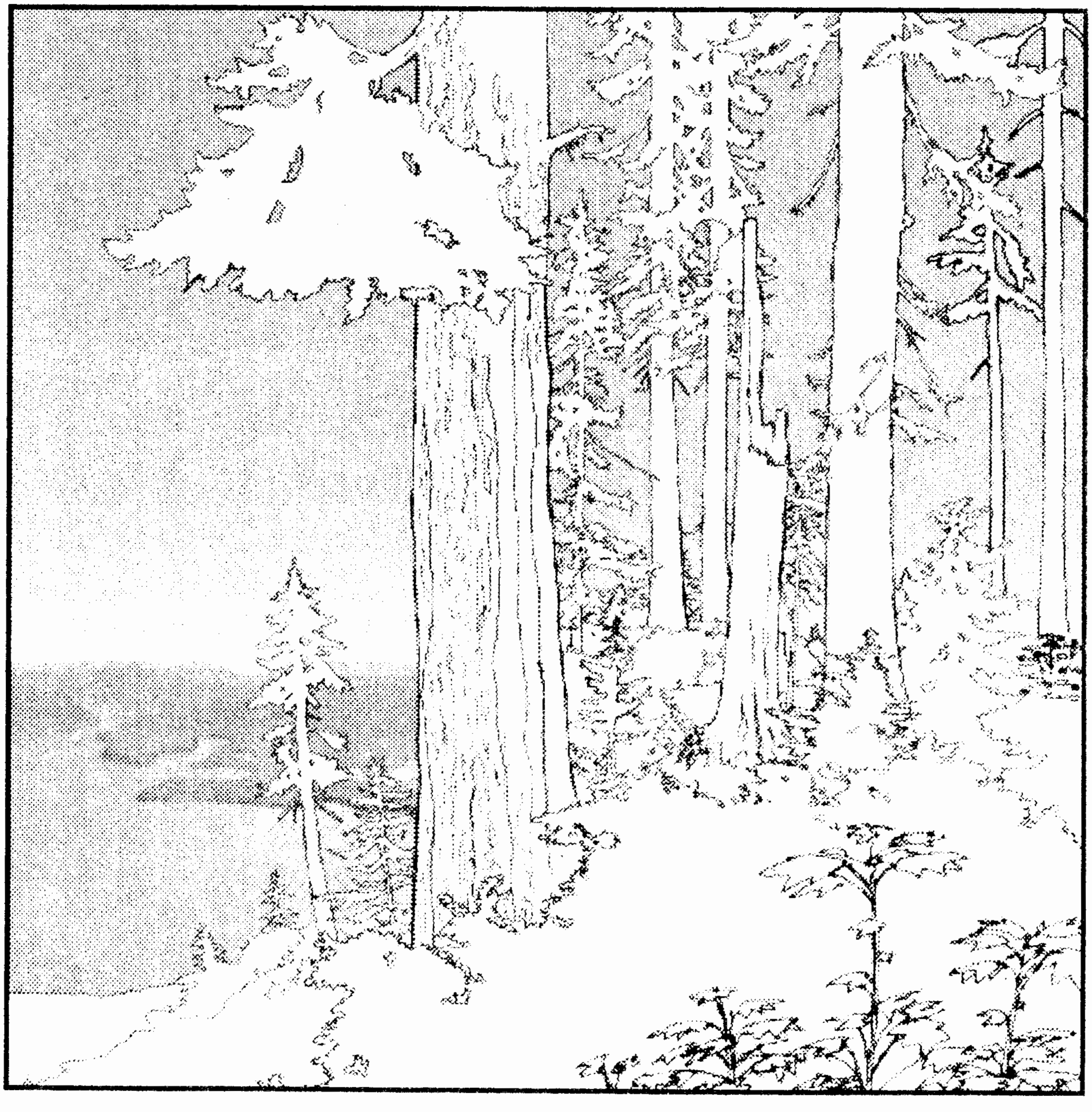
United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

General Technical
Report
PNW-GTR-392
March 1997

Assessments of Wildlife Viability, Old-Growth Timber Volume Estimates, Forested Wetlands, and Slope Stability



Controlling Stability Characteristics of Steep Terrain With Discussion of Needed Standardization for Mass Movement Hazard Indexing: A Resource Assessment

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Issue Definition

This paper presents an overview of factors controlling soil stability on steep terrain in southeast Alaska. A Forest-wide standardized approach for stability hazard assessment in the Tongass National Forest (Tongass) also is presented.

