GRAIP Roads Assessment

Upper East Fork Weiser River and Boulder Creek

Payette National Forest

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Nathan Nelson[1], Richard Cissel[1], Tom Black[1], and Charlie Luce[2]

[1]Hydrologist
[2]Research Hydrologist
US Forest Service
Rocky Mountain Research Station
322 East Front Street, Suite 401
Boise, Idaho, 83702 USA

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1.0 Background

The National Forest Transportation System represents a major public investment and provides many benefits to forest managers and the public. Roads, however, also have negative effects on water quality, aquatic ecosystems, and other resources. There is currently a large backlog of unfunded maintenance, improvement, and decommissioning work needed on the National Forest roads. Critical components of the infrastructure (e.g., culverts) are also nearing or have exceeded their life-expectancy, adding further risk and impacts to watershed and aquatic resources. Road-related fine sediment can damage salmonid spawning areas and reduce other available habitat for fish and macro-invertebrates.

The Geomorphic Roads Analysis and Inventory Package (GRAIP) data collection and analysis procedure provides land managers with field-based data that captures the extent to which roads and road-related sediment influence hydrologic function and stream channel conditions. GRAIP identifies precise locations where sediment delivery has occurred, where drainage features are compromised, and where road maintenance or decommissioning is required. Detailed information can then be used to prioritize actions to minimize adverse watershed and aquatic impacts from roads.

2.0 Objectives and Methods

GRAIP is formulated to assess the geomorphic and hydrologic impacts of roads, their physical condition and associated stream connections. It is a relatively intensive field-based method that provides detailed information designed to improve understanding of the overall effect of roads on key watershed processes. Specifically, the project was designed to address the following in the Upper East Fork Weiser River and Boulder Creek watersheds:

- identify the current level of fine sediment delivery from roads to streams
- identify the types and sources of road-related hydrologic risk in the watershed
- select and prioritize future restoration actions to improve watershed conditions and move towards an ecologically (and economically) sustainable road system.

GRAIP is used to inventory and model the risk profile of each of the road segments and drain features included in the study. The GRAIP system consists of a detailed, field-based road inventory protocol combined with a suite of geographic information system (GIS) models. The inventory is used to systematically describe the hydrology and condition of a road system with Geographic Positioning System (GPS) technology and automated data forms (Black et al., 2012). The GIS applications couple field data with GIS terrain analysis tools to analyze road-stream hydrologic connectivity, fine sediment production and delivery, downstream sediment accumulation, stream sediment input, shallow landslide potential with and without road drainage, gully initiation risk, and the potential for and consequences of stream crossing failures (Cissel et al, 2012). Detailed information about the performance and condition of the road drainage infrastructure is also supplied.

3.0 Study Areas

The upper East Fork of the Weiser River (UEFWR) is underlain primarily by Columbia River basalts, namely the Grande Ronde formation and the Imnaha formation (Figure 1, Table 1). The headwaters area in the southern portion of the watershed was glaciated, though the rest of the watershed has not been, even at elevations equivalent to the glaciated areas. The lower limit of the project area was the confluence with Bench Creek; the watershed above this point is considered to be potential habitat for Bull Trout. Some additional work was done in the adjacent Granite Creek sub-watershed of the Middle Fork of the Weiser River; that work is also included in this analysis.

The Boulder Creek watershed is also underlain primarily be the Imnaha and Grande Ronde basalts, at least in the roaded portion, though some of the western ridge is underlain by amphibolite and biotite-hornblende gniesses (Figure 2, Table 1). Boulder Creek is a tributary to the Little Salmon River and provides spawning habitat for anadromous salmonids. Some additional data were collected on non-system roads in the headwaters of the adjacent Weiser River basin and included in this analysis.

Table 1: Geologic units present in the project areas.

Label	Description	Age
Qs	Surficial deposits	Quaternary
Tcb	Columbia River Basalt Group	Miocene
Tib	Imnaha Basalt	Miocene
Tgr	Grande Ronde Basalt	Miocene
Kibwhbt	Idaho batholith, western border zone, foliated hornblende-biotite tonalite	Late Cretaceous
Ksutgd	Salmon River suture zone complex, gneissic porphyritic biotite granodiorite	Late Cretaceous
Kbmqd	Blue Mountains island arc, quartz diorite and tonalite	Cretaceous
Kibfbgd	Idaho batholith, foliated biotite granodiorite	Cretaceous
KPbmvp	Blue Mountains island arc, metamorphosed volcanic/plutonic complex	Cretaceous-Permian
JPbmms	Blue Mountains island arc, muscovite-chlorite schist, Rapid River area	Jurassic-Permian
JPbmgn	Blue Mountains island arc, biotite (+hornblende) gneiss and biotite schist	Jurassic-Permian
JPbmam	Blue Mountains island arc, amphibolite gneiss	Jurassic-Permian
JPbmmr	Blue Mountains island arc, metamorphosed rocks, undivided	Jurassic-Permian
^bmwd	Blue Mountains island arc, Wallowa terrane, Doyle Creek Formation	Late Triassic
^bmwm	Blue Mountains island arc, Wallowa terrane, Martin Bridge Formation	Late Triassic
^Pbmws	Blue Mountains island arc, Wallowa terrane, Seven Devils Group, undivided	Triassic-Permian

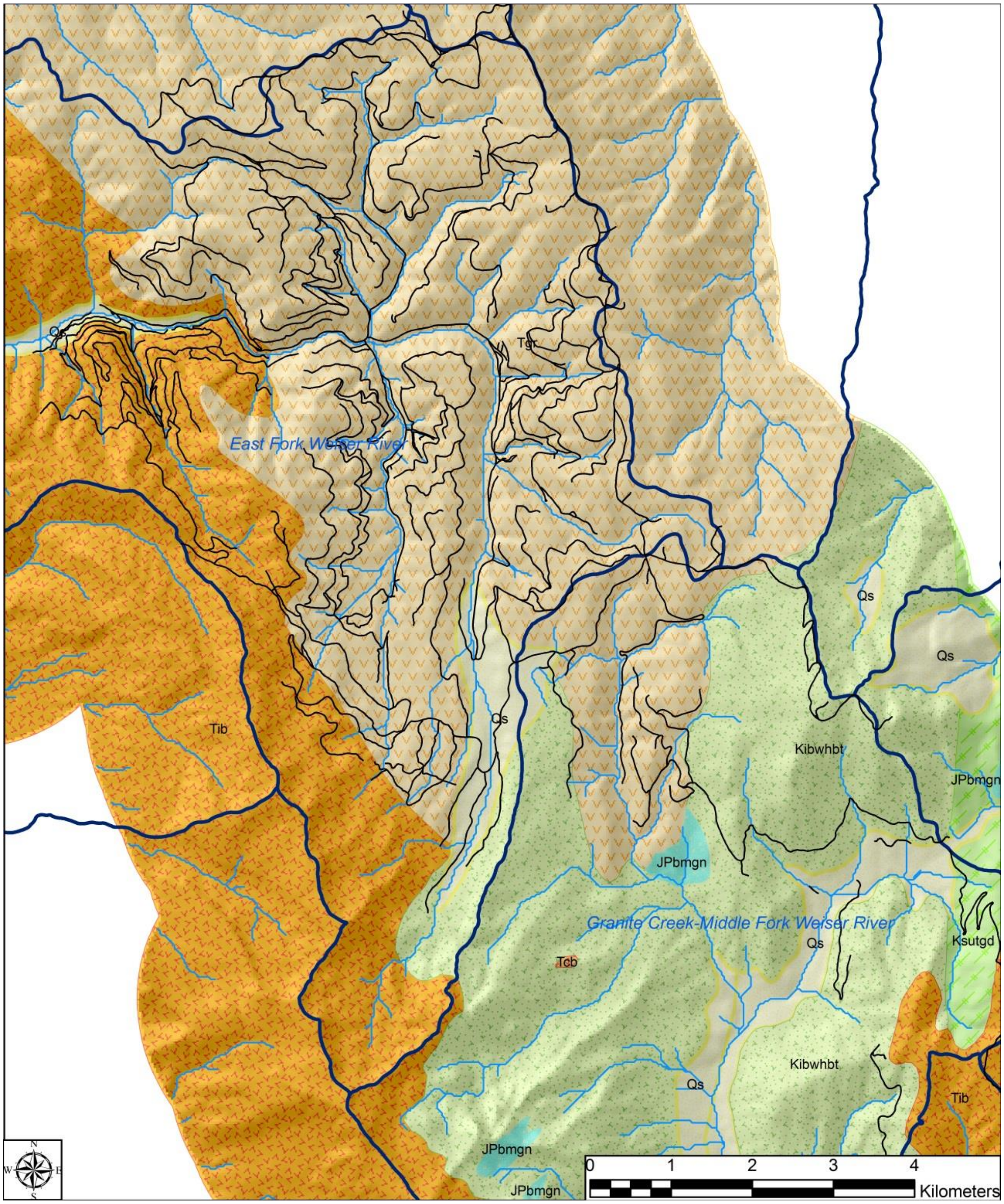

Figure 1: Geologic map showing the study area in the upper East Fork of the Weiser River (UEFWR), and the area where additional data was collected.

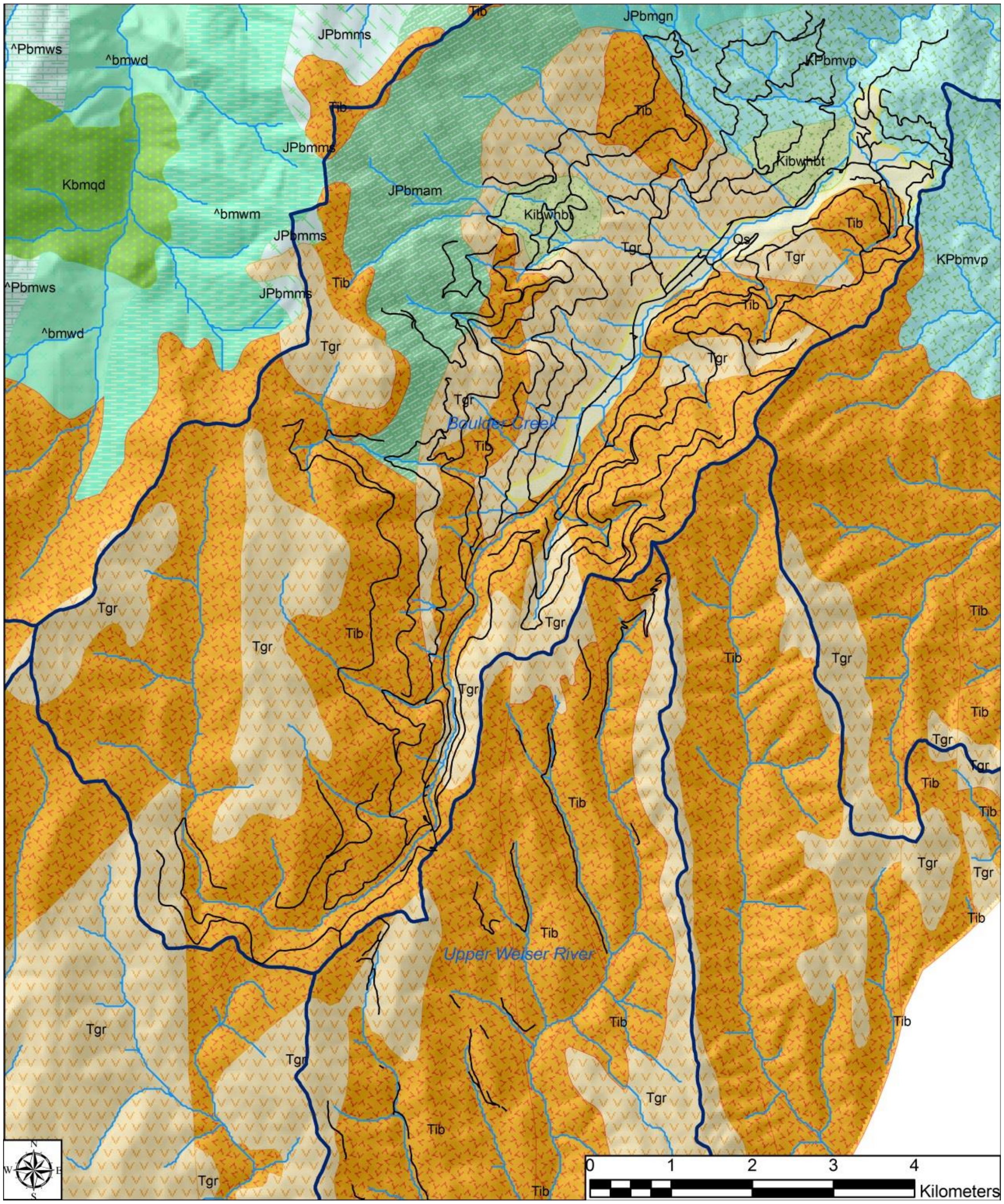

Figure 2: Geologic map showing the Boulder Creek study area and adjacent areas.

