



GEOLOGICAL SURVEY OF CANADA

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**Snow depth and density measurements,
Norman Wells pipeline study sites,
Mackenzie Valley 1985 to 1991**

M.M. Burgess

1993



Energy, Mines and
Resources Canada

Énergie, Mines et
Ressources Canada

Canada

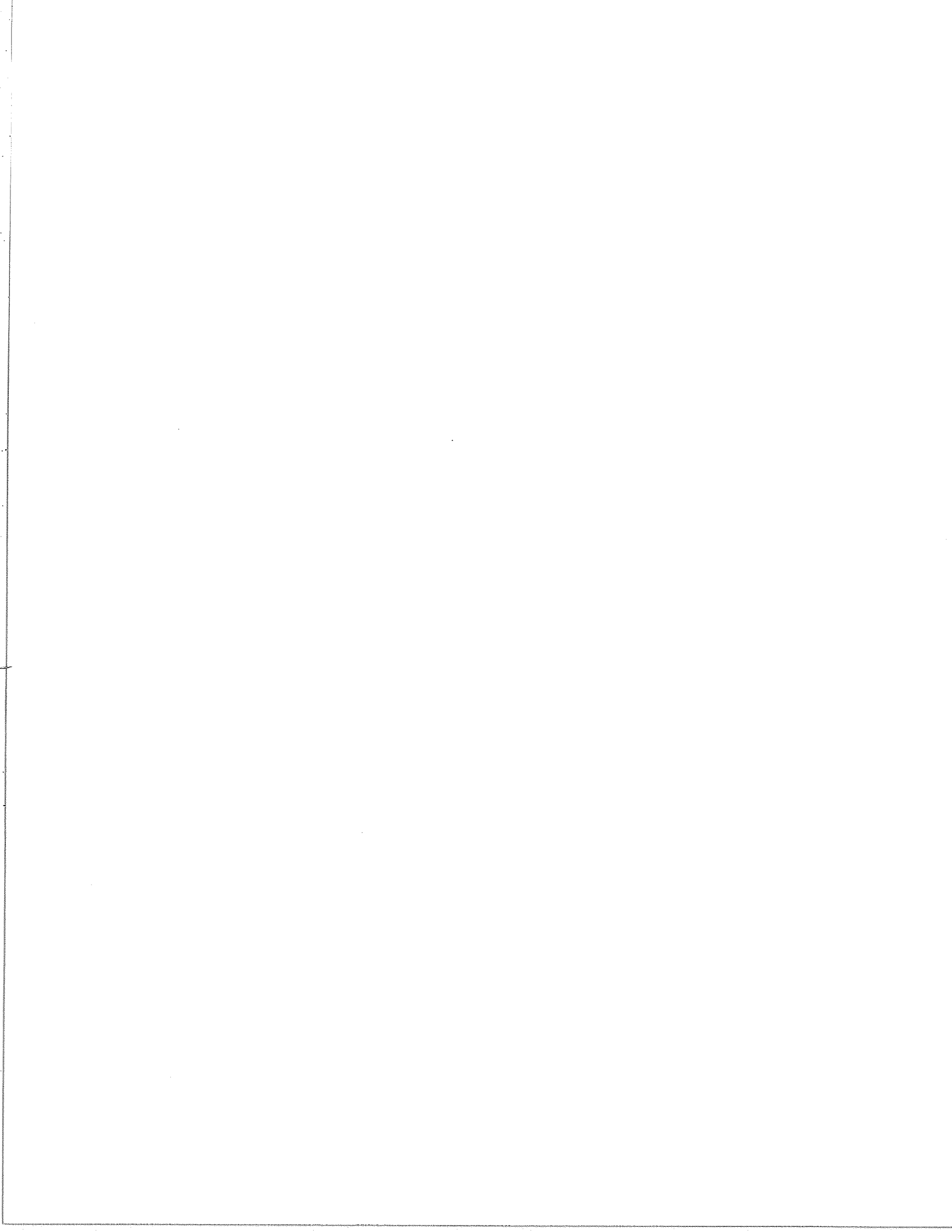
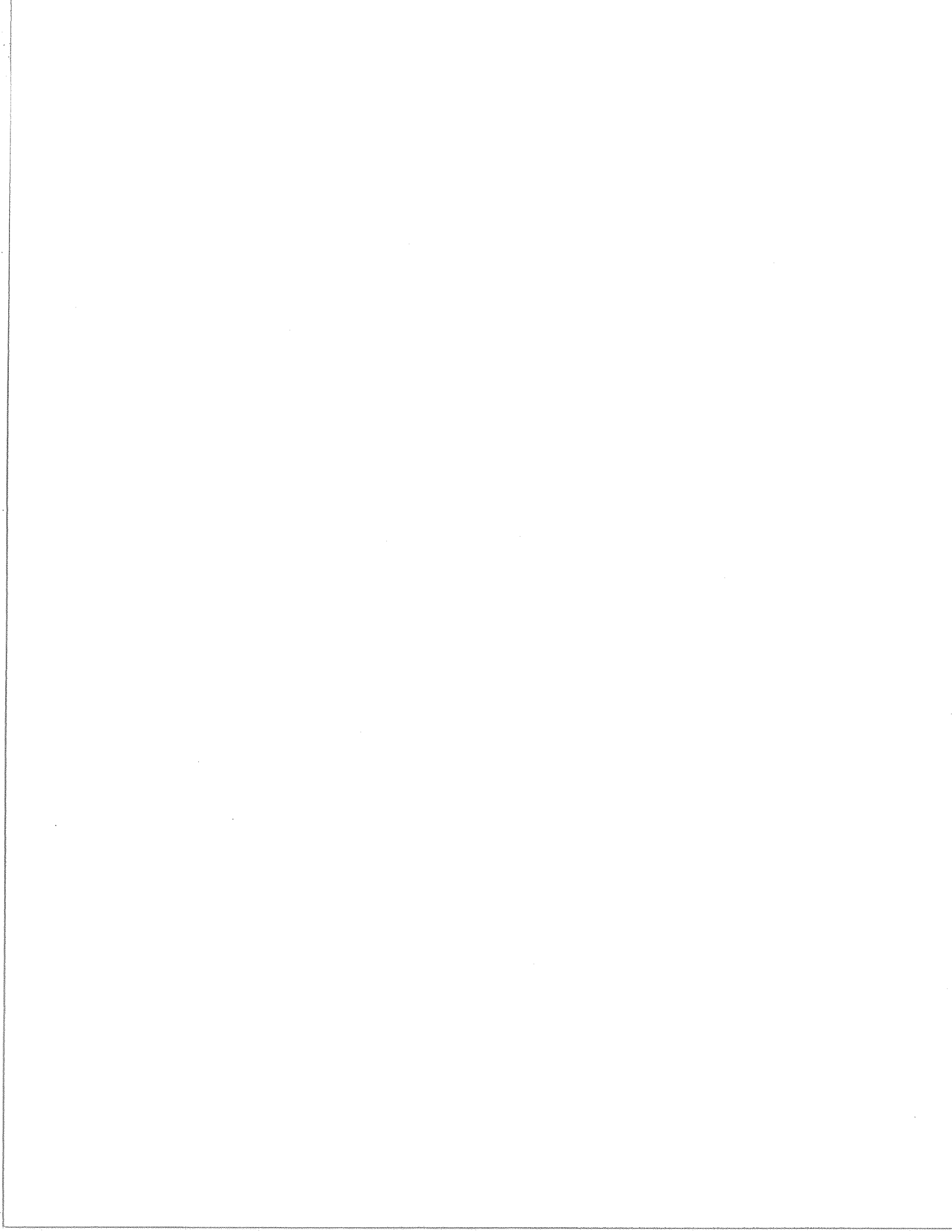


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INTRODUCTION

The federal Departments of Energy, Mines and Resources (EMR) and Indian and Northern Affairs (INAC) have established several instrumented study sites in the Mackenzie Valley as part of a Permafrost and Terrain Research and Monitoring Program carried out along the Norman Wells, N.W.T. to Zama, Alberta pipeline corridor. The 869 km long pipeline is the first fully buried oil pipeline in permafrost terrain in Canada, traversing the discontinuous permafrost zone in a more or less north-south direction.

A major component of the research program is the quantification and analysis of changes in the ground thermal regime. Observations are made both on the disturbed pipeline right-of-way (ROW) and off the ROW in "undisturbed" terrain, to determine the effects of pipeline construction and operation, as well as those of climate change. In permafrost areas, the ground thermal regime is greatly influenced by snow cover (Goodrich, 1982) - of particular importance are time of onset, thickness, density and duration. A thorough examination the response of permafrost terrain to natural and anthropogenic changes thus requires data on the snow cover.

The Atmospheric Environment Service (AES) of Environment Canada maintains records of snow depths at several airport weather stations along the Mackenzie Valley. However, these data are not necessarily representative of the general surrounding area, as has recently been emphasized by a comparison of observations at snow courses in the Norman Wells area to snow depths recorded at the Norman Wells airport weather station (Stuart et al. 1991). Snow measurements have thus formed an integral component of the data collection program at the pipeline monitoring sites since 1985.

This open file report is a compilation of the snow data collected at the EMR/INAC study sites from 1985 through to the end of the winter of 1990/1991. Tables and plots of snow depths recorded each year during regular fields trips over the winter months are presented. Qualitative comparisons of snow depths at the study sites to snow depths at the closest AES stations are made, as well as comparisons of on right-of-way to off right-of-way conditions. Snow density measurements recorded each March since 1986 are also tabulated.

The purpose of this report is to gather together all the measurements made to date. A thorough analysis of the Norman Wells pipeline snow data and of the effects of the clearing of the right-of-way on the snowpack characteristics will form the subject of a later report. The influence of a simulated transport corridor on the snowpack, in the vicinity of Fort Norman, N.W.T., has recently been discussed by Kershaw (1991).

General background information on the pipeline research and monitoring program is first presented and references are provided to guide the reader interested in more documentation on the overall pipeline research program.

BACKGROUND

The small diameter, buried, uninsulated and "ambient" temperature Norman Wells pipeline has been in operation since April 1985 and is owned by Interprovincial Pipe Line (NW) Ltd (IPL). Several novel engineering approaches were implemented in order to limit energy exchange with the environment, minimize terrain disturbance and assure pipe integrity in the discontinuous permafrost terrain (Nixon et al., 1984; McRoberts et al., 1985; MacInnes et al., 1989).

Monitoring the ground thermal regime forms part of the larger multidisciplinary Permafrost and Terrain Research and Monitoring (PTRM) Program established by INAC in 1983 following the signing of an Environmental Agreement with IPL. The overall program objectives include: assessing the impacts of construction and operation of the pipeline on permafrost terrain, recommending improvements in the design and construction of future projects, and increasing the knowledge of the regional environmental framework and the terrain response to climate change as well as man-induced disturbances.

A description of the PTRM program, the selection, location and layout of monitoring sites, and a discussion of observations and analyses from 1983 to 1988 are outlined in greater detail in two volumes by MacInnes et al. (1989 and 1990). The focus of the quantitative research is 23 study sites, called thermal fences, instrumented with ground temperature cables (Figure 1 and Table 1).

A site establishment report (Pilon et al., 1989) provides detailed information on the location and establishment of each thermal fence. Compilations of the thermal data from the sites are regularly released as Geological Survey of Canada Open Files (most recently, Burgess and Naufal, 1990). Annual progress reports, discussing all aspects of the PTRM program, are available through the program coordinator: Dr. K.L. MacInnes, INAC, Land Resources, P.O. Box 1500, Yellowknife, N.W.T., X1A 2R3.

Appendix A provides the site plan of each thermal fence where snow measurements are regularly made. Appendix B provides the schedule of winter field trips undertaken from the winter of 1985/1986 through the winter of 1990/1991.

SNOW DEPTH

Permanent snow depth markers have been located at all but four study sites. There are two markers, one located off-ROW near the ground temperature cable designated as T4 and one on-ROW, generally near the deep cable designated T3. The sites without markers are sites 4B, 5A, 5B and 6; the latter three are located in Northern Alberta and only visited once during the winter months. The Northern Alberta sites are therefore not included in the plots or tables of snow depth. At site 4B, where markers are absent, hand measurements of snow depths are made at T3 on-ROW and at T4 off-ROW; three measurements are generally made and averaged at each spot.

Snow depth measurements have also been made using a hand rule at the location of the remaining ground temperature cables at most of the study sites. However, these records have been somewhat inconsistent from year to year and from site to site, and are not presented in this report.

Appendix C contains plots for each site of the changes in snow depth recorded over the winter months at both the on-ROW and off-ROW marker or equivalent locations. The plots have been grouped for each winter season from 1985/1986 to 1990/1991.

Appendix D tabulates the snow depths recorded at the markers. These tabulations have been simplified to show only the month in which the measurement was made. Additional information on the timing of field measurements is included in Appendix B, which provides the schedule of monitoring trips since 1985.

The snow depths recorded at the AES weather stations in Norman Wells and Fort Simpson have been plotted and tabulated for comparisons. These data, showing the snow depth on ground recorded at the end of the month, are included in Appendices C and D.

SNOW DENSITY

Measurements of mean vertical snow density have been made each March since 1987 using an MSC snow sampler. Three to five samples are taken (and averaged) at the location of the snow depth markers, or, when markers are absent, at the cables where hand measurements of snow depth are made.

Appendix E tabulates for each March the mean snow depth (cm) and the mean density (gr/cm^3) determined at each site.

DISCUSSION AND SUMMARY

Table 2 summarizes for each year the general seasonal trends at each site. The summary is based on comparing on-ROW to off-ROW snow depths as plotted in Appendix C. Most sites have measurements taken several times throughout the winter; the few sites with data gathered only during the March trips (when density measurements are made) are grouped separately at the bottom of the table.

The descriptions used in Table 2 refer to the following:

- OFF>ON: off-ROW snow depths are generally greater than on-ROW throughout the winter months
- ON>OFF: on-ROW snow depths are generally greater than off-ROW throughout the winter months
- ON>=OFF: on ROW snow depths are either greater than or equal to off-ROW throughout the winter months
- OFF>=ON: off ROW snow depths are either greater than or equal to on-ROW throughout the winter months
- ON>OFF;OFF>ON: at the start of the winter snow depths on-ROW are greater than those off-ROW; the opposite occurs later in the winter
- ON>OFF;ON=OFF: at the start of the winter on-ROW snow depths are greater than those off-ROW; later in the winter the snow depths are similar
- OFF=ON;OFF>ON: off-ROW and on-ROW snow depths are similar at the start of the winter; later the off-ROW snow depths are greater
- OFF>ON;ON>OFF: at the start of the winter snow depths off-ROW are greater than those on-ROW; the opposite occurs later in the winter
- VARIABLE: several variations over the winter
- SAME: on and off-ROW snow depths are similar over most of the winter months

The comparisons in Table 2 clearly show that from site to site, and from year to year at a given site, there is great variation in the relationship between on-ROW and off-ROW snow depths. Over the years, there are 6 sites where OFF>ON occurred more frequently, 4 sites where ON>OFF was more common, 2 sites where ON was either > or = to OFF in the early part of winter then OFF>ON in the later part of winter, and several sites where there was no predominant pattern.

Additional information on each site, such as ROW width and orientation which may be relevant to interpreting the above trends, is provided in Table 3.

Table 4 provides a qualitative comparison of the on-ROW and off-ROW snow depths to measurements of snow cover made at the AES airport weather stations in Norman Wells (NW) and Fort Simpson (FS). The comparison of sites in the northern end of the pipeline route (km 0-79) to Norman Wells data indicates that both on-ROW and off-ROW snow depths are greater than those observed at the AES station. Sites in the Wrigley (km 272) area have been compared to both NW and FS data; both on-ROW and off-ROW are greater than the NW observations, but there is no clear pattern when comparing to the FS data. The southern study sites (km 478-819) are quite variable, from year to year, from site to site, and from on-ROW to off-ROW.

Table 5 summarizes the range in snow density measured each March and indicates where the minimum and maximum values were recorded. Only data from sites along the pipeline were used in this summary. On average, snow density measurements are similar both on-ROW and off-ROW. There is no specific site which consistently has the highest or the lowest density, either on-ROW or off-ROW.

ACKNOWLEDGEMENTS

The Permafrost and Terrain Research and Monitoring Program is coordinated by Kaye MacInnes of INAC. The monitoring has been primarily funded by INAC's Northern Affairs Program, with contributions from the Northern Oil and Gas Action Program (NOGAP). Additional funding and other assistance has been provided by the former Earth Physics Branch of EMR, the Geological Survey of Canada, the Federal Panel on Energy Research and Development (PERD), and IPL.

The field data presented in this report has been collected with the help of many individuals within INAC, EMR, IPL, Agriculture Canada and the National Research Council. Janice Naufal and Jan MacDonald provided invaluable assistance in the snow data management.

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FIGURE 1. LOCATION OF STUDY SITES

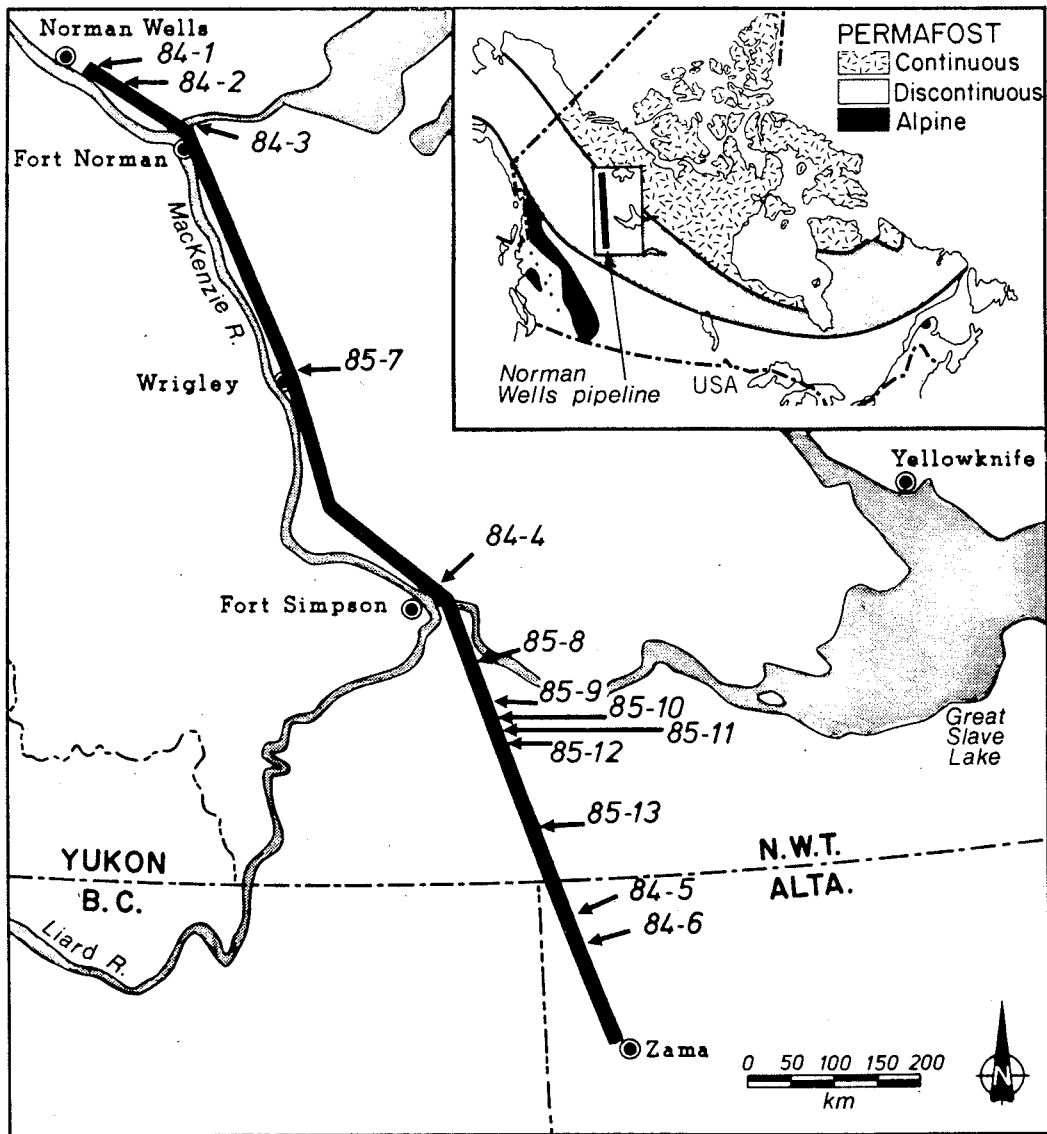


TABLE 1. SITE DESCRIPTIONS

No.	NAME	KM	DESCRIPTION (at time of establishment)
84-1	Pump Station 1.....	0.02	Widespread permafrost Ice-rich silty clay; widespread permafrost
84-2	Canyon Creek		Previously cleared alignment, thaw sensitive slopes, widespread permafrost.
	A	19.0	Level location, frozen till with low ice content
	B	19.3	East-facing slope with a 1 m insulating wood chip cover
	C	19.6	Uninsulated section of west-facing slope
84-3	Great Bear River.....		Joint IPL site with thaw sensitive slope
	A	79.2	Stratigraphically complex ice-rich alluvial terrace deposits in widespread permafrost; cliff-base
	B	79.4	Cliff-top lacustrine deposits with aeolian veneer
85-7	Table Mountain.....		Joint IPL site with thaw sensitive slopes
	A	271.2	Ice-rich lacustrine plain(old seismic line)
	B	272.0	Drillpad clearing at bend on top of north facing slope, ice-rich lacustrine plain
	C	272.3	New clearing on ice-rich lacustrine plain
84-4	Trail River.....		Pipeline previously traversed frozen ground
	A	478.0	Unfrozen saturated sands/silts in dune hollow
	B	478.1	Dry sands and silts in dune crest
85-8	Manner's Creek.....		Rapidly changing permafrost conditions
	A	557.8	Thin peat with thick (10 m) permafrost
	B	558.2	Thick(2.7 m) peat with thin(4 m) permafrost
	C	558.3	Thin peat (1 m) with thin (1 m) permafrost
85-9	Pump Station 3.....	583.3	Pipe previously traversed frozen section Unfrozen granular soils
85-10	Mackenzie Highway South ...		Unfrozen/frozen interface
	A	588.3	Helipad clearing in unfrozen terrain
	B	588.7	Thin (3 m) permafrost with 2 m peat cover
85-11	Moraine South	597.4	Thin (<4 m) permafrost in helipad clearing
85-12	Jean Marie Creek.....		Unfrozen/frozen interface
	A	608.6	Thin unfrozen peat
	B	608.7	Thick ice-rich peat plateau; 4 m permafrost
85-13	Redknife Hills.....		Frozen/unfrozen interface; single cables only
	A	682.2	Frozen (6 m) terrain surrounding large fen
	B	682.4	Frozen (6 m) terrain at fen border
	C	682.6	Unfrozen terrain in fen
84-5	Petitot River North.....		Degrading peat plateau
	A	783.0	Ice-rich peat (3.5 m); (15-18 m) permafrost
	B	783.3	Very thick icy peat (7 m); 12 m permafrost
84-6	Petitot River South.....	819.5	Peat plateau preceded by unfrozen fen Thick (5 m) ice-rich peat; 7 m permafrost

TABLE 2: SNOWDEPTHS: ON VS OFF ROW

SITE	85/86	86/87	87/88	88/89	89/90	90/91	PREDOMINANT (MOST FREQUENT) PATTERN
<u>Sites with data throughout the winter</u>							
1	off>on	variable	variable	off>on	off>on	off>on, slightly	off>on
2A	off>on	off>on	off>on	off>on	variable	off>on	off>on
2B	off>on	off>on	off>on	off>on	off>on	off>on	off>on
2C	off>on	on>=off	off>on	on>off;	off>on	off>on	off>on or on>off
3A	on>off;	off>=on	off>on	on>off;	off>on	off>on	off>on
3B	on>off;	variable	off>on	on>off;	off>on	off>on	on>off or off>on
7A		off=on;	off>=on	on>off;	off>on	no data on ROW	on>=off early, off>on late
7B		off=on;	off>on	on>off;	off>on	on>off;off>on	on>=off early, off>on late
7C		off=on;	off>on	on>off;	off>on	on>off;off>on	off>on
4A	+/-same	variable	+/-same	off>on	off>on	off>on	+/-same
4B	+/-same	off>=on	on>off;off>on	on>off;	off>on	off>on;	no dominant pattern
8A	on>off;off>on	on>off	on>off	on>off	on>off	off>on;	on>off
8B	variable	on>off	on>off	on>off	on>=off	off>on;	on>off
8C	on>off;off>on	on>=off	variable	variable	off>on	on>off;	no dominant pattern
9	off>on	variable	variable	on>off	on>off	off>on	no dominant pattern
10A	off>=on	on>off	on>off	on>off	on>off	on>off	on>off
10B	off>=on	on>off	on>=off	on>off	variable	on>off	on>off
11	off>on	off>on	on>off;off>on	on>off	on>off;on=off	variable	no dominant pattern
12A	off>=on	off>=on	off>=on	on>off	+/-same	on>off;off>on	off>=on
12B	off>on	off>on	variable	off>on	off>on	off>on;	off>on

SUMMARY STATISTICS

	85/86	86/87	87/88	88/89	89/90	90/91
OFF>ON	6	4	5	5	6	7
ON>OFF	-	4	5	7	5	3
ON>=OFF	-	2	1	-	1	-
OFF>=ON	3	3	2	-	-	-
ON>OFF;OFF>ON	3	-	2	6	-	4
ON>OFF;ON=OFF	-	-	-	-	1	-
OFF=ON;OFF>ON	3	-	-	-	-	-
OFF>ON;ON>OFF	-	-	-	-	-	3
VARIABLE	1	4	4	1	2	1
SAME	2	-	1	-	3	-
TOTAL SITES	15	20	20	19	18	18

Sites with March data only

5A	on>off	off>on	on>off	off>on	off>on	+/-same
5B	off>on	off>on	+/-same	off>on	off>on	on>off
6	off>on	off>on	+/-same	off>on	on>off	on>off

Note: see text for further details on descriptions.

TABLE 3: CHARACTERISTICS OF EACH STUDY SITE

SITE	KMP	ROW ORIENTATION	ROW WIDTH (m)	DISTANCE (m) OF SNOWDEPTH SITE FROM EDGE ROW, approx.		DOMINANT SNOWDEPTH PATTERN	PREVAILING WINDS AES station (2)
				on ROW	off ROW (1)		
1	0.02	N-S	26.5	12	7E	OFF>ON	WNW (NWA)
2A	19.0	NW-SE	25.1	9	11W	OFF>ON	WNW
2B(slope)	19.3	NW-SE	21.4	7	12W	OFF>ON	WNW
2C(slope)	19.6	NW-SE	21.7	6	8E		WNW
3A	79.2	NW-SE	64.7	5	12W	OFF>ON	WNW
3B	79.4	NW-SE	16.3	6	15W		WNW
7A	271.2	NW-SE	25.5	3	5E	ON>=OFF;OFF>ON	SE (WA)
7B	272.0	NW-SE	25.2	4	8E	ON>=OFF;OFF>ON	SE
7C	272.3	NW-SE	24.3	3	10E	OFF>ON	SE
4A	478.0	NW-SE	21.4	4	12W	OFF=ON	NW, NNW (FS, FSA)
4B	478.1	NW-SE	24.5	5*	11E		NW, NNW
8A	557.8	NW-SE	25.9	4	10E	ON>OFF	NW, NNW
8B	558.2	NW-SE	24.8	4	9E	ON>OFF	NW, NNW
8C	558.3	NW-SE	23.6	3	8E		NW, NNW
9	583.3	NW-SE	23.1	3	10E		NW, NNW
10A	588.3	NW-SE	26.7	3	10W	ON>OFF	NW, NNW
10B	588.7	NW-SE	26.3	2	9W	ON>OFF	NW, NNW
11	597.4	NW-SE	25.7	4	12W		NW, NNW
12A	608.6	NW-SE	25.7	3	10W	OFF>=ON	NW, NNW
12B	608.7	NW-SE	24.8	4	8W	OFF>ON	NW, NNW
5A	783.0	NW-SE	25.2	5	10W		N (HL)
5B	783.3	NW-SE	26.0	6	10W		N
6	819.5	NNW-SSE	25.0	5	10W		N

Notes:

1. E or W indicates whether the off-ROW snow depth marker is on the east or west side of the ROW.
 2. Prevailing winds are from the closest AES station, given in bracket: NWA = Norman Wells Airport, WA = Wrigley airport, FS = Fort Simpson, FSA = Fort Simpson Airport, HL = High Level. Prevailing wind directions are from 1951-1980 climate normals (Environment Canada, 1982)
- * Indicates the marker on ROW is on the opposite side of the pipeline from the off-ROW marker

TABLE 4: COMPARISON OF SNOWDEPTH ON AND OFF-ROW AT STUDY SITES TO AES SNOWCOVER DATA

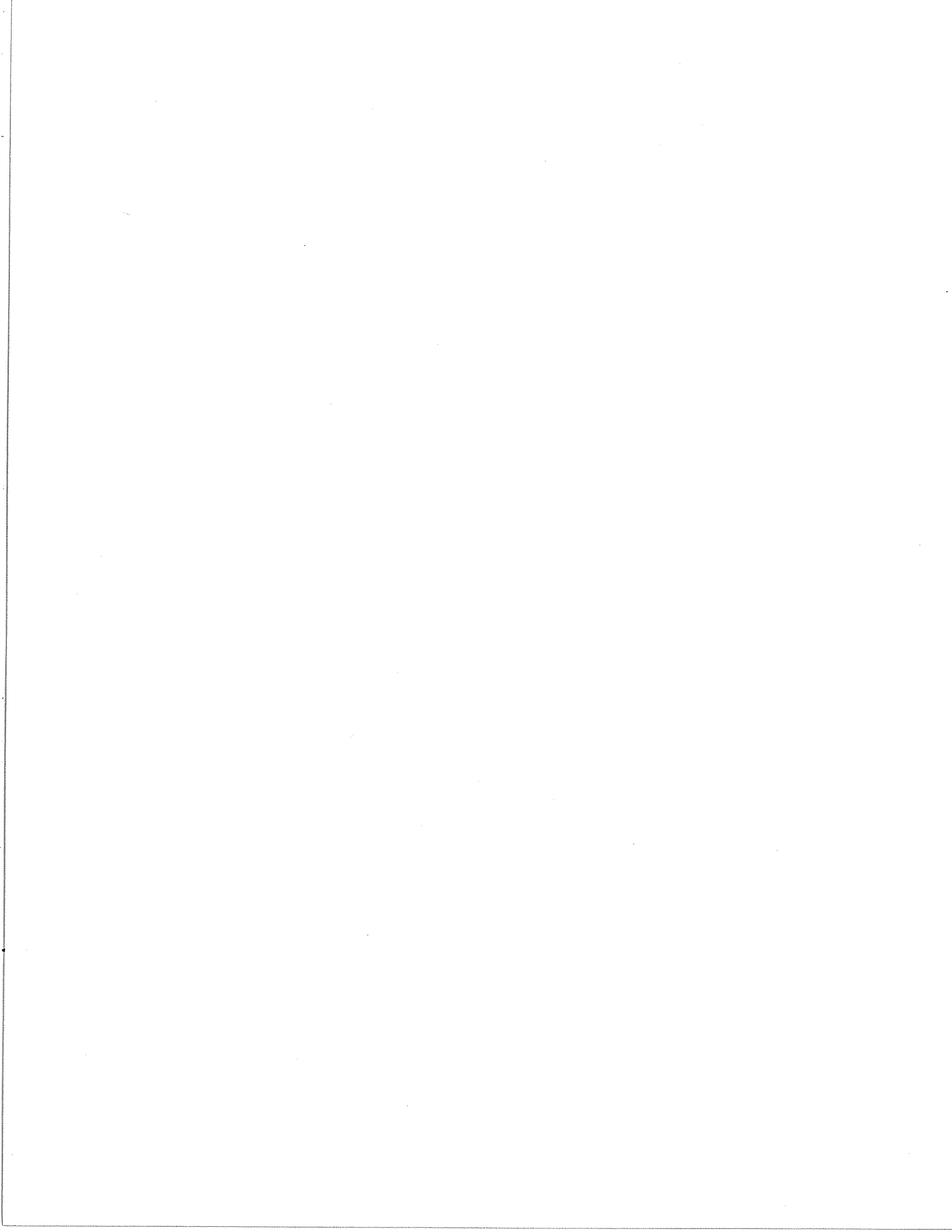
SITE	KMP	85/86		86/87		87/88		88/89		89/90		90/91	
		ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
1	0.02	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW		
2A	19.0												
2B(slope)	19.2	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW		
2C(slope)	19.6	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW		
3A	79.2	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW		
3B	79.4	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW	>NW		
7A	271.2												
7B	272.0	>NW;~FS	>NW;>FS	>NW;<FS	>NW;<FS	>NW;<FS	>NW;<FS	>NW;~FS	>NW;~FS	>NW;>FS	>NW;>FS	>NW;>FS	>NW;>FS
7C	272.3	>NW;<=FS	>NW;=FS	>NW;~FS	>NW;~FS	>NW;~FS	>NW;~FS	>NW;>FS	>NW;>FS	>NW;>FS	>NW;>FS	>NW;>FS	>NW;>FS
4A	478.0	>=FS	>=FS	~FS	<FS	~FS	<FS	~FS	~FS	~FS	~FS		
4B	478.1	>FS	>FS	>=FS	>FS	<=FS	<FS	~FS	~FS	~FS	~FS		
8A	557.8	~FS	~FS	~FS	<FS	~FS	>FS	>FS	<FS	~FS	~FS		
8B	558.2	~FS	~FS	<FS	<FS	~FS	~FS	>FS	>FS	>FS	>FS		
8C	558.3	~FS	~FS	<FS	<FS	~FS	~FS	>FS	>FS	~FS	~FS		
9	583.3	>FS	>FS	~FS	<FS	~FS	~FS	>FS	~FS	>FS	>FS		
10A	588.3	>FS	>FS	>FS	<=FS	>=FS	~FS	>FS	>FS	>FS	>FS		
10B	588.7	>FS	>FS	~FS	<FS	~FS	~FS	>=FS	~FS	>FS	>FS		
11	597.4	~FS	>FS	~FS	>=FS	~FS	~FS	>FS	>FS	>FS	>FS		
12A	608.6	>FS	>FS	>=FS	>FS	~FS	~FS	>FS	>FS	>FS	>FS		
12B	608.7	~FS	>=FS	>=FS	=FS	~FS	<=FS	<FS	~FS	~FS	~FS		

Notes:

NW is Norman Wells airport AES station
 FS is Fort Simpson airport AES station
 > greater than, < less than, >= greater than or equal to
 <= less than or equal to, = similar,
 ~ varies over the winter

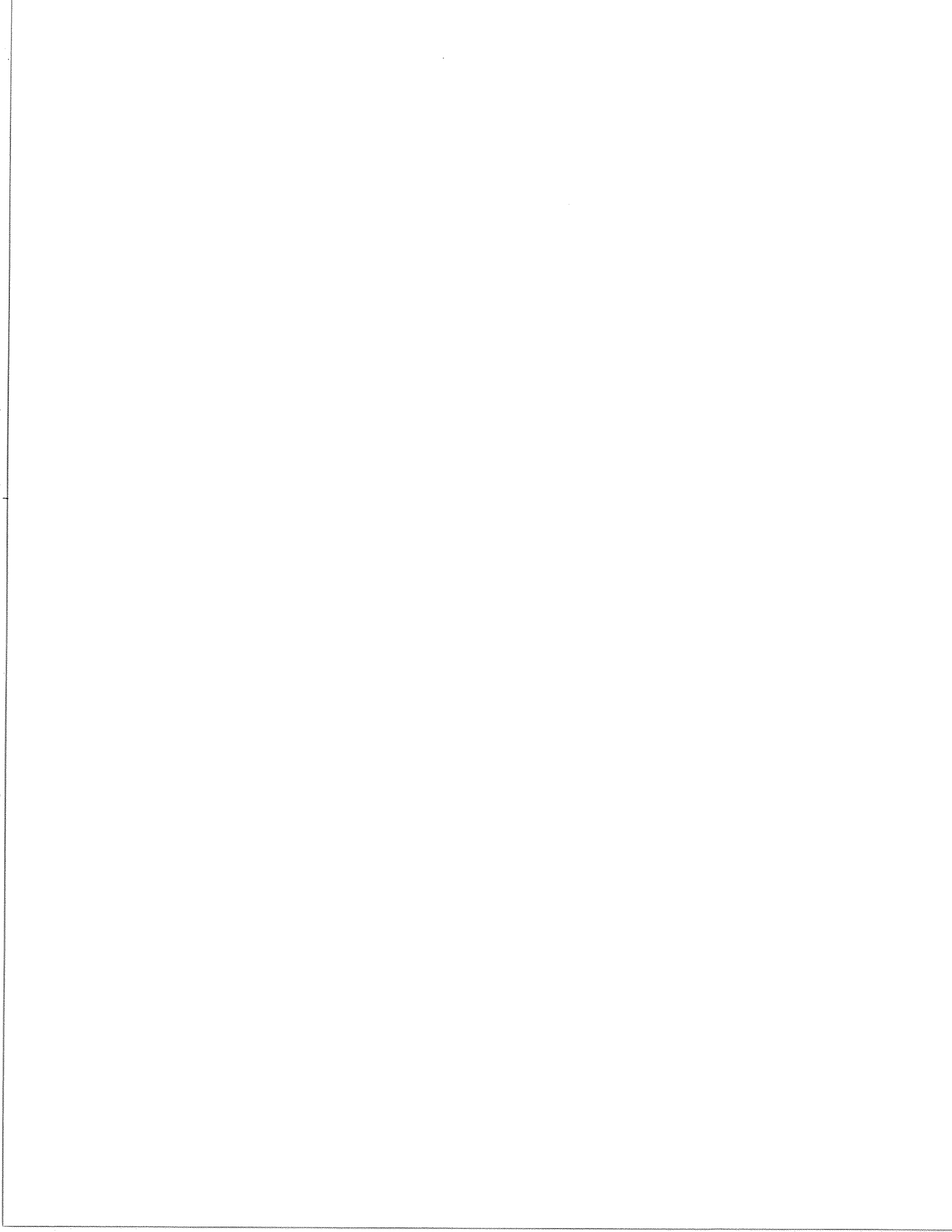
TABLE 5: SUMMARY SNOW DENSITY DATA (GR/CM³)

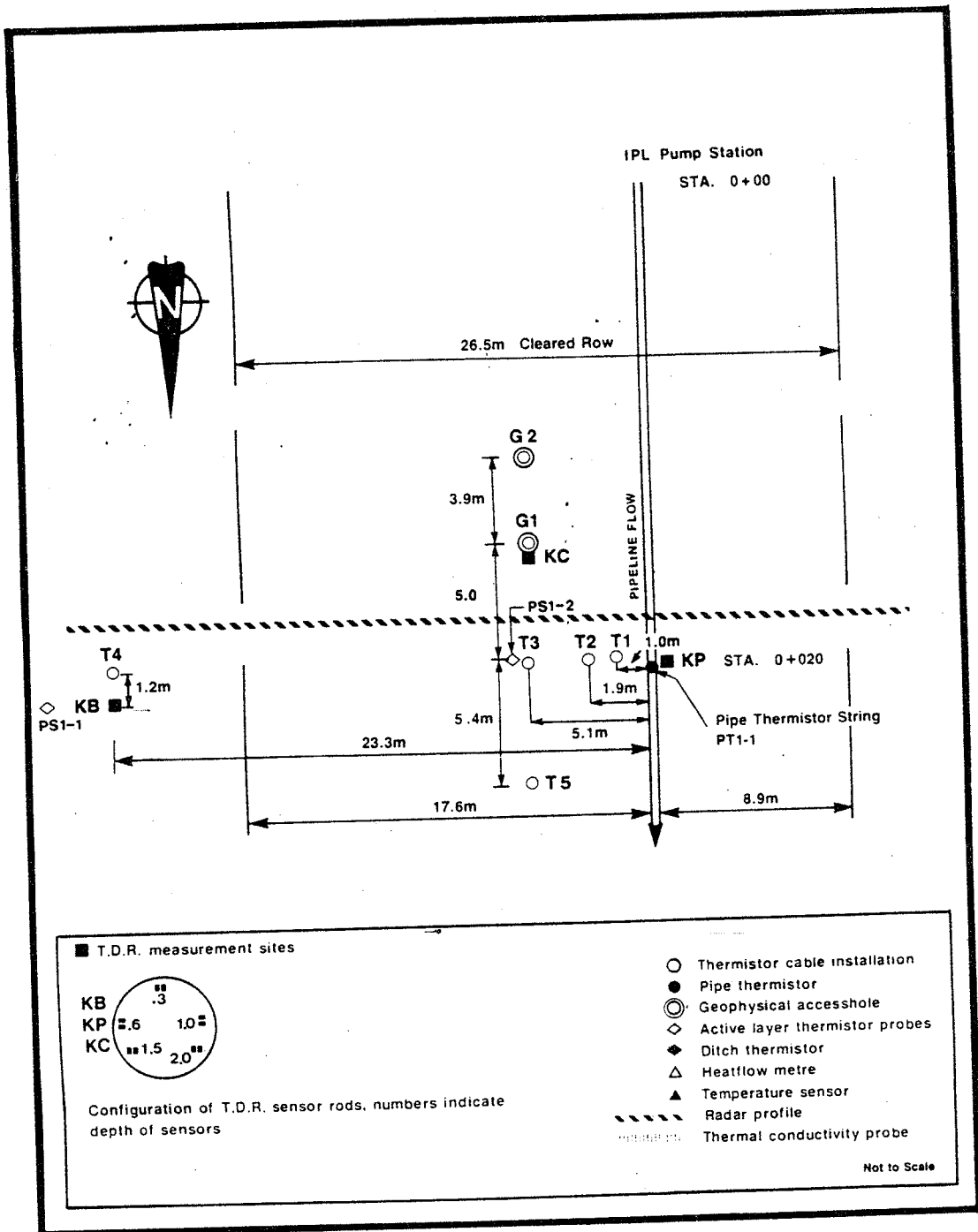
YEAR	AVERAGE	MINIMUM	SITE	MAXIMUM	SITE
OFF-ROW					
1987	.186	.150	85-7B	.238	84-3A
1988	.211	.138	85-7B	.277	84-1
1989	.168	.146	85-10B	.216	84-2C
1990	.204	.167	85-9	.226	85-12B
1991	.202	.147	84-3A	.252	84-2B
ON-ROW					
1987	.207	.120	84-5B	.402	84-3B
1988	.205	.147	84-2C	.283	85-10B
1989	.178	.119	85-11	.236	84-2C
1990	.199	.110	84-3A	.276	84-2C
1991	.195	.138	84-1	.236	85-8C



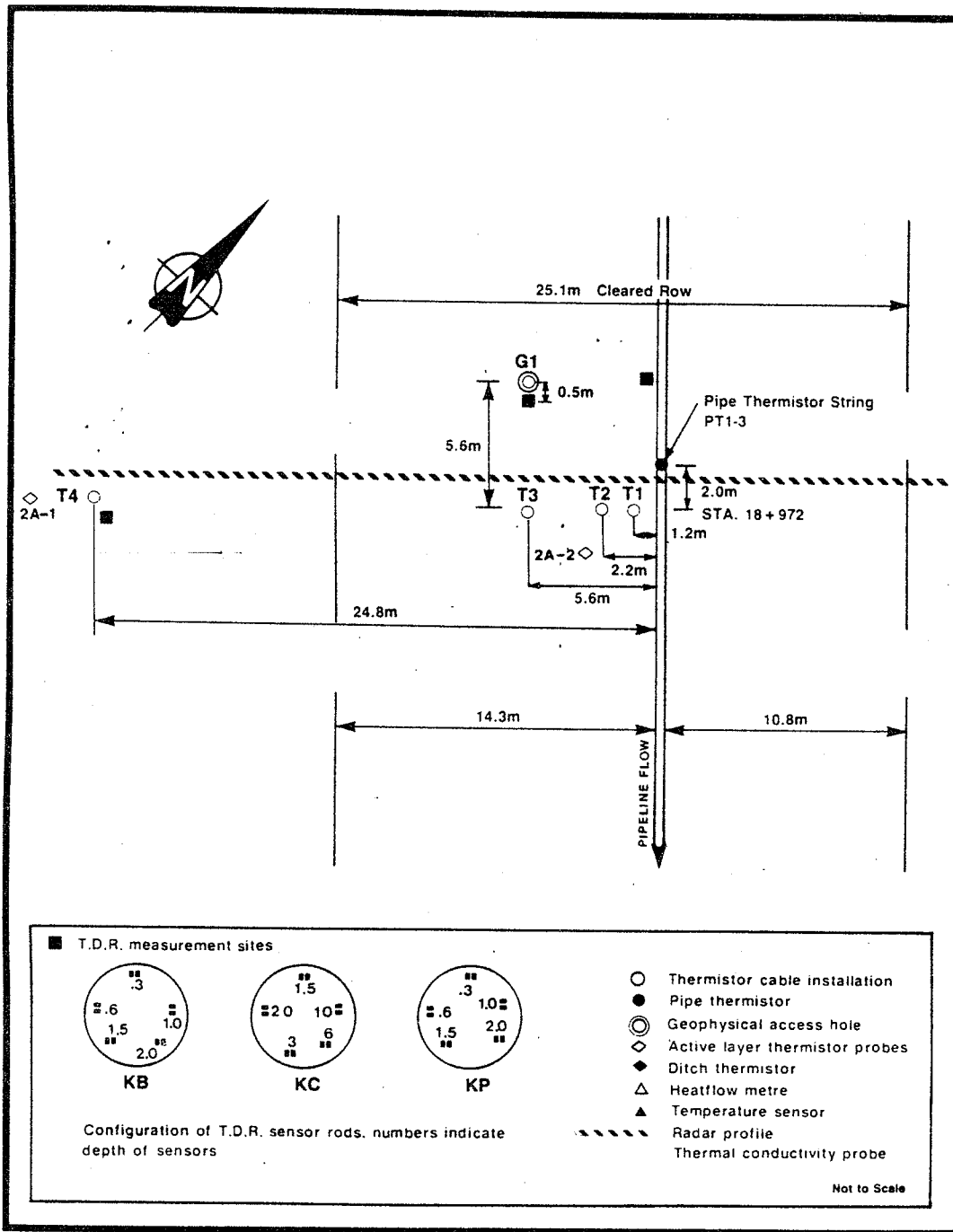
APPENDIX A

SITE PLANS

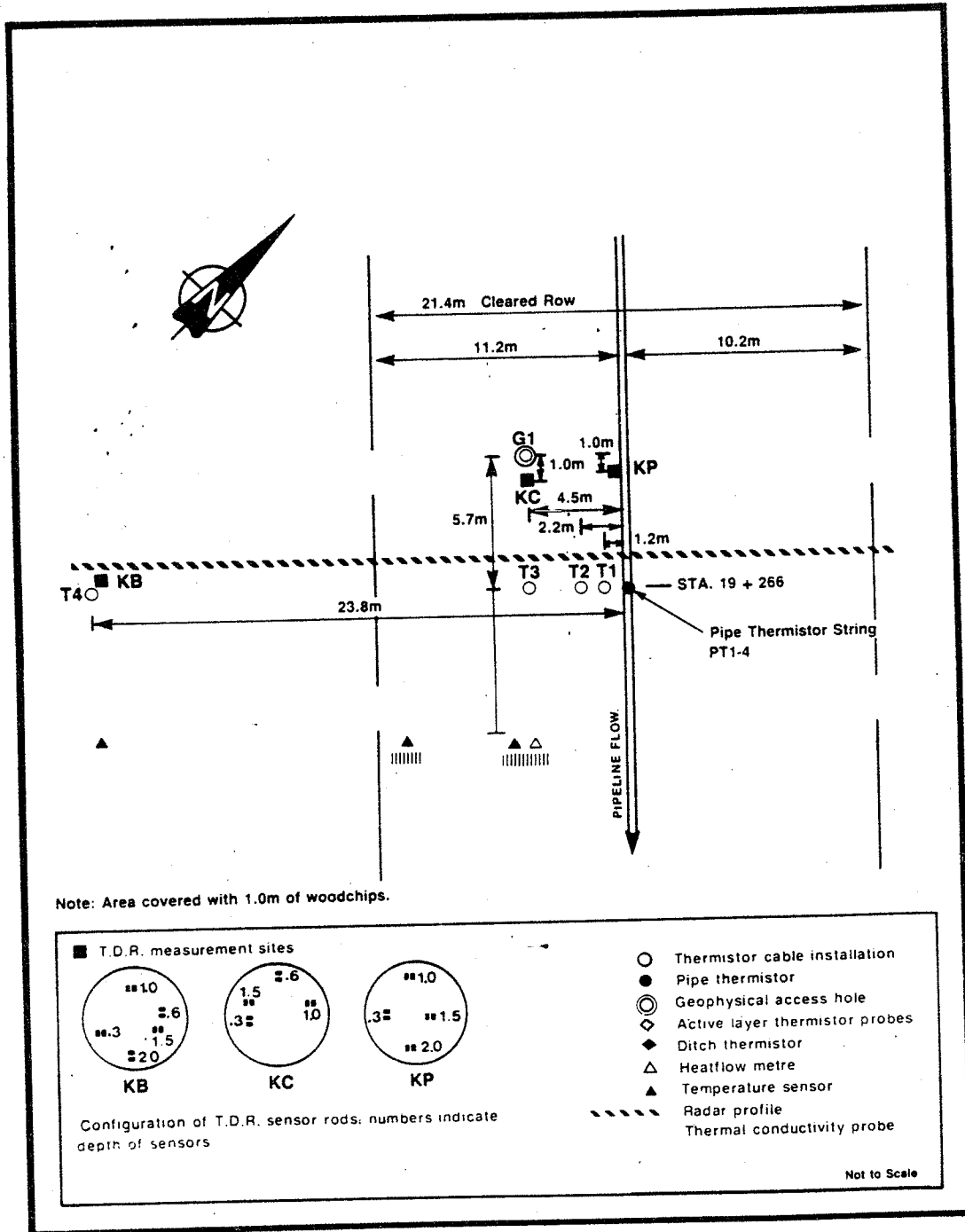




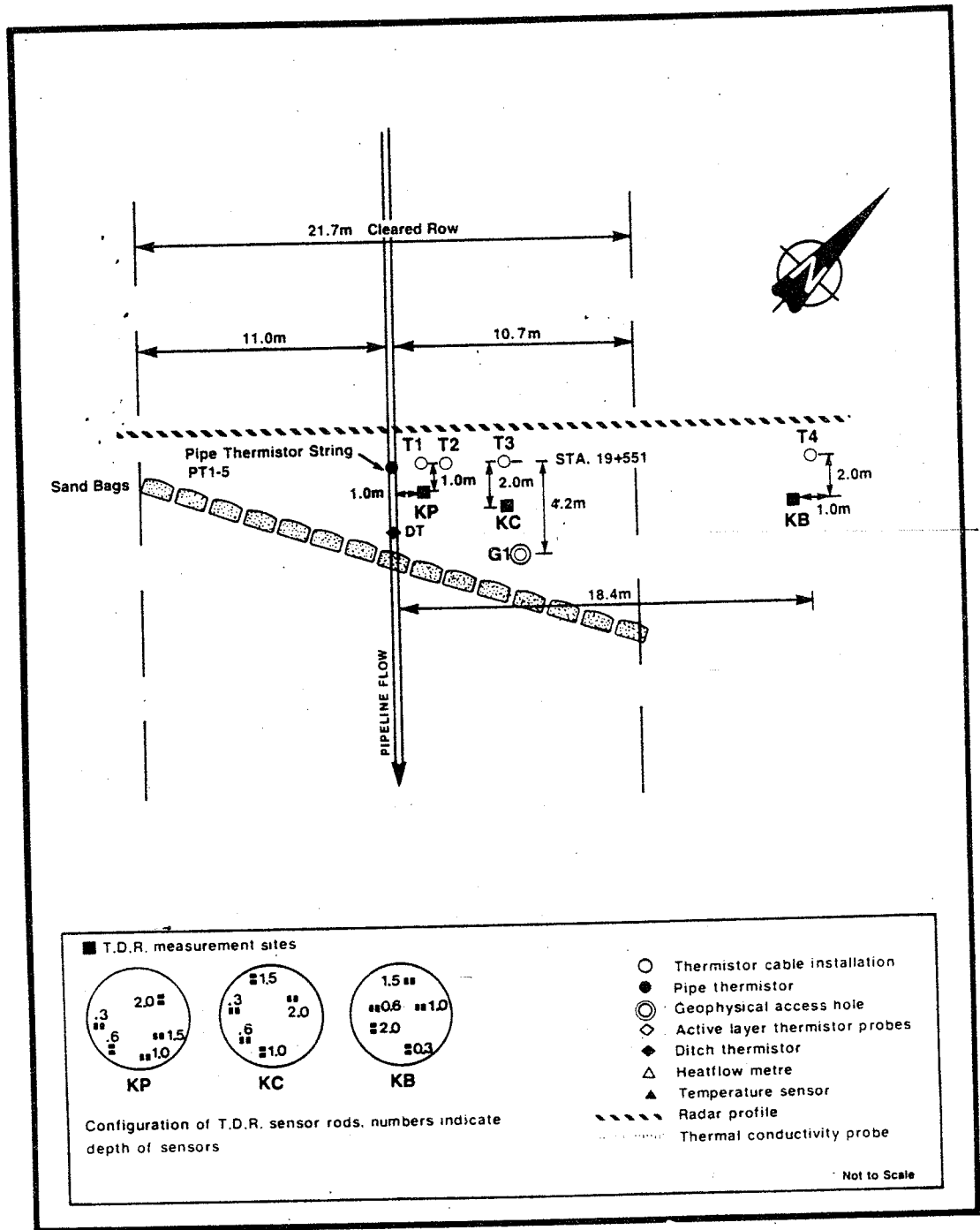
Site plan of EMR/INAC site 84-1, Norman Wells, Pump Station No. 1



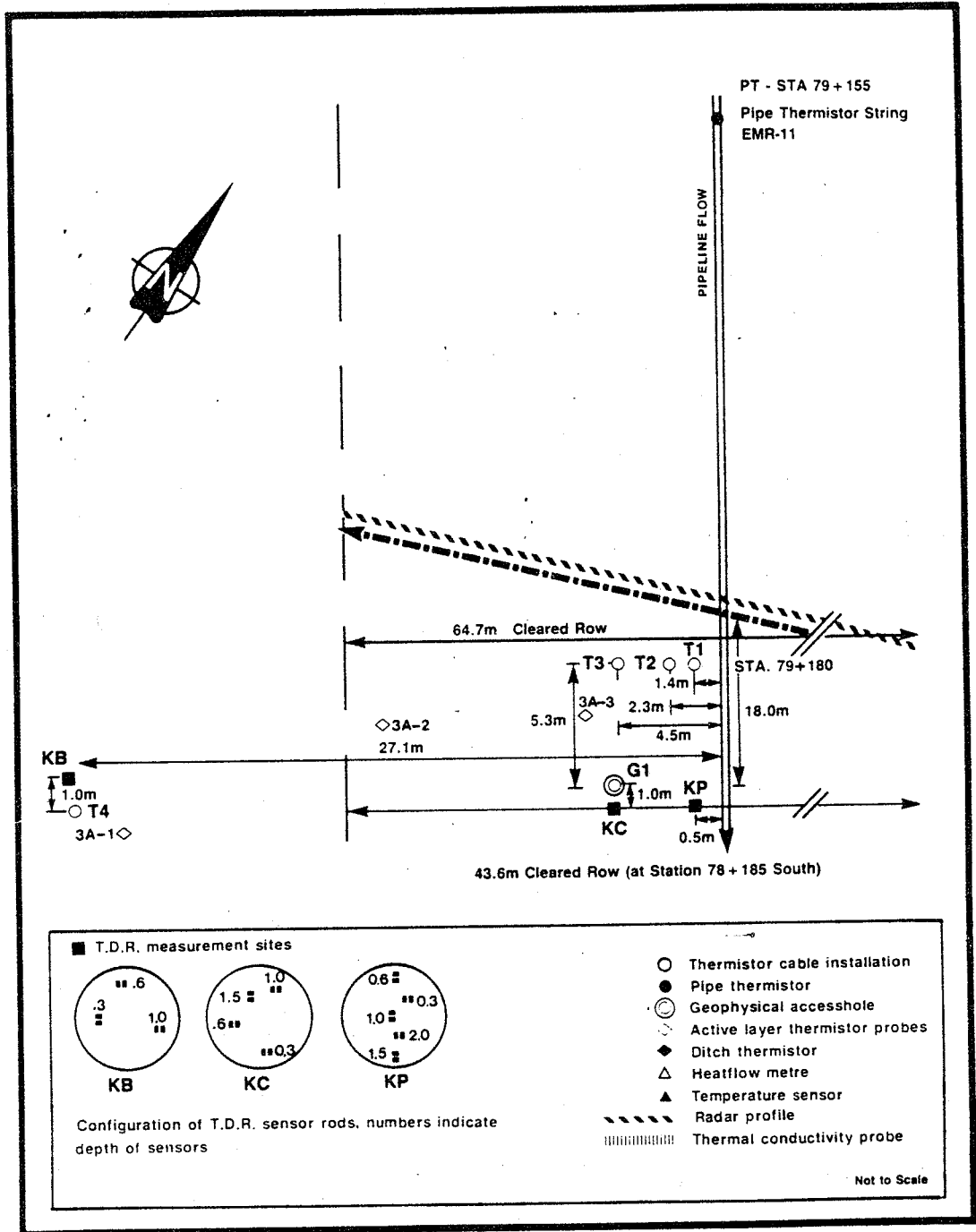
Site plan of EMR/INAC site 84-2A, Canyon Creek



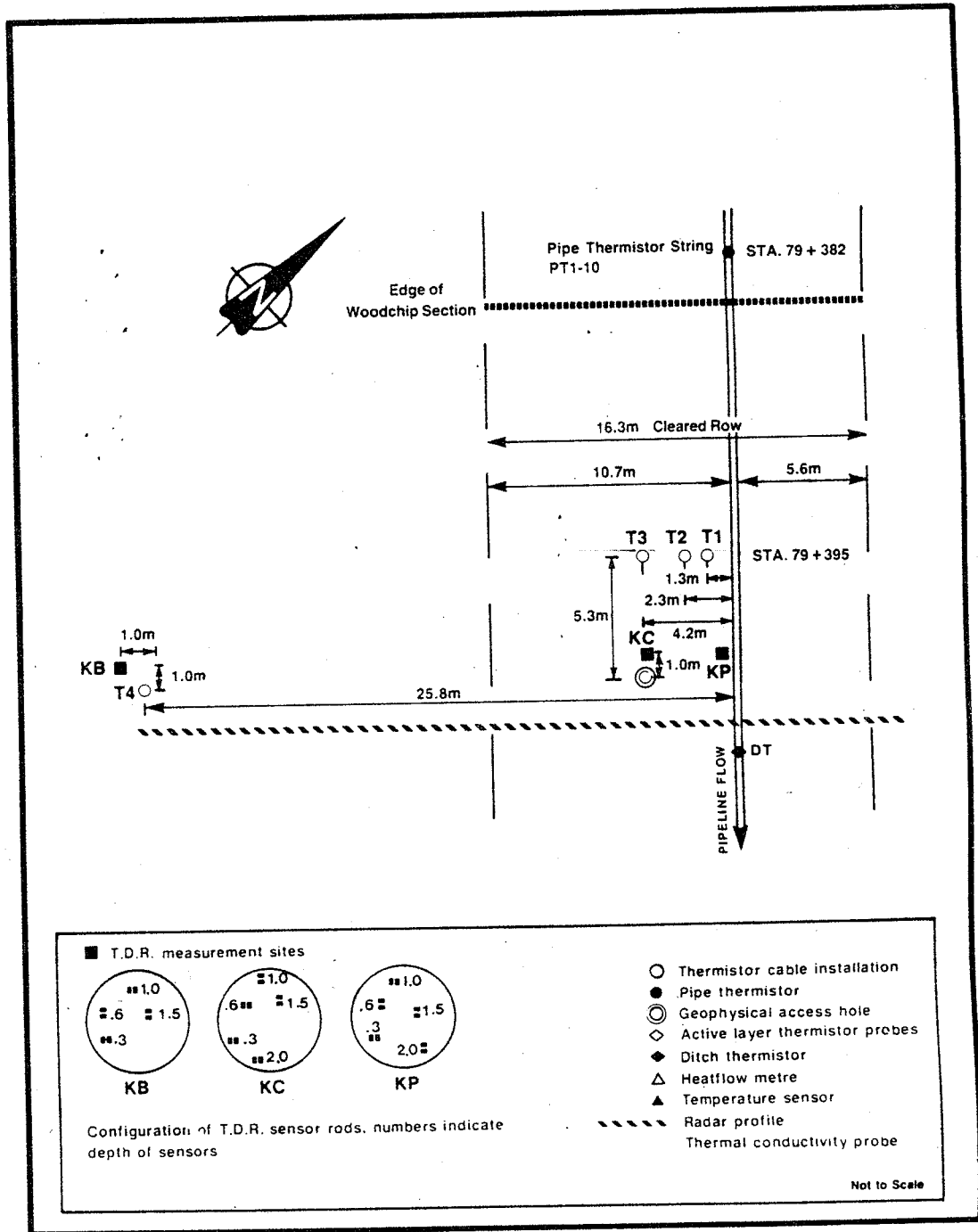
Site plan of EMR/INAC site 84-2B, Canyon Creek



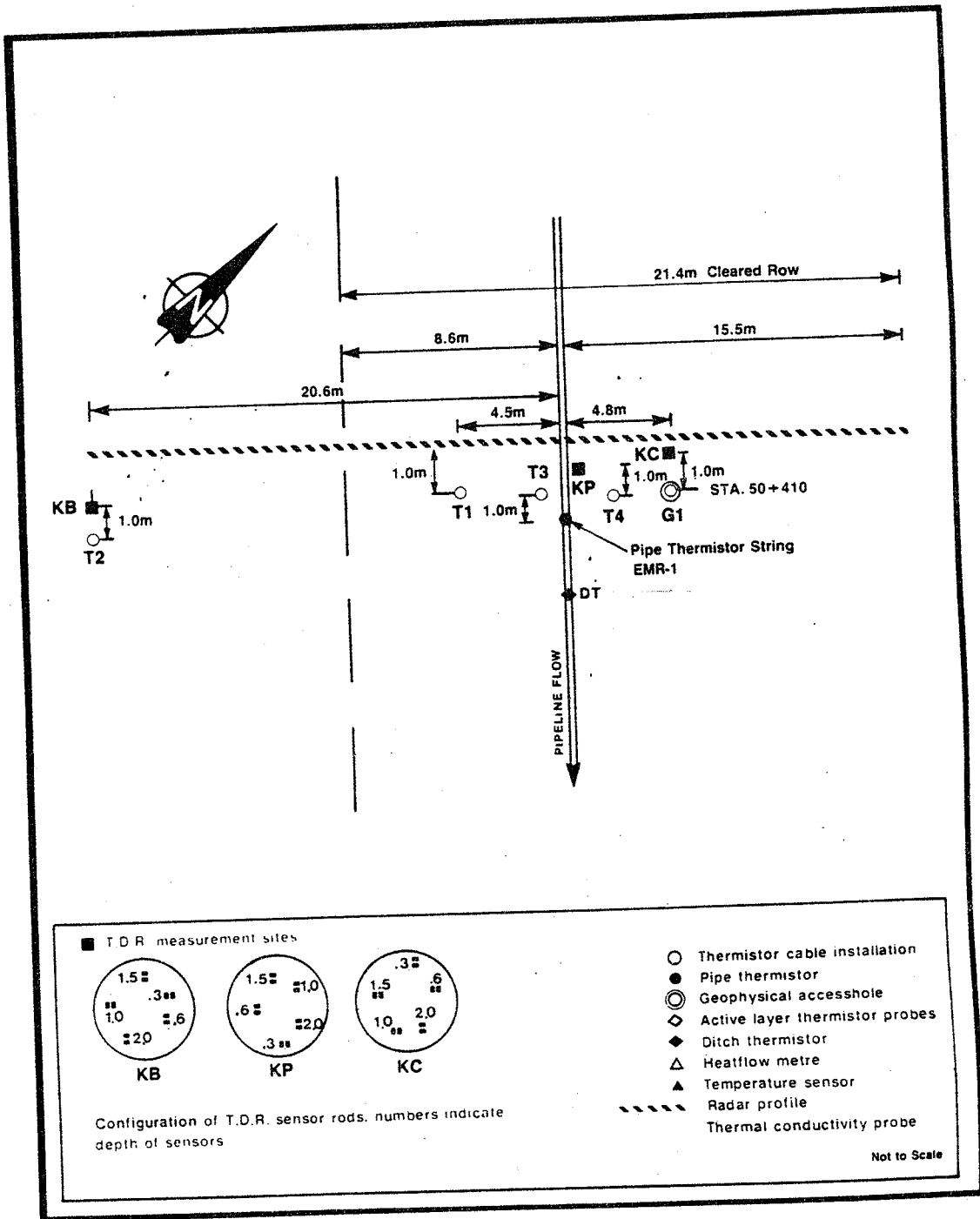
Site plan of EMR/INAC site 84-2C, Canyon Creek



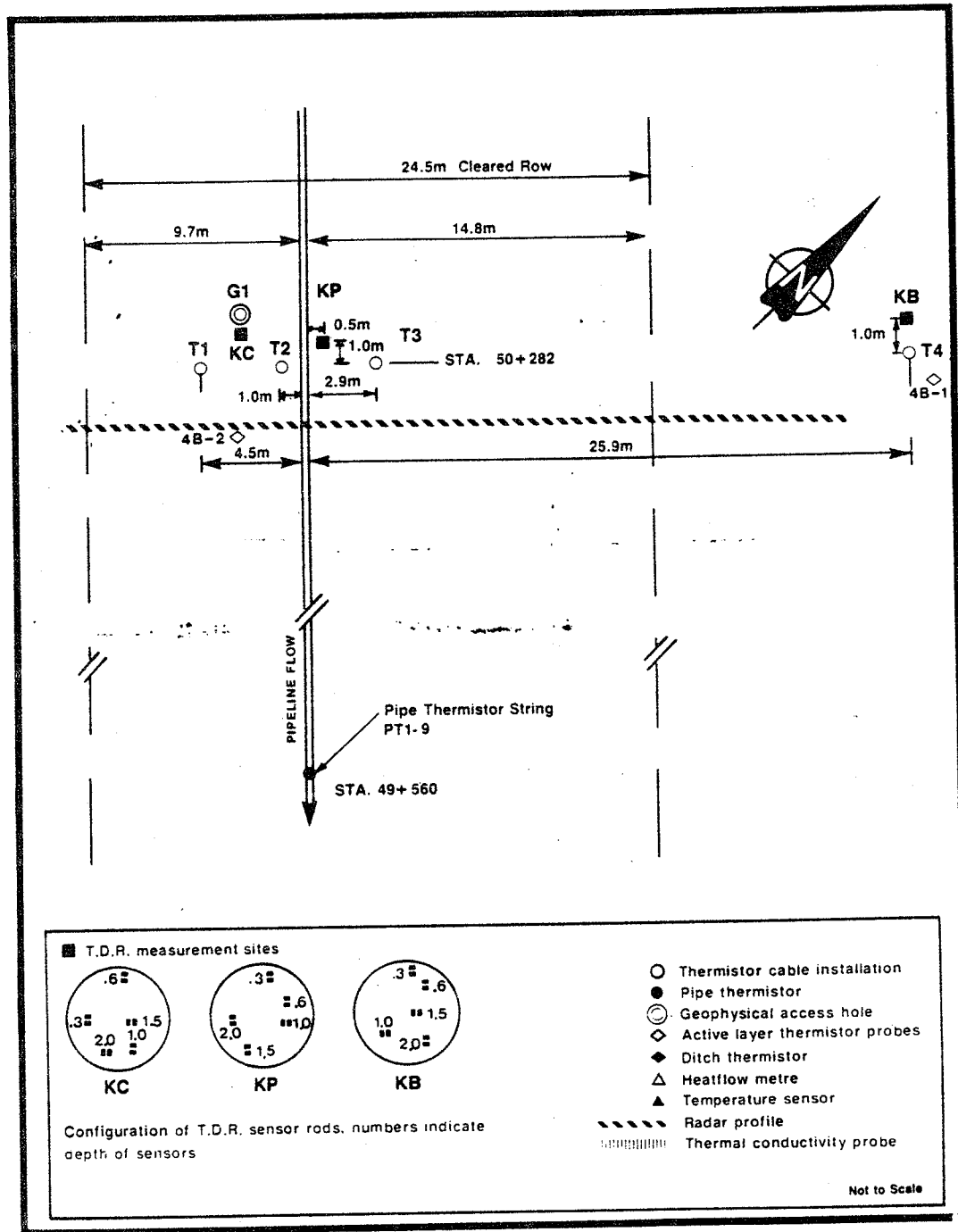
Site plan of EMR/INAC site 84-3A, Great Bear River



