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MISSOURI COOPERATIVE HIGHWAY RESEARCH PROGRAM
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EVALUATION OF THE EFFECTIVENESS OF VARIOUS VEGETATIVE COVERS IN CONTROLLING SLOPE DISTRESS

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EVALUATION OF THE EFFECTIVENESS OF VARIOUS VEGETATIVE COVERS IN CONTROLLING SLOPE DISTRESS

STUDY NO. 81-1

Prepared By

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

Division of Materials and Research

Final Report

October 1984

in cooperation with

U. S. DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

The opinions, findings, and conclusions expressed in this publication are not necessarily those of the Federal Highway Administration.

ABSTRACT

Distressed highway slopes and randomly chosen, non-distressed slopes were selected throughout Missouri and surveyed to determine type and density of vegetation, soil properties, slope geometry and orientation and types of any distress. Several sites were instrumented and depths of freezing monitored as were seasonal moisture variations. The study confirmed some expected relationships between slope performance and slope geometry, soil properties and vegetation type and density. Although limited data suggested some positive influence by vines, brush and trees, no significant differences could be confirmed among other vegetation types in controlling the occurrence of slides and sloughs.

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INTRODUCTION

The Missouri Highway and Transportation Department has established criteria for cut and fill slope design based on the geologic origin and ASTM classification of the soils involved. Highway slopes built to these criteria have a low incidence of the sloughs and slides which continue to be experienced on many miles of highway slopes which were constructed steeper than would be permitted by present design criteria.

It has been observed that many, if not most, slope failures are initially quite shallow. It is believed that many such shallow failures involve softening of the slope surface as a consequence of swell, a loss of cohesion from desiccation cracking and the introduction of seepage stresses by rainfall filling the cracks. A recent research project[1] established that development of ice lenses was responsible for some failures of near vertical slopes in loess. This phenomenon has also been suspected in failures of flatter slopes in other soils.

Some observers have suggested that some ground covers are more effective than others in controlling such shallow slope failures. It is postulated that a dense vegetative mat may tend to insulate the slopes from extreme moisture and temperature changes and that the roots may reinforce the zone subject to damage by desiccation cracking and freeze-thaw cycles.

This study was established in an attempt to determine if some commonly used types of vegetation have been more effective than others in controlling shallow sloughs and slides and, where possible, to determine the comparative degree of soil moisture change and depth of frost penetration as a function of type of vegetation cover. A secondary objective was to determine if certain forms of vegetation have been more effective than others in controlling erosion.

CONCLUSIONS

1. No conclusive evidence was found of significant variation in the incidence of slides and sloughs which could be attributed to the presence of any of the common legumes, grasses or weeds found in the slope survey. However, the limited data available for a subgroup which included all vines, brush and trees tended to confirm a positive influence in controlling slides and sloughs.

2. The relative density of vegetation was found to be related to the occurrence of all forms of distress, i.e., the less dense the cover of whatever kind, the greater the likelihood of slides, sloughs and erosional problems.

3. As expected, it was found that the legumes, excepting crownvetch, were associated with a higher frequency of erosional problems than were the grasses.

4. Of those types of vegetation on instrumented slopes, only creeping juniper was associated with a significantly greater freezing depth which is believed due to the drying effect from continued moisture demand during the winter. Sericea lespedeza was found associated with the least depth of freezing within similar climatic and soil conditions and with the highest measured soil moisture contents, perhaps due to low moisture demand except during the summer growing season. Due to the limited number of test sites with Sericea, additional study would be required to confirm the latter observations.

5. A number of relationships were confirmed with respect to slope performance and soil properties and slope geometry. Among these are the following.

(1) High-plasticity clay soils, CH by ASTM classification, were disproportionally associated with higher frequencies of all forms of distress, including erosion. Also highly erosive were the gravelly and sandy clays and all of the non-plastic soils. Least erosive were low-plasticity clay soils, CL by ASTM classification.

(2) The incidence of all forms of distress increased with increasing plasticity as well as with increasing slope height.

(3) Slope performance is influenced by the direction the slopes face. North and east facing slopes were found most prone to slides and sloughs while west and south facing slopes were found most erosion prone. North facing slopes were consistently wettest.

(4) Cut slopes were found to be more erosion prone than fills.

(5) Slope performance is related to soil regions. The northern glacial regions were found to be the most prone to slides while the southwestern prairie, west Ozark border and Ozark regions were most prone to erosional problems.

IMPLEMENTATION

This report will be disseminated throughout the Department for informational purposes. However, this study did not result in findings of such significance as to justify recommendations for changes in present practices.

SCOPE

A survey of distressed and failing roadway slopes was conducted throughout the State of Missouri. The Missouri Highway and Transportation Department's ten districts were requested to list at least twenty specific locations where slope maintenance problems were prevalent. Distress forms were categorized as slides, sloughing, or severe erosion. Both fill and cut slopes were surveyed but failures involving foundation soils under fills were excluded. These areas were then surveyed for types of vegetation cover, vegetation density, soil types, slope geometry and any other factors possibly related to the observed distress. Soil samples were secured for indices and classification tests. To establish a base for comparison, slopes having no distress were randomly selected and similarly surveyed. A few comparative sites were monitored for seasonal soil moisture changes through continued routine sampling. Using frost tubes at these sites, comparative depths of frost penetration were also determined under various types of vegetation.

The derived data was evaluated to attempt to determine if certain types of vegetation are more effective than others in controlling shallow slope failures and erosion.

SLOPE SURVEY

A survey of distressed slopes and of randomly chosen, nondistressed slopes was conducted during 1981 and 1982, mainly during the summers. In all, 280 distressed slopes and 191 randomly chosen slopes were surveyed.

Conventions of the Survey

Distressed slope locations were chosen by each of the Department's 10 districts which were requested to list at least 20 specific locations where slope maintenance problems were prevalent. No criteria was established for the districts in compiling the submitted lists except that foundation failures were to be excluded.

Failure or distress forms were categorized as slides, sloughs and erosional problems. Sloughs are considered to be shallow failures principally involving the sod or root zone and, in no case exceeding 3 feet in depth. Obviously sloughs may be precursors of slides and differ from slides only in degree.

The randomly chosen, non-distressed slopes were all selected by the principal researcher. While no attempt was made to select slopes by vegetation or soil type, for example, selection criteria did include requirements that slopes must be at least 10 feet in height, must include both cuts and fills (except in the southeast lowlands where only fills meet the first requirement) and must be essentially divided between east-west and north-south oriented roads. Ultimately some additional slopes were added to more nearly equalize the number of slopes surveyed in each of seven soil regions.

The survey included photographs, sketches, soil sampling and completion of a detailed check list which included the major vegetation types, vegetation density, soil types, degree of slope, height, orientation, and, where appropriate, the degree and forms of distress or failure. Testing was

limited to plasticity index determination and ASTM classification on samples taken from the face of the slope and from areas of failure or distress where these were in evidence. An example of a completed field survey form is shown as Figure 1.

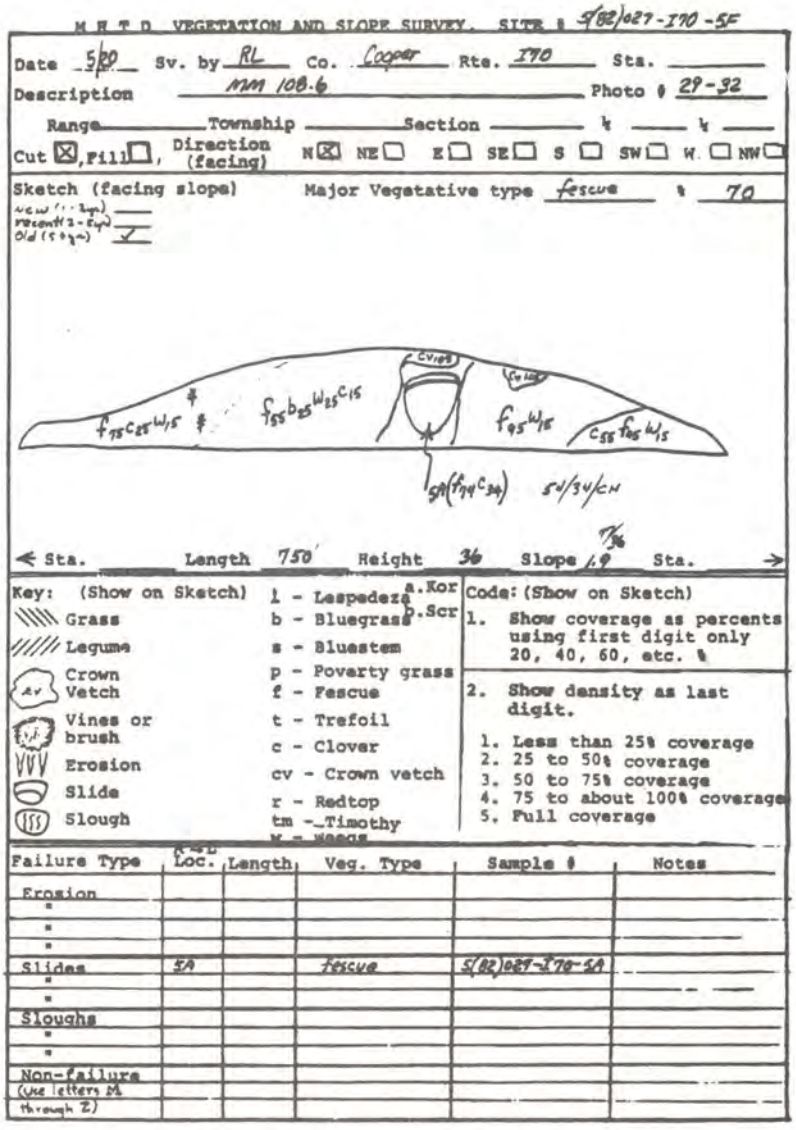

Figure 1, Example of a Completed Field Slope Survey Form

Areas of different vegetation, vegetation densities or various combinations thereof were sketched on slope survey forms and described using letter abbreviations to indicate vegetation type followed by a 2 or 3 digit numerical code. The first digit(s) indicate the estimated percentage of

the area occupied by that type of vegetation in 10 percent increments with 1 indicating 10 percent, 2 indicating 20 percent, etc. The last digit, which varies from 1 to 5, indicates the estimated density of the vegetation in 25 percent increments with 1 indicating that more than 75 percent of the ground is visible, etc. For example, the description for the area of vegetation in the center of the slope sketched in Figure 1 is $f_{55}\ b_{25}\ w_{25}\ c_{15}$. This indicates that this area is estimated to be 50 percent fescue, 20 percent bluegrass, 20 percent weeds and 10 percent clover, totalling 100 percent. All of the last digits are 5 indicating that the density of coverage approaches 100 percent, i.e., the ground is virtually obscured.

Field data were subsequently retabulated to convert vegetation density factors to percent bare ground with the vegetation types as percents of an area proportionally reduced to this new base such that percents of vegetation types plus percent bare ground total 100. Finally, all data were recalculated to determine overall percentages of each vegetation type and of bare ground (100 total) for the entire slope with weighting based upon relative area sizes as sketched on the field survey form.

The variety of vegetation types encountered in significant amounts was not as great as had been initially supposed. However, some grouping was still required both to expedite the survey and facilitate analysis. Major subgroups of this survey include: (1) grasses, (2) legumes, (3) broadleaf weeds, and (4) vines, brush, and trees (VB and T). The grasses were further subdivided into the following categories: (1) common grasses (timothy, redtop, etc.); (2) fescue, all types; (3) orchard and brome grass; (4) light grasses (cheat, foxtail, etc.); (5) broomsedge; (6) Bermuda grass, and (7) native grasses (bluestem, switchgrass, etc.).

The legumes were subdivided as follows: (1) Korean lespedeza, (2) Sericea lespedeza, (3) birdsfoot trefoil, (4) clover (all types), and (5) crownvetch.

The broadleaf weed subgroup is self-explanatory. The fourth subgroup, vines, brush, and trees, is composed almost exclusively of naturally seeded native varieties. The principal exceptions include honeysuckle and some ornamentals (trees comprise a very small percentage of this subgroup).

Distribution of Distress Forms by Soil Region

The data obtained were first evaluated according to geographic location based on general soil regions as adapted from definitions by the University of Missouri's College of Agriculture[2]. The soil regions are: northern Missouri, southwestern prairie, west Ozark region, Ozark region, east Ozark border, and southeast lowland. For this study, the largest, northern Missouri, was further subdivided into northeast glacial and northwest glacial for a total of seven soil regions. The general outlines of these regions are shown in Figure 2.

Figure 2, Soil Regions of Missouri (Adapted from Reference 2).

Table 1 summarizes the distribution of the surveyed slopes and the types of distress reported for these soil regions. Slides comprised 52 percent of all distress forms reported statewide and 64 percent or more of the reported distress in the two soil regions north of the Missouri River, in the southeast lowlands and the east Ozark border. When slides and sloughs, a related distress form differing in degree, are combined, percentages for these four regions vary from 83 to 100. Erosional problems were reported more frequently than other distress forms in the southwestern prairie, west Ozark border and Ozark regions.

TABLE 1

Distribution of Surveyed Slopes and Types of Distress by Soil Region

Soil Region (See Fig. 2)	No. of Slopes		Types of Distress, % for Region		
	Random	Distressed	Slides	Sloughs	Erosion
Northeast Glacial	33	51	88	8	4
Northwest Glacial	33	53	70	13	17
East Ozark Border	29	25	64	32	4
Southwestern Prairie	24	39	15	8	77
West Ozark Border	20	51	10	35	55
Ozark Region	30	32	38	22	40
Southeast Lowland	22	29	76	24	0
Averages:	--	--	52	20	28

Slope Performance Related to Soil Properties

The survey data were next analyzed to determine the relationship of performance to physical soil properties as indicated by ASTM soil classification[3] and plasticity index (PI). In these and some subsequent tables, the percentage of occurrence of a particular property as found in the random survey of non-distressed slopes was used as a base to establish a ratio to the percentage of occurrence of that property among the slopes having one or more forms of distress. These ratios, shown in parentheses, provide a

more convenient means of assessing the significance of the data presented. Such ratios were omitted where there were less than 4 observations for a property for either the distress form or for the random survey base.

Tables 2 and 3 show the percentages of the various distress forms and of the randomly surveyed slopes by ASTM soil classifications and by PI ranges. Most of the surveyed slopes are composed of high or low PI clay soils (CH or CL). Other individual soil types generally are 5 percent or less of the total for each form of distress. The most significant relationship shown here is that CH soils, as a ratio of their percentage of occurrence, were found more frequently in association with all forms of distress than in the random survey. Only 22 percent of the non-distressed slopes of the random survey were composed of CH soils while 35 percent, or 1.6 times as many, of the slides surveyed occurred on slopes composed of CH soils. This ratio was even higher, 1.9 and 1.8, for sloughs and erosion respectively.

