THUNDER CREEK BASIN

Skagit County

Report of DNR Study Team

by

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Crown Pacific

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ILLUSTRATIONS

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SUMMARY

Landsliding affected the entire Thunder Creek basin during the immediate post-glacial period (12,000 years ago). Portions of the northern basin above 2000 feet elevation have moved only tens of feet and remain largely intact. Much of the southern basin above that elevation consists of the scars and remnants of ancient, fairly deep-seated landslides. The "inner basin", generally that part below 2000 feet, consists largely of the deposits of these landslides. These deposits have been deeply incised by the mainstem and major tributaries of Thunder Creek, forming a steepwalled "inner gorge".

The foregoing geologic history has influenced the basin's topography, hydrology, soils, and slope stability. Recent landslide activity has been largely confined to relatively small shallow slumps, flows, and debris avalanches along the inner gorge and upper south wall. Drainage patterns in the less disturbed materials of the upper, especially northern basin, are characterised by many small and closely-spaced parallel channels. Elsewhere, more normal, convergent channels are predominant. Soils in the basin are generally quite permeable, but have a relatively impermeable substrate within three or four feet of the surface.

These characteristics coupled with basin climate have important implications to both timber harvest and road construction. Orographic effects imposed on warm, wet Pacific storms by the lowland-fronting mountains, such as Lyman Hill, create not only significantly greater precipitation but also higher intensity storms. The elevations place much of the basin in the "transient snow zone"; thus, rain-on-snow events are common. Clearcutting results in increased snowpack and permits more rapid melting during such events. The already wetter soils of the clearcut have little unused storage capacity and water is available quicker for streamflow.

The climatic conditions and the naturally disturbed and perennially more moist soils, present special challenges for road building and maintenance. Cutbanks tend to be unstable even in till or "bedrock." This compounds the problem of maintaining ditches. Much of the material, especially in the inner basin, is unsuitable for fill, but fills may need to be larger than "normal" because of deep channel incision. In and along channels the slide-disturbed materials are readily erodible, providing much bedload material during periods of peak runoff. This bedload can drop out in lower gradient stretches, causing channel shifts and/or culvert blockage.

Even greater "slugs" of bedload could be mobilized through the breakage of debris dams or the disturbance of sediment-trapping large woody debris by an avalanche-triggered debris torrent. Such a torrent would be apt to evolve into a debris-laden flood in the lower reaches of the basin. Both the dropping of excess bedload and jams of large floating debris could cause stream diversion and localized flooding of low lying areas along the channel between the powerlines and the railroad bridge.

NW5,db346a

INTRODUCTION

The Thunder Creek drainage is located in Township 36 North, Range 5 East, Skagit County. The drainage is almost entirely within Sections 16, 17, 19, 20, 21, 22, and 29. The approximately 1,830 acre (almost 3 square mile) area lies on the southwest slopes of Lyman Hill. It ranges in elevation from 240 feet at the mouth to more than 4,000 feet along the upper divide. As in much of this area, logging in the Thunder Creek basin began at lower elevations and by the early 1940's most of the basin below 3,000 feet elevation had been cut (Fig. 1). Clearcutting of second growth is currently well advanced.

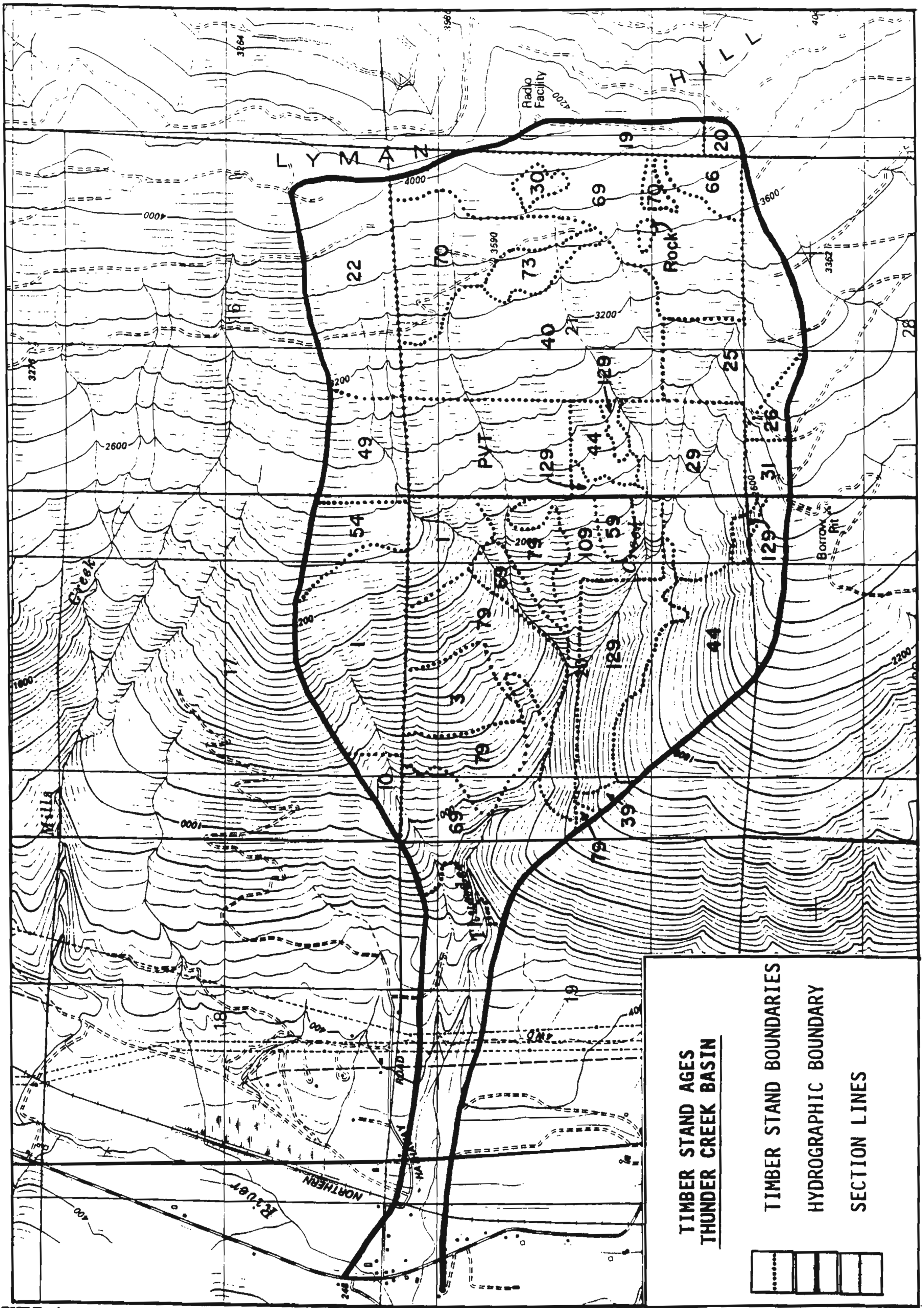
The lower channel and fan of Thunder Creek are traversed (from upstream to down) by three high-voltage powerlines, a buried gas pipeline, a major rail line, and State Highway 9. The fan has been largely developed for small farms and residences. Residential development has only recently occurred along the channel above the fan, but will undoubtedly continue unless restricted by local government.

After the 1983 and 1984 debris torrents in neighboring Mills Creek, concerns were raised regarding the potential for downstream impacts in the Thunder Creek drainage. In response to these concerns, the major property owners in the watershed agreed in 1988 that an overview of the basin should be conducted. This reconnaissance was to identify the nature and areas of potential stability problems as well as downstream areas potentially subject to impacts. In addition, the overview was to assemble data useful for forest land management within the basin.

An interdisciplinary team of specialists from the staff of the Department of Natural Resources was selected to participate in this study. The team, composed of Louis Halloin, Soil Scientist; Jim Ryan, Hydrologist; and Jerry Thorsen, Geologist; was directed to conduct the basin-wide overview. A separate effort focusing on roads, with emphasis on orphan roads, was conducted by Noel Wolff, Hydrologist/Soils Specialist; and Jeff Brown, Forest Engineer. In addition to involvement with the overview, Thorsen compiled and edited the individual findings into this report. All involved spent at least a week in the field on the project.

Considerable space is devoted in the text to explaining the geologic history and origin of landforms of the basin, and its relationship to Lyman Hill as a whole. It is hoped that these discussions will give the forester/engineer laying out a road or harvest block a better understanding of the terrain, its evolution, and its present limitations. Such an understanding will help enable them to surpass the inherent limitations of this reconnaissance-level study in the conduct of their work.

NW5,ts356



TIMBER STAND AGES
THUNDER CREEK BASIN
TIMBER STAND BOUNDARIES
HYDROGRAPHIC BOUNDARY
SECTION LINES
LYMAN HILL
Radio Facility
Rock Creek
Borrow Pit
PVT
Mills Creek
NORTHERN
River
ROAD

FIGURE 1

PHYSICAL SETTING

Climate/Hydrology

Lyman Hill lies along the Cascade front, directly facing incoming warm, wet, Pacific storms. Its extreme relief (4000 ft) causes variability in the quantity of precipitation falling on the Thunder Creek watershed. Orographic influences cause more precipitation to fall at the higher elevations than at the lower elevations. (The effect of such a setting is illustrated by records from the Jim Creek radio station to the south. There annual precipitation averages 82 inches while Arlington, only 8 miles to the west and 400 feet lower, receives 47 inches.) Based on available data, the average annual precipitation over the entire Thunder Creek watershed is estimated to be at least 70 inches.

With such extreme relief, precipitation form varies considerably within the watershed. During the winter months, rain is the dominant form of precipitation at elevations below 2000 feet. Portions of the watershed between 2000 and 3500 feet in elevation are in what is called the transient snow zone. Snow accumulations commonly occur within this zone. However, they are subject to frequent depletion. Depletion rates can be quite rapid during periods of rainfall accompanied by warm winds (Fig. 2). Snow accumulations are more persistent above 3500 feet.

Incoming precipitation follows the storage and transport processes normally occurring within forested watersheds on the west side of the Cascades. Some precipitation is intercepted by vegetation and lost through evaporation. That which reaches the forest floor infiltrates the soil where it is either stored or moves vertically until a less permeable layer is reached. Water stored in the soil will eventually evaporate or be extracted by plants for transpiration. Free water reaching a less permeable layer will move laterally downslope below the soil surface until it reaches a channel or a road cutbank where it becomes surface flow.

A layer of relatively impermeable till, present over a large portion of the upper watershed, is a significant factor in controlling subsurface flow. The rather permeable soils formed over the till average 20 to 40 inches deep. Therefore, the time required for free water to begin moving laterally is short. The rate of lateral movement is increased by macropores in the moderately well drained soils. These macropores function as pipes carrying water downslope in small subsurface streams.

Where present, the till has also influenced the formation of first order channels. Numerous, almost parallel, channels are present on upper slopes, especially on the north side of the watershed. In some cases these channels are less than 100 feet apart. Consequently, subsurface travel distance to a channel is often very short. This factor, along with relatively shallow soils over an impermeable or perennially saturated layer and rapid subsurface flow, explains why channel flow responds quite quickly to incoming precipitation and snowmelt.

