YAKIMA BASIN
FISH AND WILDLIFE
RECOVERY BOARD

Geomorphic Assessment of the Little Naches River Mainstem

prepared for the Yakima basin Fish and Wildlife Recovery Board
by
WPD, LLC, May 2017

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Hoda Sondossi

Executive Summary

The Little Naches River is one of the five main tributaries of the Naches River, and designated critical habitat for two ESA listed species. It has a recent, well-documented, history of alteration by human activity. We conducted a LiDAR-based topographic analysis of the Little Naches River floodplain to assist in planning and prioritizing ecological restoration actions. One of the primary causes of ecological degradation of the Little Naches mainstem is the 1900 Road, the main access to the drainage. In this report we review available data and describe each reach of the Little Naches, the impairments impacting that reach, and potential restoration actions. Table 3 summarizes the identified impairments and possible actions to address them.

We consider the recommendations in Table 3 preliminary, and hope that they can serve as the basis for future project prioritization and planning.

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Introduction

The Little Naches River, along with the American, Bumping, and Tieton Rivers and Rattlesnake Creek, is one of five main tributaries of the Naches River. It drains the east slopes of the Cascades in Central Washington (Figure 1). The majority of the Little Naches basin acreage, and almost all of the floodplain areas, are managed by the U.S. Forest Service (USFS). Timber company lands in the upper Little Naches basin were recently purchased by The Nature Conservancy, and are expected to be transferred to the USFS over time.

The Little Naches River system provides important habitat for steelhead and rainbow trout (*Oncorhynchus mykiss*), Chinook salmon (*Oncorhynchus tshawytscha*), Coho salmon (*Oncorhynchus kisutch*), bull trout (*Salvelinus confluentus*), cutthroat trout (*Oncorhynchus clarkii*), mountain whitefish (*Prosopium williamsoni*) and numerous other fish and amphibian species. Much of the Little Naches mainstem and several tributaries are designated critical habitat for Middle Columbia River Steelhead and Bull Trout, which are listed as threatened under the federal Endangered Species Act (ESA).

The instream and riparian ecosystem of the Little Naches basin has been altered by human activities including: logging, construction of an extensive network of roadways, active removal of naturally occurring large woody debris (LWD) and riparian vegetation from the river channel and floodplain, and earth moving for recreation facilities and flood control. Currently, intense recreational use (e.g., ATV and UTV use, hiking, camping, horseback riding, snowmobiling, fishing, and hunting) throughout the year continues to impact the hydrologic, geomorphic, and ecological processes of the Little Naches River system.

Some of the activities that have affected the upland, instream, and riparian habitats were intended to improve habitat. These activities included connecting springs to the mainstem Little Naches, placing rock structures and LWD to improve instream habitat (and protect the roadway from erosion), and excavating the river bed to improve fish passage. These activities have had varying degrees of success, but have failed to improve conditions noticeably; some have even had unintended detrimental effects on the habitat.

The USFS has identified watershed restoration and forest health as core management objectives (Strategic Plan for 2010-2015). One of the USFS’s goals in the watershed is to:

> “…restore degraded watersheds by strategically focusing on watershed improvement projects and conservation practices at the landscape and watershed scales” (USDA 2011) under the 2010 mandate of the “Watershed Condition Framework (WCF).”

The Okanogan-Wenatchee National Forest (OWNF) identified the road network within the Little Naches Watershed as the primary cause of impaired watershed function. The 1900 Road is the main two-lane paved access road into the Little Naches River basin. This road is in the active geomorphic floodplain of the Little Naches River for the majority of its length. It has caused the disconnection of major portions of the floodplain, blockage of significant secondary channels, and relocation of the primary stream channel to accommodate roadway slope and curvature requirements (Yakama Nation, 2008). Fisheries advocates have cited the 1900 Road’s impact on floodplain functions as one of the most significant impairment in the Little Naches basin. Also, the river regularly damages sections of the road, which require costly repairs by the USFS to maintain public access.

In 2010 Light Detection and Ranging (LiDAR) data were acquired for two priority reaches of the mainstem Little Naches River. The purpose for LiDAR data was to evaluate how the road network has impacted the floodplain of the mainstem Little Naches River. LiDAR data were acquired again in 2015 to encompass the entire floodplain of the mainstem Little Naches and the lower ends of the South, Middle and North Forks in order to allow a more complete analysis of existing conditions.

This document uses these LiDAR data and other available data, including historical records, aerial photographs, field observations, and all available literature, to describe the extent and nature of floodplain alterations. The report assesses how these alterations have impacted physical processes, and the way those changes both contribute to ecological degradation and threaten to damage the existing road network. The availability of LiDAR data allows topographic analysis at a finer scale than previously possible, making it possible to discern detailed geomorphic changes. The availability of aerial images prior to logging and aggressive topographic alterations provides a unique opportunity to gain insight into a virtual reference state.

This report gives general recommendations about how to alleviate or minimize these negative impacts in each reach of the Little Naches River. It is hoped that these recommendations will help the USFS and its partners to identify, prioritize, and implement effective floodplain restoration projects. This document is intended to facilitate planning of any restoration activities, roadway maintenance, and recreational use. No predictions are made as to when potentially catastrophic natural events will occur, but particularly vulnerable locations are identified, and potential consequences are outlined.

Basin Overview

The basic physiography, and land use history of the Little Naches basin is documented by Haring (2001), Muir (2003), Okanogan-Wenatchee National Forest (2011), and Northwest Hydraulic Consultants (2015). Here we give a brief synopsis to provide the background for our findings.

Physiography and Geology

The basin area is approximately 385 square kilometers (149 square miles). The Little Naches Basin is underlain by a mixture of igneous rocks, and sedimentary rocks derived from erosion of the igneous rocks (Figure 2). There is little evidence of recent glaciation in the basin; however, pre-Fraser glacial moraine deposits are shown on 1:100,000-scale U.S.G.S. geologic maps, adjacent to the Little Naches River floodplain near the mouth of Crow Creek. There are numerous fault systems in the basin, and the alignment of the Little Naches River is thought to be determined by a major fault (White River Fault). The U.S.G.S. map shows numerous mass wasting deposits adjacent to the alluvial deposits of the Little Naches River mainstem. For most of its length, the Little Naches River floodplain is underlain by coarse, extremely well-drained and highly permeable alluvium.

Land use History

The lower 10.5 miles of the 1900 Road was built in the 1930s. The road was originally intended to be the main highway across the Cascade Range, and therefore meets specifications of curvature and slope for highways. Tens of thousands of cubic yards of riprap and road base material were placed in the floodplain of the Little Naches mainstem and channel. LWD was also removed from the channel and floodplain in the process of road construction (Torretta, written communication). In several locations, the stream channel was re-aligned (shortened and straightened) to accommodate a straighter road; in at least one location an entire meander bed was artificially cut off. In addition, fill was placed in several locations identified as wetland to transform these locations into more suitable campsites.

The USFS extended and widened the 1900 Road multiple times in the decades following its initial construction. Our investigation revealed the road was approximately 10.5 miles long at the time the 1949 and 1954 aerial photos were flown, and ended approximately 900 feet upstream of Bear Creek (Figure 1). The alignment of this road is largely in the natural floodplain of the Little Naches River. The majority of earth-moving associated with the construction and subsequent expansion of the road involved filling in sections of channel and floodplain rather than removing hillsides or bedrock walls (Ryan Hampton, USFS, personal communication). Sections of road in direct contact with the stream channel have been severely damaged and have required frequent repair and maintenance. The first of the repairs took place in 1934, which required rebuilding 7 miles of the road, possibly due to flooding the previous year (Torretta, written communication).

Heavy logging in the Little Naches basin did not begin at a large scale until 1970s. This was when the largest expansion of the 1900 road took place. Logging peaked in the 1980s and diminished in the 1990s. This included clear-cutting of thousands of acres of old-growth coniferous forest. The most notable adverse effect of this action is the documented increase of fine sediment load to the Little Naches aquatic system immediately following logging (Haring, 2001). Following the cessation of logging, the fine sediment load gradually decreased as clear-cut plots and de-commissioned haul roads re-vegetated (Haring, 2001; Torretta, written communication). USFS continues efforts to reduce fine sediment inputs and drainage alterations caused by the road network.

The 1970s also saw widespread removal of large woody debris (LWD) and shrubby vegetation from the floodplain of the Little Naches River for the intended purpose of flood control, and also as part of road repairs and widening (Torretta, written communication). The majority of the LWD was in seven complex logjams which were identified as problems, gathered in slash piles, and burned. A total of 70,000 cubic yards of wood were removed from the system in this manner (Ryan Hampton, U.S.F.S., personal communication). Large floods occurred in the late 70s, and in 1979 the channel below Salmon Falls was bulldozed to increase flood conveyance (i.e., transport of floodwaters downstream with little if any damage) and create levees on the channel sides. In the early 1980s, the channel in this reach was excavated again, this time in an attempt to reduce dewatering during dry periods, caused by the excavation of the fish pond north of the 1900 Road.

Disruption and degradation of riparian and instream habitat resulting from logging, vegetation clearing, road building and other activities was locally severe. In the 1990s the USFS completed a number of restoration actions to counteract the effects of these unintended impairments. They created rock and wood habitat features and excavated side-channels and off-channel pools in order to improve instream and riparian habitat.

The campgrounds and other recreational facilities in the floodplain of the Little Naches experience heavy use annually. Because off-road recreation activities have been reduced in other parts of the Okanogan-Wenatchee National Forest, the Little Naches basin has become a destination area for off-road vehicle and snowmobile use. There is an extensive trail network, and concerns have been raised about impacts of trails on riparian and instream habitat and the sediment regimes of tributaries and mainstem Little Naches River. Recreational groups have worked cooperatively with the Naches District of the Okanogan-Wenatchee National Forest to reduce and/or minimize negative impacts associated with their form of recreation.

Data Analyzed and Generated

Several data sources were used for this analysis in addition to LiDAR data. Data were also generated as a result of the analysis. For a detailed list of data used and generated, and a description of methods used, refer to Appendix I.

Results

Hydrology

The Little Naches River's discharge regime is dominated by snowmelt, and the range of discharge varies greatly by season. Peak discharge typically occurs in late spring/early summer, however, rain-on-snow events in winter also produce large floods with similar peaks. The snowmelt floods are generally more sustained and have more gradual rise and fall; rain-on-snow floods are typically short-lived and abrupt. The average elevation of the Little Naches Basin is lower than that of other headwaters of the Naches River. This means that the snowmelt floods generally peak earlier and that the Little Naches sub-basin is more prone to rain on snow events. These factors make the system relatively flashy (i.e., prone to sudden floods and rapid fluctuation between high water and low water).

We analyzed mean daily discharge data, as well as the 15-minute interval instantaneous discharge data, collected at the stream gauge near the mouth of the Little Naches River (Figure 1). This gauge was installed on 3/5/1970; however, the first recorded discharge value is dated 5/1/1980. Figure 3A is a chart as downloaded on May 2, 2016 from the U.S. Bureau of Reclamation's (USBOR) internet data portal, showing the current and previous water years, as well as the average of all years. This is assumed to be the arithmetic mean of all available discharge values for each calendar date.

Mean daily discharge at the Little Naches River gage ranges from less than 100 cfs at base flow, to nearly 4,500 cfs at flood stage (Figure 3A-3C). Mean daily discharge values were used for the basic hydrologic analysis presented here, as is the convention. These data have many gaps with no value reported for many flood peaks, presumed to be due to gage malfunctions at high flow. This was confirmed by comparing the mean daily discharge values to the instantaneous 15-minute data.

According to the USBOR's 15-minute interval instantaneous discharge data (Figure 4A), the highest discharge between the dates of April 20, 2000 and April 21, 2016 is 2,043,563 cfs. This is greater than typical flood stage discharge of the Mississippi River, and obviously erroneous. There are at least a dozen other peak discharges exceeding 100,000 cfs reported in the dataset for the period of record. This is a clear indication of malfunction by the gage at high discharge.

It appears that the only correction made to the mean daily discharge dataset was to omit data corresponding to the erroneous instantaneous discharge values. Unfortunately, the missing data correspond to days when floods peaked; days leading up to the gap show flow rising, and days following the gap show flow falling.

Instantaneous discharge values are reported based on the corresponding stage value recorded by the gage, which is used to develop the rating curve for that particular gauge from repeated discharge measurements. The primary reason for generating mean daily discharge values is to estimate weekly, monthly, and annual volumes. The convention for calculating mean daily discharge values is to average peak instantaneous values for each calendar date, over 3 days (using the day before and after each date). Therefore the value recorded for each day is invariably different than the instantaneous discharge value for that day, and is heavily influenced by the discharge rates in the day before, and the day after the date in question.

Figures 4B and 4C show a basic hydrologic analysis using the available mean daily data, and Table 1A shows a summary of discharge ranges associated with significant recurrence intervals. Data from the missing dates are dropped (i.e., pretending those high flows did not occur). These figures clearly underestimate actual flow rates at longer recurrence intervals. Because some of the largest flood peaks are not included in the mean daily discharge dataset, the Little Naches River experiences higher discharge peaks than this analysis indicates.

Table 1B, provided by Scott Nagel, staff hydrologist at the USFS Naches District, lists recurrence interval of significant floods. These values are not based on empirical data. They are estimates generated based on regional averages (in this case, one of four regions for the state of Washington), intended for estimating flow ranges for ungauged streams. These values are higher than those in Table 1A for smaller floods (2-10 year recurrence interval), but are remarkably close to those of Table 1A for larger floods (25-year recurrence interval and higher).

Table 1A. Recurrence intervals of flood discharge, based on analysis of existing discharge data for the Little Naches River gauge. <u>These discharge values are underestimates, because of many missing flood peaks in the data record</u>.

Recurrence interval (years)	Discharge (ft^3/s)
2	1400
5	2200
10	2800
50	4300

Table 1B. Recurrence intervals of flood discharge, as generated by Scott Nagel (USFS Naches Ranger District) using National Streamflow Statistics, a USGS Web application that estimates recurrence interval of ungagged streams based on regional averages that takes into account basin characteristics such as area, precipitation, and canopy cover (in this case 149 mi2, 60 in/yr, and 60%, respectively).

Recurrence interval (years)	Discharge (ft^3/s)
2	2810
5	3440
10	3830
25	4290
50	4710
100	5040
200	5380
500	5830

Geomorphic Character

We analyzed the entirety of the Little Naches River and its floodplain, from the confluence of the North Fork Little Naches and Middle Fork Little Naches to the Little Naches' confluence with the Bumping River. The mainstem Little Naches River is approximately 14.4 miles long in the study area. The study area also includes the lowermost 2.4 miles of the North Fork Little Naches River, and the lowermost 1 mile of the Middle Fork Little Naches River (Figure 1 and Plate 1A). The focus of the project is the mainstem Little Naches River, and above-mentioned tributaries, and their associated floodplains. The basic physical descriptors of floodplain width and slope, main channel sinuosity and slope, as well as presence or absence of secondary channels (Table 2A and 2B in Appendix A) were used to divide the study reach into 9 distinct reaches. Each of these reaches are discussed in detail below.

Perhaps the most significant earth surface process affecting topography and overall character of the Little Naches River and its associated floodplain is mass wasting (Plate 1B). There are numerous tributary alluvial fans, debris flows, landslides, and slumps affecting the course, gradient, sinuosity, and sediment transport regime of the river. These deposits dominate the character of the floodplain, cause numerous constrictions along its course, and are the primary sediment source of the river's sediment—both bedload (gravel and coarser) and suspended load (sand, silt, and clay).

The most notable example of mass-wasting deposits is the large slide that formed the canyon section of the Little Naches River, within which the confluence with the Sand Creek lies (Reach 3 on Plate 1). Another example is the young landslide that created Salmon Falls. These are discussed in some detail later in this report.

Plate 1B shows mass-wasting deposits identified in: a) existing U.S.G.S. 1:100,000-scale geologic maps, and b) identified as part of this report based on the LiDAR based topographic data as part of the analysis for this report. LiDAR data provide finer scale “bare earth” topography than the aerial imagery used to generate the USGS maps. Our updated map shows a greater extent of mass-wasting deposits that influence the geomorphic character of the Little Naches River.

The characteristics of the 9 reaches in the study area vary significantly based on the geology, which determines reach-scale slope, floodplain width, groundwater table elevation, and sediment transport regimes. For example, the steepest reach within the study area is Reach 3 (Table 2A and 2B), within which there is a single channel, carved through a thick layer of landslide material. The remainder of the reaches have a range of floodplain widths, and are at different stages of widening in their natural evolution. However, most of them have similar gradient, sinuosity, and side channel lengths; therefore, the most significant difference amongst these remaining reaches is the width of the geomorphic floodplain.

As previously mentioned, human activity, including the construction and maintenance of the 1900 Road, other earth moving, recreation, logging and management activities, has disrupted natural process in many places. These changes include changes in main channel alignments, altered flood flow paths, disconnection of secondary channels, and reduced river access to parts of its natural floodplain. These impacts are discussed in detail for each reach. Table 3 in Appendix A includes a summary of all impairments by reach and preliminary recommendations to correct the impairments, based on a preliminary prioritization. A unique identifier in bold text is included in recommendations for each reach which corresponds to the impairment listed in Table 3, for convenient cross-referencing.

Reaches 1, 1A, and 1B

Reach 1 is the upstream-most reach of the mainstem Little Naches River (Plate 2). Reaches 1A and 1B are the downstream-most reaches of the North Fork Little Naches River and Middle Fork Little Naches, respectively, and define the upstream boundary of the study area. The North Fork Little Naches is assumed to be the mainstem river, due to its greater contributing drainage area, valley position, channel form, and slope and floodplain slope and character.

Reach 1 extends between River Miles 13.4 and 14.5, and is geomorphically unaffected by human activity, except at its upstream end (RM-14.46), immediately downstream of the confluence of the North Fork Little Naches River, and Middle Fork Little Naches River. Here, the floodplain is constricted by a crossing of the 1913 Road (the only road crossing in this reach), and has been affected by a dispersed USFS camp site. Upstream and downstream from this location, the channel form is essentially unaltered. While some portions of the floodplain have been heavily logged, there is generally a robust canopy of conifers adjacent to the channel. The 1900 Road crosses the Middle Fork Little Naches River near RM-0.9. Fawn Creek also flows under the 1900 Road before entering the Little Naches River mainstem floodplain near RM-14. The road does not interact directly with the stream channel in this reach, and there are no known records of repair to the 1900 Road in this reach.

There are several floodplain haul roads that were used to transport logs. These can act as unnatural flow paths and are prone to erosion, particularly at side-channel crossings. However, the two such crossings in Reach 1 (Plate 2) are far enough away from the main channel not to represent a risk of fine sediment entering the Little Naches River main channel. We were not able to obtain 1954 aerial imagery for this reach. However, we assume the haul roads were developed decades after the historical aerials were acquired.

There is abundant naturally occurring LWD present throughout this reach. These occur in numerous logjams of varying sizes, most of which appear mobile. Numerous secondary channels cross the floodplain. These channels appear unaltered by human activity. Extensive signs of beaver activity are present throughout the floodplain in Reach 1, particularly in the Fawn Creek channel near Timothy Meadows.

The two large persistent logjams in this reach are at RM-14.2 and RM-13.8 in the main channel. The logjam at RM-13.8, was observed re-directing flow into the Fawn Creek channel during the Summer 2015 low flow period. During Summer 2016 this logjam caused the avulsion (i.e., rapid abandonment of existing river channel and formation of a new river channel, on the scale of several meander bends) of the Little Naches River into the Fawn Creek Channel, discussed below. It is unclear whether log jams at these sites were removed as part of the wood clearing projects prior to the 1990s.

The character of Reach 1A is similar to that of Reach 1, as noted above. The North Fork Little Naches River and its floodplain are affected by the alluvial fan of Blowout Creek between RM-1.1 and RM-1.9. Blowout Creek joins the North Fork Little Naches River from the north (River Left) at approximately RM-0.55. Before flowing into the North Fork, Blowout Creek flows across the floodplain essentially parallel to the Little Naches main channel for 3,324 feet (0.63 miles). This alignment is not permanent; there are numerous secondary channels connecting the main channel of Blowout Creek to the Little Naches channel, which can become dominant during moderate floods. The massive sediment input from the Blowout Creek drainage forces the North Fork Little Naches channel to the south, against the opposite valley wall (Plate 2).

The remainder of the reach is fairly flat and broad. There are numerous splay deposits composed of fine-grained sediments deposited during overbank flows in sub-reaches with particularly flat channel and floodplain slopes. Splays are discernible on aerial imagery as open meadows with few trees. There are numerous locations with buried LWD, as deep as 6 feet below the surface of the floodplain, in exposed banks within the splay deposits (photo on Plate 2). The high clay content in splay soils render them unsuitable for establishment of most trees and shrubs.

Log weirs spanning the bankfull channel were observed in a few locations in the main channel of the North Fork Little Naches. These were installed as habitat improvement elements by the USFS during the 1980s and 90s.

Reach 1B is the downstream-most reach of the Middle Fork Little Naches River. The Middle Fork is a smaller stream than the North Fork Little Naches, and has a narrower, steeper floodplain and channel. It joins North Fork Little Naches from the south (River Right) to form the mainstream Little Naches River. Motorized access to the riparian zone of the Middle Fork Little Naches was blocked near the 1900 Road crossing near the campground by the USFS (Torretta, personal communication).

2016 Avulsion of Little Naches Main Channel into Fawn Creek

Fawn Creek enters the Little Naches River floodplain at approximately RM-13.55 (Plate 2) near the downstream end of Reach 1. Prior to summer 2016, Fawn Creek flowed 4,245 feet (0.8 miles) on the south side of the Little Naches floodplain, crossed through a culvert under the 1900 Road, and joined the Little Naches River at RM-12.47, in Reach 2. During the annual snowmelt flood of 2016, a large, persistent logjam in the lower end of Reach 1 caused an avulsion of the main channel of Little Naches River, re-directing the majority of the flow into the new main channel. The channel of Fawn Creek captured the Little Naches main channel, and began conveying the majority of the Little Naches River flow at base flow (Figures 5A and 5B). The river miles were not updated to reflect this change, partly because the main channel prior to the avulsion remains the main flood conveyance channel.

Fawn Creek flows through old growth floodplain forest, and contains abundant LWD. Even in Summer 2015, prior to the avulsion, the majority of the base flow in the Little Naches main channel was re-directed into the Fawn Creek channel by the logjam. High concentrations of spawning by chinook salmon were observed in this reach of Fawn Creek in 2015.

Aerial images acquired on 9/1/1954 indicate that the Little Naches River and Fawn Creek channels were more or less in their current alignment (Figure 5C). The 1900 Road was not yet extended into Reach 1 at the time of photography, but its alignment is shown for spatial reference. The existing side channels, including the one likely to become the primary channel of the Little Naches, are clearly visible in these aerial images (Figures 5C-F). A prominent meander bend of the Fawn Creek channel has migrated toward the above-mentioned side channel (Figure 5C and 5F), providing additional evidence that this is the most likely natural development, and part of the inevitable long-term evolution of the stream system. Interestingly, the scour of the 1900 Road shoulder is in a naturally occurring swale that appears wet in the historical images. However, the damage to the road shoulder was observed by USFS staff in 2013 (Torretta, written communication) providing evidence the alignment of the 1900 Road has expedited this erosion by blocking and redirecting out of bank flows.

Restoration Opportunities and Constraints

With the notable exception of the 1913 crossing (**1a** in Table 3), this reach is in a functional natural state. Naturally occurring logjams occur throughout this reach and appear to be expanding in the last few years. No action is recommended. The avulsion of the Little Naches main channel into the Fawn Creek channel was caused by a natural logjam. This logjam should be left untouched.

Reach 2

Reach 2 extends from RM-8.8 to RM-13.4 (Plate 3). This reach is similar to Reach 1 in overall character, but has a shallower channel slope (0.63%) and floodplain slope (0.87%) than any other reach in this study (Table 2A and 2B). Because slope is the only measurable variable to change, it is the criteria used to separate Reaches 1 and 2. The upstream boundary of Reach 2 is at the point along the longitudinal profile where the channel slope of Reach 1 transitions to a flatter one (Longitudinal profile on Plate 1A). The downstream boundary of Reach 2 is very clearly defined by the river’s entrance into a canyon.

The most likely explanation of the flat floodplain and channel slope of Reach 2 is the large mass-wasting event that created Reach 3, discussed below. This event dammed the river and caused a backwater that extended the full length of Reach 2, and possibly beyond into Reach 1. This would have converted this reach into a depositional environment, capturing the entire sediment load from upstream, until the Little Naches River had enough time to carve the canyon within which Reach 3 lies. The Little Naches River is currently in the process of downcutting through the slide material. Further investigation, involving time in the field, may reveal a more detailed sequence of events, and the upstream extent of the backwater.

