Drainage Plans: A Comprehensive Planning Tool in High-Risk Terrain

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ABSTRACT

Drainage plans can be a powerful tool in the proactive management of terrain instability events. The methodology used to undertake drainage plans is currently non-standardized, which results in products being submitted that vary greatly in quality and cost. To achieve some standardized approach, resource managers and the professionals who conduct the plans must agree on their objectives, components, application, and implementation. The drainage plans are used to delineate drainage patterns over a hillslope, including the location of drainage divides and watercourses (perennial and ephemeral). In addition, drainage plans are used to locate culverts or cross-ditches along high-risk road segments that will maintain or re-establish natural drainage patterns. It is suggested that a risk analysis approach (where Risk = Hazard × Consequence) be used by resource managers to determine where drainage plans are appropriate. Drainage plans should be considered where there is a high or very high risk (moderate or high-hazard and a high consequence) of a slide occurring on or below the area where development or deactivation is proposed. To accurately locate watercourses and drainage divides, a three-step methodology is suggested, which includes a preliminary air photograph review, detailed fieldwork, and accurate presentation of the information for easy incorporation into operational plans. As a minimum, the drainage plan deliverables should include watercourse and divide line work transferred onto an accurate topographic base map and flagged in the field. Experience indicates that incorporating information from a drainage plan into operational plans is the most difficult aspect of all. If drainage plans are to be successfully used as a tool for minimizing development- or deactivation-related slides in high-risk areas, all levels of management—from planners to operations supervisors to hoe operators—must be made aware of where and why the plans are being undertaken.

INTRODUCTION

Comprehensive study of landslides and their causes is ongoing in the Nelson Forest Region, located in southeastern British Columbia. Preliminary findings indicate that most development-related landslides (at least 33% and possibly as high as 69%; Table 1) in British Columbia's southern Interior occur as a result of drainage diversion and concentration along resource roads (Jordan 2001).

TABLE 1 *Landslide study data, Nelson Forest Region (Jordan 2001)*

Total number of landslides:	582
natural	135
development-related	447
Distribution by apparent cause:	
road fill[a]	36%
drainage diversion, road	25%
drainage diversion, skid trails	8%
road cut	2%
clearcut	2%
other	4%
natural	23%

a Many caused by water diversion flowing over and saturating fillslope.

In British Columbia, the Forest Practices Code regulations require road designs and prescriptions to maintain slope stability when roads are proposed on potentially unstable or unstable terrain. Drainage structures are prescribed as part of the road design to maintain natural drainage patterns along a proposed road right-of-way.

Although most road surveys locate drainage structures for permanent watercourses, the location of short-duration (ephemeral) watercourses, which often have no obvious channel (also referred to as non-classified drainages or NCDs), are commonly missed during road surveys that are undertaken after the freshet. Drainage divides that form the natural topographic separation between these small sub-basins may also be ignored. As a result, intercepted ditch water often flows across subtle drainage divides before being discharged from the road prism.

The location of ephemeral watercourses and the location of drainage divides are two pieces of information that are essential for reducing the number of resource road–related landslides in the southern Interior. These two pieces of information are also critical for maintaining slope stability where roads are proposed above potentially unstable or unstable terrain.

Drainage plans that identify the location of watercourses and divides can be an effective tool in pre-emptive management of terrain instability events related to resource road construction or deactivation. This paper introduces the concept of drainage plans, presents methods and deliverables that have been used by the authors over the past 3 years, and discusses difficulties that have been encountered in the application and incorporation of drainage plan information into operational plans and activities.

DRAINAGE PLAN OBJECTIVES

A drainage plan is a map that delineates surface drainage features, including watercourses and divides over a hillslope. The primary objectives of a drainage plan are:

- to identify drainage features over a slope; and
- to locate drainage structures to minimize drainage diversion and concentration and reduce the occurrence of slides caused by drainage diversion and concentration.

Secondary objectives can include:

- locating drainage structures to avoid saturating areas were there is existing downslope instability; and
- delineating areas for hydrological risk assessment of proposed forest development activities.

