Technical Memorandum

To: **Skagit Watershed Council**
Richard Brocksmith, Executive Director

From: **Natural Systems Design, Inc**.
Shawn Higgins, Tim Abbe, PhD, PEG, PHG, Jen O'Neal, Colin Riordan, and Danny Stratten

Date: November 22, 2022

Subject: Geomorphic Mapping and Channel Migration Evaluation for the Sauk River Habitat Plan

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INTRODUCTION

This memorandum presents a characterization of floodplain topography and channel migration processes in the Sauk River. The scope of work completed as part of this task includes:

- Development of a Relative Elevation Model (REM) from existing lidar data;
- Calculation of channel migration rates;
- Evaluation of trends in channel width and area; and
- Summary of historical channel migration patterns.

The study area extends downstream to the Sauk River delta at the confluence with the Skagit River and upstream to the tributary junction with Clear Creek near River Mile (RM) 25 and approximately 3 miles south of Darrington (Figure 1). Results derived from this assessment will support future planning efforts to identify protection and restoration actions as part of the Sauk River Habitat Plan currently in development by the Skagit Watershed Council.

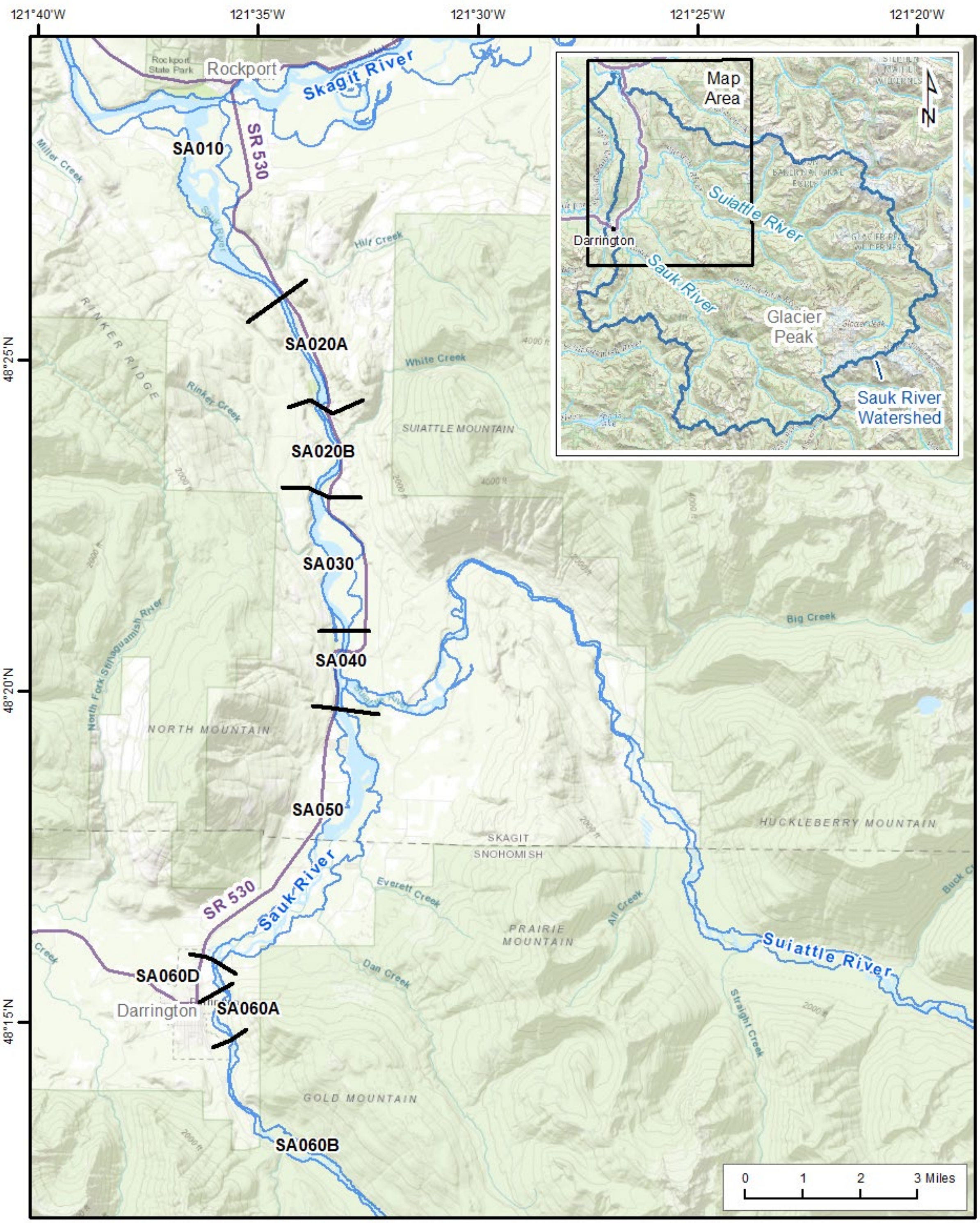


Figure 1. Reference map with geomorphic reaches.

DATA AND METHODS

Floodplain topography and geomorphic features of the Sauk River valley were evaluated based on interpretation of a Relative Elevation Map (REM) derived from a composite of two lidar data sources. The Glacier Peak 2015 lidar data cover the portion of the study area between RM 8 and the upstream boundary near RM 25. 2016 lidar were used to represent the lower reaches downstream of RM 8 to the Skagit River confluence (SA010 and SA020). Both sets of lidar data were hydroflattened bare earth models (not topobathymetric) and had a spatial resolution of 1 square meter.

Valley spanning transects were digitized in GIS and attributed with the elevation of the lidar data at the intersection between each transect and the channel centerline. The reference values in the channel are representative of the low flow water surface elevation corresponding to flow conditions at the time that lidar data were collected. The transects were then used to construct a reference plane representing the downstream trend in the channel slope. The REM was derived as the relative difference between the bare earth lidar data and the reference plane representing the water surface elevation in the adjacent channel.

Historical channel changes were assessed from a GIS database of historical aerial imagery and channel features previously digitized by Skagit River System Cooperative (SRSC). The channel features digitized by SRSC are classified into feature types including: main channel, side channel, gravel bar, vegetated bars and vegetated islands. The time series of aerial imagery and digitized channel features has minor differences for reaches upstream and downstream of the Suiattle River confluence. The Lower Sauk River (downstream of the Suiattle River) includes imagery from the years: 1944, 1956, 1972, 1981, 1992, 2006, and 2015. The Middle Sauk River (upstream of the Suiattle River) includes imagery from the years: 1949, 1964, 1974, 1981, 1992, 1998, 2006, and 2015.

NSD analyzed the historical channel data provided by SRSC to assess rate of lateral channel migration, changes in active channel width, and change in the total channel area. The channel type evaluation grouped wetted channel and unvegetated gravel bar areas for main channel and side channels and classified these areas as active main channel or active side channel. Total area of active main channel and active side channel were measured within the bounds of each reach for each data year.

Total channel width was evaluated on a cross sectional basis, sampling the total width of active channel (main or side channel) intersected by transects at 500-foot intervals. Cross sectional transects were derived using the Transect Generation Tool from the Department of Ecology's Channel Migration Toolbox. Transects were oriented along a generalized valley centerline, and sized to span the active channel for all available years. Channel width within each reach was evaluated by taking the average channel width measured on each transect with a given reach for each data year.

Channel migration rate was evaluated by comparing the active channel polygons between two data years for each time step. Areas defined as active channel in the latter data year, but not the earlier data year, were considered erosional areas. The width of these erosional areas was evaluated using the same transect approach as the channel width analysis. The width of erosional area on each transect was divided by the number of intervening years in the time step to determine an estimated annual erosion rate at that location (Figure 2). Annual erosion rates were averaged across all transects in a given reach for each time step, and for the full time series.

Results of the channel migration analyses were summarized by channel reach using reach delineations from the Skagit Chinook Recovery Plan. Reach boundaries are shown in Figure 1 and overlaid with the REM map book (attached). Reaches SA020A and SA020B were combined into a single reach for summary of channel migration rates. Reach SA060 is subdivided into several subreaches in the Chinook Recovery Plan. Reach SA060D is a short, 0.5-mile-long segment in a confined reach at the Sauk Prairie Road Bridge in Darrington. Reach SA060A is another short segment (about 1 mile long) upstream of SA060D. Reach SA060B then continues upstream approximately 9 miles to the White Chuck River near RM 32. Given that over 70% of reach SA060B is upstream of the study boundary, data from reach SA060B were not used in calculation of channel migration rates, channel width, or channel area. Reaches SA060B and SA060D were combined to derive calculations for the segment upstream of Darrington.

Historical maps drafted by U.S. Geological Survey (USGS) in 1915 were georeferenced and overlaid with other GIS data to extend the time period of historic channel dynamics. Results derived from the geomorphic mapping and channel migration analysis were summarized by reach to describe the floodplain topography and landforms in relation to the channel migration history.

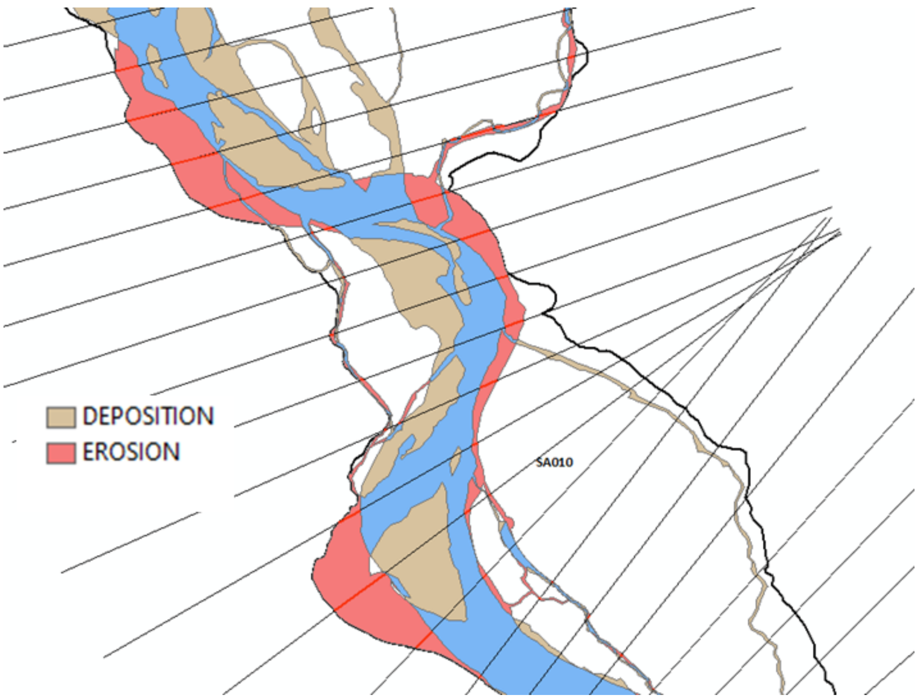


Figure 2. Example of GIS overlay used to identify areas of deposition and erosion between two sets of historical aerial images and transects used to measure channel migration rates between images

RESULTS

The Sauk River Relative Elevation Model (REM) developed as part of this assessment provides a tool for evaluation of floodplain topography and landforms. The REM is delivered as a 1:24,000 scale mapbook attached to this memorandum and as a digital file for use in future GIS applications. Examples of channel and floodplain features highlighted in the REM are shown below in Figure 3. The geomorphic floodplain of the Sauk River includes: (1) the active channel characterized by frequent scour and bedload transport during large floods; (2) vegetated floodplain surfaces that are periodically inundated by overbank flow during high flow and generally areas of fine sediment deposition; and (3) low terraces that represent older floodplain surfaces which have been disconnected from the channel by incision resulting in only infrequent inundation during periods of extreme flood. The active channel is a composite of the wetted, low flow channel, adjacent gravel bars, braid channels, side channels, and alcoves. Sloughs occupy abandoned channel features in the floodplain and are seasonally inundated features of the active channel. Swales are also abandoned channel features on the floodplain or terrace surfaces that are disconnected from the channel at low flow but are connected at large floods.

The geomorphic floodplain of the Sauk River is inset below a series of high terraces composed of lahar deposits that originated from eruptions at Glacier Peak and filled the valley with sediment between 12,000 and 1,800 years ago. Additional landforms that overlap with the geomorphic floodplain include alluvial fans that drape sediment over the floodplain where tributary channels emerge into the unconfined alluvial valley.

Channel migration processes interact with riparian vegetation and large wood jams to form distinctive channel patterns and are important to the creation and maintenance of side channel and off-channel habitats. Dynamic channel processes that have important controls on the type and distribution of floodplain landforms include: lateral meander migration and concurrent point bar expansion, channel avulsion, channel incision or aggradation, channel expansion/widening or narrowing.

Channel dynamics and channel migration history in the Sauk River were evaluated from the existing record of historical channels digitized by SRSC for use in describing the floodplain landforms in the 2015-2016 REM. Historic channel migration rates for the period 1944-2015 are summarized by reach in Table 1 and Table 2. The average rate of channel migration ranged between 4 and 41 feet/year and reveals a significant difference in channel migration between the confined (SA020, SA040, and SA060) and unconfined reaches (SA010, SA030, and SA050). Maximum rates of channel migration observed from the historical record are noted for the periods 1972-1981 and 1992-2006 and correspond to the two largest floods in the period of record (December 1980 and October 2003).

Measurements of active channel width reveal reach scale trends toward channel widening over the study period (Figure 4). The three unconfined channel reaches all expanded in width rapidly between the 1940s and subsequent imagery collected in the 1950s and 1960s. Channel width also increased rapidly in the period 1972-1981 (likely due to large flood in December 1980). Reach SA010 has since decreased in width from the maximum in 1981 to yield a net increase of 10% during the period 1944-2015. Reach SA030 continued to widen between 1981 and 1992 and then decreased slightly to yield a net 20% increase in channel width between 1944 and 2015. Reach SA050 was the most sensitive to changes in channel width showing a net 54% increase between 1949 and 2015 (Figure 4).

The database of historical channel features were further evaluated to quantify changes in the total amount of channel area and relative proportions of main channel and side channel areas. A general trend toward increasing amount of total channel area was noted in most reaches (Figure 5), with the magnitude of increase proportional to the changes in channel width noted above. The relative amounts of main channel and side channel areas with the reaches varied with time and by reach. Overall, the proportion of side channel habitat decreased 6% in reach SA010 and 11% in reach SA050 since the 1940s. The relative proportion of side channel area increased 8% in reach SA030 during the same period. Uncertainty associated with limitations identifying and mapping side channel habitat in historical imagery is likely comparable to the differences noted in the results.

Additional discussion continued below presents a summary of observations, organized by reach, relating the channel migration history to the distribution of floodplain topography and landform as shown in the Sauk River REM.

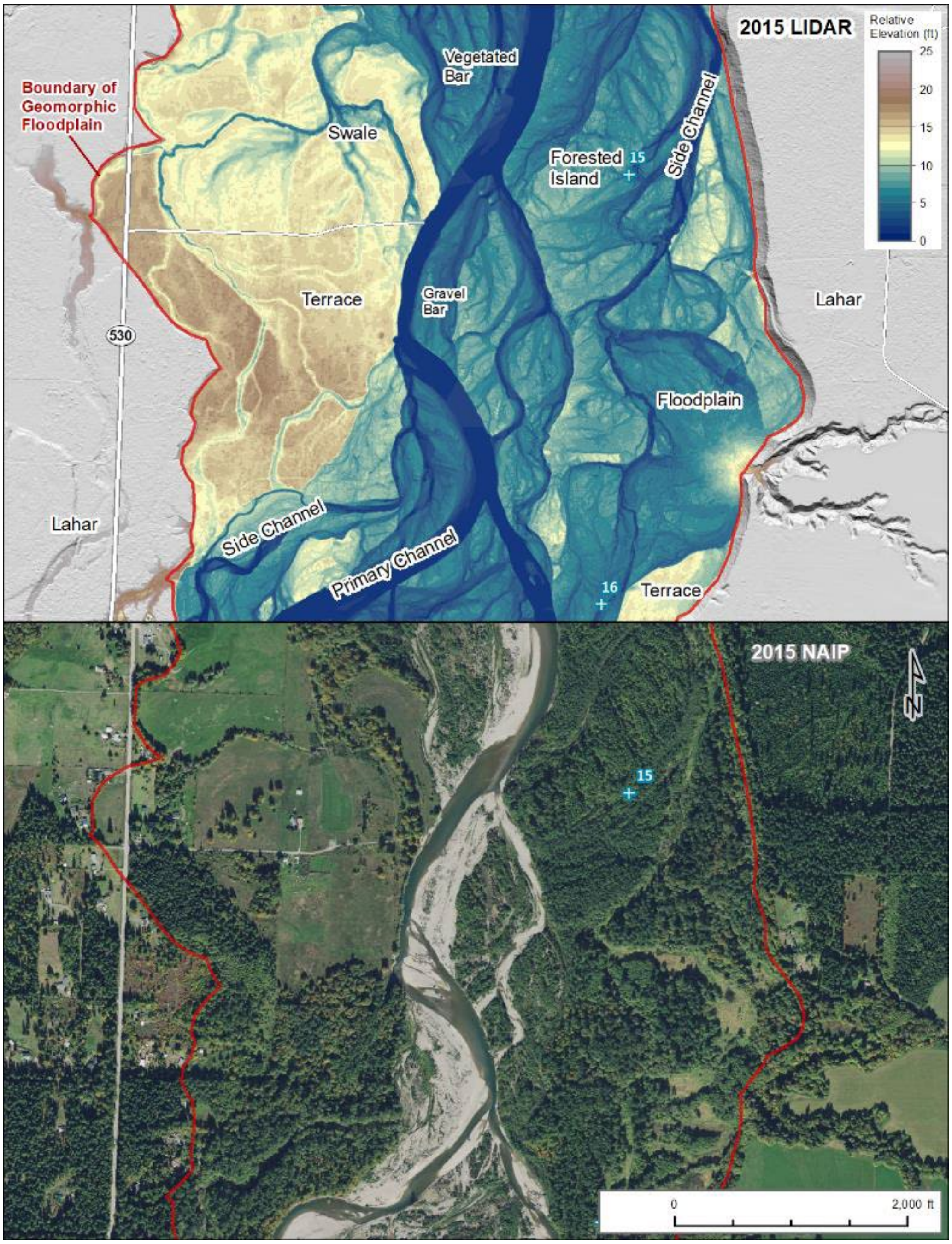


Figure 3. Example of lidar REM highlighting channel and floodplain landforms of the Sauk River.

Table 1. Summary of average channel migration rate in reaches SA010 – SA040 for the period 1944-2015.

	SA010 (FT/YR)	SA020 (FT/YR)	SA030 (FT/YR)	SA040 (FT/YR)
1944-1956	31	4	24	3
1956-1972	25	2	15	3
1972-1981	46	8	30	8
1981-1992	30	4	28	10
1992-2006	31	4	16	4
2006-2015	26	4	23	13
1944-2015	**32**	**4**	**23**	**8**

Table 2. Summary of average channel migration rate in reaches SA050 and SA060 for the period 1949-2015.