Background

Failure Type

A debris avalanche, defined as the failure of a finite mass of water-charged overburden material along a more-or-less planar or flat surface (Swanston 1974b), is the dominant failure type on steep forested slopes in southeast Alaska. Once failure occurs, the initial mass rapidly breaks apart owing to internal stresses; because of the high water content, it is transformed into a mixture of water, soil, rock, and organic debris that rapidly moves downslope. This type of secondary failure is called a debris flow.

Failure Mode

These landslides primarily occur at a shallow depth (1 to 3 feet) and develop entirely in the soil overburden. Few involve bedrock failure or deep rotational failures in silts and clays. Failure generally occurs along a well-defined plane marking the boundary between soil overburden and either bedrock or compact glacial till (fig. 1).

Once failure occurs, movement is predominantly translational (all particles of the soil mass move with the same velocity along parallel paths) with displacement along and parallel to the failure surface. Because of the shallow nature of the soil overburden, the gradient of the potential failure surface is approximately equal to the slope gradient.

Soil Overburden Characteristics

The soil overburden texture is characteristically gravely sandy silt or gravely silty sand (MH-ML; SM-GM according to the Unified Classification System [U.S. Army Corps of Engineers 1953]); less commonly the texture may be sandy gravel (Schroeder and Swanston 1987). Soil overburden with these textural characteristics generally has low liquid limits and low plasticity, indicating little or no cohesion. The dominant steep-slope soil types in southeast Alaska are no exception (Schroeder and Swanston 1987). For the most part, these index properties (called Atterberg Limits) are of little value for judging strength characteristics. Plasticity is so low (except for marine silts) as to have little influence on cohesion. Organic content has no significant effect on cohesive strength. The organic content is highly variable, however, and may exceed 30 percent locally owing to downward migration of organic particles into the mineral soil zone. This occurrence could substantially increase plasticity and apparent cohesion at some sites.

Figure 1—Debris avalanche-debris flow in Marten Arm, northern shore of Bradfield Canal, southeast Alaska.

These soil overburden materials compress readily during shear, thereby reflecting low densities (80 to 100 pounds per square foot) and high void ratios (Wu and others 1979, Wu and Swanston 1980). The materials are commonly assumed to be cohesionless for general analysis purposes, although some cohesion usually is present. This becomes significant in determining the resistance to failure on very steep sites where the angle of internal friction of the material exceeds the slope gradient.

Potentially unstable slope gradients range from 60 to 72 percent. Engineering analyses of soils in southeast Alaska (Schroeder and Swanston 1987) indicate that slopes must be considered highly unstable when they exceed 72 percent. Based on statistical analysis of grouped samples of dominant soil types on steep terrain in southeast Alaska, the mean effective angle of internal friction for till and colluvial soils is 72 percent (Schroeder and Swanston 1987). This mean drops to 70 percent for residual soils. The mean values may be used for general assessment of soil behavior (i.e., for Forest planning purposes). The fifth percentile values for these soil groups is 51 percent for colluvium and till soils and 65 percent for residual soils. The fifth percentile is the value such that only 5 percent of the values of a normally distributed sample population are less than this. The fifth percentile values are comparative and should be used in sensitive situations where the consequences of occasional failures are undesirable.

