K. U. WEYER:

SALT DISSOLUTION, KARST GEOLOGY, GLACIAL EVENTS AND GROUNDWATER FLOW IN THE PINE POINT REGION, N.W.T.

VOL 1: TEXT

National Hydrology Research Institute
Ground Water Division
101 - 4616 Valiant Drive N.W.
Calgary, Alberta
T3A 0X9

Draft, March 1983
subject to final revision

Vol. 1: Text
Vol. 1: Figures
Vol. 3: Tables and Appendices

Table of Contents

Note: Text is contained in Volume 1
Figures are contained in Volume 2
Tables and Appendices are contained in Volume 3.

List of Contents

List of Figures

List of Tables for Climate

3.8. Deviation (in %) of annual precipitation from 1951 to 1980 normal at Fort Smith Airport, Hay River Airport and High Level Airport for calendar years (A) and water years (B).

3.9. Symbolic classification table for deviations of precipitation from 1951-1980 normal at Fort Smith Airport, Hay River Airport and High Level Airport for calendar years (A) and water years (B).

[illegible] Table [illegible]

[illegible]

[illegible] Table [illegible]

[illegible] Minimum and maximum daily [illegible] (19[illegible]-82) of [illegible] Lake [illegible] ([illegible] station [illegible] 07S [illegible]) and [illegible] ([illegible] station [illegible]). Data from [illegible]

TABLE FOR LAKE LEVEL FLUCTUATIONS OF GREAT SLAVE LAKE

2. II. Minimum and maximum daily gage heights (1970-82) of Great Slave Lake in Yellowknife Bay (WSC - station: 075B001) and Fort Resolution (WSC - station: 07B001). Data from Water Survey of Canada, Yellowknife office.

TABLES FOR DISCHARGE IN RIVERS SOUTH OF GREAT SLAVE LAKE.

3-12 ~~1.~~ 1975-1982 monthly summary of daily discharges [m^3/s] at gaging stations at the rivers.

A. Buffalo River (WSC - station No. 07PA001)
B. Little Buffalo River (WSC - station No. 07PB002) and
C. Hay River (WSC - station No. 07B001)

Data from Water Survey of Canada, Yellowknife office.

3-13 ~~2.~~ Annual discharges and related total precipitations 1975-1982 for the rivers

A. Buffalo River (WSC - station No. 07PA001
B. Little Buffalo River (WSC - station No. 07PB002)
C. Hay River (WSC - station No. 070B001)

aquifer. Flow in the aquifer is from highlands to lowlands.

Chapter 3

Chapter 4

stripes, isotopic balances were calculated from measured $\delta^{34}S$ values and concentrations of sulphate and sulphide ions. In areas without stripes, measured $\delta^{34}S$ values for sulphates only were used, since sulphide data were lacking.

Chapter 5

List of Tables

Note: Where measurements by other agencies are quoted, results are given in the original units; if these are not in SI units, conversions are added in parentheses.

List of Appendices

ACKNOWLEDGEMENTS

This report results from a Joint Research Project between Pine Point Mines Ltd. and the Federal Department of Environment. The project was proposed by the late W. H. Gibney, Manager of Pine Point Mines. J. P. Bruce, N. H. James, the late E. R. Peterson and D. H. Lennox implemented and supported the project within the Inland Waters Directorate of the Federal Department of Environment.

Much support was received from Mr. K. J. Durston, chief engineer of Pine Point Mines. Early discussions with Mr. P. Santos, D. Adams, K. Newman, H. Skall and S. Hoffmann of Pine Point Mines and Cominco Ltd. were particularly useful. Discussions were also held with N. Zarkos, J. Collins, K. Carter, R. Armstrong and T. Healy of Pine Point Mines. All their contributions are gratefully acknowledged. D. Adams, Cominco Ltd., Calgary, cooperated in core investigations at the Institute of Sedimentary and Petroleum Geology (ISPG) and provided valuable advice regarding stratigraphic and sedimentological matters.

D. Hocking, Canadian Forestry Service, first confronted me with groundwater flow south of Great Slave Lake. The Water Survey of Canada (G. Morton, K. Davies) made the facilities and services of the Fort Smith Office (A. Wilson, D. Dube, T. Wilson) available to us. Part of our chemical analyses were provided by the Water Quality Branch, Calgary (M. Korchinsky). Microbiological studies were done by the Environmental Protection Service, Edmonton (J. Bell, G. Elliott, F. Zaal). Parks Canada, Winnipeg (J. Mathers) and Parks Canada, Ft. Smith (B. Liefs, A. Starko) provided permission to install a discharge gaging station in Wood Buffalo National Park.

Within the National Research Institute, I worked closely together with Mrs. W. C. Horwood-Brown. Much help was also received from J. A. Banner, R. O. van Everdingen and E. Pearn. G. Hint, R. Gardiner and J. Ruitenbeek temporarily worked as students within the research project.

The stable isotope facilities at the University of Calgary (H. R. Krouse, M. A. Shakur) received financial support for this study from the Natural Sciences and Engineering Research Council of Canada. Technical assistance was provided by L. Boreiko, J. Pontoy and N. Lozano.

A. G. Redshaw, R. Hale and the Water Resources Division of DIAND, Yellowknife, assisted in data collection. D. Graham, Northwest Territories Forestry Service, DIAND, Ft. Smith, often released helicopters for our use during forest fire seasons. Most of the borehole data and valuable discussions were provided by W. Padgham and W. Gibbons, DIAND, Yellowknife and D. D. Brown, DIAND, Ottawa.

Borehole data were also made available by Westmin Resources (A. Soregaroli, A. Rendall).

The many contributions from the Geological Survey of Canada (EMR) are appreciated. Several geologic aspects of the study were discussed with H. Geldsetzer, O. Hughes, L. Jackson, N. Meijer-Drees, D. Morrow, T. Powell, D. Sangster and K. Williams. A. E. Foscolos, J. Wong, A. Heinrich, O. McEwan, W. Kalkreuth, K. Pratt and G. P. Michael analysed various rock samples. The core-storage facility of the ISPG (W. J. Banning) made boreholes files and cores available for inspection. Photographs of cores from oilwells Iskut Little Buffalo K-22 were prepared by B. C. Rutley and W. B. Sharman. Library service was received from the ISPG (M. Jones) and from the Gallengher and main library of the University of Calgary. R. McQueen (ISPG and University of Waterloo) made a prepublication copy of paper by Krebs available.

In an early stage of the investigation K. Werner of the Geological Survey of N.W., Krefeld, Germany, analysed mineral precipitates in discharge channels.

The Department of Public Works of the NWT provided accommodation in Pine Point during the first two years.

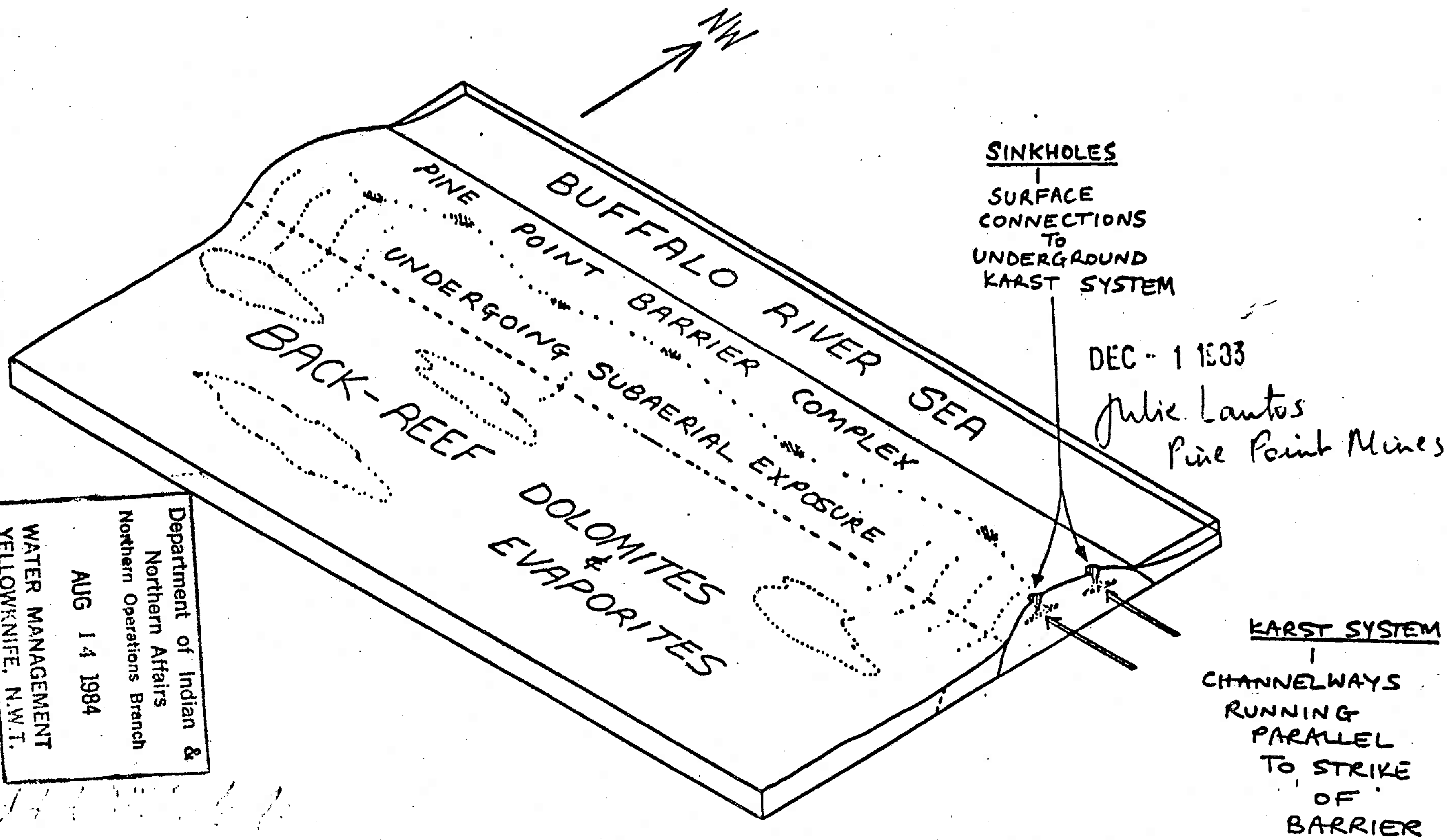
We would like to thank all the many individuals who have contributed to the success of this study. Parts or all of the manuscript have been read by R. O. van Everdingen, H. Geldsetzer and G. Holdsworth who also provided comments. Thanks are due to E. Pearn, S. Diocee and D. Petrunia for typing the manuscript, to W. C. Horwood-Brown and U. von der Dick for drafting part of the figures, to W. C. Horwood-Brown and J. Ruitenbeek for computer data processing and last not least to W. Weyer for proofreading and organisational help.

Chapter 1

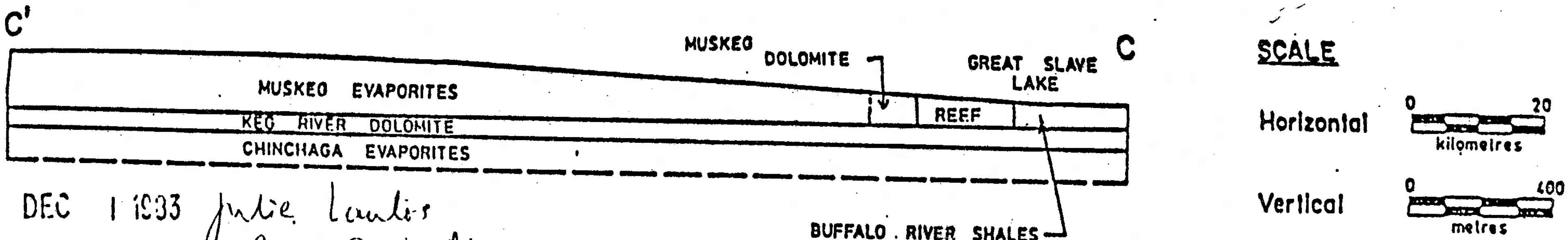
Add Don's requests

add ment to [illegible]

add [illegible]
Pine Point mine
(Tuda landed [illegible])

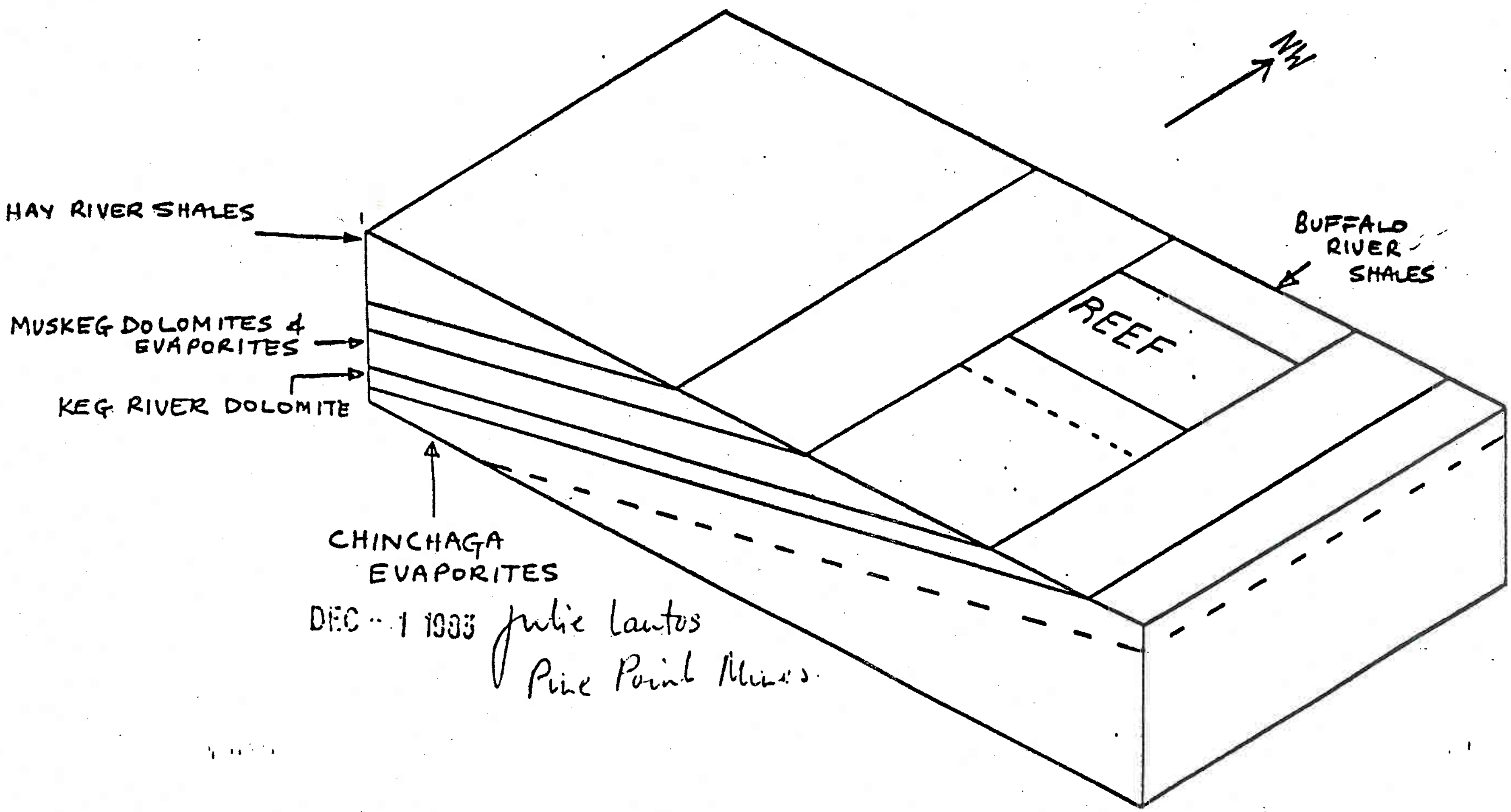


PINE POINT :- KARST PARALLEL TO STRIKE OF BARRIER
- DEVELOPED FROM SURFACE DOWN



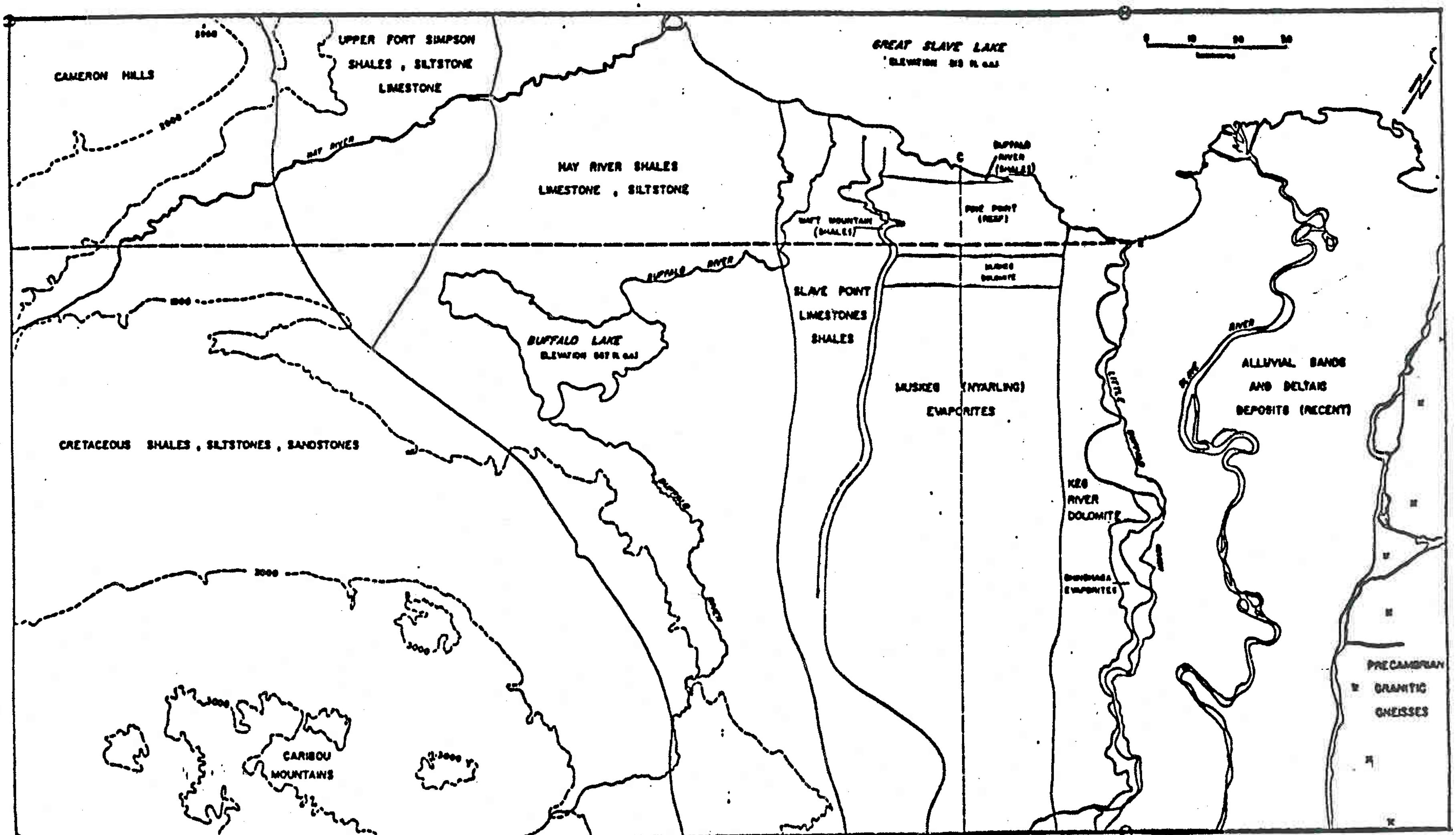
DEC 1 1983

Julie Lawlor
Pine Point Mines

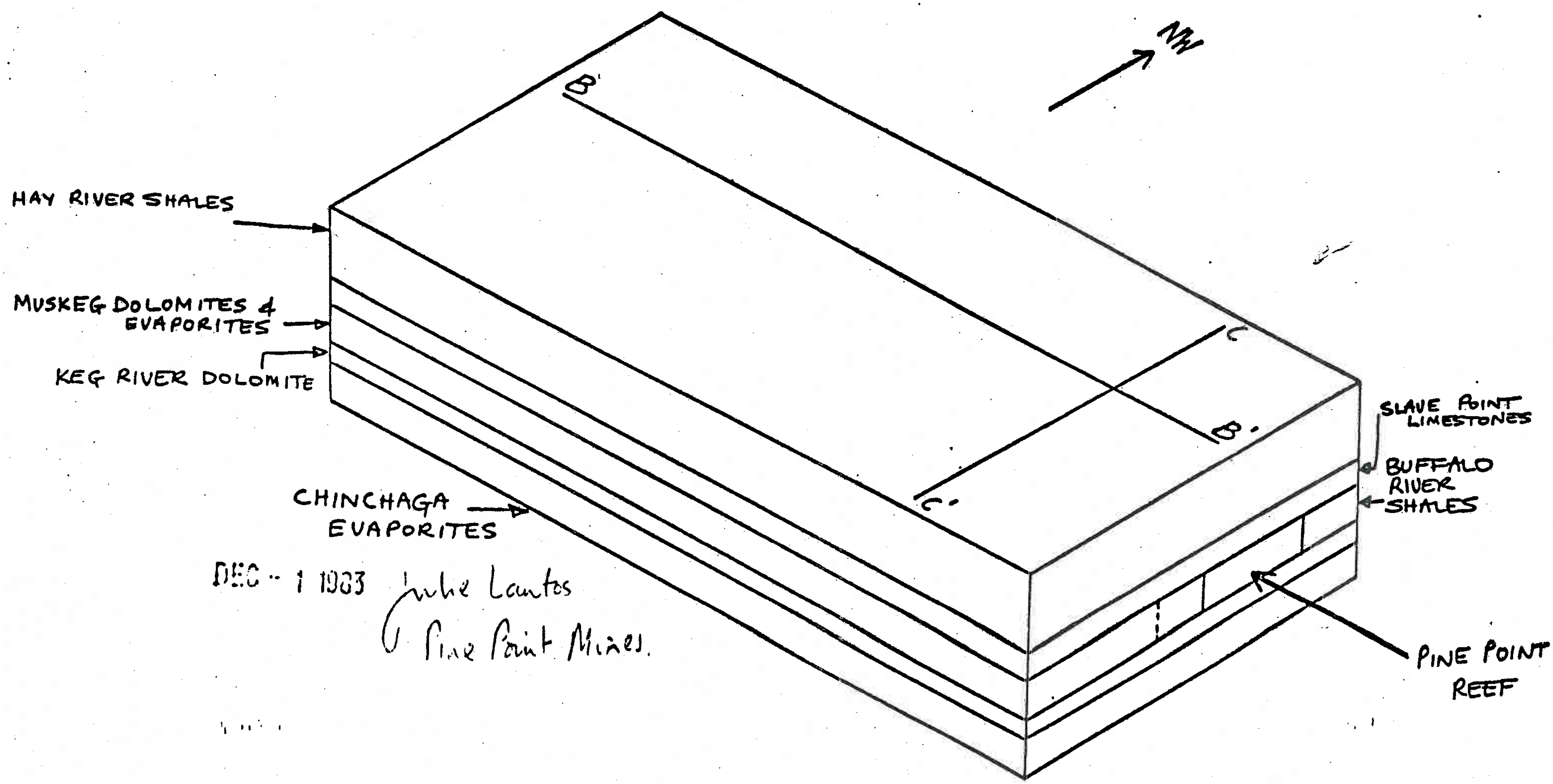


DEC - 1 1993

Julie Lautos
Pine Point Mines



DEC - 1 1983 Julie Lantos Pine Point Mines


NW
B
B'
C
C'
HAY RIVER SHALES
MUSKEG DOLOMITES & EVAPORITES
KEG RIVER DOLOMITE
CHINCHAGA EVAPORITES
SLAVE POINT LIMESTONES
BUFFALO RIVER SHALES
PINE POINT REEF
DEC - 1 1983
Julie Lantos
Pine Point Mines.

