SMALL BASIN HYDROLOGY IN THE DISCONTINUOUS PERMAFROST ZONE

by

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ABSTRACT

The response of small northern basins to similar rainfall events can vary greatly due to dramatic changes with time in basin parameters. An attempt is made to understand and quantify these changes and suggestions to incorporate systematic variation in model parameters are made in order to produce a more reliable 'northern' model. Of particular interest are the permafrost regime, the vegetative cover, the evaporation process and the attenuation of the hydrographs making antecedent conditions important in predicting peak flows. Further ideas are presented to produce a deterministic model which incorporates both random and systematic changes in parameters in order to yield more reliable estimates of flow statistics for use in design.

The background study was sponsored by Canadian Arctic Gas Study Limited during their bid to construct a pipeline in the Mackenzie Valley.

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1.0 INTRODUCTION

While the permafrost regions of Canada constitute approximately one-half of the total land area of the country, very little attention has been focused on this vast area until recently. As a result, relatively little experience and virtually no base data exist to support the accelerated push of modern man into the vast regions of muskeg and permafrost. This dearth of experience and data is particularly apparent when dealing in the area of hydrologic design including drainage, erosion and environmental impact, since disturbing the water regime of an area can have far reaching environmental implications. Part of the solution applied to bridge this lack of information is the hydrologic modelling approach. Unfortunately the methods developed in southern regions often do not describe the northern environment well, resulting in inappropriate designs.

This thesis describes a preliminary examination of the hydrologic mechanisms under northern conditions, based on a study initiated by the Canadian Arctic Gas Study Limited during their bid to build a Mackenzie Valley Gas Pipeline. The study, at Chick Lake, N.W.T. (see Figure 1), set out to examine the summer hydrology of the muskeg/permafrost terrain type frequently encountered in the north, particularly in the transportation corridor of the Mackenzie Valley. Field work over a period of three years produced little in the way of 'hard' data, but from observations a great deal was learned about the processes involved and the inter-relation of the vegetation, permafrost and water regime. The work entailed

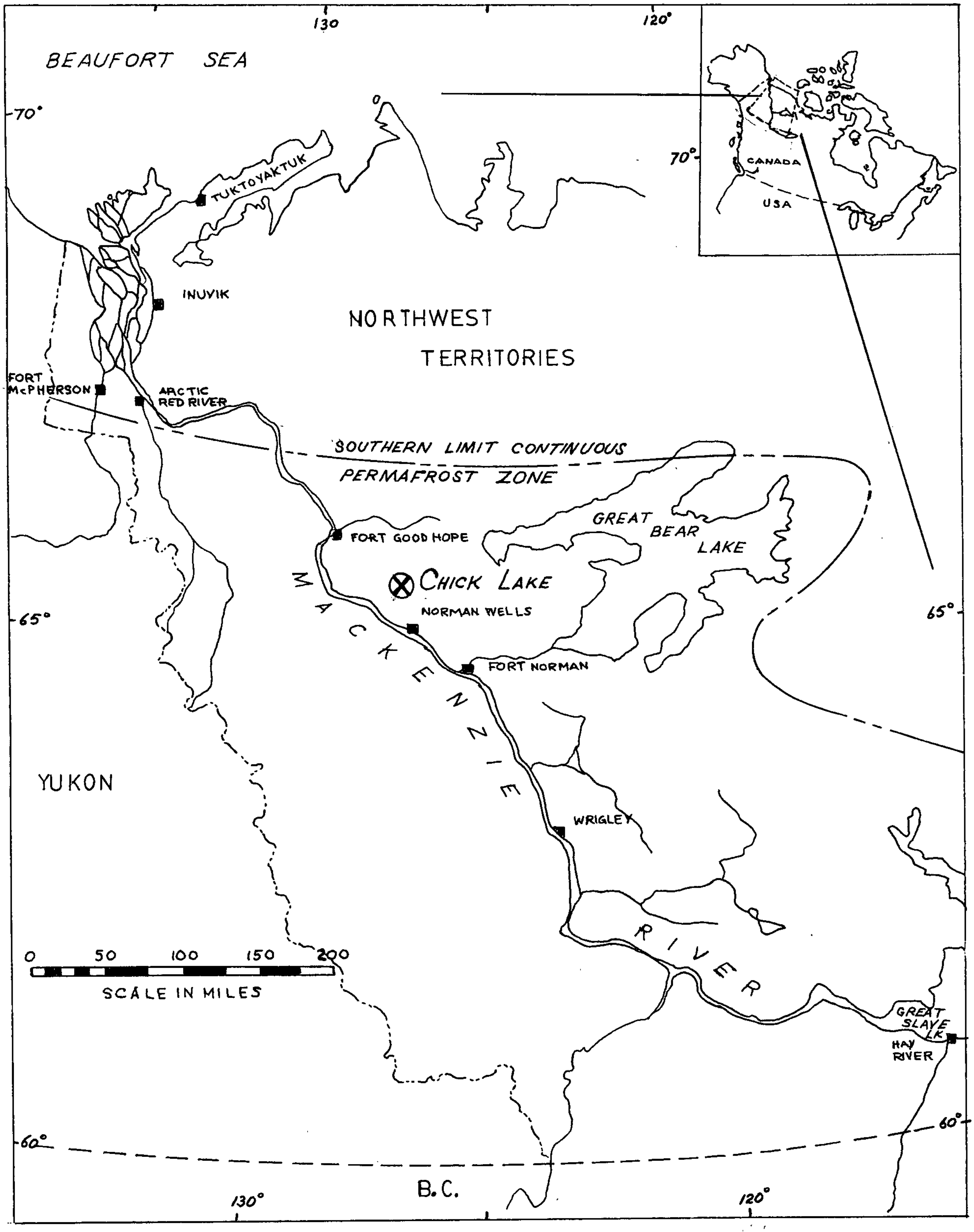


FIGURE 1: GENERAL LOCATION MAP

monitoring four small drainage basins, and correlating streamflows with rainfall data collected on site. This data was to provide the basis for designing and calibrating a suitable model for generating flood frequency data for structural design.

The results showed that some serious inaccuracies could arise from the direct application in northern areas of hydrologic techniques developed in temperate regions. The main point is that the basin (and thus the model) parameters change dramatically through the summer season. Further, since the surface layer storage is large, hydrographs of even small basins are greatly attenuated and thus the assumption that independent rainfall events produce independent flood peaks of similar return periods is generally invalid. Finally, the assumption that evaportation is negligible can be shown to be quite incorrect, and the process is an important mechanism when attempting to model the regime to provide valid flood frequency estimates.

The muskeg and permafrost regions of northern Canada are fundamentally different from a hydrologic viewpoint from those in the south. Over design can lead to as serious problems as can under design, since drainage of normally wet land will cause changes in the permafrost regime which in turn can seriously disrupt the ecology of a large area, or the development being constructed. Unfortunately, all to often 'southern' techniques are transplanted directly north and the effect of the permafrost and muskeg on the water regime is ignored. A brief survey conducted by Newbury (Newbury, 1974) indicated that a disturbing number of consultants and government departments with northern responsibilities fail to recognize the importance of permafrost on the water regime, and furthermore, are not interested in expanding their expertise in order to improve the quality of design. Hopefully, this potentially disastrous situation is gradually being rectified.

This thesis is broken into four somewhat overlapping sections plus an appendix. The first section presents terminology and concepts as envisioned by the author combined with general introduction to northern work. This followed by a detailed summary of the Chick Lake study. The third section combines the information from the first two and presents some ideas about applying the concepts to the design of a northern hydrologic model.

Since, of necessity, any major work in the north will require some field work there is an appendix outlining the hard and expensive lessons that were learned during the study, as well as some guidelines on what to look for and some of the limitations encountered while 'north of 60'. Finally, general conclusions and a summary round out the paper.

2.0 WHAT'S NORTH AND WHY

The most significant feature of the northern environment is the extreme winter cold. The low temperatures, the long hours of darkness, relatively little snow cover in winter and the warm, dry, brief summers of long sunlit days combine to produce an environment which is foreign to our training, theories and understanding. Permanently frozen ground (permafrost) exists in varying distribution from the southern limit of the continuous zone to the northern regions of the Canadian provinces. The scant available water and flat topography common to much of the heavily glaciated northern regions combined with the harsh environment are responsible for the development of the floral communities which play an important role in controlling the hydrologic regime.

Since this study was an attempt to gain some insight applicable to culvert and erosion design, only the maintenance of natural drainage is considered from these points of view. This eliminates truly low lying muskeg sinkholes, bogs and fens. The scenario which would generally apply is that of a mildly sloping basin, with perhaps localized flats, that ultimately would require some form of treatment to control flow if a structure (pipeline, road bed, etc.) were constructed in the downstream reaches. To this end an understanding of the mechanisms of basin response is required in order to model and finally synthesize short term flood statistics for return period events from meteorological records. Each important aspect of the environment is considered separately, followed by a discussion in general terms of the interrelation between aspects of the environment and the mechanisms important in northern regions.

2.1 PERMAFROST

The most tangible evidence of the harsh environment lies below the ground surface as permanently frozen soils and subsoils. An excellent summary of the terminology associated with the study of permafrost as well as a detailed map of the distribution of the continuous and discontinuous permafrost zones has been prepared by Brown(1974). The aspects of this phenomena of particular concern to hydrologists consist of:

(a) the depth to the top of the frozen zone at a given time and location (the depth to the frost table)

(b) the material of the "active layer" (that surface strata that experiences annual freezing and thawing)

(c) the areal extent of the permafrost.

These three items interact with the rest of the environment to change the basin characteristics markedly over the summer season, while more subtle evolutionary changes occur over the years.

With the onset of spring, what snow exists is rapidly melted and either runs off or is stored in the surface voids of the moss layer which overlies the concrete-like frozen peats (see Figure 2). This initial rush of snowmelt generally causes few erosion problems in small basins since the frozen surface material is not easily distrubed. As more solar energy is absorbed, the frost table moves down releasing material and water from the frozen grasp of winter. The rate of progress of the frost table is dependent on:

(a) the amount of incoming energy to the surface

(b) the transfer of this energy to the frozen soils.

Local weather, climate, latitude, aspect, topography and "high" vegetation cover (ie: tree cover) control the energy input while the surface and subsurface material, their history, local disturbance, type, colour, water content and relative location are important to the transfer of this energy. It is the latter area to which the bulk of the hydrologist's special attention must be focused in the development and use of a suitable technique for providing flood statistics.

After about the first two weeks of spring melt the frost table has moved through the surface mosses into the solid peat below. The rate of regression of the frost front is affected by the insulating value of the overlying material; as well as the incoming energy. It is in the function of a thermal insulator that the characteristics of unfrozen material become important. The common situation in the discontinuous permafrost zone is a ground cover of moss over peat, in which the vegetative mat provides excellent thermal protection and the downward progress of the frost front deccelerates as the summer progresses (see Figure 2). However, the