Gravelly and sandy clays (GC & SC) are also shown to be disproportionally erosion prone. The sands and silty sands (SP, SW & SM) also exhibited higher erosion ratios but not as much as might be expected. Insufficient data were developed to confirm the expected high erosion potential of the silts (ML).

TABLE 2

ASTM Soil Classification of Surveyed Slopes

ASTM Soil Classification	% of Distress Form by Soil Class. (Ratio to Random % Base) Slides	Sloughs	Erosion	% of Random Survey Slopes
CH	35 (1.6)	41 (1.9)	39 (1.8)	22
CL	60 (0.9)	45 (0.7)	40 (0.6)	64
CL-CH	1	6	2	1
CL-ML	1	-	-	2
MH	2	2	2	3
ML	-	4	1	3
GC & SC	-	-	11	-
SM, SP & SW	1	2	6 (1.2)	5
Number of Tests	142	54	83	191

Table 3 indicates a general trend of soils with higher PI ranges being associated with an increased incidence of distress in all forms. Surprisingly, the incidence of erosion in the highest PI bracket is especially high. This is not inconsistent with the association, indicated in Table 2, of sandy and gravelly clays with erosion. It should be kept in mind that PI is based on only that fraction of the soil which passes the No. 40 sieve. The over-40 PI's include many gravelly residual clays which may have a very low percentage of material passing the No. 40 sieve. This is also consistent with the high reported incidence of erosion from those soil regions where residual soils predominate (Table 1).

TABLE 3

Slope Performance and Plasticity Index (PI)

PI Range	% of Distress Form by PI Range (Ratio to Random % Base) Slides	Sloughs	Erosion	% of Random Survey Slopes
0-9	4 (0.3)	6	11 (0.9)	12
10-19	24 (0.8)	26 (0.9)	28 (0.9)	30
20-29	35 (0.9)	44 (1.1)	14 (0.4)	39
30-39	24 (1.6)	15 (1.0)	16 (1.1)	15
40+	13 (3.3)	9 (2.3)	31 (7.8)	4
No. Tests:	143	54	83	191
Avg. PI:	27	25	28	22
Avg. LL:	48	44	48	44

Slope Performance Related to Slope Geometry and Orientation

Survey data were next tabulated to assess possible influences on performance of degree of slope, slope height, and direction faced by the slope. These data are summarized on Tables 4, 5, and 6.

Table 4 could be interpreted to suggest that slope performance is inversely related to steepness of slope, i.e., the steeper the slope, the lower the likelihood of distress. It is believed that the limited data for 1.5:1 slopes is anomalous. Certainly the bulk of the data is for 2:1 slopes which experience all forms of distress in about the same proportion as 2:1 slopes occur in the random survey of non-distressed slopes. Table 5 confirms an expected trend for a higher incidence of slides and sloughs with increasing slope height and also shows increased erosion on the highest slopes. Table 6 indicates that more erosion occurs on south and west facing slopes which are presumably subject to more drying and a somewhat higher frequency of sloughs and slides occur on the wetter and more frost susceptible north and east facing slopes.

TABLE 4

Slope Performance and Degree of Slope

Slope*	% of Distress Form by Slope (Ratio to Random % Base) Slides and Sloughs	Erosion	% of Random Survey Slopes
1.5:1	9 (0.5)	8 (0.4)	18
2:1	68 (1.1)	62 (1.0)	63
2.5:1	14 (1.2)	19 (1.6)	12
3:1	9 (1.3)	11 (1.6)	7
No. Obs:	196	83	191
Avg. Slope:	2.2:1	2.2:1	2.1:1

*Slopes were sorted to closest fit to ranges noted.

TABLE 5

Slope Performance and Slope Height

Slope Height, ft.	% of Distress Form by Height (Ratio* to Random % Base) Slides and Sloughs	Erosion	% of Random Survey Slopes
< 19	39 (0.7)	46 (0.9)	53
20-29	28 (1.0)	25 (0.9)	28
30-39	20 (1.7)	11 (0.9)	12
40-49	8 (2.0)	6 (1.5)	4
50+	5 (1.7)	8 (2.7)	3
No. Obs:	197	83	191
Avg. Height:	26	26	23

TABLE 6

Slope Performance and Slope Orientation

Slope Exposure	% of Distress Form by Slope Exposure (Ratio to % of All Distressed Slopes) Slides and Sloughs	Erosion	All Distressed Slopes, %
North	34 (1.3)	8 (0.3)	26
South	27 (0.9)	36 (1.2)	30
East	19 (1.0)	17 (0.9)	19
West	20 (0.8)	39 (1.6)	25
No. Obs.	197	83	280

Performance of Cuts Vs. Fills

Table 7 shows that cut and fill slopes experience significantly different rates of erosion. Slides and sloughs were equally common on both fills and cuts while erosional problems were nearly twice as frequent on cut slopes.

TABLE 7

Performance of Cuts Versus Fills

	% of Distress Form (Ratio to % of All Distressed Slopes)		
	Slides and Sloughs	Erosion	All Distressed Slopes, %
Cuts	72 (1.0)	72 (1.0)	75
Fills	28 (1.1)	13 (0.5)	25
No. Obs.	213	85	298

Slope Performance and Vegetation Type

Because there was insufficient data for detailed breakdowns by most specific varieties of vegetation, major vegetation subgroups were used in compiling the tables of this section. However, two varieties, crownvetch and fescue, were included due to their prevalence. The average percentages of total slope areas occupied by the various subgroups and varieties are shown in Table 8 while Table 9 is based on percentages of slopes where one vegetation type occupies 50 percent or more of the slope area. For this table, slides and sloughs are grouped together due to the smaller data base. A breakdown is provided by soil region of the average percentages of total slope areas occupied by the various vegetation types for slides and sloughs combined in Table 10 and for eroded slopes in Table 11.

TABLE 8

Slope Performance and Vegetation Type

Vegetation Subgroup	Average % of Slope Area for Distress Form (Ratio to Random % Base)						% of Slope Area of Random Survey
	Slides		Sloughs		Erosion		
Grass	52	(0.9)	40	(0.7)	30	(0.5)	55
(Fescue)	(40)	(0.9)	(29)	(0.6)	(29)	(0.6)	(46)
Legumes	19	(1.0)	26	(1.3)	28	(1.4)	20
(Crownvetch)	(11)	(1.4)	(10)	(1.3)	(7)	(0.9)	(8)
Weeds	9	(1.1)	9	(1.1)	7	(0.9)	8
VB & T	6	(0.7)	7	(0.8)	1		9
Bare	14	(1.8)	18	(2.3)	34	(4.3)	8
No. Obs.	145		54		84		210

Table 8 shows a markedly higher association for all forms of distress, most notably erosion, with "bare" ground. (As noted in the discussion of the survey conventions, "bare" is used here as an indication of average vegetation density for the total slope.) This association indicates that type of vegetation is less significant than the density.

The next strongest association shown is a relatively low incidence of erosion with the grasses and a relatively high incidence of erosion with all legumes combined. Interestingly, this association is not confirmed for crownvetch alone. A surprising trend of Table 8 is the higher association of crownvetch (but not all legumes) with slides and sloughs. Not surprisingly, the incidence of slides and sloughs associated with vines, brush and trees (VB & T) is low although perhaps not as low as might be revealed if a larger data base were available for this category.

Table 9, which considers only those slopes where one vegetation type comprises 50 percent or more of the slope area, confirms the foregoing trends although to greater or lesser degrees. Legumes are shown by this table to have an even higher ratio of erosion, grasses somewhat less and crownvetch a somewhat lower but still positive (i.e., greater than unity) association with slides.

Table 9

Slope Performance Vs. Vegetation Types Occupying 50% or More of Slope Area

Predominant Vegetation Subgroup	% of Distressed Slopes (Ratio to Random % Base) Slides and Sloughs		Erosion		% of Random Survey Slopes
Grass	76	(1.0)	55	(0.7)	79
(Fescue)	(59)	(0.9)	(50)	(0.7)	(69)
Legumes	21	(1.5)	36	(2.6)	14
(Crownvetch)	(14)	(1.8)	(14)		(8)
Weeds	2		5		3
VB & T	1		5		4
No. Obs.	103		22		132

Study of Tables 10 and 11 suggests a strong regional association with the relative performance of the grasses and fescues. The legumes (including crownvetch) have a much lower association with slides and sloughs in the northeast glacial soil region and a much higher association in the northwest glacial region. Grasses have a reverse association which is somewhat less marked. Table 11 confirms the previously observed association of legumes with erosional problems and the superior performance of the grasses in this respect. However, some of the data base is limited so that meaningful comparisons are not possible in Table 11 and, to a lesser extent, in Table 10 where data for slides and sloughs were combined.

TABLE 10

Vegetation Types on Sliding and Sloughing Slopes by Soil Region

Vegetation	% Vegetation by Soil Region (Ratio to Random % Base for Region)						
	NE Glacial	NW Glacial	E. Ozark Border	SW Prairie	W. Ozark Border	Ozarks	SE Lowland
Grass	58 (1.4)	46 (0.7)	53 (1.0)	54 (0.9)	27 (0.7)	60 (0.9)	44 (0.7)
(Fescue)	(51) (1.3)	(33) (0.7)	(34) (0.7)	(52) (0.9)	(24) (0.7)	(55) (1.0)	(14) (0.4)
Legumes	22 (0.5)	31 (2.5)	21 (1.4)	12	25 (0.8)	20	3
(Crownvetch)	(14) (0.6)	(20) (4.1)	(9)	(10)	(5)	(12)	(0)
Weeds	7	5	5	8	8	6	23 (1.4)
VB & T	6	4	7	1	12	4	12
Bare	7	14 (1.4)	14	25	28 (2.8)	10	18 (5.0)
No. Obs.	49	44	25	9	23	19	29

TABLE 11

Vegetation Types on Eroded Slopes by Soil Region

Vegetation	% Vegetation by Soil Region (Ratio to Random % Base for Region)						
	NE Glacial	NW Glacial	E. Ozark Border	SW Prairie	W. Ozark Border	Ozarks	SE Lowland
Grass	18	32	85	30 (0.5)	24 (0.6)	42 (0.7)	0
(Fescue)	(18)	(32)	(38)	(30) (0.5)	(22) (0.7)	(42) (0.8)	(0)
Legumes	49	56 (3.1)	0	23 (1.4)	31 (0.9)	16 (1.6)	0
(Crownvetch)	(26)	(43)	(0)	(1)	(3)	(1)	(0)
Weeds	0	4	15	7	11	3	0
VB & T	0	0	0	0	1	6	0
Bare	33	8	0	40 (2.4)	33 (3.4)	33	0
No. Obs.	2	9	1	30	28	13	0

The trends suggested by Tables 8 and 9 that legumes, particularly crownvetch, have an apparent higher association with slides and sloughs is not supported in full by Table 10. Discussion with those knowledgeable about the Department's seeding policies has revealed a non-quantifiable time factor.

Crownvetch, in particular, has been overseeded on older slopes, many of which were already so distressed by slides, sloughs, and erosional problems that establishment of some form of vegetation not requiring mowing on dangerously steep slopes was a departmental objective. It is concluded that while there is a logical and positive link between the occurrence of legumes and erosional problems, no definite conclusions can be drawn with regard to such a link between crownvetch and the occurrence or non-occurrence of slides and sloughs.

FROST DEPTH PENETRATION

A secondary objective of this study was to determine if depth of frost penetration was influenced by types of vegetation. For this purpose, freeze tubes were installed during the fall of 1981 at selected sites and monitored through the winter of 1981-82. This winter was extremely cold with significant but variable snow cover. An attempt was also made to monitor selected installations in the central part of the state during the winter of 1982-83. However, this winter was unusually mild and so little freezing was observed that no meaningful comparisons are possible. Therefore, the data reported is limited to the winter of 1981-82.

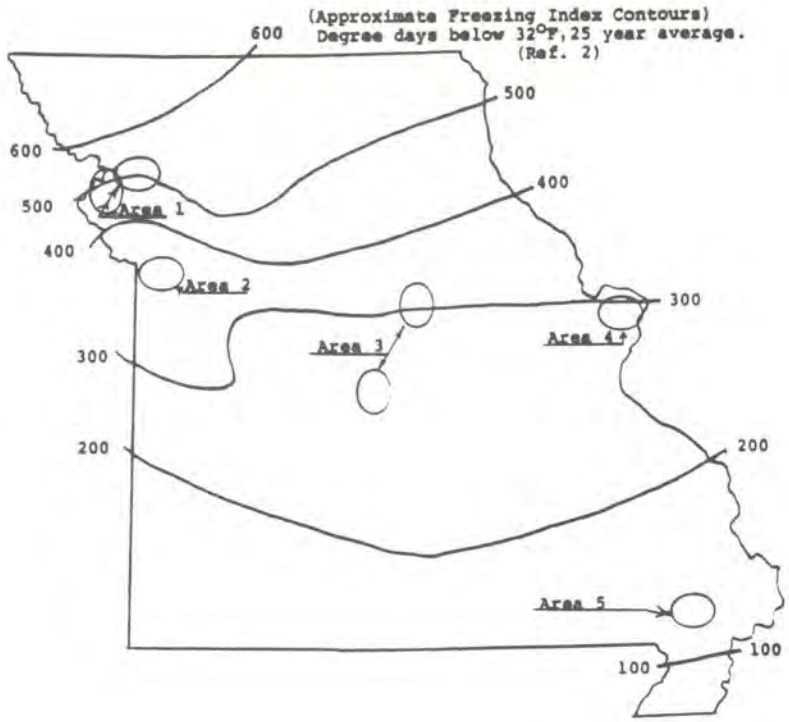

Figure 3, Location of Freeze-Tube Installations

General locations selected for freeze-tube installations are shown in relation to mean freezing index contours in Figure 3. The contours are based on climatological data for a period of 25 or more years[4].

Freeze-tubes were constructed of clear plastic tubing filled with a diluted solution of methylene blue which freezes clear. Flexible 3/8-inch diameter acrylic tubing was plugged at each end and vented at the top. These were installed in casings consisting of 3/4-inch PVC pipe which had been placed in the ground and capped at selected locations to depths of at least 36 inches. Freezing depth was determined by measuring the depth of clear ice above the blue solution in the bottom of the tube.

Table 12 summarizes the various instrumentation sites, the general location, the direction of slope exposure and the type of vegetation immediately surrounding the installation.

