SOIL MOISTURE GROUND TRUTH

STEAMBOAT SPRINGS, COLORADO, SITE
WALDEN, COLORADO, SITE

March 8-10, 1976

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Mission Report--March 8-10, 1976, Mission

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INTRODUCTION

This report contains the ground-truth data taken at Steamboat Springs and Walden, Colorado, in support of the NASA mission in these areas during the period of March 8, 1976, through March 11, 1976. The general locations of these areas are shown in Figure 1. These data were taken by M. W. Bittinger & Associates, Inc., personnel with assistance from Dr. Albert Rango, NASA-GSFC; James Foster, NASA-GSFC; and USDA Soil Conservation Service personnel from both the Steamboat Springs and Walden, Colorado, offices.

STEAMBOAT SPRINGS, COLORADO, SITE

The location of the Steamboat Springs site is shown in Figure 2, and the detailed site locations are shown in Figure 3. This line is approximately 4.0 miles (6.45 Km) in length oriented in a generally North-South direction in the Yampa River Valley a few miles south of Steamboat Springs, Colorado. Data taken on this primary line were as follows:

Snow depths at intervals of 100 feet

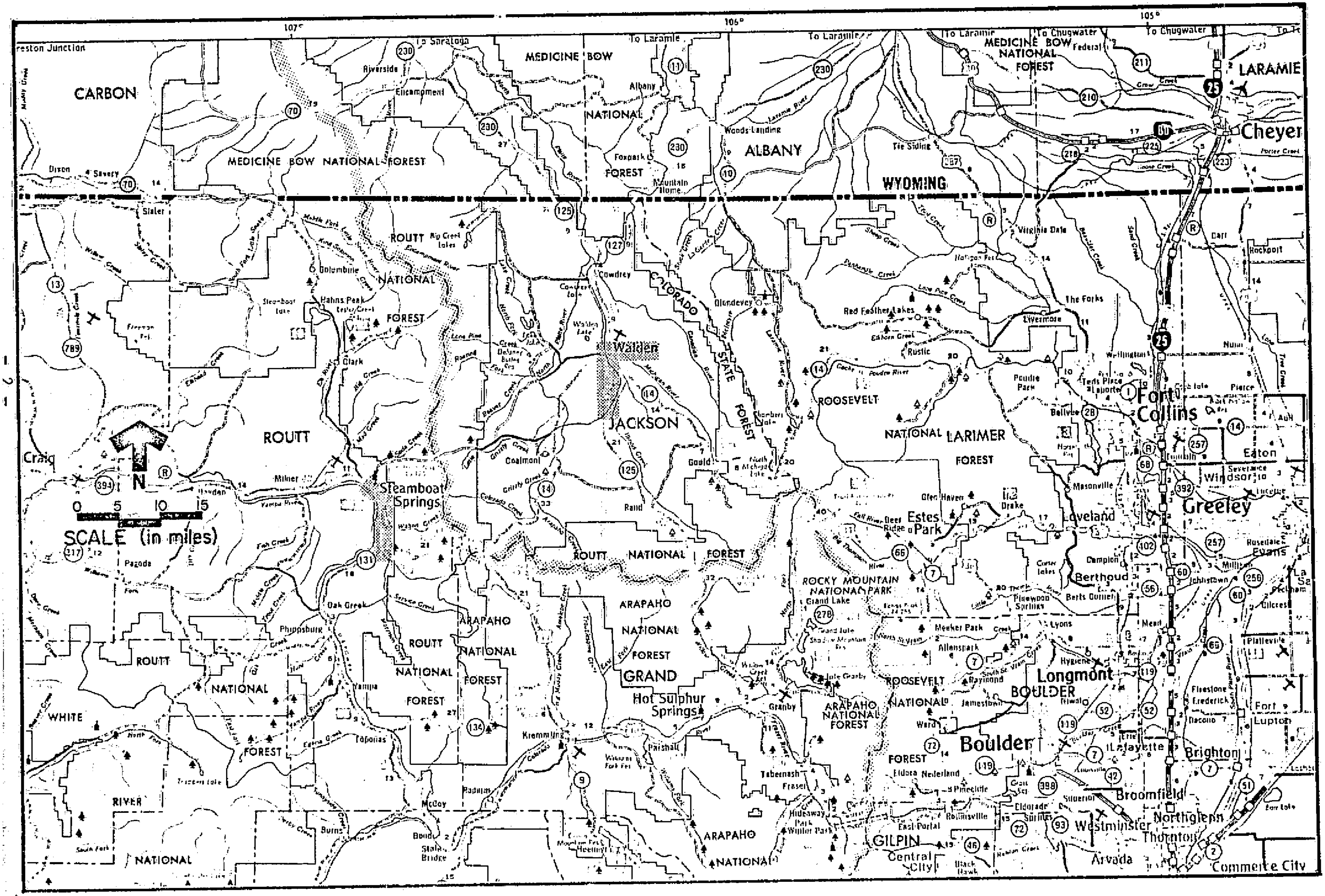
Snow densities and water equivalents at intervals of 1000 feet (using a Mount Rose snow tube)

Snowpack characterizations at intervals of 1000 feet --
- Grain size (Sommerfeld 1969)
- Apparent wetness (CRREL 1962)
- Ski penetration (Commission on Snow and Ice 1954)

Snow pits for liquid water determinations (freezing calorimetry) (Leaf 1966) and vertical layer classification (Sommerfeld 1969) at five selected locations, shown on Figure 3.

In addition to this primary line, six East-West transects of 1000 feet each were used for additional depth and density measurements. The snowpack depth and density determinations for the primary line and transects are summarized in Table 1, and the detailed data are presented in Appendix A. Liquid water determinations are summarized in Table 2. Supporting this are the detailed snow pit characterizations in Appendix B and the details of the liquid water determination in Appendix C.