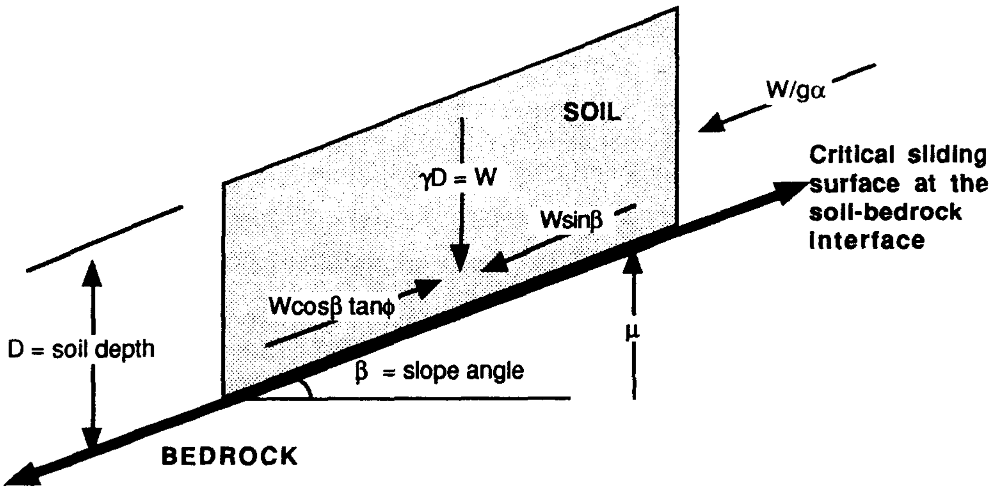
Typical of coarse-grained materials in general, these soils have a high hydraulic conductivity or permeability (Terzaghi and Peck 1960). Unsaturated flow rate is about 1.3 inches per hour, and saturated flow rate is about 0.25 inch per hour (Vandre and Swanston 1977). Infiltration rates are rapid and capable of transmitting low-intensity precipitation virtually without surface runoff occurring. During high-intensity storms, input of rainfall may reach or exceed the infiltration rate, and a steady state of transmission of infiltrating water downward to an impermeable surface occurs. Because of the lower saturated flow rate for these materials, water ponds above this impermeable surface and a temporary water table develop. If precipitation intensities are great enough and rainfall duration is long enough, the water table will reach the surface and runoff will occur.

Slope microtopography is an important factor in determining where and how often landslides occur (Swanston 1974b, Swanston and Howes 1991). Linear depressions or "hollows" (also called zero-order basins) initially produced by differential weathering and erosion along fractures and joints in bedrock, and by prehistoric landslide activity, are widespread on steep slopes of southeast Alaska (Swanston 1974b, Sidle and others 1985). Over geologic time periods, these hollows fail cyclically. Once failure occurs, they refill with soil and debris from local slumping and with sliding from the sides of the hollows. Soils in these areas commonly display well-developed horizons and support mature forest growth, suggesting a minimum of 300- to 500-year land slide intervals in individual hollows. Such sites are natural foci of convergent ground water flows, where the accumulated soil and debris become locally saturated and form temporary water tables that initiate landslides. These features are the points of origin of most of the landslides in southeast Alaska (Swanston 1967). The degree of soil development (indicating relative age) within the hollows, the thickness of soil and debris infill, and the spacing of the hollows on steep slopes are strong indicators of landslide hazard. In general, land slide hazard increases with increases in deposit thickness and age and landslide spacing (number per unit area). Water table depth in these overburden materials depends on factors such as, but not limited to:

- Antecedent moisture conditions—how much rain has fallen and how much water is present in the overburden at the time of a high-intensity storm.
- Hydraulic conductivity along the soil-rock interface.
- Storm intensity—for overburden materials characteristic of southeast Alaska, a rainfall intensity of 6 inches per 24 hours is usually adequate to completely saturate the overburden and thus develop a temporary water table with a piezometric surface at or near the ground surface (Schroeder and Swanston 1987, Sidle and Swanston 1982, Swanston 1967).

Failure Mechanics

Because of the coarse soil textures, shallow overburden, and planar nature of the underlying bedrock or till surfaces on which sliding occurs, these debris avalanches and debris flows can be analyzed from a practical engineering standpoint by using the infinite slope model (Hough 1957, Swanston 1970, Terzaghi 1950, Terzaghi and Peck 1960, Wu 1966). The infinite slope model considers forces acting on a block of material of unit thickness and width situated on a slope of infinite length. The forces developed in the overburden material upslope of the block and tending to push the block downslope are countered by equal and opposite forces tending to maintain the block in situ. The same is true for lateral forces acting against the block.