1. INTRODUCTION

SCOPE OF STUDY AND REPORT

This paper describes an investigation of groundwater flow, water chemistry, porosity and permeability distribution and their relationship to salt dissolution, karstification and glacial events on a regional and local scale in the area of Pine Point, N.W.T., a by now famous Canadian lead-zinc deposit of the Mississippi-Valley type.

During spring of 1976, difficulties had been encountered in achieving the dewatering goals at open pits of Pine Point Mines, in particular at the open pit R-61 as had been predicted by the Hydrology Research Division (HRD; K. U. Weyer) during a visit in November, 1975. In July 1976, W. H. Gibney, Manager, Pine Point Mines Ltd., proposed a joint research study to the Hydrology Research Division (D. H. Lennox, Chief) of Environment Canada[1)] to investigate the mechanisms of groundwater flow in the Pine Point region and their effect on the dewatering of the Pine Point ore bodies.

It was agreed that Pine Point Mines would carry the operational costs while HRD/NHRI provided mantime and office space for the joint research project. Because of federal constraint programs Pine Point Mines, at a later stage, also carried some of the personnel costs. The joint research project was terminated at the end of 1981. Since then all costs have been carried by NHRI.

Hydrogeologic field studies and data processing commenced in 1977 and continued until 1981, intermittently, because of inherent circumstances. Finally, limitations of resources and the time-consuming collection of geologic data during 1982 restricted not only the time available for actual preparation of this report but also thereby its scope.

1) The groundwater section of HRD is now the Ground Water Division, National Hydrology Research Institute (NHRI) of the federal Department of Environment (Environment Canada).

EARLIER STUDIES

Groundwater flow in northeastern Alberta and adjacent parts of the Northwest Territories has been dealt with in a number of papers, notably those of Cameron (1917), Camsell (1917), Brandon (1965), Richmond (1965), Hitchon (1969a, 1969b, 1971), and Hitchon et al. (1969). Davidson (1967a, b), Billings et al. (1969) and Kesler et al. (1972) refer to groundwater flow conditions at the time of ore genesis.

Major springs were observed along the south shore of Great Slave Lake from Little Buffalo River to Sulphur Point (see Fig. 3-1 for geographic locations), and along the north-west shore from Windy Point to Sulphur Bay by Cameron (1917). The springs close to Little Buffalo River were salty-tasting while sulphur dominance was reported for a "very large spring" on the west side of Sulphur Point and for "large sulphur springs" (accompanied by numerous seepages of petroleum) in the vicinity of Windy Point (ibid). "Strongly flowing sulphur springs" were abundant at Sulphur Bay (ibid.). At Slave Point, close to Windy Point, "a small sulphur spring was noted and the interior of the point contains a large, open gravel and clay area, apparently the basin of a large alkaline sulphur spring now dried up. Large quantities of decayed and salt-encrusted timber are scattered about this area, many pieces having the yellowish tinge of sulphur" (Cameron, 1917, p. 73). With regard to dolomitization and petroleum occurrence at Windy Point, Cameron (1917) suspected the following process at work: "The sulphur-bearing waters rising from below carry considerable quantities of calcium and magnesium salts and percolating through the overlying thin bedded limestones change them to crystalline magnesian limestones and dolomites. In the process the bitumen is set free and forced either into the cavities formed in the dolomites or through the fissures, developed during dolomitization, to the surface to form the tar and oil pools."

Camsell's (1917) chemical analysis of water from a spring discharging "about two gallons per minute" (0.15 l/s) on August 14, 1916, at Sulphur

Point is listed in Table 1.1, as well as analyses by Brandon (1965) taken at Sulphur Point on July 26, 1960, and at High Point on July 27, 1960.

Camsell's water sampling was motivated by "the possibility of finding salts of potassium associated with the gypsum beds of this region" (Camsell, 1917, p. 142). More samples were taken by Camsell in the regions east and south of the Caribou Mountains. None of the waters analyzed contained an unusual proportion of potash and it was concluded that potash was not present in commercial quantities in the vicinity of the points where samples were collected.

Richmond (1965) collected water samples from five springs and six sinkholes south of Great Slave Lake east of Copp and Needle Lake "in an attempt to detect updip flow of saline connate water from subsurface" (ibid., p. 231). The springs were at the base of a small scarp that marks the eastern edge of carbonate exposure. Chloride concentrations were found negligible and "seepage of connate water and solution of bedded halite are considered to be non-existent" (ibid., p. 232). Down-dip flow of groundwater was assumed (ibid., p. 236). The down-dip direction would be in an approximate south-westerly direction.

Brandon (1965) reported 420 mg/1 chloride from a water sample taken in August 1961 at the mouth of the Buffalo River. Based on the results of a two dimensional cross-sectional electric analog model he postulated flow from Buffalo Lake through lower Devonian layers in an easterly direction toward the Little Buffalo River.

Hitchon (1969a, b, 1971) concluded from the analysis of fresh-water heads in oil wells that groundwater in Alberta is, in general, flowing from the Rocky Mountain and Foothills belt in a NE direction towards the edge of the Western Canada Sedimentary Basin. "Despite significant differences in geology from one part of the basin to another, the dominant fluid potential in any part of the basin corresponds closely to the fluid potential at the topographic surface in that part of the basin" (Hitchon 1969a, p. 194).

Figure 1-1

Showing hydraulic-head distribution between the elevation +1000 ft to -1250 ft, Figure 1-1 of this report (ibid., Fig. 5) indicates recharge in the Caribou Mountains and radial groundwater flow away from the circular plateau of the Caribou Mountains.

In a later paper, Hitchon (1971, Fig. 5) gave the impression that flow in the deeper Keg River Formation underflows the Caribou Mountain system from SW to NE. The 1000 ft (305 m) hydraulic-head isoline shows that two rivers to the northwest and south of the Caribou Mountains act as major recipients for groundwater flow, the Hay River to the north-west and the Peace River to the south. Hitchon et al. (1969a) suggested that the chloride contents of the Slave River originate in groundwater containing dissolved Middle Devonian halite. K/Na ratios in brines discharging in springs near the Salt River are very low, suggesting an origin from dissolved halite (ibid., p. 1401).

At the time of ore genesis groundwater flow within the Pine Point reef structure is thought to have been from the west (Billings et al.,1969), in both directions along a path trending N50°E (Kesler et al., 1972) and in both directions along eastern and SE pathways (ibid.). Billings et al. (1969) base their deductions on a chemical and isotope comparison with the Rainbow oil field in northwestern Alberta. Kesler et al. (1972) base their conclusions on a study of asymmetrical growth of sphalerite and galena crystals from Pine Point ore bodies and vertical joint sets in open pits.

Davidson (1966) discusses the genetic relationship between ore deposits and evaporites. For the Pine Point region Davidson (1967 a, b) suggests the origin of lead and zinc from dissolving Elk Point salt to the south and hence implies groundwater flow from the south. This view is supported by Roedder (1968a).

DIAGENESIS AND ORE-DEPOSITION MODELS

Early in the course of the investigation it was recognized that the present-day groundwater flow systems utilized the same or similar porosity systems of a karstic and tectonic nature as did probably the dolomitizing and the ore-forming fluids. At first glance, groundwater flow and biochemistry seemingly allow metal sulfides to be formed even today in the same area (Weyer, 1975, Weyer et al.,1979). Porosity development in the Pine Point area has been affected by both ore genesis and dolomitization. Thus some attention will be devoted to the possible and probable interaction between these processes and groundwater flow.

Several models have been proposed in the past for the genesis of Mississippi-Valley type lead-zinc deposits and for the spatially associated dolomitization.

DOLOMITIZATION AND PRESQU'ILIZATION

Dolomitization is a diagenetic change of a calcium-carbonate system into a magnesium-calcium carbonate system; presqu'ilization is the often late diagenetic change to a coarse crystalline dolomite (Skall, 1975).

Morrow (1982b) differentiates seven major dolomitization models: (1) in the *hypersaline basin and seepage reflux model,* seawater infiltrates into the bottom of lagoonal systems and at some later time seeps seaward again: (2) in the *burial compaction model,* Mg^{2+} -bearing compaction water is expulsed into carbonate reef bodies, causing dolomitization; (3) (4) in the *coorong model* and *sabkha model,* groundwater fills ephemeral lagoonal lakes, precipitating dolomite mud and magnesite when the lakes evaporate in the summer; (5) the *mixed water* or *dilution model,* documented by Hanshaw et al. (1971), explains deep burial dolomitization under the influence of fresh groundwater extracting the Mg^{2+}-ions from marine sources (mixing of fresh with salt water); a modification of this model is the pene-contemporaneous dolomitization by shallow coastal fresh-water aquifers;

(6) *solution cannibalization* refers to the derivation of Mg^{2+} from the dissolution of magnesian calcite and reprecipitation of low-magnesium calcite; *pressure solution* along solution seams and stylolites has also been seen as a major cause of dolomitization; and (7) *tectonic or hydrothermal dolomite* cross cuts strata as a coarsely crystalline white sparry dolomite; it has been designated as tectonic or hydrothermal as it often occurs near known fault systems; these fault systems may be conduits for groundwater flow and therefore may provide additional amounts of Mg^{2+}-ions for enhanced dolomitization.

Common to nearly all of the above models is the assumption that sea-water of recent or ancient nature, not necessarily salt water in general, is the important ingredient for the dolomitization (D. Morrow, oral communication, 1982).

At Pine Point, presqu'ilization is commonly considered to have been caused in a reefal environment by reflux of brines (Skall, 1975). The reef is regarded as being highly permeable along its depositional strike, whereas the surrounding rocks towards the south, the north, and underneath are assumed to be practically impermeable (J. Collins, personal communication, 1981; K. Carter, personal communication, 1982). Movement of fluids is thought to be restricted to the reef and permeable rocks close by. Flow is supposed to be mainly in an approximate E-W direction along the main trend of the reef.

ORE DEPOSITION

Already several hundred years ago, miners in the famous Annaberg mining district of Europe suspected that water flowing in the subsurface controlled the presence and abundance of mineral accumulations (Agricola, 1556). About one hundred years ago it was recognized that fluids of magmatic and meteoric origin cause the accumulation of ore bodies (summarized in Daubree, 1887).

Ore deposition models for Mississippi-Valley type (MVT) lead-zinc deposits have been summarized by Ohle (1959), Brown (1970), and more recently, by Anderson and Macqueen (1982). Various hypotheses involving syn-sedimentary, early diagenetic and epigenetic processes are all alive and well for the various types of sediment-hosted deposits and although certain genetic factors are reasonably clear for each type, the interrelation of these factors and their role in the overall process of basin evolution is still not clear in many respects (Anderson and Macqueen, 1982).

In North American opinion, the late diagenetic or epigenetic aspects prevail for MVT deposits whereas in Europe the syngenetic approach is emphasized, especially by the Amstutz-school in Heidelberg (Brown, 1970). In both views, the precipitation of ore from fluids is closely associated with permeable pathways, either mud channels (syngenetic view) or dissolution structures (diagenetic view; classical paper: Grogan, 1949). The later view seems much more reasonable to most long-term students of the situation in the Southern Illinois district (Brown 1970). Nevertheless, studies of the Amstutz-school in the same area showed that at least part of the ore showings could also be interpreted as being syngenetic (Brown, 1970).

Important for the purpose of this report is the common consensus regarding the association of ore genesis with permeable zones. Within these permeable system MVT ore deposits are simply unusually large representatives of an ubiquitous phenomenon: occurrence of sphalerite and galena are commonplace in carbonate successions (Anderson and Macqueen, 1982).

Individual mining districts may be distributed over hundred of square kilometres, arguing against strictly local sources for metals and sulphur (Anderson and Macqueen, 1982). According to the same authors, there is evidence that mineralization took place at relatively shallow depths, from perhaps a few hundred to about 1,000 m, under average host-rock temperatures that are significantly less than 100-150°C, requiring either a heat source at shallow depth or migration of heated fluids from a deeper source (White, 1974).

Although early workers commonly suggested that deposits were located within carbonate reef masses, subsequent work on many deposits has demonstrated that actual reef-hosted deposits form a minority (Anderson and Macqueen, 1982). Deposits are closely controlled by the prior development of porosity, and thus may be located in platformal carbonates of different character. At Pine Point, ore bodies are located in carbonates of biostromal character, in back-reef and in fore-reef setting (Skall, 1975).

Metal transport and deposition are explained by two basic models: the *basin brine hypothesis* assumes brine is flowing towards the deposit, continuously leaching metal-ions from various sedimentary strata along the flow path and releasing them at the site of the orebody. Jackson and Beales' (1967) model with shale-derived metals is a classical example of this hypothesis. The second model sees metal-ions transported from the Precambrian basement toward the orebody and precipitated. This formerly popular *magmatic-hydrothermal hypothesis* is no longer widely supported (Anderson and Macqueen, 1982).

Imprints of mineral-forming fluids are preserved in fluid inclusions in coarse sphalerite, carbonates, ~~fluorite~~ and barite. All MVT fluid inclusions are similar, showing the following characteristics (Roedder 1976, 1979): (1) the fluid density is commonly greater than 1.1 with salinities often greater than 15% by weight and up to 30%; (2) inclusions contain concentrated Na-Ca-Cl brines with minor amounts of K, Mg, Br and locally heavy metals such as Cu and Zn; (3) organic matter is common (not at Pine Point); (4) K/Na ratios are all higher than the highest values in oil field waters; (5) fluid temperatures on average appear to have ranged from 80°C and 200°C (Roedder, 1976, 1979). Item (4) can be interpreted that the ore-forming fluids are at least partly composed of fluids from evaporite beds enriched in residual K. Fluid-inclusion data are commonly used as indicators to rule out ore-genesis models that feature cold surface waters alone as ore-forming fluids, including seawater or groundwater (Anderson and Macqueen, 1982). Newhouse (1932) considered $CaCl_2$ contents as characteristic of waters transporting lead and zinc.

For the Pine Point ore bodies, fluid-inclusion studies by Roedder (1968a) suggested fluid temperatures between 50 and 100°C. They also "indicate the presence of other salts in addition to NaCl" (ibid., p. 444). Vasquez' (1968) results of semiquantitative analyses (Table 1.2) seem to confirm the presence of comparatively high amounts of $CaCl_2$ in fluid inclusions in carbonates from Pine Point. In sample 0-42-48a3, the Ca-ion is even more abundant than the Na-ion. From freezing temperatures the salinity of fluid inclusions has been estimated to be about 23 percent in sphalerite (Roedder, 1968a) and considerably less in calcites (Roedder, 1968a, Vasquez, 1968).

Macqueen and Powell (1983) interprete the immature nature of the indigenous organic matter on the Pine Point property as indicating a generally low temperature environment (60°C maximum). Sulphur incorporated in MVT ores is generally isotopically heavy. Sulphate reduction by bacteria is said to be restricted to temperatures below 80°C.

Chloride-rich brines have the ability to leach trace quantities of metals from rocks (Ellis, 1968; Carpenter et al., 1974). Sedimentary source rocks could be shales, carbonates and also evaporite beds (Davidson, 1966), especially gypsum and anhydrite as shown by Thiede and Cameron (1978) for the Elk Point Basin south of Pine Point. In the Mississippi-Valley district, lead isotopes are of the radiogenic J-type variety, indicating a basin-brine history (Heyl et. al., 1974). Lead isotopes at Pine Point, however, and in mining districts in England, Siberia, Tunesia and Italy are of the normal N-type variety, which implies a shallow crustal source according to Heyl et al. (1974).

Transport of metal-ions in NaCl brines would be hampered by the extremely low solubility of ZnS and PbS if significant amounts of H_2S were present (Anderson, 1975).

For precipitation of ore, non-mixing models (one fluid carrying both metal and reduced sulphur) and mixing models (sulphur supplied at the site of precipitation) are applied. For the mixing model, two sources of reduced sulphur are available: sulphate in rock and sulphate in one of the participating fluids. Several MVT deposits are not in close proximity of an abundance of sulphate minerals (Anderson and Macqueen, 1982), but they may be engulfed in fluids containing dissolved sulphate.

In Pine Point, colloform minerals are abundant. They are rare however in the Mississippi-Valley district (A. Heyl, oral communication, 1982). Roedder (1968b) considers this form not as colloidal in origin but as the precipitation of minute druses of euhedral crystals from a fluid.

While the development of mineral sciences and related geological sciences lead to a succession of ore genesis models, modern hydrodynamic methods for analysis of groundwater flow have only been developed relatively recently. The advent of computers and refined analog models opened the way for the application of realistic models attempting to understand the basic rules of regional groundwater flow. Complex variations of topographic and hydrogeologic boundary conditions, and of geological parameters, were applied in the work of Tóth (1962, 1963), and Freeze and Witherspoon (1966, 1967), based on the fundamental work of Hubbert (1940, 1957).

More recently, an attempt has been made to couple selected theoretical conditions of both hydrodynamical and hydrochemical nature with a simple geologic history and framework in a numerical model of relative mathematical complexity. From the infinite number of possible quantitative answers, Garven (1982) and Garven and Freeze (1982) report a 90,000 year accumulation for zinc showings of up to 3 ppm in the modelled carbonate aquifer system. The limitations of the modelling methods, the available computer storage space and processing time restricted the choice of parameters and boundary conditions to very simple model conditions only. Groundwater can be even more effective than this in the creation of ore bodies. Jonasson et al. (in press) report an orebody of 80,000 tons of 30% Zn-ore accumulated within 8,000 years; Cannon (1955) found a post-glacial accumulation of 2000 tons zinc and lead in peat beds in Orleans County, N.Y.

DEDOLOMITIZATION

Dedolomitization is the reverse process of dolomitization and is brought about by solutions with a high Ca^{2++}/Mg^{2+} ratio reacting with dolomite to form calcium carbonate (Evamy, 1967), according to the equation

$$CaCO_3 \cdot MgCO_3 + Ca^{++} \underset{\text{dolomitization}}{\overset{\text{dedolomitization}}{\rightleftharpoons}} 2CaCO_3 + Mg^{++} .$$

The work of de Groot (1967) indicates that dedolomitization can only take place where the P_{co_2} is much lower than 0.5 atm, temperatures are not higher than 50°C and a high rate of water flow is present. The former two conditions suggest that, in nature, dedolomitization is a near surface, process. Because of this the presence of de-dolomite may be used to infer that near-surface diagenesis has taken place (Evamy, 1967, p. 1205).

Yanat'eva (1955) studied the effect of dissolved gypsum on the solution of dolomite. She demonstrated that the presence of calcium sulphate in solution enhances the rate of the incongruent solution of dolomite at low P_{co_2} (reported in Evamy, 1967, p. 1204).

Evamy (1967) showed that dedolomitization can lead to an enhancement of porosity and permeability as well as, at a later stage, cementation with $CaCO_3$.

Dedolomitization so far has not been identified as an important diagenetic process in the Pine Point area. It is conceivable, however, that this process caused precipitation of some of the secondary calcite present in the Pine Point dolomites.

Lippmann (1973, p. 166), however, is doubtful whether the process described by the above equation is of any consequence in nature. He feels that "the process interpreted as dedolomitization may consist actually of the preferential dissolution of calcian dolomites accompanied by the reprecipitation of calcium carbonate " (ibid., p. 166, 167).

