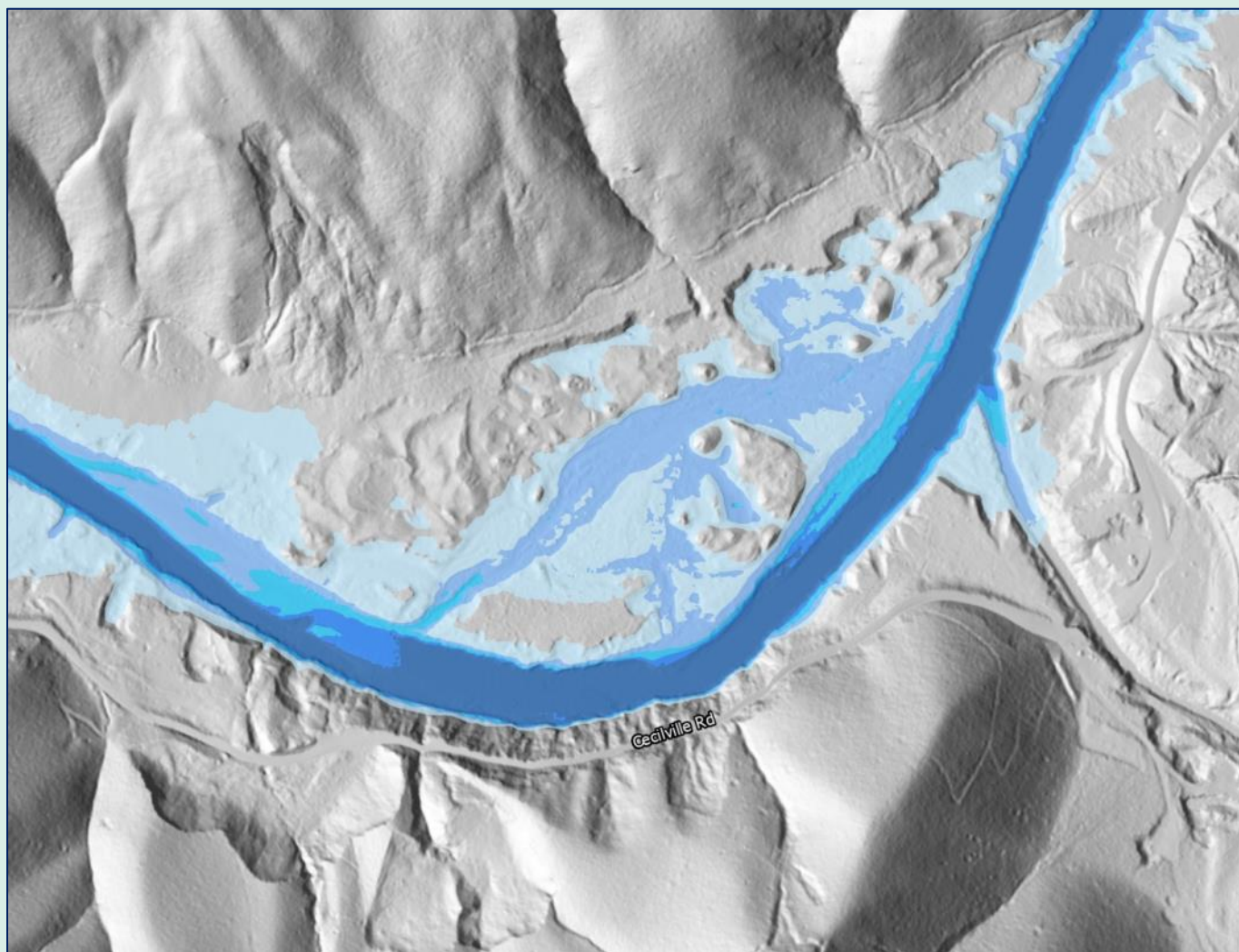


TECHNICAL MEMORANDUM • SEPTEMBER 2014

# LiDAR Analysis of Salmon River Floodplain and Mine Tailing Restoration and Enhancement Opportunities



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Cover photo: LiDAR image of the Knownothing Creek pilot floodplain restoration site with inundation mapping under current conditions showing lack of floodplain inundation and function due to mine tailings.

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Appendix A. Maps of Geomorphic Reaches

# 1 INTRODUCTION

The Salmon River Restoration Council (SRRC) contracted Stillwater Sciences to assess potential opportunities for restoring and enhancing floodplain areas and associated mine tailing piles along 55 miles of the Salmon River from the vicinity of Nordhemeier Creek to the Wilderness Area boundaries (Figure 1). Downstream of the lower project area boundary, the Salmon River is almost entirely bedrock dominated and the few floodplain areas are generally undisturbed by past gold mining. For these reasons this portion of the river was excluded from this analysis and for consideration for restoration treatments. The project area contains alluvial dominated reaches with more extensive floodplains and legacy impact from gold mining with numerous opportunities for meaningful restoration and enhancement. The initial assessment reported herein focuses on results from analyzing LiDAR data that was recently acquired thanks to funding from the US Forest Service and the USFWS Yreka Field Office. The purpose of such restoration and enhancement is ultimately to improve water temperature conditions and increase spring, summer, and winter rearing habitat quantity and quality to benefit coho and spring Chinook salmon.

The process of identifying restoration and enhancement opportunities involved the following two primary steps: (1) delineating channel reaches throughout the Project area based on geomorphic characteristics and floodplain restoration potential; and (2) conducting a more detailed analysis and conceptual restoration design for a pilot site on the South Fork Salmon River in the vicinity of Knownothing Creek (also shown on Figure 1). The tasks performed for the pilot site were designed to test, refine, and demonstrate approaches for assessing restoration opportunities and feasibility so that these methods can be efficiently applied to other priority reaches as appropriate. This technical memorandum describes methods and results of this effort and is supplemented by electronic deliverables (GIS, CAD, and KMZ layers and files).

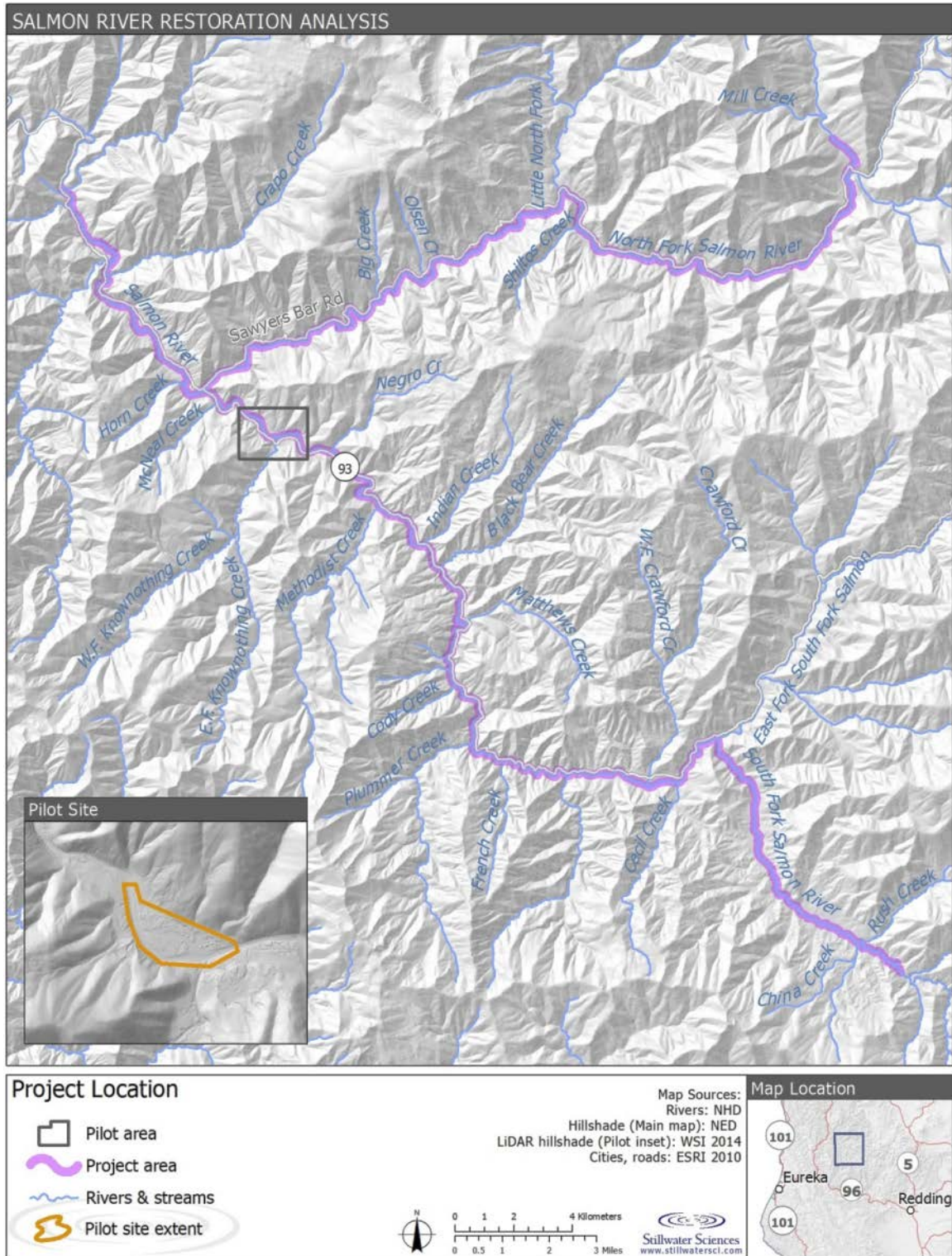


Figure 1. Salmon River project area and the pilot site at Knownothing Creek.

## 2 BACKGROUND

Major stressors to the juvenile life-stages of endangered Klamath Basin coho salmon (SONCC ESU) and depressed spring Chinook salmon include lack of floodplain and channel structure, degraded riparian conditions, and impaired water quality (i.e., elevated water temperatures). The SRRC, in conjunction with the efforts of Project partners, has already completed much of the work needed to address fish passage barriers and sediment delivery from roads within the Salmon River watershed. Restoration and enhancement of degraded floodplain areas within alluvial reaches is the highest priority watershed work remaining to be done, which would address critical aspects of the stressors listed above. Legacy impacts from extensive hydraulic and placer dredge gold mining within the watershed continue to degrade habitat conditions primarily due to mine tailing piles on the floodplain and riparian corridor that prevent inundation and riparian plant succession. In addition to negatively impacting spring rearing and over-wintering habitat, these legacy impacts create a major heating effect rather than the cooling effect of functioning floodplains that contain riparian forests and complex hyporheic and groundwater interactions. Such degraded floodplain and riparian areas are hardened against natural recovery processes and need human intervention to recover within human and salmon population time scales. This type of restoration will provide immediate improvements to rearing and over-wintering habitat and long-term resiliency from global warming impacts (i.e., increased summer water temperatures and winter flooding).

The Salmon River watershed has unique value as a long-term refuge for Klamath Basin coho (plus spring Chinook and summer steelhead) that will significantly contribute to recovery and resiliency of the SONCC ESU for the following reasons: (1) the Salmon River is almost entirely within federal ownership (i.e., USDA Forest Service) and already has significant legislative protections in place; (2) the local community actively supports and is engaged in restoration activities under the leadership of SRRC; (3) the watershed does not contain significant consumptive water uses and lacks the social conflict that is an impediment to restoration in other areas of the Klamath Basin; (4) the Salmon River is the most mountainous and highest of all Klamath River sub-basins, which will allow snow pack and snowmelt run-off to persist as global warming advances; and (5) the Salmon River is more removed from Klamath Basin hatcheries and has less risk of being genetically compromised than other sub-basins or populations. To realize this potential, the Salmon River's historic floodplain areas and associated mine tailing piles need to be restored as soon as possible. Research on the effectiveness of restoration treatments for compensating global warming impacts have shown restoring floodplain connectivity to be the most effective treatment (Beechie et al. 2012)

## 3 TASK 1—PROJECT-WIDE REACH DELINEATION

The first activity performed under this task was to transform the LiDAR data collected by Watershed Sciences Inc. (WSI) in the winter and spring of 2014 into a format that facilitated use in ArcGIS. This involved creating a mosaic of bare earth LiDAR tiles for the project area. Raster files of LiDAR hillshade are provided as electronic deliverables. Maps showing the LiDAR hillshade in areas with high restoration potential are included in Appendix A.