TABLE 12
Freeze-Tube Installations

Site No.	Located Near	Slope Faces	Principal Vegetation	Area No.*	Site No.	Located Near	Slope Faces	Principal Vegetation
1	St. Joseph	South	Fescue	3	31	Columbia	East	Crownvetch
2	St. Joseph	South	Fescue	3	32	Columbia	South	Creep. Juniper
3	St. Joseph	North	Fescue	3	33	Columbia	South	Fescue
4	St. Joseph	South	Orchard & Brome	3	34	Columbia	East	Crownvetch
5	St. Joseph	South	Bare slope	3	35	Columbia	East	Bare Slope
6	St. Joseph	North	Orchard & Brome	3	36	Columbia	West	Fescue
7	St. Joseph	South	Crownvetch	3	37	Columbia	West	Bare Slope
8	St. Joseph	North	Fescue	3	38	Columbia	West	Crownvetch
9	St. Joseph	North	Crownvetch	3	39	Columbia	East	Fescue
10	St. Joseph	East	Orchard & Brome	3	40	Columbia	East	Fescue
11	St. Joseph	West	Orchard & Brome	3	41	Columbia	East	Crownvetch
12	Independence	South	Fescue	3	42	Columbia	East	Fescue
13	Independence	North	Crownvetch	3	43	Columbia	East	Fescue
14	Independence	South	Honeysuckle	3	44	Eldon	East	Sericea Les.
15	Independence	North	Orchard & Brome	3	45	Eldon	West	Sericea Les.
16	Independence	South	Crownvetch	3	46	Eldon	East	Crownvetch
17	Independence	South	Orchard & Brome	3	47	Eldon	East	Bare Slope
18	Independence	East	Bare Slope	3	48	Eldon	East	Fescue
19	Independence	North	Honeysuckle	4	49	Kirkwood	East	Fescue
20	Independence	North	Fescue	4	50	Kirkwood	East	Crownvetch
21	Independence	East	Orchard & Brome	4	51	Kirkwood	East	Crownvetch
22	Independence	West	Orchard & Brome	4	52	Kirkwood	West	Fescue
23	Columbia	North	Creep. Juniper	4	53	Kirkwood	West	Bare Slope
24	Columbia	North	Bare Slope	4	54	Kirkwood	North	Crownvetch
25	Columbia	North	Fescue	4	55	Kirkwood	South	Fescue
26	Columbia	West	Fescue	5	56	Sikeston	East	Fescue
27	Columbia	West	Crownvetch	5	57	Sikeston	West	Fescue
28	Columbia	North	Crownvetch	5	58	Sikeston	West	Bermuda
29	Columbia	East	Creep. Juniper	5	59	Sikeston	North	Fescue
30	Columbia	East	Crownvetch	5	60	Sikeston	South	Bermuda

*See Figure 3

Freezing depths at each location, snow cover, and daily local temperature extremes are plotted on Figures 4 through 35. Table 13 summarizes average and maximum freezing depths for the principal vegetation types by slope exposure direction while Table 14 summarizes average and average maximum freezing depths recorded for all vegetation types including bare slopes. "Average freezing depths" are

TABLE 13

Average Depths of Frost Penetration in Inches
for
Principal Vegetation Types by Slope Exposure Direction

		Direction Faced by Slope											
		East			West			North			South		
Veg.	Area*	No.	Avg.	Max.	No.	Avg.	Max.	No.	Avg.	Max.	No.	Avg.	Max.
Fescue	1	-	-	-	1	5.0	16.8	2	8.4	17.4	2	5.5	10.4
"	2	-	-	-	-	-	-	1	7.0	13.9	1	3.5	9.4
"	3	4	6.7	14.1	2	7.2	15.1	1	8.0	15.7	1	2.6	6.4
"	4	1	4.9	13.3	2	7.7	16.0	-	-	-	1	1.8	7.3
"	Avg. 2, 3 & 4	-	5.8	13.7	-	7.5	15.6	-	7.5	14.8	-	2.6	7.7
"	5	1	1.0	4.6	1	1.3	4.5	1	2.8	5.2	-	-	-
Crownvetch	1	-	-	-	-	-	-	1	5.6	13.5	1	5.0	8.5
"	2	-	-	-	-	-	-	1	3.9	6.5	1	1.4	4.2
"	3	5	5.1	11.5	2	8.8	15.8	1	10.0	17.8	1	4.1	9.5
"	4	1	3.6	9.2	-	-	-	1	7.8	13.5	-	-	-
"	Avg. 2, 3 & 4	-	4.4	10.4	-	-	-	-	7.2	12.6	-	2.8	6.9
Orchard & Brome Grass	1	2	9.9	18.2	1	8.2	15.5	-	-	-	1	9.0	16.7
"	2	1	4.7	9.5	1	4.1	11.8	1	5.7	10.5	1	3.9	10.2

* Reference Figure 3

referenced to a common time frame which is the longest period for which frost was recorded at any site in the state, regardless of latitude. "Average maximum freezing depths" are averages of actual maximums for the indicated areas as referenced to Figure 3. It should also be noted that "bare" as used here means that the ground around the installation is essentially barren of all vegetation and is not to be interpreted as an indicator of relative vegetation density as in the slope survey portion of this study.

Direct comparison of the various sites is complicated by many factors, most notably snow cover depth, soil moisture, latitude, degree of slope and slope orientation. However, some trends seem evident when comparisons are restricted to sites within the same general latitudes or zones of mean freezing index contours as shown in Figure 3. Those sites in Area 1 are in a somewhat colder zone than those sites in Areas 2, 3, and 4 where climatic differences are small and for which data can be averaged and compared. Sites in Area 5 are in a much warmer zone.

Average frost depths recorded in Area 5 in the southeast lowlands were relatively insignificant, averaging only 1.7 inches and with only a 5.2 inch maximum depth. These are only about one third of the magnitude of the frost depths recorded, both average and maximum, in the central and northwestern parts of the State. Moreover, Figures 26 through 29 indicate that there was no snow cover to mitigate freezing depths at these sites. The freezing depths recorded seemed unlikely to be a source of slope degradation in this part of the state. The same cannot be said of the freezing depths recorded in the central and northwest part of the state which appear sufficient to normally exceed the depth reinforced by the root zones of most sods. While the reported data was recorded during a winter which was considered severe, none of the freezing depths came close to the maximum values reported in standard tables and charts for Missouri. In general, the maximum values cited in the literature exceed the maximum observed values by factors of 2 to 3.

Table 13 indicates significant variation in recorded freezing depths as a function of the direction faced by the slope. As would be expected, north facing slopes have the greatest freezing depth, followed closely by west facing, and then by east and south facing slopes. In general, south facing slopes were found to freeze to depths of only 1/2 to 1/3 that of north and west facing slopes.

The prevalent vegetation types at the instrumentation sites were fescue, orchard and brome grass, crownvetch, creeping juniper, honeysuckle and bermuda grass. Fescue was the only vegetation type occurring in all the five areas studied.

There appears to be a somewhat greater overall average freezing depth associated with fescue than with crownvetch and orchard and brome grasses. However, the difference is slight (10-15%) and may well be attributable to other variables. The most dramatic increase in freezing depths was observed beneath the installations covered by creeping juniper. Presumably this can be attributed to the drying effect as a consequence of continued moisture demand during the winter. The least frost penetration depths in the central or northwestern parts of the State were measured at two sites with Sericea lespedeza cover. As will be noted later, soil moisture contents of these sites were particularly high.

TABLE 14

Average Frost Penetration Depth Under Various Vegetative Covers

Location*	Vegetation Type	Avg. Depth In.	Avg. Max. Depth In.
Area 1	Fescue	6.3	14.9
	Orchard & Brome Grass	9.0	16.8
	Crown Vetch	5.3	11.0
	Bare Slope	4.8	10.4
Areas 2, 3 & 4 Combined	Fescue	5.4	12.2
	Orchard & Brome Grass	4.6	10.5
	Crown Vetch	4.8	10.0
	Honeysuckle	6.5	11.8
	Creeping Juniper	9.9	20.3
	Sericea Lespedeza	2.3	3.5
	Bare Slope	4.9	12.2
Area 5	Fescue	1.7	4.8
	Bermuda Grass	0.4	1.1

*Reference Figure 3

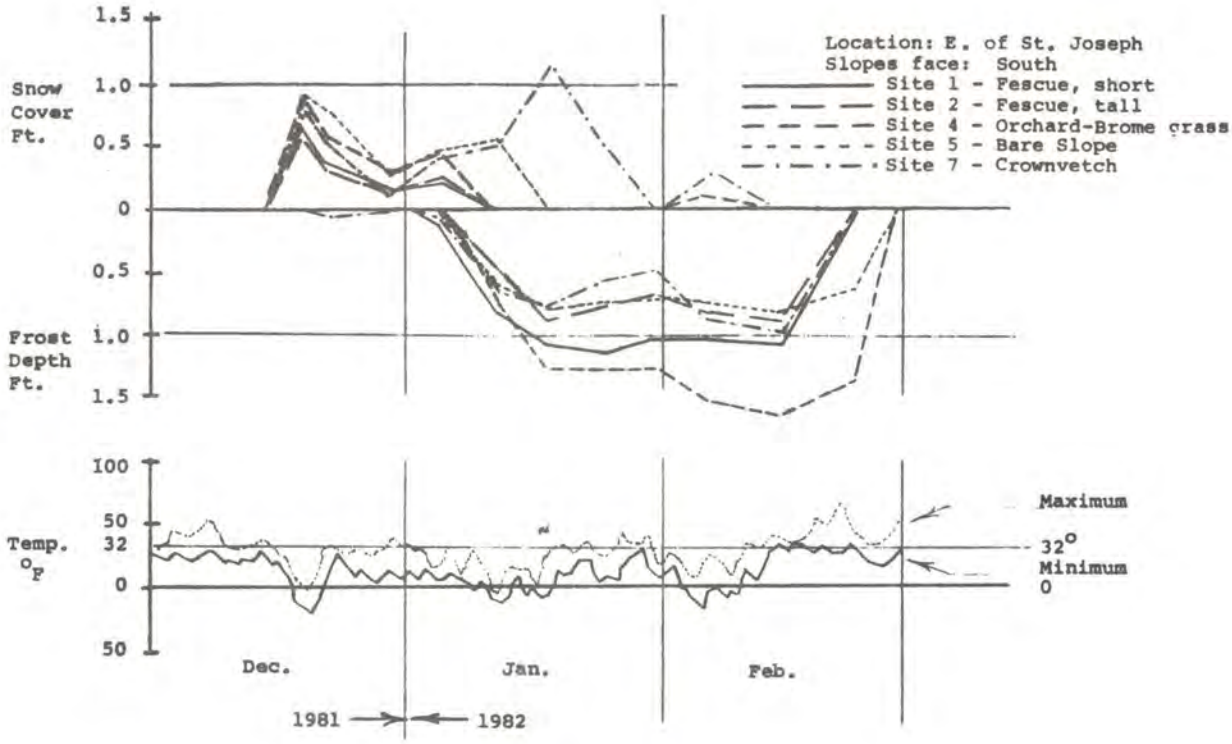

Figure 4, Frost Penetration Diagram for Sites 1,2,4,5,& 7.

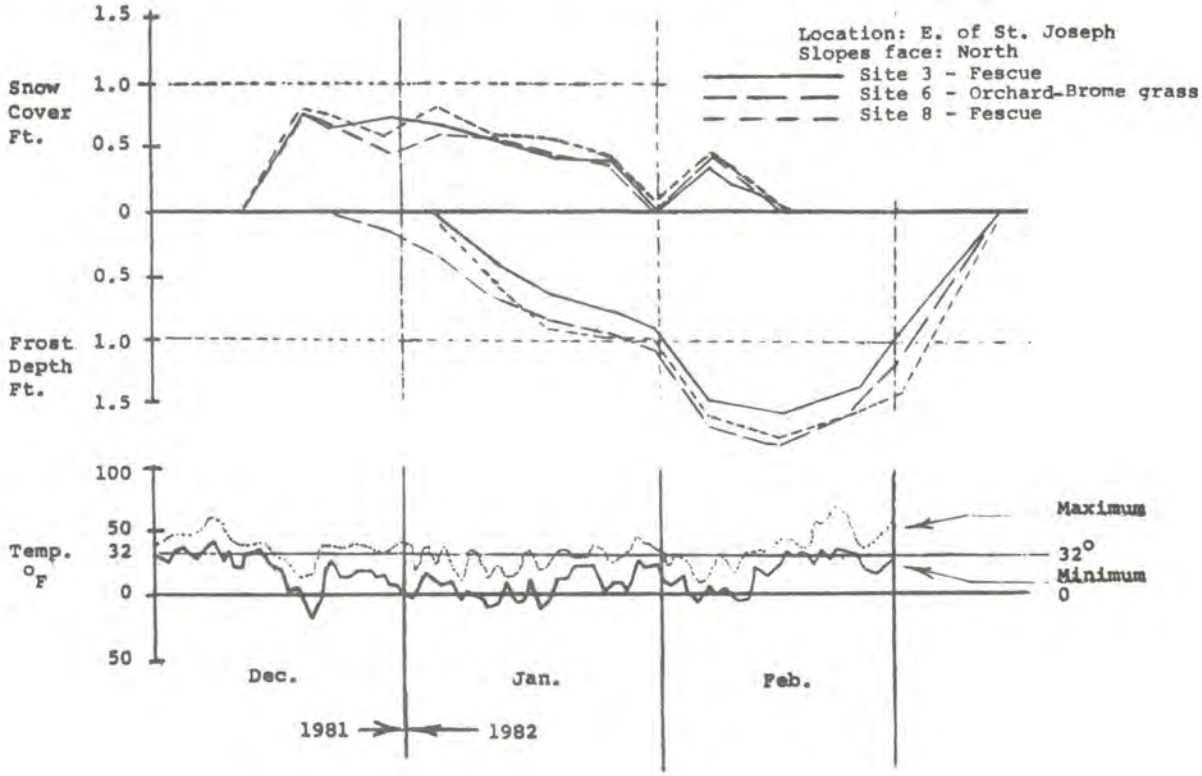

Figure 5, Frost Penetration Diagram for Sites 3,6,& 8.