SEQUENCE OF DIAGENETIC EVENTS

Within the Western Canada Sedimentary Basin, dolomitization and associated development of highly permeable systems occurred in areas of several hundred kilometres in length and width, from Pine Point in the east into the area of northeastern British Columbia (Skall, 1975: Presqu'ile; Morrow, 1975: Manetoe dolomite).

The Presqu'ile facies in the NWT is similar to the Manetoe dolomite in NE British Columbia (Morrow, 1975). Morrow (personal communication, 1982) identified four major diagenetic changes: (1) creation of solution porosity (solution collapse breccia) and subsequent dolomitization of host rocks with coeval infilling of porosity with white mega-crystalline dolomite, (2) precipitation of translucent crystalline quartz, coeval with or followed by the appearance of bitumen (high sulphur asphaltenes), (3) growing of stylolithes cutting across the previous structures and (4) precipitation of sphalerite and galena.

Precipitation of the coarsely crystalline Presqu'ile-type dolomite was associated with the development of the karst-type dolomitic aquifers. The aquifer-like dolomite system were well developed before precipitation of the ore took place. Ore-forming solutions then flowed along available permeable systems and, under favourable circumstances, orebodies were formed. Presqu'ile dolomite may have been remobilized or dedolomitized and reprecipitated. This process would cause the often complicated paragenesis of minerals found today at some of the Pine Point orebodies (Krebs, 1982, unpublished manuscript). The precipitation of ore may also have increased the porosity, because of the formation of hydrochloric acid according to the chemical reaction

$$ZnCl_2(aq) + H_2S = ZnS + 2HCl(aq).$$

METHODOLOGY

SOURCES OF DATA

Engineering data for dewatering boreholes and pump tests at open pits were provided by the engineering department of Pine Point Mines Ltd. (K. Durston, T. Healy).

A total of 497 isotope, 82 bacteriological and 620 hydrochemical samples were collected by NHRI (K. U. Weyer, W. C. Horwood-Brown). The chemical samples were analysed by commercial laboratories (Diamin Laboratories, Calgary, R. Barefoot; Chemex Labs (Alberta) Ltd., Calgary, D. Laberge; Seakam Oceanography Ltd., Sydney, B.C., D. Thomas; Chemistry Laboratories, University of Calgary, F. W. Bachelor) and by the Water Quality Laboratory of Environment Canada in Calgary (M. Korchinsky). Isotope data were determined by the Stable Isotope Laboratory of the University of Calgary (H. R. Krouse). Bacteriological water samples were cultivated and analysed by the Microbiological Laboratories of the Environmental Protection Service of Environment Canada in Edmonton (J. Bell).

Discharge measurements of major rivers were performed by the Fort Smith office of the Water Survey of Canada (WSC: A. Wilson, D. Dube, T. Wilson), discharge measurements at karst springs and at Pine Point dewatering channels were performed by NHRI (Weyer, Horwood-Brown, J. A. Banner). Gaging stations at karst springs were devised by NHRI (Weyer, Banner) and installed jointly by WSC (A. Wilson, D. Dube) and NHRI (Banner, Weyer). Automatic time-lapse cameras were built and installed at several spring sites by NHRI (Banner; Banner, Weyer; description of system in Banner and van Everdingen, 1979).

Cores of the oil wells CDR Wood Buffalo C-74, CDR Wood Buffalo L-42, and Iskut Little Buffalo K-22 were described with regard to porosity features by NHRI (Weyer) at the core storage facilities of the ISPG in Calgary. The core of the mineral exploration hole Pyramid 202A was examined at the open-air core-storage facilities of Pine Point Mines Ltd. in Pine Point, N.W.T., together with D. Adams of Cominco Ltd. D. Adams also determined the facies of 14 core samples from CDR Wood Buffalo C-74 used for permeameter testing. The ISPG made 8 core samples available for porosity and permeability measurements (NHRI: Banner, Weyer; Core Laboratories-Canada Ltd., Calgary), 8 core samples for x-ray diffraction analysis (ISPG: A. E. Foscolos, J. Wong, A. Heinrich), 2 core samples for petrological thinsection analysis (ISPG: H. Geldsetzer, O. McEwan), 1 core sample for analysis of organic components (ISPG: W. Kalkrenth, A. E. Foscolos, K. Pratt) and 1 core sample for infrared spetrometric analysis (ISPG: G. P. Michael). Samples of mineral precipitates in dewatering ditches at Pine Point were analysed by K. Werner, Geological Survey of NW, Krefeld, West Germany.

D. Sangster (GSC, Ottawa) searched the CANMINDEX and related computer files of the GSC for Pb and Zn-deposits occurring east of Pine Point in the Canadian Shield on NTS maps 75 E, F, J, K, L, O, P and 85 H, I.

METHODOLOGY AND DATA PROCESSING

At chemical sampling sites pH, Eh (calomel-electrode), temperature (ASTM) and conductivities were measured. Up to six individual water samples were taken at each sampling site for major ions, trace ions, H_2S in water, $\delta^{34} S_{SO_4}$, $\delta^{34} S_{HS^-}$ and δ^2H determinations. Major-ion and $\delta^{34} S_{SO_4}$ samples were filtered with Whatman 40 paper, the trace-ion samples with Millipore 0.45 µm (bottles were acid washed). The HS^- samples and the δ^2H samples were not filtered. The following additives were added in the field:

$\delta^{34}S$ in $SO_4{}^{2-}$	- conc. HCl, $BaCl_2$
$\delta^{34}S$ in HS^-	- NaOH pellets, Cd-acetate
HS^-	- Zn-acetate
trace ions	- HNO_3

Bottles used were Nalgene linear polyethylene, except for δ^2H where glass bottles were used. All water samples were sent by air freight (non-freezing) to the laboratories as soon as possible and, in the commercial laboratories, analyses were started upon receipt of the samples.

Nearly all samples were analysed for Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, $SO_4{}^{2-}$ and $HCO_3{}^-(CO_3{}^{2-})$, and for sulfur and hydrogen isotopes, most for H_2S, and some for trace ions and for oxygen isotopes in $SO_4{}^{2-}$ and H_2O. Chemical analyses were done according to standard methods as described by Alberta Environment (1977) and Environment Canada (1979).

Cultivation and incubation of bacteriological samples were started at Pine Point in the moveable microbiology laboratory of EPS, Edmonton, by J. Bell, G. Elliot, and F. Zaal. The moveable laboratory was driven back to Edmonton and upon completion of incubation samples were counted with the MPN (Most Probable Number) - system.

Discharge measurements by the Water Survey of Canada (WSC) made use of the Price cup-current meter and of the time-saving standard North-American two-point method (velocity measurements at 0.2 and 0.8 of the total water depth; WSC, Field Manual) introduced by Cunningham (1883) and Teichmann (1883). Discharge was calculated in the field by means of arithmetic methods. The accuracy of the discharge determination is said to be between three and five percent. In shallow water depth (less than about one meter depth) the one-point method was used by WSC (0.6 of total water depth). The accuracy of this method is somewhat less than that of the two-point method.

NHRI measured discharge at karst springs, at small creeks and at the Pine Point dewatering channels, using the Ott-C1 screw type minicurrent meter with six exchangeable propellers with 2 to 4 cm diameter.

Investigation of return flows from dewatering ditches to the pumps called for extreme accuracy in NHRI's discharge measurements. The time-consuming standard European multi-point method (also called vertical velocity method: Corbett, et al. 1943, Buchanan and Somers, 1969) was applied. Discharge was calculated using Harlacher's method (Harlacher, 1872, 1881, United Nations, 1954; depth-velocity, integration method) and the computer program CURMET (Weyer, 1973) which calculates, documents and plots all field data and results. This program's calculation method closely follows graphical integration methods. All six propellers had been calibrated previously by the manufacturer and the actual calibration measurements had been supplied to us. These calibration data were analysed interactively with the program METCAL (Ruitenbeek and Weyer, 1979a). Instead of the standard two equations, an improved set of five revolution-velocity equations were then determined.

The multipoint measurement method and its documentation, calculation and plotting with the program CURMET allows an accurate and reproducable error determination. We were able to reduce the error for small flows to well under 1 percent. Appendix 1 shows an example of two consecutive discharge measurements about 1.2 km apart in the dewatering channel of the open pit S-65 at Pine Point Mines. The two measurements differ by only 0.4% (78.4 compared to 78.7 l/sec).

In the Pine Point area, three discharge gaging stations were operated by NHRI from 1978 to 1982 in areas only accessible by helicopter; two at karst springs close to and within Wood Buffalo National Park, the third one at a saltwater creek west of Buffalo River close to Great Slave Lake. The two gaging stations at the karst springs were equipped with bellows-type recorders for monitoring of back pressure in bubbling lines. Attempts to determine a stage/discharge curve were hampered by differential movements of the solid surface in the area of the Angus Tower Spring, due to variations in groundwater discharge, and by a wide channel and low flows at the Halfway Spring.

Altimeter readings for the two karst springs Angus Tower Spring and Halfway Spring were taken on August 13, 1981, with a Wallace & Tiernan surveying altimeter model FIA-112-1-3 in comparison with a known altitude at Fort Smith Airport (initial control reading: 11:00; final control reading: 21:20). Between stations the instrument was transported by helicopter over a total distance of 190 km each way. Elevation readings at the springs were at 12:10 (Angus Tower Spring) and 12:55 (Halfway Spring).

In general mid-day readings and long transportation distances are of disadvantage for accurate readings with altimeters. Nevertheless, the difference between the readings at the two springs might be quite reliable as they were taken only 45 minutes apart. Altimeter readings, linearly corrected for barometric changes, were 796 ft/243 m for Angus Tower Spring (Helicopter 780 ft /238 m) and 754 ft / 230 m for Halfway Spring (Helicopter 754 ft / 221 m.). Corresponding elevation differences would be 42 ft/12.80 m and 71 ft /21.60 m. In lieu of more accurate levelings we assume the elevation of Angus Tower Spring to be about 790 ft/ 241 m while Halfway Spring would be about 750 ft / 229 m. Hence the elevation of the overflow at Halfway Spring would be about 40 ft /12 m lower than that at Angus Tower Spring.

For independent recording of water levels, time-lapse cameras were installed at two of the three gaging stations. An additional camera was installed for one year at a prominent but dry sulphur spring near the east bank of the Buffalo River close to the formerly artesian Pine Point borehole 104.

The large number of discharge, chemical, borehole and geologic data accumulated necessitated the use of computer data banks for storage and retrieval. For this purpose four major computer data storage and retrieval systems were developed: DISBNK, CHEMBNK, BORBNK and GEOBNK. DISBNK stores about 10 000 digital readings (6 hour interval) of the discharge at the

Buffalo River gaging station of WSC; CHEMBNK stores the results of chemical field measurements, laboratory analyses and elevation and position data, together about 35 000 pieces of information; BORBNK contains about 20 000 data for 1,507 mineral exploration boreholes and 64 oilwells in the study area. GEOBNK contains more than 50 000 data of hydrogeologic, karstic, mineralogical and organo-chemical (bitumen, tar, oil) nature.

Data from the data banks are processed by means of the following computer programs:

- DISBNK:

  METCAL (Ruitenbeek and Weyer, 1979a)
  HGRAPH (Ruitenbeek and Weyer, 1979b)

- CHEMBNK

  SEMILOG (Horwood-Brown and Weyer, 1980)
  ISODATA (Horwood-Brown, Krouse and Weyer, 1977)
  CHEMBNK (Horwood-Brown, 1979)

- BORBNK:

  NEARLC (Horwood-Brown and Weyer, 1982)
  GSRUG (Geodetic Survey of Canada, 1973)

- GEOBNK:

  SRHGEO (Horwood-Brown, 1982)

The program CHMEDT and SRHGEO have been used as interface for commercially available contouring and 3-D plotting programs, i.e. SURFACE, TERRAPLOT, etc.

REPRESENTATIVENESS OF BOREHOLE DATA

The geologic and hydrogeologic evaluation of borehole data was based on logs of about 1,500 mineral exploration boreholes from files of the Mining Division offices of DIAND in Yellowknife (W. Padgham) and Ottawa (D. D. Brown). It also made use of logs of 64 oil wells stored at the Institute of Sedimentary and Petroleum Geology (ISPG: W. J. Banning) of the Geologic Survey of Canada (GSC), and at the Alberta Energy Conservation Board, both of Calgary (see Appendix 2 for list of boreholes; see table 1.3 for hydrogeologic evaluation of oil wells). Altogether more than 230 km of boreholes have been evaluated; the depth of the boreholes ranged from 9 meters to 1518 meters with an average depth of 147 m. The majority of these holes had been cored in the bedrock (D in column T of Appendix 2).

Upon request, Westmin Resources, Vancouver (A. Soregaroli), freely made available the locations and elevations of their exploration boreholes in the Pine Point area. Westley Mines of Vancouver, through the Geology Department of DIAND, Yellowknife, also made available the locations of 7 of their exploration boreholes in the area. A limited number of borehole locations and elevations were finally made available from Pine Point Mines (T. Healy, K. Carter). Some of their data needed to be corrected, some may still need to be. Approximate positions of many boreholes were determined using claim maps made available by the office of the Mining Recorder of DIAND in Yellowknife, and by using a 1974 property map of Pine Point obtained from government files.

Stratigraphic data were taken from borehole logs as far as listed and acceptable. For about 50 percent of the boreholes, the stratigraphy had to be determined by NHRI (Weyer) from the lithological description, the fossil contents and a comparison with listings of boreholes nearby. A suitable stratigraphic system was devised by NHRI (Weyer) in discussions with D. Adams of Cominco Ltd., Calgary, modifying Skall's (1975) system. Extraction of geologic and hydrogeologic data was done by NHRI (Weyer, Horwood-Brown, R. Gardner). Regarding geology, there was no significant input received from the Geology Department of Pine Point Mines Ltd. (N. Zarkos, J. Collins, R. Armstrong, K. Carter).

Borehole logs for about 1500 boreholes in the study area were obtained from the Mining Recorder offices in Yellowknife and Ottawa. Two questions arose:

(1) how representative are the submitted borehole logs, and

(2) how accurate are the interpretations adopted by us?

In answer to question (1) we will consider stratigraphic information and other geologic information separately, followed by discussion of information on borehole position and elevation. Unfortunately, many of the borehole logs submitted to the Mining Recorder do not contain stratigraphic information (Appendix 2, Column LS, L - contains lithologic information, S - contains stratigraphic information) which includes many submitted by Pine Point Mines in the past. All borehole logs from Westmin Resources, as well as most of the more recent submissions by Pine Point Mines, however, contained detailed stratigraphic data. Because of changing stratigraphic concepts, some of the older pre-1970 submissions by companies needed to be revised. The stratigraphy of all relevant boreholes was determined and re-evaluated by us. We accomplished this cumbersome and time-consuming task using a computer program for locating and displaying distances and directions to neighboring boreholes (Program NEARLC, Horwood-Brown and Weyer, 1982). Stratigraphic markers (Amco-Shale and E-shale) and 'iterative' comparison with established stratigraphy in nearby holes aided in the evaluation. With increasing experience and knowledge of some of the finer points of local stratigraphy and facies, the stratigraphic evaluation became more reliable. Naturally some of the early holes had to be redone. Partway through this process, D. Adams of Cominco Ltd. provided valuable assistance by cross-checking our evaluations with his own interpretation, and suggesting final adjustments of our evaluation procedure. We now consider our stratigraphic evaluation to be quite reliable. Computer listings of the geological evaluation have been sent to Pine Point Mines and were found acceptable by their geology department (K. Carter, personal communication, 1982).

In regard to geologic and hydrogeologic information the situation is a little more complex. From a comparison of borehole logs submitted more than once it became obvious that all the information collected is not always included in the records submitted to the Mining Recorder. Also, some geologist have certain preferences stressed above all other points, like fossil associations, facies considerations, classification of breccia types, cavity fillings, core losses and recovery rates, classification of porous systems such as vugs, fractures, pin point and intergranular porosity, and listing of minerals and organic material. Hydrogeologic parameters such as water flow from the hole and its origin at a certain depth, were in general poorly described. Understandably, this information was only provided in a minority of cases, because it may have been regarded as unnecessary information in view of current ore genesis and exploration concepts.

It is clear that all of the above reasons have a tendency to lead to an under-representation of any one particular rock property in the Pine Point area. This tendancy would be even more serious for deeper strata because the number of boreholes penetrating these strata is smaller.

A further cause for under-representation originates in our own learning process during transcription of the data into computer files. In the first attempt to collect sufficient geologic data we limited ourselves to about 400 boreholes chosen at random and evaluated for a few characteristics, like vugs and cavities, only. It soon became clear, however, that all available borebole logs would have to be evaluated. In the course of this evaluation, the number of parameters recorded kept growing to about one hundred, apace with our insight into the geologic and hydrogeologic intricacies. Also, we would identify a feature more readily as our understanding of the geology grew. Unfortunately, we did not get the opportunity to include earlier omissions in a second round of data transfer. Editing had to be curtailed to the bare minimum because of managerial directives. Nevertheless, we feel that we have eliminated the major discrepancies.

Our biggest problem and most time consuming task was the determination of the precise location of the boreholes, and their surface elevations. Again, many submissions to the Mining Recorder were found woefully inadequate. Upon inquiry, Westmin Resources made the precise coordinates and elevations of all their boreholes readily available. Pine Point Mines did make similar data available only for a limited number of holes towards the end of our data-gathering period. Fortunately we were able to locate, at the mining geologist's office in Yellowknife, a Pine Point property map that showed the position of a number of holes. Positions of other boreholes of Pine Point Mines and of other exploration companies were determined from claim maps, which is a very time-consuming process. The claim maps were provided by the Mining Recorder's office in Yellowknife. D. Adams of Cominco Ltd. made available coordinates for about 50 'exotic' boreholes, the position of which he had determined previously. For the Pine Point property we checked the position of boreholes against the site descriptions given in the bore logs (as for example cut lines etc.), and found that in extreme cases coordinates submitted to the Mining Recorder's office were off by more than 30 km. We believe that by now our location data are accurate to within 50 feet (15 m) in most cases; in some extreme cases they may be out by up to 500 m.

Location data were recorded using four systems: geographic north, UTM (zones 11 and 12), Pine Point engineering coordinates, and Pine Point geology coordinates. All data were then transformed into the rectangular UTM system with an extended zone 11, using the program GSRUG made available to us by the Geodetic Survey of Canada (P. Henderson).

For the Pine Point property, data on elevation were taken from borehole listings. Some additional data were later received from Pine Point Mines. The data were first checked against neighbouring boreholes and eliminated if obviously erroneous. Then elevation data were contoured with the commercially available contouring program TERRAPLOT, using a scale of 1:250,000. The position of isohypses then was compared with those on 1:250 000 topographical maps. Good agreement was found except for some localized 'holes' and 'mountains'. Eliminations or, in some obvious cases, appropriate corrections were made. We are now confident that elevation data used for the plotting of the top of Amco shale, E-shale and bedrock are adequate.

In summary it can be said that the regional computer plots of specific geologic or hydrogeologic properties of the rocks in the Pine Point are, to the best of our knowledge, reliable with regard to position and elevation, within the limitations described above. They rather under- than over-represent the properties shown.

2. PRINCIPLES OF REGIONAL GROUNDWATER FLOW

BACKGROUND

The concept of regional groundwater flow may not be familiar to all mining and ore geologists. It is therefore discussed in some detail here. First of all, the definition of the term groundwater needs some clarification. Groundwater is not only the rather thin veneer of freshwater in the overburden, as is sometimes assumed, but any aqueous solution in the subsurface in (hydrodynamically) saturated state, whether it be fresh, saline or salty. Natural brines in the subsurface are considered part of the groundwater system. The concept of density stratification in groundwater is a myth in as far as it assumes that denser fluids automatically concentrate downdip in the deeper parts of basins. All fluids, both aqueous ones of different density and hydrocarbons, are moved by the same coupled forcefield integrating mechanical, chemical, osmotic and temperature related forces (Weyer, 1978a).

The door leading to the modern development of the science of regional groundwater flow was opened by Hubbert (1940). His fundamental message about gravitational groundwater flow was visualized in one simple figure, here reproduced as Figure 2-1.

Figure 2-1

Before Hubbert's publication and for decades after he published his paper, thinking on groundwater flow was dominated by the Dupuit-Forchheimer assumptions (Dupuit, 1863, Forchheimer, 1930) whereby the flow was assumed to be horizontal and the hydraulic gradient assumed to be equal to the slope of the groundwater table. Hubbert's (1940) figure showed the water to flow downwards under the recharge area of the highland (flow directed through the groundwater table into the groundwater body if recharge occurs) and upwards under the discharge area of the lowlands (flow directed upwards from the groundwater body into surface water or towards evaporation). It is difficult to think of any other single figure which has exerted more influence on the development of modern thinking about regional and basin-wide groundwater flow than Hubbert's (1940) ingeniously simple visualization of complicated physical and mathematical derivations.

If we were to insert open ended standpipes (piezometers) into the groundwater body along a flow line from the recharge to the discharge area than the water columns in those pipes would rise according to the energy level encountered at the open bottom end of the pipes.

Figure 2-2

Figure 2-2 shows the top of the water columns in the piezometers in the recharge areas (numbers (2) and (3)) to be lower than the groundwater table; in the discharge area the water column in piezometer (4) rises higher than the groundwater table. If the groundwater table is close to the surface of the valley and if the head in the piezometer is high enough, then the flowing conditions of an artesian well will occur. Figure 2-2 shows that flowing conditions can occur even if an artesian aquifer or an aquitard are <u>not</u> present. The physical nature of the forces involved were discussed in detail by Weyer (1978a). In the following we will focus our attention on artesian conditions in geological systems with aquifers (highly permeable layers) and aquitards (layers with lower permeability).

