WASHINGTON STATE HIGHWAY DEPARTMENT RESEARCH PROGRAM REPORT **8.1**

AVALANCHES ON THE NORTH CASCADES HIGHWAY (SR-20)

SUMMARY
RESEARCH PROJECT

Y-1301

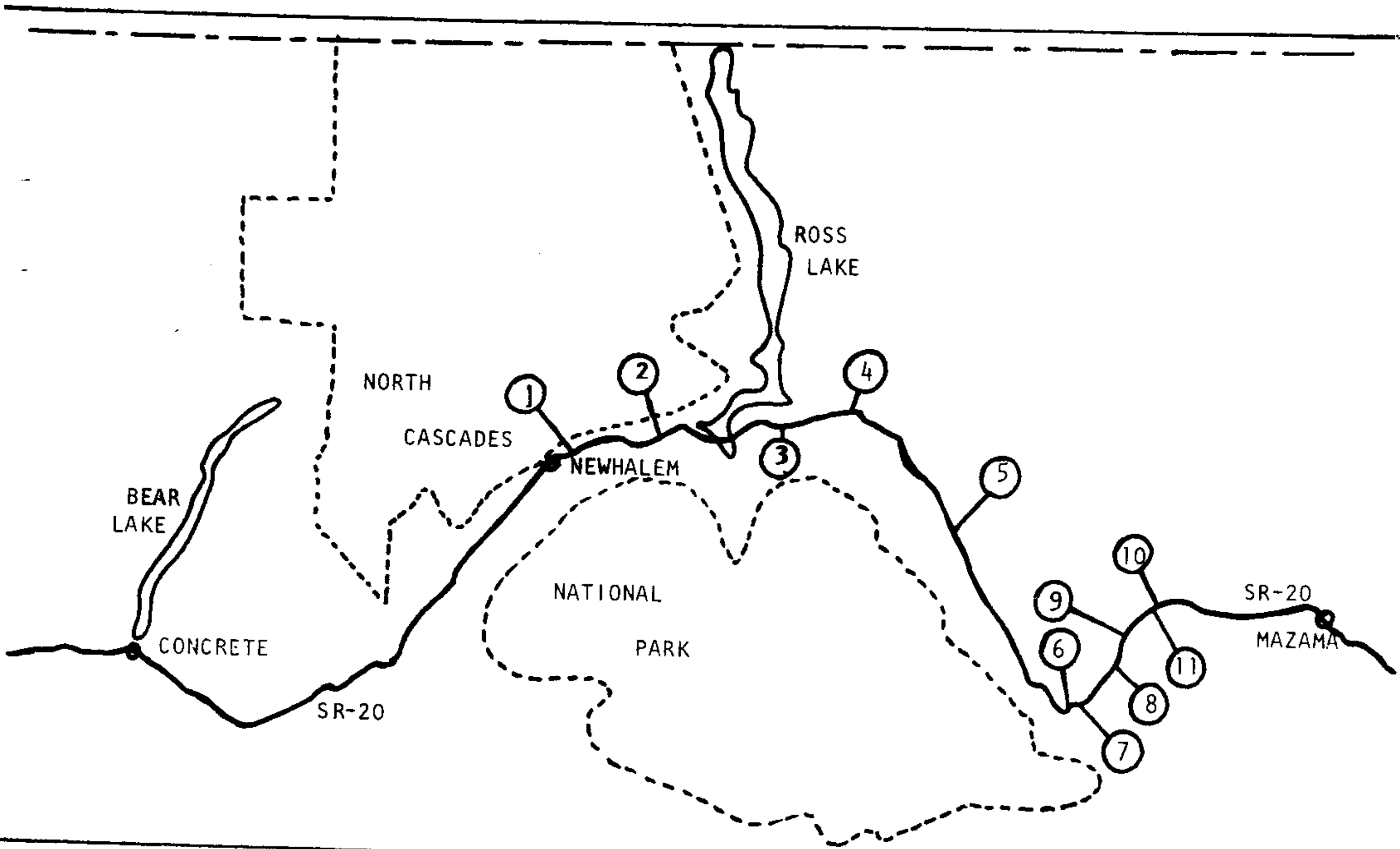
SEPTEMBER 1971

PREPARED FOR
WASHINGTON STATE HIGHWAY COMMISSION
IN COOPERATION WITH
U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

E. R. LACHAPELLE
ASSOCIATE PROFESSOR
GEOPHYSICS PROGRAM AND
DEPT. OF CIVIL ENGINEERING
UNIVERSITY OF WASHINGTON

TABLE OF CONTENTS

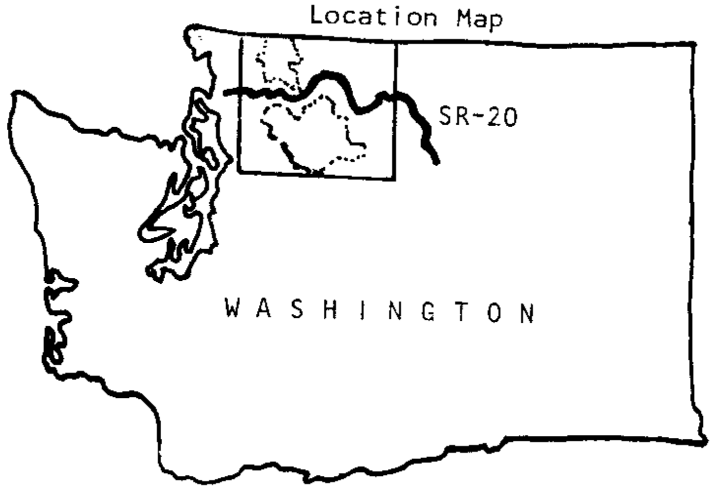
SCHEMATIC MAP OF NORTH CASCADES HIGHWAY
AND
MAIN AVALANCHE GROUPS



KEY: Main Avalanche Groups

1. Powerhouse
2. Newhalem
3. Ruby Mountain
4. Crater Mountain
5. Granite Creek
6. Rainy Lake
7. Liberty Bell
8. Kangaroo Ridge
9. Cutthroat Ridge
10. Delancy Ridge
11. Silver Star

Location Map



ABSTRACT

Snow and avalanche climate varies widely across the parts of the Cascade Mountains spanned by SR-20. Little information is presently available about temperatures and weather patterns over the passes, but a limited amount of snow depth data are available from snow courses. These snow data are presented and analyzed.

Several distinct zones of avalanche activity are identified, extending from Newhalem on the west to Early Winters Creek on the east. These zones each have distinct types of avalanche occurrence and patterns of hazard for the highway. Periods of high hazard for the different zones are not likely to coincide in time. Due to the wilderness nature of the highway and lack of public facilities, the whole highway probably will have to be closed each time hazard develops in any one zone. The most serious danger from avalanches to both the public and to maintenance crews exists in the Liberty Bell and Cutthroat Ridge zones between Washington Pass and Cutthroat Creek.

Although a limited application of avalanche defense structures might be technically possible, especially the selected use of snowsheds, any such measures will be severely limited by the dedication of this part of the Cascade Mountains to recreation and scenic uses.

The recommended method of dealing with avalanche hazards on SR-20 is the operational management of traffic flow, closures and artificial avalanche release by artillery fire. The percentage of time the highway can be kept open in the winter depends on a trade-off with costs and desired level of public safety. In general, a decrease in closure time can be obtained only at the price of increasingly complex and costly avalanche forecasting and control operations. Reducing closure time lower than 15 - 20% does not presently appear feasible. This level of operation should be sought only after several years of experience have been acquired with snow and avalanche conditions.

LIST OF FIGURES

LIST OF TABLES

Introduction

This report covers activities for the eixteen months ending September 1971 under a Washington State Highway Department Contract for Research Project No. Y1301 with the University of Washington. The University research has been executed jointly by the Geophysics Program and the Department of Civil Engineering. Co-Principal Investigators are Dr. Edward R. LaChapelle, Associate Professor of Geophysics, and Dr. Colin B. Brown, Professor of Civil Engineering. The activities described in this Report are for the first year of an intended three-year program of research entitled Methods of Avalanche Control on Washington Mountain Highways. This first year deals with field reconnaissance of avalanche conditions on the North Cascades Highway (SR-20). The field work has been carried out by Dr. LaChapelle and by Mr. Ray Leonard, graduate student in Civil Engineering.

The major result of the first-year field reconnaissance has been the compilation of an Avalanche Atlas for the North Cascades Highway. This Atlas includes annotated maps and photographs, avalanche path profiles, and a detailed description and analysis of each significant avalanche affecting the North Cascades Highway. It is being furnished separately to users of these data and to key recipients of this report. The report itself discusses the overall pattern of avalanches and

---

Cover Photograph: This major avalanche across the North Cascades Highway in Diablo Gorge fell late in January 1971 on the path known as Brown's Slide, designated in the Avalanche Atlas as Newhalem No. 5.

climate along SR-20, general conclusions concerning the nature of the avalanche hazard on this highway and methods for dealing with it. More detailed discussion of specific topics, such as the present operation at Rogers Pass and results of our winter survey or Early Winters Creek, along with the comments of Mr. Peter Schaerer, Swiss engineer and avalanche consultant, are presented in the Appendices.

Summary

General

The North Cascades Highway has an extensive and persistent avalanche hazard problem. No other highway in the United States which normally is open to traffic all winter has avalanche hazard of a similar magnitude. The only similar situation in North America is the Rogers Pass section of the Trans-Canada Highway between Golden and Revelstoke, British Columbia. Because a backlog of operational experience now exists (see Appendix 2) for Rogers Pass, a brief comparison of the two areas is useful.

At Rogers Pass, 74 avalanches affect the highway within a span of 27 miles. Climate and snow conditions vary within this area, but less so than across the Cascades. The Trans-Canada Highway is operated for maximum possible open use of traffic consistent with public safety. The avalanche hazard is managed through a complex combination of defense structures, snow sheds, an avalanche forecasting team with high-altitude observatories and data telemetry, and an artillery program. See Appendix 2 for operational details including costs.

The North Cascades Highway is exposed to 74 avalanche paths over a distance of about 70 miles. Climate, winter snow cover and avalanche behavior vary widely from east to west.

At Rogers Pass the concentration of large and dangerous avalanche paths is higher than on any one part of the North Cascades Highway.

On the other hand, Rogers Pass has nothing comparable to the two miles of almost continuous avalanche along Cutthroat Ridge.

Both highways traverse essentially wilderness terrain, but Rogers Pass has a substantial town on either side at Golden and Revelstoke, plus public facilities and accomodations at the Pass itself. SR-20 has nothing between Diablo and Mazama, and neither of these villages offer any substantial public facilities.

The avalanche hazard on the North Cascades Highway has the following peculiarities:

1) It is spread out over a long distance, with many stretches of hazard-free highway in between the avalanche zones.

2) The variation of climate and snow conditions is sufficiently large that an avalanche zone in one part of the highway may be dangerous at any given time while another zone many miles away is perfectly safe. During a progression of severe winter storms, these conditions can shift rapidly from one zone to another. It will be rare for all zones to be equally hazardous at the same time. Unless the entire highway is closed each time a single zone becomes hazardous, there is a high probability of traffic being stranded or trapped in the middle of the wilderness.

3) As a consequence of 1) and 2), highway closure will invariably be governed by the zone of most frequent hazard.

4) Due to accidents of terrain and highway location, two of the most severe hazard areas, Diablo Gorge and Cutthroat Ridge, are

very poorly disposed for artillery control. In Diablo Gorge the avalanche release zones, far up on the ridge-tops, are either invisible from the highway or poorly located for targeting. In addition, few suitable and accessible sites exist within the Gorge area for gun emplacements.

For Cutthroat Ridge there simply are no safe locations along the highway from which artillery fire can be directed into the release zones. Furthermore, the intricate character of the many release zones would require heavy expenditure of ammunition to insure stabilization. The only suitable gun emplacement for Cutthroat Ridge is a site across the valley of Early Winter Creek, to which a special access road would have to be constructed.

In general the location of this highway is satisfactory in respect to minimizing avalanche hazard. The one exception is the area of Cutthroat Ridge, where location of the highway on the opposite side of Early Winters Creek would have substantially reduced the problems of winter maintenance. Such a location would place the highway under Kangaroo Ridge, where large, well-defined avalanche paths discharge snow to the valley floor perhaps two or three times a winter at most. Unlike Cutthroat Ridge, these paths are readily amenable to artillery control.

The North Cascades Highway has two important problems which must be considered in any plan for management of the avalanche hazard, but which are not technically related to the avalanche problem.

