Schultz Fire and Flood Assistance Area

Sediment Analysis Refinement & Reduction Options

Final Report

February, 2012
Revised May 2012

Natural
Channel
Design, Inc.

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Final Report

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EXECUTIVE SUMMARY

The objective of this sediment refinement study is to define the origins and amount of sediment delivered to the private lands downstream of the Shultz Fire Burn Area. Additionally, the study provides estimates of how much sediment can be kept in place or stopped in transport before it reaches the private lands through installation of channel and watershed restoration practices on U.S. Forest Service lands. Estimates were made for each watershed in both the upper and lower portion of the watershed.

Sediment sources were estimated from channel bank erosion, hill slope erosion and roadway erosion. Channel bank data were estimated from visual surveys of over 60 miles of stream channel using the BANCS model. Roadway and hillslope data were estimated by Coconino National Forest, utilizing the ERMITT model. Sediment contribution from streambank erosion greatly outweighed contributions from combined other sources for all watersheds. While hillslope and roadway erosion will diminish over time with maintenance and natural recovery, bank contributions are expected to continue at high rates due to channel evolution processes. Comparison of current bank conditions with target erosion rates for restored bank conditions indicate that bank source sediment can be reduced by an order of magnitude or more for areas below the Forest Road 420 (FR 420) that are accessible for treatment. High contributions from steeper slopes above the FR 420 reduce the overall sediment reduction. However, some watersheds show the potential for greater than 30% reduction by working below the FR 420.

Estimation of sediment transport through the different reaches provides an understanding of where channels are aggrading or incising and the magnitude of these sediment processes. Sediment transport was estimated for each watershed at FR 420, midway through the lower watershed and at boundary between USFS and private lands for each watershed. Estimates were made using FlowSed/PowerSed as programmed in RiverMorph v5 beta. This analysis is dependent on construction of annual flow duration curves and regional suspended and bedload sediment rating curves. Flow duration curves and suspended sediment rating curves were developed from data collected at Beaver Creek Experimental Forest. Regional hydrology and bankfull discharge was estimated using local stream gage data in and around Flagstaff. Bedload suspended sediment was estimated from regional data from poor condition/high bedload streams in Colorado.

Comparisons of the sediment transport results with sediment source results indicate that sediment supply is generally much greater than sediment transport. However, the balance of the sediment is in unstable channels ready to be transported in future storm runoff events. Sediment transport results also indicate that several areas in each watershed could be utilized to store sediment on alluvial fans for longer periods of time. These areas are generally located along the FR 420 and near the USFS/private land boundary. In many cases these historic alluvial fans have been gullied through and are now active sources of sediment rather than sediment sinks. These multi-thread, alluvial fan channels have a large potential for storage of sediment sourced from higher in the watershed. Additionally, the sediment transport analysis indicates that restoration of single thread channels from poor condition channels to stable channels provides an order of magnitude less sediment transport, mainly due to the use of sediment transport relations more appropriate to stable channels.

The results of the sediment refinement analysis indicate that if natural channel sediment reduction practices are constructed on the USFS lands, the sediment transport and supply can be reduced to the point where single-thread natural channels can be successfully constructed through the neighborhoods if rights-of-way and other issues can be overcome. The practices considered for the USFS lands consist of channel reconstruction of single-thread channels to reduce sediment transport rates and the enhancement of existing alluvial fans to maximize sediment aggradation. Work is suggested for areas with milder slopes (<10%) from just upstream of the FR 420 to the boundary with private lands. All or major

portions of the channels within a watershed would need to be restored in order to meet the sediment reduction targets for construction of channels within the private lands. All watersheds considered have the potential to meet these sediment reduction targets. However, due to the lack of opportunities for meaningful sediment reduction practices below the FR 420 in the Lenox watershed, sediment aggradation fans here will have a shorter lifespan (~10 years). If major portions of the remaining watersheds can be treated with sediment reduction practices active aggradation is expected to be possible for 25-100 years depending on the fan in question.

Maps of potential work area and estimated lengths of channel and earthwork are provided on a conceptual level to aid in prioritization and planning.

OBJECTIVE

The purpose of this assessment is to refine the sediment analysis, locate possible sediment reduction options within the Coconino National Forest, and determine the feasibility of structural measures within the developed areas to lessen the threat of flood damage from increased runoff and sediment discharge. The sediment work strategy provides an integrated approach that incorporates existing studies, identifies data gaps, details key sediment source areas, and refines sediment assessment needs to develop mitigation strategies for sediment reduction options in both the short and long term post fire periods. The study analyzed sediment sources and transport capacities to provide sediment yield refinements for final planning of proposed recovery measures.

The analysis assumes that significant structural improvements on non-forest land will not be sustainable without the identification of drainages within the forest which have significantly lower levels of sediment or have potential of significant reductions in sediment transport.

The Watershed Assessment of River Stability and Sediment Analysis (WARSSS, 2006) methods will be used. WARSSS is designed to identify the location, nature, extent and consequences of land use impacts and understand the cause of impairment. This approach was developed by Dave Rosgen (Wildland Hydrology) for application on large watersheds with a practical, rapid screening component that integrates hillslope, hydrologic, and channel processes. This approach has been applied in a variety of situations around the country to provide watershed wide assessments of sediment sources and stream stability. Recently WARSSS has been applied to post fire stream degradation and sediment supply issues in Colorado. A design plan by Rosgen, “Trail Creek Watershed Assessment & Conceptual Restoration Plan”, will be used as a case study that illustrates assessment and watershed treatment application for the post fire (Hayman Fire, 2002) in the Pike National Forest (Colorado). While the geomorphic setting of the Haymen Fire is not perfectly analogous to the Shultz Fire area, there are key similarities that make it an appropriate study model. Both areas have experienced post fire increases in runoff, which has triggered channel instability and increased sediment supply. Both fires have occurred in forests dominated by ponderosa pine and highly erodible soils. Additionally, the geomorphology of both areas creates opportunities for the construction and rehabilitation of alluvial fans. The Hayman Fire occurred mostly on very erodible decomposed granite soils while the Shultz Fire occurred on volcanic soils and very steep slopes. Additionally, the density of housing and infrastructure in close proximity to debris fans is not as high in the case of the Hayman Fire as it is around the outflow of the Shultz Fire.

BACKGROUND

The Schultz burn area is located on steep mountain slopes uphill of an established rural residential area. The developed area is located on flatter slopes at the base of the mountain on the leading edge of a previously inactive alluvial fan. Initial flooding in the summer immediately following the 2010 fire caused landslides in the steeper portions of the watershed and higher than normal flows from the watershed. Flooding deposited large amounts of sediment in the neighborhood as the watershed slopes flattened. Existing drainage features and channels were overwhelmed with sediment and flooding was widespread.

Emergency response to the fire and subsequent flooding has come from numerous government entities (Coconino County, US Forest Service, City of Flagstaff, USDA Natural Resources Conservation Service, Arizona Department of Emergency Management, Arizona Department of Transportation, etc.) Initial response to the flood hazard reduction above the developed area provided immediate erosion control work as part of the U S Forest Service Burn Area Emergency Response (BAER 2010) plan. Treatments were aimed at minimizing soil loss from steep slopes (aerial straw mulch) and preventing damage to forest roads and downstream infrastructure (culvert removals and road abandonment). U S Forest Service

(USFS) and Rocky Mountain Research Station continue to analyze runoff and sediment yield from forest lands, while making additional treatments to speed recovery of the burned area.

The Schultz Flood Drainage Master Plan (DMP) quantifies hazards and analyzes alternatives to assist with flood relief through the developed areas. As part of that plan, Coconino County funded a hydrology study (Civiltec, 2010), hydraulics and sediment study (JE Fuller, 2011), as well as development of conceptual plans for channel sizing and routing to pass flow and sediment through and around the neighborhood. Initial results of the sediment yield analysis indicate that a significant quantity of sediment can be expected to impact the developed area for years to come. These studies were based on a 24- hour design storm event. Design and construction of flood relief channels that can route sediment are dependent on an understanding of average annual rates of flow and sediment movement as well as an understanding of a single design event. Consequently, there is a strong need for refinement of sediment predictions to determine if structural measures within the developed areas are feasible.

The current high danger and probability of flooding is expected to decrease over time as the upstream watershed conditions recover. While many areas of the watershed have lost all soil and will be severely limited in their ability to retain runoff, other areas will likely recover to some degree as vegetation becomes re-established. The time frame for recovery is subject to great uncertainty and cannot be reliably predicted. Estimates range from five to twenty years before watershed runoff and sediment yield rates are reduced to substantially lower levels. “Studies indicate that the greatest increases in erosion occur one to two years after a wild fire, and that a sediment-yield recovery period of three years can be expected for low-severity burn areas, seven years for moderate-severity burn areas, and 14 years for high-severity burn areas” (JE Fuller, 2011). However, the forest cover critical to reducing hydrologic yields will likely take multiple decades to return to pre-burn conditions. The sources of sediment are likely to shift from hillslope to channel derived sediment during this prolonged recovery period. Strategies for management of sediment should focus on processes that have the highest sediment reduction potential.

The current challenge for the County and Forest Service is to provide a solution matrix that effectively reduces the likelihood of flood damage to property and infrastructure, minimizes the long-term operation and maintenance, as well as minimizing the exposure to liability related to failure of the system. Several key issues drive the current sediment study and all further restoration/flood relief efforts. Central to the issue is the underlying geomorphology of the area. Parts of the developed area are located in areas that would naturally receive and store sediment during extreme flood events. These depositional areas that the neighborhoods were built on are formed by the aggradation of soil and sediment materials washed from the steep slopes of the mountain. Thus, these areas should be considered as subject to flood inundation and sediment deposition even without the added risk created by the fire. The watershed changes induced by the fire exacerbated an existing hazard. There is strong evidence that episodic debris flows have contributed materials to the more gradual slopes at the base of the mountain. This debris forms fans at the mouths of the major drainages off the hill slopes.

Sediment loads are problematic and very difficult to predict with accuracy. Sediment yield from high severity fires can overwhelm even stable natural channels. If channels are not sized and shaped properly to carry the sediment loads, then the channels will fill with sediment with a consequent reduction in flood capacity and flood inundation in undesired locations. Current estimates of sediment yield from the forest are based upon a Level II quantitative geomorphic standard design analysis (ADWR, 1985) utilizing the Modified Universal Soil Loss Equation and bed-material load sediment transport functions. The results of this model indicate that sediment loads from the given design storm are sufficiently high to prohibit many of the infrastructure improvements currently under consideration. However, the current model does not provide sufficient detail to provide sediment transport information in specific locations within the study area. Sediment sources and transport capacities may not be homogenous across all affected watersheds and there may be opportunities to provide adequate flood protection infrastructure in some areas.

Previous studies of annual post-fire sediment yields indicate that the primary sources of sediment from channels are far greater (~75%) than from hillslopes (Moody, 2009). Eleven watersheds of concern were delineated by the BAER team during initial post-burn assessment in July 2010 (BAER 2010). These watersheds delineations were modified slightly during this studies field investigations. They are shown in Figure 2. Sediment yield refinements should focus on these basins or specific sites for final planning of proposed structural measures including channels and basins.

While there is considerable error associated with the estimates of sediment delivery, the general conclusion of the sedimentation analyses is that sediment loads will be high and could overwhelm current combinations of proposed channels and sediment basins. Sediment overload presents not only a maintenance issue but also poses a significant threat of failure of the channel system with increased likelihood of flooding. Early recommendations for sizing of channels through the neighborhood utilized the 2010 post fire 5-year storm event. This flow is expected to decrease over time as the watershed heals and the channels would be expected to have the capacity for less frequent, high flow events.

Prior to the fire and subsequent flood disaster, the Timberline Area had very few defined channels and flow seldom ran in channels east of Highway 89. Surface flows were spread over wide areas and were absorbed into the ground. High flows, since the fire, have contributed surface flows as far as Cinder Lakes, the landfill, and Doney Park. These flows have contributed layers of fine sediment to the area, which can clog the cinder soils and altered local infiltration. While initial studies by USGS indicate that critical impairment of groundwater recharge has not yet occurred, there is a need to insure that high sediment loads over a long-term recovery period do not significantly alter the important watershed function.

METHODS

GENERAL ANALYSIS STEPS

Several key steps have been identified as major tasks for the sediment refinement study. It should also be noted that several entities (Coconino National Forest, Blue Mountain Consulting, and Wildland Hydrology) have been instrumental in supplying data, analysis and review to Natural Channel Design for these tasks. A flow chart of key steps in the data gathering and analysis are provided in Figure 1. Key tasks outlined for the sediment refinement study are:

- Refine Sediment Yield Estimate - Conduct a field assessment of channel bank erosion hazards and rates to combine with USFS estimates of hillslope and road erosion to determine the processes responsible for high sediment source. Utilize these estimates to target sets of practices that will be most successful at reducing sediment. The BANCS model (Rosgen 2002) was utilized to estimate sediment supply from channel bank sources while the ERMITT model was utilized for hillslope and road sediment sources.

- Survey Channels - Conduct detailed geomorphic field data acquisition for selected, representative sites within the watershed. This data will provide the basis for quantitative analysis of both channel and bank processes that contribute to sediment supply and transport. Maps of channel types (Rosgen 1996) are utilized to prioritize areas that have the highest potential for sediment supply.

- Evaluate Hydrologic Processes - Utilize Blue Mountain Consulting to develop dimensionless flow duration curves, estimate additional water yield from post fire watersheds and determine bankfull discharges for each watershed to be utilized in estimating flow related increases in sediment yield from channels. This task will utilize the WRENNS model to predict additional hydrologic yield from disturbed watersheds and partition the new yield over a flow duration curve. Prediction of bankfull instantaneous discharge for each subwatershed were made using regional curves for bankfull cross-sectional area and relationships of stream bankfull velocity to watershed size. These bankfull predictions were utilized to dimensionalize the dimensionless flow duration curves produced through the WRENNS modeling exercise.

- Estimate flow-related sediment rating curves - Develop sediment concentration relationships from available data to determine bankfull estimates of suspended and bedload sediment for each watershed. These estimates are utilized to scale previously published dimensionless sediment rating curves (Rosgen 2010) .
- Analyze Sediment Transport Capacity - Utilize FLOWSED/POWERSED sediment transport model (Rosgen 2006) to determine sediment transport capacity for current and proposed design channels throughout the watersheds. The FLOWSED portion of the model is utilized to estimate flow related increases in sediment transport, while the POWERSED model estimates channel geometry related changes in sediment transport.
- Develop Treatment Options - Analyze data to determine feasibility of watershed recovery options on federal and private lands and flood relief efforts on private lands.

All analyses are based on breaking each watershed into two major portions, above the Shultz Pass Road (FR 420) and downstream of the Shultz Pass Road to the boundary with private lands. The reason for this division is that the road provides a reasonable divisor between very steep upper watershed slopes and more moderate lower watershed slopes. Logistical and environmental concerns make addressing sediment source and transport issues on steeper slopes problematic, so dividing each watershed into treatable and untreatable reaches aids analysis and prioritization. Additionally, older alluvial fans are associated with the slope changes adjacent to the road. These alluvial fans and associated valley geometry are important drivers of any natural channel sediment reduction practices.

The results from these efforts will provide a technical basis to help determine feasibility of watershed restoration efforts. These technical results will be evaluated along with other technical, social and financial concerns to prioritize specific practices and work areas on USFS and private lands that will help restore watershed functionality and provide improved flood relief through developed areas below the Shultz Fire burn area.

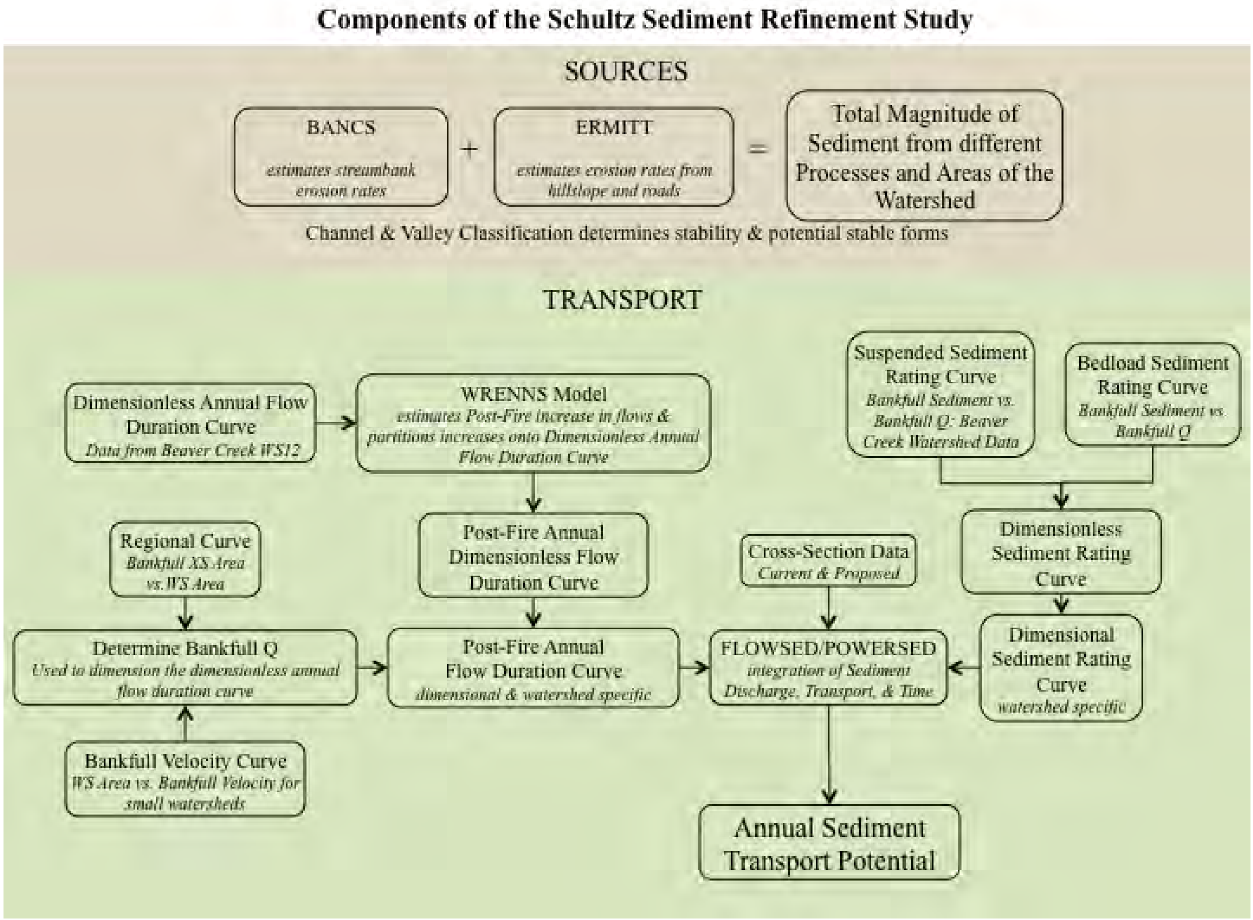


Figure 1. Flow chart of study design and data sources.

The process, location and magnitude of sources were estimated using the BANCS and ERMITT models to estimate bank erosion, hill slope erosion and road erosion. Sediment transport potential under current and proposed conditions was modeled using the Flowsed / Powersed model with inputs derived from WRENNS model and other sources.

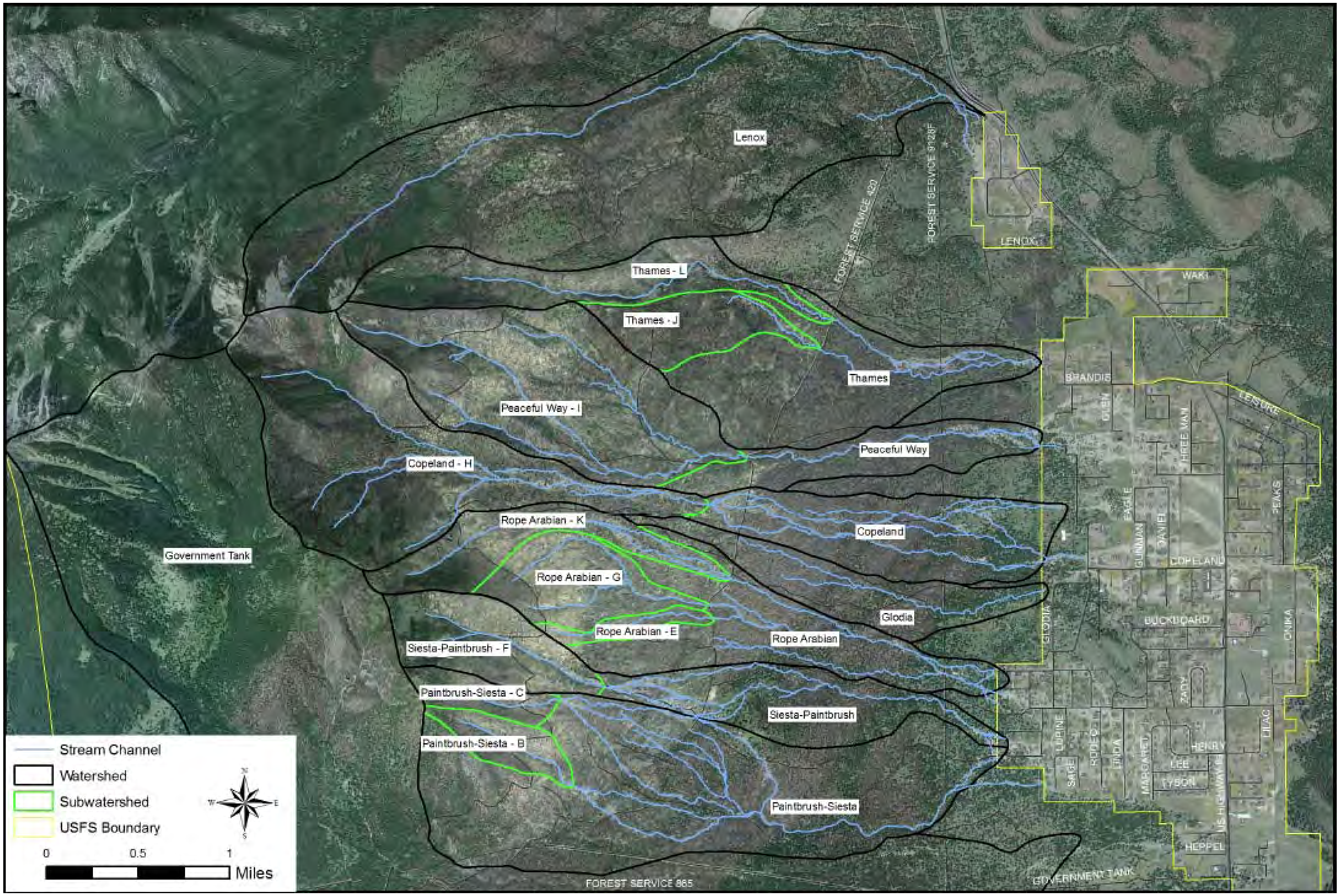


Figure 2. Location of watersheds and sub-basins.

BANK, HILL SLOPE AND ROAD EROSION ESTIMATES

The purpose of estimating stream bank erosion is to determine the magnitude of this source of sediment to for comparison to hill slope and road erosion rates. Additionally, high erosion rate areas can be identified for treatment prioritization.

The basic steps for estimating bank erosion rates are:

1. Conduct a field reconnaissance of all channels to provide locations and visual estimates of stream type and Bank Erosion Hazard Index (BEHI).
2. Perform geomorphic survey of representative channels (more than 30) to verify and calibrate visual estimates.
3. Utilize BANCS model to determine current annual sediment yield from bank erosion and efficacy of different treatment scenarios.
4. Tabulate data from surveys and compare with results from the US Forest Service (USFS) Hill Slope and Road Erosion Model to determine magnitude of sources and processes.
5. Utilize channel mapping to refine watershed boundary maps and provide new watershed boundaries for revised hydrologic modeling.

Methodology

Visual surveys of channels were conducted and mapped using a resource grade Global Positioning System (GPS) to document the location of each channel contributing water and sediment to the neighborhoods below the burn area. Surveyors noted: channel type and valley type (from the Rosgen Stream Classification System, 1996), BEHI (Rosgen, 2002), Near Bank Stress (NBS) (categorized from channel shape), and streambank heights. The lengths of each channel type and of each BEHI score could be measured from GPS paths after data processing. Bank erosion rates (tons per year per foot of bank) were calculated using the BANCS model. On-the-ground mapping of over 60 miles of flow paths also helped to clarify and refine watershed boundaries within the project area.

In order to validate each surveyor’s visual estimation of channel type and BEHI, subsequent geomorphic surveys were performed in a channel that represented each surveyor’s BEHI estimations using Real-Time Kinematic (RTK) GPS or laser level to measure channel cross sections, actual bank angle and heights. Representative pebble counts were collected at each site and a formal BEHI survey of representative banks was conducted to capture channel morphology and slope. Each surveyor’s estimates of BEHI were validated so calibration of the visual surveys could be done. These surveys also provided calibration of estimates of NBS to complete the data collection required for the BANCS model. The BANCS model developed by Rosgen (2002), has been calibrated for channels in the Verde River watershed (Moody et al, 2003), and accepted by US Environmental Protection Agency (USEPA) nationwide. The BANCS model provide reliable estimates of bank erosion which can be compared directly to hill slope and road erosion rates. However the BANCS model can underestimate bank erosion rates resulting from higher than normal flooding and over estimate rates from years with very low peak flows (Rosgen 2002).

The USFS provided hill slope and road erosion rates that were adapted to conform to the field-verified watersheds from the visual and calibration surveys. Rory Steinke, Watershed Program Manager USFS Coconino National Forest, provided hill slope and road erosion estimates from WEPP ERMIT models. The results of this modeled effort were slightly modified by NCD to incorporate modified watershed boundaries.

The survey results were uploaded into Geographic Information Systems (GIS) in order to tabulate the collected data from each of the 924 different channel reaches surveyed. Each NBS and BEHI field was assigned a value based on their severity in order to calculate the BER (in feet of streambank recession per year) using relationships between BEHI and NBS developed by Rosgen (2002) for streams in Colorado. The BEHI and NBS correlation for streams in Yellowstone NP and alpine systems was used in the rare case that a channel was determined to have very low BEHI. The lengths and heights of each reach were multiplied by the BER to determine the volume and mass of sediment produced from each section of each watershed. For comparison, another metric was derived from this analysis by dividing the channel length into the BER to view tons of sediment produced per year per foot of channel. Combining the streambank erosion rates with the data provided by the USFS on hill slope and road erosion rates, allowed for the determination of total annual sediment yield from the burn area (Table 3).

There were some sections of the mountain that were not surveyed due to their altitude, extremely steep grades, and availability of time (and subsequent incoming winter storms). These were located above the Waterline Road, which served as a useful stopping point in the surveys. Erosion from areas above the Waterline Road was determined by assuming that each reach (drawn in GIS) from the ridge to the road had 3-foot tall vertical banks with Very High NBS and Extreme BEHI. This assumption was based on photographs and estimates from the surveyors who observed these highest points in the watershed from the waterline road.

Target BEHI and NBS scores were utilized to estimate the potential reduction in sediment supply through restoration of stable channel banks. Target restoration values of BEHI and NBS values were assigned to degraded sections of channel between FR420 and the Forest Boundary that are readily accessible for restoration efforts. Steep slopes and permitting issues limit restoration opportunities on channels upstream of the FR420 road even though these have a high sediment supply. These different BEHI and NBS values represent restoration of the channels from extreme, very high, and high BEHI and NBS to low levels of both BEHI and NBS (Table 4). This is a conservative estimate of treatment resulting in restoring bank stability to heavily degraded channel reaches. This analysis does not include account for sediment supplied from incision of gullied channels and will underestimate sediment contributions from bank failures during high, infrequent flood events. Carrol 2010 showed that there was considerable sediment stored in channel beds in the Shultz Fire Burn area that could easily be reintrained and transported.

SEDIMENT TRANSPORT AND CHANNEL PROCESSES

The BANCS and WEPP ERMIT models provide estimates of the magnitude and origin of sediment sources to the fire area. Once the sediment has reached defined channels, its fate is determined by the transport rate through the channels. Transport rate is a function of the amount and duration of flow as well as the slope, shape and condition of the transport channel. Transport rate can change along the length of the watershed as channel slope, shape, and condition change. Additionally, increased watershed size can mean higher, longer duration flows, which can increase sediment transport rates as well.

Post-fire changes in runoff yield, as well as disturbances to channel shape have altered the sediment transport capabilities of channels in the burned area. The purpose of this portion of the sediment refinement study is to understand the transport capabilities of the channels in relation to the current sediment sources and to understand the potential for either slowing or increasing the rate of sediment transport through the watershed.

The FLOWSED/POWERSED model described by Rosgen (2006) as programmed in Rivermorph™ V5beta was utilized to estimate sediment transport at specific locations throughout the watersheds. This model requires specific data that was developed as part of this study. The model utilizes a dimensionless flow duration curve developed for the project region and post fire conditions. This dimensionless flow duration curve is made dimensional at each specific site location by multiplying the estimated mean daily bankfull flow at the site. Additionally, the model utilizes dimensionless sediment rating curves for suspended and bedload sediment at good or poor conditions. These dimensionless curves are made dimensional utilizing the bankfull estimates of suspended and bedload concentrations at each site of interest.

This data was not readily available for local sites. A concentrated effort was made to gather appropriate local data to make these estimates. The following sections describe the data and analysis required by the Flowsed Powersed model.

HYDROLOGIC ANALYSIS: DEVELOPMENT OF DIMENSIONLESS FLOW DURATION CURVE

Objective

Develop dimensionless flow duration curve that integrates estimated change in water yield modeled from the WRENSS analysis, over time. The dimensionless flow duration curve can be used in conjunction with dimensionless sediment transport rating curves to evaluate sediment loading in various sub-drainages to help estimate potential for restoration/storage within the Schultz Fire impacted area.

Basic Steps

Blue Mountain Consulting (Jim Nankurvis) provided guidance and analysis for the development of dimensionless flow duration curves and bankfull discharges for each drainage and sub-drainage.
The basic steps for development of this information are as follows.

1. Obtain change in water yield for a given drainage or sub-drainage
2. Create dimensionless flow duration curve representing pre-fire conditions
3. Distribute change in water yield over dimensionless flow duration curve
4. Re-calculate dimensionless flow duration curve incorporating change in yield

Methodology

Assumptions:
Beaver Creek Experimental Watersheds data used to create the dimensionless flow duration curves represent similar climatological and hydrological conditions as the Schultz Fire area. Watershed #12 bankfull discharge = 21 cfs (momentary maximum flow). Watershed #12 bankfull discharge = 8 cfs (daily mean flow equivalent). See Appendix A for bankfull estimates for Schultz Fire basins and sub-basins.

Estimates of bankfull discharge were derived from pre-treatment flow frequency curves (Beaver Creek Watershed#12) and regional curve data developed from local stream gages in and around Flagstaff, and watershed area-bankfull velocity relationships developed by Troendle/Nankervis (unpublished).

Estimating Change in Water Yield

The Schultz Fire dataset was divided into ten basins and ten sub-basins containing 6940 unique polygons describing vegetation cover type and size, aspect, monthly precipitation and area for pre-burn conditions. Overlaying the post-burn coverage over pre-burn polygons defined post-fire vegetation conditions for each polygon (burned/unburned). Using only the forested polygons (6276), two runs of the WRENSS model were made using the Rocky Mountain Modified version of WRENSS (Troendle et al, 2003): one reflecting the pre-fire conditions and, one reflecting post-fire conditions. The difference between the two model runs indicates the change water yield (inches) as a function of forest vegetation reduction. Changes in water yield for each basin and sub-basin are reported in Appendix A.

Pre-Fire Flow Duration Curve

A flow duration curve was developed from the Beaver Creek Experimental Watershed # 12, pre-treatment data (1959-1966) that represent pre-disturbance flow conditions. Flow measurements in Watershed #12 actually started in 1958 but do not contain all records for a complete water year and were excluded from this analysis. Dividing each daily mean flow observation by the estimated bankfull value (8 cfs – the daily mean flow corresponding to the instantaneous bankfull value) creates a dimensionless discharge observation. Sorting all dimensionless observations in descending order and dividing the rank order by the total number of observations in the period of record provides the percent time a given dimensionless flow value is equaled or exceeded.

Distributing Change in Water Yield

The procedure for distributing the change in water yield over the dimensionless flow duration curve was a modification of the hydrograph approach described in the WRENSS handbook (1980) for the Rocky Mountain/Inland Intermountain hydrologic regions. Averaging the “Open” percentages for the three aspects in tables III.11-III.13, provides a general means to apportion the increased flow over time. The percentages are sorted in descending order and each percentage is associated with the appropriate time interval. Defining regular time intervals in 0.01 increments (except for the five largest discharge values) and extracting the associated dimensionless flow values and percent increases per time interval, generates a template upon which to base the dimensionless flow duration calculations for the basins of interest (Appendix A).

Calculate Dimensionless Flow Duration Curve for Basin/Sub-Basin of Interest

Water yield for the basin of interest was converted from inches into cubic feet per second per day (DMF) for each time interval using the equation: (Inches/12)*Basin Area in Acres)/1.9834). Then, multiply DMF by: ((Percent Time Increase/6)/Bankfull for Basin of Interest) to get the dimensionless increase in flow for each time interval. Finally, add the dimensionless increase in flow for each time interval to the Beaver Creek Watershed #12 dimensionless flow value (baseline) to obtain the dimensionless flow duration curve for the basin of interest. In order to calculate a dimensionless flow duration curve for any basin or sub-basin in the Schultz Fire area three values specific to that drainage are needed: 1) change in water yield (inches), 2) watershed area (acres), and 3) bankfull discharge (cfs). A MS Excel spreadsheet was provided to Natural Channel Design, Inc containing all the information necessary to compute dimensionless flow duration curves for each of the basins and sub-basins of interest in the Schultz Fire impacted area.

Calculation of bankfull discharge for Basin/Sub-basin of Interest

The bankfull discharge for each sub-basin is required to properly dimension the dimensionless flow duration curves. Bankfull discharge was estimated utilizing the continuity equation (Q = V*A, where Q is discharge, V is mean velocity, and A is cross sectional area). Cross sectional area and mean velocity were estimated from relationships to watershed size. These relationships are provided below in Figure 3 and Figure 4 . Estimated bankfull discharges for each sub-watershed are given in Table 1.

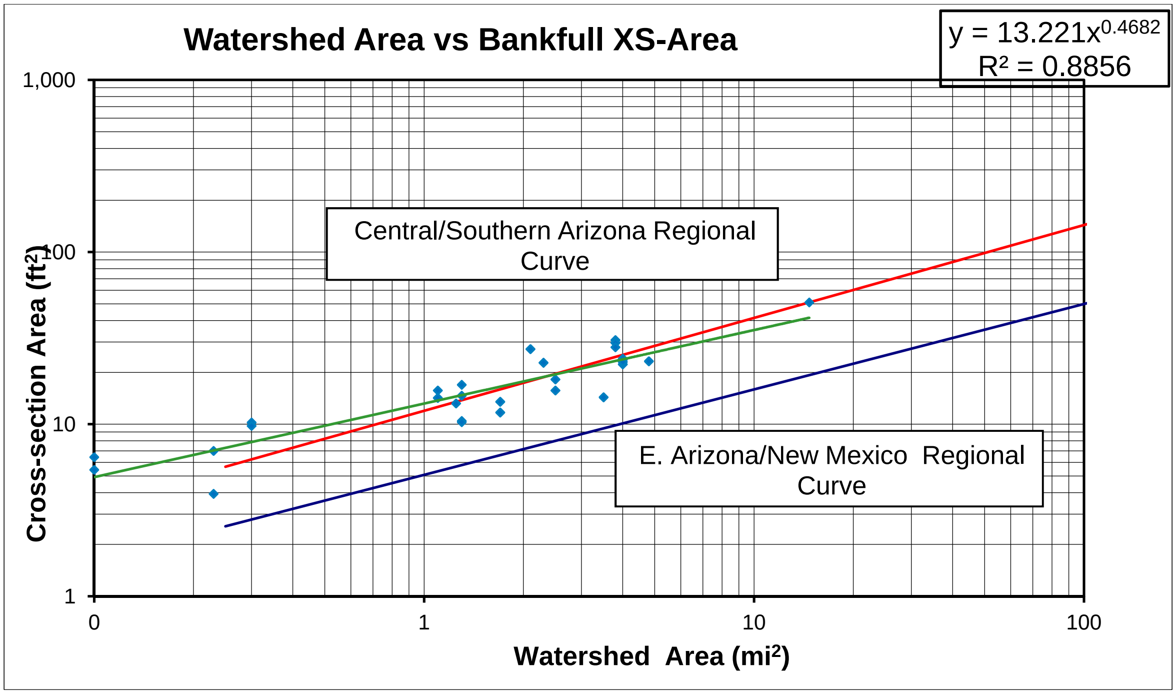


Figure 3. Watershed area vs. bankfull cross-section area.

Red and blue lines represent regional curves for Arizona and New Mexico. Green line indicates local conditions of post fire channels from historical burned areas. While there is no significant difference between the local post burn channels and the overall Arizona regional curve, the local curve was utilized for analysis of bankfull discharge.

