Document 4c

Road-stream connectivity methods ideas for scoping proposal

For the 14 March 2025 IRST meeting

Methods idea 1

This method

☒ **follows Dubé** ☐ modified Dubé (plus sampling framework) ☐ is a modeling effort

☐ is another option:

This method pertains to

☐ water ☒ **"water plus"**

General description of the method

The Dubé methods in terms of data that is collected, definition of hydrologic connectivity at sample sites is strong and seems to continue to align with current understanding of hydrologic connectivity of roads. There are two elements that could be improved:

1) The sample design is does not reflect integration of modern techniques, and may reflect the absence of available and accurate road networks. Although accurate road networks on private timber lands is still outstanding, road networks derived with LiDAR imagery might be an avenue to developing a more comprehensive road layer to facilitate better representative road sampling designs. I am unfamiliar with methods that could be used for this, but I think that others on the IRST have expertise in this regard. Once a reasonably reliable road network is available, then a sample design could be developed to inventory roads could be developed. A stratified random design would likely be useful, with stratification based on road location in relation to streams as one possible stratification criteria (e.g., roads in floodplains/roads within 200 feet of a stream, etc). It could also be informative to include stream order as a stratification criteria, allowing characterization of roads with connectivity in headwaters (e.g. Strahler stream order 1), compared with larger rivers (e.g. Strahler stream orders 3-5).
2) Hydrologic connectivity inventoried by Dubé appears to be founded on proximity to stream channels as well as road characteristics. However, it may be that road features such as slope confer connection differently during low compared to high precipitation events. Climate is changing, and an anticipated (and already experienced) change is the intensity of winter storm events is under way. Expanding the scope of the inventory to understand hydrologic connectivity during different types of storm events could help in tracking road/hydrology connection in Oregon over time. As the frequency and intensity of peak events change in the future, so too may the vulnerability of roads. Additional research that could inform the IRST in considerations of seasonal storm event intensity and how that changes aspects of hydrologic connectivity for roads could be useful.

Feasibility or practicality of the method

A different sampling design that relies on a road network is feasible. It may not be practical since there are essentially two project needs. One would be the development of the road network, and then the classification of the road network to quantify hydrologic connectivity.

Pros and Cons of the method

Pros – a rigorous definition the population of interest (e.g., forest roads) would allow for long term monitoring from a solid foundation.

Cons – there is not an accurate road layer currently available.

Sampling frame – how it is structured (pluses and minuses)

Sampling frame is described in methods, and mostly relates to better defining the population of interest (forest roads) and then using a stratified random design to select representative locations for monitoring.

Field methods – what do you gather when you go to the field

Field methods would align with Dubé .

Estimated cost

☐ $ ☐ $$ ☒ **$$$**

References

Dubé, K., A. Shelly, J. Black, and K. Kuzis. 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.

Methods idea 2

This method

☐ follows Dubé ☒ **modified Dubé (plus sampling framework)** ☐ is a modeling effort

☐ is another option:

This method pertains to

☐ water ☒ **"water plus"**

General description of the method

Assumption that this is a statewide study on private forested lands.

- Because the bottom line of the PFA is the effect of roads on "species of concern" (salmonids and amphibians) this evaluation of road-stream connectivity would first identify "Stream segments of concern"--the habitats for the species of concern.
- Consider rating critical vs non-critical sites along streams and relation to roads: eg: gravels for redds, pools for resting, influence on cold-water seeps and other refugia that are mapped/known.

- From this population of watercourses, it would choose either randomly or by some specific criteria--at least six sampling/modeling drainages that represent disparate geographies/ecoregions of Oregon, preferably an equal number from East-side and West-side.

- These geographies (biogeoclimatic zones) should include the Klamath Mountains, Coast Range, Western Cascades, East slopes of the Cascades, Blue Mountains, Columbia River Gorge, and High Desert (Burns/Silvies area, for example, though species of concern are not present in this regional ecosystem as far as I know.)

- Road type and density in sub-basins connected to mainstem stream could be measured and characterized in a manner similar to Dubé , et al 2004, or could be determined in part by LiDAR.

- Road traffic and its effects on road surfaces could be included in the data.

