Environmental Studies No. 65

Groundwater Databases for Yukon and NWT

Canada

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Northern Affairs Program

Piteau Engineering
Integrated Environments

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Indian and Northern Affairs Canada
Affaires indiennes et du Nord Canada

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RÉSUMÉ

Les eaux souterraines constituent des ressources précieuses qu'il faut mettre en valeur et protéger pour les années à venir. Reconnaissant cette réalité, le ministère des Affaires indiennes et du Nord canadien a entrepris l'élaboration d'une base de données sur les eaux souterraines pour chacun des territoires du Nord. Il marque ainsi la première étape d'un recensement exhaustif de ces ressources. Avec le temps, le répertoire comprendra aussi des données sur les puits d'approvisionnement en eau, les puits d'exploration, les sources et les infiltrations ainsi que d'autres renseignements en matière d'hydrogéologie.

La présente publication comprend trois grandes parties. D'abord, on fait une brève introduction sur les eaux souterraines des régions au nord du 60^{e} parallèle, le bien-fondé du projet et les avantages qu'il offre. Ensuite, on enchaîne avec les détails des bases de données, la configuration logicielle et les besoins en matériel, la nature et l'organisation des données, les procédures d'accès et de mise à jour. Finalement, on explique les possibilités d'application des bases de données dans des domaines tels que la recherche des eaux souterraines, la protection de l'environnement, la recherche scientifique et les contrôles réglementaires, on brosse un tableau des techniques hydrogéologiques et on fait le point sur les mesures législatives touchant les eaux souterraines au Yukon et dans les T.N.-O.

Dans les pages qui suivent, on présente également au ministère des Affaires indiennes et du Nord canadien des recommandations quant aux renseignements à inclure dans les bases de donneés, aux études portant sur l'hydrogéologie dans les régions arctiques et subarctiques et à l'amélioration de la gestion des eaux souterraines au Yukon et dans les T.N.-O.

SUMMARY

Groundwater is a valuable resource which must be fostered and protected for the future. Recognizing this, Indian and Northern Affairs Canada has moved to establish a computerized groundwater database system for each of the northern territories. This database is seen as the first step towards the compilation of a detailed inventory of groundwater resources, which will eventually include all available data on water supply wells, monitoring wells, springs and seeps, and other information of hydrogeological interest in Yukon and NWT.

This publication consists of three main sections. The first offers a brief introduction to groundwater in the north of sixty degrees regions and explains the need for and benefits of the databases. Part two provides details of the databases their design, software and hardware requirements, the nature and organization of data they contain, and procedures for accessing and submitting data. The third section discusses the potential applications of the databases in such fields as groundwater exploration, environmental protection, scientific studies and regulatory control, while providing an overview of hydrogeologic technology and the current state of groundwater regulations and legislation in Yukon and NWT.

This publication includes recommendations to Indian and Northern Affairs Canada on new data collection for the databases, on studies addressing the subjects of arctic and subarctic hydrogeology, and on development of groundwater management in Yukon and NWT.

GROUNDWATER DATABASES
FOR YUKON AND NWT

1. INTRODUCTION

Over the past five decades, groundwater has become a valuable source of domestic and industrial supply which must be fostered and protected for the future. Recognizing this fact, Indian and Northern Affairs Canada has moved to establish a computerized groundwater database system for each of the northern territories. These databases are the first step towards the compilation of a groundwater resource inventory for the territories, which will eventually include all available data on water supply wells, monitoring wells, springs and seeps, and other information of hydrogeological interest.

This publication consists of three main sections. The first offers a brief introduction to groundwater in the north of sixty degrees regions and explains the need for and benefits of the databases. Part two provides details of the databases, their design, hardware requirements and the types, and organization of data contained. The third section discusses the potential applications of the databases in such fields as groundwater exploration, scientific study and policy making, while providing an overview of hydrogeologic technology in the north and the current state of groundwater regulations and legislation in Yukon and NWT.

1.1 GROUNDWATER IN YUKON AND NWT - The Importance of the Resource

Approximately one in every four Canadians rely on groundwater as their main source of domestic water supply, and only in Prince Edward Island is groundwater of greater importance for domestic supply than in Yukon (Hess, 1986) (Figure 1).

Over 15,000 people in Yukon depend on groundwater for day-to-day domestic use, representing approximately 63 percent of the population. In 1981, the last time a comprehensive study of groundwater use in Canada was conducted, groundwater supplied 13,700 municipal users in Yukon with over 3,400,000 cubic metres of water. These figures stand in sharp contrast to those of NWT, where only about one percent of the population depends on groundwater for domestic supply. In 1981, groundwater supplied about 19,000 cubic metres to 2020 users in NWT (Hess, 1986). However, groundwater is of significant importance for industrial use in NWT; in 1981 the mining sector pumped over 9,100,000 cubic metres of groundwater, accounting for about 62 percent of total industrial water use. In comparison, industrial groundwater use in Yukon was negligible (Hess, 1986). Figure 2 shows the overall importance of groundwater as a source of domestic supply, and Figure 3 the breakdown of groundwater use by different sectors for each of the two territories.

Figure 4 shows a map of groundwater use in Yukon and NWT (after Hess, 1986). This map shows that over two-thirds of Yukon is covered with aquifers that have potential yields of over 0.5 l/s. NWT, in comparison, has fewer areas hydrogeologically suited to groundwater abstraction; here, groundwater has special significance to large industrial operations such as mines.

Another area of increasing concern to the public, government and industry is the protection of groundwater supplies from contamination. Throughout Canada, the USA and Europe, the incidence and severity of aquifer contamination associated with all manners of industrial, municipal and agricultural wastes is increasing. Contamination can render water supplies unfit for use, requiring development of expensive alternate supplies; the presence of toxic or carcinogenic substances in drinking water may pose a danger to public health; and environmental damage to

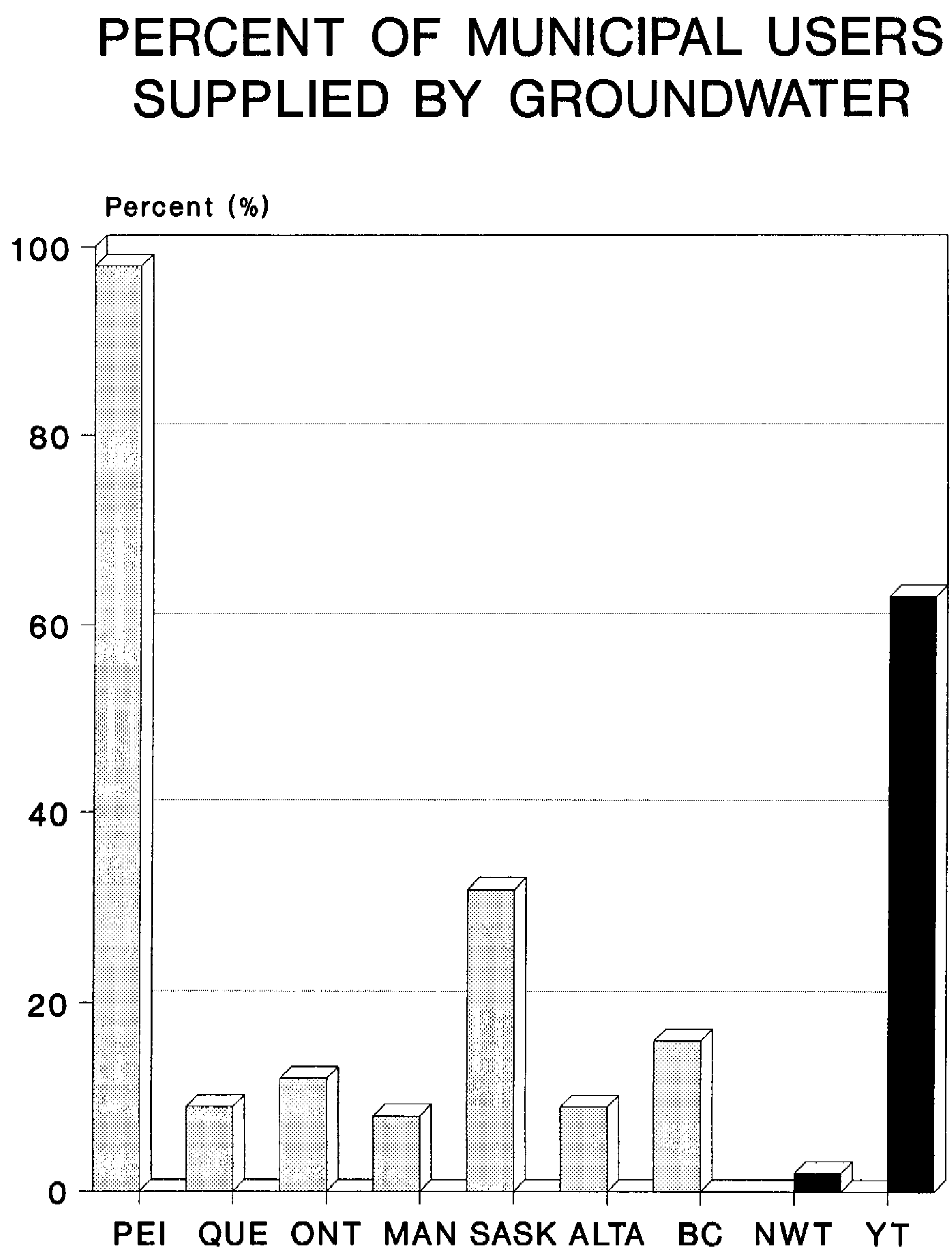

PERCENT OF MUNICIPAL USERS
SUPPLIED BY GROUNDWATER
Percent (%)
100
80
60
40
20
0
PEI
QUE
ONT
MAN
SASK
ALTA
BC
NWT
YT

Figure 1

POPULATION RELIANT ON GROUNDWATER
After Hess (1986)

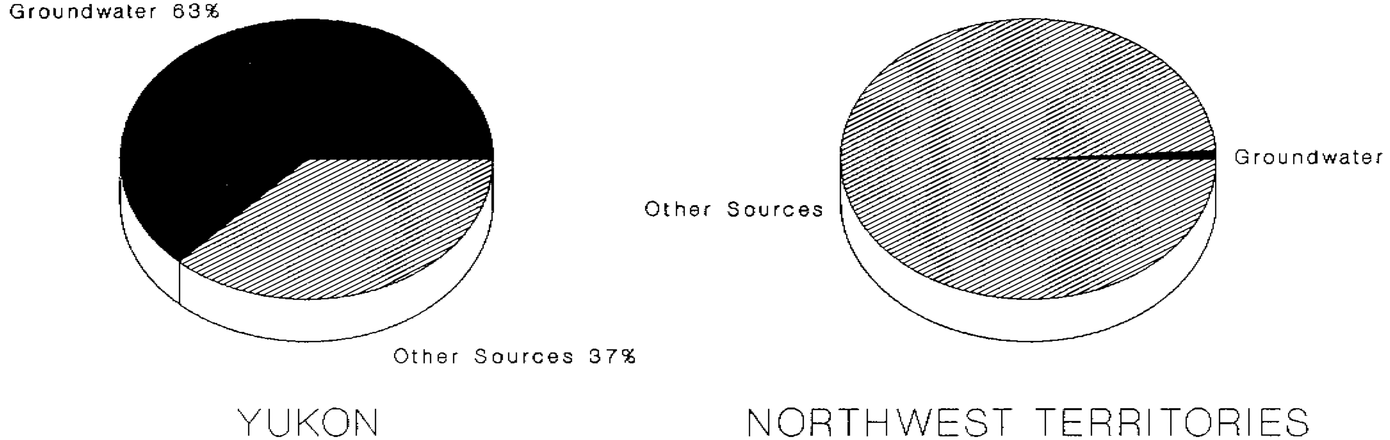


Figure 2

GROUNDWATER USE IN NORTHERN CANADA

After Hess (1986)