FIGURE 1. GENERAL LOCATION MAP



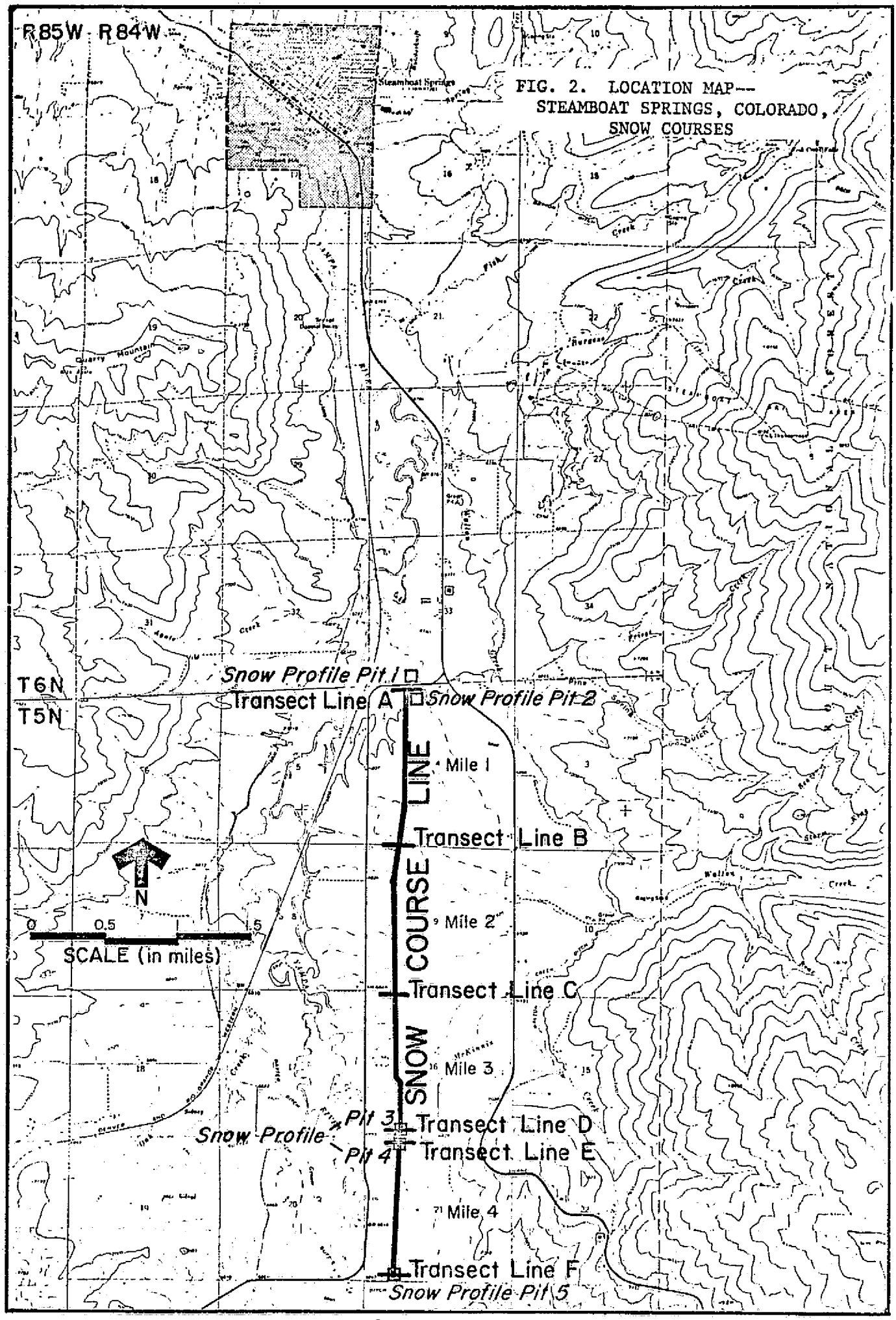


FIG. 2. LOCATION MAP--
STEAMBOAT SPRINGS, COLORADO,
SNOW COURSES

FOLLOUT FRAME

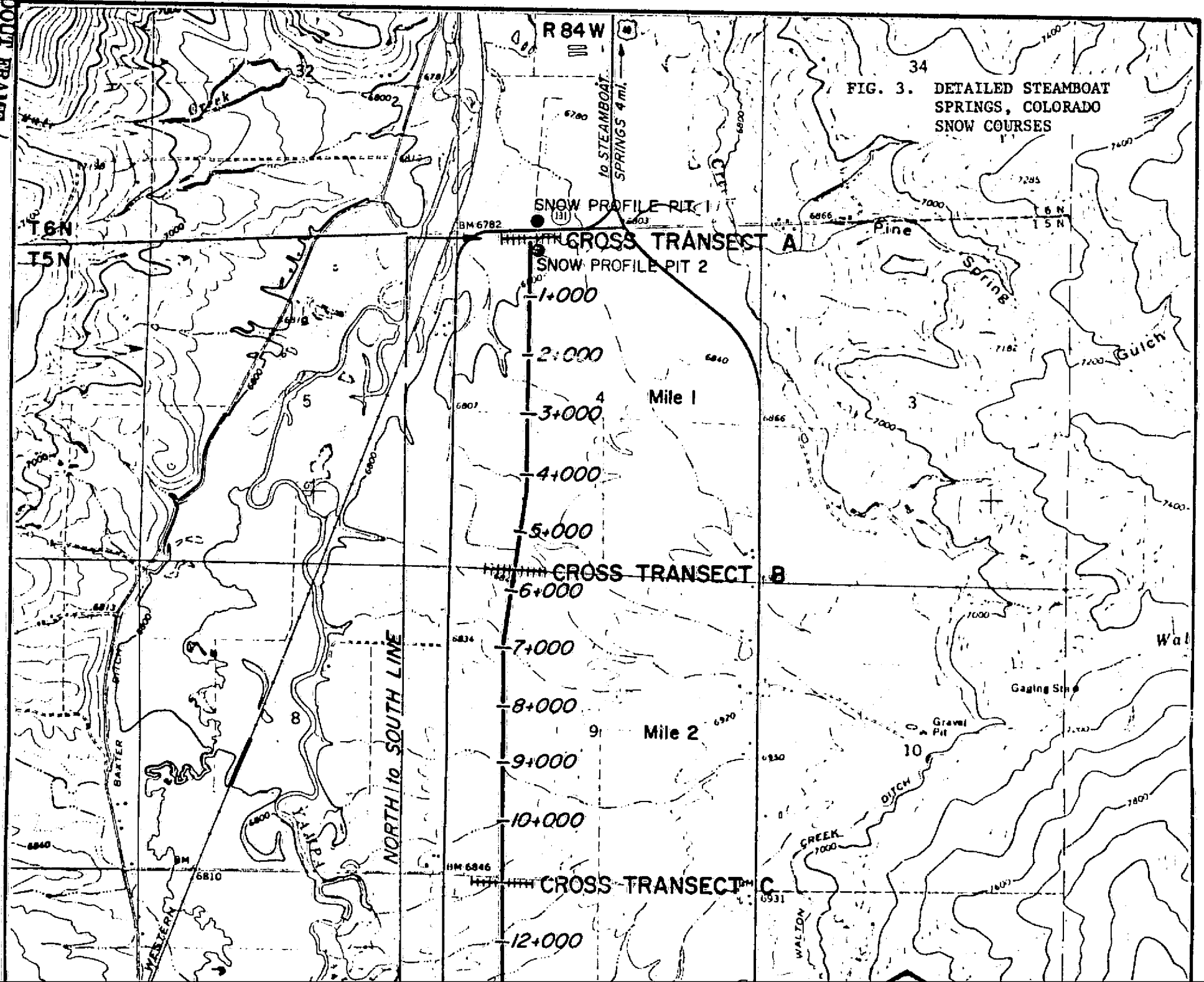
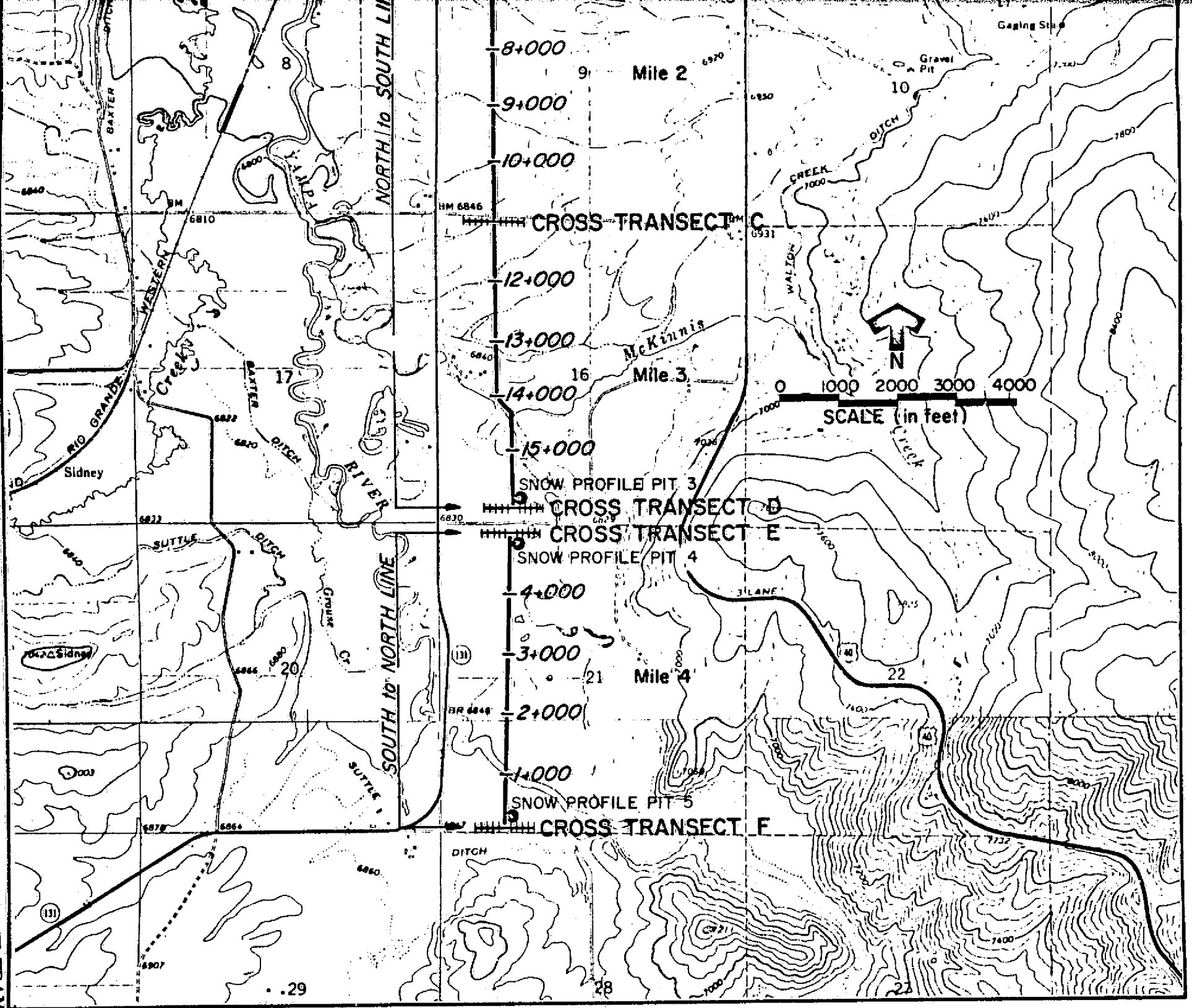


FIG. 3. DETAILED STEAMBOAT SPRINGS, COLORADO SNOW COURSES



FOLDOUT FRAME 2

Table 1.

