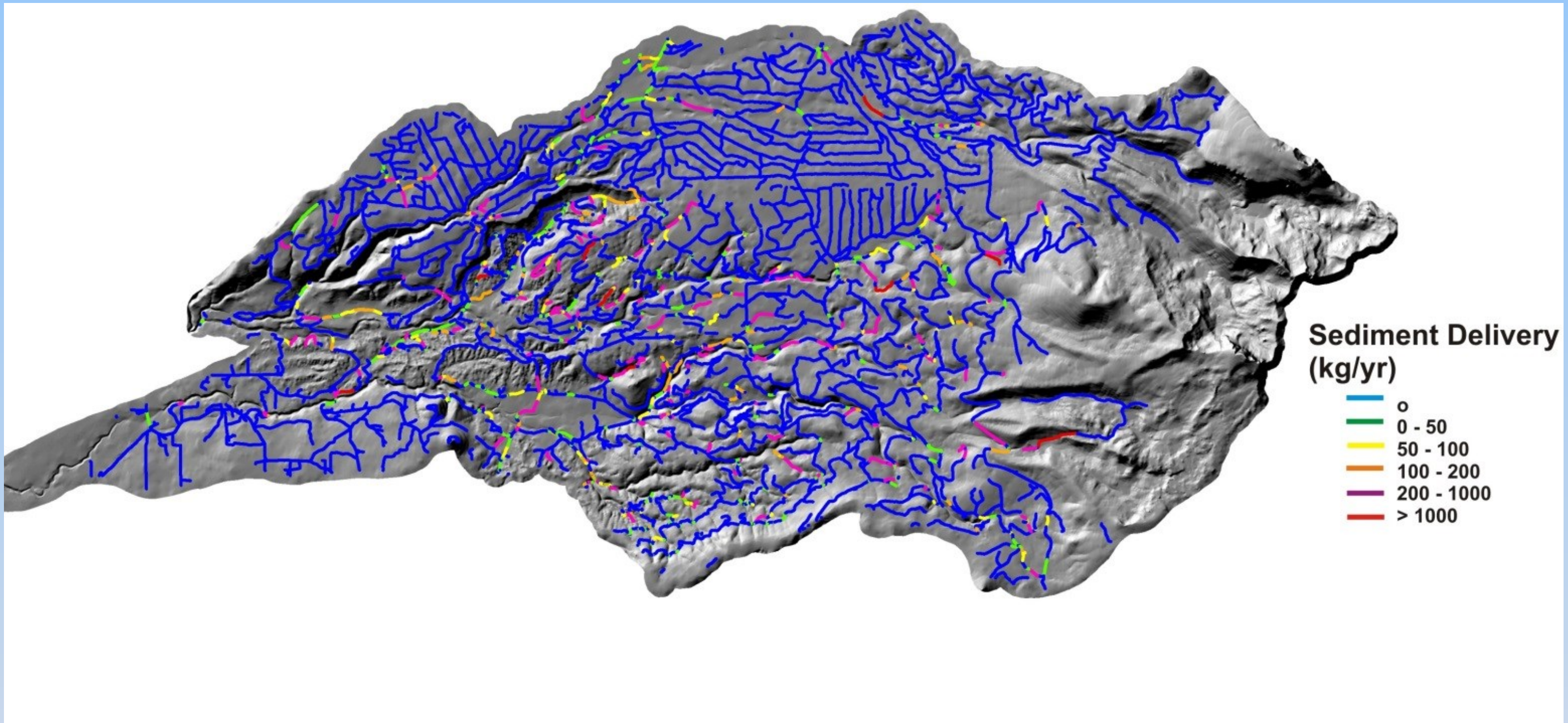
Forest Road Analysis and Post Fire Road Risk Assessment using NetMap



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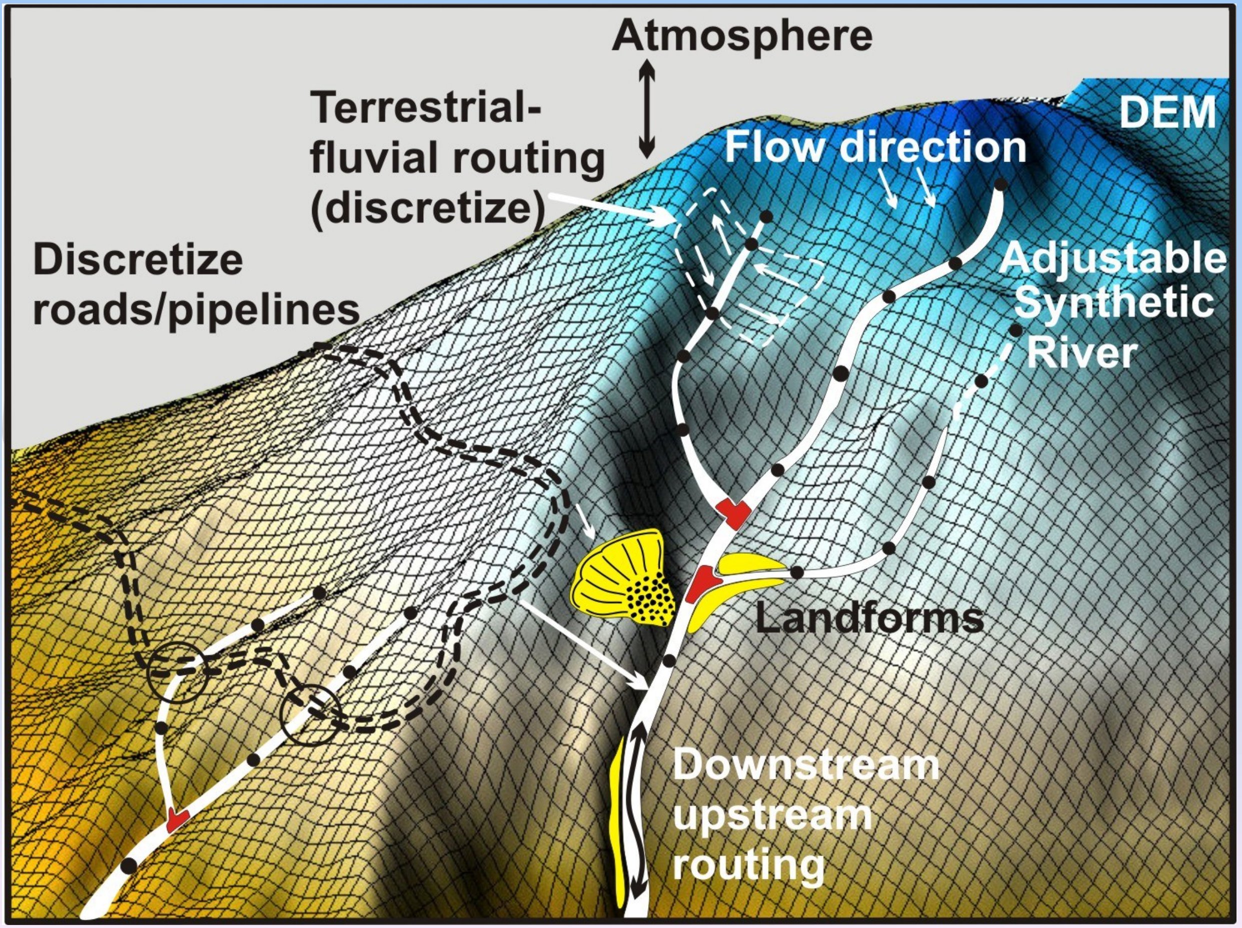
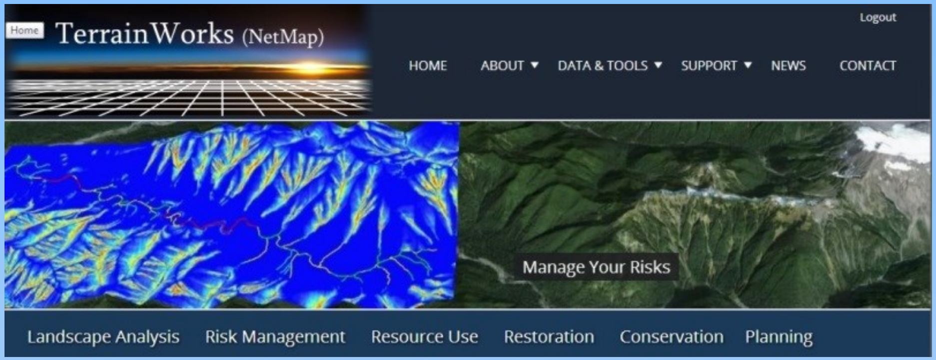
NetMap's virtual watersheds (and synthetic stream layer) are a geospatial simulation of riverine landscapes used to define watershed landforms and processes, and human interactions over a range of scales





NetMap is a collaborative enterprise since 2007

-National Forests (WA, OR, NCA, AK, ID, MT)
-Forest Service Research: PNW; PSW, RMRS
-US Fish & Wildlife
-NOAA
-BLM
-EPA
-Oregon Dept of Forestry
-OR/WA Fish and Wildlife
-NGOs (TNC, Ecotrust, Wild Salmon Center)
-Province of Alberta
-Watershed Councils
-Universities
-Private
-International

TerrainWorks collaborated with US Forest Service, Intermountain Research Station, Boise ID to incorporate GRAIP-Lite and WEPP road erosion models into NetMap

Study Part 1: Two questions are addressed:

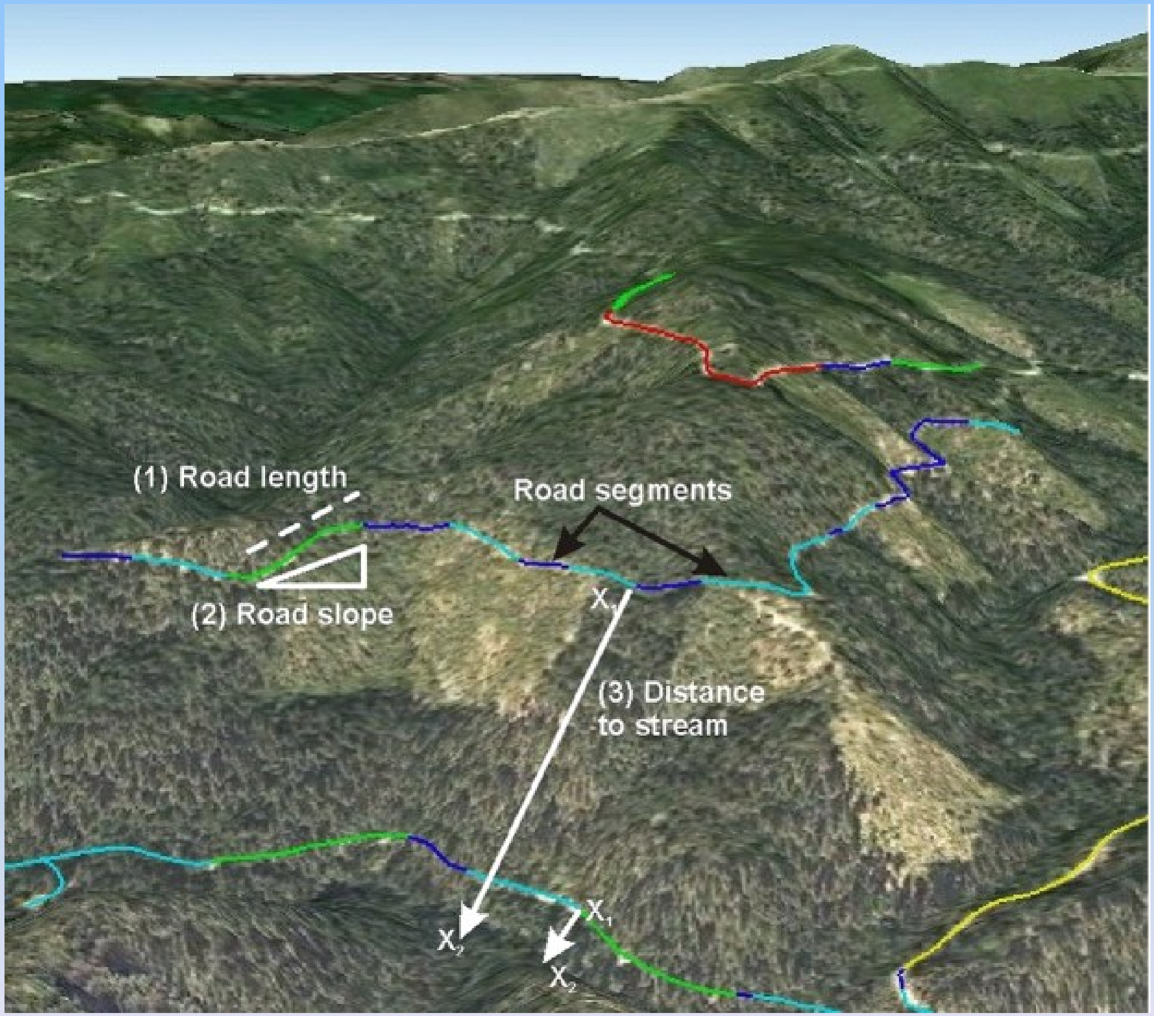
(1) How much forest road erosion and sediment delivery has been reduced due to <u>existing</u> management?

(2) Where would future forest road management be most effective at further reducing road erosion and sediment delivery to streams?

Roads drainage

Roads surface erosion/ sediment delivery to streams

Important universal drivers of road erosion and sediment delivery to streams



Road surface erosion

- *road segment length (hydrologically connected)*
- *road slope*
- *road surface type*
- *road maintenance*
- *traffic*
- *geology/soils*

Delivery to streams

- *road segment length*
- *distance to stream*
- *soils/infiltration capacity*
- *hillslope topography*

Analysis of road erosion and sediment delivery in NetMap includes:

1) road sediment production

2) road sediment delivery to streams

Road sediment production

GRAIP-Lite model of road surface erosion (in NetMap)

(USFS, Rocky Mountain Research Station, Boise ID)

$$E = B * R * S * V$$

where E is road sediment production to streams (kg/yr), B is the "base" surface erosion rate (empirical), R is the elevation difference between the road segment end points (length) and thus slope, S is the road surface factor and V is the vegetation factor.

V = 1 – 0.86x, where x is the fraction of the road length where flow path vegetation (ditch) is greater than 25%; R (elev. diff) is slope x road segment (hydrologic) length.

- *Example base rates:*
- *Oregon Coast Range = 79 kg/yr*
- *Idaho Batholith = 33 kg/yr*
- *Montana (Belt sedimentary) = 7 kg/yr*
- *Eastern Oregon (Umatilla, Basalt) = 1.5 kg/yg*
- *Eastern Sierra = 11 kg/yr*

Objective – to model sediment travel distance below road drains to match local data

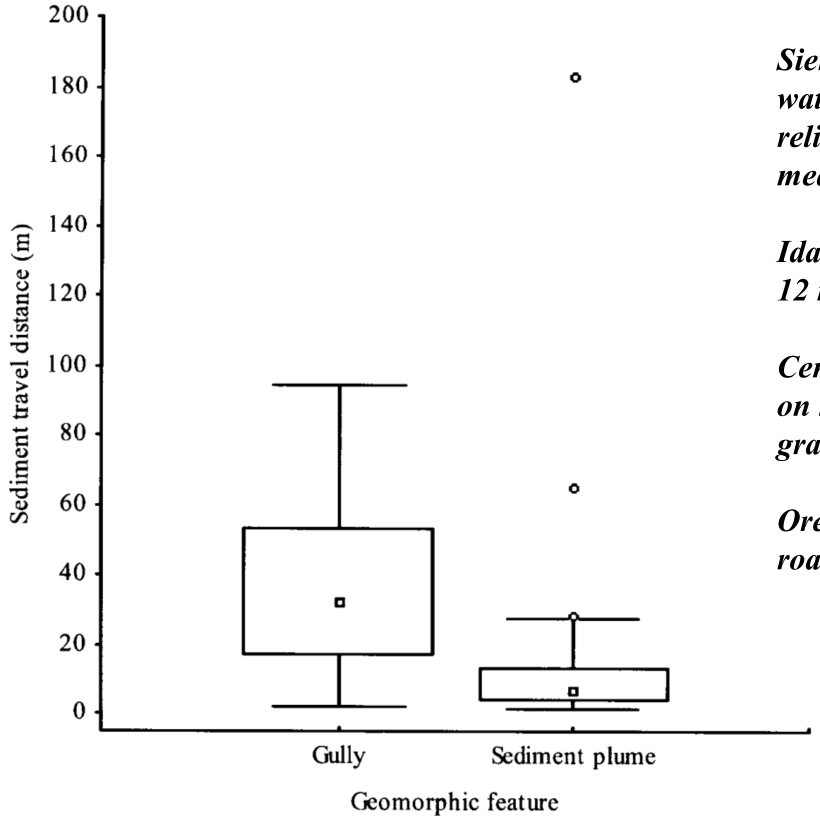


Figure 3.5. Lengths of gullies and sediment plumes for the segments classified as CC2, CC3, and CC4. The small squares are the median length, the boxes indicate the 25th and 75th percentiles, the bars show the 95% confidence interval, and the open circles represent outliers.

Sierras: mixed lithologies, 29 m w/relief culverts, 6 m water bars/rolling dips; weathered granitics 37 m w/ relief culverts, 12 m waterbars and rolling dips (overall mean 9 m (Coe 2006).

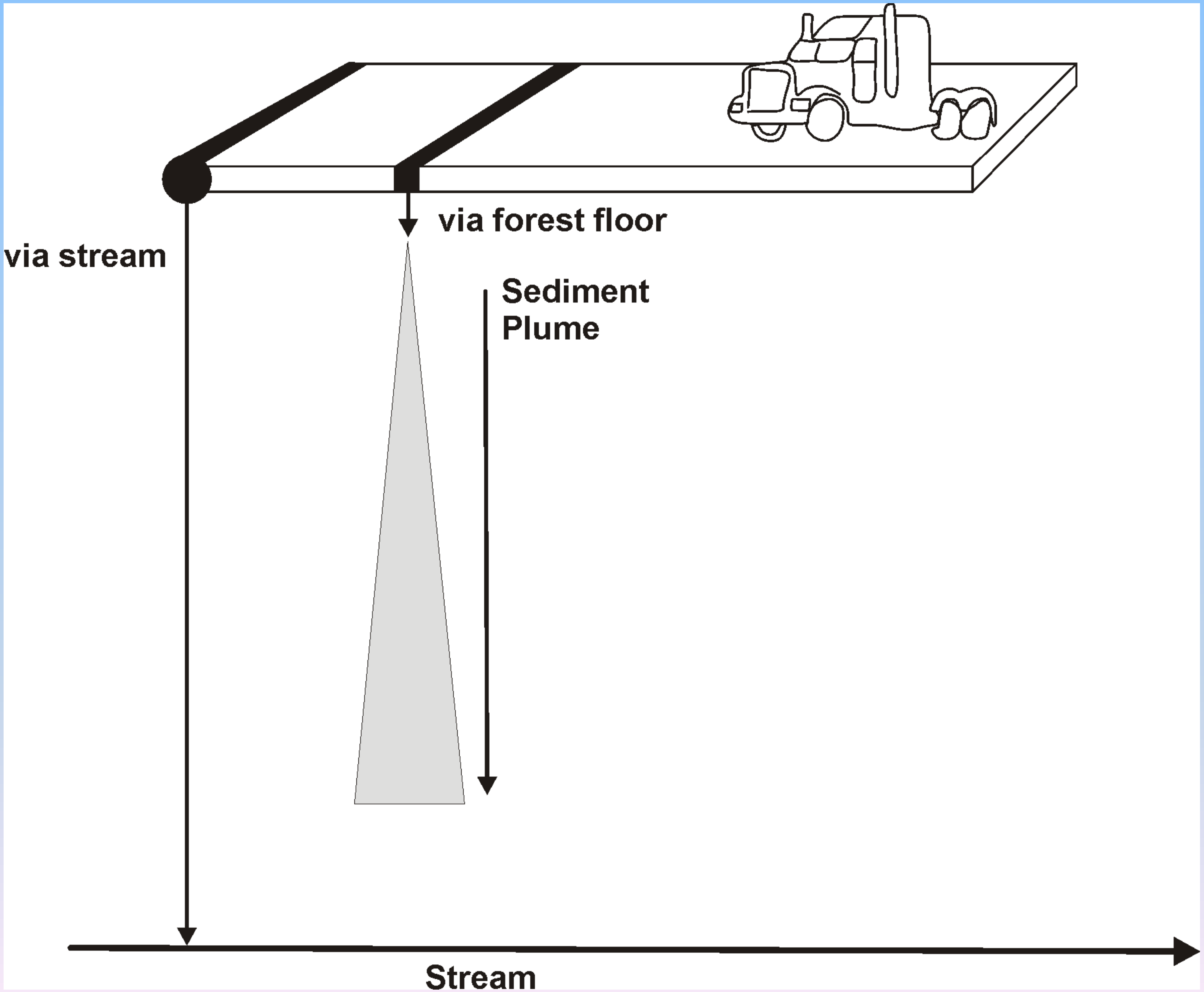
Idaho Batholith: 53 m w/relief culverts 12 m rock drains (Megahan & Ketcheson 1996).