In this report the term artesian is used in its original meaning as flowing well. The term originates from the area of Artois in France where famous flowing wells were drilled during the middle ages. Jacob (1939, 1940, 1950) changed the meaning for North American engineering by using it for "confined water". In Jacobs usage, artesian stands for water in a confined aquifer, with a head higher than the top of the aquifer. This report uses the term artesian in its original meaning in the same way as the french "artésian" and the german "artesisch".

Figure 2-3

Figure 2-3 introduces an aquifer (relative permeability K = 100) of limited extent located below a less permeable aquitard (relative permeability K = 1). Flow is concentrated into the aquifer and directed towards the lowland. Vertical upward flow occurs in the lower lying part of the discharge area.

Figure 2-4

Figure 2-4 shows the general case of an artesian aquifer without outcrop. Flow is from the highland through the aquitard into the aquifer. Flow directions within the aquifer are from the highlands towards the valleys and then from the aquifer through the aquitard up into the valleys. The valleys have artesian discharge. The topography of the surface is reflected in the head distribution within the aquifer.

Figure 2-5

Proceeding one step further, Figure 2-3 is modified by extending the aquifer below the lowlands towards and underneath a lake as shown in Figure 2-5. The permeability contrast has been strengthened. Recharge is now in the highland and in parts of the lowland. An area adjacent to the lake and the lake itself have the potential for artesian wells. Again, recharge and discharge pass through the aquitard system while the regional flow is concentrated within the confined aquifer system.

We will show later that the schemetic cross-section in Figure 2-5 depicts in principle the situation along a south-north cross-section from the Caribou Mountains to Great Slave Lake.

Artesian system thus do not need the artesian aquifer outcropping in an elevated mountain area, as is often postulated by conventional models (see Fig. 2-6).

Figure 2-6

HYDRAULIC TIME LAG

IMPORTANCE OF POSTULATE

Recently Tőth (1978, 1980) postulated hydraulic-time lags in the order of millions of years in the response of deep aquifers to changes in topographic boundary conditions. For the Red Earth region in Alberta he concluded that it would take 4 million years for the deeper aquifer to adjust completely to the instantaneous formation of a major river valley by erosion. As a computer program was used to calculate this time lag, the result of several million years carries the appearance of accuracy. Details of the program and the assumptions used are discussed in Tőth (1978, 1980).

If Tőth's results were universally valid, this concept would be of utmost importance for regional groundwater flow. Therefore, it deserves close scrutiny of all the assumptions involved and also a sensitivity analysis to assess the extent to which the assumptions determine the results of the computer calculations. The following discussion closely follows Weyer (1980).

FIELD RESULTS AND THEIR INTERPRETATION

Pursuing our topic, let us first list some of Tőth's (1980) field results and their interpretation (compare figure 2-7):

Interdependance of permeability and hydraulic gradient.

Physically the interdependance of permeability and hydraulic gradient are expressed in Darcy's equation as formulated by Hubbert (1940)

$$\vec{q} = \delta \ \text{grad} \ \Phi \qquad (1)$$

where $\vec{q}$ = flux vector
δ = permeability
Φ = potential.

Mathematically similar is the often used used equation

$$q = k \cdot \text{grad} \ h \qquad (2)$$

where q = flux $[L^3 L^{-2} T^{-1}]$
k = hydraulic conductivity $[L T^{-1}]$
h = head $[L]$
L = length
T = time

The head can be directly measured in ~~the field~~ piezometers installed in the field ~~as show~~ as shown in figure 2-7.

— — — — — — —

Fig. 2-7

— — — — — — —

~~More~~ Detailed discussions of the physical meaning of the above properties are contained in Weyer (1978a). For the purpose of this paper we will consider the groundwater flux q to be constant

$$q = \text{constant} \qquad (3)$$

the following mathematical and physical interdependence exists now between the permeability (hydraulic conductivity) and the hydraulic gradient (head gradient) in equations (1) and (2):

~~(1) is~~

- is the head gradient along a flow field increased in a flow field, say by a factor of 10, than the permeability in the area of the increase of the gradient ~~??~~ (see fig 2-8a) is smaller by an equivalent amount (divided by 10)

- ~~?~~ is the head gradient (decreased) along the flow path in a flow field, say by a factor of 10, than the permeability in the area of the decrease of the gradient (see fig 2-8b) is larger by an equivalent amount (multiplication with 10).

// The above interdependence allows a reliable and direct determination of relative permeabilities from piezometric maps if ~~flow conditions~~ the condition in equation (3) holds true. This paper will make use of these interdependencies to determine the relative permeabilities of karst systems within and outside the Pine Point barrier reef system (see chapter 4).

Fig. 2-8

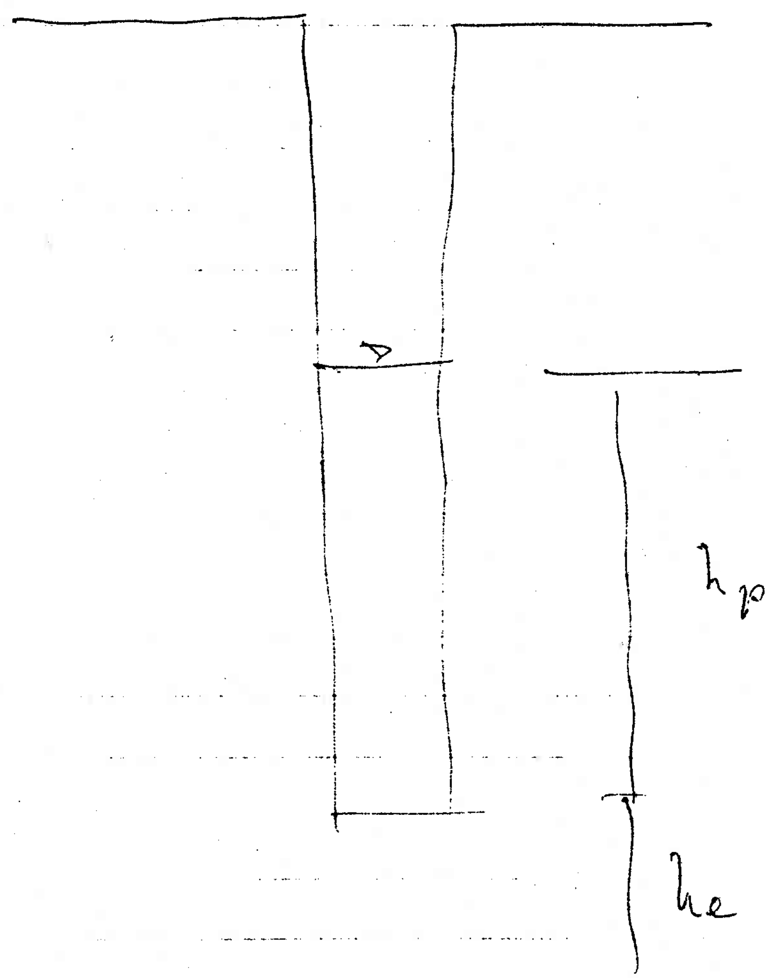


Fig. 2-7 head measurements in the field (from Winter 1974a)

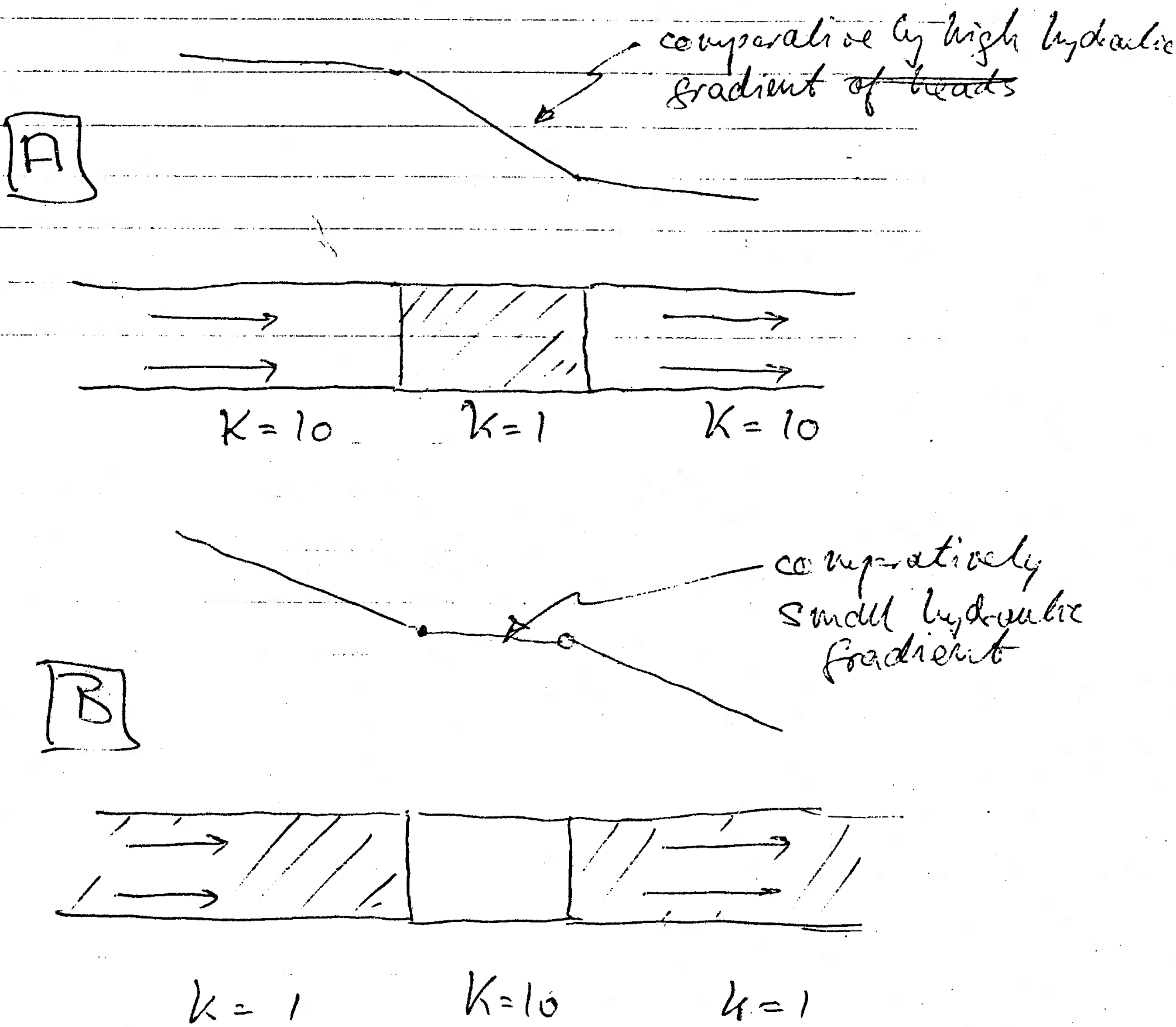


Fig. 2-8. Interdependancies of permeabilities (K) and hydraulic gradients in a flow field.

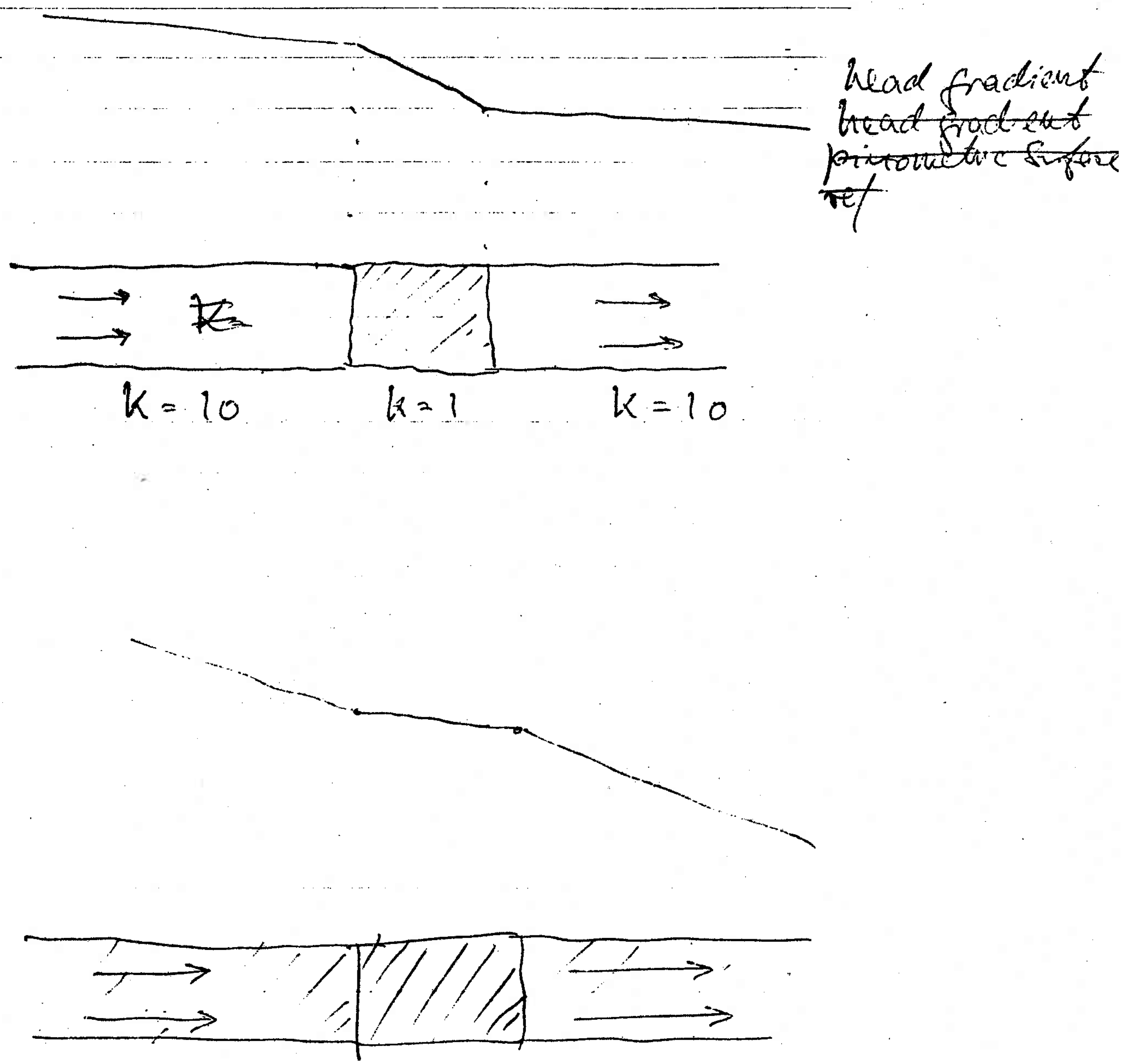


Fig 2.8 Interdependencies of permeabilities and hydraulic gradients in a flow field

---

Figure 2-7

(a) In the Red Earth region a general similarity exists between the potentiometric surface in the deep and confined D_I unit and the present land surface. As pointed out by Tóth (1980, p. 141) this suggests "a genetic relation between the energy distribution in the basal or Devonian I (D_I) conducting unit and the topographic relief."

(b) According to Tóth (1980, p. 143) "the general flatness and low value of the potentiometric surface of the intervening Devonian III unit (Fig. 24 of Tóth 1980, p. 143) indicates that no energy from above is being transfered across that zone to the D_{II} unit". Therefore "the rather well defined correlation between the D_I unit (Fig. 23) and the land surface (Fig. 22) becomes an enigma" (Tóth 1980, p. 142-143; figure numbers refer to Tóth, 1980).

(c) For the Red Earth region "the potential distribution observed today is not a result of the present topography despite the apparent correlation. Rather, it reflects the Pliocene topography which was similar to the present land surface" (Tóth 1980, p. 148). "As pointed out earlier,the time required for these potential differences to dissipate completely through the overlying rocks is approximately four million years. However, only about 100,000 years have elapsed since the previous boundaries changed; this was enough for the systems in groups D_{III} and higher to adjust but not for the ones below D_B - which explains the apparent relation between land surface and potentiometric surface in D_I *in spite of the intervening low energy drain in* D_{III}." (Tóth, 1980, p. 148, italics inserted).

STATEMENT OF PROBLEM

In short the problem to be discussed is the following

(a) the piezometric surface in the deepest layer D_I follows today's topographic surface suggesting hydraulically effective connections between the two and also quasi steady-state conditions in the system;

(b) between the topographic surface and deep aquifer D_I there is a layer D_{III} with *mechanical* energy potentials that are lower than those in the deeper layer D_I, seemingly interrupting the hydraulic continuity between the topographic surface and the deep aquifer D_I;

(c) the author explains this situation by postulating non-steady state conditions with a time lag of 10^5 to 4×10^6 years for the deep aquifer D_I to respond to the changed boundary condition of today's topography; consequently, the potentials in the deep layer D_I are said to reflect the Pliocene pre-glacial topography.

There are other explanations worth considering, for example, the possible existence of osmotic and chemical potentials not considered in Tóth's analysis. If such potentials occur then a discontinuity in the *mechanical* potential would appear within an existing hydrodynamic continuity; the thermodynamic principle of conservation of energy, in a situation like this, requires continuity only of the total potential but not of the mechanical one.

For this reason the model calculation of the time lag becomes of decisive importance. If the assumptions used and the calculation procedure itself are valid then the time-lag model would be convincing. If, however, the assumptions and the calculation procedure are not valid then Tóth's time-lag model would be only one of the possible explanations and its merits would have to be compared to other possible explanations.

METHOD OF COMPUTER CALCULATION

According to Tóth (1978, p. 840) "the computation was based on the one dimensional non-steady-state solution of the heat flow equation for a multilayer column (Carslaw and Jaeger, 1959, p. 326) with hydraulic parameters substituted for equivalent heat flow parameters". From this statement it is clear that the computation procedure should be adequate for the problem considered, although one might also include variability of permeability as a function of potential gradients (forces).

PERMEABILITY OF CONFINING SEQUENCE $D_A + D_{II} + D_B$

Regarding the parameters used, "values for K [hydraulic conductivity] and z [thickness of layers] were established from core analyses and drill stem tests and from stratigraphic information, respectively (Table 3), *as well as from the literature.* Storage coefficients were based exclusively on data from literature (Bredehoeft and Hanshaw, 1968)" (Tóth, 1978, p. 840, italics inserted). In Tóth's Table 3, K-values are 2.5 x 10^{-5}cm/s for Devonian I (D_I) and 8 x 10^{-7} cm/s for the Devonian II. The table does not give any permeability value for the total of the confining layer $D_A + D_{II} + D_B$. Nowhere in the paper is it explained why these confining layers were assigned a permeability of 5 x 10^{-11} cm/s (Tóth, 1978, p. 841, Fig. 41). The low magnitude of 5 x 10^{-11} cm/s is somewhat surprising in light of the field value of 8 x 10^{-7} cm/s assigned in Tóth's Table 3 to one of these layers, the D_{II}. The average hydraulic conductivity of 8 x 10^{-7} cm/s was determined from drill stem tests. It is about 4 orders of magnitude higher than the value taken for the model calculations (5 x 10^{-11} cm/s).

Because of the absence of literature references regarding the permeability value of 5 x 10^{-11} cm/s it is only possible to infer the source of the extremely low permeability value. Bredehoeft and Hanshaw (1968) was checked because reference had been made to this paper in regard to the storage coefficients taken. Their Table 2 (ibid., p. 1100) lists selected hydraulic conductivities measured on specimens in the laboratory. It seems likely that Toth's low permeability value may have originated from this table which reports laboratory test results for shale of 6.0×10^{-10} cm/s (Shale D, Neves Field, Montana), of 2.0×10^{-12} cm/s (Shale G, Williams Field, NW Mexico) and of 1.3×10^{-11} cm/s (Natural Shale).

All these test results were determined using unbroken laboratory specimens. They did not contain the fractures and fault zones that are present in the field. Therefore caution has to be applied in substituting laboratory tests for in-situ field data. Bredehoeft and Hanshaw (1968, p. 1100) expressed their opinion in the following way: "The few attempts at in-situ measurements of clay permeabilities that have been made suggest that the in-place permeability may be somewhat higher than that measured in the laboratory." Rowe (1972) obtained in-place permeabilities 10^2 to 10^3 times larger than those obtained from laboratory consolidation tests, due to the presence of fractures. Grisak and Cherry (1975) found the bulk vertical conductivity estimated for a site with fractured till one to two orders of magnitude larger than intergranular values estimated from laboratory tests on samples from the site.

In general there is a strong suspicion that effective field permeabilities can be 2 to 4 orders of magnitude higher than permeabilities from laboratory tests, because of fractures. Unfortunately, actual field tests are very rare. The ratio between field and laboratory permeabilities can be increased by an additional one or two orders of magnitude if regions are considered where fault zones, stratigraphic windows or reef pinnacles protrude through the confining layers. All these phenomena have been described for the confining layers in certain areas of the Red Earth region (Tóth, 1978, p. 810-811).

In view of the above, it does not seem justified to assume an effective hyraulic conductivity of only 5×10^{-11} cm/s for the confining layers. The reported value obtained by in-situ testing (8×10^{-7} cm/s) seems to be more appropriate.

SENSITIVITY ANALYSIS

Regarding a sensitivity analysis for the permeability parameter, Bredehoeft and Hanshaw (1968, p. 1099) used exactly the same mathematical system for their analysis of time-lags as did Tóth.

