LANDSLIDE TERRAIN MANAGEMENT
USING
HAZARD ZONATION AND RISK EVALUATION

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ABSTRACT

A technique for the assessment of risk of landslide activation due to impact generated by road building and logging is presented. This technique involves assignment of activity levels and influence zones to all landslides and subsequent determination of hazard levels. These data are used to develop qualitative risk tables and quantitative estimates of potential impact in both cubic yards of sediment produced and acres of surface area lost. The technique produces valuable input for land management decision making. In addition, the technique can be used to gain access to some basins previously inaccessible due to stability problems, plus will allow unstable land to be easily identified and protected.

INTRODUCTION

The technique of landslide risk evaluation outlined in this paper has been developed in order to present landslide stability data in a form that can be readily assimilated into the interdisciplinary decision-making process. Using this technique, alternative proposals for an area can be compared with minimum effort. It should be stated that the technique is continuing to develop and evolve. As specific projects arise and the technique is applied to them, improvements in the use or application develop as the actual "problem solving" progresses.

Field and aerial photograph inventories of existing active and old landslides provide the principal data on which the zoning and hazard evaluation are based. The topographic map base must be sufficiently detailed to depict true ground features; a scale of 1 inch = 300 feet with 20-foot contour intervals is commonly used.

Data from which activity levels are developed is recorded on a field form for each landslide which includes: (1) failure and deposit volumes; (2) dimensions and form in long and cross-profile; (3) scarp elevation, height, aspect and degree of weathering; (4) character of material at slide surface; (5) strike and dip of strata or other planar structures; (6) slope gradient; (7) vegetation size and type; and (8) evidence of distorted tree growth. Subjective estimates of the availability of surface and subsurface water, and of the relative stability of the surrounding area, are recorded for evaluation of reactivation risks.

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Although not developed in this paper, semi-quantitative methods of activity level assignment have been made by rating the above factors on a 1 (least stable) to 3 (most stable) scale and then summing up and dividing (by the number of factors) to get a sensitivity (to instability) number (D'Allura 1980). The procedure for full quantitative derivation of the factors of safety vs activity levels has been developed but not employed to any great extent. The generalized procedure is described in the Road Investigation and Design section of this paper. Position on the slope and the slope form below the failure relate to the estimated proportion of the failed material reaching a stream channel. These factors are noted for potential impact evaluation. Stream channel is also noted where debris has reached or may reach a channel. If further failures are deemed likely at the site, the probable volume is also estimated from field data.

ZONATION AND RISK EVALUATION

The basic rule in the application of landslide hazard zonation principles is that any forest management activity (road building, logging) which increases the ground water or surface water entering landslide terrain or potentially unstable slopes, increases the risk of failure or reactivation. The landslide hazard zonation map is a tool which can be used to minimize unwanted environmental impacts associated with timber harvesting and road building. The technique (see Figure 1) involves: (1) stratifying the landslides into their individual "activity levels", (see Table 1 and Figure 2); (2) outlining the surface water and ground water influence zones of landslides, using upslope surface water drainage boundaries (see Figure 3); and (3) assigning hazard levels (potential for failure) due to specific land management impacts; i.e., clear-cutting, partial cutting, road contributed water, etc. (see Table 2 and Figure 3). The technique develops sufficient ground data so that terrain with failure potential, but not containing mappable landslide forms, can be readily assigned "activity levels" from which hazard levels can be assigned. Hazard levels are strongly influenced by the activity level assigned to landslides within any piece of terrain, but many other factors are also taken into account in assigning the hazard level. These include:

- Slope angle and changes in slope angle - upslope and downslope;
- Shape of the upslope area contributing surface and ground water - i.e., V-shaped, A-shaped or H-shaped (converging, diverging, or parallel flow paths);
- Size of the upslope area contributing water to potentially active zones;
- Concentration of surface and ground water by roads, skid trails, etc.;
- Position of the potentially active area along the slope profile, lower slope positions being rated more hazardous then otherwise similar upper slope positions;
- Effects of other geomorphic processes; e.g., stream undercutting;
- Character of regolith material; e.g., clay-rich regolith rated as higher hazard;
- Slope aspect, with north and east facing slopes rated as higher hazard;
- Bedrock geology and structure; e.g., sheared serpentinite, graphite schist, highly foliated and jointed rocks form surfaces prone to failure.

