

Document 2: IRST assignments (roads)

For 3 April 2025 IRST meeting

Sampling design, watershed approach

Watersheds represent a fundamental organizational feature for rivers and streams that drain, and form, complex aquatic-terrestrial landscapes (Hynes 1975). Overlaid on this foundation are patterns of land use and natural disturbance processes that, in forested areas, create a mosaic of stand ages and vegetation conditions. Of particular interest in this assessment is the connectivity between roads on private forestlands and freshwater features, including streams, rivers, wetlands, and ponds. Roads have the potential to alter hydrology and contribute fine sediments to freshwaters that are detrimental to effective ecological function (e.g., MacDonald and Coe 2008; Kastridis 2020). Current evaluation of the status and trends of hydrologic connectivity on private forest roads, is required to evaluate the effectiveness of current Forest Practices Administrative Rules to achieve the Biological Goals and Objectives of the Oregon Forest Practices Act Habitat Conservation Plan (OFPA HCP).

To facilitate understanding about how freshwater features are affected by conditions in the lands they drain, the USGS delineated watershed boundaries in a system of hierarchically nested Hydrologic Units across the United States (Seaber et al 1987). Hydrologic units at the 5th-field level and 6th-field level, HUC10- and HUC12-scale respectively, have been widely used to research and monitor how aquatic ecosystems are influenced by land use, including roads. For example, the Aquatic and Riparian Effectiveness Monitoring Program for the Northwest Forest Plan uses HUC12-scale units (Reeves et al., 2004) and the USDA FS Watershed Condition Framework uses a variety of HUC scales as part of their assessments (USFS 2011). For perspective, HUC12-scale units in western Oregon range in area from about 15 to 60 sq mi, with an average size of 40 sq mi.

A watershed-based sampling approach is being proposed here to determine the status of, and monitor trends in, hydrologic connectivity between roads and streams. This would be a departure from the grid-based sampling approach used in Dubé et al. (2010), but has the advantage of centering on the aquatic, rather than the terrestrial, system. The grid-based approach identifies only the total miles of connected road. The watershed-based approach being proposed here will provide that information in addition to the miles of “potentially” connected road that are actually connected as verified by field sampling.

Defining the population of interest: This option proposes to use HUC12-scale hydrologic units as the foundation for sampling. The population of interest will be HUC12-scale units containing at least 25% of the area in forestland ownership and will be stratified into large forestland owners and small forestland owners (< 5000 acres). Private timber ownership that constitutes less than 25% of the area in a HUC12-scale unit may not contain a sufficient length of roads for meaningful assessment. In each sampled unit, the lengths of existing private forestland roads with a potential to deliver to a stream that is mapped on the LiDAR-derived regulatory stream network will be

identified based on connectivity metrics that consider factors such as distance and slope between a road segment and the nearest stream reach (e.g., Najafi et al. 2021; Hooke and Souza 2021).

Although the size of units at the HUC-12 scale is relatively small, not all of these units are “true” watersheds, with no upstream inlet and one outlet. Some of the units are “composite” watersheds in that these have one or more upstream inlets and a single outlet. Thus, the HUC12-scale provides the opportunity to include samples across a spectrum from small, headwater streams to the larger rivers.

Sample selection: Once the watersheds in our population of interest have been identified, a random sample of HUC12-scale units will be selected for both western and eastern Oregon. Sample size will be determined following a power analysis. To determine the status of hydrologically connected roads, two sets of HUC12-scale units will be selected for the first sampling period. One of these sets will be sampled only once (e.g., once-only sites). The second set will be used for repeated measurements over time (e.g., repeated sites). When repeated measurements are taken, another set of once-only sites will also be selected and sampled. This approach of randomly selecting one set of hydrologic units and repeated sampling in the other set at each time step will reduce bias and increase precision in monitoring trends.