NW5,ts339

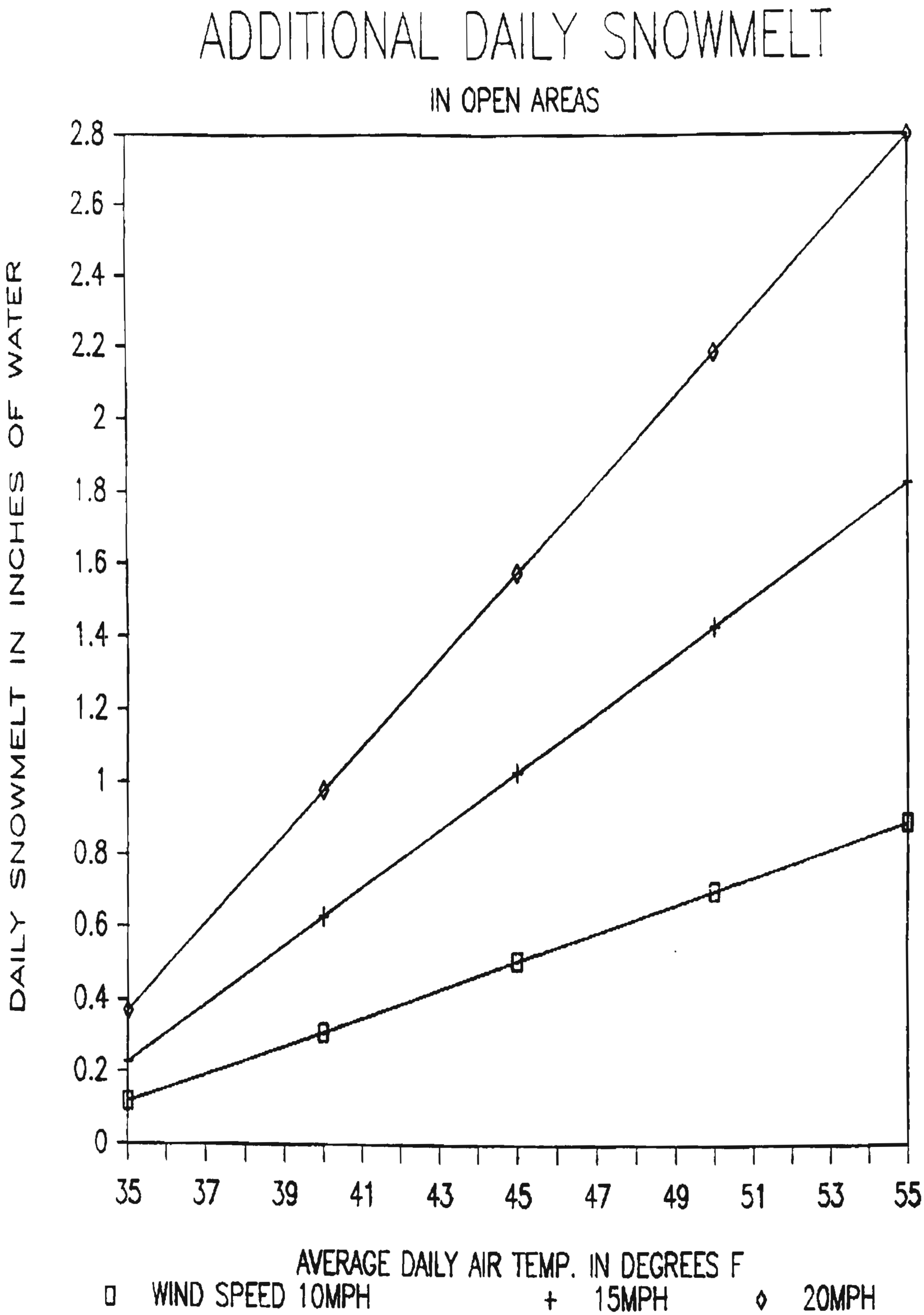

ADDITIONAL DAILY SNOWMELT
IN OPEN AREAS
DAILY SNOWMELT IN INCHES OF WATER
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
35
37
39
41
43
45
47
49
51
53
55
AVERAGE DAILY AIR TEMP. IN DEGREES F
□ WIND SPEED 10MPH
+ 15MPH
◇ 20MPH

FIGURE 2

Average channel flow near the mouth of Thunder Creek is approximately 6.5 cubic feet per second (cfs). Variation from this average is considerable on a seasonal basis. During the wet winter months flows range between 6 and 35 cubic feet per second most of the time. Towards the end of the dry summer season, flows are below 6 cfs. The maximum annual peak storm response averages approximately 200 cfs.

The lower 8000 feet of Thunder Creek is considered to be a Type 3 stream on the water type map (Plate 1). Note that the water type map, based on an enlargement of 1917-18 planetable topography, bears little resemblance to the drainage shown on the 1981 U.S. Geological Survey base map (Fig. 4b) of larger original scale and photogrammetric origin.

Soils

Soils in the Thunder Creek basin are shown in Figures 3, a and b, adapted from the State Soil Survey. For additional soils data such as drainage, site preparation and regeneration the reader is referred to the Forest Soil Summary Sheets. It is felt that the slope stability interpretations therein have been superceded by those in this report. Nevertheless, there is considerable general agreement. For example, the areas mapped as 0141 and 0126 correspond roughly to our "inner gorge" and "south wall" respectively. The soils mappers considered both to have severe limitations in regard to roads and timber harvest. We considered them to be the least stable areas of the basin (slope stability Category 4, see "Slope Stability").

Soils in the inner and upper basin areas have been identified as Diobsud gravelly silt loam, 30 to 65 percent slopes (MU 1662); Getchell gravelly silt loam, 30 to 65 percent slopes (MU 2452); Montborne-Rinker complex, 30 to 65 percent slopes (MU 4792); and Van Zandt very gravelly loam, 15 to 30 percent and 30 to 65 percent slopes (MU's 8723 and 8724 respectively). Excluding the Rinker soil, all of these moderately well drained soils formed mainly from till and overly dense unweathered till at depths of 20 to 40 inches. These soils typically occur in the upper basin and in less steep areas of the inner basin.

The well drained Rinker soil formed mainly in colluvium from phyllite. Rinker soils are about 20 to 40 inches thick over phyllite rock. Rinker soils are expected to occur most commonly in the steeper areas of the inner basin. The inner gorge is walled by a variety of materials difficult to map as discrete soils at a reasonable map scale. Deep glacial drift and mixed landslide debris are the major soil parent materials. In its lower reaches Thunder Creek has cut a broad, steeply incised channel through a terrace of gravelly materials deposited by glacial meltwater. Slope gradient on the terrace escarpment is about 70 percent. Despite this steep slope we have mapped it as "Category 2", mainly because although the well-drained materials are subject to dry ravel, they should hold few surprises for the forest engineer. Soils formed in the outwash are identified as part of the deep, somewhat excessively drained Barneston series.

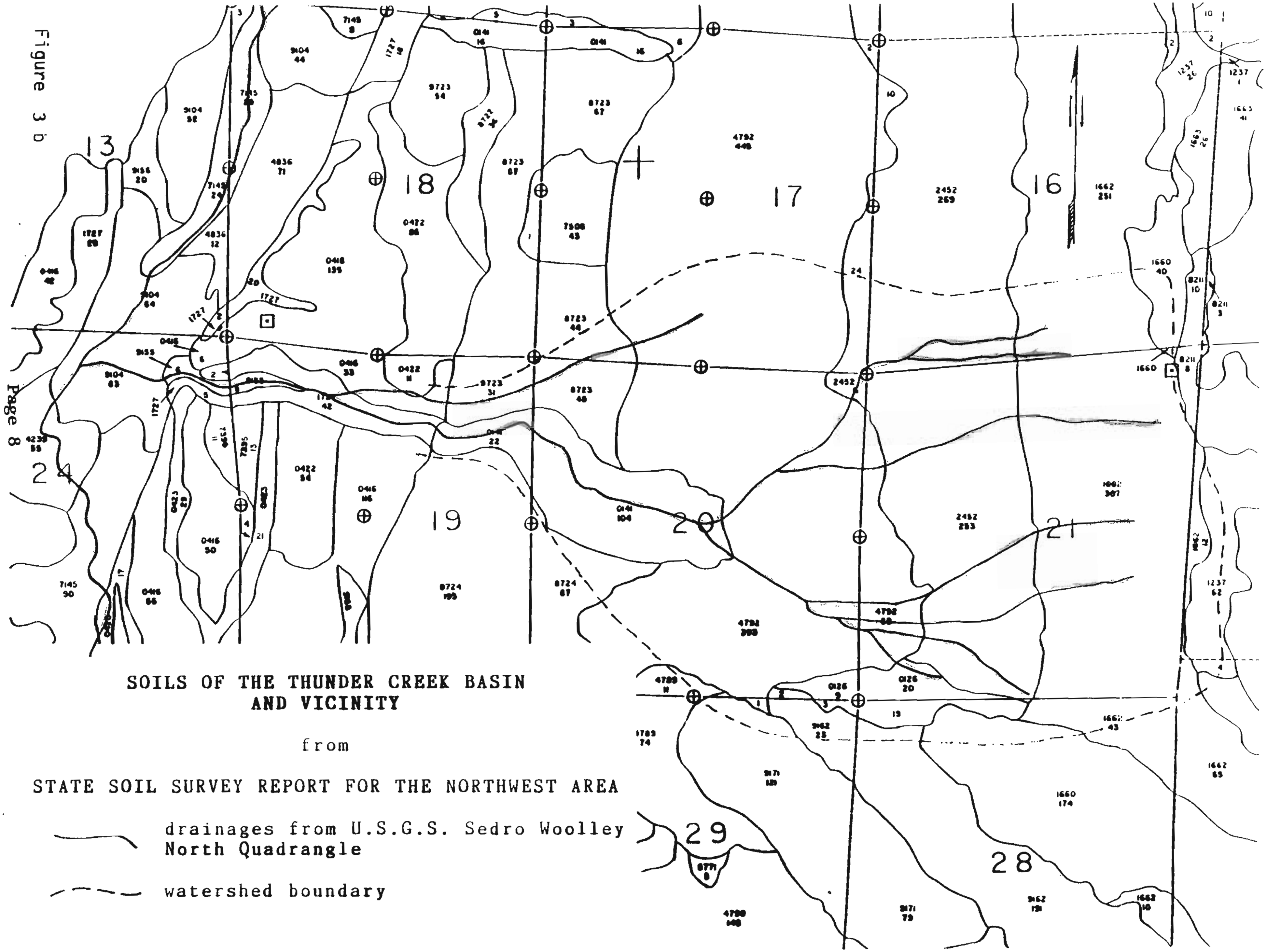
Figure 3.a

SOILS OF THE THUNDER CREEK BASIN *

Symbol	Soil Name	Slope, percent	Cut, Sidecast, fill hazard	Logging system limitation	Site index
9104	Wickersham silt loam	0 - 8	slight	moderate	DF-132
9155	Wiseman channery sandy loam	0 - 8	slight	slight	DF-115
0416	Barneston gravelly loam	8 - 30	moderate	moderate	DF-121
1727	Dystric Xerorthents	50- 80	severe	severe	DF-117
0423	Barneston very gravelly sandy loam	30- 65	severe	moderate	DF-121
7395	Skipopa silt loam	0 - 8	N/A	moderate	DF-110
0422	Barneston very gravelly sandy loam	8 - 30	moderate	moderate	DF-121
0141	Andic Xerochrepts -rock outcrop complex, warm	65- 90	severe	diff.-severe	DF-115
8723	Van Zandt very gravelly loam	15- 30	moderate	moderate	DF-133
8724	Van Zandt very gravelly loam	30- 60	moderate	moderate	DF-133
4792	Montborne-Rinker complex	30- 65	moderate	moderate	WH-111
2452	Getchell gravelly silt loam	30- 90	moderate	moderate	WH-90
0126	Andic Cryochrepts-Rock outcrop complex	60- 90	severe	severe	WH-90
9162	Wollard gravelly silt loam	30- 65	moderate	moderate	WH-96
1662	Diobsud gravelly silt loam	30- 65	moderate	moderate	WH-75
1237	Crinker-Rock outcrop	50- 90	moderate	moderate	WH-80
1660	Diobsud gravelly silt loam	3 - 30	moderate	moderate	WH-75