Roads and trails constructed with cutslopes less than 0.5 m can intercept surface and subsurface flows. A road that traverses a slope at a constant grade cuts through gentle topographic swales and ridges that originally functioned to maintain disperse surface and subsurface flows. The identification of these subtle features allows for placement of drainage structures that reduce the opportunity for water carried in the ditch line to be diverted across divides. In addition, identification of ephemeral surface flows and the corresponding divides (micro-drainages) on the face of slopes allows for a more precise assessment of level of harvest within these micro-drainage basins where downslope terrain stability is a concern. Identification of these micro-drainages also allows drainage structures to be placed so that culvert discharge can be avoided or minimized on slopes where downslope terrain instability is identified.

INFORMATION REQUIREMENTS

The information required to complete a drainage plan includes an understanding of the nature of drainage over the hillslope, the location of permanent and seasonal watercourses, the location of drainage divides, and the location of existing drainage diversions.

Nature of Slope Drainage

Hillslope drainage patterns are dependent on cross-slope and longitudinal slope profiles, soil depth (i.e., depth to restricting layer), relic glacial landforms, and bedrock structure.

Slope Profile Slope profile generally plays the most significant role in controlling the overall drainage pattern (Figure 1). Convex slopes can have complex drainage patterns, including divergent drainage patterns that occur when small unconfined streams pool behind and split around obstructions such as bedrock knolls or overturned root wads. Drainage divides on convex slopes are subtle and often discontinuous. Convergent drainage patterns occur on concave slopes where ephemeral streams converge downslope, becoming larger and more entrenched. Drainage divides on convex slopes generally converge downslope and become more defined.

Soil Depth Groundwater and interflow in unsaturated soil (vadose zone) can play a significant role in slope drainage patterns in areas with shallow soils or restricting layers. These conditions often exist on convex slopes where the processes of glaciation have scraped the noses of the upper convex slopes bare of soil. Seeps and springs can develop where subsurface and groundwater flow is concentrated through shallow soils (Figure 2).

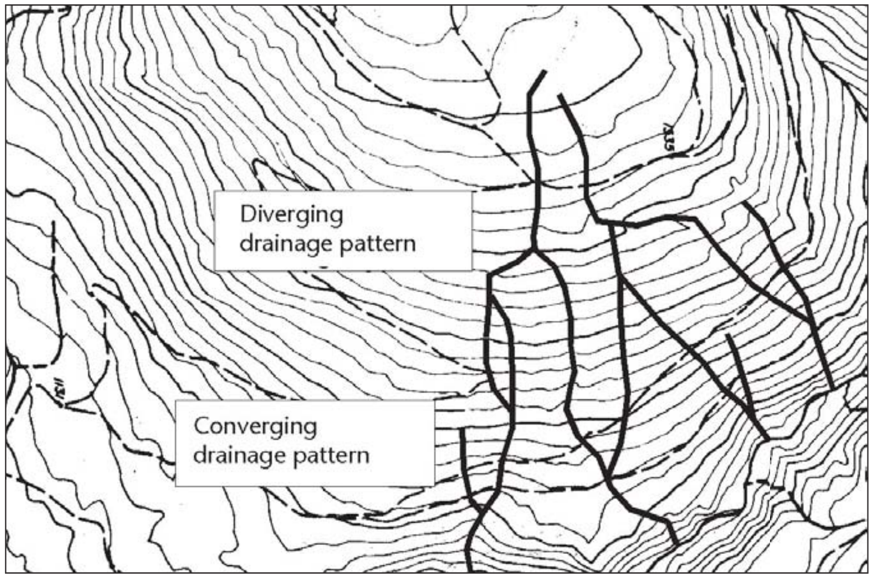

FIGURE 1 *Simplified representation of drainage patterns on convex and concave slopes.*