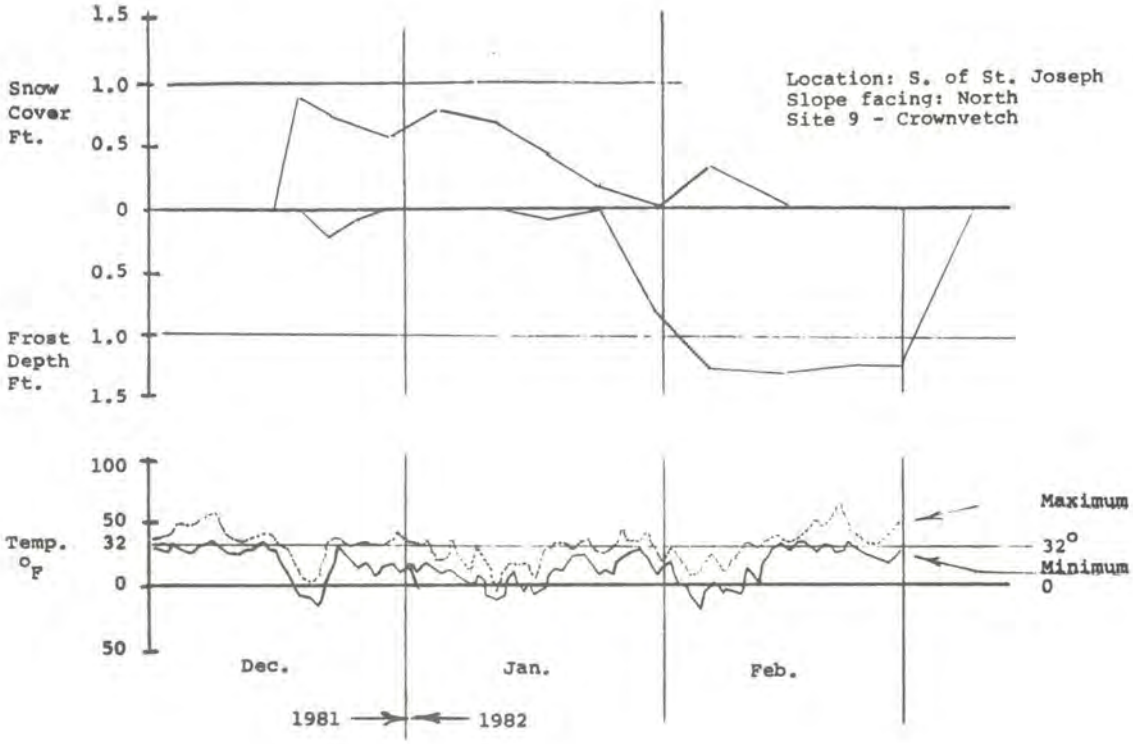

Figure 6, Frost Penetration Diagram for Site 9.

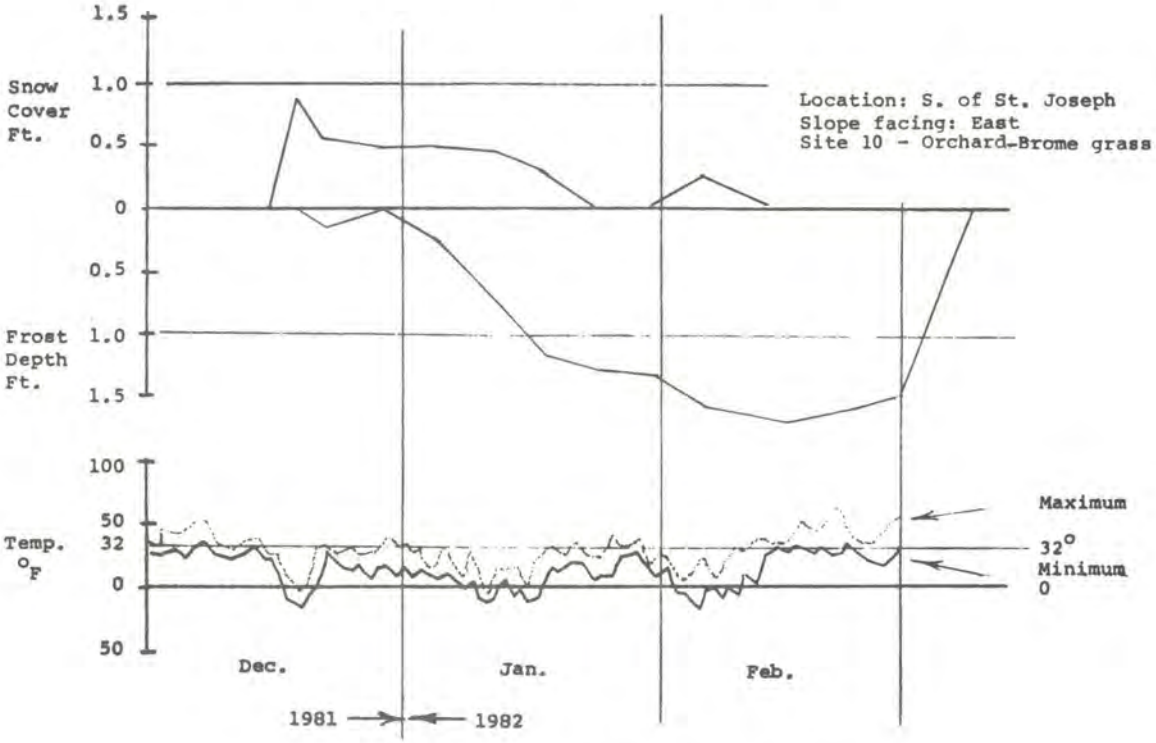

Figure 7, Frost Penetration Diagram for Site 10.

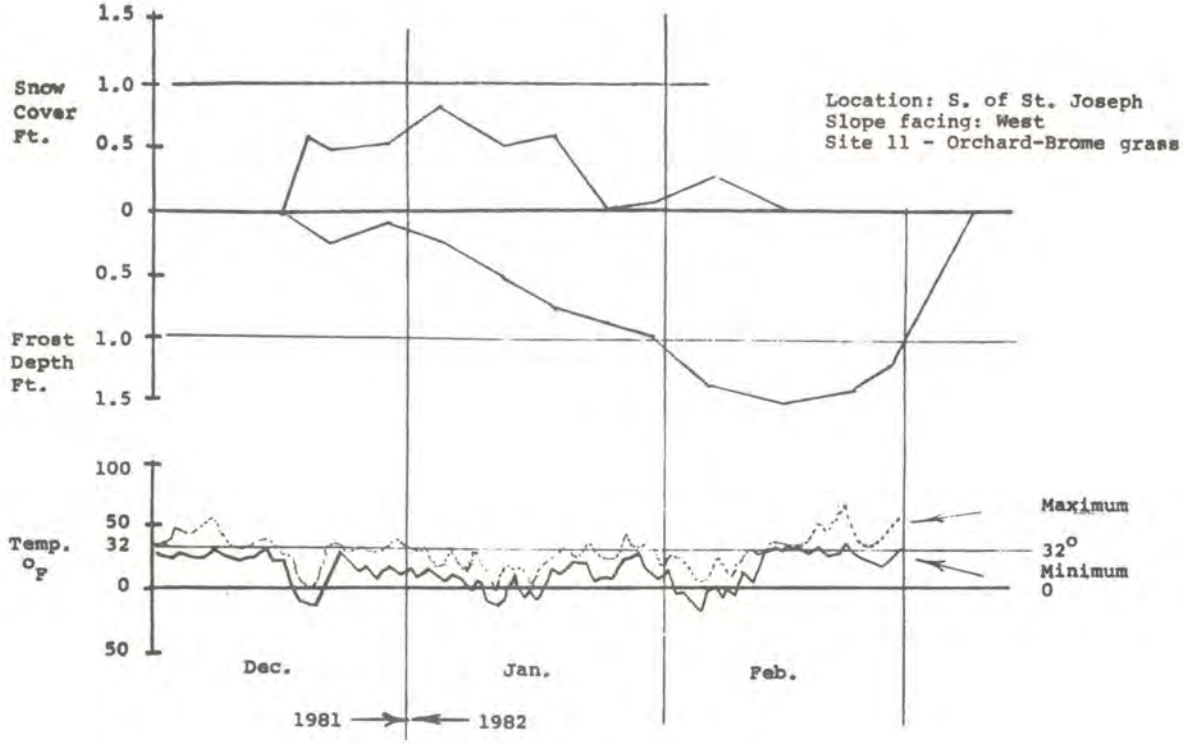

Figure 8, Frost Penetration Diagram for Site 11.

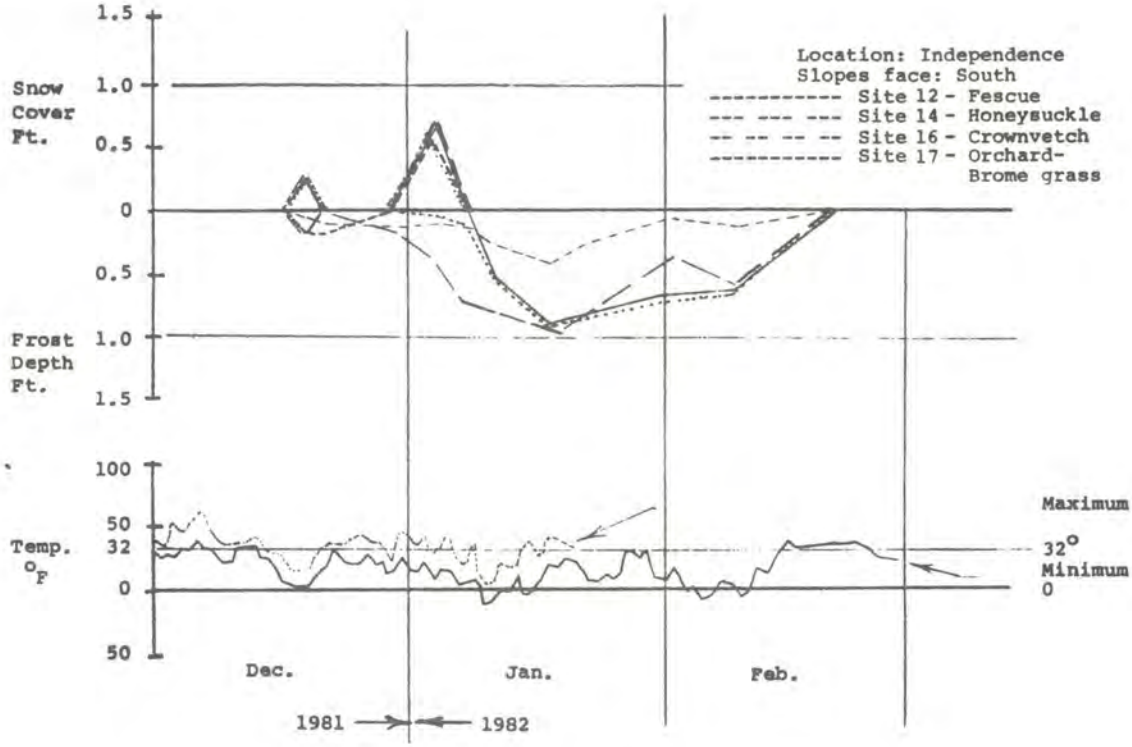

Figure 9, Frost Penetration Diagram for Sites 12,14 16&17.

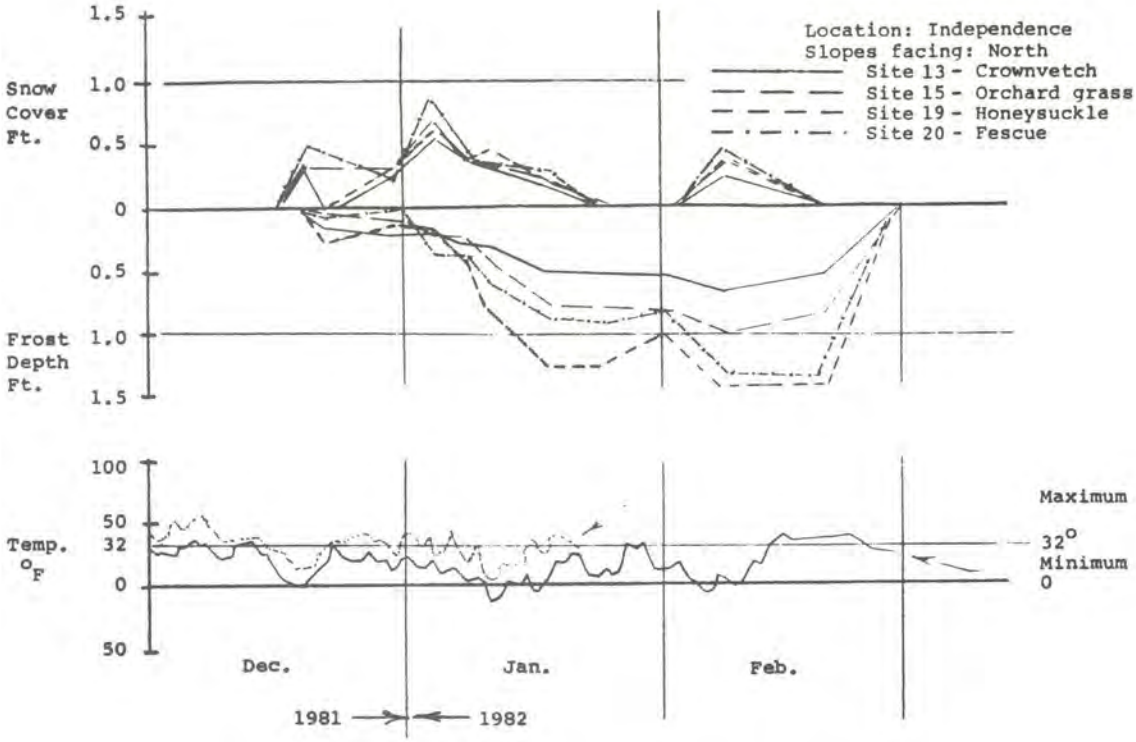

Figure 10, Frost Penetration Diagram for Sites 13,15,19&20.

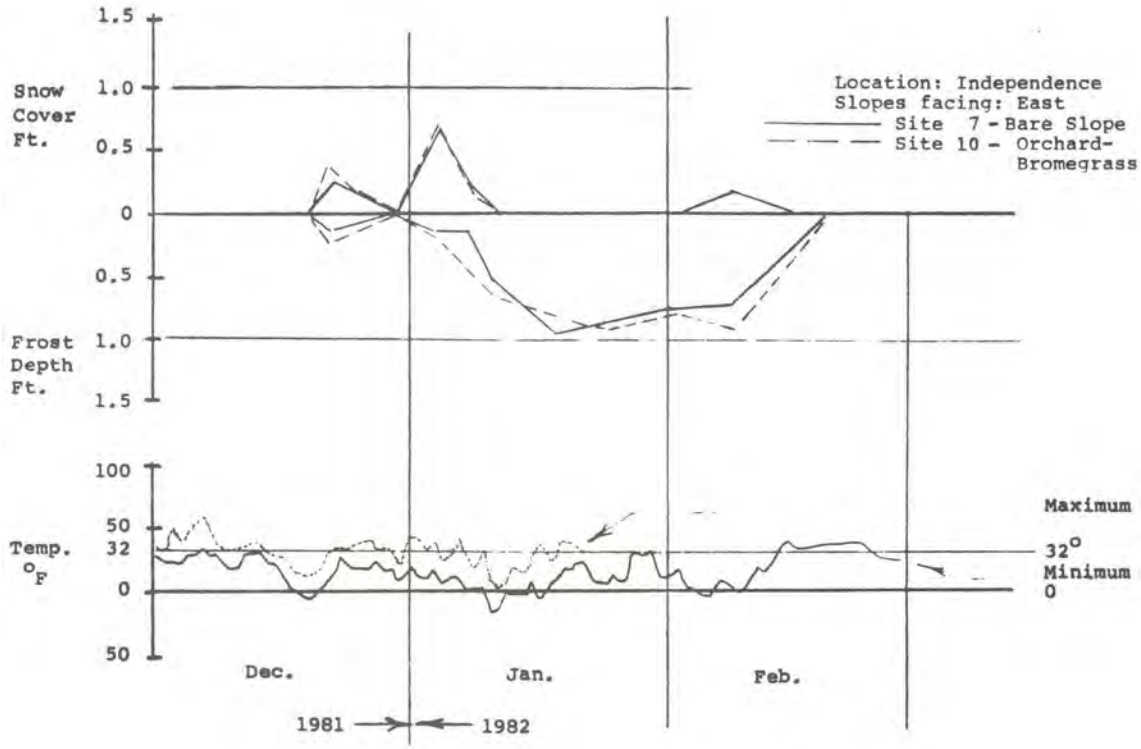

Figure 11, Frost Penetration Diagram for Sites 18&21.

