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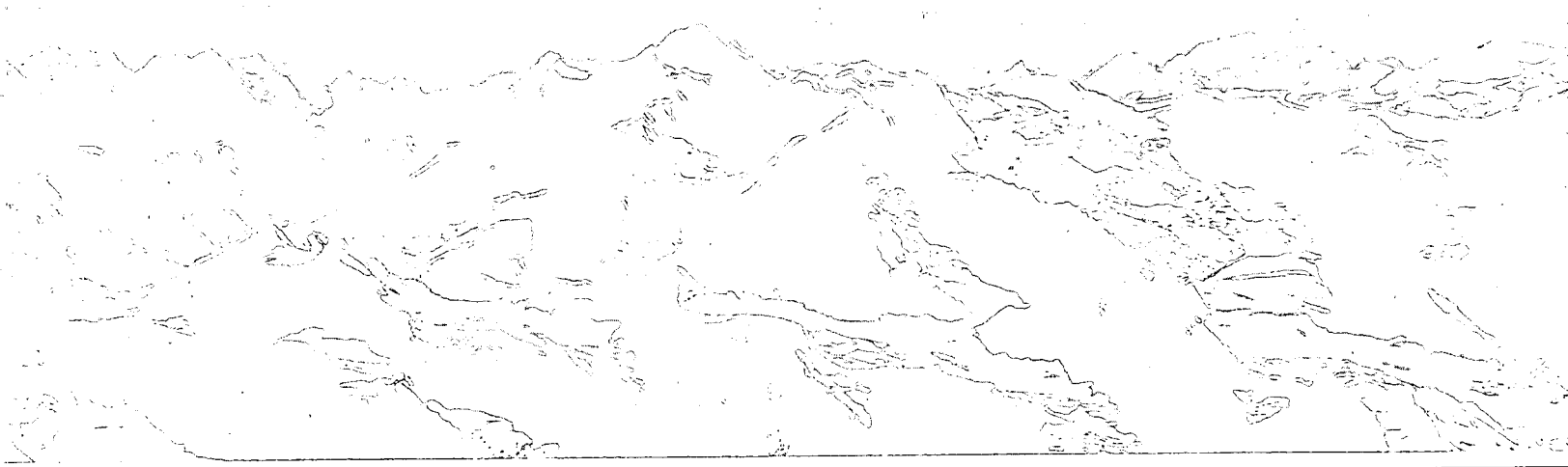
Hydrology Research Division

Summaries of Progress and Short Research Reports



REPORT SERIES NO. 42

INLAND WATERS DIRECTORATE,
WATER RESOURCES BRANCH,
OTTAWA, CANADA, 1975.

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Research Program, Hydrology Research Division

Summaries of Progress and Short Research Reports

INTRODUCTION

The Hydrology Research Division is one of two research arms of the Water Resources Branch, Inland Waters Directorate, Environment Canada. Its activities fall into two distinct categories: (1) hydrogeologic research and (2) research into other aspects of the hydrologic cycle in general. In both of these categories, selection of research projects or programs is guided by two broad objectives:

1. To develop hydrologic techniques and methodologies for water resource management.

2. To identify operational areas in the water resource field where there are needs for research and to implement appropriate research projects and programs.

At the present time the Hydrology Research Division has five main research programs comprising some 30 individual projects. The programs include: (1) the Maritime Research Program to investigate salt-water intrusion into coastal aquifers and flow through fractured media; (2) the Subsurface Contamination Research Program to investigate the infiltration of fluid contaminants into the subsurface and their movement through the ground; (3) the Northern Hydrogeology Program to gather information on the groundwater-permafrost system of northern Canada and to improve our understanding of its response to environmental disturbances; (4) the GOWN program to develop an operational computerized system for the storage, processing and retrieval of groundwater data; and (5) the Interface Hydrology Program to develop, investigate and improve hydrologic simulation and forecast models.

This publication contains a series of brief papers and reports on various aspects of these research programs. In some cases, they report generally on progress made during the period of about a year terminating in the early autumn of 1974; in others, detailed results are given for some selected completed portion of the research study. Our objective for this publication has been to process the contributions reasonably quickly in order to get the information out while it is still fresh.

This publication has evolved from an earlier series of project catalogues presenting somewhat similar information on research progress. The format for the earlier members of the series, however, was a tabular

one with information being presented under a series of standard headings. We believe the new narrative presentations will be both more interesting and more informative. The older tabular project outline formats are nevertheless being retained, but primarily for internal use.

The preceding publications in the project catalogue series were as follows:

The Federal Research Program in Hydrogeology
1967-68, 60p.

The Federal Groundwater Program.
Annual Project Catalogue 1968-69.
IWB Rept. Series 3, 82p.

The Federal Groundwater Program.
Annual Project Catalogue 1969-70.
IWB Rept. Series 8, 108p.

The Federal Groundwater Program.
Annual Project Catalogue 1970-71.
IWB Rept. Series 13, 113p.

Research Program. Hydrology Research
Division. Project Catalogue 1971-73.
IWD Rept. Series 31, 145p.

Limited numbers of these earlier publications are still available.

THE EFFECT OF WASTE DISPOSAL BASINS ON THE GROUNDWATER REGIME

Project No. GW 67-12

J.A. Vonhof*

This study is conducted near the International Minerals and Chemical Corporation K_2 Mine near Esterhazy, Saskatchewan. The objectives are 1. To evaluate long-term effects of brine storage in ponds on the groundwater regime in the area. The effects on surface-water resources of the area are also being monitored. 2. To determine if and when remedial measures must be taken to limit the spread of subsurface pollution. 3. To recommend possible alternative solutions to long-term waste disposal problems of the potash industry.

Several test drilling programs were conducted over the period 1968 - 1973 to define the geological model. Observation wells were constructed in 1971 to obtain data on the hydrodynamic response of the system. Water level recorders were installed in all observation wells and the water levels have been recorded continuously since 1971. The same wells are used for sequential water sampling to determine if any changes in the groundwater chemistry have occurred as a result of the operation of the large brine disposal ponds.

Preliminary interpretation of the results indicates that there is no immediate danger of groundwater pollution.

* Hydrology Research Division, Calgary

NICOMEKL - SERPENTINE BASIN STUDY, FRASER LOWLAND, B.C.

Project No. GW 67-16

E.C. Halstead*

This is a representative basin study included in the IHD program. The Nicomekl and Serpentine Rivers drain an area of 322 km^2 within the western part of Fraser Lowland. The drainage basin is underlain by more than 300 m of unconsolidated deposits through which regional flow systems discharge groundwater commonly with high total dissolved solids and in particular a high sodium chloride content. Throughout the year observation wells are measured and samples are collected for water quality analysis.

The basin is entirely within that area studied under Project No. GW 71-1 and the two projects are contiguous. The original purpose of the study was to analyze the hydrogeologic regime in a thick sequence of unconsolidated surficial deposits constituting a valley fill. It is now anticipated that all results from this study will be incorporated into the more broadly based GW 71-1.

*Hydrology Research Division, Vancouver

HYDROGEOLOGICAL MAPS OF THE LAKE ONTARIO BASIN

Project No. GW 68-4

R.L. Herr*

The principal objective of this project is to develop computer methods for the construction of hydrogeological maps.

Previous work consisted of the development of a plotting routine for checking digitized values of parameters to be mapped with the actual plotted values. The editing and compilation of well data for the Lake Ontario basin have also been completed and a portion of these edited data have been inserted into the GOWN system.

A series of retrievals have been made on the data in the GOWN system to produce overburden isopach and bedrock structure contour maps for the following sub basins of the Lake Ontario Basin:

1. Duffin Creek
2. Oakville Creek
3. Wilmot Creek

These maps have been constructed using GOWN data and Calcomp's General Purpose Contour Program with the objective of comparing these maps with hand-drawn maps prepared by the staff of the Ontario Ministry of the Environment in Toronto.

At the present time these maps are being objectively compared to test the validity of maps produced from the data stored in the GOWN system.

From the initial tests it would appear that the computer-constructed maps, despite some fundamental limitations, are useful for a first approximation of an area and can be improved as additional data are acquired. Their chief advantages lie in the rapidity and relative economy of their preparation from a computerized groundwater data file; their limitations are related to a present inability to cope with certain commonly recurring geologic, hydrologic and topographic phenomena. These include: faulting, abrupt surface elevation changes or fluctuations, and the coincidence of the water table with adjacent fresh-water bodies. The basic contouring program would have to be radically modified to allow for these phenomena in the mapping process. Costs would thereby be increased and there is some question whether the advantage of rapid production might also be lost.

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* Hydrology Research Division, Ottawa

GOWN - OPERATION AND MAINTENANCE

Project No. GW 68-5

G. Grove*

For logistical reasons a set of programs for the GOWN data storage and retrieval system is maintained only on an IBM 360 computer system. In anticipation of the possible implementation of the GOWN system on a CDC computer at Dalhousie University in Halifax, conversion of the programs from the IBM 360 to CDC 6400 computer systems was undertaken. During the conversion process, machine-dependent syntax was rewritten using ANSI standard COBOL and other changes made to guarantee compatibility of the programs between the two systems.

The syntactical conversions, preparation of control cards and setting up of data files for both the data storage and data retrieval systems were completed by a student during the summer of 1973. Production testing in the fall revealed no major problems for conversion of the data storage programs. However, a major difference in internal mode of operation for identical syntax was experienced for several of the programs in the data retrieval system. Extensive reprogramming to provide compatibility between the two computer systems was necessary. The IBM versions of the programs now only need to be put through a code converting utility program and some minor changes (which have been noted) made for differences in file definition in order to make the programs operational on the CDC 6400.

The problems associated with the conversion of the GOWN system to metric units have been investigated and it has been ascertained that few changes to the basic system should be required. Changes to the format of three or four basic data items on the master files due to the change in magnitude of numbers or units of measurement, and some changes to the reasonable limits which are used for checking the validity of data items are the only changes which will be required in the present programs. Conversion programs will have to be written to convert the appropriate fields from British units to metric units on the existing master files.

Perhaps the most complex aspect of the conversion process will be the transition period required for users to adapt to the new system of units. Although it is possible to arrange for the conversion of the basic data files and for the implementation of a new set of programs on a predetermined date, it is recognized that the data provided by the users will not always be in one consistent set of units. Therefore, provision must be made for processing data in either set of units for an indefinite period of time before and after the date set for conversion of the basic system.

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* Hydrology Research Division, Ottawa

During the summer of 1974 a student was assigned to design and write pre-edit programs for the well data and well log files. If the data are known to be coded in the British system of units the programs convert the data to metric units. Otherwise, the data values are scanned and, based upon probable ranges of data and other edit checks, those data items which are known to be coded in British units will be converted to metric units and those data items which are suspected of being coded in British units will be flagged by a warning message but no conversion will be performed. The user may then take appropriate action.

A HYDROCHEMICAL STUDY IN THE INTERSTREAM AREA OF THE OTTAWA AND ST. LAWRENCE RIVERS

Project No. GW 68-7

J.E. Charron*

The objective of this project is, through hydrochemistry, to determine the direction of groundwater flow in the interstream area between the Ottawa and St. Lawrence Rivers. The study area includes Russell, Prescott, Glengarry and Stormont Counties in Ontario as well as the relatively smaller interstream area located in Quebec. After five field seasons the field work was completed in September of 1973. The field work consisted in gathering data on over 10,000 water wells and sampling 440 of these wells as representative wells. One report on the Russell County, Ontario portion of the study area is ready for publication early in 1975. The maps have all been printed and the text edited.

Since October 1, 1973 the work on this project has consisted in programming and analyzing computerized hydrochemical contour maps and comparing them with the hand drawn maps of the same area that had been drawn over the past five years. The results are more encouraging than had been initially anticipated. The computerized and hand-drawn contours are compatible in delineating the direction of groundwater flow. Besides, from the groundwater viewpoint, the computerized contour maps are more accurate and bring out more details locally and regionally than do the hand-drawn maps. Furthermore this work makes possible for the first time a comparison between the chemical and the piezometric head approaches to groundwater flow. Again the two methods are compatible. However it would seem that the chemical approach gives much more detail using the same number of control points than does the piezometric approach.

This project should be completed by early 1975 and handed in for publication. The data contained on four contour maps, notably the static water level (SWL) elevation map, the depth to SWL map, the bedrock elevation map, and the depth to bedrock map could be of great help in planning parts of the oil pipeline route proposed between Sarnia and Montreal.

REFERENCE

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* Hydrology Research Division, Ottawa

POTENTIAL EVAPORATION - SIGNIFICANCE AND MEASUREMENT

Project No. GW 68-8
F.I. Morton*

A primary objective of the project has been the development of a model for estimating the areal evaporation, i.e. the evaporation and transpiration from a large area, using only routine climatological observations. The basic assumption is that changes in the availability of water for areal evaporation are reflected in the temperature and humidity of the overpassing air in such a way as to produce complementary changes in the potential evaporation. This means that the sum of the areal and potential evaporation should be equal to twice the potential evaporation that would occur if the areal evaporation were not limited by the availability of water. Until recently the latter quantity was assumed equal to one-half the absorbed insolation (Morton, 1971). However Priestley and Taylor (1972) have suggested a more rational and better documented alternative. This alternative has provided the basis for a major breakthrough in the formulation of the model during the past year.

The new version of the model permits monthly values of areal evaporation to be estimated from routine observations of temperature, humidity and sunshine duration. The only other inputs are the average atmospheric pressure (a function of station altitude) and the extra-atmospheric insolation (a function of station latitude and the time of year). Most of the empirical components have been found in the literature. However, the snow-free albedo was assumed to vary from 0.25 in arid regions to 0.18 for the darker vegetation of more humid areas, with transitional values estimated from a relationship with the average summer humidity. Two other components were derived from a regression analysis of climatological data from the arid southwestern United States, where it may be assumed that the monthly values of areal evaporation are equal to the monthly precipitation. Thus the model is completely calibrated and requires no local optimization of parameters or assumptions concerning the soil-vegetation system. It has been programmed for computers and for the Hewlett Packard 9100 A - 9101 A Desk Calculator.

Figures 68.8.1 and 68.8.2 are maps of the southeastern United States and of Canada to the east of the Pacific Divide which show isopleths of average annual areal evaporation for five-year periods. The maps are based on the accumulation of monthly model estimates for the climatological stations reporting both air and dew point temperatures. The isopleths were plotted by linear interpolation

* Hydrology Research Division, Ottawa

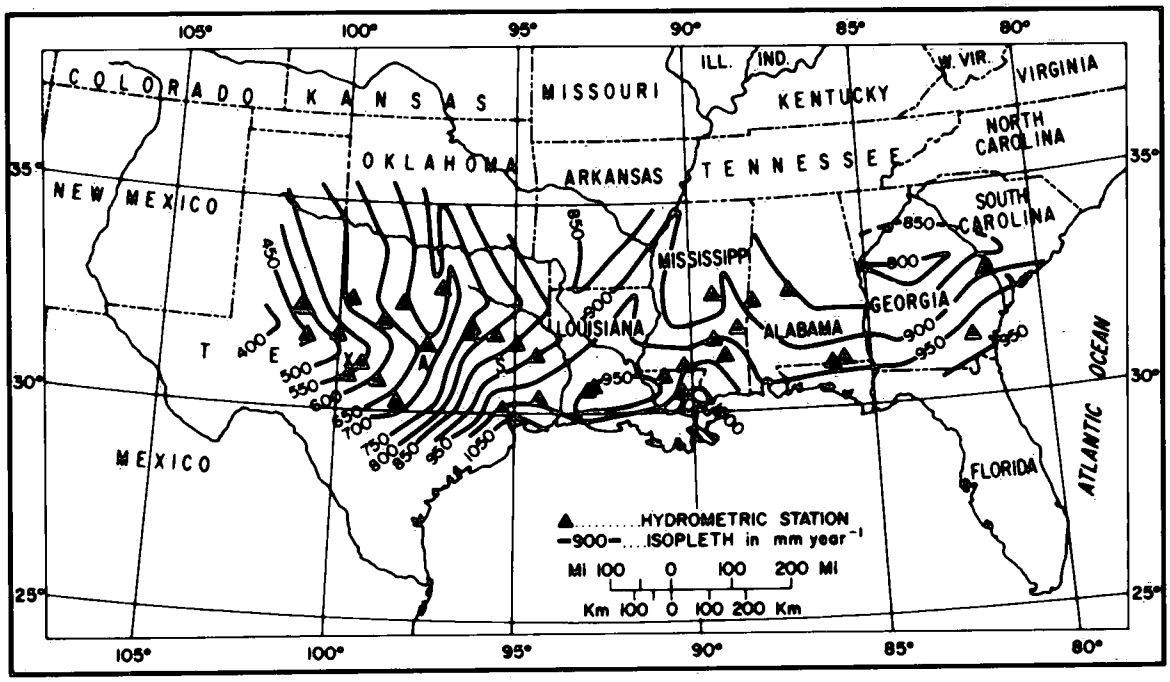

Figure 68.8.1. Isopleths of areal evaporation for the southeastern United States.

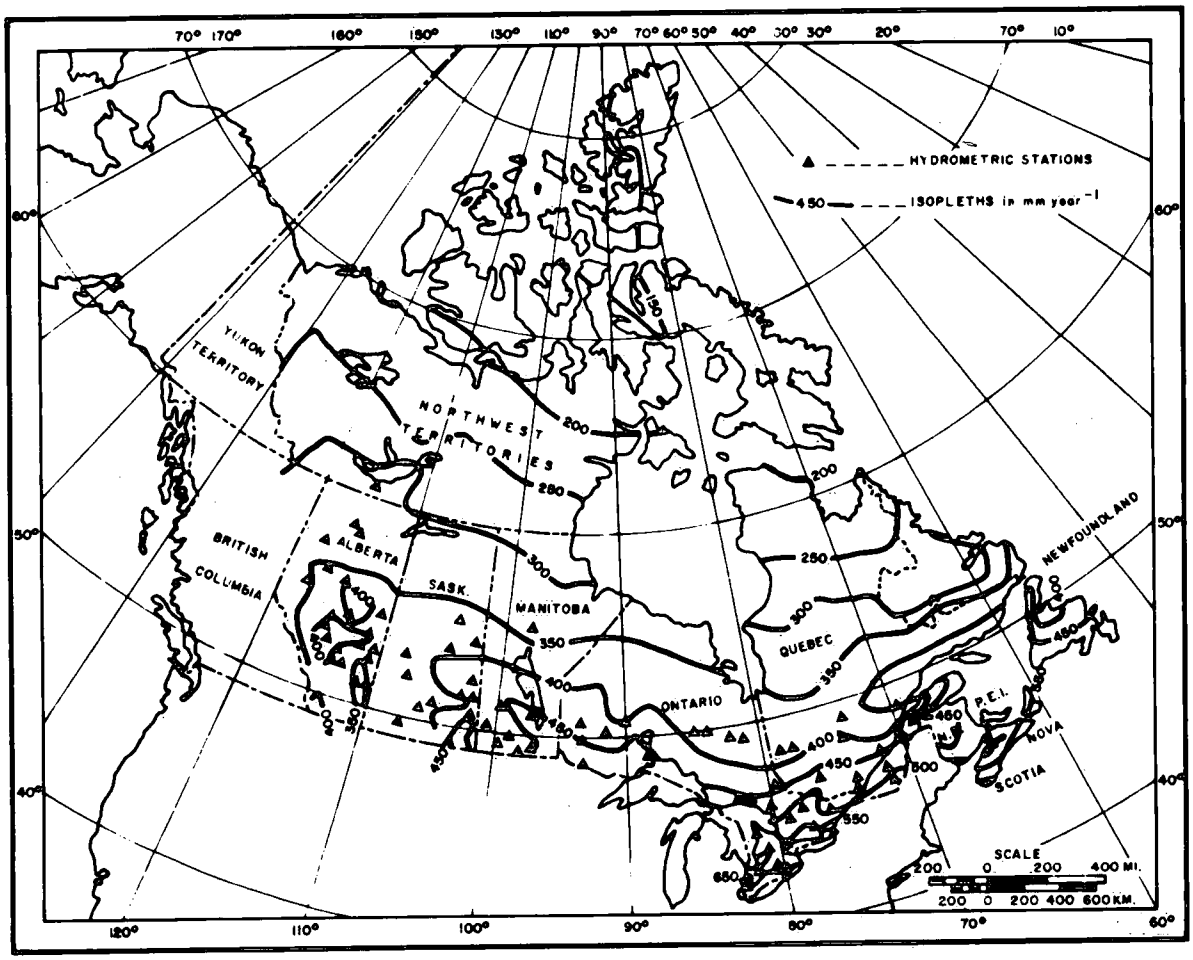

Figure 68.8.2. Isopleths of areal evaporation for the parts of Canada to the east of the Pacific Divide.

