NATURAL RESOURCES

Southern Willapa Hills Retrospective Study

January 2013

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Peter Goldmark - Commissioner of Public Lands

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Executive Summary

Washington State has a rigorous forest practices regulatory program, which regulates forest management activities in a way that protects public resources such as water, fish and wildlife on more than 12 million acres of private and state-owned forestlands. The forest practices regulatory program is flexible and responsive to new information, which provides the ability to make changes in protective measures as science and knowledge evolves. As new information or concerns develop, the issue can be addressed through the Forest Practices Adaptive Management Program and if warranted, Forest Practices (FP) rule and/or guidance changes recommended to the Forest Practices Board (the Board).

In 2007, a concern arose regarding how well unstable slopes protection in the FP rules was working after the December 1-3, 2007 storm event initiated numerous landslides on forestlands in the Chehalis Basin area. The Board requested follow-up analysis to address this concern. The study called *"The Mass Wasting Effectiveness Monitoring Project: An examination of the landslide response to the December 2007 storm in Southwest Washington"* (Stewart and others, 2012), and commonly referred to as the Post-Mortem study, was part of the follow-up effort.

The Post-Mortem study contained several findings associated with landslides and forest management. One such finding related to FP rule-identified landforms (RILs), which are potentially unstable geomorphic landforms that exhibit slope characteristics sensitive to forest management and are specifically defined in FP rules. The Post-Mortem study found that 50 percent of the study area harvested since 2001 contained at least one partially harvested RIL. This finding seemed inconsistent with FP rule implementation because a Forest Practices Application (FPA) with a RIL progresses through a rigorous review process that often restricts harvesting on a RIL. The apparent inconsistency between the Post-Mortem study findings and FP rules provided an opportunity to conduct a new, more focused, and specialized study called the Southern Willapa Hills Retrospective Study (Willapa Hills study), which reviewed a subset of the same geographic areas analyzed in the Post-Mortem study (See Appendix Maps 2, 3A-F).

The Willapa Hills study reviewed a subset of FPAs approved and harvested on industrial forestland between July 1, 2001 and December 1, 2007. The objectives of the Willapa Hills study were to:

- Verify if landslides initiated from within RILs or other types of landforms,
- Determine if timber harvest had occurred on RILs, and if so,
- Find if harvest on RILs was governed by a geotechnical report or an approved watershed analysis (WSA) mass wasting prescription in accordance with FP rules, and
- Evaluate the justification for harvest on the RILs.

Field investigators included an FP forester and one of two licensed engineering geologists (LEG) (FP "qualified experts") who field-reviewed 103 harvest-related landslides in 37 approved FPAs. The following are the major findings from both remote analysis and field observations:

- 71 landslides (69 percent) initiated from non-RILs (landforms not meeting FP rule criteria) (See Appendix Figure 1).

- 28 landslides (27 percent) originated from probable[1] RILs; five contained no trees harvested within the probable RIL, two were partially harvested, and 21 were completely harvested (See Discussion section Table 1and Appendix Figure 1).

- 4 landslides (4 percent) could not be determined due to the high volume of material evacuated from the feature that rendered post-failure field interpretation of the original landform impossible. Lack of pre-storm light distance and ranging (LiDAR) data inhibited pre-storm landform identification.

- 22 landslides that initiated in probable RILs where some level of harvest had taken place, were governed either under an FPA with a geotechnical report or under an approved WSA (See Discussion section Table 1).

- One landslide that initiated in a probable RIL and was harvested was not governed by a geotechnical report or an approved WSA (See Discussion section Table 1).

- FPA file documentation did not provide all information needed for study assessment. Geotechnical reports varied in content, the quality of some maps were poor (due to the scanning process) and complete historical documentation was not retained in the nine archived FPA files.

- Results regarding geotechnical report justification of allowed harvest on probable RILs were inconclusive on a study-wide basis due to insufficient information as described in the previous bullet.

Conclusions from the Willapa Hills study include the following:

- Landslides originated from both non-RILs and RILs;

- The majority of the landslides (69 percent) initiated from non-RILs (See Appendix Figure 1);

- 22 landslides that initiated in probable RILs where some level of harvest had taken place, were governed either under an FPA with a geotechnical report or under an approved WSA (See Discussion section Table 1);

- One landslide that initiated in a RIL was processed under standard FP rules as if a RIL was not present (See Discussion section Table 1);

- For the most part, FPAs were processed in accordance with FP rules. Study scope precluded the ability for authors to investigate the reason one FPA out of 37 FPAs with a probable RIL, that had some level of harvest, was not governed by a geotechnical report or an approved WSA;

[1] The modifier "probable" is used after field review by licensed engineering geologists and is due to the difficulty of determining the pre-landslide slope morphology. The word probable will be used associated with RIL for this purpose throughout the report.

- Given the majority of landslides initiated on non-RILs and landslides initiating from probable RILs that had no harvest on them at all (per field observations), it may be that the concentrated magnitude of the December 2007 storm event and its effects eclipsed the protection standards provided by FP rules;
- Due to time, financial, and remote sensing capability limitations, it is likely that some RILs were missed in the past and will be missed during future FPA screening, especially when they are small and separate from commonly traversed areas such as roads, drainages, and unit boundaries;
- The lack of available high-resolution LiDAR digital elevation model (DEM) data can limit the ability of FP foresters and geologists' to accurately and precisely characterize slope form when assessing an area in an FPA;
- FPA file documentation did not provide all information needed for study assessment. Geotechnical reports varied in content, the quality of some maps were poor (due to the scanning process) and complete historical documentation was not retained in the nine archived FPA files.
- Results regarding geotechnical report justification of allowed harvest on probable RILs were inconclusive on a study-wide basis due to insufficient information as described in the previous bullet.

Section 1: Introduction

Background

Washington State has a rigorous forest practices regulatory program, which prescribes forest management practices in a way that protects public resources such as water, fish and wildlife on more than 12 million acres of private and state-owned forestlands. Forest Practices (FP) are regulated through the Department of Natural Resources (DNR) FP program by means of the Forest Practices Act, established by the legislature, and the FP rules established by the Forest Practices Board (Board). The Board is charged with creating rules to protect the state's public resources while maintaining a viable timber industry. The Forest Practices Act applies primarily to all non-Federal and non-tribal forestland. FP rules address many types of protections, among them protections related to potentially unstable slopes.

The forest practices regulatory program is flexible and responsive to new information, which provides the ability to make changes in protective measures as scientific and other pertinent knowledge evolves. As new information or concerns develop, the issue can be addressed through the Forest Practices Adaptive Management Program and if warranted, FP rule and/or guidance changes recommended to the Board.

Periodically, natural events or new scientific knowledge cause the Board or involved stakeholder groups to consider changes in FP protective measures. The intense storm event of December

2007, that brought heavy precipitation and high winds to southwest Washington, was one such event. As much as 19 inches of rain fell near the Rock Creek drainage in Wahkiakum County. Wind gusts exceeded 80-miles per hour along the coast and more than 140 miles per hour at Radar Ridge just west of Naselle (DNR, 2009b).

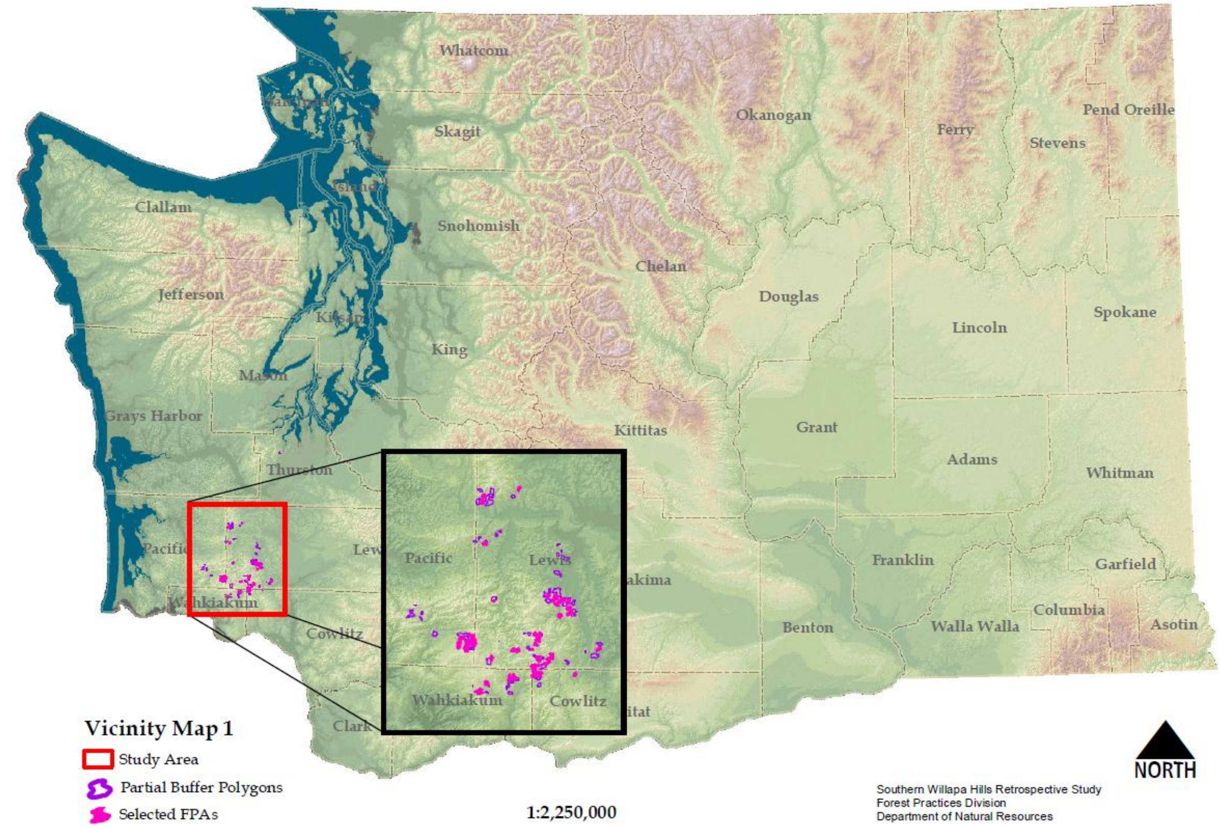
Heavy rain resulted in extensive flooding in the Chehalis River and deposited sediment and woody debris in forested streams and rivers. The strong winds and high rainfall combined with rapid snowmelt to cause severe downstream effects. The impact on forestland included extensive damage to forest roads, bridge washouts, numerous landslides, and substantial tree blow-down along the coast.

The Board devoted its February 13, 2008 board meeting to the December storm and its effects. Presentations were made to the Board describing the storm, its effects, and actions taken to assist recovery in the aftermath of the storm. The DNR Geology and Earth Resources Division (DGER) Manager provided a presentation that focused on landslides that occurred during the storm. In the aftermath of the storm, DGER surveyed and mapped more than 1,000 landslides in southwest Washington. More information can be found in the Division's report, *Landslide Reconnaissance Following the Storm Event of December 1-3, 2007 in Western Washington*.

The Board asked whether current FP rules had been followed in harvest units that contributed to storm damage, and whether FP rules were sufficient to protect against damage in future storms. The Board committed to a thorough review of the potential relationship between forest practices and the impacts of the storm.

In an attempt to help answer the Board's questions and to understand the relationship between forest practices and the impacts of the storm, a study was conducted by the Uplands Processes Scientific Advisory Group (part of the Cooperative Monitoring, Evaluation, and Research committee). The study, *"The Mass Wasting Effectiveness Monitoring Project: An examination of the landslide response to the December 2007 storm in Southwest Washington"* (Stewart and others, 2012), or Post-Mortem study, focused on landslides on forestland initiated during the 2007 storm. The study contained several findings associated with landslides and forest management; one such finding indicated that 50 percent of the study area harvested since 2001 contained at least one partially harvested rule-identified landform (RIL) (Stewart and others, 2012). This finding seemed inconsistent with FP rule implementation because a Forest Practices Application (FPA) with a RIL progresses through a rigorous review process that often restricts harvesting on a RIL. The apparent inconsistency between the Post-Mortem study findings and FP rules provided an opportunity to conduct this Southern Willapa Hills Retrospective study (Willapa Hills study), which reviewed a subset of the same geographic areas analyzed in the Post-Mortem study (See Appendix Maps 2, 3A-F).

The Willapa Hills study was conducted in southwest Washington, primarily in western Lewis County, but also involved adjacent portions of Pacific, Wahkiakum, and Cowlitz counties (See Vicinity Map 1 below).