*Listed generally in order of lowest to highest elevation (east to west)
From: Forest Soil Summary Sheets, State Soil Survey - Northwest Area, Forest Land Management Division, DNR

Figure 3 b



SOILS OF THE THUNDER CREEK BASIN AND VICINITY

from

STATE SOIL SURVEY REPORT FOR THE NORTHWEST AREA

drainages from U.S.G.S. Sedro Woolley **North Quadrangle**

watershed boundary

Geology

Lyman Hill is essentially made up of phyllite, a grayish metamorphic rock with a silky sheen on cleavage surfaces due to the parallel orientation of its fine platey minerals. This preferred orientation of mineral grains results in many parallel planes of weakness, tending to make the rock break into irregular flakes and slabs. In addition, the phyllite is commonly folded and cut by faults. Thus, the bedrock of Lyman Hill is, in general, mechanically weak.

Lyman Hill was completely overridden by the ice sheet of the last continental glaciation. The ice rounded and smoothed the crest and flanks of the Hill and left till smeared over much of the terrain. During this time the much thicker ice occupying the valleys apparently eroded and oversteepened lower valley walls while still buttressing the slopes. When the ice sheet melted this support was removed. The lack of vegetation immediately after the ice receded, coupled with a climate that was probably wetter than today's, compounded the destabilization of such slopes.

Slopes in the general area with different geology responded to the conditions just described in different ways. Some slopes in the Kendall area failed as massive earth flows that moved out into adjacent valley floors. Other valley walls made up of sandstone and shale, where bedding planes sloped steeply towards the valley, failed as massive collapses that disintegrated into fast moving sheets of bouldery debris that swept completely across adjacent valleys.

In contrast to such well-defined failures, some mountains and foothills cored by the weaker phyllite, such as Lyman Hill, tended to simply "sag" or "settle" when the support of the valley ice was removed. Individual planes of failure were discontinuous and movement along a given plane was often probably less than ten yards. Thus, head scarps tend to be lower and the slide mass, even where still intact, more subdued than with a typical slump of similar size. The rock quarry near the northeast corner of Section 29 (Fig. 4b) is in such a scarp. These ancient and now dormant slope failures left subtle but characteristic landforms in the Thunder Creek and adjacent basins.

DISCUSSION

Terrain Analysis

The gross profile of an ice-rounded mountain with glacially oversteepened valley walls may resemble the cap of a broad mushroom. Subsequent "sagging", gravitational spreading, or large scale deep-seated rock creep can further alter that form so that its profile may approach that of an inverted onion. An east-west profile along the divide between Hansen and Thunder Creeks would show this characteristic downward steepening of the slopes. However, the signs of the subsiding top and bulging sides may be partially masked by subsequent erosional processes. For example, both east and west-flowing drainages have eroded much of the crest of Lyman hill above Thunder Creek. The narrow ridge remaining now, in places, resembles one left by diverging valley glaciers.

In spite of the extensive post-glacial erosion, Lyman Hill retains characteristics of gravitational spreading or sag, some too small to show up even on 1 in equals 400 ft topographic maps. Spreading creates tension along central ridges. Evidence of tension is abundant in the form of discontinuous troughs and ridges paralleling the crest. The troughs are sites of bedrock tension cracks, now largely filled with rubble. Such features rim the entire head of the Thunder Creek basin. Uphill-facing scarps are another sign of mountain spreading or sag. A classic example of such, just south of the basin at the east quarter corner of Section 28 (Fig. 4b), has diverted streams into right angle bends. One might also expect the lower oversteepened flanks of such a mountain to be susceptible to secondary smaller-scale landslides. Such slides, now apparently dormant, are common below 2000 ft between Thunder and Hansen Creeks.

Subtle flank scarps are visible in places along the north edge and within the Thunder Creek basin. Such scarps commonly occur where one slide "block" has moved further than an adjacent one. Steep, angular rock faces can be seen in the central and southern upper basin. The inner basin contains abundant hummocky terrain, with small discontinuous benches and steep-nosed ridges, all indicative of landslide deposits. (The large deeply dissected fossil fan at the mouth of the ancestral Thunder Creek (Fig. 4b) developed as the stream flushed slide material out onto the glacial outwash.) Although the basin undoubtedly existed in some form prior to glaciation, these features and those along the ridge crest are too delicate to have survived glaciation, thus, they must be post glacial. The abundance of till as a soil parent-material in the upper basin suggests, however, that there was relatively little churning as a result of all this slide activity.

The processes just described are now essentially dormant; however, the present basin landscape is still evolving as a result of the combined processes of stream erosion, slumps and earthflows, and debris avalanches. Most of this current activity is concentrated along the banks of the deeply incised mainstem and major tributaries of Thunder Creek. Stream incision has been particularly deep and apparently rapid between 600 ft and about 2000 ft elevations because it was largely cutting through

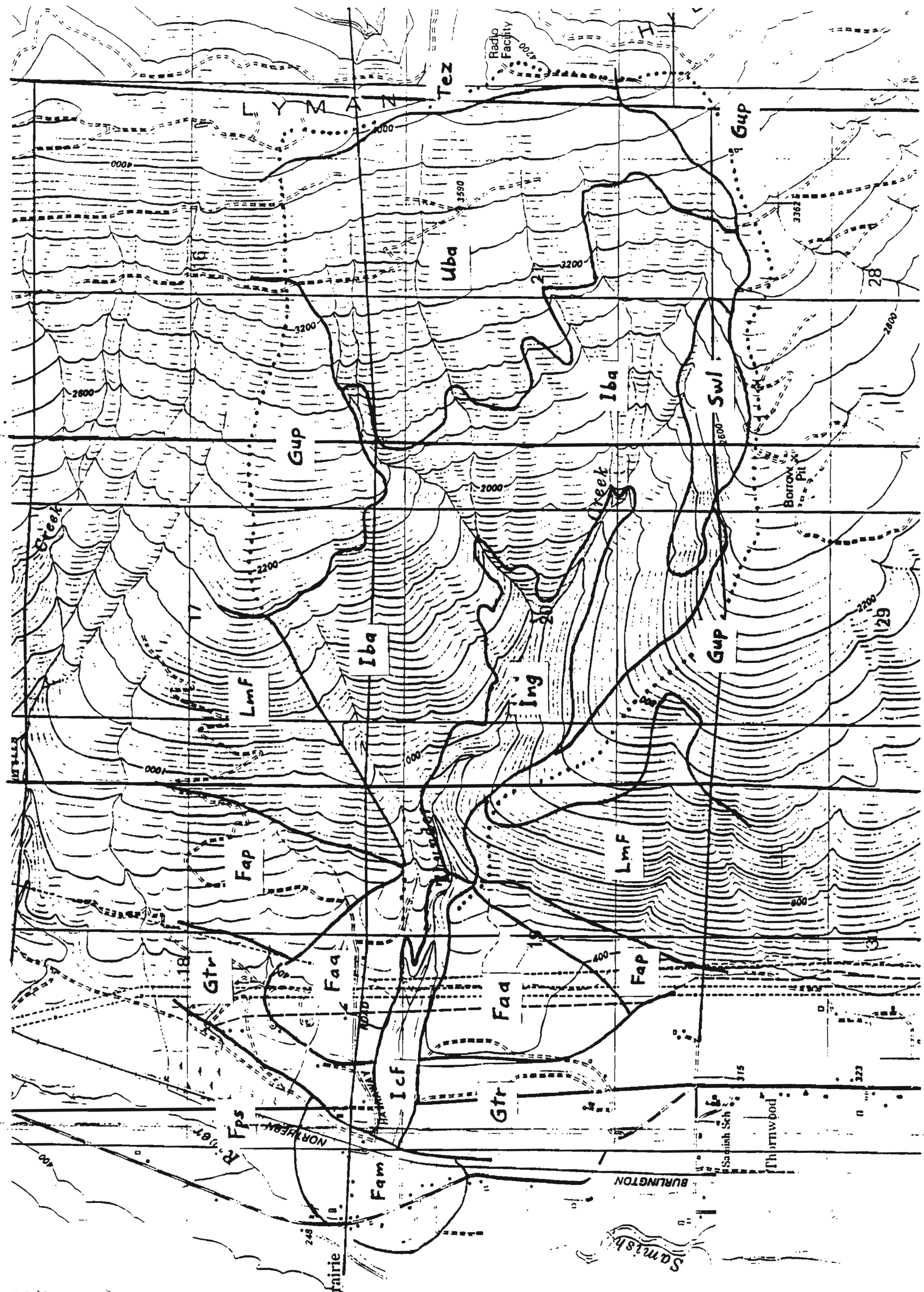
EXPLANATION, GENERALIZED LANDFORM MAP

THUNDER CREEK BASIN AND ADJACENT TERRAIN

Symbol	Map Unit Description
Fps	Floodplain and swamps of modern Samish River, primarily sand, silt and peat
Fam	Fans, modern, fairly well-defined alluvial fans - sediments coarsen toward fan apex
Gtr	Glacial terrace and outwash plain remnant of late glacial gravelly sand valley fill
Faa	Fan, ancient, deposited by ancestral Thunder Creek, may include bouldery sand mudflow deposits
Icf	Incised channel and floodplain of modern Thunder Creek, cobbly gravelly sand
Fap	Fan aprons, coalescing small fans and colluvial deposits, reworked from drift and phyllite
Lmf	Lower mountain flanks, oversteepened by glaciation and "sag", ancient landslides common
Ing	Inner gorge, deeply-incised mainstem and major tributaries cut into glacial and landslide deposits
Iba	Inner basin, hummocky ancient slide deposits, incised drainages generally converging
Uba	Upper basin, oversteepened by ancient landslides, rocky scarps, slide remnants, parallel drainages
Gup	Glaciated uplands, includes some large intact "sag blocks", ice-smoothed, commonly till covered
Swl	South wall, steep rocky faces, benches. Flank of major ancient slide modified by secondary slides
Tez	Tension zone along crest, NS-trending cracks, discontinuous troughs - rock ridges, low rocky scarps

NW6,ts360

FIGURE 4 a



LYMAN
Tez
Radio Facility
Gup
Uba
Iba
Swl
Borrow Pit
Creek
LmF
Ing
Fap
Faa
Gtr
IcF
Fps
Fam
NORTHERN
BURLINGTON
Samish Sch
Thornwood
River
Samish
Prairie

FIGURE 4 b

the easily erodible ancient landslide deposits. Another area of activity is along the oversteepened ancient landslide scarps forming the south wall of the basin. An understanding of the origin of such landforms can be helpful in explaining the processes still active today; processes important to basin management.

