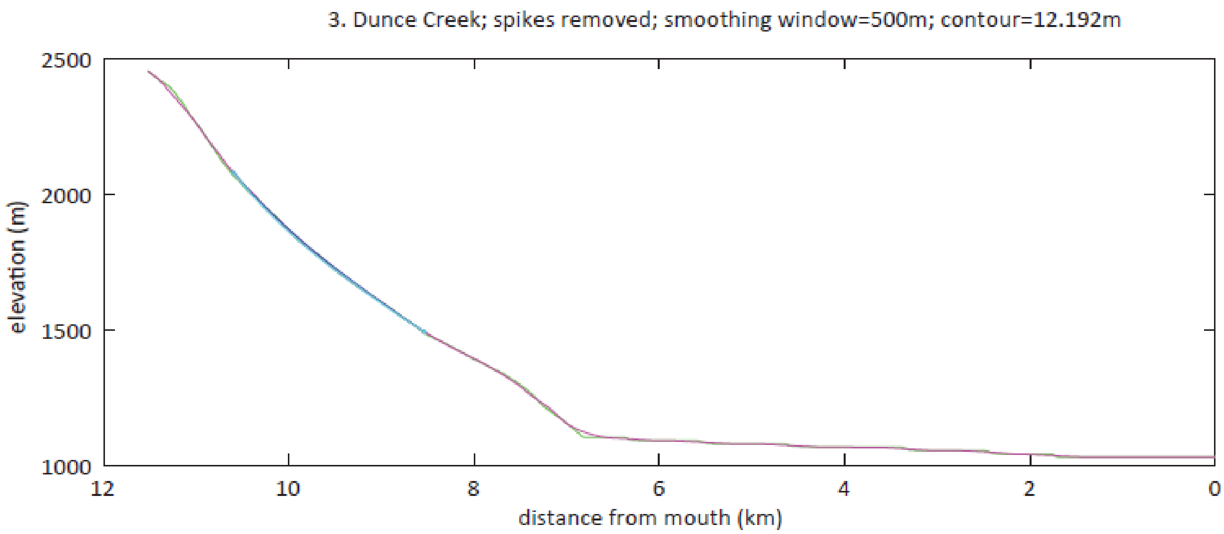

30. Beaver Creek
θ=1.5 ± 0.42
k_{sn}=79.5
$θ_{ref}$ = 0.45
gradient
drainage area (m^2)

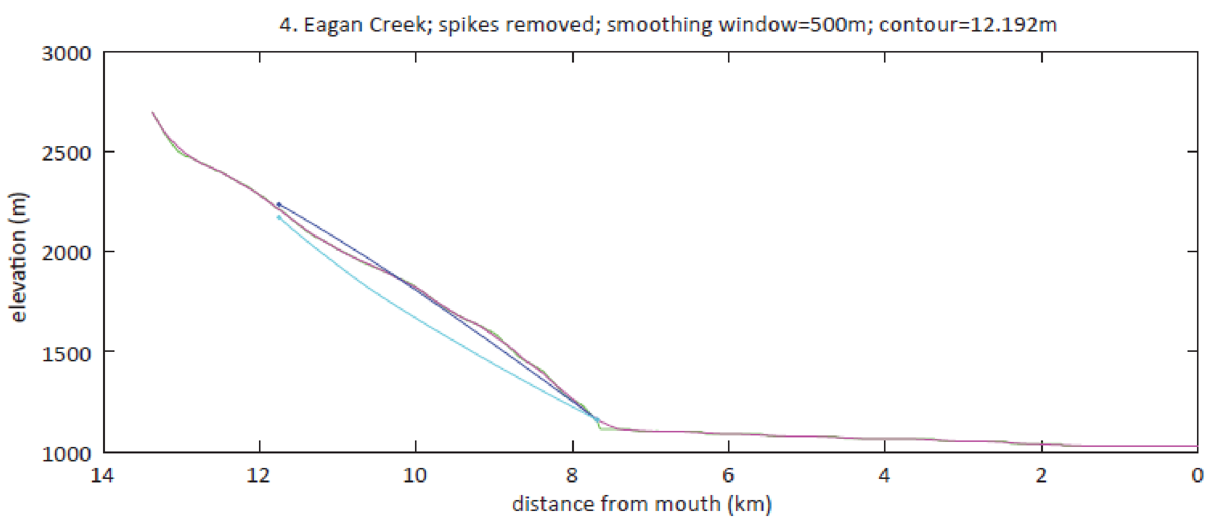

31. Little Marble Creek
gradient
drainage area (m 2)
k sn =63.3
θ=0.67 ± 0.086
θ ref = 0.45


32. Smith Creek
gradient
drainage area (m 2)
k sn =76
θ=0.27 ± 0.069
θ ref = 0.45

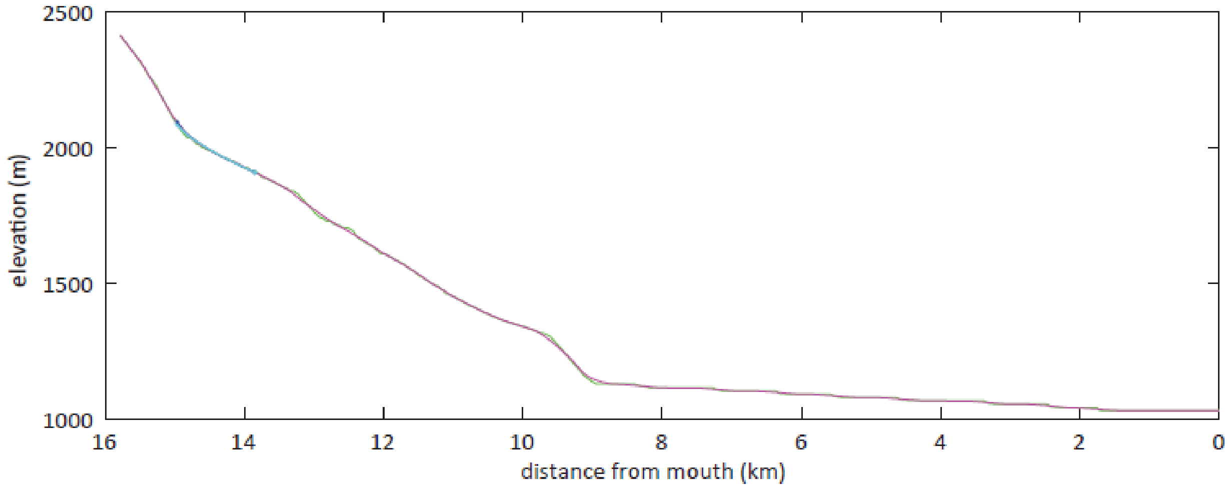

1. Breeching Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
distance from mouth (km)


2. Burnt Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
distance from mouth (km)
3000
2500
2000
1500
1000
14
12
10
8
6
4
2
0

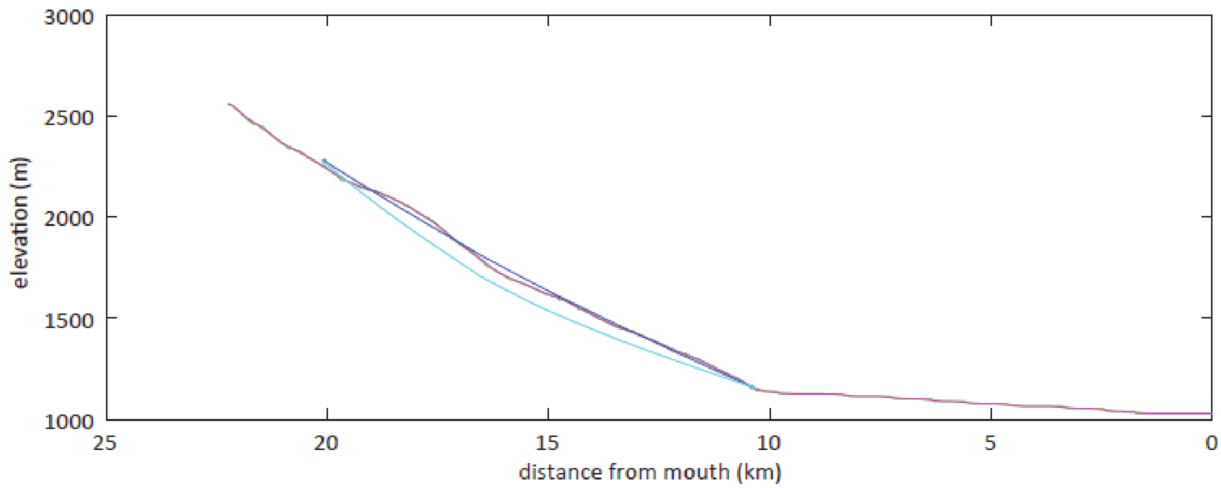

3. Dunce Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
distance from mouth (km)
2500
2000
1500
1000
12
10
8
6
4
2
0