Forest Practices Rules and Application Processing With Respect To Unstable Slopes

Specific FP rules address the potential for forest management-related landslides that could deliver sediment or debris to public resources or threaten public safety. Protection is provided through an outcome-based, decision-making process conducted in accordance with the Forest Practices rules and the State Environmental Policy Act (SEPA) (chapter 43.21C RCW; and chapter 197-11 WAC SEPA Rules). The only exception to this outcome-based, decision-making process occurs in areas where a watershed analysis (WSA) has been conducted and approved and management prescriptions are in place to address potentially unstable slopes. Additionally, the WSA prescriptions must be specific to the site or situation and not call for additional analysis (WAC 222-16-050(1)(d)(iii)). In these cases, proposed timber harvest and road construction activities on potentially unstable slopes must adhere to the approved management prescriptions stated in the WSA. The details of the WSA process as outlined in WAC222-22 are described later in this section.

The first step in the outcome-based decision making process is a review of FPAs. All FPAs are reviewed to determine the class of the application as well as screened for other administrative purposes. Forest practices are classed based on the potential for the proposed activity to adversely affect public resources – from Class I forest practices that have no direct potential for damaging a public resource to Class IV–Special forest practices that have the greatest potential for impact. During review, the applications are screened for potentially unstable slopes using data provided by Geographic Information Systems (GIS) and remote sensing review of aerial photographs, maps, and local knowledge. When unstable slopes are potentially present, FP foresters conduct a field review and assess those areas indicated by the screening. If the field review and consultation with an FP geologist confirm the presence of a potentially unstable slope(s) and timber harvest and/or road construction is proposed in those areas, the FPA is classified as Class IV-Special and becomes subject to review under SEPA, adding additional rigor to the review process. If the potentially unstable slope is bounded out of the FPA or if the FPA follows "specific" mass wasting watershed analysis prescriptions for unstable slopes, the FPA is a Class III and is not required to go through the SEPA process.

Class IV-Special forest practices related to unstable slopes include – as described in WAC 222-16-050 (1)(d) – timber harvests, or construction of roads, landings, gravel pits, rock quarries, or spoil disposal areas, on potentially unstable slopes or landforms (see WAC 222-16-050 (1)(d)(i) below) that have the potential to deliver sediment or debris to a public resource or that have the potential to threaten public safety, and which has been field verified by DNR.

Potentially unstable slopes are often identified according to dominant landform type. WAC 222-16-050 (1)(d)(i) recognizes five groupings of potentially unstable slopes. These groups are often referred to as "Rule Identified landforms":

- Inner gorges, convergent headwalls, or bedrock hollows with slopes steeper than 35 degrees (70 percent);
- Toes of deep-seated landslides, with slopes steeper than 33 degrees (65 percent);
- Groundwater recharge areas for glacial deep-seated landslides;
- Outer edges of meander bends along valley walls or high terraces of an unconfined meandering stream; or
- Any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes.

FPAs classed as Class IV-Special require compliance with both the Forest Practices Act and SEPA because they have the potential for a substantial impact to the environment. SEPA provides a way to identify possible environmental impacts that may result from governmental decisions. Through this process, DNR evaluates proposed timber harvest and construction activities on potentially unstable slopes to determine if the activities will have a "probable significant adverse impact." The determination is based on the agency's evaluation of the proposal – conducted in consultation with other agencies and affected tribes – as well as comments received from interested parties through the SEPA review process.

The SEPA rules require applicants to complete an environmental checklist for Class IV-Special FPAs. The checklist is a detailed listing of potential environmental impacts associated with the proposed activity. The Board has established additional SEPA policies that are specific to forest practices (WAC 222-10-030). These policies require, in part, specific mitigation measures or conditions designed to avoid accelerating rates and magnitudes of mass wasting that could deliver sediment or debris to a public resource. The policies also require applicants to conduct and submit a geotechnical assessment of proposed forest practice(s) prepared by a qualified expert. A qualified expert is a licensed engineering geologist (LEG) with at least three years of experience in evaluating relevant problems in forestlands (WAC 222-10-030 (5)).

In addition to reviewing information submitted by the applicant, DNR staff conduct their own evaluation of proposals involving potentially unstable slopes, including a review of the applicant's geotechnical assessment. The evaluation often includes document and field review by an FP geologist and/or interdisciplinary team. FP geologists are both "qualified experts" and LEGs. Interdisciplinary team members typically represent other agencies and affected tribes and often have expertise with potentially unstable slopes.

After reviewing the proposal, consulting with other agencies and affected tribes, and considering comments received from other interested parties through the SEPA review process, DNR issues a decision under SEPA commonly known as a "threshold determination." In making a decision, FP rules require DNR to consider:

- if the proposal is likely to increase the probability of mass movement on or near the site,
- whether sediment or debris would be delivered to a public resource or be delivered in a manner that would threaten public safety, and
- whether such movement and delivery are likely to cause significant adverse impacts (WAC 222-10-030(2)).

If DNR determines the proposed activities are likely to have a probable significant adverse impact, a "determination of significance" is issued and the applicant must prepare an Environmental Impact Statement (EIS) in accordance with SEPA requirements. If DNR determines the adverse impacts identified in the EIS are significant and reasonable measures are insufficient to mitigate the impacts, the FPA is denied. If DNR determines the proposed activities are not likely to have a probable significant adverse impact, a "determination of non-significance" (DNS) is issued and the FPA is approved. When the landowner proposes sufficient methods of protection for public resources in the SEPA process, a Mitigated Determination of Non-Significance (MDNS) is issued which results in an approved FPA. Additionally, in many cases, DNR's approval of an FPA contains "conditions" or additional requirements with which the applicant must comply. The conditions usually include protection measures that must be implemented to mitigate impacts to public resources associated with the proposal.

Mitigation measures range from avoiding potentially unstable slopes to altering the methods or techniques used in timber harvest and/or construction operations. Potentially unstable slopes avoidance is the most commonly used mitigation measure and results in the lowest hazard and risk. Where timber harvest and/or road construction activities occur on potentially unstable slopes, a variety of mitigation measures are employed to reduce the likelihood of mass wasting. Possible mitigation measures can include but are not limited to; full suspension log yarding to reduce soil disturbance and damage to residual vegetation and measures that relate to the design and/or location of roads, drainage structures, and landings. Full-bench end-haul (i.e. no fill or sidecast material) construction techniques are routinely required on side slopes that exceed a gradient of 60 percent, which have the potential to deliver sediment to any typed water or wetland. Where fill material is necessary, the use of quarried rock rather than "native" soil or fill is often required to increase the structural strength of road prisms and stream crossings. These are just a few examples of the many mitigation measures used to address potentially unstable slopes. The measures used in a given situation are dependent upon the nature of the impact being mitigated.

The WSA process is addressed in WAC 222-22. The purpose of WSA rules is to address cumulative effects of forest practices on public resources in a watershed. The rules establish a system for identifying the probability of change and the likelihood of this change adversely affecting public resources and for developing and using forest management prescriptions to avoid or minimize significant adverse effects from forest practices. The process involves interdisciplinary teams of highly qualified individuals assessing within a watershed, the state of the resources, areas of resource sensitivity and vulnerability, and creating maps that show the location of these areas. A team of experts writes prescriptions based on the resource sensitivity and vulnerability information, which indicate restrictions that must be followed during forest management on these mapped areas to protect both public resources and public safety. By law, the prescriptions must be designed to provide forest landowners and operators with as much flexibility as is reasonably possible while addressing the area of resource sensitivity.

During the prescription process authors do not write prescriptions to restrict activities when there is no need. Prescriptions are written as a result of observing resource harm; hence in the areas lacking prescriptions the resources' sensitivity was low. The expert analyses, resource sensitivities maps, and prescriptions (i.e. Draft watershed analysis) are all submitted to DNR for review and either approval or disapproval.

DNR selects prescriptions and circulates the draft watershed analysis to the State Departments of Ecology and Fish and Wildlife, affected Indian tribes, local governmental entities, forest landowners in the watershed and the public for review and comment. The draft watershed analysis is also processed through SEPA where an additional rigorous review process (including public input) takes place. DNR has 30 days from the receipt of prescriptions to approve or disapprove the draft watershed analysis.

Once a watershed analysis is approved, applicants can choose to follow the WSA prescriptions or not. When applicants follow the WSA prescriptions for particular resource sensitivities, the FPA is a Class III application (unless the prescription is not "specific") for that resource sensitivity. When applicants choose not to follow the WSA for particular resource sensitivities, the FPA is a Class IV-Special application for that resource sensitivity and must go through the SEPA process.

Prescriptions are either "specific" or "non-specific" (See Appendix, Table 2, for approved WSA prescriptions in the study area). Specific prescriptions give clear direction on how to protect public resources for that area. When a WSA contains a specific prescription the applicant will follow the specific prescription; and the FPA is a Class III application. "Non-specific" prescriptions are more general and require extra scrutiny by a geologist, engineer, or qualified expert[2]. FPAs following non-specific mass wasting WSA prescriptions are Class IV-Special, go through SEPA, and overwhelmingly require a qualified expert review or report (DNR 2009a).

By law, DNR cannot further condition FPAs in an area of resource sensitivity in a watershed administrative unit (WAU) where the applicant will use a prescription contained in the WSA. DNR also cannot further condition FPAs outside an area of resource sensitivity in a WAU except

[2] WSA usually required that an engineer, a geologist, or expert on slope instability to field verify the conditions on site and determine how the issues will be addressed. These numerous experts are identified in WAC-222-10-030 (5) as qualified experts.

for reasons other than the watershed processes analyzed in the approved WSA or to correct mapping errors, misidentification of soils, landforms, vegetation, or streams features or other similar factual errors.

When no prescription exists in the approved WSA for a particular activity regarding particular resource sensitivities, it is because the prescription writers and draft WSA reviewers did not see a need for prescriptions restricting that activity due to low risk to public resources.

Approved WSAs must periodically go through reanalysis (as determined by DNR) to keep them current. When a reanalysis is necessary DNR must notify forest landowners in the WAU that a reanalysis is required. If no forest landowners in the WAU want to participate and commit resources to the reanalysis, DNR can rescind the prescription(s) it identified for reanalysis.

Study Objectives:

The objectives for the Willapa Hills study were:

- Verify if landslides initiated from within RILs or other types of landforms,
- Determine if timber harvest had occurred on RILs, and if so,
- Find if harvest on RILs was governed by a geotechnical report or an approved WSA mass wasting prescription in accordance with FP rules, and
- Evaluate the justification for harvest on the RILs.

Section 2: Methodology

Selecting landslides for field-review for the Willapa Hills study necessitated several digital datasets and analysis in GIS. The following describes the databases and steps used to analyze data for this study. The first step was to rectify Post-Mortem study landslide points with more recent (2008) post-storm orthophotography to ensure correct location for field verification. The second step determined which of those landslides were located in an approved FPA with specific criteria. The last steps included FPA documentation review, remote sensing review and field verification.

Landslide Inventory

Data analysis began with obtaining landslide data points that had been used for the Post-Mortem study. Stewart (personal communication, 2012) provided the Post-Mortem landslide inventory as point data. This GIS shapefile contains tabular data including the interpreted RIL where the landslide initiated. Participants in the Willapa Hills study found that the Post-Mortem landslide data points did not correlate well with post-storm aerial photographs flown and orthorectified in spring 2008; so, the Willapa Hills study rectified the landslide points to correspond with the potential landslide initiation areas observed in the orthophotographs. Rectification consisted of relocating Post-Mortem data points from areas near a landslide to the nearest landslide head visible on 2008 orthophotographs. Sixteen additional landslides not provided in the Post-Mortem data were identified in 2008 orthophotographs and were included in the Willapa Hills landslide inventory.

While rectifying data, it was decided that road related landslides would be excluded from the Willapa Hills study due to their complexity, difficulty of determining initiation cause, and time and budget limitations. Many factors influence road-related landslides and contribute to their complexity including: road location, road construction techniques, maintenance frequency, spacing and size of drainage culverts, cut and fill slope angles, and drainage area above the road.

Forest Practices Application Areas

The Willapa Hills study was focused only on landslides that occurred in approved FPA areas with defined characteristics. Therefore, FPA polygon data (i.e. the area of approved harvest units) included in the Willapa Hills study, were selected from FPAs that met the following criteria:

- Timber harvest FPAs received and approved by DNR, and harvested between July 1, 2001 (the enactment date of current FP rules) and the date of the 2007 storm event.
- FPAs that had at least 10 percent of their area overlap with Post-Mortem study Partial Buffer polygons (See Glossary below) were included because according to the Post-Mortem study the Partial Buffer polygons indicated the presence of at least one harvested RIL. Areas with less than 10 percent overlap may not provide a representative sample and could have resulted from mapping errors.
- FPAs with non-road-related landslides that resulted from the 2007 storm within the FPA/Partial Buffer polygon overlap.

Rectified landslide points that fell within these FPA and Partial Buffer polygons were selected as a landslide for field-review. Landslides must have initiated within the FPA. This permitted a relatively simple analysis of FP rules, WSA prescriptions, and forest management activities conducted within the FPA. FPAs that failed to meet the above criteria were excluded from the study.