Risk evaluation is presented in the form of a table (Table 3) showing the various hazard levels of the terrain rated against logging and road building impacts. The table prepared shows estimated natural risk of failure to use as a comparison with estimated risk of failure due to man's impact. Simplifying assumptions are presently required to develop the various failure risk percentages (i.e., percent of risk of failure of the various hazard level terrains). At present, the highest risk (100%) is assigned to the most severe hazard level terrain (e.g., active and subactive landslides) receiving the maximum planned impact (e.g., clear-cutting). The minimum risk (generally 0-20%) is assigned to the least hazard level terrain receiving the minimum planned impact (e.g., 50% vegetation removal in partial cutting). All terrain falling between these two extremes is then assigned risks that decrease from the maximum down to the minimum risk.

In order to evaluate the potential for activated landslides to affect downstream structures, land values, reservoirs, fisheries, etc., a simple semi-quantitative technique is used. Landslides which have a high likelihood of reaching a flowing stream are indicated on a separate map or overlay. The volume of material potentially involved is shown on a table relating percentage risk of arrival (at the stream) versus activity level of landslides. This procedure provides an additional weighing factor for use in the selection of logging units for a particular project and for assessment of the environmental risks.

Estimation of some environmental and loss-of-production costs is possible using the landslide area and volume figures for potential impact in Table 3, pro-rated by the percentages shown for various levels of cutting and converted to costs with appropriate multipliers. For hazard zone 1 in the example shown, the potential volume impact is 10,000 cubic yards of landslide debris; multiplication by the estimated costs of removal from downstream reservoirs ($\$8/yd^3$) provides an estimate ($80,000) of one environmental cost of clear-cutting. The area lost from production for hazard zone 1, in this example, is estimated as four acres. If production is lost for three rotations of 20,000/MBF, the total cost of lost production is estimated to be $48,000. Other costs may be semi-quantitatively estimated in like fashion, using appropriate multipliers.

ZONATION IN VARYING TERRAIN TYPES

The identification of areas of active or potential landsliding is relatively simple in areas underlain by cohesive soil mantle material; e.g., where slump/earthflow type landslides have developed in soil mantles derived from serpentinite, metamorphic rocks, clay/silt sedimentary rocks, etc. In such terrain, landslides of widely varying sizes and ages are easily mappable because the zonation technique commonly uses maps at a scale of 1 inch = 300 feet with 20-foot contour intervals. Designation of activity levels and influence areas, and development of hazard level zones and accompanying risk of activation, present no problem in such areas. However, in terrain composed of non-cohesive soils (e.g., weathered granitic rock areas), the sites of potential failures cannot always be identified by surface form alone, and special techniques are required. These procedures include study of old failures to determine the ground conditions contributing to failure and field investigations using hand auger holes and resistivity and electro-magnetic surveys.

ROAD INVESTIGATION AND DESIGN*

In addition to evaluating the effect of logging on slope stability, the effect of the roads proposed to access the timber sale for logging equipment and trucks

This phase of the process is shown on Figure 1 in STAGES V and VI.

must be studied. Cut and fill slope design are part of the work accomplished, but this paper will only focus on the effect of the road on landslides crossed (or impacted) by a road. Landslides are primarily impacted by road construction excavation and by increasing the volume (and change of timing) of water flows to the landslide.

The detailed landslide mapping completed for the zonation process is usually sufficient to delineate and describe the aerial (plan) view of the landslides. However, in order to obtain the surface and subsurface geometry of the landslide for use in stability analyses, substantially more detail is required. The technique used is described as the "field-developed cross section" method, as described by Williamson and Neal (1980). The field-developed cross section, the landslide mapping completed for zonation, commonly subsurface exploration and, as needed, soil testing allows the stability of specific landslides to be quantitatively analyzed. In addition, changes in road alignment and design can be made, if needed, to reduce impact of the road on the landslide.

