Prediction of Erosion from Forest Road Networks

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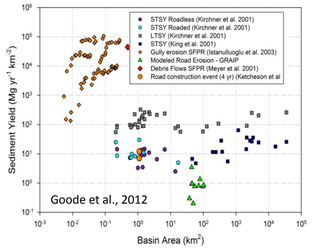
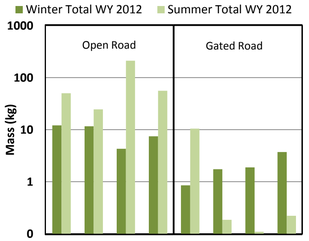
Sources of Erosion from Roads

Erosion plot studies of forest roads provide insight into the controls on surface erosion such as flow path length, slope, material properties, traffic and surfacing. Current challenges are to understand sediment transport from the road network as it interacts with the hillslope and channel network. Additional challenges arise in quantifying the risks associated with mass erosion (gullies and landslides) below road drainage features and due to flow diversions at stream crossings. We present two models, the Geomorphic Roads Analysis and Inventory Package (**GRAIP**) which makes predictions at a road segment scale and **GRAIP-Lite** which is designed to predict road risks at a watershed scale.





Un-surfaced forest roads in Western Montana (MTC) open to light vehicle traffic had 20 times the fine sediment production of similar gated roads with little or no traffic. Despite a deep seasonal snowpack, most transport occurred during a few convective storm events during the spring and summer.

Forest roads have been found to be a major source of human caused fine sediment to headwater channels. Road surfaces have low infiltration rates that generate direct runoff and intercept shallow subsurface flow. Runoff and sediment are concentrated and discharged to streams and to steep hillslopes. Sediment is mobilized and delivered to streams through several pathways including surface erosion from road surfaces and ditches, gully erosion below drainage features, accelerated landslide rates and erosion due to stream channel diversion. Surface erosion is greatest on new roads and those with high levels of traffic and maintenance disturbance.

Gully and landslide related to excess road drainage onto steep slopes

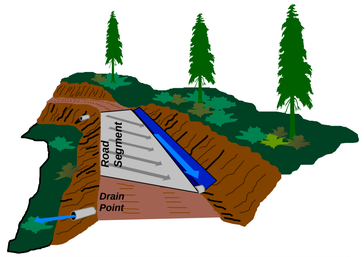
Undersized and poorly designed road stream crossing allows flow to divert down the road.

Surface erosion due to stream capture below poorly engineered stream crossing.

Geomorphic Roads Analysis and Inventory Package (GRAIP)

GRAIP is a detailed road segment scale GPS inventory procedure combined with a set of GIS tools that simplify the analysis of the various dimensions of road risks (Black et al 2012, Cissel et al 2012).

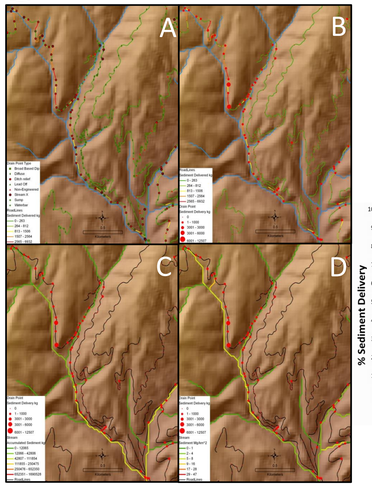
Fine sediment production ***E*** is predicted based on empirical relationships between plot length and slope found by Luce and Black (1999). Sediment delivery to the channel is predicted by modifying the sediment production at a drainage location based on observations of sediment transport across the hillslope.



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

E = base erosion rate (kg/m of elevation change)
L = road length contributing to the drain point (m)
S = slope of road in the travel direction (m/m)
R = road surfacing factor
V = vegetation cover factor for the flowpath

The model predicts road segment scale surface erosion (A). Eroded sediment is accumulated at drainage locations and stream delivery is determined (B). Delivered sediment is routed to the downslope channel and accumulated through the network (C). Specific sediment per unit area is calculated to consider relative impact (D).