### 3.1 Geomorphic Delineation

The next step under Task 1 was to separate the project area into geomorphic reach types (alluvial versus bedrock dominated) based on channel and valley width, presence of alluvial channel and

floodplain characteristic, and extent of bedrock control. Less confined reaches with cobble-gravel bars, low alluvial floodplains, and less bedrock control historically offered more spring rearing and over-wintering habitat for anadromous salmonids. A combination of 2014 LiDAR data (WSI) and 2013 aerial imagery was used to delineate the approximate extent of the 100-year floodplain throughout the project area. This estimated delineation was based on river bank elevations in relation to the channel thalweg as well as topographic evidence of historic fluvial processes seen in the LiDAR data. In general, the floodplain delineation was conservative, erring on the side of delineating a broader area for this initial analysis so as to not exclude areas that could be potentially restored to a functioning floodplain, especially in areas where historic mining activity and tailing piles were evident. Six polylines were digitized in ArcGIS representing the right and left bank floodplain extent for the Salmon River mainstem, and North Fork and South Fork respectively (refer to the shapefile: *floodplain.shp* within the ArcGIS map package *SalmonRestoration\_Phase1.mpk*).

### 3.2 Delineation of Restoration Potential

In addition to geomorphic conditions, a key component in assessing floodplain restoration potential is the level of anthropogenic disturbance. For this project, areas of mining disturbance within and adjacent to the 100-year floodplain were also digitized (refer to the shape file: *tailings.shp*) and included on the LiDAR hillshade reach maps in Appendix A. The potential for floodplain habitat restoration and enhancement within the project area was then determined based on geomorphic reach type, degree of legacy mining disturbance, and presence of existing human infrastructure.

Restoration potential for each reach was determined according to the following criteria:

- High to moderate potential—wide or moderately wide floodplains.
- Low potential—narrow reaches dominated by bedrock.

Floodplain widths are defined as follows:

Main-stem Salmon River: Narrow < 400' ft.; Moderate 400' to 600'; Wide > 600'.

North and South Fork Salmon River: Narrow < 300'; Moderate 300' to 450'; Wide > 450'.

The project area was divided into 25 reaches according to these criteria. The reaches are described in Table 1 and shown in Figure 2 (and in more detail in Appendix A). These reaches can also be viewed in Google Earth using the kmz file: *RestorationPotential.kmz*. Reaches are included in the shape file: *Reaches\_RestPotential.shp*. Results from Task 1 can be viewed in the ArcGIS map package file: *SalmonRestoration\_Phase1.mpk*.

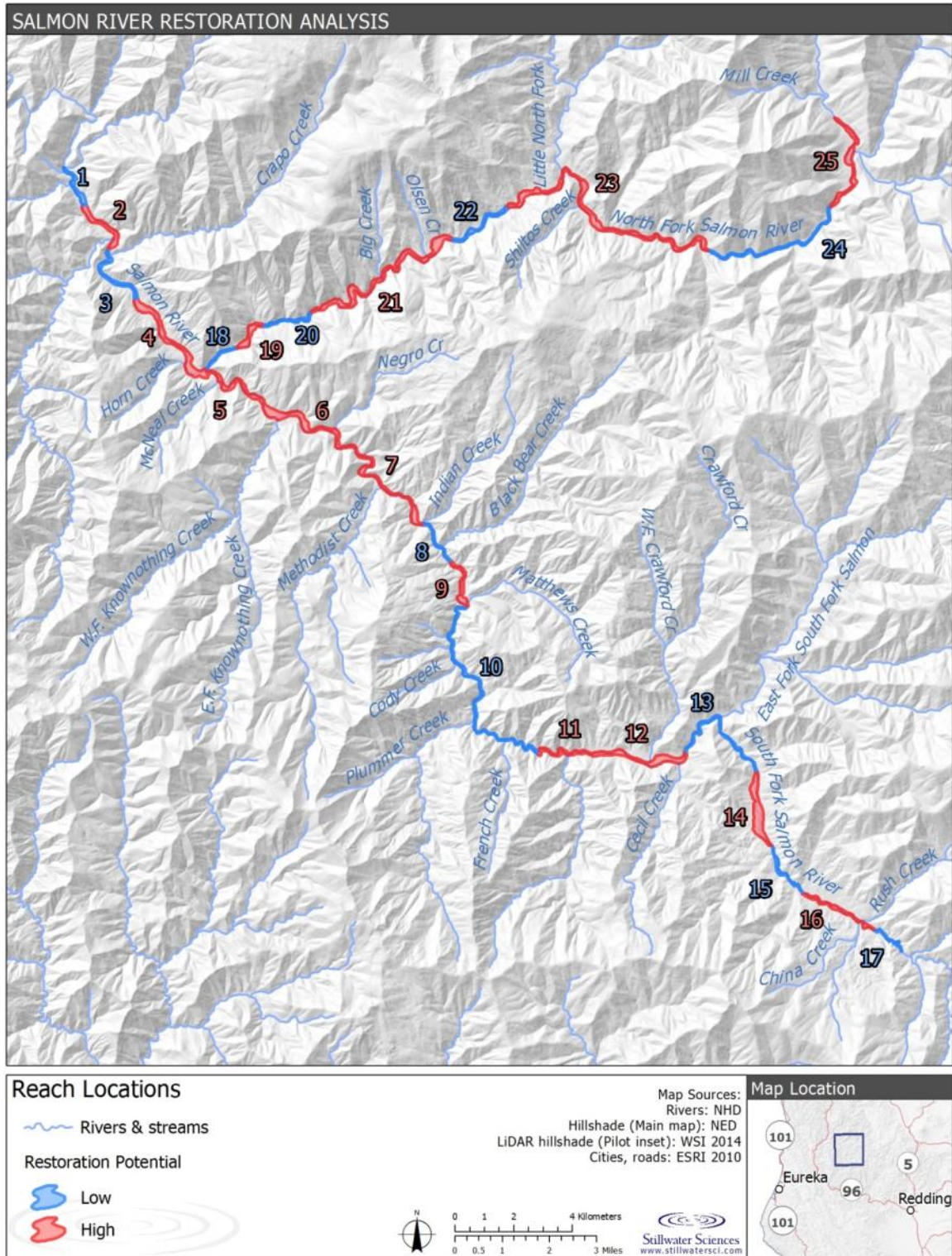


Figure 2. Project-wide geomorphic reach delineation map.



Table 1. Summary of attributes of geomorphic reaches (high to moderate restoration potential reaches shaded in grey, which total 37 of the 55 river miles in the project area).

Reach #	River segment	Length (miles)	Width	Average width (ft)	Bedrock	Mine tailings	Restoration potential	Notes/ Comments
1	Mainstem	1.0	Narrow	350	Yes	No	Low	Downstream extent
2	Mainstem	1.3	Moderate	540	Yes	Yes	High	
3	Mainstem	1.7	Narrow	280	Yes	No	Low	
4	Mainstem	2.4	Wide	740	No	Yes	High	Confluence with NF & SF
5	SF	1.4	Moderate	410	Yes	Yes	High	Confluence with mainstem
6	SF	1.8	Wide	750	Yes	Yes	High	
7	SF	4.2	Moderate	360	Yes	Yes	High	
8	SF	1.1	Narrow	180	Yes	No	Low	
9	SF	1.3	High	470	Yes	Yes	High	
10	SF	5.1	Narrow	230	Yes	No	Low	
11	SF	1.5	Moderate	310	Yes	No	High	
12	SF	2.3	Moderate	440	No	Yes	High	Cecilville reach
13	SF	2.7	Narrow	190	Yes	No	Low	
14	SF	1.7	Wide	620	No	Yes	High	
15	SF	1.4	Narrow	190	Yes	No	Low	
16	SF	1.8	Moderate	320	No	Yes	High	
17	SF	0.9	Narrow	130	No	No	Low	Upstream extent
18	NF	0.9	Narrow	190	Yes	No	Low	Confluence with Mainstem
19	NF	1.0	Wide	500	Yes	Yes	High	
20	NF	1.2	Narrow	220	Yes	Yes	Low	
21	NF	4.9	Moderate	400	Yes	Yes	High	
22	NF	1.5	Narrow	270	Yes	No	Low	
23	NF	6.4	Moderate	340	Yes	Yes	High	Sawyers Bar reach
24	NF	3.4	Narrow	180	Yes	No	Low	
25	NF	2.5	Moderate	420	No	No	High	Upstream extent

## 4 TASK 2—PILOT SITE ANALYSIS AND CONCEPTUAL DESIGNS

To test, refine, and demonstrate approaches for analyzing restoration feasibility and opportunities at a project site scale within a high potential reach, further analysis and conceptual design development was completed for a pilot site in the vicinity of Knownothing Creek (Figure 1, Figure 2 reach 6). This task began with the creation of a shape file with one foot contours derived from the LiDAR data in ArcGIS. This shape file was exported from ArcGIS and imported into AutoCAD Civil3D 2014 (CAD) where the existing ground surface was created using the contours. This existing ground surface was used as the basis for existing conditions hydraulic modeling and conceptual design work in CAD.

### 4.1 Hydraulic Modeling

To better understand floodplain dynamics, hydraulics within the pilot site were modeled using the US Army Corps of Engineers' *Hydrologic Engineering Center's River Analysis System* (HEC-RAS). HEC-RAS is an integrated system of software that performs one-dimensional steady and unsteady hydraulic calculations. The model was developed with cross-sections spaced every 200 feet (Figure 3). The site topography used as the baseline for the model was imported from CAD.

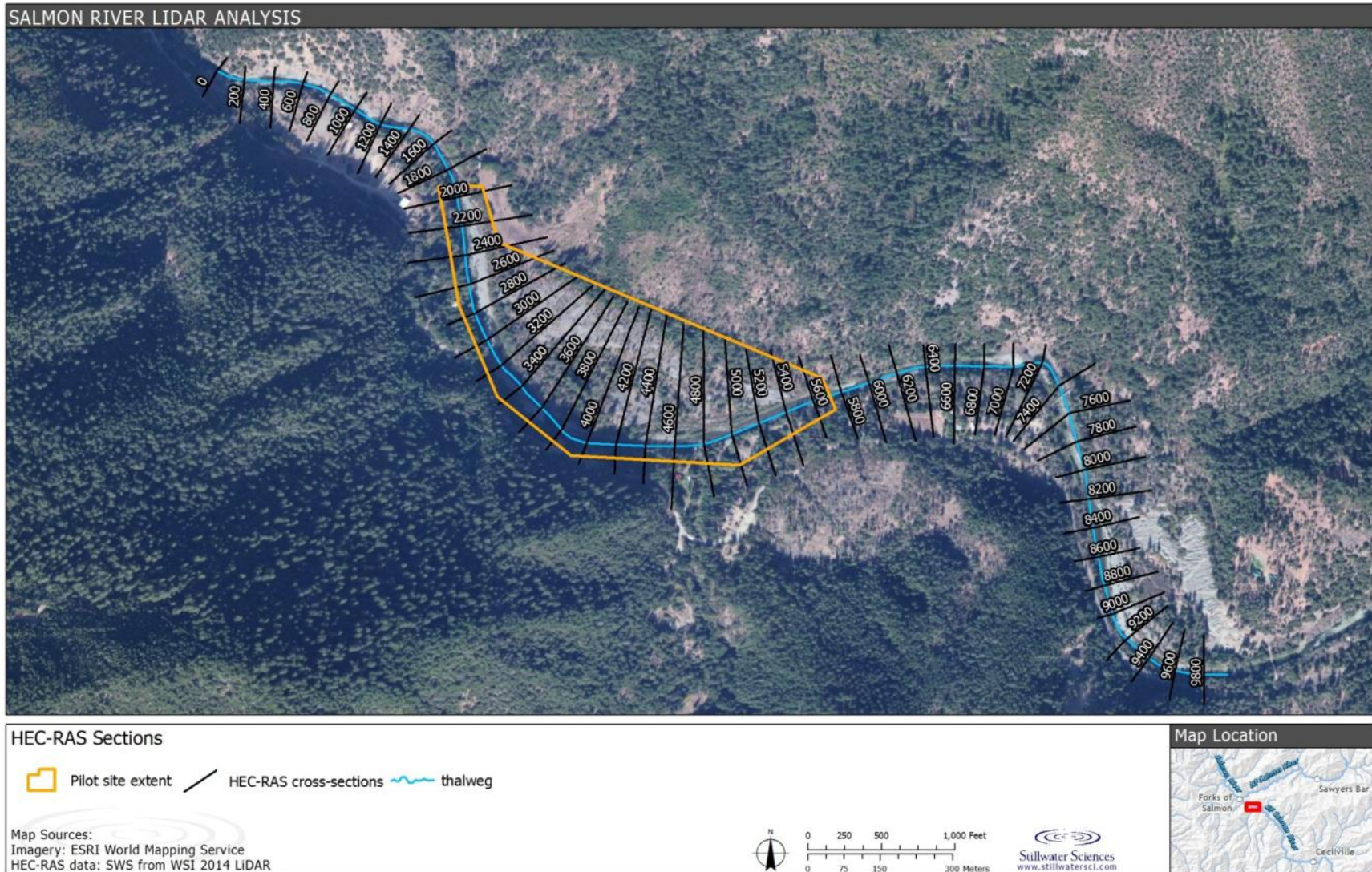


Figure 3. HEC-RAS cross sectional layout.