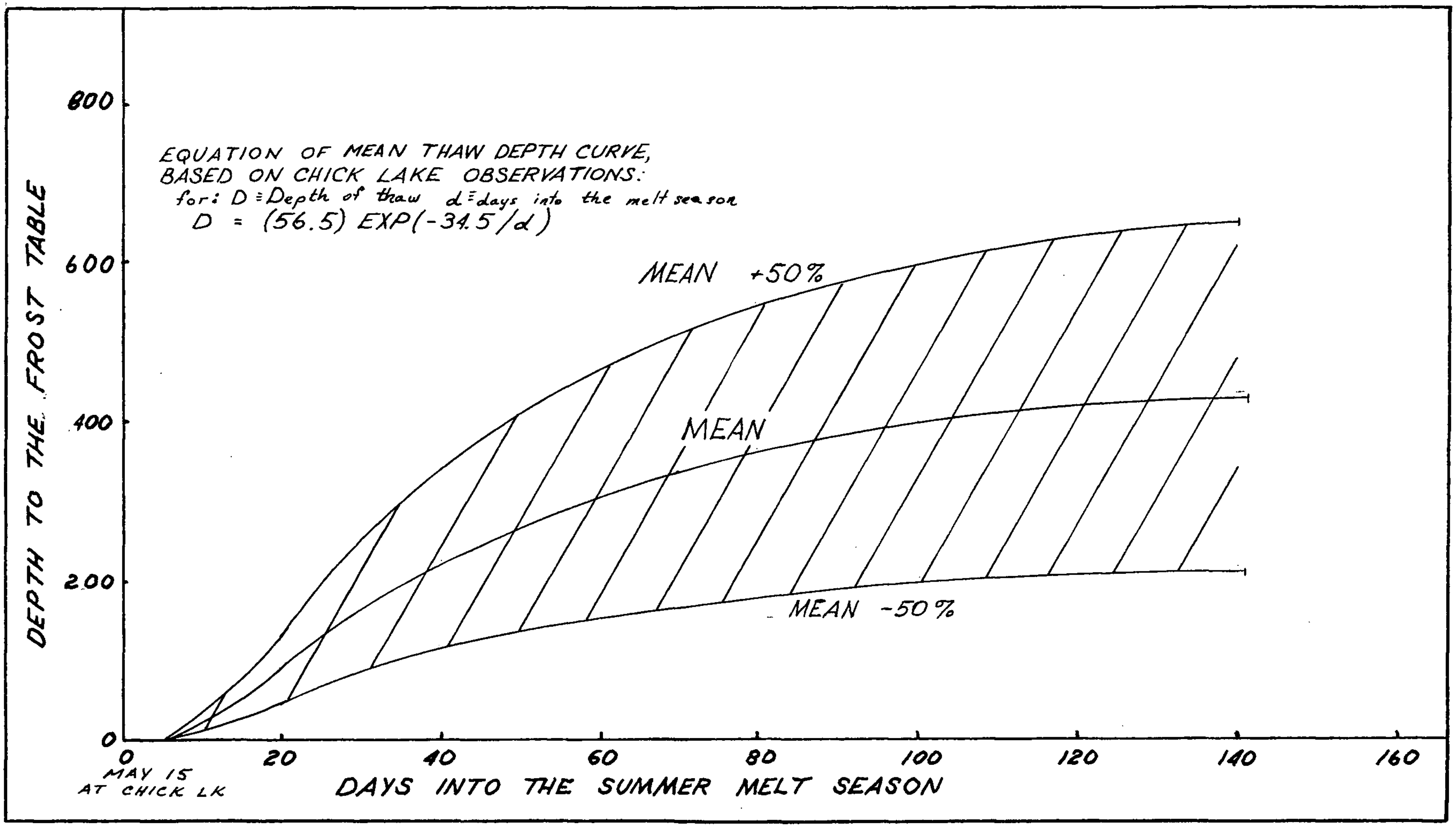


FIGURE 2 : DEPTH TO THE FROST TABLE

insulative efficiency of the cover varies over two orders of magnitude depending on its moisture content (Gill, 1979), (Williams, 1968) being the poorest insulator when saturated. Thus the frost table below minor local low spots may be two or three times deeper than an adjacent high perhaps only one metre away. This creates an impermeable surface below ground level more irregular than the surface topography and which may hold very significant volumes of subsurface depression storage. An extension of this idea is the concept that if the topography of the frost table changes throughout the season, some basic basin characteristics such as basin area, the flow pattern and depression storage which are often considered "fixed" can in fact vary significantly throught the season and can be radically changed by new construction. A surface disturbance such as a road, seismic or survey cutline or game trail with increased insolation due to tree removal and possibly impaired insulating capability through disturbing, or compressing the cover can cause a depression in the sub-surface impermeable layer and hence a major change in hydrologic response. Upland flow collects in the depression further disrupting the insulating capabilities. What can finally happen is a "short-circuiting" of the upland area to an adjacent basin, thus changing the areal characteristics of each basin.

An estimate of the position of the frost table at a given location and time is possible by fitting an exponential decay curve to a few observed depths of thaw taken throughout a summer season. Failing observations an assumption of 15 cm of thaw approximately two weeks after the passage of the 0° C is isotherm provides an initial point which appears reasonable in comparison to observed data. A shallow drill hole using a hand auger will disclose the average maximum depth of thaw since color variations characteristic of weathering will appear only in the material of the active layer. It is suggested that several such probes be made in a variety of locations to provide an average value as well as confirm the homogeneity of the surface materials and thickness.

2.2. VEGETATION AND SOILS

The importance of the material cover, to permafrost hydrology results from its effect on the rate of the basin frost table lowering through the summer season which in turn affects the basin characteristics. These effects are proportional to changes with depth of the material properties themselves, either within the same horizon or at the interface between horizons. The magnitude of the variations dictate whether the subsurface flow and storage characteristics can be characterized by a single, non-variable parameter, or by parameters which must be allowed to change with time. For example, a northern basin of exposed bedrock or thin organic layer overlying a silty, clay till of low porosity and permeability could reasonably be described by a single parameter similar to that used in the south. Alternatively, in an area with a deep organic soil with a thick active layer, formulations for storage, hydraulic conductivity, time of concentration all varying as a function of date, antecedent conditions and event magnitude may be required. It is this latter situation which is common along northern transportation corridors and in areas where development is likely to take place, and is the case under consideration.

Starting above the surface, the open black spruce forest and shrubs reduce the size and velocity of incoming raindrops, thus reducing their erosion potential. The sphagnum moss cover has a sufficiently high infiltration rate that overland flow is virtually eliminated except when the water table is particularly high, as may be the case in early summer when the frost table is near the surface. Progressing downward the moss grades into peat, the hydraulic conductivity and porosity of which decrease with depth. Below this organic mat lies the mineral soil, generally a permanently frozen remnant of glacial times. While it can be generally assumed for estimating peak flows that this frozen subsoil of fine grained material is impermeable, this is not strictly true and definite movement of liquid water is possible in the frozen zone (Carlson, 1979).

Result is an examination of the soil profile encountered at the Chick Lake study area together with soil properties are shown in Figure 3. While it is not clear, from the data, a relation between time of concentration of the basin and the hydraulic conductivity in the zone of water movement should exist.

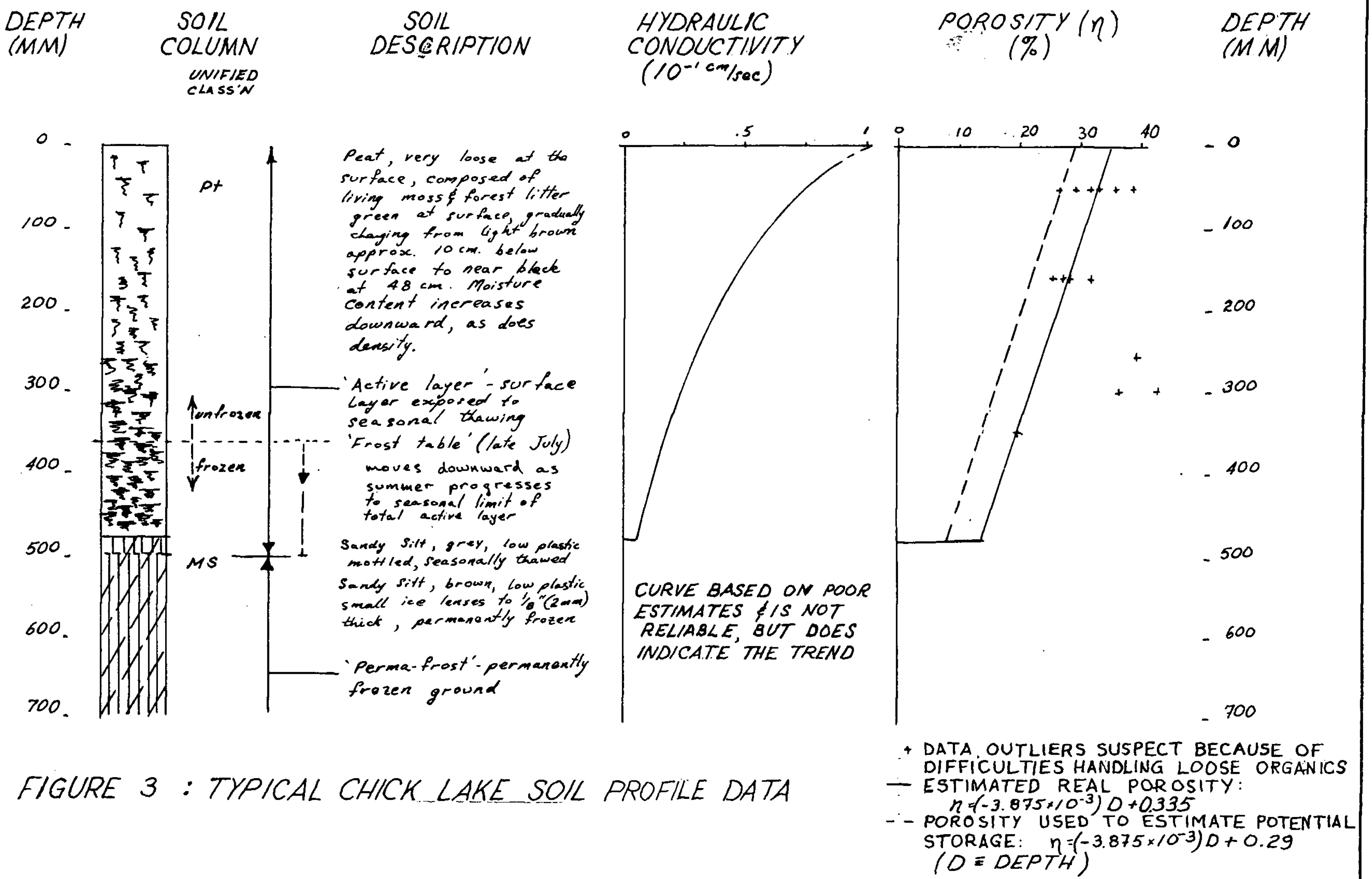


FIGURE 3 : TYPICAL CHICK LAKE SOIL PROFILE DATA

2.3 POTENTIAL AND AVAILABLE STORAGE

Potential storage is considered to be that storage volume potentially available in the surface horizon assuming no water is being stored either as a result of previous rain, snowmelt or ground melt, and includes the "subsurface" depressional storage caused by low areas in the frozen interface. Based on the active layer thaw curve and soil porosity, a relationship of potential storage versus time can be derived (Figure 4).

Available storage is that portion of the potential storage not already occupied by liquid water, at a given time.

Thus, potential storage at a given time during the summer is predictable (within practical limits) given the relative consistency of the active layer melt and the soil properties. The available storage is a function of potential storage and antecedent conditions which, because of the areal variability associated with precipitation, can be considered at least partically random in nature.