Feasibility or practicality of the method

- Similar to Dubé , and could produce a model.

- Relies on fewer sites than Dubé , et al.

- Samples across different ecosystems ad forest types.

Pros and Cons of the method

- provides physical evidence, data re both water and sediment erosion from roads, and likely input to streams. It would be interesting to determine temperature of road-derived water as one component of input to streams.

- Connects road study to potential inputs to important habitats.

- employs graduate /undergraduate students

- Time consuming.

- Requires travel and/or stationing team members in multiple locations acrross the state to ensure timely data collection.

- Not the most cost-efficient method.

Sampling frame – how it is structured (pluses and minuses)

- Sampling framework would be smaller than Dubé , et al.

- But study would be more easily relatable to habitat.

- Study could be designed to samples with relatively similar substrates (as much as possible)

- LiDAR could be applied to choose basins with similar (or dissimilar) road segment lengths and slopes.

- Framework here relies on physically collecting data. This data could then be applied to construct a model that may include effects of roads on regional ecosystems/species of concern, and methods recommended for hydrologic disconnection.

Field methods – what do you gather when you go to the field

- Site-specific precipitation data: dates, duration, quantity of rainfall.
- Snow pack, snow-melt, contribution to road run-off.
- Road segment data: slope, road surface and erodibility, tread, ditch configuration and condition, road-adjacent wetland (salamander) habitat where appropriate, sites of connection to stream.
- For some steep road segments, and other segments of concern, where water and sediment may enter the stream, video or other remote monitoring/recording might be used?
- Runoff of both sediment and water could be captured in catchments adjacent to the stream before these materials enter the stream. These could be made impermeable and measured and then cleaned after each major/significant storm event. at each site.(Labor-intensive)
- Connect study to real-world potential effects on known habitat of species of concern.

Estimated cost

☐ $ ☐ $$ ☒ **$$$**

References

Dubé, et al, 2004.

Freeman, M. C., Pringle, C. M., & Jackson, C. R. (2007). Hydrologic connectivity and the contribution of stream headwaters to ecological integrity at regional scales 1. *JAWRA Journal of the American Water Resources Association*, *43*(1), 5-14

Pringle CM (2003) What is hydrologic connectivity and why is it ecologically important? Hydrol Process 17(13):2685–2689

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

Methods idea 3

This method

☐ follows Dubé ☒ **modified Dubé (plus sampling framework)** ☒ is a modeling effort

☐ is another option:

This method pertains to

☐ water ☒ **"water plus"**

General description of the method

A watershed-based sampling approach to collect field data for hydrologic connectivity – coupled if desired with a sediment model

Feasibility or practicality of the method

High

Pros and Cons of the method

Pro - Driven by aquatic resources rather than roads; takes advantage of newer methods; allows more targeted field sampling

Cons – requires an accurate road map for sampled watersheds

Sampling frame – how it is structured (pluses and minuses)

5th / 6th field watersheds; eliminate those containing less that contain a specified threshold of private lands; select a sample of watersheds; develop a road layer from LIDAR for these watersheds; overlay the road layer with the ODF stream layer; identify a sample of roads that fall within a specified distance of a stream for field sampling. Separate sampling frames for eastern and western Oregon. Need to ensure enough small forest landownerships are included in the sample of watersheds – could do this a priori or post hoc.

Field methods – what do you gather when you go to the field

For water: identify road surface type, indications of surface connection to the stream, type of road connected feature (ditch, crossing, surface); distance between road and stream

For sediment: whatever is required to run the desired sediment model, which will likely be a more modern than WARSEM (e.g., GRAIP or GRAIP-lite)

Estimated cost

☐ $ ☒ **$$** ` ☐ $$$

References

Methods idea 4

This method

☐ follows Dubé ☒ **modified Dubé (plus sampling framework)** ☐ is a modeling effort

☐ is another option:

This method pertains to

☐ water ☒ **"water plus"** (can add sediment)

General description of the method

The study design could use a stratified random approach to select large watersheds that are lands primarily under the direction of the PFA as the unit of replication. Using existing GIS information, stratification could occur on PFA landowner type as a continuous variable (e.g., % of watershed that are small landowners or % of watershed that are large landowners), geographic region (west vs. east), road-stream crossings, etc.