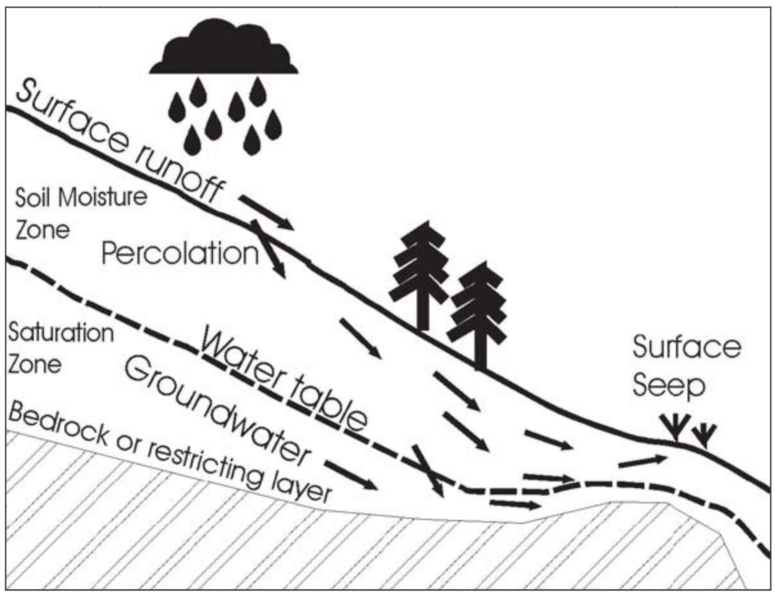

FIGURE 2 *Subsurface and groundwater flow can account for a significant proportion of slope drainage in some areas. Seeps develop where subsurface water is brought to surface.*

Glacial Landforms About 11 000–20 000 years ago, massive valley glaciers and ice sheets covered most of the lowland areas and occupied all of the large British Columbia Interior valleys. During deglaciation, rivers and streams flowed on top of and along the margins of the melting glaciers and from the toes of the glaciers. Sediment scoured from beneath the glacial ice was deposited over the landscape as the ice downwasted. A ridged and hummocky topography formed by the glacial sediments is often exposed at the mid-elevations along the main Interior valleys and on the valley sides and interfluves of larger tributary valleys. In some locations, these ridges and hummocks control surface drainage patterns (Figure 3).