Central Idaho: gully and sediment plumes 20% shorter on metasedimentary lithologies than volcanic and granitic (Burroughs and King 1989).

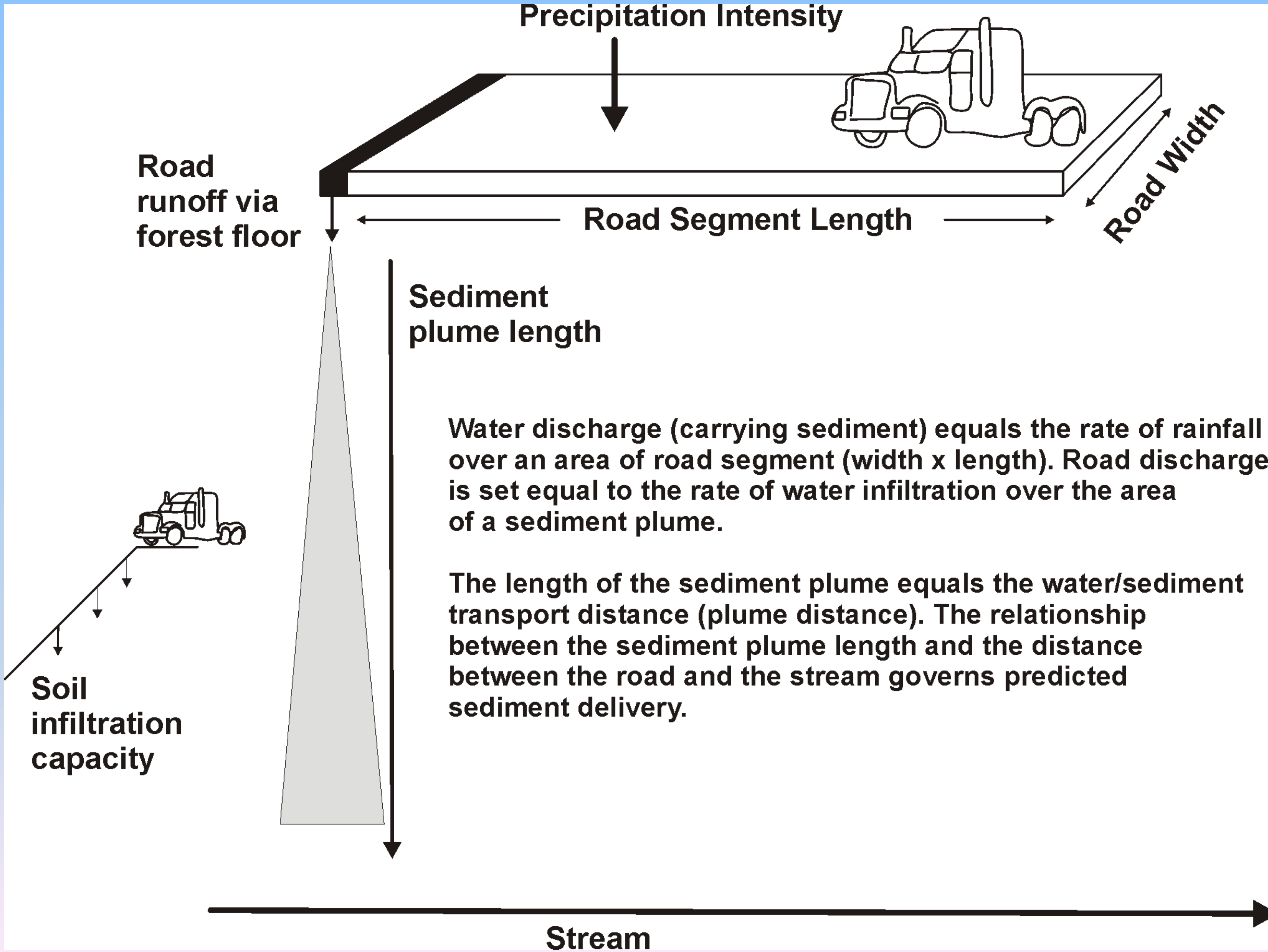
Oregon Coast Range: 5.1 m old roads, 9.3 m for new roads (Brake et al. 1997).

Coe, D. Sediment production and delivery from forest roads in the Sierra Nevada, California
MS thesis, Colorado State University. 2006.

Modes of sediment delivery

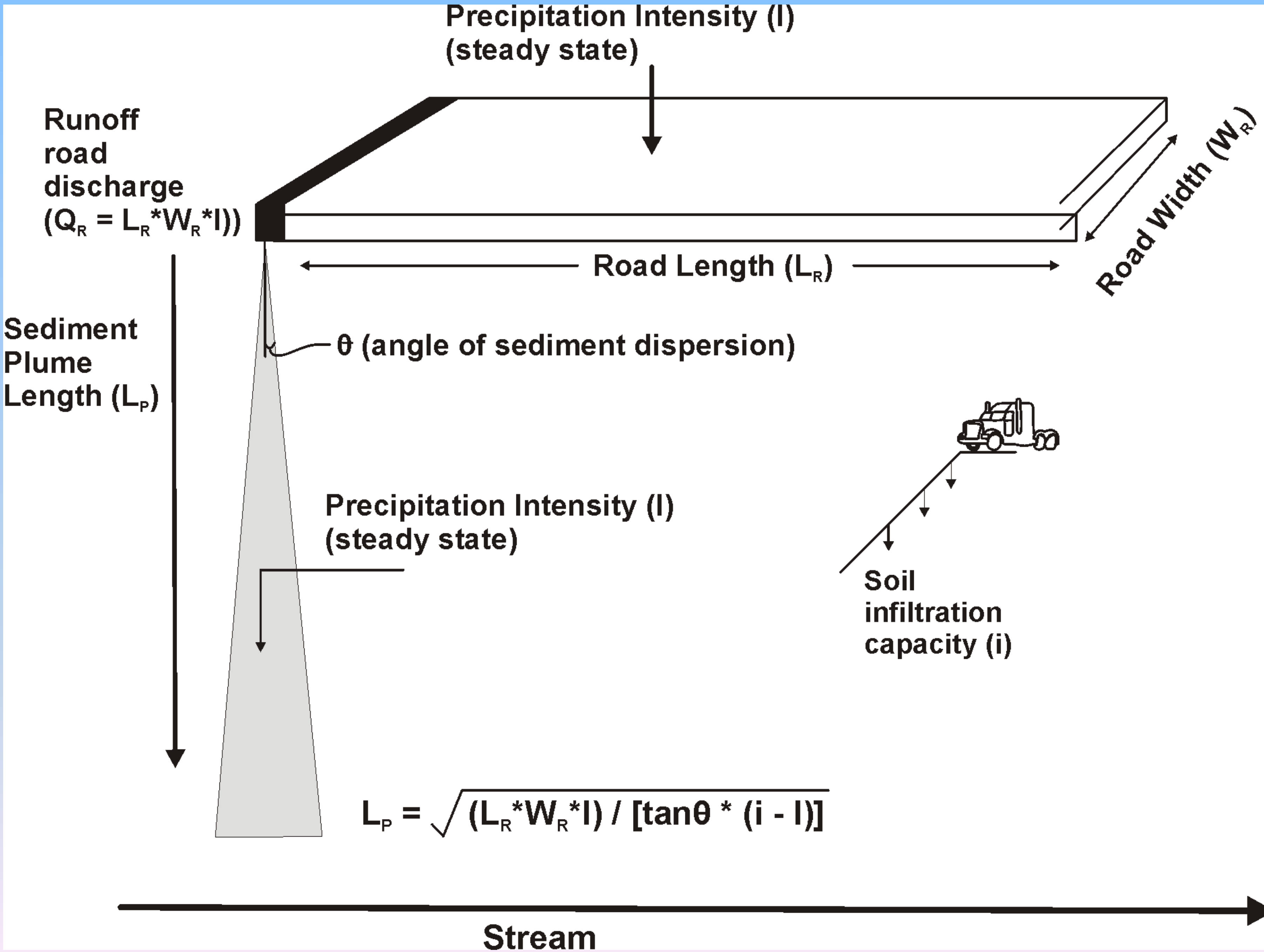


Road sediment delivery to streams – conservation of mass

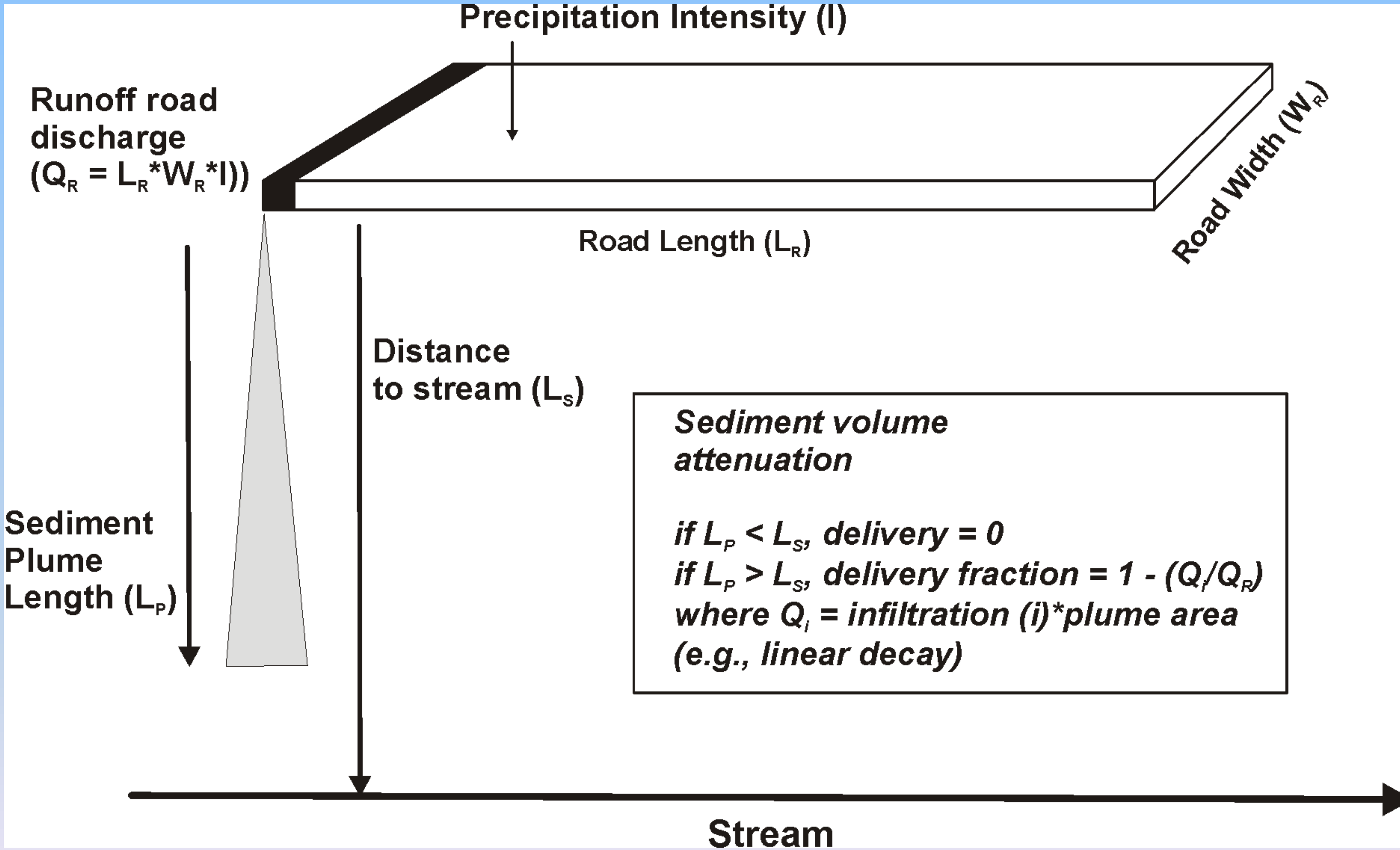


Water discharge (carrying sediment) equals the rate of rainfall over an area of road segment (width x length). Road discharge is set equal to the rate of water infiltration over the area of a sediment plume.

The length of the sediment plume equals the water/sediment transport distance (plume distance). The relationship between the sediment plume length and the distance between the road and the stream governs predicted sediment delivery.



Precipitation Intensity (I)
(steady state)
Runoff road discharge ($Q_R = L_R*W_R*I$)
Road Width (W_R)
Road Length (L_R)
Sediment Plume Length (L_P)
θ (angle of sediment dispersion)
Precipitation Intensity (I)
(steady state)
Soil infiltration capacity (i)
$L_P = \sqrt{(L_R*W_R*I) / [\tan\theta * (i - I)]}$
Stream


Precipitation Intensity (I)
Runoff road discharge
($Q_R = L_R * W_R * I$)
Road Length (L_R)
Road Width (W_R)
Distance to stream (L_S)
Sediment Plume Length (L_P)
Sediment volume attenuation
if $L_P < L_S$, delivery = 0
if $L_P > L_S$, delivery fraction = $1 - (Q_i/Q_R)$
where Q_i = infiltration (i)*plume area
(e.g., linear decay)
Stream

Road sediment delivery to streams (NetMap model)

Requires data:

(1) road segment length (NetMap, adjustable using drain points)
(2) distance to stream (NetMap)
(3) road sediment production (GRAIP-Lite, adjustable with surface/maintenance)
(4) road segment width (adjustable)
(5) storm precipitation intensity (adjustable)
(6) soil infiltration capacity (adjustable)
(7) geometry of sediment plume (currently dispersion - triangular, could include other geometry)

The goal is to match field data.

Road sediment delivery to streams

Data used:

-road segment width = 6m
-storm precipitation intensity (design storm)
5 yr, 6 hr: 0.31 in/hr (0.0078 m/hr)
-soil infiltration capacity (0.06 m/ hr)
-geometry of sediment plume (triangular)
-angle of dispersion of sediment plume (5^o)

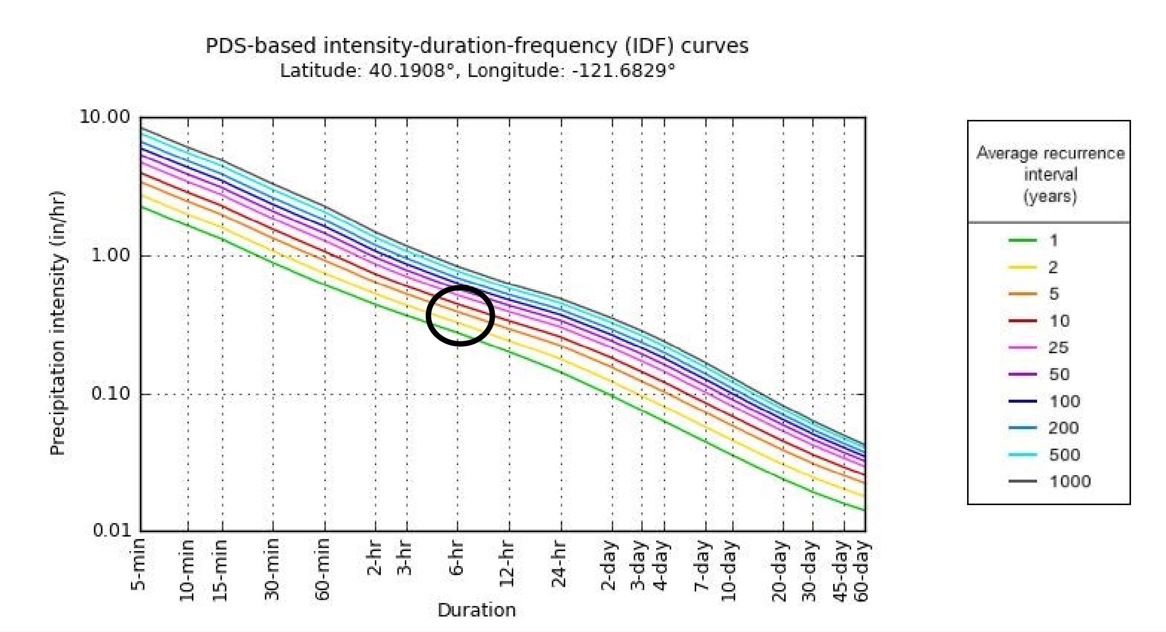
GRAIP-Lite production
Base = 11 kg/yr

TABLE I

Infiltration Capacity[a]

Ecosystem	Capacity (mm hr^{-1})
Undisturbed forest floor	60
Forest floor without litter and humus layers	49
Forest floor burned annually	40
Pasture, unimproved	24
Succession vegetation	
Old pasture	43
Pine forest, 30 yr old	75
Pine forest, 60 yr old	63
Oak–hickory forest	76

[a] Source: Lull (1964, pp. 6-14, 6-15).



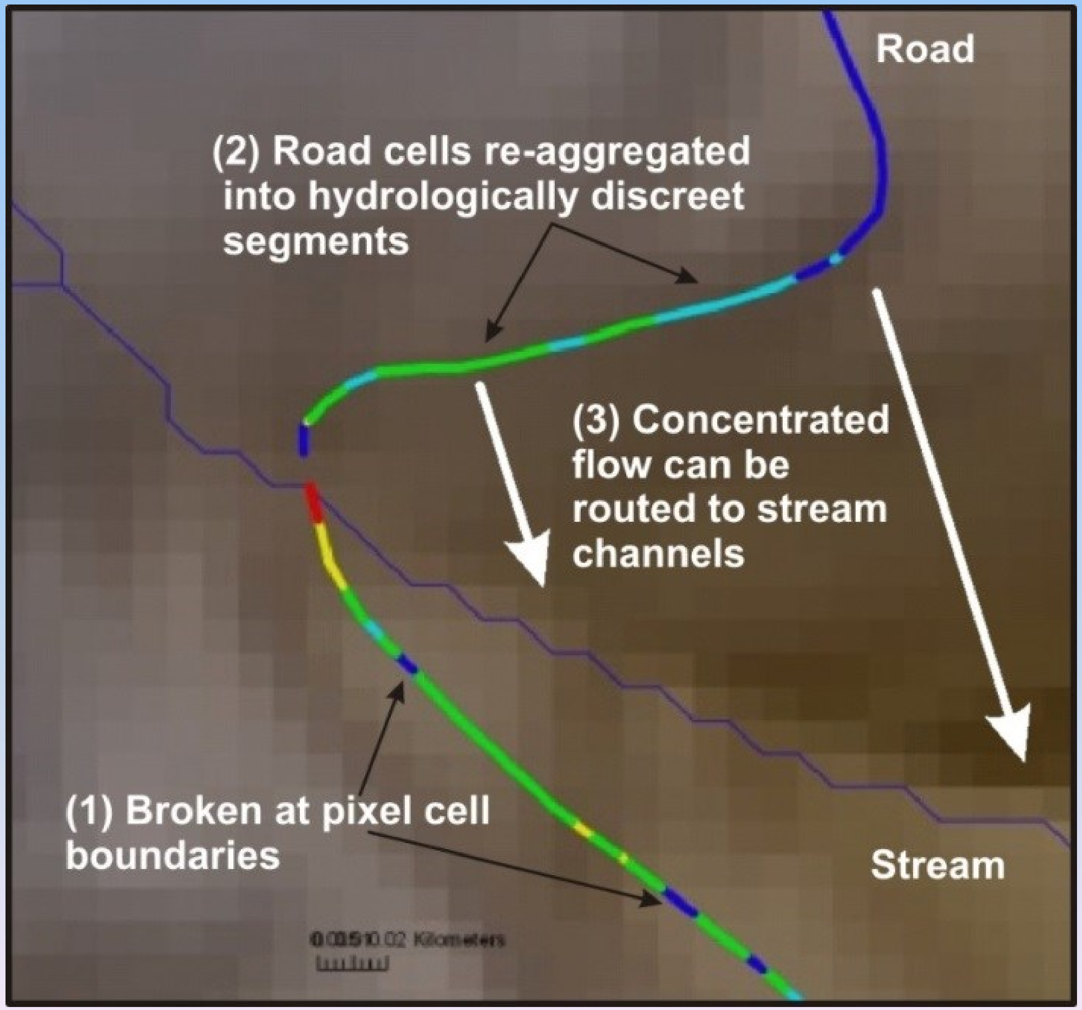
Study Part 1 - Analysis Scenarios

1) Sediment production & delivery with intrinsic drainage and no surfacing improvement (all native) and no additional engineered drainage points.

