
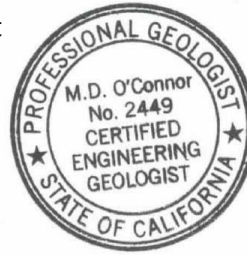


December 30, 2014

TO: Sierra Cantor and John Green  
Gold Ridge Resource Conservation District  
2776 Sullivan Road  
Sebastopol, CA 95472

FROM:   
Matthew O'Connor, PhD, CEG #2449  
President, O'Connor Environmental, Inc.



SUBJECT: SEDIMENT SOURCE ASSESSMENT FOR UPPER GREEN VALLEY CREEK

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## Introduction

This memorandum summarizes our quantitative assessment of sediment sources in upper Green Valley Creek beginning at the confluence of Green Valley Creek and Atascadero Creek. This sediment source assessment includes Purrington Creek, and excludes Atascadero Creek.

The primary purpose of this assessment is to estimate sediment supply to the vicinity of Green Valley Road where sedimentation has caused aggradation of the stream bed at the Green Valley Road Bridge of about 9 ft since 1968 (~0.2 ft/yr). Sedimentation of Green Valley Creek near Green Valley Road has contributed significantly to increased frequency of flooding on Green Valley Road just east of the bridge and the adjacent vineyard. As described in a companion memorandum describing site history and hydrologic and hydraulic analyses, flooding in this area is also caused by dense riparian vegetation growth throughout the area, including the confluence with Atascadero Creek, beginning c. 1960, and the hydraulic effects of levees upstream and downstream of the bridge.

This sediment source assessment also complements watershed management plans and geomorphic analyses of fish habitat conditions (Gold Ridge RCD, Green Valley Creek Watershed Management Plan, March 2013 and Upper Green Valley Creek Watershed Management Plan, 2010). In particular, the sediment source assessment provides perspective on the relative abundance of gravel sources and potential spawning habitat in the watershed. Finally, this sediment source assessment provides a watershed-scale estimate of erosion from stream banks and native-surface roads. Estimates of erosion from roads were accomplished by extrapolating the results of a prior field investigation of road erosion conducted by Pacific Watershed Associates (2008).

This sediment source assessment provides quantitative estimates of annual sediment delivery to stream channels from native surface roads and stream banks. Sediment delivery is apportioned between the Purrington Creek and upper Green Valley Creek watersheds, and is estimated in size classes relevant for sediment transport analysis and fish habitat: gravel (> 2 mm diameter), sand (>0.05 mm and < 2 mm), and silt & clay (< 0.05 mm).

## Methods

### Overview

The methods employed in this sediment source assessment are comparable to those used for Clean Water Act TMDL studies of erosion used throughout northern California. It is comprised of three sediment sources thought to represent most of the principal erosion processes in the watershed: road erosion, small-scale bank erosion of tributary streams, and large-scale bank erosion along the incised mainstem valleys of Purrington Creek and upper Green Valley Creek.

The scope of sediment sources evaluated in this study is limited in that erosion associated with large-scale landslides is excluded. Although this source is typically a significant erosion process in Coast Range watersheds, review of available historic aerial photographs of the watershed early in the project timeline did not reveal evidence of landslides. Gold Ridge RCD staff has alerted us to two locations where landslides have occurred in upper Purrington Creek.

At the outset of this analysis, it was anticipated that we would only have limited access for field surveys and would rely on available maps and aerial photography to assess the extent of roads, streams and landslides. In addition, observations of LiDAR-derived DEM's that became available early in 2014 have revealed further evidence of landslides, mostly deep-seated rockslides and earthflows, but also including a few shallow debris slides. However, available resources for this project did not permit systematic mapping of landslides from the LiDAR DEM's.

Geographic Information System software (ESRI ArcEditor) was used to map and quantify roads and streams and to overlay these with soils data obtained from USDA. Roads were mapped from the existing Sonoma County GIS data set, from aerial photographs, and finally, using the Sonoma County LiDAR Digital Elevation Model (DEM) that became available in early 2014 from the Agricultural Preservation and Open Space District. This latter source enabled identification of 49% of the 127.4 miles of roads we mapped in the watershed. Many of the LiDAR-identified roads appeared to be historic and likely unmaintained roads built for logging c. 1950 in upper Green Valley Creek.

The County LiDAR was also used to develop a map of the stream channel network in the watershed. We used the TOPAZ tool in the WMS software package to synthesize the channel network using a threshold drainage area to establish a stream channel of 5 acres. This produced 80.0 miles of stream channel in the watershed; the drainage density is 8.25 miles per square mile. Even with this density of channels, inspection of LiDAR DEM's suggest that substantial additional length of ephemeral channels likely to exist on the ground were not included in our calculations. Excluding mainstem reaches discussed below, erosion from this portion of the channel network is estimated by applying a "standard" bank erosion rate.

Field surveys of the mainstem valley reaches of Purrington Creek and upper Green Valley Creek conducted by OEI from 2010 through 2012 revealed extensive stream incision and bank erosion.

Vertical elevation differences between the channel bottom and the valley floor are about 25 to 30 ft in Purrington Creek and about 12 to 15 ft in upper Green Valley Creek. A custom LiDAR flight of these mainstem channels was conducted to facilitate a watershed hydrologic/hydraulic modeling project, and the LiDAR DEM was sufficiently detailed to permit measurement of the geometry of erosion scarps. We limited the use of this method to the portions of Purrington and upper Green Valley Creek that we had surveyed for our prior geomorphic assessment of channel conditions.

Finally, the County LiDAR DEM's allowed us to locate on-stream reservoirs in the watershed that would be expected to prevent delivery of sediment downstream. These reservoirs were generally evident in aerial photography and were documented in the State Water Rights data base (eWRMIS). Using GIS tools, we were able to exclude roads and streams located in the upstream drainage areas of these reservoirs from the set of roads and streams that deliver sediment to streams in this assessment.

### **Road Erosion Estimates**

Surveys of 27.9 miles of roads conducted by PWA in 2008 covered roughly twenty percent of the watershed. The PWA survey protocol focuses on potential future sediment delivery based on observation of existing erosion processes, and the volume of erosion expected to occur over a ten-year period was calculated (PWA 2008, Table 2, p.14). We assumed that their survey was a representative sample of road conditions and erosion processes in the watershed. These field-based erosion estimates allowed us to calculate an erosion rate estimate per unit length of hydrologically-connected road. PWA found that 39% of the road length surveyed was hydrologically-connected and could therefore deliver sediment to streams and we assumed that proportion of the road network was hydrologically-connected throughout the watershed.

