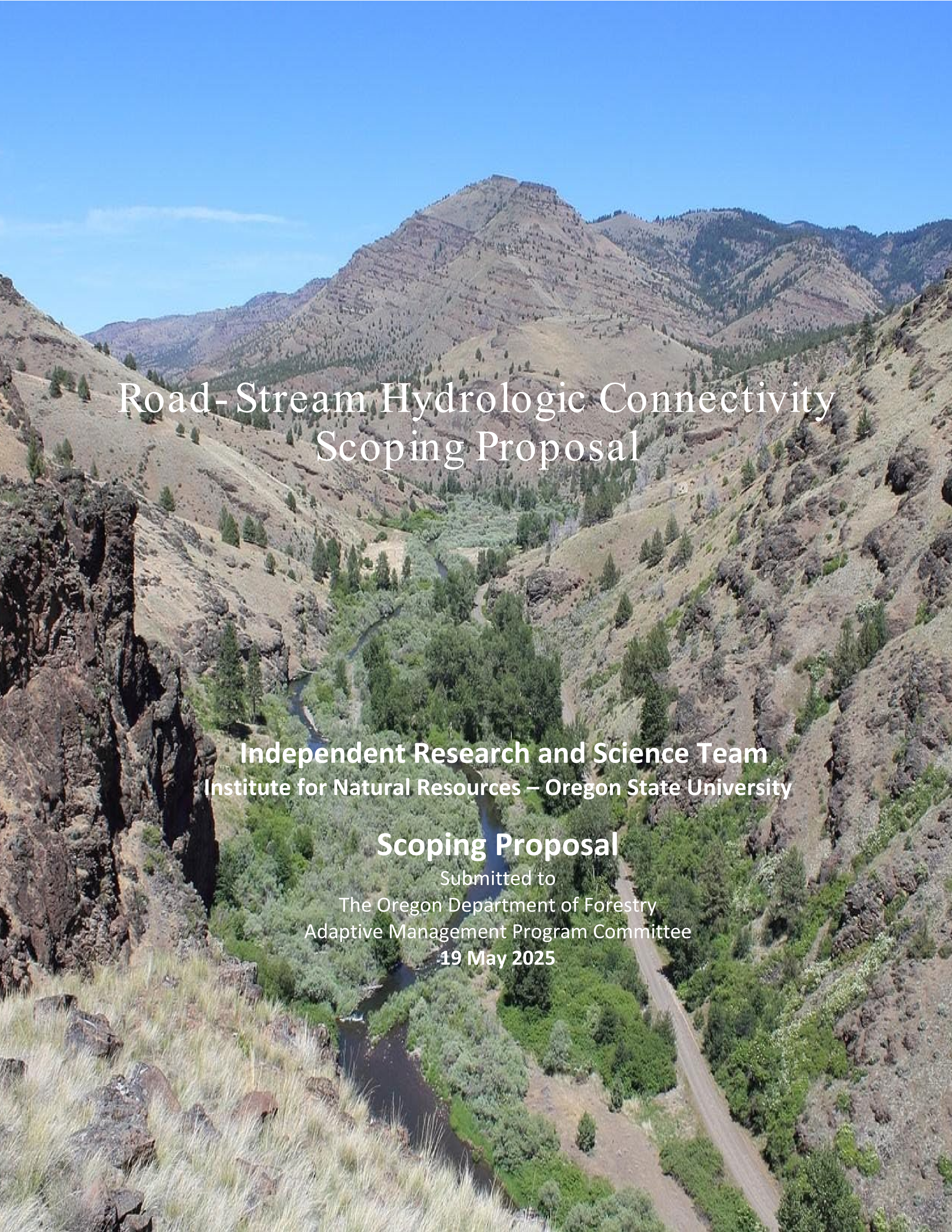

Road-Stream Hydrologic Connectivity Scoping Proposal

Independent Research and Science Team

Institute for Natural Resources – Oregon State University

Scoping Proposal

Submitted to
The Oregon Department of Forestry
Adaptive Management Program Committee
19 May 2025

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Authors

The Independent Research and Science Team

Prepared by

The Institute for Natural Resources

The Institute for Natural Resources' mission is to provide access to integrated, management-relevant information that informs discussions and decisions about the long-term stewardship of Oregon's natural resources. Institute for Natural Resources is an Oregon public universities institute located at Oregon State University and Portland State University.

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Disclaimer

This scoping proposal is submitted to the Adaptive Management Program Committee as a requirement of the Oregon Department of Forestry Adaptive Management Program rules (Chapter 629, Division 603).

The contents of this report reflect the views of the Independent Research and Science Team (IRST), which is solely responsible for the facts and accuracy of the material presented. This scoping proposal does not constitute a standard, specification, or regulation.

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Abbreviations and Acronyms

AMPC	Adaptive Management Program Committee
AQI	Aquatic Inventories Program
AREMP	Aquatic and Riparian Effectiveness Monitoring Program
BGO	Biological, Goals, and Objectives
BLM	Bureau of Land Management
BMP	Best Management Practices
CMER	Cooperative Monitoring, Evaluation, and Research
FPR	Forest Practices Rules
FRIA	Forest Road Inventory and Assessment
GIS	Geographic Information Systems
GRAIP	Geomorphic Road Analysis and Inventory Package
HCP	Habitat Conservation Plan
HUC	Hydrologic Unit Code
INR	Institute for Natural Resources
IRST	Independent Research and Science Team
ISPRC	Independent Scientific Peer Review Committee
LiDAR	Light Detection and Ranging
NMFS	National Marine Fisheries Service
OAR	Oregon Administrative Rules
ODF	Oregon Department of Forestry
OSU	Oregon State University
PFA	Private Forest Accord
PIBO	PACFISH/INFISH Biological Opinion
QA/QC	Quality Assurance/Quality Control
RCA	Road Condition Assessment
READI	Road Erosion and Sediment Delivery Index

RFP	Request for Proposals
RMAP	Road Maintenance and Abandonment Plans
RSHC	Road-Stream Hydrologic Connectivity
QA/QC	Quality Assurance/Quality Control
WARSEM	Washington Road Surface Erosion Model
WEPP:Roads	Water Erosion Prediction Project: Roads

Executive Summary

The Independent Research and Science Team (IRST) was established to support the work of the Oregon Department of Forestry Adaptive Management Program Committee (AMPC) by developing research and monitoring options in response to AMPC-developed research question packages.

The AMPC submitted the following research questions related to road-stream hydrologic connectivity (RSHC):

1. Baseline report
    a. What is the baseline status of hydrologic connectivity of roads prior to the implementation of the OFPA road rules effective Jan 1, 2024?
    b. How does the status of hydrologic connectivity differ based on landowner type and East/West region?
    c. How do particular elements of the regulatory framework (e.g., road location) or site characteristics (e.g. geology) contribute to hydrologic connectivity?
2. Trend monitoring
    a. What are the trends in the status of hydrologic connectivity of roads over 5-year intervals? These trends should be assessed for the same variables in question 1.
3. Determination of rule effectiveness
    a. Within 25 years, to what extent are road rules associated with hydrologic disconnection effective at achieving biological goals and objectives?

The biological goals and objectives referenced in Question 3 are still under development as part of the Habitat Conservation Plan (HCP), therefore this scoping proposal focuses on the baseline and trend monitoring questions (Q1 and Q2).

The IRST reviewed the literature on RSHC, emphasizing the measurement and monitoring methods relevant for answering the AMPC's research questions. The following is a brief summary of key findings from the review:

- A number of RSHC models exist but the accuracy of modeled outputs depends on the quality of road and stream data as inputs.
- Numerous site-specific factors can influence connectivity and sediment delivery, so field data collection is still needed even when models are used.
- While water and sediment contributions from roads to streams have been quantitatively monitored over small areas, monitoring over broader spatial extents, such as for the area covered by the FPA, often necessitates using simpler, qualitative estimates of connectivity and/or modeling based on a small set of road characteristics.
- Monitoring over a broad area also means that a complete census of roads is typically infeasible, so some method for selecting a statistical sample will be necessary. The Dubé et al. (2010) study in Washington selected 60 four square mile land blocks and then collected data on all road segments within these.
- A sample of sub-watersheds rather than land blocks could better link RSHC monitoring results to effects on aquatic ecosystems.