FPA Documentation Review, Remote Sensing Review, and Field Verification

All selected landslides went through the following three step review process.

FPA Documentation Review

FPA files were reviewed to determine presence of a geotechnical report, or coverage by an approved WSA, and justification for harvest on RILs. The Study authors wanted to understand what factors influenced timber harvest layout and execution on or near 2007 landslides.

Mass wasting map units[3] from approved WSAs including: Stillman Creek (Weyerhaeuser Timber Company, 1994), Willapa Headwaters (Weyerhaeuser Timber Company, 1994a), Chehalis Headwaters (Weyerhaeuser Timber Company, 1994b), and North Elochoman

[3] Mass wasting map units are spatial data representing areas with similar mass wasting characteristics and triggering mechanisms typically at the watershed adminstrative unit (WAU) level. The mechanisms are the specific geomorphic processes that appear to contribute to mass wasting. Unique units are described if the mass wasting processes are similar (e.g., shallow debris flow), but the triggering mechanisms are different (e.g., roads versus loss of root strength on hillslopes).

(Washington Department of Natural Resources, 1996) were geographically rectified in GIS (See Appendix Map 4). The overlap of WSA and FPA layers permitted the identification of applicable mass wasting maps units and associated harvest prescriptions for each FPA and the landslides within them. All harvest prescriptions were reviewed for each of the WSAs.

Remote Sensing Review

The remote sensing portion of the review examined pre- and post-storm aerial imagery (See Glossary), digital derivatives of both two meter grid light distance and ranging (LiDAR) digital elevation model (DEM) analysis (limited extent, See Appendix Map 5) and 10 meter grid DEM analysis. Of the 3,131 acres reviewed within selected FPAs, 889 acres (28 percent) had pre-2007 storm LiDAR coverage.

Initial GIS review characterized a landslide's size, slope form, and possible pre-storm landform. Landslide perimeters were digitized using the 3-dimensional (3-D) photogrammetry program Socket Set® with 2008 orthophotographs in GIS by a professional photogrammetrist. The 2008 aerial imagery, rectified Post-Mortem study landslide point data, and digitized landslide perimeters were overlaid in GIS to determine whether landslides were road related and, if so, they were subsequently excluded from this study.

The LiDAR DEM permitted remote review of potential[4] RILs (e.g. bedrock hollows and inner gorges) using a simple slope-convergence modeling technique (see explanation below). The model, called the Landform Remote Identification Model (LRIM: Slaughter, 2009), overestimated potential RILs (outputs consisted of very convergent and steep (>68 percent) slopes), but model outputs permit simple location of potential RILs for field verification. The overestimation helped to ensure that the study would not miss any RILs in areas with LiDAR DEM coverage. Separate approaches were used for areas with pre-storm LiDAR and areas without. In areas with pre-storm LiDAR, LRIM helped evaluate potential RILs for comparison to the head (uppermost area of a landslide) of 2007 landslides. Clusters of more than 10 pixels, identifying steep and convergent slopes, typically indicated a potential RIL (See Appendix Map 6). Additional criteria measured from pre-storm LiDAR DEM review included landform shape at the head of the landslide (e.g. convergent, planer, divergent). Finally, data collected from pre-storm aerial imagery and GIS data were compared to post-storm orthophotographs and field data to describe and categorize buffers on landslides from probable RILs and non-RILs.

In areas without pre-storm LiDAR, included landslides were reviewed using 2003 orthophotography and measured with 3-D photogrammetry to characterize landforms prior to slope failure. To approximate the landform detail provided by pre-storm LiDAR, a small DEM encompassing the landslide initiation area was created with 3-D photogrammetry from 2003 and 2008 orthophotographs. Study participants intended to apply LRIM to the small DEMs to model pre-storm slope and convergence. Unfortunately, pre-harvest forest cover present in 2003 orthophotographs prevented accurate ground elevation determination with sufficient detail to determine pre-landslide landforms and the exercise proved ineffective. Thus, only a fraction of the 103 landslides were analyzed remotely, so the data are not included in this study.

[4] The modifier "potential" is used because RIL validation requires field assessment by a qualified expert and these RILs were identified by the Landform Remote Identification Model.

Field Review
In the Willapa Hills study, approximately 48 percent of Post-Mortem study Partial Buffer polygons were sampled during field review. Field review was performed by an LEG ("qualified expert") and an FP forester.

Fieldwork began August 13, 2012, and concluded September 26, 2012. Landslides were located with orthophotographs and the rectified landslide data points uploaded into a global positioning system (GPS). At each landslide head, an LEG and an FP forester documented landslide characteristics including geology, surrounding slope form and likely landslide initiation point. Width and depth of the head of the landslide scar were measured with a laser range finder. Slope gradient adjacent to the landslide scar was measured in slope percent with a clinometer. A digital photograph was taken at most landslides. The final step was an estimation of the presence, likelihood, and likely type of pre-landslide RIL that existed before the 2007 storm. Field review corroborated, clarified, or refuted remote sensing assessments of potential RILs. Authors reviewed all selected landslides in harvested areas with two exceptions; a small landslide nested in a larger landslide that could not be approached or walked upon safely, and a small landslide that was part of a larger landslide and could not be located.

Challenges of the Willapa Hills Study

- RIL interpretation is inherently difficult. Conducting a post-landslide descriptive study five years after landslides initiated is extremely difficult. This is especially apparent when attempting to collect accurate, pre-storm, field measurements of a landslide scar from a slope that no longer exists. Additional head-cutting, secondary scarp failures, or slope ravel can alter the landslide scar and mask visual evidence of landslide origins, initiation area, and initial size. In addition, the head of a landslide does not necessarily indicate the area of landslide initiation. For example, a landslide may have initiated in a RIL and subsequent upslope head-cutting can create the appearance that the landslide initiated upslope of the true initiation area. Thus, it can be assumed that the failure originated from the most unstable landform associated with a landslide, but without observing the sequence of failures, origins cannot be specifically located.

- Remote identification of potential RILs is extremely challenging in areas where LiDAR was not available. LRIM applied to areas with pre-storm LiDAR proved effective at remotely locating landforms with grid clusters greater than 10 pixels and required field review by an LEG. After thorough field review, many LRIM grid clusters were determined non-RILs. Though LRIM over-predicts RILs, the intent is to ensure field review of all areas that may be a potential RIL. An example of how well the combination of LRIM and LiDAR worked together was the fact that together they picked up on a probable RIL as small as 40 feet wide and 40 feet long. These smaller RILs can evade scrutiny during remote review, timber sale layout, and the FPA review process. Bedrock hollows were the most commonly harvested RIL type, which was likely because bedrock hollows are commonly located mid-slope and can be masked by thick groundcover and underbrush.

- The application of 3-D photogrammetry to assess pre-landslide landforms using 2003 orthophotographs proved largely unsuccessful. Pre-harvest canopy cover reduced the analyst's ability to accurately determine ground surface elevation and generate a DEM. In areas harvested prior to 2003, DEMs were created that allowed modeling with LRIM. The process followed by the Willapa Hills study photogrammetrist showed promise for assessing landforms prior to failing by using orthophotographs collected before landform failure (landslide), and after timber harvest. Areas with available historic orthophotographs not obscured by canopy cover can generate DEMs of sufficient resolution to apply LRIM. In the future, this analysis can allow interested individuals the opportunity to model pre-landslide landforms.

Section 3: Results

Willapa Hills study participants field-reviewed and remotely analyzed 103 landslides and found the following:

- 71 landslides (69 percent) initiated from non-RILs (landforms not meeting FP rule criteria) (See Appendix Figure 1).
- 28 landslides (27 percent) originated from probable[5] RILs; five contained no trees harvested within the probable RIL, two were partially harvested, and 21 were completely harvested (See Discussion section Table 1 and Appendix Figure 1).
- 4 landslides (4 percent) could not be determined due to the high volume of material evacuated from the feature that rendered post-failure field interpretation of the original landform impossible.
- 22 landslides that initiated in probable RILs where some level of harvest had taken place, were governed either under an FPA with a geotechnical report or under an approved WSA (See Discussion section Table 1).
- One landslide that initiated in a probable RIL and was harvested was not governed by a geotechnical report or an approved WSA (See Discussion section Table 1).
- FPA file documentation did not provide all information needed for study assessment. Geotechnical reports varied in content, the quality of some maps were poor (due to the scanning process) and complete historical documentation was not retained in the nine archived FPA files.
- Results regarding geotechnical report justification of allowed harvest on probable RILs were inconclusive on a study-wide basis due to insufficient information as described in the previous bullet.

[5] The modifier "probable" is used after field review by licensed engineering geologists and is due to the difficulty of determining the pre-landslide slope morphology. The word probable is used associated with RIL for this purpose throughout the report.

Section 4: Discussion

FP rules and approved WSA mass wasting prescriptions seek to minimize sediment delivery to typed waters from forest management activities on or adjacent to unstable slopes, in part, by restricting timber harvest on RILs. Therefore, when the Post-Mortem study indicated that 50 percent of their study area harvested since July 1, 2001 contained at least one partially harvested RIL, the FP program opted to conduct this new, more focused, and specialized study. The study sampled a subset of the same geographic areas analyzed in the Post-Mortem study. The Willapa Hills study intended to:

- Verify if landslides initiated from within RILs or other types of landforms,
- Determine if timber harvest had occurred on RILs, and if so,
- Find if harvest on RILs was governed by a geotechnical report or an approved WSA mass wasting prescription in accordance with FP rules, and
- Evaluate the justification for harvest on the RILs.

When discussing the Willapa Hills study it is important to note the FP rules are directed at protecting public resources on a statewide basis when conducting forest practices activities and are not necessarily meant to provide protection for public resources during extreme or catastrophic events. Rare events, like extreme precipitation during the 2007 storm, create an environment where landslides can occur in any timber age, regardless of protection, and possibly on more gentle slopes than is typical. No comparable large storm was recorded since the 1920's (Sarikhan, 2012). This was further compounded by the geological characteristics of the interaction of thick, basalt-derived soils with the extreme precipitation found on the Willapa Hills landscape (Sarikhan, 2008).

The following discussion focuses primarily on landslides originating from probable RILs. Twenty eight (27 percent) of the 103 landslides observed in the Willapa Hills study originated from probable RILs and four landslides (4 percent) were indeterminable. The remaining 71 landslides (69 percent) originated from non-RILs. The non-RIL landslides include areas that did not display sufficient slope steepness or slopes convergence to qualify as a RIL, specifically they did not meet FP rule requirements to qualify as a bedrock hollow or inner gorge. Therefore, the following discussion describes the findings for those 27 percent that were probable RILs located in the Willapa Hills study area. In this study the overall confidence for identification of non-RILs and RILs is moderate[6].

The study's field observations to determine slope gradient and morphology (i.e. convergence) were based on the area adjacent to a landslide scar. Geologists used slope gradient as the primary method to identify probable RILs, followed by slope morphology. Geologist confidence was

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[6] Confidence level rating is based on Peterson (2008).

High confidence generally indicates judgments based on high-quality information, and/or the nature of the issue makes it possible to render a solid judgment. However, high confidence judgments still carry a risk of being wrong.

Moderate confidence generally means credibly sourced and plausible information, but not of sufficient quality or corroboration to warrant a higher level of confidence.

Low confidence generally means questionable or implausible information was used, the information is too fragmented or poorly corroborated to make solid analytic inferences, or significant concerns or problems with sources existed.

higher with smaller landslide scars, where the surrounding landscape could be easily observed and analyzed. However, as the landslide size increased, geologist's confidence decreased because the adjacent area was not an appropriate surrogate for pre-landslide conditions. In some cases, dense vegetation such as firs and alder obscured the surrounding landscape, complicating geologist observations and analysis.

Twenty-eight of the 103 landslides observed originated from a probable RIL within an approved FPA. The FP rules provide a process for assessing risk of potentially unstable slopes so that appropriate protection measures can be applied when needed (as explained above in the FP rules section). The Willapa Hills study field investigation revealed that out of 28 probable RILs that failed, five probable RILs had no harvest on them, two probable RILs had partial harvest on them and 21 probable RILs were completely harvested (see Table 1 below). Given this information, the next logical step was to determine what governed harvest protection measures in the FPAs on probable RILs with harvest (23 out of 28 landslides). The Willapa Hills study also sought to determine what justification was used to allow for the harvest. This information would help determine if FPAs were administered in accordance with FP rules.

There are two methods in the FP rules for governing harvest on potentially unstable slopes: approved WSA mass wasting prescriptions and FP required geotechnical reports prepared by qualified experts. Table 1 shows that 23 probable RILs had some level of harvest, 19 occurred in FPAs under approved WSA mass wasting prescriptions (17 of which also had a geotechnical report), three occurred in FPAs containing a geotechnical report by a qualified expert and one was approved without either the inclusion of WSA mass wasting prescriptions or a geotechnical report.