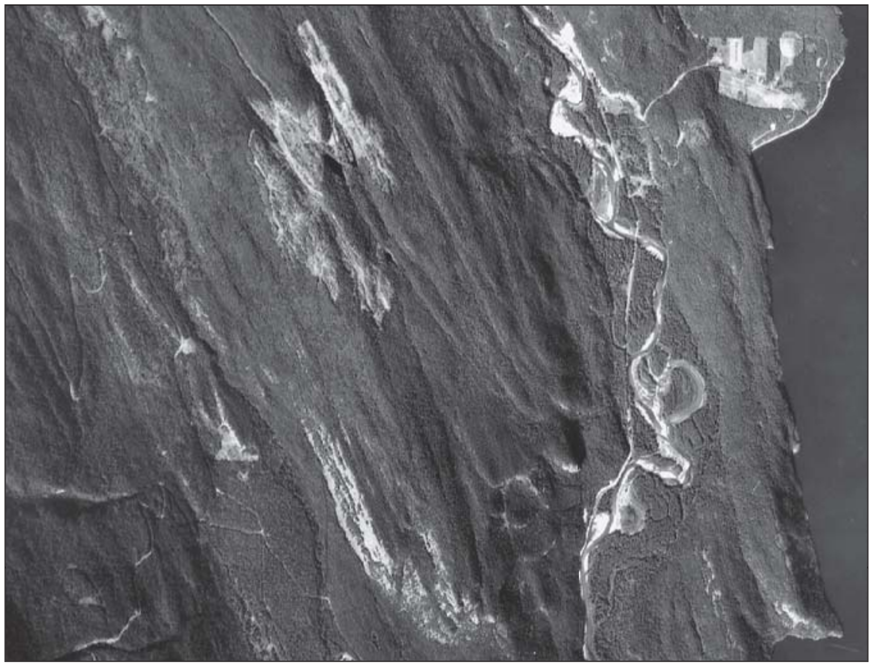

FIGURE 3 *Relic glacial topography controlling surface drainage patterns.*

Bedrock Structure Faulted, jointed, and foliated metamorphic and sedimentary rocks and, to a lesser extent, intrusive rocks underlie much of the landscape throughout the southern Interior of British Columbia. Where soil is shallow and bedrock is exposed or close to the surface, joints and fractures in the rock can control surface and subsurface drainage patterns (Figure 4). Locating permanent and ephemeral streams and the divides that separate them is essential to maintaining natural drainage patterns over a hillslope. Permanent watercourses are usually identifiable on air photos and on the ground. However, the locations of permanent watercourses on digital base maps are often incorrect and need adjusting.

FIGURE 4 *Rectangular jointing in weakly foliated metamorphic rocks in the Castlegar area.*

FIGURE 5 *Ephemeral stream flowing over the forest floor.*

Location of Ephemeral and Permanent Watercourses and Divides

The location of ephemeral or seasonal streams may be identifiable on air photos but many are difficult to identify on the ground due to the lack of defined channels. In many cases, ephemeral streams flow over the forest floor (Figure 5), leaving little evidence of a channel once the flows cease.

Location of Existing Drainage Diversions

If natural drainage patterns have been previously disrupted by old roads and trails, additional road or trail construction can compound existing drainage diversion and concentration (Figure 6). Where there has been a significant amount of past road or trail development on a hillslope, it may be necessary to start at the top of a drainage basin and work downwards to identify the extent of existing diversions.

SUGGESTED METHOD AND OUTPUTS

Three steps are suggested to complete a drainage plan. The first step is to delineate all obvious watercourses and divides on recent 1:20 000 (or larger) air photos. Where significant development has occurred, older air photos can be used to help identify original drainage patterns.

The second step is to conduct fieldwork to verify and/or correct watercourse and divide locations on air photos and identify on the ground (at least along the proposed road right-of-way) with tags, paint, or flags. Fieldwork should be done during the spring freshet to aid in identifying the location of ephemeral watercourses.

The third step is to transfer information from the air photos onto accurate topographic base maps. The transferring can be done by hand or through stereo transfer methods.

Outputs

The outputs for a drainage plan project vary depending on the scope of the project. The basic product is a topographic map that identifies the location of watercourses, divides, and existing diversions (Figure 7).

Where a road is proposed, the location of any additional drainage struc-

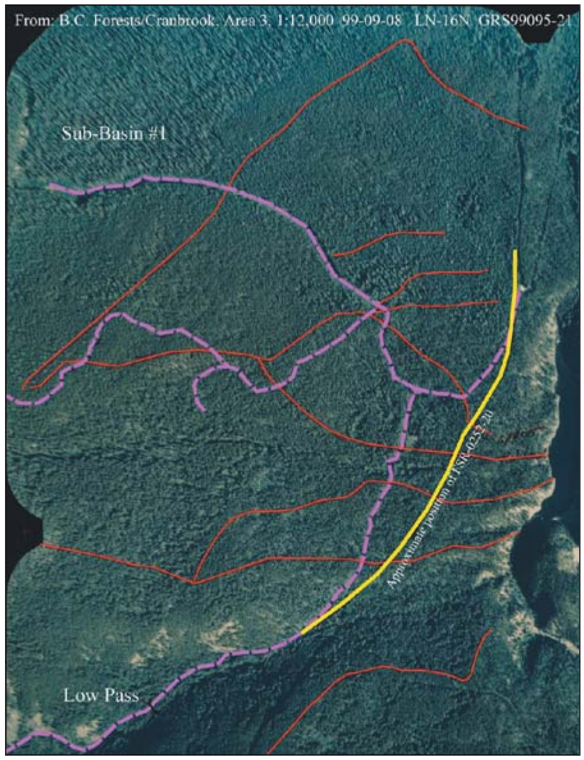

FIGURE 6 *The location and extent of existing drainage diversions must be determined before new road construction occurs downslope to avoid compounding problems (existing road – pink; proposed road – yellow; drainage divides – red)*

tures required to maintain natural drainage patterns should also be presented on the topographic base map. Where plans and profiles exist, the locations of additional drainage structures should be presented directly on the plans and profiles.