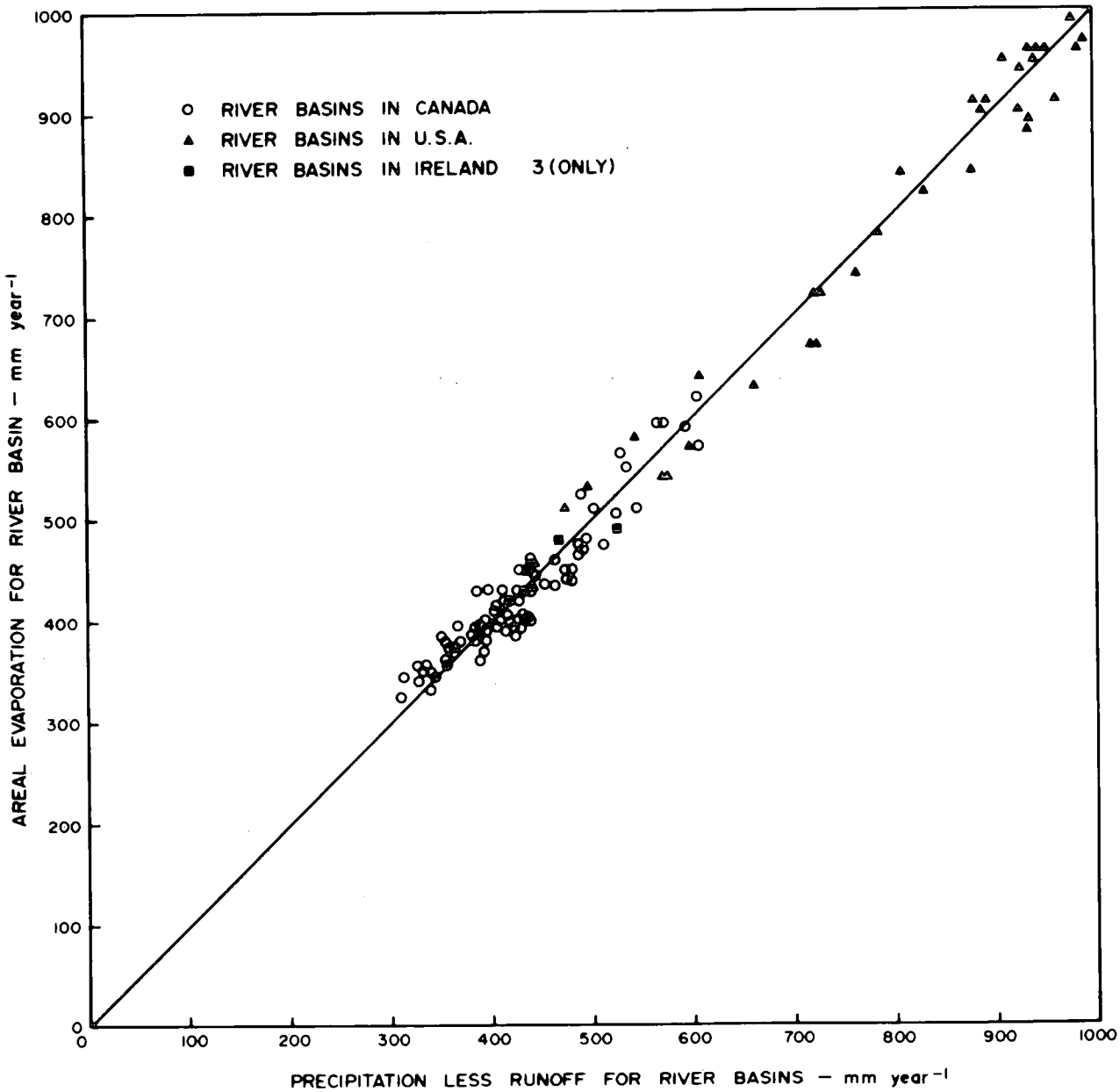

Figure 68.8.3. Comparison of model and water budget estimates of areal evaporation.

between stations. The model was tested by comparing the areal evaporation determined from the maps for 115 river basins with precipitation less runoff values for the corresponding five years. Similar comparisons were made for three river basins in Ireland. The results are shown in Figure 68.8.3. The good agreement between five-year averages does not prove that the model provides adequate seasonal values of areal evaporation. However the environmental diversity represented by the river basins, as shown by the locations of the hydrometric stations in Figures 68.8.1 and 68.8.2, provides reasonable assurance that the monthly values are realistic.

Evaporation and transpiration consume much of the water and energy that are available to the land portion of the earth's surface and thereby influenced all hydrological and most meteorological processes. Unfortunately, reliable estimates have been extremely difficult to obtain. Instrumental techniques are appropriate only in a research context, when small areas are subject to intensive study. Many techniques have been devised to estimate evaporation and transpiration from routine climatological observations. However they have depended on questionable assumptions about the soil-vegetation system and have been impossible to test because of their need for local fudge factors. In this context, the model appears to fill a large gap in hydrological and climatological studies.

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Priestly, C.H.B. and Taylor, R.J., 1972, On the assessment of surface heat flux and evaporation using large-scale parameters: Monthly Weather Review, 100, 2, 81-92.

GEOPHYSICAL METHODS APPLIED TO THE STUDY OF SEAWATER INTRUSION

Project No. GW 68-12

H. Lazreg*

This project was originally exclusively concerned with seawater intrusion into coastal aquifers. Its objectives were the application of geophysical methods to (1) the location of the interface or transition zone between fresh and saline waters, (2) the determination of horizontal and vertical variations in groundwater quality in the vicinity of this interface or zone and (3) the observation of natural or man-made changes in it.

The project has involved resistivity and induced polarization field surveys in the Shippegan, Cap Pélé and Chatham-Newcastle areas of New Brunswick; in the Eliot River and Summerside areas of Prince Edward Island; and on Sable Island and in the Halifax area of Nova Scotia. A related project (No. HR 74-8) also reported on in this volume has extended these studies to the Strait of Canso area of Nova Scotia. The scope of the project has been widened to include resistivity studies at Mer Bleue, Ontario (Project No. GWO 69-3) and Esterhazy, Saskatchewan and application of the VLF ground survey method to the Shippegan salt-water intrusion problem.

In general, the resistivity technique has been found useful in locating the subsurface salt water - fresh water contact or transition zone and in defining areas of natural or man-made intrusion into coastal aquifers. The induced polarization technique has proved a valuable supplement to resistivity since it can be used to discriminate between permeable sandstones saturated with salt water and fresh water shales, something that cannot be done on the basis of resistivity results alone.

Three publications have resulted from these studies and are listed below. Manuscripts are now in various stages of preparation describing the results obtained at (1) Sable Island, N.S., (2) Chatham-Newcastle area, N.B., and (3) Summerside, P.E.I.

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* Hydrology Research Division, Ottawa

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SNOWMELT INFILTRATION AND ASSOCIATED GROUNDWATER RECHARGE

Project No. GW 69-2

R.L. Harlan*

An experimental plot was established in 1969 as a cooperative effort between the Glaciology and Hydrology Research Divisions for the investigation of the physics of snowmelt, infiltration into frozen soil, and the mechanisms of groundwater recharge. The plot was intended specifically for the collection of field data for the development and verification of alternative computer-orientated simulation models.

The Mer Bleue experimental plot is located just east of the city of Ottawa, Ontario on the Central Experimental Forest maintained by the Canadian Forestry Service, Environment Canada. The surficial geology consists of Uplands sand overlying dense marine clay. Hydrologically, the study plot is in an area of groundwater recharge. Because of the impedment to subsurface drainage imposed by the clay layer, the site proved to be unsatisfactory for the purpose for which it was intended. During much of the snowmelt period in the spring, for instance, the water table was at or very close to the ground surface, thereby preventing infiltration.

Although the Mer Bleue site was not suited for its original purpose, a variety of types of instrumentation was installed and tested there. Soil-moisture instrumentation included standard Colman fiberglass resistance blocks, thermocouple psychrometers, and a twin-probe gamma attenuation device for measurement of changes in total or wet soil density. Of the soil-moisture instrumentation, the Colman resistance blocks, although the least quantitative of the instruments tested, provided the most consistent and reliable results. In general, the thermocouple psychrometers did not provide much useful information, largely because the soil was at or too close to saturation throughout most of the measurement period.

Fluctuations in the position of the groundwater table were measured using a Stevens type F water-level recorder and float. Piezometric levels in four deep piezometers were observed using a bubbler system connected to a scanning valve and a single pressure transducer. The output from the pressure transducer was recorded on magnetic tape for subsequent data processing.

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Combined with the field data collection program was a theoretical study of the mechanism of infiltration to and water movement in frozen and partially frozen soil. The results of the theoretical study are summarized by Harlan (1971; 1973a; 1973b). This study showed, for example, that the mechanisms for water migration in frozen soil are completely analogous to those in an unsaturated soil at temperatures above $0^{o}C$ ($32^{o}F$). The primary mechanism for water movement in frozen as in unsaturated soils is by liquid transfer through the adsorbed films on the surfaces of the soil particles and in clay platelets.

Using the analogy between the mechanisms of water movement in frozen and unsaturated soils, a set of equations describing coupled heat-fluid transport in porous media with freezing and thawing was derived and solved on a digital computer. Results of computer simulation studies show that under shallow water table conditions, the groundwater table is highly responsive to freezing and thawing at the soil surface. The nature and magnitude of the response were shown to vary with depth to the water table, soil type, and the temperature within the soil profile and at the boundaries (Harlan, 1973a).

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HYDROGEOLOGY OF FRACTURED MEDIA IN THE HALIFAX AREA

Project No. GW 70-1
J.E. Gale

Development and Use of an Instrument for Measuring in situ Changes of Fracture Aperture

by J.E. Gale[1] and J.A. Welhan[2]

A field investigation of fluid flow in fractured rock masses was conducted in the Halifax area during the 1970 through 1973 field seasons. Emphasis was placed on measuring the opening and closing of fractures in response to changes of fluid pressure within the fracture plane. It was anticipated that these measurements of fracture deformation would provide an indication of the extent to which stress-dependent permeability affected well behaviour in fractured rock aquifers.

In the context of this paper, the word "fracture" refers to a planar discontinuity bounded by two rock blocks. A fracture will generally have a lateral extent measured in tens or hundreds of feet, with an opening or aperture measured in fractions of an inch.

DEVELOPMENT OF FRACTURE DEFORMATION GAUGE

A major objective of Project No. GW 70-1 was to measure the changes in fracture openings that were produced by either increasing or decreasing the fluid pressure in the plane of a natural fracture. A review of rock and soil mechanics literature revealed that the necessary measurements could not be made with existing instruments. Thus it was necessary to design and develop a special instrument that could be placed in a borehole and be used to measure changes in fracture openings of as little as 10^{-5} inches. The senior author, in conjunction with the Instrumentation Section of the Inland Waters Branch, designed and developed an instrument (Figure 70.1.1) which we shall refer to as a "Fracture Deformation Gauge" (FDG). The actual engineering design and fabrication work was performed by Fildebrandt Precision Industries of Ottawa, Canada. It should be clearly understood that use of the above company name and brand names for individual components of the deformation gauge does not imply recommendation either by the authors or by the Canadian Government.

[1] Department of Civil Engineering, University of California, Berkeley

[2] Department of Earth Sciences, University of Waterloo, Waterloo, Ontario

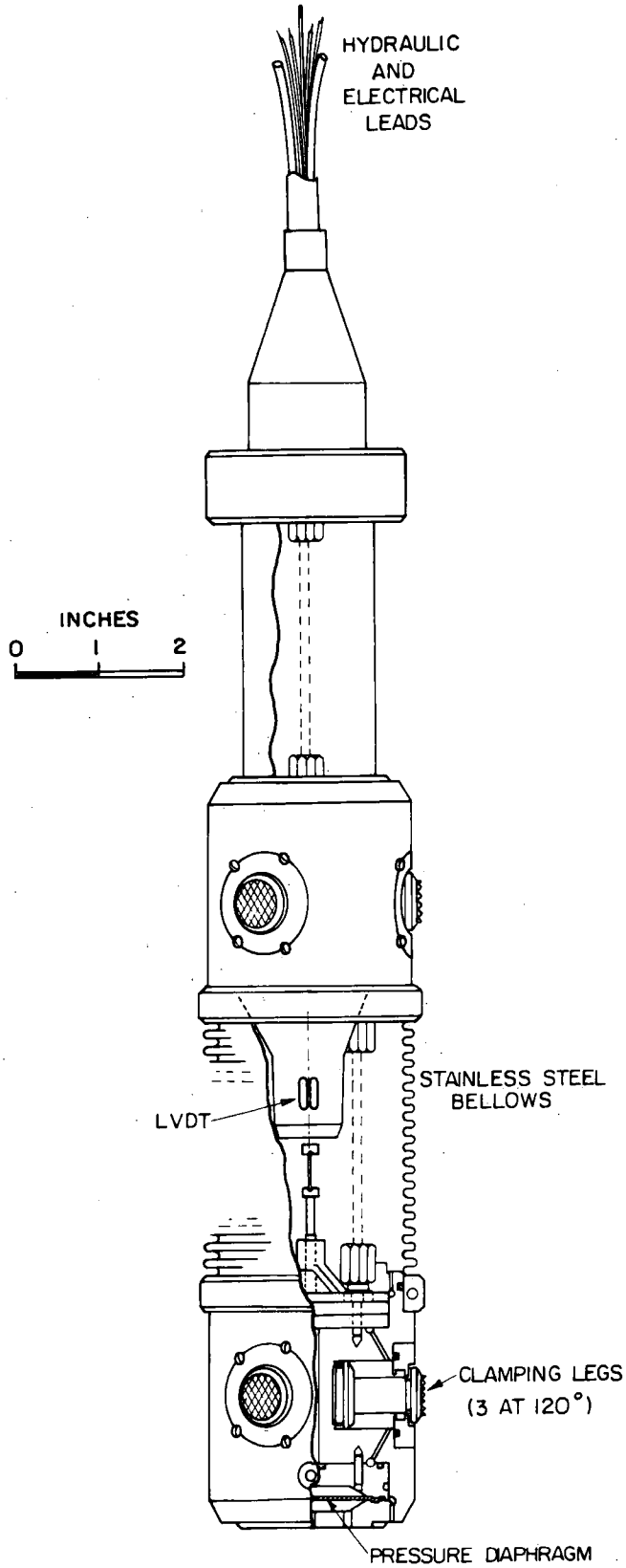

Figure 70.1.1. Fracture deformation gauge.

The fracture deformation gauge (Figure 70.1.1) consists of four basic components: 1) an upper and lower clamping section, 2) a stainless steel bellows connecting the two clamping sections, 3) a displacement measuring device - a linear variable differential transformer (LVDT) - and 4) a pressure diaphragm for balancing the internal and external fluid pressures. The instrument was designed for operation in 3-inch (NX) boreholes and is approximately 2½ inches in diameter with a distance of 6 inches between the upper and lower clamping legs. The details on the development and design of the FDG and the engineering specifications can be obtained from the Hydrology Research Division. A patent for this instrument was applied for in 1973 by the Division.

The displacement measuring device (LVDT) was a Hewlett Packard 24-DCDT (see Hewlett Packard Technical Data Sheet 10-68) utilizing direct current input with the oscillator and demodulator included in the LVDT itself. The only external equipment required is a direct current power supply and a direct current voltmeter. The relationship between output voltage and displacement was determined by calibrating the instrument against a known displacement.

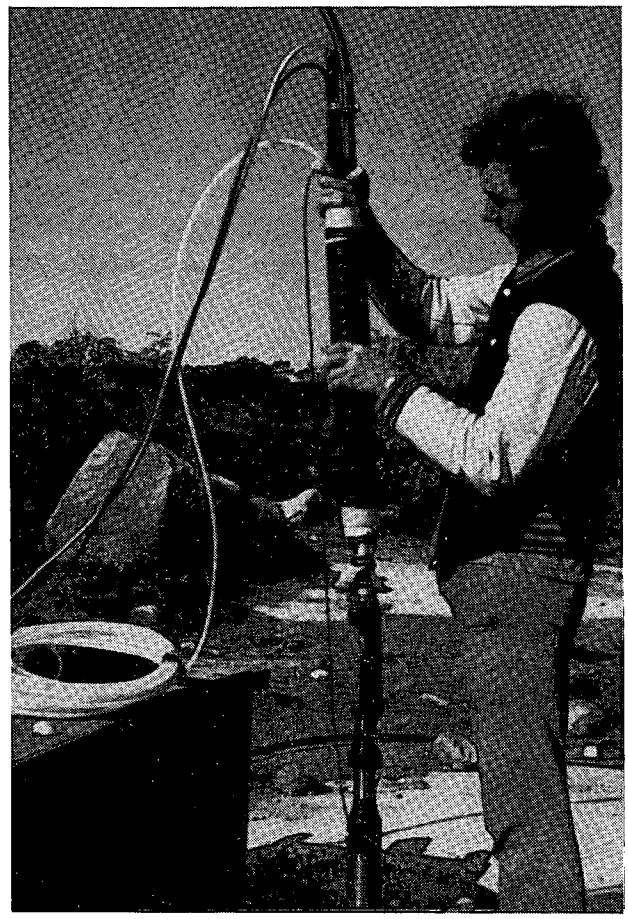

Figure 70.1.2. Fracture deformation gauge assembled and ready to be lowered into the borehole.

MEASURING CHANGES IN FRACTURE APERTURE

In order to use the FDG to measure changes in fracture openings, the fracture is first located in the borehole using a borehole periscope (Trainer and Eddy, 1964). The FDG is attached to an inflatable packer assembly (Figure 70.1.2) and then lowered into the borehole and positioned with the lower clamping legs below and the upper clamping legs above the selected fracture. The instrument is then locked in place by hydraulically activating the upper and lower clamping legs. Thus, any displacement normal to the fracture walls will be reflected in a differential movement of the upper and lower clamping legs. The fracture deformation gauge can be used to measure both the opening and the closing of fractures and thus can be used during either injection or withdrawal tests. The arrangements for both pumping out and pumping in are shown in Figure 70.1.3.

A typical field test, for example an injection test, consists of 1) locking the FDG across the selected fracture, 2) sealing the borehole above the FDG with an inflatable packer, 3) placing a double packer assembly across the same fracture in an adjacent borehole to serve either as an injection point or as another pressure measuring point in the fracture plane. Water is injected and both the fluid pressures and the output from the LVDT are recorded. The LVDT output can be converted directly to change in fracture opening in the appropriate units of measurement.

After completing the injection test, the fracture deformation gauge is removed from the borehole and placed in a pressure tank. The FDG is locked into a three-inch steel pipe and the pressure history during the injection test in the borehole is repeated. This is necessary in order to remove the pressure response effects from the test results.

The fracture deformation gauge has been modified in order to reduce the response of the instrument to changing fluid pressures and the results of laboratory tests with the modified instrument will be included in a later report.

Field tests showed that the fracture deformation gauge could be used to measure the change in fracture opening with change in fluid pressure. In addition, during the field test one measures the displacement (fracture opening) and the force (fluid pressure). Thus, the FDG provides a means of measuring *in situ* the normal stiffness properties (force-displacement relationship) of the fractures (Gale, et al., 1974).

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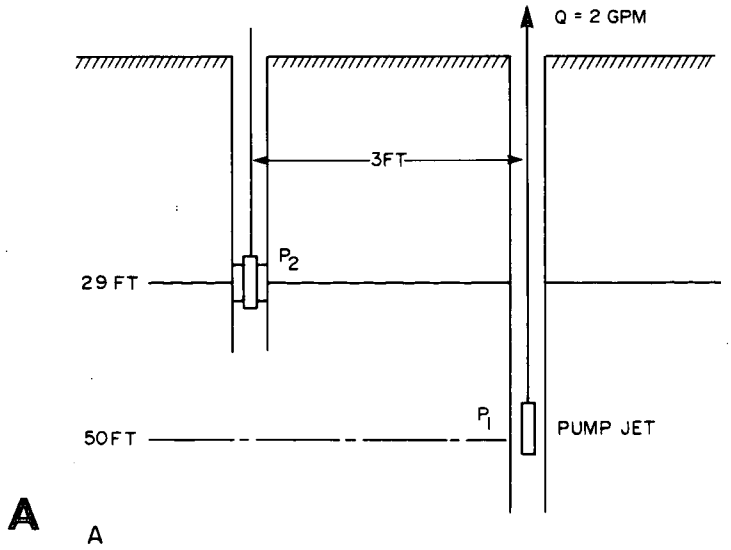

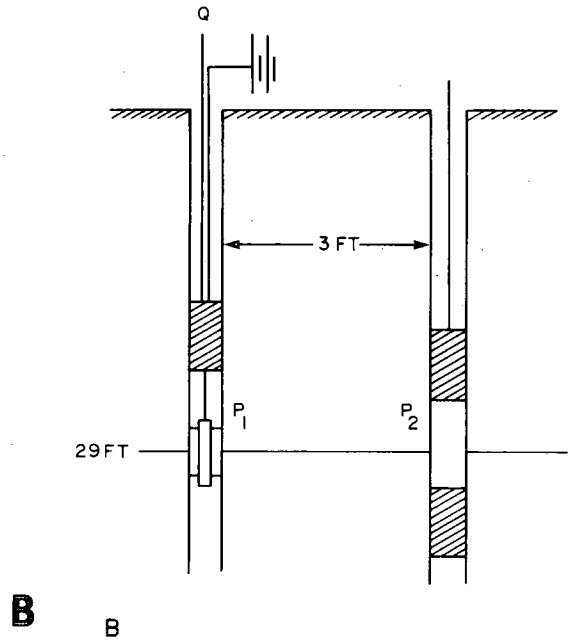

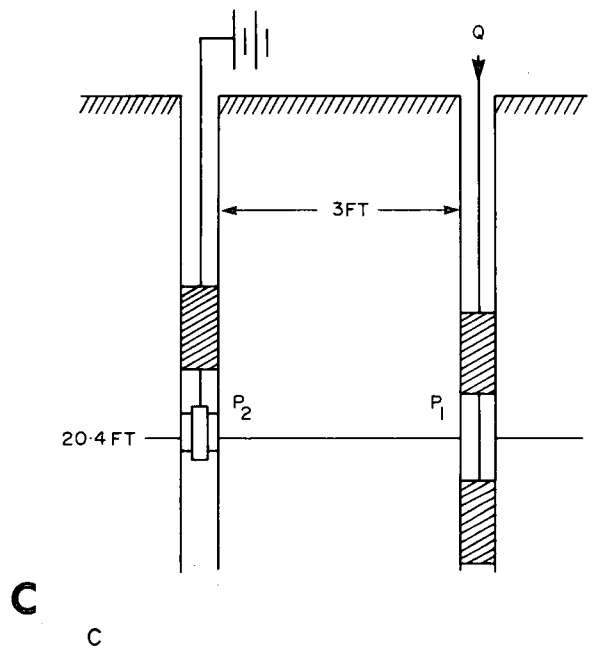

Figure 70.1.3. Test arrangement of fracture deformation gauge for (A) pumping out test, (B) injection test - deformation gauge in injection well and (C) injection test - deformation gauge in observation well.

HYDROGEOLOGY OF FRACTURED MEDIA IN
THE HALIFAX AREA

Project No. GW 70-1
J.E. Gale

Construction of a Simple Inflatable Packer for Use in Shallow Wells

by J.E. Gale[1] and J.A. Welhan[2]

Two types of reusable packers are commercially available: mechanical packers and inflatable packers. Both types of packers are expensive to purchase or rent. Because of their weight, they are cumbersome and it is difficult to handle even the smaller ones without the aid of a drill rig. For groundwater investigations with well depths of one to two hundred feet it is feasible to construct lightweight inflatable packers in the field. Such packers have been described by Maini (1971) and the construction of the inflatable packers used during the Halifax area fracture flow study and described below closely follows his method.

Double packers were required to measure the permeability of one or more fractures. For injection tests to determine permeability in crystalline or metamorphic rock, a two-foot packer seal should be adequate to prevent leakage. When a double packer assembly is being used, the distance between the upper and lower packers should be variable, thus permitting the straddling of steeply dipping fractures that intersect the borehole.

Packer shells, approximately three quarters of an inch smaller than the diameter of the borehole, were constructed from polyvinylchloride pipe (PVC). PVC pipe combines light weight and high tensile and compressive strength with easy machining properties (it can be cut easily with a standard wood saw).

The pipe was cut into 2-foot lengths. Two ¼-inch holes were drilled into the walls of the pipe approximately 8 inches from each end and an air line consisting of ¼-inch high-strength plastic tubing or 1/8-inch copper tubing was seated in the holes using a waterproof epoxy (Figure 70.1.4A). The same procedure was repeated for the lower packer. The injection pipe (¾-inch PVC pipe) and cables for pressure transducers, etc., was placed inside the packer shells (Figure 70.1.4B). The space remaining inside this PVC pipe was then filled using a room temperature curing urethane (Flexane 95 manufactured by Devcon Corporation). Any nonshrinking epoxy would be an adequate filler.