4. Eagan Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
distance from mouth (km)
3000
2500
2000
1500
1000
14
12
10
8
6
4
2
0

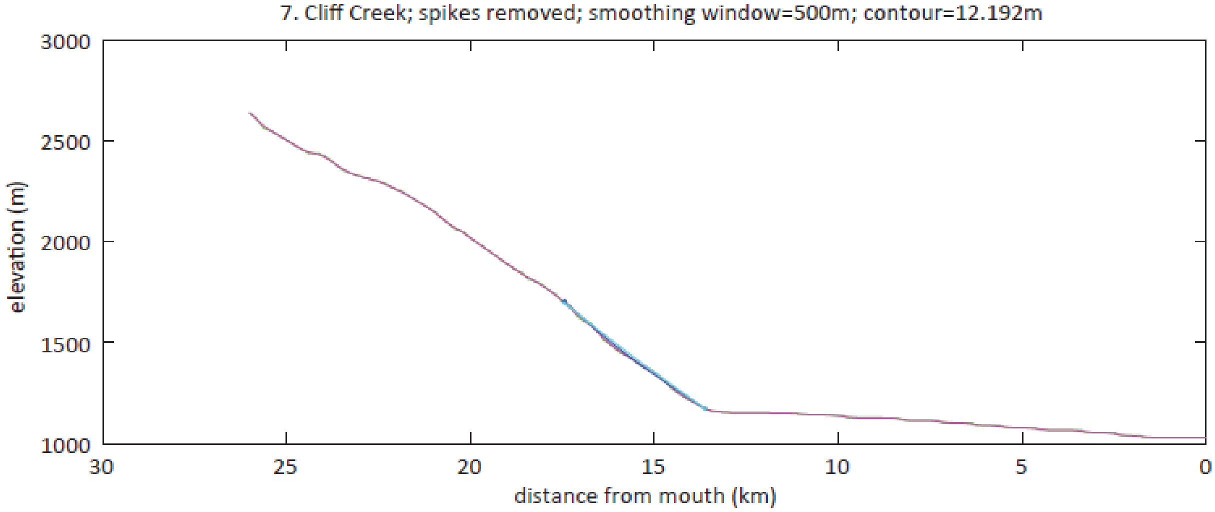
5. Goat Creek; spikes removed; smoothing window=500m; contour=12.192m



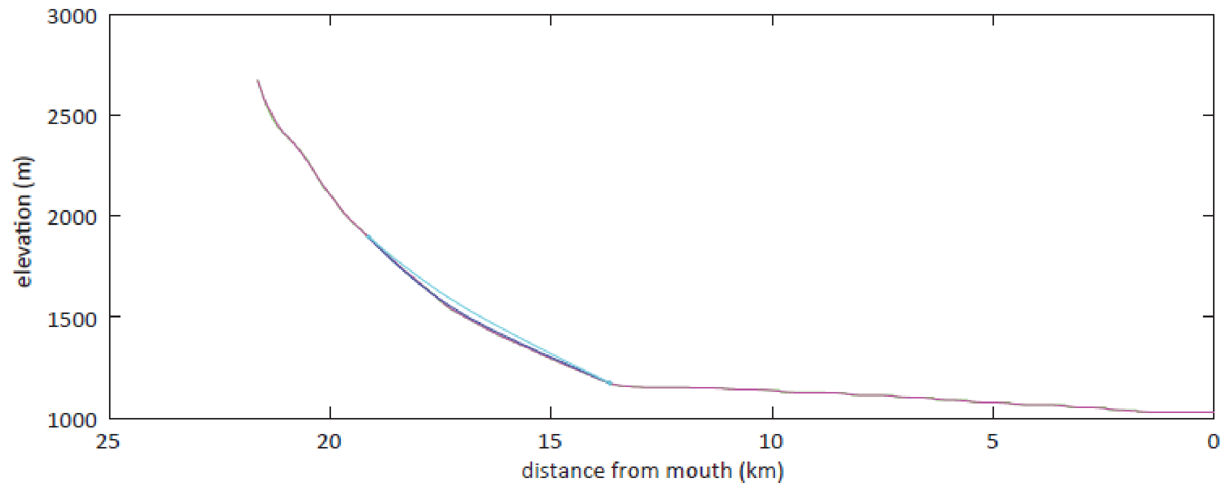
6. Cougar Creek; spikes removed; smoothing window=500m; contour=12.192m



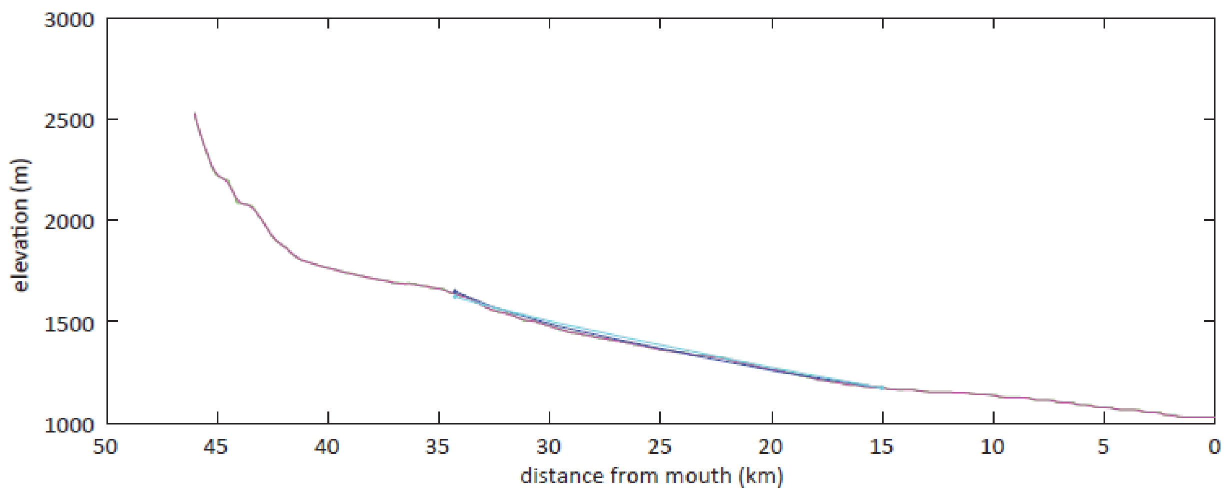
7. Cliff Creek; spikes removed; smoothing window=500m; contour=12.192m



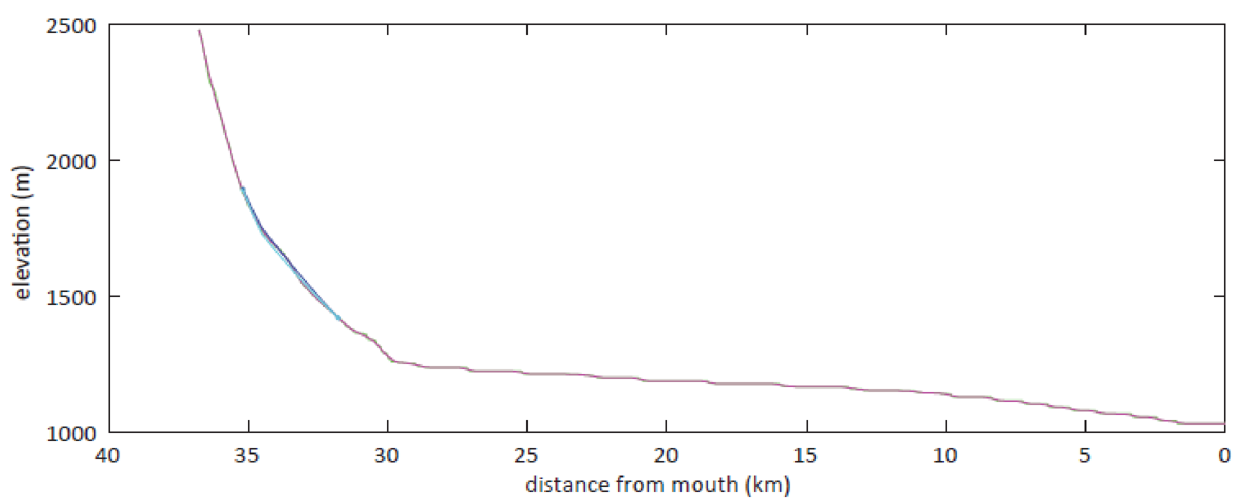
8. Pioneer Creek; spikes removed; smoothing window=500m; contour=12.192m



