The Current State Of Engineering Geology, Slope Stability and Harvest Unit Plans

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INTRODUCTION

For most of its history, significant changes in the logging industry have occurred primarily as a result of technological advances, such as railroads, steam donkeys, chain saws, trucking and feller-buncher machines. More recently; however, significant changes in the logging industry have been brought about as a result of public policy and regulations in an effort to address environmental concerns. These recent changes have resulted not only in a reduction in the locations, number and size of timber harvest units, but also a change in the planning of harvest unit layouts and harvest methods employed.

One area of timber harvesting that has received substantial attention recently is the potential for timber harvesting to increase the frequency of landslides and the resulting negative impacts on the environment. In order to address these potential impacts, engineering geologists are being asked to provide guidelines and recommendations so that areas where harvest-initiated landslides may occur can be avoided or mitigated. These recommendations are being applied on a harvest unit (50 to 100 acres) to watershed (20,000 to 80,000 acres or more) scale.

This paper will: 1) summarize some of the current public regulations affecting timber harvesting and slope stability in California, Oregon, and Washington, 2) discuss some of the methods used by engineering geologists to evaluate stability of forested slopes, 3) address some of the mitigating measures that can be used to reduce the potential impact of timber harvesting on slope stability, and 4) provide some concluding remarks regarding the role of engineering geology in the development of timber harvest plans.

TIMBER HARVEST PLANS AND PUBLIC REGULATIONS

Regulations governing timber harvesting on private and state-owned lands in California, Oregon and washington are enacted and enforced by state agencies. Initially, these regulations were initiated at the state and local level; however, more recent regulations, and revisions to existing regulations have been implemented in response to federally-mandated laws such as the Endangered Species Act and the Clean Water Act.

The following presents a brief summary of the history and extent of California, Oregon and Washington state regulations regarding timber harvest plans and slope stability.

California

The Z’berg-Nejedly Forest Practice Act was enacted in California in 1973 to regulate logging on private lands (http://www.fire.ca.gov/resourceManagement/ForestPractice/.asp). The California Department of Forestry and Fire Protection (CDF) enforces these laws. Additional and revised regulations are enacted by the State Board of Forestry and Fire Protection. The

Forest Practice Act requires Timber Harvesting Plans (THPs) to be prepared by a Registered Professional Forester (RPF) and submitted to the CDF for approval.

A first review of the THP to determine if it is complete is conducted by a multi-agency team. When a THP is complete, it is filed, after which written public comments are accepted and reviewed and a Pre-Harvest Inspection is conducted. A second team review is conducted and final recommendations are prepared and submitted to the RPF for response. After receiving the RPF's responses, the CDF Director reviews and either approves or denies the THP. The CDF will inspect the logging operation and implement enforcement actions, if needed. Legal actions may be taken against the RPF and/or the Licensed Timber Operator.

The THP must include "An outline of the methods to be used to avoid excessive accelerated erosion from timber operations to be conducted within the proximity of a stream." and "Special provisions, if any, to protect any unique area within the area of timber operations." To address these concerns, an engineering geologic report may be required as part of the THP. The engineering geologic report can only be prepared by a Geologist, Certified Engineering Geologist, Civil Engineer or Geotechnical Engineer who is registered in California.

Oregon

Oregon introduced the nation's first Forest Practices Act in 1971, which became effective on July 1, 1972 with adoption of the Forest Practice Rules (http://www.odf.state.or.us/FP/BackgroundPg/background.htm). The rules, which are enforced by the Oregon Department of Forestry, set standards for reforestation, road construction, and streamside buffers. New rules, amendments and revisions are implemented by the Oregon State Board of Forestry. In September 1983, a comprehensive revision of road construction and harvest rules was undertaken in response to severe landsliding during winter storms. The concept of 'high risk sites' and written harvest plans was introduced in these revisions.