1) From Diablo Dam to Mazama, the highway crosses a wilderness region of the Cascades Mountains. There are no public facilities, no gas stations, no buildings of any kind for winter refuge, no telephones, or other communications. Presumably construction of a winter maintenance camp would remedy this situation in small measure, but would not solve the lack of public facilities. Motorists suffering simple breakdowns in mid-winter, let alone involvement with avalanches, have little recourse save the chance assistance from passing vehicles. In the event of an avalanche accident of any kind, rescue parties would have to be summoned from Newhalem, Diablo, Mazama or Winthrop, possibly at the cost of several hours delay. Any operational plans for winter use of this highway will be severely conditioned by this isolation.

2) The highway traverses the Ross Lake National Recreation Area and parts of the Mt. Baker, Wenatchee and Okanogan National Forests dedicated to recreational and scenic use. The highway itself is designated as a scenic highway. Any plans for large-scale disruptions of or intrusions on the landscape are likely to be vigorously opposed by both the Federal agencies administering the land and by conservation groups. This places an immediate and severe limitation on possible deployment of avalanche defense structures as a protective measure. Quite aside from the economic question of whether such structures are feasible, the environmental considerations may well limit or prohibit off-highway construction before the cost-benefit question ever arises.

Conclusions

It is assumed that the ultimate decision of whether or not to maintain winter use of SR-20 when it opens, or at some more distant time, will be governed in part by factors of economics, traffic volume and public demand which lie outside the scope of this study. With this limitation in mind, we now make the following recommendations:

1) The primary means of dealing with avalanche hazard on SR-20 should be by closures plus artillery fire.

2) A full-scale winter use of this highway should be delayed until sufficient experience has been gained with snow and avalanche conditions to assure reliable avalanche forecasting. We envision a progression through Options 2 through 4 over a period of perhaps five years (see pages 46-50).

3) The public should be widely appraised of the winter operating problems on this highway from the start, with explicit emphasis on the fact that a substantial percentage of closure time is going to be a fact of winter life in the foreseeable future.

Winter Climate of the North Cascades Highway

The North Cascades Highway spans a wide range of climate zones between Newhalem on the west and Mazama on the east. These variations are related to both altitude (500 foot elevation at Newhalem to 5500 feet at Washington Pass) and to the very marked transition from a maritime climate on the west side of the Cascade Mountains to a semi-continental climate on the east. This climate pattern profoundly affects the persistence, maximum depth and character of the winter snow cover in different parts of the highway, and as a consequence the number and character of snow avalanches.

West of approximately Ruby Creek, snowfall, temperature and consequent vegetation patterns strongly reflect conditions characteristic of the western slopes of the Cascade Mountains. Winter precipitation is frequent and heavy. It falls predominantly as snow above about 5000 foot elevation, but periods of rain can occur at any time during the year below this elevation. Below about 3000-3500 feet, the snow cover tends to vary widely in depth from year to year, being governed largely by fluctuating freezing levels which determine whether a given winter storm will bring rain or snow.

The Granite Creek valley appears to mark a transition zone in climate, with a trend toward less winter rain and colder conditions. The alpine and sub-alpine vegetation patterns along the mountains flanking the east side of Granite Creek exhibit a definite climate difference from the mountains farther to the west.

East of Rainy Pass and especially east of Washington Pass, the transition to east-slope climate characteristic of the Methow Valley becomes more pronounced. The alpine vegetation becomes much more sparse above timberline and the evidence of a drier climate becomes progressively more clear at lower elevations. Larch, a mountain tree type unknown on the western slopes of the Cascades, first appears in the vicinity of Washington Pass. On the descent down Early Winters Creek, alder as a slide path climax species is abruptly replaced by aspen a short distance east of Cutthroat Creek. Winter temperatures tend to be much lower, the high altitude snow cover shallower, and the low-altitude snow cover persists much longer. Winter rain is much less frequent.

Practically, the climate, snow and avalanche conditions in Diablo Gorge are well known from many years of experience by Seattle City Light, first through operation of a railroad in the Gorge and in latter years maintenance of the western end of SR-20, which was completed through the Gorge in 1957. The written records, however, are scanty. In general, snow conditions on this section of the highway tend to be more persistent than those at comparable elevations (500 - 900 feet) along other highways in the western Cascade Mountains, owing to the prevailing cold winds which often descend the Gorge from the interior region around Ross Lake and eastward.

The only available long-term climatological record is that from Diablo Dam, elevation 896 feet. This record dates back for 42 years, although the early part is spotty. Reliable snow data are available for

18 of the past 20 years, with little information dating prior to 1951. The persistence of snow on the ground at Diablo is shown for this period of record in Fig. 1. The wide variations in snow cover from year to year are obvious. The mean length of time on the ground for a persistent snow cover is 1.6 months.

Maintenance experience on the section of SR-20 between Diablo Dam and Thunder Arm, now accumulated for nearly a decade, indicates that the snow cover along this section of the highway typically persists from December through March. In the light of the Diablo snow cover data shown in Fig. 1, this experience presumably refers to the higher elevations up to 1500 feet on this section of the highway. At the elevations involved, the depth of snow on the ground and its persistence can be expected to vary widely from year to year according to the freezing level of winter storms.

East of Thunder Arm no climatological records are available until the Methow Valley is reached on the east side of the Cascade Mountains. Prevailing temperatures can be estimated only indirectly. As noted above, the Methow Valley data and deductions from character of vegetation and snow cover suggest that temperatures run substantially colder east of Rainy Pass than they do to the west. Observations now under way as part of the second year of this research project include a thermograph record for Washington Pass and Cutthroat Creek. Rather than offer guesses about the temperature ranges at this time, we will defer further discussion until these actual temperature records are available for presentation in the next report.

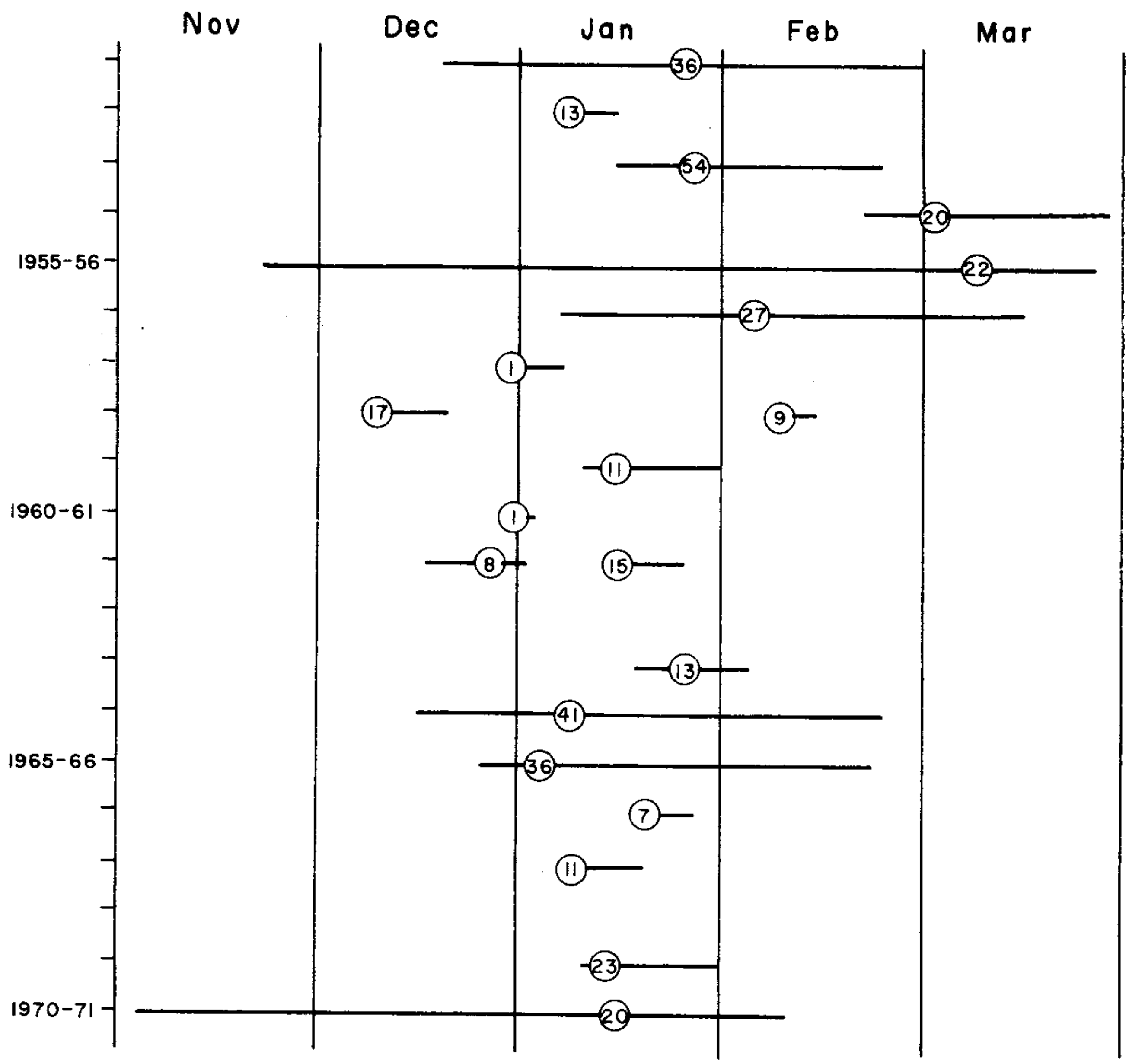


FIG. 1 DIABLO DAM. PERSISTENCE OF SNOW COVER ON THE GROUND FOR 18 YEARS OF RECORD. NUMBERS IN CIRCLES GIVE THE MAXIMUM WINTER SNOW DEPTH; POSITIONS OF THE CIRCLES GIVE DATE OF OCCURRENCE.

A limited amount of snow depth records between Diablo Townsite and the Methow Valley are available from snow course measurements. The only snow course directly adjacent to the highway right-of-way is the one at Rainy Pass (4780 feet), where records of April 1st snow depths and water content have been obtained since 1928 and continuously since 1936 by Soil Conservation Service Cooperative Snow Surveys. These data are plotted in Fig. 2. Yearly fluctuations in total snow depth are wide, indicating that the cost of winter snow removal in this area will vary widely and unpredictably from year to year.

Three other cooperative snow courses in the North Cascades have been selected which appear to be reasonably representative of snow conditions which may be expected at higher elevations along the North Cascades Highway. All have over 20 years of record. These three snow courses are:

Harts Pass (6500 feet), located 14 miles NNE of Rainy Pass.

Dagger Lake (5200 feet), located 5 miles SE of Rainy Pass.

Thunder Basin (4200 feet), located 14 miles ENE of Rainy Pass.