	SA050 (FT/YR)	SA060 (FT/YR)
1949-1964	38	4
1964-1974	30	3
1974-1981	51	8
1981-1992	26	3
1992-1998	56	7
1998-2006	42	7
2006-2015	38	5
1949-2015	**41**	**5**

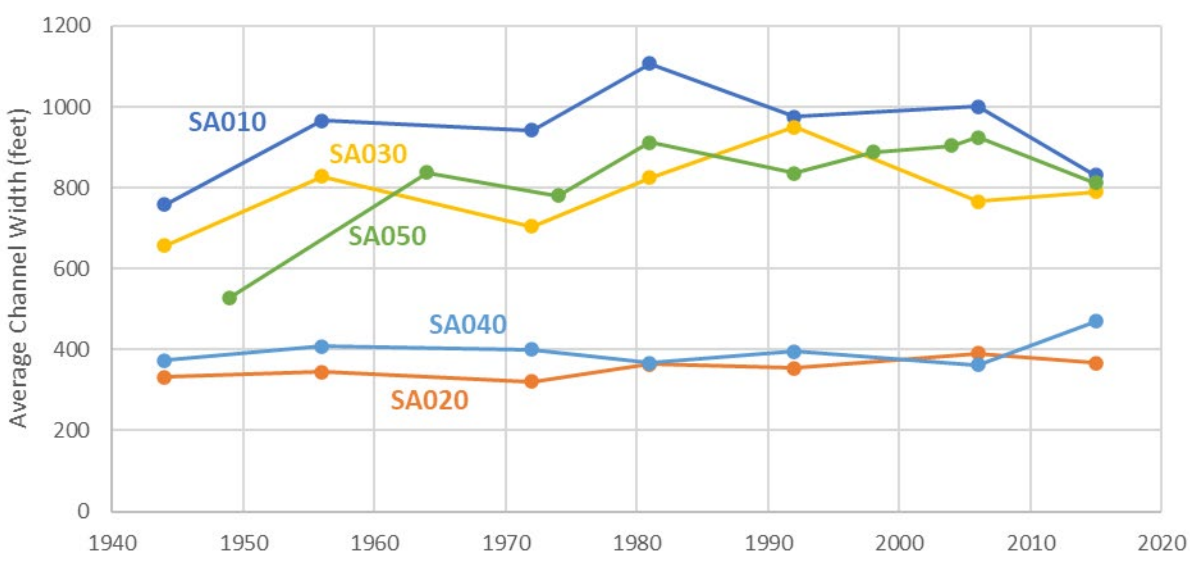


Figure 4. Time series of average channel width, by reach.

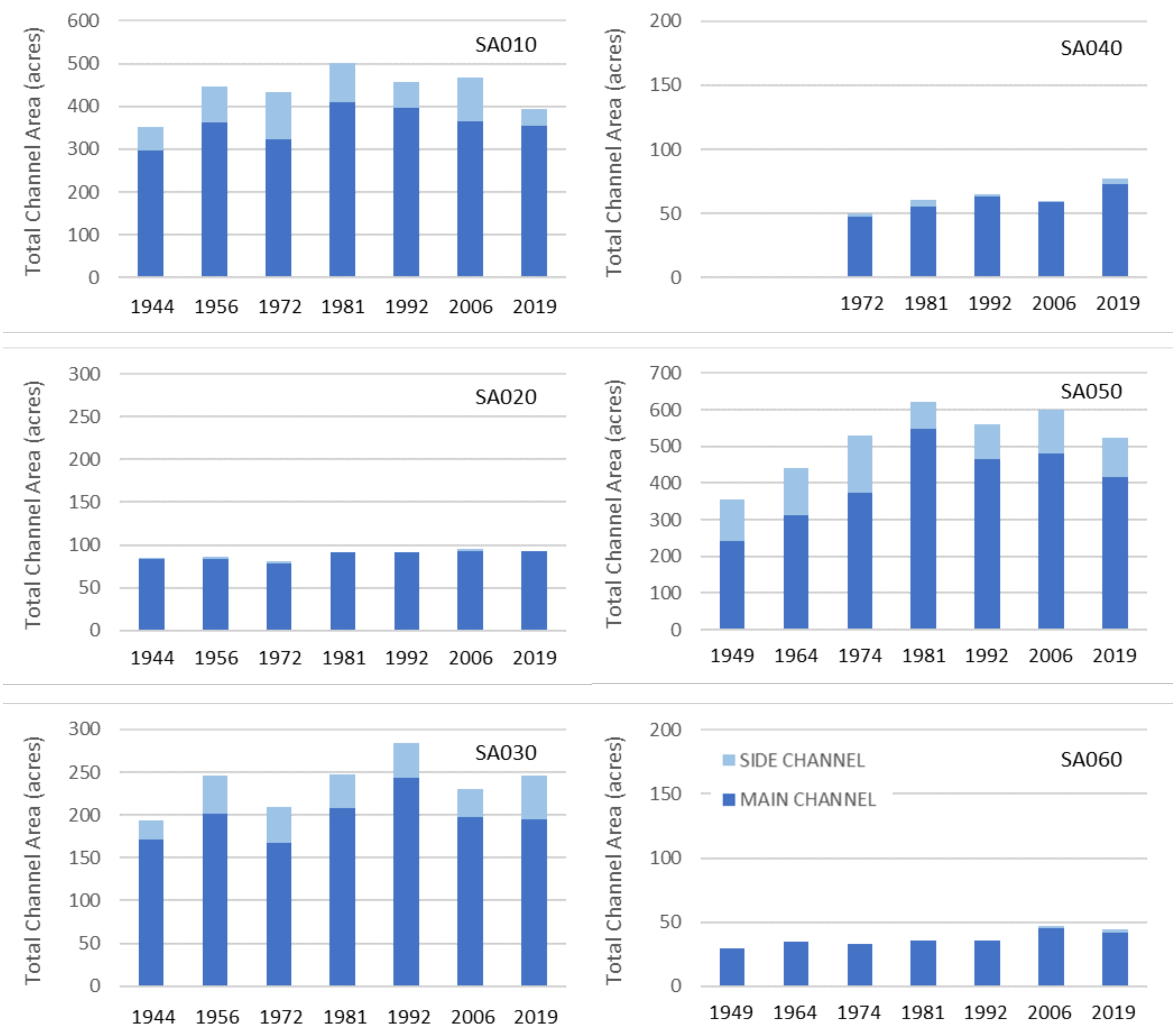


Figure 5. Time series plots showing relative amount of side channel and main channel areas, by reach.

Reach SA010

The Sauk River emerges into a broad alluvial valley downstream of RM 5 and has a broad, dynamic floodplain that forms a delta at the confluence with the Skagit River. Multiple channels meander across the floodplain surface over an area that is greater than a mile wide extending from the valley wall along the western side of the valley to a series of abandoned channel features east of the present alignment of State Route (SR) 530 and around Martin Road. Historical channels from the 1915 USGS map are overlaid with the 2016 REM in Figure 6. Historic channel features digitized by SRSC are overlaid with the 1915 channel in Figure 7. Figure 8 and Figure 9 present the 2016 lidar REM and 2019 aerial imagery of the project reach, respectively. Cross-sections A-A’ and B-B’ are overlaid with the REM in Figure 8 and annotated cross-sectional profiles are shown in Figure 10.

The 1915 USGS map shows a flow split with two dominant flow paths that diverge about 2.5 miles upstream of the Skagit River. Earlier mapping from the 1884 GLO survey showed an active channel extending further eastward across the modern alignment of SR 530. The 1884 meander is visible from the ground looking south from Rockport-Cascade Road just west of the intersection with Martin Road. By 1944, the Sauk River established a dominant flowpath along the channel alignment identified as McLeod Slough in the 1915 USGS map. The eastern fork of the Sauk River shown in 1915 has since narrowed with sediment deposition and vegetation encroachment but is still an active side channel.

The historical record of channel migration in reach SA010 includes several examples of floodplain channel features formed through a dynamic sequence of bar growth, meander extension, and bend cutoffs leading to channel avulsions. Examples of floodplain dynamics observed in reach SA010 include:

- Eastward migration of the Sauk River between RM 0 and RM 1 during the period 1944-1972 followed by a channel cutoff between 1972 and 1981 (Figure 11). Abandoned channel features resulting from this cutoff form depressional wetlands and secondary channels crossing the floodplain between the Sauk River and Skagit River.
- Between RM 1 and RM 2, the Sauk River had a multi-threaded channel pattern in 1944 with channel migration forming a large forested island between RM 1 and RM 2 over the period 1944-1992. Further channel migration between 1992 and 2006 abandoned the longer, more sinuous channel (Figure 12).
- At the upper end of reach SA010 dynamic channel processes has resulted in two sequences of meander development and subsequent abandonment to form new floodplain surfaces. Between 1915 and 1956, the Sauk River made a high amplitude meandering pattern directing flow toward SR 530 on the east side of the valley between RM 3 and RM 4. A series of meander scrolls on the floodplain surface to the east of the Sauk River between RM 4 and 5 indicate a downstream translation of this meander prior to 1915. A cutoff formed along the inside of the bend between 1956 and 1972 and abandoned the channel on the east side of the valley near RM 3 (Figure 13). The cutoff reset the meander geometry in the reach and led to development of a new meander on the west side of the valley. The channel migrated rapidly to the west and eroded into a high terrace. Erosion undercut the steep bank damaging a segment of Concrete-Sauk Valley Road. A new cutoff then formed prior to 2015 leading to split flow condition with a developing vegetated bar in between the two channels (Figure 13).

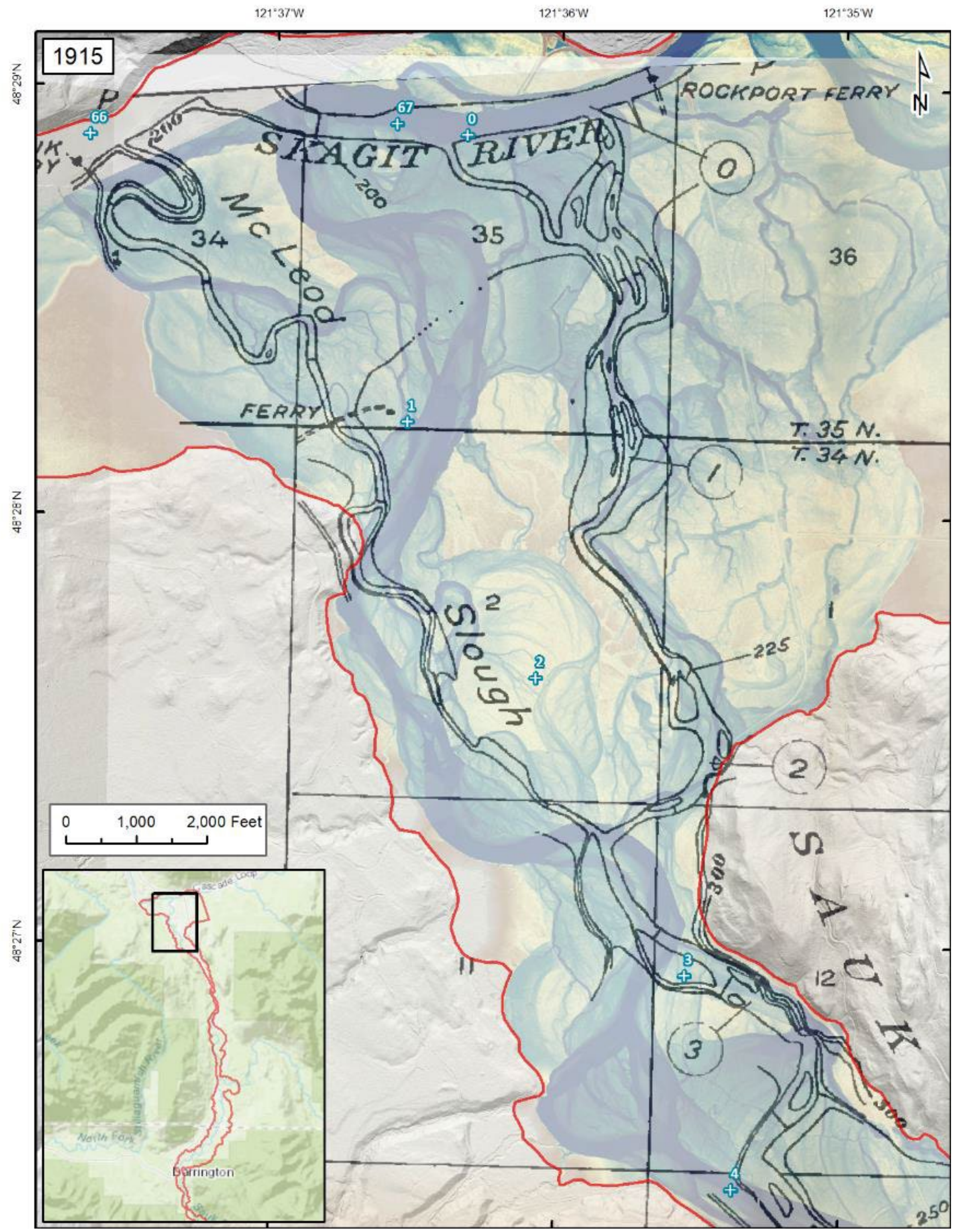


Figure 6. 1915 map showing historical channels at the Sauk River delta (Reach SA010) overlaid with a semi-transparent background of 2016 lidar REM for reference.

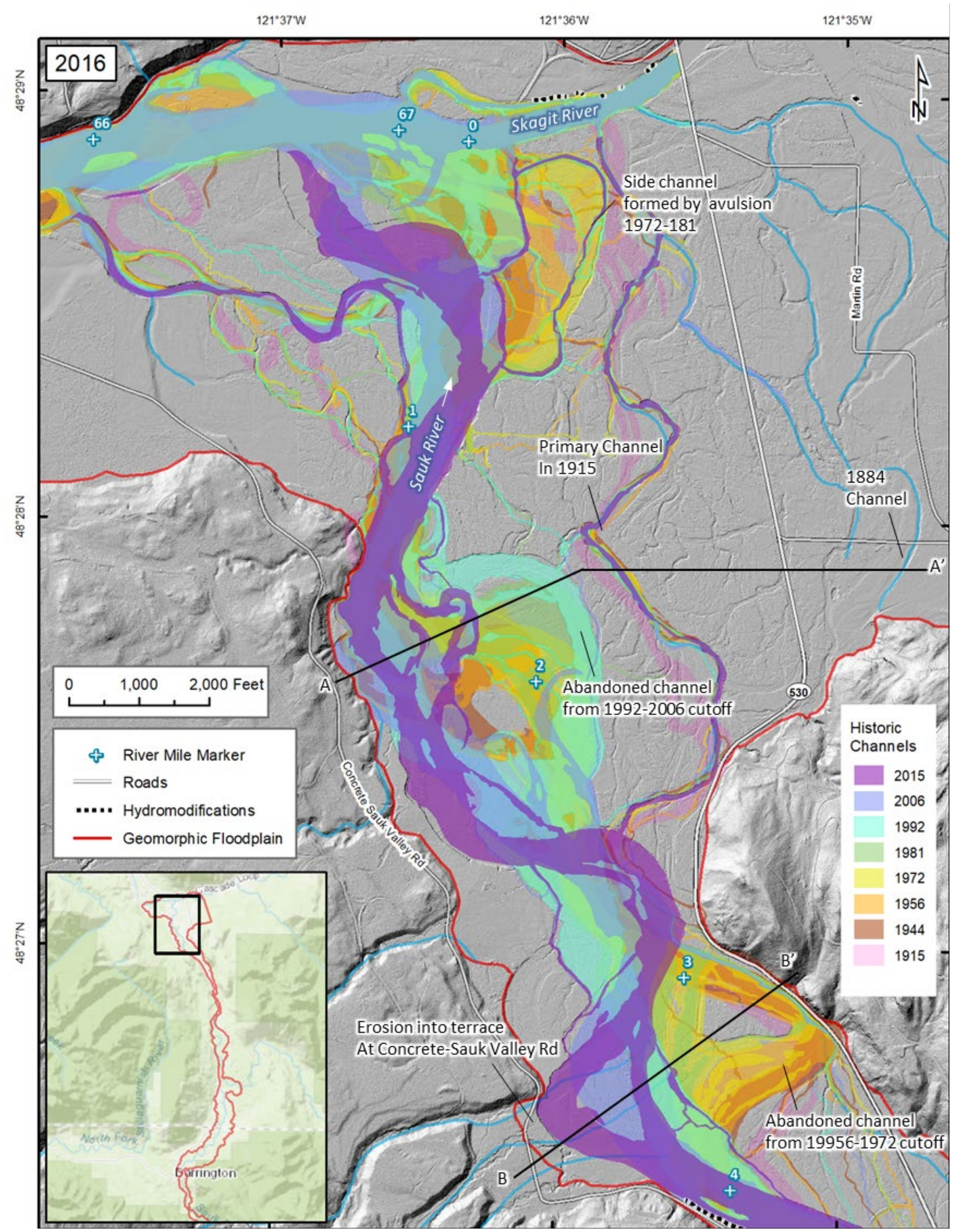


Figure 7. Historic channel features from aerial imagery (data source: SRSC) and 1915 map (USGS).

