

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



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Chapter 4

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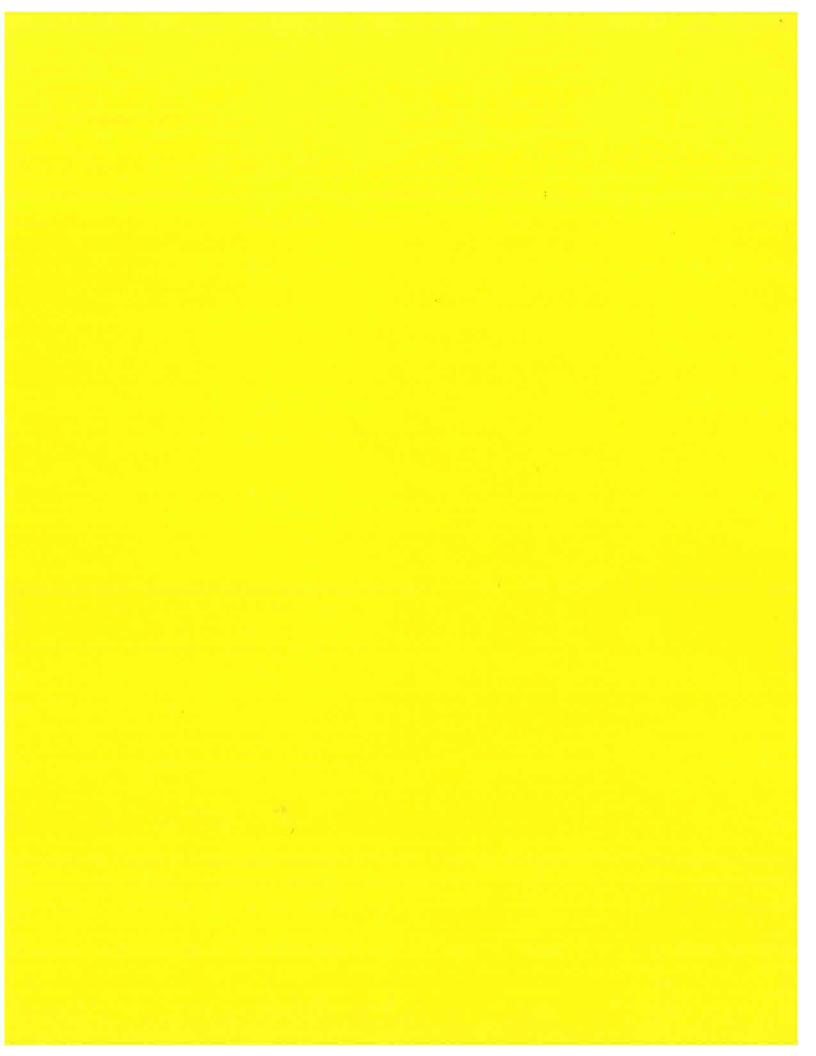
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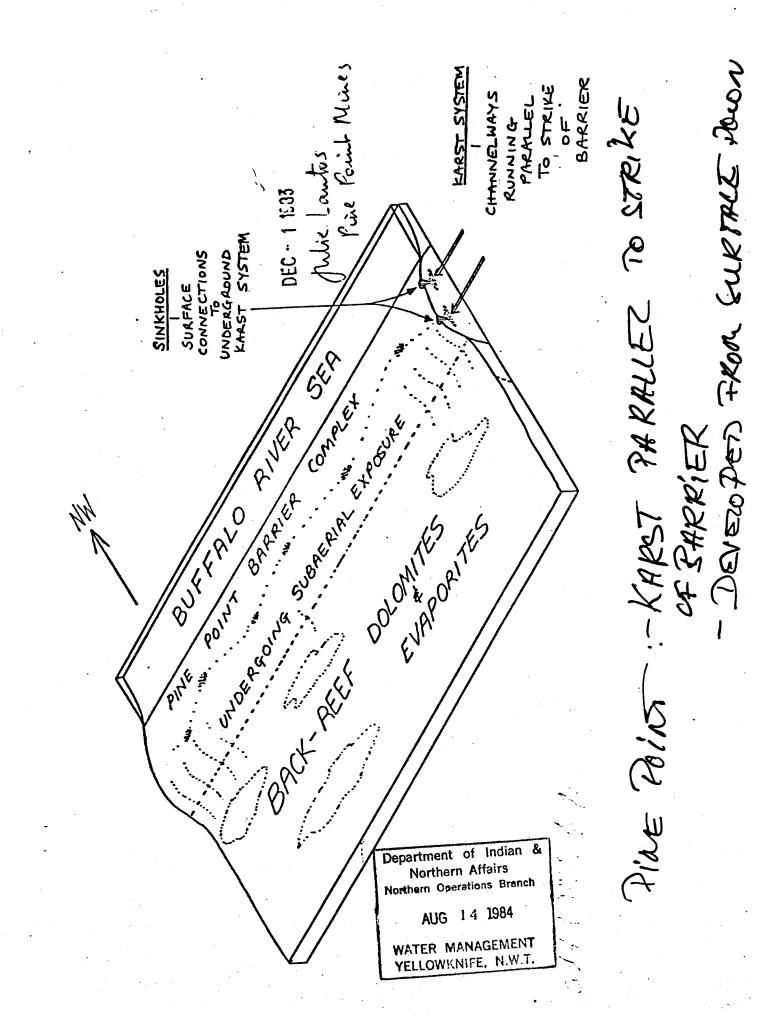


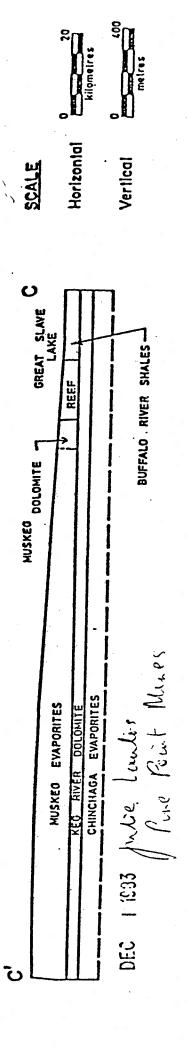
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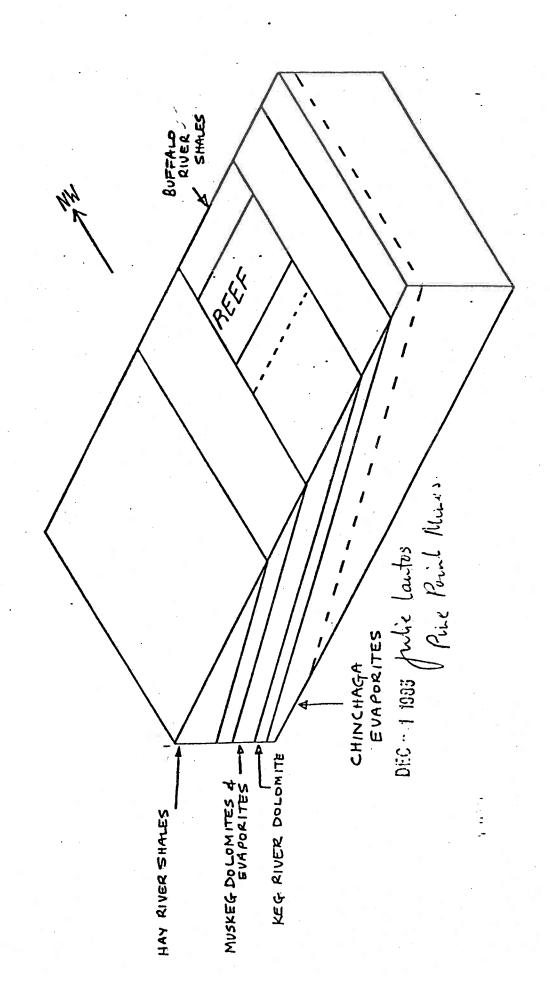
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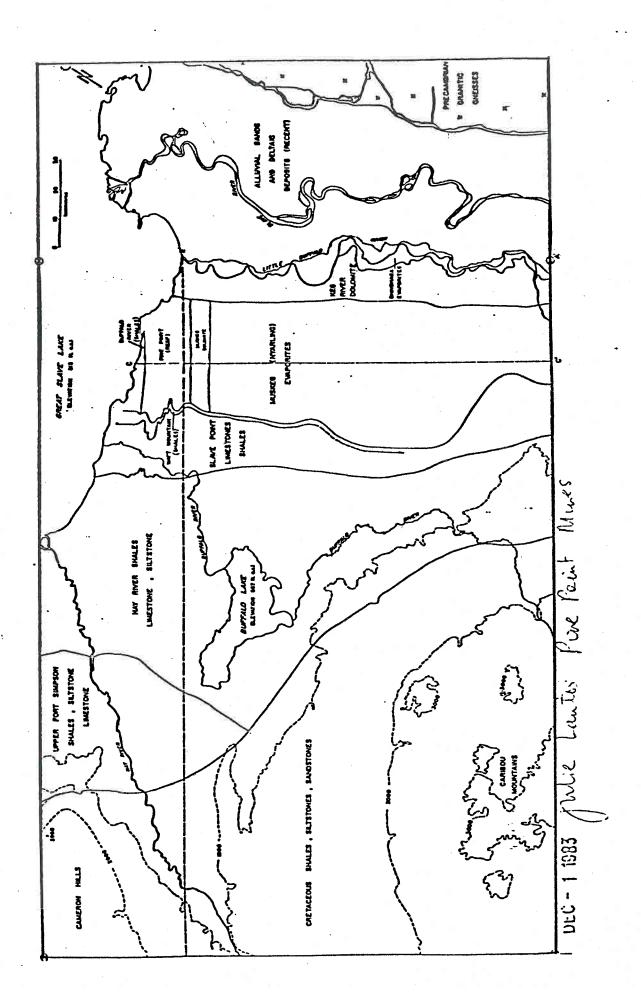
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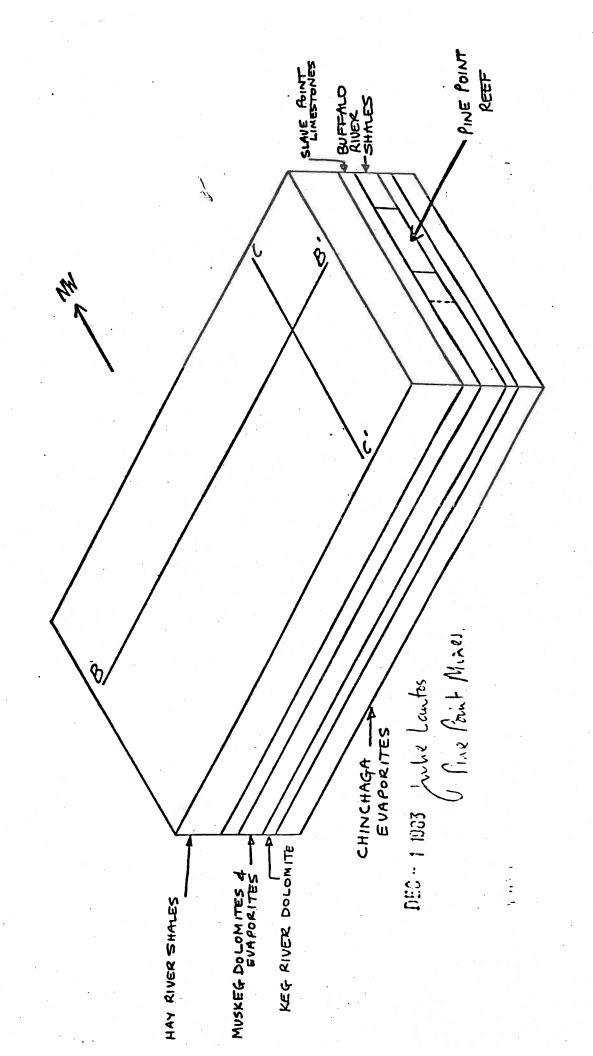
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1. INTRODUCTION

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 devectoring 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 Canada¹⁾ 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 Creat 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 1/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/l 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).