In July 1999, a rule was adopted to provide for public safety below steep, unstable slopes on forest land. This rule requires written timber harvest plans are required if the proposed unit is adjacent to a sensitive area, such as lakes, specific streams, or threatened or endangered species. Under Oregon regulations, written harvest plans may require engineering geology evaluation if the harvest unit contains "high risk" sites (http://arcweb.sos.state.or.us/rules/OARS_600/OAR_629/629_630.html). These sites are defined as steep slopes (75 to 80 percent or steeper) and headwalls (65 to 70 percent or steeper) in western Oregon on which "rapidly moving landslides" that could impact occupied buildings or high-traffic volume roads might occur. The practice of professional geology and engineering services is regulated by the State of Oregon.

Washington

Washington State enacted their Forest Practices Act in 1974 (http://www.wa.gov/dnr/htdocs/fp/fpb/fpb.html). This act regulates activities related to the growing, harvesting or processing of timber on all local, state, and private lands. Rules are established by the Washington State Forest Practices Board and enforced by the Washington State Department of Natural Resources (DNR). A Forest Practice Application (FPA) is required to conduct most forest practices. Each application is reviewed by DNR staff, local governments and Timber, Fish and Wildlife (TFW) Agreement members. The TFW, a cooperative team of industry, public agency, Indian and environmental organizations, was established in 1987 to protect public resources while maintaining a viable timber industry. In 1999, Washington adopted the Salmon Recovery Act, which put further requirements and limitations on timber harvesting.

The DNR determines the classification of the FPA. FPAs for proposed timber harvest and road construction on “potentially unstable slopes or landforms” from which sediment can be delivered to and impact a public resource, can be classified as a Class IV-special. To determine if the proposed forest practices may or may not have a significant impact on public resources, the FPA must include information prepared by a ‘qualified expert’ regarding the potentially unstable slopes or landforms, including mitigating measures to avoid significant impacts. Class IV-special FPA’s are subject to State Environmental Protection Act (SEPA) review and could require an environmental impact statement. A qualified expert must have a graduate degree or postgraduate coursework in geology/geomorphology, 3 years of field experience, and be approved as a qualified expert by the DNR. In addition, the professional practice of geology and engineering requires state licensure.

Washington State has also instituted a Watershed Analysis program in which watershed conditions, such as mass wasting, are evaluated and prescriptions are developed to reduce or avoid impacts to public resources from timber management activities. However, recent regulations included in the Salmon Recovery Act have replaced the need for evaluation of most of the watershed condition modules (except mass wasting). Analysts who perform watershed analyses must have sufficient and relevant education and experience, as well as pass a watershed analysis training program.

ENGINEERING GEOLOGY IN THE PLANNING OF HARVEST UNITS

To meet the various state regulations and reduce potential adverse environmental impacts, an engineering geologic evaluation can be employed to identify unstable slopes and landforms, and to assist with the development of mitigative measures so that timber harvesting can be conducted in an environmentally-sensitive manner. Typically, an engineering geologist will be asked by the forester responsible for developing the written harvest plan to evaluate the harvest unit prior to submittal of the completed application. Alternatively, a submitted forest application may be denied until an engineering geologic evaluation is conducted. Currently, the application of engineering geology to the planning of harvest units relies primarily on the opinions of qualified individuals. These opinions are based on knowledge gained from the evaluation of conditions in and adjacent to the proposed harvest unit, as well as from the individual’s past education and experience.

An engineering geologic evaluation requires review of existing information, as well as a field visit. Review of existing information should be conducted prior to the field visit so features of interest can be identified and later observed in the field. In addition to the harvest unit, the review should include, at a minimum, ground on the adjacent slopes and/or adjacent drainage basins, and evaluation of previously logged harvest units in the vicinity.

Existing Literature

Geologic maps published by state agencies and the US Geological Survey can be reviewed to assess the specific geologic stability of a harvest unit. Scales and coverage of these maps can vary substantially. Of particular interest on geologic maps are the occurrence of weak rocks, such as some sedimentary and volcanic rocks; faults, dip directions, and mapped landslides.

Maps and descriptions of soils may be available from the US Natural Resource Conservation Service (NRCS, previously the Soil Conservation Service) and state agencies. Useful information from soils reports includes soil depths and grain size distribution. Soil maps are commonly prepared with aerial photographs as a base map. These maps often indicate past landslides, and the aerial photographs, though of limited quality, can be used to evaluate historic conditions.