- If accurate road and stream maps are available, efficiency can be gained by a pre-survey that:
    - First identifies and then collects field data on only the road segments with a higher probability of being connected to a stream; and
    - Characterizes essential metrics of road segments from available high-resolution digital elevation models, reducing field-data collection to a small set of variables.
- Although the ultimate purpose of the road connectivity rules is to reduce impacts on aquatic habitats and organisms, measuring impacts on those endpoints specific to the new road rules is likely infeasible given the large area involved, the cryptic nature of aquatic organisms, movement into the ocean by anadromous species, and multiple other confounding factors and mixed ownership patterns. Coordinating RSHC field sampling with existing habitat and population monitoring programs, however, could help understand these linkages in the future.

Based on the results of our literature review, we provide two primary survey options: 1) assessment of only the physical hydrologic connectivity between roads and streams, and 2) assessment of connectivity with a modeled estimate of sediment delivery. In addition, we provide two pre-survey options, which could be added to test and improve the digital (GIS) road and stream data, helping to target where and what data are collected in the field. All options are summarized below (Table Ex-1).

Costs are highly dependent on the number of field sampling units. Dubé et al. (2010) determined that a sample size of 60 land blocks would provide sufficient statistical power for an accurate statewide estimate of RSHC, and so that sample size informs the lower end of our cost estimates. If AMPC desires to detect changes at the sub-state level (east/west, large/small landowners), the same number of samples would likely be required for each of these four strata, and so a four-fold increase is used as the upper bound for the cost estimates. Costs for Survey Options 1 and 2 may be reduced by implementing one or both of the Pre-survey options.

Table Ex-1. Summary of scoping proposal options, timeframes, costs, and knowledge contributions.

Option	Estimated Timeframe (months)	Cost	Knowledge Contributions
Survey Option 1: Physical Connectivity Only	36 months	$1.1-$4.4 million (for baseline sample)	• A faster and less expensive means to address the AMPC's basic question related to status and trends of RSHC than Option 2 due to less field time and data processing. • Characterizes the length of road segments identified as draining to streams by a number of measures (% of total, per stream mile, etc.) • Can inform performance targets and effectiveness of road rules at achieving BGOs related to hydrologic disconnection but less so than for Option 2
Survey Option 2: Physical Connectivity + Sediment Modeling	48 months	$1.35-5.4 million (for baseline sample)	• Takes one year longer and costs ~20% more than Option 1 but provides estimates of sediment delivery. • Outputs would include all the connectivity-only metrics listed in Option 1, plus the modeled tons of road sediment delivered to streams. • Can inform the development of performance targets and the effectiveness of road rules at achieving BGOs related to hydrologic disconnection and sediment delivery.
Pre-survey Option 1: Digital Data Accuracy Assessment)	6 months	< $10k	• Increases confidence that sampling locations selected are a relatively unbiased sample. • Reduces time and expense by limiting field data collection to road segments with a higher probability of connectivity.
Pre-survey Option 2: GIS-LiDAR Road Segmentation	8 months	$80k	• Reduces time and expense by limiting the data collected in the field on each road segment. • Improves the accuracy and consistency of road segment data.

1. Introduction

1.1 Background and Project Purpose

The Independent Research and Science Team (IRST) was established via Senate Bill 1501 as part of the Oregon Department of Forestry's Adaptive Management Program. The IRST supports the work of the Adaptive Management Program Committee (AMPC) by responding to AMPC-developed research questions packages. Per rule, and in consultation with the AMPC, the IRST refines preliminary research questions into final research questions, then develops scoping proposal(s) to address those questions. The scoping proposal(s) need(s) to include:

- A literature review that specifies the need for, or the type of, monitoring, research, commissioned studies, or other means of scientific inquiry necessary to answer the finalized research questions mentioned above;
- A preliminary estimate of the budget for each year of the research, and a timeline to complete the research project with specific deliverables; and,
- A preliminary description of research project requirements, scope of work including an estimate of the timeline and key milestones, and an estimate of the degree to which knowledge may be improved if the research proposal is implemented.

As per OAR 629-603-0200, the IRST develops requests for proposals (RFP) in an open, competitive process after the AMPC and Board of Forestry approve an AMPC research agenda that is based on IRST scoping proposal(s) (Figure 1).

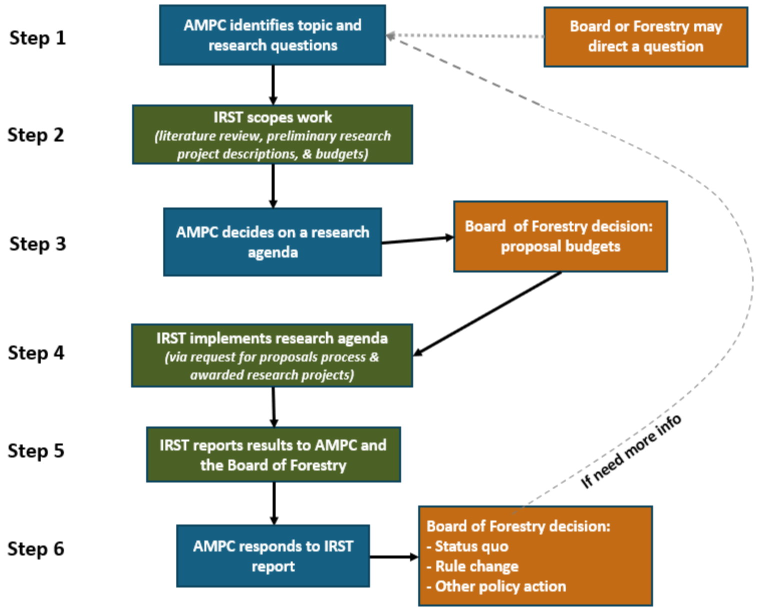

Figure 1. Adaptive Management Process.

1.2 Research questions

On June 24, 2024, the AMPC approved the finalized research questions package (Appendix A) pertaining to road-stream hydrologic connectivity (RSHC). The final questions were structured around baseline status and trend monitoring and determining rule effectiveness (Table 1).

Table 1. AMPC road-stream hydrologic connectivity research questions.

1. Baseline report	a. What is the baseline status of hydrologic connectivity of roads prior to the implementation of the OFPA road rules[1] effective Jan 1, 2024? b. How does the status of hydrologic connectivity differ based on landowner type and East/West region? c. How do particular elements of the regulatory framework (e.g., road location) or site characteristics (e.g., geology) contribute to hydrologic connectivity?
2. Trend monitoring	What are the trends in the status of hydrologic connectivity of roads over 5-year intervals? These trends should be assessed for the same variables in question 1.
3. Determination of rule effectiveness	Within 25 years, to what extent are road rules associated with hydrologic disconnection effective at achieving biological goals and objectives?

The biological goals and objectives (BGOs) referenced in question 3 are still under development as part of the Habitat Conservation Plan (HCP), therefore this scoping proposal focuses on the baseline and trend monitoring for RSHC. It is expected that further links to the BGOs will be considered by the AMPC as the HCP is finalized along with a broader effectiveness monitoring framework. However, there are potential opportunities to estimate the percentage reduction in RSHC through implementation of the OFPA Road Rules.

The Private Forest Accord Report (2022), which informed the development of HB1501 and the Adaptive Management Program, provided the following background on this request:

> *1. Baseline and Trend Monitoring for Hydrologic Disconnection: The methodology for the monitoring shall be based off of Dube et al. (2010) and Martin (2009). The purpose of the monitoring for hydrologic disconnection is to establish a baseline and to monitor and report the change in hydrologic connectivity over time as the FRIA is implemented. The overarching goal is to ensure that all forest roads and landings shall be hydrologically disconnected to the maximum extent feasible from waters of the state. The Adaptive Management Program Committee shall use the results of the baseline and trend monitoring to develop regional goals consistent with that monitoring. All hydrologic connectivity data should be public and shared as it becomes available to help focus goals, identify accomplishments, and inform statewide learning.*

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[1] A summary of relevant OFPA road rules is provided in Appendix B.

2. Literature Review

Introduction

A large body of scientific literature details the impacts of forest roads on hydrologic processes. Reviews can be found in Dubé et al. (2004), the Private Forest Accord Report (2022), and Kastridis (2020). The factors controlling how overland flow and interception of subsurface stormflow by cutbanks concentrate runoff on road surfaces and convey fine sediment and other materials to streams have been well studied using empirical and physically-based approaches. Rather than focusing on these well-studied impacts, this scoping proposal reviews relevant measurement and monitoring methods to answer the AMPC's research questions.