The annual delivery rate of sediment from roads that we applied was 136.8 cubic yards per mile. Of this total, 87.4 cubic yards per mile (63.9%) was attributed to surface erosion of the road prism. The character of this erosion process--rainsplash and sheetflow--is not expected to transport gravel-size sediment (> 2 mm diameter) in significant quantity, hence an adjustment was made when separating road erosion into size-classes based on sediment size distributions of the soils to exclude gravel production from this road erosion process. Sand, silt and clay from road surface erosion was included in the estimate of sediment delivered to streams from roads.

These estimates were extrapolated to all the native-surface (i.e. dirt and/or gravel) roads identified in the watershed. Paved roads were excluded, even though erosion of cut-slopes and drainage ditches along paved roads undoubtedly deliver some sediment to streams.

### **Watershed Stream Bank Erosion**

Stream banks are recognized as an important source of sediment because they are typically steep, because they are frequently disturbed by stream erosion, and because they deliver soil material directly to stream channels. It is difficult to directly measure this process in the absence of detailed field surveys and/or monitoring. For many purposes, this process is estimated by applying a representative bank

erosion rate extrapolated from a comparable watershed where data exist; in some cases the bank erosion rate is equated with a downslope soil creep rate.

Buffleben (2009) reviewed various methods and estimates for bank erosion rates, and conducted a field study to measure soil voids in stream banks in the forested Elk River watershed (Humboldt County) in the Coast Range. In his field study, he estimated bank erosion rates of about 5 mm/yr (0.016 ft/yr) with an average bank height of about 2 ft. Washington Department of Natural Resources (1997) for watershed analysis recommend using a bank erosion rate of 2 mm/yr when adjacent slopes are >30%.

We applied a rate of 2 mm/yr and selected 3 ft as the typical bank height in the watershed based on field observations. The erosion rate of 5 mm/yr might be reasonable for this watershed based on overall similarity of terrain and geology, however, the mean annual rainfall at the Elk River watershed is about fifty percent greater, and is subject to a greater degree of landslide activity, both which would be expected to elevate observed bank erosion. A rate of 1.6 mm/yr was used by the North Coast Regional Water Quality Board for the Gualala River Watershed TMDL (2001) and by the California Geological Survey (Fuller and Custis, 2002) for streams not located in landslide terrain for an analysis of erosion rates in the Gualala River.

### **Mainstem Stream Bank Erosion**

High quality LiDAR DEM's were used to measure the volume of soil eroded from stream banks in discreet locations where streamside scarps from soil slumps and debris slides were identified. This technique requires interpretation of the geometry of stream bank features, and was conducted by Dr. Matt O'Connor, CEG #2449, who conducted field surveys of these mainstem reaches and has expertise in geomorphology. In many cases, eroded scarps had been directly observed in the field, thus providing a significant degree of confirmation regarding identification of these erosion features.

The LiDAR DEM, projected in a hillshade view in GIS, was used to identify features from their geometry and position along the stream. The volume of eroded material was determined using GIS tools to measure the dimensions of the feature. The GIS 3-d Analyst tool was used, along with channel cross-sections cut from the DEM at 10 ft intervals, to determine the length parallel to the stream, the width of the feature normal to the stream, and the average depth of the feature normal to the scarp surface. The product of these three dimensions was the estimate of soil eroded from the feature.

While the volume of eroded soil was estimated with relatively high accuracy, determination of the age of individual erosion features was beyond the scope of this assessment. Consequently, we assumed that all of the observed erosion occurred within a 50-year period based primarily on the approximate age of mature trees on the banks. This interval is expected to be conservative; much of the erosion likely occurred more recently based on evidence of management efforts to control bank retreat and the age of vegetation on scarps relative to adjacent vegetated stream banks.

### Sediment Size Distribution of Eroded Sediment

The foregoing describes how we estimated the volumetric rate of erosion in the watershed. To gain perspective on downstream sedimentation rates, however, it was necessary to estimate the quantity of eroded sediment large enough to be temporarily retained in the stream channel. Sediment size distribution of sediment in upper Green Valley Creek between the Purrington Creek confluence and Green Valley Road was determined from five samples collected in 2013. About seventy percent of the bed material was coarser than 2 mm diameter (i.e. gravel), and all but about one to two percent of the remainder was sand-size (coarser than 0.05 mm).

Soil Survey data available from the USDA includes representative sediment size distributions for each soil type mapped in the watershed. The volume of soil eroded from roads and stream banks within each soil type as represented in the GIS was determined. We represented the sediment size distribution of soil eroded within each soil type as the depth-integrated size distribution. The Soil Survey data gives size distribution for each soil horizon in the soil, so it was necessary to determine the depth-integrated size distribution. We did not attempt to adjust the estimates for overall soil depth, and assumed that erosion in each soil type occurred evenly through the whole profile. This approximation is satisfactory for purposes of this assessment; a more detailed representation is beyond the scope of this assessment. Furthermore, soil types that represent less than one percent of the length of streams or roads contributing sediment to downstream reaches were grouped together and a representative size distribution was applied. Sediment size distributions for depth-integrated soil profiles are summarized in Table 1.

**Table 1. Depth-integrated sediment size distribution for soils in the watershed.**

Soil Name	Soil Map Symbols	% Gravel (> 2mm)	% Sand (< 2mm, > 0.05 mm)	% Silt & Clay (< 0.05 mm)
Arbuckle	AkC	25	28	47
Blucher	BhA, BhB, BIB	0	33	67
Goldridge	GdC, GdD, GdD2, GdE, GdE2, GdF, GdF2	2	59	39
Henneke	HgG2	38	19	43
Hugo	HkF, HkG, HIG	30	32	38
Huse	HyG	23	16	60
Josephine	JoE, JoF, JoF2, JoG	15	38	47
Montara	MoE, MoG	34	23	43
Suther	StF	23	22	55
Others	HnG, McF, ShF, RaE	5	35	60

## Results

The attached maps show the distribution of roads, watershed streams, mainstem stream erosion scarps, and soils discussed above. The Road Map distinguishes three road types for purposes of this assessment: paved roads, native surface roads from County GIS sources and aerial photos, and native surface roads mapped by interpretation of LiDAR DEM's. Also shown on this map are envelopes within which PWA conducted road surveys and sub-drainages that drain to reservoirs. Within these sub-drainages, road length was excluded from erosion calculations.

The Stream Map distinguishes mainstem reaches in which we measured erosion using LiDAR DEM's and GIS tools from the watershed tributary streams in which erosion was estimated using a uniform rate estimate and a uniform bank height. Also shown on this map are sub-basins that drain to reservoirs; streams in these sub-basins were excluded from erosion calculations. Close inspection of the LiDAR hillshade on this map reveals a substantial number of small valleys that probably contain stream channels that were not captured in the routine used to generate the stream channel network.