Though not as commonly used, other potential sources of existing literature include 1) college thesis studies, 2) reports of government research conducted in, or in the vicinity of, the harvest unit, 3) watershed analysis documents, and 4) forest practice applications for past activities in the vicinity.

Aerial Photographs

Stereo pairs of aerial photographs usually provide the best information regarding the past timber management activities in a harvest unit, as well as areas of slope and channel instability. Aerial photographs can provide a good record of activities (timber harvest, road building, skid roads, yarding corridors) and resulting impacts, if any. The aerial photograph review should begin with the oldest set of photographs available and include subsequent sets of photographs at 5- to 10-year intervals. Climatic records can be reviewed to determine periods of severe precipitation events. Aerial photographs taken within several years following these events, if available, should be reviewed to evaluate the storm's effects on the landscape.

Computer Slope Stability Modeling

Increasingly, government agencies are relying on computer models to assist with evaluating slope stability conditions and the potential impacts on these slopes as a result of timber harvest.

Computer slope stability models generally use limit equilibrium methods that calculate a Factor of Safety (FS, the ratio of driving forces to resisting forces). A FS greater than 1.0 implies a stable slope under the modeled conditions, while a FS less than 1.0 implies slope failure. Geotechnical factors common to most models include slope angle, dry and saturated soil weight, soil cohesion and friction angles, and groundwater levels. The influence of root strength can be addressed independently in some models, or accounted for by adjusting the soil cohesion values.

Slope stability analyses may be deterministic or probabilistic. Deterministic models calculate a single FS for one set of values for the various geotechnical factors. Because of the natural variability of the geotechnical factors, a design FS of 1.2 to 1.5 is commonly used to allow for this variability. Probablistic analyses calculate the probability of failure by using a range of values for the various geotechnical factors.

Slope stability models can be applied to a site-specific condition, such as a road cut-and-fill or a particular slope that is proposed for harvest. An example of this type of model is STABLE, which is a deterministic model initially developed by Purdue University ( ). The model uses Janbu's 'method of slices' to evaluate rotational and block slides. Later versions include XSTABLE and PCSTABLE. Substantially more rigorous, deterministic, site-specific, computer-modeled analyses can be conducted using finite element analysis models.

Increasingly, slope stability models are being developed that utilize a Geographic Information System (GIS) data base to evaluate slope stability conditions on a watershed-scale. These models have been referred to as 'distributed' slope stability models. The GIS-data base includes a digital terrain model developed from digital elevation maps (DEM), as well as values for the various geotechnical factors (slope, cohesion, friction, soil weight, etc.).

Most of the GIS-based slope stability models utilize the infinite slope stability model and assume groundwater flow is steady state and controlled by surface topography. The authors of these computer models generally recommend that the computer-model output for a watershed should be compared to mapped locations of actual landslides within the watershed. The geotechnical factors should then be adjusted in the computer model to more closely reflect actual slope stability conditions. Following is a summary of some of the more common GIS-based, distributed, slope stability models used.

LISA – (Hammond et al., 1992) Although not a GIS-based model, the Level 1 Slope Stability Analysis model is a distributed model that was developed by the US Forest Service to evaluate slope stability over a typical harvest-unit size area. This probalistic model uses an infinite slope stability model. The area of interest is divided into polygons based on soil maps and/or other criteria. Characteristics (slope, soil strength, soil depth, root strength, groundwater depth) are assigned to each polygon. Output is presented as a probability of failure for each polygon.

dSLAM – (Weimin Wu and Roy Sidle, 1993). This GIS-based, deterministic model is based on an infinite slope model, a kinematic wave groundwater model, and continuous change over time in root vegetation strength. Output is presented as polygons with assigned FS values.

SHALSTAB – (D. Montgomery and W. Dietrich, 1994). This model is a deterministic, distributed, GIS-based model using infinite slope stability and steady-state groundwater flow alogrithims. Output of shallow slope stability is presented as polygons of precipitation rates required to initiate failure. Several extensions of the model have been developed since the original version.

SMORPH –(Shaw and Johnson, 1995). A GIS-based model that relies only on topographic data from which slope form (concave, planar, or convex) and gradient are determined. No slope stability analysis is employed. Output is presented as polygons assigned a high, moderate or low slope stability rating.