Bear Creek joins the mainstem Little Naches River at approximately RM-11.6 from the north (River Left). South Fork Little Naches River joins the mainstem Little Naches River from the south (River Right) at approximately RM-10.53. Mathew Creek joins the mainstem Little Naches River from the north (River Left) at approximately RM-9.97.

There are 3 crossings of 1900 Road over the Little Naches River mainstem, at RM-12.5, RM-10.4, and RM-9.9. There is also a crossing of Bear Creek just above the mouth, near RM-11.6. There is only one known section of the 1900 Road, 241 feet long, at approximately RM-10.8 that is protected by riprap due to its adjacency to the Little Naches River channel.

Between RM 10.6 and 11.3 there are numerous channels and determination of primary and secondary channels is extremely difficult. One of two, or both channels, appear to carry the majority of flow at below bankfull ranges (Figures 6A). Both of the prominent channels convey flood flow and are within the flood conveyance corridor (Plate 3, and Figure 6A). Muir (2003) identified this location as the site of an avulsion. Our investigation was not nearly as conclusive due to above-mentioned reasons. However, for the purposes of river miles, we chose the northern channel (River Left) (Plate 3 and Figure 6A-C). Examination of 1954 aerial images also indicates the presences of multiple channels, and large areas of inundated and/or wet sand/gravel bars (Figure 6B). Identification of primary and secondary channels is difficult using these images as well.

There is an extensive network of secondary channels in this reach (Plate 3). The 1900 Road blocks significant secondary channels in two locations. These are at approximately RM-10.7 and RM-12.3 (Plate 3). The downstream location is potentially more important for the natural evolution of the system. An abandoned oxbow is visible in the 1954 aerial image (Figure 6B). A secondary channel is propagating upstream toward the 1900 Road at this location (Figure 6D), and may have become the primary channel of the Little Naches River in the future, because it is shorter and steeper. This is no longer possible if the 1900 Road remains and continues to block the flow path. The portion of this channel downstream of the 1900 Road appears to receive groundwater input, and it currently conveys a small amount of surface water, enough to sustain beaver.

2016 Avulsion of Little Naches Main Channel into Fawn Creek

The most significant natural channel change in Reach 2, in the last few decades, is the avulsion of the Little Naches River main channel into the Fawn Creek channel. The upstream portion of this change, in Reach 1, is described above (Figures 5A-5E). As a result of this avulsion, the undersized culvert under the

1900 Road, intended only for Fawn Creek (Figures 5A and 5B), has been overwhelmed by the full flow of the Little Naches during low to moderate flow periods. During high and very high flows, many secondary channels re-route water to the former channel of the Little Naches River, and this culvert is largely bypassed. Flow has been redirected along the north side of the 1900 Road at least since 2013 (Torretta, written communication), incising a channel, eroding the road shoulder, and causing damage to the road immediately upstream of the bridge over the Little Naches. In 2016, baseflows through the culvert were high enough to create a presumed velocity barrier to fish, preventing summer/fall migrating chinook and potentially, bull trout, from reaching upstream spawning areas. Increasing conveyance capacity at this crossing would allow improved fish passage and reduce flows into the new channel along the road. However, it is unlikely that the Fawn Creek channel and the new roadside channel will be the persistent, “natural” alignment of the Little Naches main channel.

Given the floodplain geometry, flat slope of the channel and floodplain, and the natural increase in wood loading upstream, the most likely location for a more persistent channel is in an existing side channel which re-enter the Little Naches main channel at RM-12.7, upstream of the bridge under the 1900 road (Figures 5A and 5B). The dense stand of coniferous trees along Fawn Creek, upstream of the culvert, will likely collect large logjams and redirect flow into the existing secondary channel. The most hydraulically efficient flow path in moderate and large floods is via this and other secondary channels and the previous main channel of the Little Naches, which cross a sparsely treed splay deposit (Figure 5B). This splay formed in a persistent natural slack water, and is composed of fines, particularly clay. The backwater, indicative of shallow floodplain slope, is caused by fact that the bed of the Little Naches main channel flows over resistant bedrock just below the bridge at RM-12.5 (Figures 5A and 5B). The 1900 Road bridge over the Little Naches at RM-12.5 is adequately sized to convey most flood flows and is not a likely cause of the avulsion. However, the bridge and the roadway alignment disrupt geomorphic process by preventing natural spreading of flood water at above-bankfull flow range.

Alluvial Fan of South Fork Little Naches

The massive alluvial fan of the South Fork Little Naches River affects the character and position of the Little Naches River floodplain for over 1.5 miles (between RM-9.1 and RM-10.6). Here the alluvial fan constricts the Little Naches River floodplain. This constriction is natural and is indicative of the large amount of coarse sediment the South Fork Little Naches introduces to the mainstem floodplain, compared to the capacity of the mainstem Little Naches to transport this sediment downstream. However, the longitudinal profile of the Little Naches River main channel does not show a significant change at this location (Longitudinal profile on Plate 1A), indicating that the Little Naches River transports enough of the sediment introduced by the South Fork Little Naches River (i.e., has enough carrying capacity) to maintain the current configuration of the alluvial fan, at least until the next mass-wasting event.

The 1900 Road crosses the mainstem Little Naches floodplain twice in this area. These bridges are adequately sized to convey most flood flows, but do confine the river and prevent overbank flows at flood stage. This increases the likelihood of mass-wasting events affecting natural processes, and increasing risk of damage to the 1900 Road and bridges themselves.

The alignment of the 1900 has forced the confluence of the South Fork Little Naches with the mainstem Little Naches to remain upstream of the crossing at RM 10.44, and west of the 1906 Road (Figure 6A). While the main channel of the South Fork enters the Little Naches upstream of the Little Naches Road, distributary channels direct flood flows from the South Fork toward the approach to the upstream bridge. In addition, the 1906 Road has prevented South Fork water from accessing the majority of its own alluvial fan, and avulsing into a prominent channel east of the 1906 Road, that may have become the main channel of the South Fork Little Naches, below both bridges (Figure 7A). The combination of these effects, in addition to destabilization associated with the FS camp site in this location represents a disruption of channel evolution and sediment transport processes, which in turn cause chronic instability. In other words, the alignment of the 1900 and 1906 Roads, in relation to the stream channels, contributes to their own need for frequent repairs.

Just east of River Mile 9.9, the 1900 Road blocks a secondary channel of Mathew Creek. This is not a significant impairment, but is another instance of natural channel evolution being prevented, because Mathew Creek is forced to stay in its current configuration.

Other past actions associated with adverse impacts, included clearing of all wood, and shrubby vegetation between approximately RM-8.8 and RM-9.4. This sub-reach has largely recovered and appears to have a well-established canopy of conifers. However, the flood conveyance corridor is slightly wider here than the rest of Reach 2 (Plate 3). Large, sparsely vegetated gravel bars, persist in this sub-reach, and much of the main channel lacks bank vegetation (photo on Plate 3).

The USFS installed a complex logjam in the early 21st Century at approximately RM-10.8 to serve the dual purpose of protecting the 1900 Road and improving instream habitat.

Restoration Opportunities and Constraints

This reach shows significant natural recovery of logjams and vegetation in the floodplain. There is also recent evidence of beaver activity. Addition of LWD and planting of shrubby vegetation in the floodplain will likely accelerate recovery by providing additional anchor points to capture and retain more LWD naturally, and encourage beaver establishment. Difficulty of access is both a constraint, and an advantage in this reach. It represents difficulty in getting heavy equipment to the site, but it also means less human traffic and disturbance.

The alignment of the 1900 Road, where it crosses the mainstem channel near the alluvial fan of South Fork Little Naches River twice, and confines the channel of the South Fork Little Naches, is one of the most significant issues with the roadway.

Consideration should be given to the following actions in Reach 2:

- Relocating the 1900 Road near the S.F. Little Naches alluvial fan, **(2b, 2c, 2d, 2e, 2f, and 2g)**,
- Relocating the 1906 Road so that the South Fork Little Naches River channel has the option to occupy the areas east of its current alignment **(2b)**,
- Replacing the Fawn Creek channel culvert on the 1900 Road just west of the bridge at RM-12.7 with a culvert or bridge with greater conveyance capacity **(2a)**,

- Protecting the north side of the 1900 Road between the Fawn Creek channel culvert and the bridge over the Little Naches **(2b)**,
- Placing LWD in lower third of the reach, also incorporating LWD structures into existing road shoulder riprap **(2h)**,
- Planting willows in riprap shoulder **(2i)**, and
- Allowing natural re-occupation by beaver and/or Releasing orphaned or dislocated beaver from elsewhere in the lower third of this reach **(2j)**.

Reach 3

Reach 3 extends between RM-7.1 and RM-8.8 (Plate 4). The floodplain in this reach is the narrowest and steepest of all reaches in this study, except Reach 4A (Tables 1A and 1B). This reach flows through a canyon incised in a large landslide (Plate 1A and 1B). This massive slide blocked the entire floodplain of the Little Naches River with a blanket of coarse material and dislodged bedrock, up to 150 feet thick and more than 7,000 feet long. This slide is recent enough (perhaps Holocene age; certainly after the most recent glaciation, perhaps as a result of retreating glacier) that although the River has carved a canyon through the deposits and remove the impoundment, it has not yet removed enough material to achieve a main channel and floodplain slopes similar to other reaches (longitudinal profile on Plate 1A).

The mass-wasting deposits that created this canyon reach would have caused a massive backwater, with the upstream end reaching present day Reach 1, until the canyon was carved. This is the most likely explanation for the flat slope of the floodplain and main channel of the Little Naches River in Reach 2 (Plate 1A). The channel has numerous large boulder-forced pools and steep drops. There are numerous naturally occurring logjams in this reach that have accumulated more wood in the last two years. There is no apparent human-induced topographic alteration in this reach. Aerial photographs of 9/1/1954 show almost no change in the planform position of the main channel in this reach (Plate 4). Sand Creek joins the mainstem of the Little Naches River in this reach, from the south (River Right) at approximately RM-7.4.

Restoration Opportunities and Constraints

Reach 3 is the most intact in this study. It is the most difficult to access, with the narrowest floodplain, and no recreation opportunity except hiking and angling. Large complex logjams may be flushed out of this reach during very large flood events; but they persist and grow with small to large flood events. No action is recommended for this reach.

Reach 4

Reach 4 extends between RM-4.5 and RM-7.1 (Plate 5). This reach is affected by mass-wasting deposits nearly for its entire length. The floodplain of the Little Naches River is bounded on both sides by slide deposits for nearly the entire length of the reach, and the downstream boundary of the reach is defined by a landslide that created Salmon Falls (Plate 1B and 5).

Pileup Creek and Jungle Creek join the Little Naches River from the north (River Left) at approximately RM-6.9 and RM-5.6, respectively. Both these tributaries flow through culverts under the 1900 Road, which have been replaced in the last decade, and appear to be adequately sized. Approximately 3,139 linear feet (0.6 mile) of the 1900 Road protected by riprap in this reach, due to adjacency to the active channel of the Little Naches River (Plate 5).

The Little Naches River floodplain, still connected in Reach 4, is 364 feet wide on average—reduced 10% from the natural width of 403 feet (Table 2A and 2B). The floodplain is relatively narrow (Reaches 3, 4A, and 6 are narrower) but the reach-average slopes of the main channel and the floodplain are similar to those of wider reaches (Reaches 1, 1A, 2, and 5). However, the channel slope changes near the confluence of Jungle Creek. The main channel slope upstream from this location is 1.01% (steeper than the wider reaches), and 0.50% downstream (shallowest of all mainstem reaches) (longitudinal profile on Plate 5). This suggests the backwater associated with the landslide that created Salmon Falls extended as far as the mouth of Jungle Creek (approximately 4,500 feet).

The most significant human-caused alteration in Reach 4 was caused by the construction of the 1900 Road. The alignment of the 1900 Road was established by 1954 (Figure 8B). A meander bend was artificially cut off and abandoned north of the roadway, and 2 sections of floodplain totaling 10.8 acres in area were disconnected from the mainstem Little Naches River (Plate 5 and Figures 8A-8D). The 608-foot long abandoned portion of the stream channel is clearly identifiable from the LiDAR data (Figure 8A). The 1900 Road has needed repeated repairs over the decades at this location to prevent further damage. Currently, a 414-foot riprap line protects the roadway.

Several popular official and dispersed campgrounds exist in this reach. The most notable of these is Longmire Meadow Campground, managed by the USFS. All these campgrounds are within the active geomorphic floodplain of the Little Naches River. There have been attempts to raise the ground surface in the unofficial campground north of the 1900 Road in Longmire Meadow (USFS, personal communication), which may explain the unusually smooth topography at this location. The floodplain is frequently inundated by floods, despite the raised ground surface. Therefore, we consider the geomorphic impact of the fill negligible. Examination of 1954 aerial images supports this conclusion (Figure 8B). The heavy human traffic at the Longmire Meadow campground is a more significant factor which prevents the establishment of shrubby vegetation and trees, and destabilizes river banks. Other factors contributing to the unvegetated state may include unsuitable soils with high clay content.

Reach 4A is the short steep reach where Salmon Falls lies (Plate 5). It was created by the young landslide that separates Longmire Meadow from the wide valley containing the excavated borrow pit/fish pond (Plate 1A and 5, Figures 9A-D). Prior to the movement of this landslide, the floodplain containing Longmire Meadow was likely part of Reach 5, and distinct from Reach 4 due to its wider floodplain. The backwater caused by the initial release of the slide likely extended upstream to the confluence of Jungle Creek, and possibly beyond, until enough time passed for the River to carve through the slide material and establish its current configuration. Reach 4A, along with Reach 3, is one of two erosional reaches in this study. These reaches were formed similarly, but are different in age and scale as the Salmon Falls landslide is smaller and younger. The 1900 Road crosses the Little Naches River twice in Reach 4A. These crossings are inherently unstable due to their position at the toe of a slide, but represent little-to-no geomorphic impact because they are at natural constrictions of the floodplain.

There are numerous tree stumps in the channel of the Little Naches River (photo on Plate 5) just upstream of Reach 4A. These stumps appear to be those of mature coniferous trees and rise 1-2 feet above the river bed. It is likely that these trees were germinated on a surface topographically lower than the present bed of the river because their root masses are buried under river gravel. This suggests rapid deposition, after the Salmon Falls landslide, and consequent battering by the bedload of the river to break off the tops, leaving the stumps. Although many factors can contribute to preservation of wood, the fact that these stumps are still present, suggests the landslide is young, perhaps even no older than a century or two. The longitudinal profile of the Little Naches River (Plate 1A) provides additional evidence that the Salmon Falls landslide is fairly young—certainly younger than the larger slide that created Reach 3. Tree core age dating of trees on the slide surface, and on the reworked sediment downstream of the slide, in the rock quarry, would provide the most reliable minimum age of the slide because they would have germinated after the slide occurred. Upstream fish passage was considered an issue in the 1980s, and prompted the construction to the fish ladder at Salmon Falls.

Restoration Opportunities and Constraints

Reach 4 has largely recovered from clearing of LWD and floodplain vegetation. Dense stands of willows are becoming established and natural LWD recruitment is expanding existing logjams. Beaver activity has been observed in several locations in this reach.

Recommendations to consider are as follows:

- Relocating 1900 Road, or installing two bridges and/or culverts to allow activation of existing meander bend at least at flood stage **(4a and 4c)**,
- Planting shrubby vegetation, particularly on riprap road shoulders to improve cover and support existing beaver populations **(4b)**,
- Incorporating small LWD structures into the existing riprap to create roughness, cover, deeper pools, and encourage bar development **(4b)**, and
- Limiting access to unofficial campgrounds may also minimize danger of harassment to beaver **(4d)**.

Reach 5

Reach 5 extends between approximately RM-2.4 and RM-4.1 (Plate 6). The entire length of the Little Naches River floodplain abuts mass-wasting deposits on the north side (Plate 1B). The exact extent of mass-wasting deposits on the south side is unclear and may need to be verified, but these deposits are very near the floodplain and probably contribute sediment during severe rainstorms and large flood events. A large lobe of a landslide separates the broad valleys of Kaner Flats campground and the confluence area of Quartz Creek (Plate 1B and Plate 6). The upstream and downstream boundaries of this reach are also defined by landslides that formed natural constrictions in the floodplain that separate this reach from upstream and downstream reaches. (Plate 1B and Plate 6). The 1900 Road does not cross the mainstem Little Naches River in this reach, but the 1902 Road does, at RM-3.05 (Plate 6).

Quartz Creek joins the mainstem Little Naches River in this reach at approximately RM-3.26 from River Left, crossing under the 1900 Road. Crow Creek joins the mainstem at RM-3.12 from River Right.

Reach 5 is the most heavily impacted by human activity. The construction of the 1900 Road altered the topography, as well as the hydrologic, geomorphic, and ecological function of this reach. The 1900 Road nearly bisects the floodplain of the Little Naches River in this reach (Figure 10A); 52.6 acres (45% of total acreage) of floodplain are disconnected from the River (Table 1A and 1B). As much as 1660 linear feet of secondary Little Naches channels are also disconnected from the River. The area north of the reworked slide deposits where the rock quarry is, would have been a very valuable backwater for rearing juvenile salmonids (Figure 10A-10D). Disconnection of the floodplain by the 1900 Road prism diminishes backwatering of this area, because floodwaters of the Little Naches can only access this area much farther downstream through the Quartz Creek bridge. This means the backwater pool is at a lower elevation and inundates a smaller portion of the upstream floodplain. The current alignment of the 1900 Road was established prior to 1954, but the levees and fish pond were constructed decades later (Figure 10B).

The existing fish pond was excavated as a borrow pit for road base material for widening the 1900 Road in the 1980s (Torretta, written communication). This excavation lowered the water table locally, and dewatered the floodplain north of the 1900 Road, reducing outflow from the spring at the toe of the slide, northwest of the fish pond (Figure 10A). It is assumed that the source of this spring is at least in part augmented by the Little Naches River itself upstream of the slide in Longmire Meadow. The locally lowered water table in the unconsolidated, highly permeable, and well-drained matrix of the valley floor also caused a section of the Little Naches channel to nearly dewater at base flow conditions. In the 1980s low flows created concerns about fish passage. Bulldozers were used to scrape the channel of the Little Naches between RM 3.6 and 3.9, by as much as 6 feet (Garrigues, Thomas, personal communication). The material was pushed up on either side to expand and reinforce the levees that are present today. This increased ground water flow into the channel by intercepting local sub-surface flow paths which further lowered the local water table and reducing availability of surface water for the habitat north of the 1900 Road.

The levees have created an artificial constriction in the floodplain, causing the river to flow deeper and faster at flood stage, increasing stream power, and transport capacity. This, along with the abrupt widening at the downstream end of the levees, causes deposition of bedload in the sub-reach below the levees. This excessive bedload deposition and the earlier removal of large wood and vegetation from the floodplain have caused the reach immediately downstream of the levees to destabilize. The sediment deposition overwhelms the transport capacity of the river causing frequent channel migrations at flood stage. A comparison of the 2010 and 2015 LiDAR data for this area shows significant reworking of gravel bars and rapid channel changes (Figure 10C).

It had been previously assumed that the entirety of the Kaner Flats campground was within the active floodplain of the Little Naches River. Our analysis indicates that only a portion of this campground is within the geomorphic floodplain of the River (Figure 11). Although a significant portion of the floodplain is disconnected from the River (9.2 acres) by the 1900 Road, much of the campground is topographically too high to be included in the floodplain (Transects 50 and 54 on Plate 6). The valley bottom where the campground lies, is steeper than the floodplain, and is largely made up of reworked sediment from the slide that constricted the floodplain separating the Kaner Flats area from the Quartz Creek confluence area.

Other than separating a piece of floodplain, construction of the 1900 Road caused little other change to the course of the Little Naches River through Kaner Flats. The channel position of the Little Naches River in this vicinity is virtually unchanged since 1954 (Figure 11B).

A total of 1,593 linear feet (0.3 mile) of riprap currently protect the 1900 Road in this reach (Figures 10 and 11). The most prominent section of riprap is where the River channel abuts the 1900 Road near the downstream end of the Kaner Flats campground.

Restoration Opportunities and Constraints

Without a doubt, removing the 1900 Road would improve habitat conditions in Reach 5. However, restoring a more natural exchange of surface water and groundwater will require additional work. This work can be achieved even without re-aligning the 1900 Road, or prior to it if road relocation is an option. We recommend the following actions for this reach:

- Consider relocating or modifying the 1900 Road **(5e,5g, and 5h)**
- Remove the levees to allow the River to access its floodplain **(5a, 5b, and 5f)**
- Fill in the fish pond, or build a series of causeways perpendicular to the floodplain aspect to raise the water table to a more natural level, if refilling is too cost prohibitive **(5c)**
- Install robust, complex in-channel logjams to encourage bar development, bed aggradation, and revegetation **(5a and 5b)**
- Install small simple logjams throughout floodplain, designed to accumulate additional LWD naturally **(5f)**
- Plant shrubby vegetation, particularly on road shoulder riprap **(5d, 5f, and 5g)**
- Disallow camping in the vicinity of the fish pond to allow beaver establishment **(5d)**—this location is also particularly vulnerable to future landslide activity which is exacerbated by, and dangerous to, campers and recreationists.

Reach 6

Reach 6 extends between RM-0.0 to RM-2.4. Horsetail Falls is on the north side of Little Naches River floodplain, at approximately RM-0.8 (Plate 7). The floodplain of the Little Naches River abuts mass-wasting deposits for nearly the entire length of this reach on the north side (Plate 1B). There are several privately-owned cabins on leased USFS property in the downstream end of this reach. These cabins are within the geomorphic floodplain of the Little Naches River, although the USFS's Naches District personnel claim no records of flooding exist. Presence of a low-lying levee at the upstream end of the cabin sites, indicates that there have at least been concerns about flooding in the past (Plate 7).

During construction of the 1900 Road several deep pools were filled in (Hampton, personal communication). These pools would have been valuable holding water for anadromous fish during their spawning migration. These changes are documented in fairly good detail in the original as-built design sheets, still stored in the Naches District files. The natural floodplain of the Little Naches River in Reach 6 is relatively narrow. The 1900 Road prism takes up a proportionally larger section of the total width available to the river than in other reaches, and thus has a greater adverse impact.

This reach appears more or less intact, although it is considered biologically impaired (Torretta, written communication), particularly where the channel interacts with the road shoulder. There is 4,302 linear feet (0.82 mile) of riprap on the shoulder of the 1900 Road in Reach 6—longer than any other reach in this study. This riprap has caused the loss of vegetative cover, the filling of what were once deep scour holes, and diminished capacity for establishment of logjams. Additionally, it has been shown that the grain size of gravel bars in this reach coarsened between 1935 and 1990 (Haring, 2001), an indication of increased stream power due to narrowing of the floodplain. Chinook salmon spawning was observed in this reach in 2015, suggesting some recovery since 1990, however a grain size analysis is required to confirm or deny this.

Restoration Opportunities and Constraints

The greatest opportunity in Reach 6 is ease of access as long as the 1900 Road remains open. Much of the work can be done from the road shoulder. Strategic use of LWD structures can make use of the River's own energy to excavate deep pools. We recommend the following:

- Consider relocating the 1900 Road **(6a, 6b, 6c, and 6d)**,
- Place LWD designed to encourage pool scour, provide cover, and bar deposition **(6a and 6b)**, and
- Plant shrubby vegetation around the placed LWD, as well as the existing riprap **(6a and 6b)**.

Discussion

The degradation caused by human activity in the Little Naches River and its floodplain falls under two basic categories of 1) directly related to the 1900 Road, and 2) indirectly related, or unrelated, to the 1900 Road. This presents both challenges and opportunities. Challenges are that some of the ecological impairment is not correctible without complete removal of the roadway prism, which would come at high expense and result in reduced access to some areas. The opportunities are that many of the most severe impairments can be corrected without, or prior to, the removal of the roadway prism.

The system has mobilized and retained fairly high quantities of naturally occurring logjams in the last 2-3 years in all the reaches. Natural LWD has increased significantly in this time period. These logjams are numerous, but many are small. They are likely to be mobilized during a flood larger than the one that deposited them. Retention of this wood in the system should be a top priority in the management of this river. Even if nothing is done, these locations will naturally accumulate LWD. One of these locations is the upstream end of the avulsion that took place during Summer 2016, occupying the Fawn Creek channel. A persistent large logjam forced an existing secondary channel to serve as the main channel, carrying the majority of the flow at baseflow and small flood stages into the Fawn Creek channel.

The locations of historically persistent, large logjams are known from records of their removal. Some of these locations are naturally beginning to accumulate wood and form logjams, particularly in Reaches 1 and 2. Installation of additional LWD structures in all but the erosional reaches, designed to capture additional LWD naturally, would expedite recovery.