In their opinion, "in most circumstances anomalous pressure can only persist in a geologic sequence where rocks of low permeability predominate. For example, beds in the Gulf Coast deposits, which have unusually high pressures, are, generally, discontinuous sand bodies interbedded in a sequence where shale predominates. It is apparent that in a reasonably homogeneous, laterally extensive hydrologic unit of low permeability the flow will be almost entirely in a vertical direction. This greatly simplifies the analysis; the problem is that of one-dimensional non steady flow" (Bredehoeft and Hanshaw, 1968, p. 1099).

It appears unlikely that the extensive, fractured and faulted permeable layers of the Red Earth region meet all of the above requirements. In the Red Earth region a two-dimensional analysis might be superior to the one-dimensional calculation.

A sensitivity analysis for the permeability parameter was undertaken by Bredehoeft and Hanshaw (1968). Comparison of the two graphs of their Figure 3 reveals that the time lag calculated is directly related to the permeability used as input, in the following manner: a change in the permeability by an order of magnitude changes the calculated time-lag by an order of magnitude as well.

Using Tóth's assigned value of 5×10^{-11} cm/s, the resulting time-lag interval would be 10^5 to 4×10^6 years. Using more likely permeability values (in the range of the field test, 8×10^{-7} cm/s) decreases the time-lag for a complete response of the confined deep aquifer by four orders of magnitude, from 4 million years down to only about four hundred years.

VALIDITY OF LAG POSTULATE

It seems that the reflection of the topographical surface in the piezometric surface of the deep layer D_I in the Red Earth region might well be the expression of a genetic relationship and a quasi steady-state regional groundwater-flow system, caused by today's topography, not by Pliocene conditions. Because of the uncertainty in the permeability values, the mathematical model does not support the transient concept presented by Tőth (1978, 1980).

The hydraulic time-lag concept has therefore not been considered in the present analysis of regional groundwater flow in the area south of Great Slave Lake.

Chapter 3

3. FRAMEWORK FOR GROUNDWATER FLOW IN STUDY AREA

TOPOGRAPHY

The groundwater table constitutes the most important boundary condition for a gravitational groundwater flow system. Groundwater tables in turn closely follow the topographical surface of the earth. It is therefore that the topography of a region determines the distribution of recharge and discharge areas. The overall direction of flow is always from the highlands towards the lowlands.

The area dealt with in this report extends over about 250 km from the Caribou Mountains in the south (Fig. 3-1, elevation up to 1000 m) to Great Slave Lake in the north (elevation 156 m). In the east-west direction the area extends for about 200 km from west of the Hay River (elevation 250 m to 156 m) to the Slave River in the east (elevation 200 m to 156 m).

FIGURE 3-1

The topographic framework would indicate groundwater flow from the recharge area in the Caribou Mountains in a radial pattern to all sides. Exactly that pattern has been found by Hitchon (1969a, see Figure 1-1 of this report).

Additional recharge would occur in the low-lying foreland between the Caribou Mountains and the artesian discharge areas, similar to the situation shown in the schematic cross section in Figure 2-5.

add here climatological data

GEOLOGY

SUBSURFACE INFORMATION

Parts of the geologic description of the area are based on the evaluation of 1507 mineral exploration boreholes and 64 oil wells in the area (Appendix 2). The distribution of the mineral exploration and oil boreholes adjacent to Great Slave Lake is shown in Figure 3-2A;

~~Chapter 3~~

CLIMATOLOGICAL DATA.

GENRAL INFORMATION

In the area between Great Slave Lake and the Peace River climatological data have been recorded at eight stations, all of them with broken records (compare table 3.1). The most complete records exist for Fort Smith Airport (east of Caribou Mountains), and for Hay River Airport (south shore of Great Slave Lake), less complete ones are available for the Fort Resolution Airport (south shore of Great Slave Lake), for Hay River Paradise Gardens (about 30 km south of Hay River Airport) and for the High Level Airport (SW of Caribou Mountains). Very incomplete records exist for Angus Tower and Pine Point (both not to far away from the south shore of Great Slave Lake). No climatological data were available for the Caribou Mountains plateau.

In general total precipitation (1961-1980 normal) between Great Slave Lake and Caribou Mountains is between 305 and 360 mm/a, with 32 to 47% deposited as snow during the winter (Table 3.2). Annual mean daily temperatures range from -4.0 to -3.3°C with extremes from -53.9 to +35.6°C. Records from Pine Point (1975-1980 normal only) appear to be anomal with a total precipitation of only 244.9 mm and a relatively warm annual mean daily temperature of -2.4°C. This has probably been caused by annomally low precipitation and warm temperatures during the time interval from 1975 to 1980.

Climate in the High Level area (SW of Caribou Mountains) appears to be wetter and warmer than that in the flat lands towards the north and and east of the Caribou Mountains.

Based on methods by Morton (1983) aerial values of evaporation and sublimation have been calculated (Morton 1983, personal communication for three climatological stations in the area (table 3.2-6). At all three stations sublimation of moisture from the air prevails during winter months (November - March) while evaporation prevails during the rest of the year (April - October). According to Morton (1983, personal communication) "actual evaporation" is about equivalent to precipitation at ~~FSFH~~ Resolution and 20 to 30% less at Ft. Smith and Hay River. It appears that these comparatively high evaporation values can only be reached if water would be available for evaporation during the whole length of the evaporation season. Hence, for the purpose of this report, the above evaporation values should be considered potential evaporation. They should not be taken to determine possible recharge ~~by comparing precip~~ to the groundwater system by comparing precipitation with evaporation.

Climate in the Caribou Mountains plateau should be colder and possibly wetter due to higher topographic elevations of up to 1000 m.

OCCURRENCE OF DRY YEARS

Available monthly, annual and normal precipitation and temperature records and indices for the calendar years 1975 to 1982 of the climatological stations, Fort Smith Airport, Hay River Airport, High Level Airport, Fort Resolution Airport, Hay River Paradise Hardens and Pine Point (Station B in table 3.1) are contained in tables 3.3 A to F. For the station Angus Tower records do not exist for this time interval. Complete records for this time interval exist only for the stations Fort Smith, Hay River Airport and High Level Airport. Of these three stations only Fort Smith and Hay River Airport have reliable 1951-1980 normal (code 1, table 3.2) while High Level Airport 1951-1980 normal is somewhat less reliable (code 8, table 3.2).

Records for the stations Fort Resolution Airport, Hay River Paradise Gardens and Pine Point between 1975 and 1982 contain a significant number of data gaps leading to a lack of annual values for precipitation and temperature.

Because of the above reasons the following discussions of the climate between 1975 and 1982 are based mainly on records for the three main stations Fort Smith Airport, Hay River Airport and High Level Airport. Of these three stations Hay River Airport is best representative for the study area between Great Slave Lake and Caribou Mountains, due to its geographical position towards the north of the Caribou Mountains.

Table 3.4 presents a synopsis of the annual snowfall (in water equivalents) rain and total precipitation for these three stations by (A.) calendar year and (B.) water year (October 1 to September 30). Table 3.5 (A to C) lists the monthly and seasonal snowfall and water equivalent of the snowfall for the winters 1975 to 1982 in comparison to the 1951 to 1980 normals, while table 3.6 A and B show the snow depth at the end of the month.

Tables 3.7, 3.8 and 3.9 have been extracted from the previous tables 3.1 to 3.6. They list by calendar year (A) and water year (B) for the three main climatological stations rain, snow, snow water equivalent and total precipitation in percentage of 1951 - 1980 normal (table 3.7), as % deviation from the 1951-1980 normal (table 3.8) and finaly as a synoptic symbolic classification table (table 3.9)

(and figure 3-1a)
Table 3-10 ~~shows~~ in turn shows the 1945-1983 records change of ~~precipitation~~, rainfall snow fall (depth and water equivalent) and total precipitation for the ~~[illegible]~~ station Hay River ~~Airport~~. This station is ~~closest to our investigation~~ within the area of investigation and about 80 km distant from Pine Point. ~~It appears that~~

(and on figure 3-1 b cont'd)

From the table 3 ~~7 to~~ 3-10 it appears that in general there prevailed since about 1969 a trend to dry years. ~~the trend~~ Important for the groundwater recharge is the water equivalent snow fall. Corrected calculations for the water year (~~1 October - September~~) are contained in the table 3-7 to 3-9. They show that the winter 1975/1976 was a normal year, ~~while~~ or above normal year, ~~while~~ the winters ~~period~~ 1976/77 to 1980/81 were dry to very dry and the season 1981/82 was about normal again.

In chapter 5 the occurrence of the dry years ~~[illegible]~~ ~~is considered in~~ will be compared with the pumping record in order to assess ~~the~~ the relative effects on ground water flow.

In the following ~~we will~~ the effect of the dry years on the lake levels in Great Slave lake and on the discharge of three main rivers in the area will be discussed. Table 3-11a lists the lake level fluctuations ~~from for~~ of Great Slave lake ~~for the period~~ at the stations Yellowknife and Fort Resolution for the ~~stations~~ period 1970 - 1982. During this period ~~this~~ the fluctuation of the minimum annual lake level is about 1.5 ft (50 cm) at Yellowknife and about 2.5 ft (75 cm) at Fort Resolution. The small magnitude of these fluctuations exclude a significant effect ~~on~~ on the regional flow systems in ~~the area so~~ the area under investigation.

The dry years showed a more pronounced effect on the discharge in the rivers (listed from west to east) Hay River, Buffalo River and Little Buffalo River as measured at gauging stations operated by the Water Survey of Canada. The 1975-1982 monthly summary of daily discharge at these stations are contained in tables 3-13 A, B and C. The Annual discharges for the period 1975-1982 are related to the total precipitations ~~1975-1~~ in tables 3-13 A, B, and C.

Table 3-13 A, B and C show that in terms of mean ~~flow~~ annual flow the years 1980 to 1982 appear as ~~extremely~~ dry years for the Buffalo and Hay River (with 1980 probably the worst dry year). At the Little Buffalo River the years 1977, 1978 and 1980 to 1982 appear as dry years (record for 1981 insufficient).

In chapter 5 these records will be compared to discharge records of karst springs in the area and to the pumping record at Pine Point Mines. It will be shown how changes in the discharge at the karstic springs timewise correlate with the pumping pattern at Pine Point Mines but not with the discharge records of the rivers in the area.

	Latitude	Longitude	Elevation [m]	Broken records	Continuous records
Angus Tower[1)]	60°26'N	114°28'W	238	1968-1975	
Fort Resolution Airport	61°11'N	113°41'W	164	since 1930	
Fort Smith Airport	60° 1'N	111°57'W	203	1913-1947	since 1948
Hay River Airport	60°50'N	115°47 W	166	1893-1944	since 1945
Hay River Paradise Gardens	60°39'N	116°0'W	213	since 1962	
High Level Airport[2)]	58°37'N	117°10'W	338		since 1970
High Level Ranger Station	58°31'N	117°06W	324	1962-1979	
Pine Point a.	60°50'N	114°28'W	238	1953-1965	
b.	60°52'N	114°22'W	224	since 1975	

1) records cover June-August

2) called Footner Lake Airport from 1970-1976

TABLE 3.1

			Normal					Annual mean daily temperature	Extreme temperatures	
	period	code 1)	rain [mm]	snow [cm]	w.e 2) of snow [mm]	total precip. [mm]	snow 3) %	[°C]	min. [°C]	max. [°C]
Angus Tower	1951-1980									
Ft. Resolution Airport	1951-1980	2	162.4	174.0	144.1	306.5	47	-4.0	-51.1	+33.3
Ft. Smith Airport	1951-1980	1	219.2	145.9	130.1	349.3	37	-3.3	-53.9	+35.0
Hay River Airport	1951-1980	1	184.4	165.0	155.5	339.9	46	-3.6	-48.3	+35.6
Hay River Paradise Gdns.	1951-1980	8	209.6	139.2	149.3	358.9	42	-3.8	-51.1	+35.6
High Level Airport	1951-1980	8	257.9	163.6	128.8 5)	386.7	33	-2.0	-50.6	+34.4
High Level Ranger St.										
Pine Point a.										
b.	1975-1980 4)	6	165.4	79.4	79.5	244.9	32	-2.4		

Notes:
1. code for length of record: 1 - complete 30 years; 2-25 to 29 years; 5 - 10 to 14 years; 6 - less than 10 years but more than 4 years; 8 - adjusted normals based on 5 to 19 years, inclusive, from 1951 to 1980 and any other available data from 1931 to 1950.
2. w.e. = water equivalent
3. in percent of total precipitation
4. normals for Pine Point mainly based on dry years
5. annual normal determined from annual records

TABLE 3.2 a

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL	ANNUAL PRECIP.
Fort Resolution	-1.8	-2.4	-1.6	+20.8	+63.8	+77.0	+87.6	+59.4	+20.2	+5.8	-5.0	-3.4	320.4	318
Fort Smith	-2.0	-2.6	-0.2	+28.0	+47.2	+64.8	+73.6	+50.4	+18.6	+7.0	-5.0	-3.8	276.0	333
Hay River	-1.8	-2.4	-1.4	+27.4	+56.0	+77.4	+81.8	+44.2	+17.0	+7.6	-3.8	-3.4	298.6	318

Actual aerial value of evapotranspiration (in mm) for the period 1965-1969. Source of data F. I. Morton, NHRI, based on the Complimentary Relationship Areal Evaportranspiration Model (CRAE - Model). For particulars of model see Morton, F.I., 1983. Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. J. of Hydrology, vol. 66, p. 1-76.

FORT SMITH AIRPORT

		Jan.	Feb.	Mar.	Apr.	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Annual Total	Index
1975	R	0.0	1.0	0.0	6.6	63.2	40.9	73.2	109.5	34.3	5.3	0.8	0.3	335.1	153
	S	27.2	10.4	5.1	2.0	3.6	0.0	0.0	0.0	0.0	15.0	51.1	21.1	135.5	93
	P	23.4	9.7	4.8	8.6	66.5	40.9	73.2	109.5	34.3	19.6	46.0	19.3	455.8	130
	T	-28.0	-21.8	-15.5	+0.5	+8.4	+14.8	+17.7	+13.0	+9.0	-0.6	-14.5	-23.4	-3.4	+0.1°C
1976	R	0.0	TR	TR	TR	12.4	58.2	70.1	7.1	33.5	7.1	TR	0.0	188.4	86
	S	30.5	42.2	26.4	0.8	0.0	0.0	0.0	0.0	0.0	0.8	32.5	20.1	153.3	105
	P	26.9	29.5	19.6	1.3	12.4	58.2	70.1	7.1	33.5	7.9	27.9	16.0	310.4	89
	T	-25.0	-22.8	-16.3	-4.2	+10.7	+13.4	+16.4	+15.5	+9.8	-1.1	-9.7	-23.7	-2.4	+0.9°C
1977	R	TR	TR	TR	3.0	14.7	119.3	58.2	48.6	21.6	11.6	TR	0.0	277.0	126
	S	22.8	19.7	9.9	8.8	TR	TR	0.0	0.0	0.0	4.4	20.1	20.9	106.6	73
	P	21.6	18.9	6.9	8.1	14.7	119.3	58.2	48.6	21.6	15.6	13.0	17.4	363.9	104
	T	-23.3	-11.7	-10.4	+1.0	+10.6	+13.7	+14.2	+10.4	+8.9	+1.9	-11.7	-26.7	-1.9	+1.4°C
1978	R	0.0	0.0	TR	2.2	14.1	38.6	64.7	8.5	69.0	12.0	0.8	TR	209.9	96
	S	-12.6	1.0	10.2	14.9	TR	0.0	0.0	0.0	0.0	17.5	8.0	23.7	87.9	60
	P	9.0	0.3	7.6	13.1	14.1	38.6	64.7	8.5	69.0	28.0	6.6	19.5	279.0	80
	T	-23.8	-15.5	-13.3	-2.4	+7.6	+13.1	+13.6	+13.0	+8.2	+1.2	-12.6	-23.2	-2.8	+0.5°C
1979	R	0.0	0.0	TR	5.7	15.4	23.1	57.9	27.0	32.5	18.0*	0.4*	0.2	180.2*	82
	S	3.5	8.1	13.1	18.4	4.9	0.0	0.0	0.0	TR	10.2*	11.0*	21.0	90.2*	62
	P	1.7	6.5	10.7	20.5	20.7	23.1	57.9	27.0	32.5	28.2	11.4*	15.5	255.7*	73
	T	-23.4	-31.9	-16.7	-6.4	+6.4	+13.1	+18.6	+12.9	+9.3	+2.1*	-5.0*	-15.4	-3.0*	+0.3°C
1980	R	TR	0.0	0.0	2.0	44.5	29.2	23.0	75.0	49.1	9.5	2.4	TR	234.7	107
	S	25.4	8.7	3.6	0.2	TR	0.0	0.0	0.0	0.2	2.1	26.4	23.8	90.4	62
	P	16.9	7.5	2.7	2.2	44.5	29.2	23.0	75.0	49.3	11.6	20.7	22.2	304.8	87
	T	-24.4	-16.7	-13.6	+5.7	+9.6	+15.3	+16.1	+14.9	+5.9	+3.5	-8.3	-27.3	-1.6	+1.7°C
1981	R	TR	0.0	0.0	10.4	1.7	68.2	43.7	9.5	30.3	23.2	0.3	0.0	187.3	85
	S	17.2	19.0	21.5	21.2	T	0.0	0.0	0.0	TR	41.9	44.5	51.9	217.2	149
	P	14.4	15.2	18.9	30.0	1.7	68.2	43.7	9.5	30.3	56.8	32.1	26.8	347.6	100
	T	-12.2	-17.6	-7.9	-4.8	+9.9	+13.3	+17.0	+17.9	+8.7	-1.9	-7.0	-19.3	-0.3	+3.0°C
1982	R	0.0	TR	0.0	6.8	32.9	15.1	36.8	29.9	59.5	2.9	TR	0.0	183.9	84
	S	6.5	21.9	10.2	15.3	11.7	0.0	0.0	1.6	4.5	15.6	34.0	40.0	161.3	111
	P	4.6	12.2	4.5	17.0	43.2	15.1	36.8	31.5	64.0	14.4	19.5	24.9	287.7	82
	T	-35.7	-23.1	-17.1	-2.6	+7.4	+12.9	+16.2	+12.1	+8.9	+1.5	-17.2	-22.3	-4.9	-1.6°C
Normal 1951 to 1980	R	TR	0.1	0.2	3.9	23.2	41.0	56.9	42.5	39.1	11.0	0.9	0.4	219.2	
	S	21.4	18.4	15.9	13.5	4.8	0.3	0.0	0.0	2.0	15.9	28.8	24.9	145.9	
	P	18.5	15.9	14.4	16.2	27.8	41.2	56.9	42.5	41.1	26.5	26.1	22.2	349.3	
	T	-26.8	-21.8	-14.8	-2.2	+7.9	+13.6	+16.0	+14.2	+7.5	+0.3	-11.6	-21.6	-3.3	

Index - for R, S and P in % of 1951-1980 normal
- for T in difference from 1951-1980 normal

R = rain [mm]
S = snow [cm]
P = total precipitation [mm]
T = mean temperature [°C]
TR = trace
m = missing
* = estimate