Slope Stability

The past geologic processes and resulting landforms just discussed may be ancient history, but they provide important clues regarding the present stability of slopes. Obviously, it is the present and localized slope conditions and their susceptibility to impacts from forest management that are of interest. An overview such as this cannot provide the detail necessary to make site-specific decisions, such as the safest place to cross a deeply incised channel. It can, however, provide the forester/engineer with background that may be useful in understanding the stability limitations of this complex terrain, and when to call for help from specialists.

In addition to an understanding of the terrain and geologic materials, some feel for the "generic" destabilizing factors operating in the basin might also be useful. Stream cutting at the toe of already steep slopes along the miles of incised channels is an obvious factor. In general, the lower in the basin and larger the stream, the more bank cutting is apt to occur during storm runoff. Not so obvious is the behavior of groundwater, abundant in the basin (see also "Climate/Hydrology"). Convergent slopes (sloping draws or swales) tend to concentrate groundwater. Divergent slopes, such as the sloping nose of a ridge, tend to disperse groundwater. The stability effects of such topography may be compounded at changes in slope gradient.

The slope stability map (Fig. 5) represents an attempt to incorporate in a generalized form, factors of geologic history and current terrain shaping processes, soils, slope, and hydrology. Obviously, the mapped stability category boundaries based on such factors are no more accurate than the known distribution of the factors themselves. Thus, the map is of variable "accuracy". Some category boundaries can be established within the limits of map scale. Other boundaries may include unidentified areas of a different slope stability category. Nevertheless, the stability categories in such a map can provide the forester/engineer as well as the land manager with information useful in their particular roles.

Areas designated as slope stability Category 4 are areas that photo recon and limited field checking have identified as probable "worst case" examples, for a variety of reasons. Such areas range from the walls of the "inner gorge" to the south wall of the "upper basin" (Fig. 4), with slopes commonly averaging 60 percent, but some exceeding 100 percent in old bedrock slide scarp areas. Both are sites of ancient deep-seated as well as shallow recent landslides. The January 1983 debris avalanche from the scarp forming the south wall (SE ¼ SE¼ Section 20) stopped on a bench formed by the head of an ancient slide. Otherwise, it almost certainly would have entered the then flood-swollen Thunder Creek at a point where stream gradients average 27 percent. In short, Category 4 slopes are known stability problem areas. The principle unknown is their exact boundaries.

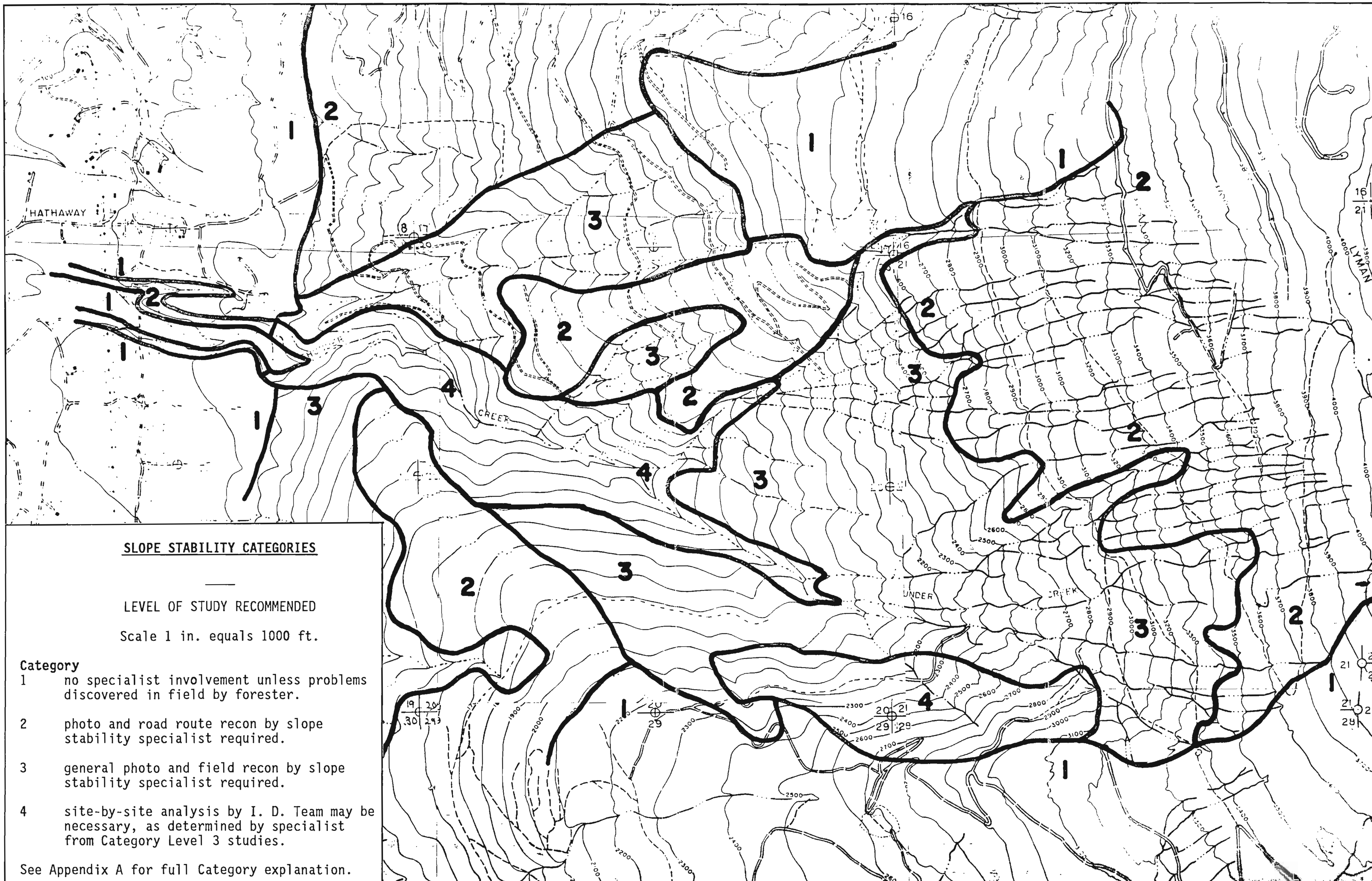

SLOPE STABILITY CATEGORIES
LEVEL OF STUDY RECOMMENDED
Scale 1 in. equals 1000 ft.
Category
1 no specialist involvement unless problems discovered in field by forester.
2 photo and road route recon by slope stability specialist required.
3 general photo and field recon by slope stability specialist required.
4 site-by-site analysis by I. D. Team may be necessary, as determined by specialist from Category Level 3 studies.
See Appendix A for full Category explanation.
HATHAWAY
CREEK
UNDER
LYMAN

FIGURE 5

Category 3 slopes are a mixed bag, no doubt including some Category 4 slopes, but also some that may be relatively stable. It is for this reason that a general field and photo recon by a slope stability specialist is deemed necessary (Appendix A). Photo interpretation should include those taken as early as possible after previous harvest of a particular site, in order to take advantage of the lack of ground cover. Category 3 terrain in the Thunder Creek basin is generally the inner basin, made up largely of slide deposits, and the steeper and more broken areas of the upper basin. The latter areas and the south wall are where the inner basin slide deposits came from. There are probably remnants of these ancient landslides still remaining in places on these slopes.

The areas mapped as slope stability Category 2 are considered, in general, to be stable. Some of this terrain may have moved as much as 50 to a 100 feet when the mountain "settled" in early post-glacial times (see "Geology"). Such "rafts" may be thousands of feet across and still more-or-less intact. They do not appear to be sensitive to the hydrologic impacts of clearcutting. However, the closely spaced incised drainages in much of this terrain tend to collect concentrations of debris from yarding. Another management-related concern in Category 2 areas relates to roads, particularly drainage. Cutbanks in these generally wet soils are commonly unstable, and the cuts may produce surface water that needs to be controlled (see "Climate/Hydrology"). Stream crossings are of concern, not only because of the sheer number, but because they are essentially all incised. Thus, small but numerous fills are needed in an area of generally unsuitable fill material.

Category 1 areas are considered to be the most stable. They are, in general, glacially smoothed upland areas with relatively gentle slopes and small or nonexistent surface drainage. Because of the rather complex geologic history of the Thunder Creek basin, Category 1 areas may include large "rafts" of displaced material and low, generally discontinuous scarps such as found in Category 2 terrain. The rocky scarps are steep and, in places shattered, but should present few surprises for the careful road builder. Slopes in this terrain may be wet but because most of it is high in the basin the size of streams and their depth of slope incision is relatively small. Additional implications for management of the various areas in various slope stability categories can be found in Appendix A.

IMPLICATIONS FOR FOREST MANAGEMENT

Timber Harvest

Timber harvesting directly increases the amount of water available for channel flow by decreasing interception losses. More precipitation in the form of rain will infiltrate into the soil. Greater snow accumulation on the ground will occur because a smaller proportion will be held in tree crowns where it is subject to rapid melt or sublimation.

Removal of vegetation also reduces plant use of soil water. This means less unused capacity for additional water; thus, a greater proportion of the incoming water from rain or snowmelt is free for lateral flow. During the winter months the water production from a recently harvested site can be as much as 20 percent greater than from the same site under forested conditions.

Another effect of opening areas by timber harvesting is to increase the rate of snowmelt during periods of rainfall. This is most common in the zone of the watershed between 2000 and 3500 feet of elevation. Circulation of warm moist air is enhanced in the open areas which allows a more rapid release of heat from condensation on the snowpack. The net effect is a greater amount of water released during a storm event. The amount of the additional water depends on the snow accumulation before the storm event, air temperature, and wind velocity. Assuming there is enough snow to sustain melt for a 24 hour period, an estimate of the added melt water in open areas for varying conditions of air temperature and wind speed is shown in Figure 2.

In general, timber harvesting increases both subsurface and stream flows. Subsurface water collecting at points of concentration will tend to decrease the stability of the slope. Whether or not the increased water will cause accelerated mass wasting depends on the particular slopes natural stability. It also depends on what proportion the contributing area is harvested. The greater the area harvested upslope, the more the increase in subsurface flow. The subsequent increase in channel flows can increase the risk of channel and bank erosion and flooding, and the mobility of any debris torrent or debris-laden floods that might develop. The risk is higher during events involving both rain and snowmelt.