Assessing connectivity between roads and streams requires a standardized definition (Furniss et al. 2000). The Oregon Forest Practices Act (FPA) defines hydrologic disconnection as "the removal of direct routes of drainage or overland flow of road runoff to waters of the state" (OAR 629-600-0100 (71)). However, the Oregon Forest Practices Rules (FPR) lack a definition of hydrologic connection. On 6 March 2025, the IRST accepted the following as its working definition of road-stream hydrologic connectivity (RSHC): "A road segment is considered hydrologically connected where surface runoff from road cuts, ditches, running surfaces, and fills exhibits a continuous surface flow path to a natural stream channel." This definition was derived from the IRST's literature review and is used throughout the scoping proposal.

We reviewed the literature for methods of RSHC effectiveness monitoring that examined: 1) only the physical connection of water runoff between roads and streams, hereafter referenced as physical connectivity; 2) sediment inputs from roads to streams; 3) runoff and sediment effects on aquatic habitats; and 4) runoff and sediment effects on populations of aquatic species. The primary interest of AMPC appears to be the physical connections between roads and streams; however, the third question references achieving BGOs, which include both runoff and sediment as related to covered species habitat requirements. Given the AMPC questions and the Dubé et al. (2010) and Martin (2009) examples, the literature review prioritized methods for measuring or estimating connectivity. However, we also reviewed methods for estimating sediment inputs and impacts to habitat or aquatic species. Because of the overlap in methods among connectivity and sediment monitoring and habitat/population monitoring, the literature review was collapsed into two corresponding sections.

The full literature review is in Appendix C. Here we summarize the key takeaways considered in the developing the options presented in Section 3. The takeaways are organized under three principal aspects of option design: ways to measure connectivity, statistical sampling designs, and assessment of results.

Key Takeaways

Measurement

- A number of very site-specific factors can have a large influence on connectivity and sediment delivery, so field verification of conditions is still considered essential.
- Observer bias was substantial n field assessments of RSHC even with extensive training. Thus, enhanced standardized training and coordination in the field are recommended.

- Field measurement of connectivity and modeling of sediment are possible at a state-wide scale as demonstrated by Dubé et al. (2010). However, direct field measurements of sediment production and delivery from a census of road segments across a broad spatial extent, such as the area covered by the FPA, is infeasible.
- Numerous site-specific factors can influence connectivity and sediment delivery so that quantifying field covariates is essential for exploring relationships between RSHC and local conditions.
- Availability of models and improvements in remote sensing methods and GIS data may reduce the amount of field work needed, particularly when relative estimates of RSHC are sufficient.
- RSHC data to be collected under FRIA may complement but not fulfill the effectiveness monitoring needs for numerous reasons.

Sampling Design

- For large areas of interest, monitoring for RSHC requires sampling rather than a census of all roads.
- Because of the focus on hydrologic processes, most studies sampled and/or assessed based on hydrologic units, such as sub-watersheds; however, Dubé et al (2004) and Martin (2009) documented reasons to sample by land grids.
- Past studies have consistently determined that most impacts from RSHC are associated with relatively few road segments. These “high probability of delivery” segments can be identified and characterized using existing GIS data and modeling tools before going to the field. This focuses field data collection, potentially decreasing sampling costs or cost-effectively increasing sample size. However, applying such “pre-survey” approaches depends on the quality of GIS roads and streams data available.

Assessment

- Although the ultimate purpose of the road connectivity rules is to reduce impacts on aquatic habitats and organisms, measuring such impacts specific to the new road rules is likely infeasible given the large area involved, the cryptic nature of aquatic organisms, movement into the ocean by anadromous species, and multiple other confounding factors and mixed ownership patterns. Coordinating RSHC field sampling with existing habitat and population monitoring programs, however, could help understand these linkages in the future.
- Accurate estimates of the *absolute* amounts of sediment delivered to streams is infeasible over large areas. However, field measurement of road characteristics coupled with erosion and delivery modeling can provide *relative* measures of sediment inputs.
- Although most studies have addressed physical connectivity and sediment delivery together, connectivity can be addressed alone and would save on both field work and analysis resources.
- Dubé et al. (2010) were able to compare their results to Washington performance target ranges from prior agency work, however, knowledge or context of sediment yield numbers or how they should inform management actions is lacking in Oregon (e.g., what is difference between a 5 cu yd and 15 cu yd annual yield?).

3. Scoping Proposal Options

3.1 Introduction

Based on the results of our scoping literature review, we provide options for RSHC status and trend monitoring (AMPC Questions 1 and 2). We do not address the full breadth of potential effectiveness monitoring approaches (Question 3) for habitat or populations. Rule effectiveness can be inferred from status and trends monitoring of RSHC and the likely reduction through time. More specific BGOs, monitoring metrics, and performance targets that would be necessary to quantitatively assess effectiveness are not finalized through a fully executed HCP. Thus, the options presented here are intended to support the development of achievable targets for lowering RSHC through time.

Below we describe two primary survey options: 1) assessment of only the physical connectivity between roads and streams, and 2) assessment of connectivity with a modeled estimate of sediment delivery. We also provide two pre-survey options. These could be added to test and improve the digital (GIS) roads and streams data that will be used in planning the field survey, helping to better target where and what data are collected in the field.

3.2 Survey Options

Survey Option 1: Physical Connectivity

Approach

This option documents the connectivity of surface runoff from roads to streams without collecting the parameters and other data required to model road-related sediment production and transport. The length of road-related features (e.g., road tread, road cuts, ditches, fill slopes) that capture and deliver water to streams will be measured in the field-for status and trend reporting. Based on GIS analysis, points of connectivity to natural water bodies (e.g., wetlands, lakes) other than streams, as defined in the Oregon Forest Practice Rules (FPR), will be included if these can be identified comprehensively in advance of or in conjunction with initial fieldwork.

Sampling Design

The two sampling approaches considered are the land-grid–based road census approach used by Dubé et al. (2010) and an approach that targets road segments most likely to have a high degree of RSHC. The latter approach would be watershed-based (sampling within HUC 12 sub-basins with significant private forestland ownership) and entails a pre-survey step to identify the road segments with a high probability of delivering sediment using a GIS-based road-stream proximity assessment. This latter approach may decrease overall field survey costs or be used to cost-effectively increase sample size. Any approach will require a large random sample to provide valid statistical data to draw inferences and detect trends across the state of Oregon. The sample could be stratified by landowner type (large/small) and geography (eastside/westside). These four sampling frames are hereafter referred to as “strata.” Numerous sampling designs are possible for trend analysis, including paired, unpaired, and rotating panel designs. A statistical power analysis will be necessary to determine the sample size needed for each stratum and sampling period to reliably evaluate the baseline status and detect trends.

Data Collection Methods

We envision data collection methods similar to the field protocol of Dubé et al. (2010), as described in Watershed Professionals Network (2009) with potentially more recent updates (e.g., Bohle and Dubé 2016). Field crews will drive roads included in the sample and use GPS to spatially record features indicating various types and levels of connectivity (such as the five types in Dubé et al. (2010)). Crews will measure variables describing and affecting pathways for delivery of runoff water from each sampled road segment. Typical variables would include ditch lengths, road segment slope, and road surface type. Field crews will be sufficiently trained to competently reduce within- and among-observer errors to within specified tolerances (TBD) and a QA/QC program will be developed to quantify data collection variability.

Baseline Status and Trend Analysis

As part of this study, summary statistics will be calculated on each measured variable related to RSHC for each reporting unit (e.g., all the roads in a watershed or land grid). The baseline status will be summarized by strata (landowner class in each geo-region). Depending on the sampling approach, the summarized baseline status would be something like the length of connected road over total road length (or sampled area) or length of actually connected road per length of potentially connected road.

To establish the pre-PFA baseline status for physical connectivity, ODF records of road work completed since January 2024 will be used. New FPRs went into effect in 2024, including the FRIA process that directed large landowners to begin identifying and remediating as soon as possible High Conservation Value sites. These are areas known to have road stream connectivity or chronic sedimentation. Small landowners are exempt from FRIA but must conduct a Road Condition Assessment (RCA) for roads used in active harvest operations. Data from FRIA and RCA would help identify road segments affected by these post-rule changes, which then could either be dropped from the sample or assumed connected in the baseline.

AMPC question 2 requests a trend analysis at 5-year intervals, which seems reasonable given the 20-year timeframe of the FRIA process and the remediation of the worst roads in the first five years. The request for a specific design of repeated sampling through time would be integrated into the Request for Proposals.