Available records of April 1st snow depth and water content for these three snow courses are given in Figs. 3, 4, and 5. Like Rainy Pass, wide snow depth variations from year to year are notable at all three sites. Climatological trends over the period of record become more apparent when these data in Figs. 2 through 5 are smoothed through plotting as 10-year moving averages. Such plots are given in Fig. 6, where at higher altitudes light snow years in the 1940's are followed by a peak

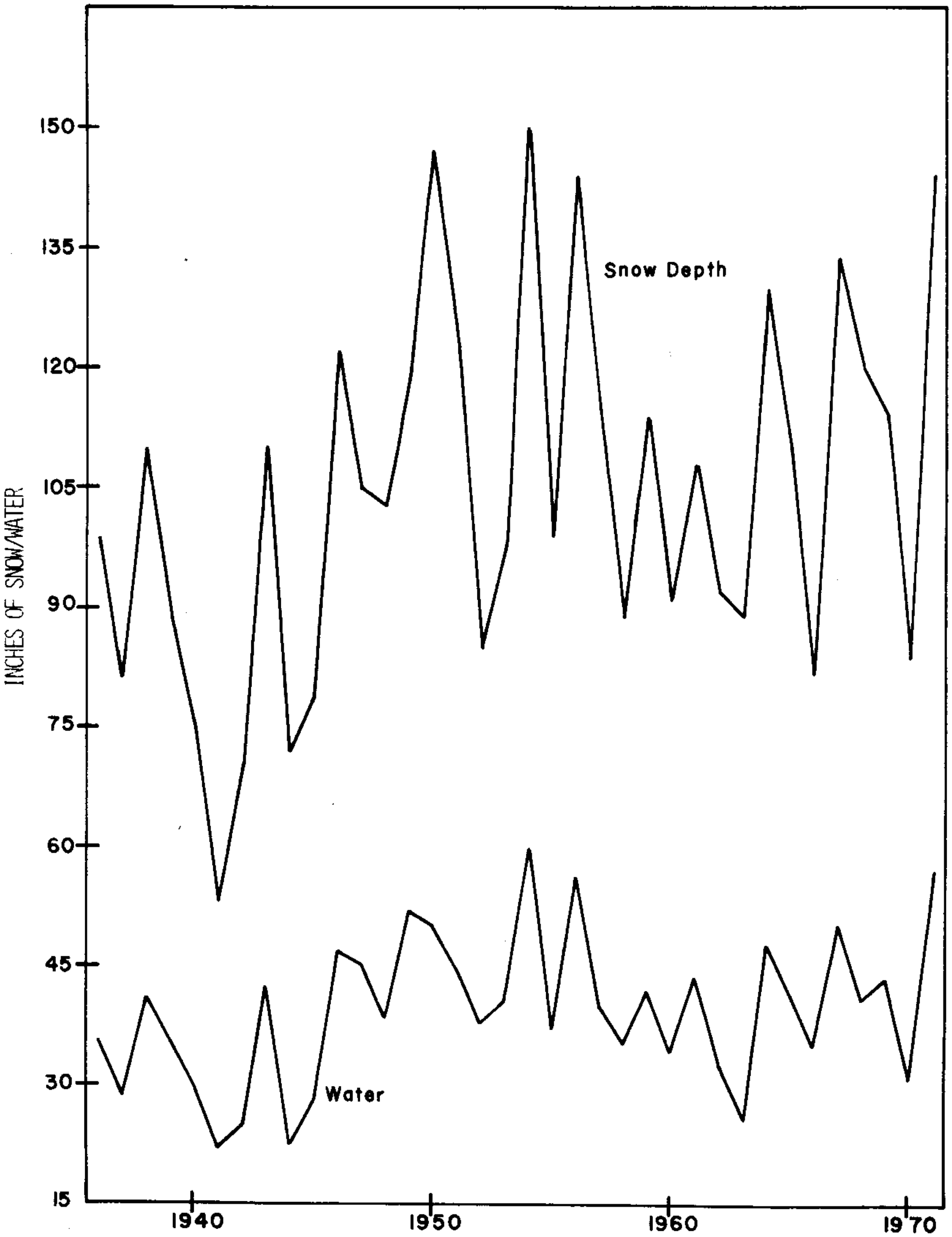


FIG. 2 RAINY PASS. APRIL 1ST SNOW DEPTH AND WATER EQUIVALENT FOR CONTINUOUS PERIOD OF RECORD BEGINNING 1936. ELEVATION 4780 FT.

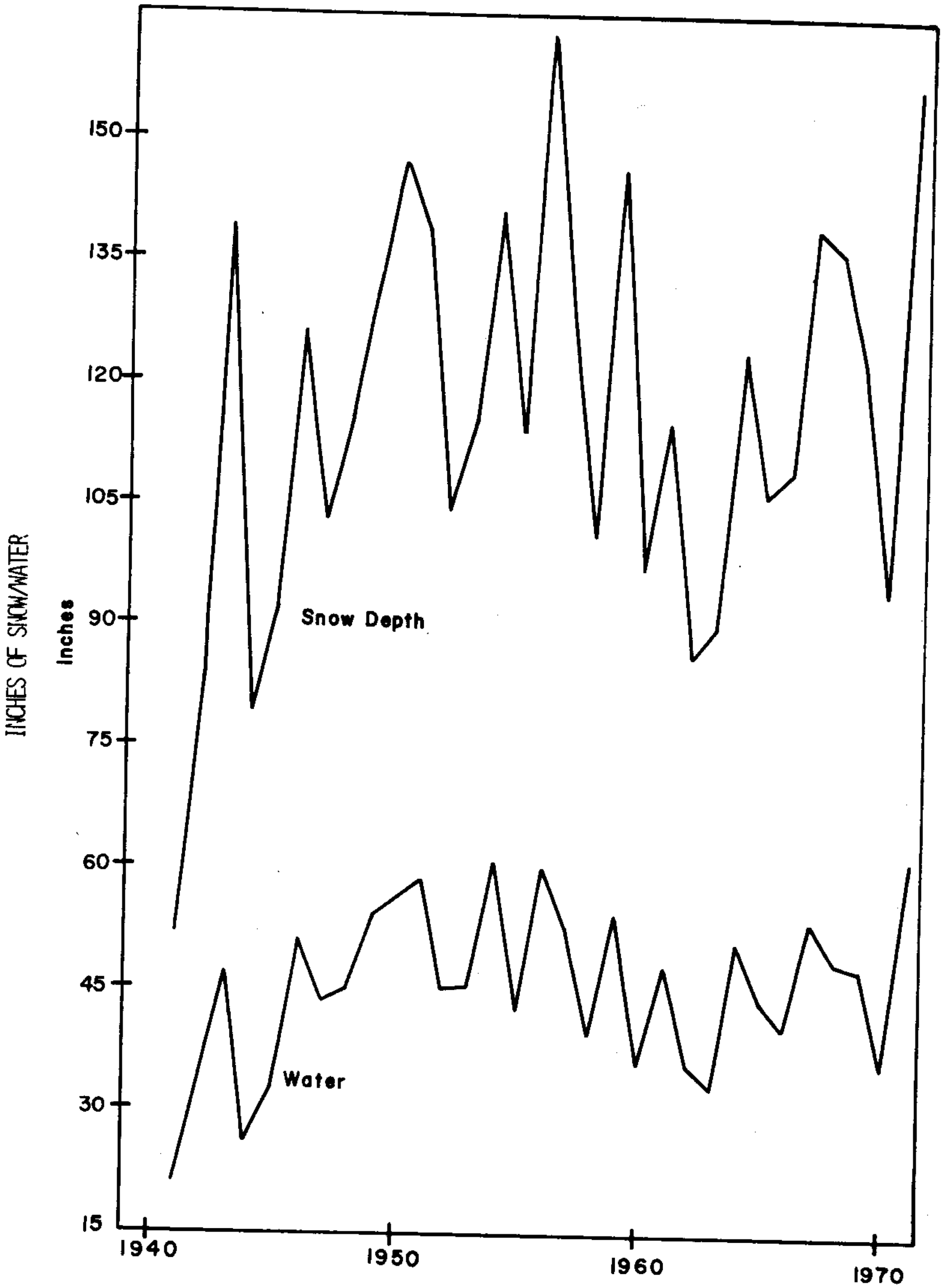


FIG. 3 HARTS PASS. APRIL 1ST SNOW DEPTH AND WATER EQUIVALENT FOR CONTINUOUS PERIOD OF RECORD BEGINNING 1941. ELEVATION 6500 FT.

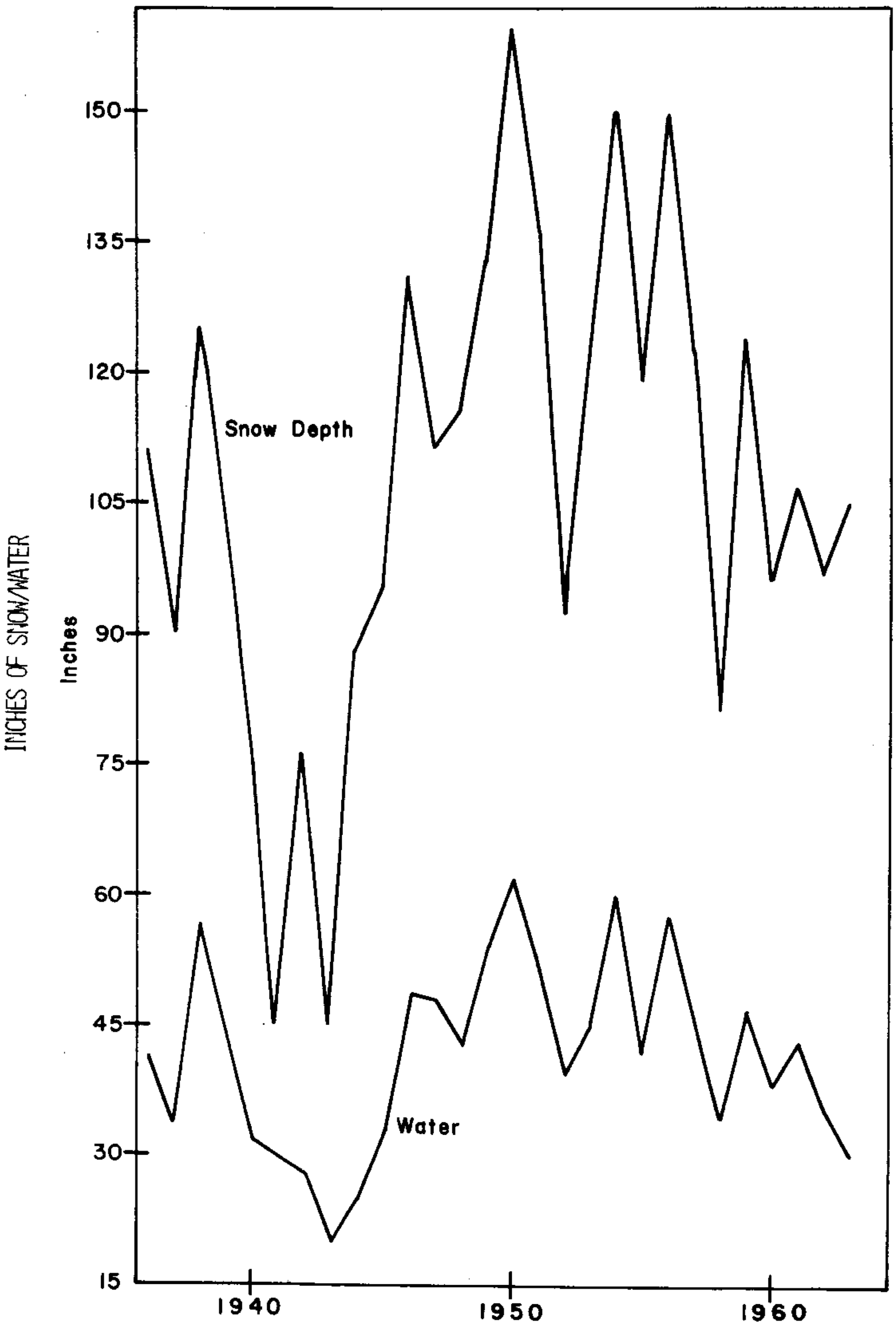


FIG. 4 DAGGER LAKE. APRIL 1ST SNOW DEPTH AND WATER EQUIVALENT FOR CONTINUOUS PERIOD OF RECORD BEGINNING 1936. ELEVATION 5200 FT.