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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 northwest 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).

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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, Mg²⁺ -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 Mg²⁺-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 Mg²⁺ 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 Mg²⁺-ions for enhanced dolomitization.

Common to nearly all of the above models is the assumption that seawater 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'ill zation is commonly considered to have been caused in a reefal environment by reflux of brines (Skall, 1975).

The reaf 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 CaCl₂ 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 CaCl₂ 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 H₂S 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 Toth (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 Ca²⁺⁺/Mg²⁺ ratio reacting with dolomite to form calcium carbonate (Evamy, 1967), according to the equation

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, $\rm H_2S$ in water, δ^{34} $\rm S_{SO_4}$, δ^{34} $\rm S_{HS^-}$ and $\delta^2 \rm H$ determinations. Major-ion and δ^{34} $\rm S_{SO_4}$ 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 $\delta^2 \rm H$ samples were not filtered. The following additives were added in the field: .

δ³⁴S in SO₄²⁻ δ³⁴S in HS⁻ HS⁻

- conc. HCl, BaCl₂

- NaOH pellets, Cd-acetate

- Zn-acetate

trace ions - HNO₃

Bottles used were Nalgene linear polyethylene, except for $\delta^2 H$ 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⁺, Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻ 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.

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 1/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.

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.

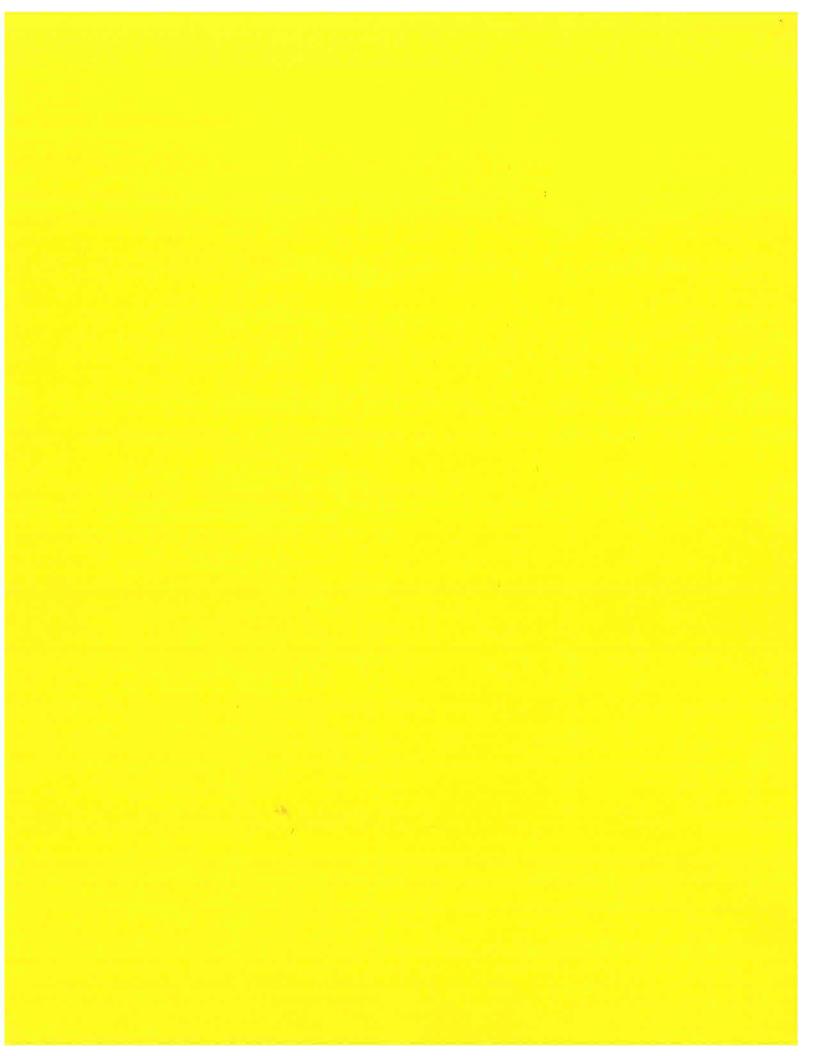
Our biggest problem and most time consuming task was the determination of the precise location of the boreholes, and their surface elevations. Again, many submissions to the Mining Recorder were found woefully inadequate. Upon inquiry, Westmin Resources made the precise coordinates and elevations of 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 not 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 "artesian" 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 Toth (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 Toth (1978, 1980).

If Toth'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 Toth's (1980) field results and their interpretation (compare figure 2-7):

Tube dependance of perneability and bydrowlic fradient.

Physically the intedependance of penned 5: lity and hydroutic fradient as femilated by Hollis (1940)

Ly Hollis (1940)

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where g = flux vector g = prime ability g = postutial

hathematically similar is the after used used equation

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whie

9 = flux [#3 ki 7-1] k = lydraulix could disity [47-1] h = Wead [47

h = head Like

T = time

the head can be directly measured in the field pregometic installed in the field show as shown in figure 2-2

hz. 2-7

there Detailed discussions of the plujeical meaning of the alone properties are contained in Weyer (1978a). For the perpose of this paper we will consider the fround water flux 9 to be constant

9 = constant (37

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

- is the bread fradient along a
flow field increased in a flow field

hay by a factor of 10, than
the permeatibility in the orea of
the increase of the fractient The

(see hig 2-8 a) is smaller by
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bey 6)

this the head fradient valous the flow path in a flow field, song by a jathor of 103, than the permeality in the over of the decrease of the gradient (tee his 2-86) is longer by an equivalent

amount (milliphication with 10).

The above into dependance allows a reliable and direct defermination of oblative permeatibles from prinometric maps if flow conditions the condition the conditions the condition in equation (3) holds forme. This paper will make me of these interdependancies to defermine the relative permeatilities of least systems within and outside the Pine Point barrier rect system (see chapter 4).

19.2-8

he

Fig. 2-7 head meastrements in the feld (from Winger 197-la)

comparative by high hydralic gradient of trads K=10_ conjustively Small hydrundic K=10 4=1

Fig. 2-8 Tubsdependancies of peneasibilities (K), and by danbic gradients in a flow field.

head fractions
head fractions
head fractions
prinomity of England

K=10 k=1 k=10

Fi, 2.8 Forse dependencies of permoliheties and hydroulie pradients 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 $D_{\rm I}$ unit and the present land surface. As pointed out by Toth (1980, p. 141) this suggests "a genetic relation between the energy distribution in the basal or Devonian I ($D_{\rm I}$) conducting unit and the topographic relief."
- (b) According to Toth (1980, p. 143) "the general flatness and low value of the potentiometric surface of the intervening Devonian III unit (Fig. 24 of Toth 1980, p. 143) indicates that no energy from above is being transferred 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" (Toth 1980, p. 142-143; figure numbers refer to Toth, 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" (Toth 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}." (Toth, 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 DI to respond to the changed boundary condition of today's topography; consequently, the potentials in the deep layer DI 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 Toth'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 Toth'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 Toth (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 DA + DII + DB

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)" (Toth, 1978, p. 840, italics inserted). In Toth's Table 3, K-values are 2.5×10^{-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 (Toth, 1978, p. 841, Fig. 41). The low magnitude of 5×10^{-11} cm/s is somewhat surprising in light of the field value of 8×10^{-7} cm/s assigned in Toth's Table 3 to one of these layers, the DII. 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 $(5 \times 10^{-11} \text{ cm/s}).$

Because of the absence of literature references regarding the permeability value of 5×10^{-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 (Toth, 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 x 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 Toth.

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 Toth'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 $D_{\rm I}$ 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 Toth (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.

3. FRAMEWORK FOR GROUNDWATER FLOW IN STUDY AREA

TOPOGRAPHY

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The groundwater table constitutes the most important boundary condition for a gravitational groundwater flow system. tables in turn closely follow the topographical surface of the 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 thre divistologial dala

GEOLOGY

SUBSURFACE INFORMATION

Parts of the geologic description of the area are based on the evaluation of 1507 mineral exploration boreholes and 64 ofl 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;

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) verial values of evaporation and Entitionation have been calculated (Morton 1983, personal Commication for three climate logical stations in the over (table 3.2-6). At all three stations sublimation of moisture pour the air prevails during ninter months (November - March) while evaporation (April - Octobe). According to Moston (1983, personal commication) actual exerciation à about equivalent to prehignitation at FEAH! Resolution and le to 30% less at It. Swith and Hay River 74 appears that Phese t Compeatively high evaporation values can only be readed if works would be owailable for evaporation during the whole length of the levaporation season Hence, for the purpose of this report the clave evaporation values should be convided pobertial evaporation. They should not be taken to determine possible the ground water cys Tem by congrains

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

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

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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 finally as a synoptic symbolic classification table (table 3.9)

alt 3.2 d.

(and have 3-1a) Table 3-20 Volumes in furn shows the 1445-1983 records change of meninetalian, rainfaul Enow foul (blopsh and works equivalent) and to bal menintation for the called Station How Rives Aifort. This station is closes to our invetigation unthin the one a of investigation and about to lim dissount from Pine Porul. Hoffeen from the table 3 I to 3-10 it appears that in Jewal thou prevailed lince about 1969 a trend to dry years. The trends Try Fair for the ground water inlanger in the water volanger in the water en united the water of fail. Cone Aed calculations for the work- section (29 October - textender) one can begine die the table 3-7 to 3-7%. They show that the wroter 1975 the 1976 was a named year, while would see to the word of the word of the the word of the season 198/192 was about nomal again. Indaptes the occurrence of the doing your trace the purpose record in adult assess wate flow

In the planing we will the effect of the dry years on the Lake-levels in front slave take and on the dishange of the main rivers in the one a will be discussed. Table 3-1/2 hists the lake level fluctuations from for of frent Slave take for the period of the Stations Tellow lunge and Fort Mischitan das fle stations juried 1970 - 1982. Durny Hisperiod How the fluctuation of the uninimum Take level is about 1.5 ft (socm) at Allow lunfe and about 2.5 Hotel top Resolution. The small inguitable of these fluctuations exclude on Simplant effet of on the reponal

flow Eyllens, in the ever son the avea wuder investigation. The dry years showed a more pronounced effect on the disdays in the nows ("listed from west to least) Hoy River as meatined at saying Chatians appealed by the both Somey of Canada. The 1975-1982 monthly sermon of daily disdange at There Stations are combained in table 3-13 A, Band ConThe Annal diedanges tarthe period One related to the to tal precipitations
FITS-I in tables 3.17 A. B.C. It Total 3-13A, Bound C chan that in teme of mean flow annal flow the years 1780 to 1982 armer as extender du years for the Britisto and Hoay River (with 140 polathe the wort) year). At the little Buffilo Rive the Jon 1974 and 1980 to 1982 appear ds du pears (record for 1971 in Rufficient).

In lapter 34 5 we there records will be compared to dicharge records of extents will be compared to the best and to the purposing record at Pine Point Unives. It will be shown the how the charge in the disclare records at the howter springs time whe correlate with the purposing pattern at Pine Point Mine but I not with the disclare records of the with the disclare records of the river in the areq.