Approved WSAs can include prescriptions that indicate restrictions that must be followed during forest management activities or a requirement to obtain additional analyses for areas of resource sensitivity. WSA prescriptions have been categorized by DNR into three groups for FPA processing:

- No approved WSA mass wasting prescriptions written,
- Specific approved WSA mass wasting prescriptions, and
- Prescriptions that are not specific (non-specific prescriptions).

The classification of the FPAs differs based on the following types of WSA prescriptions:

- When no WSA mass wasting prescriptions were written, the FPA is a Class III because the WSA prescription authors and draft WSA reviewers did not see a need for prescription restrictions due to low risk to public resources.
- When a specific approved WSA mass wasting prescription is being followed, the FPA is a Class III (unless there are other non-related reasons for a Class IV-Special such as the presence of threatened and endangered species). Specific WSA prescriptions provide clear direction on what protections are needed for the resource sensitivity.
- Approved WSA mass wasting non-specific prescriptions direct the applicant to obtain additional scrutiny by a geologist, engineer, or qualified expert and often require the applicant to submit a geotechnical report.

The process of classifying FPAs that follow a non-specific prescription has changed since the 2007 storm. Prior to the 2007 storm these FPAs would have been a Class III FPA as long as they contained the required supporting information (such as a geotechnical report) required by the WSA prescription. Since the 2007 storm, the FP program has issued new FP guidance requiring FPAs following approved WSA non-specific mass wasting prescriptions for timber harvest in a particular resource sensitivity area to be a Class IV-Special (DNR, 2009a), requiring the preparation of a geotechnical report by a qualified expert and requiring the FPA to go through SEPA.

Table 1 shows that of the 19 probable RILs in approved WSA areas with harvest on them 17 also had a geotechnical report. The Willapa Hills study evaluated the FPAs for the 19 landslides occurring on probable RILs, and found:

- In areas where eight of the landslides occurred there were no existing approved WSA mass wasting prescriptions for timber harvest,
- There were specific approved WSA mass wasting prescriptions for timber harvest in areas where two of the landslides occurred, and,
- Nine landslides occurred in areas where approved WSA mass wasting prescriptions offered the FPA applicants a choice between a specific prescription and a non-specific prescription which required the preparation of a geotechnical report. Geotechnical reports had been submitted with the FPAs associated with all nine landslides. Of these nine landslides, the FPA file documentation clearly showed that five of the landslides were in an FPA where the applicant chose the non-specific prescription option and submitted the required geotechnical report. The remaining four landslides were in an FPA that did not clearly state that the applicant had selected the non-specific prescription option, however, it is assumed the applicant did chose the non-specific prescription option because the FPA had an accompanying geotechnical report. Additionally, this FPA had been submitted by the same applicant who submitted the FPA showing clearly that the applicant had chosen the non-specific prescription option.

Since the beginning of the WSA process, a total of 52 watershed analyses have been completed statewide. When new FP rules were adopted in 2001 as a result of the 1999 Salmon Recovery Act, some of the WSA prescriptions became less relevant because the new FP rules incorporated many of the prescriptions learned through the WSA process into a new, more protective set of rules. At that time, RIL definitions were incorporated into the Class IV-Special requirement in WAC 222-16-050 and SEPA policies were added for potentially unstable slopes and landforms, including qualified expert requirements. The Board in response to the 2007 storm, through the adaptive management process, adopted new rules requiring periodic review by DNR of approved WSA and the ability for DNR to require reanalysis of approved WSA mass wasting prescriptions. The new rules allow DNR to rescind approved WSA mass wasting prescriptions when landowners choose not to conduct mass wasting prescription reanalysis. For those approved WSA containing rescinded mass wasting prescriptions, landowners will be required to apply the standard FP rules for potentially unstable slopes. DNR is in the process of rescinding the mass wasting prescriptions for 35 out of the 52 approved WSAs. The process will be complete as soon as the SEPA process is completed.

The Willapa Hills study shows, for the most part, FPAs were processed in accordance with FP rules. Twenty-two out of 23 landslides initiating in a probable RIL occurred in FPAs containing approved WSA mass wasting prescriptions or a geotechnical report prepared by a qualified expert. The FPAs under WSA mass wasting prescriptions were classed according to the WSA prescription categories at the time. However, one out of the total 37 FPAs containing the 23 landslides initiating in a probable RIL, did not have a geotechnical report or was not covered by an approved WSA. This FPA could have been processed/analyzed more thoroughly (see Table 1 below). It is unknown why this particular probable RIL was not identified in the FPA. It may have been missed in the FPA screening process due to screening tool limitations such as a lack of LiDAR coverage. Better screening tools such as LiDAR would help to ensure a greater number of potential RILs in an FPA are identified. Study scope precluded authors from further investigating why the probable RIL was not identified.

The Willapa Hills study intended to compare all landslides that initiated in probable RILs on approved FPAs, with their accompanying geotechnical reports, to verify required protection and how it was applied. However, due to the varied quality of FPA documentation and FPA availability this step was not feasible. FPA file documentation contained geotechnical reports that varied in content, poor quality copies of maps (most likely due to the scanning process) and a lack of complete historical documentation in the nine FPA files that had been archived. Geotechnical content was found to vary considerably. Justification within geotechnical reports ranged from observations of adjacent harvest units on similar terrain that contained no observable landslides to an explanation of a landform's inability to deliver sediment to a public resource. Available file documentation in files ranged from summary documents (primarily in archived files) to complete FPA documentation. The lack of high quality documents, standard content in geotechnical reports and missing documentation are important. FP foresters need reliable and high quality documentation for screening, geologists need standardized documentation to analyze geotechnical reports and retrospective examinations of operational processes require complete FPA documentation. The FP Program has addressed the issue of varied content found in geotechnical reports. The FP Program recognized in 2006 that content of geotechnical reports varied and issued new FP guidance (DNR, 2006) that delineated standardized content for geotechnical reports. When reports are submitted without the standard information, the FPA is rejected as incomplete and disapproved.

Table 1. Documents governing forest management activities, harvest type, and RIL type for landslides originating from probable RILs. Data were collected 8/13/12-9/26/12 by Forest Practices Division for the Southern Willapa Hills Retrospective Study. See Appendix Figure 2 for a visual representation of Table 1.

	No harvest			***Partial harvest***		***Complete harvest***				
Governing document(s)	**BH**[1]	**Inner gorge**	**Toe of deep-seated landslide**	**BH**	**Inner gorge**	**BH**	**Inner gorge**	**Toe of deep-seated landslide**	**Other instability**	**Total**
geotech[2], WSA	-	2	-	-	1	10	1	3	2	**19**
geotech only	-	-	-	-	-	1	2	-	-	**3**
WSA only	1	-	-	1	-	1	-	-	-	**3**
FP rules	-	-	2	-	-	-	1	-	-	**3**
Total	**1**	**2**	**2**	**1**	**1**	**12**	**4**	**3**	**2**	**28**

[1]Bedrock hollow, [2]geotechnical report

Section 5: Conclusions

Willapa Hills study objectives were, for the most part, met:

- Landslides originated from both non-RILs and RILs;
- The majority of the landslides (69 percent) initiated from non-RILs (See Appendix Figure 1);
- 22 landslides that initiated in probable RILs where some level of harvest had taken place, were governed either under an FPA with a geotechnical report or under an approved WSA (See Discussion section Table 1);
- One landslide that initiated in a probable RIL was processed under standard FP rules as if a RIL was not present (See Discussion section Table 1);
- For the most part, FPAs were processed in accordance with FP rules. Study scope precluded the ability for authors to investigate the reason one FPA out of 37 FPAs with a probable RIL, that had some level of harvest, was not governed by a geotechnical report or an approved WSA;

- Given the majority of landslides initiated on non-RILs and landslides initiating from probable RILs that had no harvest on them at all (per field observations), it may be that the concentrated magnitude of the December 2007 storm event and its effects eclipsed the protection standards provided by FP rules;

- Due to time, financial, and remote sensing capability limitations, it is likely that some RILs were missed in the past and will be missed during future FPA screening, especially when they are small and separate from commonly traversed areas such as roads, drainages, and unit boundaries;

- The lack of available high-resolution LiDAR DEM data can limit FP foresters and geologists' ability to accurately and precisely characterize slope form when assessing an area in an FPA;

- FPA file documentation did not provide all information needed for study assessment. Geotechnical reports varied in content, the quality of some maps were poor (due to the scanning process) and complete historical documentation was not retained in the nine archived FPA files;

- Results regarding geotechnical report justification of allowed harvest on probable RILs were inconclusive on a study-wide basis due to insufficient information as described in the previous bullet.

Section 6: Recommendations

- The FP program should consider adopting a longer FPA records retention schedule either in paper or electronic format.

- The FP program should continue focusing on improved documentation by FP staff and submitted geotechnical reports associated with FPAs.

- The state should aquire both LiDAR coverage and an accepted convergence model at a minimum for recognized areas of potentially unstable slopes in the state. This would allow for better identification of potentially unstable landforms for land managers and would improve FPA screening for those landforms. It may be possible to reduce costs of acquiring these products through cooperation with landowners; federal, state and local government agencies; as well as Tribes.

- It would be beneficial to assess FP program needs for producing high resolution copies of all documents and to invest in products and/or process changes to ensure production of the high quality documents needed for successful FP operations. A part of the solution may include acquiring better scanning equipment.

Glossary

Aerial imagery- Combination of orthophotography and LiDAR.

Bedrock hollow- Spoon-shaped area of convergent topography with concave profiles on hillslopes. They tend to be oriented linear up and down-slope. Their upper ends can extend to the ridge or begin as much as several hundred feet below the ridge line. Most hollows are approximately 75 to 200 feet wide at their apex (but they can also be as narrow as several feet across at the top), and narrow to 30 to 60 feet downhill.

Convergent headwalls- Funnel-shaped landforms, broad at the ridgetop and terminating where headwaters converge into a single channel. A series of converging bedrock hollows may form the upper part of a convergent headwall. Convergent headwalls are broadly concave both longitudinally and across the slope, but may contain sharp ridges that separate the bedrock hollows or headwater channels.

Inner gorge- Canyons created by a combination of stream down-cutting and mass movement on slope walls. Inner gorges are characterized by steep, straight or concave side-slope walls that commonly have a distinctive break in slope.

Orthophotography- Aerial photograph geometrically corrected ("orthorectified") such that the scale is uniform: the photo has the same lack of distortion as a map. Unlike an uncorrected aerial photograph, an orthophotograph can be used to measure true distances, because it is an accurate representation of the Earth's surface, having been adjusted for topographic relief, lens distortion, and camera tilt.

Outer edge of meander bend- Streams can create unstable slopes by undercutting the outer edges of meander bends along valley walls or high terraces of an unconfined meandering stream. The outer edges of meander bends are susceptible to shallow landsliding including debris avalanching and small-scale slumping, and deep-seated landsliding. The outer edges of meander bends may be protected by the riparian management zone (RMZ) or channel migration zone (CMZ) rules if the slopes are not particularly high and are contained within the riparian leave areas or within the CMZ (See Board Manual Section 2). As with other situations of overlapping forest practices rules, the harvest unit layout should reflect the extent of the greater of the protections.

Partial Buffer- While the term "Partial Buffer polygons" and "Partial Buffer treatments" were used in the Post-Mortem study, a point of clarification is appropriate for the use of the term "Buffer" as it applied to RILs and the Willapa Hills study. The word "Buffer" typically indicates that a defined space exist between a natural feature and forest management activities. To be compliant with FP rules regarding RILs, no harvest of trees with roots inside the feature's footprint is permitted. There is no rule-defined distance around a RIL where harvest or other forest management activities are restricted. The Willapa Hills study refers to Partial Buffer polygons and Partial Buffer treatment only to indicate areas identified in the Post-Mortem study as containing trees less than 21 years-old that contain at least one RIL with some, but not all, trees harvested from the RIL, or more than one RIL with at least one RIL completely harvested and one with no trees harvested. For the Willapa Hills study, study participants evaluated whether trees were harvested from the probable RIL, or not. Harvest associated with probable RILs in the Willapa Hills study and discussed in this report is described as completely harvested, partially harvested, or not harvested.