Summary of Steamboat Flight Line Data

	Snow Depth (in.)			Density (%)		
Mile	Number of samples	Mean of samples	Standard deviation	Number of samples	Mean of samples	Standard deviation
1	57	30.22	2.95	6	21.5	7.23
2	53	30.51	2.13	5	18.8	5.81
3	53	28.65	4.03	6	21.5	5.13
4	50	29.90	2.89	7	22.4	10.24
Total for N-S line	213	29.82	3.13	24	21.2	7.22
Transect						
A	10	29.75	2.13	10	22.4	4.17
B	10	29.60	1.17	10	26.5	3.95
C	10	28.20	1.87	10	25.2	2.49
D	10	30.45	3.38	10	24.6	7.38
E	10	28.80	3.16	10	24.9	8.85
F	10	28.10	4.95	10	28.6	1.84

Table 2.

Liquid Water Summary--
Steamboat Line

Pit no.	Top 6"			Mid-pack			Ground	
	Temp. (°C)	Quality factor	Liquid water content (%)	Temp. (°C)	Quality factor	Liquid water content (%)	Temp. (°C)	Soil moisture content (%)
1	-8	1.08	0	-4	1.14	0	0*	45.4
2	-7	1.14	0	-4	1.19	0	0*	34.6
3	-4	1.12	0	-4	1.07	0	0*	19.7
4	-7	1.09	0	-4	1.04	0	0*	27.1
5	-4	1.01	0	-3	1.06	0	0	31.3

*Ground was not frozen.

WALDEN, COLORADO, SITES

Two lines were sampled in the vicinity of Walden, Colorado. The first was the North-South line, approximately 4.5 miles (7.25 Km) in length and is shown in Figure 4. The shorter East-West line, approximately 2.75 miles (4.5 Km) in length is shown in Figure 5. These lines were sampled much less intensively than was the Steamboat Springs line. Data taken on the Walden lines were limited to specific points approximately 0.1 mile (0.16 Km) apart. At each point snow depths were measured, and at each fifth point snow density, water equivalent, snowpack characterizations, and a soil sample for gravimetric soil-moisture determinations were taken. The summary of this information is presented in Table III, and the detailed data are shown in Appendix D (North-South line data) and Appendix E (East-West line data). The soil-moisture report is presented in Appendix F.

SITE CONTRASTS

The Walden lines were of a lesser snow depth than Steamboat Springs, and for much of the lines the vegetation was of a "sagebrush type" which extended above the snowpack.

The line at Steamboat Springs was generally located over flat meadowland, and all but riparian vegetation, excluding farmsteads, was totally snow covered. This led to the sample plan which was reviewed on site with NASA personnel.

