Museum Fire Sediment Reduction Project

Sediment Budget Analysis

Natural Channel Design, Inc.

January 2022

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Submitted to:

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COCONINO
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January 2022

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January 6, 2022

Christopher Tressler, PE, CFM
Coconino County Flood Control District
5600 E Commerce Drive
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RE: Museum Fire Sediment Reduction Project
Sediment Budget Analysis

Dear Mr. Tressler

Natural Channel Design, Inc. is pleased to present this final report relative to the Museum Fire Sediment Reduction Project – Sediment Budget Analysis. The analysis included herein is based upon our team knowledge and past experience with geology, geomorphology, hydrology and civil engineering practices with respect to post-fire watershed restoration and flood mitigation. Conclusions presented herein relative to the sediment budget analysis and potential reductions in average annual sediment yield from the burn scar are intended to support pending funding and designs for on-forest and off-forest mitigation practices.

As the Coconino County Flood Control District, City of Flagstaff and partner federal agencies move forward with mitigation work to reduce post-fire sediment delivery to downstream neighborhoods and public infrastructure, we would look forward to providing additional design, analysis and construction phase assistance. If you have any questions regarding the content of this report, please feel free to call us at your earliest convenience.

Sincerely,

Allen Haden
Aquatic Ecologist, President
Natural Channel Design, Inc.

Jacob Fleishman, PE, CFM
Civil Engineer
Natural Channel Design, Inc.

Registered Professional Engineer (Civil)
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EXECUTIVE SUMMARY

Post-fire flooding from the Museum Fire burn area has resulted in high-discharge flooding and associated sediment yields that have exacerbated flooding issues in downstream residential areas. To implement practices that are designed to reduce downstream sediment delivery, there is a need to first estimate sediment source areas, quantities, and transport rates. This sediment reduction analysis will **a)** assess the geomorphic state of all post-fire impacted channels within the watershed, **b)** estimate the Museum Fire watershed's average annual and precipitation event-based sediment yield, **c)** determine the sediment transport of channels in their current state (fall 2021) and after treatment (based on conceptual-level designs), and **d)** develop treatment options capable of reducing the downstream sediment delivery.

This assessment quantified sediment yields from specific upstream source areas to prioritize downstream work areas. Specific work areas were evaluated for sediment transport capacity through existing and redesigned channel cross sections to identify potential sediment reduction practices within the Coconino National Forest, City of Flagstaff property, and private lands.

When reviewing the results of this study, it is important to note that the study relies upon modeled *average annual sediment yields* rather than *event-based sediment yields*. Average annual sediment yield is more useful for designing and implementing watershed wide restoration practices, but the annual sediment yield values provided should not be confused with event-based sediment yield estimates that are derived from large, infrequent storm events. We have provided an event-based sediment yield from specific storm events to provide a framework for event-based vs. average annual sediment yield comparison, but NCD cautions direct comparison of the two estimation methods. Lastly, it should be noted that the methods utilized in this study separate sediment supply (a function of hillslope and channel bank sediment yield) from sediment transport (a function of channel geometry and hydrologic properties). In this analysis, sediment transport is provided at discreet areas utilizing typical riffle cross sections and slopes that control sediment transport function. Sediment transport estimates are provided in average annual units and are not directly comparable to event-based analyses.

Data collection and modeling for this analysis included:

- Field surveys (14 miles) of stream channels in the Museum Fire watershed to estimate bank erosion.
- Rapid geomorphic assessment and field surveys of channel cross sections, channel slope, Rosgen channel type, and valley setting.
- Utilization of the BANCS model to estimate channel bank annual sediment yield in tons per year
- Utilization of the ERMiT model to estimate hillslope annual sediment yield in tons per year.
- Utilization of the Modified Universal Soil Loss Equation to estimate specific precipitation event-based hillslope sediment yield in tons per 1-inch, 2-inch and 3-inch storm events (one hour duration).
- Utilization of FLOWSED/POWERSED model to estimate sediment transport efficiency within channels in their existing condition (fall 2021) and proposed, conceptual redesign.

The results provide several key insights to sediment supply and delivery from the Museum Fire burn area:

- Models estimate large sediment yield from both bank and hillslope erosional processes. Upstream sediment yield to downstream channels are generally higher than channel sediment transport capacity, indicating a chronic, long-term source of extra sediment available for downstream transport.

- Contrary to previous post-fire studies Natural Channel Design has conducted within the San Francisco Peaks geographic area, several sub-watersheds of the Museum Fire burn scar still have hillslope sediment yield which are equal to or higher than channel bank sediment yield multiple years post-fire. Higher hillslope sediment yield indicates a slow recovery of hillslope vegetation in these specific sub-watersheds and potential long-term recovery issues for the entire Museum Fire watershed.
- Channel condition was poorest and channel bank sedimentation highest in extremely steep, inaccessible portions of the watershed. There are very limited opportunities to treat erosion safely and successfully in these locations. High sediment yields from the upper portion of the watershed can be expected for many years to come until these channels and adjacent hillslopes naturally return to a more stable condition.
- Within the Museum Fire watershed, several key areas are available to decrease downstream sediment transport and promote sediment retention on naturally occurring, alluvial fan surfaces. Alluvial fans on the mainstem of Spruce Ave Wash above Mount Elden Estates in the county and on USFS land and above Paradise Road within the City of Flagstaff are currently retaining modest amounts of sediment, but still do not retain as much sediment as they should in an unaltered state. Additionally, a third alluvial fan area on the western tributary of Spruce Avenue Wash has been severely degraded to the point that the incising channel is now sourcing sediment from bank erosion.
- The sediment transport model indicates that proposed practices, primarily redesigned channels and restored or enhanced alluvial fans, can significantly reduce downstream sediment transport (approximately 60- 80%) at proposed work areas.
- The proposed practices on alluvial fans and within channels in the lower portions of the watershed can induce a dramatic reduction in downstream sediment delivery and promote a more rapid recovery to the pre-fire watershed function. However, large and infrequent storm events have the potential to deliver problematic amounts of sediment. Relatively short, steep channels and degraded alluvial fans in the upper watershed are capable of delivering large volumes of sediment during extreme precipitation events. The poor hillslope and channel conditions within the upper watershed will continue to be major contributors of sediment.

Recommendations include:

- The analysis of the sediment transport and supply for current and rehabilitated areas indicate that it will be possible to significantly reduce downstream sediment transport on Coconino National Forest and private lands, resulting in an overall reduction in sediment delivery to rural and city of Flagstaff residential areas. Alluvial fan restoration and channel grade control will have a lasting and positive effect on watershed function going into the future.
- Recovery of hillslope condition in several sub-watersheds is currently slower than desired. These areas should be monitored for the next several years to determine whether they are trending towards recovery or if they will require specific recovery interventions by land managers. Additionally, an extension of channel improvements and restoration to areas upstream of the proposed work areas in the upper watershed could improve downstream channel function and better protect Mt. Elden Lookout Road from wash-out. However, these mitigations are likely to improve downstream sedimentation only marginally.
- Monitoring the effects and performance of the channel restoration practices is highly recommended. The steep, relatively short fans are located a short distance upstream of important infrastructure and residential areas. Frequent assessment of how sediment is accumulating on the

alluvial fan surfaces and the performance of grade control features will be key to ensuring that sediment accumulation does not inadvertently force surface water flows into sensitive areas.

- The restoration techniques proposed have been successfully utilized in other similar situations and areas of the Coconino National Forest and should help land managers better manage post-fire flooding.

OBJECTIVE

Post-fire flooding from the Museum Fire burned scar has resulted in high sediment yields that are exacerbating flooding issues in downstream areas. Maintenance and cleanup post-flooding are a prolonged financial burden for local governments and is an inherent risk to downstream residential areas and recreational users within the Museum Fire watershed. Sediment reduction projects could be implemented to improve sediment retention and reduce the risk of downstream flooding to residential areas. To implement practices that are designed to reduce downstream sediment delivery, there is a need to estimate sediment source areas, quantities, and transport rates.

The purpose of this sediment budget analysis is to **a)** assess the geomorphic state of all post-fire impacted channels within the watershed, **b)** estimate the Museum Fire watershed's annual and precipitation event-based sediment yield, **c)** determine the sediment transport of channels in their current state (fall 2021) and after treatment, and **d)** develop treatment options capable of altering the downstream sediment delivery.

This sediment budget analysis will focus on quantifying relative sediment sources relating to channel and hillslope erosional processes. To accomplish this, the Museum Fire will be divided into sub-watersheds to identify problematic, high-sediment yield areas. Areas downstream from high sediment yield areas will be identified as work areas for sediment control practices that will have the greatest impact on limiting downstream sediment transport.

BACKGROUND

The Museum Fire burn area is located on the steep, mountainous slopes of Dry Lake Hills and Mount Elden which are located within the United States Forest Service (USFS) managed lands and uphill from established residential areas within Coconino County (CC) and the City of Flagstaff (CoF) (Figure 1). Mount Elden Estates (MEE) is a rural residential neighborhood and is the uppermost residential area within the Museum Fire Watershed. Approximately one mile downstream of MEE and separated by open USFS land are the urban residential areas of Paradise/Sunnyside, which are within the CoF city limits.

MEE is located on flatter slopes near the base of Dry Lake Hills on the leading and lower edge of previously inactive alluvial fans (areas of sediment deposition, referred to as "fans" from here on). Paradise/Sunnyside are on the toe of inactive fans and adjacent to the broad, ephemeral, and formerly unchannelized Spruce Ave Wash.

Prior to the Museum Fire, the Paradise/Sunnyside neighborhoods had one defined channel/pipe system and surface water flow seldom occurred within these existing channels. Up gradient of the neighborhoods on USFS land, intermittent surface flows were spread over wide fans and were easily absorbed into the unconsolidated sediment. Consequently, surface water flows within the channels and storm drains within the residential areas occurred primarily due to runoff from local CoF streets during normal precipitation events.

The Museum Fire burned in August 2019. For the duration 2019 and 2020, the Flagstaff region saw well-below normal amounts of winter snow and summer monsoonal rain with little to no post-fire impacts. Initial flooding occurred during the above average 2021 summer monsoon season, resulting in debris flows in the upper watershed and higher than normal surface water flows in downstream areas. As the post-fire impacts changed the upper watershed, vast amounts of downstream sedimentation and flooding resulted within residential areas. Existing drainage features and channels were overwhelmed with post-fire sedimentation and flooding was widespread (Figure 2).

Emergency response to the Museum Fire and subsequent flooding has come from numerous government entities such as CC, USFS, CoF, USDA Natural Resources Conservation Service (NRCS), Arizona Department of Emergency Management, and more. Initial post-fire response included flood hazard reduction above the residential areas which provided immediate erosion control work as part of the USFS Burn Area Emergency Response (BAER 2019) plan. Treatments were aimed at minimizing soil loss from steep slopes (aerial wood mulch in some areas), preventing damage to forest roads and critical infrastructure (gas pipelines, access to Mt. Elden communication towers), and enhancing downstream infrastructure (culvert removals, culvert widening and cleaning, road abandonment, sandbags, concrete k-rails, etc.).

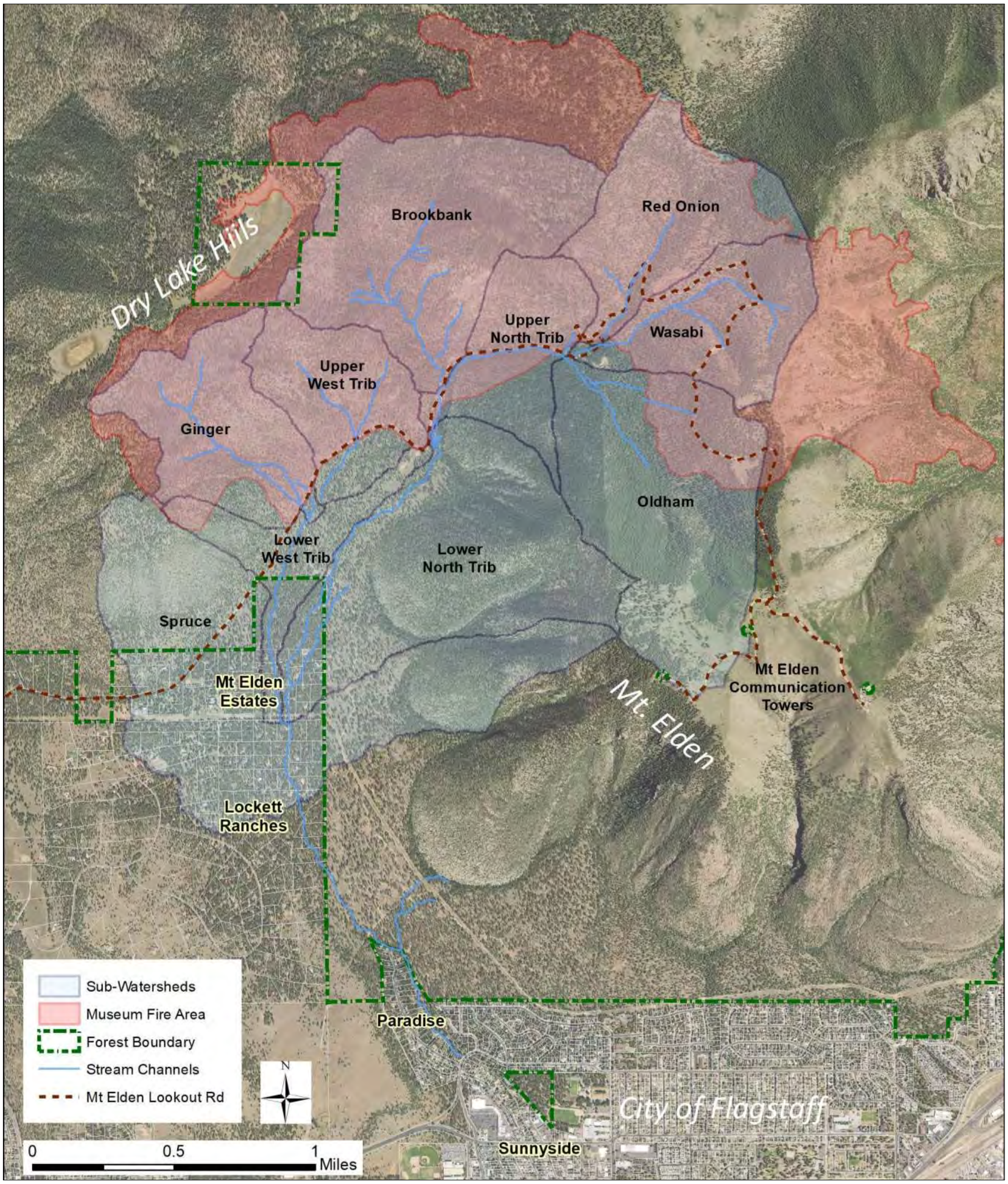

Figure 1. Overview map of the Museum Fire watershed.

Map includes named sub-watersheds, ephemeral tributaries within the Museum Fire watershed, and locations of impacted residential areas in Coconino County and Flagstaff.

Figure 2. 2021 flooding at Linda Vista and Grandview Drives just below the Paradise neighborhood.

Since the initial emergency post-fire stabilization, several additional flood-related projects have been implemented. CC and the USFS cooperated on a grade control project that was constructed during the spring of 2020 but was limited in scope. This project utilized native materials to form grade control structures at critical points along the main channel of the Spruce Ave Wash above MEE on USFS lands. The goal of the project was to prevent further incision and degradation of the adjacent, unstable fan. The CC Flood Control District funded an additional project during the Spring of 2021 in MEE. The goal of this project was to protect homes that were identified to be at high risk of flooding and protect road infrastructure to minimize post-flood maintenance that would be required to keep MEE roads open.

Lastly, NRCS funded exigency watershed repairs after flooding in 2021. These repairs were focused on grade control and channel bank protection within the MEE and to prevent further erosion of channels through the MEE and the downstream Lockett Ranches neighborhoods. The outcome of these projects has generally been positive and erosion control interventions performed as planned. Grade control promoted sediment accumulation on unstable fans within USFS lands and work within the residential areas mitigated major damage to critical infrastructure and homes. However, each additional flood event has created new areas of erosion and has highlighted the need for a watershed-wide restoration approach. The goal for CC and the USFS is to produce longer lasting solutions that most effectively reduce the likelihood of flood damage to property and infrastructure; minimizes long-term operational and maintenance costs; and minimize the exposure to liability relating to failure of the post-fire erosion and flooding systems.

Post-fire watersheds are variably impacted by fire severity, resulting in a widespread unpredictability in post-fire runoff and subsequent sedimentation. Sediment yield from high severity fires can overwhelm downstream channels (Figure 3). While there is considerable error associated with predicting sediment yield and transport, direct observations support the general conclusion that sedimentation within the Museum Fire watershed is high enough to overwhelm the current combination of channels, fans, and sediment retention structures, especially within CoF neighborhoods.

Post-fire sedimentation not only presents a downstream maintenance issue for the CoF, but it also poses a significant threat for continued channel failure within the Museum Fire watershed. This threat further increases the likelihood of post-fire flooding, which in turn promotes continued erosion and further increases downstream flooding and subsequent sedimentation.

Figure 3. Burned watershed, altered channels and hillslopes in the West Tributary below Dry Lake Hills.

While the effects of post-fire runoff are expected to decrease over time as vegetation within the Museum Fire burn scare recovers, the downstream channels and fans in their current condition convey sediment too efficiently downstream and pose significant risk for continued flooding and damage to critical infrastructure and residential areas. It is recognized that while post-fire flooding will continue to be a problem until the watershed is healed, a reduction in sediment transport can alleviate channel maintenance, lessen post-flood cleanout needs in downstream areas, and promote the efficiency of engineered flood conveyance systems through downstream residential areas.

In 2010, NCD was retained by CC to evaluate the sediment yield from and to design on-forest mitigation measures for the Schultz Fire post-fire flooding. In 2021, NCD was again tasked by CC to evaluate the sediment budget for the Museum Fire burn area. Upon completion of the sediment budget and transport analysis, treatment options capable of altering the downstream sediment delivery will be discussed in the "Recommendations" portions of this study. Using the Shultz Fire flood remediation project as a model, several potential work areas have been identified with the Museum Fire watershed as locations that can help reduce downstream sediment delivery from post-fire flooding. It is likely that increased sediment retention will be accomplished through the rehabilitation of existing fans and channels in addition to the creation of sediment basins to store excess sediment.

METHODS

Methods used in this sediment budget analysis will **a)** assess the geomorphic state of all post-fire impacted channels within the watershed, **b)** estimate the Museum Fire watershed's sediment yield, and **c)** determine the sediment transport of channels in their current state (fall 2021) and after redesign.

Methods will be based on the Watershed Assessment of River Stability and Sediment Analysis (WARSSS) (Rosgen 2009), which is the same methodology used for the Schultz Fire sediment analysis (NCD 2012). WARSSS is designed to identify the location, nature, extent, and consequences of land use impacts on sediment and understand the cause of watershed impairment. This approach was developed by Dr. Dave Rosgen (Wildland Hydrology) for application on large watersheds. This methodology is appropriate for the Museum Fire because it uses practical, rapid screening field observations that integrate hillslope, hydrologic, and channel processes. The analysis focuses on average annual yield of sediment rather than the more standard event-based analyses. The average annual yields do not ignore sediment delivery from large flood events but do consider the overall frequency of these types of flows. This type of analysis is ideal for understanding watershed function and developing watershed restoration practices.

The WARSSS method relies on estimating bank erosion using the Bank Assessment of Non-Point Source Consequences of Sediment (BANCS) model and can quantify bank erosion rates and sediment supply for years with normal discharge patterns Average annual hillslope erosion is estimated using the Erosion Risk Management Tool (ERMiT) (Robichaud et al. 2014). The Modified Universal Soil Loss Equation (MUSLE) (Williams 1975) is utilized to estimate sediment supply from hillslopes during specific precipitation events. Discharge from these events has been estimated by JE Fuller, Inc as part of their post flood modeling efforts. The MUSLE estimates are provided here as a reference point for larger events. Direct comparison of the different methods is difficult. While post-fire hillslope erosion will diminish over time with natural recovery, sediment bank contributions are expected to continue at high rates for many years due to post-fire channel evolution processes which tends to widen incised channels.

Sediment transport estimates are used to look at how supplied sediment can move through the channel system. Sediment transport modeling uses the FLOWSED/POWERSED platform in the RiverMorph software and provides estimates of average annual sediment transport through a specific cross section of channel given an annual flow scenario. Estimates of transport into a reach can be compared to channel conditions within the reach to estimated aggradation or degradation for both existing and proposed design. This analysis is sensitive to several data inputs including annual flow duration curves, bankfull discharge, suspended sediment and bedload sediment rating curves, channel configuration, and slope. These data are difficult to obtain for ungauged ephemeral systems. NCD utilized sediment rating curves and dimensionless flow duration curves developed during the Schultz Fire sediment analysis which were derived from regional data and research from the Beaver Creek Research Watershed Effort. Utilization of this previously developed data will significantly shorten the duration of the study and reduce the level of effort required to produce meaningful results.

Once problematic high-sediment yield areas are identified, sediment transport analyses will be conducted at specified downstream proposed work areas in the Museum Fire watershed. In addition to providing an analysis of sediment transport across channels in their current state (fall 2021), an analysis of sediment transport across a conceptualized design channel will be used to understand the feasibility of altering the downstream sediment delivery and will be based on the upstream sediment supply

METHODOLOGY APPROACH

There are several essential steps for accurately modeling upstream sediment yield and downstream transport. A sediment budget and transport analysis of this magnitude requires extensive field surveys and data collection, integration of multiple local and regional models, collaboration with government entities and consulting firms, and specialized modeling software.

ASSESSING THE GEOMORPHIC CONDITION OF CHANNELS

- *Collection of BEHI Data-* To qualitatively evaluate all eroding channels within the Museum Fire watershed, bank erosion hazard index (BEHI) surveys were used (Rosgen 2002). During BEHI surveys, data was collected by teams of two NCD field staff on tablets with the MapItFast application, which enables the user to rapidly tabulate and georeference all field data on pre-formatted field forms (Figure 4). Collected data consists of channel bank height (left and right bank), channel and bank material, length of channel, vegetation and root density, bank slope angle (left and right), valley and stream type classification (Rosgen Stream Classification System 1996), and near bank stress (NBS). MapItFast was used to rapidly map the locations and conditions of all channels in the Museum Fire watershed. Collected field data was manually checked for quality assurance and control using ESRI ArcGIS geospatial software.
- *Channel Surveys-* To accurately assess the Museum Fire channels in their current condition, detailed geomorphic field surveys was conducted. To accurately model sediment transport through channels and assess channel characteristics, unique channel geomorphic surveys were completed proximal to proposed work areas. To evaluate the channel slope and characteristics of specific channel reaches, 33 cross sections surveys, longitudinal channel profiles, and pebble counts were completed.

Figure 4. NCD surveyors completing the BEHI analysis on a typical channel along Spruce Ave Wash.

ESTIMATING SEDIMENT YIELD

- Channel Sediment Yield- The BANCS model was used to estimate annual sediment yield (Rosgen 2002).
  - *Bank Assessment for Non-point source Consequences of Sediment (BANCS)*-BEHI data collected during the geomorphic assessment of the channels was used in the BANCS model, which is a part of the RiverMorph software package. The BANCS model utilizes BEHI and NBS survey data to estimate sediment supply from channel bank sources and yields a sediment supply in tons per year. BANCS model is accepted by US Environmental Protection Agency (USEPA) and other U.S. government agencies. The BANCS model provides reliable estimates of bank erosion but can underestimate bank erosion rates resulting from higher-than-normal flooding and overestimate rates from years with very low peak flows (Rosgen 2002). Channel sediment supply was converted to tons/year/foot for all evaluated reaches and then graphically displayed with ArcMap.
- Hillslope Sediment Yield- The ERMiT and MUSLE model were used to estimate hillslope sediment yield. The ERMiT model predicts sediment yield annually while the MUSLE modeled is based on precipitation events (storm-based).
  - *Erosion Risk Management Tool (ERMiT)*- The ERMiT models uses soil burn severity, vegetation type, rock content, hillslope gradient, soil type, hillslope length, and annual precipitation to model sediment yield (tons/year) up to five years post-fire. For the scope of this analysis, 2021 was used as the second-year post-fire. Therefore, only years 3 (2022), 4 (2023), and 5 (2024) sediment yield was modeled. To capture the variability in hillslope impacts, the Museum Fire watershed was subdivided into sub-catchments using watershed delineation in ArcMap. Each catchment was evaluated individually for its sediment yield.
  - *Modified Universal Soil Loss Equation (MUSLE)*- The MUSLE is based on the Universal Soil Loss Equation (USLE) but utilizes transport efficiency and soil erodibility. For the post-fire watersheds, the MUSLE model is particularly useful for modeling post-fire sediment yield because soil erodibility increases due to hydrophobic, ash laden soils, and transport efficiency increases due to increased runoff from decreased infiltration and retention. The MUSLE model input requires instantaneous peak discharge and total volume of 1”, 2” and 3” precipitation events in addition to watershed area, slope, and soil erodibility. Unlike the ERMiT model, the MUSLE model predicts event-based sediment yield in tons/event.

EVALUATING SEDIMENT TRANSPORT AND RETENTION

- FLOWSED/POWERSED, which is part of the RiverMorph software package, was used to model sediment transport through channels in their current condition and through conceptual redesigned channels. Based on preliminary sediment budget analyses, FLOWSED/POWERSED was modeled at eight proposed work areas (Figure 5). Each analysis consisted of an upstream sediment source cross-section and a proposed work area cross-section. Upstream sediment source and work area cross-section geometries were obtained from previously completed geomorphic surveys. Each analysis was then rerun using the same upstream sediment source cross-section and a conceptual design cross-section. The design cross-section was set on the same slope as the work area cross-section, but with a standardized Manning’s n value, and drawn in RiverMorph to incorporate a best practice design that promotes sediment retention. For each model run, FLOWSED/POWERSED requires the following inputs: bankfull cross-sectional area (ft^2), Manning’s n value, bankfull discharge (cfs), slope (ft/ft), suspended sediment (mg/L), measured bankfull bedload (lb/s), a flow duration curve, and a sediment rating curve comparison.

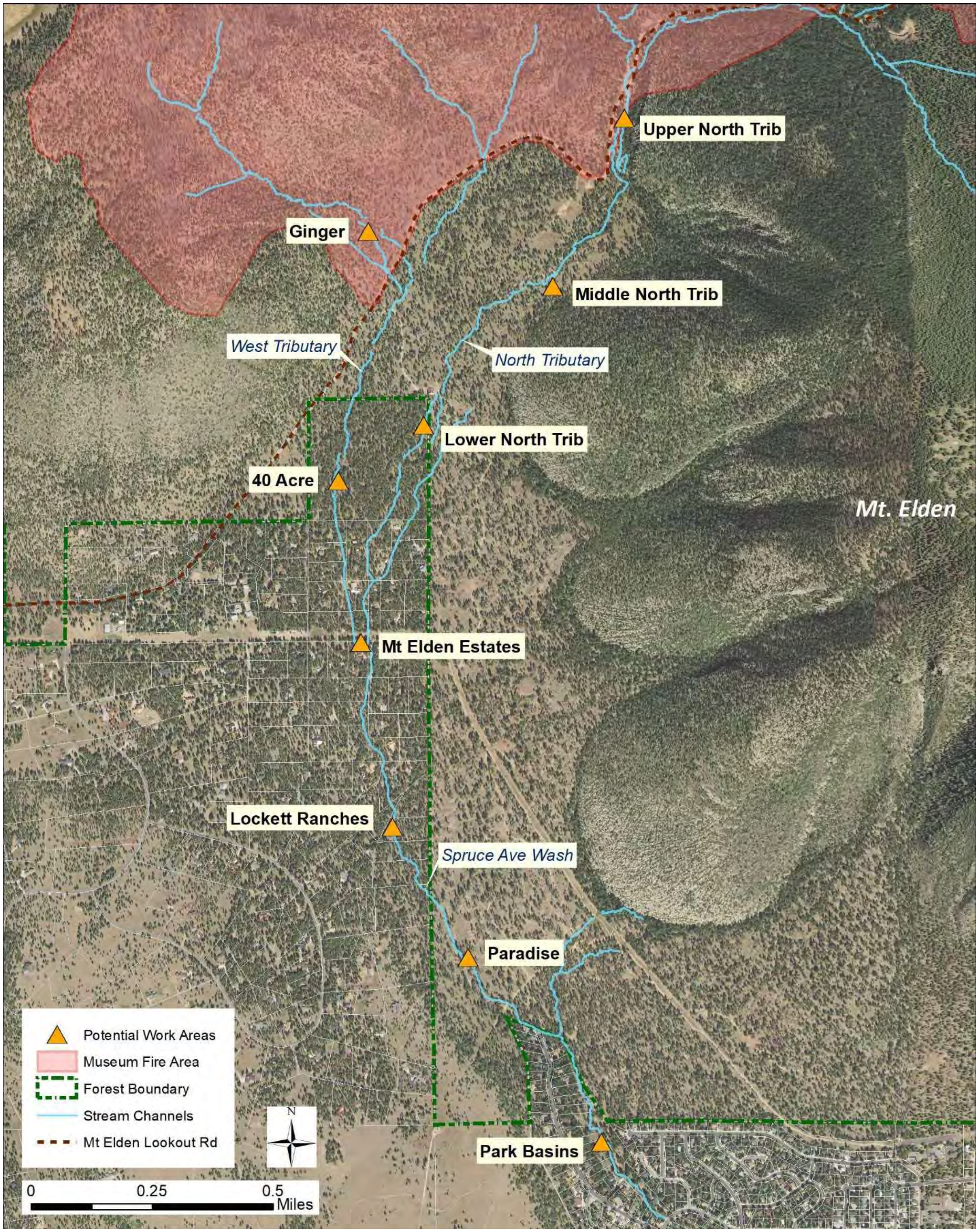

Figure 5. Proposed work area locations modeled in FLOWSED/POWERSED.

The southern edge of the Museum Fire burn scar is shown in red on the map.

ANALYSES

GEOMORPHIC CONDITION OF CHANNELS

Surveys of channels were conducted and mapped to document the location of each channel contributing water and sediment within the Museum Fire watershed. On a few occasions, surveys had to be rerun due to faulty equipment or to verify collected results. On-the-ground surveys consisted of mapping nearly 14 miles of Museum Fire watershed channels. 171 unique reaches were identified and evaluated with the BEHI and NBS methods. Individual reach data was entered into ArcMap to graphically display results.

In all reaches, bankfull height was difficult to determine due to recent flooding that generally obliterated any bankfull features, therefore, bankfull cross sectional area was estimated from local regional curves (Moody et al., 2003) and utilized as needed for more detailed analysis. Channel surveys resulted in 33 cross-sections and longitudinal profiles. Cross sections were primarily focused in proposed work areas, but additional cross-sections were recorded to evaluate additional reaches as needed.

ESTIMATED SEDIMENT YIELD

Channel Sediment Yield

BEHI and NBS ratings are used in the BANCS model to derive annual streambank erosion rates. The bank erosion rates are predicted from equations (based on measured data from Colorado for streams found in sedimentary and/or metamorphic geology) that relate BEHI and NBS to annual bank erosion rates in feet per year (Rosgen 2009). The annual erosion rate is multiplied by the bank height and bank length for each reach to estimate the annual erosion rate in cubic feet per year. The erosion rates for each reach are summed for an estimate of the total annual bank erosion rate which is then converted to tons per year.

Hillslope Sediment Yield

The ERMiT model was run using the online, open-source ERMiT model interface. To capture the variability in Museum Fire burn severity, size, and slopes, the Museum Fire watershed was further subdivided into 61 sub-catchments using user defined pour points and watershed delineation in ArcMap. All 61 sub-watersheds (ArcMap polygons) used the same Flagstaff climate data (Flagstaff WB AP AZ), sandy loam soil texture, and forest vegetation type inputs. The ERMiT model requires hillslope gradient to be divided into three sections: top 10%, middle 80%, and bottom 10%. To determine the slopes at these locations, slope was calculated from a DEM in ArcMAP using the slope tool and was overlaid by the 61 watersheds (polygons) and averaged in each watershed (polygon). Using open-source Museum Fire burn severity maps, soil burn severity was calculated and averaged for each polygon. The ERMiT model uses soil rock content as a way of estimating small scale hillslope erosion around rock fragments within the soil. Increased rock content increases soil erosion and decreased rock content decreased soil erosion. For the ERMiT model, rock content is capped at 50% because rill erosion is thought to be the predominate process after 50% rock content. Soil rock fragments were qualitatively assessed during the BEHI data collection and channel surveys. Each polygon was assigned an averaged rock content as a percentage. Hillslope length was determined in ArcMap. However, all but 4 polygons were over 1000 ft in length and the ERMiT model assesses hillslopes over 1000 ft as “likely to channelize”, therefore diminishing the watershed’s ability for continued hillslope sediment yield. Each of the 61 polygons had 1 to 2 model runs and were compared with observed sedimentation and other sediment models for accuracy. The sediment yield of the 61 sub-watersheds were graphically displayed using an ArcMap color ramp that displayed results in tons/year and tons/acre.

The MUSLE model was completed using 9 sub-catchments that were defined by pour points and watershed delineation in ArcMap. While both the ERMiT and MUSLE model compare hillslope sedimentation, they are not meant to be a direct comparison and therefore do not use the same watershed delineation techniques. The MUSLE model uses cumulative watershed size in downstream reaches to model the impact of 1”, 2” and 3” storms. As stated in the above methods, MUSLE requires the runoff volume, peak runoff rate, watershed area, soil erodibility factor (K), slope length and steepness factor (SL), conservation practice, and a crop management factor. Because of the added complexity in modeling event-based surface flows in post-fire watersheds, NCD utilized instantaneous peak discharge and total flow volume estimates as provided by J.E. Fuller for the 1”, 2” and 3” storm events. J.E. Fuller Hydrology and Geomorphology modeled the Museum Fire watershed for CC with the FLO-2D software in 2019, soon after the fire. In fall 2021, J.E. Fuller updated the FLO-2D model for CC and provided NCD with hydrology data based on this latest model run. The “up and down slope” was used as the conservation practice for these watersheds and its value was set at 1 (dimensionless). For this watershed, the crop management factor was determined to be “forest” and was set at 0.003 (dimensionless) for all sub-catchments. Slope length was calculated using the slope (%), watershed length (ft), and a NN value of 0.5 (dimensionless) and a constant of 72.5 (dimensionless). The soil erodibility factor (K) was modeled using low K values (low soil burn severity), medium K values (moderate burn severity), and high K values (high severity burn). The resulting event-based soil loss from each model run (in tons) was compared to annual ERMiT modeled sediment yield and observed Museum Fire sedimentation. Based on these comparisons, it was determined that the best fit for modeling Museum Fire soil erodibility was a moderate K value, which is similar to sandy loam K values (dimensionless).

EVALUATED SEDIMENT TRANSPORT AND RETENTION

At each of the eight work area cross-sections, upstream watersheds were calculated in ArcGIS using user defined pour points and the watershed delineation tool in ArcMap. Using previously modeled bankfull area, bankfull velocity was modeled using various Manning’s n values such as Jarrett’s *n*, stream type *n*, Limerinos *n*, Flagstaff Area modeled *n*, and Central and Southern Arizona modeled *n*. These modeled velocity calculations were then used to calculate bankfull discharge (bankfull area * velocity) and were then compared to other known Flagstaff area bankfull discharge, bankfull area, and watershed area data. Within the disturbed Museum Fire watershed, the best fit for bankfull velocity and discharge was the Central and Southern Arizona modeled *n* values which then were used to calculate discharge.

Suspended sediment in mg/L was modeled using local watershed area and measured suspended sediment (NCD 2012). Bedload was modeled using discharge from highly disturbed, post-fire watersheds within the Southwest (NCD 2012).

Dimensionless flow duration was modeled using the same modeling approach as the Shultz Fire sediment analysis (NCD 2012). Dimensionless flow was calculated using direct change in water yield observations from the Wet Beaver Creek paired watershed study (NCD 2012). Changes in water yield observations were a direct result of a variety of disturbed watershed treatments, such as thinning treatments and prescribed burning. The change in water yield is a direct result of burned watersheds and these were modeled for the Museum Fire based on watershed size. FLOWSED/POWERSED dimensionalizes the dimensionless discharge based on modeled discharge to produce annual predicted flow for each work area cross section.

Results from FLOWSED/POWERSED modeling were compared at each work area for its efficiency at retaining or passing suspended sediment or bedload. For each work area, a design cross-section was produced to conceptualize the impacts of rebuilding fans or reshaping the channel.

RESULTS

CONDITION OF CHANNELS

Approximately 20% of the channels in the Museum Fire watershed are incised “G” type channels with high sediment contribution from channel and bank processes. G channels were found primarily in the burned, steep, upper reaches of the watershed; however, some were found in reactivated fans. Bank erosion from this type of channel can be an order of magnitude higher sediment contribution from bank and channel processes (Rosgen 2002). Aggrading “D” type channels or valleys that can support aggrading channels are roughly 15% of the watershed. While these channels have the potential to store large amounts of sediment, many are gullied and now function as sediment sources rather than sediment sinks. The Rosgen channel type was determined visually during the BEHI surveys, and the results are shown in Figure 6.

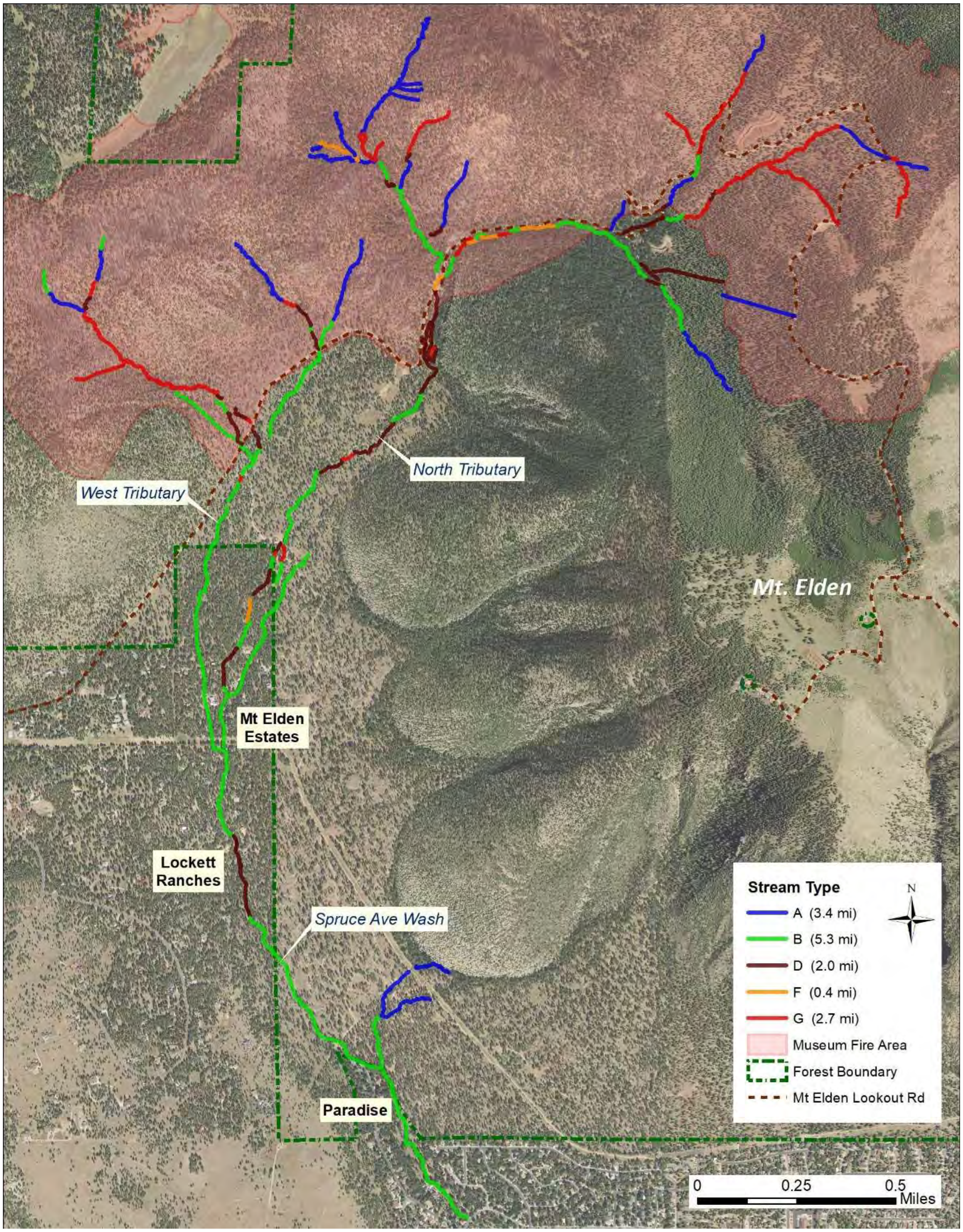

Figure 6. Museum Fire channel types.