Outputs for a drainage plan can also include a hydrological assessment of proposed harvesting and road construction activities for small face unit drainages adjacent to high-value streams.

Where drainage plans are conducted in conjunction with road deactivation activities, divide and watercourse information should be included on deactivation maps.

INCORPORATING DRAINAGE PLANS INTO OPERATIONS

Two main challenges have been encountered by the authors and resource managers who have undertaken drainage plans:

1. initial incorporation of the drainage plan information into operations; and
2. retaining the information through maintenance, reconstruction, and deactivation activities.

The initial incorporation of drainage plan data into operations has proven difficult in a number of road projects where plans and profiles (RPS) have

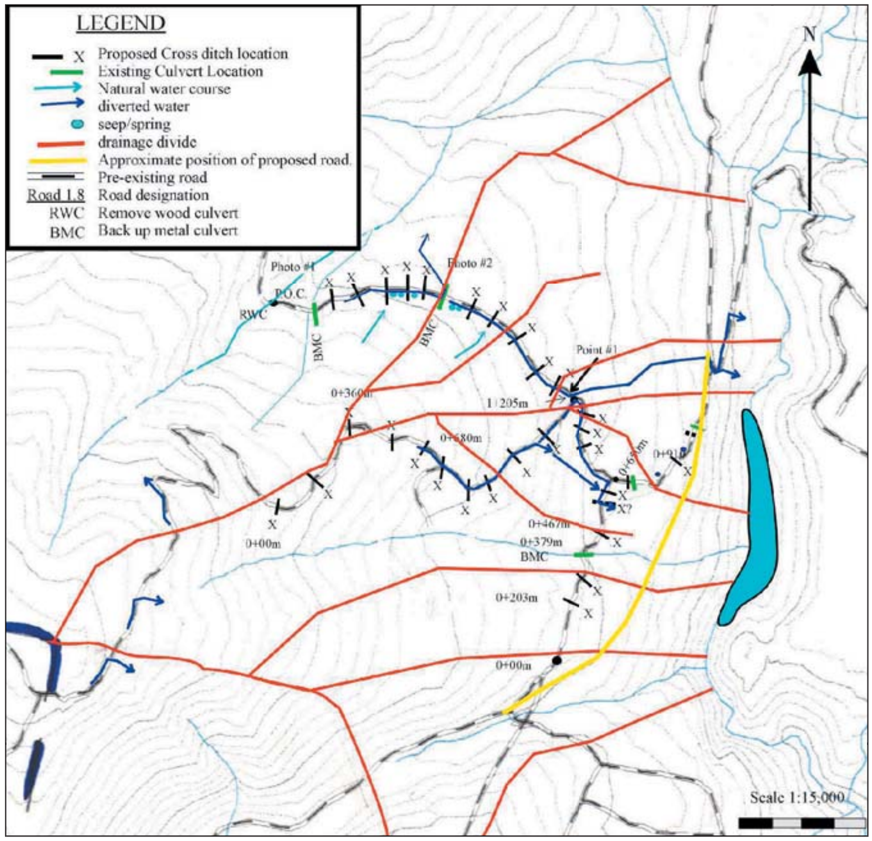

FIGURE 7 *Example of drainage plan map.*

been produced independently of drainage plans. Confusion due to overlapping prescriptions occurs where operations managers and equipment operators are trying to work with the information from two separate plans and field markers.

The most difficult challenge over the long term has been in retaining the information from drainage plans through maintenance, reconstruction, and deactivation activities. This is primarily due to the lack of a formal process for archiving and retaining information from drainage plans—particularly if the drainage plan has been produced as a stand-alone product.