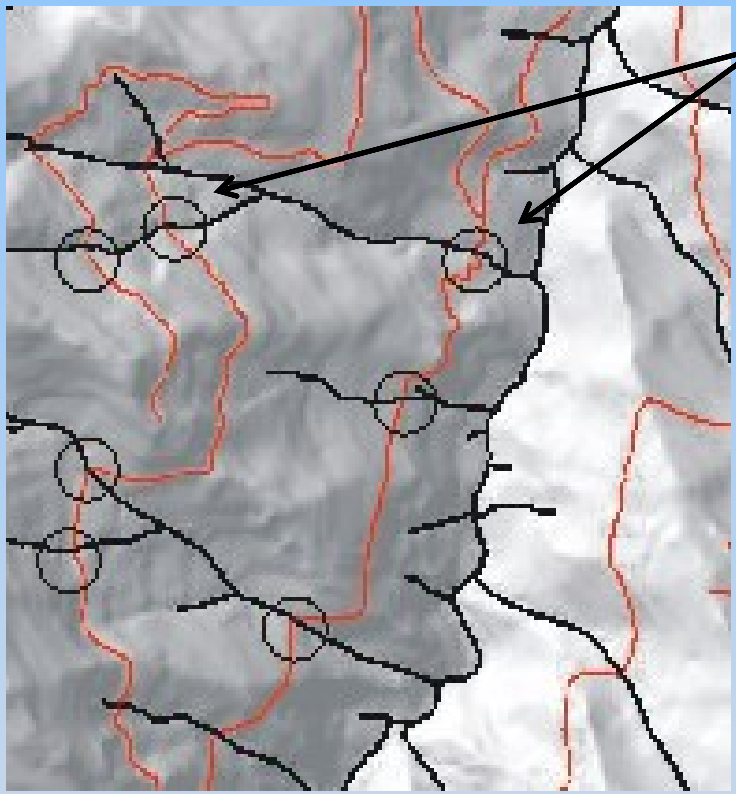
2) Sediment production & delivery with surfacing, intrinsic drainage and no additional engineered drainage points.

3) Sediment production & delivery with surfacing, intrinsic drainage and with additional engineered drainage points.

Using "intrinsic" and engineered drain points, calculate hydrologically connected road segments and connections to streams.

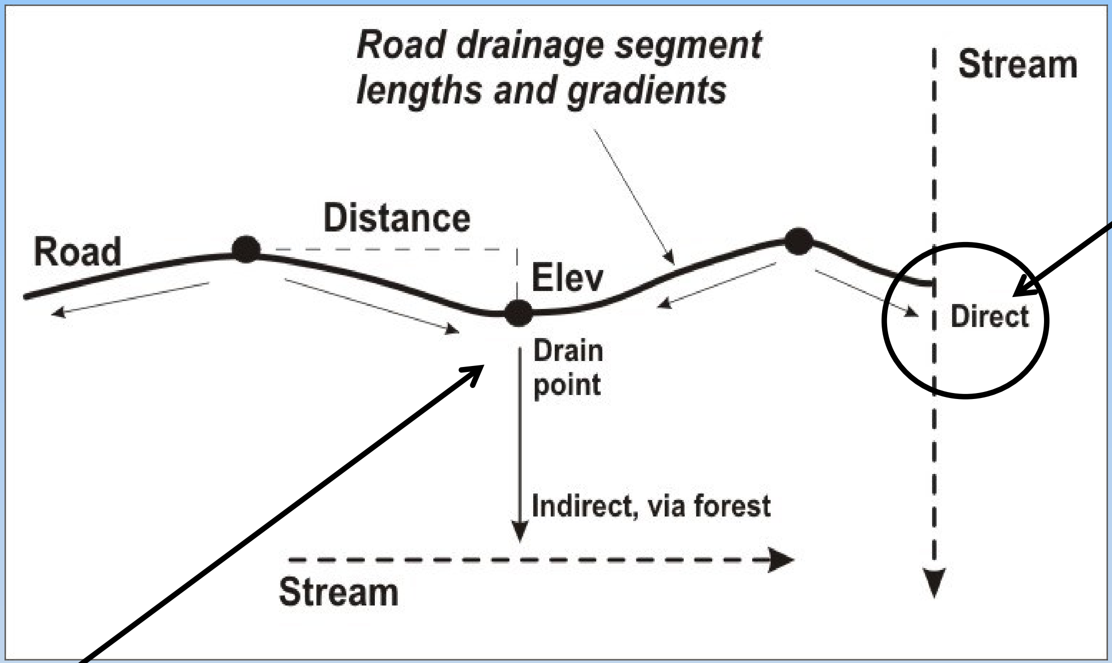


Determining road drainage and road (hydrologically connected) segment lengths



<u>First type</u> of "intrinsic" road drainage in NetMap: road – stream crossings

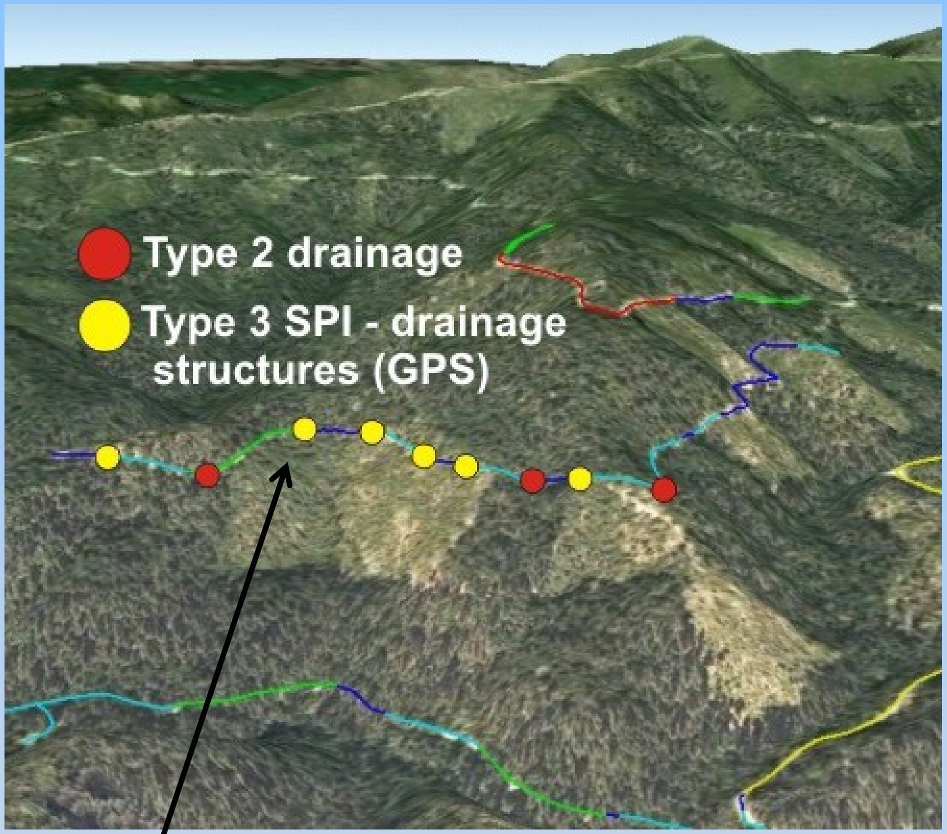
Determining road drainage and road (hydrologically connected) segment lengths



First type (direct to stream)

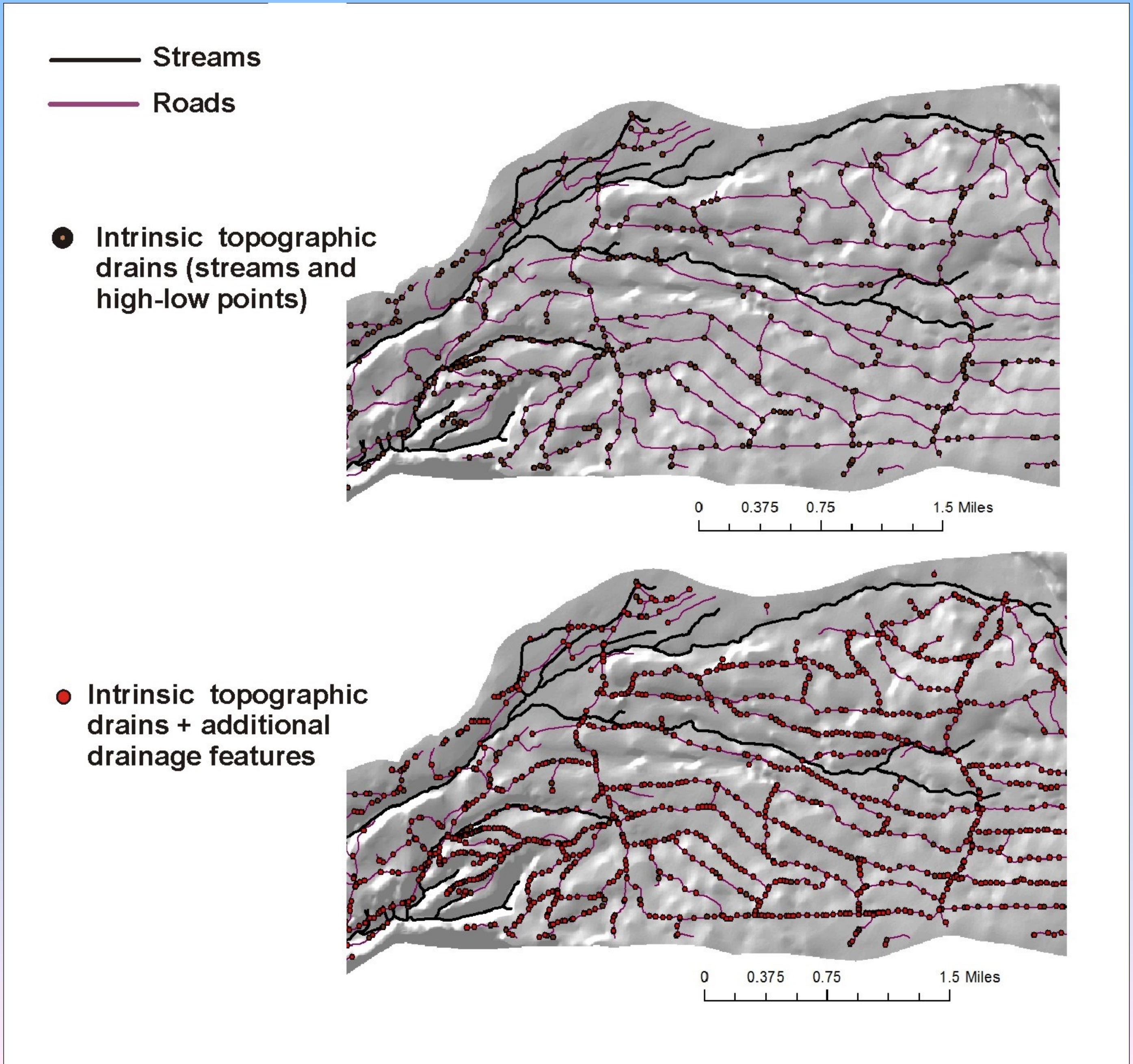
<u>Second type</u> of "intrinsic" road drainage: indirect to streams by topographically controlled road – drain points (may or may not have engineered structures)

Determining road drainage and road (hydrologically connected) segment lengths



<u>Third type</u> of road drainage: engineered structures (GPS)

Watershed: road drains



100% increase over intrinsic drainage

Results

Parameter	Intrinsic, no surfacing	with surfacing, no added drains	Percent change	surfacing and added drains	Percent Change
Drain Points	4983	4983 →		10,015	+101%
Road Segments	7931	7931 →		14,289	+80%
Road segment length (m)					
Distance to stream (m)					
Sediment production (kg/yr)					
Sediment delivery (kg/yr)					
Drainage Area (hectares)					
Sediment yield (kg/ha/yr)					
Average road width (m)					
Average road segment sediment production (kg/yr)					
Average road sediment production ($kg/m^2/yr$)					

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Road Segments	7931	7931		14,289	+80%
Road segment length (m)	105	105 →		59	-44%
Distance to stream (m)	364	364 →		638	+75%
Sediment production (kg/yr)					
Sediment delivery (kg/yr)					
Drainage Area (hectares)					
Sediment yield (kg/ha/yr)					
Average road width (m)					
Average road segment sediment production (kg/yr)					
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Sediment production (kg/yr)					

Increasing number of drain points leads to an increasing number of road segments. This leads to decreasing road segment lengths and increasing distances to streams.

Decreasing road segment lengths leads to a reduction in road water/ sediment runoff volume. This, in combination with increasing distances to streams, results in a reduction in water/sediment transport distances below road drains and thus a reduction in delivered sediment.

Comparison of model outputs to field data: road segment length

Table 2.7. Definitions of connectivity classes and the associated potential for sediment to be delivered to the stream network.

Connectivity class	Drainage characteristics	Potential for sediment delivery
1	Drainage feature <10 m long.	Very low
2	Drainage feature <20 m long.	Low/moderate
3	Drainage feature >20 m long but more than 10 m from a stream channel.	Moderate/high
4	Drainage feature to within 10 m of a stream channel, regardless of length.	High

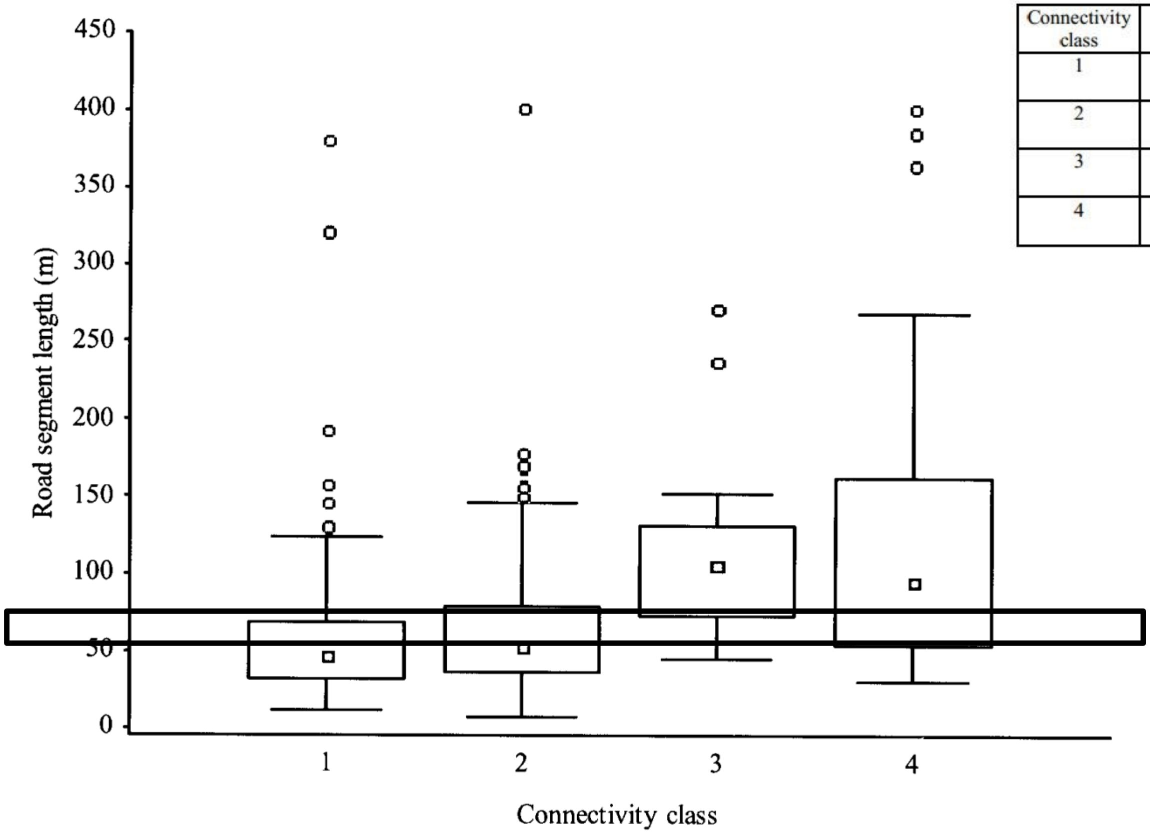

Figure 3.3. Road segment length by connectivity class. The small squares are the median segment length, the boxes indicate the 25th and 75th percentiles, the bars show the 95% confidence interval, and the open circles represent outliers.

Predicted 54-65m

Coe, D. Sediment production and delivery from forest roads in the Sierra Nevada, California MS thesis, Colorado State University. 2006.

Sediment travel distance below road drains (plume length)

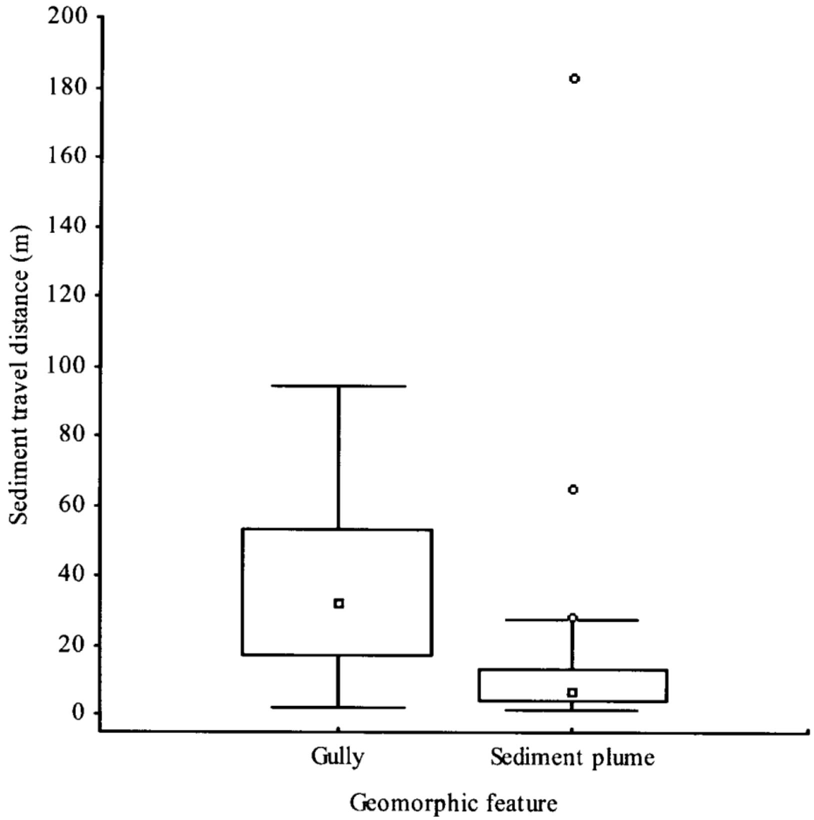

Figure 3.5. Lengths of gullies and sediment plumes for the segments classified as CC2, CC3, and CC4. The small squares are the median length, the boxes indicate the 25th and 75th percentiles, the bars show the 95% confidence interval, and the open circles represent outliers.