4.0 Results

A total of 8,075 road segments and 6,538 drain points were surveyed in 4 months of field work. Data analysis provides specific information on the condition and function of 472 km of roads, 219 km of which are within the Upper East Fork Weiser River watershed (Figure 3) and 178 km of which are in the Boulder Creek watershed (Figure 4); the remainder were collected in adjacent watersheds. GRAIP inventory data and modeling tools were used to characterize the following types of impacts and risks:

- Road-stream hydrologic connectivity
- Fine sediment production and delivery
- Drain point condition
- Downstream sediment accumulation
- Stream crossing failure risk
- Landslide risk

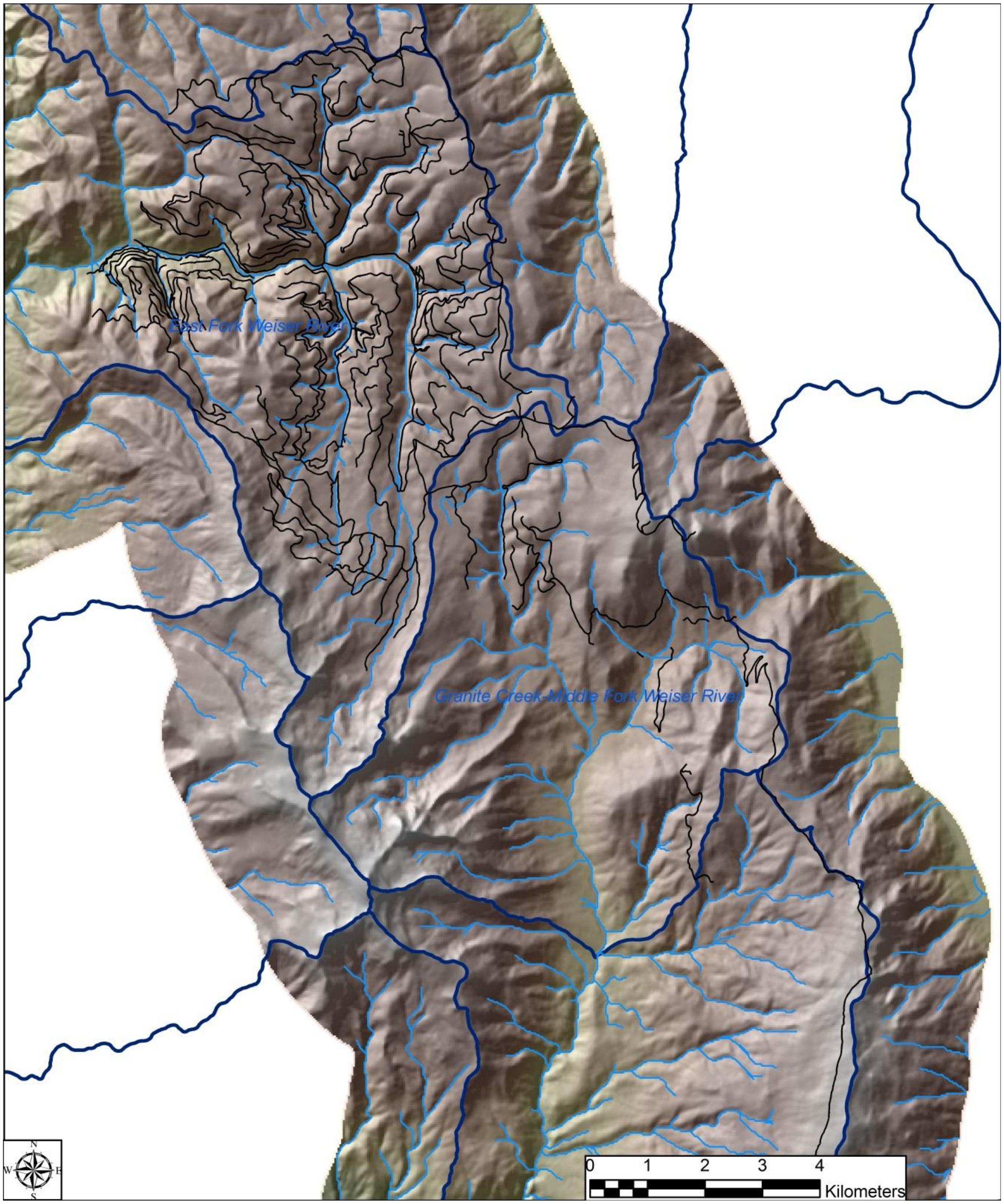

Figure 3: Maps showing the inventoried roads in the UEFWR project area.

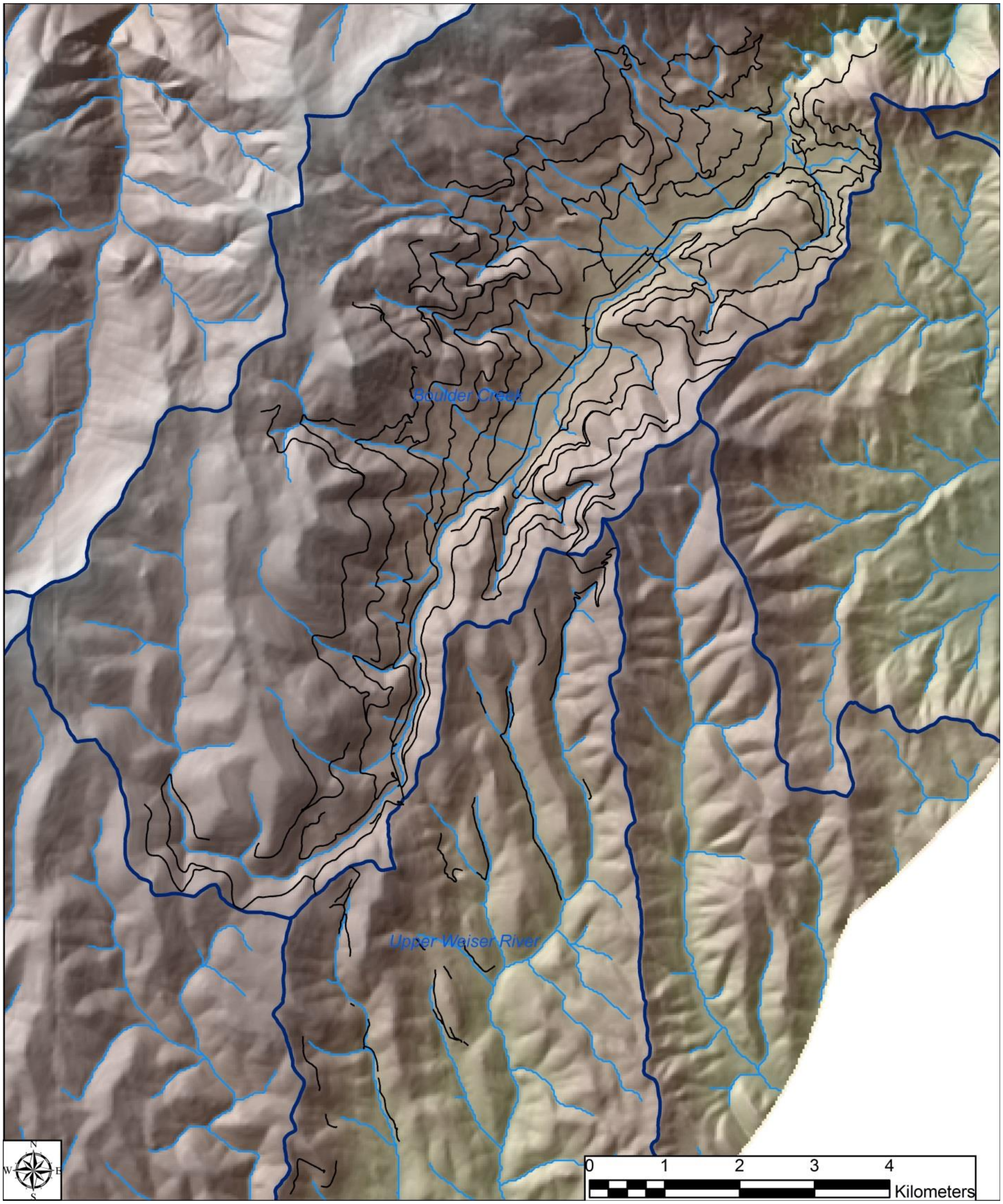

Figure 4: Map showing the inventoried roads in the Boulder Creek project area.

4.1 Road-Stream Hydrologic Connectivity

Roads often intercept shallow groundwater converting subsurface flow to surface runoff, resulting in local hydrologic impacts when water is discharged directly to channels (Wemple et al., 1996). Additional runoff is also produced from compacted road surfaces. Basin-scale studies in the Oregon Cascades suggest that a high degree of integration between the road drainage system and the channel network can increase some peak flows (Jones and Grant, 1996).

The hydrologically-connected portion of the road is calculated in GRAIP using the field assessment of drain point connection and a road segment flow routing system. The flow path below each drain point is followed until evidence of overland flow ceases or the flow path reaches a natural channel.

The crews identified 38.4 km (14% of the road network) of stream connected road in the Upper East Fork Weiser River project area (Figure 5) and 25.4 km (13%) of stream connected road in the Boulder Creek project area (Figure 6). While a significant amount of this occurs along valley bottom roads along the main stems of the two streams, much of the stream connected road is associated with mid-slope roads near crossings with small tributaries. These connections allow sediment to enter high in the stream network and potentially impact more of the stream habitat.