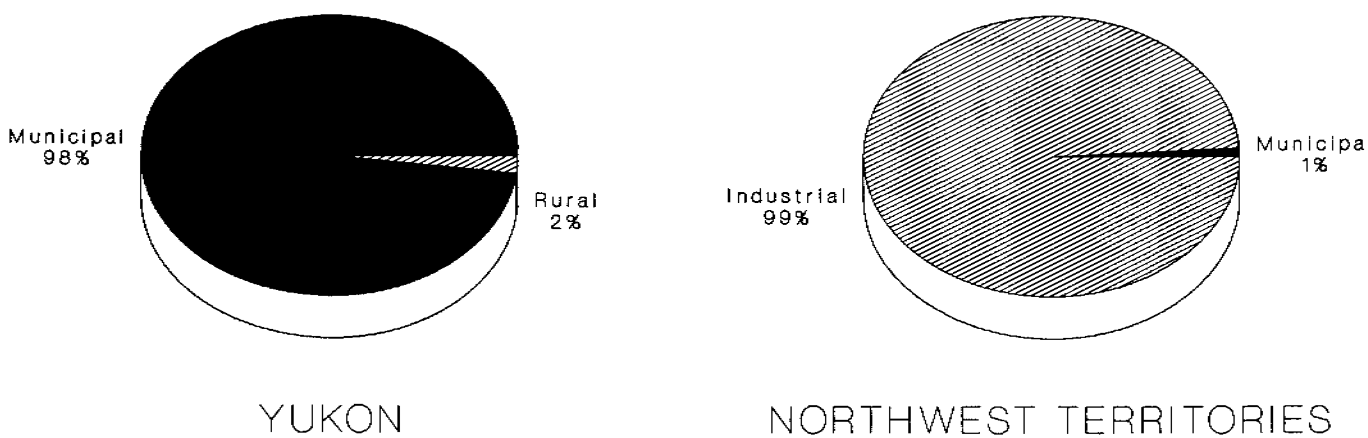
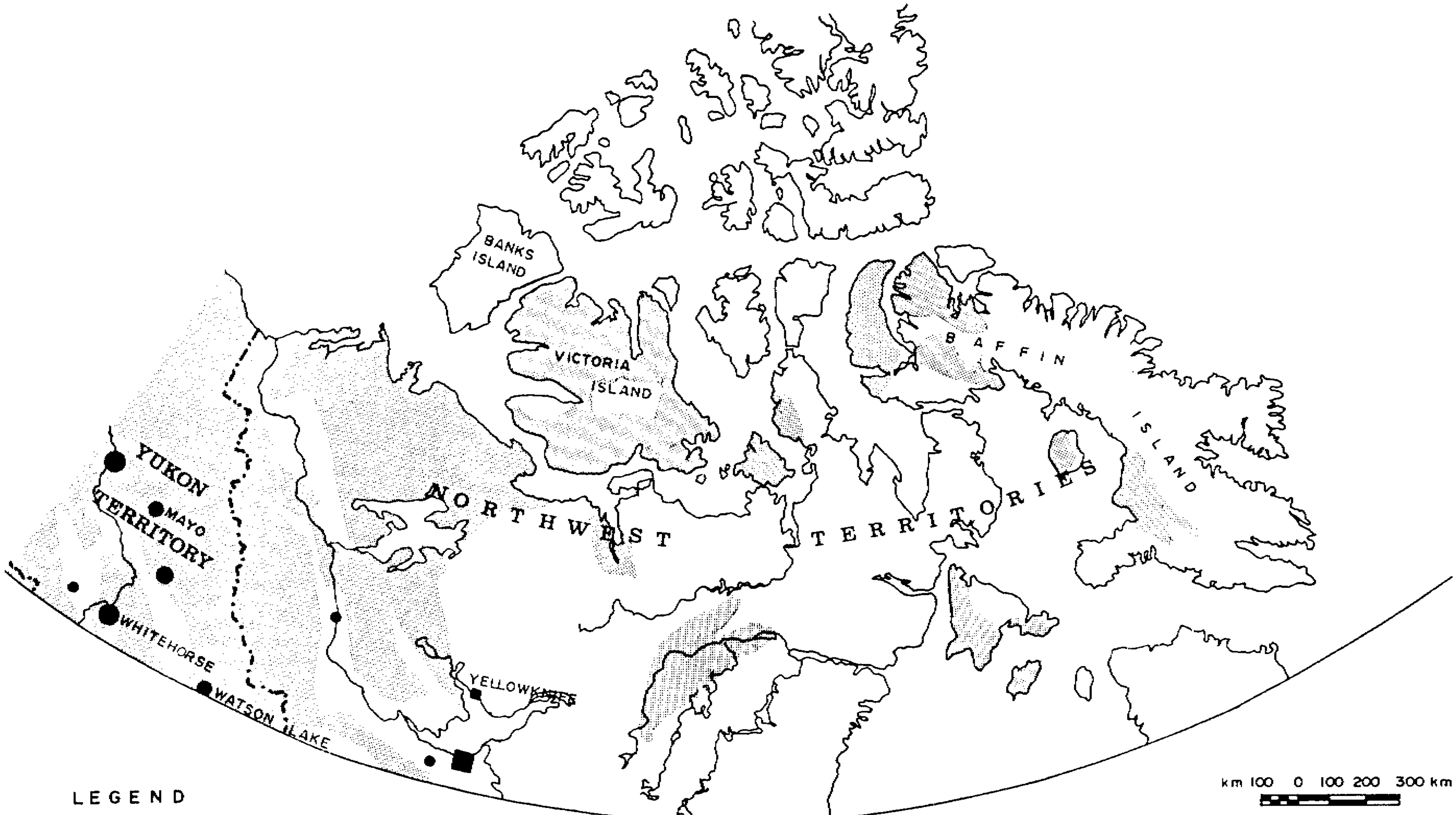


Figure 3

JOB No. A88-2298



LEGEND

MUNICIPAL USERS	(IN 1000 m³/year)	INDUSTRIAL USERS
●	≤100	■
●	101 - 500	■
●	501 - 1000	■
●	1001 - 5000	■
●	5001 - 10000	■
●	>10000	■

AQUIFERS THAT YIELD GREATER THAN 0.5 L/s

PITEAU ENGINEERING LTD.
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS
VANCOUVER CALGARY

ANNUAL GROUNDWATER USE IN THE YUKON AND NWT
(AFTER HESS, 1981)

BY: M.T.
DATE: JAN. /89
APPROVED: [signature]
FIGURE: 4

streams and lakes may occur. In response to such problems, many jurisdictions have introduced regulations requiring groundwater monitoring and aquifer restoration.

To date, concerns over groundwater contamination in Yukon and NWT have not been significant, but with increased water use, industrial development and rapid population growth, this is sure to change.

1.2 DATABASE RATIONALE - The Need for and Benefits of the Databases

The statistics presented in the previous section underline the importance of groundwater to the people of the Canadian North. Yet until now, there has existed no single repository of hydrogeological data for Yukon and NWT. All Canadian provinces have established groundwater data management schemes and regulatory bodies to control the use, development and protection of groundwater.

Hydrogeological data exist for Yukon and NWT, but are scattered amongst various federal and territorial government departments, private consultants, drilling contractors, and archives across the country. The databases will bring together all existing data in an organized fashion. This will allow gradual establishment of a groundwater resource inventory in the territories, consisting of a complete and wide ranging set of hydrogeological information accessible to government, industry, and the public.

Such an inventory will allow the resource to be put into perspective in terms of its distribution, use, value, and susceptibility to long and short term damage. It will also provide the necessary data with which regulatory bodies may make informed decisions regarding the management and protection of groundwater in the future.

Applications for the databases are foreseen in such areas as licensing of wells, determination of abstraction limits, establishment of aquifer protection and monitoring programs, data reporting, and formulation of legislation and policy. Computer filing, sorting and retrieval of information also make the databases a powerful tool for groundwater exploration and development by industry, consultants, and drilling companies, and the popular and accessible personal computer format of the databases allows the information to be utilized by a large number of individuals and organizations.

2. YUKON AND NWT GROUNDWATER DATABASES

The following sections describe the design, contents and operation of the databases, provide information on how groundwater data may be accessed by the public and other interested groups, and how data may be submitted for inclusion in the databases. The final section discusses the storage and retrieval needs of the databases in the future.

2.1 DATABASE DESIGN

2.1.1 What is a Database?

In simple terms, a database is a collection of information on a given subject organized and indexed for easy retrieval, much like a specialized library. With computers, the database can be rapidly searched for specific pieces of information and this data printed out. For example, one could ask the computer to search for all wells in the Whitehorse area and print out their locations and depths. The ability to quickly search for and sort through large numbers of data make databases powerful tools for decision making, statistical analysis, and scientific study.

2.1.2 Software

The Databases are based on the popular dBase IV software, the improved version of the well known dBase III and III Plus packages developed by Ashton-Tate Corporation. DBase IV is recognized as one of the leaders in database systems for micro-computers. DBase has been the industry standard for many years and is unquestionably the most widely used database management system for micro-computers. The advantages of user familiarity, compatibility with most PC's and ease of operation make the dBase line of programs a popular choice. Many other DBMS's emulate dBase and files can be used interchangeably.

The choice of software for the databases was made following a detailed assessment of users needs, preferences and hardware constraints. Several database systems were evaluated, and a review of presently available "environmental software" packages was completed.

2.1.3 Hardware

The databases are designed to run on IBM compatible PC, XT, AT, and 386 machines. Minimum requirements include 640K RAM, 3 Mb of hard disk space, and DOS 3.1 or newer. Speed of operation will vary depending on processor power and speed; for example an AT/286 machine will sort and retrieve data more quickly than a basic XT. Colour or monochrome monitors are supported. Program discs can be supplied in either 5 1/4 inch or 3 1/2 inch formats.

2.1.4 Design and Contents

Each database is divided into five main information categories:

1. **General Information:** Includes well or spring location, owner information, references, types of data available, and comments.

2. **Well Construction Data:** Includes well depth, diameters, casing and screen information, completion details, depth of groundwater-bearing zones, and pump data.

3. **Geology:** Provides a complete lithological/drilling log for the well, including depth and geological descriptions, geophysical logging and permafrost information.

4. **Aquifer Characteristics:** Multiple aquifer test data can be accommodated and are indexed by test date. For each record, such things as test type and duration, test yield, drawdown, transmissivity, storativity, hydraulic conductivity and static water level can be recorded.

5. **Water Quality:** Includes main ion chemistry, metals, organics, a full suite of trace organic compounds including hydrocarbons, EPA volatile and extractable priority pollutants, and bacteriological parameters. Multiple analyses are indexed by sampling date, allowing water quality data from several years to be stored for a given well or spring.

Each database has specific slots for over 280 hydrogeological parameters, and large comment fields at the end of each of the five data fields for written notes and observations. Figures 5 through 5D show reproductions of the nine database screens, showing each parameter slot and screen layouts. Figure 6 shows a schematic diagram of the database structure, illustrating the five information categories.