The above described landslide analysis method can be used to further quantify the zonation process. It requires the selection of representative landslides which are then analyzed. The factors of safety developed are combined with activity level groupings and used to quantify the impact of logging and road construction on specific terrain.

SUMMARY

The hazard zoning and risk evaluation technique presented here is based on detailed inventorying of active and formerly-active landslides. Qualitative assessments of risk of failure are presented to the land manager in a map of hazard zones and quantitative estimates of the area and volume impacts of landslides in those zones. Failure risks are estimated for a range of management activities, and the estimated volume and area impacts (which may be used to estimate some direct costs of various management operations) provide valuable background data for the interdisciplinary decisions by land managers and land-use planners. The technique allows the potential road-generated impacts to be integrated into the full assessment of risk of entry.

ACKNOWLEDGMENTS

A number of associates aided in the development of details of this technique. Most notably, Richard D. Smith, who was intimately involved in the first sequence of projects utilizing the technique.

REFERENCES CITED

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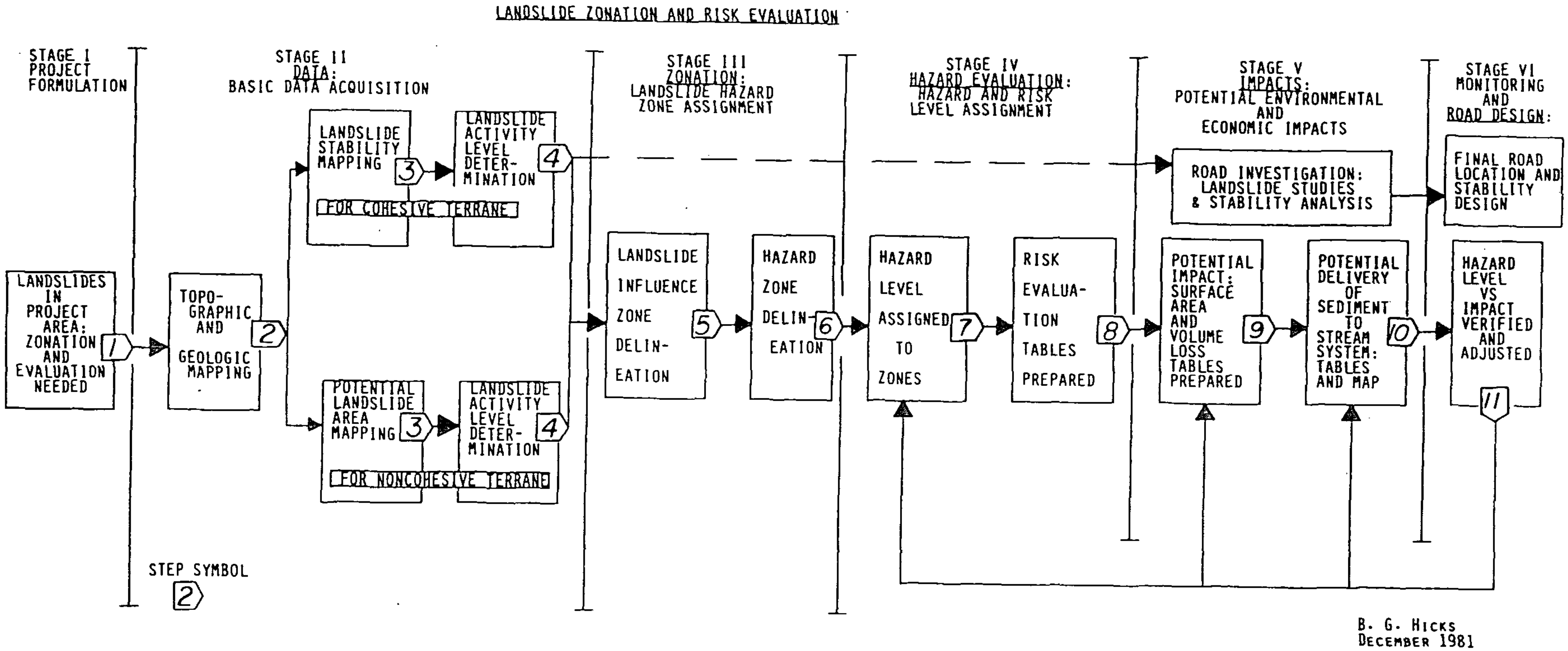

FIGURE 1 FLOW CHART: LANDSLIDE ZONATION AND RISK EVALUATION.