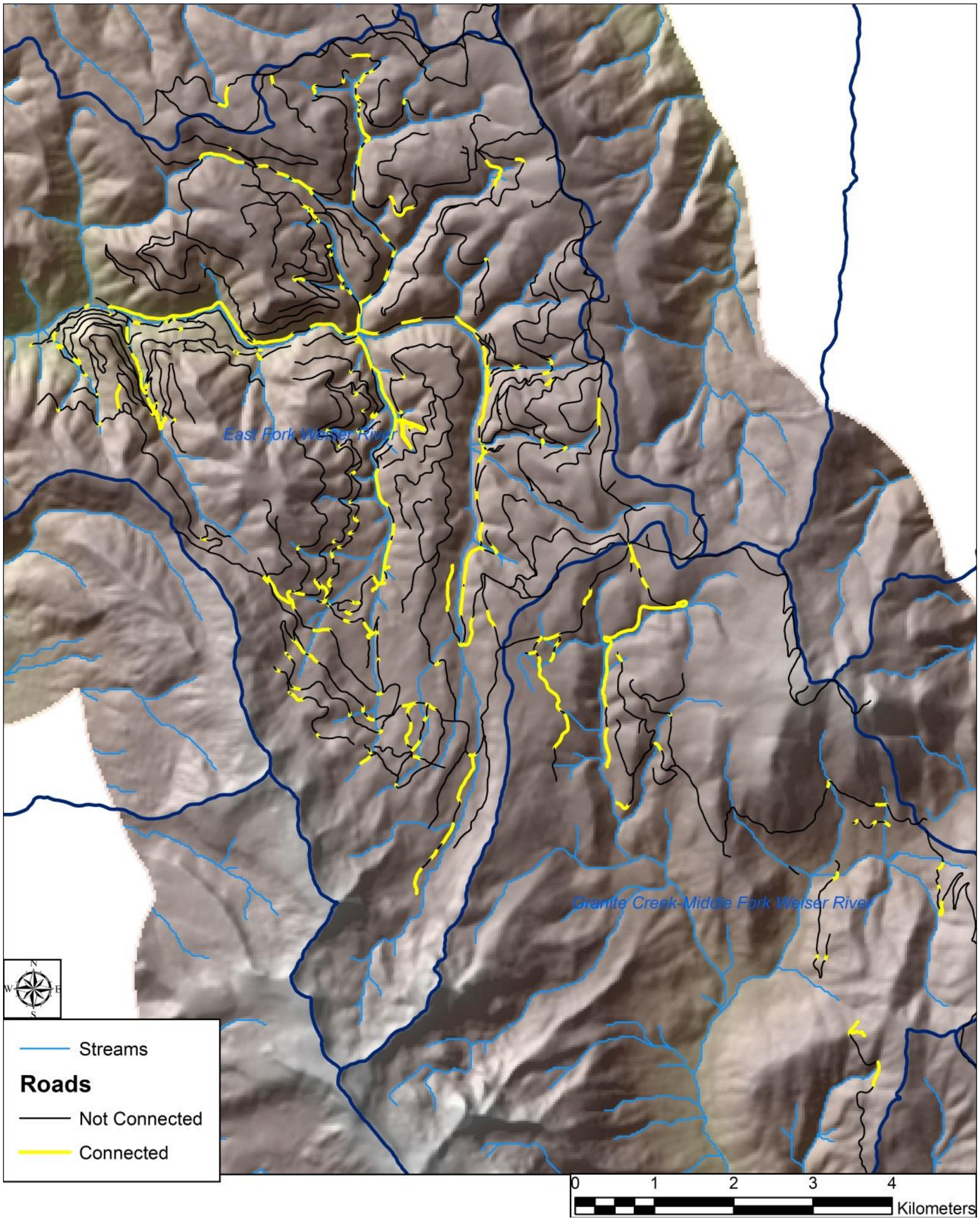

Figure 5: Stream-connected road segments in the UEFWR project area.

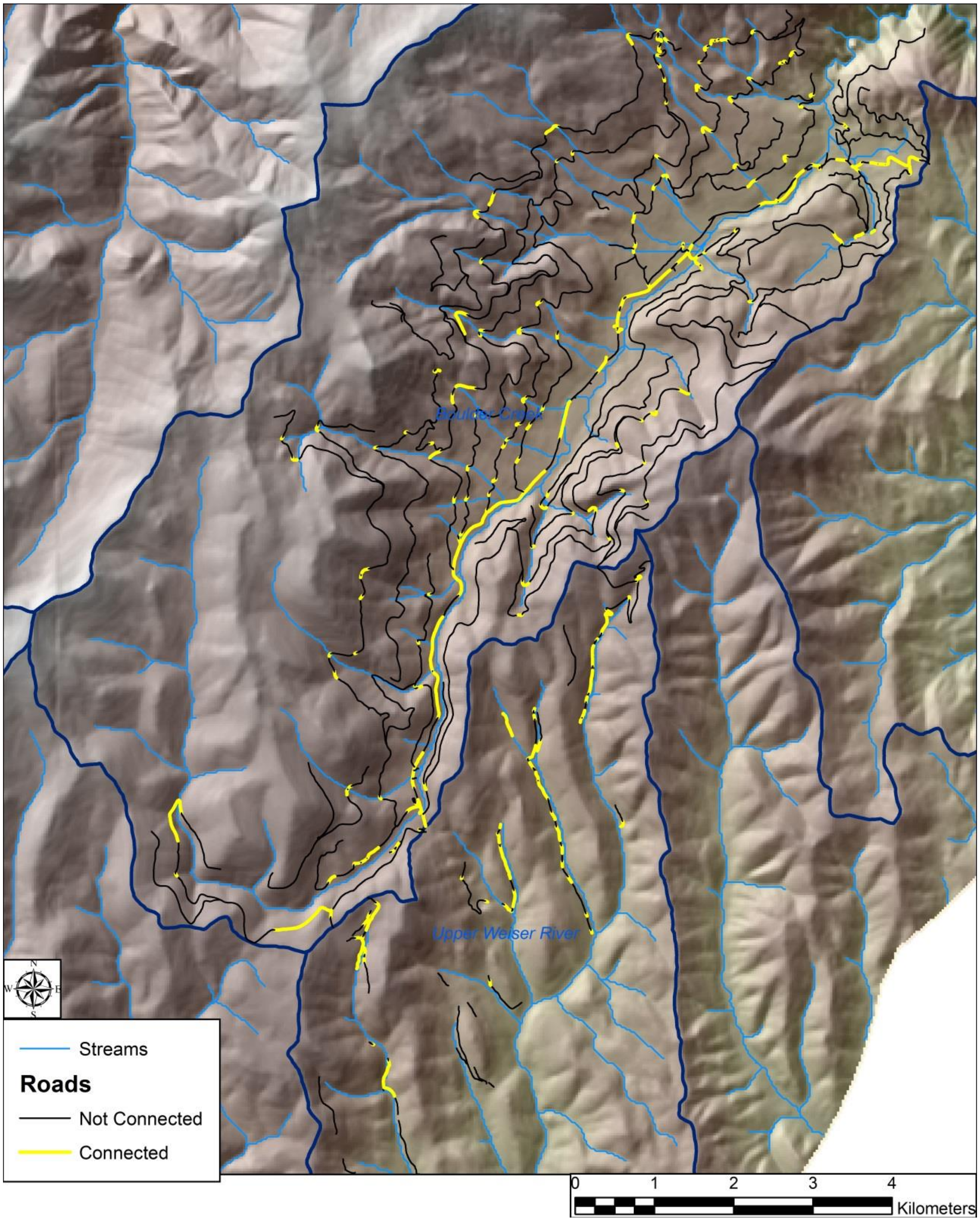

Figure 6: Stream-connected road segments in Boulder Creek project area.

4.2 Road Surface Fine Sediment Production, Delivery, and Accumulation

Fine sediment production for a road segment (E) is estimated with a base erosion rate and the properties of the road (Luce and Black ,1999; Cissel et al., 2009; Prasad, 2007), as shown below.

$$E = B \times L \times S \times V \times R$$

B is the base erosion rate[1] (kg/yr/m)
L is the road length (m) contributing to the drain point
S is the slope of the road (m/m) contributing to the drainpoint
V is the vegetation cover factor for the flow path
R is the road surfacing factor

Delivery of eroded sediment to the channel network is determined by observations of each place that water leaves the road. Each of these drain points is classified as either stream connected or not stream connected. No estimate of fractional delivery is made because there is insignificant hillslope sediment storage in locations where there is a clear connection to the channel under most circumstances. GRAIP tracks sediment production from road surfaces, delivery through drain points, and accumulation in the stream network.

The roads in the UEFWR project area are expected to produce 1,162 Mg/yr of sediment and deliver 143 Mg/yr to the stream network. This yields a delivery rate of 12%. In the Boulder Creek project area, the roads are expected to produce 877 Mg/yr and deliver 111 Mg/yr, or 13% of the produced sediment. Figures 7 and 8 show the sediment production and delivery in the UEFWR project area and the Boulder Creek project area, respectively. These maps often make it seem like most areas are problems; however, Figure 9 shows the cumulative amount of sediment delivered with the cumulative length of road. Fixing the worst 8% of the roads in each watershed could reduce sediment delivery by over 90%.

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[1] For this analysis, a base erosion rate of 50 kg/yr/m of vertical drop along the road based one season of data from the sediment traps in the Upper East Fork Weiser River. Data from additional seasons will likely result in adjustments to this baserate.

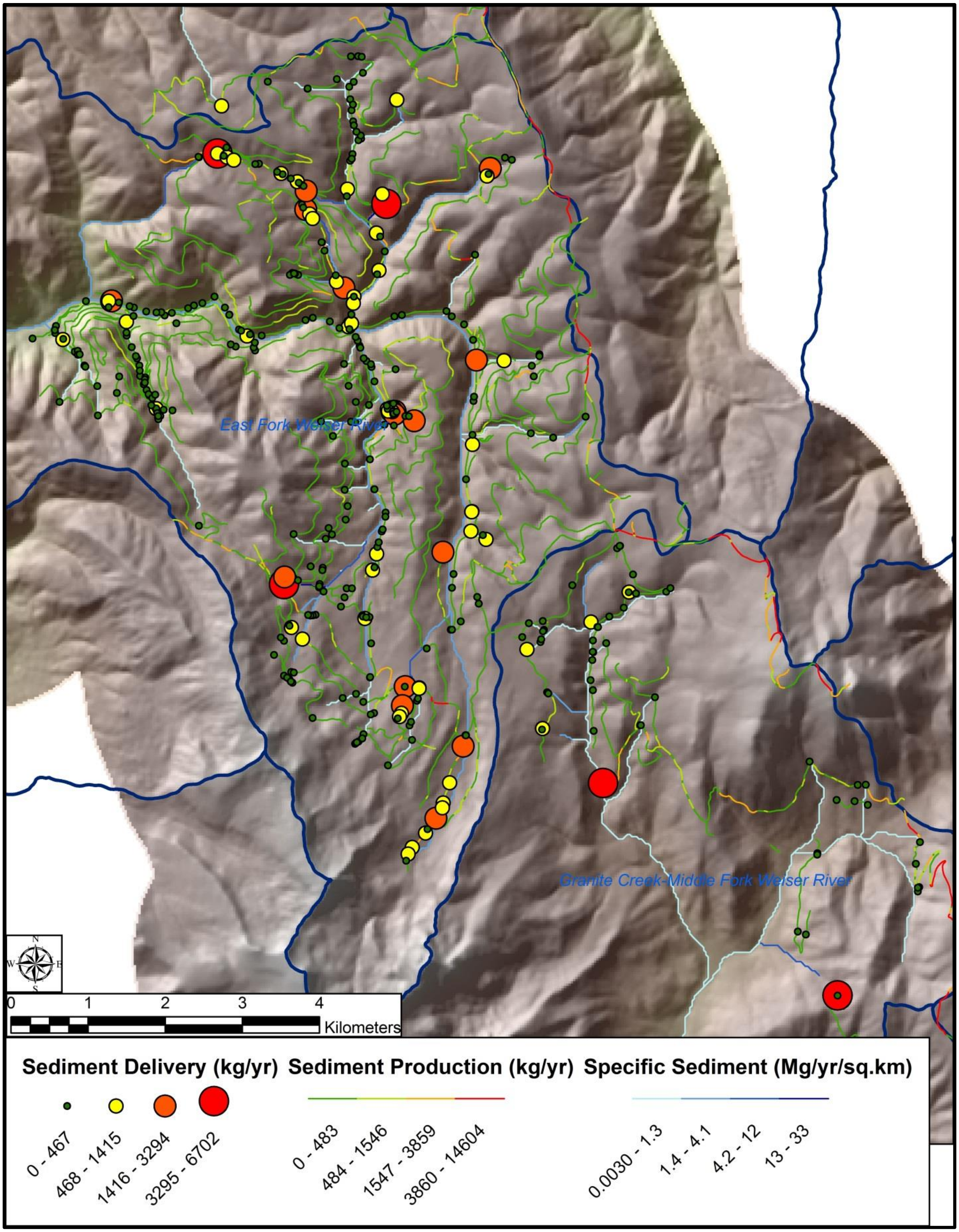

Figure 7: Road surface sediment production on individual road segments, delivery at drainpoints, and specific sediment in stream reaches for the UEFWR project area.