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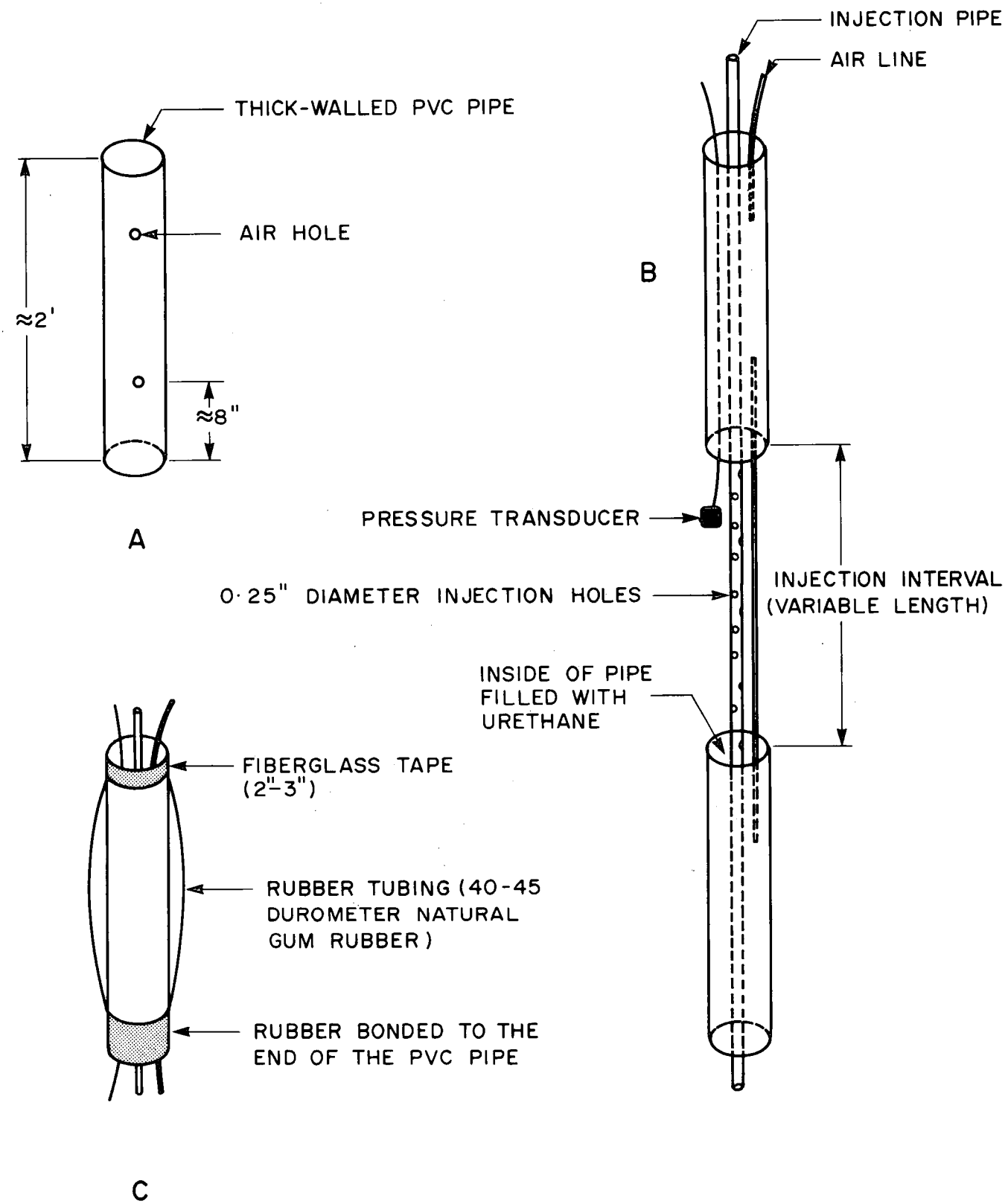

Figure 70.1.4. Construction of inflatable packer; (A) PVC pipe, (B) components of double packer assembled and (C) completed packer.

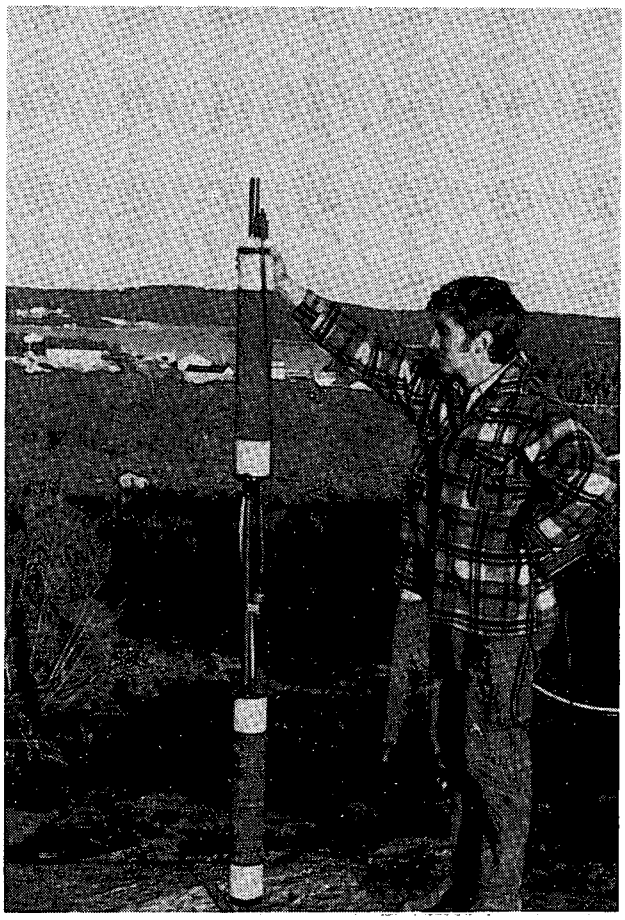

Figure 70.1.5. Double packer assembly.

After the urethane had solidified, a 2-foot length of 40-45 durometer natural gum rubber tubing (available from Rubberline Products, Kitchener, Ontario) with a fabric coating and a $^1/_8$-inch wall thickness was slipped over the PVC pipe. A 3- to 4-inch section of the ends of the packer shells and rubber tubing was cleaned and a quick-setting epoxy applied. The rubber tubing and packer shells were then bonded together using a fiberglass tape which gave added strength to the epoxy seal. The finished packer is shown in Figure 70.1.5.

To seal the packer in the borehole, air is pumped into the space between the rubber tubing and the packer shell. Field tests demonstrated that the rubber seals could withstand a differential pressure of up to 100 psi. A differential pressure (air pressure in the packer minus the water pressure in the injection cavity) of 30 to 40 psi is generally sufficient to prevent water leakage past the packer. Packer leakage can be detected during an injection test by suddenly increasing the air pressure in the packer and observing the fluid pressure in the injection cavity. A sustained increase in the fluid pressure indicates that leakage is occurring.

REFERENCE

Maini, Y.N.T., 1971, In situ hydraulic parameters in jointed rock - their measurement and interpretation (Ph.D. Thesis): Imperial College, University of London.

HYDROGEOLOGY OF FRACTURED MEDIA IN
THE HALIFAX AREA

Project No. GW 70-1
J.E. Gale

Controlling Well Discharge with a Constant Head Tank

by J.E. Gale[1] and J.A. Welhan[2]

During many pump tests the flow rate varies with the drawdown and also as a result of variations in the pump performance. Most water wells completed in fractured rock aquifers generally produce less than 10 gallons per minute. Thus, a small change in the pumping rate during a pump test will represent a significant percentage of the flow rate. A variation of as little as 4 per cent in the flow rate will tend to invalidate the pump test analysis, depending on the method of analysis used (T. Hurr, USGS, Denver, Colorado; pers. comm. 1971). Thus it is important to be able to control the flow rate during a pump test.

The pump test arrangement shown in Figure 70.1.6 was used to control the flow rate during pump tests. The main component of the test arrangement is the "constant head control tank", suggested by Mr. T. Hurr of the USGS, Denver office. The control tank operates on the principle that the volume of water withdrawn from the well will be slightly greater than the well discharge required. An internal overflow in the control tank returns the excess water to the well and also acts to maintain a constant water level in the tank. This constant head (H) produces a uniform flow from the tank outlet resulting in a constant discharge from the well. The magnitude of the flow rate depends on the size of the tank outlet. The test tank was constructed from an old hot water tank and modified to give a constant head of approximately 3 feet. This tank was able to handle pumping rates up to 10 gallons per minute.

The test procedure consists of:

1. Setting up the pump and control tank and filling the system with water. Care should be taken to ensure that the tank or pump does not leak water since the test must be started with the system full. Also, the position of the open end of the pipe attached to the tank outlet must be fixed since any change in the elevation of the end of the pipe during the pump test will change the hydraulic head and thus the flow rate.

2. When the well has stabilized, the pump should be started and water pumped through the system. The system is closed during this period and it is usually referred to as "cycling" since all the water that

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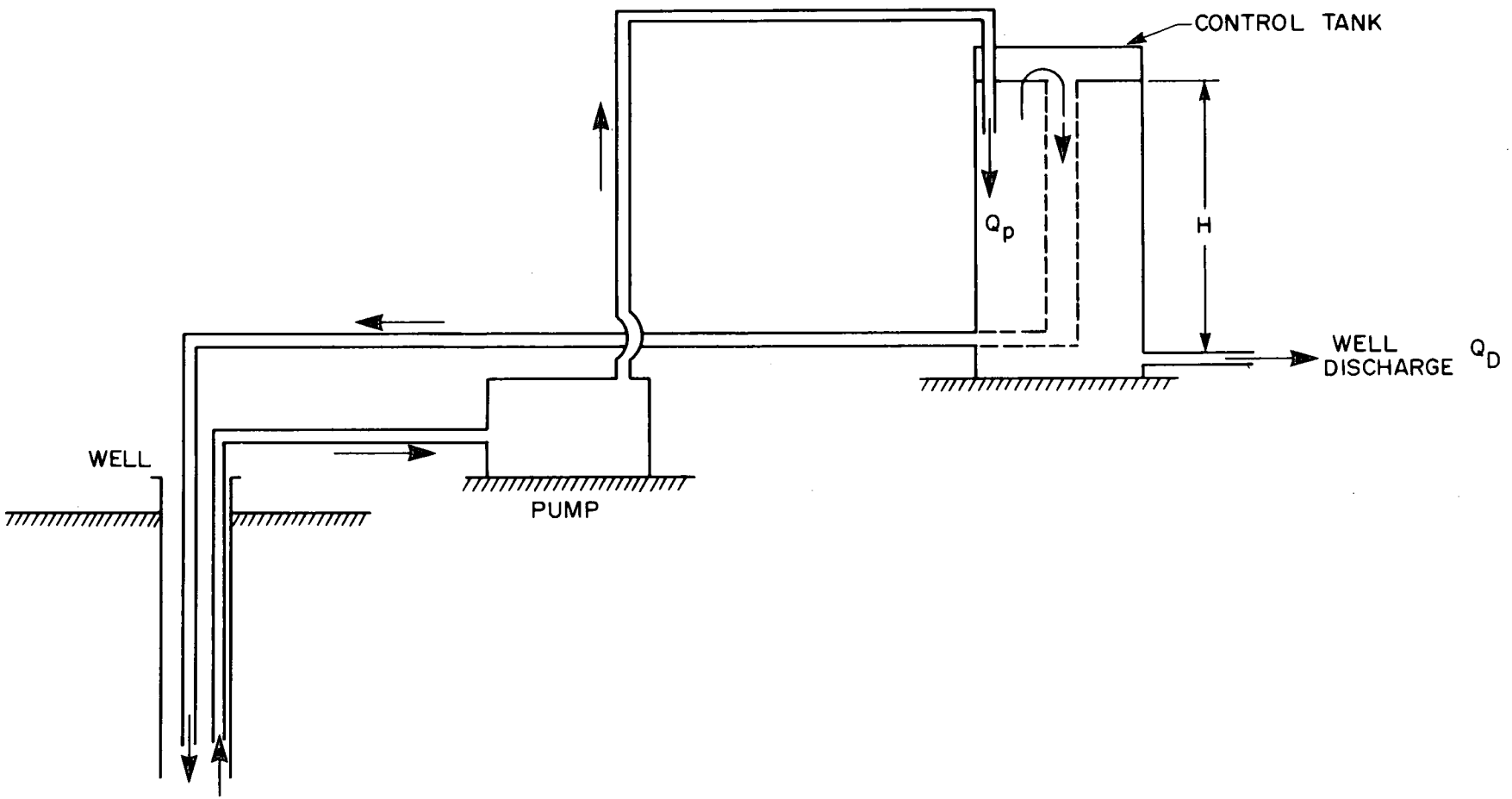

Figure 70.1.6. Arrangement of equipment for a pump test using the discharge control tank.

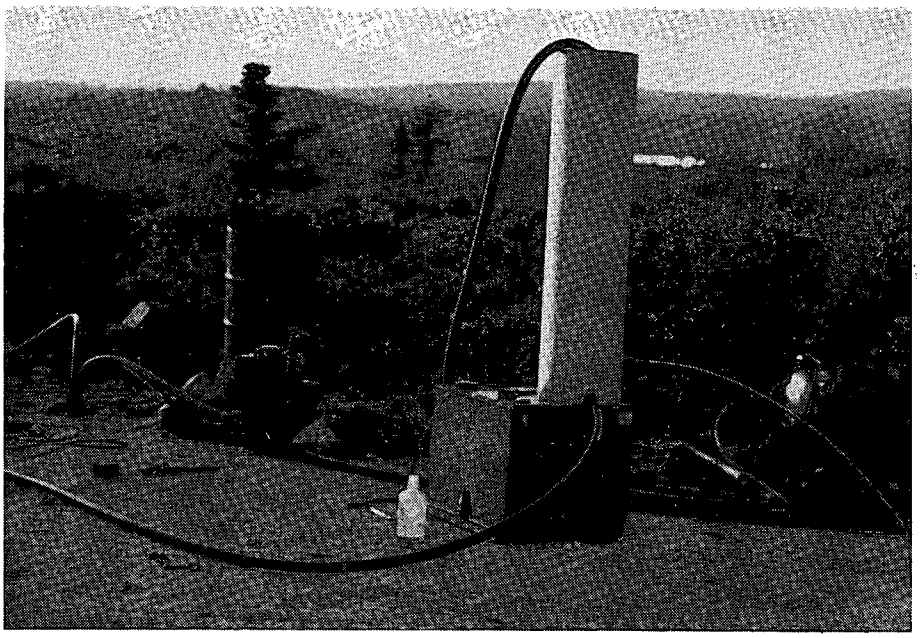

Figure 70.1.7. Discharge control tank being tested.

is pumped out of the well is immediately returned to the well through the overflow system in the control tank. The tank outlet must be sealed during this cycling phase and the pumping rate should be kept at a minimum. The pipe used to return the excess water from the control tank to the well should extend for a considerable distance down the well - at least below the anticipated level of maximum drawdown. The water level in the pumping well should be monitored during the cycling phase and the cycling maintained until the water level in the well is completely stable.

3. After the water level in the well has stabilized, the pump test can be started. First, the pumping rate is increased to the desired value of Q_p (Figure 70.1.6) and then the tank outlet is opened (zero time). Q_p must always be maintained slightly greater than Q_D , either by increasing the pumping rate or, in the case of excessive drawdowns in the well, by decreasing the flow rate from the control tank. After the operator obtains some experience, both in the use of the control tank and in estimating the well behaviour, there should be no need to adjust the tank flow rate during the pump test period.

   Figure 70.1.7 shows the discharge control tank in operation during testing. The use of a constant head control tank will greatly improve the quality of pump test data, since one major variable - fluctuations in the pumping rate - will be removed.

NATURAL GROUNDWATER MOTION IN COASTAL AQUIFERS

Project No. GW 70-7

G. van der Kamp*

The main objective of this project was to carry out a detailed study, both theoretical and empirical, of tidal and other periodic fluctuations in coastal aquifers induced by water level fluctuations of the adjacent surface water. This study was further subdivided into investigations of two distinct phenomena: (1) the initiation of the fluctuations in the aquifer through direct inflow of water and through loading effects, and (2) the propagation of the fluctuations through the inland part of the aquifer.

Investigation of tidal loading effects led to a modification of previously accepted theory (van der Kamp, 1972). However, this aspect of the study was not carried further because, although theoretical treatment of complicated cases is possible, both good data and possibilities of practical application of the theory are very limited at present. The difficulty here is that one is looking for rather subtle effects in the region under and very near the sea where reliable data on fluctuations of piezometric head are not easy to obtain.

On the other hand it is relatively easy to carry out accurate determinations of the propagation of tidal fluctuations through the inland part of an aquifer, and consequently this aspect of the problem was studied in detail. A theoretical description of the propagation of periodic fluctuations through thin aquifers has been obtained for confined, semiconfined and unconfined flow, including the effects of water table storage and of vertical flow and elastic storage in both aquifers and aquitards. The range of applicability of the equations is quantitatively defined. These results, and a detailed evaluation of them on the basis of empirical results, have been published (van der Kamp, 1973) and the project is thereby essentially completed.

In addition to the main effort, a subsidiary study was carried out on the removal of tidal effects from water level data obtained for coastal aquifers. A method for the elimination of tidal effects has been developed (van der Kamp, 1973 Chapter 4). It gives fairly good results for short pump tests, allowing the removal of tidal effects to within better than 10 per cent of the total tidal fluctuation in the well. The method is applicable for any combination of semidiurnal and diurnal tides. The main source of difficulty would seem to be the effect of irregular and unpredictable fluctuations of sea level.

Measurements of natural salt water intrusion were also obtained in the course of the study. These are being analyzed at present and interpreted in terms of tidal, seasonal and secular changes of water levels.

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REFERENCES

van der Kamp, G., 1972, Tidal fluctuations in a confined aquifer extending under the sea: 24th Int. Geol. Cong., Section 11, 101-106.

_____, 1973, Periodic flow of groundwater: Editions Rodopi, Keizersgracht 302-304, Amsterdam, The Netherlands, 121 p.

HYDROGEOLOGICAL RECONNAISSANCE STUDY NEWCASTLE-CHATHAM AREA

Project No. GW 70-9

H. Lazreg*

The objectives of this study were (1) to determine the hydrostratigraphy of the Newcastle-Chatham region of New Brunswick in relation to future development of municipal and industrial groundwater supplies and (2) to identify saline groundwater intrusion problems on which future groundwater development research might be focused.

The field work included 40 deep resistivity soundings to delineate the hydrostratigraphy of the area and to detect groundwater quality variations. A number of test holes were also drilled. These served to confirm the presence of salt-water intrusion along the south side of the Miramichi River at Chatham. The total study also took into consideration available water-well inventory data.

The study results are presented in a manuscript now under review in the Division and intended for publication in the Canadian Journal of Earth Sciences.

PUBLICATIONS

Lazreg, H., Hydrogeology of Chatham-Newcastle area, N.B. - a geoelectrical study (in preparation).

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HYDROGEOLOGY, FRASER VALLEY

Project No. GW 71-1
E.C. Halstead*

The objective of this project is to evaluate the source, movement and distribution of groundwater in the Lower Fraser Valley. Throughout the year considerable attention was given to the collection of records from drilling contractors, visits to well drilling operations and the collection of water samples. More than 500 records were collected during the period October 1, 1973 to September 30, 1974 and 160 water samples were collected for chemical analyses. The hydrochemistry of the groundwater suggests the possible definition of local, intermediate and regional flow systems on the basis of total dissolved solids, parent materials and residence time. The records of the materials penetrated during drilling are correlated to produce block diagrams showing the geological framework through which the groundwater is recharged, transmitted and discharged. Also as a result of the water quality investigations areas have been identified where nitrate concentrations are reaching levels at or beyond recommended limits. The areas of significant nitrate accumulations are underlain by sand and gravel at or near the surface, up to 100 feet thick, that constitute free water table aquifers. A number of wells in these areas are monitored on a regular 6-week basis to assess the rate of change in the nitrate concentration. An observation well 85 feet deep was installed in one aquifer to monitor seasonal water level fluctuations and nitrate concentrations. Block diagrams are being prepared for publication to show the hydrology of 10 townships in the central part of Fraser Valley south of Fraser River and bounded by the International Boundary. This area is to include the municipalities of Surrey, Langley and Matsqui.

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HYDROGEOLOGY, MACKENZIE VALLEY

Project No. GW 71-3
R.L. Harlan*

This project was set up in 1971 to evaluate groundwater and permafrost conditions in the Mackenzie River Valley and to identify those hydrogeological situations that pose special problems for northern development in general and for the design, construction and operation of oil or gas pipelines in particular. The project terminated in 1974 although related work is being conducted in another project (HR 74-2). Much of the work carried out under this project was made possible by the financial support provided by the Environmental-Social Program, Northern Pipeline Studies, Department of Indian and Northern Affairs.

An important aspect of the project was the sponsoring of a contract study of groundwater features and conditions in the Mackenzie River Valley. This study was based principally on a reconnaissance aerial photograph interpretation and led to a series of surficial hydrogeology and bedrock hydrogeology maps for a band about 50 miles in width centred approximately on the Mackenzie River and extending from Fort Simpson to Fort McPherson, N.W.T.

Drilling programs were conducted at Norman Wells and Inuvik, N.W.T. and an instrumented cross section was installed at Norman Wells for the determination of hydrodynamic gradients and seasonal fluctuations in temperature and head. Difficulties of northern operation and deficiencies in the original installation gave rise to breakdowns in power supplies, recording devices and other associated equipment so that extensive modification of the installation was required as is documented elsewhere in this volume (Project No. HR 74-2). This modification was carried out as part of Project No. HR 74-2 to which the Norman Wells installation has now been transferred.

The project was concluded with the preparation of a summary report on hydrogeological considerations in northern pipeline development.

REFERENCES

Harlan, R.L., 1974, Hydrogeological considerations in northern pipeline development: Report prepared for Environmental-Social Program, Northern Pipeline Studies, 35 p.

Mollard, J.D., and others, 1972, Reconnaissance study of hydrogeology of the Mackenzie River Valley region: Inland Waters Directorate, Unpubl. internal rept.

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WATER BALANCE, IHD REPRESENTATIVE BASINS

Project No. GW 71-4
S.Y. Shiau*

A basin data file has been created and maintained for the Trapping Creek basin and the generalized hydrologic model (Project No. HR 74-5) applied for the simulation of streamflow. Trapping Creek is a mountainous basin in central British Columbia with elevations ranging from 870 to 2300 meters above mean sea level. The basin has a drainage area of 142 square kilometers with approximately 80% forest cover. The tremendous amount of snow accumulation, particularly on the higher level of this basin, presents a difficult problem which has to be resolved before the simulation is possible. Programs SNOAA1 and SNOAA2 (Project No. HR 74-5) have been applied to simulate the snowpack water content and the effective daily rain plus melt at various elevation levels. The weighted daily rain plus melt instead of the precipitation data is then used as moisture input for calibration and simulation. Calibration of the basin was based on 1968 to 1970 data and the results were then used to simulate 1971 and 1972 streamflows. The computed values compared reasonably well with the observed discharge records.