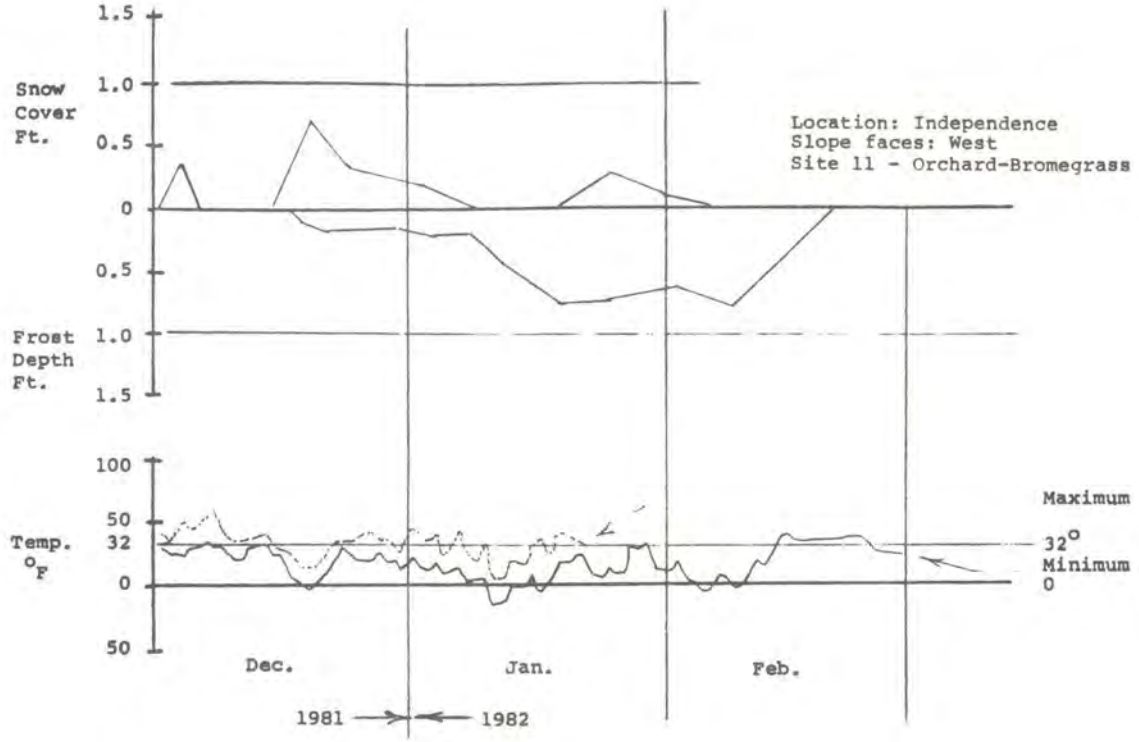

Figure 12, Frost Penetration Diagram for Site 22.

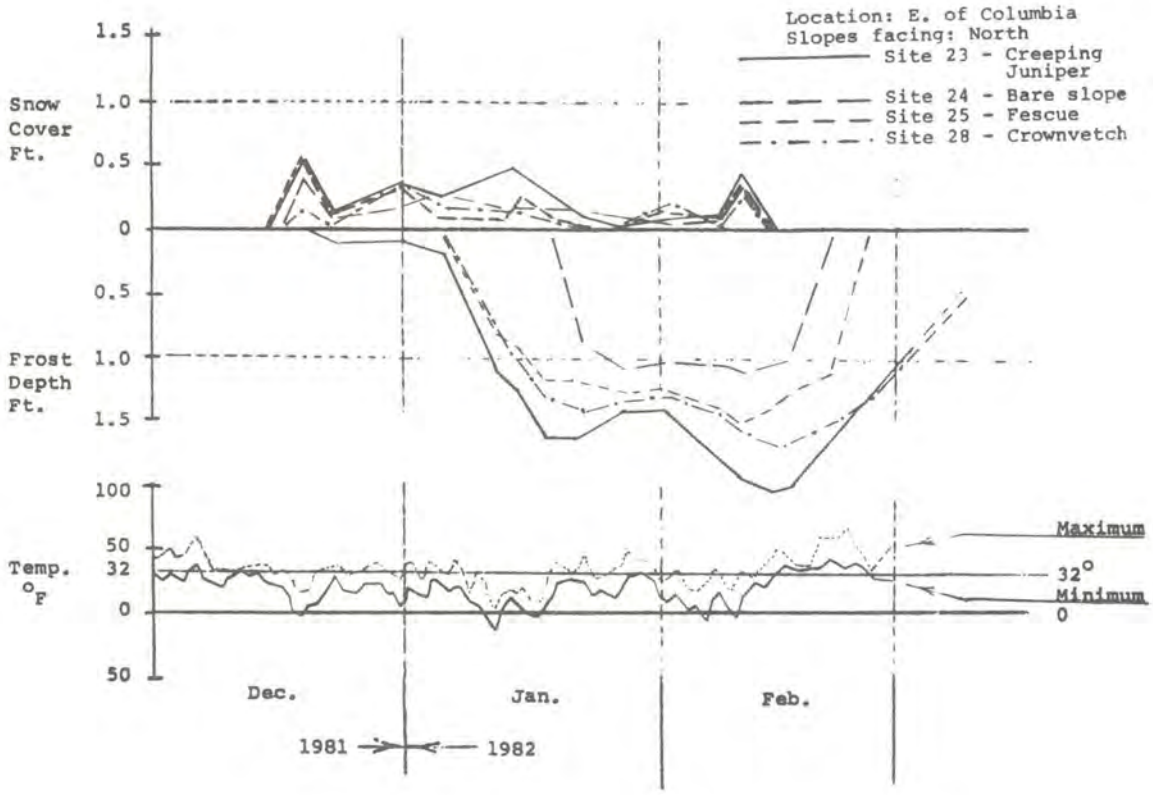

Figure 13, Frost Penetration Diagram for Sites 23,24,25&28.

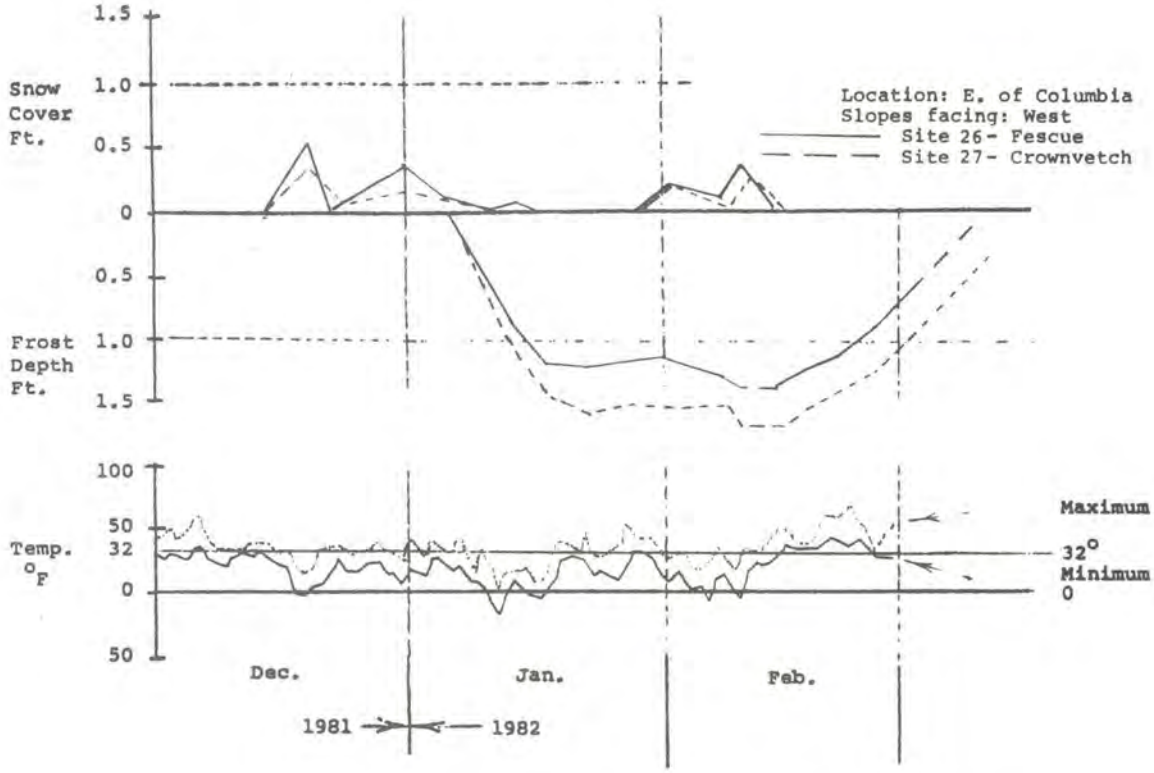

Figure 14, Frost Penetration Diagram for Sites 26&27.

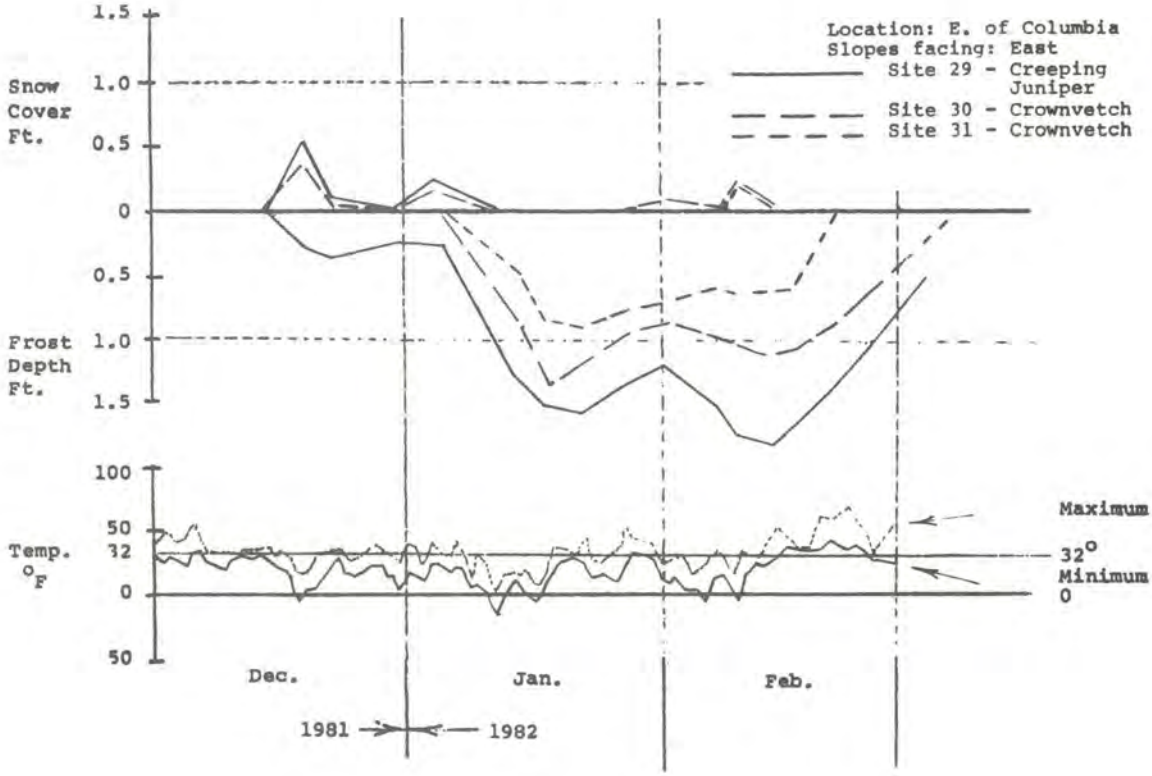

Figure 15, Frost Penetration Diagram for Sites 29,30&31.

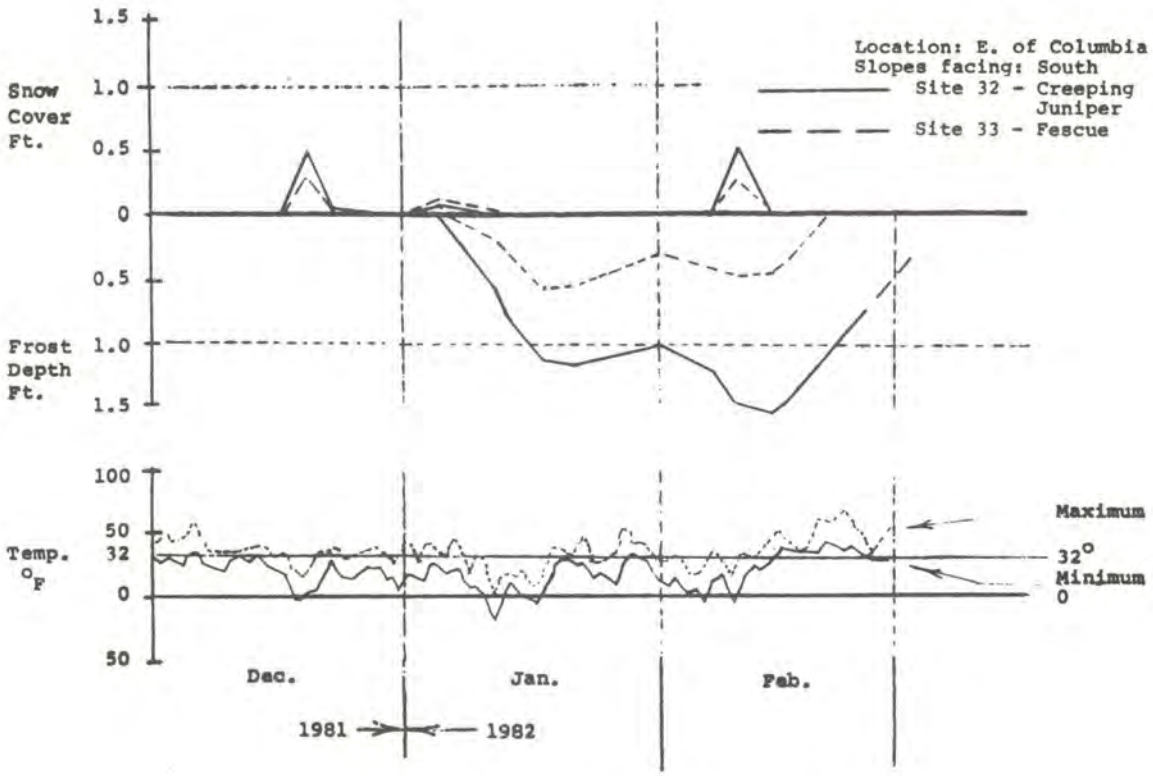

Figure 16, Frost Penetration Diagram for Sites 32&33.