In particularly damaged sections of floodplain, such as Reaches 5 and 6, where narrowing top width and creating deeper and better covered pools is a priority, a tight network of small but durable logjams, and aggressive planting of shrubby plants is recommended. This would be a very cost effective way to retain more of the naturally available wood, and accelerate the recovery of the system naturally. The patchwork of logjams would be designed to capture mobilized large wood at flood stage. These structures would in turn encourage the deposition of bars above bankfull (i.e., flow stage at which water begins spilling out of the channel and into the floodplain), in effect deepening pools. This is a far less expensive approach than moving many tons of fill material to create the desired topography.

In Reach 5, past addition of LWD and plantings, as well as natural revegetation have triggered remarkable recovery, particularly immediately downstream of the levees. Removal of the levees, filling in the fish pond (or building causeways across it to raise the water table), and addition of numerous robust complex logjams in key locations in the main channel, could result in further recovery by letting the river do the work of depositing sediment naturally, and stabilize itself.

In Reach 6, where the floodplain is naturally narrower, and the 1900 Road takes up a larger proportion of the floodplain width, large logjams represent a risk to the 1900 Road. LWD placed in this reach should be smaller, but more numerous. These smaller logjams could be incorporated into the riprap protecting the shoulder to encourage deep pool development. Aggressive planting of shrubby vegetation could be a critical element of the overall design of the logjams. This can add additional natural stability to the road shoulder, and provide shade and cover for the pools the LWD creates. The structures are likely to encourage deposition of sediment in pockets, which can expedite further natural revegetation.

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Appendix A

Figure 1. Site Map of Little Naches basin and the study area. The extents of 2010 (orange hillshade) and 2015 (gray hillshade) LiDAR data are shown.

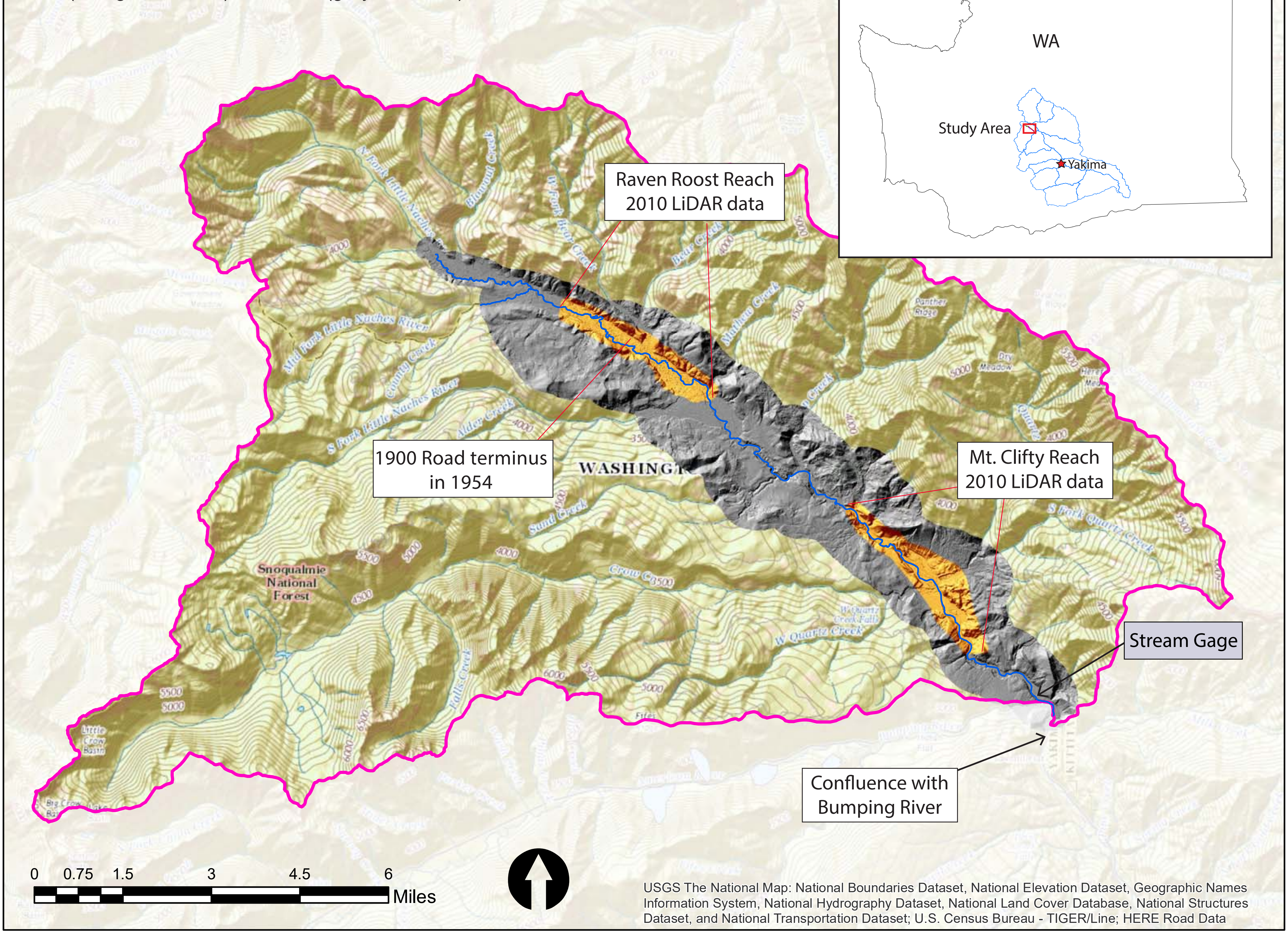


Figure 2. Geologic map of the Little Naches Basin, adapted from USGS 1:100,000-scale maps. Mass wasting deposits are depicted with a red outline for easier viewing.

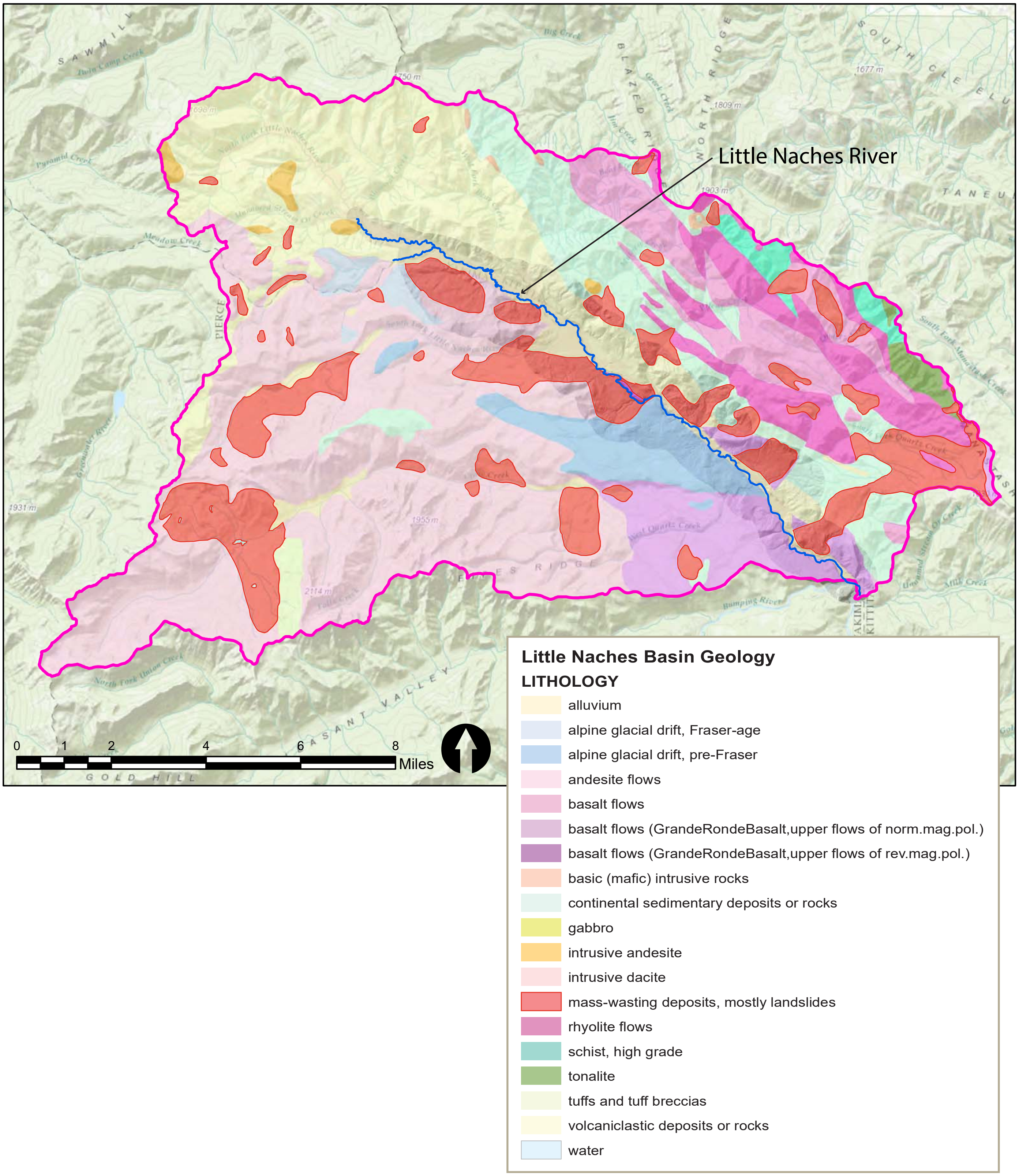


Figure 3A. "Current Data Graph" as plotted by the U.S. Bureau of Reclamation online data portal, of mean daily discharge of the Little Naches gage.

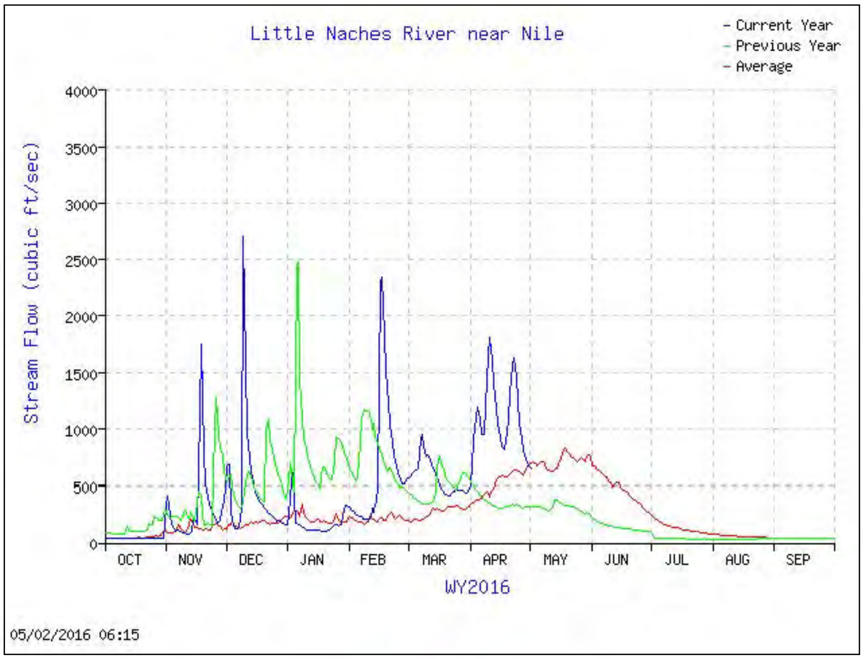


Figure 3B. Naches River mean daily discharge at gage near mouth, for the period of record.

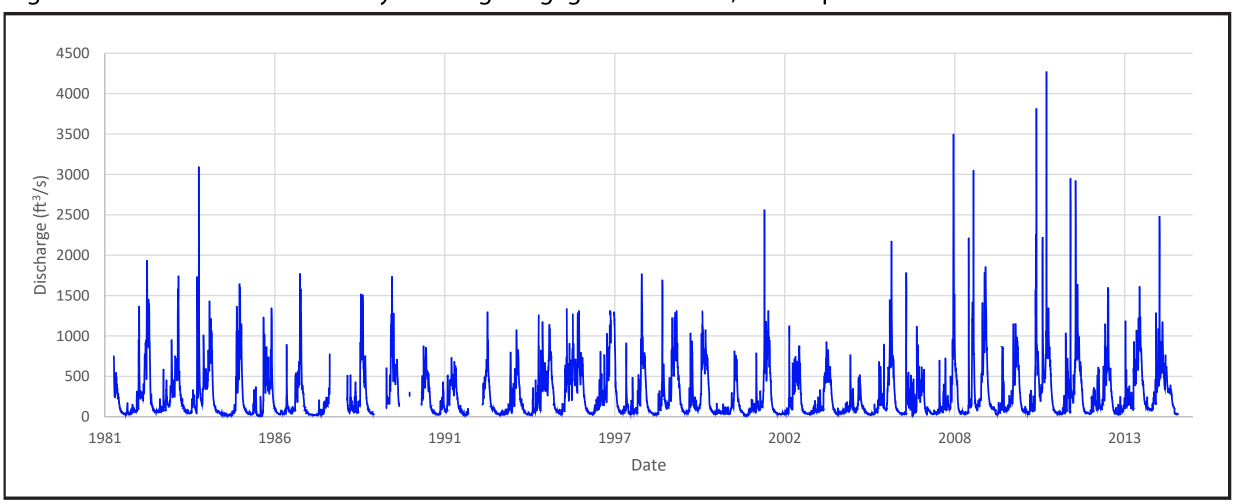


Figure 3C. Naches River mean daily discharge for the period bracketing LiDAR data collection dates.

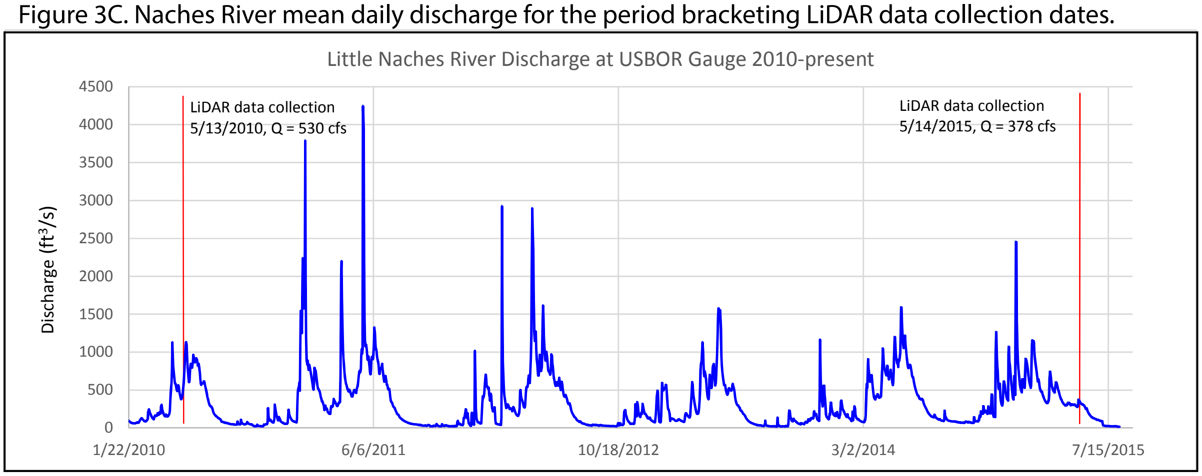


Figure 4A. Instantaneous 15-minute interval discharge of the Little Naches gage, for the period of record.

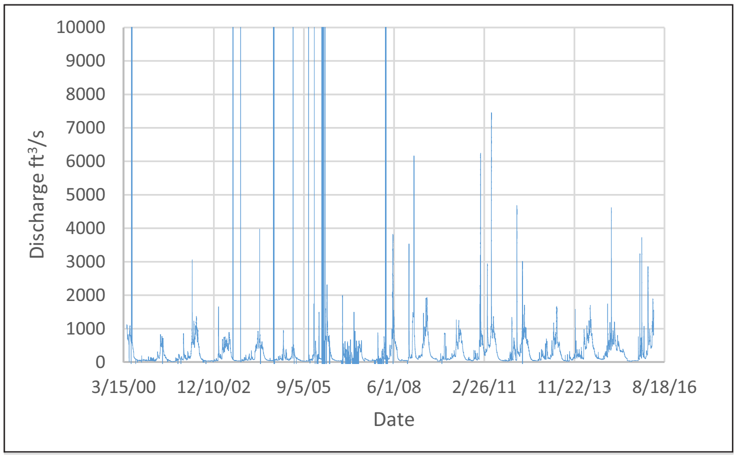


Figure 4B. Flow duration curve for the Little Naches gage.

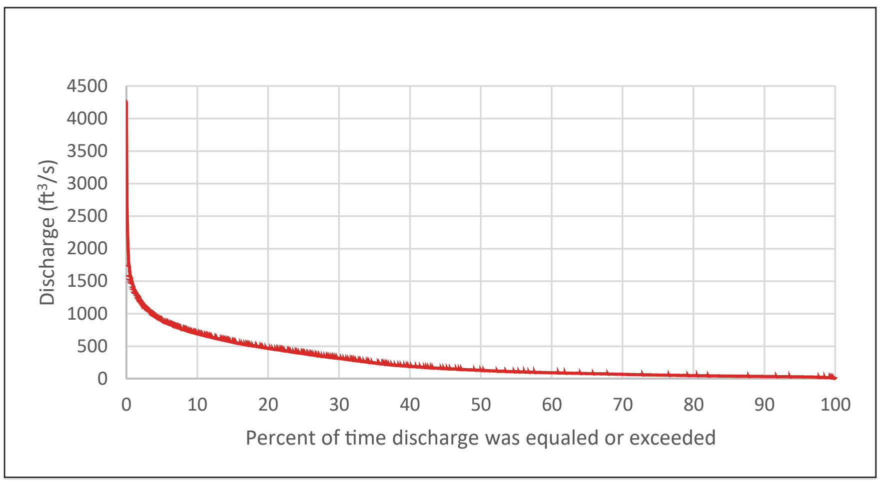
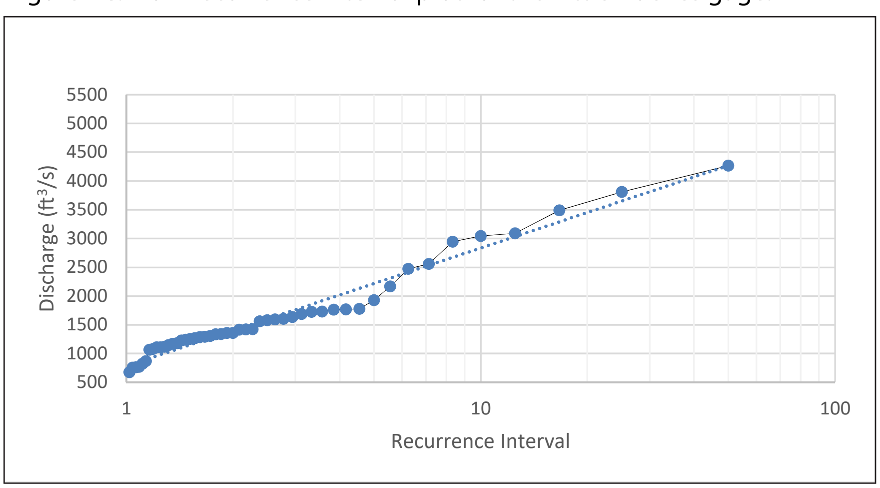


Figure 4C. Flow recurrence interval plot for the Little Naches gage.



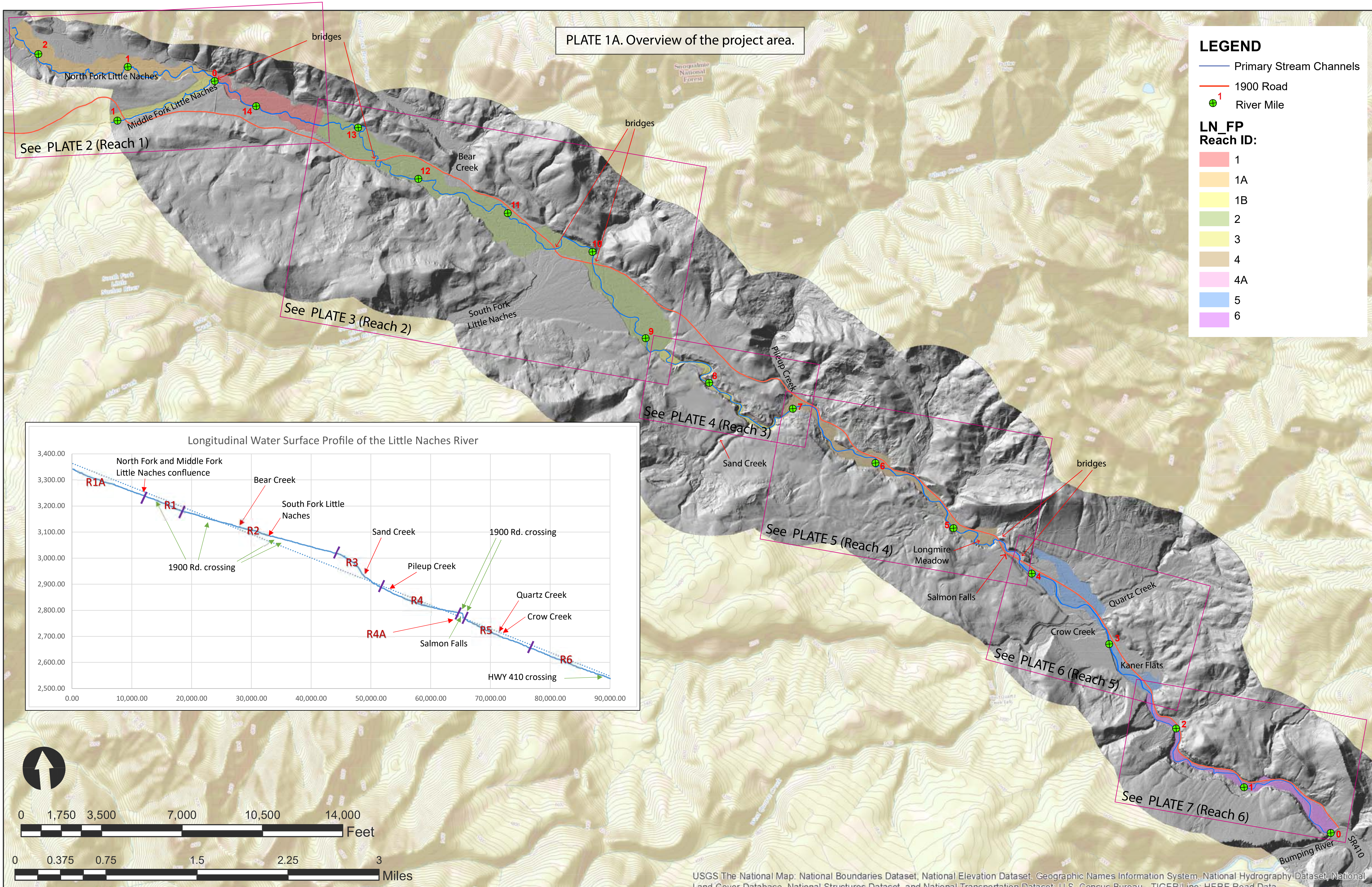


PLATE 1A. Overview of the project area.