The Mainstem Erosion Map (four panels) shows polygons identifying erosion scarps along Purrington Creek and upper Green Valley Creek. It should be noted that the volume of erosion estimated in each watershed was about equal, despite the fact that the Purrington Creek reach is half the length of the upper Green Valley Creek reach. This is attributed to both the greater bank height and greater severity of stream incision in Purrington Creek. For reference, the mean bank erosion rate for both channels was about 6 mm/yr.

The Soils Map shows the distribution of soils listed in Table 1. Note that the Hugo soil, among the common forest soils of the Coast Range, is widely distributed in upper Green Valley Creek but absent in Purrington Creek. The Hugo soil contributes over 90% of the gravel calculated to be delivered from the watershed. Other soils that contribute substantial quantities of gravel include the Josephine, Huse, Arbuckle and Henneke.

The quantitative results of the erosion rate assessment are summarized by sediment sources (roads, watershed streams and mainstem streams) and by grain size (gravel, sand and silt & clay) in three graphs on the following page. The first graphs shows erosion rates for the entire study area; the two subsequent graphs show upper Green Valley Creek and Purrington Creek separately.

The estimated annual production of gravel (> 2mm) that comprises about 70% of the bed material in the channel of Green Valley Creek near Green Valley Road is 410 cubic yards per year (about 8% of the total). Gravel moves relatively slowly and is likely retained in the watershed for decades before it is transported through the watershed. Sand-size bed material < 2 mm and > 0.05 mm that comprises about 28% of the bed material near Green Valley Road is eroded from the watershed at a rate of about 2,250 cubic yards per year (about 42% of the total). It moves both in suspension and as bed load, and probably moves through the watershed over a period of several years. Silt & clay is transported in

suspension and is expected to move through the watershed in one year or less; about 2,610 cubic yards of silt and clay (about 50% of the total) are eroded annually in the watershed.

## Discussion

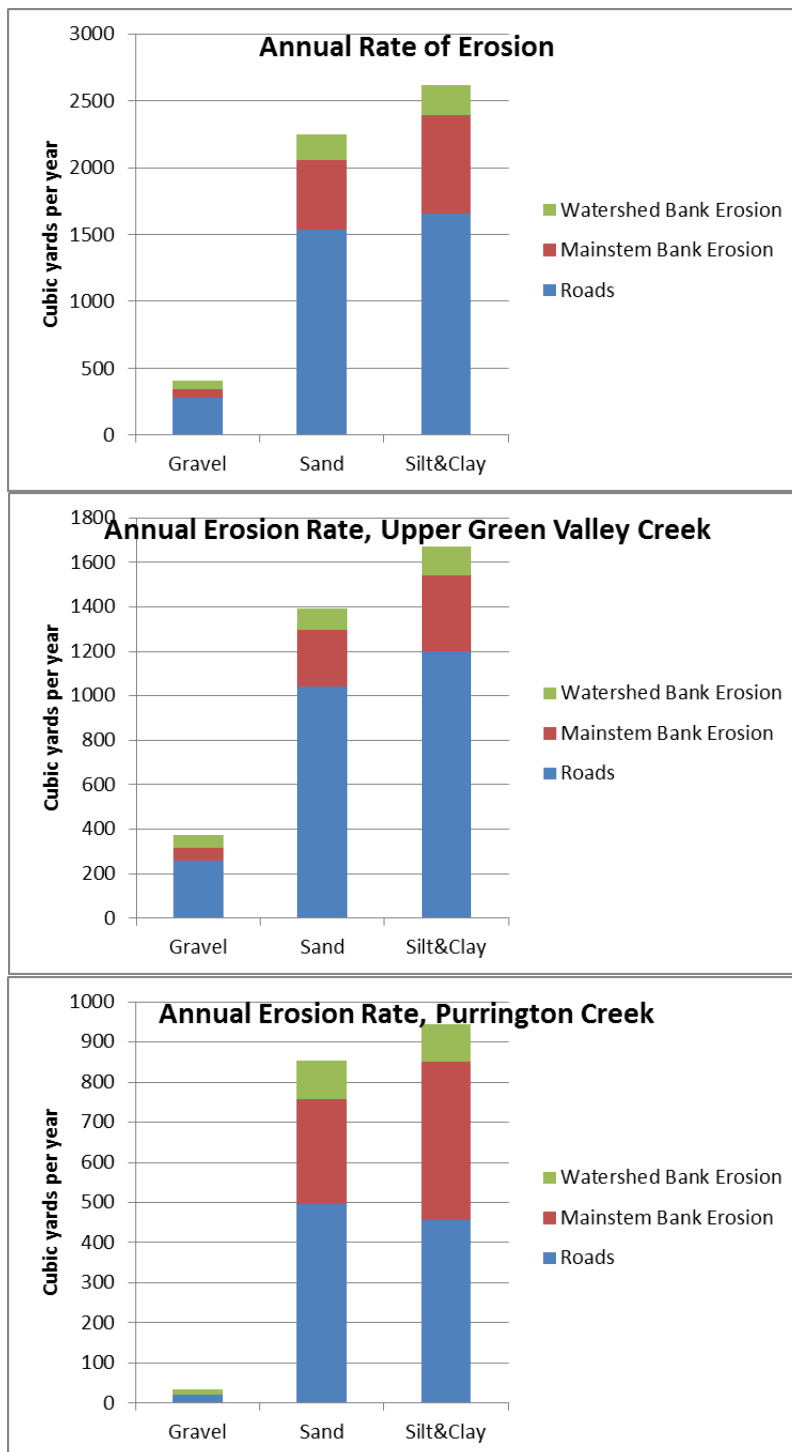
The erosion rate for the watershed is equivalent to about 800 tons per square mile per year using a soil bulk density of 1.48 tons per cubic yard. This is a relatively high erosion rate considering that it does not include much of the landslide erosion that likely exists in the watershed. As noted earlier, we believe that landslide rates in this watershed are lower than that found in many other Coast Range watersheds, however, they would probably be comparable to or greater than watershed stream bank erosion. In our experience the PWA survey protocol probably overestimates erosion rates, so that may also contribute to the somewhat high erosion rates estimated exclusive of most landslides. The PWA protocol included landslides associated with surveyed roads, but this accounted for only about 8% of their estimated erosion rate. PWA road erosion estimates of this type are included in most sediment source assessments in the northern California Coast Range.

In other respects, this sediment source assessment is expected to underestimate erosion rates in the watershed. In addition to the absence of direct sediment delivery by landslides in this assessment, accelerated bank erosion rates along stream channels in the upper watershed associated with earthflows and rockslides are excluded. In addition, erosion of cut slopes and along drainage ditches adjacent to paved roads are excluded. The watershed stream channel network developed from the LiDAR DEM underestimates the extent of stream channels, reducing erosion estimates from this source. Finally, mainstem bank erosion was estimated to have occurred over a fifty year period; this is a conservative estimate and probably underestimates mainstem bank erosion rates. Each of these sources could be better quantified in a more detailed analysis.