Reporting

The baseline status of physical connectivity at each sampling interval, and trends over time between intervals, will be reported for each stratum. Potential metrics include:

- Total road length draining to streams.
- Density of roads and road length draining to streams (road miles/sq mi).
- Percent of road network draining to streams.
- Miles of roads delivering to streams per miles of stream.
- Average percentage of high probability road length delivering to streams.
- Characteristics of delivering road segments, including the portion of road cross section that is connected to streams.
- Presence of or delivery to adjacent wetlands and lentic water bodies (i.e. lakes).

- Regression plot of the estimated percentage of roads that meet current BMPs vs. percentage of high probability road length delivering to streams.

Landowner-specific information collected in the sample will not be identified in any reporting and will be held confidential.

Timeline

Determining baseline status for this project should entail 6–12 months to prepare for sampling, one or two field seasons to collect field data, and 6–12 months for data analysis. The final report on baseline status results would be expected in about 3 years from project initiation.

For trends, the sampling interval will likely be at least 5 years and the duration at least 20 years. The 3-year timeline projected for the baseline status will apply for each iteration of trend sampling, but with some time savings likely in subsequent sampling periods.

Table 2. Timeline for Option 1.

Task	Who	Estimated Time Needed (months)
Administrative Start up (i.e., contracting, etc.)	OSU/INR	2
Initial planning	IRST & Contractor	1
Site selection & screening,	Contractor	4
Recruitment & training of field teams	Contractor	6
Landowner permissions and access coordination	Contractor	2
Field sampling	Contractor	10
Data analysis & report writing	Contractor	8
IRST review	IRST	1
Final report	Contractor	1
Administrative closing	OSU/INR	1
Total		**36**

Costs

There is insufficient information to estimate sampling densities needed for different levels of statistical certainty or the potential cost differences between alternative sampling approaches at this time. Thus, costs and precision related to the Dubé et al. (2010) study are assumed to provide an adequate basis for this scoping proposal. Dubé sampled 60 land blocks, which they estimated would provide a statistical power of 80% to detect a change of 30% in delivering road length on a statewide basis.

CMER recorded an overall cost of $878,000 for the Dubé study (which probably did not include some additional CMER staff time). Using an inflation calculator for 2007 (midpoint of the 2006–2008 monitoring effort) to 2025 provides an overall cost equivalent of $1.35 million. Based on the line-item budget in the pilot study (Raines et al. 2005), not collecting and analyzing data needed for the sediment modeling is estimated to reduce the costs by 20%, resulting in a cost of approximately $1.1 million for the baseline sampling event. Raines et al. (2005) estimated costs would be approximately 25% less for a second round of sampling after five years resulting in an estimate of $800,000 for each of the second and subsequent iterations.

If AMPC desires to detect changes at the sub-state level (east/west, large/small landowners) with a similar amount of statistical power, the same number of samples may be required for each of these strata. Thus, four strata may require 240 sampling units and cost approximately $4.4 million for the initial sampling iteration.

The range of costs reflect the options below. Options affecting costs:

- Field time, including travel between sites and rigor of field measurements.
- Whether field data collection can target only the road segments likely to be connected i.e., proximate to streams versus a complete census of roads in the sampling framework.
- Whether road segments can be characterized from high-resolution LiDAR, reducing the metrics for which data collection in the field is required.
- The number of strata for which physical connectivity is to be estimated.

Knowledge Contribution

- Provides a faster and less expensive means to address the AMPC's basic question related to baseline status and trends of RSHC than Option 2 due to less field time and data processing.
- Baseline status would be available approximately three years after project initiation. An initial trend estimate could likely be available five years after the baseline.
- Result metrics, all based on the length of road segments identified as draining to streams, would include: total length, percent of road network, length per mile of stream.
- If additional road characteristics are collected (cutslope vegetation, road surface type, traffic levels), connectivity could additionally be reported by these categories.
- Can inform the development of performance targets and effectiveness of road rules at achieving BGOs related to hydrologic disconnection.
- Cannot support quantitative targets or effectiveness for sediment-related BGOs, although a more qualitative assessment of sediment could be inferred from levels of physical connectivity but with a lower level of confidence than Option 2.

Survey Option 2: Physical Connectivity Plus Modeled Estimates of Sediment Delivery

Approach

This effort expands the field sampling, analysis, and reporting of Survey Option 1 to include modeled estimates of sediment generated by roads and delivered to streams both episodically and annually.

Field Methods

The field methods for this option require data collection to support modeling the estimated amounts of sediment generation and delivery. Raines et al. (2005) describes the types of variables for which field data will be collected. These include variables such as road surface, road age, and cut slope vegetation coverage. Other needed variables (e.g., road traffic or maintenance activities) may be derived from landowner interviews. The exact variables will depend on the model selected.

Baseline and Trend Analysis

Similar to Survey Option 1, with the addition of all variables that relate to the generation and delivery of sediment to streams (e.g., surfacing, traffic, age, cut slope vegetation coverage), and a modeled estimate of the amount of sediment delivered by the surveyed road segments per year. Estimates of sediment delivered could be stratified across landowner type and region and analyzed through time as the FPRs are implemented.

Reporting

Reports will include the baseline status of physical connectivity plus sediment delivery at each sampling interval, and trends over time between intervals, for each stratum. The following metrics will be included in addition to those in Survey Option 1, :

- Density of sediment delivery to streams (tons/sq mi/year).
- Volume of road sediment delivered to streams per mile of stream (tons/stream mi/year).
- Percentage of high probability road length delivering to streams.
- Modeled tons of road sediment delivered to streams per miles of stream per year by the percent of road length meeting performance standards.
- Characteristics of high delivery road segments (surfacing, traffic, etc.).
- Sediment delivery to adjacent wetlands and lentic water bodies that may store/divert delivery to streams.
- Expected sediment delivered by certain levels of storm/meltwater runoff events.

Landowner-specific information collected in the sample will not be identified in any reporting and will be held confidential.

Timeline

Determining the baseline for this project should be the same as for Option 1, requiring 6-12 months to prepare for sampling. However, field sampling and data analysis will take longer than for Option 1 given the need to collect and analyze sediment data. Thus, two seasons will likely be necessary to collect field data, and 15 months for data analysis. The final report for baseline results would be expected in about four years from project initiation.

For trends, the sampling interval will likely be at least five years and the duration at least 20 years. The four-year timeline projected for the baseline will apply for each episode of trend sampling, but with some time savings likely for subsequent sampling periods.

Table 3. Timeline for Option 2.

Task	Who	Estimated Time Needed (months)
Administrative Start up (i.e., contracting, etc.)	OSU/INR	2
Initial planning	IRST & Contractor	1
Site selection & screening	Contractor	4
Recruitment & training of field teams	Contractor	6

Landowner coordination & interviews	Contractor	4
Field sampling	Contractor	12
Data analysis & report writing	Contractor	15
IRST review	IRST	1
Final report	Contractor	2
Administrative closing	OSU/INR	1
Total		**48**

Cost

Costs are estimated based on the Dubé et al. (2010) study, similar to Option 1. To establish a statewide connectivity baseline with sediment modeling would cost an estimated $1.35 million. Subsequent iterations on five-year intervals would cost approximately 25% less, resulting in an estimate of $1 million for each round of sampling. If AMPC desires to detect changes at the sub-state level (east/west, large/small landowners) with a similar amount of statistical power, the same number of samples may be required for each of these strata. Thus, four strata may require 240 sampling units and cost approximately $5.4 million for the initial sampling iteration. Costs may be reduced if field data collection can target only the road segments likely to be connected and if road segments can be characterized from high-resolution LiDAR data, reducing the metrics for which data collection in the field is required.

Knowledge Contribution

Same as for Survey Option 1, except that Option 2:

- Takes one year longer and costs ~20% more than Option 1 but provides estimates of sediment delivery in addition to simple connectivity.
- Provides a baseline status estimate in approximately four years after project initiation. An initial trend estimate could likely be available five years after the baseline.
- Metrics would include all the connectivity-only metrics listed in Option 1, plus the modeled tons of road sediment delivered to streams.
- Includes additional road characteristics needed for sediment modeling (cutslope vegetation, road surface type, traffic levels) that will be reported by road length.
- Can inform the development of performance targets and the effectiveness of road rules at achieving BGOs related to hydrologic disconnection and sediment delivery.