Note: Variation with percentage saturation neglected.

Figure 2—Infinite slope model.

The only forces that need to be considered in the analysis are illustrated in figure 2:

- Weight of the soil block (W).
- Component of the weight directed upslope as frictional resistance along the failure surface (Wcos βtanφ).
- Component of the weight directed downslope as gravitational stress (Wsinβ).
- Cohesion (C), or the ability of individual soil particles to stick together because of weak electrical bonding of clay components or capillary tension during dry periods.
- Root stabilization (R) developed in the overburden by (a) anchoring of roots through the shallow overburden and into the underlying till, and (b) reinforcing and binding of the overburden materials laterally.

The relative stability of a site can be approximated by considering the factor of safety against failure (FS) developed along the potential failure surface (Swanston 1970). This factor is expressed as the ratio of the strength (S) or forces tending to resist failure and the shear stress (T) or forces tending to cause failure. Weight of the soil block is the product of the unit weight of the soil (γ), and soil depth (D). Cohesion (C), root strength effects (R), and the frictional resistance developed along the sliding surface (Wcosβtanφ) are forces within the overburden that help constitute its strength (S) or resistance to failure. Gravitational stress (Wsinβ) and any external dynamic stresses developed due to cyclical loading caused by machinery, earthquakes, or blasting (W/gα) constitute forces tending to cause failure:

$$FS = \frac{S}{T} = \frac{C + R + W\cos\beta\tan\phi}{W\sin\beta + W/g\alpha} \quad (1)$$

where:

β = gradient of the failure surface,

ϕ = angle of internal friction,

g = acceleration of gravity (32 feet per second per second), and

α = peak particle acceleration generated by vibrations of materials.

The stability of materials on steep forested slopes is strongly influenced by the development of a temporary water table and by slope gradient. Saturation of materials and development of a water table produce a vertical force called pore-water pressure (μ) that reduces the effective weight (and thus frictional resistance) of the material acting along the failure surface by creating a buoyancy effect. If slope gradient approaches or exceeds the angle of internal friction of the material, then stability of a site is decreased to a critical level. In the absence of any water table, gradient alone controls slope stability. This situation is illustrated by reformulation of the factor of safety equation and consideration of conditions typical of steep, unstable slopes in southeast Alaska:

$$FS = \frac{C + R + (W - \mu)\cos\beta\tan\phi}{W\sin\beta + W/g\alpha}. \quad (2)$$

Cohesion and root strength effects are small in these coarse granular materials but significant on extremely steep, unstable sites; cohesion is generally less than 206 pounds per square foot (Schroeder and Swanston 1987). Root strength is generally less than 144 pounds per square foot (Wu and others 1979). If these forces are ignored, then the factor of safety equation can be rewritten as:

$$FS = \frac{(W - \mu)\tan\phi}{W\tan\beta} \quad (3)$$

Under natural undisturbed conditions, the factor of safety and therefore the stability of a site, is controlled by the angle of internal friction, gradient of the slope, and the presence or absence of a temporary water table (Swanston 1970).

General Stability Situation of Forested Slopes in Southeast Alaska

Slopes with gradients at or near the angle of internal friction of the overburden materials are in a delicately balanced state relative to stability. They are highly susceptible to any activity that might upset the balance of forces acting to maintain the overburden materials in place. Factors affecting their stability include:

- Destruction or reduction of stabilizing root system effects through a windthrow, fire, or management activity.
- Destruction or reduction of cohesion by collapse of soil structure or saturation of overburden materials.
- Removal of the weight of trees. Although rare, this removal may be a stabilizing factor on steep slopes underlain by deep, fine-grained residual soils and elevated glaciomarine silts and glacial lake clays. This stability factor is generally not significant in southeast Alaska, but may be important on individual sites.