Channel types are from Rosgen classification system. "A" and "B" types are generally stable with little sediment contribution. "F" and "G" channel types are generally unstable and contribute large amounts of sediment to channel transport. "D" channel types are typically aggrading systems that are capable of storing sediment in-channel.

SEDIMENT YIELD

Channel and Hillslope (ERMiT) Sediment Yield

The BANCS model estimates a total sediment yield of 10, 373 tons per year from streambank erosion while the ERMiT model estimates that hillslope erosion will yield 6,956 tons of sediment in 2022. Sediment yield resulted in a cumulative 17,329 tons per year of predicted sediment for the channels in their current conditions and predicted hillslope erosion for the year 2022 (3 years post-fire) (Table 1). The total erosion rate (bank + hillslope) was converted to a **total** unit erosion rate by dividing the total rate by the acreage for each sub-watershed. The unit erosion rates are displayed in Figure 7.

The BANCS model also calculates the unit **bank** erosion rate which is the erosion rate per foot of streambank. Figure 8 presents the unit bank erosion rate for channels in the Museum Fire, indicating the channels with the highest expected erosion rates. The Ginger and Wasabi sub-watersheds, which are two steep watersheds in the burned area, have the highest unit bank erosion rates. The results of the ERMiT model showing the predicted hillslope erosion rates are presented in Figure 9 which generally show the highest hillslope erosion rates are also in the steeper, heavily burned areas of the watershed.

Table 1. BANCS, ERMiT, Total, as well as Unit Erosion Rates for Museum Fire sub-watersheds.

Sub-Watershed	Bank Erosion	Hillslope Erosion in 2022	Total Erosion	Area	Total Unit Erosion
	(tons/year)	(tons/year)	(tons/year)	(acres)	(tons/year/acre)
Brookbank	1109	**2190**	3299	402.6	8.2
Ginger	2943	1270	4213	215	19.6
Lower North Tributary	721	3	724	419.6	1.7
Lower West Tributary	361	1	362	124.1	2.9
Oldham	349	267	616	402	1.5
Red Onion	591	**1086**	1677	220.8	7.6
Spruce	400	4	404	519	0.8
Upper North Tributary	351	334	685	152.5	4.5
Upper West Tributary	507	**668**	1175	170.4	6.9
Wasabi	3039	1133	4172	182.1	22.9
TOTAL	**10,373**	**6,956**	**17,329**		

BANCS modeled bank erosion is a result of BEHI channel surveying in their current condition while hillslope erosion is year 3 post-fire ERMiT modeled sediment yield. Bold numbers in the hillslope column indicate sub-watersheds where hillslope erosion is predicted to be larger than bank erosion. See Figure 7 for a map of the watersheds listed within this table.

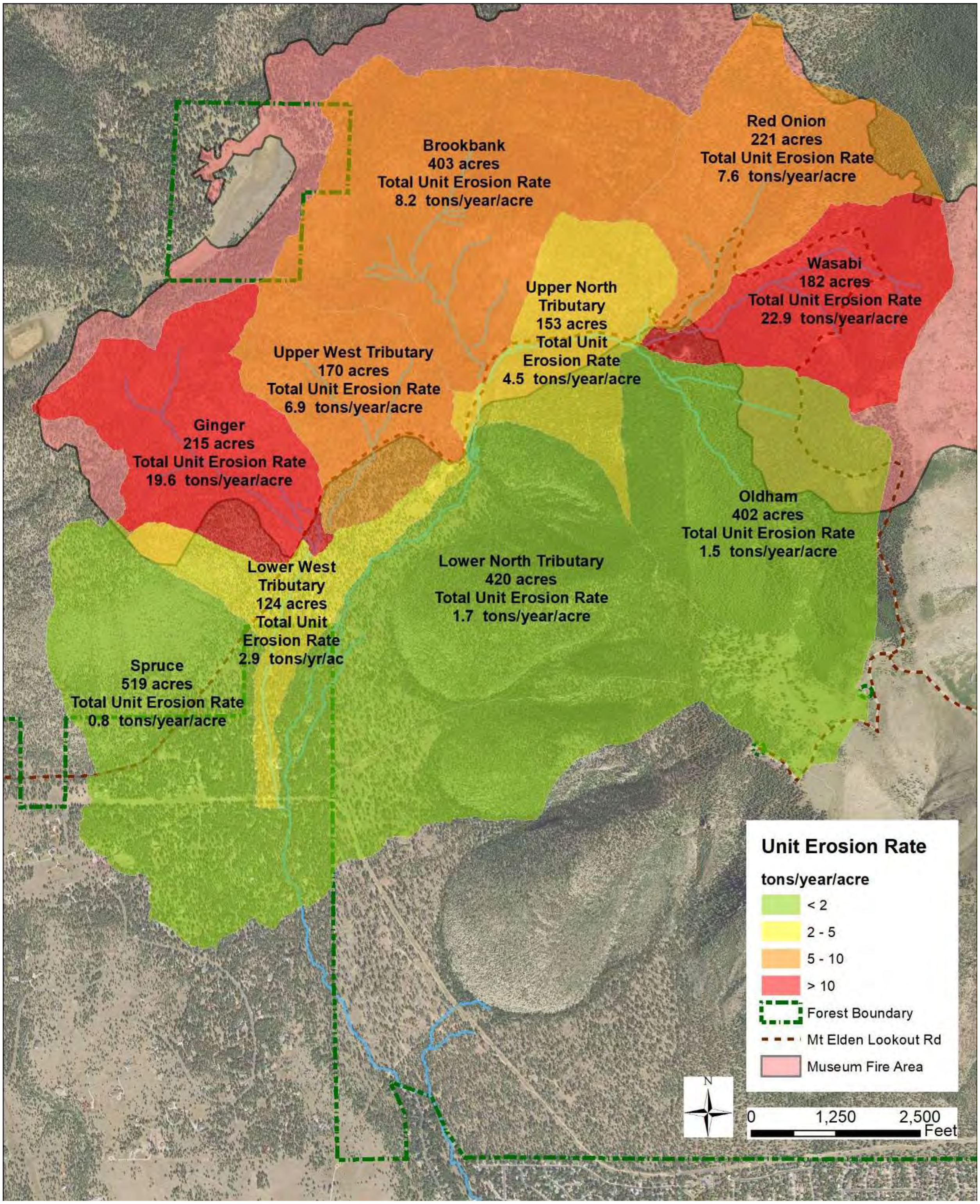

Figure 7. Unit erosion rates for each sub-watershed.

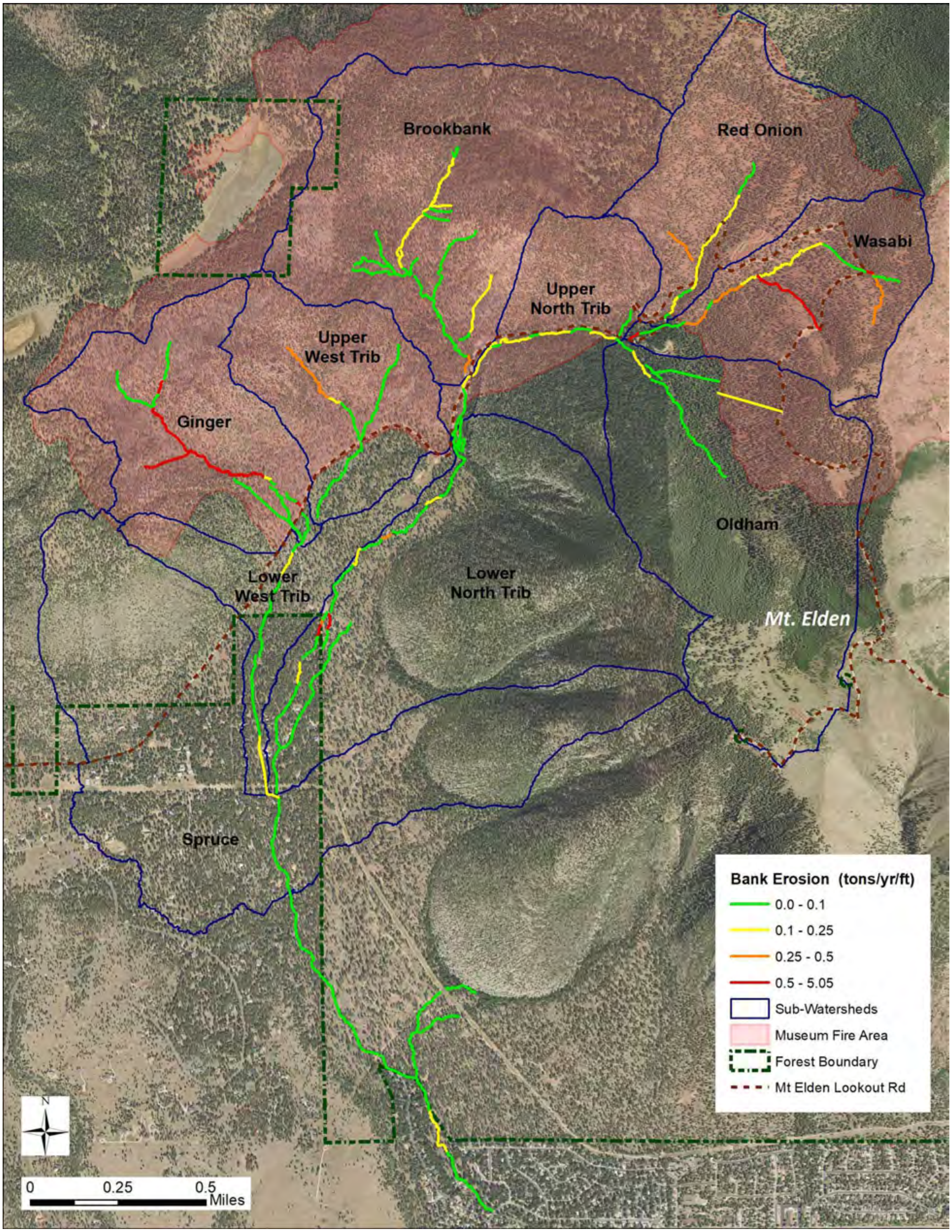

Figure 8. Results of BANCS modeled unit bank erosion rate from Museum Fire channels.

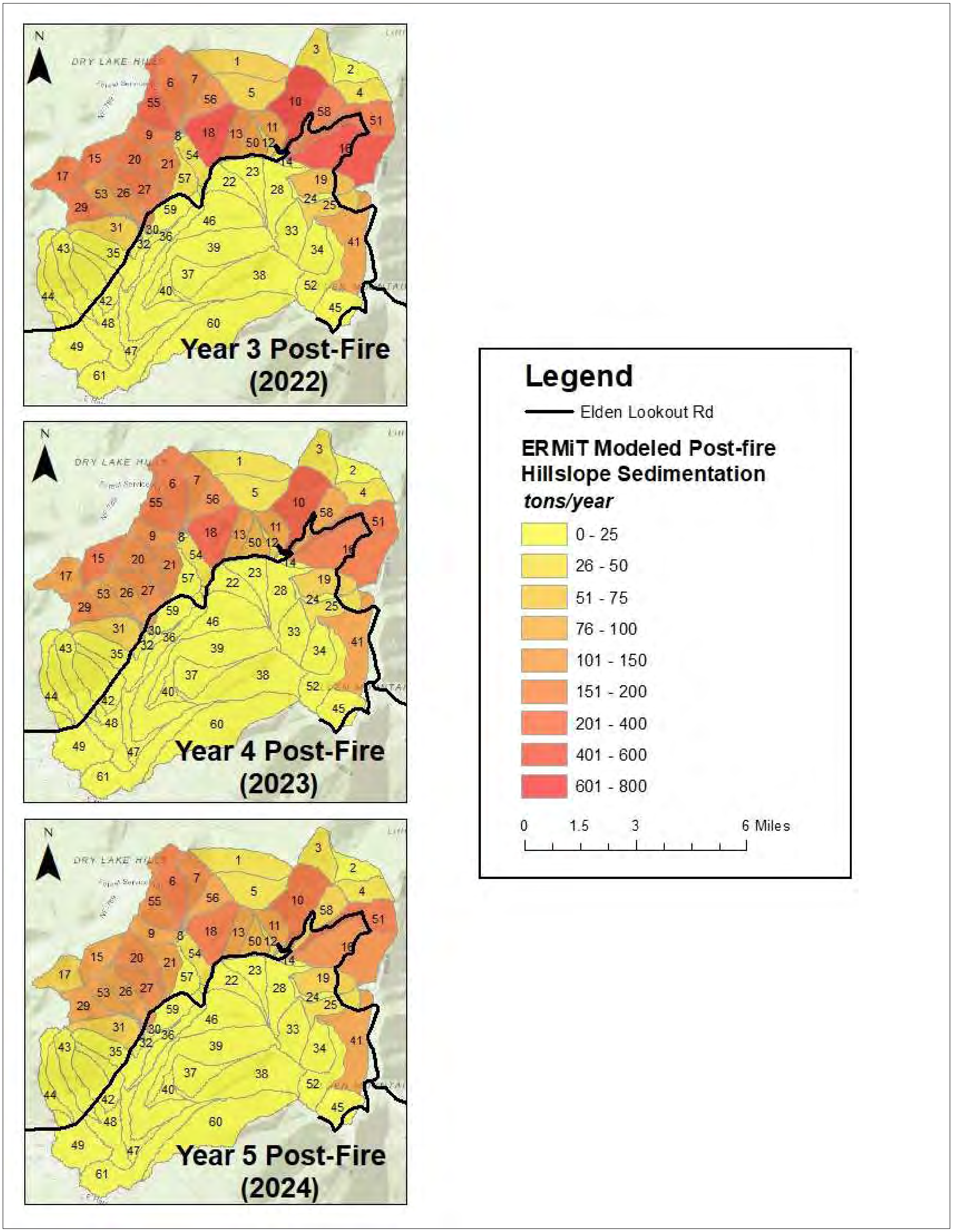

Figure 9. Modeled ERMiT hillslope erosion rates for 2022, 2023, and 2024.

Hillslope (MUSLE) Sediment Yield

The MUSLE model also estimates high rates of hillslope erosion for the three modeled precipitation events. The pour points utilized for the analysis are the similar as those utilized for the average annual sediment transport estimates from the FLOWSED/POWERSED analysis (Figure 10). The results vary widely depending on the precipitation event that was used and the erodibility factor (K) of the soils (Table 2). Based on field observations, the medium K value likely represents the best estimate of aggregate soil conditions in the various sub-watersheds within the burn area. The complete set of modeled inputs and results can be found in Appendix A. It should be noted that this represents hillslope erosion and not

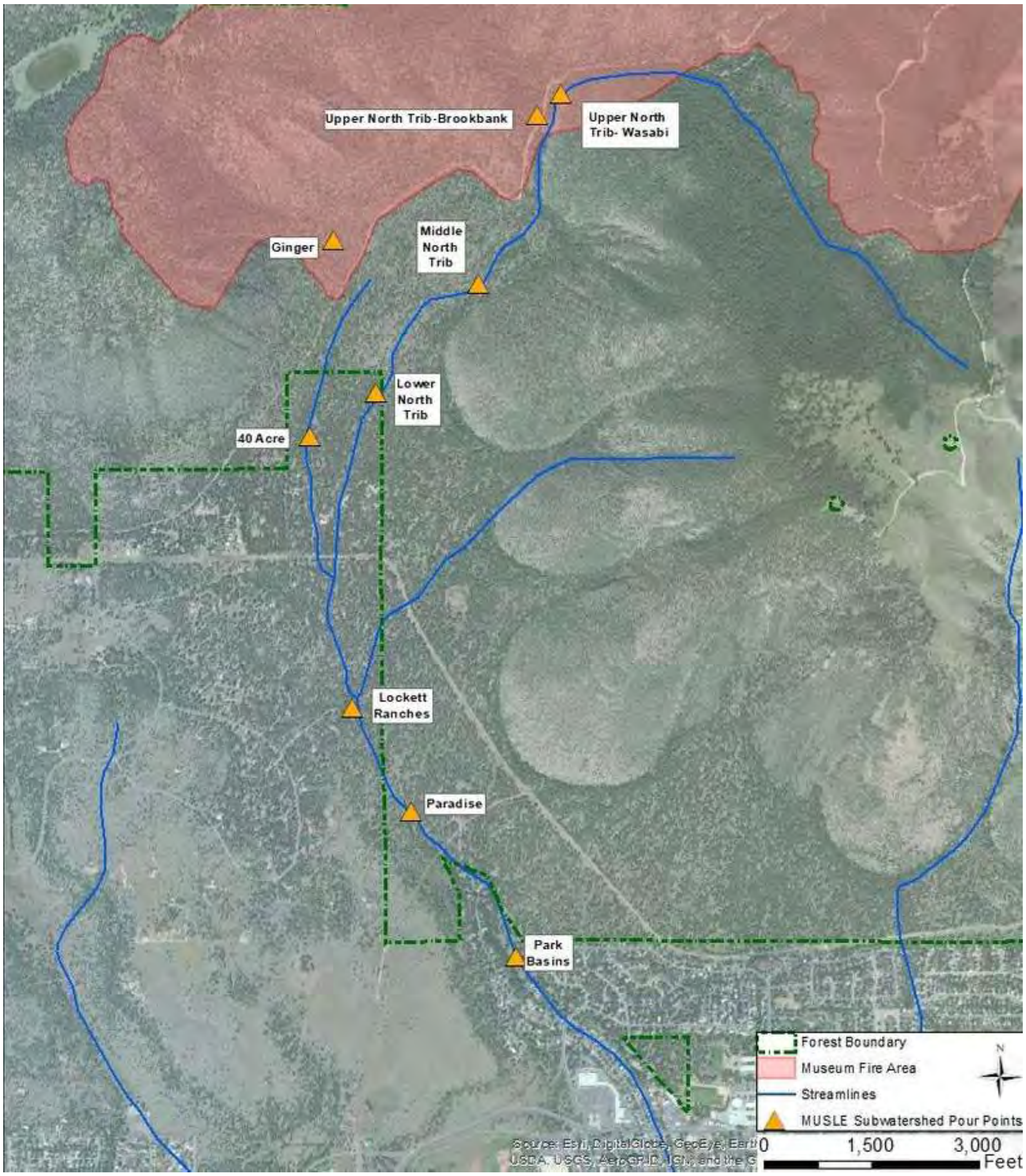

Figure 10. Pour points used for MUSLE calculations.

Note that these pour points are similar to the sediment transport pour points but include points higher up in the Brookbank and Wasabi channels, which are located upstream of proposed work areas.

necessarily sediment transport downstream of the hillslope via channel processes. Where the hillslope erosion is greater than the conveyance channel's ability to transport sediment, aggradation will occur until subsequent events can transport the sediment downstream.

Table 2. Results of modeled MUSLE sediment yield in the Museum Fire watershed's current condition. *Results show estimated soils loss in tons based on three different soil erodibility factors (K) for three different precipitation events: 1", 2", and 3" storm events. The medium K value is likely the best approximator for the Museum Fire in its fall 2021 condition.*

	Soil Loss with low K value			Soil Loss with medium K value			Soil Loss with high K value		
Sub-Watershed (WS) Name	1"	2"	3"	1"	2"	3"	1"	2"	3"
	tons	tons	tons	tons	tons	tons	tons	tons	tons
Ginger	203.8	814.5	1604.0	383.1	1530.6	3014.3	562.3	2246.8	4424.7
40 Acre	219.0	1162.9	3094.1	411.5	2185.5	5814.7	604.0	3208.0	8535.4
Upper North Trib - Wasabi	368.8	2059.2	4632.7	693.2	3869.8	8706.2	1017.5	5680.4	12779.8
Upper North Trib - Brookbank	664.8	3241.8	7311.4	1249.4	6092.4	13740.3	1833.9	8943.0	20169.3
Middle North Trib	413.5	2156.5	4991.9	777.2	4052.7	9381.3	1140.8	5949.0	13770.7
Lower North Trib	215.9	922.5	1541.5	405.7	1733.7	2896.9	595.5	2544.9	4252.3
Lockett Ranches	404.4	2510.5	6385.7	759.9	4717.9	12000.7	1115.5	6925.4	17615.7
Paradise	217.3	1503.6	3964.4	408.4	2825.6	7450.3	599.4	4147.7	10936.3
Park Basins	211.9	1722.7	4708.7	398.2	3237.6	8849.1	584.5	4752.4	12989.6

Likely the best approximator for Museum Fire

Sediment Transport and Retention

FLOWSED/POWERSED modeling determined that 5 of the 7 proposed work area channel cross sections currently pass more sediment than is supplied to them, potentially leading to headcutting and erosion (highlighted red in Table 3). The work area cross sections consist of an upstream, single thread "feeder" channel and a degraded, multithread "fan" channel downstream. These five evaluated work area cross-sections pass sediment more efficiently than the upstream sediment source cross section due to channel geometry, generally due to active headcuting that alters a "D" channel and degrades it into a "G" channel. Once this process has begun, it exacerbates headcutting, fan degradation, channel migration, bank erosion, and provides little-to-no sediment aggradation (retention or deposition) on the now disconnected fan. Without direct intervention, these fans and channels will continue to efficiently transport sediment downstream towards the CoF and residential areas.

To increase sediment retention at all evaluated work areas, the FLOWSED/POWERSED model was used to estimate the effect of rebuilding fans and channel stabilization techniques. At each work area, a conceptual design channel cross-section was used and evaluated for its efficiency in sediment transport. Design cross sections consist of a restored fan feature with the eroded/incised channel banks flat-to slightly banked. Results indicate that design channel cross-sections retain an average of 70% more sediment in proposed work areas than the fans and channels in their current (fall 2021) condition (Table 3). This added sediment retention was accomplished by widening and repairing the existing channel into a designed fan channel to fill the incised channel bottom. This reduces the ability of the channel to transport sediment by lowering shear stress, which is a function of slope and depth. The slope of the channel remains the same, but the depth is decreased by forcing flows over a wider flow channel. The modeled 70% reduction in sediment transport removes all but 3,440 tons of sediment on an average annual basis, per this analysis. It should be noted that large storm events in excess of those experienced in an average year are not modeled by this analysis and are likely to deliver additional sediment.

Table 3. Sediment Transport and Retention Results from the FLOWSED/POWERSED model.

Potential Work Area Name (*Figure 5*)	**Incoming** Transport Capacity	**Current** Channel Transport Capacity	**Design** Channel Transport Capacity	Difference between **Incoming** and **Current** Transport Capacity	Difference between **Incoming** and **Design** Transport Capacity	Sediment Retention at Proposed **Design** Channel	Percent Sediment Retained by **Design** Channel
-	(tons/ year)	(tons/ year)	(tons/ year)	(tons/year)	(tons/year)	(tons/year)	%
-	**A**	**B**	**C**	**D**	**E**	**F**	**G**
-	-	-	-	= A - B	= A - C	= E - D	= (1-C/A)*100
Ginger	416	357	59	59	357	298	86
40 Acre	1093	1462	297	-369	796	1165	73
Upper North Trib	586	3368	237	-2782	349	3131	60
Middle North Trib	1243	1502	440	-259	803	1062	65
Lower North Trib	1422	2581	486	-1159	936	2095	66
Lockett Ranches	2000	1572	840	428	1160	732	58
Paradise	2236	5101	496	-2865	1740	4605	78

CONCLUSIONS

As evidenced by recent flooding events, sediment supply from the burn area is quite high. Poor channel condition as well as hillslope conditions provide very high sediment contribution to the downstream channels. Most high erosion areas are located high in the Museum Fire watershed on steeps slopes in areas of high burn severity. Steep slopes and accessibility likely preclude active restoration of these channels or any hillslope activities other than on the ground revegetation by field crews. The nature of the channels (mostly G and F type channels) indicate that the channel form is in the early stages of evolving to a stable form. The formation of small floodplains, properly functioning fans, and reasonably stable channel side slopes (2H:1V minimum) will require the erosion of significant amounts of sediment over the course of many years. In its natural condition, this watershed wide process will likely take years or decades before relative channel and sedimentation stability has been reached. Until this occurs, there will be a continued high potential for downstream flooding and sedimentation for the foreseeable future.

Several sub-watersheds were identified that exhibited higher hillslope erosion rates than adjacent channels. Previous studies of this nature have found that channel processes are generally larger sources of erosion than hillslopes. Consequently, these poor hillslope conditions are cause for concern. If these hillslopes do not begin to improve more rapidly, high sediment loads from hillslopes will likely contribute to further degradation of the downstream receiving channels. Hillslope erosion and rilling hinder seed establishment and subsequent hillslope recovery. However, two consecutive years of drought are likely the main causes of poor hillslope conditions and have further slowed recovery. These areas should be monitored over the next few growing seasons and may need specific interventions to fully recover.

The sediment transport models indicate a high potential for successful reduction in sediment as flows across restored fan areas. Our sediment transport modelling suggests that restored fan surfaces can reduce sediment transport across the fan features approximately 70%. Some fan areas (especially the West Tributary or Ginger) have the potential to not only reduce sediment transport but also sediment contribution from bank erosion. High bank erosion rates can be reduced by eliminating the currently incised channels and restoring the fan's functionality. Fan areas such as the main channel of Spruce Avenue Wash, which already stores modest amounts of sediment, can be significantly improved by grade work and will restore the sediment retention of the fan.

Care should be taken to ensure that fan surfaces are as large as possible to provide many years of sediment storage without concentration of flow. Given that the potential for sediment transport to fan areas is high and likely a long-term consequence of post-fire flooding, fan areas should be extended as much as possible to provide the maximum lifespan of these sediment retention features. Additionally, the small fan areas and high sediment loads suggest that some areas may require maintenance to prevent accumulated sediment from directing flows to sensitive areas.

Sediment output from the restored fans appears to be moderate over a long-term average. However, the relatively steep fans will produce higher shear stresses at high, infrequent flows. For example, peak discharges modeled for a 2" per hour precipitation event over the whole watershed (~1300 cfs) produce enough shear stress on the proposed Paradise fan to move 10-inch diameter particles. Consequently, these infrequent precipitation scenarios will have the potential to move large quantities of material through the fan system, even though most is retained on the fan.

The watershed restoration practices also have a great potential to kick start the recovery of the watershed by promoting channel and slope stability, which will improve revegetation recovery and long-term watershed health.

RECOMMENDATIONS

Analysis of the sediment transport and supply for current and rehabilitated areas indicate that it will be possible to significantly reduce sediment transport on USFS and private lands before Linda Vista Dr. This section of the report provides descriptions of the types of recommended practices and their potential locations. Several important considerations guided the development of these recommendations:

- Work with machinery (and in some cases hand crews) on the steepest slopes upstream of Mount Elden Lookout Road is not recommended in most locations. These areas are extremely difficult to access and working in them will likely be too difficult and dangerous to outweigh the potential benefits. The outcome of this constraint is that the upper drainages will continue to have high sediment supply even after restoration efforts until they restore themselves naturally.
- All proposed practices should mimic the natural function appropriate to the geomorphic setting. By understanding and mimicking the natural potential of the channel, practices will enhance the natural function of the channel, while minimizing the need for maintenance and upkeep. Additionally, enhancing the natural function of the channel fits within the USFS management criteria and will enhance the overall management of the forest.
- All practices must be flexible enough in design to be readily adjusted to field conditions, such as the discovery of archaeological sites, bedrock, or errors in topography.

The recommended practices will focus on increasing sediment storage and reducing erosion. The overall concept for sediment storage is to utilize existing valley types that are appropriate for long-term stable fans to create or enhance sediment storage. Storage is induced by the creation of an over-widened channel (fan) with low sediment transport capacity. In addition to sediment storage on alluvial fans, sediment sourcing from channels can also be addressed by reshaping channels to a more stable condition directly up and downstream of the fans. Sediment source reduction is accomplished by creating stable “B” channels from degraded “F” or “G” channels. The new stable channels contribute less sediment from banks or in-channel sources and decrease the amount of sediment that must be stored in over-widened channels. It is important to create at least a short reach of stable channel below the fans to prevent erosion from a degraded channel from immediately cutting back into and damaging the created fan feature. Together these practices can reduce the sediment supply reaching the neighborhood and improve the health and stability of the watershed.

TYPICAL PRACTICES

Fan Rehabilitation

In order to reduce sediment transport and actively store sediment within channels several conditions must be met. Primarily the valley containing the channel needs to be broad and relatively flat across the width of the valley. Secondly, the channel within the valley must be wide and shallow (Width to Depth Ratio > 40). There are multiple examples of working fan channels within the Museum Fire area (Figure 11). However, many fans have been incised and damaged as a result of recent flooding (Figure 12). Incised channels within the proper valley type have the potential to be restored to conditions that will enhance sediment storage. This is accomplished by filling in the incised channel to raise the bed of the channel up to a pre-fire flood elevation that forms a wide shallow channel (Figure 13 and Figure 14). The new channel is a wide, flat channel that allows for deposition of sediment and formation of fan features (Figure 15). Considerable volumes of fill are required to fill the incised channel in many cases. Fill is borrowed from the adjacent banks to minimize haul distance and limit the disturbance area. Additionally, trenches can be constructed within the fans that can be used as borrow areas (Figure 16). A trench extends across the entire channel cross-section, forming a deep depression (10-15 ft) with shallow slopes on all sides. The slopes are protected with rock to prevent head cutting. The trench, or borrow pit, is left open to catch excess sediment, providing additional storage.

Figure 11. Typical active fan within the Museum Fire area.
Note the debris and sediment aggradation extending valley wide.

Figure 12. An incising channel in reactivated fan in the Museum Fire watershed.

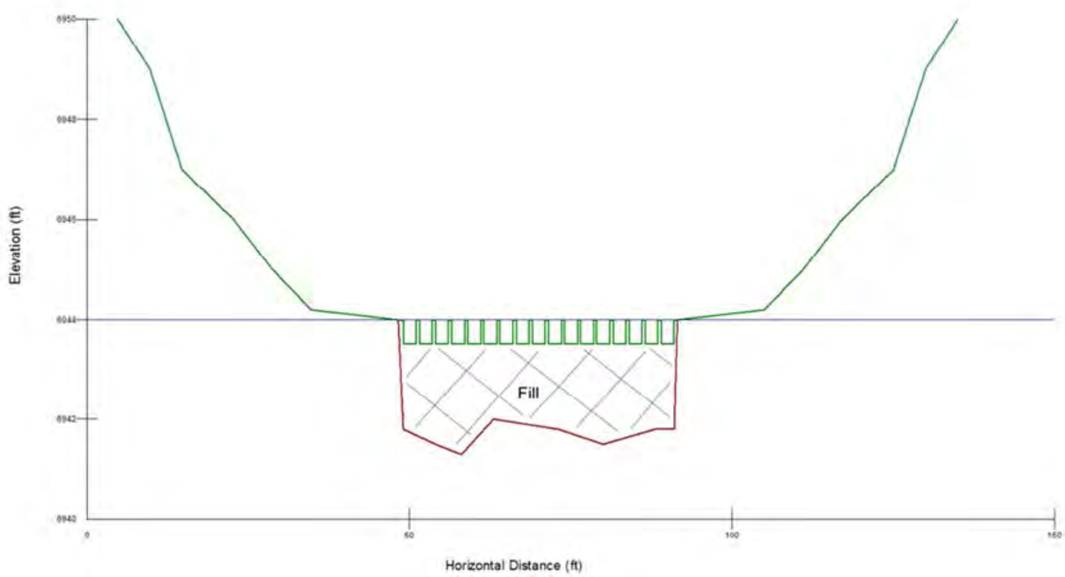

Figure 13. Typical cross-section for “F” to “D” conversion.

Over-wide, multi-thread channel cross section is achieved by filling gullied “F” or “G” channel back to original valley floor elevation. Green represents proposed cross section of wide, multithread, flattened channel. Red indicates the existing incised channel.

Figure 14. Typical area of fill for construction of over-widened "D" channel.

Orange area shows approximate location of fill material through incised channel.

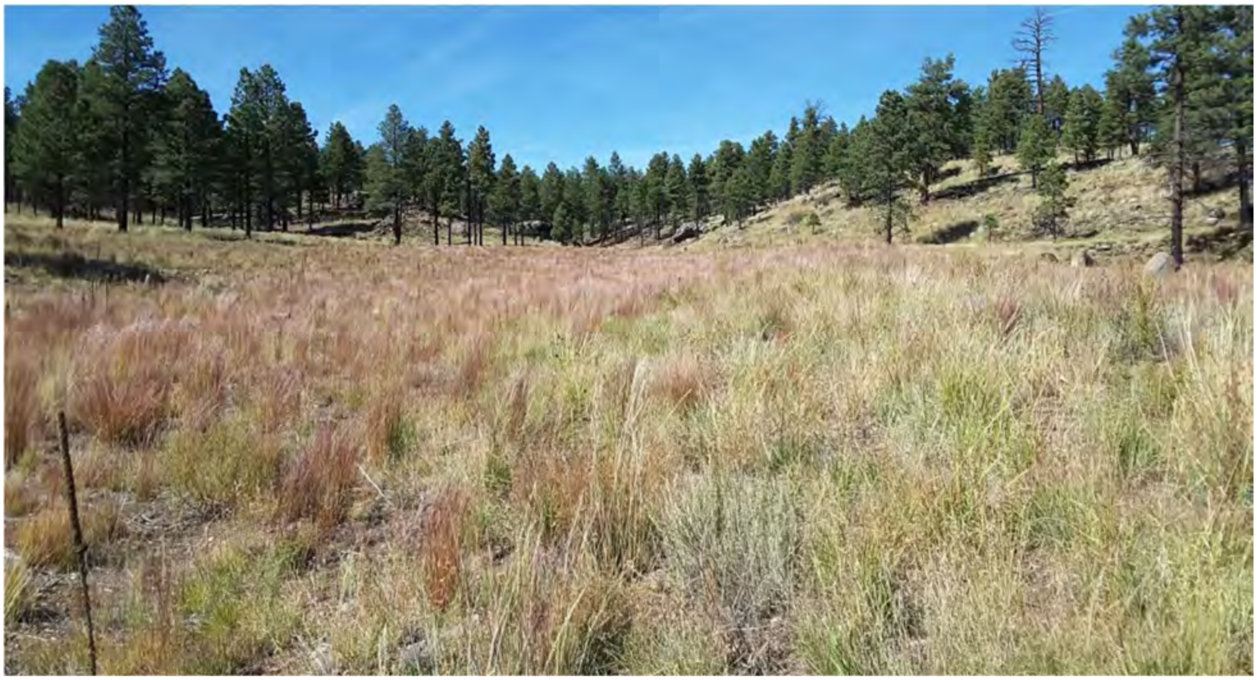

Figure 15. Example of rehabilitated alluvial fan in the Schultz Fire area.

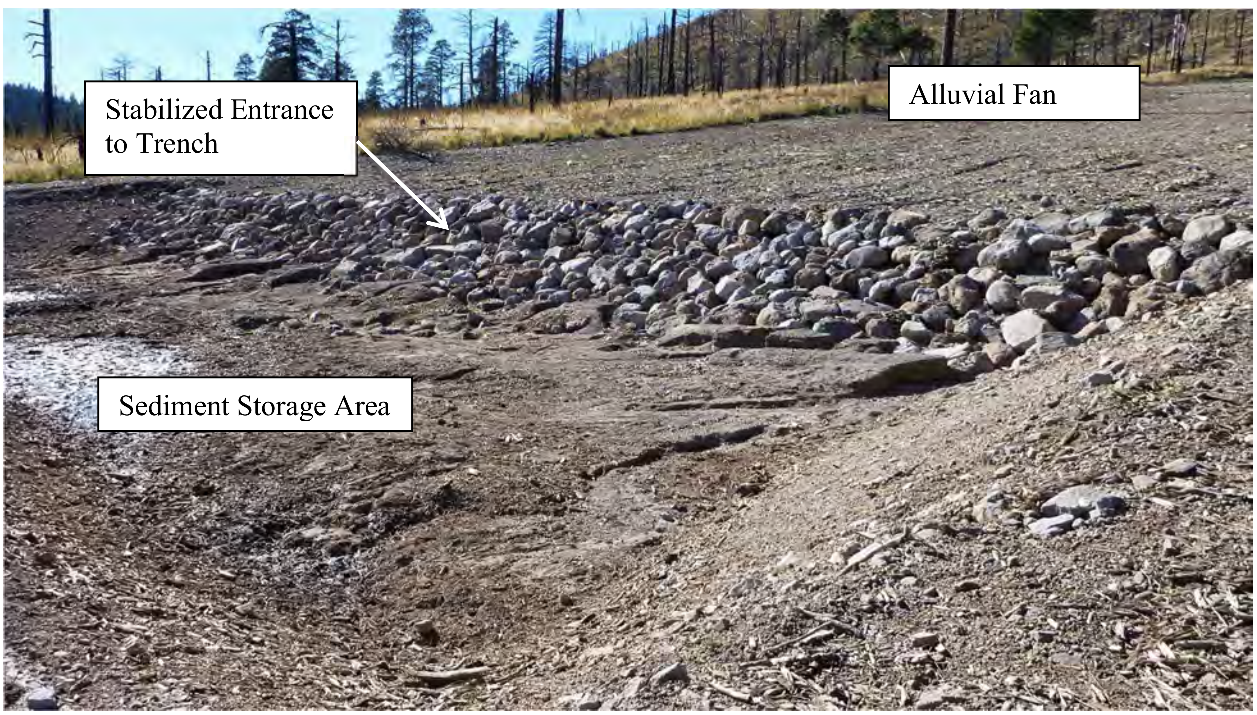

Figure 16. Trench in a fan in the Schultz Fire area.
Note the stabilized rock slope on the upstream side and sediment filling in the trench below the flat fan surface.

Sediment Basins

Sediment basins are created for additional sediment storage. They can be built into fan structures, as trenches, or within a single thread channel. When built into a fan, once full they become a continuation of the fan surface. Basins can often be built near convenient access points to allow sediment removal, when needed, to provide long-term storage space.

Stabilization Structures

Fans and downstream channels in the Museum Fire burn area may experience significant shear stresses during flow events and the relatively fine surface of fans could be subject to erosive forces, especially as deposition begins to create more complex flow patterns around flood debris. Fan stabilization structures are most important in the lower end of the fan system and in areas of higher slopes. Fan slopes in the Spruce watershed vary from 3% near Linda Vista Drive to 15% at the base of the Dry Lake Hills.

Rock or Log Sills

Sills are used to stabilize fans and consist of a line of rocks or logs buried at grade, perpendicular to the direction of flow across the entire width of the fan (Figure 17 and Figure 18). The purpose of a sill is to prevent rilling on the fan surface from developing headcuts through the fan. These structures are installed in series along the fan surface with spacing determined by the fan slope. Logs, if used, will be sourced on site from trees that must be removed for fan grading. It should be noted log sills are not a permanent grade control and will rot out within 3-6 years.

Figure 17. Rock sill maintaining upstream fan gradient in Shultz Burn area.

This particular rock sill is on the Shultz Fire watershed and shown following a 1000-year storm event on the upstream watershed in which it held grade, despite flows well in excess of the design storm event.