Overall, the calculated erosion rate is reasonably consistent with that found in other North Coast watersheds. For example, the Gualala River TMDL (NCRWQCB, 2001) found erosion rates of about 1,220 tons per square mile per year. The Bolinas Lagoon TMDL (TetraTech, Inc., 2001) found erosion rates of about 780 tons per square mile per year. Erosion rates in a sub-watershed of Lagunitas Creek, San Geronimo Creek (drainage area 9.2 sq. mi.) were estimated to be about 1,280 tons per square mile per year in the Lagunitas Creek TMDL sediment source analysis (SFBWQCB 2014).

Watershed erosion rates of coarse sediment that comprises most of the bed material stored in the channel of Green Valley Creek near Green Valley Road are about 410 cubic yards per year. The estimated rate of deposition in the 1,000 ft reach of Green Valley Creek extending upstream from Atascadero Creek beyond the Green Valley Road Bridge since 1968 is about 220 cubic yards per year (1,000 ft long x 30 ft wide x 0.2 ft/yr). Bedload transport rates in the reach of Green Valley Creek near Green Valley Road calculated from hydraulic data are spatially variable, and also vary considerably depending on the transport equation used, but are in the range of values given by estimated annual gravel inputs and estimated annual sedimentation. Taken together, these findings suggest that watershed supplies of coarse sediment contributing to sedimentation above Green Valley Road and

finer sediment contributing to floodplain sedimentation in lower Green Valley Creek are abundant and unlikely to abate in the foreseeable future.





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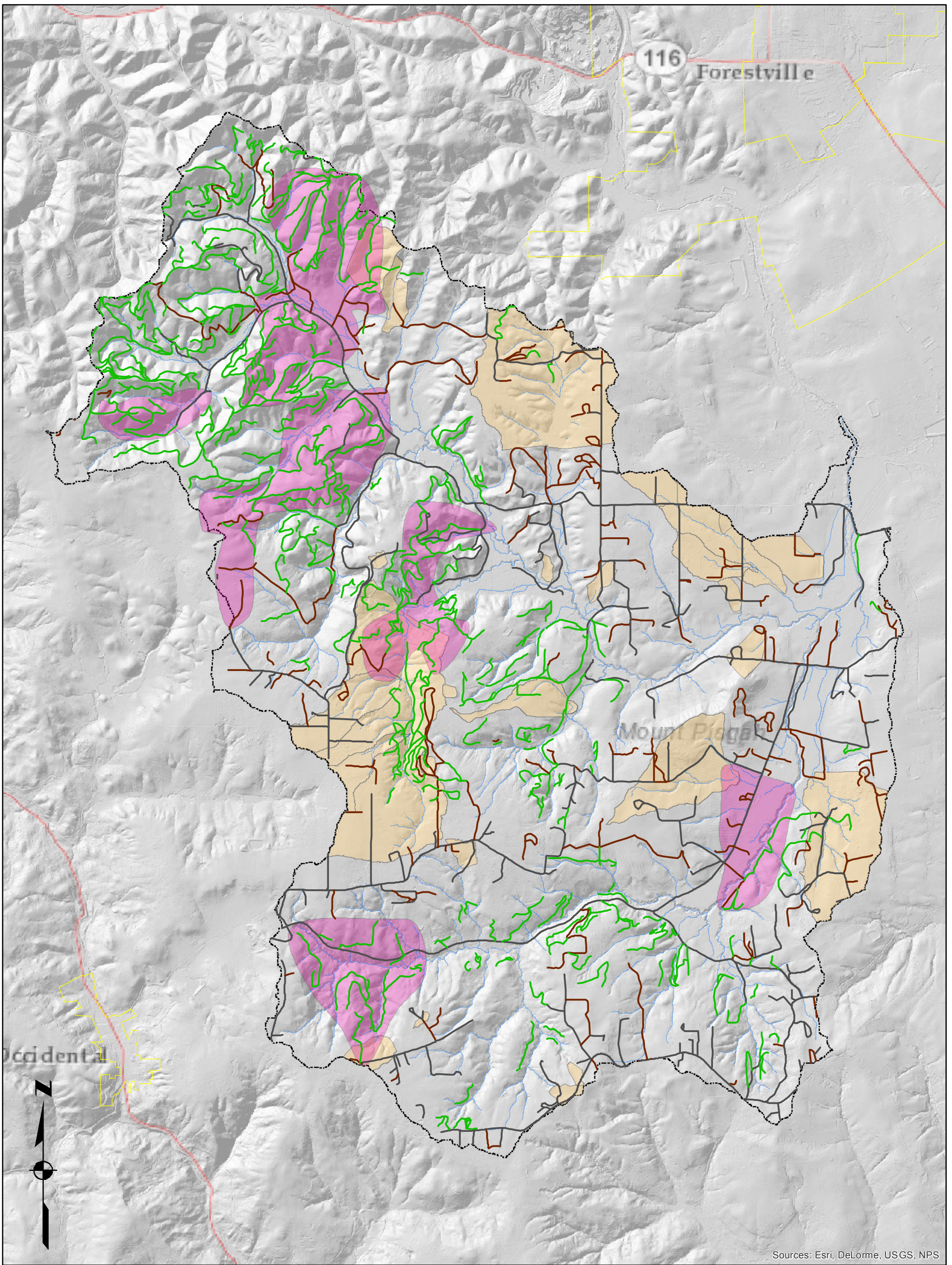
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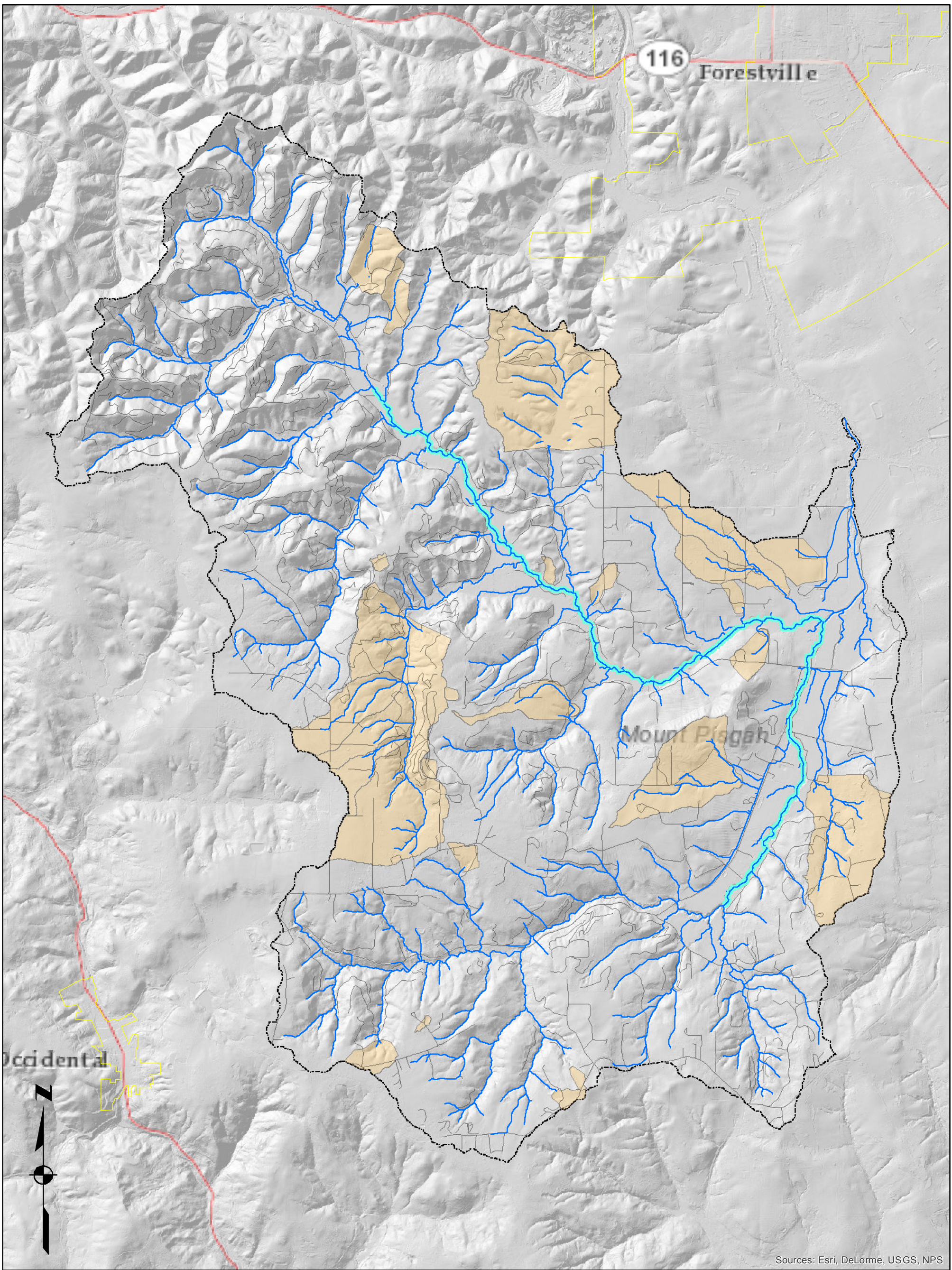