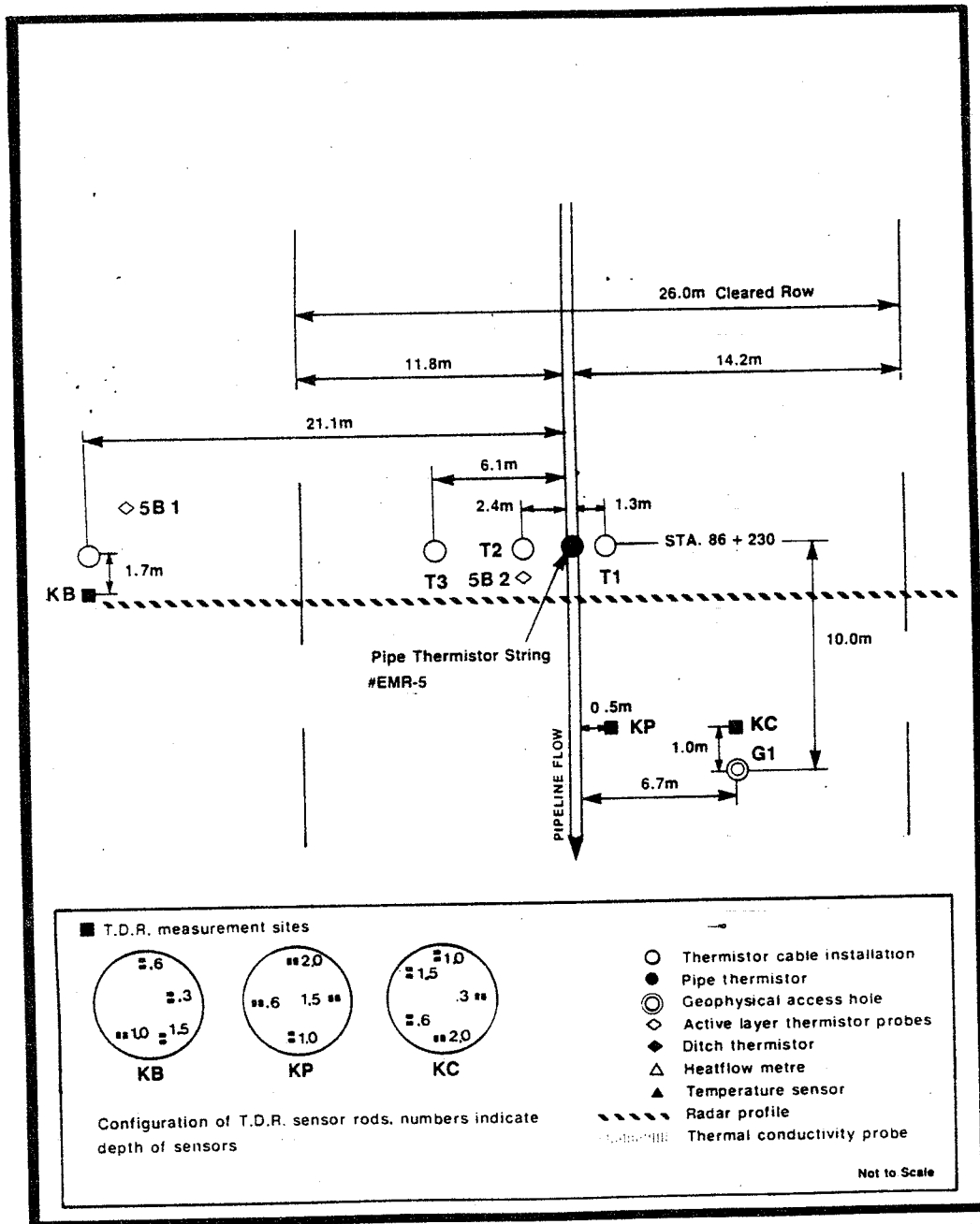
Site plan of EMR/INAC site 84-3B, Great Bear River



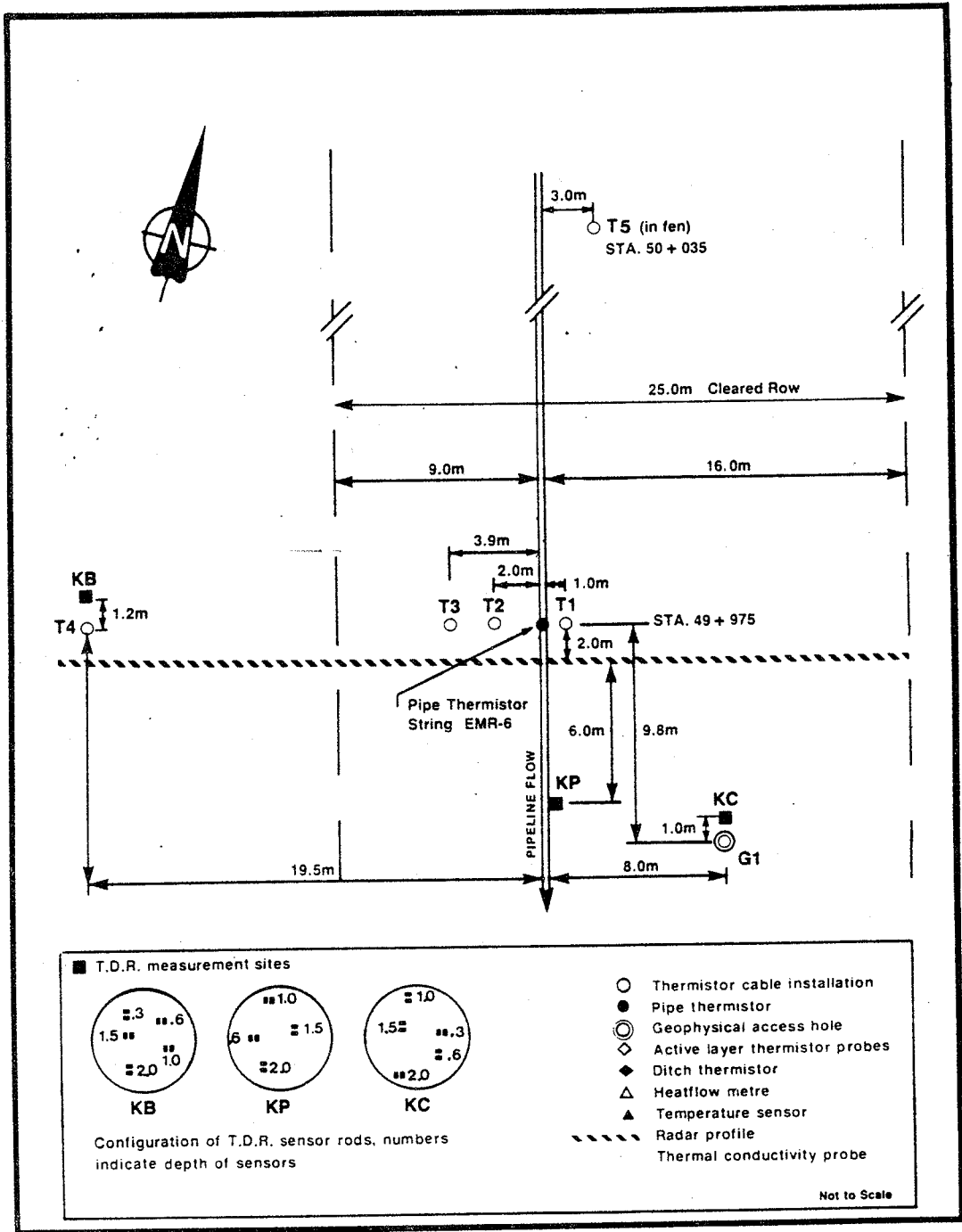
Site plan of EMR/INAC site 84-4A, Trail River



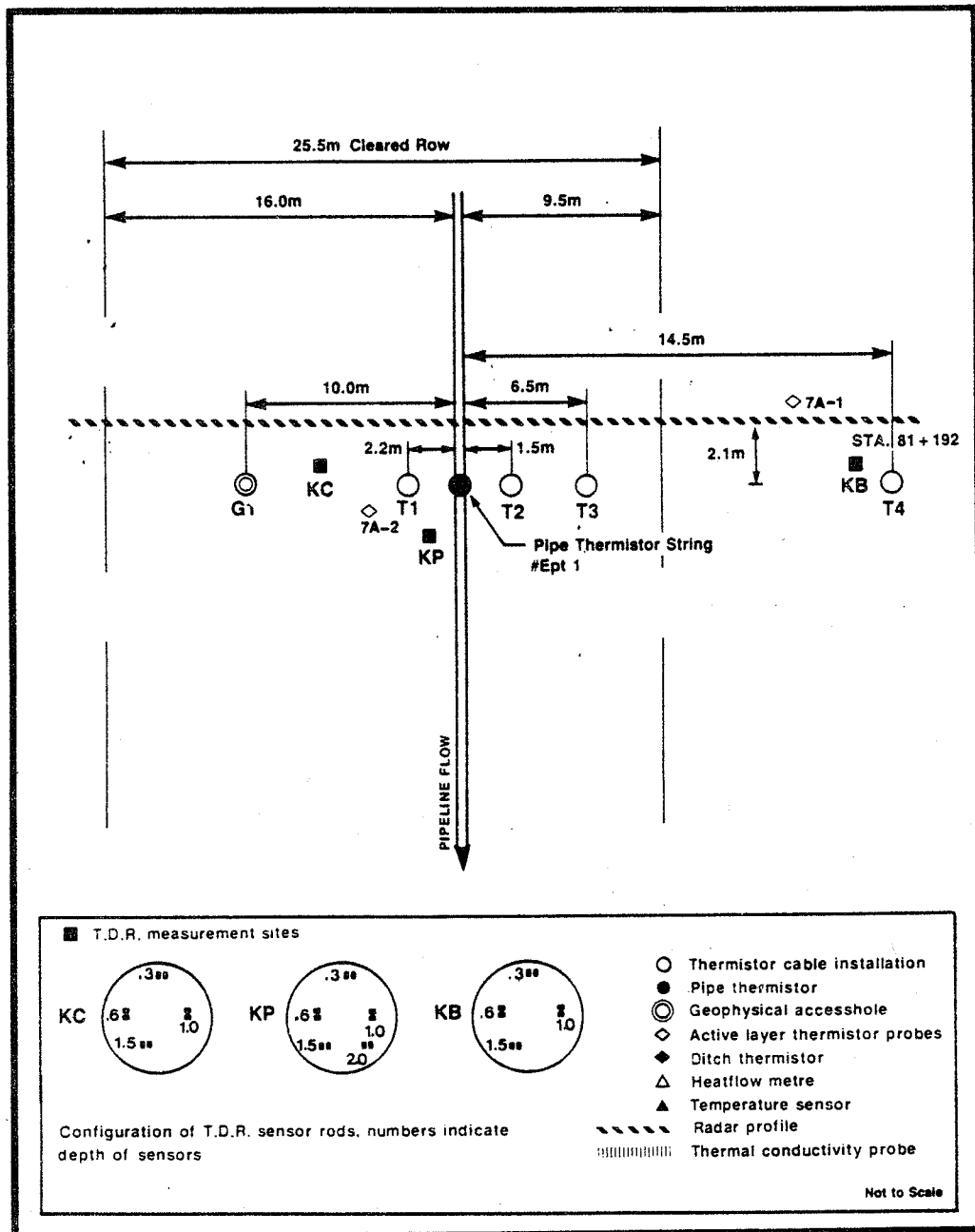
Site plan of EMR/INAC site 84-4B, Trail River



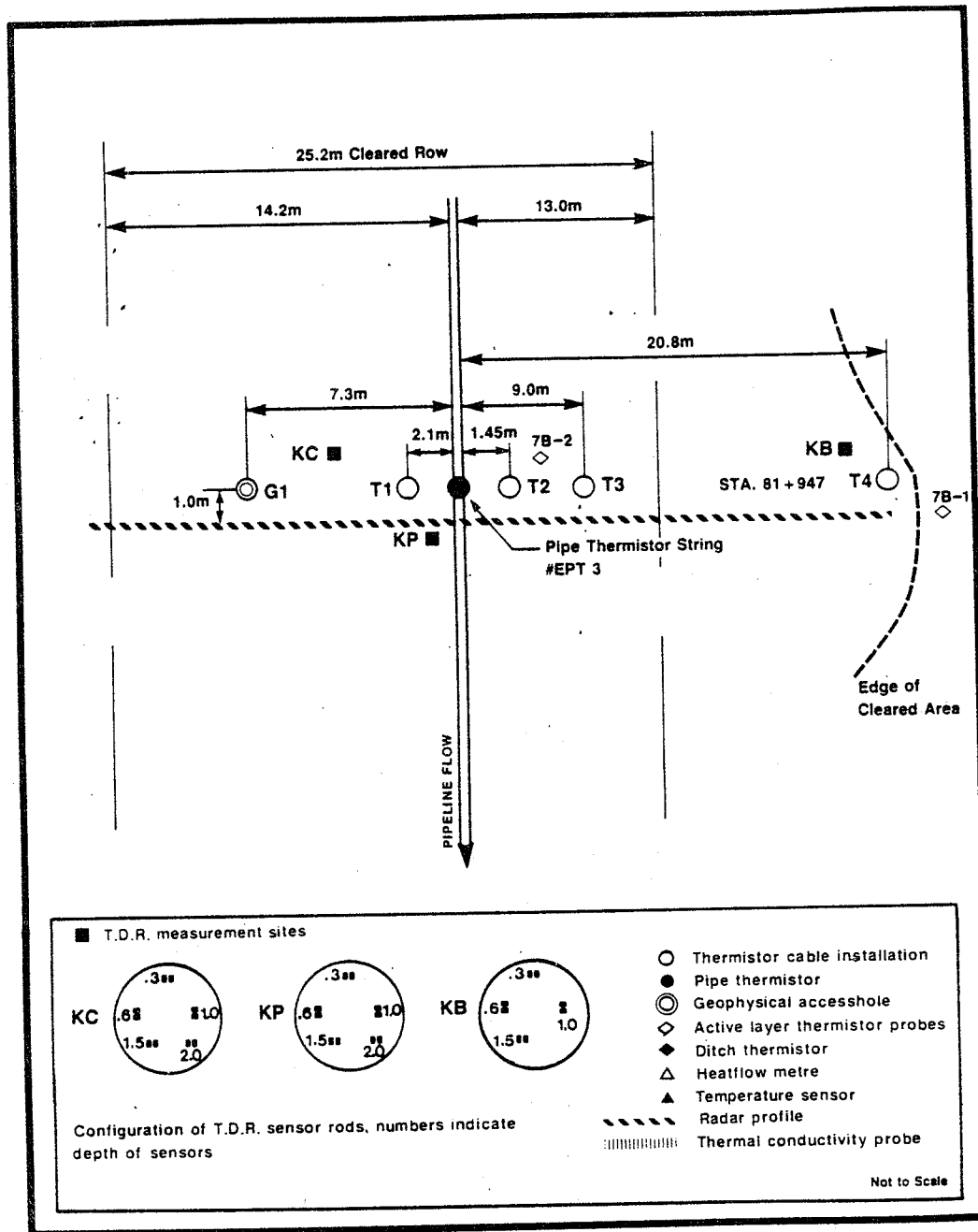
Site plan of EMR/INAC site 84-5B, Petit River South



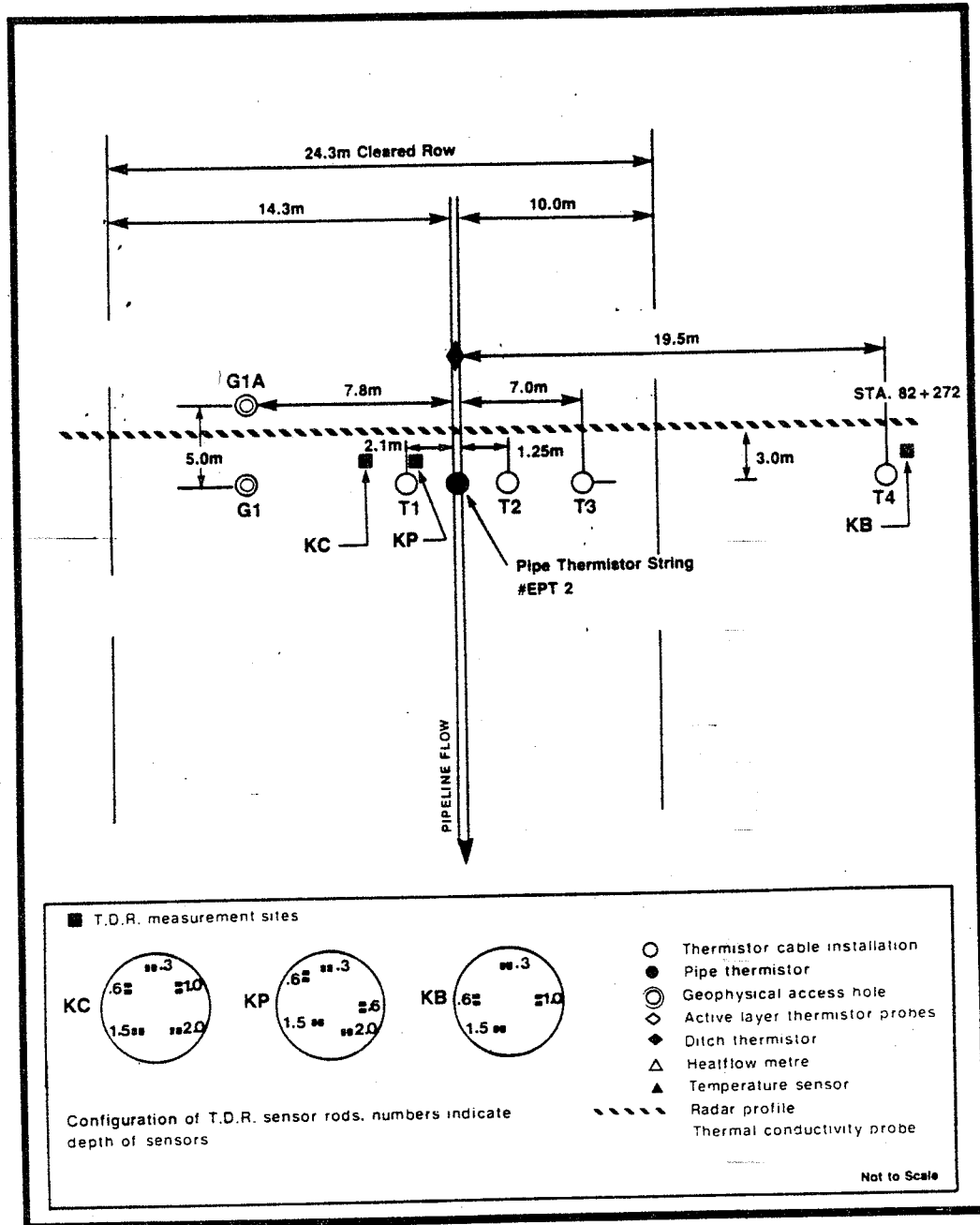
Site plan of EMR/INAC site 84-6, Petitot River South



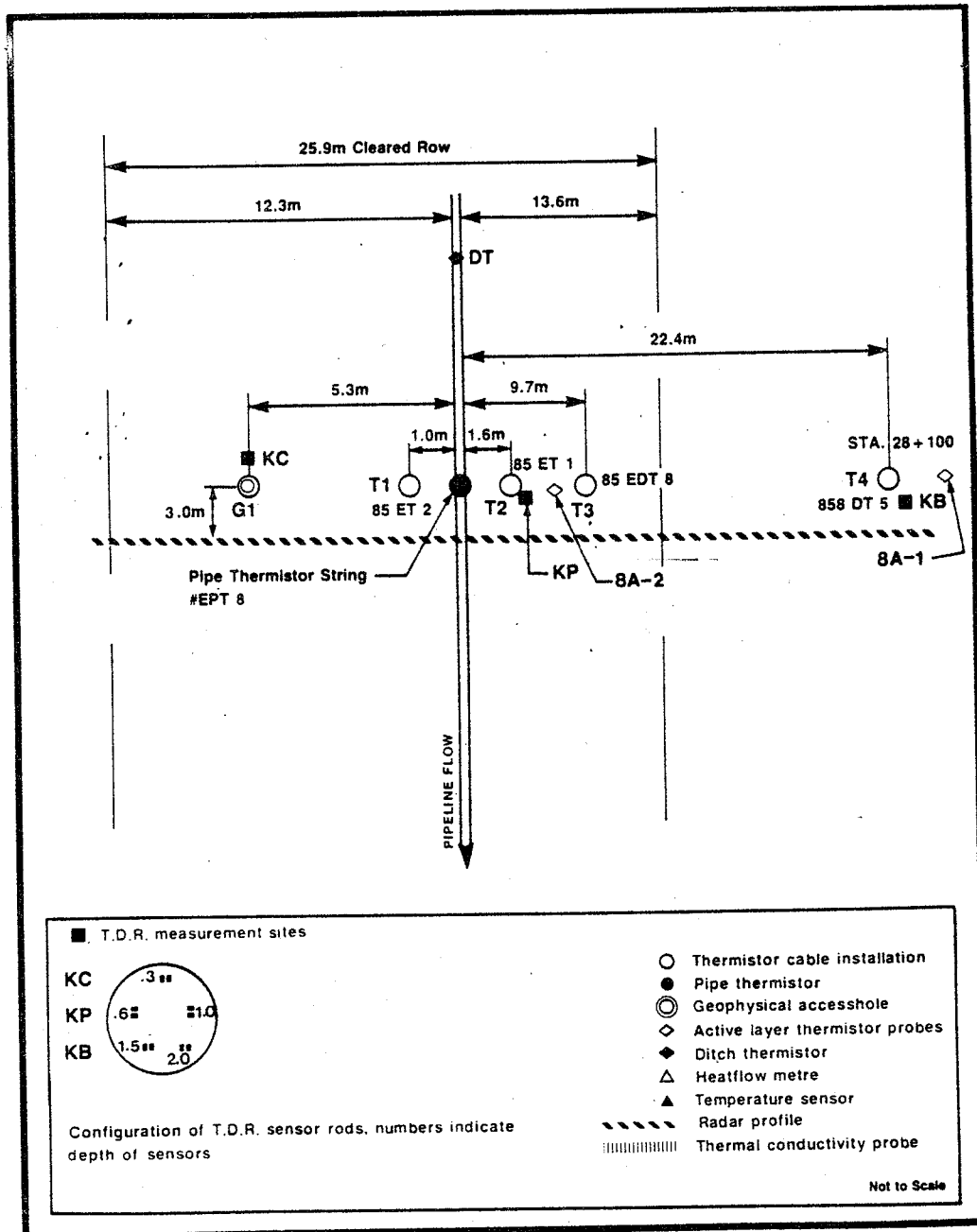
Site plan of EMR/INAC site 85-7A, Table Mountain



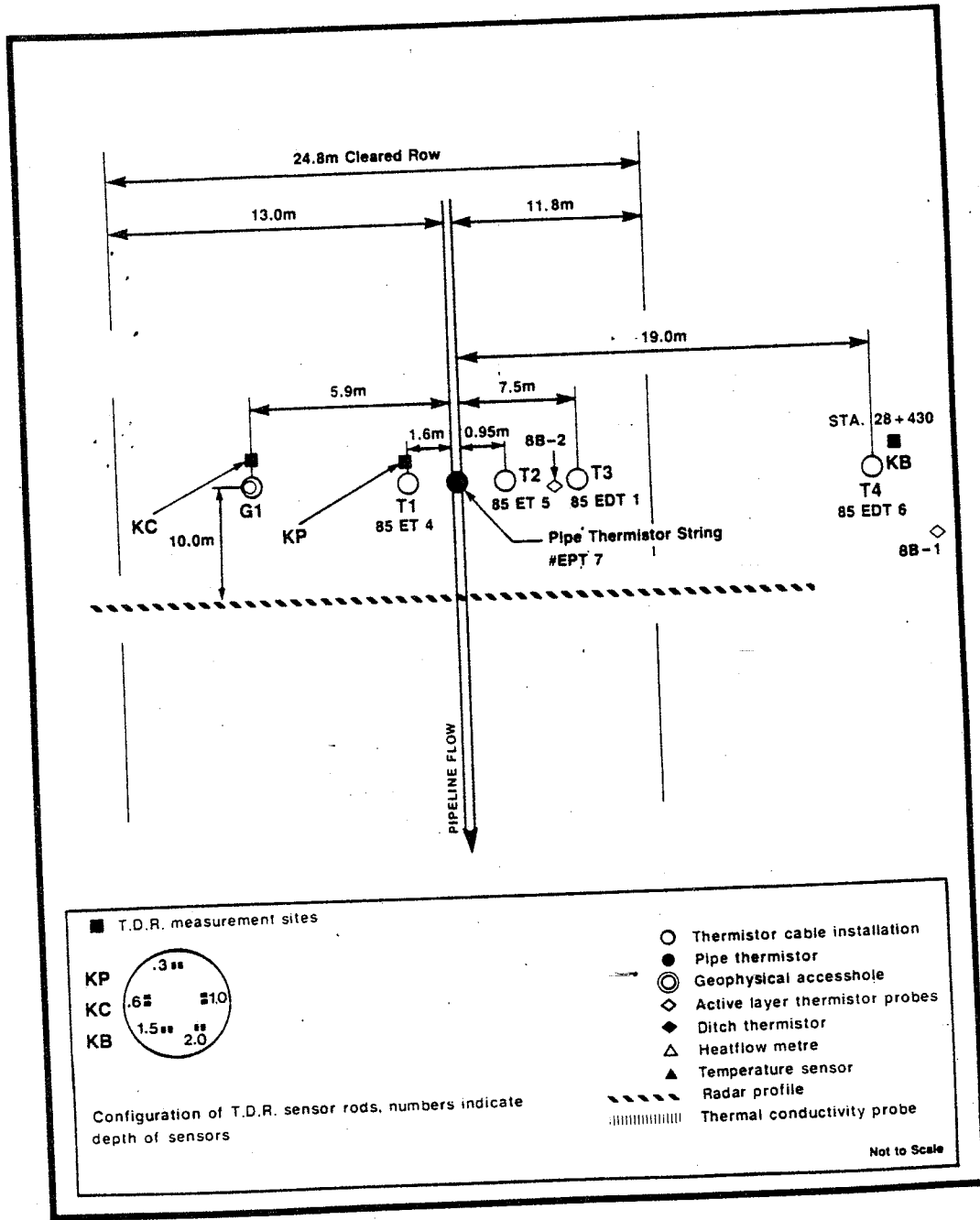
Site plan of EMR/INAC site 85-7B, Table Mountain



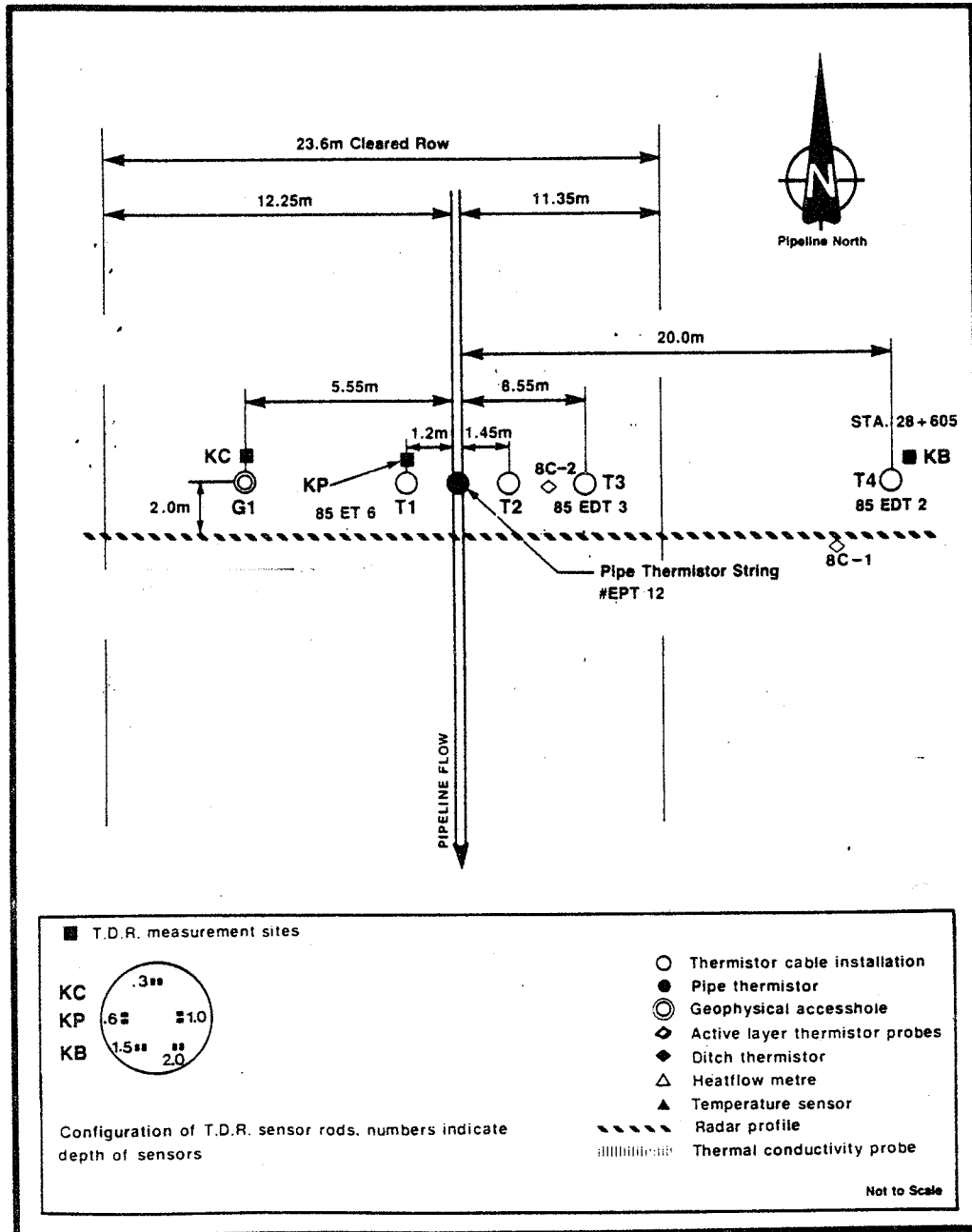
Site plan of EMR/INAC site 85-7C, Table Mountain



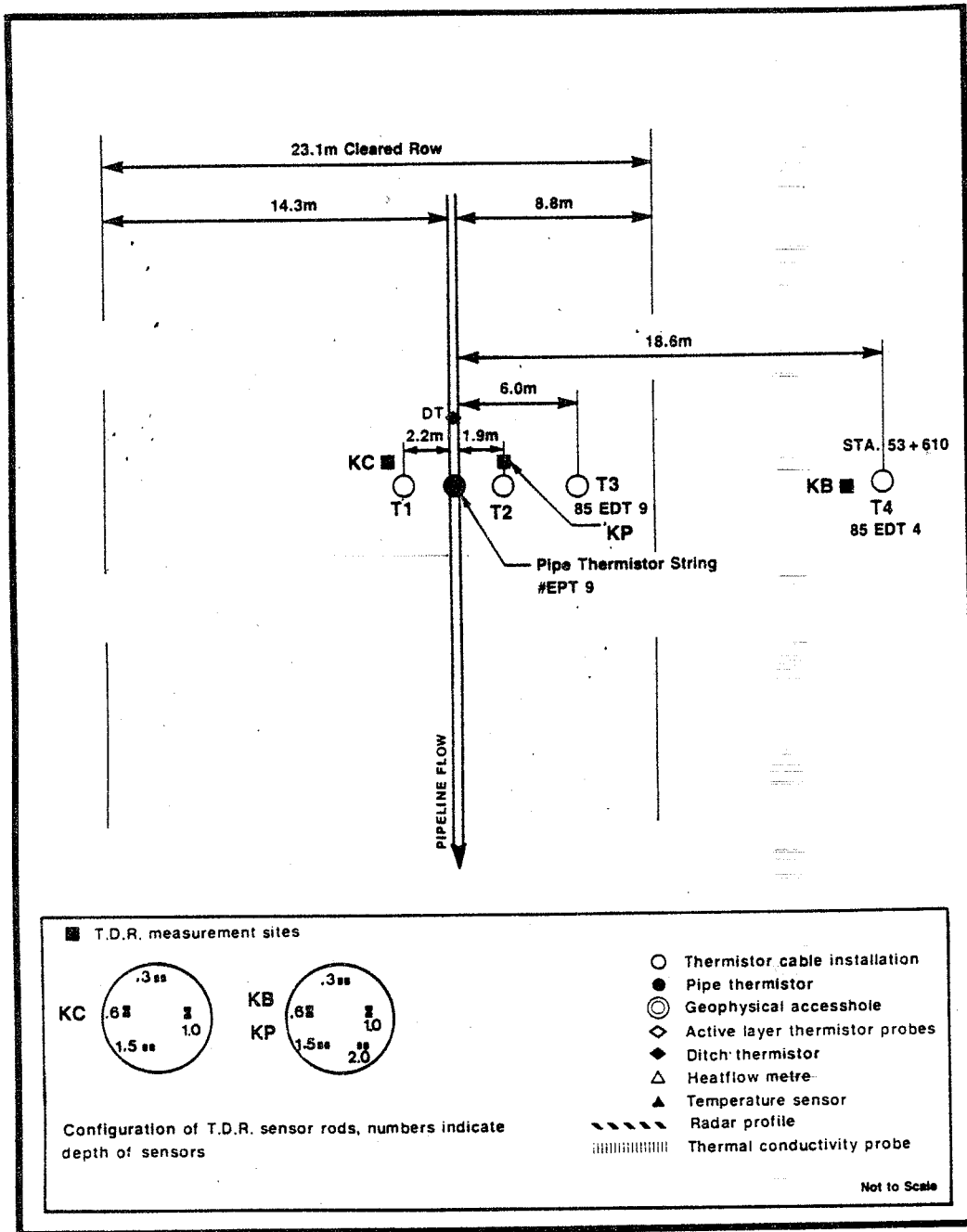
Site plan of EMR/INAC site 85-8A, Manner's Creek



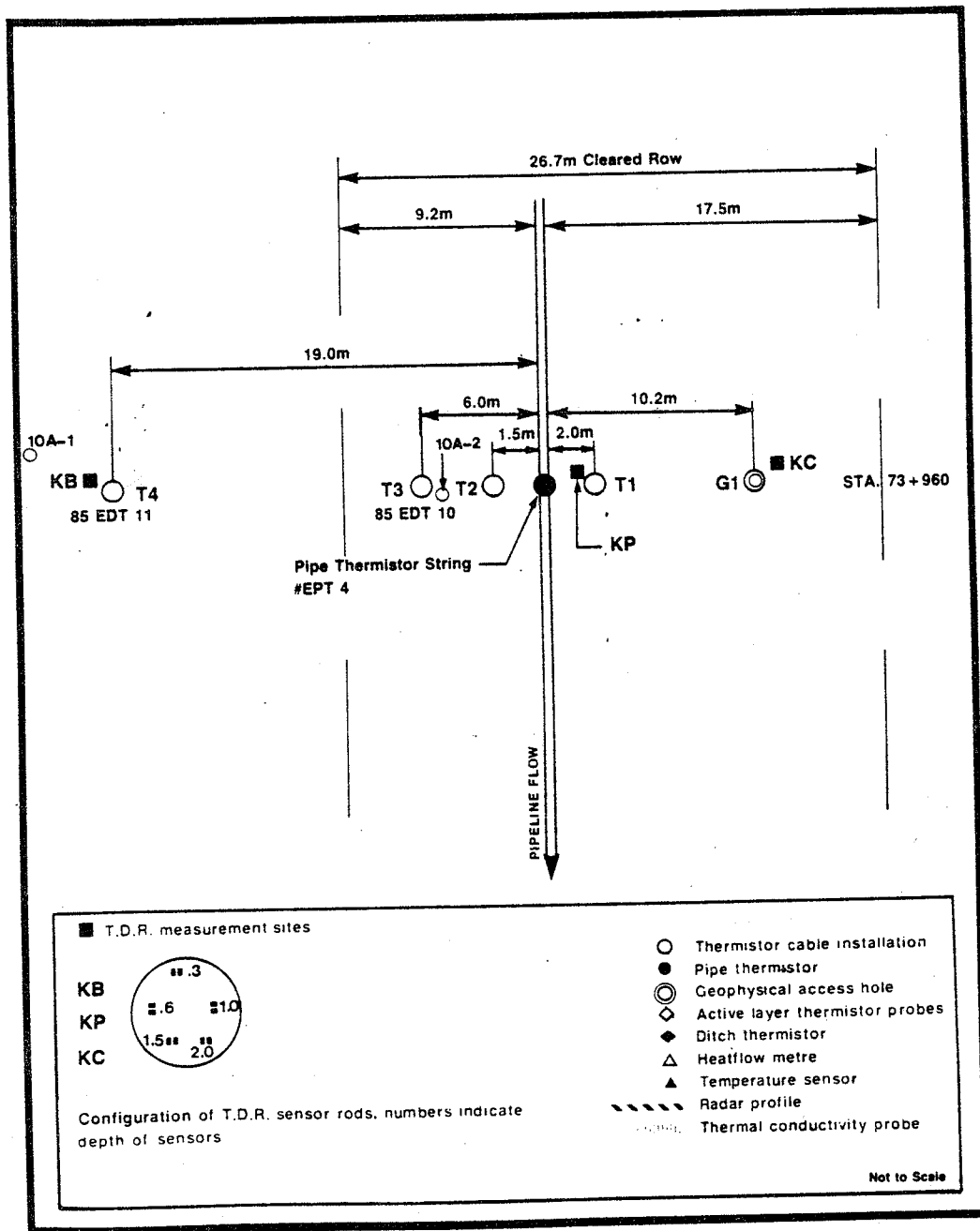
Site plan of EMR/INAC site 85-8B, Manner's Creek



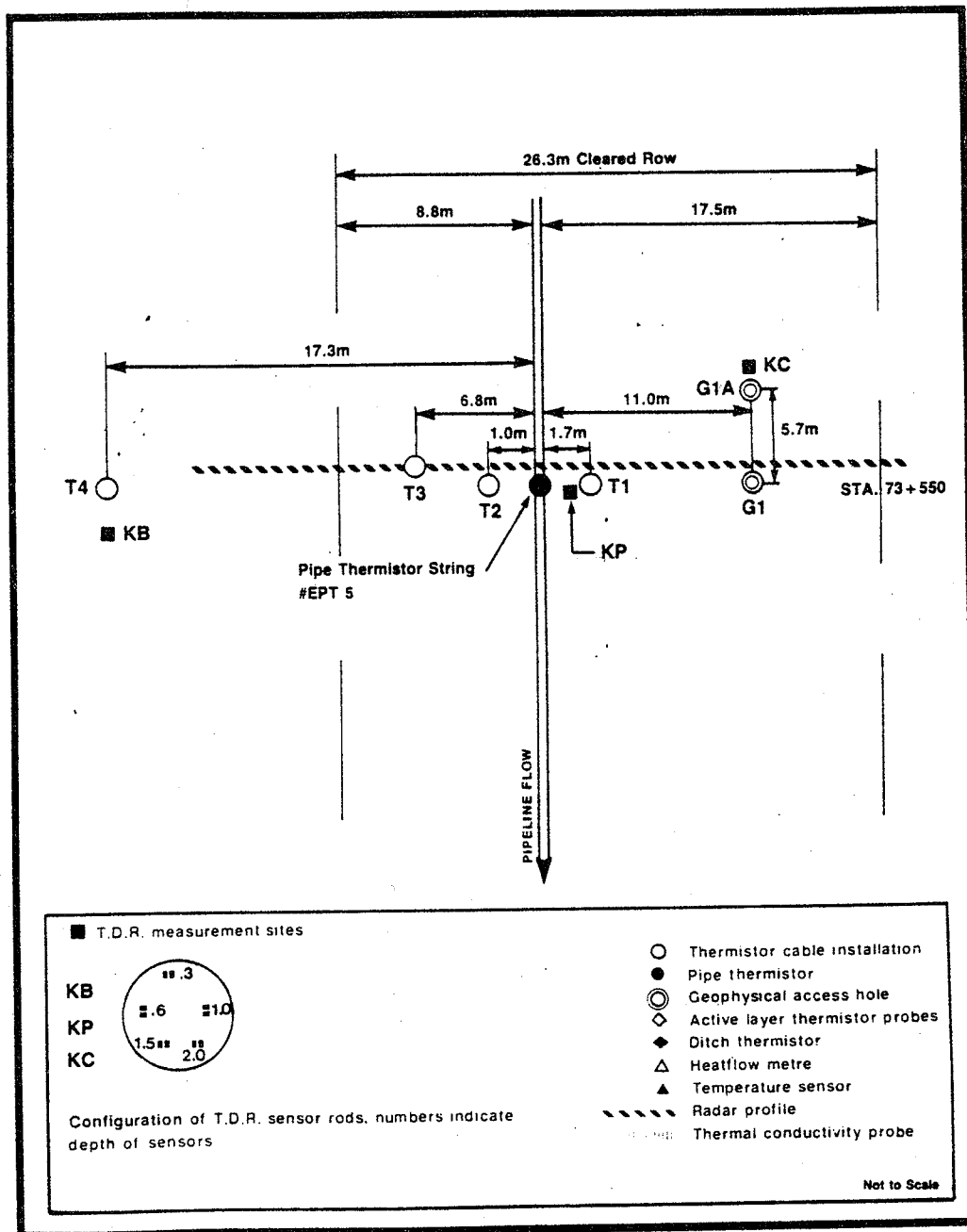
Site plan of EMR/INAC site 85-8C, Manner's Creek



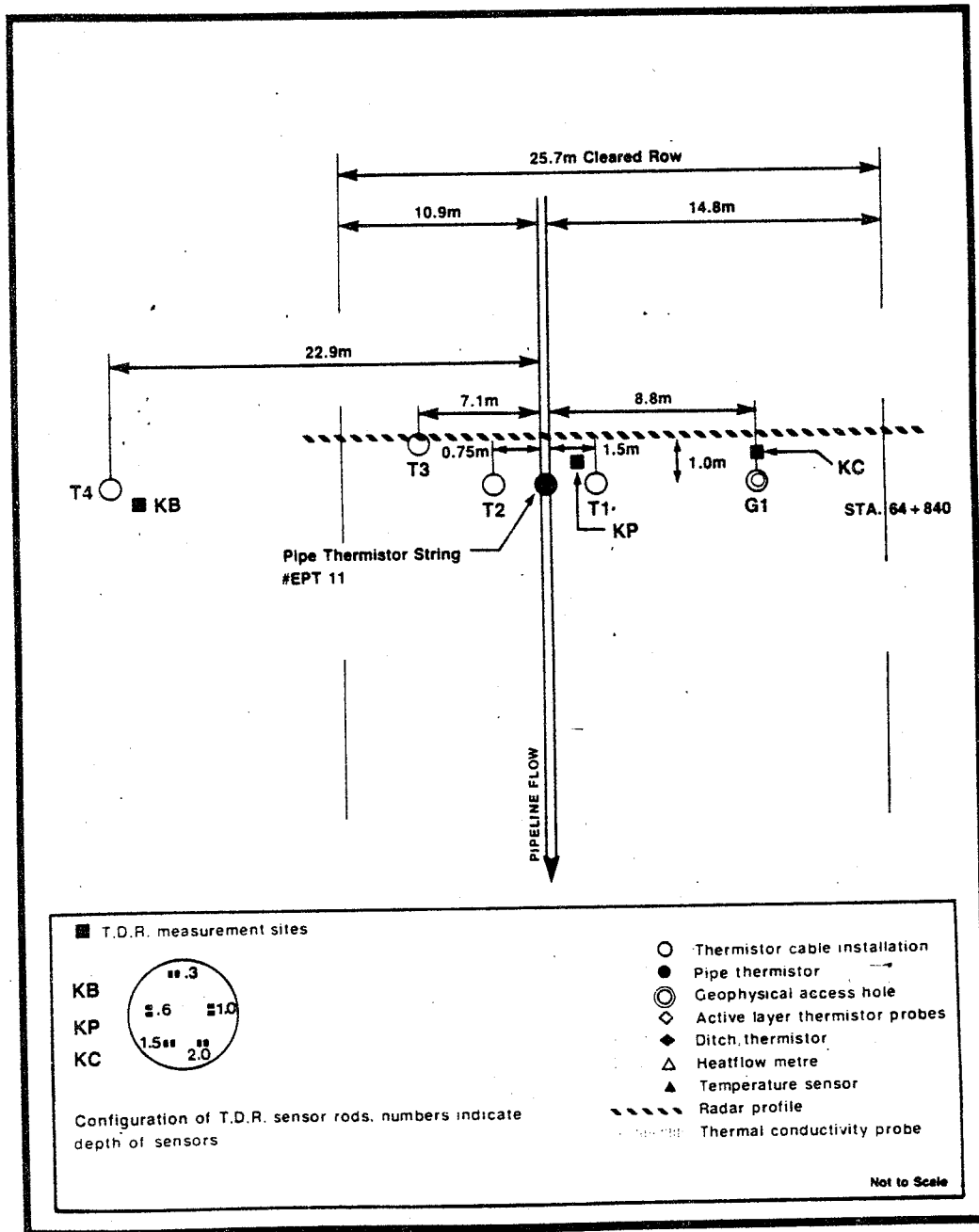
Site plan of EMR/INAC site 85-9, Pump Station 3



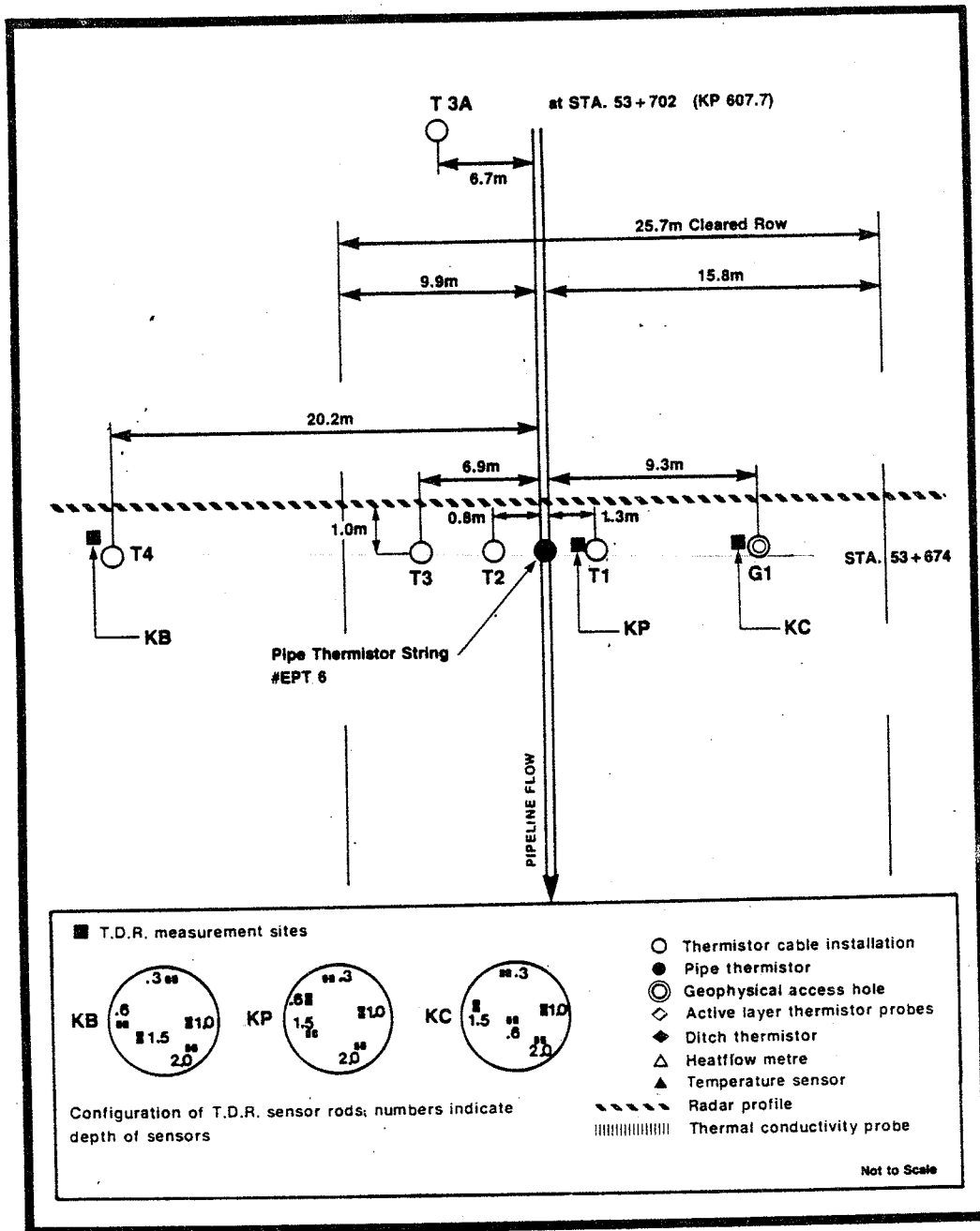
Site plan of EMR/INAC site 85-10A, Mackenzie Highway South



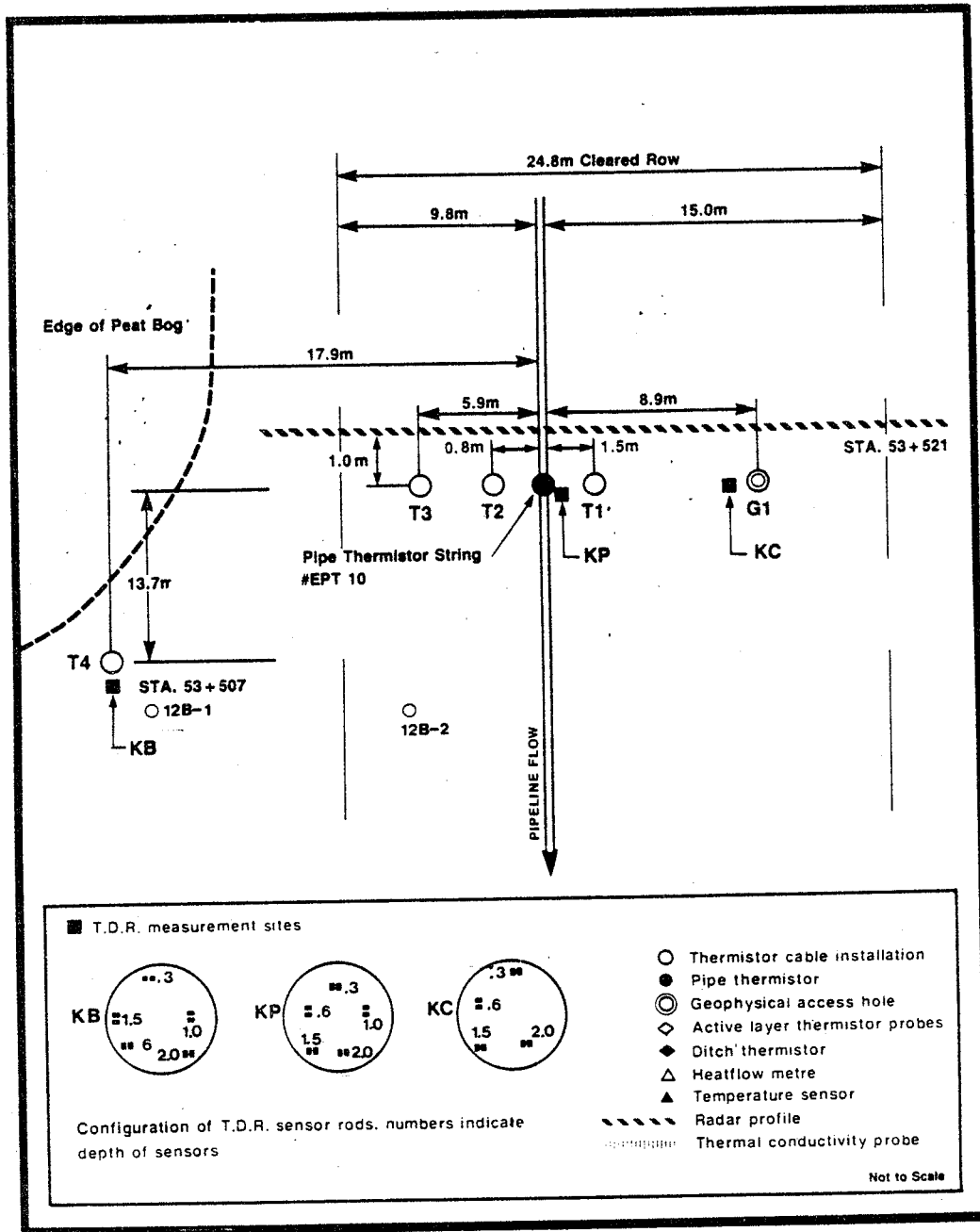
Site plan of EMR/INAC site 85-10B, Mackenzie Highway South



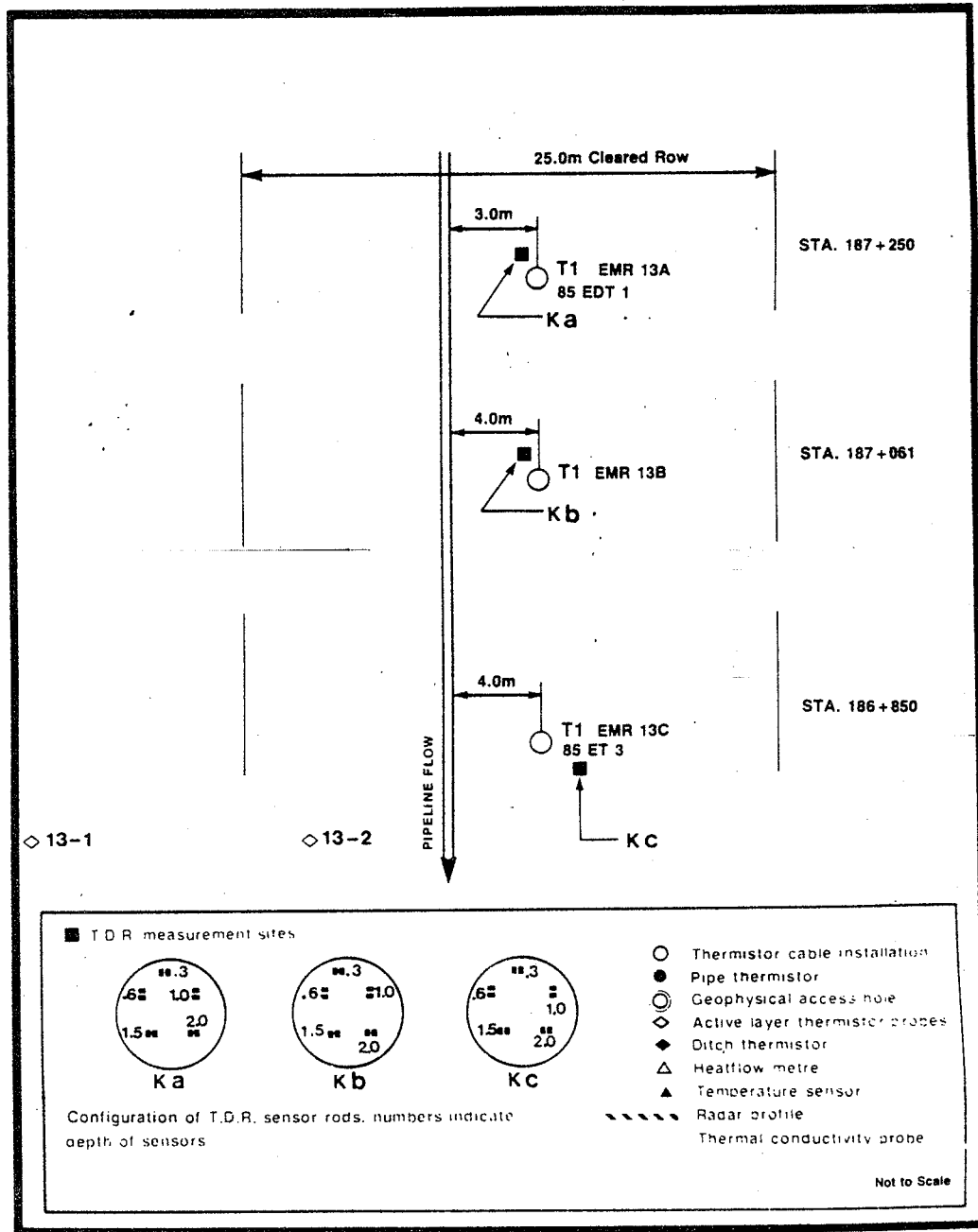
Site plan of EMR/INAC site 85-11, Moraine South



Site plan of EMR/INAC site 85-12A, Jean Marie Creek



Site plan of EMR/INAC site 85-12B, Jean Marie Creek

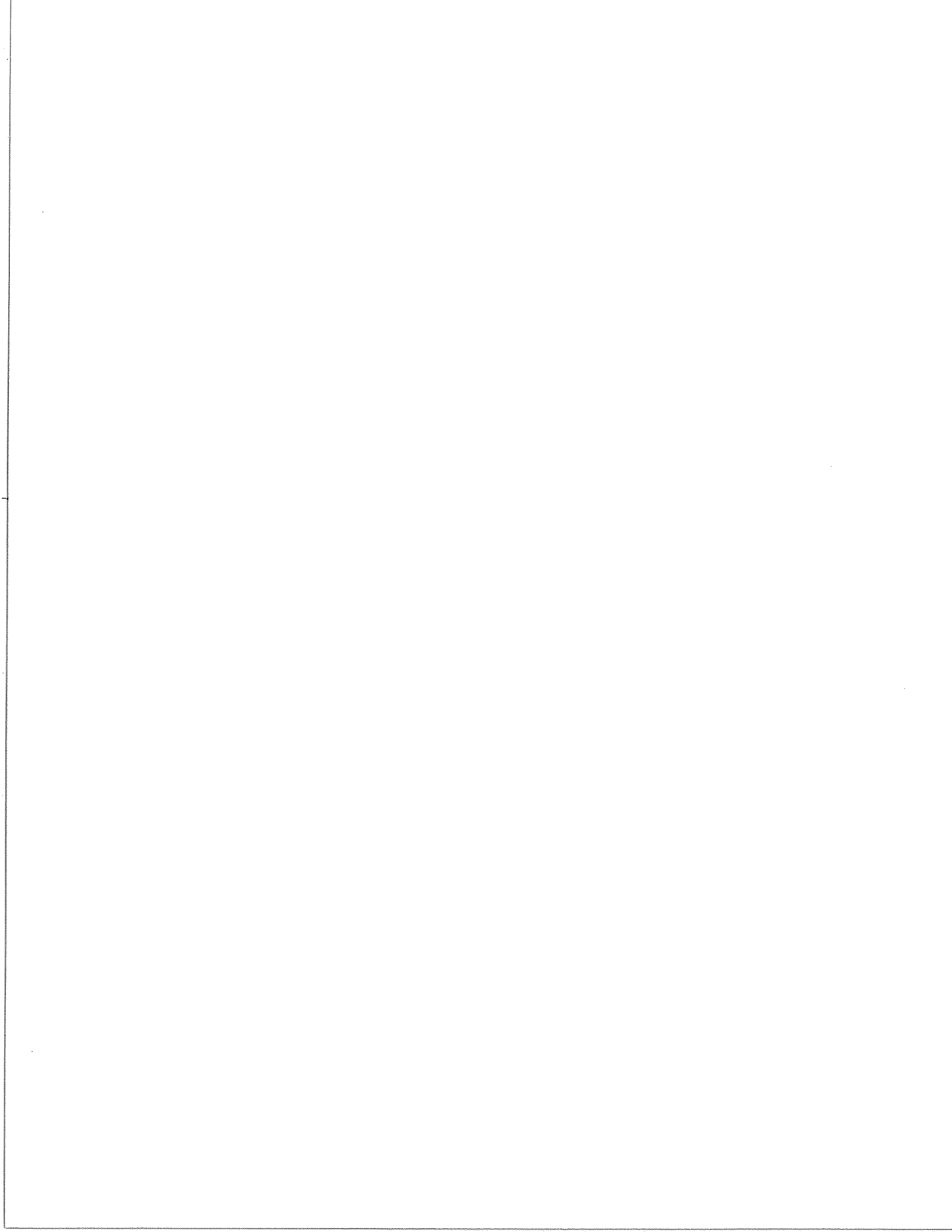


Site plan of EMR/INAC site 85-13, Redknife Hills

APPENDIX B

SCHEDULE OF FIELD TRIPS

1985 to 1991



Schedule of winter field work from 1985/1986 through 1990/1991.

DATES	OBSERVERS	PURPOSE
<u>1985</u>		
October 11-17	M. Burgess, V. Allen	Data-all sites
November 13,15	L. Schmidt, N. Sancartier	Northern Data (INAC)
November 20	J. Hayes, W. LaFleur	Southern Data (INAC)
December 10,18,19	N. Sancartier, L. Schmidt	Northern Data (INAC)
December 12,13,16	K. Beraska, B. Hoover, J. Hayes, D. Trudeau, W. Lafleur	Southern Data (INAC)
<u>1986</u>		
January 14,17	P. Rivard, N. Sancartier, L. Schmidt	Northern Data (INAC)
January 13-15	B. Hoover, W. Lafleur K. Beraska, D. Trudeau	Southern Data (INAC)
February 21	D. Elliott	Northern Data (INAC)
February 19,20	J. Hayes, W. Lafleur	Southern Data (INAC)
March 3-5	K. MacInnes, J. Pilon, W. Pollard	Northern Data (INAC, EMR)
March 12,24,26	D. Trudeau, W. Lafleur, K. Beraska	Southern Data (INAC)
April 9,10,12	D. Trudeau, B. Hoover, W. Lafleur	Southern Data (INAC)
April 30	L. Schmidt, N. Sancartier	Northern Data (INAC)
September 25-30	K. MacInnes, F. Adelm, H. Baker	Data-all sites (INAC, NRC)
October 22-30	M. Burgess, V. Allen	Data-all sites (EMR)
November 12	D. Elliott, L. Schmidt P. Rivard	Northern data (INAC)
November 19-20	D. Trudeau, B. Hoover	Southern data (INAC)
December 10	L. Schmidt, D. Elliott	Northern data (INAC)
December 16-17,19-22	D. Trudeau, B. Hoover	Southern data (INAC)
<u>1987</u>		
January 15-16	P. Rivard, L. Schmidt	Northern data (INAC)
January 16, 20-21	B. Hoover, D. Trudeau	Southern data (INAC)
February 4-9	J. Pilon, A. Judge	All sites (EMR)
March 9-15	K. MacInnes, A. McRobert	All sites (INAC)
April 15-16	L. Schmidt, P. Rivard, D. Elliott	Northern data (INAC)
April 9, 13	D. Trudeau	Southern data (INAC)

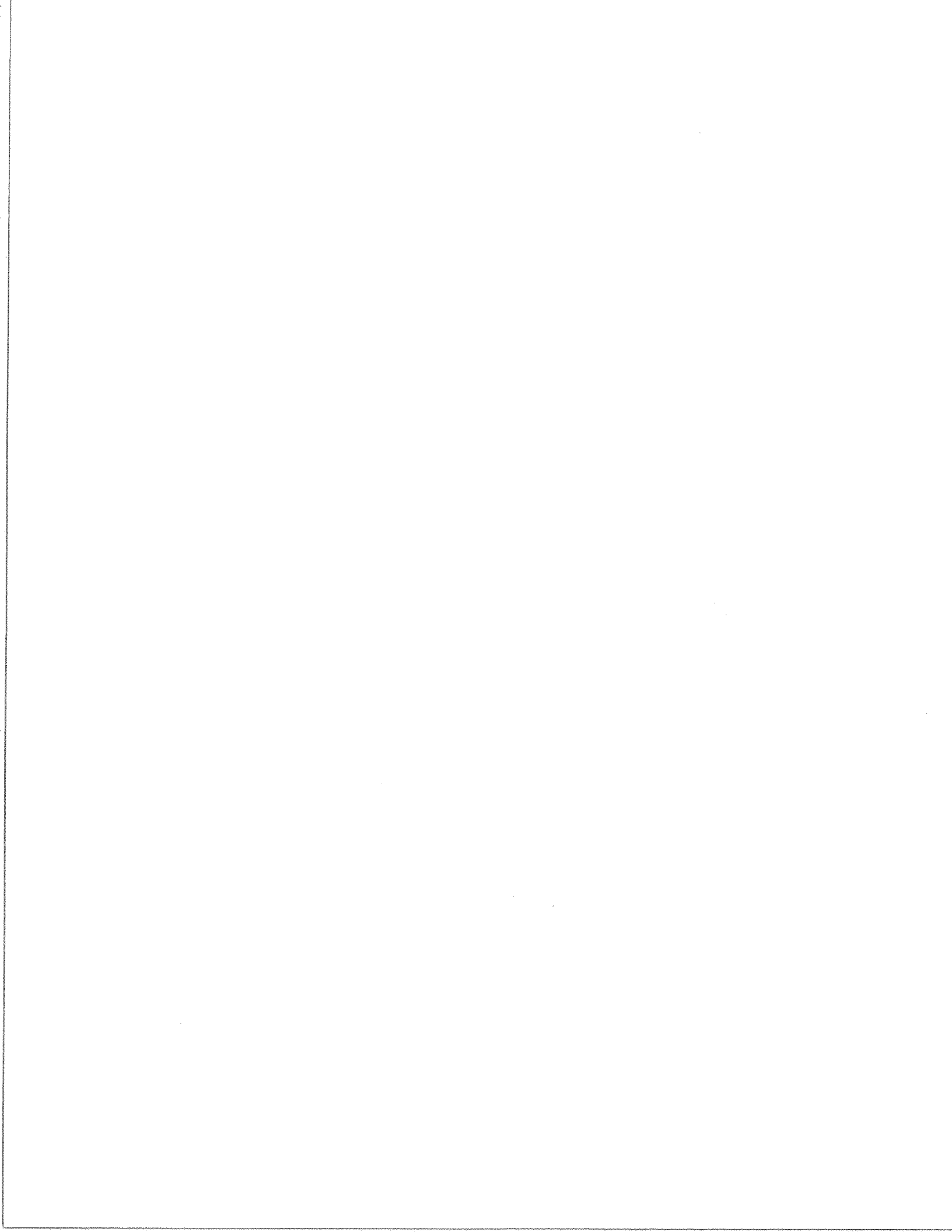
Notes:

Observers include staff from Indian and Northern Affairs Canada (INAC) Region and Districts, Energy, Mines and Resources (EMR), University of British Columbia (UBC) and National Research Council (NRC). Northern data refers to sites from km 0 to 79. Southern data refers to site from km 270 to 608. All sites refers to sites from km 0 to 819.

