

Streamline

B.C.'s Watershed Restoration Technical Bulletin

Vol. 3 No. 3

Evaluation of Hill Slope Geometry and Composition Required to Prevent Landslide Initiation

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The techniques presented in this paper are a critical element of calculating the cost benefit value of hill slope stabilization work. Specifically, these techniques can be used to determine the down slope damages (consequences) of a potential road fill failure. With accurate estimates of a road fill failure's down slope consequences it is possible to assess landslide risk (risk = hazard x consequences), the opportunity cost of permitting a failure to occur, and the cost benefit value of stabilizing the roadway. This paper is a "toolkit" of

assessment procedures and analytical techniques that forestry and watershed personnel can use to better manage road related landslide risk.

Overly conservative management of prospective sidecast road fill failures may have unsafe and costly consequences. For example, pulling back sidecast road fill which cannot trigger a significant landslide may unduly jeopardize worker safety and is generally not cost effective. The excessive use of specialized methods, such as over-reliance on full bench and end haul, or 3/4 bench, road construction techniques, is costly and may result in inordinate, difficult to rehabilitate, soil disturbance.

continued

Editor's Note

Thank you to all those who sent in ideas in response to a call for a potential new name for "Streamline." Thank you as well, to the numerous individuals who wrote, called, and e-mailed to protest a name change. It has been decided that "Streamline" will remain the name for this technical bulletin about watershed restoration. This decision does reflect that Forest Renewal BC and its Board has recently directed that all restoration, including hillslope restoration, is to be associated with damaged streams.

We welcome comments and ideas from our readers. This issue of Streamline is based on a request that asked Streamline to provide information on "evaluation." Evaluation is a word that means different things to different people. To some, evaluation is a process of risk-assessment; to others, a method of estimating costs and benefits; and to yet others, a technique to measure project effectiveness. Evaluation is often a criterion for decision-making, and, as the trend to funding reduction continues, evaluation will become more important. We appreciate the authors who provided different perspectives on evaluation for this issue. Also included in this Streamline is an insert containing the proceedings of the WestLand Conference held in Prince George, Oct. 7 - 9, 1998: Watershed Restoration Techniques in North/Central B.C.

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The leading cause of conservative road fill failure management is uncertainty. Most forestry and watershed personnel specify heavy pull back, or full bench and end haul; few are willing to explore letting nature “take its course.” Overall this common sense approach to landslide risk management is well advised. However, through well established engineering knowledge and by extrapolation of recent research data, we can infer which road fill failures are unlikely to trigger landslides. Specifically, road fill failures:

- should accumulate volume (propagate) on hillslopes >40%;
- may lose volume (deposit) on hillslopes between 30 to 40%; and
- should deposit on hillslope gradients less than 30%, given that the bench the road fill falls upon is at least nine m long (or wide) and is composed of low fines till, or colluvium.

The greater the distance between the toe of the fill slope and the beginning of the hillslope bench <40%, the longer (wider) the bench must be to assure terminal landslide deposition. In general a 30 to 70 m long (wide) bench is required to assure terminal deposition of a road fill failure which has traveled >20 m before reaching a hillslope bench <40%.

The above “rules of thumb” do not apply on smooth concave, convex or gullied hillslopes, or hillslopes composed (or covered in a veneer) of organic, clay or silt rich soils; such slopes promote long runout landslides.

In addition to the above “rules of thumb” there are six additional evaluation methods commonly used in the forest sector. The methods are summarized in Figure 1. The methods are:

1. Field review, measurement and analysis of actual

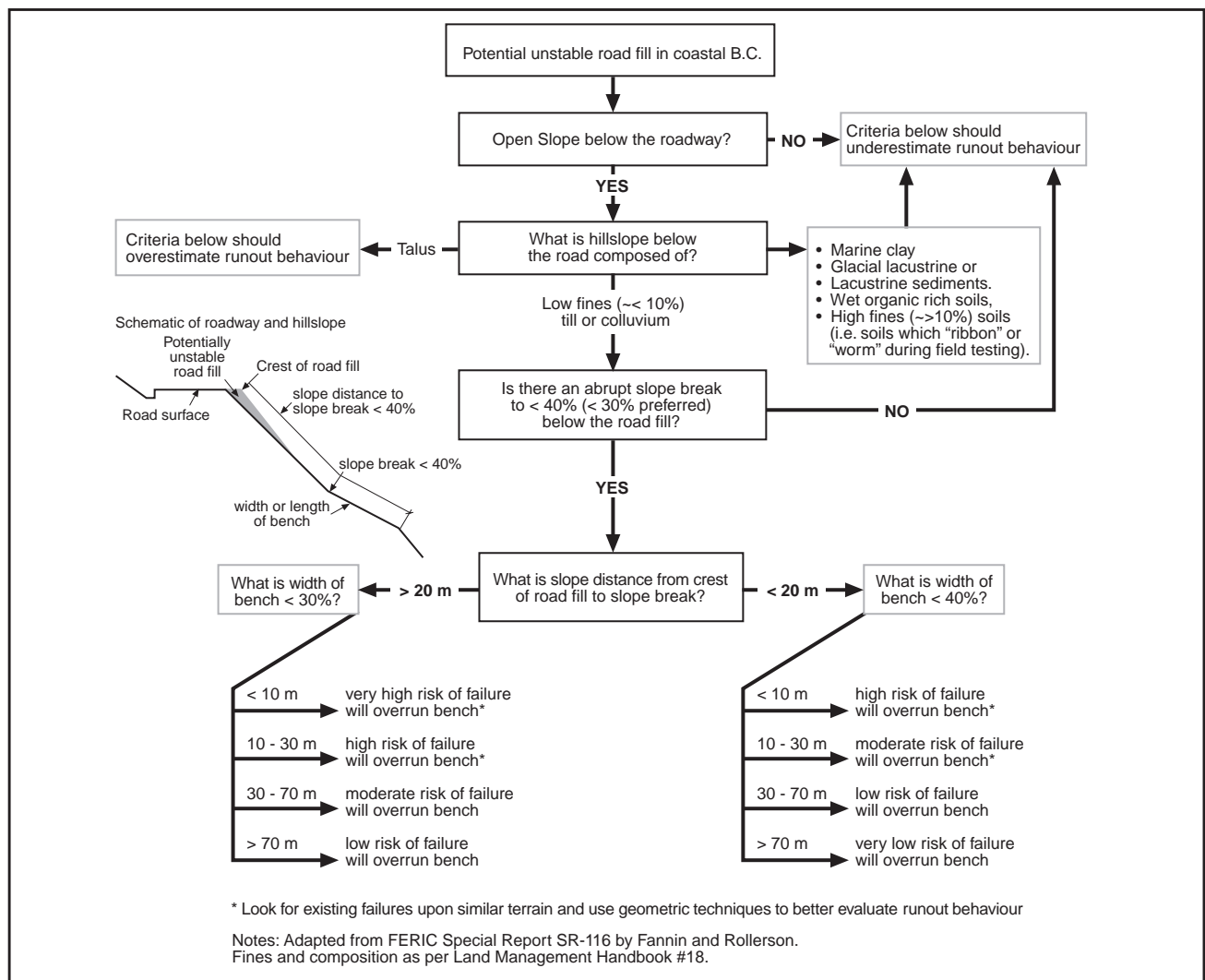


Figure 1. Flowchart to determine landslide runout behaviour.

fill slope failures along the roadway in question. Office review of road related land slides recorded in air photographs of a site provide similar, if less accurate, information regarding local debris flow initiation potential and runout behavior. This is a common, if informal and poorly documented, practice on many WRP projects.

2. Generalization of the conclusions from method 1 to similar roads, on similar terrain. Very detailed documentation of actual road fill failures would improve the usefulness of this assessment procedure.
3. Generalization from well documented slope stability and landslide runout research. Specifically, Table D of the Gully Assessment Procedure (GAP) and key conclusions from Assessing Debris Flow Behavior in Coastal British Columbia: Runout Behavior (R.J. Fannin and T.P. Rollerson, 1996).

Table D of GAP (Figure 2) is based on back analysis of thousands of gully sidewall failures and hundreds of debris flows. Minor gully sidewall failures approximate road fill failures; both “styles” of slope failures generally fall from like terrain to like terrain (that is, the composition of hill slope is usually constant). As sidecast road fill slopes are frequently >10 metres slope distance to the nearest hill slope bench, Table D suggests road fill failures affecting terrain >40%, below the roadway in question, have a moderate or high probability of triggering a debris flow or slide. However, Table D of GAP must be used with extreme caution when assessing the debris flow potential of road fill failures.