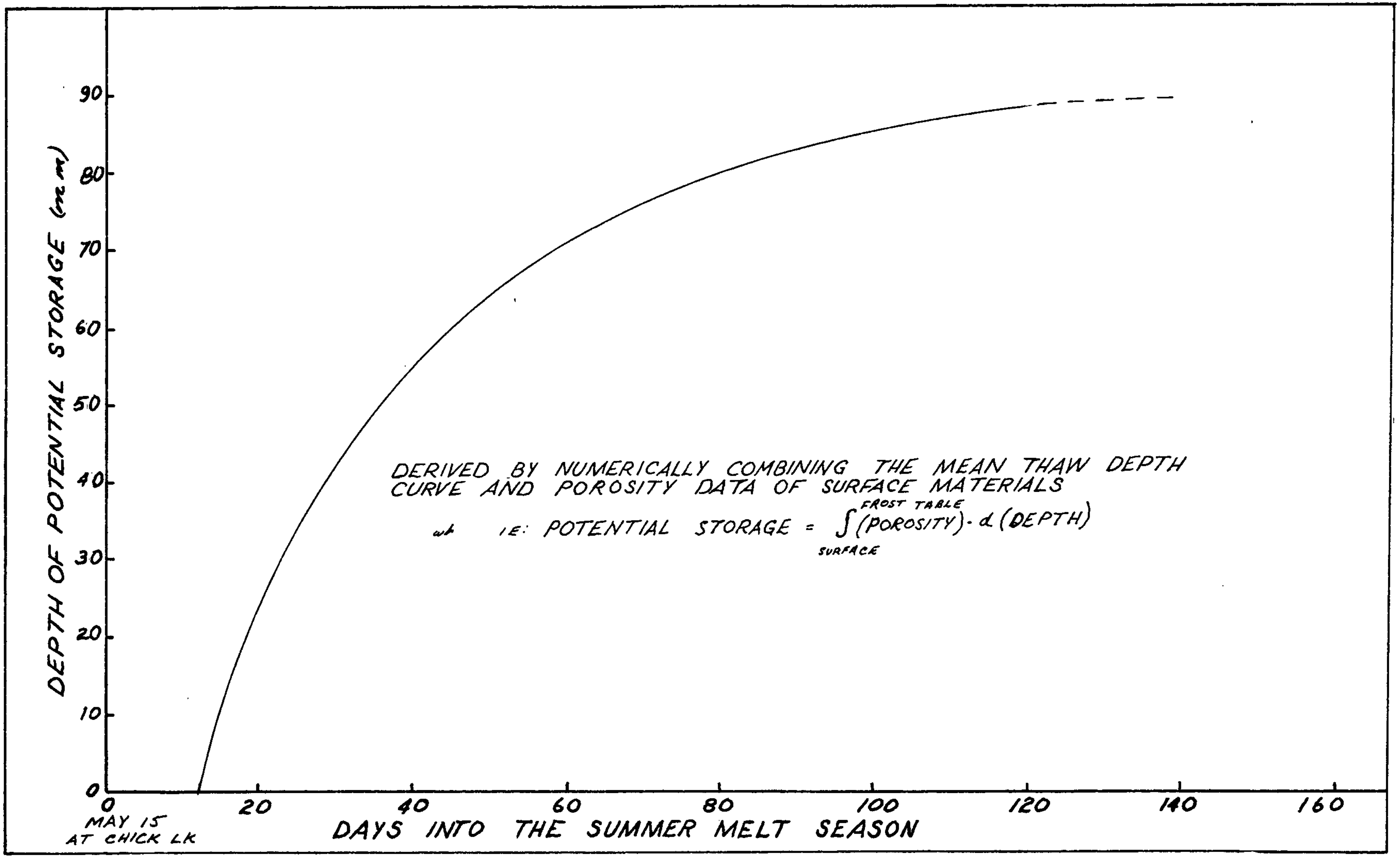


FIGURE 4: POTENTIAL STORAGE

2.4 THE EFFECTS OF PERMAFROST MELT ON RATE OF RUNOFF AND POTENTIAL STORAGE

Ignoring antecedent moisture for the present, consider the increase in potential storage due to the increase in thaw depth as summer progresses. Initially the entire active layer is frozen and snow covered. Snow melt occurs and runs off fairly rapidly contributing to the spectacular spring break-up characteristic of the large northern rivers. As the depth of thaw increases, potential storage in the moss layer is opened and two things may happen. If the active layer is relatively dry, an impermeable layer of ice will progress downward with the thawing front and the thawed potential storage will be converted almost totally to available storage. Alernatively, if the active layer is saturated, the potential storage is available only at the rate the moisture freed by thawing can be removed through some combination of evapotranspiration and drainage. Therefore, the available storage is a function of the depth to the frost table and moisture present at a given time.

2.5 EVAPORATION

The removal of water from storage occurs in two ways, drainage and evaporation. Due to the large storage capabilities of the surface layer once thawed, and the relatively slow movement of water through the soil mantle, evaporation is an important factor in determining the available storage at the occurrence of a major precipitation event as well as when considering the seasonal water balance.

Using the Thornthwaite (Thornthwaite and Mather, 1949) approach based on mean monthly data, a seasonal potential evaporation of 326 mm is calculated. This compares favorably with 180 mm shown in the Hydrologic Atlas of Canada (A.E.S., 1977) and a few actual measurements at Norman Wells (A.E.S., 1972-77) showed 340 mm. The results are shown as Figure 5 and Table I for the Chick Lake study.

Hare and Thomas (1970) illustrated the average potential losses at Chick Lake to be in the order of 240 mm. Specific phenomena contributing to these losses include the constant light winds, long days with relatively high air temperatures (see Table I), the generally moist moss cover and low relative humidity. Dingman (1971) commented in reference to a similar study in Alaska that the evaporative losses are expected to be low, owing to the non-vascular nature of the moss cover and the low demands of the relatively open tree and shrub vegetation. While this may be true in absolute terms, evidence is that the mosses "wick" moisture upward and provide large surface areas conducive to evaporation. Bredthouer (1979),

TABLE I: Calculation of Evaporation at Norman Wells, N.W.T., by Thornthwaite's method based on mean monthly data.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Temperature (°F)	-19.7	-15.8	-2.	18.7	41.2	56.6	60.9	55.7	42.5	24.7	-.6	-14.6	
Temperature (°C)	-28.7	-26.6	-18.9	-7.4	5.1	13.7	16.1	13.2	5.8	-4.1	-18.1	-25.9	
I	-	-	-	-	1.03	4.60	5.87	4.35	1.25	-	-	-	17.1
Unadjusted Potential Evap (mm)	-	-	-	-	37.	60.	80.	60.	42.	-	-	-	
Adj. factor of lat. + 50°	.74	.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	.92	.76	.70	
Adjusted Potential Evap. (mm)	-	-	-	-	49.2	81.6	109.6	75.	44.5	-	-	-	
Precipitation (in)	.82	.68	.49	.56	.60	1.44	2.21	2.43	1.33	.99	.86	.76	13.17
Precipitation (mm)	20.8	17.3	12.4	7.0	15.2	36.6	56.1	61.7	33.8	25.1	21.8	19.3	348.
Precip-Potential Evap (mm)	21.	17.	12.	7.0	-34.	-45.	-53.5	-14.3	-10.7	25.	22.	19.	-58.5
Accumulated Potential Water loss (mm)	-	-	-	(0)	-34.	-79.	-132.5	-146.8	-157.5	-	-	-	
Storage ST (mm)	263.	280.	292.	299.	268.	230.	192.	183.	176.	201.	223.	244.	
Change in storage dST (mm)	+21	+17	+12.	+7.	-31.	-38.	-38.	-9.	-7.	+25.	22.	19.	
AE Actual Evaporation (mm)	-	-	-	-	46.	74.	94.	71.	41.	-	-	-	326
Deficeit (mm)	-	-	-	-	3.	7.	26.	5.	4.	-	-	--	
Surplus (mm)	-	-	-	-	0	0	0	0	0	-	-	-	

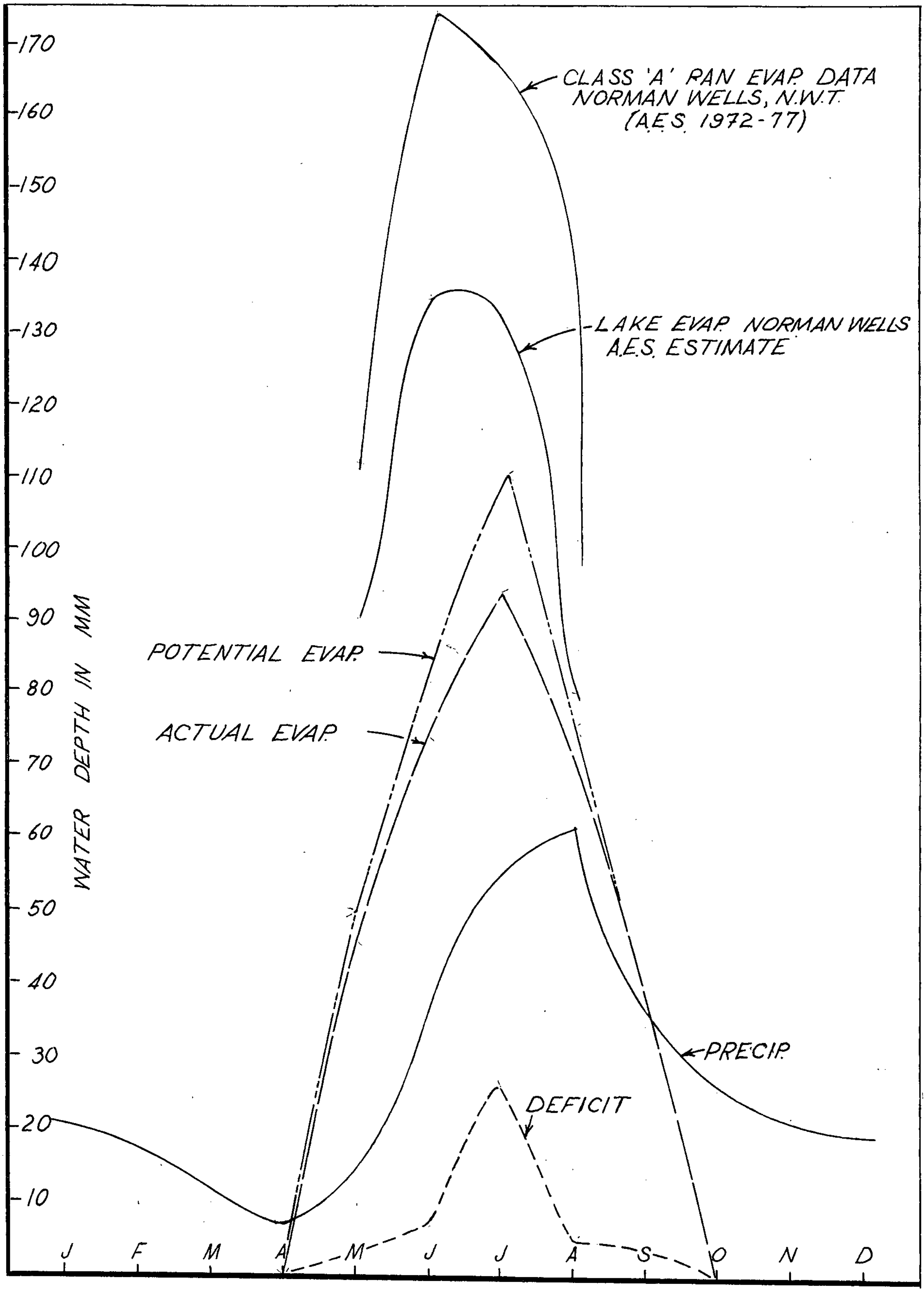


FIGURE 5 : EVAPORATION AT NORMAN WELLS, N.W.T.
CALCULATION BY THORTHWAITE'S METHOD BASED ON 30 YR. CLIMATIC MEANS

also of C.R.R.E.L., reports that lysimeters filled with sphagnum moss show significantly higher water loss rates when compared to adjacent Class A pans in a study near Fairbanks, Alaska.

While the seasonal evaporation rates are not large when compared to those experienced in southern regions, comparison to summer and annual precipitation shows that evaporation alone could potentially account for all of the available moisture. Furthermore, with the wicking action of the moss, the loss rate is much less restricted when the water table falls below the surface than the usual southern case of dealing with mineral or decomposed organic soils.

In relative terms, with a total annual mean precipitation of 330 mm (Burns, 1973) of which 170 mm occurs as snow and runs off before evaporation rates reach a maximum, the potential exists for all of the summer rains to be consumed by evaporation. The usual low levels of small lakes and ponds in July and August would argue in favour of high evaporative losses.

The main point is that evaporation is important as a primary "drainage" mechanism removing water from the mantle and increasing the available storage. This storage volume controls the magnitude of the flood peak and the shape of the hydrograph. Furthermore, evaporation generally accounts for more than 50% of the summer precipitation as shown by observations at Chick Lake (Figure 10) and thus must be considered in water balance calculations.

2.6 SURFACE DISTURBANCE

As previously mentioned, basin area can change as a result of the subsurface "short-circuiting" caused by a trough or ridge developing in the frost table. This distrubance could take the form of the construction of a seismic line or game trail which tend to form a trough due to increased energy reaching the surface and the compression of the peat mat, thus reducing its insulating value. A ridge might be caused by the construction of a road where artificial insulation or a thick layer of well draining gravel is introduced, providing extra protection to the frozen soils, and allowing the perma-frost level to, or a pipeline, which in itself provides an obstacle, but when chilled gas is the product being moved a frost bulb develops around the line and is maintained frozen throughout the year. This latter situation was examined by Soulis and Reid (1976) in a separate study at the Chick Lake site.

Other natural disturbances which could change the flood characteristics of an area include the proliferation in recent years of the Canadian beaver and forest fires which are generally allowed to burn unchecked in the muskeg terrain.

3. THE CHICK LAKE STUDY

3.1 BACKGROUND

The Chick Lake Study was intended to provide an understanding of the hydrology of the Northern Boreal Forest underlain by permafrost. This landform constitutes a major portion of the Mackenzie Valley, the area most developed in the Northwest Territories and most likely to sustain further development primarily by the mineral, petroleum and transportation industries. In terms of the proposed pipeline development, erosion control and small basin drainage works were estimated to represent 10% (or one billion dollars) of the capital outlay. Of the approximate one third of the route in the discontinuous zone, about 70% lay in the relatively flat open black spruce forest characterized by poorly defined drainages and abundant shrub and moss cover. Considering that significant savings could be realized if a less conservative design could be justified, a hydrological research program in the Chick Lake study area was set up in conjunction with several other studies.