DATES	OBSERVERS	PURPOSE
<u>1987</u>		
October 1-7	M. Burgess, V. Allen	All sites (EMR)
November 12-13	D. Elliott, L. Schmidt	Northern data (INAC)
November 12-13	D. Trudeau, A. Boyer P. Boyle	Southern data (INAC)
December 14-16	D. Elliott	Northern data (INAC)
December 15, 16, 18	D. Trudeau, A. Boyer	Southern data (INAC)
<u>1988</u>		
January 14, 22	D. Elliott, A. McRobert	Northern data (INAC)
January 18-19	A. Boyer, D. Trudeau	Southern data (INAC)
February 8, 10, 12	A. Boyer, D. Trudeau	Southern data (INAC)
March 7-11	K. MacInnes, D. Trudeau	All sites (INAC)
April 14, 18	D. Elliott, L. Elliott	Northern data (INAC)
April 19-20	A. Boyer, F. McGowan	Southern data (INAC) meter, km 19 (NRC)
<u>1988</u>		
October 22-28	M. Burgess, V. Allen	All sites (EMR) Install logger at 12B
December 7-9	A. Boyer, J. Ginter	Southern sites (INAC)
December 13-14	J. Bowen, D. Elliott	Northern data (INAC)
<u>1989</u>		
Jan. 24, 25	A. Boyer, J. Ginter	Southern data (INAC)
Feb. 1, 2	D. Elliott, J. Bowen	Northern data (INAC)
Mar. 13-19	K. MacInnes, M. Burgess A. Taylor	All sites (INAC, EMR)
April 7	D. Elliott, J. Bowen	Northern data (INAC)
April 11	A. Boyer, J. Ginter	Southern data (INAC)
<u>1989</u>		
Oct. 25	J. Bowen	Northern sites (INAC)
Oct. 26-27	D. Trudeau, J. Ginter	Southern sites (INAC)
Dec. 13-14, 20	J. Bowen	Northern sites (INAC)
Dec. 27-28	D. Trudeau, J. Ginter	Southern sites (INAC)
<u>1990</u>		
Feb. 7-8	S. Davidson, J. Ginter	Southern data (INAC)
Feb. 20-21	J. Bowen	Northern data (INAC)
Mar. 19-24	K. MacInnes, J. Bowen D. Riseborough	All sites (INAC, EMR)
May 5-10	K. MacInnes, H. Baker	All sites (INAC, NRC)
<u>1990</u>		
Oct. 11-16	M. Burgess, A. Wilkinson	All sites (EMR)
Dec. 7, 10	D. Unrau	Northern data (INAC)
Dec. 11-12	M. Swyripa, J. Ginter	Southern data (INAC)
<u>1991</u>		
Jan. 22-23	J. Bowen, P. Rivard	Northern data (INAC)
Jan. 28-30	M. Swyripa, D. Deschene J. Ginter	Southern data (INAC)
Mar. 7-12	K. MacInnes, M. Burgess V. Allen	All sites (INAC, EMR)
May 8-13	K. MacInnes, W. Savigny	Sites to kp 608 (INAC, UBC)

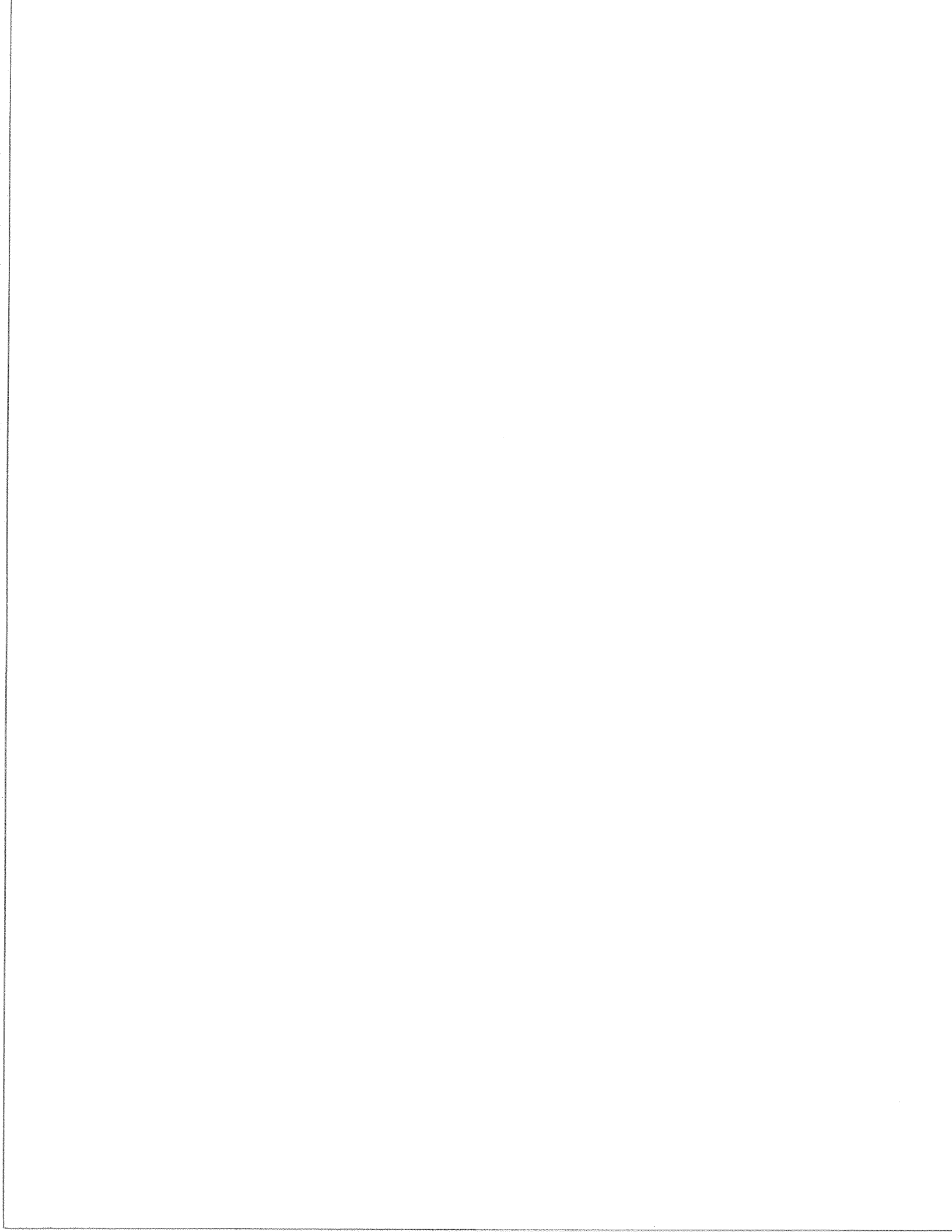
ABSTRACT

Snow depth and density measurements have been collected at 23 study sites in the Mackenzie Valley since 1985, as part of the Permafrost and Terrain Research and Monitoring Program along the Norman Wells to Zama pipeline . The data gathered through to the end of the winter of 1990/1991 are compiled and plotted for each site. The effect of right-of-way clearance is not straightforward. Comparisons of snow depths on the pipeline right-of-way and to those off the right-of-way show great variability from year to year, and from site to site. Similarly snow densities measured each March show no predominant trend from on to off right-of-way, from year to year or from site to site. Snow depths in the northern part of the pipeline route are greater than those recorded at the Atmospheric Environment Service's (AES) station in Norman Wells. In the southern part of the route, comparisons of both on and off right-of-way snow depths to Fort Simpson AES station data reveal no clear pattern.

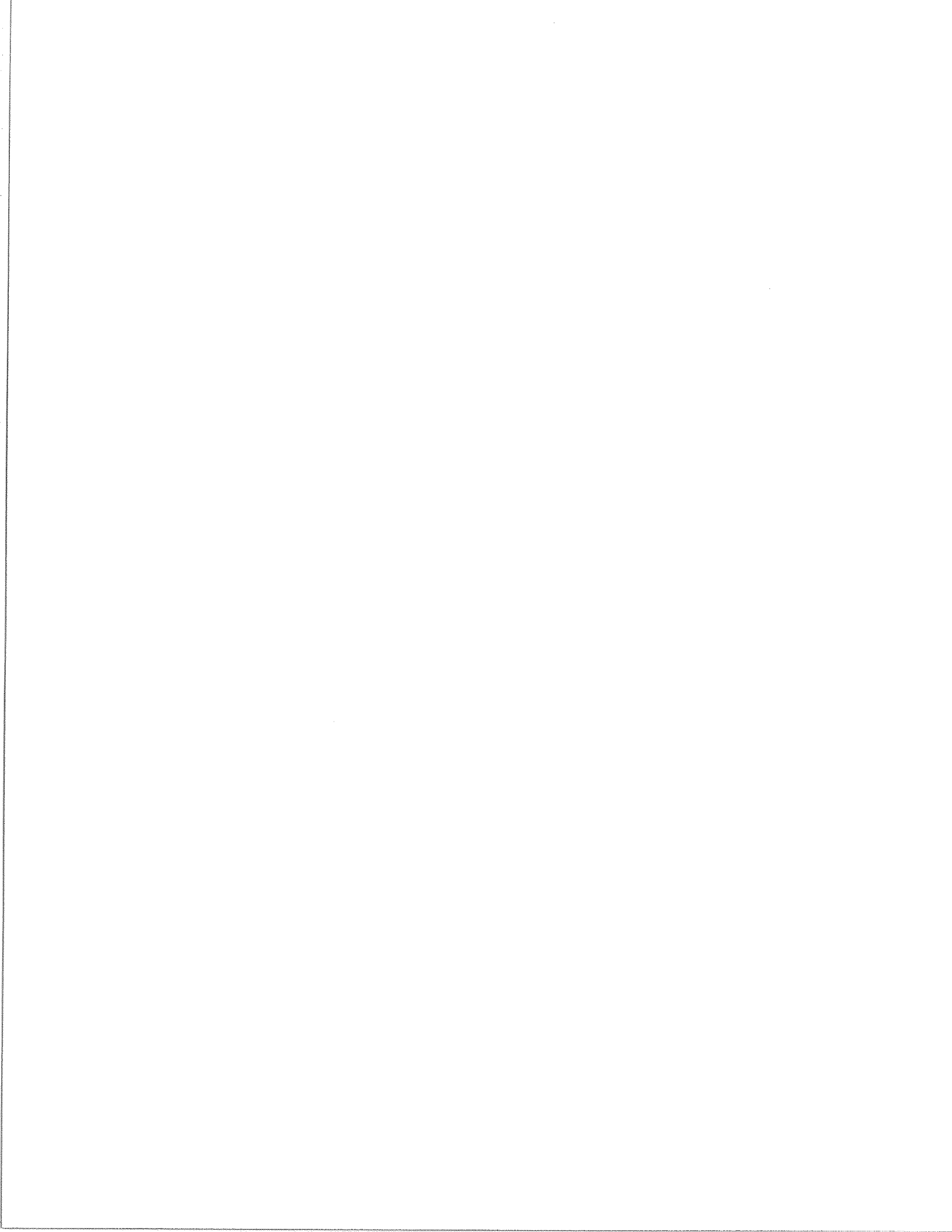


APPENDIX C

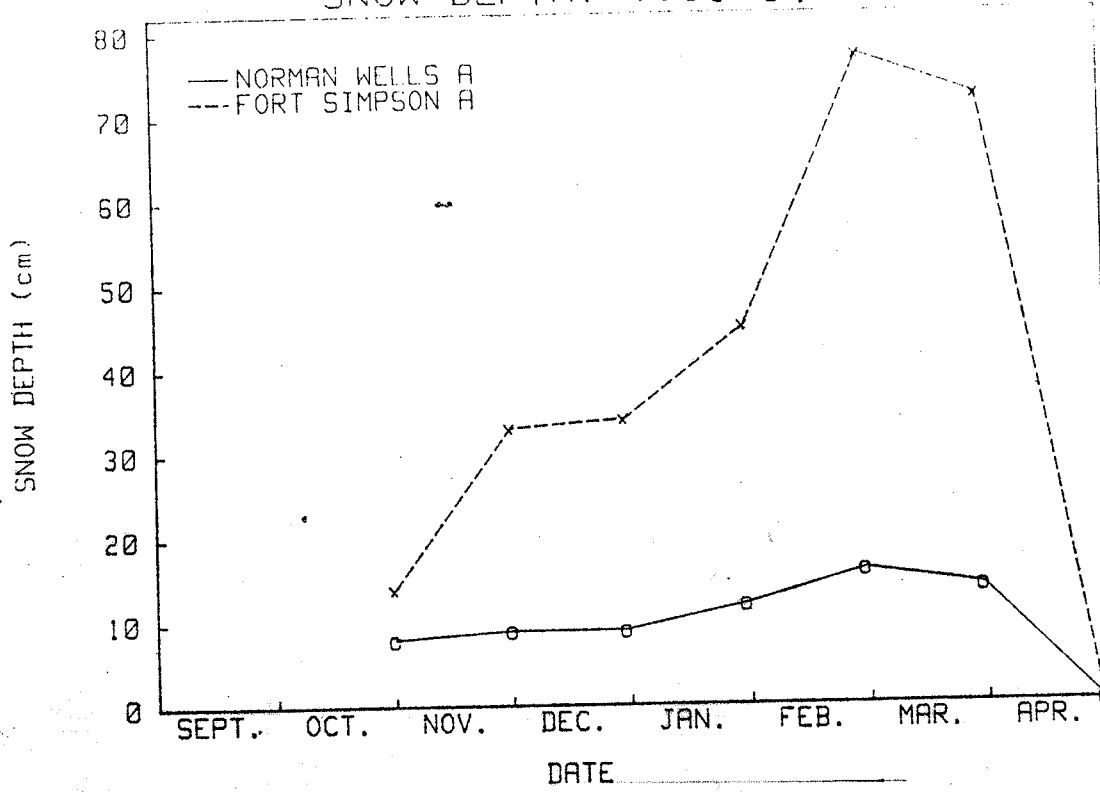
SNOW DEPTH PLOTS



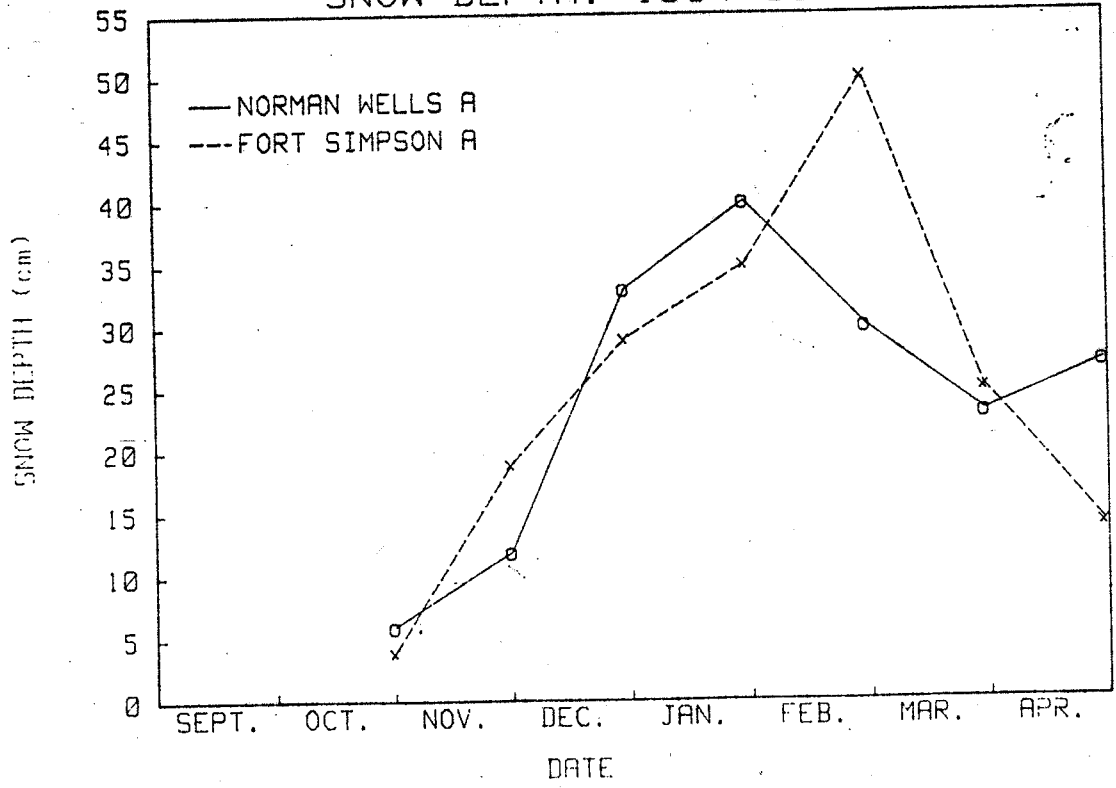
SNOW DEPTH PLOTS - NORMAN WELLS AND FORT SIMPSON AES STATIONS



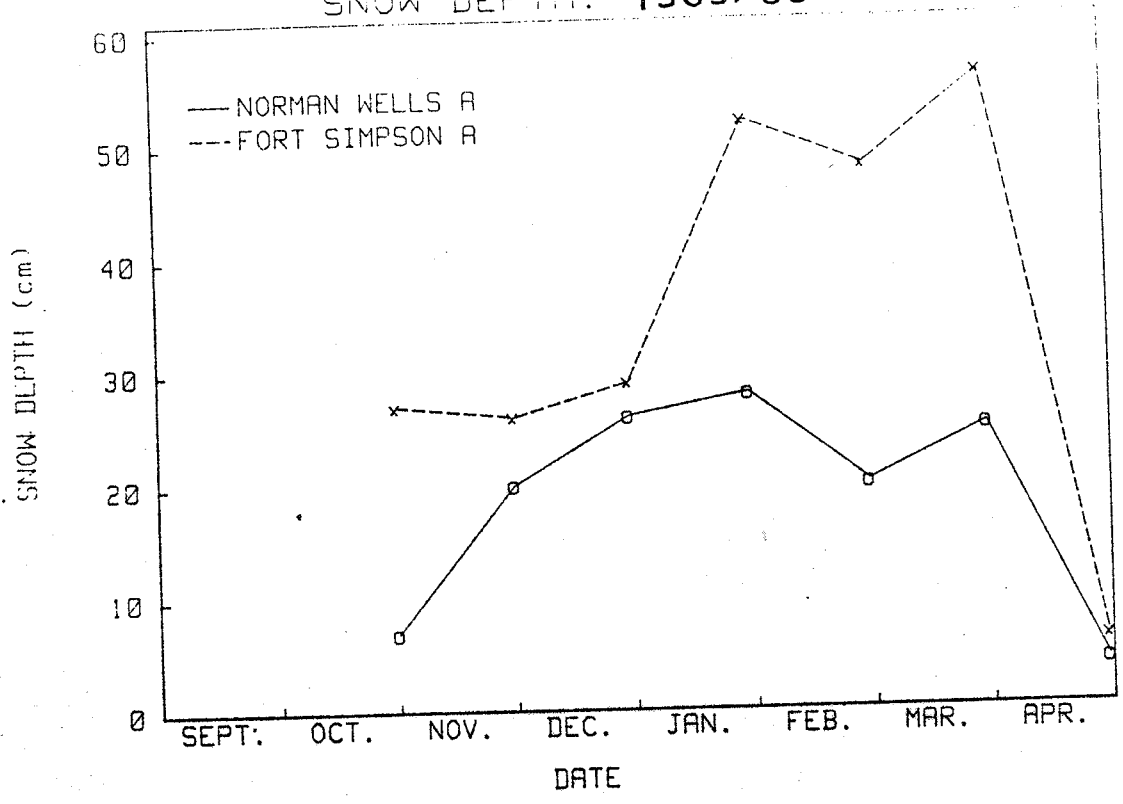
SNOW DEPTH: 1983/84



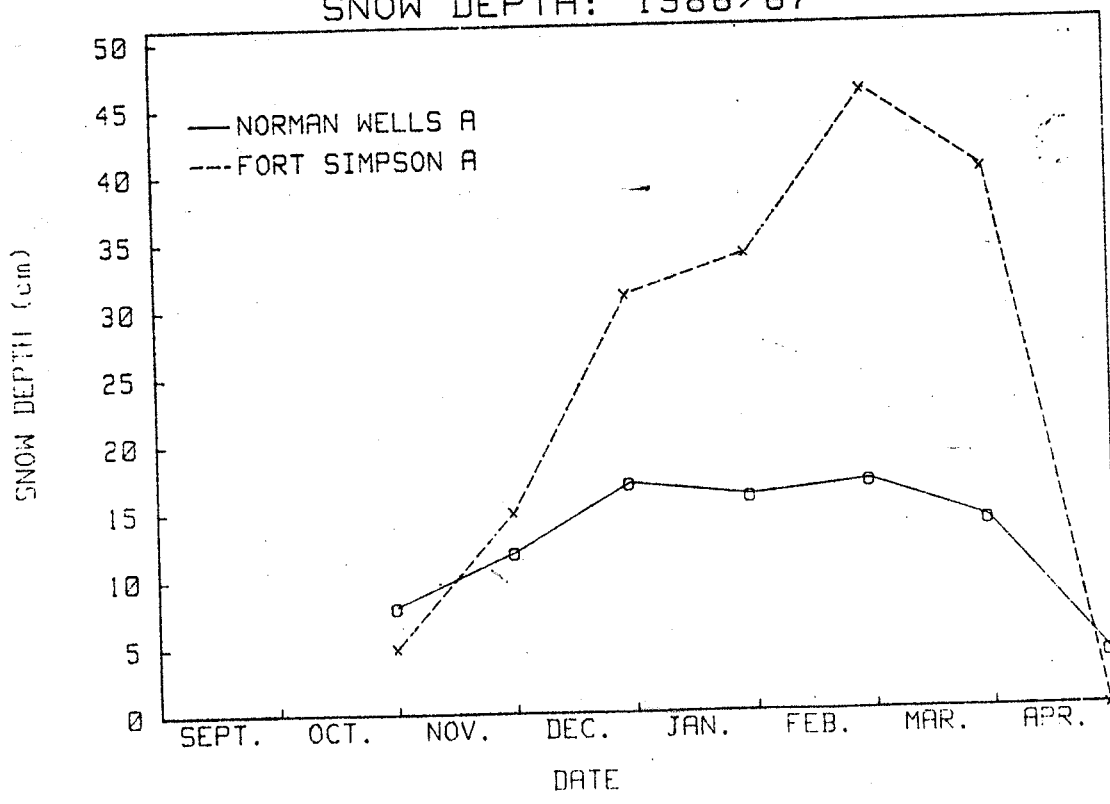
SNOW DEPTH: 1984/85



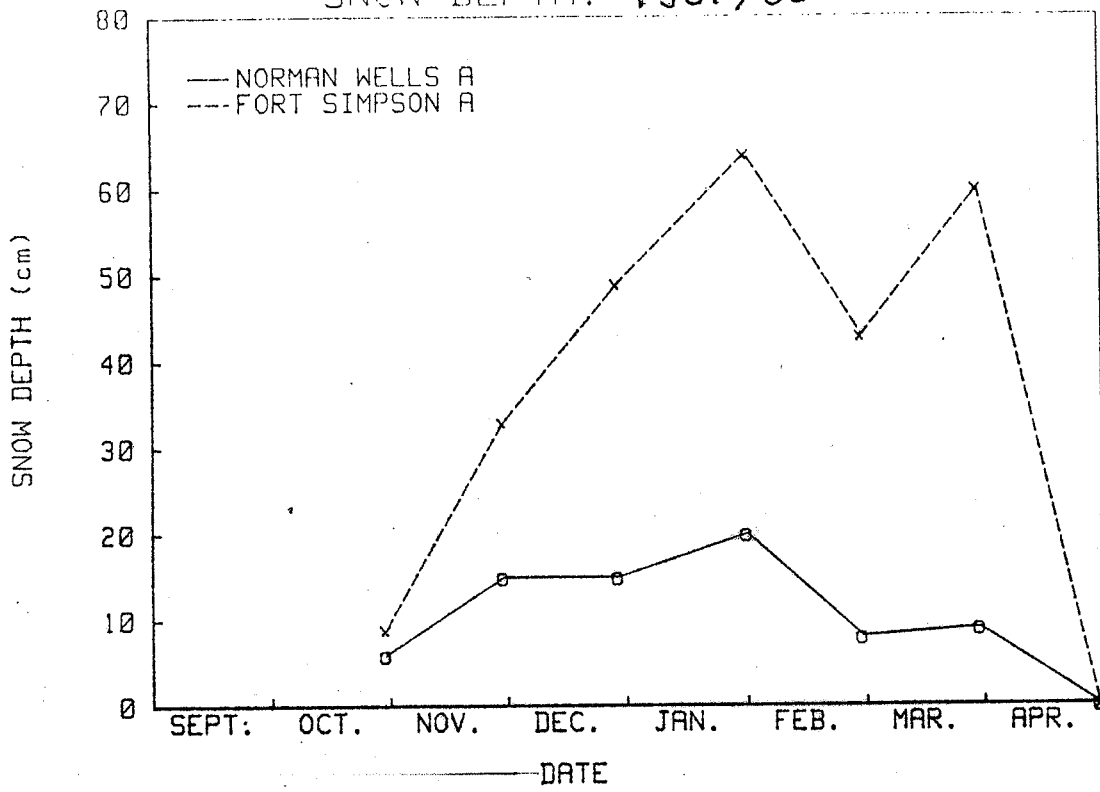
SNOW DEPTH: 1985/86



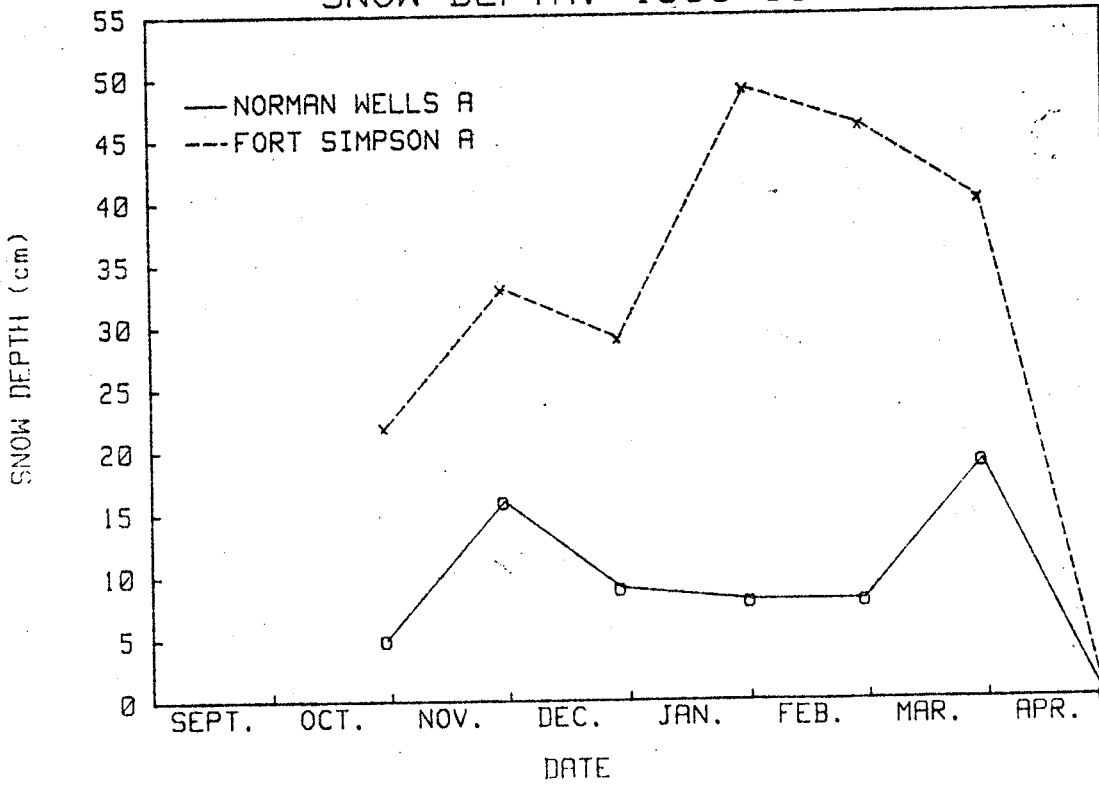
SNOW DEPTH: 1986/87



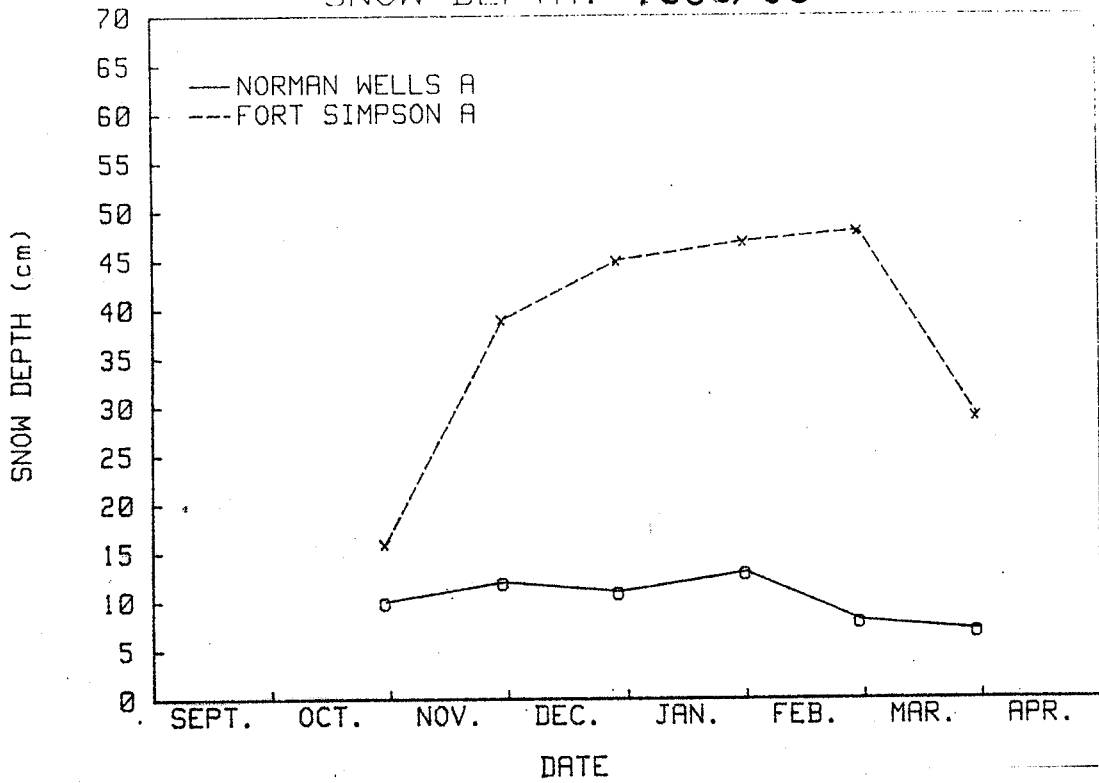
SNOW DEPTH: 1987/88



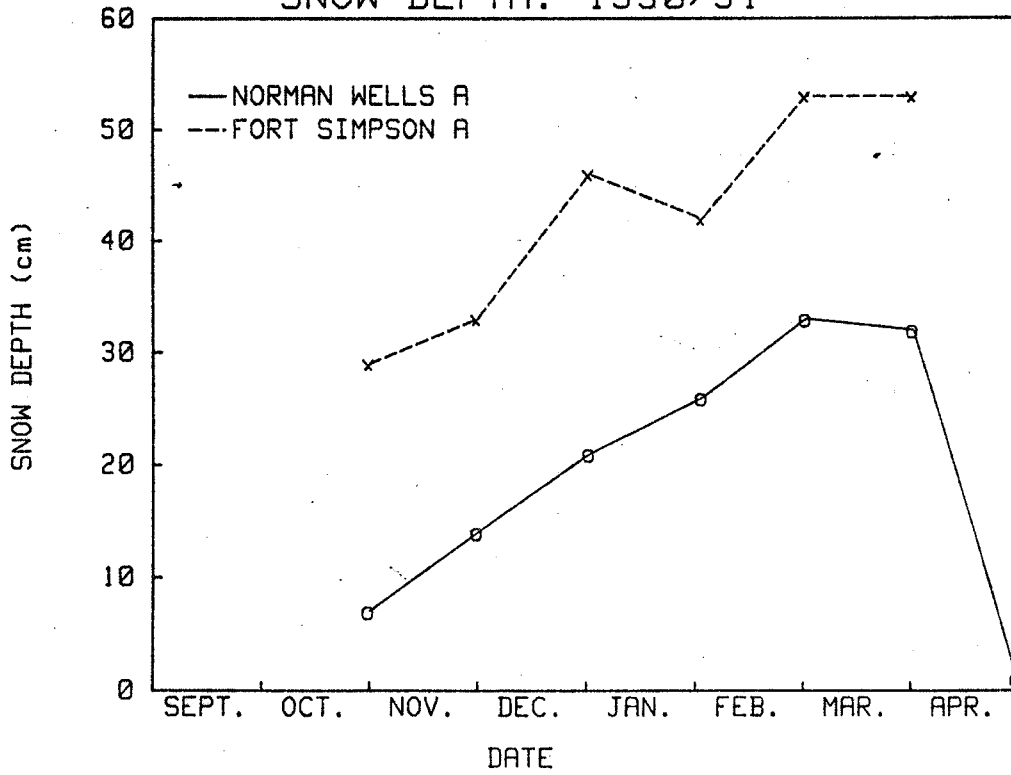
SNOW DEPTH: 1988/89



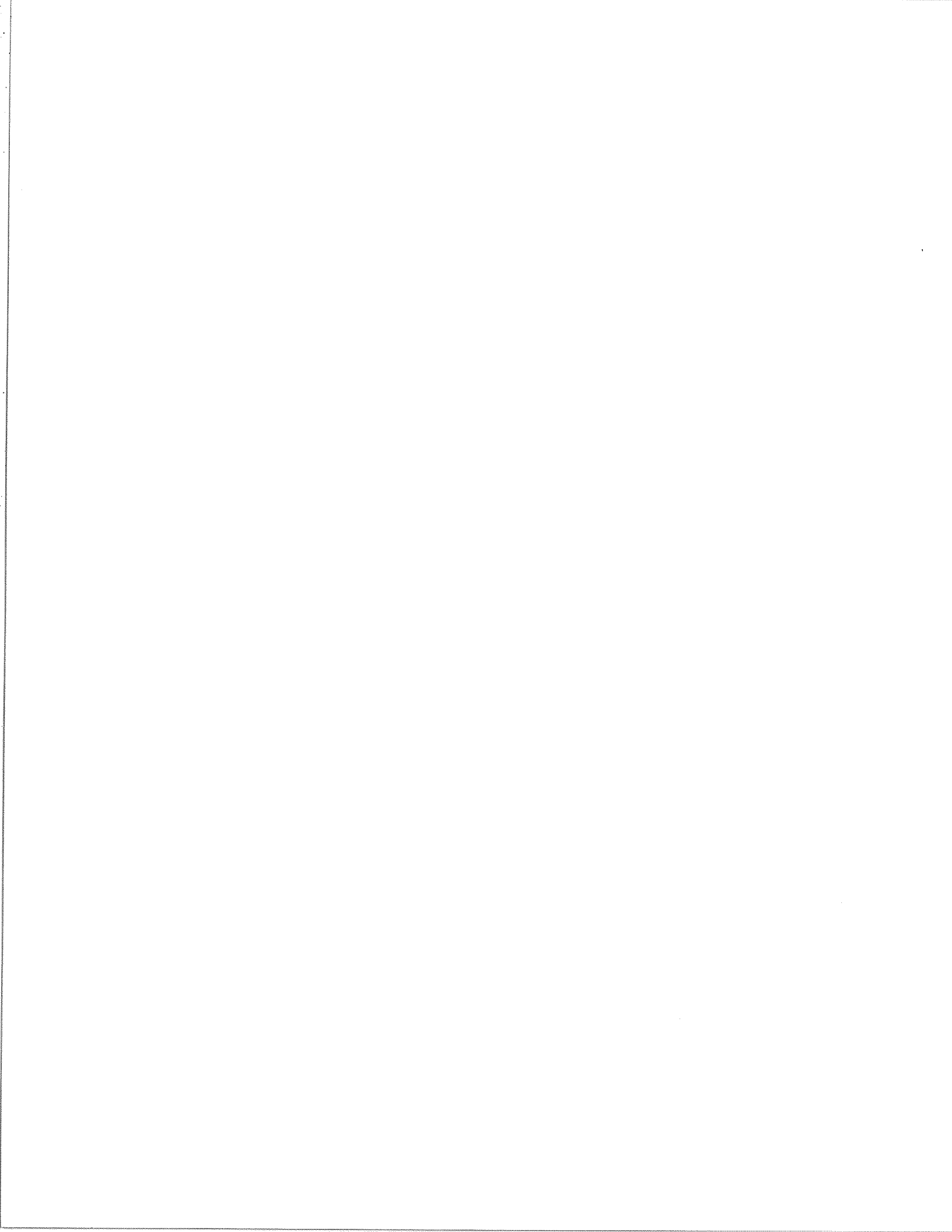
SNOW DEPTH: 1989/90



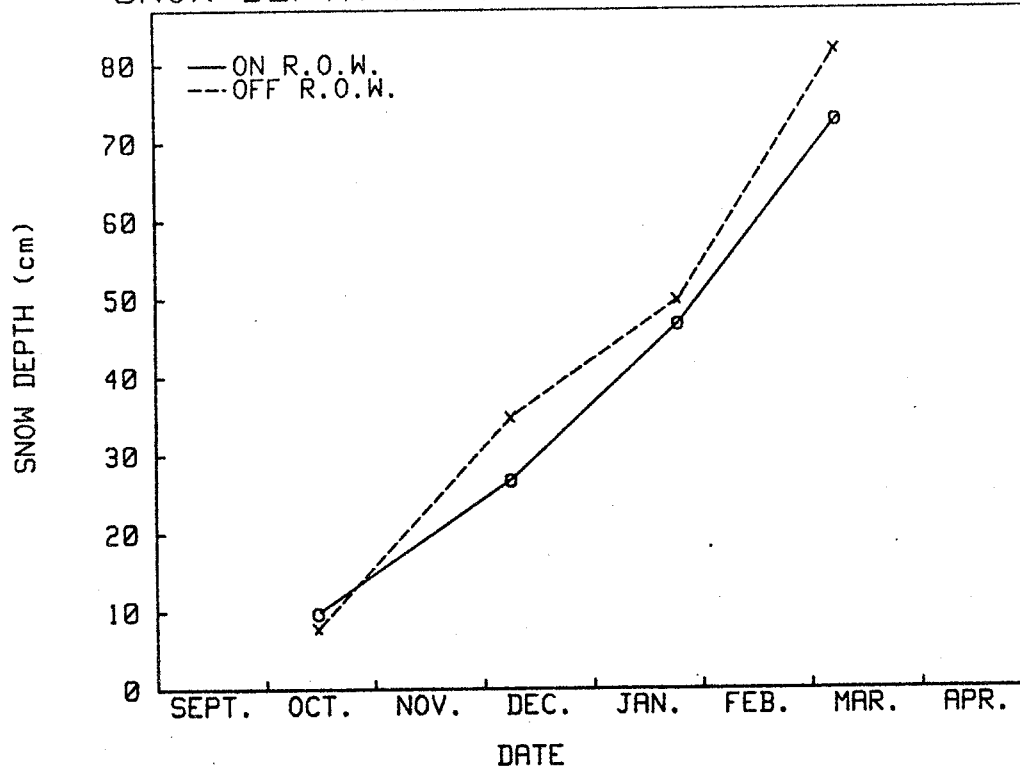
SNOW DEPTH: 1990/91



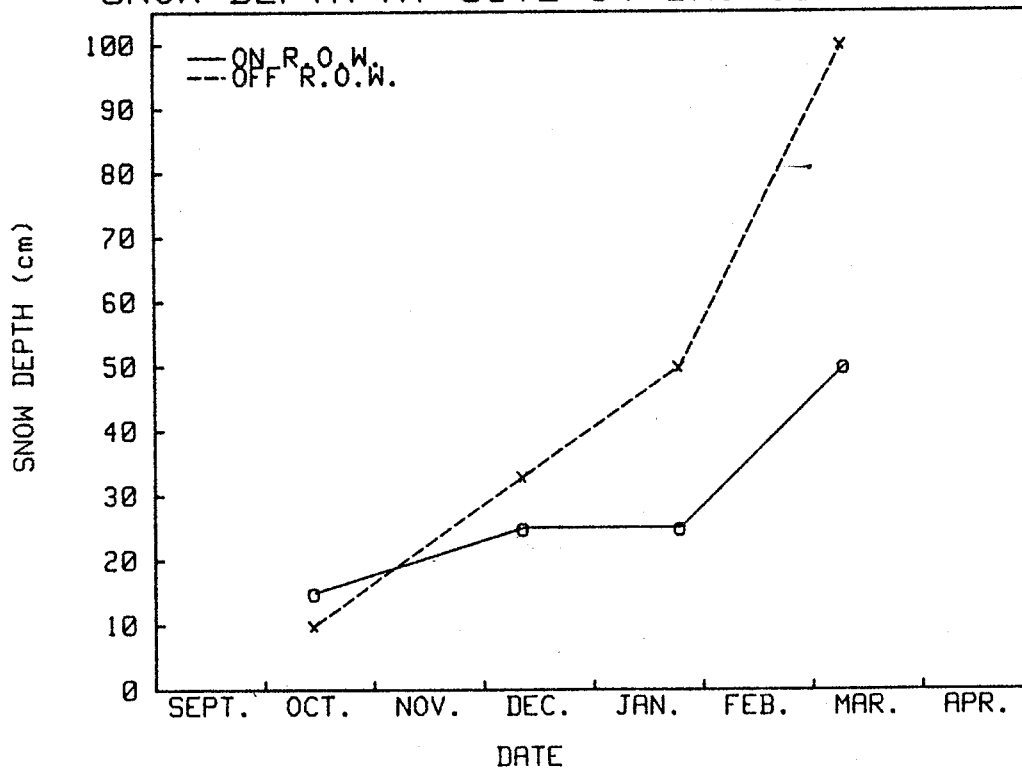
SNOW DEPTH PLOTS - STUDY SITES 1990/1991



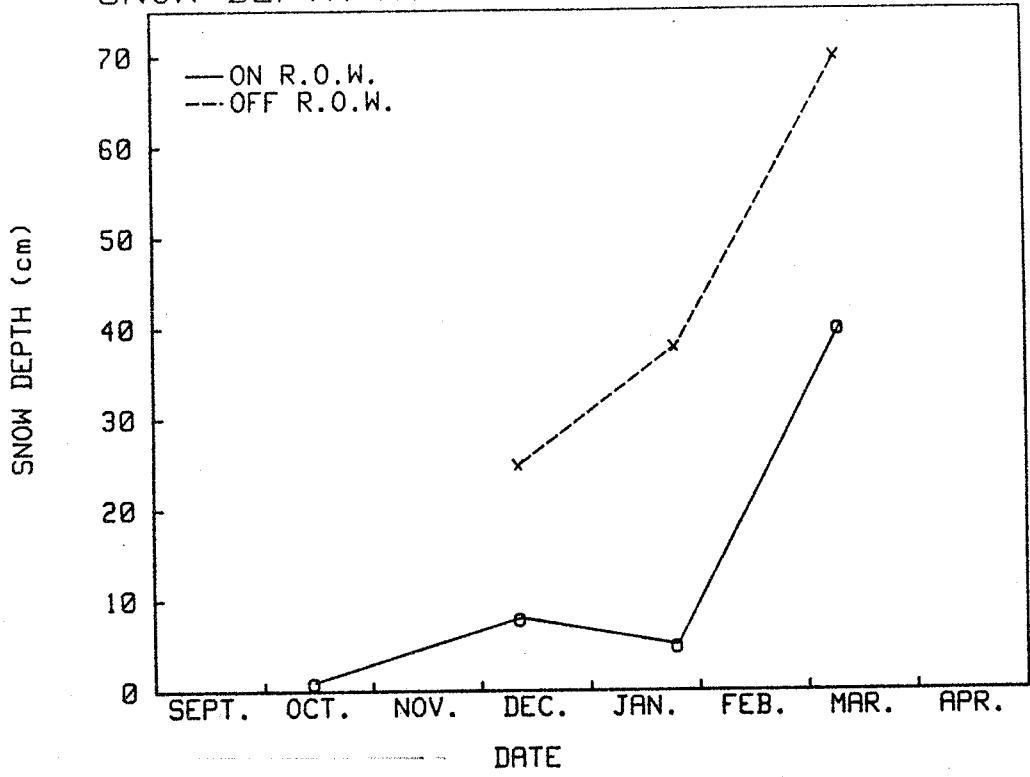
SNOW DEPTH AT SITE 84-1: 1990/91



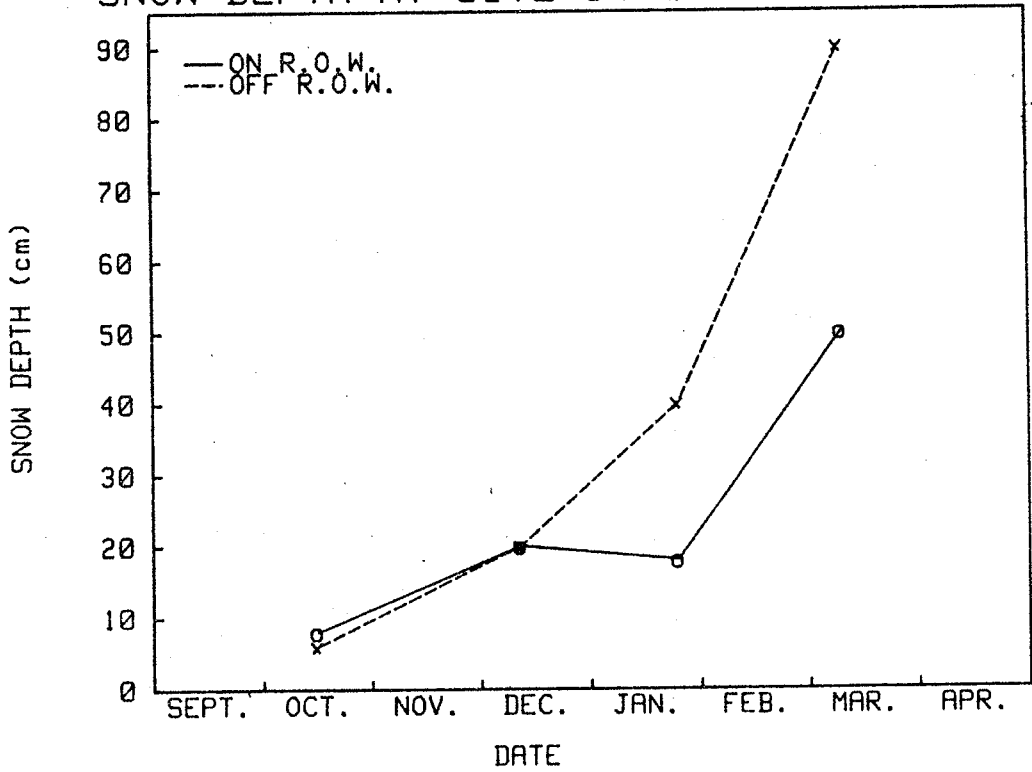
SNOW DEPTH AT SITE 84-2A: 1990/91



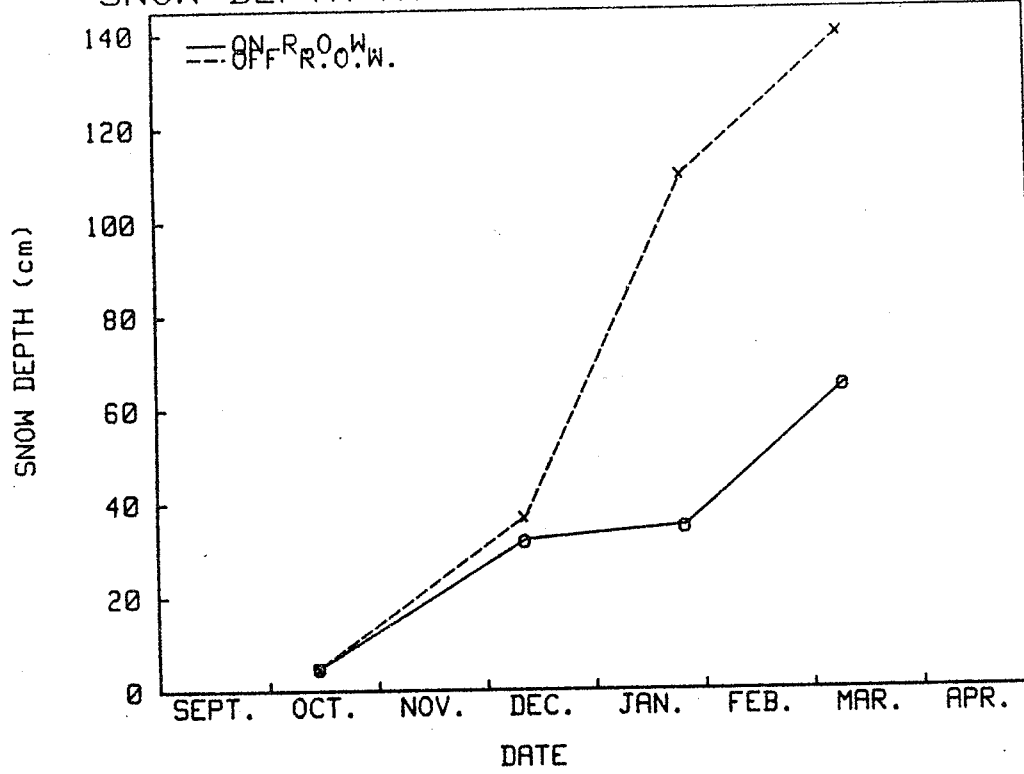
SNOW DEPTH AT SITE 84-2B: 1990/91



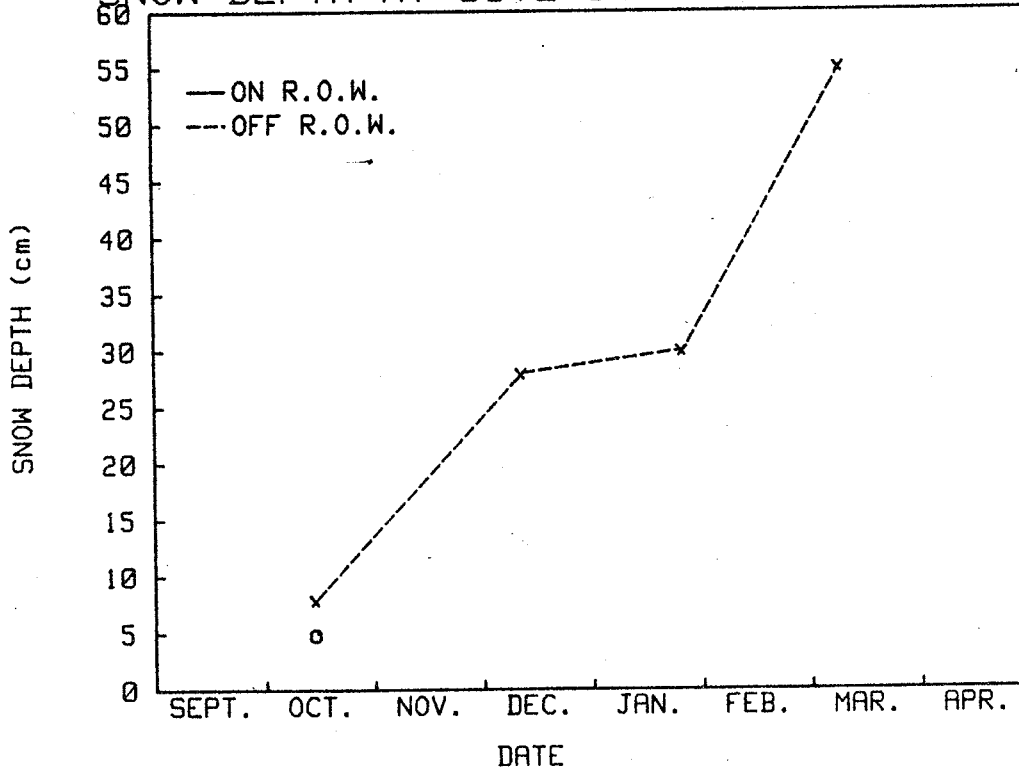
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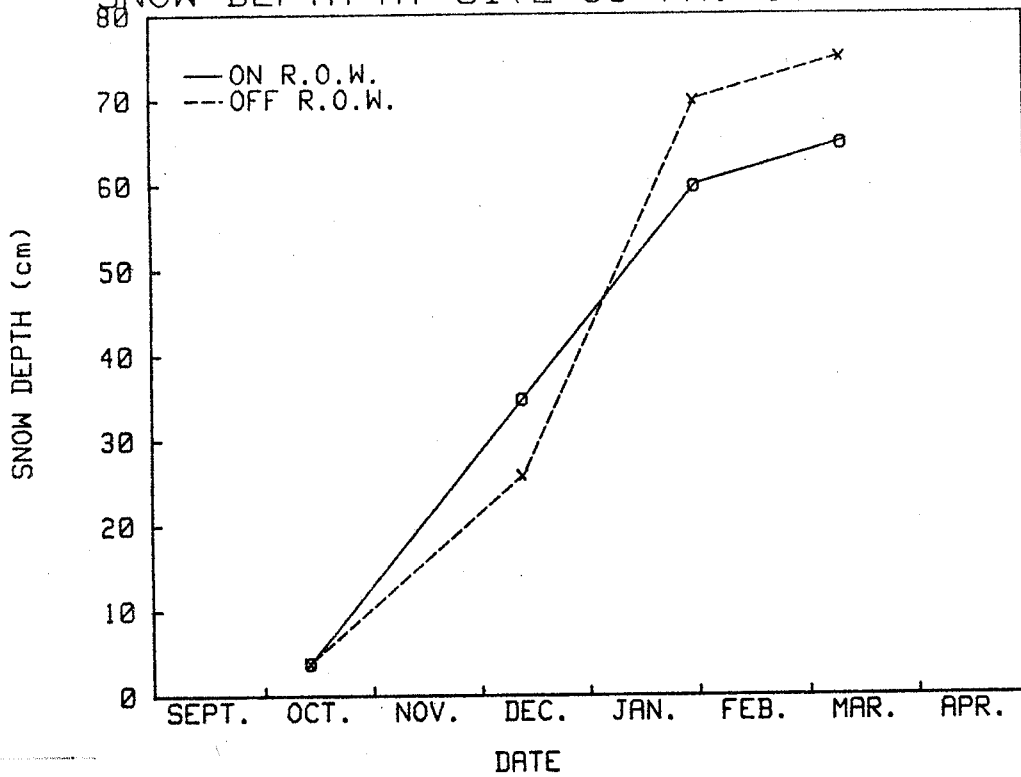
SNOW DEPTH AT SITE 84-3A: 1990/91