SINMAP – Stability Index MAPping (R.T. Pack, D. G. Tarboton and C.N. Goodwin, 1998). This probabilistic, GIS-based model utilizes an infinite slope stability model in which a range of values for soil characteristics can be input. Output is presented as polygons or grids of relative hazard, as indicated by a Stability Index.

PISA – Probabilistic Infinite Slope Analysis (Haneberg Geosciences, 2001). A GIS-based, slope stability model in which geotechnical parameters can be input as constant or random variables to each polygon. Output is presented as FS values or probability of failure.

Field Review

A field review is the most essential element of an engineering geologic harvest unit evaluation. Many features on aerial photographs may be hidden by vegetation. Topographic maps, which are generally based on aerial photographs, commonly miss headwalls and small drainage channels, features where landslides commonly occur.

The field review should be conducted following review of the available information and development by the forester of an initial harvest unit layout, but prior to completing the final harvest plan. Ideally, the harvest unit boundaries will be laid out on topographic maps and flagged in the field by the forester prior to the field visit. The initial harvest unit layout should include the buffers and leave areas that may be required by regulations. In addition, it is preferable to conduct the site visit with the forester or forest engineer so that specific sites and possible mitigation measures can be discussed. Alternatively, sites of interest should be flagged in the field and clearly marked on a large scale, topographic map of the unit.

During the field review, all moderate to steep slopes should be traversed. Sites of previous or potential instability, as determined from the aerial photographs, geologic maps, and other information, should be observed. Also, sites of historic logging activities, such as landings and skid trails, as determined from aerial photographs, should be reviewed for stability. If a GIS-based slope stability model of the area has been developed, the areas of high and moderate risk should also be field evaluated. In conjunction with identified unstable slopes, the potential impacts of a landslide should be assessed, such as the potential for debris torrent initiation of for delivery of sediment and debris to public resources.

Shallow landslide initiation sites are generally concentrated in bedrock hollows and topographic swales where groundwater may be concentrated, in inner gorges, along the edges of past landslides, or where concentrated surface water is discharged. Evidence of excessive water on the slopes, such as seepage areas, shallow gullies, and vegetation adapted to wet areas, should be noted.

Deep-seated landslide deposits and their scarps should be evaluated. These landslide deposits may be characterized by sag ponds, deranged drainage, benches, and/or hummocky ground. Although the entire slide mass may not be moving, portions of it may continue to periodically slump. Movement is generally concentrated along the toe and edges, and along channels incised through the landslide body. Evidence of movement includes shallow scarps, ground cracks, swooped trees, bulging soil deposits, and exposures of disturbed, unvegetated soil.

Slope angles should be measured throughout the harvest unit on both stable and potentially unstable slopes. Soil grain size should be noted. Soil compactness can indicate relative rates of creep; ie, loose, surficial soil may be a result of more rapid creep and may have a greater potential for slippage. Other indicators of rapid creep include excessive soil deposited on the upslope sides of trees. Evidence of bedrock, whether it is outcrops or ‘float’ (clusters of cobble to small boulder-size rocks on or near the surface) can indicate depth of soils. The size and type of trees, and any growth characteristics, such as pistol-butted trunks, or swooped or jackstrawed trees, should also be noted.

MITIGATIVE MEASURES

The measures available to mitigate for potential slope instabilities resulting from timber harvesting are limited – the trees are either cut or they are not. It should be recognized that timber harvesting does not improve slope stability. The question to be answered is how much impact will the harvesting have on slope stability.

Currently, buffers of varying widths are usually required along fish-bearing streams and for a certain distance along non-fish-bearing streams upstream from their confluence with fish-bearing streams. These buffers are intended primarily to maintain fish habitat, such as water temperature and LWD source. However, the buffers commonly include unstable ground along stream banks, and can also serve as a buffer from upslope sediment inputs.

Leave areas (isolated patches of timber of various sizes within a larger harvest unit) can be recommended where there is ground that may be adversely impacted by harvesting. Leave areas are commonly recommended in headwalls, inner gorges, colluvial-filled, bedrock hollows, and areas of steep, wet ground or where past slope failures have occurred. Leave areas can commonly satisfy the requirement for wildlife and reforestation leave trees that may be required by forest practice regulations.