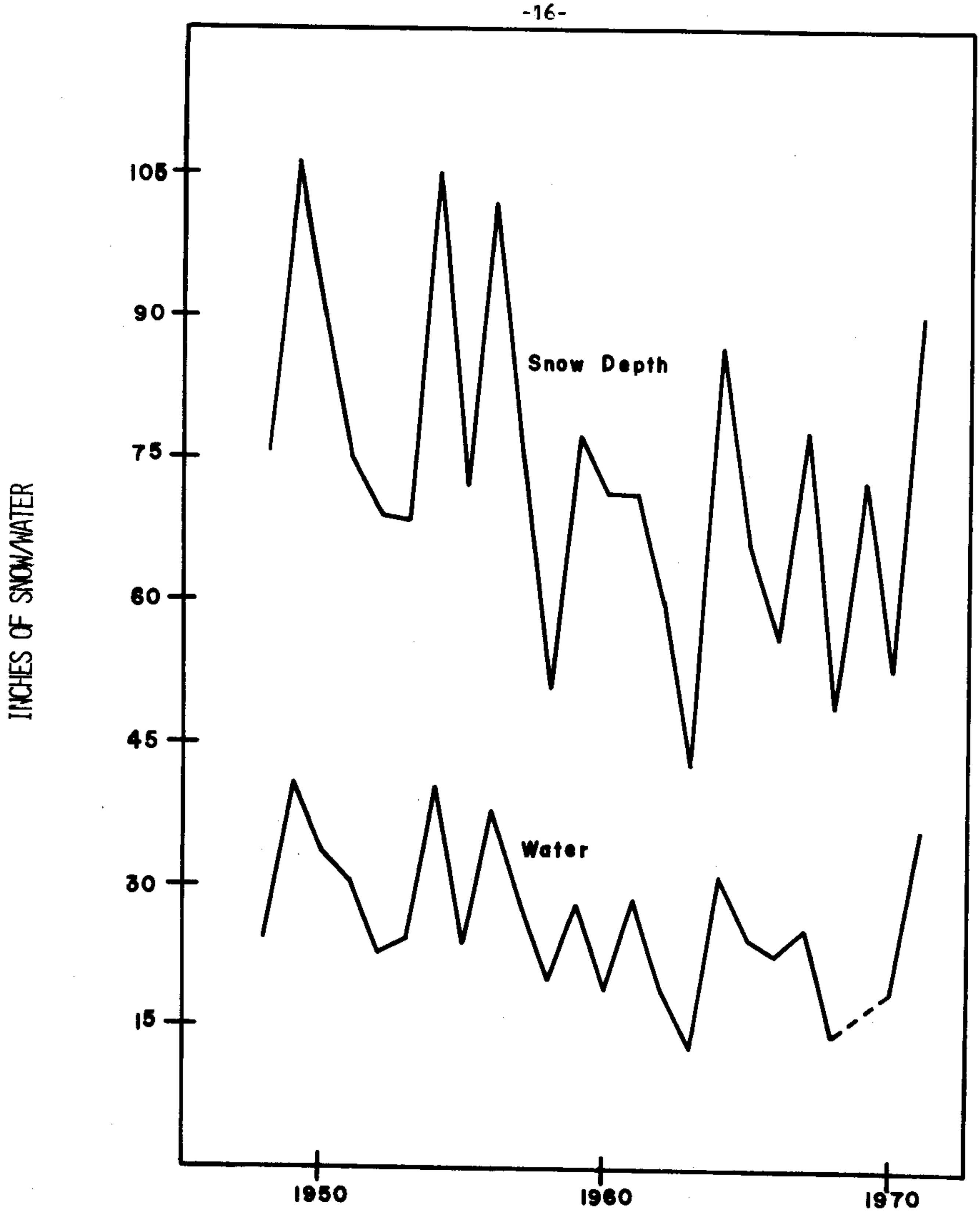


FIG. 5 THUNDER BASIN. APRIL 1ST SNOW DEPTH AND WATER EQUIVALENT FOR CONTINUOUS PERIOD OF RECORD BEGINNING 1948. ELEVATION 4200 FT.

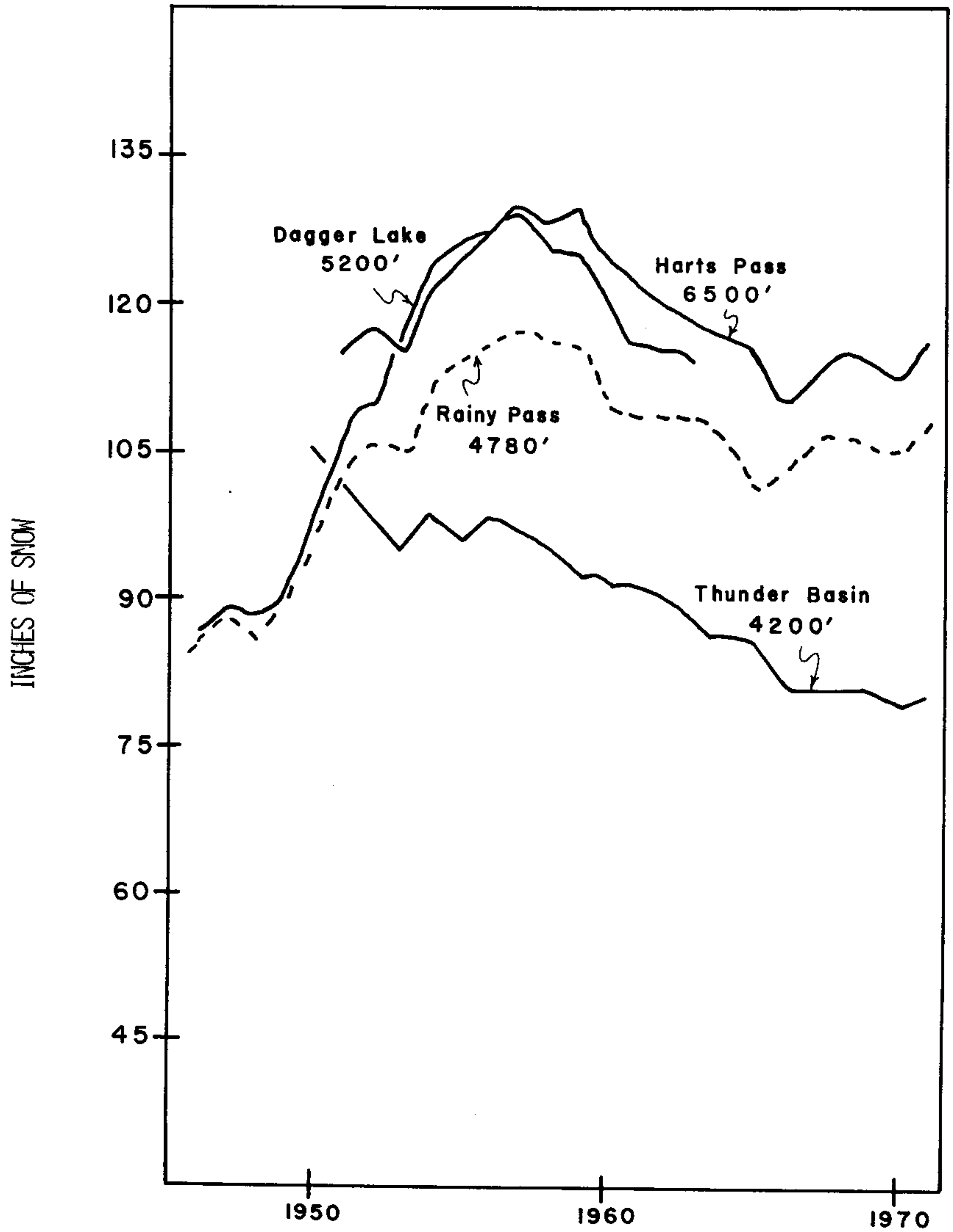


FIG. 6 TEN-YEAR RUNNING MEANS FOR APRIL 1ST SNOW DEPTH DATA PRESENTED IN FIGS. 2 - 5.

of snow cover depths in the late 1950's and a subsequent moderate decline in the 1960's. The Thunder Basin snow course, the lowest of the four, shows a different pattern of steady decline in snow cover thickness over the period of record.

The available 39 years of April 1st snow depth record for Rainy Pass is sorted in Fig. 7 according to the frequency of occurrence of different snow depths. For purposes of highway maintenance, this usefully illustrates that April 1st (and approximately maximum) snow depths ranging from 80 to 120 inches are most likely to be encountered at Rainy Pass, with a distinct peak from 80 to 90 inches.

A program of snow observations conducted as part of this research study by Mr. Len Miller of Mazama has produced additional data about snow depths east of Washington Pass for the winter 1970-71. Snow stakes were located along the highway between Mazama and Washington Pass at 500 foot intervals of elevations. These stakes were visited several times during the winter and snow depths recorded. Data from these stakes are given in Table I, where the consistent dependence of snow depth on elevation is readily apparent. Miller has also furnished similar data (Table II) for a series of snow stakes at different elevations on Sandy Butte from an independent survey he carried out for a proposed ski development. Sandy Butte is an outlying peak on the east side of the Cascade Mountains immediately above the confluence of Early Winters Creek and the Methow River. Its easterly position places it in a

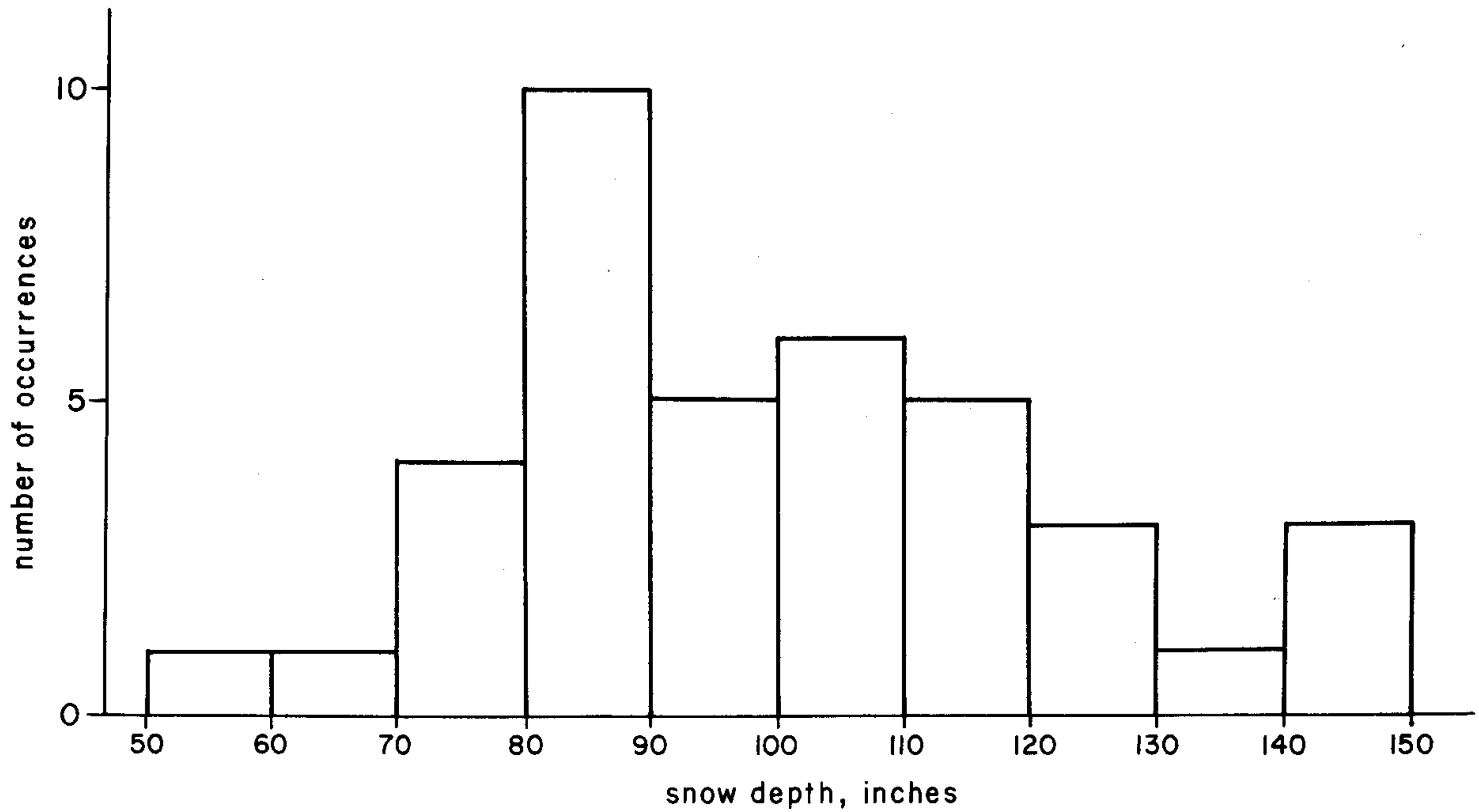


FIG. 7 RAINY PASS. FREQUENCY OF APRIL 1ST SNOW DEPTHS BY INTERVALS OF 10 INCHES FOR 39 YEARS OF RECORD OVER THE PERIOD 1928 - 1970.

distinctly lighter snowfall zone for given elevations than is found around Washington Pass. Snow depth is much less clearly a function of elevation on Sandy Butte.

Since the snowfall climate east of Rainy Pass is especially important to evaluating avalanche hazards on the North Cascades Highway, a program is now being planned for the winter of 1971-72 to collect weather, snow and avalanche data along Early Winters Creek and into Washington Pass. A wind and temperature recorder will be installed at the Pass. An observer will be in residence at Cutthroat Creek during most of the time December through March to maintain daily records for later comparison with general storm patterns over the Cascades. Washington Pass will be visited approximately once each week to check snow conditions. Snow stakes distributed along the highway will again be observed, but this year at more frequent intervals than last. The eventual aim of this observation program is to produce useful climatological data for the area as a background for planning avalanche forecasting and control measures.

Some qualitative information about general snow and avalanche conditions along Early Winters Creek has been obtained from Mr. Jack Wilson of Mazama, who has had many years experience trapping in this area. See Appendix 3.