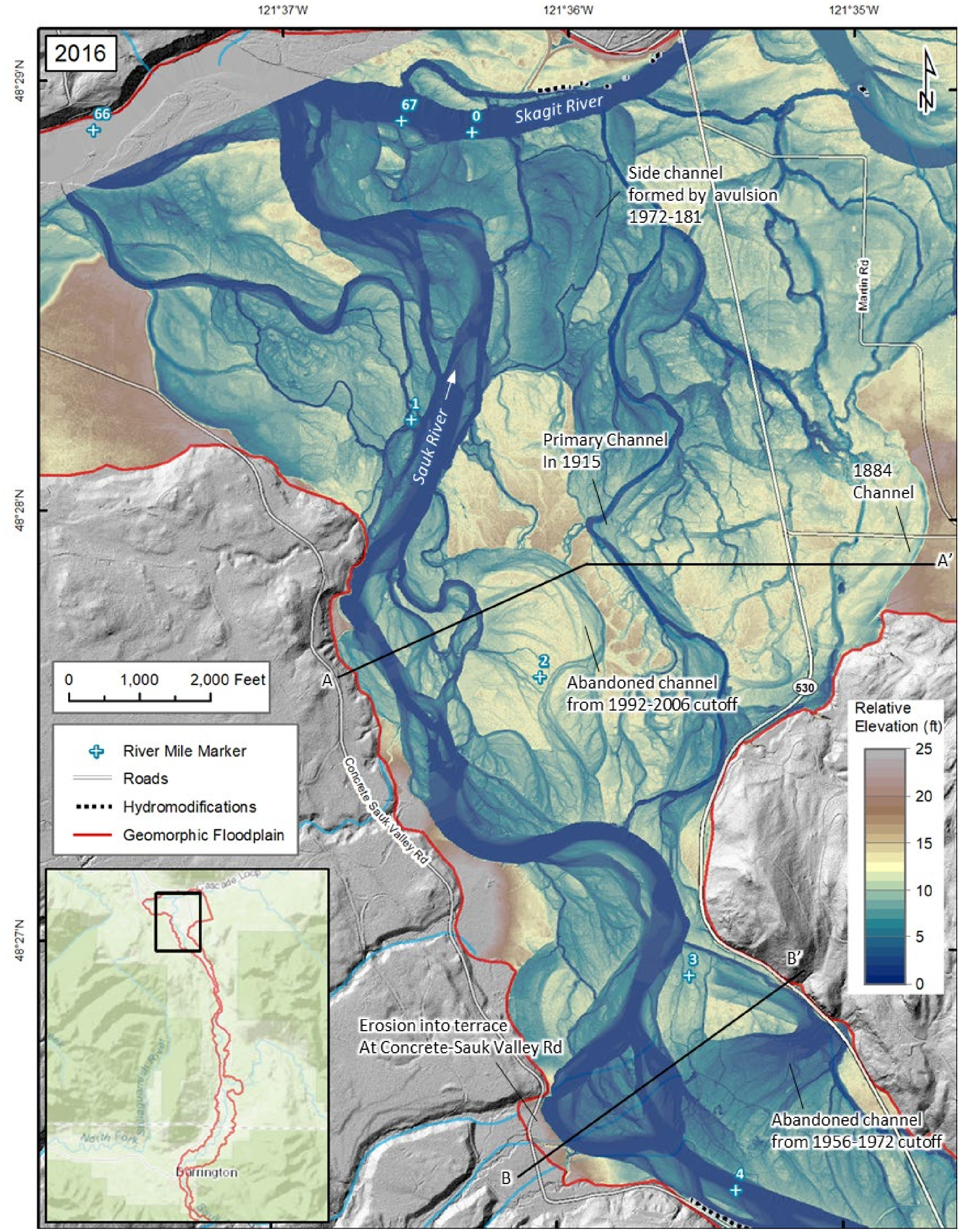


Figure 8. 2016 Lidar REM showing floodplain topography at the Sauk River delta (Reach SA010).

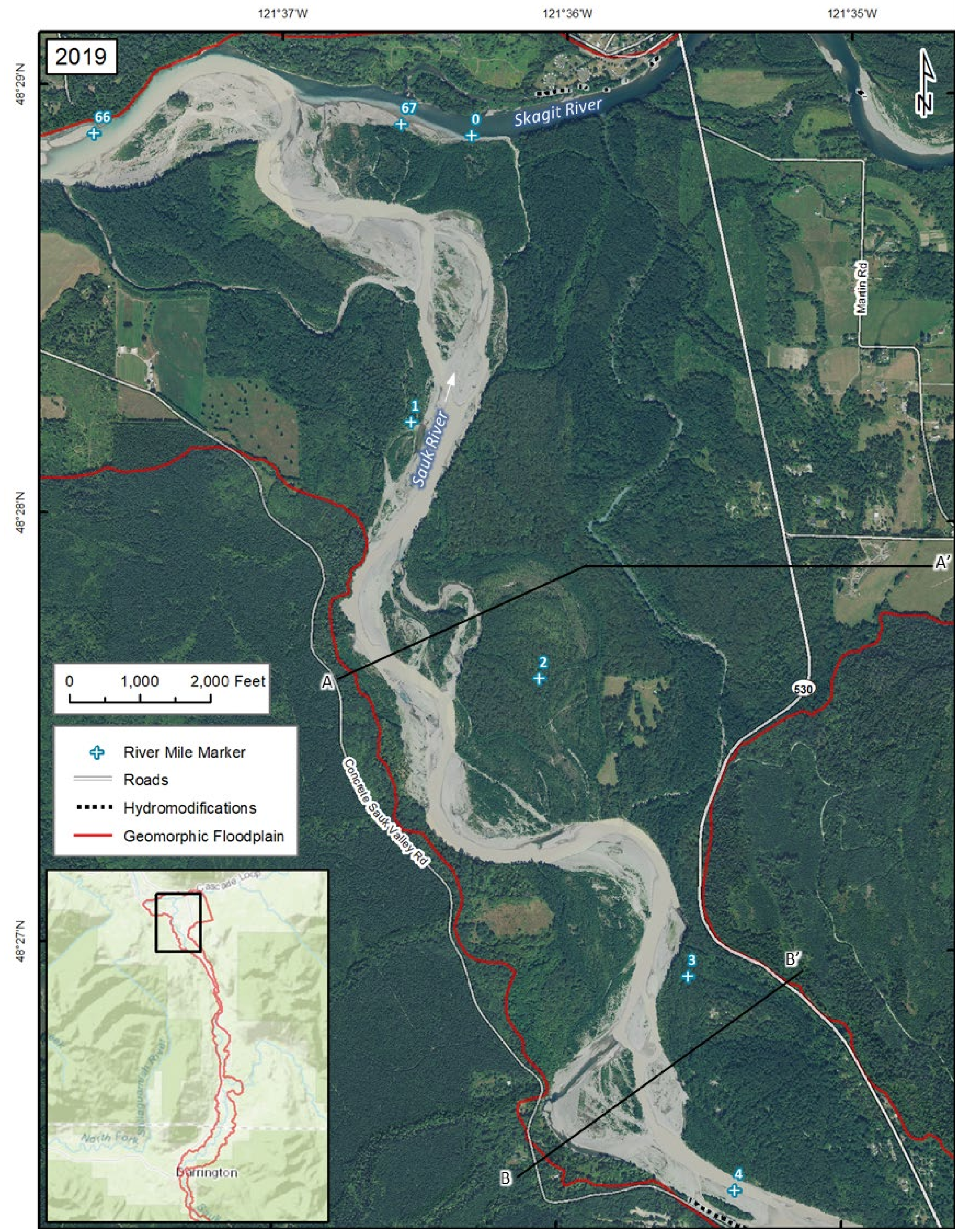
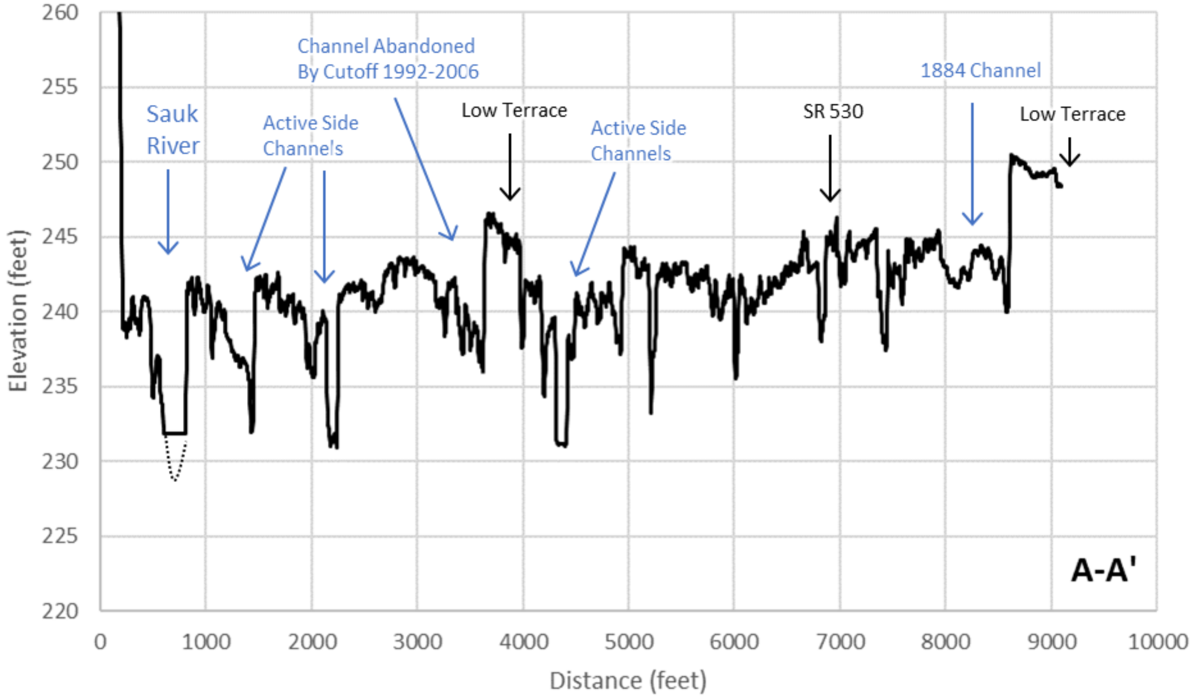


Figure 9. 2019 aerial imagery of the Sauk River delta (SA010).



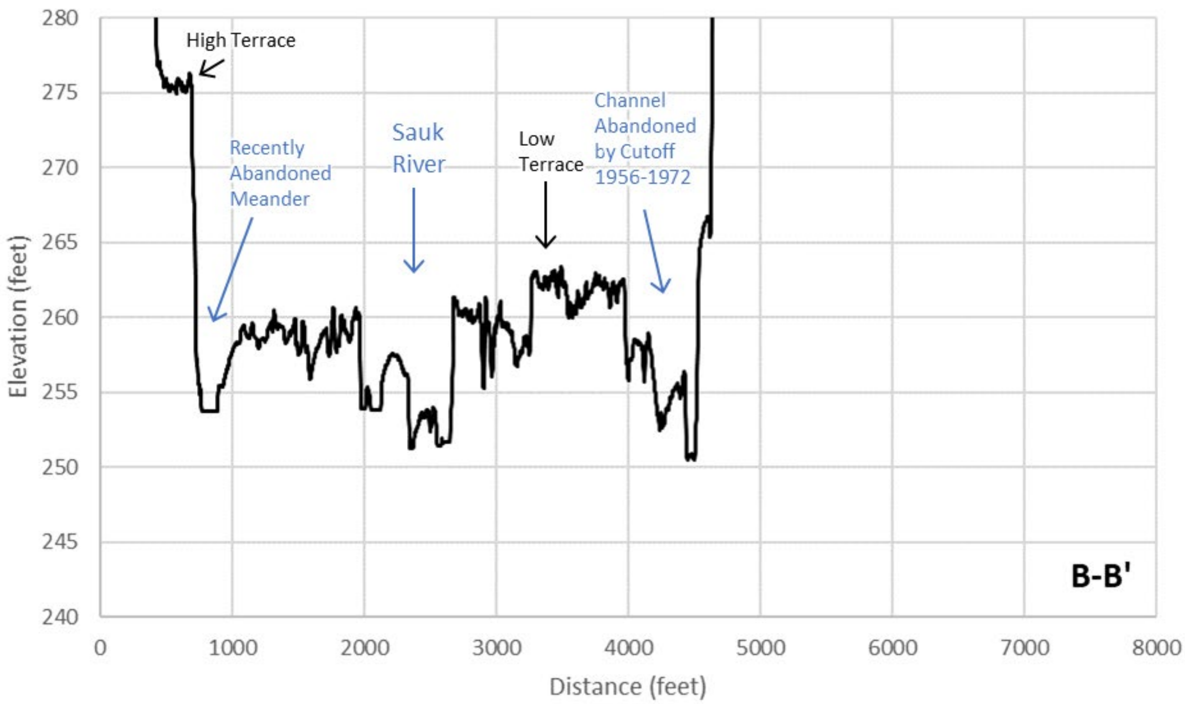


Figure 10. Cross-sections showing floodplain topography and landforms in reach SA010.

Figure 11. Time series of channel change between 1944-2019 at the confluence of the Sauk River and Skagit River.

Figure 12. Time series of channel change between 1944-2019 showing abandonment of the channel feature between RM 1 and RM 2.

Figure 13. Time series of historical channel change 1944-2019 showing two sequences of bend cutoffs between RM 3 and RM 4.

Reach SA020

The Sauk River flows through a narrow valley confined by steep hillslopes between RM 5 and RM 9 (Figure 14 and Figure 15). The channel morphology is relatively straight and uniform through this reach and historic channel mapping shows little to no lateral migration since the 1940s (Figure 16). The channel is pinned along the west side of the valley between RM 5 and RM 7. A terrace surface fills the east side of the valley and displays meander scrolls and other indicators of previous channel migration activity (Figure 17). The 1915 map shows the channel in the same alignment as present day suggesting little channel migration has occurred within this reach over the historical period. The channel makes consecutive 90-degree bends through a narrow gap at RM 7 where the bridge at Concrete-Sauk Valley Road spans the channel. Immediately downstream of the bridge there is a side channel that splits laterally along the valley wall and returns to the mainstem downstream. The side channel is separated by an island at the same relative elevation as the terrace downstream. Review of the historical imagery shows there has been some lateral migration that has eroded the east side of the island and then a lower, inset floodplain developed with subsequent deposition and vegetation encroachment into the eroded area (Figure 18).

Reach SA030

Reach SA030 is an unconfined reach continuing upstream of the valley confinement at RM 9 to another confined valley segment at the SR 530 bridge near RM 12. The historic map from 1915 shows an alternating channel pattern with both anabranching and meandering channel segments in the reach (Figure 19). Historic channel features digitized by SRSC are overlaid with the 1915 channel in Figure 20. The 2015 REM (Figure 21) and recent aerial imagery Figure 22 show the current channel pattern and distribution of floodplain landforms. Cross-sectional profiles relating the main channel, side channels, and abandoned channel features in the floodplain are plotted below in Figure 23.

Historical channel dynamics have been dominated by downstream translation and lateral extension of meander bends. There is existing off channel habitat within an abandoned channel near RM 11 that formed as a result of a channel avulsion that cut off the bend on the east side of the floodplain between 1956 and 1972 (Figure 24). The meanders downstream of RM 11 have been increasing in sinuosity in years since the avulsion (prior to 1972). The lateral migration rate has been greatest along the right bank upstream of RM 10 (Figure 24). There is a side channel along the edge of the floodplain that is growing in size and capturing additional flow from the mainstem as the channel migrates closer to the on the east side of the valley. This process is driving an avulsion toward the side channel that will likely cut off the meander bend on the west side of the valley between RM 9.5 and RM 10.5 and is creating an erosion hazard to SR 530 on the east side of the valley.

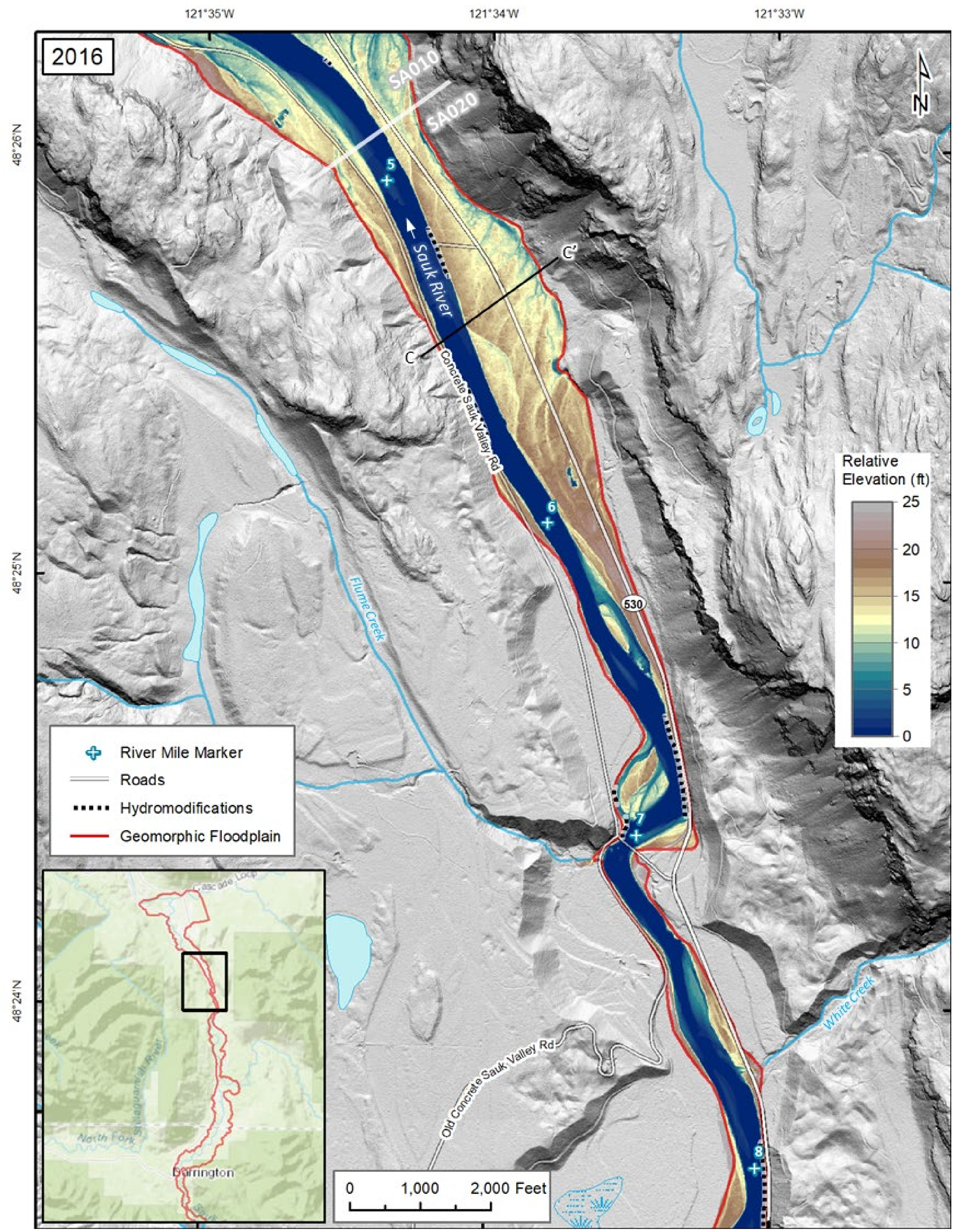


Figure 14. 2016 Lidar REM showing floodplain topography in reach SA020.