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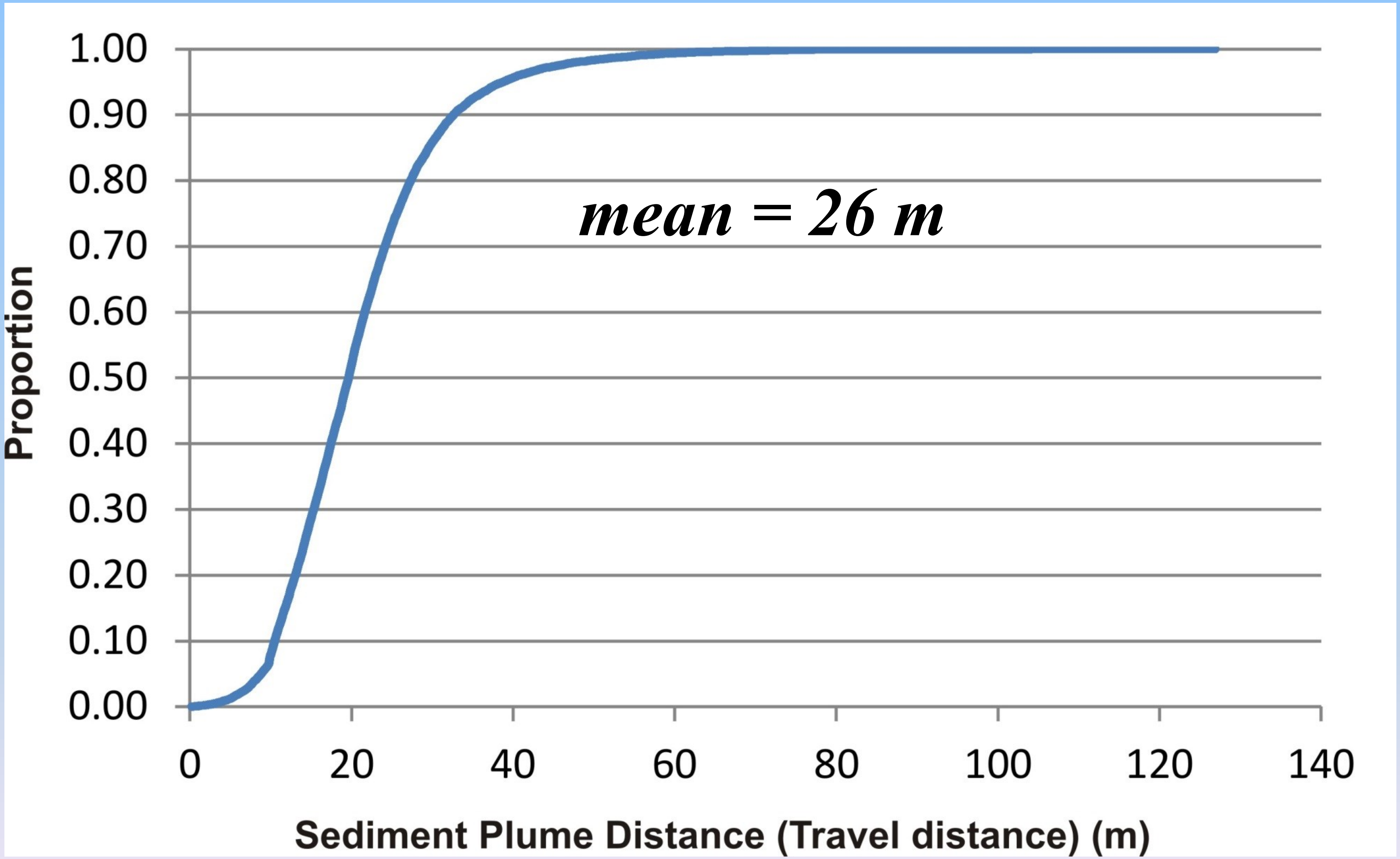
NetMap modeled sediment travel distance (L_P) below roads (intrinsic drainage and with additional drains)



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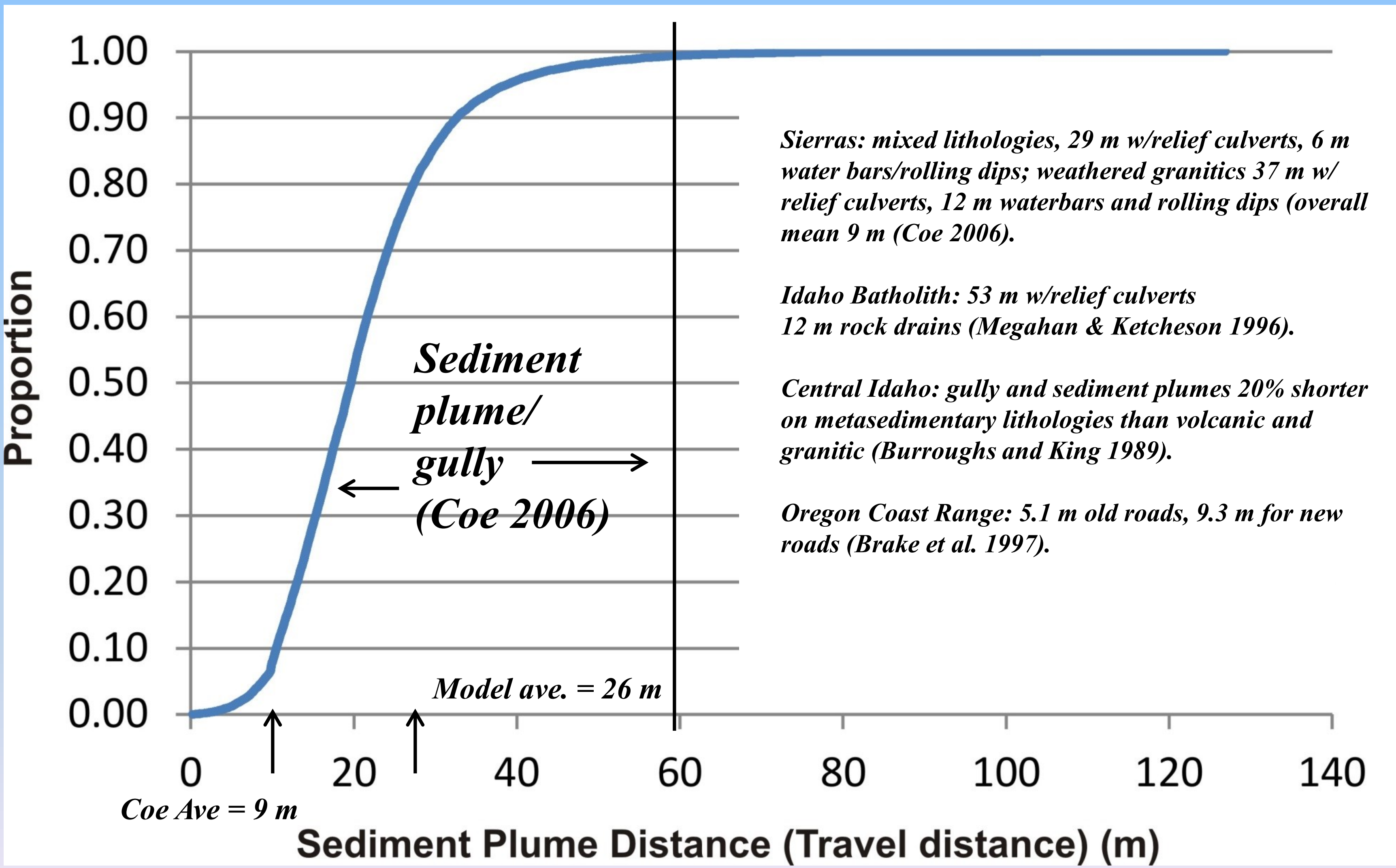
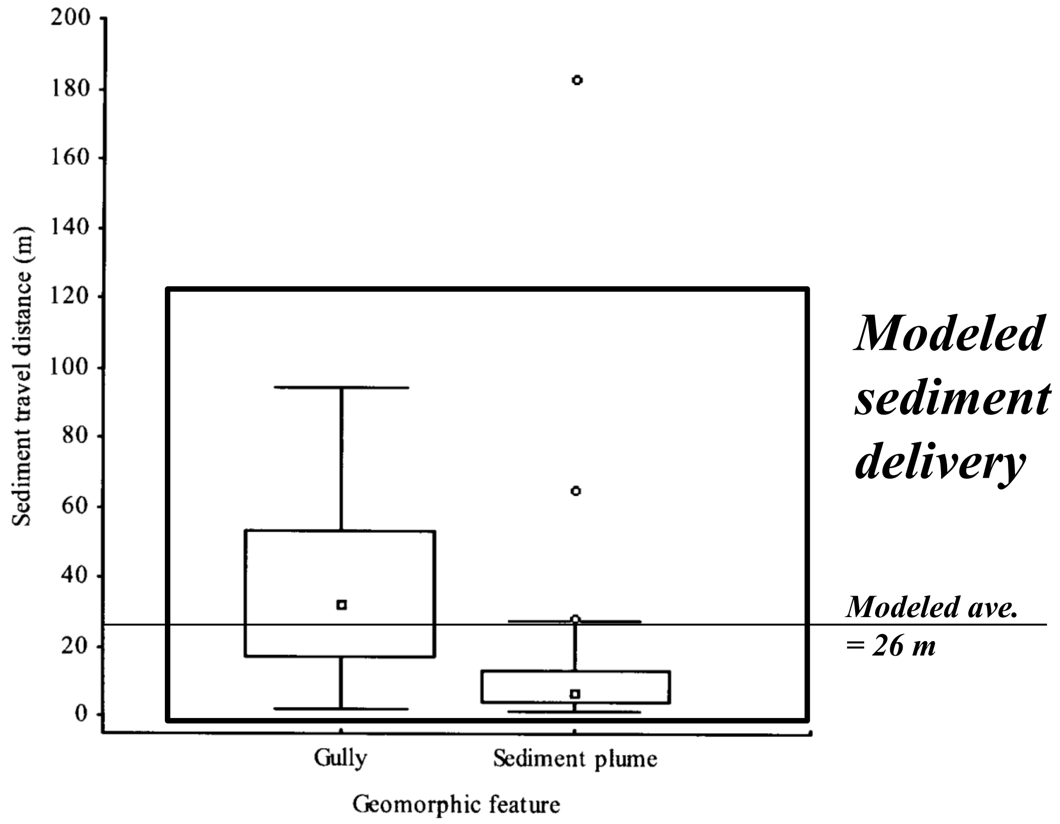


Sediment travel distance below road drains (plume length)



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Road segment length (m)	105	105		59	-44%
Distance to stream (m)	364	364		638	+75%
Sediment production (kg/yr)	1,401,675	1,054,136	-25%	1,054,136	
Sediment delivery (kg/yr)	373,105	110,495 (11% delivered)	-29%	60,025 (6% delivered)	-84% (total reduction)
Drainage Area (hectares)		29,300		29,300	
Sediment yield (kg/ha/yr)				2.04	
Average road width (m)				6	
Average road segment sediment production (kg/yr)				74	
Average road sediment production (kg/m^2/yr)				0.21	

Comparison of model outputs to field data: sediment production

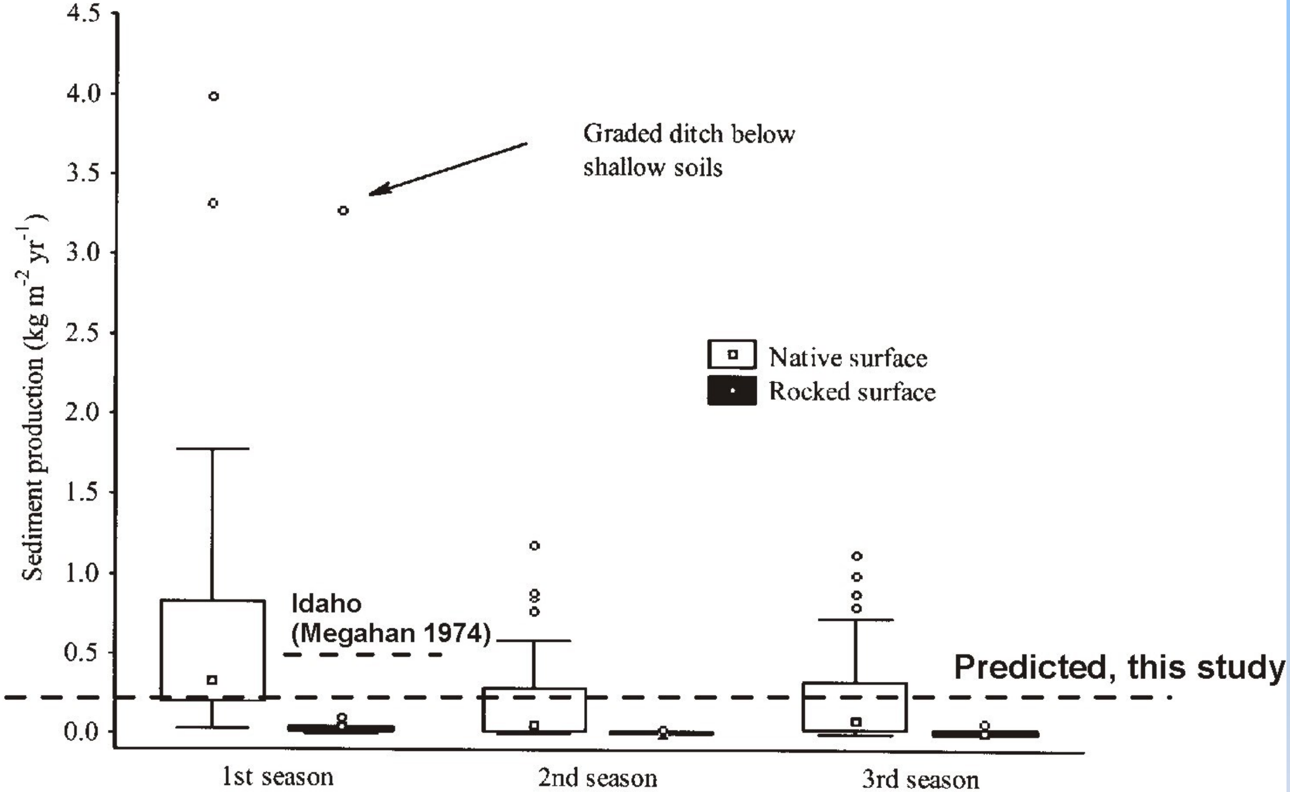

Figure 2.5. Annual sediment production rates for native surface and rocked road segments by wet season. Boxes represent the 25th to 75th quartiles, and the small boxes represent the median value. Circles represent outliers.

Coe, D. Sediment production and delivery from forest roads in the Sierra Nevada, California
MS thesis, Colorado State University. 2006.

Conclusions:

Predicted road sediment production in general agreement with field data.

Predicted sediment transport distances below road drains in general agreement with field data.

More local field data preferable (gully vs sediment plume length, geometry of plume)

First question:

(1) How much forest road erosion and sediment delivery has been reduced due to existing management?

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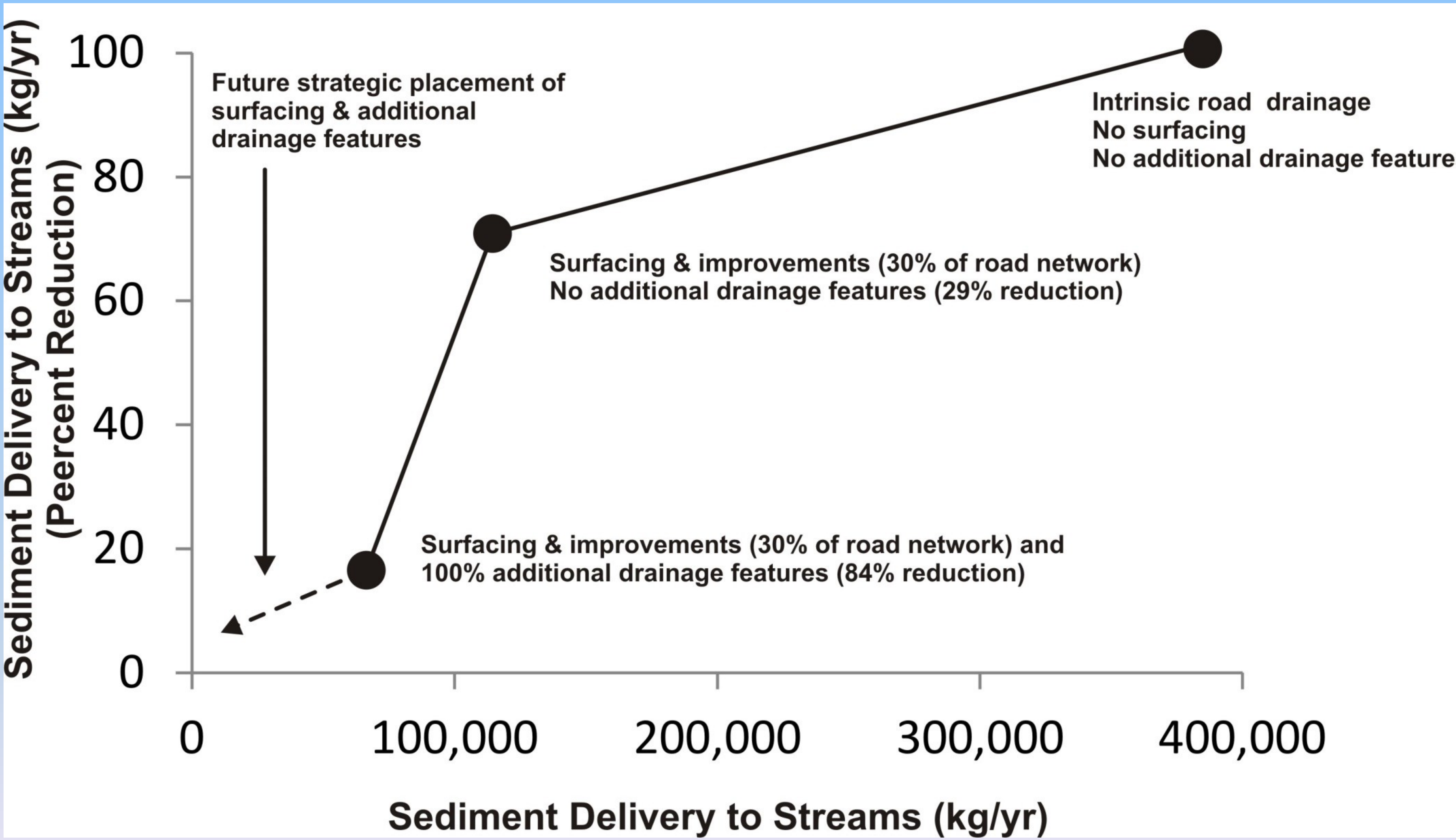
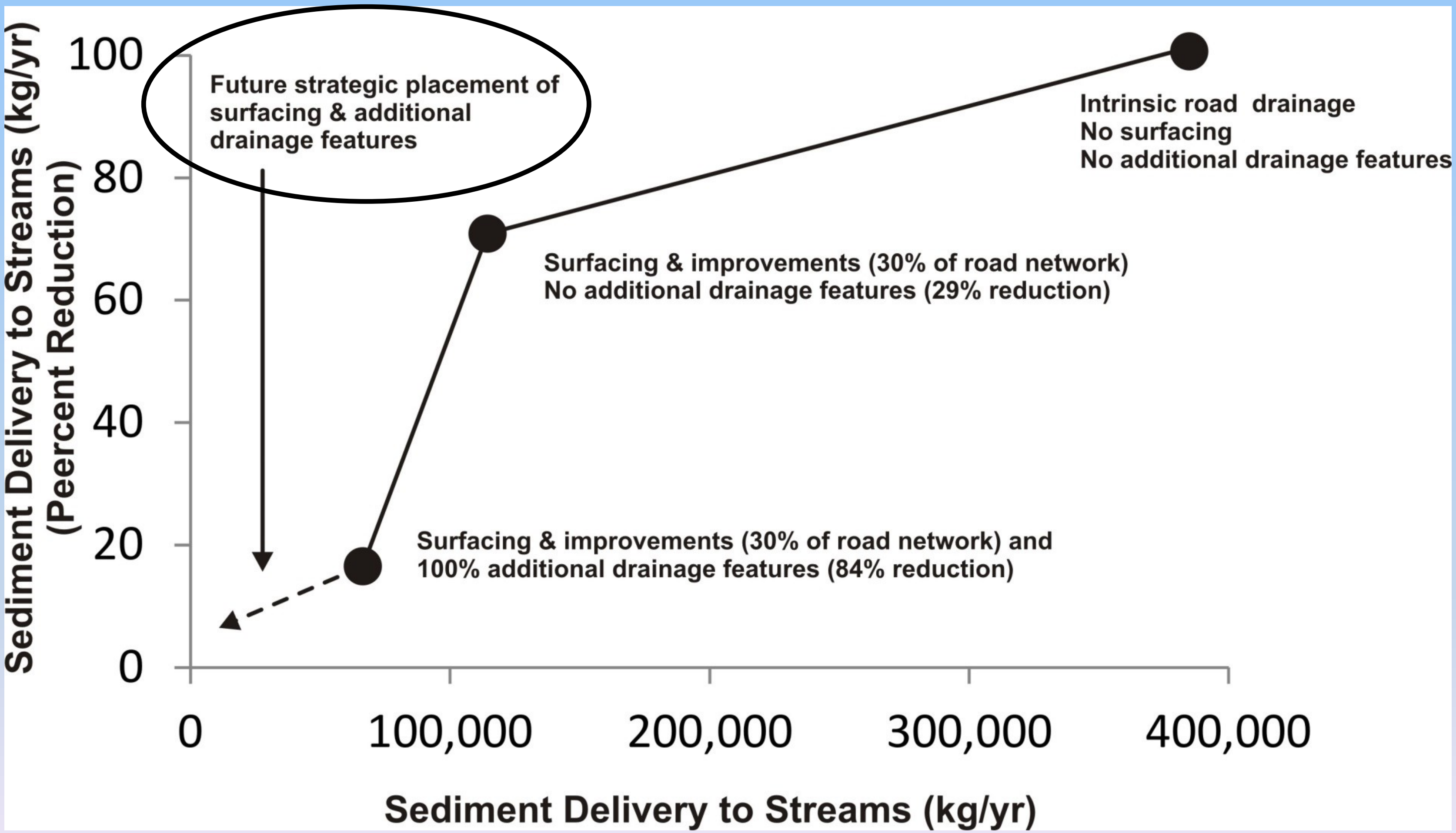
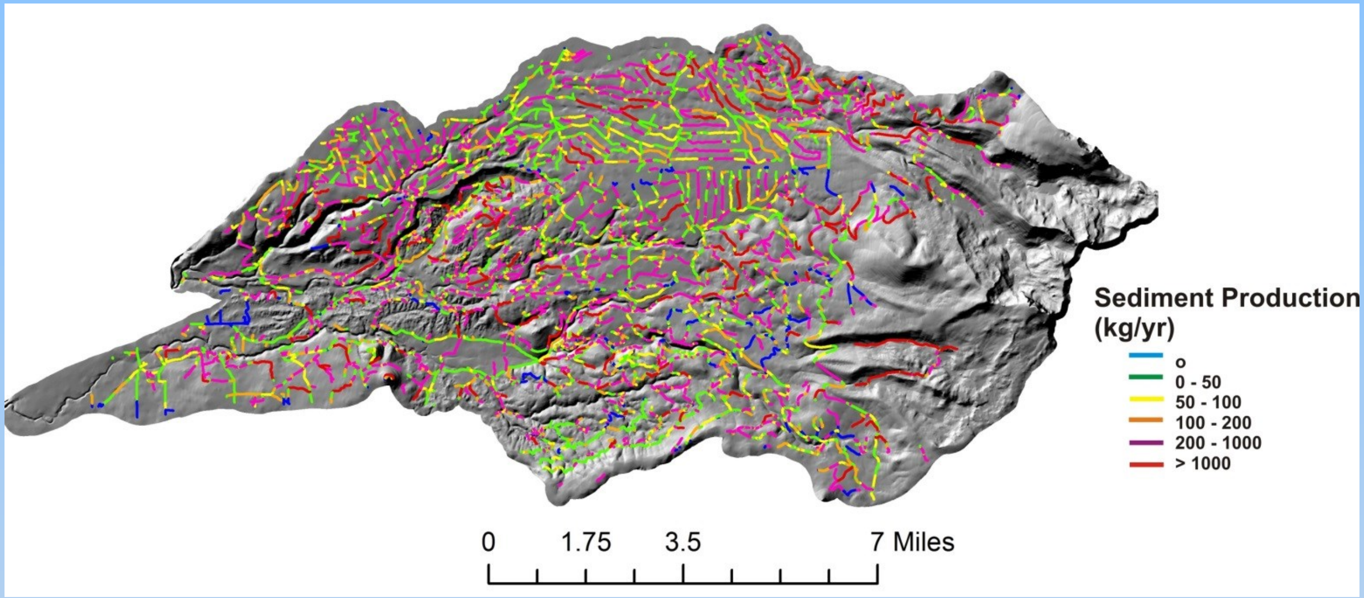