Figure 18**. Log sill installation on fan surface in Schultz Burn area.**

<u>*Rock Chute*</u>

Rock chutes are used to drop flow over large, short grade breaks and are sized to contain large flow events (Figure 19 and 20). Rock chutes are a pad of graded rip rap, sized to resist shear stresses over the grade break with a "pool" at the downstream end to reduce velocities. Rock chutes are placed at the terminal trench at the downstream end of the fan structures and at grade breaks in channels to prevent headcutting.

Figure 19. Rock chute at terminal trench in Schultz Burn area.

Figure 20. Rock chute in a channel at grade break caused by Schultz Pass Rd.

Cross-Vane Weir

The rock cross vane weir provides both bank protection and grade control. Cross vane weirs may be placed in the channel leading into and out of fans or in a stabilized channel to reduce erosion. It consists of a row of rocks arranged in a U-shape with the bottom of the U on the upstream side at the channel bottom elevation with the arms extending downstream and up to bankfull elevation (Figure 21). A single row of rock beginning approximately halfway down the weir arms and set perpendicular to the flow forms a step that is lower than the weir throat. All rocks used in the weir will have footer rock on the downstream side to protect against undermining. The cross-vane weir arms serve to redirect flows and slow velocities along the outside of the bend, minimize bank erosion while centering flow in the channel, and protect the channel bed from upstream headcut migration.

Figure 21. Cross vane weir installed in Spruce Wash channel looking upstream at weir.

J-Hook Rock Vane

The J-hook rock vane provides both bank protection and grade control and is similar to a cross vane weir with a single arm (Figure 22). It consists of a single row of rock in a "J" shape with the curve on the upstream side at the channel bottom elevation with the arm extending downstream but sloping up to bankfull elevation on the outside the meander. All rocks used in the vane will have footer rock on the downstream side to protect against undermining. The vane serves to redirect flows and slow velocities along the outside of the bend and minimize bank erosion while protecting the channel bed from upstream headcut migration. The area just downstream of the vane should be excavated slightly at installation to initiate a small pool. Several J-hooks can be used in succession along the outside of meanders.

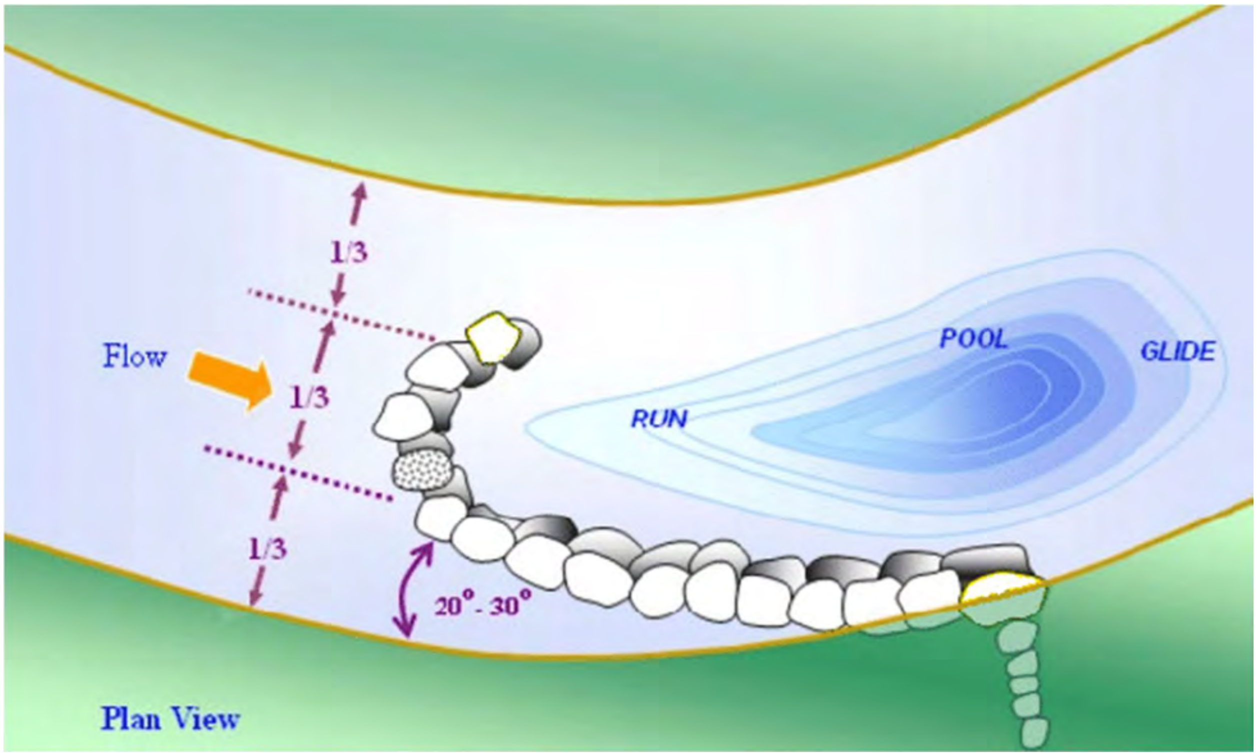

Figure 22. J-hook rock vane.

Image from Part 654 Stream Restoration Design National Engineering Handbook, Chapter 11 Rosgen Geomorphic Channel Design. USDA Natural Resources Conservation Service. August 2007.

Stable Channel Conversion

In areas with narrower valley floors that will not support aggrading channels, the best solution is to convert incised, poor condition channels (Rosgen F and G types) to single thread, stable channels (Rosgen B type) (Figure 23). This is accomplished by cutting away the steep banks and creating a less incised channel, with a small floodplain surface at bankfull stage (Figure 24 and Figure 25). The new channel will need to be built with natural roughness features that help dissipate energy. These features are built of logs or large boulders and form a pool drop system to dissipate energy and help keep the newly formed bed intact. However, the key element is the formation of a bankfull stage floodplain to lower velocities and shear at higher stages.

Figure 23. Existing stable single thread channel after high flow event.

Stable channels in the fire area provide a model for design of restored channels. Note stable bank slopes and no sediment sourcing from this reach even after multiple large events passed through channel from burn area upstream.

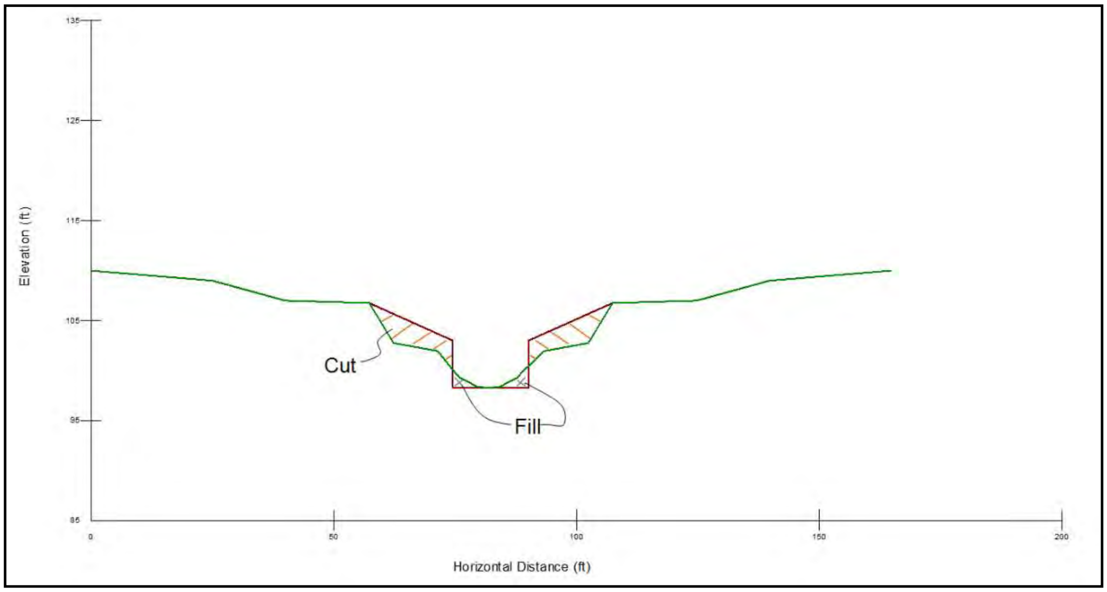

Figure 24. Typical cut and fill for single thread channel conversion.

Overlay of typical design channel (green) on typical incised channel cross section (red) indicates area of cut and fill required to reshape the channel.

Figure 25. Typical incised channel to stable channel conversion.

Shaded areas show cut (red) and fill (yellow) areas for a typical conversion of unstable, incised channel to stable channel with small floodplain at bankfull stage.

PRACTICE LOCATIONS

The Museum Fire watershed has several potential locations for fan enhancement and channel stabilization, which are shown in Figure 26. The areas to be treated have been purposefully limited to areas below the Mt Elden Lookout Road or vitally important areas on moderate slopes immediately upstream of the road (Ginger Fan). The estimated potential area for rehabilitated fans is shown in Table 4.

Table 4. Area of potential fan enhancement.

Drainage	Fan Rehabilitation (acres)
Upper North Tributary Fan	1.6
Middle North Tributary Fan	3.9
Ginger Fan	7.7
Private 40 Acre Fan	6
Lockett Ranches Fan	3.9
Paradise Fan	4.4

MONITORING

While these practices are intended to be self-sustaining for a long period of time, it is highly recommended that a monitoring program be in place to document their function and to trigger maintenance as needed. The fan areas are all proximal to important roadways, gas lines, homes, and other infrastructure. Additionally, the potential sediment supply in the upper Museum Fire is substantial when compared to the amount of surface area available for restoration and enhancement of the fans. High discharges have the potential to overload the fan systems with excessive sediment deposition. The deposited sediment could force flows into areas on the old fan surfaces that could endanger infrastructure. While all due care can be taken during the design process to ensure adequate storage and free board, high discharges precipitation events should be thoroughly monitored and analyzed. In addition, a robust monitoring program has the potential to greatly improve future understanding and restoration for impaired watersheds with high severity burn areas.

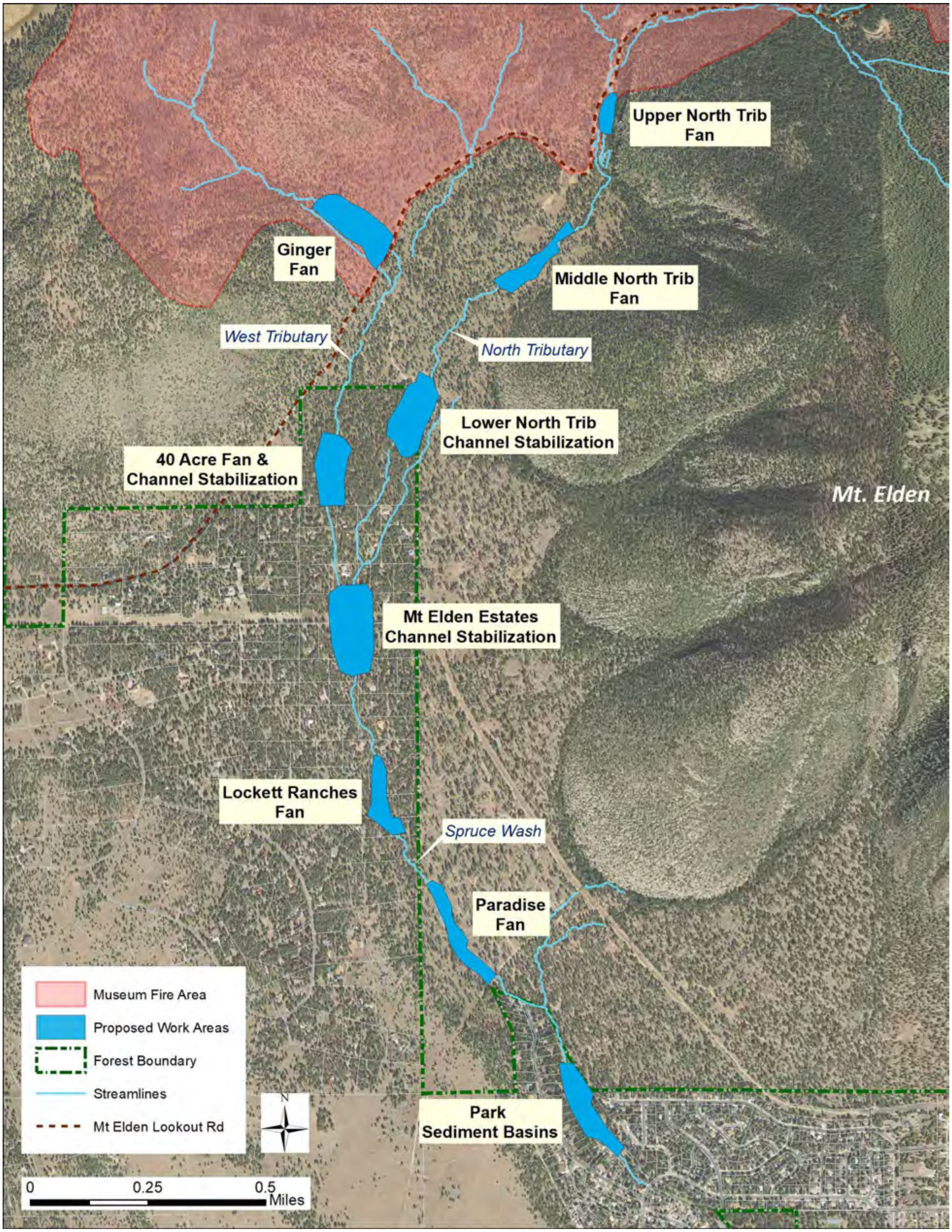

Figure 26. Proposed treatment areas for each watershed.

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APPENDIX A

MUSLE Model Results

Below is a complete set of model inputs and results:

Watershed (WS) Name	WS AREA	WS AREA	Avg. Slope	WS Length	SL	P Value	C Value
	miles^2	(acres)	%	(ft)	-	-	-
Ginger (West Trib)	0.4	251.4	45	4280	103.89	1	0.003
40 Acre (West Trib)	0.8	484.1	30	6127	55.55	1	0.003
Upper North Trib - Wasabi	1.5	957.4	45	9760	155.80	1	0.003
Upper North Trib - Brookbank	0.6	400.3	45	6531	127.83	1	0.003
Middle North Trib	2.2	1424.4	25	11274	52.18	1	0.003
Lower North Trib	2.7	1731.9	20	13619	36.84	1	0.003
Lockett Ranches	4.4	2826.8	20	17749	41.91	1	0.003
Paradise	4.9	3142.9	15	17964	23.92	1	0.003
Park Basins	5.5	3491.3	15	21792	26.26	1	0.003

	sandy loam	sandy loam + high burn	high burn
Watershed (WS) Name	K Value_low	K Value_med	K Value_high
	-	-	-
Ginger (West Trib)	0.29	0.545	0.8
40 Acre (West Trib)	0.29	0.545	0.8
Upper North Trib - Wasabi	0.29	0.545	0.8
Upper North Trib - Brookbank	0.29	0.545	0.8
Middle North Trib	0.29	0.545	0.8
Lower North Trib	0.29	0.545	0.8
Lockett Ranches	0.29	0.545	0.8
Paradise	0.29	0.545	0.8
Park Basins	0.29	0.545	0.8

	Peak Runoff Rate			Runoff Volume		
Watershed (WS) Name	**1"**	**2"**	**3"**	**1"**	**2"**	**3"**
	m^3/s	**m^3/s**	**m^3/s**	**m^2**	**m^2**	**m^2**
Ginger (West Trib)	2.46	9.34	17.87	4810.6	15048.5	26396.5
40 Acre (West Trib)	3.79	17.90	42.62	10854.6	45392.1	109409.7
Upper North Trib - Wasabi	2.07	11.19	24.55	8017.6	31947.1	61920.7
Upper North Trib - Brookbank	5.27	22.57	45.87	12828.2	50696.0	106572.7
Middle North Trib	6.80	32.20	70.23	21092.5	84986.8	174414.1
Lower North Trib	4.64	17.92	27.07	18008.8	62414.1	103365.6
Lockett Ranches	6.94	38.43	93.28	29356.8	138149.8	301462.5
Paradise	6.29	39.30	99.31	29110.1	147277.5	329215.8
Park Basins	5.24	39.98	104.40	28246.7	156158.6	360176.2

	Soil Loss with low K value			Soil Loss with medium K value			Soil Loss with high K value		
Watershed (WS) Name	**1"**	**2"**	**3"**	**1"**	**2"**	**3"**	**1"**	**2"**	**3"**
	tons	tons	tons	tons	tons	tons	tons	tons	tons
Ginger (West Trib)	203.8	814.5	1604.0	383.1	1530.6	3014.3	562.3	2246.8	4424.7
40 Acre (West Trib)	219.0	1162.9	3094.1	411.5	2185.5	5814.7	604.0	3208.0	8535.4
Upper North Trib - Wasabi	368.8	2059.2	4632.7	693.2	3869.8	8706.2	1017.5	5680.4	12779.8
Upper North Trib - Brookbank	664.8	3241.8	7311.4	1249.4	6092.4	13740.3	1833.9	8943.0	20169.3
Middle North Trib	413.5	2156.5	4991.9	777.2	4052.7	9381.3	1140.8	5949.0	13770.7
Lower North Trib	215.9	922.5	1541.5	405.7	1733.7	2896.9	595.5	2544.9	4252.3
Lockett Ranches	404.4	2510.5	6385.7	759.9	4717.9	12000.7	1115.5	6925.4	17615.7
Paradise	217.3	1503.6	3964.4	408.4	2825.6	7450.3	599.4	4147.7	10936.3
Park Basins	211.9	1722.7	4708.7	398.2	3237.6	8849.1	584.5	4752.4	12989.6

Likely the best approximator for Museum Fire

APPENDIX B – DETAILED SITE CROSS SECTION DATA

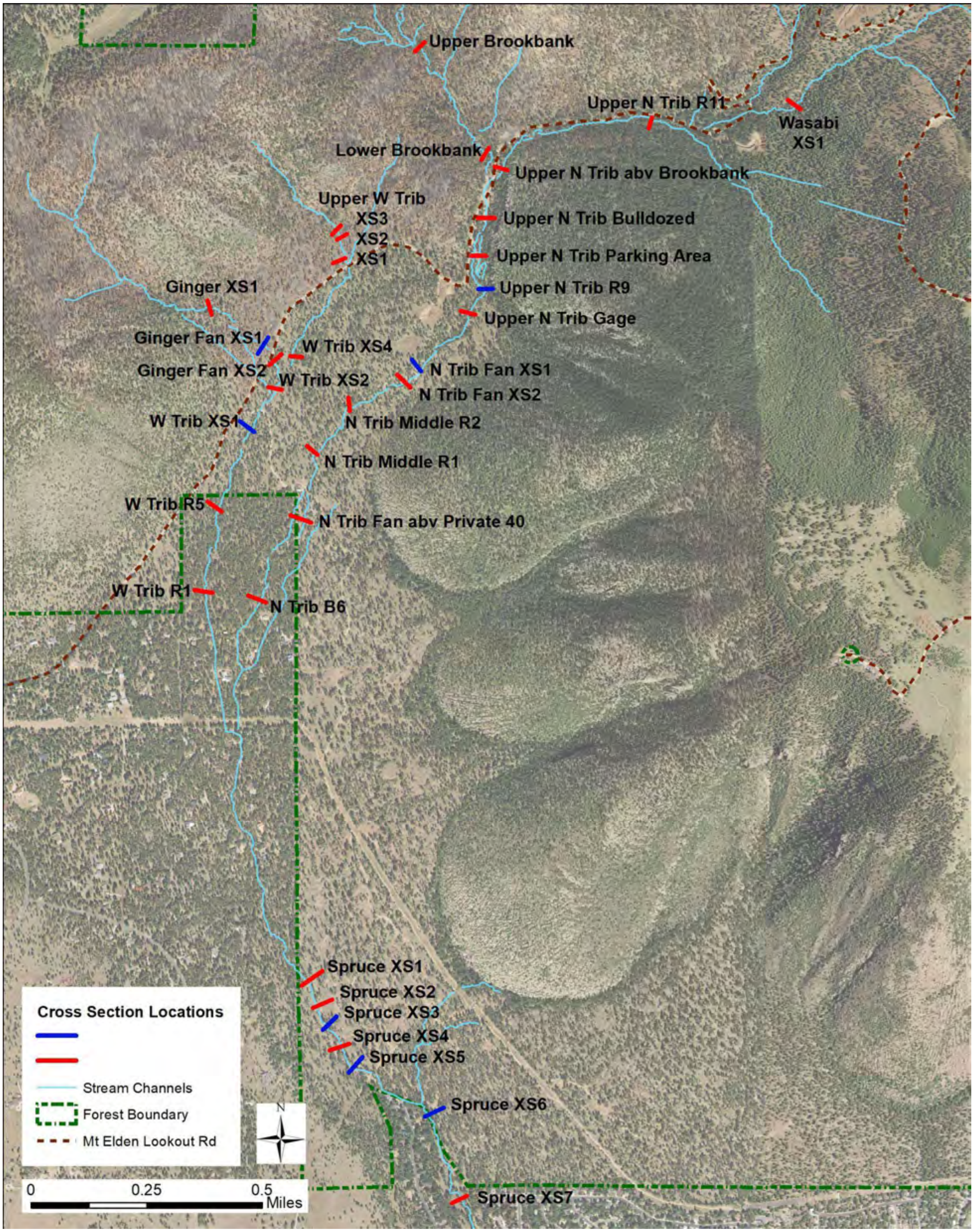


Figure 1. Cross section locations. Red cross sections are presented in Appendix B. Pebble counts were not collected at blue cross sections and the data for these cross sections is not presented in this Appendix.

SPRUCE AVENUE WASH - MAIN STEM

This portion of the watershed is a single thread channel in good condition with little bank erosion. The channel slope averages 2.3% and is in a moderately confined valley.

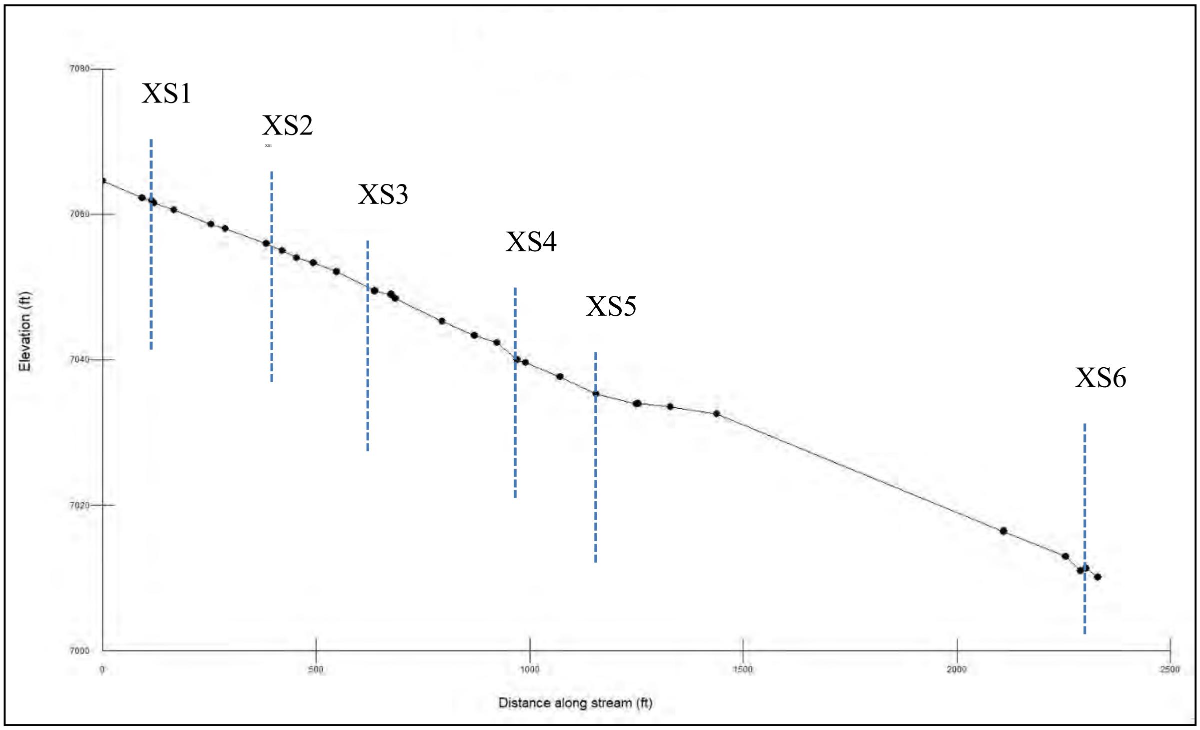


Figure 2. Longitudinal profile of the surveyed reach of Spruce Wash. Channel slope averages 2.3%.

Spruce XS1

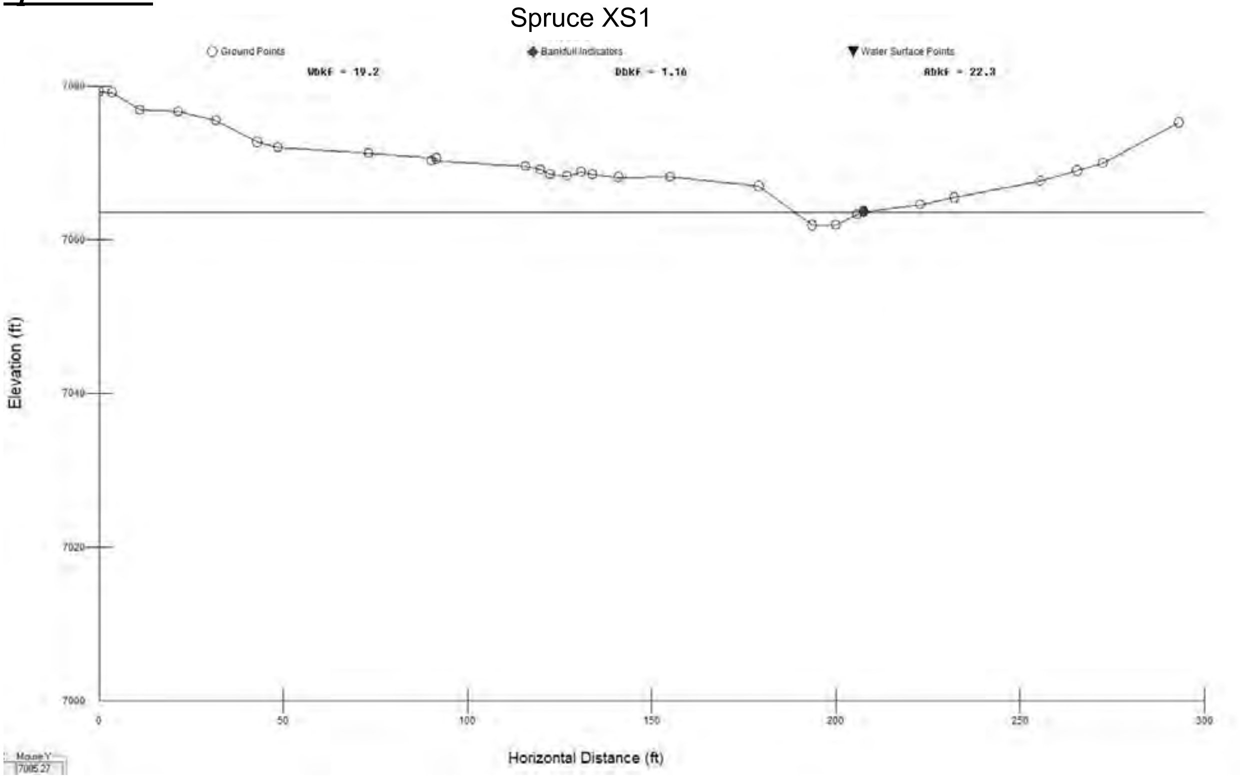


Figure 3. Spruce cross section (XS) 1 surveyed at the upstream end of the Spruce Wash just below private lands (Lockett Ranches).

Particle Size Analysis

D16 (mm)	0.2
D35 (mm)	0.91
D50 (mm)	5.03
D84 (mm)	40.41
D95 (mm)	106.13
D100 (mm)	255.99
Silt/Clay (%)	2.65
Sand (%)	36.5
Gravel (%)	49.74
Cobble (%)	11.11
Boulder (%)	0
Bedrock (%)	0

Total Particles = 189

D50 5.03 mm

Figure 4. Representative pebble count at Spruce XS1.

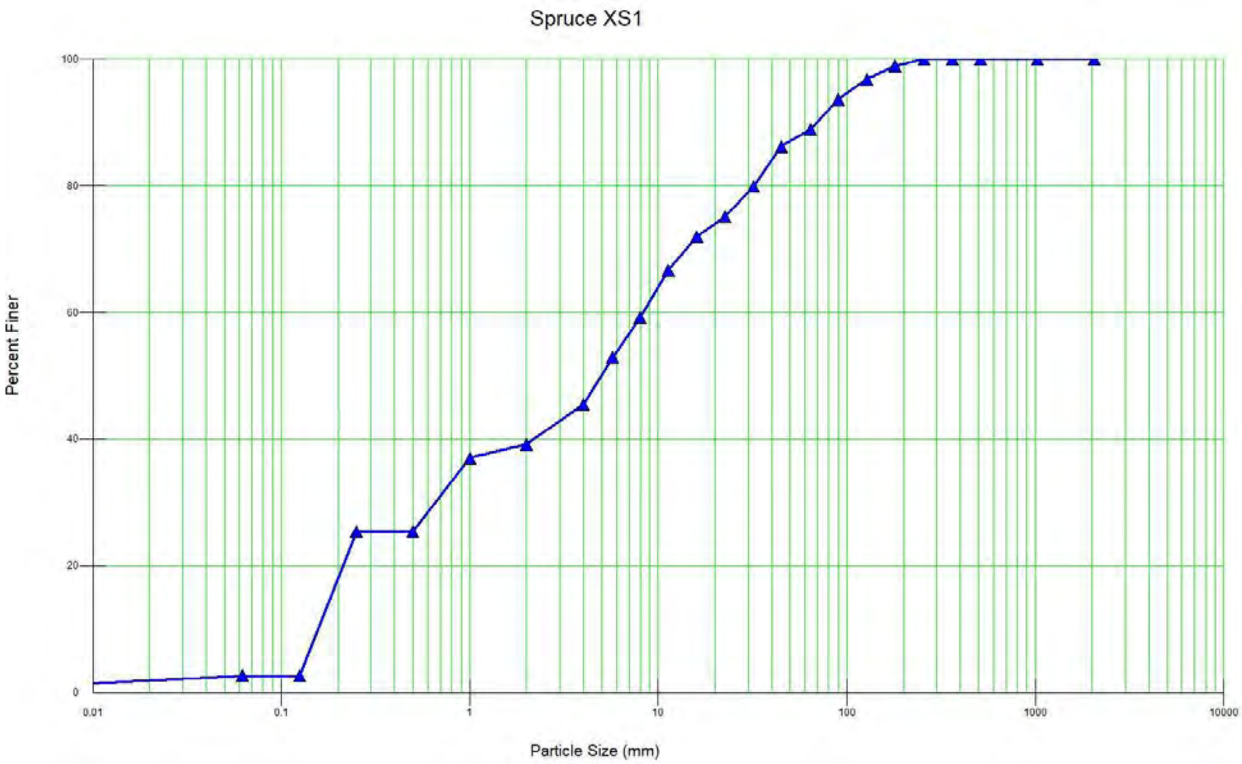


Figure 5. Representative Pebble Count at Spruce XS1, D50 = 5.0 mm.

Figure 6. Spruce XS1, looking downstream.

Spruce XS2

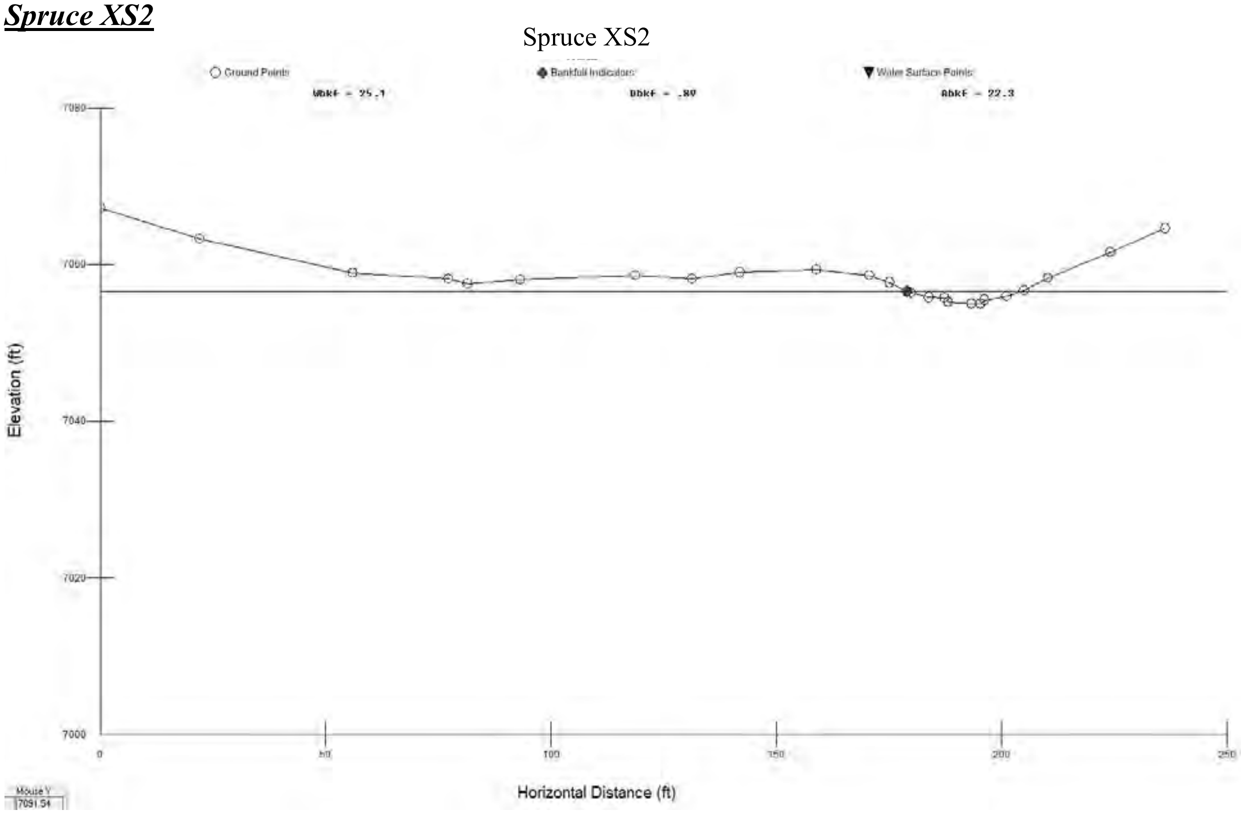


Figure 7. Spruce XS2.

Particle Size Analysis

D16 (mm)	2.95
D35 (mm)	6.72
D50 (mm)	10.14
D84 (mm)	31.58
D95 (mm)	86.11
D100 (mm)	256
Silt/Clay (%)	6.21
Sand (%)	6.83
Gravel (%)	78.26
Cobble (%)	8.7
Boulder (%)	0
Bedrock (%)	0

Total Particles = 161

D50 10.14 mm

Figure 8. Representative pebble count at Spruce XS2.

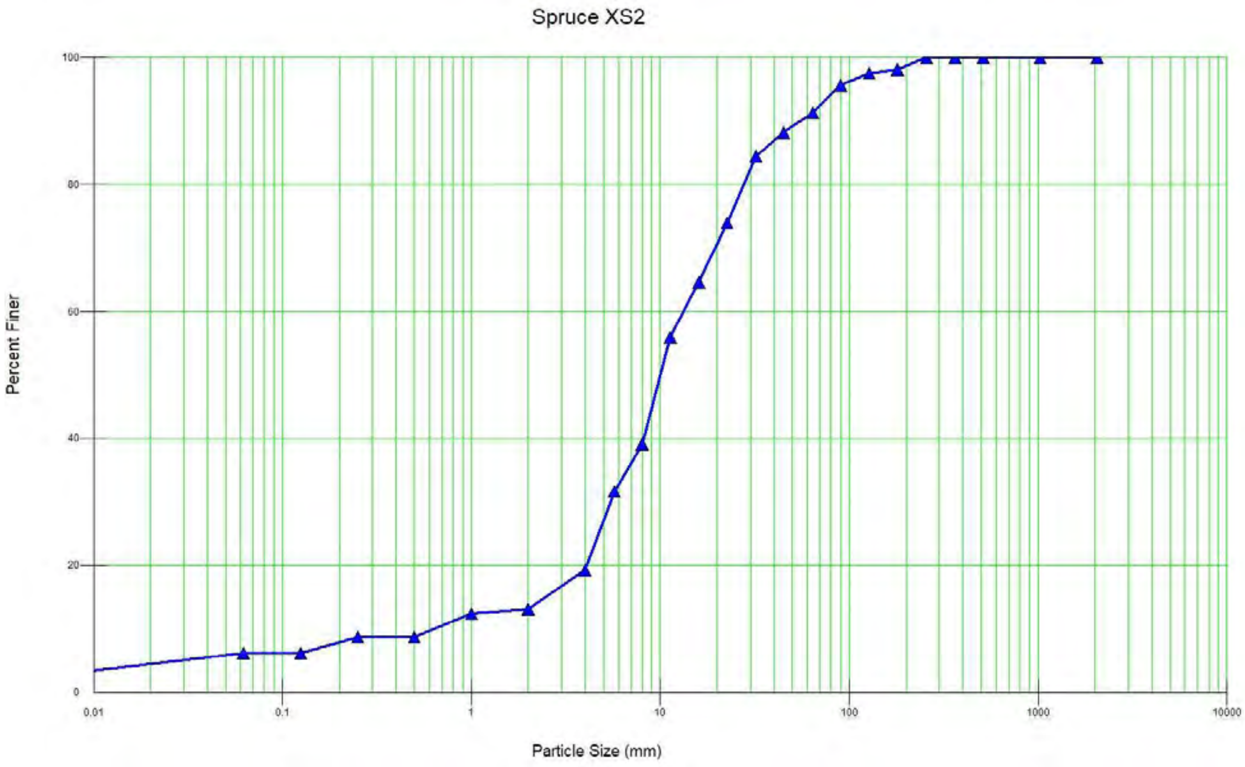


Figure 9. Representative Pebble Count at Spruce XS2, D50 = 10 .1mm.

Figure 10. Spruce XS2, looking upstream.