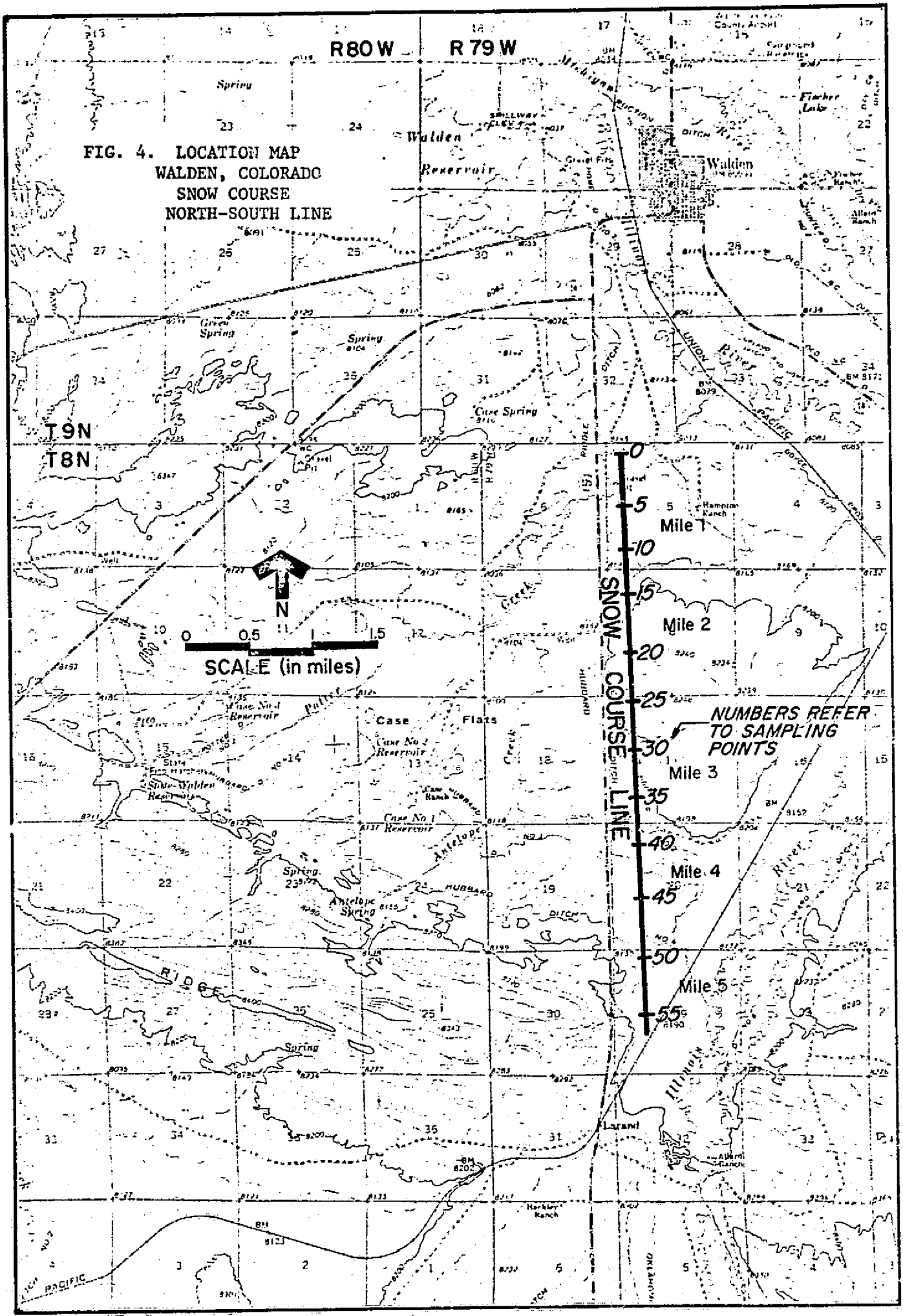


FIG. 4. LOCATION MAP
WALDEN, COLORADO
SNOW COURSE
NORTH-SOUTH LINE

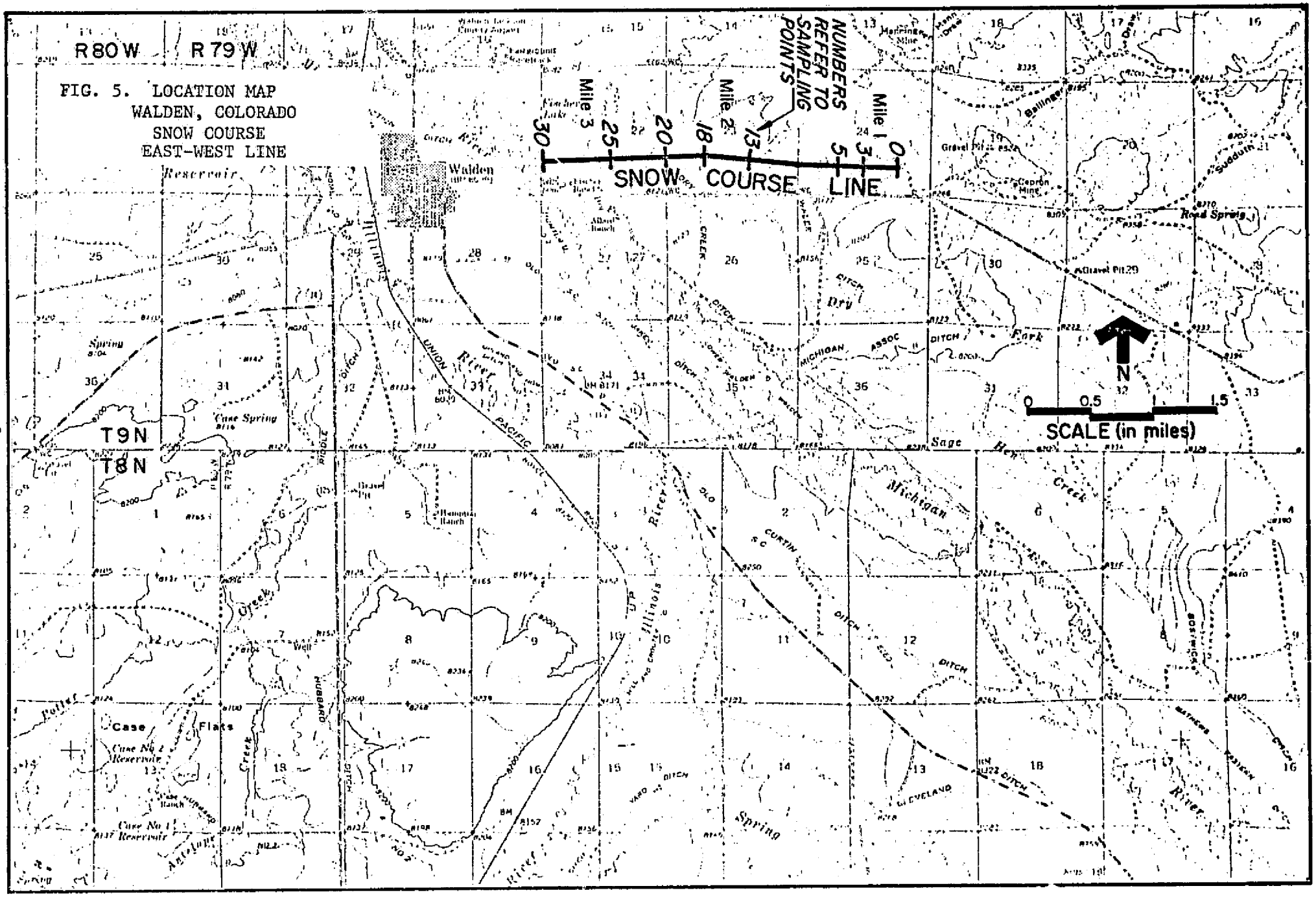


FIG. 5. LOCATION MAP
WALDEN, COLORADO
SNOW COURSE
EAST-WEST LINE

Table 3.

Summary of Walden Flight Lines Data

Mile	Snow Depth (in.)			Density (%)		
	Number of samples	Mean of samples	Standard deviation	Number of samples	Mean of samples	Standard deviation
			- - North-South Flight Line - -			
1	12	5.58	1.55	3	33	9.2
2	13	5.23	0.88	2	32	--
3	13	4.54	1.51	3	24	7.02
4	12	4.38	1.21	2	24	--
5	6	8.58	3.90	2	38	--
Total	56	5.32	2.08	12	29.7	8.09
			- - East-West Flight Line - -			
1	11	3.68	0.85	3	23	1.74
2	12	3.96	1.37	3	31	7.77
3	10	4.92	1.81	2	26	--
Total	33	4.15	1.43	8	26.9	5.79

REFERENCES

Leaf, Charles F., 1966, Free Water Content of Snowpack in Subalpine Areas, Proceedings--34th Western Snow Conference (April 19-21, 1966, Seattle, Washington), pp. 17-24.

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CRREL, 1962, Instructions for Making and Recording Snow Observations, Instruction Manual 1, U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire (pages numbered by sections).

Sommerfeld, R. A., 1969, Classification Outline for Snow on the Ground, USDA, Forest Service Research Paper RM-48, Rocky Mountain Forest and Range Experiment Station, USDA, Fort Collins, Colorado, 24 pp.

APPENDIX A

Steamboat Springs Snow Course Data

Steamboat Springs Snow Course

3/8/76

Transect A

Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Remarks
E-100	31.0	15.5	21.0	15.0	6.0	19	
E-200	29.5	14.5	21.0	15.0	6.0	20	
E-300	33.0	14.5	20.5	15.0	5.5	17	
E-400	27.5	11.5	19.5	15.0	4.5	16	
E-500	33.5	22.0	23.5	15.0	8.5	25	
W-100	28.0	13.0	22.0	15.0	7.0	25	
W-200	29.5	24.0	23.5	15.0	8.5	29	
W-300	29.0	18.5	22.0	15.0	7.0	24	
W-400	29.0	19.5	22.0	15.0	7.0	24	
W-500	27.5	19.5	22.0	15.0	7.0	25	

Transect B

Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Remarks
E-100	29.0	17.0	18.0	11.0	7.0	24	
E-200	29.0	25.0	20.0	11.0	9.0	31	
E-300	31.0	27.0	20.0	11.0	9.0	29	
E-400	30.0	24.0	19.0	11.0	8.0	27	
E-500	32.0	24.0	20.0	11.0	9.0	28	
W-100	29.0	20.0	18.0	11.0	7.0	24	
W-200	28.0	25.0	19.0	11.0	8.0	29	
W-300	29.0	16.0	16.0	11.0	5.0	17	
W-400	29.0	26.0	19.0	11.0	8.0	28	
W-500	30.0	25.0	19.0	11.0	8.0	27	

Transect C

Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Remarks
E-100	32.0	23.0	19.0	11.0	8.0	25	
E-200	29.0	27.0	18.0	11.0	7.0	24	
E-300	29.0	23.0	19.0	11.0	8.0	28	Mud plug
E-400	29.0	27.0	19.0	11.0	8.0	28	
E-500	27.0	24.0	18.0	11.0	7.0	26	
W-100	28.0	19.0	17.0	11.0	6.0	21	
W-200	25.0	22.0	18.0	11.0	7.0	28	
W-300	27.0	24.0	17.0	11.0	6.0	22	
W-400	29.0	22.0	18.0	11.0	7.0	24	
W-500	27.0	24.0	18.0	11.0	7.0	26	

Transect D

Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (im.)	Density (%)	Remarks
E-100	35.5	16.0	23.0	15.0	8.0	23	
E-200	34.0	13.5	22.5	15.0	7.5	22	In willows
E-300	29.0	13.0	21.5	15.0	6.5	22	In drainage
E-400	23.0	13.0	24.0	15.0	9.0	39	Edge of drainage
E-500	32.5	13.5	23.0	15.0	8.0	25	" " "
W-100	30.0	8.0	20.0	15.0	5.0	17	
W-200	30.0	7.0	20.0	15.0	5.0	17	
W-300	31.0	15.0	24.0	15.0	9.0	29	
W-400	30.5	10.0	20.5	15.0	5.5	18	
W-500	29.0	16.0	25.0	15.0	10.0	34	

Transect E

Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Remarks
E-100	30.0	9.0	21.0	15.0	6.0	20	
E-200	33.0	11.0	21.0	15.0	6.0	18	In cattails
E-300	24.0	21.0	26.0	15.0	11.0	46	Creek edge, free water below
E-400	28.0	14.0	22.0	15.0	7.0	25	Damp mud at bottom
E-500	31.0	8.0	20.0	15.0	5.0	16	
W-100	34.0	14.0	22.0	15.0	7.0	21	
W-200	26.0	17.0	22.0	15.0	7.0	27	
W-300	28.0	12.0	21.0	15.0	6.0	21	Slight hill
W-400	27.0	11.0	21.0	15.0	6.0	22	Hill continued
W-500	27.0	17.0	24.0	15.0	9.0	33	Flat again

Transect F

Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Remarks
Center line--							
E-100	24.0	*	22.0	15.0	7.0	29	
E-200	16.0	*	20.0	15.0	5.0	31	
E-300	26.0	*	22.0	15.0	7.0	27	
E-400	32.0	*	23.0	15.0	8.0	25	
E-500	31.0	*	24.0	15.0	9.0	29	
W-100	29.0	*	24.0	15.0	9.0	31	Near edge of once plowed road
W-200	30.0	*	23.0	15.0	8.0	27	Flat area
W-300	31.0	*	24.0	15.0	9.0	29	Crust at 7"
W-400	31.0	*	24.0	15.0	9.0	29	Even flat area
W-500	31.0	*	24.0	15.0	9.0	29	

*Not reported.

Steamboat Springs Snow Course

3/8/76

Time	Station *	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski penetration (cm)	Wetness	Remarks
7:30	0+000	29.5	23	23	15	8	27	fine	5	dry	100' S of north line of Sec. 4, moving south
	0+100	30.0									
	0+200	29.0									
	0+300	29.0									
	0+400	31.5									
	0+500	30.0									
	0+600	28.5									
	0+700	27.0									
	0+800	30.0									
	0+900	31.0									
9:00	1+000	31.0	20.5	23	15	8	26	large crystalline	6	dry	
	1+100	30.0									
	1+200	29.5									
	1+300	29.0									
	1+400	28.5									
	1+500	27.5									
	1+600	31.0									
	1+700	30.5									
	1+800	31.0									
	1+900	28.0									
9:06	2+000	29.0	13	19	15	4	14	large crys.	5	dry to moist	
	2+100	29.5									
	2+200	29.5									
	2+300	41.0									Drift next to haystack
	2+400	29.0									
	2+500	31.0									
	2+600	33.0									

*Stationing runs from North to South (1000's of feet + feet).