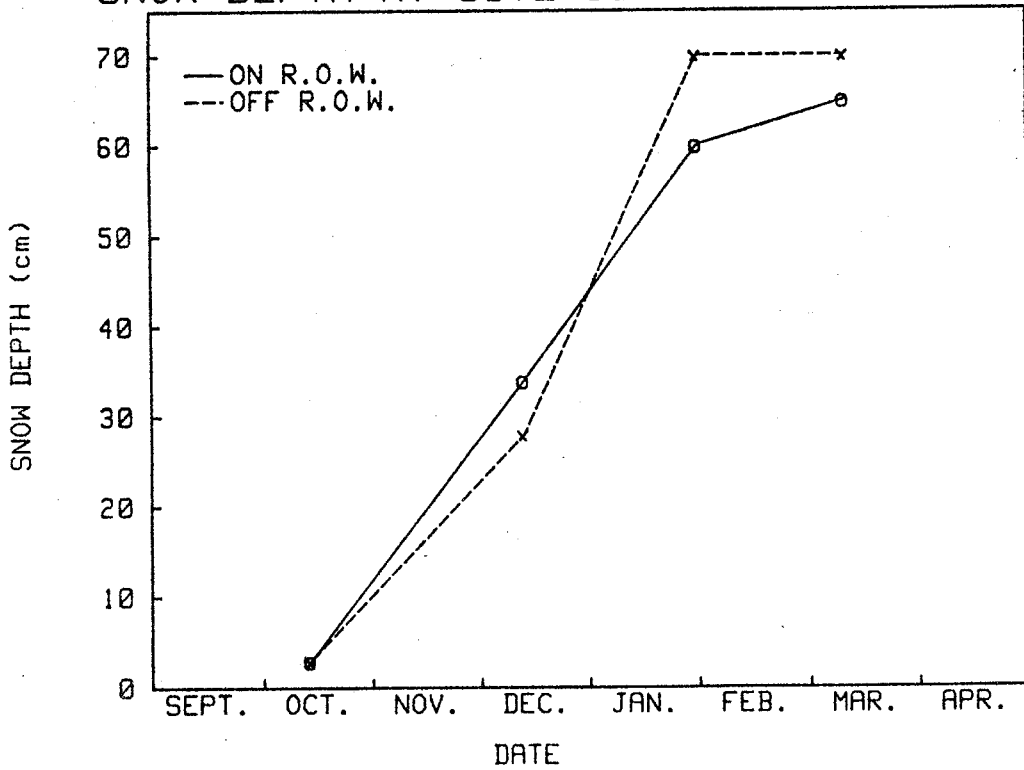
SNOW DEPTH AT SITE 84-3B: 1990/91



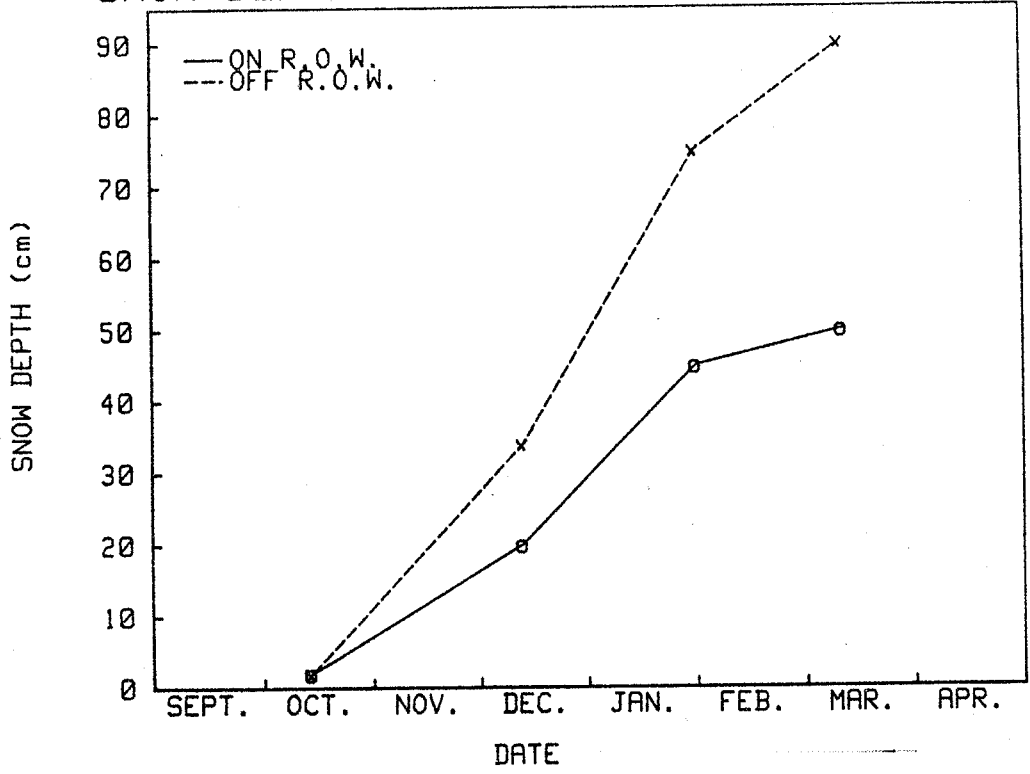
SNOW DEPTH AT SITE 85-7A: 1990/91



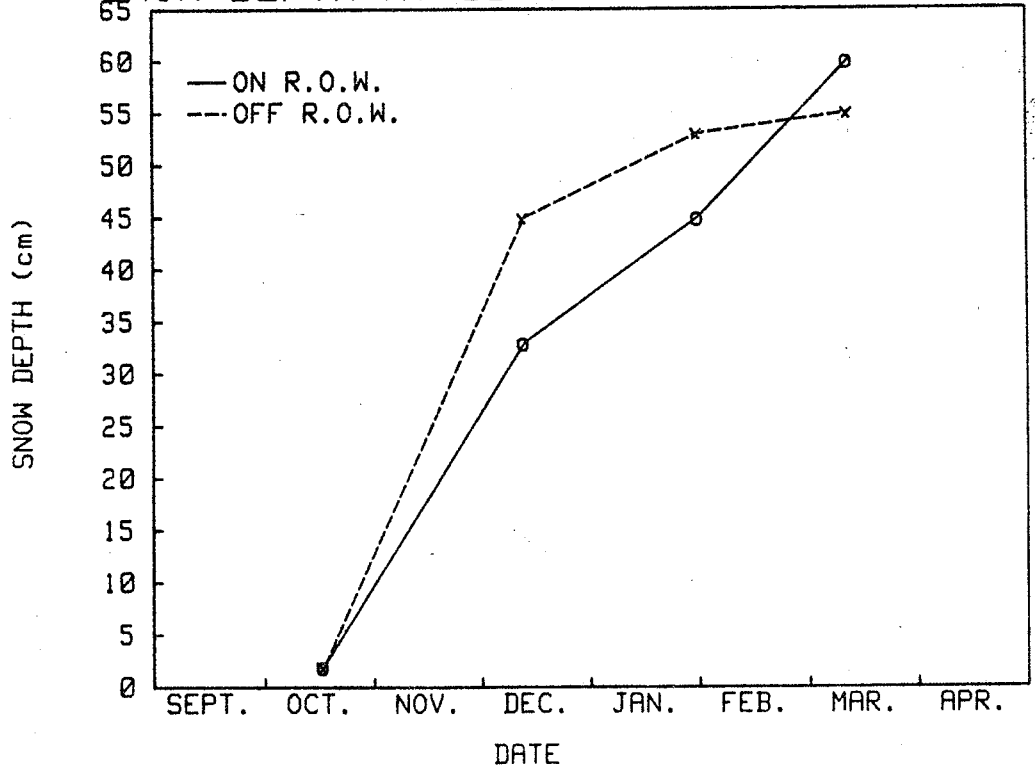
SNOW DEPTH AT SITE 85-7B: 1990/91



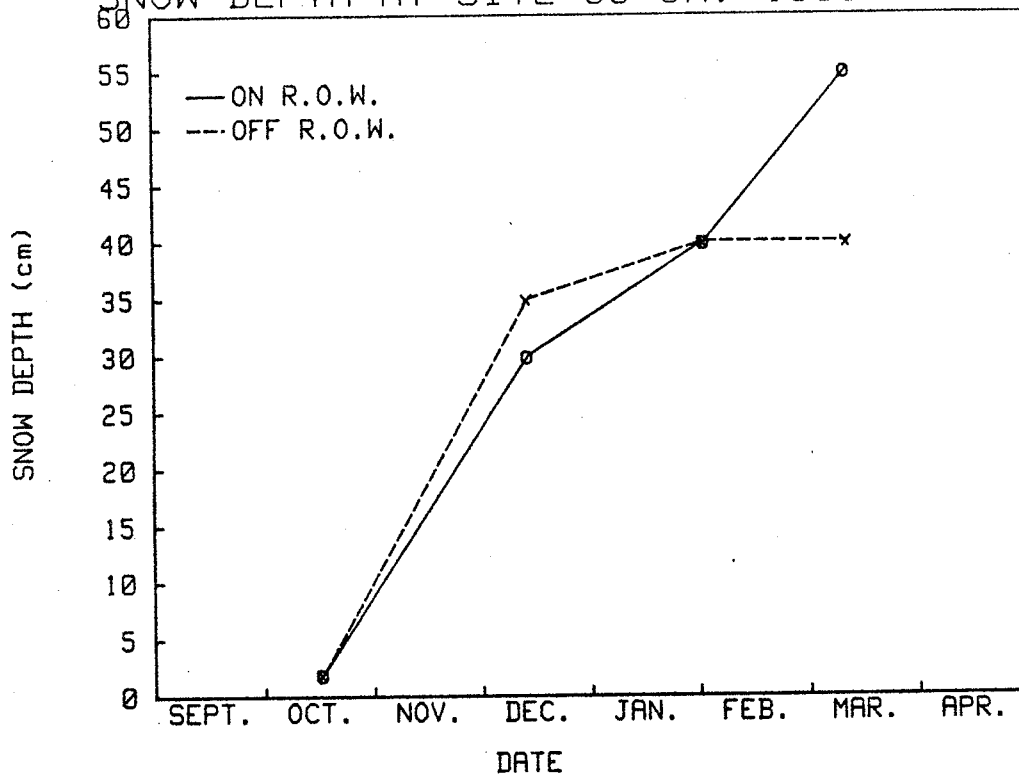
SNOW DEPTH AT SITE 85-7C: 1990/91



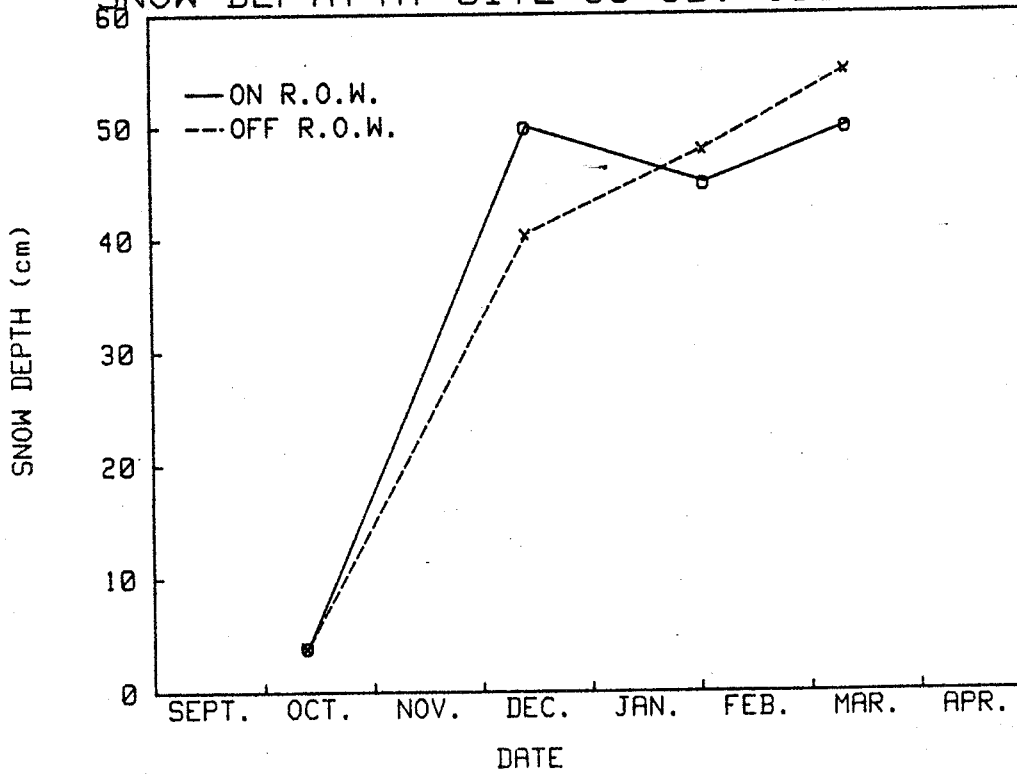
SNOW DEPTH AT SITE 84-4B: 1990/91



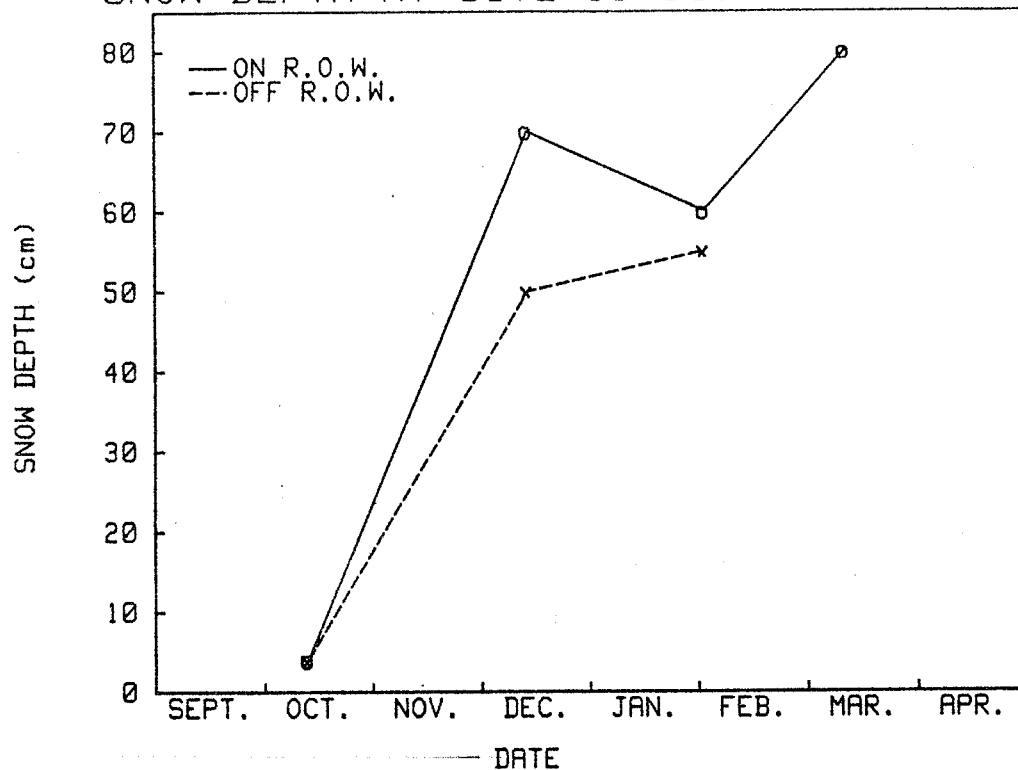
SNOW DEPTH AT SITE 85-8A: 1990/91



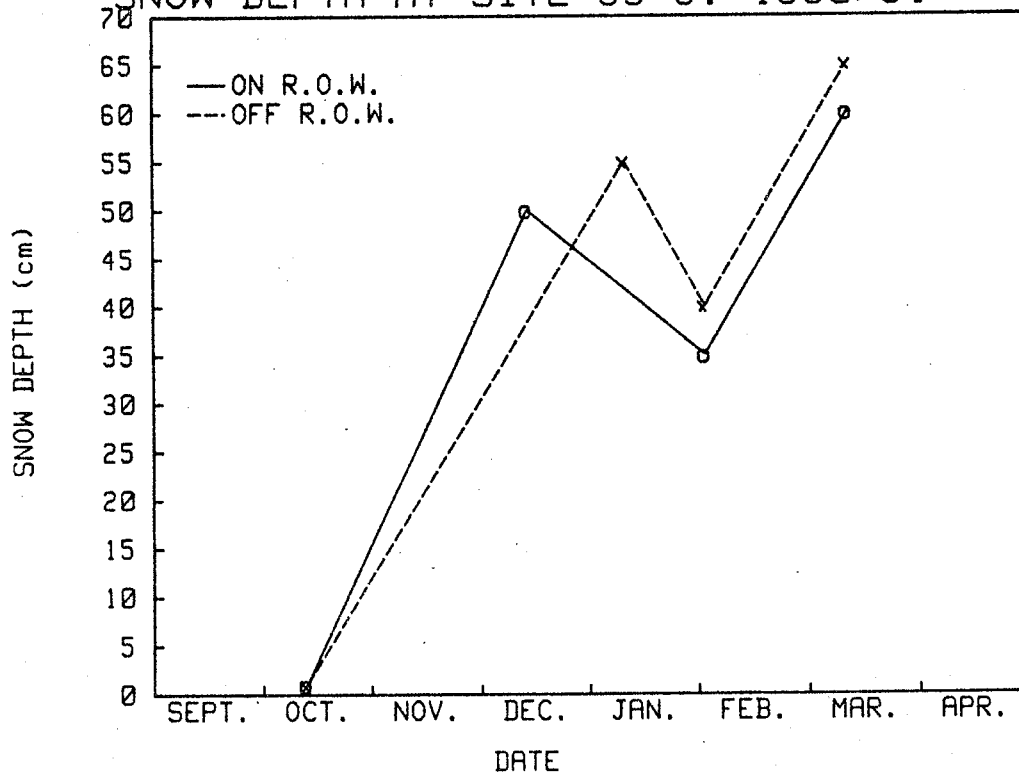
SNOW DEPTH AT SITE 85-8B: 1990/91



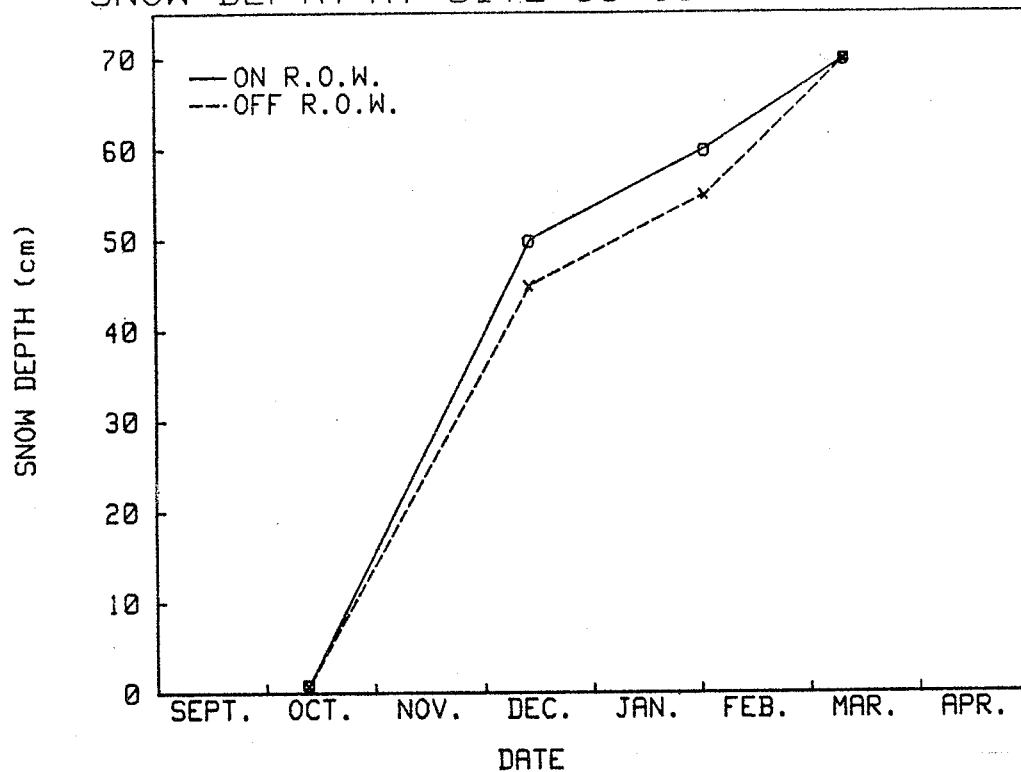
SNOW DEPTH AT SITE 85-8C: 1990/91



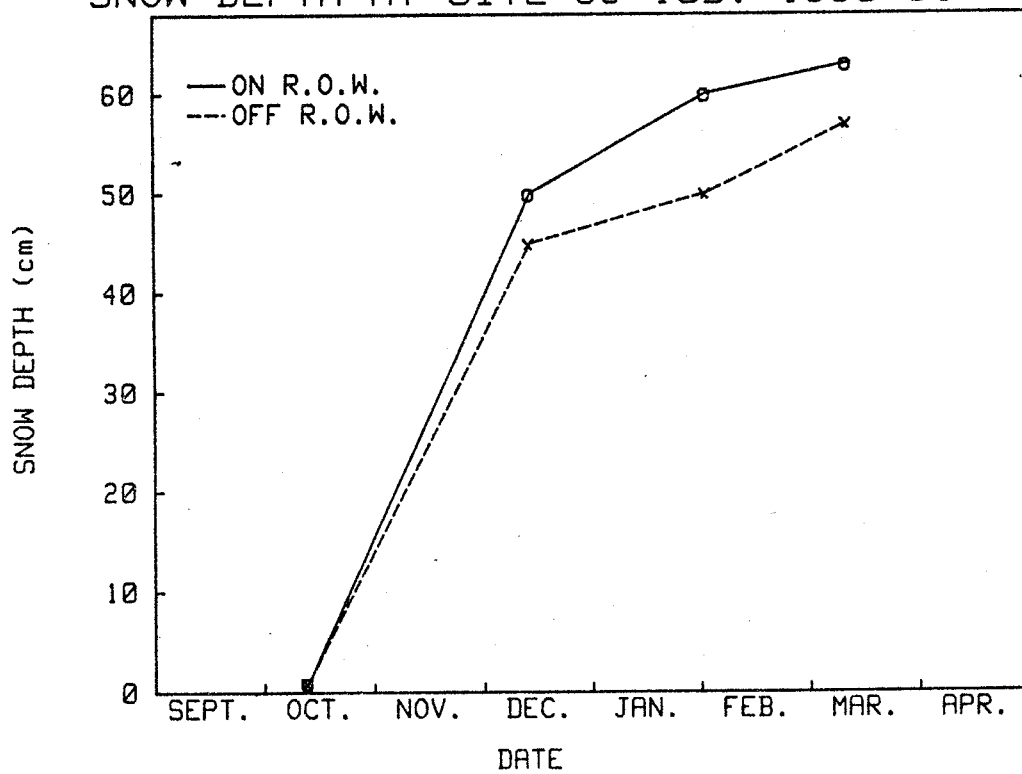
SNOW DEPTH AT SITE 85-9: 1990/91



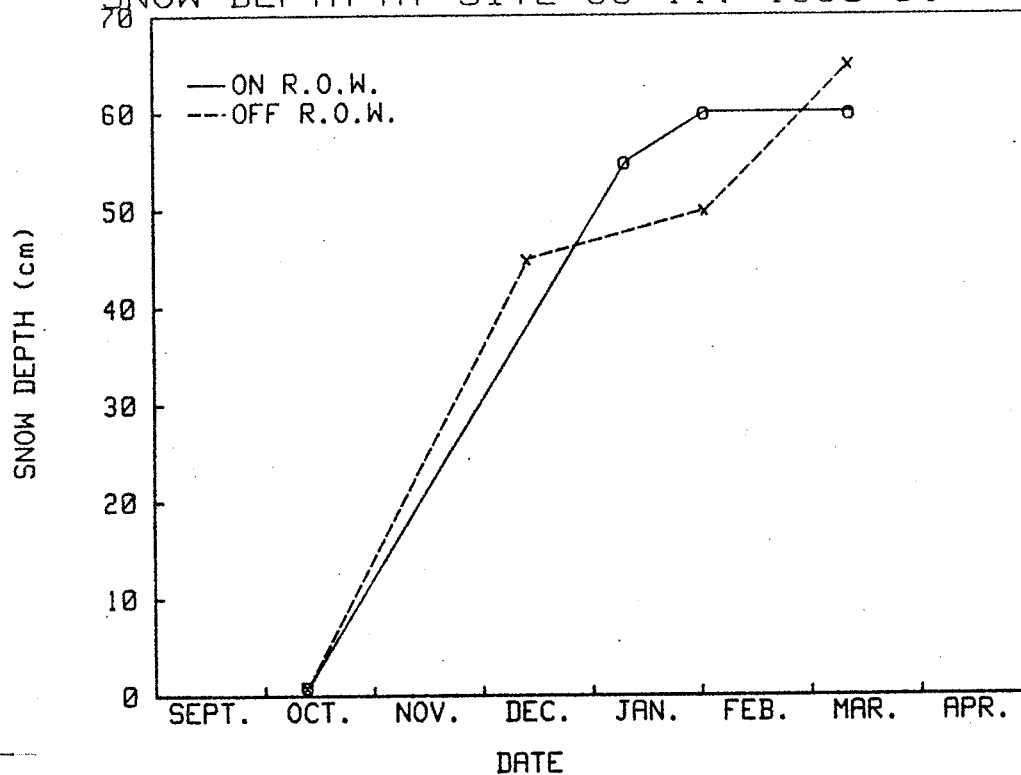
SNOW DEPTH AT SITE 85-10A: 1990/91



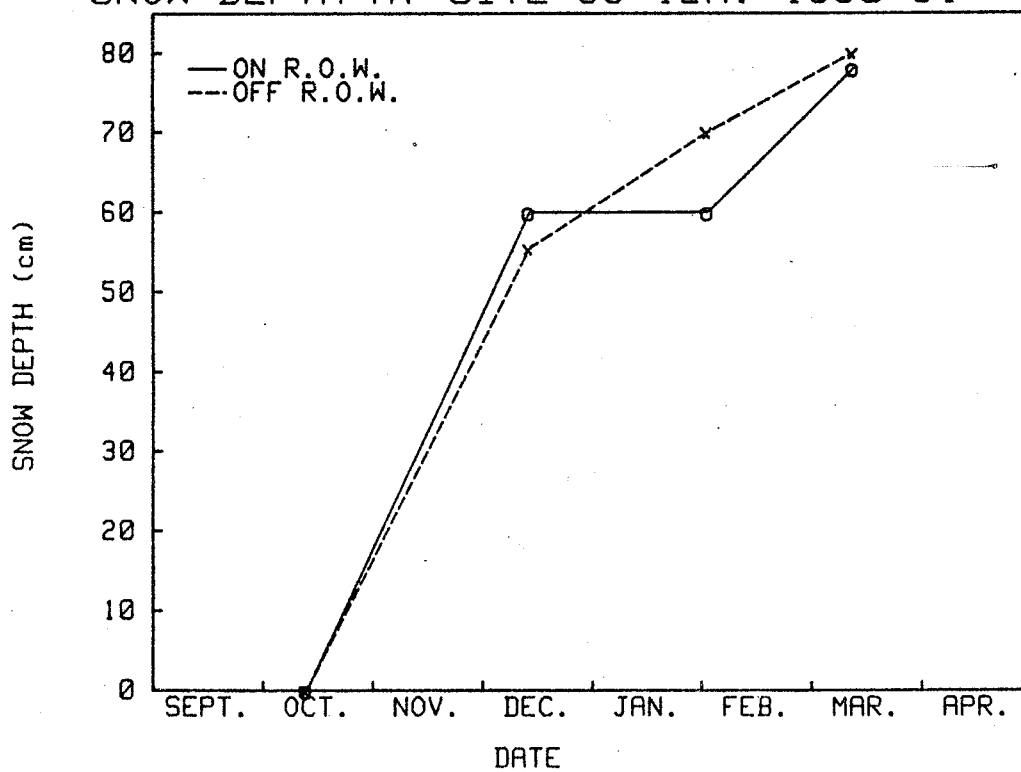
SNOW DEPTH AT SITE 85-10B: 1990/91



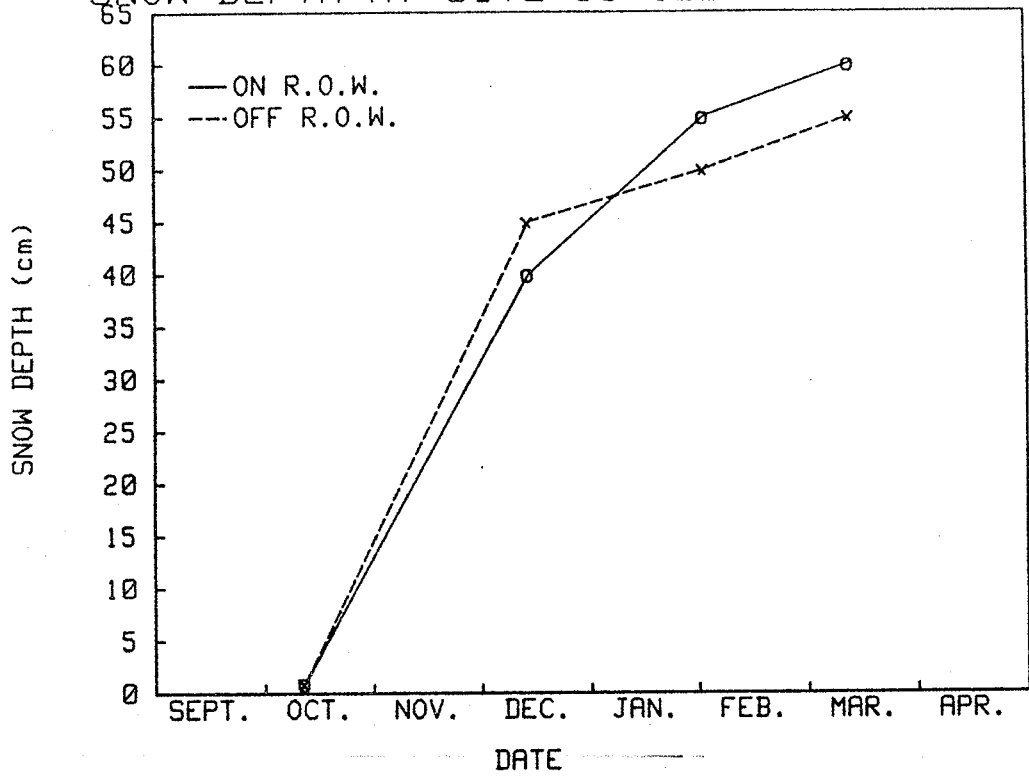
SNOW DEPTH AT SITE 85-11: 1990/91



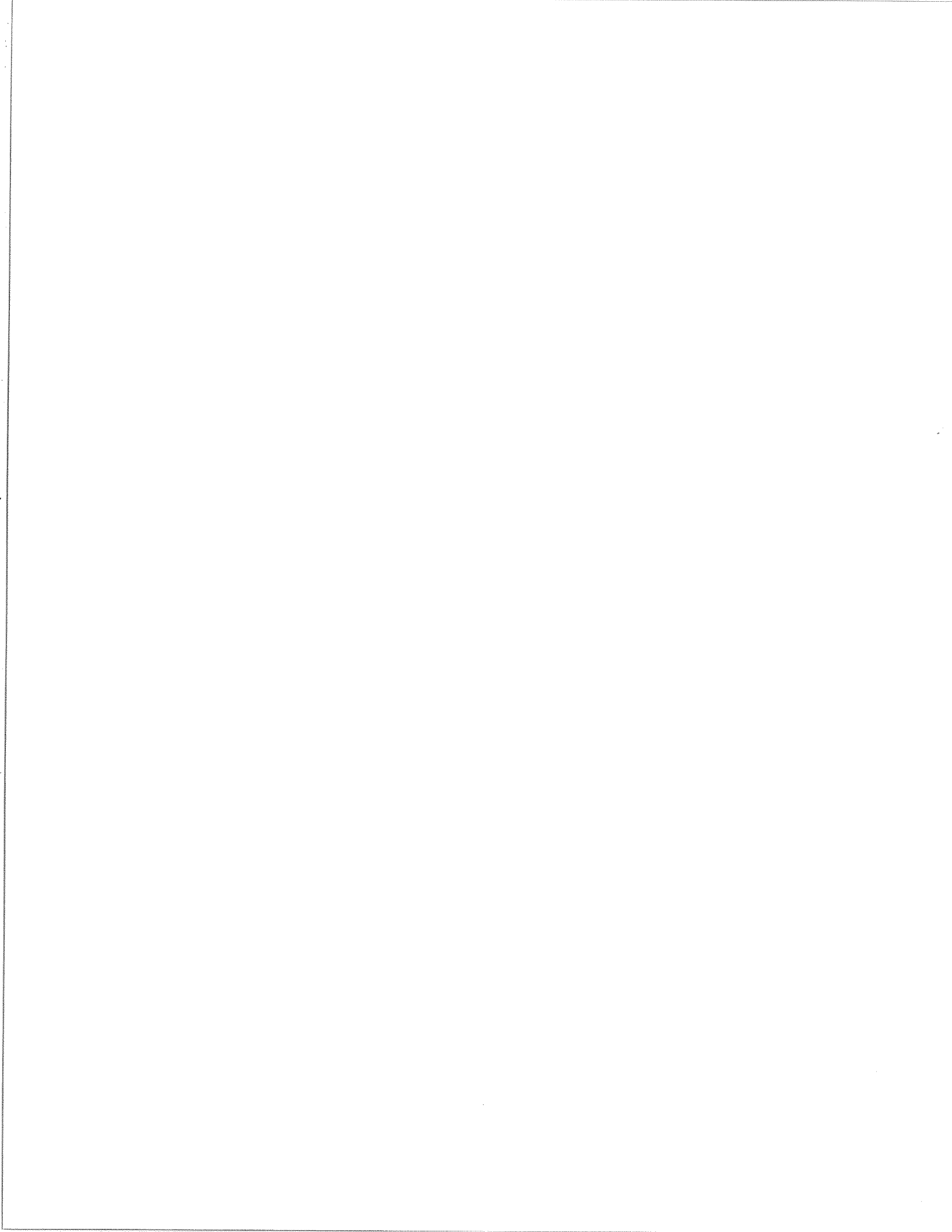
SNOW DEPTH AT SITE 85-12A: 1990/91



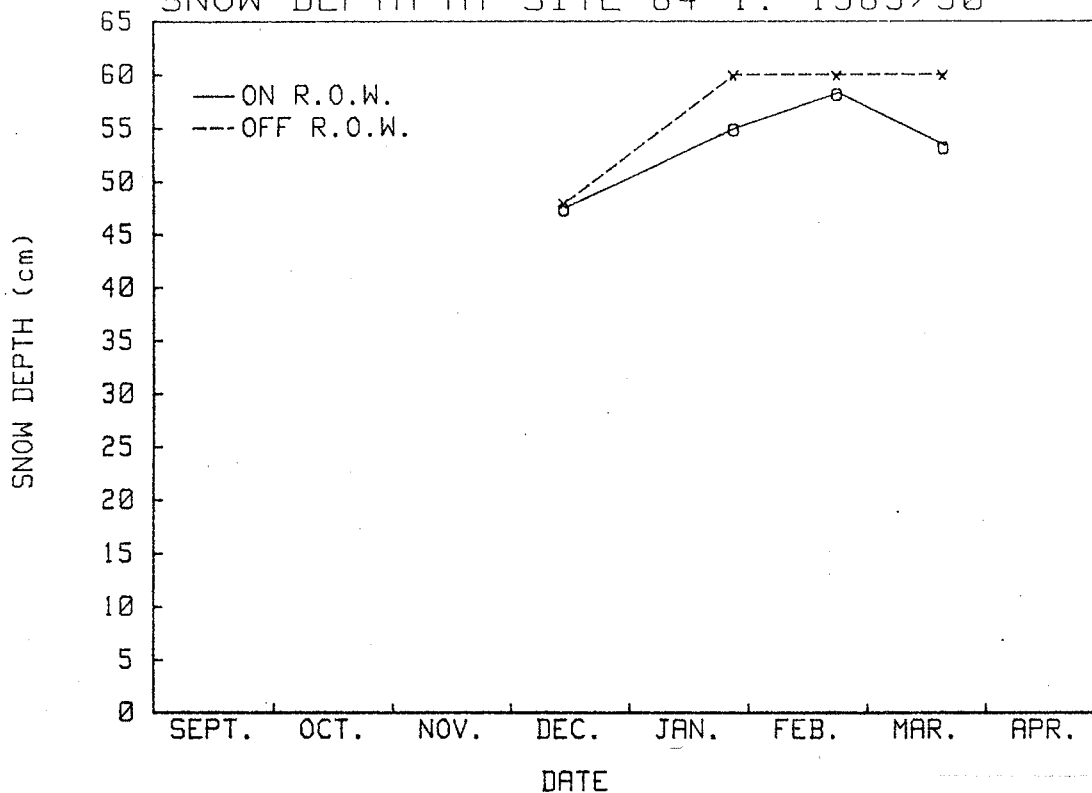
SNOW DEPTH AT SITE 85-12B: 1990/91



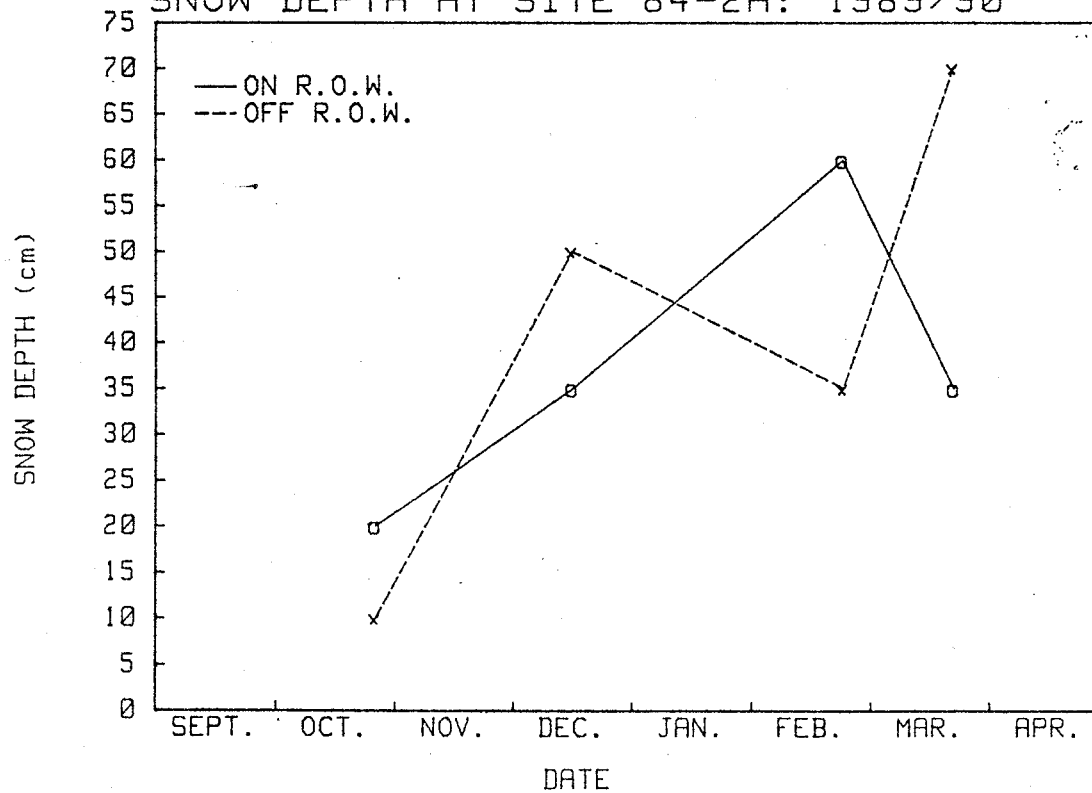
SNOW DEPTH PLOTS - STUDY SIRES 1989/1990



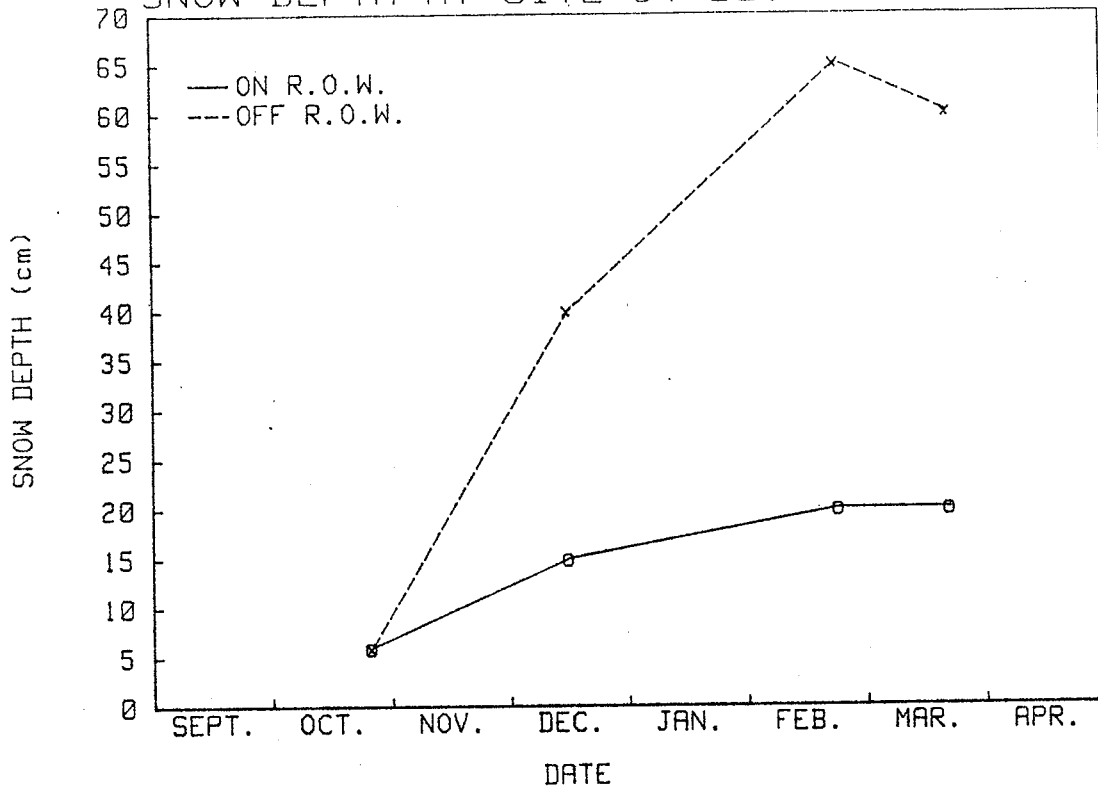
SNOW DEPTH AT SITE 84-1: 1989/90



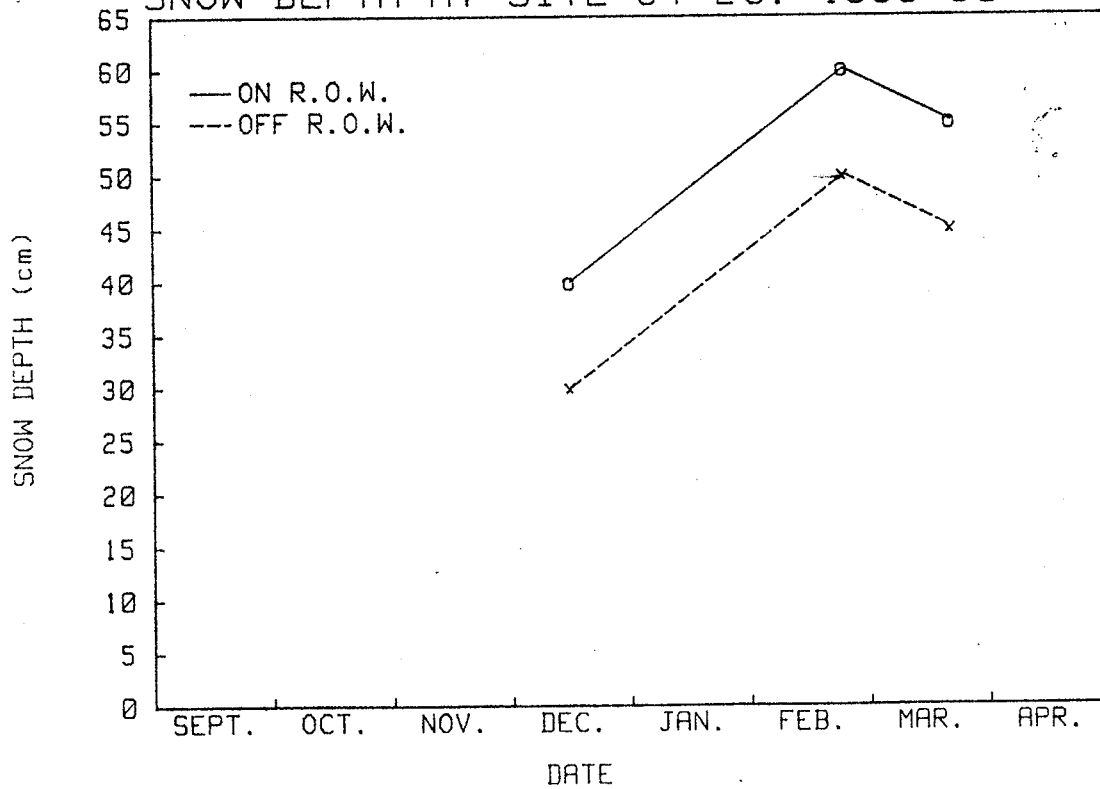
SNOW DEPTH AT SITE 84-2A: 1989/90



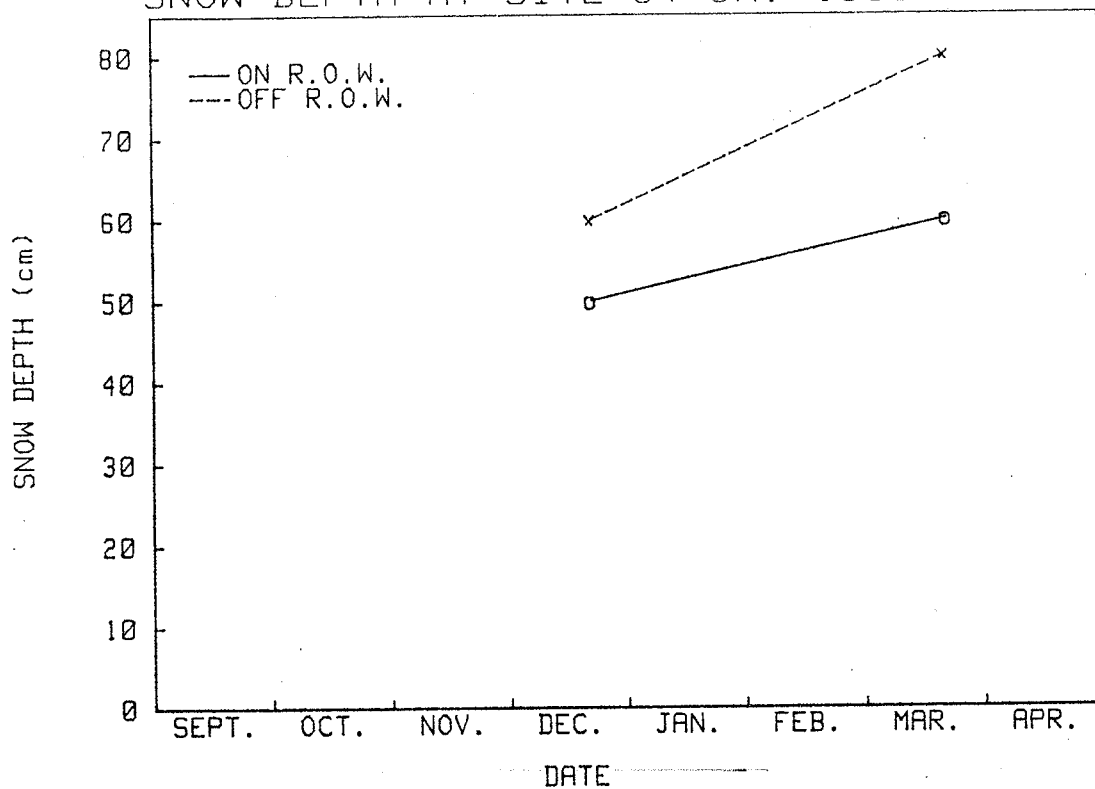
SNOW DEPTH AT SITE 84-2B: 1989/90



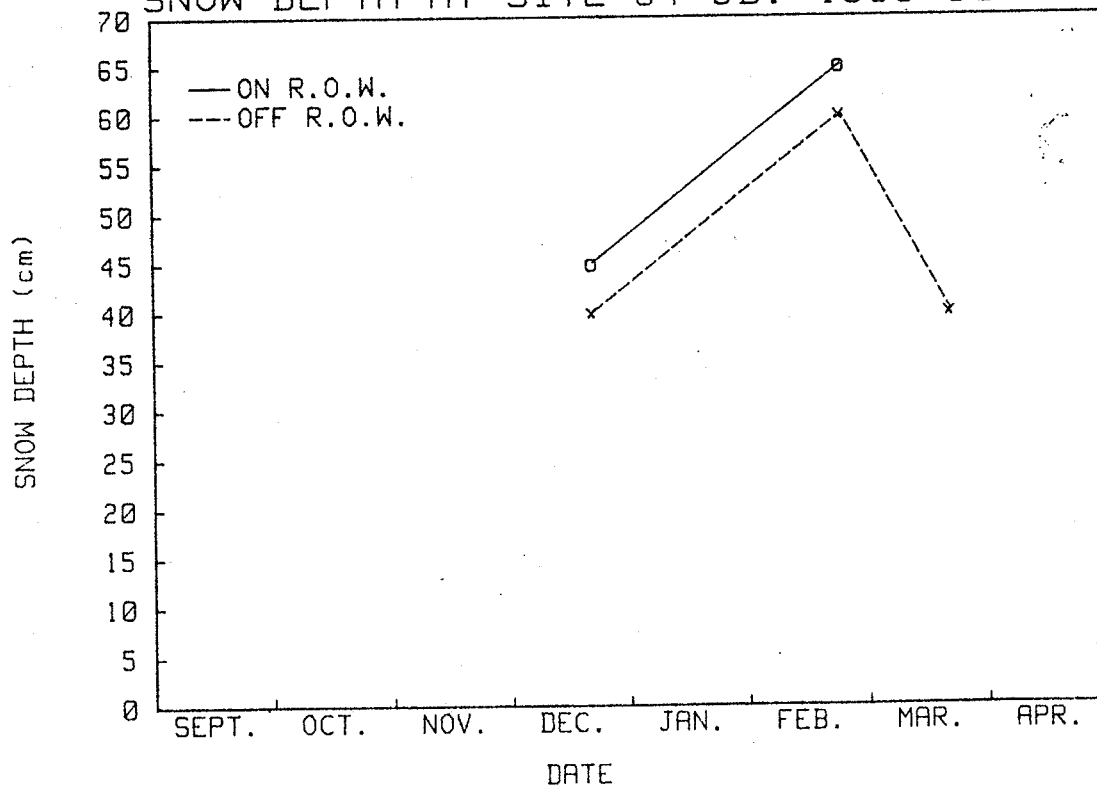
SNOW DEPTH AT SITE 84-2C: 1989/90



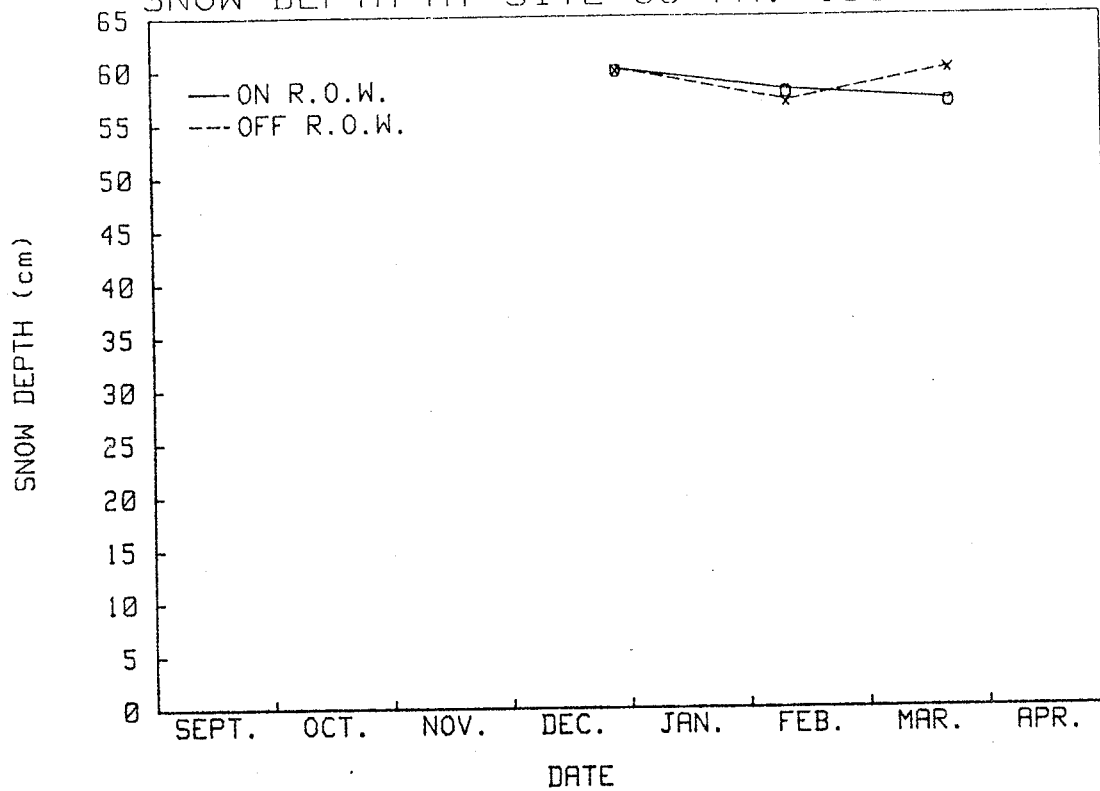
SNOW DEPTH AT SITE 84-3A: 1989/90



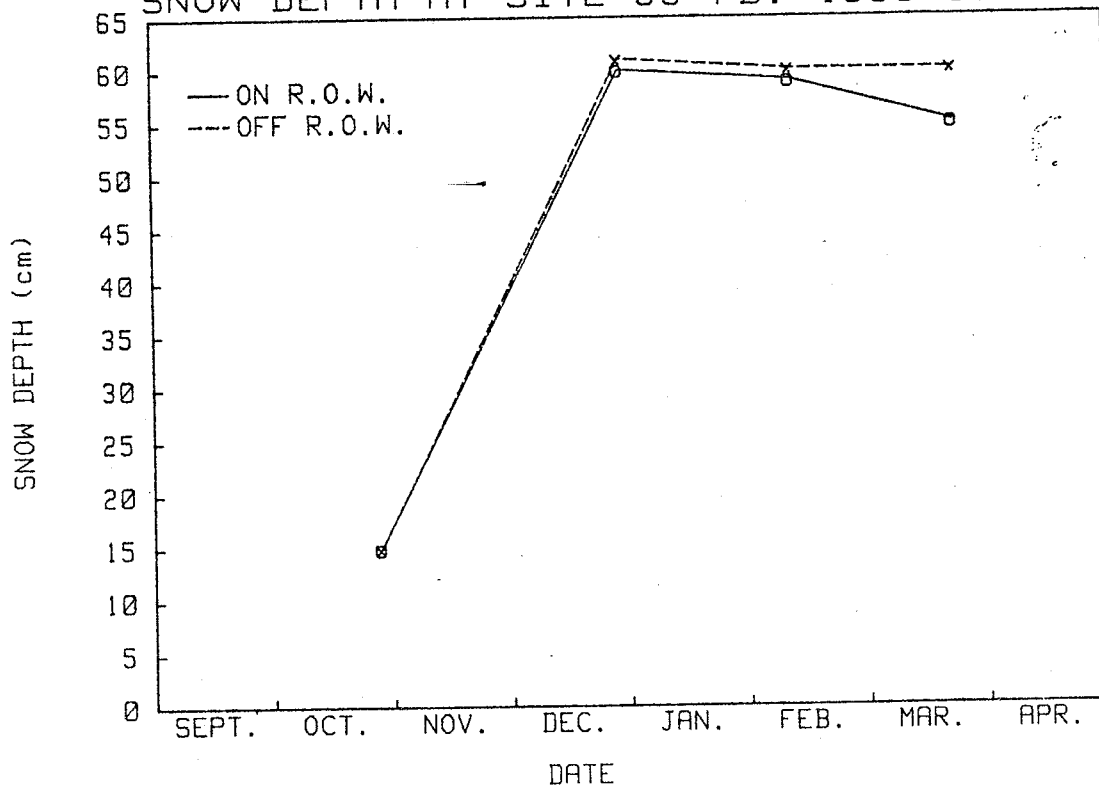
SNOW DEPTH AT SITE 84-3B: 1989/90



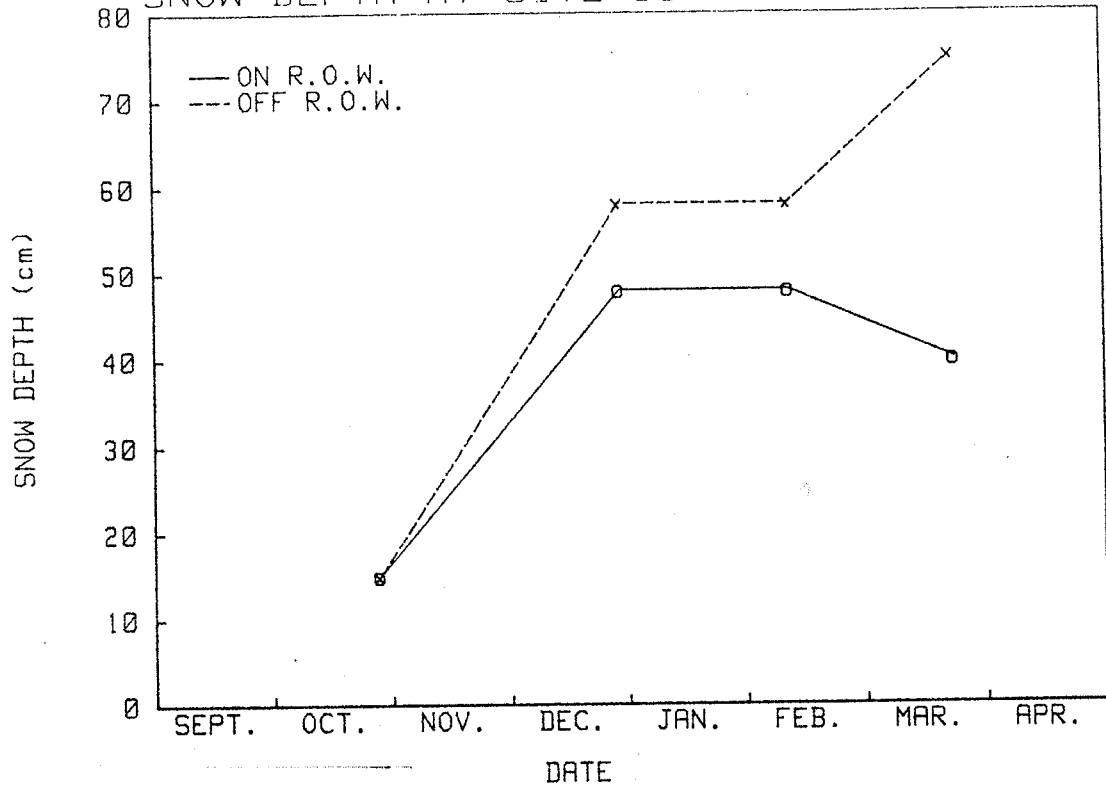
SNOW DEPTH AT SITE 85-7A: 1989/90



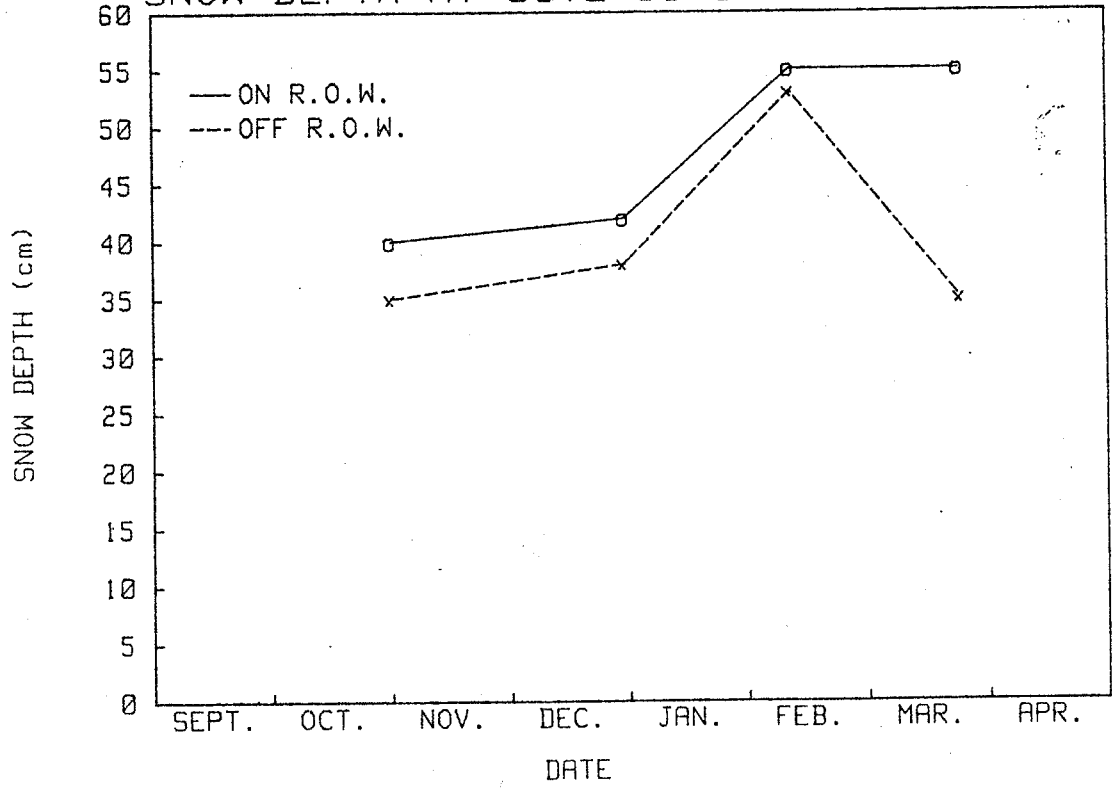
SNOW DEPTH AT SITE 85-7B: 1989/90



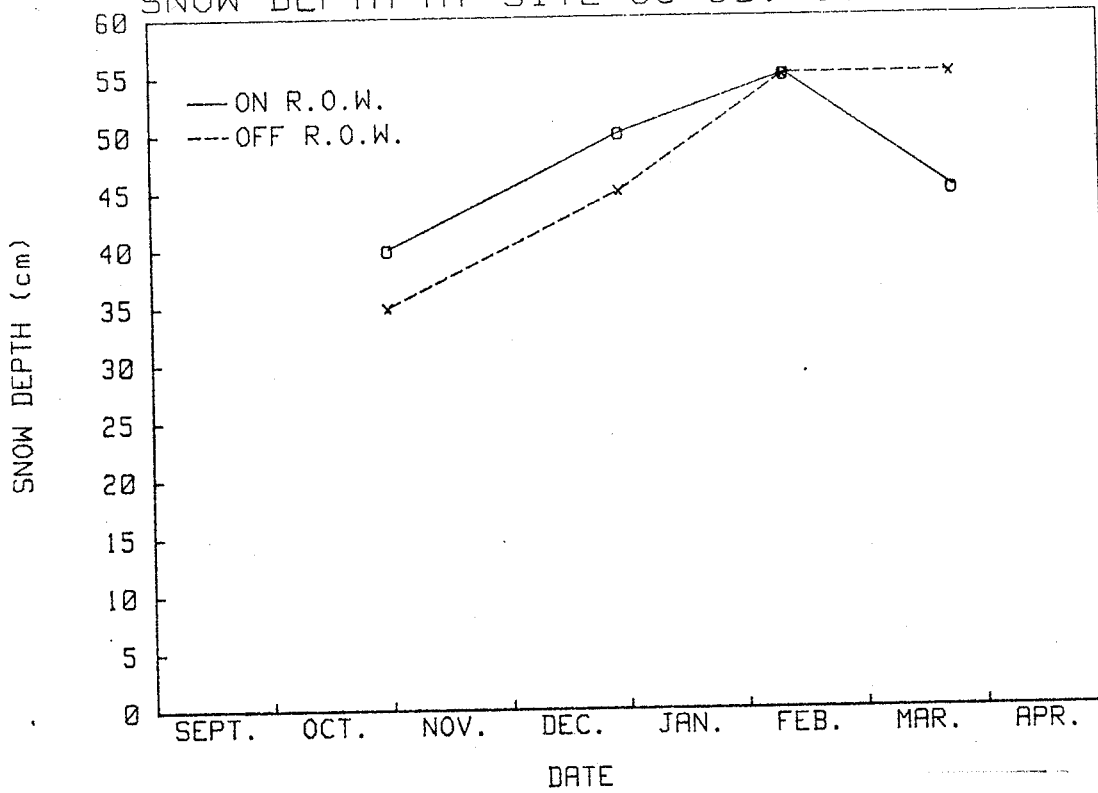
SNOW DEPTH AT SITE 85-7C: 1989/90



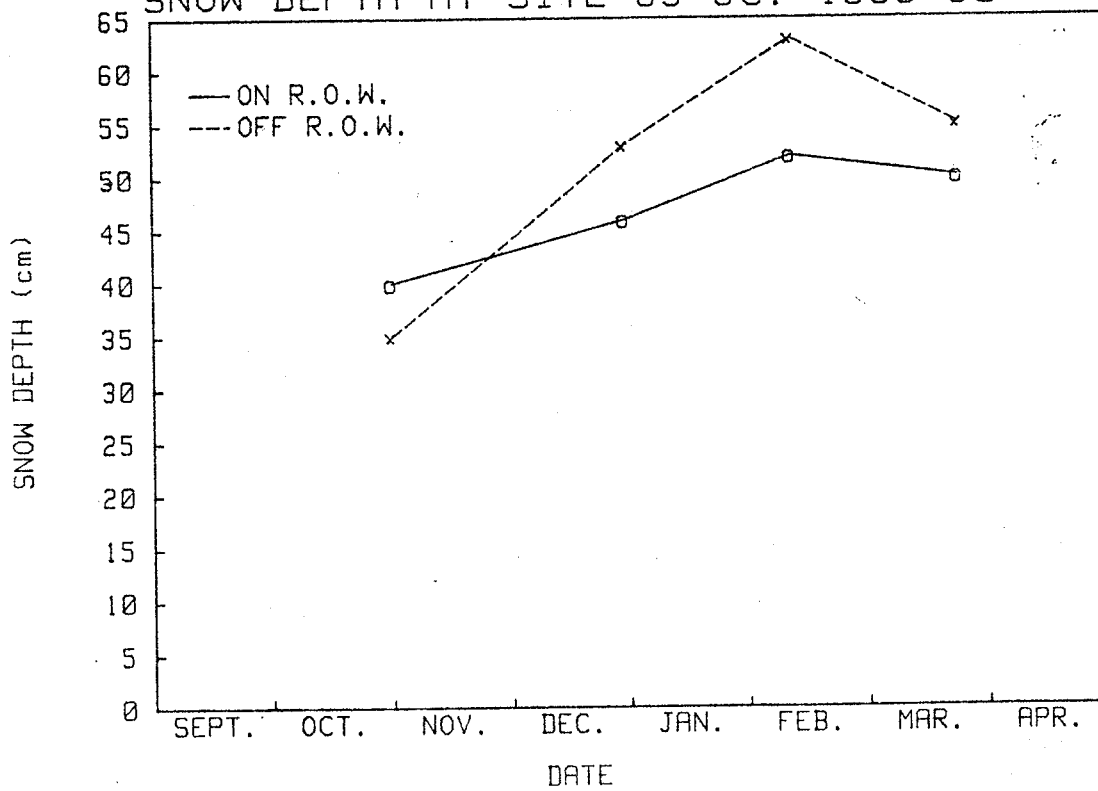
SNOW DEPTH AT SITE 85-8A: 1989/90



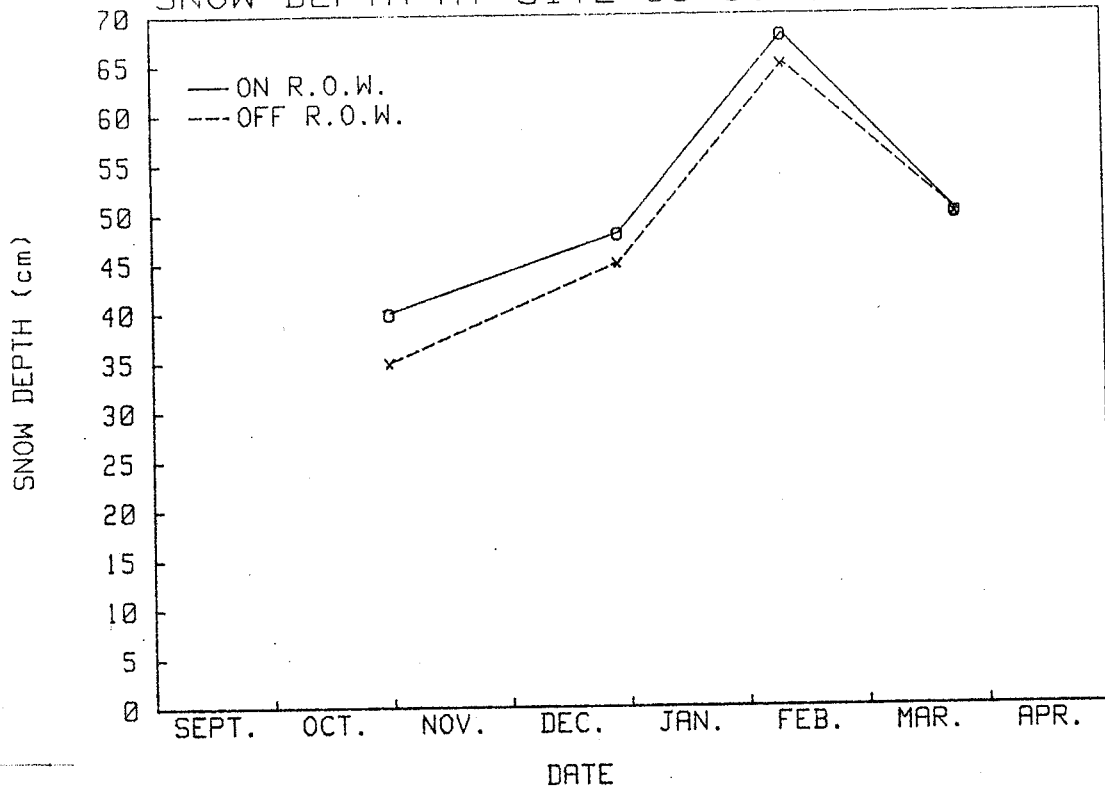
SNOW DEPTH AT SITE 85-8B: 1989/90



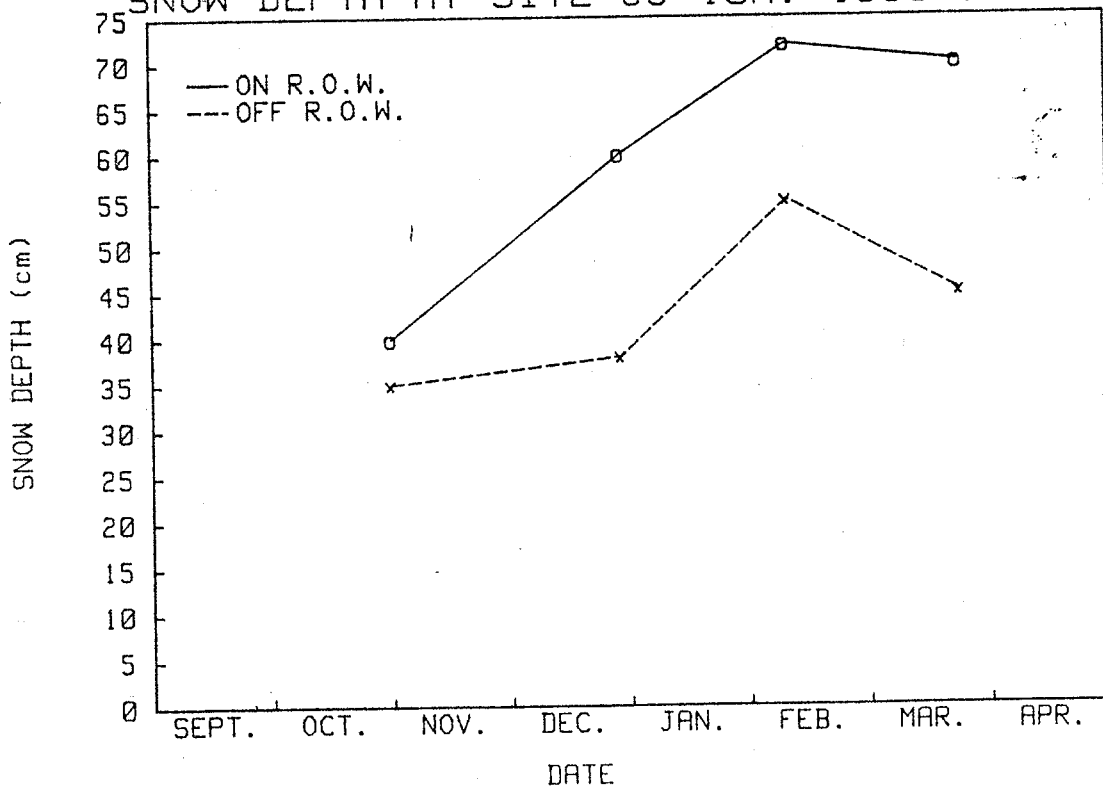
SNOW DEPTH AT SITE 85-8C: 1989/90



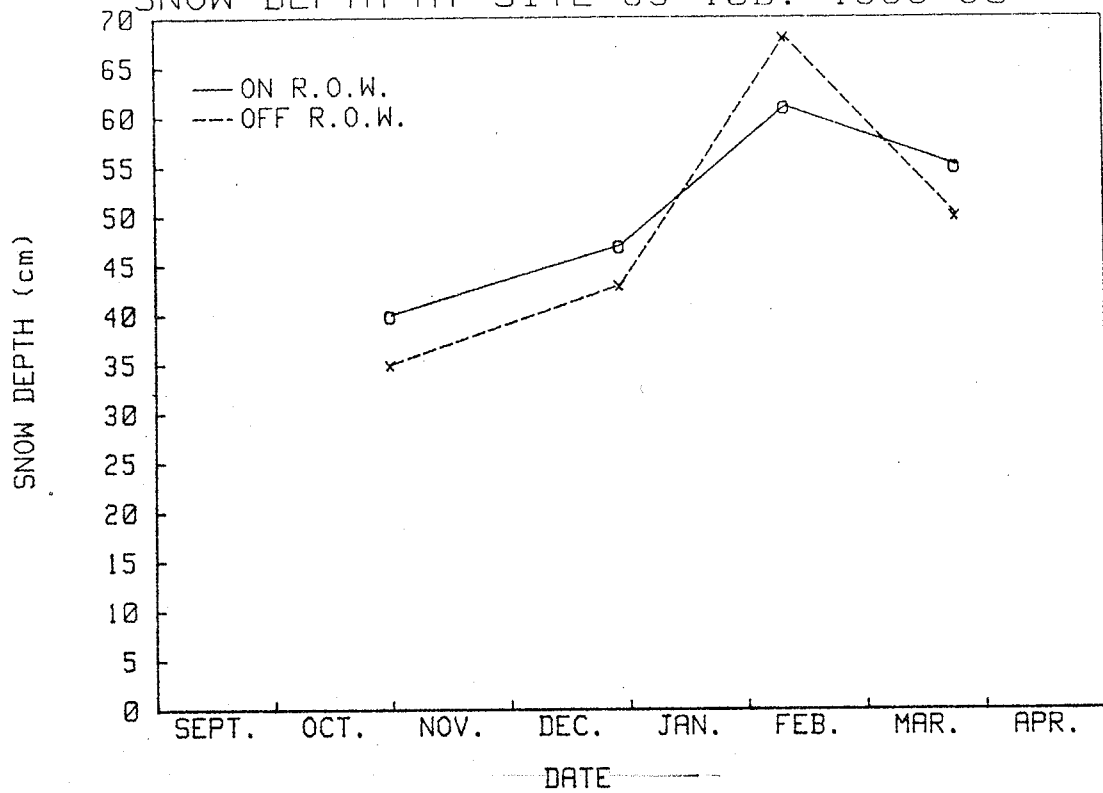
SNOW DEPTH AT SITE 85-9: 1989/90



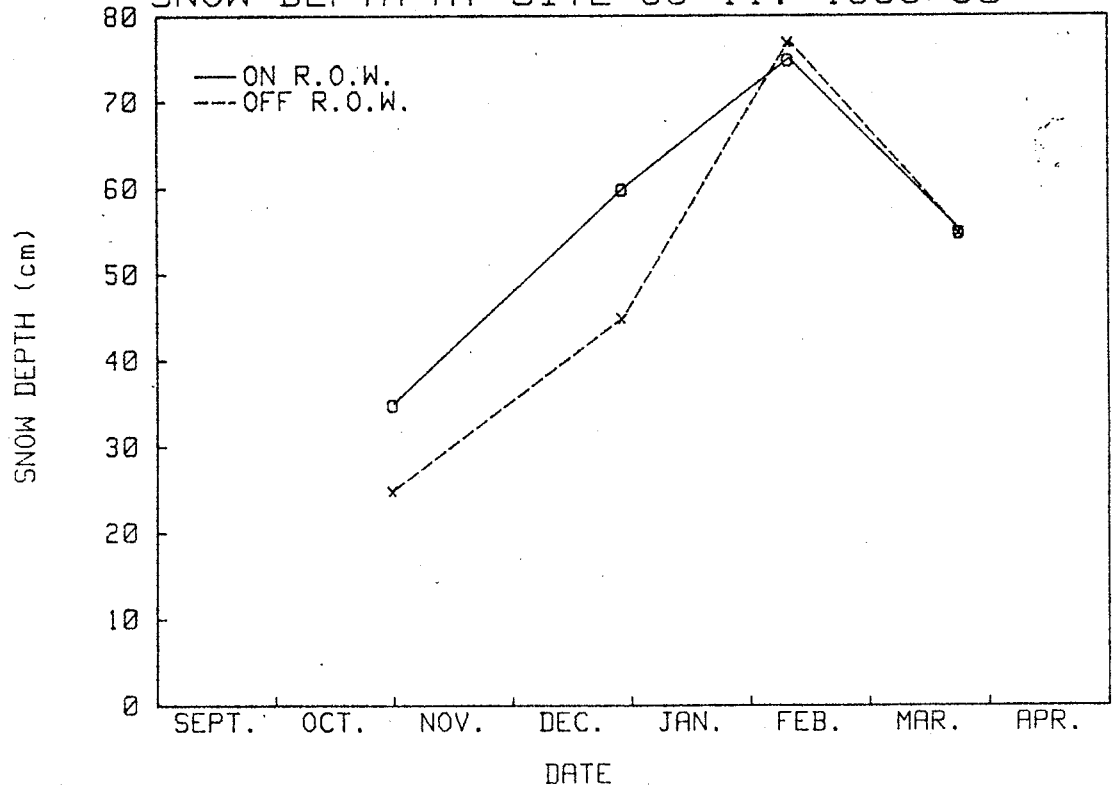
SNOW DEPTH AT SITE 85-10A: 1989/90

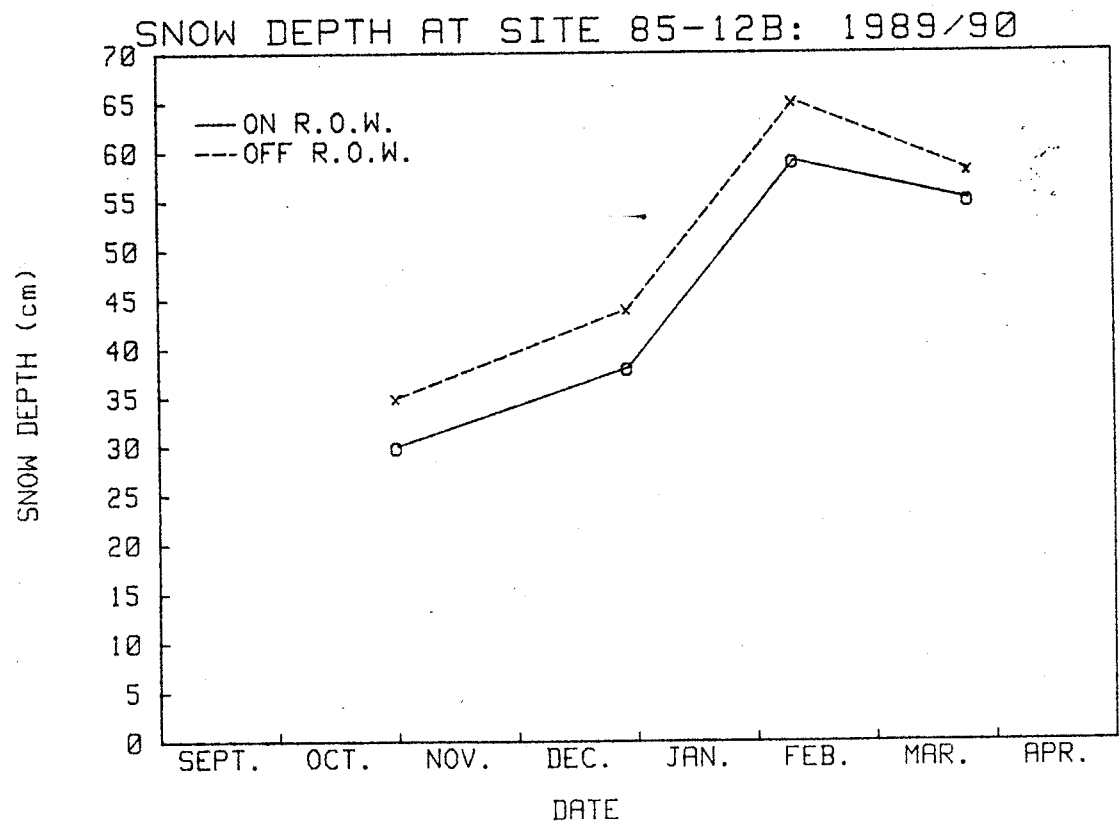
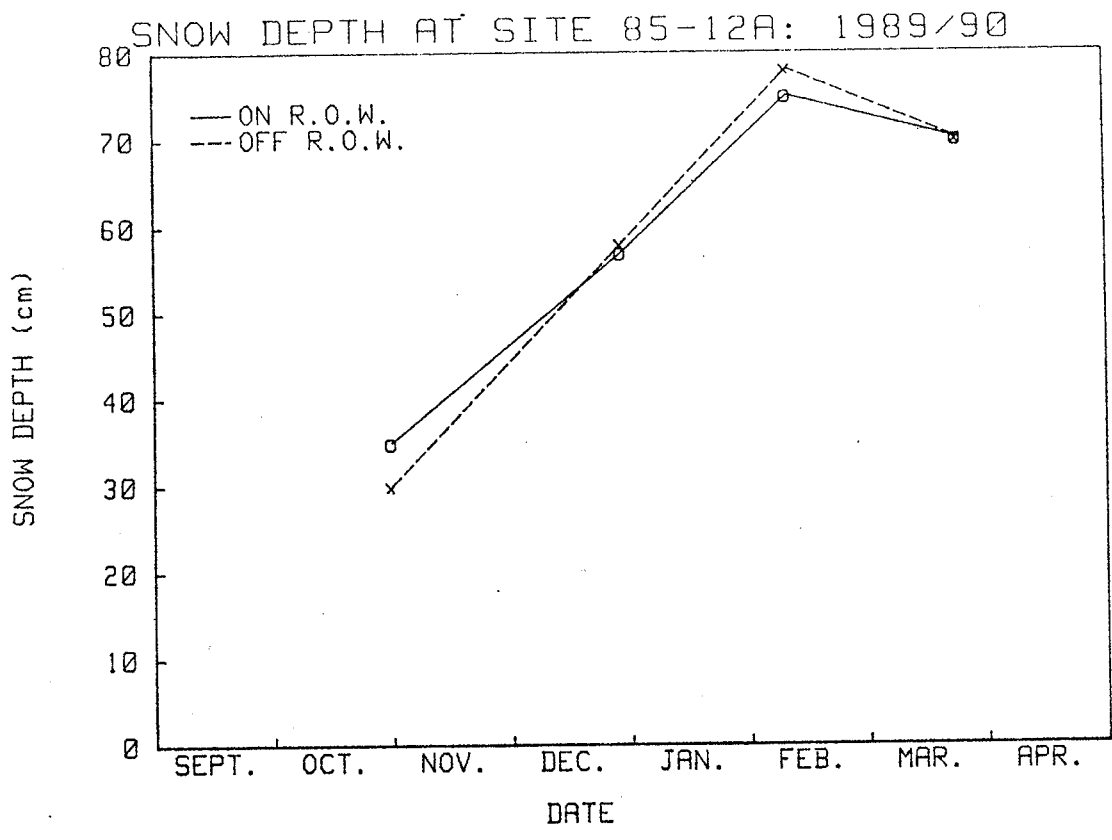