Our inspection trips to the North Cascades Highway have produced the following additional information about extent of persistent snow on the highway:

The aerial reconnaissance of 24 May 1970 found the highway snow-free except for a few patches in Washington Pass and avalanche debris under Liberty Bell Mountain and along Cutthroat Ridge. The avalanche snow under Liberty Bell persisted until late September.

The aerial photography flight of 28 January 1971 found snow on the highway from Newhalem to Mazama, except where plows had been at work in Diablo Gorge.

A ground reconnaissance on 12 April 1971 found the highway snow-covered from Mazama to Washington Pass, with a maximum depth of around 120 inches at the pass.

On 9 May 1971 another aerial reconnaissance found snow on the highway from Silver Star Creek on the east to lower Granite Creek (approximately four miles above junction with Canyon Creek) on the west.

Pictures taken on the aerial photography flight of 27 May 1971 show snow on the highway extending from Lone Fir Campground on the east to the 3700 foot elevation along Granite Creek on the west.

The snow cover in Washington Pass did not disappear in 1971 until early July.

TABLE I

EARLY WINTERS CREEK SNOW STAKES

STAKE	ELEVATION	DATE (1971)												
		10/20	10/24	11/7	11/8	11/19	11/28	12/25	1/12	1/16	1/28	2/18	3/31	4/12
1	3000						20	35.5	37	63	128	48	55	47
2	3500		1			2.5	23.5	43	45	72	118	69	71	ND
3	4000		4		2	6	27.5	47	61	84	138	95	98.5	91
4	4500		7		2	12	35.5	55	65	70	ND	112	89	102
5	5000	0.5	8	Tr.	4	10	24.5	ND	ND	ND	ND	ND	ND	117
6	5500	2	12	8	12	20	41	ND	ND	ND	120	ND	ND	118

Snow depths in inches.

Tr. = Trace of snow.

ND = No data due to either destroyed stake or inacessibility.

TABLE II

SANDY BUTTE SNOW STAKES

STAKE	ELEVATION	DATE (1971)							
		11/19	12/4	12/10	12/22	1/7	1/29	2/17	3/26
1	2300	0	17	25	29	35	44	36	49
2	2300	---	---	---	lost stake	---	---	---	---
3	3000	0	20	30	32	35	54	42	58
4	3500	trace	23	30	34	39	51	38	56
5	4000	2.5	25	34	38	44	55	48	66
6	4500	2.5	N/A	-	36	-	56	42	-

Snow depths in inches.

N/A = Not available.

Avalanche Conditions

Avalanche hazards exist on the North Cascades Highway from Newhalem at 500' elevation on the west to the 3200' level on the Early Winters Creek on the east. Within this stretch of highway we have identified 74 separate avalanche paths which presently cross the highway. In addition, there are another 18 avalanche paths which do not presently cross the highway by evidence of activity in recent years but which potentially may do so in the event of severe avalanche conditions. Each of these 92 avalanche paths are photographed, mapped and described in detail in the Avalanche Atlas.

Distinctions of terrain and climate readily divide the avalanches on the North Cascades Highway into separate zones. Avalanches within each zone generally react in similar fashion to winter snow and storm conditions but from zone to zone the behavior of the avalanches, the modes of forecasting, and methods of control may differ widely at any given time. The principal zones are as follows:

1. The Diablo Gorge avalanches, designated as Powerhouse and Newhalem avalanche paths in the Atlas.

2. The Ruby Mountain avalanches which fall from the northern flanks of Ruby Mountain where the highway skirts Skagit River, Ruby Arm and Ruby Creek.

3. Crater Mountain avalanches.

4. The Beebe Mountain avalanche, an isolated but large avalanche path opposite Crater Mountain.

5. The Granite Creek avalanches falling from both sides of the Granite Creek valley but predominantly from the east side of the valley.

6. The Whistler Mountain, Helicopter Slide and Rainy Lake avalanches located between Rainy and Washington Passes.

7. The Liberty Bell avalanches, including Spire Gulch, falling from the northeast flank of Liberty Bell Mountain and Early Winter Spires.

8. The Kangaroo avalanches falling westward from Kangaroo Ridge.

9. The Cutthroat Ridge avalanches falling eastward from the crest of Cutthroat Ridge.

10. The Delancy Ridge avalanches falling predominantly in a southern direction from Delancy Ridge to Early Winters Creek.

11. The Silver Star avalanches falling from the northern flank of Silver Star Mountain and the northwestern flank of Vasiliki Ridge.

These avalanche zones are discussed separately below.

Diablo Gorge

The avalanches in Diablo Gorge are readily divided into two distinct types. One of these types is the very short avalanche paths falling from the steep slopes and cliffs immediately above the highway. Examples are the four Powerhouse slides and Newhalem 1a, 2a, and 4. The other types are the large avalanches which originate at high elevations to the north of the Gorge, with starting zones in the range of 4 to 5,000 feet or higher. These latter avalanches descend to the highway level through long and sometimes winding stream channels and generally reach the highway as wet snow avalanches. Their release zones are all facing toward the south or southeast. A single exception in this area is Newhalem No. 10 which falls from a north-facing slope under point 5888 into Gorge Lake and presents potential wind blast damage to the highway area across the Lake. The small, low-altitude avalanches generally present a problem only during periods of unusually heavy snow at low elevations and usually can be expected to run as a result of such snow fall followed by rain. Newhalem No. 4 falls from a short but extremely steep slope immediately above the road and appears to present the hazard of rather frequent small new-snow avalanches following heavy snowfall low in the Gorge.

The large avalanches are generated by snow conditions high above the Gorge and in many cases the release zones are not readily visible from the highway. In most of these paths dry snow avalanching is probably frequent at upper elevations but very seldom descends far enough down the stream channels to pose a problem to the highway. Past experience in this area has shown that these large avalanches generally run when rain at higher elevation follows a heavy snow fall or when a general spring thaw sets in. On these occasions damp or wet slab avalanches are released over large areas and in sufficient volume to descend to the highway, often crossing it to reach the Skagit River or Gorge Lake. An excellent example of such slide activity occurred in January of 1971 when heavy falls of snow were followed by rising temperatures and rain at higher elevations resulting in extensive release of wet avalanches throughout the western Cascades. A number of large wet avalanches descended the large Newhalem slide paths this time and blocked the highway in Diablo Gorge. (See cover photo.)

Due to difficulty of access to the release zones or even to representative snow observation sites, it appears that the hazard from these slide paths will necessarily be forecast by strictly meteorological methods. The accuracy of such forecasts can be substantially improved if air temperature telemetry is established to provide air temperature data from approximately the 3 and 5,000 foot levels in this area. Newhalem No. 10, due to its northerly orientation, will react to snow and weather conditions in a different fashion than the rest of the large Newhalem slides and normally can be expected to slide at different times.

In general, the avalanche paths in Diablo Gorge present a rather serious avalanche hazard to the highway from time to time, but a hazard which in most cases can be clearly anticipated and identified.

Ruby Mountain

The Ruby Mountain avalanches all fall from northerly slopes originating in open basins or gulleys well below timberline with the exception of Ruby Mountain No. 5, the largest of these avalanche paths whose release zone lies in a large basin above timberline under the northeast ridge of Ruby Mountain. Progressing eastward along the highway the frequency of avalanche activity increases for the Ruby Mountain paths. Ruby Mountain No. 10 is a path which apparently is active at least annually and possibly more often. Numerous other avalanches fall from the northern flanks of

Ruby Mountain but the ones identified in the Atlas are the only ones deemed to present any serious problems for the highway. For instance, the basin at the head of Lillian Creek produces many avalanches but the general configuration of terrain is such that there is very little likelihood that sliding snow will reach all the way to the level of the highway. Many of the Ruby Mountain avalanches probably will reach the highway only at infrequent intervals.

Once the planned Park Service tram to the top of Ruby Mountain has been completed and winter access to this elevation is available, excellent snow and weather data can be obtained from the upper slopes of Ruby Mountain as an aid to forecasting avalanche occurrence on these paths. Should it become necessary to maintain the North Cascades Highway in the winter time, the Park Service facility at the top of Ruby Mountain will in fact become a key observation station in the avalanche forecasting network for this highway.

<u>Crater Mountain</u>

Several large avalanches fall from the 4 to 5,000 foot level on the southern flanks of Crater Mountain. Two of these just west of the Canyon Creek-Granite Creek junction show evidence of having reached as far as Ruby Creek in the past and are of sufficiently large size that even a very small over-run of the existing path will bring snow across Ruby Creek and onto the highway, which here lies very close to the Creek and to the valley bottom. Under normal conditions these avalanches will not pose any particular problem to highway maintenance or safety.

Beebe Mountain

A single large avalanche falls from the north basin of point 6285, descends by a long and winding channel to Ruby Creek to reach the valley floor between the two Crater Mountain avalanches described previously, but from the opposite side of the valley. There is no way from the highway to identify this as an avalanche path except by close examination of damage to vegetation along the stream channel. The release zone far above on the flank of Beebe Mountain is invisible from the highway. Normally, avalanching on this path is confined to the upper reaches and probably in most years does not descend below the 3,000 foot level. Unusually large avalanches can follow the stream channel all the way to the highway, as one did in January 1971. Like the Crater Mountain avalanches, this one normally will not pose any particular problem for the highway.

Granite Creek

Three major avalanches have been identified on the west side of Granite Creek Valley. All three of these exhibit evidence of major avalanche occurrence at some time in the past but no evidence of frequent recurrence. Normally these will pose little threat to the highway except in exceptional avalanche conditions, in which case very large amounts of snow laden with timber debris can be expected to reach the highway. On the east side of the valley, avalanche paths numbers 2, 4, and 6 through 15 all have a generally similar character, differing mostly only in size and area of release zone. All of these paths fall in a generally westerly direction and the release zones face to the west or southwest with avalanche activity frequent in the upper elevations generally above 4 to 5,000 feet each winter. The larger avalanches generated on these paths descend long and sometimes winding stream channels to reach the valley floor and the highway. Some of the paths, for example numbers 2, 4, and to some degree 7, have multiple release zones with the possibility of more than one avalanche originating in a short period of time. Paths numbers 11, 12, 14 and 15 do not presently show a trimline in the timber which reaches all the way to the highway. However, the timber screen between the present boundary of the avalanche paths and the highway is very thin and a very small overrun of the path by any of these avalanches could deposit snow (and timber) on the highway. In normal years avalanche activity can be expected on many of these paths, but the probability of more than one or two of them reaching the highway in any given year appears to be small. There may very well be years when none of them brings snow to the highway or to the valley floor. On the other hand, winter seasons of exceptionally heavy avalanche activity could produce a large number of avalanches reaching the highway from the east side of Granite Creek. Such avalanches are apt to be heavily laden with timber debris and consequently a problem for road clearing. This would be especially true of Granite Creek No. 7 where the highway intersects the talus cone of the avalanche path with a deep cut. Any large avalanches falling on this path, as vegetation evidence shows they have done in the past, would fill this cut to a depth as much as 50 feet with snow and timber debris.

Although the average hazard from the Granite Creek avalanches is relatively low due to the low frequency of avalanches large enough to reach the highway, this area nevertheless may prove to be a problem for winter operations of the North Cascades Highway. The reason for this is the expected difficulty in forecasting the hazard to the highway from these avalanches. Such forecasting is difficult on two counts. One of them is the transitional character of the climate in this area and its consequent effect on avalanche formation which cannot be clearly established until after numerous years of record. The other reason is the character of the terrain and particularly the long outrun paths of the avalanches which make it difficult to determine how far the avalanches will fall and whether in any given instance they will in fact reach the highway. Presumably highway closures due to hazards in this area initially would reflect caution. With developing experience it may be possible to keep closures due to the hazard along Granite Creek to a low minimum. A further handicap to the forecasting is the difficulty of obtaining representative snow data from the elevation of the release zone.

There appears to be some possible hazard on lower Granite Creek from the very steep cut banks above the highway shortly after it turns up Granite Creek from Ruby Creek. In the event of substantial heavy snow falls at this elevation, or snow falls followed by rain, numerous small slides can be expected to reach the highway from these cutbanks, possibly in some instances triggered by plowing operations. There is a particularly high cutbank at approximately station 920 which may prove a recurrent problem in this respect. This is the same cutbank which experienced a mud slide in the spring of 1971. Also in this lower area of Granite Creek is a slide identified on the map as Granite Creek Shoulder, a narrow tongue which descends through cliff banks to the Creek on the opposite side of the canyon from the highway. Normally this avalanche should present no problem, but there is a possibility that an exceptionally large amount of snow could cross the Creek and reach the highway on the opposite side.