- Reduction in frictional resistance along the potential failure surface by:
  —development of a temporary water table.
  —reduction in weight of overburden.
- Increasing downslope stresses by:
  —removing downslope support of the soil block.
  —increasing overburden weight by saturation or surcharging.
  —dynamic loading of the soil mass by earthquake or other external stresses.

Management directly influences stability condition through timber harvesting, road construction, and quarry development. Clearcut harvesting results in degradation of anchoring and reinforcing root systems (Sidle 1991, 1992; Sidle and Swanston 1982; Swanston 1969, 1970; Wu and others 1979; Wu and Swanston 1980; Ziemer and Swanston 1987). It also changes the hydrologic regime through decreases in evapotranspiration and increased water levels in the soil during the fall rainy season. Road construction may (1) undercut slopes; (2) surcharge or load the surface by sidecast, rock overlayment, and stockpiling waste; (3) concentrate surface and subsurface water in ditches and culverts that may discharge into unstable sites; and from (4) cause dynamic loading of the soil mass by machinery vibration and right-of-way blasting (Swanston 1971a, 1971b, 1974a, 1975). Quarry development may increase surcharging from dumping of stripped materials onto unstable waste sites and from dynamic loading of steep-slope soil surfaces from ground vibration and rock-throw during blasting. Dynamic loading during periods of temporary water table development is important. The temporary water table couples soil and bedrock together and transmits lateral stresses to the soil from blasting vibration (Vandre and Swanston 1977).

A Revised Methodology for Mass Failure Hazard Indexing

Current Indexing Methodology

Hazard indexing for mass failure is a qualitative measure of the expected increase in frequency of mass failures when vegetation is cleared or the land is disturbed. Although sufficient baseline data are not available to develop a quantitative index of mass failure hazard, a qualitative system was developed to rate soils of the Tongass as part of the land management plan revision process (Alexander 1987). This mass movement index methodology is based on characteristics of identified and mapped soil units across the Tongass and on the inherent slope, drainage, and landform characteristics that control stability of the overburden on the slope. The methodology, with modifications by the Chatham, Ketchikan, and Stikine Administrative Areas of the Tongass, has been applied since 1989 and is used extensively in Forest- and project-level planning to assess risks related to the amount and method of timber harvest. The index values also are used in the Tongass FORPLAN model to construct soil management unit tables that identify lands with a high hazard of landslide initiation following management activity.[1]

In this indexing procedure, five mass movement classes were recognized across the Forest. These classes are listed with expected effects of disturbance in table 1.

As initially used, the susceptibility for mass failure identified by these indices was a function of slope gradient, expressed in 15-percent increments, and by parent material type (related to soil series) as mapped on Administrative Area soil resource inventories and displayed in the Alaska Region Geographic Information System (GIS).

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[1] Information available from the Tongass land management planning record, U.S. Department of Agriculture, Forest Service, 8465 Old Dairy Road, Juneau, AK 99801.

Table 1—Definitions of mass movement indices developed as part of the 1987 Tongass land management plan revision

Movement index	Expected effect of disturbance on the frequency of mass failures
Extreme	Highly probable increase
High	Likely increase
Moderate	Moderately probable increase
Low	Unlikely increase
Nil	Improbable increase

The locations are identified by surface characteristics related to slope gradient, vegetation cover, drainage, and soil properties measured in sample sections. These surface characteristics and properties are also soil resource inventory (SRI) and GIS mapping criteria.