The results of simulation (which include the daily listing of storage contents and runoff and evapotranspiration components) are used to determine the monthly and annual water balances. Table 71.4.1 summarizes the annual water balance for the period 1968 to 1972. The table indicates that annual evapotranspiration loss from Trapping Creek basin ranges from 46% (1972) to 67% (1970) of the annual moisture input while the streamflow ranges from 38% (1970) to 52% (1972). Detailed simulation results and monthly water balances for the Trapping Creek basin are available upon request.

The preparation and creation of basin data files for Good Spirit Lake and Oak River basins in Saskatchewan and Manitoba, respectively, are in progress. The generalized hydrologic model will again be applied to calibrate these two parkland representative basins and the results used to evaluate the monthly and annual water balances.

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TABLE 71.4.1. Summary of Annual Water Balance - Trapping Creek Basin Area = 142 sq.km.

	1968		1969		1970		1971		1972	
	cm	%	cm	%	cm	%	cm	%	cm	%
Rain plus Melt	72.4	100.	71.4	100.	51.6	100.	72.9	100.	81.5	100.
Evapotranspiration-Demand	49.8	69.	50.5	71.	54.9	106.	51.1	70.	48.0	59.
Evapotranspiration-Used	40.9	56.	36.6	51.	34.8	67.	38.6	53.	37.8	46.
Streamflow-Computed	31.1	43.	34.3	48.	19.6	38.	37.6	51.	42.2	52.
Streamflow-Observed	32.5	45.	35.1	49.	17.9	35.	38.4	53.	44.5	55.
Storage Change	+ 0.6	1.	+ 0.5	1.	- 2.8	- 5.	- 2.9	- 4.	+ 1.4	2.

HYDROGEOLOGICAL MAPS OF MANITOBA

Project No. GW 71-6
R.L. Herr*

The objective of this project has been to construct hydrogeological maps of selected areas in Manitoba utilizing the GOWN computerized groundwater data storage and retrieval system.

The water well data for approximately 9,000 Manitoba wells were collected and coded in the GOWN format as part of a 1971 federal government winter works program. These data have now been keypunched, the well locations digitized, and all data put on magnetic tape for editing.

Some of these data have been edited over the summer of 1974 but presently the project is in a hold situation due to other priorities.

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* Hydrology Research Division, Ottawa

DEEP-WELL DISPOSAL, SOUTHWESTERN ONTARIO

Project No. HR 72-1

A. Vanden Berg*

This field study of deep-well disposal and the associated review and analysis of water-well and oil-field information in southwestern Ontario (primarily Lambton County) were initiated in 1972 as part of the Subsurface Contamination Research Program. The study was undertaken as a joint effort of the Hydrology Research Division of Environment Canada, the Water Quality Management Branch of the Ontario Ministry of the Environment, and the Petroleum Resources Division of the Ontario Department of Mines and Northern Affairs. It had two specific objectives. These were to use hydrochemical maps of the shallow groundwater zone and piezometric maps of the disposal zone in the study area:

1. To indicate the directions of groundwater flow in each zone and

2. To provide information on the hydrochemical effects of deep-well injection of brines and industrial wastes.

For the preparation of the piezometric map of the disposal zone-located in and adjacent to the boundary between the Dundee Formation and the Detroit River Group - 2,980 records from oil and gas wells were available, from which 2,473 records of a water occurrence could be taken. The bulk of these were in a relatively narrow depth interval centered on the Dundee - Detroit River contact. A number of piezometric contour maps, each for a different depth interval, were computer contoured. The piezometric data were also separated on the basis of (1) the presence or absence of hydrogen sulfide and (2) the year of drilling, all in an effort to eliminate data from other than the main disposal zone.

Although the different maps exhibited, as expected, widely varying features due to the imprecise nature of the data, a number of these were common to all maps and could safely be accepted as genuinely characteristic of the piezometric surface of the disposal zone; they indicate a regional groundwater movement, probably very slow in nature, directed to the northwest.

The chemistry data used in the preparation of the hydrochemical map consisted of 102 well-water samples, collected during the summer of 1972, and analysed for the major ions. Schoeller's semilogarithmic diagrams were prepared for each analysis and on the basis of the pattern which developed the analyses were divided into seven chemical types. A map showing the occurrence of each type indicated that groundwater movement in the shallow zone is directed to the west and northwest, except for the extreme eastern edge of Lambton County, where the flow is directed to the east.

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Furthermore, some of the samples which did not clearly fit into the regional chemical pattern may be indicating contamination - either by disposal brines or by deep formation waters forced up into the shallow aquifer along localized zones of high permeability such as fractures or faults, or through the short circuits provided by old abandoned oil or gas wells.

The final report describing the study, which also contains recommendations for further study and for monitoring of the disposal operations, is near completion.

Another contribution to this project has been the development of a finite element model to investigate the response of the disposal zone to a number of hypothetical injection situations. This model study was carried out under contract by the University of Waterloo and has appeared as an M.Sc thesis.

REFERENCES

Smith, J.B., 1973, A finite element model for liquid waste movement in a two-dimensional nonhomogeneous groundwater system [Unpubl. M.Sc. thesis]: Univ. Waterloo, 177 p.

EFFECTS OF MODEL HETEROGENEITY ON THE MODELLING PROCESS

Project No. HR 73-1

V. Klemes*

The similarity in the mathematical form of many supposedly different hydrological models has led researchers to the conclusion that their apparent heterogeneity is in many cases but a heterogeneity in the notation. For instance, one broad category of models identified as a linear time invariant system (Dooge, 1972) includes the unit hydrograph, the system of linear differential equations, the moving average process, the autoregressive process, the integrated autoregressive-moving average process, and the routing process associated with a cascade of linear reservoirs.

So far the transformation of one model into another has been discussed in the literature mostly in a formally mathematical context, i.e. in terms of the formal correspondence of mathematical formulations from which physical similarities are hypothesized.

The approach in the present project has been just the opposite. In particular, an attempt is being made to derive the various mathematical formulations from a single physical concept. The most promising concept has been identified as a cascade of semi-infinite discrete reservoirs (Klemes, 1973). In the past year an effort has been made to formalize this concept analytically for a cascade of linear reservoirs. The response function has been derived and explicit formulations developed for the marginal distribution of the cascade output in case of a single upstream stochastic (pure random or autoregressive) input. The results were summarized in a paper (submitted for publication) on "Output from a cascade of discrete linear reservoirs with stochastic input" by V. Klemes and L. Boruvka.

REFERENCES

Dooge, J.C.I., 1972, Mathematical models of hydrologic systems: Proc. Symp. Modelling Techniques in Water Resources Systems: Environment Canada, 1, 171-189.

Klemes, V., 1973, Watershed as semi-infinite storage reservoir: Jour. Irr. and Drain. Div., ASCE, 99, IR4, Proc. Paper 10213, 477-491.

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* Hydrology Research Division, Ottawa

APPLICATION OF RUNOFF FORECASTING TO STORAGE RESERVOIR OPERATION

Project No. HR 73-2

V. Klemes*

The results of the preliminary work concerned with the assessment of the so called 'perfect forecasting' have indicated that the effect of forecasting will significantly depend on the structure of the forecasting model (or procedure). On the one hand, the model selection will depend on the kind, quantity and quality of available data; on the other hand, the adopted model type, together with the data base, will determine the error structure of the forecasts which is the most important element in the assessment of the forecast's operational value.

To obtain a better picture of the state of the art in hydrological forecasting, it was decided to comply with a request of the World Meteorological Organization (WMO) to review and update a report on "Hydrological Forecasting Practices" prepared by the WMO Working Group for Hydrological Forecasting for publication in the WMO "Technical Notes" series. The review, which was done on the basis of the original Russian text, took 3 months (January - March, 1974) to complete. The revised manuscript was favourably received by WMO.

The work on the project was to be carried out by Mr. D. Egar who was hired by the Division on a term basis but subsequently resigned to take on a permanent position in the Division of Engineering Hydrology. However, it was arranged with the Department of Civil Engineering of the University of Ottawa, where Mr. Egar is registered as a graduate student, that he would be working on the project within his study program. It was agreed that he would undertake a project involving an investigation of the influence of forecast errors on reservoir performance, and that this project would be carried out under the supervision of the principal investigator. This arrangement went into effect in August, 1974. By the end of September a computer program was developed and tested, and an analysis of a flood control reservoir operation was started.

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* Hydrology Research Division, Ottawa

APPLICATION OF RUNOFF AND TEMPERATURE MEASUREMENTS IN THE ANALYSIS OF BASEFLOW DATA

Project No. HR 73-4
K.U. Weyer*

Field work on this co-operative project with the University of Waterloo was completed during the summer of 1974 with a short field trip. A planned joint 4-week major study could not be undertaken because of a shortage of funds.

In spite of this handicap the field work provided significant results in respect to the role of runoff and infiltration in the hydrologic cycle:

1. During and after a summer storm the resulting runoff in Wilson Creek consisted of direct runoff (6% of total storm runoff) and groundwater discharge in response to the storm (>94% of total storm runoff and more than 70% of the peak runoff).

2. The groundwater flow responded very quickly and the groundwater was derived from fracture systems.

These results were based on a combination of accurate runoff measurements, major-ion analysis and stable isotope studies.

These results are in agreement with the results of the principal investigator's research in Germany and shows that the models used there are applicable to Canadian conditions. They also show that the wet-area response theory, strongly emphasized by Freeze during the last few years, seems to be applicable only in a small number of cases. The results are basic for a better understanding of the hydrologic cycle in Canadian watersheds, for a proper application of hydrologic models to real-world situations, and for improved management of Canadian water resources. Similar results have been found this summer in the Kenora Research Watershed, where similar field studies were conducted for 4 weeks.

The following papers have been presented at scientific meetings or are in preparation for presentation and/or publication:

Fritz, P., Bottomley, D.J., Cherry, J.A., Harrington, R.F. and Weyer, K.U., Storm runoff and baseflow studies in small forested watersheds using stable isotopes and major ions: 1974 Ann. Mtg. Geol. Assoc. Amer., Miami.

Weyer, K.U., Cherry, J.A. and Fritz, P., Groundwater response during storm-runoff in a forested watershed. (In preparation).

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* Hydrology Research Division, Ottawa

Weyer, K.U., Cherry, J.A. and Fritz, P., Grundwasseranteil im Regenabfluss eines mittelgrossen Einzugsgebietes (22 km^2) in Manitoba, Kanada: In preparation for Ann. Mtg. Hydrogeologische Vereinigung, West Berlin, May 1975.

The results of the Wilson Creek and Kenora studies: A paper to be presented by Fritz, P. at the IAEC-HQ, Vienna, Austria, Jan. 1975.

Weyer, K.U., The role of fracture systems in groundwater response: In preparation for Int. Cong. Hydrogeol., Porto Alegre, Brazil, March 1975.

GROUNDWATER CHEMISTRY - FLUCTUATIONS AND ANALYTICAL PROBLEMS

Project No. HR 73-5

J.A. Vonhof*

Two different studies currently form part of this project:

1. Evaluation of laboratory versus field analyses of both groundwater and surface water samples. The objective of this study is to determine the ionic stability and the magnitude of chemical changes that take place in water samples from the moment that they are collected until analysis has been completed in a central laboratory.

2. Daily variations in groundwater chemistry. The objective of this study is to determine if the ionic content of groundwater varies in a regular way with time.

The field area and sampling sites are located near Esterhazy, Saskatchewan. Analytical techniques used in the field are essentially the same as those used in the Water Quality Laboratory (Calgary, Alberta). The field laboratory is also equipped with a Dial Atom II Atomic Absorption unit. Daily bulk samples have been collected at 4 sampling sites (one surface water and three groundwater) over a period of 25 days. The bulk samples were subsequently split and one sample of each site was forwarded to the laboratory in Calgary for analysis.

The field program was conducted by Mr. C. Davison, University of Waterloo. The results of this study are to be used as the basis for a M. Sc. thesis.

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* Hydrology Research Division, Calgary.

USE OF WELL HYDROGRAPHS IN THE EVALUATION OF GROUNDWATER RESOURCES

Project No. HR 74-1

G. van der Kamp*

This progress report is concerned principally with the early stages of this project in which the research direction was initially defined. The choice of research direction was based on a series of discussions of groundwater problems in the Maritime provinces of Canada. These discussions were carried on both at meetings of the Maritime Groundwater Committee and during visits to the provincial water agencies in the spring of 1974.

Within the wider context of groundwater exploitation one particular area of concern came to the fore, namely the problem of designing and analyzing pump tests in fractured and inhomogeneous media such as the sandstones of the Permo-Carboniferous basin of the Maritimes. Evaluation of this problem in terms of research needs and possibilities indicated that research on the analysis of groundwater hydrographs could be a more fruitful approach to the solution of problems in groundwater management. The reasoning that led to this conclusion will be briefly outlined in this essay.

PROBLEMS OF PUMP TEST ANALYSIS

The immediate problem with pump test analysis is that in many cases the observed drawdowns do not correspond to any of those predicted by the standard models described in the literature for confined, semi-confined, or unconfined flow in ideal aquifers. Even when the drawdown curves appear individually to conform to the "ideal" cases, the hydrogeologist can be confronted with another common problem: large apparent variations in storage coefficient and transmissivity with time or with observation well location.

"Ideal" is here taken to imply, amongst other characteristics: flow obeying Darcy's law, aquifer homogeneity, and no variation with time of hydraulic characteristics. Effects such as those due to delayed yield from water table storage, anisotropy or finite extent of the aquifer have been treated in the literature and are, in principle at least, amenable to analysis by known methods. Hence, they also are ideal cases.

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IS FRACTURE FLOW THE CULPRIT?

It was generally suspected that anomalous pump test results in the Maritimes might be due to the effects of fracture flow. Here a possibility of semantic confusion arises. In principle, flow in fractured bedrock is nearly always fracture flow for the greatest part, but in most cases such flow can be treated by the standard methods developed for flow in unfractured or homogeneous media. The problem is whether the observed anomalies are due to effects which are peculiar to fractures. At least two possibilities stand out: (1) Changes of fracture aperture due to changes of pore pressure may cause a variation of hydraulic conductivity with time. Work done by Gale at Sambro, Nova Scotia (Gale et al., 1974) indicates that this effect can be significant. Little attention is being paid to it in current pump test literature. (2) If the over-all transmissivity of an aquifer is largely due to widely spaced and highly conductive fractures then the aquifer cannot be treated as homogeneous. For such cases the transmissivities obtained by pump tests will tend to vary from well to well, and the effective regional transmissivity may well be larger than the average obtained from localized aquifer tests which will tend to miss the important fissures.

BUT WHY CARRY OUT PUMPING TESTS?

For nearly all pumping tests, in the Maritimes as elsewhere, the final objective is not the determination of the hydraulic properties of the aquifer, but the prediction of the long-term behaviour of a well-aquifer system under various pumping stresses. A further investigation of pumping test problems might well not be the most fruitful approach to this final goal. It might pay to stand back at times and ask whether other methods of studying groundwater systems should not receive a little more attention. Perhaps there has been a tendency in the recent past to over-emphasize pumping test methods. A quote from Walton (1970, p. 9) is to the point: "Forced by the necessity of solving pressing groundwater problems, most recent advances in groundwater resources evaluation have dealt with water-well hydraulics and well-field designs. The most striking trend in 1968 was the renewed interest in Darcy's law and all aspects of regional groundwater flow as opposed to the previous preoccupation with hydraulics of water wells and well fields."

For problems of long-term prediction an aquifer must nearly always be viewed as a conduit of finite extent and limited storage capacity. Flow into and out of the aquifer, both vertical and lateral, must be taken into account, i.e. the groundwater must be viewed as part of the hydrologic cycle. All the hydraulic parameters are in general irregular in space and time. The question then is how much information about the properties of the system is needed to allow a satisfactory solution for a given groundwater management problem, and how can this information best be obtained? Programs of aquifer testing should be designed on this basis.

TYPES OF AQUIFER TESTS

The most common method of obtaining information on a groundwater system is through the measurement and analysis of water level fluctuations

in wells and piezometers. The present discussion will be limited to this type of test. They can be classified in three groups according to the duration of the fluctuation:

(1) Practically instantaneous tests. These include slug tests and very short pump or bailer tests. Such tests yield only very localized hydraulic conductivities and give little or no information on storage coefficients. They yield no information on the recharge to the groundwater system.

(2) Short-term tests. These are tests involving fluctuations with duration of approximately one day. This category includes most pumping tests, and also the recording and analysis of barometric and tidal fluctuations. Such tests can yield information on hydraulic conductivities over an intermediate distance scale. They yield at best a short-term storage coefficient which usually bears little or no relation to the long-term storage capacity of the groundwater system. Under favorable circumstances they can provide information on recharge and discharge rates.

(3) Long-term tests. These involve fluctuations with durations of the order of a year or more, such as seasonal changes or long-term pumping effects. Such measurements can, in principle at least, provide information on the entire groundwater system, including such parameters as the regional transmissivity, long-term storage capacity and recharge and discharge rates.

Two general observations can be made about the types of tests listed, above. First, in most cases only long-term tests can yield a reliable measure of long-term storage capacity. Second, the longer the duration of the test, the less localized are the values of the hydraulic parameters determined by means of that test.

WHAT TYPE OF TEST TO USE?

Virtually all groundwater exploitation problems are concerned with long-term predictions involving times of a year or longer. It follows that long-term tests are the most appropriate to use in tackling such problems. In particular for instance, the storage coefficient determined by short-term tests is often virtually irrelevant to long-term management problems. In practice of course long-term tests are often not possible and one has to make do with what is available.

In any case there is one important type of information for which short tests can be used. This concerns the transmissivity near a pumped well, which largely governs the drawdown in the well, and is therefore essential to the design of pumping systems. If the proposed pumping rates are very small compared to the total storage capacity in or flow through the system, then the transmissivity near the wells is the only important information that is needed. Current hydrogeological mapping programs in Canada, to the extent that they are concerned with groundwater quantity make use largely of data from short-term tests, apparently because groundwater is not being intensively exploited in most areas.

In the recent past there has been a tendency to use pump tests for the solution of groundwater problems without due regard for the final objective. For instance, when the proposed pumping stress is very small, pump tests can be used, but inexpensive slug or bailer tests may well be perfectly adequate. On the other hand, for cases where the groundwater system is to be subjected to intensive pumping stress, short-duration pump tests can lead to erroneous predictions because they usually do not yield reliable estimates of recharge rates or long-term storage capacities.

In general the type of test that is used should match the requirements of the particular problem that is to be solved.

RESEARCH NEEDS

Short-term pump tests have been extensively discussed in the groundwater literature of the last few decades. In view of this and the considerations presented above, it seems safe to say that research on pump tests has probably been pushed as far as it needs to go for a while. More research on very short tests such as slug tests could well be fruitful, although various types of such tests have been developed and are being used already.

In terms of research on long-term tests, an intriguing possibility is a greater use of the information contained in long-term well hydrographs. Water level data from observation wells are being collected by various agencies and the network of such wells is expanding. In principle seasonal fluctuations of water levels are very similar to the effects of long-term pumping and could yield valuable information for the management of groundwater resources. Thus both the availability of data and the nature of groundwater problems would suggest a more intensive use of well hydrographs. Research in this direction has certainly been done, but has not seen much application. This project is intended to rectify this situation through an intensive inquiry into the use of groundwater hydrographs for the evaluation and management of groundwater resources.

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USE OF WELL HYDROGRAPHS IN THE
EVALUATION OF GROUNDWATER RESOURCES

Project No. HR 74-1

G. van der Kamp*

Absence of fall recharge in 1971 for an aquifer near Cap Pelé, New Brunswick

As part of a study of the groundwater hydrology of coastal aquifers, weekly water level data were collected from a number of wells at a study site on the shore of Northumberland Strait near Cap Pelé, New Brunswick. During the time that the measurements were carried out (September 1970 through October 1972) an unusual occurrence was observed, namely, the apparent absence, in 1971, of significant fall recharge to a water table aquifer. The possibility of such an occurrence may be of some importance for groundwater developments in the region, and is therefore described in this brief report.

The location of the study site and a sketch of the hydrostratigraphy are given in Figures 74.1.1 and 74.1.2. Pump tests, slug tests and tidal analysis show that the upper (water table) aquifer has a transmissivity of about 280 m^2/day within 200 meters of the sea and a transmissivity of about 50 m^2/day between wells 7-85 and 4-87. The lower sandstone aquifer has a much lower transmissivity of about 0.20 m^2/day. The claystone unit between the two aquifers is estimated to have a vertical hydraulic conductivity of about 3×10^{-4} m/day, and acts effectively as an impervious base for the upper aquifer. Analysis of eight core samples from a test hole near well 2-18 yielded a porosity for the upper sandstone of 0.22.

Water levels as determined by weekly measurements are presented graphically in Figure 74.1.3. They are given with respect to mean sea level as determined during the summer of 1970 by means of a tidal gauge at Petit Cap (Fig. 74.1.1). The amplitude of tidal fluctuations in well 2-18 was reduced from about 50 cm to less than 5 cm by filling the well filter with sand. All the wells are subject to irregular fluctuations of up to 5 cm due to changes in atmospheric pressure.

Also shown in Figure 74.1.3 are the monthly precipitation and mean temperature, taken from the Monthly Record of Meteorological Observations in Canada published by the Atmospheric Environment Service of the Department of the Environment. Prior to November 1971 no data are available for Cap Pelé, and the data quoted are for Moncton airport, about 40 km west of Cap Pelé.