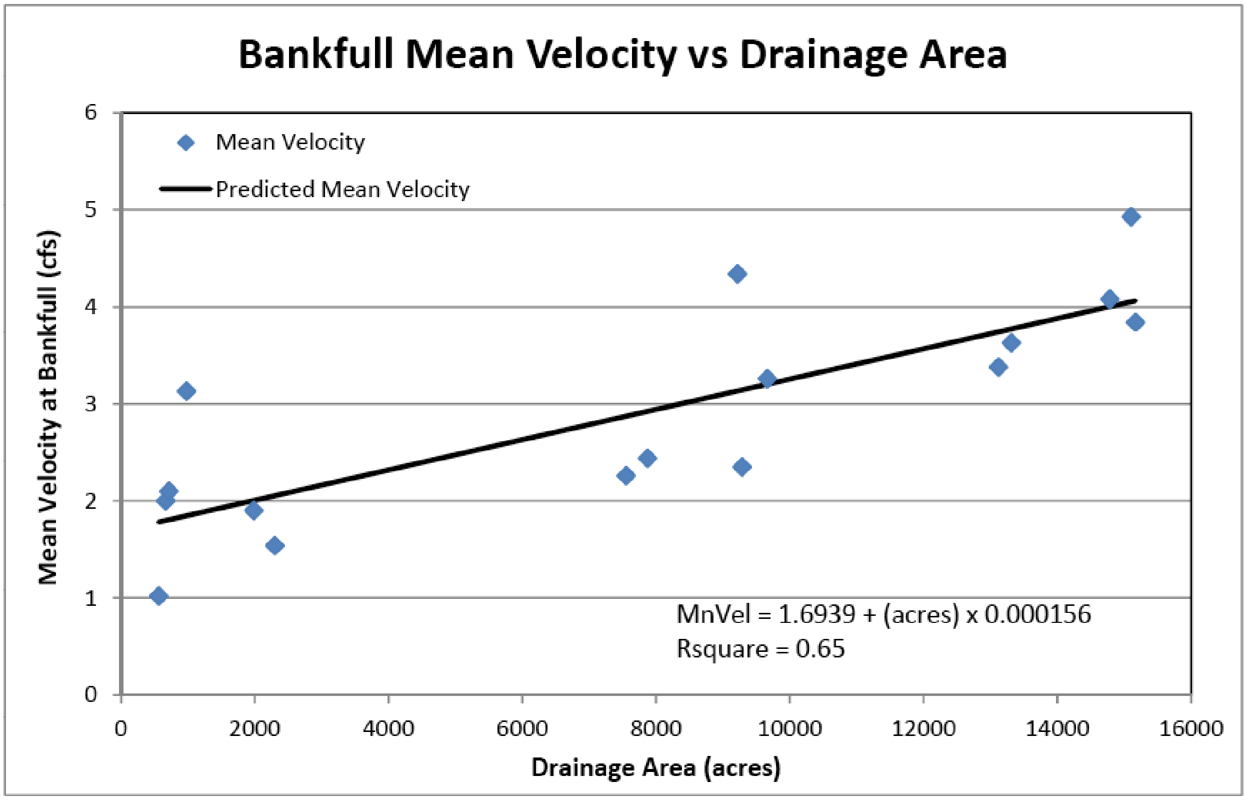


Figure 4. Watershed area vs. bankfull velocity.

Data are from Nankervis unpublished data.

Table 1. Estimated bankfull discharge for each sub-watershed.

Table indicates the change in water yield due to post-fire conditions, the mean daily bankfull discharge and the instantaneous bankfull discharge. Difference between mean and instantaneous discharge is due to rain generated storm peaks that produce "flashy" hydrology.

Basins	Total Watershed Area (acres)	Water Yield Change (in)	Mean Daily Bankfull Discharge (cfs)	Instantaneous Qbf cfs
Copeland	1421.5	5.9	14.2	37.3
Glodia	293.4	5.0	6.4	16.7
Government Tank	3909.1	2.4	26.9	70.7
Lenox	1828.5	5.0	16.5	43.3
Offenhauser	1541.3	1.2	14.9	39.1
Paintbrush-Siesta	1518.6	6.0	14.7	38.6
Peaceful Way	1084.7	7.4	12.2	32.1
Rope Arabian	1010.3	6.2	11.8	31.1
Siesta-Paintbrush	615.7	6.1	9.2	24.2
Thames	1115.7	6.3	12.4	32.7
SubBasins				
Copeland - H	950.4	6.2	11.4	30.0
Paintbrush-Siesta - B	101.2	7.4	3.9	10.3
Paintbrush-Siesta - C	93.0	8.1	3.7	9.8
Peaceful Way - I	818.2	7.9	10.5	27.6
Rope Arabian - E	55.8	5.6	2.9	7.7
Rope Arabian - G	243.8	6.1	5.8	15.2
Rope Arabian - K	250.0	7.2	5.9	15.5
Siesta-Paintbrush - F	260.3	7.4	6.1	15.9
Thames - J	186.0	7.5	5.2	13.7
Thames - L	378.1	7.0	7.1	18.8

REGIONAL SEDIMENT RATING CURVE DEVELOPMENT

Objective

The purpose for developing a regional sediment rating curve is to allow for the estimation of sediment loads within regional stream channels at bankfull flows. Regional sediment loadings are needed in order to calculate the capacity of channels to transport sediment and to design stabilized channels. Estimates of bankfull sediment loads are utilized to expand dimensionless sediment rating curves developed by Rosgen et al 2010 to local conditions.

Basic Steps

1. Utilize suspended sediment rating curves developed for six experimental Beaver Creek watersheds.
2. Determine suspended sediment concentrations at bankfull discharge for each of the Beaver Creek watersheds and from Southern Colorado regional curves developed by Rosgen.
3. Develop a regional curve for bankfull suspended sediment concentrations.
4. Utilize the suspended sediment to bedload sediment relationship developed by Jim Nankervis to determine bedload transport rates for subbasins within the Shultz Fire study area.

Methodology

Suspended sediment curves were developed by Lopes et al. (2001) for several watersheds in Arizona. Six watersheds were utilized in Beaver Creek (watersheds 1, 2, 3, 12, 13, and 14) that had similar soil conditions and vegetation type to the Schultz Fire area to calculate the suspended sediment concentrations at bankfull discharge for each of these watersheds. Bankfull discharge was determined using flood frequency evaluation to determine bankfull discharge at each watershed. Bankfull discharge is based on a return interval of 1.5 years, which has been shown to be an average return interval for bankfull flows within the region (Moody et al 2001).

Bankfull suspended sediment concentrations were calculated utilizing curves developed by Lopes (2001) and plotted against watershed size. Two regional suspended sediment curves were developed. One curve represents local baseline (or good) conditions and the other represents disturbed (or poor) conditions. Five watersheds were utilized to develop the local ‘good’ condition curve. The ‘poor’ condition curve was developed by utilizing the same slope as the ‘good’ condition curve and fitting the curve through the data point for Watershed 12 (poor condition). These curves are shown in and are compared to similar curves developed by Rosgen (2010) for North-Central Colorado River Basin streams with both poor and good stability. The approximate difference between the good and poor conditions curves is similar (order of magnitude) to the difference between the Colorado Curves and is within the approximate difference projected by Simon (2004).

Bedload transport rates were determined from suspended sediment concentrations by a general relationship between bankfull suspended sediment yield (tons/acre) and bankfull bedload estimates (tons/acre) for 14 western watersheds (Nankervis unpublished data) and from a relationship of bankfull discharge to bankfull bedload from poor condition streams with high bedloads developed from data collected by Dave Rosgen (Wildland Hydrology) and others. These relationships are shown in . Relationships for good conditions streams, poor condition streams and the suspended sediment to bedload sediment are all shown for comparison. Upon inspection of the site, a determination was made that the best bedload estimates for the Shultz Fire area would be determined by the poor condition, high bedload data provided by Wildland Hydrology.

For the purposes of the FlowSed/PowerSed sediment transport model the suspended sediment concentration was split into the sand fraction (settle able material) and wash load. The sand fraction was estimated utilizing the sand fraction of the local soil type (~65% of suspended material). Results for each subasin are shown in .

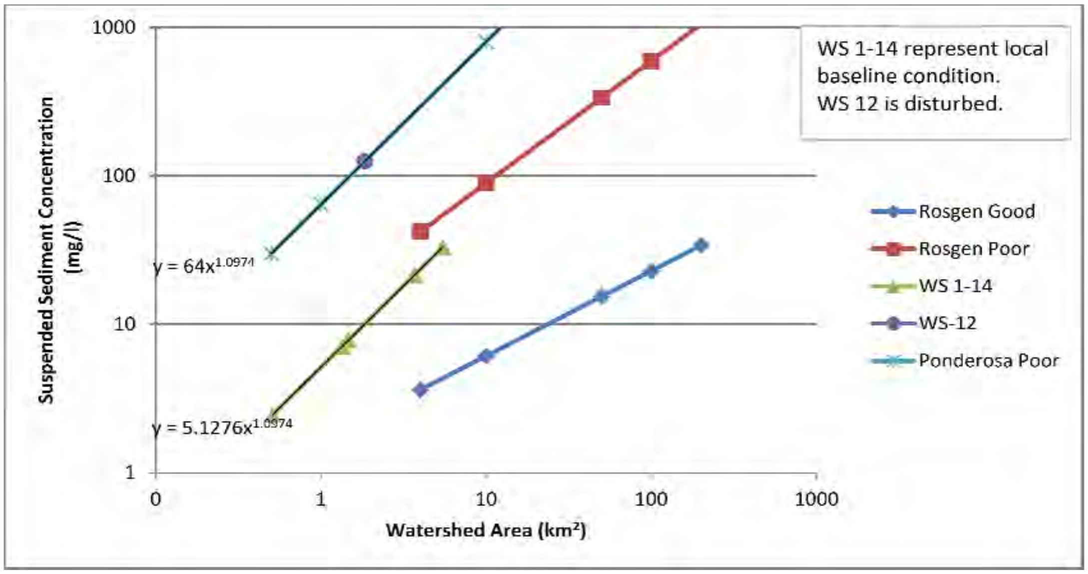


Figure 5. Regional bankfull suspended sediment curve.

Regional curve was developed from Beaver Creek Experimental Watershed data for good and poor condition watersheds. Southern Colorado regional curves developed by David Rosgen are shown for reference.

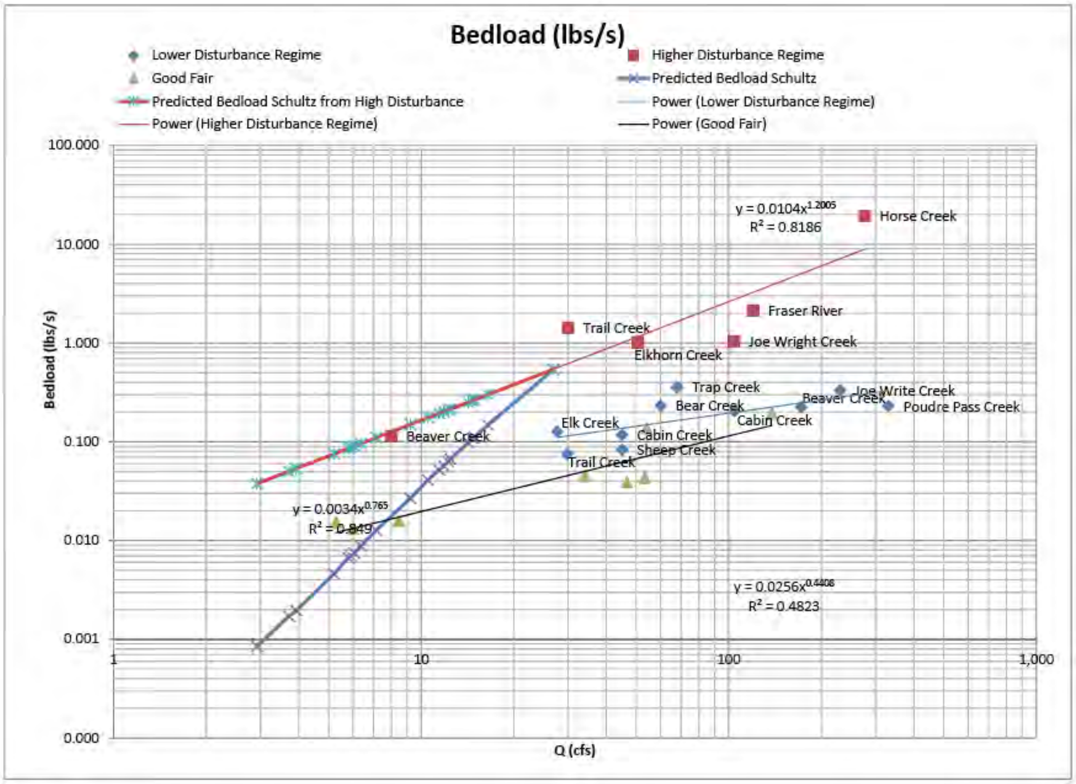


Figure 6. Bedload estimates for bankfull discharge.

Data shows bankfull discharge and bedload sediment for good, fair, and poor condition streams as well as bedload predicted from suspended sediment for Shultz Fire area. The relationship for bankfull bedload for poor condition streams was utilized to predict bedload for Shultz Fire Area. Predicted data are shown in blue along red trend line.

Table 2. Bankfull bedload and suspended sediment estimates for sub-basins.

Basins	Total Watershed Area (Acres)	Total Watershed Area (sq miles)	Bankfull Suspended Sediment Conc. (mg/l)	Bankfull Discharge (cfs)	Bedload (lb/s)	Suspended Sediment Sand Fraction (65%)
Copeland	1421	2.22	437	37	0.243	284
Glodia	293	0.46	77	17	0.020	50
Government Tank	3909	6.11	1325	71	1.376	861
Lenox	1829	2.86	576	43	0.370	374
Offenhauser	1541	2.41	477	39	0.279	310
Paintbrush-Siesta	1519	2.37	469	39	0.271	305
Peaceful Way	1085	1.69	324	32	0.157	211
Rope Arabian	1010	1.58	300	31	0.141	195
Siesta-Paintbrush	616	0.96	174	24	0.064	113
Thames	1116	1.74	335	33	0.164	218
SubBasins						
Copeland - H	950	1.49	281	30	0.127	182
Paintbrush-Siesta - B	101	0.16	24	10	0.004	16
Paintbrush-Siesta - C	93	0.15	22	10	0.004	14
Peaceful Way - I	818	1.28	238	28	0.100	155
Rope Arabian - E	56	0.09	12	8	0.002	8
Rope Arabian - G	244	0.38	63	15	0.015	41
Rope Arabian - K	250	0.39	65	15	0.016	42
Siesta-Paintbrush - F	260	0.41	68	16	0.017	44
Thames - J	186	0.29	47	14	0.010	30
Thames - L	378	0.59	102	19	0.030	66

SEDIMENT TRANSPORT ANALYSIS

The previously developed data for hydrology and sediment load were utilized to predict sediment transport through existing and proposed design channel cross-sections within each sub watershed to determine sediment transport capacity and sediment sourcing from channel transport. This analysis was made utilizing the FlowSed/PowerSed model within RiverMorph™ software. This platform allows for the comparison of mean annual sediment transport (tons/year) in supply and project cross-sections under the same flow regime. This analysis can be utilized to compare sediment transport under current conditions and under proposed conditions. The results allow estimation of the sediment reduction potential of converting to over-widened, aggrading channels or conversion of incised channels to stable channel configurations. The model also allows for the use of different dimensionless sediment transport equations to reflect the changing channel conditions and associated change in sediment transport capacity.

Models were run on measured cross sections and conceptual design cross sections for several scenarios throughout each sub basin. These are:

- Current supply channel and current project channel cross sections
- Current and proposed supply channels on proposed design channels
- Proposed design supply channels and proposed conceptual transport channels through the neighborhood.

From these results channel transport capacity was compared to sediment sources from roads, hill slopes and channel banks to determine channel stability and storage. Additionally, comparison of current channels to proposed channels give strong indicators of the effectiveness of design treatments, and finally analysis of supply cross sections entering the neighborhood with transport channels through the neighborhood provides information on the effectiveness of these treatments.

RESULTS

CHANNEL TYPES

Each watershed has considerable length of incised “G” and “F” type channels with high sediment contribution from channel and bank processes. Bank erosion from these types of channels can be an order of magnitude higher sediment contribution from bank and channel processes (Rosgen 2002). Aggrading channels “D types” or valley types that can support aggrading channels are generally located along the FR 420 and just upstream of the USFS boundary with private lands, although several watersheds have relatively extensive aggrading channels throughout. 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 results of the Rosgen (1996) channel type mapping are shown in Figure 7 .

The channel type mapping provides a map of priority treatment areas for sediment reduction. Conversion of “F” and “G” channel types to more stable “A” or “B” forms can have large sediment reduction potential due to the redistribution of shear stress away from the toe of the bank and towards the center of the channel. Rates of down cutting in incised channels can be reduced by allowing higher flows to spread onto a small flood plain typical of the more stable forms. Degraded channels are expected to evolve towards more stable forms over time. The channels will follow a general trend of incision, widening and formation of stable channel forms within the new incised stream bed (Schumm and Lichty, 1965). The objective of conversion from stable to unstable forms of channel shortens this natural process and reduces the amount of sediment that would be released over time as the channel deepens and widens to create a new pattern, dimension, and profile.

While channels upstream of FR420 are have a very high potential for sediment contributions related to instability, channels in less steep slopes below the road are far more accessible to equipment. Channels below the FR420 provide the greatest potential for restoration. The approximate total lengths of each channel type downstream of the FR 420 are:

Type	**Miles**
A	**2.4**
B	**5.3**
D	**11.8**
F	**5.9**
G	**8.0**

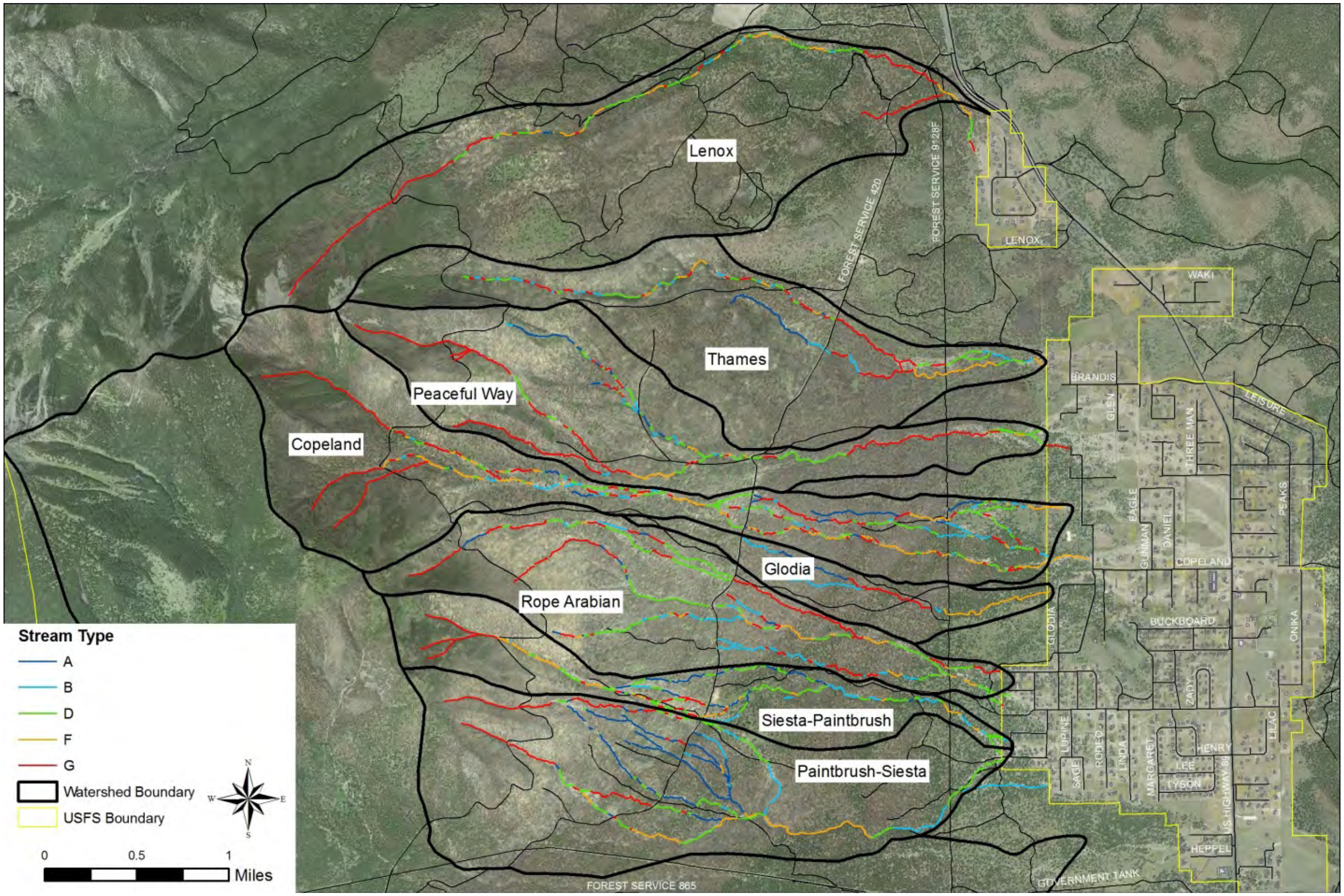


Figure 7. Mapped channel types.

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.

CURRENT EROSION RATES

The general condition of streambanks and channels are shown in Figure 8. The surveys indicated that there were many continuous reaches of incised channels with steep erodible banks. The streambank, hill slope, and road erosion rates from each of the watersheds were combined to produce the estimated erosion rates shown in Table 1. Each watershed was subdivided into three main reaches (above waterline, waterline to 420 Rd. and 420 road to USFS boundary to show relative contributions of each portion of the watershed. Because the USFS ERMITT analysis did not break the watersheds into a sub watershed at the Waterline Road, the hill slope and road erosion rates are reported as a combination of the reaches “Above Waterline” and “Waterline to ~FR420.” Stream lengths are generally much longer below the FR 420 road due to the multiple split channels in this reach.

Table 3. Schultz Fire - Current Sediment Sources and Supply Rates

	Watershed	Channel Length (ft)	Streambank Erosion (tons/yr)	Hillslope Erosion* (tons/yr)	Road Erosion* (tons/yr)	**Total (tons/yr)**	**Total (tons/yr/ft)**
Copeland	Above Waterline	10,564	4,034				
	Waterline to ~FR420	23,156	8,031	3753**	2.4**		
	~FR420 to FS Boundary	40,799	7,598	188	0.9		
	Copeland Total	74,518	19,662	3941	3.3	**23,607**	**0.32**
Glodia	~FR420 to FS Boundary						
	Glodia Total	12,896	314	118	0.6	**432**	**0.03**
Lenox	Above Waterline	6,327	2,416				
	Lenox Total	28,921	6,743	2235	3.1	**8,981**	**0.31**
Paintbrush-Siesta	Above Waterline	3,700	1,413				
	Waterline to ~FR420	17,428	3,967	892**	0.4**		
	~FR420 to FS Boundary	40,151	3,117	1331	2.5		
	Paintbrush-Siesta Total	61,279	8,497	2223	2.9	**10,723**	**0.17**
Peaceful Way	Above Waterline	3,772	1,440				
	Waterline to ~FR420	26,756	35,790	2227**	1.7**		
	~FR420 to FS Boundary	12,566	368	128	0.5		
	Peaceful Way Total	43,093	37,598	2355	2.2	**39,955**	**0.93**
Rope Arabian	Above Waterline	1,973	753				
	Waterline to ~FR420	24,469	7,620	1359**	1.1**		
	~FR420 to FS Boundary	30,253	2,327	245	0.9		
	Rope Arabian Total	56,695	10,700	1604	2.0	**12,306**	**0.22**
Siesta-Paintbrush	Above Waterline	4,964	1,896				
	Waterline to ~FR420	14,496	11,095	1275**	0.7**		
	~FR420 to FS Boundary	22,446	1,865	144	1.3		
	Siesta-Paintbrush Total	41,907	14,855	1419	2.0	**16,276**	**0.39**
Thames	Waterline to ~FR420	15,168	1,554	1449	1.1		
	~FR420 to FS Boundary	16,378	498	323	1.0		
	Thames Total	31,545	2,052	1772	2.1	**3,826**	**0.12**
	Total	**350,853**	**100,422**	**15,667**	**18.2**	**116,107**	**0.33**

* Rates adapted to the above watersheds from Schultz Hill Slope and Road Erosion Model (USFS) data
** Includes the sum of both "Above Waterline" and "Waterline to ~FR420" values

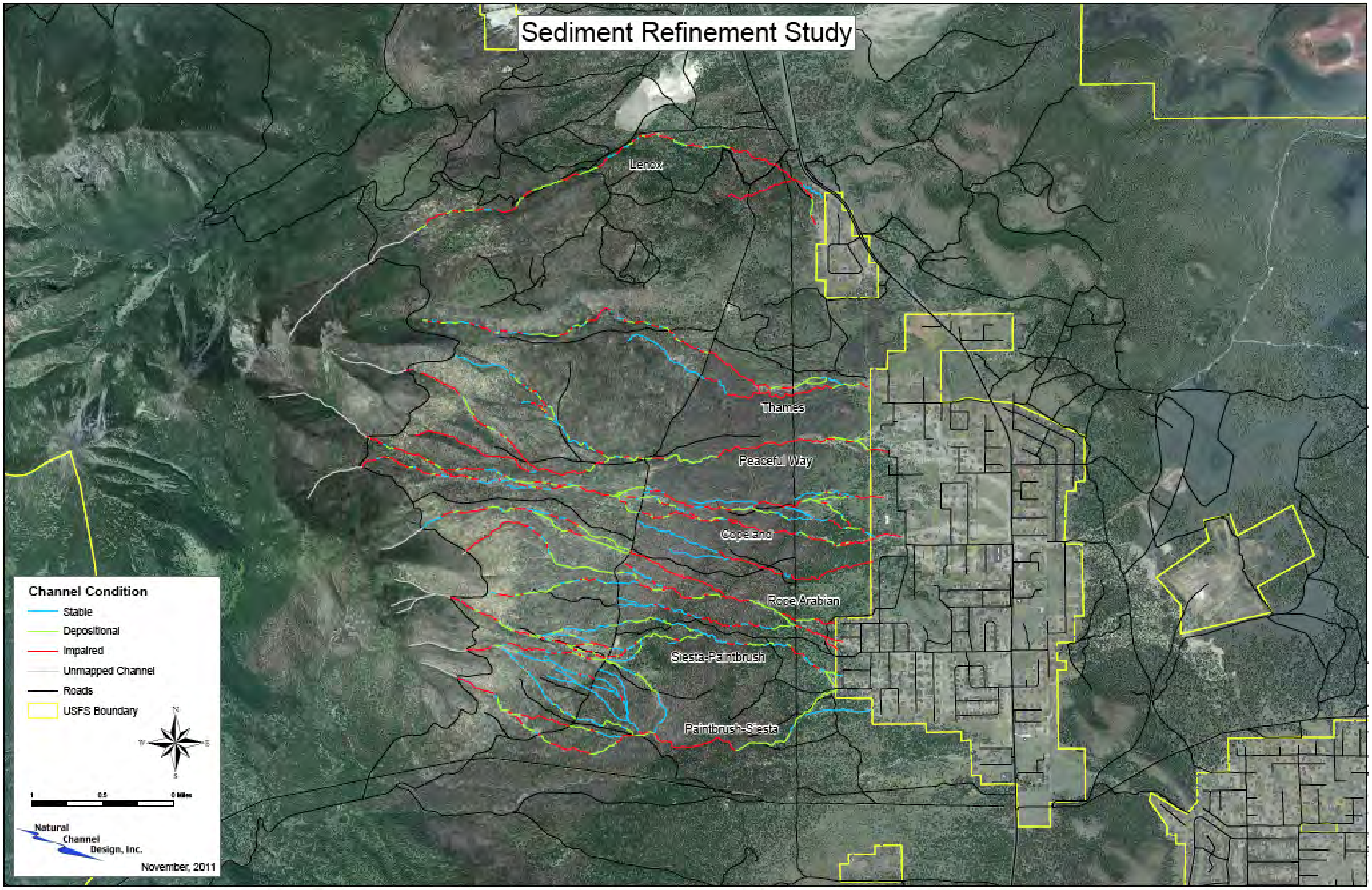


Figure 8. Channel and streambank conditions in Shultz Fire Area.

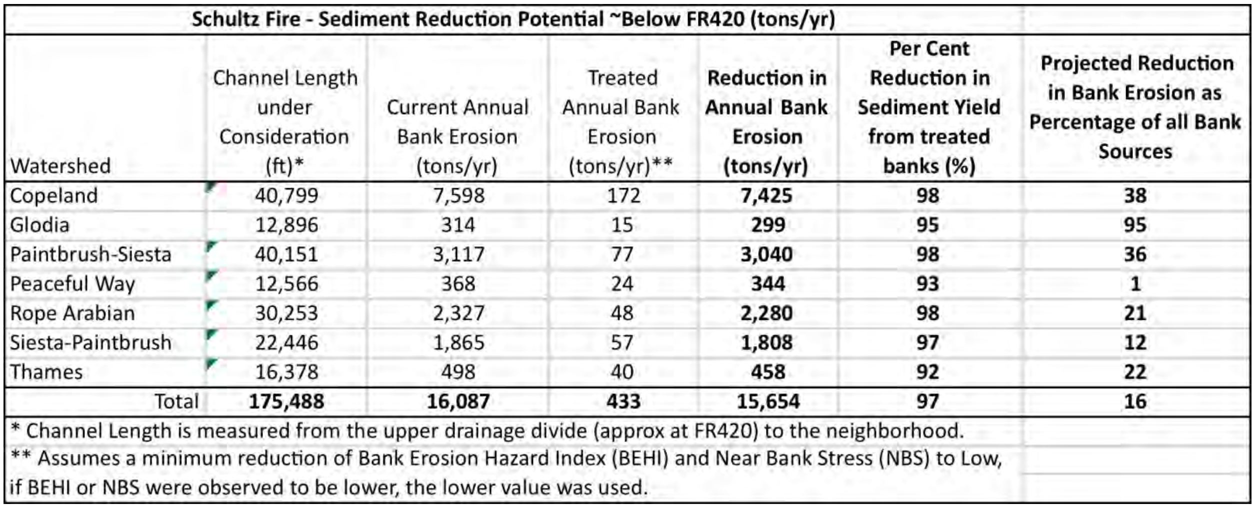
Red lines indicate poor condition, incised channels with highly erodible streambanks. Blue indicates relatively good condition channels with low to moderate bank erosion rates. Green indicates channels that are currently aggrading or in areas that can support further aggradation of sediments. Banks in these reaches are generally, low and stable.

RESULTS OF MODELED BANK EROSION TREATMENT SCENARIOS

The effects of successful bank stabilization were modeled with the BANCS model: reducing the BEHI and NBS values to a low rating from the current high, very high, and extreme ratings. The results of these analyses are tabulated in Table 4.

The results in Table 4 represent portions of the watershed from near FR420 to the USFS boundary at the neighborhood. Reduction in bank erosion rates can be very successful at reducing the amount of sediment contributed from the banks. However, this sediment reduction is limited in scope due to the in accessibility of the upper watershed, which also has very high sediment loads. Total reduction in sediment loads from bank restoration below FR420 range from approximately 1% at Peaceful Way to 38% at Copeland. Glodia watershed has a very high potential for sediment reduction from bank stabilization (95%) because a majority of the channel length is found below FR420. However, the overall reductions in the total sediment from bank stabilization below FR420 is not enough to achieve the goals necessary to promote flood relief in the neighborhoods.

Table 4. Sediment Reduction Potential (Low BEHI & NBS) Below ~FR420
Percent reduction in total sediment yield represents the reduction achieved from treating bank erosion in the lower watershed (FR 420 to FS Boundary).



Schultz Fire - Sediment Reduction Potential ~Below FR420 (tons/yr)

Watershed	Channel Length under Consideration (ft)*	Current Annual Bank Erosion (tons/yr)	Treated Annual Bank Erosion (tons/yr)**	**Reduction in Annual Bank Erosion (tons/yr)**	**Per Cent Reduction in Sediment Yield from treated banks (%)**	**Projected Reduction in Bank Erosion as Percentage of all Bank Sources**
Copeland	40,799	7,598	172	**7,425**	**98**	**38**
Glodia	12,896	314	15	**299**	**95**	**95**
Paintbrush-Siesta	40,151	3,117	77	**3,040**	**98**	**36**
Peaceful Way	12,566	368	24	**344**	**93**	**1**
Rope Arabian	30,253	2,327	48	**2,280**	**98**	**21**
Siesta-Paintbrush	22,446	1,865	57	**1,808**	**97**	**12**
Thames	16,378	498	40	**458**	**92**	**22**
Total	**175,488**	**16,087**	**433**	**15,654**	**97**	**16**

* Channel Length is measured from the upper drainage divide (approx at FR420) to the neighborhood.
** Assumes a minimum reduction of Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) to Low, if BEHI or NBS were observed to be lower, the lower value was used.

Analysis of **Error! Reference source not found.** shows that hill slope and road erosion are minimal below FR420. It also shows that a majority of the sediment supply is from channel processes, not hillside and road erosion. Further analysis shows that treatment of these eroding channels can achieve high rates of sediment reduction, areas that can be treated. Comparing the two reductions in treated BER in and Table 4 shows an order of magnitude difference between the two treatment scenarios. One can expect actual results to likely fall somewhere between these two sets of values, but a large reduction in sedimentation can be achieved through restoration. The findings that a majority of the sediment is coming from higher in the watershed suggest that storage of the sediment above FR420 in combination with source reduction treatments below FR 420 would produce the greatest sediment reductions.

SEDIMENT TRANSPORT RESULTS

Channel cross-sections were measured at representative reaches throughout each watershed (Figure 9). Descriptions of cross-sections are provided in Appendix B.

Comparison of channel transport through current channel cross-sections with hillslope, road and bank sediment supply indicates that there is more sediment coming into channels than can adequately be transported through the lower portion of the watersheds. All representative cross sections indicate that there should be significant aggradation of sediments throughout the sub-basin channels (Table 5). This fits observations of most channels in the lower portion of the watershed that show signs of deposition of finer sediments and the findings of Carrol (2010). This aggradation likely does not represent a stable situation in many reaches. In narrowly confined channels, finer sediments are easily picked up and rerouted by storm flows resulting in channel beds which are easily reactivated and continually contributing sediment to downstream reaches.

However, several areas within the watershed have valley widths that are wide enough to support stable aggradation of sediment. These areas are located generally along the FR 420, and upstream of the USFS boundary with private lands. In an effort to estimate the magnitude of sediment storage within these areas, the FlowSed/PowerSed model was used to compare existing supply channels with existing and proposed widened, aggrading channels. The model was again utilized to estimate the reduction in sediment contribution from poor condition channels by comparing existing and proposed channel geometry. A good/fair condition dimensionless sediment rating curve was utilized to model restored channels. The results of this analysis show that large proportions of the routed sediment can be stored in over-widened aggrading channels (Table 6). Given the large supply and limited transport capabilities indicated in Table 5, storage of sediment within channels is an extremely function to improve if sediment supply to the neighborhoods is to be reduced.

Sediment supply will also need to be addressed where ever possible to promote return of watershed function. Analysis of sediment transport also indicates that there is a significant amount of transported sediment that can be eliminated by the conversion of degraded single thread channels. These channels are currently either “F” or “G” type channels that have a high contribution of sediment from the channel bed and the banks. Reshaping the channels to appropriately sized “B” channels redistributes the flow stresses on banks and channel bottoms, allowing a reduction in the sediment transport curve from ‘poor” to ‘good/fair’. Comparison of sediment transport at existing and proposed conditions shows high levels of sediment transport reduction that can be applied throughout the watershed (Table 7).

Analyses of the final cross sections upstream of the USFS boundary provide an estimate of sediment transported into the neighborhoods, which requires routing through single thread channels and engineered conveyances. Comparison of these sediment loads to the sediment transport capacity of the neighborhood flood channel system will provide insight as to the feasibility of constructing flood conveyance channels through private lands. The results of this analysis suggest that single thread channels through the neighborhood will have the capacity to transport sediment without being overwhelmed by sediment from USFS lands once the USFS channels have been restored. See Table 8 for results.