Floodplain inundation within the pilot site was modeled at eight discharges ranging from the 20% exceedance flow to the 100-year recurrence interval flood flow (Table 2). Exceedance flows and recurrence intervals are two different methods of identifying reference discharges significant to habitat function and restoration design. Exceedance flows represent the percent of time throughout the year when flows are above a specific discharge. Recurrence interval or flood frequency flows represent higher flows that are expected to occur at a specific frequency; i.e., a 100-year flow would be expected to occur every 100 years on average. Reference discharges determined by these methods have biological significance for restoration, especially related to spring rearing and over-wintering habitat for salmonids. The 20% exceedance flow represents typical spring base flows (i.e., average snowmelt flows) that commonly occur during important rearing periods for juvenile salmonids. Higher flows, especially those from 0.5 of bankfull to 2-year discharges, are also biologically significant because they occur during most winters and are swift enough to flush salmonids out of the system and/or cause mortality if insufficient low-velocity floodplain habitat is available at such flows. For this analysis, 1.5-year recurrence interval flows are considered to be synonymous with “bankfull” flows.

Table 2. Discharge estimates at the pilot restoration site near Knownothing Creek on the South Fork Salmon River.

<b>20% Exceedance discharge (cfs)</b>	<b>10% Exceedance discharge (cfs)</b>	<b>0.5 Bankfull discharge (cfs)</b>	<b>Bankfull discharge (cfs)</b>	<b>2-Year discharge (cfs)</b>	<b>5-Year discharge (cfs)</b>	<b>10-Year discharge (cfs)</b>	<b>100-Year discharge (cfs)</b>
1,100	1,600	2,900	5,900	8,100	12,800	18,400	56,800

Because no discharge records exist at the pilot site, flows were estimated using data from the USGS Gaging Station No. 11522500 (Salmon River at Somes Bar). Exceedance and recurrence interval flows for the pilot site were calculated differently. Exceedances at the pilot site were estimated by prorating exceedances calculated from average daily discharge at USGS No. 11522500, and proration was conducted using the ratio of drainage areas at USGS No. 11522500 (751 mi<sup>2</sup>) and the pilot site (285 mi<sup>2</sup>).

Recurrence interval flows were determined by averaging two flow estimation methodologies. The first method utilized a Log-Pearson Type III distribution to determine the peak flows at the USGS Gage No. 11522500, these values were then prorated by the ratio of drainage areas (751 mi<sup>2</sup>: 285 mi<sup>2</sup>). The second method also used the Log-Pearson Type III distribution, but flows at the pilot site were determined using the USGS formula for calculating magnitude and frequency of floods in California:

$$Q_u = Q_g(A_u/A_g)^b$$

Where: b = 0.9 for 2 year event and b = 0.87 for 100 year event

Q<sub>u</sub> = Ungauged discharge

Q<sub>g</sub> = Gauged discharge

A<sub>u</sub> = Ungauged drainage area

A<sub>g</sub> = Gauged drainage area.

This combined approach led to a 5% to 7% increase in peak flow estimates from the simple drainage area proration. Values in Table 2 are rounded to two significant digits to reflect the uncertainty of these estimates.

Throughout the pilot site, a Manning's  $n$  value of 0.035 was used for the channel roughness and a value of 0.055 was used for floodplains roughness in the HEC-RAS model. A mixed flow regime (subcritical and supercritical) was modeled with normal depth upstream and downstream boundary conditions. The HEC-RAS model is provided in the following folder: *Salmon\_Pilot1\_HEC-RAS*, and the output water surface elevations provided the basis for inundation mapping at the pilot site.

#### 4.2 Existing Conditions Inundation Mapping

Results from the HEC-RAS model were exported into ArcGIS to create inundation maps for the pilot reach that included the 20% exceedance flow, 0.5-bankfull discharge, 2-year discharge, 10-year discharge, and 100-year discharge (Figure 4). Results from the inundation mapping with the relic mine tailing piles under existing conditions highlight the near complete lack of floodplain habitat at the pilot site. Minimal floodplain inundation occurs at flows below the 2-year recurrence interval of 8,100 cfs. This is due to a combination of mine tailing piles on the floodplain and the presence of bedrock at the surface or shallow sub-surface. These inundation surfaces are also defined as polygons in the geodatabase file: *PilotSite.gdb* within the ArcGIS map package *SalmonRestoration\_Phase1.mpk*.

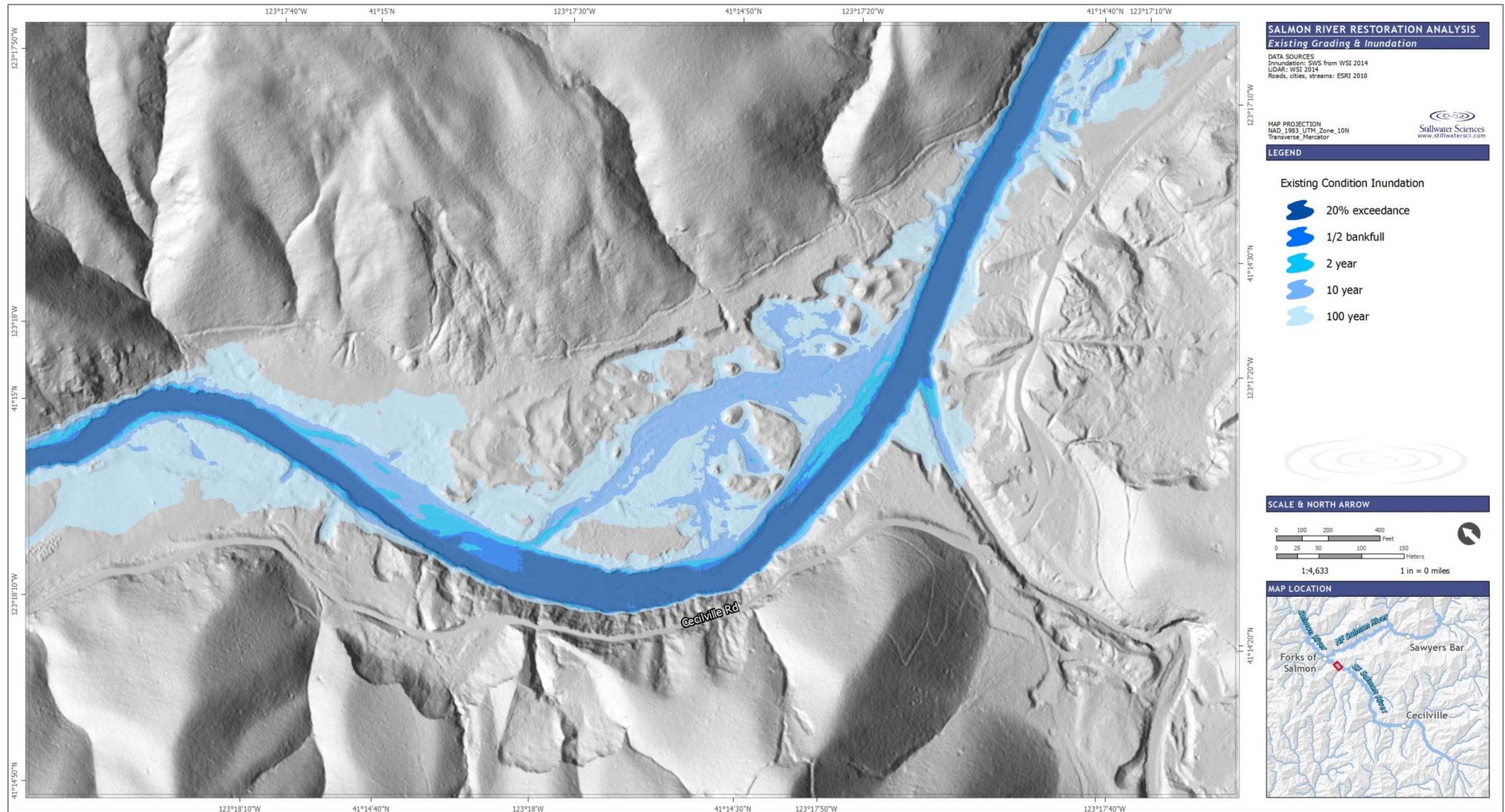


Figure 4. Existing conditions inundation mapping at the pilot site showing the lack of floodplain inundation and associated fish habitat.

### 4.3 Detailed Geomorphic Mapping at the Pilot Site

Geomorphic mapping is an important step in the restoration design process because it identifies areas with similar genesis, form, material composition, and geomorphic process that are suitable for different types of enhancement activities, in particular feasibility of excavation. A geomorphic map of the pilot site was created based on the LiDAR (Figure 5), aerial imagery (Figure 6), and results from the inundation mapping. The pilot site was divided into ten geomorphic units described below and shown on Figure 7:

1. Wetted Channel
2. Mine Tailings
3. Bedrock
4. Strath Terrace above 100-year floodplain
5. Channel inundated by 0.5 bankfull discharge
6. Channel inundated by bankfull discharge
7. Channel inundated by 5-year discharge
8. Terrace inundated by 10-year discharge
9. Terrace inundated by 100-year discharge
10. Alluvial Fan.

These geomorphic units are defined as polygons in the shape file: *GeomorphUnits.shp* within the ArcGIS map package: *SalmonRestoration\_Phase1.mpk* and in the kmz file *Pilot\_Geo\_Units\_v3.kmz*.

For this project, geomorphic features such as mine tailings, bedrock, and strath terraces (bedrock with some overlying loose sediment) above the 100-year floodplain were the most critical mapping units. These units helped to define the footprint of the conceptual design with restoration focused in areas with mine tailings and alluvium and excluded from areas with bedrock and high natural strath terraces. Areas of the channel and floodplain that were inundated at specific flows were also important for the design because these delineations helped to define relative elevation above the thalweg, and thereby the extent and volume of excavation and grading required to restore and enhance the floodplain within that area.