Proposed Indexing Methodology

With new information and analyses, a more quantitative approach to hazard indexing was developed from identified critical slope gradients, soil (regolith) depth estimates, soil strength criteria as defined by measured engineering properties, simple soil drainage estimates, and limiting landform characteristics (Schroeder and Swanston 1987; Swanston 1969, 1974b; Swanston and Howes 1991; Wu and Swanston 1980). The direct effects of soil depth are greatest in very deep cohesive soils, such as unconsolidated marine silts and glacial lake deposits of silts and clays. In such materials, slope and failure surface gradients are low and thus mass of the potential sliding material becomes more important. In the soil overburden typically underlying forested slopes in southeast Alaska, depths are shallow, averaging about 3 feet or less, and mass plays a much less important role. Such materials are coarse textured, highly permeable, and underlain by relatively impervious substrata that inhibit or stop vertical water movement and promote saturation and lateral drainage through the shallow overburden. Soil strength is a function of particle size, shape, composition, and structure (Alexander and Poff 1985, Mitchell 1976, Terzaghi 1950, Terzaghi and Peck 1960). Together, these variables control porosity, permeability, intragranular friction, and friction along various planes within the soil mass. Strength is largely determined by intragranular friction and frictional resistance developed along the potential failure surface that is controlled by engineering properties inherent to the soil material. The mean and fifth percentile values of engineering properties of a limited sample of dominant surface geologic materials in southeast Alaska (Schroeder and Swanston 1987) are displayed in table 2.

These materials also have been mapped as soil series at the broad, Forest-wide, landscape level as part of the Tongass integrated resource inventory; as such they are part of the Tongass GIS database. Series corresponding to dominant steep-slope geologic material types are shown in table 3.

Table 2—Estimated range of engineering properties (angle of internal friction $[\phi']$ and unit weight $[\gamma]$ for surface geologic materials in southeast Alaska

Geologic origin	Mean[a] (ϕ')	5th percentile[b] (ϕ')	Mean[a] (ϕ')	5th percentile[b] (ϕ')	Mean[a] (γ)
	--- *Percent* ---		-------- *lb/ft²* --------		
Colluvium and till soils	72	51	206	0	116
Marine sediments	65	36	312	0	131
Alluvium	78	60	182	0	109
Volcanic ash	62	21	240	210	82
Residual soils	70	65	115	85	102

[a] Mean values should be used for general assessment of soil behavior.

[b] 5th percentile values should be used for conservative analysis of sensitive areas.

Table 3—Important soil resource inventory (SRI) series by geologic origin

Soil series	Geologic origin
Karta	Compact glacial till (basal till)
Tokeen	Residual soil derived from igneous rocks
Ulloa	Residual soil derived from carbonate rocks
Wadleigh	Compact glacial till (basal till)
Mitkof	Colluvium and ablation glacial till
Traitors (Vixen)	Residual soil high in micacious materials derived from phyllite and schist
Tolstoi	Residual soil derived from noncalcareous rocks

By using the existing soil series boundaries from individual maps, the Tongass GIS database, the mean engineering properties, and measured slope gradients (table 2), a revised and more accurate mass movement indexing methodology can be developed. At the Forest plan level, ratings made with this revised index are based on SRI soil series criteria and mapped boundaries, mean engineering properties of soil series obtained from the literature, and slope gradients estimated from the Tongass GIS database. At the Area and project levels, accuracy and reliability of the indexing system can be improved by considering several factors. These include direct sampling and analysis of soil engineering properties, using indirect indicators of instability—such as dissection frequency, soil drainage condition, and parent material characteristics—using more accurate mapping of soil series boundaries, and measuring slope gradients directly. Thus, the system can be used for any Administrative Area of the Tongass, regardless of variations in detailed soil map unit differentia, where the soil taxonomic units, or series, are the same. Detailed soil unit differentia including variations in soil properties, and topographic conditions can be used in the rating system to improve class definitions and hazard assessments, particularly at Administrative Area and project levels. These include (1) variations in parent material type and origin, which provide useful additional information on density, texture, porosity, permeability, and degree of weathering; (2) depth, local variations of which may alter estimated driving and resisting forces; (3) drainage class, which provides an indication of local groundwater conditions; and (4) landform type, which identifies specific terrain conditions, such as slope configuration and dissection, conducive to landslide initiation and increased frequency.