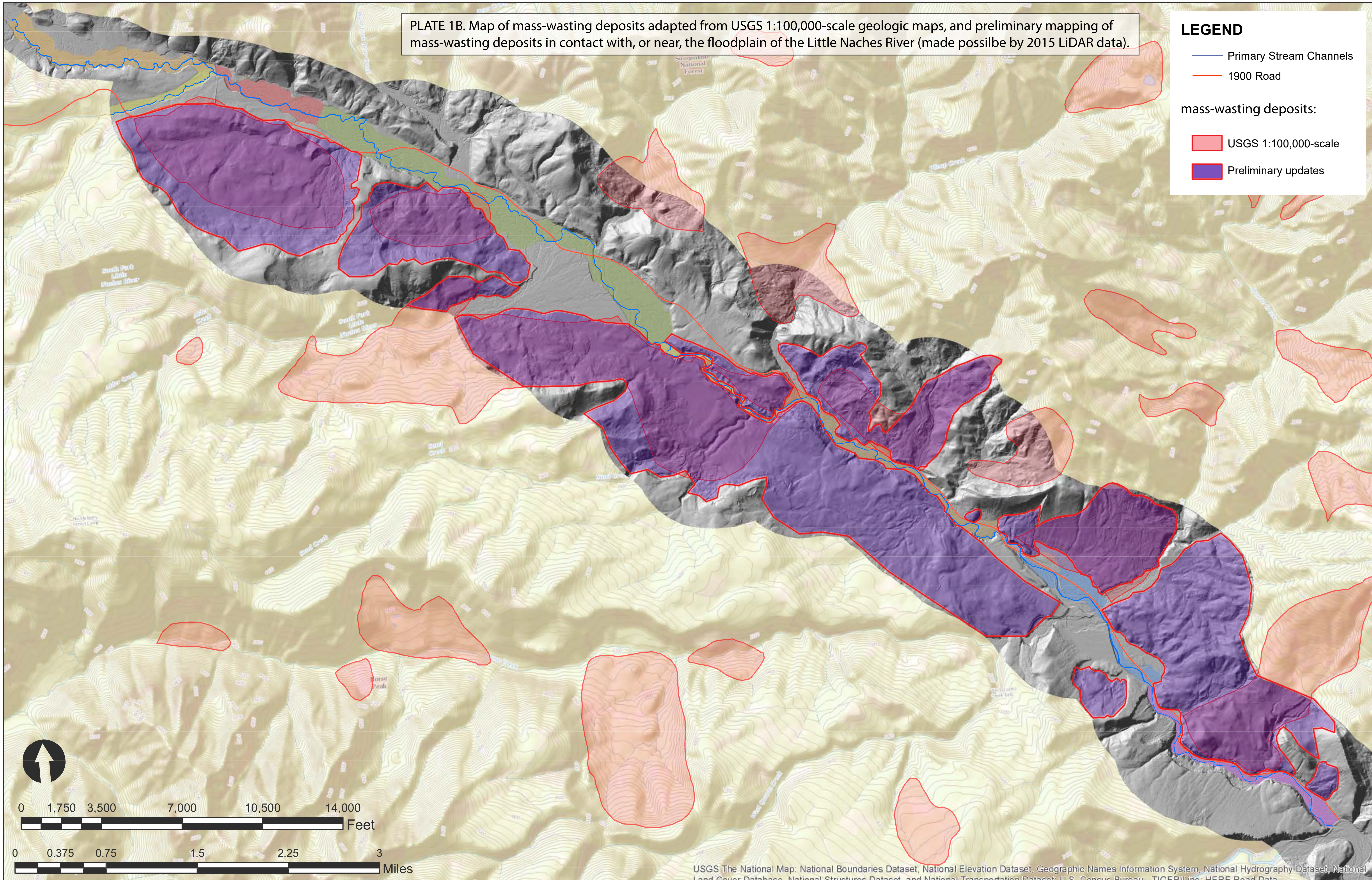


PLATE 1B. Map of mass-wasting deposits adapted from USGS 1:100,000-scale geologic maps, and preliminary mapping of mass-wasting deposits in contact with, or near, the floodplain of the Little Naches River (made possilbe by 2015 LiDAR data).

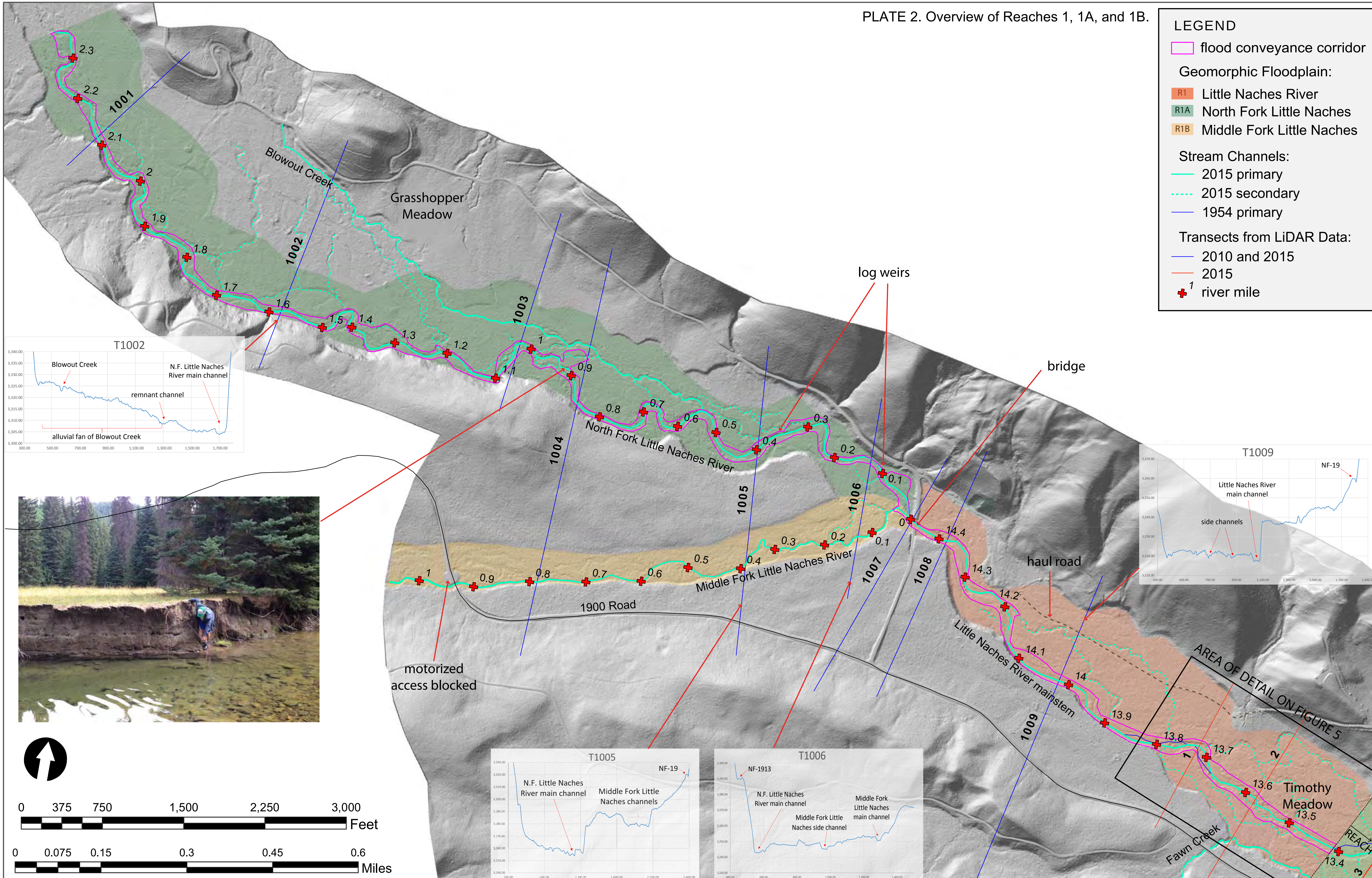


PLATE 2. Overview of Reaches 1, 1A, and 1B.

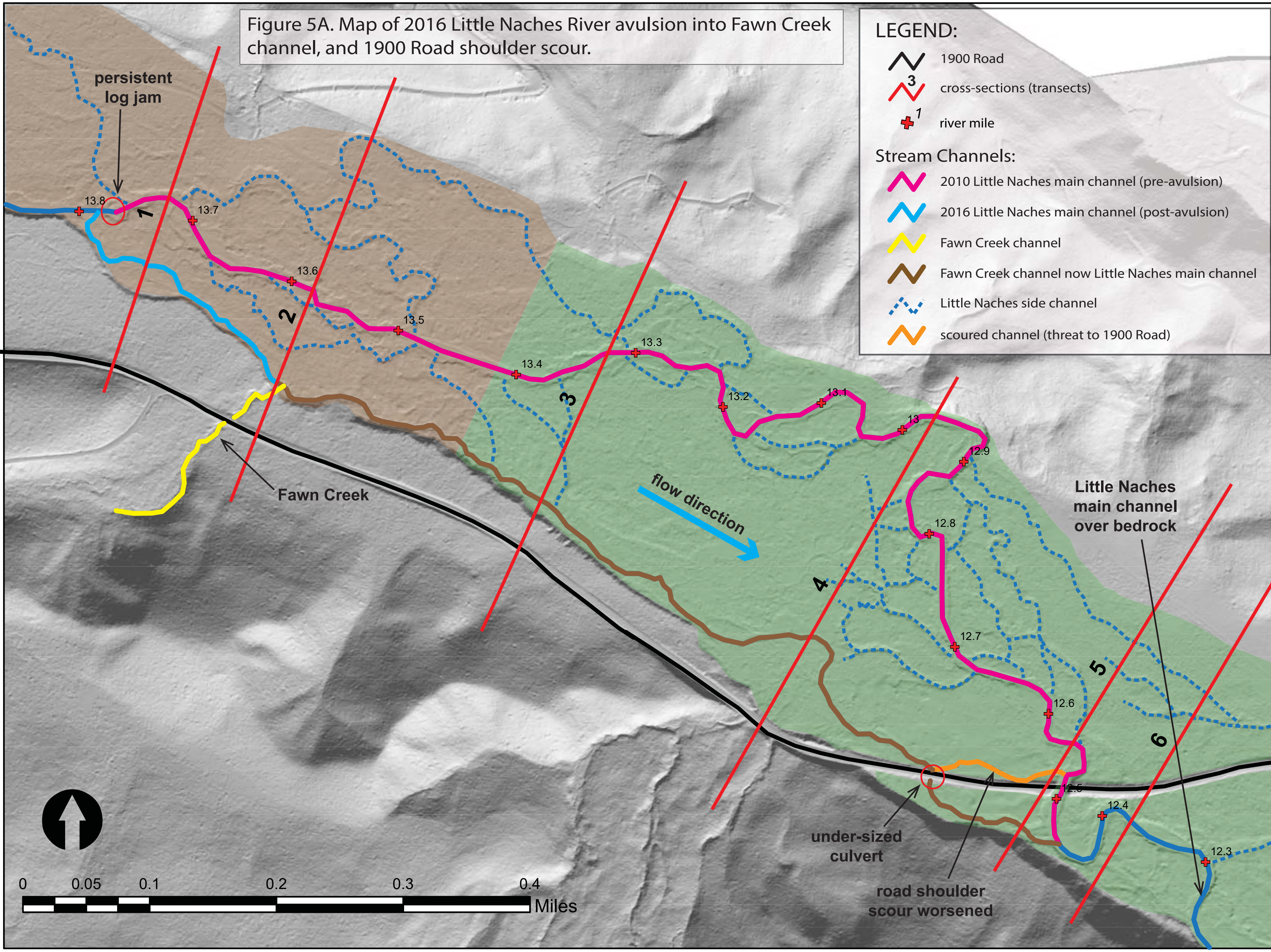
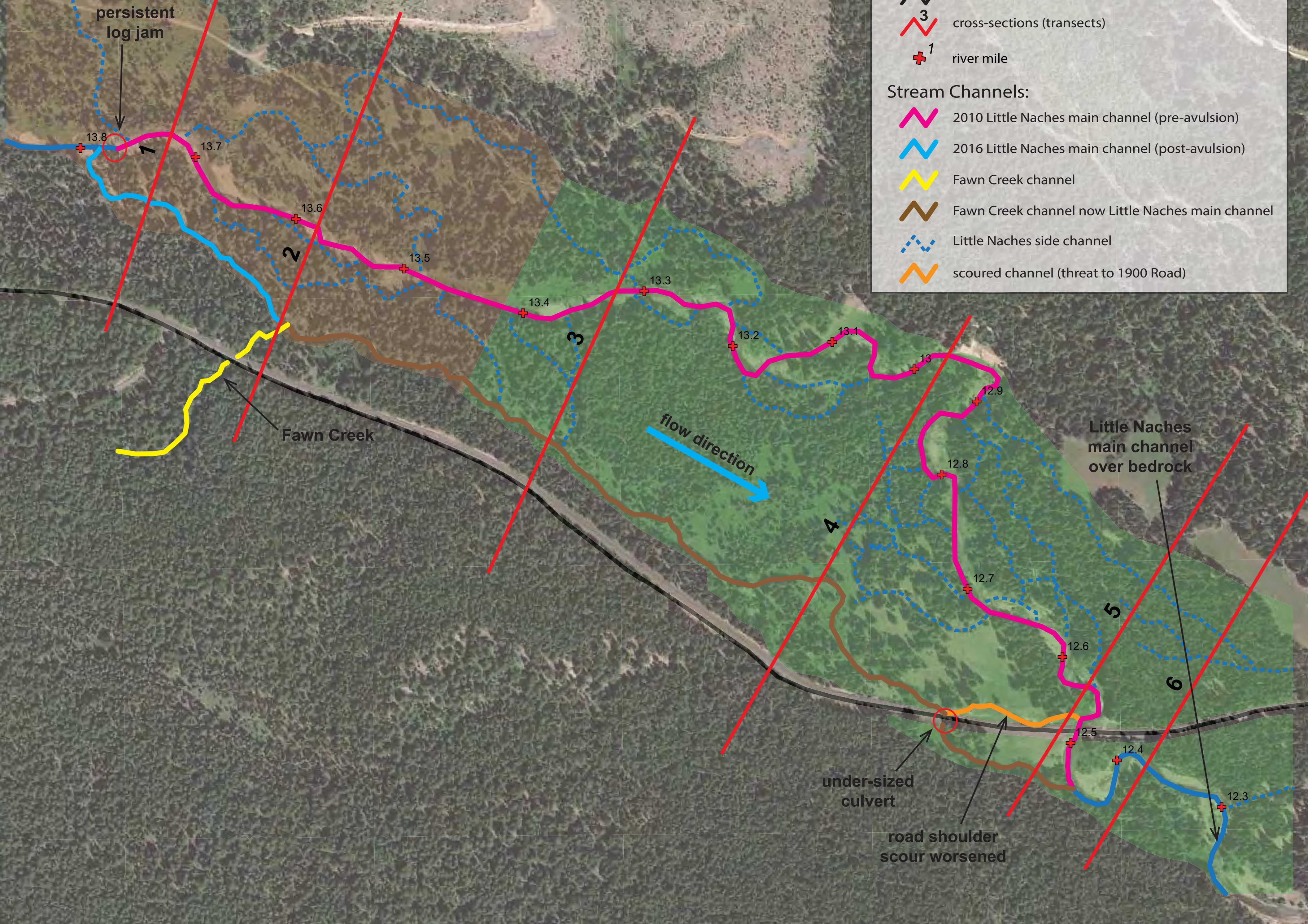


Figure 5A. Map of 2016 Little Naches River avulsion into Fawn Creek channel, and 1900 Road shoulder scour.
LEGEND:
1900 Road
cross-sections (transects)
river mile
Stream Channels:
2010 Little Naches main channel (pre-avulsion)
2016 Little Naches main channel (post-avulsion)
Fawn Creek channel
Fawn Creek channel now Little Naches main channel
Little Naches side channel
scoured channel (threat to 1900 Road)
persistent log jam
Fawn Creek
flow direction
Little Naches main channel over bedrock
under-sized culvert
road shoulder scour worsened
13.8
13.7
13.6
13.5
13.4
13.3
13.2
13.1
13
12.9
12.8
12.7
12.6
12.5
12.4
12.3
1
2
3
4
5
6
0
0.05
0.1
0.2
0.3
0.4
Miles

Figure 5B. Map of 2016 Little Naches River avulsion into Fawn Creek channel, and 1900 Road shoulder scour.



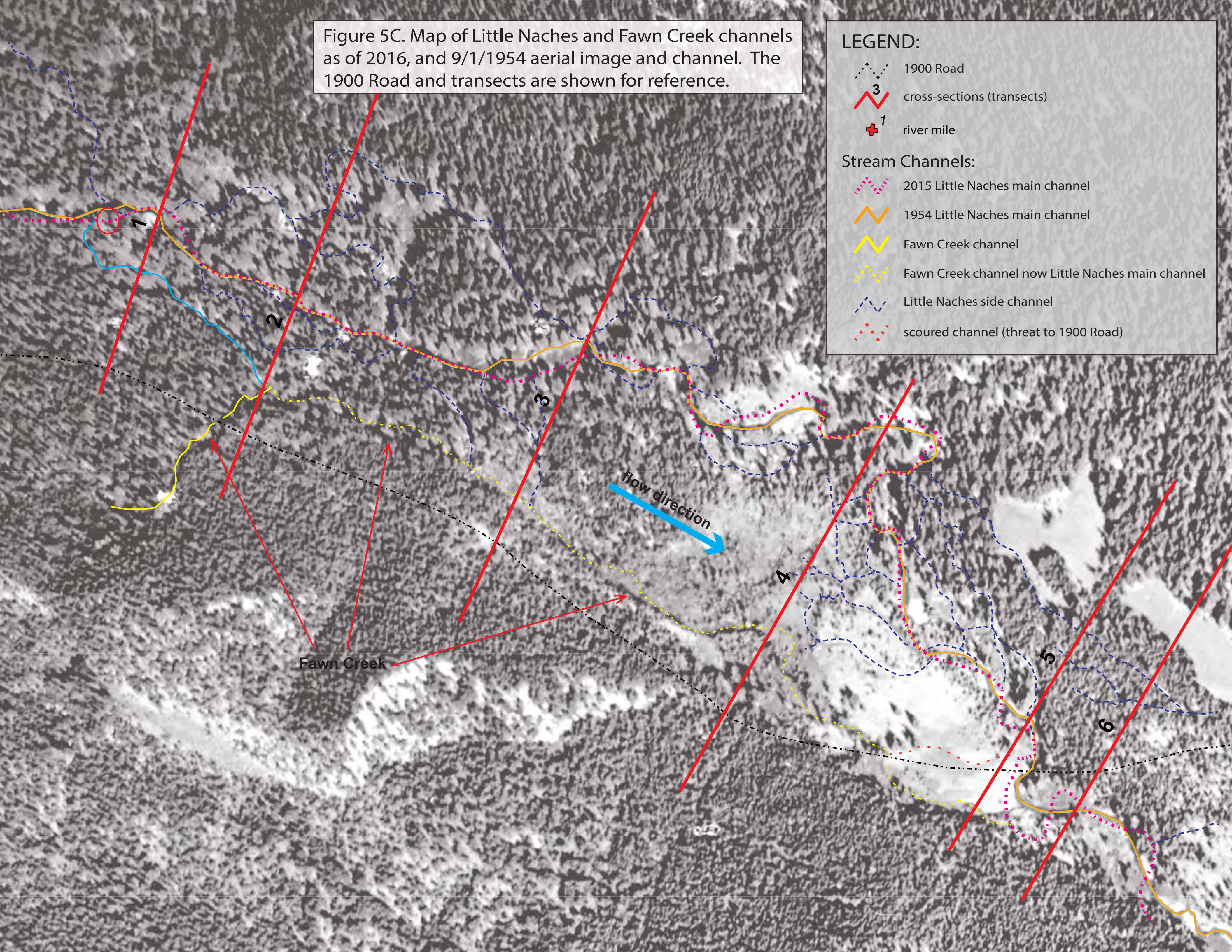


Figure 5C. Map of Little Naches and Fawn Creek channels as of 2016, and 9/1/1954 aerial image and channel. The 1900 Road and transects are shown for reference.
LEGEND:
1900 Road
3
cross-sections (transects)
1
river mile
Stream Channels:
2015 Little Naches main channel
1954 Little Naches main channel
Fawn Creek channel
Fawn Creek channel now Little Naches main channel
Little Naches side channel
scoured channel (threat to 1900 Road)
1
2
3
4
5
6
flow direction
Fawn Creek

Figure 5D. Transect 1 in Reach 1, upstream of the new Fawn Creek confluence.

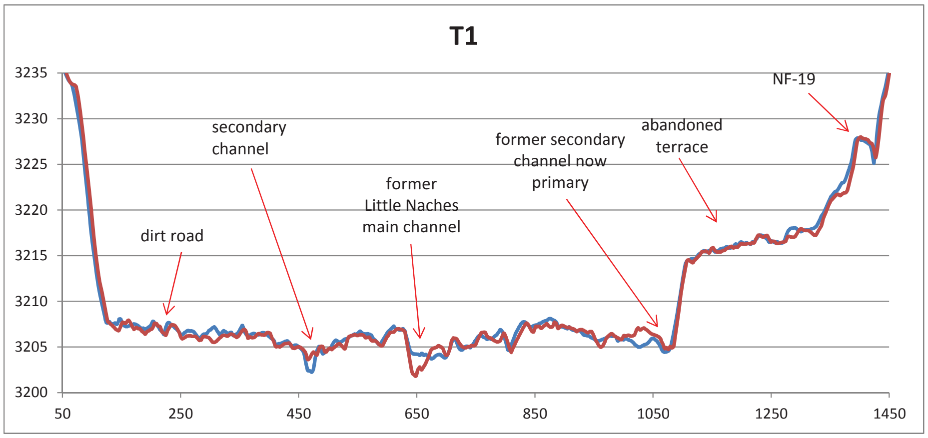


Figure 5E. Transect 3 in Reach 2, downstream of the new Fawn Creek confluence.

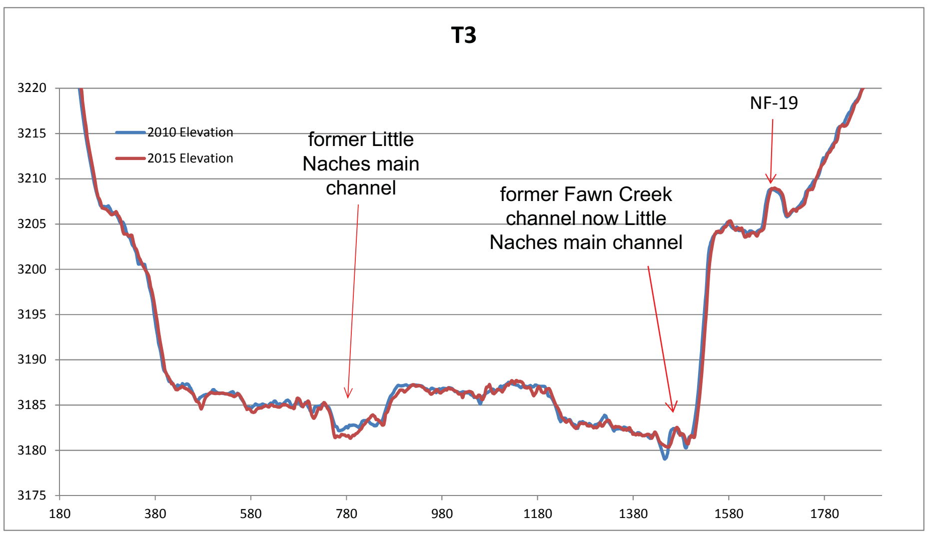
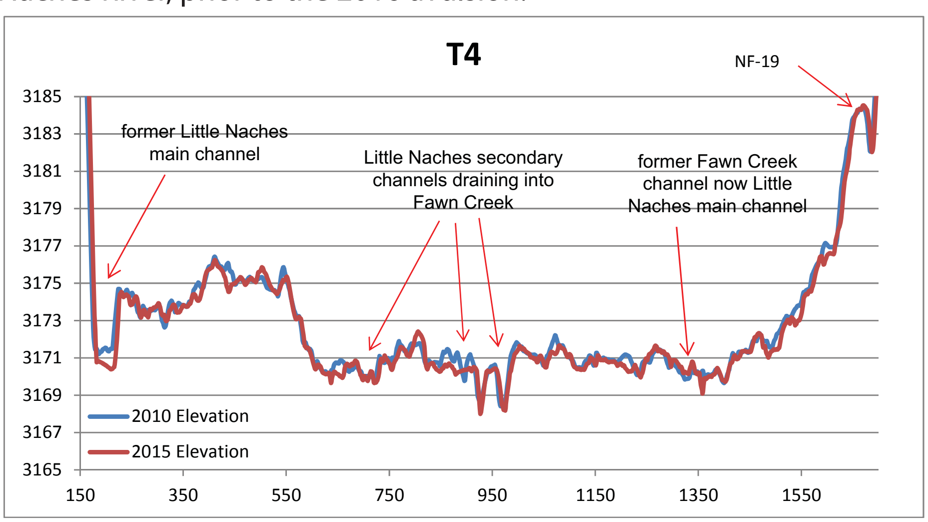


Figure 5F. Transect 4, showing the perched main channel of the Little Naches River, prior to the 2016 avulsion.