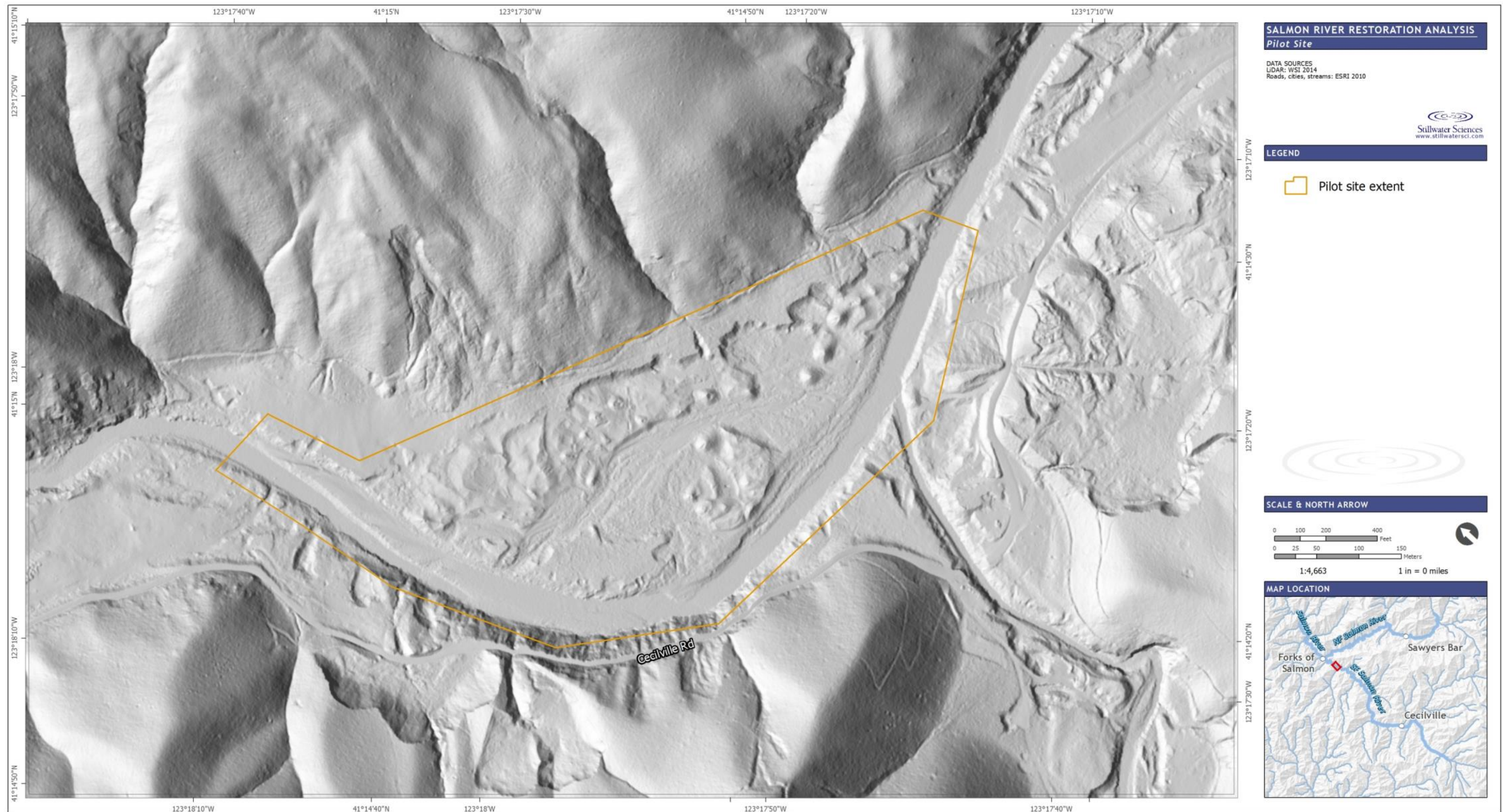


Figure 5. Existing conditions LiDAR of the pilot site.



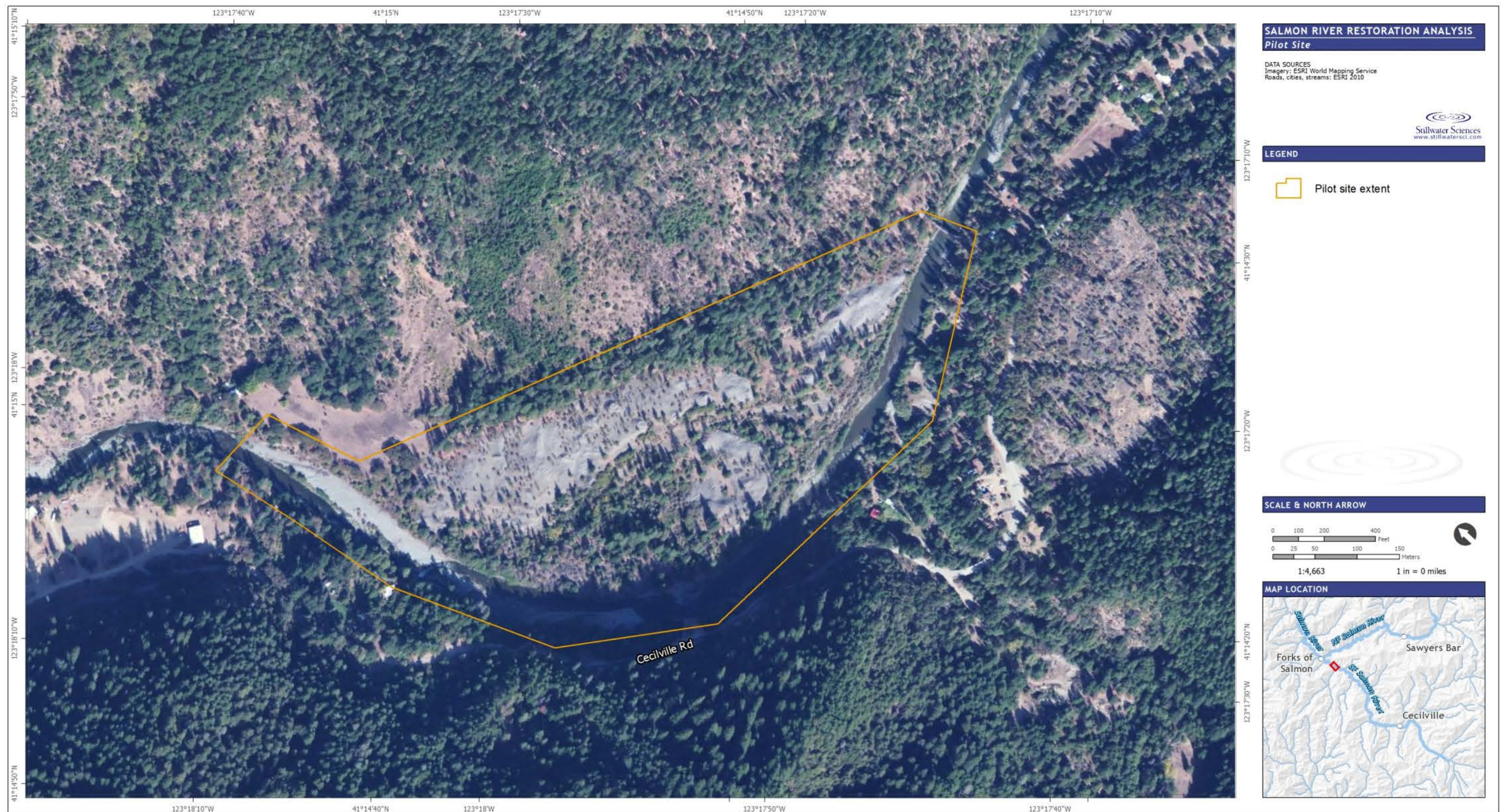


Figure 6. Aerial imagery of existing conditions at the pilot site.

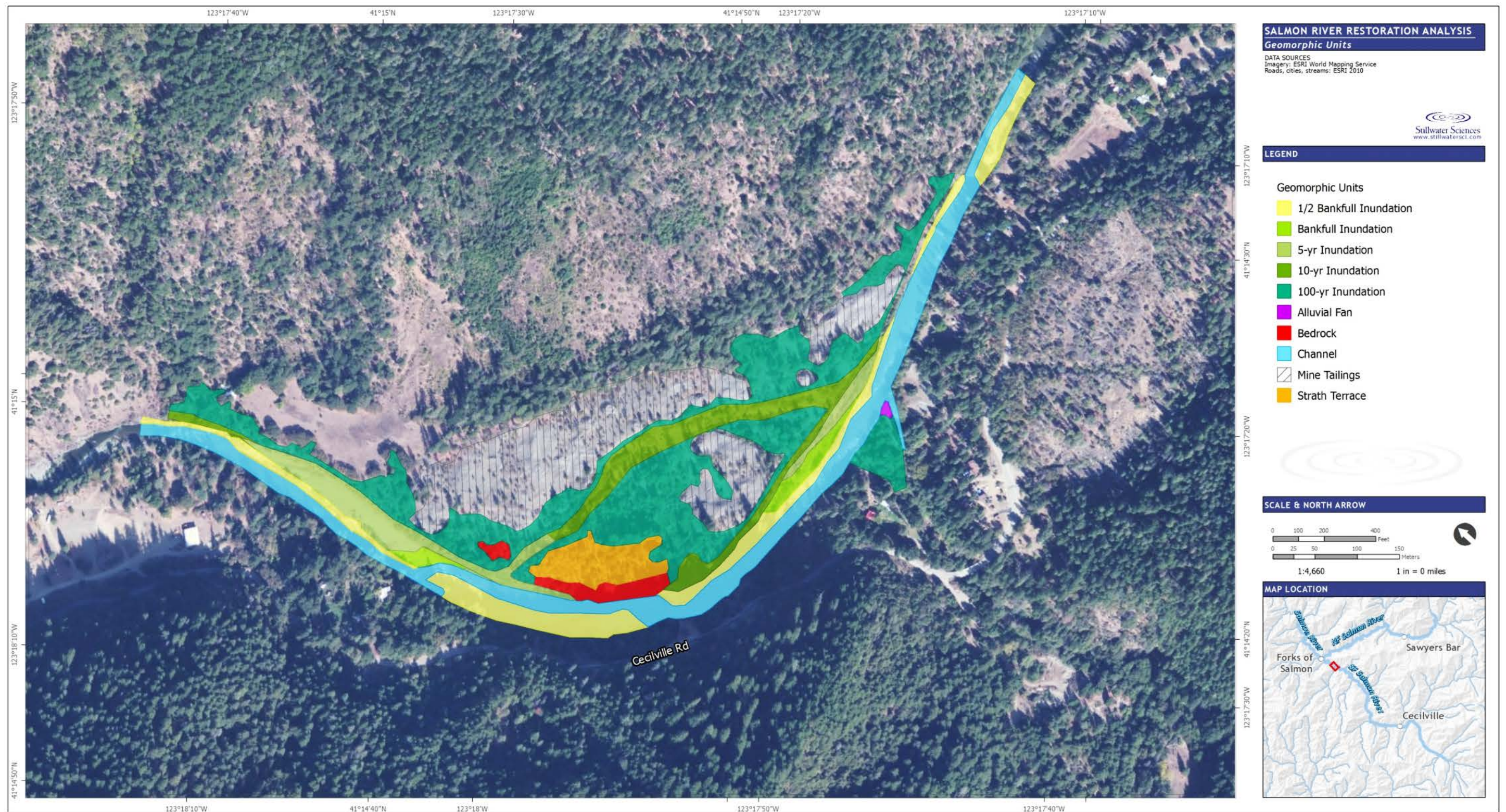


Figure 7. Pilot site geomorphic mapping.

#### 4.4 Pilot Site Conceptual Restoration Design

A conceptual restoration design for the pilot site was developed based on existing site constraints and opportunities and habitat objectives with an emphasis of spring rearing, over-wintering, and summer refuge habitat. The resulting conceptual restoration design was then created in CAD. The conceptual design includes enhancing and lowering existing high flow channels within the right bank terrace, constructing four blind alcoves for winter and/or summer refuge habitat, placing large wood, and shaping and vegetating existing mine tailings (Figure 8). The conceptual design was exported from CAD (*Salmon-pilot1.zip*) into a PDF format (*Salmon-pilot1\_v2.pdf*), preserving the layers for each proposed project feature. Thus project components can be turned on and off for easy viewing by clicking the eye icons of the left-side navigation pane in the PDF.

In addition to creating the conceptual design plan, the volume calculation tool in CAD was used to analyze the earthwork required to implement the conceptual design. Overall, excavation and relocation on the order of approximately 100,000 cubic yards will be required to implement the design shown on Figure 6; adjustments to the plan in subsequent design iterations could reduce the required cut and fill and much of the material could likely be placed on site.



#### 4.5 Proposed Conditions Inundation Mapping

Based on the conceptual grading plan, inundation of the enhanced site was analyzed for the 20% exceedance flow, 0.5-bankfull flow, and 2-year discharge (Figure 9). Results from the inundation mapping show how the conceptual design would increase floodplain habitat area at the pilot site by approximately 70–75% for the three study flows as demonstrated in Table 3. It is important to note that the existing condition inundation areas listed on Table 3 represent all areas outside of the low flow channel, many of which are lower bar formations along the channel margin that don't necessarily provide high-quality floodplain habitat or refuge from high flows.

These inundation maps are defined as polygons in the geodatabase file: *PilotSite.gdb*. All GIS related components from Task 2 can be viewed in the ArcGIS map package file *SalmonRestoration\_Phase1.mpk*.