Roads

Road construction disturbs natural water drainage in several ways. Midslope roads in particular intercept subsurface flow and direct it via road ditches to a nearby channel. This has the effect of accelerating water transport rates. Depending on the location and amount of roading, the influence of roads can increase peak flows which increases the risk of channel erosion. Another effect of roads is the diversion of water from one channel into another. The increased flows in the receiving channel will tend to have a destabilizing influence. Even where this increase is not sufficient to disturb sediment-trapping organic debris, it will increase bedload, especially in disturbed and easily erodible materials such as make up much of the Thunder Creek basin. This added bedload may drop out at the next decrease in channel gradient. If such a decrease happens to also be the entrance to a culvert, blockage is possible.

The relatively weak and broken rock and the generally fine-grained and water-retaining soils in much of the Thunder Creek basin present problems that need extra attention in road layout, construction, and maintenance as well as abandonment. For example, the newest road in the basin, (currently inactive) even though traversing an area of less than 30 percent slopes, has areas of almost continuous cutbank failure. Cutbanks are too low (5-10 feet) for such failures to be large enough to directly threaten the road, however, their abundance and the fact that they appear to occur even in the "dry" season makes them a serious ditch maintenance problem. The shattered phyllite rock and fine-grained glacial soils also make poor water bars, susceptible to erosion if overtopped by even a trickle.

Any such problems are compounded by the high density of drainages throughout much of the basin. As mentioned in "Climate/Hydrology", the upper half of the basin, especially on the north side, is characterised by closely spaced (in places, less than 100 ft) drainages. Combining these drainages via road ditches can be a serious risk, as each may carry considerable water during storm events. Thus, higher than normal costs of culverts and culvert maintenance should be anticipated in such areas.

Potential problems associated with soil water retention are compounded where soils are disturbed by construction, making sidecast and fill saturation a year round potential. The lower permeability of subsoils increases the potential for gullying on steeper road segments. This potential is again compounded by the density of drainages in the mid-to-upper basin. The foregoing characteristics mean that laying out roads on a gentle grade is especially desirable. Roads built in the 1940's and orphaned in the 1950's and 60's have stood up quite well for decades where laid out on the contour, with the exception of poorly constructed or poorly drained fills and landings. This suggests that roads in disturbed glaciated phyllite terrain may take longer than normal to "mature" (i.e. develop stable cut and side cast slopes) but once a properly located and built road matures, it can be quite stable. It also suggests that where grades are significant, backup precautions such as "rolling" the grade at channel crossings can be important, especially upon abandonment.

Potential Downstream Impacts

During the torrential rains of January 10, 1983, on an already wet snowpack, four significant debris avalanches occurred on Lyman Hill. Two stopped on benches and two entered flood-swollen streams and evolved into damaging debris torrents. In contrast, the same storm triggered hundreds of shallow debris avalanches on the sandstone terrain of nearby Stewart Mountain. Nearly all entered streams and, with few exceptions, traveled their full lengths causing millions of dollars in damage.

The January 1983 rainstorm and snowmelt produced stream flow in Thunder Creek that, based on markings on trees, was more than three times greater than the predicted 100 year flood. The 1983 flood eroded the edges of, but did not occupy a "fossil" floodplain along the creek between the powerlines and the fan and about 5 ft above the creek's current floodplain. This old floodplain is now occupied, in places, by homes and large second growth. The 1983 event demonstrated that a high rate of runoff, by itself, is highly unlikely to impact structures on the old, higher floodplain.

The results of this storm event suggest that terrain underlain by phyllite may be less susceptible to debris avalanching than that underlain by sandstone. It also provided evidence indicating that large woody debris in channels within phyllite terrain are generally quite stable. Thus, they are not apt to fail in domino-fashion, releasing slugs of debris and stored bed load, even during extreme floods. Nevertheless, the Childs Creek and Mills Creek debris torrents testify that such events can be triggered in phyllite terrain by debris avalanching. Had the major avalanche from the South Wall of the Thunder Creek basin (see "Slope Stability") reached the Creek, a debris torrent would almost certainly have developed.

The foregoing indicates that Thunder Creek, like many other creeks in the region, will eventually experience a debris torrent. Given that assumption, questions that arise include: How far is such a torrent apt to travel? What is the potential hazard to structures along the lower incised channel or on the fan? If a debris torrent did occur in Thunder Creek, the risk of it causing direct damage downstream is very low. This is primariy because of the long stretch of low channel gradient where the Creek has incised the late-glacial terrace and fan.

Based on observed debris torrent deposition throughout the world, a conservative estimate of the gradient where deposition begins is six percent. The main channel of Thunder Creek reaches this gradient over 3000 ft upstream from the 300-foot elevation mark. Experience elsewhere in the region has shown that where basins are large enough, debris torrents may evolve into floods laden with large floating debris. Probably the main hazard to residences along Thunder Creek is from such an event developing a jam. Such a jam could divert water onto the old floodplain or onto the fan if it occurred at the railroad bridge. Flooding on the fan would be apt to be confined to the northern quadrant and be relatively free of large debris.

In regard to other potential impacts, a jam at the railroad bridge obviously could impede rail traffic as a result of track obstruction and/or erosion. However, it seems unlikely that woody debris large enough to form a jam would reach the highway bridge. The dropping of coarse bedload, mobilized by major flood or debris torrent, along the lower reaches (including at the highway bridge) would reduce channel capacity, increasing flooding tendencies. Some finer sediments (mostly silt and sand) would reach the upper Samish River system and result in a temporary decrease in water quality.

CONCLUSIONS AND RECOMMENDATIONS

GENERAL

Conclusions: Debris avalanches potentially capable of triggering a debris torrent have occurred in the Thunder Creek basin and no doubt will occur again. Lower channel and floodplain characteristics are such that any torrent would be very unlikely to reach existing residences. However, such an event could transport and concentrate enough debris so that channel blockages downstream are possible. Thus, damage by flooding could occur to residences on the flood plain or fan apex upstream from the railroad track and possibly, to a lesser extent, on the northern quadrant of the fan.

Recommendations: Efforts should be made to schedule harvesting in time and place within major sub-basins so as to lessen possible hydrologic impacts. Harvest within areas of significant channel incision should be avoided or conducted only after careful study and with minimal soil disturbance. Abnormal concentrations of harvest-generated debris in such channels should be removed.

New roads should be located, constructed, maintained, and abandoned with higher than "normal" standards to minimize chances of road-related avalanches. New residential development of the flood plain/fan apex upstream from the railroad tracks, should be discouraged.

NEW ROADS

Conclusions: The geologic materials and hydrologic conditions in much of the Thunder Creek basin present a range of problems for road construction and maintenance, especially in regard to fill and cut bank stability and road drainage.

Recommendations: Wherever practical, access roads should gain elevation outside the basin and enter it along the contour. Construction activities should be confined to the dry season. Where significant grades are unavoidable, extra precautions are needed to assure proper road drainage. Drainage system failures, including culvert and ditch blockage, should be anticipated and backup provided. Roll grades at significant stream crossings to minimize fills, avoid water transfer resulting from plugged culverts, and simplify road abandonment. Avoid crossing major incised tributaries. Bridge where crossings are absolutely necessary.

ORPHANED ROADS

Conclusions: The myriad road types, conditions, age, setting, and accessibility preclude generalizations regarding appropriate treatment (see Appendix B and Plate 2). Piecemeal or site specific priority-based abandonment could result in the isolation of road segments and limit future treatment options.

Recommendations: An overall orphaned road treatment plan should be developed before further abandonment work. Various treatment options and combinations (including heavy equipment, handwork, helicopter support, and explosives) should be evaluated.

APPENDIX A

RELATIVE SLOPE STABILITY

EXPANDED MAP EXPLANATION

SLOPE
CATEGORY: DESCRIPTION AND MANAGEMENT LIMITATIONS

1. Map unit description*
   Slopes averaging 30% or less, with no known destabilizing factors.

   Specialist involvement recommended
   None, unless potential stability problems are encountered during recon for proposed activity.

   Timber harvest/road construction**
   Use standard techniques, with extra care where Category 1 land abuts "Category 3 or 4" mapping units or incised channels.

2. Map unit description*
   Slopes generally average 30-to-45%. May include areas such as "benchy" terrain where average slope is less but steep pitches (and/or low rocky scarps) are common, known wet areas, or upper basins of streams that drain into Category 3 or 4 terrain.

   Specialist involvement recommended
   Photo recon should be conducted. Road route field recon required with special attention to stream crossings.

   Timber harvest/road construction**
   Use techniquies appropriate to local terrain and minimize soil disturbance. Specialists should be consulted regarding crossings of channels incised more than about 10 feet, headwalls of such channels, or where recon has encountered potential stability problems.

3. Map unit description*
   Slope gradients generally erratic and locally exceed 70%. May include small recent landslide masses, large ancient and poorly-defined slide areas, including scarps and remnants of slide masses. Also includes incised channels and headwall areas in steep terrain.

*See also "Discussion - slope stability"
**See also "Implications for Forest Management"

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Specialist involvement recommended
General field reconnaissance should be conducted. Aerial photo analyses should include earliest available flights after initial timber harvest. Proposed road routes must be walked. Incised channel/headwall areas may need to be examined in detail.

Timber harvest/road construction**
Harvest techniques that minimize soil disturbance and runoff concentration required. Category 3 includes some areas where harvest may not be practical. Road routes must be carefully planned to avoid potential trouble sites. Roads may require special construction and/or drainage techniques.

Comments
In places, Category 3 terrain could be considered a "mixture" of 2 and 4, where boundaries between the two are unknown or poorly defined. Elsewhere, it may be a homogeneous unit, such as a single ancient landslide, that requires closer study than typical Category 2 terrain.

4. Map unit description*
Slopes generally exceed 60% along walls of deeply incised mainstem and major tributaries. Includes areas of near-vertical cliffs that appear to be stable on a large scale but may be sources of falling and/or rolling rock. Includes ancient, dormant slide areas with oversteepened and eroding headscarps. Includes areas that contain debris avalanche tracks and active rock chutes.

Specialist involvement recommended
On-site investigation generally needed to accurately delineate the boundaries of Category 4 areas. Photo analysis should include earliest available flights after initial harvest. Any activities within such areas should be based upon careful site-by-site analysis by an interdisciplinary study team.

Timber harvest/road construction**
Should be conducted only at sites selected by detailed study. In general, road construction should be avoided in areas confirmed by detailed studies to be in Category 4. Harvest units should be small and/or selective cuts, with special precautions taken to avoid soil disturbance.

Comment
Because of its steepness and/or other existing natural instability factors, Category 4 terrain has a relatively high potential for "exporting" slope failures to more stable terrain downslope or downstream.

*See also "Discussion - slope stability"
**See also "Implications for Forest Management"

APPENDIX B

ROADS

ROAD INVENTORY

The Thunder Creek drainage has a total of about 14 miles of truck road, railroad grade, and cat road with a defined road prism. The roads fall into the following Forest Practice categories: (see also Plate 2)

Active - There are no active haul roads or forest practice applications in the drainage. There is about one quarter of a mile of private driveway for home access.