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	Latitude	Longitude	Elevation [m]	Broken records	Continuous records
Angus Tower ¹⁾	60°26¹N	114°28°W	238	1968-1975	
Fort Resolution Airport	61°11'N	113°41° W	164	since 1930	
Fort Smith Airport	.N.I .09	111°57'#	203	1913-1947	since 1948
Hay River Airport	N.05.09	115°47 W	166	1893-1944	since 1945
Hay River Paradise Gardens	N.65.09	116°0'W	213	since 1962	
High Level Airport ²⁾	58°37'N	117°10'W	338		since 1976
High Level Ranger Station	58°31'N	117°06W	324	1962-1979	
Pine Point a.	N,05,09	114°28'W	238	1953-1965	
p •	60°52'N	114°22°W	224	since 1975	
 records cover June-August called Footner Lake Airport from 1970-1976 	ie-August ike Airport from	n 1970-1976	٠		

TABLE 3.1

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					Norma1			Annual	Extreme	
	period	code1)	rain [mm]	snow [cm]	w.e ²) of snow [mm]	total precip. [mm]	snow.3)	mean daily temperature [°C]	min. max [°C] [°C]	ures max. [°C]
Angus Tower	1951-1980									
Pt. Resolution Airport	1951-1980	~	162.4	174.0	144.1	306.5	47	-4.0	-51.1	+33.3
Ft. Smith Airport	1951-1980	-	219.2	145.9	130.1	349.3	37	-3.3	-53.9	+35.0
Hay River Airport	1951-1980	-	184.4	165.0	155.5	339.9	46	-3.6	-48.3	+35.6
Hay River Paradise Gdns.	1951-1980	∞	209.6	139.2	149.3	358.9	42	-3.8	-51.1	+35.6
High Level Airport	1951-1980	••	257.9	163.6	128.85)	386.7	33	-2.0	-50.6	+34.4
High Level Ranger St.										
Pine Point a.										
P.	1975-1980*)	•	165.4	79.4	79.5	244.9	32	-2.4		
								100		

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. Notes:

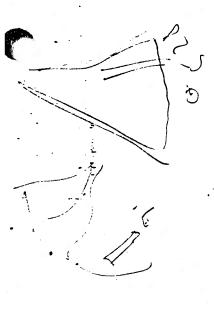
. w.e. = water equivalent

in percent of total precipitation

· normals for Pine Point mainly based on dry years

5. annual normal determined from annual records

TABLE 3.2 Q



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	JAN.	FEB.	MAR.	MAR. APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT. NOV.	NOV.	DEC.	ANNUAL	ANNUAL PRECIP.
Fort Resolution	-1.8	-2.4	-1.6	-1.6 +20.8	+63.8	+77.0	+77.0 +87.6 +59.4 +20.2	+59.4	+20.2	+5.8	+5.8 -5.0 -3.4	-3.4	320.4	318
Fort Smith	-2.0	-2.6	-0.2 +28.0	+28.0	+47.2	+64.8	+47.2 +64.8 +73.6 +50.4 +18.6	+50.4	+18.6	+7.0	-5.0	+7.0 -5.0 -3.8	276.0	333
Hay River	-1.8	-2.4	-1.4	+27.4	+56.0	+77.4	+56.0 +77.4 +81.8 +44.2 +17.0	+44.2	+17.0	+7.6	+7.6 -3.8 -3.4	-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. Actual aerial value of evapotranspiration (in mm) for the period 1965-1969.

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																X - rein [mm]	S snow [cm]		P = total	precipitation	Ī	T . Bean	temperature	ָרָ ט ָ	TR . trace		m missing	* = estimate				•	`				
Index	153	26	130		×	35	3	60 00	126		100	:		R 5	9 6	00.0		2 5	7 5	200		2	22	+1.7°C	88	149	100	*3.0°C	8	11	79].	
Annual Total	335.1	135.5	455.8	•	188.4	153.3	7.01	-2.4	277.0	106.6	161.0		2000	87.0	270.0	7.7.0	180.20	90 2	. 255. 7	. S. O.	234.7	90.4	304.8	-1.6	187.3	217.2	347.6	-0.3	183.9	201.3	7.707	484	145 0	7.07	1 17		
Dec.			19.3		0.0	20.1	16.0	-23.7	0.0	20.9	17.4	-26.7	Ĕ	23.7	10	-71.2	0.2	21.0	15.5	-15.4	ž	23.8	22.2	-27.3	0.0	51.9	26.8	-19.3	0.0	200	22.4		0.76	22.2	-21.6		
Nov.	9.0	51.1	-14.5		Æ	32.5	27.9	-9.7	Ę	20.1	13.0	-11.7	0.8	8	9.9	-12.6	3	11.0*	11.4*	-5.0	2.4	26.4	20.7	2.8-	0.3	44.5	32.1	0./-	¥ \$	5 0	-17.2	0	28.8	26.1	-11.6		
œt.	5.3	15.0	9.0		7.1	8.0	7.9	111	11.6	7.7	15.6	+1.9	12.0	17.5	28.0	+1.2	18.0	10.2	28.2	+2.1	9.5	2.1	9.11	53.5	23.2	41.9	20.8		15.5	777	+1.5	0.	15.9	26.5	÷0.	Ī	-
Sept.	34.3		7 0.0		33,5	0.0	33.5	49.8	21.6	0.0	21.6	+8.9	69.0	0.0	69.0	+8.2	32.5	ř	32.5	+9.3	49.1	0.5	49.3	\$5.9	30.3	× ;	20.3	, ,		0.79	6.8+	39.1	2.0	41.1	+7.5	0 normal	980 norms
August	109.5	. e	+13.0		7.1	0.0	7.1	251	48.6	0.0	48.6	1011	8.5	0.0	8.5	+13.0	27.0	0.0	27.0	+12.9	75.0	0.0	75.0	6.51	20.0	2 6	20.0	36.96	1.6	31.5	+12.1	42.5	0.0	42.5	+14.2	and P in \$ of 1951-1980 normal	riom 1951-1950 normal
July	73.2	73.5	+17.7		79.1	0.0	70.1	495	58.2	0.0	58.2	777	64.7	0.0	64.7	+13.6	57.9	0:0	57.9	+18.6	23.0	0.0	23.0	1			+17.0	3	0.0	36.8	+16,2	56.9	0.0	56.9	+16.0	P in \$ of	ulistence ir
June	6.0 6.0	6.0	+14.8		28.2	0.0	58.2	1	119.3	Ĕ	119.3		38.6	0.0	38.6	13.1	23.1	0.0	23.1	13:1	29.7	9 6	2.67	21313	7.0			13:51	0.0	15.1	+12.9	41.0	0.3	41.2	+13.6	R. S and	5
že,	63.2	86.5	+8.4		12.4	0.0	12.4	1000	<u>.</u>		7.61	3	7.	¥ :	14.1	÷7.6	15.4	D 1	20.7		î	¥ ;	2 4	1			6.6+	32.9	11.7	43.2	4:5	23.2	*	27.8	47.9	- for	101
Apr.	9.6	9 90	+0.5	1	#	e .		1	· ·				7.7		13.1	7.7.	2.7	9 10	20.5	-		, ,	7		21.2	9	90	8.9	15.3	17.0	-2.6	0,	2.5	16.2	-2:2	Index	
ž ,	0.0		-15.5		¥ ;	7.97	0.0		× .) (,		× ;	70.7	7.0		¥:	7.5	10.7	7,61) ·	100	7.7		21.5	0	-7.9	0.0	10.2	4.5	7-	0.2	15.9	14.4	-14.8		
. e.	10.4	9.7	-21.8	f	¥ ;	30.5	22.0	96	10.1		-	3			? ;	21313			0.0	21.0		2,0	-16.7	c	19.0	15.2	-17.6	TR	21.9	12.2	-23.1	7.5	1.6.4	2.0	8:17		
Jan.	27.2	23,4	-28.0	6	5	26.0	-25.0	F	22.8	21.6	-23.3		-12.6			000) <i>u</i>		72.7		25.4	16.9	-24.4	Z.	17.2	14.4	-12.2	0.0	5.5	9:		× ;		26.5		•	
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	= rain [mm]	= snow [cm]	- total	[mm]	- Bean	temperature	ָנ <u>ַ</u>	- 1		BITSTHE A																							•			
E	index	99 103	100	7 7.0-	126 T		2,7	٦	72	79	+1.2°C	001	55	81	+0.2°C	76	25		+0.2.C	115	46	**************************************		16.	· ·	+2.8°C	81	69	77	-1.6°C				-	rdens.	
HAY RIVER AIRPORT	Vnnual Total	182.3 169.6	339.4	3.0	231.6	113.8	323.9	0.3-	132.8	0.701	-2.4	184.7	90.7	274.8	-3.4	139.5*	90.04	230.4*	-3.4	211.8	7.5.7	1.9	, , ,	7.801	411.1	8.00	149.6	114.5	260.7	-5.2	184.4	165.0	339.9	-3.6	values for Hay River Alrort missing; substituted by values from Hay River Paradise Gardens.	
HA	Dec.	TR 19.8	20.1	-22.9	¥	13.0	12.7	-20.4	0.0	14.6	14.6	TR	25.3	25.3	-21.6	TR	12.1	12.1	-14.3	0.2	16.3	16.5	977-	Ĕ,	9.9	2.6.	0.0	19.8	19.0	-21.8	0.3	25.9	24.6	-20.9	om Hay Riv	
	Nov.	TR 61.2	50.5		2.8	11.9	10.9	-7.5	1.2	20.0	21.0	2.2	17.6	19.8	-12.2	0.4	10.0	10.4	-3.7	8.0	100	19.0	10.1	¥ .	27.8	 	7:7	14.5	14.3	-16.9	0.5	39.5	36.9	-11.3	values fr	
	Oct.	15.7	37.1	+0.4	9.8	21.1	14.5	+0.7	12.7	7.2	19.9	22.1	18.0	40.1	+0.8	15.0	10.8	25.8*	+3.0*	8.5	1.6	10.1		32.8	32.3	-0.5	13.8	16.9	30.7	+1.4	12.1	18.9	30.5	+0.9	ituted by	
	Sept.	32.3	32.3	6.6	42.9	0.0	42.9	+11.2	31.9	0.0	31.9	30.5	0.0	30.5	+9,1	22.5	0.0	22.5	+9.0	20.6	8.6	60.4		41.0		0.8+	9.0	F	49.0	+9.8	39.4	2.8	42.3	+8.1	ng: subst	
	August	70.6	70.6	+13.6	36.6	0.0	36.6	+15.5	19.6	0.0	+11.7	2.8	0.0	2.8	+12.9	29.5	0.0	29.2	+13.7	0.59	0.0	65.0	1417	54.0		+17.6	24.8	¥	24.8	+12.7	37.7	0.0	37.7	+14.4	ort missi	
	July	22.6	22.6	+17.6	42.4	0.0	42.4	+15.8	6.3	0.0	6.3	0.17	0.0	71.0	+13.2	36.3	0.0	36.3	+17.9	2.09	0.0	60.7	812.8	18.3		+17.2	23:1	0.0	23.1	+14.9	48.1	0.0	48.1	415.8	River Ain	
	June	9.9	9.9	+12.5	70.6	0.0	20.6	12.4	26.6	0.2	26.8	43.6	0.0	43.6	+12.2	5.9	0.0	5.9	+11.3	4.0	0.0	7	13.3	7.5	0.1	· · ·	26.0	Ĕ	26.0	+12.0	26.7	0.1	26.8	+11.9	s for Hay	
	May	22.6	30.2	+6.4	19.6	TR.	19.6	+9.2	34.2	2.0	38.2	8	0.2	2.0	+4.4	27.8	17.8	45.6	+3.0	20.8	0.2	21.0	+8.5	0.4	¥ .	, K	9,4	29.7	37.3	+4.2	16.2	3.0	20.1	+5.6	_	:
	April		14.0		8.1	TR		43.4	Ħ	5.0		10.7	10.1	20.8	-6.2	2.2	12.8	15.0	-8.1	0.2	0.8	0.5	_	12.6		7.7.	L		_	_	3.2	13.1	15.8	-4.2	- precipitation	
	Mar.		17.5		F.	21.8	19.6	17.3	0.0	22.6	22.2	F	10.5	10.3	-16.2	0.2	18.9	19.1	-18.2	0.0	2.1	2.1	-14.0			10.1	╀	2.6		•	0.2	19.2	18.3	-16.3		
	Feb.	0.0	17.3	-21.1	0.0	24.9	24.9	-23.6	æ	14.1	14.1	Ί	2.0		-14.5	_	6.7	6.7	-32.8			7.0	4	TR	15.6	17.0	F	18.8	18.6	-21.9	TR	19.4	18.0	-21.7	January 1982	•
	Jan.	<u> </u>	20.6		0.0	S 21.1	21.1			S 16.3	16.8	<u> </u>		7.0		1_	S 1.8				S 21.6	P 22.6	1 -23.1	1.6	3.0	9 0	L	4.4		-1			P 20.8	T -25.8	NOTE:	
		i .	19/3 P				1976 p	ı			1/61			1978	. .			1979	•			1980			1081			1982				MOLMAN	1951 to	1980		