The slope of the two line segments indicate that, in the model, additional road drains that reduce road segment lengths and water/sediment transport distances are more effective than surfacing (rock, but only 30% surfaced).

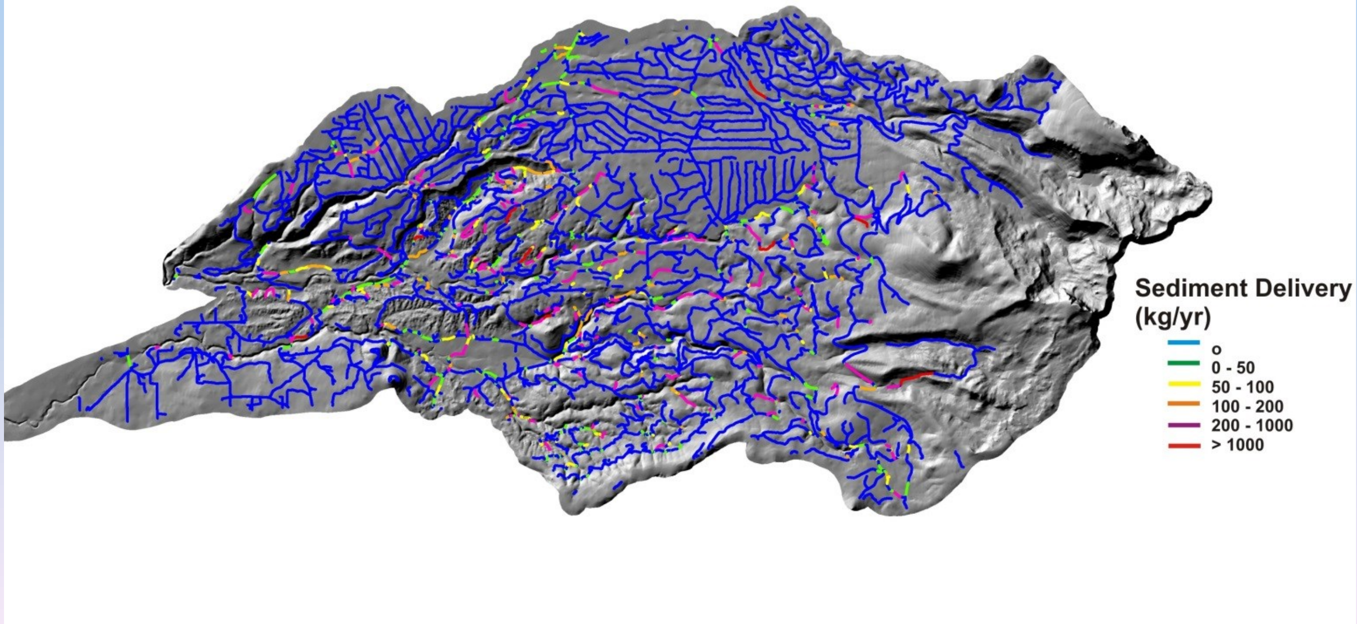
Second question: Where would future forest road management be most effective at further reducing road erosion and sediment delivery to streams?



Sediment production, with surfacing and intrinsic drainage



Almost 100% of roads produce sediment



Only 6% of road segments delivery sediment to streams based on modeled conditions (10,015 road drains)

Results

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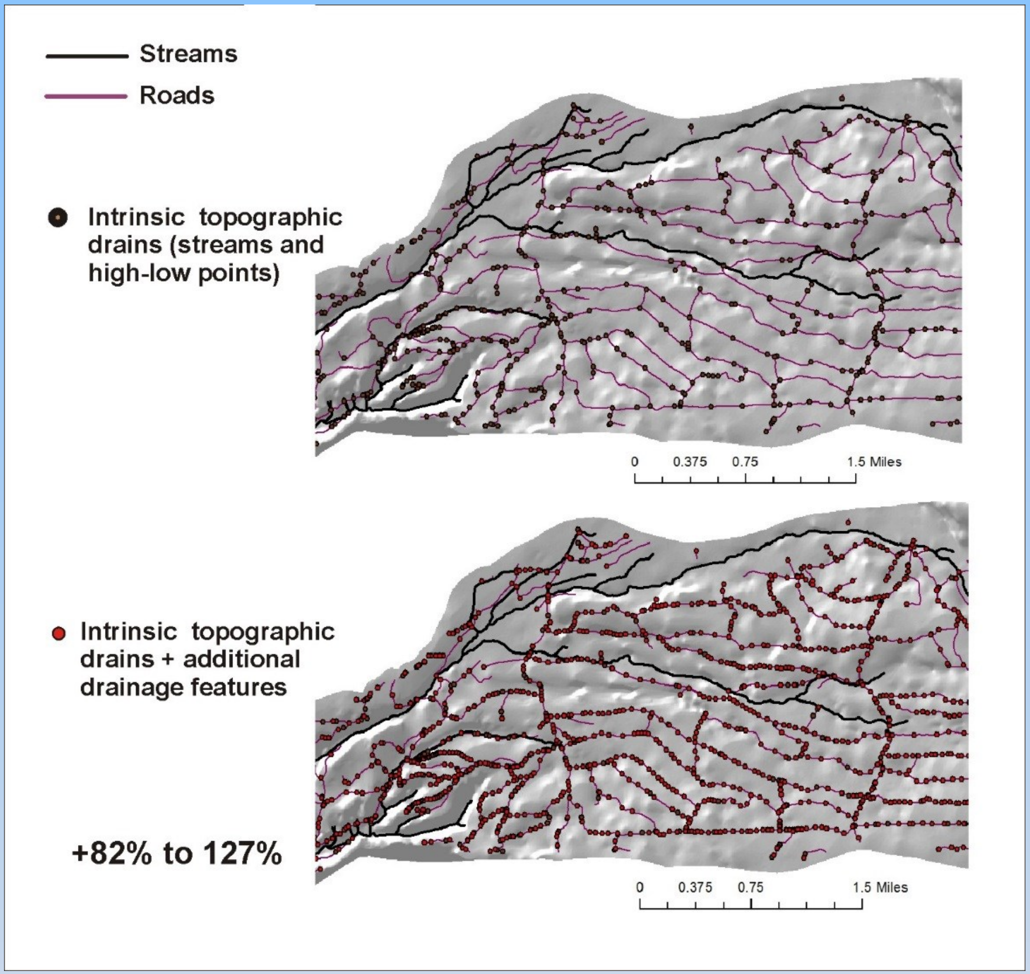
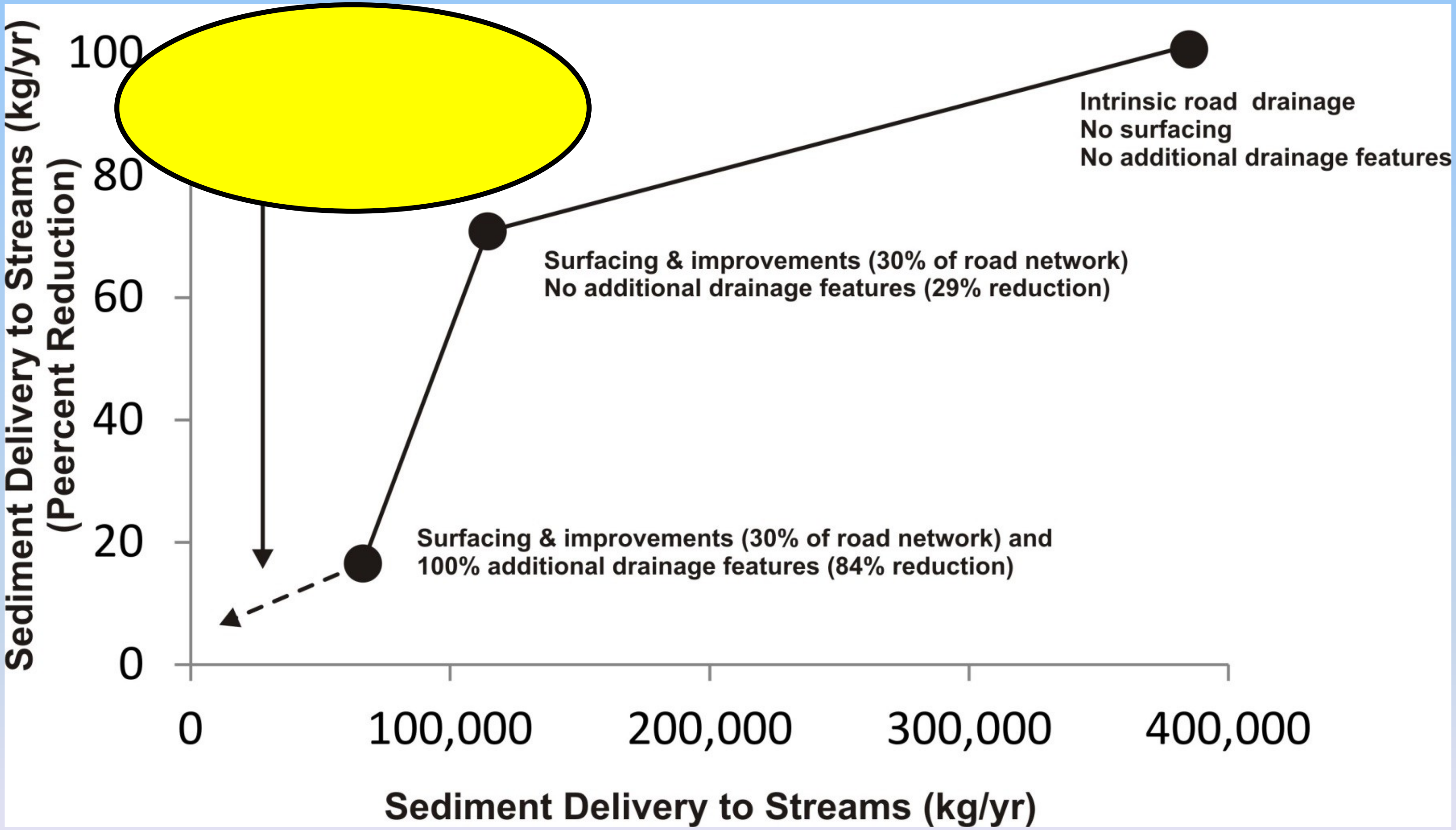


100% of all road segments produce sediment;

Only 6% of all road segments/ & their drainage features deliver sediment to streams;

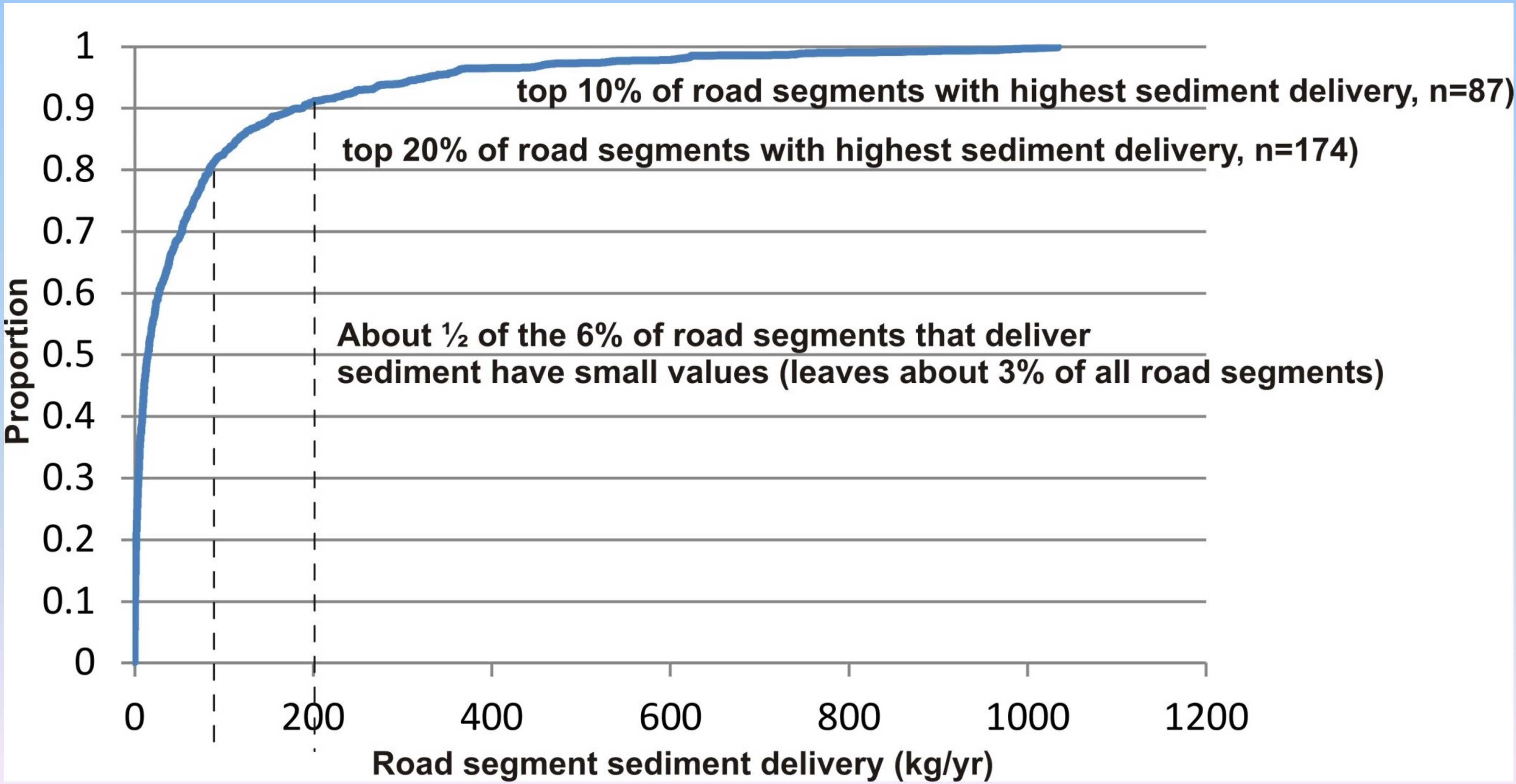
Thus, most road drainage features (90%) are not functioning to minimize road sediment delivery, but they may be serving other purposes

Where would you strategically place new surfacing and or new drains to reduce sediment delivery to optimize cost benefit?

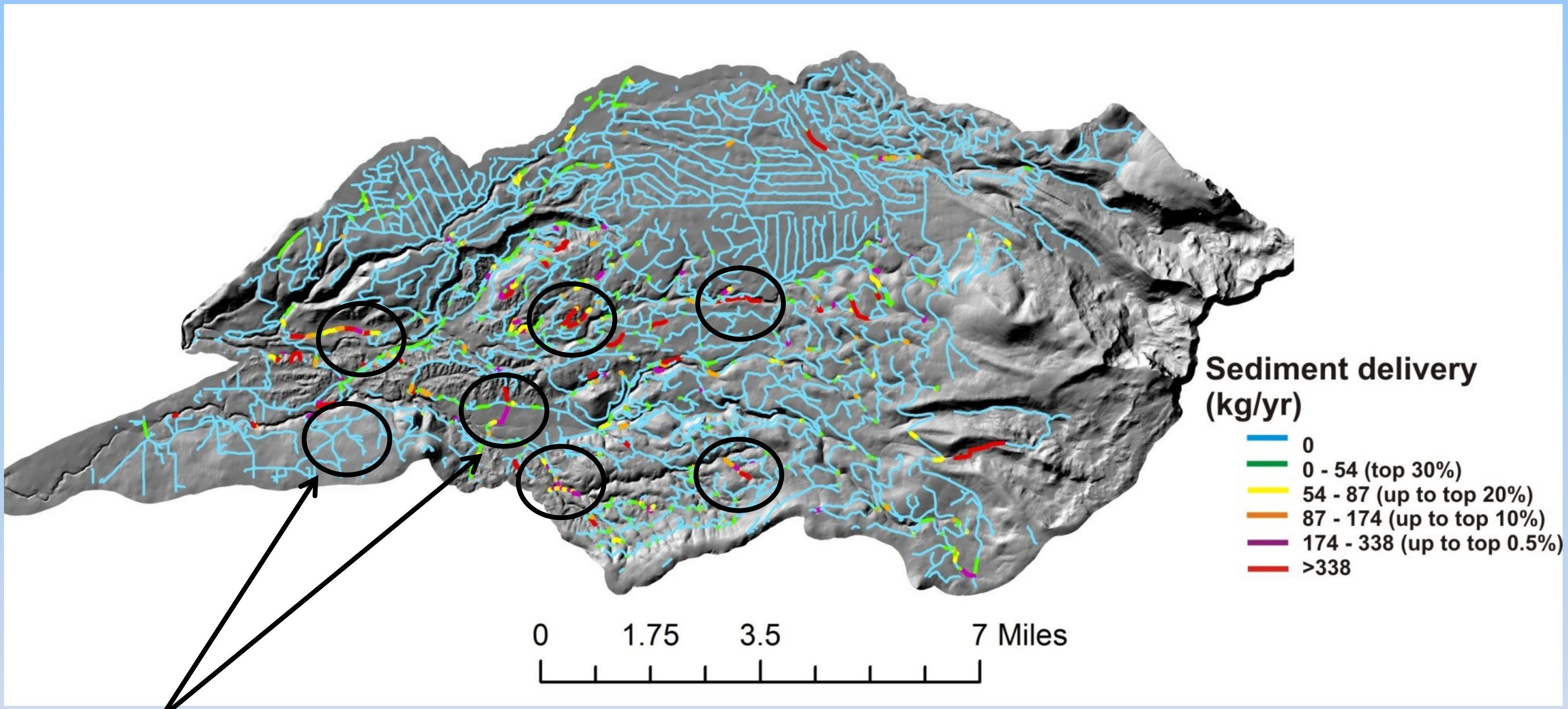


Only 6% of road segments deliver sediment to streams (n = 870 segments) under the modeled scenario, including climate (design storm).