3.3 Pre-survey Options

Pre-survey Option 1: Assessing Roads and Streams Digital Data

Approach

As described in Options 1 and 2 above, one potential way to boost sampling efficiency would be to preselect and sample only road segments with a high probability of being hydrologically connected, using either a simple distance buffer or one of the RSHC models. However, the utility of these locations for field work and eliminating potential sampling bias will depend on the accuracy of the stream and road data used to identify field sampling locations.

ODF's hydrography layer derived from LiDAR and ODF's transportation layer (both available from their GIS Data Hub) are considered the most comprehensive coverages available for private forestland ownerships in Oregon. However, the accuracy of the hydrography and transportation layers is not well quantified. Thus, using these layers to guide sampling for RSHC may introduce an unknown level of bias into estimates. For example, road locations that are inaccurate could result in higher or lower estimates of the true probability of RSHC.

Here, we propose to quantify and address potential biases of inaccurate hydrography or transportation layers through validation sampling. If the existing ODF transportation and hydrography layers have a desired level of accuracy, estimates of baseline status and future RSHC will have lower levels of bias. Conversely, if either layer is less accurate than desired, these will need to be improved or cannot be used to preselect road segments for field data collection in Survey Options 1 and 2.

Developing an improved transportation layer, for example, could be achieved by interpreting LiDAR data or by a field-mapped census. It may also be possible to draw on the complete census of roads being developed by large landowners through the FRIA process, but that census will not be available until January 1, 2029 and excludes small landowners.

Two time periods are proposed for assessing the accuracy of ODF's hydrography and transportation layers.

- A state agency, INR, or other organization could validate and estimate accuracy prior to publishing the Request for Proposal (RFP) for the Roads Questions.
- Alternatively, validation sampling could be incorporated into the RFP as an additional project component.

In either case, if the accuracy of the layers is lower than desired, additional mapping of roads and streams may be necessary in the geographic areas (e.g., sub-watersheds) selected for study. The sooner this is determined, the greater the certainty in approach as well as cost and time estimates for Survey Options 1 and 2 above.

Timeline

If undertaken prior to publishing a full RFP, evaluation of the hydrography and transportation layers could likely be completed within 6 months. Otherwise, the evaluation would be completed under the timeline of the full RFP during the start-up and initial planning months. If improved roads or streams layers are desired, the full project timelines would need to be extended.

Cost

If undertaken internally (i.e., INR or ODF) prior to publishing a full RFP, the evaluation would likely be less expensive than if conducted through a separate RFP or as part of the full RFP, which we estimate at about $10,000.

Any need to develop improved transportation or stream layers will increase costs. However, not developing needed layers may also increase cost by requiring additional field sampling in Survey Options 1 and 2. We cannot develop an accurate cost estimate until the initial data assessment is completed.

Knowledge Contribution

Estimating the accuracy of these layers could enhance the sampling design by reducing required sample sizes, facilitating selection of a relatively unbiased sample of field sites, and allowing use of the methods described in Survey Options 1 and 2 that target field sampling at the road segments most likely to be hydrologically connected. These benefits are possible only if the existing transportation and stream layers are deemed sufficiently accurate or are improved after evaluation.

Pre-survey Option 2: GIS-LiDAR Road Segment Analysis

Approach

Identifying road segments and measuring the associated attributes needed for RSHC analysis and sediment modeling takes considerable time in the field. The literature suggests that GIS (desktop) analysis prior to fieldwork could be used to generate road segments and properties from publicly available airborne LiDAR data. The goal of this option would be to test whether such an approach improves the accuracy and efficiency of road segment creation and the quantification of segment characteristics needed for RSHC analysis.

After overlaying the ODF road network atop airborne LiDAR, flow routing algorithms and other GIS tools could be used to distinguish road segments and attribute those segments with estimates of relevant properties, including length, slope, configuration, ditch width/position, cut slope height, tread width, and other geometric data. Field crews could then focus on documenting site-specific information such as road surfacing.

This approach would require workflow development and testing before adoption and rollout for field crews. Also, some legacy (or older) LiDAR datasets have lower point density, thus testing would be necessary to determine whether data limitations exist. Field validation would also be needed to assess the accuracy of this approach.

Table 4. Timeline for pre-survey Option 2.

Steps	Estimated Time Needed (months)
LiDAR Data Acquisition and Initial Processing	1
Terrain Analysis and Feature Extraction	1
Identification of Road Features	2
Road Extraction, Testing, and Refinement	2
Post-processing, Vectorization, and Characterization	2
Total	8

Cost

Assuming a cost of $10,000 per person-month, the estimated cost for this option is $80,000.

Knowledge Contribution

This option has the potential to reduce the time (and funding) needed for field crews to collect geometric data and instead focus their efforts on acquiring other relevant data. It is anticipated there would be cost savings and/or an expansion of the number of sample sites or length of roads assessed for RSHC.

3.4 Options Summary Table

The two primary survey options and two pre-survey options differ in time required, cost, and knowledge contributions (Table 5).

Table 5. Summary of scoping proposal options, timeframes, costs, and knowledge contributions.

Option	Estimated Timeframe (months)	Cost	Knowledge Contributions
Survey Option 1: Physical Connectivity Only	36 months	$1.1-4.4 million (for baseline sample)	• A faster and less expensive means to address the AMPC's basic question related to status and trends of RSHC than Option 2 due to less field time and data processing. • Characterizes the length of road segments identified as draining to streams by a number of measures (% of total, per stream mile, etc.) • Can inform performance targets and effectiveness of road rules at achieving BGOs related to hydrologic disconnection but less so than for Option 2
Survey Option 2: Physical Connectivity + Sediment Modeling	48 months	$1.35-5.4 million (for baseline sample)	• Takes one year longer and costs ~20% more than Option 1 but provides estimates of sediment delivery. • Outputs would include all the connectivity-only metrics listed in Option 1, plus the modeled tons of road sediment delivered to streams. • Can inform the development of performance targets and the effectiveness of road rules at achieving BGOs related to hydrologic disconnection and sediment delivery.
Pre-survey Option 1: Digital Data Accuracy Assessment)	6 months	< $10k	• Increases confidence that sampling locations selected are a relatively unbiased sample. • Reduces time and expense by limiting field data collection to road segments with a higher probability of connectivity.
Pre-survey Option 2: GIS-LiDAR Road Segmentation	8 months	$80k	• Reduces time and expense by limiting the data collected in the field on each road segment. • Improves the accuracy and consistency of road segment data.

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5. Appendices

Appendix A. AMPC Research Questions Package

Finalized research questions

These finalized research questions were approved by the AMPC at the June 24 2024 AMPC meeting.

4. Baseline report
    d. What is the baseline status of hydrologic connectivity of roads prior to the implementation of the OFPA road rules effective Jan 1, 2024?
    e. How does the status of hydrologic connectivity differ based on landowner type and East/West region?
    f. How do particular elements of the regulatory framework (e.g., road location) or site characteristics (e.g. geology) contribute to hydrologic connectivity?
5. Trend monitoring
    b. What are the trends in the status of hydrologic connectivity of roads over 5-year intervals? These trends should be assessed for the same variables in question 1.
6. Determination of rule effectiveness
    b. Within 25 years, to what extent are road rules associated with hydrologic disconnection effective at achieving BGOs?

Preliminary Research Questions Package: Contextual Information

The remainder of this document provides contextual information that details the context for the preliminary research questions, as required by rule[2]. The following are organized per the elements in this rule.

<u>B.1 The type of research</u>[3]

This research is of type OAR 629-603-0100(1)(a): *“Conduct effectiveness monitoring by assessing the degree to which the rules facilitating particular forest conditions and ecological processes achieve the biological goals and objectives. This assessment may include evaluation of cumulative effects.”*

<u>B.2 The rule, biological goals and objectives (BGOs), or other issue being studied</u>[4]

Note that the most recent version of the BGOs is in the Dec. 2022 draft HCP. The BGOs will be finalized within the HCP due Dec. 31, 2027.The BGOs are listed below with those applicable to these questions in bold italic:

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[2] OAR 629-603-0200 (3)(a)

[3] OAR 629-603-0200(3)(a)(A)

[4] OAR 629-603-0200(3)(a)(B)

"*Overarching Goal: Forest practices that support the survival and recovery of the covered species by providing clean, cool, connected, and complex habitats.*

Goal 1: Provide clean water and substrate for the covered species.