												m Mean tember-	ature [°C]		•	- estimate																								3
t	Index	113	126	119	0.0	119		104	ن.	Γ	-	91	+:.1°C	Γ		103	÷0.9°C	106	83	103	+0.3°C	F	9		+1.3°C	100	88	100	+2.6°C	82	0 5	J. 4.1.								934.4.1
HIGH LEVEL ATRPORT	Annua! Tota!	290.9	205.6	461.0	-2.0	307.8	116.2	403.6	-0.1	258.3	104.2	351.8	+0.1	307.6	106.7	397.6	-1.1	273.1*	135.7*	400.1	-1.7	0.262	105.6	393.6	-0.7	258.4	143.2	387.2	0.0	128 1	320.2	-3.4	257.9	163.6	386.7	-2.0	tons			
HIGH	Dec.	1.5	30.7	19.3	-22.5	٤	14.2	9.6	-18.2	¥	21.2	17.9	-23.6	Ħ	11.0	7.5	-20.8	0.2	24.0	50.6	-15.4	TR	52.6	50.8	-28.3	T.	16.1	20.01	0.61	15.7	30.0	-19.6		30.9	24.7	-20.3	Level Airport missing; substituted by values from High Level Ranger stations			
	Nov.	0.3	57.4	62.7	-14.4	9.5	6.9	7.9	-5.5	9.0	31.6	26.7	-13.0	1.2	31.1	29.0	-12.0	0.0	0.4	4.0	- 4.0*	4.0	15.2	19.2	-7.3	1.0	25.3	21.5	;;;	- ¥	29.1	-16.2	7:7	. 29.1	27.9	-11.4	gh Level			
	Oct.	3.6	15.5	16.0	+1.2	7.1	30.7	34.0	+1.2	2.5	3.8	5.5	+2.9	17.5	Ĕ	17.5	+3.0	4.0	0.0	0.4	+3.8	8.0	£	8.0	+4.5	47.1	47.3	2.0	20-	11.1	27.9	+1.6	4.2	15.3	14.7	¥.	s from H			
1	Sept.	28.7	0.0	7.97	+10.2	9.1	0.0	9.1	+11.2	42.6	0.0	42.6	+9.9	88.3	0.0	88.3	+9.2	40.5	0.0	40.5	+9.5	41.6	Ĕ	41.6	+6.4	17.3	0.0	1/.5	9.6.	0.0	23.7	+9.5	33.4	1.3	33.9	+8.1	by value			
	August	9.69	0.0	0.60	+13.0	9.89	0.0	68.6	+16.0	20.3	0.0	20.3	+12,3	67.5	0.0	67.5	+13.1	57.7*	6.	57.7	+14.0*	67.1	0.0	67.1	+13.2	9:0	0.0	1.0	, 6, 7, 6	£	95.9	+11.3	58.1	0.0	57.8	+14.0	ibstituted			
	July	89.2	0,0	7.60	+18.4	84.8	0.0	84.8	+15.8	37.7	0.0	37.7	+14.8	23.5	0.0	23.5	+14.8	60.4	0.0	60.4	+17.4	78.7	0.0	78.7	+16.0	0.09	0.0	0.00	0.01	0.0	12.4	+17.5	68.9	0.0	68.9	+15.7	Issing; su			
Ī	June	9.69	0 9	0.60	714.5	86.4	Ħ	86.4	+13.2	85.4	¥.	85.4	+14.2	50.1	0.0	50.1	+14.2	47.8	0.0	47.8	+13.8	45.8	0.0	45.8	+15.3	79.3	0.5	13.5		0.0	15.2	+14.6	53.2	0.0	53.2	+13.6	Airport m			mal.
	May	21.8	1.0	2 4	13.3	39.4	0.0	39.4	+11.0	8.99	0.0	66.8	+11.2	37.0	ຄຸ	45.5	+8.9	58.0	12.4	70.4	+7.4	44.4	T	44.4	+10.2	13.7	0.0	8114	0.00	2.5	34.5	+8.4	32.0	4.3	35.5	+9.3	١ _		normal	-1980 normal.
	April	5.8	¥ ,,		1.0	11.9	£	11.9	•6.0	2.6	10.0	12.5	+4.7	22.5		7.87	7:1-	4.5	28.0	32.5	3.6	7.1	¥,	7.1	9-9+	3/.8	1.73			2.8	21.2	-0.7	2.6	14.5	17.4	+0.8	1. August 1979 - values at High	980	P in % of 1951-1980	for T in difference from 1951-
	Mar.	0.0	27.0	12.5	16.3	표	11.9	10.2	-11.7	TR	9.1	7.8	-7.5	0.0	21.3	16.8	-9.2	0.0	21.7	21.5	-12.9	0.0	12.2	11.6	-9.4		7.6	. 4.		4:1	3.3	-13.5	0.0	21.0	16.2	-11.8	979 - val	for 1951-1980	in tof	fference
	Feb.	0.8	. r		.13.3	0.0	25.1	21.8	-19 R	TR	6.2	5.5	-7.4					0.0	34.2	32.0	-28.4				7	0.0	28.6	16.5	200		15.2	-21.0	L				August 1	2. Normal f	for R, S, P	r T in di
	Jan.	¥.	34.0	22.1		0.0	27.4	20.1	-20-7	T.	22.3	23.17	-17.5	ጀ	10.7	10.0	-22.1	0.0	15.0	12.3	-22.3	2.0	23.8	24.2	-22.1	9.0	5.0	200	0.0	1.0	11.8	-32.6	0.1	26.6	20.6	-24.6	Notes: 1.		Index - fo	1
		ec 1	1975 p	-	•	~		d over	1	æ	1077 S	4		œ	1978			~ (1979			—	1980			× t	1981	- F			1982 p	-	Normal R	,	d 03 1661	1300 T	Z		-	al de production

. 141 - 7 14

- for T in difference from 1951-1980 normal

	R = rain [wm]	S = snow [cm]	P = total precipitation [cm]	T m meen temperature [0]	TO mean temperature [c]	a missing	* # estimate			`																				
Index														٤									7 (2.7)					•		
Annual																						=					162.4	174.0	306.5	
Nov. Dec. Annual	æ	Æ	E :	E						0.0	ec (23.8	0.0	11.4	11.4	E	0.0	11.2	11.2	90	7.1		0.0		Æ	-24.0*	0.1	21.7	18,7	
Nov.		æ	E 1	•						0.2	27.6	27.8	0.0	28.5	28.5	-5.7*	0.0	17.9	17.9	6	22.0	22.0	0.0		•	-16.7	0.3	53.3	-10.9	
Oct.		E	# 1							16.4	32.4	48.8	 -	E	2	E	Æ	_	#3 C*	7, 9	17.8	¥.5				7	11.0	24.4	34.2 +0.4	
Sept.	=	£	£	-						30.7	0.0	50.7	13.2	0.0	13.2	+7.6	42.3	3.4	45.7	181	0.0	18.1		0.0	#	+8.2+	36.2	5.9	39.1	
Aug.	=	Æ	s 1	=		Missin		Missing		7.6	0.0	411.8	36.8	0.0	36.8	+12.5	36.2	0.	36.2	33.4	0.0	33.4		0.0	Æ	+11.7	35.4	0.0	35.4	
July	E	2	2 1	.					•	51.9	0.0	51.9	30.2	0.0	30.2	+17.3*			e :			21.1		0.0	, E	+14.4*	42.7	0.	+15.7	
June	6.6	0.0								<u>L</u>		21.0	1	0.0		+11.2*		0.0	4.6	14.2	0.0	0.2 14.2		0.0	Æ	+11.0+	21.7	5.0	22.2 +12.4	1980 normal
May	16.5	8.1	24.6	: ;						5.2	0:0	2°5	8.9	29.7	38.6	+4.8	13.9	ř:	13.9	0	0.2	0 4	5.4	13.0	18.4	+4.5	12.0	4.7	16.5 +5.8	
April .	3.3	4.3	9.0	7:0		•				8.0	18.6	9.92	1.2	11.5	12.7	-9.2*	3,3	0.0		0.0	30.0	30.0	8.9	0.3	7.1	-4.3	2.9	10.5	12.4	P in \$ of 1951
March	0.0	4.6	4.0	8.,1-						0.0	16.1	-16.6	0.0	16.7	16.7	-19.7*	0.0	7.5	416.04	0.0	7.6	7.6	0:0	4.6	4.6	-20.4	0.1	16.2	13.0	s,
Feb.	0.0	21.6	10.3	0.77.				, i		0.0	0.4	-16.4	0.0	0.3	0.3	-33.9	0.0		× ×	0.0			+	17.6	17.6	-25.0	T.	17.9	14.2	Index - for R,
Jan.	0.0	25.7	23.1	7.53.5					,	£	6	E E	0.0	6.5	6.5	1-24.0	0.0	23.1	24.6	E	E	E12	0:0	E	E	E	0.0	21.9	17.1	Index
	~	1975 S		-	≃ w	1976 p		1977 S	1	ب	1978 5		×	S 570		Ŀ	æ	1980	- F	<u>+</u>	1081	d F	×	2 2		-	مح ا	1951 to S	1980 P	