Spruce XS4

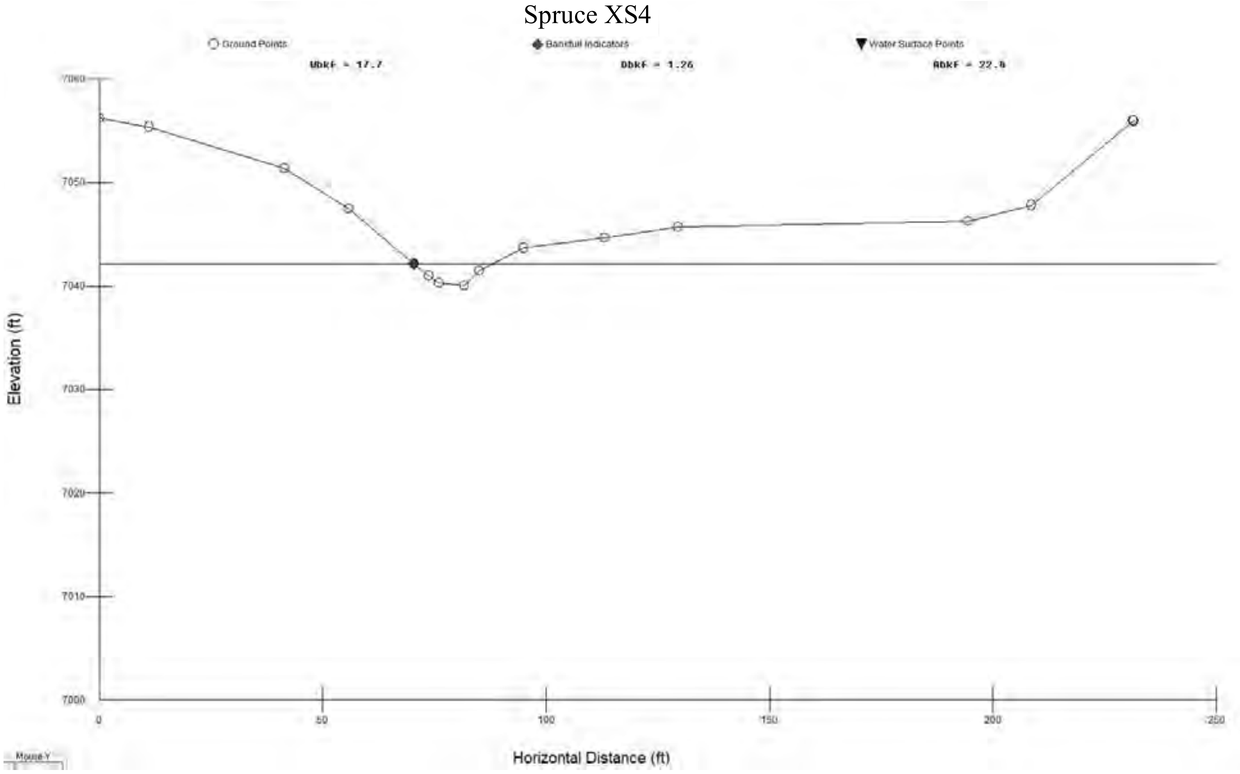


Figure 11. Spruce XS4.

Particle Size Analysis

D16 (mm)	0.2
D35 (mm)	4.69
D50 (mm)	17.1
D84 (mm)	89.62
D95 (mm)	229.32
D100 (mm)	Bedrock
Silt/Clay (%)	0.93
Sand (%)	29.91
Gravel (%)	45.8
Cobble (%)	18.69
Boulder (%)	1.87
Bedrock (%)	2.8

Total Particles = 107

D50 17.1 mm

Figure 12. Representative Pebble Count at Spruce XS4.

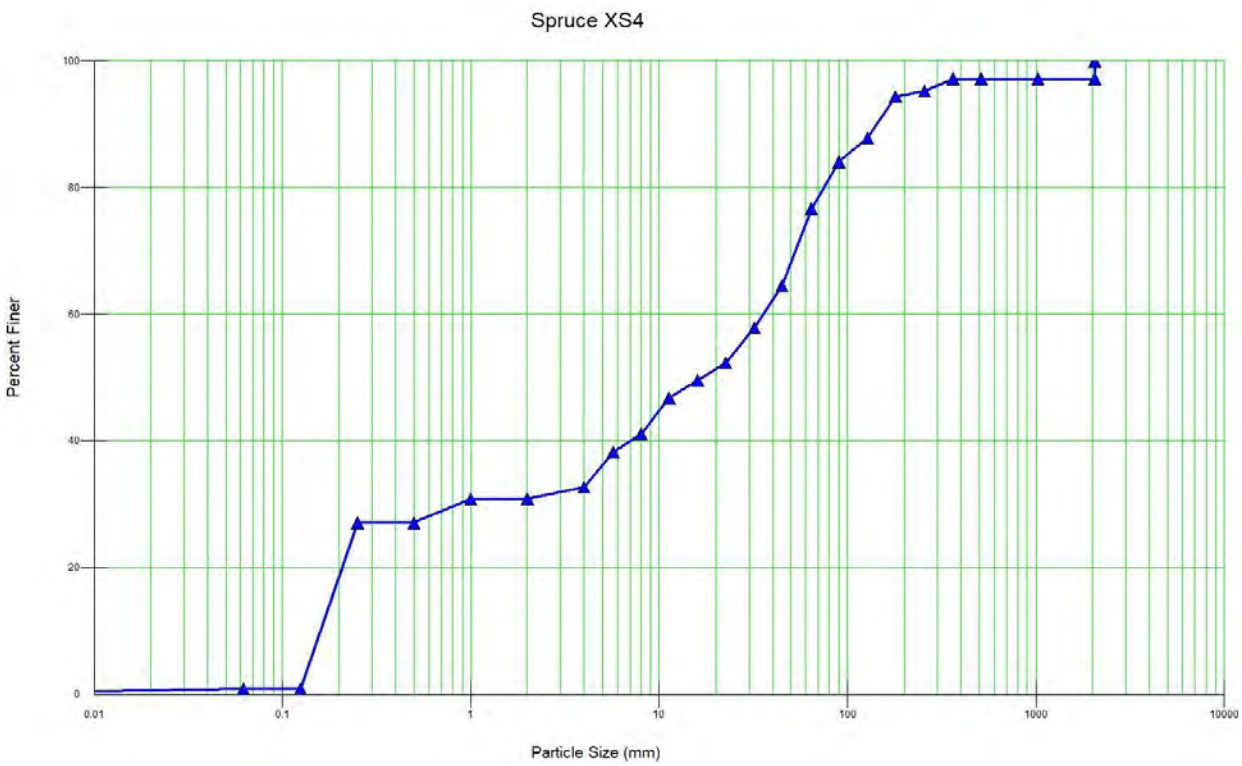


Figure 13. Representative Pebble Count at Spruce XS 4, D50 = 17.1 mm.

Figure 14. Spruce XS4 looking downstream.

Spruce XS7

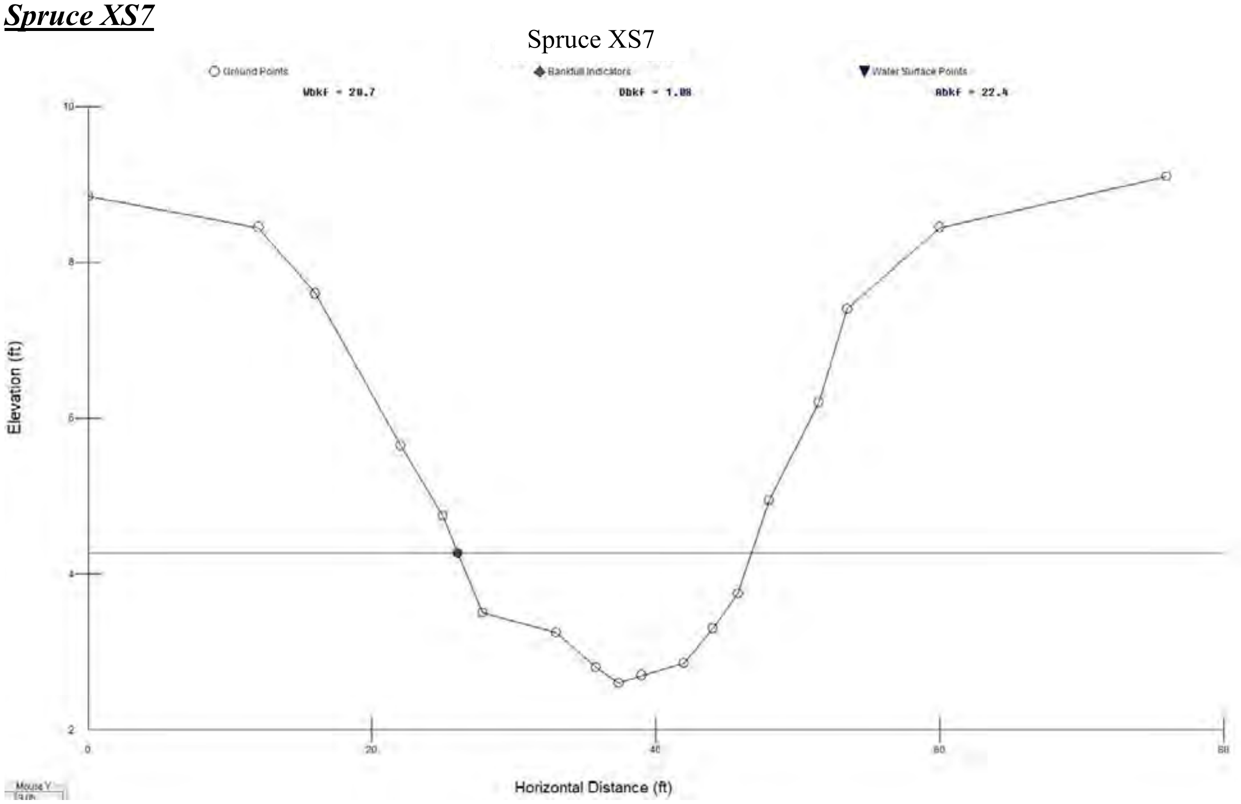
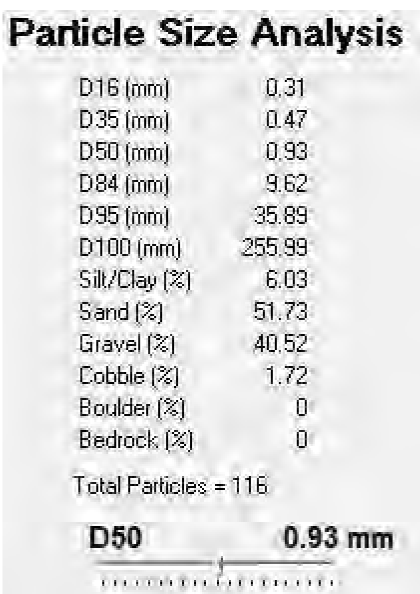


Figure 15. Spruce XS7.



Particle Size Analysis

D16 (mm)	0.31
D35 (mm)	0.47
D50 (mm)	0.93
D84 (mm)	9.62
D95 (mm)	35.89
D100 (mm)	255.99
Silt/Clay (%)	6.03
Sand (%)	51.73
Gravel (%)	40.52
Cobble (%)	1.72
Boulder (%)	0
Bedrock (%)	0

Total Particles = 116

D50 0.93 mm

Figure 16. Representative Pebble Count at Spruce XS7.

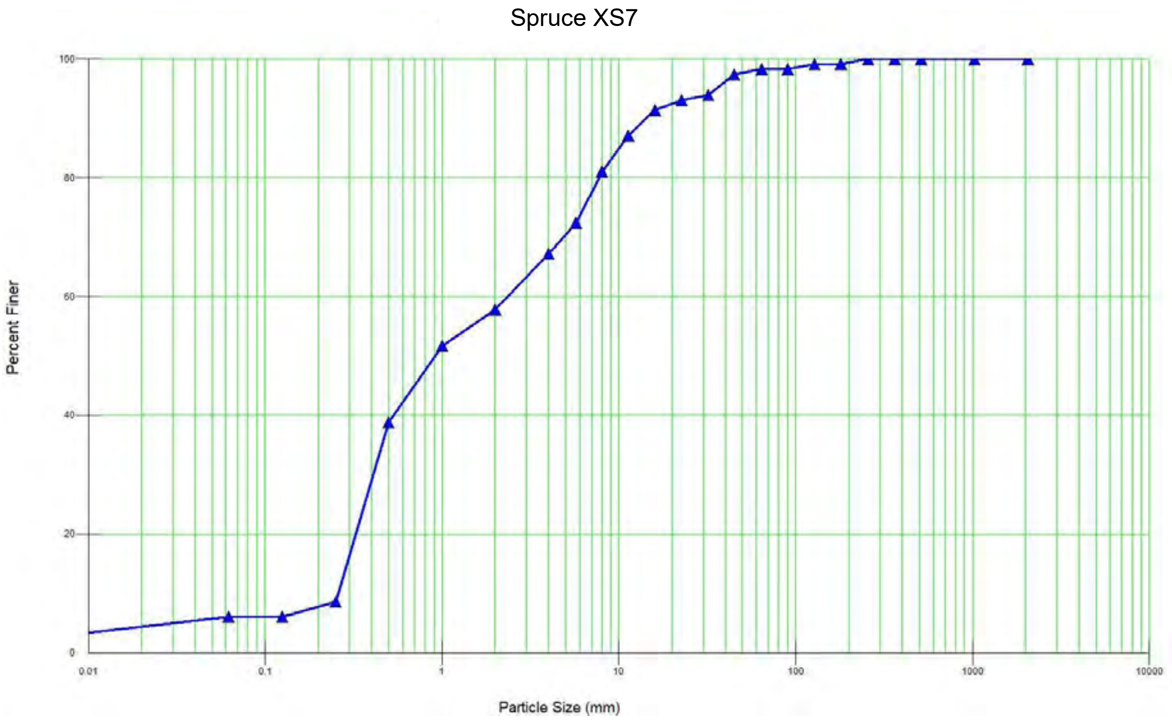


Figure 17. Representative Pebble Count at Spruce XS7, D50 = 0.9 mm.

Figure 18. Spruce XS7 looking upstream.

NORTH TRIBUTARY

This portion of the watershed contains a mix of shallow and steep slopes with functional alluvial fans and reaches with recently incised channels due to increased runoff. Representative cross sections were gathered in the fans, incised channels, intact channels and on steeper or shallower channel slopes throughout this tributary.

North Trib Reach B6

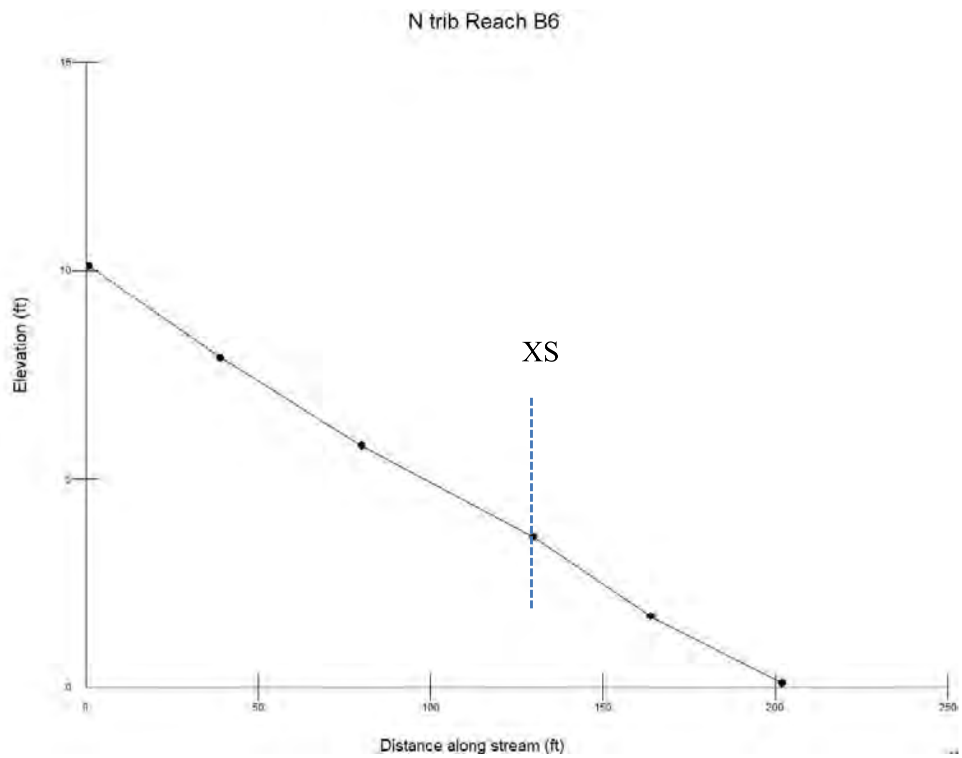


Figure 19. North Tributary Reach B6, profile slope 5.0%.

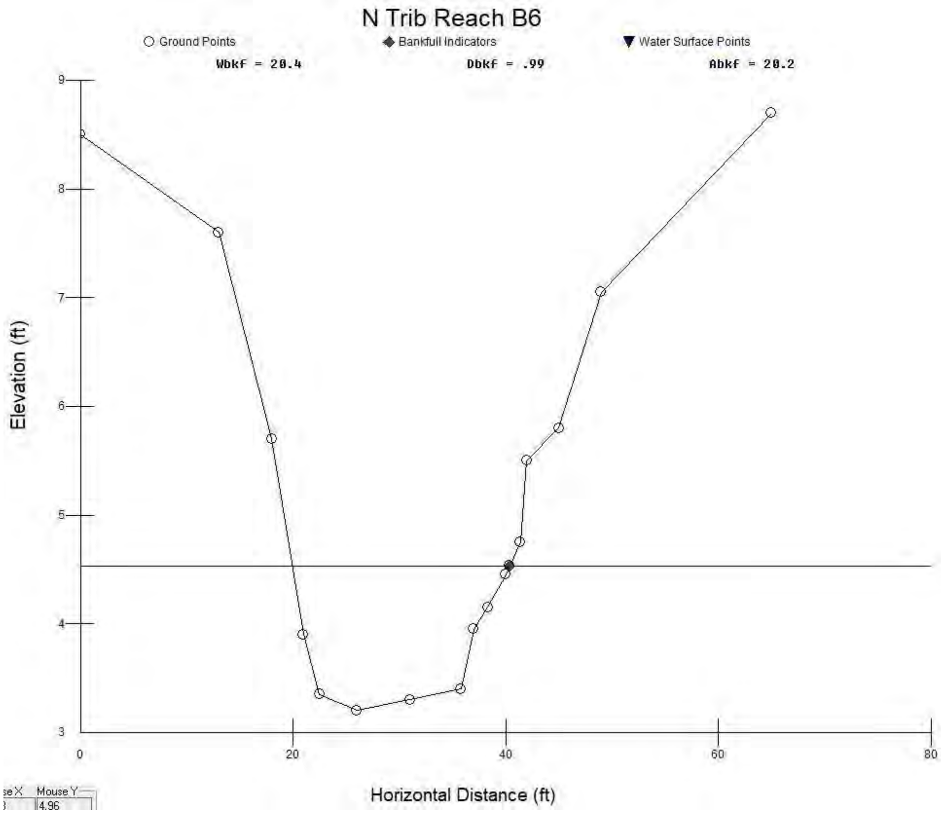


Figure 20. North Tributary Reach B6 cross section.

Particle Size Analysis

D16 (mm)	1.22
D35 (mm)	2.59
D50 (mm)	3.9
D84 (mm)	9.58
D95 (mm)	26.83
D100 (mm)	90
Silt/Clay (%)	0
Sand (%)	28.26
Gravel (%)	70.11
Cobble (%)	1.63
Boulder (%)	0
Bedrock (%)	0

Total Particles = 184

D50 3.9 mm

Figure 21. North Tributary Reach B6 pebble count.

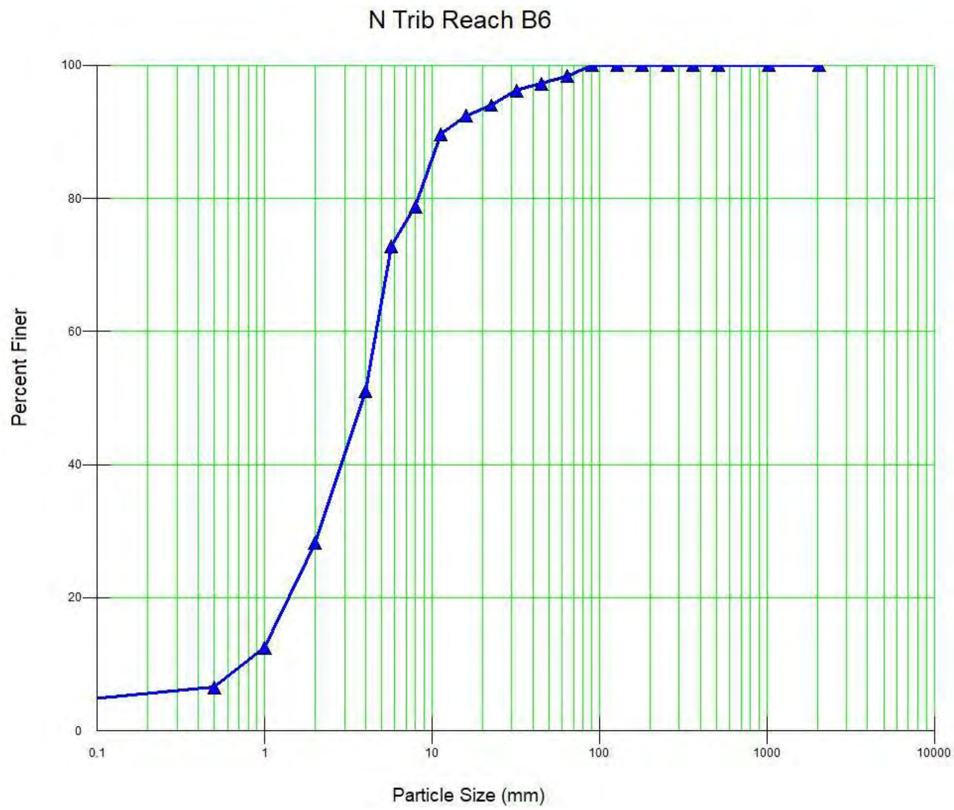


Figure 22. North Tributary Reach B6 pebble count. D50 = 3.9 mm.

Figure 23. North Tributary Reach B6 cross section looking downstream.

North Trib Fan above Private 40

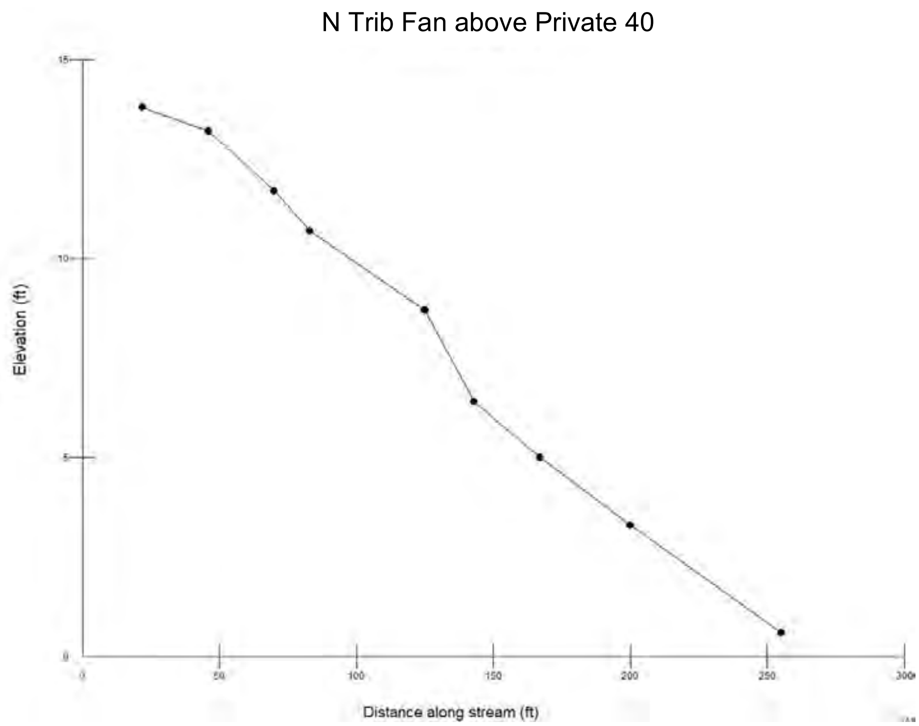


Figure 24. Profile through the North Tributary Fan above Private 40 cross section. Channel slope is 6.0%.

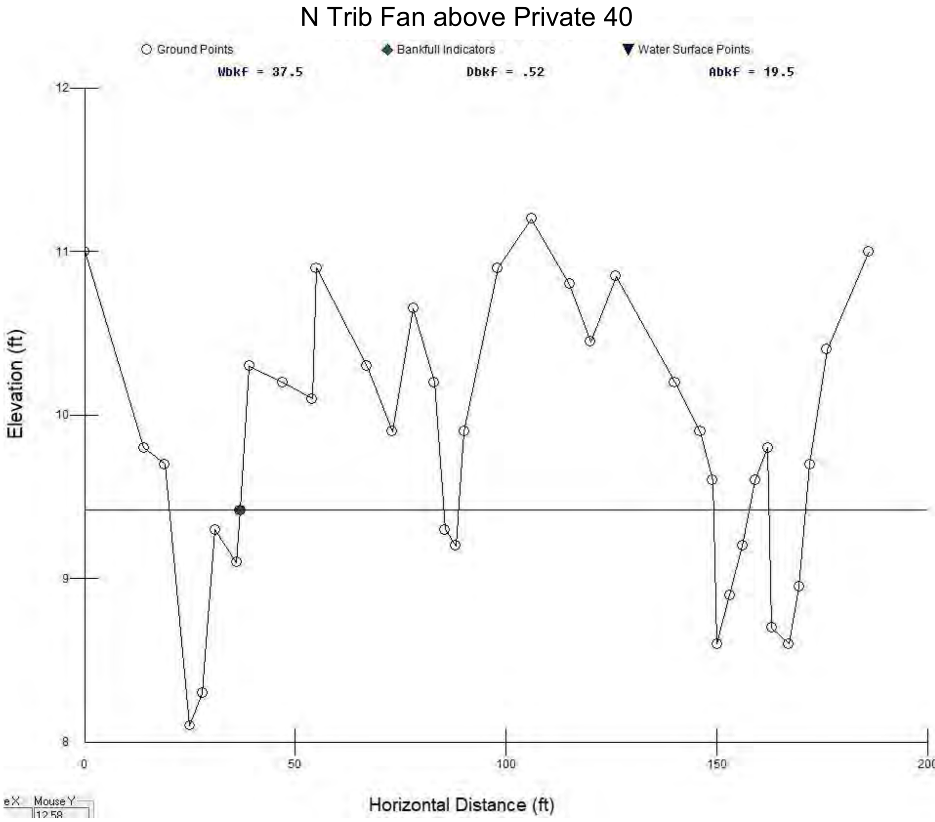


Figure 25. North Tributary Fan above Private 40 cross section.

Particle Size Analysis

D16 (mm)	0.29
D35 (mm)	0.44
D50 (mm)	4.31
D84 (mm)	64.6
D95 (mm)	215.43
D100 (mm)	511.99
Silt/Clay (%)	0
Sand (%)	42.31
Gravel (%)	41.66
Cobble (%)	14.11
Boulder (%)	1.92
Bedrock (%)	0

Total Particles = 156

D50 4.31 mm

Figure 26. Representative pebble count for North Tributary Fan above Private 40.

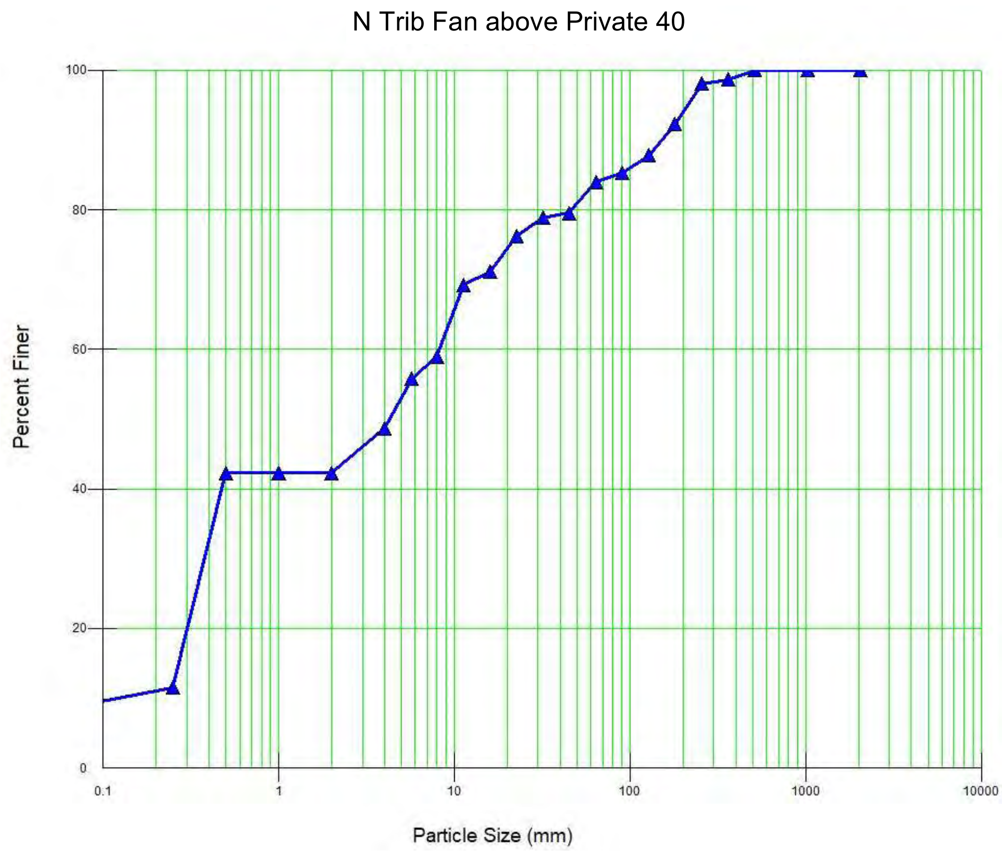


Figure 27. North Tributary Fan above Private 40 pebble count. D50 = 4.3 mm.

Figure 28. North Tributary Fan above Private 40. Note lack of defined flow path and aggregation across fan surface.

North Trib Middle Reach 1 (R1)

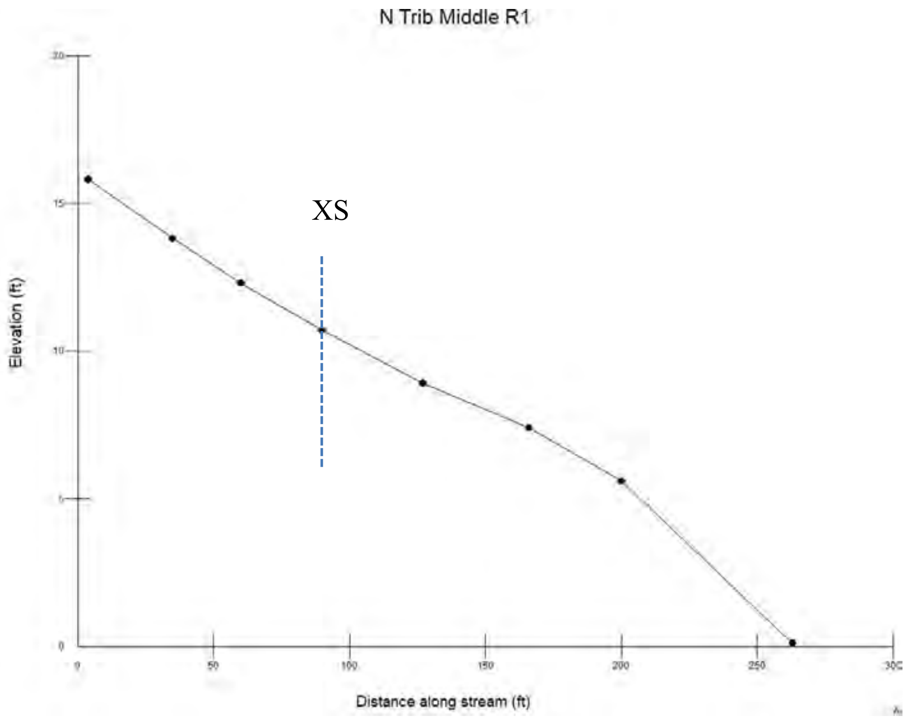


Figure 29. North Tributary Middle Reach 1 profile slope 5.1%.

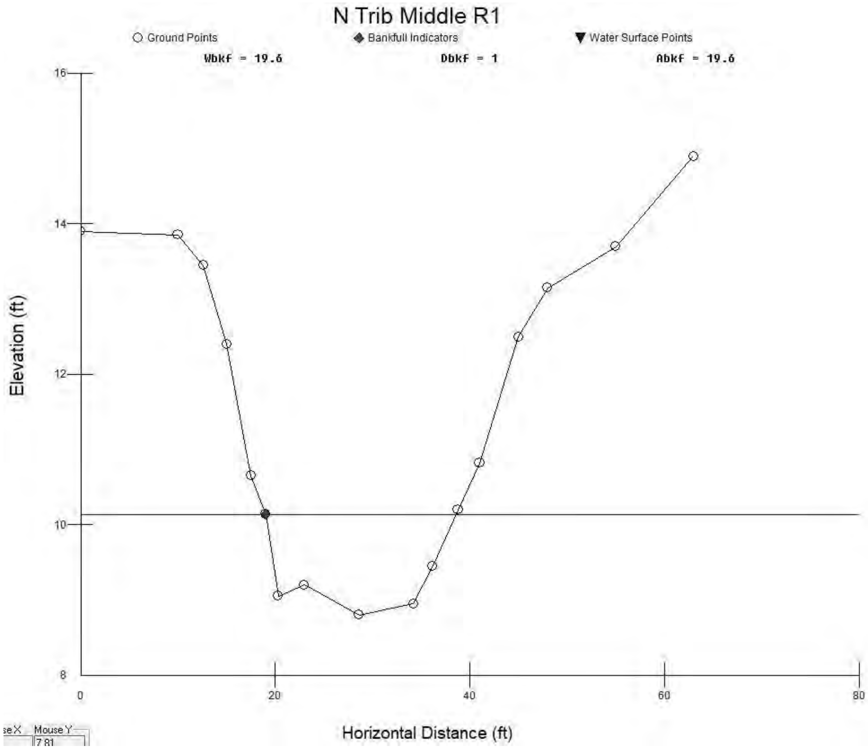
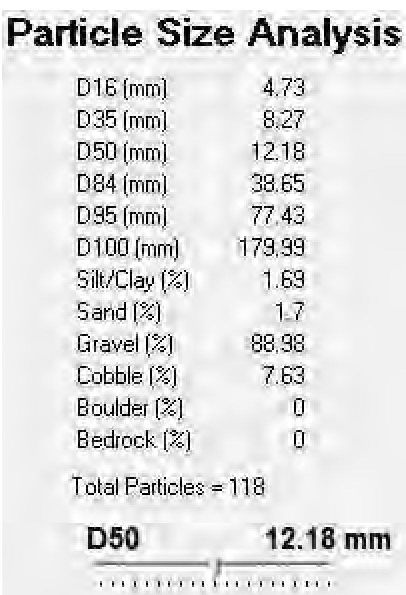


Figure 30. North Tributary Middle Reach 1 cross section.



Particle Size Analysis

D16 (mm)	4.73
D35 (mm)	8.27
D50 (mm)	12.18
D84 (mm)	38.65
D95 (mm)	77.43
D100 (mm)	179.99
Silt/Clay (%)	1.69
Sand (%)	1.7
Gravel (%)	88.98
Cobble (%)	7.63
Boulder (%)	0
Bedrock (%)	0

Total Particles = 118

D50 12.18 mm

Figure 31. North Tributary Middle Reach 1 pebble count.

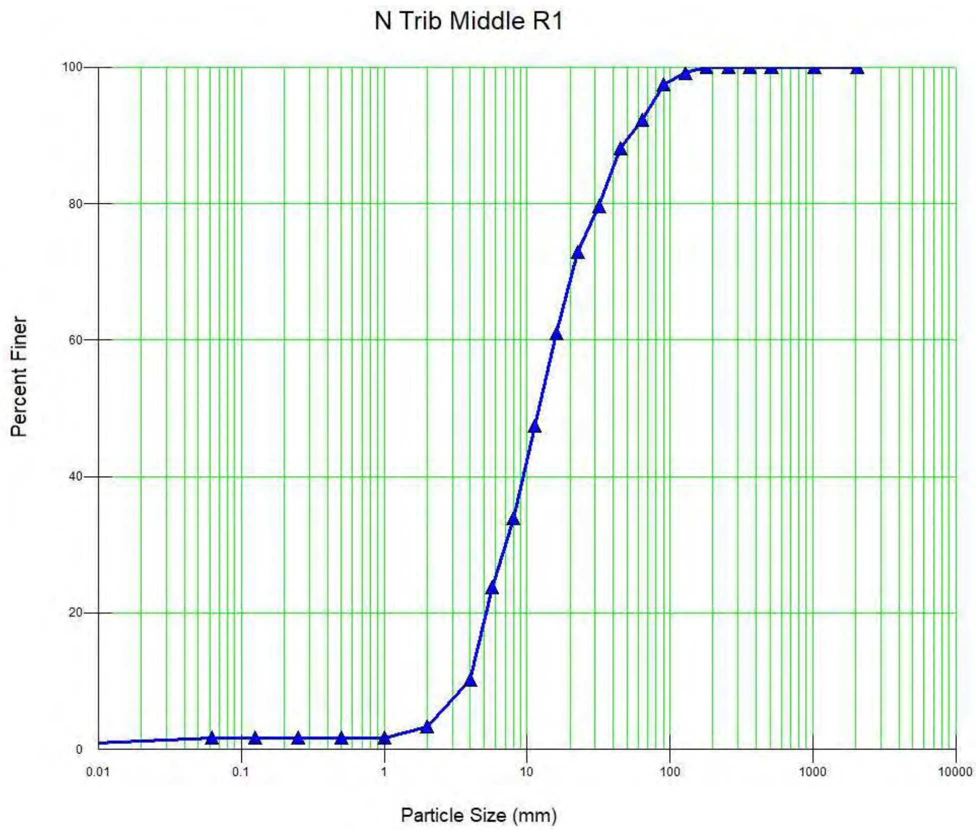


Figure 32. North Tributary Middle Reach 1 particle distribution plot D50 = 12.2 mm.

Figure 33. North Tributary Middle Reach 1 looking downstream.

Figure 34. North Tributary Middle Reach 1 looking upstream.

North Trib Middle Reach 2 (R2)

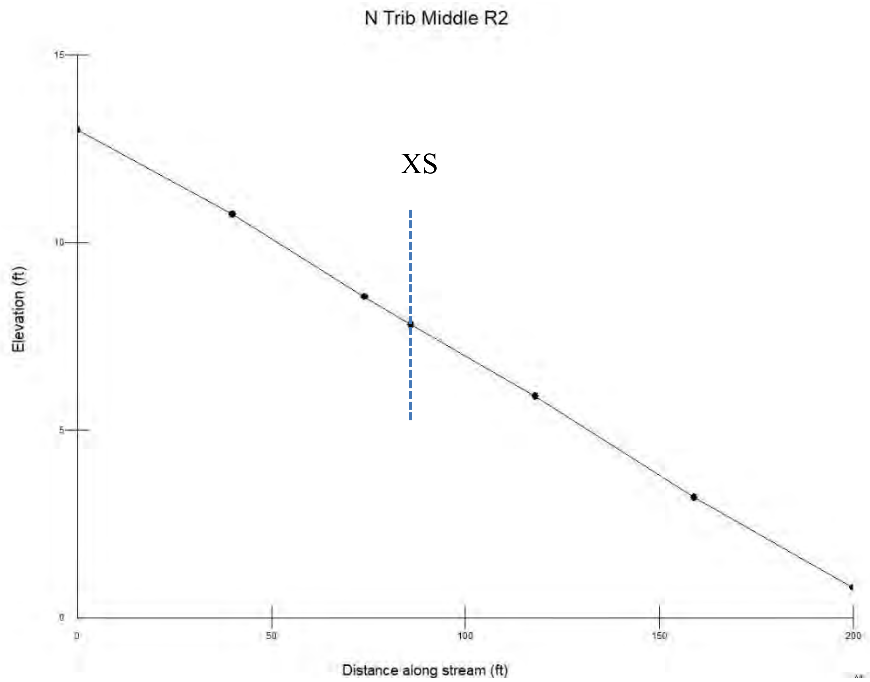


Figure 35. North Tributary Middle Reach 2 profile slope 6.1%.