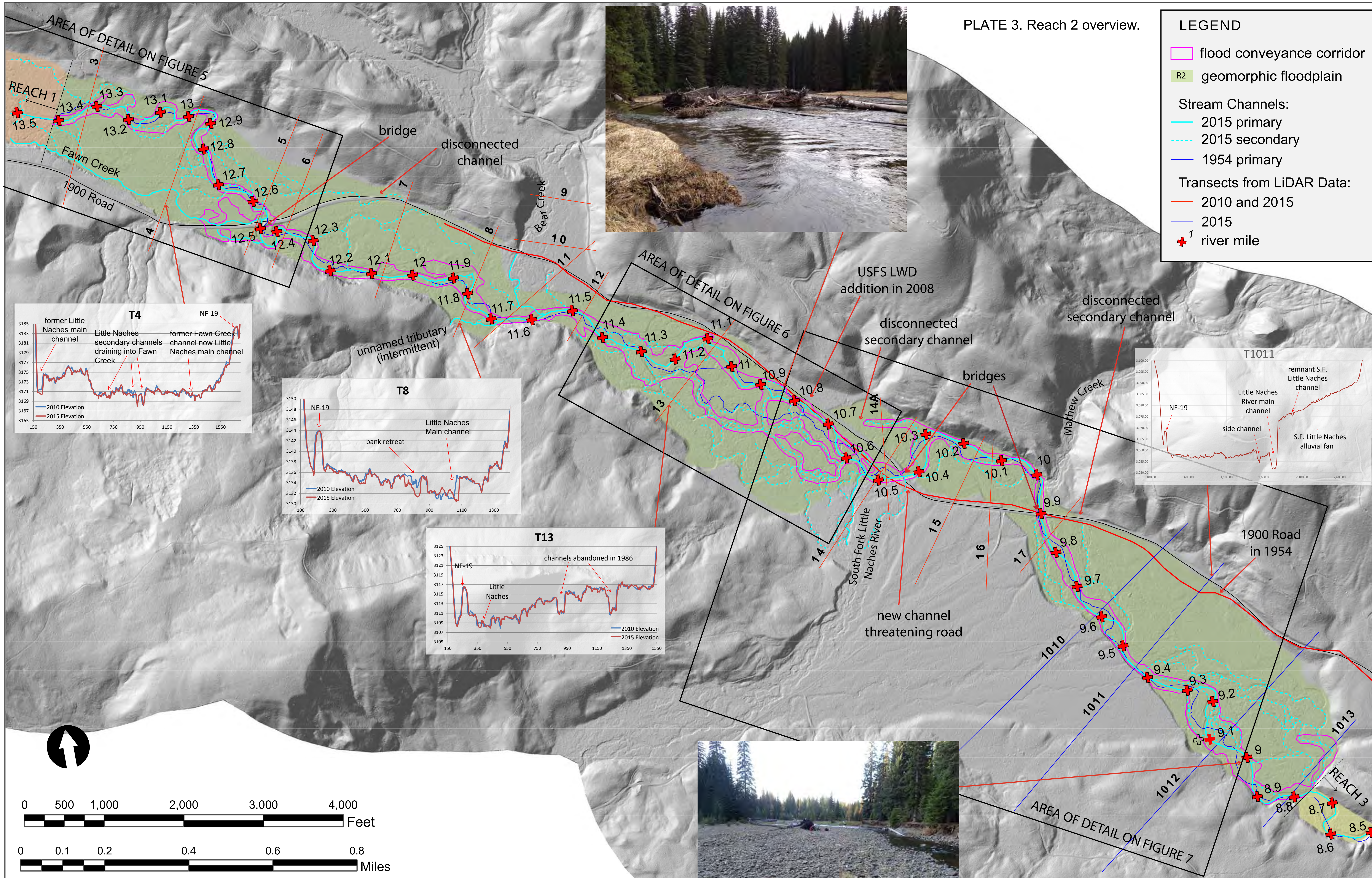


PLATE 3. Reach 2 overview.

Figure 6A. Map of the confluence of the mainstem Little Naches River and South Fork Little Naches River. A split channel has persisted for decades in the reach upstream of the confluence.

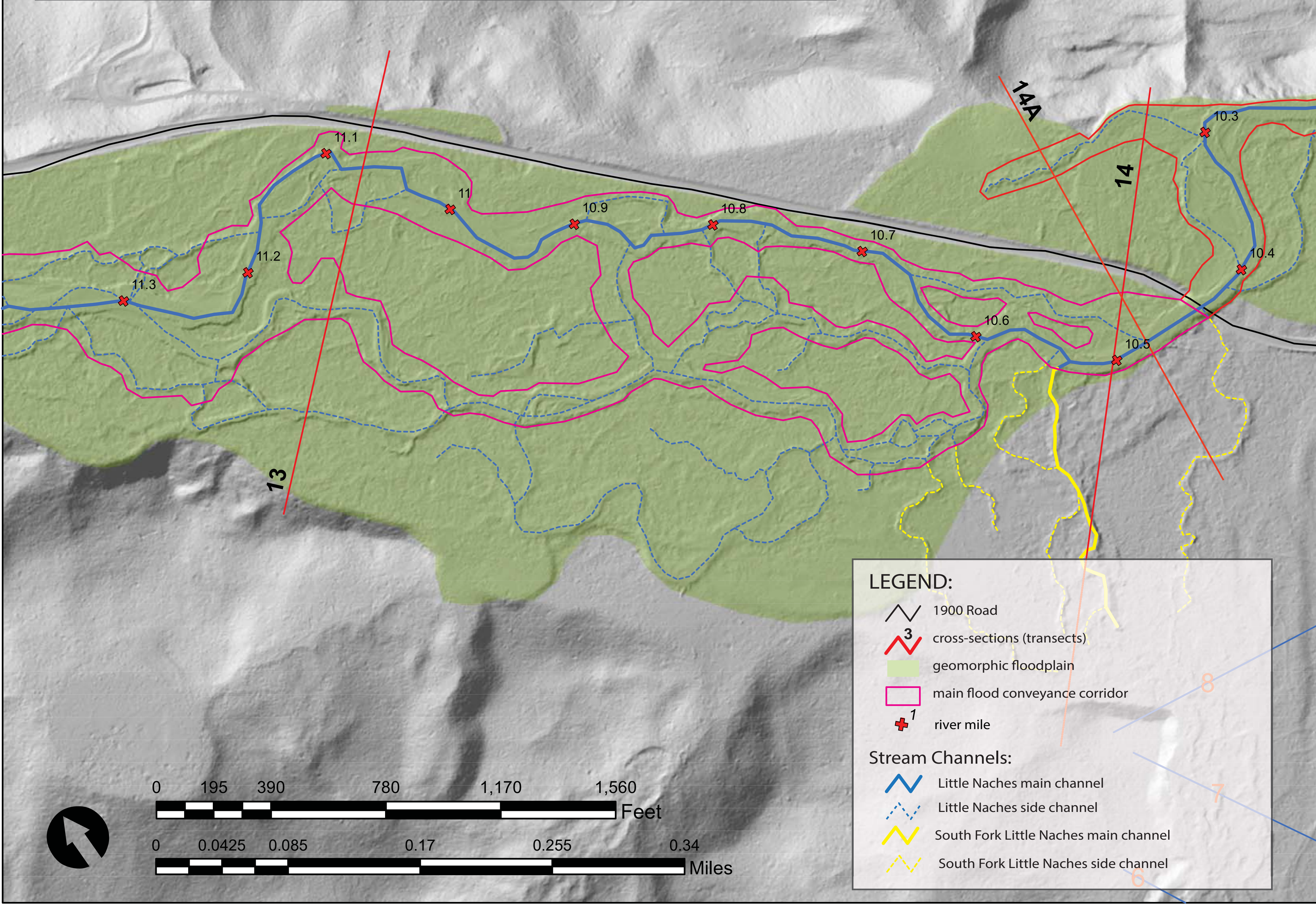


Figure 6B. Map of mainstem Little Naches and South Fork Little Naches Rivers' confluence, overlying 9/1/1954 aerial imagery. The 1900 Road's current alignment and other markers are shown for reference.

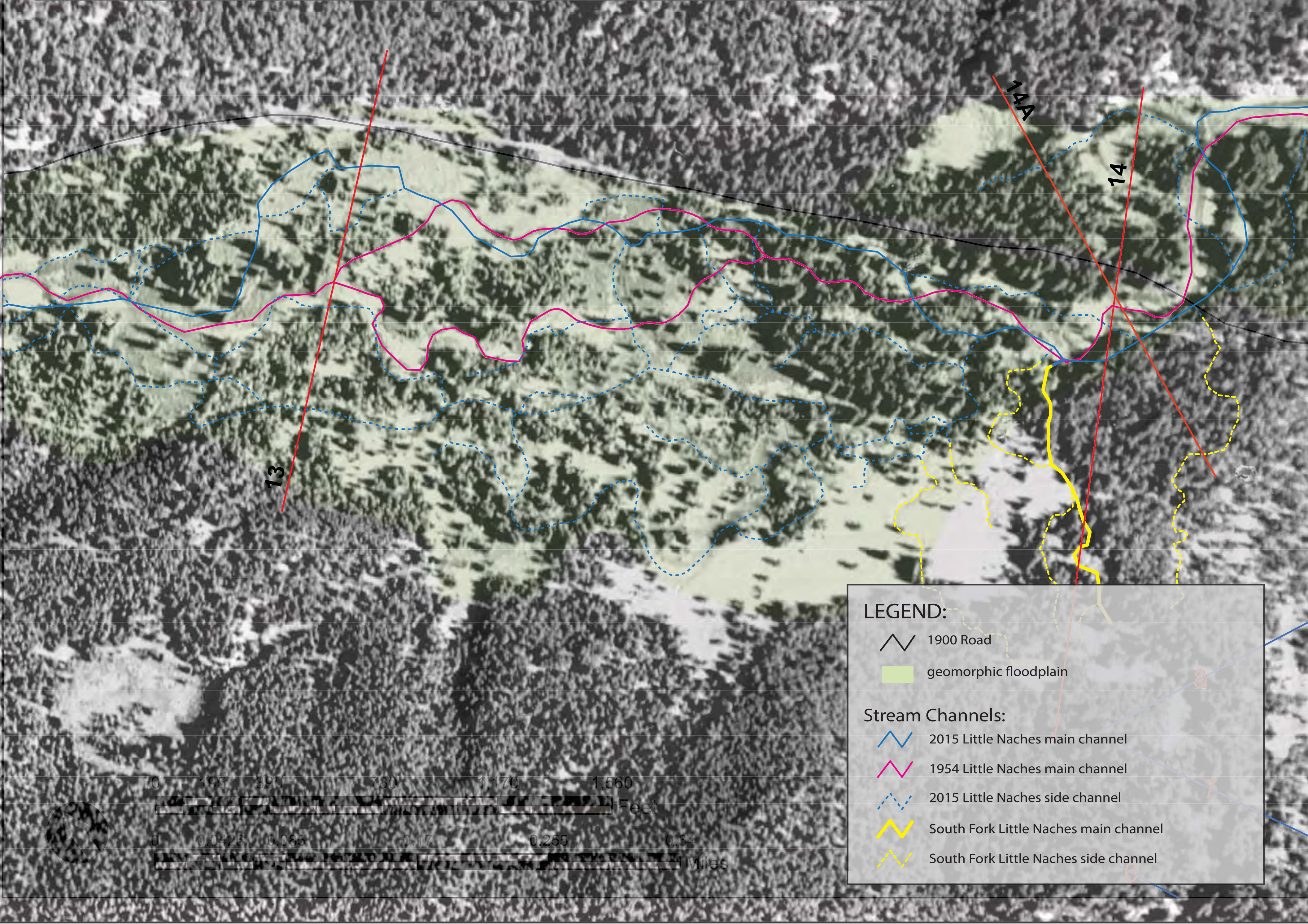


Figure 6C. Transect 14, showing the prominent alluvial fan of South Fork Little Naches. The 1900 Road prizm is also shown.

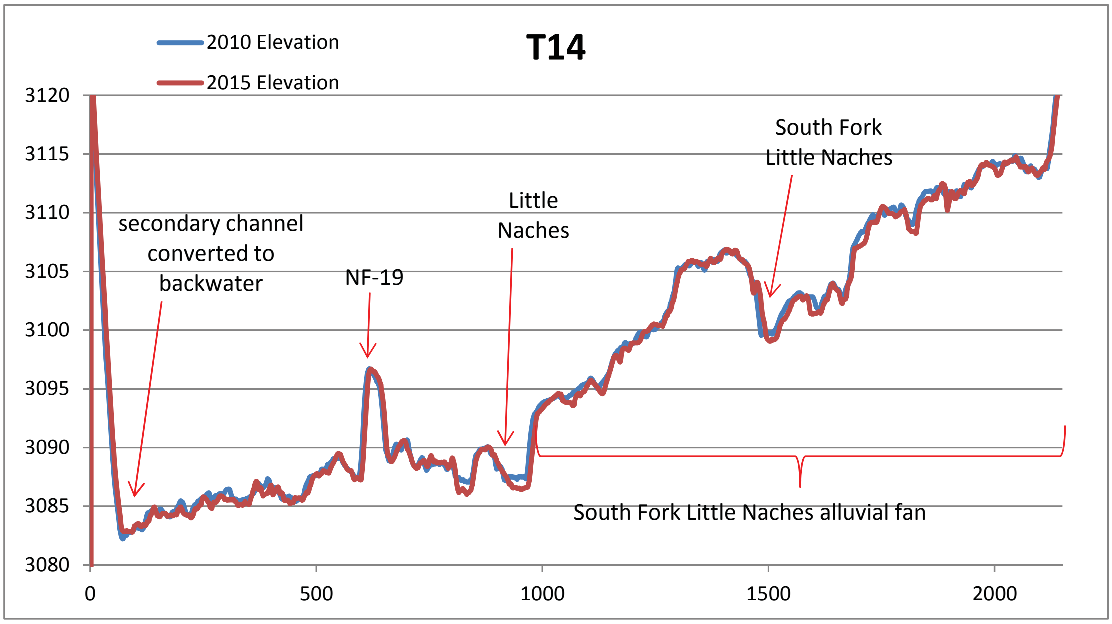


Figure 6D. Transect 14A, perpindicular to the floodplain, shows the 1900 Road prizm and secondary channels blocked by it, as well as the S. F. Little Naches alluvial fan.

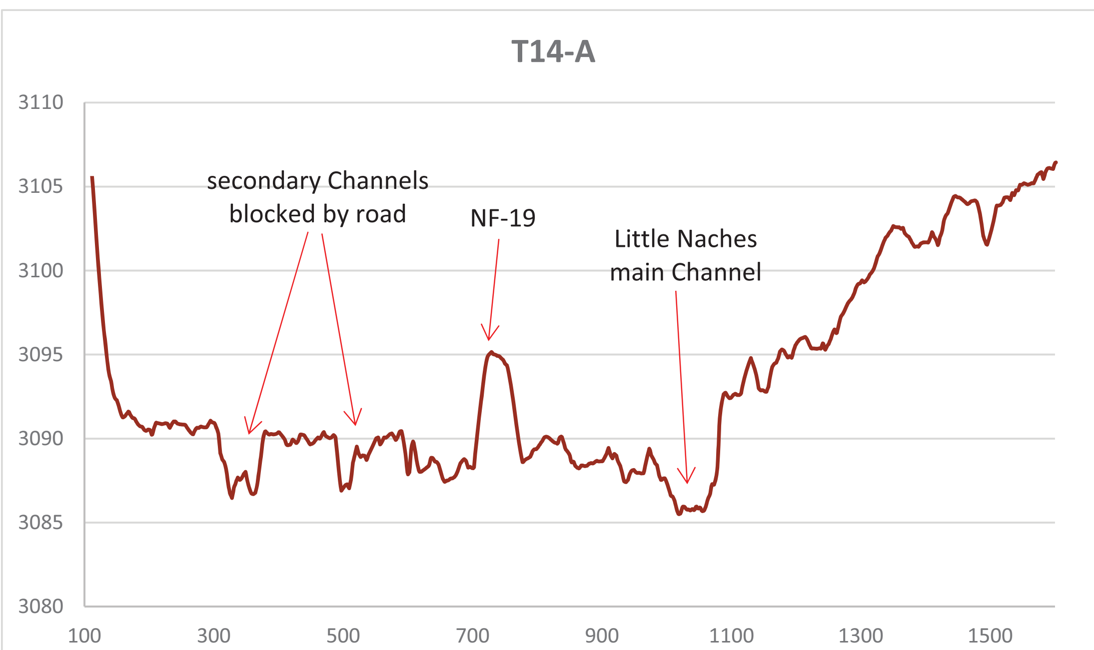
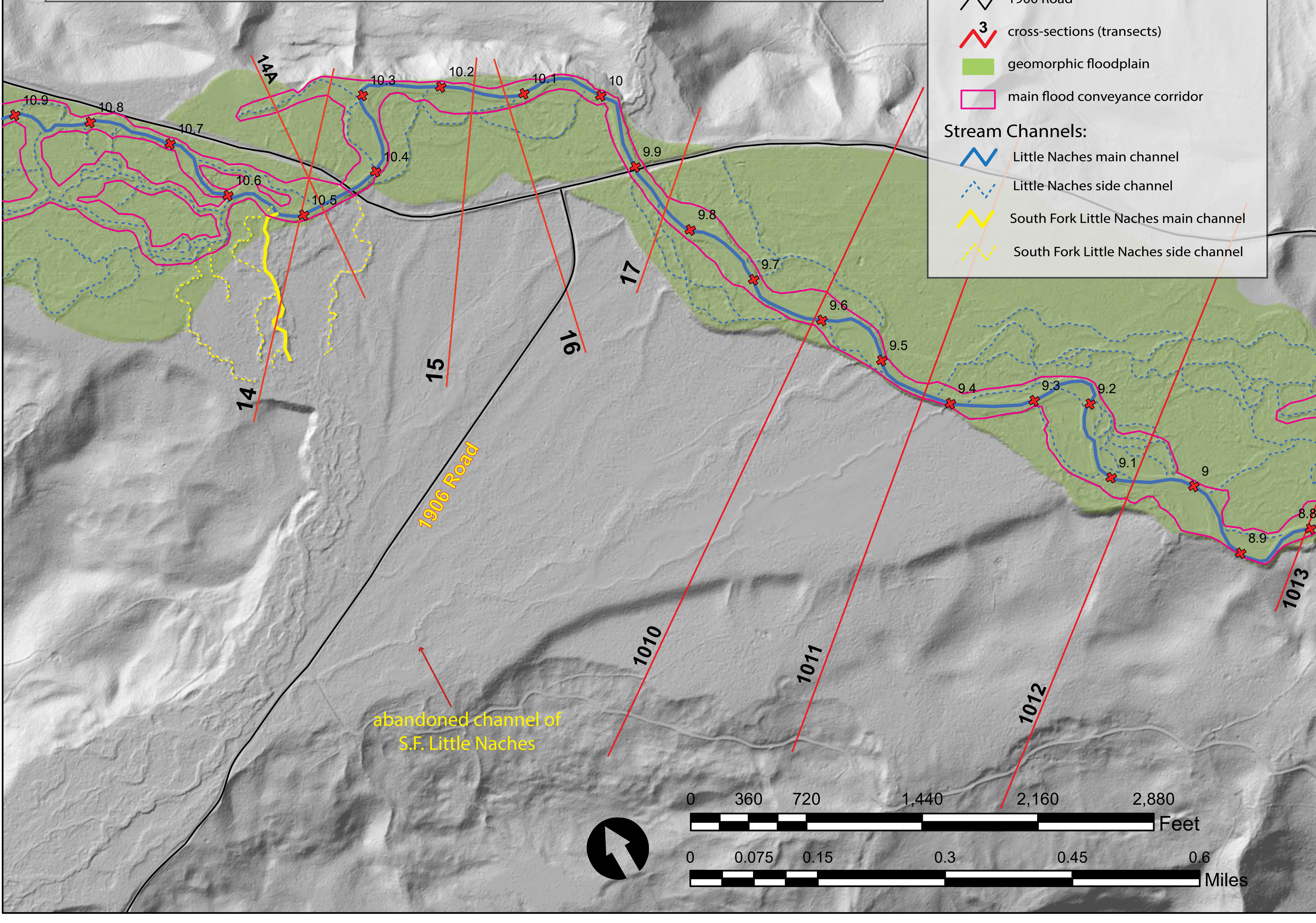


Figure 7A. Map of the confluence of South Fork Little Naches and mainstem Little Naches Rivers, as well as the large alluvial fan of South Fork Little Naches River.



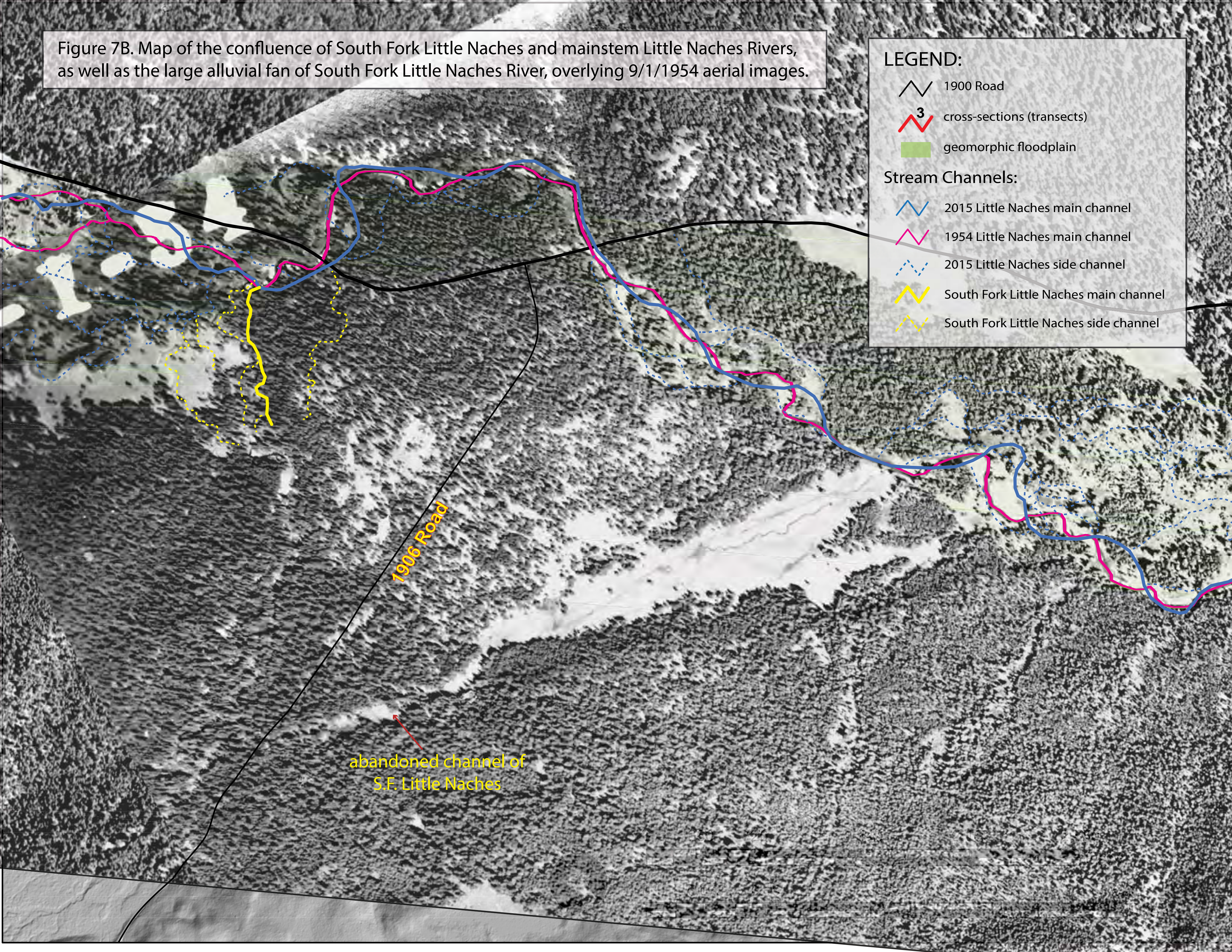


Figure 7B. Map of the confluence of South Fork Little Naches and mainstem Little Naches Rivers, as well as the large alluvial fan of South Fork Little Naches River, overlying 9/1/1954 aerial images.

Figure 7C. Transcect 15 in , shows the massive alluvial fan of S.F. Little Naches River, and the 1900 Road above the floodplain of mainstem Little Naches River.

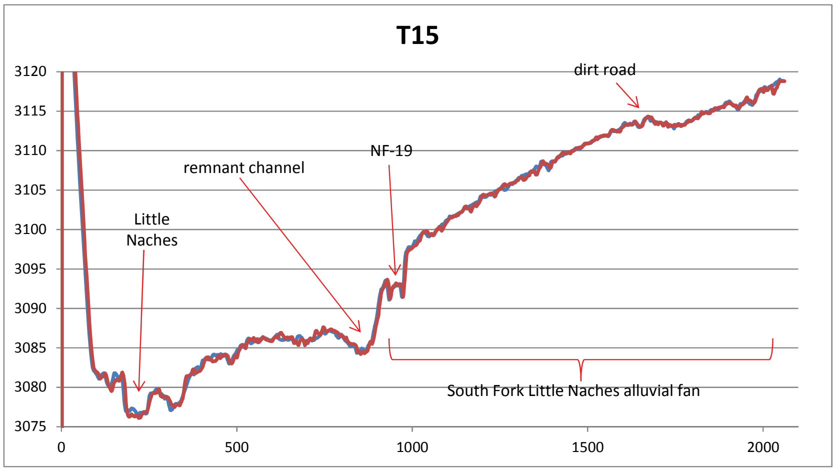


Figure 7D. Transect 17 shows the naturally narrow floodplain of the Little Naches River, and the 1900 Road prizm.