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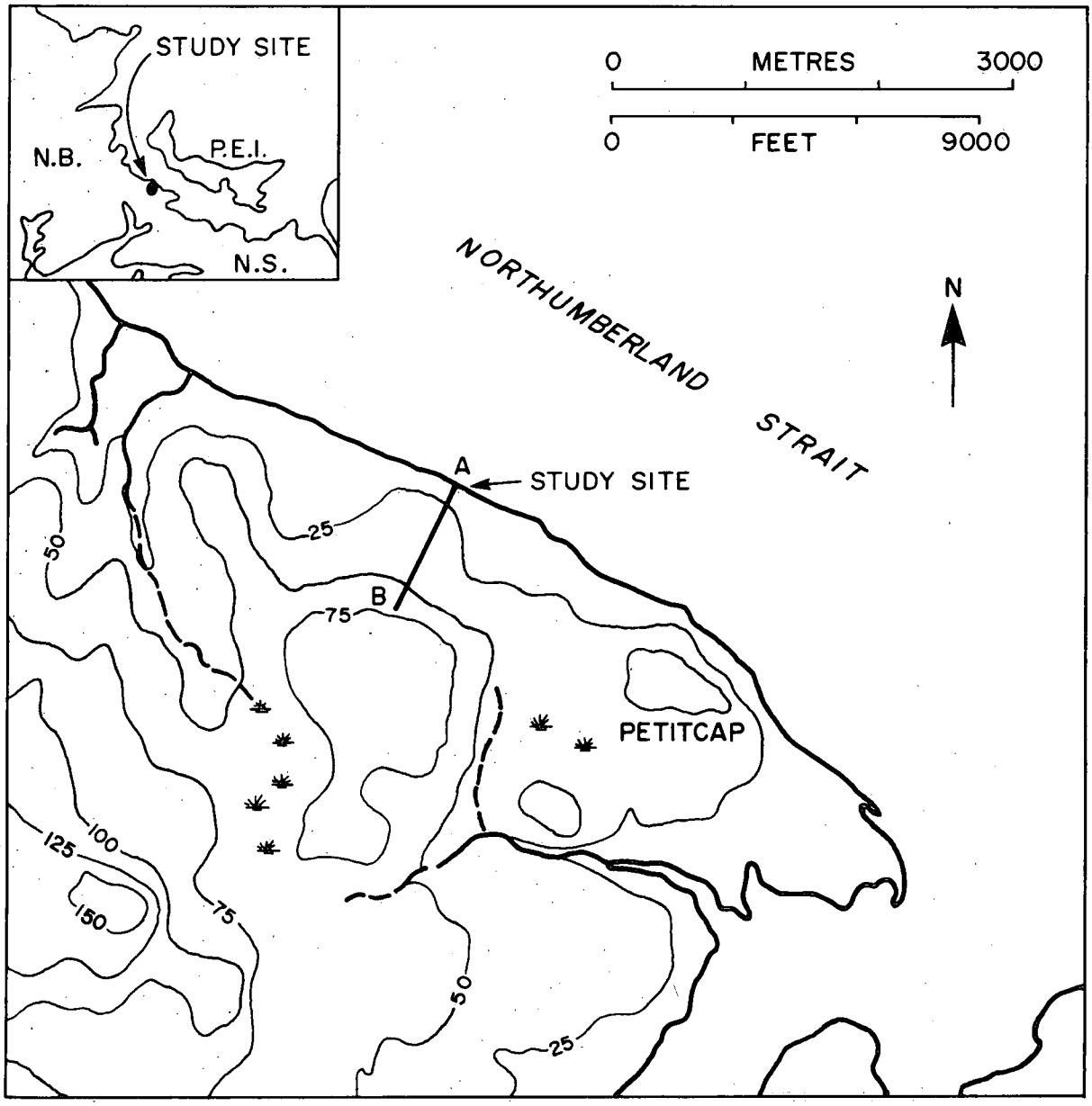

Figure 74.1.1. Location of the geohydrological study site near Cap Pelé, New Brunswick.

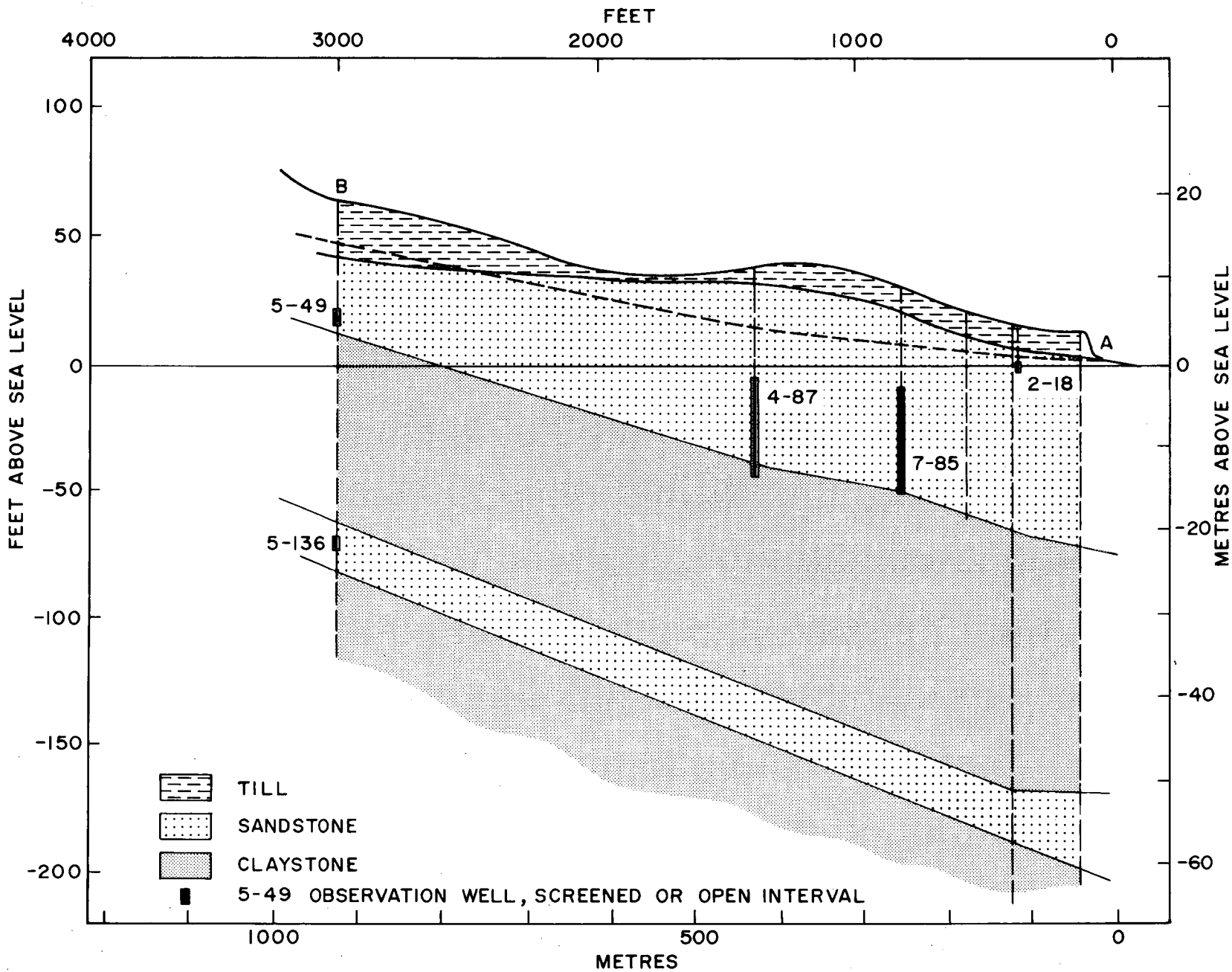

Figure 74.1.2. Hydrostratigraphy of the Cap Pelé study site.

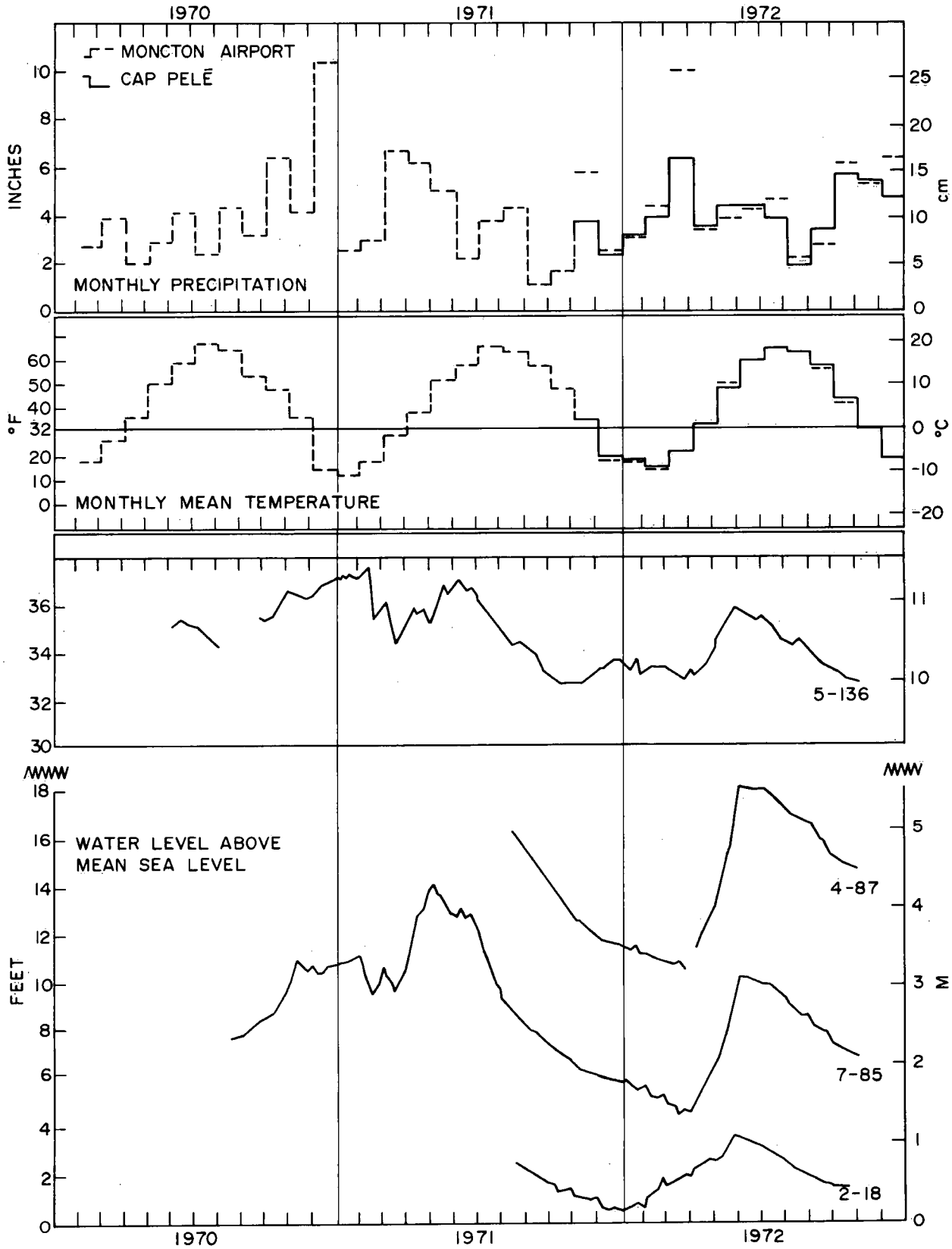

Figure 74.1.3. Groundwater levels, monthly precipitation and temperatures at Cap Pelé site.

Especially interesting in these hydrographs is the apparent absence of fall recharge in 1971 as evidenced by the hydrographs for wells 4-87 and 7-85. Data from well 5-49, further inland, are incomplete but indicate similar behaviour. The data from well 5-136, open to the deep aquifer, show some fall rise in 1971. Flow and head changes in this formation probably originate at an outcrop further inland where the water table is near the surface (see Fig. 74.1.1). Inspection of the precipitation records shows unusually low rainfall during September and October of 1971, and herein lies a probable explanation for the absence of fall recharge. It seems likely that the 1971 fall precipitation prior to ground freeze-up went largely to satisfying the soil moisture deficit near the ground surface that had accumulated during the preceding summer.

Observation wells in this region generally show both a fall and a spring recharge such as those shown by the water level record for well 7-85 in 1970 (Fig. 74.1.3). Figure 74.1.4 shows some water level records for a well near Cornwall, P.E.I., about 75 km east of Cap Pelé. These records show the fall and spring water level rises which are characteristic for the region. It might be noted that the fall rise in 1971 for this well was unusually low, indicating that the same conditions which led to the absence of a fall rise at Cap Pelé also prevailed at least to some extent on P.E.I. Trescott (1970) and Hennigar (1972) present hydrographs for wells in Nova Scotia which have a similar double recharge pattern. By way of contrast Meyboom (1966) presents data indicating that in Manitoba the absence of fall recharge is the rule rather than the exception.

The likelihood of no fall recharge in the Maritimes region cannot be estimated from the available data, but it would seem to be an unusual occurrence. The absence of fall recharge is probably most likely to occur in areas where the water table is deep below the ground surface (4-8 meters at Cap Pelé), and where the surficial deposits are fairly impervious (clayey till at Cap Pelé).

The possibility of no fall recharge could be of some interest for groundwater exploitation in the region. For one thing, it means that the lowest water levels can occur not in the fall, but in the early spring. If so, these water levels are then likely to be unusually low. It also means that in designing a groundwater development one should take into account the possibility that the groundwater reservoir might go for as long as 10 months or more without any effective recharge from precipitation. This could be particularly important for areas where salt water intrusion is a problem.

The available data allow an estimate of the recharge to the aquifer. During the period November 1, 1971 to October 31, 1972 the average water table slope between wells 4-87 and 7-85 was 0.013, and the total flow past well 4-87 during this period was therefore about 240 m^3 per meter of aquifer parallel to the shoreline. If the groundwater divide is about 1500 meters from the shoreline (see Fig. 74.1.1) then, with well 4-87 being 425 m from the shoreline, the recharge between well 4-87 and the divide is 240/1075 = 0.22 m. This compares to a total

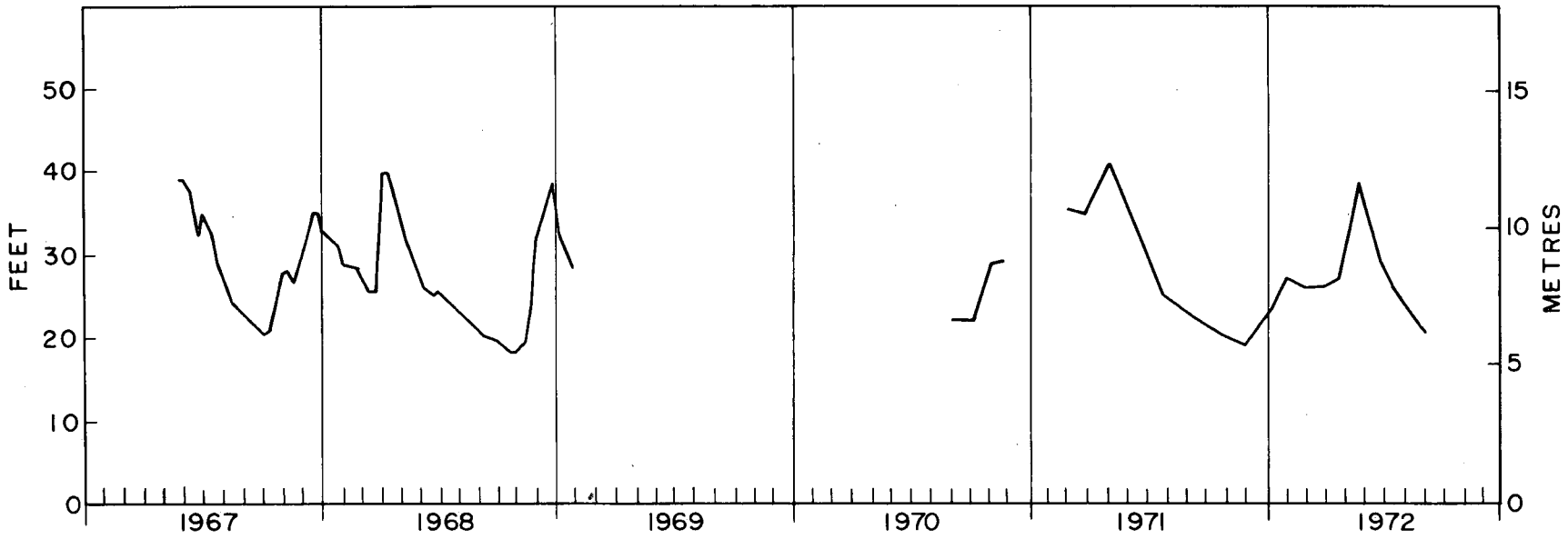

Figure 74.1.4. Water level above mean sea level in a well near York Point, P.E.I.

precipitation during the same period of 1.05 m. During normal years the recharge is greater and probably lies between 0.25 and 0.30 m. All the recharge occurred during April and May of 1972 and the water table rise during this time as indicated by the records from well 5-49 was about 4 m. Thus the specific yield or coefficient of storage at the water table is about 0.22/4 = 0.055, a rather low figure compared to the sandstone porosity of 0.22.

Thanks are due to Mr. Jean-Guy LeBlanc who carried out the water level measurements at Cap Pelé, and to the many others who assisted in various aspects of the work reported here.

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USE OF WELL HYDROGRAPHS IN THE
EVALUATION OF GROUNDWATER RESOURCES

Project No. HR 74-1

G. van der Kamp*

Use of Slug Tests to Determine Hydraulic Conductivity

INTRODUCTION

Slug tests can be a useful method of estimating hydraulic conductivities. The tests can be easily carried out and can often be completed in a matter of minutes. They are widely used by geohydrologists. In this report I will describe some measurement and analysis techniques that I have found useful, and will illustrate these with some examples of field measurements.

PRINCIPLE OF THE METHOD

A slug test consists essentially of inducing an effectively instantaneous change in the water level of a well and observing the return of the water level to the undisturbed state. This decay of the perturbation is related to the response characteristics of the well as an observation device and under appropriate circumstances can give a measure of the hydraulic conductivity of the formation.

The theory of slug tests has been described by Cooper et al. (1967) with a supplementary note by Papadopulos et al. (1973). Earlier slug test theory by Hvorslev (1951), Ferris and Knowles (1954) and others is based on inadequate models and is not reliable, although the theory of Hvorslev can be useful for estimating the effect of well response.

A basic condition for the application of the Cooper theory is that the flow in the formation due to the slug test should be perpendicular to the axis of the well, i.e. the flow is assumed to be radial. In addition the length of the well open to the formation should be known and the effective radius of the well screen should be known at least

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approximately. Slug tests on wells in highly permeable aquifers may show oscillating water levels (Bredehoeft et al. 1966). For such cases the Cooper theory is obviously not applicable. In spite of these restrictions, slug tests, if used with discretion, can be useful in many situations.

The theory of Cooper et al will not be described in detail here since the original article is readily available.

METHODS OF INDUCING A SUDDEN WATER LEVEL CHANGE

Applicability of the theory demands that the water level in the well be changed effectively instantaneously, i.e. in a time much shorter than the time required for the water level to decay back to near the undisturbed condition.

The simplest method of inducing the water level change is to pour water into the well. However this method cannot be used if the effect of water dripping down the sides of the casing is likely to be important, in other words most of the water poured into the hole has to arrive at the water level practically instantaneously.

For fast responding wells a small and very quick water level change can be induced by raising or lowering some object (such as a weighted float, sealed off hose or pipe, etc.) which is at the water level. The displacement of the object then results in a change of water level. An example of such a method utilizing displacement is given by Cooper et al.

METHODS OF MEASUREMENT

The simplest way of measuring the water level decay after the initial abrupt change is by wetted tape or similar methods. However this method can only be used when the water level decay is slow enough to allow for at least several readings before return to the initial level. The wetted tape method can therefore only be effectively used for wells with a response time of at least several minutes. (The response time can be defined as the time required for the water level to decay back to $1/e = 0.37$ of the initial displacement.) For wells in sandstone aquifers the response time is often much less than a minute. In fact the response time can be approximately calculated with the formula:

$$\tau \approx \frac{3\, r_c^{\,2}}{KL}$$

(see the accompanying list of symbols for the meaning of the symbols). This equation can of course also be turned around and used for a quick and rough calculation of K once τ has been determined by measurement.

Cooper et al used a fast-responding pressure transducer to follow the water level changes in a well with a response time of about 30 seconds.

A fairly simple and reliable method of following the water level changes in a fast-responding well is by an adaptation of the method described by Walton (1963). Here a Stevens F-type water level recorder is used with the water level sensed by a float or Keck. The recorder pen is moved by hand at speeds of up to 1 second per interval on the recorder chart. With some practice good measurements can be obtained for wells with response times as small as 3 or 4 seconds. The trick here is to induce only a very small initial water level change -- a few tenths of a foot is usually sufficient.

ANALYSIS OF THE DATA

Cooper et al give theoretically calculated values for change of water level with time after the initial perturbation. Their figures can be converted to type curves by plotting on log-log paper with $y = H/H_0$ on the vertical axis and $\beta = KLt/r_c^2$ on the horizontal axis. A series of type curves is then obtained for different values of $\alpha = r_s^2S/r_c^2$. (See figure 74.1.5).

Measured values of H are plotted against t (in any convenient units) and matched to these type curves in a procedure similar to the one used in pump test analysis. The values of H, t, y, and β, at the matchpoint can then be used to calculate H_0 and KL through the equations:

$$H_0 = H/y$$

$$KL = \beta\, r_c^2/t$$

Plotting H and y on a log scale rather than on a linear scale as Cooper et al do, makes it unnecessary to know H_0 beforehand and avoids the need to calculate H/H_0. The analysis is thus made a little easier to carry out.

The value of α must be estimated beforehand. The calculated value of KL is insensitive to the value of α, and large errors in α are

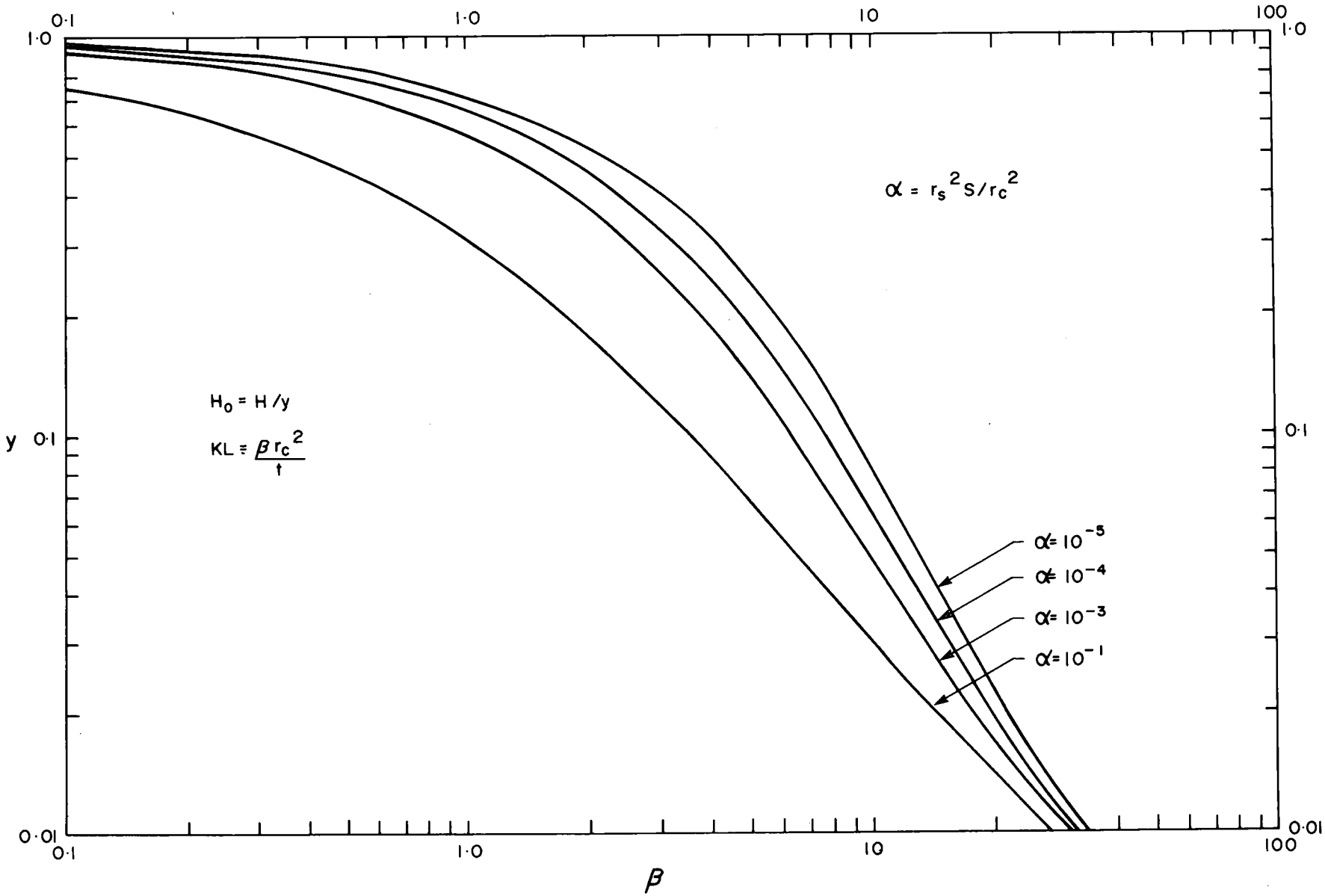

Figure 74.1.5. Type curves for slug tests.

therefore not important.