In addition to a mapped road layer, stream layer, and high-resolution DEM derived from LiDAR, other datasets will be included as needed. Information that could be summarized at a HUC12 scale include:

- Watershed area (km²)
- Land ownerships (% private timber ownership; % federal; % state, etc)
- Stream length (km)
- Strahler stream order of streams
- Area of other freshwater features such as wetlands and ponds
- Existing roads summarized for the entire watershed (km)

Additional covariates to consider for analysis or stratification include:

- Vegetation characteristics – forest stand age and composition (km²)
- Underlying lithology (percent different lithologies)
- Underlying soil characteristics (percent different conditions)

Data Resources for Road-Stream Connectivity Monitoring

Literature (& Data?) Review

(Info we think might be useful to include in this section of our scoping proposal. This could be developed into a table)

Roads data

(for more details see [ODF Roads GIS Data](#))

- ODF Statewide Roads GIS layer
- <https://oregon-department-of-forestry-geo.hub.arcgis.com/search?tags=transportation>
- Last updated April 2024. Includes surface type, name, ownership, segment length. Likely the best available data source to start with and will incorporate best available data from large privates.
- Private landowners – the extent and accuracy of roads networks will be variable across landowners, even those of a similar size. Some, especially large privates, share their road layers with ODF for wildfire response. We would need to learn about how ODF incorporates these data on what frequency. Some roads from large private landowners will be derived from LiDAR already, but likely to be a patchwork even within a single landowner.
- Coverage across ownerships looks pretty even (suggesting few missing data); a bit more spotty in eastern Oregon.

Lidar for road inventorying

- Pro: Automated extraction tools can be highly accurate (i.e., negligible false negatives and false positives) given data with sufficiently high bare earth point density.
- Con: Older Oregon lidar datasets can have low bare earth point density.
- Pro: Publicly available lidar coverage is nearly comprehensive for much of the state but with variable point density. High point density data will become increasingly available.
- Pro: accurate roads enable lidar-based hydrologic routing prior to field work for hydrologic connectivity mapping
- Con: tools for automated extraction still in development and testing using performance metrics
- Con: initially labor intensive. many person-hours required for workflow development and testing
- Con: ODF attempted using lidar to identify abandoned roads but efforts no longer active
- Con: lacking access to private lidar datasets

Streams data

- A new state-wide streams layer (Statewide Hydrography Flow Line) has been developed and adopted as part of the PFA process (ODF 2023) <https://oregon-department-of-forestry-geo.hub.arcgis.com/search?tags=hydrography>

- The stream layer was developed by a contractor (Terrainworks.com) using the best available digital elevation models (DEMs) from either 1-meter resolution Lidar data where available or the 10-meter National Elevation Dataset.
- Streams are categorized into 3 size classes based on mean annual flow (modeled by the contractor): small (<2 cfs, <7 ft width), medium (2-10 cfs, 7-12 ft), large (>10 cfs, <12 ft) (ODF 1994: Tech Note 1)
- Streams are further categorized by fish and domestic water use:
 - SSBT streams have salmon, steelhead or bull trout use
 - Type F streams have fish and may also be used for domestic water.
 - Type D streams are used for domestic water, have no fish and are more likely to be small streams.
 - Type N streams have no fish or domestic use.
 - Type Np streams are small Type N perennial streams that flow water year round and have no fish or domestic use.
 - Type Ns streams are small, seasonal Type N stream reaches that have flowing water only during certain times of the year.
- Private landowners may request or conduct field surveys that can be used to verify or overwrite the modeled results for stream seasonality, stream channel end, and fish use.
- For detailed information on modeling methods, please refer to the [Private Forest Accord Report](#) (Chapter 2 & Appendix B).

Ownership data

- ODF has compiled a [Private Industrial Ownership](#) GIS layer that distinguishes large (>5000 ac) from small non-industrial ownerships (similar to PFA road rules, but ownerships <10 ac were dropped)
- It shows most lands are in the large, industrial category

LandManager	FREQUENCY	SUM_GISAcres	Percent
Private non-Industrial Forestland	391	237,838	4.0%
Private Industrial Ownership	120	5,637,592	96.0%
Total	511	5,875,430	

ODF Forest Roads Inventory & Analysis (FRIA) Process

(for more details see [ODF Forest Roads Inventory & Analysis](#) & [ODF FRIA Notes \(Jeff Light\)](#))

- Year 1 landowners currently inventorying and prioritizing connected roads at high conservation value sites
- CON: Limited metadata required to be collected by landowners.
- Compliance monitoring not effectiveness monitoring
- CON: Small private landowners are not required to conduct FRIA but must assess roads as part of harvest notifications.
- CON: Timeline – several years until inventory is completed (Jan 2029)