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			R * rain [mm] S * snow [cm]	P = total precipitation	T w mean temper-		TR = trace	* * estimate												-	•									
CARDENS	Index	98	-0.2°C																					,			i		1	-
HAY RIVER PARADISE GARDENS	Annual Total	134.3	4.0																							209.6	139.2	358.9		
HAY	Dec.	15.7	-25.1	14.2	14.2	0.0	12.1	12.1	0.0	23.6	23.6	0.77-	¥:	11.2	16.0	0.0	14.0	14.0	0.0	24.9	24.9	-20.3	0.0	41.7	-22.8	0.0	19.8	21.4		
	Nov.	8.99	-17.0		: =			£ ;			g i	*	16.4	16.4	4.4	1.6	31.7	33.3	0	30.0	30.0	-9.Z	¥ 2	15.0	-19.5	0.3	34.5	39.7		
	Oct.	4.6	+0.1	17.8	18.8			14.2		15.9	40.0	4.0.4	12.8	22.8	+1.9	=	s	# 1				I I	# 1	E 6	5 6	8.5	13.8	22.7		
	Sept.	0.0	+9.7	3	45.5	19.3	0.0	19.3	27.7	0.0	27.7	200	0.0	28.0	+9.3	58.2	3.6	61.8	36.7	0.0	36.7	2	22.0	55.6	8.8	37.3	1.4	38.8		
	August	0.0	+13.4	0.0	88.9	26.4	0.0	+11.8	T.	F	無日	E 2	50	35.0	+13.9*	40.5	0.0	40.5	54.2	0.0	54.2	416.9	S.1.0			48.7	0.0	48.7		
	July	0.0	+18.0	0.0	52.1	8.1	0.0		98.1	0.0	66.1						0.0	64.0	29.3	0:0	29.3	小	\ C	37.7	+15.7	55.0	0.0	55.0		
	June	0.0	+14.3	0.0	47.2	36.0	0.0	13.0	31.2	0.0	31.2	1		8.3	+13.2	19.6	0.0	19.6	E	E	E		8.0	8.05	+13.4	32,4		32.5	1980 normal	- 1980 normal.
	May	1.0	**	0.0	68.6	33.0	Ĕ	33.0	0.8	Ĕ;	\$ · · ·		27.9	58.4	+4.6	18.6	TR	18.6	Ē	E	E I	, i	6.1.9	62.9	46.0	24.1	9.0	27.5	١.	
	Apri1	1.5	-0.2	ΉT	1.0		#	# 0. 6.0+		29.7	0. 4.		E 16	5	E		E		13.1	51.0	64.1					3.1	11.8	15.2	% of 1951	ence from
	Mar.	16.8	-18.3	18.3	18.3	0.0	20.9	-13.1	0.0	16.8	12.4	L			_	0.0	1.2	1.2	0.0	10.9	10.9	200	2.4	2.4	-18.9	0.0	18.0	19.0	- for R, S, P in	for T in difference from 1951
	Feb.	15.0 15.0	-22.7	17.0	17.0	TR	9,0	O E	0.0	8.6	-15.8	P	2.0	2.0	-33.7	0.0	4.4	15.0	0.0	13.6	13.6	70	20.6	20.6	-23.5	0.0	17.5	18.7	- for R,	- for T
	Jan.	9.1			25.4	·		-21.4	0.0		22.0		4.3		-23.4	# T	,	15.3	T.		9.0	'	4.4		'			19.7	Index	
	-	1975 S	_	R	d 9/61		1977 S	1	#	1978 S				1979		- '	1980		-	1981	4		1982			Normal R		1951 to P 1980 T		

								•	S = Snow [CH]	P = total	precipitation		T = mean	(C)		IN T CTRII	# B 564-1904												
Index																													
Annual Total																										165.4	79.4	244.9	-2.4"
Dec.	14.5	14.5	ő.ö.	11.7	-20.9	0.0	8.5	3.5	6		5.6			#			F	•		Æ	E	. #	о: 6	E 1	-22.5*	0.0	10.1	10.1	-19.7
Kov	62.0	62.0	¥,	9.0	-7.2	0.0	F	# 1	6	26.7	26.7	-12,0*	0.0	12:1	17.1	0.0	æ	#	=	0.0	13.0	13.0	0:0 0	# 1	-18.2	£	56.9	26.9	-9.7*1
3			6.6	15.0	+1.0	37.70	3.5	6.0	7. 7.	, e	30.5	+1.2	29.2	2.0	21.5	2,5	0.7	3.2	+4.20	18.7	13.2	5.15 E	27.5	9.6	36.9	21.0	3.2	24.2	+2.0*
4			42.2	42.6	+10.7	20.6	0.0	20.6*			44.4	+8.3*	34.0	0:	2 o	10.67	0.0	49.6	+6.4	E	# 1	+9.0+	49.8	0.0	+10.2	38.2*	0.0	38.2	+8.9
Aumust			7.7	28.2	+14.9	48.1	0.0	48.			5.2	+12,5	15.7	0.	15.7	9.96	0.0	9.96	+14.5	33.3	0 1	+18.1	E	0.0	+12.6	36.0	0.0	36.0	+13.6*
भूम			34.3	34.3	+16.7	17.0	0.0	17.0	2 2		48.8	+12.4*	41.9	0.0	6.14	1	0.0	25.7	+15.8	30.19	0.0	30.9	14.2	0.0	14.2	33.5	0.0	33.5	+15.7*
Lime			33.3	200	+13.4		£	# £	 	0.10	21.0	+12.7	12.9	2.0	11.8	E	E	•		26.8	0.0	26.8				22.4	0.0	22.4	+12.7
May			e (E f		£	E	£ ;	ŀ	0.0	1.7	£	28.5	2.7	+2.14	19:4	0.0	10.7	+9.2*	£	E	F E	14.5	22.6	37.1	13.6	1.2	14.9	+7.2
Ē.			1.3	0.0	44.3	E	E	E 8	E	=	E	Æ	0.0	9 6	Æ			E	The state of	£	E	e e	3.6	11.2	14.8	0.7	2.0	2.7	24.3
Mar			0.0	. : :	-16.0	E	E 1	E E	0.0	21.8	21.8	£	0.0	13.2	-20.0*		. E	£	E	0.0	2.4	2.4	0.0	15.2	15.2	0.0	15.6*	15.6*	-18.1-
Esp.			0:0	. «	-24.6	E.	E	6 : 6	e.	4.2	4.2	-17.2	0.0	2 0	-31.9	-	E	Æ	E	0.0	£	EE	0.0	4.4	4. 4	0.0	4.3	A.5	-24.5
Jan			æ	E 1	e e	0.0	6.5	-2.5	0.0	36.7	36.7	æ	0.0	, v	; E		E	£	Б	E	E	#4.6-	0.0	9.0	9.6	0.0	16.1	16.1	7:12-
	~ v	19/5 p	æ (1976 P	L F	× (1977 S	<u> </u>	×		19/0 p		× 0	1979 p	į		: 6/3	1980 p	T	æ	S 1991	4	~	1087 S		Normal R	1975 S	to 1980P	7

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		Ft.	Ft. Smith Airport	rport	·			Hay Ri	Hay River Airport	ort				High Level Airport	vel Air	brt		-
	Show w.e	10.13	rain		precip	total precipitation mm %/	Snow w.e.	*.e. 1)	E E	rain '.	total precipitation	tation	Snow	snow w.e. 1)	rain	<u> </u>	total precipitation	tation
1975	120.7	93	335.1	153	455.8	130	157.1	101		g	7 011	100	1		E			, :
1976	122.0	94	188.4	86	310.4	8	92.3	59	231.6	126	323.9	8	95.8	132	307.8	113	461.0	119
1977	86.9	67	277.0	126	363.9	104	101.6	65	132.8	72	234.4	69	93.5	. 22	258.7	1	351.8	5 5
1978	69.1	53	209.9	96	279.0	80	90.1	58	184.7	100	274.8	8	90.0	2	307.6		397.6	103
1979	75.5	80	180.2	82	255.7	73	90.9	58	139.5	8	230.4	68	127.0	80	273.1	106	400.1	103
1980	70.1	54	234.7	107	304.8	87	75.2	4	211.8	115	287.0	84	101.6	79	292.0		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		387.2	100
1982	103.8	80	183.9	84	287.7	82	111.1	17	149.6	81	260.7	77	110.0	88	210.2	82	320.2	85 53
1951-1980 normal [mm]	13	130.1	215	219.2	349.3	8:	155.5	S	184.4	1	339.9	6	129	129.1 ²⁾	257	257.9	386.7	7.
LL LL	, i.e.	rater ec	W.e. m water equivalent		2) normal determined from monthly records	etermine	d from	monthly	records	1								

TABLE 3,4A

State Stat		1	1							
State Attack State Attack State Attack Atta		tation	1.16	6	102	111	06	86	93	6.7
Ft. Smith Airport Hay River Airport Hay River Airport High Level Air Level		total precipi	450.3	353.0	393.7	429.1	347.8	332.3	358.9	38
Ft. Smith Airport Hay River Airport Hay River Airport High Level Air Level	l git	_	81.	102	113	112	113	83	94	.9
### Ft. Smith Airport ### Snow w.e. 1	vel Air	ra	305.6	263.0	291.8	287.6	291.4	215.1	243.2	257
Ft. Smith Airport Hay River Airport snow ve. 1) rain °/• mm °/•	High Le	¥.e. 1)	1		79	110	44		06	9.1
### Smith Airport ### Smow w.e. 1		Snow	144.7	90.0	101.9	141.5	56.4	117.2	115.7	129
### Smith Airport ### Smow w.e. 1		tation	116	64	72	79	85	7.3	06	6
Ft. Smith Airport total hay River Airport snow w.e.1 rain */* mm */* mm */* mm */* 155.8 120 187.7 86 343.5 98 157.6 101 235.9 1 97.2 75 272.5 124 369.7 106 86.7 56 130.3 1 80.3 62.2 48 208.7 95 270.9 78 76 148.4 1 64.0 49 241.4 110 305.4 87 61.6 39 227.5 1 110.7 85 175.7 80 286.4 82 104.7 64.9 144.9 1134.0 10.3 210.6 96 344.6 99 138.0 88 166.4 130.1 219.2 349.3 156.0 184.4		tote precip	393.5	217.0	245.1	267.3	289.1	249.6	304.4	339.
### Smith Airport	år	in.	128	7	95	80		79	06	1.4
### Smith Airport	/er Airp	i	235.9	130.3	174.3	148.4	227.54	144.9	166.4	184
### Ft. Smith Airport	Hay Riv	(1.°.	101	56	45	26		67	88	0.
### Ft. Smith Airport ###		Mous	157.6	86.7	8.02	118.9	61.6	104.7	138.0	156
### Ft. Smith Airport ### -/- ### -/- 155.8		otal itation "/"	86	106	82	73	87	82	66	83
### Smith Airpor ###		precip	343.5	369.7	270.9	254.7	305.4	286.4	344.6	349.
97.2 97.2 62.2 80.3 80.3 110.7	port	:	86	124	93	80	110	80		9.2
97.2 97.2 62.2 80.3 64.0 110.7 134.0	nith Aiz	rain	187.7	272.5	208.7	174,4	241.4	175.7	210.62	21.
97 1155 110 1110	Pt. Si	G.,	120						103	0.1
		w work	155.8	97.2	62.2	80.3	64.0	110.7	134.0	13(
				1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1951-1980 потта1 [тт]

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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.