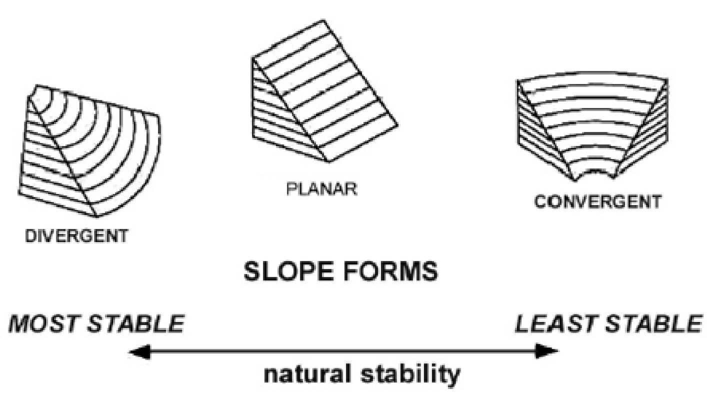
Partial Buffer polygon- Areas designated by the Post-Mortem study that contain timber harvest units less than 21 years old and at least one RIL that had some, but not all, of the trees harvested from the RIL. These designated areas may also contain more than one rule-identified landform. Complete harvest of one rule-identified landform and no harvest on other rule-identified landforms within the same area were also designated Partial Buffer polygons.

Post-Mortem study- A study conducted by the Uplands Processes Scientific Advisory Group, (part of the Cooperative Monitoring, Evaluation, and Research committee) that focused on landslides on forestland that were initiated during the 2007 storm. An outcome of the study was an unpublished paper called "*The Mass Wasting Effectiveness Monitoring Project: An examination of the landslide response to the December 2007 storm in Southwest Washingto*n" (Stewart et. al., 2012).

Qualified expert- A person licensed under chapter 18.220RCW as either an engineering geologist or as a hydro-geologist (if the site warrants hydrologist expertise), with at least three years of field experience in the evaluation of relevant problems on forestlands.

Rule-identified landform (RIL)- Inner gorges, convergent headwalls, or bedrock hollows with slopes steeper than 35 degrees (70 percent); Toes of deep-seated landslides, with slopes steeper than 33 degrees (65 percent); Ground water recharge areas for glacial deep-seated landslides; Outer edges of meander bends along valley walls or high terraces of an unconfined meandering stream; or Any areas containing features indicating the presence of potential slope instability which cumulatively indicate the presence of unstable slopes.

Slope Form- There are three major slope forms to be observed when looking across the slope (contour direction): divergent (ridgetop), planar (straight), and convergent (spoon-shaped). Landslides can occur on any of these slope forms but divergent slopes tend to be more stable than convergent slopes because water and debris spread out on a divergent slope whereas water and debris concentrate on convergent slopes. Convergent slopes tend to lead into the stream network, encouraging delivery of landslide debris to the stream system. Planar slopes are generally less stable than divergent slopes but more stable than convergent slopes. In the vertical direction, ridgetops are convex areas (bulging outward) and tend to be more stable than planar (straight) mid-slopes and concave areas (sloping inward).



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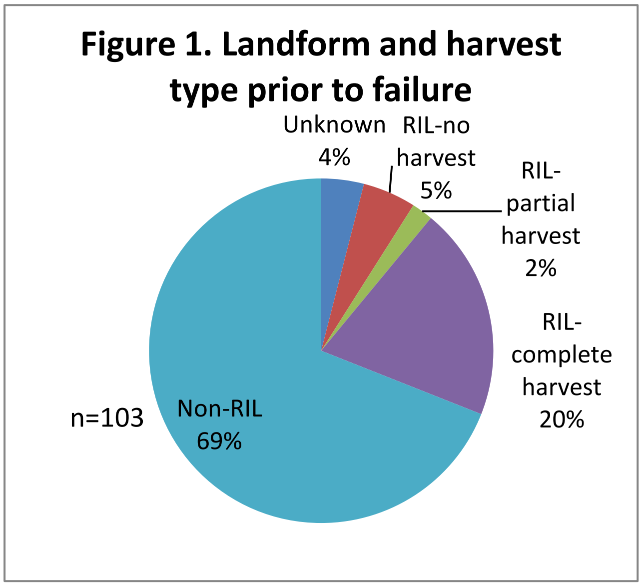
Appendix

Figures 1 and 2.



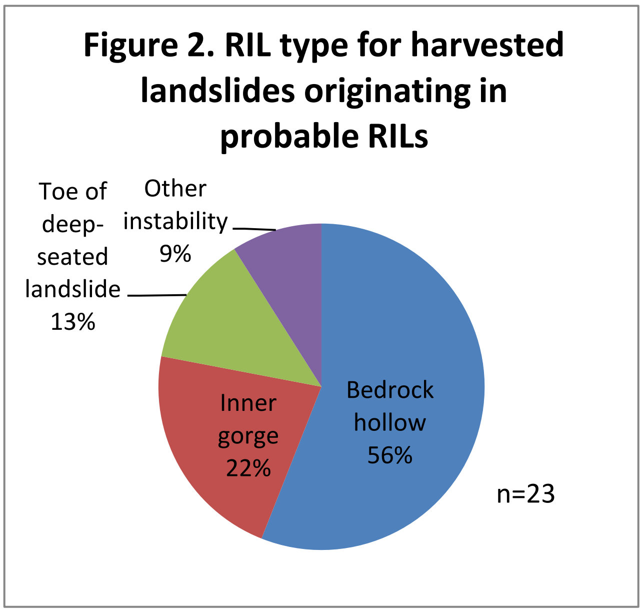


Table 2. Approved watershed analysis mass wasting prescriptions applicable to the Willapa Hills study area.

				Prescription	
Watershed Analysis Unit	**Prescription No.**	**MW map unit/ARS**	**Activity**	**Specific**	**Non Specific**
Chehalis Headwaters	1	1	Roads	No construction below slope break in segment 103 & 124	
			Harvest		
	2	2	Roads	no construction in scarp area, abandon spur road, in 2A no new construction in unstable area	1B2.construction not in a bedrock scarp that isn't fully engineered requires geological review, construction in scarp with review by qualified geologist or geomorphologist, in MWMU 2A construction in stable areas need qualified geologist or geomorphologist review
			Harvest	2A- no harvest in unstable areas	stable areas require qualified geologist or geomorphologist review
	3	5	Roads	no road over 60%, fully engineered on 40-60%, eliminate side cast from existing road	
			Harvest	No harvest in unstable areas	Stable areas require review by qualified geologist or geomorphologist
		6	Roads	new - end haul, fully engineered. Abandon spurs, remove side cast	
			Harvest	no harvest in unstable areas, okay on stable areas	
	4	7	Roads	end haul >60%, fully engineered	
			Harvest	end haul landings on >60%, pull back perched landings, no harvest on unstable areas, stable areas okay.	

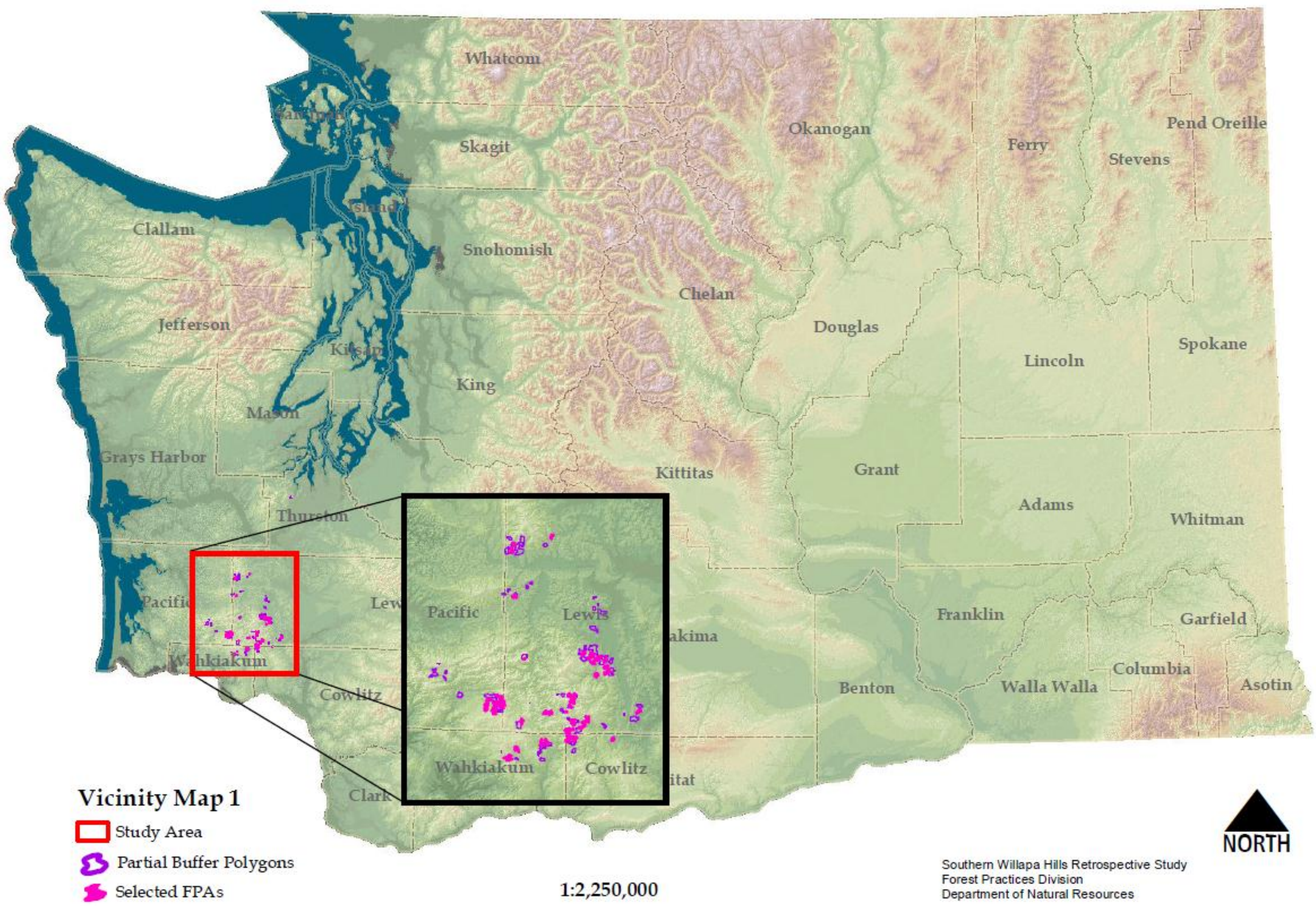
				Prescription	
Watershed Analysis Unit	**Prescription No.**	**MW map unit/ARS**	**Activity**	**Specific**	**Non Specific**
Chehalis Headwaters	5	4	Roads	no new construction, existing roads - abandon or remove side cast.	
			Harvest	no cut	
	6	5	Roads	no road construction if deep-seated movement, if no movement FP rules apply	
			Harvest	no harvest if deep-seated movement, if no movement FP rules apply	
Stillman	1	2	Roads	no construction except 2A with slopes<40%,	
			Harvest	no harvest on scarps or toes	in MWMU 2 requires review by qualified geologist and forest engineer
	2	7	Roads	Evaluate and prioritize existing roads, new-end haul and engineer design	
			Harvest	No prescriptions	
	3	9	Roads	Inventory for abandonment	New roads require review by qualified geologist and end haul >50% and engineer design
			Harvest	no ground operations, cable logging with partial suspension, 25 foot no entry on T4 in 18-12N-4W	
	4	10	Roads	No construction	
			Harvest	Variable buffer at base of slope, retain non-merchantable timber, no removal of downed logs	

				Prescription	
Watershed Analysis Unit	**Prescription No.**	**MW map unit/ARS**	**Activity**	**Specific**	**Non Specific**
Stillman	5	11	Roads	No construction	
			Harvest	No harvest (Option 1)	(Option 2) review by qualified geologist and forest engineer required, and 25 foot buffer on T-4
Willapa Headwaters	1	9	Roads	No construction or side cast below stream bank except for crossings, minimize stream crossings	
			Harvest	No soil disturbance, bank disturbance or vegetation removal within 25 foot or T-4&5	
	2	11	Roads	Implement road and landing construction plan, minimize new roads	New roads on >50% require review by a qualified geologist/geomorphologist/soil scientist/geotechnical engineer
			Harvest	full suspension or leading end >65%, no broadcast burn >65%, pull back landings at completion of yarding	
	3	12	Roads	No construction or pit development	
			Harvest	No harvest, avoid hanging lines, fall adjacent timber away	
	4	13	Roads	no construction between F140 &Ellis Creek, de-energize road runoff (see appendix A)	
			Harvest	between F140 &Ellis Creek thinning only, minimize vegetation and ground disturbance.	
	5	8	Roads	Landings- burn debris, pull back, revegetate, restore drainage, implement Appendix B, Minimize construction.	
			Harvest	No prescriptions	