- ***Objective 1.1 - Forest practices near streams minimize sediment delivery.***
- *Objective 1.2 – Slope Retention Areas reduce episodic sediment delivery to fish-bearing streams.*
- ***Objective 1.3 – Road runoff directly to streams is minimized.***
- ***Objective 1.4 – Roads are not a significant source of episodic sediment delivery to streams.***

Goal 2: Shade and watershed processes controlling stream temperature provide cool water compatible with the needs of the covered species.

- *Objective 2.1 – Forest practices maintain stream shade sufficient to support desired cool water temperatures on fish-bearing streams.*
- *Objective 2.2 – No-harvest RMAs maintain stream shade sufficient to support desired cool water temperatures for covered amphibians.*
- *Objective 2.3 – Forest practices near non-fish-bearing perennial streams do not notably increase water temperatures in fish-bearing streams.*

Goal 3: Stream network connectivity satisfies freshwater habitat needs for covered species.

- *Objective 3.1 – Road crossings on fish-bearing streams are passable by the covered fish species.*
- *Objective 3.2 – Forest practices maintain the hydrologic continuity of stream-associated wetlands and stream-adjacent seeps and springs to stream habitats.*
- *Objective 3.3 – Timber harvest maintains stream-associated connectivity in riparian areas along non-fish streams sufficient to support covered amphibians.*

Goal 4: Riparian areas function to support complex habitats for the covered species.

- *Objective 4.1 – Mature, complex riparian forests are fostered in no-harvest zones of RMAs.*
- *Objective 4.2 – Forest practices within tree retention areas of RMAs promote delivery of large wood.*
- *Objective 4.3 – Designated Debris Flow Traversal Areas function to deliver large wood to fish-bearing streams.*
- *Objective 4.4 – Forest practices maintain stream-associated wetlands and stream-adjacent seep and spring habitat for amphibians."*

B.3 The objective of the research[5]

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[5] OAR 629-603-0200(3)(a)(C)

1. To assess the current (baseline) status and trend of roads that are hydrologically connected to streams, and how those vary with practice, region, landowner type, and other relevant strata.
2. Determine the effectiveness of road rules associated with hydrologic disconnection at achieving BGOs.

B.4 A brief description of the context of the research question[6]

The following direction was provided in the PFA Report and provides the foundation for these research questions:

> *"4.3.5 Hydrologic Connectivity in Forest Practice Rules (FPR) Revisions and Proposed Inventory Processes*
>
> *Hydrologic connectivity occurs where road and ditch runoff is delivered to the natural stream channel system. Roads can generate overland flow due to the relatively impermeable surface of the road prism and can also intercept interflow at cut slopes, effectively converting subsurface flows to surface flows. When these surface flows have a continuous flow path between the road prism and a natural stream channel, hydrologic connectivity occurs (Furniss et al., 2000, pp. 5-6). As Furniss et al. describe, "a hydrologically connected road becomes part of the stream network" (pp. 5-6).*
>
> *Hydrologically connected roads can deliver increased runoff, sediment, and chemicals associated with roads, such as spills or oils generated on the road surface or cut slope. At the watershed scale, connections between roads and streams can also alter the drainage density of the watershed and change runoff frequency and magnitude (See Furniss et al., 2000; Weaver et al., 2015).*
>
> *The Authors agree that the goal of disconnecting roads and streams is to minimize sediment delivery, hydrologic change, and risk of road pollutants entering waters of the state."*
>
> 4.3.10 Development of Monitoring Requirements
>
> *The Independent Research Science Team (IRST) created under the PFA shall design and oversee baseline and trend monitoring for hydrologic disconnection. Compliance monitoring will be conducted through the Department's process.*
>
> 1. ***Baseline and Trend Monitoring for Hydrologic Disconnection:*** *The methodology for the monitoring shall be based off of Dube et al. (2010) and Martin (2009). The purpose of the monitoring for hydrologic disconnection is to establish a baseline and to monitor and report the change in hydrologic connectivity over time as the FRIA is implemented. The overarching goal is to ensure that all forest roads and landings shall be hydrologically disconnected to the maximum extent feasible from waters of the state. The Adaptive Management Program Committee shall use the results of the baseline and trend monitoring to develop regional goals consistent with that monitoring. All*

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[6] OAR 629-603-0200(3)(a)(D)

> *hydrologic connectivity data should be public and shared as it becomes available to help focus goals, identify accomplishments, and inform statewide learning."*

B.5 Other information the AMPC deems necessary for the IRST's work[7]

1. It is essential to maintain the role of the regulatory framework (the OFPA) throughout the design and implementation of studies, including the following considerations:
    a. There are two stratum classifications:
        A. FPA regions, of which there are two - East and West of the Cascade Mountains.
        B. Landowner classifications in the FPA (of which there are two, each with a different regulatory framework for roads) – 1) small forestland owners (RCA); 2) large forestland owners (FRIA).
    b. Assessments should differentiate Type F, SSBT, and N streams, but the design need not be stratified by stream type. Additional attributes listed in Dube et al. (2010) should also be considered.
2. The AMPC wants to know how metrics of interest (e.g., sediment delivery from roads) compares with background levels.
3. Ideally, the baseline would be for the effective date for the road rules (Jan. 1, 2024); however, the AMPC recognizes that it will take time to refine and scope the research questions, decide on the research agenda, develop and then award the RFP.
4. Research should include field data.
5. When assessing effectiveness of rules, it would be helpful to understand results both individually and cumulatively.
6. This entire research question package would be very complex, long, and expensive to implement as a single research project. Thus, the AMPC would appreciate the IRST dividing up this research question package into discrete projects and developing scoping proposals (per OAR 629-603-0200(4)) for each one.

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[7] OAR 629-603-0200(3)(a)(E)

Appendix B. Road rules relevant to the IRST's work on hydrologic connectivity

This document provides the rules that are relevant to the work of the Adaptive Management Program regarding hydrologic connectivity of roads, along with clarifying summaries where needed. These rules are provided to help the IRST develop a scoping proposal per OAR 629-603-0200(4)(c) in the context of the question package from the AMPC with the finalized research questions. Clarifications are added via comments. Parts of rules that are irrelevant to hydrologic connectivity have been omitted for brevity and focus.

OAR 629-625-0000 Purpose

(3) The purpose of the road construction and maintenance rules is to establish standards for locating, designing, constructing, and maintaining efficient and beneficial forest roads;…; identifying active and inactive roads that … contribute sediment to waters of the state, to correct conditions; and to vacate roads, rock pits, and quarries that are no longer needed in manners that provide the maximum practical protection to maintain forest productivity, water quality, and fish and wildlife habitat.

(4) To achieve the goals of the division, all roads will be designed, constructed, improved, maintained, or vacated to:

- (a) Prevent or minimize sediment delivery to waters of the state;
- (f) To the maximum extent practicable, hydrologically disconnect forest roads and landings from waters of the state;

OAR 629-625-0300 Road Design

(3) The department shall publish Forest Practices Technical Guidance that explains how to avoid and prevent potential impacts to fish, wildlife, habitat resources, and waters of the state, in support of the following rules:

- (g) OAR 629-625-0330(1) to explain how to implement rules to hydrologically disconnect forest roads and landings from waters of the state.

OAR 629-625-0320 Water Crossing Structures

(10) Construction of Water Crossings. In the construction of water crossings, operators shall do the following:

- (b) Runoff, Erosion and Sediment. Operators shall control runoff, erosion, and sediment through the following actions:
  - (A) Include a site-specific erosion and sediment control plan as part of a written plan prior to beginning work. This plan must include, but is not limited to:
    - (i) A site plan with a description of the methods of erosion or sediment control;

(iii) Measures to disconnect road surface and ditch water from all typed waters and lakes, bays, ponds, impounding reservoirs, springs, rivers, streams, creeks, estuaries, marshes, wetlands, inlets, and canals.

OAR 629-625-0330 Drainage

(1) All active, inactive, and vacated forest roads and landings shall be hydrologically disconnected to the maximum extent practicable from waters of the state to minimize sediment delivery from road runoff and reduce the potential for hydrological changes that alter the magnitude and frequency of runoff. Operators shall locate drainage structures based on the priority listed below. When there is a conflict between the requirements of sections (2) through (7) of this rule, the lowest numbered section takes precedence and the operator shall not implement the later numbered and conflicting section.

(2) Operator shall not install cross-drains and ditch-relief culverts in a way that causes stream diversion.

(3) Operators shall not concentrate road drainage water into headwalls, slide areas, high landslide hazard locations, or steep erodible fill slopes.

(4) Operators shall not divert water from stream channels into roadside ditches.