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FORT SMITH AIRPORT

													\$ 06
		Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	Total	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	9.6	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	S now [cm]	0.2	2.1	26.4	23.8	17.2	19.0	21.5	21.2			131.4	06
	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	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
1951-1980	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
* 1 2 2 2 2 2 3 4 3 4 4 4 4 4 4 4 4 4 4 4 4	Your we - water equivalent	valent	Y =										oloka ja al

									00		HAY KI	hay kiver airport	₽
		Sept	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr11	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.O. [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	OVER	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	s now [cm]	9.6	1.6	18.8	16.3	3.0	15.6	10.5	40.1			115.7	70
	w.e. [mm]	. 8*6	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	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
0061-1661	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
TO SECTION	ነገር ነው ነው ፣ = water equivalent	lent											明光 * 10 1

			-147-00		_			ī	ī		_	-	_		-			
	% of Normal	103	112	61	70	74	79	94	112	38	44	75	91	81	υb	norma1	· · · normal	
HIGH LEVEL AIRPORT	Total	168.0	144.7	99.4	90.0	121.2	101.9	153.4	141.5	62.2	56.4	122.3	117.2	132.0	115.7	163.6	129.1	
HIGH LEI	June									= 20.00								
_	May					9.3	8.5	12.4	12.4					5.6	4.8	4.3	3.5	
	April	TR		10.0	6.6	8.5	6.2	28.0	28.0			17.1	17.1	2.8	3.0	14.5	11.8	records
	Mar.	11.9	10.2	9.1	7.8	21.3	16.8	21.7	21.5	12.2	11.6	2.9	2.9	4.1	3.3	21.0	16.2	monthly
	Feb.	25.1	21.8	6.2	5.5	14.8	13.2	34.2	32.0	1.8	1.8	28.6	25.3	17.8	15.2	20.6	15.8	ned from
	Jan.	27.4	20.1	22.3	23.1	10.7	10.0	15.0	12.3	23.8	22.2	5.9	5.9	13.0	11.8	26.6	20.5	determi
	Dec.	30.7	17.8	14.2	9.4	21.2	17.9	11.0	7.5	24.0	20.4	52.6	50.8	16.1	10.8	30.9	24.6	for w.e.
	Nov.	57.4	62.4	6.9	7.4	31.6	26.3	31.1	27.8	0.4	0.4	15.2	15.2	25.3	20.3	29.1	25.7	normal
	Oct.	15.5	12.4	30.7	26.9	3.8	3.0							47.3	46.5	15.3	10.5	:; annual
٠	Sept.									=	İ		·			1.3	0.5	equivalent
	51	Snow [cm]	w.e. [mm]	S now [cm]	w.e. [mm]	Snow [cm]	w.e. [mm]	Snow [cm]	w.e. [mm]	W.e. = water equivalent; annual normal for w.e. determined from monthly records								
5		1975/76		1976/77		1977/78		1978/79		1979/80		1980/81		1981/82		Normal	DOET-TOCK	

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										FOR	T SMIT	H AIRP	ORT (r.	ecord	FORT SMITH AIRPORT (record code 1)			
	Sept	Sept.	Oct. SD Dev.	Dev.	Nov.	Dev.	Dec.	. Dev.	Jan. SD.	. Dev.	Feb.	Dev.	A K	Pev.	Apr.	1	May	
1975/76			8	-1	38	+18	14	6+	19	+15	20	+13	53	01+		ı	no.	<u>. T</u>
1976/77				-	18	-2	36	+4	52	φ	57	ę	50	+		-		1
1977/78		·			18	-2	35	+3	35	ij	32	-19	33	89	Æ			T
1978/79			8	+4	∞	-12	31	-1	32	-14	35	-16	41	-2	14	, 0		T
1979/80		. Hed. in a	E		. 13	-7	25	-7	42	4	42	6-	39	4		 	-	T
19/0861					15	-5	29	-3	28	-18	43	8-	32	17-		+		Т
1981/82			10	9+	21	7	32	0	34	-12	47	4	30	-13		1		T
1951-1980 normal [cm]	TR	w.	4		20	_	32	2	46		51		43		w.		- 0	
	SD = snow depth at end or Dev. = deviation from 19 m = missing TR = trace	now depth deviation missing trace	th at elon on from	- 01	of month [cm] 051-1980 normal [cm]	m] rma1 [c,	Ē						= .			-		

A A graphy

TABLE 3.68

			T					i i	I	
de 1)	May Dev.	·					and the second		0	
rd co	S				Ħ		·			
(reco	Apr. D Dev.			8+	+21		+21	- r	,	
PORT	Ap SD			15	26		26	2		DI .
ER AIR	r Dev.	+3	6-	-10	-4	-23	-27	-20	48	
HAY RIVER AIRPORT (record code 1)	Mar SD	51	39	38	44	25	21	78		
Ŧ	Feb.	9+	-24	-32	-23	-27	-27	-13	58	
	Feb SD	49	34	26	35	31	31	45	S.	
	Dev.	5.5	-30	-21	-20	-20	-34	-22		
	Jan. SD	48	21	30	31	31	17	29	51	
	Dev.	+15	-28	-11	7	-28	-7	r,		
	Dec. De	+		•		'			38	Ē
	SD	53	10	27	37	10	31	33] 1a1 [c
	Dev.	+19	-19	6-	6-:	-22	9-	-5	n fi	th [cm 10 norm
	Nov. SD	43	S.	15	15	2	18	19	24	t end of month [cm] from 1951-1980 normal [cm]
	Dev.	0	5-		-2	-3	-3	-2+		it end from 19
	So Oct.	3	TT.		3	2	2	12.	ß	SD = snow depth at end of month [cm] Dev. = deviation from 1951-1980 norm TR = trace
	Dev.						0			SD = snow Dev; = devi TR = trace
	Sept.									SD = Dev; TR =
	្តន			161		ı	1			
		1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1951-1980 normal	

A day property

										HIG	HIGH LEVEL AIRPORT	IL AI	RPORT	(reco	(record code 5)	le 5)	
	Sept. SD Dev.	SD Ct.	t. Dev.	Nov. SD	. Dev.	SD Cc.	Dev.	Jan.	Dev.	Feb.	Dev.	Mar Sn D	or.	Ap C	Apr.	A S	May
1975/76				ß	-14	38	+5	56	+12	1	+15		+7				
1976/77				ы	-16	10	-23	27	-17	21	-30	15	-21	4	+3	-	
1977/78	N) 3			25	9	42	6+	46	+2	43	8	92	-26			 	
1978/79	4			24	+5	28	-5	40	4	99	+15	50	+14	5	44		
1979/80	=	E		E		11	-22	25	-19	25	+26	12	-24			 	=
1980/81				7	-12	57	+24	24	-20	46	-5	5	-31				
1981/82		10	ę.	25	9+	34	+1	33	-10	38	-13	7	-29				
1951-1980 normal					19		33	44	4	21		36					
	SD = snow d Dev. = Devi m = missir TR = trace	SD = snow depth a Dev. = Deviation m = missing TR = trace		t end of month [cm] from 1951-1980 normal [cm]	onth [c	m] vrmal [4	[#3	• 10					1		. :		
ar de proposale est															-	कुर्यक है। .1	3

			10000	В	ΚEV	N.	END	CVI	-	Ī	T X	əqu		ge K Y			0220
		1975	1976	1977	1978	1979	1980	1981	1982		1975/76		-21				1981/82
	total precip.	119	104	91	103	103	102	100	83		116	16	102	111	06	98	93
VEL A.	snow w.e.	132	74	72	70	86	79	100	82		112	70	79	110	44	16	06
HIGH LEVEL A.	Snow	126	17	99	65	83	65	88	78		103	19	74	94	38	75	81
-	rain	113	119	100	119	106	113	100	82		118	102	113	112	1113	83	94
	total precip.	100	95	69	81	89	84	92	77		116	64	72	7.9	82	73	06
ER A.	snow w.e.	101	59	9	58	28	48	- 92	7.1		101	26	45	76	39	29	88
HAY RIVER A.	Snow	103	09	62	52	55	46	87	69		103	99	43	72 -	37	70	84
	rain	- 66	126	72	100	92	115	16	81		128	17	98	80	123	13	06
	total precip.	130	88	104	80	73	87	100	82		88	106	7.8	73	87	82	- 66
H A.	Snow W.e.	93	94	29	53	28	54	123	80		120	7.5	48	62	49	82	103
FORT SMITH A.	Nous	93	105	73	09	62	62	149	111		128	79	28	29	52	06	140
	rain	153	. 98	126	96	82	107	82	84		86	124	95	80	110	80	*96
		1975	1976	1977	1978	1979	1980	1981	1982		1975/76	1976/77	1977/78	1978/79	1979/80	1880/81	1981/82
				AA:	X XE	AAGI	rei	ro Ch	7	İ	19	AR emb	sďə XE	RET.	AW T	əqo	350

		D			MINE STATE	and the same				7	M	-			-		
		L			KEA	. AA	END	CAL			ı		EAR Pte		ITAI		otoC
		1975	1976	1977	1978	1979	1980	1981	1982		1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82
	total precip.	+19	+4	6	+3	+3	+5	83	+17		+16	6-	+2	+11	-10	-14	-7
VEL A.	Snow W.e.	+32	-26	-28	-30	-2	-21	ŧ	-15		+12	-30	-21	+10	-56	6-	-10
HIGH LEVEL A.	Nous	+26	-29	-36	-35	-17	-35	-12	-22		+3	-39	-26	9-	-62	-25	-19
	rain	+13	+19	21	+19	9+	+13	u	-18		+18	+2	+13	+12	+13	-17	9-
	total precip.	В	-5	-31	-19	-32	-16	8-	-23		+16	-36	-28	-21	-15	-27	-10
ER A.	Snow W.e.	+1	-41	-35	-42	-42	-52	80	-29		+1	-44	-55	-24	-61	-33	-12
HAY RIVER A.	Snow	+3	-40	-38	-45	-45	-54	-13	-31		+3	-44	-57	-28	-63	-30	-16
	rain	7	+26	-28		-24	+15	6-	-19		+28	-29	κį	-20	+23	-21	-10
	total precip.	+30	=	+4	-20	-27	-13	n	-18		-2	ş	-22	-27	-13	-18	7
SMITH A.	snow W.e.	-2	9-	-33	-47	-42	-46	+23	-20		+20	-25	-52	-38	-51	-15	+3
FORT	Snow	-1	÷	-27	-40	-38	-38	+49	+11		+28	-21	-42	-33	-45	-10	+40
İ	rain	+53	-14	+26	4	-18	+4	-15	-16		-14	+24	ų	-20	+10	-20	4
		1975	1976	1977	1978	1979	1980	1981	1982		1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82
				8	ΚEV	ЯА	ЕИD	CVF			.er			10 S			120

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				8	KEVI	ЯΑ	END	CYL		7	F	ıpeı			TER to		doso	0
		1075	1076	1077	1078	1979	1980	1981	1987		1975/76	1076/77		0////67			1981/82	
	total precip.			7.		u	B) B	•			e j	1 3		k (h 99		
/EL A.	Snow W.e.	:	1	;	:	u	ı	В	í			8			-	,		
HIGH LEVEL A.	Snow	:		1	:		- [я	:		11			i i	;	1	•	1.
-	rain				+	+	+				+	u	•				ì	39.9
8 8 8	total precip.	u		;	•	1	0	ì	. :		+	:	1	:	: 0 ■	:	t	119.9 ++ 139.9 +++
ER A.	Snow W. B.	u	į	ŀ	;	į	!	ì	ŀ		u	į	-		;	:	i	
HAY RIVER A.	Snow	н	i	1	1	ŀ	ļ	1	ï		n	į	i	:	ł	1	•	104.9
	rain	p	:	. 1	tı	ŀ	*	ŗ	•		‡	1	ı	1	:	ŀ		1:
	total precip.	*	į	tr	1	1	ì		,		п	•	ŀ	;			, m :	80.1 - 95.1
∄ A.	Snow W.e.	ă	į	ľ	1	1		‡	;		‡	1	1	,1		100	ĵa .	
FORT SMITH A.	Nous	ï	4	1	i	!	i	‡	+		‡	i	i	1			‡	Symbols: 60.1 %
	rain	‡	Ė	*	н	ŀ	+	1	Ē		ì	‡	î	1	•	1	a	Symbols: 60.1
		1975	1976	1977	1978	1979		1981	1982		1975/76	1976/77	1977/78	1978/79	1979/80	18/0861	1981/82	Symbo.
	-		-	ЯA	λE	RAG	геи	CA			18	я, qw;	Σ Σ Σ Ε	эs (DJ.	rəq	0350	