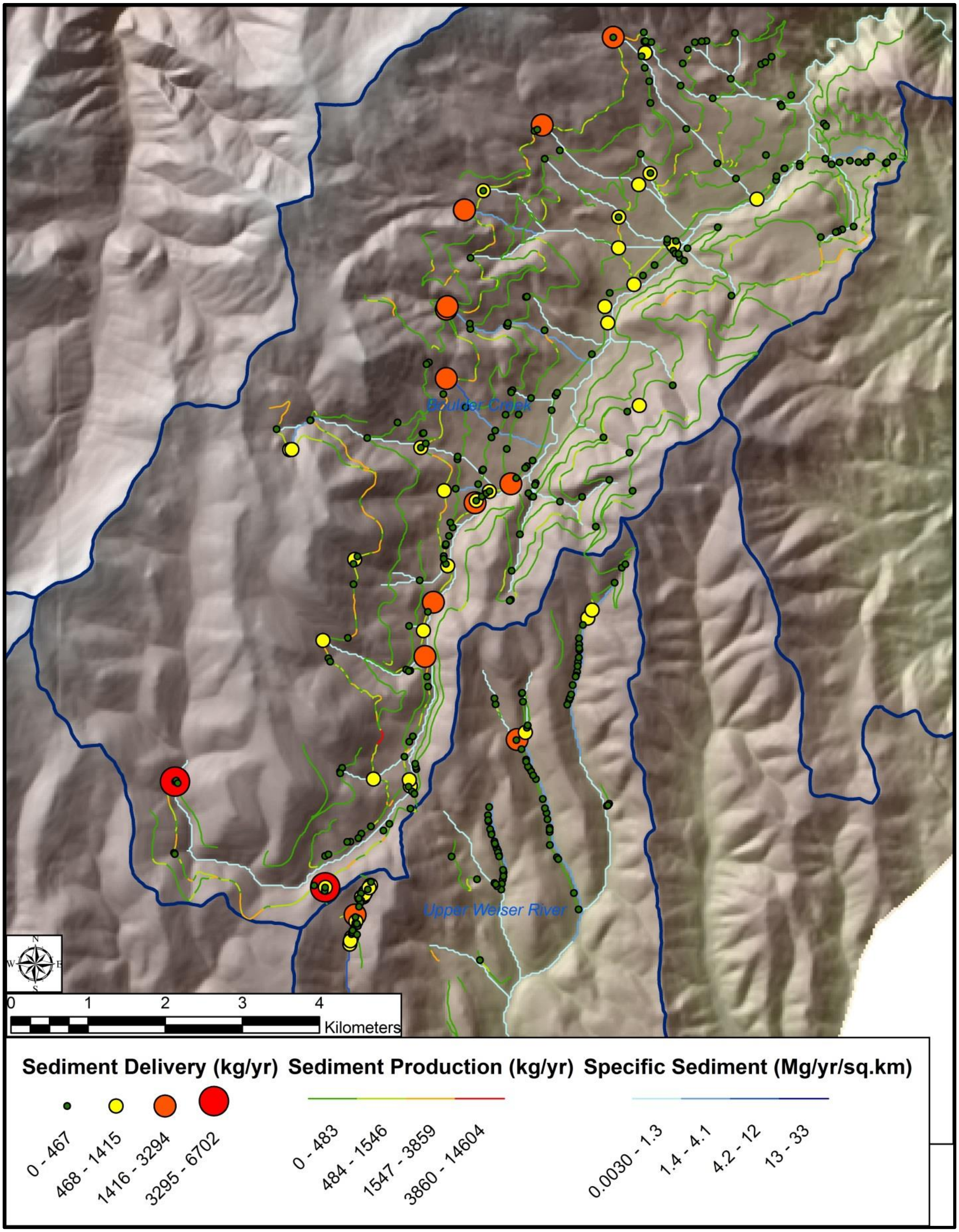

Figure 8: Road surface sediment production on individual road segments, delivery at drainpoints, and specific sediment in stream reaches for the Boulder Creek project area.

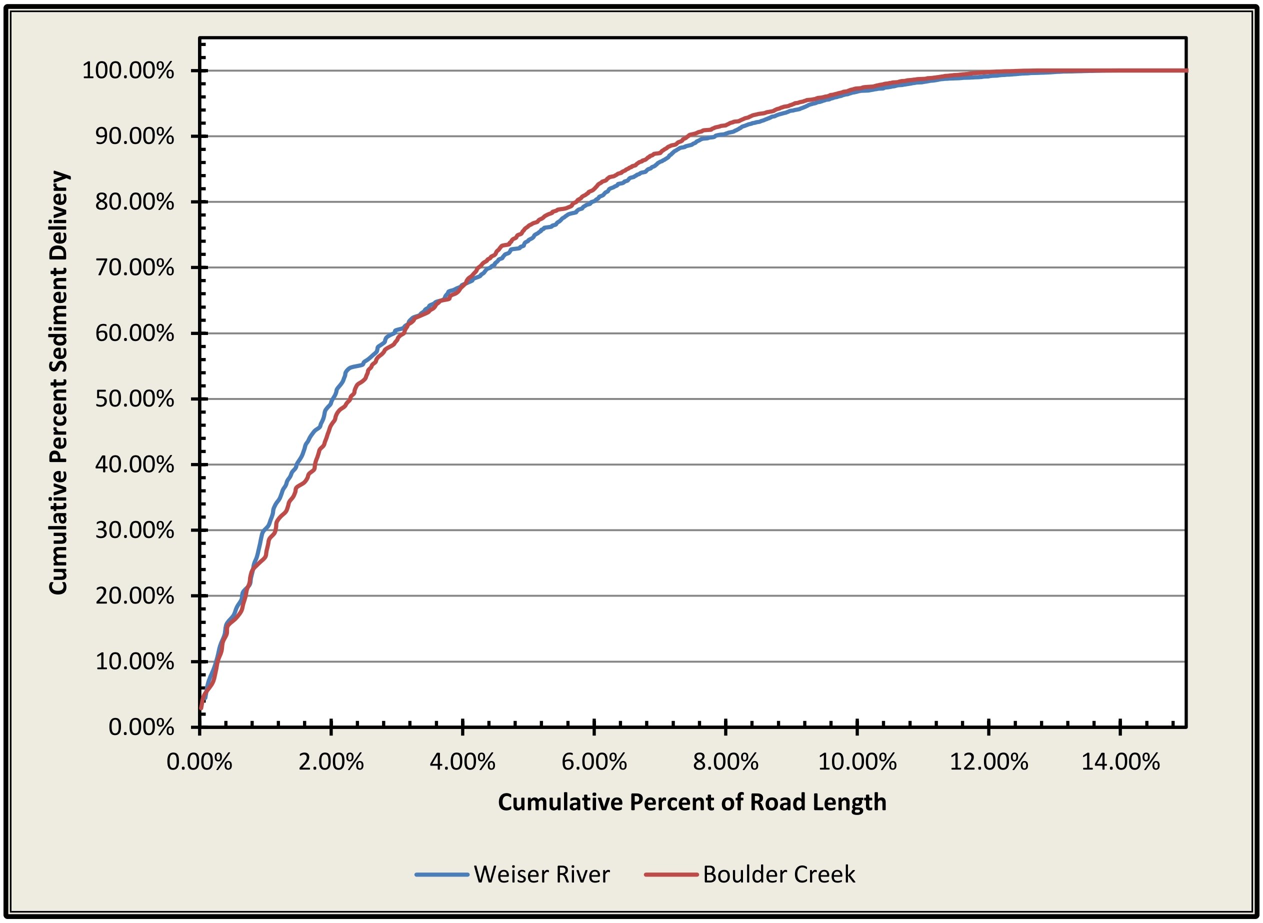

Figure 9: Graph showing cumulative sediment delivery in terms of road length. This illustrates that only a small portion of the road network in each watershed is responsible for road-related sediment problems.

In the UEFWR project area, eliminating delivery at the 15 drainpoints and associated road segments that deliver the most sediment (Figure 10; Table 2) would reduce overall sediment delivery by 34.5%, or about 49.2 Mg/yr. Similarly, the top 15 drainpoints and road segments in the Boulder Creek project area (Figure 11; Table 3) would reduce sediment inputs by 32.2%, or about 35.8 Mg/yr.

Many of these drains are located on mid-slope roads and deliver sediment to tributaries rather than to the main stem. Nearly half of all sediment in the UEFWR project area (44%) is delivered to 1st-order streams, with a further 37% of the sediment delivered to 2nd-order streams. In the Boulder Creek project area, 41% of the sediment is delivered to 1st-order streams and 30% is delivered to 2nd-order streams.

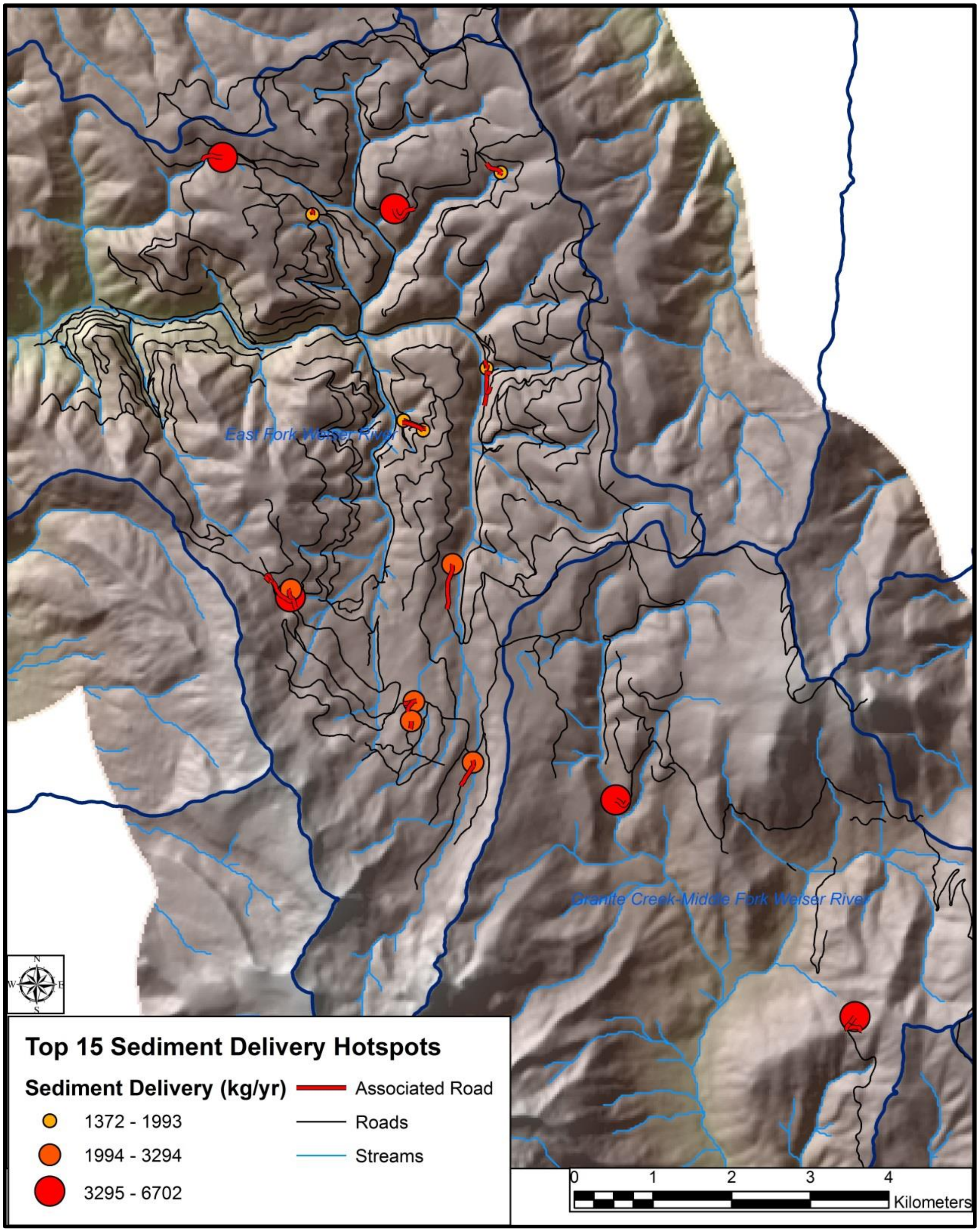

Figure 10: Map showing the locations of the 15 highest ranked drainpoints in the UEFWR project area, by sediment delivery, and the road segments draining to them.

Table 2: Top 15 drainpoints based on sediment delivery in the UEFWR project area.