Of these, only about 3% of all road segments produce and deliver relatively large sediment volumes.



Target the highest sediment and delivery producers (following field validation)



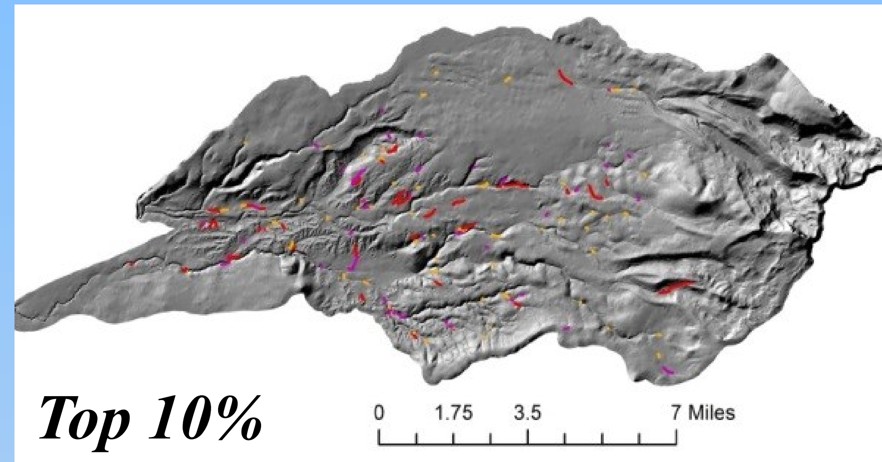
Highest 1%

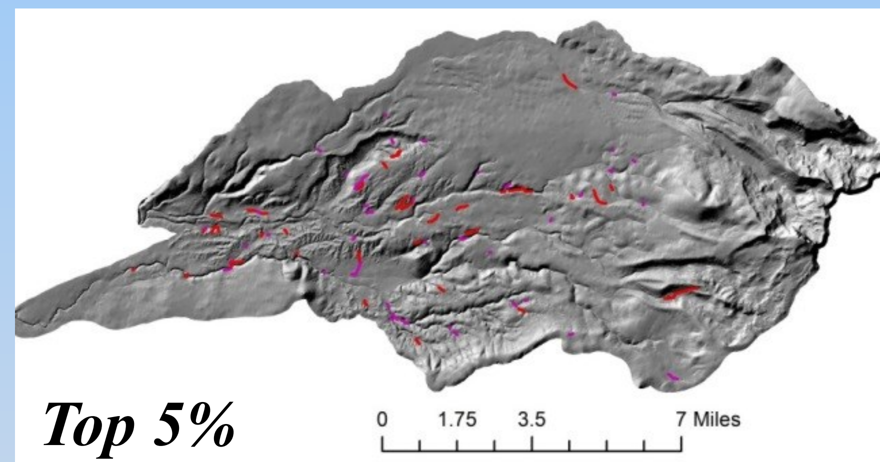
Highest road erosion and sediment delivery – native surface

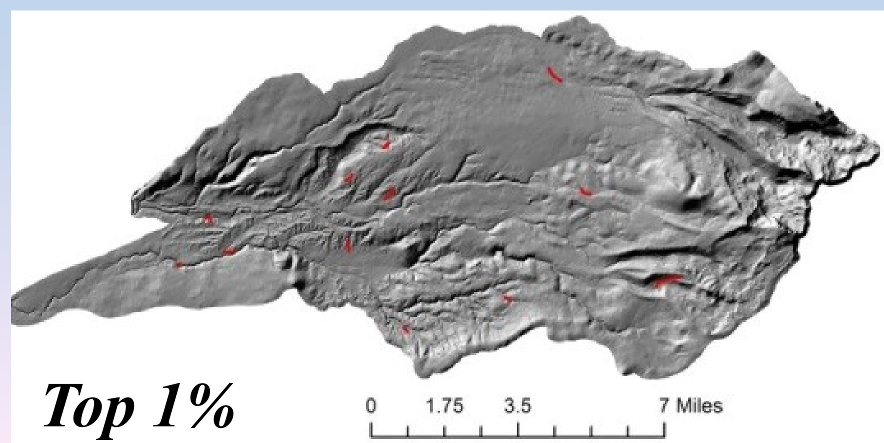
Prioritize:

-drain placement
-surfacing
-maintenance

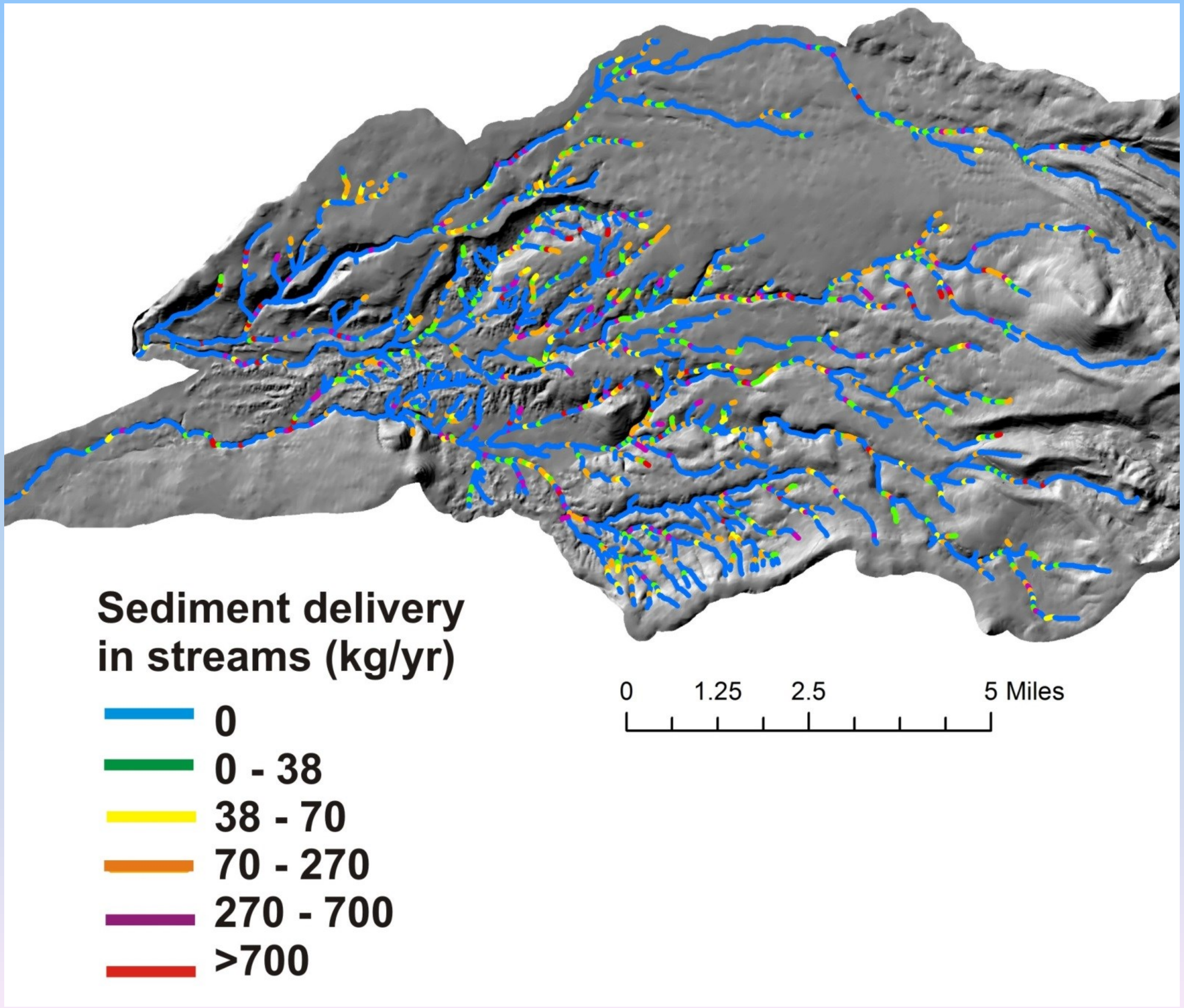
to reduce predicted road erosion and sediment delivery to streams







Additional results: road sediment delivery viewed within the channel network (e.g., predicted point sources, potentially useful for monitoring and other purposes)



Location matters: ***topography, drainage density and road density are interrelated; they influence road distance to stream, road erosion and sediment delivery rates – results will vary by watershed.***

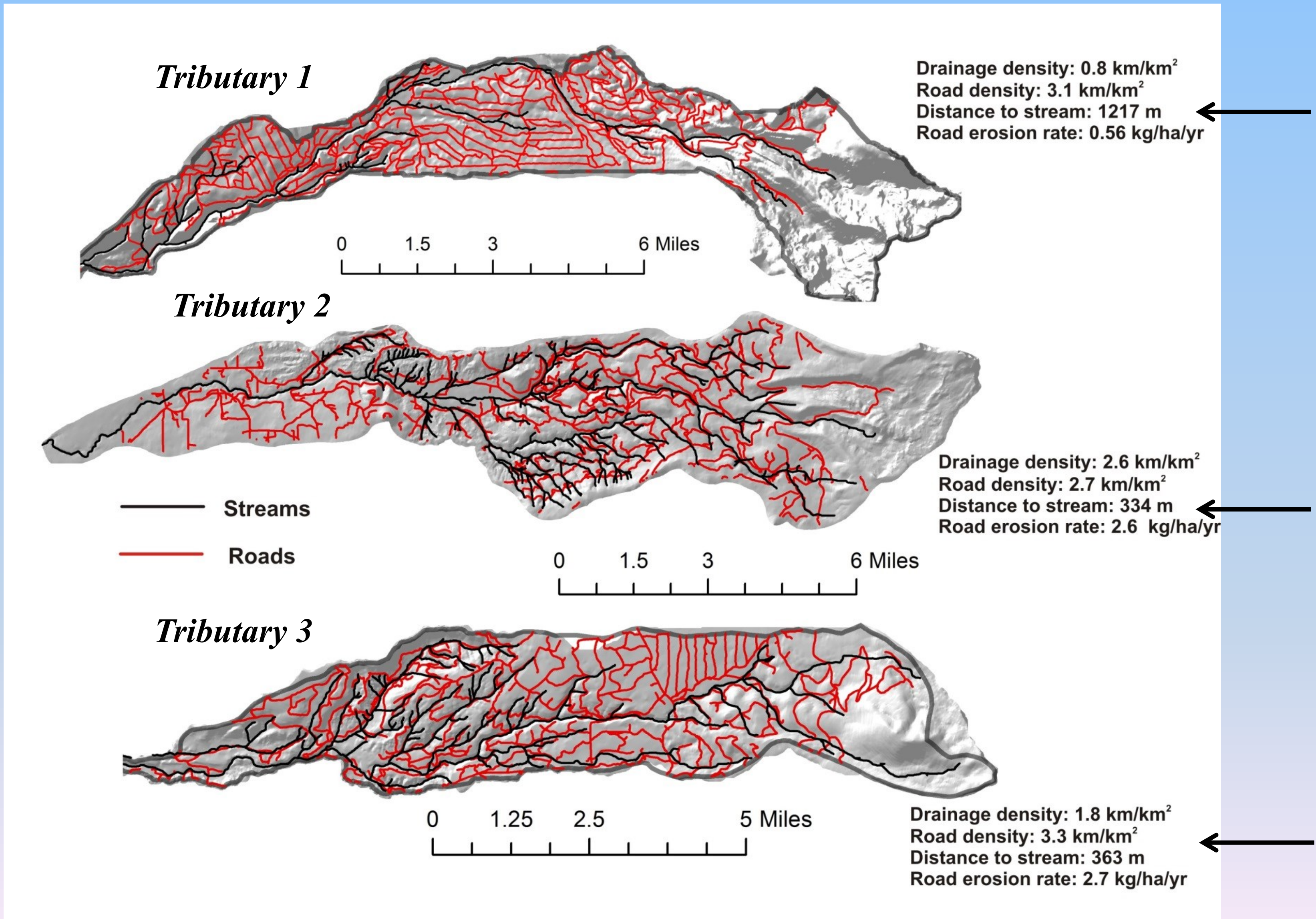


Figure from Luce et al. 2001

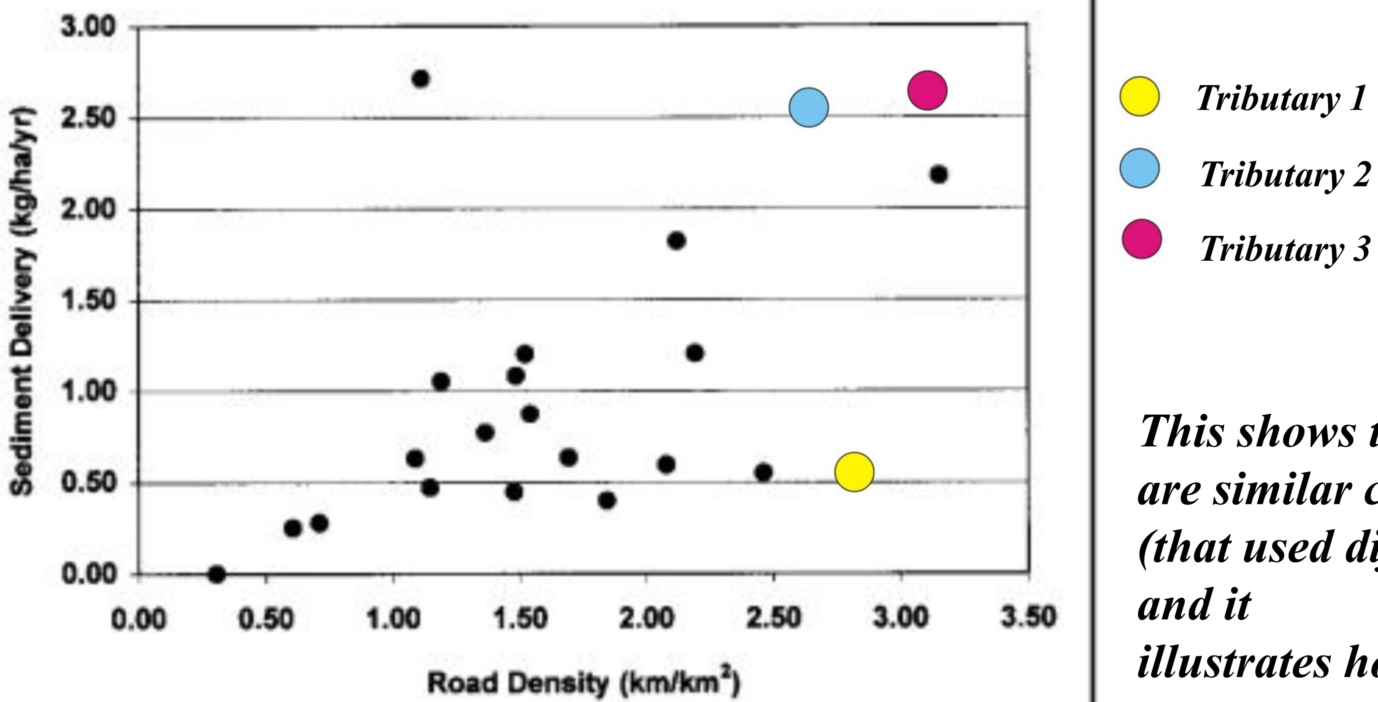
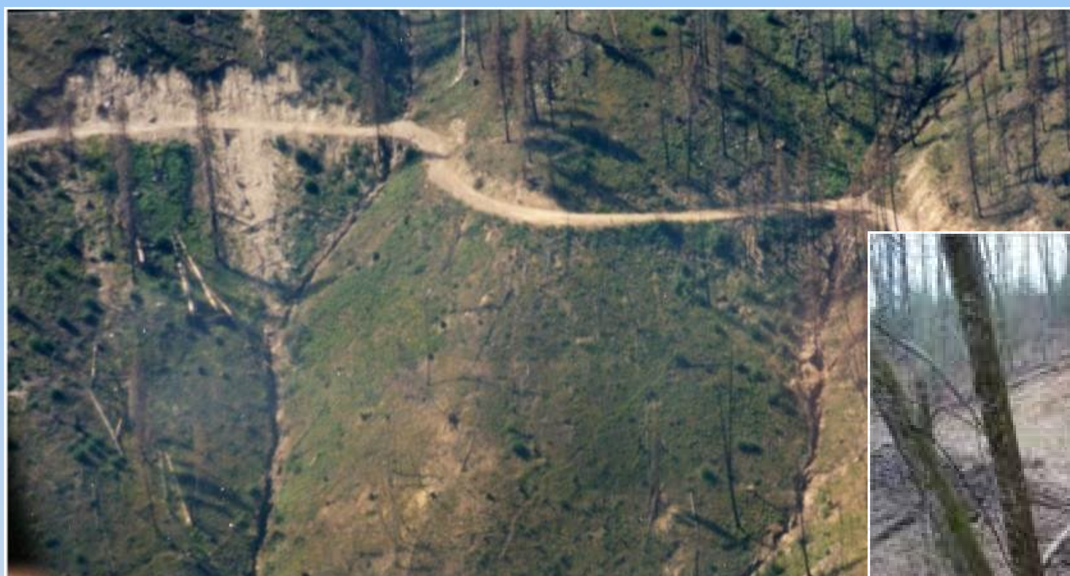


Figure 2. Relationship Between Sediment Delivery Predicted by a Surface Erosion Model and the Road Density in 19 Sixth Code HUC Basins (average about 16 km^2 each) in the Oregon Coast Range.

This shows that our predictions are similar compared to others (that used different methods) and it illustrates how location matters, how low drainage density and topography result in marked differences in predicted erosion and sediment delivery.