and the property

Calendar		total ainfall	(2) to	vfall	(3) tot	ipitation		uivalent of	I
years	[mm]	normaf	[cm]	% of normal	[mm]	% of normal	[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	ł
1947	154.6	83.8	122.9	74.5	277.6	81.7	123.0	79.1	- 1
1948	265.5	144.0	98.1	59.5	363.6	107.0	98.1	63.1	- 1
		93.8	142.7	86.5	315.6	92.9	142.7	91.8	- 1
1949	172.9						152.9	98.3	- 1
1950	184.1	99.8	152.9	92.7	337.0	99.1	152.9		_
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	- 1
1953	221.7	120.2	161.1	97.6	382.8	112.6	161.4	103.6	- 1
1954	192.0	104.1	193.4	117.2	385.6	113.4	193.6	124.5	- 1
1955	133.8	72.6	137.1	83.1	271.0	79.7	137.2	88.2	- 1
1956	210.4	114.1	154.4	93.6	364.8	107.3	154.4	99.3	8
1957	236.1	128.0	138.4	83.9	374.6	110.2	138.5	89.1	- 1
		92.6	196.0	118.8	366.7	107.9	196.0	126.0	- 1
1958	170.7				309.4	91.0	133.0	85.5	- 1
1959 1960	176.4 243.6	95.7 132.1	133.1 235.5	80.7 142.7	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	\dashv
		00.7	727 1	195.8	485.8	142.9	323.0	207.7	-
1961	162.8	88.3	323.1					150 (SS) SS (SS) SS (SS) SS (SS)	
. 1962	231.7	125.6	208.4	126.3	440.1	129.5	208.4	134.0	- 1
1963	221.9	120.3	249.0	150.9	470.9	138.5	249.0	160.1	- 1
.964	219.0	118.8	142.2	86.2	358.3	105.4	139.3	89.6	- 1
. 1965	147.1	79.8	235.9	143.0	337.0	99.1	189.9	122.1	- 1
1966	196.7	106.7	284.8	172.6	383.2	112.7	186.5	119.9	- 1
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	- 1
1969	121.3	65.8	124.8	75.6	234.0	68.8	112.7	72.5	1
1970	98.8	53.6	168.6	102.2	269.5	79.3	171.7	110.4	ı
Mean	173.7	94.2	209.6	127.0	361.4	106.3	187.7	120.7	-
1071	114.5	62.1	135.4	82.1	249.4	73.4	134.9	86.8	-
		98.2	138.6	84.0	319.6	94.0	138.5	89.1	
	181.1	124.4	136.1	82.5	348.8	102.6	119.4	76.8	1
	229.4					106.0	159.0	102.3	- 1
1974	201.3	109.2	181.7	110.1	360.3		157.1	101.0	
	182.3	98.9	169.6	102.8	339.4	99.9			
	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	
	184.7	100.2	90.7	55.0	274.8	80.8	90.1	57.9	
	139.5E	75.7	90.9E	55.1	230.4E	67.8	90.9	58.5	
	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	0.00
	149.6	81.1	114.5	69.4	260.7	76.7	111.1	71.4	
983									
Normal_ 1951-1980	184	.4	16	5.0	339	.9	15	5.5	
;	E = est	imate	<u> </u>	- Commercial					

Talls ?-10. Precinitetion at they King.
Why Just 1983

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	WSC St.	WSC Station: 075B001			-	WSC Station: 07PB001	07PB001	
Year	ft	minimum m	max ft	maximum m	ft	minimum m	ma) £t	maximum 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	.56.911
1974	513,56	156.533	69 69 69 69 69	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	•	•	•

•	87		88	37		75	12	- 53		4		0	35	12	0.220	17	0.515		174	- 46	25	31	151	15	
Dec.	45.87	36.2	26.68	4.87	2.21	1.05	13.42	7.45	0.76	48.14	40.0	25.40	8.95	3.27	0.2	2.47	0.5	0.0	0.074		0.025	0.131	0.051	0.031	
Nov.	66.55	56.8	47.01	19,68	11.8	5.24	56.07	21.7	13.99	79.29	33.3	21,69	14.0	9.83	8.11	14.2	8.37	3.38	0.571	0.329	0,077	4.31	1.46	0.146	
Oct.	154.91	137.	113,85	75.33	50.5	20.67	80.71	68.0	50.13	99.69	86.9	77.03	42.7	38.3	21.1	28.1	17.3	8.30	28.5	7.79	0,812	32.0	17.0	2.20	
Sept.	196.82	169.	127.44	97.70	78.5	65.70	98.55	86.9	76.46	84.39	62.9	42.48	53.3	44.8	41.9	22.2	13.5	3,46	24.1	9.11	6.15	33.2	21.7	4.52	
Aug.	107.05	87.0	47.86	114.70	93.9	76.18	135.83	122.	98.84	77.03	63.0	48.43	87.7	65.0	48.9	E	E	E	32.6	21.1	7.74	40.9	26.3	8.46	
July	193.99	146.	96.85	232.51	147.0	103.08	130.84	104.	81.83	93.74	69.1	57.21	182	126	80.3	E	E	E	62.3	36.3	8.22	79.4	51.4	29.8	
June	192.01	175.	154.06	214.38	179.	121.49	141.32	107.	86.94	91.76	83.5	70.23	278	241	185	E	E	E	75.5	56.6	45.1	156.	110	76.7	
May	161.71	132.	55.22	205.88	180.	131.97	113,56	102.	74.48	94.87	80.8	32.0	198.	88.5	0.760	55.5	41.9	22.0	82.1	66.7	25.2	163.	95.6	8.08	
April	42.48	5.10	0.0	172.47	42.4	0.12	63.15	7.24	0.0	23.96	1.63	0.0	0.580	0.052	0.0	47.1	11.7	0.0	13.0	0.976	0.0	5.54	0.833	0.0	
March	0.11	0.031	0.0	0.84	0.323	0.11	0.01	0.003	0.0	0.02	0.004	0.0	0.030	0.002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Feb.	0.57	0.255	0.11	8.84	3.37	0.88	0.20	0.081	0.02	0.08	0.044	0.02	1.42	0.616	0.040	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Jan.	18.27	4.66	0.59	. 02*92	18.7	9.52	1.02	0.612	0.22	89.0	0.240	0.08	24.0	10.8	1.53	0.210	0.045	0.0	0.0	0.0	0.0	0.024	0.007	0.0	= missing
1	тах.	mean	min.	тах.	mean	min.	max.	mean	min.	тах.	mean	min.	шах.	mean	min.	тах.	mean	min.	тах.	mean	min.	тах	mean	.min.	n Æ
		19/5			1976			1977			1978			1979			1980			1981	-	V V	1982	production in the	•

	F							anti i	BUFFALO RIVER	IVER - WSC	•	Station No. 07PB002	295
		Jan.	Feb.	March	Apri1	Мау	June	July	Yng	Sept	ij	Nov	Dec
1975	max.			•	5.83	8.16	5.27	5.49	15.97	15.80	13.45	7.70	3.12
			•		1.52	3.34	3,54	3,10	4.21	14.00	11.7	5.19	2.00
	max.	·				22.94	8.38	8.44	8.69	4.96	3.40		
1976	шевп	•	•	•	ı	13.30	90.9	4.60	6.95	4.28	3.02	•	ı
	min.					6.63	4.19	2.97	4.79	3.43	2.43		
						6.00	4.81	4.36	4.42	4.56	4.53		
1977	-	ı	t		•	3.63	3.40	2.79	3.27	3.33	3.87	•	ı
	min.			_		2.11	1.95	1.51	1.90	2.27	3.29	``	
						9.97	1.37	1.70	0.59	1.90	2.95	2.34	
1978			ı	,	•	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	
	тах.					30.8	11.5	3.90	1.08	0.676	0.890		
1979		1	,	•	1	15.0	8.03	1.95	0.645	0.348	0.578	1	ı
	min.	in i Tan		•		4.3	4.2	1.04	0.367	0.150	0.080		
	max.					8.42	0.812	0.276	0.131	0.264	0.555		
1980		1		•	ı	1.31	0.347	0.121	0.077	0.121	0.306	•	•
	min.				1	0.328	0.105	0.037	0.046	0.048	0.227		
	тах.					8.50	1.03						
1981	mean	•	•	•	•	3.32	0.313	•				•	•
	min.					1.15	0.013					:	
	max			١	2.19	2.15	.640	. 203	.088	.388	.274	.193	
1982	mean	1	ì	•	0:586	1.38	.249	.1	.03	.151	.156	.115	
- 8	min.				0.0	0.702	.087	.036	占	.021	107	070	
		m = missing	gu	:							=		

	-							HAY RIVE	NSC STAT	HAY RIVER WSC STATION NO. 070B001	708001		-
		T T	402	1	•								4
		Conti	reu.	March	April	Мау	June	July	Aug	Sept	킹	Now	Dec
	max.	25.52	2.18	1.69	680.	634	382	345	159	139	67.7	37.4	13.2
1975	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	202	118	60.3	57.8	39.9	13.3	5.38
	max.	5.27	3.74	3.34	685.	682	572	425	634	484	228	156	80.7
1976	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
	max.	37.4	14.2	8.95	\$30	634	1079	716	569	217	168	124	54.1
1977	mean	25.2	10.8	8.04	110	393	770	581	344	197	142	77.4	30.5
	min.	14.9	90.6	7.31	7.11	277	326	467	222	171	127	54.1	16.0
	тах.	15.6	5.8	4.76	17.3	818	442	192	132	222	180	65.4	23.6
1978	шевп	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
	max.	8.78	4.19	2.68	25.2	902.	1120	548	204	160	132	91.5	19.1
1979	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
	тах.	00.9	3.33	3.04	120.	83.7	42.6	26.0	47.4	30.1	62.4	40.0	10.8
1980	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
_	max.	2.21	1.71	1,67	12.5	790	163	65.3	20.4	6.24	9.30	7.40	3.35
1981	певп	1.97	1.63	1.65	2.19	419	112	41.7	11.3	2.07	60.9	4.51	2.63
	min.	1.73	1.60	1.62	1.57	169	8.09	21.3	6.2	4.12	3.00	3.39	2.04
	THE STATE OF THE X	2.27	2.51	3.74	5.27	657.	296	96.5	530.7	29.2	18.6	15.2	4.17
1982	mean	1.73	1.65	1.85	2.73	398.	168	55.5	24.0	25.2	15.4		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