Type	Sediment Delivery (kg/yr)	Effective Length (m)	Easting	Northing
Non-engineered Drain	6,702	357	563415	4953101
Non-engineered Drain	6,500	603	556233	4958439
Non-engineered Drain	4,409	161	560372	4955857
Diffuse Drain	4,360	284	555369	4964023
Non-engineered Drain	4,081	352	557561	4963372
Non-engineered Drain	3,122	364	558294	4958852
Broad-based Dip	3,024	372	558558	4956335
Broad-based Dip	2,685	229	557804	4957108
Stream Crossing	2,544	105	556241	4958531
Waterbar	2,339	102	557768	4956862
Stream Crossing	1,993	175	558910	4963831
Diffuse Drain	1,903	289	557923	4960557
Stream Crossing	1,860	467	558729	4961344
Diffuse Drain	1,843	262	557673	4960680
Non-engineered Drain	1,800	60	556513	4963297

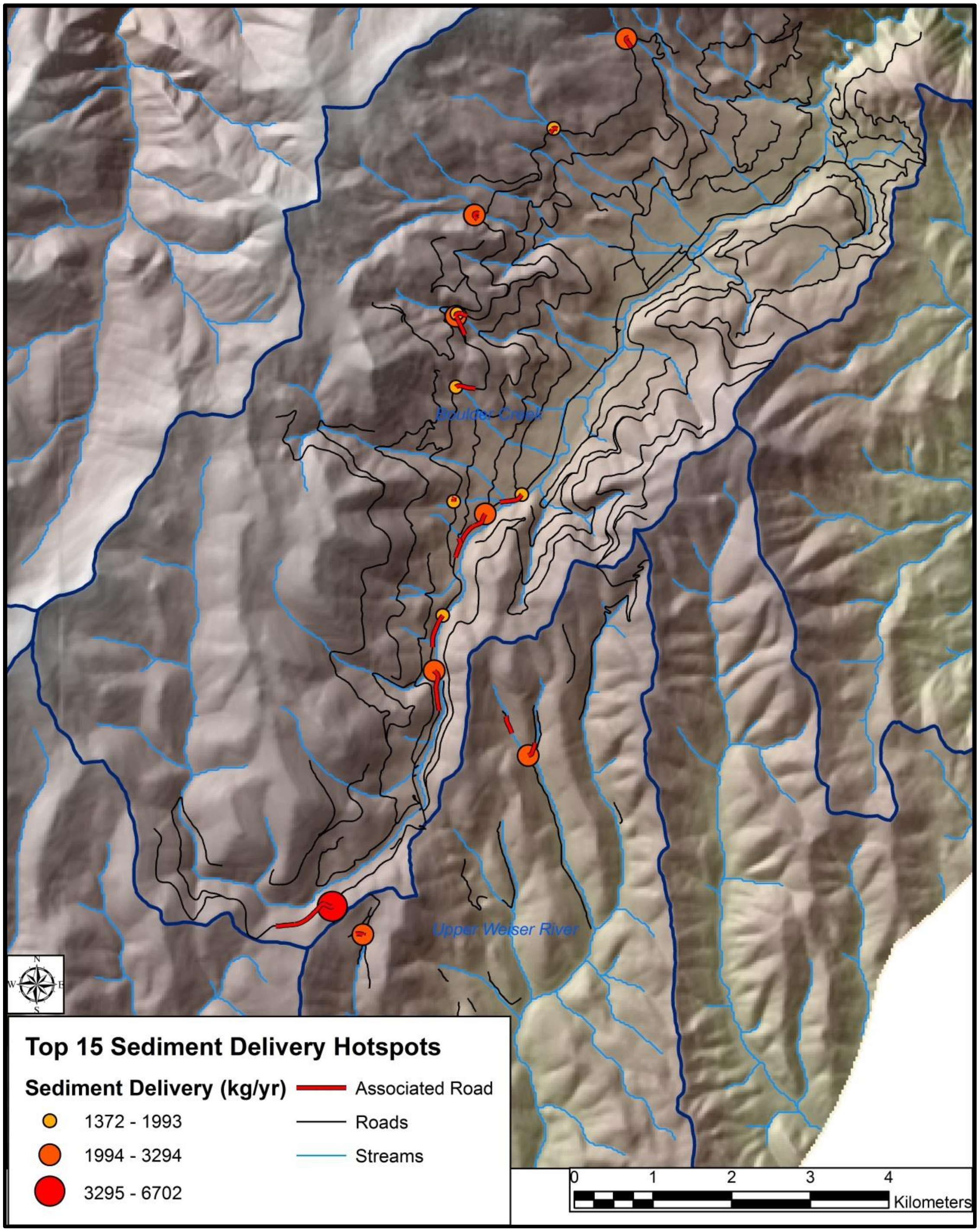

Figure 11: Map showing the locations of the 15 highest ranked drainpoints in the Boulder Creek project area, by sediment delivery, and the road segments draining to them.

Table 3: Top 15 drainpoints based on sediment delivery in the Boulder Creek project area.

Type	Sediment Delivery (kg/yr)	Effective Length (m)	Easting	Northing
Ditch Relief Culvert	4,773	434	542718	4991514
Broad-based Dip	3,294	105	544523	5000303
Stream Crossing	2,807	370	545209	4993432
Stream Crossing	2,782	392	544012	4994507
Ditch Relief Culvert	2,754	487	544664	4996503
Non-engineered Drain	2,394	116	543105	4991156
Stream Crossing	2,303	171	544289	4999014
Stream Crossing	2,296	40	544525	5000302
Broad-based Dip	2,275	101	546456	5002541
Broad-based Dip	1,878	116	545534	5001402
Ditch Relief Culvert	1,787	286	544121	4995212
Non-engineered Drain	1,776	127	544289	4998114
Non-engineered Drain	1,668	131	544303	4999048
Stream Crossing	1,626	311	545127	4996749
Stream Crossing	1,372	29	544262	4996660

4.3 Sediment Accumulation from Other Sources

The crews also collected data on other road-related sediment sources within the two project areas. Two such sediment sources recorded by the crews were gullies and landslides; for these points the crews recorded the dimensions of the feature. The third source, fill erosion, records the volume of material eroded at drainpoints within the road prism.

In the UEFWR project area, crews located 65 gullies (Figure 12) with an estimated eroded mass of 1,500 Mg[2] (750 m^3), of which 1,200 Mg (590 m^3) were assumed to have been delivered to the stream network via an observed stream connection. Crews also observed 26 landslide features with an estimated eroded mass of 12,500 Mg (6,260 m^3); six of these landslides were observed to be stream connected resulting in an estimated 3,400 Mg (1,700 m^3) of potentially delivered sediment. Some of the eroded sediment from the stream connected gullies and landslides was still sitting in fans or toes and had not yet been delivered, though such sediment is readily available for future erosion. Much of the erosion at the gully and landslide features is likely associated with a large storm event in June of 2010, though erosion is ongoing in many of these features and some features may be older. The crews also recorded 123 instances where fill erosion was at least 5 ft^3, and noted that 42 of these instances were at stream connected drainpoints. Fill erosion produced 462 Mg (231 m^3) of sediment, of which 340 Mg (170 m^3) was delivered to the stream network.

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[2] Soil density was assumed to be 2 Mg/m^3, which is the default for SINMAP and represents the higher density soils.

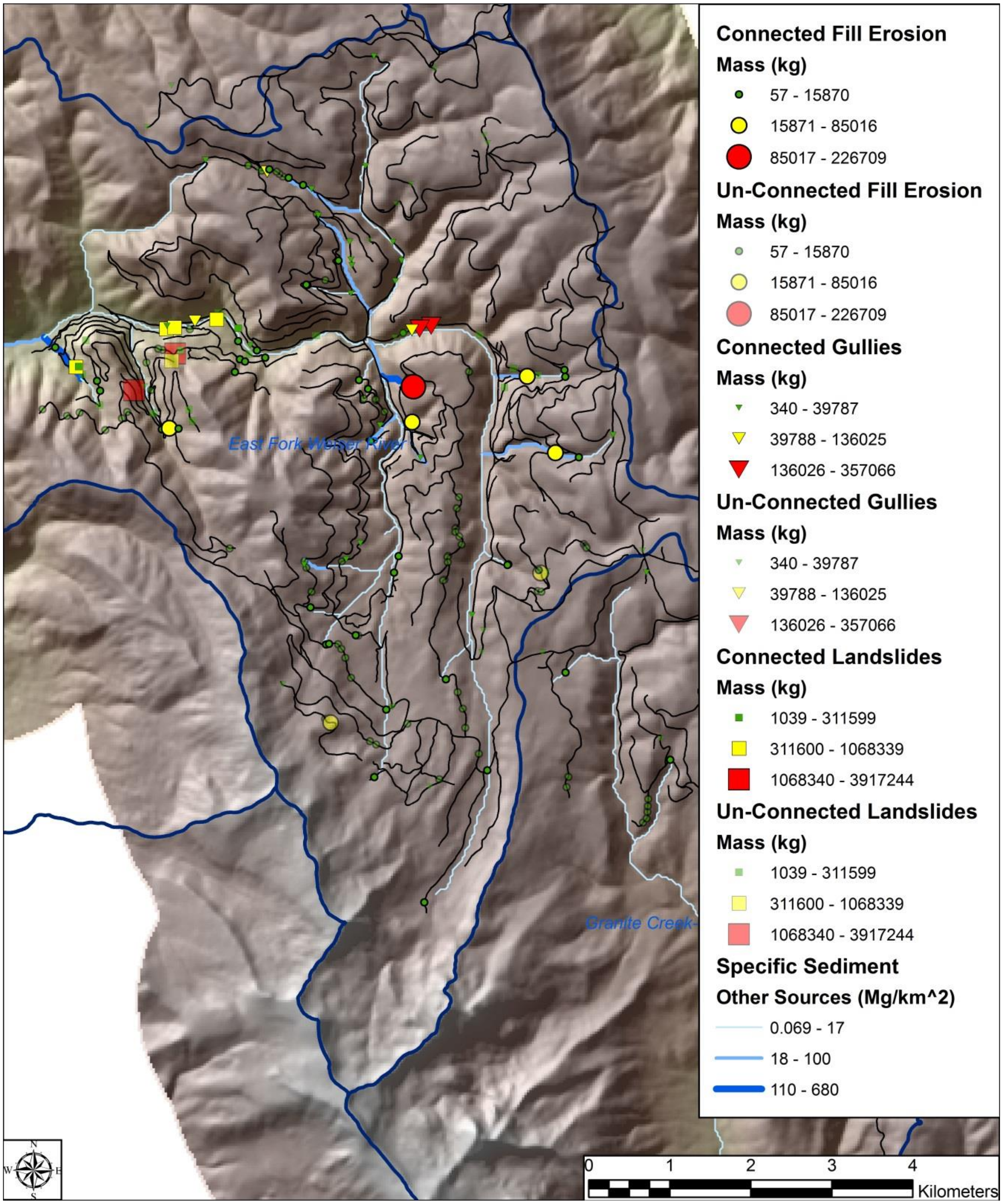

Figure 12: Map showing other road-related sediment sources in the UEFWR project area; units are in kilograms.

In the Boulder Creek project area, crews located 10 gullies (Figure 13) with an estimated eroded mass of 63.7 Mg (31.8 m^3), of which 23 Mg (11.5 m^3) were assumed to have been delivered to the stream network via an observed stream connection. Crews also observed 1 landslide with an estimated eroded mass of 712 Mg (356 m^3); this landslide was not stream connected. Some of the eroded sediment from the stream connected gullies was still sitting in fans and had not yet been delivered. Some of the erosion at the gully and landslide features may be associated with the storm event in June of 2010, though erosion is ongoing in many of these features and some features may predate the storm event. The crews also recorded 78 instances where fill erosion was at least 5 ft^3, and noted that 34 of these instances were at stream connected drainpoints. Fill erosion produced 1,160 Mg (580 m^3) of sediment, of which 1,130 Mg (570 m^3) was delivered to the stream network.