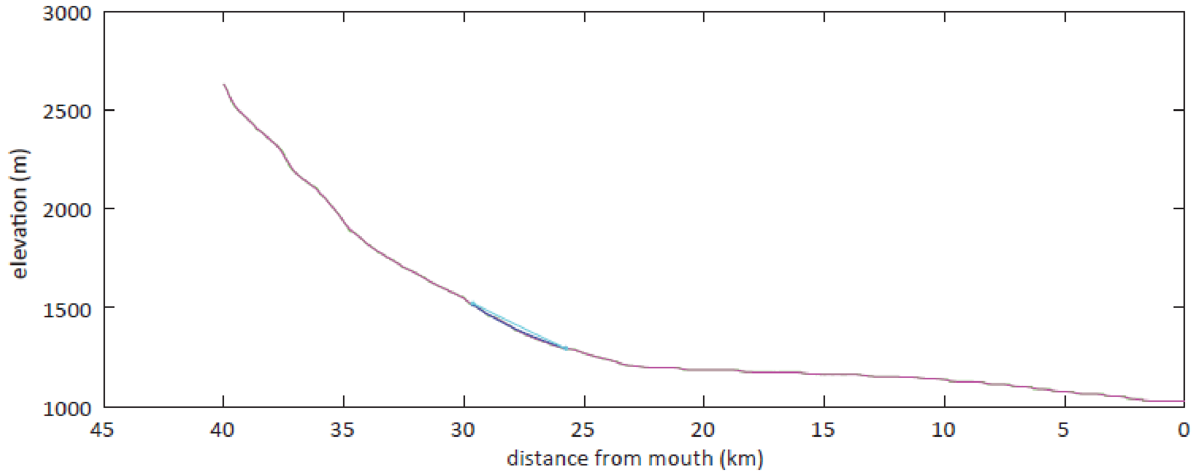
9. Rush Creek; spikes removed; smoothing window=500m; contour=12.192m



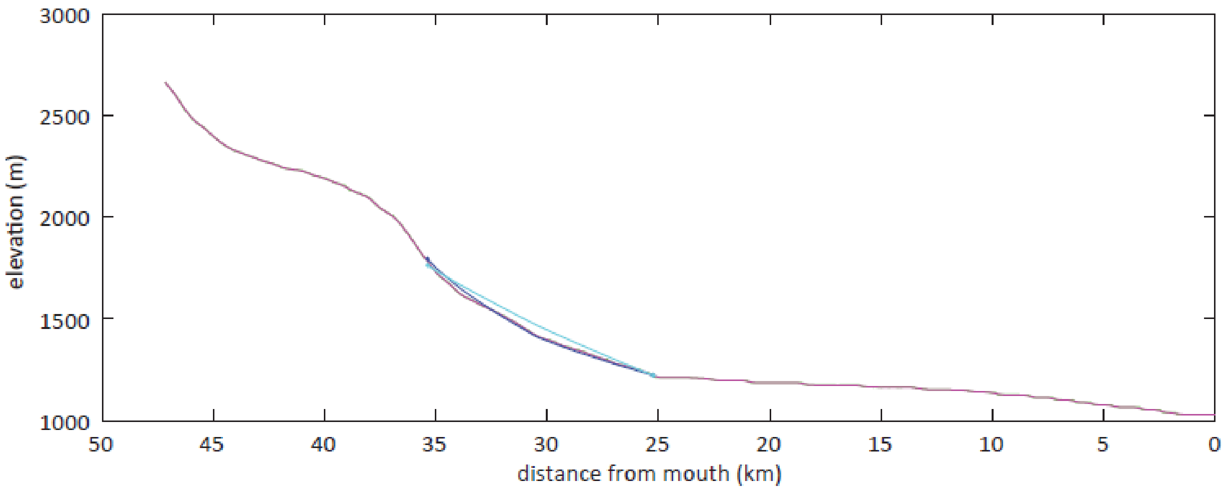
10. Canyon Creek; spikes removed; smoothing window=500m; contour=12.192m



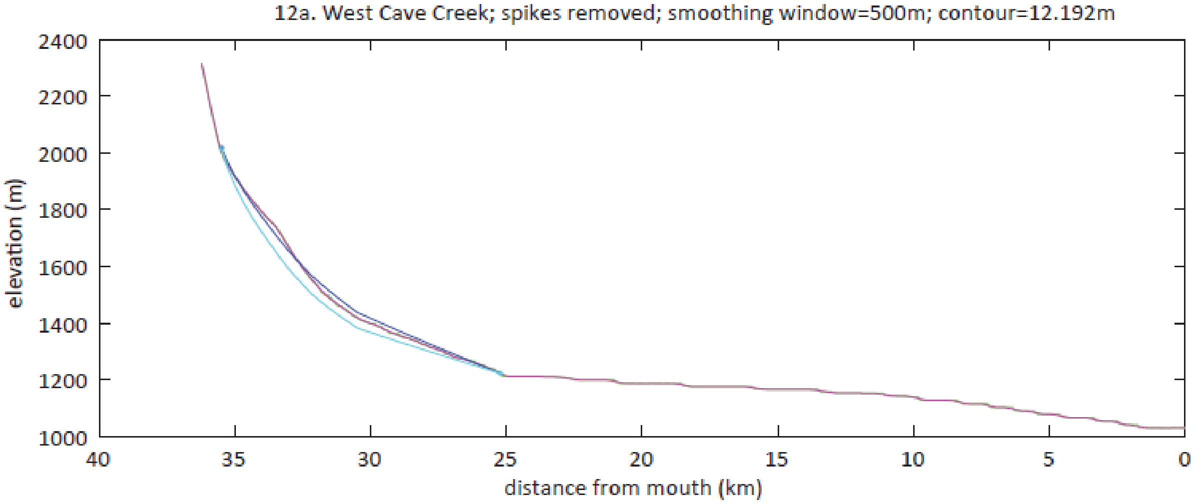
11. Cabin Creek; spikes removed; smoothing window=500m; contour=12.192m



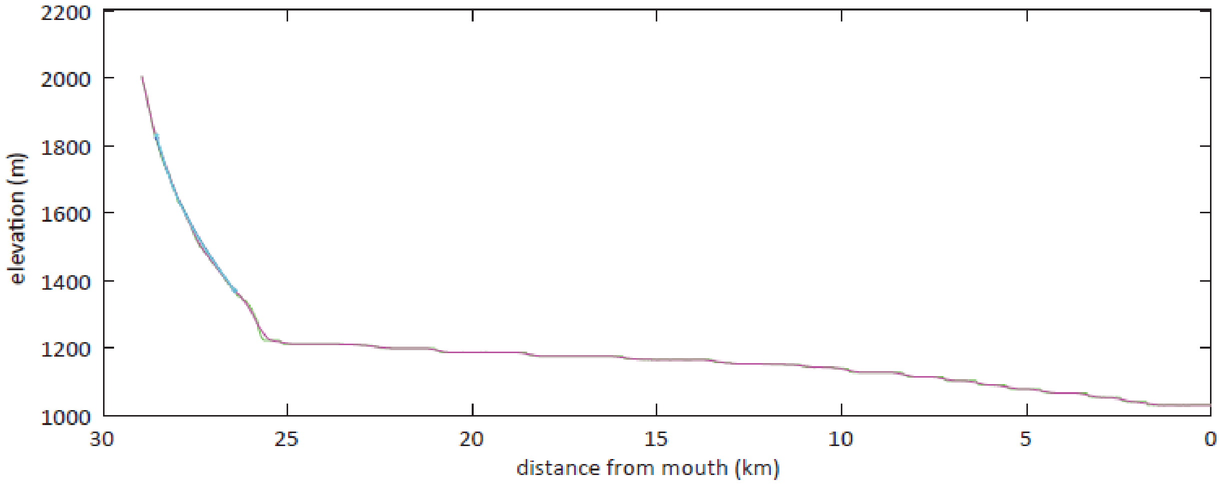
12. Cave Creek; spikes removed; smoothing window=500m; contour=12.192m