(5) Operators shall install drainage structures at approaches to stream crossings to divert road runoff from entering the stream. If placement of a single drainage structure cannot be placed in a location where it can effectively limit sediment from entering the stream, then additional drainage structures, road surfacing, controlling haul, or other site-specific measures shall be employed so that the drainage structure immediately prior to the crossing will effectively limit sediment from entering the stream. Operators may also use best management practices to manage sediment at the outflow of the drainage structure nearest to the crossing.

(6) Operators shall provide drainage when roads cross or expose springs, seeps, or wet areas.

(7) Operators shall provide a drainage system that minimizes the development of gully erosion of the road prism or slopes below the road using grade reversals, surface sloping, ditches, culverts, water bars, or any combination thereof. For new road construction, operators shall use out sloping to the maximum extent practicable when site-specific conditions allow for its safe and effective use.

OAR 629-625-0600 Road Maintenance

(1) The purpose of this rule is to protect water quality and ensure hydrologic disconnection of roads from waters of the state to the maximum extent practicable by timely maintenance of all active and inactive roads. Road surface must be maintained as necessary to:

(a) Minimize erosion of the surface and the subgrade;

(b) Minimize direct delivery of surface water to waters of the state;

(c) Minimize sediment entry to waters of the state;

(d) Direct any groundwater that is captured by the road surface onto stable portions of the forest floor;

(e) Ensure properly functioning and durable drainage features; and

(f) For existing roads with inboard ditch, avoid overcleaning of ditch lines.

OAR 629-600-0100(71) "Hydrologic disconnection" means the removal of direct routes of drainage or overland flow of road runoff to waters of the state.

Note: there is no rule-based definition of hydrologic connectivity.

Appendix C. Scoping Literature Review

For our literature review, we considered relevant measurement and monitoring methods for road-stream hydrologic connectivity (RSHC) that focused on: 1) simply the physical connection of water runoff between roads and streams; 2) sediment inputs from roads to streams; 3) runoff and sediment effects on aquatic habitats; and 4) runoff and sediment effects on aquatic species populations. Given the AMPC questions and the Dubé/Martin examples, we focused on methods for measuring or estimating physical connectivity and sediment inputs, but we also include information on a few studies and monitoring programs that include RSHC-related habitat and species metrics. Because of the overlap in methods between connectivity/sediment monitoring and habitat/population monitoring, the review has been collapsed into two corresponding sections.

Hydrologic Connectivity and Sediment Delivery Monitoring

In a forested landscape, runoff and associated chronic sedimentation are primary concerns from road-stream connectivity on aquatic species; thus, several methods have been devised to characterize these processes. Predictive models have emerged from this knowledge base and are increasingly used to estimate water and sediment inputs from roads to streams in a wide array of geologic and ecological settings (Fu et al. 2010). The literature tends to address hydrological connectivity and sediment delivery together, with the former being an element of and precursor to the latter. Martin (2009) is an exception in that only connectivity was measured.

Measuring RSHC

To characterize RSHC, roads are typically divided into segments that drain to a common point and share other related characteristics (e.g., surfacing, traffic, slope). All the efforts reviewed based their data collection and analyses on road segments, although their delineation methods varied.

Field methods

For the Dubé et al. (2010) study, physical connectivity was determined visually by field crews using a flow chart protocol (Watershed Professionals Network 2009). Six categories of connectivity were recorded in the field assessment: 1) none; 2) direct delivery; 3) 35% delivery; 4) 10% delivery sediment plume reaching or nearly reaching a stream; 5) direct via gully or from road structure; or 6) a road paralleling a stream within 20 ft. They implemented a quality assurance/quality control (QA/QC) protocol and found observer differences to be substantial, which they addressed through further training and mixing of teams. Martin (2009) did not describe RSHC determination methods, however, they are assumed to be similar to those used by Dubé et al. (2010). For modeling sediment delivery, field crews measured numerous aspects of delivering road segments, such as slope, surfacing, maintenance level, ditch conditions, cutslope conditions, and vegetation.

Several field methods have been developed to improve accuracy of estimates of sediment contributions to streams from RSHC, by directly measuring sediment outputs from road segments. These include tipping buckets, sediment traps, and visual observations of runoff turbidity (Skaugset et al. 2011). Logistics limit actual field sampling of sediment to relatively small areas. Thus, monitoring sediment delivery at the scale envisioned by AMPC has generally been done using models with various levels of field calibration.

GIS/Remote Sensing

Remote sensing and GIS analysis have been increasingly used to identify and characterize forest roads and RSHC. Given the limitations of optical imagery in dense, closed canopy forests, much of the relevant literature focuses on airborne LiDAR, which can penetrate canopy and achieve moderate-to-high 'bare earth' point density.

Several studies have tested the ability of airborne LiDAR data to map road networks and demonstrate that airborne LiDAR can be used to map road networks with high accuracy (Kardoš et al. 2024), including abandoned/deactivated roads (Beck et al. 2015; White et al. 2010). Early efforts involved manual GIS work to map road surfaces from LiDAR-derived coverages, but recent studies highlight the efficacy of automated tools for road network extraction (Even and Ngo 2021; Ferraz et al. 2016; Wiskes et al. 2023). GIS tools using LiDAR enable the quantification of road geometry, such as segment length, width, slope, cutbank height, and more, with high accuracy (Hatta Antah et al. 2021; Pradhan and Ibrahim Sameen 2020). A multitude of studies have used GIS tools to map and quantify road-stream hydrologic connectivity by using flow routing algorithms to intersect road drainage flow paths with stream layers and drainage features (Benda et al. 2019; Roelens et al. 2018). These RSHC approaches have been applied in steep as well as gentle settings and can be used to generate maps of connected road systems or revise existing maps of road-stream connectivity to inform field surveys and facilitate validation (Benda et al. 2016). GIS analysis has been shown to be effective for assessing road status (e.g., active, abandoned) and quality (e.g., structural condition, surface geometry, ditches) over relatively large areas, which greatly reduces the need for extensive field surveys (Waga et al. 2020a, 2020b).

Modeling

Numerous models have been developed to estimate runoff and sediment yield from forest roads. Two types of models are generally used: empirical and physical process-based (Elliot et al. 2009; Fu et al. 2010).

Empirical models apply relationships describing sediment production and delivery derived from research on road erosion (e.g., WARSEM [Washington Road Sediment Estimation Model, Dube et al. 2004], USLE/RUSLE [Universal Soil Loss Equation/Revised] (Dissmeyer and Foster 1980), GRAIP and GRAIP-lite [Geomorphic Road Analysis and Inventory Package] (Black et al. 2012; Cissel et al. 2012; Nelson et al. 2014). The GRAIP and most other of the empirical models predict road to stream hydrologic connectivity, sediment production and delivery to streams, downstream sediment accumulation, risks of shallow landslides caused by roads, gully initiation risk below drain points, and risks to road-stream crossings (Black et al. 2012; Cissel et al. 2012). The NW Forest Plan Aquatic and Riparian Effectiveness Monitoring Program (AREMP; Dunham et al. 2023) used the GRAIP-lite model to assess RSHC and sediment delivery. These empirical models all use similar basic inputs on road characteristics to estimate sediment production from surface erosion.

Physical process-based models simulate the finer scale subprocesses that determine runoff, such as infiltration, routing, and soil cohesion. They can use regionalized parameters for inputs and can provide estimates of sediment production from individual road segments (e.g., WEPP:Road [Water Erosion Prediction Project] (Elliot 2013), DHSVM [Distributed Hydrology Soil Vegetation Model] (Wigmosta et al. 2002), and whole watersheds (e.g., READI [Road Erosion And Delivery Index]) (Benda et al. 2019).

Tests of both types of models using field-measured sediment production show they can provide reasonable relative delivery estimates over multiple sampling locations, but that they may be inaccurate for individual locations, sometimes by large amounts (Bohle and Dubé 2015; Dubé et al. 2011; Faubion 2020; Fu et al. 2010; Skaugset et al. 2011). Calibrating the models with local sediment production data can improve the accuracy of estimates (Bohle and Dubé 2015). Despite issues with accuracy, models are useful for generating relative estimates of sediment production, which can identify road segments with the highest probability of delivering the most water and sediment to streams. Relative estimates can also be used as a proxy for measuring change in sediment inputs, for example, where efforts have been made to reduce RSHC.