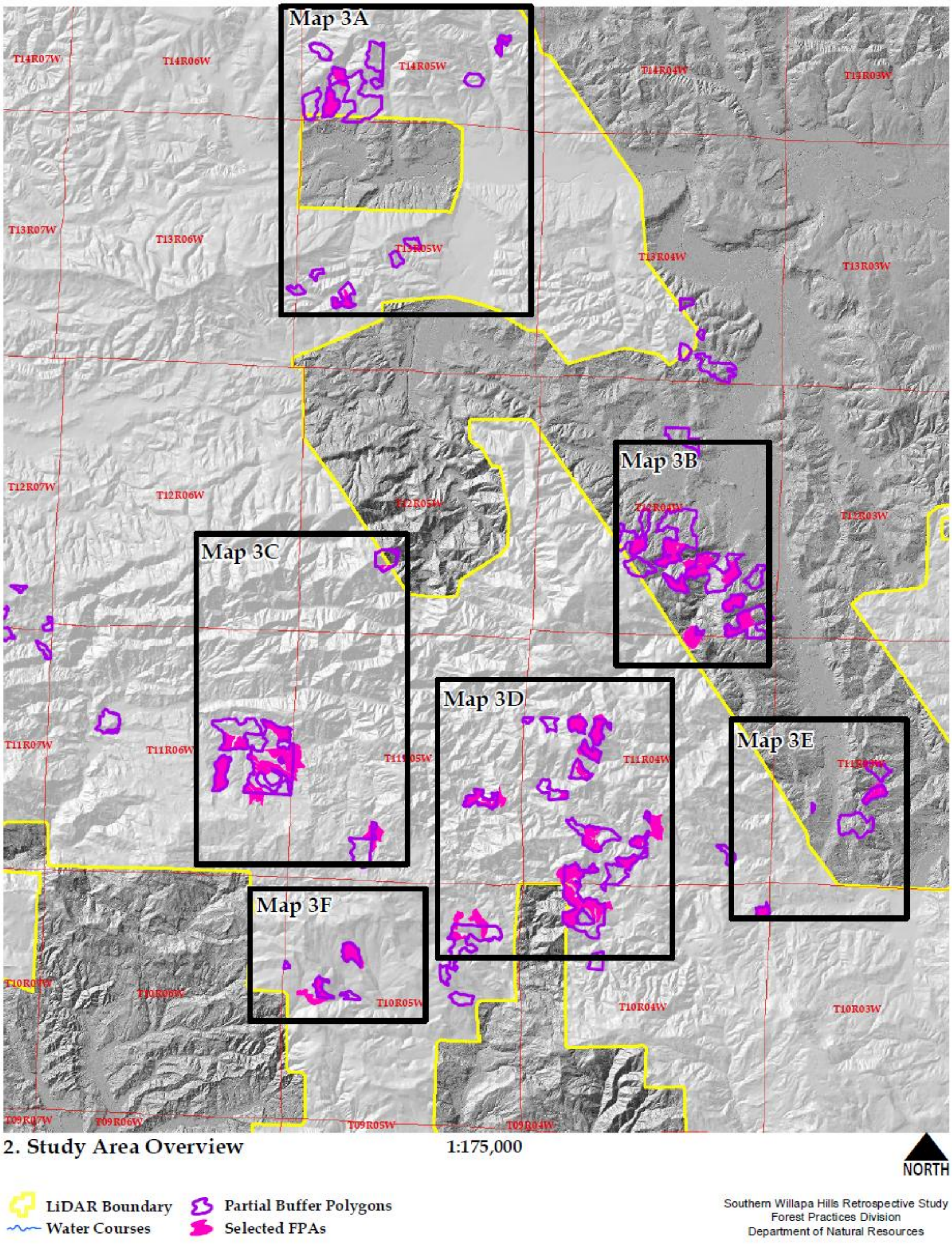
				Prescription	
Watershed Analysis Unit	**Prescription No.**	**MW map unit/ARS**	**Activity**	**Specific**	**Non Specific**
Willapa Headwaters	6	8	Roads	Landings- burn debris, pull back, revegetate, restore drainage. Implement Appendix B, Minimize construction.	
			Harvest	No prescriptions	
	7	5	Roads	assess landings and burn debris, pull back, revegetate, restore drainage. Implement Appendix B, minimize new roads.	
			Harvest	Full or partial suspension >65%, no spray or burning >65%, landing pull back after harvest >50%	
	8	5	Roads	Landings- burn debris, pull back, revegetate, restore drainage. Implement Appendix B, Minimize construction.	
			Harvest	Full or partial suspension >65%, no spray or burning >65%, landing pull back after harvest >50%	
	9	3	Roads	No construction in Forks creek	
			Harvest	No prescriptions	Harvest in Forks Creek and harvest bordering MU3 in Forks require review by a qualified geologist/geomorphologist/soil scientist/geotechnical engineer
North Elochoman	1	MW 2A	Roads	no construction on >40% slopes	construction >40% allowed with mass wasting specialist and forest engineer review
			Harvest	Option 1: harvest <65% slopes, full or leading end suspension, no ground equipment >30%, 25 feet buffer above slope break on inner gorges with >65%	Option 2: mass wasting specialist and forest engineer review required

				Prescription	
Watershed Analysis Unit	**Prescription No.**	**MW map unit/ARS**	**Activity**	**Specific**	**Non Specific**
North Elochoman	2	MW 4A, 4B	Roads	Construction okay on slopes <40%	Construction on >40% require mass wasting specialist and forest engineer review
			Harvest	Option 1: no harvest >65%, full or leading end suspension, no ground equipment>30%, 25 feet buffer above slope break on inner gorges with >65%	Option 2: mass wasting specialist and forest engineer review required
	3	MW7	Roads	no construction >40%	construction >40% require mass wasting specialist and forest engineer review
			Harvest	Option 1: harvest <65% slopes, full or leading end suspension, no ground equipment >30%, 25 feet buffer above slope break on inner gorges with >65%	Option 2: mass wasting specialist and forest engineer review required

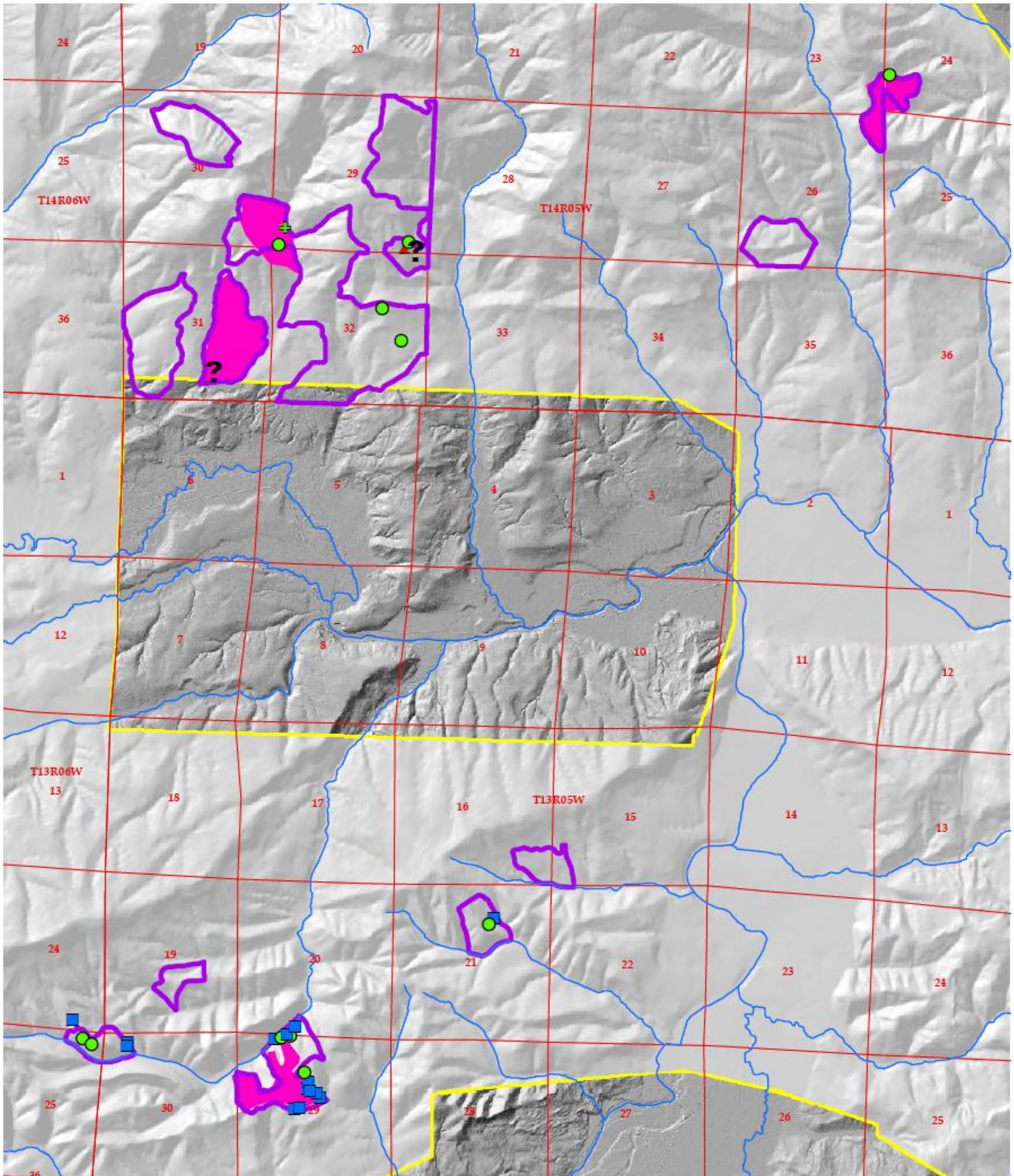
Vicinity Map 1



Map 2. Study Area Overview



Map 3A. Study Area Detail 1



Map 3A. Study Area Detail 1

1:50,000

Southern Willapa Hills Retrospective Study
Forest Practices Division
Department of Natural Resources