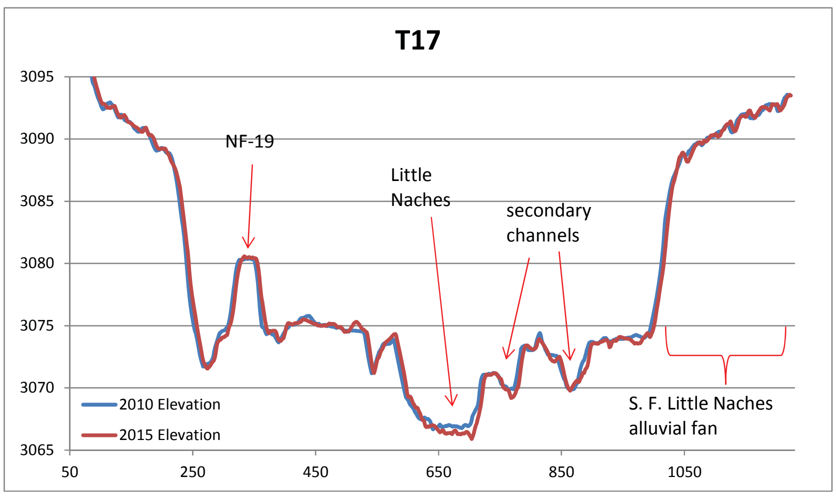


Figure 7E. Transect 1011, shows the Little Naches River channel, in its wider floodplain, attacking the toe of the S.F. Little Naches fan.

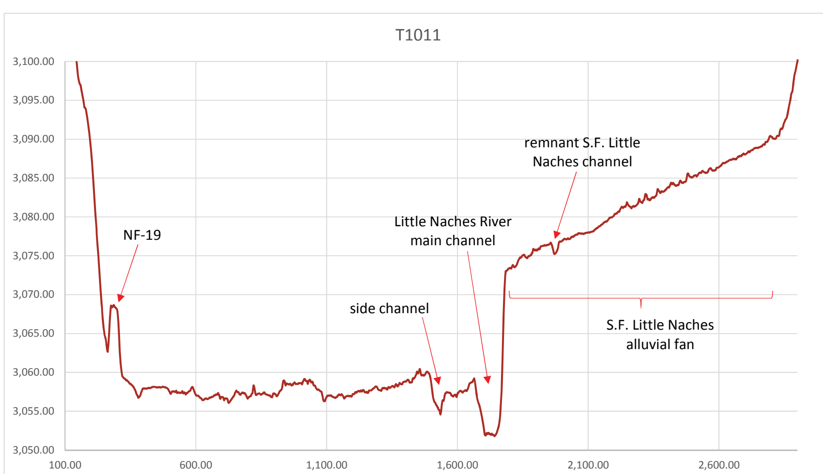
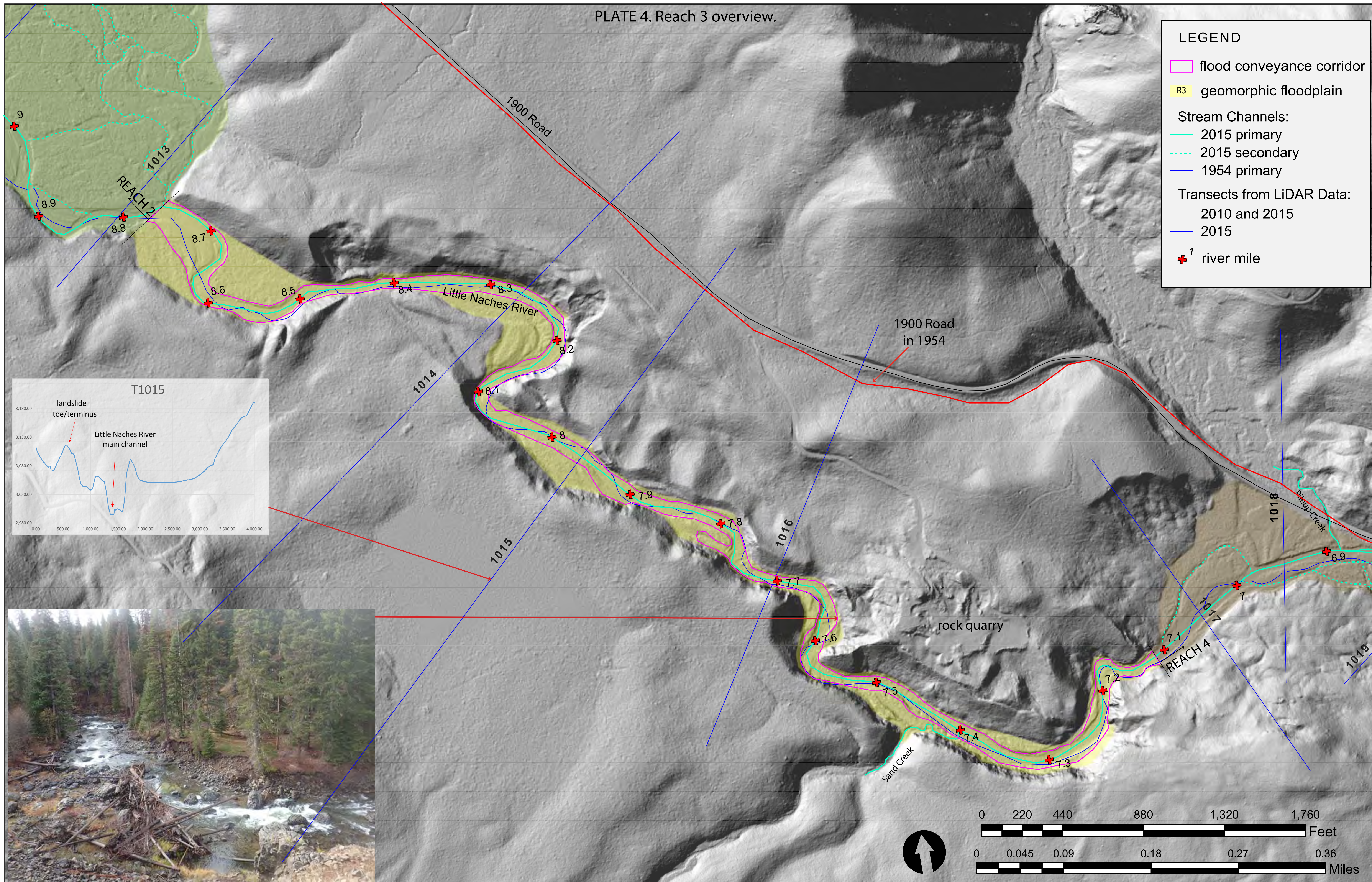


PLATE 4. Reach 3 overview.



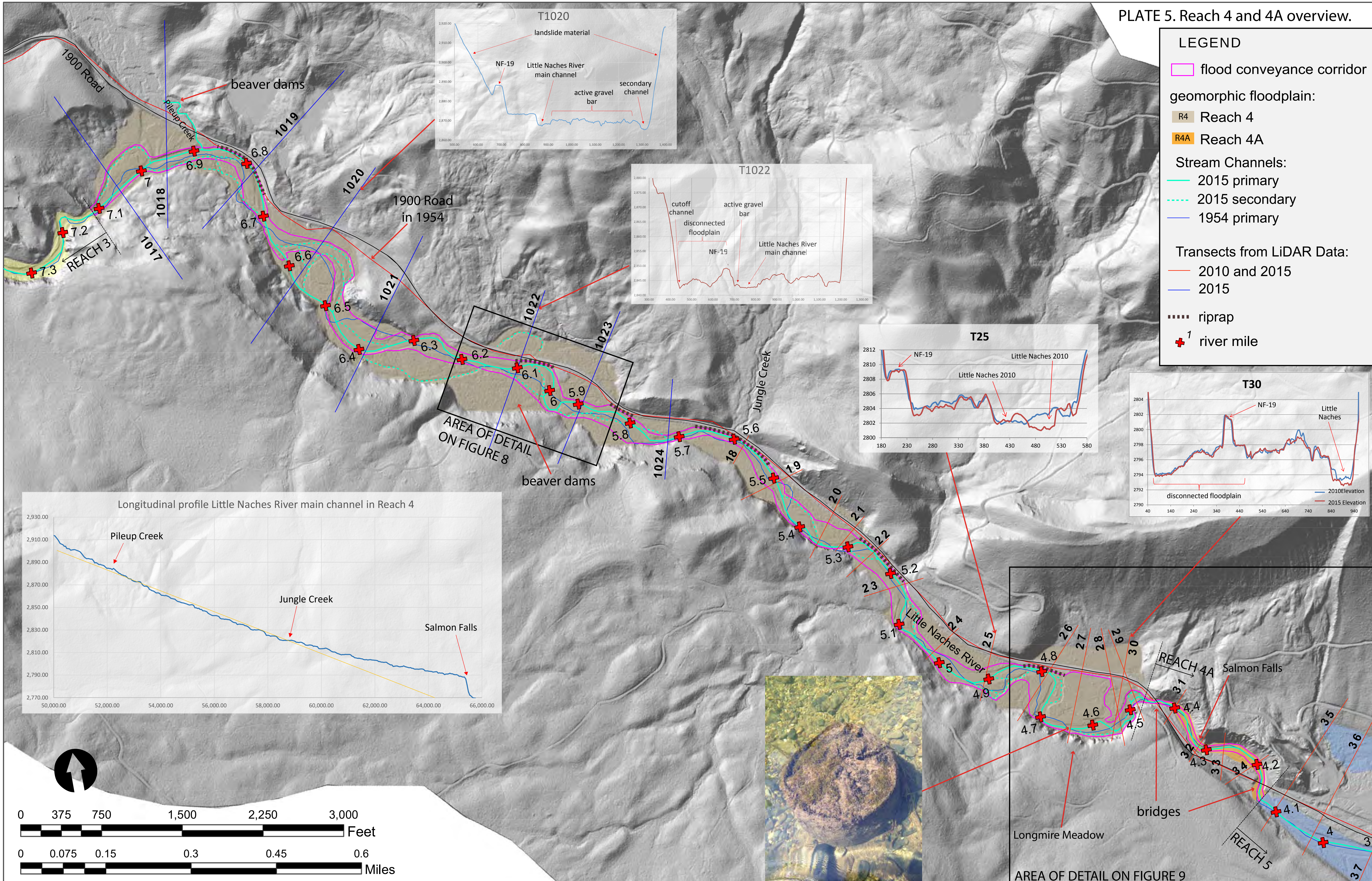


PLATE 5. Reach 4 and 4A overview.
LEGEND
flood conveyance corridor
geomorphic floodplain:
R4 Reach 4
R4A Reach 4A
Stream Channels:
2015 primary
2015 secondary
1954 primary
Transects from LiDAR Data:
2010 and 2015
2015
riprap
river mile
1900 Road
beaver dams
Pileup Creek
1900 Road in 1954
REACH 3
Jungle Creek
AREA OF DETAIL ON FIGURE 8
beaver dams
T1020
landslide material
NF-19
Little Naches River main channel
active gravel bar
secondary channel
T1022
cutoff channel
disconnected floodplain
active gravel bar
NF-19
Little Naches River main channel
T25
NF-19
Little Naches 2010
Little Naches 2010
T30
NF-19
Little Naches
disconnected floodplain
2010Elevation
2015 Elevation
Longitudinal profile Little Naches River main channel in Reach 4
Pileup Creek
Jungle Creek
Salmon Falls
Little Naches River
REACH 4A
Salmon Falls
Longmire Meadow
bridges
REACH 5
AREA OF DETAIL ON FIGURE 9
0 375 750 1,500 2,250 3,000 Feet
0 0.075 0.15 0.3 0.45 0.6 Miles

Figure 8A. Map of meander, cut off by the construction of the 1900 Road, on the mainstem of the Little Naches River. This is also the location of chronic threat to the road, requiring repeated shoulder repairs.

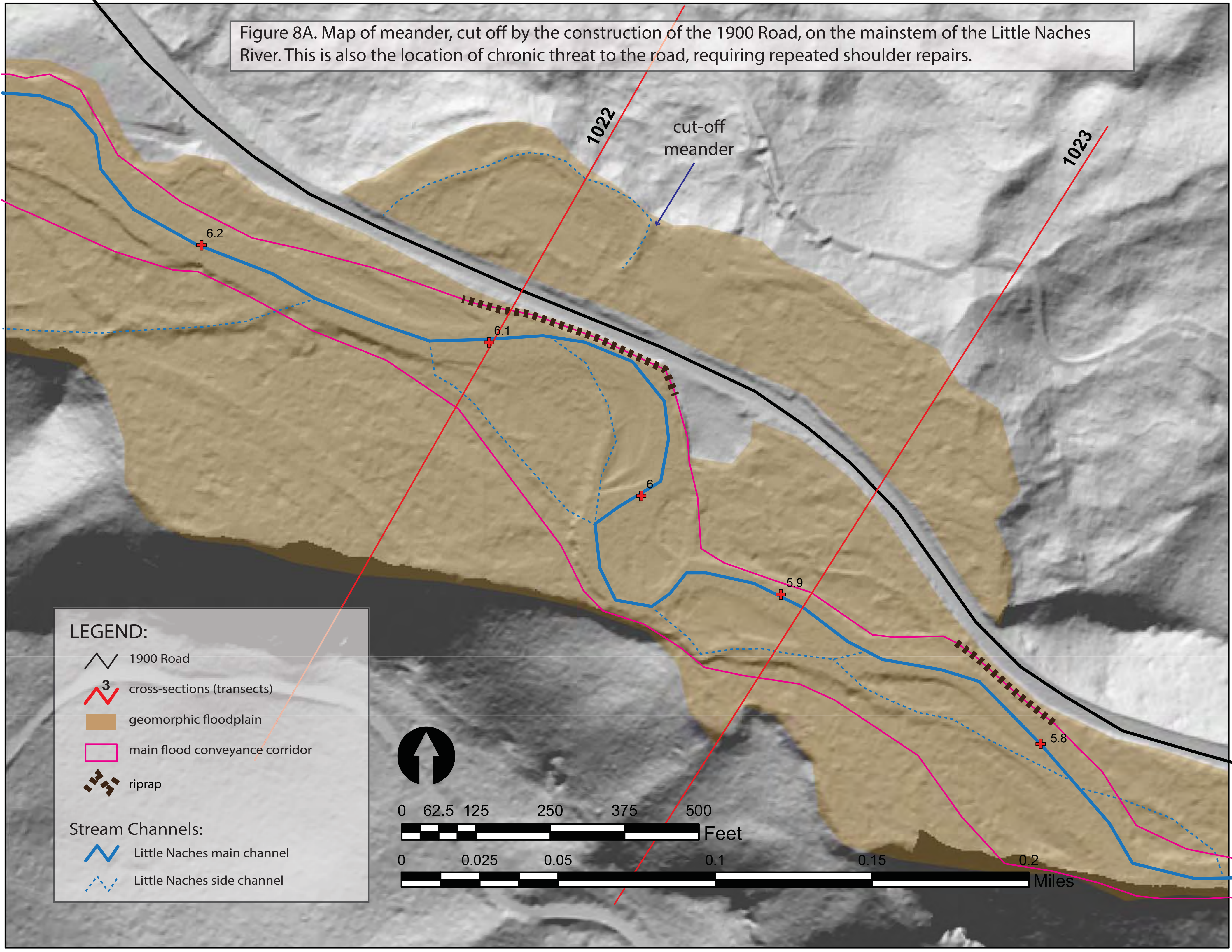


Figure 8B. Map of meander, cut off area, on the mainstem of the Little Naches River, overlying 9/1/1954 aerial imagery, and channel alignment. The 1900 Road alignment, and other markers are shown for reference.

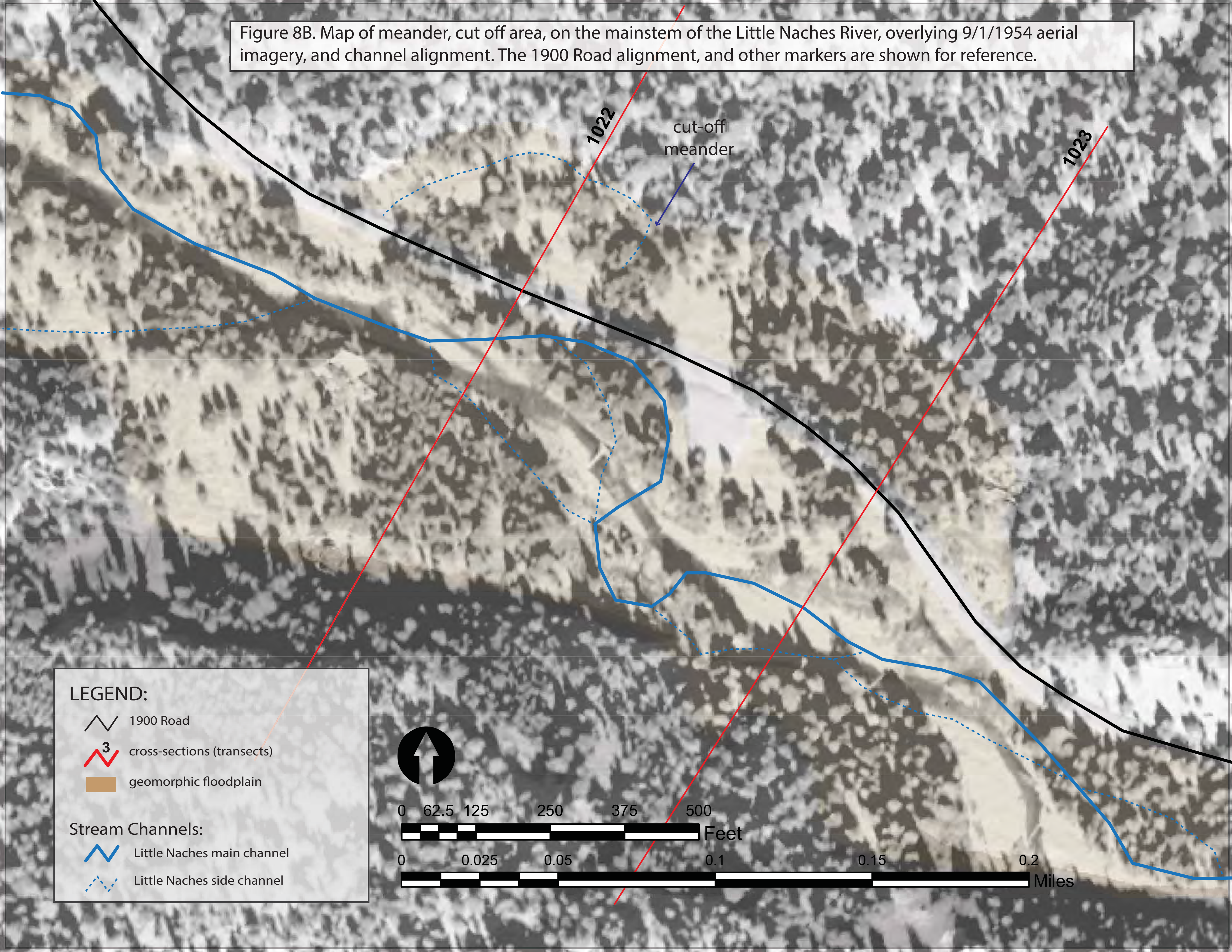


Figure 8C. Transect 1022, shows the meander cut-off by the construction of the 1900 Road.

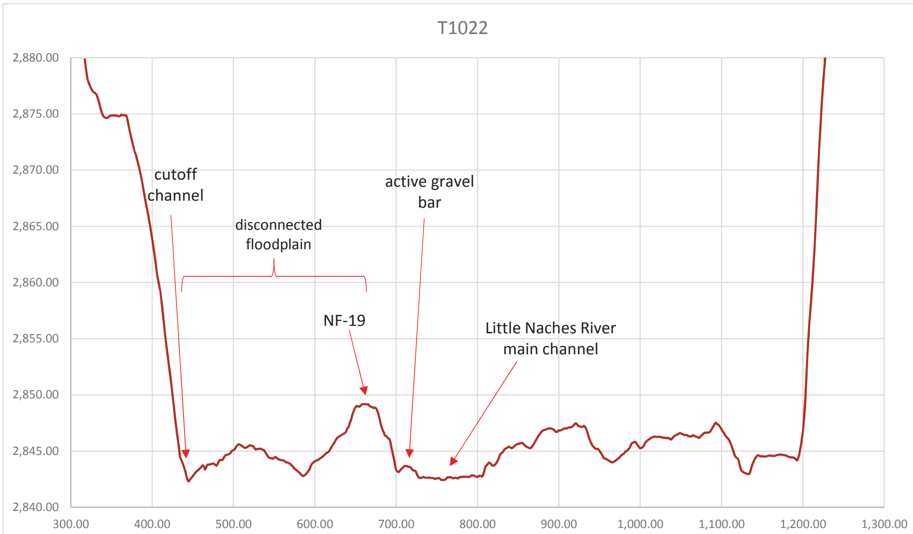
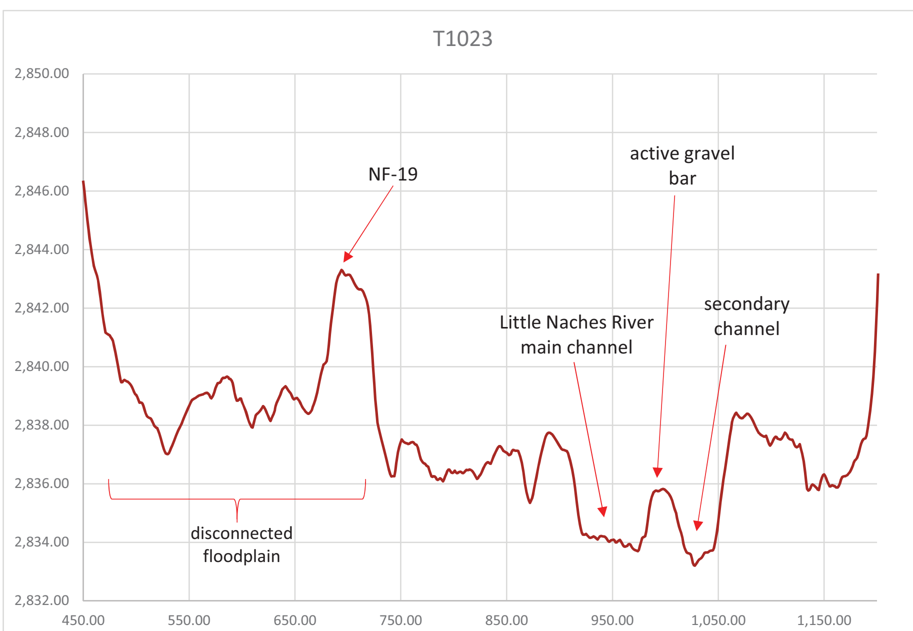


Figure 8D. Transect 1023, shows the disconnected floodplain of the Little Naches River north of the 1900 Road prizm.



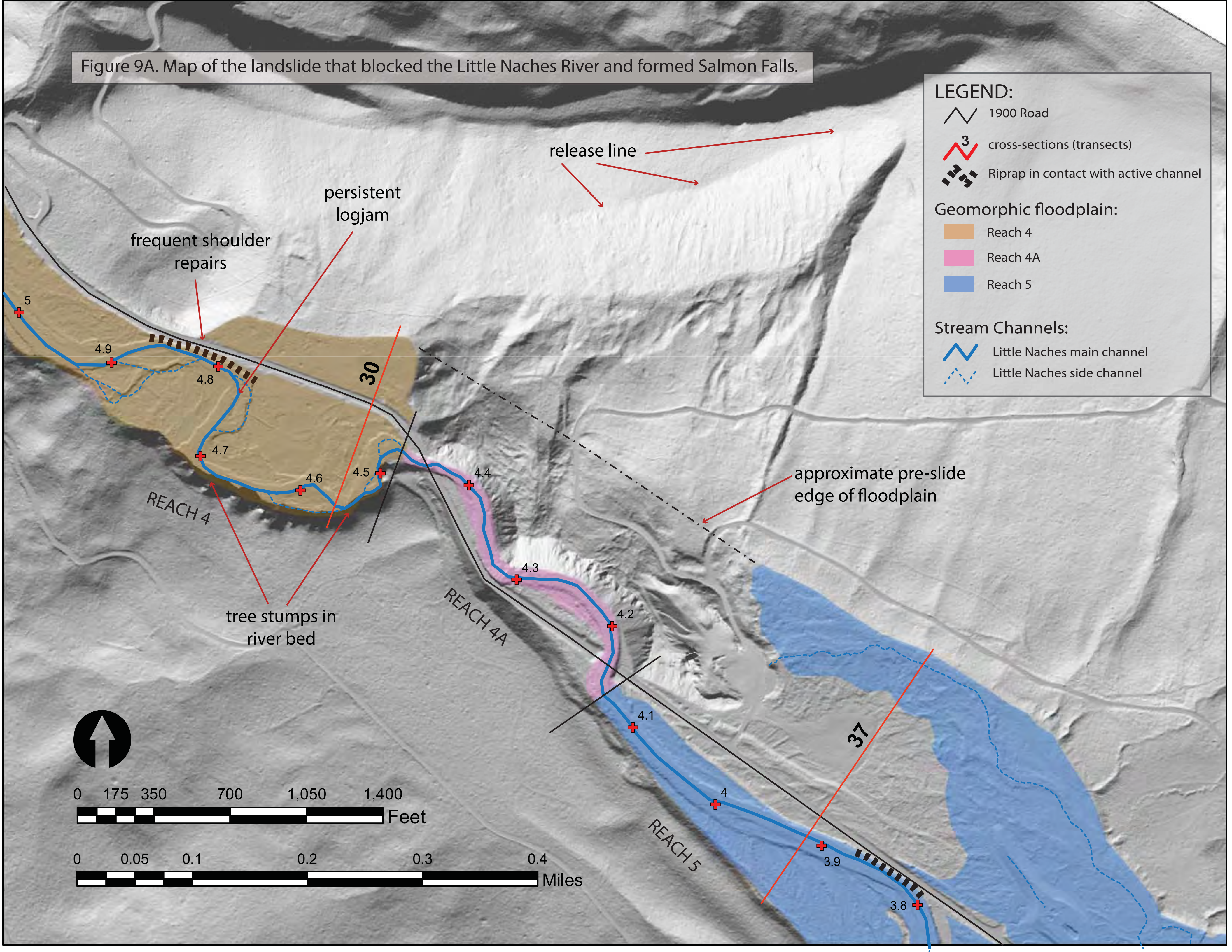


Figure 9A. Map of the landslide that blocked the Little Naches River and formed Salmon Falls.