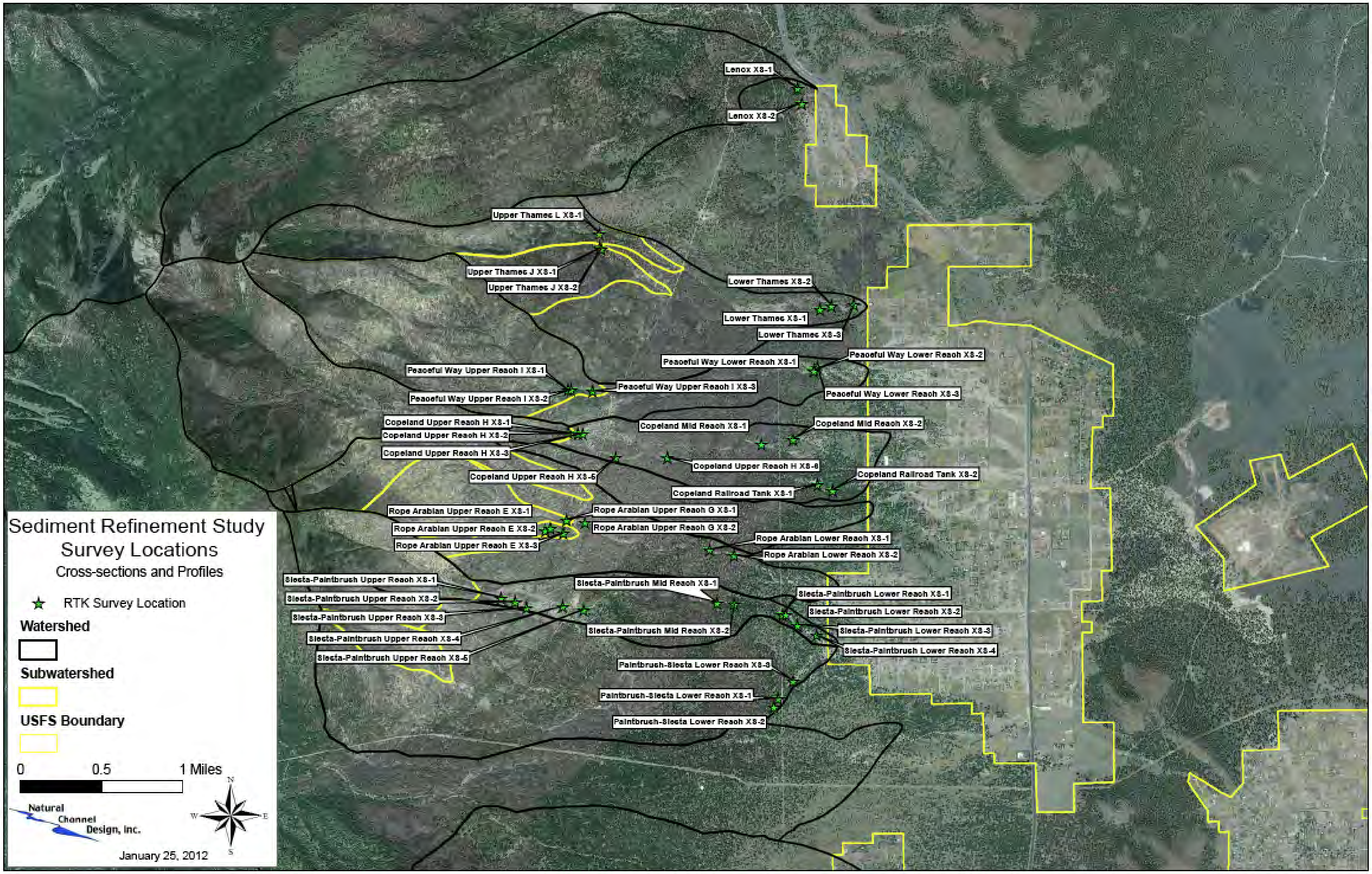


Figure 9. Channel cross section survey locations.

Table 5. Comparison of channel transport function with hillslope, road and bank supply.

Comparison of supply in each watershed indicates that there is a potentially unlimited supply that could only be slowly transported through existing channels. Consequently, stable sediment storage within the channel will necessarily be an important component of the restoration concept.

		Existing (Post-Fire)		Introduced Sediment							Streambed Scour or Deposition	
				Streambank Erosion		Roads		Hillslope Erosion				
Location	Drainage Area (mi^2)	Water Yield (ac-ft/yr)	Flow Related Sediment (Supply-XS) (tons/yr)	(tons/yr)	% of Total Introduced Sediment	(tons/yr)	% of Total Introduced Sediment	(tons/yr)	% of Total Introduced Sediment	Total (tons/yr)	Scour or Deposition	(tons/yr)
Copeland Middle Reach (North Copeland)	2.3	700	402	19,662	83	3.3	0.01	3,941	17	23606	Deposition	-23204
Copeland Lower Reach	2.3	700	402	19,662	83	3.3	0.01	3,941	17	23606	Deposition	-23204
Lenox	2.9	761	499	6,743	75	3.1	0.03	2,235	25	8981	Deposition	-8482
Paintbrush-Siesta Lower Reach	2.4	763	428	8,497	79	2.9	0.03	2,223	21	10723	Deposition	-10295
Peaceful Way Lower Reach	1.7	666	328	37,598	94	2.2	0.01	2,355	6	39955	Deposition	-39627
Rope Arabian Lower Reach	1.6	518	285	10,700	87	2.0	0.02	1,604	13	12306	Deposition	-12021
Siesta-Paintbrush Middle Reach	0.9	315	204	14,855	91	2.0	0.01	1,419	9	16276	Deposition	-16072
Siesta-Paintbrush Lower Reach	1.0	315	204	14,855	91	2.0	0.01	1,419	9	16276	Deposition	-16072
Thames Lower Reach	1.7	582	317	2,052	54	2.1	0.05	1,772	46	3826	Deposition	-3509
Copeland - H	1.5	491	277	15,629	81	2.4	0	3,753	19	19384	Deposition	-19107
Peaceful Way - I	1.3	537	264	37,230	94	1.7	0.00	2,227	6	39459	Deposition	-39195
Rope Arabian - E	0.1	26	48.1	853	86	0.1	0.01	138	14	992	Deposition	-943
Rope Arabian - G	0.4	123	104	3,728	86	0.5	0.01	605	14	4334	Deposition	-4230
Siesta-Paintbrush - F	0.4	161	118	12,991	91	0.7	0.00	1,275	9	14267	Deposition	-14149
Glodia	0.5	123	na	314	73	0.6	0.14	118	27	433	Deposition	na

Table 6. Results of sediment transport models on existing and proposed over-widened channel configurations.

Table shows results of modifying existing gullied or degraded "D" channels into more efficient "D" channels with higher sediment storage capacity. These cross sections are typical of cross sections in valley types appropriate for stable aggrading channels. Some drainages have multiple opportunities for placement of storage channels. Results do not indicate the total amount of in-channel storage potential for a watershed, only the potential storage at a single cross section due to sediment transport function.

				Current Condition - Supply				Current Condition - Project Channel				Treated Condition - Project Channel			Pre-treatment	Post-Treatment	Post-Treatment
	Basins	Total Wateshed area (sq mi)	Bankful Area	BedLoad Transport tons/yr	Suspended Transport tons/yr	Total Transport tons/yr	Slope	BedLoad Transport tons/yr	Suspended Transport tons/yr	Total Transport tons/yr	Slope	BedLoad Transport tons/yr	Suspended Transport tons/yr	Total Transport tons/yr	Channel Storage tons/yr	Channel Storage tons/yr	Treated Storage % of Supply
D-F Conversion	Copeland Middle Reach	2.2	19.5	324	78	402	0.042	286	42	328	0.043	56	42	98	74	304	76
	Copeland Lower Reach	2.3	20.0	324	78	402	0.052	110	53	63	0.052	60	42	102	339	300	75
	Lenox	2.9	21.9	388	111	499	0.045	435	128	563	0.045	69	61	130	-64	369	74
	Paintbrush-Siesta Lower Reach	2.4	20.0	339	89	428	0.032	339	92	431	0.036	59	48	107	-3	321	75
	Peaceful Way Lower Reach	1.7	17.2	273	55	328	0.045	341	88	429	0.066	75	30	105	-101	223	68
	Rope Arabian Lower Reach	1.6	16.8	247	38	285	0.05	69	21	90	0.05	46	21	67	195	218	76
	Siesta-Paintbrush Middle Reach	0.9	11.3	190	14	204	0.053	35	8	43	0.04	34	8	42	161	162	79
	Siesta-Paintbrush Lower Reach	1.0	13.5	190	14	204	0.047	72	43	115	0.035	5	8	13	89	191	94
	Thames Lower Reach	1.7	17.5	268	49	317	0.029	49	28	77	0.028	47	28	75	240	242	76
	Copeland - H	1.5	16.3	244	33	277	0.06	214	75	289	0.07	10	19	29	-12	248	90
	Peaceful Way - I	1.3	15.2	232	32	264	0.048	209	19	226	0.045	40	16	56	38	208	79
	Rope Arabian - E	0.1	4.5	48	0.1	48.1	0.054	47	0.1	47.1	0.058	4	0.1	4.1	1	44	91
	Rope Arabian - G	0.4	8.8	102	2	104	0.066	22	1	23	0.066	18	1	19	81	85	82
	Siesta-Paintbrush - F	0.4	9.2	116	2	118	0.07	38	2	40	0.088	22	1	23	78	95	81
These locations represent potential areas to treat a reach currently sourceing sediment(F) to a condition within the reach where the channel would be storing sediment (D).	These are representative reaches that have been field surveyed to determine sediment transport capacity.	Watershed area determined by watershed divide within a GIS	This bankful area has been determined through the use of a local curve and is based upon contributing watershed area to these points.	These values are the result of the FLOWSED portion of Rivermorph. The entered sediment rating curves did not include washload. These values represent the amount of sediment that the current supply channels can transport in a year given the current flow regime and sediment inputs.			Slope determined through field surveys	These values are the result of the POWERSED portion of Rivermorph. The entered sediment rating curves did not include washload. These values represent the amount of sediment that can be transported over FAN type reachs in the current condition. Currently many of these FAN type reaches have been incised with F channels which are promoting the			Slope determined through field surveys	These values are the result of the POWERSED portion of Rivermorph given a restored condtion of the FAN type reaches. The entered sediment rating curves did not include washload. These values represent the amount of sediment that can be transported over FAN type reachs in the current condition. These values can be compared to the Current			Current condition sediment storage potential upon the FAN reaches. Negative values denote transport rather than storage (positive values). The Supply Total Transport minus	Restored condition sediment storage potential upon the FAN reaches. The Supply Total Transport minus the Treated (restored) Current Condtion Project Channel Total Transport.	The percent of storage upon the treated(restored) FAN reach. The Treated Condtion Project Total Transport divided by the Supply Total Transport.

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Table 7. Results of sediment transport models on existing and proposed single-thread channels.

Table shows results of modifying existing gullied or degraded single-thread channels into more stable single thread channels. These cross sections are typical of valley types appropriate for stable, single-thread channels. Drainages have multiple opportunities for restoration of single thread channels and results do not indicate the total sediment transport reduction for a given watershed, only the potential reduction in transport due to channel restoration at a given cross section.

				Current Condition - Supply				Treated Condition - Project		
	Basins	Total Wateshed area (sq mi)	Bankful Area	BedLoad Transport tons/yr	Suspended Transport tons/yr	Total Transport tons/yr	Slope	BedLoad Transport tons/yr	Suspended Transport tons/yr	Total Transport tons/yr
F-B Conversion	Thames Upper Reach L XS-1	0.6	10.7	9	5	14	0.086	2	3	5
	Copeland Middle Reach XS-1	2.2	19.5	38	81	119	0.042	8	40	48
	Peaceful Way Lower Reach XS-1	1.7	17.2	35	56	91	0.45	3	22	25
	Thames Lower Reach XS-1	1.7	17.5	29	48	77	0.033	3	20	23
	Siesta-Paintbrush Middle Reach XS-1	1.0	11.3	15	14	29	0.053	7	11	18
	Paintbrush-Siesta Lower Reach	No "F" cross-section measured, predominantly D channel types								
	Rope Arabian Lower Reach	No "F" cross-section measured, predominantly D channel types								
	Lenox	Conversion would below the 420 road would be from F to D								
These channel types (F) represent reaches that currently contain vertical banks which are a significant sediment source. Treatment of these reaches to a more favorable condition (B) would reduce the erodeablity of the banks, thus decreaseing their production of sediment.	These are representative reaches that have been field surveyed to determine sediment transport capacity.	Watershed area determined by watershed divide within GIS	This bankful area has been determined through the use of a local curve and is based upon contributing watershed area to these points.	These values are the result of the FLOWSED portion of Rivermorph. The entered sediment rating curves did not include washload. These values represent the amount of sediment that the current supply channels can transport in a year under good/fair conditions			Slope determined through field surveys	These values are the result of the POWERSED portion of Rivermorph given a restored condtion of the F type reaches. The entered sediment rating curves did not include washload. These values represent the amount of sediment that is routed through the reach on an annual basis given a "Good-Fair" sediment rating curve.		

Table 8. Estimated output of sediment from USFS lands after restoration of single thread and aggrading channels.

Results indicate the mean annual sediment transport across the final over widened aggrading channel near the USFS boundary. Sediment rating curves were adjusted to good/fair condition to represent a high percentage of restored channels in each watershed. Lenox is not adjusted to good/fair because of the relatively small opportunity for restoration in this watershed. Comparison with conceptual design channels through private lands indicate that design channels will be able to transport sediment supply once restoration practices are in place.

		Output from Stable Reach within Forest			Output of D reach at Forest Boundary					Design Channels through the residential area		
		BedLoad Transport tons/yr	Suspended Transport tons/yr	Total Transport tons/yr	BedLoad Transport tons/yr	Suspended Transport tons/yr	Total Transport tons/yr			BedLoad Transport tons/yr	Suspended Transport tons/yr	Total Transport tons/yr
Forest Outlet Conditions Treated	Lenox	388	111	499	69	61	130	F-D poor Condition		42	115	157
	Thames	29	48	77	0.4	17	17.4	B-D Good/Fair Condtion		29	48	77
	Peaceful Way	35	56	91	6	25	31	B-D Good/Fair Condtion		35	56	91
	Copeland	38	81	119	1	31	32	B-D Good/Fair Condtion		33	71	104
	Rope Arabian	26	39	65	25	37	62	D-D Good/Fair Condtion		26	39	65
	Siesta-Paintbrush	15	14	29	0	5	5	B-D Good/Fair Condtion		15	14	29
	Paintbrush-Siesta	41	93	134	38	90	128	D-D Good/Fair Condtion		41	93	134

RECOMMENDATIONS

Analysis of the sediment transport and supply for current and proposed conditions under watershed restoration indicate that it will be possible to inhibit sediment transport on USFS lands to the point that single thread flood conveyance channels through the neighborhood will be feasible. However, the results also suggest that because the erosion and delivery rates are currently very high, a large portion of each watershed will need to be restored before sediment reduction targets can be achieved. It may not be practical to commit to implementation of structural flood relief efforts in the neighborhood without first committing to restore substantial lengths of channel within the supply watershed. As such, each watershed should be considered independently to insure that there are no social, legal or logistical impediments to doing the work to achieve the sediment reduction necessary to trigger work in the neighborhood.

This section of the report will provide descriptions of the types of practices suggested for treatment areas, estimates of the amount of treatment required, and initial earth moving calculations. It should be noted that these estimates are for initial planning and permitting purposes only. Prior to construction, more detailed survey and final design for the chosen sites is required to insure that budgets for earthmoving, and channel restoration activities are sufficiently accurate to support bidding and construction. A description of activities required in each watershed will be provided to aid in the decision making process.

Several important considerations guided the development of the recommendations. These are:

- Work with machinery (and in some cases hand crews) on the steepest slopes upstream of the FR 420 is not recommended. These areas are extremely difficult to access and work on them will likely be more difficult and dangerous than the returns. The outcome of this constraint is that there will be a considerable amount of drainages with high sediment supply after the downstream restoration efforts.
- 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, bed rock, or errors in topography.

The overall concept is to utilize existing valley types that are appropriate for long-term stable alluvial fans to create or enhance sediment storage in the alluvial fan. Storage is induced by the creation of a over-widened channel with low sediment transport capacity. In addition to sediment storage in channels, sediment source from channels can also be addressed by reshaping channels to a more stable condition. 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 to transport, and decrease the amount of sediment that must be stored in over-widened channels. Together these practices can reduce the sediment supply reaching the neighborhood and improve the health and stability of the watershed.

TYPICAL PRACTICES

Alluvail 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 Ration > 40). There are many examples of working alluvail fan channels within the Shultz Fire Area (Figure 10).

However many alluvial fans have been incised as a result of recent flooding. 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 elevation that forms a wide shallow channel (Figure 11). The new channel will have multiple threads of small channels that converge and diverge within the active bed. Considerable volumes of fill are required to fill the incised channel in many cases. Fill is borrowed from the channel upstream and downstream of the fill site to minimize haul distance and limit the disturbance area. The borrow area extends entirely across the channel cross-section, forming a deep depression (10-15 ft) with shallow slopes on all sides. The slopes are protected with logs and boulders to prevent head cutting upstream. The borrow pit is left open to catch sediment delivered into it, providing additional storage. In the Shultz Fire area there are long reaches of channel downstream of FR 420 that have the potential to store sediment. Construction of these channels would form a series of over widened channel and basins. The distance between fill and borrow areas is a function of how much fill is required to bring the incised channel back up to grade combined with a reasonable haul length (estimated 400-600 ft). Figure 12 shows a typical fill area with downstream borrow area for this practice.

Observation of functional aggrading channels within the Shultz Fire Area indicate that once the channels have been built, one to two feet of sediment can be expected to aggrade on the channel. This projected aggradation combined with the amount of sediment required to refill the borrow areas provides an estimate of the longevity of the active aggradation period. Once the material has aggraded it should remain in place as long as the fan maintains its wide and shallow form.

Estimates of the amount of time required for a system of "D" channels to fully aggrade was made by estimating cut and fill quantities from typical cross sections then extrapolating along the length of the valley valley type appropriate for installation. Sediment transport rates from upstream under restored or unrestored conditions (depending on location) were utilized to calculate the time required to fully aggrade the channels and borrow basins. These results are given in Table 9 and locations are shown in

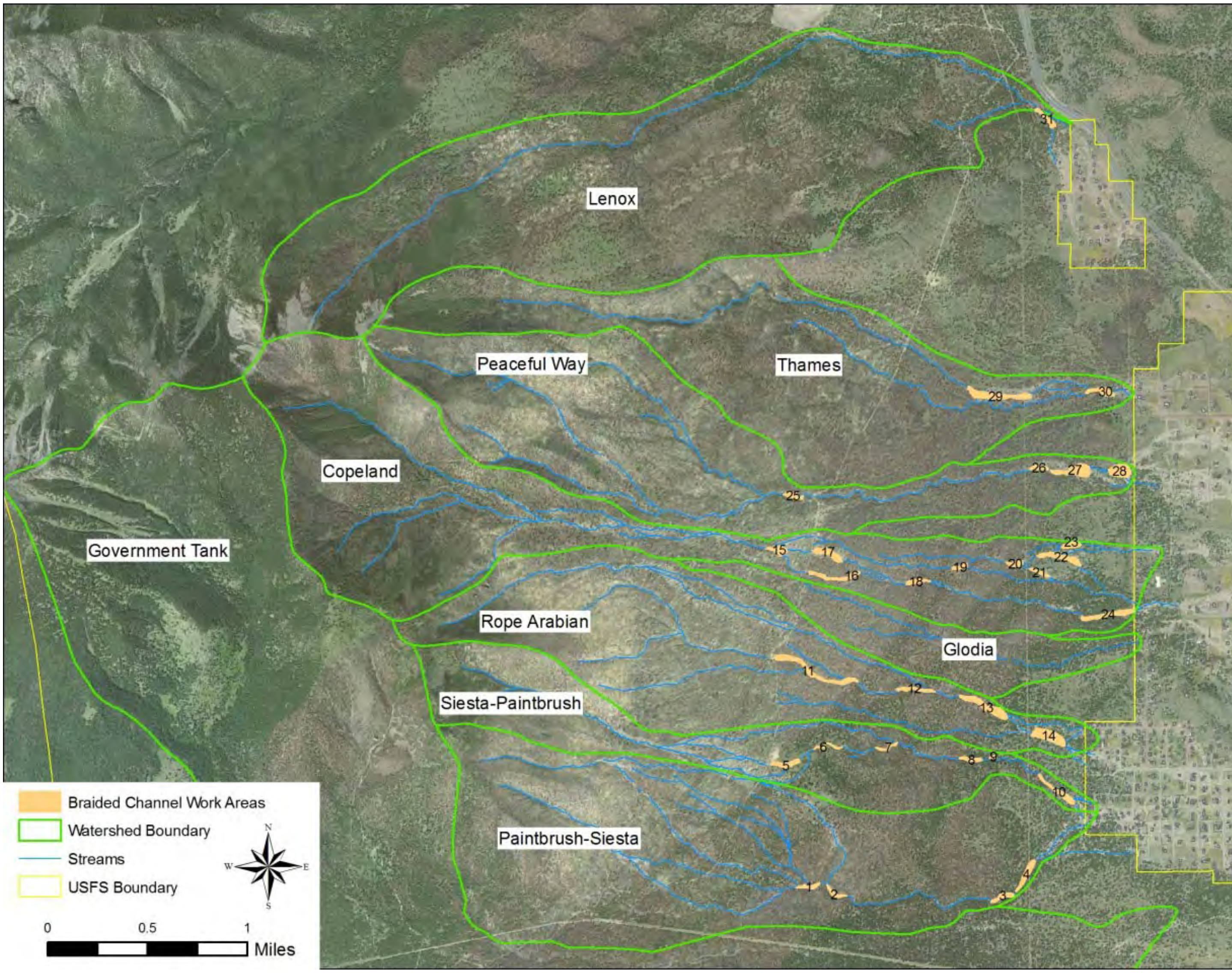


Figure 13. The life of the sediment aggradation areas can be extended by re-excavating the borrow areas when needed and utilizing the aggraded materials for road base or other purposes.

Figure 10. Typical aggrading channel within the Shultz Fire Area.

Note the very wide shallow channel extending entirely across the valley floor.

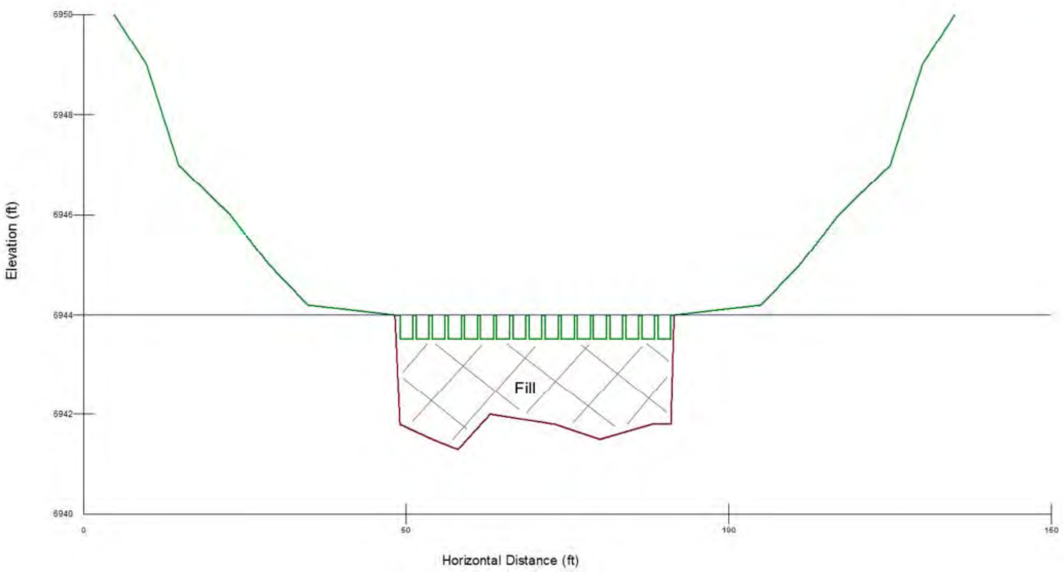


Figure 11. Typical cross-section for F to D conversion.

Over-widen, 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 channel. Red indicates current condition, incised channel.

Figure 12. Typical area of fill for construction of over-widened "D" channel.

Red area and line show approximate location of fill material through incised channel. Borrow area for fill is immediately upstream and downstream of the fill area to limit haul distance and area of disturbance.

Table 9. Estimated periods for sediment storage in aggrading channels.

Number locations of cross sections used for extrapolation are shown

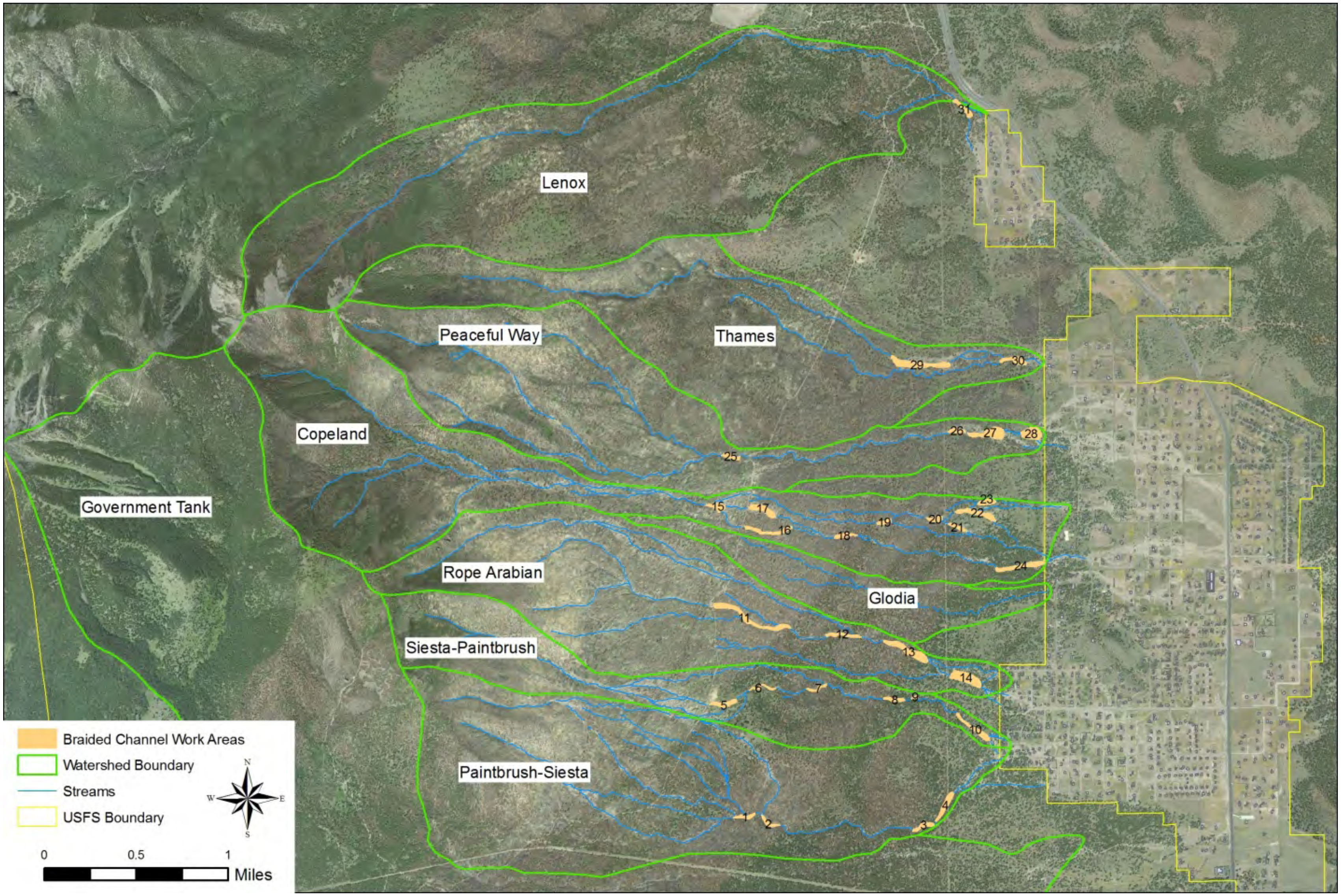
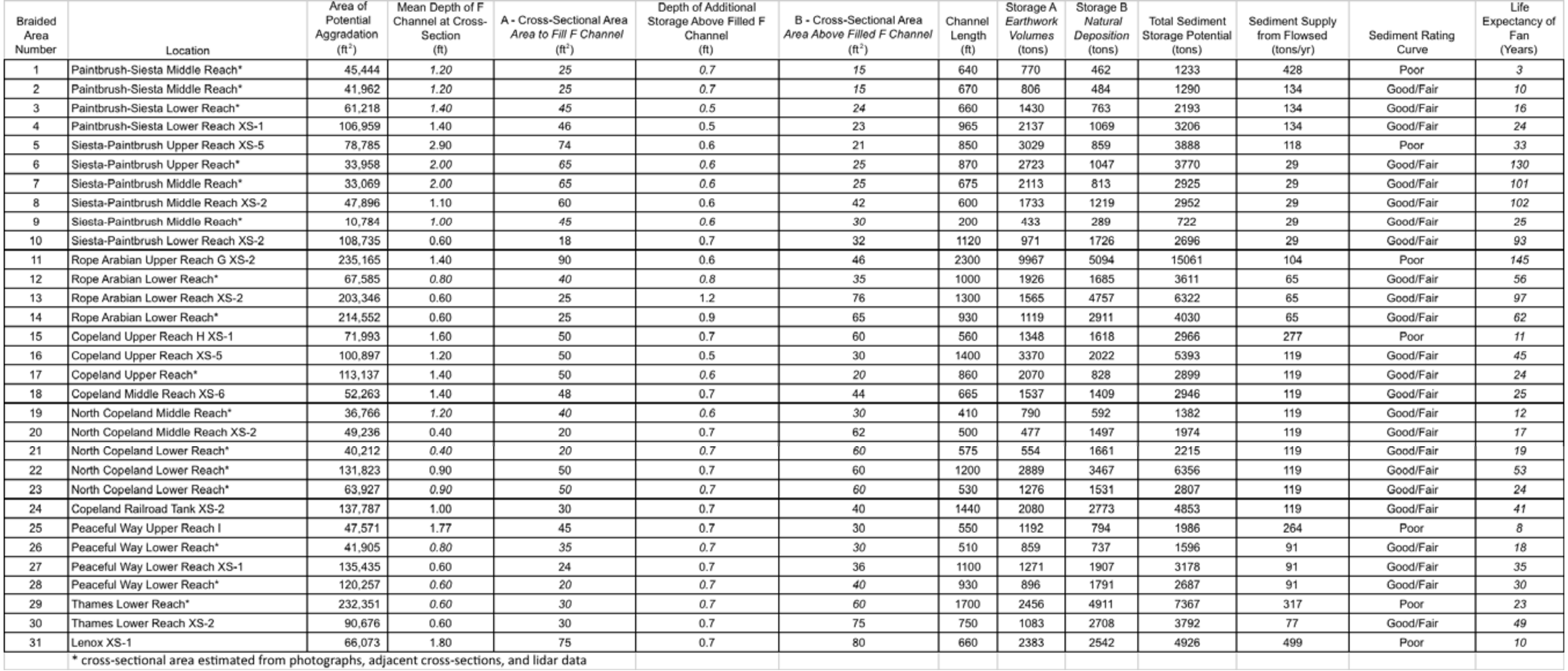


Figure 13.



Braided Area Number	Location	Area of Potential Aggradation (ft^2)	Mean Depth of F Channel at Cross-Section (ft)	A - Cross-Sectional Area *Area to Fill F Channel* (ft^2)	Depth of Additional Storage Above Filled F Channel (ft)	B - Cross-Sectional Area *Area Above Filled F Channel* (ft^2)	Channel Length (ft)	Storage A *Earthwork Volumes* (tons)	Storage B *Natural Deposition* (tons)	Total Sediment Storage Potential (tons)	Sediment Supply from Flowsed (tons/yr)	Sediment Rating Curve	Life Expectancy of Fan (Years)
1	Paintbrush-Siesta Middle Reach*	45,444	*1.20*	*25*	*0.7*	*15*	640	770	462	1233	428	Poor	*3*
2	Paintbrush-Siesta Middle Reach*	41,962	*1.20*	*25*	*0.7*	*15*	670	806	484	1290	134	Good/Fair	*10*
3	Paintbrush-Siesta Lower Reach*	61,218	*1.40*	*45*	*0.5*	*24*	660	1430	763	2193	134	Good/Fair	*16*
4	Paintbrush-Siesta Lower Reach XS-1	106,959	1.40	46	0.5	23	965	2137	1069	3206	134	Good/Fair	*24*
5	Siesta-Paintbrush Upper Reach XS-5	78,785	2.90	74	0.6	21	850	3029	859	3888	118	Poor	*33*
6	Siesta-Paintbrush Upper Reach*	33,958	*2.00*	*65*	*0.6*	*25*	870	2723	1047	3770	29	Good/Fair	*130*
7	Siesta-Paintbrush Middle Reach*	33,069	*2.00*	*65*	*0.6*	*25*	675	2113	813	2925	29	Good/Fair	*101*
8	Siesta-Paintbrush Middle Reach XS-2	47,896	1.10	60	0.6	42	600	1733	1219	2952	29	Good/Fair	*102*
9	Siesta-Paintbrush Middle Reach*	10,784	*1.00*	*45*	*0.6*	*30*	200	433	289	722	29	Good/Fair	*25*
10	Siesta-Paintbrush Lower Reach XS-2	108,735	0.60	18	0.7	32	1120	971	1726	2696	29	Good/Fair	*93*
11	Rope Arabian Upper Reach G XS-2	235,165	1.40	90	0.6	46	2300	9967	5094	15061	104	Poor	*145*
12	Rope Arabian Lower Reach*	67,585	*0.80*	*40*	*0.8*	*35*	1000	1926	1685	3611	65	Good/Fair	*56*
13	Rope Arabian Lower Reach XS-2	203,346	0.60	25	1.2	76	1300	1565	4757	6322	65	Good/Fair	*97*
14	Rope Arabian Lower Reach*	214,552	0.60	25	0.9	65	930	1119	2911	4030	65	Good/Fair	*62*
15	Copeland Upper Reach H XS-1	71,993	1.60	50	0.7	60	560	1348	1618	2966	277	Poor	*11*
16	Copeland Upper Reach XS-5	100,897	1.20	50	0.5	30	1400	3370	2022	5393	119	Good/Fair	*45*
17	Copeland Upper Reach*	113,137	1.40	50	*0.6*	*20*	860	2070	828	2899	119	Good/Fair	*24*
18	Copeland Middle Reach XS-6	52,263	1.40	48	0.7	44	665	1537	1409	2946	119	Good/Fair	*25*
19	North Copeland Middle Reach*	36,766	*1.20*	*40*	*0.6*	*30*	410	790	592	1382	119	Good/Fair	*12*
20	North Copeland Middle Reach XS-2	49,236	0.40	20	0.7	62	500	477	1497	1974	119	Good/Fair	*17*
21	North Copeland Lower Reach*	40,212	*0.40*	*20*	*0.7*	*60*	575	554	1661	2215	119	Good/Fair	*19*
22	North Copeland Lower Reach*	131,823	0.90	50	0.7	60	1200	2889	3467	6356	119	Good/Fair	*53*
23	North Copeland Lower Reach*	63,927	*0.90*	*50*	*0.7*	*60*	530	1276	1531	2807	119	Good/Fair	*24*
24	Copeland Railroad Tank XS-2	137,787	1.00	30	0.7	40	1440	2080	2773	4853	119	Good/Fair	*41*
25	Peaceful Way Upper Reach I	47,571	1.77	45	0.7	30	550	1192	794	1986	264	Poor	*8*
26	Peaceful Way Lower Reach*	41,905	*0.80*	*35*	*0.7*	*30*	510	859	737	1596	91	Good/Fair	*18*
27	Peaceful Way Lower Reach XS-1	135,435	0.60	24	0.7	36	1100	1271	1907	3178	91	Good/Fair	*35*
28	Peaceful Way Lower Reach*	120,257	*0.60*	*20*	*0.7*	*40*	930	896	1791	2687	91	Good/Fair	*30*
29	Thames Lower Reach*	232,351	*0.60*	*30*	*0.7*	*60*	1700	2456	4911	7367	317	Poor	*23*
30	Thames Lower Reach XS-2	90,676	0.60	30	0.7	75	750	1083	2708	3792	77	Good/Fair	*49*
31	Lenox XS-1	66,073	1.80	75	0.7	80	660	2383	2542	4926	499	Poor	*10*
	* cross-sectional area estimated from photographs, adjacent cross-sections, and lidar data												

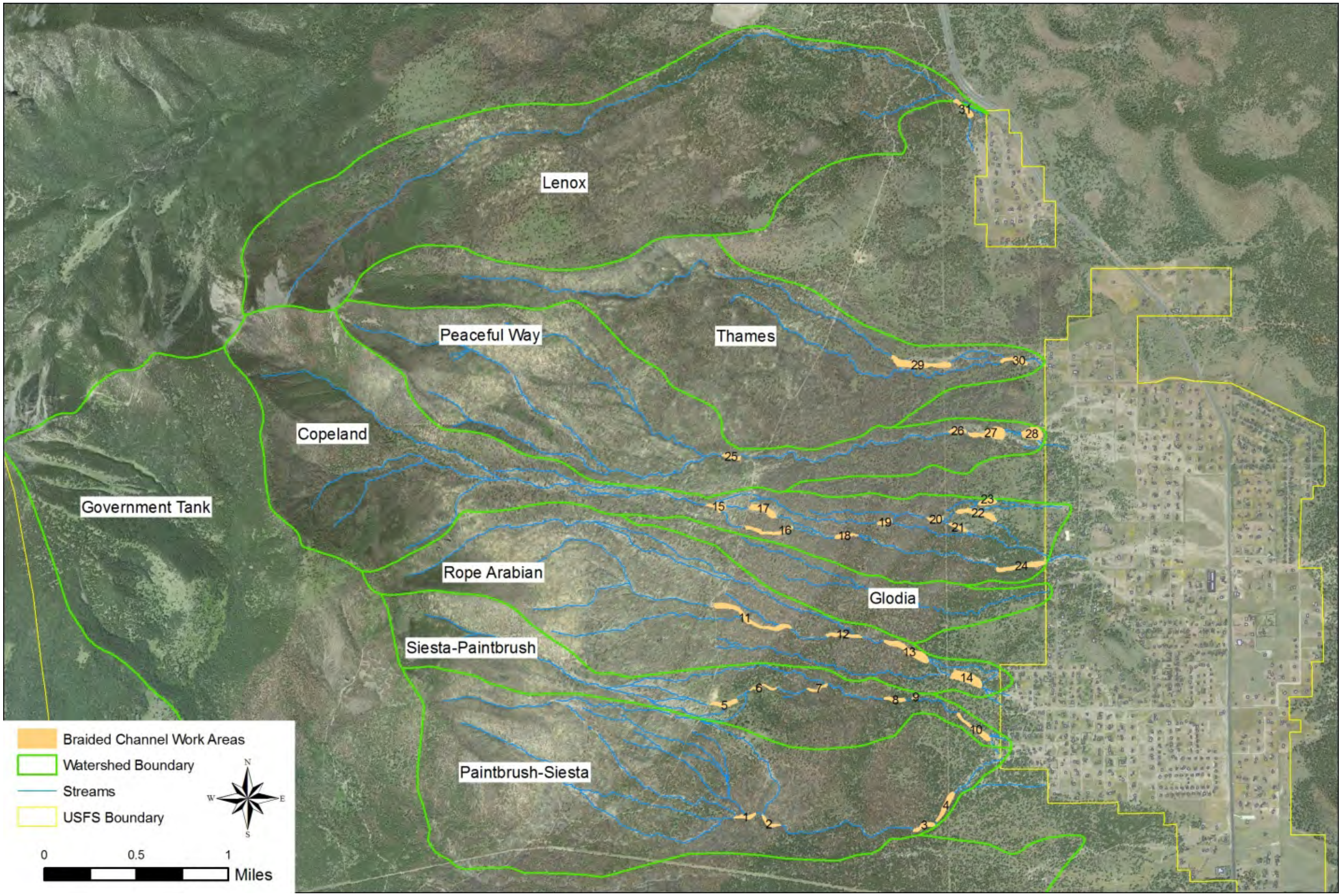


Figure 13. Treatment areas used to calculate sediment storage longevity.