TABLE 3.3A

HAY RIVER AIRPORT

Year		Jan.	Feb.	Mar.	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Annual Total	Index
1975	R	0.0	0.0	0.0	11.9	22.6	6.6	22.6	70.6	32.3	15.7	TR	TR	182.3	99
	S	22.1	18.0	18.3	1.0	8.1	0.0	0.0	0.0	0.0	21.1	61.2	19.8	169.6	103
	P	20.6	17.3	17.5	14.0	30.2	6.6	22.6	70.6	32.3	37.1	50.5	20.1	339.4	100
	T	-27.4	-21.1	-18.4	-0.3	+6.4	+12.5	+17.6	+13.6	+9.9	+0.4	-15.7	-22.9	-3.8	-0.2°C
1976	R	0.0	0.0	TR	8.1	19.6	70.6	42.4	36.6	42.9	8.6	2.8	TR	231.6	126
	S	21.1	24.9	21.8	TR	TR	0.0	0.0	0.0	0.0	21.1	11.9	13.0	113.8	60
	P	21.1	24.9	19.6	8.1	19.6	70.6	42.4	36.6	42.9	14.5	10.9	12.7	323.9	95
	T	-24.0	-23.6	-17.3	+3.4	+9.2	+12.4	+15.8	+15.5	+11.2	+0.7	-7.5	-20.4	-2.0	+1.6°C
1977	R	0.3	TR	0.0	TR	34.2	26.6	6.3	19.6	31.9	12.7	1.2	0.0	132.8	72
	S	16.3	14.1	22.6	5.0	2.0	0.2	0.0	0.0	0.0	7.2	20.0	14.6	102.0	62
	P	16.8	14.1	22.2	5.0	36.2	26.8	6.3	19.6	31.9	19.9	21.0	14.6	234.4	69
	T	-20.6	-13.4	-13.1	+0.2	+7.1	+12.7	+14.5	+11.7	+9.4	+2.4	-12.7	-26.5	-2.4	+1.2°C
1978	R	0.0	TR	TR	10.7	1.8	43.6	71.0	2.8	30.5	22.1	2.2	TR	184.7	100
	S	7.0	2.0	10.5	10.1	0.2	0.0	0.0	0.0	0.0	18.0	17.6	25.3	90.7	55
	P	7.0	1.6	10.3	20.8	2.0	43.6	71.0	2.8	30.5	40.1	19.8	25.3	274.8	81
	T	-23.0	-14.5	-16.2	-6.2	+4.4	+12.2	+13.2	+12.9	+9.1	+0.8	-12.2	-21.6	-3.4	+0.2°C
1979	R	0.0	0.0	0.2	2.2	27.8	5.9	36.3	29.2	22.5	15.0*	0.4	TR	139.5*	76
	S	1.8	6.7	18.9	12.8	17.8	0.0	0.0	0.0	0.0	10.8*	10.0	12.1	90.9*	55
	P	1.8	6.7	19.1	15.0	45.6	5.9	36.3	29.2	22.5	25.8*	10.4	12.1	230.4*	68
	T	-21.7	-32.8	-18.2	-8.1	+3.0	+11.3	+17.9	+13.7	+9.0	+3.0*	-3.7	-14.3	-3.4*	+0.2°C
1980	R	1.0	TR	0.0	0.2	20.8	4.0	60.7	65.0	50.6	8.5	0.8	0.2	211.8	115
	S	21.6	4.0	2.1	0.8	0.2	0.0	0.0	0.0	9.8	1.6	18.8	16.3	75.2	46
	P	22.6	4.0	2.1	1.0	21.0	4.0	60.7	65.0	60.4	10.1	19.6	16.5	287.0	84
	T	-23.1	-14.9	-14.0	+3.5	+8.5	+13.3	+15.8	+14.1	+6.1	+3.8	-8.7	-27.0	-1.9	+1.7°C
1981	R	1.6	TR	0.0	12.6	0.4	7.5	18.3	54.0	41.0	32.8	TR	TR	168.2	91
	S	3.0	15.6	10.5	40.1	TR	0.0	0.0	0.0	0.0	32.5	23.8	18.6	144.1	87
	P	4.6	15.6	9.3	52.7	0.4	7.5	18.3	54.0	41.0	65.3	23.8	18.6	311.1	92
	T	-9.8	-17.9	-10.1	- 8.3	+8.3	+11.8	+17.2	+17.6	+8.9	-0.5	-8.3	-18.6	-0.8	+2.8°C
1982	R	0.0	TR	0.0	3.1	7.6	26.0	23.1	24.8	49.0	13.8	2.2	0.0	149.6	81
	S	4.4	18.8	2.6	7.8	29.7	TR	0.0	TR	TR	16.9	14.5	19.8	114.5	69
	P	4.4	18.6	2.6	10.9	37.3	26.0	23.1	24.8	49.0	30.7	14.3	19.0	260.7	77
	T	-34.3	-21.9	-17.5	-4.4	+4.2	+12.0	+14.9	+12.7	+9.8	+1.4	-16.9	-21.8	-5.2	-1.6°C
Normal 1951 to 1980	R	TR	TR	0.2	3.2	16.2	26.7	48.1	37.7	39.4	12.1	0.5	0.3	184.4	
	S	22.4	19.4	19.2	13.1	3.9	0.1	0.0	0.0	2.8	18.9	39.3	25.9	165.0	
	P	20.8	18.0	18.3	15.8	20.1	26.8	48.1	37.7	42.3	30.5	36.9	24.6	339.9	
	T	-25.8	-21.7	-16.3	-4.2	+5.6	+11.9	+15.8	+14.4	+8.1	+0.9	-11.3	-20.9	-3.6	

R = rain [mm]
S = snow [cm]
P = total precipitation [mm]

T = mean temperature [°C]

TR = trace
■ = missing
* = estimate

NOTE: January 1982 - precipitation values for Hay River Airport missing; substituted by values from Hay River Paradise Gardens.
Index - for R, S and P in % of 1951 to 1980 normal;
- for T in difference from 1951-1980 normal

TABLE 3.3B

HIGH LEVEL AIRPORT

Year		Jan.	Feb.	Mar.	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Annual Total	Index
1975	R	TR	0.8	0.0	5.8	21.8	69.6	89.2	69.6	28.7	3.6	0.3	1.5	290.9	113
	S	43.9	4.3	52.8	TR	1.0	0.0	0.0	0.0	0.0	15.5	57.4	30.7	205.6	126
	P	34.0	3.6	39.9	5.8	22.6	69.6	89.2	69.6	28.7	16.0	62.7	19.3	461.0	119
	T	23.1	-19.3	12.5	+1.6	+9.5	+14.2	+18.4	+13.0	+10.2	+1.2	-14.4	-22.5	-2.0	±0.0
1976	R	0.0	0.0	TR	11.9	39.4	86.4	84.8	68.6	9.1	7.1	0.5	TR	307.8	119
	S	27.4	25.1	11.9	TR	0.0	TR	0.0	0.0	0.0	30.7	6.9	14.2	116.2	71
	P	20.1	21.8	10.2	11.9	39.4	86.4	84.8	68.6	9.1	34.0	7.9	9.4	403.6	104
	T	-20.7	-19.8	-11.7	+6.0	+11.0	+13.2	+15.8	+16.0	+11.2	+1.2	-5.5	-18.2	-0.1	+1.9°C
1977	R	TR	TR	TR	2.6	66.8	85.4	37.7	20.3	42.6	2.5	0.4	TR	258.3	100
	S	22.3	6.2	9.1	10.0	0.0	TR	0.0	0.0	0.0	3.8	31.6	21.2	104.2	64
	P	23.1	5.5	7.8	12.5	66.8	85.4	37.7	20.3	42.6	5.5	26.7	17.9	351.8	91
	T	-17.5	-7.4	-7.5	+4.7	+11.2	+14.2	+14.8	+12.3	+9.9	+2.9	-13.0	-23.6	+0.1	+2.1°C
1978	R	TR	0.0	0.0	22.5	37.0	50.1	23.5	67.5	88.3	17.5	1.2	TR	307.6	119
	S	10.7	14.8	21.3	8.5	9.3	0.0	0.0	0.0	0.0	TR	31.1	11.0	106.7	65
	P	10.0	13.2	16.8	28.7	45.5	50.1	23.5	67.5	88.3	17.5	29.0	7.5	397.6	103
	T	-22.1	-13.7	-9.2	+1.1	+8.9	+14.2	+14.8	+13.1	+9.2	+3.0	-12.0	-20.8	-1.1	+0.9°C
1979	R	0.0	0.0	0.0	4.5	58.0	47.8	60.4	57.7*	40.5	4.0	0.0	0.2	273.1*	106
	S	15.0	34.2	21.7	28.0	12.4	0.0	0.0	0.0*	0.0	0.0	0.4	24.0	135.7*	83
	P	12.3	32.0	21.5	32.5	70.4	47.8	60.4	57.7*	40.5	4.0	0.4	20.6	400.1*	103
	T	-22.3	-28.4	-12.9	-3.6	+7.4	+13.8	+17.4	+14.0*	+9.5	+3.8*	-4.0*	-15.4	-1.7*	+0.3°C
1980	R	2.0	0.5	0.0	7.1	44.4	45.8	78.7	67.1	41.6	0.8	4.0	TR	292.0	113
	S	23.8	1.8	12.2	TR	TR	0.0	0.0	0.0	TR	TR	15.2	52.6	105.6	65
	P	24.2	2.3	11.6	7.1	44.4	45.8	78.7	67.1	41.6	0.8	19.2	50.8	393.6	102
	T	-22.1	-13.8	-9.4	+6.6	+10.2	+15.3	+16.0	+13.2	+6.4	+4.5	-7.3	-28.3	-0.7	+1.3°C
1981	R	0.6	0.0	0.0	37.8	13.7	79.3	60.0	1.6	17.3	47.1	1.0	TR	258.4	100
	S	5.9	28.6	2.9	17.1	0.0	0.0	0.0	0.0	0.0	47.3	25.3	16.1	143.2	88
	P	6.5	25.3	2.9	54.9	13.7	79.3	60.0	1.6	17.3	93.6	21.3	10.8	387.2	100
	T	-10.9	-16.3	-4.6	-1.3	+11.8	+13.3	+16.6	+16.7	+9.8	-0.3	-7.8	-19.6	+0.6	+2.6°C
1982	R	0.0	0.0	0.0	18.3	29.7	15.2	12.4	95.9	23.7	15.1	TR	TR	210.2	82
	S	13.0	17.8	4.1	2.8	5.6	0.0	0.0	TR	0.0	13.7	36.1	35.2	128.3	78
	P	11.8	15.2	3.3	21.2	34.5	15.2	12.4	95.9	23.7	27.9	29.1	30.0	320.2	83
	T	-32.6	-21.0	-13.5	-0.7	+8.4	+14.6	+17.5	+11.3	+9.5	+1.6	-16.2	-19.6	-3.4	-1.4°C
Normal 1951 to 1980	R	0.1	0.1	0.0	5.6	32.0	53.2	68.9	58.1	33.4	4.2	2.2	0.1	257.9	
	S	26.6	20.6	21.0	14.5	4.3	0.0	0.0	0.0	1.3	15.3	29.1	30.9	163.6	
	P	20.6	15.9	16.2	17.4	35.5	53.2	68.9	57.8	33.9	14.7	27.9	24.7	386.7	
	T	-24.6	-18.5	-11.8	+0.8	+9.3	+13.6	+15.7	+14.0	+8.1	+1.3	-11.4	-20.3	-2.0	

R = rain [mm]
S = snow [cm]
P = total precipitation [mm]
T = mean temperature [°C]
TR = trace
* = estimate

Notes: 1. August 1979 - values at High Level Airport missing; substituted by values from High Level Ranger stations
2. Normal for 1951-1980

Index - for R, S, P in % of 1951-1980 normal
- for T in difference from 1951-1980 normal.

TABLE 3.3C

FORT RESOLUTION AIRPORT

		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Total	Index
1975	R	0.0	0.0	0.0	3.3	16.5	6.6	m	m	m	m	m	m		
	S	25.7	21.6	4.6	4.3	8.1	0.0	m	m	m	m	m	m		
	P	23.1	16.3	4.6	7.6	24.6	6.6	m	m	m	m	m	m		
	T	-29.2	-22.6	-17.8	-0.2	+7.6	m	m	m	m	m	m	m		
1976	R														
	S								Missing						
	P														
	T														
1977	R														
	S								Missing						
	P														
	T														
1978	R	m	0.0	0.0	8.0	5.2	21.0	51.9	7.6	30.7	16.4	0.2	0.0		
	S	m	4.0	16.1	18.6	0.0	0.0	0.0	0.0	0.0	32.4	27.6	8.8		
	P	m	4.0	16.1	26.6	5.2	21.0	51.9	7.6	30.7	48.8	27.8	8.8		
	T	m	-16.4	-16.6	m	m	+11.9	m	+11.8	+8.1*	m	-12.4	-23.3		
1979	R	0.0	0.0	0.0	1.2	8.9	8.5	30.2	36.8	13.2	m	0.0	0.0		
	S	6.5	0.3	16.7	11.5	29.7	0.0	0.0	0.0	0.0	m	28.5	11.4		
	P	6.5	0.3	16.7	12.7	38.6	8.5	30.2	36.8	13.2	m	28.5	11.4		
	T	-24.0	-33.9	-19.7*	-9.2*	+4.8	+11.2*	+17.3*	+12.5	+7.6	m	-5.7*	m		
1980	R	0.0	0.0	0.0	3.3	13.9	4.6	m	36.2	42.3	m	0.0	0.0		
	S	23.1	6.8	7.5	0.0	TR	0.0	0.0	0.0	3.4	m	17.9	11.2		
	P	23.1	6.8	7.5	3.3	13.9	4.6	m	36.2	45.7	m	17.9	11.2		
	T	-24.6	-18.0	+16.9*	+1.7	+7.6	+13.6	m	+13.5*	+5.0	+2.6*	-9.0	-26.0		
1981	R	m	0.0	0.0	0.0	0.0	14.2	21.1	33.4	18.1	16.7	0.0	0.0		
	S	m	m	7.6	30.0	0.2	0.0	0.0	0.0	0.0	17.8	22.0	7.1		
	P	m	m	7.6	30.0	0.2	14.2	21.1	33.4	18.1	34.5	22.0	7.1		
	T	-12.5*	-19.7	-9.3*	-8.3*	+8.5*	+11.2*	+16.7*	+16.6	+7.4	-1.7*	-7.6*	-18.5	-1.4	+2.9°C
1982	R	0.0	0.0	0.0	6.8	5.4	m	m	m	m	m	0.0	0.0		
	S	m	17.6	4.6	0.3	13.0	0.0	0.0	0.0	0.0	m	m	m		
	P	m	17.6	4.6	7.1	18.4	m	m	m	m	m	m	m		
	T	m	-25.0	-20.4*	-4.3	+4.5	+11.0*	+14.4*	+11.7	+8.2*	m	-16.7*	-24.0*		
1951 to 1980 normal	R	0.0	TR	0.1	2.9	12.0	21.7	42.7	35.4	36.2	11.0	0.3	0.1	162.4	
	S	21.9	17.9	16.2	10.5	4.7	0.5	0.0	0.0	2.9	24.4	53.3	21.7	174.0	
	P	17.1	14.2	13.0	12.4	16.5	22.2	42.7	35.4	39.1	34.2	41.0	18.7	306.5	
	T	-26.7	-23.1	-16.9	-4.9	+5.8	+12.4	+15.7	+14.1	+7.3	+0.4	-10.9	-21.2	-4.3	

R = rain [mm]
S = snow [cm]
P = total precipitation [cm]
T = mean temperature [°C]
TR = trace
m = missing
* = estimate

Index - for R, S, P in % of 1951 - 1980 normal
- for T in difference from 1951-1980 normal

TABLE 3.3D

HAY RIVER PARADISE GARDENS

		Jan.	Feb.	Mar.	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Annual Total	Index
1975	R														
	S	9.1	15.0	16.8	1.5	1.0	0.0	0.0	0.0	0.0	8.4	66.8	15.7	134.3	96
	P	9.1	15.0	16.8	8.6	39.6	11.9	33.0	87.9	19.8	20.1	66.8	15.7	344.3	96
	T	-28.1	-22.7	-18.3	-0.2	+8.1	+14.3	+18.0	+13.4	+9.7	+0.1	-17.0	-25.1	-4.0	-0.2°C
1976	R														
	S	25.4	17.0	18.3	TR	0.0	0.0	0.0	0.0	0.0	17.8	m	14.2		
	P	25.4	17.0	18.3	1.0	68.6	47.2	52.1	88.9	45.5	18.8	m	14.2		
	T	-26.1	-25.3	-17.0	+3.7	+10.4	+13.0	+15.9	+15.5	+11.0	+0.2	m	-22.1		
1977	R	0.0	TR	0.0	m	33.0	36.0	8.1	26.4	19.3*	6.1	m	0.0		
	S	8.4	9.6	20.9	m	TR	0.0	0.0	0.0	0.0	8.1	m	12.1		
	P	8.4	9.6	20.9	m	33.0	36.0	8.1	26.4	19.3*	14.2	m	12.1		
	T	-21.4	m	-13.1	+0.9	+8.6	+13.7	+15.1	+11.8	+9.6	+1.7	m	-28.7		
1978	R	0.0	0.0	0.0	11.2	0.8	31.2	66.1	m	27.7	24.1	m	0.0		
	S	8.5	2.8	16.8	29.7	TR	0.0	0.0	m	0.0	15.9	m	23.6		
	P	8.5	2.8	16.8	40.9	0.8	31.2	66.1	m	27.7	40.0	m	23.6		
	T	-22.9	-15.8	-15.1	-4.8	+6.1	+13.7	+13.6	m	+8.5	-0.4*	m	-22.6		
1979	R	0.0	0.0	0.0	m	30.5	8.3	23.8	35.0	28.0	10.0	TR	TR		
	S	4.3	2.0	33.2	m	27.9	0.0	0.0	0.0	0.0	12.8	16.4	11.2		
	P	4.3	2.0	33.2	m	58.4	8.3	23.8	35.0	28.0	22.8	16.4	11.2		
	T	-23.4	-33.7	-18.2	m	+4.6	+13.2	+18.5	+13.9*	+9.3	+1.9*	-4.4*	-16.0		
1980	R	TR	0.0	0.0	m	18.6	19.6	64.0	40.5	58.2	m	1.6	0.0		
	S	15.3	4.4	1.2	m	TR	0.0	0.0	0.0	3.6	m	31.7	14.0		
	P	15.3	4.4	1.2	m	18.6	19.6	64.0	40.5	61.8	m	33.3	14.0		
	T	-24.4	-15.9	-13.9	m	+9.9	+14.6	+15.9	+13.9	+5.9*	m	-9.3	-29.2		
1981	R	TR	0.0	0.0	13.1	m	m	29.3	54.2	36.7	m	0.0	0.0		
	S	4.6	13.6	10.9	51.0	m	m	0.0	0.0	0.0	m	30.0	24.9		
	P	4.6	13.6	10.9	64.1	m	m	29.3	54.2	36.7	m	30.0	24.9		
	T	-10.4	-19.3	-9.0	-7.2*	m	m	+17.7	+16.9	+8.6	m	-9.2	-20.3		
1982	R	0.0	0.0	0.0		21.9	30.8	37.7	31.8	55.6	m	TR	0.0		
	S	4.4	20.6	2.4		41.0	0.0	0.0	0.0	0.0	m	15.0	3117		
	P	4.4	20.6	2.4		62.9	30.8	37.7	31.8	55.6	m	15.0	31.7		
	T	-36.6	-23.5	-18.9		+6.0	+13.4	+15.7	[illegible]	+8.8	m	-19.5	-22.8		
Normal	R	0.0	0.0	0.0	3.1	24.1	32.4	55.0	48.7	37.3	8.5	0.3	0.0	209.6	
	S	18.7	17.5	18.0	11.8	3.6	0.1	0.0	0.0	1.4	13.8	34.5	19.8	139.2	
1951 to	P	19.7	18.7	19.0	15.2	27.5	32.5	55.0	48.7	38.8	22.7	39.7	21.4	358.9	
1980	T	-27.1	-22.6	-16.1	-3.5	+7.0	+13.2	+16.1	+14.2	+7.7	+0.2	-12.5	-22.4	-3.8	

Index - for R, S, P in °/. of 1951 - 1980 normal

- for T in difference from 1951 - 1980 normal.

R = rain [mm]
S = snow [cm]
P = total precipitation [mm]
T = mean temperature

TR = trace
m = missing
* = estimate

TABLE 3.3E

PINE POINT

Year		Jan.	Feb.	Mar	Apr.	May	June	July	August	Sept	Oct	Nov	Dec.	Annual Total	Index
1975	R											0.0	0.0		
	S											62.0	14.5		
	P											62.0	14.5		
	T											-14.5	-23.2		
1976	R	m	0.0	0.0	1.3	m	33.3	34.3	14.7	42.2	9.9	TR	0.0		
	S	m	8.4	11.9	0.0	m	0.0	0.0	0.0	0.0	50.8	6.6	11.7		
	P	m	8.4	11.9	1.27	m	33.3	34.3	28.2	42.6	15.0	6.6	11.7		
	T	m	-24.6	-16.0	+4.3	m	+13.4	+16.7	+14.9	+10.7	+1.0	-7.2	-20.9		
1977	R	0.0	m	m	m	m	m	17.0	48.1	20.6*	37.7*	0.0	0.0		
	S	6.5	m	m	m	m	m	0.0	0.0	0.0	3.5	m	8.5		
	P	6.5	m	m	m	m	m	17.0	48.	20.6*	40.9	m	8.5		
	T	-21.2	m	m	m	m	m	+14.8	+13.5	+9.5	m	m	m		
1978	R	0.0	0.0	0.0	m	1.7	21.0	48.8	5.1	44.4	25.7	0.0	0.0		
	S	36.7	4.2	21.8	m	0.0	0.0	0.0	0.0	0.0	4.8	26.7	5.6		
	P	36.7	4.2	21.8	m	1.7	21.0	48.8	5.1	44.4	30.5	26.7	5.6		
	T	m	-17.2	m	m	m	+12.7*	+12.4*	+12.5*	+8.3*	+1.2	-12.0*	m		
1979	R	0.0	0.0	0.0	0.0	28.5	12.9	41.9	15.7	34.0	29.2	0.0	m		
	S	5.0	0.3	13.2	4.0	3.7	0.0	0.0	0.0	0.0	2.0	12.1	m		
	P	5.0	0.3	13.2	4.0	32.2	12.9	41.9	15.7	34.0	31.2	12.1	m		
	T	m	-31.9*	-20.0*	m	+5.1*	+11.8	+18.6	+13.5*	+9.5	+1.7*	-5.1*	-15.1*		
1980	R	m	m	m	m	10.7	m	25.7	96.6	49.6	2.5	0.0	m		
	S	m	m	m	m	0.0	m	0.0	0.0	0.0	0.7	m	m		
	P	m	m	m	m	10.7	m	25.7	96.6	49.6	3.2	m	m		
	T	m	m	m	m	+9.2*	m	+15.8	+14.5	+6.4*	+4.2*	m	m		
1981	R	m	0.0	0.0	m	m	26.8	30.9	33.3	m	18.7	0.0	m		
	S	m	m	2.4	m	m	0.0	0.0	0.0	m	13.2	13.0	m		
	P	m	m	2.4	m	m	26.8	30.9	33.3	m	31.9	13.0	m		
	T	-9.7*	m	-8.5*	m	m	+14.2	+17.7*	+18.1	+9.0*	m	m	m		
1982	R	0.0	0.0	0.0	3.6	14.5		14.2	m	49.8	27.5	0.0	0.0		
	S	0.6	4.4	15.2	11.2	22.6		0.0	0.0	0.0	9.4	m	m		
	P	0.6	4.4	15.2	14.8	37.1		14.2	m	49.8	36.9	m	m		
	T	m	m	-18.0*	m	+5.2*		+16.8	+12.6*	+10.2	+2.2*	-18.2	-22.5*		
Normal 1975 to 1980	R	0.0	0.0	0.0	0.7	13.6	22.4	33.5	36.0	38.2*	21.0*	TR	0.0	165.4	
	S	16.1	4.3	15.6*	2.0	1.2	0.0	0.0	0.0	0.0	3.2	26.9	10.1	79.4	
	P	16.1	4.3	15.6*	2.7	14.9	22.4	33.5	36.0	38.2*	24.2*	26.9	10.1	244.9	
	T	-21.2	-24.5*	-18.1*	+4.3	+7.2*	+12.7*	+15.7*	+13.4*	+8.9*	+2.0*	-9.7*	-19.7*	-2.4*	