Inactive - There is about 2¼ mile of inactive road being maintained at present (including about 3000 feet along the crest of Lyman Hill).

Abandoned - There is about 3¼ miles of abandoned road in the basin. Abandonment consisted of removing fills, waterbarring, and sidecast pullback above a relatively small active slide area (see Plate 2).

Orphaned - About 8 miles of roads and grades were built and last used prior to the Forest Practice Act of 1974. The railroad grades and cat roads have little potential for future problems. Road segments B1-14 and C1-14 in Section 21 (Plate 2) have the highest potential for future problems. These roads were built in the 1940's and last used in the 1950's. There are numerous tributaries of Thunder Creek crossed by these roads. Drainage structures include wood culverts and gravel (dirt) covered log bridges. Hard labor and/or explosives may be the only feasible way to remove these structures, as the roads now support a crop of 30 to 40 year old timber as large as 18' in diameter. The traditional methods of abandonment using heavy equipment would require cutting of these trees as well as reconstruction of the roads, both probably counterproductive. Possibly some of the problem sites identified in the following "Orphaned Road Inspection Report" would warrant flying in a small backhoe.

ORPHANED ROAD INSPECTION REPORT

The present general condition of the approximately 8 miles of orphaned roads in the Thunder Creek basin is not easily characterized. Their condition reflects their age, method of construction, original intended use (railroad, truck, cat trail), and terrain (slope gradient, stability, presence of stream channels) involved - some of which vary markedly over short distances. Probably the main reason these roads have created as few problems as they have is because most were constructed with very low grades.

The decision regarding whether and how to correct potential problems on segments of orphaned roads should not be based strictly on road condition. The apparent "best solution" will depend upon the subjective weighting of factors such as: downstream values at risk; severity and number of potential problems; accessibility for the resources needed to correct problems; and, ultimately, whether the fix would likely create potential problems of equal or greater magnitude than the no-action alternative.

Road segments and specific sites are identified on the basin planimetric map (Plate I).

ROAD SEGMENT "A"

(1) Crossing structure plugged and water is diverted down road.
(1) to (2): Water on road and rills cut into road.
(2) Considerable water seepage on road in this vicinity. Stream crossing but no structure - high water flows across road while at low flow the the water follows ditch for some distance before spilling onto road.
(2) to (3): Road surface wet.
(3) Rock pit acts as pond. Lower end of pit could be opened and the drainage water ditched across road.
(3) to (4): Small streams flow onto and generally across the road but cross drains are needed.
(3) to (4): Small streams flow onto and generally across the road but cross drains are needed.
(4) Road dry in this vicinity.
(4) to (5): Seepage water intercepted by cutslope keeps road surface wet.
(5) Last stream crossing on the road segment - still functioning

Road Segment A Summary: This segment is about 1 mile in length. It is located high in the basin; therefore, not too much drainage from above. No serious problems here but road could definitely benefit from water barring. Vegetation on road is primarily willow and similar brush which could be "run down" with equipment. Reasonable access for machinery is through Scott Paper.

ROAD SEGMENT "B"

(1) Switchback.
(1) to (2): Some rilling and surface erosion is occurring but it is not serious.
(2) Stream crossing, but could not find a structure. Water is running down road.
(2) to (3): Road surface is wet and some rilling and erosion has occurred.
(3) Small stream crossing but could not find a structure.
(4) Small stream diverted onto and down road to larger crossing about 150 at (5).
(5) Stream crossing structure non-functional and water is flowing down road to north for about 200 feet.
(6) Three small streams here - all appear to have wood culvert structures which are functioning fairly well to this point in time. These crossings have very little if any impoundment potential, but there are fills involved and the outer edges have slumped.
(7) Two streams here. The south one has washed out the crossing structure and the north one is a wood culvert which still functions in a small fill.

(8) Stream crossing with combination bridge and fill. Fill is 6 feet at inlet and estimated 15 feet deep at center-line. Some impoundment potential. Fill appears to consist of large wood, cable, etc. Channel and slope gradient is steep below structure.
(9) Two small stream crossings - south one has washed out the structure and north one is wood culvert. No impoundment potential and very little fill.
(10) Swale with wood culvert.
(11) Wood culvert has washed out but considerable wood remains in stream.
(12) Good size stream crossing with wood culvert. Some impoundment potential and slope is steep below road.
(13) Stream crossing with washed out wood culvert - no problem.
(14) Stream crossing with large wood culvert and sizable fill on down-slope side. Water entering culvert, but exits from side of culvert at lower side of fill. Steep channel below.

Road Segment B Summary: This road segment is about 1.4 miles long. Small streams cross this road at close intervals. Road was constructed with wood culverts most of which have failed or are in the process of failing. Steep slopes and steep channels below the road are common. Some specific crossing structures have potential to be involved in significant debris torrents. Most practical access to this road segment is from the south through Scott Paper Company. The road is brushy and has many alder trees as large as 6+ inches DBH. Methods of removing or reducing the stream crossing fills/structures should be considered.

ROAD SEGMENT "C"

(1) Stream has eroded under and through a wooden culvert/fill. A 16+ inch cottonwood tree is growing in center of this debris. Considerable big woody debris in the remaining fill.
(2) Good size stream crossing. Structure is gone but considerable large wood and rock remains. Stream is steep below the crossing. Debris removal would be a large job.
(3) Stream crossing washed out but considerable big woody material remains in stream. Stream is steep below road. Considerable large woody debris in stream above and below crossing.
(4) Small stream crossing with small wood culvert.
(5) Same as (3).
(6) Stream crossing - structure washed out - no problem.
(7) Stream crossing with wood culvert still functioning. Fill height is about 3 feet and there is some impoundment potential.
(8) Stream crossing structure washed out - considerable big woody material remains in stream from harvest operation.
(9) Wood culvert still functional and there is no impoundment potential. Considerable big woody material is in stream from harvest operation.
(10) Water on road here and road has slumped somewhat many years ago in this vicinity.
(11) Stream crossing structure has washed out. Woody material remains in crossing, and considerable woody material is in the channel above and below crossing.

(12) Wood culvert structure still partially in place, but there are holes in the fill. Landing debris in stream above and below crossing.
(13) Small stream crossing with partially functional wood culvert and fill caving in. Channel gradient is relatively gentle but considerable big woody material in channel.
(14) Stream is not crossing road at the constructed crossing but is diverted onto and down road northward about 100 feet before going off road.

Beyond this point the "road" became nothing more than a cat trail. It was difficult to follow on-the-ground and extremely brushy.

Road Segment "C" Summary: This road segment is just over 1 mile long. Trees growing in the road are commonly 10 to 12 inches at DBH and some are 16 inches. Many stream crossing structures are washed out and the remaining ones are failing. Road gradient is relatively flat and there is little standing water on the road. Considerable harvest-related large woody material remains in most of the channels. Machinery access is not practical due to washed out crossings and large trees. There is not much that can be done on this road segment - biggest potential problem seems to be the amount of large wood in the channels.

ROAD SEGMENT "D"

This road segment is about 1 mile in length. Severe erosion of the surface and ditches was discovered in early October 1988 and treatment work was completed. The erosion resulted from diversion of several very small streams onto and down the ditches and road surface. Treatment consisted of using heavy equipment to redirect the streams into their natural channels and construction of large water bars.

ROAD SEGMENT "E"

(1) Sidecast breaking away along about 100 feet of road on an 80 percent sideslope.
(2) Very steep sideslope with sidecast breaking away.
(3) Large, old failure involving the cutslope. Failure filled road and spilled over the slope below. Seepage water on road surface and failed material.
(4) 24- inch CMP (corrugated metal pipe) open and functional but water is running on road at this point. Some of this water is (5).
(5) 30-inch CMP at this stream crossing. Stream has eroded a deep channel around the CMP. Some streamflow also diverted down road.

Road Segment E Summary: This road segment is about 2,000 feet in length and crosses the very steep scarp of a large ancient slope failure. Equipment access would require reconstruction of a part of the road and is not practical. Other means of controlling road drainage could probably help stability through the steeper/wetter sections of road.

ROAD SEGMENT "F"

This segment was not evaluated. Approximately the east one-half of the road shown on Plate 2 is not discernable on recent aerial photography. If it does exist it is apparently nothing more than a tractor trail.

ROAD SEGMENT "G"

(1) 12-inch smooth steel pipe at small stream crossing. No impoundment area.
(2) Small stream crossing but no sign of structure. Water drains across road and some is diverted down the road to the north. Road for 80 to 100 feet north of crossing has slumped a few feet. Slump probably related to diverted stream. Channel needs to be reestablished in original location to keep water off slumped portion of road.
(3) Road is gone. Failure scar is perhaps 20 years old and extends downslope about 500+ feet.
(4) Sidecast is failing. This is just west of 1983 slide scar. No water apparent. There is really nothing that can be done.
(4) to (6): Many areas with settling or failed sidecast/road material. Water is common occurrence on the road, but there is no defined source in most cases. This is simply a wet, steep & marginally stable area.
(5) Small stream crossing but no structure. Water flow across road.
(6) Remnant of large landing.
(6) to (7): Road dry.
(7) Stream crossing structure long gone. Channel confined to original route.
(7) to (8): Sidecast material settling.
(8) Stream crossing with large wood culvert. Lower end of structure is exposed but inlet not visible. Streamflow has eroded a gully into the fill.
(9) Remnant of end landing.

Road Segment G Summary: This road segment is about 0.8 mile in length and crosses the very steep scarp of a large ancient slope failure. Portions of the road have experienced debris avalanche-type failures along the steepest sideslopes and the road is gone. Settling sidecast is common and much of the road surface is wet due to seepage from the cutslopes and/or the steep basin upslope. Equipment access to most of the road is impractical but better control of surface water could help stability on portions of the remaining road.

ROAD SEGMENT "H"

(1) Very small stream crossing, no impoundment potential, no structure - no problem.
(2) The railroad grade here has washed out. No impoundment potential remains. Water standing on grade for 50+ feet as this is a natural seepage area.
(3) A high cut slope on uphill side of railroad grade and a significant draw below grade. There is some potential for fill material to move, but there are confier and hardwood trees to 12" DBH growing in this material. This is a natural wet area.
(4) 150 to 200 feet stretch of grade with water standing on surface. There is only slight fill here but slopes are 45 - 50 percent above and below grade.
(5) Small stream crossing. No significant fill and no structure. Water is flowing across grade but is not eroding.

Road Segment H Summary: This is an old railroad grade that has never been used by trucks. The segment is about 2400 in length. No stream crossing structures remain and water stands on portions of the surface. Seepage intercepted by the road is the main source of standing water. Erosion is not generally a problem but road drainage could help insure its stability through time.

ROAD SEGMENT "I"

(1) Small stream crossing still functioning. Structure consists of large logs placed parallel to the channel. There is a little potential for impoundment and the channel upslope appears stable. Fill varies from 2 to 6 or 8 feet deep and it has 9-inch DBH alder growing on it.
(2) Very small stream crossing in a shallow swale. Portions of a log culvert are visible. No impoundment potential.
(3) Between (2) and (3) the road intercepts seepage water at several locations. In some cases, during storm conditions, this water flows some distance on road. Erosion is not a problem.
(4) This spur road stops before reaching the stream.
(5) A portion of the road (it is difficult to locate exact position of original road) appears to have encroached on the stream at this point. Stream has eroded part of the road bed but nothing can be done now. Considerable woody debris in stream.
(6) This relatively flat-gradient portion of the road (cat trail) intercepts some seepage water but it drains across the road without causing erosion. Sideslopes are gentle and road is not creating a problem.