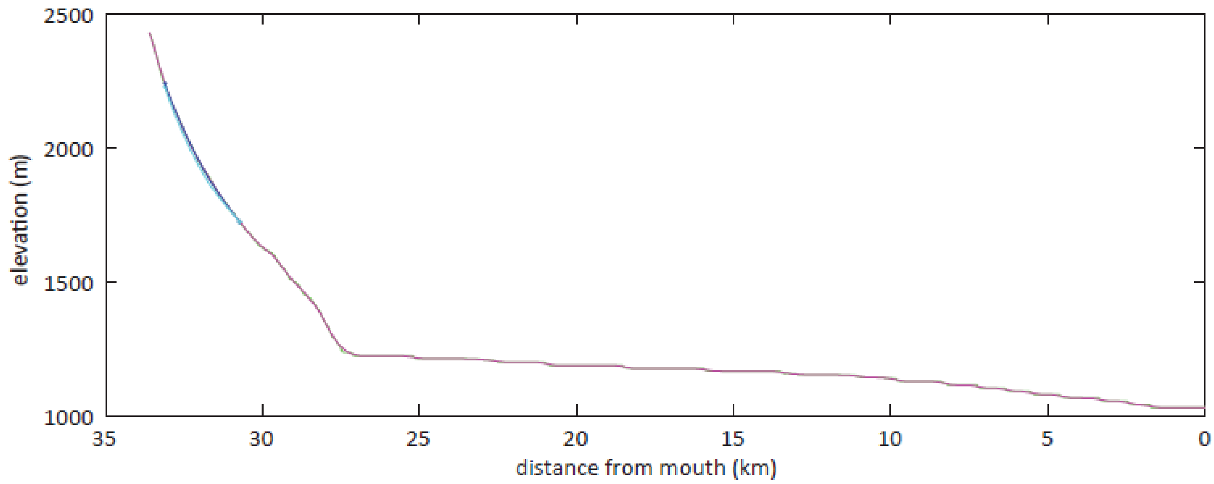
12a. West Cave Creek; spikes removed; smoothing window=500m; contour=12.192m



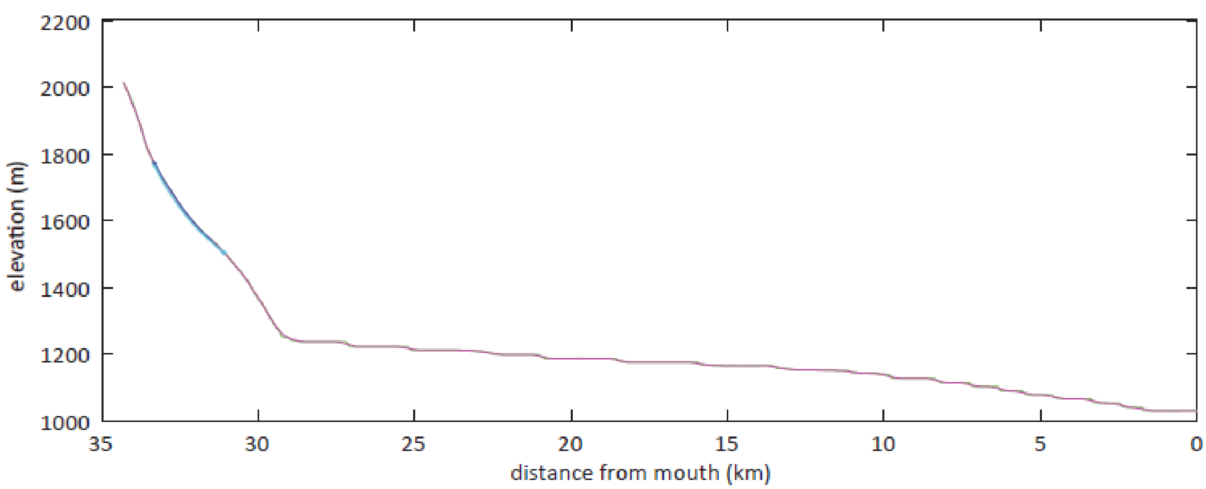
13. Coyote Creek; spikes removed; smoothing window=500m; contour=12.192m

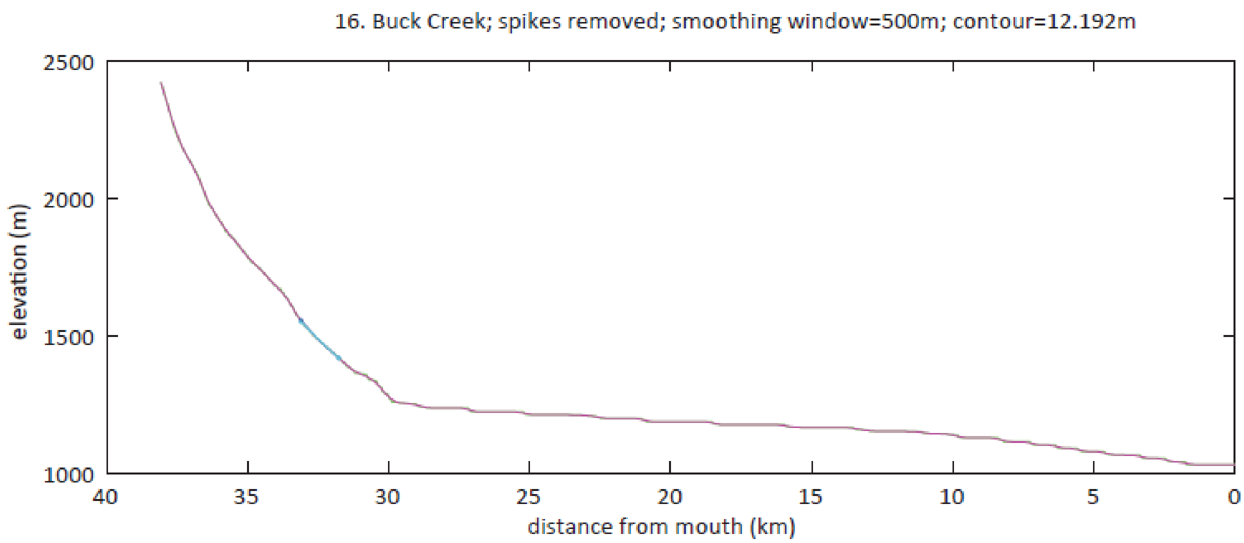


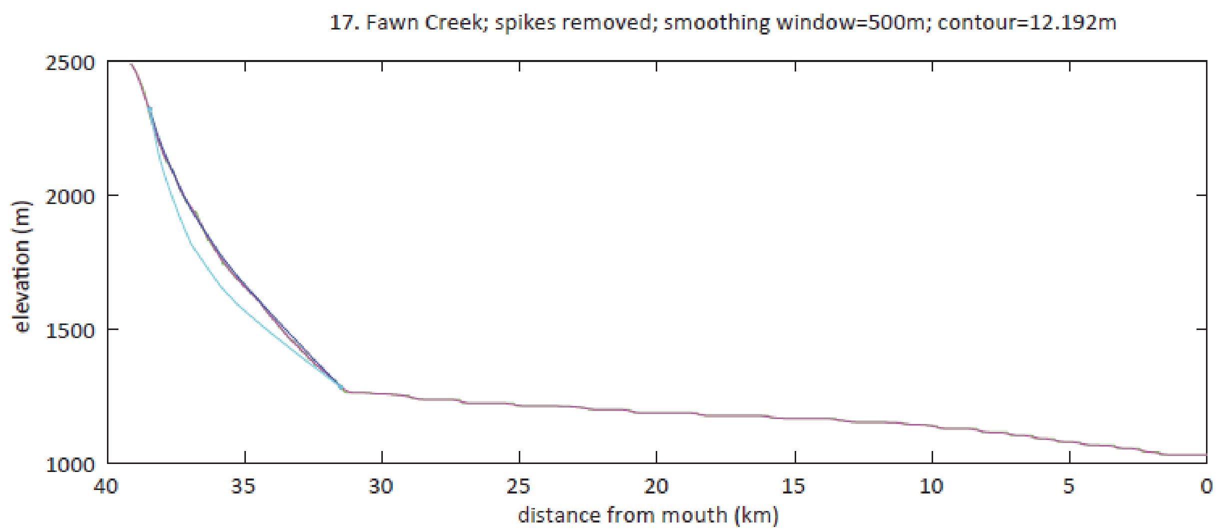
14. Doe Creek; spikes removed; smoothing window=500m; contour=12.192m