Study Part 2: **How will fire (severity) alter road erosion and sediment delivery, post fire? Where would future forest road management be most effective at reducing post fire increases in road erosion/sediment delivery?**



Agency Automated Wildfire Risk Analysis

(Transportation, Residences, Aquatic/Riparian)

Wildfire Decision Support
- pre fire
- fire fighting
- post fire (BAER)

→

Staff
selects pre-fire Flammap
or
loads post-fire BARC map

→

NetMap

← Other data:
- digital elevation
- synthetic river networks
- soils
- climate
- transportation
- fish habitat
- vegetation (incl. riparian)
- land use

Model outputs
(varies by Flammap or BARC)

Erosion/Sediment Flood Impacts

(1) Post fire surface erosion
(2) Landslide/debris flow/ gullying
(3) Post fire road erosion & sediment delivery
(4) Flash flood potential

Aquatic/Riparian Impacts

(5) Shade-thermal energy
(6) Thermal refugia
(7) Habitat above road xings
(8) Roads in floodplains

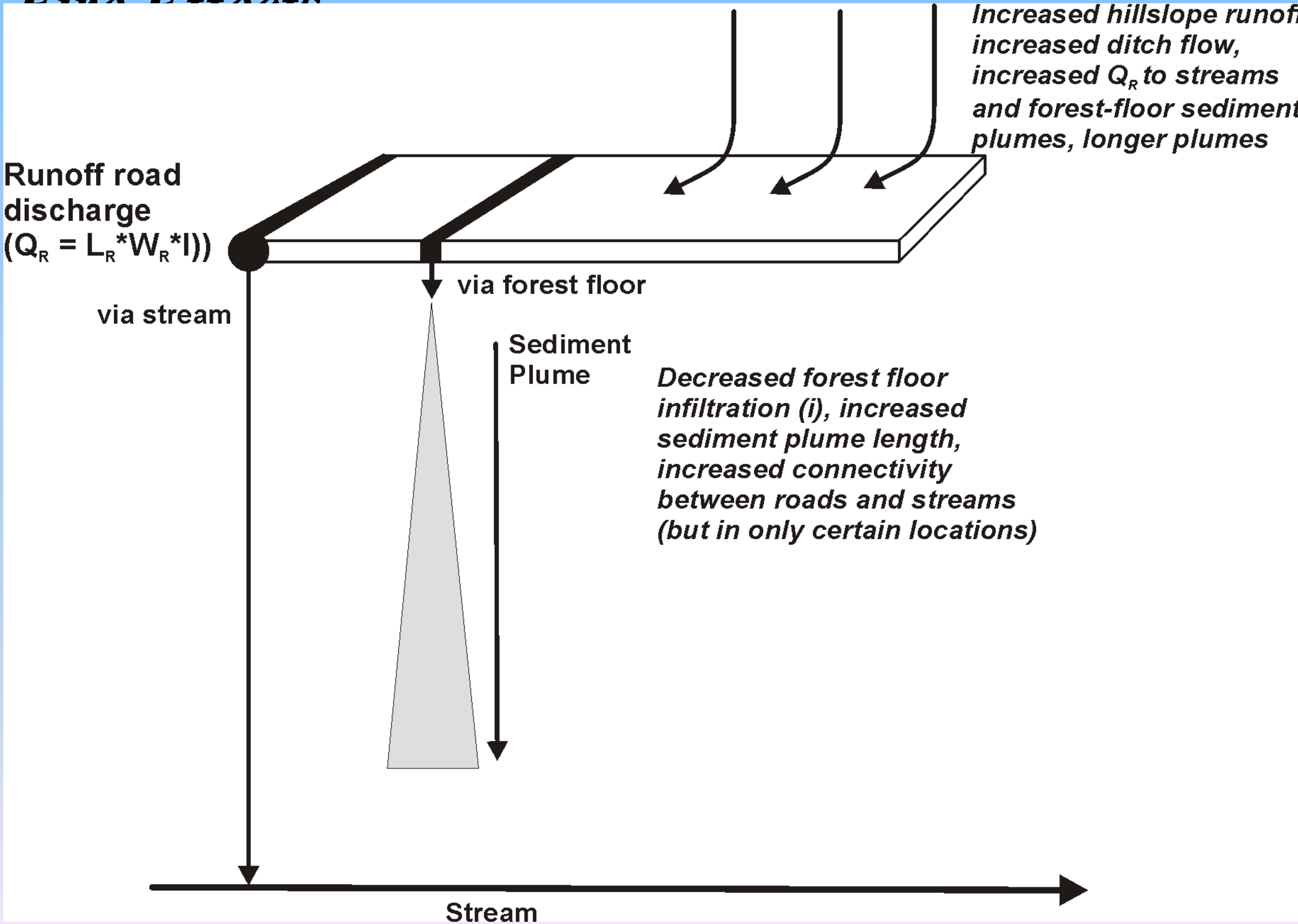
Identify at-risk infrastructure
- transportation
- energy
- water supply
- structures

Identify at-risk aquatic/ riparian resources
- fish habitats (including T&E)
- riparian habitats

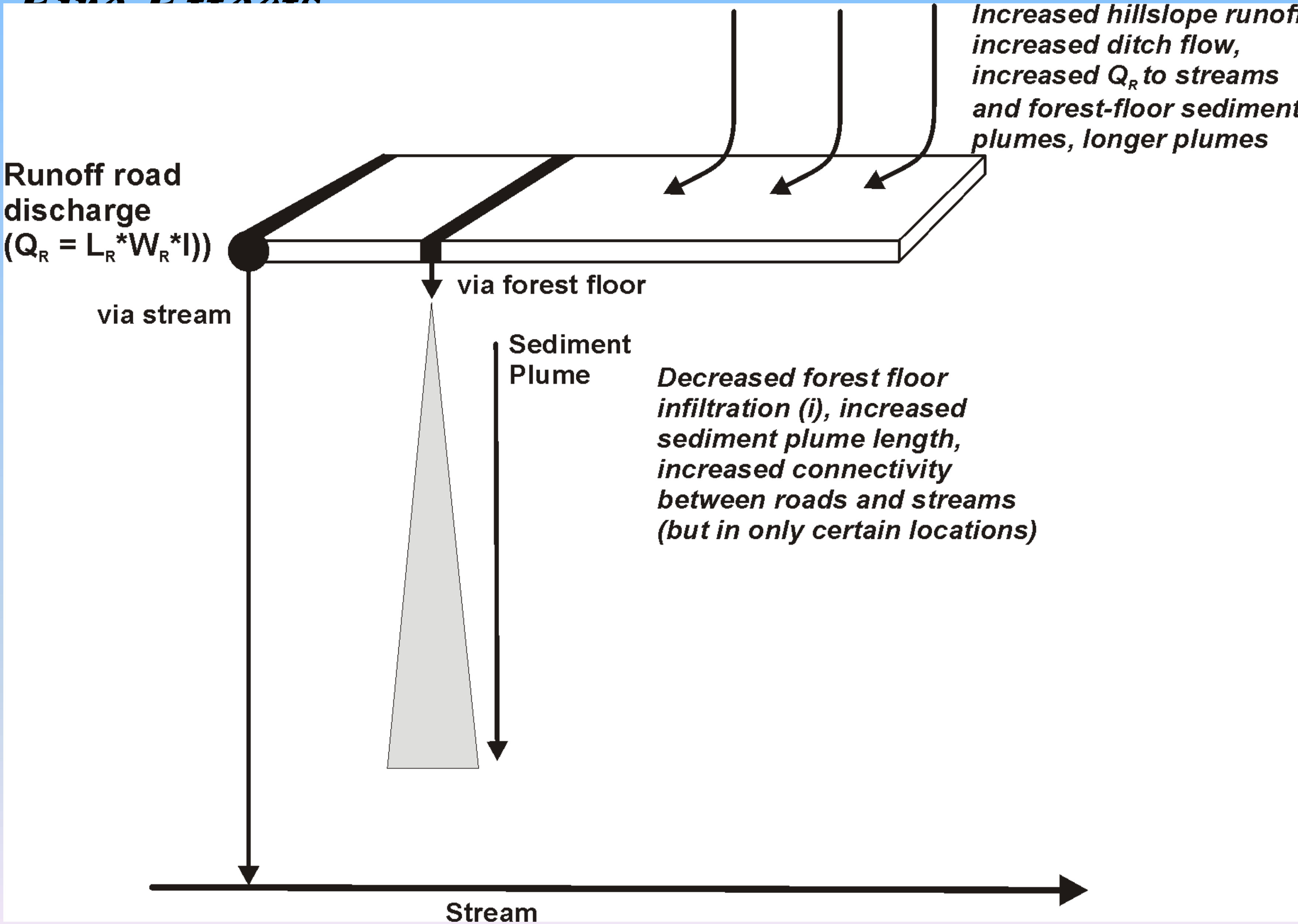
Decision Support

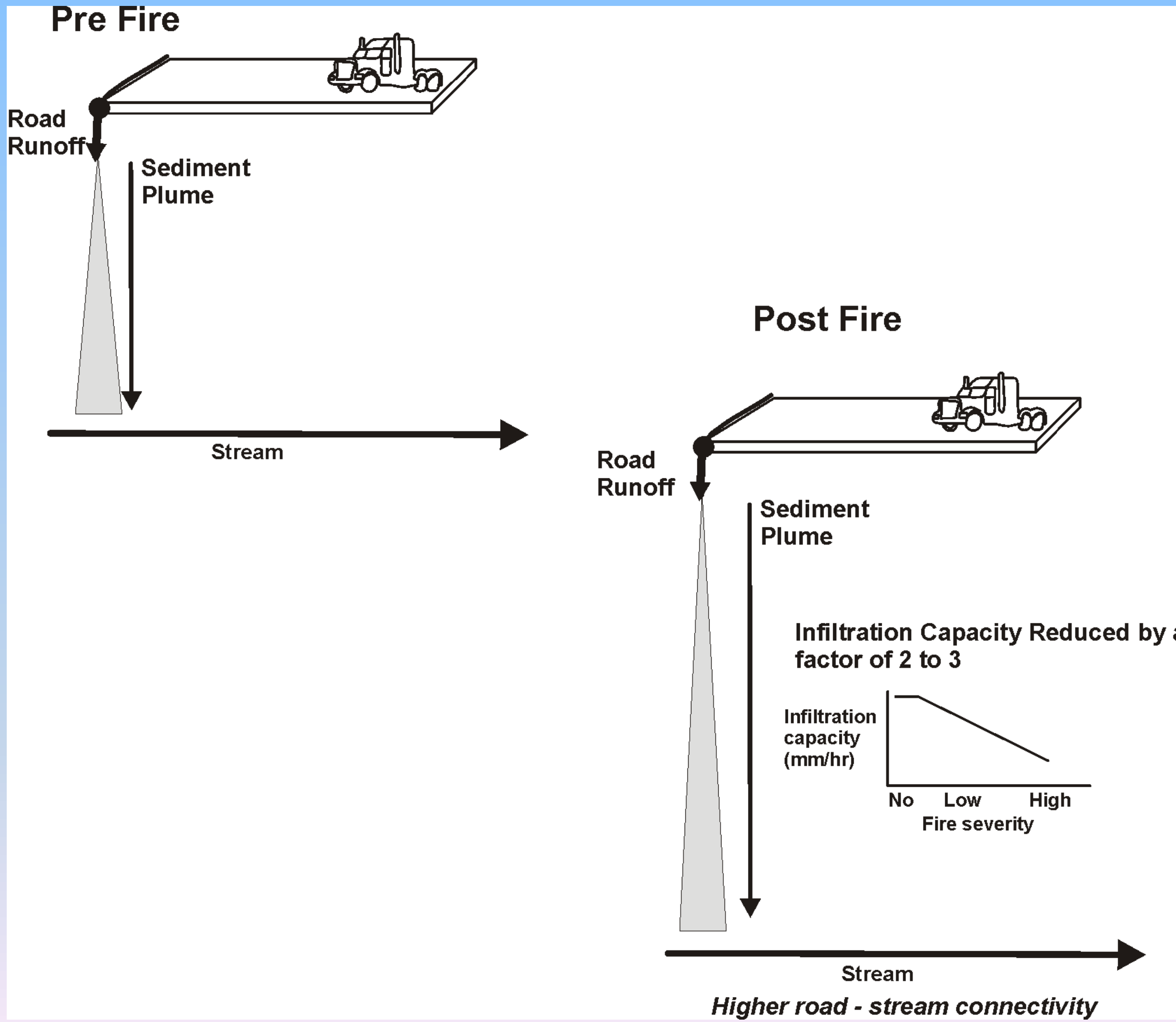
(Risk assessment, erosion mitigation, road maintenance, aquatic/riparian habitat enhancement etc.)

Fire Effects



Fire Effects

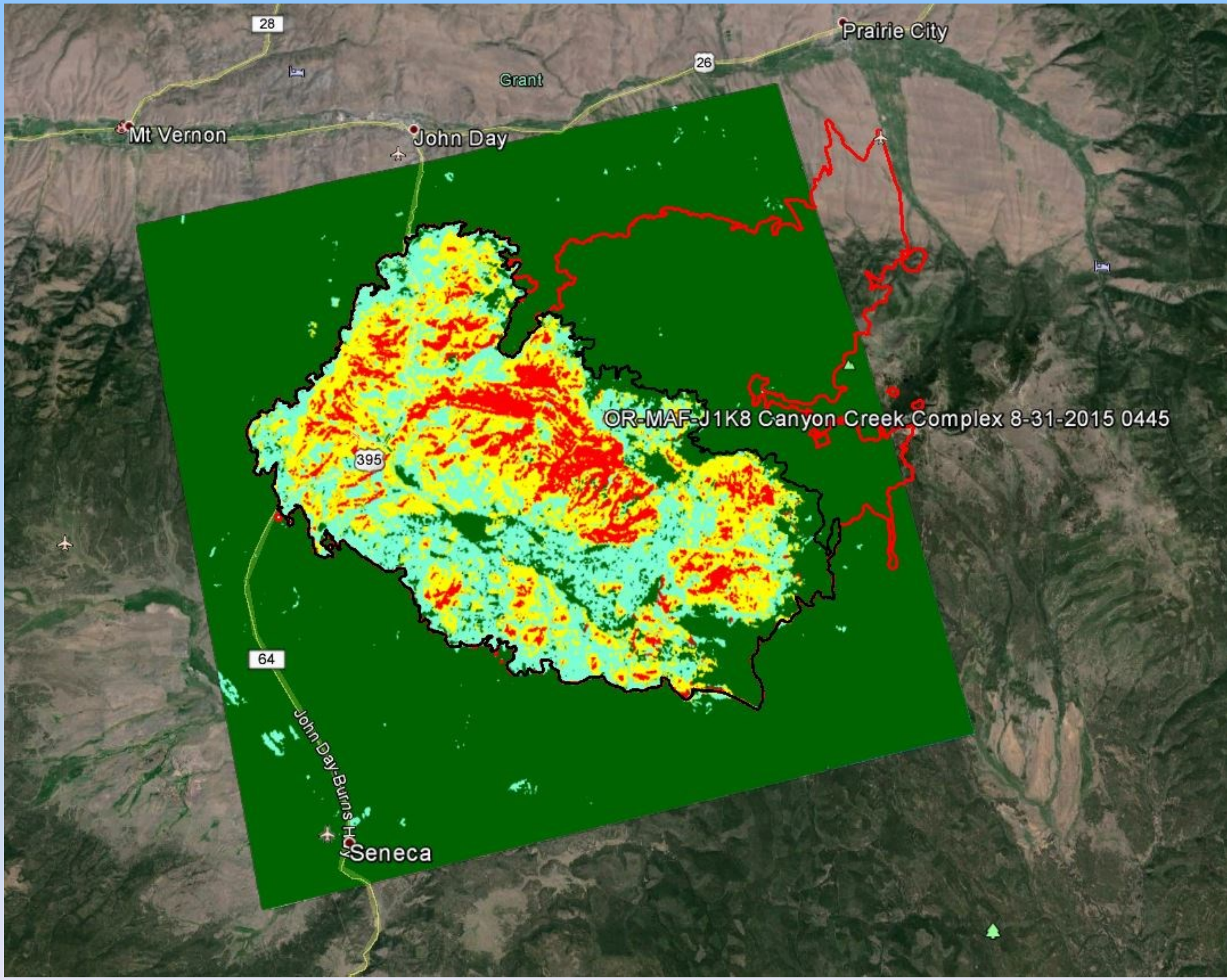




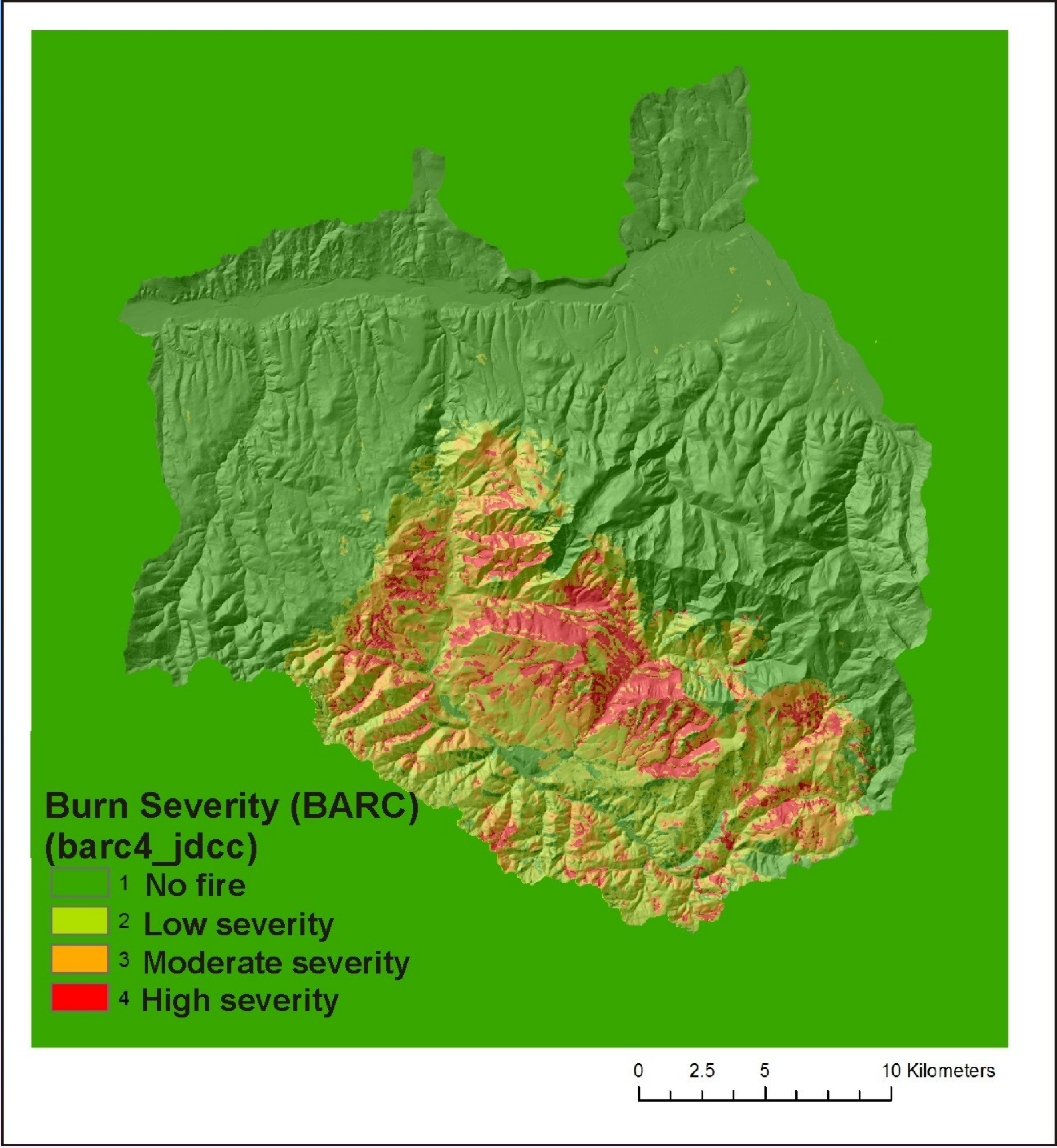
Pre Fire
Road Runoff
Sediment Plume
Stream
Post Fire
Road Runoff
Sediment Plume
Infiltration Capacity Reduced by a factor of 2 to 3
Infiltration capacity (mm/hr)
No
Low
High
Fire severity
Stream
Higher road - stream connectivity

Post fire BAER Analysis

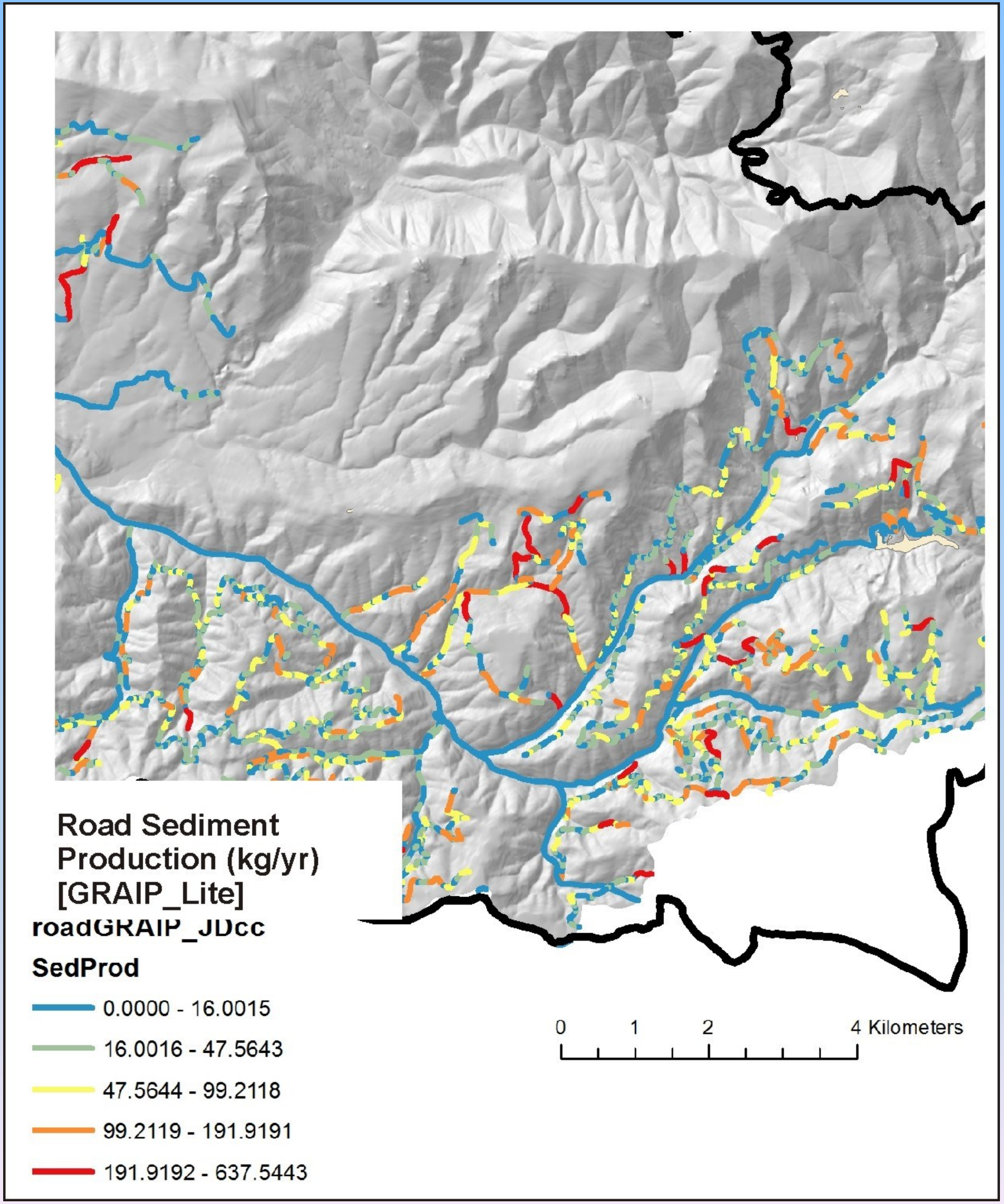
Canyon Creek Complex Wildfire, as of August 31, 2015