ODF Compliance Monitoring

(for more details see [ODF Compliance Monitoring](#))

- 2026 roads & steep slopes pilot; 2028 actual compliance monitoring starts
- Still working on details for roads monitoring
- Sampling likely to be based on prior year's forest practices applications; will have access to small as well as large landowners
- Looking specifically at compliance with rules, not effectiveness
- May try to assess "Avoid placing roads in critical locations" but could be challenging to assess objectively

Scoping Proposal Options

(Info we think might be useful to include in this section of our scoping proposal)

(these aren't full fledged options, just data aspects that could be incorporated into options)

- Use existing roads and streams data for sampling design (Intersection of ODF Statewide Roads layer and ODF Hydrography Flow layer; could use sub-basin watersheds and vary among the number of road/stream intersections, which will be different based on many factors, including topography)
- Use data (in conjunction with model) to estimate likelihood of connectivity to focus sampling effort
- Use data (in conjunction with model) to estimate sediment delivery
- Use FRIA and compliance data for trend monitoring and/or for identifying sampling
- Expand roads/streams data using Lidar and automated tools
- Use lidar to test accuracy of existing roads and streams
- Use lidar for hydrologic connectivity modeling

References

Literature/[Lidar](#)

Hernani, H.; Fedra, L. 2019. Application of LiDAR DEM Metrics to Estimate Road-stream Sediment Connectivity in Alberta Eastslopes Salmonid Habitats. University of Alberta, Department of Renewable Resources. Masters Thesis. <https://doi.org/10.7939/r3-1xrm-wj37>

Oregon Department of Forestry. 1994. Forest Practices Technical Note Number 1 Water Classification. Effective April 11, 1994. Salem, Oregon, USA. 12pp.

Appendices

(for supplementary info beyond what we think should go in Literature Review & Proposal Options sections)

- Roads/streams data
- Lidar
- FRIA & Compliance monitoring

IRST Road-Stream Connectivity Sediment Models

Literature Review

Introduction

- Four levels of RHSC monitoring could be considered: simple connectivity, estimates of sediment inputs, effects on aquatic habitats, and effects on aquatic species populations
- Emphasis of AMPC questions appears to be on simple RHSC, however, the final question references achieving the biological goals and objectives, which included runoff, chronic and episodic sediment.
- Given these questions, this scoping proposal focuses on a reliable method of measuring or estimating connectivity as the first priority but also addresses estimating sediment inputs and habitat/species impacts to a lesser degree.
- Address AMPC questions (baseline, trend, stratification) within each of these monitoring types or in stand alone sections?

Hydrologic Connectivity

- Dubé (2010) recorded 5 levels of connectivity in their field assessment
 - found observer differences to be pretty large, and this is worth effort to control, especially since we are tasked with before vs after PFA Rx implementation.

Sediment Delivery

- Is modeling of erosion and sedimentation needed? Why?
 - Chronic sedimentation is typically the main impact from road-stream connectivity on aquatic species
- Delivery influenced by both human-caused factors (location, surfacing, traffic) and environmental factors (slope, soils, geology, rainfall patterns)
 - The more factors measured, generally the greater accuracy but also greater costs
- We do not have the knowledge or context to know what the yield numbers mean or how they inform actions. (what is difference between a 5 cu yd and 15 cu yd annual yield?)

Habitat/Species Effects

- We should not promise to make useful findings on the relations between connected-road-derived sediment and fish habitat ... this is largely un-doable due to the complexities of sediment, episodic impact timing, and fish habitat suitability, lag times and so on. Our assumption is that limiting connectivity and fine sediments from roads is good practice, important, and doable.

Models

- A number of road-stream connectivity models have been developed
- Most focus on estimating sediment delivery
- Models available

- Empirical vs physical
- Empirical:
 - 1. WARSEM/SEDMODL
 - 2. USLE/RUSLE
 - 3. ROADMOD
 - 4. STJ-EROS road submodel (from US Virgin Islands application)
- Physically-Based:
 - 1. WEPP
 - 2. KINEROS2 (not developed for roads)
 - 3. G-UH/CA-KW (event based, with many simplifying assumptions, also from US Virgin Is. applic.)
- Major differences include...