arge flow discharge, precipitation, precipitation discharge, km2 141.0 339.4 147.1 141.0 339.4 119.5 323.9 32.7 2.96 93.4 234.4 234.4 234.4 234.4 234.4 235.5 2.96 93.4 235.1 24.6 3.07 96.8 295.1 235.1 248.4 235.5 248.4 235		Total	-	1,000		WSC Station U/PAGO	
1975 2.51 79.5 4.47 141.0 339.4 42 1976 2.14 67.5 3.79 119.3 323.9 37 1977 1.66 52.7 2.96 93.4 246 77.6 274.8 28 1979 1.66 52.6 2.96 93.4 230.4 28 28 1980 - - - - - 287.0 41 1981 0.834 16.9 0.95 30.0 311.1 10 1982 0.857 27.2 1.53 48.2 260.7 18 mean 1.72 54.6 3.07 96.8 295.1 33 1 2/5.6 1.753 mean 295.1 33 1 1.72 54.6 3.07 96.8 295.1 33 1 2/5.6 mean percentinal per annum 295.1 33 2 1.2/5. km 2 mean precipitation per annum		discharge [10 m3]	flov fm³/s1	discharge 1/8 . km²1		total annuals) precipitation mm	% of annual precipitation
1976 2.14 67.5 3.79 119.5 323.9 37 1977 1.66 52.7 2.96 93.4 234.6 40 1978 3.38 43.8 2.46 77.6 274.8 28 1979 1.66 52.6 2.96 93.4 230.4 41 1980 - - - - 287.0 41 1981 0.834 16.9 0.95 30.0 311.1 10 1982 0.857 27.2 1.53 48.2 260.7 18 64-1979 1.72 54.6 3.07 96.8 295.1 33 1) size of catchment area above gaging station: 17,800 km². 295.1 33 2) 1 L/s. km²is equivalent to 31.536 mm precipitation per annum 33	1975	2.51	79.5	4.47	141.0	339.4	42
1.66 52.7 2.96 93.4 234.6 77.6 274.8 40 1.66 52.6 2.96 93.4 274.8 28 1.66 52.6 2.96 93.4 287.0 41 0.857 16.9 0.95 30.0 311.1 10 1.72 54.6 3.07 96.8 295.1 33 at Hay River Airport at Hay River Airport	1976	2.14	67.5	3.79	119.8	323.9	37
1.66 52.6 2.46 77.6 274.8 28 1.66 52.6 2.96 93.4 287.0 41 0.534 16.9 0.95 30.0 311.1 10 0.857 27.2 1.53 48.2 260.7 18 1.72 54.6 3.07 96.8 295.1 33 size of catchment area above gaging station: 17,800 km². 1 L/s. km²is equivalent to 31.536 mm precipitation per annum	1977	1.66	52.7	2.96	93.4	234.4	·
1.66 52.6 2.96 93.4 233.6 41 0.534 - - - 287.0 10 0.857 27.2 1.53 48.2 260.7 18 1.72 54.6 3.07 96.8 295.1 33 size of catchment area above gaging station: 17,800 km². 1 L/s. km²is equivalent to 31.536 mm precipitation per annum at Hay River Airport	1978	1,38	43.8	2.46	77.6	274.8	788
- 287.0 16.9 0.95 30.0 311.1 10 10 10.857 27.2 1.53 48.2 260.7 18 1.72 54.6 3.07 96.8 295.1 33 33 27.2 25.2 25.1 34 27.2 25.	1979	1.66	52.6	2.96	93.4	239.4	41
0.834 16.9 0.95 30.0 311.1 10 0.857 27.2 1.53 48.2 260.7 18 1.72 54.6 3.07 96.8 295.1 33 size of catchment area above gaging station: 17,800 km². 1 L/s. km²is equivalent to 31.536 mm precipitation per annum . .	1980	0	ı	ŧ	8	287.0	
1.72 54.6 3.07 96.8 295.1 33 stee of catchment area above gaging station: 17,800 km². 1 L/s. km²is equivalent to 31.536 mm precipitation per annum at Hay River Airport	1981	0.534	16.9	0.95	30.0	311.1	10
1.72 54.6 3.07 96.8 295.1 33 size of catchment area above gaging station: 17,800 km². 1 L/s. km²is equivalent to 31.536 mm precipitation per annum at Hay River Airport	1982	0.857	27.2	1.53	48.2	260.7	18
	mean 1964-1979	1.72	54.6	3.07	8.96	295.1	
	ì			1			
		size of catch L/s . $km^2 1s$	ment area equivalent	above gaging s t to 31.536 mm	tation: 17,800 k	n². Annum	•
		at Hay River	Airport				

Buffalo River

and physical

HAY RIVER

WSC - Station No. 070B001	
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Q	Í	fotal discharge [10° m³]	mean flow [m³/s]	unit areal) discharge [2/8 . km ²]	equiv. precipitation ²⁾ [mm]	total annual precipitation3) [mm]	% of annual precipitation
	1975	3,15	93.6	2.08	68.6	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
141	1978	3.51	111	2.32	73.2	274.8	27
	1979	5.24	166	3.47	109.4	230.4	47
	1980	0.623	19.9	0.42	6-4 6-4 6-4	287.0	ī.
	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) 8	ize of catch	ment area	above gaging s	size of catchment area above gaging station: 47,900 km ²	.2.	
		. L/s. km²1s	equivalent	to 31.536 mm	1 L/s. km2 is equivalent to 31.536 mm precipitation per annum	annum	
	3) 8	at Hay River Airport.	Airport.				

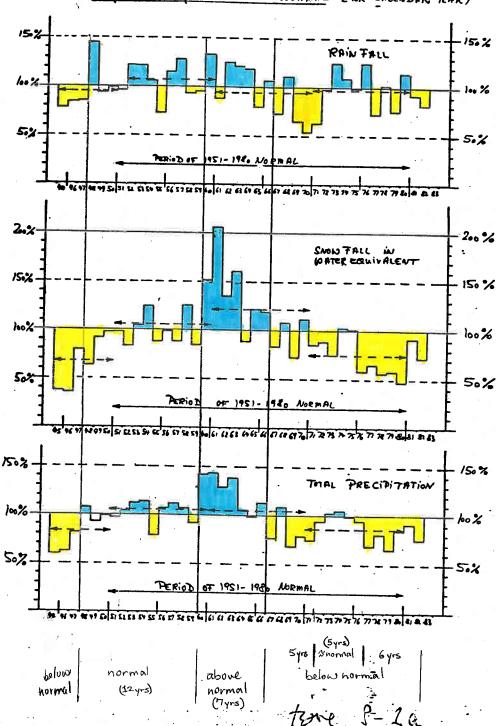
TABLE 28 8-13 8

S. Paragraphy

	discharge Hay-Oct. mean 110 m unit area line lin		total	mean flow	1.5		MOL STRI	MSC Station No. 07PB002	
0.111 6.98 4.23 1.18 37.2 455.8 0.101 6.38 3.19 0.886 27.9 310.4 0.053 3.36 1.69 0.469 14.8 363.9 0.026 1.67 0.98 0.272 8.6 279.0 0.070 4.43 2.22 0.617 19.5 258.7 Insufficient record 0.0427 1.35 0.68 0.189 6.0 287.7 0.0805 5.06 2.53 0.703 22.2 352.6 6 size of catchment area: 3600 km² 3600 km² 352.6 6 6	0.111 6.98 4.23 1.18 37.2 455.8 0.101 6.38 3.19 0.886 27.9 310.4 0.053 3.38 1.69 0.469 14.8 363.9 0.026 1.67 0.98 0.272 8.6 279.0 0.070 4.43 2.22 0.617 19.5 258.7 0.087 0.380 0.190 0.0528 3.7 304.8 Insufficient record 347.6 0.0805 5.06 2.53 0.703 22.2 352.6 size of catchment area: 3600 km²		discharge [10°m³]		annually corrected	unit area 1) discharge 1) [2 s-1 km-2]	lo B	total annual precipitation3)	% of annual Precipitation
0.101 6.38 3.19 0.886 27.9 310.4 0.053 3.38 1.69 0.469 14.8 363.9 0.026 1.67 0.98 0.272 8.6 279.0 0.070 4.43 2.22 0.617 19.5 258.7 0.0520 0.380 0.190 0.0528 1.7 304.8 Insufficient record Insufficient record 347.6 0.0805 5.06 2.53 0.703 22.2 352.6 6 size of catchment area: 3600 km²	0.101 6.38 3.19 0.886 27.9 4.35.0 0.053 3.38 1.69 0.469 14.8 363.9 0.026 1.67 0.98 0.272 8.6 279.0 0.070 4.43 2.22 0.617 19.5 258.7 0.0820 0.380 0.190 0.0528 3.7 304.8 Insufficient record 347.6 0.0805 5.06 2.53 0.703 22.2 352.6 6 size of catchment area: 3600 km² 1 Let 1 Let 1 Let 2 Let 1 Let 2 Let 3 Let 2 Let 3 Le	1975	0.111	6.98	4.23	1.18	37.2	765.0	
0.053 .3.38 1.69 0.469 14.8 363.9 0.026 1.67 0.98 0.272 8.6 279.0 0.070 4.43 2.22 0.617 19.5 278.7 0.06120 0.380 0.190 0.0528 3.7 304.8 0.0427 1.35 0.68 0.189 6.0 287.7 0.0805 5.06 2.53 0.703 22.2 352.6 6 size of catchment area: 3600 km²	0.053 3.38 1.69 0.469 14.8 363.9 0.026 1.67 0.98 0.272 8.6 279.0 0.070 4.43 2.22 0.617 19.5 279.0 0.070 4.43 2.22 0.617 19.5 278.7 0.0427 1.35 0.068 0.189 6.0 287.7 size of catchment area: 3600 km²	1976	0.101	6.38	3.19	0.886	27.9	0 000	8.2
0.026 1.67 0.98 0.272 8.6 279.0 0.070 4.43 2.22 0.617 19.5 279.0 0.06120 0.380 0.190 0.0528 2.7 304.8 Insufficient record 347.6 0.0427 1.35 0.68 0.189 6.0 287.7 size of catchment area: 3600 km²	0.026 1.67 0.98 0.272 8.6 279.0 0.070 4.43 2.22 0.617 19.5 255.7 0.0427 1.35 0.68 0.189 6.0 287.7 size of catchment area: 3600 km² 352.6 352.6	1977	0.053	. 3,38	1.69	0.469	000	310.4	0.0
0.070 4.43 2.22 0.617 19.5 258:7 0.6120 0.380 0.190 0.0528 1.7 304.8 Insufficient record 347.6 0.0805 5.06 2.53 0.703 22.2 352.6 size of catchment area: 3600 km²	0.070 4.43 2.22 0.617 19.5 258.7 0.68 0.380 0.190 0.0528 1.7 304.8 1.35 0.68 0.189 6.0 287.7 2.53 0.703 22.2 352.6 1.5 size of catchment area: 3600 km² 352.6	1978	0.026	1.67	0.98	0.272) v	363.9	4.1
0.0805 0.380 0.190 0.0528 1.37 304.8 347.6 0.0805 5.06 2.53 0.703 22.2 352.6	0.0805 0.380 0.190 0.0528 1.7 304.8	1979	0.070	4.43	2.22	0.617	2 1	2/9.0	3.1
1.35 0.0805 3.77 304.8 34.8 34.8 34.8 34.8 34.8 34.8 34.8 34.8 34.8 34.8 34.8 34.8 34.8 34.6 34.8	Insufficient record 304.8 304.8 304.8 347.6 347.6 347.6 347.6 352.6	1980	0.6120	0.380	0 100		19.5	7.30	7.6
0.0427 1.35 0.68 0.189 6.0 287.7 0.0805 5.06 2.53 0.703 22.2 352.6 size of catchment area: 3600 km²	0.0427 1.35 0.68 0.189 6.0 287.7 0.0805 5.06 2.53 0.703 22.2 352.6 size of catchment area: 3600 km²	1981				0.0528	1.7	304.8	0.6
0.0427 1.35 0.68 0.189 6.0 287.7 0.0805 5.06 2.53 0.703 22.2 352.6 size of catchment area: 3600 km²	0.0427 1.35 0.68 0.189 6.0 287.7 0.0805 5.06 2.53 0.703 22.2 352.6 size of catchment area: 3600 km² 1 L s ⁻¹ km² te continut 2.53 0.703 22.2 352.6		-	3	nsurficient r	ecord		347.6	
0.0805 5.06 2.53 0.703 22.2 352.6 size of catchment area: 3600 km²	0.0805 5.06 2.53 0.703 22.2 352.6 size of catchment area: 3600 km ²	1982	0.0427	1.35	89.0	0.189	6.0	287.7	-
catchment area: 3600 km²	catchment area: 3600 km² tm 2	mean 1967-1979	0.0805	5.06	2.53	0.703	22.2	2 632	1::7
								0.766	2.0
		U			1600 km²				

atale physics

PRECIPITATION AT HAY RIVER, 1945-1983
in percent of 1951-1980 NORMAL (FOR CALENDAR YEAR)



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