3.2 THE STUDY AREA

The Chick Lake site provided a single site where a number of separate studies could be pursued and interrelated. The site is 80 km northwest of Norman Walls, Northwest Territories and access is limited to charter air services or an arduous overland journey. During spring and fall the area is virtually inaccessible except by helicopter and this lack of public access was a major advantage of the area as an integrated research site since the environmental studies required control in order to establish baseline data, impossible to acquire in an area accessible to the public. To this end four seasons of field data on vegetation and small mammals (Douglas, 1977) was obtained as well as some subsurface flow studies (Soulis and Reid, 1977). The lake provided an assured water supply, as well as allowing the use of larger float or ski equipped aircraft to ferry equipment and personnel. Finally, a major archaeological site exists at the lake outlet to the Donnally River which required the establishment of a camp for study at some point in time.

From an engineering viewpoint the gently sloping, deep organic soils on the west side of the lake were typical of much of the proposed pipeline route. This route passed near the lake, thus before and after studies were possible in the realms of fauna, flora and hydrology, both upslope and downslope from the disturbed right of way. Finally, the lake itself provided easy local transport by power boat which potentially allowed frequent and regular service to the scientific sites, as well as some amenities for personnel on site for extended periods.

3.3 LOCAL TOPOGRAPHY, CLIMATE, GEOLOGY AND VEGETATION

The study area is located in a lake basin in the central Mackenzie River Valley approximately 80 km northwest of Norman Wells, at approximately $65^{\circ}52'$ N and $128^{\circ}07'$ W (see Figure 1). The lake basin is surrounded by the rugged terrain of the

Franklin Mountains where elevations range from 135 m ASL at lake level to 825 m ASL on top of Gibson Ridge, the most prominent local feature and the northern spur of the Norman Range which forms the western flank of the Franklin Mountains. The terrain, while extremely rugged, has been subdued by passage of the continental ice sheets, the last during the Pleistocene era which moved in a northwesterly trend leaving a particularly linear landscape of parallel ridges and grooves. This is especially evident when viewed from the air between Norman Wells and the study area. The underlying bedrock is faulted Cretaceous shale and folded and faulted Devonian limestone which contains some oil and gas deposits. Overlying the bedrock in the valley is a dense silty till generally covered by a layer of lacustrine clays and silts deposited when the area was covered by glacial meltwater.

The surface stratum in the study area consists of ice-rich layers of poorly sorted silty clay and silty sand overlain by thick (up to 2 m) organic surface layers. The actual surface is characterized as weakly to moderately hummocky (hummock diameter 0.50 to 1.0 m, height 0.25 to 0.40 m). Permafrost is found throughout the entire area, with an average maximum depth of thaw (as surveyed in 1975 and 1976) of 0.44 m. Spot measurements from all years when the site was visited indicate the mean progress of the seasonal thaw is consistent from year to year, as is the maximum thawed depth. At any time, up to 50% variation from the mean thaw depth is observed, often between two points within one meter of each other, dependent on whether the location is on a hummock (least thaw) or in a trough. This type of variation in the frost table is an exaggerated reflection of the surface topography on a micro-scale and the major source of changing subsurface depression storage.

Vegetation in the study area consisted of an open black spruce forest, average tree height approximately 4 to 5 meters, but highly variable. The largest specimens are found on the lakeshore, reach heights of 10 m and apparently enjoy some moderation of climate. Abundant shrubs and lichens provide ground cover dominated by blueberries, Labrador tea and lichens. These are rooted into a mat of sphagnum moss over peat in which the "active" layer of seasonal thaw is generally confined. It is this layer of moss and peat which is responsible for the hydrologic response of the basin.

Climate experienced in Chick Lake, as extracted from historical records (Burns, 1973) at Norman Wells (80 km S.E.) and Fort Good Hope (60 km N), is classified as "Dry Continental". The summer is short and cool followed by long cold winters. Precipitation is low, averaging approximately 330 mm annually, approximately two-thirds of which falls as snow. The mean annual temperature of -6^{o}C places the area in the northern fringes of the discontinuous permafrost zone (see Brown, 1974). Climate characteristics have been summarized in Table II.

TABLE II: Mean Monthly Weather Characteristics, Norman Wells & Fort Good Hope, N.W.T. (Burns, 1973)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Norman Wells													
mean daily temp (°C)	-28.7	-26.6	-18.9	-7.4	5.1	13.7	16.1	13.2	5.8	-4.1	-18.1	-25.9	-6.3
mean daily max. temp (°C)	-24.6	-22.0	-12.7	-1.1	10.9	19.5	21.8	18.5	10.1	- .8	-14.7	-22	-1.4
mean daily min temp (°C)	-32.8	-31.1	-25.	-13.7	- .6	7.8	10.2	7.8	1.6	-7.4	-21.7	-25.8	-11.2
no. days with frost	31	28	31	29	17	1	-	1	11	29	30	31	239
mean rain (mm)	-	-	.3	1.3	8.9	35.8	56.1	61.7	28.2	2.8	.3	-	195.3
mean snow (mm)	213.	185	127	135.	64.	7.6	-	-	58.	231	218	193	1433
mean precipitation (mm)	20.8	17.3	12.4	14.2	15.2	36.6	56.1	61.7	33.8	25.1	21.8	19.3	334.5
no. days measurable rain	-	-	-	-	4	9	11	12	9	2	-	-	47
no. days measurable snow	13	12	10	8	4	-	-	-	3	11	14	12	87

TABLE II: Mean Monthly Weather Characteristics, Norman Wells & Fort Good Hope, N.W.T. (continued) (Burns, 1973)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Fort Good Hope													
mean daily temp (°C)	-30.8	-28.9	-22.3	-10.6	3.5	12.8	15.4	12.1	4.6	-5.9	-20.9	-28.6	-8.3
mean daily max temp (°C)	-26.1	-23.9	-15.7	-3.4	9.8	19.8	22.	18.5	9.6	-2.1	-16.6	-24.3	-2.7
mean daily min temp (°C)	-35.4	-34.1	-28.9	0	-2.8	6.2	8.7	5.7	-.5	-9.8	-25.2	-32.9	-13.9
no. days with frost	31	28	31	30	22	2	-	4	17	30	30	31	256
mean rain (mm)	-	-	-	1.8	8.1	35.3	45.7	51.3	28.4	3.8	.5		175.
mean snow (mm)	160.	162.	157.	122.	79.	-	-	-	43.	231.	259.	157.	1371.
mean precipitation (mm)	16.	16.2	15.7	13.7	15.7	35.3	45.7	51.3	32.7	26.9	26.2	15.7	311.4
no. days measurable rain	-	-	-	-	4	9	10	13	9	2	-	-	47
no. days measurable snow	9	9	9	6	3	-	-	-	2	9	11	10	68

3.4 DATA COLLECTION HISTORY

Initial work began in 1973 when biological studies were initiated at the site, however it was not until late in the summer of 1974 that studies of the hydrology, including water movement in the subsoil, were initiated. During the summers of 1974, '75 and '76 some data was collected initially using Stevens F recorders which required service on a weekly basis, and later an attempt was made with Ott bubbler recorders.

The first year, 1974, was a year for learning, as the original containment dikes failed by piping and as a result no useful record was obtained. This was rather unfortunate as it was a very wet year. However, the requirement to line the stilling basin to reduce thaw and piping by increasing the length of the drainage path was established. Unfortunately, 1975 was an exceptionally dry year and while the stream gaging equipment functioned, very little flow record was produced.

In 1976 the Ott bubbler-type recorders were tried but a rather unique problem developed. The local mouse population found the rigid black polyethylene plastic tubes (used to lead to the bubbler head) a gastronomical delight and damaged the tubes, rendering the instruments useless. This was the first year when the sites were visited infrequently and thus this "foolproof" recorder failed to live up to expectations. Of interest while discussing the Ott recorders, another difficulty with them was the complex and unreliable pen mechanism which caused some problems, although it did not affect the study. Further, difficulty in handling of the compressed nitrogen gas bottles both at the undeveloped sites and in transport precluded further use of these gages.

The period of useful records was the summer of 1977 when four Stevens A recorders with 90 day mechanically driven strip charts were used. These were installed in fully lined stilling basins, with eight inch diameter floats, and the counter-weights enclosed in a stilling well. At all four sites these units functioned well, as did the tipping bucket rain gage which used a "Weather-Measure" strip recorder. Generally, the rain gage set-up, while "rustic" was standard (see Figure 6) while the V-notch weirs and basins were at least somewhat novel (see Figure 7).