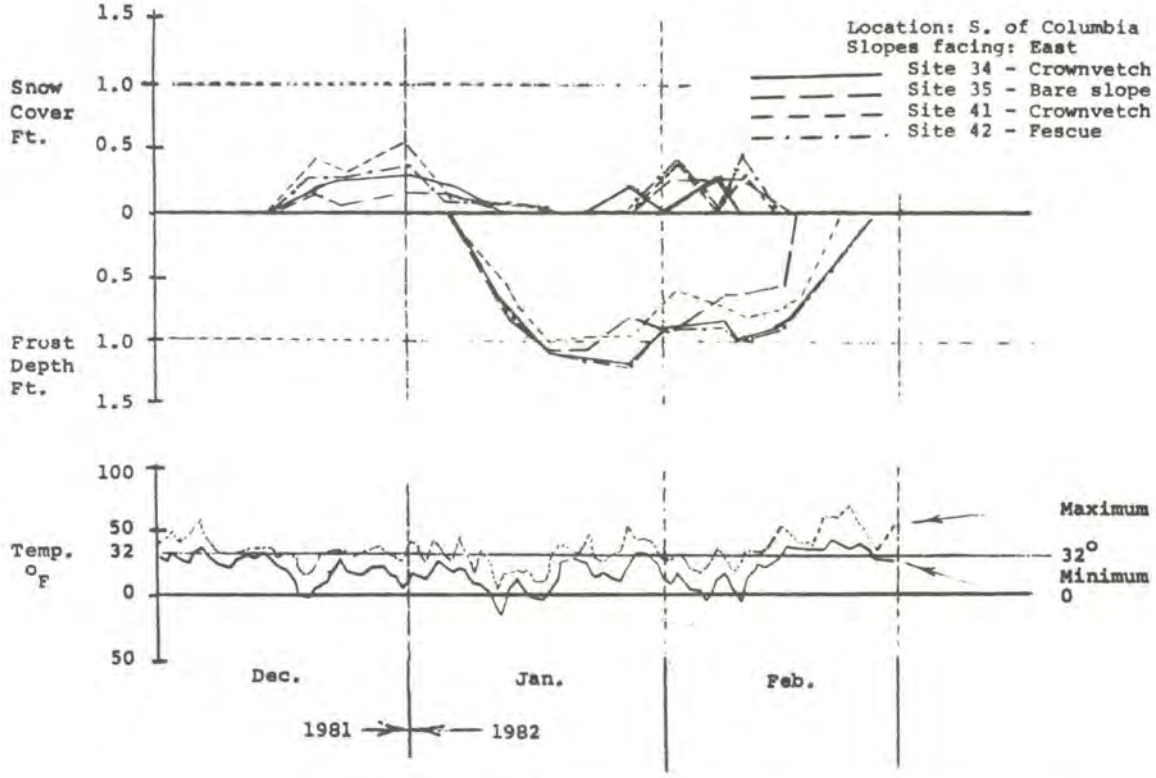

Figure 17, Frost Penetration Diagram for Sites 34,35,41&42.

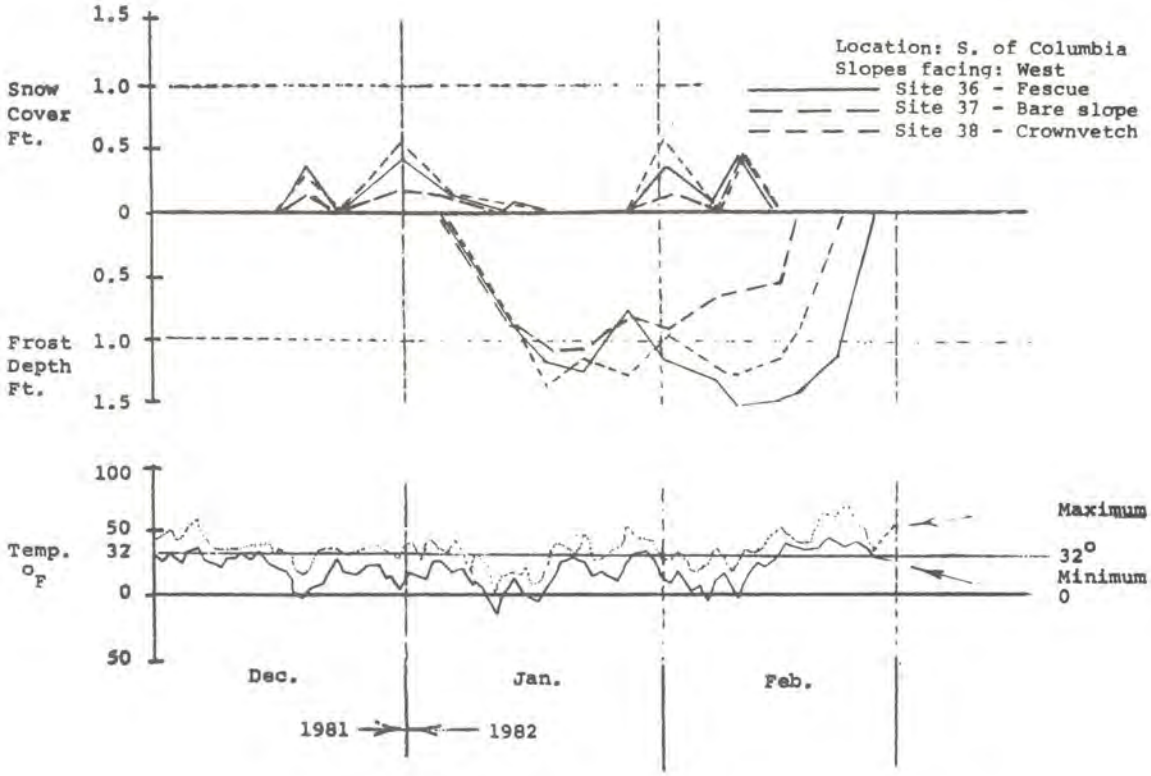

Figure 18, Frost Penetration Diagram for Sites 36,37&38.

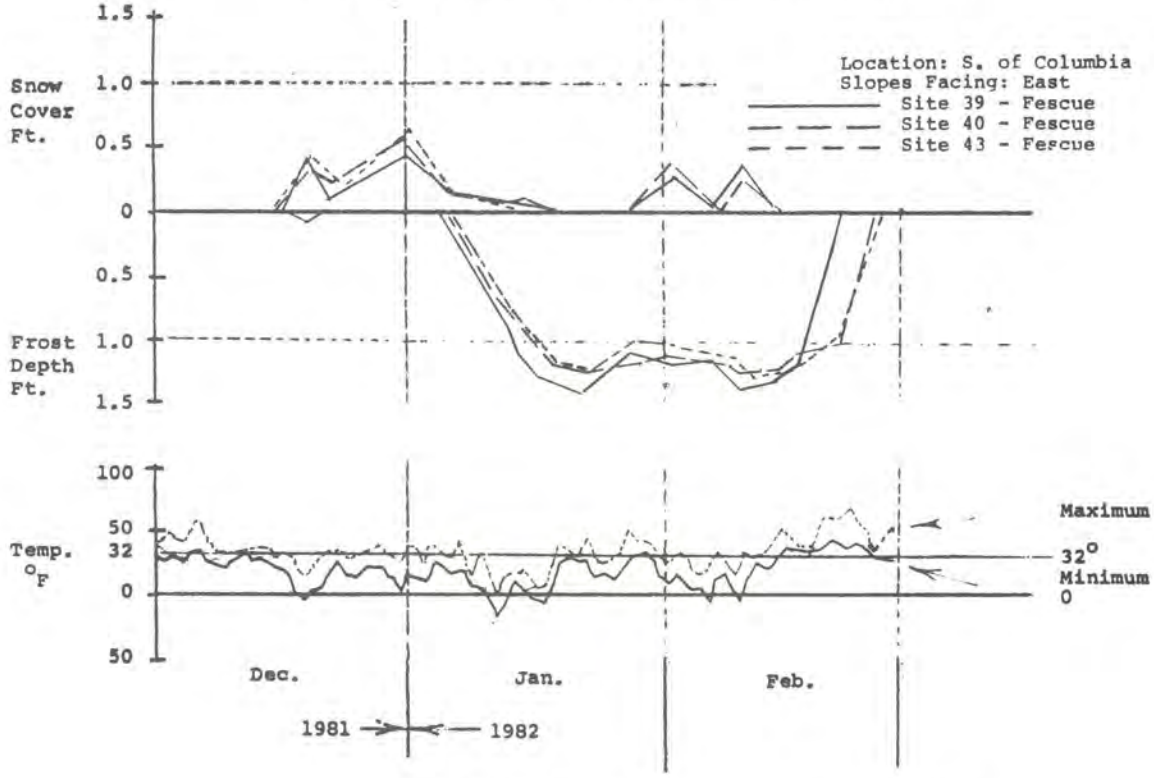

Figure 19, Frost Penetration Diagram for Sites 39,40&43.

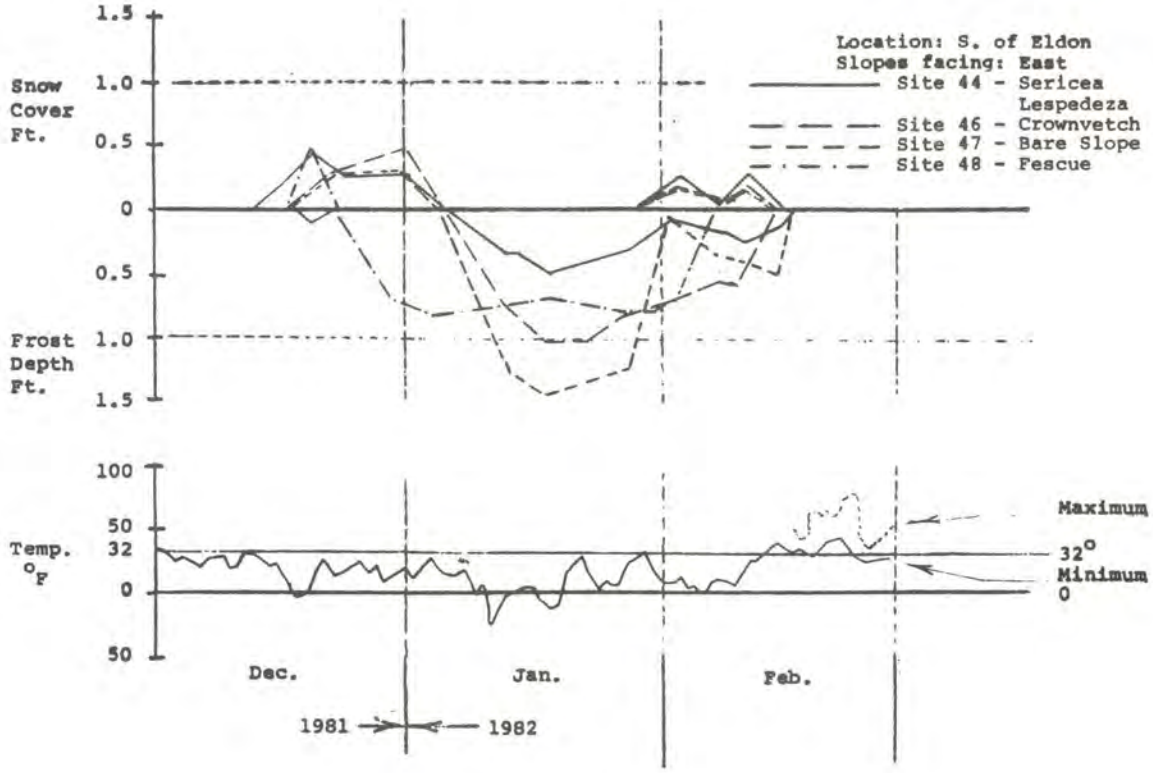

Figure 20, Frost Penetration Diagram for Sites 44,46,47&48

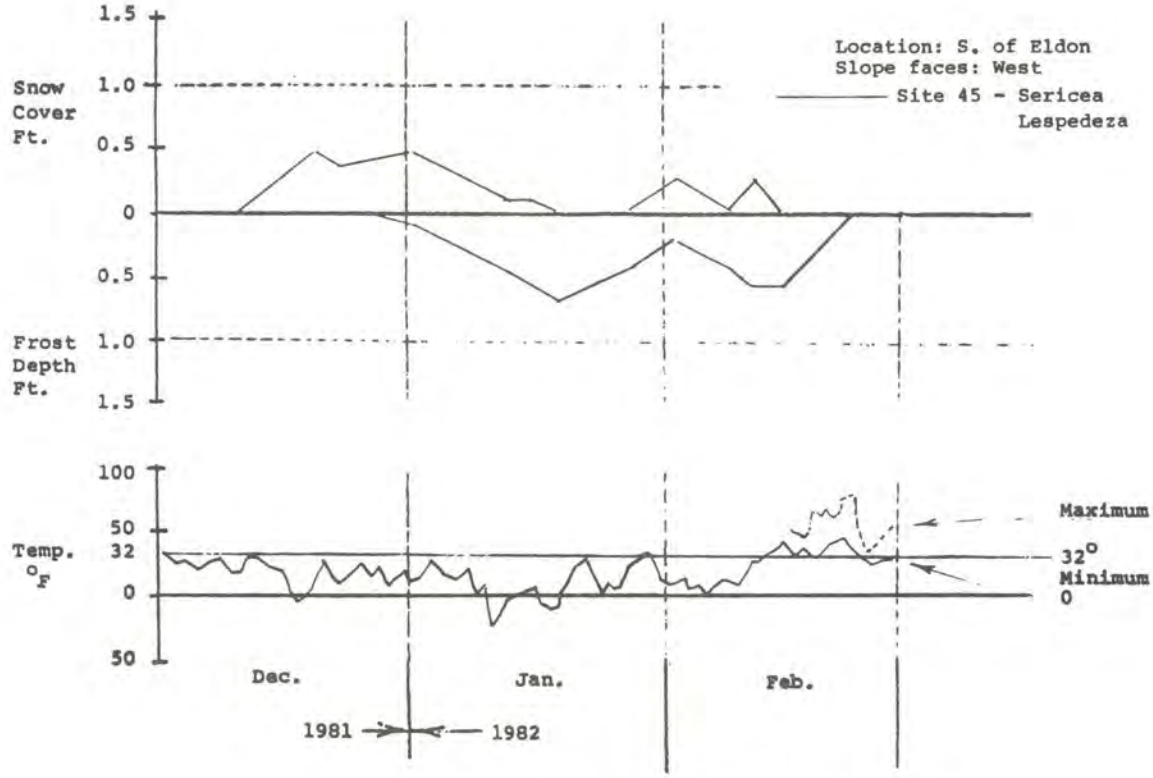

Figure 21, Frost Penetration Diagram for Site 45.