Road Segment I Summary: This road segment is about 0.7 miles long. The lower portion may have originally been an old railroad incline but the upper part appears to be only cat trails. One small stream crosses the road through a "structure" consisting of buried logs. The crossing is on the boundary of a 1988 harvest unit but it is not easily accessible to equipment.

APPENDIX C

THUNDER CREEK/MILLS CREEK COMPARISON

Any risk assessment for a basin (see "Potential Downstream Impacts") can be improved by comparison with similar basins. The adjacent Mills Creek basin experienced a devastating debris torrent during the January 10, 1983 rainstorm on a warm, already wet snowpack; with snowline below 1000 feet. Thunder Creek, with the same climatologic and geologic settings and the same elevation and aspect did not experience such an event. Both were traversed by miles of orphaned roads of about the same vintage. Both basins experienced at least one major debris avalanche. Why did Mills Creek experience a catastrophic debris torrent while Thunder Creek did not?

~~The~~ An immediate ~~answer~~ consideration is that the debris avalanche responsible for the Mills Creek torrent originated within the channel. The Thunder Creek avalanche occurred along a very steep ancient slide scarp but stopped on a bench, never reaching a stream (see "Slope Stability"). However, other slopes and channels in Thunder Creek are capable of producing torrent-generating avalanches. In comparing the downstream hazard potential of the two basins it is important to consider both their torrent-<u>generating</u>, and their torrent-<u>transporting</u> capabilities. Also important, however, is the potential for a stream to transport torrent-mobilized debris at relatively low channel gradients.

The differences in channel gradient between the mainstems of both streams are compared in Figure 6 (note the vertical exaggeration). Note that below about 1000 feet elevation the gradient of Thunder Creek averages significantly less than that of Mills Creek. Probably, even more important to debris torrent transport is the length of a relatively low gradient channel between where the streams begin deposition and the apex of any well-defined fan. This distance is barely 2000 feet at Mills Creek compared to approximately 4000 feet for Thunder Creek.

The degree of channel confinement was considered to be another important parameter. Mills Creek not only sustains it's steep gradient to a lower elevation than Thunder Creek, but averages a more restricted channel cross section through much of that distance. As mentioned previously, the distance Mills Creek traverses from its steep, restricted channel to its fan is much shorter than for Thunder Creek. Equally important is that Thunder Creek traverses much of this distance flanked by well developed flood plains.

Also, the Thunder Creek basin is substantially larger than that of Mills Creek. It's theoretical discharge rate is nearly twice as great. Thus, a debris torrent of a given size would become more diluted as it progressed

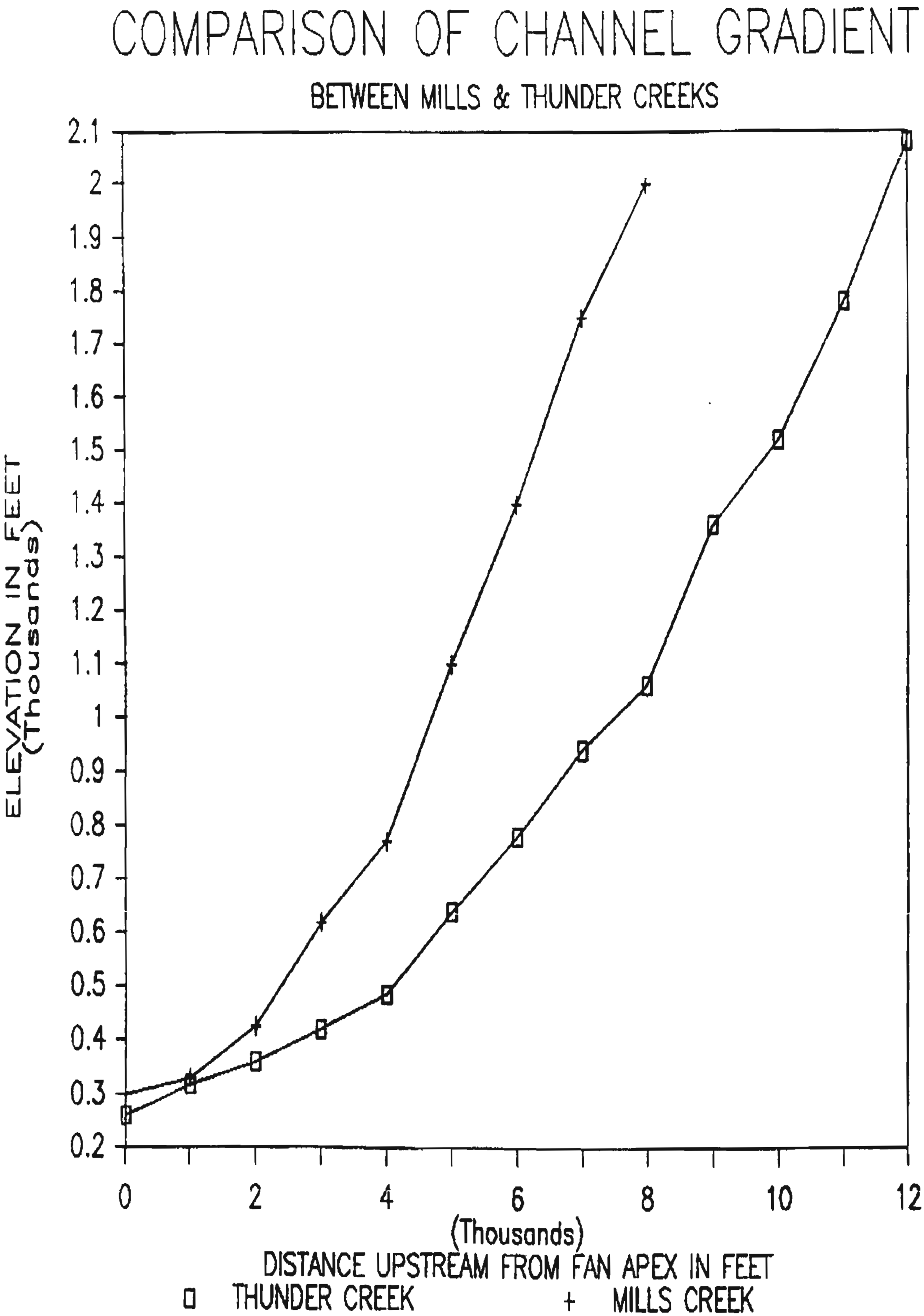
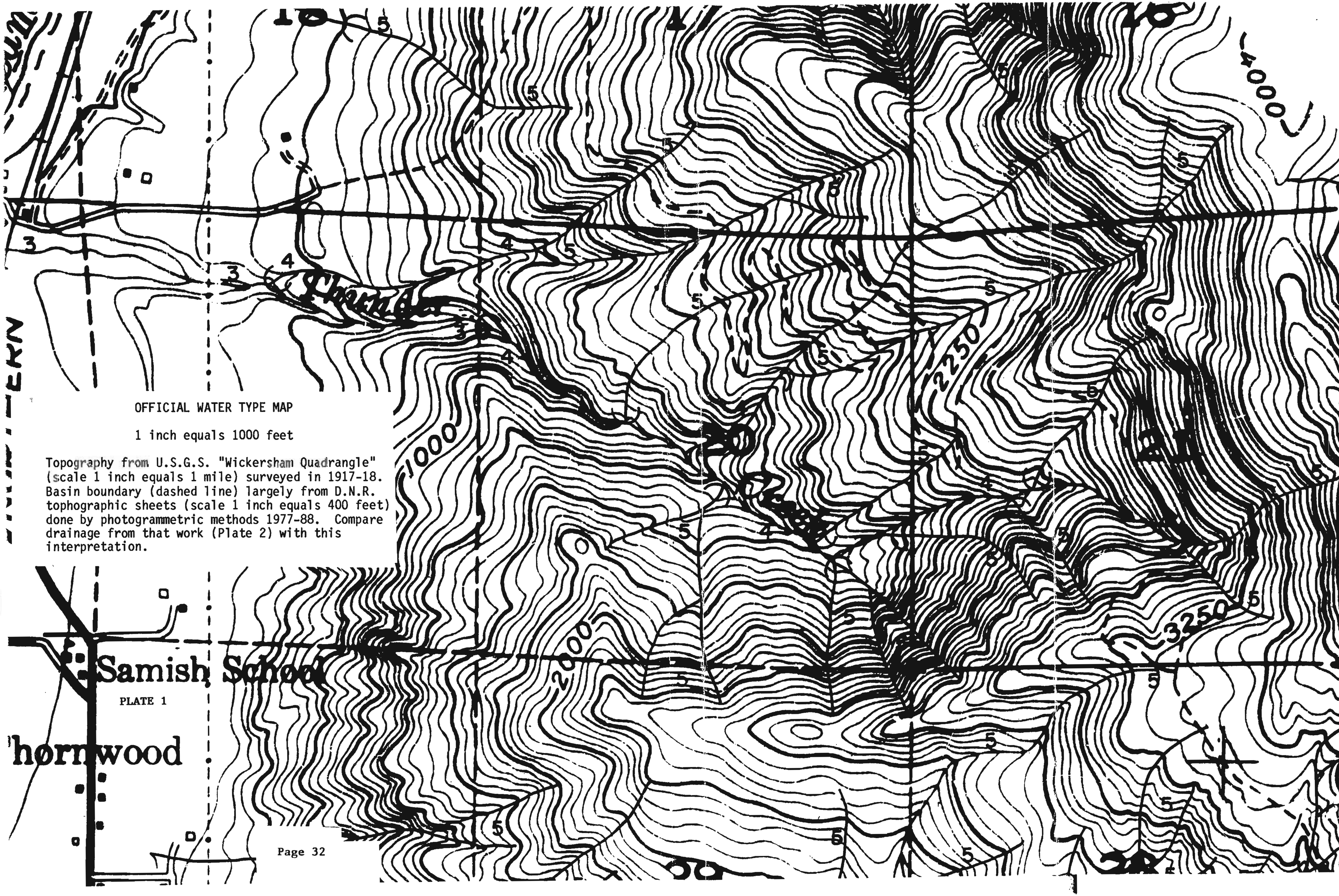

COMPARISON OF CHANNEL GRADIENT
BETWEEN MILLS & THUNDER CREEKS
ELEVATION IN FEET
(Thousands)
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
2
4
6
8
10
12
(Thousands)
DISTANCE UPSTREAM FROM FAN APEX IN FEET
THUNDER CREEK
MILLS CREEK

FIGURE 6

down Thunder Creek compared to a comparable one in Mills Creek. Everything else equal, the resulting lower slurry density for the Thunder Creek event would mean less ability to transport material, especially bedload. Thus, Mills Creek, with its steeper more confined channels, could sustain a fast-moving debris torrent to lower lelvations than could Thunder Creek.