Whistler Mountain

West of Rainy Pass the highway is exposed to avalanche paths that in almost all cases can be expected to deliver damp or wet snow avalanche debris onto the highway. East of Rainy Pass, descending toward Bridge Creek at an altitude of 4600 feet, the highway reaches for the first time an area of large avalanches at an altitude and in a climate where large dry snow avalanches may be expected. The Whistler Mountain avalanche is a major path which falls directly to the highway across a short transition zone and from which avalanches of substantial size reaching the highway may be expected as often as annually. The large avalanche which fell on this path in January of 1971 is a good example of the dry snow type of avalanche with high flow velocity accompanied in many cases by a destructive wind blast. The general destruction or damage to vegetation occurred over a broad front rather than confined to channels as common with wet snow.

The Whistler Shoulder and Whistler Shoulder East paths consist of steep, relatively open slopes dropping directly to the highway without any appreciable transition zone of gentler slopes. Especially from Whistler Shoulder numerous small avalanches can be expected with each heavy snow storm, bringing generally dry snow onto the highway at frequent intervals.

Across from the Whistler Mountain avalanche four small paths fall from the peak just east of Rainy Lake. These are designated the Rainy Lake avalanches. Only one of them presently shows a timber trimline which intersects the highway. Activity on this Rainy Lake No. 1 is probably low.

Turning up State Creek the highway passes across the outrun of the large Helicopter Slide, so named for the Helicopter Meadows in the adjacent valley floor. Under normal circumstances this avalanche should be no problem for highway maintenance, but a very clear timber trimline indicates that in the past snow has descended to State Creek, crossed the valley floor and ascended the other side well beyond the present highway location. Our observations in 1971 found that a large avalanche descended the Helicopter path, crossed State Creek in this fashion but lacked size and momentum to ascend all the way up the opposite slope to the highway.

Liberty Bell

Crossing Washington Pass to the east the highway enters a zone of especially serious avalanche hazard. This zone encompasses the stretch of highway from just east of Washington Pass to Cutthroat Creek. It can safely be anticipated that any attempt to maintain winter use of the North Cascade Highway will encounter the most serious and persistent avalanche problems along this section between Washington Pass and Cutthroat Creek. Both the random hazard to moving traffic and especially the hazard to road clearing operation will be severe during and after winter storms in this area.

Five clearly-defined avalanches descend from the northeast flank of Liberty Bell Mountain and Early Winter Spires. Three of these avalanche paths are the type which can be expected to produce sliding snow with almost every snow storm due to the extremely steep character of the release zones among the cliffs of Liberty Bell Mountain. One of them, Liberty Bell No. 3, consistently crosses both legs of the switchback at the head of Early Winters Creek and it is possible that the others may do the same under conditions of exceptionally heavy avalanching. One of these paths, No. 5, appears to be very infrequent in activity at the highway level, although smaller avalanching undoubtedly occurs on the upper part of the path as frequently as it does on the other ones which consistently reach the highway. Small embankment slides from the steep rock cut and cliffs immediately above the highway are also possible under Liberty Bell Mountain.

Southeast of Early Winter Spires is Spire Gulch, a large basin which is the release zone of numerous avalanches, some of which run as far as the upper part of early Winter Creek and onto the hairpin of the highway switchback. Sliding snow here probably will reach the highway annually and it is possible on some occasions for a large dry snow avalanche to cover the entire hairpin of the switchback across a broad front. Like the Cutthroat Ridge slides to be discussed below, those on Liberty Bell Mountain are probably amenable to forecasting on the basis of snow data collected in the vicinity of Washington Pass, plus wind and temperature data from an adjacent ridge top. Such forecasting data probably will also be applicable to the Whistler Mountain area, although the degree of climactic transition in this short distance east of Whistler Mountain has yet to be established.

Kangaroo

On the east side of Early Winters Creek, just below Washington Pass, a series of large avalanches falls from the shoulder and craggy flanks of Kangaroo Ridge. These are labelled the Kangaroo slides in the Avalanche Atlas. Only one of them directly affects the present highway grade - Kangaroo No. 6. Normally, snow falling in this avalanche path will be deflected downstream by the high fill on the lower part of the highway switchback. Nevertheless, it is possible for exceptionally large avalanches to override this deflecting fill and deposit snow on the highway. This would be especially true of dry snow avalanches moving at high velocity. Any traffic on the highway at this point when an avalanche falls with high velocity and dangerous wind blast would be severely exposed at this point to such wind blast. The other Kangaroo paths are not expected to affect the highway in any circumstances but are noted here because they are referred to again in the discussion and recommendations below.

Cutthroat Ridge

Beginning on the steep slopes immediately under point 5620, the proposed site for the Forest Service Visitors Center, and extending down-valley for over two miles along the eastern flanks of Cutthroat Ridge, an almost continuous series of avalanches descends from a complex system of rock cliffs, gulleys and couloirs. This unquestionably is the most dangerous avalanche problem on the North Cascade Highway. The annotated map and photographs in the Avalanche Atlas show eleven clearly identifiable avalanche paths in this area. These are the individual paths delineated by the terrain on which avalanches can be expected to fall in reasonably orderly fashion if conditions are not too severe. However, in winters of vigorous avalanche activity in this area (the winter of 1970-71 was an excellent example) this entire stretch of highway is inundated by virtually a continuous avalanche. The distinctions of boundary from one avalanche path to another are obscured by overlap as smaller areas of falling snow descend between those indicated on the map.

A field inspection in the spring of 1971 showed a continuous coverage of avalanche debris from just below point 5620 to approximately the site of Cutthroat Ridge No. 4. Below this there were gaps of uncovered highway between the lower avalanches on Cutthroat Ridge. The field evidence at that time indicated frequent and repeated avalanching all along this section of the highway and in fact wet spring slides were observed descending in April at the time the inspection was made. Avalanche forecasting for the Cutthroat Ridge area should be relatively easy for avalanches of some kind can be expected to fall with almost every snow storm. This pattern of avalanching is confirmed by earlier experience in this area (see Appendix 3). Prior to the construction of the highway, many of the Cutthroat Ridge avalanches descended farther into the valley toward Early Winters Creek and spread out on talus cones. The highway now provides an excellent catchment barrier for these avalanches and much of the snow which earlier descended into the valley is now caught on the highway and held there as steep debris deposits.

While the larger avalanches in this area, especially those numbered in the inventory, originate in small gulleys at the head of rock couloirs underneath the crest of the ridge where they are often triggered by the fall of huge cornices, many of the lower slopes immediately above the highway are also steep enough to slide. This raises a particularly severe problem for snow clearing operations because unless the stability of snow can be assured by artificial control measures or adequate waiting time, there exists a very high probability that the mechanical action of snow removal by snow plows or tractors will trigger additional avalanches. It is difficult to see how road clearing operations in the winter can be conducted here without extremely prudent safeguards for the maintenance crew which will be reflected in frequent and extended road closures.

The avalanche problems between Cutthroat Creek and Washington Pass are deemed sufficiently serious that in the second winter (1971-72) of this research project an observer will be stationed during the winter months at Cutthroat Creek in order to obtain more accurate records of avalanche occurrence and of snow and weather conditions.

Delancy Ridge

East of Cutthroat Creek the northern side of the Early Winters Creek valley is bounded by the Delancy Ridge. Descending the south and southeast faces of this ridge toward Early Winters Creek are many large avalanche paths, several of which directly affect the highway. West of Silver Star Creek most of the large avalanche paths from Delancy Ridge cross the highway as indicated by timber trimlines. The pattern of vegetation in these paths also indicate that sliding snow reaches the transition slopes at least once a year in many cases as far as the highway. Except for Delancy Ridge Numbers 10 and 11, short slides originating at the 4800 foot level, these are all large avalanche paths with release zones above 6,000 feet.

Below Silver Star Creek to the east, the highway lies on the south side of Early Winters Creek opposite from the avalanche paths. Three of the largest ones are identified as potential hazards to the highway for it would take only a very modest overrun of the existing trimlines across Early Winters Creek to deliver avalanche snow onto the highway. In evaluating the hazards from such paths and similar paths discussed earlier and farther west on the highway, particularly along Granite Creek, it should be remembered that long experience with the behavior of avalanches indicates that sooner or later almost all large avalanche paths overrun an existing timber trimline.

The Delancy Ridge area is firmly placed in the colder, dryer winter climate of the east side of the Cascade Mountains. There is no readily accessible site for snow observations representative of these release zones and forecasting procedures probably will have to utilize snow data from Cutthroat Creek or a similar site. The Delancy Ridge area can be expected to produce substantial amounts of avalanche hazard in both winter and spring conditions. The winter avalanches generally will fall as a result of extended heavy storms or rain on a large quantity of new snow. The south-facing exposure of Delancy Ridge insures that a spring cycle of wet avalanches is common here and this is confirmed by report of frequent wet avalanching to at least the upper part of the talus fans each year. The entire Delancy Ridge zone appears to be amenable to effective control by artificial release by artillery. The release zones for the most part are clearly defined and suitable artillery positions are available along the highway. This is a notable contrast with, for instance, the Cutthroat Ridge area immediately up Early Winters Creek. The slides from Delancy Ridge will represent a moderately serious but manageable hazard to the highway.

Silver Star

A single narrow avalanche path originating in a poorly defined release zone on the north flank of point 6436 crosses the highway at the 3400 foot level along Early Winters Creek. This has a clearly-defined timber trimline but no immediate evidence of recent activity. A short distance upstream, four distinct avalanches fall from the northwest flank of point 6460, the end of Vasiliki Ridge. Two of these, labelled Silver Star No. 2 and 3, meet Delancy Ridge No. 9 at the valley floor and, in fact, can easily cross the Creek and independently of the Delancy Ridge avalanche reach the highway. Two additional slides a short distance upstream, Silver Star No. 4 and 5, normally run only to Early Winters Creek but under unusual circumstances could be expected to cross the Creek and ascend to the highway in the vicinity of Delancy No. 12. The Silver Star avalanches can be expected to have a different pattern of release than those across the valley on Delancy Ridge due to their different exposure (largely north and northeast). This difference in performance will be especially noticeable in regard to spring avalanches.

None of the Silver Star avalanches appear to present a particularly serious hazard to the highway but may cause difficulty in years of extremely severe avalanche conditions.

Defense Structures

There are two basic ways to reduce the avalanche hazard during winter months on a highway in mountainous terrain. One is to prevent or deflect avalanches with fixed structures, including snowsheds. The other is the artificial release of avalanches, usually with artillery. The latter method has the twofold aim of releasing small avalanches in order to limit the formation of large ones, and to release them safely at times when the highway is blocked to traffic. A complete avalanche control program in an area of extensive hazard may incorporate both methods. Rogers Pass is a good example of this.

By reason of the peculiar problems of the North Cascades Highway discussed above, it seems likely that avalanche defense structures, including snowsheds, will never become an extensive part of a winter maintenance program on this highway. It is our assumption on the basis of the reconnaissance reported here that the primary method of managing avalanche hazard on this highway would be an operational combination of traffic restrictions and artificial release by artillery fire. Nevertheless, some limited structures might be used at some later date if the winter traffic level becomes high enough. For this reason the possible use of structures is discussed briefly below before the various alternatives for operational control of hazard are reviewed.

The types of defenses which might be used on the North Cascades Highway are snowsheds, supporting structures, and mounds, listed in order of their likelihood of being employed.

Snowsheds, properly designed, offer the best permanent protection against avalanches. They are also very expensive. When the Rogers Pass sheds were constructed over a decade ago, the cost averaged over $1000 per running foot. No recent figures appear to be available, but an allowance today of up to 50% over this cost for inflation seems reasonable. Snowsheds can be effectively used only where terrain configuration and channelling of the avalanche path permits a clearly-defined section of the highway to be protected. Slope profiles also need to be reasonably steep but not vertical at the highway if extensive earth-moving or construction costs are not to become excessive.

The most likely location for snowsheds is Diablo Gorge. Terrain here is suitable, most of the avalanche paths are clearly-defined, and the higher volume of traffic on this part of the highway, including daily school busses between Diablo and Newhalem, might sooner justify the cost. Aesthetically, sheds might not be too objectionable here in the Gorge where the highway grade is often narrow and bordered by cliffs, and tunnels are already a part of the scene.