APPLICATION TO ACTUAL CASES

In figure 74.1.6 the water level changes for slug tests on two wells are illustrated. These were obtained with a Stevens F-type recorder and the "moving-the-pen-by-hand" method.

Figure 74.1.6a is for a well in a sandstone aquifer at Cap Pelé, N.B. This is a six inch diameter well open to 40 feet of the formation. The water level change with time is plotted on a log-log scale in Figure 74.1.7 for application of the type curves. The final result for the horizontal conductivity K from the slug test is 32 ft/day. This value may be compared with a value for K of 44 ft/day obtained from a pump test on the same well with several observation wells.

Figure 74.1.6b shows a slug test on a well in a highly permeable sandstone aquifer at York Point, P.E.I. Here the formation is so permeable that an oscillating type slug test results, and further analysis is not possible with the theory developed to date. (See Bredehoeft et al, 1966).

Results similar to that illustrated in figure 74.1.6 have been obtained for other aquifers of diverse permeability in the Permo-Carboniferous basin of the Maritimes. Table 74.1.1 shows the resulting values for transmissivity as compared with the values obtained by pump tests. The aquifers are all sandstone formations and the wells are open holes. The agreement between the two methods of obtaining transmissivities is quite good (within 20 per cent) over a wide range of transmissivity values. The values obtained by pump tests are of course representative of a much larger portion of the aquifer.

DISCUSSION

If carried out with care slug tests can be expected to yield values for the transmissivity within 20 or 30 per cent of the value obtained by pump tests. Thus slug tests may yield a sufficiently accurate value of transmissivity for many applications. Slug tests can also be useful for exploratory work and for the design of pump tests (pumping rate, etc.).

SYMBOLS USED

H difference between disturbed and undisturbed water levels

H_o initial water level displacement

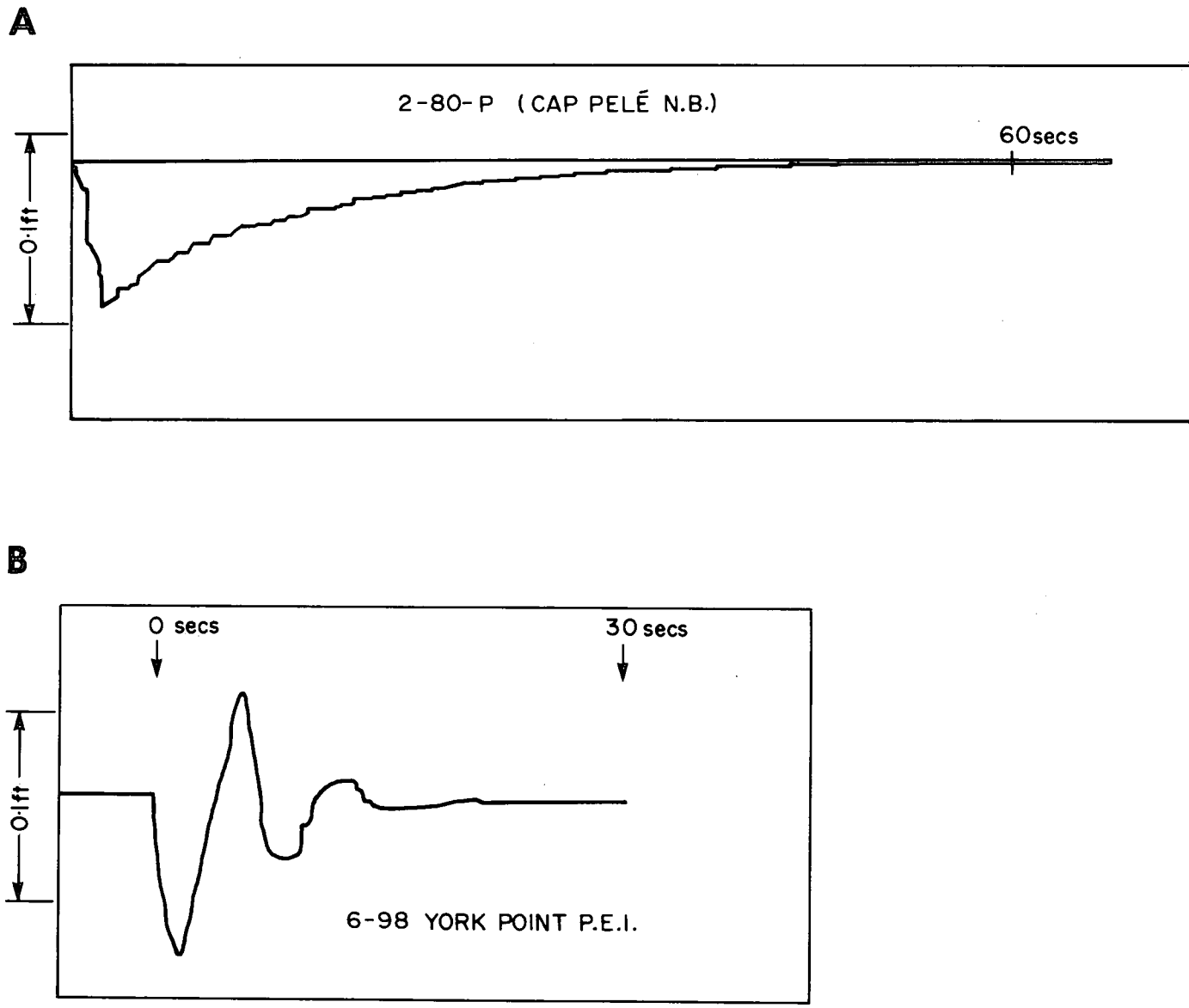

Figure 74.1.6. (A) Slug test on well 2-80-P, Cap Pélé, N.B., using hand-moved pen, Stevens F-type recorder, and Keck water level sensor, (B) Slug test on well 6-98, York Point, P.E.I., using hand-moved pen, Stevens F-type recorder, and Keck water level sensor.

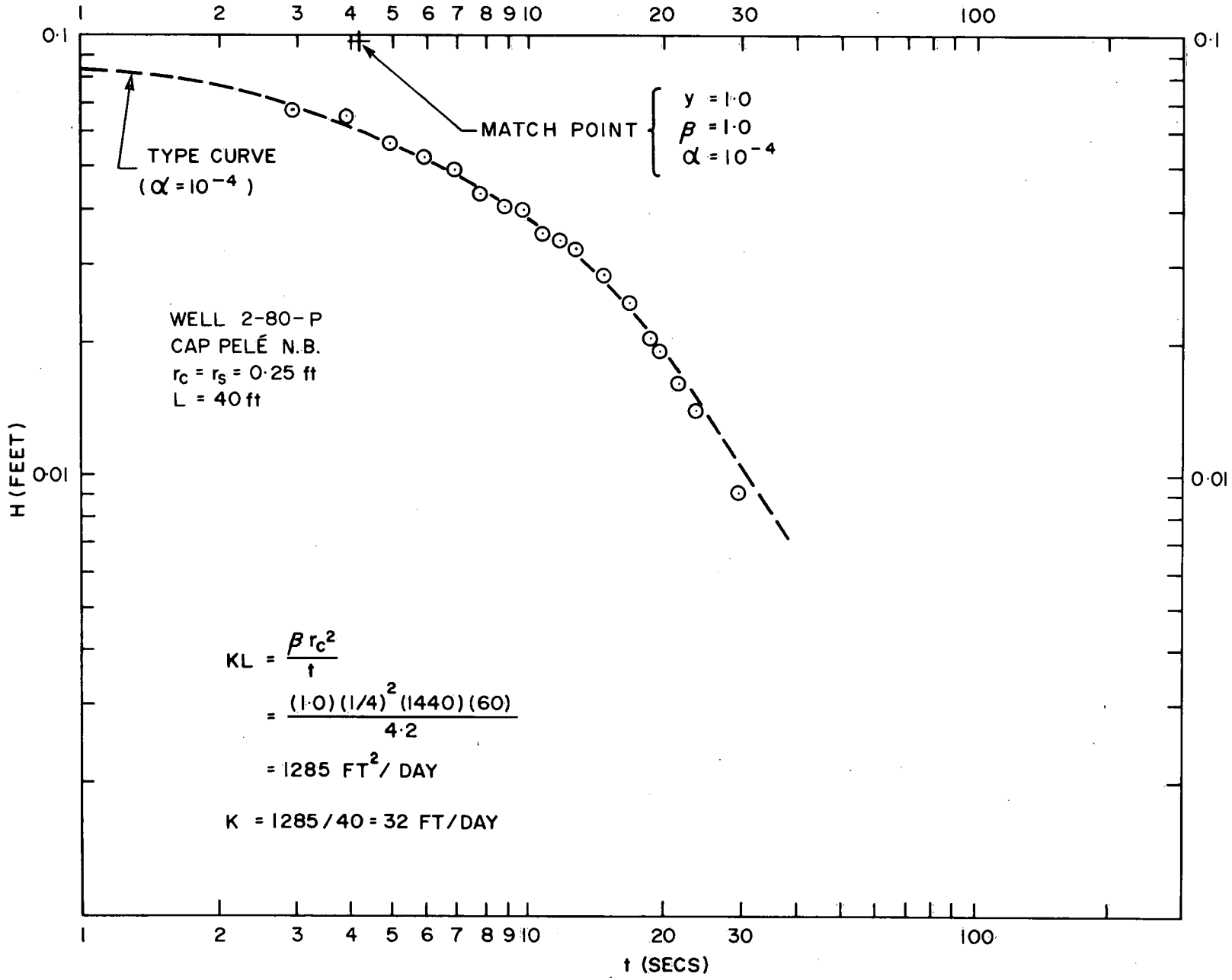

Figure 74.1.7. Match of observed data to type curves and calculation of K.

K horizontal hydraulic conductivity

L length of well or piezometer open to formation

r_c radius of well at water level

r_s radius of well screen

S storage coefficient over length of well screen

t time

y dimensionless vertical variable of type curves

α dimensionless parameter of type curves

$\beta = KLt/r_c^2$ dimensionless horizontal variable of type curves

τ response time of wells

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SITE	TRANSMISSIVITY (FT^2/DAY)	
	From slug tests	From pump tests
York Pt., P.E.I.	5200	6500
York Pt., P.E.I.	650	620
Union No. 1, P.E.I.	6000	6200
Cap Pelé, N.B.	2550	3000
Cap Pelé, N.B.	2.7	2.2

Table 74.1.1 Comparison of transmissivities obtained by slug tests and by pump tests.

NORTHERN GROUNDWATER AND ENGINEERING
PROBLEMS RELATED TO GROUNDWATER FLOW

Project No. HR 74-2
R.O. van Everdingen*

Groundwater-Level and Ground-Temperature Observations, Norman Wells, N.W.T.

by R.O. van Everdingen and J.A. Banner

INTRODUCTION

Early in 1973 an instrumented section was established near Norman Wells, N.W.T., by Ottawa staff of the Hydrology Research Division, as part of Project No. GW 71-3 - Hydrogeology, Mackenzie Valley. The purpose was to determine hydrodynamic gradients and seasonal fluctuations in head in the groundwater flow system presumably existing below the permafrost, and to gather data on the effects of surface disturbance on the permafrost and the thermal regime. A total of 18 holes, varying in depth from 18.3 to 64.0 m (60 to 210 ft.), were drilled between April 7 and April 20. The location of the section is shown in Figure 74.2.1; details of the drillholes are given in Table 74.2.1. Hole locations are listed in the table in terms of distance along the section line and displacement to the west of the line. The zero points of the line will be accurately located by a subsequent survey.

Thermistor cables were installed in holes Nos. 7, 10, 12, 13 and 17 (see Tables 74.2.1 and 74.2.2), with a minimum of 3 m (10 ft.) of cable protruding from the ground. Connector boxes with 14- or 24-pin connectors were installed on the end of the cables to facilitate measurements.

Three-inch PVC casings (schedules 40 and 80), with 6.1 m (20 ft.) saw-cut slotted bottom sections, were installed in holes Nos. 6, 9, 11 and 18.

Pressure transducers on 30 m (100 ft.) long cables were installed in the casing in holes Nos. 6, 9 and 11, to enable recording of water-level or pressure fluctuations. Pressure transducers were used to avoid problems caused by freezing of the water in the wells, which would make use of float-operated recorders impossible. The transducers were of the DC-operated strain-gauge type (Kulite Semiconductor Model OPT3-1500-100A) with a full range of 7.0 kgf/cm^2 (100 psi). Suspended 6-conductor shielded cables were run from the wells to an instrument shelter near the Mackenzie River road. Power

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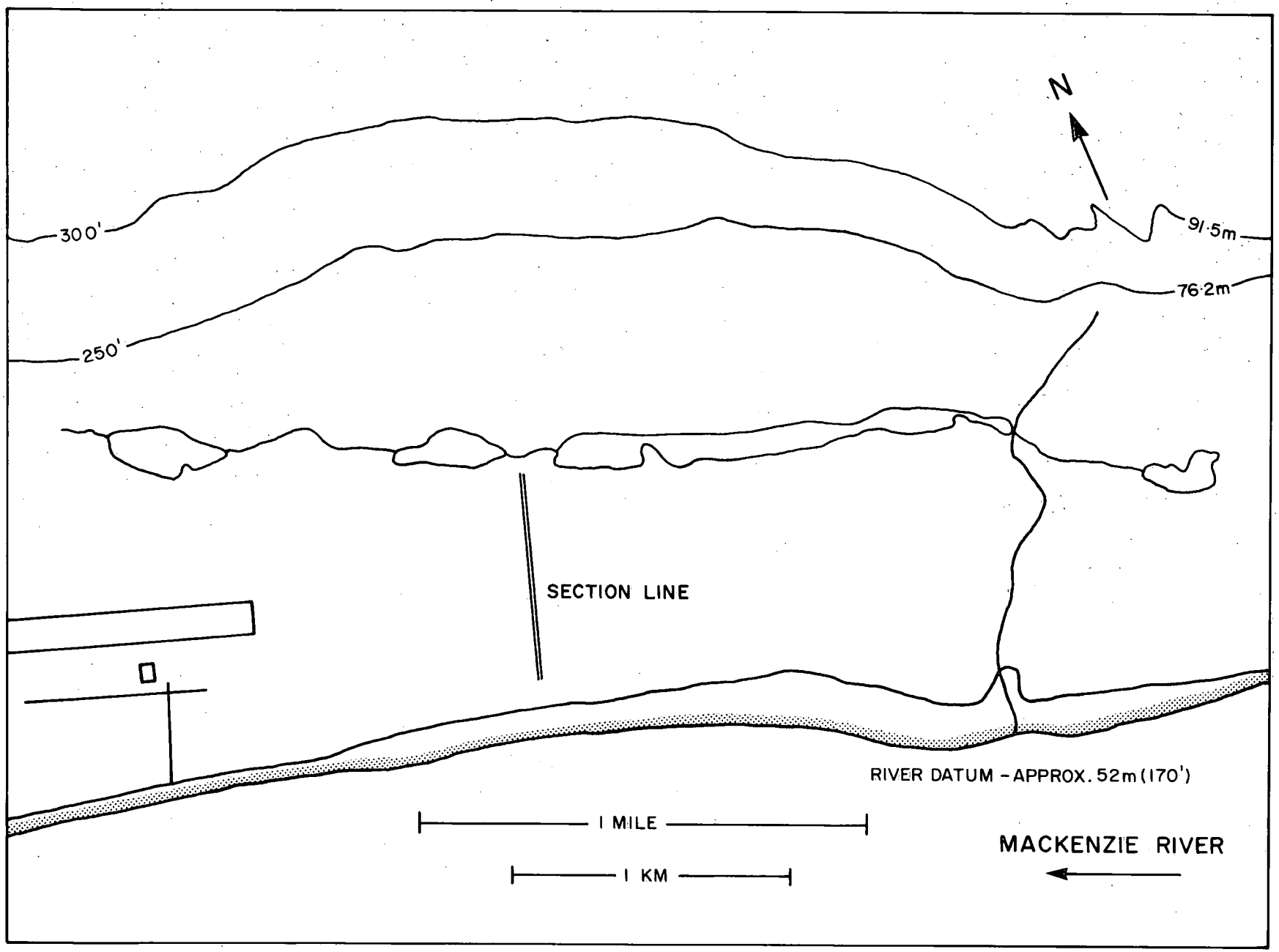

FIG 74.2.1 NORMAN WELLS SECTION

Figure 74.2.1. Location map, Norman Wells instrumented section.

for the transducers was obtained from the main supply via two battery chargers, two 12-volt wet cells and three separate +7.5/-7.5V voltage regulators. Signals from the transducers were recorded on three H.P. Model 680 strip-chart recorders, via a three-channel offset-control box. Arrangements for changing of recorder charts and measurement of thermistor resistances were made with personnel of Water Survey of Canada at Norman Wells.

Supervision of the Norman Wells section was transferred from Ottawa to Calgary on April 1, 1974. The authors visited Norman Wells from June 24 to July 1, 1974, to attempt to correct various deficiencies in the data collection system which had by that time become apparent.

DEFICIENCIES OF ORIGINAL INSTALLATION

The location of the shelter in which the recording equipment was housed enables year-round easy access, as well as connection to N.C.P.C. power. The size of the shelter (2.4 x 2.4 x 4.8 m), however, was much larger than needed, and would have required an excessive amount of energy to maintain a temperature suitable for operation of the recording equipment. As it was, no heat at all was provided during the winter of 1973/1974, with the result that the strip-chart recorders were forced to operate at ambient temperatures as much as 40 C° below the lower of the operating limits set by the manufacturer (0° to +55°C). As predicted by the manufacturer (H.P. Manual 00680 - 9002, para. 5-3), two of the three recorders suffered extensive mechanical damage.

The lead-acid storage batteries were unventilated. The battery chargers used, of the common automotive trickle-charge type, had no voltage regulation and, as a result, the batteries were continuously overcharged, thus consuming large quantities of distilled water and producing corrosive vapours which were apparently responsible for the corrosion of metal parts in the recorders.

The transducer supply voltage regulators used in the installation were stable to 0.43 m (1.4 ft.; calculated equivalent water head) for an 80 C° change in ambient temperature. All three negative supply regulators were in parallel, and the resulting interaction between them caused noisy signals requiring extremely low servo-gain settings on the recorders. The low servo-gain settings in turn caused very slow recorder response (minutes) and very wide dead band. Two of the regulators were exposed to the elements in unsealed cases and one was subjected to continuous stresses by the suspended cables it joined.

Electric pens on the recorders were badly worn, drawing lines about 15 times normal width (1.5 divisions wide compared to normal 0.1 division). The continual "chatter" caused by the noisy signals was undoubtedly responsible for this.

The offset-control unit, designed to provide zero-suppression for the transducer signals, to allow more sensitive recording, was found

with the controls for all three channels turned off. The recorders were set at 6V ≈ 84.4 m or 277 ft. H_2O full scale, although the instructions for the offset-control unit specified 120 mV ≈ 1.68 m or 5.5 ft. H_2O full scale. Tests indicated that the change in offset voltage with an 80 C° change in ambient temperature in the shelter would amount to 260 mV ≈ 3.75 m. or 12.3 ft. H_2O (which would drive the recorder off scale when on the specified settings, if they had been used).

Even with the electronics functioning properly, determination of gradients in groundwater potential between individual wells was impossible, because relative-elevation data were not available.

Measurements on thermistor cables in holes Nos. 7 and 10 were taken at 2 to 3 week intervals between May 16, 1973 and June 6, 1974 by the Geological Survey of Canada. Measurements on thermistor cables in holes Nos. 12, 13 and 17 were taken on September 3, 1973 and on February 27, April 3 and 22, May 6, 17 and 27, June 3 and 17, 1974 by Water Survey of Canada personnel.

IMPROVEMENTS MADE BY JULY 1, 1974

A 1.2 x 2.4 m (4 x 8 ft.) area of the instrument shelter was partitioned off with an insulated wall and a tight-fitting door. Additional insulation was added to the floor and ceiling, and sealed against drafts. An enclosed battery compartment with venting only to the outside atmosphere was constructed in one corner.

Two 1500W fan heaters were installed under one of the shelves and aimed toward the battery compartment and the recorder shelf. The heater thermostats, together with a wall thermostat, were set to provide fail/safe operation. (It is expected that intermittent operation of one heater will suffice to maintain a constant 18 °C in the enclosure; the second heater was provided as a spare to automatically take over if the first heater should fail.)

The damaged recorders were replaced, and the remaining recorder was serviced. The offset-control unit was reconnected and the controls adjusted for 600 mV ≈ 8.44 m or 27.7 ft. H_2O full-scale on the recorders.

The transducer in the well nearest to the shelter was tested by quickly raising the water level in the well 1 meter (3 ft.) and recording transducer response.

The recording system was set for intermittent operation, recording for 2 minutes out of every three hours. This will not only reduce chart lengths by 90 times, but should also considerably increase the lives of the recorders.