Within watersheds, forest road segments would be selected for direct sampling of characteristics that may affect hydrologic connection. A subset of watersheds could receive continuous sampling whereas others could be resampled on a 5-year interval to assist with trend development. These data would be used to understand the metrics impacting hydrological connectivity, develop qualitative information to guide future road improvements, and to integrate into erosion prediction models (e.g., WARSEM, WEPP, etc).

Feasibility or practicality of the method

This method should be feasible as it generally follows Dubé, but allows for a watershed approach rather than blocks, integration of more continuous variables, and opportunities for spatial modeling of erosion and sediment delivery as potential outcomes of hydrological connectivity.

Pros and Cons of the method

Pro: Using the watershed as the unit of replication allows for strong connections to the biological goals and objectives.

Pro: Incorporating models allow for variability associated with precipitation events of different intensities and sizes.

Pro: Field measures could incorporate additional data sampling dependent on specific goals, budgets, and logistics. For example, roads/streams could newer technologies, such as (1) UAV sampling to develop high-resolution, 3-D models of road prisms, (2) remote cameras to detect changes in turbidity in a stream, or (3) incorporating Smart Rock technologies to monitor related metrics.

Con: Requires accurate GIS layers of roads and streams, which may vary based on region and landowner.

Con: Selecting watersheds across a range of variables will be challenging.

Sampling frame – how it is structured (pluses and minuses)

Metrics: Miles of delivering road/miles of stream would be quantified via field measures and Tons of delivered sediment/year/miles of stream would be estimated via models.

Field methods – what do you gather when you go to the field

Factors to record for road segments and stream crossings include: a description of connectivity (e.g., figure below from Croke and Hairsine 2006), delivery pattern, road surface, length of connected road, stream type and size, traffic use, presence of grading and rutting, interception of cutbank sub-surface flow, distance between runoff point and waterbody, length of road abandonment, hillslope gradient and number of obstructions, volume of flow and erosion from road, quality of stream crossing (i.e., is a culvert installed correctly), frequency and effectiveness of water diversion structures (i.e, cross drains or crossings).

Smart Rocks or turbidity sensors could be used to examine model predictions of erosive potential for specific areas.

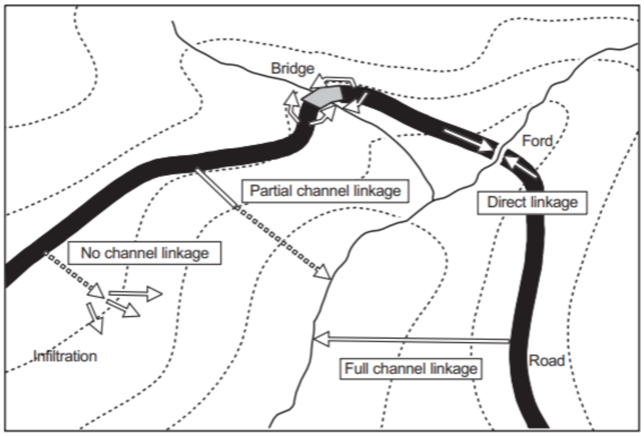
Estimated cost

☐ $ ☒ **$$** ☐ $$$

References

Croke, J.C. and P.B. Hairsine. 2006. Sediment delivery in managed forests: a review. Environmental Reviews 14: 59-87.

Fig. 5. The range of potential connectivity categories for a road. The fully connected segments are drained by a gully that has become part of the stream network; the partially connected segments are drained by a gully that stops prior to joining the stream network, direct connectivity as occurs at a bridge or ford where there is no hillslope between the road and the stream network. Where no gully or channel exists below a road drainage feature then the overland flow may be partly or fully dispersed, thus limiting or eliminating the connectivity.