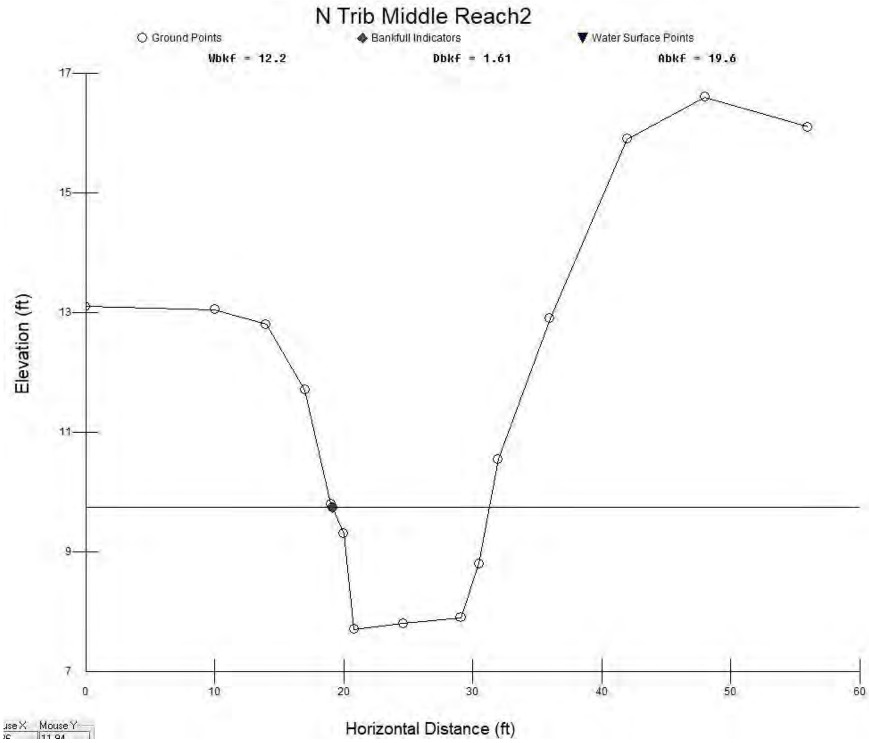


Figure 36. North Tributary Middle Reach 2 cross section.

Particle Size Analysis

D16 (mm)	0.44
D35 (mm)	0.8
D50 (mm)	1.35
D84 (mm)	7.55
D95 (mm)	31.54
D100 (mm)	1023.94
Silt/Clay (%)	0
Sand (%)	59.02
Gravel (%)	38.52
Cobble (%)	1.64
Boulder (%)	0.82
Bedrock (%)	0

Total Particles = 122

D50 **1.35 mm**

Figure 37. North Tributary Middle Reach 2 pebble count.

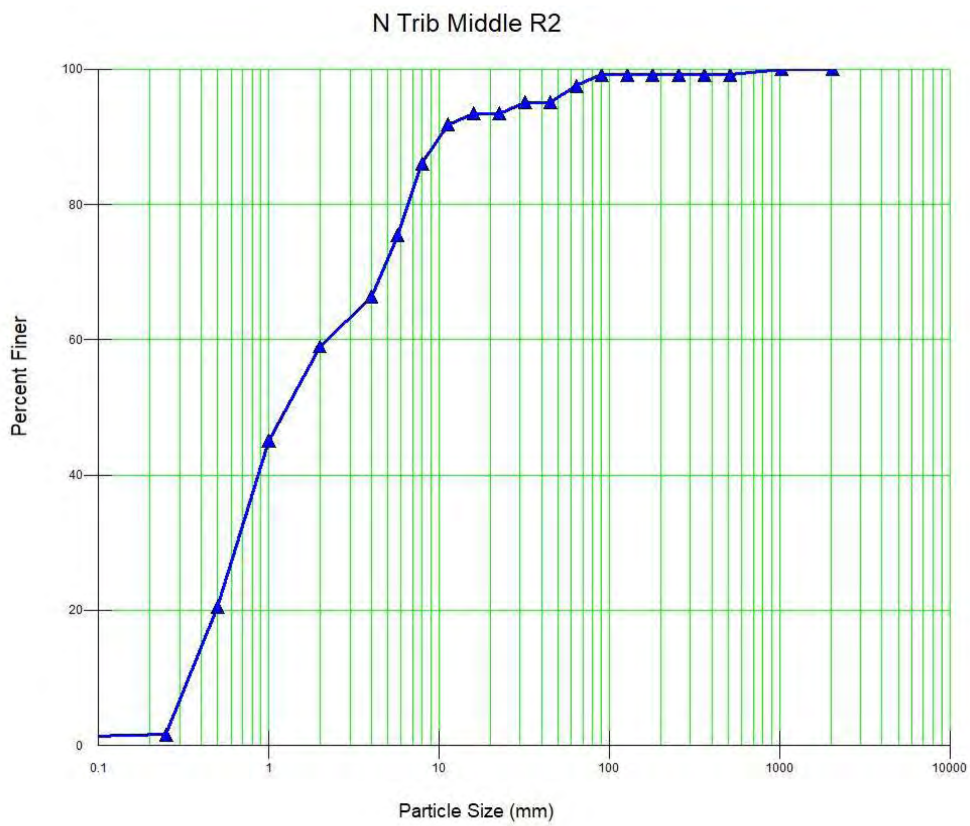


Figure 38. North Tributary Middle Reach 2 particle distribution plot D50 = 1.35 mm.

Figure 39 North Tributary Middle Reach 2 looking upstream.

Figure 40. North Tributary Middle Reach 2 looking downstream.

North Trib Fan XS2

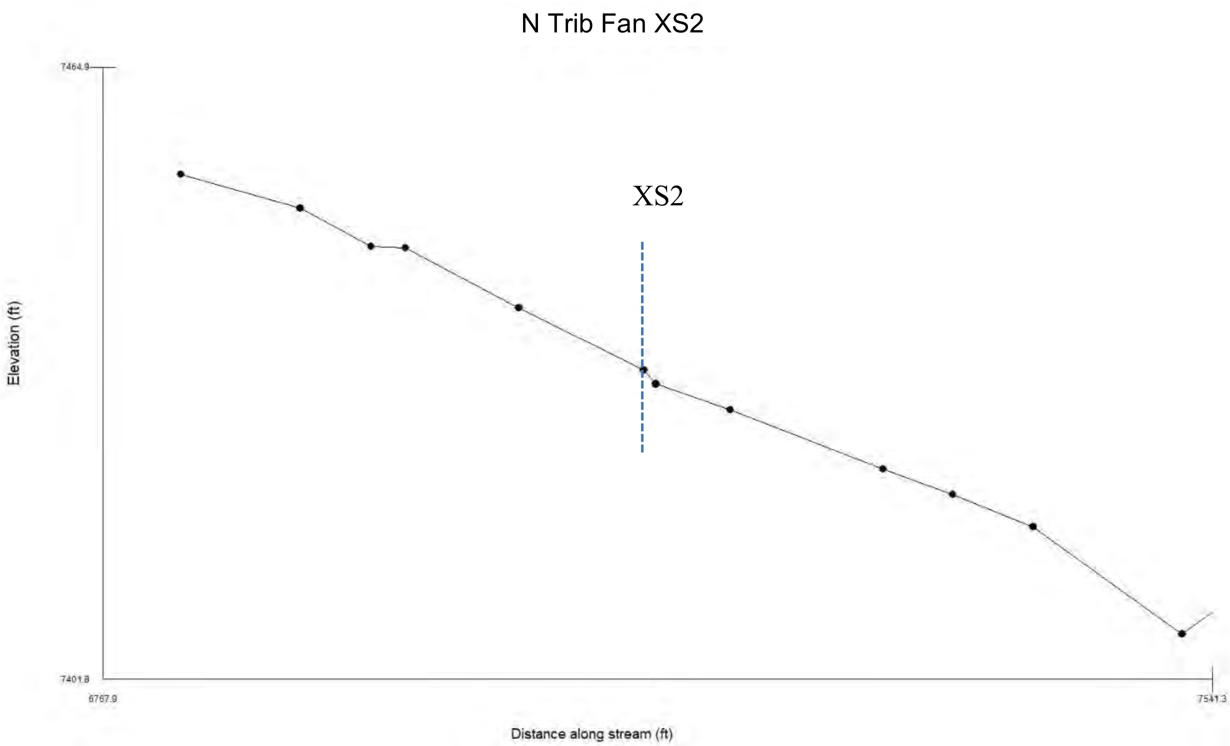


Figure 41. North tributary Fan XS2, average slope 6.5%.

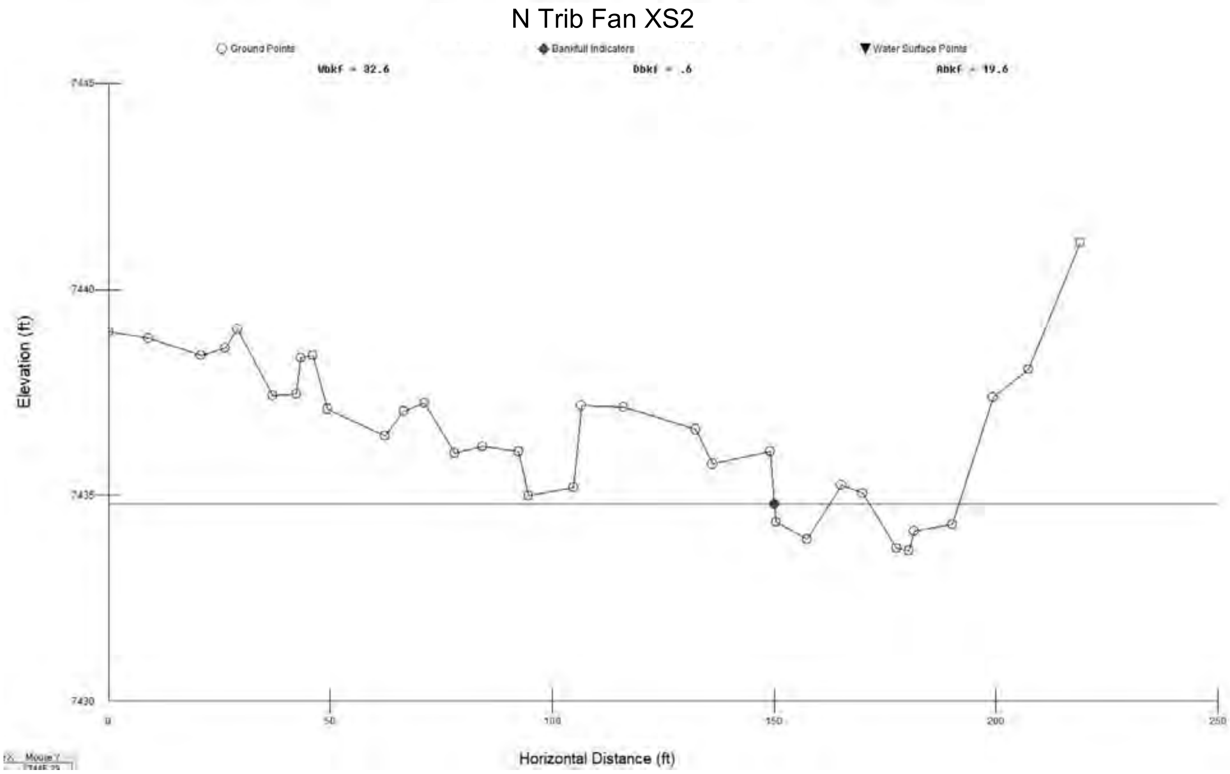
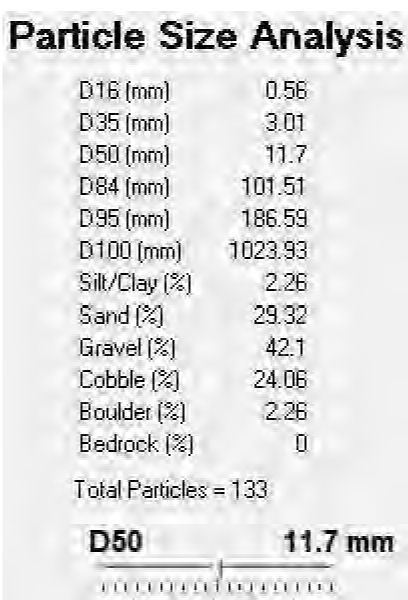


Figure 42. Representative cross section North Tributary Fan XS2.



Particle Size Analysis

D16 (mm)	0.56
D35 (mm)	3.01
D50 (mm)	11.7
D84 (mm)	101.51
D95 (mm)	186.59
D100 (mm)	1023.93
Silt/Clay (%)	2.26
Sand (%)	29.32
Gravel (%)	42.1
Cobble (%)	24.06
Boulder (%)	2.26
Bedrock (%)	0

Total Particles = 133

D50 11.7 mm

Figure 43. Representative pebble count at North Tributary Fan XS 2, D50 = 11.7 mm.

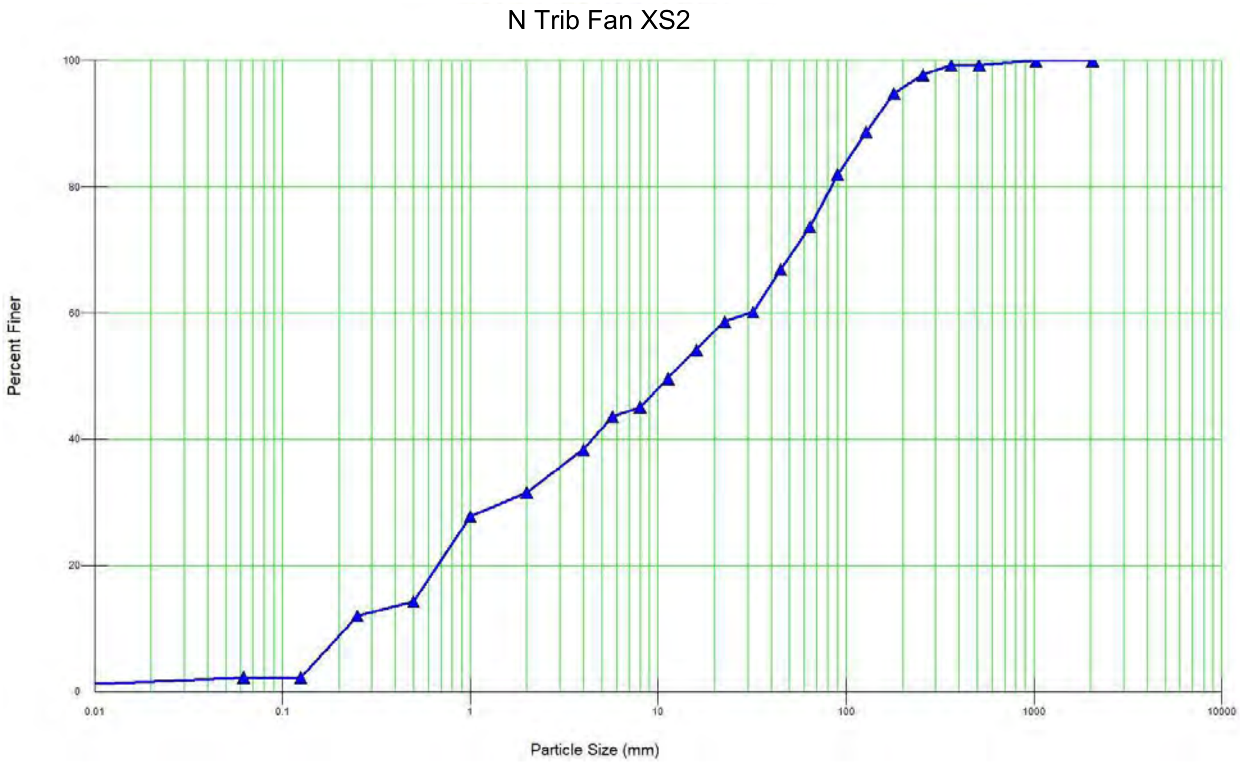


Figure 44. Representative pebble count at North Tributary Fan cross section 2.

Figure 45. Looking upstream at North Tributary Fan XS2 from bottom of fan.

Figure 46. Looking upstream at North Tributary Fan XS2 from center of fan.

Upper North Trib Gage

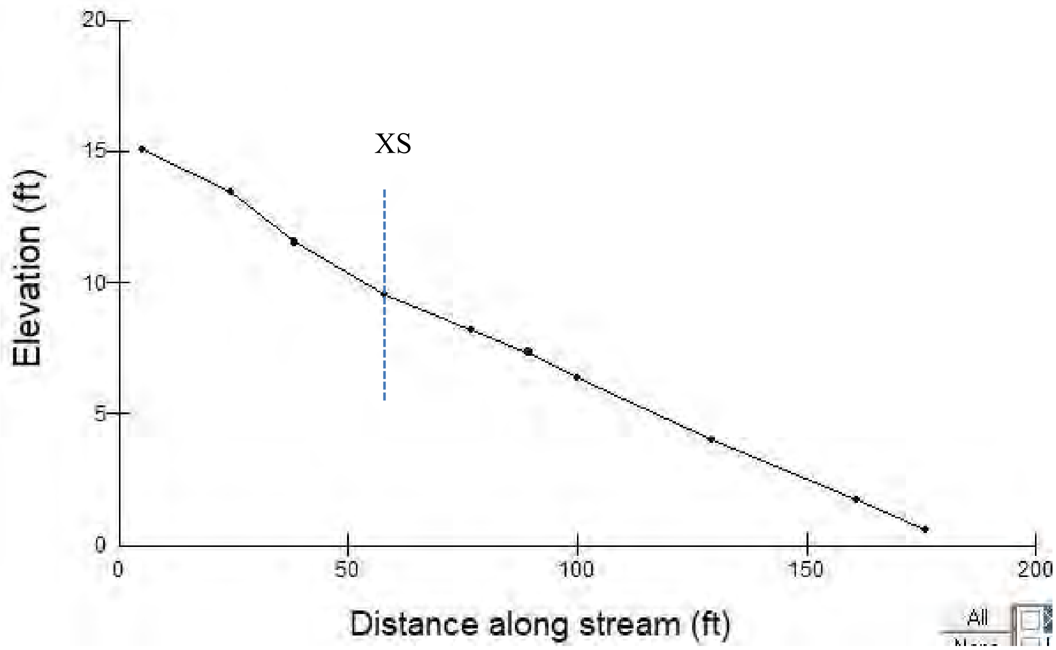


Figure 47. Upper N Trib Gage cross section profile 7.4%.

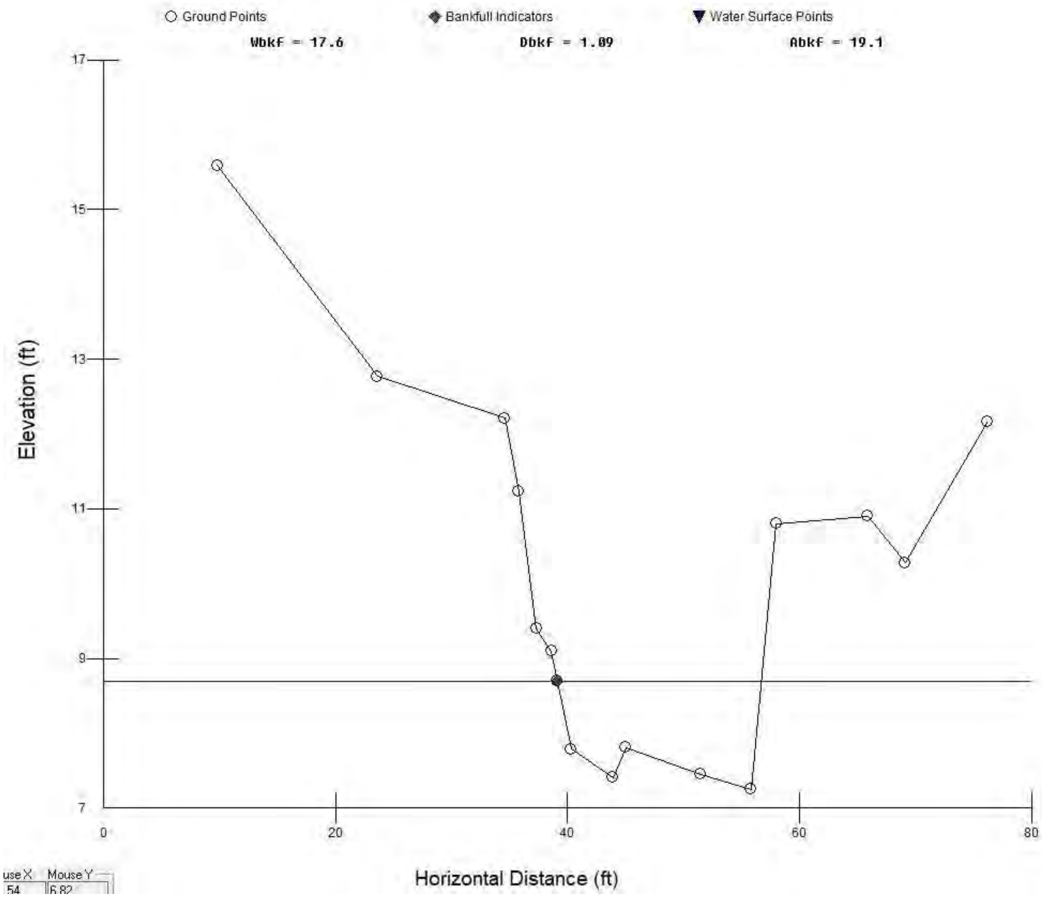
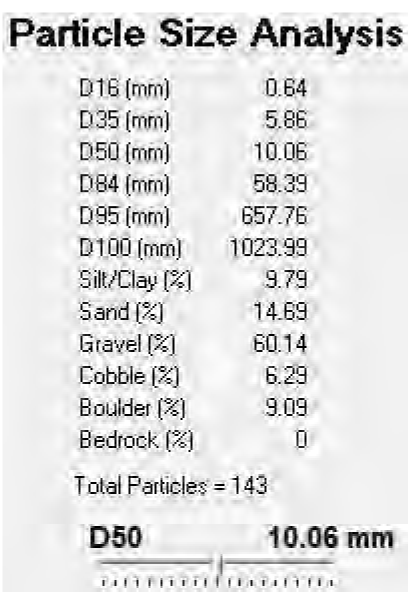


Figure 48. Upper N Trib Gage cross section.



Particle Size Analysis

D16 (mm)	0.64
D35 (mm)	5.86
D50 (mm)	10.06
D84 (mm)	58.39
D95 (mm)	657.76
D100 (mm)	1023.99
Silt/Clay (%)	9.79
Sand (%)	14.69
Gravel (%)	60.14
Cobble (%)	6.29
Boulder (%)	9.09
Bedrock (%)	0

Total Particles = 143

D50 10.06 mm

Figure 49. Upper N Trib Gage cross section pebble count.

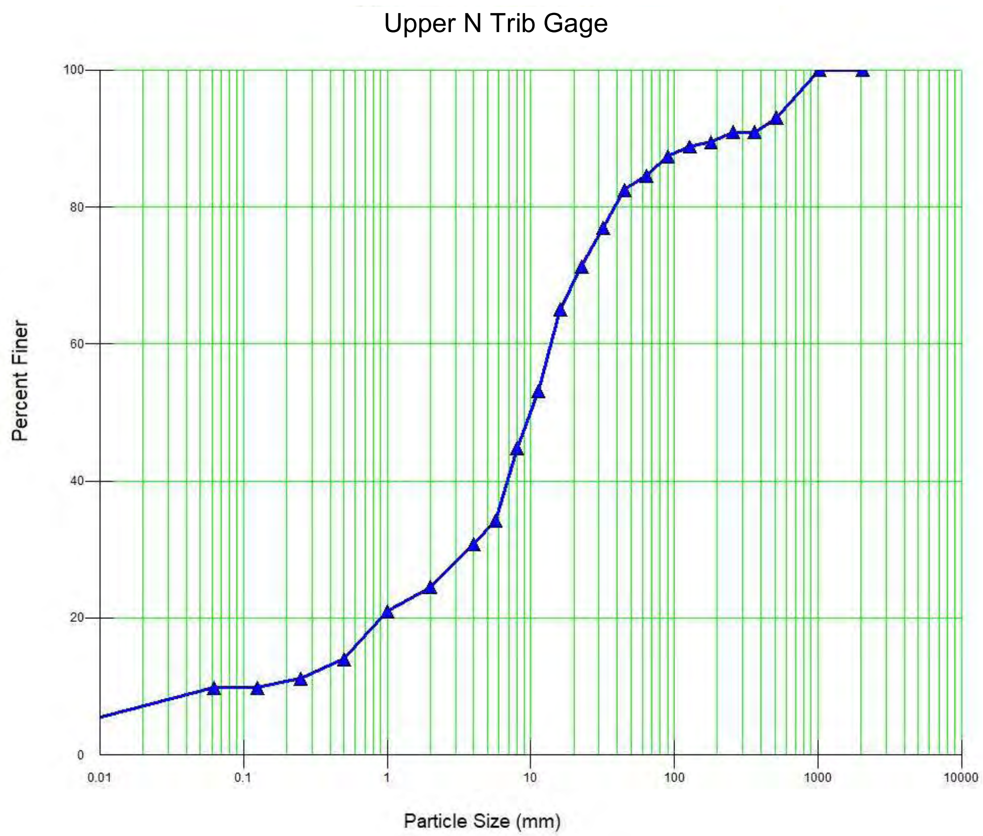


Figure 50. Upper N Trib Gage cross section particle distribution plot, D50 = 10.1 mm.

Figure 51. Upper N Trib Gage cross section looking upstream.

Upper N Trib Parking Area

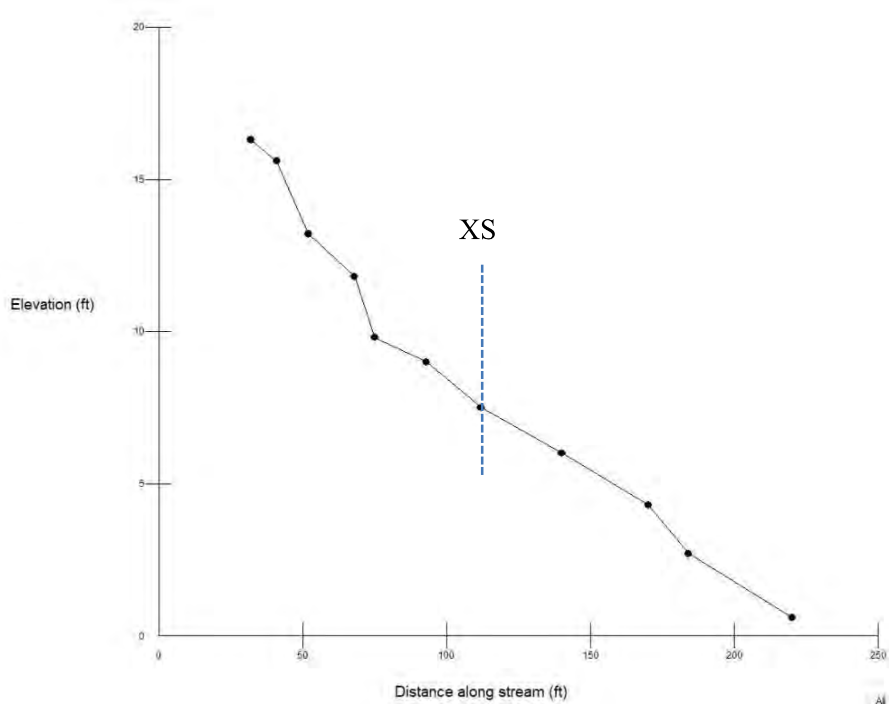


Figure 52. North Tributary Parking Area fan profile slope 6.2%.

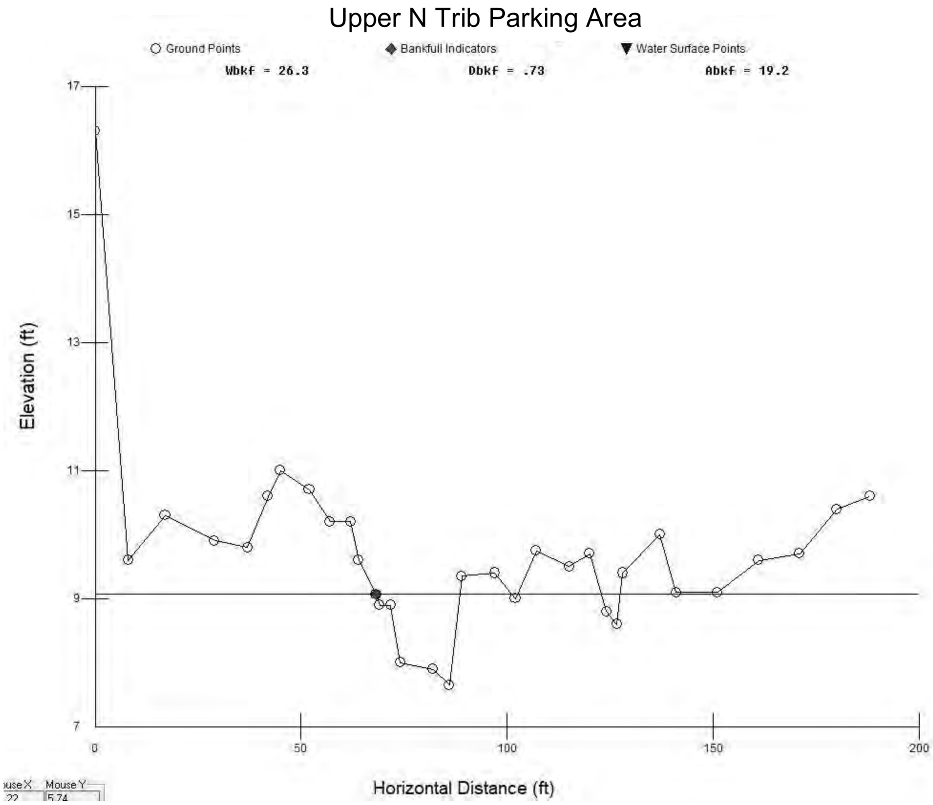


Figure 53. North Tributary Parking Area fan cross section.

Particle Size Analysis

D16 (mm)	0.83
D35 (mm)	7.54
D50 (mm)	14.55
D84 (mm)	159.74
D95 (mm)	444.61
D100 (mm)	1023.99
Silt/Clay (%)	0.86
Sand (%)	18.97
Gravel (%)	53.45
Cobble (%)	16.38
Boulder (%)	10.34
Bedrock (%)	0

Total Particles = 116

D50 14.55 mm

Figure 54. North Tributary Parking Area fan pebble count.

Figure 55. North Tributary Parking Area fan particle distribution plot, D50 = 14.6 mm.

Upper North Trib Bulldozed

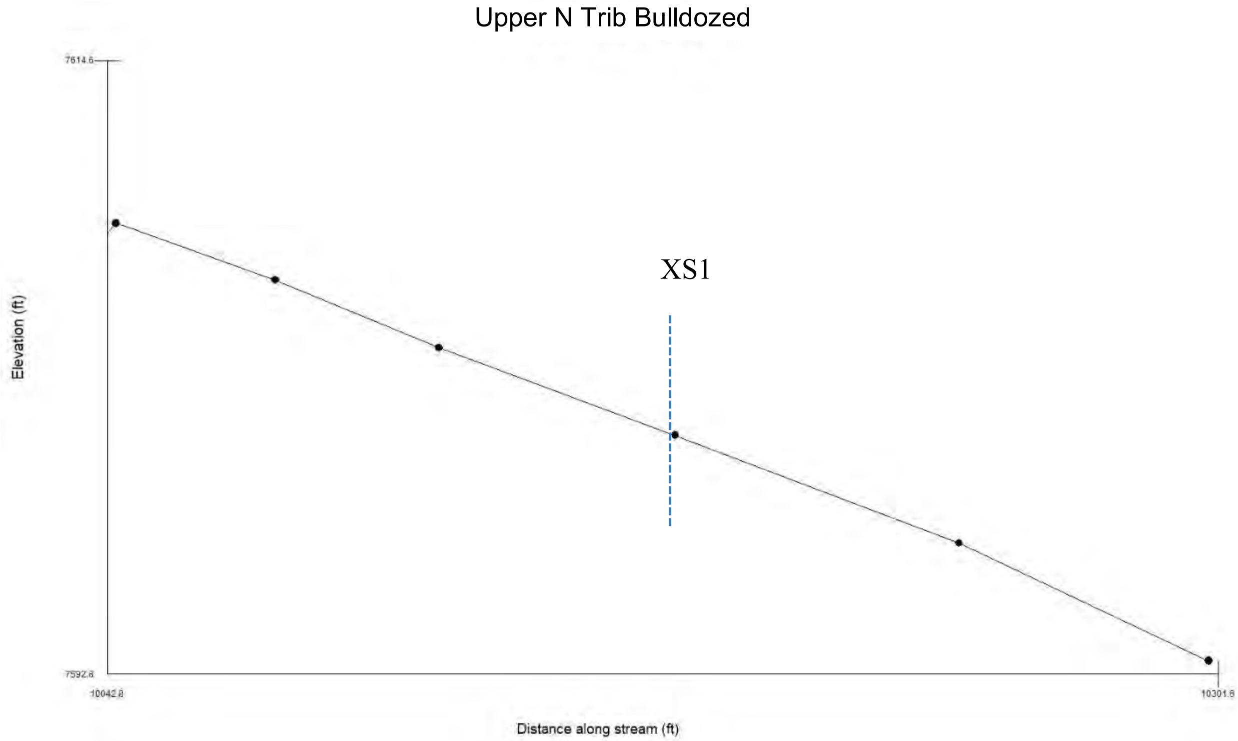


Figure 56. Upper North tributary bulldozed cross section, average slope 5.7%.

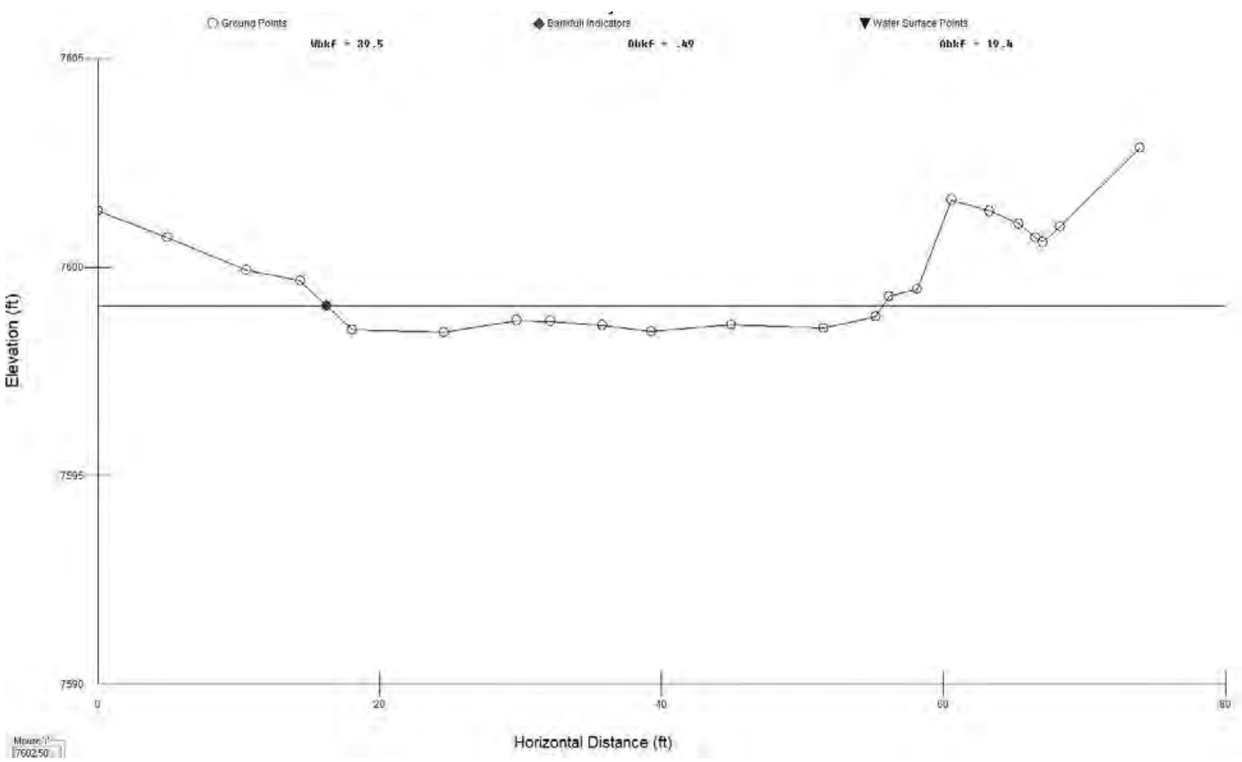
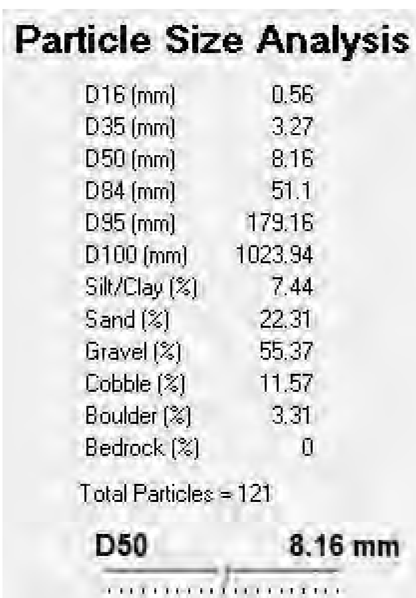


Figure 57. Upper North tributary bulldozed cross section.



Particle Size Analysis

D16 (mm)	0.56
D35 (mm)	3.27
D50 (mm)	8.16
D84 (mm)	51.1
D95 (mm)	179.16
D100 (mm)	1023.94
Silt/Clay (%)	7.44
Sand (%)	22.31
Gravel (%)	55.37
Cobble (%)	11.57
Boulder (%)	3.31
Bedrock (%)	0

Total Particles = 121

D50 8.16 mm

Figure 58. Upper North Trib Bulldozed cross section pebble count.

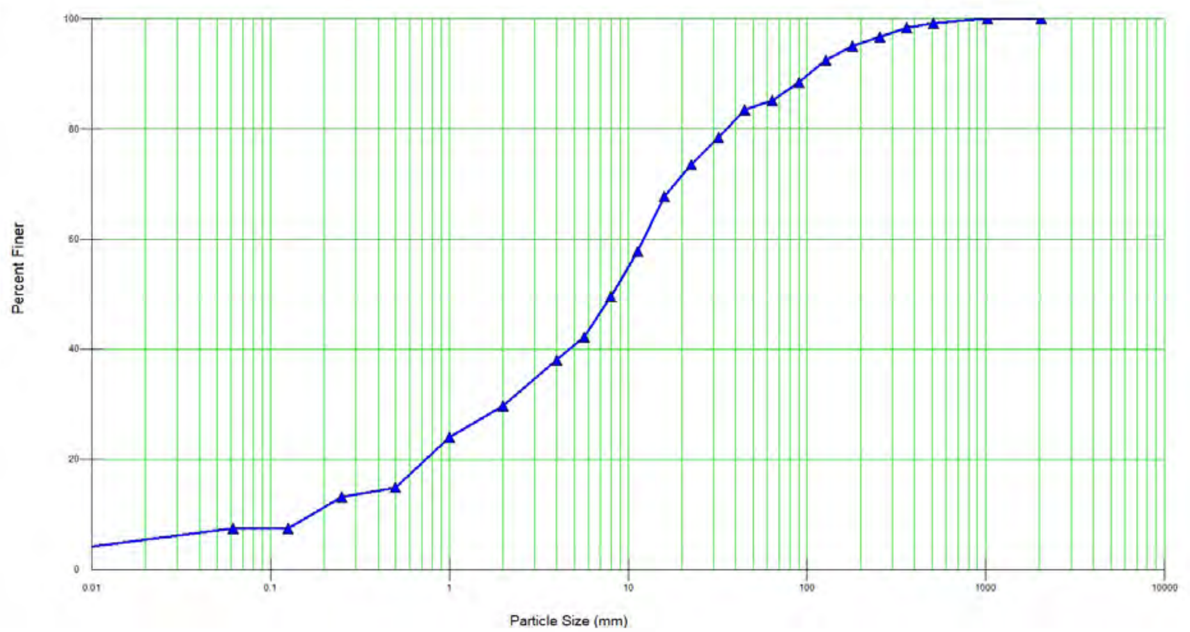


Figure 59. Upper North Trib Bulldozed cross section particle distribution plot, D50 = 8.2 mm.