FERIC Special Report SR 116 (Fannin and Rollerson 1996) is based on the back analysis of some 450 forestry related landslides on the Queen Charlotte Islands. The paper contains a number of useful “rules of thumb” for determining the initial,

Gully sidewall or headwall slope distance (m)	Channel gradient (%)				
	0-30	31-40	41-50	51-60	61-70
> 20					
16 - 20	L	M	H	H	H
11 - 15					
10 - 6	L	L	L	M	M
0 - 5					

Figure 2. Table D from the Gully Assessment Procedure (GAP) Guidebook (April 1995): Gully geometry potential for debris flow initiation.

Road fill failures loosely approximate gully sidewall failures affecting a gully channel. Therefore table D of the GAP can be used to estimate the hillslope gradient below potentially unstable road fill required to prevent debris flow initiation.

and terminal, deposition points for the more common “styles” of debris flows. Of interest to this paper are the conclusions of Fannin and Rollerson regarding the back analysis of 158 open slope to open slope, Type 1, debris flows.

The debris flows analyzed by Fannin and Rollerson occurred on hillslopes characterized by relatively thin soil mantles of colluvium and glacial soils. The debris flows generally initiated on steep, and terminated on gentle, mountainous slopes. The analyzed debris flows likely occurred during periods of high soil moisture content and peak groundwater pressures associated with extreme rainfall and snow melt conditions and/or forestry road modification of natural hillslope drainage. Such debris flows approximate the debris from a road fill failure affecting an open hillslope below a roadway.

Fannin and Rollerson found that the onset of terminal debris flow deposition is generally “triggered by a distinct change in slope gradient, such as occurs at the toe of a hillslope, and some judgment should be exercised in identifying where it occurs.” They found that significant deposition of Type 1 debris flows on slopes >41% (230) is unlikely; deposition is common upon <27% (150) hillslopes. Most Type 1 debris flows were depositing on hillslopes <13% (70). Therefore, if the hillslope below a potentially unstable roadway is >41% there is a high probability that any road fill failure which occurs will propagate and may ultimately trigger a debris flow.

The length of the terminal deposition zone for the analyzed, Type 1, open slope debris flows was highly variable. Terminal deposition only occurred in 16% of the analyzed slides on hillslope benches shorter than nine metres; such deposition was common (occurred in ~>50% of analyzed slides) on benches 31 to 40 m wide; and it occurred in 84% of analyzed slides on benches >71 metres wide. Therefore, Fannin’s and Rollerson’s research suggests there should be a <41%, 31 to 40 m wide bench below a roadway to provide creditable assurance that a prospective road fill failure will not trigger a landslide.

However, most of the analyzed debris flows (84%) travelled >23 metres before the onset of terminal deposition. Therefore, Fannin’s and Rollerson’s method could easily overestimate the gradient and length (width) of a hillslope bench immediately (i.e. 0 metres) below a roadway required to induce terminal deposition of a “dry” road fill failure affecting a “dry” hillslope.

4. Trenching, field and/or office evaluation of hillslope composition. If the hillslope below the prospective fill slope failure is composed of

Feature



Figure 3. Dramatic example of a debris flow (south mainland coast) that initiated as a minor road fill failure at the junction of two old logging roads.

silt, clay, or organic rich soils, any road fill failure affecting the slope may exhibit an unusually long runout. Earth flows have initiated and propagated on wet, organic rich, hillslopes of approximately 30% slope gradient. Marine clays can produce massive earth flows on slope gradients of 5%. Recent, very soft, lacustrine silt and clay deposits can flow on slopes as gentle as 10% when overloaded. Glaciolacustrine silts and clays are widely reported to fail at, and runout on, slope gradients 10 to 20% lower than conventional (low fines – non plastic) colluvial or till slopes. Fines rich (>10 to 16% fines) tills frequently exhibit unusually long runout behavior. Evaluation should include an assessment of soil moisture conditions within the probable failure mass and the hillslope below the roadway, at the moment of slope failure. Unusually wet sites are prone to debris flow initiation. Therefore, culverts, cross ditches, abundant cut or fill slope seepage sites, and indications of groundwater springs or “swampy” ground below a roadway, are classic indicators of sites prone to road fill failures and, all too often, subsequent debris flow initiation. Conversely, unusually “dry” sites are unlikely to produce debris flows. Talus is an excellent example of an inherently “dry,” very low fines soil type which is highly resistant to debris flow initiation.