Question:

The Effectiveness Monitoring portion of the Roads Study is meant to quantify hydrological disconnection through implementation of FRIA. From: [ODF's Forest Practices Technical Guidance Forest Road Inventory and Assessment]

"The FRIA requirements established in OAR 629-625-0900 apply to all landowners that do not qualify as a small forestland owner as defined in OAR 629-600-0100. Government owned or controlled roads that pass-through private forestland owners' property are not required to be included in the FRIA (OAR 629-6250900(4)). Private to private forest road ownership should generally follow the same framework. The underlying landowner should include all segments and crossings in their FRIA, unless there is an adjacent landowner with majority control of the road, then the adjacent landowner should include it in their road assessments. All roads within a landowner's property that are used to access forestland are required to be included in the FRIA. This includes roads that are not used for harvest activities (Table 1) and excludes roads that are owned or controlled by a government entity such as the United States, and federally recognized Indian Tribes. This technical guidance allows landowners to utilize their existing road data management system as well as other systematic methods to inspect roads and survey lands within their ownership network."

Thus, should the study design be aligned with the road systems covered by FRIA and exclude small landowners defined in rule as >10 acres but <5,000 acres, and government owned or controlled roads?

Study in an ideal world is designed around performance targets (miles/road, tons, etc) but those are not yet developed.

Methods idea 5

This method

☐ follows Dubé ☒ **modified Dubé (plus sampling framework)** ☒ is a modeling effort

☐ is another option:

This method pertains to

☐ water ☒ **"water plus"**

General description of the method

Existing methods to characterize the hydrologic connectivity of forest roads tend to rely on field-based methods for the delineation of road segments, including length, width, slope, configuration, and hydrologic connectivity. The emergence of high-resolution topography provides an opportunity to map and identify road geometry and drainage patterns remotely and thus inform field-based observations and inventories across expansive areas. The ability of lidar to accurately represent flowpaths at sub-meter scales is well-tested. For example, previous studies using lidar-derived flow accumulation maps have shown that road drainage can contribute to shallow landslide generation by the addition of excess runoff into topographic hollows or headwalls. Generating road segments and topographic attributes from lidar data would enable the identification of road segments for field assessment of hydrologic connectivity. More generally, automated classification schemes have the potential to objectively splice up the road network into segments based on metrics used in traditional schemes (Dubé, 2010) for subsampling and field observation.

The methodology for mapping roads with lidar is under development and dozens of papers address the utility of lidar to generate accurate and reproducible forest road networks in areas with and without canopy. In this sense, lidar provides an effective way to not only map active roads but also abandoned or unserviceable roads where vegetation has overtaken the surface.

In summary, the use of high-resolution topographic data to: 1) identify and inventory forest roads, 2) generate road segments and basic topographic properties, and 3) map locations of potential hydrologic connectivity, has much potential to improve and focus field work and sampling design for characterizing the hydrologic connectivity of forest roads.

Feasibility or practicality of the method

The use of lidar to map, inventory, and identify key locations in road networks for field assessment has become much more feasible with the proliferation of publicly available lidar data. Vast areas can be readily mapped in a short amount of time and numerous algorithms exist for extracting road segment properties.

Pros and Cons of the method

Pros: efficient, vast areas can be covered, a greater proportion of the road network can be sampled or characterized, lidar data is more and more available,

Cons: new protocols and training would need to be developed, culverts and sub-surface drainage features are not well expressed, approach and algorithms are under development,

Sampling frame – how it is structured (pluses and minuses)

Mapping and hydrologic analysis of road networks would be combined in GIS with stream networks to identify potential points of connectivity.

Field methods – what do you gather when you go to the field

Field crews would test lidar-derived maps and road segment properties and focus on identifying locations of connectivity. A similar study design scheme as proposed by Dubé 2010 could be used but sampling locations could prioritize road-stream intersections and areas where road flowpaths have potential to enter the stream network.