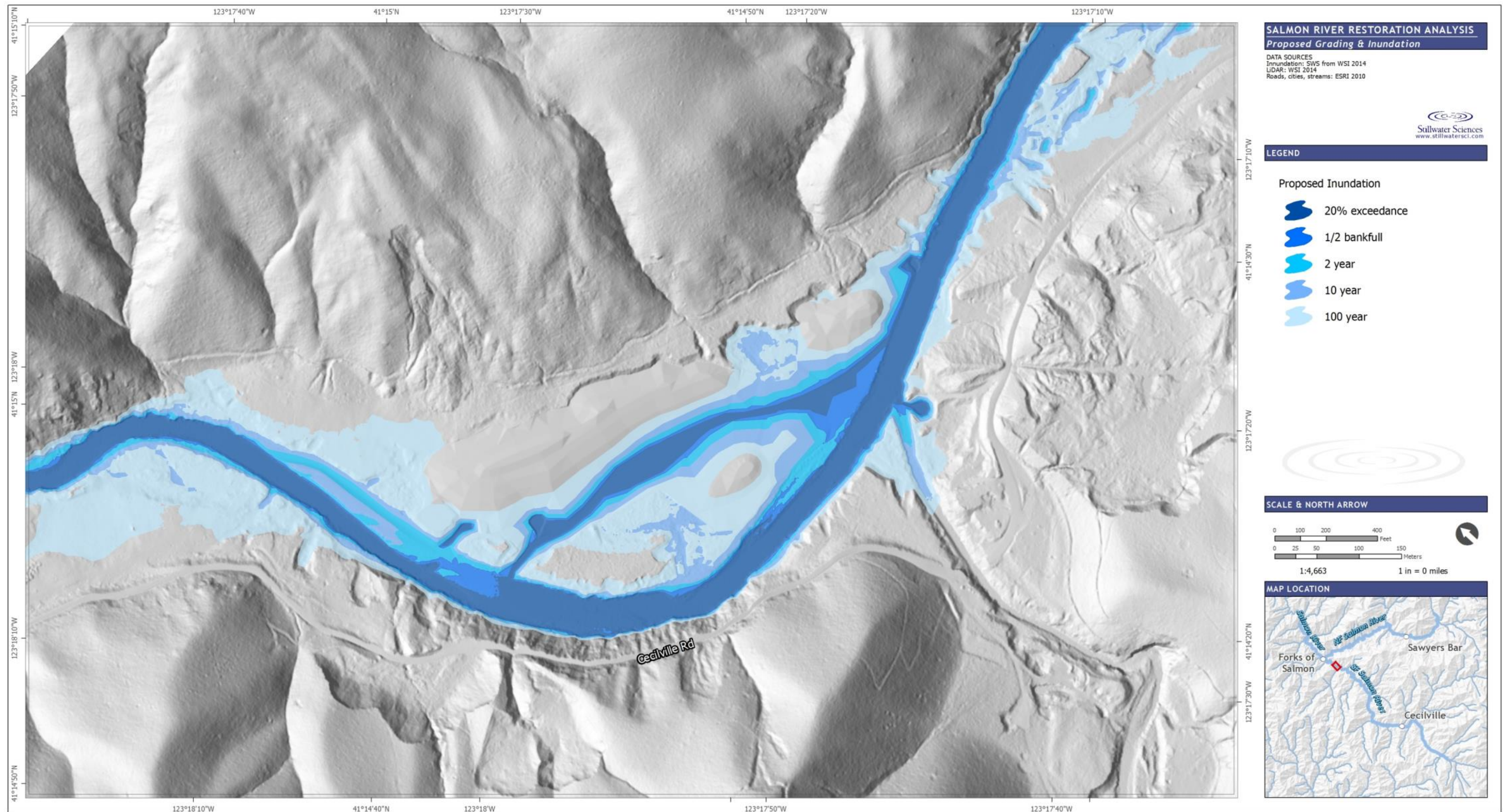


Figure 9. Proposed conditions inundation mapping at pilot site.

**Table 3.** Comparison of existing and proposed inundation areas within the extent of the pilot site (note: new summer cold-water refuge habitats would be created but are not shown here).

Pilot Site	Flow Levels						
	Summer Low Flow Existing	20% Exceedance Existing	20% Exceedance Proposed	0.5 Bankfull Existing	0.5 Bankfull Proposed	2 year Existing	2 year Proposed
Area (acres)	5.5	8.8	11.0	10.2	13.9	12.8	18.3
Total area inundated beyond low flow channel extents (acres)	-	3.3	5.6	4.7	8.4	7.3	12.8
Increase in floodplain area (acres)	-	-	2.3	-	3.7	-	5.5
% Increase in floodplain area	-	-	0.69	-	0.78	-	0.75

## 5 SUMMARY

In this analysis, we identified 14 alluvial dominated, less confined reaches (37 river miles) within the project area that have relatively high to moderate potential for restoration and enhancement of floodplain areas and associated mine tailings. At the Knownothing Creek pilot site, we demonstrate an approach for rapidly developing site-specific conceptual designs using the LiDAR analysis combined with geomorphic mapping, hydraulic analysis, and proven biologically effective restoration treatments (Beechie et al. 2012; Roni et al. 2014) that would increase spring, summer, and winter rearing habitat and lead to reduced thermal heating of the floodplain and river corridor. In combination, this approach highlights the use of LiDAR data to assess restoration potential and plan restoration activities across a broad spatial scale for a relatively low cost. Utilizing this reach-based approach will help ensure that sites in the project area with the highest restoration and enhancement potential are identified, prioritized, and treated cost-effectively while facilitating comprehensive environmental review and permitting. This integrated approach harnesses ArcGIS’ geospatial capabilities and CAD’s site specific earthwork analysis to efficiently develop effective site-specific conceptual designs that can easily be advanced to 60%, 90% and 100% construction-ready designs.

## 6 LITERATURE CITED

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Roni, P., G.R. Pess, T.J. Beechie, and K.M. Hanson. 2014. Fish-habitat relationships and the effectiveness of habitat restoration. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-127.

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## Appendices

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**Appendix A**

**Maps of Geomorphic Reaches**

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Figure A-1. Geomorphic reach, page 1 of 4.



Figure A-2. Geomorphic reach, page 2 of 4.



Figure A-3. Geomorphic reach, page 3 of 4.



Figure A-4. Geomorphic reach, page 4 of 4.

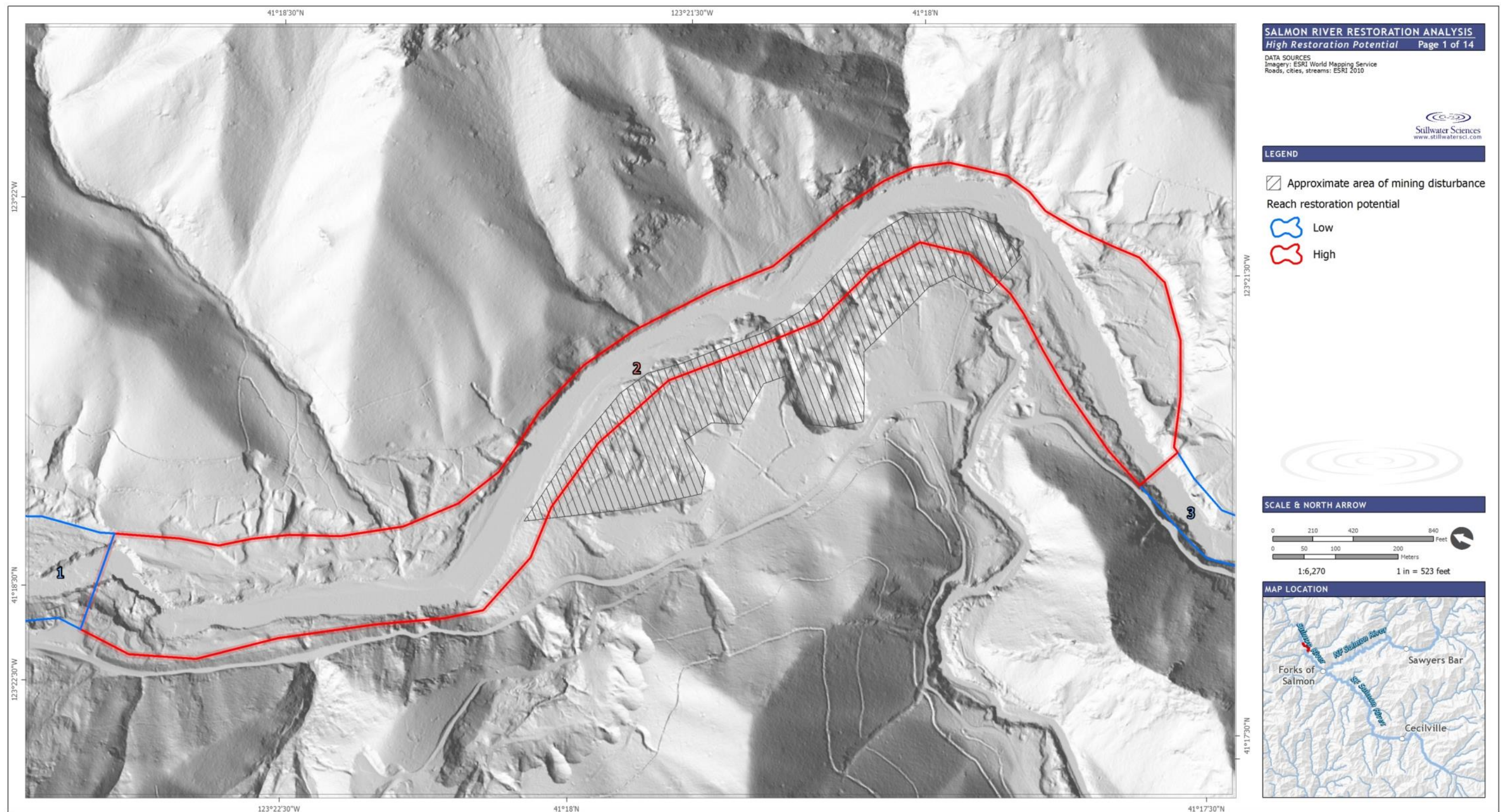


Figure A-5. High restoration potential, page 1 of 14.

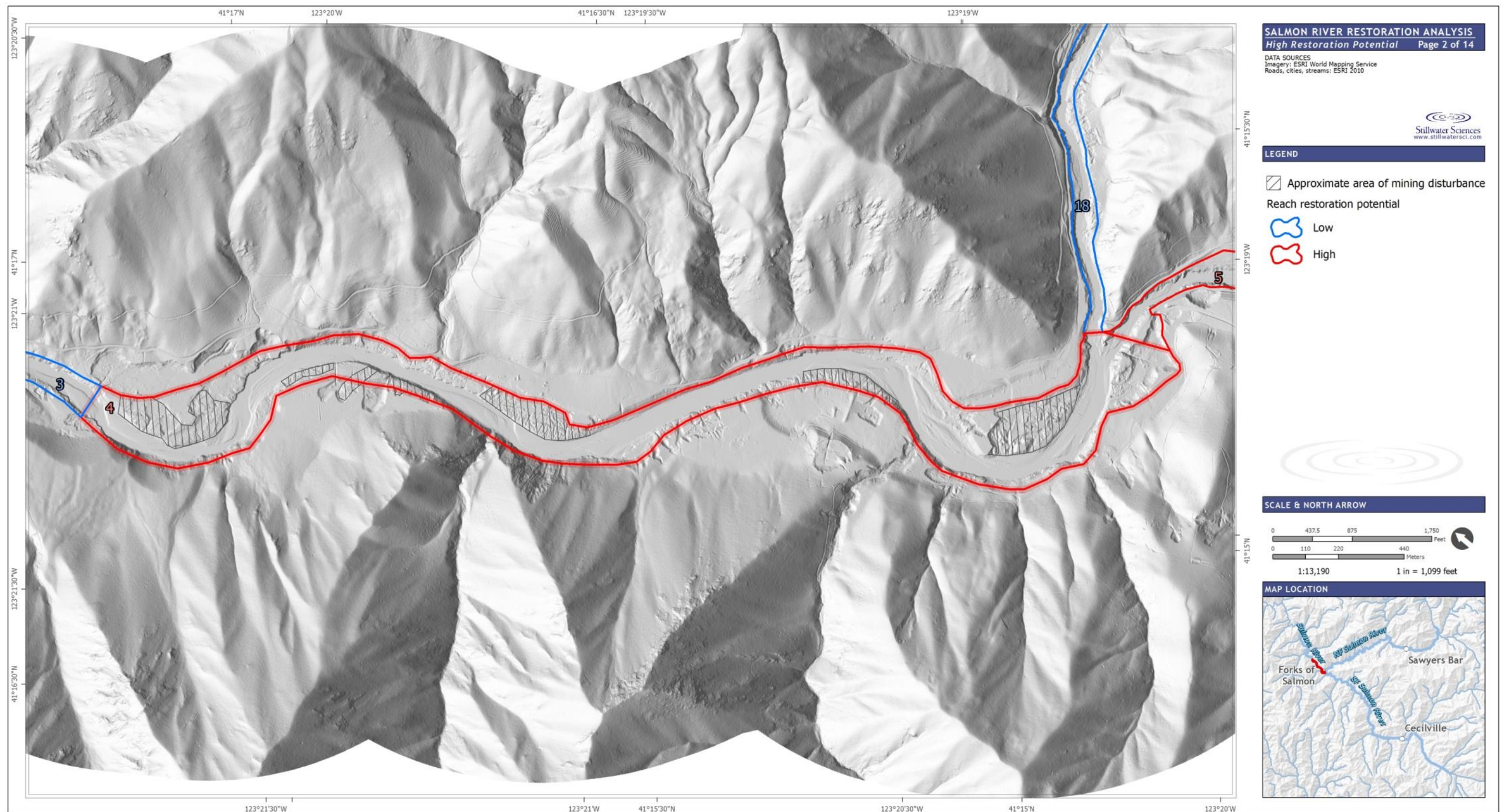


Figure A-6. High restoration potential, page 2 of 14.