SCREEN 1

GENERAL INFORMATION

WELL LOCATOR
WELL LICENCE

GROUND SURFACE ELEVATION (metres ASL)

LATITUDE: DEG MIN SEC
LONGITUDE: DEG MIN SEC
UTM COORDINATES: MAP SHEET
NORTHING
EASTING

WELL NAME
TOWN
DISTRICT
TERRITORY

LANDOWNER
ADDRESS
CITY PROV
TELEPHONE

CHECK THE FOLLOWING (Y/N)
SPRING WELL OTHER
PIEZOMETER/OBSERVATION WELL
GEOTECHNICAL BOREHOLE
SPRING YIELD M3/DAY

DATA AVAILABLE: TECHNICA GEOLOGY AQUIFER WATER QUALITY

COMMENT 1
COMMENT 2

SCREEN 2

TECHNICAL / WELL CONSTRUCTION

WELL LOCATOR
WELL LICENCE
DATA QUALITY
DATE DRILLED
DEPTH (M)

SURFACE ELEVATION
CONTRACTOR NAME
ADDRESS TEL
CITY/PROV

HOLE DIAMETER 1 FROM TO
HOLE DIAMETER 2 FROM TO
HOLE DIAMETER 3 FROM TO

GROUNDWATER BEARING ZONES:

ZONE 1
TESTED COMPLETED
SWL (M below GL)
YIELD (M3/DAY)

ZONE 2
TESTED COMPLETED
SWL (M below GL)
YIELD (M3/DAY)

ZONE 3
TESTED COMPLETED
SWL (M below GL)
YIELD (M3/DAY)

COMPLETION DETAILS:
CASING TYPE
CASING 1 DIAMETER
DEPTH
CASING 2 DIAMETER
DEPTH
FILTER PACK (Y/N) DETAILS

SCREEN TYPE
SCREEN OPENING DIMENSIONS
SCREEN BOTTOM DEPTH
SCREEN LENGTH
SCREEN DIAMETER

COMMENT 1
COMMENT 2

Figure 5 Database Display Screens 1 and 2

SCREEN 3

PUMP ASSEMBLY

WELL LOCATOR
WELL LICENCE
DATA QUALITY
INSTALL DATE

SURFACE ELEVATION

PUMP TYPE
MANUFACTURER
MODEL

DEPTH OF INTAKE (M Below GL)
RISER PIPE DIAMETER (mm)

COMMENT 1
COMMENT 2

SCREEN 4

AQUIFER CHARACTERISTICS

WELL LOCATOR
WELL LICENCE
DATA QUALITY
TEST DATE

SURFACE ELEVATION
TYPE OF TEST
TEST DURATION
AQUIFER TYPE

AQUIFER THICKNESS
AQUIFER TOP DEPTH
STATIC WATER LEVEL

TEST YIELD (M3/DAY)
MAX DRAWDOWN
SPECIFIC CAPACITY (M2/DAY)

REFERENCE DATA LOCATION
AQUIFER TEST DETAILS

DERIVED PARAMETERS:
HYDRAULIC CONDUCTIVITY (M/S) METHOD
TRANSMISSIVITY (M2/DAY) METHOD
STORATIVITY METHOD

COMMENT 1
COMMENT 2

Figure 5A Database Display Screens 3 and 4

SCREEN 5

GEOLOGY

WELL LOCATOR
WELL LICENCE
DATA QUALITY

SURFACE ELEVATION
PERMAFROST ENCOUNTERED (Y/N)
PERMAFROST THICKNESS (M)
GEOPHYSICAL LOGS (Y/N)
LOG TYPE(S)

GEOLOGICAL PROFILE:

DEPTH	TYPE	DEPTH	TYPE

COMMENT 1
COMMENT 2

SCREEN 6

WATER QUALITY - 1

WELL LOCATOR
WELL LICENCE
DATA QUALITY

SURFACE ELEVATION
SAMPLE DATE

SAMPLE DEPTH (M Below GL)
METHOD
TEMP (C)

pH	TEMP	TDS	COLOUR
EC	TEMP	TSS	TURBIDITY
			ODOUR

ALKALINITY: TOTAL AS CaCO3	(mg/l)	FLUORIDE	(mg/l)
ALKALINITY: pp as CaCO3	(mg/l)	SILICA	(mg/l)
TOTAL HARDNESS	(mg/l)		

Na	(mg/l)	(meq/l)	Cl	(mg/l)	(meq/l)
Mg	(mg/l)	(meq/l)	SO4	(mg/l)	(meq/l)
Ca	(mg/l)	(meq/l)	HCO3	(mg/l)	(meq/l)
K	(mg/l)	(meq/l)	CO3	(mg/l)	(meq/l)
			OH	(mg/l)	(meq/l)

ION BALANCE

Figure 5B Database Display Screens 5 and 6

SCREEN 7

WATER QUALITY – METALS

WELL LOCATOR		SURFACE ELEVATION	
WELL LICENCE		SAMPLE DATE	
DATA QUALITY			

	DISSOLVED	TOTAL		DISSOLVED	TOTAL
ALUMINUM			LEAD		
ANTIMONY			MANGANESE		
ARSENIC			MERCURY (ug/l)		
BARIUM			NICKEL		
BERYLLIUM			SELENIUM		
BORON			SILVER		
CADMIUM			THALLIUM		
CHROMIUM			THORIUM		
COPPER			TIN		
IRON			ZINC		
OTHER				(mg/l unless indicated)	

COMMENT 1

COMMENT 2

BACTERIOLOGICAL PARAMETERS

TOTAL COLIFORM		E.COLI	
FECAL COLIFORM			

COMMENT 1

COMMENT 2

SCREEN 8

WATER QUALITY – ORGANICS

WELL LOCATOR		SURFACE ELEVATION	
WELL LICENCE		SAMPLE DATE	
DATA QUALITY			

BOD	(mg/l)	NH4 as N	(mg/l)	NO3+NO2 as N	(mg/l)
COD	(mg/l)	TKN as N	(mg/l)	N Other	(mg/l)
TOC	(mg/l)				

DISSOLVED OXYGEN		(mg/l)	CYANIDE		(mg/l)
OIL + GREASE		(mg/l)	PHENOLS		(mg/l)
TRACE ORGANICS (Y/N)					

HYDROCARBONS

NAME	(ug/l)	NAME	(ug/l)

Figure 5C Database Display Screens 7 and 8

SCREEN 9

WATER QUALITY - ORGANICS

WELL LOCATOR
WELL LICENCE
DATA QUALITY

SAMPLE DATE

EPA VOLATILE PRIORITY POLLUTANTS		EPA EXTRACTABLE PRIORITY POLLUTANTS	
NAME	(ug/l)	NAME	(ug/l)

NITROGEN/PHOSPHOROUS COMPOUNDS

NAME	(ug/l)	NAME	(ug/l)

COMMENT 1
COMMENT 2

Figure 5D Database Display Screen 9

GROUNDWATER DATABASE
SCHEMATIC OF DATA FIELDS

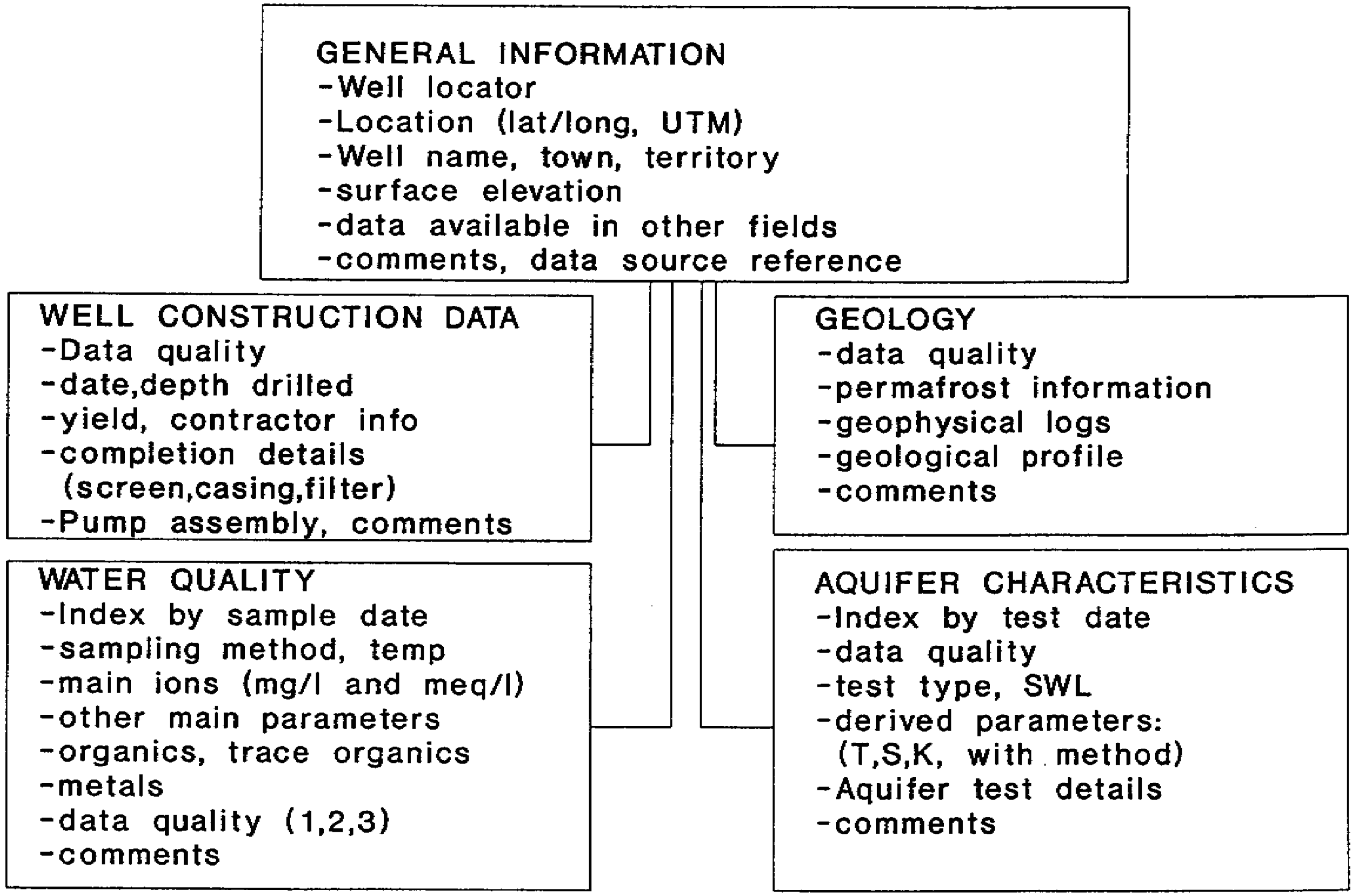


Figure 6

The database is provided as a compiled program. Compiling serves two functions, increasing program efficiency and safeguarding against accidental changes to or tampering with the program code. Both databases use the same software, hardware and structure.

Detailed user's manuals describing operation and features of the database, file maintenance and backup, and full source code listings are available at the database locations at Whitehorse and Yellowknife. (See Sec. 2.3.1)

2.2 DATA

2.2.1 Initial Data Collection

In conjunction with design and development of the databases, a data collection programme was instituted to locate and gather all available hydrogeologic data from Yukon and NWT. Sources of data included the National Hydrology Research Institute in Saskatoon, the Arctic Institute of North America, the Public Works Departments of Yukon and NWT, Agencies of Territorial Governments, DIAND and other federal government departments. Data from private sources was also collected. In total, this initial phase of data collection resulted in over 35,000 pieces of hydrogeological information, including geological/drilling logs, consultant's reports, water quality analyses, and published papers.

2.2.2 Future Data Collection

New data will be added to the databases as they become available. It is hoped that the databases will provide an incentive for concerned groups, agencies and companies to submit, on a voluntary basis, hydrogeological information which they may have available. The addition of new and recent records will substantially increase the utility of the database. Section 2.4 of this publication describes how data may be submitted to DIAND for inclusion in the database.