Although Thunder Creek is much less likely to sustain a debris torrent into currently developed areas than Mills Creek, it is more capable of transporting torrent-generated debris by flooding. Much of the damage from the 1983 storm in Whatcom County was from floods laden with floating debris initially mobilized by debris torrents. Such damage was not confined to fan apex areas, but commonly occurred along the distal edges of the fan, in areas of low gradient, and not necessarily bordering present stream channels.. As residential development progresses upstream along the banks of Thunder Creek the odds for such damage will increase, with or without forest management activities.



OFFICIAL WATER TYPE MAP

1 inch equals 1000 feet

Topography from U.S.G.S. "Wickersham Quadrangle" (scale 1 inch equals 1 mile) surveyed in 1917-18. Basin boundary (dashed line) largely from D.N.R. tophographic sheets (scale 1 inch equals 400 feet) done by photogrammetric methods 1977-88. Compare drainage from that work (Plate 2) with this interpretation.

PLATE 1

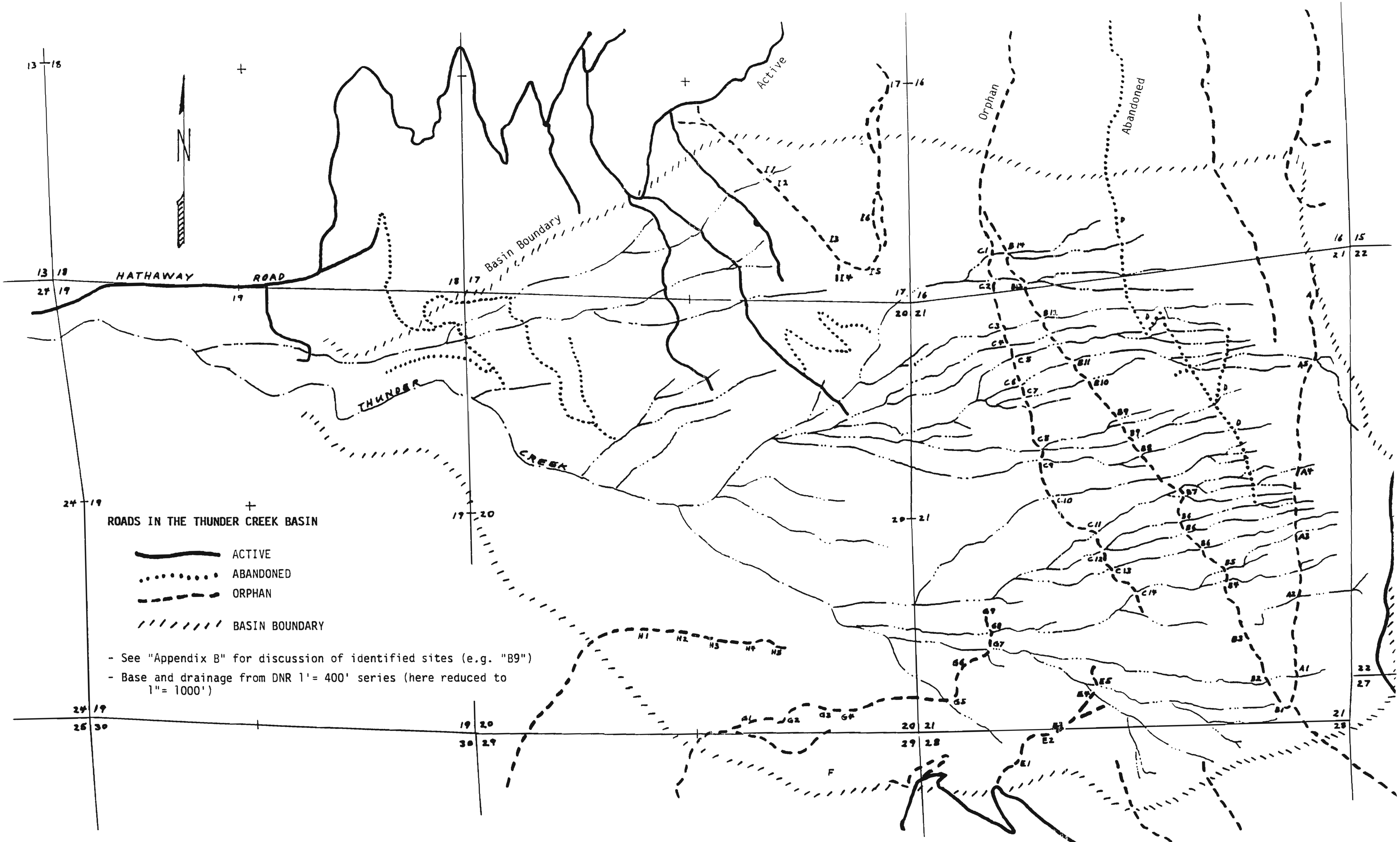

ROADS IN THE THUNDER CREEK BASIN
ACTIVE
ABANDONED
ORPHAN
BASIN BOUNDARY
- See "Appendix B" for discussion of identified sites (e.g. "B9")
- Base and drainage from DNR 1'= 400' series (here reduced to 1"= 1000')
HATHAWAY ROAD
THUNDER CREEK
Basin Boundary
Active
Orphan
Abandoned
N

PLATE 2

REG MGR
ARM RPS
ARM SL
RADIO
OFF MGR
OS HRA 1
RS AA 1

December 20, 1989

22 1989

BAKER
BAY VIEW
CASCADE
RIVERS
GOV FOR
SOILS
TBS
R/W
IRTC
ENG
PROP FOR
GEOLOGIST
GEOMAPS
REC TECH
GOV TECH

John Osborn, District Manager
Department of Natural Resources
919 N. Township
Sedro Woolley, Washington 98284

Dear John:

As we have already discussed, it was considered beyond the scope of the Thunder Creek Basin study to try to identify potential hazards in other than "generic" form. Here I will try to expand on the section of that report, "Potential Downstream Impacts". Louis Hallion, Jim Ryan, and I all agreed that a true debris torrent (a turbulent surge of muddy water, boulders, and broken trees) would be highly unlikely to reach the power line vicinity, much less progress further downstream. We did agree however, that a debris-laden flood, such as caused the damage at Smith and Olson Creeks in 1983, could reach considerably further. At those locations, as well as nearby Mills Creek, floating logs and stumps probably caused much of the structural damage.

The actual quantification of risk from a debris-laden flood is beyond my education and experience. Hydrologists and hydraulic engineers can provide water elevations for events such as "hundred-year floods" but, I suspect, even such specialists would be hesitant to try to predict the location, size, and configuration of a potential log jam. That is what is needed to quantify the potential hazard from stream blockage and diversion (the most likely hazard to structures along Thunder Creek as concluded in our report.) The positioning of a single floating large log at a channel restriction or obstruction can determine whether a jam occurs or not.

Thus, factors such as valley floor and stream channel configuration, the size and extent of stream-side trees and the existence of large glacial boulders can be critical in determining <u>if</u> a jam will occur, <u>where</u> it might occur, and the direction and magnitude of flood diversion from such an occurrence. In regard to channel stability, it is also important to consider the heavy bedload that streams such as Thunder Creek may carry even during "normal" flooding. During a recent visit I saw an active (unvegetated) channel segment just below the pipeline crossing with vertical walls 10-12 ft high and as much as 40 ft wide in places. Such a large cross-sectional area would suggest tremendous flow capacity. However, a fresh terrace remnant in one place indicated that during the last flood the bed of the stream was within 4 ft of the top of the bank. Thus, the "freeboard" one sees is not necessarily what exists during major runoff events.

Given the myriad variables possible from this blend of unknowns, I feel that a conservative approach to the question of residential development here is warranted. On the accompanying aerial photo (NWC 83, 19-48-13), I have pinpointed 3 residences on the floor of the lower Thunder Creek "valley". Lack of inundation in 1983 demonstrated that all three sites are safe from normal flooding, even one of greater than hundred-year recurrence. However, quantitative judgments regarding the level of security of such structures from stream diversion due to log jams or large trees falling across the channel are left to others. Possibly, the following observations will be of some help in making such analysis.

The Cobb residence is about 145 ft. south of Thunder Creek and a little over 200 ft west of the pipeline right-of-way. (The structure did not exist at the time of the 1983 flight.) It lies on an ancient floodplain of the ancestral Thunder Creek and is about 12 ft above the walls of the present, deeply incised channel. Rotted old growth cedar stumps to 8 ft diameter on this surface suggest that it is older than about 500 years, and probably thousands of years old. Upstream from the pipeline the active channel walls are only 5-to-8 ft. high and curve to the north (looking downstream). The valley floor slopes northerly at about 3-to-4 degrees at the pipeline crossing. Thus, it would seem that any stream diversion due to blockage at this "dogleg" of relatively shallow channel would have both distance and "incentive" to return to the channel before reaching the Cobb residence.

The Huddle residence is about 150 ft north of the active channel (see aerial photo). About half of this distance consists of a relatively young flood plain occupied by alder and cedar to 2 ft in diameter. The other 75 ft-or-so is an older terrace upon which the residence is built and is about 6 ft higher than the lower terrace. This older terrace has cedar to 4 ft diameter growing on it. However, the fact that both terraces are relatively flat in cross-section suggests that any diverted stream flow would have little incentive to immediately reenter the channel. The large trees on the older, upper terrace would help to "filter out" large floating debris, but might provide little impedance to diverted stream flow should such occur.

The large mobile home on the north bank, just upstream from the railroad bridge (see aerial photo) is another structure possibly at risk from channel diversion. The bridge has a 60 ft wide by 8 ft high opening but the four piling piers are obstructions that could be easily spanned by large floating debris. An obstruction at this site would divert floodwaters to the north and northwest due to the general slope of the fan at this point. However, the mobile home is about three feet above track level at the bridge, so it might escape flooding due to simple blockage of the bridge span. A channel blockage at the large channel bend, above the bridge, could divert floodwaters onto the broad "alder flat" here that is about 4-to-7 ft above the present channel. Whether such diversion would impact the mobile home is difficult to say, however, there are more than 100 yards of mature alder forest between this bend and the home.

I hope the foregoing will help to explain some of the reasons for my concern regarding continuing residential development along the floor of Thunder Creek's inner "valley". I have no direct evidence that any of the existing residences described are in danger from simple flood events such as have occurred in recent history. However, I feel that continued development carries some risk, especially if people are tempted to build closer to the stream than in the past. At the very least, future builders should be reminded that the Thunder Creek basin is relatively large and much of it is in the transient snow zone. Therefore, lower reaches are subject to sudden and powerful floods. Such floods can be accompanied by dramatic changes in stream bed elevation as well as severe bank erosion. Should a storm and meltwater also trigger a debris avalanche that reached the creek, the resulting abrupt increase in both floating debris and bedload could result in even greater channel instability.

Frame 13 (flight 48) is one of those you had blown up to 1 in equals 400 ft. Thus, it should be easy to transfer the locations on this contact print to the corresponding enlargement.

Sincerely,

Jerry

G. W. THORSEN