Snowsheds yield the maximum advantage for reduction of hazard and snow removal costs when they defend a highway against avalanche paths which are frequently active each winter. Such could be the case for Whistler Shoulder and the Liberty Bell and Cutthroat Ridge groups of avalanches. The Liberty Bell paths are defined sufficiently that sheds might be feasible, although construction might be expensive here. Shedding the upper leg of the hairpin turn at this point probably could be done, but would gain little advantage for highway safety and maintenance unless the lower leg were also shedded, a more difficult thing to achieve. The almost continuous nature of the avalanche slopes along Cutthroat Ridge would require an almost continuous snowshed from 1.5 to 2 miles long. It is difficult to distinguish such a structure from a tunnel.

The only places where supporting structures (barriers to prevent avalanche release) might be justified would be on small avalanche paths where sliding activity is frequent. Whistler Shoulder, Newhalem No. 4, Liberty Bell No. 1 through 4 are examples. The Liberty Bell paths have small and clearly-defined release zones where a limited number of supporting structures might be quite effective. The intrusion of these on the most spectacular mountain scenery along the entire highway would, however, be highly objectionable.

Avalanche mounds, intended to break up the flow of snow on the ground and bring it to rest, are most effective for low-angle slopes and wet snow avalanches. Many of the avalanche paths along Granite Creek meet these criteria, especially those south of Granite Creek Crossing (GC-4 through 15). Even though mounds are relatively cheap to build with bulldozers, the infrequent occurrence here of avalanches large enough to reach the highway might not justify even this expense. In any case, mounds are viewed as the least likely means of defense along SR-20 because of the extensive disruption of the landscape required for their construction. The one other avalanche zone where terrain favors mound construction is on the outrun of Delancy Ridge avalanche paths No. 4

through 13. In several of these cases the long, shallow transition slope above the highway is ideal for mound construction. Nevertheless, they would be less effective here because the large avalanches reaching the highway are much more apt to be dry snow avalanches, against which mounds are only marginally effective. In any case, the impact on the scenery would again be highly objectionable.

Operational Management of Avalanche Hazards

We conclude that any plans for future winter operation of the North Cascades Highway will be based on operational management of traffic flow, snow removal and artificial avalanche release. The eventual installation of a very limited number of structures such as snowsheds might eventually be merited as the quantity of traffic increases.

It is possible to envision several levels of operational management of this highway in the winter. These levels, or options, are discussed below in order of increasing complexity and cost.

Option 1. Leave the highway closed from the first snows of autumn until it melts free in the spring. This is the minimum-cost option, for the only extra expense beyond normal summer maintenance would be plowing out avalanche deposits which persisted on the highway after the normal snow cover melted away. This is also the minimum hazard option: the chance of anyone getting caught in an avalanche is almost zero. This option might limit public use of the highway to four or five months each year.

Option 2. Close the highway with the first snows of autumn, but keep the lower elevations plowed free of snow in winter and clear the higher elevations as early in spring as possible without risk of avalanche danger to the maintenance crews.

This option would require a limited amount of snow removal costs, plus the presence of at least one man in the area trained in avalanche forecasting who could determine during the winter the safe times to clear the lower elevations and the safe times in the spring to begin clearing at high elevations. Under this option, the highway might be kept open as far as Cutthroat Creek on the east and lower Granite Creek on the west during the winter. This would allow experience with winter conditions to be acquired which would be very valuable if one of the following options were later to be adopted. Depending on character of the winter, this plan could keep the highway open to the public one to two months longer than Option 1.

Option 3. Keep the entire highway plowed during the winter and open to traffic only during prolonged periods of minimum avalanche hazard. The highway would simply be closed to both the public and maintenance operation during and immediately after all periods of major winter storms and spring thaw.

This plan might well see the highway closed from 25% to 40% of the time. The usefulness to the public of a highway closed this much at unpredictable intervals is obviously limited. Such an option would be attractive only as an interim measure during which experience with management of snow clearing and avalanche hazards is being developed. The cost of Option 3 would include a substantial investment in snow removal equipment, plus at least one avalanche forecaster and two field observers. Beginning with Option 3, an adequate communication network along the highway is assumed.

Option 4a. Keep the highway plowed and open all winter except during periods of high hazard. During all periods of snowfall, convoy traffic at scheduled intervals.

The convoy system offers a chance to reduce substantially the hazard to the public. Even during hazardous conditions, the chances of a moving vehicle encountering a falling avalanche are relatively small. The danger to traffic rises sharply when a vehicle gets stuck under an avalanche path and sits there. A combination of miscellaneously equipped vehicles, accumulating snow and even very small embankment sluffs running onto the highway encourage the chance of someone getting stuck. If traffic is convoyed in groups travelling immediately behind a snowplow, the chances of getting stuck are greatly diminished.

Option 4a now reaches the stage of full winter operation, including a complete snow removal program, avalanche forecasting and artillery control. The avalanche program probably would require at this stage two avalanche forecasters, four to six observers, plus necessary skilled manpower to handle the artillery. The observers would require complete snow and weather observation equipment, including telemetry at selected sites. The artillery program at this stage would be used primarily to reduce hazards and allow snow removal operations to resume immediately after storms. The highway would be kept closed during high hazard periods and no attempt to plow would be made in the avalanche zones until the storm had ended and artillery fire executed.

Option 4a might reduce highway closure time to something like 10% to 20%. In winters of light snowfall and few avalanches, closure could well be less than 10%. In bad winters, it could be extensive. This option keeps danger to both public and the maintenance crews to a minimum by staying out of the avalanche zones during high hazard.

Option 4b. This differs from Option 4a only by eliminating the convoy system and allowing random movement of traffic except during actual closures. Operational costs would be the same, or possibly a little less by eliminating the cost of convoying. Hazard to the public would be higher than with 4a.

Option 5. Same as Option 4b, but escalate artillery control to include blind firing during storms as an aid to reducing avalanche occurrence as well as hazard. Close highway only during actual shooting and removal operations for avalanche debris.

This is similar to the program now followed at Rogers Pass, where closures are reduced to 3 - 5% of the winter months. Several guns with fixed firing positions would be required over the extended length of the North Cascades Highway. Ammunition consumption would be large. A sophisticated avalanche forecasting program manned by skilled forecasters would be required to insure a reasonable degree of safety for the public and for the maintenance crews. This option would probably lead to greater dangers to the public than Option 4, and most certainly greater danger for snowplow operators because they would be plowing during periods of developing hazard.

We believe that Option 5 is not readily applicable to the North Cascade Highway for the following reasons:

a) The extensive protection afforded by snowsheds on the worst slide paths is not likely to be available.

b) The Cutthroat Ridge avalanche zone does not lend itself to reliable preventive avalanche control through artillery fire by reason of the diverse release zones and many small chutes and gulleys which discharge snow onto the highway. Cutthroat Ridge, in fact, is the key avalanche problem on this entire highway. If these were absent, Option 5 might be contemplated as the ultimate mode of winter operation. But with this danger zone present and active with almost every storm, a high and probably unacceptable risk exists for plow operators even with a heavy expenditure of artillery ammunition.

APPENDIX 1

The following report from Mr. Len Miller describes the general snow and avalanche conditions between Mazama and Washington Pass during the winter of 1970-71. Mr. Miller, a resident of Mazama and an experienced avalanche expert, worked under an agreement with the University of Washington to execute and report snow, avalanche and weather observations as part of this research project. In addition to this letter, his report includes detailed weather records from Mazama, snow stake records, annotated maps, and 75 photos documenting avalanches along the North Cascades Highway. The latter data are available for inspection as needed.

P. O. Box 141
Mazama, Washington 98833
June 16, 1971

Dr. E. R. LaChapelle
Department of Atmospheric
Sciences
University of Washington
Seattle, Washington 98105

Dear Ed:

The following narrative is a summary of what I observed during the past winter on the North Cascades Highway.

I have been in residence at the mouth of Early Winters canyon since the summer of 1965 except for 6 months of the winter 1965-66 which was spent in Jackson Hole, Wyoming. After observing five winters in the area, I have seen just about everything occur during the winter except lightning. Every winter has been <u>very</u> different from the others.

The past winter began in an unusual fashion. There was little or no rain before the snow cover developed and therefore the snow was deposited on very dry ground. Old timers in the Methow Valley stated that they had not seen such a dry, cold Fall for many years.

Normally the snow cover in the Early Winters area is established by November 15. This year it was about ten days late. Snow had fallen in the higher elevations above 4500' elevation, but not in sufficient quantities to be of a hazard to the highway. A few days prior to Thanksgiving the first storm of any size blew in with good cold powder snow which extended well into the valley. Excellent skiing was available on Sandy Butte from 4500' to 2200' elevation. A general slide cycle with dry powder avalanches occurred on all slide paths along the highway. Most of the slides were small and only extended to the beginning of their deposition zones.

The Cutthroat Ridge slides reached the road and crossed it in places. Volumes were sufficient to do damage to vehicles and even push vehicles off of the road in a couple of places.

Snowfall in the observation area came in steady similar amounts with some variations. There were two outstanding exceptions, one during the period December 27 to December 31 and the other January 14 to January 19. Both of these periods brought large amounts of snow and were followed by periods of warm above freezing weather.

Appendix 1 continued

The first storm brought 108 cm of snow in five days at Mazama with 92 cm in the last 48 hrs. An excellent example of snow settlement occurred from 0800 December 30 to 1000 December 31, when 36 cm of snow fell, but the snow cover did not change its total depth. I believe that the large slide cycle that occurred on the highway took place during or just prior to the onset of this rapid settlement.

It must be noted that avalanches along the Cutthroat Ridge will occur continuously during a storm. There is nothing in the starting zones or along the paths to hold or slow down the snow. The terrain is steep and the paths are confined to terraced, smooth rock. The slides reach the road with good velocity and the dryer ones extend themselves over the road all the way to Early Winters creek. During the first large storm, dry, powder slides extended themselves the full extent of the timberlines of the slide paths.

On January 7 a Chinook wind began at the base plot with temperatures as high as 54°F recorded. This condition ablated the snow cover up to 4000' elevation on the highway. The snow cover took on a spring snow appearance both on the surface and within the pack.

When the second heavy snow period occurred on January 14 to January 19 all avalanching was on this surface. The second heavy snow was followed by rain, which caused a second cycle of slides. The first cycle occurred during the storm and slides were large and dry, with high velocities and much airborne snow. When the rain began to saturate the surface snow then a second damp to wet cycle occurred. Delancy #12 first put a large dry slide across the road and was followed a day or so later by a classic wet heavy slide, which stopped short of the road about 40 yards. Snowfall in this storm was 142 cm. All slide paths were active during the cold phase of the storm period. Avalanches that occurred during this period were very dry and the largest of the winter. Velocities were high and a considerable amount of second growth vegetation was removed from the slide paths. The wet slide cycle that followed brought down more vegetation and in places some large boulders. As you travel from east to west the slide paths go from wet to damp to dry with elevation increase.

The month of February was fairly dry compared to the previous two months. Some snowfall occurred, but the snow pack reached a low ebb during the month. March was a month of increased precipatation and a gain in the snowpack. On March 11 and 12 a good cycle occurred with large slides running the full extent of the paths in the Cutthroat section. The snowpack at the end of March had a very strong lower strata about two-thirds of the pack, while the upper one-third was fairly weak. The upper layer was not well bonded to the stronger snow. The general spring slide cycle began during the second week of May. The poorly bonded upper cover slide on the lower layer with dramatic results in the Kangaroo Ridge, Spire Gulch - Cooper Basin, area. Cutthroat #1 also put a large amount of snow, rock and trees in and over the road. The gravel stockpile that is in the road at the present time stopped a moderate volume of material, which very likely would have cleared a large portion of the second growth timber below the road.

Lone Fir (DR-13) reached and crossed the road on January 15 with deposition three to four feet deep and twelve to fifteen feet across, trees and branches. Helicopter Meadow slide reached to the edge of the highway with a large volume of snow being deposited on the road side of State creek. There were numerous avalanches along the highway, with all slide paths being active to some degree.

Mr. Don Shafer, who is my neighbor to the west, stated that last winter, 1969 - 1970, was more normal than winters in the past five years. Snow pack, according to Don, is usually four feet in the Early Winters area with wind being associated with the storms.

Mountain weather in the region of this study, North Cascade Highway, includes rain, snow (very cold - wet), freezing rain, long (two-three weeks) periods of valley fog at below freezing temperatures, Chinook winds, temperatures as cold as -52°F, and avalanching. Avalanches occur generally with every snowfall with settlement taking place rapidly below 4000'. Above 4000' the snowcover is of a more alpine nature in that it stays dry and cold and therefore unstable for much longer periods of time. Two points will be critical in forecasting in this region. First the location of the particular starting zone of a slide, with respect to an east-west line through the mountain range and second the shift in elevation of the orographic level of precipatation.