Numbered areas refer to Table 9.

Single thread incised channel to 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). This is accomplished by cutting away the steep banks and creating a less incised channel, with a small floodplain surface at bankfull stage (Figure 14, Figure 15, and Figure 16). 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 flood plain to lower velocities and shear at higher stages.

Figure 14. Existing stable single thread channel.

Stable channels in the fire area provide a model for design of restored channels. Note large boulder roughness elements, relatively low flood plain features, and the lack of eroding banks.

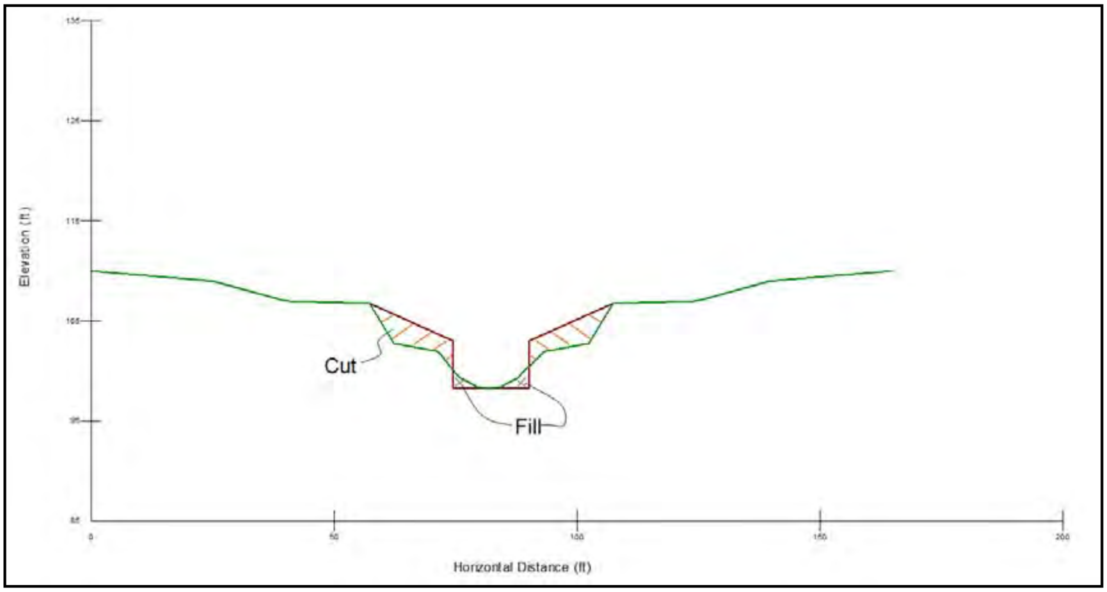


Figure 15. Typical cut and fill for single thread channel conversion.

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 16. Typical incised channel to stable channel conversion.

Shaded areas show cut and fill areas for a typical conversion of unstable, incised channel to stable channel with small flood plain at bankfull stage.

PRACTICE LOCATIONS

Each watershed has opportunities for enhancement of aggrading, multi-thread channels and stabilization of single thread channels. These locations are shown in Figure 17. The areas to be treated have been purposefully limited to areas below the FR 420 or vitally important areas on moderate slopes immediately upstream of the road. Opportunities for channel work in the Lenox watershed below the road are limited by bedrock sections of channel to a relatively short reach just upstream of the neighborhood. The length of specific treatments for each watershed is shown in Table 10.

Table 10. Lengths of potential channel treatments in each watershed.

Lengths of treatment are shown for both incised, single-thread channel conversions and enhancement of aggrading "D" channels.

Drainage	D channel enhancement (ft)	Incised Channel conversion (ft)
Paintbrush-Siesta (upstream of 420)	0	2181
Paintbrush-Siesta (downstream of 420)	2935	8117
Siesta - Paintbrush upstream of 420	0	3867
Siesta - Paintbrush	4315	2034
Rope-Arabian	5530	12793
Glodia	0	6388
Copeland (upstream of 420)	560	1523
Copeland (downstream of 420)	7580	14222
Peaceful Way upstream of 420	550	111
Peaceful Way	2540	6580
Thames upstream of 420	0	207
Thames	2450	8025
Lenox	660	1565

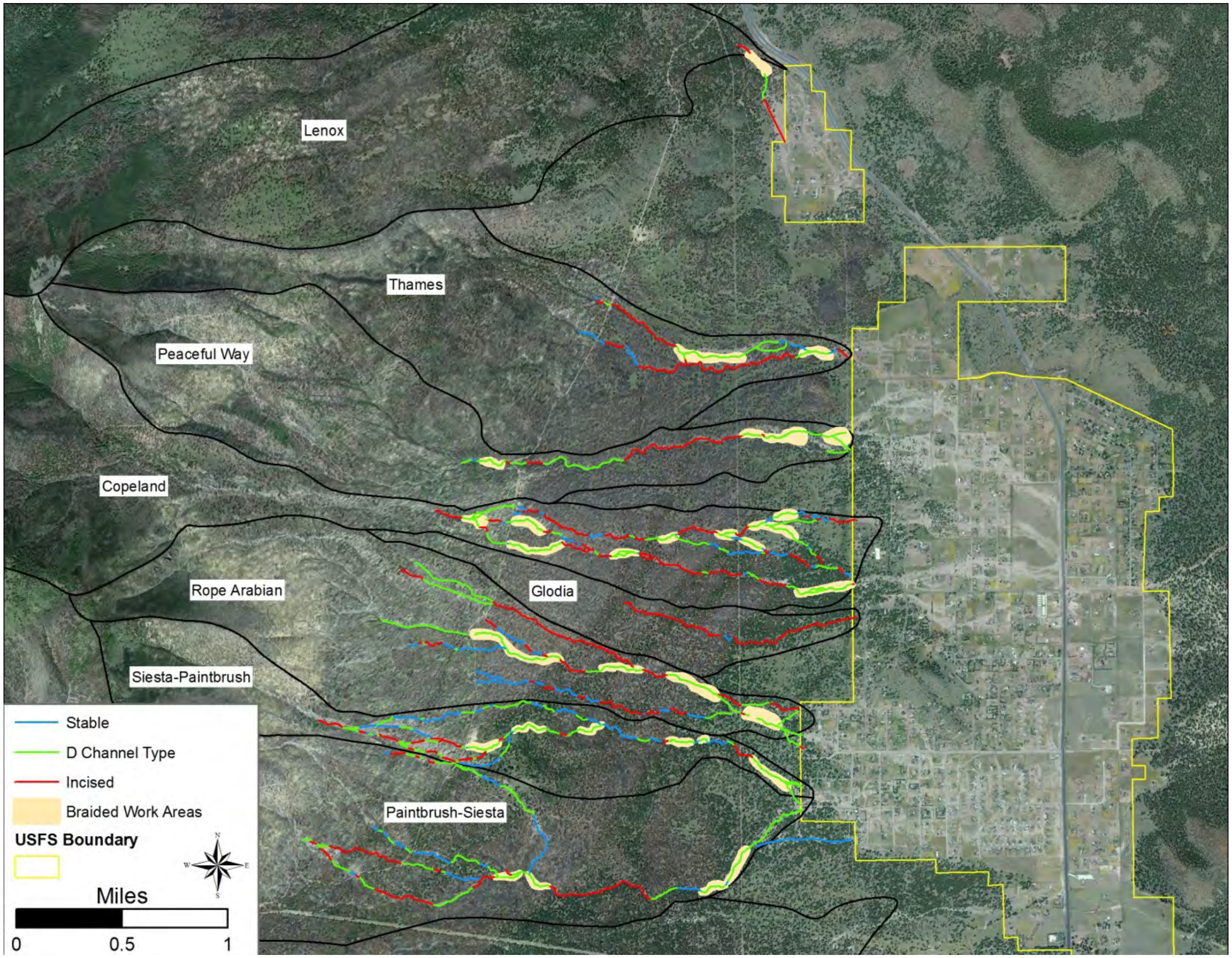


Figure 17. Proposed treatment areas for each watershed.

Incised channels would be restored to stable single thread channels. “D” channels and Braided fan areas would be enhanced to maximize sediment deposition.

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APPENDIX A – INCREASED WATER YIELD BY BASIN

Summary of predicted change in water yield, area and bankfull estimates for each basin and sub-basin in the Shultz Fire Impacted Area.

Basins	WRENSS Water Yield Change (in)	Total Watershed Area (acres)	DMF Bankfull Discharge (cfs)	Momentary Maximum Bankfull Discharge (cfs)
Copeland	5.91	1421.5	14.2	37.3
Glodia	5.04	293.4	6.4	16.7
Government Tank	2.44	3909.1	26.9	70.7
Lenox	4.99	1828.5	16.5	43.3
Offenhauser	1.18	1541.3	14.9	39.1
Paintbrush-Siesta	6.03	1518.6	14.7	38.6
Peaceful Way	7.36	1084.7	12.2	32.1
Rope Arabian	6.15	1010.3	11.8	31.1
Siesta-Paintbrush	6.15	615.7	9.2	24.2
Thames	6.26	1115.7	12.4	32.7
Sub-Basins				
Copeland -H	6.20	950.4	11.4	30.0
Paintbrush-Siesta -B	7.40	101.2	3.9	10.3
Paintbrush-Siesta -C	8.09	93.0	3.7	9.8
Peaceful Way -I	7.87	818.2	10.5	27.6
Rope Arabian -E	5.55	55.8	2.9	7.7
Rope Arabian -G	6.07	243.8	5.8	15.2
Rope Arabian -K	7.22	250.0	5.9	15.5
Siesta-Paintbrush -F	7.43	260.3	6.1	15.9
Thames -J	7.48	186.0	5.2	13.7
Thames -L	7.05	378.1	7.1	18.8

APPENDIX B – DIMENSIONLESS FLOW DURATION CURVE

Summary of Beaver Creek Watershed #12 dimensionless flow duration curves (flow values> 0).

Percent Time Equaled or Exceeded	Beaver Creek (DMF/QbDMF)	Percent Increase per Time Interval	Estimated Dimensionless Discharge (DMF/QbDMF)
0.00034	4.31982	0.1475	4.93086
0.00100	2.65100	0.1475	3.26204
0.00250	1.59885	0.1475	2.20988
0.00500	1.21299	0.1475	1.82402
0.00750	0.99606	0.1475	1.60709
0.01	0.86778	0.1475	1.47882
0.02	0.48526	0.1433	1.07904
0.03	0.28453	0.1433	0.87830
0.04	0.20120	0.1317	0.74664
0.05	0.13525	0.1158	0.61511
0.06	0.09710	0.1158	0.57695
0.07	0.07621	0.0983	0.48356
0.08	0.06412	0.0983	0.47148
0.09	0.05083	0.0825	0.39260
0.10	0.04484	0.0717	0.34173
0.11	0.03057	0.0717	0.32745
0.12	0.02468	0.0525	0.24217
0.13	0.02056	0.0525	0.23804
0.14	0.01338	0.0400	0.17909
0.15	0.01089	0.0367	0.16278
0.16	0.00785	0.0367	0.15975
0.17	0.00571	0.0217	0.09546
0.18	0.00389	0.0217	0.09365
0.19	0.00362	0.0208	0.08992
0.20	0.00225	0.0125	0.05403
0.21	0.00170	0.0125	0.05348
0.22	0.00107	0.0108	0.04595
0.23	0.00088	0.0108	0.04575
0.24	0.00088	0.0067	0.02849
0.25	0.00059	0.0033	0.01440
0.26	0.00023	0.0033	0.01403
0.27	0.00004	0.0025	0.01039
0.28	0.00000	0.0008	0.00000
0.29	0.00000	0.0008	0.00000
0.30	0.00000	0.0008	0.00000
0.31	0.00000	0.0008	0.00000
0.32	0.00000	0.0000	0.00000

APPENDIX C – DETAILED SITE CROSS SECTION DATA

MOUTH OF LENOX WATERSHED

Just Upstream of Wupatki Trails

HISTORIC D CHANNEL ERODED TO AN F

This portion of the Lenox watershed contains a recently incised channel due to increased runoff. The stability of channel reaches in this area is poor due to degradation, and active incision. This poor rating of indicates a potential for accelerated increase in flow-related sediment based on increased post-fire channel flow. At the survey location the valley type is transitioning from Type II to a Type III. The channel slope within the survey is 4.5 % with a bankfull cross-sectional area, determined by local curve, of *21.9* ft^2. The *2.9* mi^2 watershed has a bankfull discharge of *16.5 MDF/43.3 IM cfs* at the survey location. The streambank erosion rate is *0.30 tons/yr/ft*. The combined bedload and suspended load transport capacity of the current *"F"* channel is *563 tons/yr*. It is expected that the historic or restored *"D"* channel would have a transport capacity of *130 tons/yr*, a *74%* reduction over the current condition.

Figure 18. Representative photograph of the surveyed reach at the mouth of the Lenox watershed.

Note the vertical channel banks, exposed roots and collapsing trees.

Figure 19. Representative photograph taken just downstream of the surveyed reach, at the mouth of the Lenox watershed just above the Wupatki Trails neighborhood.

Note the deposition of sediment within the less-incised portion of the channel reach.

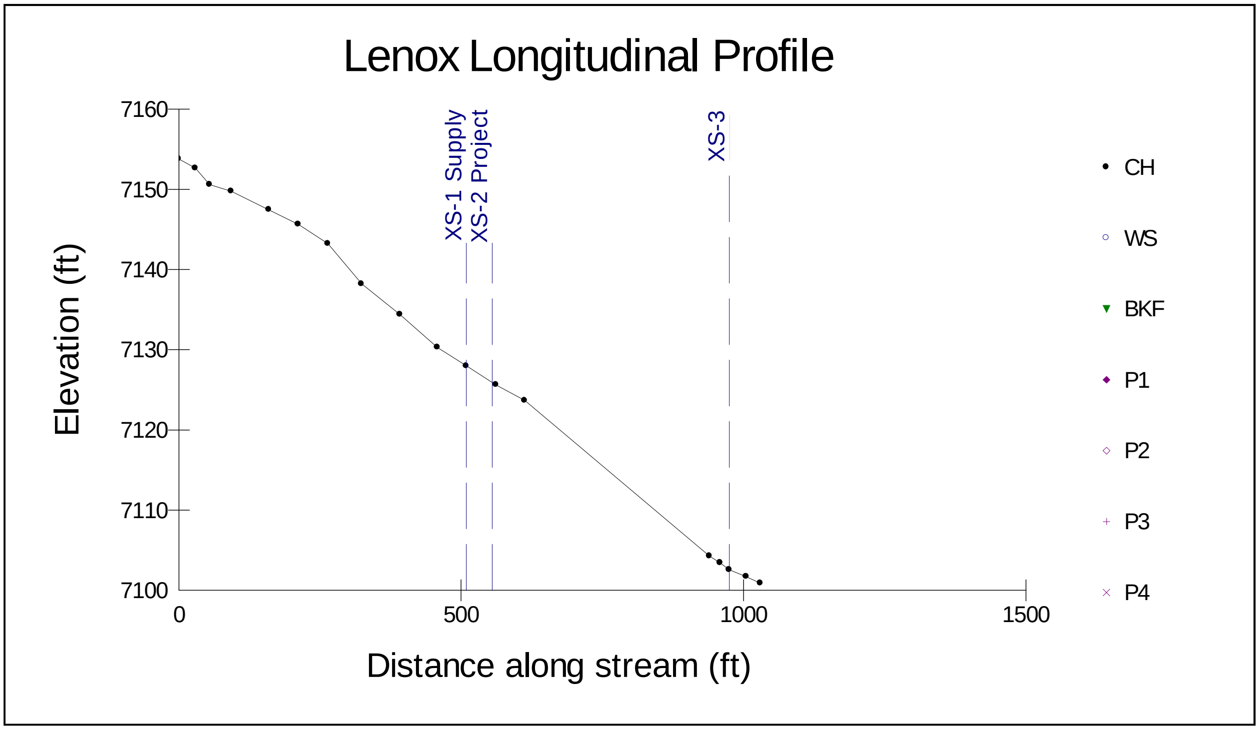


Figure 20. Longitudinal profile of the surveyed reach at the mouth of the Lenox watershed, just upstream of the Wupatki Trails neighborhood. Channel slopes average 4.5%.

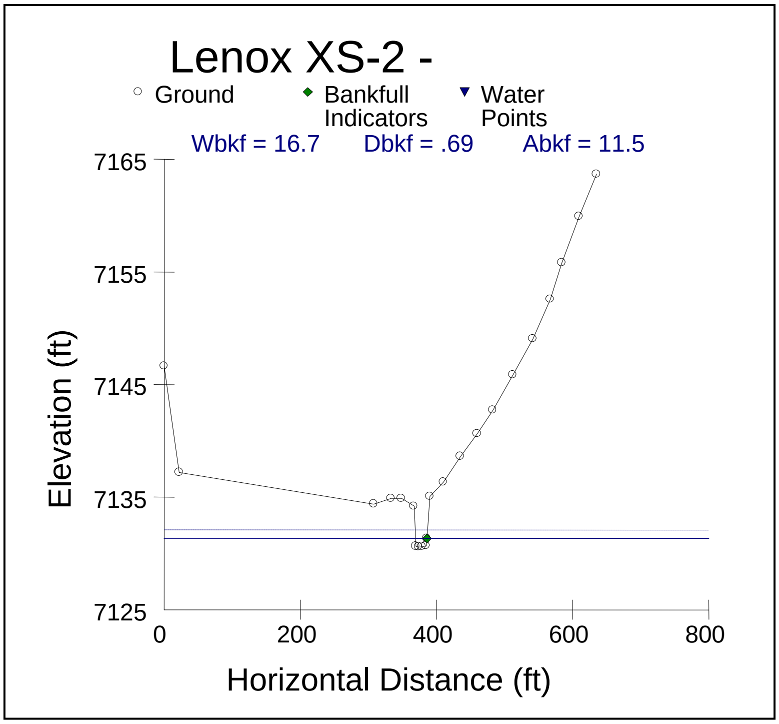


Figure 21. Representative cross-section #1 surveyed at the mouth of the Lenox Watershed.

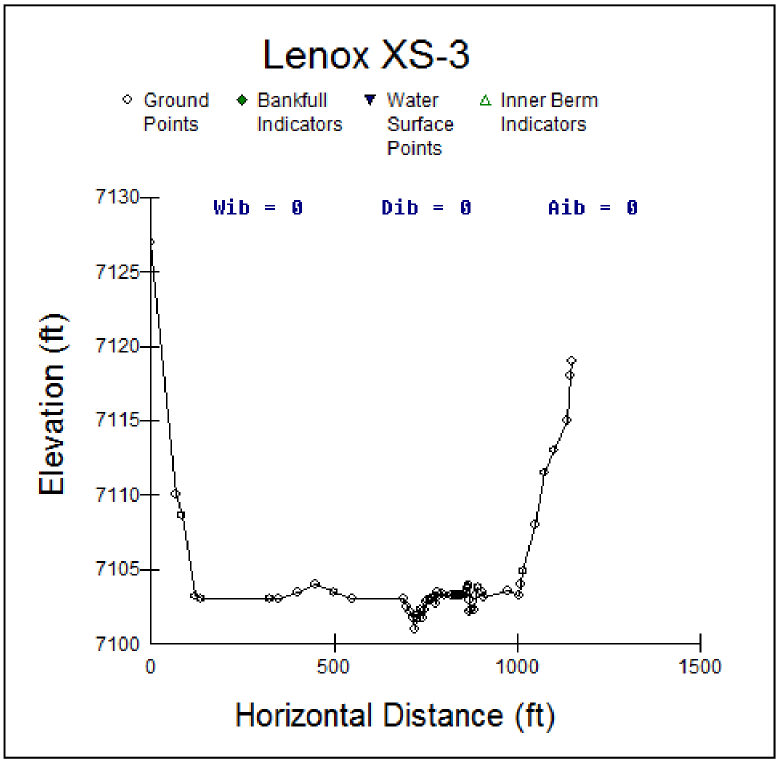


Figure 22. Representative cross-section #3 surveyed at the mouth of the Lenox Watershed.

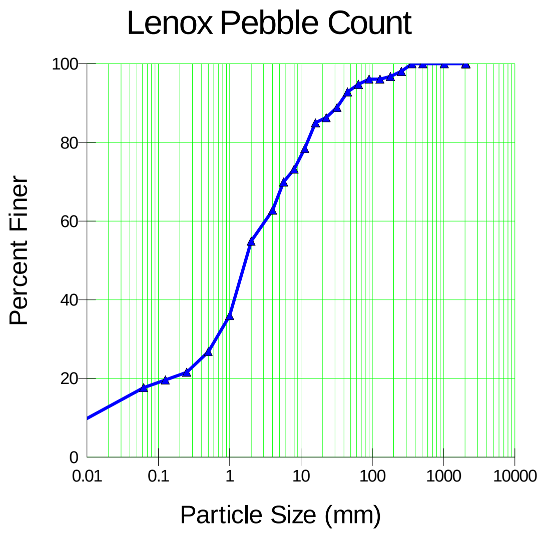


Figure 23. Representative Pebble Count, D50 = 2 mm.

UPPER THAMES L WATERSHED

This portion of the Thames watershed contains steep slopes and a recently incised channel due to increased runoff. The channel is adjusting to an increase in runoff, however the stability of these channel reaches is fair given the relatively same upstream drainage area and the large channel substrate. The streambank erosion rate is *0.22 tons/yr/ft*. At the survey location the valley is a Type II. The channel slope within the survey is 8.6 % with a bankfull cross-sectional area, determined by local curve, of *10.7* ft^2. The *0.59* mi^2 watershed has a bankfull discharge of *7.1 MDF/18.8 IM cfs* at the survey location. The combined bedload and suspended load transport capacity of the current *"G"* channel is *14 tons/yr*. It is expected that the historic or restored *"B"* channel would have a transport capacity of *5 tons/yr*, a *64%* reduction over the current condition.

Figure 24. Representative photograph (ID72) taken halfway between FR420 and the drainage divide.

Figure 25. Photo (ID73) showing sediment storage behind a temporary log jam

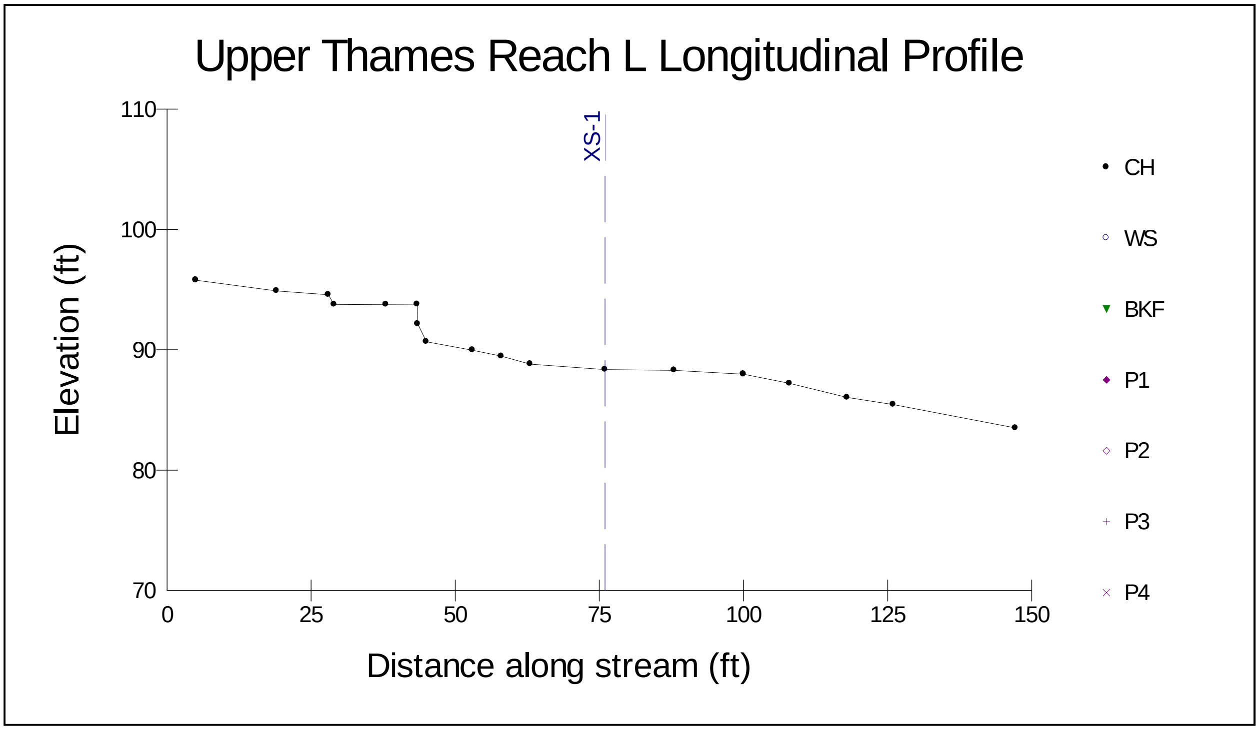


Figure 26. Longitudinal profile of the surveyed reach, channel slopes average 8.6%.

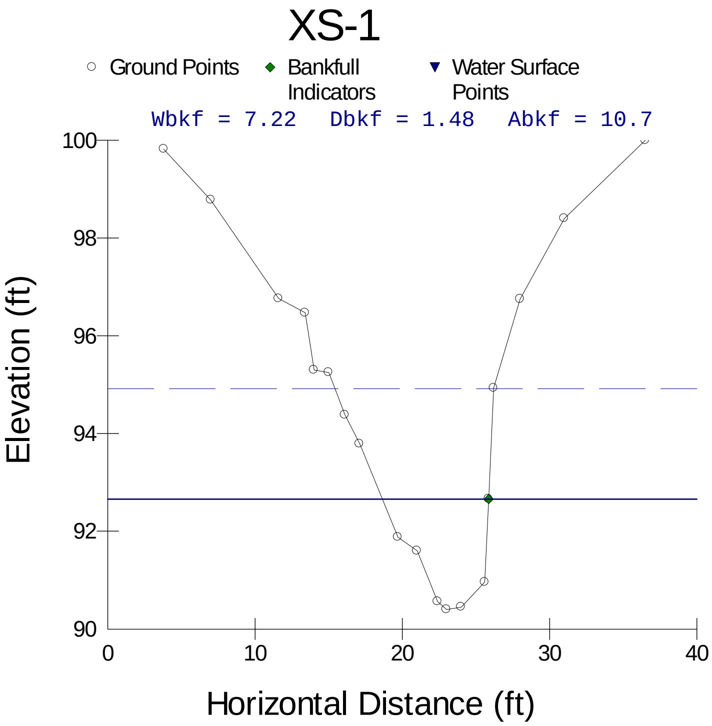


Figure 27. Representative cross-section surveyed within the lower portion of the Thames-L Watershed.

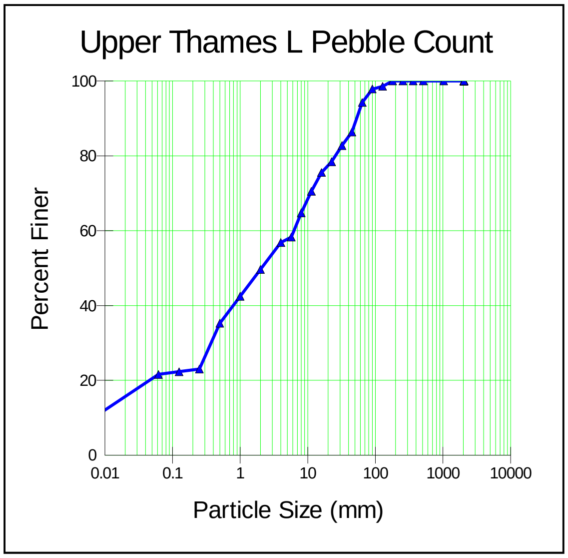


Figure 28. Representative Pebble Count, D50=2 mm.

UPPER THAMES J WATERSHED

This portion of the Thames watershed is stable and very little bank erosion is occurring through the surveyed reach. The channel is adjusting to an increase in runoff; however the stability of these channel reaches is fair given the relatively same upstream drainage area and the large channel substrate. The streambank erosion rate is *0.22 tons/yr/ft*. At the survey location the valley is a Type II. The channel slope within the survey is 7 % with a bankfull cross-sectional area, determined by local curve, of *7.9* ft^2. The *0.3* mi^2 watershed has a bankfull discharge of *5.2 MDF/13.7 IM cfs* at the survey location

Figure 29. Representative photograph (ID147) looking down a typically steep slope through Upper Thames J

This "A" channel is holding together well and can be considered a reference reach for future design.

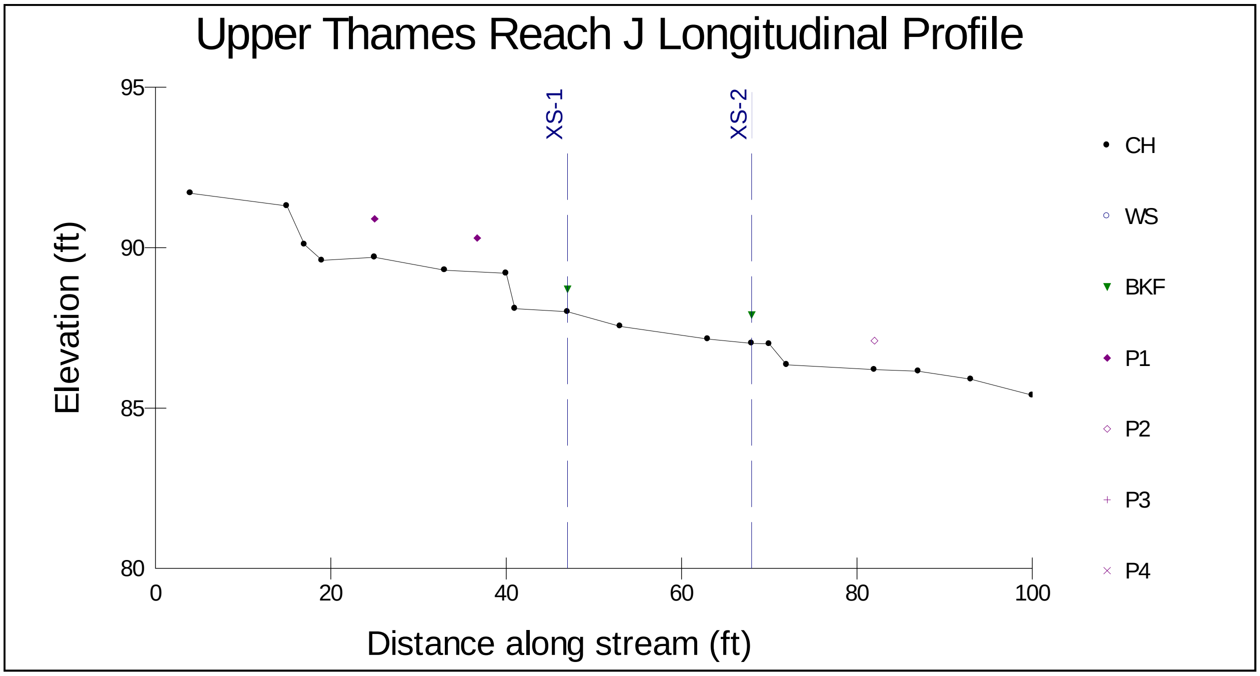


Figure 30. Longitudinal profile of the surveyed reach, channel slopes average 7%.

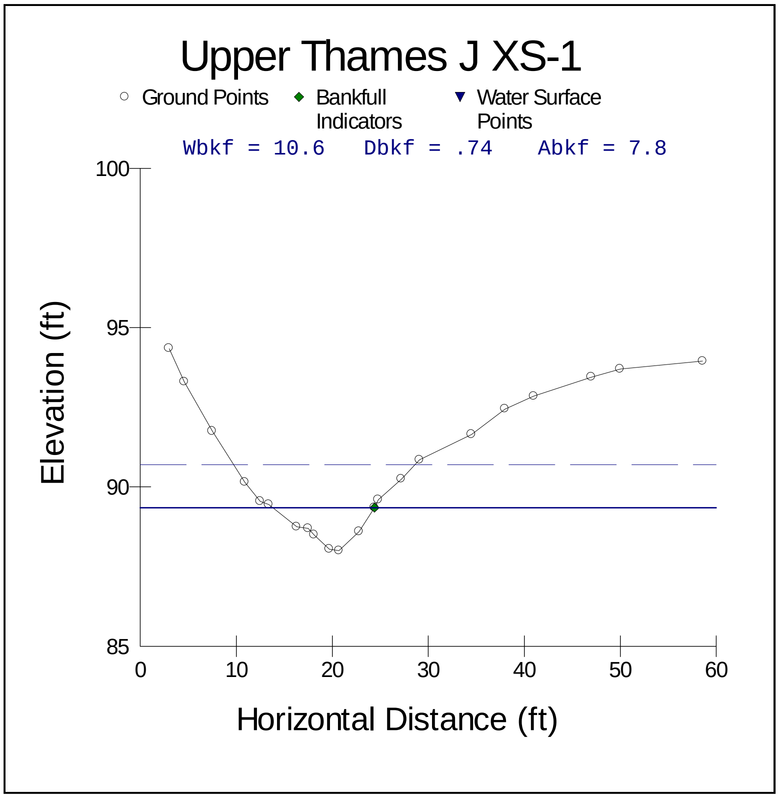


Figure 31. Representative cross-section #1 surveyed within the lower portion of the Thames-J Watershed.

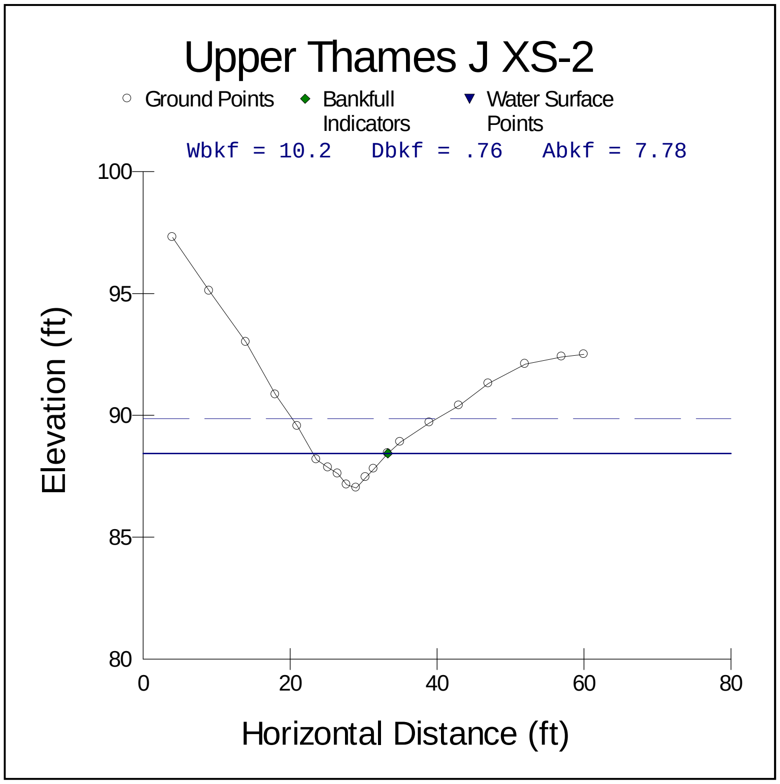


Figure 32. Representative cross-section #2 surveyed within the lower portion of the Thames-J Watershed.