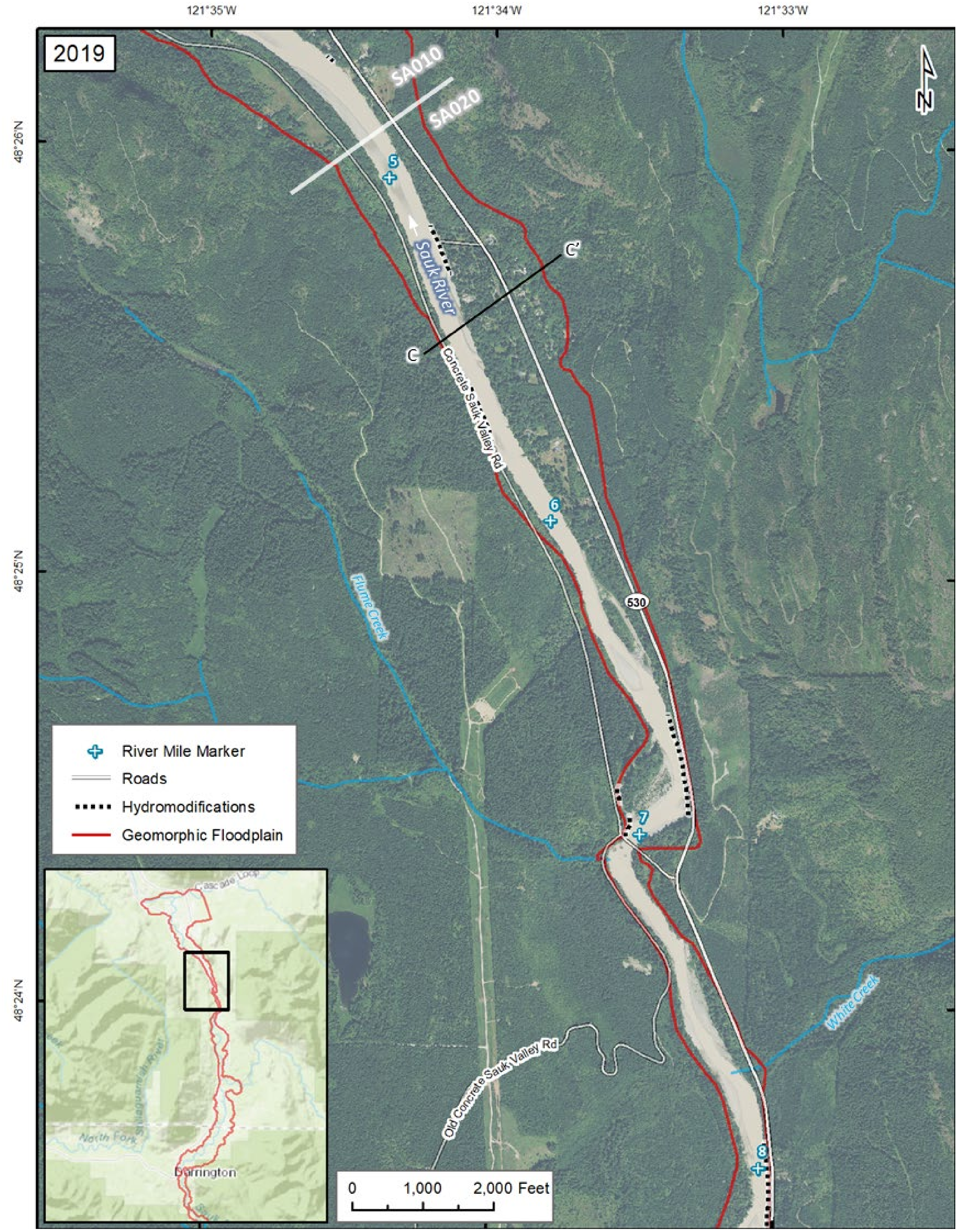


Figure 15. 2019 imagery of reach SA020.

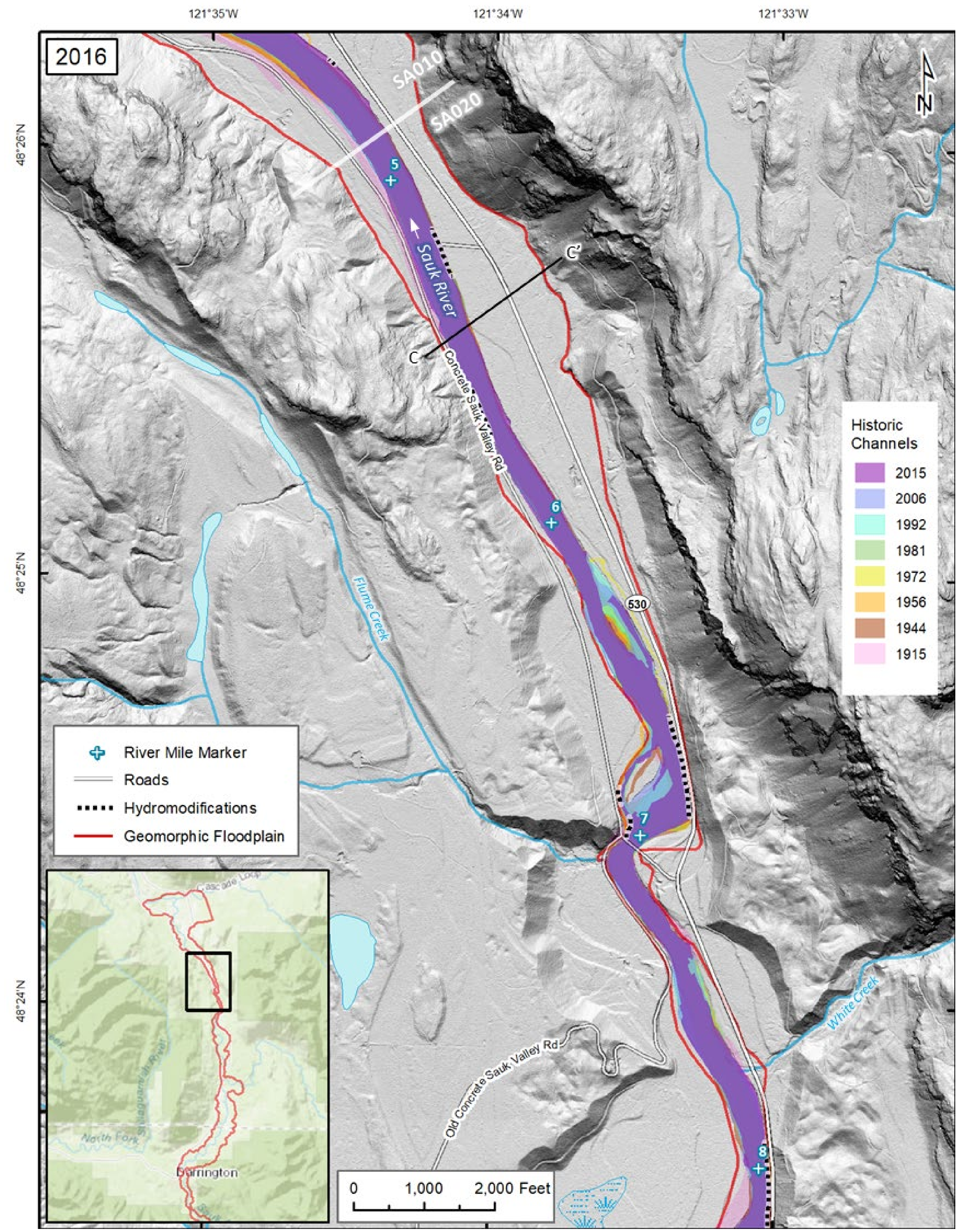


Figure 16. Historic channel features from aerial imagery (data source: SRSC) and 1915 map (USGS).

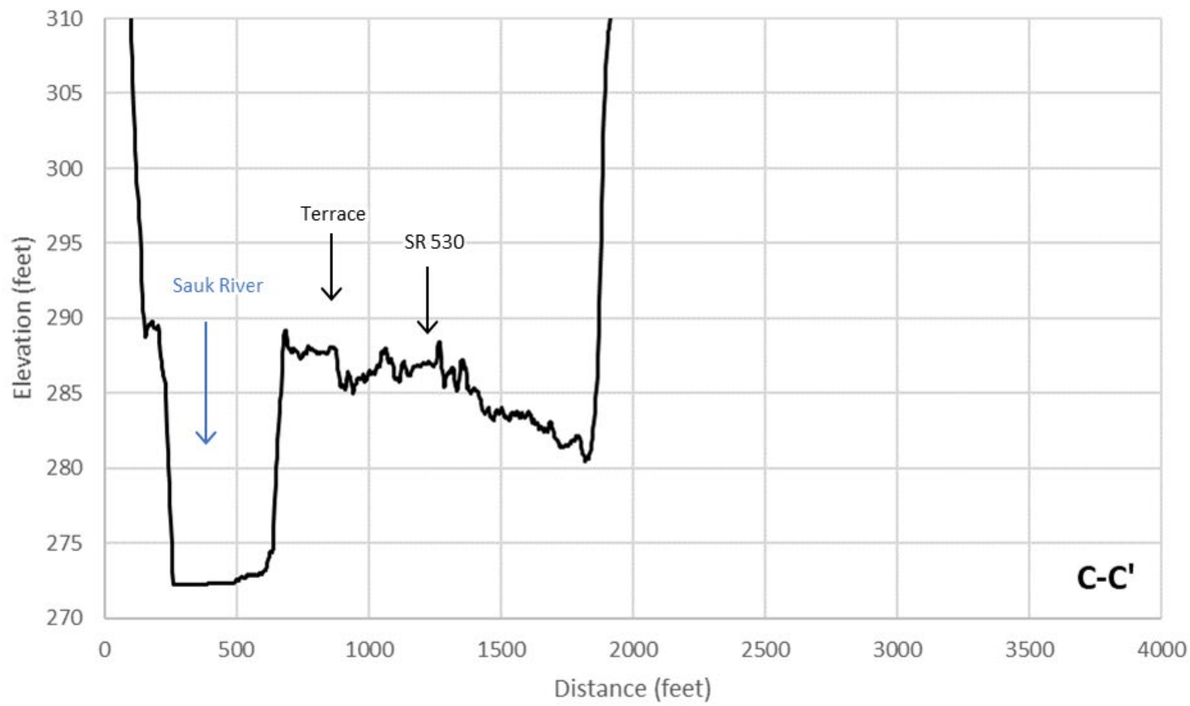


Figure 17. Cross section C-C' showing the confined channel and adjacent terrace surface in reach SA020.

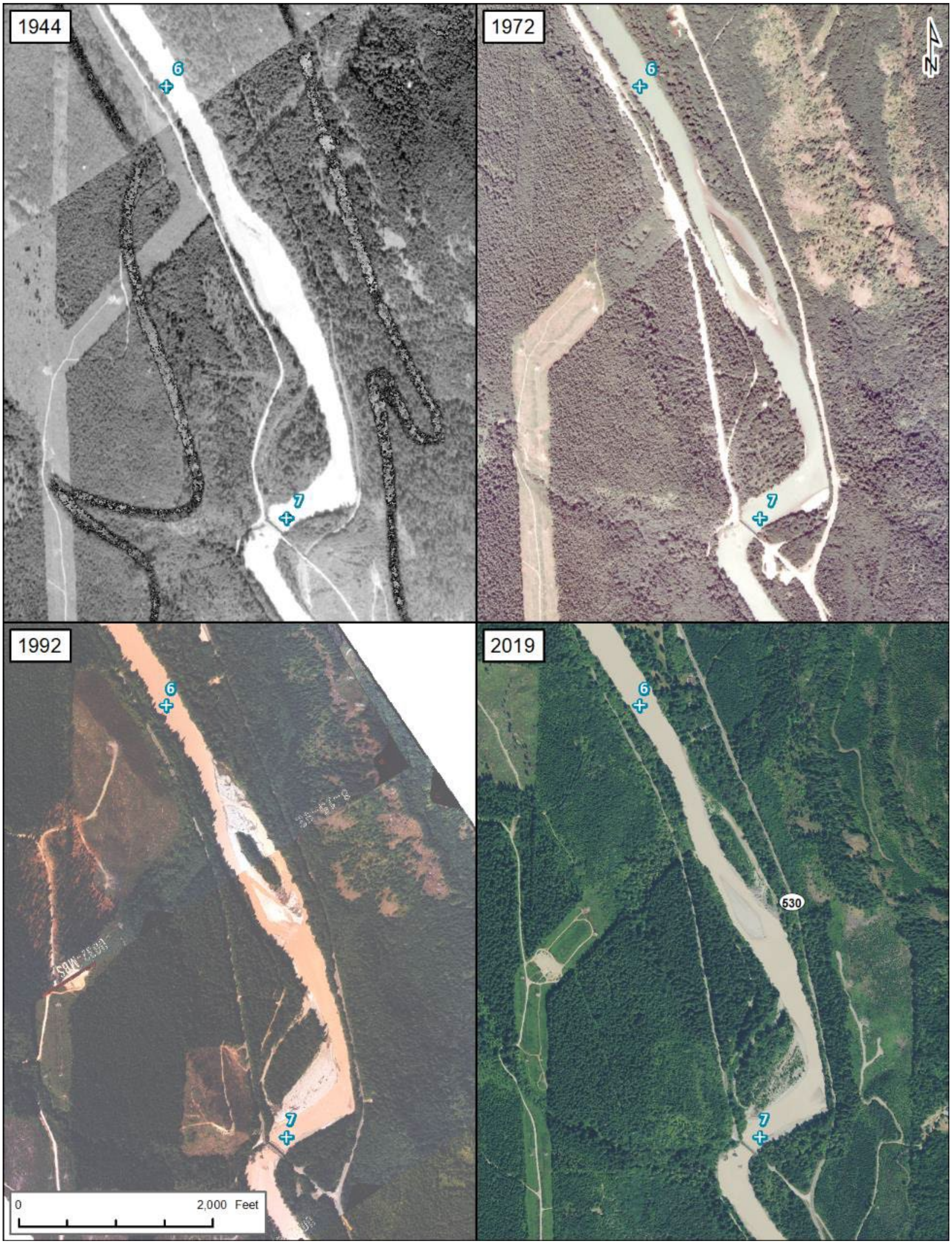


Figure 18. Time series of channel changes near the bridge at Concrete-Sauk Valley Road near RM 7.

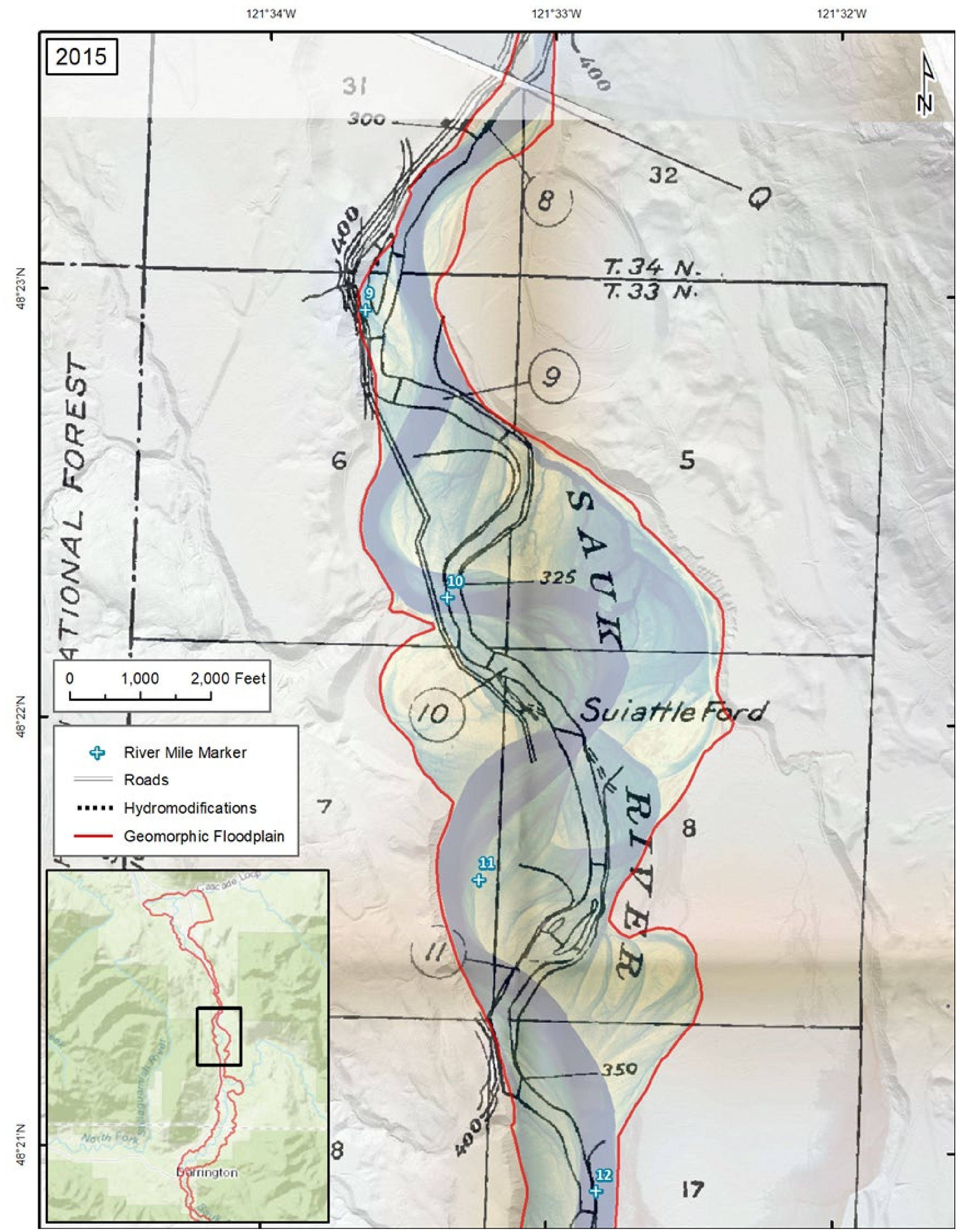


Figure 19. 1915 USGS map showing the historical channel through reach SA 030 overlaid with a semi-transparent background of 2016 lidar REM for reference

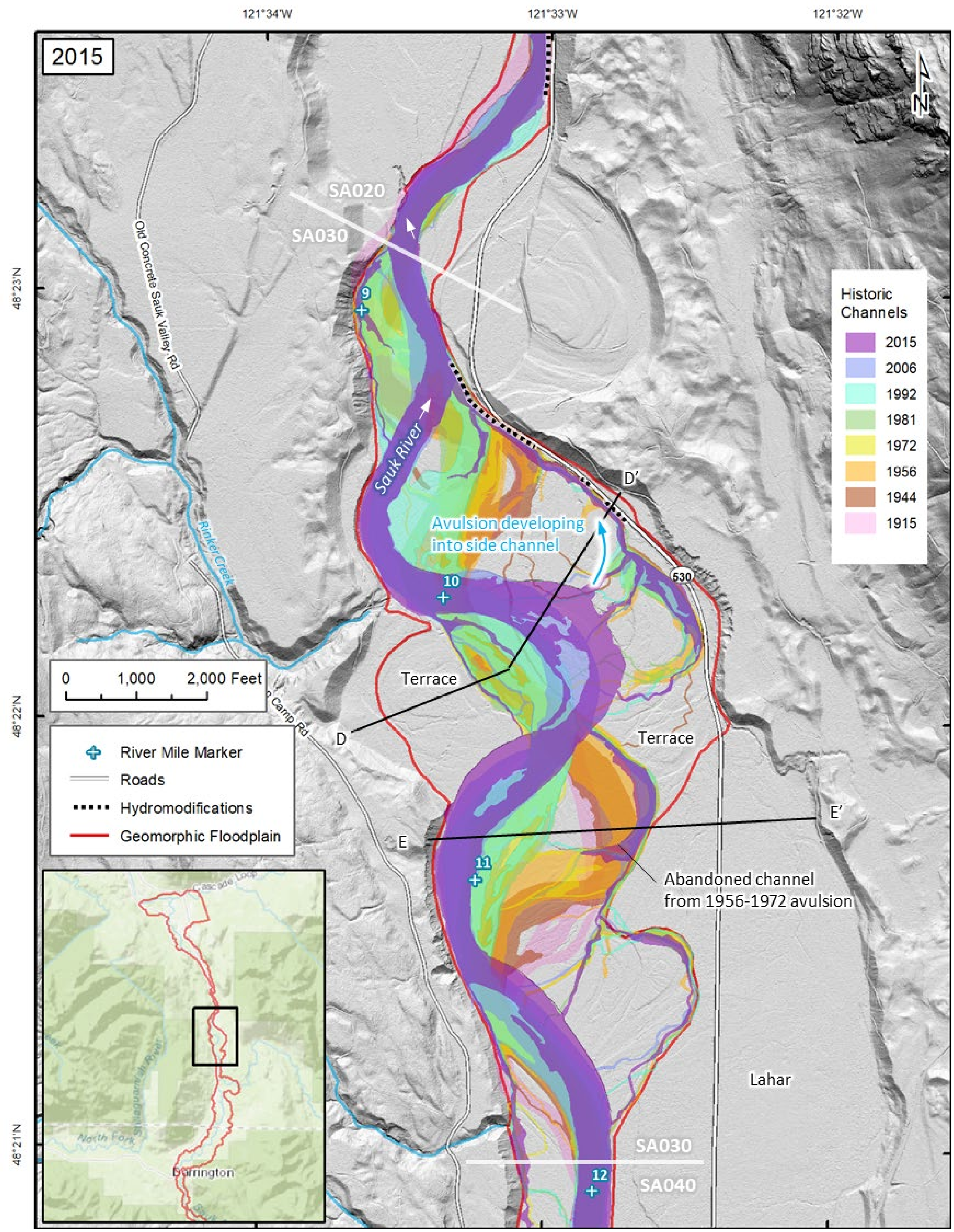


Figure 20. Historic channel features from aerial imagery (data source: SRSC) and 1915 map (USGS).