Sources: Esri, DeLorme, USGS, NPS



# Road Map for Erosion Assessment

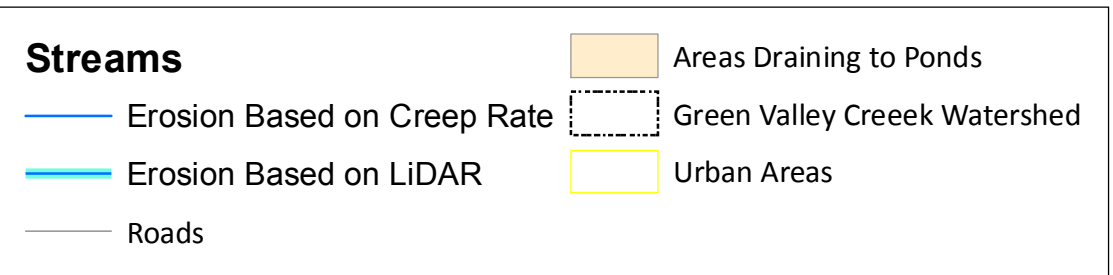
Road Type		PWA Road Survey Areas	
— Paved	— Native Surface	— Native Surface LiDAR	— Streams
— Native Surface	— Native Surface LiDAR	— Streams	— PWA Road Survey Areas
— Native Surface LiDAR	— Streams	— PWA Road Survey Areas	— Areas Draining to Ponds
— Streams	— PWA Road Survey Areas	— Areas Draining to Ponds	— Green Valley Creek Watershed
— PWA Road Survey Areas	— Areas Draining to Ponds	— Green Valley Creek Watershed	— Urban Areas
— Areas Draining to Ponds	— Green Valley Creek Watershed	— Urban Areas	