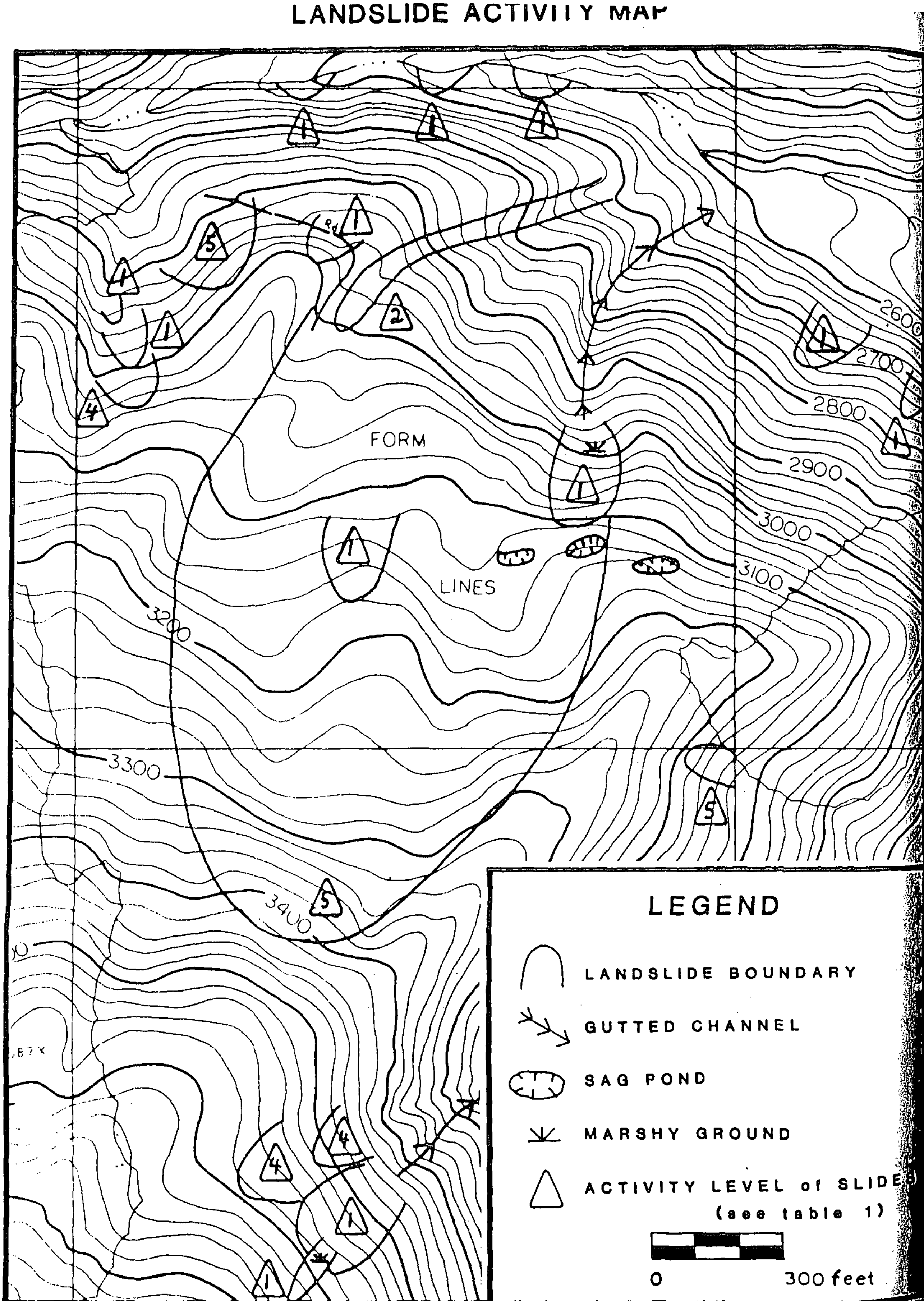
LANDSLIDE ACTIVITY MAP
FORM
LINES
2600
2700
2800
2900
3000
3100
3200
3300
3400
LEGEND
LANDSLIDE BOUNDARY
GUTTED CHANNEL
SAG POND
MARSHY GROUND
ACTIVITY LEVEL of SLIDES
(see table 1)
0
300 feet