2.2.3 Data Quality Control

All data contained in each database have been screened, checked, and rated for quality by a qualified hydrogeologist. This ensures users that data retrieved from the database accurately reflect measurements recorded in the field or laboratory, and that erroneous data has been eliminated. All data are rated on a three-tiered scale, consisting of the categories "good", "fair", and "inferior". Each rating is assigned following specific guidelines based on such factors as sources and author of data, field techniques used, type and applicability of analyses, etc. Users can specify data quality as a search parameter, or use it as an indicator of data reliability. For example, if data of quality rating 1 (good) only are desired, the database will automatically screen out fair and inferior data. Data quality ratings are assigned using the following guidelines:

1. <u>GOOD</u>
   - field work done/report prepared or compiled by a qualified hydrogeologist, engineer or scientist. Document signed and or sealed as such.
   - all parameters/values acceptable, no estimates
   - crucial indices (eg. ion balance) OK
   - methods of analysis acceptable, and of good standard. (example: Pumping test analysis:
     - appropriate evaluation technique used?
     - analysis made using valid assumptions.
   - source of information/data is known and of good reputation (consultant's reports, etc.)

2. <u>FAIR</u>
   - Field work report or document prepared by a technologist, driller, or trained, experienced person. Document signed or indicated as such;
   - most parameters/values acceptable, no estimates
   - crucial indices OK
   - methods of analysis OK in general
   - source of data/information known and reliable

3. INFERIOR
- Data compiled/report or document prepared by persons other than those mentioned in categories 1 and 2; or unknown
- some parameters/values questionable, estimates or approximations used in the data
- some crucial indices borderline or missing (note: if crucial indices such as ion balance clearly show data to be of no value, they will be excluded from the database)
- methods of analysis out of date or suspect
- source of information sketchy or unknown

2.3 ACCESSING GROUNDWATER DATA

2.3.1 How to Begin

Although primarily designed for the in-house use of the Department of Indian and Northern Affairs, the database systems can be made available to users outside the department, be they members of industry, academic institutions, other government agencies, or the public. The Yukon database resides at DIAND offices in Whitehorse, and the NWT database resides at DIAND offices in Yellowknife.

The database custodians maintain control over data input, retrieval, quality control, and are responsible for the day-to-day operation of the databases. All requests for groundwater data should be referred to the appropriate database custodian, either in writing or by telephone:

Yukon Groundwater Database
Department of Indian and Northern Affairs
Water Resources Division
200 Range Road
Whitehorse, Yukon
Y1A 3V1
Telephone: (403) 667-3219

NWT Groundwater Database
Department of Indian and Northern Affairs
Water Resources Division
7 th floor, Bellanca Building
PO Box 1500
Yellowknife, NWT
X1A 2R3
Telephone: (403) 920-8251

2.3.2 Preparing a request for data

The database has the ability to search on a wide range of parameters, including location, well depth, data quality rating, etc. Requests for data should specify **clearly** the following items:

1. Name and full address of person or organization requesting data.

2. Data desired from wells, springs, or both.

3. Location of wells or springs, or precise limits of search region.

4. Precise nature of data required: Well construction, aquifer details, water quality, geological/drilling logs, pump information.

In some cases, groups may be supplied with copies of the databases for their own needs. These copies, however, will not include data input capabilities. Experience has shown that unrestricted data input may ultimately lead to a general loss of confidence in the database. Limiting data input to a single location is seen as a prerequisite for maintaining high standards of data input and reliability.

2.3.3 Database Output

Data can be retrieved from the databases in the form of printed standard or custom reports, by modem link between computers, or as datafiles on floppy disc. Each database comes equipped with three standard reports, giving well owner/location information, a basic water quality report, and well depth/yield data. Examples of these standard reports are shown in Figure 7. Users also have the option of producing custom made reports using the add-on Relational Report Writer software provided with each master copy of the database, which provides complete flexibility in data retrieval and sorting. Relational Report Writer is a support package designed specifically for users of compiled dBase IV programs. With it, the database file user does not require the dBase program software to develop further reports from the data files. This allows a number of users to produce reports simultaneously, or in absence of the compiled program.

1. LANDOWNER REPORT

NAME	ADDRESS	CITY	PHONE	LOCATOR

2. WATER QUALITY REPORT

WELL LOCATOR

WELL NAME

SPRING F
WELL T

SAMPLE DATE
DATA QUALITY

AQUIFER SAMPLE DEPTH
M. BELOW G.L.

pH
EC
TDS

MAIN IONS:

Na
Ca
Mg
K

Cl
SO4
HCO3
CO3

3. WELL/AQUIFER DETAIL REPORT

WELL LOCATOR
TEST DATE

AQUIFER TOP DEPTH m.
TEST YIELD (M3/DAY)
STATIC WATER LEVEL m.

MAXIMUM DRAWDOWN m.
TRANSMISIVITY (m2/DAY)

SCREEN BOTTOM DEPTH m.
SCREEN LENGTH m.

FILTER PACK (Y/N)

CASING 1 DIAMETER mm.
CASING 2 DIAMETER mm.

FIGURE 7. THREE STANDARD DATABASE REPORTS

2.3.4 Hardcopy Backup Library

As backup for the database, a library of hardcopy reference files will be available at DIAND offices in Whitehorse and Yellowknife. These libraries consist of data input forms for every database file, and a complete collection of indexed source documents and reports from which raw data was extracted. Each data file contained in the database includes reference to the source documents, allowing the raw data to be reviewed by users if required.

2.4 DATA SUBMISSION

Before initiation of this project, no system existed for the reporting or collection of groundwater data in Yukon or NWT. It is hoped that the databases will provide an incentive for groups involved in northern hydrogeology to submit data as they become available, on a voluntary basis. Additions of new data are key to the long term success and utility of the databases.

Data should be submitted to the appropriate database custodian by mail (addresses are provided in Section 2.3.1 of this publication), preferably as a copy of the source document. These could include drilling/geological logs, water quality analysis reports, reports and publications, etc. Submissions of data should include the name and address of those volunteering the data so that this may be recorded - contributors to the database will be given first consideration for database access.

2.5 FUTURE OF THE DATABASES

The databases have been designed to anticipate the storage and retrieval needs of users for several years to come. However, as the volumes of data contained in the databases grow, and as the number and sophistication of user requests increases, expansion of the databases may be contemplated. This could take place within the PC environment or by moving into larger micro-computer-based systems, such as the micro-VAX-based NAQUADAT system.

Many options exist within the PC environment, and the inherent advantages of simplicity, user accessibility and local control of the system will remain in the foreseeable future. The design of the databases, using the dBase IV system, allows for flexibility. Various peripheral databases can be built to work with the existing system. Examples could include adding databases for aquifer test data, literature references, groundwater use licences and applications, and groundwater monitoring/hazardous waste site information. Hardware upgrading, say to the newer 386 or 486 machines would greatly increase the speed of database processing and the numbers of datafiles easily accommodated within the database. Upgrading to more powerful PC's can be accomplished without program modification. Database files are also designed for full compatibility with Geographic Information Systems (GIS).

3. GROUNDWATER IN YUKON AND NWT : Applications for the Databases

This section of the publication provides a brief overview of groundwater technology and legislation in Yukon and NWT. It indicates how the databases can be applied as a tool in groundwater exploration and development, as background for policy and decision making in resource management, or as a source of information for scientific study.

3.1 GROUNDWATER RESOURCE MANAGEMENT

The databases and data collection efforts described in this publication represent a first step towards a compilation of groundwater inventories for Yukon and NWT. As the importance of groundwater as a source of domestic and industrial supply increases, and as concerns over groundwater conservation, protection from contamination, and aquifer remediation grow, this information will become steadily more valuable and of interest to more groups.

If a groundwater regulatory body (such as those which exist in each of the provinces of Canada and many states of the USA) is ever considered for either Yukon or NWT, the groundwater database and its custodian may form the nucleus of such a group. In most other North American government bodies responsible for groundwater, the maintenance of a groundwater database is a key function. In British Columbia, for instance, the groundwater group, which exists under the umbrella of the Ministry of Environment, lists as its responsibilities such factors as the collection and dissemination of hydrogeological data, provision of technical advisory assistance to the public and industry, and the preparation and distribution of publications on groundwater and wells.

A synthesis of the mandates of groundwater regulatory bodies from British Columbia, Alberta, Saskatchewan, Manitoba and Alaska provides an indication of the possible roles a similar authority could play in Yukon or NWT in the future. Responsibilities could include:

- Groundwater data collection, archiving, and dissemination; maintenance of a groundwater database.

- Development of guidelines for the prevention of aquifer contamination and depletion.

- Identification and prioritization of potential sites of groundwater contamination.

- Establishment of guidelines for monitoring of hazardous and non-hazardous waste disposal sites.

- Licensing of wells and abstraction limits.

- Provision of technical advisory assistance on groundwater exploration, protection, uses and related problems.

- Preparation and distribution of publications on groundwater and wells.

- Formulation of goals and practices for groundwater management.

- Implementation of groundwater monitoring and assessment programs, hydrogeological studies, site investigations and resource inventory programs.

3.2 CURRENT HYDROGEOLOGIC TECHNOLOGY

Yukon and NWT are subject to extreme climatic and hydrogeologic conditions. Zones of continuous and discontinuous permafrost cover the majority of the north of sixty degrees area and constitute what is known as the northern hydrogeological region (Figure 8). In the continuous zone, permafrost thicknesses can reach up to 700 m, while in the discontinuous zone, where permafrost occurs as a non-uniform patchwork, thicknesses can vary from a few meters up to about 100 m (Johnson, 1981).

Permafrost impacts upon the way wells are drilled and completed, where and how groundwater may be explored for, how foundation and retaining structures are designed, and how groundwater and solutes move through the subsurface. The nature of arctic and subarctic ecosystems make the study and use of groundwater in Yukon and NWT especially challenging.

3.2.1 General Hydrogeologic Studies

Judging by the number of papers and symposia, technical interest in the northern hydrogeological region seems to have increased somewhat in recent years. Despite this, large gaps in our understanding of northern hydrogeology remain. Williams and van Everdingen (1973) identified several areas where research is required, including regional hydrochemical studies, the influences of groundwater