The soil material groups of the rating system are essentially those already in use, with little modification. The soil depth classes are based on the thickness of nonorganic material (mineral soil) over an impermeable boundary such as bedrock, compact glacial till, or fine sediments. Depths are divided into the following categories: micro—less than 7 inches; shallow—8 to 20 inches; moderately deep—21 to 40 inches; and deep—greater than 40 inches. Only the qualitative values of well, poorly, and very poorly drained classes are used to assess soil drainage. Poorly and very poorly drained soils on steep, unstable sites are strong indicators of rapid temporary water table development during storm periods and increased potential for failure.

This methodology provides a standardized base for Forest-wide stability hazard assessment at the Administrative Area and project levels. It can be expanded and adjusted to fit local needs, conditions, and knowledge. The primary purpose of the protocol is to assure that the same basic data and information are collected and used across the Forest so that effective comparisons and cross-correlations can be done on the Tongass. The framework for this suggested methodology was developed as part of the Alaska Region's watershed analysis procedures to address the 1994 Amendment by Senator Ted Stevens to the Appropriations Act (Loggy and Swanston 1994) and is based on current Chatham and Ketchikan Area field procedures. The Chatham and Ketchikan Areas have agreed to this Region-wide standardization; the Stikine Area has tentative agreed to accept the methodology for limited field use. The protocol has been further modified by the information presented in this paper.

	Mass failure hazard classes (MFHC)					Rating
Criteria	1	2	3	4	Weighting factor (WF)	(MFHC × WF)
Landform:						
Slope shape	Vertical	Broken	Convex	Concave-straight	5	—
Slope length (ft)	0-300	301-700	701-1,500	>1,500	5	—
Slope gradient (percent)	5-35	36-55	56-72	>72	20	—
Drainage feature:						
Drainage density (percentage of area)	1-9	10-19	20-39	>40	10	—
Soils:						
Soil drainage class[a]	WD, MW	[b]	SPD	VP, PD	10	—
Soil depth (in)	>40	[b]	20-40	<20	5	—
Geology:						
Parent material	Carbonate, colluvium, alluvium	Noncarbonate, granitics, glacial till	Compact till, marine sediments	Volcanic ash	5	—
Textural class	Sand, gravel, fragmental loam	Loam	Silt	Silty clay	5	—
Total of ratings						—
Map unit mass failure hazard rating (100 × total of ratings / 260)						—
						—

[a] Soil drainage classes: MW = moderately well drained; PD = poorly drained; SPD = somewhat poorly drained; VP = very poorly drained; WD = well drained.

[b] No soil drainage class or depth information is available for broken slopes.

Figure 3—Form used to calculate the mass failure hazard of a map unit.

A combination of eight quantitative and qualitative variables considered to be controlling factors in determining the stability of a soil map unit are grouped into four mass failure hazard classes to estimate a map unit's natural mass movement (fig. 3).

A mass failure hazard class of 1 is for a factor having a lower potential for contributing to a mass failure; a rating of 4 indicates a factor having the highest potential for contributing to a mass failure. Each variable is weighted based on a qualitative estimate of its degree of importance in contributing to a mass failure. Numerical ratings, multiplied by the weighting factor, yield a total rating or index for each variable. Ratings are summed, divided by the total points possible (260) and then multiplied by 100 to obtain the mass unit failure hazard rating. The range in ratings by class or index and the GIS equivalents appear in table 4. The original five classes from table 1 are reduced to four by combining high and extreme categories.

Table 4—Distributions of mass unit failure hazard ratings in relation to current mass movement indices and Tongass GIS equivalents

Mass unit failure hazard rating	Class	Mass movement index	GIS equivalent
63+	High to extreme	MMI4	High to extreme
50-62	Moderate	MMI3	Moderate
28-49	Low	MMI2	Low
0-27	None	MMI1	Low

The reasons for and identification of factors used to assess each variable in determining mass failure hazard are documented by Swanston and Rosgen (1980), Swanston and Howes (1991), Howes and Swanston (1991), and Schroeder and Swanston (1987). The methodology is designed primarily for planning-level analyses but may be modified for use at the project level if sufficient field information is available for factor assessment. The basic procedure has been well documented and used with modifications throughout the Tongass.