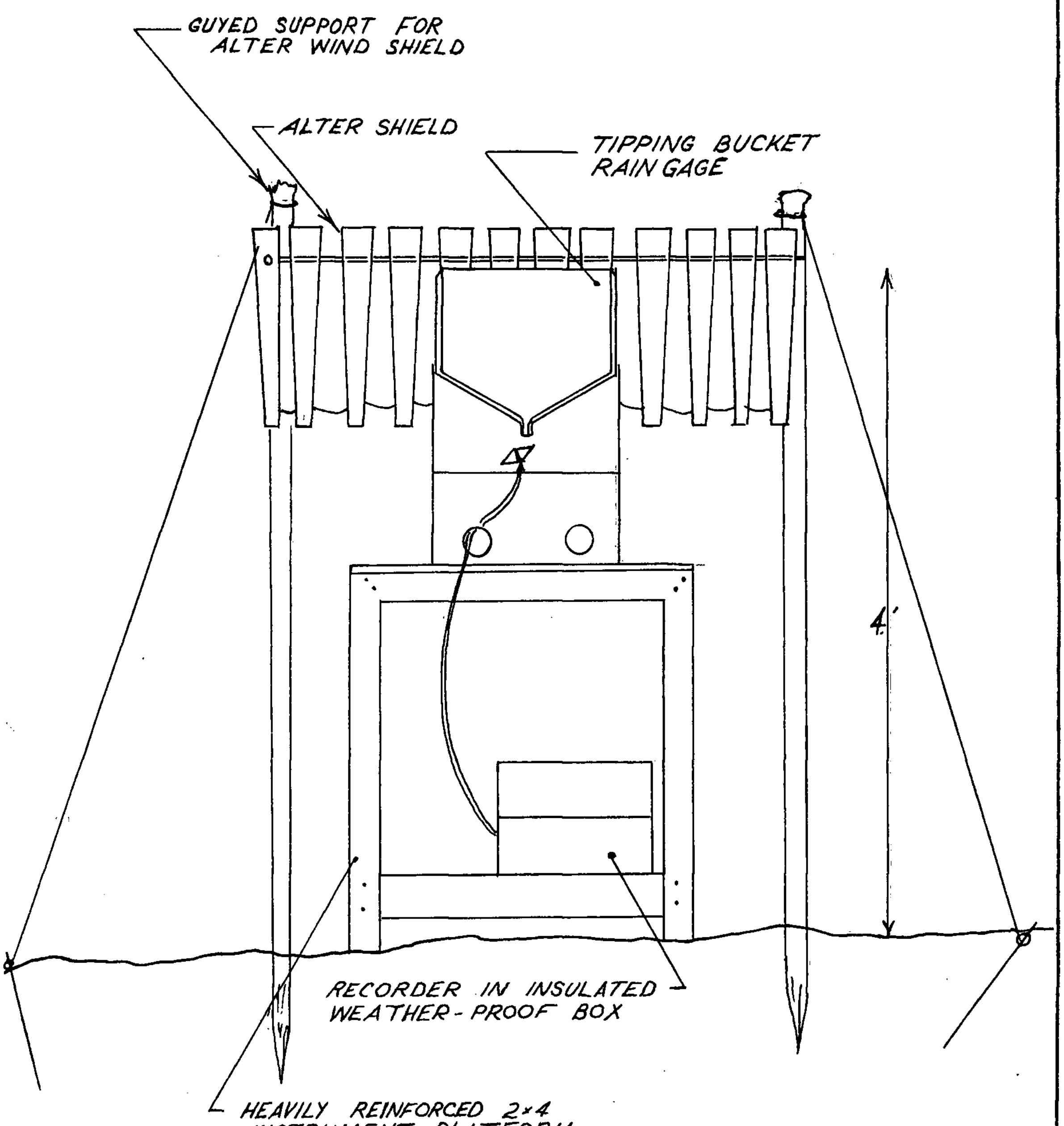


FIGURE 6 : CUT-AWAY OF RAIN GAGE SET-UP

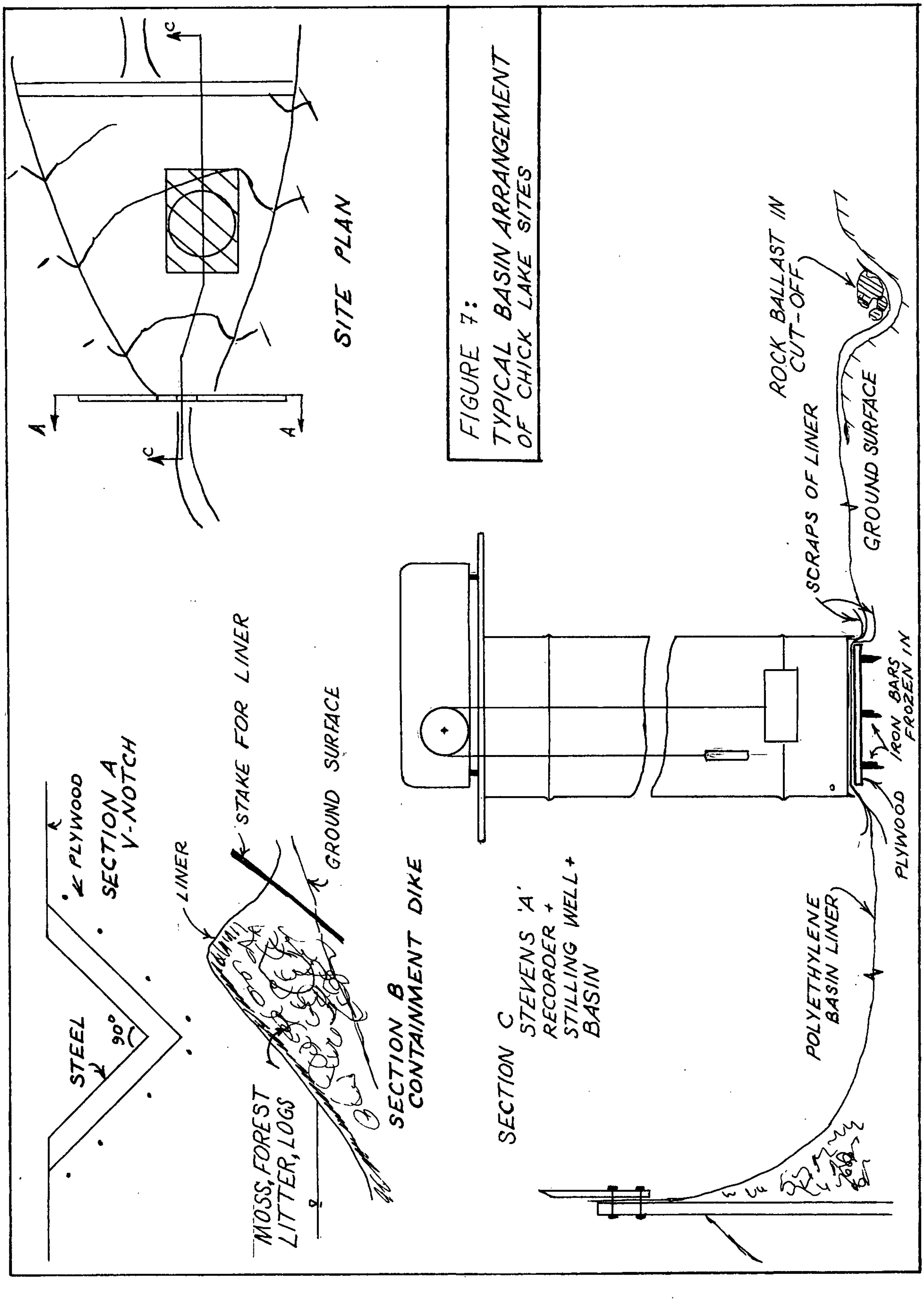


FIGURE 7:
TYPICAL BASIN ARRANGEMENT
OF CHICK LAKE SITES

3.5 GAGE SITES

After the snowmelt and break-up of the lake had occured, (allowing economical access by float plane) the stilling basins were set up. The installation, based on suggestions by Rahn (Rahn, 1967), entailed reconstructing the containment dikes, laying the plastic basin liner on the carefully cleared and cleaned basin (to avoid liner damage), initially allowing the water to flow underneath it, installing the steel "knife-edge" V-notch to the plywood cutoff, sandwiching the plastic membrane between the steel and plywood (see Figure 7), and installing the stilling well. Since there is no effective glue or tape sealing method for polyethylene sheet (except perhaps using a heat gun which is impractical under field conditions) and the objective was to have no holes at which piping might be induced through the membrane, the method of solidly installing the stilling wells required some innovation. Previously iron bars had been drilled several feet into the permafrost and these provided a solid instrument foundation. By "capping" these near ground level with a plywood disc a suitable platform was begun. Over the plywood was placed the plastic sheet, and the stilling well was placed on top.

The stilling wells consisted of two 10 gallon gasoline kegs, one with both top and bottom removed, the other with only the top removed. The latter, with 2 small flow holes drilled in the side, was placed bottom down on the plywood, its small rim locking on the appropriately cut disc. A few heavy rocks were placed inside for stability. Next the other keg was fastened on and on top of this was bolted a plywood table on which the recorder was mounted. Once together, the unit was solid, and after being heavily guyed with wire rope it was very stable.

At this point in time the upstream edge of the liner is sunk into an upstream cutoff trench and the flow is directed over, rather than under the plastic sheet. Two points are worthy of note. One is the need for an organized and fairly rapid pace between closing the "under plastic channel" and setting the upstream cutoff. In this period the steel V-notch must be installed and the membrane sandwiched under it as well as placing, if not guying the stilling well. Care must be exercised not to damage the plastic or allow the water pressure to tear the sheet. Secondly, it is important to lay only a single layer of polyethylene. Air trapped between two sheets causes no end of problems including floating the liner up out of the cutoff or dragging part of the membrane into the V-notch. The water trapped below the plastic is gradually forced sideways as the basin fills and causes no problems.

Finally, the instrument is guyed and levelled, and as the basin fills the zero flow point is registered. A manual gage and a bridge to the stilling well are convenient. At Chick Lake in 1977 these activities constituted about 3 man-days per site, all of the work done without power tools of any kind, and the major clearing done previously. Approximately two full days should be allowed for the initial clearing, dike preparation and setting of the iron bars to provide the non-settling foundation for the instrument. Final clean-up in the fall required one and a half man-days per site.

The rain gage was placed in the clearing created by the intersection of the C.N.T. right of way and that of an abandoned winter road (see Figure 8). This provided more than adequate clearance from local vegetation and other interference to the air-flow patterns. The gage consisted of a standard bucket (approximately 10 inches in diameter) equipped with a tipping bucket mechanism that provided an electrical "click" for each 0.01 inches of rain. The rim was the standard four feet above the local ground surface and wind effects were reduced by an Alter shield placed in the specified manner. Response from the tipping bucket was recorded by a mechanically driven strip chart, with a maximum record length of 60 days. The recording instrument which was enclosed in an insulated weatherproof box, performed well.

The entire set-up was heavily built and guyed in order to reduce possible ill effects from the somewhat destructive interest of the local fauna. Bear and moose can be particularly destructive, however, again the mice cause the majority of the problems and have been known to gnaw electrical leads causing shorts or creating situations where batteries drain and render electrically driven instruments useless. The alternative was to construct a semi-permanent structure; an expensive and difficult task considering the air freight and handling involved getting materials to the site. With respect to the smaller members of the animal community, care must be exercised not to create nesting sites in an instrument set-up, particularly near any free moving parts.

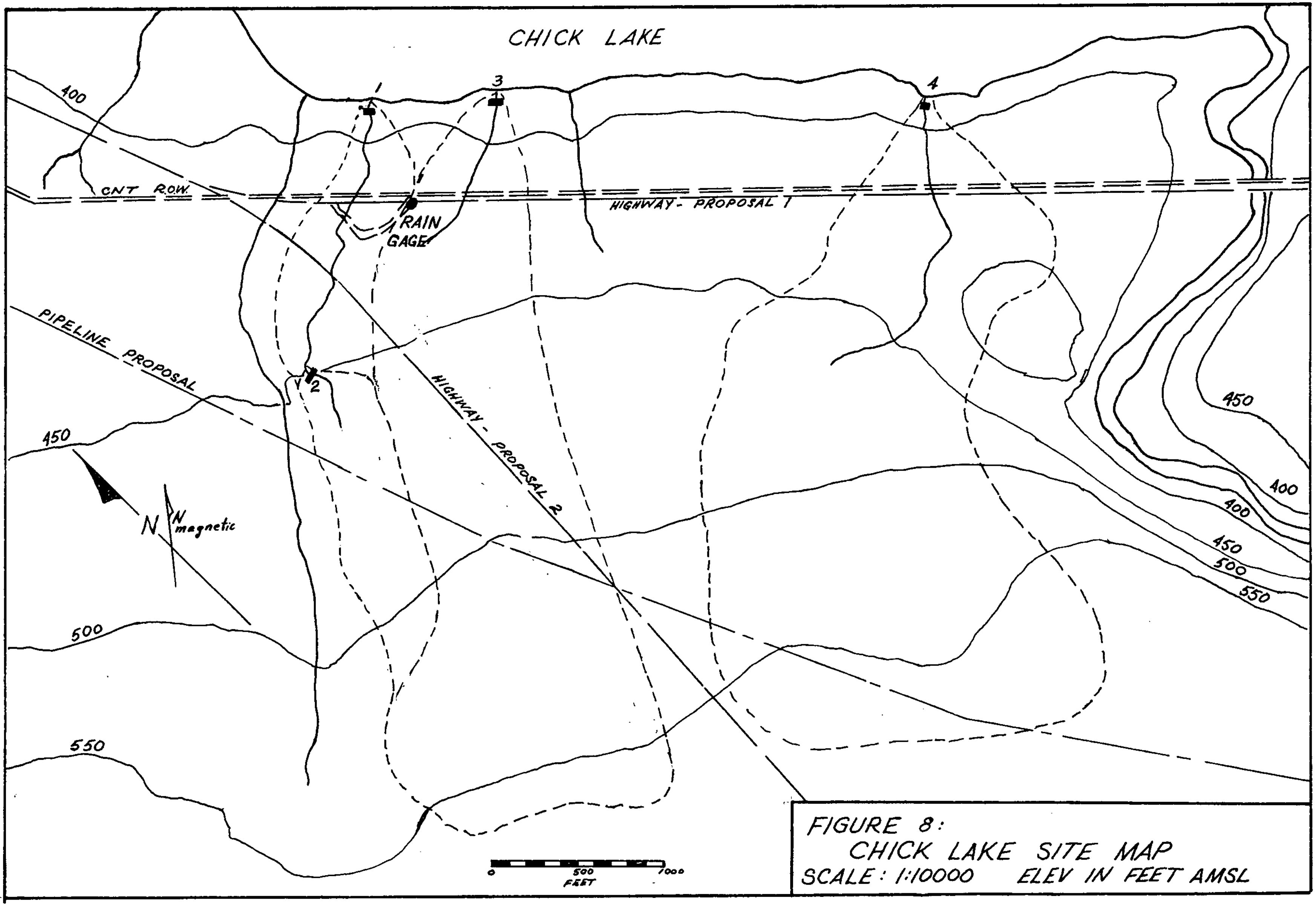


FIGURE 8:
CHICK LAKE SITE MAP
SCALE: 1:10000 ELEV IN FEET AMSL

3.6 CHICK LAKE STUDY BASINS

Three small creeks draining into the south shore of Chick Lake were chosen as typical of the situation under study as well as maintaining the option of 'before and after' monitoring if the pipeline were built. Three gage sites were located near the lakeshore and a fourth gage was located on the upstream end of one of the creeks. This provided gages upslope and downslope of the proposed pipeline location (see Figure 8). Basin characteristics are summarized in Table II while subsoil conditions were presented earlier in the discussion on soils and in Figure 3. The important information is conveyed in the mean potential storage derived by combining the subsoil porosity information and the depth to the frost table curve, as shown in Figure 4.