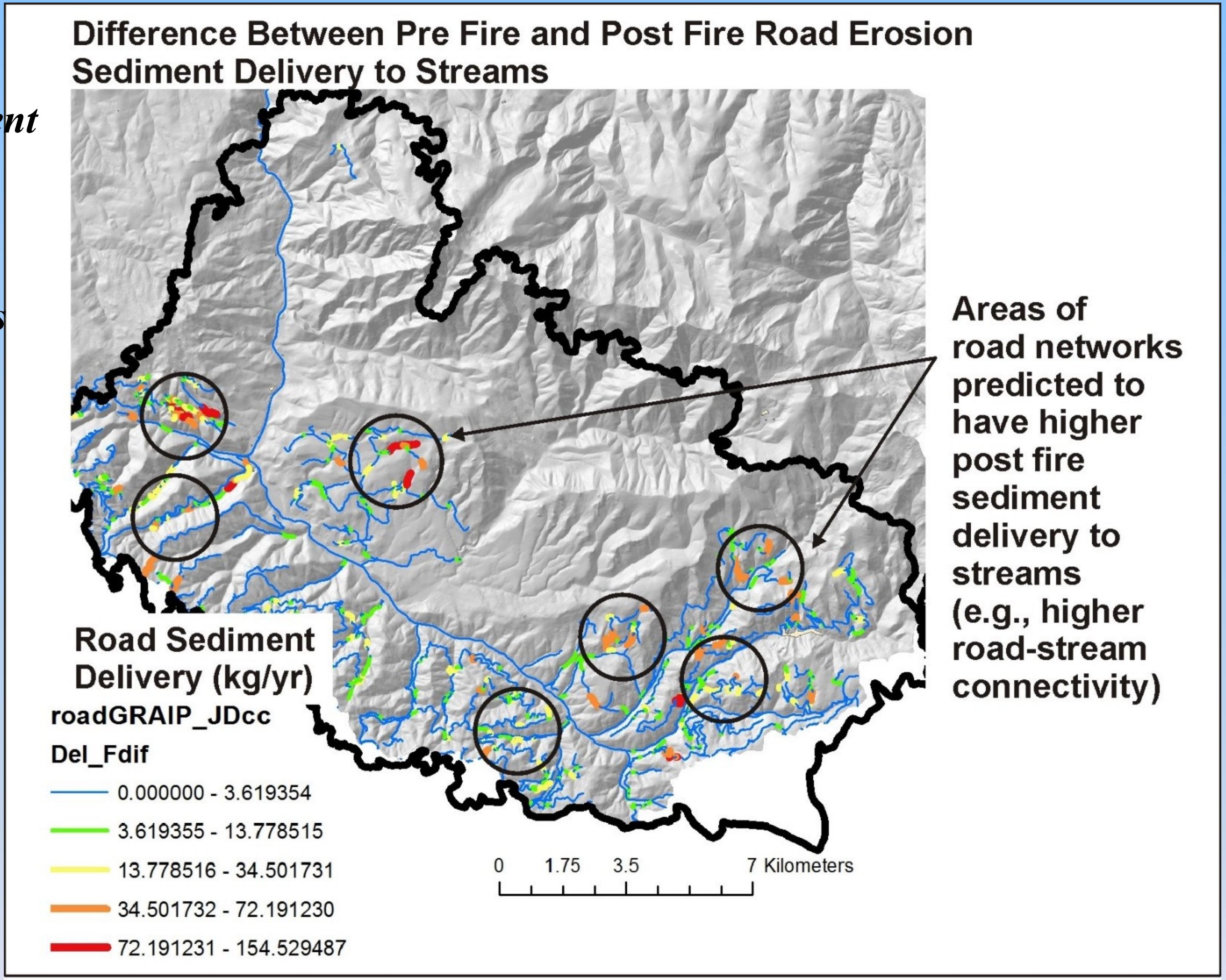
Fire severity



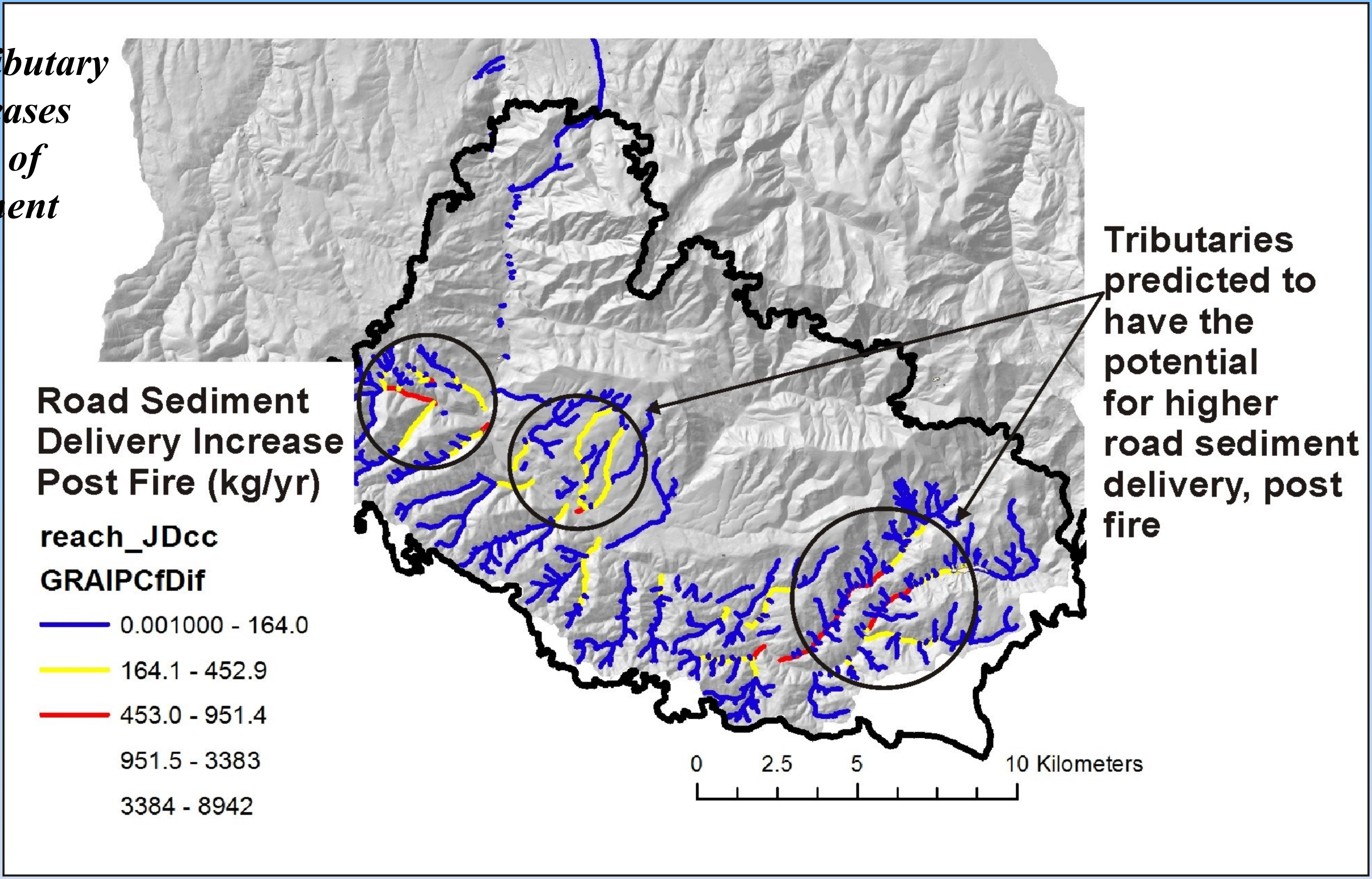
First, start with road sediment production



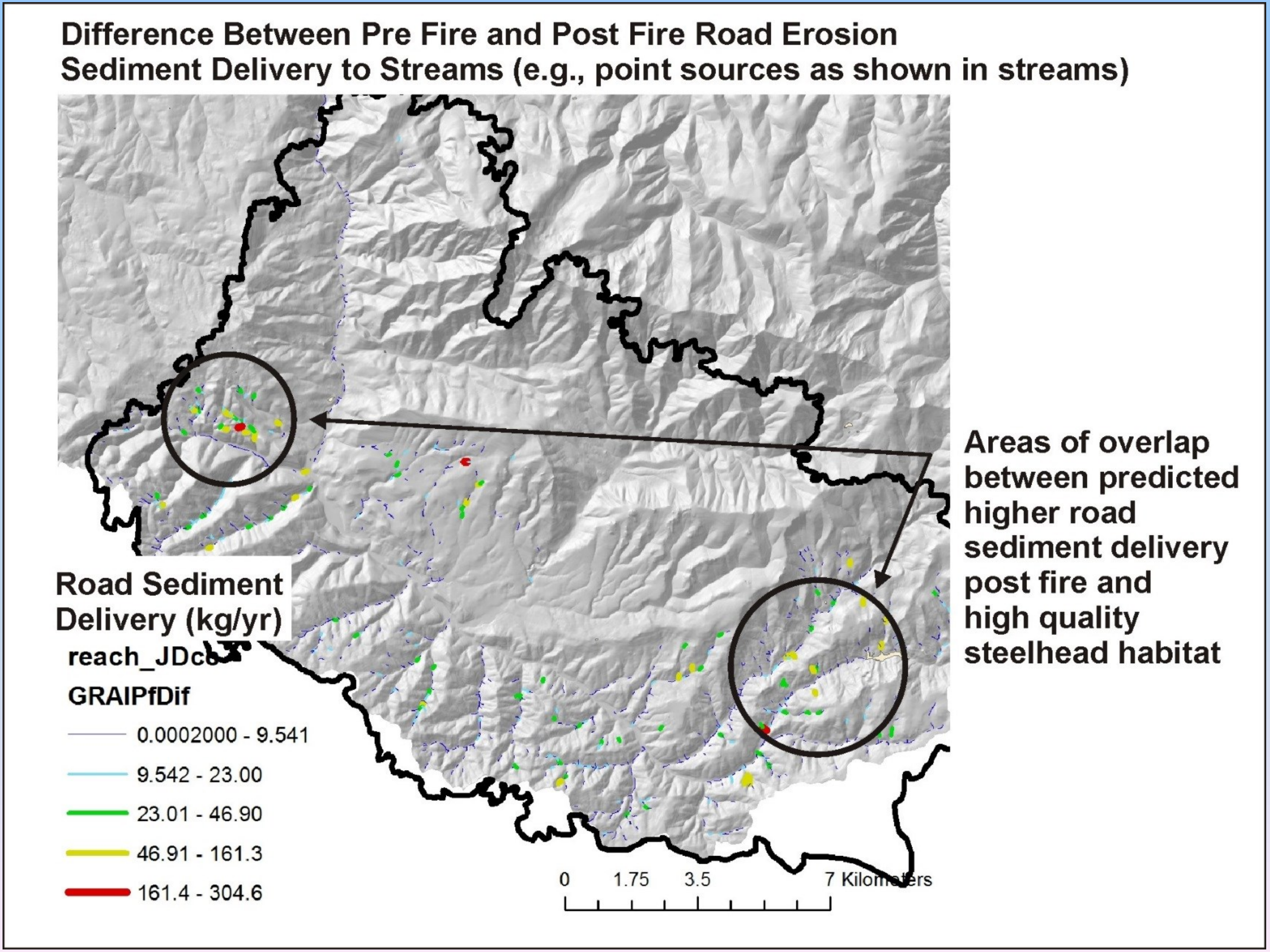
Next, calculate sediment delivery pre fire and compare that to sediment delivery post fire, and identify areas of predicted increases



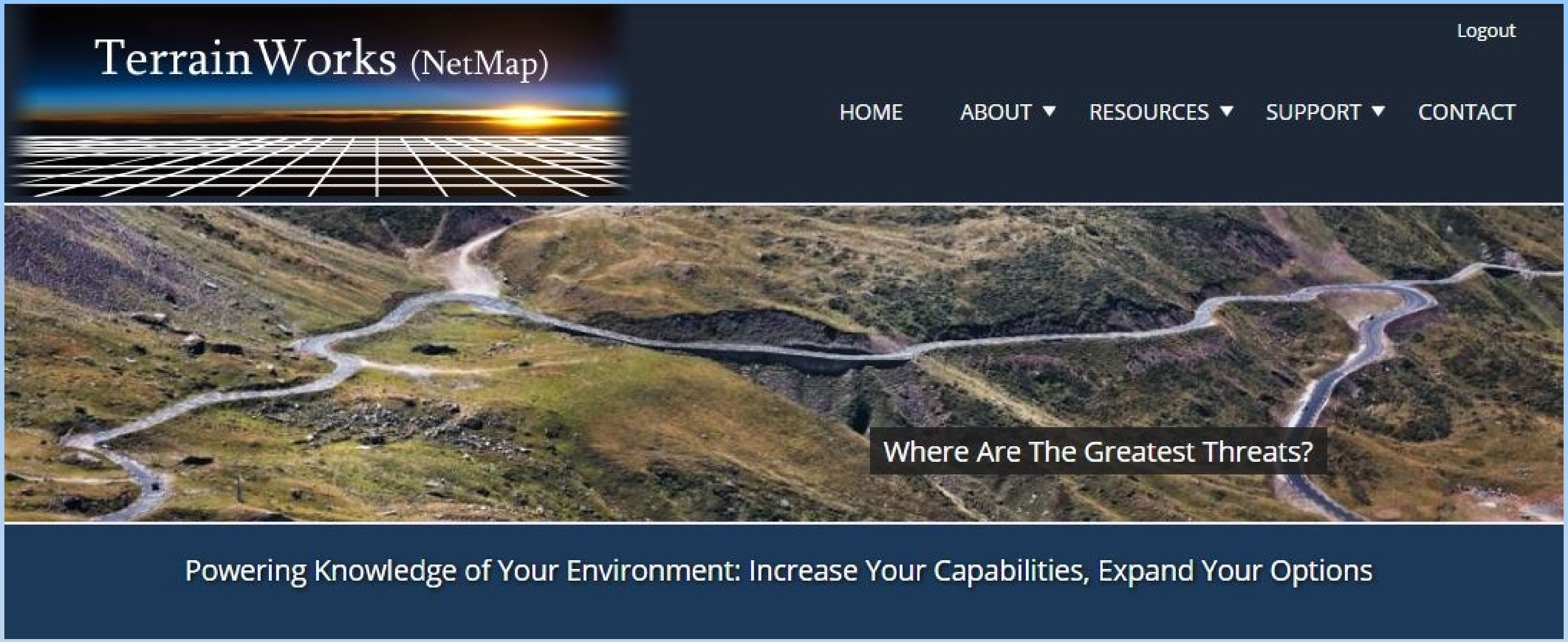
Identify tributary scale increases in delivery of road sediment



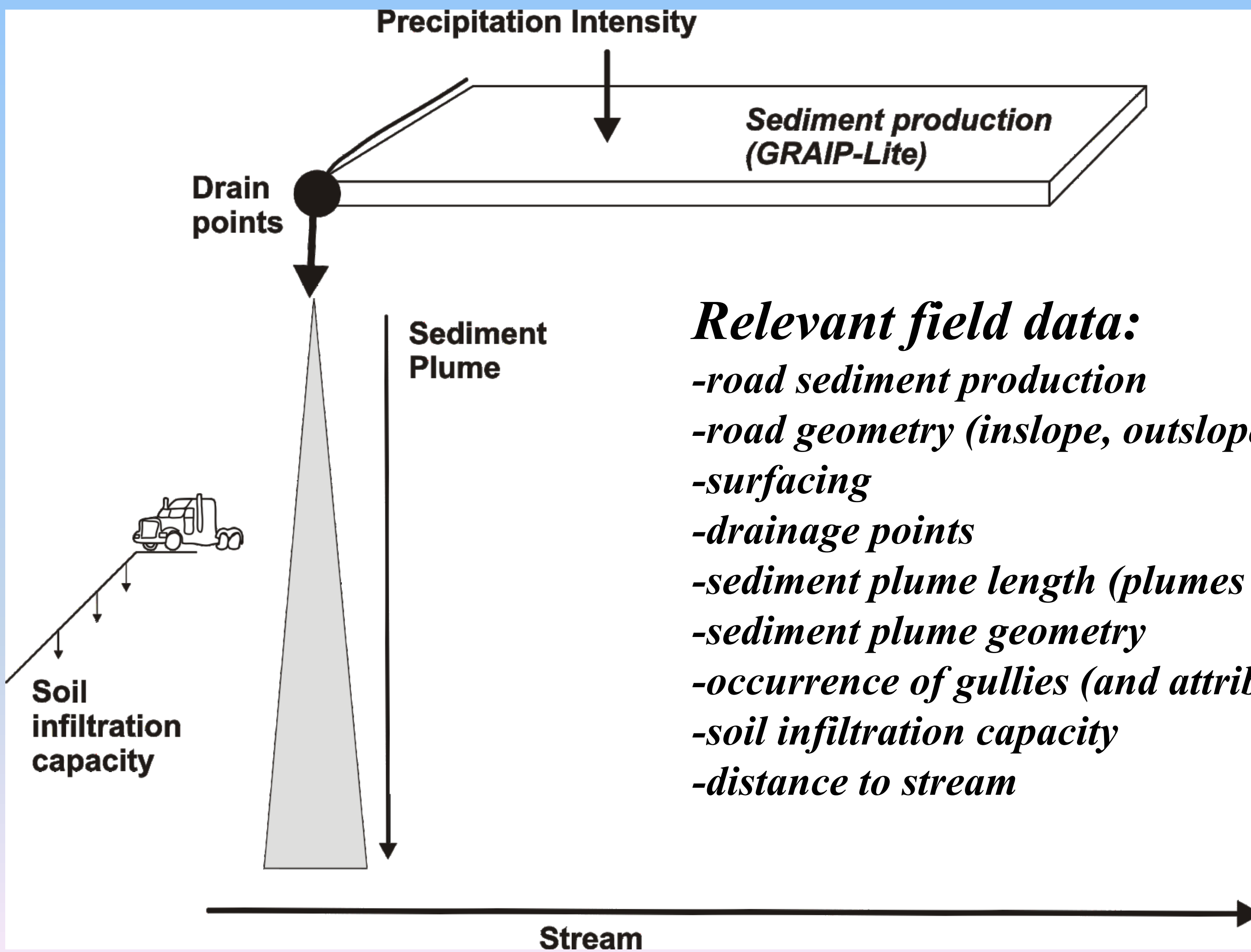
Then compare it to locations of high quality and sensitive aquatic habitats



For additional information go to www.terrainworks.com



Model results depend on adjustable variables; additional field data in specific watersheds will allow for more site specific calibration and confidence in model predictions



Relevant field data:

-road sediment production
-road geometry (inslope, outslope, crowned)
-surfacing
-drainage points
-sediment plume length (plumes vs gullies)
-sediment plume geometry
-occurrence of gullies (and attributes)
-soil infiltration capacity
-distance to stream