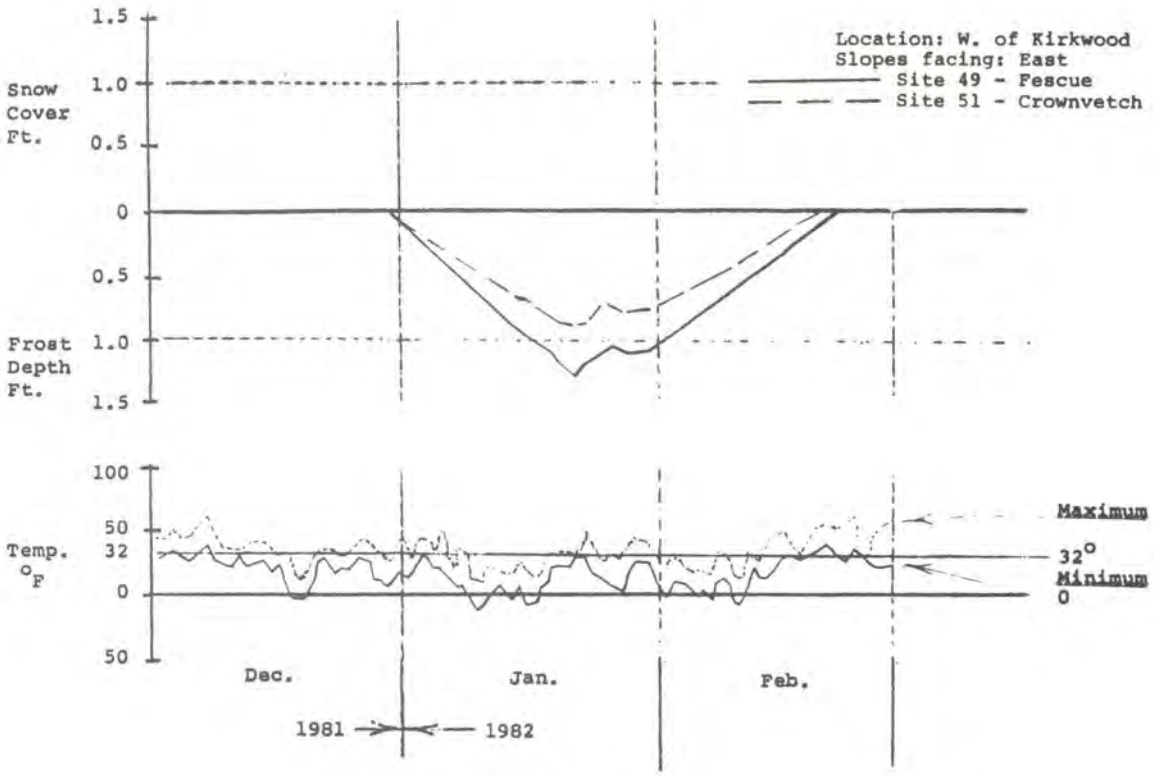

Figure 22, Frost Penetration Diagram for Sites 49&51.

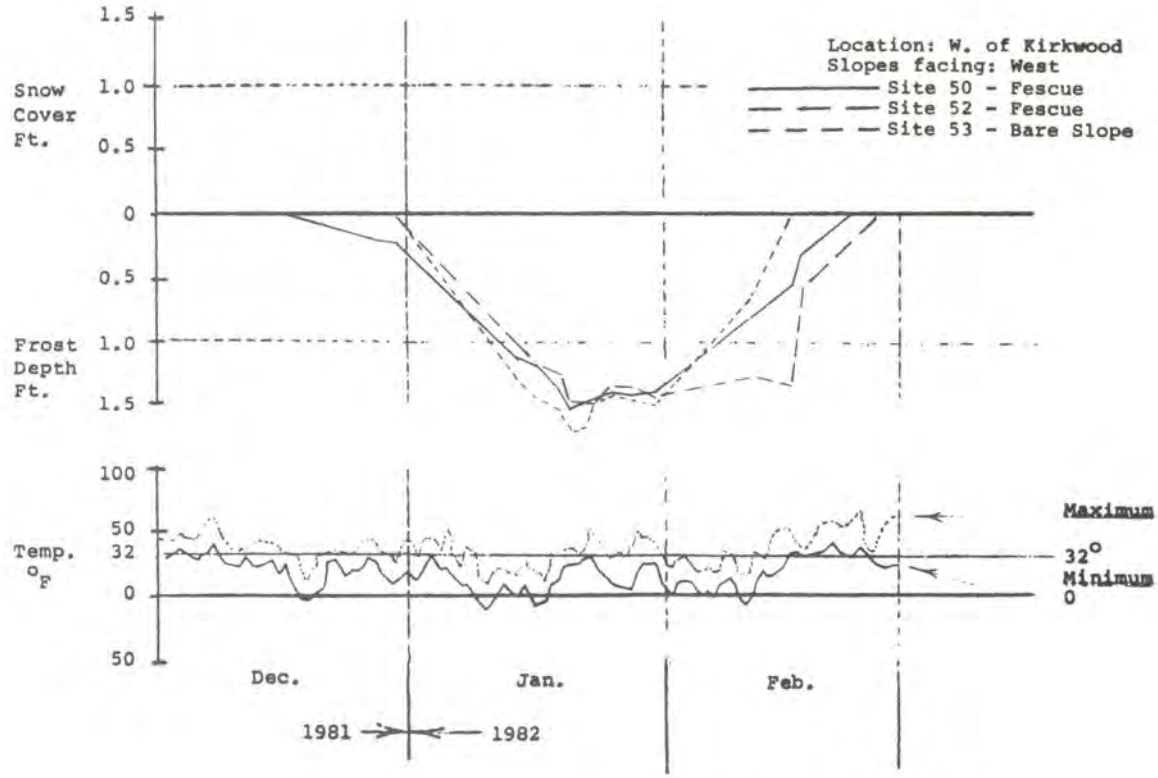

Figure 23, Frost Penetration Diagram for Sites 50,52&53.

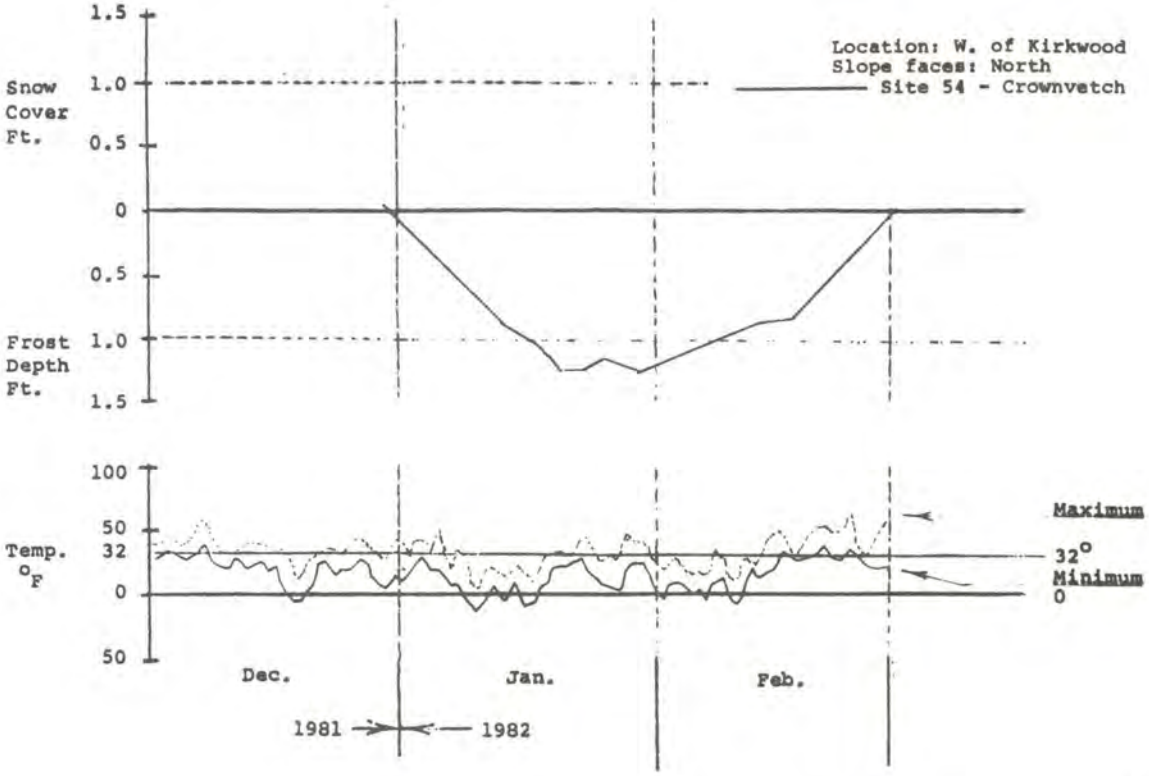

Figure 24, Frost Penetration Diagram for Site 54.

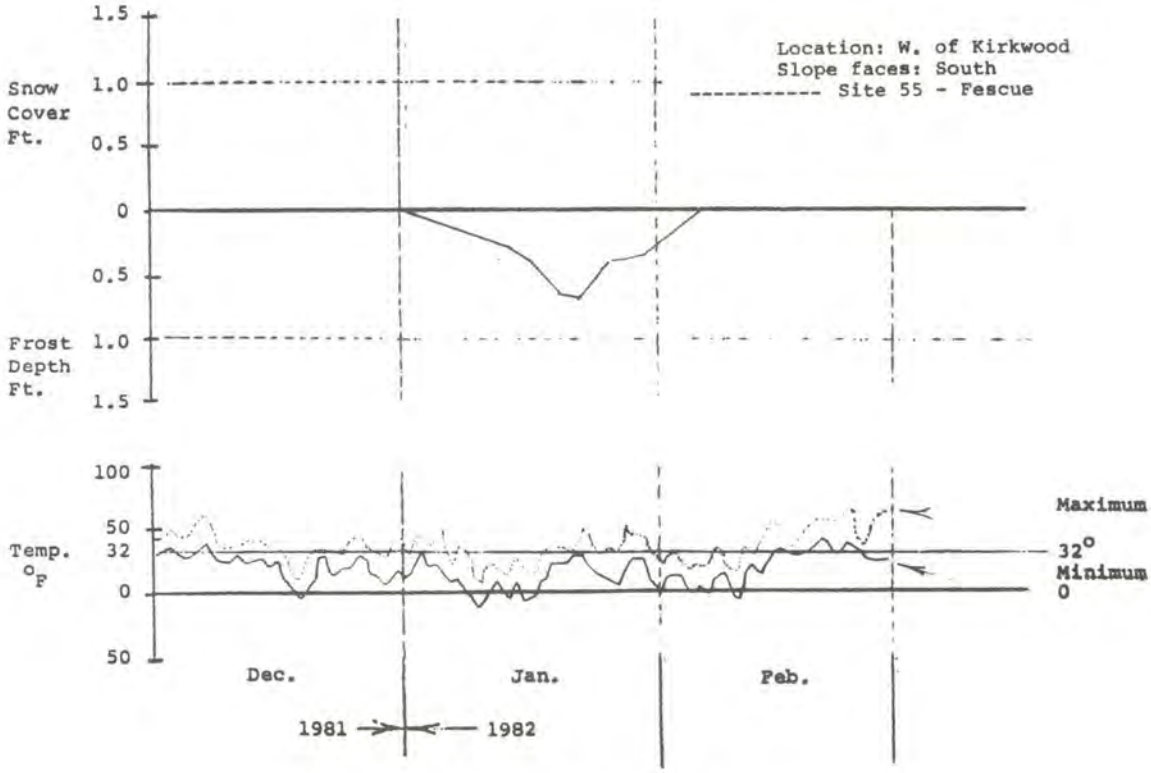

Figure 25, Frost Penetration Diagram for Site 55.

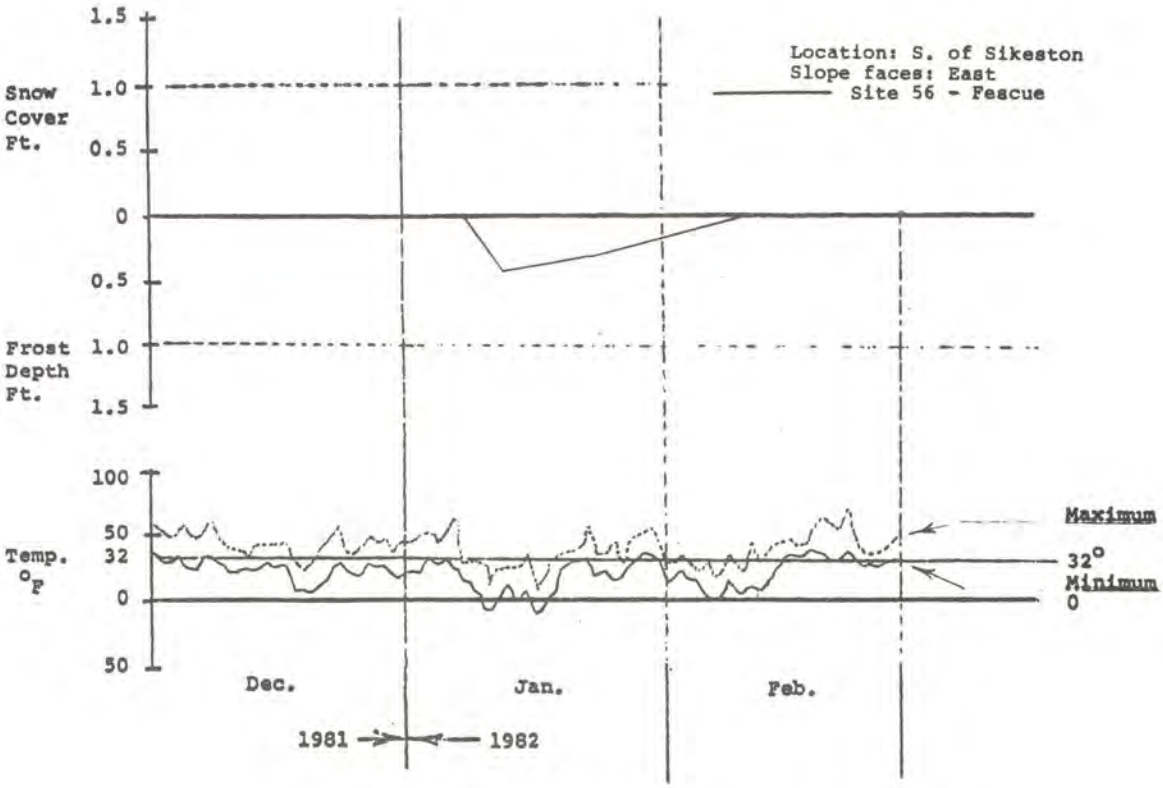

Figure 26, Frost Penetration Diagram for Site 56.