Scoping Proposal Options

(these aren't full fledged options, just modeling aspects that could be incorporated into options)

- It would seem that we can set priorities for the questions we want the RFPs to address. So, arraying the questions and taking a hard look at each could be our core product in this.
- Use a model to estimate likelihood of connectivity to focus sampling effort
- Use an uncalibrated model to estimate relative sediment delivery
- Use a calibrated model to estimate relative sediment delivery
- While in the field, I do support taking all the relevant data we can, as Dube did, and characterizing the connections thoroughly. I am especially interested in an estimate of the "unconnectability" of any given road segment. Needs discussion.

References

Black, T.A.; Cissel, R.M.; Luce, C.H. 2012. The Geomorphic Road Analysis and Inventory Package (GRAIP) Volume 1: Data Collection Method. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. <https://doi.org/10.2737/rmrs-gtr-280>

Cissel, R.M.; Black, T.A.; Schreuders, K.A.T.; Prasad, A.; Luce, C.H.; Tarboton, D.G.; Nelson, N.A. 2012. The Geomorphic Road Analysis and Inventory Package (GRAIP) Volume 2: Office Procedures. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. <https://doi.org/10.2737/rmrs-gtr-281>

Dubé, K., Shelly, A., Black, J., and Kuzis, K. 2010. Washington road sub-basin scale effectiveness monitoring first sampling event (2006-2008) report. Cooperative Monitoring, Evaluation and Research Report CMER 08-801. Washington Department of Natural Resources. Olympia, Washington.

Dubé, K.; Black, T.; Luce, C.; Riedel, M. 2011. Comparison of road surface erosion models with measured road surface erosion rates. NCASI Technical Bulletin. pp. 1–58. https://www.researchgate.net/publication/287523411_Comparison_of_road_surface_erosion_models_with_measured_road_surface_erosion_rates

- WEPP, GRAIP, and SEDMODL2

Fu, B.; Newham, L.T.H.; Ramos-Scharrón, C.E. 2010. A review of surface erosion and sediment delivery models for unsealed roads. *Environmental Modelling & Software*. 25(1): 1–14.
<https://doi.org/10.1016/j.envsoft.2009.07.013>

- compared several empirical and physically-based models used to estimate sediment inputs to streams from roads. A good place to start for our task.
- Note that the GRAIP method was not included in the review. Black et al. 2012 and Cissel et al. 2012 present the approach and methods of the early GRAIP road inventory and sediment delivery estimation methods.

Hynes, H.B.N. 1975. The stream and its valley. *Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen* 19:(1): 1-15.

Hooke, J., & Souza, J. 2021. Challenges of mapping, modelling and quantifying sediment connectivity. *Earth-Science Reviews*, 223, 103847.

James, W., Rossman, L., James, R., 2010. User's Guide to SWMM5.
<https://www.chiwater.com/Files/UsersGuideToSWMM5Edn13.pdf>

Kastridis, A. 2020. Impact of forest roads on hydrological processes. *Forests*, 11(11), 1201.

MacDonald, L. H., and Coe, D. B. 2008. Road sediment production and delivery: processes and management. In *Proceedings of the first world landslide forum, international programme on landslides and international strategy for disaster reduction* (pp. 381-384). Tokyo, Japan: United Nations University

Najafi, Saeed, Deirdre Dragovich, Tobias Heckmann, and Seyed Hamidreza Sadeghi. 2021. Sediment connectivity concepts and approaches. *Catena* 196 (2021): 104880.

Reeves, G.H, Hohler, D.B., Larsen, D.P., Busch, D.E., Kratz, K. Reynolds, K., Stein, K.F., Atzet, T., Hays, P., and Tehan, M. 2004. Effectiveness monitoring for the aquatic and riparian component of the Northwest Forest Plan: Conceptual framework and options. *USDA Forest Service General Technical Report PNW-GTR-577*, Portland, OR. 84pp.