Sampling Design

Spatial Sampling

For field-based studies or field-calibrated models, if the area of interest is small it may be possible to collect measurement on the complete road network (a full census). However, when field-based methods are desired over a large area selecting samples based on a predetermined design will be necessary, given costs and time constraints. Raines et al. (2005) (the pilot study for Dubé et al. 2010) considered sampling by Washington sub-basins (average area 6.26 mi^2), but rejected that idea because statewide mapping was incomplete. Instead, they opted for six square mile sample units based on aggregating quarter sections from the general land survey (Dubé et al. 2010 reduced these units to four square miles). A potential benefit was that sections were more likely to follow property lines creating efficiencies with landowner contacts. However, effects on aquatic systems may be better characterized using subwatersheds, which have been mapped at multiple spatial scales for the entire state of Oregon (https://geohub.oregon.gov/datasets/oregon-geo::12-digit-hu-subwatershed/explore).

For larger areas, it may not be necessary to sample depending on the information desired and whether accurate and comprehensive mapping is available for both roads and streams. For example, AREMP was able to model RSHC for all roads in their area of interest with the uncalibrated GRAIP-lite model based on a compilation of agency road inventories. However, the only road condition change categories available consistently included road segments that were active or decommissioned, thus limiting the detail of the results. FRIA will create another example of a census approach in which large landowners are required to conduct a complete inventory of their roads, but the information collected will be limited.

Covariates / Sampling Stratification

Road-stream hydrologic connectivity and sediment delivery have been found to be influenced by both human-caused factors (e.g., location, surfacing, traffic) and environmental factors (e.g., slope, soils, geology, rainfall patterns) (Kastridis 2020). Covariates reflecting such factors can be either explicitly integrated into the sampling design or data about these can be collected during field work and analyzed post hoc. The former increases chances that statistically-based conclusions can be generated but also increases the sample size needed for each covariate.

AMPC question 1b asks how results vary by OFPA landowner type, which are divided into large (>5,000 acres) and small landowners, and by OFPA geographic region (east/west). Dubé et al. (2010) did not stratify by ownership types but encountered challenges aggregating sufficient blocks in more fragmented non-industrial ownerships and in obtaining landowner permissions. As a result, ~95 percent of their sampled area came from industrial and state/local government owners. They also weighted their sampling by three geographic regions (Coastal/Spruce, West of Cascade Crest, East of Cascade Crest), which were based on performance targets established by these regions in prior watershed analyses. Their overall sample design considered the proportion of eligible lands within each of these zones.

Cabrera et al. (2016) stratified by more specific environmental variables, such as granitic and volcanic geologies, found significantly different base erosion rates. Sheridan et al. (2013) stratified by stream size because the same amount of sediment in a small stream has a greater potential to affect biota compared to that amount of sediment in a larger stream.

Temporal Sampling

Timing of sampling is critical for establishing baseline status and trend estimates of RSHC. Dubé et al. (2010) faced a number of related challenges, which are likely to be similar for the Oregon AMP process. First, the time it takes to get a baseline sampling effort executed is one such consideration. The original vision in Washington was to have a first sample before significant work on Road Maintenance and Abandonment Plans (RMAP) had been accomplished, a second sample mid-way through RMAP efforts, and a third sample after RMAP was completed. However, the first sample was not collected until 2006/2007, five years after the Washington road upgrade process was underway. Our Oregon effort may be able to use records from the FRIA process or landowner interviews to identify improvements made between the implantation of the new rules and our sampling date. These post-rule improved road segments could either be dropped from the sample or assumed connected for the baseline. Timing and budgetary constraints have delayed the follow up sampling to Dube et al. (2010), which was intended to show trend and efficacy. It is now scheduled to occur in 2028, well after RMAP completion in 2021 (CMER 2023).

Repeated sampling needs to match the time scale of processes of interest that are driving change. Sampling intervals that are too short may capture the effects of processes that are not relevant to answering the AMPC questions or result in redundant data collection for periods where the processes of interest are relatively static. Sampling intervals that are too long may miss important variability and delay information useful for decision making.

Assessment

Measurement and sampling choices should be driven by determining how to ultimately assess the data. The main studies we reviewed have used relatively simple metrics. For RSHC, Dubé et al. (2010) reported connected road length (both per square mile and per mile of stream), whereas for sediment, they used the WARSEM model to estimate tons of delivered sediment/year/mile of stream. Dubé et al. (2010) also used performance target ranges from prior agency work that were established from the low-medium categories of an expert rating of watersheds for aquatic risk.

The AREMP measured changes in modeled connected road length by Hydrologic Unit Code (HUC) 12 (km/km2). Sediment delivery values were divided by the subwatershed area to account for subwatersheds of varying size. The sediment model was not calibrated for local geology, climate, or other influences; thus, results were interpreted as relative.

FRIA will simply report on road length in each of their categories, transitioning from “not meeting” to “meeting” standards. The ODF Compliance Monitoring Program will also be assessing road conditions on randomly sampled sites; metrics are currently under discussion, however, no measure of RSHC is included at this point.

Studies have generally found that a relatively small percentage of the road network (1%–25%) is hydrologically connected to streams (Benda et al. 2019; Coe 2006; Dubé et al. 2010; Faubion 2020; Martin 2009).

Habitat and Population Monitoring

The Oregon FPA HCP is designed to minimize and mitigate take of the species of concern through the provision of adequate habitat. Studies linking particular habitat attributes and the effects on aquatic and riparian species are too numerous to discuss here. More relevant to this effort are monitoring and assessment programs that have been developed based on habitat-species links. Numerous ongoing state and federal government programs monitor aquatic habitat indicators and/or species populations in the northwestern United States. Through the Aquatic Inventories Program (AQI), the Oregon Department of Fish and Wildlife (ODFW) has been collecting aquatic and riparian habitat data for 27 years in westside wadeable streams (Anlauf-Dunn and Jones 2012; ODFW 2025). Aquatic and riparian monitoring has also been occurring on federal lands on the east (PIBO 2025; Roper et al. 2019) and west (AREMP 2025; Dunham et al. 2023) sides of the state.

Measurement

ODFW’s AQI collects information on culverts and substrate particle size by 6 classes (including fines). They also conduct fish population surveys for juvenile and spawning salmonids. The AREMP and PIBO tested aquatic organism surveys but found that their sampling intensity was not sufficient to reliably detect changes. AREMP/PIBO habitat metrics most closely related to RSHC effects include pool-tail crest fines and the distribution of substrate particle sizes along stream bed transects.

Spatial and Temporal Sampling Design

All three programs (ODFW, PIBO, AREMP) use a rotating panel design to balance the benefits of having more sites (better for status assessments) with repeat visits to sites (better for trend assessment). ODFW uses four panels with different repeat intervals: annual, 3-year, 9-year, and sites that are only visited once. The sites are selected from 1st–3rd order streams on a 1:100,000-scale map as stratified by five monitoring areas. The sample size is large enough to allow post hoc analyses by ownership class. AREMP uses a hierarchical random sample based first on HUC12 subwatersheds, then on sites within them selected from the 1:100,000 NHD streams layer. The original plan was to sample 50 subwatersheds per year on a five-year repeating cycle. Financial and logistical constraints have pushed the repeat cycle to eight years. Identifying more watersheds and sites initially was important because sites had to be delayed or dropped due to fires and other unanticipated circumstances. On the eastside of the Cascade crest, the PIBO program also samples a randomly selected subset of HUC12s on a repeating cycle but only samples at one location at the lowest point in the stream network on federal land.

Assessment

Using linear statistical models, the ODFW (2019) analyzed the first 12 years of ODFW habitat data and generally found no trends for fine sediment in riffles; however, positive or negative trends were observed in other habitat variables. Twelve years is a relatively short time period to expect such changes.

In a study examining only the first five years of data, Anlauf-Dunn and Jones (2012) compared distributions of habitat values to minimally-disturbed reference conditions and found median fine sediment values at or above reference thresholds, whereas coarser gravel values were below reference.

A study by Al-Chokhachy et al. (2016) tested for a linkage between sediment delivery predicted by the GRAIP model with PIBO instream sediment data. Although they found a positive relationship, it was highly variable across sites, which they attributed to differences in topography, geology, and other human-caused sources (off road vehicle trails, cattle grazing, forest management). In their associated literature review, they found only eight studies that attempted to link streambed fine sediment to road measures and only one that found a strong (but again variable) relationship. Similarly, whereas (Dunham et al. 2023) found declines in active road miles over 25 years, along with declines in modeled connectivity/sediment, and instream fine sediment, they cautioned against expecting high correlation given the variety of factors that can influence in-channel sediment.