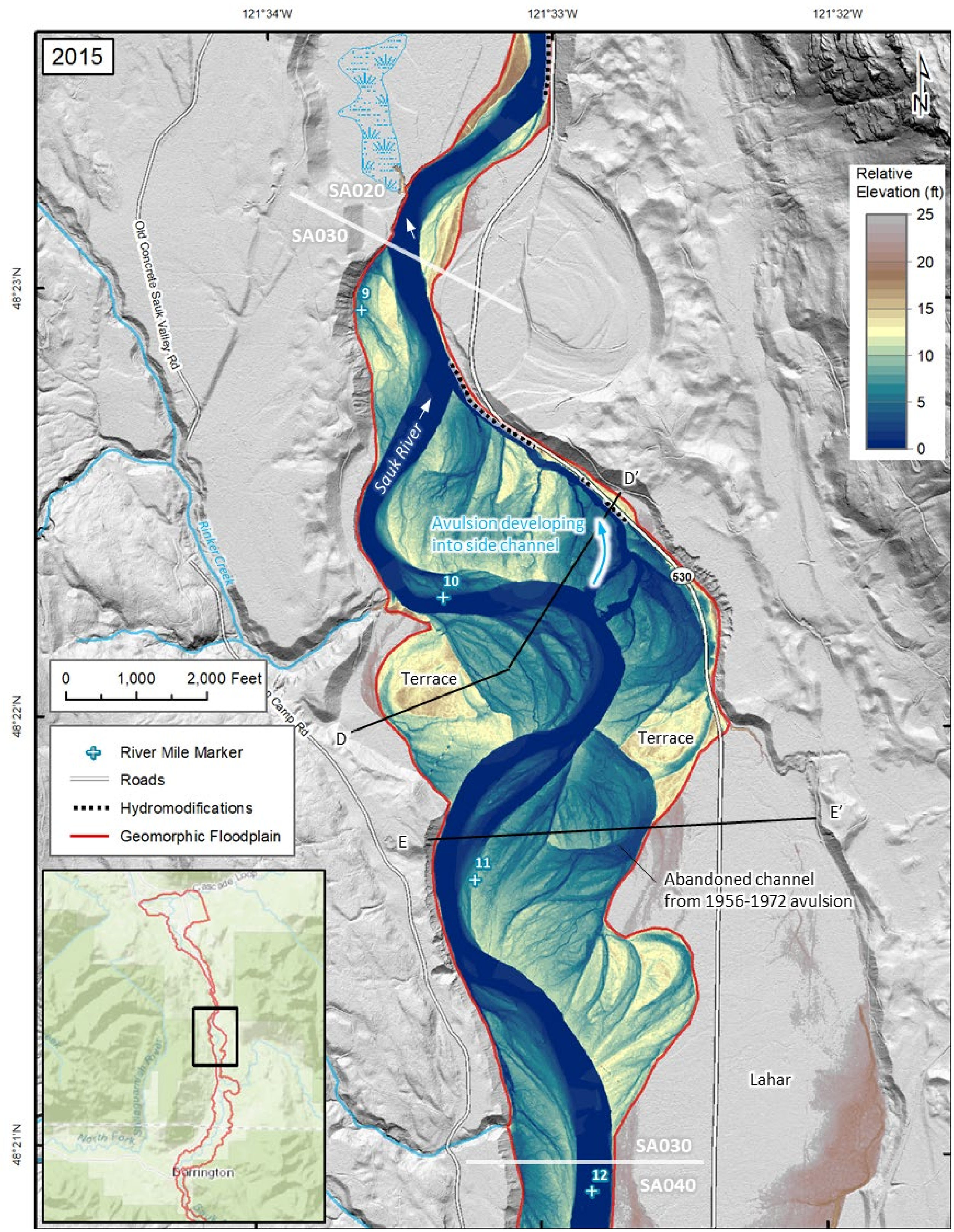


Figure 21. 2015 lidar REM of reach SA030

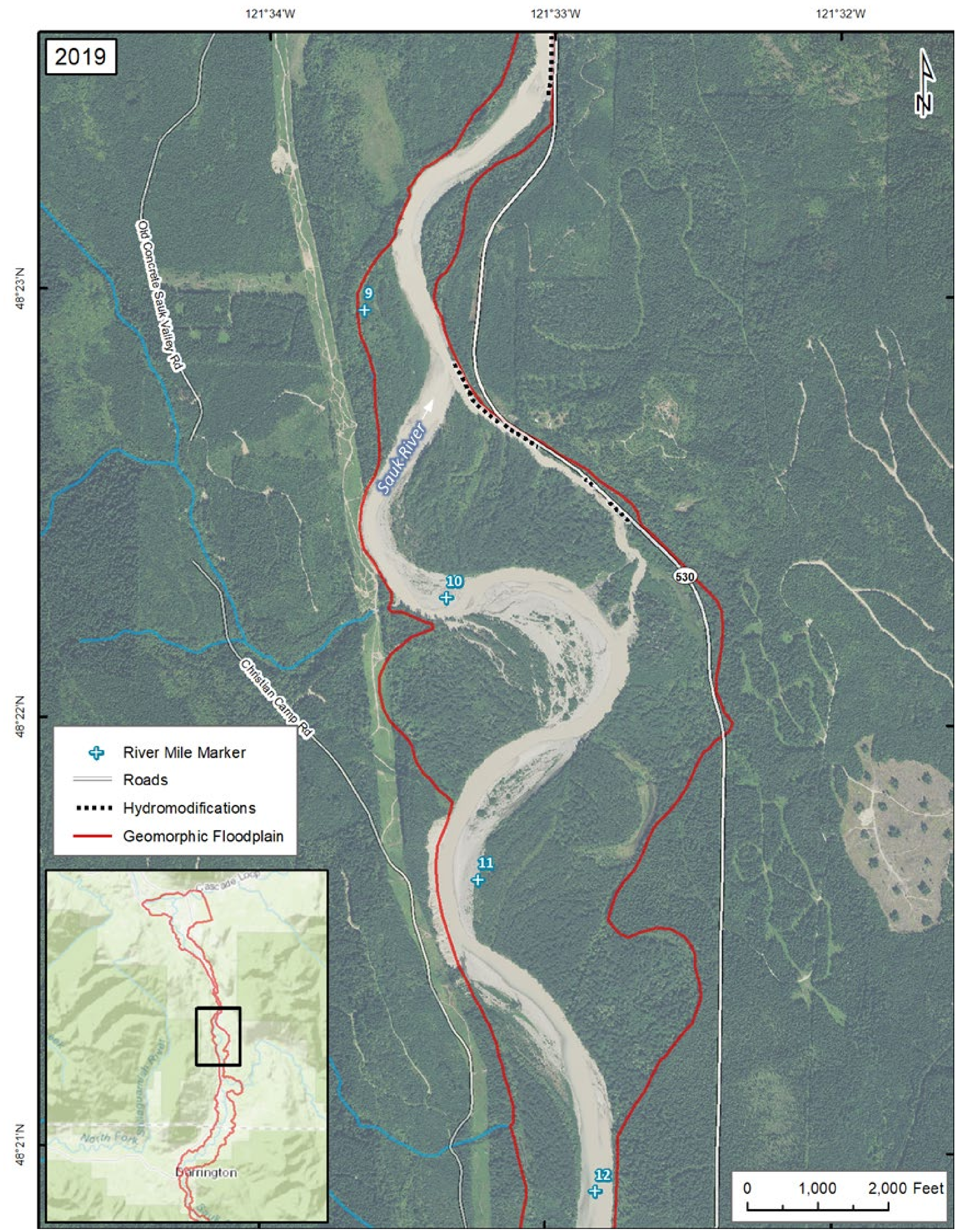


Figure 22. 2019 aerial imagery of reach SA030.

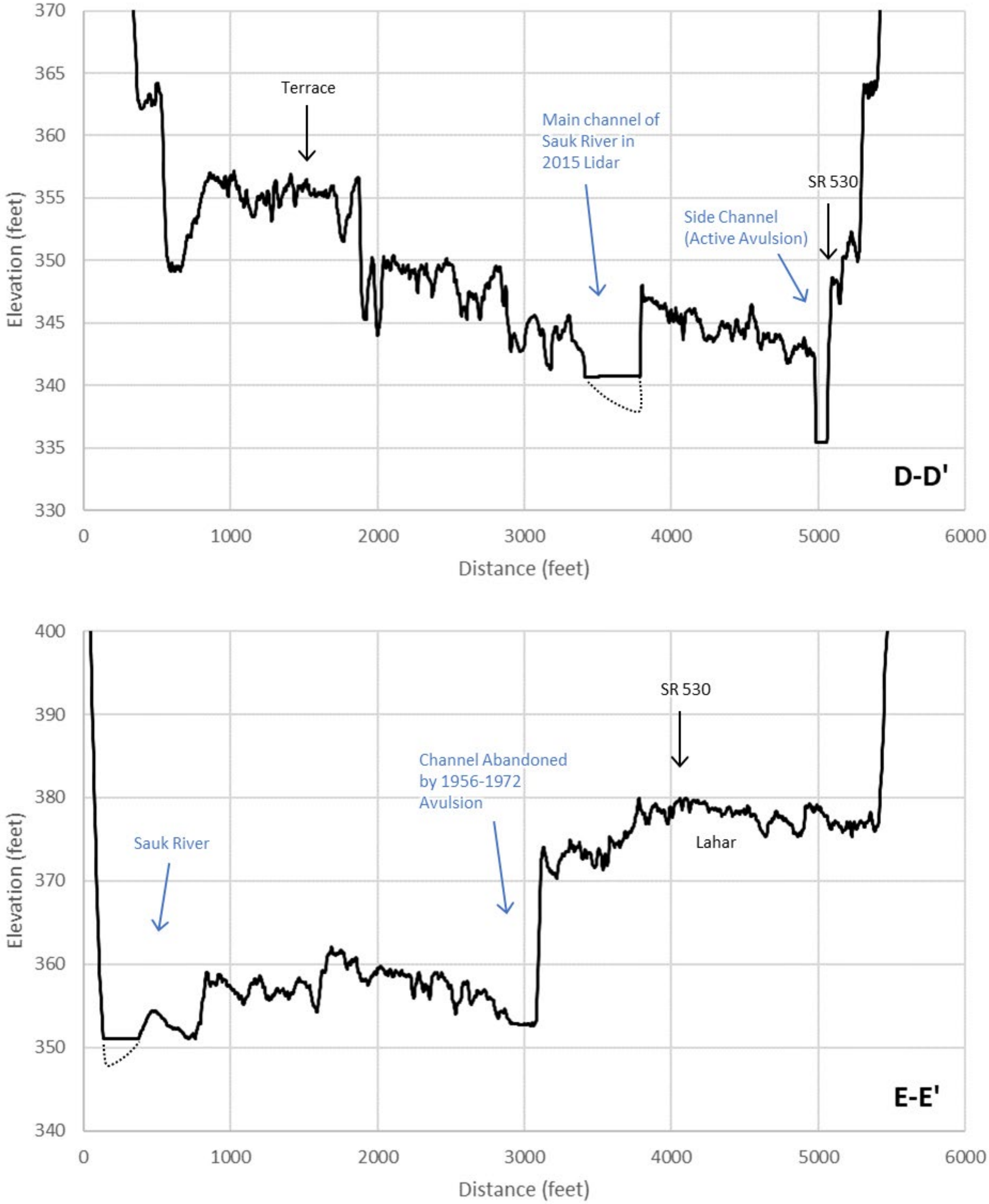


Figure 23. Cross-section profiles of floodplain topography in reach SA030.

Figure 24. Time series of historical channel changes between RM 9 and RM 11.

Reach SA040

Reach SA040 is a short segment at the confluence with the Suiattle River. Figure 25 shows the historical channel location in 1915 and historic channel features digitized by SRSC are overlaid with the 1915 channel in Figure 26. floodplain topography in 2015 REM (Figure 27), and 2019 imagery (Figure 28) at the Suiattle River confluence. Lahar deposits fill the valley and confine the floodplain width near RM 12. SR 530 crosses the river at a bridge near this location and the western bridge abutment and associated bank armoring limits connectivity with the floodplain downstream. SR 530 continues upstream along the edge of a glacial bluff and is armored with riprap protection. The Sauk River follows a straight alignment pinned to the west side of the valley by impinging flow from the Suiattle River.

Reach SA050

Reach SA050 extends upstream of the Suiattle River to Darrington through an unconfined valley between RM 14 and RM 21. The broad, unconfined valley is partially filled by lahar deposits that are 25 to 30 feet above the active floodplain. The floodplain widens and supports a complex network of side channels, forested islands, and braids. Figure 25 shows the historical channel location for the lower segment of this reach in 1915 and Figure 26 shows historic channel features digitized by SRSC. The floodplain topography and landforms are shown on the 2015 lidar REM (Figure 27), and 2019 aerial image (Figure 28). Cross-sectional profiles from the 2015 lidar are shown in Figure 29.

Multiple abandoned channel features provide areas with off-channel habitat in the floodplain. Upstream of the Suiattle River near RM 14 the historical imagery shows a large amplitude meander along the west side of the floodplain cut off by a channel avulsion between 1949 and 1963 (Figure 30). The next segment upstream includes a complex of floodplain channels along the east side of the valley between RM 14 and 15 that were more recently abandoned by channel avulsion between 1992 and 2006.

Maps of the upper segments of reach SA050 show the 1915 channel locations (Figure 31), 2015 lidar REM (Figure 33), and 2019 aerial imagery of reach SA050 (Figure 34). Comparison of the 1915 channel with the REM and recent imagery suggests that reach SA050 previously included more stable island features created by an anabranching channel pattern and that the channel alignment had an overall more sinuous path that was more likely to traverse across the floodplain. The present-day channel as characterized in the lidar REM and aerial imagery has a straighter, wider channel more closely following a braided pattern. The historical data show a 54% net increase in channel width between 1949 and 2015. Figure 35 presents a sequence of images showing the transition from anabranching to braiding channel pattern and increase in width of the unvegetated channel between RM 15 and RM 17. The right bank floodplain upstream of RM 17 includes multiple abandoned channel features that remain connected with the main channel during periods of high flow (Figure 36). Figure 37 shows an example of channel changes at the transition where the Sauk River widens downstream of the valley confinement at Darrington with a pronounced expansion of the unvegetated channel over time.

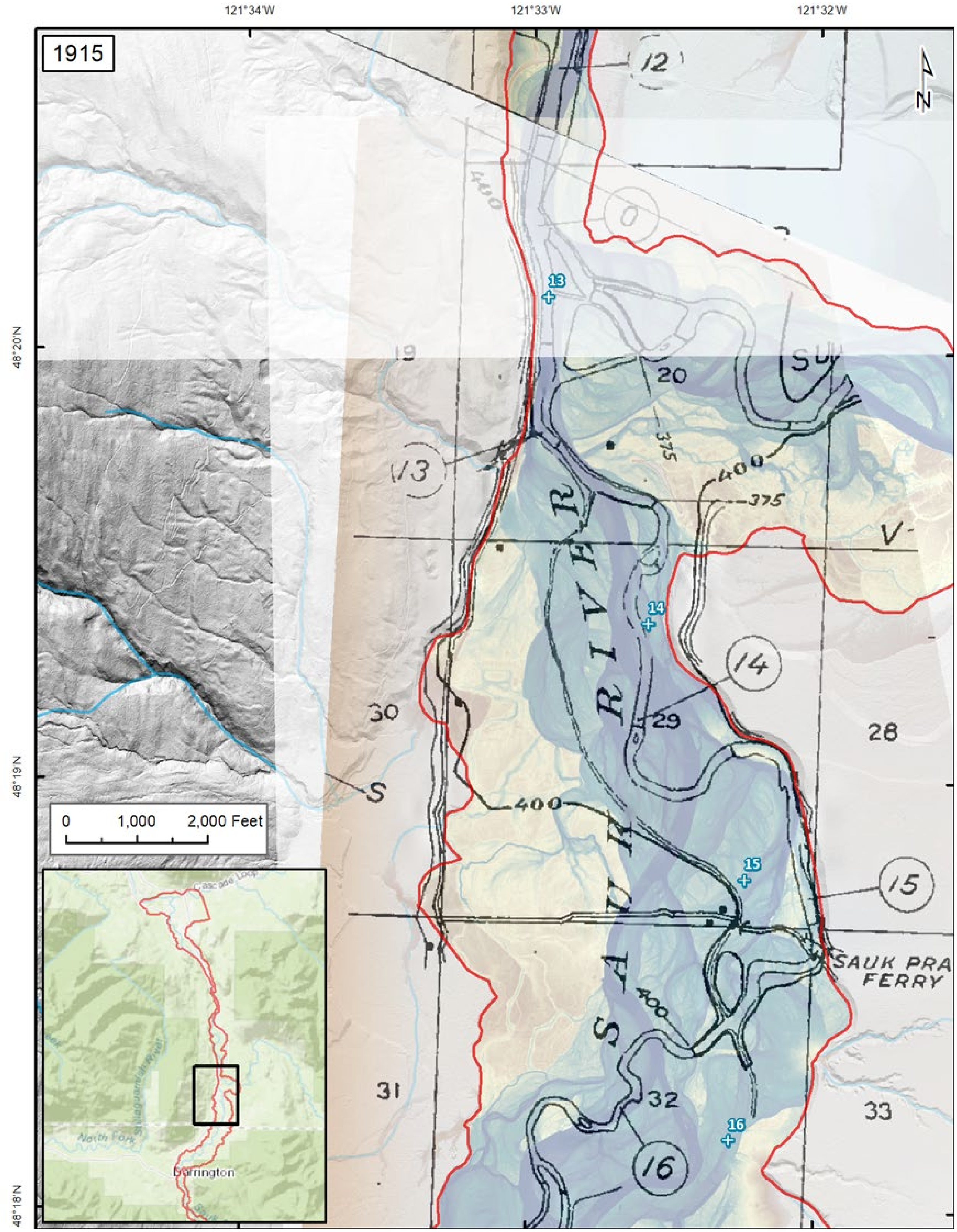


Figure 25. 1915 USGS map showing the historical channel locations in reach SA040 and lower segments of reach SA050.