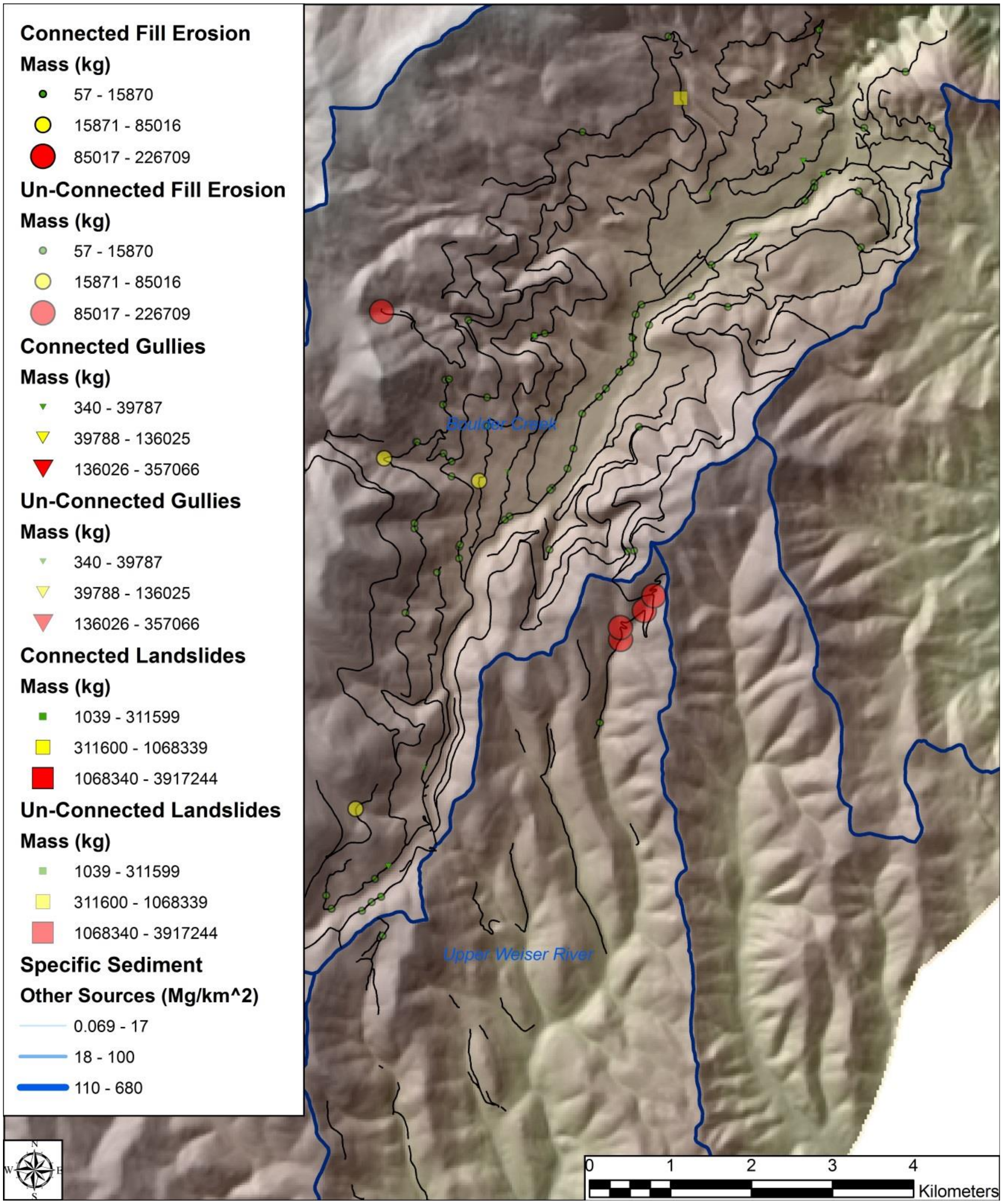

Figure 13: Map showing other road-related sediment sources in the Boulder Creek project area; units are in kilograms.

4.4 Drain Point Analysis

The road inventory also provides a look at the state of the road infrastructure, particularly in the condition of the various drainpoints. Drainpoint problems are defined in Table 4; conditions not listed are not considered to be problems.

Table 4: Drainpoint problem definitions used during analysis.

Drainpoints with multiple problems only get counted once.

There is a problem at a drainpoint if:

Broad-based Dip		
	condition =	puddles on road wetland in ditch saturated fill does not drain
Diffuse Drain		
	never a problem	
Ditch Relief Culvert		
	condition =	≥ 20% occluded buried totally crushed rusted significantly flows around pipe
	flow diversion = yes	
Excavated Stream Crossing		
	condition =	erosion flows under fill side slope landslide
Lead Off Ditch		
	condition =	gullied excess deposition
Non-engineered		
	always a problem except when	
	condition =	outsloped
	AND	
	fill erosion = no	
Stream Crossing		
	condition =	partially blocked totally blocked totally crushed rusted significantly flows around pipe scoured under bridge
	SBI ≥ 3	
	diversion = 2 AND SBI ≥ 2	
Sump		
	condition =	fill saturation puddles on road
Water Bar		
	condition =	damaged too small

The UEFRW project area had an overall problem rate of 19.6%, and the Boulder Creek project area had an overall problem rate of 9.6% (Table 5). While the UEFWR project area had higher rates for most drainpoint types, Boulder Creek had a higher rate of problems with ditch relief culverts (25.2% compared to 15.4% in the UEFWR).

Table 5: Drainpoint problem rates in the UEFWR and Boulder Creek project areas.

Drainpoint Type	Upper East Fork Weiser River			Boulder Creek		
	Total Number	Problems	Problem Rate	Total Number	Problems	Problem Rate
Broad-based Dip	342	79	23.1%	245	43	17.6%
Diffuse Drains	687	0	0.0%	373	0	0.0%
Ditch Relief Culvert	201	31	15.4%	210	53	25.2%
Excavated Stream Crossing	46	4	8.7%	67	0	0.0%
Lead Off Ditch	27	0	0.0%	10	0	0.0%
Non-engineered Drain	744	316	42.5%	358	107	29.9%
Stream Crossing	142	52	36.6%	127	26	20.5%
Sump	58	10	17.2%	11	1	9.1%
Waterbar	1,261	196	15.5%	1,629	62	3.8%
Total	**3,508**	**688**	**19.6%**	**3,030**	**292**	**9.6%**

4.5 Stream Crossing Failure Risk

Besides contributing fine sediment to streams through surface erosion, stream crossings may fail catastrophically when the culvert becomes blocked and deliver large sediment pulses to stream channels. Stream crossing failure risks were assessed using the Stream Blocking Index (SBI, Flanagan et al., 1998). The SBI characterizes the risk of woody debris plugging the culvert inlet by calculating the ratio of the culvert diameter to the upstream channel width and the skew angle between the channel and the pipe inlet. SBI values of 1 and 2 indicate low or moderate plugging risk; values of 3 and 4 indicate high or extreme plugging risk. In the UEFWR project area, 28% of the stream crossings were in the high risk categories (34 SBI_3 and 6 SBI_4, Table 6, Figure 14); in the Boulder Creek project area 15% fell into the high risk categories (18 SBI_3 and 1 SBI_4, Table 6, Figure 15).

The risk of stream crossing failure can also be viewed in the context of the consequences of failure (Flanagan et al., 1998). One consequence of concern at these stream crossings is the erosion and subsequent delivery of fill material into the stream channel. We calculated the volume of fill material that would likely be excavated in an overtopping type failure. We modeled the prism of fill at risk as bounded at the base by an area 1.2 times the channel width, with side slopes climbing to the road surface at a slope of 33%. The total fill volume at risk for all the stream crossings was 5,581 m^3 in the UEFWR project area and 4,720 m^3 in the Boulder

Creek project area (Table 6). In the UEFWR project area, fill volumes ranged from 4 m^3 to 373 m^3, and had a mean volume of 59 m^3; 2,393 m^3 (43%) was associated with stream crossings with SBI values ≥3. In the Boulder Creek project area, fill volumes ranged from 3 m^3 to 200 m^3, and had a mean volume of 56 m^3; 1,301 m^3 (28%) of this fill was associated with stream crossings with SBI values ≥3. This type of fill failure will not occur at bridges, so no fill volume risk was calculated at these locations.

Another consequence of concern at failed stream crossings is the potential diversion of stream flow onto road surfaces and unchanneled hillslopes. Once a crossing becomes occluded and begins to act as a dam, failure can occur in one of several ways. If the road grade dips into and rises out of the crossing, the failure is likely to be limited to a localized overtopping of the stream crossing. However, if the road grades away from the crossing in one or more directions, the flow may be diverted down the road and ditch and onto adjacent hillslopes, where it can cause gullying and/or landsliding (Furniss et al. 1998, Best et al. 1995). In these situations, volumes of sediment far exceeding those at the crossing can be at risk.

GRAIP addresses this issue by classifying the potential for stream crossings to divert streamflow down the adjacent road as: no potential, potential to divert in one direction, or potential to divert in two directions. In the UEFWR project area, 32 of 142 stream crossings (23%, Figure 16) had the potential to divert in one or more directions. In the Boulder Creek project area, 22 of 127 stream crossings (17%, Figure 17) had the potential to divert in one or more directions.

Table 6: Summary of stream crossing failure risks.

UEFWR				
SBI	**Risk**	**Count**	**Fill Volume at Risk (m^3)**	**Number with flow diversion potential**
0	**N/A**	51	913	4
1	**Low**	9	249	6
2	**Moderate**	42	2,026	9
3	**High**	34	1,993	10
4	**Extreme**	6	400	3
Total		**142**	**5,581**	**32**

Boulder Creek				
SBI	**Risk**	**Count**	**Fill Volume at Risk (m^3)**	**Number with flow diversion potential**
0	**N/A**	45	469	4
1	**Low**	22	843	1
2	**Moderate**	41	2,107	13
3	**High**	18	1,291	4
4	**Extreme**	1	10	0
Total		**127**	**4,720**	**22**

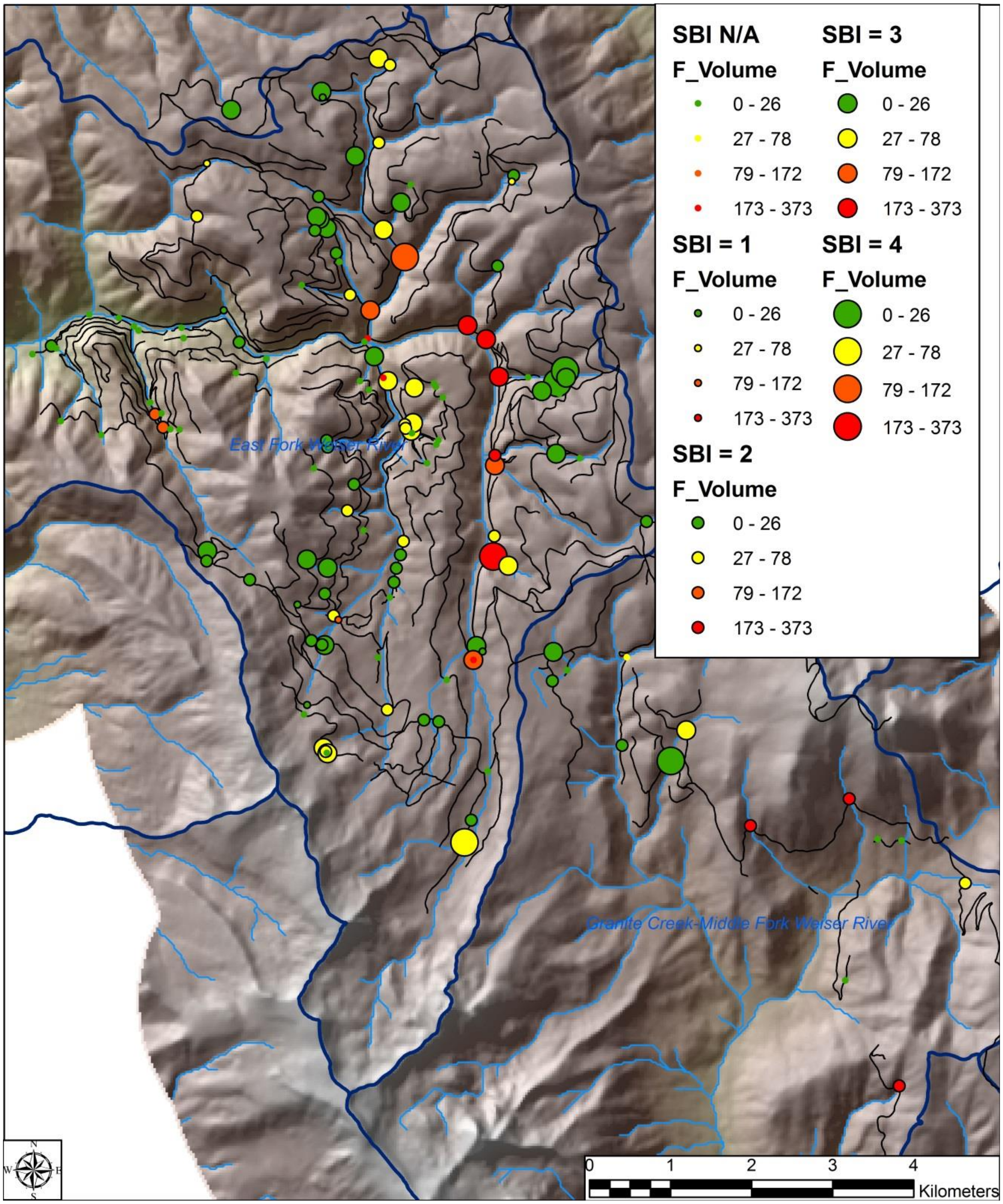

Figure 14: SBI and stream crossing potential failure volumes, UEFWR project area.