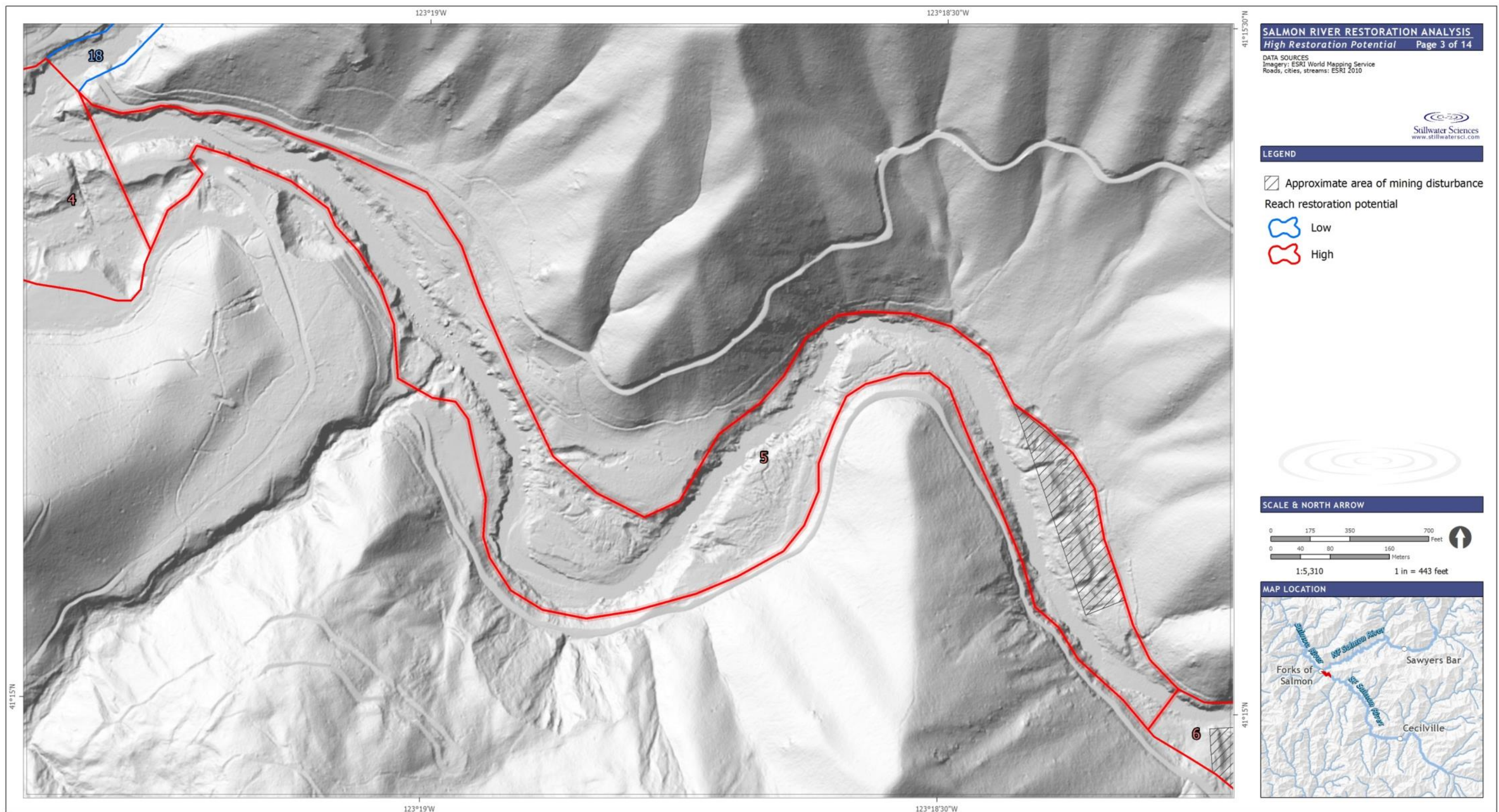


Figure A-7. High restoration potential, page 3 of 14.



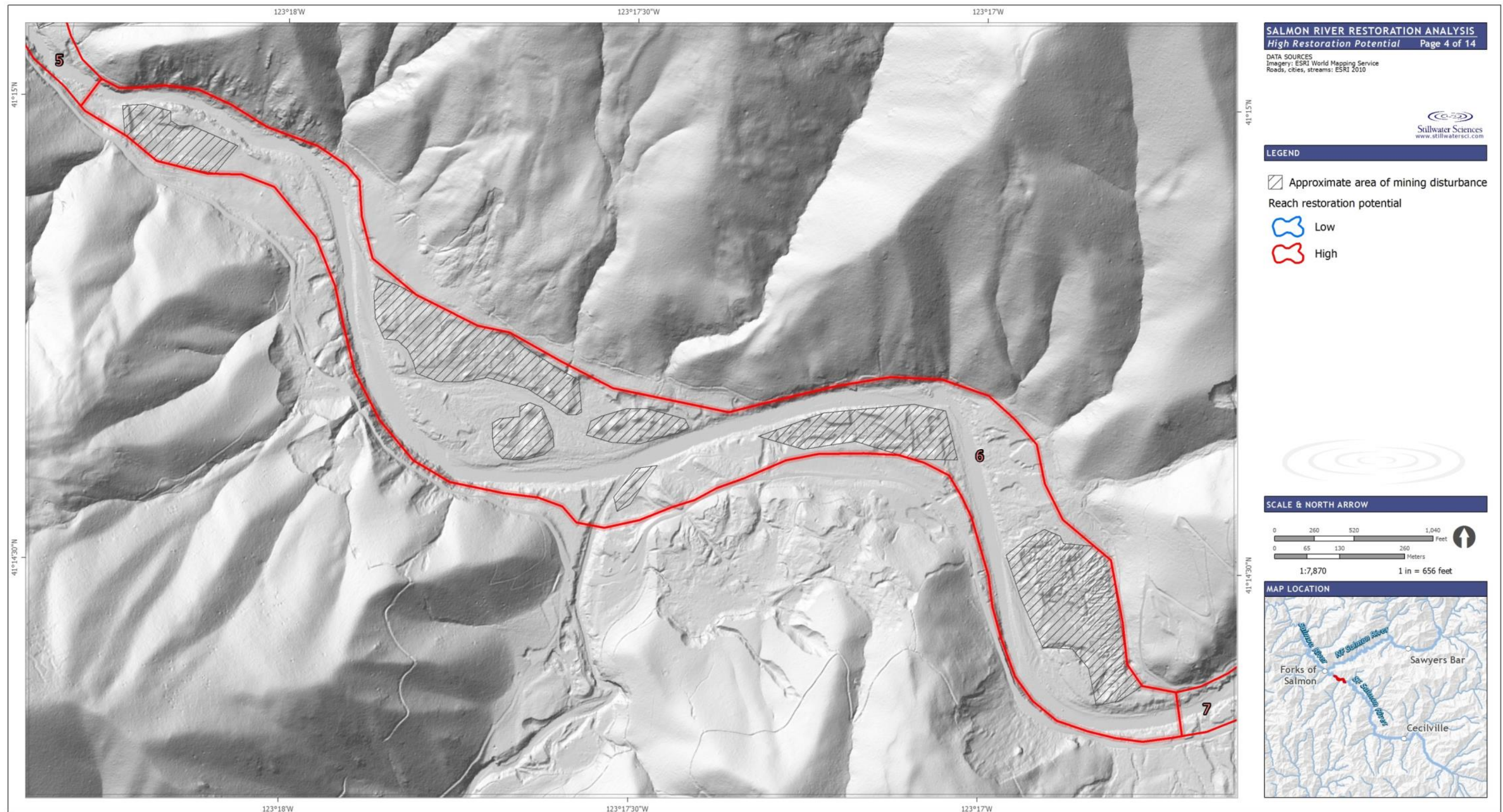


Figure A-8. High restoration potential, page 4 of 14.

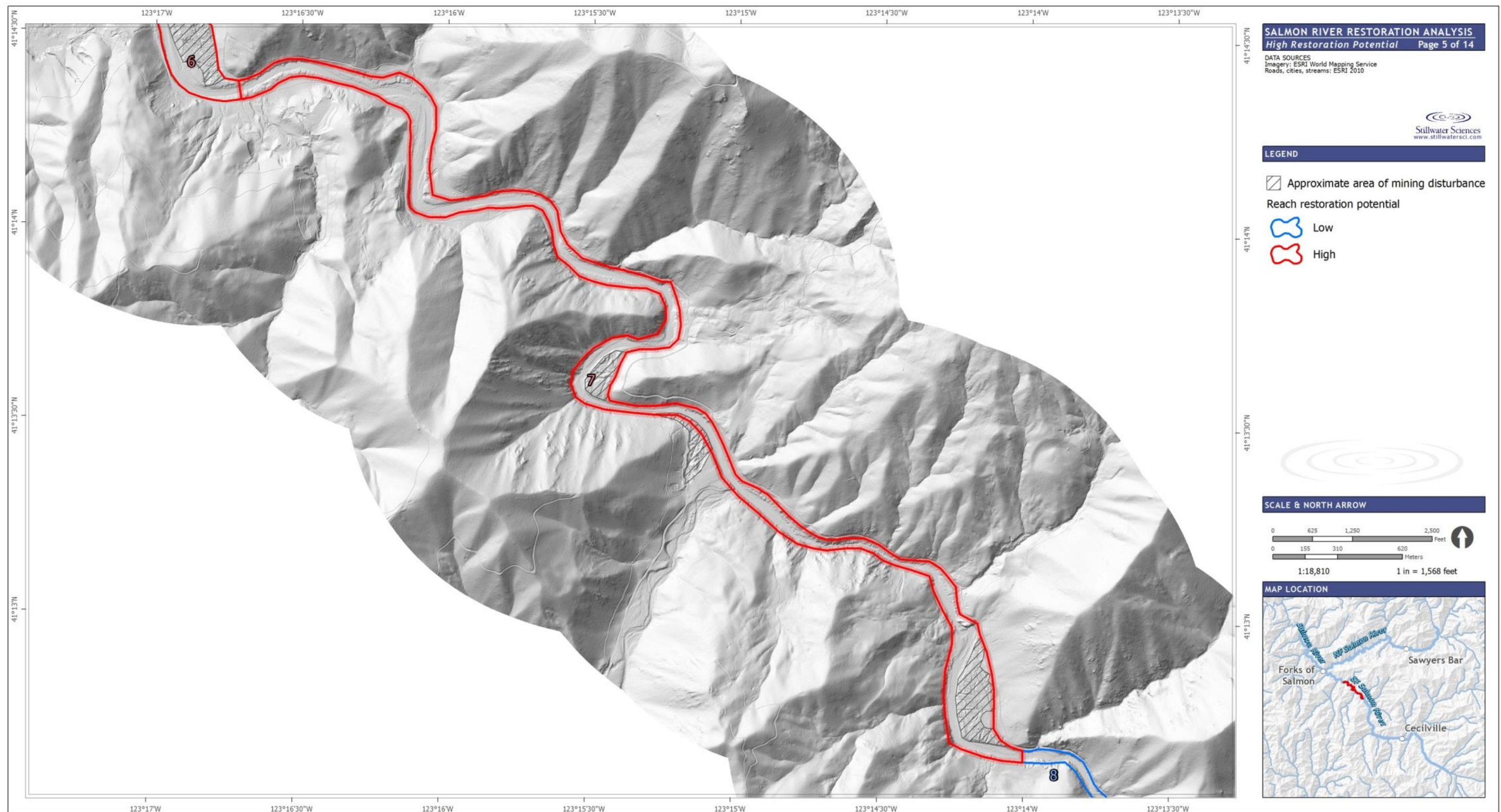


Figure A-9. High restoration potential, page 5 of 14.