Time	Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski pene-tration (cm)	Wetness	Remarks
9:06	2+700	34.5									
contd	2+800	32.0									
	2+900	31.0									
9:16	3+000	32.5	23.5	24	15	9	28	large crys.	6	dry to moist	
	3+100	30.5									
	3+200	30.5									
	3+300	42.0									Jogging slightly east to avoid stock fence
	3+400	28.5									" " " "
	3+500	27.0									" " " "
	3+600	29.0									" " " "
	3+700	23.5									" " " "
	3+800	26.0									" " " "
	3+900	28.0									
9:27	4+000	28.5	7.5	18	15	3	11	large crys.	6	dry to moist	
	4+100	26.0									Near intersection of ditch at stock pen
	4+200	32.5									
	4+300	30.0									
	4+400	31.0									At fenceline
	4+500	32.0									
	4+600	30.0									
	4+700	29.0									
	4+800	27.0									
	4+900	29.0									
9:38	5+000	31.0	16.0	22	15	7	23	large crys.	6	dry to moist	
	5+100	30.5									
	5+200	29.0									
	5+300	34.0									
	5+400	33.0									

Time	Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski penetration (cm)	Wetness	Remarks
9:38	5+500	29.5									
contd	5+600	32.0									Section line
	5+700	27.0									
	5+800	31.0									
	5+900	29.0									
9:51	6+000	31.0	10.0	19.0	15	4	13	fine granular	7	moist	
	6+100	31.0									
	6+200	31.0									
	6+300	30.5									
	6+400	30.0									Starting down into small drainage
	6+500	28.0									
	6+600	30.0									
	6+700	31.0									
	6+800	30.0									Crossing small drainage
	6+900	33.0									
9:57	7+000	32.0	16.0	22.0	15	7	22	fine granular	6	moist	At fence line other side of small drainage
	7+100	29.5									
	7+200	30.5									
	7+300	30.5									
	7+400	28.5									
	7+500	32.0									
	7+600	28.5									
	7+700	30.5									
	7+800	31.5									
	7+900	30.0									
10:07	8+000	29.0	10.5	18.5	15	3.5	12	fine granular	7	moist	
	8+100	31.0									
	8+200	36.0									
	8+300	30.0									

Time	Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski pene-tration (cm)	Wetness	Remarks
10:07	8+400	30.5									
contd	8+500	29.0									
	8+600	32.0									
	8+700	38.0									Small drainage by willows
	8+800	26.0									" " " "
	8+900	27.0									Next to drainage
	9+000	30.0	15.0	22.0	15	7	23	fine gran.	7	moist	Near drainage
	9+100	30.0									
	9+200	28.5									
	9+300	30.5									
	9+400	28.0									
	9+500	29.0									
	9+600	29.5									
	9+700	30.0									
	9+800	30.0									
	9+900	31.0									
10:25	10+000	33.0	13.0	23.0	15	8	24	fine gran.	6	dry to moist	Thin crust on top
	10+100	31.0									
	10+200	33.0									
	10+300	30.0									
	10+400	27.0									
	10+500	32.5									
	10+600	33.0									
	10+700	33.0									
	10+800	33.5									
	10+900	30.0									10,950 to ℄ of road (Sec. line)
10:34	11+000	26.0	13.5	21.0	15	6	23	fine gran.	7	dry to moist	
	11+100	38.0									
	11+200	31.0									
	11+300	32.5									
	11+400	29.5									

Time	Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski pene-tration (cm)	Wetness	Remarks
10:34	11+500	30.0									
contd	11+600	28.5									Just south of small drainage
	11+700	31.0									
	11+800	30.0									
	11+900	30.0									
10:43	12+000	30.5	16.0	22.0	15	7	23	fine gran.	6	moist	
	12+100	28.5									
	12+200	31.0									
	12+300	30.5									
	12+400	27.0									In small drainage
	12+500	27.0									
	12+600	28.5									Going into small drainage
	12+700	30.0									Coming out of small drainage
	12+800	30.5									
	12+900	28.0									
10:53	13+000	30.0	9.5	19.0	15	4	13	fine gran.	7	moist	
	13+100	7.0									Packed by livestock
	13+200	23.0									Going around fence almost in streambed
	13+300	30.0									
	13+400	28.0									
	13+500	27.5									
	13+600	29.0									At fence line behind farm
	13+700	26.0									
	13+800	29.0									
	13+900	30.0									
11:06	14+000	26.0	22.0	22.0	15	7	27	fine gran.	7	moist	
	14+100	25.0									
	14+200	21.0									Along top of cliff
	14+300	25.5									" " " "
	14+400	27.0									" " " "
	14+500	33.5									Take off for ditch (intersection)

Time	Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski penetration (cm)	Wetness	Remarks
11:06	14+600	29.0									
contd	14+700	32.0									Drainage
	14+800	33.0									
	14+900	28.5									
11:17	15+000	32.5	10.5	21.0	15	6	18	fine gran.	7	moist	
	15+100	28.0									
	15+200	30.5									
	15+300	28.0									
	15+400	28.5									
	15+500	27.5									
	15+600	30.0									
	15+700	31.0									
	15+800	30.0									
	15+900	30.5									
11:30	16+000	28.0	14.0	22.0	15	7	25	fine gran.	7	moist	
	16+100	28.0									
12:00	16+200	28.0									Almost to road
END OF NORTH TO SOUTH STATIONING											
BEGIN SOUTH TO NORTH STATIONING											
9:45	0+100	24.0	23.0	24.0	15	9	38	old gran.	3	dry	South line of Sec. 21, moving north. Very little crust
	0+200	30.0		24.0	15	9	30				Ground not frozen, damp
	0+300	29.0									Even flat area
	0+400	30.0									Light crust from drifting
	0+500	31.0									Crust at 7"
	0+600	32.0									" " "
	0+700	29.0									Very thin surface crust
	0+800	31.0									Crust at 7"
	0+900	30.0									
10:25	0+1000	16.0	14.0	20.0	15	5	31	heavy gran. crystals throughout	4-5	moist	North edge of creek, ice of river at bottom, 3/4" surface crust
	1+100	30.0									Near willow clump

Time	Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski penetration (cm)	Wetness	Remarks
10:25	1+200	31.0									Cattle fed
contd	1+300	29.0									Edge of once plowed road
	1+400	29.0									
	1+500	29.0									
	1+600	29.0									Crust 7" under
	1+700	29.0									Even flat area
	1+800	25.0									In a draw
	1+900	31.0									
	1+1000	28.0	8.0	19	15	4	14	surface fluffy, gran. below	6	moist	Crust 7"-8", could affect core depth reading
	2+100	28.0	8.0								
	2+200	32.0	8.0								Bottom of draw
	2+300	30.0	8.0								Flat area
	2+400	30.0									
	2+500	30.0	11.0								Flat area
	2+600	33.0									Within 3' of N-S fence, possible drifting
	2+700	34.0									Within 4' of fence
	2+800	31.0									" " " "
	2+900	32.0									Next to fence
11:04	2+1000	31.0	12.0	20	15	5	16	old gran.	5	moist	Small granular metamorphose, close to fence drifting
	3+100	28.0									Still hard underlying crust 7"-8"
	3+200	32.0									
	3+300	32.0									Still next to fence
	3+400	30.0									Hard underlying crust
	3+500	25.0									Willows affecting drifting
	3+600	32.0									
	3+700	32.0									Still near a fence
	3+800	33.0									" " " "
	3+900	31.0									" " " "
11:30	3+1000	32.0	6.0	19	15	4	13	old gran.	5-6	dry	Very crusty all the way, Top is changing, small granules

Time	Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski pene-tration (cm)	Wetness	Remarks
11:30	4+100	31.0									Flat area, still near fence
contd	4+200	30.0									Flat, no fences close
	4+300	28.0	8.0								
	4+400	30.0									
	4+500	29.0									Buildings starting to affect snow
	4+600	28.0									Building 50 yd. away
	4+700	31.0									
	4+800	31.0									Flat even area
	4+900	33.0									
	4+1000	34.0	9.0	20	15	5	15	old gran.	6	moist	In group of cattails, ice layer at bottom

APPENDIX B

Steamboat Springs Snow Pit Data

Steamboat Springs Snow Course

3/9/76

Pit No. 1

General location: 100' north of Route 131, near north aerial flag

Air temperature: -15°C, 0900; -11°C, 0930
Ground temperature: 0°C
Ground wet, not frozen. Pastured grass.