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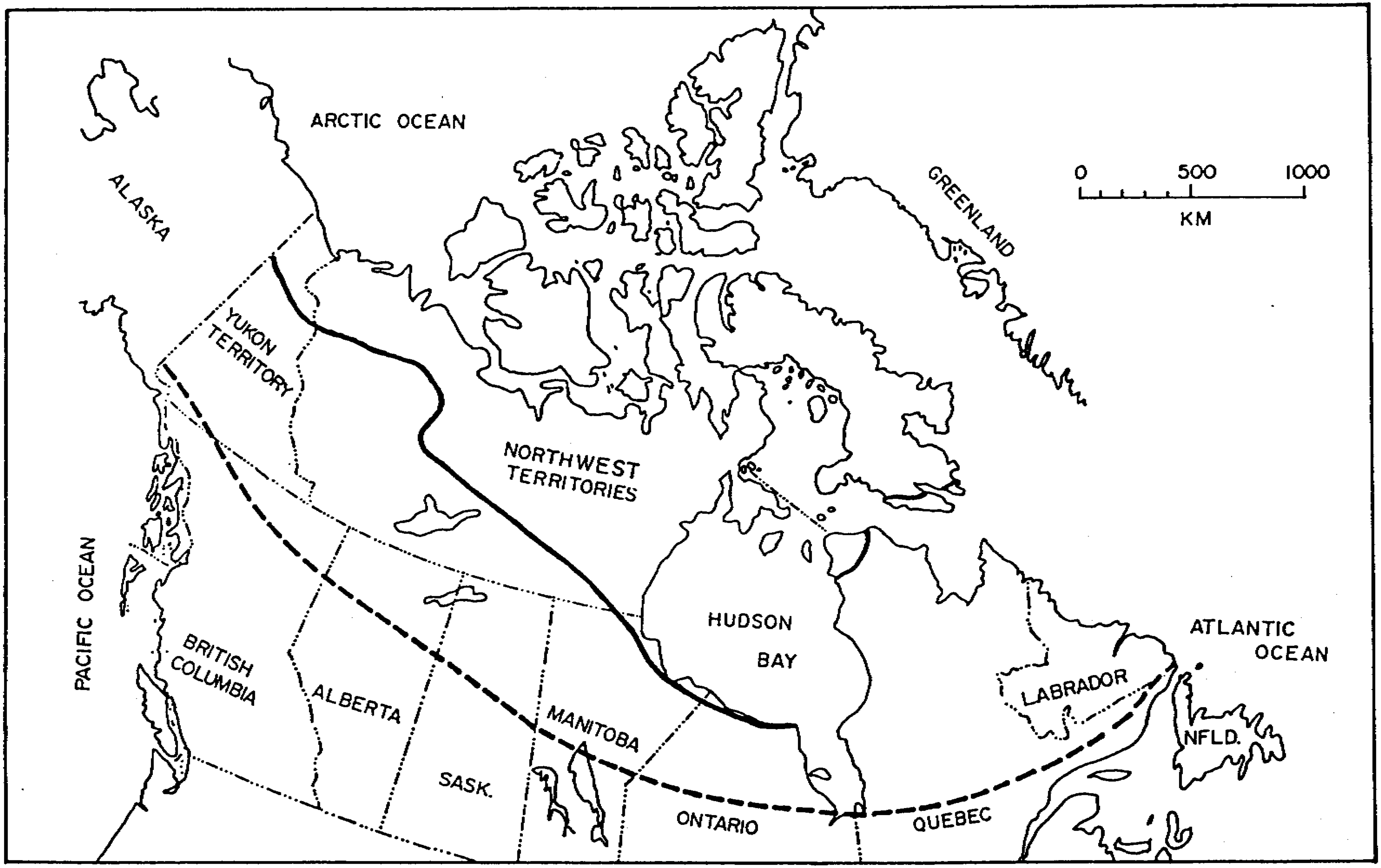

LEGEND

SOUTHERN LIMIT OF CONTINOUS PERMAFROST ZONE

SOUTHERN LIMIT OF PERMAFROST

PERMAFROST IN CANADA

(Modified after Brown and Péwé, 1973)

Figure 8

chemistry on surface water quality, and investigations of the role of permafrost barriers and seasonal freezing and thawing of aquifers on groundwater chemistry and flow. Although this list was made over fifteen years ago, these and other fundamental questions still require further study.

Many local and regional hydrogeological field surveys and general reconnaissance studies are available, including Brandon (1965), Brooks (1983, 1977), and Owen (1965). However, many areas of Yukon and NWT remain unstudied.

3.2.2 Permafrost Hydrogeology

Permafrost is defined as a thermal condition in soil or rock where temperature remains below zero degrees Celsius over at least two consecutive winters and the intervening summer; moisture in the form of water and ground ice may or may not be present (Brown and Kupsch, 1974). Its occurrence is controlled by many site specific factors, including the surface heat balance, vegetation cover, rock or soil type and moisture content, relief, snow cover, and the presence of near surface water bodies such as lakes, rivers, and the ocean.

As ground freezes, a number of its physical properties change. One of the most important effects of freezing from a hydrogeological perspective is a marked decrease in hydraulic conductivity. As temperature declines, more interstitial water freezes, and effective porosity and permeability of the material are reduced. In permafrost hydrogeology, aquifers are often grouped into three major categories:

suprapermafrost aquifers, situated above permafrost, **intrapermafrost aquifers**, describing unfrozen groundwater existing within permafrost (taliks), and **subpermafrost groundwater**, situated below and often confined by relatively impermeable permafrost. Figures 9 and 10 illustrate schematically some of the more common groundwater conditions in permafrost areas.

A relatively large body of literature exists on the nature of permafrost and the design and construction of engineering works in permafrost areas. Topics such as pipeline construction, slope stability, design of excavations, permafrost degradation and other geotechnical subjects have received a good deal of attention. However, the effects of permafrost on groundwater flow, water chemistry, and solute transport are still not fully understood.

A detailed review of the nature, occurrence and properties of permafrost is beyond the scope of this publication. General discussions of permafrost hydrogeology are given in Sloan and van Everdingen (1988), Tolstikhin and Tolstikhin (1974), van Everdingen (1974), Williams (1970), Cederstrom (1961), and Brandon (1965), among others. Specific discussions of water-ice-soil systems are found in Andersland and Anderson (1978), Low et al (1968), Hoekstra (1966), and others.

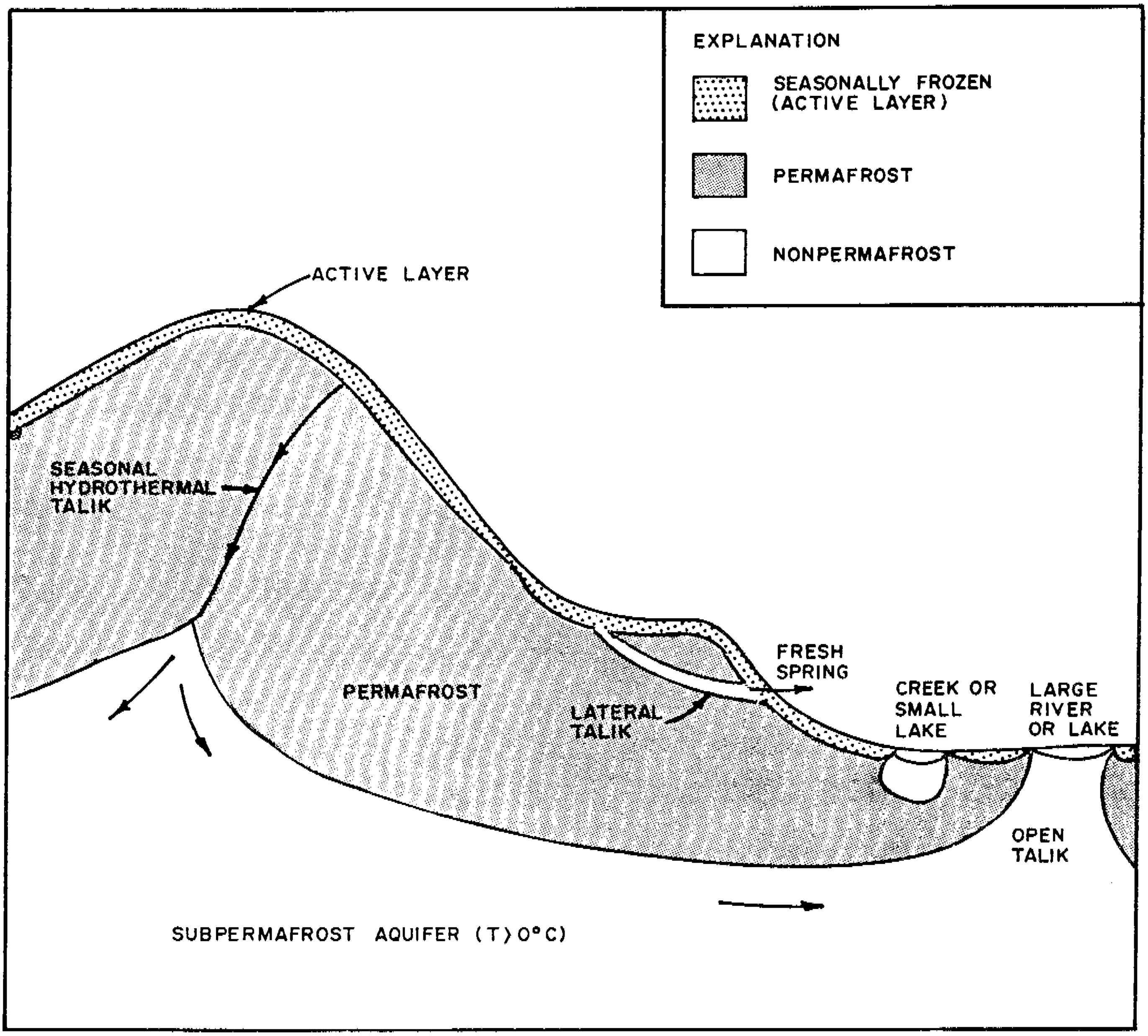

FIG. 9 GROUNDWATER CONDITIONS IN PERMAFROST, PART I
(AFTER SLOAN & VAN EVERDINGEN)

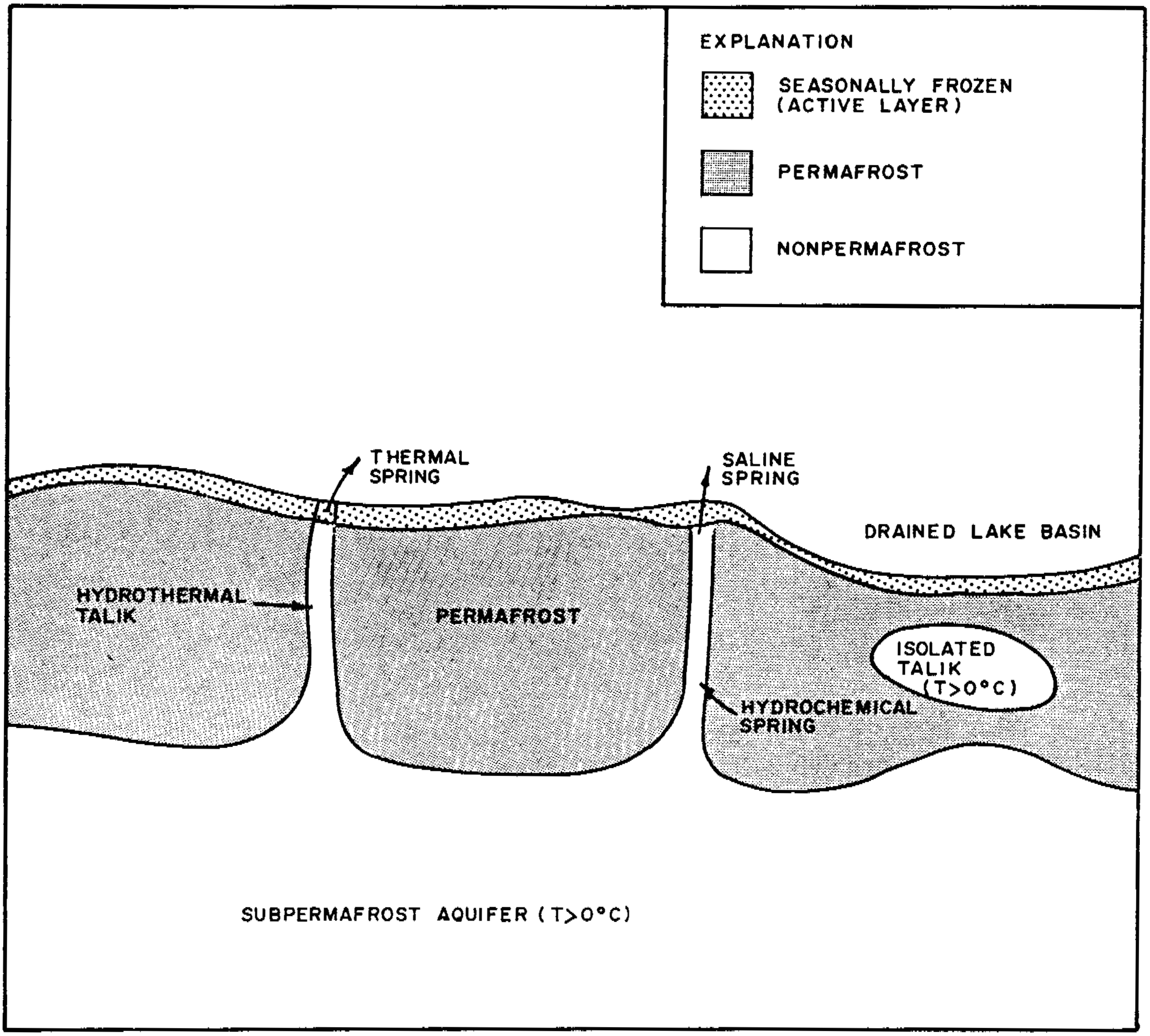

FIG. 10 GROUNDWATER CONDITIONS IN PERMAFROST, PART II (AFTER SLOAN & VAN EVERDINGEN)

Studies of groundwater flow in frozen and partially frozen rock and soil systems include Harlan (1971, 1973, 1974a and 1974b), Ershov et al (1978), and Kane et al (1978). Discussions of the effects of permafrost on groundwater quality are found in Feulner and Schupp (1963 and 1964), Kononova (1973) and Williams (1970).