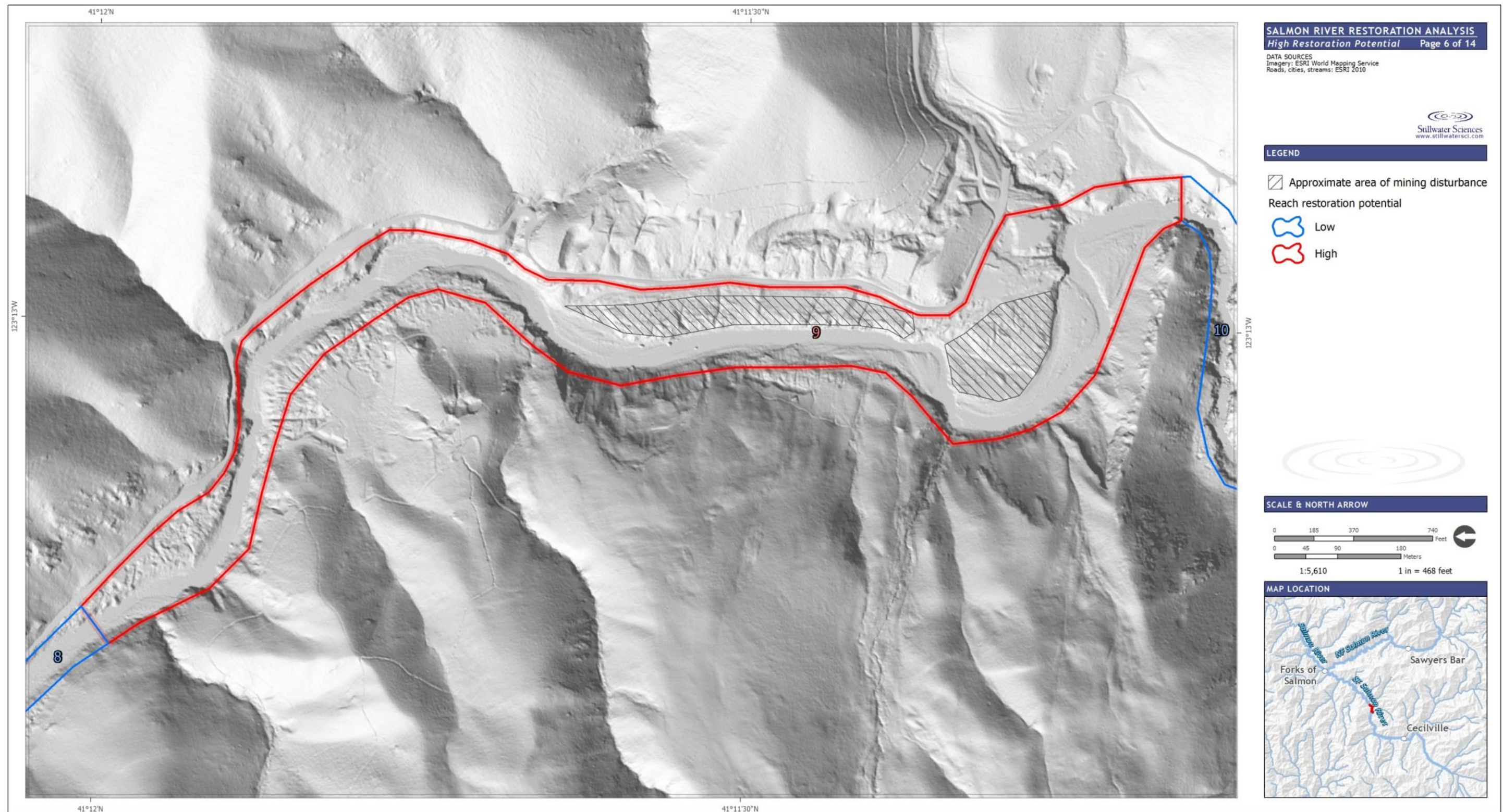


Figure A-10. High restoration potential, page 6 of 14.

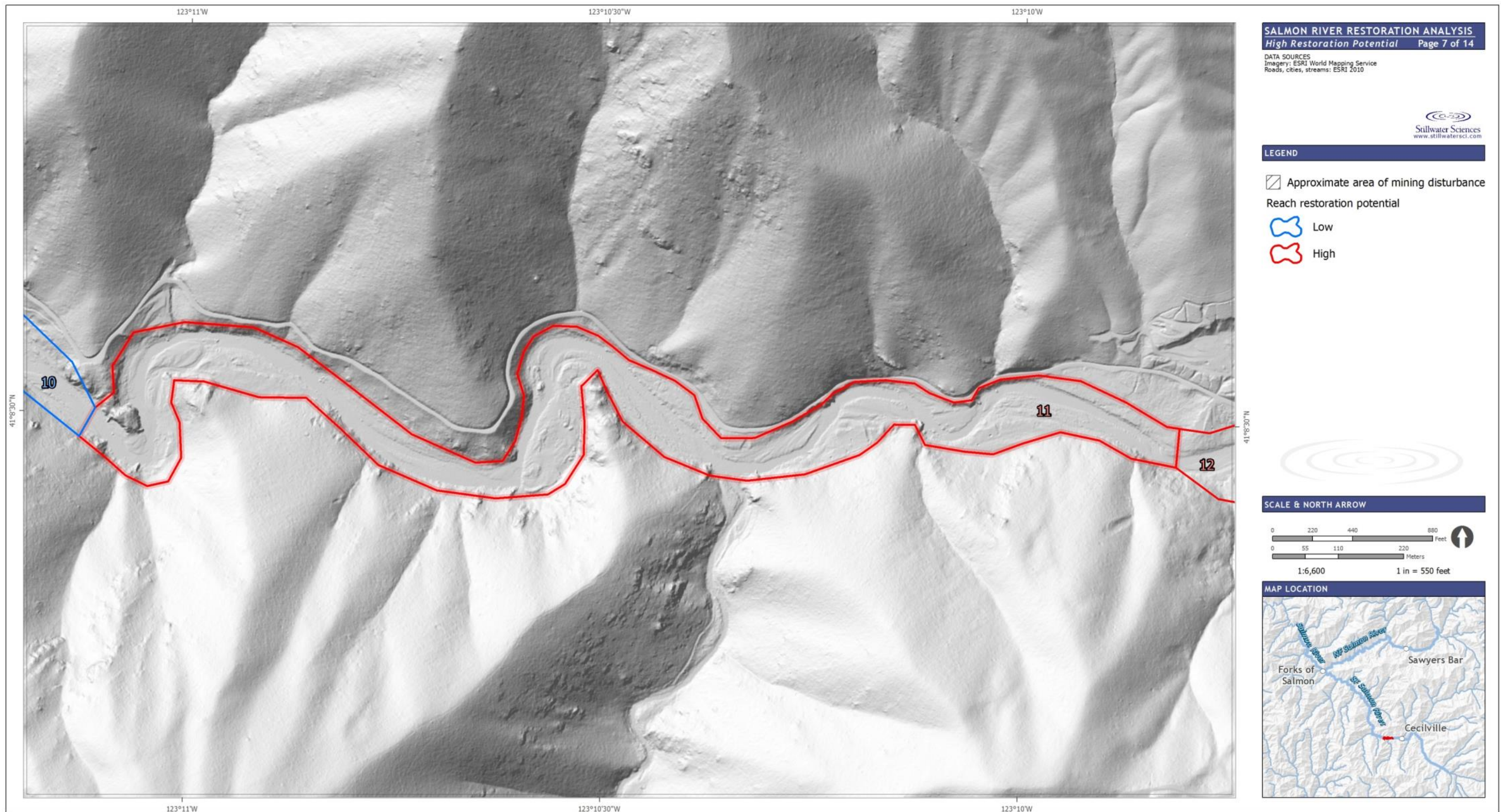


Figure A-11. High restoration potential, page 7 of 14.

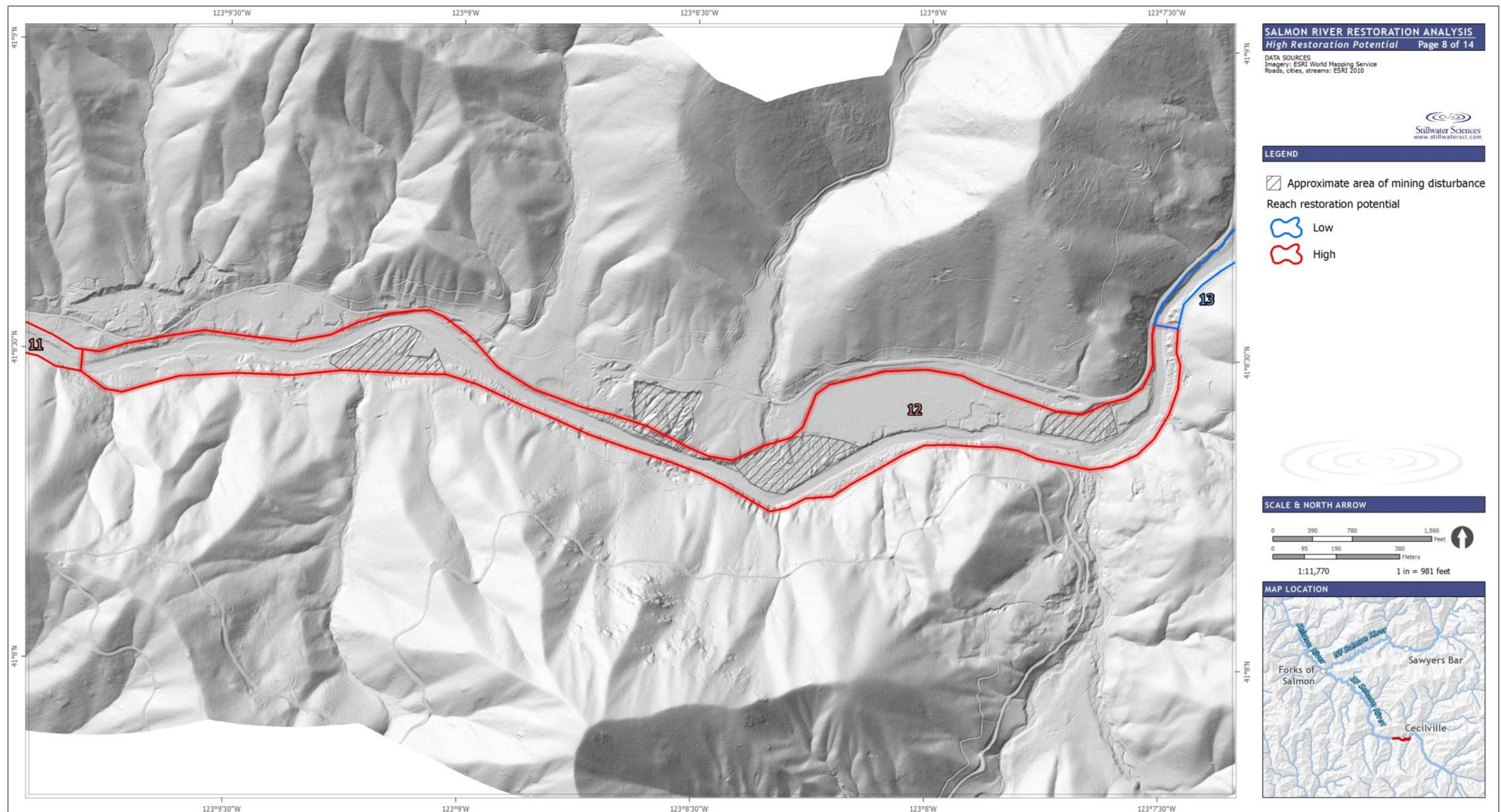


Figure A-12. High restoration potential, page 8 of 14.