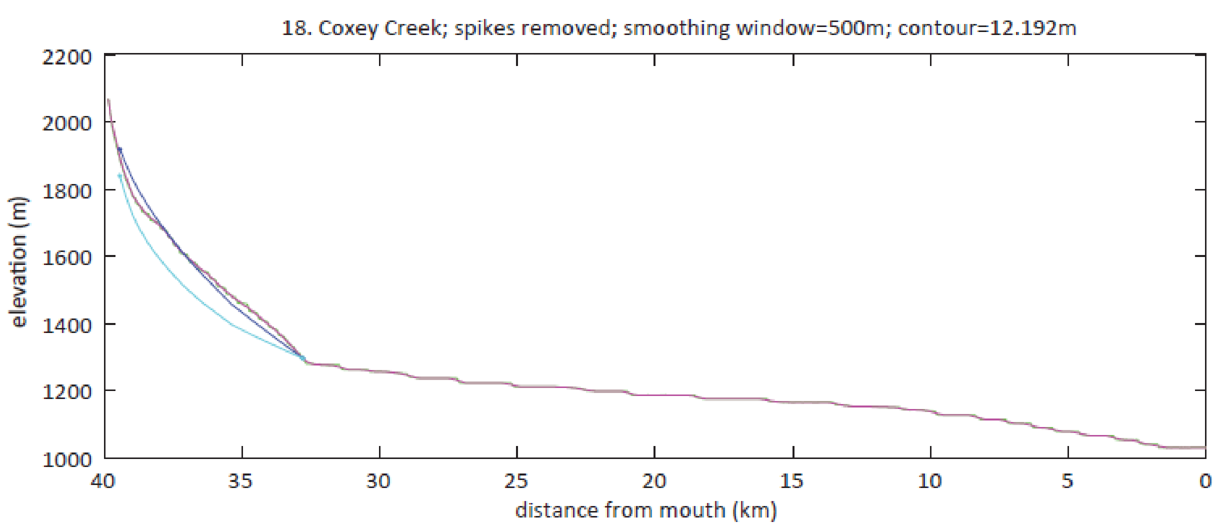


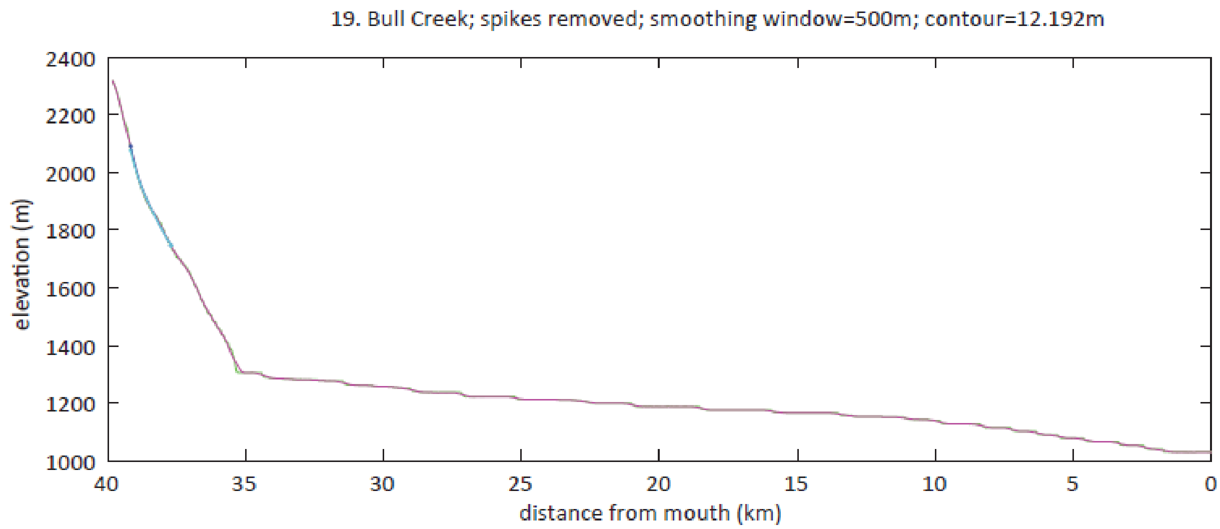
15. Garden Creek; spikes removed; smoothing window=500m; contour=12.192m

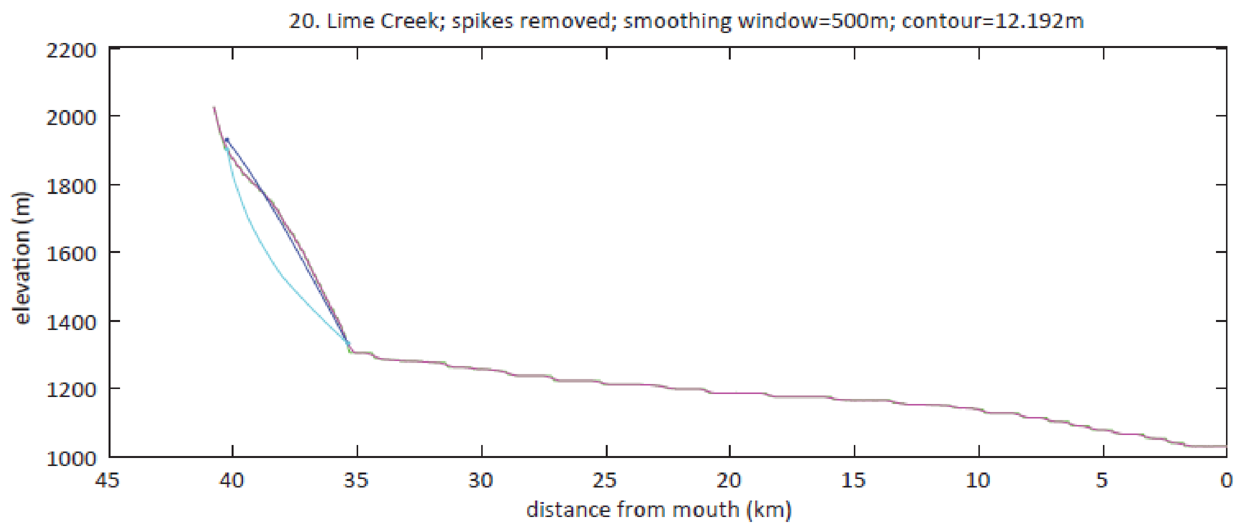


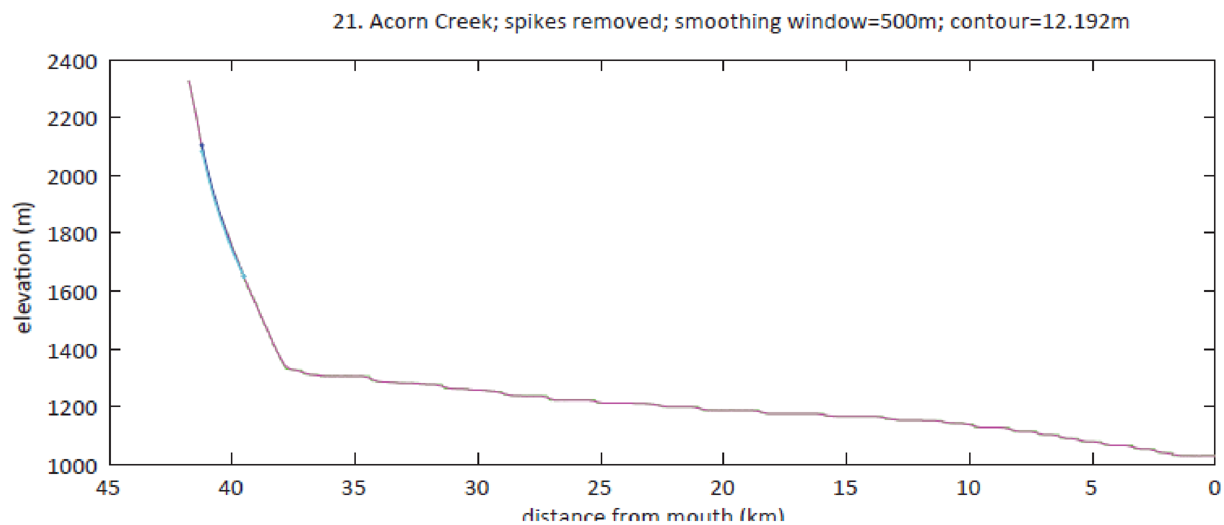

16. Buck Creek; spikes removed; smoothing window=500m; contour=12.192m
2500
2000
1500
1000
elevation (m)
40
35
30
25
20
15
10
5
0
distance from mouth (km)