The groundwater databases will provide an excellent means of quickly and efficiently accessing data on groundwater/permafrost systems and may stimulate further research in areas such as the effects of permafrost and partially frozen rock-soil media on groundwater chemistry, and the chemical behaviour of groundwater contaminants in frozen ground, among others.

3.2.3 Runoff and Recharge Processes

Surface runoff, infiltration, groundwater recharge and active layer behaviour are topics of hydrological and hydrogeological interest. These processes are important when considering water balances, groundwater contributions to stream baseflow, aquifer recharge, water table fluctuations, and vertical movement of solutes and contaminants from the surface and near surface into groundwater-bearing strata.

Literature is lacking on these processes in the northern environment. The mechanisms of groundwater recharge in frozen and partially frozen ground in particular are not well understood. Brandon (1965) discusses recharge briefly in his overview of the groundwater resources of Yukon and NWT. Other papers on the subject include Freeze and Banner (1970), Kane (1972), and Kane and Slaughter (1973), the last of which discusses lake recharge by subpermafrost groundwater.

The mechanisms of surface runoff and infiltration are also important links in the hydrological cycle. A large body of literature describes these processes in temperate and arid climates, but relatively little exists which is applicable to the northern regions. Discussions of these subjects can be found in Obradovic (1983) (groundwater and storm runoff), and Woo and Steer (1982) (surface runoff on arctic slopes).

3.2.4 Springs and Spring Hydrochemistry

The study of springs and their hydrochemistry has received considerable attention in the literature to date. In areas of permafrost, springs provide indications that groundwater movement does occur. Both Yukon and NWT boast numerous thermal springs, some of which discharge directly into streams and creeks, keeping long stretches ice-free year-round. Springs can also form icings or aufeis. Early studies of springs by Beschel (1963) and Brandon (1965) show a wide range of spring water temperature, discharge and water quality. Other work on spring water quality, including isotope geochemical studies, can be found in Cecile et al (1984), van Everdingen et al (1982), Veillette and Thomas (1979), and others.

Data collection efforts made as part of this study yielded hydrochemical analyses for over 370 springs and seeps in Yukon and NWT (see Section 2.2 of this report). Much of this work was originally sponsored by the National Hydrology Research Institute. This much hydrogeochemical data from Yukon and NWT has not been compiled in one form or location before. This information should prove valuable for future hydrogeological studies.

3.2.5 Drilling, Completion and Maintenance of Water Wells

Permafrost and harsh winter conditions in NWT and Yukon pose special problems for drilling, completion and maintenance of water wells. In general, the technology, equipment and materials used in this work are the same as in the temperate regions. Special care must be taken when operating in cold temperatures and permafrost areas.

Permafrost can form an effectively impermeable layer, which may often confine an aquifer at artesian pressure. In these situations, there is risk of uncontrolled flow from wells drilled for subpermafrost groundwater. Linell (1973) discusses this subject in some detail. Other problems associated with drilling into pressurized subpermafrost groundwater include the possibilities of piping, erosion, casing damage, and settlement of well head facilities. These can lead to formation of thaw and erosion pits, surface icings, and permafrost degradation.

In such circumstances, proper casing installation is very important. Linell (1973) suggests that casings be tightly installed, with full contact between pipe and permafrost along the full length of frozen ground. Care must be taken when driving casing into frozen rock and soil, as studies have shown that contact area between permafrost and pipe is reduced by bending and twisting of the pipe.

Water well maintenance in permafrost terrain also presents special problems. Water produced through casings set in frozen ground can either freeze inside the casing or thaw the surrounding ground (see Figure 11). Both scenarios can cause well failure. If water flow is insufficient to prevent the well from freezing, removal of ice from the well, water wastage or installation of thermal insulation may be required.

A review of unpublished reports and documents collected as part of this study indicates that most water supply wells in the Yukon and NWT have been drilled in areas where very little or no permafrost is encountered. Under these conditions, water well drilling, completion, design and maintenance follow the same procedures and use the same methods as in temperate zones. During the winter months, precautions against well freezing may have to be taken.

Local drillers have been operating in these conditions for many years, and have developed techniques and apparatus to deal with the special problems of operating in cold and permafrost regions. Many successful wells and boreholes have been drilled, and one must expect that the current high level of expertise in this area will be maintained for many years to come.

Comment fields in the databases can be used to indicate well freezing conditions or permafrost degradation problems at specific wells, and to record remedial measures, if any, applied.

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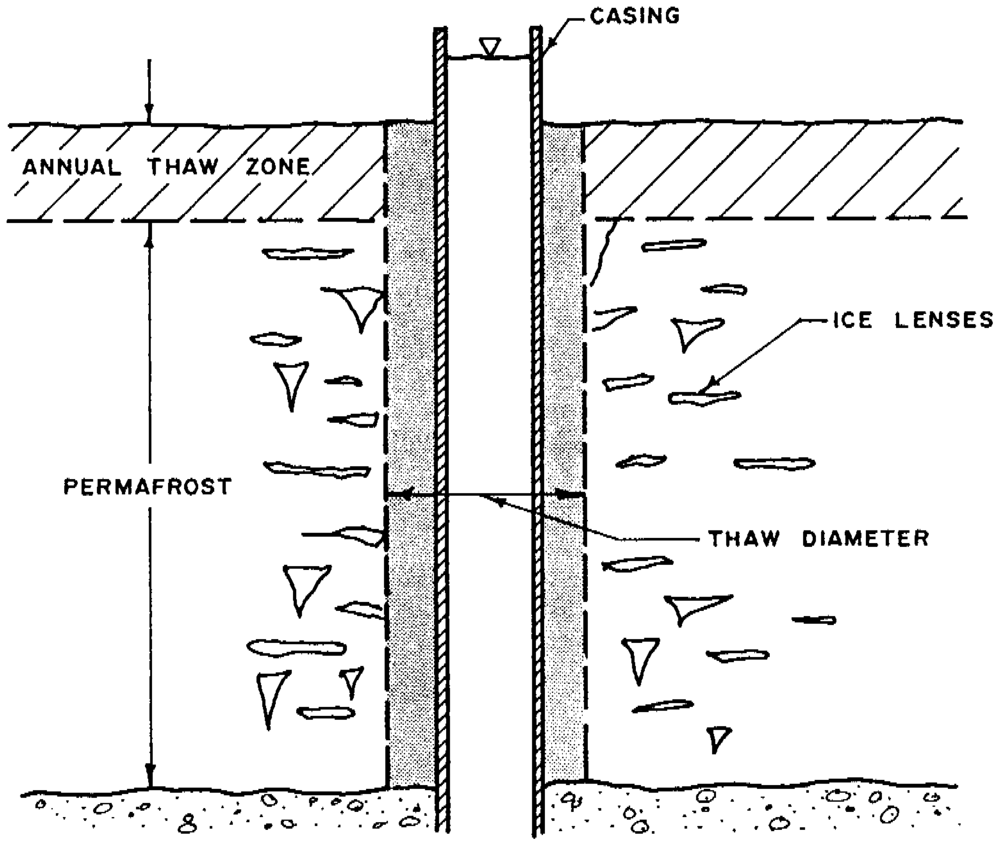

PITEAU ENGINEERING LTD.
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS
VANCOUVER CALGARY

THAW ZONE AROUND CASING SET IN PERMAFROST
(AFTER LINELL, 1973)

BY:	DATE:
M.T.	FEB./89
APPROVED:	FIGURE:
[signature]	11

3.2.6 Groundwater Exploration

The primary steps in any groundwater exploration program are independent of climate and location. Most practising hydrogeologists agree that any exploration program should begin with a thorough review of all available information from the area in which drilling is proposed. This includes collection and review of all well records for the area (where this service is available), examination of maps, air photos, and any relevant publications or papers. These sources provide the hydrogeologist with an initial idea of where and at what depth groundwater is most likely to be encountered, what flow rates and pressures can be expected, and what the quality of groundwater is likely to be. Potential test hole drilling sites can then be chosen and a field reconnaissance conducted to determine site access and geologic suitability. The hydrogeologic information can also be supplemented by geophysical surveys.

Once drilling locations are confirmed, exploratory drilling may begin. Formation samples are collected and logged, water returns measured and recorded, and the hole may be geophysically logged. This information is used to decide where the aquifer is and if the well is to be completed. Once completed, aquifer tests may be conducted to determine long term yields, drawdowns, and aquifer properties such as hydraulic conductivity, transmissivity and storativity.

Data

Exploration for groundwater can greatly benefit from the data on previous drilling programs and information on the current groundwater uses. A groundwater database is an extremely valuable tool for the explorationist. It allows quick access to a large volume of hydrogeologic data which can be selectively retrieved, depending on the needs of the user. For example, the hydrogeologist could ask the computer to print out a report listing all the water supply wells within a specified four NTS map sheet area, and list their completed intervals, yields, and main ion chemistry of the water they produced. This would provide a quick initial picture of where groundwater can be expected and in what quantities.

In the past, Yukon and NWT did not have any public information system on groundwater. The databases will make groundwater exploration much less uncertain.

Geophysics

The presence of permafrost complicates the task of geophysical survey interpretation. Groundwater potential in permafrost is greatest in unfrozen permeable materials above, within, or below permafrost. "Thaw basins" and "thaw bulbs" exist beneath bodies of water in permafrost regions, such as lakes and rivers which do not freeze to the bottom in winter. Geophysical methods applied to groundwater exploration in permafrost zones therefore concentrate on locating these thaw zones (Arcone et al, 1979).

Temperature and ice content greatly influence the electrical resistivity of rock and soil. Small drops in temperature below freezing (0°C) can substantially increase resistivity, by decreasing the content of unfrozen pore water which conducts current. Because of this effect, Arcone et al (1979) found that "thaw zones associated with contemporary lakes and drained lake basins may be delineated on a large scale with airborne adaptations of surface impedance resistivity methods" (low frequency). The same paper also discusses the application of high frequency dielectric methods to groundwater exploration in the Arctic. Hoekstra and McNeill (1973) examine the use of electromagnetic methods for probing permafrost.

In areas where permafrost is discontinuous or absent, geophysical techniques are applied and interpreted as in temperate climates.