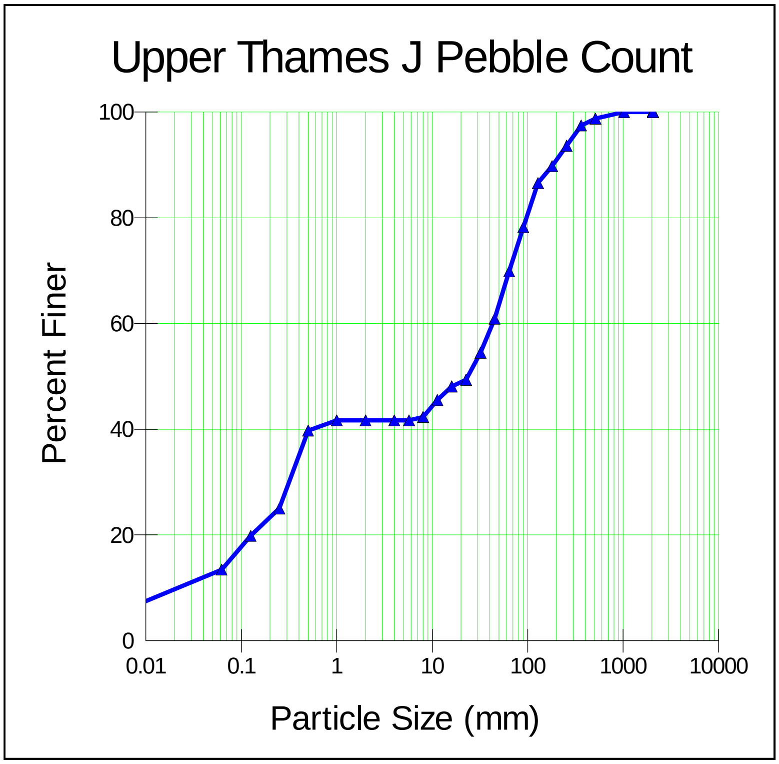


Figure 33. Representative Pebble Count, D50=24 mm.

LOWER THAMES WATERSHED

This portion of the Thames watershed has lower gradients and is more prone to deposition than erosion. The stability of the channel is poor due to the tendency of the channel to aggrade and migrate laterally. The streambank erosion rate is *0.18 tons/yr/ft*. At the survey location the valley is a Type III. The channel slope within the survey is 3 % with a bankfull cross-sectional area, determined by local curve, of *17.5* ft^2. The *1.7* mi^2 watershed has a bankfull discharge of *12.4 MDF/32.7 IM cfs* at the survey location. The combined bedload and suspended load transport capacity of the current *"F"* channel is *77 tons/yr*. It is expected that the historic or restored *"B"* channel would have a transport capacity of *75 tons/yr*, a *3%* reduction over the current condition.

Figure 34. Representative photograph (ID114) of the lower gradients found in the Lower Thames watershed

The channel is holding together fairly well in this location, however the presence of trees and other obstacles within the channel is decreasing the capacity of the channel.

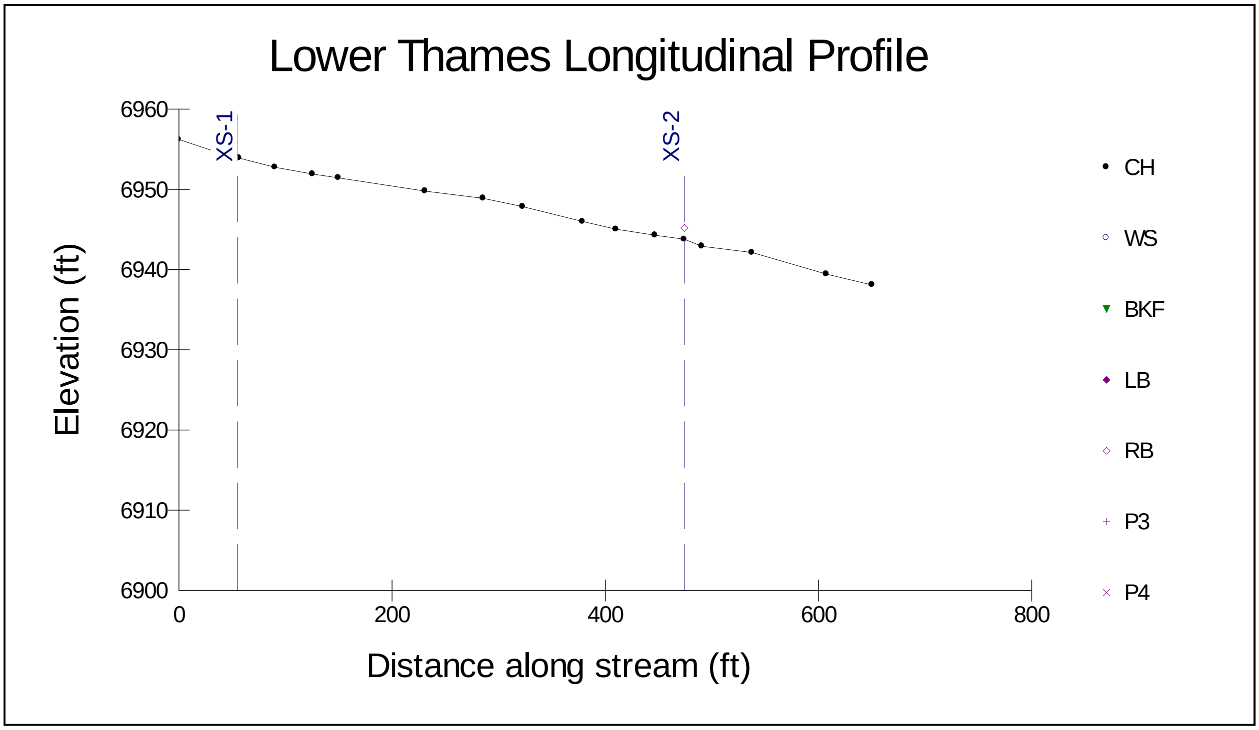


Figure 35. Longitudinal profile of the surveyed reach, channel slopes average 3%.

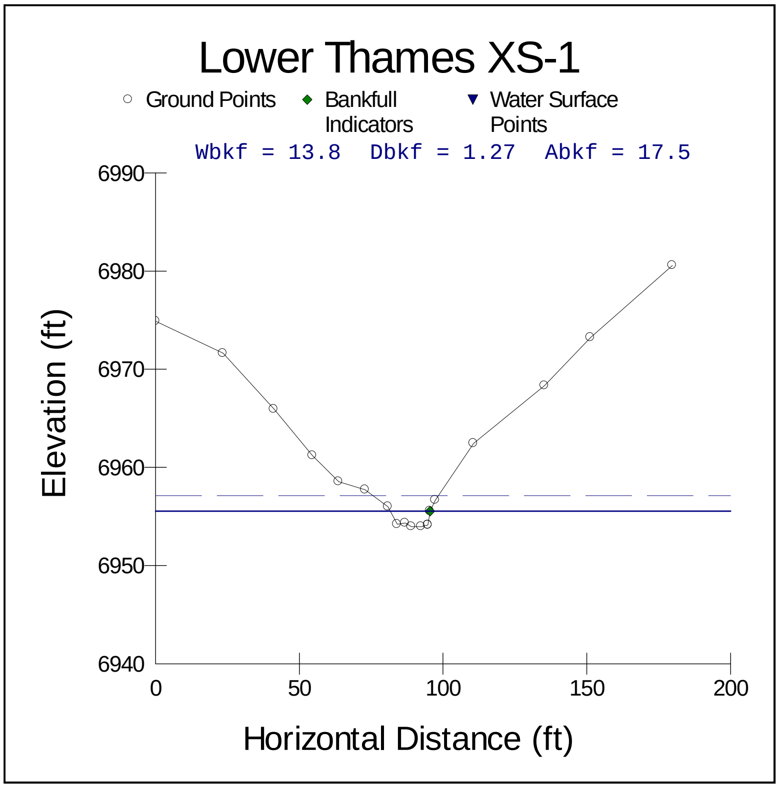


Figure 36. Representative cross-section #1 surveyed within the lower portion of the Thames Watershed.

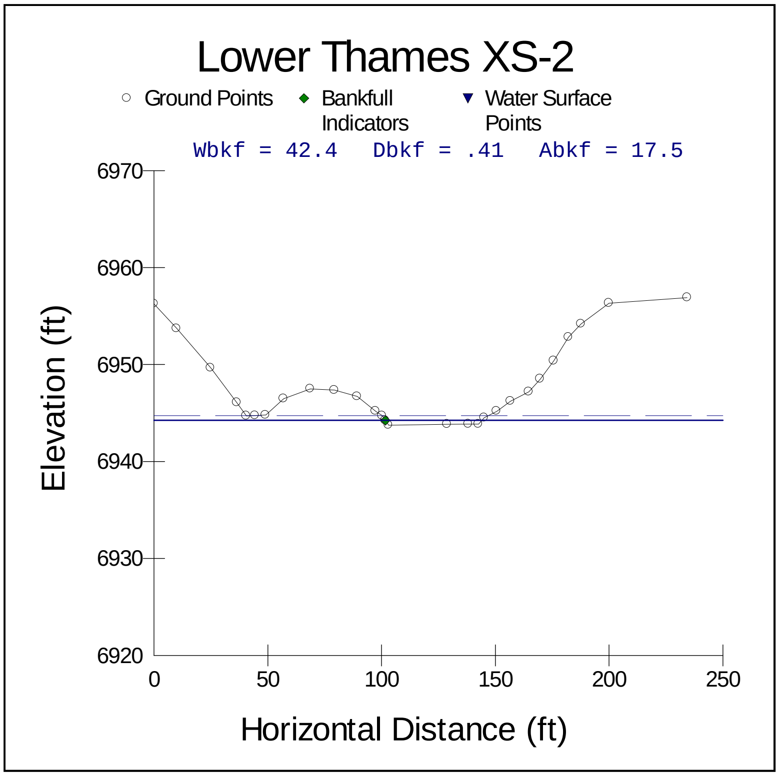


Figure 37. Representative cross-section #2 surveyed within the lower portion of the Thames Watershed.

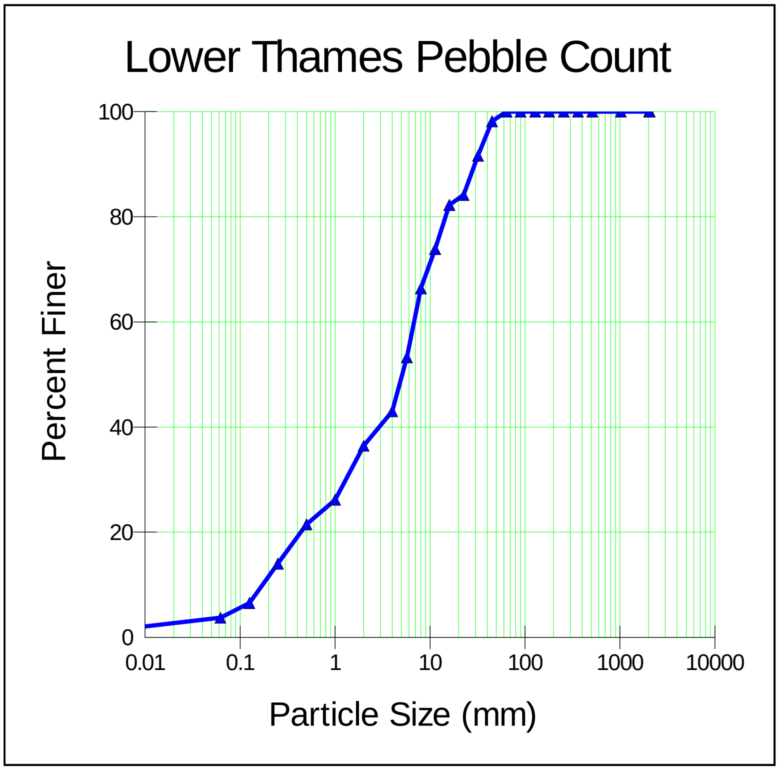


Figure 38. Representative Pebble Count, D50=5 mm.

UPPER PEACEFUL WAY

This portion of the Peaceful Way watershed contains a recently incised channel due to increased runoff. The stability of the channel is poor due to degradation, and active incision. This instability indicates a potential for accelerated increase in flow-related sediment based on increased post-fire channel flow. At the survey location the valley is largely a Type II with some reaches approaching a Type III. The channel slope within the survey is 4.8 % with a bankfull cross-sectional area, determined by local curve, of *15.2* ft^2. The streambank erosion rate is *1.66 tons/yr/ft*. The *1.28* mi^2 watershed has a bankfull discharge of *10.5 MDF/27.6 IM cfs* at the survey location. The combined bedload and suspended load transport capacity of the current *"F"* channel is *264 tons/yr*. It is expected that a historic or restored *"D"* channel would have a transport capacity of *56 tons/yr*, a *78%* reduction over the current condition.

Figure 39. Photograph (ID145) of the deeply scoured portion of Peaceful Way taken in the upper portion where the steeper slopes flatten

Figure 40. Photo (ID197) showing how a long jam has stored sediment in the Peaceful Way Watershed

Figure 41. Photo (ID193) showing how the stream spreads out where the gradient is low near FR420

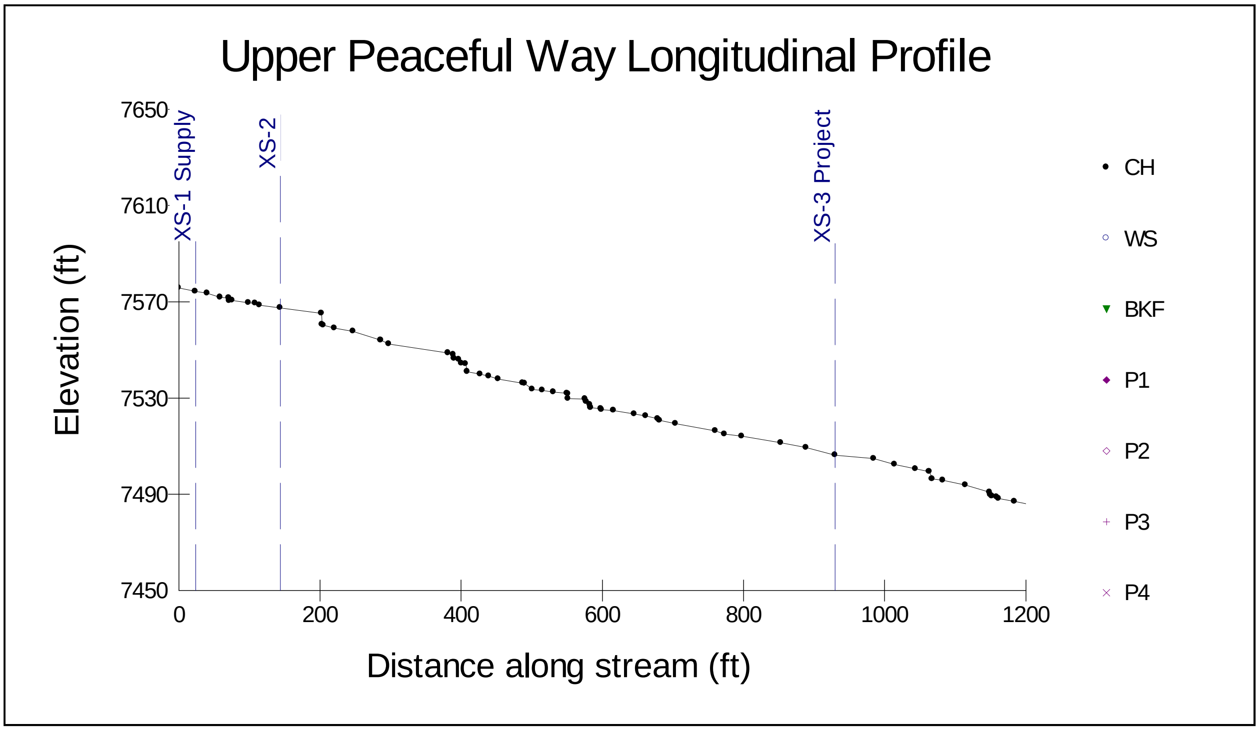


Figure 42. Longitudinal profile of the surveyed reach, channel slopes average 4.8%.

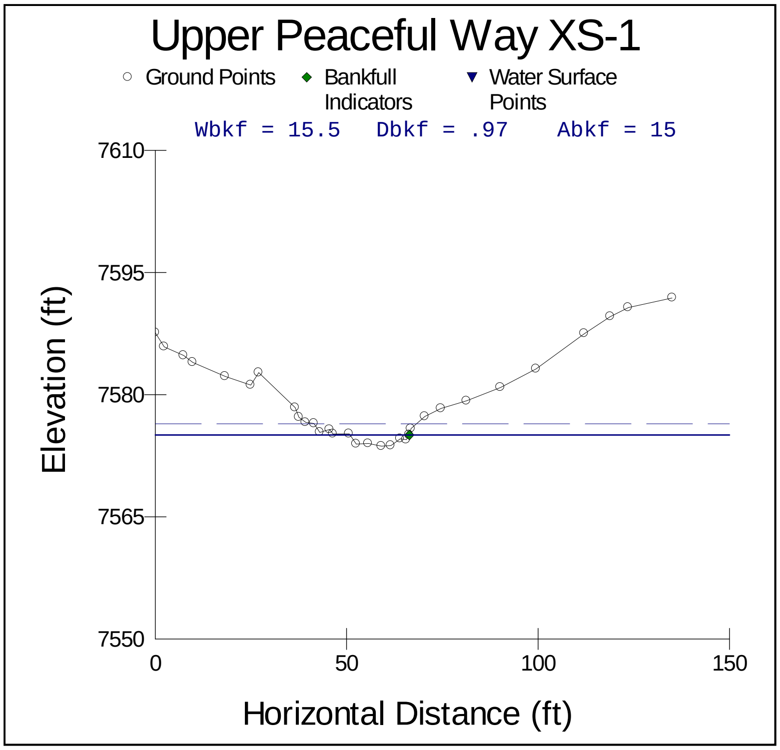


Figure 43. Representative cross-section #1 surveyed within the upper portion of the Peaceful Way Watershed.

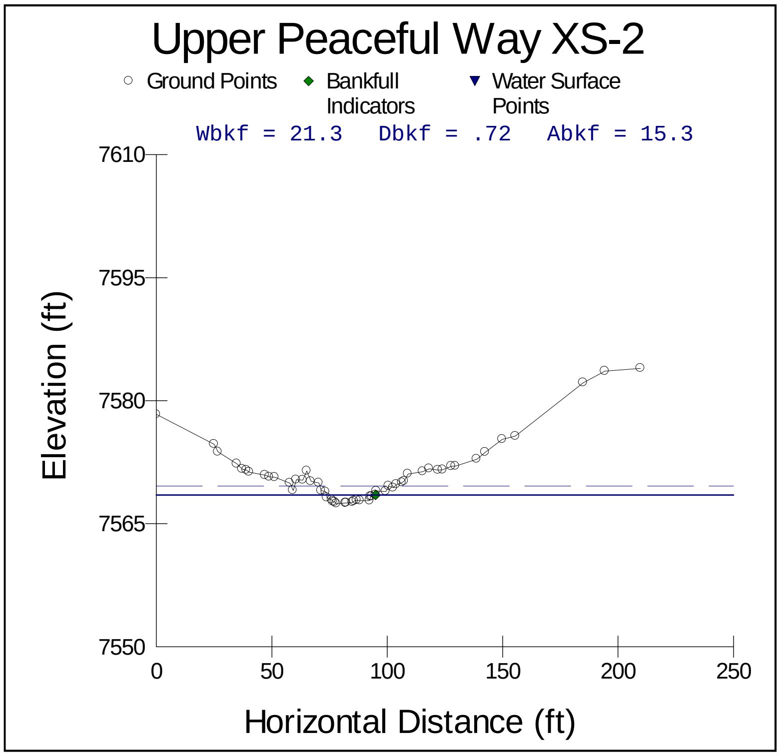


Figure 44. Representative cross-section #2 surveyed within the upper portion of the Peaceful Way Watershed.

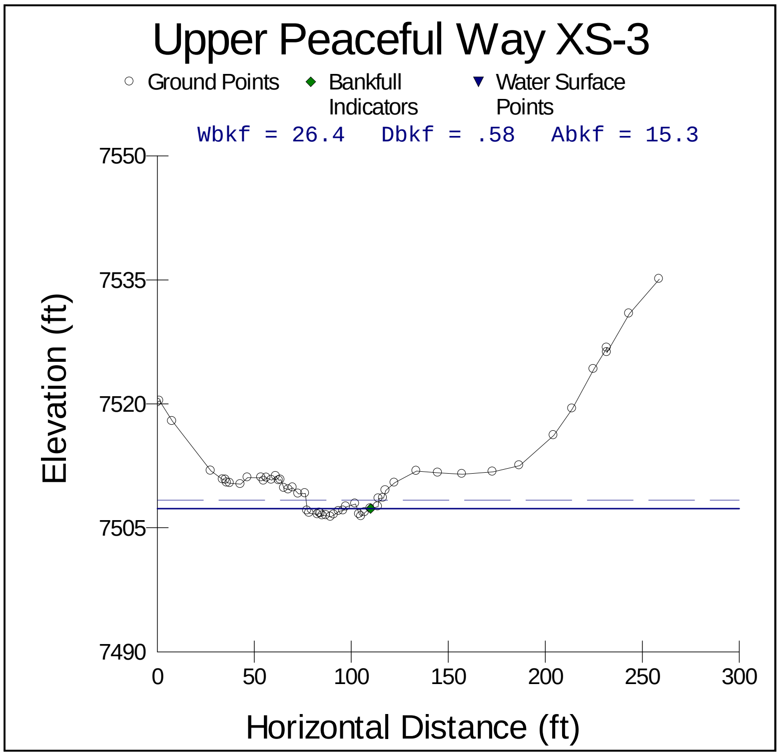


Figure 45. Representative cross-section #3 surveyed within the upper portion of the Peaceful Way Watershed.

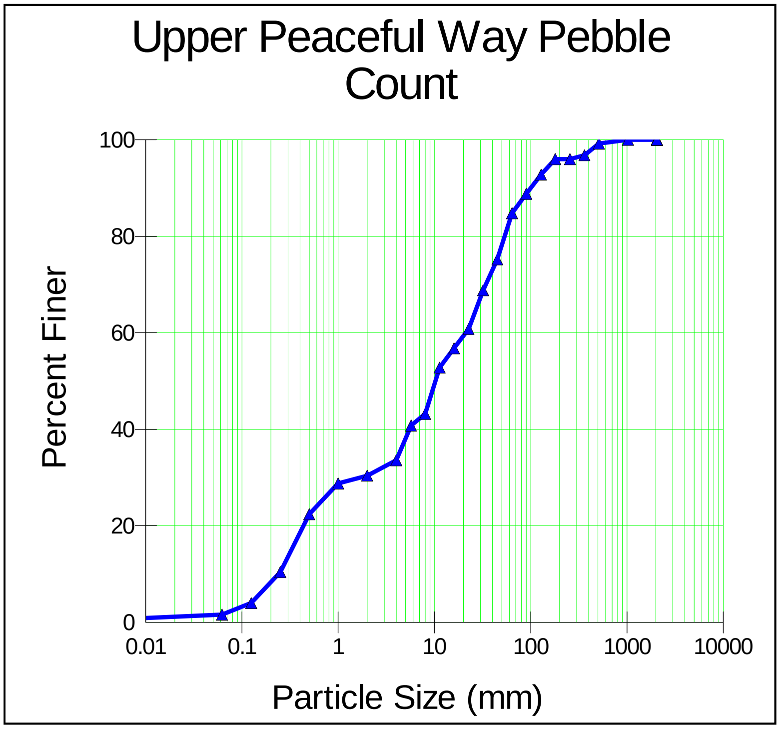


Figure 46, Representative Pebble Count, D50=10 mm.

LOWER PEACEFUL WAY WATERSHED

This portion of the Peaceful Way watershed is relatively stable and is more prone to deposition than degradation. The stability of the channel is poor due to the tendency of the channel to aggrade and migrate laterally. At the survey location the valley is a Type III. The channel slope within the survey is 4.5 % with a bankfull cross-sectional area, determined by local curve, of *17.2 ft*^{2}. The *1.7 mi*^{2} watershed has a bankfull discharge of *12.2 MDF/32.1 IM cfs* at the survey location. The streambank erosion rate is *0.12 tons/yr/ft*. The combined bedload and suspended load transport capacity of the current *"F"* channel is *328 tons/yr*. It is expected that the historic or restored *"D"* channel would have a transport capacity of *105 tons/yr*, a *68%* reduction over the current condition.

Figure 47. Representative photo (ID120) of the breadth of channel in the lower reaches of the Peaceful Way watershed

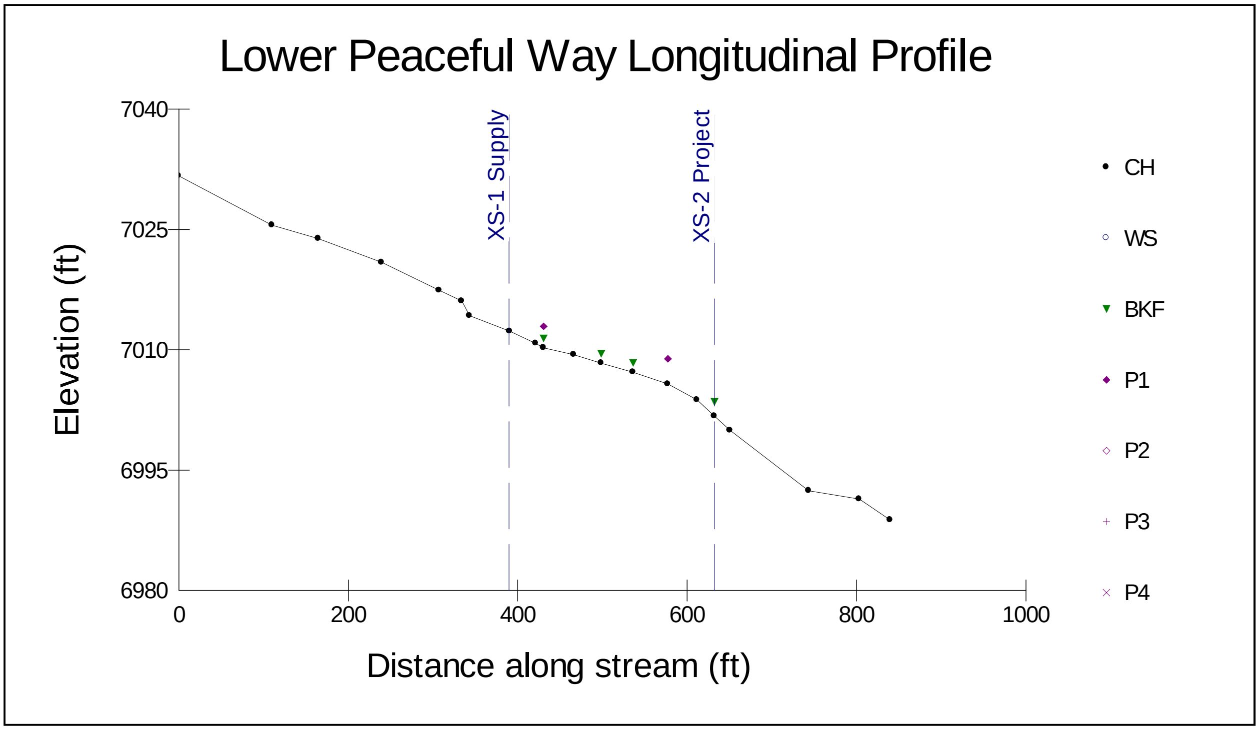


Figure 48. Longitudinal profile of the surveyed reach, channel slopes average 4.5%.

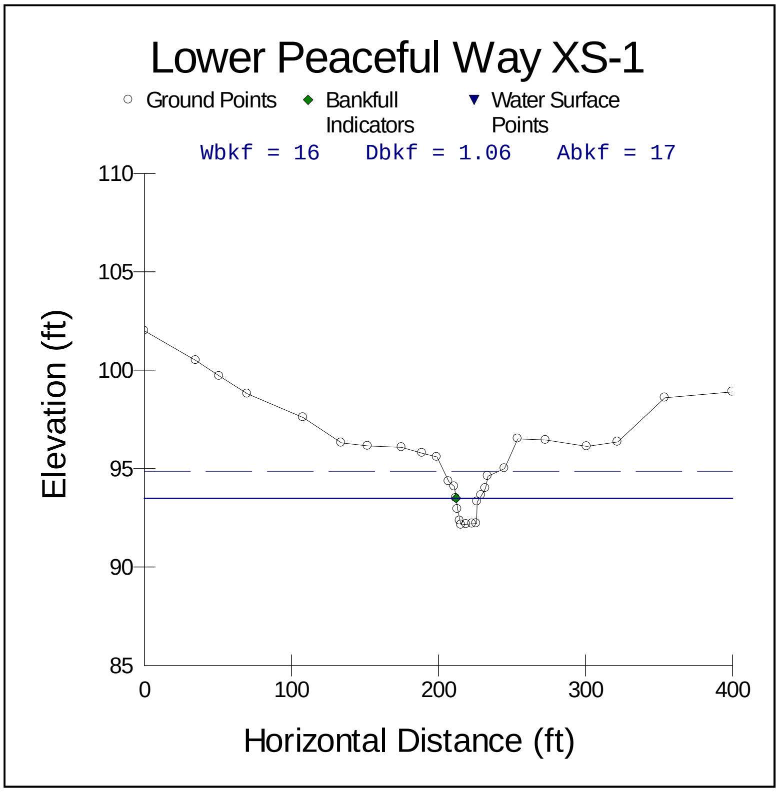


Figure 49. Representative cross-section #1 surveyed within the lower portion of the Peaceful Way Watershed.

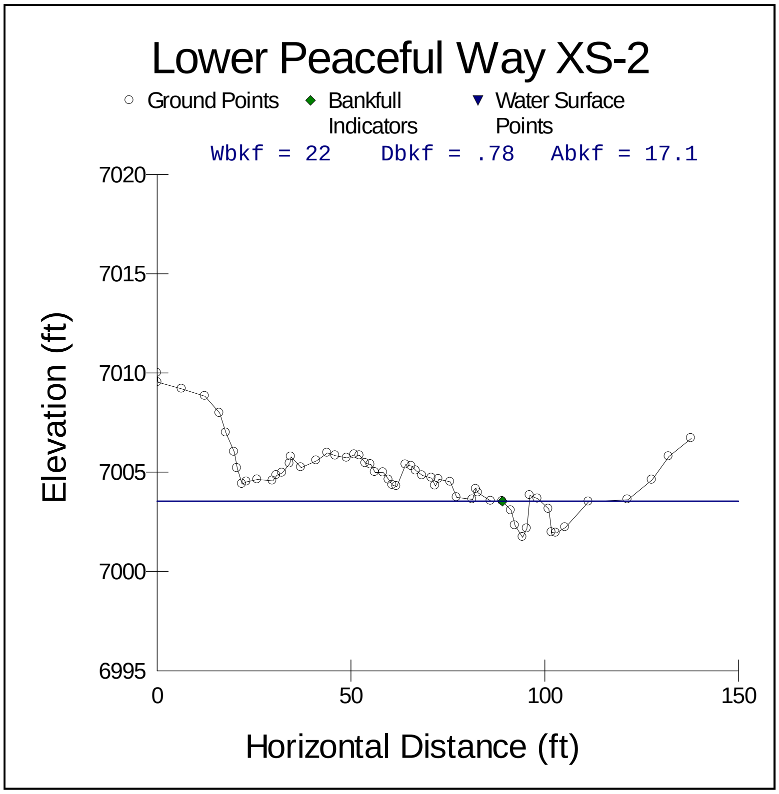


Figure 50. Representative cross-section #2 surveyed within the lower portion of the Peaceful Way Watershed.

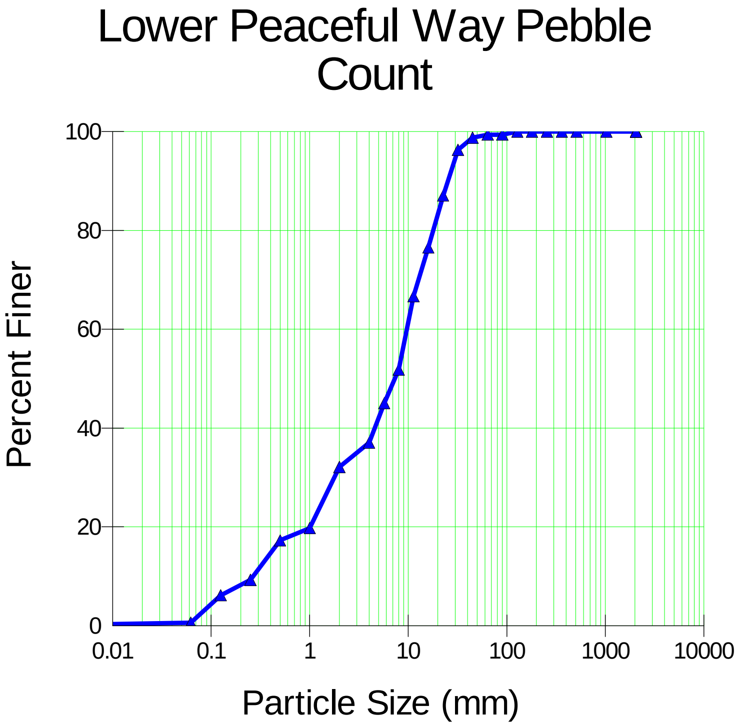


Figure 51. Representative Pebble Count, D50=7 mm.

UPPER COPELAND

This portion of the Copeland watershed contains a deeply incised channel due to increased runoff. The stability of the channel is poor due to degradation, and active incision. The poor condition of the channel indicates a potential for accelerated increase in flow-related sediment based on increased post-fire stream flow. At the survey location the valley is a Type III. The channel slope within the survey is 6.0 % with a bankfull cross-sectional area, determined by local curve, of *16.3* ft^2. The *1.49* mi^2 watershed has a bankfull discharge of *11.4 MDF/30.0 IM cfs* at the survey location. The streambank erosion rate is *0.46 tons/yr/ft*. The combined bedload and suspended load transport capacity of the current *"F"* channel is *277 tons/yr*. It is expected that the historic or restored *"D"* channel would have a transport capacity of *29 tons/yr*, a *90%* reduction over the current condition.

Figure 52. Photo (ID54) showing the degradation of the steep upper reaches of the Copeland watershed at the Waterline Road

Note the incision that exposed the waterline that was once buried under the service road.

Figure 53. Representative photo (ID60) of the incised channels in the upper reaches of the Copeland watershed

Figure 54. Representative photo (ID49) showing how the channel spreads out where the gradients are less

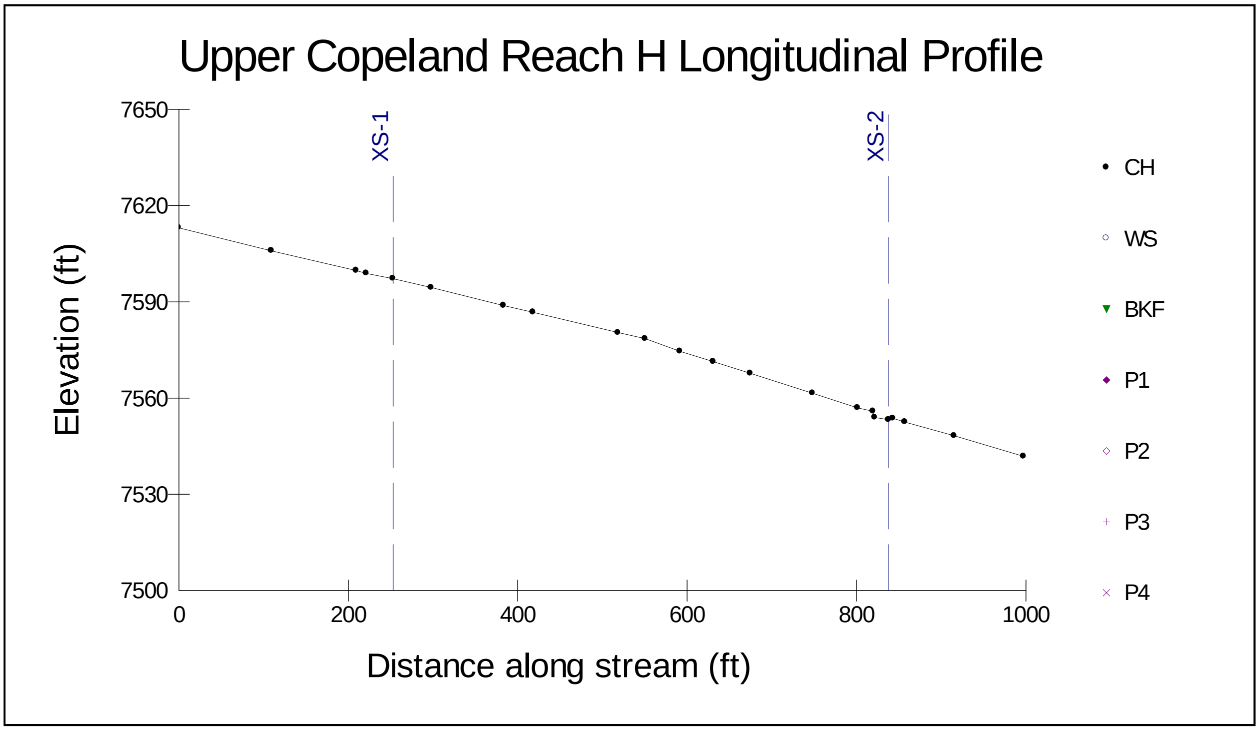


Figure 55. Longitudinal profile of the surveyed reach, channel slopes average 6%.