Estimated cost

☐ $ ☒ **$$** ` ☐ $$$

References

White, R.A., Dietterick, B.C., Mastin, T., Strohman, R., 2010. Forest Roads Mapped Using LiDAR in Steep Forested Terrain. Remote Sensing 2, 1120–1141. https://doi.org/10.3390/rs2041120

Kiss, K., Malinen, J., Tokola, T., 2015. Forest road quality control using ALS data. Can. J. For. Res. 45, 1636–1642. https://doi.org/10.1139/cjfr-2015-0067

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Pradhan, B., Ibrahim Sameen, M., 2020. Road Geometric Modeling Using Laser Scanning Data: A Critical Review, in: Pradhan, B., Ibrahim Sameen, M. (Eds.), Laser Scanning Systems in Highway and Safety Assessment: Analysis of Highway Geometry and Safety Using LiDAR. Springer International Publishing, Cham, pp. 15–31. https://doi.org/10.1007/978-3-030-10374-3_2

Waga, K., Malinen, J., Tokola, T., 2020. A Topographic Wetness Index for Forest Road Quality Assessment: An Application in the Lakeland Region of Finland. Forests 11, 1165. https://doi.org/10.3390/f11111165

Even, P., Ngo, P., 2021. Automatic Forest Road Extraction from LiDAR Data of Mountainous Areas, in: Lindblad, J., Malmberg, F., Sladoje, N. (Eds.), Discrete Geometry and Mathematical Morphology. Springer International Publishing, Cham, pp. 93–106. https://doi.org/10.1007/978-3-030-76657-3_6

Jones, K.L., Poole, G.C., O'Daniel, S.J., Mertes, L.A.K., Stanford, J.A., 2008. Surface hydrology of low-relief landscapes: Assessing surface water flow impedance using LIDAR-derived digital elevation models. Remote Sensing of Environment, Applications of Remote Sensing to Monitoring Freshwater and Estuarine Systems 112, 4148–4158. https://doi.org/10.1016/j.rse.2008.01.024

Methods idea 6

This method

☐ follows Dubé ☐ modified Dubé (plus sampling framework) ☐ is a modeling effort

☒ **is another option:**

This method pertains to

☐ water ☒ **"water plus"**

General description of the method

Assess the potential benefit of using the USFS Geomorphic Road Analysis and Inventory Package (GRAIP) for implementation. Combined with the GRAIP_Lite protocol, these tools are streamlined and efficient and supported by research at the Rocky Mountain Research Station.

Feasibility or practicality of the method

Well utilized

Pros and Cons of the method

Pros: frequently used

Cons: new and somewhat different

Sampling frame – how it is structured (pluses and minuses)

Field methods – what do you gather when you go to the field

Estimated cost

☐ $ ☐ $$ ☐ $$$

References

https://research.fs.usda.gov/rmrs/projects/graip

https://research.fs.usda.gov/rmrs/projects/graiplite

Preamble to methods ideas 7 & 8

This is a useful start, but picking methods seems premature now and not well advised for a science team.

We should first establish the "**requirements**" for any methods to be evaluated. Without an agreed-to set of requirements, we may all be working on something different and we have skipped an essential step.

- What are the desired endpoints? What do we need to know and how bad do we need to know it?
- What are the primary and secondary (if any) needed information, and how does that fit into an interpretive and reporting framework?
- What are the relative costs in time, personnel, and coordination?
- Is modeling of erosion and sedimentation needed? Why?
- What are the options for sampling?
- How does the sampling approach relate to a full implementation approach (all roads inventoried for RSHC and potential remediation).
- Does the method inform the setting of priorities for remediation? Is priority-setting needed if all roads are to be evaluated and remediated to the extent practical?
- Are there benefits to a coarse/larger scale remote sensing effort to stratify watersheds, set up sampling, and possibly set priorities?
- Is the method to identify RSHC alone, or also identify remediable stream segments, predict sediment inputs, and attempt to distinguish the degree of RSHC?
- Should the method be integrated with other road information needs, such as Aquatic Organism Passage, diversion potential at stream crossings, landslides?
- And so on

In the "definition discussion, I listed a few design criteria (but not a detailed requirements document) but we did not have time to discuss these at all:

1. Simple and easy to understand
2. Observable in the field without specialized expertise or instrumentation (but training OK)
3. Tied to and reported by identifiable road segments (drainage reaches) and drainage areas, such as in Dubé et al. 2010)
4. It is usually a binary determination (connected or not), but can it accommodate nuances (such as almost connected?)?
2. Straight-forward field method(s) for observation, recording, data aggregation, and interpretation.
3. Helps distinguish disconnectable vs non-disconnectable segments

4. Recognizes that RSHC is strongly tied to the proximity of roads to streams and stream crossings.
5. See:https://docs.google.com/presentation/d/1TTvIX5cWIxoddZPBIvcv1qxpboBnTjzp/edit?usp=sharing&ouid=102191688941803819623&rtpof=true&sd=true
6. Data collection and reporting formats are commensurate across ownerships.
7. It is inexpensive to inventory/sample while obtaining reliable information
8. Adequately indicates the treatment area for "hydrologic disconnections."