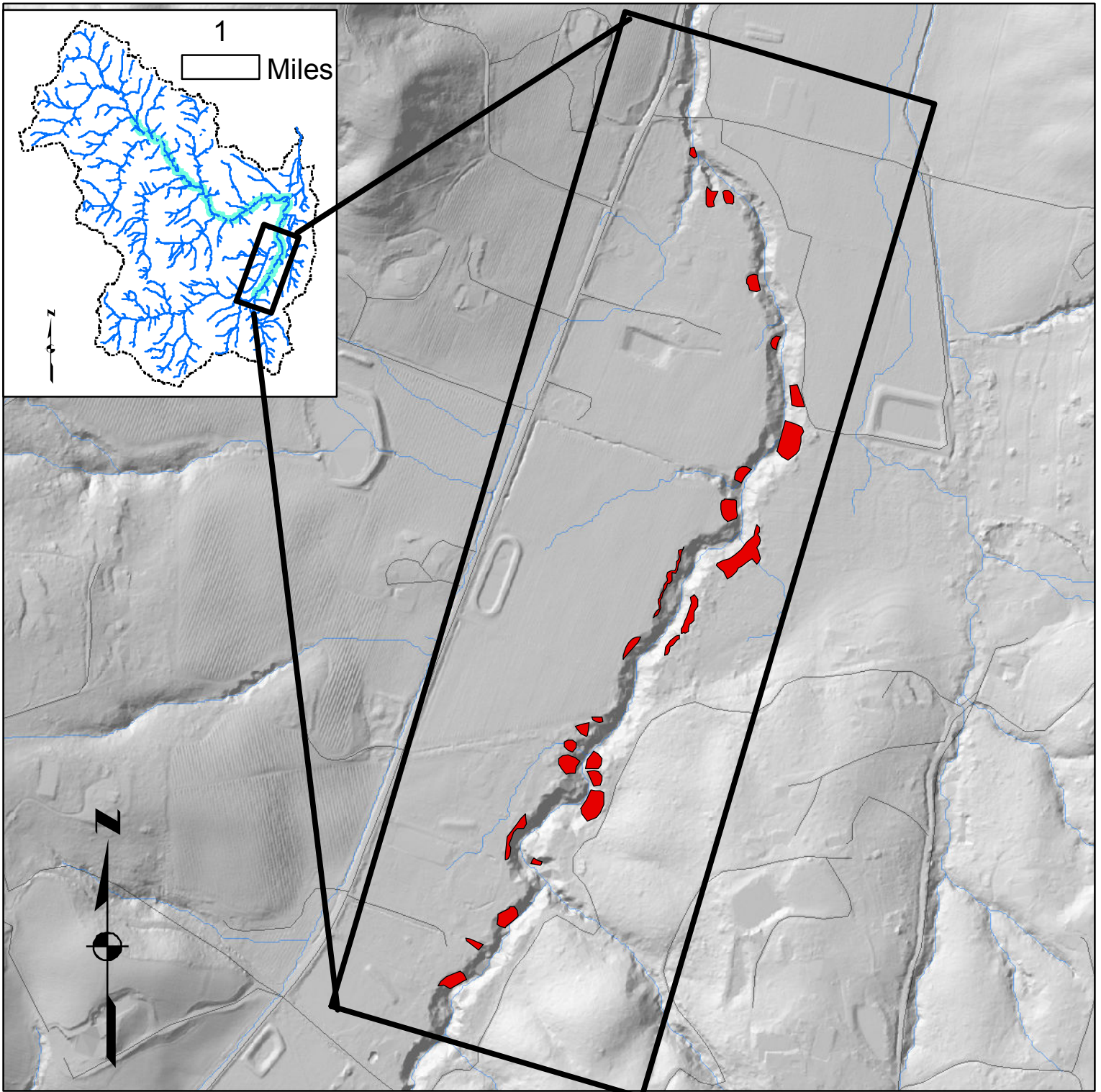


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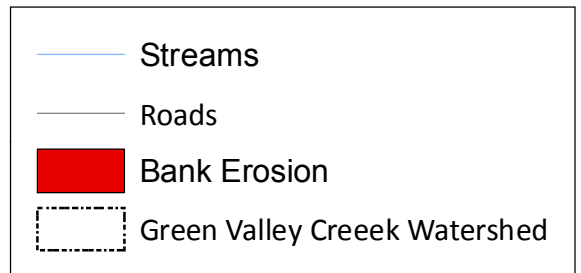


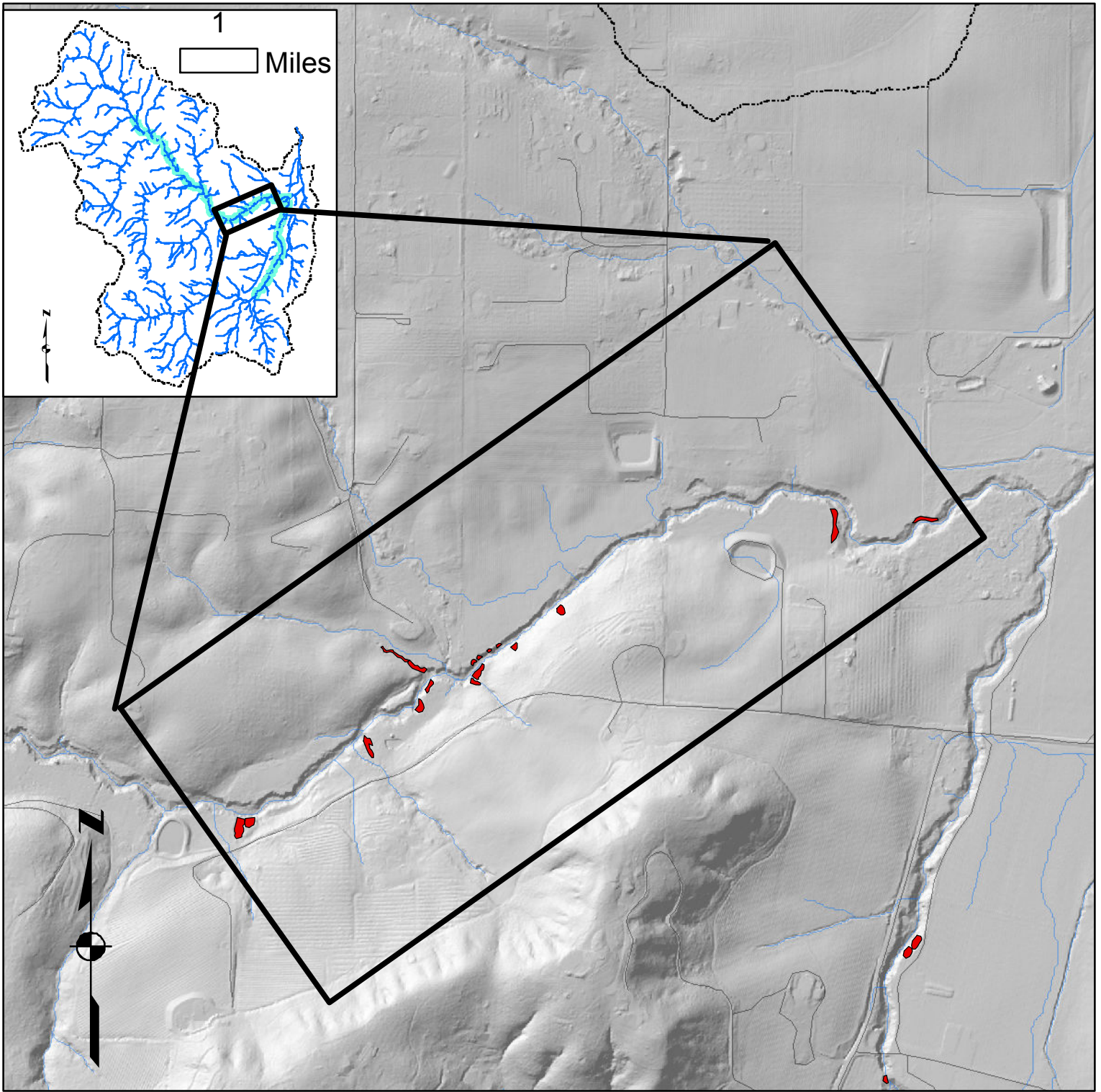
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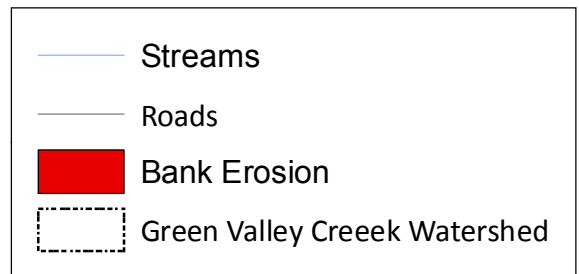