3.2.7 Groundwater Contamination, Protection and Environmental Concerns

Groundwater contamination can occur as a result of many different activities. The concentration of large numbers of people and industrial operations usually produce vast quantities of wastes, from sewage effluent to household garbage to industrial by-products. Many of these wastes may affect the open environment, rivers, streams and lakes and in the long run they may contaminate groundwater. Sanitary landfills and dumps may contain wastes which can greatly contribute to deterioration of water quality. Landfills, dumps, storage tanks and waste collection areas located on or near permeable geologic units, unconsolidated sediments, or fractured and jointed bedrock have the potential to contaminate groundwater. Precipitation can percolate through uncovered material, leaching out and carrying away contaminants. Leaking containers and tanks can introduce liquids directly into the ground. Potentially dangerous substances stored in unlined pits, spread or spilled onto the ground may eventually make their way to the water table and underlying aquifers.

Groundwater quality may also be impacted through agricultural operations, road construction and right-of-way maintenance. Chemical fertilizers, pesticides, herbicides, farm waste, and other chemicals can contaminate aquifers. Streams and lakes polluted by sewage or industrial effluents can affect aquifers with which they are in hydraulic connection.

A contaminant "plume" will migrate away from the original source, depending on natural and induced hydraulic gradients and conductivities. Over time, an initially small and local contamination problem can become quite widespread and expensive to control.

Groundwater flow rates are generally slow. It may take years or decades for contaminants to travel a few hundred metres. However, clean-up of contaminated aquifers is difficult and expensive. The longer a plume is allowed to spread, the more expensive will be the arrestation and clean-up program, and the greater will be the potential for impact on users of groundwater.

The level of technology and attention presently being applied to the problems of groundwater contamination and aquifer protection in Yukon and NWT falls well behind that of the rest of Canada, Europe and the USA. Woo and Drake (1988) provide a modelling study of the potential effects of uranium mine tailings on permafrost. Reviews of surface disposal of waste drilling fluids in the arctic can be found in French (1985) and Piteau Engineering Ltd. (1988). The literature contains relatively little on groundwater pollution in the arctic and subarctic.

Zenone and Anderson (1978) present a brief discussion of the incidence of groundwater pollution in Alaska in their overview of the groundwater resources of that state. Problems mentioned include pollution from septic tanks, leakage of sanitary sewers, infiltration of urban runoff, and contamination of groundwater by polluted surface water bodies. Accidental spills of oil, fuels and other liquids, and disposal of petrochemical and industrial wastes are also cited as areas of concern. Zenone, Donaldson and Grunwaldt (1975) discuss solid waste disposal in frozen ground, and the possibilities for groundwater contamination. Straughn (1972) presents an interesting discussion of the sanitary landfill in the subarctic. His case study shows that bacterial degradation of solid waste is extremely slow in the sub-arctic environment, and questions the suitability of this disposal method.

Technology and expertise that can be applied to the monitoring and remediation of contaminated aquifers is steadily improving. In temperate regions, many different processes for contaminant exploration, detection, monitoring, sampling, modelling and removal have been developed.

Geophysical methods and/or exploratory drilling and piezometer installation are used to delineate contaminant plumes. Monitoring of groundwater quality provides data on hydrochemical concentrations and trends. Samples may be collected using bailers, dedicated samplers, and a variety of special pumps. Many different analytical and numerical models have been developed to simulate contaminant migration and dispersion, and predict future movement of solutes (see Konikow and Bredehoeft, 1978). Such models are also applied to determine the most efficient recovery methods and configurations for a specific site (see Freeberg, Bedient and Connor, 1987). A discussion of aquifer remediation technology presently available is far beyond the scope of this report, and could fill several volumes. Methods include pumping wells, infiltration galleries, large diameter well passive collection systems, bioremediation, interception ditches, and many others. Application of these technologies is widespread and growing in both the USA and Canada.

Yukon and NWT, however, have so far had very little exposure to this side of the groundwater industry. This will likely change in the future, as the incidence of aquifer contamination, and the desire to prevent such contamination, increase.

The databases will find many uses in effective groundwater protection. For example, hydrogeological background information can be compiled using the database, problem areas defined and examined, and information gaps detected and addressed. Trends in water quality can be identified, and the data from future investigation and remedial actions can be stored in an organized fashion to be retrieved when necessary.

3.3 GROUNDWATER REGULATIONS AND LEGISLATION

As the demand for groundwater for domestic and industrial purposes increases in Yukon and NWT, and as the potential sources of aquifer pollution multiply, effective control measures supported by sound legislation and regulations become more necessary. This section provides a brief overview of the regulations now in place which pertain to groundwater in Yukon and NWT, and a review of some aspects of legislation related to groundwater in other Canadian provinces, Europe and the state of Alaska. Several recommendations regarding regulatory control of groundwater in Yukon and NWT are offered.

3.3.1 Legislation in Yukon and NWT

Specific legislation governing water use and protection comes under the Northern Inland Waters Act (NIWA) and its Regulations. The Act deals with the conservation, development and proper utilization of the water resources of Yukon and NWT. The Yukon Territory Water Board and the Northwest Territories Water Board have licensing powers under this Act.

All water use applications to the Water Boards undergo a formal review process which includes determining if a licence is required, posting of notices, inviting interested parties to a public hearing, technical review, and ministerial approval should a licence be required. All applications, be they for groundwater or surface water licences, are dealt with by the Boards. Licences are also required for discharge of wastes into inland waters.

Any proposed use of inland waters in NWT and Yukon by a municipality, company, agency or private individual must either be licenced by the appropriate Water Board or authorized by the Regulations. The licence sets out conditions governing the large-scale use of surface water and groundwater. Individual landowners using water adjacent to their property for domestic use are exempt from these conditions. This includes abstractions from private wells. In Yukon and NWT, licences are not required for abstractions of less than 50,000 imperial gallons (225 m^3) per day .

At present, no legislation pertaining specifically to groundwater in Yukon and NWT exists. There are some implications concerning groundwater in guidelines published by INAC on topics such as reclamation, land use, pits and quarries, well sites and tailings impoundment. (See References)

No legislation, guidelines or voluntary system at present exist for the submission of well drilling records in the territories. Nor are there any detailed regulations regarding monitoring requirements and minimum aquifer protection standards at industrial plants and waste disposal sites.

3.3.2 Legislation in Other Jurisdictions

To put the current situation in Yukon and NWT in perspective, it is useful to examine briefly some aspects of the groundwater management regulations and legislation developed in some Canadian provinces and abroad.

Legislation and Regulations

In Canada, responsibilities for management of water resources are shared between the federal and provincial governments under the framework of the Canada Water Act of 1970. In each province or territory, there is at least one water resource management agency. These organizations have powers to approve and licence water use and manage water quality through establishment of guidelines regarding waste disposal practices.

Most Canadian provinces maintain an agency or department responsible for the regulation and protection of groundwater resources. For example, in Alberta, responsibility for regulation of groundwater quality and pollution control is assigned to the Groundwater Protection Branch, Waste and Chemicals Division of Alberta Environment. This branch also initiates investigations of specific sites where potential for groundwater contamination may exist, and funds aquifer remediation and site clean-up programmes. Groundwater exploration permits, abstraction limits and licensing and the overall management of groundwater resources are controlled through the Hydrogeology Branch, part of the Technical Services Division of Alberta Environment.

Most other Canadian provinces, including Manitoba and Saskatchewan, have adopted a legislated approach to groundwater management similar to that of Alberta. In British Columbia, however, groundwater use is not licensed at the present time. The Water Management Branch of the B.C. Ministry of Environment does, however, maintain a Groundwater Section. The main activities of this group are the operation and maintenance of a groundwater database file, the provision of technical advisory services and information on groundwater to the public, operation of a province-wide observation well network, and the implementation of a groundwater quality monitoring and assessment program. Regulations and guidelines are in place to provide some protection against point-source contamination of groundwater by facilities such as landfills.

Much of Europe is densely populated and highly industrialized, and groundwater legislation in many countries reflects legitimate concerns over pollution and aquifer depletion. Most of the major European countries, including Britain, France and West Germany, have specific legislation in place to regulate groundwater resources. The West German Federal Water Act, for example, requires all groundwater abstractions to be licensed, with certain exceptions granted to small private users and collections from naturally flowing springs. Discharges that may pollute groundwater are tightly controlled and certain aspects of land use, such as construction of conveyances of substances potentially harmful to groundwater, are also regulated.

Use and protection of water resources, including groundwater, in the United Kingdom is presently the responsibility of the ten water authorities established under the Water Act of 1973. This, however, may change if government plans to privatize the water industry go ahead. The Water Authorities control abstraction and recharge of groundwater through a licensing system similar to that of West Germany. Power to protect groundwaters from pollution is granted them under the Control of Pollution Act, 1974. Under the act, it is an offence to pollute "specified" underground waters, such as aquifers set aside for particular purposes. Provisions are made, however, for waste discharge into certain aquifers, subject to the terms of a disposal licence. Such a system of designating specific aquifers as "reserve" or "protected" is becoming increasingly popular. In many eastern European countries, aquifers of outstanding purity and quality, or of especial importance as supplies of drinking water, are strictly protected. Land use in these areas is regulated to protect the aquifers and strict controls are placed on all forms and mechanisms of potential contamination (Economic Commission for Europe, 1986).

The use of groundwater in the State of Alaska is more developed than in regions with similar conditions in Yukon and NWT.

The use of groundwater in Alaska is regulated under the Alaska Water Quality Standards, by which all waters of the state are classified into "protected use classes" based on water use (i.e. drinking and food processing, agriculture, industrial, etc.). The Alaska Department of Environmental Conservation (DEC) has adopted US federal primary and secondary drinking water standards, and narrative and numerical quality criteria are assigned to each class. Permits are required from the Department of Natural Resources (DNR) for all groundwater withdrawals in the state. Each permit is reviewed to determine its impact on the groundwater basin and determine maximum safe yield. All well drillers must be licensed by DNR and they must follow approved DNR well construction guidelines and standards (American Petroleum Institute, 1988).

The DEC maintains responsibility for administration of hazardous and non-hazardous waste management programmes. Groundwater monitoring is required at all disposal sites with monitoring frequency and parameters determined individually for each site. The state of Alaska is also involved with the federal EPA Superfund program and undertakes investigations of uncontrolled waste disposal sites where there is risk of potential damage to the environment, health and groundwater supplies.

Specific pieces of legislation relevant to groundwater in Alaska include the Alaska Environmental Conservation Law, Alaska Solid Waste Management Regulations and the Alaska Drinking Water Regulations.

Data Collection and Archiving

All agencies responsible for groundwater reviewed in this report maintain a data system for hydrogeological information as a fundamental responsibility.

Alberta Environment requires drillers to submit drilling records for each well completed in the province. These reports are provided on a standard form. Records are stored by the Groundwater Resources Information Service (GWRIS), which consists of over 12,000 microfiche prints of water well driller's reports, groundwater chemical analyses, geophysical logs, springs, flowing shot-holes (seismic) and structural test holes. The records are continuously updated and computer generated data outputs are available on request. Alberta Environment also keeps an up-to-date microfiche library of over 4,200 groundwater related reports, complete with an author and NTWS bibliography. This information is available to any member of the public or industry for a nominal charge.

All provinces in Canada, with the exception of British Columbia and Newfoundland, have enacted legislation requiring that drilling firms be licensed and that they submit a standard report for each well drilled. In British Columbia, a compromise has been reached. Data are provided to the Groundwater Section of the Ministry of Environment on a voluntary basis by drillers and water well contractors. This practice has, to date, proved reasonably successful, and it is estimated that records are submitted for approximately three-quarters of all wells drilled (P. Wilkinson, 1989, personal communication). The data are currently being input into a micro-VAX computer database system which will provide access to the estimated 60,000 records presently available. This system of voluntary data submission requires concerted public relations efforts by the Ministry of Environment. Legislation requiring the filing of records by water well drillers is anticipated in the next two years.