Seaber, P. R., Kapinos, F. P., & Knapp, G. L. 1987. Hydrologic unit maps (Vol. 2294, p. 1987). Washington, DC, USA: US Government Printing Office.
https://pubs.usgs.gov/wsp/wsp2294/pdf/wsp_2294.pdf

Skaugset, A.E.; Surfleet, C.G.; Meadows, M.W.; Amann, J. 2011. Evaluation of Erosion Prediction Models for Forest Roads. *Transportation Research Record: Journal of the Transportation Research Board*. 2203(1): 3–12. <https://doi.org/10.3141/2203-01>

- Washington Road Surface Erosion Model (WARSEM); Sediment Model 2 (SEDMODL2); WEPP:Road, an interface for the Water Erosion Prediction Project Model; and the revised universal soil loss equation (RUSLE)

USDA Forest Service (USFS). 2011. *Watershed Condition Framework: A framework for assessing and tracking changes to watershed condition*. USDA Forest Service FS-977, Washington DC. 34 pp.

Monitoring/measurement techniques: Roads

The monitoring techniques and procedure in Dube' et al are comprehensive. I've only found a few that might augment these. They include:

Rex, J. F., & Peticrew, E. L. (2011). Fine sediment deposition at forest road crossings: an overview and effective monitoring protocol. *Sed. Transport Aquatic Environ*, 5, 89-122.

Describes techniques for measuring and monitoring sediments contributed to streams at road crossings by measuring sediment load immediately above and below the crossing. Notes that roads contribute sediment when under construction and with seasonal variation. Seems not to address the fact that construction of a bridge with abutments, may influence sediment deposition downstream.

Techniques include:

- monitoring a variety of stream channel morphologies where there were crossing, including pools, riffles and rapids.
- characterizing streambed morphologies, including pebble/cobble sizes and distributions
- Measuring water depth and velocity and stream gradient
- Use of modified McNeil corer, gravel buckets, and infiltration bags to measure/trap transported sediment.
- Sample size determined using coefficient of variation approach.

Recognized that gradient of the roads approaching the crossings was an important factor. but did not specifically monitor for this. Should be considered!

Brown, K. R., Aust, W. M., & McGuire, K. J. (2015). Monitoring sediment production from forest road approaches to stream crossings in the Virginia Piedmont.

Techniques include:

- use sediment traps to measure annual rates of sediment delivery from forest road approaches to stream crossings due to road reopening in the Virginia Piedmont,
- compare sediment delivery rates of reopened bare road approaches with existing graveled road approaches

- Sediment traps were constructed in-stream downstream from the road crossing. These extended across the entire stream. At the same time, sediment traps were placed across the road surfaces upslope from the stream crossing. These were monitored during periods of high streamflows to determine maximum transport by both road and stream.
- This study focused on reopening "legacy" roads that had not been used for some time and were vegetated.

Kahklen, K. (2001). A method for measuring sediment production from forest roads. Res. Note PNW-RN-529. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. 17 p, 529.

Focuses on delivery of fine sediment from forest roads to streams.

Site selection criteria included:

- preference for uniform road gradient where it approaches the stream
- To quantify the sediment produced primarily from the road surface, the road section should have cut slopes and a ditch with stable, erosion-resistant surfaces. Hence does not include sediment delivery from ditches!!!
- Required minimal interceptions of groundwater by the road ditches.
- Road segment monitored should be typical of most roads in the area.

Techniques and equipment included:

- Rain Gauge: A 15.2-centimeter diameter tipping bucket rain gage with a 0.25-millimeter bucket is connected to the data logger, which records total rainfall for 15-minutes. Gauge manufacturer, Unidata,
- Traffic counters
- Parshall flume and hydrostatic pressure transducer.
- Suspended sediment samples were collected by using American Sigma pumping samplers, which have a microprocessor with the necessary software programs to setup a sampling scheme.
- Sediment from the road is channeled into the ditch just above the stream. Sedimentation from the road surface is measured there.
- Measurements collected after rainfall events.

FIELD MEASUREMENTS AND DETERMINATIONS FOR ROAD-STREAM HYDROLOGIC CONNECTIVITY

MJFuniss. March 31, 2025

Dube et al.

Dubé, Kathy, et al. "Washington Road Sub-basin Scale Effectiveness Monitoring First Sampling Event (2006–2008) Report." Department of Natural Resources, State of Washington 102 (2010).