FIGURE 2

HAZARD ZONATION MAP

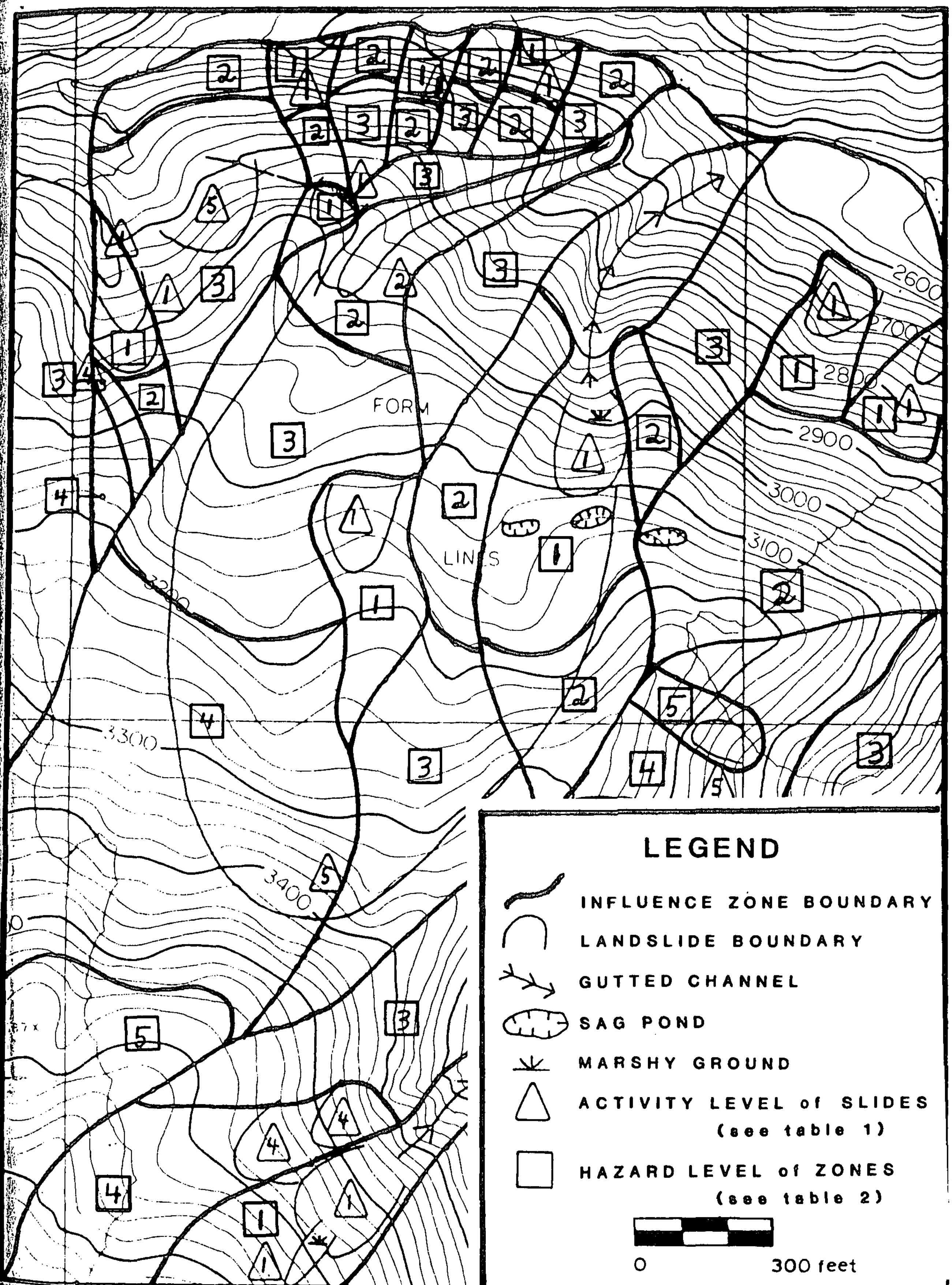

FIGURE 3

NOTE: Activity levels shown for clarity, actual technique uses overlays

TABLE 1: LANDSLIDE ACTIVITY LEVEL DESCRIPTIONS

△1 ACTIVE	Currently active or active in the very recent past. May have fresh scarp or cracks. Leaning trees may indicate recent movement; i.e., straight, healthy conifer leaning from the base indicates recent movement. Broadly-bowed, living conifer indicates movement over a period of time. Hummocky terrain, terrace-like slopes not deeply weathered may indicate recent movement.
△2 SUB-ACTIVE	Movement occurring periodically, landslide features more weathered (e.g., flatter slope to scarp) than △1. Leaning or bowed trees may indicate no very recent movement; i.e., temporarily dormant.
△3 POSSIBLY ACTIVE	No clear indications of recent movement. Landslide features not so heavily weathered as to indicate long-term stability. More subtle features often without obvious scarps or cracks. Possible low, constant creep rate; i.e., currently creeping at rate sufficiently slow that obvious cracks do not form.
△4 DORMANT	No active movement within recent past. Landslide features moderately weathered. Only larger trees show indications of movement. Conditions (i.e., parameters of stability such as slope angle, shape and area of influence zone) make reactivation possible.
△5 INACTIVE	No indication of movement within recent past. Only oldest trees show indications of movement. Landslide features well weathered and revegetated. Interpretation (i.e., location and form) may be only from topographic map or aerial photographs. Field evidence for this type of landslide is difficult to interpret.
△6 ANCIENT INACTIVE	Ancient features, which are easily discernible only from topographic map and aerial photographs. Field indications obscured by weathering, erosion and revegetation. Very low risk of reactivation. Creep rate, if present, is too slow to visibly affect tree growth.

TABLE 1