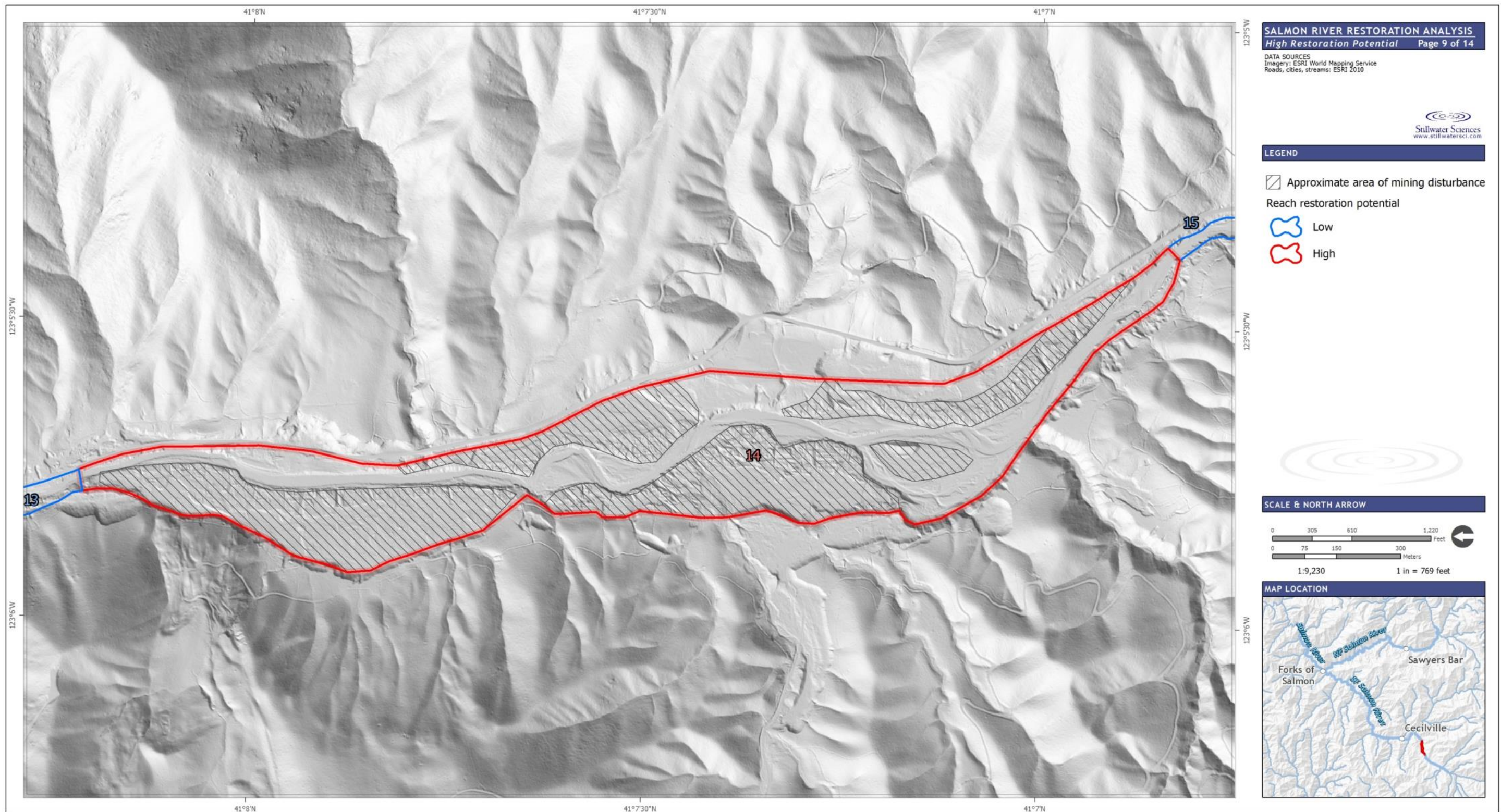


Figure A-13. High restoration potential, page 9 of 14.

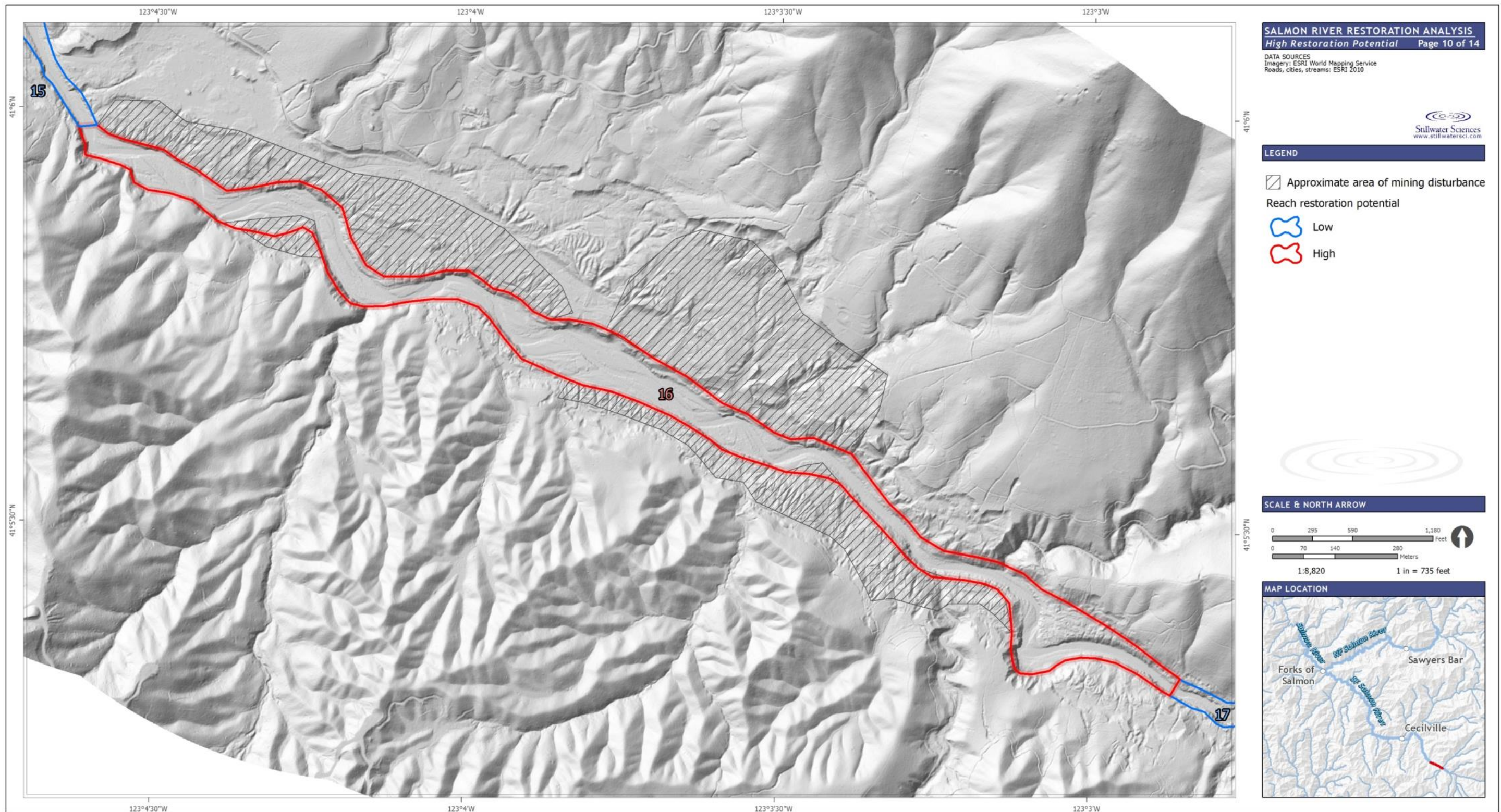


Figure A-14. High restoration potential, page 10 of 14.



Figure A-15. High restoration potential, page 11 of 14.



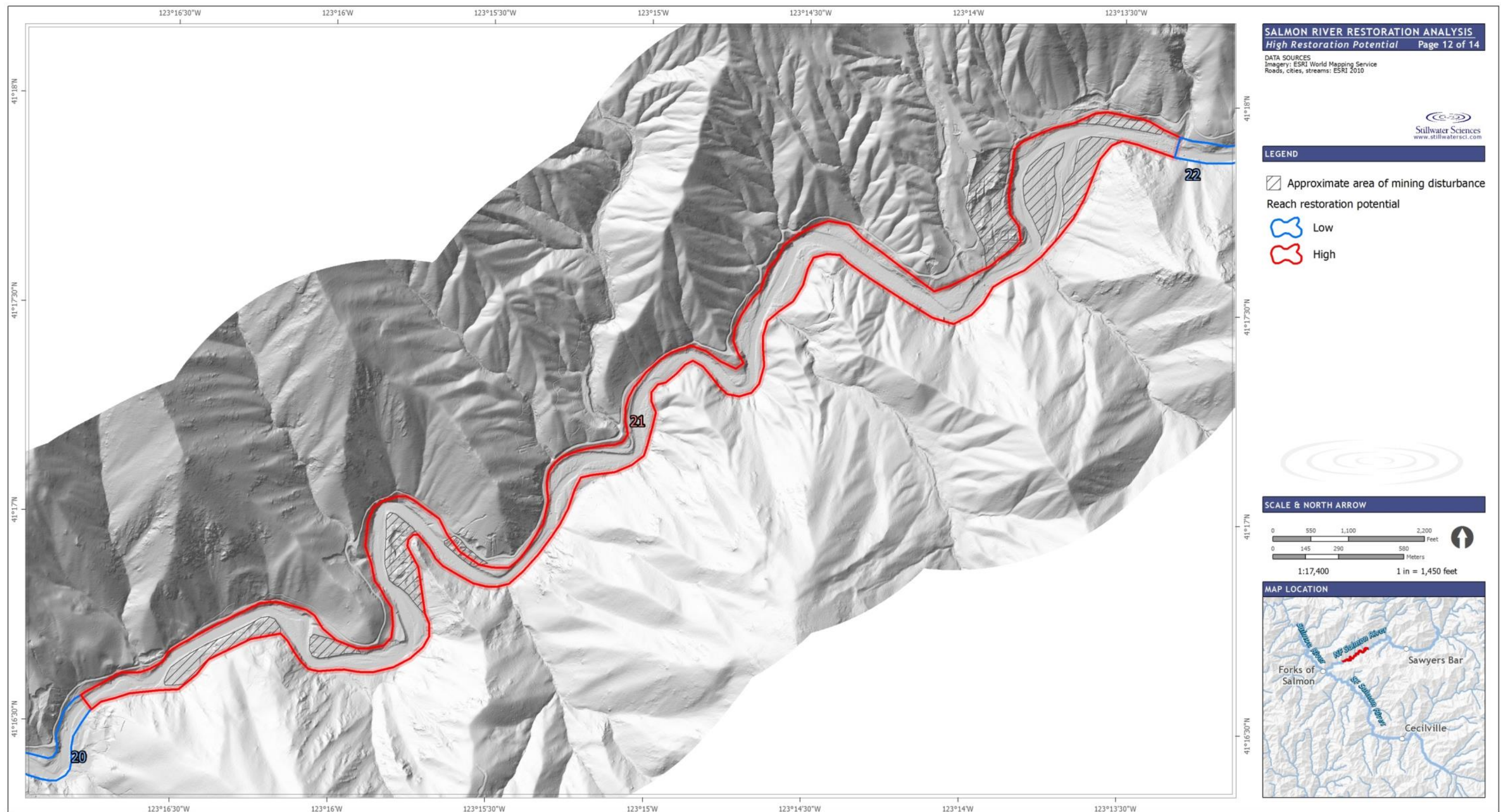


Figure A-16. High restoration potential, page 12 of 14.



Figure A-17. High restoration potential, page 13 of 14.



Figure A-18. High restoration potential, page 14 of 14.