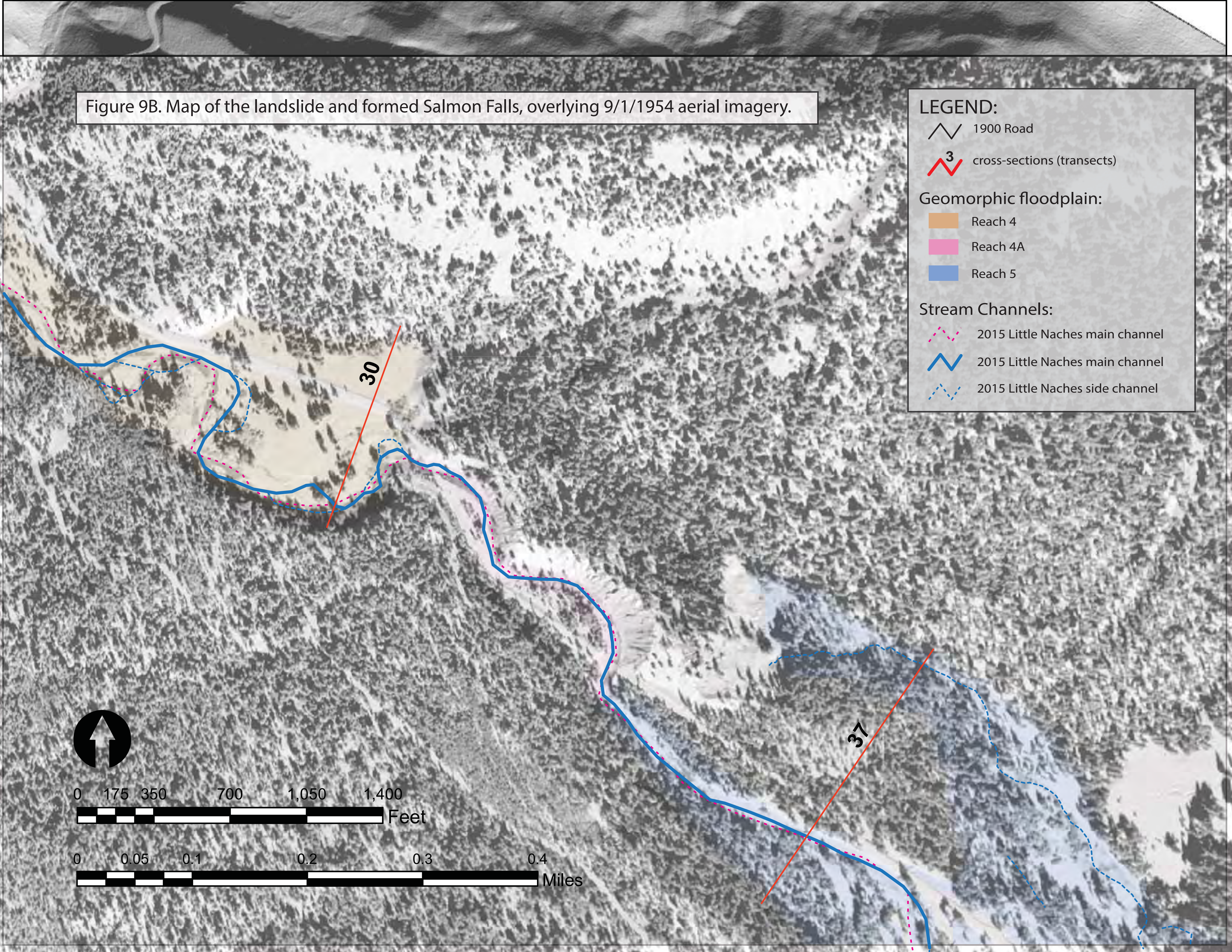


Figure 9B. Map of the landslide and formed Salmon Falls, overlying 9/1/1954 aerial imagery.
LEGEND:
1900 Road
3
cross-sections (transects)
Geomorphic floodplain:
Reach 4
Reach 4A
Reach 5
Stream Channels:
2015 Little Naches main channel
2015 Little Naches main channel
2015 Little Naches side channel
30
37
0 175 350 700 1,050 1,400
Feet
0 0.05 0.1 0.2 0.3 0.4
Miles

Figure 9C. Transect 30 in Longmire Meadow, shows the disconnected floodplain north of the 1900 Road.

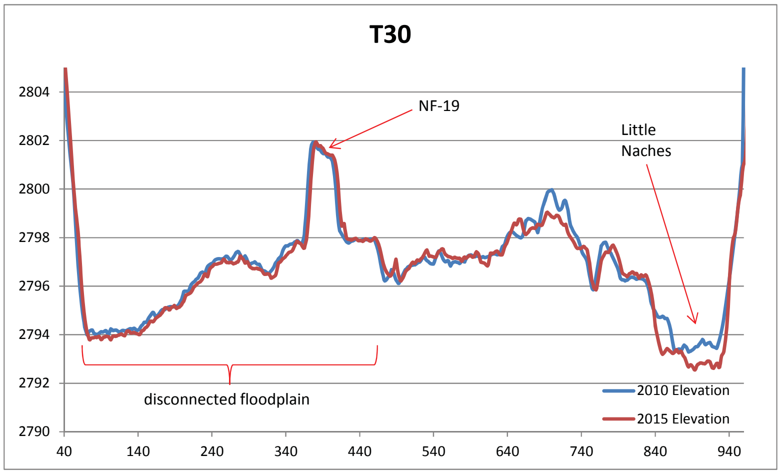


Figure 9D. Transect 37 below the slide that formed Salmon Falls. Note that the north side of the disconnected floodplain is topographically lower than the main channel of the Little Naches River, and probably housed the channel prior to slide release.

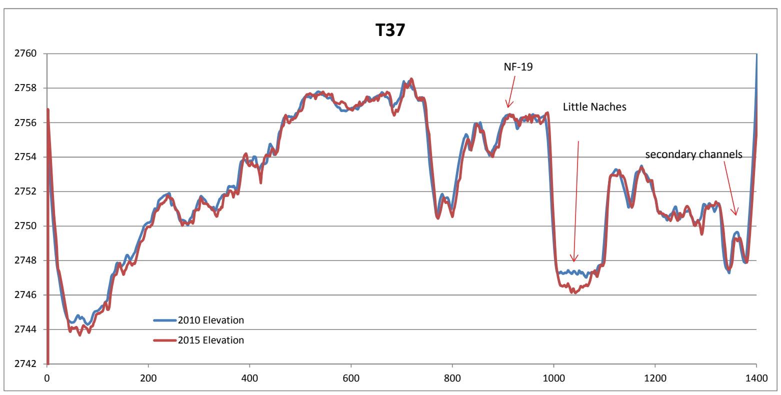
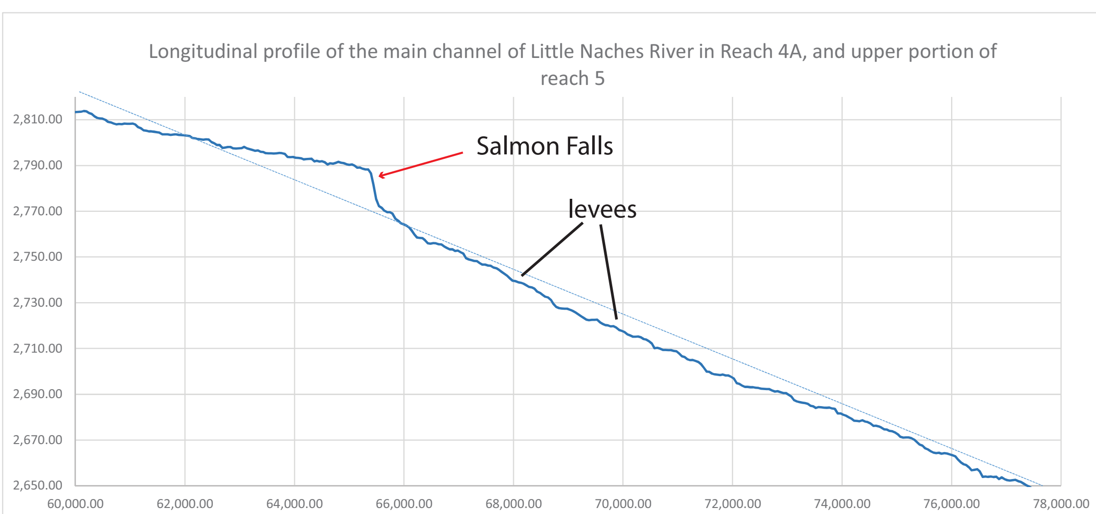


Figure 9E. Longitudinal water surface profile of the Little Naches main channel through Salmon Falls. Location of levees are also shown.



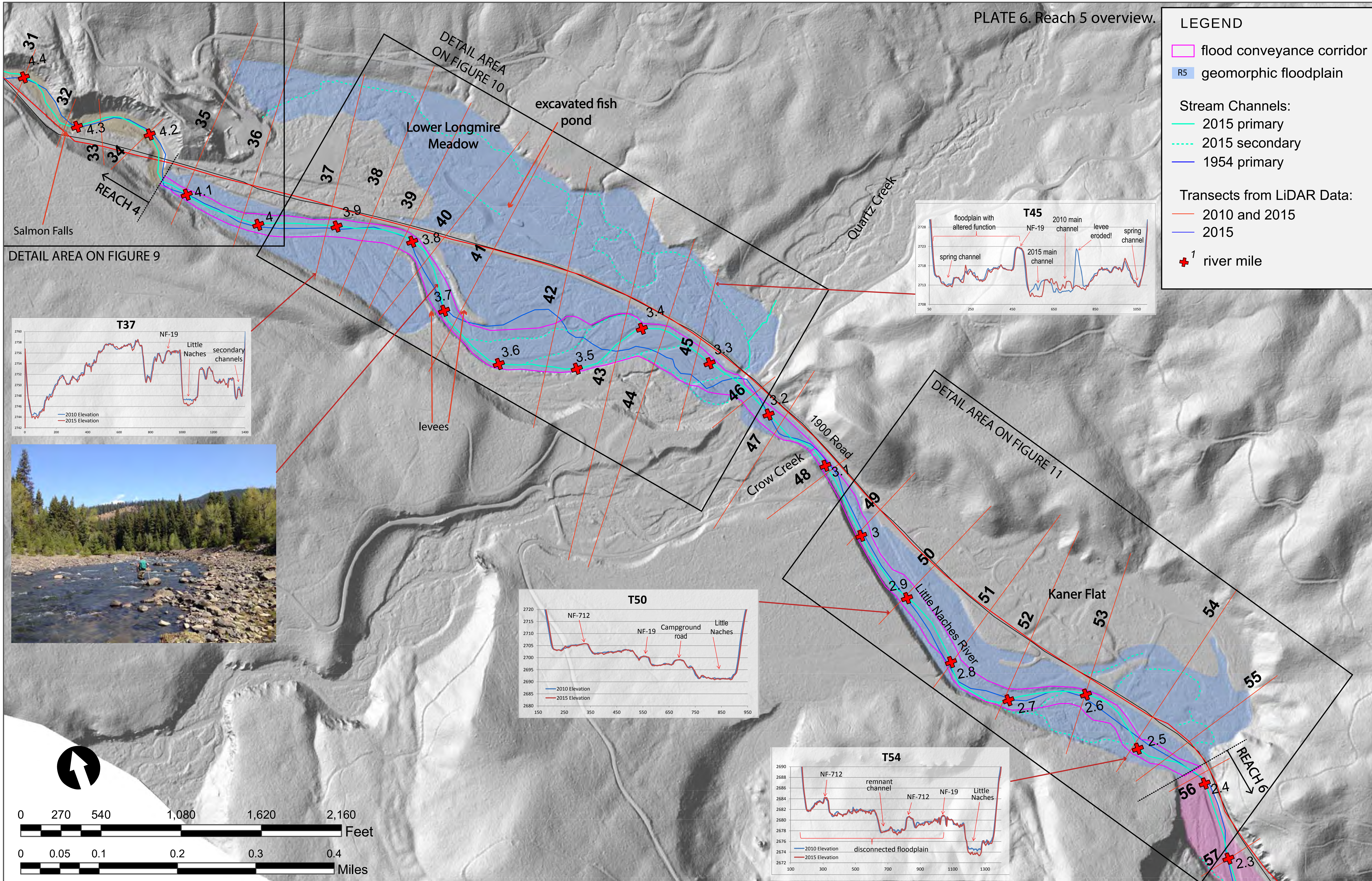
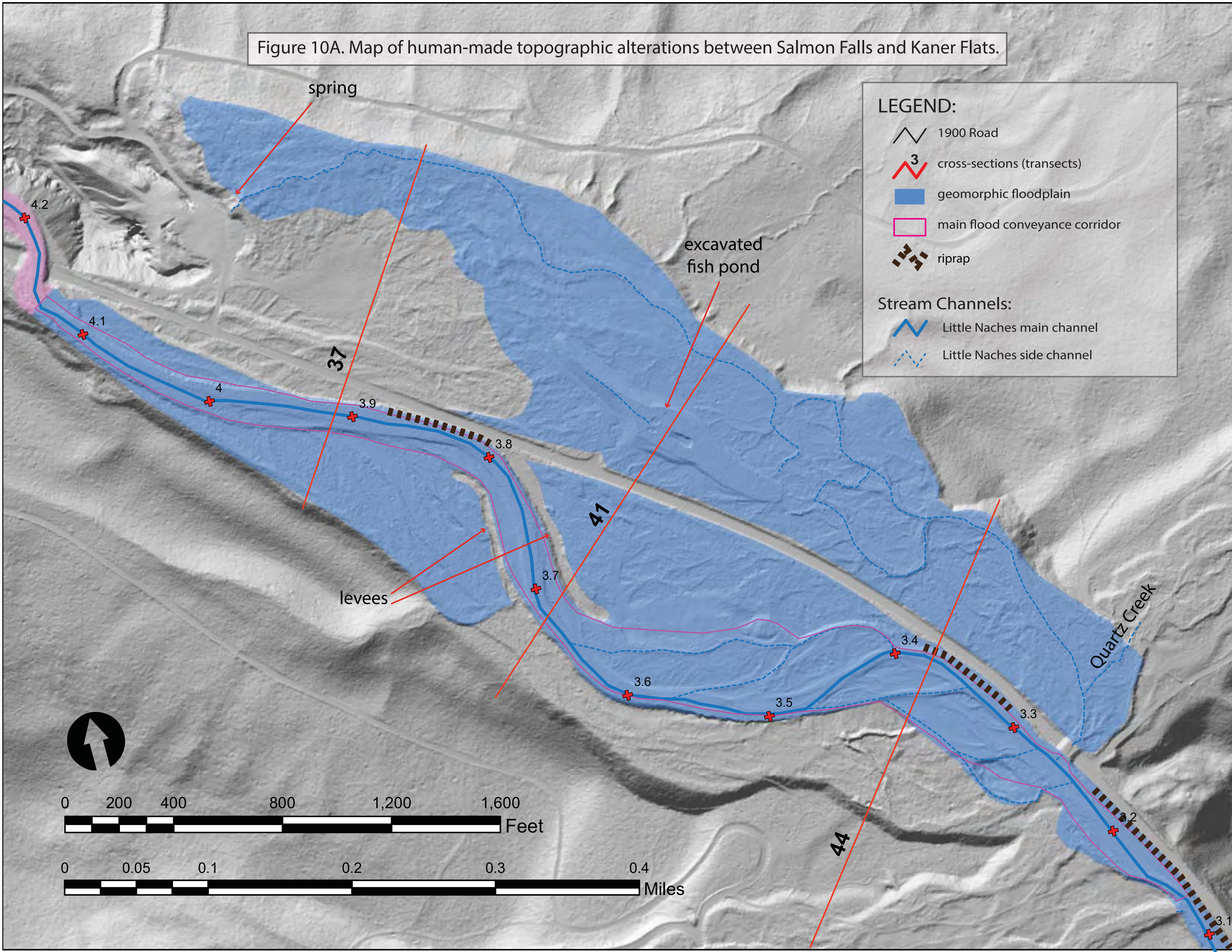


PLATE 6. Reach 5 overview.

Figure 10A. Map of human-made topographic alterations between Salmon Falls and Kaner Flats.



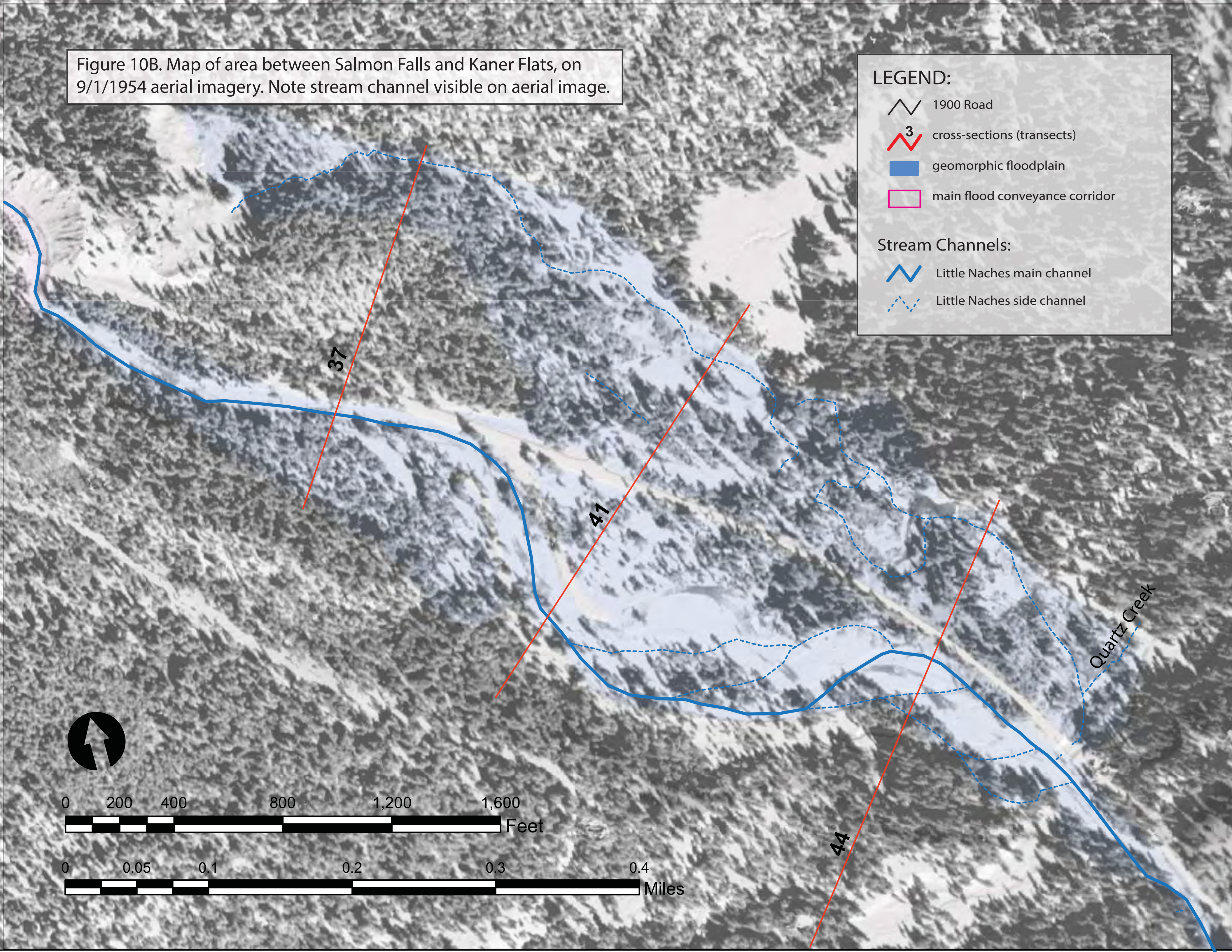


Figure 10B. Map of area between Salmon Falls and Kaner Flats, on 9/1/1954 aerial imagery. Note stream channel visible on aerial image.
LEGEND:
1900 Road
3
cross-sections (transects)
geomorphic floodplain
main flood conveyance corridor
Stream Channels:
Little Naches main channel
Little Naches side channel
37
41
44
Quartz Creek
0
200
400
800
1,200
1,600
Feet
0
0.05
0.1
0.2
0.3
0.4
Miles

Figure 10C. Transect 41, shows the disconnected floodplain by the 1900 Road, and the excavated borrow pit, now used as a fish pond, as well as the levees.

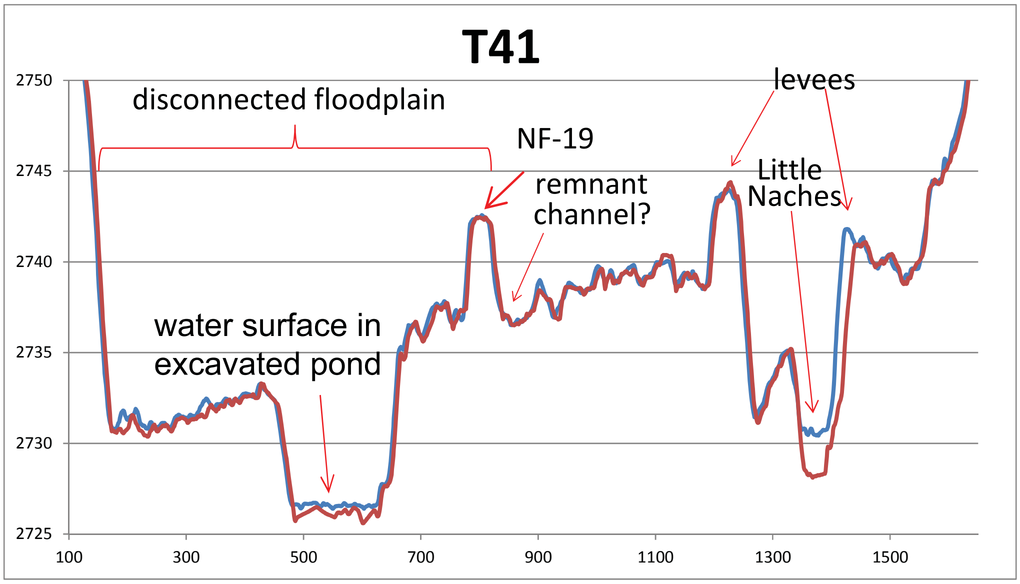
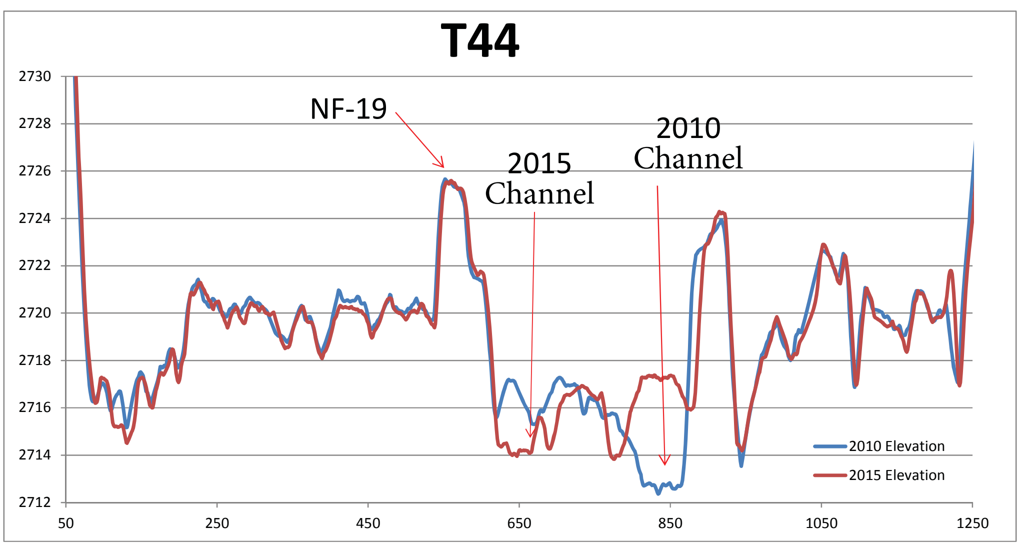


Figure 10D. Transect 44, shows the disconnected floodplain of the Little Naches River north of the 1900 Road prizm, and the reworking of gravel bars between 2010 and 2015.