Where practical, partial harvests can be recommended in areas that are moderately stable, but where some level of root strength and evapotranspiration above that in a clearcut is considered necessary. However, partial harvests commonly require increased ground disturbance, such as additional roads and landings to access the unit, and/or increased ground-based logging methods. These potential impacts should be compared to the potential impacts of a clearcut harvest, which could cause less ground disturbance, and to no harvest.

Where yarding may impact the ground, measures that can be employed to reduce these impacts include partial and full suspension, seasonal restrictions, yarding from the bottom of the unit first so that timber is dragged over fallen timber and not the ground, and yarding away from sensitive areas, such as swales, headwalls and wet ground.

CONCLUDING REMARKS

These is no question that geologic slope stability evaluations and the more careful planning of harvest units has resulted in a decrease in the size and frequency of harvest-related landslides; however, there will always be some risk of slope instability associated with timber harvesting. Landslides are a natural phenomena in steep, forested mountains and a landslide may occur on a forested slope whether the timber on it has been harvested or not. However, if the landslide-impacted slope had been recently harvested, the timber harvesting will likely be associated with the cause of the landslide. Determining whether such landslides are primarily the result of natural causes, or the result of timber harvesting, is problematic.

Although timber resource companies are primarily concerned with current and future conditions on their lands; hence, more current aerial photographs, their historic aerial photographs are a valuable and irreplaceable resource that documents past landuse and impacts, if any. These historic photographs should be protected from deterioration (sealed in plastic) and maintained for quick access (filed in a logical order and with associated flight maps).

The GIS-based computer models offer a new tool to supplement the existing tools in evaluating timber-harvest-related slope stability. However, the results of these models should not be considered a substitute for a careful evaluation that uses all the available sources of information (aerial photographs, site visits, etc.). The development and use of distibuted, GIS-based models is generally not economical on a harvest unit scale, but should be considered for use on a watershed scale. Although these models provide an attractive way for public agencies to regulate harvest on potentially unstable ground, the model output is generally too broad-based and can be too conservative with regards to harvest-related impacts. Sensitivity of the models to the various geotechnical factors should be addressed. For instance, in a recent study of a landslide in the Puget Sound area of Washington, an increase of 0.7 percent in the soil cohesion value resulted in a 20 percent increase in the FS (Debray and Savage, 2001). In addition, the slope stability models do not consider delivery potential and impacts to public resources.

As stated above, there are relatively few measures that can be employed to mitigate for timber harvesting on a slope, and the benefits of such measures are not entirely clear. For instance, there may be a high potential for windthrow in a leave area around a headwall or within a bedrock hollow. Such windthrow can result in substantial ground disturbance and an instantaneous loss of root strength. Alternatives could include harvesting the trees so that the stumps and roots are retained, or to substantially increase the size of the leave area and hope that windthrow does not impact the critical slopes. Another mitigative measure for which the beneficial effects are not well understood are partial harvests. Intuitively, it makes sense that leaving some trees results in a more stable slope than leaving none at all. However, is there a substantial difference between a 25 percent and a 50 percent, or even a 75 percent partial cut? There is clearly a need to monitor and document the effectiveness of the various timber harvest mitigative measures.

Numerous studies, as well as personal experience, have shown that by far the predominant timber-management-related impact to slope stability is from roads (cuts, fills, and stream crossings). Although impacts from harvest-related landslides can be substantial, significantly more attention should be given to the location, construction and maintenance of roads.

While more data (soil parameters, groundwater characteristics, precipitation data) may provide a clearer answer to potential harvest impacts on slope instability, there is a practical limitation of time and money associated with the collection of such data during a harvest unit evaluation. In the end, timber managers will still rely on the opinions of individuals whose qualifications (education and experience) and personality (high- or low-risk tolerance) can vary substantially. Often, there may be areas where there is a low-to-moderate geotechnical risk for a harvest-related slope failure, but the political/public relations risk for such a slope failure are substantially higher. In other cases, there may be a moderate to high potential for a slope failure, but there is a low to no potential for impact to public resources. In these instances, the landowner will have to decide, with input from the geologist, whether to propose harvesting these areas or not.

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