NORTH

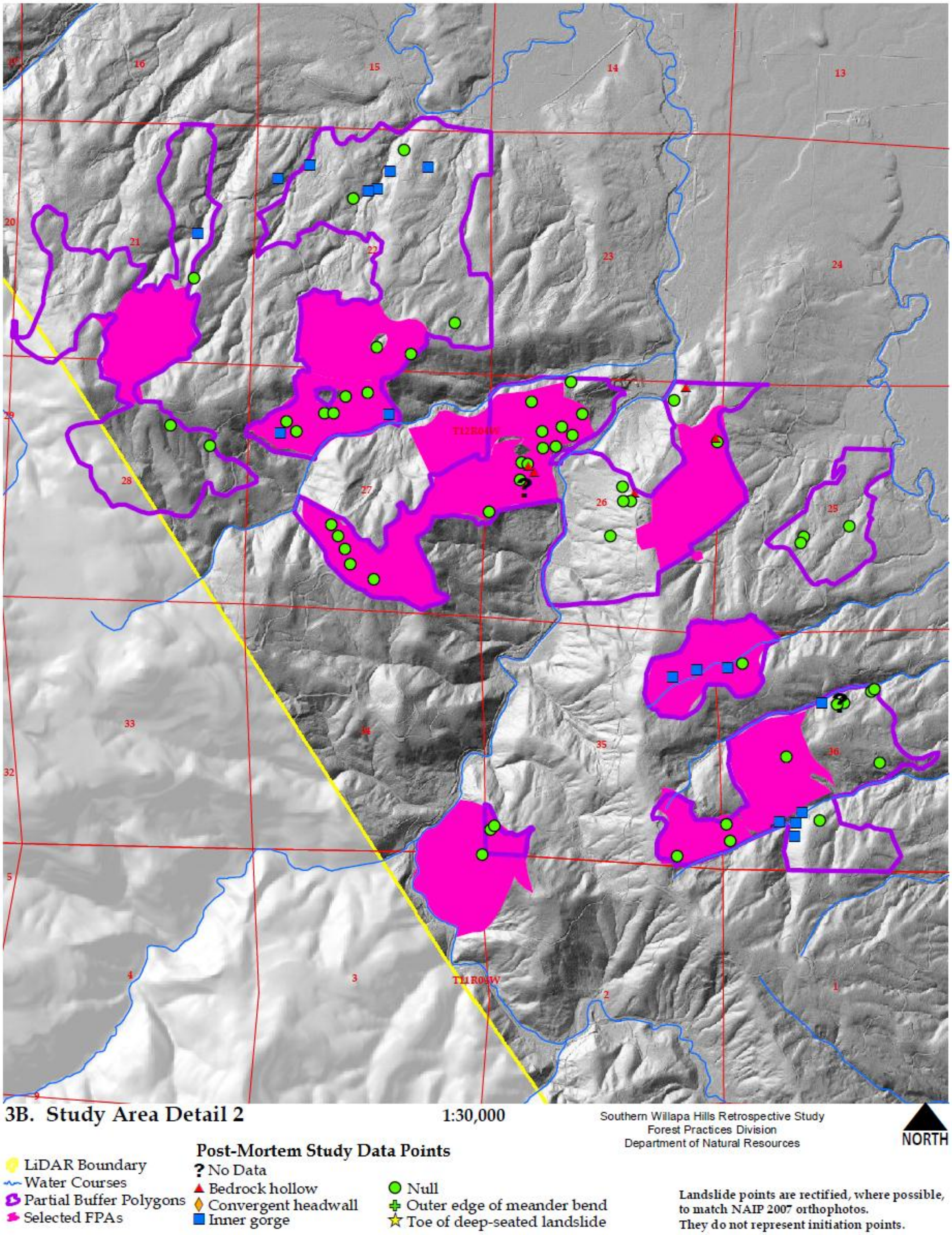
Post-Mortem Study Data Points

- LiDAR Boundary
- Water Courses
- Partial Buffer Polygons
- Selected FPAs

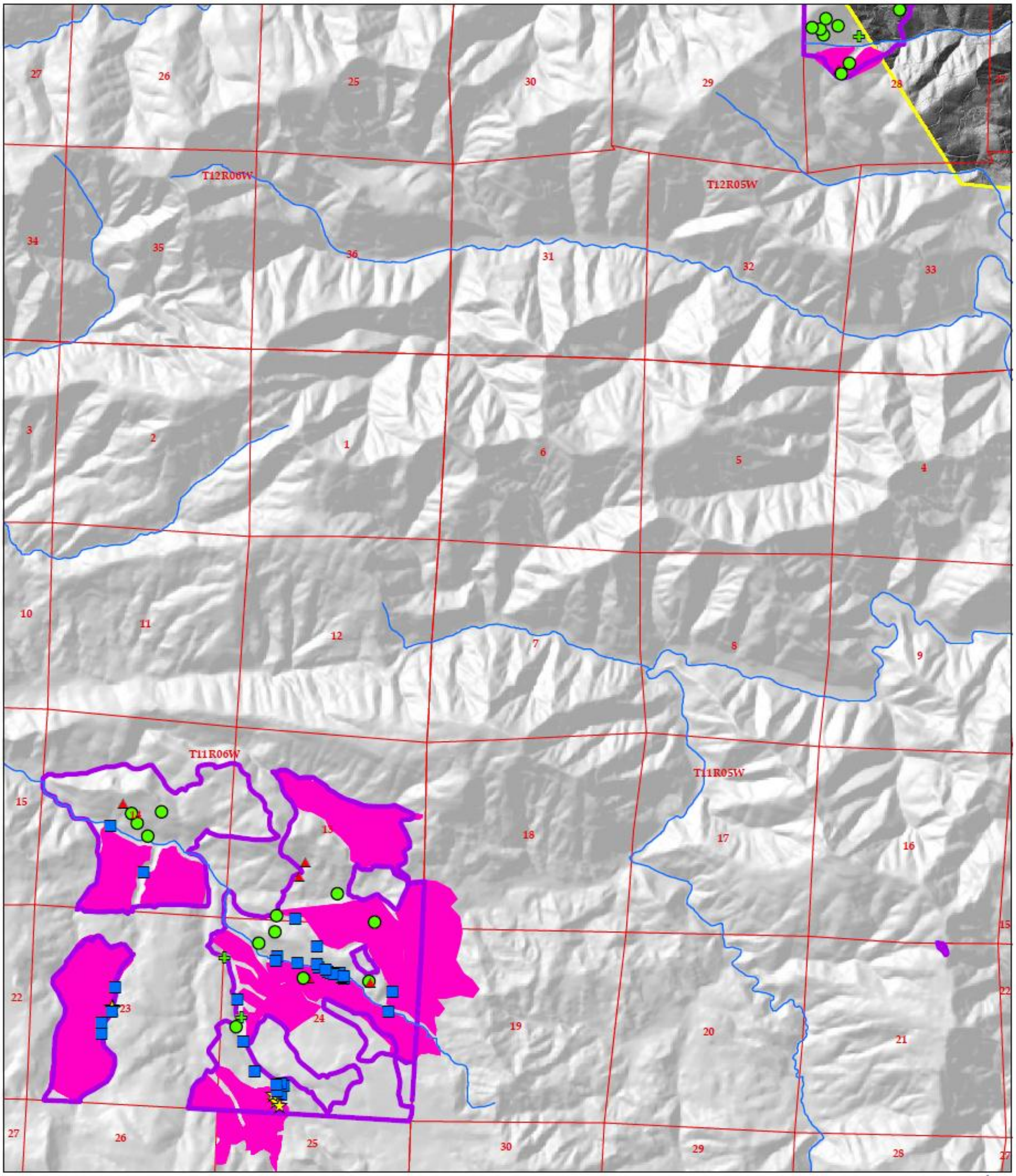
- ? No Data
- ▲ Bedrock hollow
- ◊ Convergent headwall
- ■ Inner gorge
- ○ Null
- ✚ Outer edge of meander bend
- ☆ Toe of deep-seated landslide

Landslide points are rectified, where possible, to match NAIP 2007 orthophotos. They do not represent initiation points.

Map 3B. Study Area Detail 2



Map 3C. Study Area Detail 3



3C. Study Area Detail 3

1:40,000

Southern Willapa Hills Retrospective Study
Forest Practices Division
Department of Natural Resources

NORTH

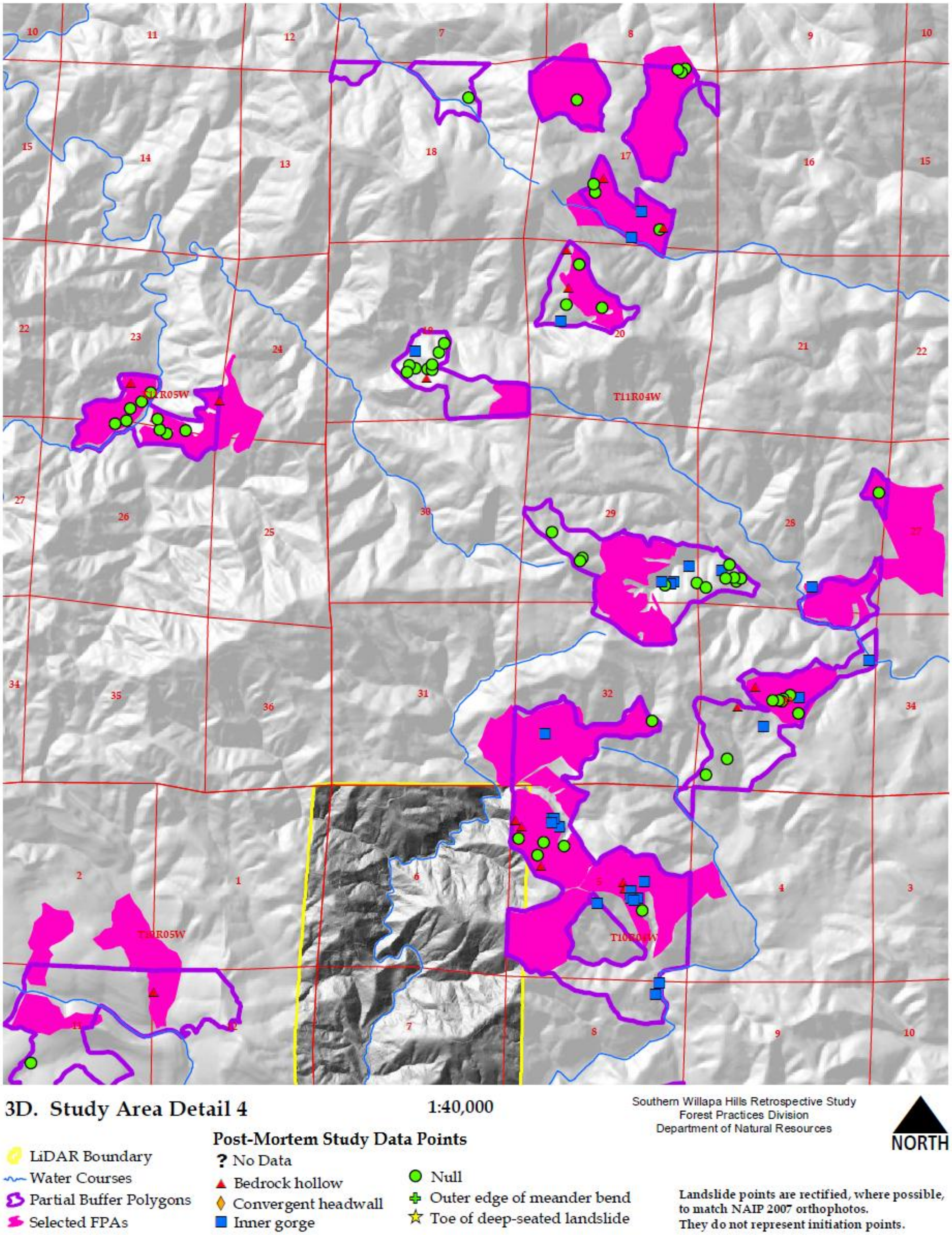
LiDAR Boundary
Water Courses
Partial Buffer Polygons
Selected FPAs

Post-Mortem Study Data Points

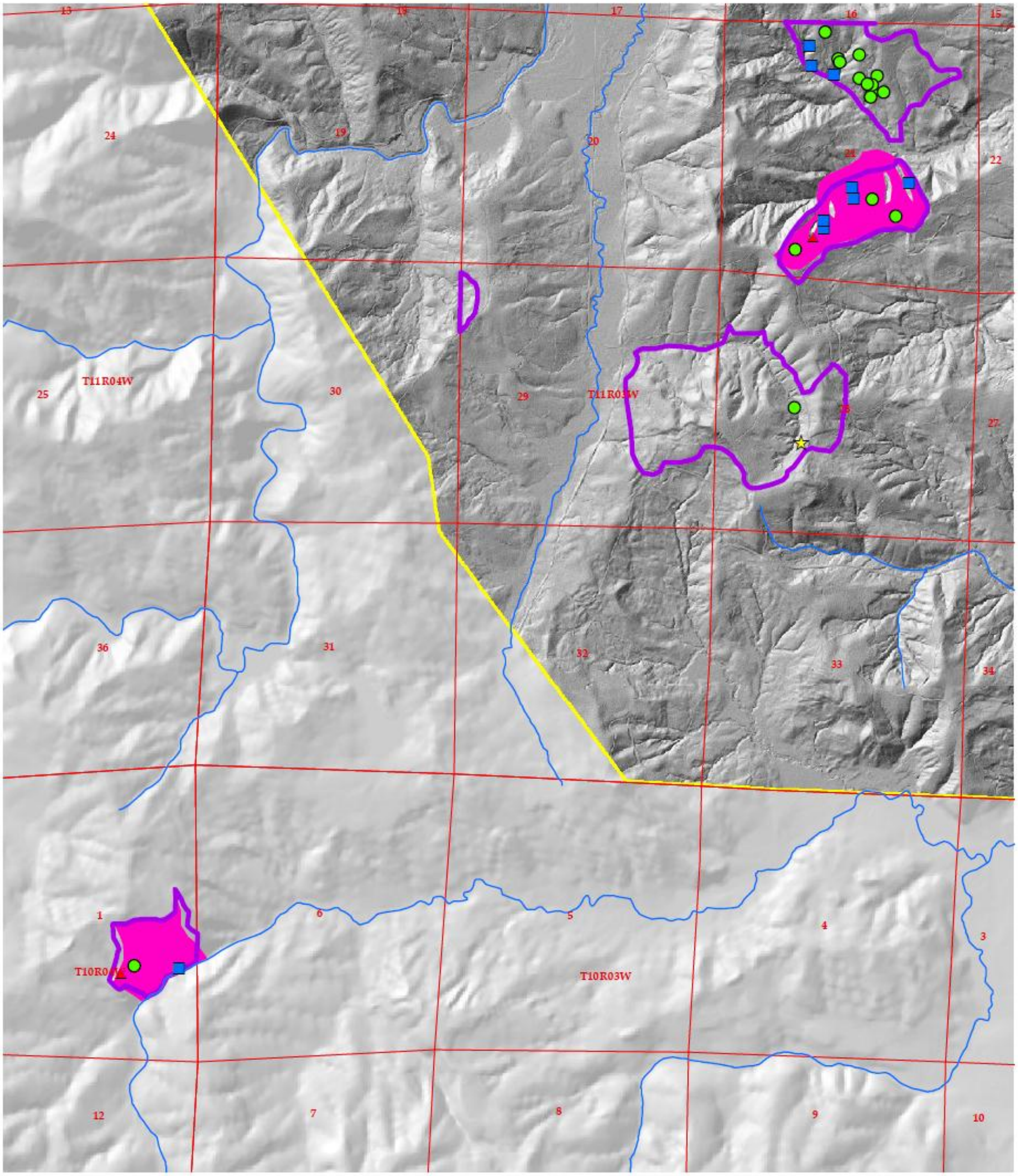
? No Data
Bedrock hollow
Convergent headwall
Inner gorge
Null
Outer edge of meander bend
Toe of deep-seated landslide

Landslide points are rectified, where possible, to match NAIP 2007 orthophotos. They do not represent initiation points.

