UNSTABLE SLOPE CRITERIA PROJECT:
OBJECT-BASED MAPPING WITH HIGHRESOLUTION TOPOGRAPHY

Answers to Six Questions from the CMER / Policy Interaction Framework Document

February 24, 2026

Approved by CMER on: Insert Date
Presented by the: Upslope Processes Science Advisory Group (UPSAG)
Co-chairs: Jennifer Parker and Michael Maudlin

Type of Product in Review:
Prospective Answers: ☐Charter ☐Scoping Document ☐Study Design
Retrospective: ☐ Completed Pilot/Study Phase ☒ Completed Final Study Report

Brief Description:
The current framework for identifying landslide-prone areas that are potentially sensitive to forest-practice activities is based on landforms. The regulated subset of landforms, known as Rule-Identified Landforms (RILs), and criteria for their identification include specific slope and geomorphic characteristics which were established through extensive surveys and analyses by the Washington Watershed Analysis Program and the Landslide Hazard Zonation Project (LHZ). The Unstable Slopes Criteria (USC) Project uses new data and analysis methods to evaluate RILs in accordance with the Habitat Conservation Plan's (HCP) adaptive management strategy.

The objective of this sub-project of the larger USC Project was to identify methods for consistent automated delineation of landforms using computer-based techniques and high-resolution lidar Digital Terrain Models (DTMs) and/or other data sources. The automated landform model will provide the baseline geomorphic context from which to evaluate landslide susceptibility and runout in future sub-projects, and it will incorporate data from process-based models to train the automated classification of landforms.

1. **Does the study inform a rule, numeric target, Performance Target, or Resource Objective?**

   Not on its own. The Unstable Slopes Criteria Project, of which this study is a sub-project, is intended to inform WAC-222-16-050.

2. **Does the study inform the Forest Practices Rules, the Forest Practices Board Manual guidelines, or Schedules L-1 or L-2?**

   Not on its own.

3. **Was the study carried out pursuant to CMER scientific protocols (i.e., study design, peer review)?**

   Yes. The study was designed by UPSAG and approved by CMER and ISPR. The final report has been approved by the Project Team, UPSAG and CMER. The document proceeded through and was approved by ISPR.

4a. What does the study tell us?

To provide discrete landform boundaries across the landscape that are produced efficiently using repeatable, consistent, and transparent methods, we chose to explore automated computer-based methods for landform mapping. We evaluated two approaches, both of which use lidar DEMs as the primary input data: Object-Based Image Analysis (OBIA) and a Virtual Watershed (VW) terrain analysis.

To evaluate the adequacy of OBIA and VW terrain analysis at landform delineation, the Project Team conducted several exercises over 2 phases:

- Phase 1 focused on spatial comparisons of computer-based map products and manually drawn map products and,
- Phase 2 was a qualitative evaluation of computer-based map products by subject matter experts.

Phase 1 of this sub-project provided valuable insight into the interpretation challenges that arise when remotely mapping rule-identified bedrock hollows and inner gorges. Both the computer and manual landform mapping methods were based on the criteria for unstable slopes and landforms in WAC-222-16-050 to identify Rule-Identified Landform (RIL) features (as described in Board Manual Section 16 and Section 1.1 of the final report). Some of these rules do not have a quantitative requirement and leave substantial room for individual interpretation. The inconsistencies in the manually drawn maps hindered our ability to reliably use them to evaluate the computer-drawn maps. However, these insights allowed us to take what we learned from Phase 1 and design an exercise for Phase 2 that focused on utilizing the subject-matter experts' knowledge of unstable slopes and RILs to evaluate the automated landform maps in a new way.

Automated models offer consistency and scalability, but their effectiveness hinges on the specification of input parameters. Our review of mapper feedback and topographic-attribute distributions provided actionable insights into where and why models produced results that deviated from expectations of Experienced Practitioners, offering a roadmap for refining these methods in the next phase of this project. Specifically, Phase 2 determined that targeted improvements to input parameterization, particularly those parameters controlling convergence and planform curvature thresholds, are needed to improve the models' abilities to accurately delineate bedrock hollows and inner gorges.