Note: long ago, I did an informal roundup of road inventory methods. It is old and incomplete, does not include Dubé, is way behind on GRAIP, and is California biased, but provides some useful background and a sense of a range of approaches (some are not "methods" per se). Please see:
(Road_Inventory_Methods_Furniss2010.docx 2010) pasted below.

I would also point the team to this important document from 2000. Appendix 1 contains a comprehensive range of key *questions* and brief treatments related to the environmental effects of roads. https://www.fs.usda.gov/eng/road_mgt/DOCSroad-analysis.shtml
This is essentially designed to be "troubleshooting" for the ~380,000 miles of roads on the national forests of the USA.

It might be especially useful to see a roundup of all the work that WA TFW etc. did on roads, as the WA and USFS efforts may be the most comprehensive so far.

By close of business on 12 March 2025 send Lisa Gaines, one to two method ideas for the road-stream connectivity scoping proposal. Each idea should be in 1 to 2 pages. *You may wish to look at Dubé – what would you have liked it to answer that it did not answer – build off of Dubé as the foundation – could be cost and accuracy improvements.*

The analysis below should be what the scoping proposal does, informing the selection of methods to be implemented. It is unreasonable to expect the IRST- as most members (with abundant due respect) do not have expertise or experience in road inventory or interpretation and the large range of methods available, and in one week.
Why choose two? We ought to look across all existing methods and the probability of devising a new method.

That said, Dubé et al. (2010) is stellar and thorough, and may be quite adequate for a sampling approach, but expensive for broad implementation across the subject lands and could be simplified for the broad census of RSHC.

Methods idea 7

This method

☒ **follows Dubé** ☐ modified Dubé (plus sampling framework) ☐ is a modeling effort

☐ is another option:

This method pertains to

☒ **water** ☐ "water plus"

Estimated cost

☐ $ ☐ $$ ☒ **$$$**

References

Methods idea 8

This method

☐ follows Dubé ☒ **modified Dubé (plus sampling framework)** ☐ is a modeling effort

☒ is another option: Simplify to focus primarily on RSHC without erosion modeling, which is highly uncertain and not clear how it informs decision making.

This method pertains to

☒ **water** ☐ "water plus"

Estimated cost

☐ $ ☐ $$ ` ☒ **$$$**

References

Methods idea 9: Considerations

I am in favor of using the Raines et al. (2005) study design with amendments to methods made by Dubé et al. (2010). After re-reading these documents, I am struck by the amount of effort that went into their study design, and how closely their work aligns with ours. Aspects I would keep include:

1. Use of land grid for sample site selection.
2. Use of at least 60 sample areas for state-wide assessment; possibly more total sites if we study landowner class and eastside vs. westside separately.
3. Use of RLEN as primary metric for hydrologic connectivity estimates. A focus on gathering and reporting data on this metric would be our quickest and cheapest alternative.
4. Use of RSED as primary metric for sediment delivery estimates. Gathering data for this metric could be done cost-effectively during the field work for the RLEN metric, but calculation and reporting would take more time and cost more.
5. Use of the same RLEN and RSED performance metrics as done in Washington for westside and eastside.

Aspects that I would change include:

1. Sampling large and small private landowners separately
2. Use eastern and western Oregon as a priori sampling criteria, while gathering but leaving geology and other potential stratification criteria for post sampling analysis.

3. Focus sampling on road segments most likely to be hydrologically connected, vs. sampling entire road systems in the sampling areas (requires our ability to identify these; possibly using Michael's GIS ideas).

I would also propose to AMPC that there is merit in designing and implementing a research project in the near term to revise or improve performance metrics.

All of this and more I am happy to discuss with you Friday.