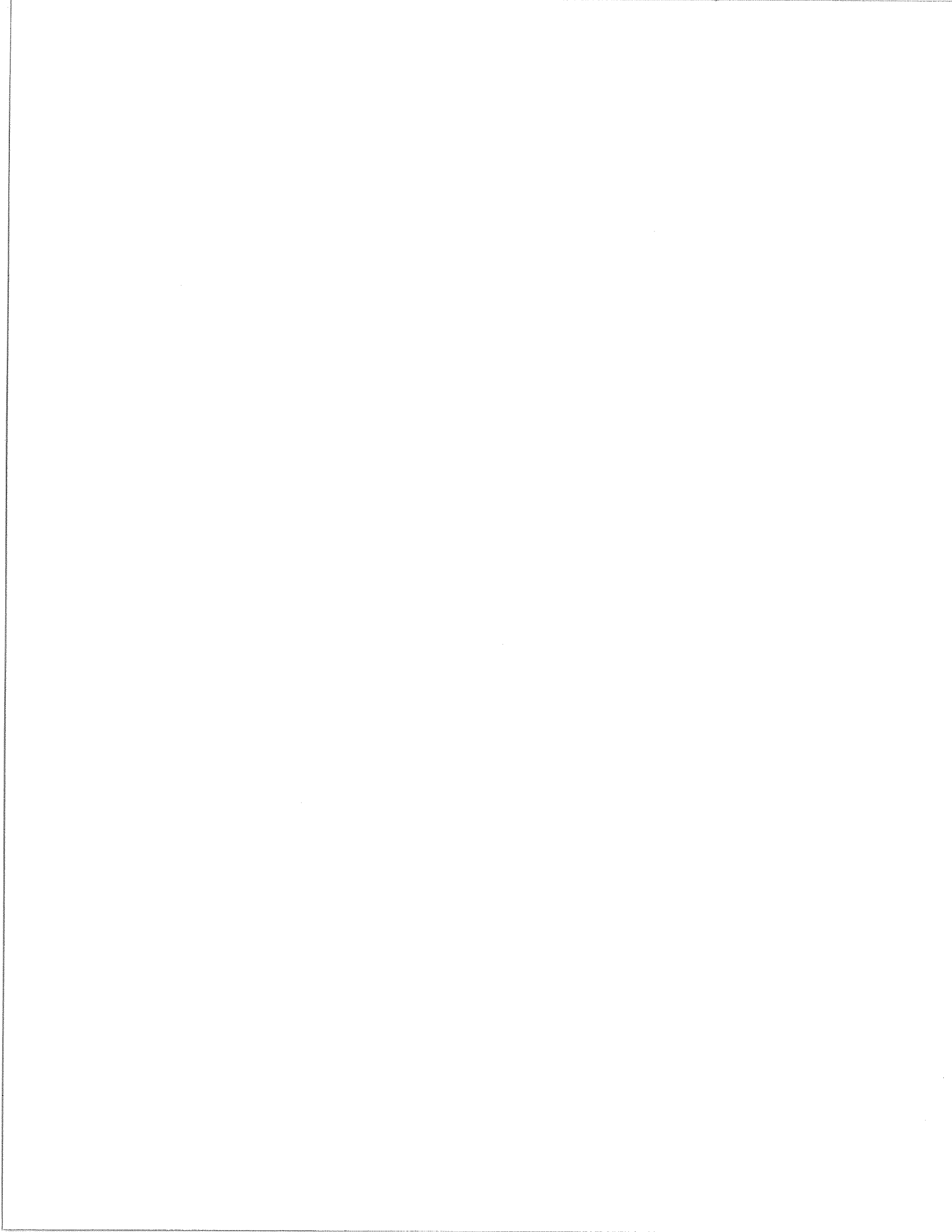
SNOW DEPTH AT SITE 85-10B: 1989/90



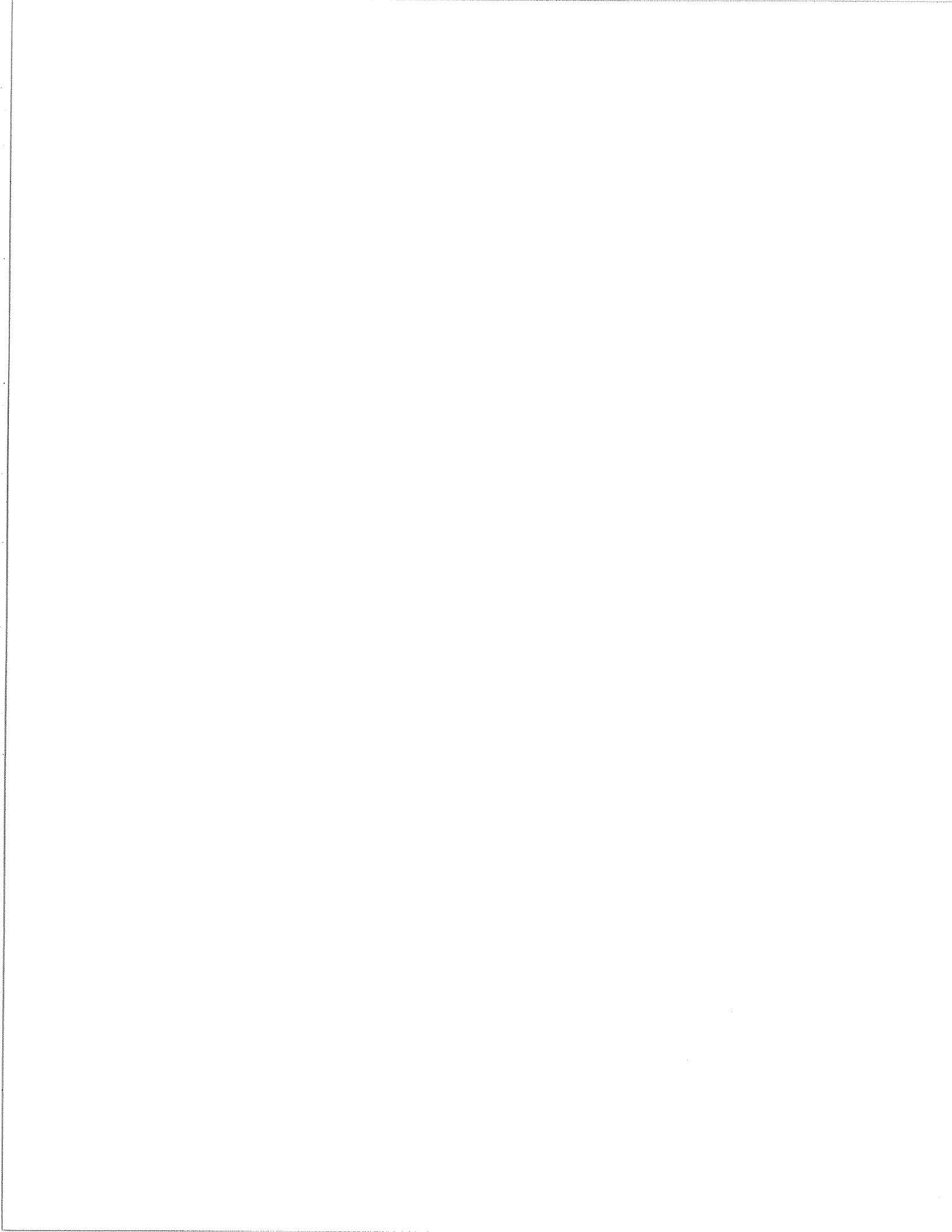
SNOW DEPTH AT SITE 85-11: 1989/90



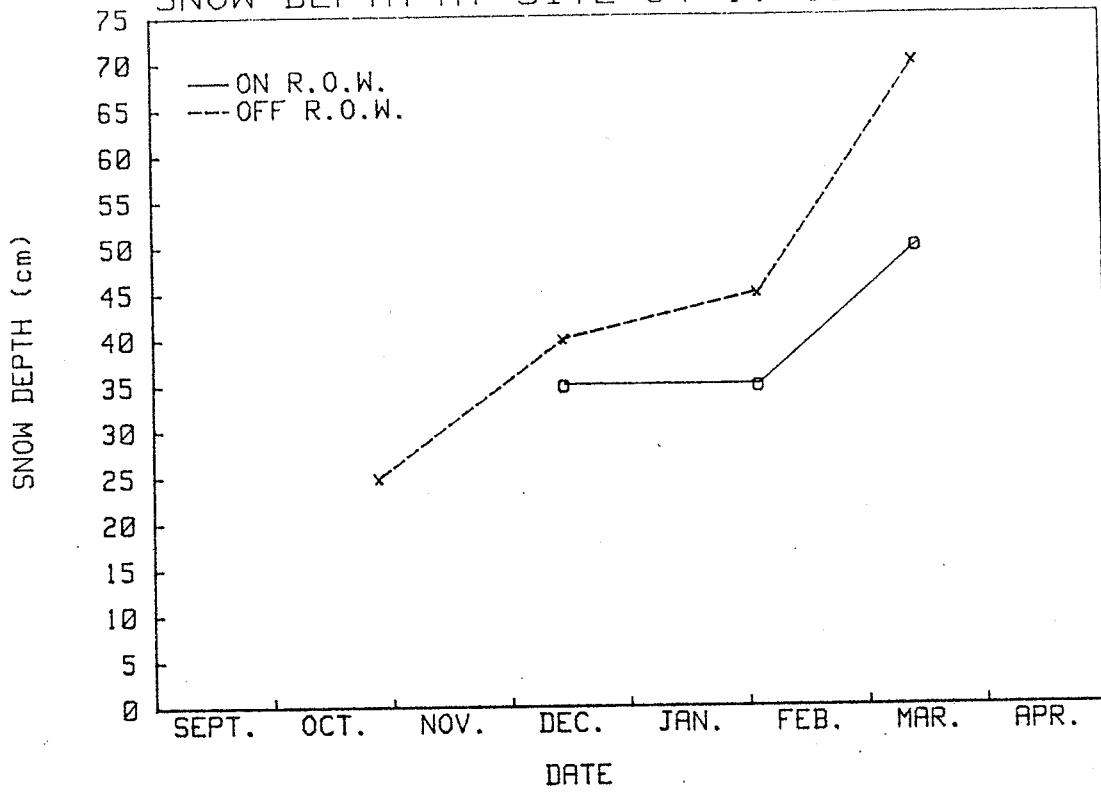




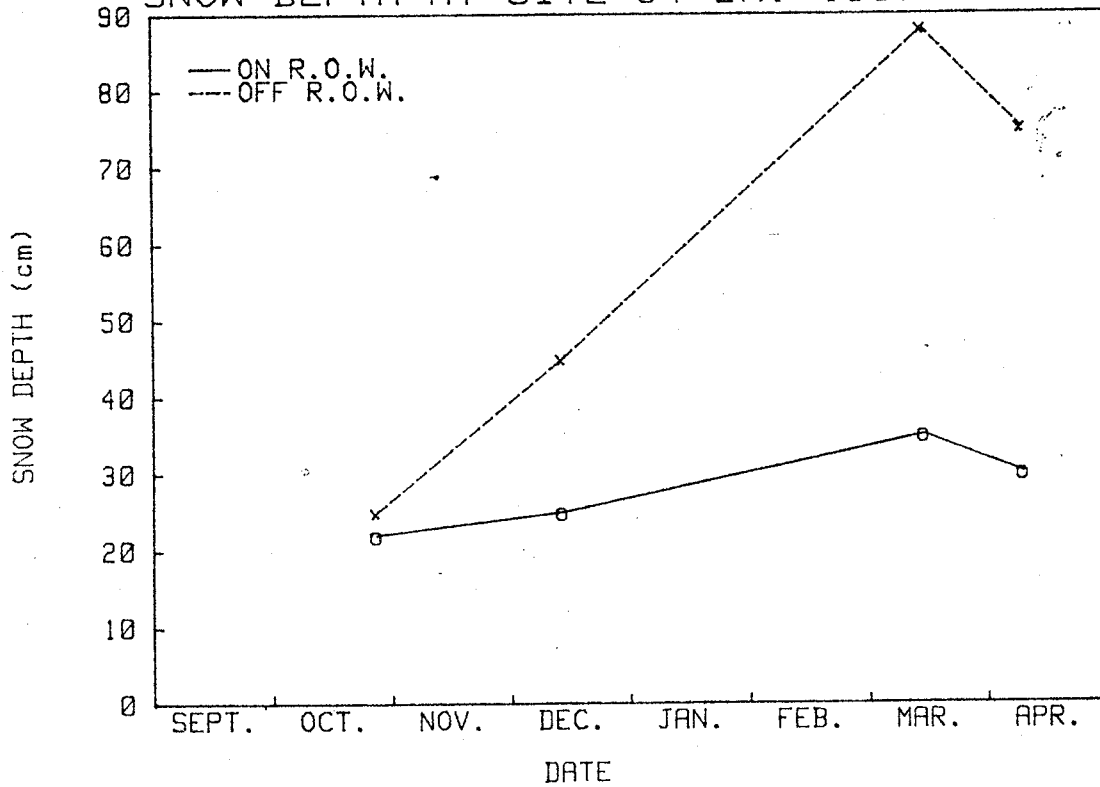
SNOW DEPTH PLOTS - STUDY SITES 1988/1989



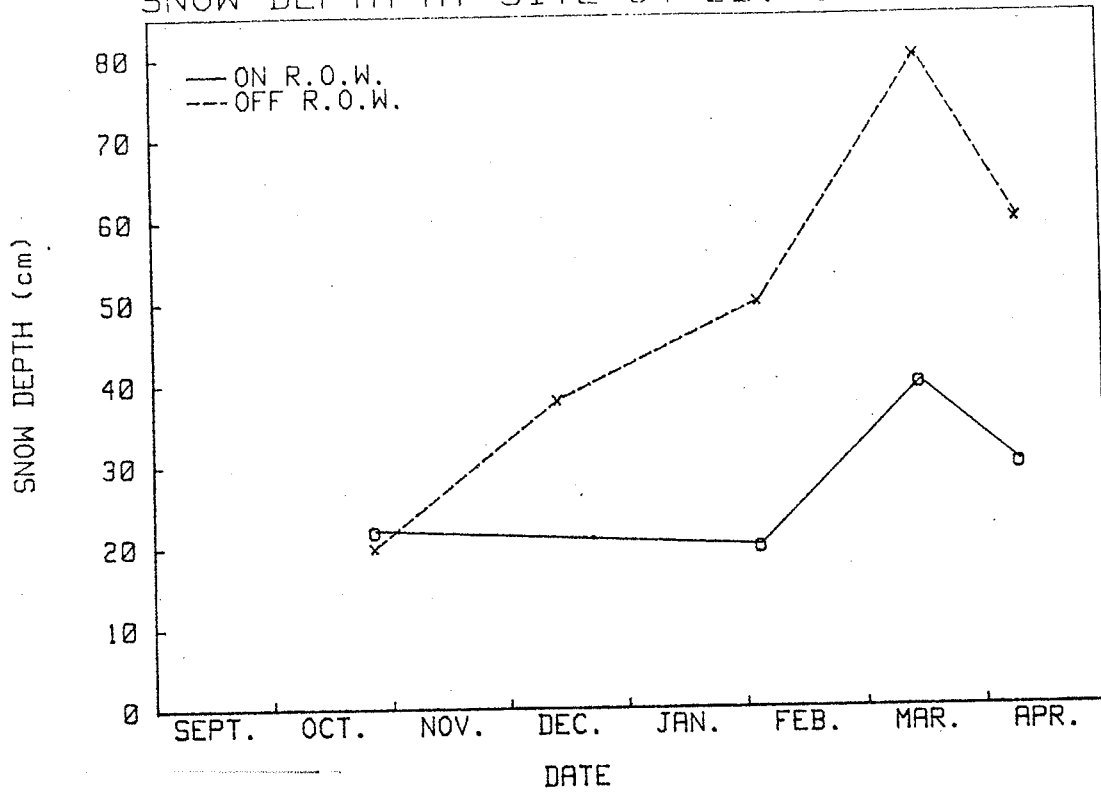
SNOW DEPTH AT SITE 84-1: 1988/89



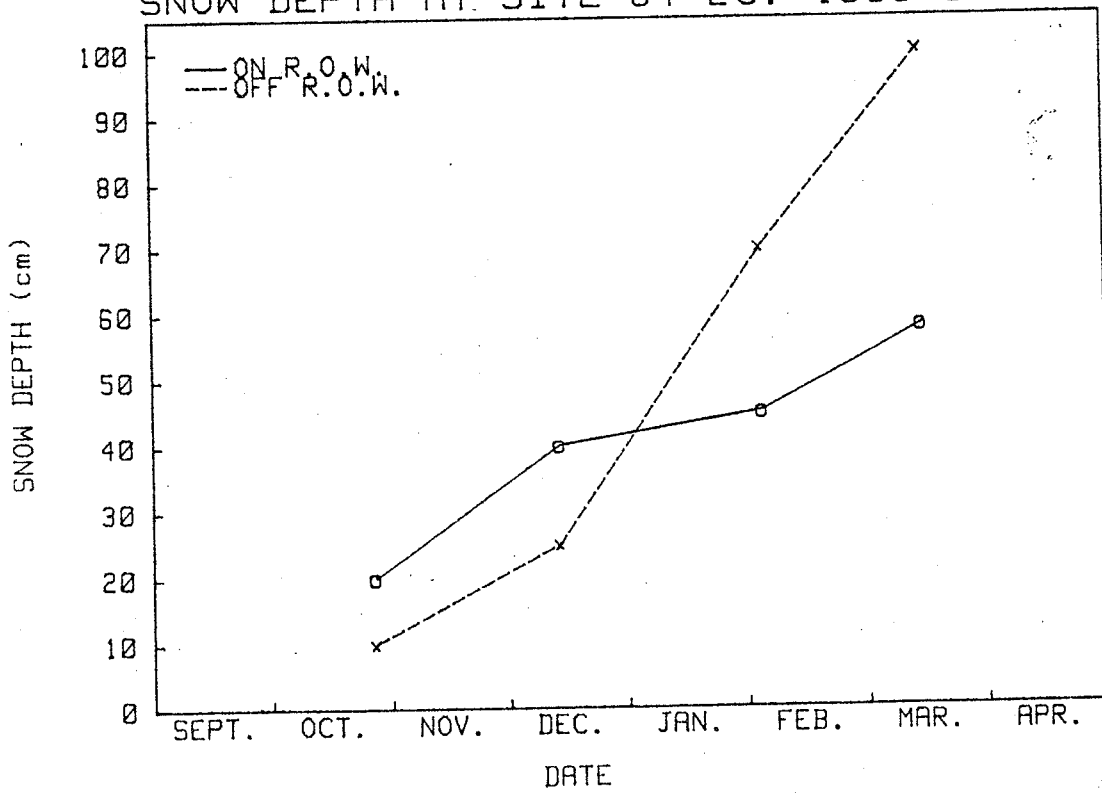
SNOW DEPTH AT SITE 84-2A: 1988/89



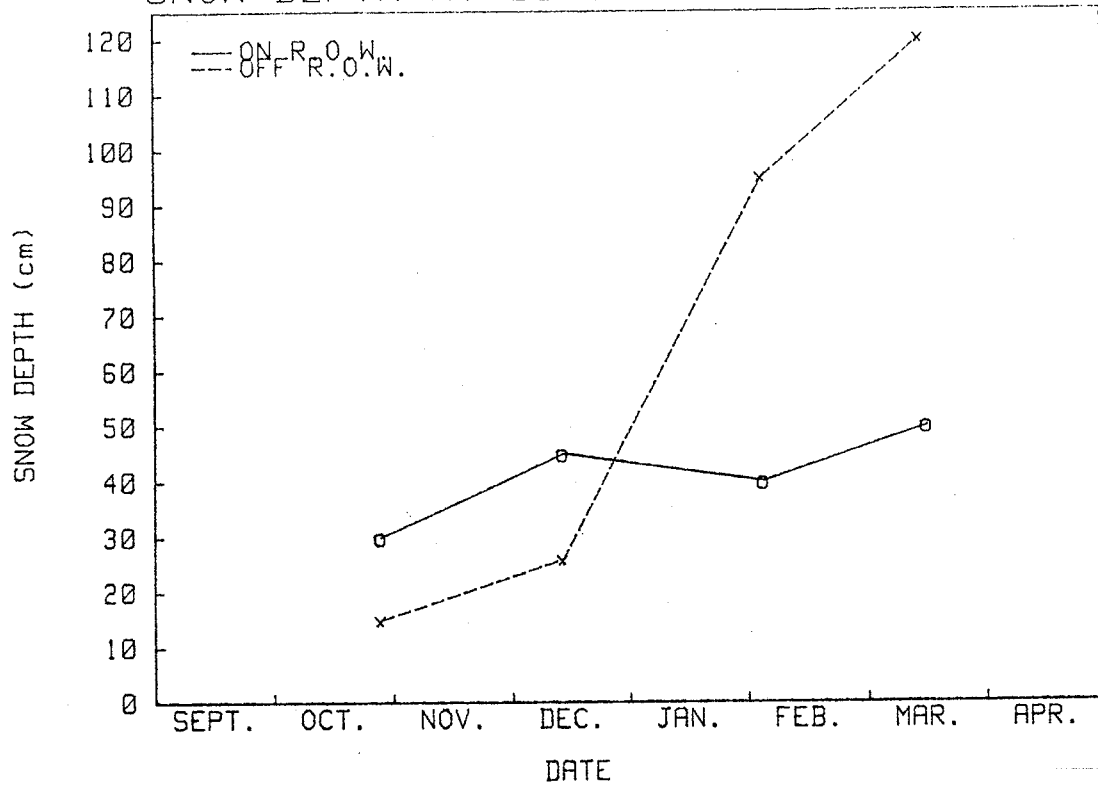
SNOW DEPTH AT SITE 84-2B: 1988/89



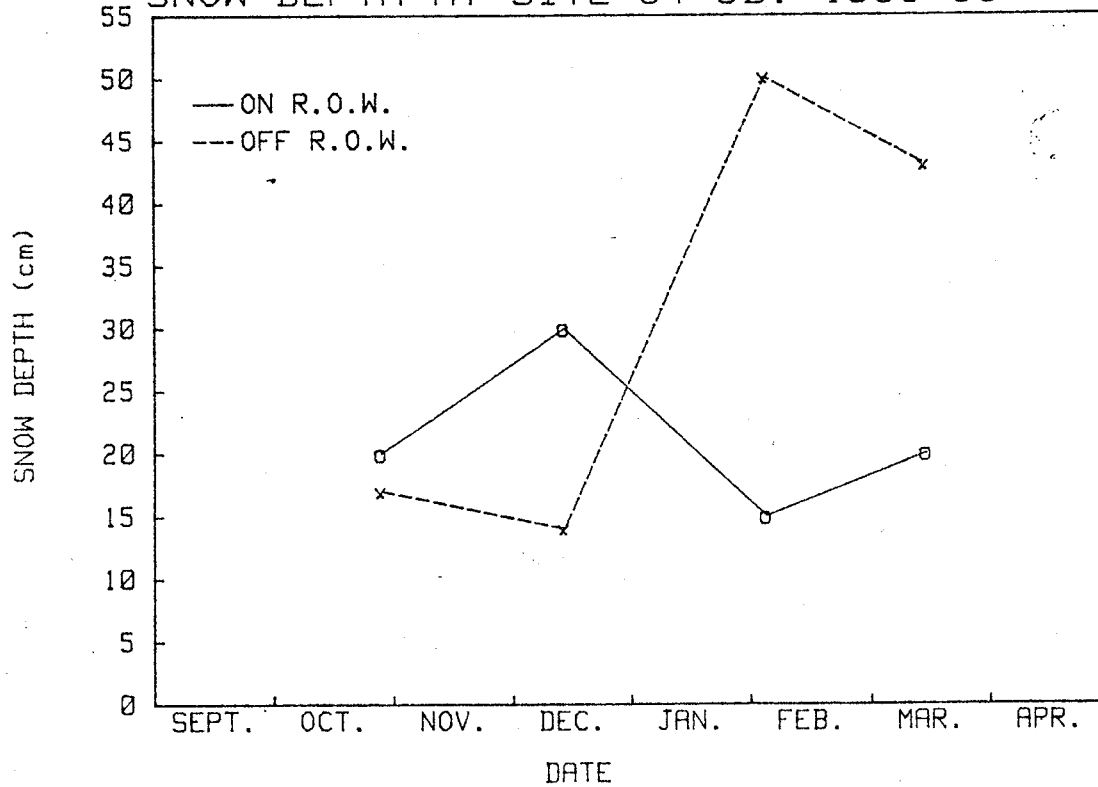
SNOW DEPTH AT SITE 84-2C: 1988/89

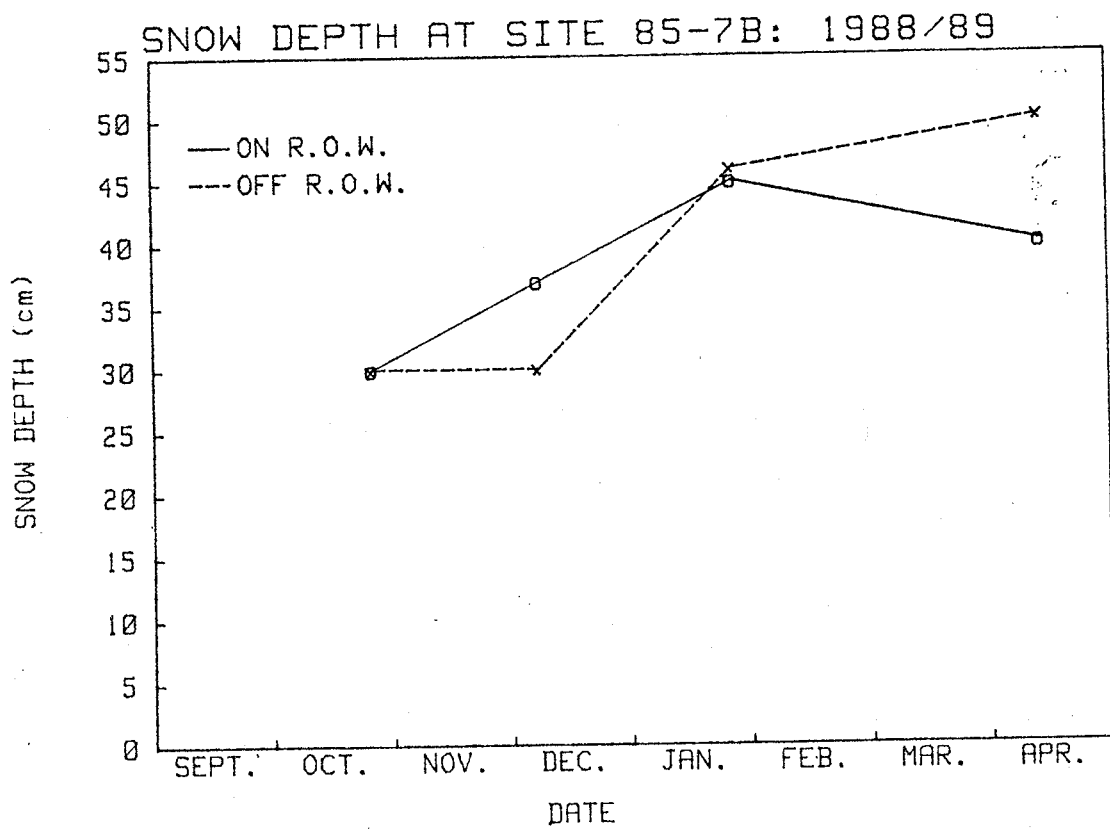
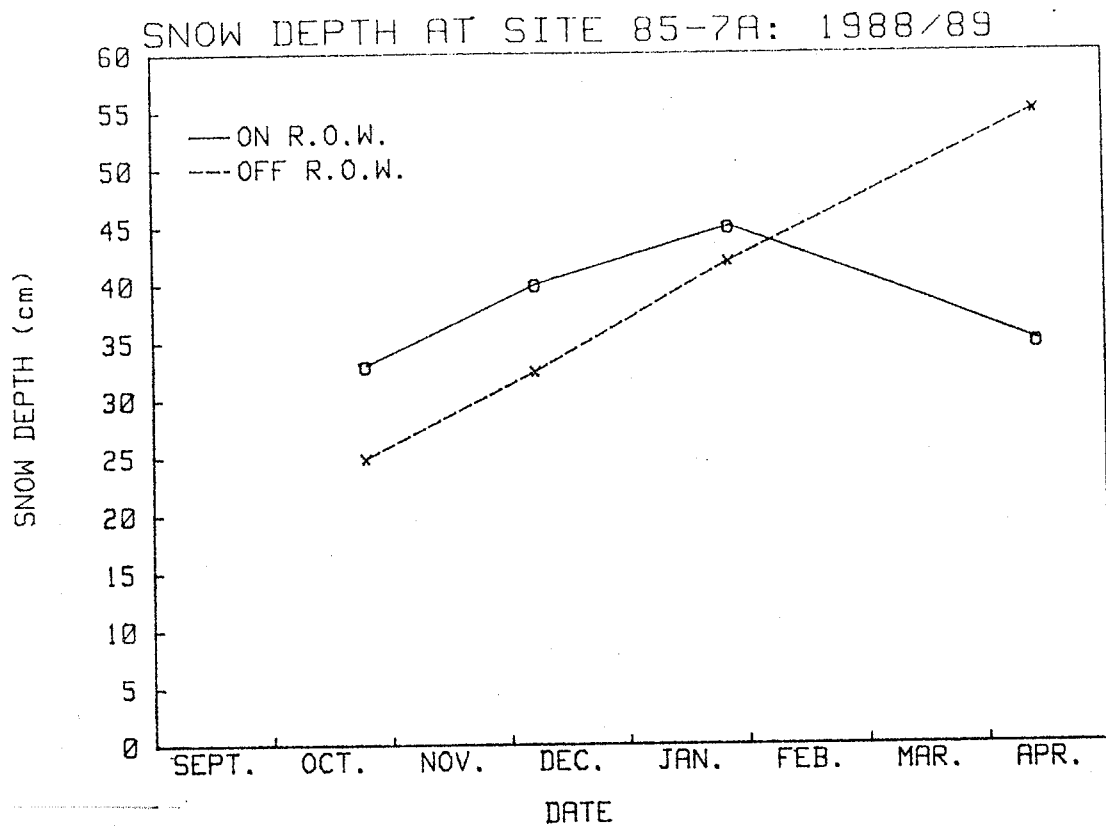


SNOW DEPTH AT SITE 84-3A: 1988/89

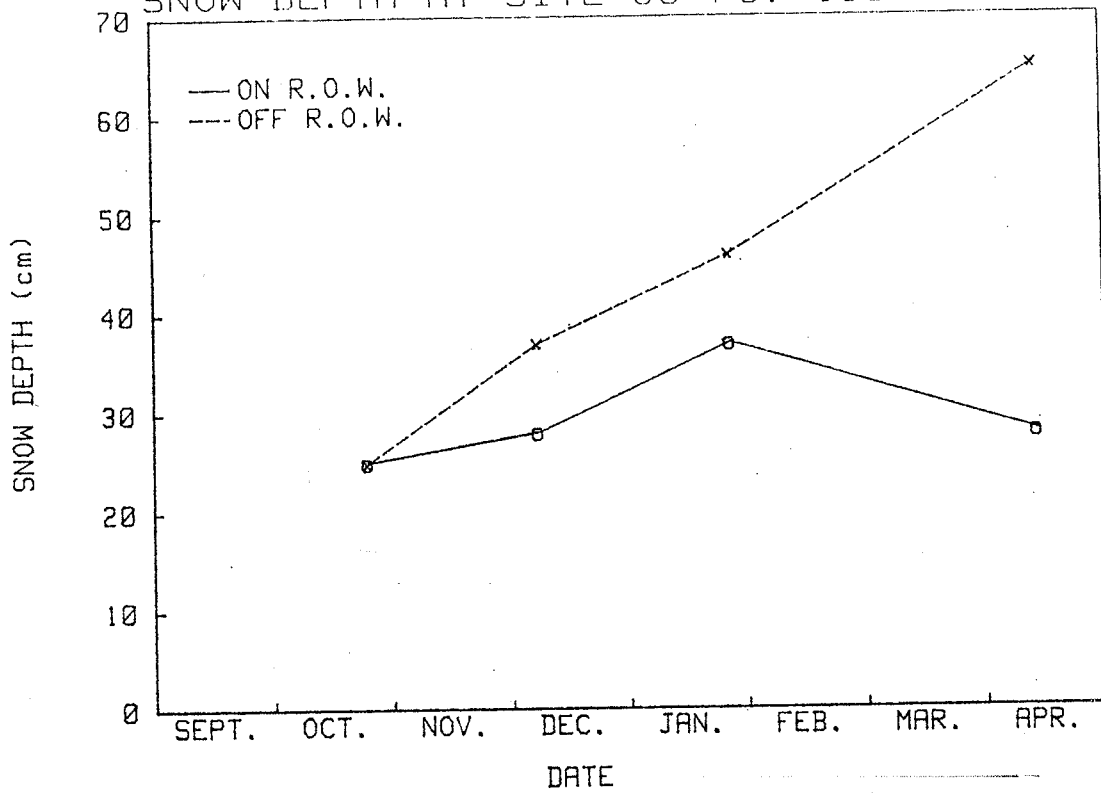


SNOW DEPTH AT SITE 84-3B: 1988/89

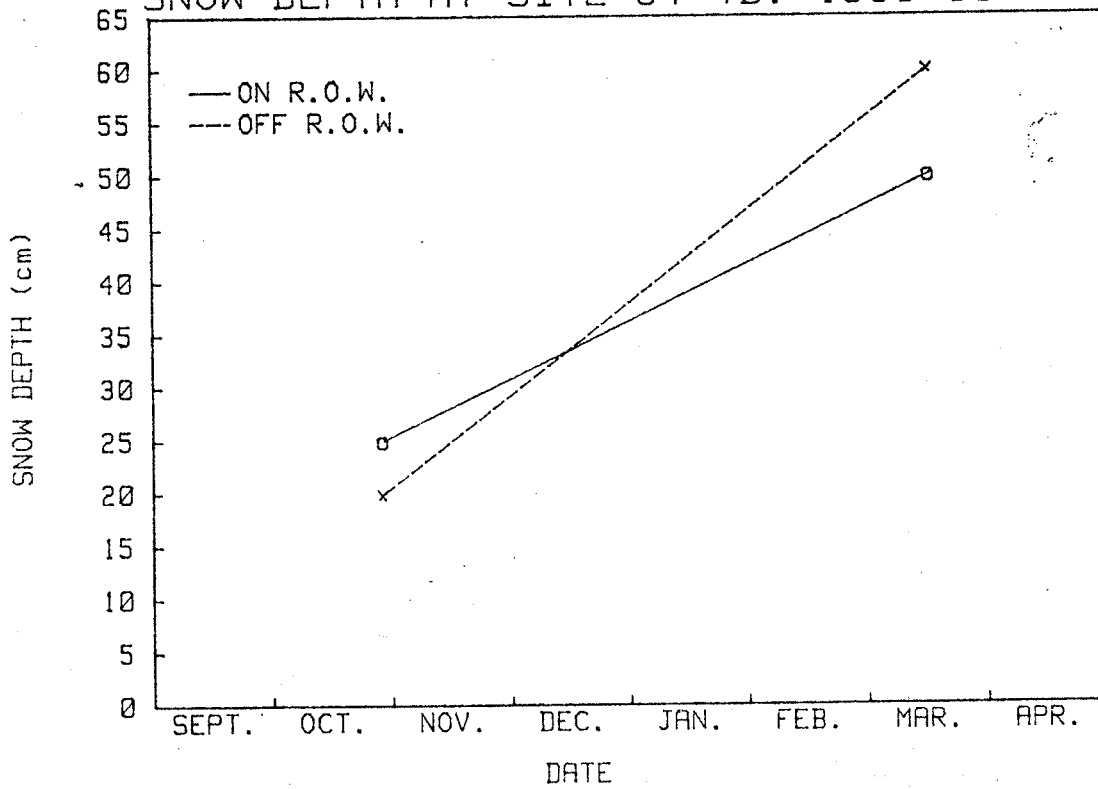




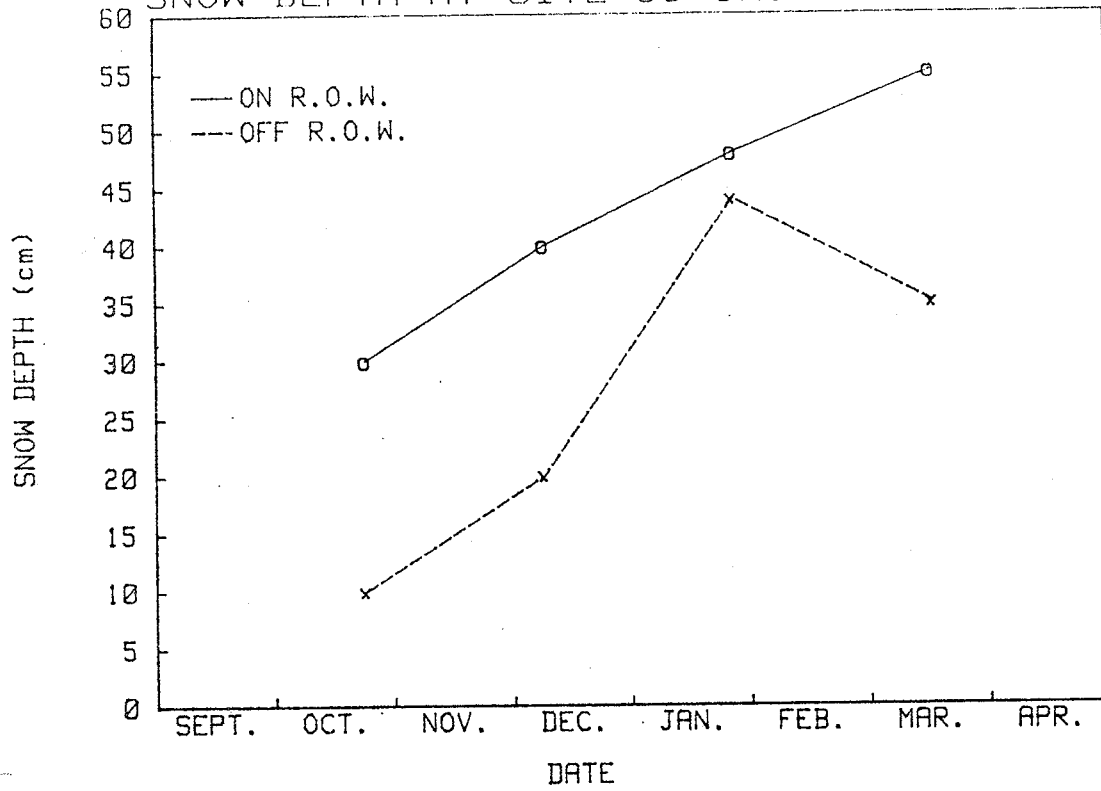
SNOW DEPTH AT SITE 85-7C: 1988/89



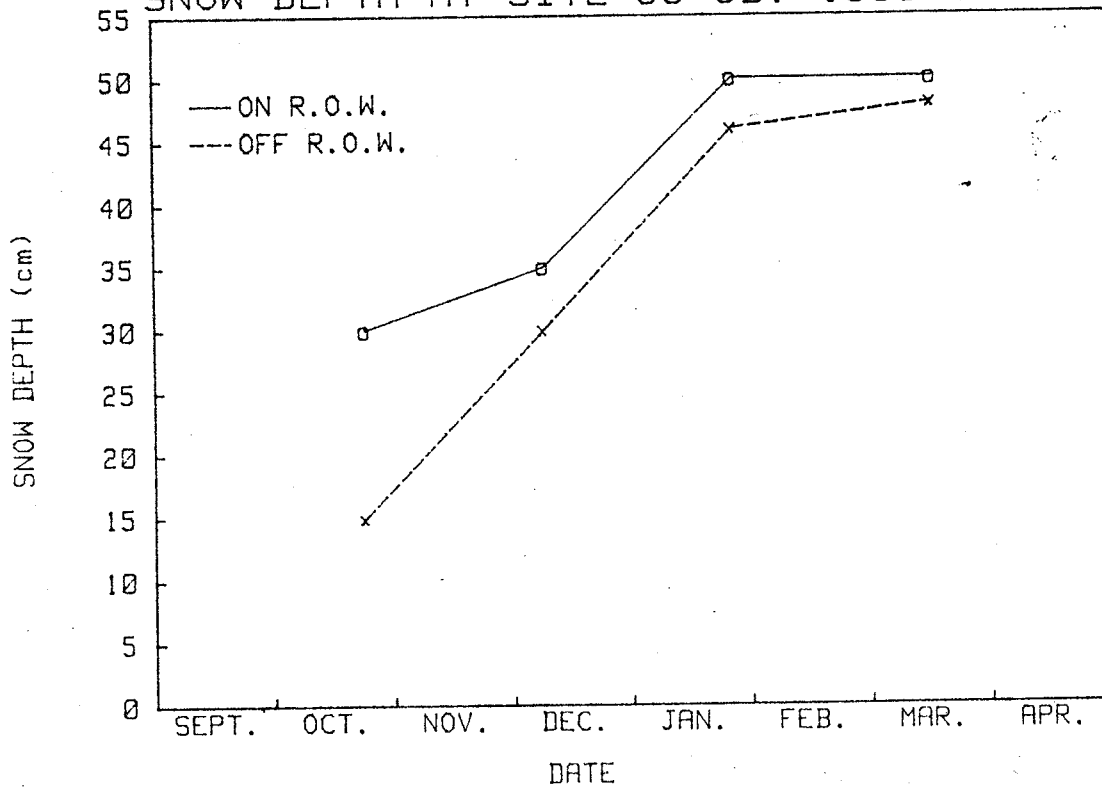
SNOW DEPTH AT SITE 84-4B: 1988/89



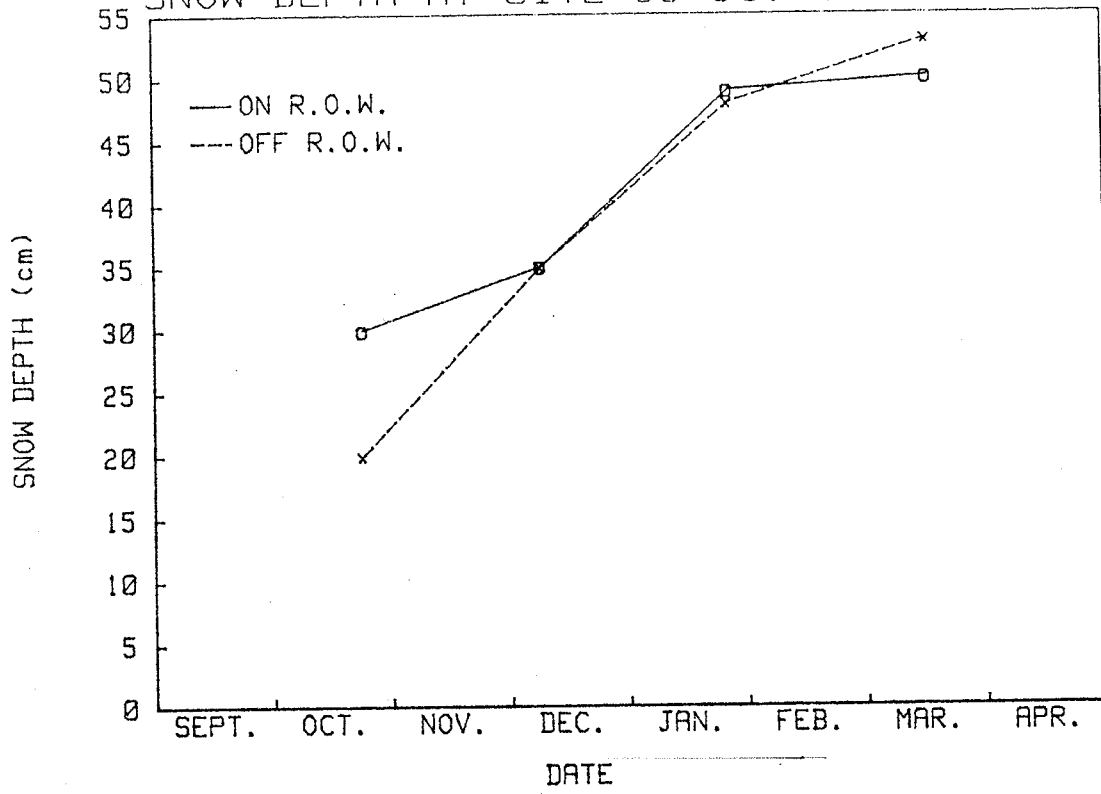
SNOW DEPTH AT SITE 85-8A: 1988/89



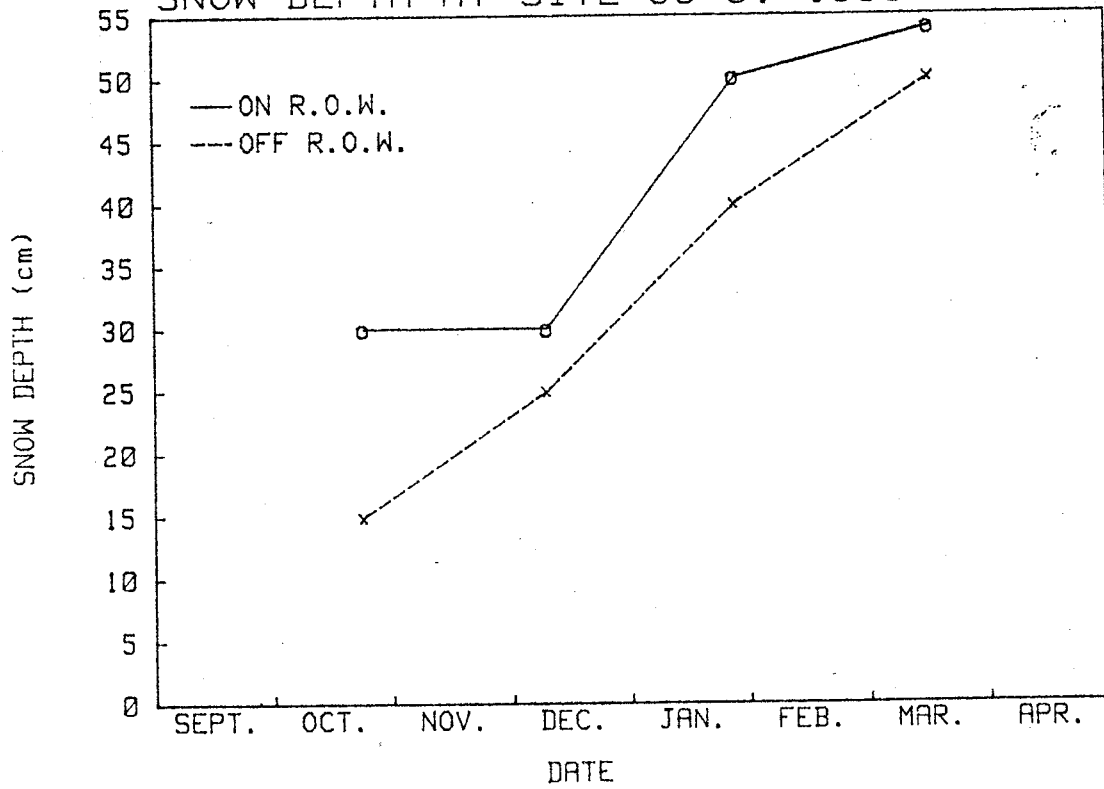
SNOW DEPTH AT SITE 85-8B: 1988/89



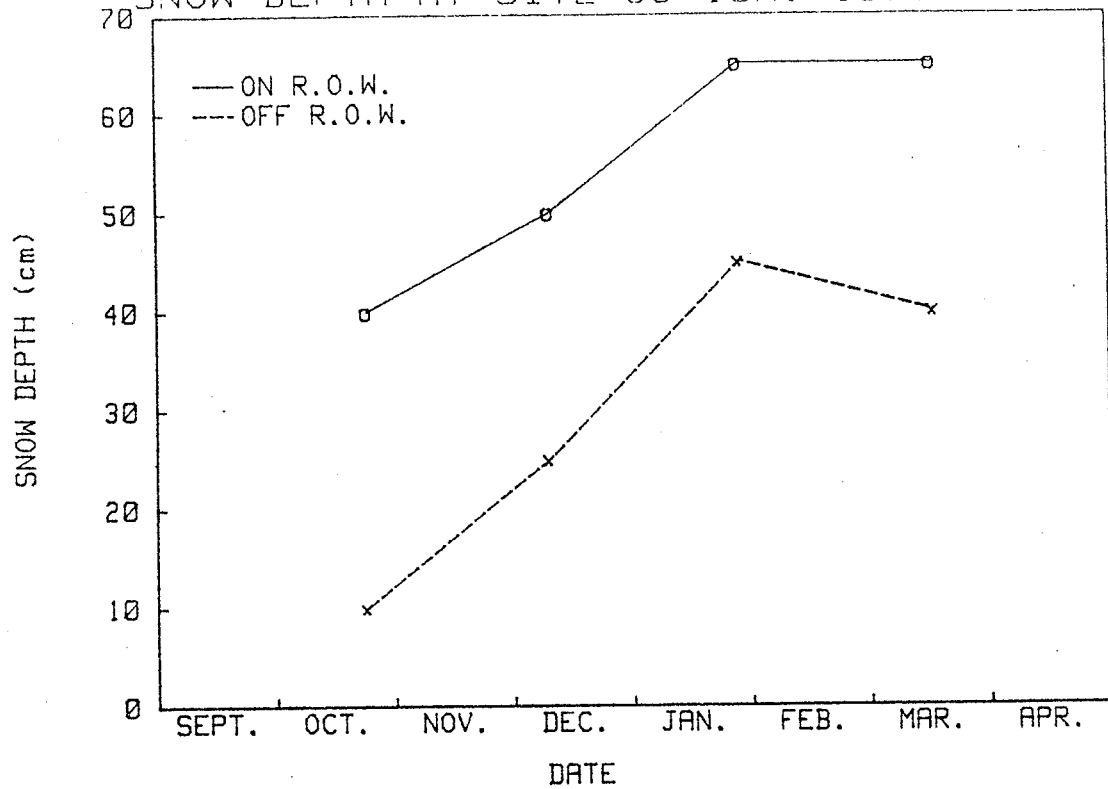
SNOW DEPTH AT SITE 85-8C: 1988/89



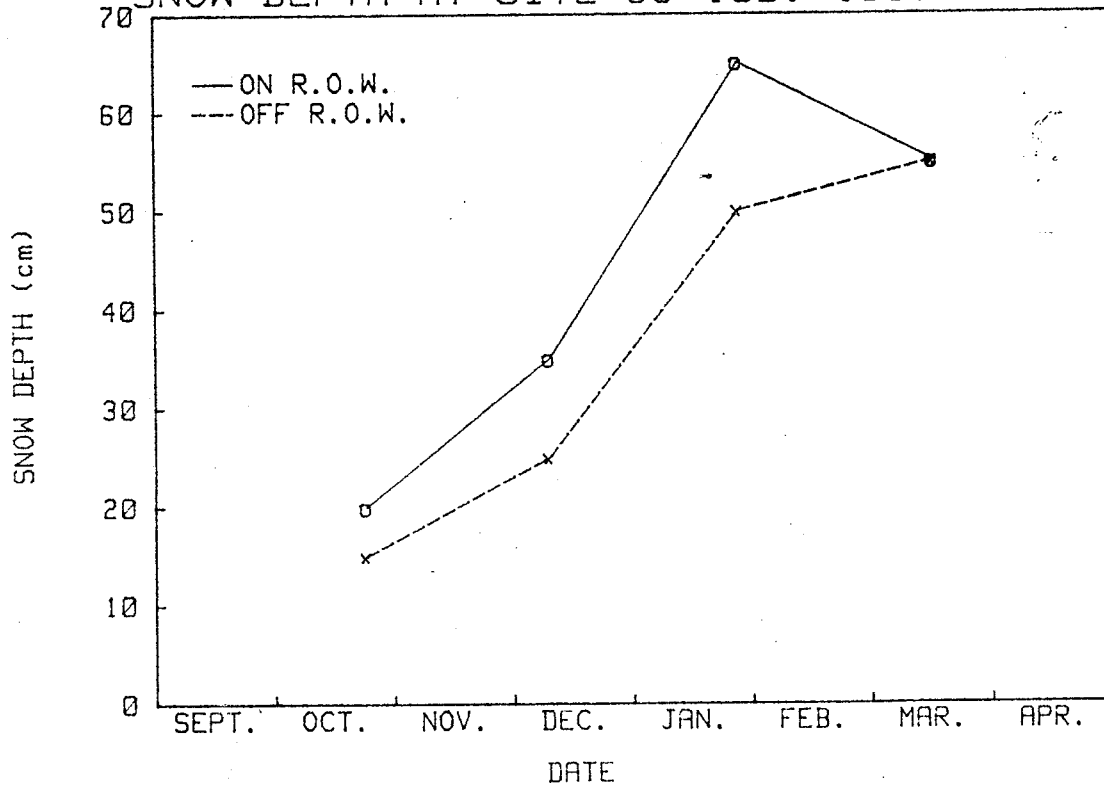
SNOW DEPTH AT SITE 85-9: 1988/89



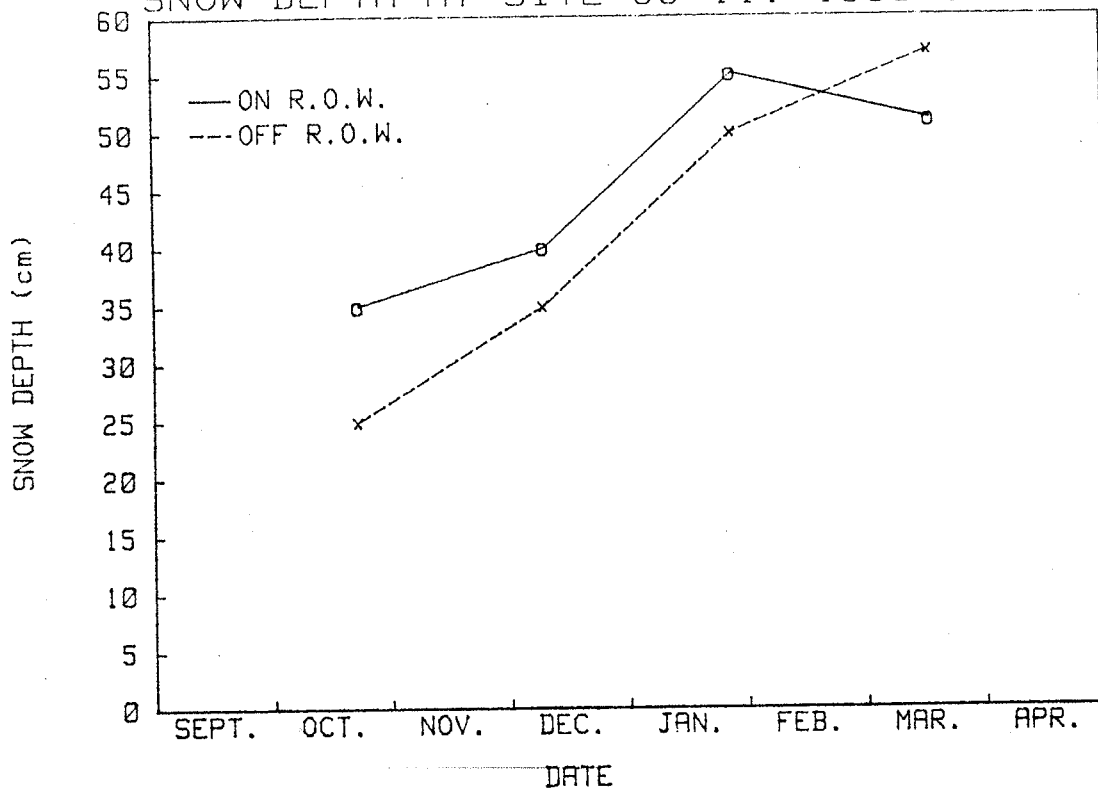
SNOW DEPTH AT SITE 85-10A: 1988/89



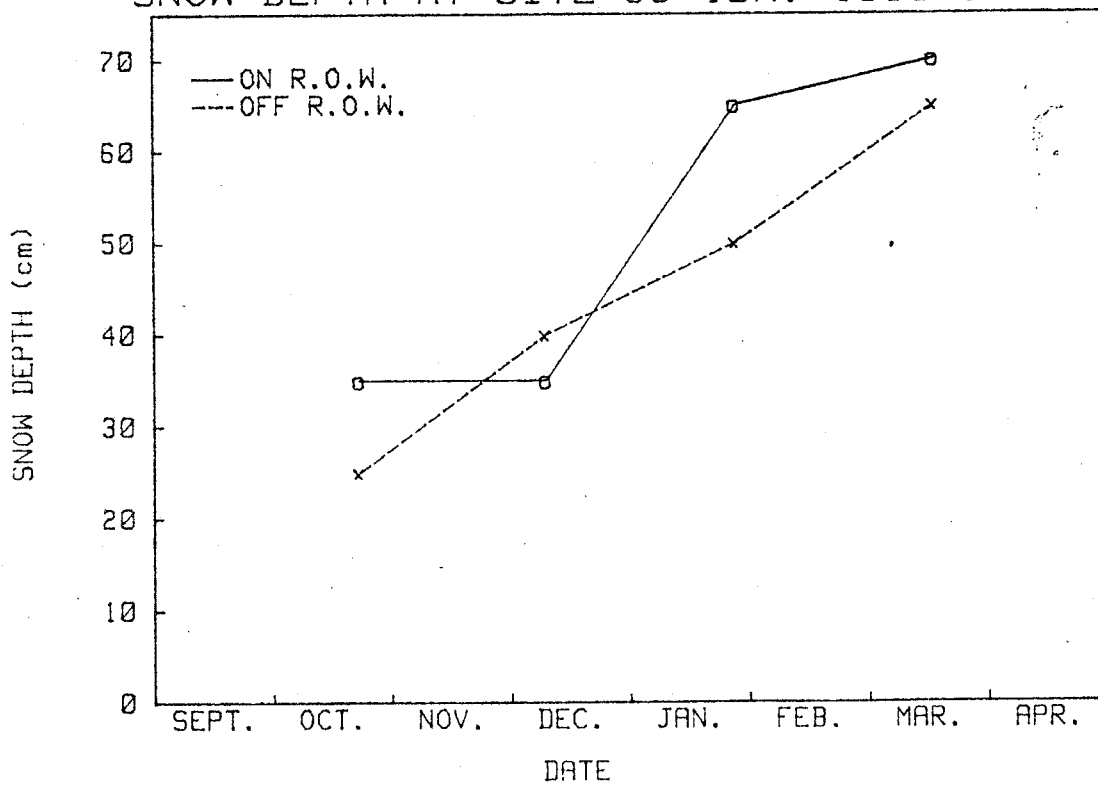
SNOW DEPTH AT SITE 85-10B: 1988/89



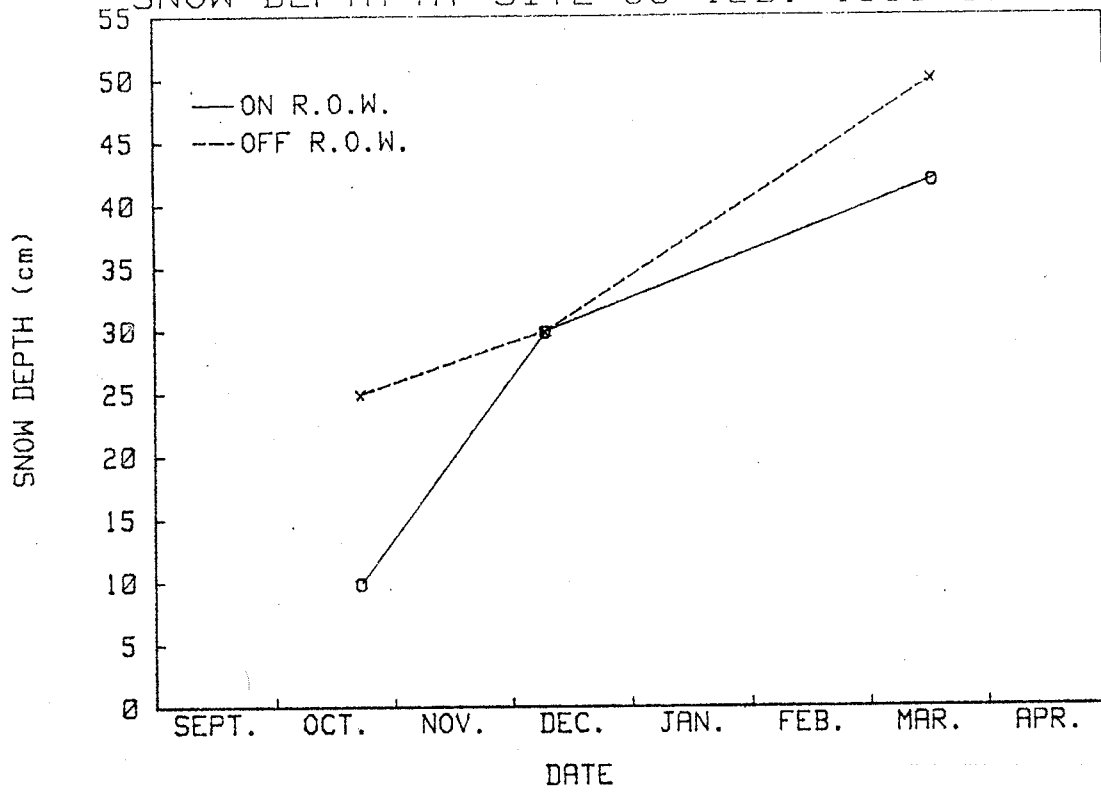
SNOW DEPTH AT SITE 85-11: 1988/89



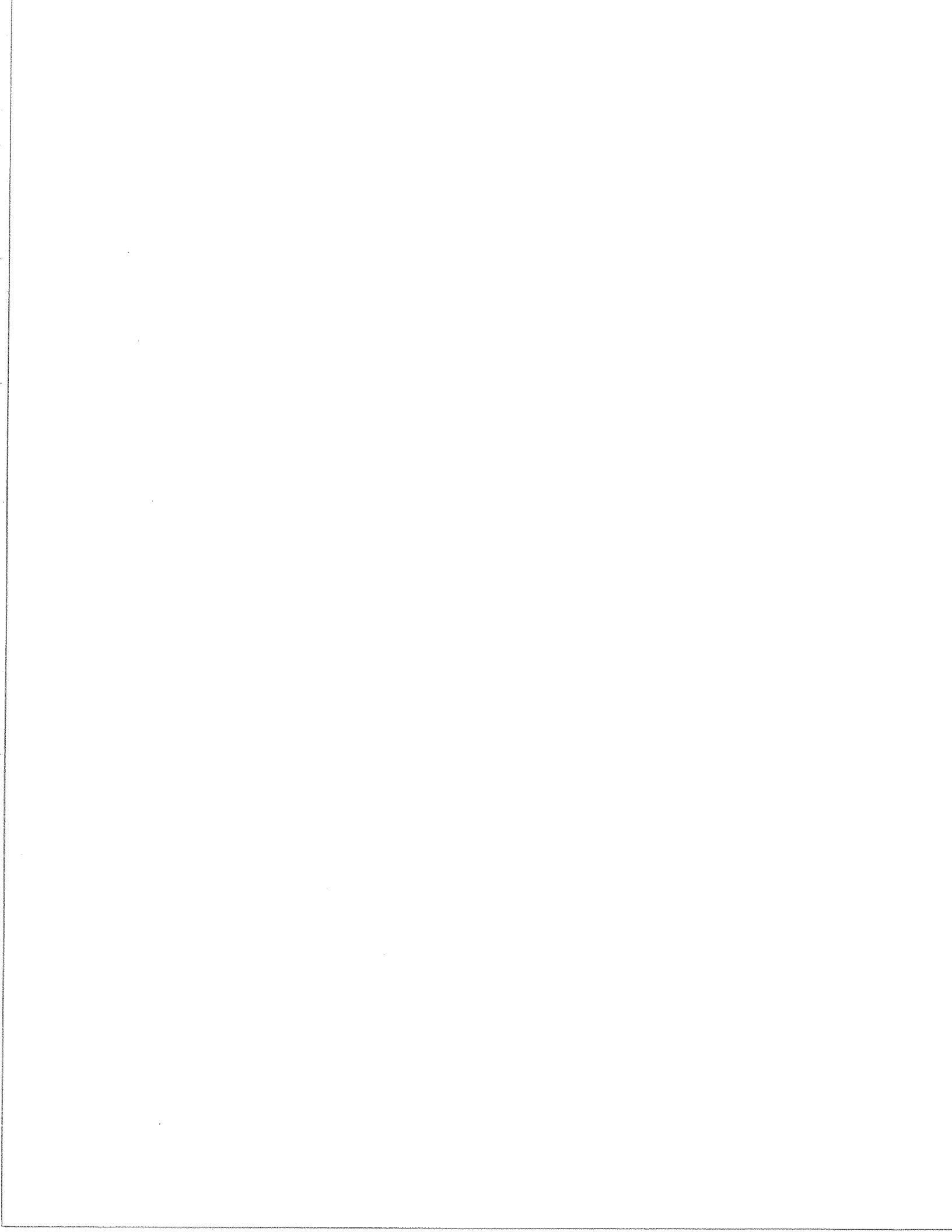
SNOW DEPTH AT SITE 85-12A: 1988/89

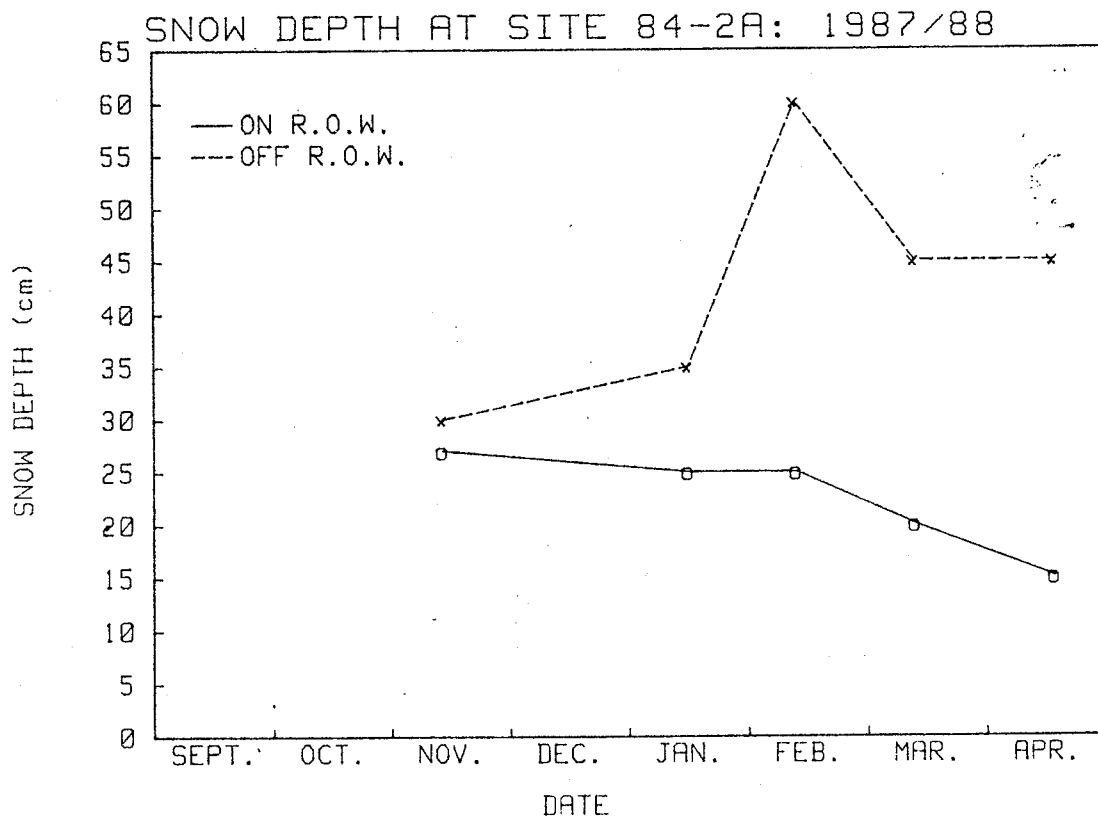
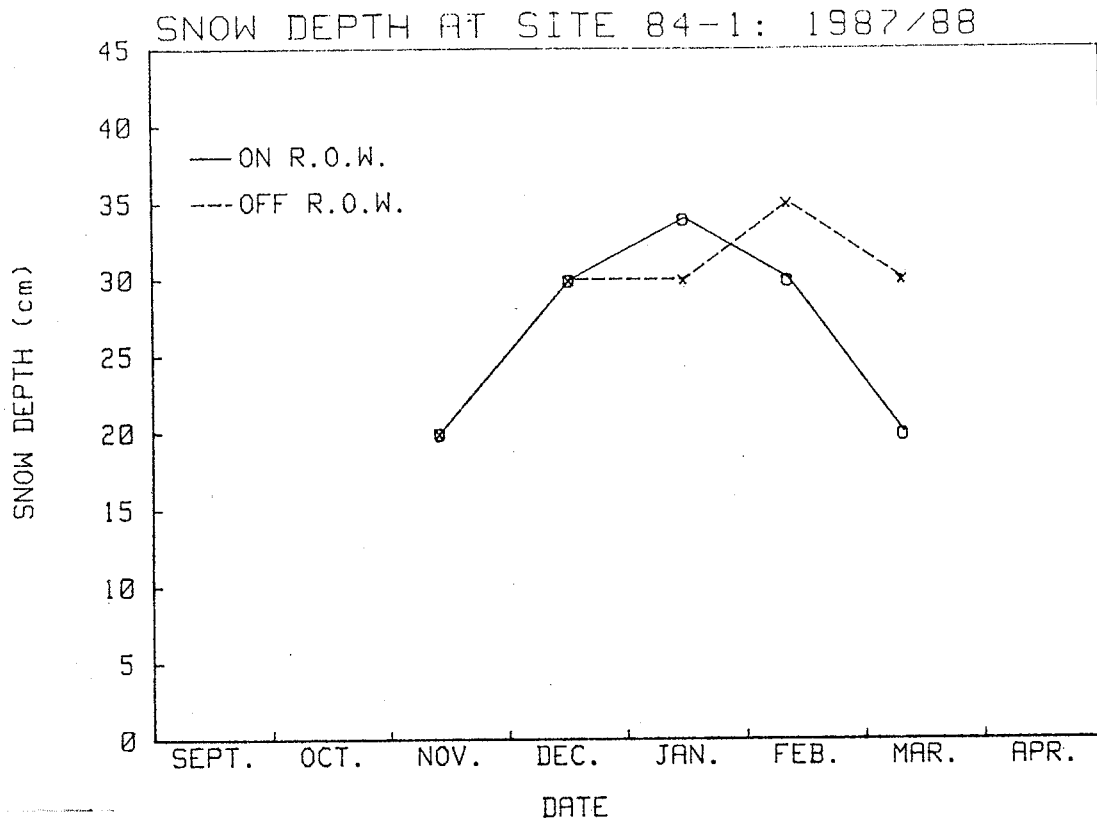