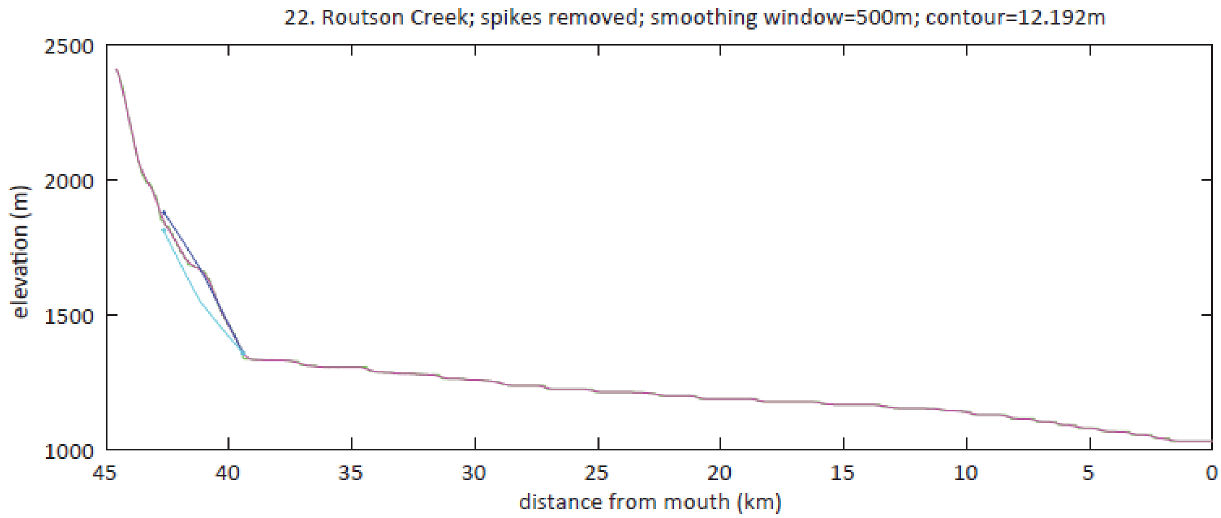

17. Fawn Creek; spikes removed; smoothing window=500m; contour=12.192m
2500
2000
1500
1000
elevation (m)
40
35
30
25
20
15
10
5
0
distance from mouth (km)

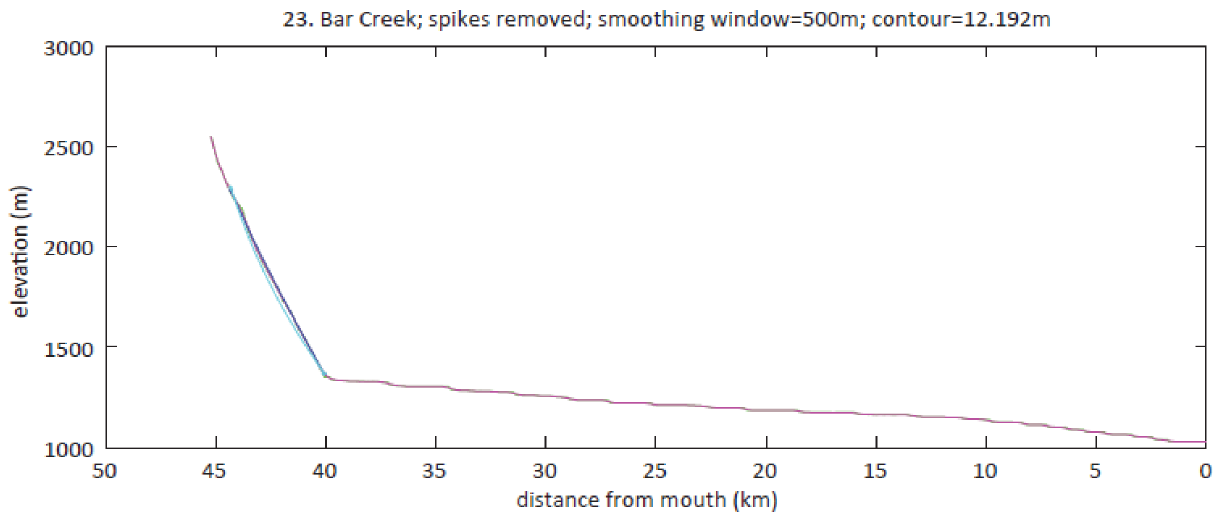

18. Coxey Creek; spikes removed; smoothing window=500m; contour=12.192m
2200
2000
1800
1600
1400
1200
1000
elevation (m)
40
35
30
25
20
15
10
5
0
distance from mouth (km)

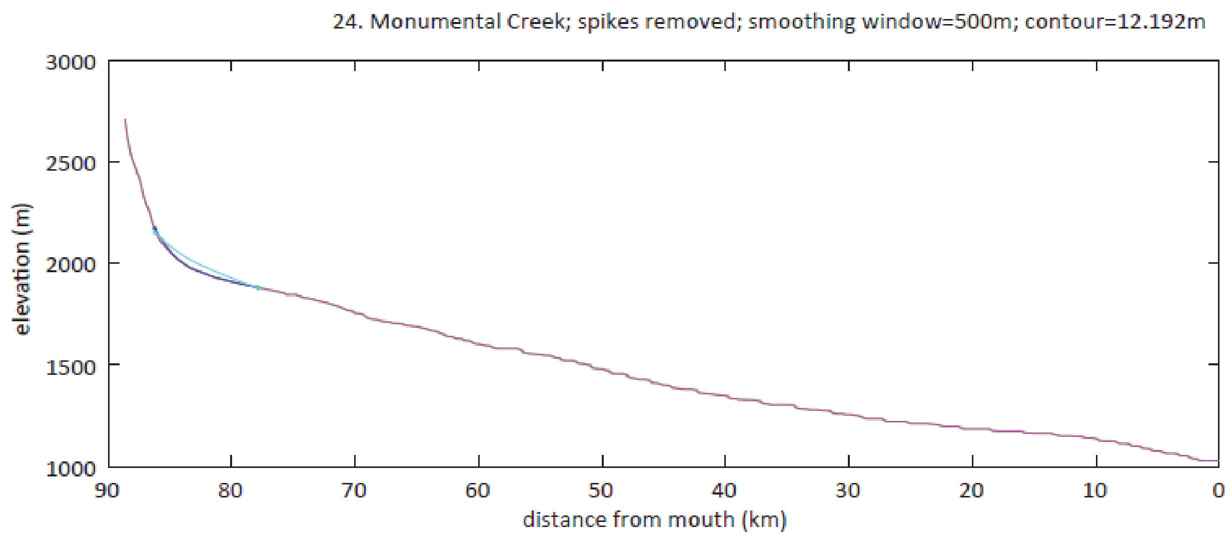

19. Bull Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
distance from mouth (km)
2400
2200
2000
1800
1600
1400
1200
1000
40
35
30
25
20
15
10
5
0

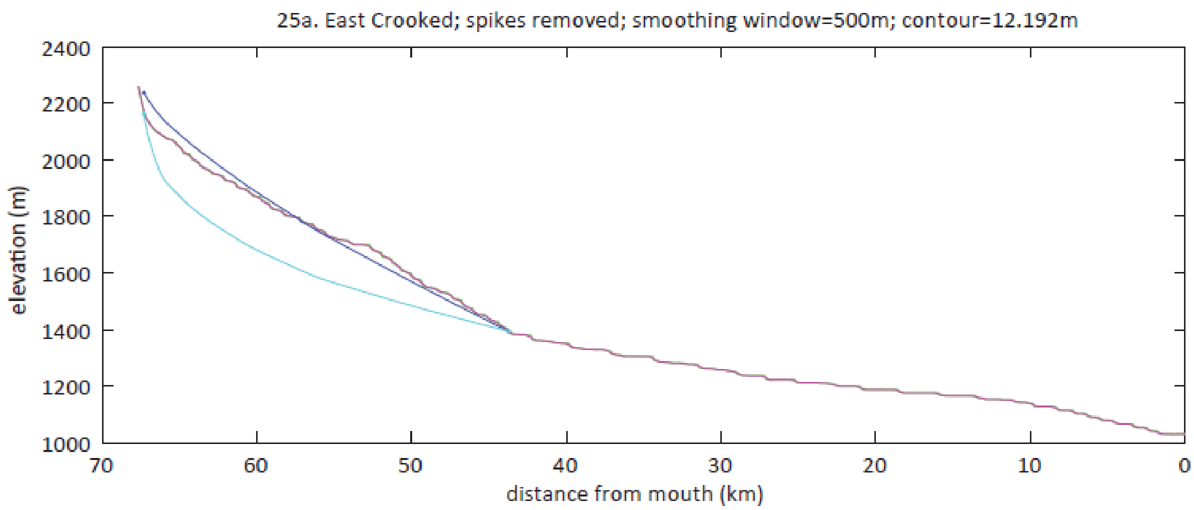

20. Lime Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
distance from mouth (km)
2200
2000
1800
1600
1400
1200
1000
45
40
35
30
25
20
15
10
5
0