This study applied computer-based, automated methods for mapping discrete landforms. We have demonstrated that these methods can accommodate adjustments in landform definitions to meet subject-matter expert's interpretation of the rules governing delineation of bedrock hollows and inner gorges and of the topographic information available for discerning landform boundaries.

4b. What does the study not tell us?

The study did not tell us how to more effectively map landslide risk using remote methods, which was not an objective of this sub-project. At present, automated mapping methods may only be feasible for a subset of the RILs, and the study demonstrated that qualitative aspects of the definitions of those RILs precluded accurate delineation using automated methods because automated methods rely on quantitative 'rules' to define landform characteristics. These automated mapping methods will need continued development for use in subsequent Unstable Slopes Criteria sub-projects (further explained in section 5, below). These models are not intended to replace field review of individual Rule-Identified Landforms.

This precursor method development study did not evaluate landform susceptibility to landslides, including that of RILs as currently described. It only informed us whether we could objectively map a subset of RILs, for use in future planned sub-projects.

5. What is the relationship between this study and any others that may be planned, underway, or recently completed?

By implementing three sub-projects, the USC Project aims to answer the critical question:

What modifications to the unstable slopes criteria and delivery-assessment methods would result in more accurate and consistent identification of:

i. *unstable slopes and landforms,*
ii. *unstable slopes and landforms sensitive to forest-practices-related changes in landslide process, and*
iii. *locations susceptible to impacts from upslope landslides such that an adverse impact to public resources or a threat to public safety is possible?*

To start to answer these questions, the Project Team developed automated models designed to map landforms based on current RIL definitions. In the next sub-project, the models will expand upon what was learned in the first sub-project by delineating a set of landforms using an expanded suite of topographic attributes derived from lidar DTMs, including gradient, curvature, contributing area, topographic position, feature size, and the distance between features. The Project Team will evaluate how the landforms relate to existing landslide (and landslide runout) locations using density calculations. Landform criteria will be iteratively adjusted and re-evaluated against landslide data to determine if changes in the criteria could result in significant changes in landslide density by landform. We will also look at spatial and geographical changes in landslide densities. The result of this process of modifying the landform definitions to match regional variability in landslide location could inform forest practices rules or board manual guidance.

This study reports on a sub-project of the encompassing USC project. The next sub-project involves collection of detailed and precise landslide inventories, over a broader study area, using lidar differencing and machine-learning methods to identify statistical relationships with a broad range of terrain features. With this first sub-project, we have identified two computer models that both use lidar-derived DTMs as inputs but employ different methods to generate preliminary maps of bedrock hollows and inner gorges in five watersheds. With these two methods we will compare modeled landform maps with landslide densities, incorporating topographic elements to revise the modeled landform maps. An integrated map can be made from an ensemble of the two methods.

In subsequent sub-projects, the resulting landslide inventories, landform maps, and statistical analyses produced using this protocol will still undergo expert review and field validation to ground-truth mapped landslides and evaluate the relationship of mapped landforms to current RIL boundaries. If appropriate, the project team will use this information to develop field-based descriptions that refine landform criteria. We have engaged experts in sampling design and statistical analysis to aid in designing robust and informative review procedures.

6. What is the scientific basis that underlies the rule, numeric target, performance target, or resource objective that the study informs? How much of an incremental gain in understanding do the study results represent?

A fundamental basis for rule definitions, targets, and objectives is the assumption that geomorphically defined landforms can serve as proxies for landslide susceptibility. Although this sub-project does not evaluate landslide susceptibility (to be investigated during subsequent sub-projects using landform mapping products, as noted above), it does establish a repeatable, consistent, and transparent method for delineating landforms. These landforms can be adjusted to match site-specific landslide characteristics and will provide the baseline geomorphic context from which to evaluate region-specific landslide susceptibility and runout in later phases of this project.