SNOW DEPTH AT SITE 85-12B: 1988/89

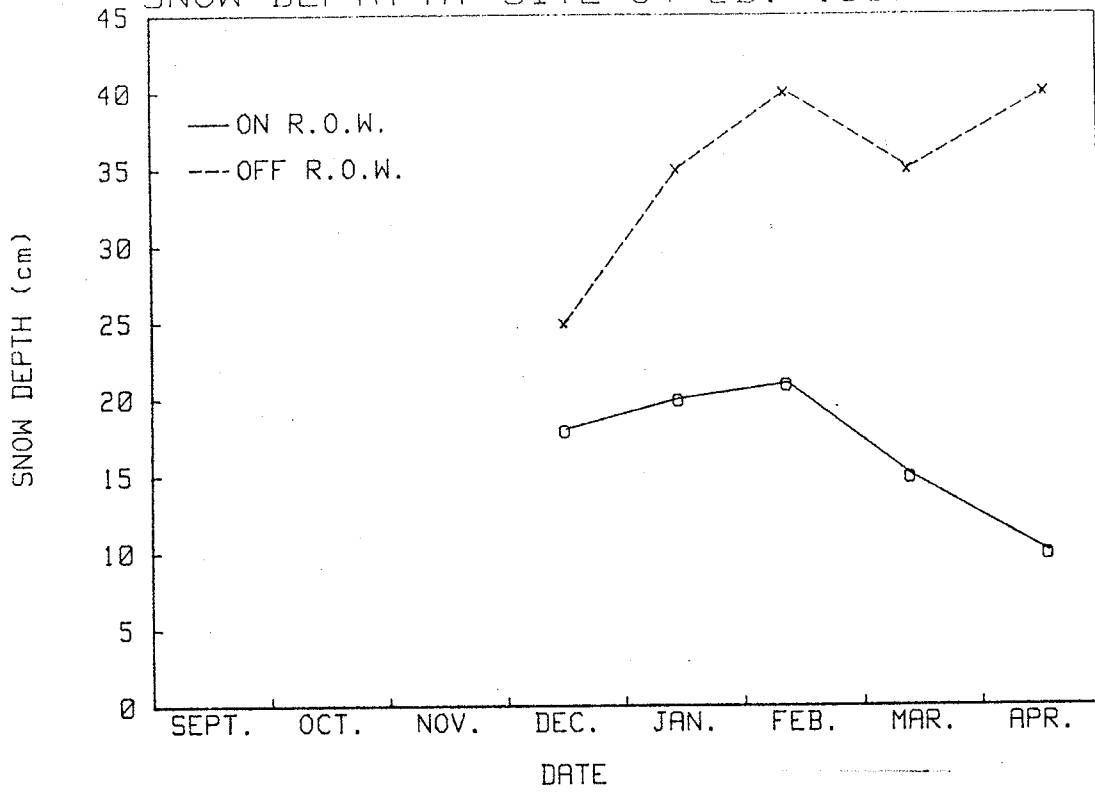


SNOW DEPTH PLOTS - STUDY SITES 1987/1988

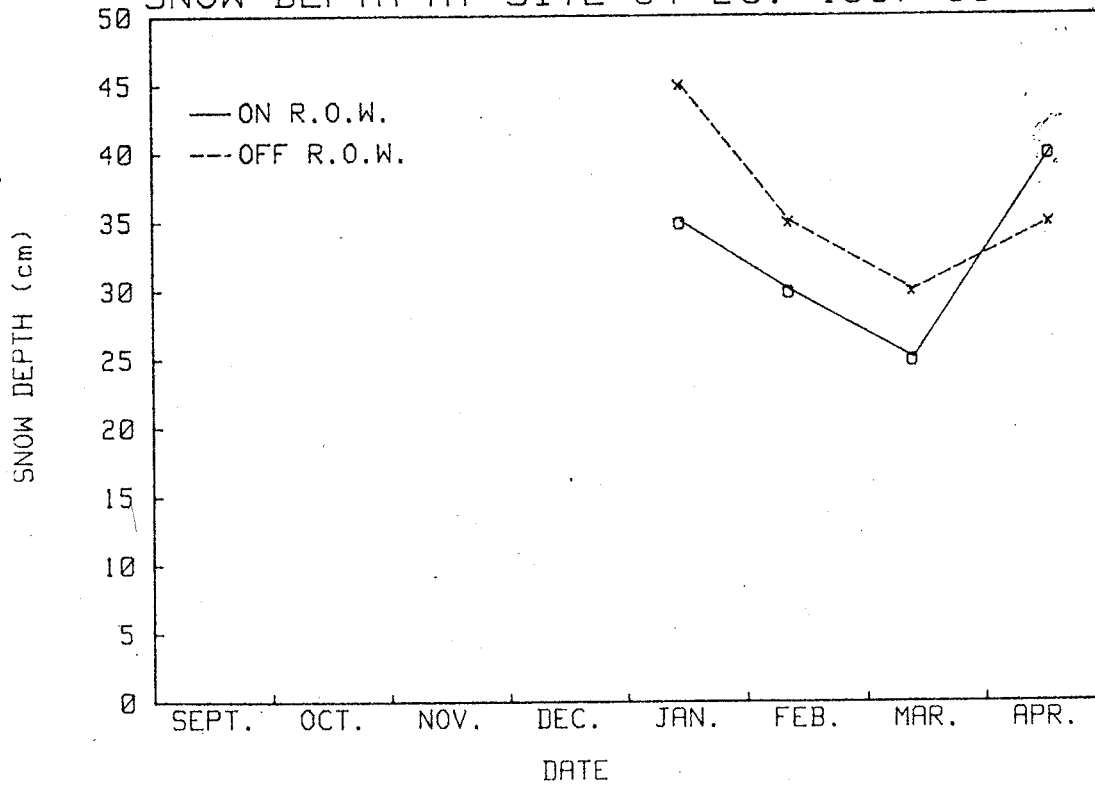




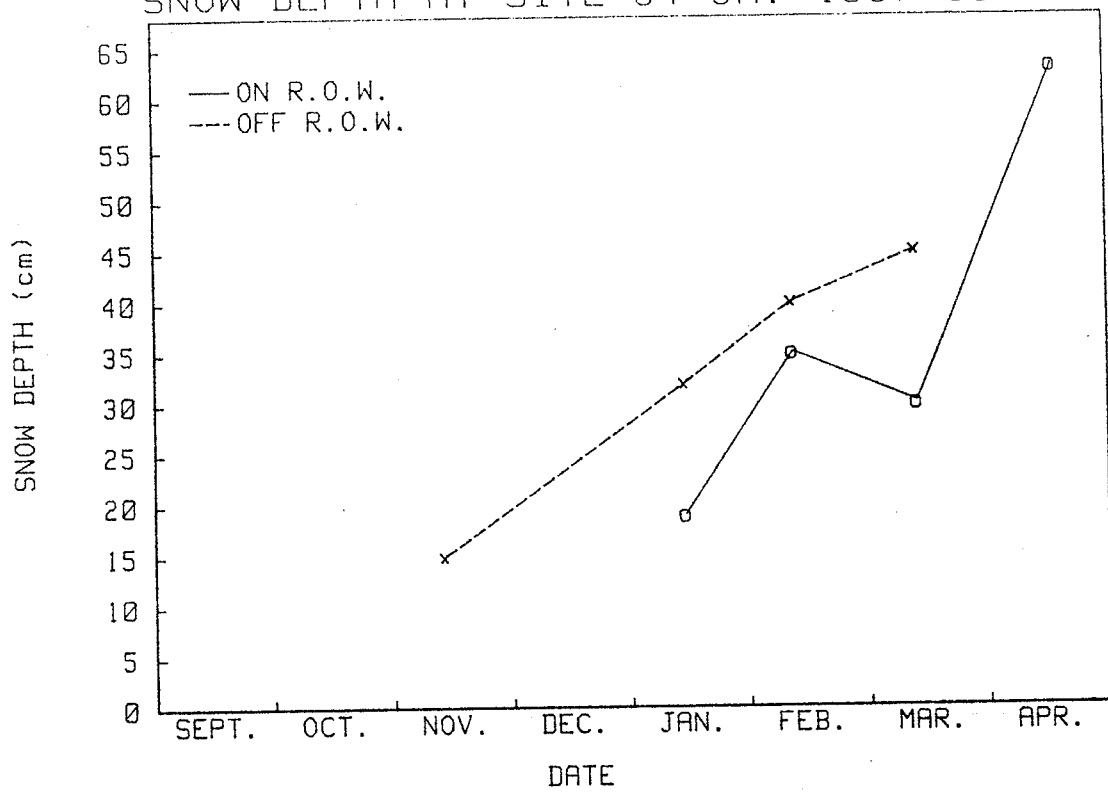
SNOW DEPTH AT SITE 84-2B: 1987/88



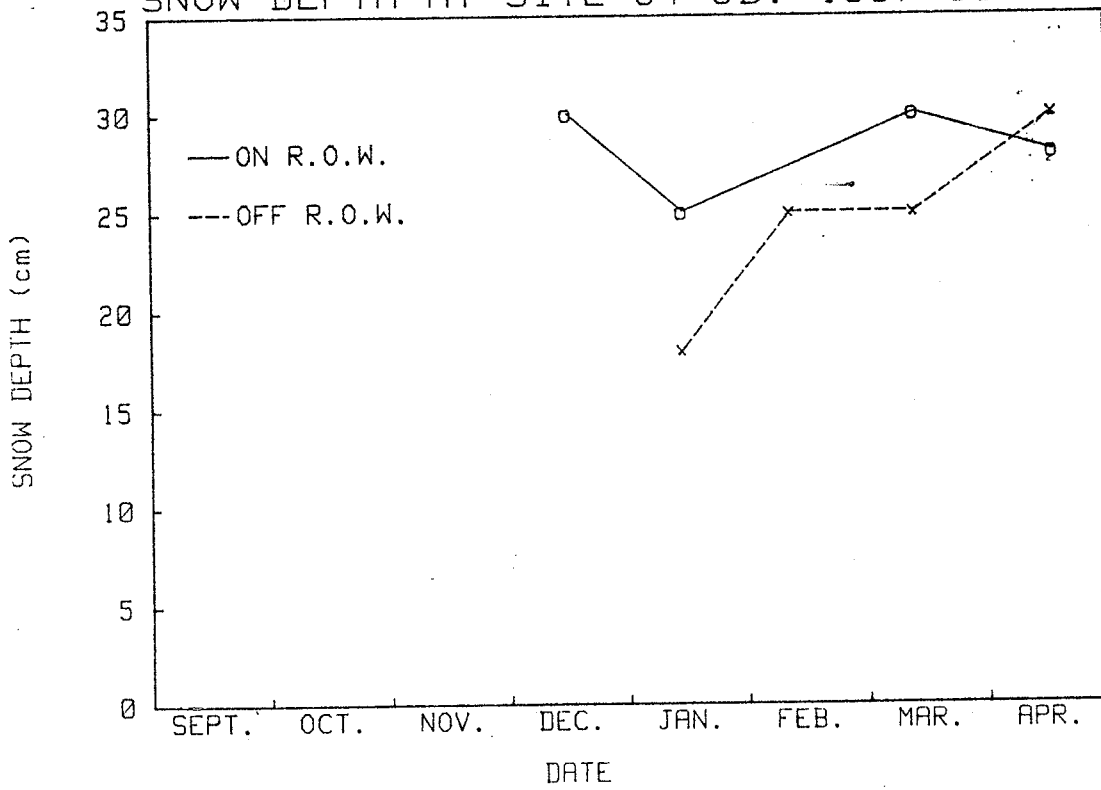
SNOW DEPTH AT SITE 84-2C: 1987/88



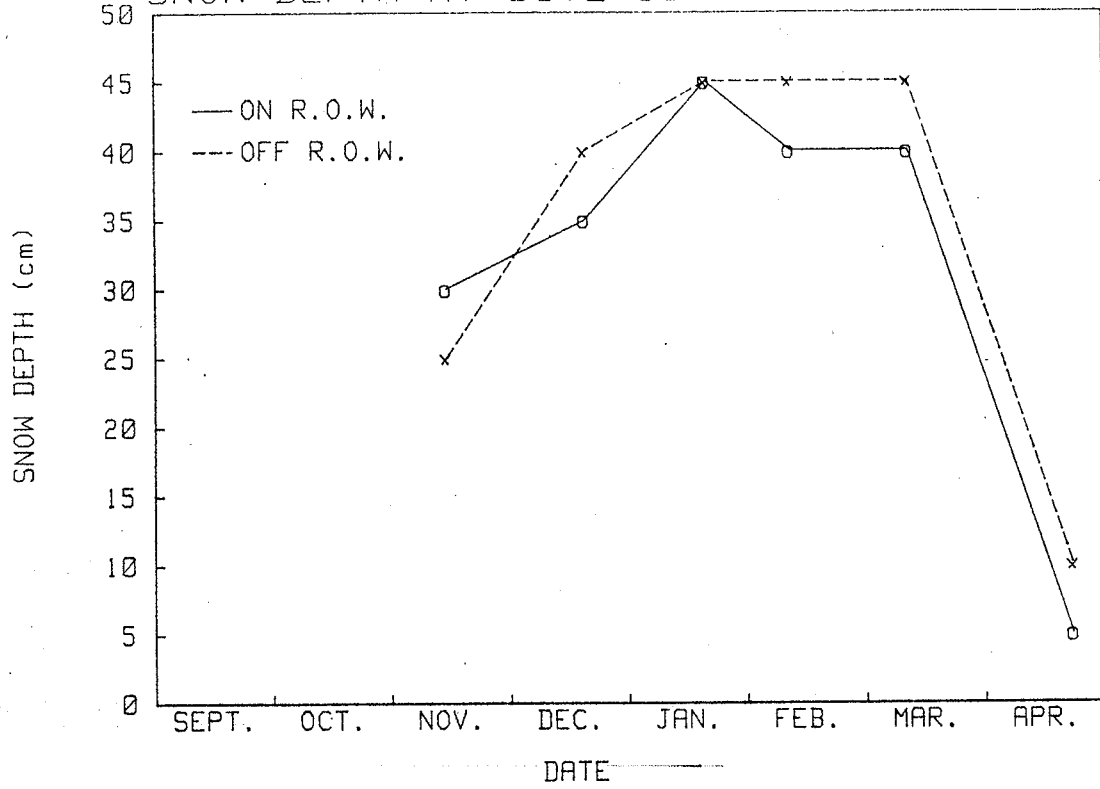
SNOW DEPTH AT SITE 84-3A: 1987/88



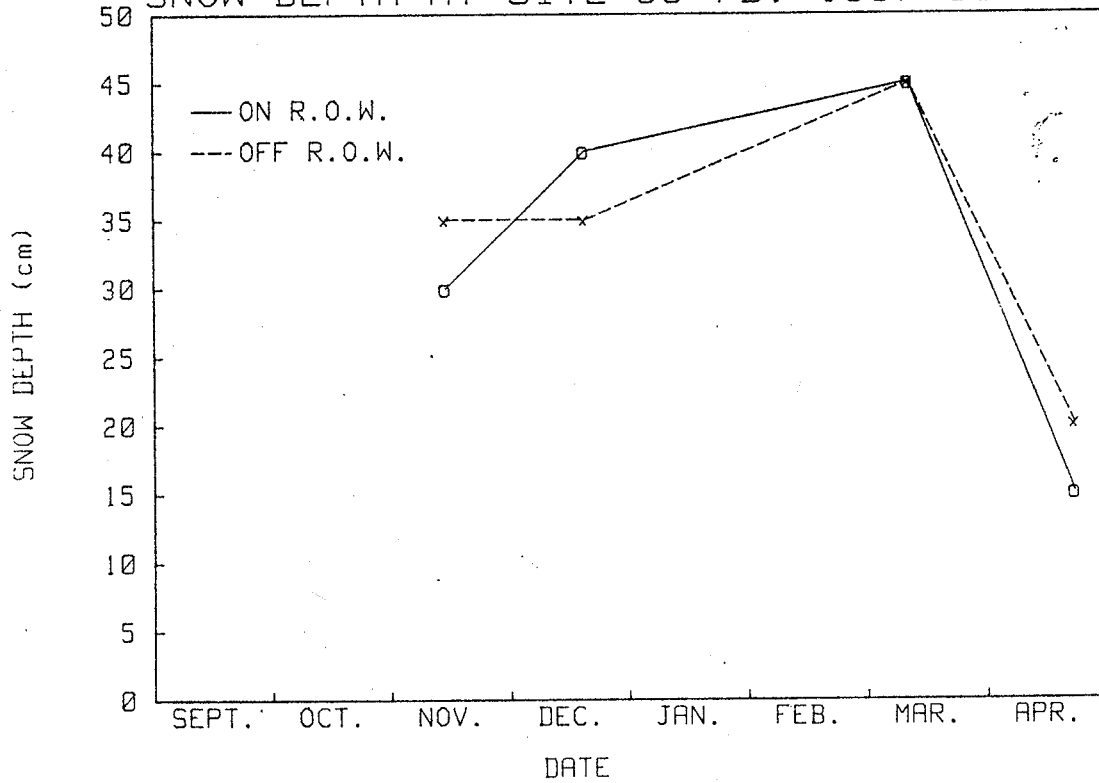
SNOW DEPTH AT SITE 84-3B: 1987/88



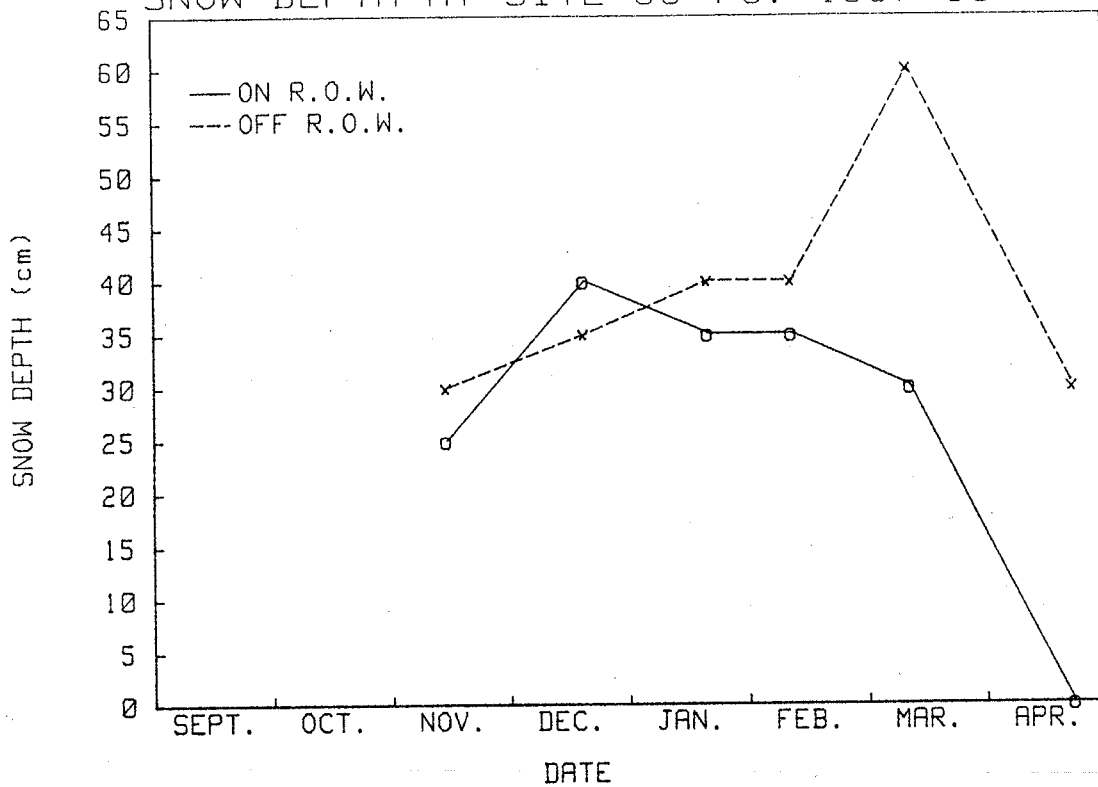
SNOW DEPTH AT SITE 85-7A: 1987/88



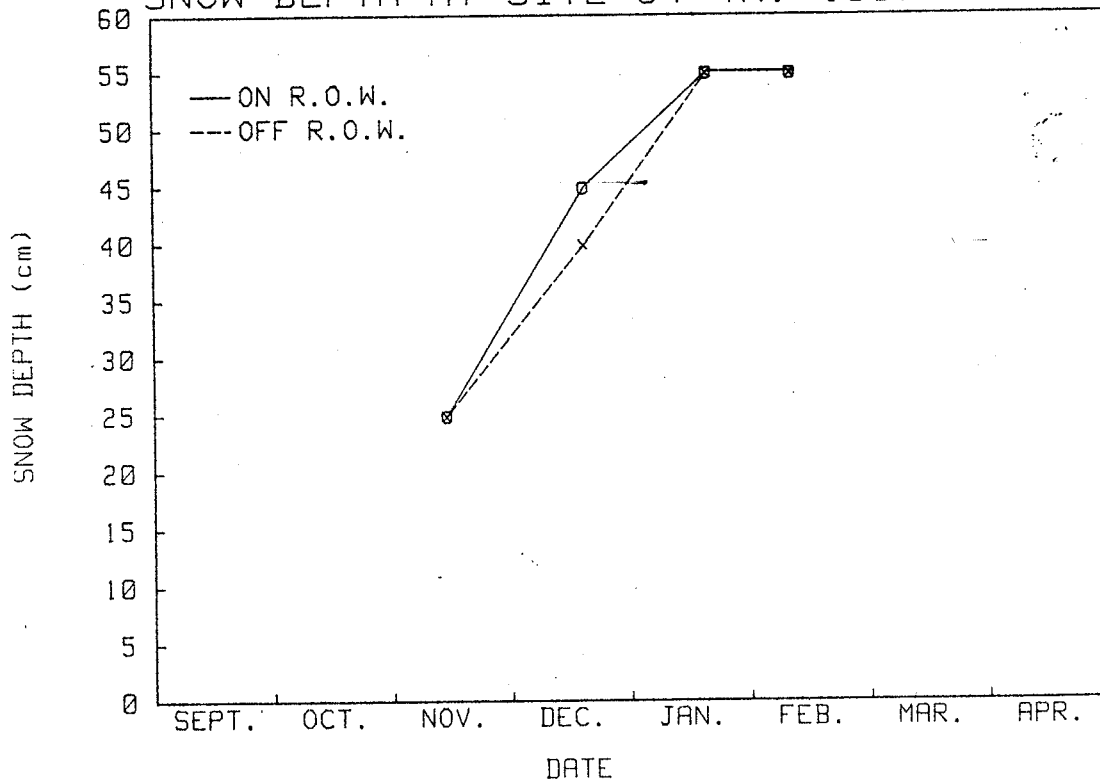
SNOW DEPTH AT SITE 85-7B: 1987/88



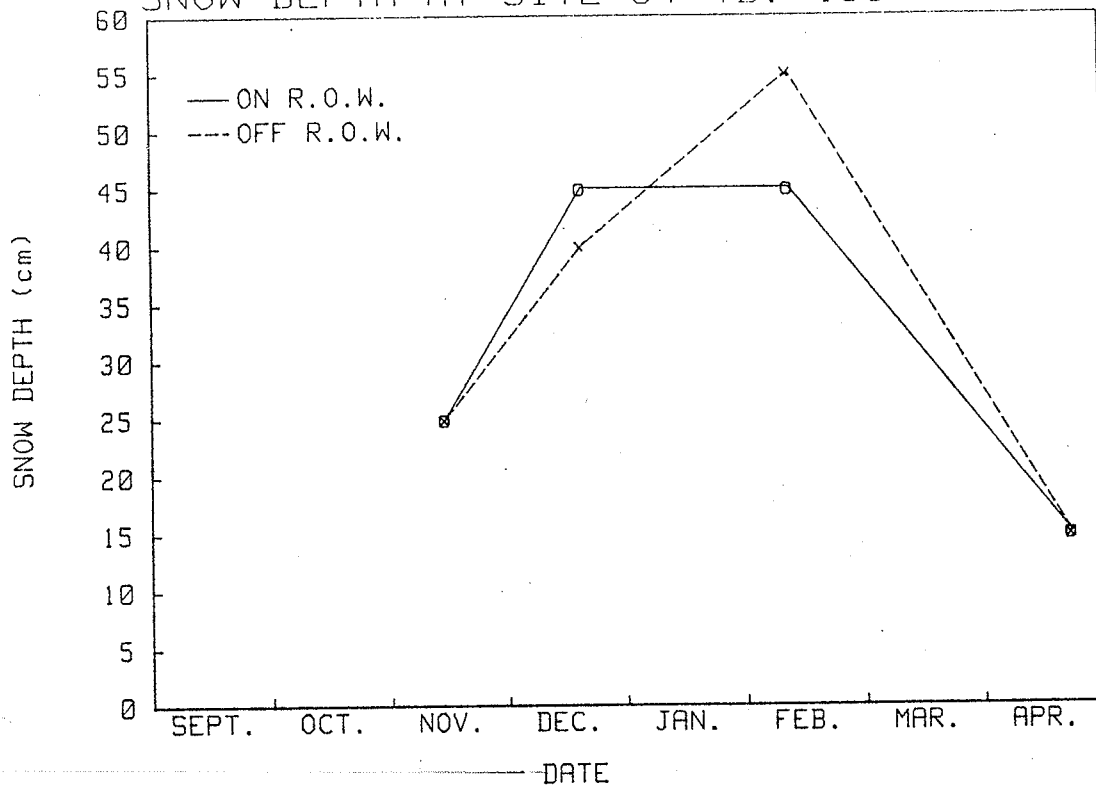
SNOW DEPTH AT SITE 85-7C: 1987/88



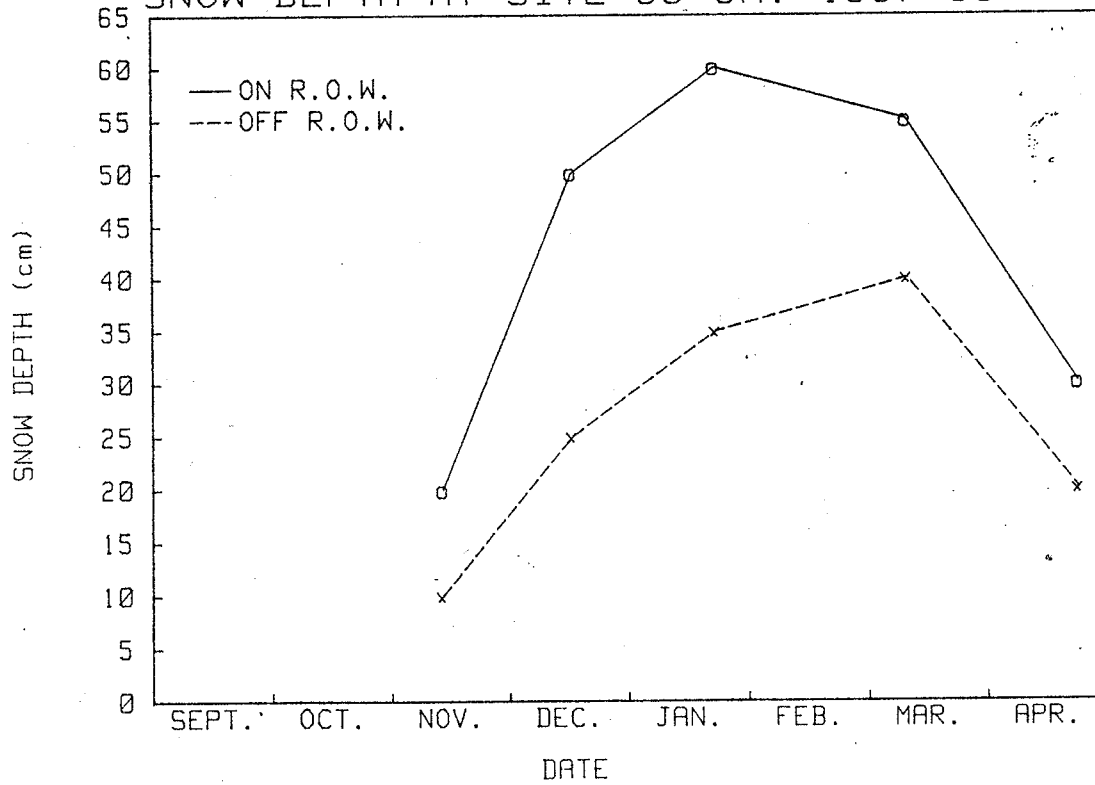
SNOW DEPTH AT SITE 84-4A: 1987/88



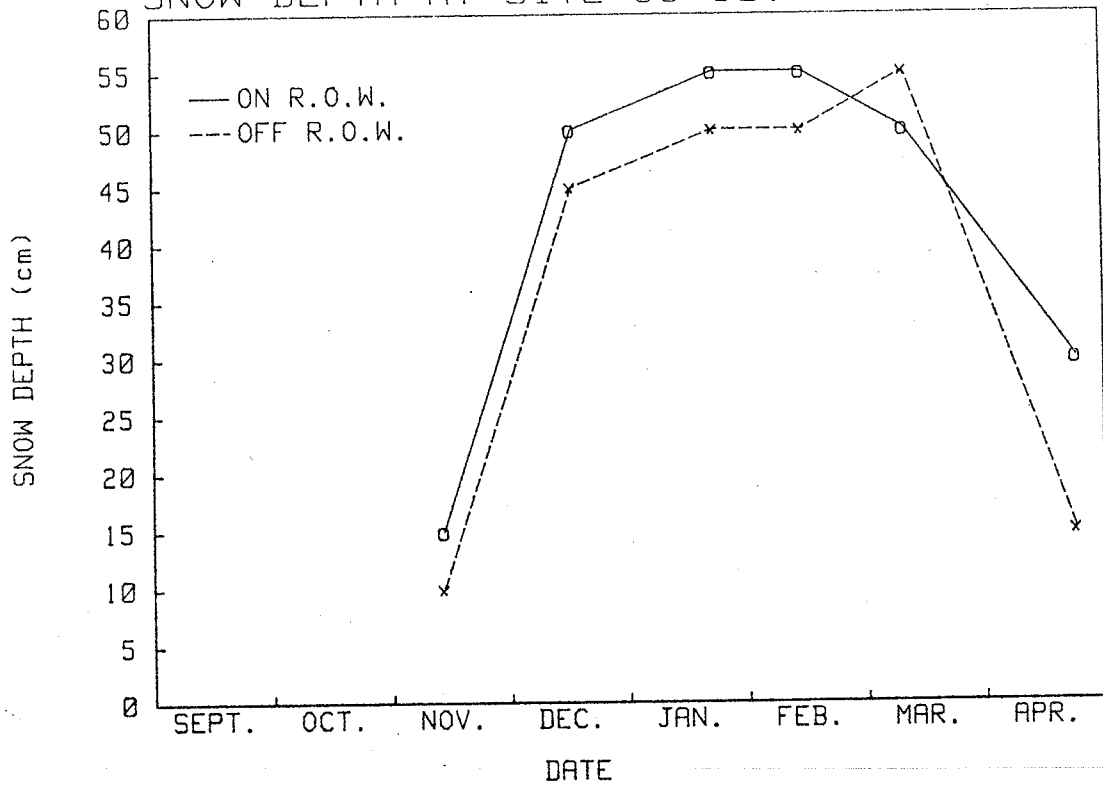
SNOW DEPTH AT SITE 84-4B: 1987/88



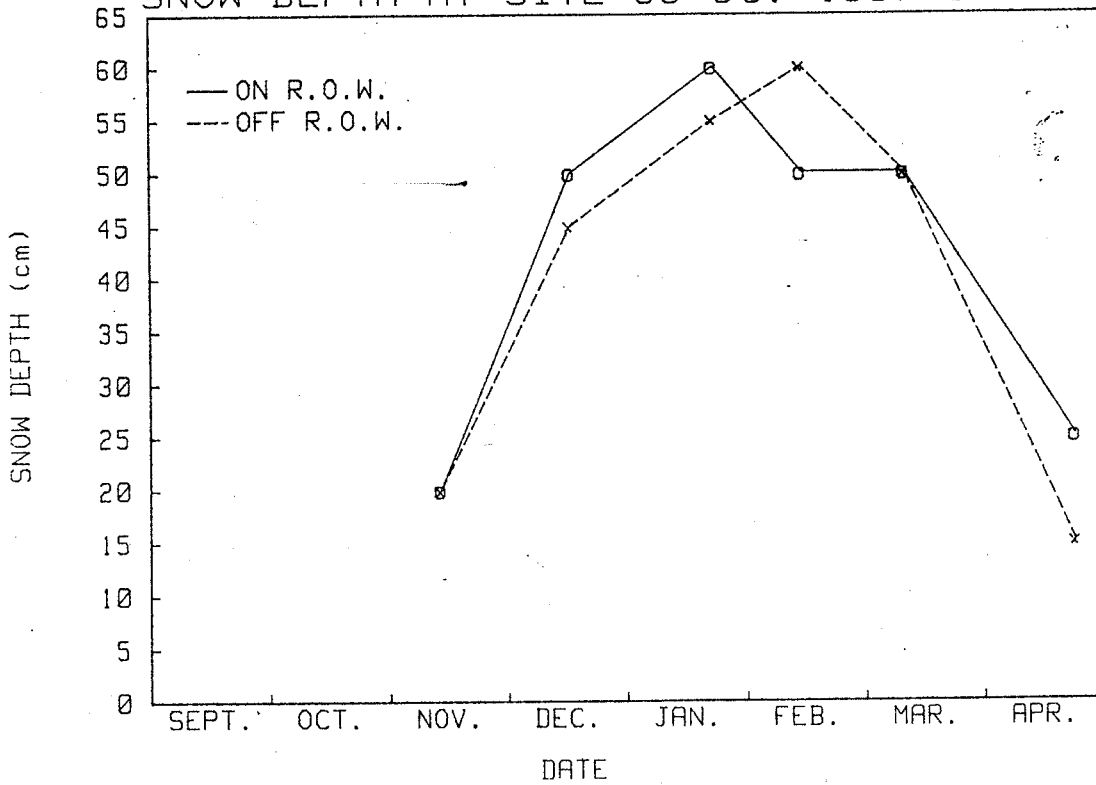
SNOW DEPTH AT SITE 85-8A: 1987/88



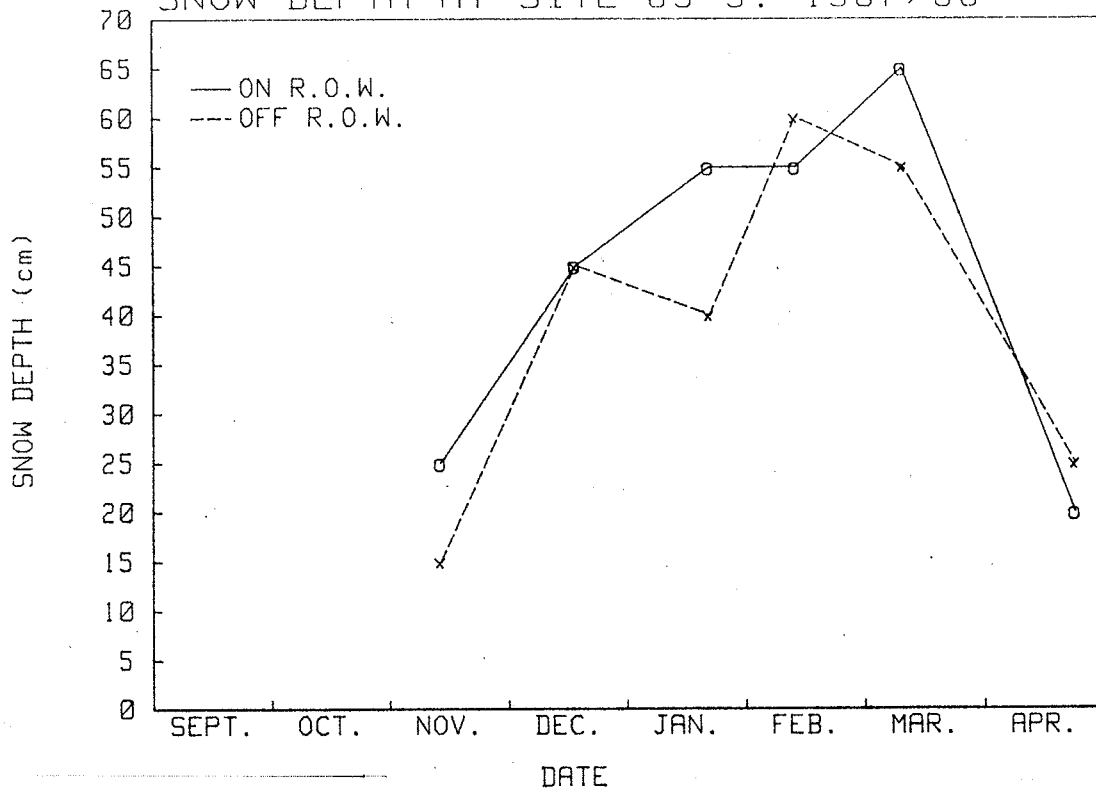
SNOW DEPTH AT SITE 85-8B: 1987/88



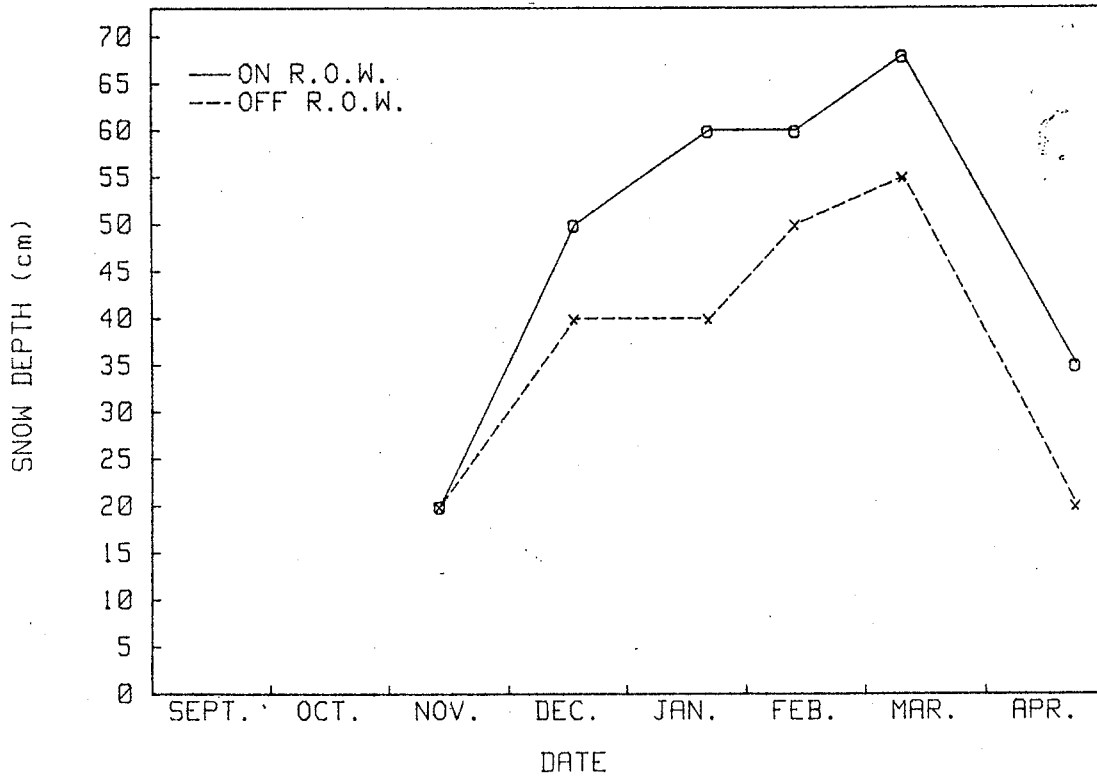
SNOW DEPTH AT SITE 85-8C: 1987/88



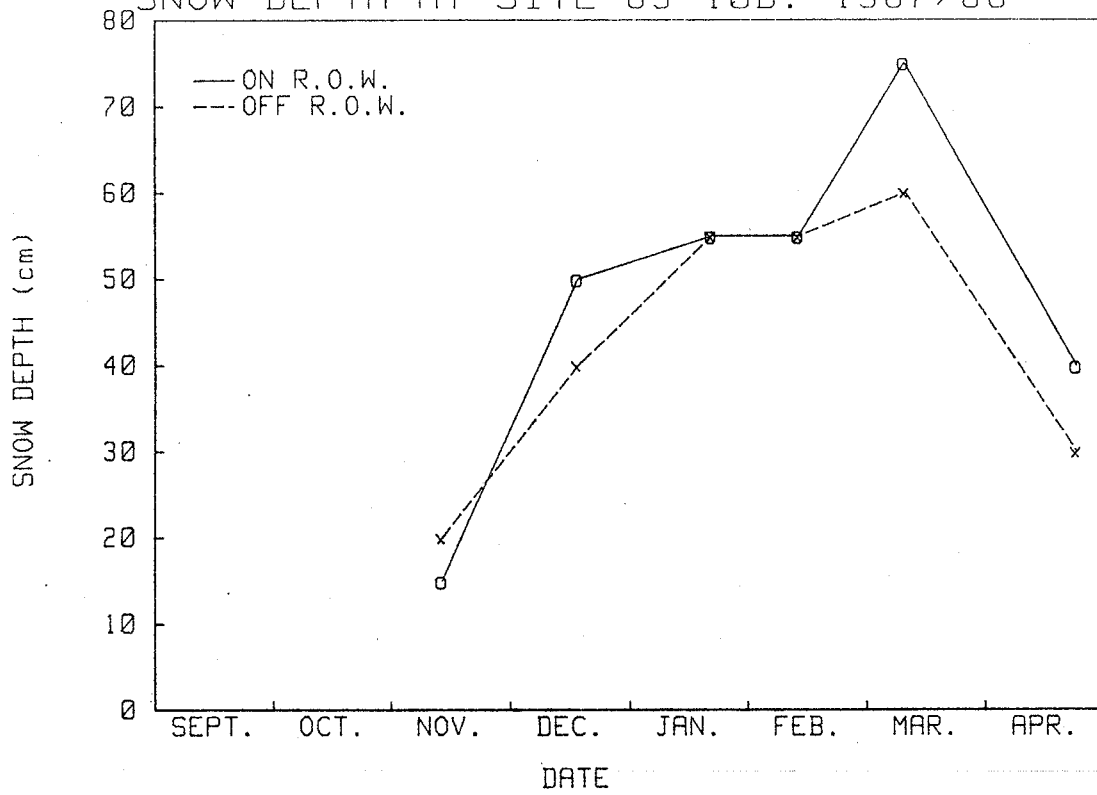
SNOW DEPTH AT SITE 85-9: 1987/88



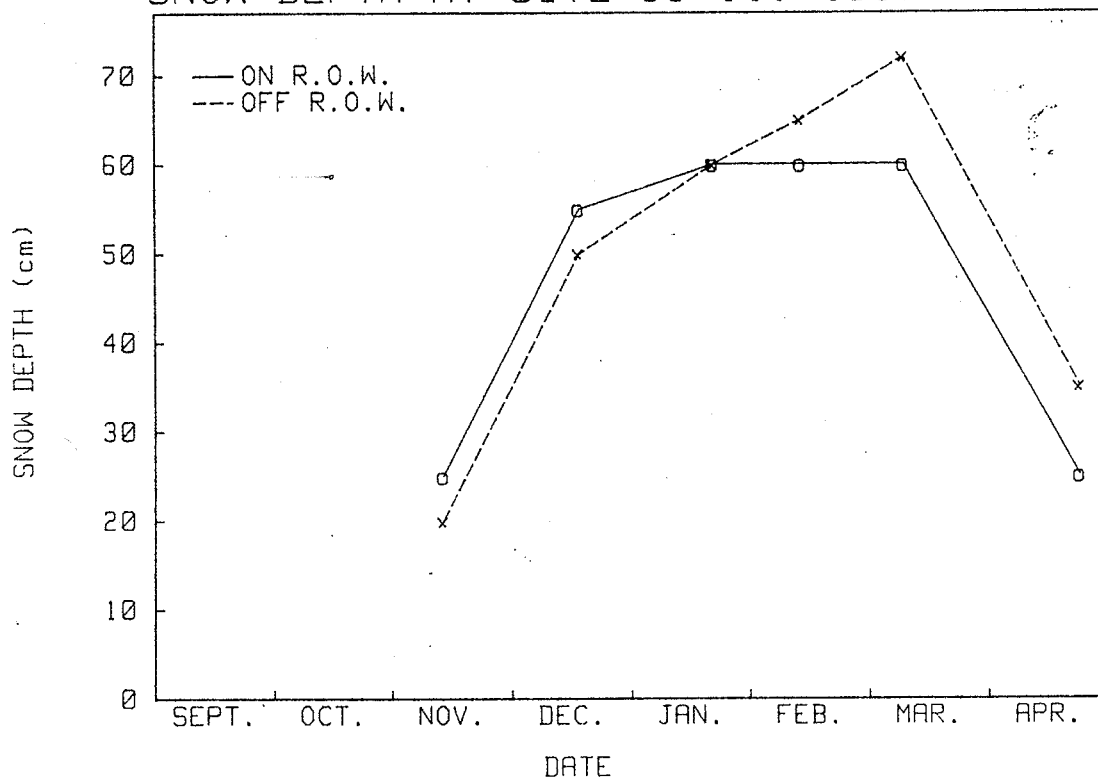
SNOW DEPTH AT SITE 85-10A: 1987/88



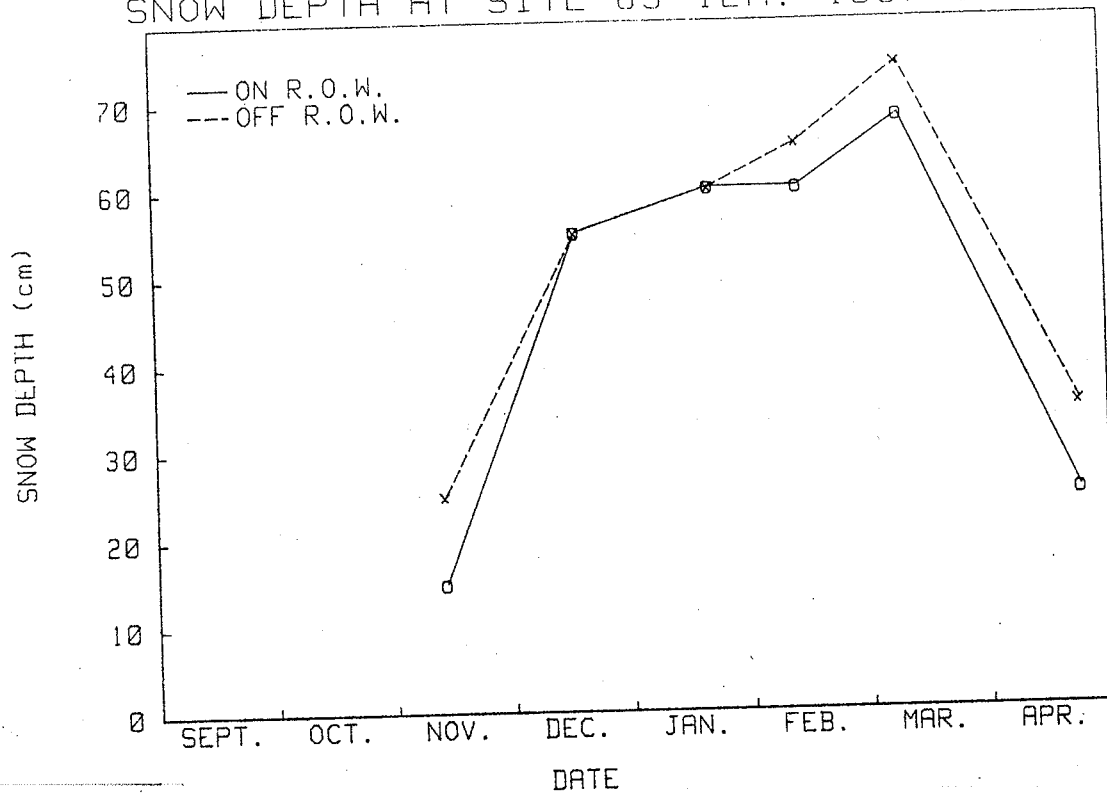
SNOW DEPTH AT SITE 85-10B: 1987/88



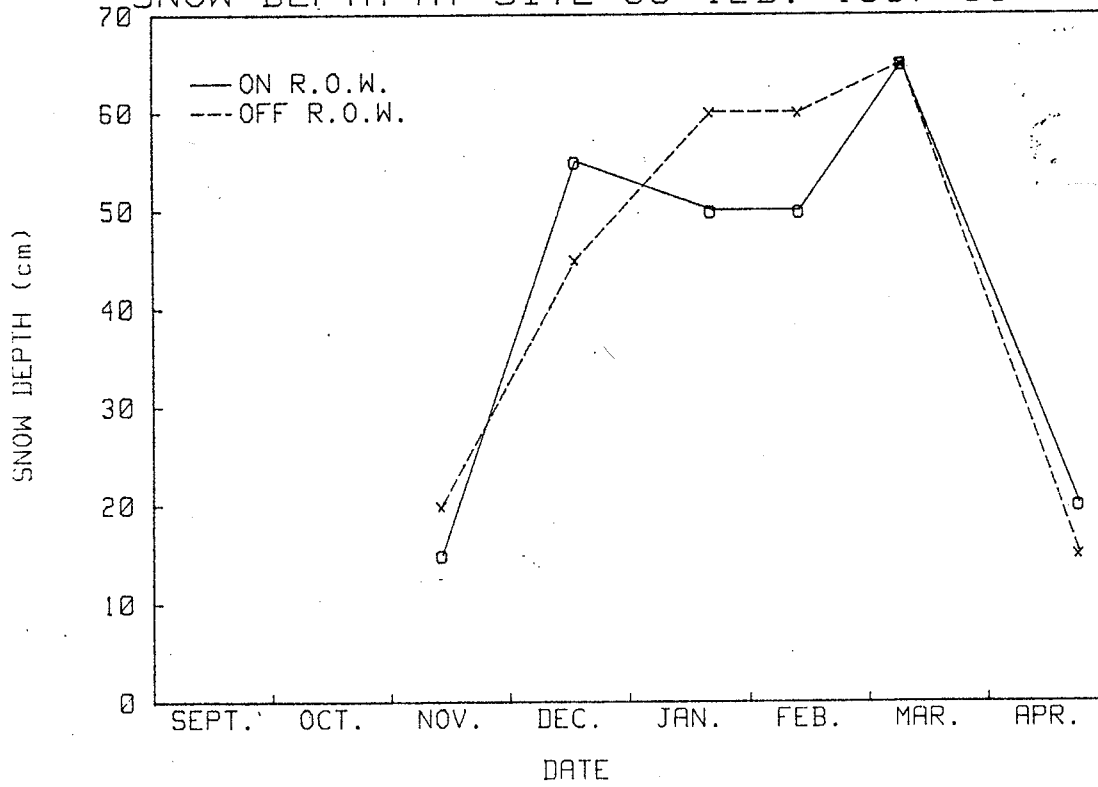
SNOW DEPTH AT SITE 85-11: 1987/88



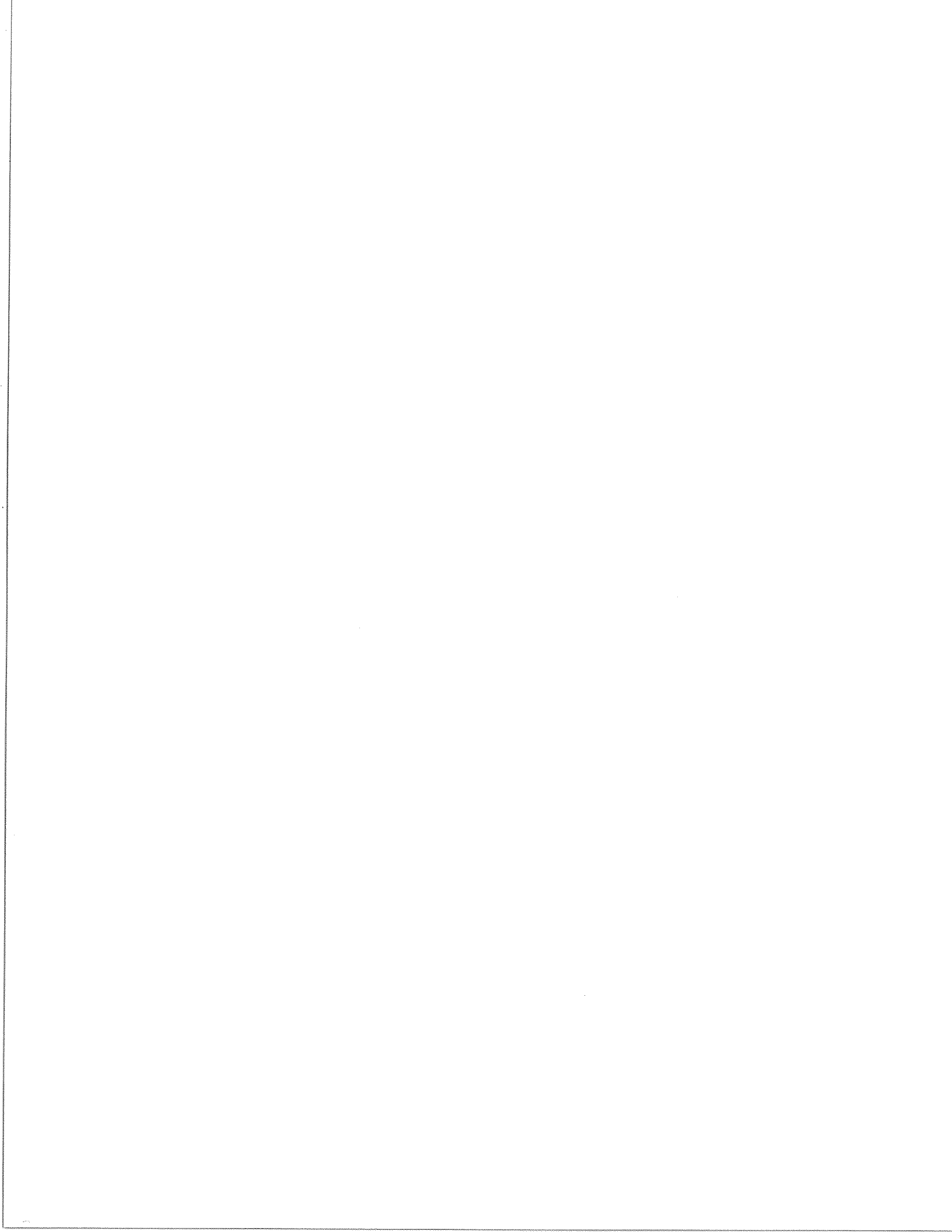
SNOW DEPTH AT SITE 85-12A: 1987/88



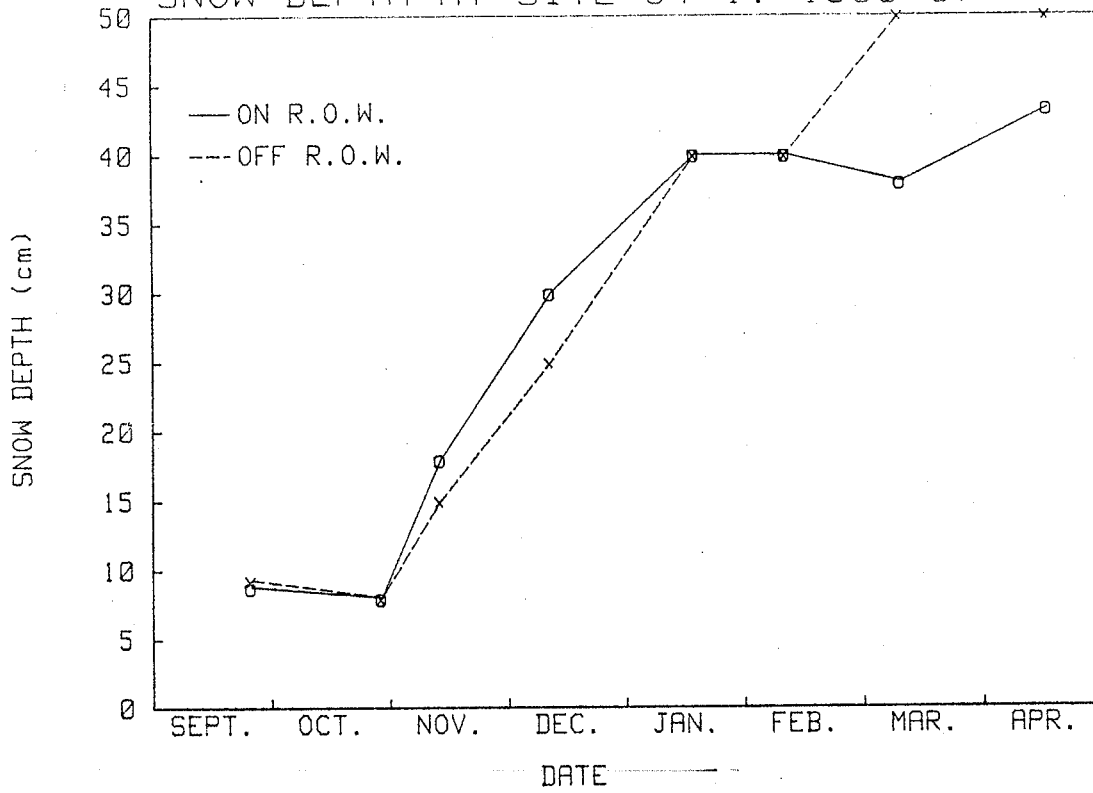
SNOW DEPTH AT SITE 85-12B: 1987/88



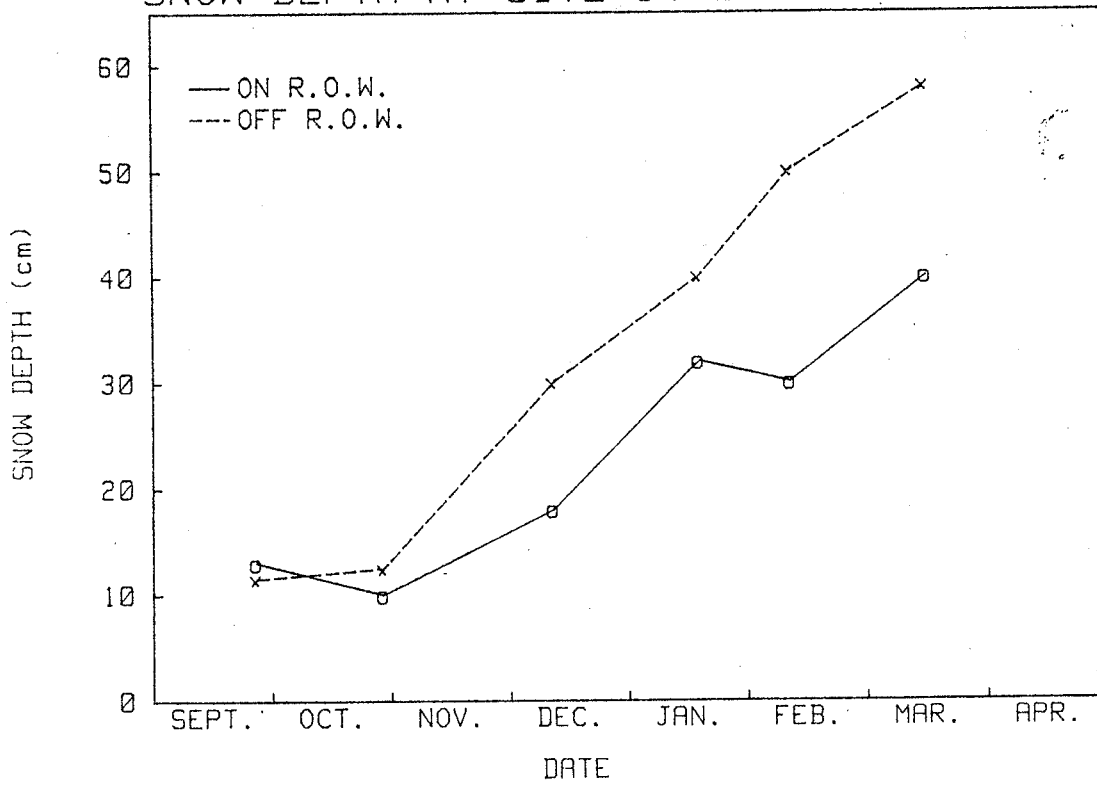
SNOW DEPTH PLOTS - STUDY SITES 1986/1987