Figure 60. North tributary bulldozed cross section looking upstream.

Note channel is shaped by equipment activity after flows during cleanup effort to make Elden Lookout Road passable.

Upper North Trib above Brookbank

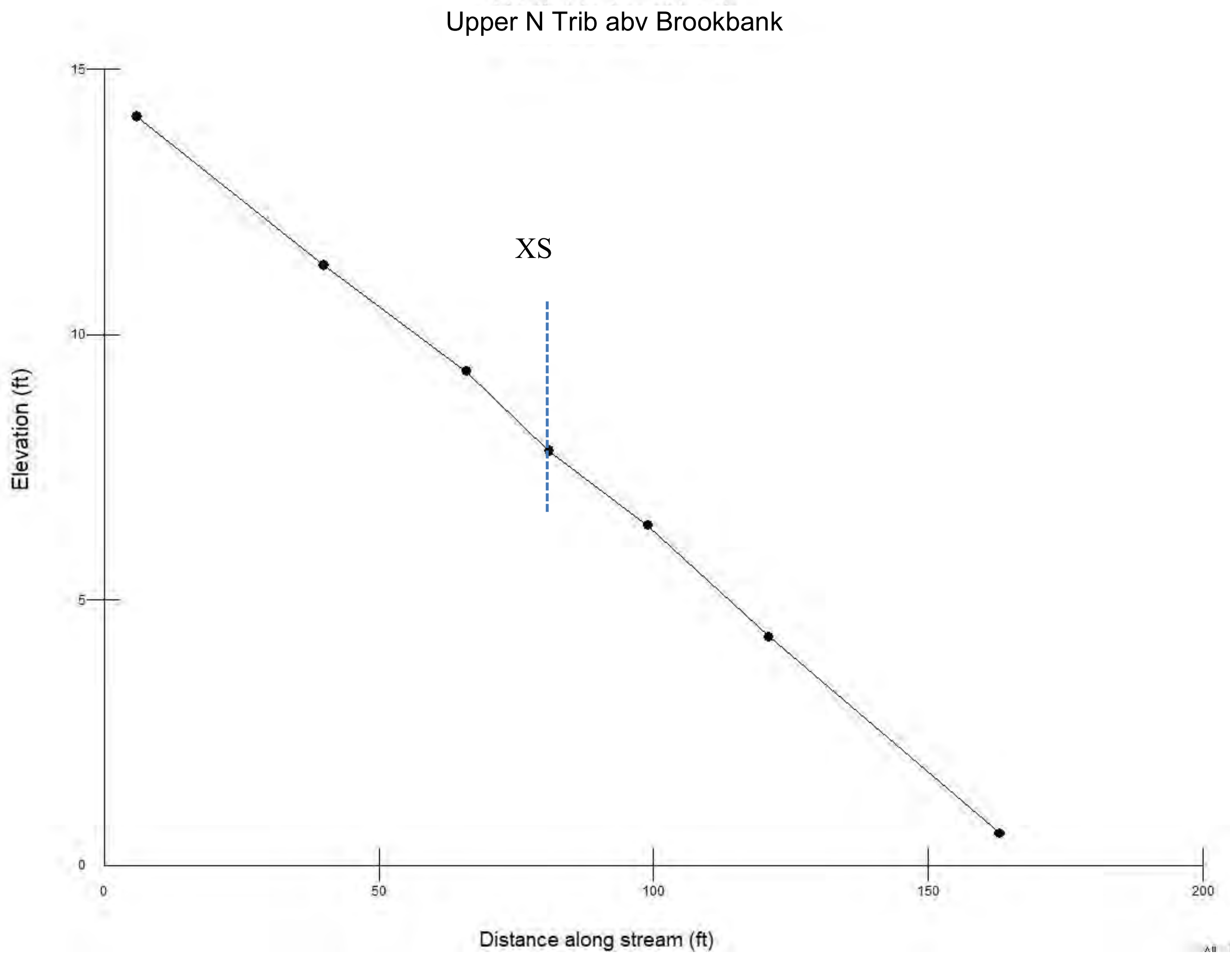


Figure 61. Upper North Tributary above Brookbank profile slope 8.6%.

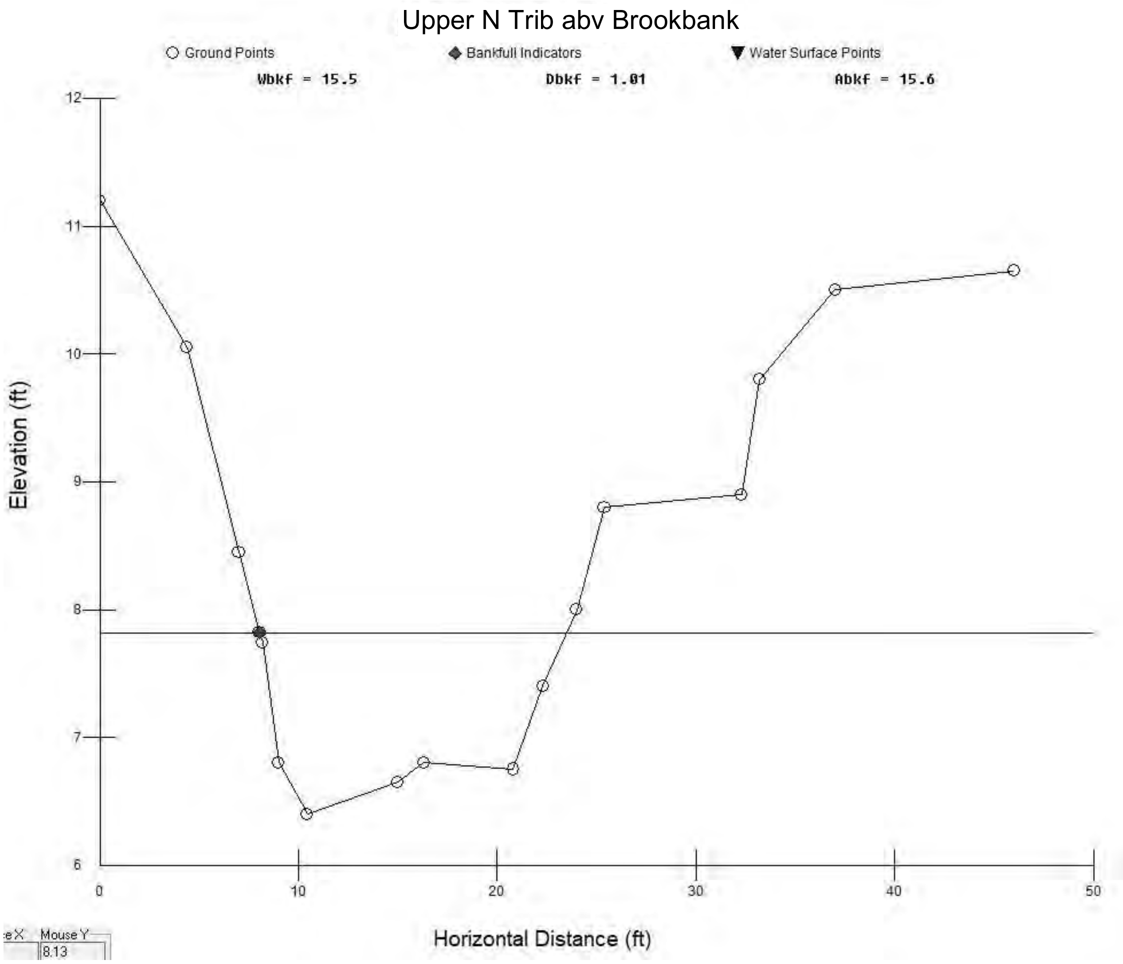


Figure 62. Upper North Tributary above Brookbank cross section.

Particle Size Analysis

D16 (mm)	3.69
D35 (mm)	5.3
D50 (mm)	7.21
D84 (mm)	14.84
D95 (mm)	61.17
D100 (mm)	511.98
Silt/Clay (%)	0
Sand (%)	8.26
Gravel (%)	87.15
Cobble (%)	3.67
Boulder (%)	0.92
Bedrock (%)	0

Total Particles = 109

D50 7.21 mm

Figure 63. Upper North Tributary above Brookbank cross section pebble count.

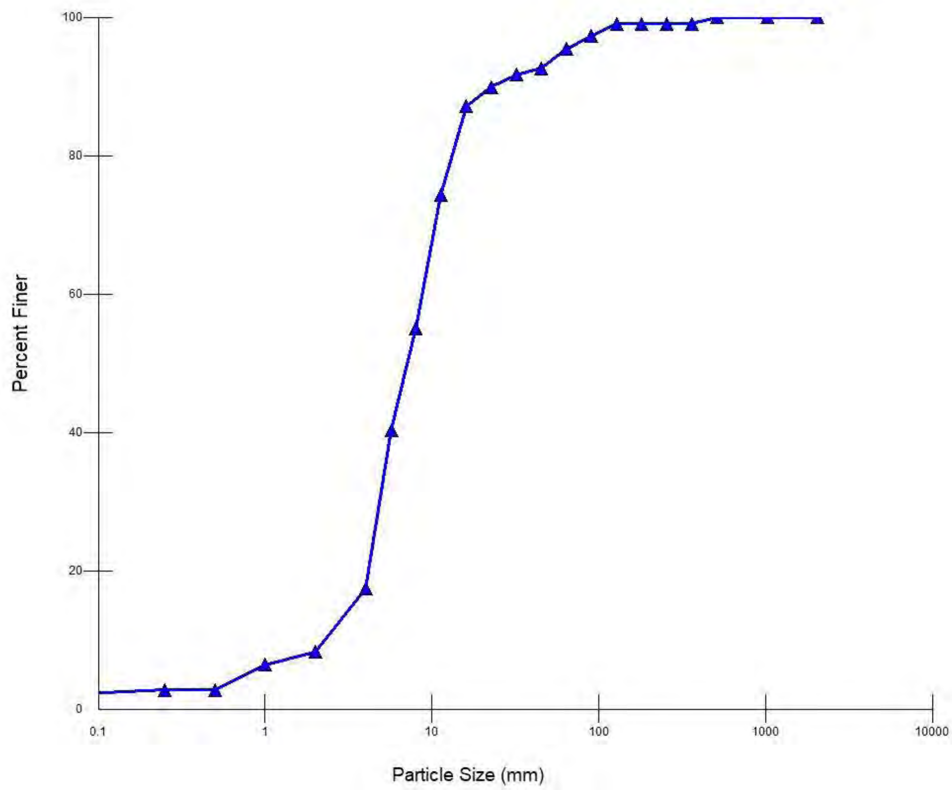


Figure 64. Upper North Tributary above Brookbank cross section particle size plot, D50 = 7.2 mm.

Figure 65. Upper North Tributary above Brookbank cross section looking upstream.

Figure 66. Upper North Tributary above Brookbank cross section looking downstream.

Upper North Trib Reach 11 (R11)

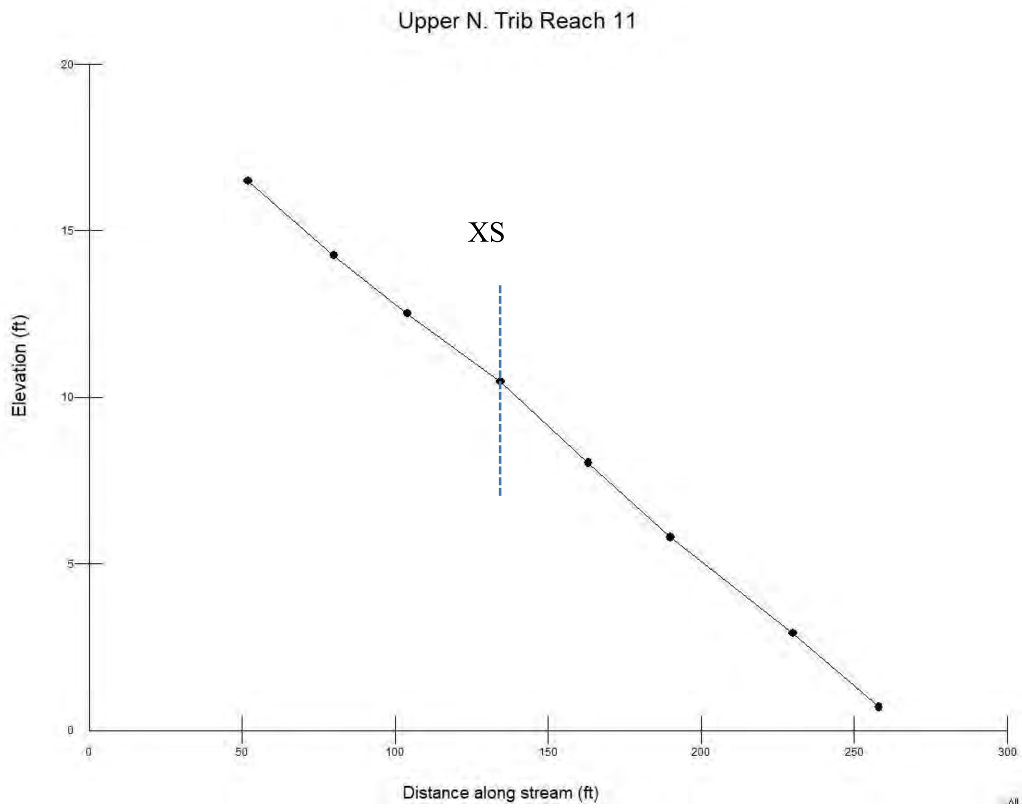


Figure 67. Upper North Tributary R11 profile slope 7.7%.

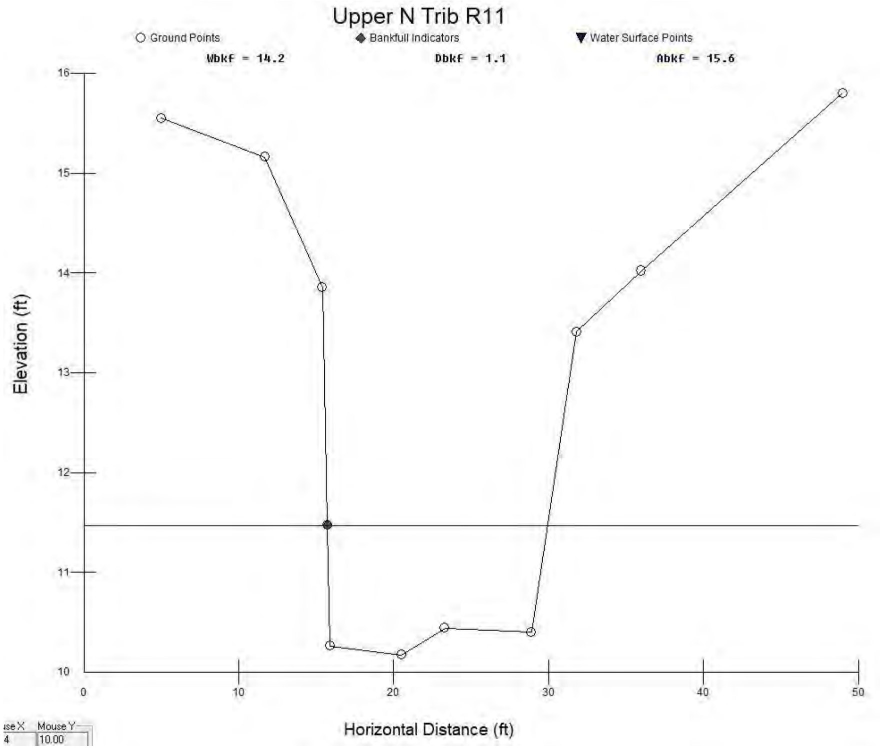
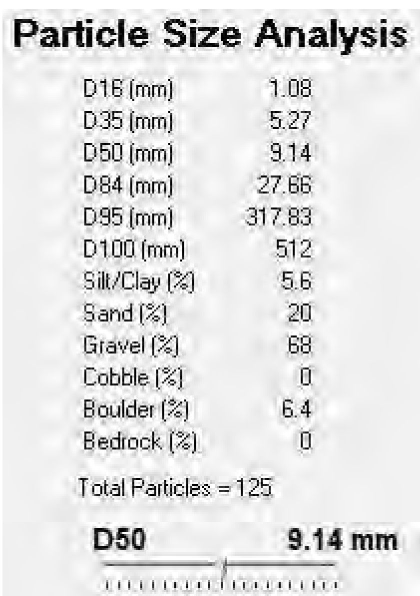


Figure 68. Upper North Tributary R11 cross section.



Particle Size Analysis

D16 (mm)	1.08
D35 (mm)	5.27
D50 (mm)	9.14
D84 (mm)	27.66
D95 (mm)	317.83
D100 (mm)	512
Silt/Clay (%)	5.6
Sand (%)	20
Gravel (%)	68
Cobble (%)	0
Boulder (%)	6.4
Bedrock (%)	0

Total Particles = 125

D50 9.14 mm

Figure 69. Upper North Tributary R11 cross section pebble count.

Figure 70. Upper North Tributary R11 cross section particle distribution plot, D50 = 9.1 mm.

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Figure 71. Upper North Tributary R11 cross section looking upstream.

Figure 72. Upper North Tributary R11 cross section looking downstream.

WASABI TRIBUTARY

This portion of the watershed contains steep channel slopes in Type 1 valleys recently incised due to increased runoff. Representative cross sections were gathered in the incised channels. The channel is adjusting to an increase in runoff and the stability of these channel reaches is poor and appears to still be incising and widening.

Wasabi XS1

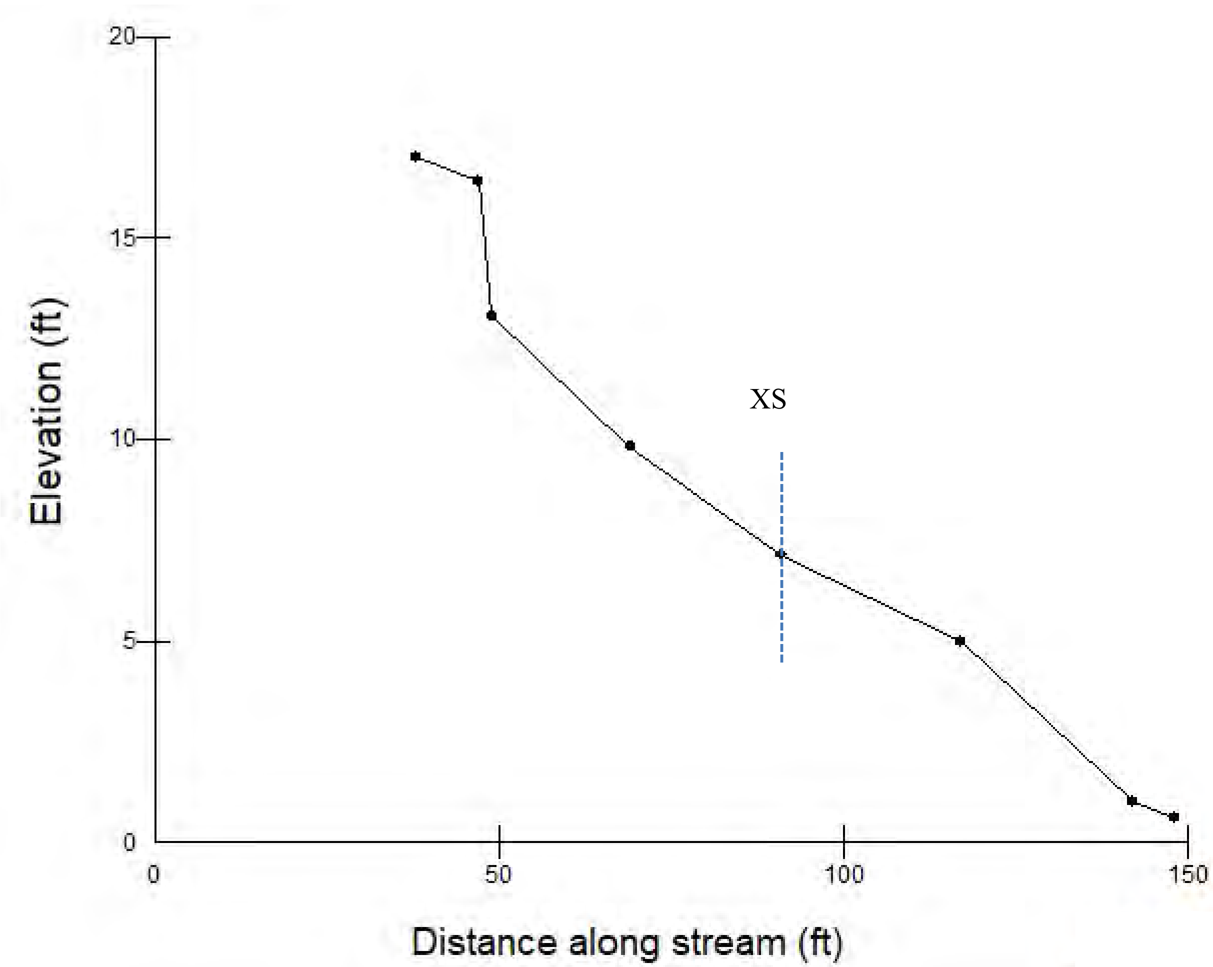


Figure 73. Wasabi XS1 profile slope 12%.

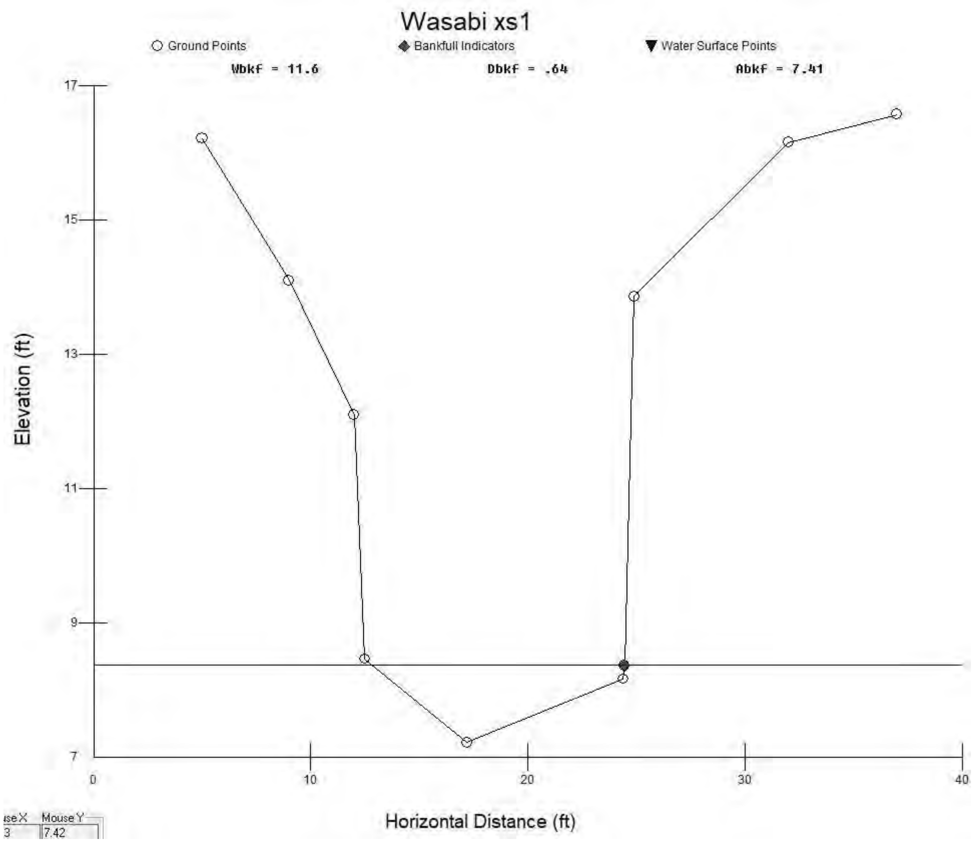


Figure 74. Wasabi XS1 cross section.

Particle Size Analysis

D16 (mm)	1.16
D35 (mm)	10.69
D50 (mm)	19.67
D84 (mm)	147.77
D95 (mm)	477.06
D100 (mm)	2047.97
Silt/Clay (%)	0.78
Sand (%)	17.19
Gravel (%)	51.56
Cobble (%)	17.97
Boulder (%)	12.5
Bedrock (%)	0

Total Particles = 128

D50 19.67 mm

Figure 75. Wasabi XS1 pebble count.

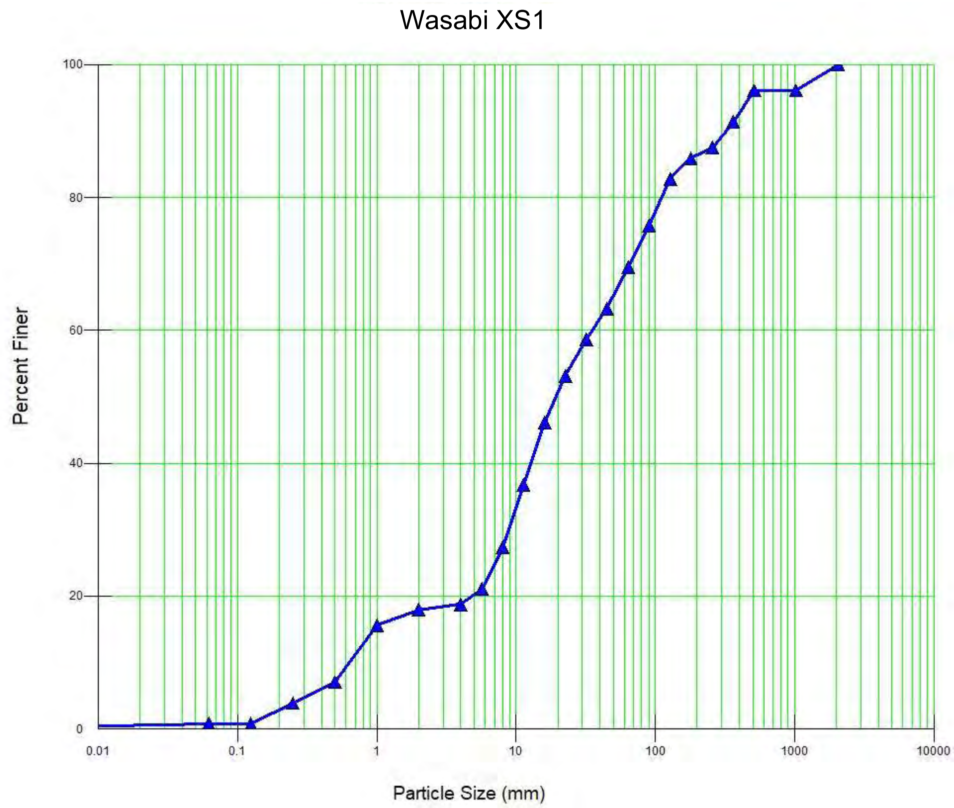


Figure 76. Wasabi XS1 particle distribution plot, D50 = 19.7 mm.

Figure 77. Wasabi XS1 looking downstream.

Figure 78. Wasabi XS1 looking upstream.

BROOKBANK TRIBUTARY

This portion of the watershed contains a mix of shallow and steep slopes with functional narrow alluvial fan features in the lower reaches and reaches recently incised channel due to increased runoff in the upper reaches. Representative cross sections were gathered in the lower reaches of the watershed, not including the alluvial fan features. The lower channel is adjusting to an increase in runoff; however, the stability of these channel reaches is fair given the condition of portions of the upstream watershed. The channel has portions of incision and portions in relatively good condition, large bed material and portions of bedrock have prevented this reach from incising continuously.

Lower Brookbank

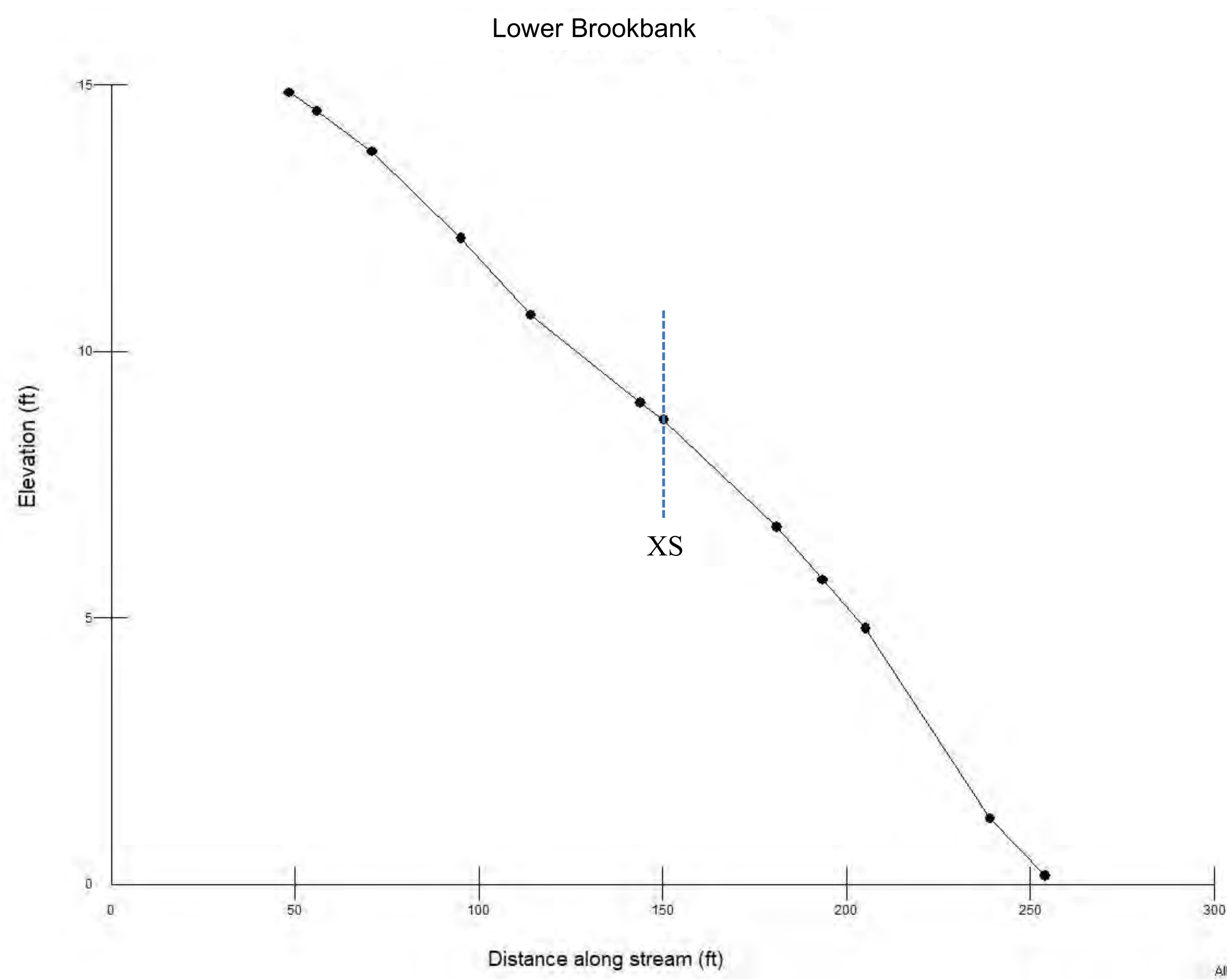


Figure 79. Lower Brookbank profile slope 6.5%.

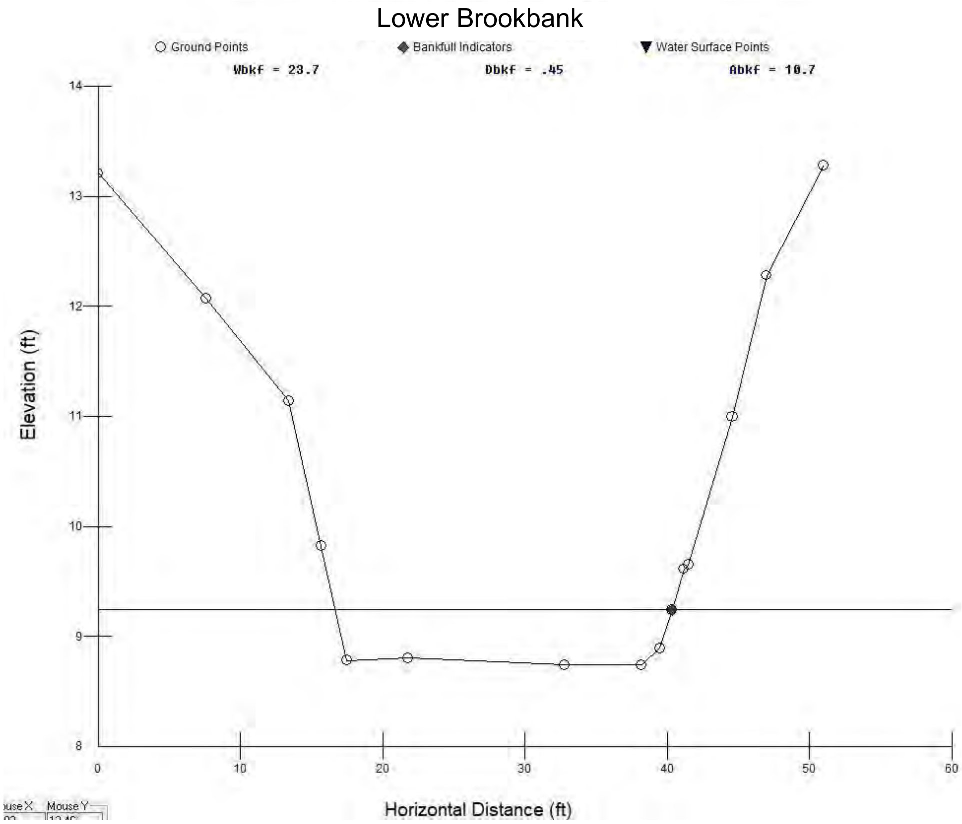


Figure 80. Lower Brookbank cross section.

Particle Size Analysis

D16 (mm)	0.49
D35 (mm)	1.28
D50 (mm)	4.57
D84 (mm)	15.51
D95 (mm)	60.26
D100 (mm)	255.99
Silt/Clay (%)	0
Sand (%)	40.24
Gravel (%)	54.88
Cobble (%)	4.88
Boulder (%)	0
Bedrock (%)	0

Total Particles = 164

D50 4.57 mm

Figure 81. Lower Brookbank cross section pebble count.

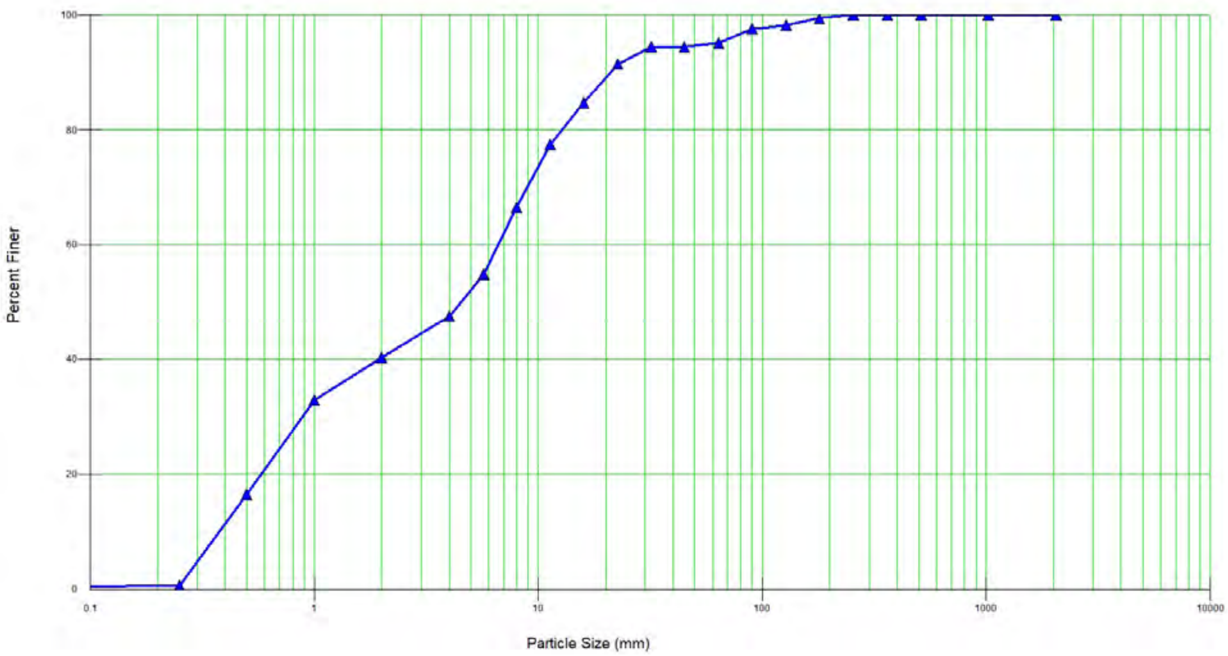


Figure 82. Brookbank lower cross section particle distribution D50 = 4.6 mm.

Figure 83. Lower Brookbank cross section looking upstream.

Upper Brookbank

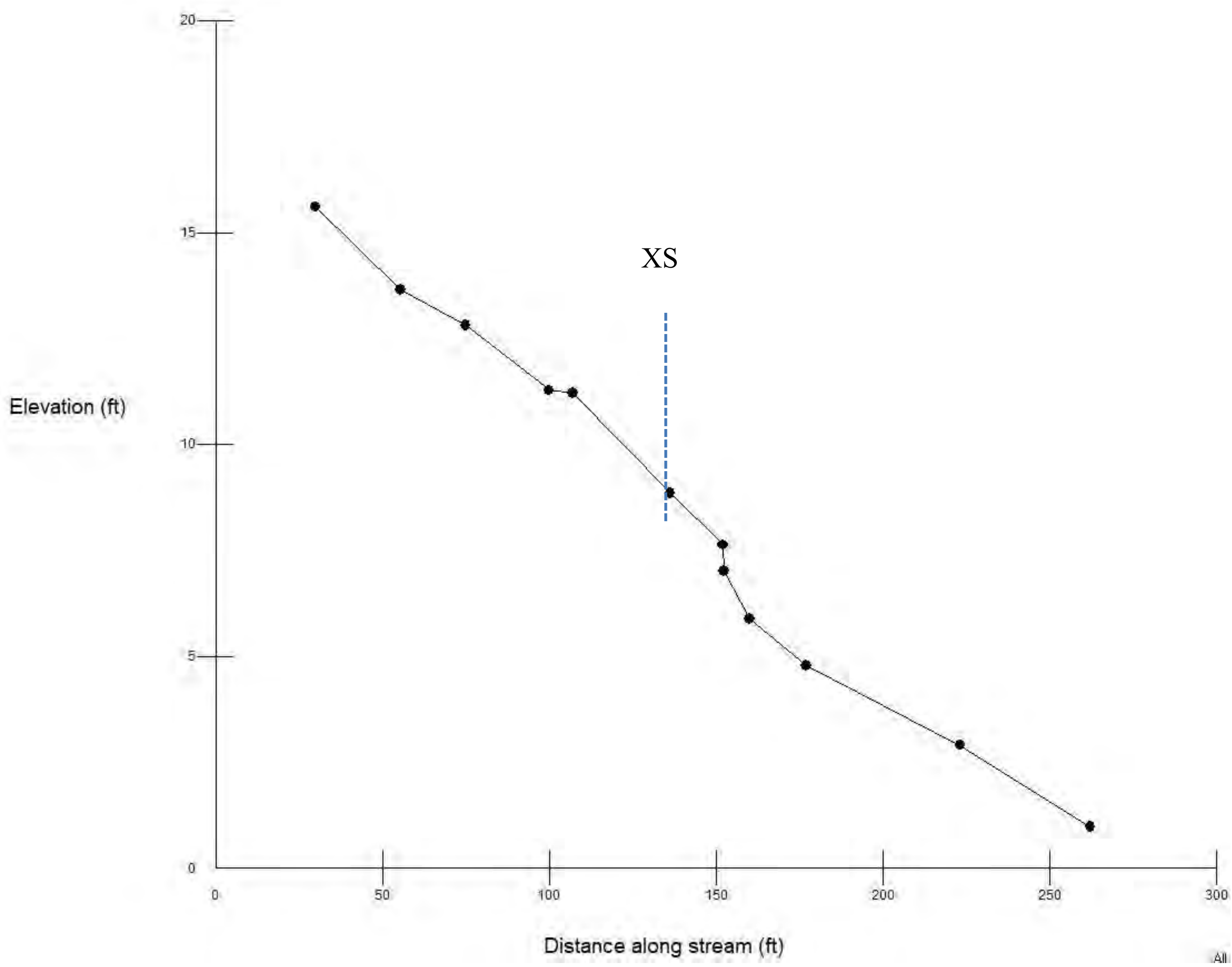


Figure 84. Upper Brookbank profile slope 6.4%.