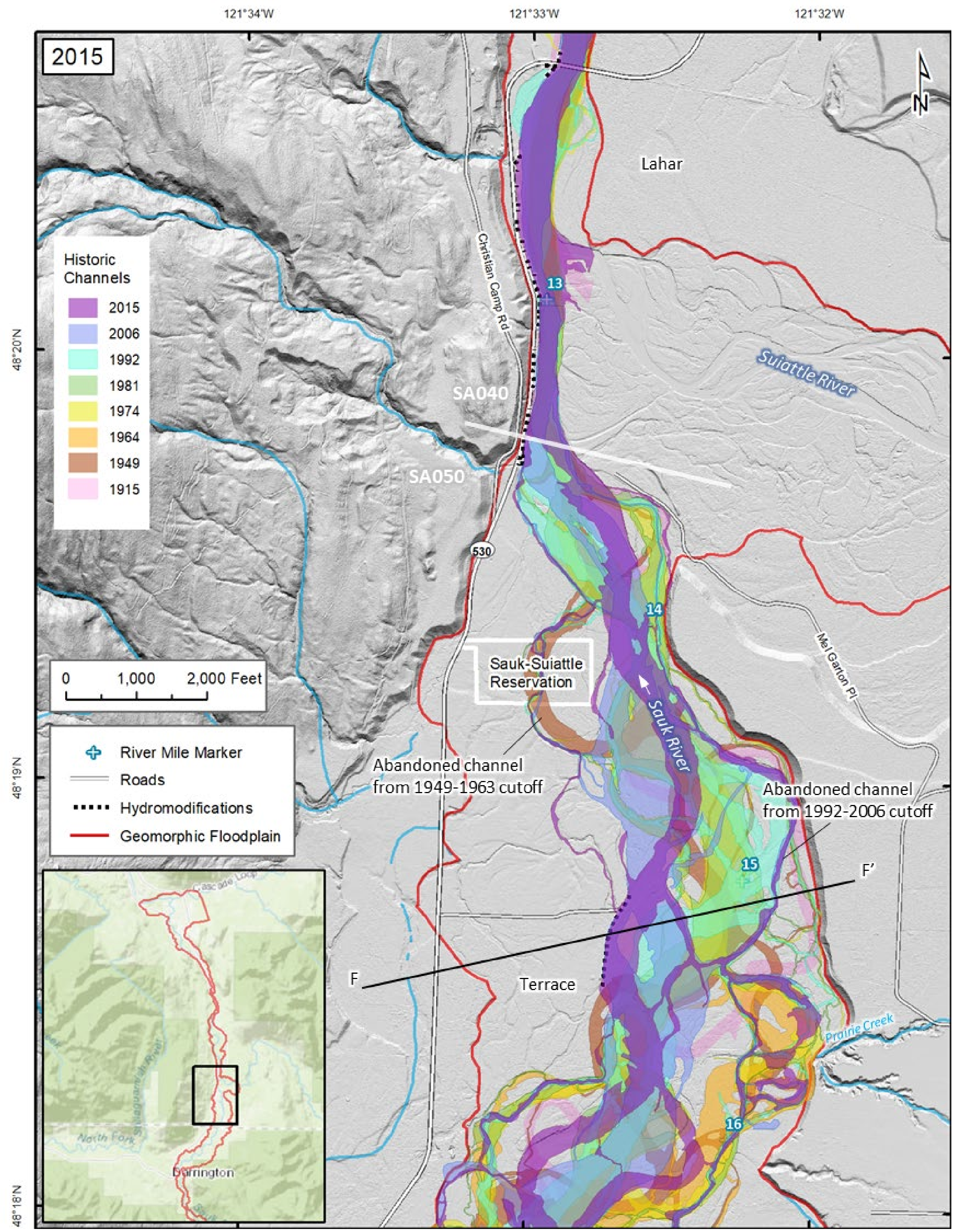


Figure 26. Historic channel features from aerial imagery (data source: SRSC) and 1915 map (USGS).

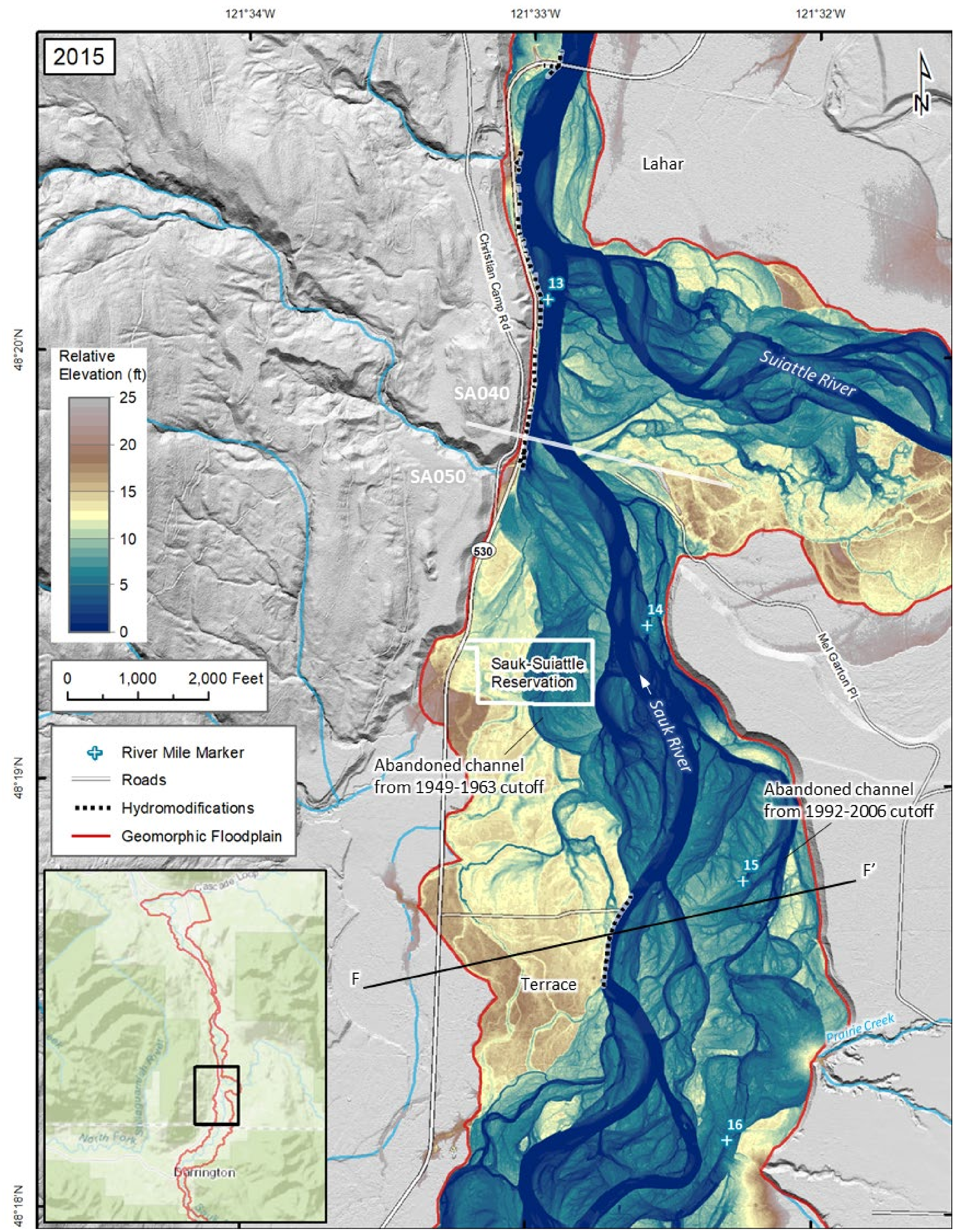


Figure 27. 2015 REM showing floodplain topography and landforms in reach SA040 and lower segments of reach SA050.

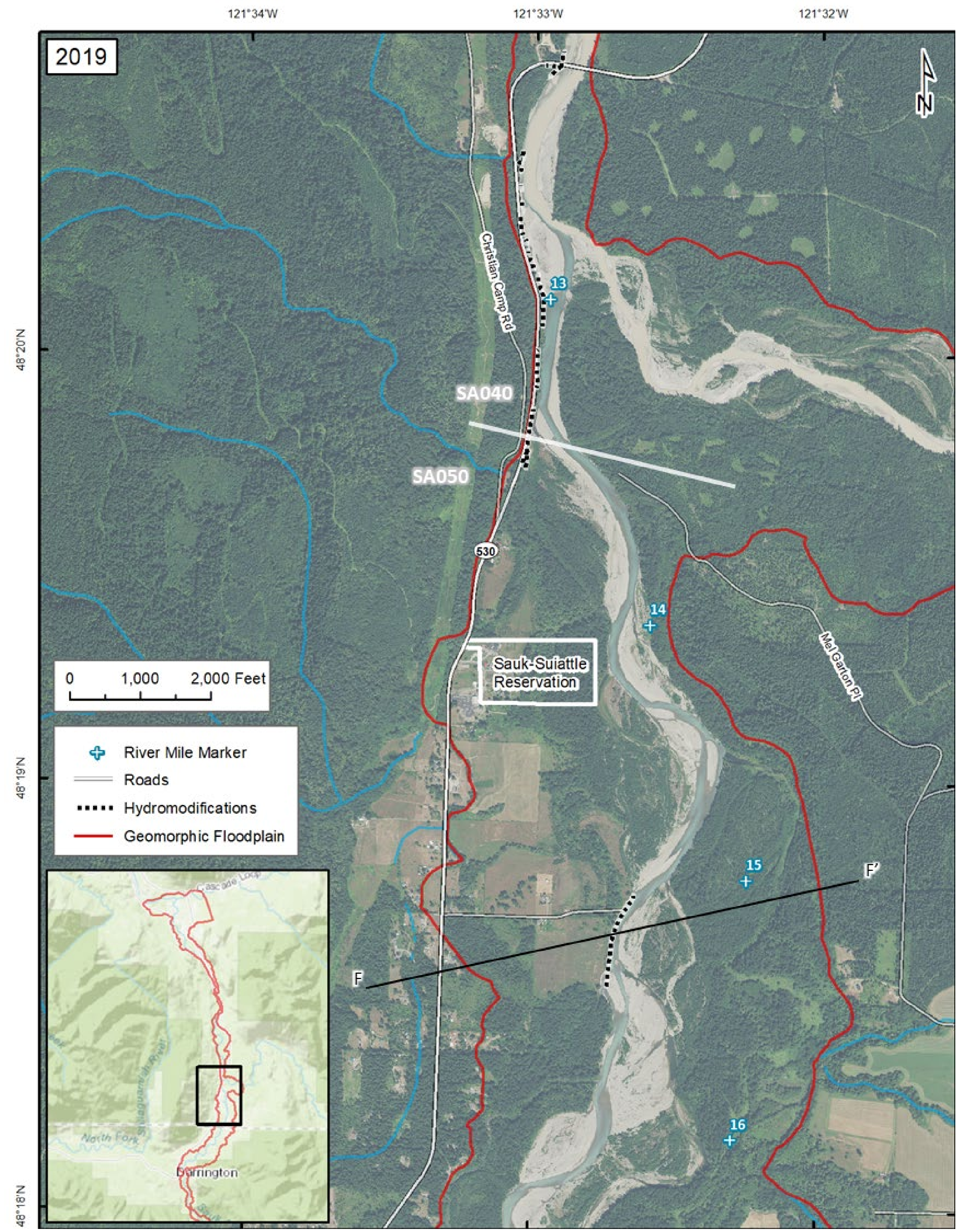


Figure 28. 2019 aerial image of reach SA040 and lower segments of reach SA050.

Figure 29. Cross-sectional profiles from 2015 lidar in reach SA050.

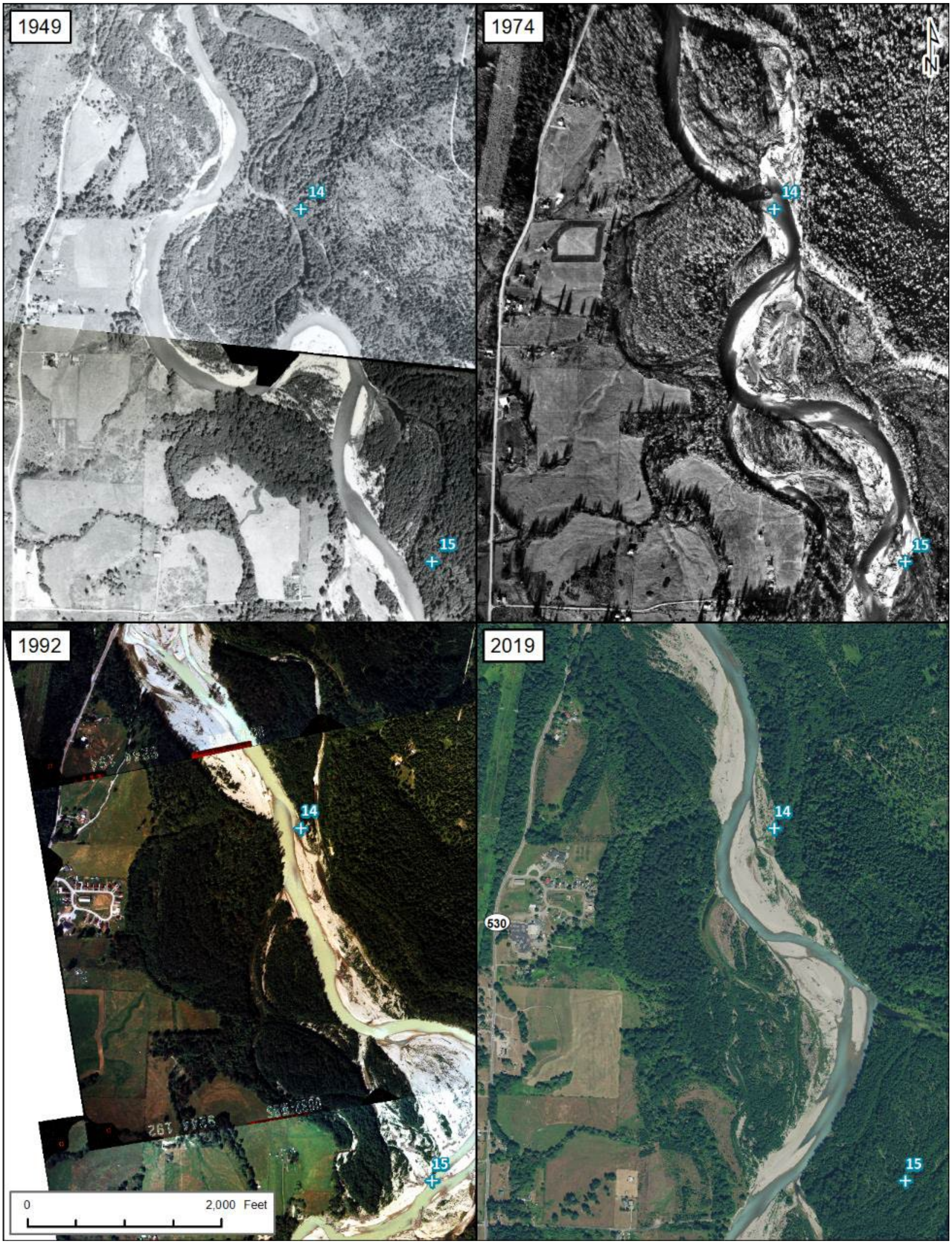


Figure 30. Time series of historical channel changes upstream of the Suiattle River between RM 14 and 15.