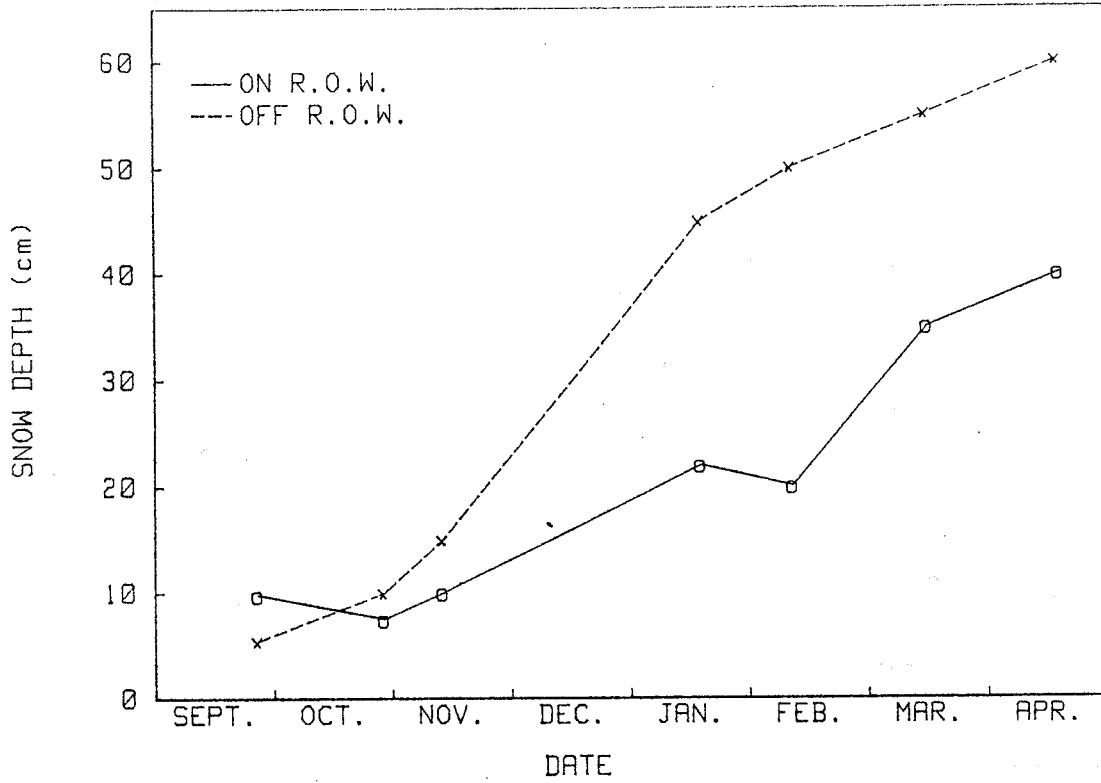
SNOW DEPTH AT SITE 84-1: 1986/87



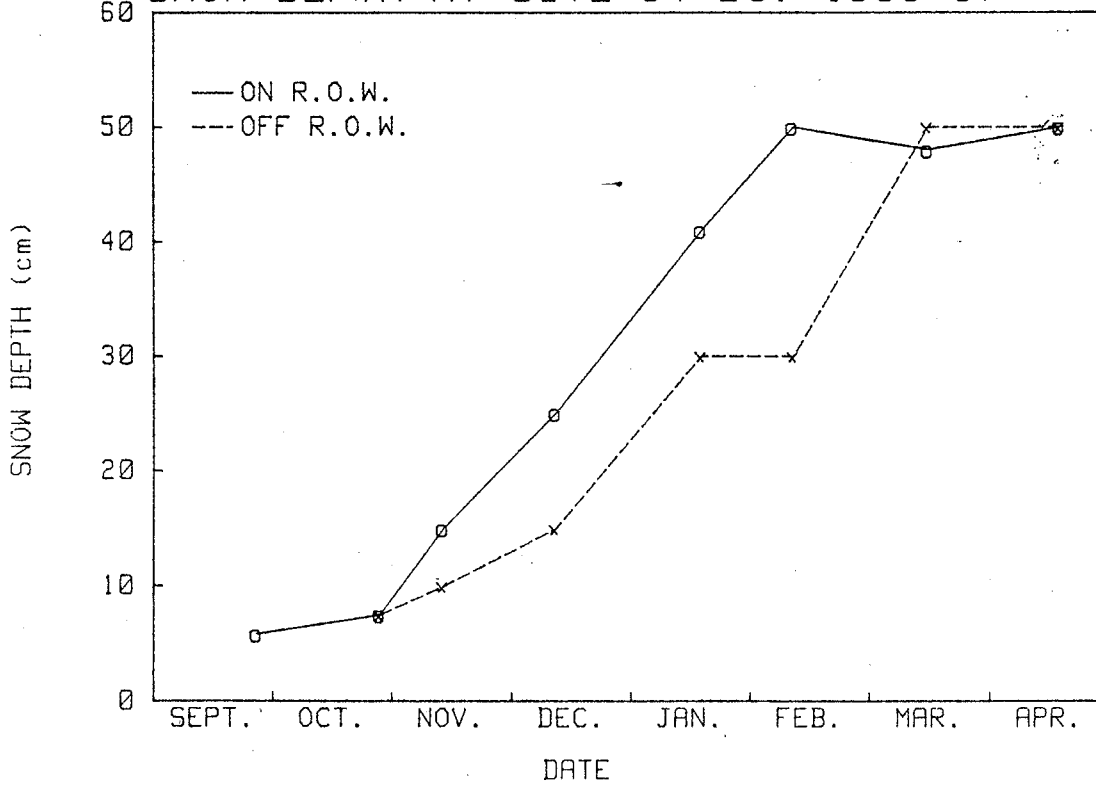
SNOW DEPTH AT SITE 84-2A: 1986/87



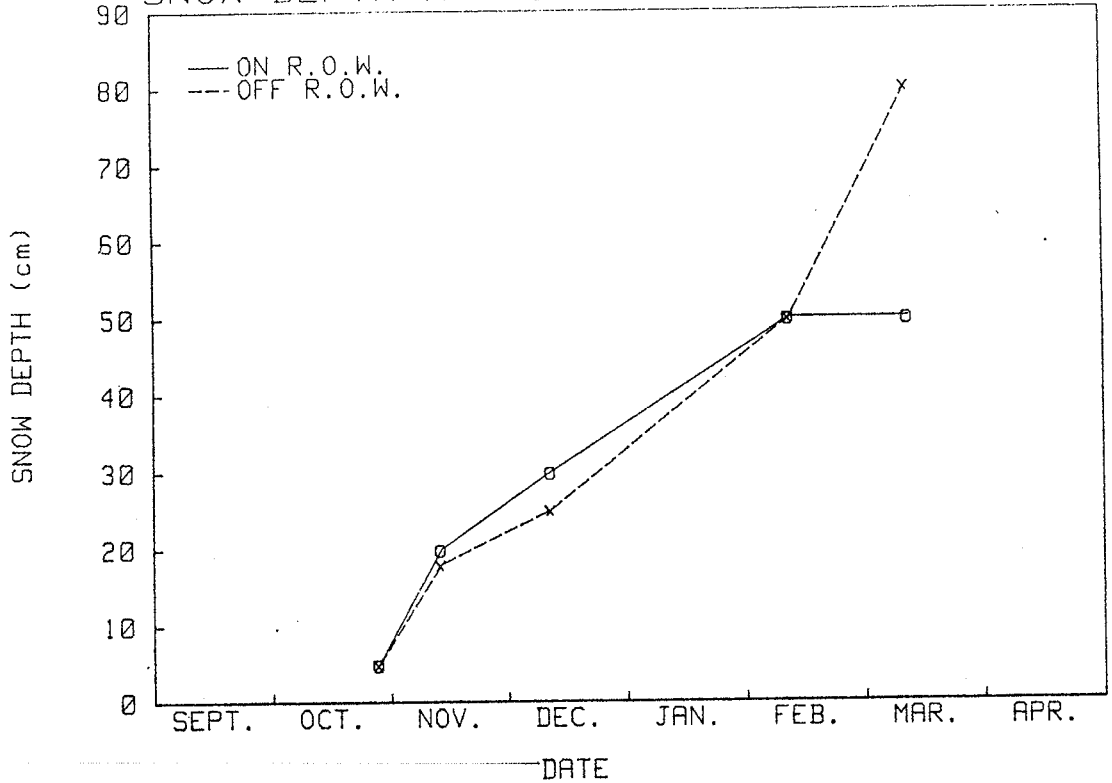
SNOW DEPTH AT SITE 84-2B: 1986/87



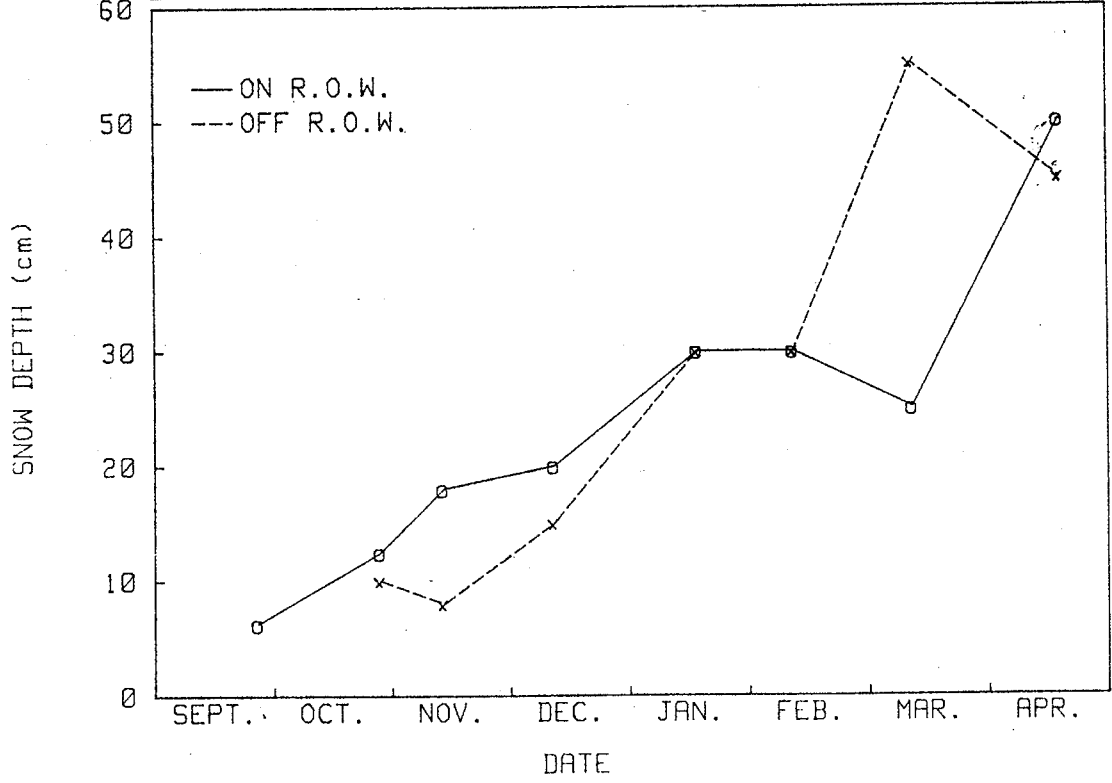
SNOW DEPTH AT SITE 84-2C: 1986/87



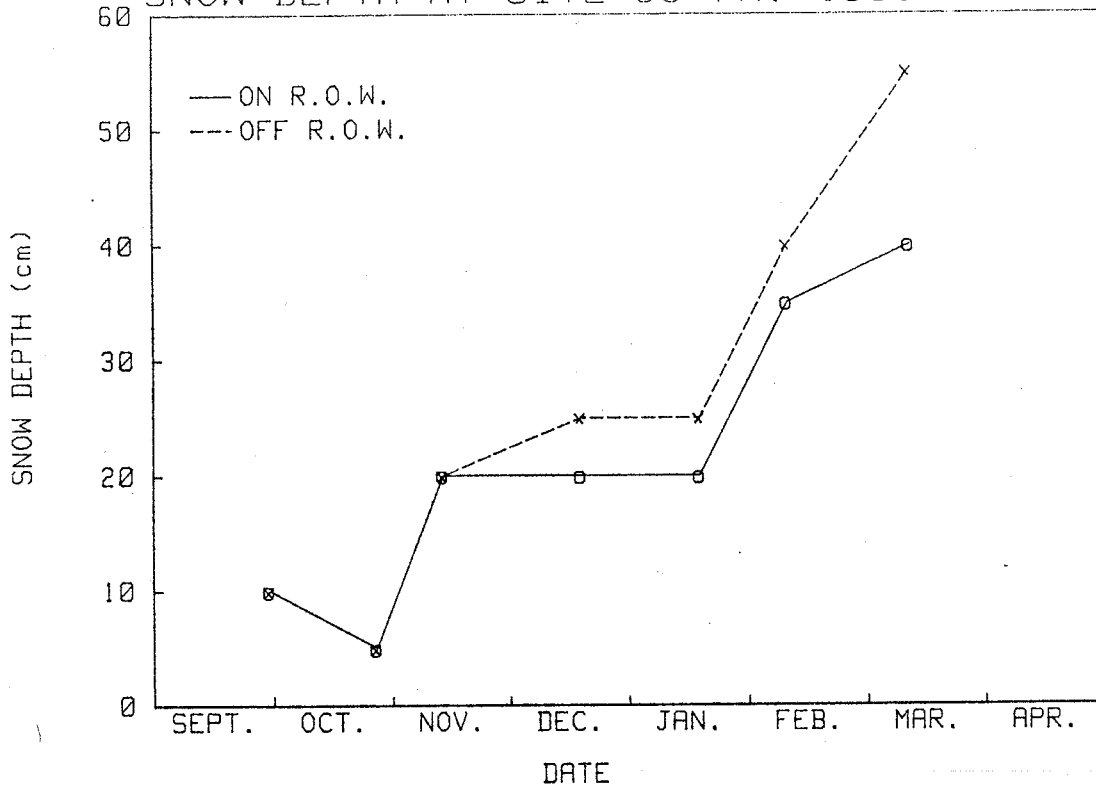
SNOW DEPTH AT SITE 84-3A: 1986/87



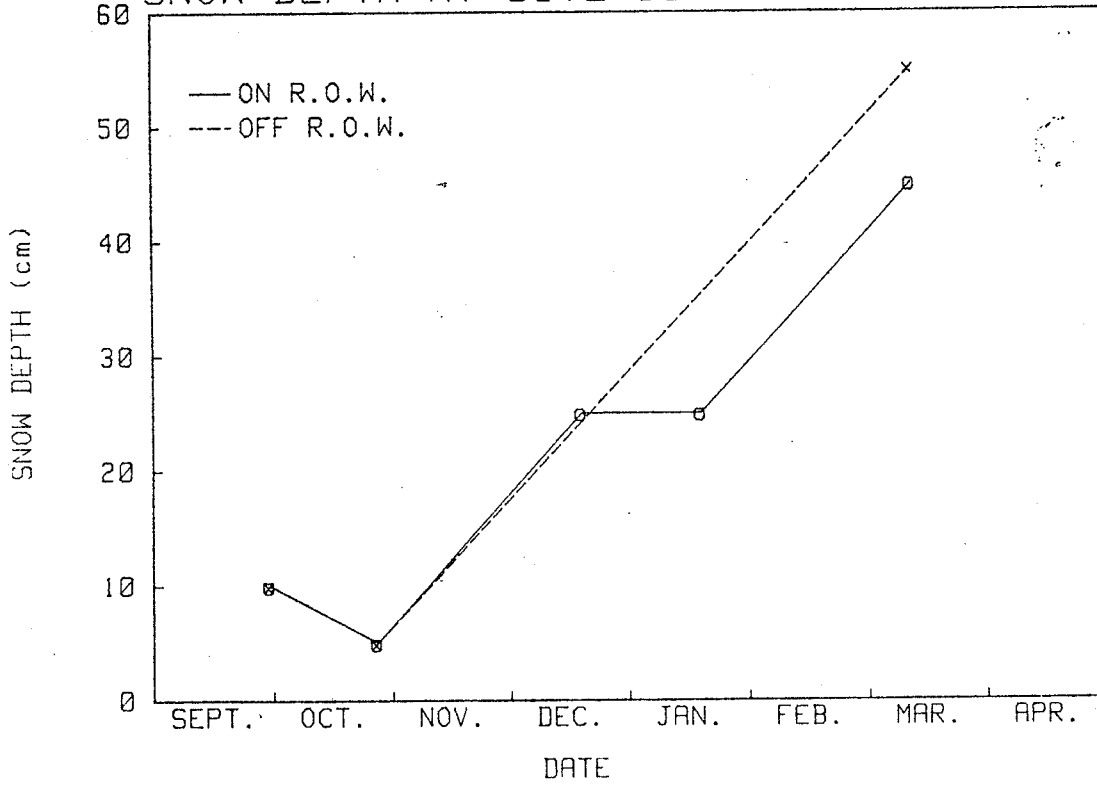
SNOW DEPTH AT SITE 84-3B: 1986/87



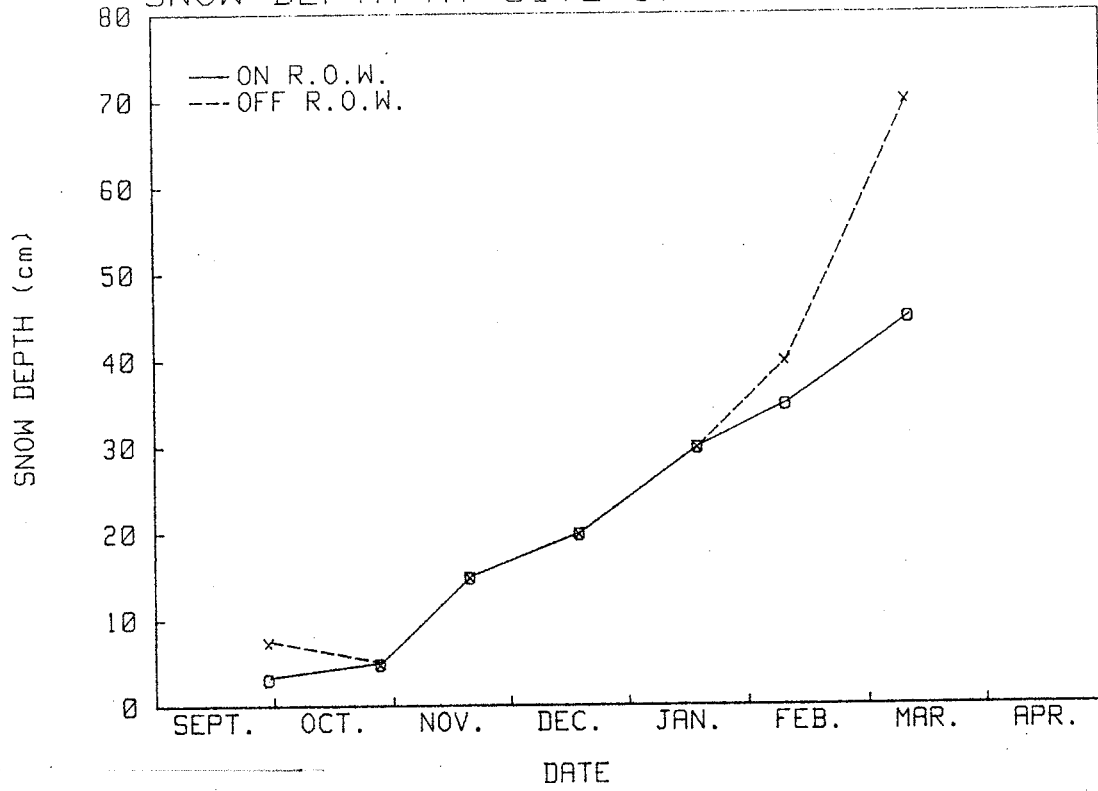
SNOW DEPTH AT SITE 85-7A: 1986/87



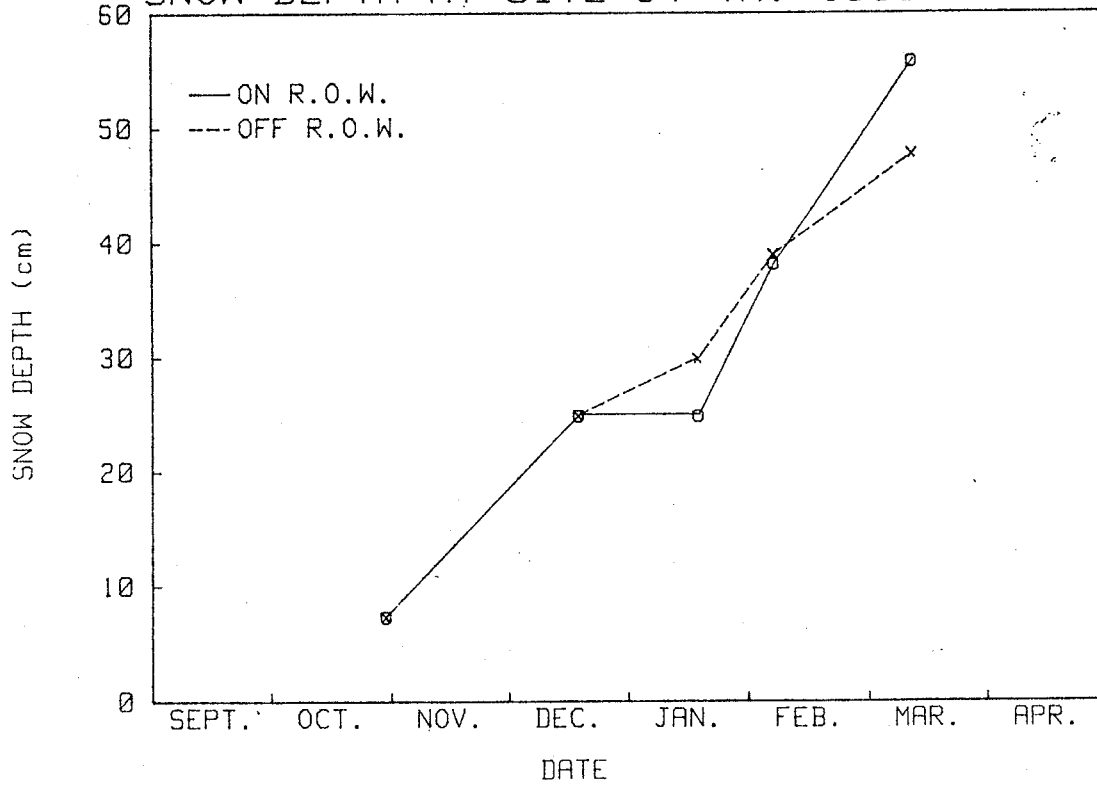
SNOW DEPTH AT SITE 85-7B: 1986/87



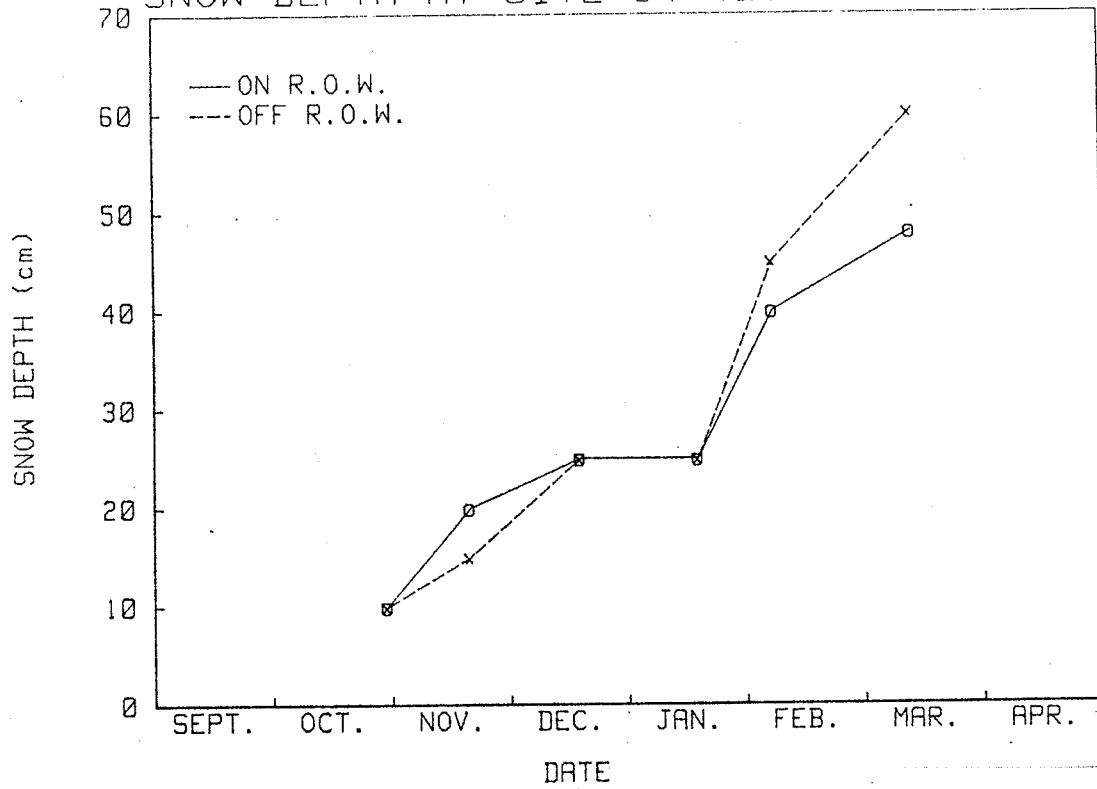
SNOW DEPTH AT SITE 85-7C: 1986/87



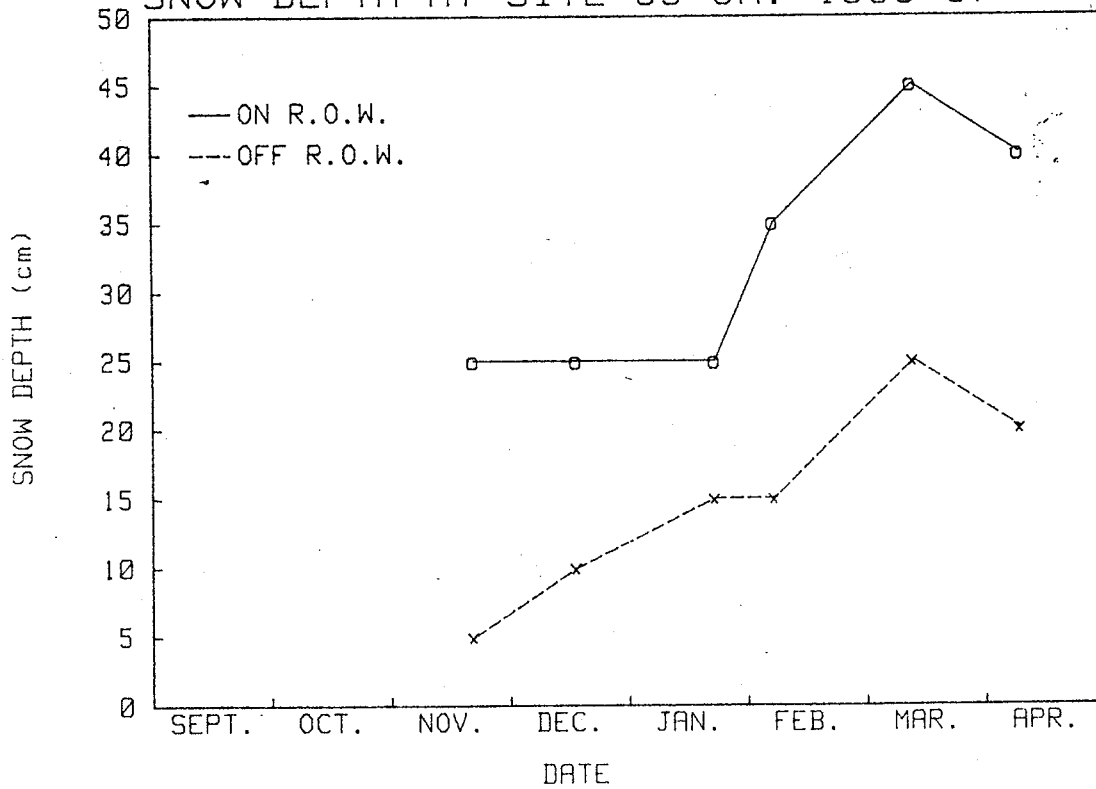
SNOW DEPTH AT SITE 84-4A: 1986/87



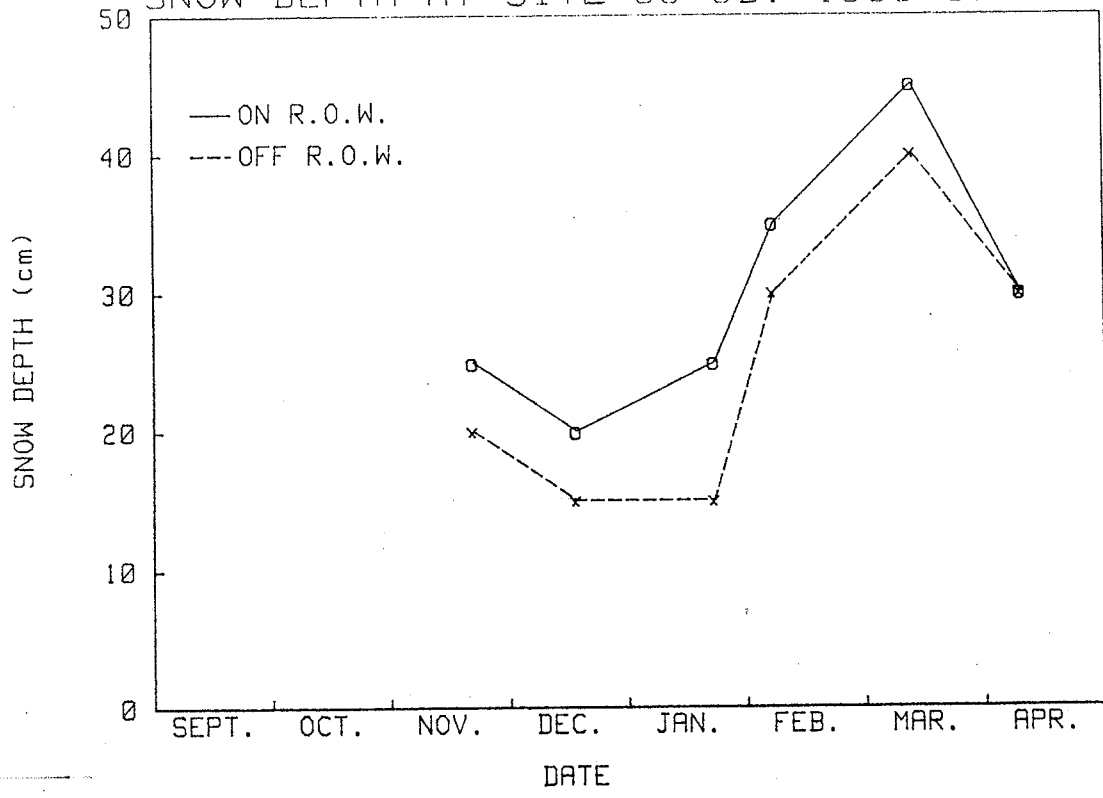
SNOW DEPTH AT SITE 84-4B: 1986/87



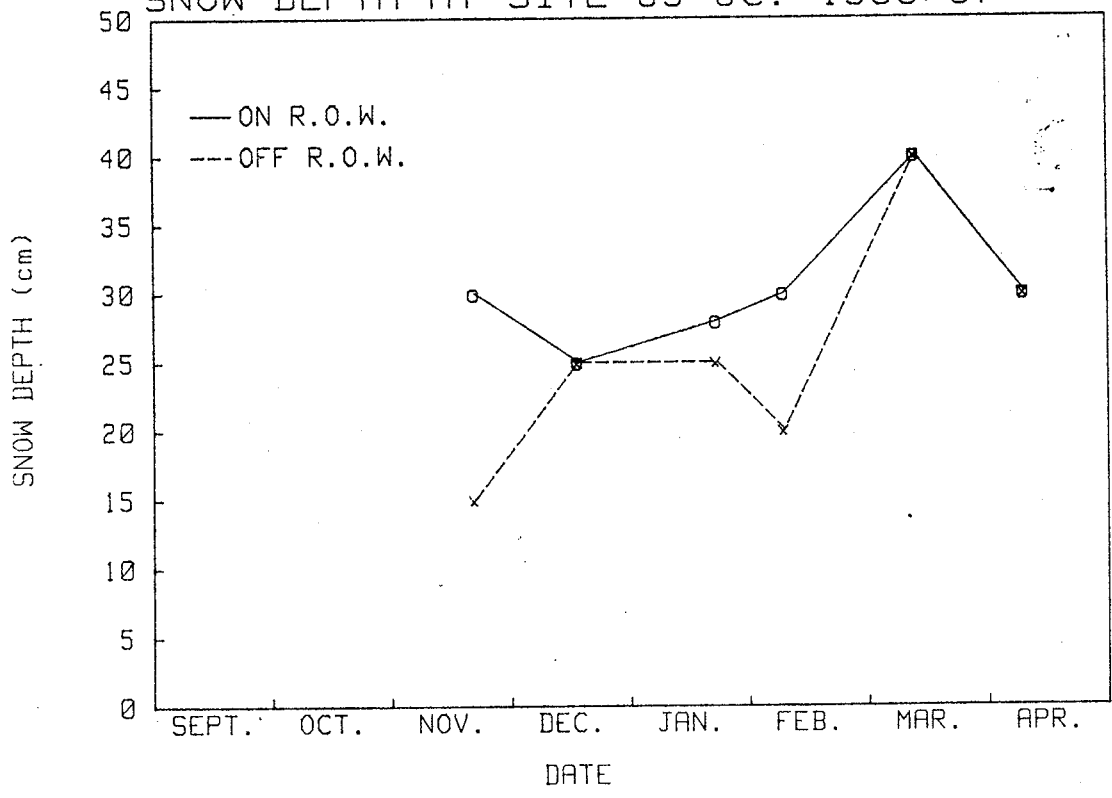
SNOW DEPTH AT SITE 85-8A: 1986/87



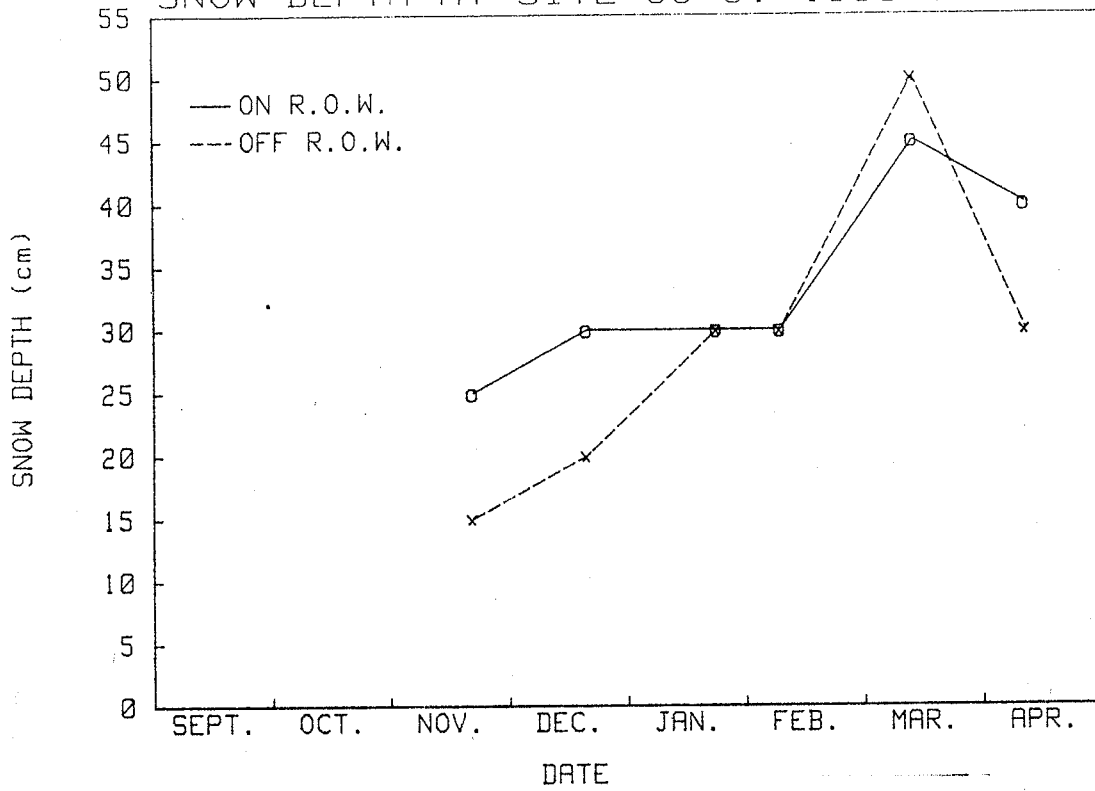
SNOW DEPTH AT SITE 85-8B: 1986/87



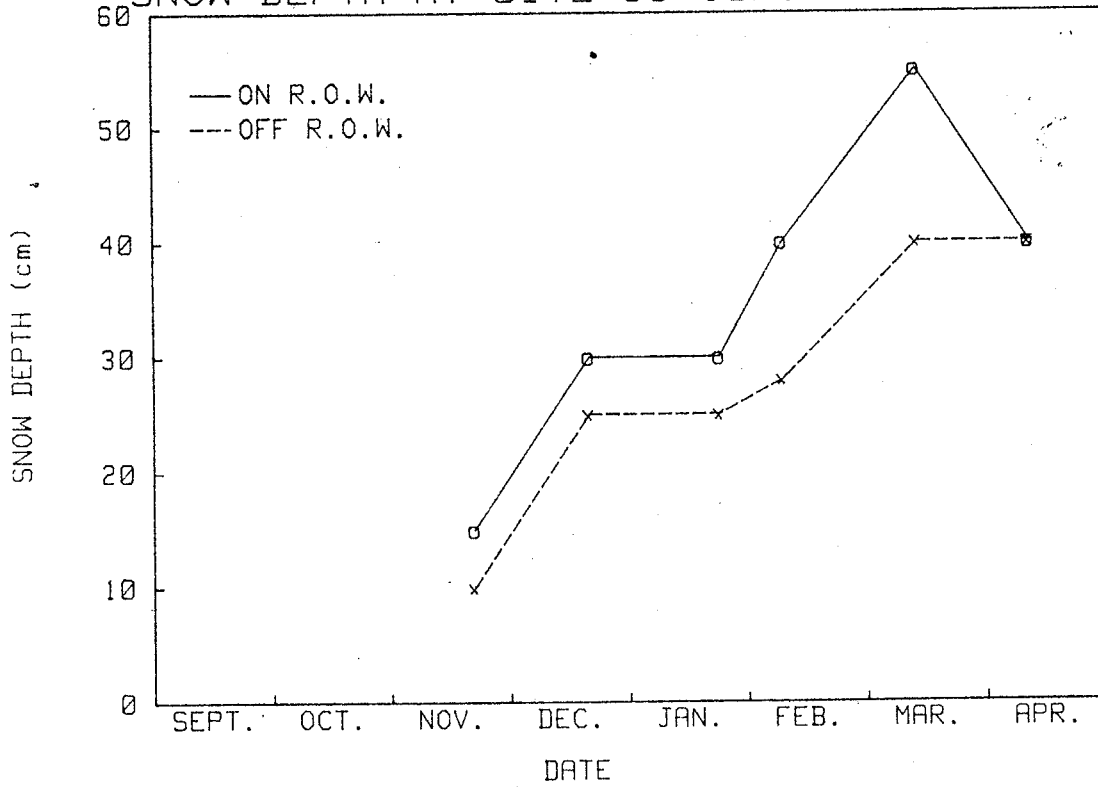
SNOW DEPTH AT SITE 85-8C: 1986/87



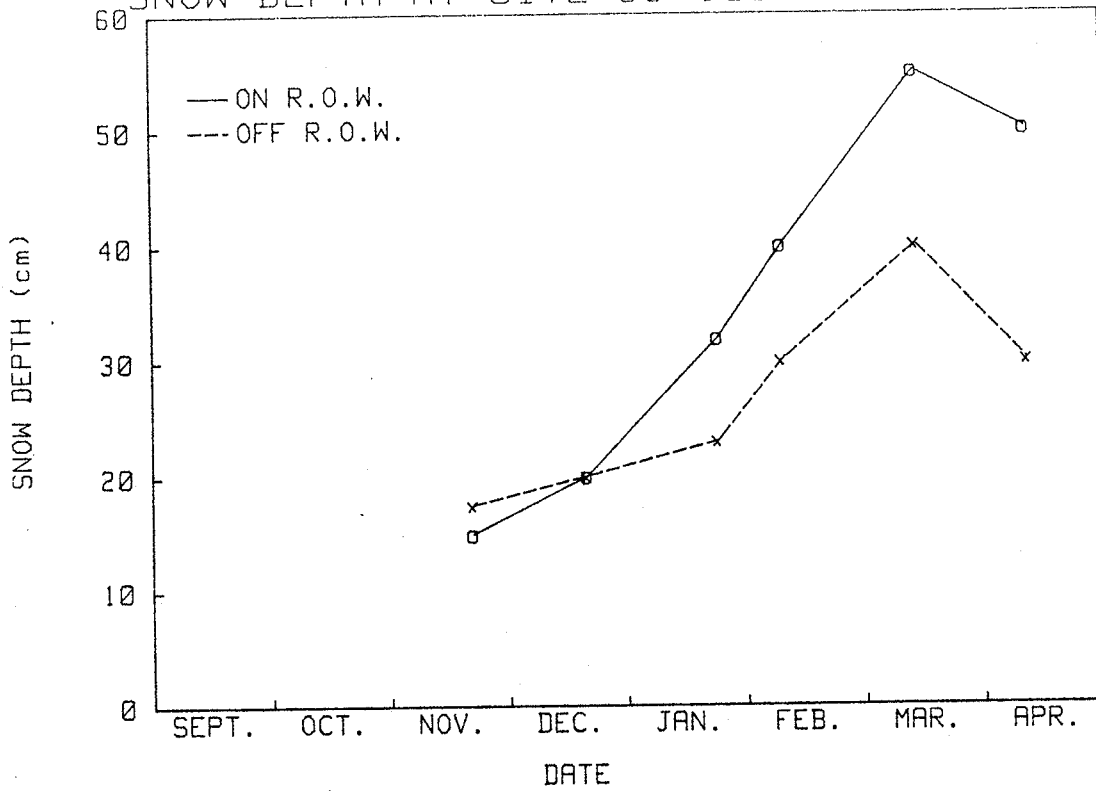
SNOW DEPTH AT SITE 85-9: 1986/87



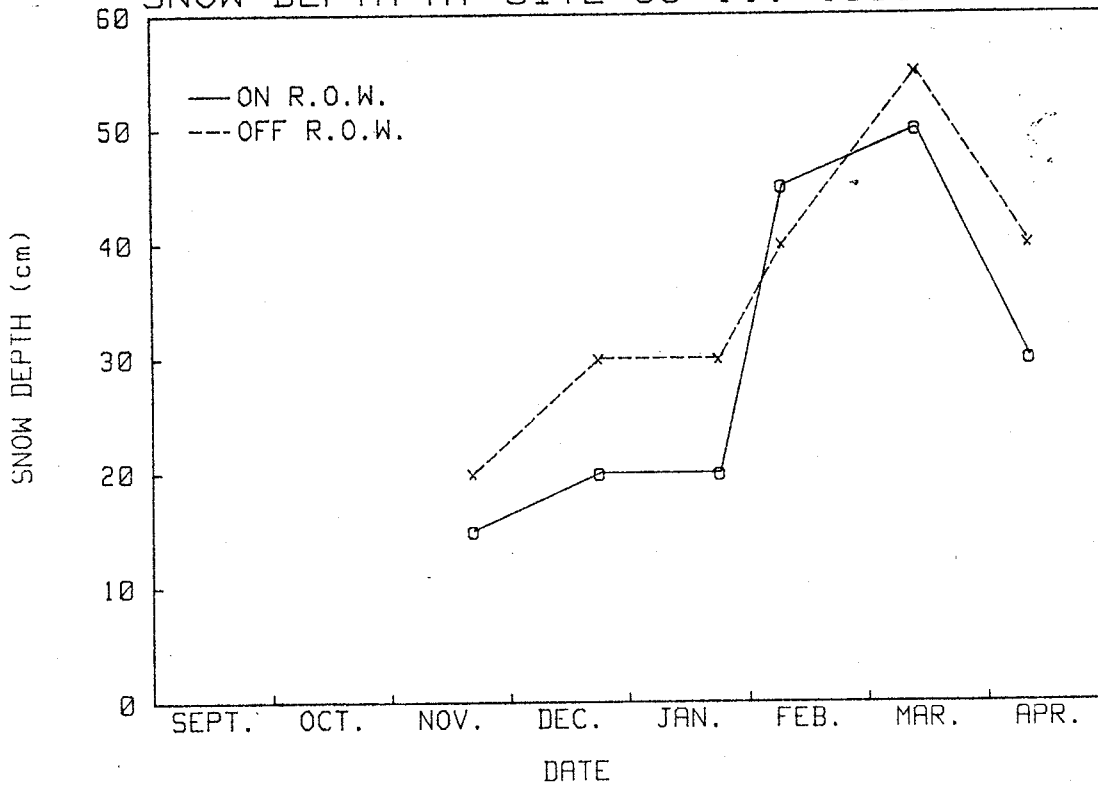
SNOW DEPTH AT SITE 85-10A: 1986/87



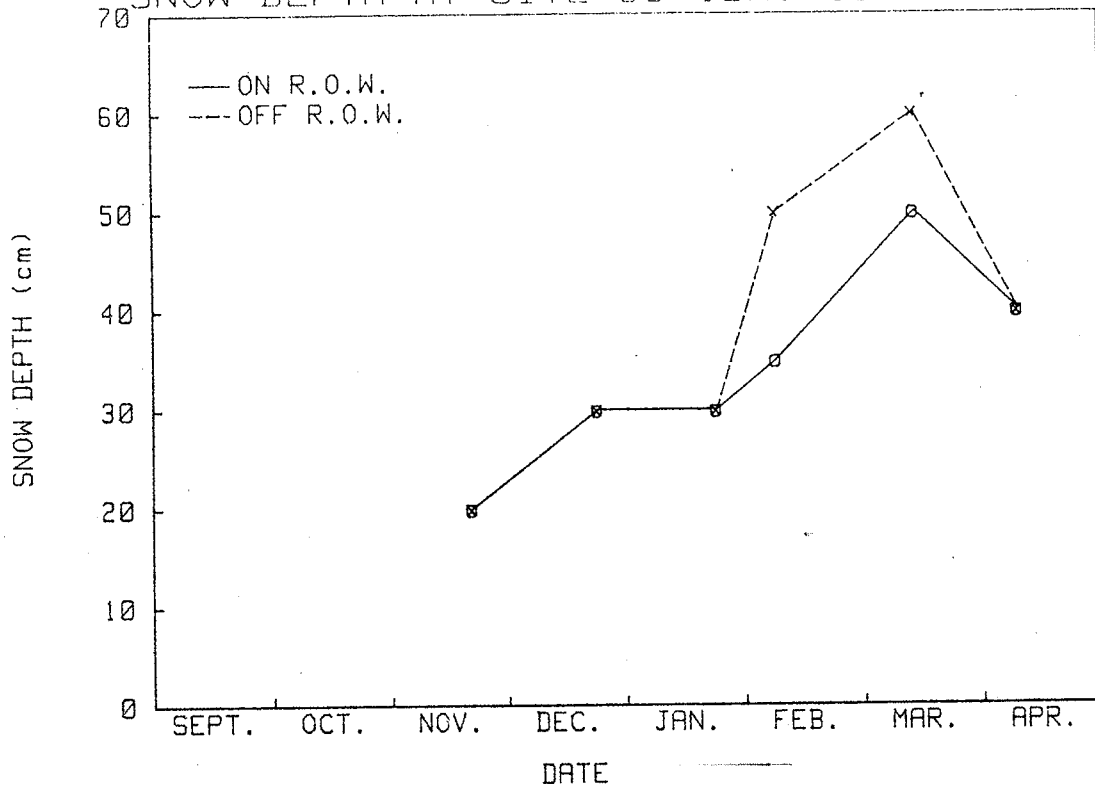
SNOW DEPTH AT SITE 85-10B: 1986/87



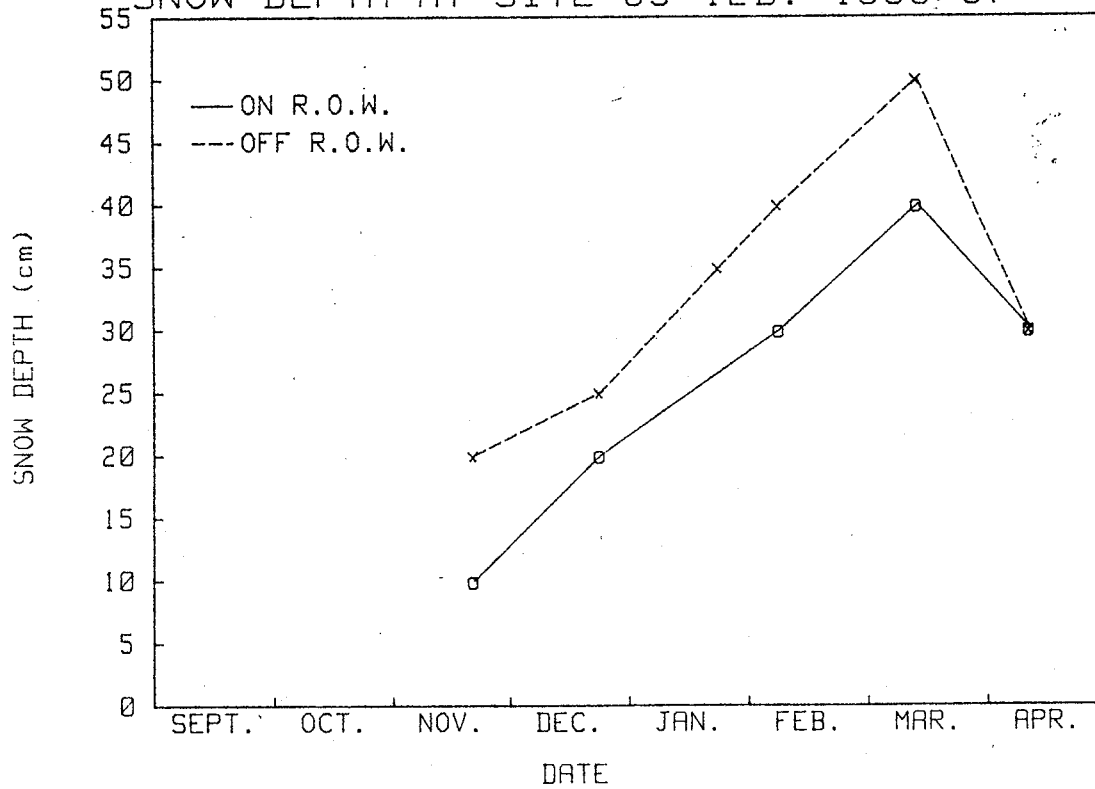
SNOW DEPTH AT SITE 85-11: 1986/87



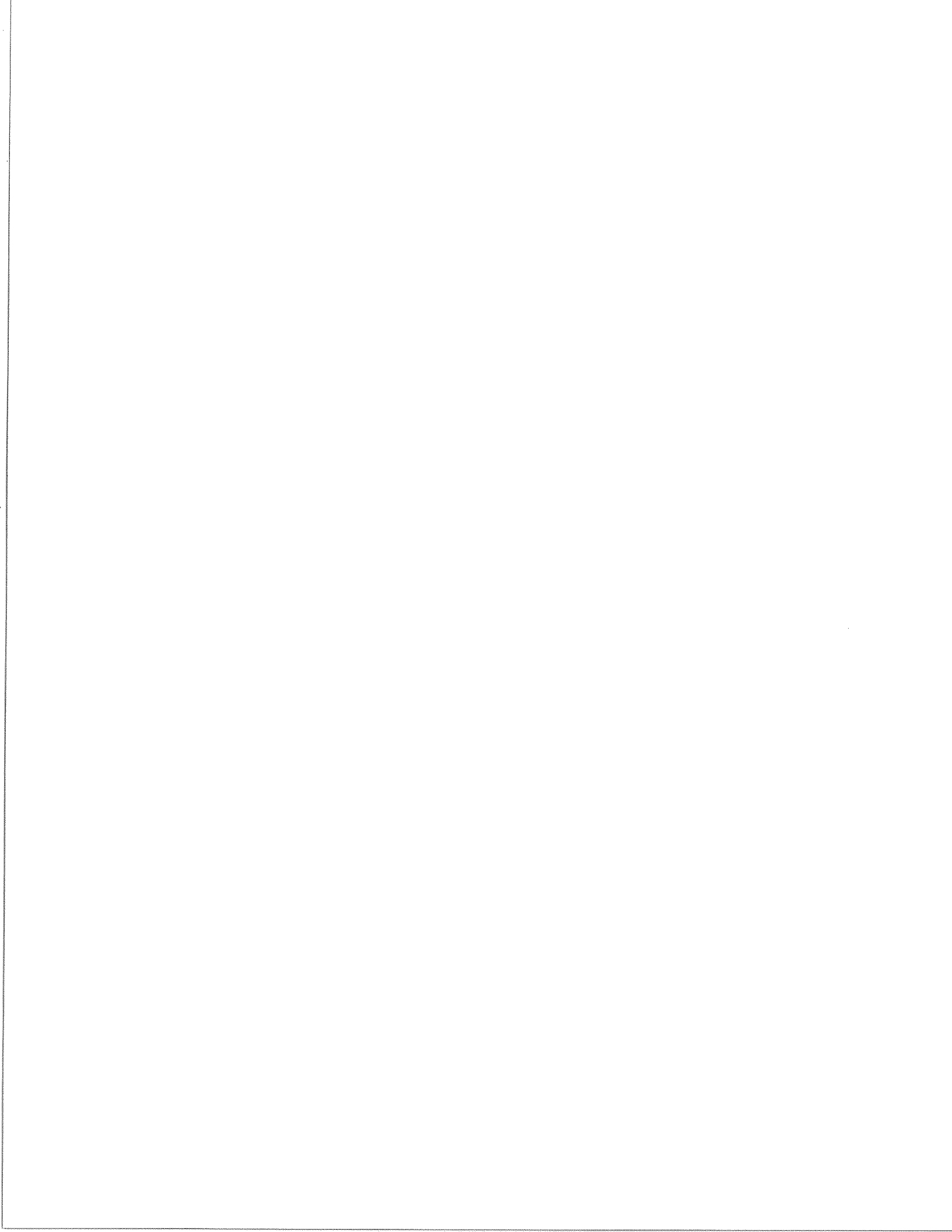
SNOW DEPTH AT SITE 85-12A: 1986/87



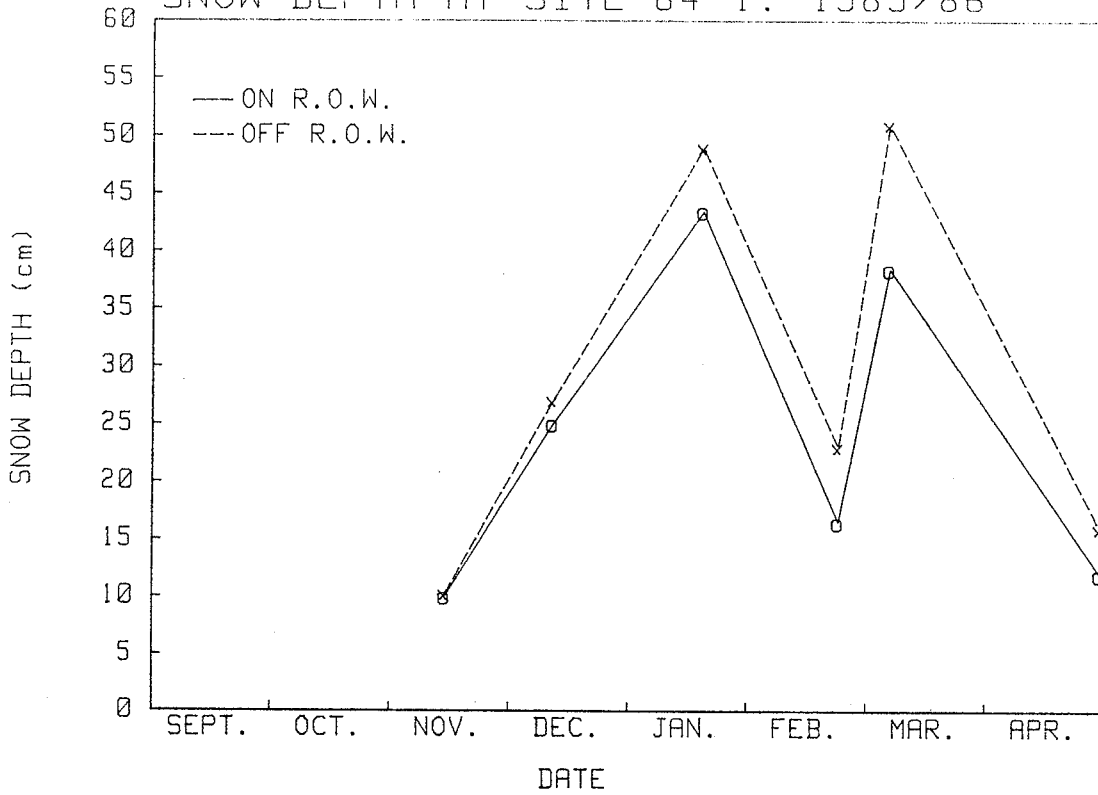
SNOW DEPTH AT SITE 85-12B: 1986/87



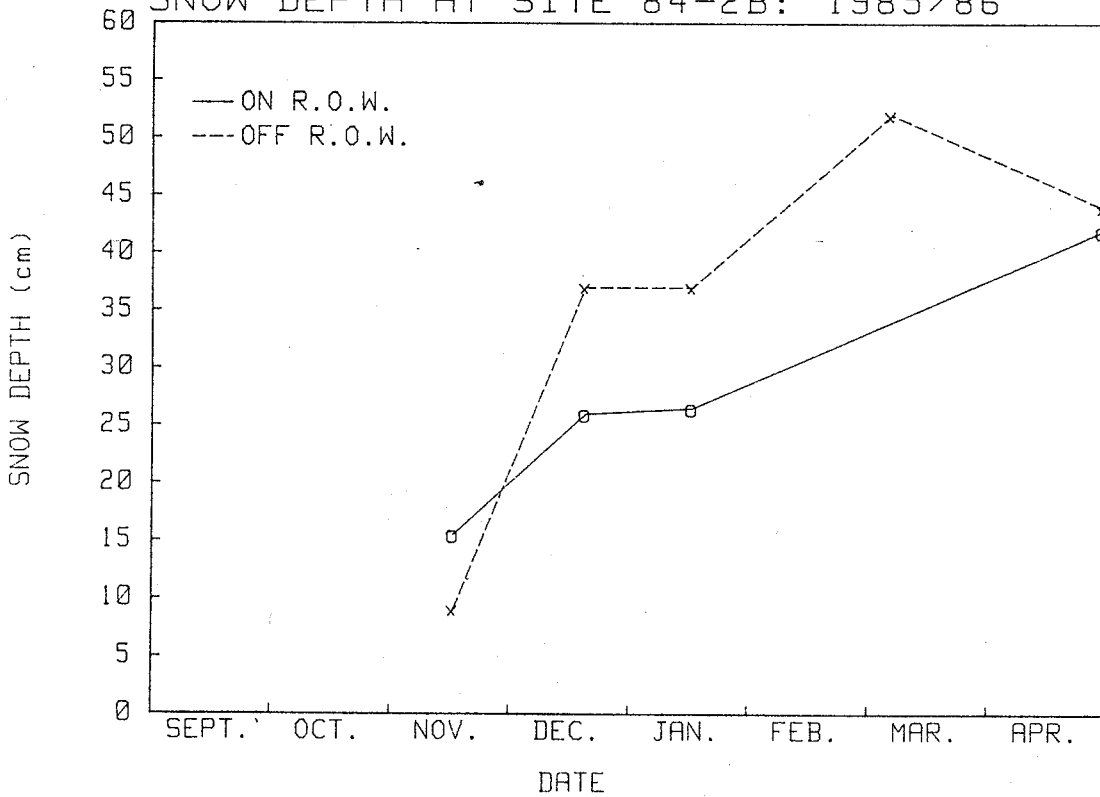
SNOW DEPTH PLOTS - STUDY SITES 1985/1986