Some suggestions to address these challenges include:

1. developing company protocols for dealing with drainage plans;
2. placing signs along road segments where water diversions pose a risk to downslope resources. Signs also provide a non-verbal means to communicate the existence of a drainage plan in multiple user group situations; and
3. incorporating drainage plans into Ministry of Forests road design and road deactivation requirements.

RECOMMENDED APPLICATIONS OF DRAINAGE PLANS

A simple risk analysis approach (where Risk = Hazard × Consequence) is suggested for identifying, at a reconnaissance level, areas where drainage plans should be undertaken (Table 2). Drainage plans are recommended

TABLE 2 *Risk determination matrix (Moore 1994)*

Consequence	Hazard: Low	Hazard: Moderate	Hazard: High
Low	Low	Low	Moderate
Moderate	Low	Moderate	High
High	Moderate	High	Very High

where development or deactivation activities are proposed *on or above* areas with moderate or high likelihood of a slide (i.e., Class IV or V, or "P" or "U" terrain) that are situated above areas where the consequence of a slide occurring would be moderate to high (e.g., settlement or transportation corridors, community watershed intakes, high-value fisheries streams).

Drainage plans are also useful in identifying and maintaining slope drainage in "gentle-over-steep" terrain, which has been identified in the southern Interior landslide study as accounting for a significant number of slide events, as indicated by the following quote from Jordan (2001).

> An important category of landslides occurs some distance below roads, below a culvert or a point of accidental drainage discharge. In many of these cases, the road itself is on gently-sloping, low-hazard terrain, and the landslide occurs on steeper terrain below. This is known as the "gentle-over-steep" situation.

Drainage conditions in gentle-over-steep terrain generally consist of numerous small ephemeral streams in a dispersed or divergent drainage pattern (Figure 8). Road construction in this situation can easily concentrate and divert numerous unrecognized ephemeral watercourses. Concentrated and diverted water is discharged from the road prism and flows downslope onto steeper terrain, triggering slides due to the significant increase in surface and subsurface runoff (Grainger 2002).

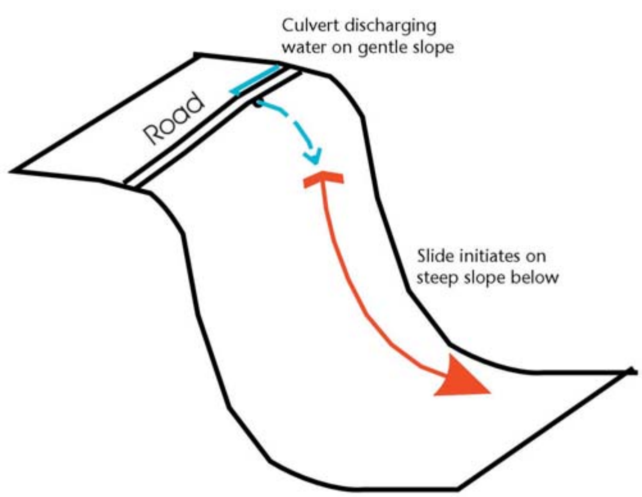

FIGURE 8 *The "gentle-over-steep" situation.*

CONCLUSIONS

Where development or deactivation activities are proposed on or above high-risk terrain, the placement of drainage structures based on road gradient or preliminary road location surveys alone is often insufficient to maintain natural drainage patterns and slope stability. Drainage plans can be effective tools in reducing the occurrence of terrain instability events associated with resource road construction and deactivation.

Professionals undertaking drainage plans should use similar survey methods and provide standard outputs to reduce confusion surrounding the definition and utility of drainage plans.

Forest managers, planners, technicians, and professionals involved in resource road construction and deactivation need to take the first step in identifying where drainage plans should be undertaken and conducting drainage plans as part of road designs and deactivation prescriptions in high-risk terrain.

Due to the liability associated with prescribing drainage structures in high-risk situations, drainage plans should be completed and signed off by qualified registered professionals who have a comprehensive knowledge of air photo interpretation, slope hydrology, and terrain stability analysis.

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