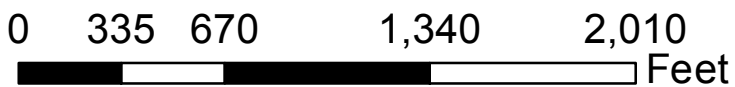
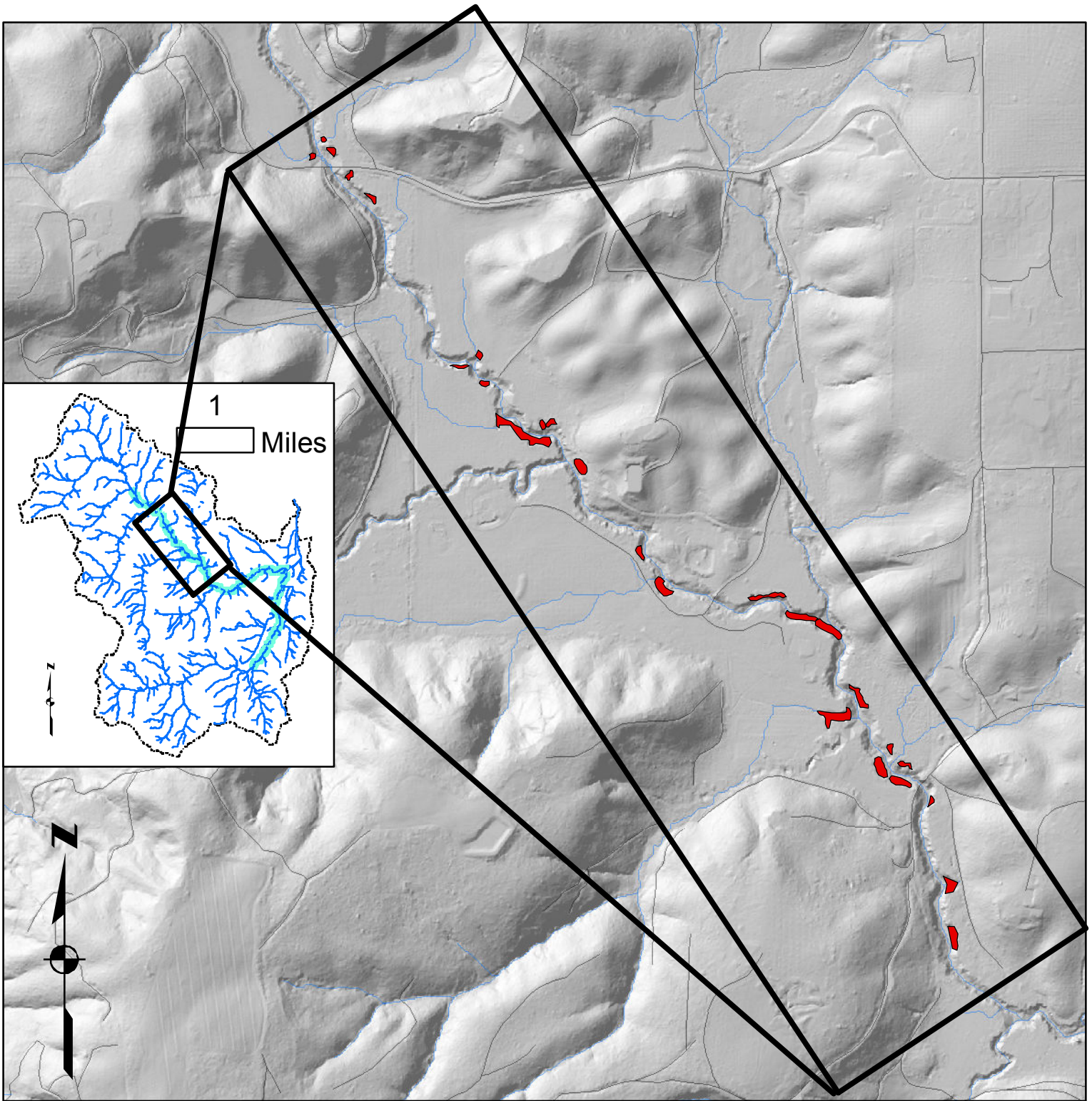
## Mainstem Bank Erosion Purrington Creek



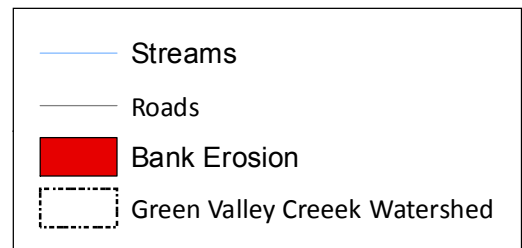


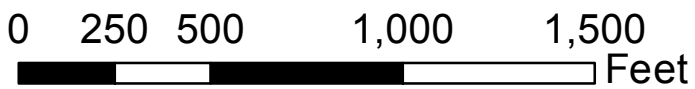
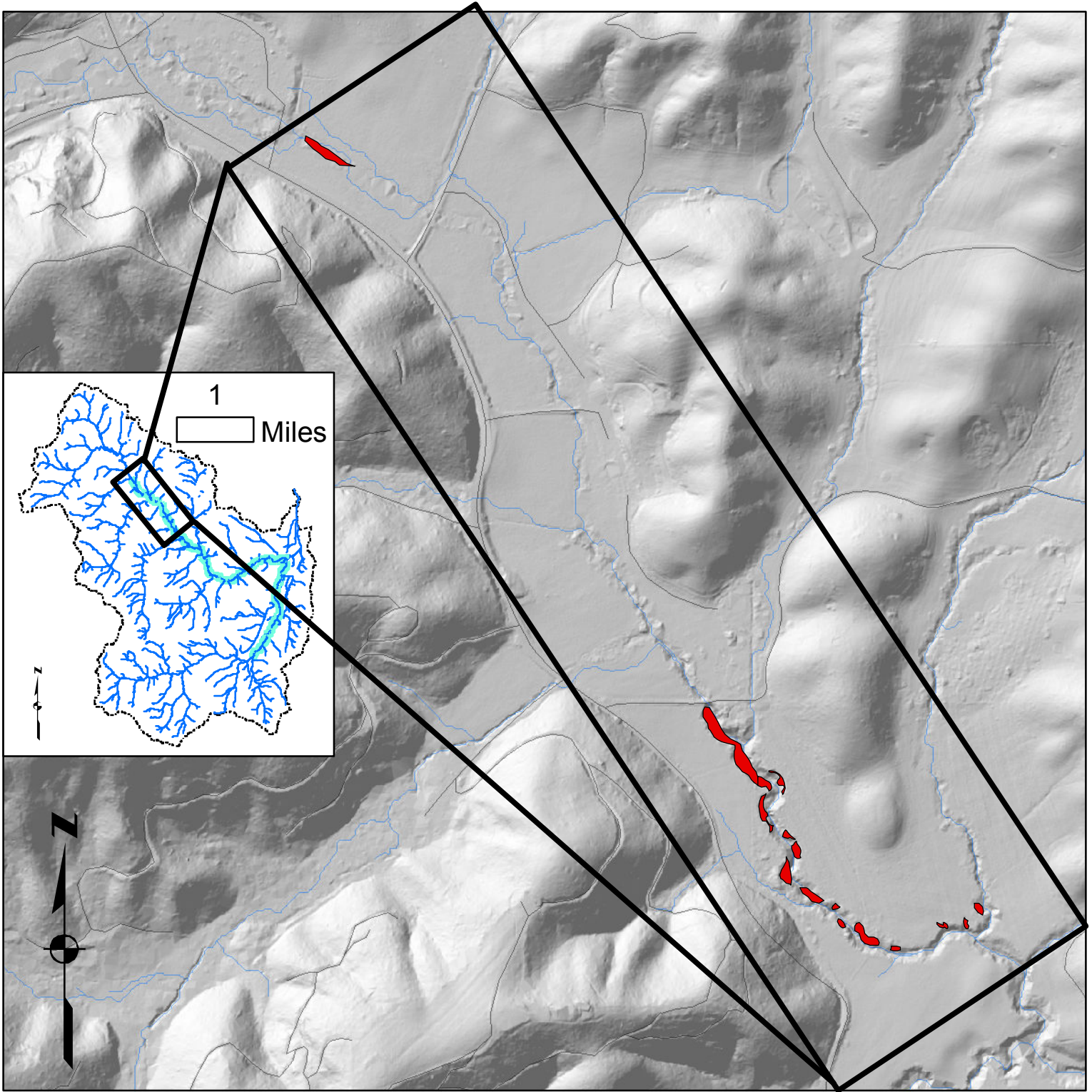
**Mainstem Bank Erosion  
Upper Green Valley Creek  
1 of 3**