The document by Dube et al., titled Washington Road Sub-Basin Scale Effectiveness Monitoring First Sampling Event (2006-2008) Report, outlines several field measurements used in their study. These measurements were designed to evaluate the effectiveness of road management practices under Washington State forest regulations. Below is a summary of the field measurements employed:

Field Measurements Used in the Study:

1. Road Length and Connectivity:
 - Total road length delivering to streams per unit area.
 - Percent of road network hydrologically connected to streams.
2. Road Surfacing and Traffic Levels:
 - Percent of delivering road network by surfacing type.
 - Percent of road network categorized by traffic level.
3. Cutslope and Drainage Features:
 - Percent of road network by cutslope cover category.
 - Percent of drainage points categorized by connectivity class.
4. Rutting and Erosion Indicators:
 - Percent of delivering road length categorized by rutting severity.
 - Miles of delivering road with ruts interfering with drainage.
5. Sediment Delivery and Hydrology Metrics:
 - Sediment delivered per year per mile of stream.
 - Miles of delivering road per mile of stream (used to assess hydrology performance targets).
6. Road Density and Sediment Yield:
 - Road density in sampled units.
 - Sediment production estimates for roads in sample units.
7. New Roads Evaluation:
 - Characteristics and potential impacts of newly constructed roads.

These measurements were collected across 60 randomly selected four-square-mile sample units in Washington State between 2006 and 2008, focusing on roads subject to the Forest Practices Rules. The data aimed to assess compliance with performance targets for hydrology and sediment delivery as outlined in the Forests & Fish Report (FFR).

GRAIP field Measurements Used in Ajay Prasad's Thesis

Prasad, A., (2007), "A Tool to Analyze Environmental Impacts of Roads on Forest Watersheds," MS Thesis, Civil and Environmental Engineering, Utah State University.

The thesis titled **A Tool to Analyze Environmental Impacts of Roads on Forest Watersheds** by Ajay Prasad (2007) details several field measurements and analyses conducted to evaluate the environmental impacts of forest roads. Below is a structured list of the field measurements and derived parameters used in the study, formatted for MS Word with proper indentation:

Field Measurements and Derived Parameters

1. Road Inventory Data

- Road segment attributes, including slope, length, and surface condition.
- Flow path vegetation characteristics for each road segment.
- Drain point locations and associated attributes.

2. Digital Elevation Model (DEM) Analysis

- DEM-derived overland flow directions.
- Terrain slope and stability indices derived from DEM data.

3. Sediment Production Metrics

- Sediment production calculated for each road segment based on:
 - Slope.
 - Length.
 - Road surface condition.
 - Flow path vegetation.
 - Accumulation of sediment production at each drain point.

4. Erosion Sensitivity Index (ESI)

- ESI calculated using:
 - Slope at each drain point.
 - Contributing road length draining to each point.
 - Prediction of gully formation based on ESI values.

5. Slope Stability Analysis

- Specific discharge due to road drainage calculated as an input for slope stability modeling.
- Stability Index Map created using terrain slope and specific discharge.

6. Stream Crossing and Fish Habitat Fragmentation

- Identification of stream crossings using GIS tools.

- Assessment of potential fish passage barriers at stream crossings.
- Habitat segmentation analysis based on stream crossing blockages.

7. Mass Wasting Potential Analysis

- Evaluation of potential mass wasting events triggered by road drainage.

8. Validation and Comparison

- Comparison of sediment production and erosion sensitivity predictions with observed gully formations at surveyed drain points.

These measurements were integrated into a GIS-based toolset called GRAIP (Geomorphic Road Analysis and Inventory Package) to analyze the environmental impacts of roads in forested watersheds. The study also included validation against existing USDA Forest Service methods for road impact analysis.

Overview of GRAIP (<https://research.fs.usda.gov/rmrs/projects/graip>)

The construction and use of forest roads can have a significant negative impact on geomorphic processes and erosion patterns in forested basins. To analyze this impact, the Tarboton Group and the USDA Forest Service (USFS) developed the GRAIP (Geomorphologic Road Analysis and Inventory Package) process. Charles Luce and Thomas Black of the Forest Service developed much of the theory and the road inventory based approach which forms the foundation of GRAIP. Most of the work on the GRAIP tools was done by Ajay Prasad as his MS project with significant revisions and updates by Kim Schreuders, both under the supervision of David Tarboton. GRAIP is designed to help forest managers effectively manage road and road drainage systems and hence minimize the negative impacts of forest roads.