The rating is based on how the soils will react at soil saturation but without water table development and without application of major destabilizing events, such as high-intensity storms, rockfall, windthrow, earthquakes, and human-caused disturbance. It thus reflects the natural stability (or instability) of a slope under normal or average conditions. Other factors, such as anchoring by roots, bedrock structure, and hollows, are important to maintaining soil and forest cover at an otherwise unstable site. These modifying factors can and should be used to adjust index values at the Area and project level to reflect local experience and knowledge. For example, rating limits have been adjusted in all Areas to allow for limited management activities on MMI4 soils that are found on historically stable land forms or have locally variable gradients verified in the field to be below critical levels (72 percent).

The stability hazard class ratings for mass movement listed in table 4 represent general guidelines only. At the project level, each soil map unit should be rated individually because various combinations (fig. 3) of landform, drainage, dissection frequency, soils, and geology may yield ratings either above or below individual class limits.

Descriptions of Mass Failure Rating Classes

Descriptions of the rating classes with their controlling and contributing variables are provided below.

High to Extreme

Map units in this class have a high to extreme risk of failure and fall into the 63+ value range of the high to extreme hazard class (table 4). Natural mass failures in this class are often frequent and large, and there is a high risk of management-induced failure. Standard management practices can be expected to have only limited success, and on-the-ground assessment is necessary to determine the need for mitigating measures. There is a moderate risk of failure even with the use of mitigation. Some portions of the units may have a significantly lower risk of failure due to local benching or higher risk due to cliffs and very steep slope breaks. Soils with gradients in the 72- to 85-percent range with low levels of dissection, well-drained soils, and stable parent materials may be operable with adequate on-the-ground verification and site-specific investigation before any management activity is undertaken.

Characteristics of this class include:

- Moderately steep slopes (36 to 55 percent) with high levels of dissection and either unstable parent materials or reduced soil drainage (i.e., somewhat poorly drained or poorly drained).
- Steep slopes (55 to 72 percent) with moderate to high levels of dissection and well-drained soils.
- Steep slopes (55 to 72 percent) with high to extreme levels of dissection, somewhat poorly to poorly drained soils, and unstable parent materials.
- Very steep slopes (>72 percent) with moderate to high levels of dissection and well to poorly drained soils.
- Very steep slopes (>72 percent) with evidence of prior mass wasting or snow avalanching.

Moderate

Map units in this class have a moderate risk of failure and fall into the 50-to-62 value range of the moderate hazard class (table 4). In this class, natural mass failures are usually small and infrequent, but there is a moderate risk of management-induced failure. Standard and best management practices are usually successful but on-the-ground investigation is still recommended. Mitigating measures occasionally may be needed. Characteristics of this class include:

- Gentle slopes (5 to 35 percent) with moderate to high dissection, poor to very poor drainage, and unstable parent materials.
- Moderately steep (36 to 55 percent) frequently dissected slopes with stable parent materials and somewhat poorly drained soils.
- Steep slopes (56 to 72 percent) with low levels of dissection, well-drained soils, and stable parent materials.

Low

Map units in this class have a very low risk of failure and fall into the 28-to-49 value range of the low hazard class. Natural mass failures in this class usually are rare or small. There is a low risk of management-induced failure except on unstable microsites, such as scarps, V-notches, and streambanks. Standard best management practices that control surface disturbance and stream flows can be expected to be highly successful without special mitigating measures. Characteristics of this class include:

- Gentle slope gradients (5 to 35 percent), with unstable parent materials or reduced soil drainage (somewhat poorly or poorly drained).
- Moderately steep slope gradients (36 to 55 percent) with low to moderate dissection, well-drained soils, and stable parent materials.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters
Feet	0.305	Meters
Miles	1.609	Kilometers
Square miles	2.59	Square kilometers
Acres	0.405	Hectares
Cubic feet	0.028	Cubic meters
Board feet	0.007	Cubic meters
Board feet per acre	0.017	Cubic meters per hectare
Pounds	0.45	Kilograms
Pounds per square foot	47.9	Newtons per square meter

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