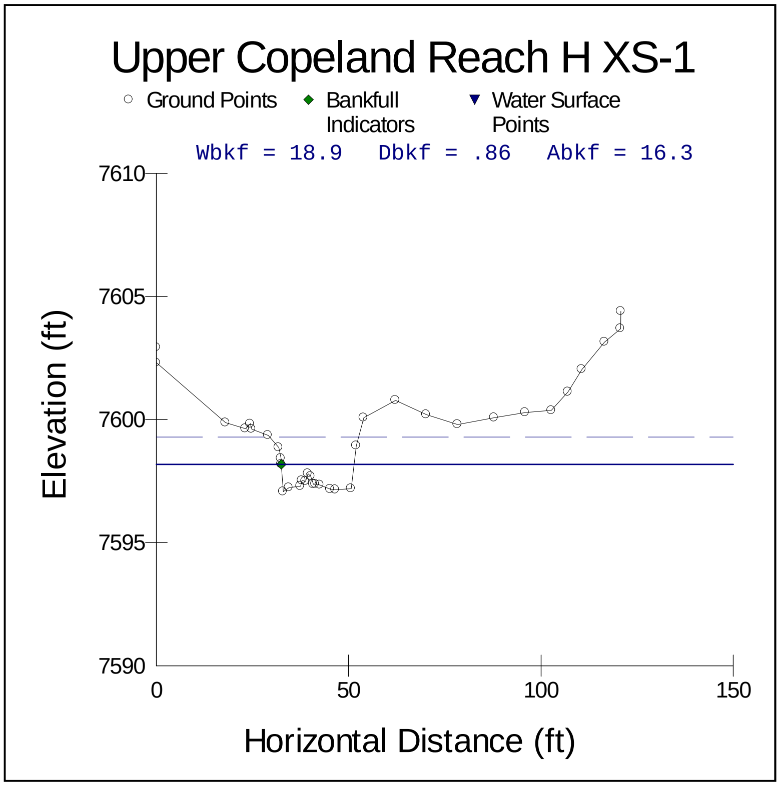


Figure 56. Representative cross-section #1 surveyed within the lower portion of the Copeland-H Watershed.

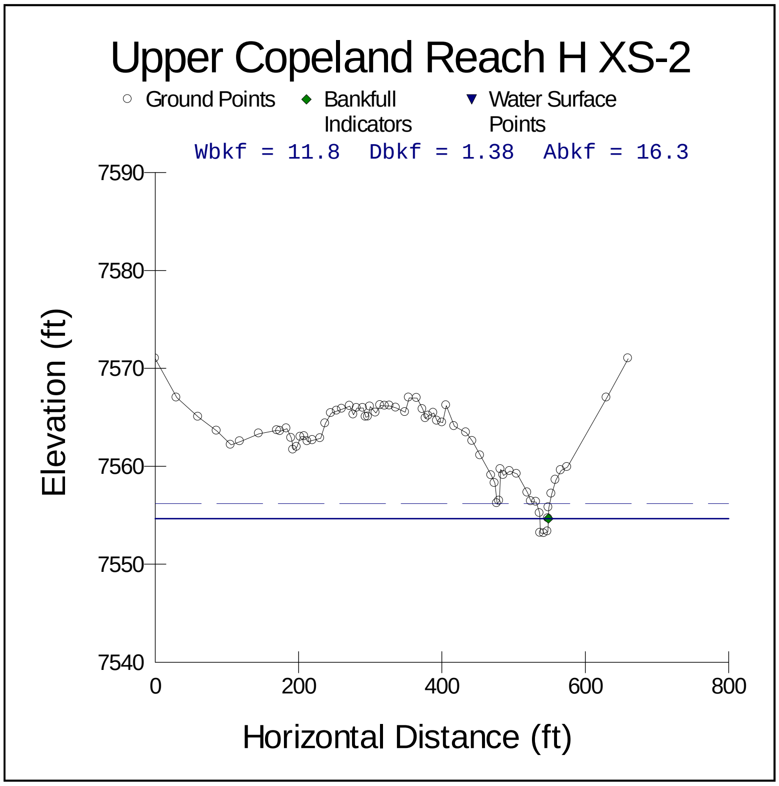


Figure 57. Representative cross-section #2 surveyed within the upper portion of the Copeland-H Watershed.

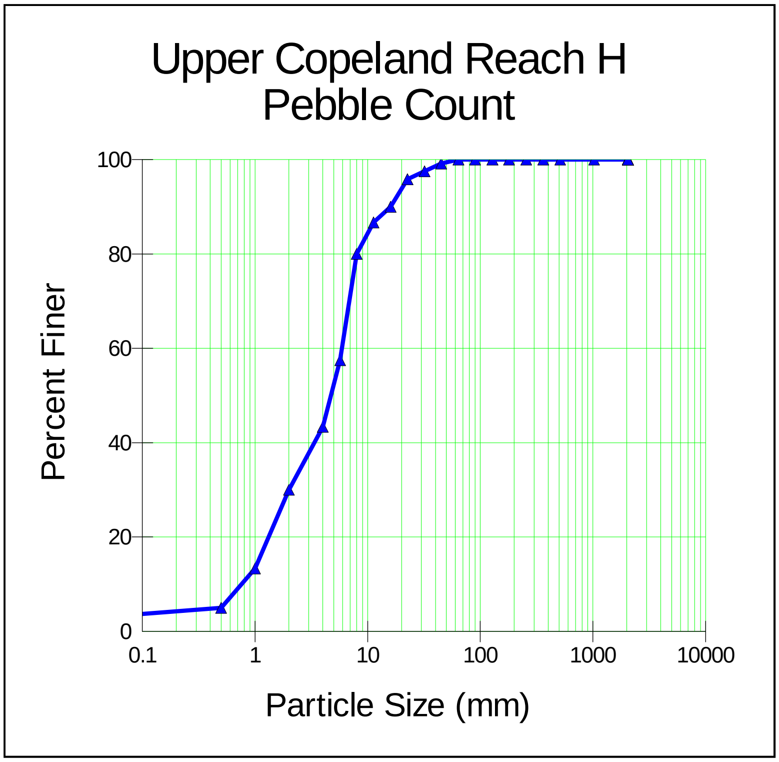


Figure 58. Representative Pebble Count, D50=5 mm.

NORTH COPELAND REACH

This portion of the Copeland watershed is eroding due to increased runoff. The stability of the channel is poor due to degradation, and active incision. Since the flow divides upstream, it is unknown what portion of flow and sediment reaches this stream. If all the flow was directed in this direction, the streambank erosion rate would be *0.40 tons/yr/ft*. The poor condition of the channel indicates a potential for accelerated increase in flow-related sediment based on increased post-fire stream flow. At the survey location the valley is a Type III. The channel slope within the survey is 4.2 % with a bankfull cross-sectional area, determined by local curve, of *20.0* ft^2. The *2.2* mi^2 watershed has a bankfull discharge of *14.2 MDF/37.3 IM cfs* at the survey location. If the entirety of the flow is directed to this area, the combined bedload and suspended load transport capacity of the current *"F"* channel is *402 tons/yr*. It is expected that the historic or restored *"D"* channel would have a transport capacity of *98 tons/yr*, a *76%* reduction over the current condition.

Figure 59. Representative photo (ID105) of the incision occurring through the middle-section of the Copeland watershed

Figure 60. Representative photo (ID106) 'D' channel found in the lower reaches of the Copeland watershed

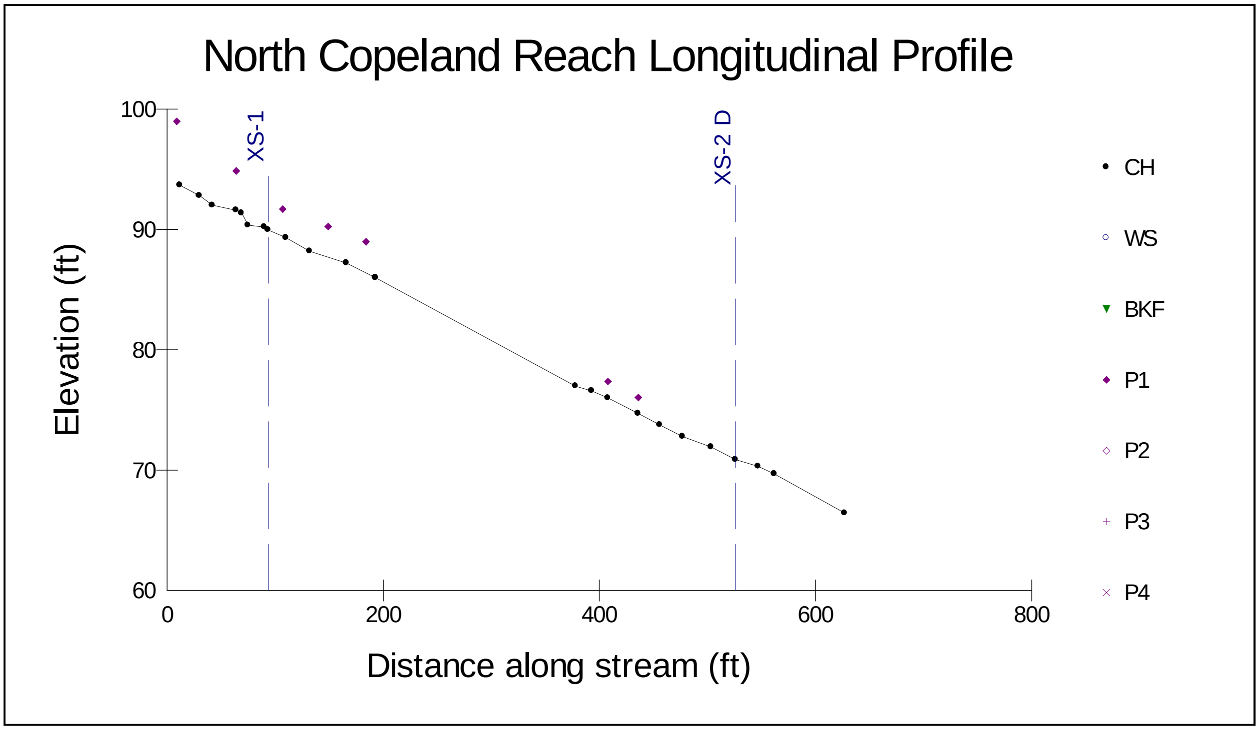


Figure 61. Longitudinal profile of the surveyed reach, channel slopes average 4.2%.

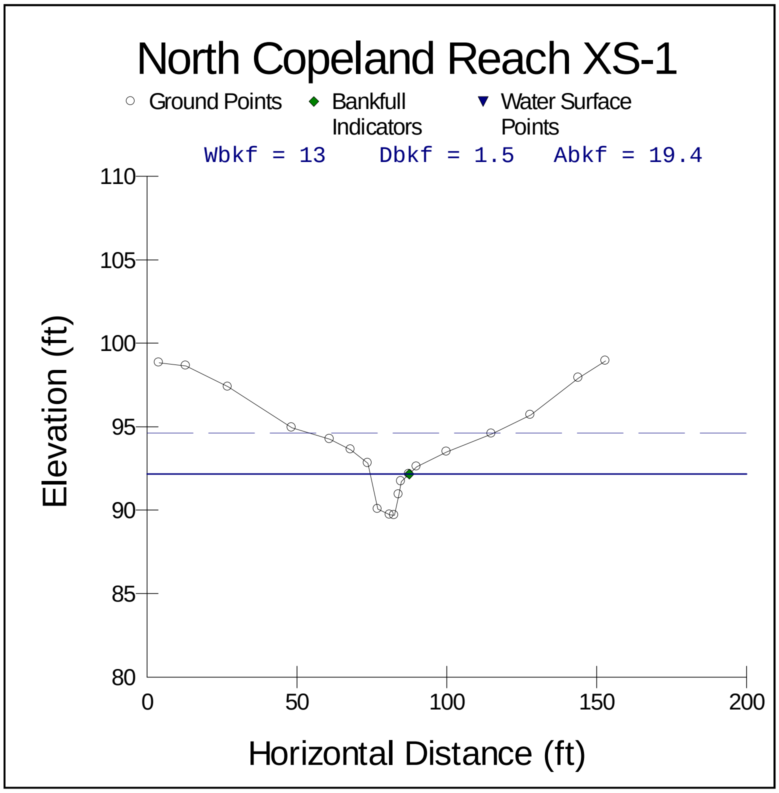


Figure 62. Representative cross-section #1 surveyed within the northern portion of the Copeland Watershed.

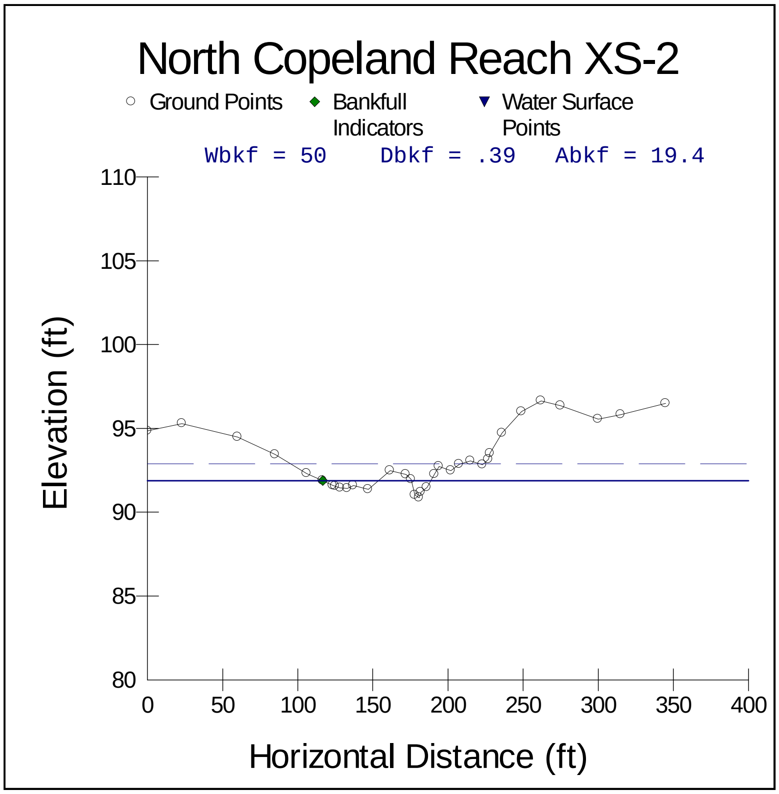


Figure 63. Representative cross-section #2 surveyed within the northern portion of the Copeland Watershed.

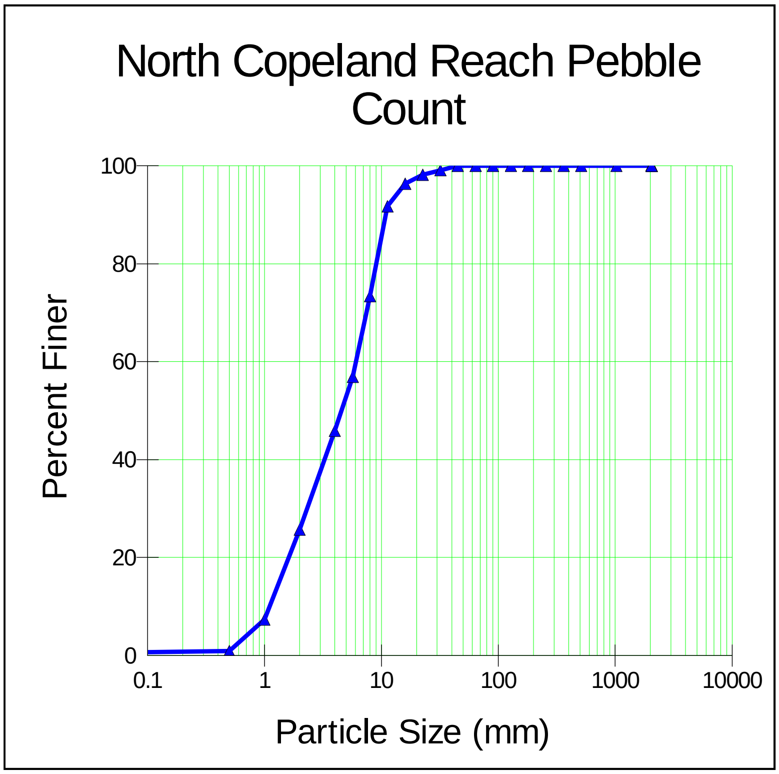


Figure 64. Representative Pebble Count, D50=5 mm.

LOWER COPELAND REACH - RAILROAD TANK

This portion of the Copeland watershed is eroding due to increased runoff. The stability of the channel is poor due to the tendency of the channel to aggrade and migrate laterally. At the survey location the valley is a Type III. Since the flow divides upstream, it is unknown what portion of flow and sediment reaches this stream. If all the flow was directed in this direction, the streambank erosion rate would be *0.40 tons/yr/ft*. The channel slope within the survey is 5.2 % with a bankfull cross-sectional area, determined by local curve, of *20.0* ft^2. The *2.3* mi^2 watershed has a bankfull discharge of *14.2 MDF/37.3 IM cfs* at the survey location. If the entirety of the flow is directed to this area, the combined bedload and suspended load transport capacity of the current *"F"* channel is *402 tons/yr*. It is expected that the historic or restored *"D"* channel would have a transport capacity of 102 *tons/yr*, a *75%* reduction over the current condition.

Figure 65. Photo (ID127) looking downstream showing aggradation over previously incised channel near Railroad Tank

Note the latter aggradation has effectively blocked the secondary channel to the right in this photo. The downstream portions of both channels have incised.

Figure 66. Photo (ID127) looking upstream showing sediment storage behind a temporary log jam

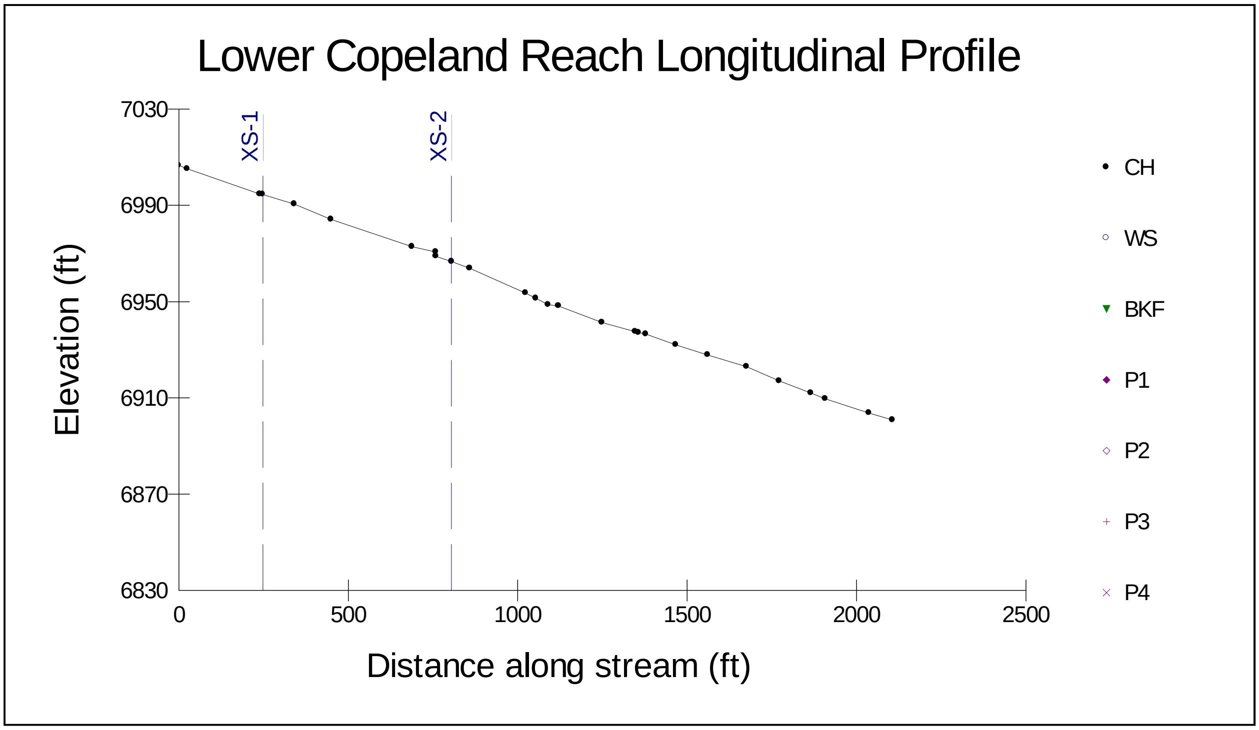


Figure 67. Longitudinal profile of the surveyed reach, channel slopes average 5.2%.

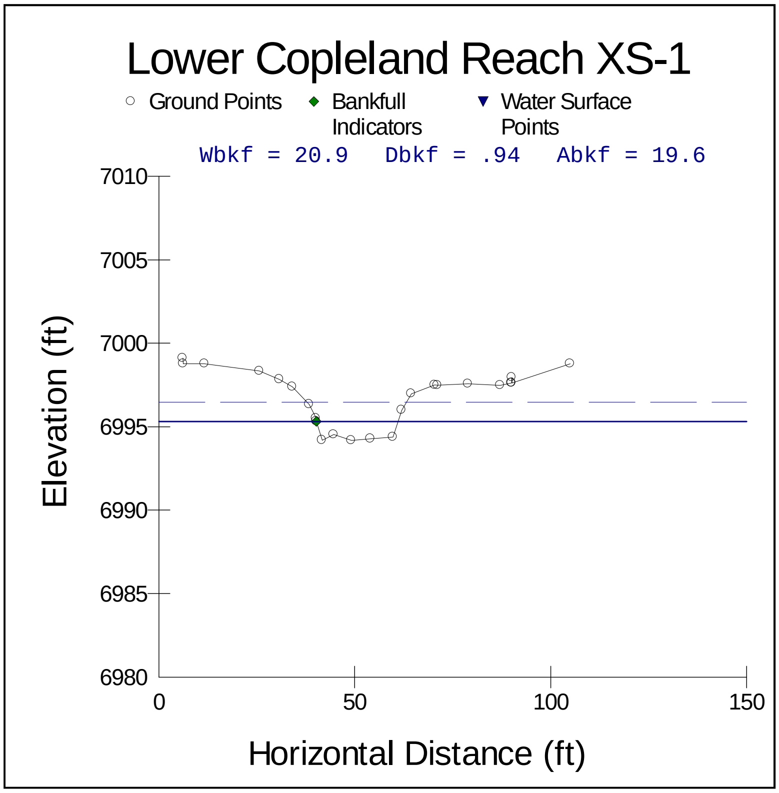


Figure 68. Representative cross-section #1 surveyed within the lower portion of the Copeland Watershed.

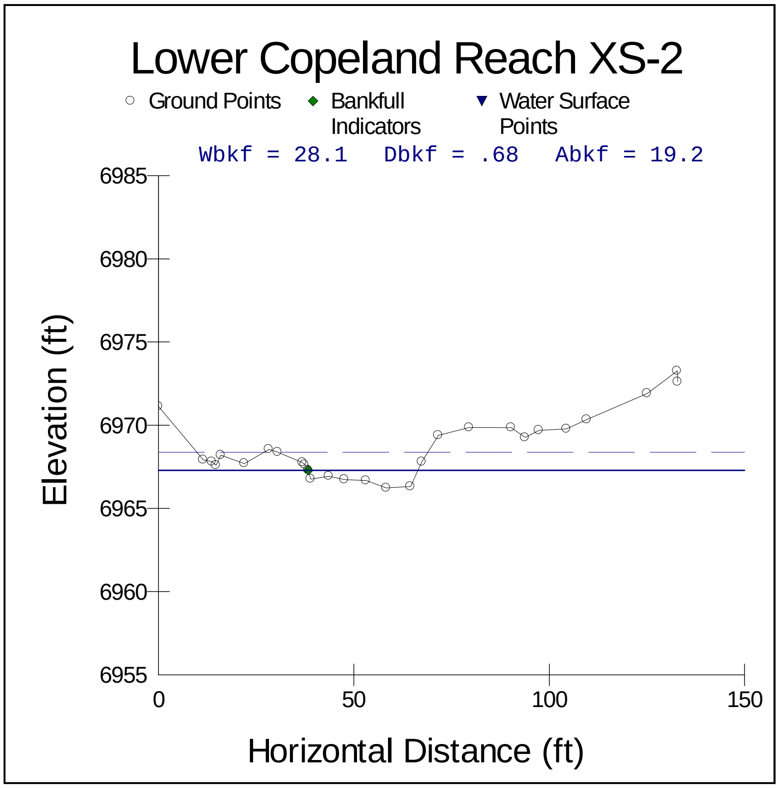


Figure 69. Representative cross-section #2 surveyed within the lower portion of the Copeland Watershed.

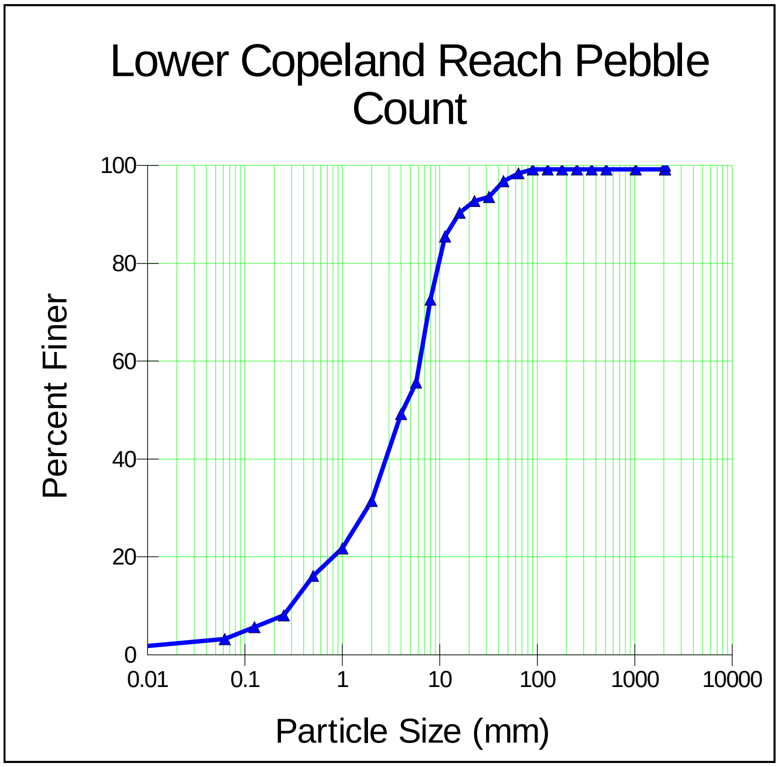


Figure 70. Representative Pebble Count, D50=4 mm.

ROPE ARABIAN UPPER REACH E

This portion of the Rope Arabian watershed has low gradients and is prone to aggradation. The stability of the channel is poor due to the tendency of the channel to aggrade and migrate laterally. At the survey location the valley is a Type III. The channel slope within the survey is 5.4 % with a bankfull cross-sectional area, determined by local curve, of *4.5* ft^2. The streambank erosion rate is *1.29 tons/yr/ft*. The *0.1* mi^2 watershed has a bankfull discharge of *2.9 MDF/7.7 IM cfs* at the survey location. The combined bedload and suspended load transport capacity of the current channel is *48 tons/yr*. It is expected that the historic or restored *"D"* channel would have a transport capacity of *4 tons/yr*, a *92%* reduction over the current condition.

Figure 71. Representative photo (ID195) showing the 'D' channels found in the upper Rope Arabian watershed

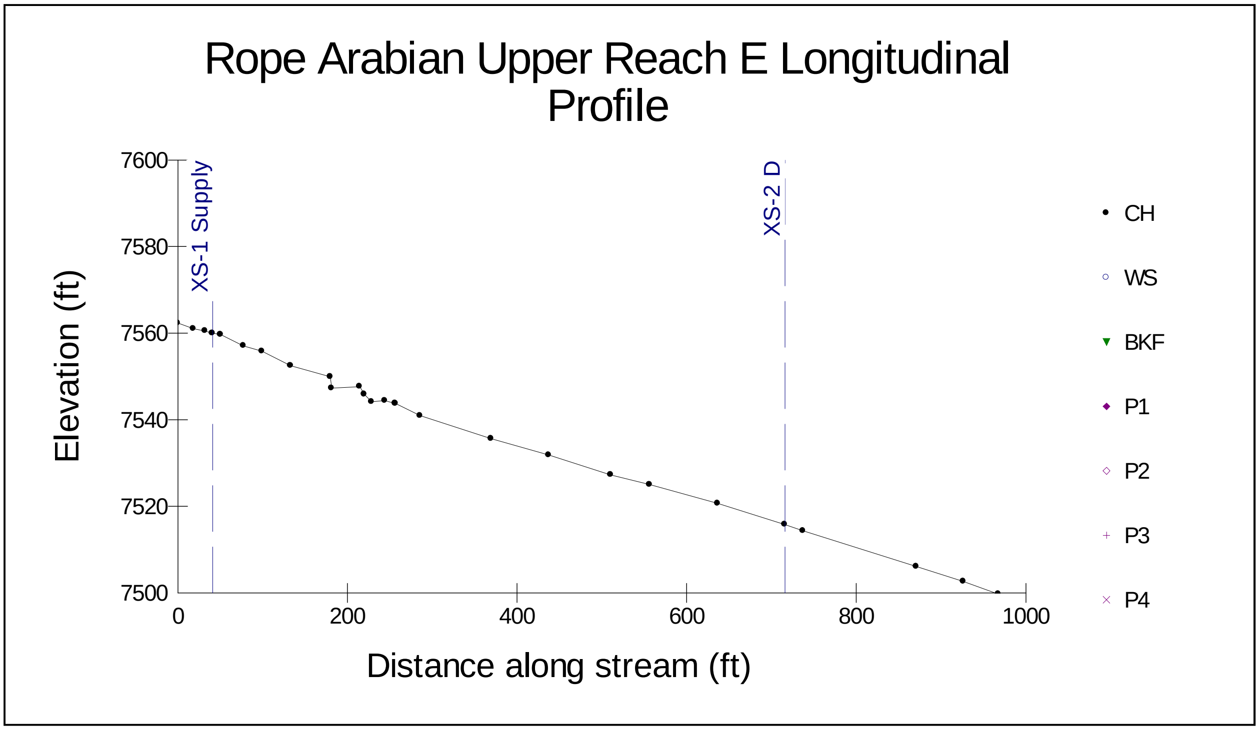


Figure 72. Longitudinal profile of the surveyed reach, channel slopes average 5.4%.

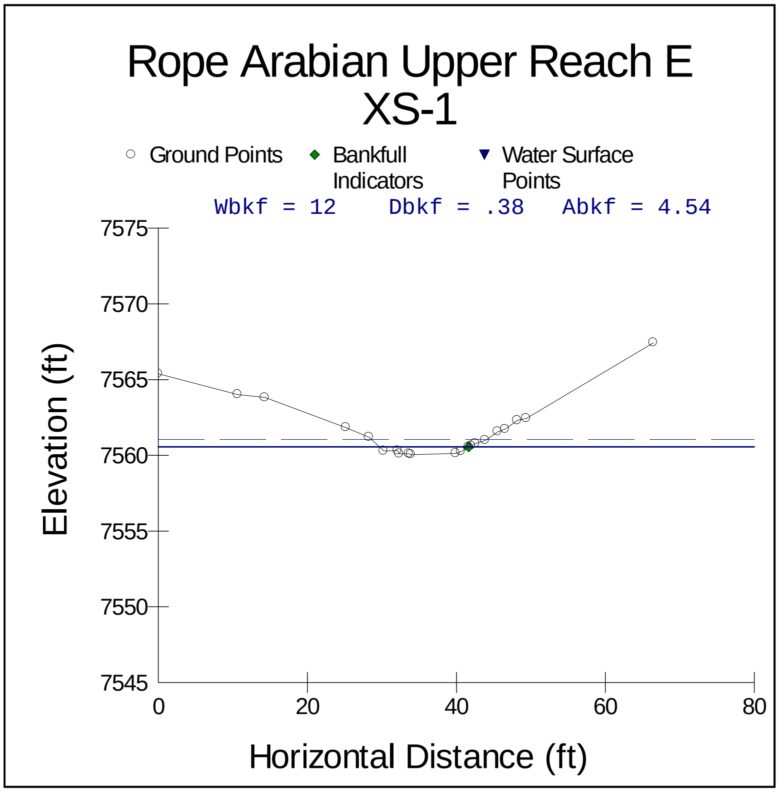


Figure 73. Representative cross-section #1 surveyed within the lower portion of the Rope Arabian-E Watershed.

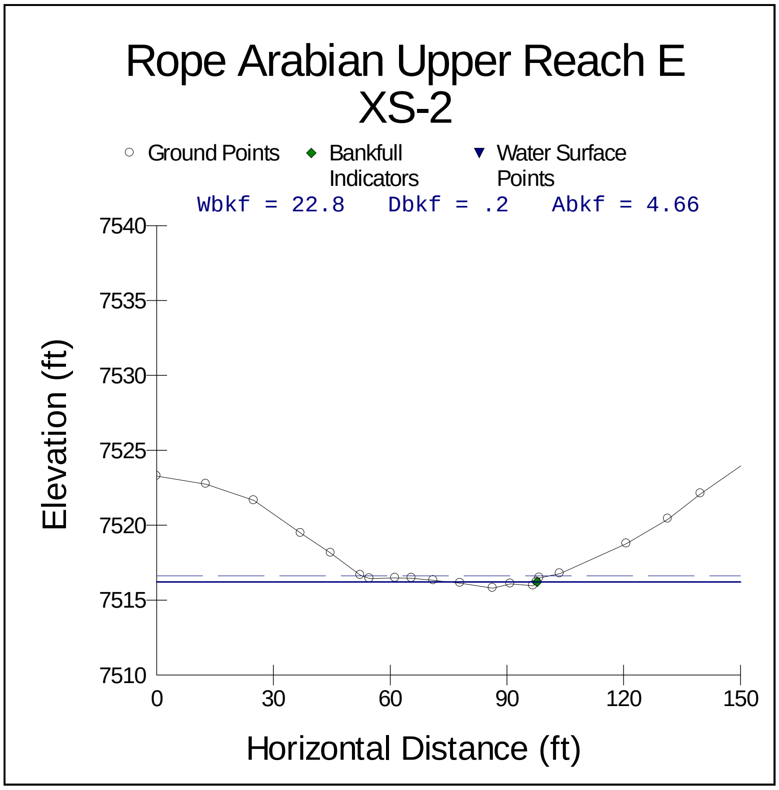
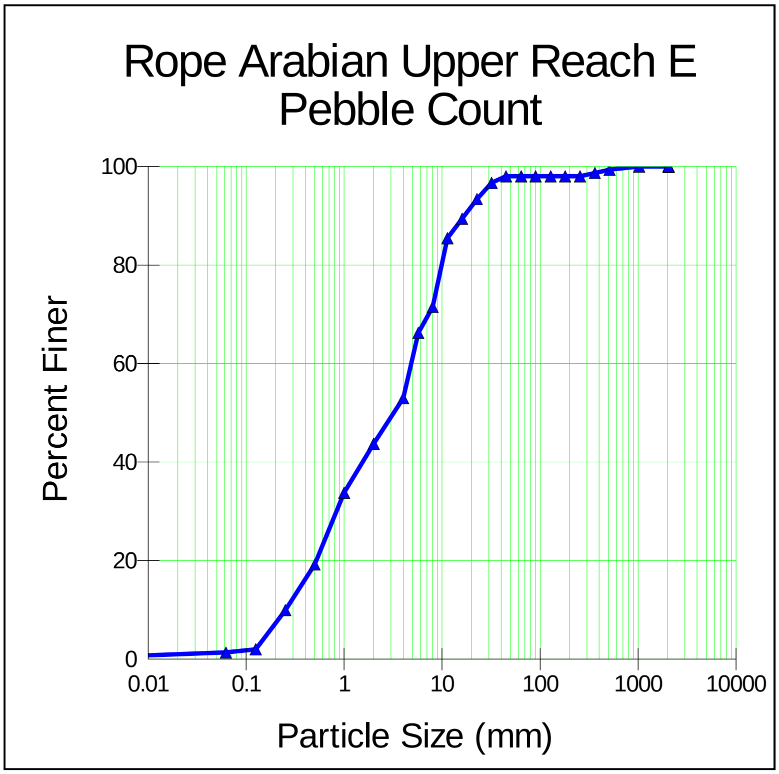


Figure 74. Representative cross-section #2 surveyed within the lower portion of the Rope Arabian-E Watershed.