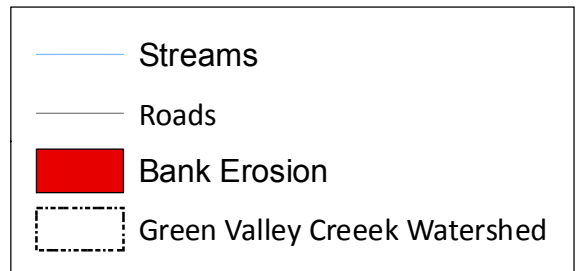
**Mainstem Bank Erosion  
Upper Green Valley Creek  
2 of 3**

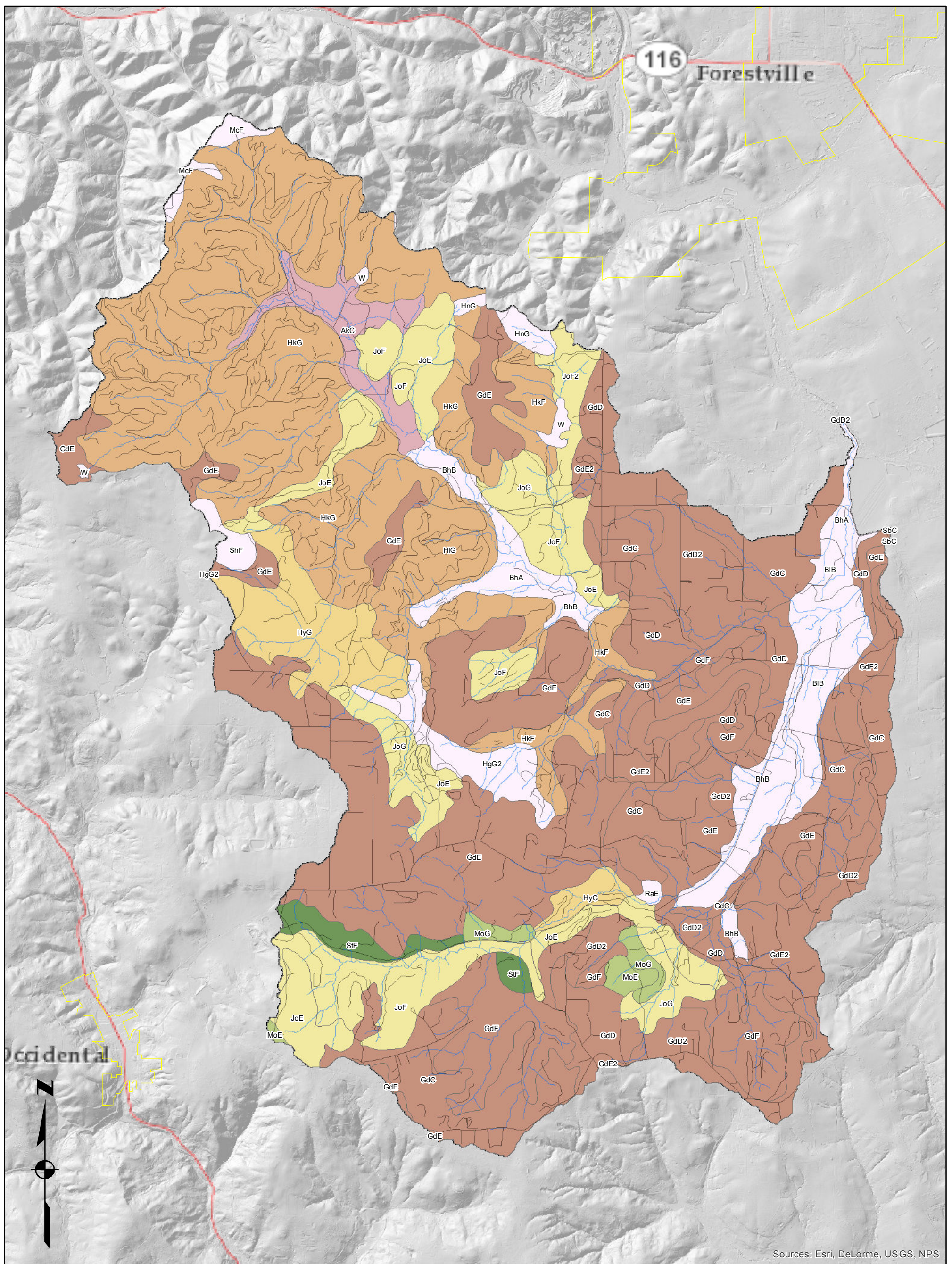




**Mainstem Bank Erosion  
Upper Green Valley Creek**

**3 of 3**





Sources: Esri, DeLorme, USGS, NPS

0 0.25 0.5 1 1.5 Miles

# Soil Map for Erosion Assessment

Soil Type	
	Other
	Arbuckle
	Goldridge
	Hugo
	Huse
	Josephine
	Montara
	Suther