Map 3D. Study Area Detail 4



Map 3E. Study Area Detail 5



3E. Study Area Detail 5

1:30,000

Southern Willapa Hills Retrospective Study
Forest Practices Division
Department of Natural Resources

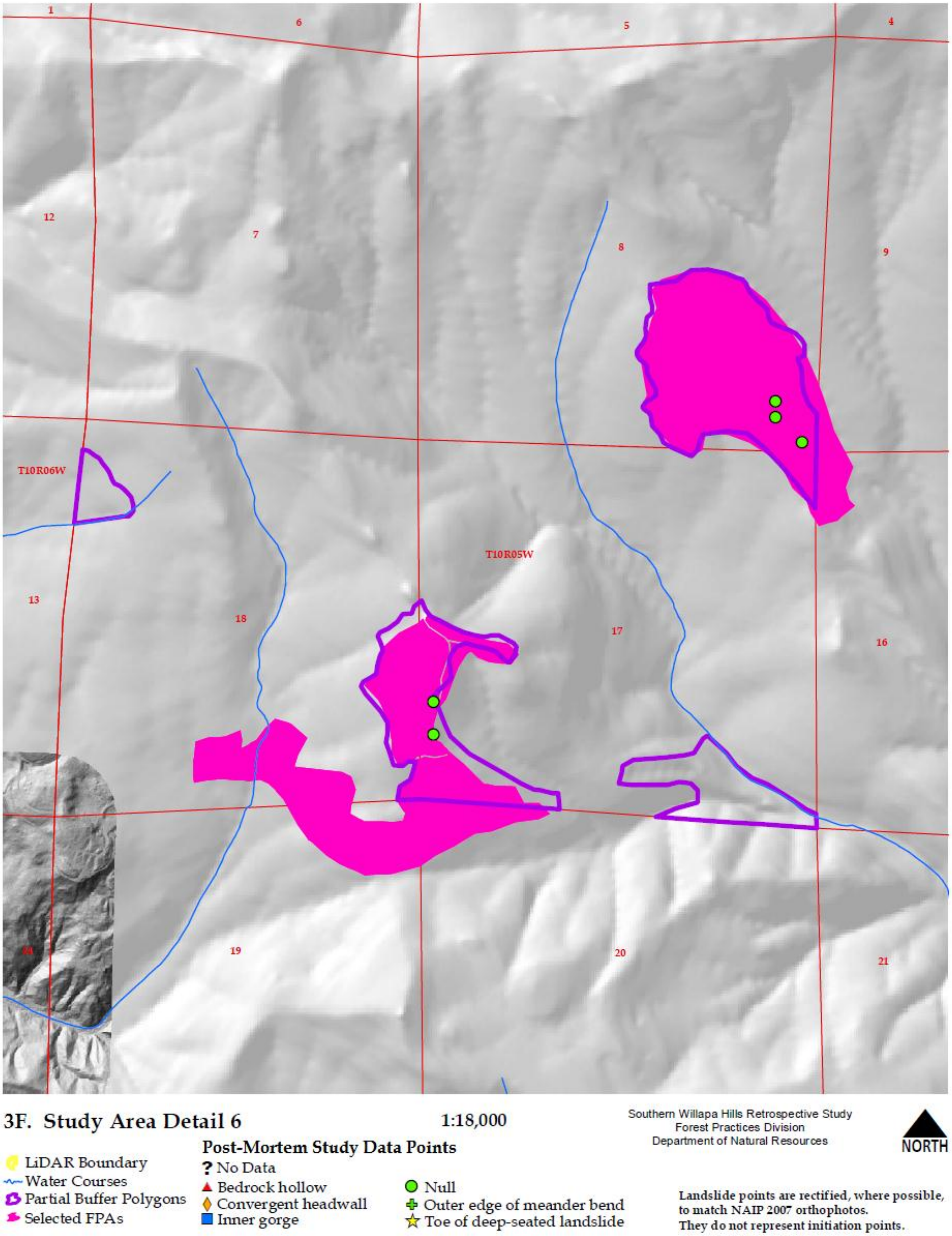
NORTH

LiDAR Boundary
Water Courses
Partial Buffer Polygons
Selected FPAs

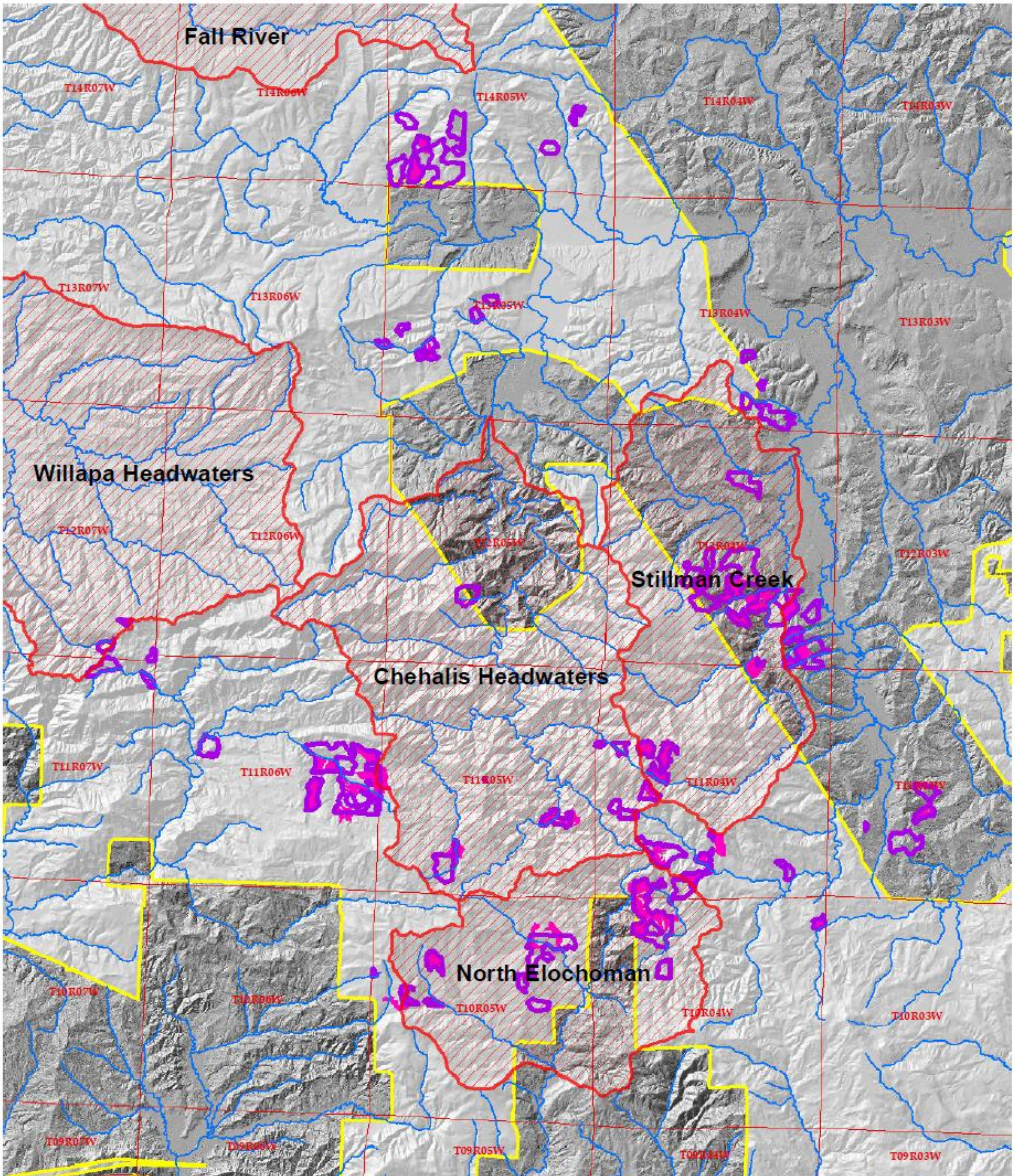
Post-Mortem Study Data Points
? No Data
Bedrock hollow
Convergent headwall
Inner gorge
Null
Outer edge of meander bend
Toe of deep-seated landslide

Landslide points are rectified, where possible, to match NAIP 2007 orthophotos. They do not represent initiation points.

Map 3F. Study Area Detail 6



Map 4. Approved watershed analyses



4. Approved watershed analyses

1:200,000

Southern Willapa Hills Retrospective Study
Forest Practices Division
Department of Natural Resources

NORTH

Approved Watershed Analysis

Partial Buffer Polygons

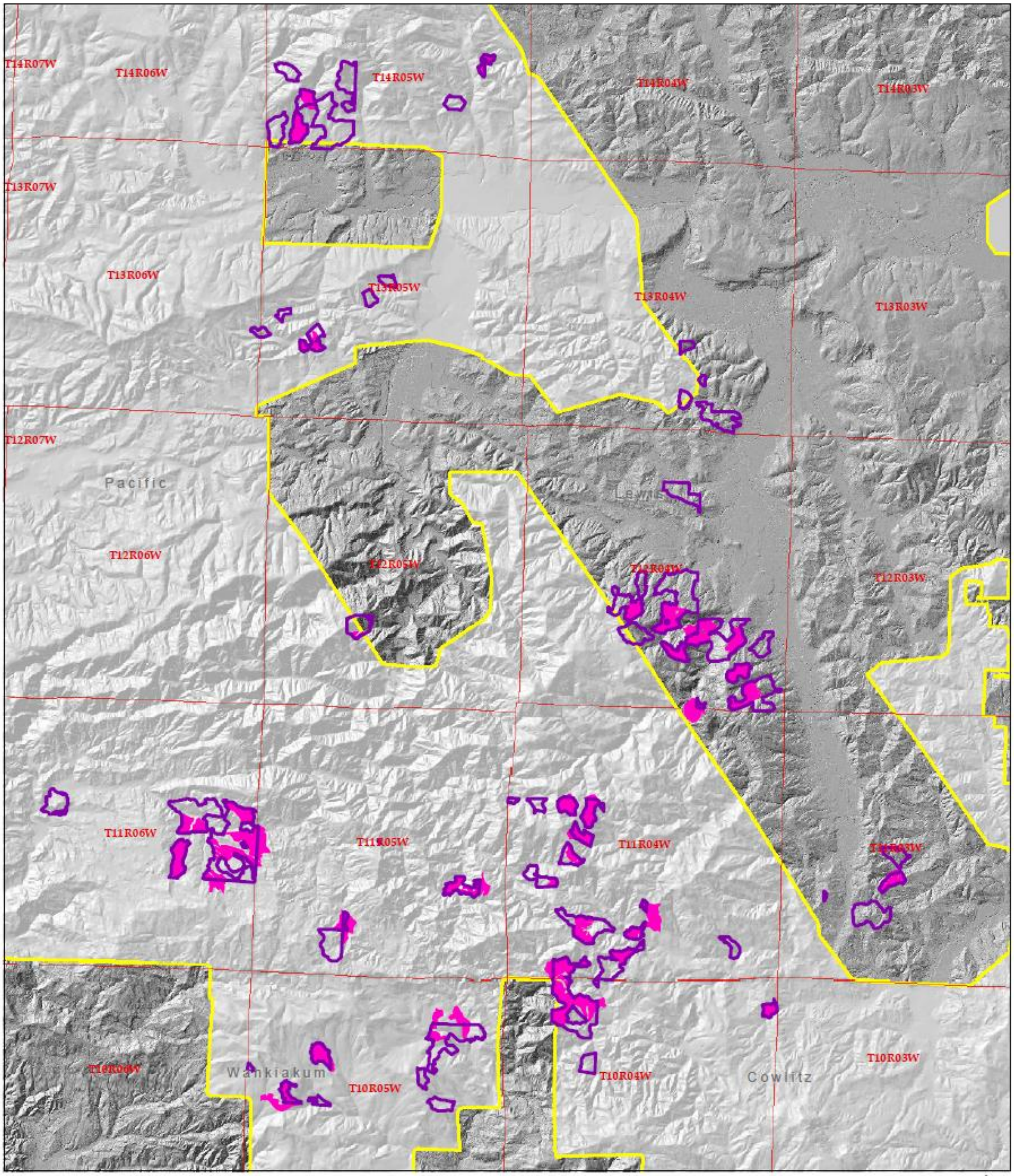
Selected FPAs

Water Courses

LiDAR Boundary

Landslide points are rectified, where possible, to match NAIP 2007 orthophotos.
They do not represent initiation points.

Map 5. LiDAR Coverage of Study Area



5. LiDAR Coverage of Study Area 1:175,000

NORTH

Partial Buffer Polygons
Selected FPAs
LiDAR Boundary

Southern Willapa Hills Retrospective Study
Forest Practices Division
Department of Natural Resources

Map 6. LRIM outputs