5. Geometric variations on the above techniques. Geometric analysis involves cross sectioning of the potentially unstable road fill, hillslope bench length (width) and gradient. The assessor then attempts to “fit” the forecast volume of potentially unstable road fill (and hillslope debris that a road fill failure may entrain) on the available bench. Should the forecast quantity of slide debris be unusually deep or steep compared to similar road fill failures on similar terrain, further analysis is required. This may include assessing pull back of potentially unstable road fill to reduce the quantity of debris that the bench below the roadway must accommodate. In some cases it may be appropriate to use alternative road construction techniques such as a placed rock fill, or retaining wall, rather than attempting to “catch” a road fill failure on a narrow or >30% hillslope bench. In general, geometric analysis tends to be costly, site specific, and inconclusive; it is best used in conjunction with techniques 1 and 2 above.
6. Composite methods. In situations where down slope values are high, or slope conditions difficult to quantify, several, sometimes all, of the above techniques can be used to evaluate the debris flow potential of a specific roadway.

Once the likely runout (down slope consequences) of a specific road fill failure are known, it is possible to calculate the opportunity cost of "letting nature take its course," or only taking very modest measures to reduce the likelihood of slope failure. Conventional wisdom in the forest sector is that:

- it is rarely cost effective to stabilize road fill that is incapable of triggering a landslide causing <0.05 ha of soil disturbance, or of terminating within a fish bearing, or community watershed, stream;
- it is generally cost effective to prevent road fill failures that would disturb significant quantities (>0.05 ha) of immature regenerative forest, although the pay-back period on such an investment could approach 100 years; and
- it is almost always cost effective to prevent road fill failures that could affect significant quantities of salable timber, fish bearing streams, advanced regenerative forest, homes, highways, railroads, utilities (hydro, gas, fibre optic lines), or forestry bridges.

However, the landslide depicted in the photograph in Figure 3, for example, had numerous severe downslope

consequences including the depreciation of an estimated half million dollars worth (about \$100 000 stumpage value) of standing timber, and heavy sedimentation of a fish-bearing stream. Thorough deactivation in a timely manner of the roads that produced the slide, would have been a sound forestry and watershed conservation investment.

References

- Fannin, R.J. and T.P. Rollerson. 1996. Assessing debris flow behavior in coastal British Columbia: Runout behavior. FERIC Special Report SR-116.
- Province of British Columbia. 1995. Gully Assessment Procedure Guidebook (GAP). Forest Practices Code of British Columbia.

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Evaluating Resource Benefits from Hillslope and Stream Restoration Programs

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A. Screening Criteria for Restoration Projects

The fundamental goal of the Watershed Restoration Program (WRP) is to restore, protect and maintain fisheries, aquatic, and forest resources that have been adversely affected by past logging operations. Although a project's rehabilitation costs can be measured in reasonably straightforward ways, the multiple resource benefits that are associated with these projects are time-dependent, and may be uncertain. The restoration of aquatic resources involves improvements in the quality of stream-flows, fish-rearing habitats, riparian forest lands and associated wetlands. It also involves the reduction in hillslope erosion through road-bed restoration, the restoration of forest cover with appropriate species selection and, wherever possible, the restoration of natural drainage channels. Aquatic rehabilitation and forest regeneration are often both

required to restore recreational values.

This paper describes in detail a *net present value (NPV)* approach to project screening and ranking of a potential set of projects, a necessary approach given that the potential resource benefits associated with aquatic rehabilitation and forest regeneration accrue only gradually. This approach can be used to assess these potential resource benefits and to weigh them against project costs. The *NPV* valuation method can be used to assess the relative merits of alternative rehabilitation projects, or to assess the potential benefits of an integrated restoration program for an entire watershed.

This paper complements my chapter in *Fish Habitat Rehabilitation Procedures: WRP Technical Circular*