Height to top of layer (in.)	Thickness (in.)	Layer classification	Grain size (mm)	Density (Kg/m^3)	Temp. (°C)	Gen. layer wetness	Layer hardness	Remarks
6.0	6.0	well developed depth hoar	1½	274	-1	dry	soft	
12.0	6.0	depth hoar	1	294	-1	dry	soft	
18.0	6.0	constructive metamorphosed beginning	½-1	322	-3	dry	soft	
20.0	2.0	firnification	½-1	302	-6	dry	med. soft	Melt-freeze crust layer
20.5	0.5	ice				dry	hard	Ice lense
21.5	1.0	firnification	½-1		-7	dry	med. soft	Very thin ice lense on top of this layer
29.0	7.5	unmetamorphosed	¼-½	226	-9	dry	soft	Some firnification starting in top layer

Note: Soil moisture 45.4%--sample contained a high percentage of organic material.

Steamboat Springs Snow Course

3/9/76

Pit No. 2

General location: 175' south of Route 131, along northernmost E-W transect.

Air temperature: -8°C, 1000
Ground temperature: 0°C

Ground wet, not frozen. Pastured grass.

Height to top of layer (in.)	Thickness (in.)	Layer classification	Grain size (mm)	Density (Kg/m^3)	Temp. (°C)	Gen. layer wetness	Layer hardness	Remarks
6.0	6.0	well developed depth hoar	1½	292	0	dry	soft	
12.0	6.0	depth hoar	1	274	-1	dry	soft	
18.0	6.0	beginning cont. metamorphism	½-1	304	-3	dry	soft	
20.0	2.0	firnification	½-1	286	-7	dry	med. soft	
20.5	0.5	ice lense				dry	hard	
21.5	1.0	firnification	½-1		-7	dry	med. soft	
21.75	0.25	ice lense				dry	hard	
24.75	3.0	firnification	½-1	306	-10	dry	med. soft	
30.0	5.25	new snow, unmetamorphosed	¼-½	166	-11	dry	soft	

Note:
P-3 overhead at 1020. Several passes, 2-3 to west of line, 1-2 over line, last pass at about 1045, last 3 passes: (1) S-N slightly east of line
(2) N-S over line
(3) S-N slightly west, 1045

Soil moisture 34.6%--sample contained a high percentage of organic material.

Steamboat Springs Snow Course

3/8/76

Pit No. 3

General location: SW ¼, 16 - 100' north of north fence

Air temperature: -2°, 11:15; -1°, 11:30
Ground temperature: 0°C
Ground wet, not frozen, pastured grass.

Height to top of layer (in.)	Thickness (in.)	Layer classification	Grain size (mm)	Density (Kg/m^3)	Temp. (°C)	Gen. layer wetness	Layer hardness	Remarks
6.0	6.0	well developed depth hoar	1½	254	0	dry	soft	0-12" advanced temp. gradient meta.
12.0	6.0	depth hoar	1	254	0	dry	soft	" " "
23.0	11.0	metamorphosed	2	250	-3	dry	soft	partial temp. grad. meta.
24.5	1.5	melt crust firnification	½	328	-7	dry	med. hard	melt freeze metamorphose limited
30.5	6.0	new snow	<½	248	-8	dry	soft	unmetamorphosed

Note: Soil moisture 19.7%.

Steamboat Springs Snow Course

3/8/76

Pit No. 4

General location: NW ¼, 21 - 100' south of south fence

Air temperature: -5°, 10:25 a.m.; -4°, 10:45
Ground temperature: 0°C
Ground wet, not frozen, pasture grass

Height to top of layer (in.)	Thickness (in.)	Layer classification	Grain size (mm)	Density (Kg/m^3)	Temp. (°C)	Gen. Layer wetness	Layer hardness	Remarks
6.0	6.0	well developed depth hoar	1½	276	-2	dry	soft	0-12" advanced temp. gradient meta.
12.0	6.0	depth hoar	1	276	-2	dry	soft	" " "
19.0	7.0	metamorphosed	2	254	-4	dry	soft	partial temp. grad. meta.
19.5	1.5	ice layer					hard	
24.0	4.5	crust firnification	½	260	-8	dry	med. soft	melt-freeze metamorphose limited
30.0	6.0	new snow	<½	182	-10	dry	soft	unmetamorphosed

Note: Soil moisture 27.1%.

Steamboat Springs Snow Course

3/8/76

Pit No.5

General location:

Air temperature: 4°C, 2:30
Ground temperature: 0°C, 2:45
Ground wet, not frozen, pasture grass

Height to top of layer (in.)	Thick-ness (in.)	Layer classification	Grain size (mm)	Density (Kg/m^3)	Temp. (°C)	Gen. layer wetness	Layer hardness	Remarks
6.0	6.0	well developed depth hoar	1½	296	-1	dry	soft	0-12" advanced temp. gradient meta.
12.0	6.0	depth hoar	1	296	-1	dry	soft	" " "
19.0	7.0	metamorphosed	2	282	-3	dry	soft	partial temp. grad. meta.
19.5	0.5	ice layer					hard	
24.0	4.5	crust firnification	½	290	-6	dry	med. hard	melt-freeze metamorphose limited
30.5	6.5	new snow	<½	204	-3	dry	soft	unmetamorphosed

Note: At 12" from bottom--slight melt crust--advanced depth hoar above and below.
Soil moisture 31.3%--sample contained a high percentage of organic material.

APPENDIX C

Steamboat Springs Snow Quality Data

MEASUREMENT OF SNOW QUALITY

(Freezing Calorimetric Technique)

Station P-1 Observer Leaf-Rango

Date 9 March 1976 Hour 1100

Location and description of sampling point

Northern most Pit, 100' North of Route 131

Top 6"

Layer temp -8° C

Data

Sample thermos No. 1 Air Temperature -5 $^{\circ}$C

Height of sample from ground surface 26 inches.

(1) Tare weight of calorimeter 767.1 gr.

(2) Weight of calorimeter and toluene 1154.3 gr.

(3) Weight of calorimeter + toluene + snow 1290.2 gr.

(4) Calorimeter constant (E) 55.22 gr.

Heat Balance

$W_i C_i (t_2 - t_1) + t_2 C_s S = L F$

where

W_i = (2) - (1) + E, gr.

c_i = specific heat of toluene

t_1 = initial temp. $^{\circ}$C

* t_2 = final temp. $^{\circ}$C

C_s = specific heat of ice

S = (3) - (2), gr.

L = latent heat of melting

F = weight of free water, gr.

Snow Quality

$Q_f = 1 - W_i C_i (t_2 - t_1) / LS - C_s t_2/L$

$t_1 = -46^{\circ}$ C

$C_i = 0.374$

$Q_f = 1.078$

$t_2 = -37^{\circ}$ C

$C_s = .464$

MEASUREMENT OF SNOW QUALITY

(Freezing Calorimetric Technique)

Station P1 Observer Leaf-Range

Date 9 March 1976 Hour 1100

Location and description of sampling point

Northern most pit, 100' North of Route 131

Mid Pack

layer temp -4° C

Data

Sample thermos No. 2 Air Temperature -5 °C

Height of sample from ground surface 15 inches.

(1) Tare weight of calorimeter 767.1 gr.

(2) Weight of calorimeter and toluene 1146.7 gr.

(3) Weight of calorimeter + toluene + snow 1305.3 gr.

(4) Calorimeter constant (E) 55.22 gr.

Heat Balance

$W_i C_i (t_2 - t_1) + t_2 C_s S = L F$

where

W_i = (2) - (1) + E, gr.
C_i = specific heat of toluene
t_1 = initial temp. °C
t_2 = final temp. °C
C_s = specific heat of ice
S = (3) - (2), gr.
L = latent heat of melting
F = weight of free water, gr.

Snow Quality

$$Q_f = 1 - W_i C_i (t_2 - t_1) / LS - C_s t_2/L$$

$t_1 = -49°$ C $\quad t_2 = -41°$ C

$C_i = 0.374 \quad C_s = 0.464$

$Q_f = 1.135$

MEASUREMENT OF SNOW QUALITY

(Freezing Calorimetric Technique)

Station P-2 Observer Leaf-Rango

Date 9 March 1976 Hour 1200 (noon)

Location and description of sampling point

175 feet south of Route 131 in pit

upper 6"

Upper layer temp -7°C

Data

Sample thermos No. 1 Air Temperature -2 °C

Height of sample from ground surface 27 inches.

(1) Tare weight of calorimeter 768.1 gr.

(2) Weight of calorimeter and toluene 1145.3 gr.

(3) Weight of calorimeter + toluene + snow 1249.4 gr.

(4) Calorimeter constant (E) 55.22 gr.

Heat Balance

$W_i C_i (t_2 - t_1) + t_2 C_s S = L F$

where

W_i = (2) - (1) + E, gr.
c_i = specific heat of toluene
t_i = initial temp. °C
t_2 = final temp. °C

C_s = specific heat of ice
S = (3) - (2), gr.
L = latent heat of melting
F = weight of free water, gr.