To conclude - this past winter was interesting in the large number of avalanches that were observed. Some of the large paths, that appeared to be active every year, did not produce slides of significant size to reach the road, while others moved into new ground because of the construction of the road. The road from Cutthroat creek to Washington Pass and beyond captures a lot of small to medium size slides and has only a small effect on the large slides that pass over it.

The Cutthroat ridge, Liberty Bell, Spire Gulch and Whistler shoulder are very dangerous areas. Avalanching will occur constantly during storm periods in these areas and therefore will be of danger to crews maintaining the road. It appears that a full time forecasting and control program will be needed to keep the road open and then it may only be possible 80% of the time.

Appendix 1 continued

It is recommended that more complete instrumentation be placed along the highway and in the starting zones. Also additional equipment is necessary at the base plot to obtain a more accurate and continuous record. Sufficient information is on hand to recommend that a pilot forecasting and control program be started on the highway so that sufficient experience and data are available when the highway is opened on a year round basis.

Len Miller

Attachments: photo album
annotated maps
snow records
weather records

APPENDIX 2

Inspection Trip to Rogers Pass, B.C.

Ray Leonard

The Rogers Pass Avalanche Control is within the Glacier National Park and is composed of three climatological zones stretching a total distance of twenty-seven miles. The three zones are from west to east, a wet snow or coastal condition, a mixed zone and a dry zone, which is on the east side of the mountain range.

The forecasting staff totals eight men during the winter and it was indicated this was barely sufficient.

The staff furnished the following data for the past year (1970-71) along with some averages.

Number of slides while closed	Number of slides while warning existed	Number of slides - no warning	Total
18	13	2	33
54.55%	39.40%	6.05%	100%

Of the above, seventeen slides resulted in road closures of less than two hours. The six year average for road closure is 130 hours per year with 30 hours being the longest single time, occurring only once.

Total number of targets	Average number of targets shot per storm	Average ammunition used per year
134	30	660 rounds

Job Description:

The eight-man crew has two forecasters, one for the week and one for the weekend and night shift. The forecaster establishes the data requirements which the observers gather, analyzes the data, and posts conditions for the road crews. The forecaster also decides when the road is to be closed and is solely responsible for the closure. He answers to the park superintendent after the fact.

The observers, of which there are two full-time and four part-time, gather the required data, visit the study plots and instruments and do most of the field work. The part-time observers work only during the avalanche season.

The Rogers Pass personnel wish to add a trainee position which would train a person as an observer and then forecaster. The comment was made that while many people could be trained as observers there was a problem in finding a person who could make good decisions based on the variable information and uncertainty involved.

Equipment and Sites:

The Rogers Pass complex has two permanent sites manned 24 hours a day. One at Rogers Pass (elevation 4200') where the forecast and the maintenance headquarters are located, and the other at 6200' at the opposite end of the pass. There are two remote stations; one 2000' above the maintenance yard and the other 1000' above the other station. These stations are linked to the manned stations by telemetery and are installed in duplicate, one being on stand by. Estimated cost $100,000.

Additional to the above there are two study plots and two temperature and snow fall stations. The latter are at the east and west gates of the park.

In the early stages of the forecasting program, the forecasters attempted to aid the provincial highway department with forecasts but found they lacked the data for reliable predictions.

It is thought that another remote station, study plot and observer would be necessary to add the additional 12 miles. This problem was solved by three large snow sheds at the major problem areas.

Stabilization Program:

The philosophy of control at Rogers Pass is one of stabilization through artillery. In other words, they use a schedule of shooting based on the nature of the storm to either release or stabilize the snow cover. This program requires that the gun crew be readily available for dispatch at any time at the discretion of the forecaster. Any delay can prove to be extremely hazardous to the gun crew and road crew.

Artillery control has proved successful in minimizing the size of the slides, ensuring safe clearing conditions for the road crews and improving the certainty of the knowledge of the conditions of the slopes, thus reducing the danger to the motorist and time required for closure. Artillery control does not eliminate the spring slide cycle as it is not effective on wet heavy snow. The program does reduce the probability of really large spring slides.

The Canadian Army furnishes and pays a 9-man gun team. The park provides the 105mm. howitzer, ammunition, transportation to the park, quarters, and food. The last three cost an estimated $12,000 a year. The army team is available 24 hours a day and thus eliminates any time lag.

The choice of the weapon was dictated by the availability of spare parts and consistence of supply. Problems are that the gun weighs 2 1/2 tons and the gun pads along the road must be kept clear of snow and ice.

Shooting sets up a sliding surface, and once a slide path has been shot it must be controlled for the rest of the winter. Because of this, the slide paths are evaluated for frequency, size and potential damage. Static defenses are used in three ways -- the first to retard or delay avalanche release until the gun crew can get to the path; the second is to reduce the probability of a slide reaching the road. This latter use, along with the evaluation of frequency, requires expert judgment and constant watching of the paths so that a hazard does not develop unnoticed.

The third use involves snowsheds. Snowsheds have been used in several areas with much success. Initially some motorist hit the center columns but this was stopped with the installation of blinking lights and signs. During spring there was some problem with cars slamming between the sides due to ice in the sheds. This was solved by reduction of the speed limit to 30 mph through the sheds.

Summary and Conclusions:

With a blend of various avalanche control techniques it has been possible to limit highway closure to 130 hours per year. It appears that no one solution is sufficient and trade-offs must be accepted.

The nature of Rogers Pass is similar in climatological regions to the North Cascades Highway. However, it must be noted that it is only 27 miles long compared to 65 miles in the Washington road.

The regions for the North Cascades can be roughly grouped to the west coast zone (Newhalen Slides, lower Ruby Mountain), mixed zone (Ruby Mountain and Granite Creek), and dry (Early Winters Creek). In all likelihood the area would require two forecasting complexes, one for the west end and one for the east. Also, means of blocking the road should be provided which do not require endangering personnel. Presently, Rogers Pass has a request for automatic or remotely controlled gates. Holding areas free from avalanche danger should be established so that people might not be caught by avalanches released due to gun fire at other avalanche paths.

In closing, the Rogers Pass personnel noted a turnover problem due to the remoteness of the area and stated use of people familiar with the area and road made for more efficient operation.

The following statistics concerning Rogers Pass are added in supplement to Mr. Leonard's report:

The Rogers Pass section of the Transcanada Highway is protected by a total of 6200 linear feet of snowsheds. These sheds were built at a cost of approximately 6-1/2 million dollars about ten years ago.

Annual rate of ammunition expenditure is around 650 rounds per year. Most of this is 105 mm howitzer ammunition which costs $60 per round.

The avalanche safety staff consists of 4 men employed all year, plus 4 additional observers who work only in the winter, plus one winter trainee.

The 9-man army gun crew is housed and fed all winter at Rogers Pass, the cost being born as part of the avalanche operations.

Of the average of 130 hours closures per year, fully 80% to 90% occur as short closures which delay traffic no more than two hours.

An approximate summary of annual costs for the avalanche safety program is:

Ammunition..................	$ 40,000
Army logistics..............	5,000
Salaries	
full-time................	40,000
part-time................	28,000
Total......................	$113,000

This total does not include maintenance and depreciation of the observation equipment, including two high-altitude observatory buildings and some elaborate telemeters.

APPENDIX 3

Notes from interview by LaChapelle with Jack Wilson, Mazama, Washington, on 9 May 1971 (also helicopter trip on this date over Washington and Rainy Passes down Granite Creek to about GC No. 1).

Wilson trapped up Early Winters Creek from 1947 to 1963. Has been back most years since by snomobile.

Same general avalanche conditions have persisted over this period from 1947.

Spire Gulch slide this year brought more snow onto highway than Wilson has seen in past few years (since about 1966). NOTE: Spire Gulch slide was large slab avalanche orginating about half way up the gulch and very fresh on 9 May -- apparently no more than 24 hours old.

Cutthroat Ridge runs all the time -- avalanches fall with every storm.

Most of the time slides from Delancy Ridge stop on transistion and do not reach highway. Only a few winters have brought big slides all the way to the creek.

Around 1960 -- give or take a couple of years -- there was a winter of heavy snow with 6' snow at Mazama around 15-20 January. At this time all of Delancy Ridge paths slid to present highway grade.

Delancy Ridge No. 1 once filled creek bottom 75' deep. (Notes not clear whether this was same time as 1960 slides mentioned above.)

Around 1958 (definitely <u>not</u> same year as 1960 mentioned above) there was a big storm in January of 4' new snow followed by a thaw. Precip turned to rain 3 miles below Lone Fir. But all of Delancy Ridge slid as dry snow avalanches before the thaw and rain.

Around 3-4 years ago in mid-March, with 5-7' snow in upper Early Winters Creek, DR No. 2 through 10 slid to the ground, with big wet slides stacked up on transitions.

Between Silver Star No. 1 and 2 -- on mapped drainages (2) -- two slides came down to creek around mid-February (not clear which year).

Wilson can't recall ever seeing a slide come down SS No. 1.

DR. No. 9 once crossed creek onto SS No. 2 and 3. Wilson did not observe this, but deduced from vegetation scars.

Around 1963, early in January, a very big avalanche fell in Pine Creek valley. Wilson heard it from cabin at Lone Fir. Much timber destruction.

The big slide path from end of Vasiliki Ridge directly across from Cutthroat Creek was made by a large avalanche which fell around 1963.

Main trail problem along upper Early Winters Creek would be in crossing creek. The creek freezes "from the bottom up." Cutthroat Ridge slides used to run closer to creek, but most of them are now caught by the highway grade.

Guy Imus, Stehekin, Washington, used to trap and snow survey around Rainy Pass -- came up from Stehekin and down Granite Creek.

Ten years of weather records available at Mazama -- station about 5 miles below Wilson's place.

APPENDIX 4

The following report from Mr. Peter Schaerer outlines his preliminary observations on the avalanche problems of the North Cascades Highway. Mr. Schaerer inspected this highway at our invitation in September of 1970.

Mr. Schaerer is a Swiss engineer specializing in the planning and design of avalanche defense structures. He was responsible for the design of the defense systems at Rogers Pass, British Columbia, the most extensive such system in North America. Mr. Schaerer is presently employed by the National Research Council of Canada to conduct avalanche research in the Rogers Pass area.

Appendix 4 continued

Peter A. Schaerer,
P.Eng.

Vancouver, B.C. 22 June 1971

Dr. E.R. LaChapelle,
Associate Professor,
Geophysics Program,
University of Washington,
Seattle, Washington 98105.

Dear Dr. LaChapelle:

Washington North Cross State Highway.

On 10 September 1970 I made a preliminary reconnaissance of the partially completed North Cross State Highway and gathered the following impressions concerning the avalanche hazard and control.

The highway crosses numerous sites where avalanches can be dangerous to traffic and where deep snow deposited by them would close the road for periods up to five days several times every year. Considering not only the avalanche hazard, but also the design specifications, construction and maintenance cost, soil, and drainage we may say that in general the best possible location was chosen for the highway. Only at a few sites, e.g. at Granite Creek it would have been advantageous to move the centreline of the highway in order to avaid deep snow deposits.

The first step in choosing an avalanche defense is to make an inventory of the avalanche sites and to determine for each site the frequency of occurrence, type, and size of the avalanches that could be expected. An important question that must also be answered at this stage is the timing of the avalanches, whether or not the avalanches usually occur simultaneously at many sites. The next step will be to make a cost-benefit analysis of various types of defense and choose the one that combines best protection, short closures and low cost.

A great difficulty for the avalanche control of the North Cross State Highway is the spread of the avalanche sites over a distance of 70 miles. This is a long distance for an operational control unit, e.g. a crew with a gun. Furthermore the terrain and the weather changes inside this area and influences the formation of avalanches.

Appendix 4 continued

At this stage two areas can be distinguished:

a) East of Rainy Pass.

The avalanche sites are concentrated in a relative small area. Control by gunfire should be used extensively where it is practical. Structures, such as dams and sheds should be considered at sites only where the gunfire is not possible, but the frequency of avalanche occurrences makes a defense mandatory. This first impression indicates that few or no structures would be required.

b) West of Rainy Pass.

The avalanche tracks are scattered over a long distance. The avalanches appear to reach the highway less frequently than on the East side. The terrain makes control by gunfire difficult at many sites. The low frequency of occurrence of dangerous avalanche does probably not warrant a protection at most sites, and at the other sites structures must be built.

Yours sincerely,

Peter Schaerer

Peter Schaerer