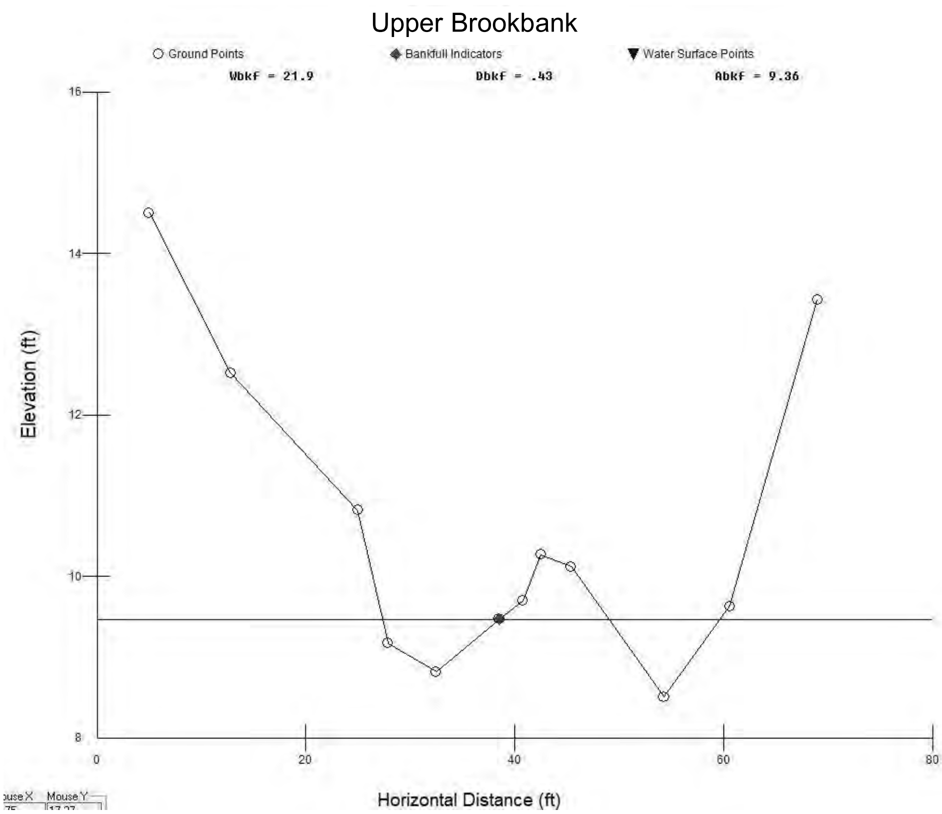
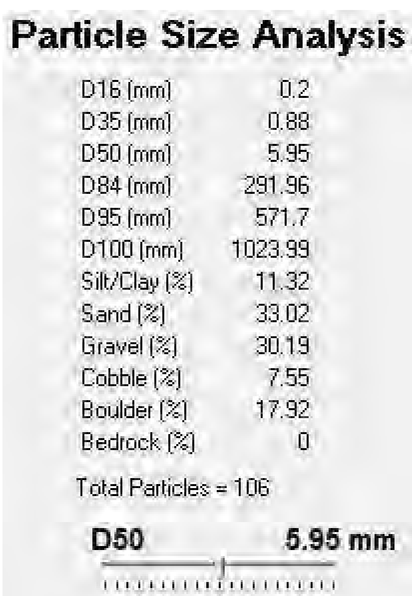


Figure 85. Upper Brookbank cross section.



Particle Size Analysis

D16 (mm)	0.2
D35 (mm)	0.88
D50 (mm)	5.95
D84 (mm)	291.96
D95 (mm)	571.7
D100 (mm)	1023.99
Silt/Clay (%)	11.32
Sand (%)	33.02
Gravel (%)	30.19
Cobble (%)	7.55
Boulder (%)	17.92
Bedrock (%)	0

Total Particles = 106

D50 5.95 mm

Figure 86. Upper Brookbank cross section pebble count.

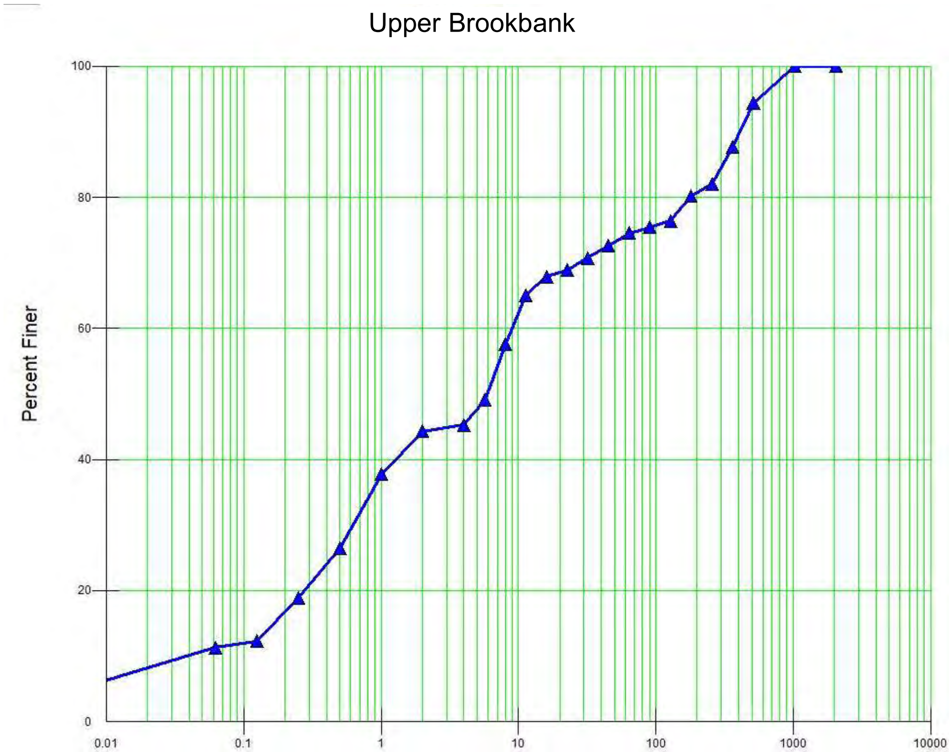


Figure 87. Upper Brookbank upper section particle distribution plot, D50 = 5.95 mm.

Figure 88. Upper Brookbank cross section looking upstream.

Figure 89. Upper Brookbank cross section looking downstream.

WEST TRIBUTARY

This portion of the watershed contains a mix of shallow and steep slopes with functional alluvial fan features and reaches recently incised channel due to increased runoff. Representative cross sections were gathered in the fans, incised channels, intact channels and on steeper and shallower channel slopes through this tributary.

West Trib Reach 1 (R1)

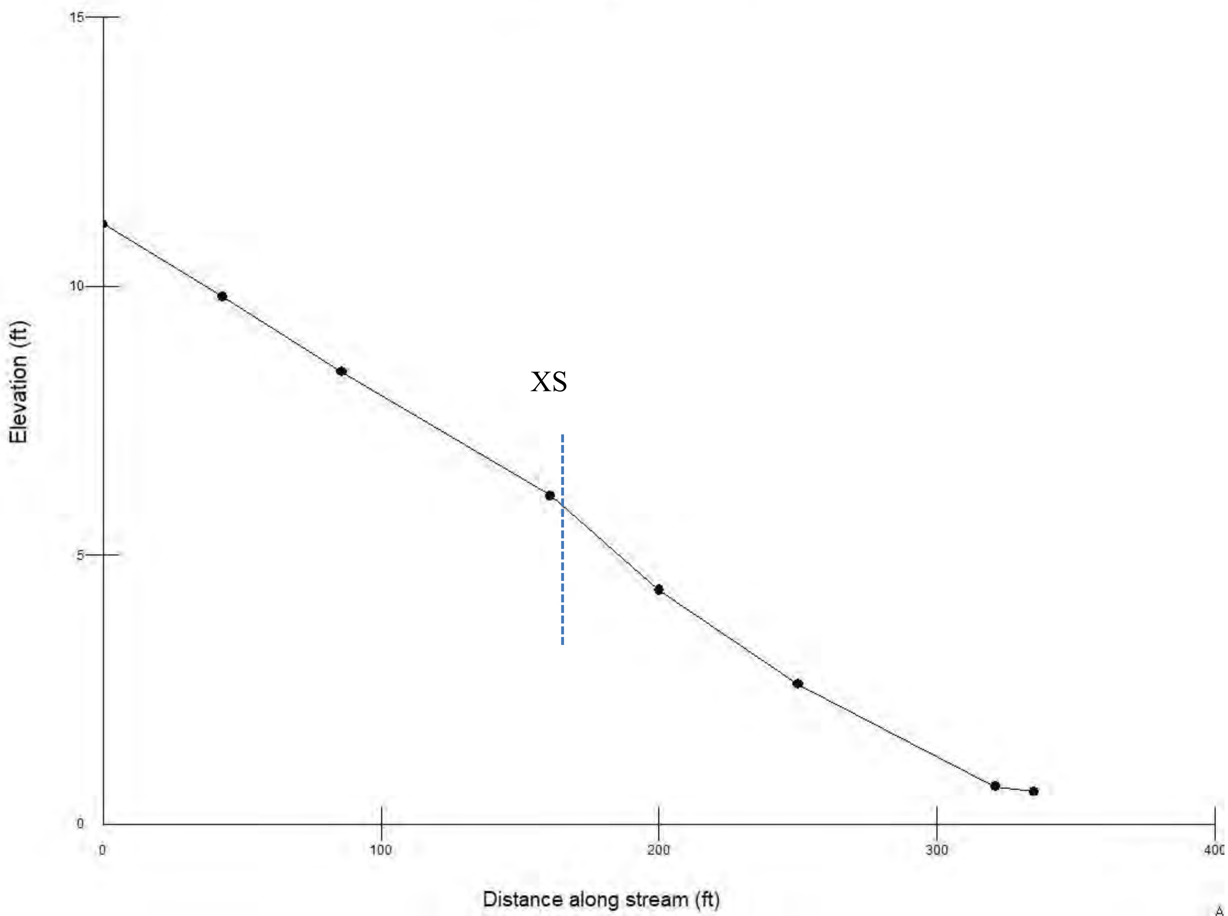


Figure 90. West Tributary Reach 1 profile slope 3.3%.

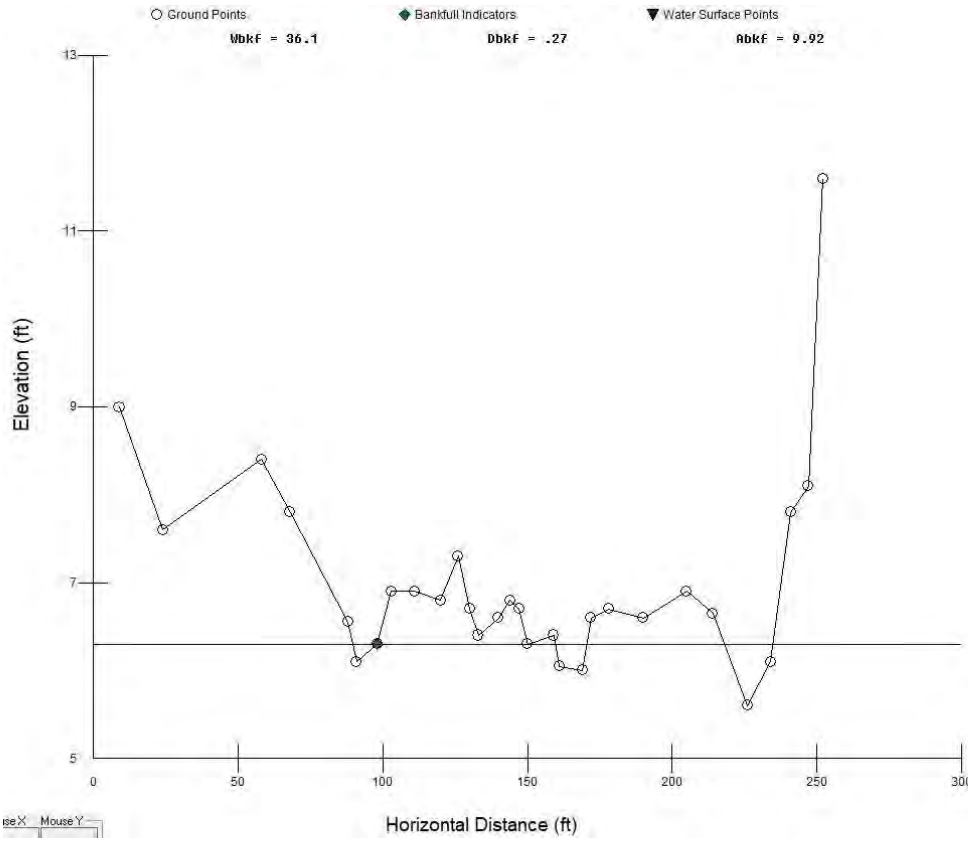
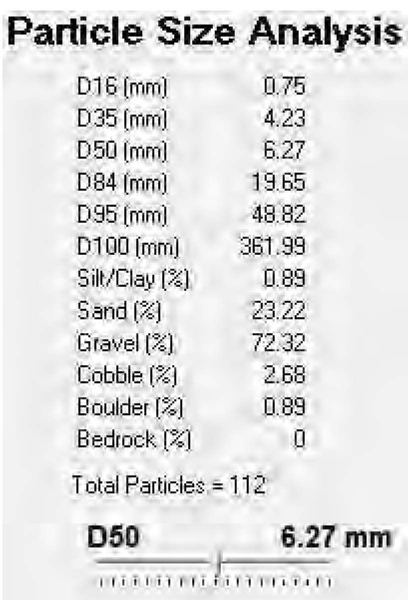


Figure 91. West Tributary Reach 1 cross section.



Particle Size Analysis

D16 (mm)	0.75
D35 (mm)	4.23
D50 (mm)	6.27
D84 (mm)	19.65
D95 (mm)	48.82
D100 (mm)	361.99
Silt/Clay (%)	0.89
Sand (%)	23.22
Gravel (%)	72.32
Cobble (%)	2.68
Boulder (%)	0.89
Bedrock (%)	0

Total Particles = 112

D50 6.27 mm

Figure 92. West Tributary Reach 1 pebble count.

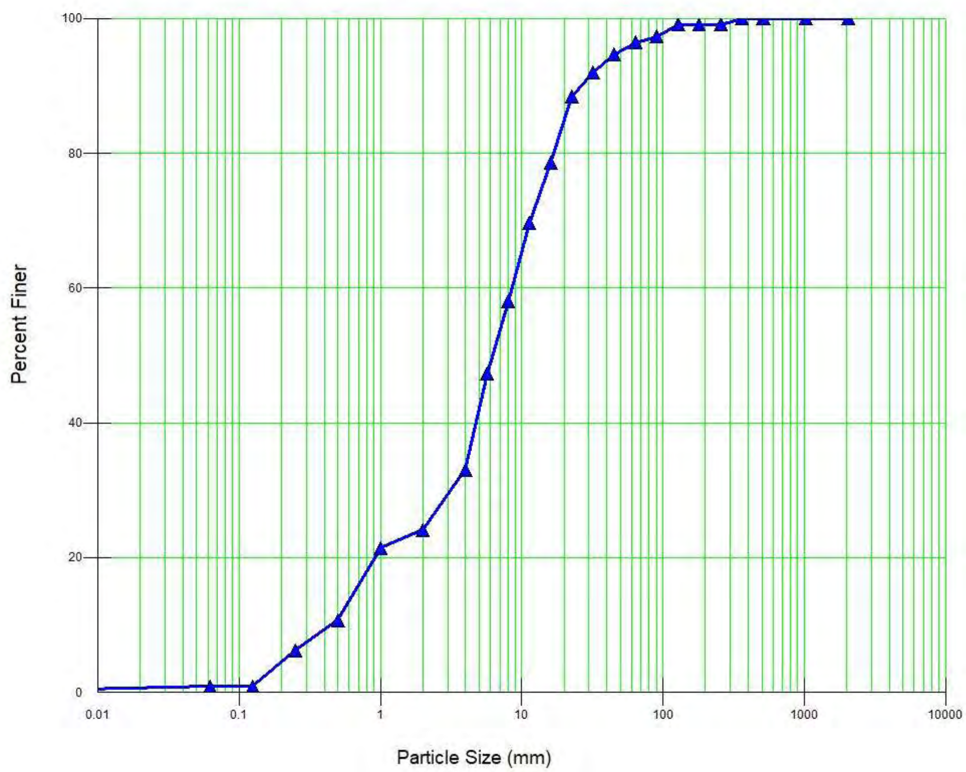


Figure 93. West Tributary Reach 1 particle distribution D50 = 6.3 mm.

Figure 94. West Tributary Reach 1 looking downstream.

West Trib Reach 5 (R5)

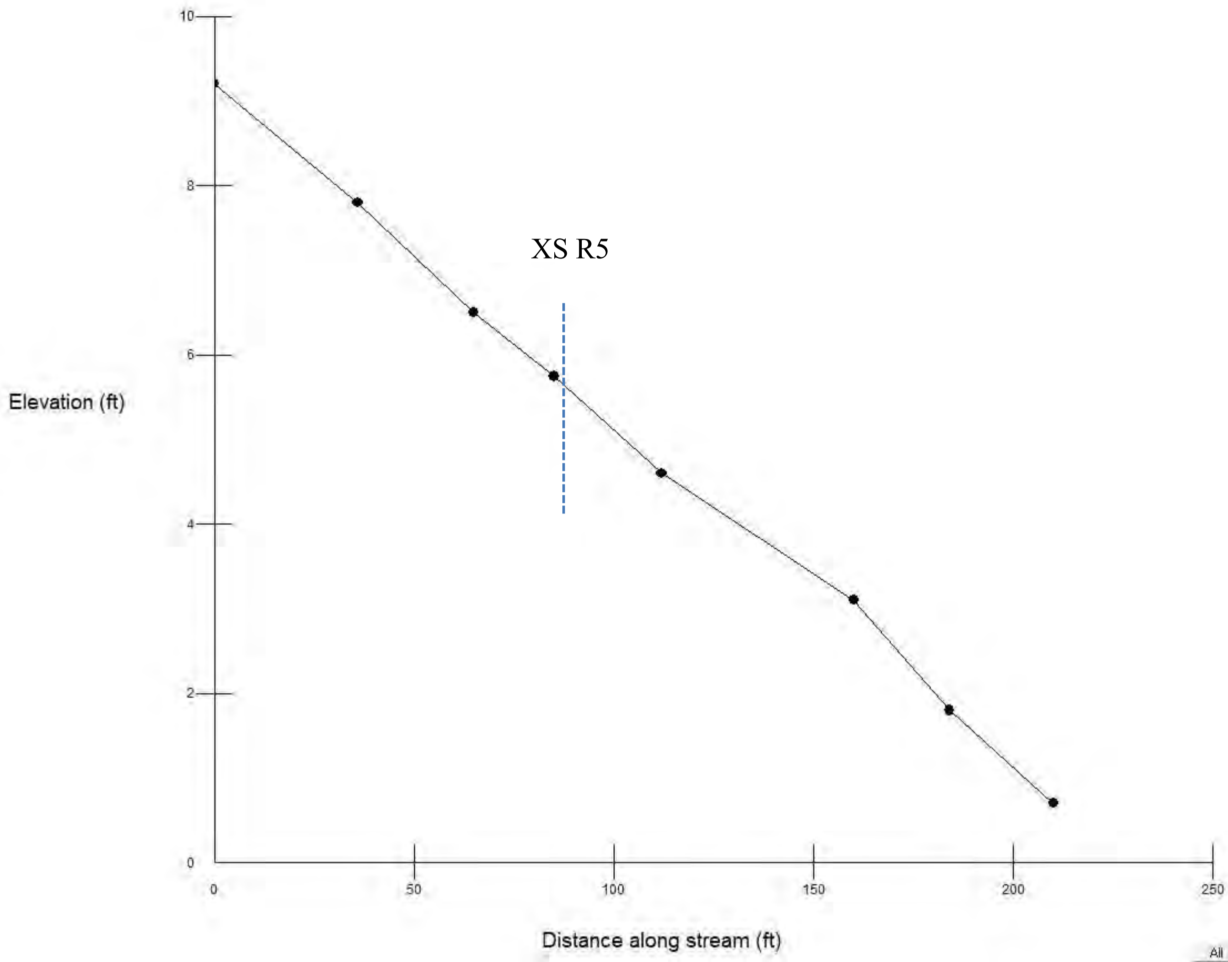


Figure 95. West Tributary Reach 5 profile slope 4.0%.

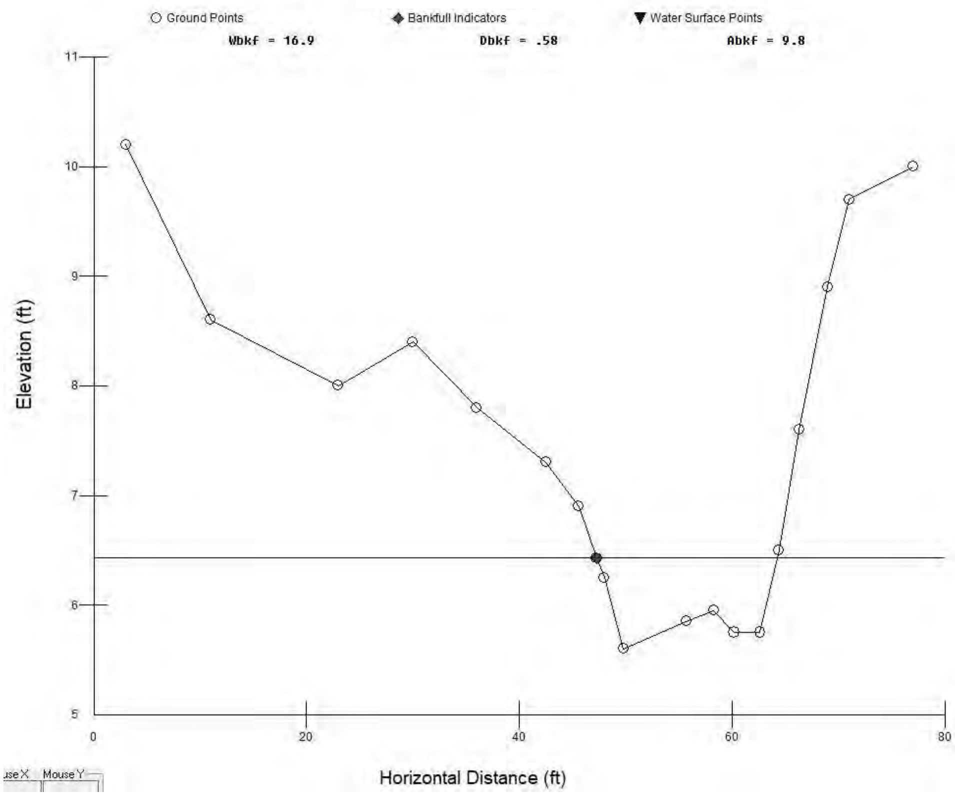


Figure 96. West Tributary Reach 5 cross section.

Particle Size Analysis

D16 (mm)	1.31
D35 (mm)	3.04
D50 (mm)	4.89
D84 (mm)	10.63
D95 (mm)	29.29
D100 (mm)	128
Silt/Clay (%)	1.23
Sand (%)	24.54
Gravel (%)	72.39
Cobble (%)	1.84
Boulder (%)	0
Bedrock (%)	0

Total Particles = 163

D50 4.89 mm

Figure 97. West Tributary Reach 5 pebble count.

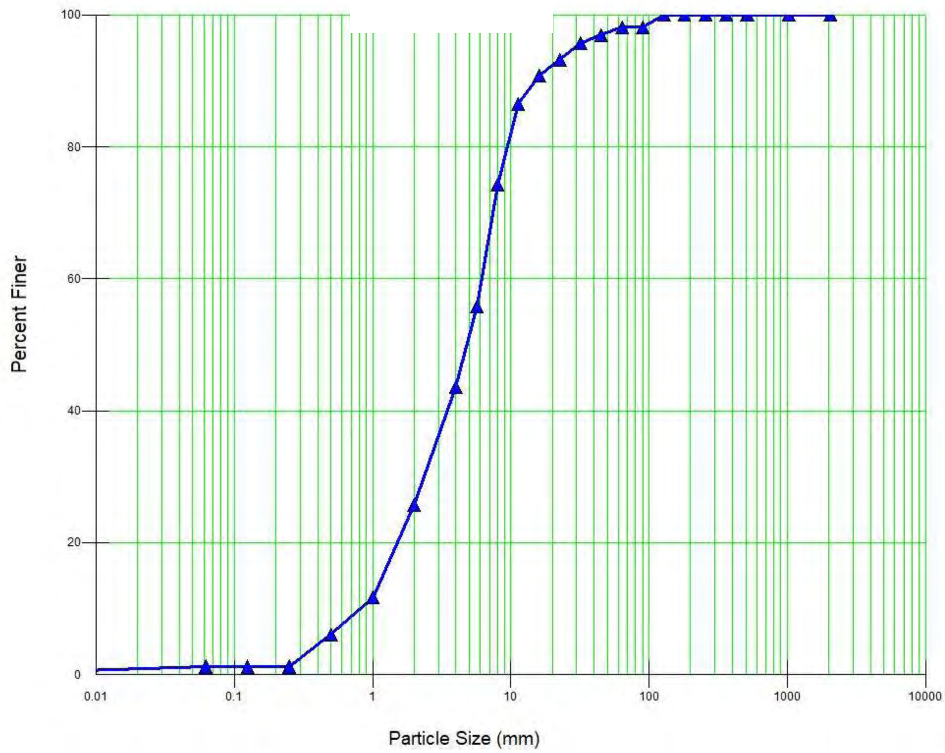


Figure 98. West Tributary Reach 5 particle distribution, D50 = 4.9 mm.

Figure 99. West Tributary Reach 5 looking downstream.

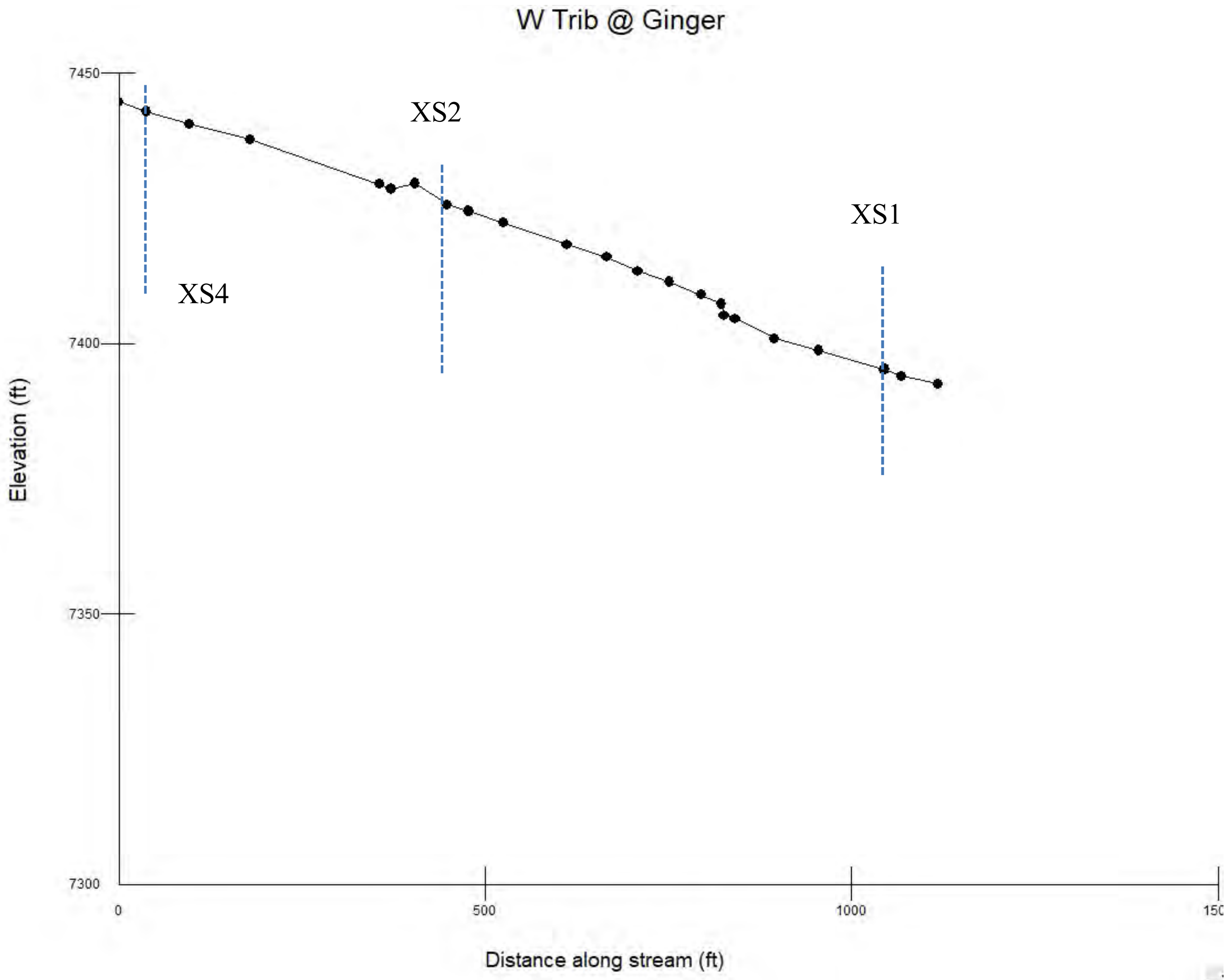


Figure 100. West Tributary profile through cross sections XS1, XS2, and XS4 at the confluence with the Ginger tributary; profile slope 4.5%.

West Trib XS2

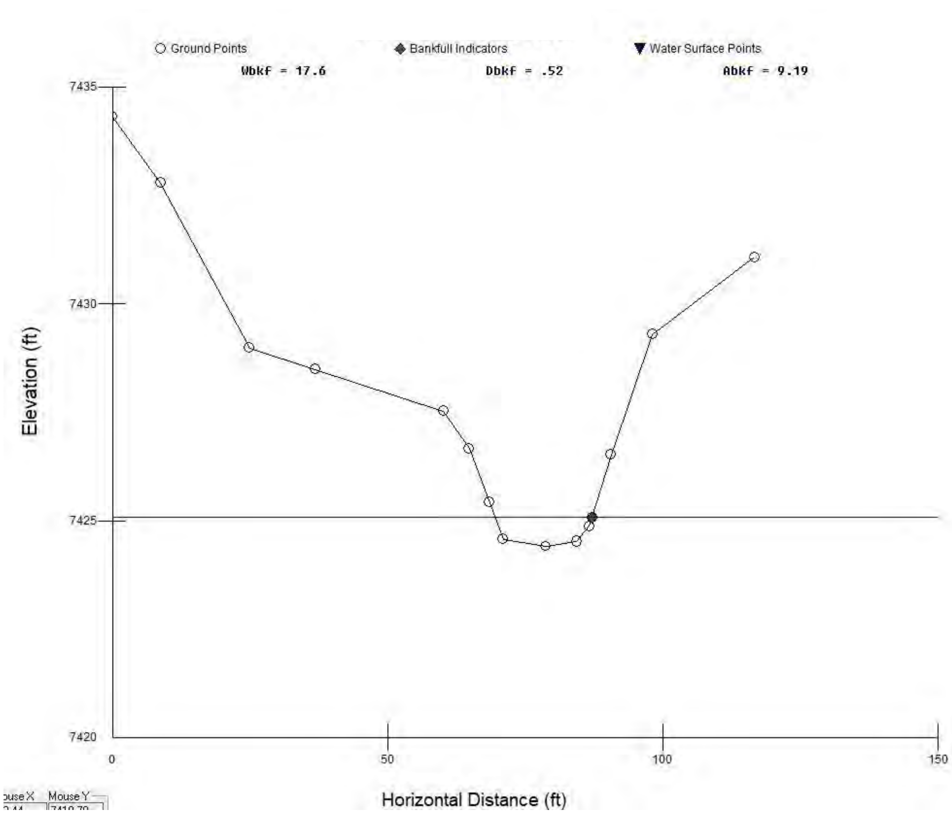


Figure 101. West Tributary XS2.

Particle Size Analysis

D16 (mm)	1.72
D35 (mm)	4.17
D50 (mm)	7.29
D84 (mm)	23.31
D95 (mm)	44.56
D100 (mm)	511.98
Silt/Clay (%)	11.76
Sand (%)	5.89
Gravel (%)	80.39
Cobble (%)	0.98
Boulder (%)	0.98
Bedrock (%)	0

Total Particles = 102

D50 7.29 mm

Figure 102. West Tributary XS2 pebble count.

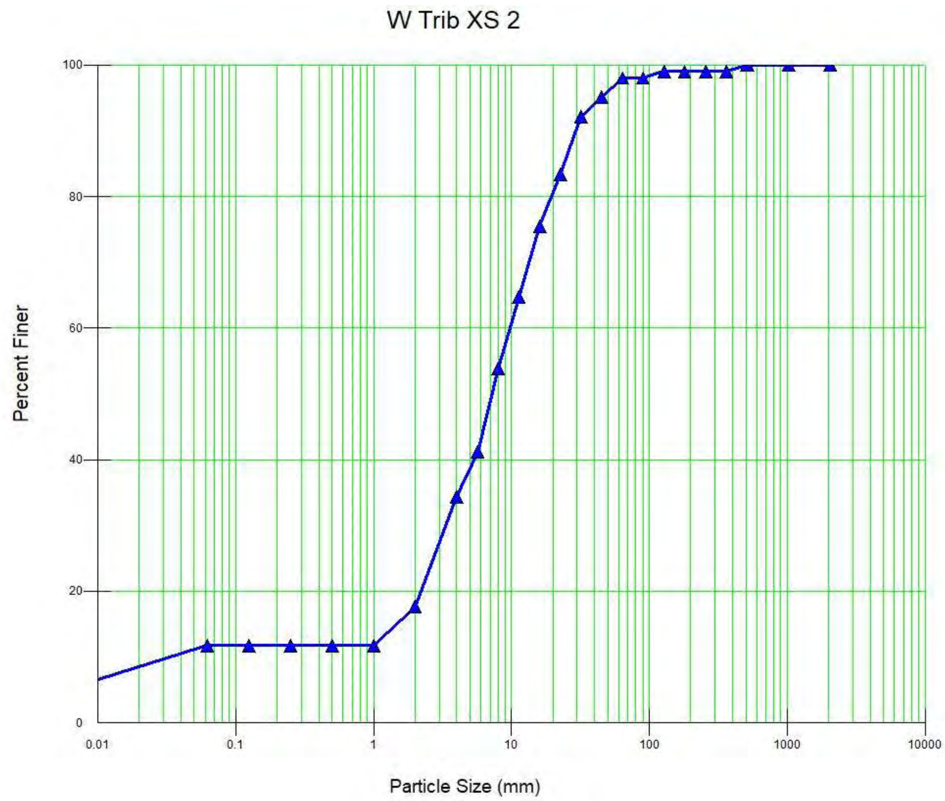


Figure 103. West Tributary XS2 particle distribution D50 = 7.3 mm.

Figure 104. West Tributary XS2 looking downstream.

West Trib XS4

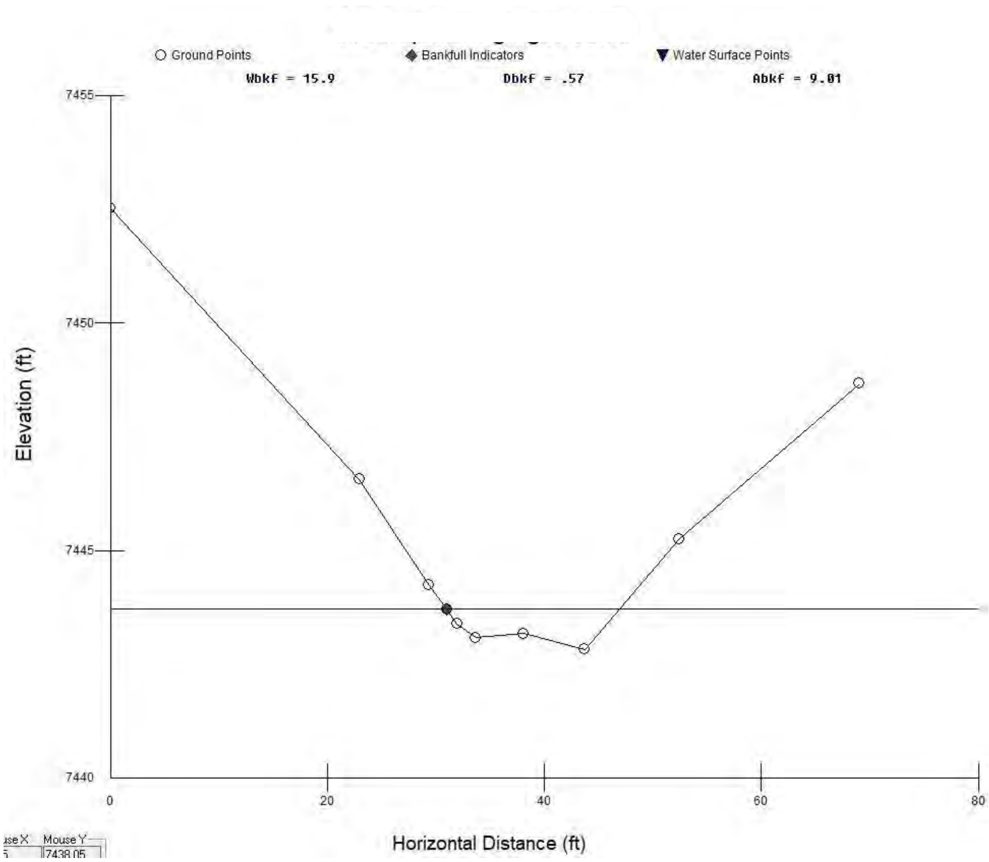


Figure 105. West Tributary XS4.

Particle Size Analysis

D16 (mm)	0.57
D35 (mm)	5.26
D50 (mm)	10.64
D84 (mm)	72.76
D95 (mm)	168.54
D100 (mm)	362
Silt/Clay (%)	5.88
Sand (%)	18.63
Gravel (%)	57.84
Cobble (%)	14.71
Boulder (%)	2.94
Bedrock (%)	0

Total Particles = 102

D50 10.64 mm

Figure 106 West Tributary XS4 pebble count.