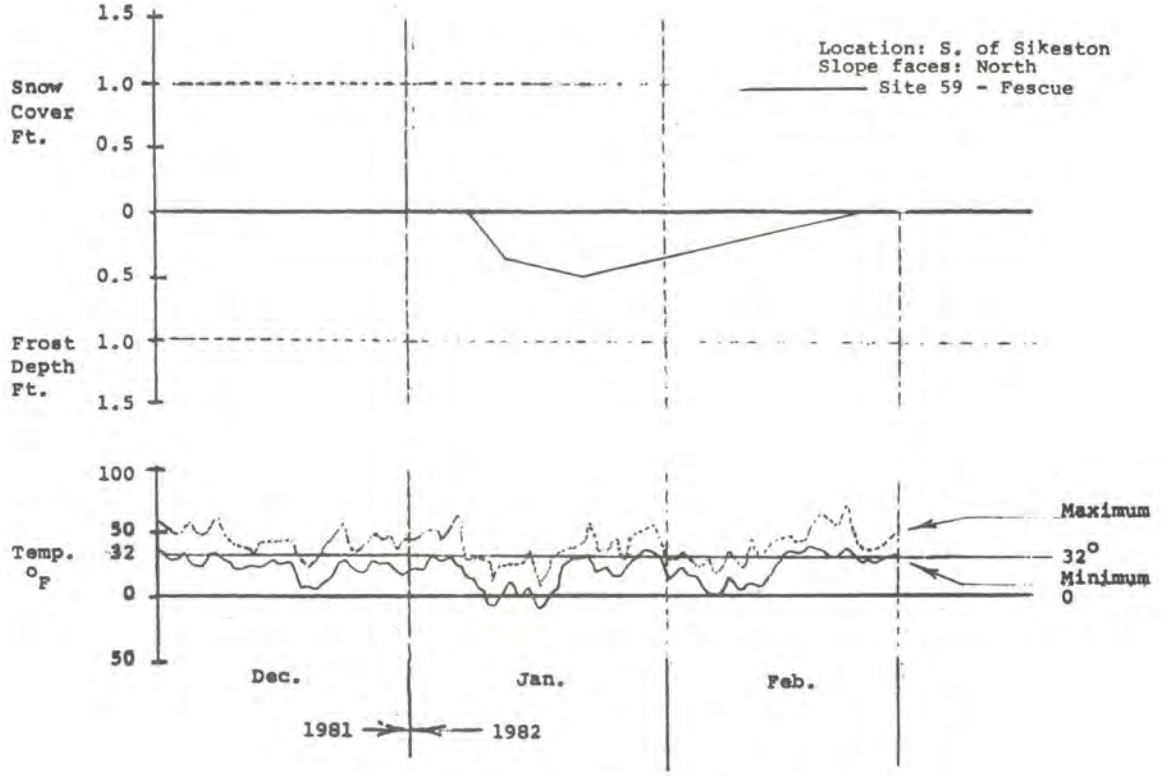

Figure 27, Frost Penetration Diagram for Site 59.

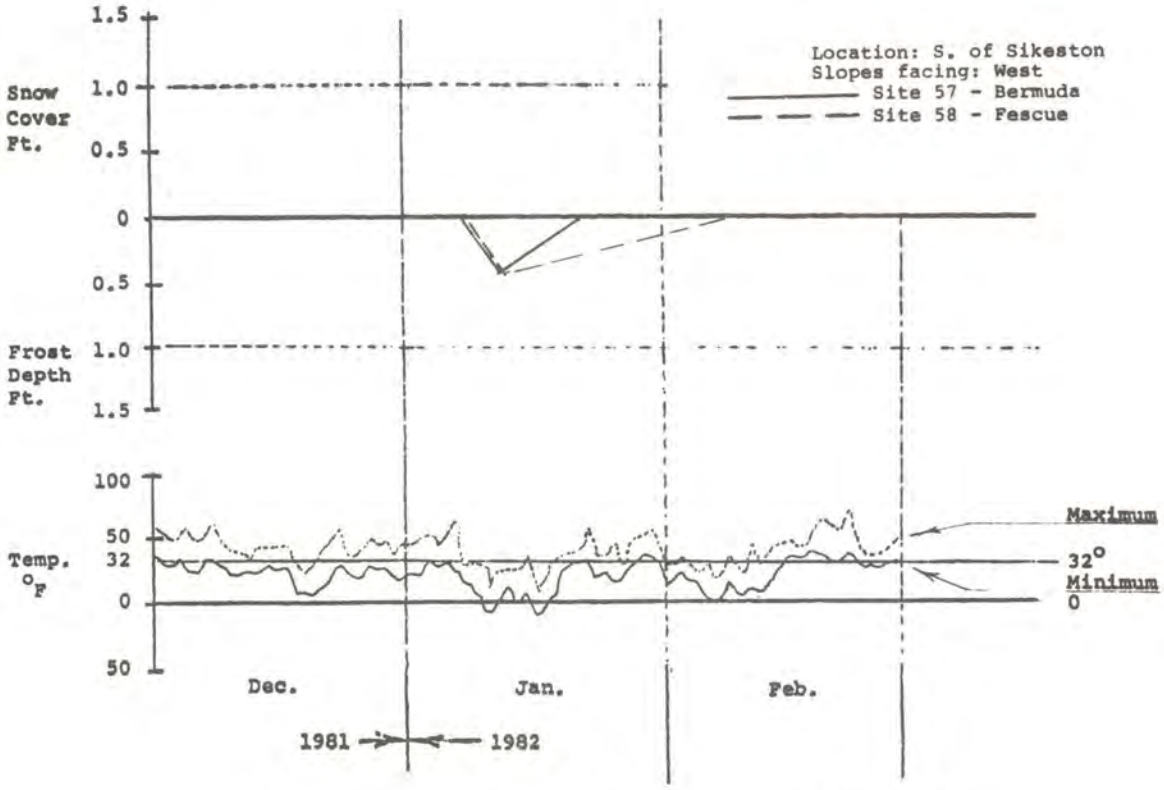

Figure 28, Frost Penetration Diagram for Sites 57&58.

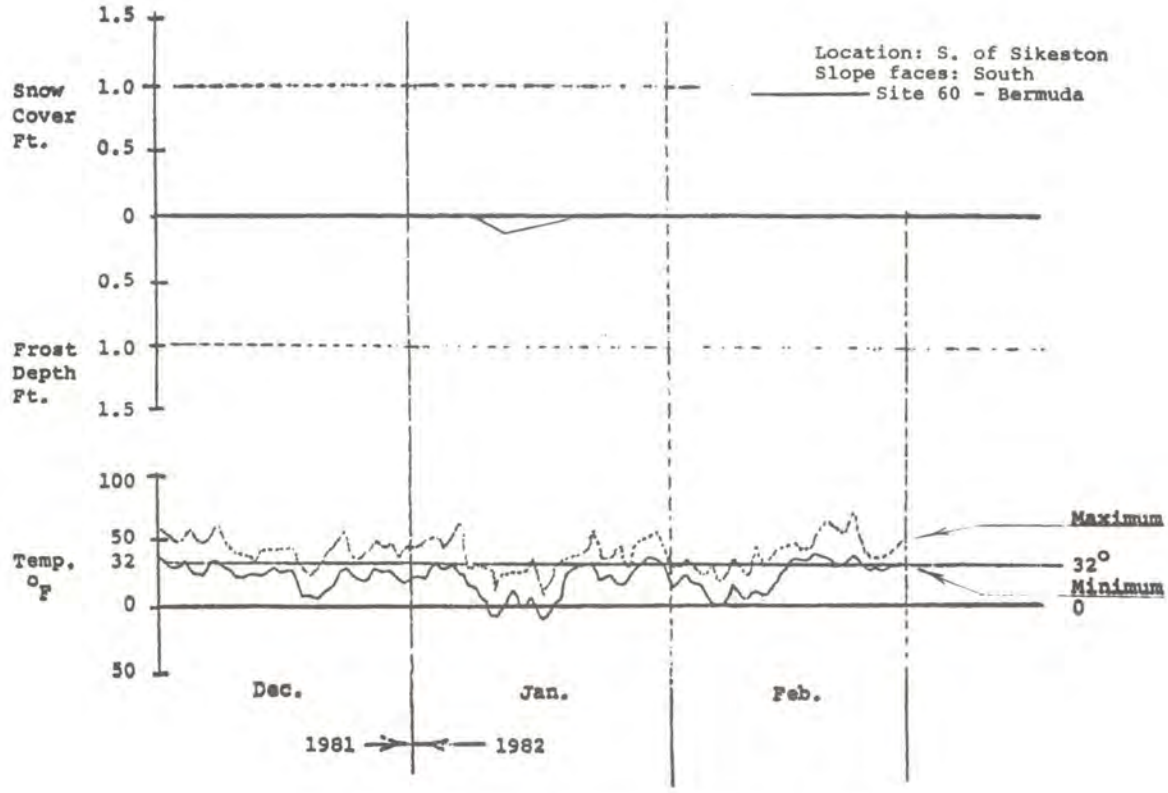

Figure 29, Frost Penetration Diagram for Site 60.

It is concluded that, within similar climatic zones and conditions, there was little significant difference between overall average freezing depths beneath most of the vegetation types studied and even beneath bare ground. The most notable exception was the much greater freezing depth beneath creeping juniper. The much lesser observed freezing depth beneath the two sites covered with Sericea lespedeza deserves further study to determine whether or not this was an anomalous condition.

SOIL MOISTURE CONTENTS

Soil moisture content samples were secured in the fall of 1981 and the spring and fall of 1982 at most of the sites where frost tube indicators were installed. Samples were obtained at 6 inch intervals to a maximum depth of 30 inches except where prevented by high rock content in the soils (for example the sites under Sericea lespedeza cover where rocky residual soils severely limited ability to secure samples).

TABLE 15

Soil Moisture Contents (Wn) By Depth Increment and Slope Exposure
Averaged For All Sites

Depth	Fall, 1981 Avg. Wn %, For Slopes Facing					Spring, 1982 Avg. Wn %, For Slopes Facing					Fall, 1982 Avg. Wn %, For Slopes Facing				
	N	E	S	W	Avg.	N	E	S	W	Avg.	N	E	S	W	Avg.
6"	26.5	20.6	20.6	23.2	23.2	30.3	23.6	23.7	24.5	26.0	22.3	22.0	21.5	22.3	22.2
12"	23.6	21.3	20.6	22.4	22.4	28.1	23.1	23.7	26.4	25.8	26.4	20.4	25.3	23.5	24.4
18"	25.6	21.3	20.7	23.4	23.4	26.0	22.5	23.1	23.6	24.5	27.3	23.7	21.4	22.5	24.4
24"	24.8	21.3	20.4	22.5	22.5	25.0	21.1	22.7	23.4	23.4	25.3	21.4	23.8	24.2	24.0
30"	23.7	22.0	19.8	22.3	22.3	25.4	23.0	22.5	23.1	23.9	24.3	24.3	22.7	22.7	23.9
Avg.	24.8	21.3	20.4	24.4	22.8	26.9	22.7	23.1	24.2	24.7	25.5	22.4	23.6	23.0	24.1

All available data were averaged by depth increment for all slope exposures and vegetation types in Table 15. This table shows that north and west facing slopes were wettest and south facing slopes driest. Average moisture contents did not vary greatly by depth increment but were somewhat higher in the fall in the 12 to 18-inch depth range and lowest in the spring at the 24 to 30-inch depths. In the spring, soil moistures had increased at all depths, but were highest toward the surface.

All moisture contents were averaged for each area and vegetation type, in Table 16, for each season sampled and by direction of slope exposure. Average plasticity indexes were also included to aid in interpretation of the significance of the indicated values. For example, the two sites in Area 5 had abnormally low moistures which can be attributed

TABLE 16

Average Soil Moisture Contents

Area*	Vegetation Type	Avg. PI	Fall 1981 Slope Facing N	E	S	W	Spring 1982 Slope Facing N	E	S	W	Fall 1982 Slope Facing N	E	S	W
1	Orchard & Brome	17.3	18.1	--	28.8	--	23.0	32.9	22.1	28.2	23.5	29.1	25.4	28.6
1	Fescue	18.1	--	--	19.8	--	27.9	--	22.7	--	31.5	--	22.6	--
1	Crownvetch	22.6	--	--	23.6	--	26.5	--	24.6	--	30.8	--	15.3	--
1	Bare	25.3	--	--	24.3	--	--	--	31.6	--	--	--	32.3	--
2	Orchard	24.0	25.2	23.5	25.7	28.2	26.1	25.9	28.5	28.9	31.0	25.8	21.9	27.0
2	Fescue	22.5	24.2	--	--	--	30.1	--	--	--	26.9	--	--	--
2	Crownvetch	23.1	27.0	--	25.2	--	23.2	--	29.0	--	23.8	--	20.7	--
2	Honeysuckle	23.6	25.2	--	27.2	--	30.1	--	26.3	--	25.8	--	20.7	--
2	Bare	20.0	--	23.9	--	--	--	26.2	--	--	--	24.8	--	--
3	Fescue	20.4	--	--	19.6	--	--	--	22.3	--	--	--	20.9	--
3	Crownvetch	18.7	--	22.3	--	--	--	23.1	--	--	--	19.3	--	--
3	Creep. Jun.	18.0	22.0	--	20.7	--	23.6	--	23.7	--	21.1	--	24.0	--
3	Ser. Les.	23.4	--	33.5	--	--	--	37.7	--	26.2	--	32.1	--	28.9
3	Bare	18.4	27.4	27.1	--	26.5	27.6	22.8	--	28.0	23.6	21.5	--	26.4
4	Fescue	20.3	--	25.7	25.2	19.4	--	27.3	31.5	23.0	--	21.6	21.7	25.0
4	Crownvetch	20.3	19.6	24.4	--	--	23.3	26.2	--	--	25.4	24.7	--	--
4	Bare	21.1	--	--	--	19.1	--	--	--	23.5	--	--	--	23.0
5	Fescue	NP	10.7	10.7	--	--	11.6	13.9	--	--	9.4	5.4	--	--
5	Bermuda	NP	--	--	8.3	7.5	--	--	8.8	10.4	--	--	4.6	9.1

*See Figure 3

to the non-plastic sandy soils. Within soils of generally similar plasticity, the sites with Sericea lespedeza which has high moisture demand only during the summer growing season, had the highest moisture contents (and also experienced the least depth of freezing) while the creeping juniper sites had the lowest moistures (and also experienced the greatest freezing depth, probably due to continued moisture demand during the winter). With the foregoing exceptions, differences in moisture contents associated with the various vegetation types does not appear to be significant.

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