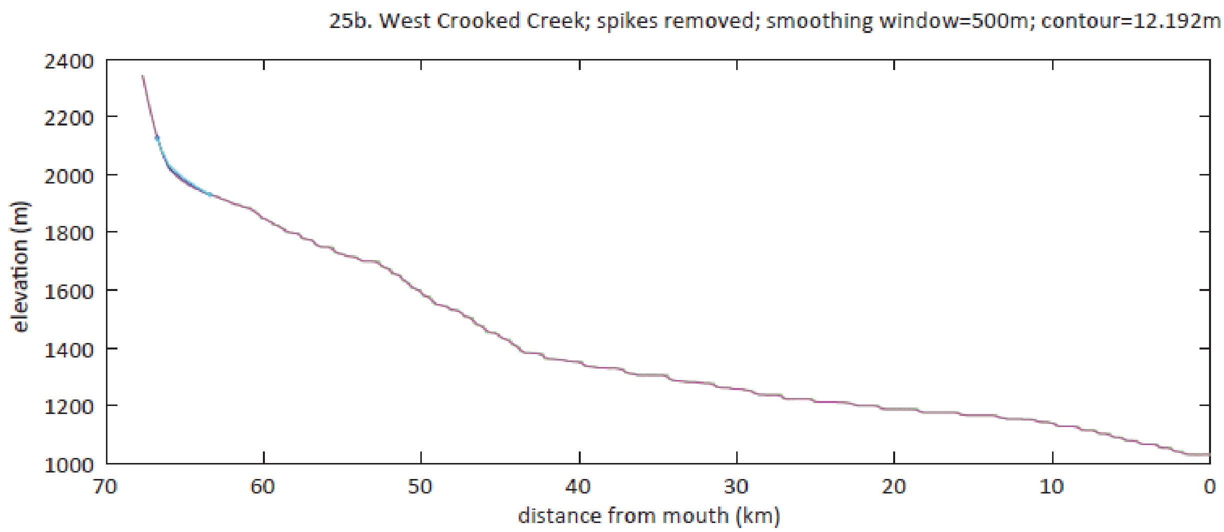

21. Acorn Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
2400
2200
2000
1800
1600
1400
1200
1000
45
40
35
30
25
20
15
10
5
0

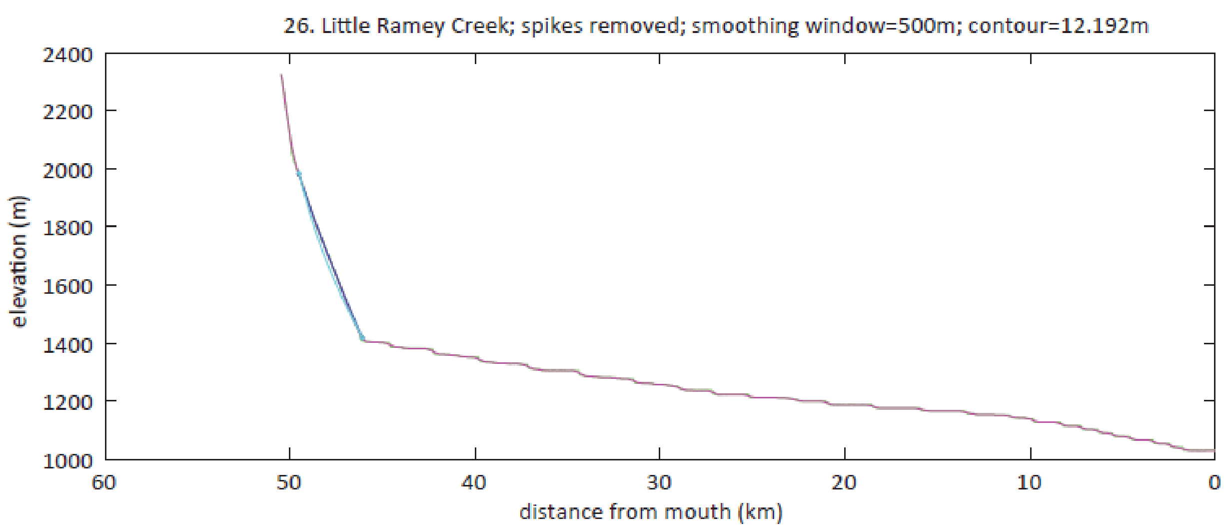

22. Routson Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
2500
2000
1500
1000
45
40
35
30
25
20
15
10
5
0
distance from mouth (km)


23. Bar Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
3000
2500
2000
1500
1000
50
45
40
35
30
25
20
15
10
5
0
distance from mouth (km)

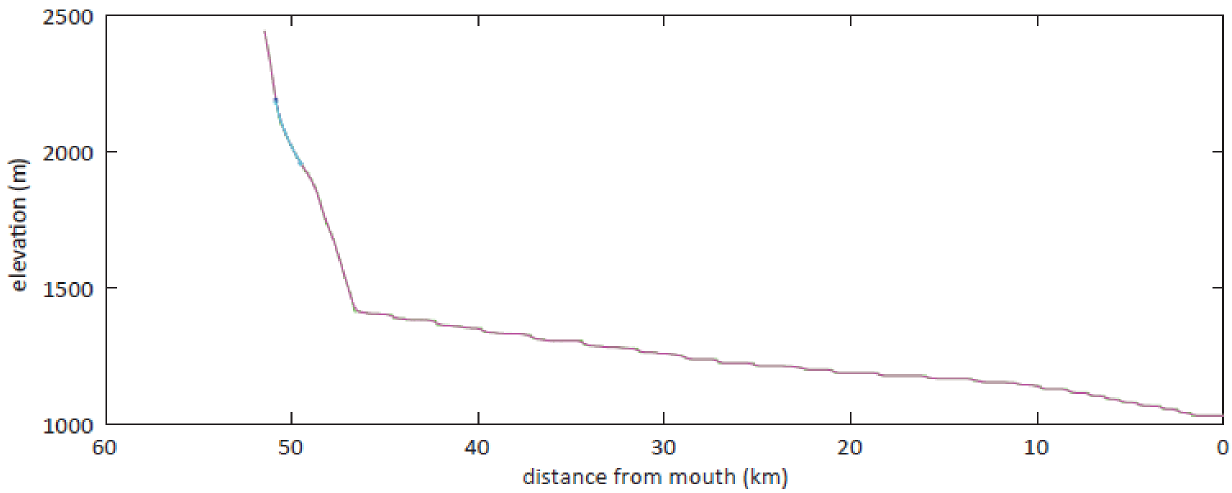

24. Monumental Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
3000
2500
2000
1500
1000
90
80
70
60
50
40
30
20
10
0
distance from mouth (km)


25a. East Crooked; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
distance from mouth (km)

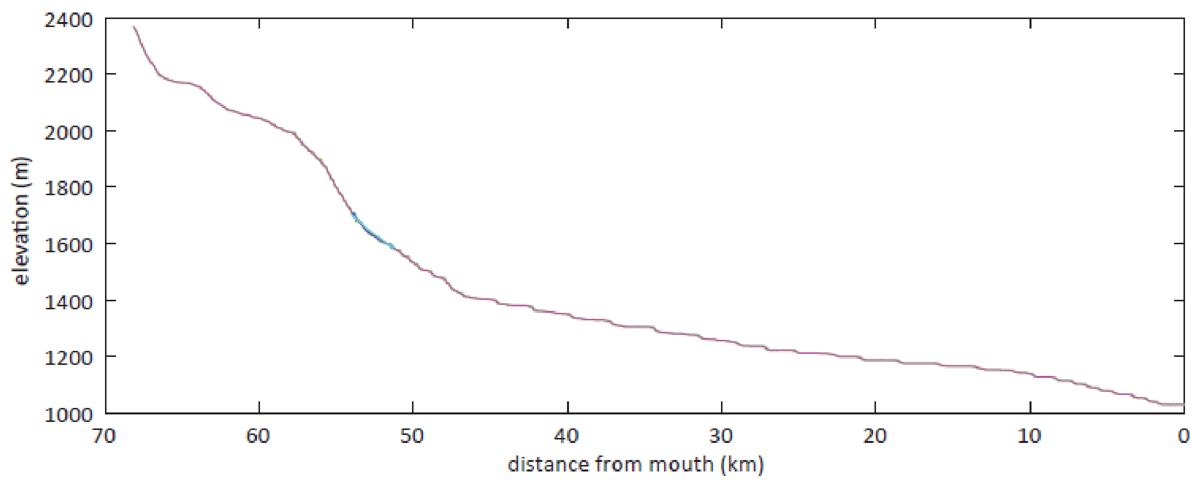

25b. West Crooked Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
distance from mouth (km)