ADDITIONAL INSTRUMENTATION

Two pressure transducers (Celesco Model P7D, full range ±1.75

kgf/cm^2 or 25 psi, AC-operated, variable-reluctance type), in probes similar to those used in the 16th Avenue test at Calgary (Banner and van Everdingen, 1974) were installed at stations 45.7 and 46.9 to depths of 37 and 82 cm, respectively, below groundlevel. Holes for the transducers were drilled with a power auger, backfilled with excavated material, and tamped. The transducers were connected, via a switching relay and carlon-protected cable, to a transducer readout (Celesco Model CD25) and a strip-chart recorder (H.P. Model 680) in the instrument shelter. A timer is used to operate the recorder for 2 minutes out of every 3 hours, and to divide the recording time between the two transducers (30 seconds on one, 90 seconds on the other) for identification of the signal sources. The recorders for the three original transducers were also operated via this timer.

An electrical-resistance frostgauge with 22 stainless-steel strip electrodes and 5 thermistors (Banner and van Everdingen, 1974) was installed near station 46.6 to a depth of 103 cm (base of lowest electrode). This gauge was connected via carlon-protected wires to a patch panel in the instrument shelter, where an AC ohmmeter is used to measure thermistor and ground resistance.

FURTHER CHANGES

The pressure transducer No. 003 in drillhole No. 9 ceased functioning on July 19, 1974 for unknown reasons.

In September, 1974, after the necessary components were obtained and assembled, the original transducer power supply and the recorder offset-control unit were replaced by an integrated mains-operated power supply, precision regulated and temperature-compensated reference supply, and triple offset supplies with offsets controlled by digital tenturn potentiometers, calibrated to read directly in p.s.i. The inline +7.5/-7.5V regulators were replaced with new ones, referenced to the precision supply and housed in sealed cases.

The pressure transducer No. 002 in drillhole No. 11 failed during testing of the new power supply and voltage regulators on September 26. As of September 26, 1974, signals from transducer No. 001 (drillhole No. 6) and from the two shallow pressure transducers are being recorded for 2 minutes out of every three hours. Measurements of temperature and ground resistance are being taken on a weekly basis.

DATA

Table 74.2.2 lists temperature measurements for thermistor cables in drillholes Nos. 7 and 10, taken on September 10, 1973, as received from Geological Survey of Canada; for thermistor cables in drillholes Nos. 12, 13 and 17, taken on September 23, 1974; and for the frostgauge thermistors, taken on September 25, 1974. These data represent maximum measured penetration of thawing.

It may be useful to point out here that because of the 10 to 20 ft. (3 to 6 m) thermistor spacing used in cables Nos. 12, 13 and 17, neither the maximum penetration of the upper 0°C isotherm (base of the active layer) nor the position of the lower 0°C isotherm (base of the permafrost) could be accurately determined. But even if these temperature-defined limits could be delineated accurately, other information would still be needed to determine the thickness of the permanently frozen zone. The freezing point of the groundwater may be significantly depressed below 0°C by dissolved minerals and by the presence of clays in the formation. Because of this freezing-point depression, both the base of the frozen zone and the top of the unfrozen water may occur a considerable distance above the base of the temperature-defined permafrost.

As a result of inadequate instrumentation, no conclusive information is as yet available on seasonal fluctuations in piezometric pressures in the subpermafrost aquifer at the Norman Wells section. Vertical hydrodynamic-gradient components cannot be determined because the three instrumented holes were screened at approximately the same depth. Horizontal gradient components cannot be determined because relative elevations of waterlevels in the three instrumented drillholes were not determined at the time of installation, and ground conditions in Norman Wells were unsuitable for a level survey when the section was visited during late June and late September in 1974.

REFERENCE

Banner, J.A. and van Everdingen, R.O., 1975, Instrumentation for groundwater studies in permafrost areas: I. Test of electrical pressure transducers. (to be submitted to Can. Geotech. Jour.).

TABLE 74.2.1A

Drill Hole Data, Norman Wells Section.

April 1973

Hole No.	Hole Location: Distance along line, m	Hole Location: Distance West of line, m	Total Depth, m	Frost to, m	Water Struck at m (static level, m)	Sensors Installed
7	53.3	2.74	64.0	18.3	40.2;50.3	Thermistor cables No. 1 and No. 6
6	54.9	1.52	64.0	22.9	50.3 (6.61)	Pressure transducer No. 001 at 29.6 m.
5	129.5	4.6	22.9	9.1	17.7	
4	259.1	3.05	32.0	18.3	24.4	
3	310.9	3.05	18.3	3.05	8.8;13.1	
2	323.1	4.6	18.3	1.52	6.1	
18	323.1	13.7	32.0	-*	-	Casing to 30.8m; bottom 6m slotted
16	325.5	6.1	41.1	-*	-	
15	326.7	6.1	41.1	-*	-	
17	329.8	7.6	22.9	10.7	12.2	Thermistor cable No. 17
14	339.9	7.6	41.1	-	18.3	Closed casing to 39.9m
13	341.4	6.7	41.1	13.7	18.3 (4.57)	Thermistor cable No. 13
12	354.2	6.7	41.1	-	17.4	Thermistor cable No. 12
11	355.1	4.6	64.0	16.8	18.3 (6.25)	Pressure transducer No. 002 at 29.4 m.
8	423.7	4.6	13.7	6.7	10.7	
10	662.9	4.6	64.0	-	24.4	Thermistor cables No. 2 and No. 7
9	662.9	6.1	64.0	22.9	22.9 (7.13)	Pressure transducer No. 003 at 29.5 m
1	667.5	6.1	22.9	18.3	22.9	

* Drill log states: "not carefully logged, not frozen."

TABLE 74.2.1B

Drill Hole Data, Norman Wells Section.

June 1974

Hole No.	Station, m	West of line, m	Depth, m	Frost to, m	Sensors Installed
19	45.7	2.60	0.40	beyond bottom	Pressure transducer C at 0.37 m
20	46.9	1.98	0.86	beyond bottom	Pressure transducer B at 0.82 m
21	46.6	3.50	1.12	beyond bottom	Frostgauge, lowest electrode at 1.03 m

TABLE 74.2.2A

Temperature Data, Norman Wells Section.
Thermistor Cables in Holes Nos. 7 and 10.
Sept. 10, 1973.

Thermistor No.	Hole No. 7, Cables No. 1 and No. 6		Hole No. 10, Cables No. 7 and No. 10	
	Depth, m	Temperature, °C	Depth, m.	Temperature, °C
1	0.01	+1.95	0.01	+2.05
2	0.15	+1.70	0.15	+2.21
3	0.30	+1.35	0.30	+1.58
4	0.61	+0.48	0.61	+0.37
5	0.91	-0.24	0.91	-0.24
6	1.52	-0.94	1.52	-0.72
7	3.05	-1.89	3.05	-1.54
8	4.57	-2.52	4.57	-1.96
9	6.10	-3.16	6.10	-2.06
10	7.62	-2.69	7.62	-2.05
11	9.14	-2.58	9.14	-1.95
12	10.67	-2.34	10.67	-1.77
13	12.2	-2.22	12.2	-1.51
14	13.72	-2.09	13.72	-1.35
15	15.24	-1.96	15.24	-1.17
16	16.76	-1.82	16.76	-1.04
17	18.29	-1.55	18.29	-0.91
18	19.81	-1.40	19.81	-0.79
19	21.34	-1.22	21.34	-0.63
20	22.86	-1.08	22.86	-0.52
21	24.38	-0.93	24.38	-0.37
22	27.43	-0.81	27.43	-0.12
23	30.48	-0.60	30.48	+0.05
1	30.48	-0.78	30.48	+0.03
2	33.53	-0.57	33.53	+0.38
3	36.58	-0.29	36.58	+0.36
4	39.62	-0.28	39.62	+0.39
5	42.67	-0.21	42.67	+0.69
6	45.72	-0.12	45.72	+0.93
7	48.77	+0.14	48.77	+1.05
8	51.82	+0.22	51.82	+1.30
9	54.86	+0.30	54.86	+1.42
10	57.91	+0.38	57.91	+1.65
11	60.96	+0.45	60.96	+1.78

TABLE 74.2.2B

Temperature Data, Norman Wells Section.
Thermistor Cables Nos. 12, 13 and 17,
Sept. 23, 1974.

No. 12			No. 13			No. 17		
Depth, m	Temp., °C	Thermistor No.	Depth, m	Temp., °C	Thermistor No.	Depth, m	Temp., °C	Thermistor No.
0.076	+7.38	7	0.076	+4.47	7	0.076	+5.89	7
6.17	-1.33	6	6.17	-0.58	6	3.12	+0.04	1
12.27	-0.41	5	12.27	-0.08	5	6.17	+0.09	6
18.36	+0.02	4	18.36	+0.14	4	9.22	+0.14	2
24.46	+0.33	3	24.46	+0.35	3	12.27	+0.20	5
30.56	+0.53	2	30.56	+0.56	2	15.32	+0.22	3
36.65	+0.77	1	36.65	+0.77	1	18.36	+0.32	4

TABLE 74.2.2C

Temperature Data, Norman Wells Section.
Frostgauge Thermistors, Sept. 25, 1974.

No.	Depth, cm	Temp., °C
2	6.5	0.68
3	36.5	1.16
4	66.5	0.58
5	96.5	-0.16

NORTHERN GROUNDWATER AND ENGINEERING
PROBLEMS RELATED TO GROUNDWATER FLOW

Project No. HR 74-2

R.O. van Everdingen*

Use of ERTS-1 Imagery for Monitoring of Icings, N. Yukon and N.E. Alaska

SPRINGS

Perennial discharge of groundwater occurs in a number of stream valleys in the northern portion of the Yukon Territory and the adjoining portion of Alaska. Large fresh-water springs are known in the headwater regions of Firth River, Joe Creek, Babbage River and Canoe River (also known as Fish Hole Creek). Fresh-water springs are also found along some streams in the coastal plain and on the deltas of Firth River and Malcolm River.

Chemical analyses of spring water are available for most of these springs, and discharge measurements have been made at some of the spring locations (Bryan, 1973; van Everdingen, 1974). Table 74.2.3 lists the physical and chemical data for the springs; ranges given for the various parameters in Table 74.2.3 are based on field measurements and laboratory analyses of samples collected during the period from October 1972 to November 1973. Approximate locations of these springs are indicated by number on Figure 74.2.2.

SPRING ICINGS

Water discharged by a perennial spring during the winter usually maintains an open-water reach in the stream it feeds. Unless the stream carries considerable winter flow, the water from the spring will eventually cool off and start freezing at some distance downstream from the spring site. The distance between the point of discharge and the point where freezing starts is a function of the discharge rate, water temperature, dissolved mineral and gas contents and channel slope, and also of the variable conditions of air temperature, relative humidity and windspeed and direction.

Freezing of the spring water will gradually build a layered ice deposit or icing, that covers the full width of the river channel, in some cases over a considerable distance. The areal extent and the thickness of the icings associated with perennial springs continue to increase throughout the winter, until mean daily temperatures rise above 0°C. The maximum

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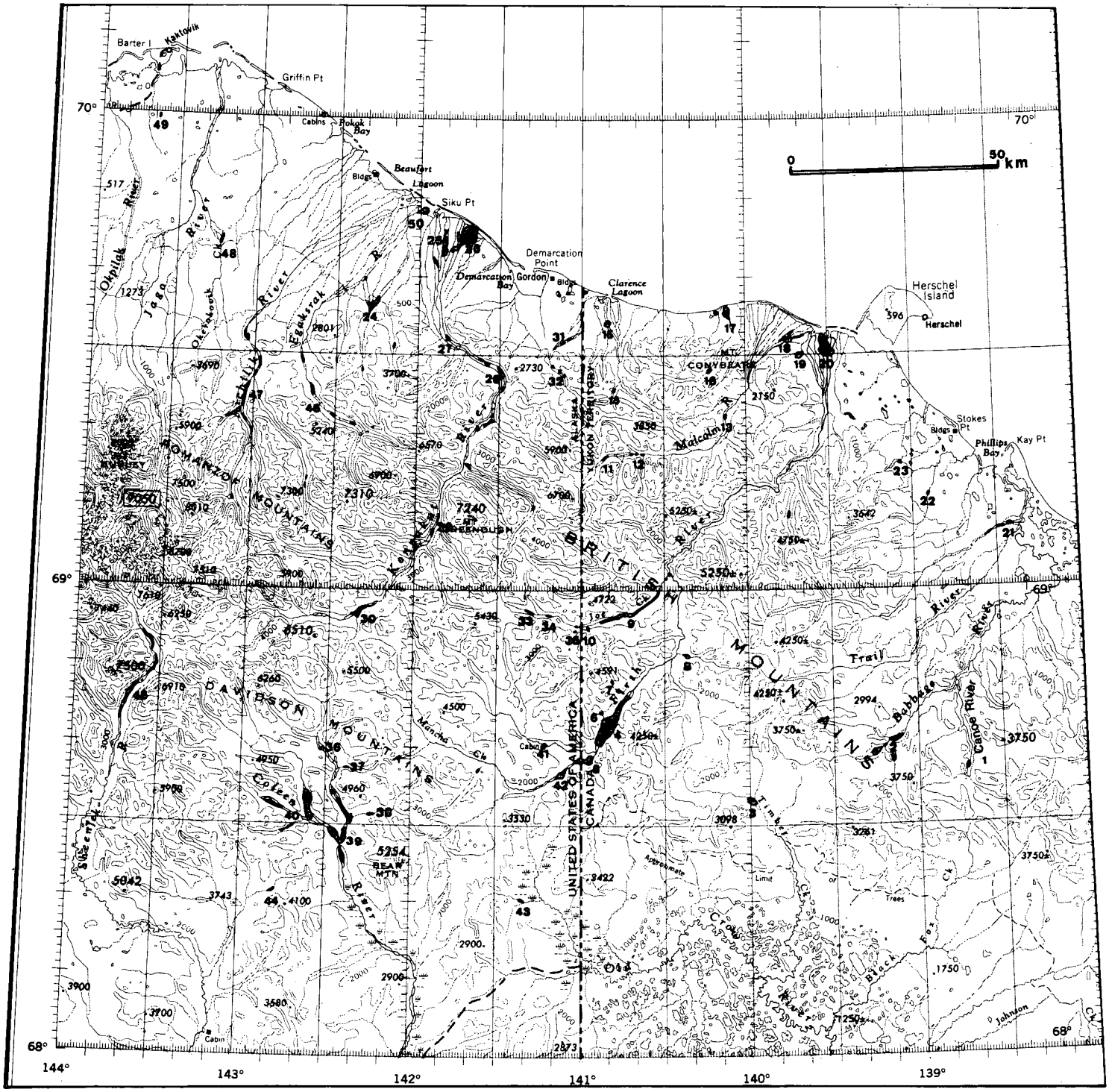

Figure 74.2.2. Location map of study area, indicating major icings. Elevations in feet, Numbers refer to those in Tables 74.2.3, 74.2.4 and 74.2.5.

size of such an icing is a function of the discharge rate of the springs and the duration of the period with mean daily temperature below 0°C. The shape of the icing depends on the morphology of the stream valley; icings in narrow valleys tend to be longer and thicker than those in wider valleys, other conditions being the same. Some of the spring icings in the Northern Yukon are so large that portions of the ice could remain unmelted after a summer with below-average temperatures. Examples include the main Firth River icing, about 3 km wide and 12 km long (2 x 7.5 miles), and the Canoe River icing, the thickness of which exceeded 2.5 m (8.2 ft.) on June 27, 1973.

Icings may also develop in locations where water moving downstream through permeable river bed materials is forced to the surface by changes in the available transmissivity. In the strict sense of the word such icings are also the result of groundwater discharge, even though no discrete springs may be detectable.

All the major icings in the Northern Yukon can be found on air photos available for the area. As most of the photography was taken between mid-July and late August (in the period from 1951 to 1956), the maximum extent of the icings is not shown. The air photos, moreover, do not give any indication of the rate of melting or dissipation during the summer, or of the size of the area that remains covered with ice at the start of the next winter. So far, few observations have been made on any of the icings in the field and no detailed studies of icings have been made in Canada.

The icings in the northern Yukon cause a significant seasonal redistribution of surface runoff, through temporary above-ground storage of groundwater discharge during the winter. The open-water reaches between the spring sites and their associated icings provide overwintering and spawning areas for various fish species (Bryan, 1973). In addition, some of the springs and associated icings may cause serious problems for engineering developments (roads, pipelines) in the area. It would, therefore be useful if additional information could be obtained about the maximum extent of the icings as well as on their seasonal growth and dissipation.

High costs would be involved in the periodic inspection visits necessary to obtain the above information for each of the icings. Besides, the time available for observations is restricted by short daylight hours in winter, and by high incidence of fog and low cloud during spring and fall. For these reasons the potential usefulness of satellite imagery for the study of the regime of spring icings in the northern Yukon has been investigated.

ERTS-I IMAGERY

A preliminary check of the first good-quality imagery of the study area obtained from the Multi-Spectral Scanners on the ERTS-I satellite, launched by NASA on July 23, 1972 (image E1030-20424, August 22, 1972; Fig 74.2.3) enabled identification of a number of

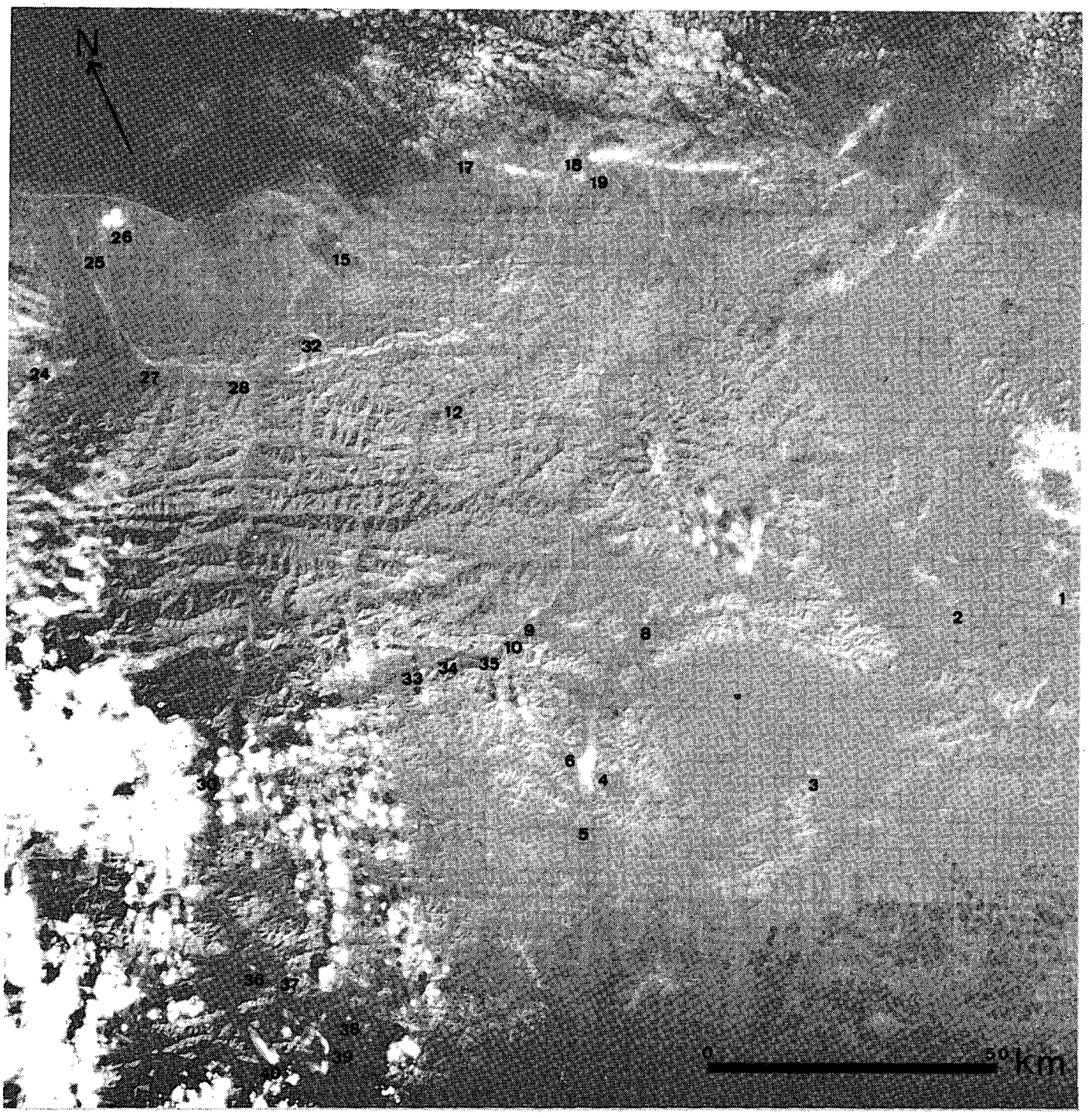

Figure 74.2.3. ERTS image E1030-20424, band 5, taken on August 22, 1972. Numbers indicating icing locations correspond to Fig. 74.2.2. Icings show white.

known icings, as well as of some that were not previously known to the author (Tables 74.2.4 and 74.2.5). Of the four spectral bands for which imagery is normally available from ERTS-I (band 4- blue/green, 500-600 NM; band 5- red, 600-700 NM; band 6- near infrared, 700-800 NM; band 7- near infrared, 800-1000 NM), bands 4 and 5 showed the strongest contrast between the icings (white) and the surrounding terrain (medium to dark grey). The image also showed that caution has to be exercised not to mistake small (white) clouds for icings. The black shadows, offset from the white cloud spots in one direction, help to distinguish between clouds and icings.

Subsequently all good or better quality ERTS-I imagery with less than 50 per cent cloud cover, available for the study area up to May 1974, was acquired in the form of 10 x 10 inch black-and-white prints, through the National Air Photo Library in Ottawa. The Cold Regions Research and Engineering Laboratory, U.S. Army Corps of Engineers, in Hanover, N.H., provided imagery for the area immediately west of the Yukon/Alaska border for this study. This valuable assistance is gratefully acknowledged.

The use of ERTS imagery for monitoring of icing activity in the northern Yukon during winter was initially thought impossible, on account of poor contrast expected between icings and the surrounding snow-covered terrain. However, early-and-late-winter imagery now available for the area revealed that a contrast in reflectivity does exist, at least for the wavelengths included in bands 6 and 7. Figure 74.2.4 presents a late-winter image for the study area (No. E1624-20375, band 7, April 8, 1974). Active icings, marked with numbers corresponding to those on Figure 74.2.2, show up dark grey to black in contrast with the white-to-grey of the surrounding terrain.

A composite of sequential imagery for part of the area covered by Figures 74.2.3 and 74.2.4 is reproduced in Figure 74.2.5. The sequence represents the period from August 22, 1972 to April 8, 1974. As only good or better quality images with less than 50 percent cloud were used for the composite, time intervals between the images vary considerably. No useful imagery is available for the area for the period between October 28, 1973 and February 27, 1974, mainly as a result of lack of light.