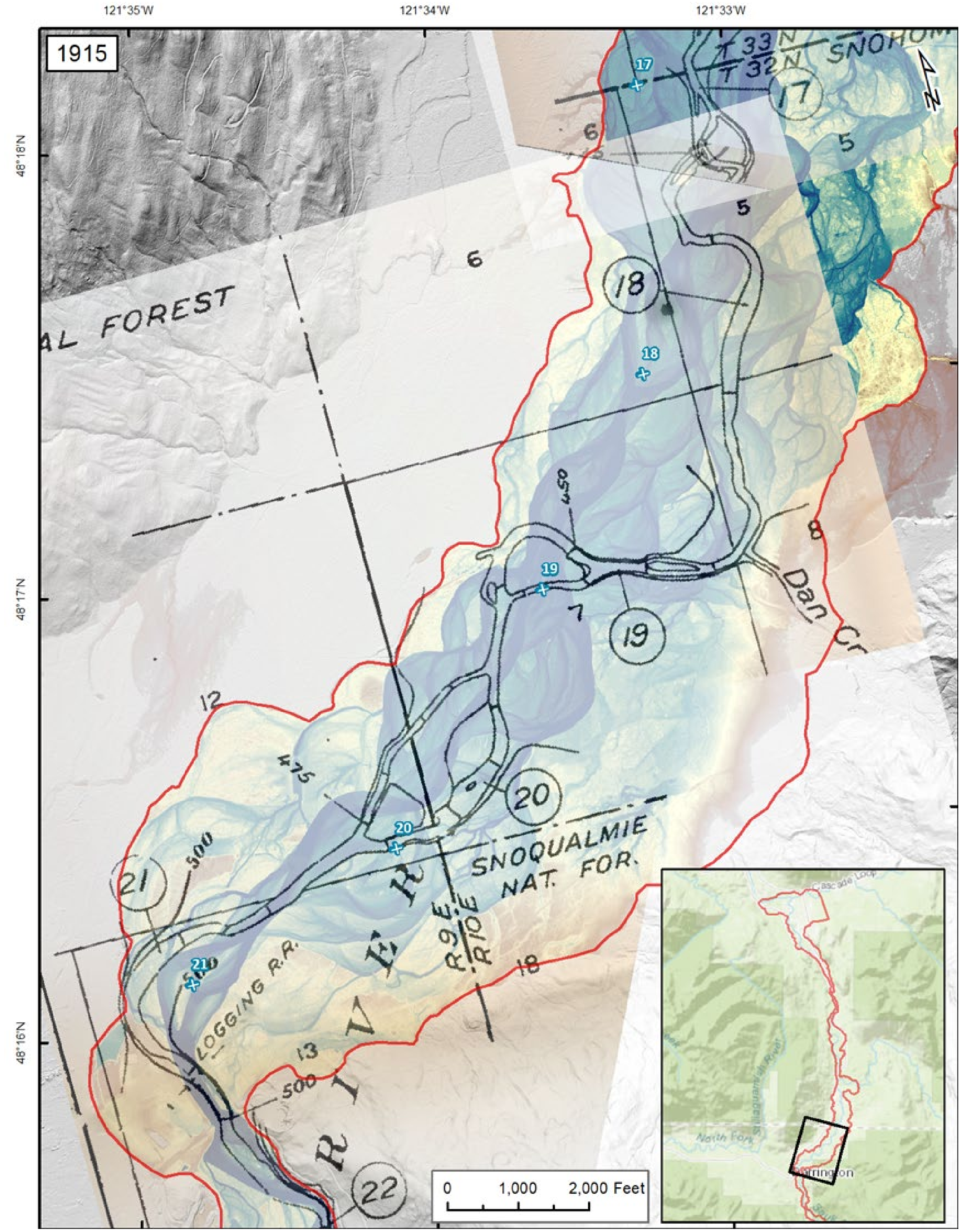


Figure 31. 1915 USGS map showing historical channel locations in reach SA050.

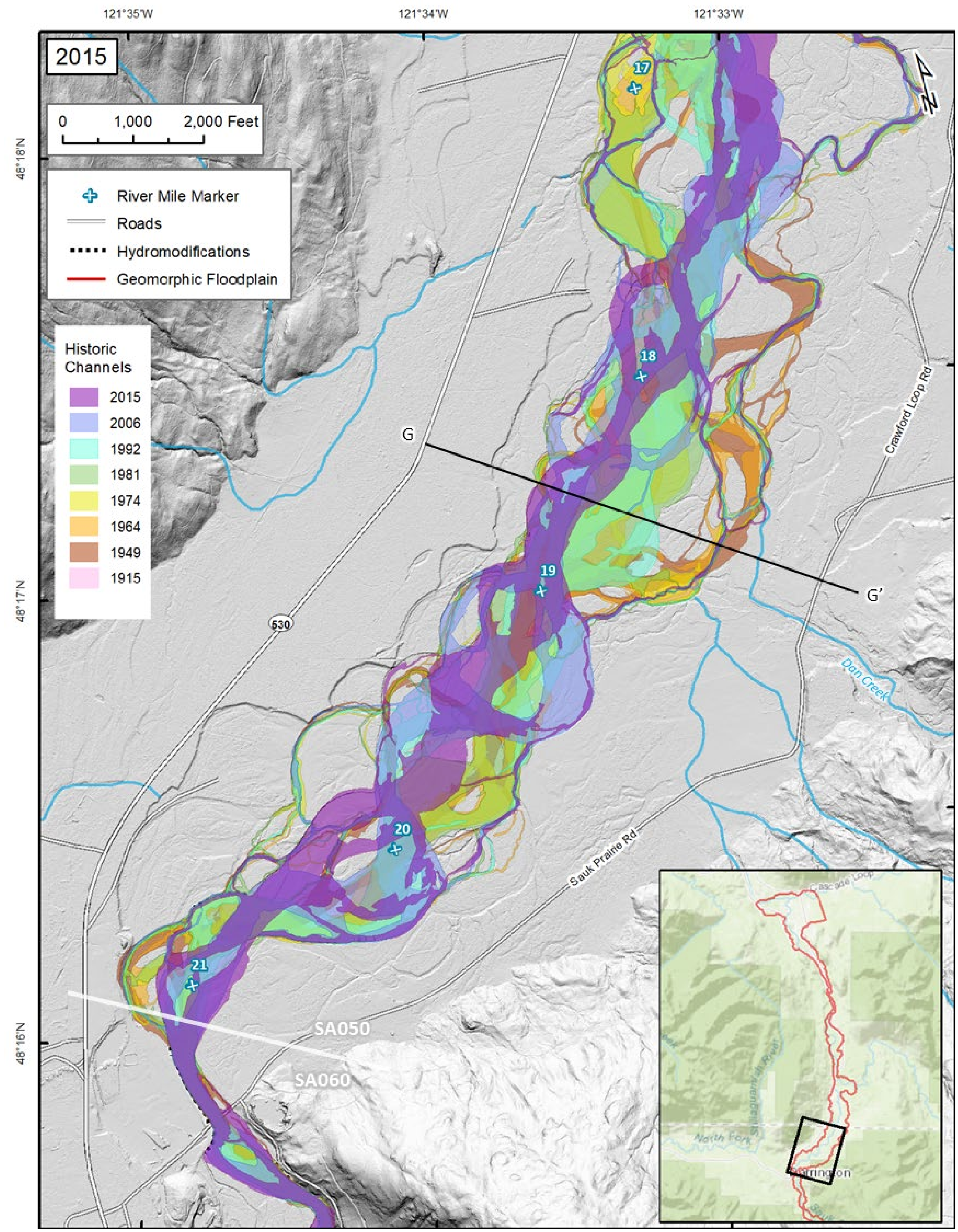


Figure 32. Historic channel features from aerial imagery (data source: SRSC) and 1915 map (USGS).

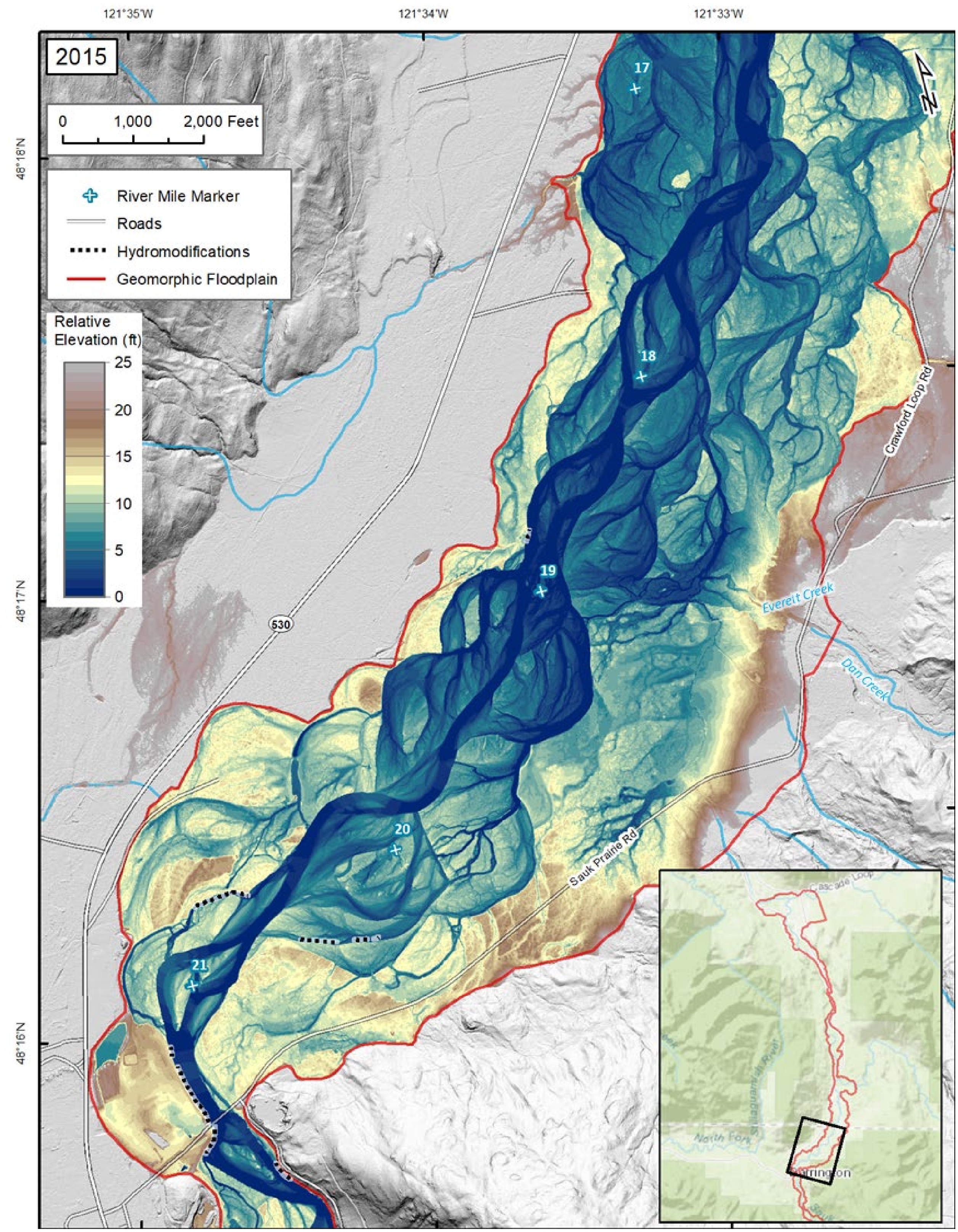


Figure 33. 2015 REM showing floodplain topography and landforms in reach SA050.

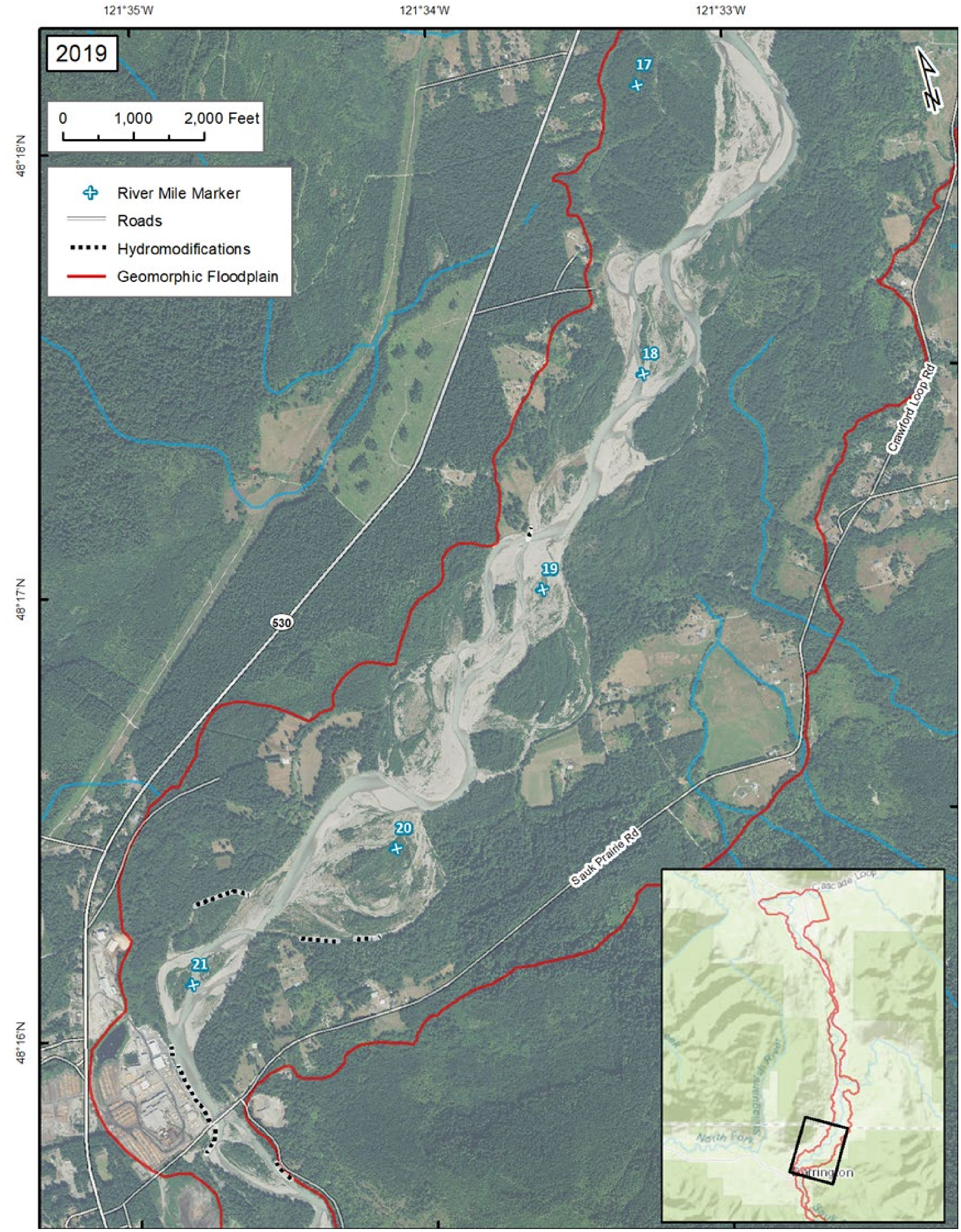


Figure 34. 2019 aerial imagery showing reach SA050.

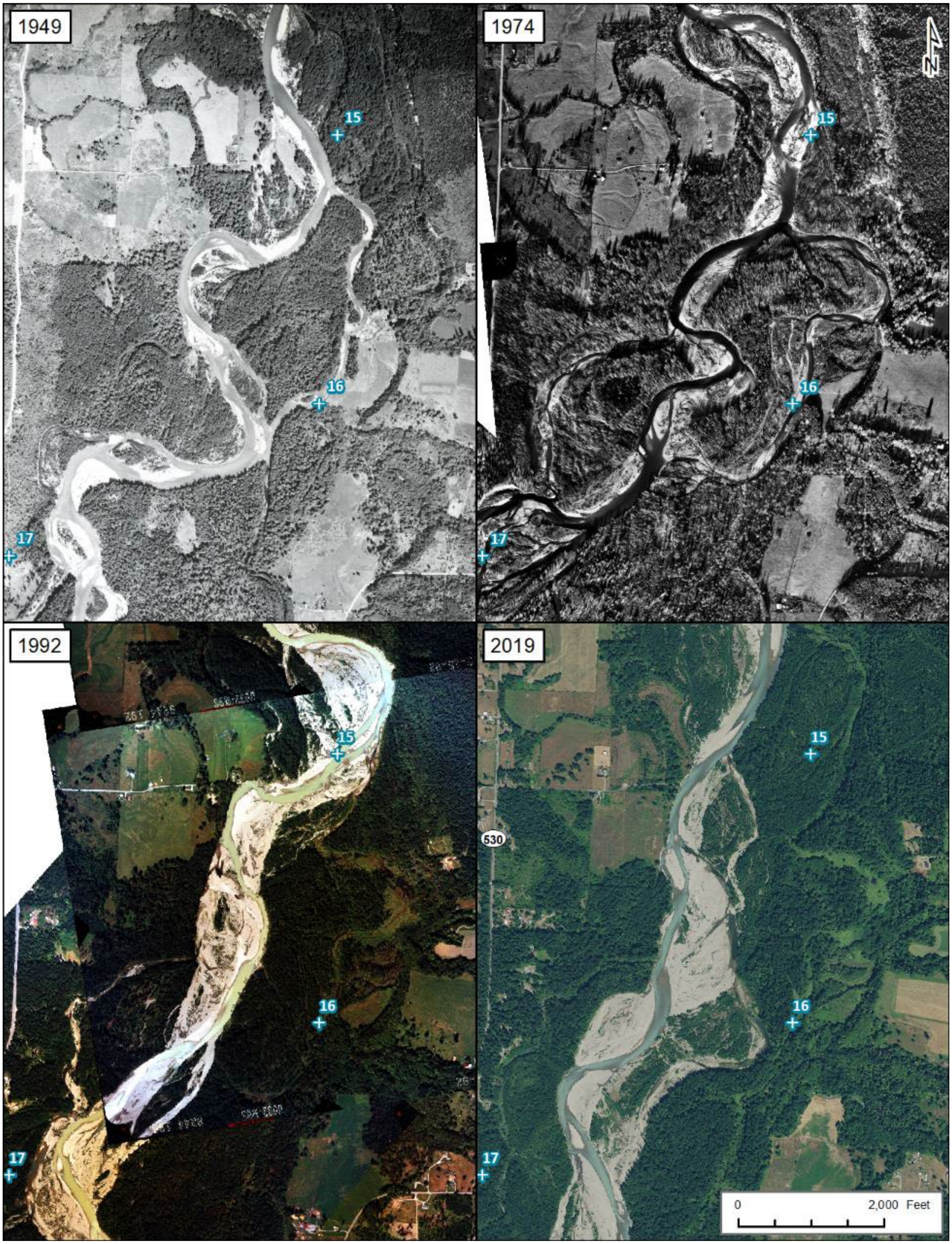


Figure 35. Time series of historical channel changes in reach SA050 between RM 15 and RM 17.

Figure 36. Time series of historical channel changes in reach SA050 between RM 17 and 19.