26. Little Ramey Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
distance from mouth (km)

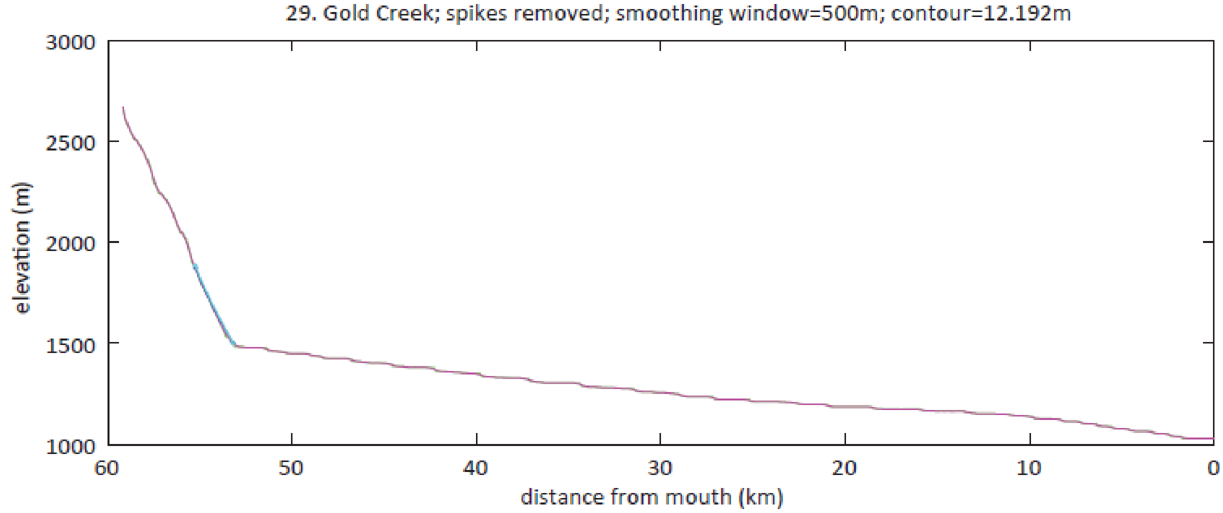
27. Whiskey Creek; spikes removed; smoothing window=500m; contour=12.192m

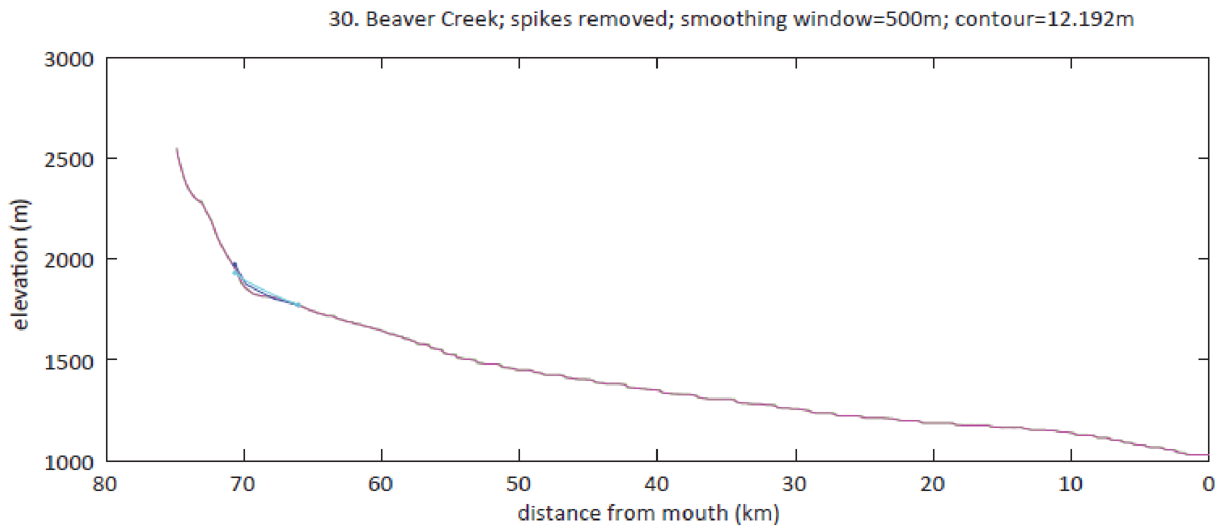


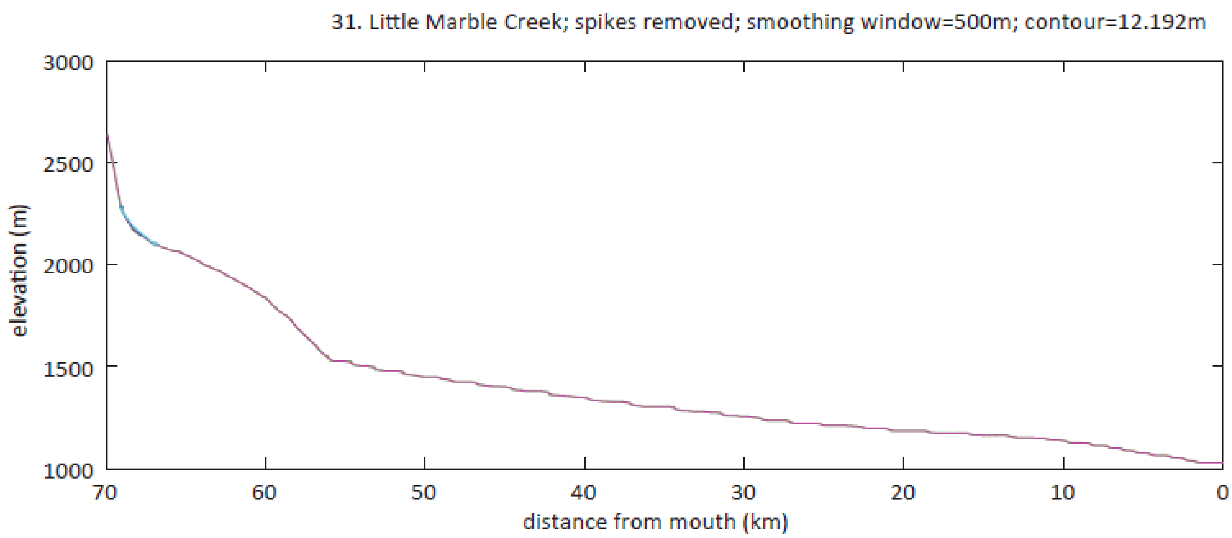
28. Big Ramey Creek; spikes removed; smoothing window=500m; contour=12.192m

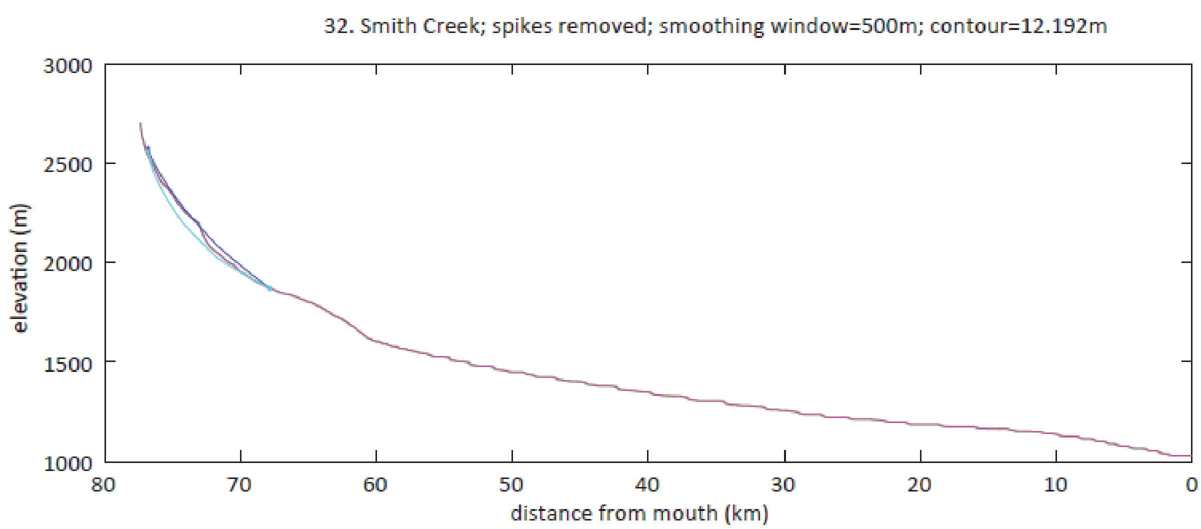


29. Gold Creek; spikes removed; smoothing window=500m; contour=12.192m




30. Beaver Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
3000
2500
2000
1500
1000
80
70
60
50
40
30
20
10
0
distance from mouth (km)


31. Little Marble Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
3000
2500
2000
1500
1000
70
60
50
40
30
20
10
0
distance from mouth (km)


32. Smith Creek; spikes removed; smoothing window=500m; contour=12.192m
elevation (m)
3000
2500
2000
1500
1000
80
70
60
50
40
30
20
10
0
distance from mouth (km)