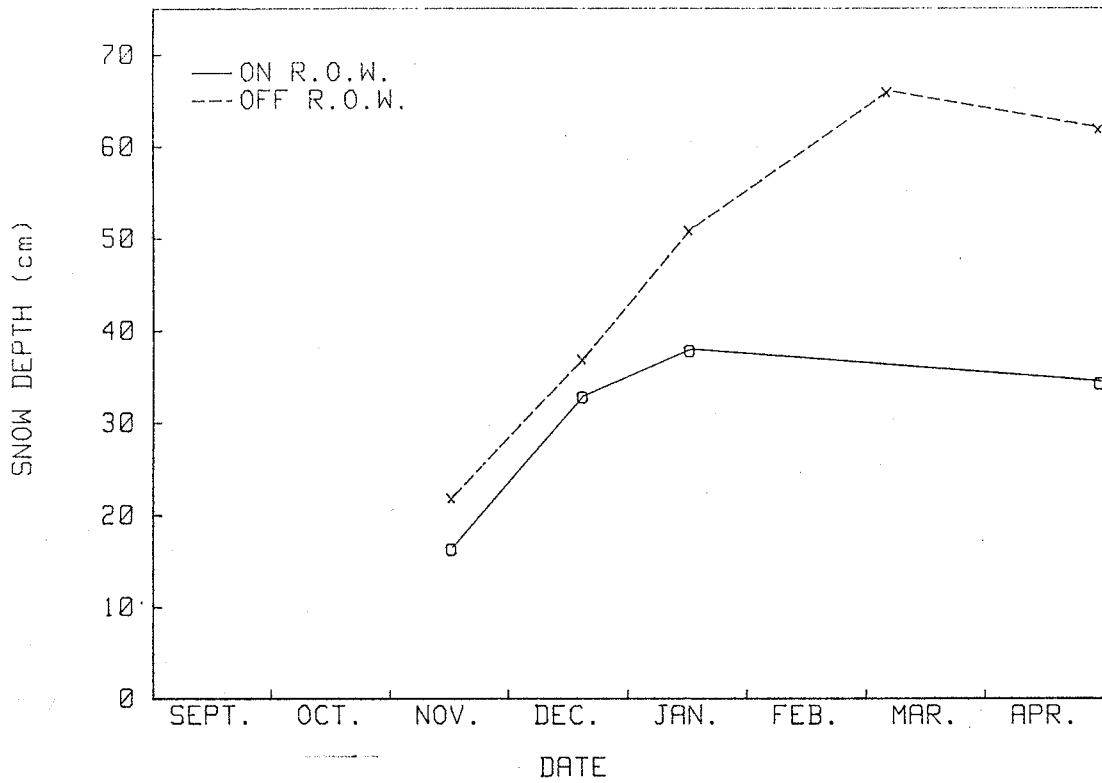
SNOW DEPTH AT SITE 84-1: 1985/86



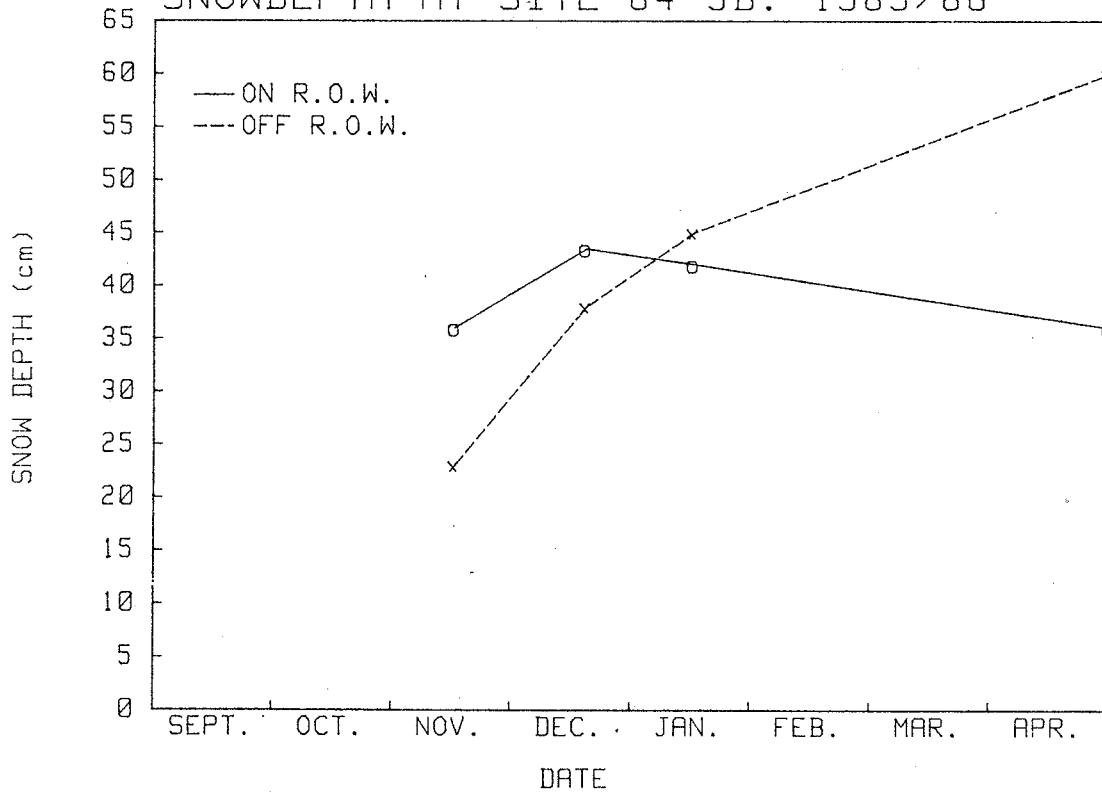
SNOW DEPTH AT SITE 84-2B: 1985/86



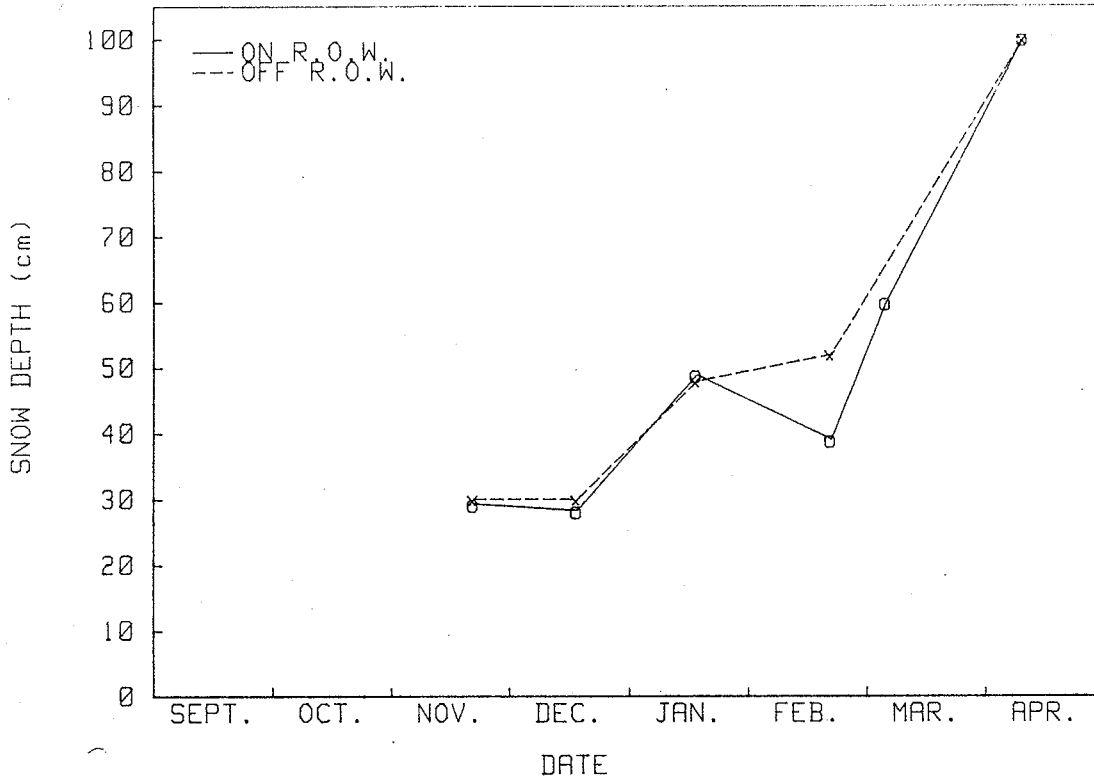
SNOW DEPTH AT SITE 84-2C: 1985/86



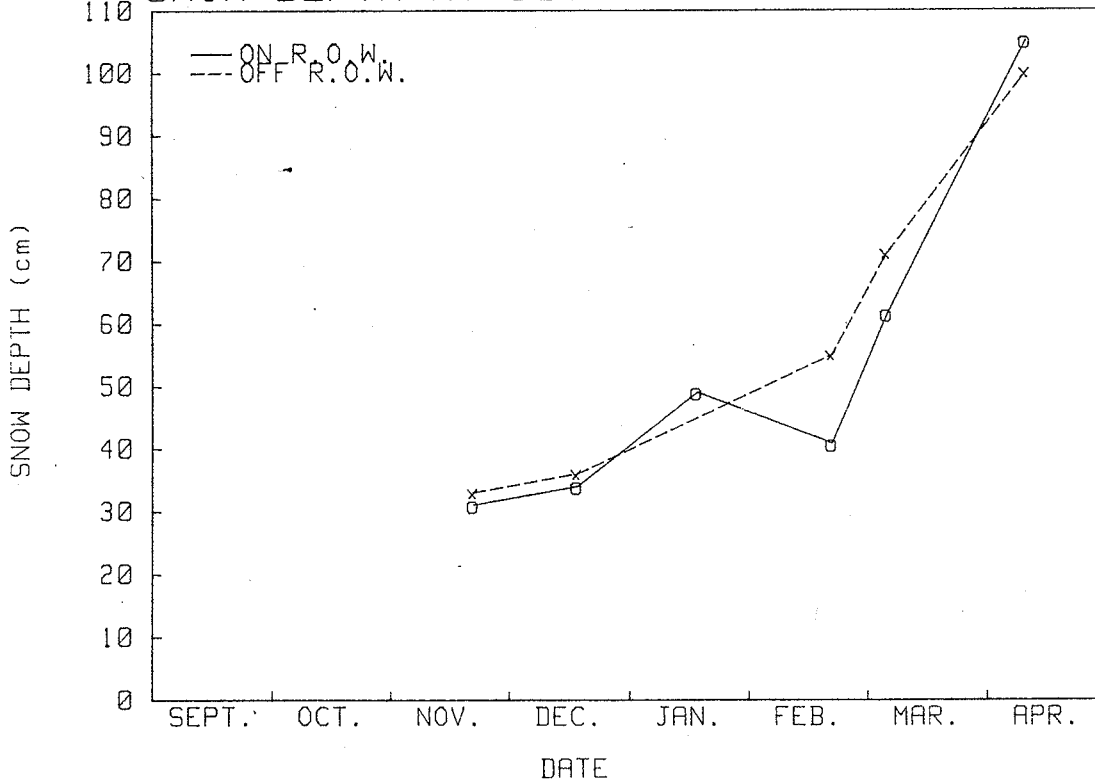
SNOWDEPTH AT SITE 84-3B: 1985/86



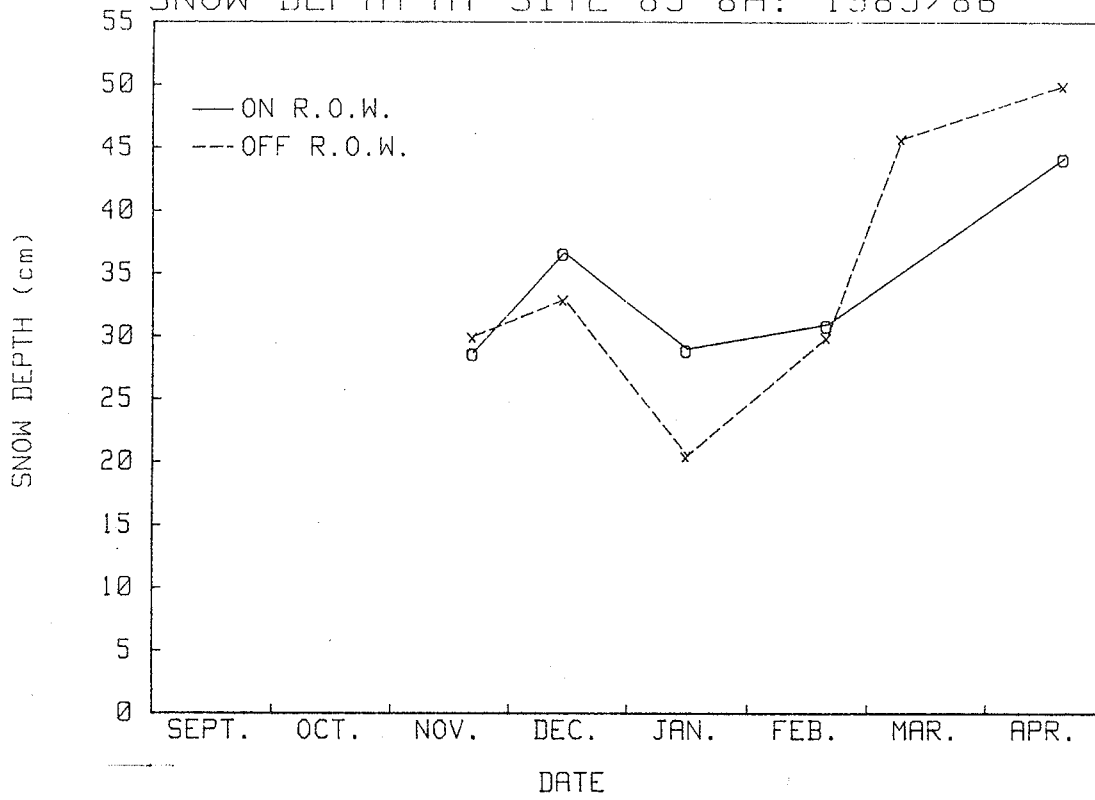
SNOW DEPTH AT SITE 84-4A: 1985/86



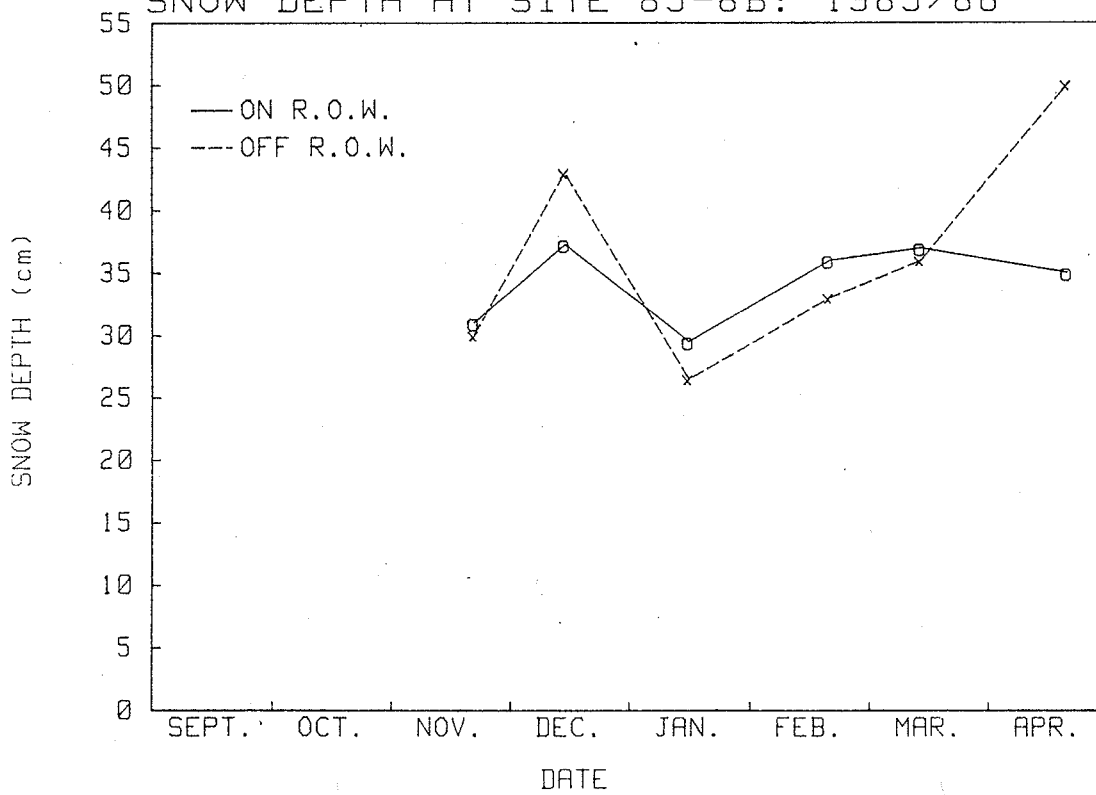
SNOW DEPTH AT SITE 84-4B: 1985/86



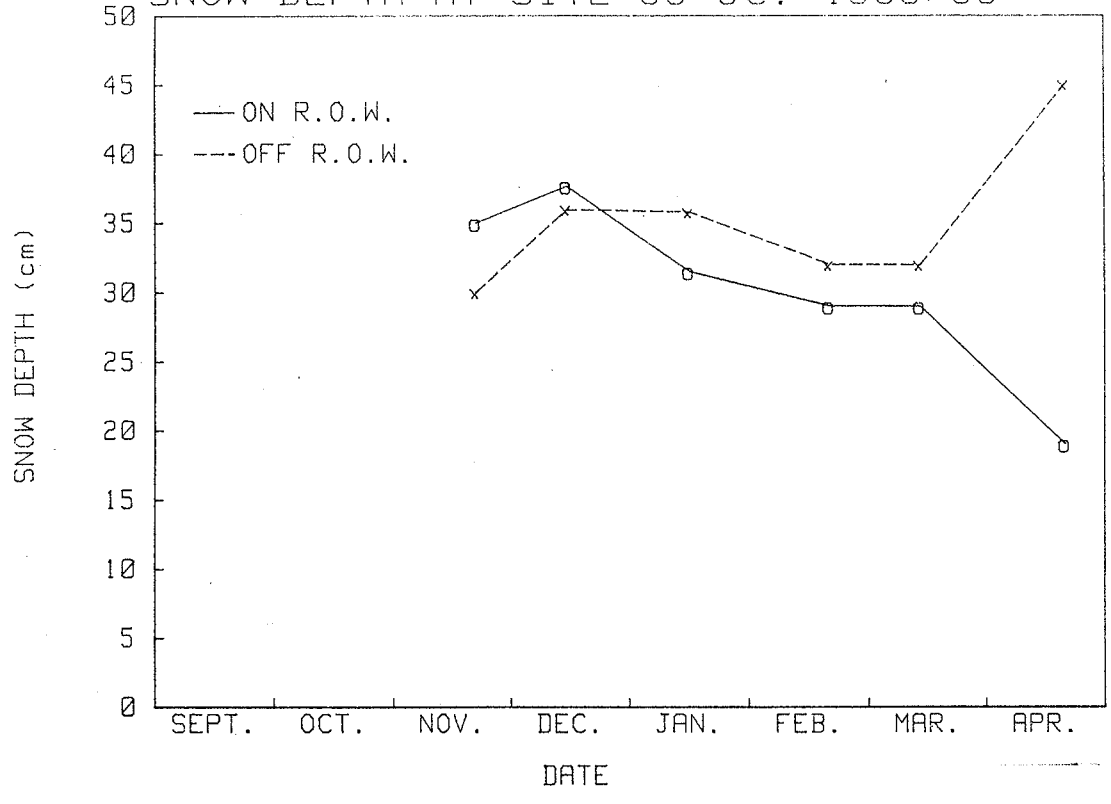
SNOW DEPTH AT SITE 85-8A: 1985/86



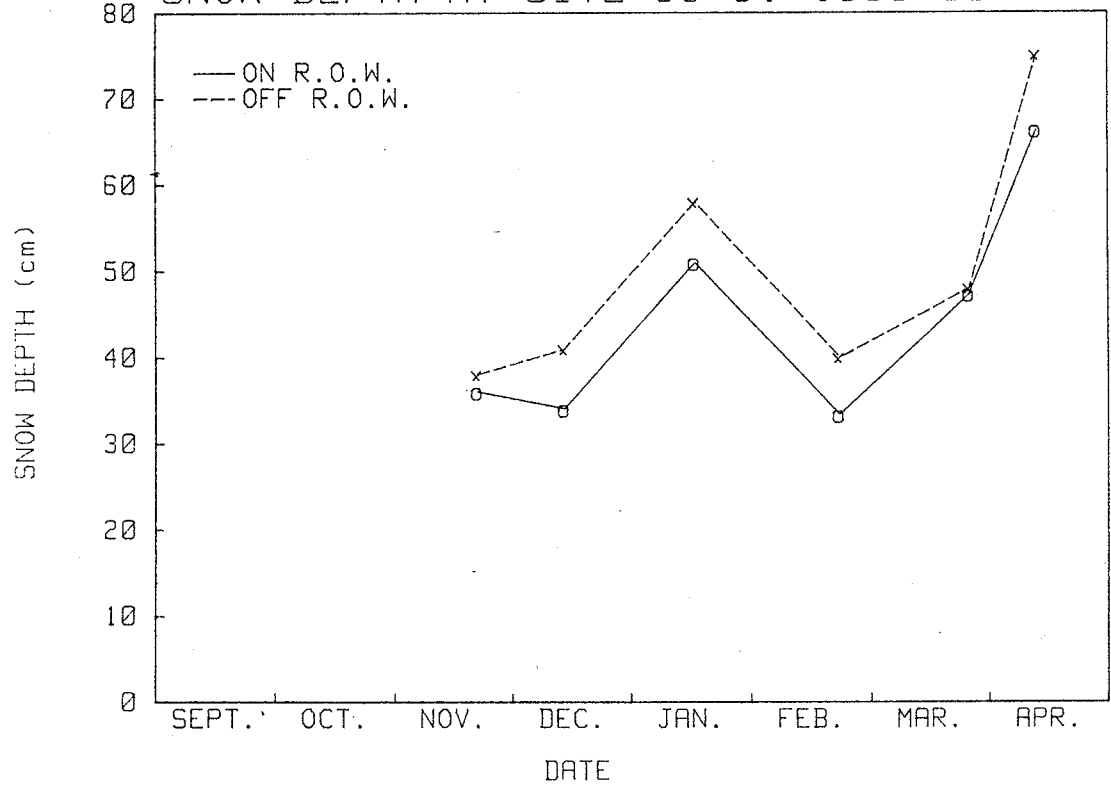
SNOW DEPTH AT SITE 85-8B: 1985/86



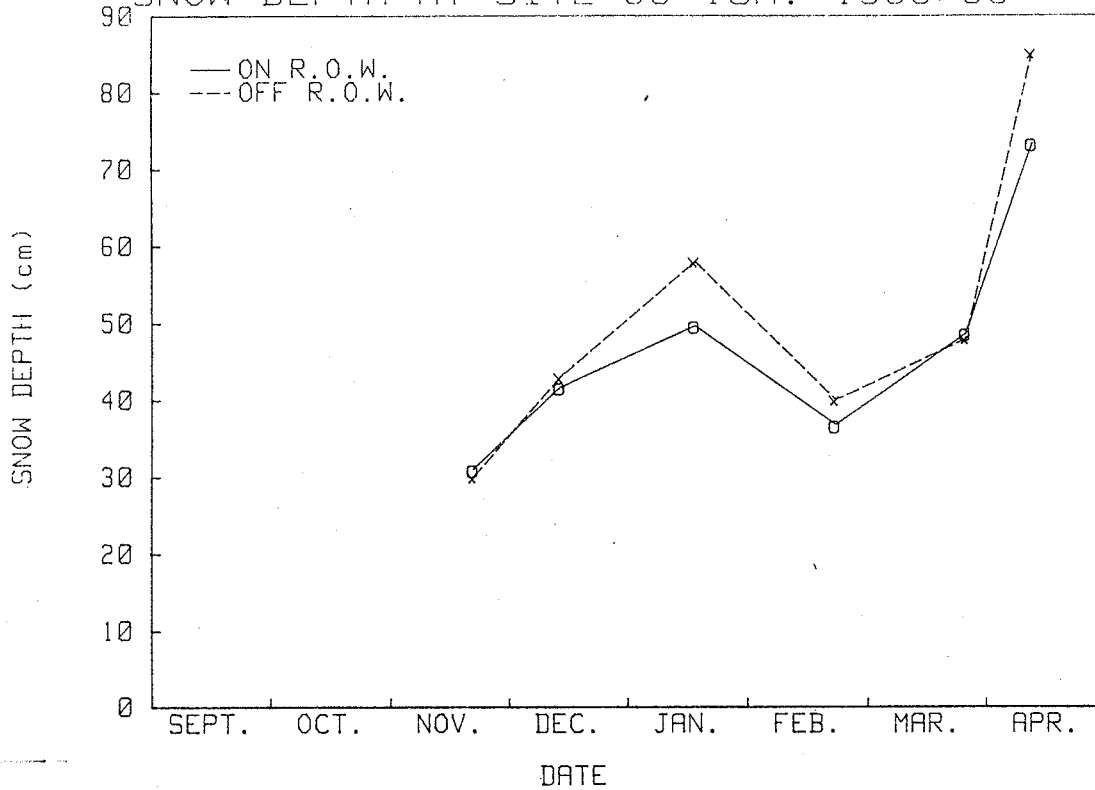
SNOW DEPTH AT SITE 85-8C: 1985/86



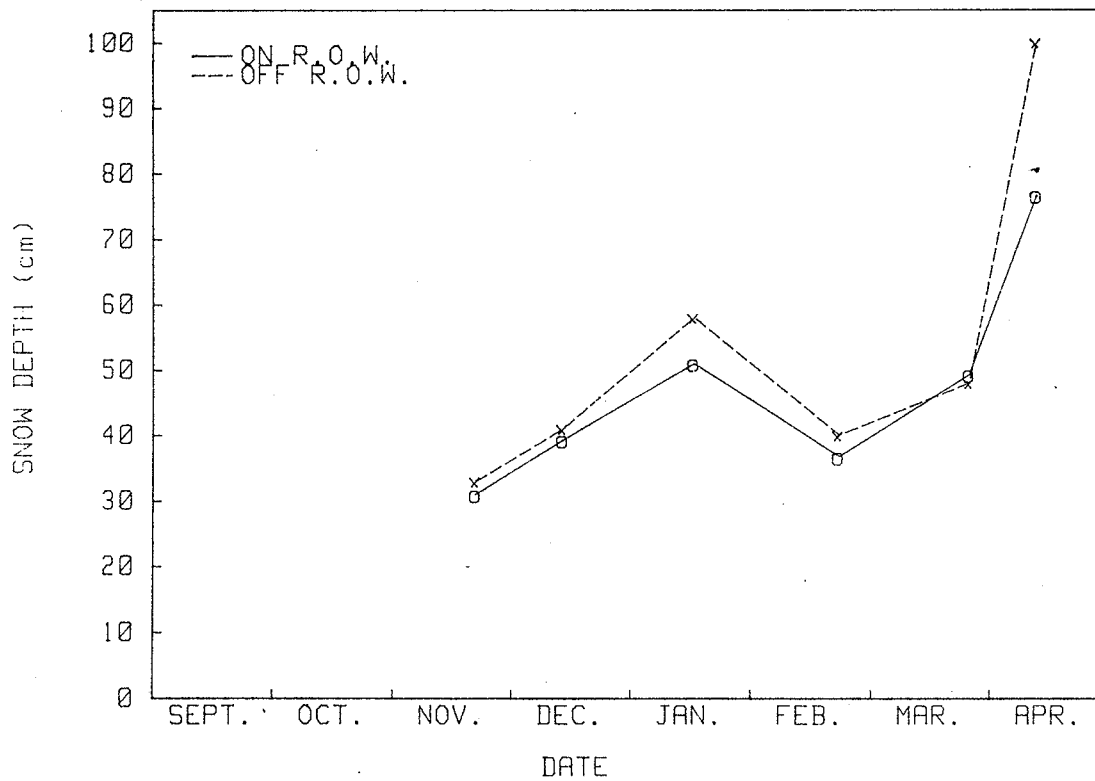
SNOW DEPTH AT SITE 85-9: 1985/86



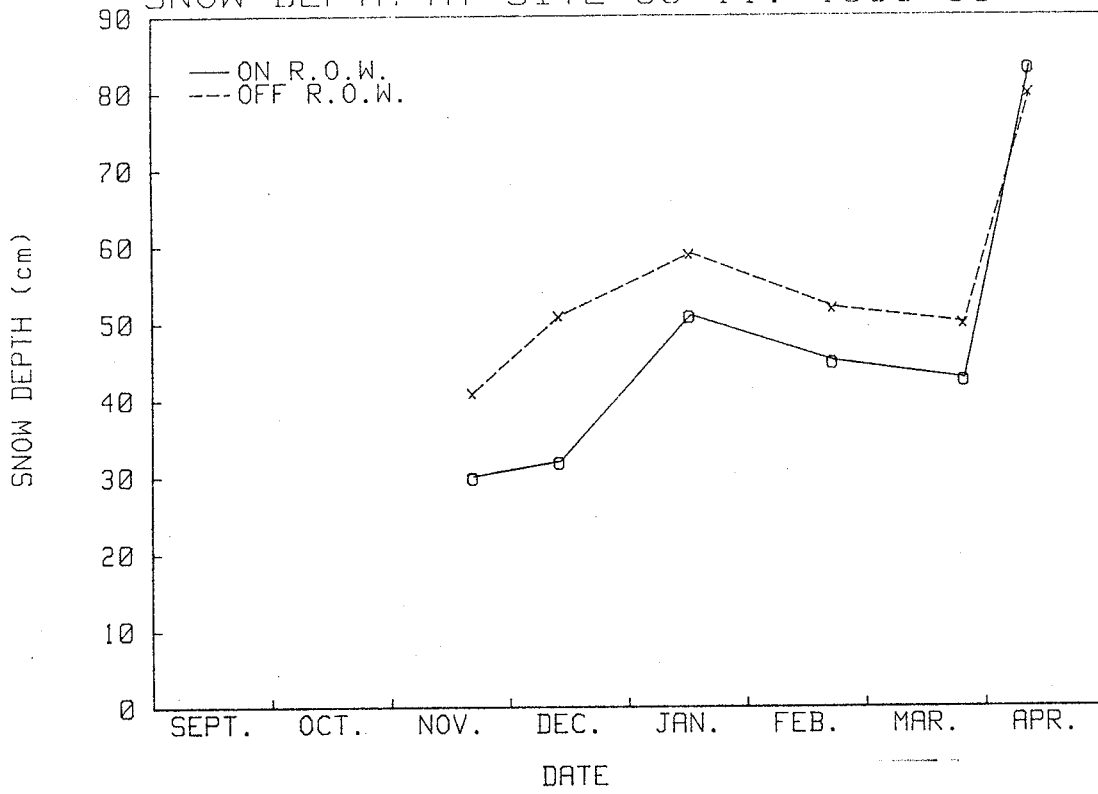
SNOW DEPTH AT SITE 85-10A: 1985/86



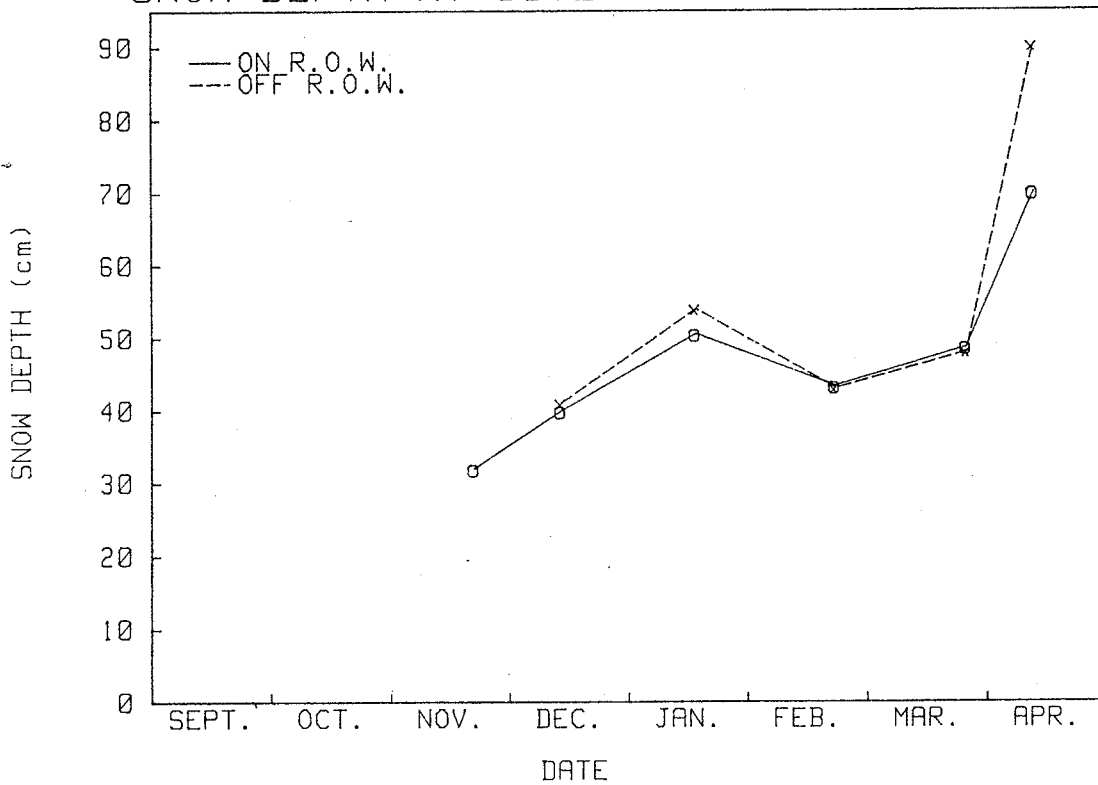
SNOW DEPTH AT SITE 85-10B: 1985/86



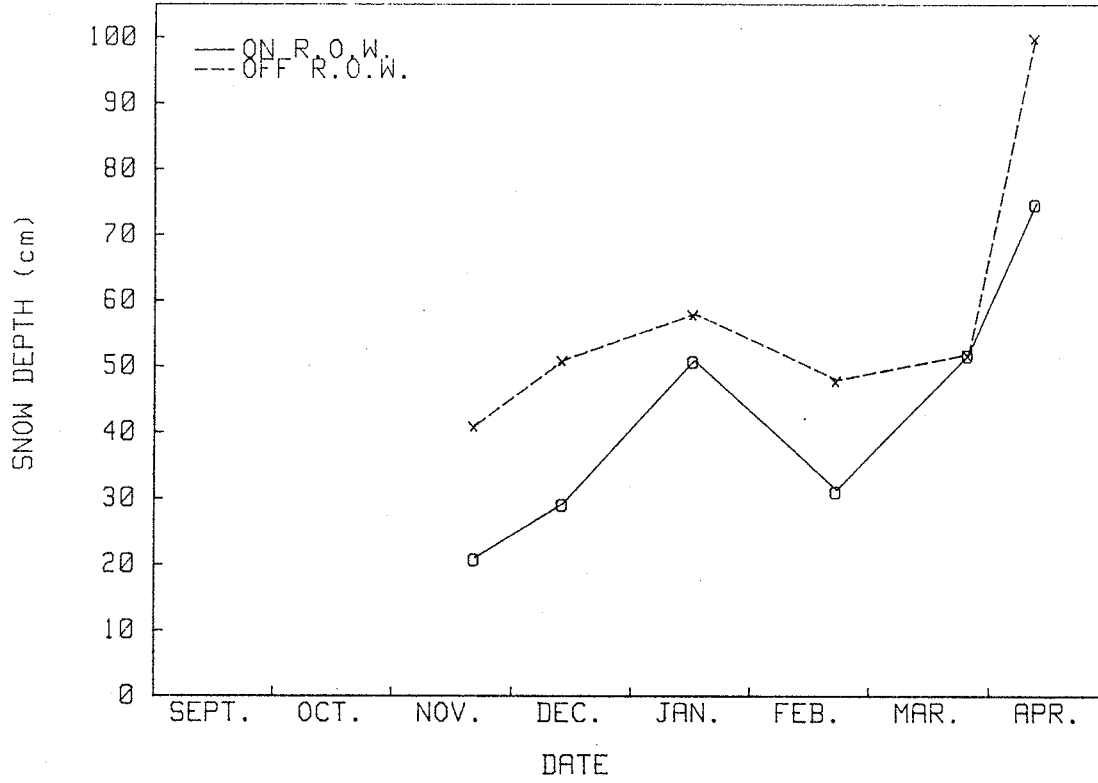
SNOW DEPTH AT SITE 85-11: 1985/86



SNOW DEPTH AT SITE 85-12A: 1985/86

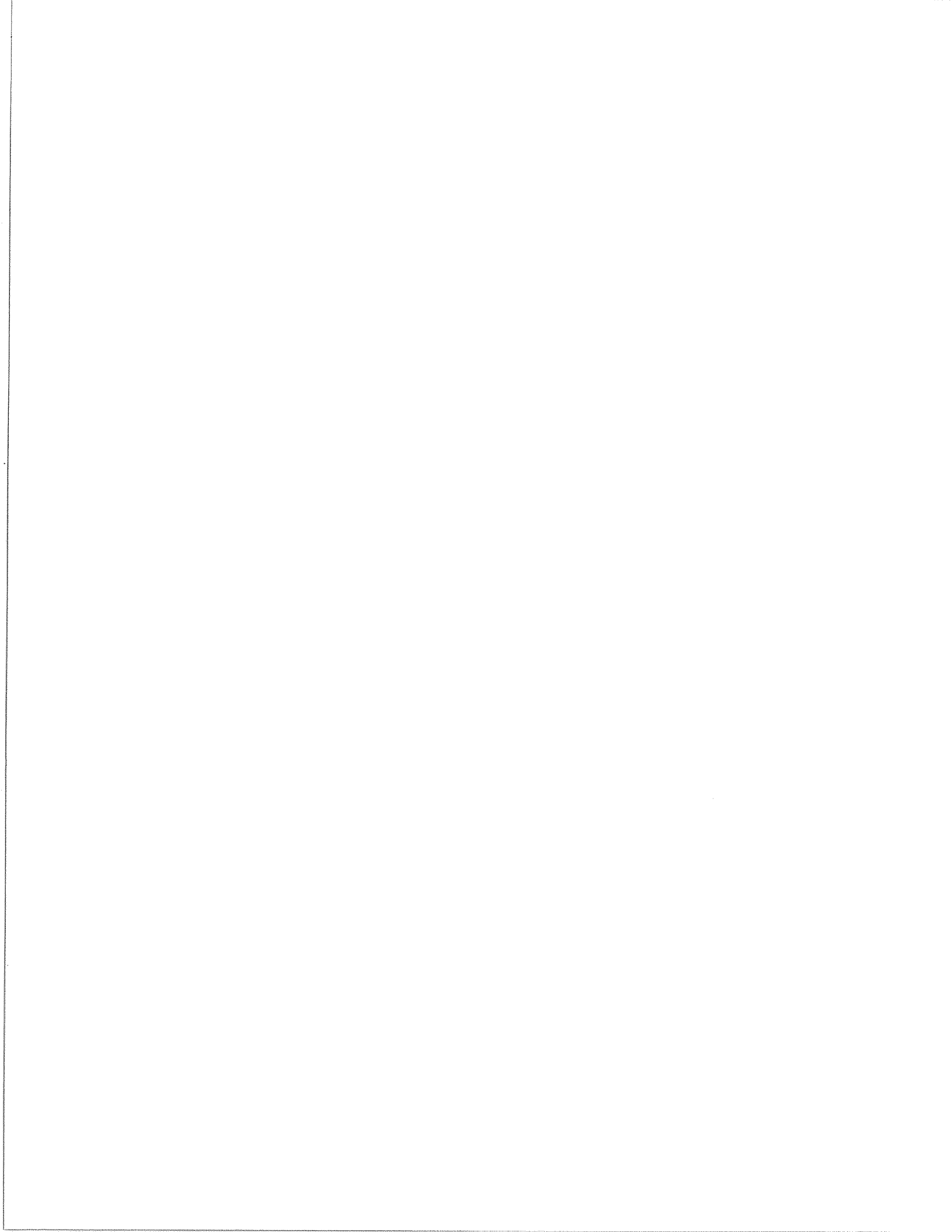


SNOW DEPTH AT SITE 85-12B: 1985/86



APPENDIX D

TABLES OF SNOW DEPTH MEASUREMENTS



Norman Wells to Zama Pipeline Snowdepths (cm)
kmp 0.0 to 272.3

Site	September	October	November	December	January	February	March	April	May
1 - on ROW 84/85							32.5	100	
1 - off ROW 84/85							63	150	
1 - on ROW 86/87	8.75	8	18	30	40	40		43.3	
1 - off ROW 86/87	9.25	8	15	25	40	40		50	
1 - on ROW 87/88			20	30	33.3	30	22.5		
1 - off ROW 87/88			20	30	30	35	30		
1 - on ROW 88/89				35		35	50		
1 - off ROW 88/89		25		40		45	70		
1 - on ROW 89/90				47.5	55	58.3	53.3		
1 - off ROW 89/90				48	60	60	60		
1 - on ROW 90/91		10		27	46.6				
1 - off ROW 90/91		8		35	50				
2A - on ROW 84/85			15						
2A - on ROW 86/87	13	10		18	32	30	40		
2A - off ROW 86/87	11.5	12.5		30	40	50	58		
2A - on ROW 87/88			27		25	25	20	15	
2A - off ROW 87/88			30		35	60	45	45	
2A - on ROW 88/89		22		25			35	30	
2A - off ROW 88/89		25		45			88	75	
2A - on ROW 89/90		20		35		60	35		0
2A - off ROW 89/90		10		50		35	70		20
2A - on ROW 90/91		15		25	25				
2A - off ROW 90/91		10		33	50				
2B - on ROW 84/85			15						
2B - on ROW 86/87	9.75	7.5	10		22	20	35	40	
2B - off ROW 86/87	5.5	10	15		45	50	55	60	
2B - on ROW 87/88				18	20	21	15	10	
2B - off ROW 87/88				24.5	35	40	35	40	
2B - on ROW 88/89		22				20	40	30	
2B - off ROW 88/89		20		38		50	80	60	
2B - on ROW 89/90		6		15		20	20		
2B - off ROW 89/90		6		40		65	60		
2B - on ROW 90/91		1		8	5				20
2B - off ROW 90/91				25	38				
2C - on ROW 84/85			15						
2C - on ROW 86/87	5	7.5	15	25	41	50	48	50	
2C - off ROW 86/87		7.5	10		30	30	50	50	
2C - on ROW 87/88					35	30	25	40	
2C - off ROW 87/88					45	35	30	35	
2C - on ROW 88/89		20		40		45	58		
2C - off ROW 88/89		10		25		70	100		
2C - on ROW 89/90				40		60	55		0
2C - off ROW 89/90				30		50	45		0
2C - on ROW 90/91		8		20	18				
2C - off ROW 90/91		6		20	40				
3A - on ROW 84/85			60						
3A - on ROW 86/87		5	20	30		50	50		
3A - off ROW 86/87		5	18	25		50	80		
3A - on ROW 87/88					19	35	30	63	
3A - off ROW 87/88			15		32	40	45		
3A - on ROW 88/89		30		45		40	50		
3A - off ROW 88/89		15		26		95	120		
3A - on ROW 89/90				50			60		0
3A - off ROW 89/90				60			80		30
3A - on ROW 90/91		5		32	35				
3A - off ROW 90/91		5		37	110				
3B - on ROW 84/85			15						
3B - on ROW 86/87	6.25	12.5	18	20	30	30	25	50	
3B - off ROW 86/87		10	8	15	30	30	55	45	
3B - on ROW 87/88				30	25		30	28	
3B - off ROW 87/88					18	25	25	30	
3B - on ROW 88/89		20		30		15	20		
3B - off ROW 88/89		17		14		50	43		
3B - on ROW 89/90				45		65			0
3B - off ROW 89/90				40		60	40		0
3B - on ROW 90/91		5							
3B - off ROW 90/91		8		28	30				
7A - on ROW 85/86							64.5		
7A - on ROW 86/87	10	5	20	20	20	35	40		
7A - off ROW 86/87	10	5	20	25	25	40	55		
7A - on ROW 87/88			30	35	45	40	40	5	
7A - off ROW 87/88			25	40	45	45	45	10	
7A - on ROW 88/89		33		40	45			35	
7A - off ROW 88/89		25		32.5	42			55	
7A - on ROW 89/90				60		58	57		0
7A - off ROW 89/90				60		57	60		0
7A - on ROW 90/91		4		35	60				
7A - off ROW 90/91		35		26	70				

Norman Wells to Zama Pipeline Snowdepths (cm)
 kmp 0.0 to 272.3

Site	September	October	November	December	January	February	March	April	May
7B - on ROW 85/86							94		
7B - on ROW 86/87	10	5		25	25		45		
7B - off ROW 86/87	10	5					55		
7B - on ROW 87/88			30	40			45	15	
7B - off ROW 87/88			35	35			45	20	
7B - on ROW 88/89		30		37	45			40	
7B - off ROW 88/89		30		30	46			50	
7B - on ROW 89/90		15		60		59	55		0
7B - off ROW 89/90		15		61		60	60		0
7B - on ROW 90/91		3		34	60				
7B - off ROW 90/91		3		28	70				
7C - on ROW 86/87	3.25	5	15	20	30	35	45		
7C - off ROW 86/87	7.5	5	15	20	30	40	70		
7C - on ROW 87/88			25	40	35	35	30	0	
7C - off ROW 87/88			30	35	40	40	60	30	
7C - on ROW 88/89		25		28	37			28	
7C - off ROW 88/89		25		37	46			65	
7C - on ROW 89/90		15		48		48	40		0
7C - off ROW 89/90		15		58		58	75		0
7C - on ROW 90/91		2		20	45				
7C - off ROW 90/91		2		34	75				
Norman Wells A 82/83		16	23	35	28	30	18	0	
Norman Wells A 83/84		8	9	9	12	16	14	0	
Norman Wells A 84/85		6	12	33	40	30	23	27	
Norman Wells A 85/86		7	20	26	28	20	25	4	
Norman Wells A 86/87		8	12	17	16	17	14	4	
Norman Wells A 87/88		6	15	15	20	8	9	0	
Norman Wells A 88/89		5	16	9	8	8	19	0	
Norman Wells A 89/90		10	12	11	13	8	7	0	
Norman Wells A 90/91		7	14	21	26	33	32	1	

Snow Depths (cm) at AES Weather Stations

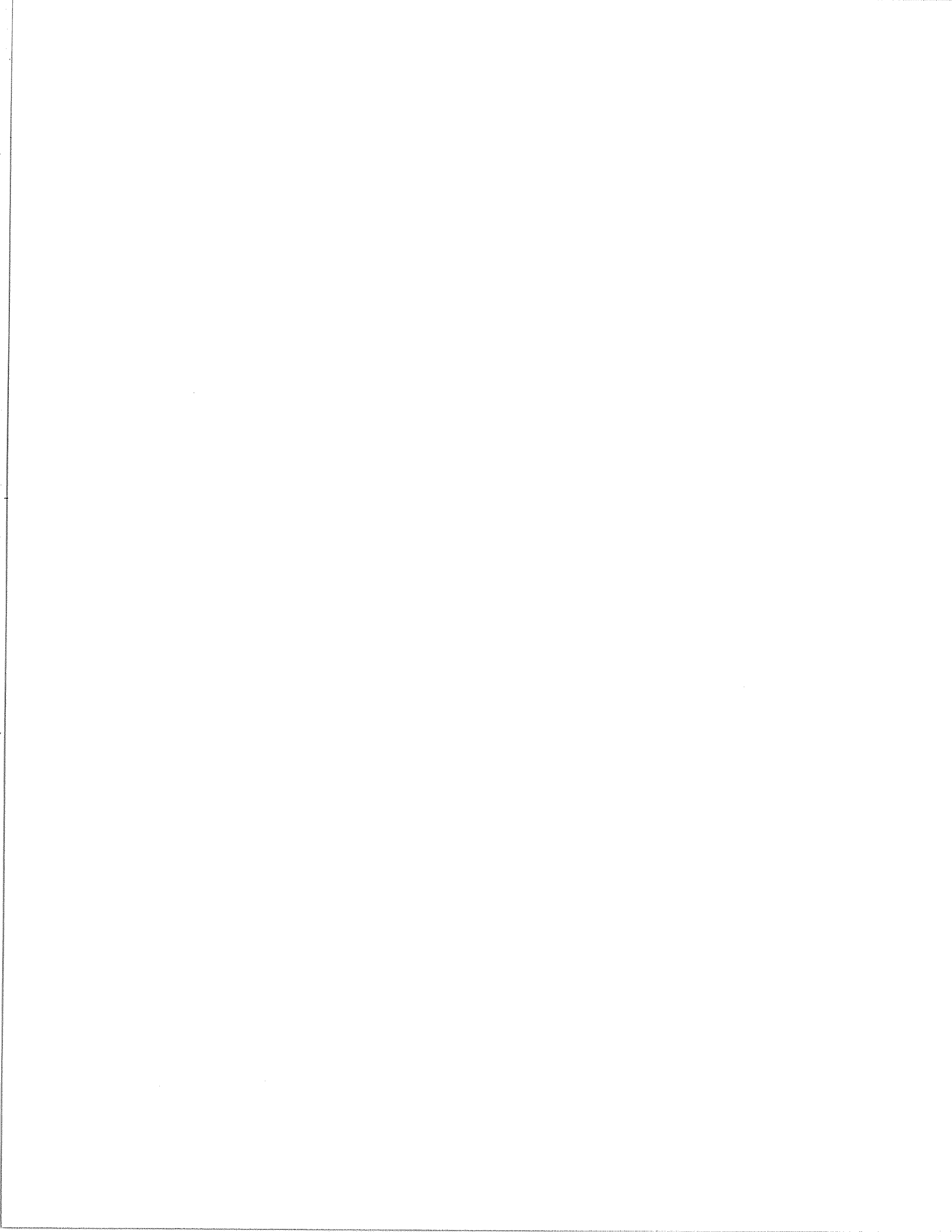
Site	October	November	December	January	February	March	April
Norman Wells A 82/83	16	23	35	28	30	18	0
Norman Wells A 83/84	8	9	9	12	16	14	0
Norman Wells A 84/85	6	12	33	40	30	23	27
Norman Wells A 85/86	7	20	26	28	20	25	4
Norman Wells A 86/87	8	12	17	16	17	14	4
Norman Wells A 87/88	6	15	15	20	8	9	0
Norman Wells A 88/89	5	16	9	8	8	19	0
Norman Wells A 89/90	10	12	11	13	8	7	0
Norman Wells A 90/91	7	14	21	26	33	32	1
Fort Simpson A 82/83	37	44	50	59	66	66	0
Fort Simpson A 83/84	14	33	34	45	77	72	0
Fort Simpson A 84/85	4	19	29	35	50	25	14
Fort Simpson A 85/86	27	26	29	52	48	56	6
Fort Simpson A 86/87	5	15	31	34	46	40	0
Fort Simpson A 87/88	9	33	49	64	43	60	0
Fort Simpson A 88/89	22	33	29	49	46	40	0
Fort Simpson A 89/90	16	39	45	47	48	29	0
Fort Simpson A 90/91	29	33	46	42	53	53	TR

Norman Wells to Zama Pipeline Snowdepths (cm)
 kmp 478.0 to 819.5

Site	September	October	November	December	January	February	March	April	May
4A - on ROW 84/85						120			
4A - on ROW 86/87		7.5		25	25		55.9		
4A - off ROW 86/87		7.5		25	30		47.8		
4A - on ROW 87/88			25	45	55	55			
4A - off ROW 87/88			25	40	55	55			
4A - on ROW 90/91		2							
4A - off ROW 90/91		2							
4B - on ROW 84/85						120			
4B - on ROW 86/87		10	20	25	25	40	48		
4B - off ROW 86/87		10	15	25	25	45	60		
4B - on ROW 87/88			25	45		45		15	
4B - off ROW 87/88			25	40		55		15	
4B - on ROW 88/89		25					50		
4B - off ROW 88/89		20					60		
4B - on ROW 89/90							60		0
4B - off ROW 89/90							62		0
4B - on ROW 90/91		2		33	45				
4B - off ROW 90/91		2		45	53				
8A - on ROW 86/87		trace	25	25	25	35	45	40	
8A - off ROW 86/87		trace	5	10	15	15	25	20	
8A - on ROW 87/88			20	50	60		55	30	
8A - off ROW 87/88			10	25	35		40	20	
8A - on ROW 88/89		30		40	48		55		
8A - off ROW 88/89		10		20	44		35		
8A - on ROW 89/90		40		42		55	55		0
8A - off ROW 89/90		35		38		53	35		0
8A - on ROW 90/91		2		30	40				
8A - off ROW 90/91		2		35	40				
8B - on ROW 86/87		trace	25	20	25	35	45	30	
8B - off ROW 86/87		trace	20	15	15	30	40	30	
8B - on ROW 87/88			15	50	55	55	50	30	
8B - off ROW 87/88			10	45	50	50	55	15	
8B - on ROW 88/89		30		35	50		50		
8B - off ROW 88/89		15		30	46		48		
8B - on ROW 89/90		40		50		55	45		0
8B - off ROW 89/90		35		45		55	55		0
8B - on ROW 90/91		4		50	45				
8B - off ROW 90/91		4		40.5	48				
8C - on ROW 86/87		trace	30	25	28	30	40	30	
8C - off ROW 86/87		trace	15	25	25	20	40	30	
8C - on ROW 87/88			20	50	60	50	50	25	
8C - off ROW 87/88			20	45	55	60	50	15	
8C - on ROW 88/89		30		35	49		50		
8C - off ROW 88/89		20		35	48		53		
8C - on ROW 89/90		40		46		52	50		
8C - off ROW 89/90		35		53		63	55		
8C - on ROW 90/91		4		70	60				
8C - off ROW 90/91		4		50	55				
9 - on ROW 86/87		trace	25	30	30	30	45	40	
9 - off ROW 86/87		trace	15	20	30	30	50	30	
9 - on ROW 87/88			25	45	55	55	65	20	
9 - off ROW 87/88			15	45	40	60	55	25	
9 - on ROW 88/89		30		30	50		54		
9 - off ROW 88/89		15		25	40		50		
9 - on ROW 89/90		40		48		68	50		
9 - off ROW 89/90		35		45		65	50		
9 - on ROW 90/91		1		50	35				
9 - off ROW 90/91		1		55	40				
10A - on ROW 86/87		trace	15	30	30	40	55	40	
10A - off ROW 86/87		trace	10	25	25	28	40	40	
10A - on ROW 87/88			20	50	60	60	68	35	
10A - off ROW 87/88			20	40	40	50	55	20	
10A - on ROW 88/89		40		50	65		65		
10A - off ROW 88/89		10		25	45		40		
10A - on ROW 89/90		40		60		72	70		0
10A - off ROW 89/90		35		38		55	45		0
10A - on ROW 90/91		1		50	60				
10A - off ROW 90/91		1		45	55				
10B - on ROW 86/87		trace	15	20	32	40	55	50	
10B - off ROW 86/87		trace	17.5	20	23	30	40	30	
10B - on ROW 87/88			15	50	55	55	75	40	
10B - off ROW 87/88			20	40	55	55	60	30	
10B - on ROW 88/89		20		35	65		55		
10B - off ROW 88/89		15		25	50		55		
10B - on ROW 89/90		40		47		61	55		
10B - off ROW 89/90		35		43		68	50		
10B - on ROW 90/91		1		50	60				
10B - off ROW 90/91		1		45	50				

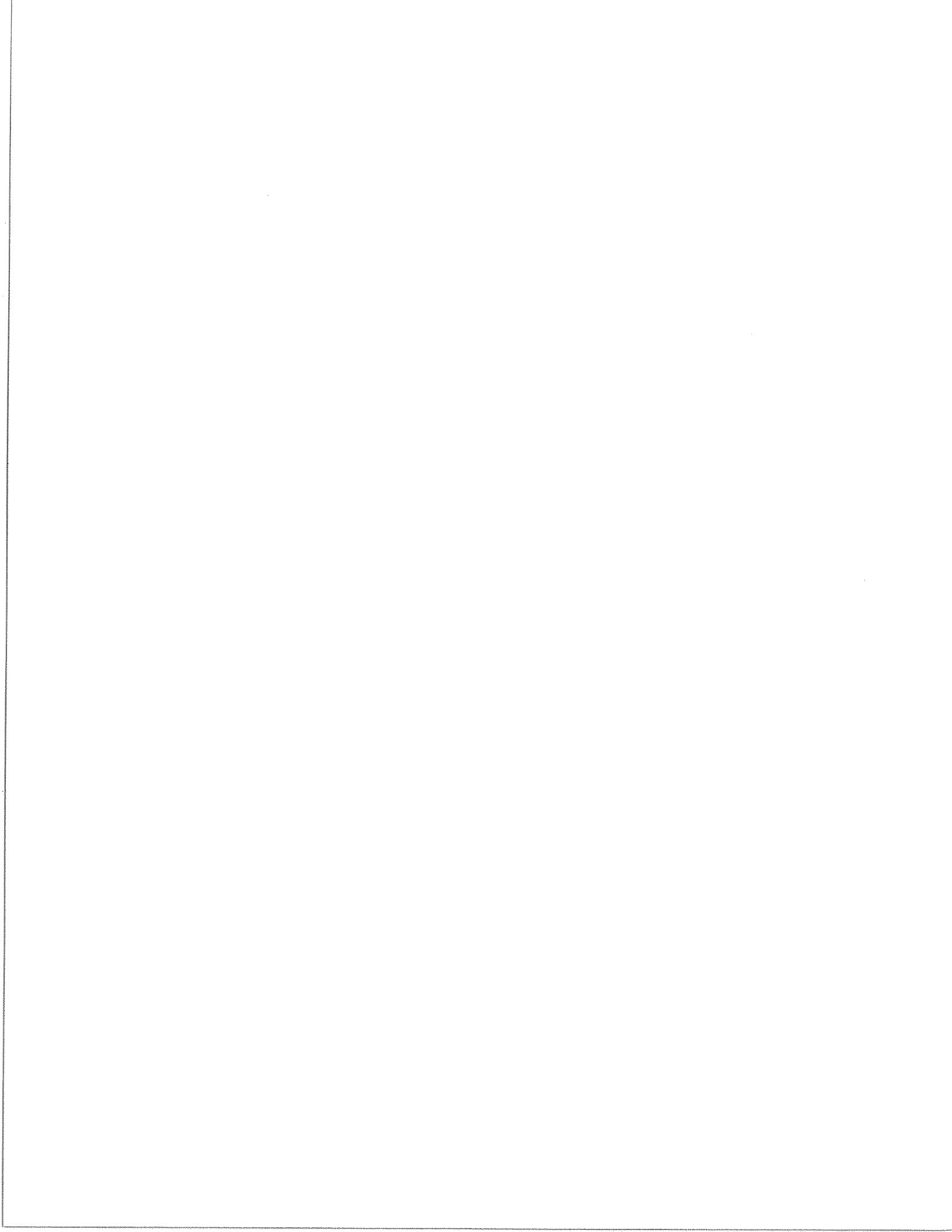
Norman Wells to Zama Pipeline Snowdepths (cm)
kmp 478.0 to 819.5

Site	September	October	November	December	January	February	March	April	May
11 - on ROW 86/87		trace	15	20	20	45	50	30	
11 - off ROW 86/87		trace	20	30	30	40	55	40	
11 - on ROW 87/88			25	55	60	60	60	25	
11 - off ROW 87/88			20	50	60	65	72	35	
11 - on ROW 88/89		35		40	55		51		
11 - off ROW 88/89		25		35	50		57		
11 - on ROW 89/90		35		60		75	55		0
11 - off ROW 89/90		25		45		77	55		0
11 - on ROW 90/91		1		55	60				
11 - off ROW 90/91		1		45	50				
12A - on ROW 86/87		trace	20	30	30	35	50	40	
12A - off ROW 86/87		trace	20	30	30	50	60	40	
12A - on ROW 87/88			15	55	60	60	68	25	
12A - off ROW 87/88			25	55	60	65	74	35	
12A - on ROW 88/89		35		35	65		70		
12A - off ROW 88/89		25		40	50		65		
12A - on ROW 89/90		35		57		75	70		0
12A - off ROW 89/90		30		58		78	70		0
12A - on ROW 90/91		trace		60	60				
12A - off ROW 90/91		trace		55.5	70				
12B - on ROW 86/87		trace	10	20		30	40	30	
12B - off ROW 86/87		trace	20	25	35	40	50	30	
12B - on ROW 87/88			15	55	50	50	65	20	
12B - off ROW 87/88			20	45	60	60	65	15	
12B - on ROW 88/89		10		30			42		
12B - off ROW 88/89		25		30			50		
12B - on ROW 89/90		30		38		59	55		0
12B - off ROW 89/90		35		44		65	58		0
12B - on ROW 90/91		1		40	55				
12B - off ROW 90/91		1		45	50				
13 - on ROW 86/87		trace					38.5		
13 - off ROW 86/87		trace							
13 - on ROW 90/91		trace							
13 - off ROW 90/91		trace							
5A - on ROW 84/85						120			
5A - on ROW 86/87							75.4		
5A - off ROW 86/87							67.7		
5A - on ROW 87/88			11						
5A - on ROW 90/91		dusting							
5A - off ROW 90/91		dusting							
5B - on ROW 84/85						90			
5B - on ROW 86/87							62.7		
5B - off ROW 86/87							66.5		
5B - on ROW 87/88			11.5						
5B - off ROW 87/88			20						
5B - on ROW 90/91		trace							
5B - off ROW 90/91		trace							
6 - on ROW 87/88							41		
6 - on ROW 90/91		trace							
6 - off ROW 90/91		trace							
Fort Simpson A 82/83		37	44	50	59	66	66	0	
Fort Simpson A 83/84		14	33	34	45	77	72	0	
Fort Simpson A 84/85		4	19	29	35	50	25	14	
Fort Simpson A 85/86		27	26	29	52	48	56	6	
Fort Simpson A 86/87		5	15	31	34	46	40	0	
Fort Simpson A 87/88		9	33	49	64	43	60	0	
Fort Simpson A 88/89		22	33	29	49	46	40	0	
Fort Simpson A 89/90		16	39	45	47	48	29	0	
Fort Simpson A 90/91		29	33	46	42	53	53	TR	



APPENDIX E

SNOW DENSITY MEASUREMENTS



SNOW SAMPLING MSC CORER MARCH 1987

Kmp	SITE	DATE D/M/Y	ON R.O.W.		OFF R.O.W.	
			Mean Depth(cm)	Mean Density	Mean Depth(cm)	Mean Density
18.97	84-2a	14/03/87	43.6	0.285	66.9	0.209
19.27	84-2b	14/03/87	45.7	0.296	48.7	0.174
19.55	84-2c	14/03/87	36.0	0.398	70.3	0.198
79.16	84-3a	10/03/87	56.7	0.195	90.5	0.238
79.40	84-3b	10/03/87	47.4	0.402	53.3	0.206
271.23	85-7a	10/03/87	48.3	0.137	51.2	0.199
271.99	85-7b	10/03/87	43.6	0.136	53.8	0.150
272.31	85-7c	10/03/87	49.1	0.206	49.5	0.183
477.99	84-4a	11/03/87	55.9	0.190	47.8	0.168
478.08	84-4b	11/03/87	50.0	0.212	49.5	0.188
557.83	85-8a	11/03/87	57.6	0.169	30.0	0.196
558.16	85-8b	11/03/87	38.5	0.176	42.7	0.178
558.33	85-8c	11/03/87	50.4	0.176	46.6	0.181
583.34	85-9	12/03/87	42.7	0.241	42.3	0.171
588.28	85-10a	12/03/87	50.4	0.158	41.5	0.153
588.69	85-10b	12/03/87	55.0	0.167	52.5	0.186
597.40	85-11	12/03/87	53.3	0.167	56.3	0.173
608.56	85-12a	12/03/87	50.4	0.203	54.2	0.164
608.72	85-12b	12/03/87	41.9	0.161	47.4	0.187
682.6	85-13c	12/03/87	38.5	0.165	--	--
782.96	84-5a	12/03/87	75.4	0.213	67.7	0.188
783.25	84-5b	12/03/87	61.4	0.120	66.0	0.198
819.51	84-6	12/03/87	62.7	0.189	67.7	0.200

Kmp = kilometre post along Norman Wells pipeline, south of Norman Wells.

Densities are in gr/cm³.

SNOW SAMPLING MSC CORER MARCH 1988

Kmp	SITE	DATE D/M/Y	ON R.O.W.		OFF R.O.W.	
			Mean Depth(cm)	Mean Density	Mean Depth(cm)	Mean Density
0.02	84-1	10/03/88	28.9	0.162	45.0	0.277
18.97	84-2a	10/03/88	26.3	0.179	46.0	0.216
19.55	84-2c	10/03/88	23.8	0.147	42.9	0.222
79.18	84-3a	10/03/88	28.9	0.164	46.3	0.166
79.40	84-3b	10/03/88	34.8	0.272	42.5	0.200
271.23	85-7a	09/03/88	44.2	0.129	51.8	0.181
271.99	85-7b	09/03/88	46.7	0.158	54.3	0.138
272.31	85-7c	09/03/88	44.8	0.186	49.3	0.217
477.99	84-4a	08/03/88	58.6	0.250	51.8	0.180
478.08	84-4b	08/03/88	56.1	0.193	61.2	0.224
557.83	85-8a	08/03/88	61.7	0.211	44.2	0.250
558.16	85-8b	08/03/88	50.6	0.185	20.5	0.220
558.33	85-8c	08/03/88	46.3	0.183	58.7	0.214
583.34	85-9	08/03/88	66.3	0.221	67.6	0.220
588.28	85-10a	08/03/88	70.3	0.209	23.8	0.213
588.67	85-10b	08/03/88	77.3	0.283	64.6	0.234
597.40	85-11	07/03/88	62.0	0.229	71.4	0.223
608.56	85-12a	07/03/88	67.0	0.221	67.1	0.234
608.72	85-12b	07/03/88	63.6	0.209	68.9	0.212
682.42	85-13c	07/03/88	56.8	0.251	--	--
782.96	84-5a	07/03/88	68.9	0.260	63.8	0.226
783.25	84-5b	07/03/88	47.6	0.227	47.2	0.208
819.51	84-6	07/03/88	42.9	0.193	41.2	0.175

Kmp = kilometre post along Norman Wells pipeline, south of Norman Wells.

Densities are in gr/cm³.

SNOW SAMPLING MSC CORER MARCH 1989

Kmp	SITE	DATE D/M/Y	ON R.O.W.		OFF R.O.W.	
			Mean Depth(cm)	Mean Density	Mean Depth(cm)	Mean Density
0.02	84-1	13/03/89	51.4	0.144	70.1	0.186
18.97	84-2a	14/03/89	43.4	0.200	86.7	0.193
19.27	84-2b	14/03/89	39.5	0.202	67.2	0.177
19.55	84-2c	14/03/89	54.4	0.236	91.8	0.216
79.16	84-3a	14/03/89	51.0	0.177	65.0	0.162
79.40	84-3b	14/03/89	19.5	0.199	66.3	0.187
271.23	85-7a	15/03/89	42.8	0.219	70.1	0.180
271.99	85-7b	15/03/89	54.8	0.189	57.4	0.175
272.31	85-7c	15/03/89	56.1	0.133	59.9	0.187
477.99	84-4a	16/03/89	56.6	0.170	49.7	0.172
478.08	84-4b	16/03/89	56.1	0.161	54.1	0.173
557.83	85-8a	16/03/89	63.8	0.189	39.1	0.215
558.16	85-8b	16/03/89	47.7	0.159	52.8	0.172
558.33	85-8c	16/03/89	53.6	0.200	55.3	0.175
583.34	85-9	16/03/89	54.8	0.145	56.6	0.161
588.28	85-10a	16/03/89	58.7	0.130	52.5	0.157
588.69	85-10b	16/03/89	59.4	0.224	51.5	0.146
597.40	85-11	17/03/89	62.1	0.119	63.0	0.160
608.56	85-12a	17/03/89	56.9	0.188	65.0	0.157
608.72	85-12b	17/03/89	48.5	0.154	59.2	0.163
782.96	84-5a	17/03/89	61.7	0.196	70.9	0.175
819.51	84-6	17/03/89	58.7	0.176	69.4	0.197
Gib Gap.		14/03/89	--	--	68.9	0.149

Kmp = kilometre post along Norman Wells pipeline, south of Norman Wells.

Densities are in gr/cm³.

Gib Gap = permafrost-climate site located in Gibson Gap, north of Norman Wells

SNOW SAMPLING MSC CORER MARCH 1990

Kmp	SITE	DATE D/M/Y	ON R.O.W.		OFF R.O.W.	
			Mean Depth(cm)	Mean Density	Mean Depth(cm)	Mean Density
0.02	84-1	25/03/90	52.3	0.152	60.4	0.207
18.97	84-2a	20/03/90	37.0	0.182	65.5	0.205
19.27	84-2b	20/03/90	28.5	0.304	57.0	0.203
19.55	84-2c	20/03/90	58.2	0.276	66.3	0.193
79.16	84-3a	20/03/90	59.1	0.110	65.9	0.195
79.40	84-3b	20/03/90	64.4	0.273	58.7	0.181
271.23	85-7a	21/03/90	62.1	0.210	66.0	0.191
271.99	85-7b	21/03/90	62.5	0.213	63.8	0.216
272.31	85-7c	21/03/90	61.2	0.213	74.4	0.223
477.99	84-4a	22/03/90	62.1	0.187	56.1	0.222
478.08	84-4b	22/03/90	71.8	0.207	57.8	0.223
557.83	85-8a	22/03/90	59.9	0.212	47.6	0.216
558.16	85-8b	22/03/90	42.9	0.180	57.0	0.219
558.33	85-8c	22/03/90	53.6	0.180	51.4	0.217
583.34	85-9	22/03/90	57.0	0.168	63.8	0.167
588.28	85-10a	22/03/90	70.6	0.157	60.8	0.174
597.40	85-11	22/03/90	60.7	0.159	69.3	0.191
608.72	85-12b	23/03/90	59.9	0.200	62.5	0.226
783.25	84-5b	23/03/90	57.8	0.191	65.0	0.208
819.51	84-6	23/03/90	57.0	0.206	52.7	0.201
Parsons L.		25/03/90	--	--	20.4	0.314
Travaillant L.		24/03/90	--	--	63.8	0.189
Yeltea		24/03/90	--	--	63.8	0.168

Kmp = kilometre post along Norman Wells pipeline, south of Norman Wells.

Densities are in gr/cm³.

Parsons L., Travaillant L. and Yeltea are permafrost/climate sites in the Mackenzie Valley, north of Norman Wells.

SNOW SAMPLING MSC CORER MARCH 1991

Kmp	SITE	DATE D/M/Y	ON R.O.W.		OFF R.O.W.	
			Mean Depth(cm)	Mean Density	Mean Depth(cm)	Mean Density
0.02	84-1	07/03/91	72.7	0.138	83.6	0.187
18.97	84-2a	08/03/91	55.3	0.153	97.8	0.201
19.27	84-2b	08/03/91	54.4	0.237	69.7	0.252
19.55	84-2c	08/03/91	49.3	0.194	90.1	0.249
79.16	84-3a	08/03/91	62.5	0.164	85.0	0.147
79.40	84-3b	08/03/91	--	--	81.6	0.166
271.23	85-7a	09/03/91	70.1	0.216	89.3	0.239
271.99	85-7b	09/03/91	66.8	--	76.5	--
478.08	84-4b	10/03/91	53.1	0.195	56.1	0.167
558.33	85-8c	10/03/91	49.2	0.236	63.8	0.181
583.34	85-9	10/03/91	68.4	0.172	70.1	0.215
588.28	85-10a	10/03/91	68.3	0.172	61.6	0.207
597.40	85-11	11/03/91	66.7	0.197	74.8	0.186
608.56	85-12a	11/03/91	52.7	0.201	79.6	0.197
682.60	85-13c	11/03/91	48.9	0.212	--	--
782.96	84-5a	11/03/91	75.7	0.226	72.3	0.218
819.51	84-6	11/03/91	75.7	0.215	51.4	0.213

Kmp = kilometre post along Norman Wells pipeline, south of Norman Wells.

Densities are in gr/cm³.