ROPE ARABIAN UPPER REACH G

This portion of the Rope Arabian watershed has low gradients and is prone to aggradation. The stability of the channel is poor due to degradation, and active incision as well as areas where the channel has tendency to aggrade and migrate laterally. This poor condition of the channel indicates a potential for accelerated increase in flow-related sediment based on increased post-fire stream flow. At the survey location the valley type has just transitioned from Type II to a Type III. The channel slope within the survey is 6.6 % with a bankfull cross-sectional area, determined by local curve, of *8.8 ft*^{2}. The streambank erosion rate is *1.29 tons/yr/ft*. The *0.4 mi*^{2} watershed has a bankfull discharge of *5.8 MDF/15.2 IM cfs* at the survey location. The combined bedload and suspended load transport capacity of the current *"F"* channel is *104 tons/yr*. It is expected that the historic or restored *"D"* channel would have a transport capacity of *19 tons/yr*, an *82%* reduction over the current condition.

Figure 75. Photo (ID163) showing scour through previous aggradation in the upper portion of the Rope Arabian G watershed

Figure 76. Photo (ID162) showing how the channel spreads out where gradients are lower near FR420

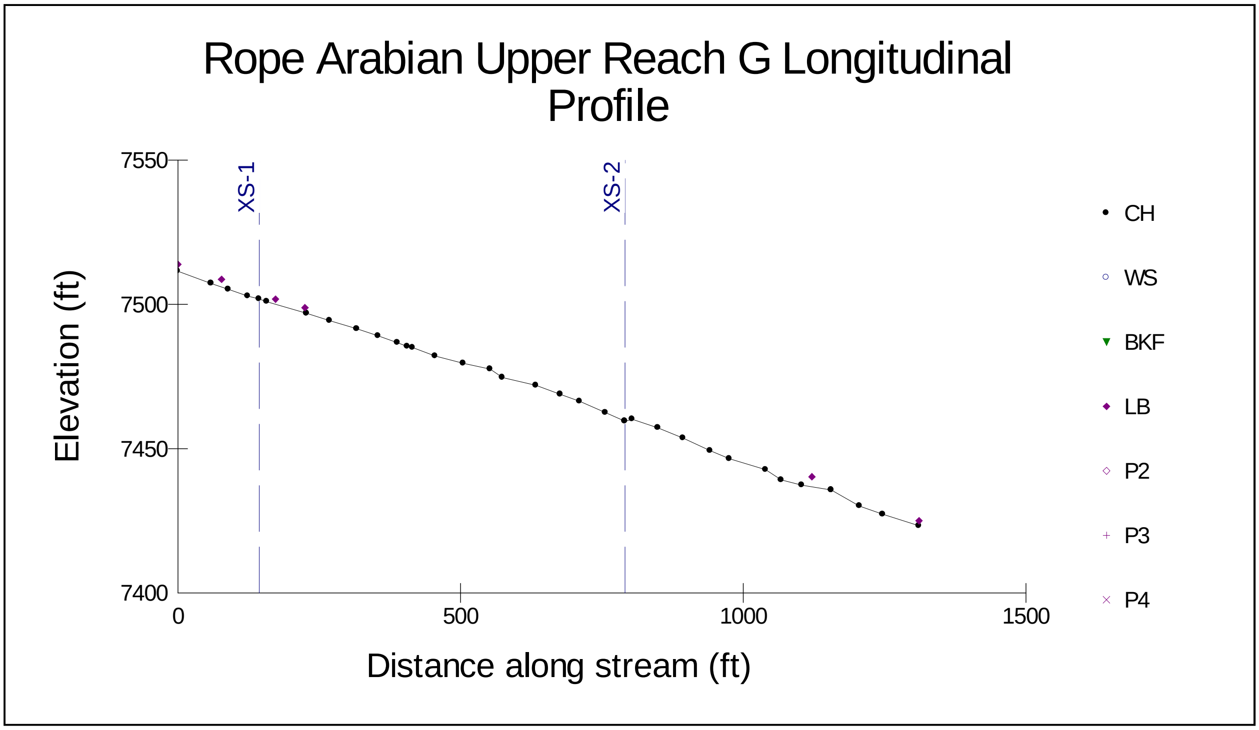


Figure 77. Longitudinal profile of the surveyed reach, channel slopes average 6.6%.

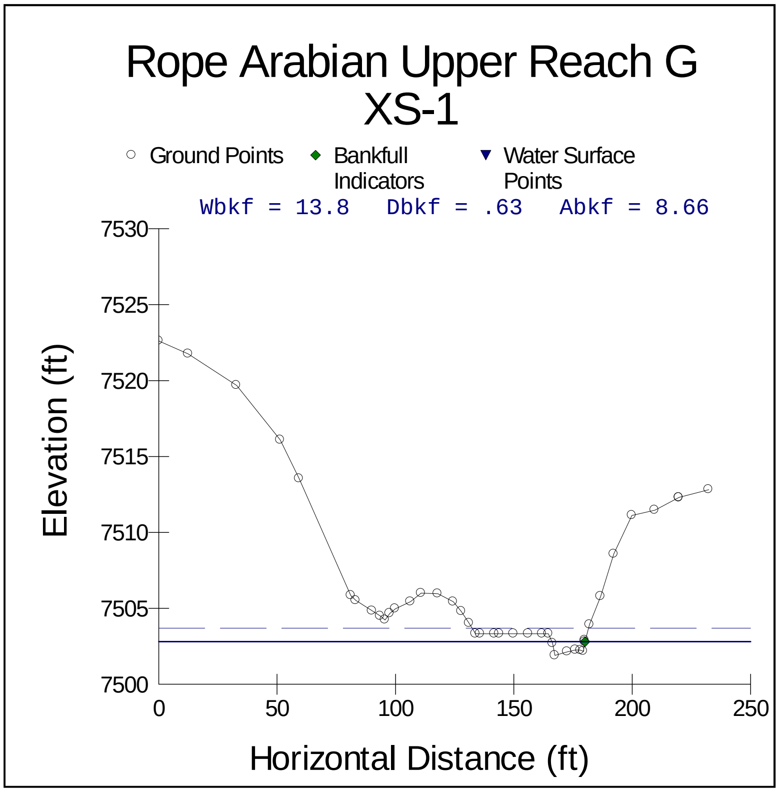


Figure 78. Representative cross-section #1 surveyed within the lower portion of the Rope Arabian-G Watershed.

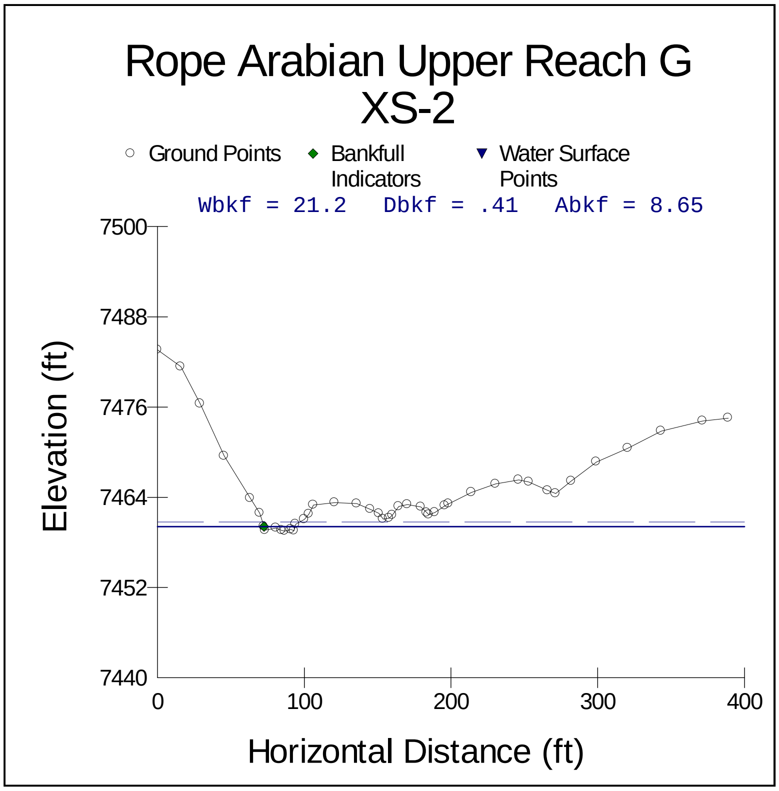


Figure 79. Representative cross-section #2 surveyed within the lower portion of the Rope Arabian-G Watershed.

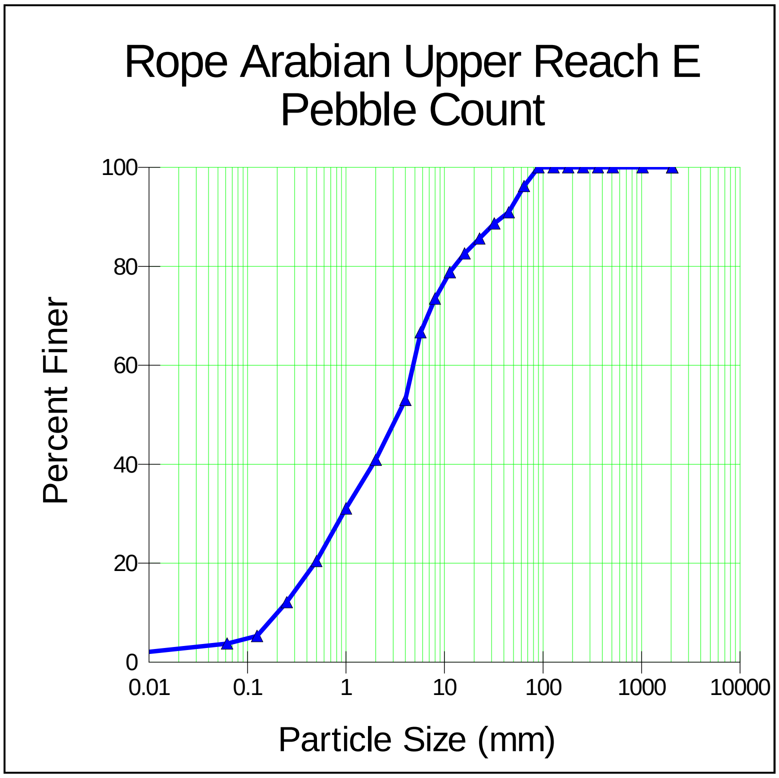


Figure 80. Representative Pebble Count, D50=3 mm.

ROPE ARABIAN LOWER REACH

This portion of the Rope Arabian watershed is fairly stable and more prone to aggradation than degradation. The stability of the channel is poor due to the tendency of the channel to aggrade and migrate laterally. At the survey location the valley is a Type III. The channel slope within the survey is 5.0 % with a bankfull cross-sectional area, determined by local curve, of *16.8* ft^2. The streambank erosion rate is *0.22 tons/yr/ft*. The *1.6* mi^2 watershed has a bankfull discharge of *11.8 MDF/31.1 IM cfs* at the survey location. The combined bedload and suspended load transport capacity of the current *"F"* channel is *285 tons/yr*. It is expected that the historic or restored *"D"* channel would have a transport capacity of *67 tons/yr*, a *76%* reduction over the current condition.

Figure 81. Representative photo (ID178) of the fairly stable channels found throughout the lower reaches of the Rope Arabian watershed

Figure 82. Representative photo (ID38) of the spreading out of the channel in the lower reaches of the Rope Arabian watershed

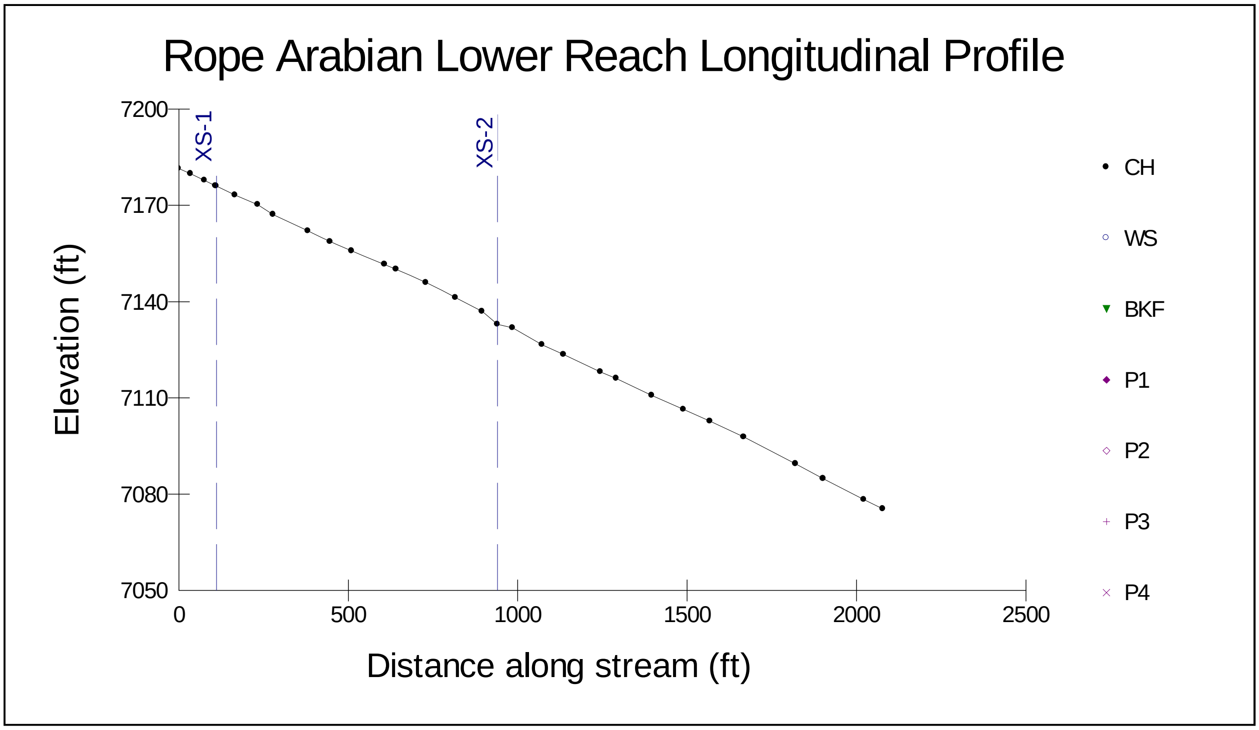


Figure 83. Longitudinal profile of the surveyed reach, channel slopes average 5%.

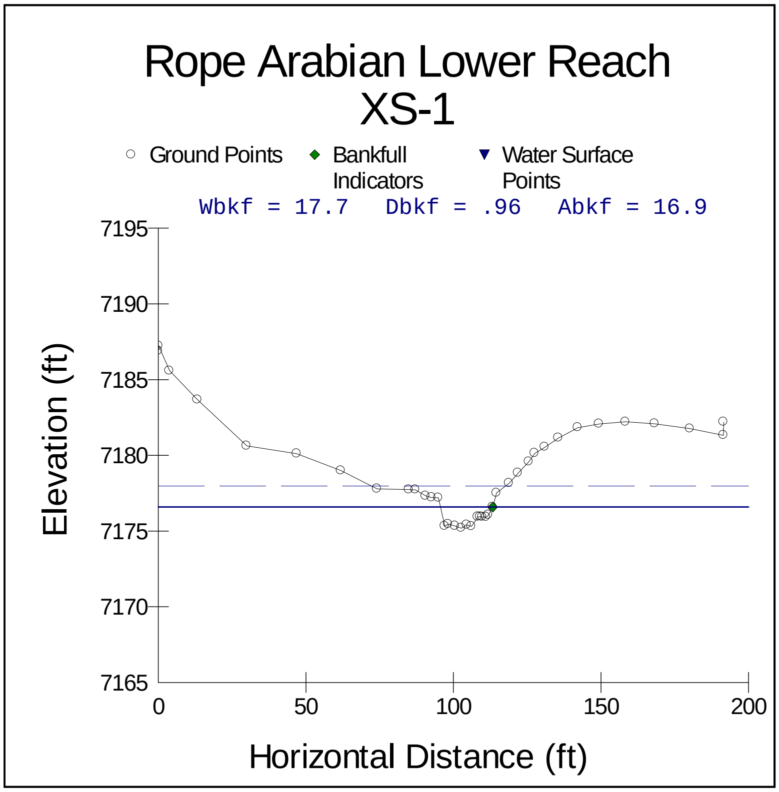


Figure 84. Representative cross-section #1 surveyed within the lower portion of the Rope Arabian Watershed.

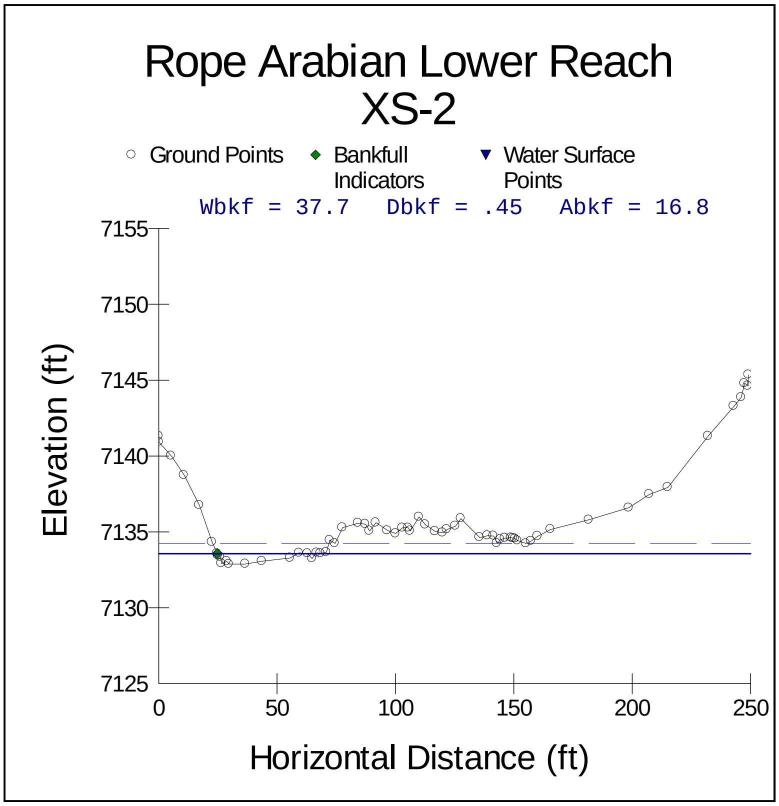


Figure 85. . Representative cross-section #2 surveyed within the lower portion of the Rope Arabian Watershed.

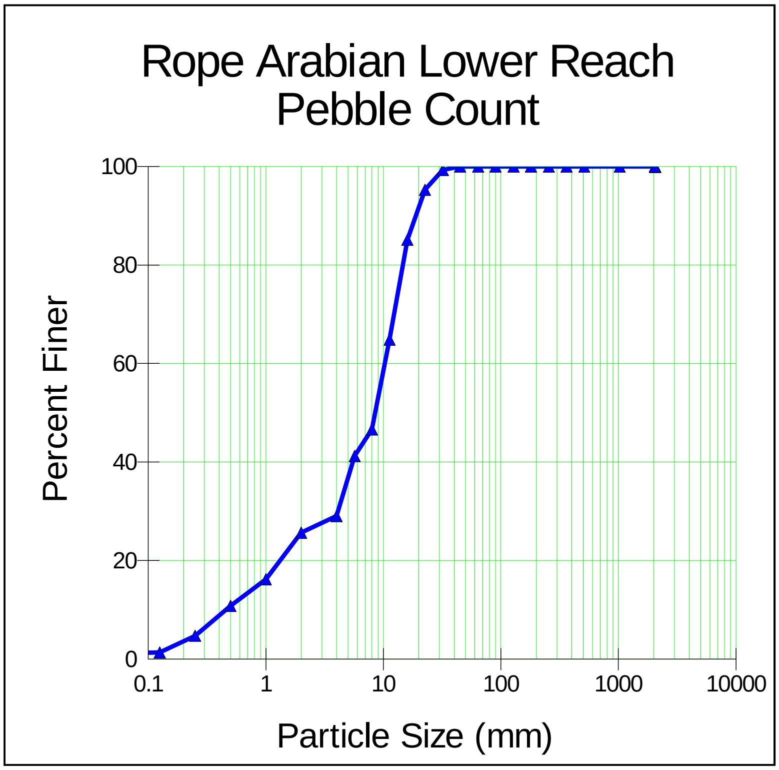


Figure 86. Representative Pebble Count, D50=9 mm.

SIESTA-PAINTBRUSH UPPER REACH

This portion of the Siesta-Paintbrush watershed is characterized by recently incised channels due to increased runoff. The stability of the channel is poor due to degradation, and active incision. The poor condition of the channel indicates a potential for accelerated increase in flow-related sediment based on increased post-fire channel flow. At the survey location the valley is a Type II. The channel slope within the survey is 7.0 % with a bankfull cross-sectional area, determined by local curve, of *9.2* ft^2. The streambank erosion rate is *0.77 tons/yr/ft*. The *0.4* mi^2 watershed has a bankfull discharge of *6.1 MDF/15.9 IM cfs* at the survey location. The combined bedload and suspended load transport capacity of the current *"F"* channel is *118 tons/yr*. It is expected that the historic or restored *"D"* channel would have a transport capacity of *23 tons/yr*, a *81%* reduction over the current condition.

Figure 87. Representative photo (ID7) of the highly incised channels found in the steeper reaches of the upper Siesta-Paintbrush watershed

Figure 88. Representative photo (ID6) of the incised channels found in the less steep reaches of the upper Siesta-Paintbrush watershed

Figure 89. Representative photo (ID4) of the spreading of sediment where gradients are lower

Figure 90. Representative photo (ID11) of the 'D' type channels found near FR420

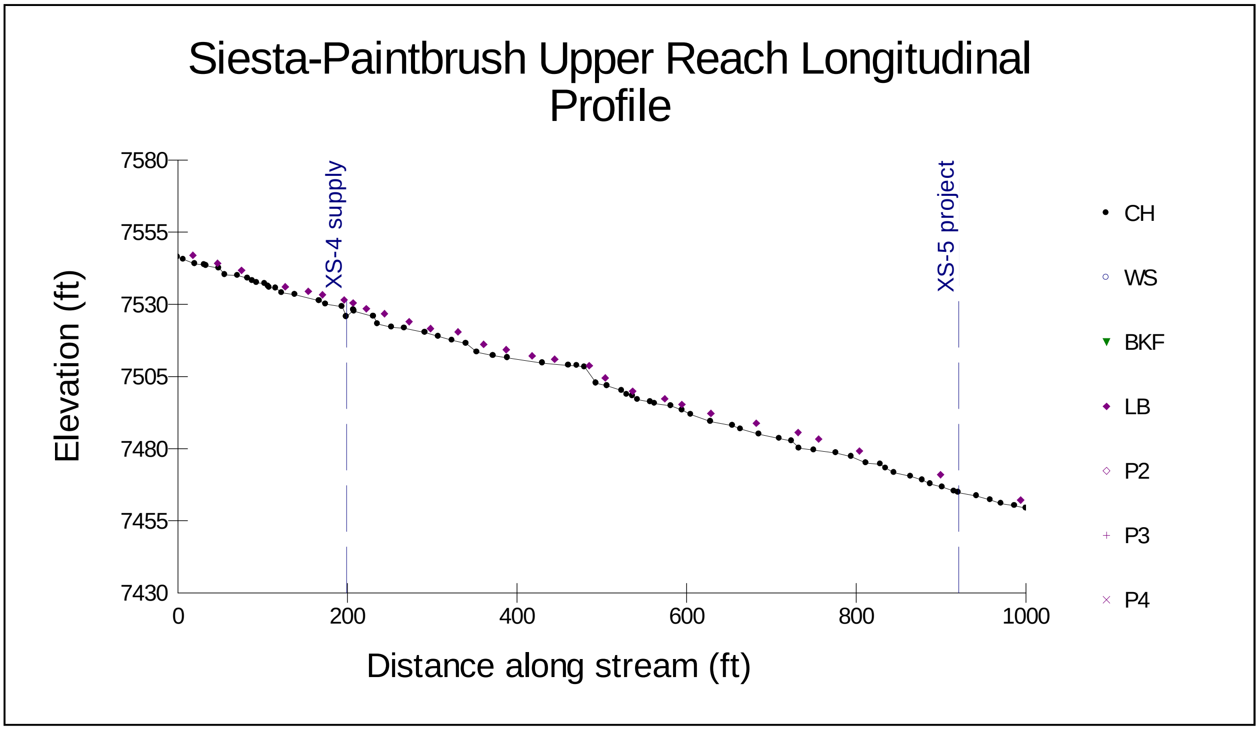


Figure 91. Longitudinal profile of the surveyed reach, channel slopes average 7%.

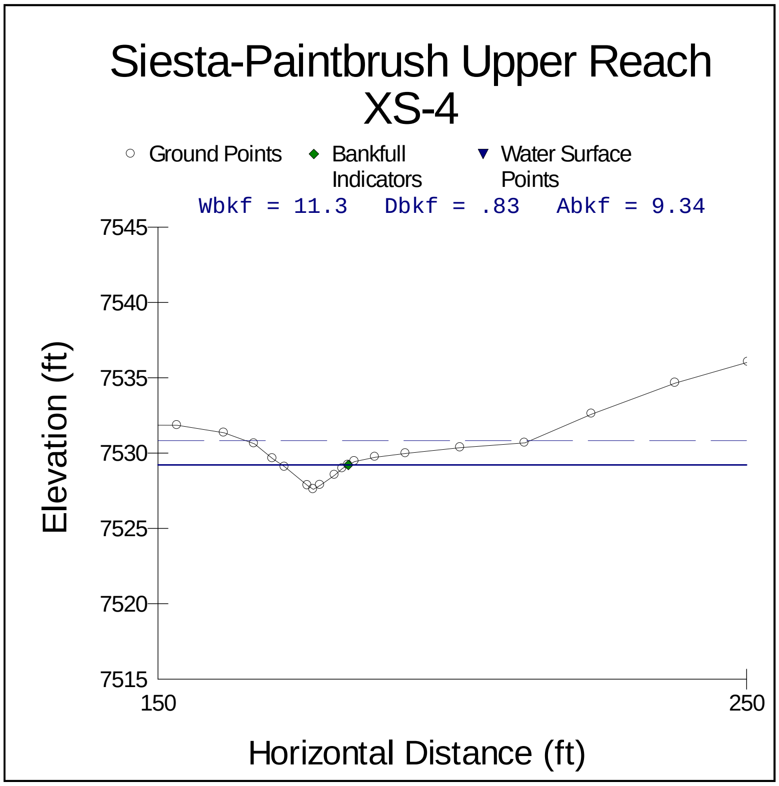


Figure 92. . Representative cross-section #4 surveyed within the upper portion of the Siesta-paintbrush Watershed.

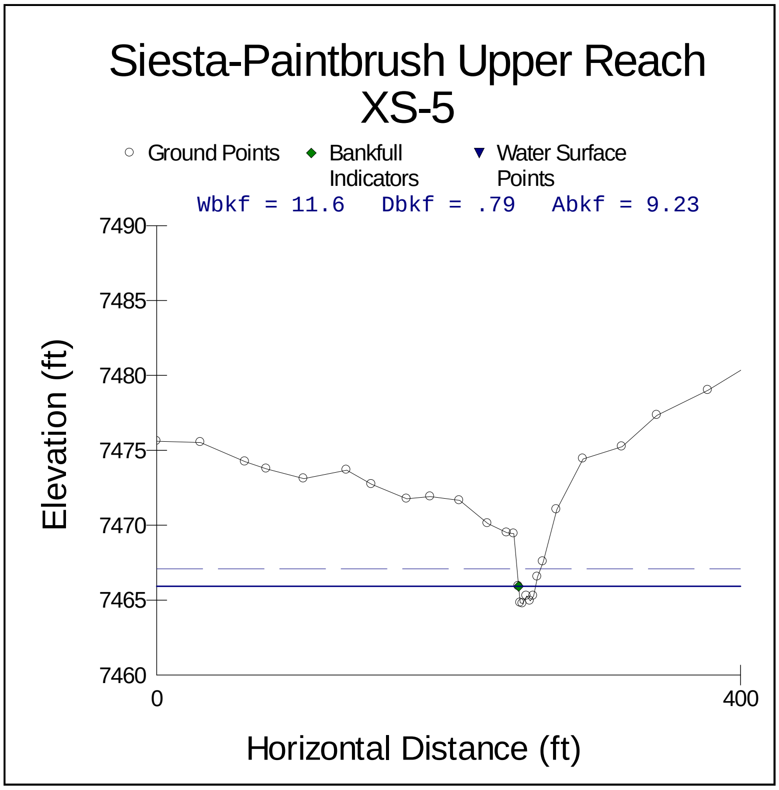


Figure 93. Representative cross-section #5 surveyed within the upper portion of the Siesta-paintbrush Watershed.

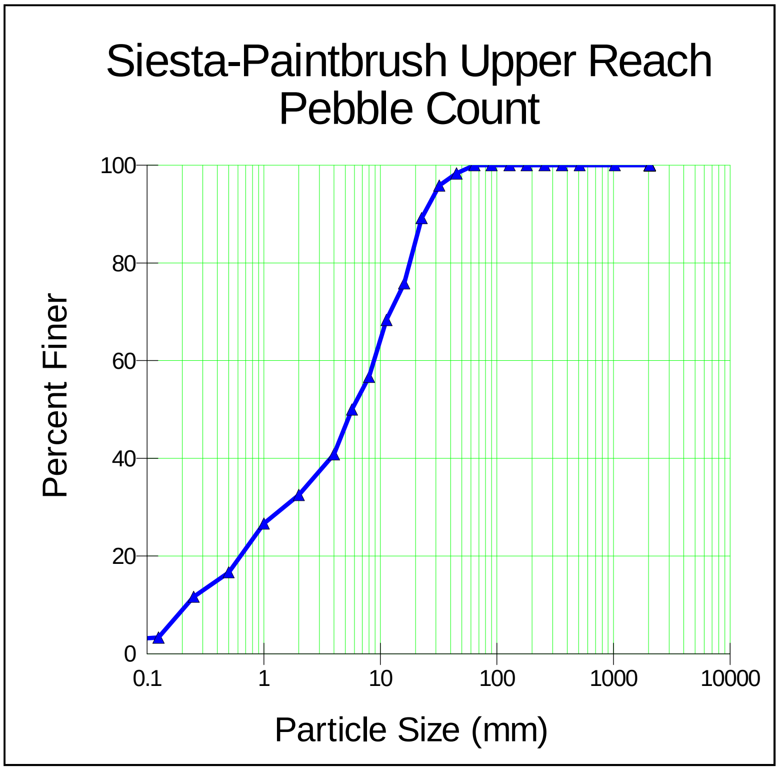


Figure 94. Representative Pebble Count, D50=6 mm.

SIESTA-PAINTBRUSH MID REACH

This portion of the Siesta-Paintbrush watershed has lower gradients and more aggradation has been observed than degradation. The stability of the channel is poor due to the tendency of the channel to aggrade and migrate laterally. At the survey location the valley is a Type III. The channel slope within the survey is 5.3% with a bankfull cross-sectional area, determined by local curve, of *11.3* ft^2. The streambank erosion rate is *0.28 tons/yr/ft*. The *0.9* mi^2 watershed has a bankfull discharge of *9.2 MDF/24.2 IM cfs* at the survey location. The combined bedload and suspended load transport capacity of the current channel is *402 tons/yr*. It is expected that the historic or restored *"D"* channel would have a transport capacity of *39 tons/yr*, a *90%* reduction over the current condition.

Figure 95. Representative photo (ID24) of the stable channels found in the mid reaches of the Siesta-Paintbrush watershed

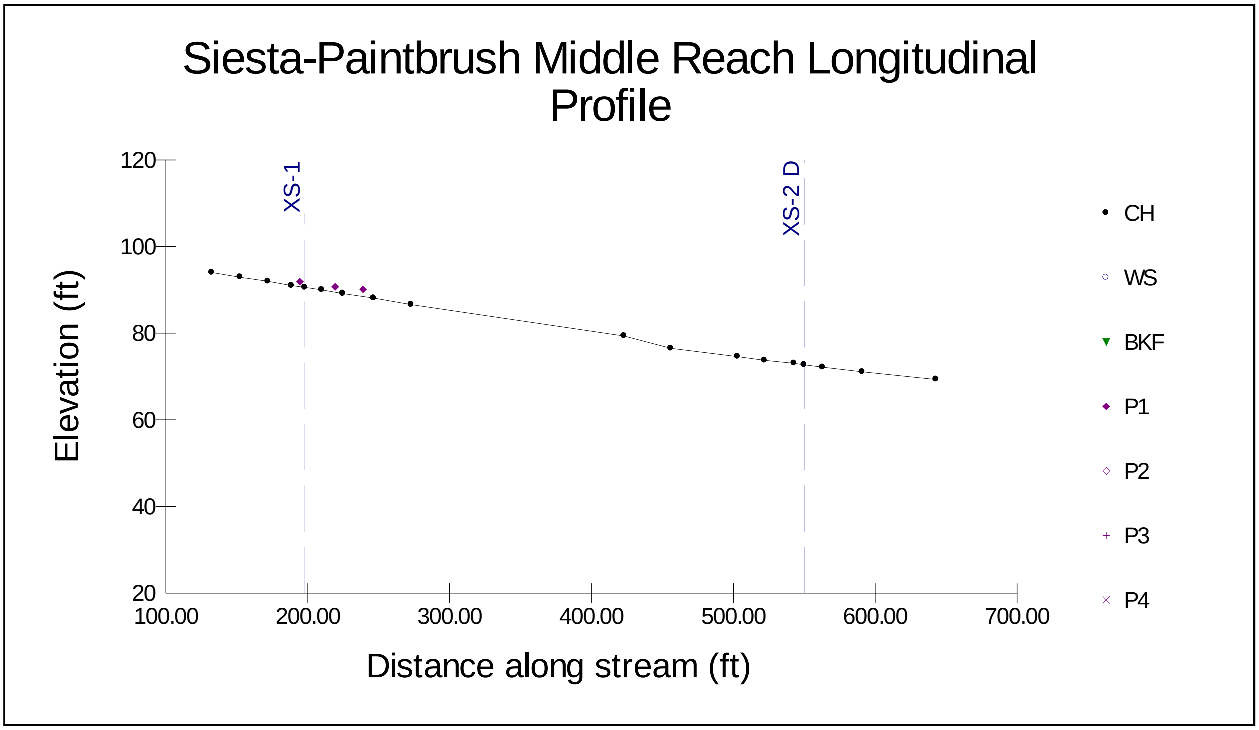


Figure 96. Longitudinal profile of the surveyed reach, channel slopes average 5.3%.

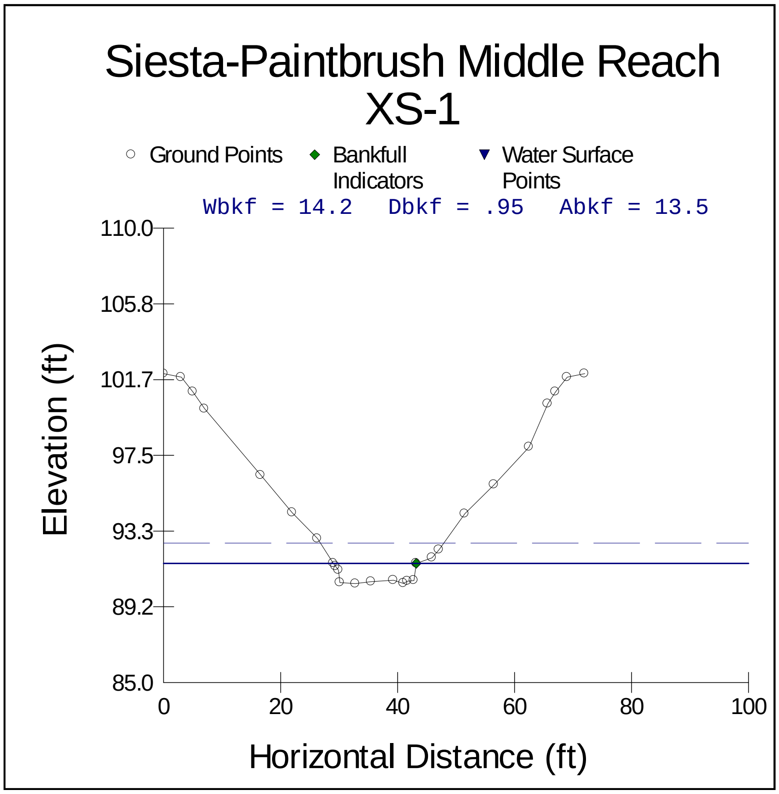


Figure 97. Representative cross-section #1 surveyed within the middle portion of the Siesta-paintbrush Watershed.

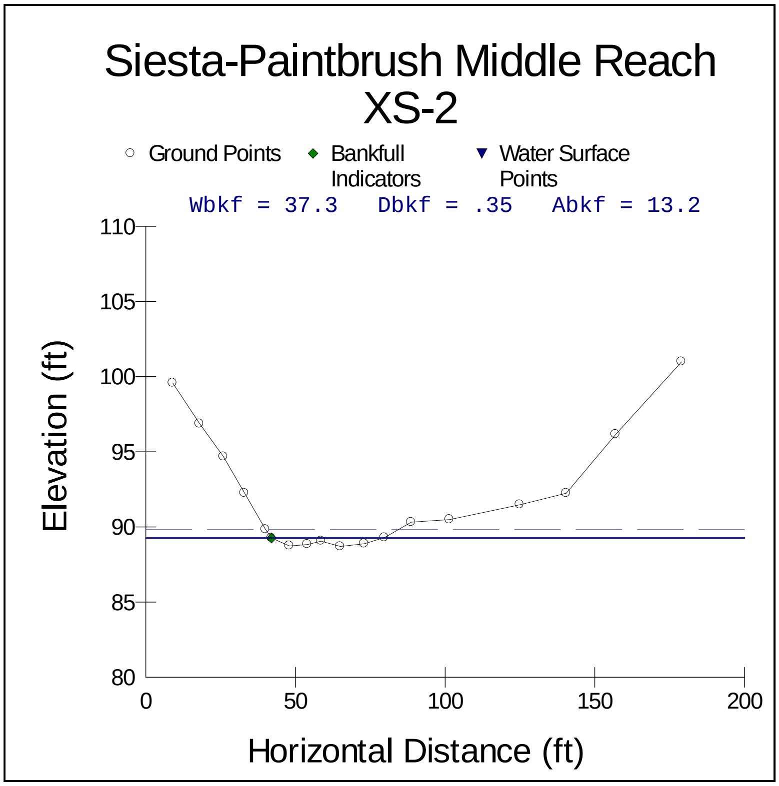


Figure 98. Representative cross-section #2 surveyed within the middle portion of the Siesta-paintbrush Watershed.