R = rain [mm]
S = snow [cm]
P = total precipitation [mm]
T = mean temperature [°C]
TR = trail
m = missing
* = estimate

Index - for R, S and P in % of 1951 -1980 normal
- for T in difference from 1951-1980 normal

TABLE 3.3F

	Ft. Smith Airport						Hay River Airport						High Level Airport					
	snow w.e.[1]		rain		total precipitation		snow w.e.[1]		rain		total precipitation		snow w.e.[1]		rain		total precipitation	
	mm	°/。	mm	°/。	mm	°/。	mm	°/。	mm	°/。	mm	°/。	mm	°/。	mm	°/。	mm	°/。
1975	120.7	93	335.1	153	455.8	130	157.1	101	182.3	99	339.4	100	170.1	132	290.9	113	461.0	119
1976	122.0	94	188.4	86	310.4	89	92.3	59	231.6	126	323.9	95	95.8	74	307.8	119	403.6	104
1977	86.9	67	277.0	126	363.9	104	101.6	65	132.8	72	234.4	69	93.5	72	258.3	100	351.8	91
1978	69.1	53	209.9	96	279.0	80	90.1	58	184.7	100	274.8	81	90.0	70	307.6	119	397.6	103
1979	75.5	58	180.2	82	255.7	73	90.9	58	139.5	76	230.4	68	127.0	98	273.1	106	400.1	103
1980	70.1	54	234.7	107	304.8	87	75.2	48	211.8	115	287.0	84	101.6	79	292.0	113	393.6	102
1981	160.3	123	187.3	85	347.6	100	142.9	92	168.2	91	311.1	92	128.8	100	258.4	100	387.2	100
1982	103.8	80	183.9	84	287.7	82	111.1	71	149.6	81	260.7	77	110.0	85	210.2	82	320.2	83
1951-1980 normal [mm]	130.1		219.2		349.3		155.5		184.4		339.9		129.1[2]		257.9		386.7	

1) w.e. = water equivalent 2) normal determined from monthly records

TABLE 3.4A

	Ft. Smith Airport						Hay River Airport						High Level Airport					
	snow w.e.[1]		rain		total precipitation		snow w.e.[1]		rain		total precipitation		snow w.e.[1]		rain		total precipitation	
	mm	°/•	mm	°/•	mm	°/•	mm	°/•	mm	°/•	mm	°/•	mm	°/•	mm	°/•	mm	°/•
1975/76	155.8	120	187.7	86	343.5	98	157.6	101	235.9	128	393.5	116	144.7	112	305.6	118	450.3	116
1976/77	97.2	75	272.5	124	369.7	106	86.7	56	130.3	71	217.0	64	90.0	70	263.0	102	353.0	91
1977/78	62.2	48	208.7	95	270.9	78	70.8	45	174.3	95	245.1	72	101.9	79	291.8	113	393.7	102
1978/79	80.3	62	174,4	80	254.7	73	118.9	76	148.4	80	267.3	79	141.5	110	287.6	112	429.1	111
1979/80	64.0	49	241.4	110	305.4	87	61.6	39	227.5[4]	123	289.1	85	56.4	44	291.4	113	347.8	90
1980/81	110.7	85	175.7	80	286.4	82	104.7[3]	67	144.9	79	249.6	73	117.2	91	215.1	83	332.3	86
1981/82	134.0	103	210.6[2]	96	344.6	99	138.0	88	166.4	90	304.4	90	115.7	90	243.2	94	358.9	93
1951-1980 normal [mm]	130.1		219.2		349.3		156.0		184.4		339.9		129.1		257.9		386.7	

1) w.e. = water equivalent; 2) snow in August (1.6 mm w.e.) and September (4.5 mm w.e.) added;
3) snow in September 1980 (9.8 mm w.e.) not included; 4) snow in September 1980 (9.8 mm w.e.) added.

TABLE 3.4B

FORT SMITH AIRPORT

		Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	Total	% of Normal
1975/76	snow [cm]		15.0	51.1	21.1	30.5	42.2	26.4	0.8			187.1	128
	w.e. [mm]		14.3	45.2	19.0	26.9	29.5	19.6	1.3			155.8	120
1976/77	snow [cm]		0.8	32.5	20.1	22.8	19.7	9.9	8.8			114.6	79
	w.e. [mm]		0.8	27.9	16.0	21.6	18.9	6.9	5.1			97.2	75
1977/78	snow [cm]		4.4	20.1	20.9	12.6	1.0	10.2	14.9			84 1	58
	w.e. [mm]		4.0	13.0	17.4	9.0	0.3	7.6	10.9			62.2	48
1978/79	snow [cm]		17.5	8.0	23.7	3.5	8.1	13.1	18.4	4.9		97.2	67
	w.e. [mm]		16.0	5.8	19.5	1.7	6.5	10.7	14.8	5.3		80.3	62
1979/80	snow [cm]		10.2	11.0	21.0	25.4	8.7	3.6	0.2			80.1	55
	w.e. [mm]		10.2	11.0	15.3	16.9	7.5	2.7	0.2			63.8	49
1980/81	snow [cm]	0.2	2.1	26.4	23.8	17.2	19.0	21.5	21.2			131.4	90
	w.e. [mm]	0.2	2.1	18.3	22.2	14.4	15.2	18.9	19.6			110.9	85
1981/82	snow [cm]		41.9	44.5	51.9	6.5	21.9	10.2	15.3	11.7		203.9	140
	w.e. [mm]		33.6	31.8	26.8	4.6	12.2	4.5	10.2	10.3		134.0	103
Normal 1951-1980	snow [cm]	2.0	15.9	28.8	24.9	21.4	18.4	15.9	13.5	4.8	0.3	145.9	normal
	w.e. [mm]	2.0	15.5	25.2	21.8	18.5	15.8	14.2	12.3	4.6	0.2	130.1	normal

w.e. = water equivalent

TABLE 3.5A

HAY RIVER AIRPORT

		Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	Total	% of Normal
1975/76	snow [cm]		21.1	61.2	19.8	21.1	24.9	21.8				169.9	103
	w.e. [mm]		21.4	50.5	20.1	21.1	24.9	19.6				157.6	101
1976/77	snow [cm]		7.1	11.9	13.0	16.3	14.1	22.6	5.0	2.0	0.2	92.2	56
	w.e. [mm]		5.9	8.1	12.7	16.5	14.1	22.2	5.0	2.0	0.2	86.7	56
1977/78	snow [cm]		7.2	20.0	14.6	7.0	2.0	10.5	10.1	0.2		71.6	43
	w.e. [mm]		7.2	19.8	14.6	7.0	1.6	10.3	10.1	0.2		70.8	45
1978/79	snow [cm]		18.0	17.6	25.3	1.8	6.7	18.9	12.8	17.8		118.9	72
	w.e. [mm]		18.0	17.6	25.3	1.8	6.7	18.9	12.8	17.8		118.9	76
1979/80	snow [cm]		10.8	10.0	12.1	21.6	4.0	2.1	0.8	0.2		61.6	37
	w.e. [mm]		10.8	10.0	12.1	21.6	4.0	2.1	0.8	0.2		61.6	39
1980/81	snow [cm]	9.8	1.6	18.8	16.3	3.0	15.6	10.5	40.1			115.7	70
	w.e. [mm]	9.8	1.6	18.8	16.3	3.0	15.6	9.3	40.1			114.5	73
1981/82	snow [cm]		32.5	23.8	18.6	4.4	18.8	2.6	7.8	29.7		138.82	84
	w.e. [mm]		32.5	23.8	18.6	4.4	18.6	2.6	7.8	29.7		138.0	88
Normal 1951-1980	snow [cm]	2.8	18.9	39.3	25.9	22.4	19.4	19.2	13.1	3.9	0.1	165.0	normal
	w.e. [mm]	2.9	18.4	36.4	24.3	20.8	18.0	18.1	12.6	3.9	0.1	155.5	normal

w.e. = water equivalent

TABLE 3.5B

HIGH LEVEL AIRPORT

		Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	Total	% of Normal
1975/76	snow [cm]		15.5	57.4	30.7	27.4	25.1	11.9	TR			168.0	103
	w.e. [mm]		12.4	62.4	17.8	20.1	21.8	10.2				144.7	112
1976/77	snow [cm]		30.7	6.9	14.2	22.3	6.2	9.1	10.0			99.4	61
	w.e. [mm]		26.9	7.4	9.4	23.1	5.5	7.8	9.9			90.0	70
1977/78	snow [cm]		3.8	31.6	21.2	10.7	14.8	21.3	8.5	9.3		121.2	74
	w.e. [mm]		3.0	26.3	17.9	10.0	13.2	16.8	6.2	8.5		101.9	79
1978/79	snow [cm]			31.1	11.0	15.0	34.2	21.7	28.0	12.4		153.4	94
	w.e. [mm]			27.8	7.5	12.3	32.0	21.5	28.0	12.4		141.5	112
1979/80	snow [cm]			0.4	24.0	23.8	1.8	12.2				62.2	38
	w.e. [mm]			0.4	20.4	22.2	1.8	11.6				56.4	44
1980/81	snow [cm]			15.2	52.6	5.9	28.6	2.9	17.1			122.3	75
	w.e. [mm]			15.2	50.8	5.9	25.3	2.9	17.1			117.2	91
1981/82	snow [cm]		47.3	25.3	16.1	13.0	17.8	4.1	2.8	5.6		132.0	81
	w.e. [mm]		46.5	20.3	10.8	11.8	15.2	3.3	3.0	4.8		115.7	90
Normal 1951-1980	snow [cm]	1.3	15.3	29.1	30.9	26.6	20.6	21.0	14.5	4.3		163.6	normal
	w.e. [mm]	0.5	10.5	25.7	24.6	20.5	15.8	16.2	11.8	3.5		129.1	normal

w.e. = water equivalent; annual normal for w.e. determined from monthly records

TABLE 3.5c

FORT SMITH AIRPORT (record code 1)

	Sept.		Oct.		Nov.		Dec.		Jan.		Feb.		Mar		Apr.		May	
	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.	SD.	Dev.	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev
1975/76			3	-1	38	+18	41	+9	61	+15	64	+13	53	+10				
1976/77					18	-2	36	+4	52	+6	57	+6	50	+7				
1977/78					18	-2	35	+3	35	-11	32	-19	35	-8	TR			
1978/79			8	+4	8	-12	31	-1	32	-14	35	-16	41	-2	14	+9		
1979/80			m		13	-7	25	-7	42	-4	42	-9	39	-4				
1980/81					15	-5	29	-3	28	-18	43	-8	32	-11				
1981/82			10	+6	21	+1	32	0	34	-12	47	-4	30	-13				
1951-1980 normal [cm]	TR		4		20		32		46		51		43		5		0	

SD = snow depth at end of month [cm]

Dev.= deviation from 1951-1980 normal [cm]

m = missing

TR = trace

TABLE 3.6A

HAY RIVER AIRPORT (record code 1)

	Sept.		Oct.		Nov.		Dec.		Jan.		Feb.		Mar		Apr.		May	
	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.
1975/76			3	0	43	+19	53	+15	48	-3	64	+6	51	+3				
1976/77			TR	-5	5	-19	10	-28	21	-30	34	-24	39	-9				
1977/78					15	-9	27	-11	30	-21	26	-32	38	-10	15	+8		
1978/79			3	-2	15	-9	37	-1	31	-20	35	-23	44	-4	26	+21	TR	
1979/80			2	-3	2	-22	10	-28	31	-20	31	-27	25	-23				
1980/81	1	0	2	-3	18	-6	31	-7	17	-34	31	-27	21	-27	26	+21		
1981/82			12	+7	19	-5	33	-5	29	-22	45	-13	28	-20	2	-5		
1951-1980 normal	1		5		24		38		51		58		48		7		0	

SD = snow depth at end of month [cm]

Dev. = deviation from 1951-1980 normal [cm]

TR = trace

TABLE 3.6B

HIGH LEVEL AIRPORT (record code 5)

	Sept.		Oct.		Nov.		Dec.		Jan.		Feb.		Mar		Apr.		May	
	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.	SD	Dev.
1975/76					5	-14	38	+5	56	+12	66	+15	43	+7				
1976/77					3	-16	10	-23	27	-17	21	-30	15	-21	4	+3		
1977/78					25	+6	42	+9	46	+2	43	-8	10	-26				
1978/79					24	+5	28	-5	40	-4	66	+15	50	+14	5	+4		
1979/80			m		m		11	-22	25	-19	25	+26	12	-24				
1980/81					7	-12	57	+24	24	-20	46	-5	5	-31				
1981/82			10	+9	25	+6	34	+1	34	-10	38	-13	7	-29				
1951-1980 normal			1		19		33		44		51		36		1			

SD = snow depth at end of month [cm]

Dev. = Deviation from 1951-1980 normal [cm]

m = missing

TR = trace

TABLE 3.6C

		FORT SMITH A.				HAY RIVER A.				HIGH LEVEL A.						
		rain	snow	snow w.e.	total precip.	rain	snow	snow w.e.	total precip.	rain	snow	snow w.e.	total precip.			
A	CALENDAR YEAR 1975	153	93	93	130	99	103	101	100	113	126	132	119	1975	CALENDAR YEAR	A
	1976	86	105	94	89	126	60	59	95	119	71	74	104	1976		
	1977	126	73	67	104	72	62	65	69	100	64	72	91	1977		
	1978	96	60	53	80	100	55	58	81	119	65	70	103	1978		
	1979	82	62	58	73	76	55	58	68	106	83	98	103	1979		
	1980	107	62	54	87	115	46	48	84	113	65	79	102	1980		
	1981	85	149	123	100	91	87	92	92	100	88	100	100	1981		
	1982	84	111	80	82	81	69	71	77	82	78	85	83	1982		
B	WATER YEAR October to September 1975/76	86	128	120	98	128	103	101	116	118	103	112	116	1975/76	WATER YEAR October to September	B
	1976/77	124	79	75	106	71	56	56	64	102	61	70	91	1976/77		
	1977/78	95	58	48	78	95	43	45	72	113	74	79	102	1977/78		
	1978/79	80	67	62	73	80	72	76	79	112	94	110	111	1978/79		
	1979/80	110	55	49	87	123	37	39	85	113	38	44	90	1979/80		
	1980/81	80	90	85	82	79	70	67	73	83	75	91	86	1980/81		
	1981/82	96*	140	103	99	90	84	88	90	94	81	90	93	1981/82		

Precipitation in % of normal; w.e. = water equivalent; * snow in August (1.6 mm w.e.) and September (4.5 mm w.e.) added.

TABLE 3.7

		FORT SMITH A.				HAY RIVER A.				HIGH LEVEL A.					
		rain	snow	snow w.e.	total precip.	rain	snow	snow w.e.	total precip.	rain	snow	snow w.e.	total precip.		
A CALENDAR YEAR	1975	+53	-7	-7	+30	-1	+3	+1	=	+13	+26	+32	+19	1975	CALENDAR YEAR A
	1976	-14	+5	-6	-11	+26	-40	-41	-5	+19	-29	-26	+4	1976	
	1977	+26	-27	-33	+4	-28	-38	-35	-31	=	-36	-28	-9	1977	
	1978	-4	-40	-47	-20	=	-45	-42	-19	+19	-35	-30	+3	1978	
	1979	-18	-38	-42	-27	-24	-45	-42	-32	+6	-17	-2	+3	1979	
	1980	+7	-38	-46	-13	+15	-54	-52	-16	+13	-35	-21	+2	1980	
	1981	-15	+49	+23	=	-9	-13	-8	-8	=	-12	=	=	1981	
	1982	-16	+11	-20	-18	-19	-31	-29	-23	-18	-22	-15	+17	1982	
B WATER YEAR October to September	1975/76	-14	+28	+20	-2	+28	+3	+1	+16	+18	+3	+12	+16	1975/76	WATER YEAR October to September B
	1976/77	+24	-21	-25	+6	-29	-44	-44	-36	+2	-39	-30	-9	1976/77	
	1977/78	-5	-42	-52	-22	-5	-57	-55	-28	+13	-26	-21	+2	1977/78	
	1978/79	-20	-33	-38	-27	-20	-28	-24	-21	+12	-6	+10	+11	1978/79	
	1979/80	+10	-45	-51	-13	+23	-63	-61	-15	+13	-62	-56	-10	1979/80	
	1980/81	-20	-10	-15	-18	-21	-30	-33	-27	-17	-25	-9	-14	1980/81	
	1981/82	-4	+40	+3	-1	-10	-16	-12	-10	-6	-19	-10	-7	1981/82	

TABLE 3.8

		FORT SMITH A.				HAY RIVER A.				HIGH LEVEL A.					
		rain	snow	snow w.e.	total precip.	rain	snow	snow w.e.	total precip.	rain	snow	snow w.e.	total precip.		
A CALENDAR YEAR	1975	+++	-	-	++	=	=	=	=	+	++	++	+	1975	CALENDAR YEAR A
	1976	-	+	-	-	++	---	---	-	+	--	--	=	1976	
	1977	++	--	--	=	--	--	--	--	=	--	--	-	1977	
	1978	=	---	---	--	=	---	---	-	+	--	--	=	1978	
	1979	--	--	---	--	--	---	---	--	+	-	=	=	1979	
	1980	+	--	---	-	+	---	---	-	+	--	--	=	1980	
	1981	-	+++	++	=	-	-	-	-	=	-	=	=	1981	
	1982	-	+	--	-	-	--	--	--	-	--	-	-	1982	
B WATER YEAR October to September	1975/76	-	++	++	=	++	=	=	+	+	=	+	+	1975/76	WATER YEAR October to September B
	1976/77	++	--	--	+	--	---	---	--	=	--	--	-	1976/77	
	1977/78	-	---	---	--	-	---	---	--	+	--	--	=	1977/78	
	1978/79	--	---	--	--	--	--	--	--	+	-	+	+	1978/79	
	1979/80	+	---	---	-	++	---	---	-	+	---	---	-	1979/80	
	1980/81	--	-	-	-	--	--	--	--	-	--	-	-	1980/81	
	1981/82	=	+++	=	=	-	-	-	-	-	-	-	-	1981/82	

Symbols: --- 60.1 % -- 80.1 - 95.1 = 104.9 + 119.9 ++ 139.9 +++
w.e. = water equivalent

TABLE 3.9

Calendar years	(1) total rainfall [mm]	% of normal	(2) total snowfall [cm]	% of normal	(3) total precipitation [mm]	% of normal	water equivalent of snowfall (3)-(1) [mm]	% of normal
1945	144.8	78.5	58.9	35.7	203.7	59.9	58.9	37.9
1946	152.7	82.8	56.1	34.0	208.7	61.4	56.0	36.0
1947	154.6	83.8	122.9	74.5	277.6	81.7	123.0	79.1
1948	265.5	144.0	98.1	59.5	363.6	107.0	98.1	63.1
1949	172.9	93.8	142.7	86.5	315.6	92.9	142.7	91.8
1950	184.1	99.8	152.9	92.7	337.0	99.1	152.9	98.3
Mean	174.3	94.5	105.8	64.1	280.1	82.4	105.8	68.0
1951	178.0	96.5	153.1	92.8	331.3	97.5	153.3	98.6
1952	222.3	120.5	129.3	78.4	351.6	103.4	129.3	83.2
1953	221.7	120.2	161.1	97.6	382.8	112.6	161.1	103.6
1954	192.0	104.1	193.4	117.2	385.6	113.4	193.6	124.5
1955	133.8	72.6	137.1	83.1	271.0	79.7	137.2	88.2
1956	210.4	114.1	154.4	93.6	364.8	107.3	154.4	99.3
1957	236.1	128.0	138.4	83.9	374.6	110.2	138.5	89.1
1958	170.7	92.6	196.0	118.8	366.7	107.9	196.0	126.0
1959	176.4	95.7	133.1	80.7	309.4	91.0	133.0	85.5
1960	243.6	132.1	235.5	142.7	479.2	141.0	235.6	151.5
Mean	198.4	107.6	163.2	98.9	361.7	106.4	163.3	105.0
1961	162.8	88.3	323.1	195.8	485.8	142.9	323.0	207.7
1962	231.7	125.6	208.4	126.3	440.1	129.5	208.4	134.0
1963	221.9	120.3	249.0	150.9	470.9	138.5	249.0	160.1
1964	219.0	118.8	142.2	86.2	358.3	105.4	139.3	89.6
1965	147.1	79.8	235.9	143.0	337.0	99.1	189.9	122.1
1966	196.7	106.7	284.8	172.6	383.2	112.7	186.5	119.9
1967	132.4	71.8	167.4	101.5	262.6	77.3	130.3	83.7
1968	204.4	110.8	192.2	116.5	372.3	109.5	167.9	108.0
1969	121.3	65.8	124.8	75.6	234.0	68.8	112.7	72.5
1970	98.8	53.6	168.6	102.2	269.5	79.3	171.7	110.4
Mean	173.7	94.2	209.6	127.0	361.4	106.3	187.7	120.7
1971	114.5	62.1	135.4	82.1	249.4	73.4	134.9	86.8
1972	181.1	98.2	138.6	84.0	319.6	94.0	138.5	89.1
1973	229.4	124.4	136.1	82.5	348.8	102.6	119.4	76.8
1974	201.3	109.2	181.7	110.1	360.3	106.0	159.0	102.3
1975	182.3	98.9	169.6	102.8	339.4	99.9	157.1	101.0
1976	231.6	125.6	99.8	60.5	323.9	95.3	92.3	59.4
1977	132.6	71.9	102.0	61.8	234.4	69.0	101.8	65.5
1978	184.7	100.2	90.7	55.0	274.8	80.8	90.1	57.9
1979	139.5E	75.7	90.9E	55.1	230.4E	67.8	90.9	58.5
1980	211.8	114.9	75.2	45.6	287.0	84.4	75.2	48.4
Mean	180.9	98.1	122.0	73.9	296.7	87.3	115.8	74.5
1981	168.2	91.2	144.1	87.3	311.1	91.5	142.9	91.9
1982	149.6	81.1	114.5	69.4	260.7	76.7	111.1	71.4
1983								
Normal 1951-1980	184.4		165.0		339.9		155.5	

E = estimate

Table 3-10. Precipitation at Hay River Airport [illegible] 1983

add 1983

Year	Yellowknife WSC Station: 075B001				Fort Resolution [1)] WSC Station: 07PB001			
	minimum		maximum		minimum		maximum	
	ft	m	ft	m	ft	m	ft	m
1970	512.54	156.222	513.84	156.618	512.46	156.198	513.82	156.612
1971	512.85	156.317	514.32	156.765	513.21	156.426	514.13	156.707
1972	512.80	156.301	514.81	156.914	513.49	156.512	514.79	156.908
1973	513.54	156.527	514.86	156.929	513.91	156.640	514.80	156.911
1974	513.56	156.533	515.23	157.042	514.84	156.923	515.64	157.167
1975	513.28	156.448	514.92	156.948	513.58	156.539	514.97	156.963
1976	513.36	156.472	514.80	156.911	513.93	156.646	514.81	156.914
1977	513.37	156.475	514.68	156.874	513.61	156.548	514.71	156.884
1978	512.97	156.353	514.49	156.817	513.33	156.463	514.30	156.759
1979	512.78	156.287	515.08	156.988	513.64	156.551	514.95	156.950
1980	512.46	156.189	513.76	156.587	512.54	156.216	513.59	156.536
1981	512.19	156.108	513.96	156.647	512.71	156.268	514.03	156.668
1982	512.57	156.223	513.88	156.624	-	-	-	-

1) records only for ice free season.