Delineation of the individual drainage basins was attempted using a small scale contour map based on aerial photographs. While the contour interval was small, analysis of the flow data indicates the basin divides may have been incorrectly placed. A problem exists in dealing with such basins with poorly defined divides and dominant subsurface flow in that the surface may not reflect what is going on below. This is especially true in a permafrost situation since variable lowering of the frost table can drastically alter the basin shape. It would appear that part of the area attributed to basin 1 is contributing to the ungaged stream to the east.

3.7 CHICK LAKE - DATA PRESENTATION AND ANALYSIS

Stream gages were installed in early June, 1977 and removed in early September with no apparent malfunctions. The rain gage functioned properly during the same period. Total measured precipitation in 1977 was 105 mm which compares favorably with 67 mm recorded in 1975, a particularly dry summer and 158 mm in 1976, a very wet summer. Histogram of 1977 precipitation is presented in Figure 9. Total summer precipitation for the same periods (June through August) in 1975, '76 and '77 for Norman Wells and Fort Good Hope were 83 mm, 86 mm and 67 mm and 58 mm, 77 mm and 114 mm respectively. While daily temperatures were not recorded for sufficient periods to present useful plots, diurnal range and the trend of the daily mean follows that observed at Norman Wells, allowing for local variations in weather caused by the compact convective systems which dominate the summer weather and the proximity of Norman Wells to the Mackenzie River.

Streamflows as recorded in 1977 are also presented in Figure 9, along with the "best fit" obtained using the Clarke's method computer model. Table II provides a summary of the data collected and the results of the analysis. A problem in defining the basin areas and boundaries is evident by examining the V/A (total recorded flow volume over basin area) ratio and by plotting the falling limb of the hydrographs on log paper. However, precisely how to "improve" the estimates is not clear considering the area characteristics is variable with time and the 1977 data did not provide sufficiently separate events,

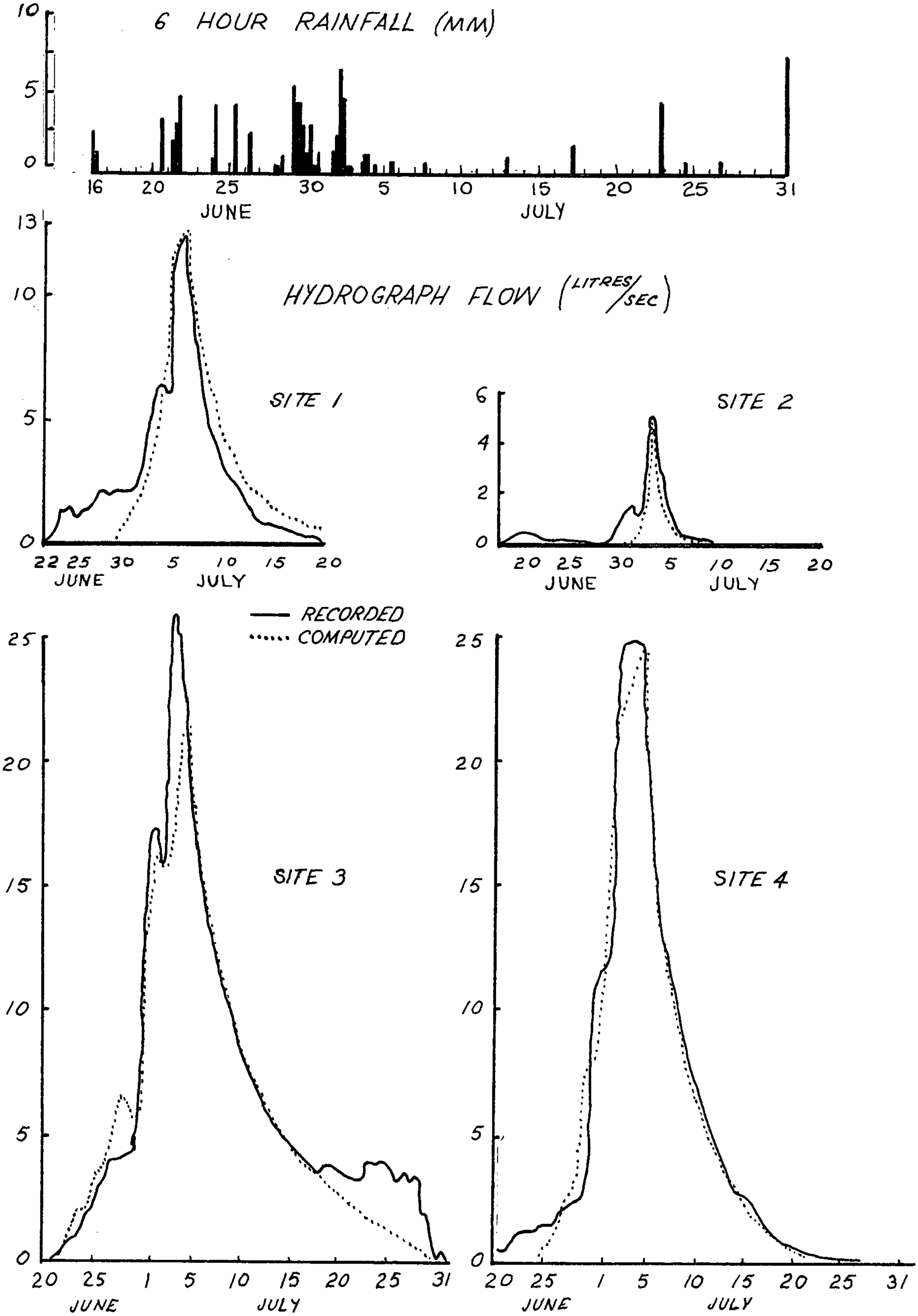


FIGURE 9 : 1977 RAINFALL & RUNOFF DATA, CHICK LAKE

or a long enough record to indicate the trend. Comparison of basin response to particular precipitation events gives some insight into the changes in the basin with time. While the intense event of August 1 solicited no response on any stream chart, even minor events in mid June were recorded on the hydrograph. This provides support for the contention that response of a permafrost basin is dominated by the depth to the frost table (ie: the date into the summer season) and antecedent conditions.

While no data was collected on evaporation, indications from work done in Alaska are that it is extremely important in terms of accounting in water balance calculations and as a drainage mechanism increasing the available storage.

4.0 DATA PREPARATION AND ANALYSIS

The basis of the analysis was the simple single event, fixed parameter Clark's hydrograph model programmed for use with an interactive graphics terminal. The methodology of the model is described by Gray (Gray, 1970), the original work presented by Clark (Clark, 1945) and used by the United States Corps of Engineers in their HEC-1 Flood Hydrograph Package (HEC, 1973).

The strip charts obtained from the four recorders for the summer of 1977 were first digitized by Water Survey of Canada and then converted into hourly flow records using a program written by the author. This was converted into a seasonal hydrograph plot and was input in this form to the Clark model. The precipitation record was manually reduced into a histogram suitable for input to the model together with flow data and was used to estimate the basin parameters of time of concentration and a storage constant. An estimate of the travel time versus contributing area was made for each catchment based on watershed shape and the assumption that flow velocity would be relatively constant throughout the basin at any given time. This is reasonable since the basins have fairly constant slopes and the surface layer is consistant throughout. The baseflow component was assumed to be zero in all cases. Input data is illustrated in Figure 9.

The data for each site was examined using the two step iterative procedure programmed for the graphics terminal. The first step involves estimating effective precipitation by using the two fitting parameters of initial loss and infiltration rate to match flow estimated by the model to that recorded. The initial loss could be considered that precipitation which is initially required to "wet" vegetation and soil surface before flow begins, and is lost forever to evaporation. Infiltration would be the minor losses to the frozen sub-soil which are not entirely impermeable, losses around the weir, and evaporation since the model makes no provision for these losses which would be significant over the four week period of analysis. Figure 10 illustrates the relationships obtained between infiltration rate and initial loss. The values chosen to go into the second step of the hydrograph synthesis turned out not to be critical but were chosen to reflect the "expected" losses, approximately half of the total losses to each of initial loss and infiltration.

The model is extremely sensitive to the choice of storage constant and time of concentration except when large times of concentration were required, thus within a few iterations quite an acceptable and unique fit with the recorded hydrograph was obtained. Figure 9 illustrates the "best" fit condition for each hydrograph and Table III summarizes input data and results.

The above results do not show any of the patterns one would expect of four basins close together in similar terrain and of such similar characteristics of slope, aspect, and basin shape. The obvious conclusion is that some of the data is probably incorrect; and the most likely problems are with basin area and subsurface flow bypassing the weirs. It was extremely difficult to delineate the apparent basin boundary

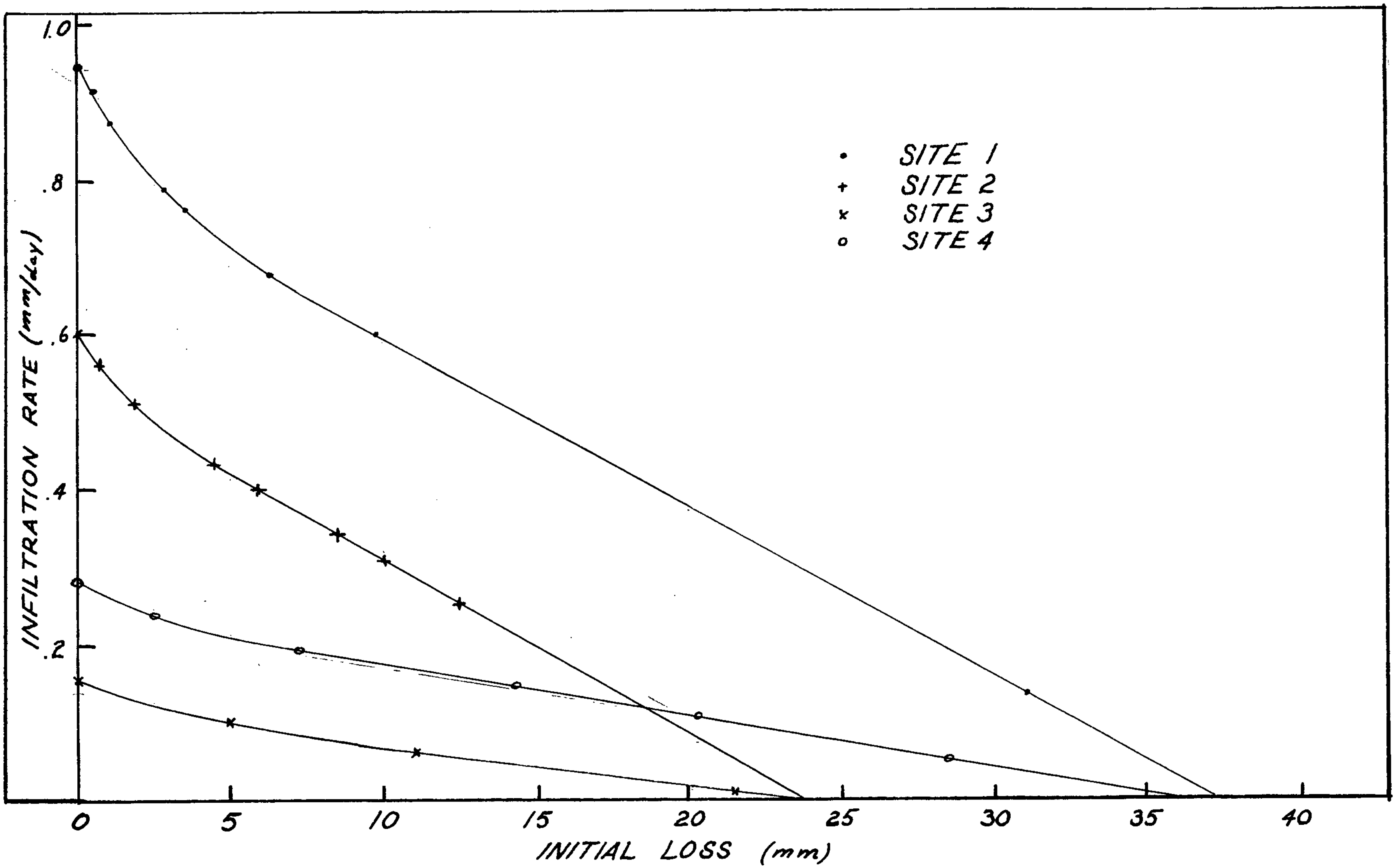


FIGURE 10: INFILTRATION RATE VS INITIAL LOSS

TABLE III: SUMMARY OF RESULTS

Basin No.	1	2	3	4
Area (hectares)	22.4	15.3	46	61.8
Basin Length (m)	1450	1000	1575	1350
Mean Basin Slope (%)	3.7	3.7	3.4	3.9
Stream length (m)	600	150	400	350
Stream slope (%)	3.3	2.5	3.5	4.4
Peak flow (L/S)	12	5	26	25
Peak flow (L/sec/ha)	.54	.33	.57	.40
Average Basin Runoff Depth (mm)	33	7.	52	31
Time of Concentration, T_c (hours)	.80	10	40	80
Storage Constant, R (hours)	120.	40	100	80

from the available mapping, and the moss covered terrain introduced further uncertainty with respect to the location of the real divides. Basin 2 appears to have been overestimated while basin 3 has been underestimated.