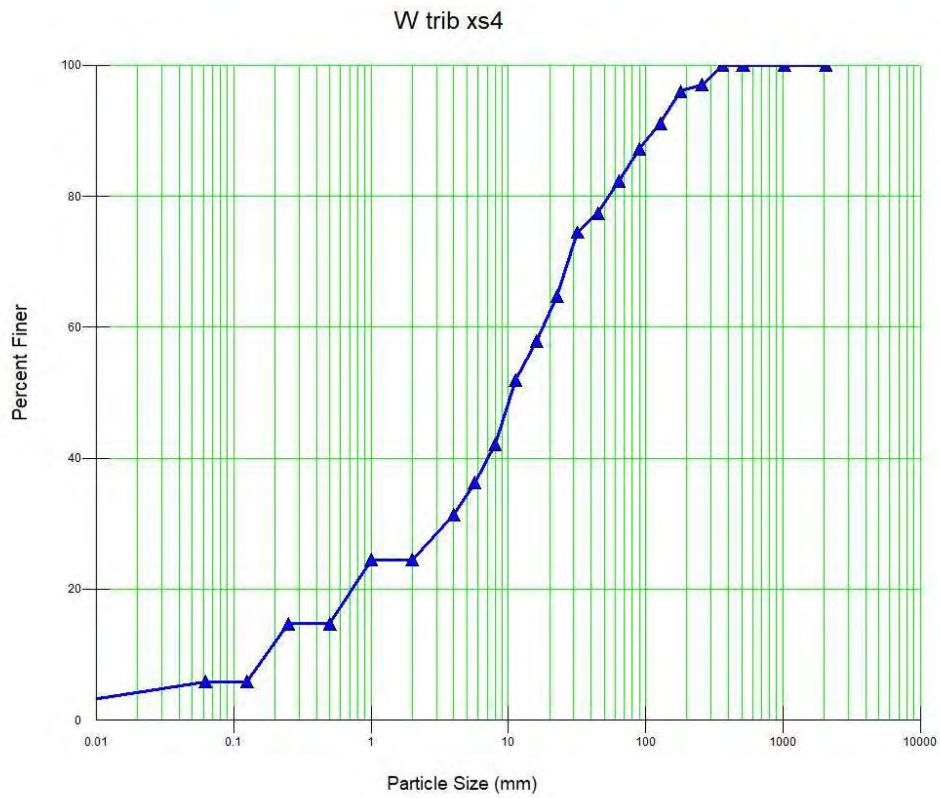


Figure 107. West Tributary XS4 particle distribution plot, D50 = 10.6 mm.

Figure 108. West Tributary XS4 looking upstream.

UPPER WEST TRIBUTARY AND GINGER

This portion of the watershed contains very steep channels that end in alluvial features where the slope is less than 15%. Channels in these reaches are heavily incised channels with slopes up to and sometimes exceeding 50%. These channels were incised during high flow events and large debris fans were formed at the base of the hillslopes where slopes are 15% or less.

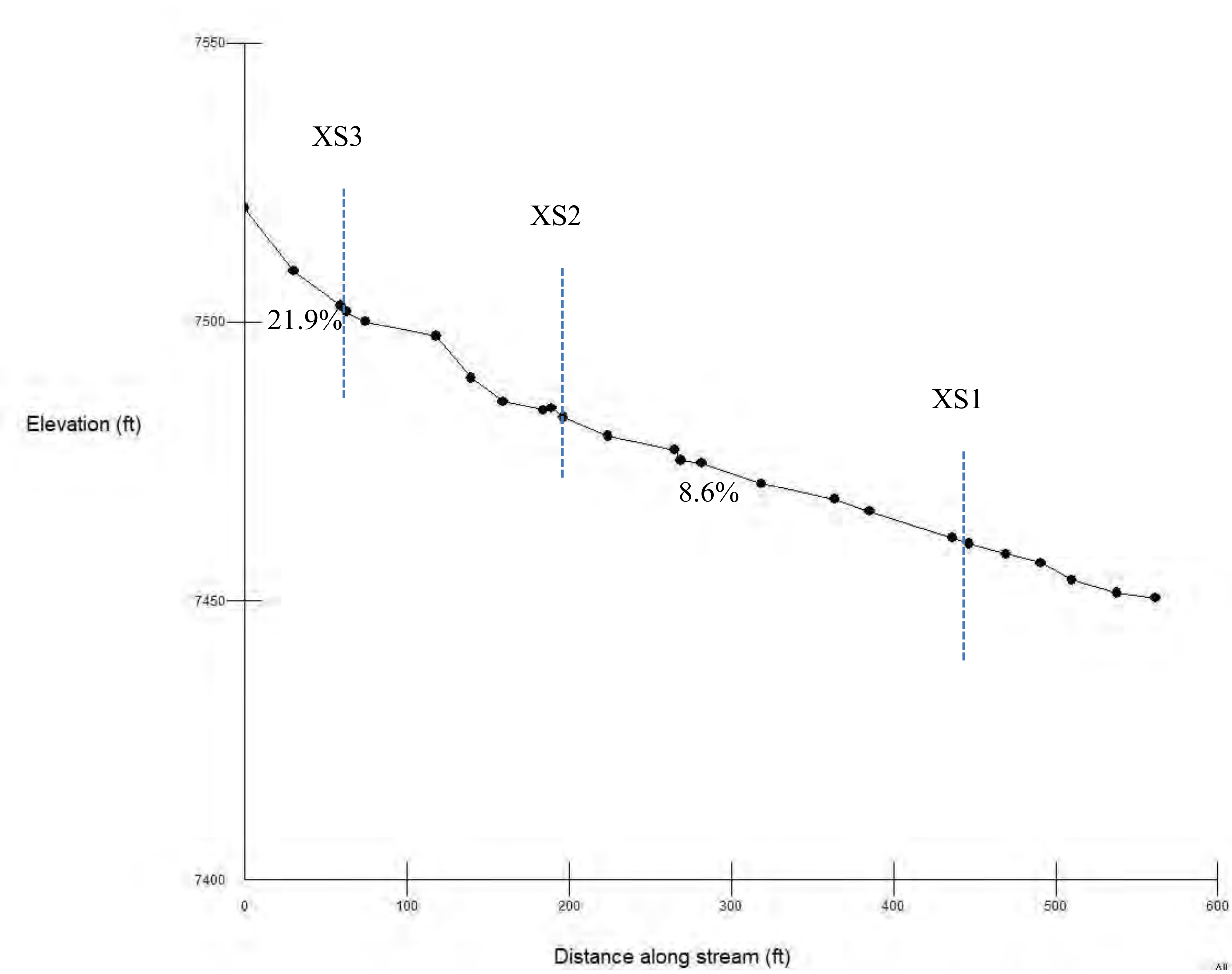


Figure 109. Upper West Tributary profile through cross sections XS1, XS2, and XS3; upper slope 21.9%, lower slope 8.6%.

Upper West Trib XS1

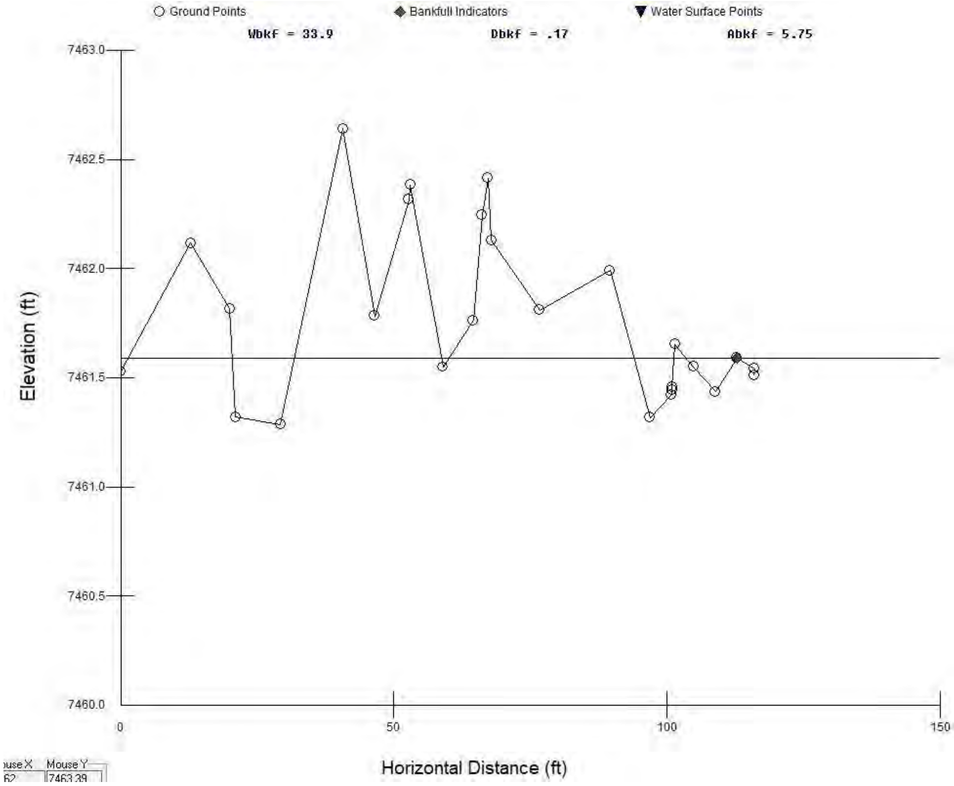
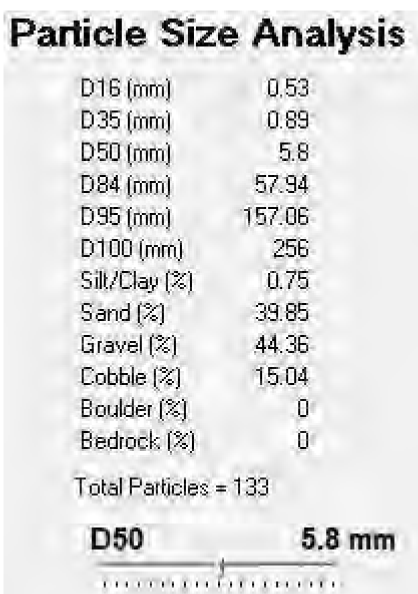


Figure 110. Upper West Tributary XS1.



Particle Size Analysis

D16 (mm)	0.53
D35 (mm)	0.89
D50 (mm)	5.8
D84 (mm)	57.94
D95 (mm)	157.06
D100 (mm)	256
Silt/Clay (%)	0.75
Sand (%)	39.85
Gravel (%)	44.36
Cobble (%)	15.04
Boulder (%)	0
Bedrock (%)	0

Total Particles = 133

D50 5.8 mm

Figure 111. Upper West Tributary XS1 particle distribution.

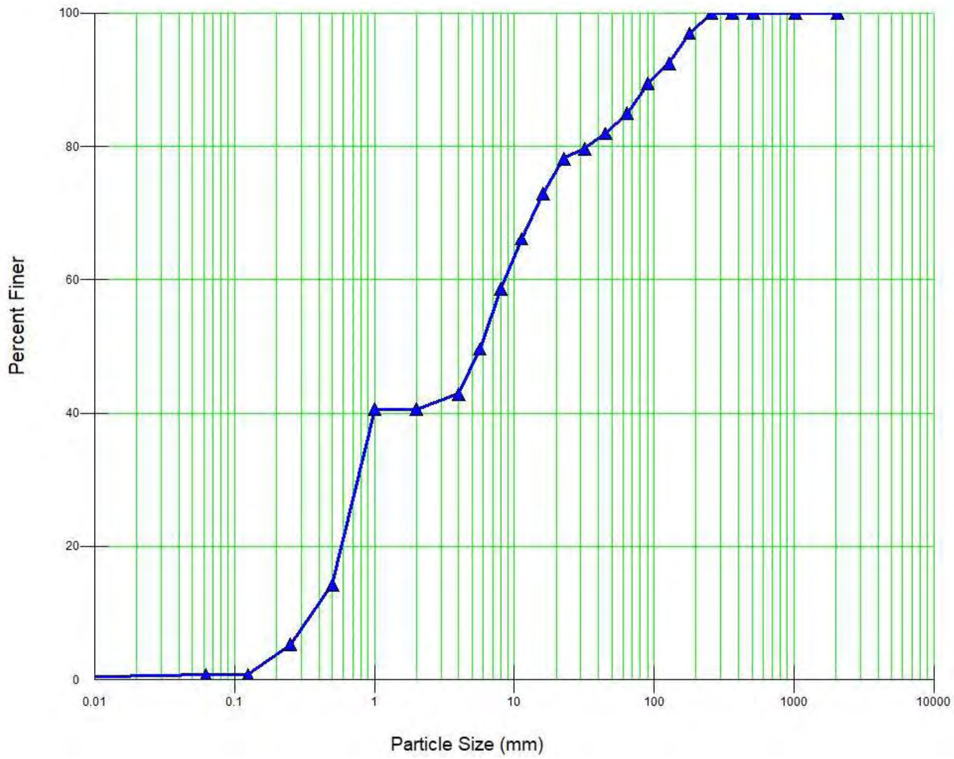


Figure 112. Upper West Tributary XS1 particle distribution D50 = 5.8 mm.

Figure 113. Upper West Tributary, looking downstream toward XS1.

Upper West Trib XS2

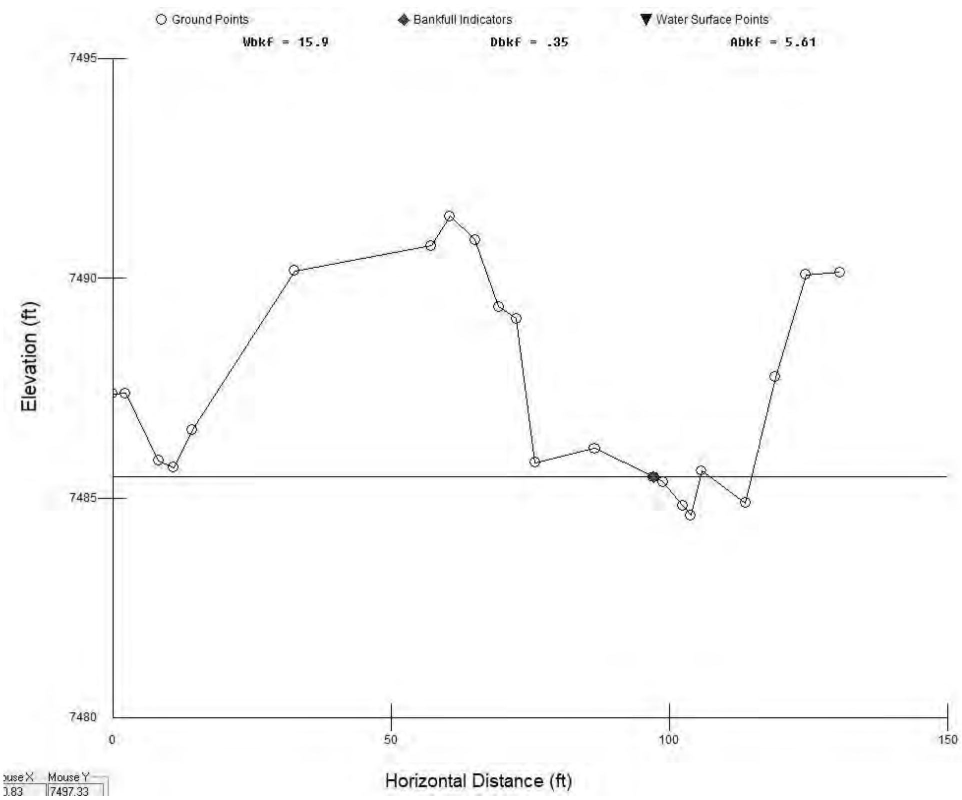


Figure 114. Upper West Tributary XS2.

Particle Size Analysis

D16 (mm)	0.58
D35 (mm)	6.09
D50 (mm)	9.9
D84 (mm)	88.79
D95 (mm)	243.63
D100 (mm)	511.99
Silt/Clay (%)	2.26
Sand (%)	26.31
Gravel (%)	51.13
Cobble (%)	15.79
Boulder (%)	4.51
Bedrock (%)	0

Total Particles = 133

D50 9.9 mm

Figure 115. Upper West Tributary XS2 pebble count.

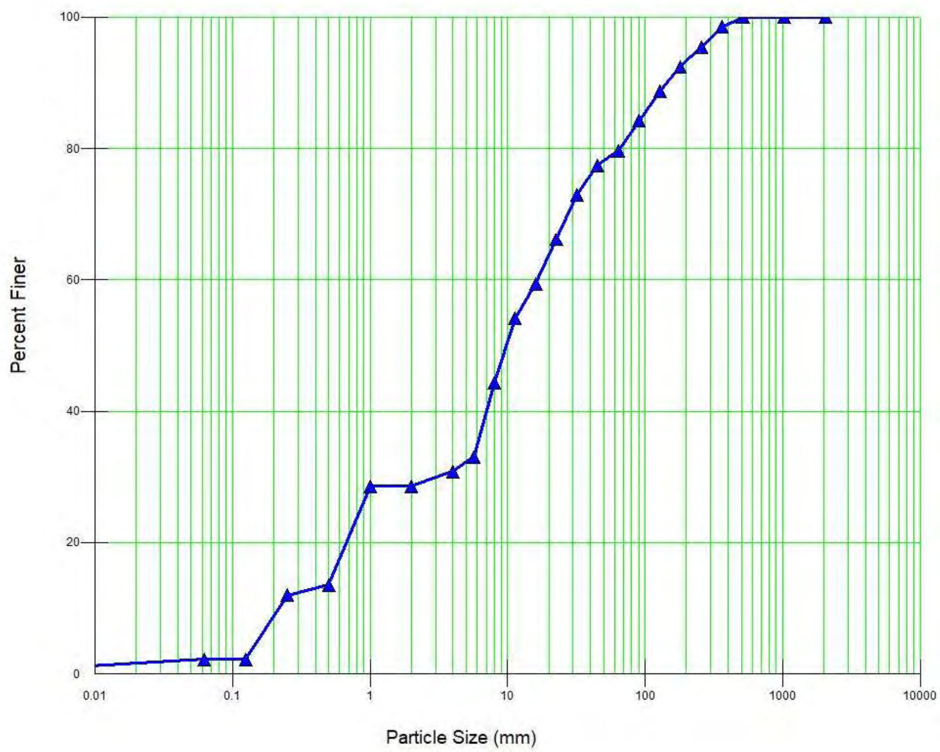


Figure 116. Upper West Tributary XS2 particle distribution D50 = 9.9 mm.

Figure 117. Upper West Tributary XS2 on fan.

Upper West Trib XS3

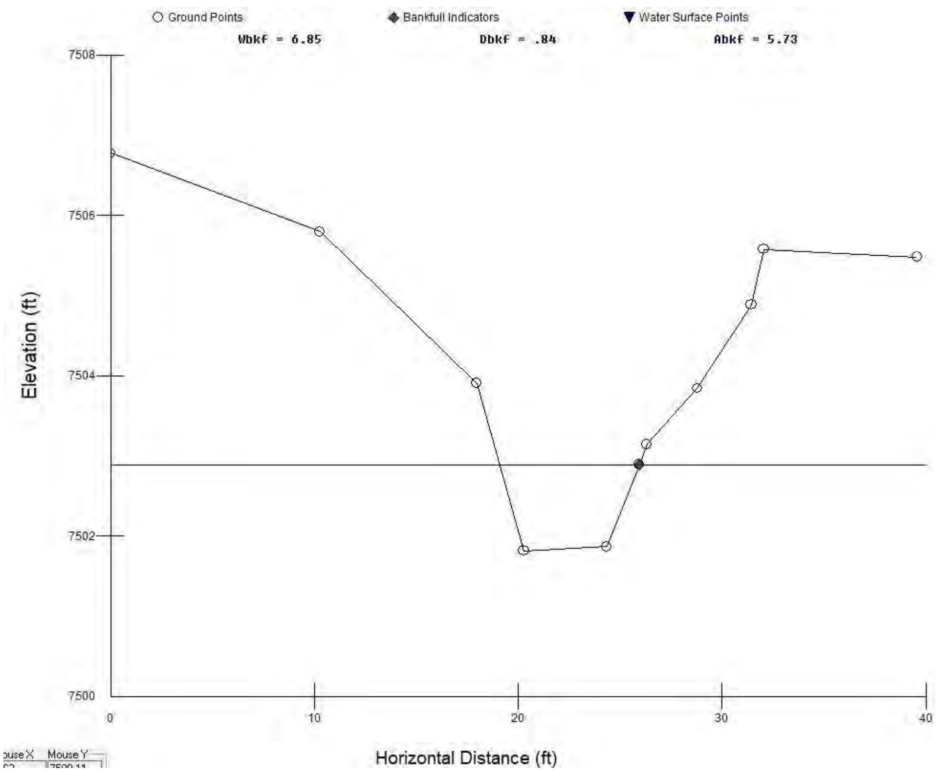


Figure 118. Upper West Tributary XS3, incised channel above fan.

Particle Size Analysis

D16 (mm)	0.52
D35 (mm)	6.38
D50 (mm)	13.36
D84 (mm)	270.64
D95 (mm)	428.76
D100 (mm)	512
Silt/Clay (%)	7.21
Sand (%)	22.52
Gravel (%)	33.33
Cobble (%)	19.82
Boulder (%)	17.12
Bedrock (%)	0

Total Particles = 111

D50 13.36 mm

Figure 119. Upper West Tributary XS3 pebble count.

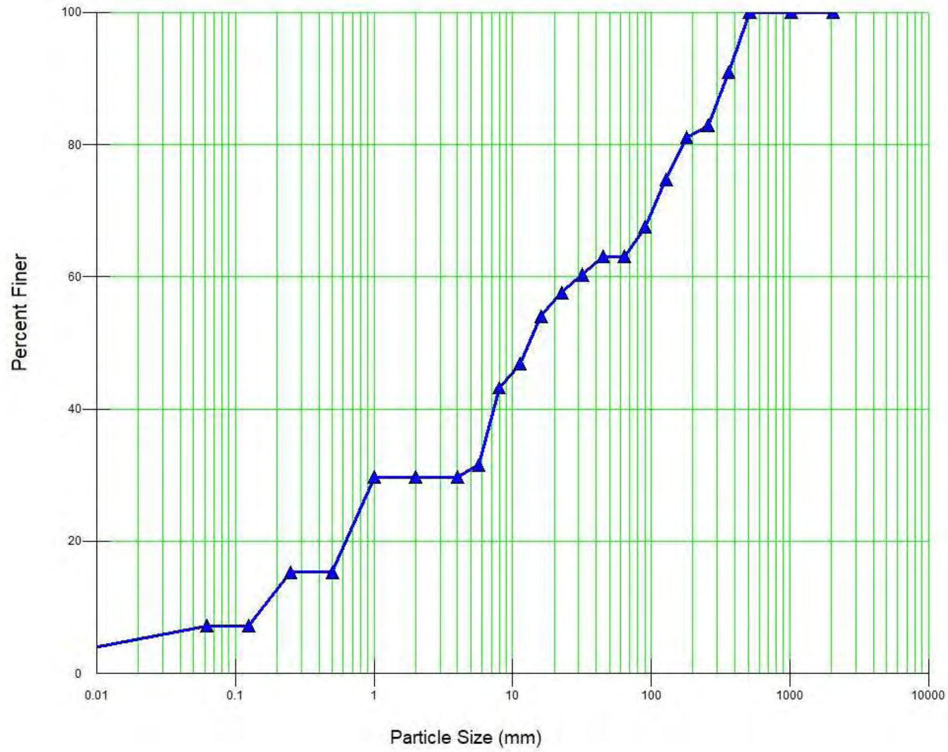


Figure 120. Upper West Tributary XS3 particle distribution D50 = 13.4 mm.

Figure 121. Upper West Tributary XS3 channel leading into fan.

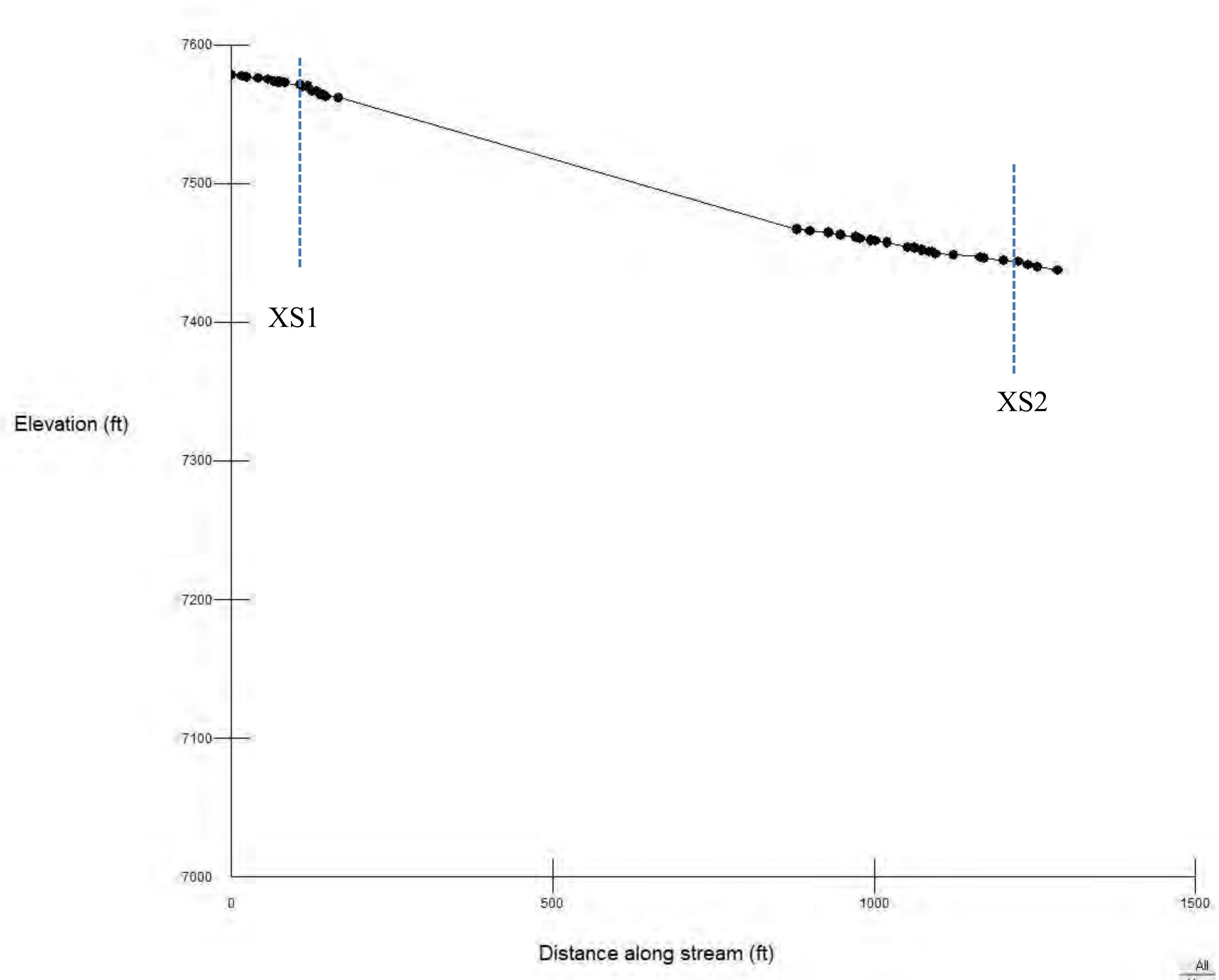


Figure 122. Ginger alluvial fan profile through cross sections XS1 and XS2; upper slope 11.5%, lower slope 7.1%.

Ginger Fan XS2

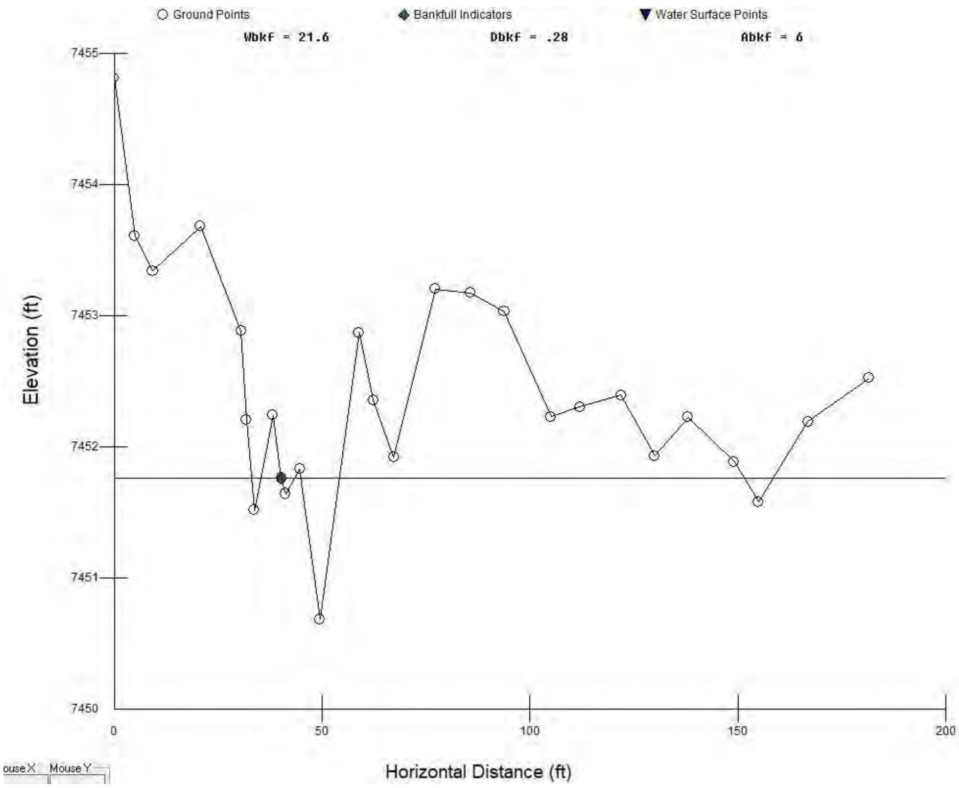
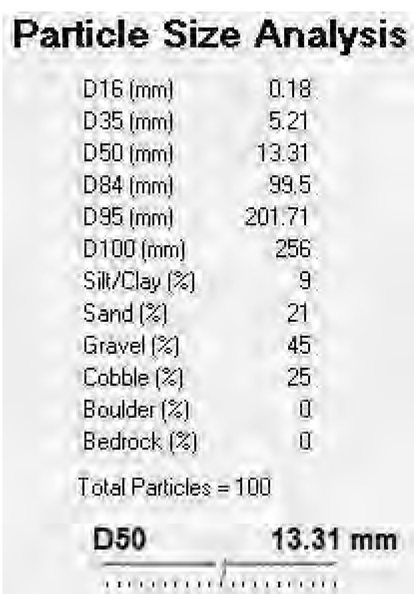


Figure 123. Ginger Fan XS2.



Particle Size Analysis

D16 (mm)	0.18
D35 (mm)	5.21
D50 (mm)	13.31
D84 (mm)	99.5
D95 (mm)	201.71
D100 (mm)	256
Silt/Clay (%)	9
Sand (%)	21
Gravel (%)	45
Cobble (%)	25
Boulder (%)	0
Bedrock (%)	0

Total Particles = 100

D50 13.31 mm

Figure 124. Ginger Fan XS2 pebble count.

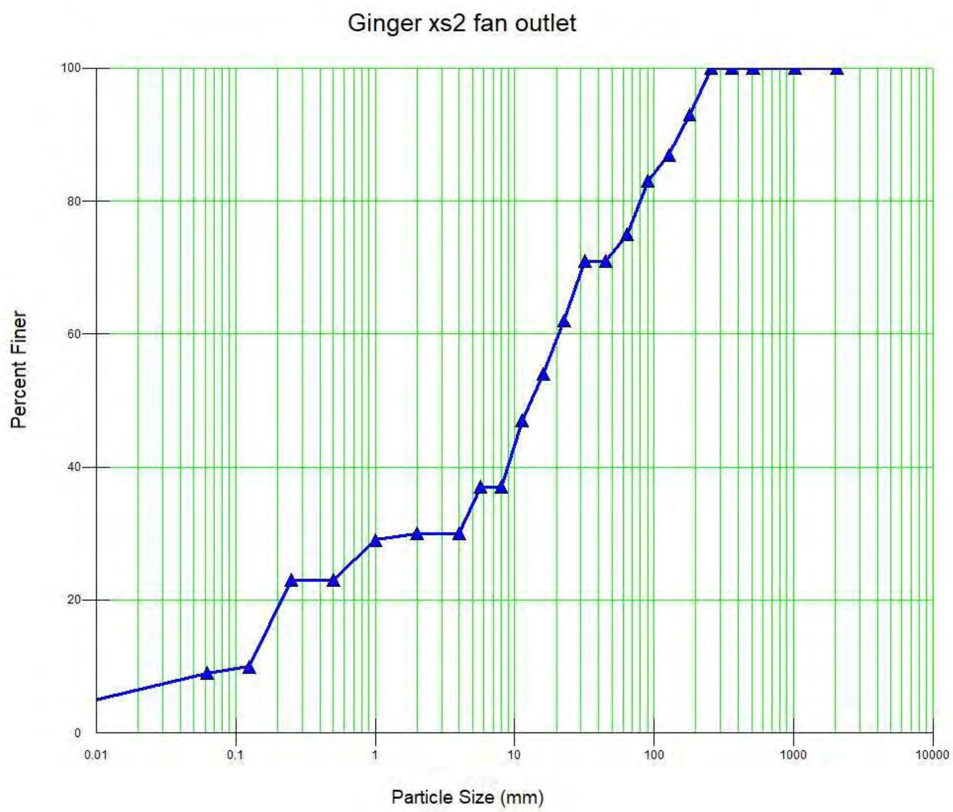


Figure 125. Ginger Fan XS2 particle distribution D50 = 13.3 mm.

Figure 126. Ginger Fan XS2 looking downstream at cross section.

Ginger XS1

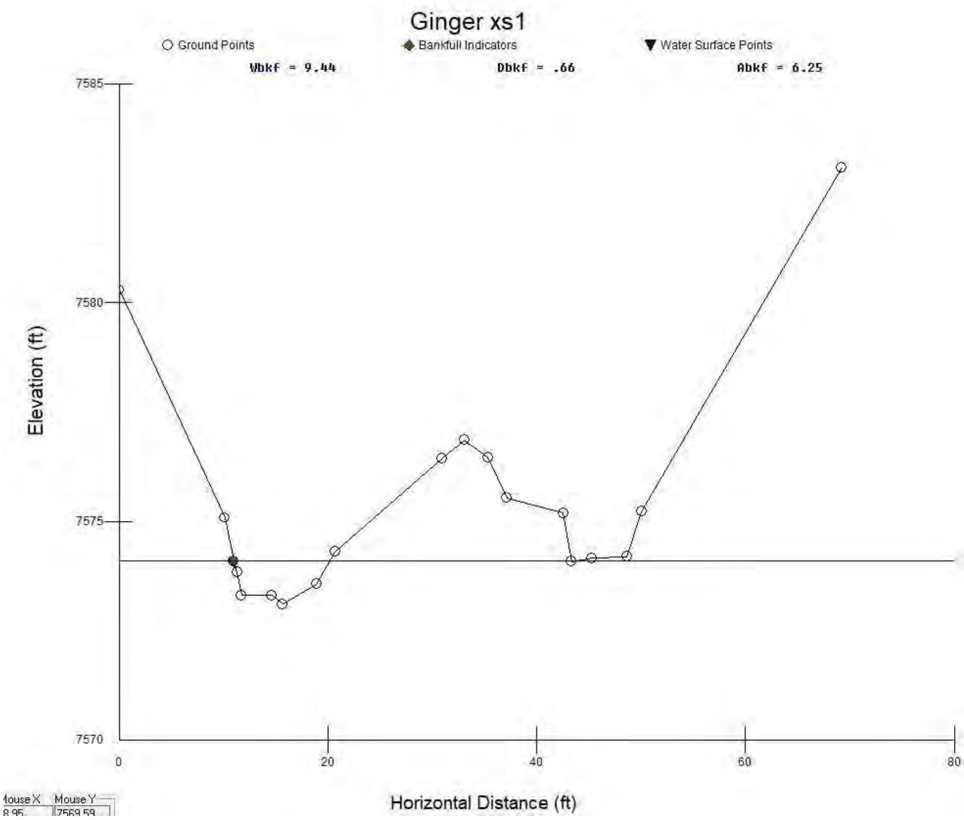
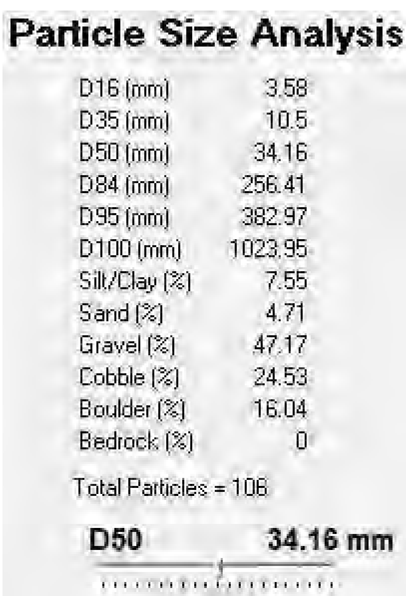


Figure 127. Ginger XS1.



Particle Size Analysis

D16 (mm)	3.58
D35 (mm)	10.5
D50 (mm)	34.16
D84 (mm)	256.41
D95 (mm)	382.97
D100 (mm)	1023.95
Silt/Clay (%)	7.55
Sand (%)	4.71
Gravel (%)	47.17
Cobble (%)	24.53
Boulder (%)	16.04
Bedrock (%)	0

Total Particles = 106

D50 34.16 mm

Figure 128. Ginger XS1 pebble count.

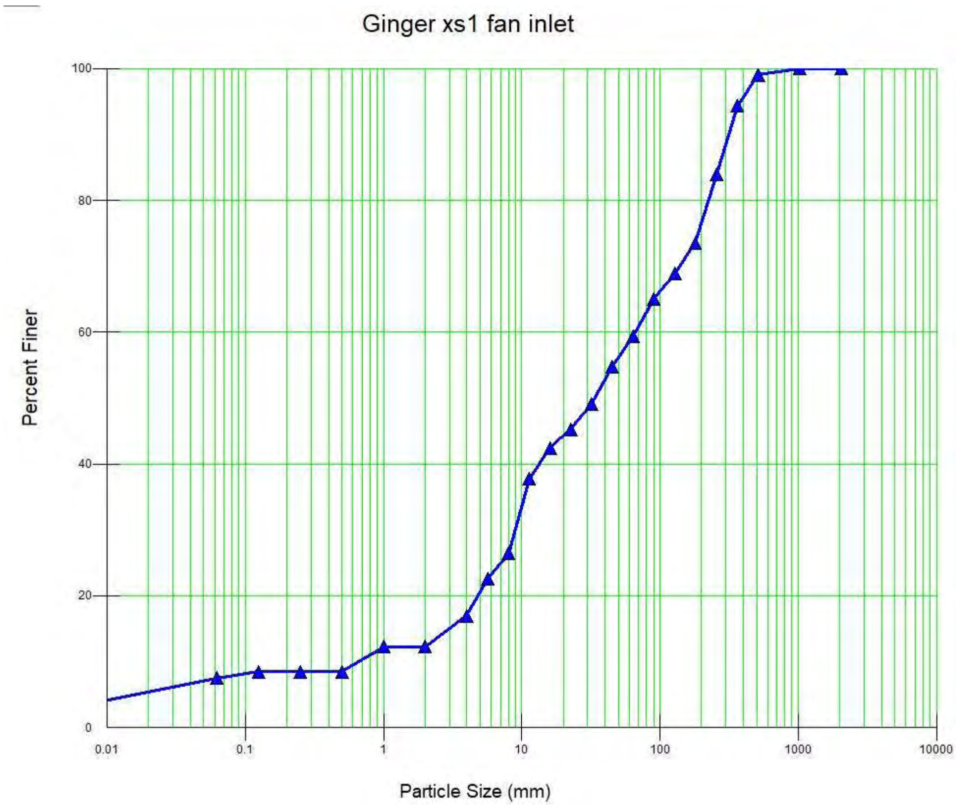


Figure 129. Ginger XS1 particle distribution plot, D50 = 34.2 mm.

Figure 130. Ginger XS1 looking downstream.