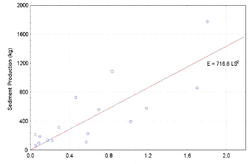
Watershed Study Results

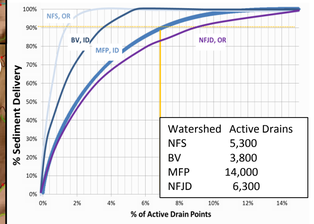
Inventories were collected on over 3,200 km in 5 areas with unique geo-climatic properties in the Western US. The portion of the road network connecting to the channel across the hillslope ranges from 4-27%.

Locally observed base erosion rates and sediment delivery varied more than two orders of magnatude. Road density does not correspond well to sediment delivery per unit area.

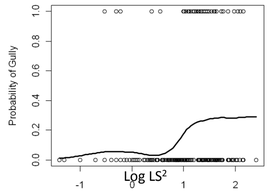
	MTC, Montana	BV, Idaho	MFP, Idaho	NFJD, E. Oregon	NFS, W. Oregon
Connected Road length (%)	4	13	17	27	4
Road Sediment Delivery (%)	5	10	20	26	3
Specific Sediment Delivery (Mg/km^2)	0.24	0.46	5.5	0.05	0.2
Base Erosion Rate (kg/m Elevation)	7	18	18	2	79
Road Density (km/km^2)	1.8-3.4	0.6	1.1	2.0	1.3

Erosion plot studies using settling basins have indicated that road length and slope are suitable predictors of fine sediment mobilization from typical forest roads.





The majority of sediment delivery to channels occurs at less than 10% of all observed road drainage locations. Prioritizing restoration by sediment delivery can reduce costs.

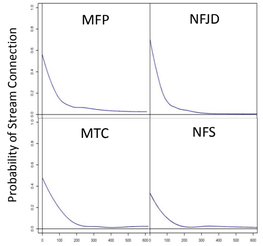


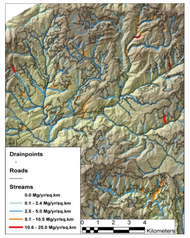
Probability of gully occurrence as predicted by the erosion sensitivity index, road length multiplied by the square of hillslope angle.

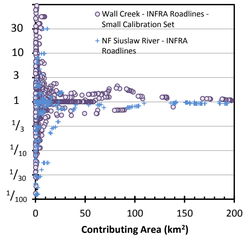
GRAIP-Lite

GRAIP-Lite is a broad scale field-calibrated GIS method that predicts sediment production on forest roads, delivery of that sediment to streams, and accumulation of that sediment within the stream network. The model is intended to work as a prioritization tool to determine areas of higher road sediment impact where more detailed inventory work is needed.

The fraction of sediment reaching the stream from each drainpoint is estimated using a regression model that describes the probability of each drainpoint being connected to the stream in terms of a predictive landscape variable, most commonly the flow distance to the stream. Specific sediment, or accumulated sediment normalized by contributing area, is used to identify areas of greater road sediment impact.



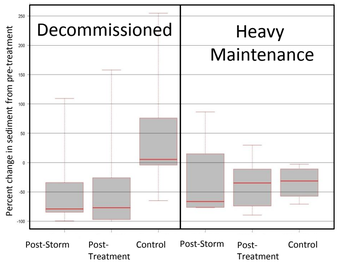




Sediment accumulation predictions were generally within one order of magnitude of the GRAIP model predictions once the drainage area was greater than 13 km^2 and within a factor of three at contributing areas greater than 21 km^2.

Monitoring Restoration

We are currently using GRAIP to monitor the hydrologic and geomorphic effects of road removal and road improvement efforts occurring on public lands at 47 sites throughout the Northwestern United States. Selected roads and paired control segments each about 6 km in length are inventoried before treatment. Treated sites are re-measured after treatment is completed and following a 5-7 year storm event.



Roads decommissioned by recontouring the hillslope had a 77% reduction in sediment delivery and an 79% reduction following a storm event. Control roads had a variable response. Roads receiving heavy maintenance had a reduction of 35% following treatment and 66% post-storm. Control roads had a post storm decrease of 31%

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