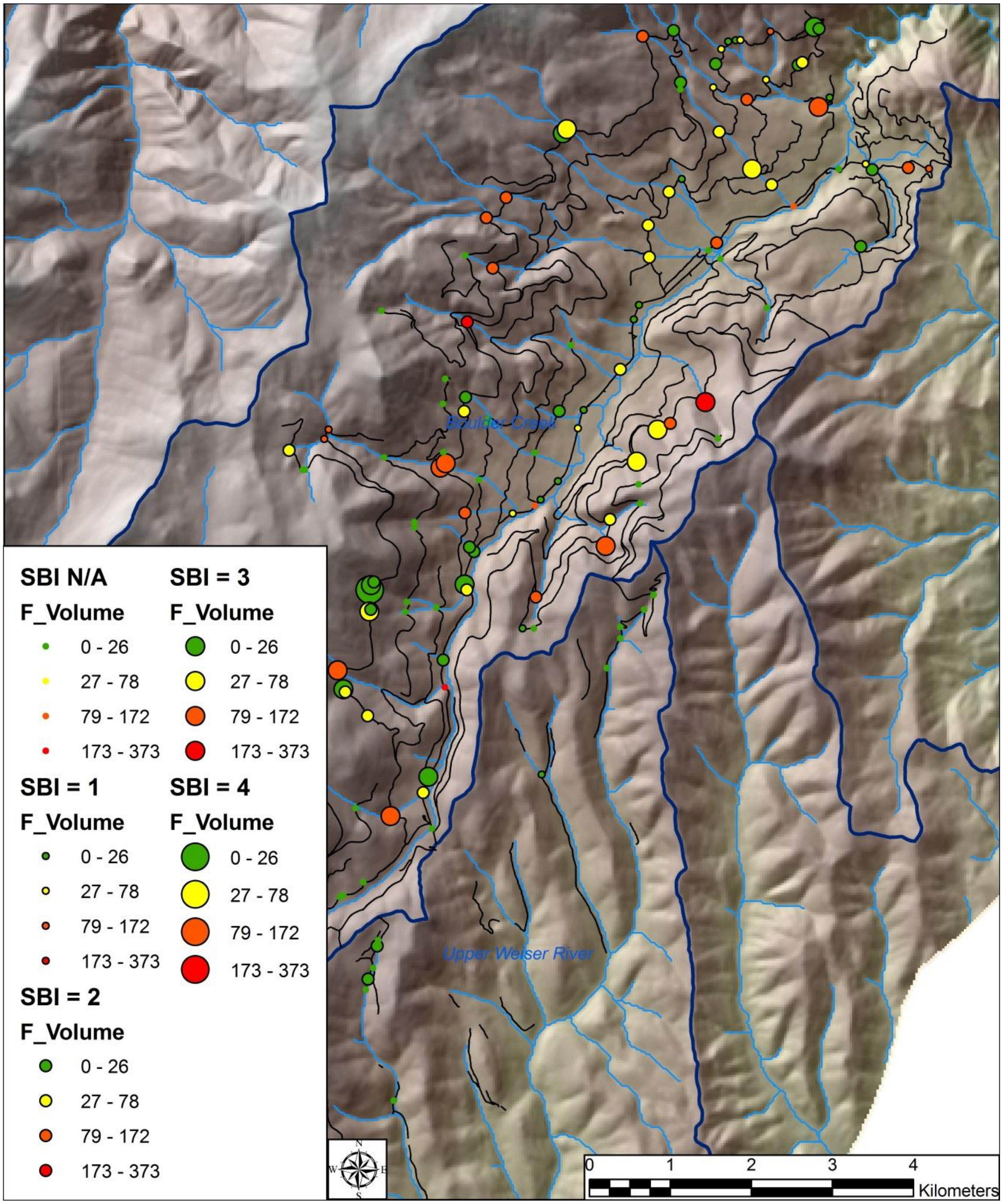

Figure 15: SBI and stream crossing potential failure volumes, Boulder Creek project area.

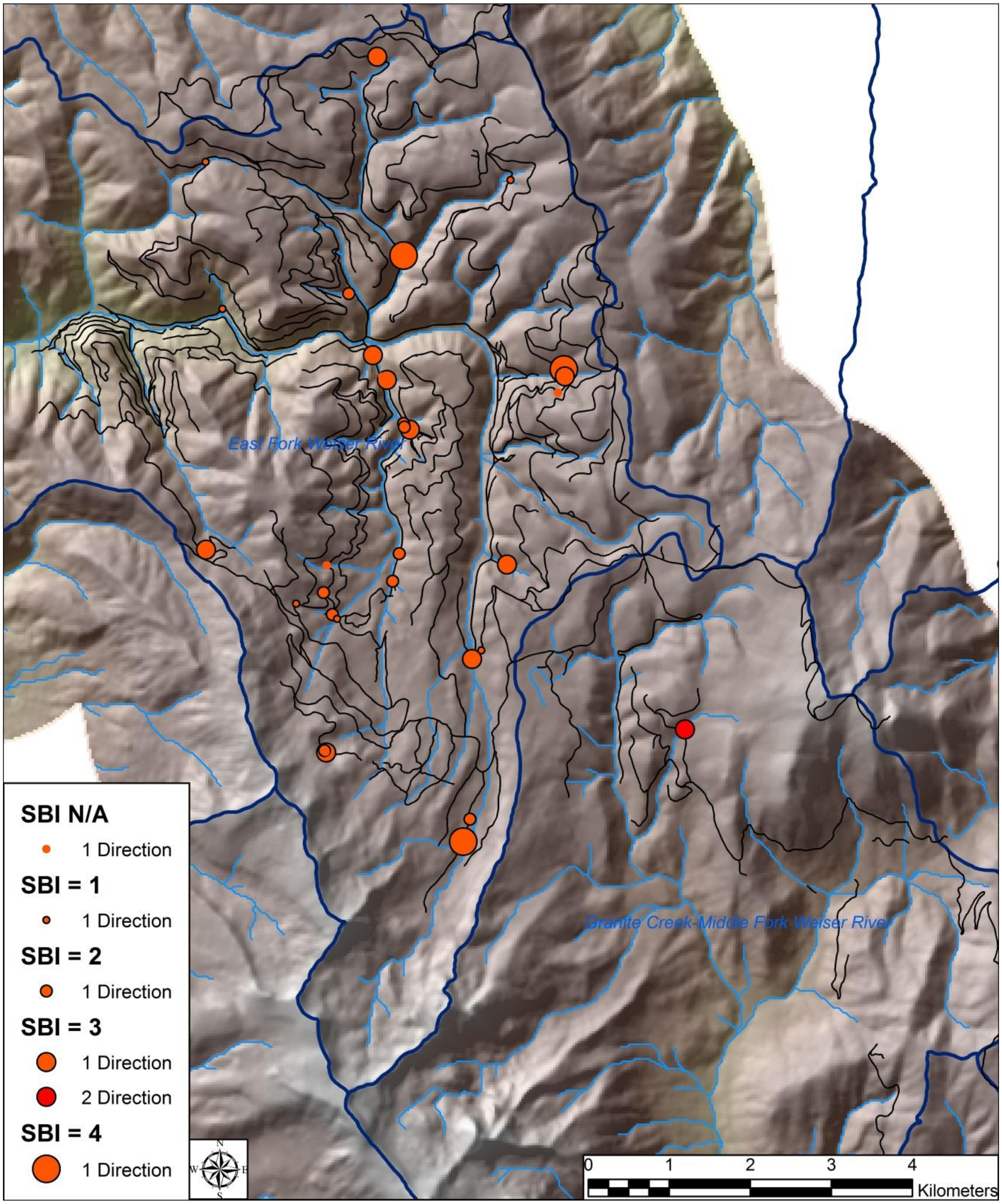

Figure 16: SBI and stream diversion potential in the UEFWR project area.

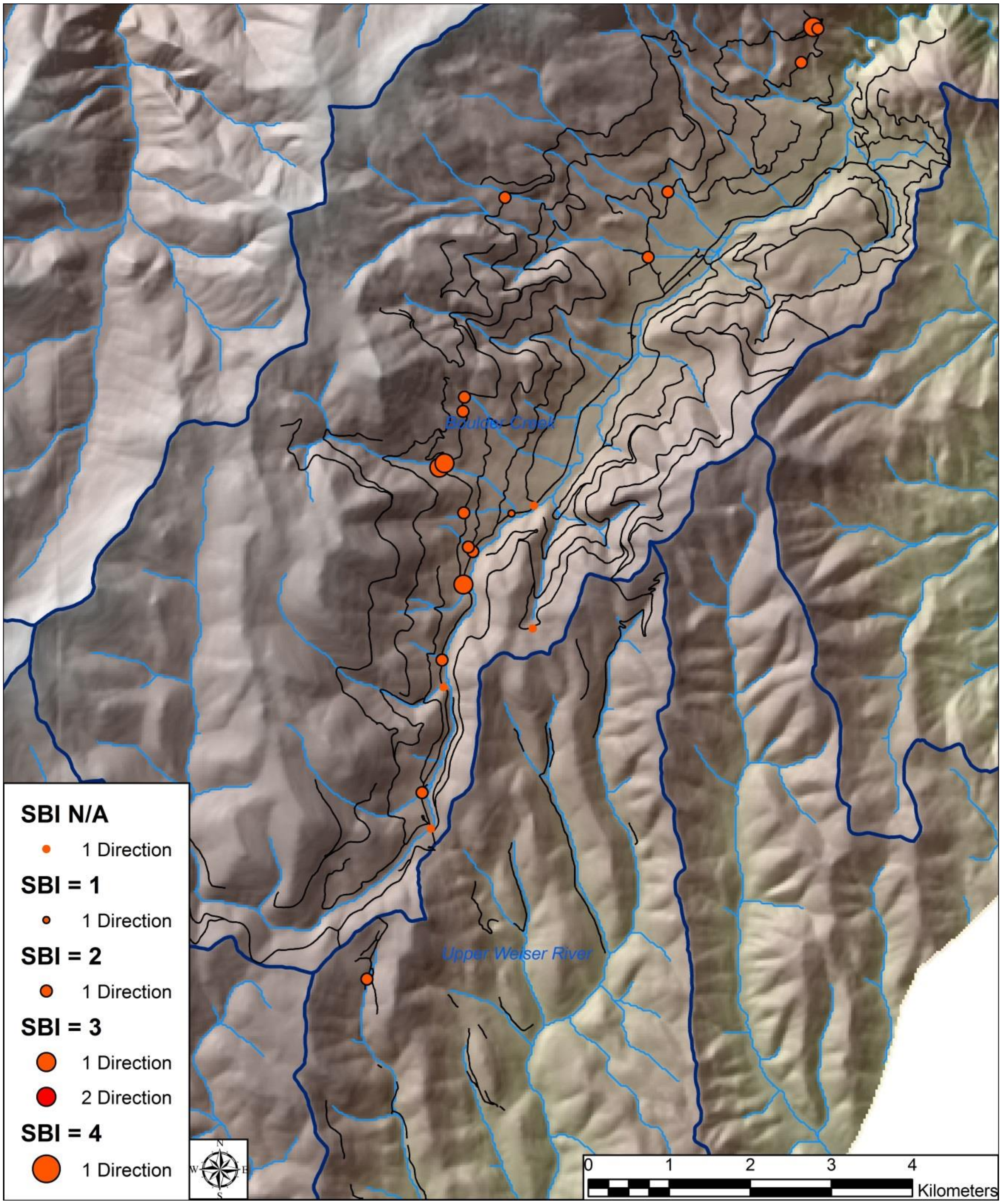

Figure 17: SBI and stream diversion potential in the Boulder Creek project area.