The rainfall losses (the difference between the rain which fell and that which eventually showed up as runoff) were in the order of 70 mm and this volume never did appear as subsequent streamflow. This volume is approximately equal to the amount of evaporation one would expect during the period analysed. As has been previously discussed, annual evaporation is in the order of 240 mm.

The significant feature of the results is the relatively large values obtained for time of concentration and storage constant considering the size and slope of the basins. Ignoring site 2, times of concentration of 2 to 4 days for basins less than 75 hectares in area implies that the super-position of events is important in defining the sequence of storms responsible for major runoff. It certainly negates efforts to use independent short duration storms as the design criteria for erosion structures. This procedure is attractive since the long term daily meteorological records can be analysed statistically (Soulis and Vincent, 1977) but since storm sequence and timing are not accounted for, the results may not be realistic.

Unfortunately, insufficient independent and separable events were recorded throughout the summer season to show the expected trending in basin response. Of some importance is that the most significant rainfall event of the year, which occurred in early August, solicited no response from any of the recorders while very minor rainfalls in June produced distinct flood peakes. It would appear, based on the possibilities for large capital savings implied by the observations that further work is justified in defining the necessary parameters and the manner in which they trend through the summer season, thus affecting the design statistics.

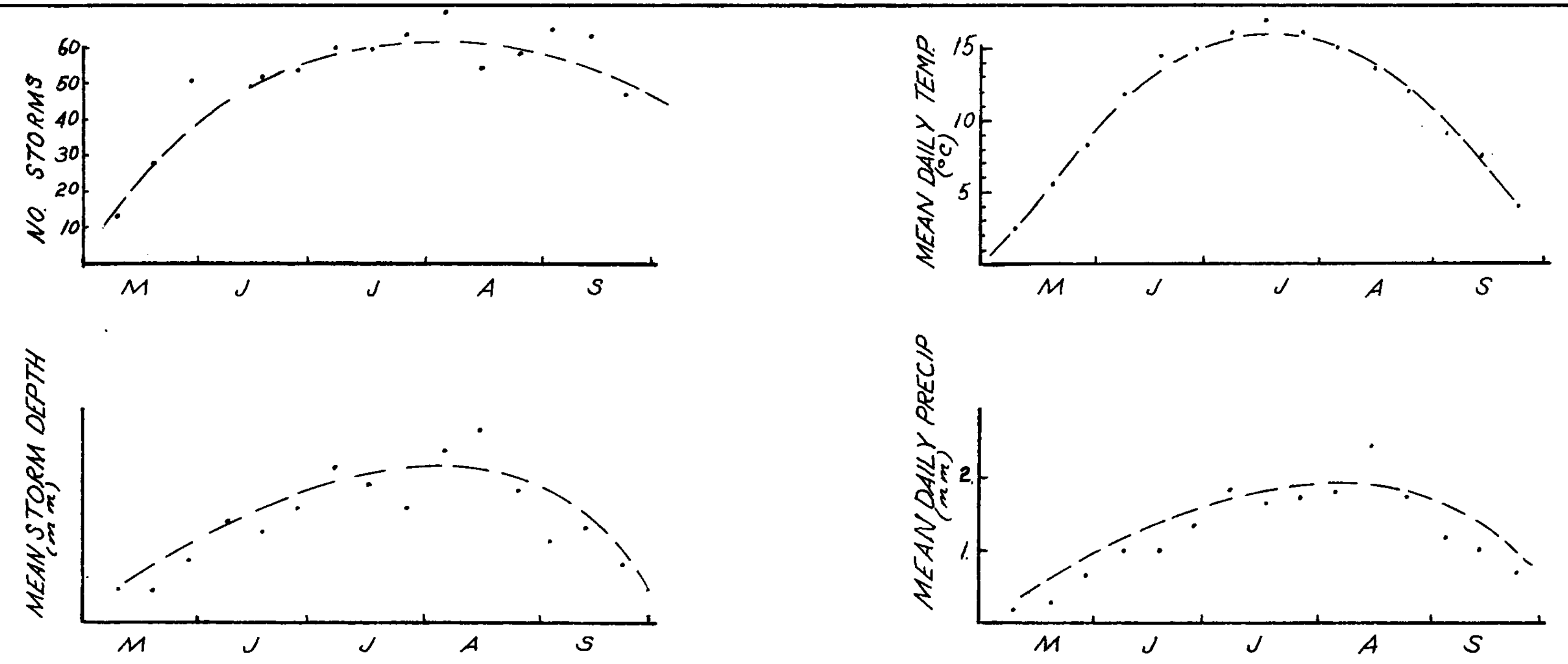
4.1 THE NEXT STEP

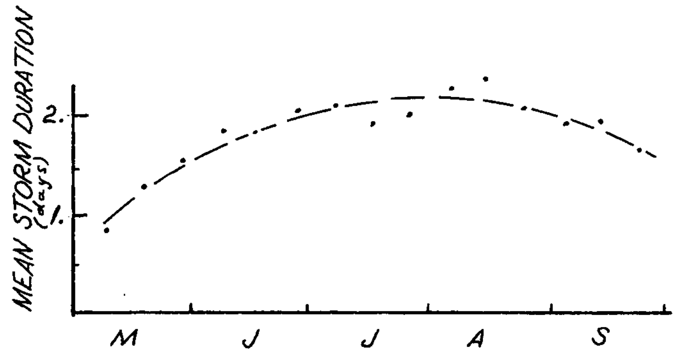
The Chick Lake study has indicated that the typical modelling approach for small basins is incorrect since calibration is based on single independent events. An appropriate model would have to take into account the systematic and random changes in the basin characteristics as well as the superposition of adjacent events. Since there is a certain random "wander" in basin parameters due to conditions beyond the resolution of common measurements, an appropriate model might consist of elements deterministically modelled, but each element described by a distribution rather than a single number. Further, those elements which follow a time trend change should do so and the outcome should reflect these changes.

Is this effort worth it? If we can show that virtually all rain falls early in the summer, for instance, perhaps a single event calibration plus a statistical analysis of early season storms is all that is justified. If the character of the rain events also change with time during the season, then this also should be taken into account. Analysis of storm distribution based on 30 years of daily records at Norman Wells shows that this is not apparently the case (see Figure 11). The distributions of storm starts, volume, and intensity appear quite consistent; even when combinations of events are considered. Thus, the trending in basin response due to the lowering of the frost table will in fact justify the effort in designing an appropriate model which can be calibrated on a minimum of data or field measurements and is simple enough to allow the generation of flow statistics by routing the available historical meteorological record through it.

A cursory look at summer records of precipitation as compiled over thirty-five years at Norman Wells illustrates the point. In no respect do the size of frequency of events trend, as illustrated in Figure 11. This implies that the storm event or combination of events of a given exceedence level, applied to a basin model of fixed parameters will lead to excessively conservative results. This conclusion is based on the concept that the available flow data and thus the model calibration tends to be from early in the year when data is easiest to acquire because the response characteristics are most severe.

The framework for the appropriate model already exists in the form of the Clark's model used for data analysis in this study. This model is sufficiently simple that even with extensions to allow trending in parameters, including basin storage, it should be reasonably efficient in terms of computer use. Furthermore, a random element can be introduced to allow for natural uncertainty in data and characteristics. This type





PLOTS WERE EXTRACTED FROM DAILY METEOROLOGY OBSERVATIONS AT NORMAN WELLS, FROM 1943 → 1977

- 10 DAY MOVING TOTALS ARE PRESENTED SINCE TRENDS ARE CLEARER
- A STORM IS SEPARATED & CONSIDERED AN INDEPENDENT EVENT IF AT LEAST ONE 'DRY' DAY SEPARATES IT FROM ANOTHER EVENT (SOULIS & VINCENT, 1977)
- 810 STORMS WERE DEFINED AS INDEPENDENT SUMMER RAINFALL EVENTS OVER THE 35 YEARS ANALYZED

NB: WHILE MILD TRENDS IN STORM CHARACTERISTICS ARE EVIDENT, THEY ARE NOT STRONG ENOUGH TO JUSTFY EITHER A FIXED PARAMETER OR A RAIN EVENT BASED STATISTCAL APPROACH

FIGURE 11: INVESTIGATION OF TRENDS IN SUMMER STORMS AT NORMAN WELLS

of model could be run on long term meteorological records and used to deterministically produce synthetic flow records from which design statistics could be extracted. A model for southern use (non-trending parameters) incorporating uncertainty in basin characteristics at the time of the event has been designed by Russell (1977) for estimating flow statistics for municipal design.

This technique has some advantage in that some flexibility is allowed since, with further work, estimates of basin parameters and their trends should be possible with relatively few field measurements. Uncertainty in these estimates can be introduced into the random nature of the parameters while the required real data, the rainfall sequence, can be transferred using the more complete available knowledge of the weather patterns. The resulting long term hydrograph, while not likely correct in absolute terms, should be statistically reasonable and provide some basis for a rational structural design.

Clark's model, about the simplest rainfall-runoff model available, takes account of both travel time and storage and has been widely used (it is the basis of the U.S. Corps of Engineers HEC-1 program (HEC-1973)). Lacking anything better it is suggested that peak flows be computed on the basis of seasonal modelling of the runoff using, as input, rainfall data from the nearest long term meterological station (Norman Wells would have to serve for a wide area) either on a daily basis or shorter time period if suitable data are available.

(1) Keep a running total of storage space - evaporation less rainfall losses (total rainfall less the effective rainfall which contributes to runoff) assuming that the storage space is full at the end of the snowmelt season.

(2) Model the runoff using Clark's method when there is a rainfall surplus after filling the space created by evaporation, assuming:

(i) "Losses equal split between initial loss and constant rate infiltration loss (these losses should completely fill the storage space at the time).

(ii) T_c in hours = $L_o/V_o + L_c/V_c$

where L_o = length of overland flow (m)

V_o = velocity of overland flow (m/hr)

V_o = 250 S where S = mean slope

L_c = channel length in m

V_c = channel velocity in m/hr computed from Manning's or other standard formula.

(iii) R in hours = $2T_c$

The above procedure should yield flow hydrographs for the site in question. From these, annual peaks could be abstracted and anlayzed by standard frequency methods. To allow for uncertainty the hydrologist may wish to put bounds on his assumed parameters and incorporate these in the analysis by a procedure such as that outlined by Russell (1977).

5.0 CONCLUSIONS

The Chick Lake study was intended primarily as a learning exercise rather than a definitive data gathering study. The how and why of the subarctic hydrology of a particular terrain type was the subject, and in this respect the study was at least a partial success.

The difficulties of gathering meaningful data under harsh conditions are discussed at length in the Appendix which is intended as a guide around the major difficulties and a directory of events which affect that remote data gathering study. Determining what to measure and why when dealing with basins of muskeg vegetation types in the discontinuous permafrost zone was a necessary part of the overall study which initiated the work at Chick Lake simply because northern hydrology is still in its infancy relative to the study in more temperate climes. Some of the questions which initiated the study, the answers of which inevitably resulted in further questions were as follows:

(a) Is permafrost important?

(b) To what extent is basin response affected by the presence of permafrost?

(c) What processes of the permafrost regime are hydrologically important?

(d) What misconceptions of the northern environment do we labor with?