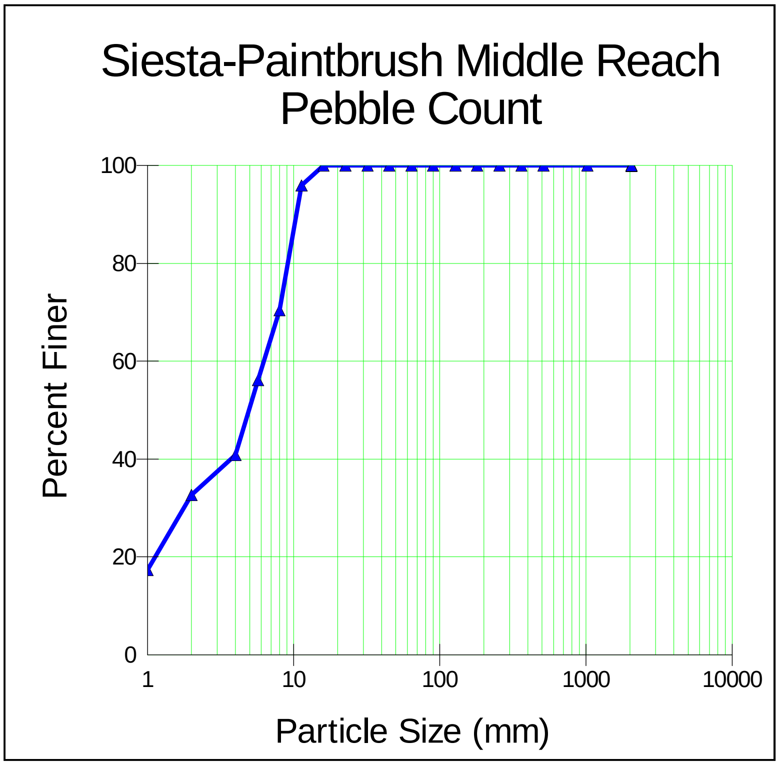


Figure 99. Representative Pebble Count, D50=5 mm.

SIESTA-PAINTBRUSH LOWER REACH

This portion of the Siesta-Paintbrush watershed is slightly confined and is more prone to aggradation than degradation. The stability of the channel is poor due to the tendency of the channel to aggrade and migrate laterally. At the survey location the valley is a Type III. The channel slope within the survey is 4.7 % with a bankfull cross-sectional area, determined by local curve, of *13.5* ft^2. The streambank erosion rate is *0.28 tons/yr/ft*. The *1.0* mi^2 watershed has a bankfull discharge of *9.2 MDF/24.2 IM cfs* at the survey location. The combined bedload and suspended load transport capacity of the current channel is *204 tons/yr*. It is expected that the historic or restored *“D”* channel would have a transport capacity of *13 tons/yr*, a *94%* reduction over the current condition.

Figure 100. Representative photo (ID27) of the aggradation in a previously incised channel

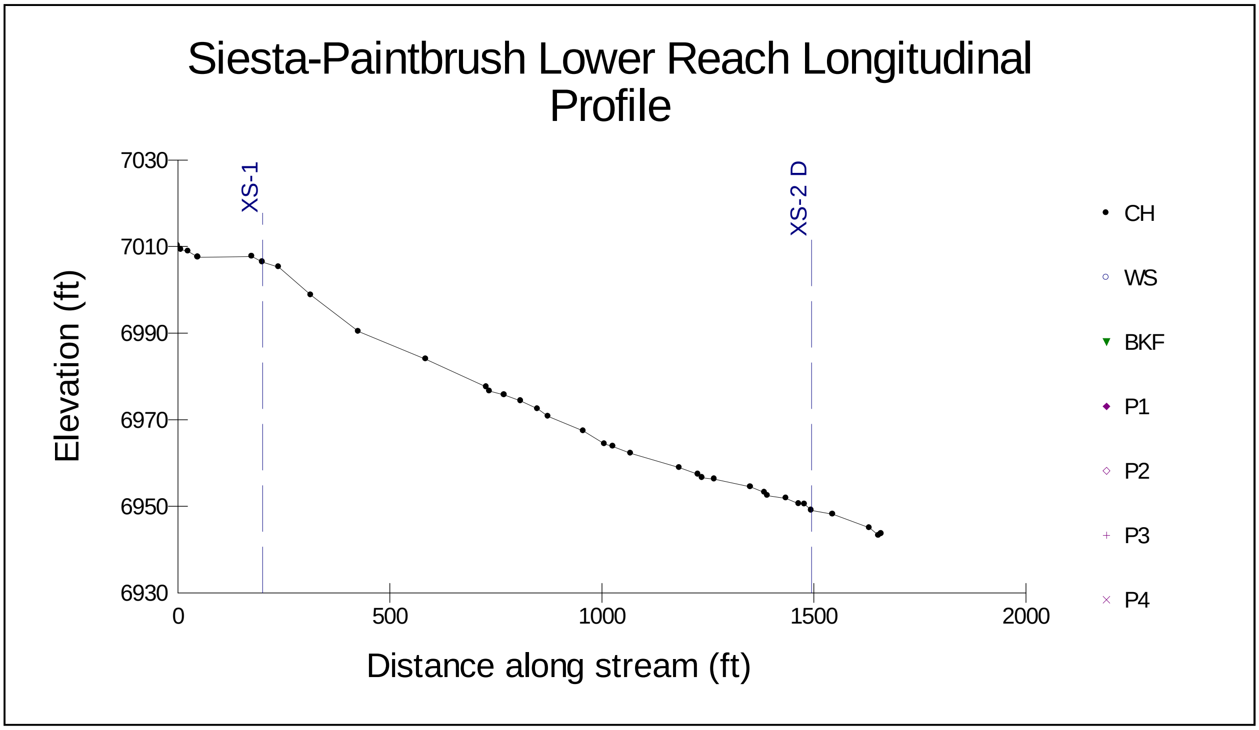


Figure 101. Longitudinal profile of the surveyed reach, channel slopes average 4.7%.

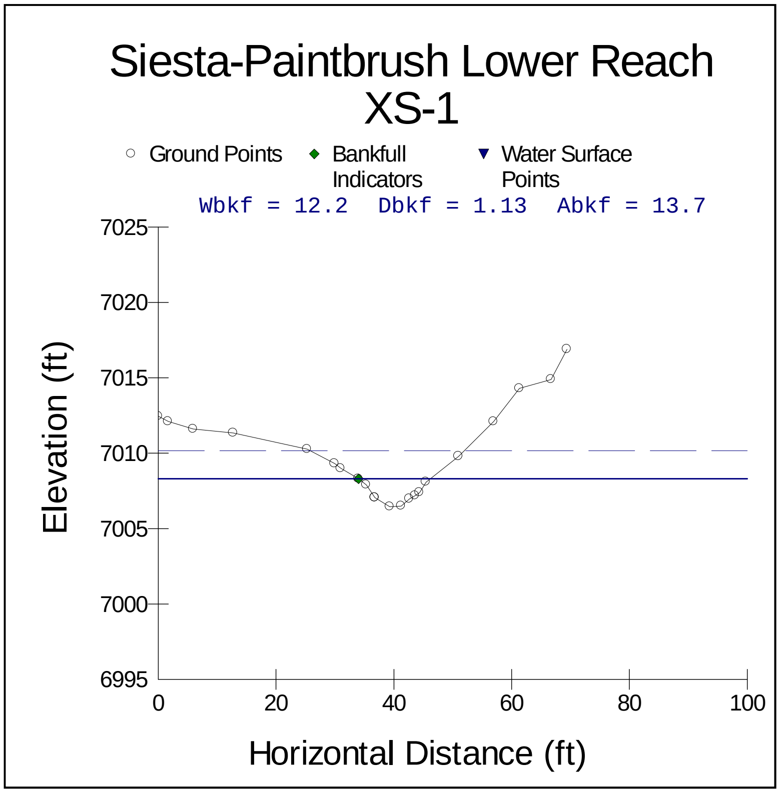


Figure 102. Representative cross-section #1 surveyed within the lower portion of the Siesta-paintbrush Watershed.

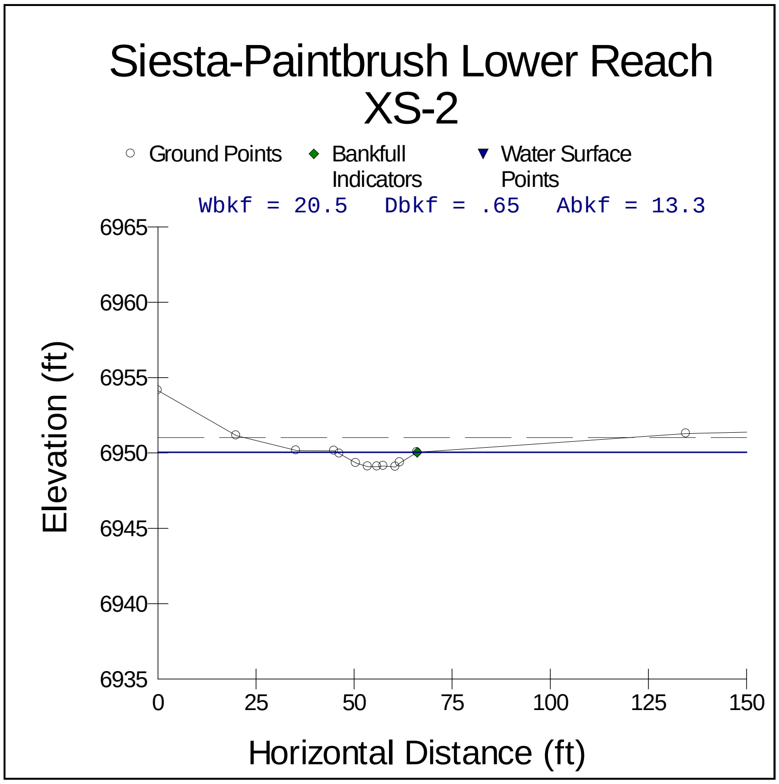


Figure 103. Representative cross-section #2 surveyed within the middle portion of the Siesta-paintbrush Watershed.

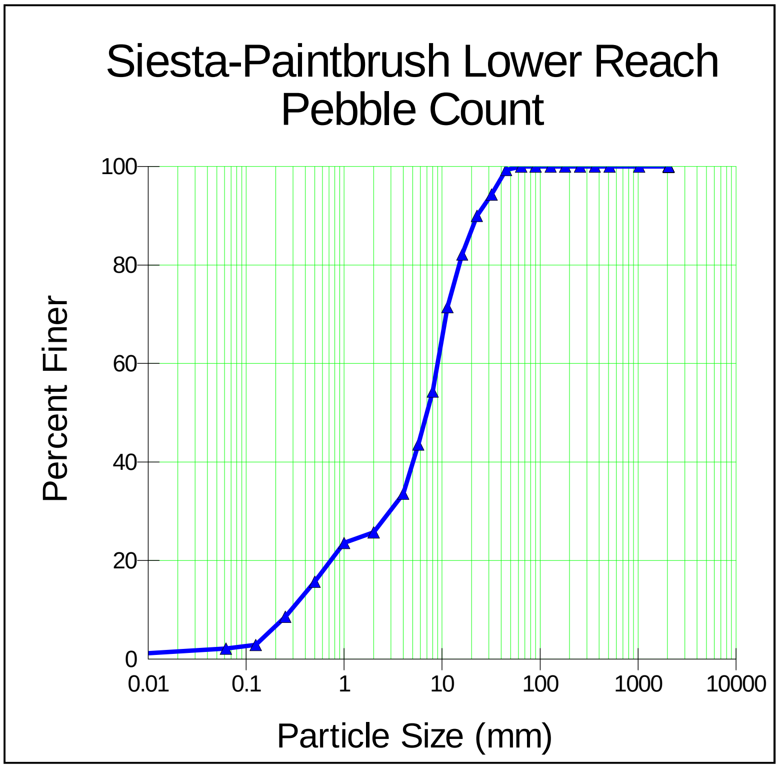


Figure 104. Representative Pebble Count, D50=7 mm.

PAINTBRUSH-SIESTA LOWER REACH

This portion of the Paintbrush-Siesta watershed is very flat and prone to aggradation. The stability of the channel is poor due to the tendency of the channel to aggrade and migrate laterally. At the survey location the valley is a Type III. The channel slope within the survey is 3.2 % with a bankfull cross-sectional area, determined by local curve, of *20.0* ft^2. The streambank erosion rate is *0.33 tons/yr/ft*. The *2.37* mi^2 watershed has a bankfull discharge of *14.7 MDF/38.6 IM cfs* at the survey location. The combined bedload and suspended load transport capacity of the current *"F"* channel is *429 tons/yr*. It is expected that the historic or restored *"D"* channel would have a transport capacity of *105 tons/yr*, a *76%* reduction over the current condition.

Figure 105. Representative photo (ID95) of the wide spread-out channels found in the lower reaches of the Paintbrush-Siesta watershed

Figure 106. Photo (ID96) showing the unconfined flows as it approaches the neighborhood

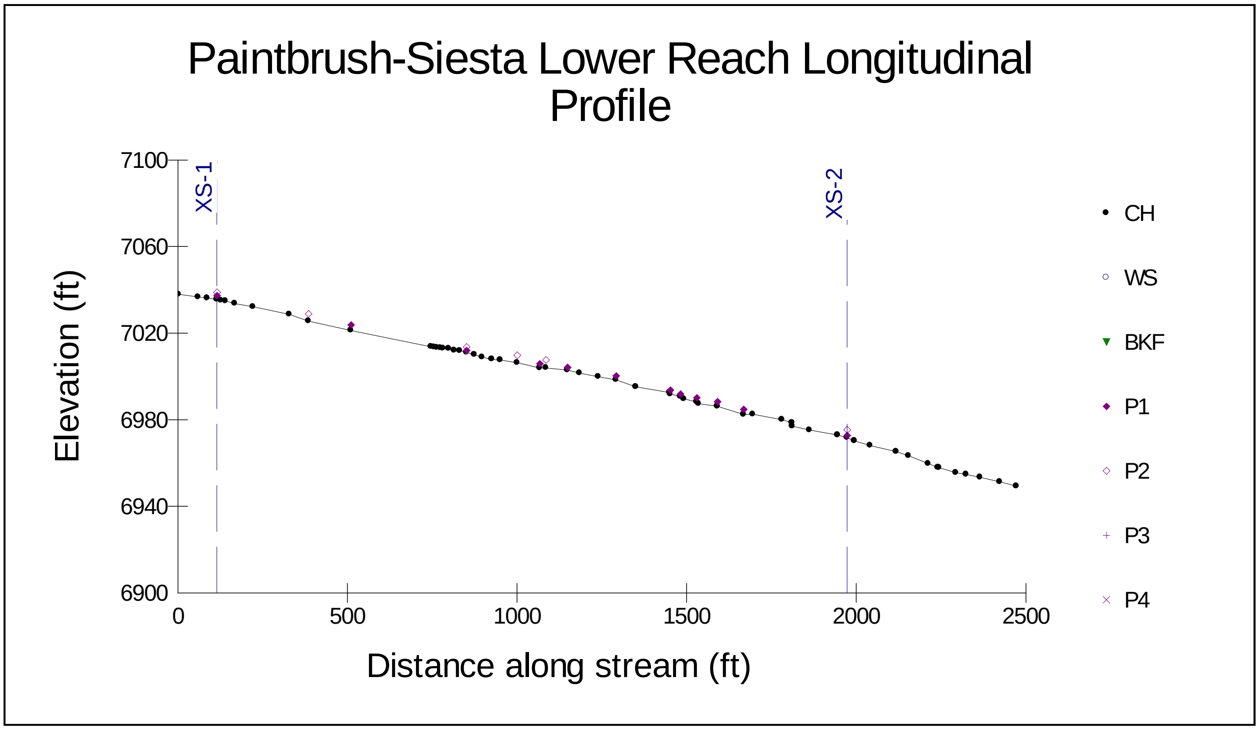


Figure 107. Longitudinal profile of the surveyed reach, channel slopes average 3.2%.

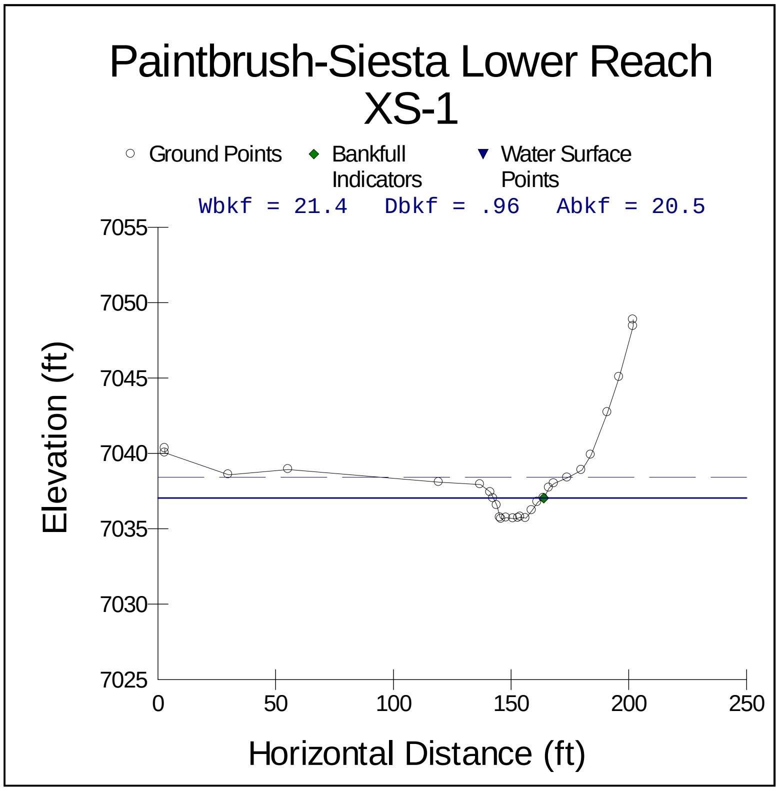


Figure 108. Representative cross-section #1 surveyed within the lower portion of the Paintbrush-siesta Watershed.

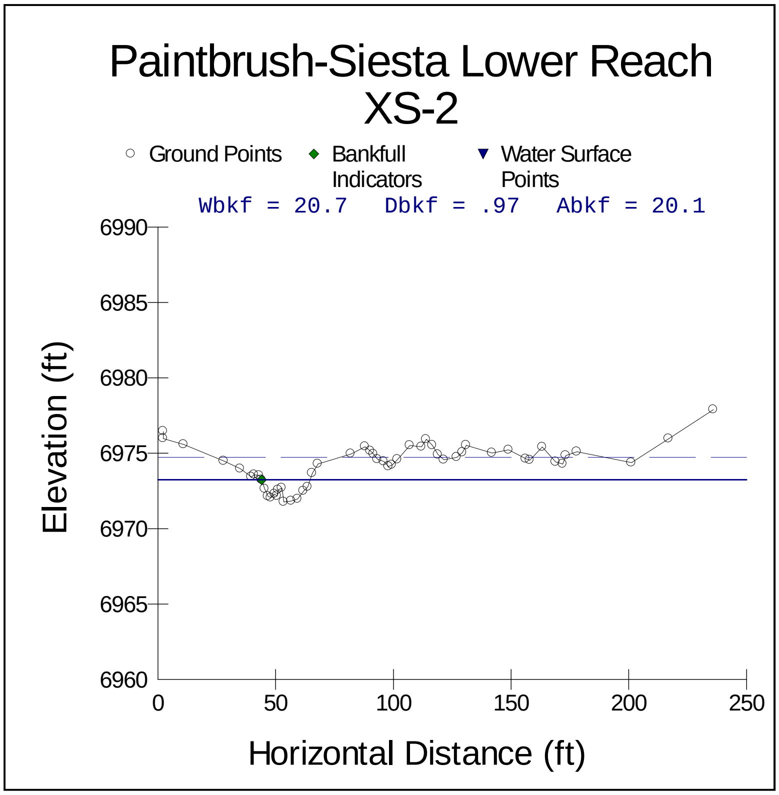


Figure 109. Representative cross-section #2 surveyed within the lower portion of the Paintbrush-siesta Watershed.

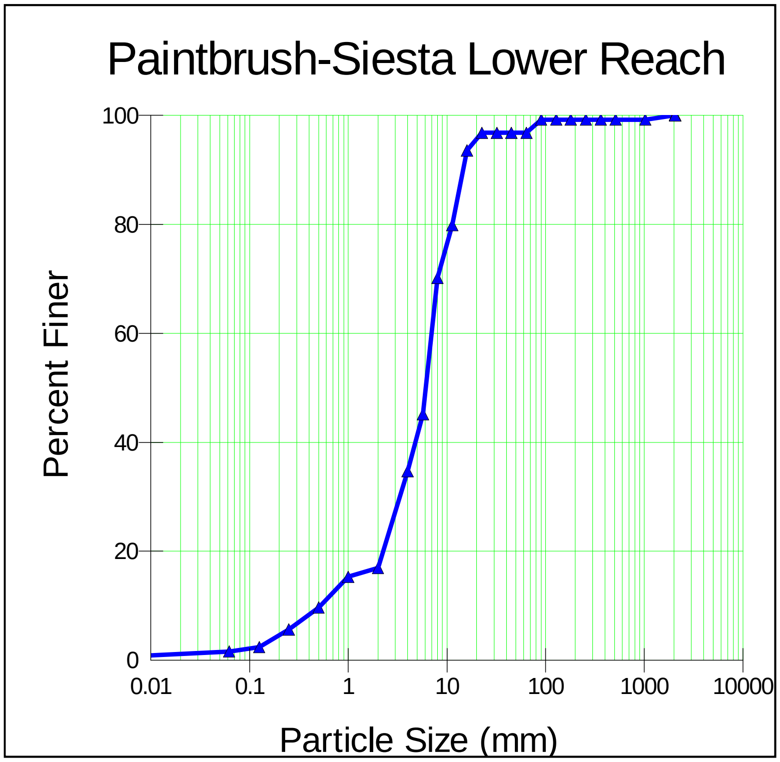


Figure 110.Representative Pebble Count, D50=6 mm.

APPENDIX D – COMMENTS FROM REVIEWERS

This document was greatly improved from its original form by comments and suggestions from reviewers. Reviewers included: Tom Runyon – Hydrologist Coconino National Forest, Dan Neary, PhD –USFS Rocky Mountain Research Center, David Rosgen, PhD – Wildland Hydrology, Branden Rosgen, Wildland Hydrology. We have done our best to incorporate everyone's suggestions and the presentation of the data has been greatly improved. The explanation of the methods and the relationships between methods focused on understanding the scope of sources vs. the sediment transport issues has been greatly improved thanks to all the reviewers. We appreciate the time and energy that each put into this work.

While the majority of comments were editorial in nature and focused on presenting the material in a more understandable fashion, Dan Neary's comments focused on the basic premise of the study methodology. Dr. Neary is especially concerned about the nature of flows that provide the bulk of the sediment transport. These comments could not readily be incorporated into this document and maintain the flow and scope of the document in an easily approachable manner. Instead, Dr. Neary's comments and a brief answer to them are provided in this appendix.

Dan Neary's comments to Draft Sediment Refinement Study

REPORT REVIEW

TITLE: Schultz Fire and Flood Assistance area: Sediment Analysis Refinement & Reduction Options
AUTHORS: Natural Channel Design
DATE: 20 April 2012

GENERAL COMMENTS:

This report summarizes a thorough reconnaissance and analysis of sediment conditions on the alluvial fan within and below the Schultz Fire of 2010. The analysis followed WRENSS methodology and used the FLOWSED and POWERSED sediment models to predict sediment delivery across the diverse landscape of the Schultz Fire alluvial fan. Estimates of sediment reduction from channel restoration efforts appear to be underestimates because sediment delivery during peakflow events was not adequately addressed or explained. Bankfull flows were used as the basis of analysis but these estimates were 1-2 orders of magnitude below indirectly measured peakflows. On-site measurements of sediment transport during peakflows were not available to validate modeling efforts, but indirect peakflows were determined from the 20 July 2010 flood. Personal observations by the reviewer provided a frame of reference on the sediment dynamics of flow off of the Schultz Fire burned area. If channel restoration activities proceed, it should be with a strong recognition that sediment delivery could be higher than expected and that long-term maintenance should be an integral part of management plans for channels on USFS lands and within the Timberline community.

SPECIFIC COMMENTS:

1. SUMMARY Page 1, Para 2, Lines 1-2: Consider not using the word "stream" here and throughout the document as it has the connotation of continuous flow. These are surface runoff drainage channels. Alluvial fans may or may not have streams associated with them. Rivers, creeks, brooks, and runs are considered "streams" (source: *Fluvial Geomorphology*). Temporary surface runoff occurs in channels.

2. SUMMARY Page 1, Para 2, Lines 9-11: State the ranges and means from Tables 2 & 3, as well as the average, not just the highest. Also see the comment on Tables 2 & 3.

3. SUMMARY Page 1, Para 4, Lines 1-11: There are a number of true statements here since you are dealing with an alluvial fan. The channels are unstable, but, there is no indication in the Summary of what the “balance” is. Also you are stating with a high degree of certainty that the channels on the fan can be restored to a “stable” condition. This is debatable since the analysis doesn’t really address the peakflow issue (see later Comments).

4. SUMMARY, Page 2, Para 1, Lines 1-7: You state that “All or major portions of the channels within a watershed would need to be restored in order to meet the sediment reduction targets for construction of channels within the private lands. All watersheds considered have the potential to meet these sediment targets.” Then you begin to address a major issue that there is a range of lifespans for these “restoration” projects, but don’t really address the “maintenance” issue that is a concern for the Forest Service. Also, there is no discussion of in-channel sediment highlighted by Carroll (2011) or of the effects of peakflows on sediment transport and restoration “lifespans”. The last sentence mentions the potential for sediment reduction but doesn’t address the ranges displayed in Tables 2 & 3.

Carroll, M. 2010. Movement of channel-borne sediments in the 2010 Schultz Fire burn area. A Thesis Submitted in Partial Fulfillment Of the Requirements for the Degree of Master of Science In Engineering, Northern Arizona University, May 2011. 60 p.

5. Page 3, Para 3, Lines 1-8: Care needs to be taken in extrapolating the WARSSS Method and the Trail Creek experience to the Schultz Fire alluvial fan since there are significant differences in geomorphology.

6. Page 3, Para 5, Line 2: Insert “(USFS)” after “US Forest Service” since the abbreviation is used elsewhere.

7. Page 3, Para 5, Line 7: Spell out “Rocky Mountain Research Station” since it is not used elsewhere in the report.

8. Page 4, Para 3 & 4: Combine into 1 paragraph.

9. Page 4, Para 5, Line 1: Replace “intense” with “high severity”

10. Page 4, Para 5, Line 14: Cite “BAER 2010” here

11. Page 4, Para 5, Line 1: Replace “analysis is” with “analyses are”

12. Page 5, Para 3 & Bullets: Although the bullets do address the steps in this analysis, it would be beneficial to have a flow diagram to help any readers to navigate through the analysis. The process is clear for the authors but anyone else reading the document for the first time can get “lost” in the details. The intent should be to not only document the results of the analysis but also the process to get to the study conclusions.

13. Page 5, Para 4: Replace “All analysis is” with “The analyses are”

14. Page 10, Table 1: Channel bed as a sediment source is not mentioned (Carroll 2010). Also, erosion rates above the Waterline Road are probably a big underestimate. Table 1 points out the large amount of sediment estimated to originate between Waterline Road and FR 420. More discussion and explanation of the erosion rates presented in Table 1 is needed. Erosion rates in terms of tons/acre/year would be useful to make comparisons between the watersheds. Also, there should be a footnote to explain that the tons/yr/ft in column is tons/ac/ft of channel.

15. Page 12, Para 2, Lines 4-5: Missing reference

16. Page 12, Tables 2 & 3: These paragraphs need much more explanation and discussion. Does BANCS assume linear sediment erosion rates? That needs to be discussed in light of the huge topographic variations across these watersheds. Are the reduction in sediment rates projected for Copeland, Glodia, and Paintbrush-Siesta an artifact of the greater stream length below FR420 or does it factor in the last sentence that “the majority of the sediment is produced above FR420? The sediment above FR420 provides the bedload that Carroll (2011) addressed in his study and analysis. I suspect that BANCS might overpredict the sediment reduction rate if it doesn’t deal with bedload transport during peakflows. Does FLOWSED adequately deal this problem later in the analysis? It is not clear where Column 9, “Percent Reduction in Total Sediment Yield” comes from. Are you implying that the average “Percent Reduction in Total Sediment Yield” in Table 2 is 12%? The average of column 9 is 19.6 not 12. These tables need to be explained more clearly. These tables need a lot more explanation.

17. Page 13, Para 1, Line 1: Missing reference

18. Page 13, Para 1, Lines 3-4: This statement needs to be clarified since Tables 2 & 3 only deal with bank erosion rates. Channel erosion rates are not included. A lot this statement and the Conclusions rests on data presented in Tables 2 & 3. However, Tables 2 & 3 refer to reductions in bank erosion only between FR 420 and the USFS boundary. However Table 1 has already indicated that erosion rates above FR 420 are greater than FR 420 to the FS boundary. Erosion of sediment above FR 420 forms a lot of the sediment that

Carroll (2011) indicates is sitting in channel beds waiting to be transported by storm flows. It is not clear at this point in the analysis how much sediment can be stored above FR 420 by restoration techniques.

19. Page 16, Figure 5: The Table heading and y-axis caption state “Mean Velocity” but cfs is discharge, not velocity. I assume that what you mean to graph is discharge.

20. Page 17 - 26: A lot of this part of the analysis relies on bankfull discharge. Bankfull Discharge is the dominant channel-forming flow with a recurrence interval seldom outside the 1-2 year range (*Fluvial Geomorphology*). Peakflows are the most important in sediment movement down the alluvial fan below the Schultz Fire. The instantaneous peakflows listed in Table 4 are 1-2 orders of magnitude below the peakflows estimated by indirect methods after the Schultz Fire. I believe that the bedload sediment data found in figures 5-9 are most likely an underestimate of the true bedloads. Granted that there are no empirical data from the Schultz Fire alluvial fan to compare with and that FLOWSED/POWERSED models are the next best thing, these are still underestimates.

21. Page 27, Para 1, Lines 3-7: These sentences address the core of the problem with the Schultz Fires alluvial fan. Erosion and sediment delivery rates are currently very high. This affects any efforts to deal with the problem. The big unknown is whether or not the proposed channel restoration rates can reduce sediment delivery enough to make structural relief efforts in the Timberline and other neighborhoods functional. My opinion and belief is that these efforts won’t be enough to function without significant maintenance work both on Forest lands and in the residential area. The big unknown factor not being addressed is bedload transport during peakflows. Carroll (2011) hints at the magnitude of the problem, but his efforts are not given any consideration in this analysis. Rainfall events and their subsequent flows will be difficult to predict at best given the variability of Monsoon storms and the current Southwest drought. Experience from the Hayman Fire indicates that substantial peakflows can occur 10 years out from the fire.

22. Page 27, Para 3, Considerations: The 1st bullet points out the core of the problem – high erosion rates above FR 420 and steep terrain that make restoration efforts impossible or too dangerous. The upper part of the mountain feeds both high energy water and sediment onto the lower parts of the alluvial fan. This connects to the key point of the 2nd bullet, the need for maintenance and upkeep of the system. I suspect that these efforts will be more than minimal.

23. Page 27, Para 4, Lines 1-9: It is a point well noted that over-wide channels with low sediment transport capacity will enhance sediment storage on the alluvial fan. There are good examples where this occurred naturally by flow jumps onto adjacent terraces.

However, despite a lot of these wide-channel areas between the Powerline Road and the USFS boundary there have been substantial sediment-laden flows onto Campbell Avenue that completely choked up the ditch on the north side of Campbell and blocked all 3 box culverts. The open question here is whether or not constructed, stable B channels, will remain that way or revert to F or G channels. This whole geomorphic feature is an aggrading alluvial fan with few bedrock graded-controlling structures. It is what it is and may or may not be amenable to what we see as "restoration" efforts. Alluvial fans are not "stable" landscape features. They are dynamic and evolving geomorphic features. The Schultz Fire reactivated what appeared to most people as a "stable" landscape. Their frame of reference was too short.

24. Page 34, Table 10: It is interesting to note from the FLOWSED outputs in Table 10 that the watershed segments with the highest sediment supplies had the shortest life expectancies (40% <10 years) for "restored" aggrading channels.

25. REVIEWED BY: Daniel G. Neary Ph.D., CPSS, FSSA, FASA; Research Soil Scientist, Air-Water-Aquatic Environments Program, Rocky Mountain Research Station, Flagstaff, AZ

Authors Answers to Dan Neary's concerns.

We appreciate and respect Dr. Neary's concerns and especially appreciate his time to review and comment on the sediment refinement study document. We have attempted to incorporate all of the editorial comments into the final report. Several of his comments are directed towards fundamental principles of the study and we believe deserve specific answers. The core of his comments revolve around three basic concerns: 1) The ability of high flows to move large amounts of sediment and the lack of ability to predict these flows, 2) our lack of understanding of re-entrainment of stored sediments in the channels, and 3) the lack of ability to restore 'dynamic' geomorphic features such as alluvial fans.

The analysis does take into account the sediment moved during very high flows. Dr. Neary is correct that high flows have the ability to move large amounts of sediment. However, these flows are less likely to occur than lower discharges that can move sediment on a more frequent basis. Research by Leopold and others (Leopold et al. 1995) has shown that frequent lower discharge floods move more sediment than large flows over a long period of time. The "bankfull" or high frequency, low intensity flood events are utilized to dimensionalize the dimensionless flow duration curves developed from regional streamflow data. These curves provide a probability distribution of all flows expected from the watershed from low to high. The short duration, high flows are part of the sediment transport model. The integration of both low discharge / high frequency and high discharge / low frequency floods provides a more accurate design parameter for natural stream systems than a single high discharge since natural channels evolve around the whole range of flows rather than a single large event.

Re-entrainment of sediment deposited in the channel bed is a core portion of the sediment transport analysis. It is not considered in the BANCS analysis that focuses solely on bank erosion. The BANCS analysis likely underestimates the true sediment budget but does not change the major finding of that portion of the study, ie. stream channels provide the majority of the sediment in the study area. However, the Flowsed / Powersed analysis does take into account re-entrainment of deposited sediments. Comparison of sediment transport for supply and study channels shows re-entrainment of sediment when study channels have higher transport capacity than inflow channels. Modification of the shape of these channels to reduce sediment transport capacity is central to the study and its recommendations. Dr. Neary's comments about the amount of sediment transported across the potentially aggrading reaches upstream of Campbell Avenue is testimony to the degraded condition of these potentially aggrading channels and how the alluvial fans are no longer providing an essential service. The focus of this study is to understand those conditions that cause re-entrainment of deposited sediments and utilize that understanding to reverse this process.

Finally, Dr. Neary's concerns about the restoration potential for alluvial fans is fully appreciated. However, our experience with severely degraded stream systems in the southwest indicates that there is potential for enhancement of ecosystem services in many cases. The key to understanding the potential for restoration or enhancement is understanding the fundamental principles at play. In the case of alluvial fans, they are quiescent during periods of low hydrologic and sediment input and respond immediately as a function of increased flow and sediment. However in order to grow, the fan needs both sediment and discharge. Investigation of alluvial fans in the area show that singlethread channels are formed on the downstream fringe of the fan as sediment supplies decrease and discharges remain high. This model provides the basis of the recommendations outlined in this study. By effectively reducing the sediment supply, we can make singlethread channels sustainable through neighborhoods that exist on the fringe of the fan. While few have attempted to use these geomorphic practices on this large of scale after a large natural disaster, the principles on which they are based have been tested and proved in many regions, including the southwest.

The study presented here is based on the soundest, practical principles currently available to us. As planned, the study indicates that both the USFS and County's objectives can be met and result in resource that returns to proper function in as short a length of time as possible. Undoubtedly there will be many opportunities to improve our understanding of both the processes and methods as the recommendations are implemented. These opportunities will help future planners in similar situations.

Sincerely,
Allen Haden, Ecologist, Natural Channel Design, Inc.
Christopher Tressler E.I.T, Engineer/Geomorphologist, Natural Channel Design, Inc.

Luna B. Leopold, M. Gordon Wolman, John P. Miller. (1995). *Fluvial processes in geomorphology*. New York: Dover Publications. ISBN 0-486-68588-8.