Snow Quality

$$Q_f = 1 - W_i C_i (t_2 - t_1) / LS - C_s t_2/L$$

$t_1 = -49°$ C $\quad t_2 = -45°$ C

$C_i = .374 \quad C_s = 0.464$

$Q_f = 1.183$

MEASUREMENT OF SNOW QUALITY

(Freezing Calorimetric Technique)

Station P-2 Observer Leaf-Rango

Date 9 March 1976 Hour 1200 (noon)

Location and description of sampling point

175' south of Route 131 in pit

mid layer of pack

layer temp -4° C

Data

Sample thermos No. 2 Air Temperature -2 $^{\circ}$C

Height of sample from ground surface 16 inches.

(1) Tare weight of calorimeter 768.1 gr.

(2) Weight of calorimeter and toluene 1142.7 gr.

(3) Weight of calorimeter + toluene + snow 1297.0 gr.

(4) Calorimeter constant (E) 55.25 gr.

Heat Balance

$W_i C_i (t_2 - t_1) + t_2 C_s S = L F$

where

W_i = (2) - (1) + E, gr.

c_i = specific heat of toluene

t_1 = initial temp. $^{\circ}$C

* t_2 = final temp. $^{\circ}$C

C_s = specific heat of ice

S = (3) - (2), gr.

L = latent heat of melting

F = weight of free water, gr.

Snow Quality

$$Q_f = 1 - W_i C_i (t_2 - t_1) / LS - C_s t_2/L$$

$t_1 = -49^{\circ}$ C $\qquad t_2 = -44^{\circ}$ C

$C_i = 0.374$ $\qquad C_s = .464$

$Q_f = 1.190$

MEASUREMENT OF SNOW QUALITY

(Freezing Calorimetric Technique)

Station Pit No. 3 Observer Leaf-Howell

Date 8 March 1976 Hour 1:20 P.M.

Location and description of sampling point

Top 6" @ -4°

Data

Sample thermos No. 4 Air Temperature +7 °C

Height of sample from ground surface 27 inches.

(1) Tare weight of calorimeter 766.8 gr.

(2) Weight of calorimeter and toluene 1199.7 gr.

(3) Weight of calorimeter + toluene + snow 1339.2 gr.

(4) Calorimeter constant (E) 55.22 gr.

Heat Balance

$W_i C_i (t_2 - t_1) + t_2 C_s S = L F$

where

W_i = (2) - (1) + E, gr.
c_i = specific heat of toluene
t_1 = initial temp. °C
t_2 = final temp. °C
C_s = specific heat of ice
S = (3) - (2), gr.
L = latent heat of melting
F = weight of free water, gr.

Snow Quality

$Q_f = 1 - W_i C_i (t_2 - t_1) / LS - C_s t_2/L$

$t_1 = -31°$ C
$C_i = .374$
$Q_f = 1.12$
$t_2 = -24°$ C
$C_s = .464$

MEASUREMENT OF SNOW QUALITY

(Freezing Calorimetric Technique)

Station Pit No. 3 Observer Leaf-Howell

Date 8 March 1976 Hour 1:30 P.M.

Location and description of sampling point

Pit No. 3 - Mid-pack @ -4° C

Data

Sample thermos No. 3 Air Temperature +8 $^{\circ}$C

Height of sample from ground surface 15 inches.

(1) Tare weight of calorimeter 766.8 gr.

(2) Weight of calorimeter and toluene 1148.0 gr.

(3) Weight of calorimeter + toluene + snow 1304.3 gr.

(4) Calorimeter constant (E) 55.22 gr.

Heat Balance

$$W_i c_i (t_2 - t_1) + t_2 C_s S = L F$$

where

W_i = (2) - (1) + E, gr.

c_i = specific heat of toluene

t_1 = initial temp. $^{\circ}$C

t_2 = final temp. $^{\circ}$C

C_s = specific heat of ice

S = (3) - (2), gr.

L = latent heat of melting

F = weight of free water, gr.

Snow Quality

$$Q_f = 1 - W_i C_i (t_2 - t_1) / LS - C_s t_2/L$$

$t_1 = -46.5^{\circ}$ C

$C_i = .374$

$Q_f = 1.0717$

$t_2 = -36^{\circ}$ C

$C_s = .464$

MEASUREMENT OF SNOW QUALITY

(Freezing Calorimetric Technique)

Station Pit No. 4 Observer Leaf-Howell

Date 8 March 1976 Hour 12:10

Location and description of sampling point

Pit No. 4 - Center of Top 6" of new snow.

Data

Sample thermos No. 4 Air Temperature 2 °C

Height of sample from ground surface 27 inches.

(1) Tare weight of calorimeter 766.8 gr.

(2) Weight of calorimeter and toluene 1141.8 gr.

(3) Weight of calorimeter + toluene + snow 1274.1 gr.

(4) Calorimeter constant (E) 55.22 gr.

Heat Balance

$$W_i C_i (t_2 - t_1) + t_2 C_s S = L F$$

where

W_i = (2) - (1) + E, gr.

c_i = specific heat of toluene

t_1 = initial temp. °C

* t_2 = final temp. °C

C_s = specific heat of ice

S = (3) - (2), gr.

L = latent heat of melting

F = weight of free water, gr.

Snow Quality

$$Q_f = 1 - W_i C_i (t_2 - t_1) / LS - C_s t_2/L$$

$t_1 = -38^\circ$ C $\quad t_2 = -32^\circ$ C

$C_i = .374$ $\quad C_s = .464$

$Q_f = 1.0944$

MEASUREMENT OF SNOW QUALITY

(Freezing Calorimetric Technique)

Station Pit No. 4 Observer Leaf - Howell

Date 8 March 1976 Hour

Location and description of sampling point

Pit No. 4 - Mid-pack, Approx 15" from ground

Temp: -4° C

Data

Sample thermos No. 3 Air Temperature 4 $^{\circ}$C

Height of sample from ground surface 15 inches.

(1) Tare weight of calorimeter 766.8 gr.

(2) Weight of calorimeter and toluene 1162.4 gr.

(3) Weight of calorimeter + toluene + snow 1319.2 gr.

(4) Calorimeter constant (E) 55.22 gr.

Heat Balance

$W_i C_i (t_2 - t_1) + t_2 C_s S = L F$

where

W_i = (2) - (1) + E, gr.
c_i = specific heat of toluene
t_1 = initial temp. $^{\circ}$C
* t_2 = final temp. $^{\circ}$C
C_s = specific heat of ice
S = (3) - (2), gr.
L = latent heat of melting
F = weight of free water, gr.

Snow Quality

$$Q_f = 1 - W_i C_i (t_2 - t_1) / LS - C_s t_2/L$$

$t_1 = -33^{\circ}$ C $\quad t_2 = -44.5^{\circ}$ C

$C_i = .374 \quad C_s = .464$

$Q_f = 1.0368$

MEASUREMENT OF SNOW QUALITY

(Freezing Calorimetric Technique)

Station Pit No. 5 Observer Leaf - Howell

Date 8 March 1976 Hour 3:10

Location and description of sampling point

Pit No. 5 - new snow layer

Data

Sample thermos No. 4 Air Temperature +6 °C

Height of sample from ground surface 27" @ -4° C inches.

(1) Tare weight of calorimeter 766.8 gr.

(2) Weight of calorimeter and toluene 1147.8 gr.

(3) Weight of calorimeter + toluene + snow 1281.6 gr.

(4) Calorimeter constant (E) 55.22 gr.

Heat Balance

$W_i C_i (t_2 - t_1) + t_2 C_s S = L F$

where

W_i = (2) - (1) + E, gr.

c_i = specific heat of toluene

t_1 = initial temp. °C

* t_2 = final temp. °C

C_s = specific heat of ice

S = (3) - (2), gr.

L = latent heat of melting

F = weight of free water, gr.

Snow Quality

$Q_f = 1 - W_i C_i (t_2 - t_1) / LS - C_s t_2/L$

$t_1 = -45^\circ$ C $\qquad t_2 = -33.3^\circ$ C

$C_i = .374$ $\qquad C_s = .464$

$Q_f = 1.0148$

MEASUREMENT OF SNOW QUALITY

(Freezing Calorimetric Technique)

Station Pit No. 5 Observer Leaf-Howell

Date 8 March 1976 Hour 3:20

Location and description of sampling point

Pit No. 5 - Mid-pack @ -3° C

Data

Sample thermos No. 3 Air Temperature +1 °C

Height of sample from ground surface 15" inches.

(1) Tare weight of calorimeter 767.5 gr.

(2) Weight of calorimeter and toluene 1118.7 gr.