The GRAIP process begins by creating a detailed road inventory using GPS (Global Positioning System) based surveys. Then, a GRAIP analysis uses a number of GIS tools including the GRAIP tools along with a DEM (Digital Elevation Model) to derive environmental impact information from this inventory.

The GRAIP analysis begins by using the GRAIP Preprocessor, a standalone application, to review the road inventory data for inconsistencies, document the inconsistencies, adjust and filter the data, and then builds the GRAIP database and the consolidated drain point and road shapefiles. This process ensures a minimum data quality and allows the data to be represented in a structured format that is more suitable for analysis.

The remainder of the analysis is performed using a number of tools including the GRAIP Toolbar, an ArcGIS 9.1/9.2 toolbar, that performs the heart of the analysis. In addition, a GRAIP analysis uses ArcGIS 9.1/9.2, TauDEM, Hawth's Tools and SINMAP2.0.

In terms of the field/empirical determination of the inputs of sediment from roads, this is well described by several research efforts, most notably by Luce and Black and others, and by MacDonald and others. Some references are linked below:

<p>[PDF] Road sediment production and delivery: processes and management</p> <p>LH MacDonald, DBR Coe - Proceedings of the first world landslide ..., 2008 - coast.noaa.gov</p> <p>... road sediment production from surface erosion and landsliding; 2) compare road sediment ... potential off-site effects of road-related sediment from surface erosion and mass movements...</p> <p>☆ Save Cite Cited by 69 Related articles All 5 versions »»</p>	<p>[PDF] noaa.gov</p>
<p>Modelling road surface sediment production using a vector geographic information system</p> <p>DM Anderson, LH Macdonald - Earth Surface Processes and ..., 1998 - Wiley Online Library</p> <p>... that unpaved roads are the largest sediment source on St ... road surfaces were used to establish an empirical relationship to predict annual road surface erosion as a function of road ...</p> <p>☆ Save Cite Cited by 102 Related articles All 11 versions</p>	<p>[PDF] colostate.edu</p>
<p>Runoff and road erosion at the plot and road segment scales, St John, US Virgin Islands</p> <p>LH MacDonald, RW Sampson... - ... Surface Processes and ..., 2001 - Wiley Online Library</p> <p>... The goal of this project was to quantify the effect of unpaved roads on runoff and sediment production on St John, and to better understand the key controlling factors. To this end runoff ...</p> <p>☆ Save Cite Cited by 218 Related articles All 10 versions</p>	<p>[PDF] colostate.edu</p>
<p>Reductions in road sediment production and road-stream connectivity from two decommissioning treatments</p> <p>G Sosa-Pérez, LH MacDonald - Forest Ecology and Management, 2017 - Elsevier</p> <p>... Unpaved forest roads can be an important source of sediment to streams. Road decommissioning ... the effects of key variables on road sediment production before decommissioning; (2) ...</p> <p>☆ Save Cite Cited by 54 Related articles All 9 versions</p>	<p>[PDF] sciencedirect.com</p>
<p>Runoff and suspended sediment yields from an unpaved road segment, St John, US Virgin Islands</p> <p>..., LH MacDonald - ... : An International Journal, 2007 - Wiley Online Library</p> <p>... sediment production from a mostly unpaved road segment ... sediment rating curves to predict sediment yields; and (4) compare the predicted sediment yields against predicted sediment ...</p> <p>☆ Save Cite Cited by 110 Related articles All 13 versions</p>	<p>[PDF] researchgate.net</p>
<p>Measurement and prediction of sediment production from unpaved roads, St John, US Virgin Islands</p> <p>..., LH MacDonald - Earth Surface Processes ..., 2005 - Wiley Online Library</p> <p>... : (1) measure sediment production rates at the road segment ... on road sediment production; (3) develop an empirical road ... Sediment production from 21 road segments was monitored ...</p> <p>☆ Save Cite Cited by 152 Related articles All 14 versions</p>	<p>[PDF] uvi.edu</p>