The state of Alaska began its groundwater data compilation program in 1977 as a cooperative venture between the Alaska Department of Natural Resources (DNR) and the U.S. Geological Survey. All well drillers in the state must be licensed by DNR, and must report hydrogeologic data from each well drilled.

3.2.3 Recommendations

Groundwater legislation, as discussed by the Economic Commission for Europe's Committee on Water Problems (Economic Commission for Europe, 1986), should attempt to achieve a few basic objectives:

- promote rational use of groundwater and the prevention and control of groundwater pollution;
- recognize groundwater as a commodity with economic and ecological value;
- promote strategies consistent with the socio-economic policies of the region;
- ensure that state control be at least partially established over groundwater resources in order to allow for monitoring and implementation of pollution control and prevention measures;
- establish, when and if required, groundwater protection zones or designated aquifers to ensure long-term supply of high quality potable water;

- integrate groundwater and surface water use and protection, recognizing their inherent interdependence in the hydrologic cycle;

- regulate quantity and quality aspects of groundwater resource use;

- provide for the continuing study of groundwater use, occurrence, quality and behaviour in the region, emphasizing the special concerns of local inhabitants.

More specifically, any legislation which may be contemplated for the protection of groundwater in Yukon or NWT should:

- ensure licensing of well drillers and implementation of a well record submission system. A voluntary system of data submission, modelled after the one in British Columbia, may provide an interim solution;

- establish minimum requirements for monitoring of groundwater at all hazardous and non-hazardous waste disposal sites and key industrial facilities;

- clarify responsibility for the costs of remedial actions and environmental protection of aquifers. The "polluter-pays" concept is worthy of review;

- establish groundwater agencies, or expand the role of the Water Boards to be made responsible for the regulatory control of groundwater, formulation of guidelines for well construction and drilling procedures, data archiving, and the promotion of sound practices in groundwater use and protection.

3.4 NEEDS FOR FUTURE HYDROGEOLOGICAL STUDIES

The scope of potential hydrogeological studies and investigations that could be undertaken in Yukon and NWT is large and diverse. Hydrogeology of arctic and subarctic regions is still a relatively new area of study; the little work done to date in this field is mostly related to water supply projects. This section summarizes some of the perceived needs for expansion and improvement of hydrogeologic knowledge, procedures and techniques in Yukon and NWT.

3.4.1 Data Collection, Input and Expansion of the Database

The groundwater databases described in this publication facilitate the use of hydrogeologic data in Yukon and NWT. Governments and the private sector should make every effort to enhance the volume and quality of data they house. As the amount and variety of data which can be accessed grow, so too will interest in and use of the systems.

3.4.2 General Hydrogeological Studies

The general level of information on Yukon and NWT hydrogeology lags behind information on temperate parts of the world. This deficiency extends from regional and basin studies to subjects of particular interest in arctic and subarctic regions. The following topics are recommended for additional studies:

- Regional and basin hydrogeological studies. Mapping of hydrogeological units, variation in water chemistry, expected yields, locations of springs and seeps, and water balance estimates.

- Processes in recharge of subsurface water in permafrost regions. The roles of permafrost and ground ice and the behaviour of the active layer as a seasonal aquifer.

- Investigation of physical, chemical and biological variables controlling quality and quantity of groundwater.

- Review of current drilling and well completion practices. Formulation of guidelines to promote sound practice and protection of aquifers.

- Examination of the use and effectiveness of various geophysical techniques in groundwater exploration in permafrost zones.

- Monitoring of key aquifers to determine water levels, groundwater circulation regime and hydrochemical trends. This monitoring could determine if certain aquifers are being overpumped or contaminated, and indicate measures required for management of groundwater.

- o Forecasting of long-term trends in groundwater use. Expected long-term changes in groundwater use and recommendations for management of water resources to provide for anticipated demands in water supply.

- o Assessment of the implications of climatic change for management and protection of groundwater.

3.4.3 Groundwater Contamination Studies

Studies on contamination of groundwater and its protection place emphasis on investigations of the physical, chemical and biological processes influencing the behavior of organic and inorganic contaminants in both the unsaturated and the saturated zones.

The subject of contaminant hydrogeology has to date received little attention in Yukon and NWT. The large area and low population density of the territories seem to have buffered to some extent the impacts of groundwater pollution on the environment and groundwater users. This situation, as experience in many other parts of the world has shown, cannot be expected to continue indefinitely. Several instances of contamination of groundwater have been identified in Yukon, and it is expected that new cases will come to light as development in the North grows, and as contaminants from various activities begin to show up in groundwater seeps, springs and wells.

Potential contamination of groundwater exists at waste oil and industrial liquids disposal sites, fuel service stations, permanent fuel tanks and temporary fuel caches, abandoned waste disposal pits from the war and post-war years which may contain oils and pesticides such as DDT, herbicides and other chemicals, municipal landfills, storage facilities with hazardous wastes and other sites.

Site Investigations

Selected sites in Yukon and NWT, where the potential for contamination of groundwater exists or is suspected, should be investigated. Experience gained would enhance understanding of contaminant movement and behaviour in groundwater under arctic and subarctic conditions.

Such investigations could involve literature and data review, field reconnaissance and evaluation, hydrogeological field investigations, sample analysis and conclusions with recommendations for follow-up actions.

Possibilities also exist for the development of numerical computer models for simulation of transport of contaminants in subsurface water in the permafrost regions of northern Canada. This topic has also received little attention to date. Once such models are successfully applied to a specific site and adapted or modified for permafrost and low temperature solute behaviours, they could be readily applied to other areas of interest in Yukon and NWT.

One or more case studies on sites which involve contamination of groundwater and monitoring or recovery schemes should be initiated to develop locally suitable techniques and gain experience which could be applied throughout similar areas of Yukon and NWT.

Each groundwater database will provide both a source of data for preliminary investigation and a recording medium for new data collected, allowing future work to take full advantage of the information collected and experience gained.

Research

Research is needed into the mechanisms and effects of groundwater contamination in arctic and subarctic environments. Topics which could be considered for future research include:

- Processes of contaminant advection and dispersion in frozen or partially frozen ground. How do key parameters in the solute transport/dispersion equations vary in these conditions?

- Behaviour of various common contaminants/solutes (such as chlorides, metals, organics) in frozen or partially frozen ground. How are retardation factors and chemical mobility affected by the presence of ice and low temperatures? What effects do contaminants have on frozen ground?

- Chemical breakdown rates in the arctic: What differences in bacteriological and chemical degradation processes exist between temperate and cold regions? This is particularly applicable to the study of landfills and their leachates.

- Effects of various contaminants on the arctic and subarctic environments. Bearing in mind the nature of northern ecosystems, what detrimental effects may be caused by release of different concentrations of various contaminants into the environment. Polluted groundwater may find its way into lakes, rivers, streams, bogs and marshes and so may impact on the physical and biological environment.

- Remedial techniques of contaminated sites in arctic and subarctic environments. The many techniques available should be evaluated and tested under northern conditions. In-situ bioremediation technology, for example, may be ineffective at low temperatures.

- Methods for disposal and containment of wastes suitable for Yukon and NWT. Innovative techniques should be developed to eliminate or minimize potential effects from wastes on surface and groundwater quality.

- o Protection of aquifers from contamination. Aquifers of particular importance, such as those used for domestic water supply should be investigated for susceptibility to contamination, and preventive measures for their protection developed.

In summary, the scope for potential research in contaminant hydrogeology in Yukon and NWT is both large and varied. Several site-specific investigations, aimed at areas of suspected or known groundwater contamination should be conducted. These cases could serve as a basis for wider application of the techniques learned and experience gained. They would also provide opportunities for research into topics of particular interest in the field of northern contaminant hydrogeology, such as the effects of groundwater-delivered pollutants on arctic and subarctic ecosystems.

The groundwater databases will provide an excellent source of background information and test data for these types of research.

4. CONCLUSIONS

4.1 DATABASE DEVELOPMENT

1. PC-based groundwater information management systems have been developed for Yukon and NWT.

2. A considerable volume of good quality hydrogeological data from Yukon and NWT has been assembled and entered into the database.

4.2 HYDROGEOLOGIC TECHNOLOGY REVIEW

1. The overall level of understanding and study of hydrogeologic processes in arctic and subarctic climates lags behind that of more temperate regions.

2. The large body of literature that exists on the subject of permafrost deals mostly with topics of geotechnical interest. Relatively little, however, has been published on the effects of permafrost on groundwater quality and flow.

3. Permafrost and harsh winter conditions pose special problems for drilling, completion and maintenance of water wells.

4. Where no frozen ground is encountered, water well drilling and completion follows the same procedures and makes use of the same technology as in temperate zones.

5. The general level of research and technology presently being applied to the problems of groundwater contamination and aquifer protection in NWT and Yukon falls well behind that of the rest of Canada and the USA. References to such topics in the literature are scarce. There are various techniques available for investigations of contaminated aquifers and remedial actions at contaminated sites. As of yet, little of this expertise has been applied in Yukon and NWT.

4.3 NEEDS FOR ADDITIONAL STUDY

1. All areas of hydrogeology in NWT and Yukon would benefit from additional study. Areas of particular concern include systematic collection of new data, characterization of regional hydrogeological conditions, and the effects of permafrost on groundwater quality and flow.

2. The subject of contaminant hydrogeology in arctic and subarctic regions requires much study. In general, instances of groundwater contamination are becoming more frequent and serious. This trend should be expected to continue with increasing population and development.

3. Potential sources of aquifer contamination in Yukon and NWT include municipal and industrial landfill sites, leaking gasoline service station storage tanks, abandoned and operational waste disposal sites, septic fields, mine tailings, and sites storing fuels and other hazardous materials.

4.4 GROUNDWATER LEGISLATION AND GUIDELINES

1. Most Canadian provinces maintain an agency or program responsible for regulation and protection of groundwater resources. In general, such agencies grant licences for groundwater abstraction, disposal and use, and require that drillers be registered and submit records for all wells drilled. Most agencies maintain a computerized groundwater data system.

2. No comprehensive guidelines for monitoring of groundwater quality at industrial and waste disposal sites are available for Yukon and NWT.

3. No regulations now exist to ensure the protection of aquifers of particular importance or quality in Yukon and NWT.

5. RECOMMENDATIONS

1. The amount of data contained in the groundwater databases should be increased. New data should be systematically collected and the databases kept up-to-date. Remaining existing data should be gathered and included in the databases. Government departments and agencies, industry and the public should be made aware of the existence of the databases, their uses, and the need for continuing submission of hydrogeologic data.

2. Studies addressing the subjects of arctic and sub-arctic hydrogeology should be encouraged. Particular areas of concern include topics pertaining to the contamination of groundwater and remedial actions at contaminated sites, occurrence, movement and quality of groundwater in regions, and the effects of permafrost on natural and contaminated groundwater. Selected sites where the potential for groundwater contamination exists or is suspected should be investigated.

3. The databases should be be used in management and regulatory control of groundwater. Consideration should be given to promulgation of stringent regulations governing use and protection of groundwater resources. These could possibly include guidelines for groundwater exploration, completion and abandonment of water wells, and monitoring of groundwater at sites where potential for contamination exists. Other guidelines could address licensing of water well drillers, and protection of aquifers of special importance such as for domestic water supply.

4. Consideration should be given to clarification of policy objectives and preparation of action plans for development, management and protection of groundwater. Such a plan should contain a program for public awareness on the significance of groundwater and the needs for its protection.

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