(3) Weight of calorimeter + toluene + snow 1284.4 gr.

(4) Calorimeter constant (E) 55.22 gr.

Heat Balance

$W_i C_i (t_2 - t_1) + t_2 C_s S = L F$

where

W_i = (2) - (1) + E, gr.

c_i = specific heat of toluene

t_1 = initial temp. °C

x t_2 = final temp. °C

C_s = specific heat of ice

S = (3) - (2), gr.

L = latent heat of melting

F = weight of free water, gr.

Snow Quality

$Q_f = 1 - W_i C_i (t_2 - t_1) / LS - C_s t_2/L$

$t_1 = -46.5°$ C

$t_2 = -34.5°$ C

$C_i = .374$

$C_s = .464$

$Q_f = 1.0625$

APPENDIX D

Walden Snow Course Data

(North-South Line)

Walden Snow Course
3/9/76
North-South Line

Time	Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski pene-tration (cm)	Wetness	Remarks
10:00	0	7.0	6.0	7.0	4	3.0	43	fine drifted	N.A.	dry	Soil sample #9, 21%
	1	5.5									At edge of gravel pit
	2	3.0									" " " " "
	3	6.0									Going into small draw
	4	6.5									Demi-sage
	5	6.5	6.0	6.0	4	2.0	31	fine drifted	N.A.	dry	Soil sample #100, 27.9%
	6	6.5									Grass
	7	5.5									"
	8	3.0									"
	9	5.5									"
	10	8.0	5.0	6.0	4	2.0	25	fine drifted	N.A.	dry	Soil sample #108, 96.4%*
Mile 1	11	4.0									Grass
Mile 2	12	6.0									"
	13	5.0									Along ditch, grass
	14	4.5									Along ditch, grass, sage
	15	7.0	5.5	6.5	4	2.5	36	fine drifted	N.A.	dry	Soil sample #76, grass, sage 23.6%
	16	4.0									Small sage
	17	6.0									Small swail, sage
	18	5.5									Small sage
	19	5.0									Small sage, grass
	20	5.5	5.0	5.5	4	1.5	27	fine drifted	N.A.	dry	Soil sample #80, 23.1% small sage, grass
	21	4.5									Sage, some grass
	22	5.0									Sage
	23	6.0									Sage
Mile 2	24	4.0									Sage, some grass

*Soil sample high in organics--sample results not considered meaningful.

Walden N-S line (continued)

Time	Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski pene-tration (cm)	Wetness	Remarks
Mile 3	25	6.0	4.5	5.0	4	1.0	17	fine drifted	N.A.	dry	Soil sample #16, 21%, mostly sage, some grass
	26	6.5									Sage, grass
	27	3.5									Grass, sage
	28	6.0									Sage, grass
											Top of draw, north side
	29	5.0									Starting up out of draw--south
	30	4.0	3.0	5.0	4	1.0	25	fine drifted	N.A.	dry	Soil sample #1, 16.9%, mostly sage, some grass
	31	4.0									Mostly sage
	32	4.0									" "
	33	4.0									" "
	34	4.5									" "
	35	6.5	6.0	6.0	4	2.0	31	fine drifted	N.A.	dry	Soil sample #90, 70.4%* mostly sage
	36	1.0									Some bare patches, sage, grass
	37	4.0									Sage, grass,
Mile 3											drifting to 10" around
Mile 4	38	4.0									Bare ground
	39	3.5									" "
	40	4.5	3.5	5.0	4	1.0	22	fine drifted	N.A.	moist	Soil sample #101, 18.7%, some small sage
	41	4.5									Bare ground
	42	3.5									Small sage
	43	4.0									Sage
	44	7.0									At fence, 1/4 corner marker, Sec. 19,20 base of pole
	45	4.0	4.0	5.0	4	1.0	25	fine drifted	N.A.	moist	Soil sample #95, 21.7%
	46	4.5									Grass, sage
	47	3.5									Tall grass
	48	3.0									Bare grass, patches
Mile 4	49	6.5									Bare grass, patches, drifting around clumps of sage

*Soil sample high in organics--sample results not considered meaningful.

Walden N-S line (continued)

Time	Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski pene-tration (cm)	Wetness	Remarks
Mile 6	50	16.0	15.0	11.0	4	7.0	44	fine drifted	N.A.	moist	Soil sample #4, 76.5%* bare grass patches, drifting around clumps of sage
	51	6.0									" " " " " "
	52	7.5									" " " " " "
	53	9.0									" " " " " "
	54	5.0									" " " " " "
Mile 6	55	8.0	5.5	6.5	4	2.5	31	fine	N.A.	moist	Soil sample #97, 37.7% End of sampling, 56+50 to RR ROW fence line.

*Soil sample high in organics--sample results not considered meaningful.

APPENDIX E

Walden Snow Course Data
(East-West Line)

Walden Snow Course
3/9/76
East-West Line

Time	Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski penetration (cm)	Wetness	Remarks
13:45	0	4.5	4.0	5.0	4	1.0	22	fine drift	N.A.	moist	Soil sample #104, 23.1%, just west of road by panel
Mile 1	1	3.0									Small sage
	1.5	3.0									" "
	2	3.5									" "
	2.5	5.0									" "
	3	4.0	4.0	5.0	4	1.0	25	fine drift	N.A.	moist	Soil sample #103, 18.6%
	4	3.0									Small sage
	5	4.5	4.0	5.0	4	1.0	22	fine drift	N.A.	moist	Soil sample #77, 20.1%
											small sage
	6	3.0									Behind dump, small sage
	7	4.5									At fence corner, NW edge of dump
Mile 1	8	2.5									Small sage
Mile 2	9	5.5									" "
	10	2.5									" "
	11	3.5									" "
	12	3.0									" "
	13	5.0	4.0	6.0	4	2.0	40	fine drift	N.A.	moist	Soil sample #73, 18.8%
	14	2.0									Small sage
	15	4.0									Edge of stock pond, small sage
	16	4.0									Small sage
	17	3.0									" "
	18	4.0	3.5	5.0	4	1.0	25	fine drift	N.A.	moist	Soil sample #88, 37.9%*
	19	4.0									Bottom of pond, flat & open
Mile 2	20	7.0	6.5	6.0	4	2.0	29	fine drift	N.A.	moist	Soil sample #86, 27.0%
Mile 3	21	3.0									Very small sage, some bare ground
	22	3.5									" " "
	23	3.5									" " "
	24	5.0									Pasture

*Soil sample high in organics.

Walden E-W Line (continued

Time	Station	Depth (in.)	Core length (in.)	Total weight (in.)	Tare weight (in.)	Water equiv. (in.)	Density (%)	Grain size	Ski pene-tration (cm)	Wetness	Remarks
	25	8.0	7.0	6.0	4	2.0	25	fine drift	N.A.	moist	Soil sample #74, 566.2%*
	26	5.5									Big bare spot close by, pasture
	27	3.5									Pasture
	28	6.0									"
	29	3.5									"
Mile 3	30	7.5	6.5	6.0	4	2.0	27	fine drift	N.A.	moist	Soil sample #81, 242.2%* end of sampling

*Soil samples high in organics--these results considered not meaningful.

APPENDIX F

Soil Moisture Report

Empire Laboratories, Inc.

P.O. Box 429 • 214 North Howes
Fort Collins, Colorado 80522 • Telephone (303) 484-0359

March 17, 1976

Bittinger and Associates
105 South Meldrum
Fort Collins, CO 80521

Attention: Mr. Bruce Jones

Gentlemen:

Re: Moisture Samples NASA Steamboat/Walden Flight 3-9-76
ELI Project No. 2251-76
M. W. Bittinger Project No. 581

Enclosed please find test results for the above-referenced project. Moisture contents were determined for twenty-five samples received in our laboratory. The results of these tests are included on page 2. Samples containing high percentages of organic material are noted on the summary sheet.

Very truly yours,

EMPIRE LABORATORIES, INC.

Neil R. Sherrod
Engineering Geologist

pal

Enclosure

NASA Steamboat/Walden Flight

MWB Project No. 581

March 9, 1976

Summary of Test Results

Test No.	Sample No.	Can No.	Percent Moisture
1	P-1	82	45.4*
2	P-2	83	34.6*
3	Pit #3	93	19.7
4	Pit #4	84	27.1
5	Pit #5	89	31.3*
6		1	16.9
7		4	76.5*
8		9	19.7
9		16	21.0
10		73	18.8
11		74	566.2*
12		76	23.6
13		77	20.1
14		80	23.1
15		81	242.2*
16		86	27.0
17		88	37.9*
18		90	70.4*
19		95	21.7
20		97	37.7*
21		100	27.9
22		101	18.7
23		103	18.6
24		104	23.1
25		108	96.4*

* indicates sample contains high percentage of organic matter