TABLE ~~1~~ 3.11

BUFFALO RIVER, WSC - Station No. 07PA001

Year		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1975	max.	18.27	0.57	0.11	42.48	161.71	192.01	193.99	107.05	196.82	154.91	66.55	45.87
	mean	4.66	0.255	0.031	5.10	132.	175.	146.	87.0	169.	137.	56.8	36.2
	min.	0.59	0.11	0.0	0.0	55.22	154.06	96.85	47.86	127.44	113.85	47.01	26.68
1976	max.	26.20	8.84	0.84	172.47	205.88	214.38	232.51	114.70	97.70	75.33	19.68	4.87
	mean	18.7	3.37	0.323	42.4	180.	179.	147.0	93.9	78.5	50.5	11.8	2.21
	min.	9.52	0.88	0.11	0.12	131.97	121.49	103.08	76.18	65.70	20.67	5.24	1.05
1977	max.	1.02	0.20	0.01	63.15	113.56	141.32	130.84	135.83	98.55	80.71	56.07	13.42
	mean	0.612	0.081	0.003	7.24	102.	107.	104.	122.	86.9	68.0	21.7	7.45
	min.	0.22	0.02	0.0	0.0	74.48	86.94	83.83	98.84	76.46	50.13	13.99	0.76
1978	max.	0.68	0.08	0.02	23.96	94.87	91.76	93.74	77.03	84.39	99.69	79.29	48.14
	mean	0.240	0.044	0.004	[illegible]	80.8	83.5	69.1	63.0	62.9	86.9	33.3	40.0
	min.	0.08	0.02	0.0	0.0	32.0	70.23	57.21	48.43	42.48	77.03	21.69	25.40
1979	max.	24.0	1.42	0.030	0.580	198.	278	182	87.7	53.3	42.7	14.0	8.95
	mean	10.8	0.616	0.002	0.052	88.5	241	126	65.0	44.8	38.3	9.83	3.27
	min.	1.53	0.040	0.0	0.0	0.760	185	80.3	48.9	41.9	21.1	8.11	0.220
1980	max.	0.210	0.0	0.0	47.1	55.5	m	m	m	22.2	28.1	14.2	2.47
	mean	0.045	0.0	0.0	11.7	41.9	m	m	m	13.5	17.3	8.37	0.515
	min.	0.0	0.0	0.0	0.0	22.0	m	m	m	3.46	8.30	3.38	0.0
1981	max.	0.0	0.0	0.0	13.0	82.1	75.5	62.3	32.6	24.1	28.5	0.571	0.074
	mean	0.0	0.0	0.0	0.976	66.7	56.6	36.3	21.1	11.6	7.79	0.329	0.046
	min.	0.0	0.0	0.0	0.0	25.2	45.1	8.22	7.74	6.15	0.812	0.077	0.025
1982	max	0.024	0.0	0.0	5.54	163.	156.	79.4	40.9	33.2	32.0	4.31	0.131
	mean	0.007	0.0	0.0	0.833	95.6	110	51.4	26.3	21.7	17.0	1.46	0.051
	min.	0.0	0.0	0.0	0.0	8.08	76.7	29.8	8.46	4.52	2.20	0.146	0.031

m = missing

TABLE 1A

LITTLE BUFFALO RIVER - WSC - Station No. 07PB002

Year		Jan.	Feb.	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec.
1975	max.				5.83	8.16	5.27	5.49	15.97	15.80	13.45	7.70	3.12
	mean	-	-	-	1.52	4.72	4.31	3.10	4.21	14.00	11.7	5.19	2.00
	min.				0.0	3.34	3.54	1.54	0.52	12.43	6.54	3.23	1.59
1976	max.					22.94	8.38	8.44	8.69	4.96	3.40		
	mean	-	-	-	-	13.30	6.06	4.60	6.95	4.28	3.02	-	-
	min.					6.63	4.19	2.97	4.79	3.43	2.43		
1977	max.					6.00	4.81	4.36	4.42	4.56	4.53		
	mean	-	-	-	-	3.63	3.40	2.79	3.27	3.33	3.87	-	-
	min.					2.11	1.95	1.51	1.90	2.27	3.29		
1978	max.					9.97	1.37	1.70	0.59	1.90	2.95	2.84	
	mean	-	-	-	-	4.16	0.999	0.818	0.261	1.16	2.58	1.75	-
	min.					1.42	0.74	0.35	0.15	0.18	1.92	0.99	
1979	max.					30.8	11.5	3.90	1.08	0.676	0.890		
	mean	-	-	-	-	15.0	8.03	1.95	0.645	0.348	0.578	-	-
	min.					4.3	4.2	1.04	0.367	0.150	0.080		
1980	max.					8.42	0.812	0.276	0.131	0.264	0.555		
	mean	-	-	-	-	1.31	0.347	0.121	0.077	0.121	0.306	-	-
	min.					0.328	0.105	0.037	0.046	0.048	0.227		
1981	max.					8.50	1.03						
	mean	-	-	-	-	3.32	0.313	-	-			-	-
	min.					1.15	0.013						
1982	max				2.19	2.15	.640	.203	.088	.388	.274	.193	
	mean	-	-	-	0.586	1.38	.249	.1	.03	.151	.156	.115	
	min.				0.0	0.702	.087	.036	m	.021	.107	.070	

m = missing

TABLE 1B

HAY RIVER WSC STATION NO. 07OB001

Year		Jan.	Feb.	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1975	max.	5.52	2.18	1.69	680.	634	382	345	159	139	67.7	37.4	13.2
	mean	3.64	1.44	1.53	59.6	352	264	224	109	92.4	56.3	19.0	8.08
	min.	2.28	1.00	1.34	1.30	246	205	118	60.3	57.8	39.9	13.3	5.38
1976	max.	5.27	3.74	3.34	685.	682	572	425	634	484	228	156	80.7
	mean	3.48	3.40	2.93	170.	360	392	313	327	333	206	112	56.9
	min.	2.89	3.06	2.52	3.00	217	244	254	183	221	161	76.7	39.1
1977	max.	37.4	14.2	8.95	530	634	1079	716	569	217	168	124	54.1
	mean	25.2	10.8	8.04	110	393	770	581	344	197	142	72.4	30.5
	min.	14.9	9.06	7.31	7.11	277	326	467	222	171	127	54.1	16.0
1978	max.	15.6	5.8	4.76	17.3	818	442	192	132	222	180	65.4	23.6
	mean	10.2	5.23	4.54	5.52	433	274	130	101	176	129	44.8	14.1
	min.	5.9	4.76	4.42	3.94	231	198	100	78.4	110	66.3	25.9	8.9
1979	max.	8.78	4.19	2.68	25.2	902.	1120	548	204	160	132	91.5	19.1
	mean	5.76	3.46	2.14	9.33	448.	691	333	172	142	107	63.5	10.0
	min.	4.25	2.73	1.93	1.92	25.5	383	205	136	133	78.8	63.5	6.2
1980	max.	6.00	3.33	3.04	120.	83.7	42.6	26.0	47.4	30.1	62.4	40.0	10.8
	mean	3.96	3.19	2.89	29.4	38.3	28.8	19.2	28.6	21.9	40.2	18.0	4.08
	min.	3.01	3.05	2.74	2.64	18.2	18.5	14.2	18.1	17.1	19.9	9.1	2.22
1981	max.	2.21	1.71	1.67	12.5	790	163	65.3	20.4	6.24	9.30	7.40	3.35
	mean	1.97	1.63	1.65	2.19	419	112	41.7	11.3	5.07	6.09	4.51	2.63
	min.	1.73	1.60	1.62	1.57	169	60.8	21.3	6.2	4.12	3.00	3.39	2.04
1982	max	2.27	2.51	3.74	5.27	657.	296	96.5	30.7	29.2	18.6	15.2	4.17
	mean	1.73	1.65	1.85	2.73	398.	168	55.5	24.0	25.2	15.4	7.3	2.81
	min.	1.27	0.73	0.27	0.98	7.35	100	25.6	18.9	18.9	9.0	4.5	2.06

TABLE ~~1c~~ 2-12C

Buffalo River
WSC Station 07PA001

	Total discharge $[10^9\ m^3]$	mean flow $[m^3/s]$	unit area discharge[1] $[\ell/s\ .\ km^2]$	equiv. precipitation[2] mm	total annual[3] precipitation mm	% of annual precipitation
1975	2.51	79.5	4.47	141.0	339.4	42
1976	2.14	67.5	3.79	119.5	323.9	37
1977	1.66	52.7	2.96	93.4	234.4	40
1978	1.38	43.8	2.46	77.6	274.8	28
1979	1.66	52.6	2.96	93.4	230.4	41
1980	-	-	-	-	287.0	
1981	0.534	16.9	0.95	30.0	311.1	10
1982	0.857	27.2	1.53	48.2	260.7	18
mean 1964–1979	1.72	54.6	3.07	96.8	295.1	33

1) size of catchment area above gaging station: 17,800 km^2.
2) 1 $\ell/s.\ km^2$ is equivalent to 31.536 mm precipitation per annum
3) at Hay River Airport

lag

TABLE ~~2A~~ 3-13 A

HAY RIVER

WSC - Station No. 070B001

	Total discharge [10^9 m^3]	mean flow [m^3/s]	unit area discharge 1) [ℓ/s . km^2]	equiv. precipitation 2) [mm]	total annual precipitation 3) [mm]	% of annual precipitation
1975	3.15	99.6	2.08	65.6	339.4	19
1976	6.02	190.	3.97	125.2	323.9	39
1977	7.25	230	4.80	151.4	234.4	65
1978	3.51	111	2.32	73.2	274.8	27
1979	5.24	166	3.47	109.4	230.4	47
1980	0.628	19.9	0.42	13.1	287.0	5
1981	1.62	51.5	1.08	33.9	311.1	11
1982	1.87	59.3	1.24	39.0	260.7	15
mean 1964-1979	3.53	112	2.34	73.7	306.1	24

1) size of catchment area above gaging station: 47,900 km^2.

2) 1 ℓ/s. km^2 is equivalent to 31.536 mm precipitation per annum

3) at Hay River Airport.

TABLE ~~2B~~ 3-13 B

Little Buffalo River

WSC Station No. 07PB002

	total discharge $[10^9 m^3]$	mean flow May-Oct. $[m^3 s^{-1}]$	mean flow annually corrected	unit area discharge 1) $[\ell\ s^{-1}\ km^{-2}]$	equivalent precipitation 2) [mm]	total annual precipitation 3) [mm]	% of annual Precipitation
1975	0.111	6.98	4.23	1.18	37.2	455.8	8.2
1976	0.101	6.38	3.19	0.886	27.9	310.4	9.0
1977	0.053	3.38	1.69	0.469	14.8	363.9	4.1
1978	0.026	1.67	0.98	0.272	8.6	279.0	3.1
1979	0.070	4.43	2.22	0.617	19.5	255.7	7.6
1980	0.0120	0.380	0.190	0.0528	1.7	304.8	0.6
1981	insufficient record					347.6	
1982	0.0427	1.35	0.68	0.189	6.0	287.7	2.1
mean 1967-1979	0.0805	5.06	2.53	0.703	22.2	352.6	6.3

1) size of catchment area: $3600\ km^2$

2) $1\ \ell\ s^{-1}\ km^{-2}$ is equivalent to 31.536 mm precipitation per annum.

3) at Fort Smith Airport

TABLE ~~2c~~ 3-13c

PRECIPITATION AT HAY RIVER, 1945-1983

in per cent of 1951-1980 NORMAL (FOR CALENDAR YEAR)

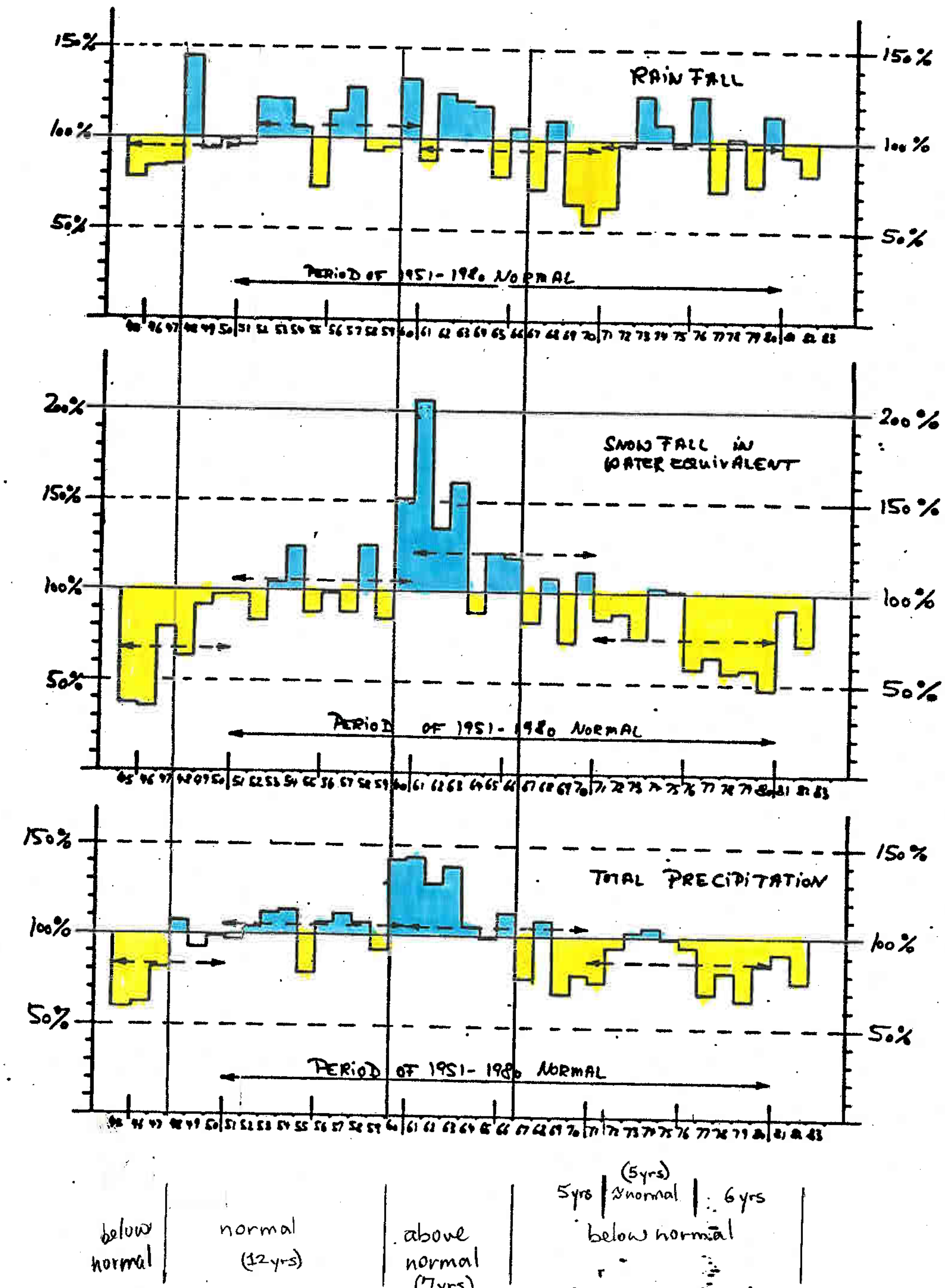
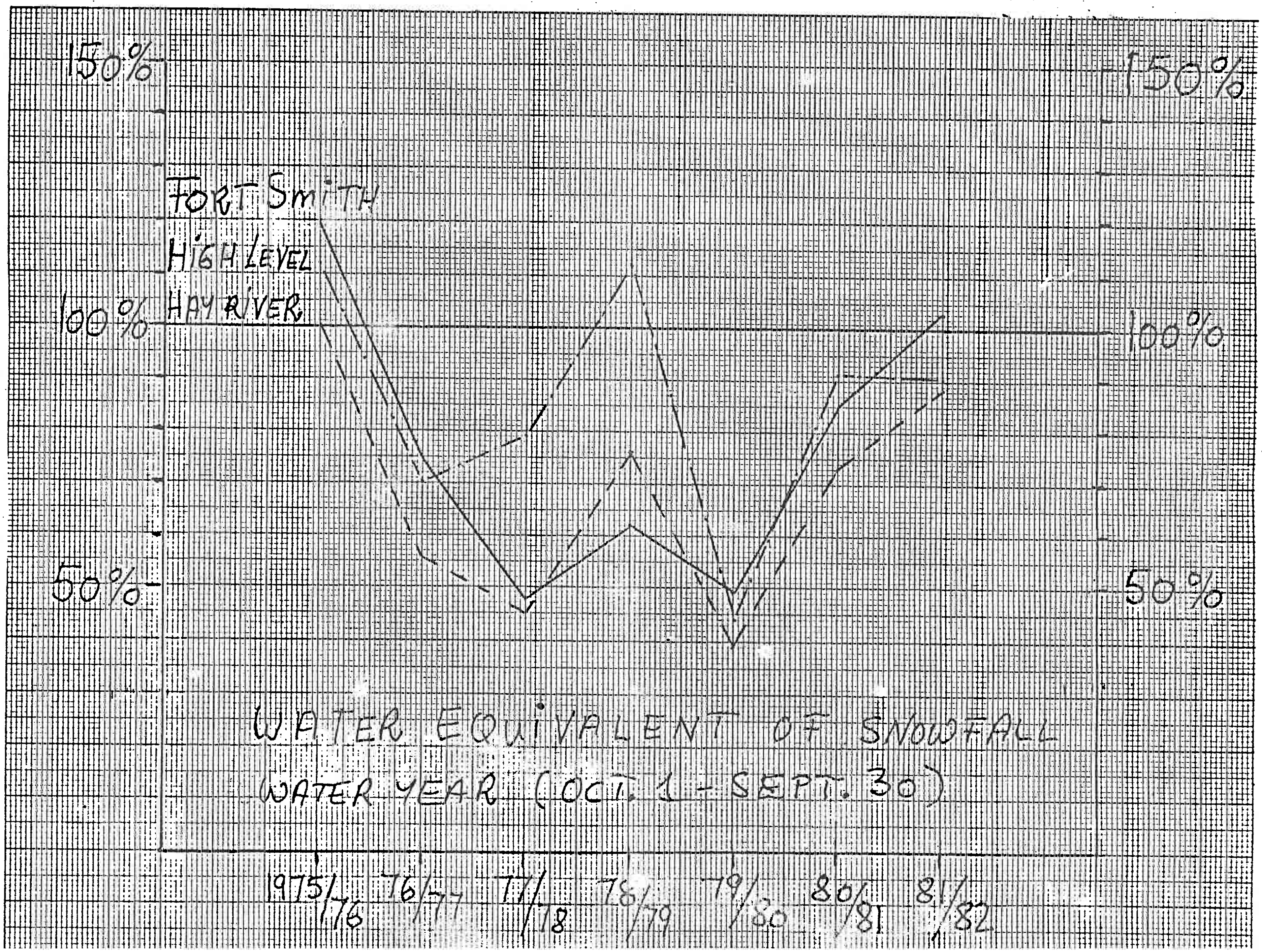


Figure B-1a

Fig. 3-2


150%
100%
50%
150%
100%
50%
FORT SMITH
HIGH LEVEL
HAY RIVER
WATER EQUIVALENT OF SNOWFALL
WATER YEAR (OCT. 1 - SEPT. 30)
1975/76
76/77
77/78
78/79
79/80
80/81
81/82