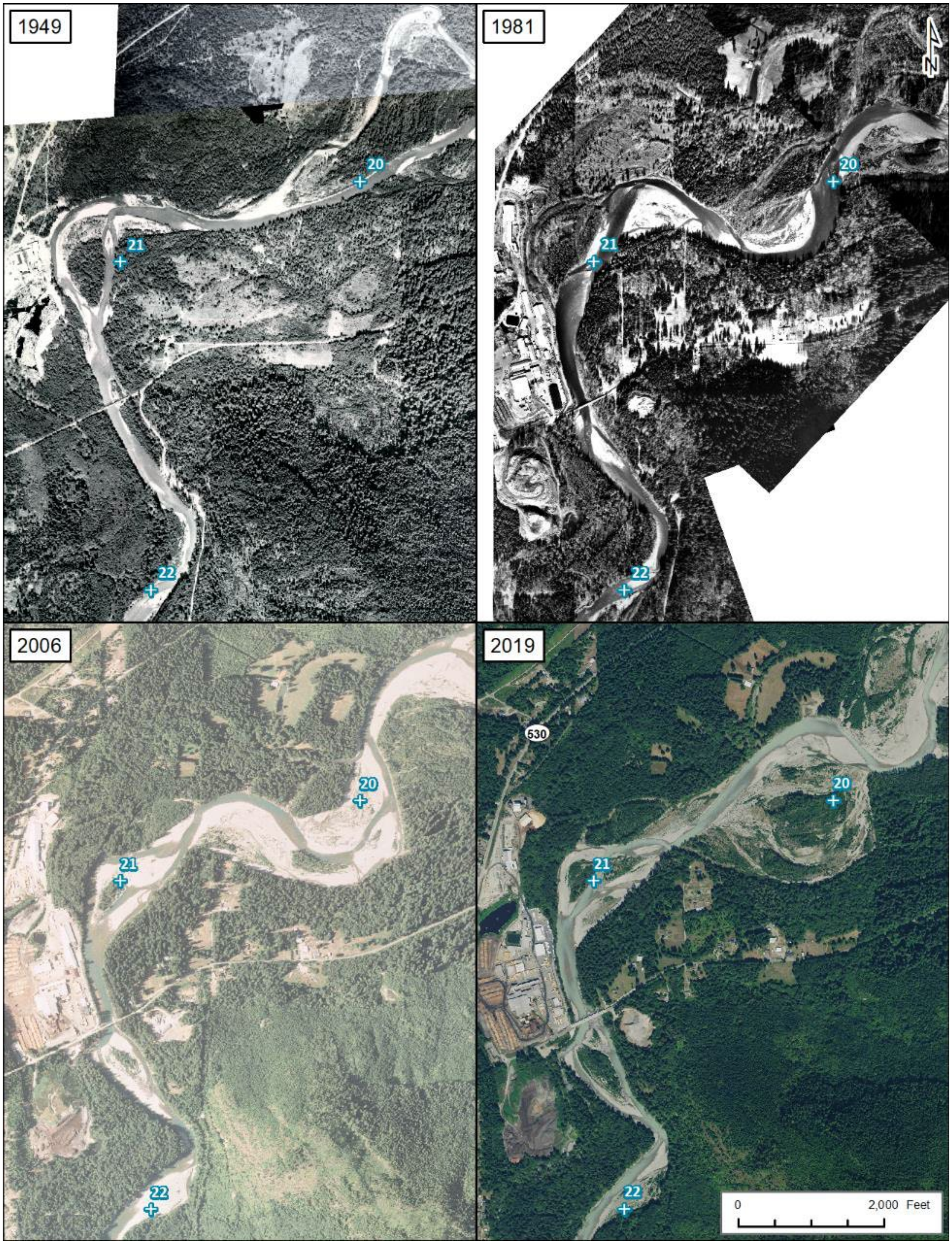


Figure 37. Time series of historical channel changes in reach SA050 between RM 19 and 21.

Reach SA060

The study evaluated a portion of reach SA060 upstream of Darrington to the tributary junction at Clear Creek near RM 25. This segment includes subreaches SA060D, SA060A, and a short segment at the downstream end of subreach SA060B. The area includes the Hampton Lumber Mill site on the left bank floodplain in addition to the Sauk Prairie Road bridge. The channel and floodplain are narrow and confined and the floodplain is the least connected of the Sauk River reaches. Below the Sauk Prairie Rd bridge nearly the entire floodplain is isolated or impaired and the river is restricted to a single thread channel. Above the bridge the river is less confined and splits around a forested island. The channel gradient begins to steepen in SA060D, which continues through to the top of the reach assessment in reach SA060B. Reach maps are included below showing the 1915 channel (Figure 38) and the historic channel alignments digitized by SRSC (Figure 39). The 2015 lidar REM highlighting the floodplain topography and landforms is shown in Figure 40 and 2017 imagery is shown in Figure 41. The channel has remained in a relatively stable alignment since the 1915 map and channel migration has been limited to moderate amount of lateral bank erosion near RM 22 and near RM 24.5.

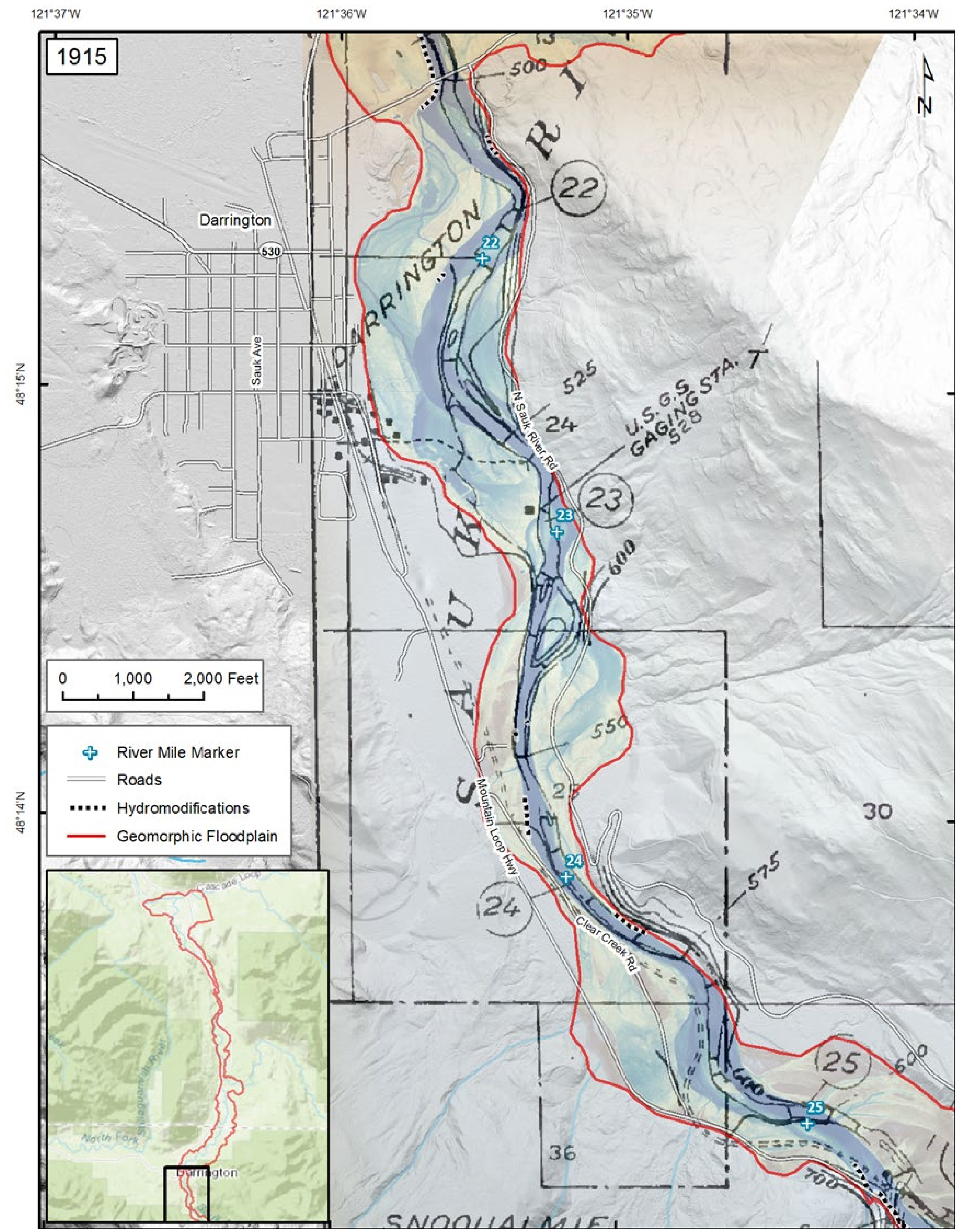


Figure 38. 1915 USGS map showing the historical channel location in reach SA060.

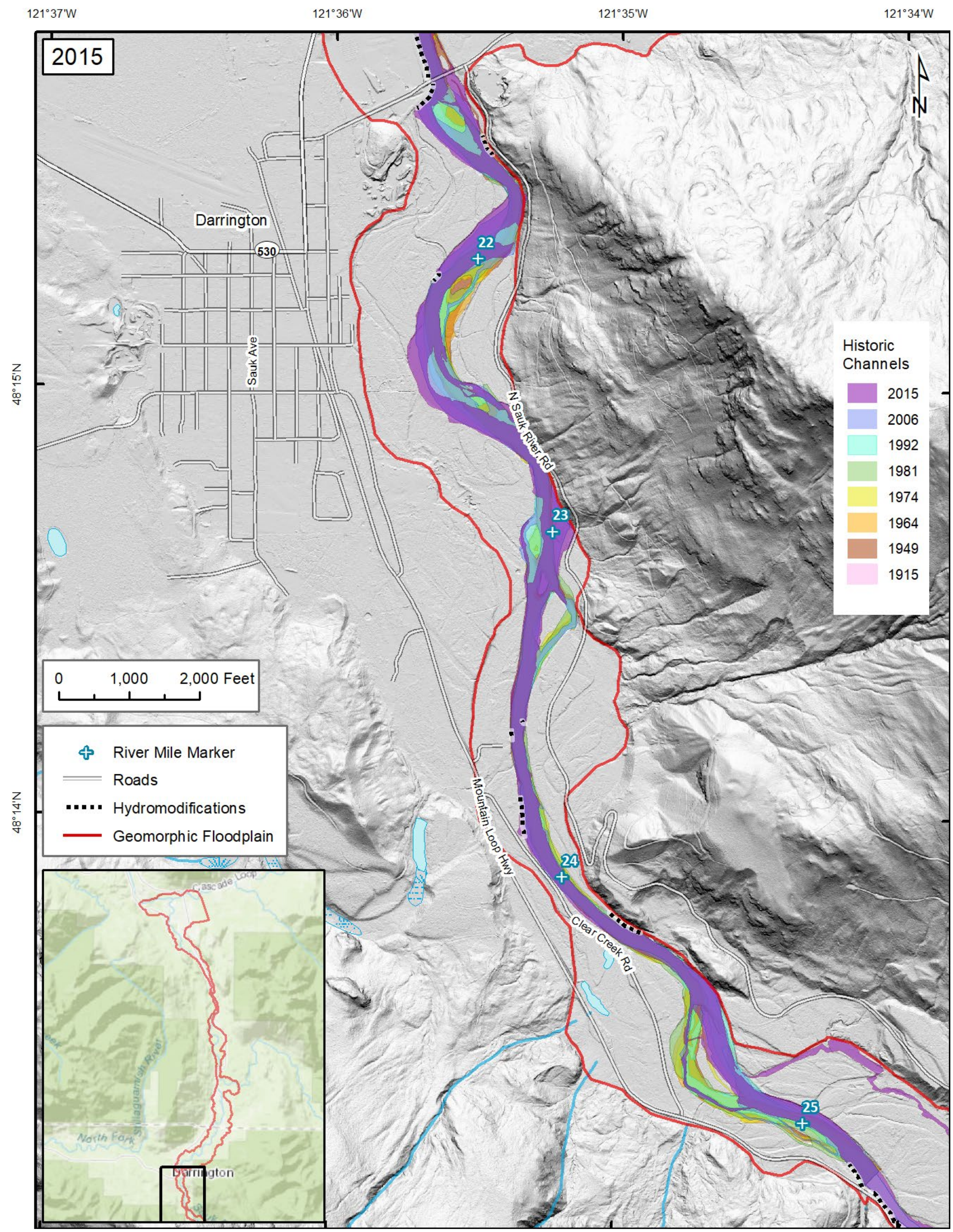


Figure 39. Historic channel features from aerial imagery (data source: SRSC) and 1915 map (USGS).

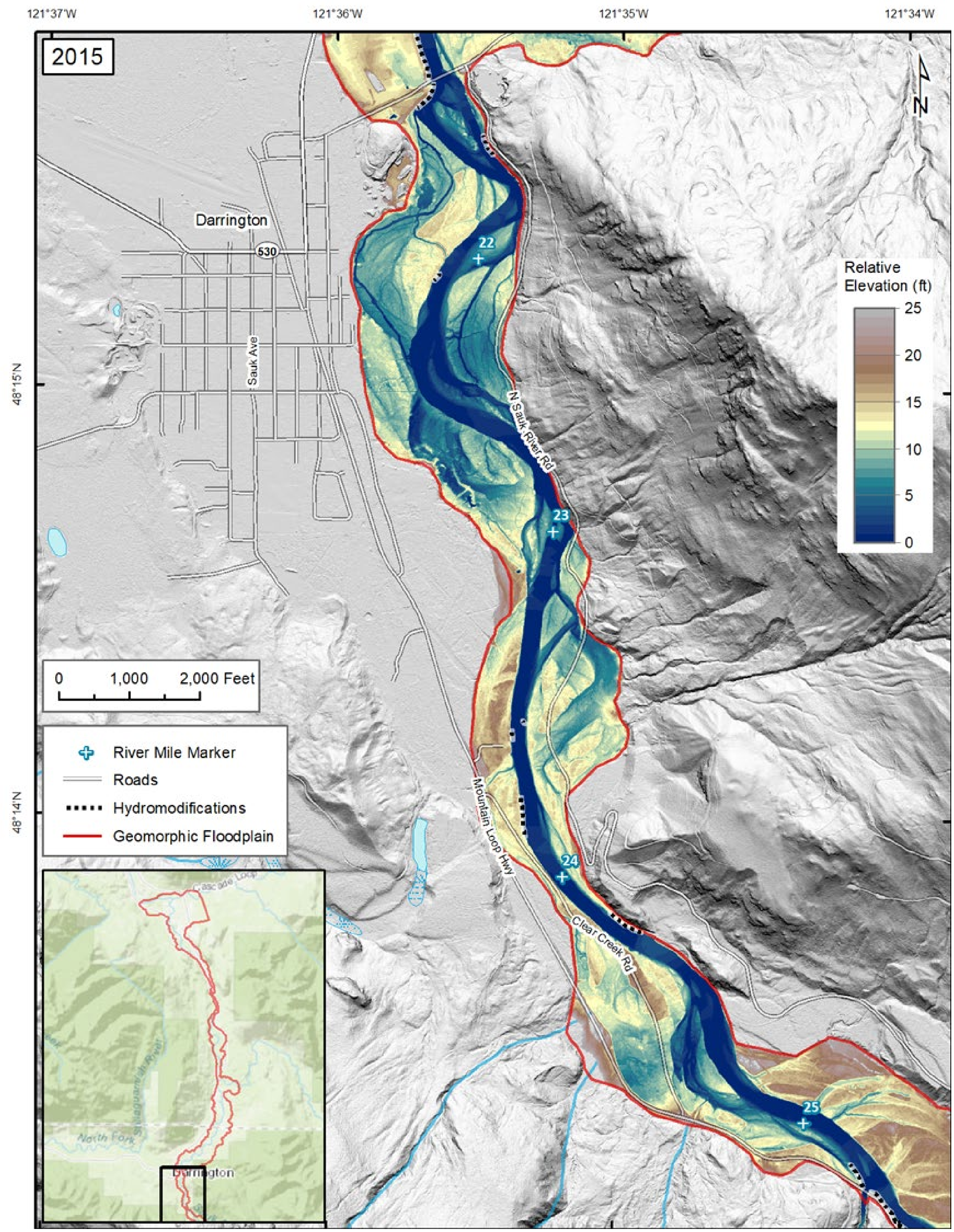


Figure 40. 2015 REM showing floodplain topography and landforms in reach SA060.

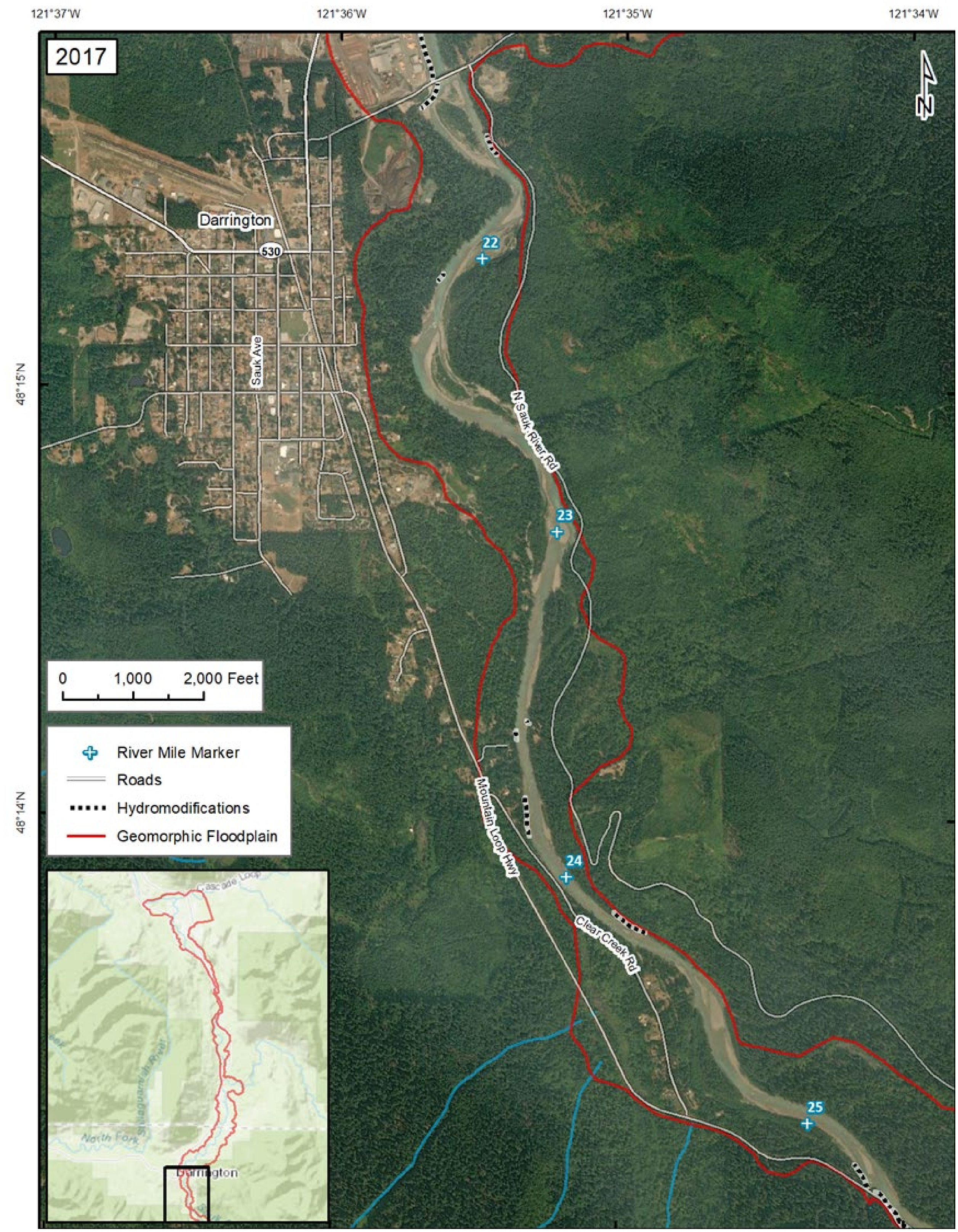


Figure 41. 2017 aerial imagery showing reach SA060.