1	Zone which includes active landslides or actively gutting channel and/or includes the portion of the influence zones directly impacting the landslide or channel; i.e., the portion of the influence zone believed to require as much caution as the landslide or gutted channel due to instability and/or impact on the landslide or gutted channel.
2	Zone which is slightly less sensitive than the 1 zone. Often adjacent to or within the influence zone of an area of active landsliding. This hazard level used for type △2 landslides and portion of the influence zone directly impacting the landslide when other factors do not indicate greater instability.
3	This zone may be determined by proximity to active landslides or by potential for impacting active landslides. It is used for type △3 landslides and their immediate impact zones. Additional key parameters are percent slope and position of the zone on the slope (i.e., proximity to creeks or drainages). Some zones delineated by specific combinations of hazard parameters.
4	This zone usually does not impact active landsliding area except from considerable distance upslope. Applies to type △4 landslides and their immediate impact zones.
5	Most stable zone. Rarely located in an influence area of active landslide. Applies to type △5 landslides and their immediate impact zones.

ABLE 2

TABLE 3

EXAMPLE RISK EVALUATION AND POTENTIAL IMPACT

HAZARD ZONE (LEVEL) ↓ / % CUT (LOGGING) ---->	0% (NATURAL CONDITIONS	50% (SELECTIVE, ETC., CUT)	100% (CLEAR-CUT)	POTENTIAL (2) IMPACT CUBIC YDS. / ACRES
1	50 - 80% (1)	80 - 90%	90 - 100%	10,000 / 4
2	40 - 60%	60 - 80%	80 - 90%	5,000 / 2
3	30 - 40%	40 - 50%	60 - 70%	2,000 / 1
4	15 - 25%	20 - 30%	40 - 60%	5,000 / 2
5	10 - 20%	15 - 25%	20 - 30%	8,000 / 3
----> TIME	50 - 500 Years	5 - 10 Years	5 - 10 Years	

(1) 50 - 80% risk of landslide activation; under natural conditions activation may not occur for a long time period, or may occur during a long time period (50-500 years) but with impact can occur post-cutting and pre-regrowth (5-10 years)

(2) Impact listed if for one alternative only

TABLE 3