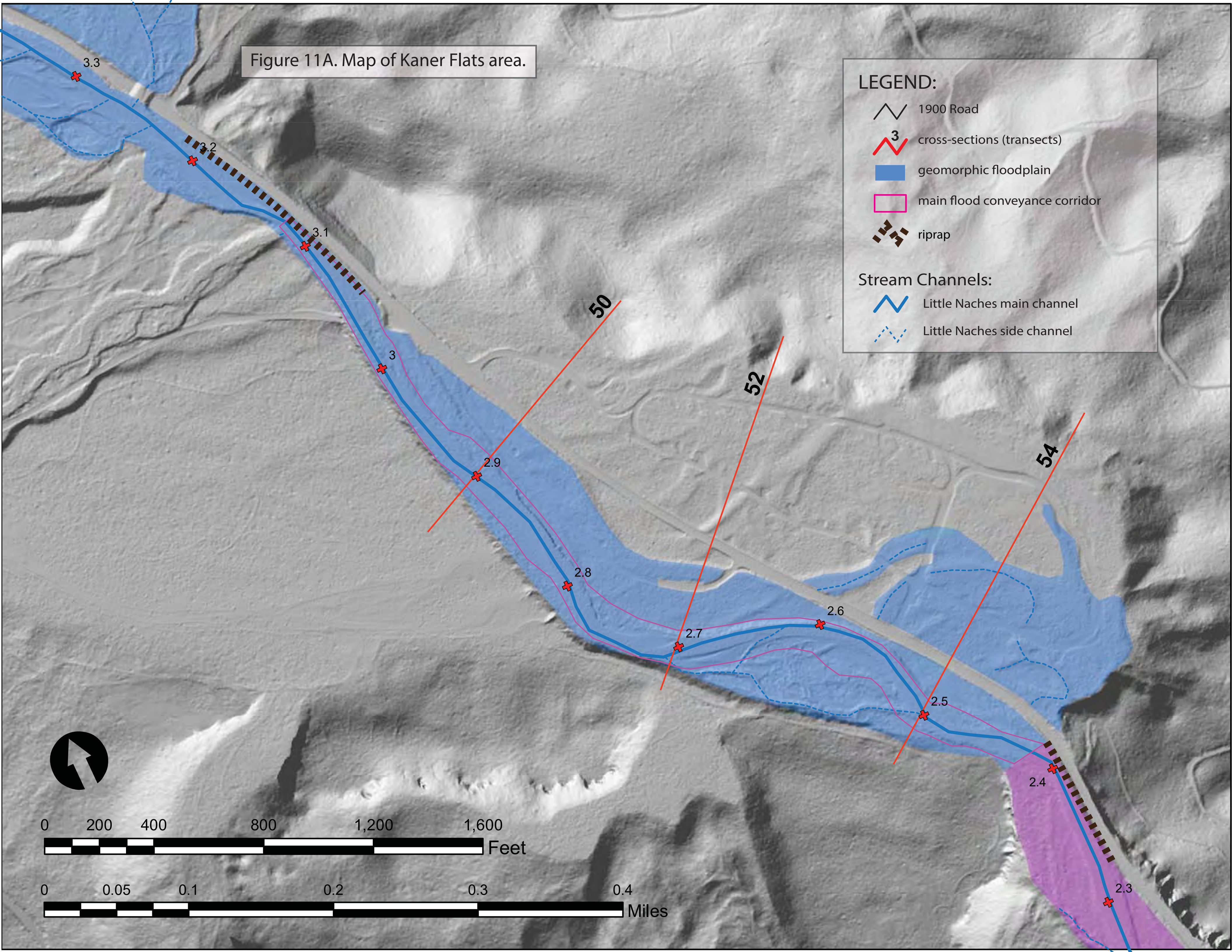


Figure 11A. Map of Kaner Flats area.
LEGEND:
1900 Road
3
cross-sections (transects)
geomorphic floodplain
main flood conveyance corridor
riprap
Stream Channels:
Little Naches main channel
Little Naches side channel
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
50
52
54
0
200
400
800
1,200
1,600
Feet
0
0.05
0.1
0.2
0.3
0.4
Miles

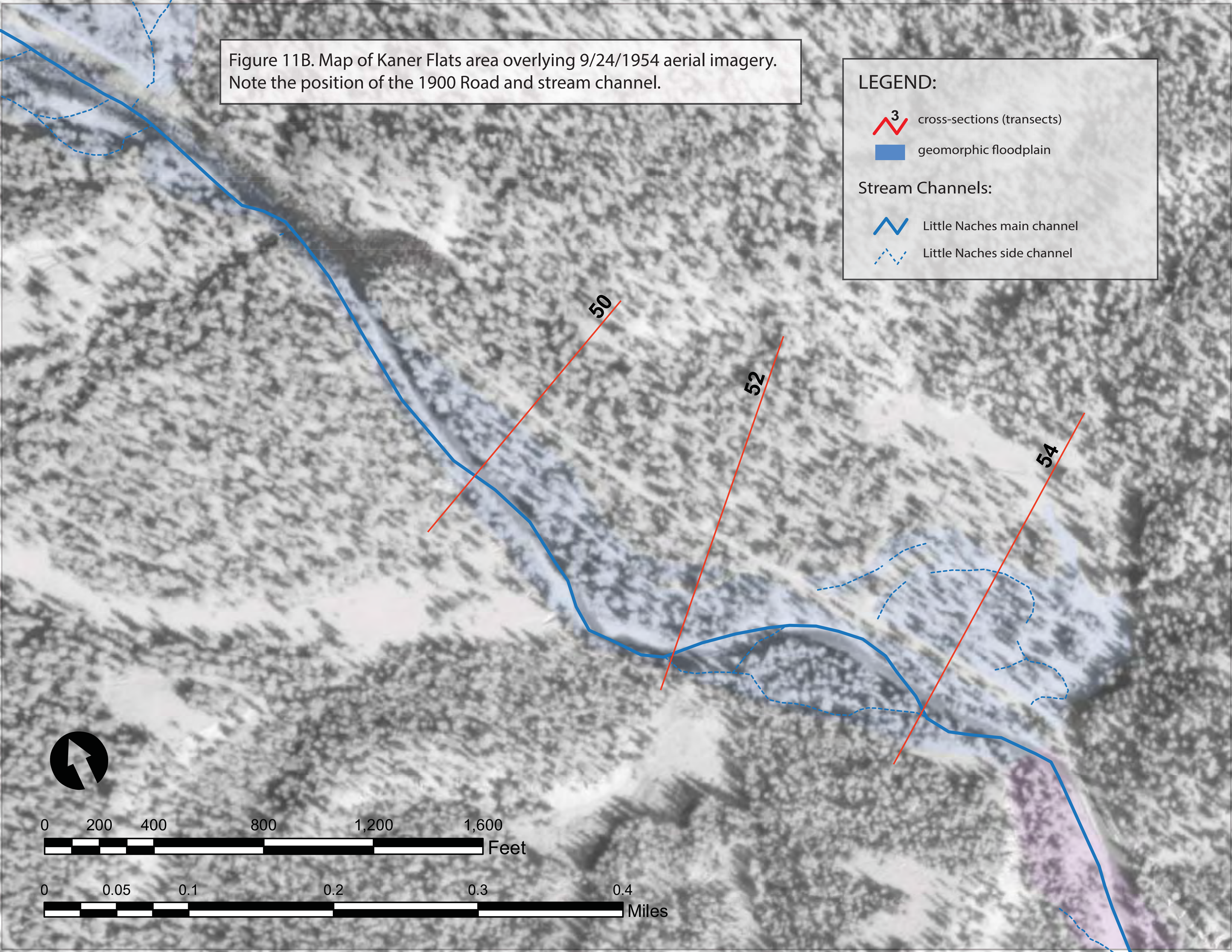


Figure 11B. Map of Kaner Flats area overlying 9/24/1954 aerial imagery.
Note the position of the 1900 Road and stream channel.
LEGEND:
3
cross-sections (transects)
geomorphic floodplain
Stream Channels:
Little Naches main channel
Little Naches side channel
50
52
54
0
200
400
800
1,200
1,600
Feet
0
0.05
0.1
0.2
0.3
0.4
Miles

PLATE 7. Reach 6 overview.

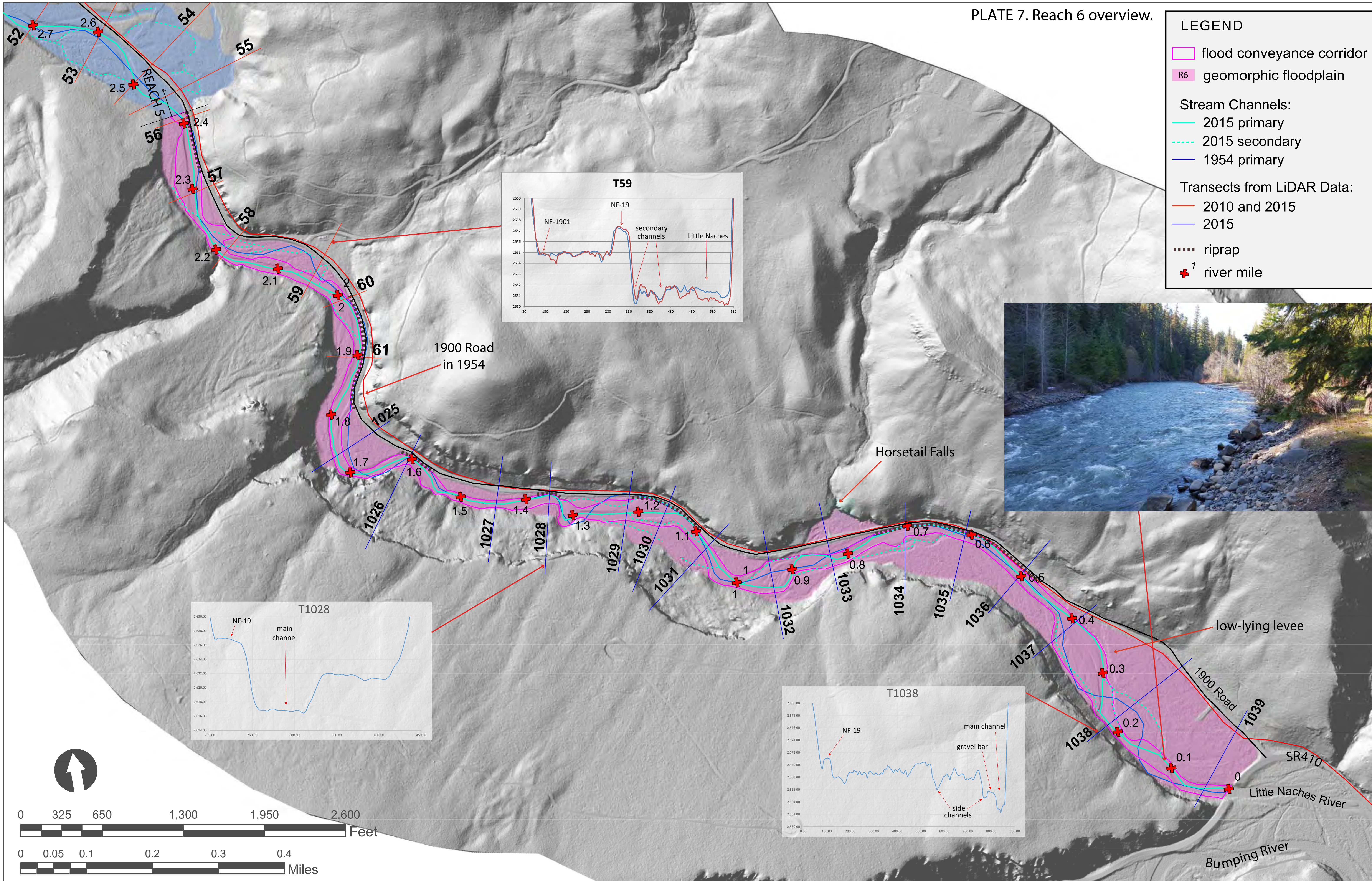


Table 2A. Channel characteristics, by reach, of the mainstem Little Naches River in the study area. Reaches include the lowest reaches of the Middle Fork, and North Fork Little Naches Rivers.

Reach	Main Channel Length (ft)	main channel sinuosity	main channel mean slope (%)	secondary channel length (ft)	disconnected secondary channel length (ft)	tributary channel length (ft)
1A	12518	1.38	0.84	10309	0	8426
1B	5570	1.15	2.27	5737	0	0
1	5538	1.13	0.92	11254	0	952
2	24578	1.38	0.63	64137	0	8278
3	8684	1.47	1.49	0	0	474
4	14005	1.15	0.78	13518	608	149
4A	1713	1.19	1.96	0	0	0
5	9044	1.13	0.98	6570	1660	6432
6	12793	1.28	0.89	9727	0	0

Table 2B. Floodplain characteristics, by reach, of the mainstem Little Naches River in the study area.

Reach	Floodplain Area conn. (acres)	Floodplain Area disconn. (acres)	Main Channel Length (mi)	Mean Floodplain Width Conn. (ft)	Mean Natural Floodplain Width (ft)	Width Reduced (%)	Mean Slope (%)
1A	145.3	0.0	2.4	662	662	0	1.16
1B	39.8	0.0	1.1	354	354	0	2.61
1	89.5	0.0	1.0	746	746	0.0	1.04
2	461.5	1.4	4.7	1,071	1,075	0.3	0.87
3	32.6	0.0	1.6	183	183	0.0	2.19
4	100.8	10.8	2.7	364	403	9.7	1.18
4A	3.5	0.0	0.3	92	92	0.0	2.29
5	64.7	52.6	1.7	339	614	44.9	1.11
6	84.1	1.5	2.4	317	323	1.7	1.15

Table 3. Summary of impairments by reach, and location where applicable. Also included are ***preliminary*** cost/benefit valuations, priority levels, and recommendations.

ID	impairment	Reach	River Mile	recommendation	action cost/benefit	no action cost/benefit	PRIORITY	next steps?
1a	1913 crossing prevents natural channel evolution	1,1A	14.45, 0	none	negligible	negligible	VERY LOW	
2a	undersized Fawn Creek culvert (passage barrier and road risk)	2	~12.7	enlarge, replace w/ bridge	passage enabled, road risk minimized	no fish passage, repeated road repairs	HIGH	
2b	Erosion of 1900 Road btwn Fawn Creek culvert and LN bridge	2	12.5	relocate road, or protect it	road protection	repeated road repairs	MED-HIGH	
2c	Secondary channel disconnected by 1900 Road	2	12.3	relocate road or install culvert/bridge	natural process restored	no natural process, road repairs	LOW	
2d	Bear Creek secondary channel disconnected	2	11.5	relocate road or install culvert/bridge	natural process restored	no natural process	LOW	
2e	crossings at SF Little Naches halt natural channel evolution	2	9.9, 10.4	relocate road or install culvert/bridge	natural process restored	no natural process, road repairs	MED-LOW	
2f	SF Little Naches chronic instability	2	10.5	relocate road or install culvert/bridge	expense, displaced public users	road repairs, fish passage issues	LOW	
2g	Secondary channel disconnected by 1900 Road	2	10.3-10.7	relocate road or install culvert/bridge	natural process restored	no natural process, road repairs	MED-LOW	
2h	Matthews Creek secondary channel disconnected	2	9.9	relocate road or install culvert/bridge	natural process restored	no natural process	LOW	
2i	lacks LWD	2	8.8-9.5	place simple LWD to expedite natural accumulation	difficult access	minimal risk, naturally occurring	MED-HIGH	
2j	lacks willows	2	8.8-9.5	plant	beaver food	minimal risk, naturally occurring	MED-HIGH	
2k	limited beaver activity in high potential area	2	8.8-9.5	relocate/release/minimize harrassment	little human traffic	minimal risk, naturally occurring	MED	
4a	Pileup Creek secondary channel disconnected	4	7	relocate road or install culvert/bridge	negligible	negligible	LOW	
4b	riprap shoulders	4	multiple	small LWD structures, plant willows	improved habitat	Little or no instream cover	MED-HIGH	
4c	artifical meander cuttoff by 1900 Road	4	6.1	relocate road or install culvert/bridge (X2)	improve habitat and process	chronic road instability	MED-LOW	
4d	campground management	4	multiple	limit camping, improve management	improve shrub recruitment	potential for fish harassment remains	MED-LOW	
5a	Channel bulldozed and LWD removed	5	3.7-4.0	Large in-channel LWD structures after levee removal	encourage aggradation		HIGH	
5b	Levees constrain channel	5	3.7	remove levees	chronic instability above Quartz Creek	drastically damaged rearing habitat	HIGH	
5c	Pond lowers local water table	5	3.7	fill in, or build causeways to preserve fishing	chronically lowered water table	drastically damaged rearing habitat	HIGH	
5d	north of 1900 road disturbed, devegetated, no beaver	5	3.3-4.0	beaver, campsite removal, access management…	risk to campers, habitat improved	chronic habitat degradation	MED-HIGH	
5e	1900 Road disrupts floodplain and channel migration	5	3.2-4.1	Relocate or modify road	improved natural process	no natural process	MED-LOW	
5f	Unstable channel below levees and above Quartz Creek	5	3.3-3.7	floodplain-wide LWD structures	improved process: bars and vegetation	chronic channel instability	MED-HIGH	
5g	riprap shoulder	5	3.3, 3.8	small LWD structures, plant willows	improved habitat	Little or no instream cover	MED-HIGH	
5h	1900 Rd constrains floodplain in lower Kaner Flat	5	2.4-2.7	Relocate or modify road	improve habitat and process	no natural process	LOW	
6a	deep pools filled in during 1900 Road construction	6	multiple	relocate road, install LWD, plant willows	improved habitat	chronic habitat degradation	MED-HIGH	
6b	lacks LWD	6	0-2.4	install LWD in riprap	improved habitat	chronic habitat degradation	MED-HIGH	
6c	riprap shoulder	6	multiple	small LWD structures, plant willows	improved habitat	chronic habitat degradation	MED-HIGH	
6d	Floodplain cutoff	6	2.1	Relocate or modify road	improved habitat	negligible	VERY LOW	
6e	Horsetail Falls 1900 Rd floodplain cuttoff	6	0.8	Relocate or modify road	improved habitat	negligible	VERY LOW	

Appendix B

Data Sources Used in this Assessment

The following data were used in the analyses of this report:

Hydrologic data:

- Instantaneous stream discharge data, at 15-minute intervals
- Mean Daily Discharge data

Stream discharge data—obtained online through the U.S. Bureau of Reclamation portal: https://www.usbr.gov/pn/hydromet/yakima/yaktea.html

RS/GIS data used:

- 5/13/2010 LiDAR for the Raven Roost and Mt. Clifty reaches (raster [bare earth], and vector [raw data])

- 5/14/2015 LiDAR for the entire floodplain of the Little Naches River mainstem, as well as most downstream reaches of North Fork, and Middle Fork Little Naches Rivers (raster [bear earth], and vector [raw data])

- Aerial imagery from 1949, 1954, and 2015 (raster) – contiguous coverage from confluence with the Bumping River to within 0.3 mile of confluence of North Fork and Middle Fork Little Naches Rivers

- Roads data provided by Okanogan-Wenatchee National Forest, Naches District staff (vector)

- USGS digital geologic maps 1:100,000 scale (vector) – downloaded from the Washington State Department of Natural Resources webpage: http://www.dnr.wa.gov/programs-and-services/geology/geologic-maps

2015 LiDAR data were the primary source used for topographic analysis in this report. These data were compared to the 2010 LiDAR data in the areas of overlap. This would not have been possible using the LiDAR data as provided, because although each dataset (of each date) was internally consistent, they did not overlay properly because they were not registered properly. Quantum Spatial was contacted in 2016 about this issue. They did not acknowledge or address the issue.

In order to make the comparison valid, we generated a sample of roughly 100 points selected at locations not subject to topographic change (primarily road prisms known to have remained intact in the interim between the two flights) distributed evenly throughout the area. We compared LiDAR-reported elevations for these reference points on each date to check for uniformity of difference, and to calculate an average difference. Removing this difference effectively registered both datasets into a common vertical datum, and allowed the generation of “change” maps. We used these change maps to spot check the accuracy of both data sets and validate other analyses.

New Data Generated in this Assessment

Several new datasets were created as part of this assessment. These include:

- 5/14/2015 LiDAR data ***adjusted*** to match 2010 data in the vertical direction (raster GIS [bare earth]).

- Topographic contours for the entire extent of the 2015 LiDAR dataset, at 10-foot interval (vector GIS).

- Mapped alignment of all stream channels visible within the mapped geomorphic floodplain, including secondary channels and tributary channels (vector GIS). These were mapped using 2015 LiDAR data and aerial imagery from various years, and were field verified.

- Mapped geomorphic floodplain of the Little Naches River, and lower portions of the North Fork and Middle Fork Little Naches Rivers (vector GIS). This was completed by examining the LiDAR data and cross sections extracted from the LiDAR data, and visiting sites for field verification.

- Georeferenced digital aerial imagery from 1949 and 1954 (raster GIS) for most of the study area. We were not able to obtain a full set of aerial imagery from both dates, but the combined set of imagery from both dates were used for analyses.

- Mapped alignment of primary stream channels as visible in georeferenced 1949 and 1954 aerial images (vector GIS).

- Mapped alignment of the 1900 Road as visible in georeferenced 1949 and 1954 aerial images (vector GIS). These data were used to assess the accuracy of georeferencing the historical aerial images, as well as assess historical land use.

- Mapped flood conveyance corridor, primarily from aerial imagery, with some help from LiDAR data and field verification (vector GIS). The conveyance corridor was mapped as the channel and surrounding areas without continuous forest canopy. This is the portion of the stream corridor that experiences the highest velocity flow and the majority of the bedload sediment transport. The remainder of the floodplain is under a contiguous tree canopy, is inundated during moderate to large flood events, and is the zone of deposition for fine sediment, as well as abundant buried LWD. This is very useful for providing a qualitative understanding of floodplain dynamics.

- River Miles points (vector GIS) based on the stream-wise distance from the SR-410 bridge over the Little Naches River (River Mile 0), upstream along the main channel of the Little Naches

River as they were in 2015. This dataset was used to describe locations in this report. Separate River Miles were generated for Reaches 1A (North Fork Little Naches) and 1B (Middle Fork Little Naches) beginning with RM-0 where each fork meets the mainstem Little Naches. River Mile data were not updated after the Summer 2016 avulsion of the Little Naches River into the Fawn Creek channel.

- Transects taken throughout the study area (vector GIS) – these transects were used to interpret topographic data and were a critical part of mapping the geomorphic floodplain and depicting man-made topography. Many of these transects are perpendicular to the flow direction of the Naches River.

- Excel spreadsheets of all transects generated from GIS – all of these transects were used to evaluate the stream and its floodplain in cross-section. Not all transects are shown in this report, but all were used in various analyses.

- Longitudinal profile of water surface for the entire project area in Excel spreadsheet format – generated from stream-wise distance between points along the main channel line, and the LiDAR-derived elevations of these points. This is not a "true" water surface profile, but is a slightly less accurate proxy, very useful for a study of this scale and scope.

- Areas of Riprap along the road shoulder (vector GIS), initially digitized using 2015 aerial imagery, and checked in the field. These data represent the most persistent interaction between stream channels and roads, as well as the most vulnerable sections of road.

- Location of known significant locations pertinent to this study (vector GIS). These include historical accounts of known human-induced alterations with brief notes.

- Basic physical descriptors of the stream channels and floodplain, generated from analyses of all data. These include channel lengths, sinuosity, slope, floodplain area, width, slope. Portions of channels and floodplain affected by the 1900 Road, as well as other human activity are identified and summarized in this report.