4.6 Landslide Risk Analysis

The risk of shallow landslide initiation is predicted using SINMAP 2.0 (Pack at al. 2005, http://hydrology.neng.usu.edu/sinmap2/), modified to account for contributions of road surface runoff, and using a local calibration based on previous computer landslide risk modeling work done by Mike Dixon (Dixon, 2003). SINMAP has its basis in the infinite plane slope stability model and produces raster grids that illustrate slope stability based on hillslope and specific catchment area at each DEM grid cell.

SINMAP calibration data from Mike Dixon was correlated to landtype data, which was then used as calibration for the SINMAP and GRAIP model runs. This provided calibration data for most of the area of interest.

Un-roaded and roaded risk grids are subjected to a series of mathematical operations that result in grids that show the important changes to landslide risk due to the presence of the roads. These change grids are compared to the natural landslide risk grid to show how the roads affect slope stability in the context of the background risks (i.e. the risks without the influence of road drainage). Important grid cell changes are those un-roaded to roaded differences that show a risk change from stable to unstable, or the areas that were unstable without roads and became less stable after road construction.

The areas where landslide risks are significantly impacted by roads are relatively small compared to the whole areas. In the UEFWR project area, a total of 0.11 km^2 was made unstable by road-related drainage and 0.13 km^2 of naturally unstable land was made more unstable (Figure 18). In the Boulder Creek project area, a total of 0.09 km^2 was made unstable by road-related drainage and 0.07 km^2 of naturally unstable land was made more unstable (Figure 19). Except for the Cold Springs Creek area in the UEFWR project, the crews did not record many landslides in areas predicted to have increased risks. However, road-related drainage to such areas should be reduced if possible to reduce risks, especially during high-intensity and rain-on-snow events.

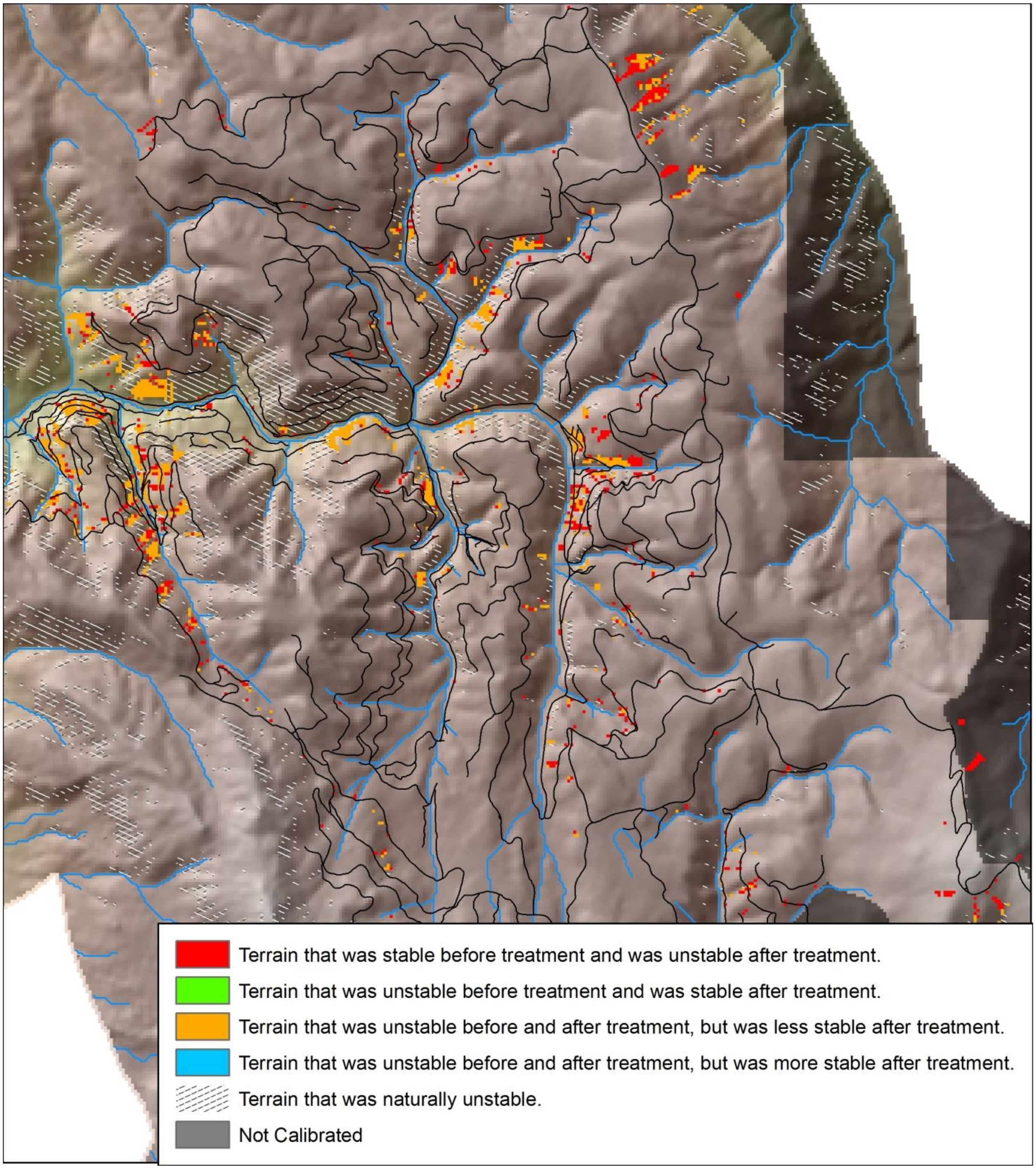

Figure 18: Road-related landslide initiation risks in the UEFWR project area. The treatment in this case is the presence of the road.

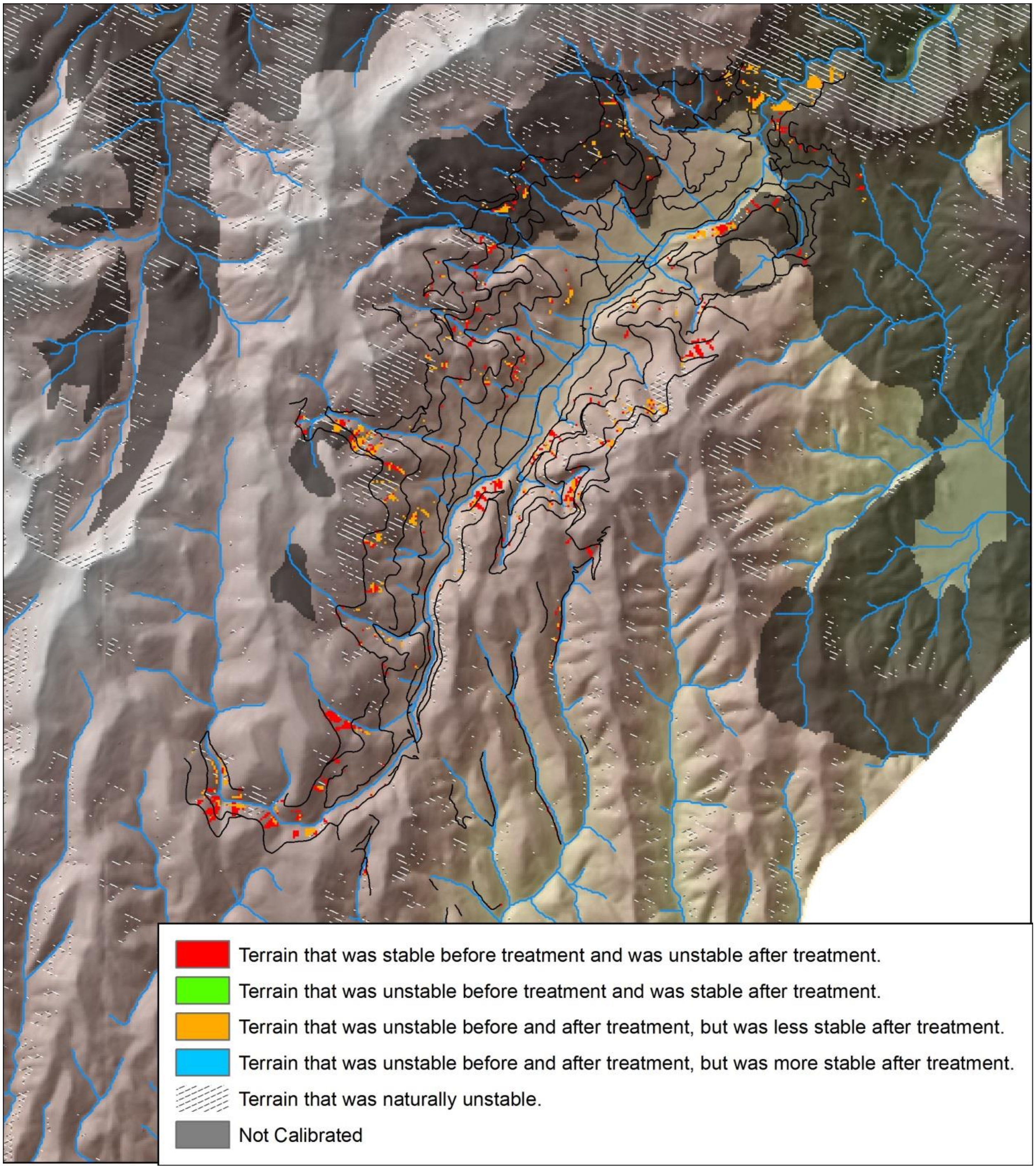

Figure 19: Road-related landslide initiation risks in the Boulder Creek project area. The treatment in this case is the presence of the road.

5.0 Summary & Conclusions

During the summer of 2013, GRAIP inventory data was collected on 472 km of road in the UEFWR and Boulder Creek project areas; 219 km were within the UEFWR watershed and 178 km were within the Boulder Creek watershed with the remainder in adjacent watersheds. The inventory included 8,075 individual road segments and 6,538 individual drain points. Fourteen percent of the road network in the UEFWR project area and 13% of the road network in the Boulder Creek project area is connected to the stream network. In the UEFWR project area, the roads are expected to produce 1,162.7 Mg/yr of sediment and deliver 12.3%, or 142.6 Mg/yr, to the stream network. In the Boulder Creek project area, the roads are expected to produce 876.9 Mg/yr and deliver 12.7%, or 111.0 Mg/yr, to the stream network. In both project areas, fixing the worst 8% of the road network could reduce sediment delivery by over 90%. Most of the sediment delivery is to 1st- and 2nd-order stream channels rather than to main stem channels.

The crews recorded 65 gullies, 26 landslides, and 123 instances of fill erosion in the UEFWR project area with a total estimated mass of 14,462 Mg, of which 4,940 Mg were delivered or are likely to be delivered to the stream network. In the Boulder Creek project area, the crews found 10 gullies, 1 landslide, and 78 instances of fill erosion totaling 1,936 Mg, with 1,153 Mg were likely to be delivered to the stream network; most of the delivered sediment in Boulder Creek comes from fill erosion.

In the UEFWR project area, 28% of the stream crossings were considered to be at a high risk of blockage with an estimated fill volume at risk of 2,393 m^3 at these crossings; 23% of all stream crossings in the UEFWR project area would divert water in at least one direction if plugged. In the Boulder Creek project area, 15% of the stream crossings were considered to be at a high risk of blockage with an estimated fill volume at risk of 1,301 m^3 at these crossings; 17% of all stream crossings in the UEFWR project area would divert water in at least one direction if plugged.

The road network is expected to have impacted the stability of 0.24 km^2 of land in the UEFWR project area and 0.15 km^2 in the Boulder Creek project area; however, landslide activity was generally not observed in these areas outside of the Cold Springs Creek area within the UEFWR project area.

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