As alluded to, the existence of permafrost is important, particularly the thaw process and the material composition of the active layer. If this layer is composed of an organic mat which behaves like a sponge whose thickness increases with time, then basin parameters change and these changes must be taken into account. Also, since the point lowering of the frost table is highly variable, local lows are formed in the table where moisture accumulates which reduces the insulating value of the cover further increasing the rate of progress of the frost table. Thus the topography of the frost table becomes an exaggerated replica of the surface unless some form of discontinuity is caused by surface disturbance. This creates increasing depressional storage and can also change the basin definition with time.

Evaporation has occasionally been ignored when calculating a water balance in the north, particularly if a close look at the amounts of water involved has been avoided. While total evaporation is not large (300 mm estimated for Chick Lake) when compared with the limited annual precipitation (approximately 330 mm at the study site) about half of which falls as snow, it becomes important. This is particularly true since it can be shown that the real evaporation approaches the potential evaporation in organic terrain units since the water table cannot fall far below the surface due to the location of the frost table, and a constant wicking action of the all important organic mat. Again, why is evaporation important? It appears to act as a secondary drainage mechanism which removes water from the surface cover, thus creating potential storage for incoming precipitation. The more storage that is available, the less significant the basin response. Where does this all lead?

Simply, the intelligent design of minor hydraulic structures and erosion control works is generally based on some acceptable level of failure relative to the costs and risks of damage. The sizing therefore, is based on some form of statistical analysis which provides a design flow of small return period floods. Unfortunately, in northern latitudes both flow data and experience is in short supply, with the meteorological data situation being only somewhat better. The simplest approach to define the design flood is to define a single set of basin parameters and choose the storm event of the required statistical level and route this through the fixed basin model. However, since it has been shown that the basin parameters change significantly with time, all storm events must be considered. It has been further demonstrated that even for small basins the hydrologic response is attenuated to the extent that the storm hydrographs overlap and thus event combinations must be considered. Thus, to define the necessary design hydrographs, the design model must allow the basin parameters to vary with time, must take into account antecedent conditions, and must allow the superposition of adjacent events.

Finally, it has been shown that the storm series, based on the Norman Wells record, are not sufficiently skewed to early summer to justify accepting the common design approach. This approach, generally based on a single basin calibration obtained early in the year and then applied to all storm events regardless of their timing tends to conservatively estimate single event peaks, but ignores, and therefore is seriously unconservative with respect to event superposition.

A simple model, based on the Clark method of hydrograph synthesis (see Gray, 1970 and HEC, 1973) is proposed which could be set up to allow both random and systematic changes in basin parameters. Use of a simple model allows a large amount of meteorological data to be utilized to provide the flow statistics. An extension of the process involves the input of basin parameters as ranges (or for time varying information as bands) and by using two or three specific values from the range and calculating flow based on each combination of the parameters, a large set of statistically significant flow peaks are generated (see Russell, 1976).

To utilize this method the manner in which the parameters change must be defined. Of particular interest are the spatial and temporal variation of the lowering of the frost table and the evaporation rate as a function of depth to the water table and date. Changes in model parameters such as the variation of time of concentration and storage coefficient with the depth of thaw and water table and/or moisture content of the surface cover must be investigated. To examine and define these concepts further, detailed studies are required, including extensive field work.

The definition of these mechanisms will lead to a better understanding of northern hydrology as well as reducing the "conservativeness of ignorance" which is costly both in terms of money and environmental damage resulting from overdrainage by the oversizing of drainage structures for northern communities and transportation links.

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APPENDIX: NORTHERN FIELD OPERATIONS

NORTHERN FIELD OPERATIONS

In a northern data gathering program there are a number of considerations generally outside the usual realm of experience of many field personnel. The comments which follow are a collection of suggestions and considerations based on experiences which may be of use to the first time northerner in the planning of a program, presented briefly in point form.

1. Transportation

- air freight costs are high and often the only alternative, but given sufficient lead time overland or water transport can be used to advantage.
- freight leap-frogging is useful. (ie: transport by relatively cheap means as far as possible in order to reduce the expensive jump to the site. eg: barge to a nearby point and then sling in using a helicopter.)

a) Aircraft

Fixed Wing - cheaper, faster and generally larger capacity than helicopters.
- awkward shapes and sizes difficult because of the limitations of doors.
- spring and fall usefulness sometimes limited since ice conditions limit float and ski access and temporary strips are often unuseable due to frost heaves or soft ground.
- useable for reconnaisance but the inability to land at will, fly low and

slow or hover reduce their value.

Helicopters - expensive

- fuel is a problem; high consumption and limited tankage require careful planning and possible fuel caches.
- the correct machine will handle almost any freight as doors are better placed or items can be slung below. Further, the freight can be placed precisely where it is wanted.
- useful as a construction tool - sky hook.
- probably the best reconnaisance vehicle available as cabin visibility is excellent, personnel can be put almost anywhere, and the hover capability is most useful.

b) Boats

- for moving heavy freight, barges and tugs can be used in the Mackenzie Valley but lead time of almost a full year is necessary.
- canoes, jet boats and other small craft are useful for moving small amounts of freight, water sampling programs, etc. and their availability is generally good.

c) Overland

- with the opening of the Dempster Highway to Inuvik and the construction of the Mackenzie Highway, this possibility is becoming more viable. Contact the Department of Public Works in Edmonton for access and conditions.
- in winter the winter road network may be of use but will require investigation by the planner. Often the frozen waterways become the highways of the north.
- in summer overland transport off the all-weather roads is difficult and discouraged due to the damage to the flora.

2. Instrumentation

- choice becomes closely aligned with the mode of transport available; a choice often beyond the manipulation of the planner.
- must be simple, robust and very reliable. There are very few repair facilities in the north.
- freight handlers are not tender with boxes; neither are the occasional bear or moose once an instrument is in the field.
- before anything goes into the field it must be assembled and checked.
- suitable spare parts should go with each unit.
- every effort must be made to ensure that field personnel are familiar with how things work in order to effect repairs or improvise when necessary.

- the environment is extreme; therefore weatherproof the instruments (rigid foam boxes) and mount them well. Again bear and moose present a problem.
- care must be taken not to provide nesting sites for the birds, animals and insects in the instruments. Therefore screen or plug openings where possible.
- mechanical drives for charts seem to work better than electrical ones. They don't have batteries to freeze which can be forgotten on a service trip and they tend to "tick" loud enough that there is some assurance the unit is working after being placed in its weatherproof box.
- use lots of desicant; preferably one pouch in each instrument of the variety that changes color as its capacity is used up. This provides a useful check.
- carry a general tool kit, as well as specific parts anticipated to give problems.
- useful items to bring along:
    - fibreglass packing tape
    - epoxy glue
    - quart of resin, some fibreglass cloth and catalyst
    - push-type hand drill
    - nuts, bolts, some metal screws and nails
    - hack saw blade, axe file
    - axe
    - vice grips, pliers with wire cutters, crescent wrench

- spare electrical lead
- bailing wire

- these items along with those items definitely required for servicing or installation should be taken.
- How is the instrumentation to be installed? Is it a reasonable set-up given the tools and site conditions? Packing a nitrogen bottle through a swamp is not pleasant, however it becomes reasonable if a helicopter is available to long line pieces in to awkward locations.
- flow recorders
    - Ott bubbler recorders involve the above mentioned nitrogen bottle, plastic tubing which must be protected from mice, a finicky pen and a battery chart drive.
    - Stevens F float-type recorders are simple, require a more elaborate stilling well and a non-settling foundation, but are very reliable. They do however also require frequent service.
    - Stevens A float-type recorders with a mechanical chart drive, and a 90 day strip chart proved the most reliable. Of particular interest is the simple pen design with a back-up pencil trace, and good resolution thanks to a reversing pen drive.
- rain gages
    - standard Weather Measure tipping bucket gages fitted with a mercury type switch worked well.

3. Environment

weather - best described as extreme, the author has experienced snow and freezing conditions in all months, as well as a large insect hatch when there was 90% snow cover. Winter is predictable - cold.

survivial - go prepared; while aircraft are required to carry kits, they are occasionally neglected and often have been "raided".

- an Arctic-type parka is good insurance from October through May in the Discontinuous Zone - all year further north.
- all personnel take a good course which includes aircraft safety and first aid, carry the gear and play by the rules.

insects - always carry insect repellent; in particularly bad conditions, gloves and a headnet are necessary combined with long sleeves and trousers.

daylight - during summer it is often possible to work nearly 24 hours as far south as in the northern extremes of the provinces. This can often be used to advantage during service trips when the work is light and the travel time between sites is long.

- in winter, the short day can seriously limit access since flying time is curtailed.

flora - muskeg can be deceiving with respect to its apparent bearing capacity.

- in spring, when frozen, all is well, while by summer instrumentation has been tumbled into a fen thanks to differential thawing and settlement.

- one solution: using an auger, drill through to the permafrost and embed stakes to act as a pile foundation. This is best done in the fall since the drilling is easier, active layer is melted, and the piles will be frozen in solid over the winter.
- summer access is often difficult since the surface is very spongy.
- at times in summer, the fire hazard is extreme and great care must be exercised. Fire will spread even with standing water a few inches below the top of the moss layer.
- the growth rate of willow along the river banks is incredible and new growth can obscure flagging, clearing, etc. in weeks. Keep this in mind when flagging and writing site descriptions.

fauna - bears, unpredictable, have been known to destroy an instrument site for no apparent reason.

- moose or cariboo seem to prefer setups for scratching poles, particularly where the trees are few or spindly.
- build platforms, etc. with this in mind. Protect the instruments if possible.
- survey flagging often gets eaten by moose. Spread lots around and maybe some will be left.
- polyethylene rolls for basin liners, if left on the ground, are great "chews" for bear, wolf and mice. Have enough to allow for the outer layers

of the roll to be damaged. Once spread the attraction is diminished.

- mice chew electrical insulation. Therefore install wire tightly and place wire so it won't short or ground and drain the battery.

4. Communications

   - Motorola "lunch box" FM radios provide excellent person to person and ground to helicopter communication during field operations. Further, the unit can be set up for multiple channels to tie into the radio telephone network. Range is limited to about 25 miles line of sight either between units or to the repeater station.
   - short wave communication is necessary for longer distances where the line of sight is obstructed. While it does work, it should only be considered for semi-permanent camp operations since operating schedules are required and a base station should be maintained.

5. Accommodation

   - fly camps are often costly to set-up, particularly in terms of time lost towards program objectives.
   - permanent camps
     - Department of Public Works runs a series of camps for northern highway construction and is often helpful.
     - oil companies operating in the area sometimes allow their drill or seismic camp facilities to be used; some generally discreet inquiries are in order.

  - contact Lands and Forests, particularly if some connection to environmental concerns can be made by the investigation.
  - fishing and hunting camps - contact the tourist bureau.
- hotels, motels, etc.
  - check the major towns. There is often some form of rental accommodation.
- small villages
  - a call to the R.C.M.P. of the community can result in either an invitation to stay at the station or a lead to further inquiries.

6. Personnel
   - field experience is important, particularly remote experience.
   - familiarity with equipment, first aid, survival skills.
   - practical, innovative and open-minded.
   - healthy.
7. Contingency
   - what happens if things go wrong? Back-up is important in northern operations.
   - plan for unexpected costs. As a rough guide is to add 15 to 20% to estimated cost, excluding aircraft charges. Add a 30% contingency to those.
   - plan for lost time due to mechanical problems, scheduling difficulties and most of all weather.
   - back-up parts and spares are necessary items, but don't let them stop at the instrumentation. A pair of lost

perscription glasses can be just as devastating to a program as a case of odd size dead batteries.

- before you go north, ask the "what if?" questions to cover each aspect of the program and provide for a solution where possible.

The foregoing is a somewhat disjoint series of comments which will hopefully provide a starting point in planning; an operation which is designed to eliminate uncertainty and cover possible events which may occur during field operations. Of necessity, any program is a compromise of what can be accomplished with certainty, and what might be; all within the available budget. Perhaps the first question should be "Are we looking at the right source of information by going into the field?" Once it has been decided that field data is necessary, the questions: "Is it possible to get meaningful results?" and "How are we going to analyse the results?" must be answered so that all of the necessary data that is required is obtained. Finally, "Are we measuring the correct things; are there factors within this unusual environment which should be measured?" (eg: "Is permafrost important?").

Program planning is a series of answering the appropriate questions with the best possible solutions. Northern programs are inherently very expensive, but the failure to plan properly, or to gather the correct information with the right equipment generally results in economic disaster. It is difficult and often impossible to "patch up" errors in judgement when dealing with the north.