In the summer part of the sequence (Fig. 74.2.5 d, e, f and a) a gradual reduction in the size of the icing can be detected. During this period the icing becomes thinner and melting around the edges reduces the size very slowly. Meltwater and runoff from upstream start eroding channels through the icing.

By August 1 (Fig. 74.2.5 f) the icing has been divided into several individual pieces by the erosive action of surface runoff and meltwater streams. The icing is much reduced in size by late August (Fig. 74.2.5 a). It is not known whether the icing vanishes completely before the onset of winter. The first snowfalls have covered the

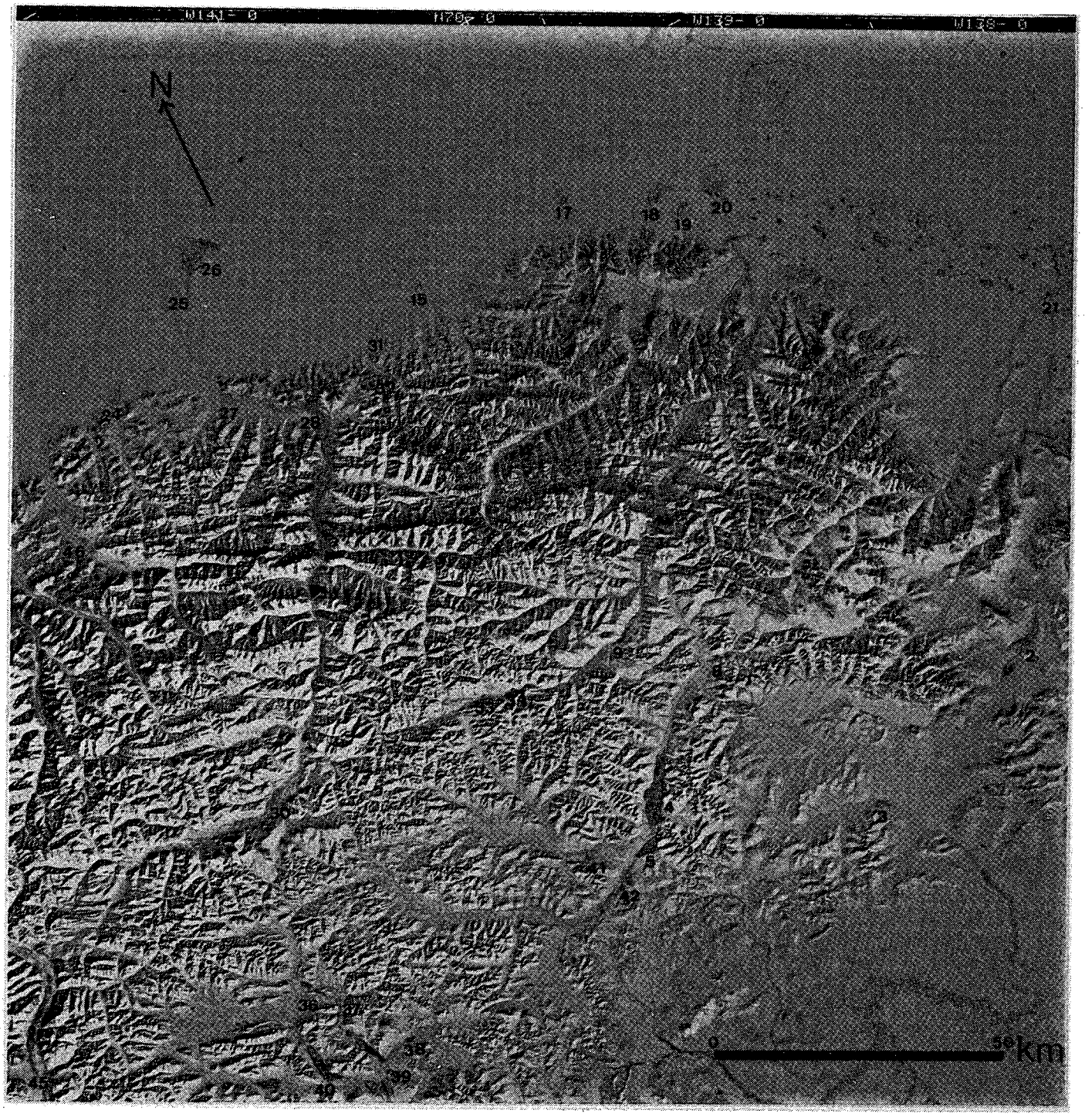

Figure 74.2.4. ERTS image E1624-20375, band 7, taken on April 8, 1974. Numbers indicating icing locations correspond to Fig. 74.2.2. Active discharge of groundwater shows dark grey.

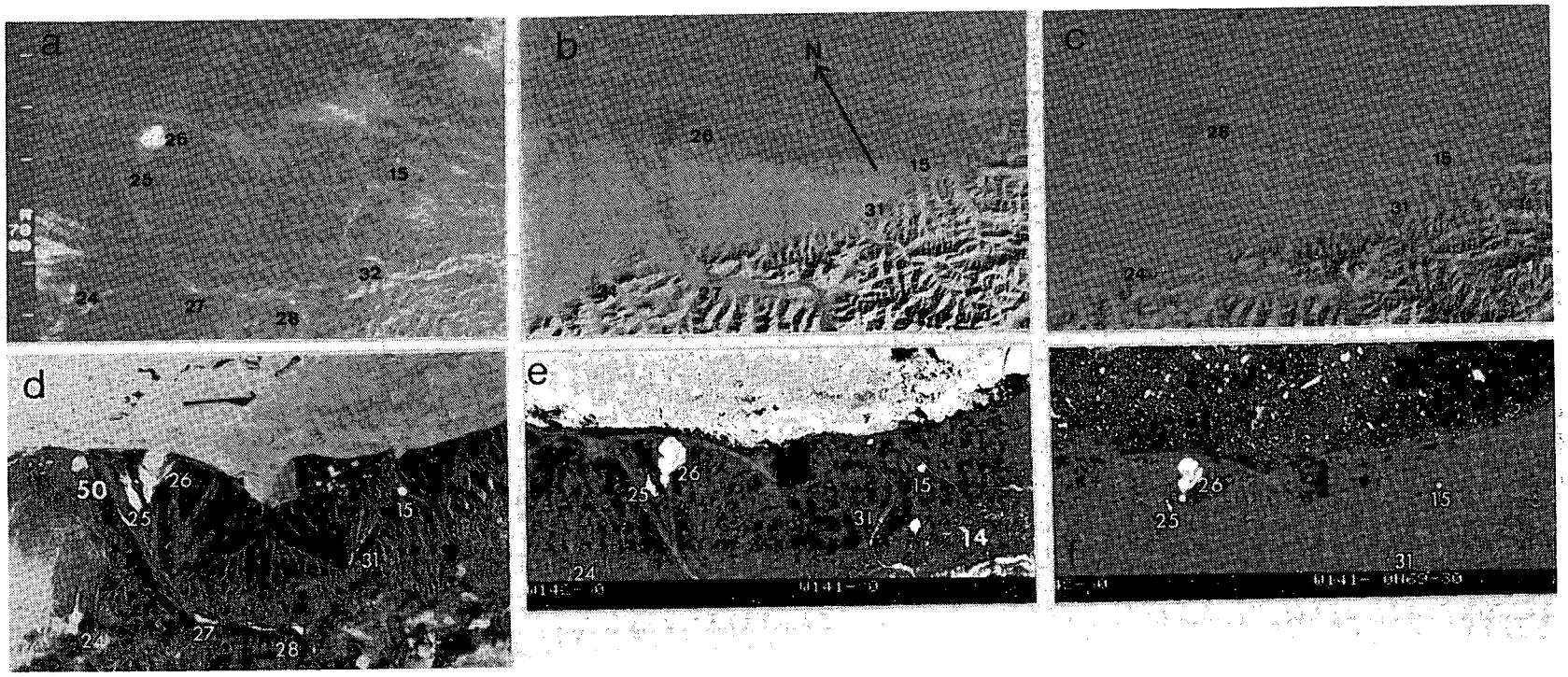

Figure 74.2.5. Sequential imagery for the Kongakut Delta area. (Width of individual images is 80 km.).

surrounding area by early October, and unfrozen water in the icing area shows black on the images of bands 6 and 7 (Fig. 74.2.5 b,c).

Similar sequences are shown for other icing areas in Figures 74.2.6 and 74.2.7. It appears from a comparison of Figures 74.2.5, 74.2.6 and 74.2.7 that the icings in the Kongakut, Firth and Malcolm Deltas are reduced in size earlier in the summer than those in the Firth River and Coleen River headwaters. The reason for this lies in the differences in morphology of the various icing locations. The Coleen River and Firth River icings, confined within relatively narrow valleys will have a greater thickness than the less confined icings on the deltas. The icings in the river valleys will, therefore, last longer than the icings in the deltas, for the same rate of surface melting.

Figure 74.2.6 also illustrates another feature requiring caution during the interpretation. Small ice-covered lakes or ponds may continue to show white for some time after the melting of the snow in the area. Subsequent images should be checked to determine whether the white (ice) areas have turned black (indicating water) on bands 4 and 5, or greyish (river channel bottom exposed after melting of an icing). The fact that some of these lakes show black on bands 6 and 7 of the winter imagery (Fig. 74.2.6 f-i), and white on post-snowmelt imagery (Fig. 74.2.6, c and d) could be caused by groundwater discharge in winter, which causes a heavier ice cover that takes longer to melt in spring. Patches of brownish-yellow ice were observed remaining on some of these lakes during a reconnaissance flight on June 28, 1973.

Some small icings known in the northern Yukon from the study of air photographs cannot be identified with certainty on the available imagery (Table 74.2.4, No. 13). The reason for this lies in the limited resolution of the scanners, which does not allow detection of "objects" smaller than about 100 meters. It is possible that image-enhancement techniques may enable improvements in this respect.

Estimates of the thickness of the icings, which might be possible when low-level air photographs are used, are not possible with the available satellite imagery.

The present imagery does, however, enable detection of the larger icings, and of the discharge from major spring areas during the winter. It also enables monitoring of icing dissipation during the summer.

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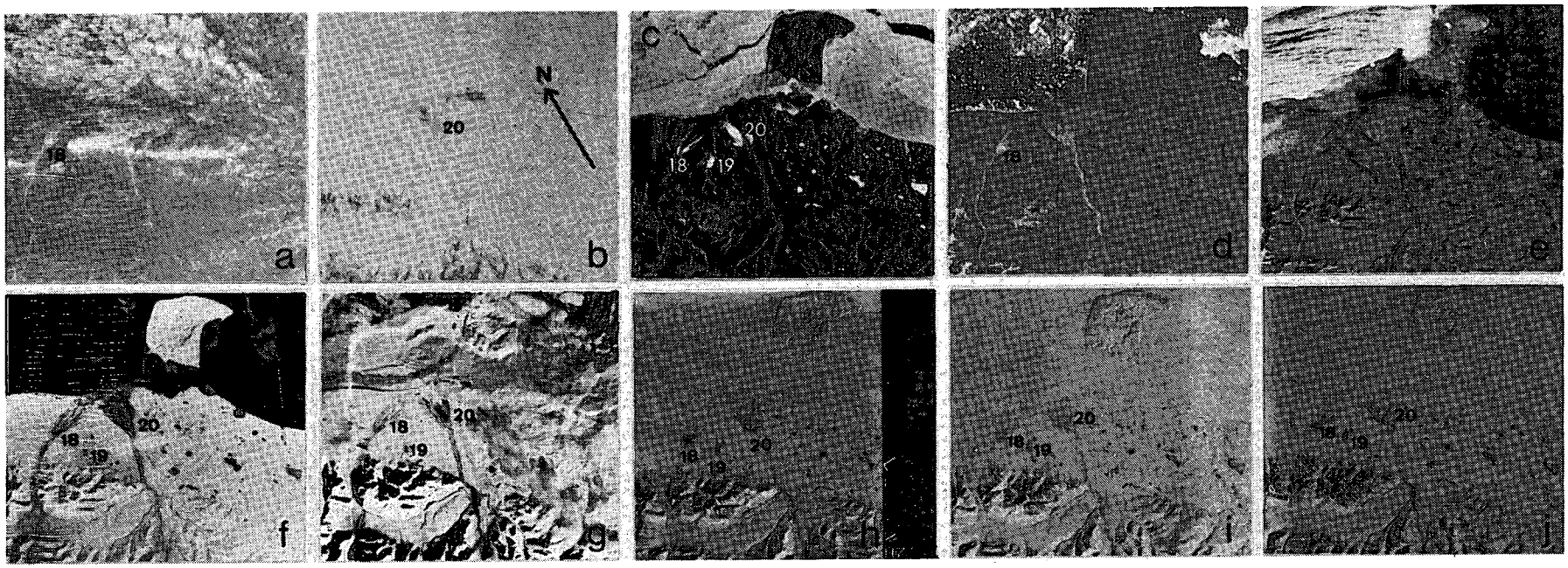

Figure 74.2.6. Sequential imagery for the Malcolm River and Firth River Deltas. (Width of individual images is 51 km.).

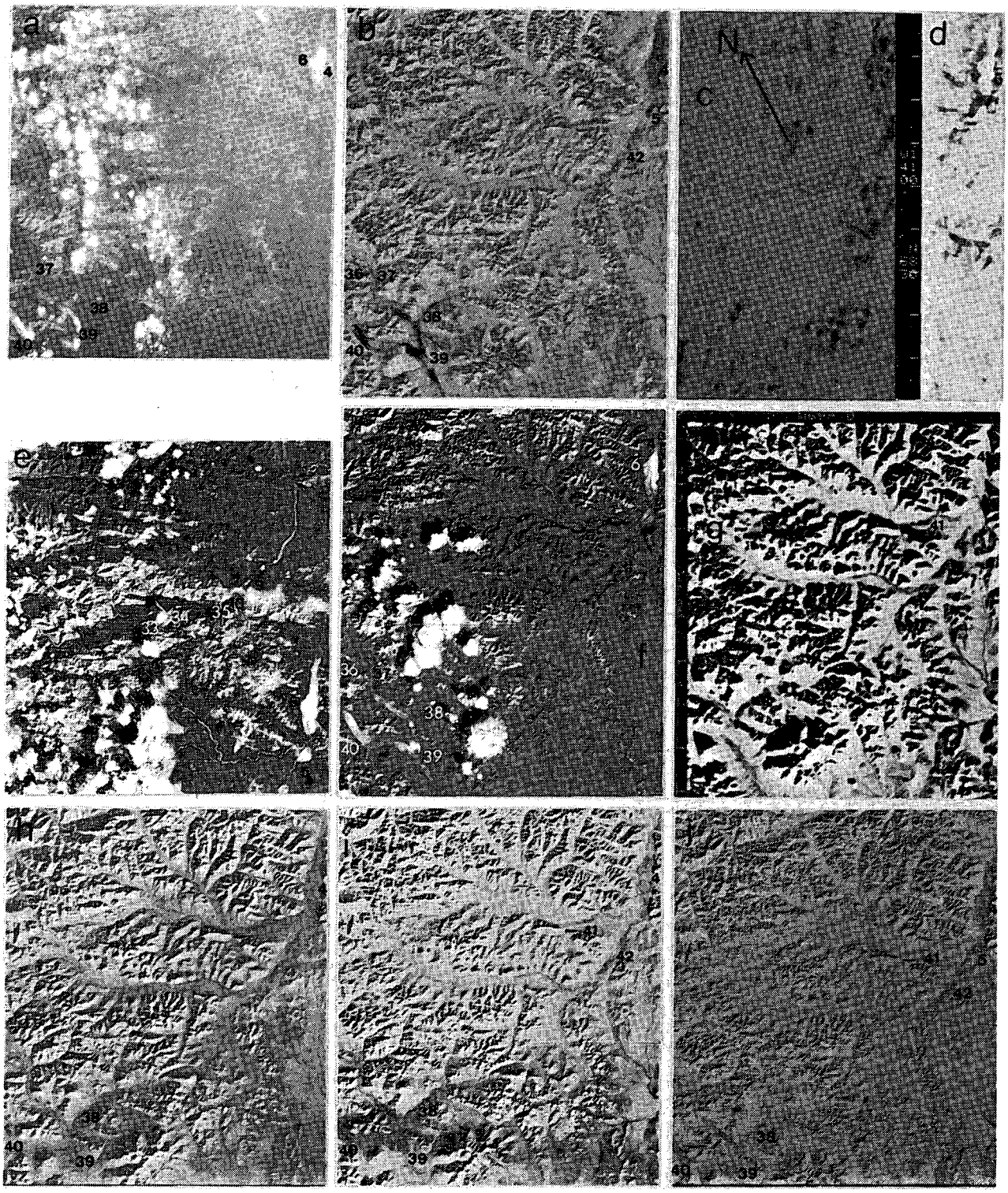

Figure 74.2.7. Sequential imagery for the Upper Firth River - Coleen River area (Width of individual images is 61 km.).

Table 74.2.3

Physical and Chemical Data for Fresh-Water Springs in the Northern Yukon Territory
(Ranges for Dissolved Oxygen and Ion Concentrations are Given in mg/l)

Name of Stream fed by springs, and Number on Fig.1.	Upper Firth River #5	Joe Creek #9	Upper Babbage River #2	Fish Hole Creek #1	Crow River #21	Spring River #22	Fish Creek #16	New Creek #19
Discharge, l/sec*	900	470	1400	898	42	-	120	355
Temperature, °C	1.5	4.0	4.0-4.8	4.0-4.5	2.0-5.0	0.5-3.0	2.0-3.0	2.0-3.5
Conductivity, μmhos/cm	310-365	230-240	192-306	220-245	277-310	140-171	295-325	410-520
pH, units	7.1-8.0	7.0-7.7	7.5-8.0	7.2-7.5	7.5	6.5-7.3	7.2-7.8	7.3-8.3
Dissolved oxygen	4.8	10.2-14.5	4.6-11.0	8.4-10.0	2.6-3.6	3.0-5.0	4.4-5.0	5.6-6.2
Ca	47.6-63.0	40.6-43.0	36.0-48.0	35.0-41.0	47.0-59.0	20.0-21.5	52.6-54.5	56.0-66.0
Mg	6.5-12.9	5.0-6.0	6.6-8.5	6.9-7.4	5.0-6.5	3.4-4.1	5.5-6.6	8.0-11.2
Na	0.3-1.0	0.1-0.5	0.4-0.9	0.3-0.7	0.5-1.8	2.3-6.1	2.1-8.7	18.0-33.0
K	0.3	0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.7	0.4-0.7	1.0-1.8
Fe	<.05-0.12	<.05	<.05-0.42	<.05	<.06-0.10	<.06-0.08	<.05	<.05
Mn	<.05	<.005	<.011-0.015	<.005	<.008-0.031	0.008	<.005	<.005
Cu	0.001-0.002	0.001	<0.001	0.001	<.001	0.001-0.002	0.001-0.003	<.001
Pb	<.006	<.006	<.006	<.006	<.004	<.004	<.004	<.004
Zn	0.005-0.011	0.002	0.003-0.078	0.002-0.19	0.002-0.003	<.001-0.013	0.003-0.005	0.024-0.15
HCO_3	201.3-203.7	134.2-141.5	135.4-172.0	123.2-140.3	150.1-184.2	68.3-75.5	161.0-168.4	162.3-167.1
SO_4	6.4-10.1	7.9-9.3	3.8-13	13.2-17.0	13.0-14.0	6.4-13.5	20.7-37.0	48.0-98.3
Cl	0.20-0.22	0.1-0.8	<.1-0.3	0.2-0.4	1.2	1.3-6.2	1.0-2.3	13.0-26.2
F	0.11-0.12	0.20-0.24	0.14-0.19	0.12-0.16	0.05-0.07	0.05-0.06	0.08-0.2	0.08-0.1
NO_3	0.12-0.13	0.07-0.20	0.05-0.17	0.06-0.16	0.05-0.19	0.04-0.08	<.01-0.11	0.09-0.11
PO_4	<.003	<.003	<.003	<.003	-	-	-	<.003
SiO_2	5.0-5.3	4.7-5.1	4.8-5.4	3.9-4.3	2.9-3.9	3.7-4.0	4.6-5.3	4.7-4.8
Sum	278-309	195-205	187-247	185-205	222-270	106-131	250-283	312-409

* Discharge data from Aquatic Environments Ltd., Calgary; Upper Firth River from Bryan, 1973.

Table 74.2.4

Icings in Northern Yukon Territory, Canada

Number on Fig. 1	Name of Stream (Number of Separate Icings in Brackets)	Date of Air Photos	Identification*
1	Canoe River (Fish Hole Creek)	8-8-52	A/F/E**
2	Babbage River (4)	28-8-52 27-7-53	A/F/E**
3	Timber Creek	14-7-51 7-8-54	A/E
4	Firth River	15-7-51	A/F/E**
5	Firth River	15-7-51	A/E/F
6	Firth River tributary	15-7-51	A/E
7	Firth River tributary (2)	15-7-51	A/E
8	Firth River tributary	14-7-51	A/E
9	Joe Creek (3)	15-7-51	A/F/E**
10	Joe Creek tributary	15-7-51	A/E
11	Malcolm River	15-7-51	A/E
12	Malcolm River (3)	15-7-51	A/E
13	Malcolm River	15-7-51	A
14	Unnamed Creek	15-7-51	A/E
15	Unnamed Creek	15-7-51	A/E
16	Fish Creek	15-7-51	A/F/E**
17	Fish Creek delta (2)	15-7-51	A/E
18	Malcolm River delta	15-7-51	A/E
19	New Spring Creek	27-7-53 15-8-56	A/F/E** (No icing visible)
20	Firth River delta (2)	27-7-53	A/E
21	Crow River	6-8-52	A/F/E** (icing very small)
22	Spring River	6-8-52	F/E**
23	Unnamed Creek	6-8-52	F/E

* A-Air photos; F- field; E- ERTS imagery.
** These icings are related to perennial springs in Table 74.2.3.

Table 74.2.5

Icings in Northeastern Alaska, U.S.A.

Number on Fig. 1	Name of Stream (Number of Separate Icings in Brackets)	Identification
24	Egaksrak River tributaries (3)	ERTS
25	Kongakut River delta (2)	ERTS
26	Kongakut River delta	ERTS
27	Kongakut River	ERTS
28	Kongakut River (9)	ERTS
29	Kongakut River (2)	ERTS
30	Kongakut River	ERTS
31	Clarence River (3)	ERTS [PHOTOS (15-7-51)]
32	Clarence River (3)	ERTS [PHOTOS (15-7-51)]
33	Joe Creek	ERTS
34	Joe Creek	ERTS
35	Joe Creek (2)	ERTS [PHOTOS (15-7-51)]
36	Coleen River	ERTS
37	Coleen River tributary	ERTS
38	Coleen River tributary	ERTS
39	Coleen River and major tributary (5)	ERTS
40	Coleen River and two tributaries (3)	ERTS
41	Firth River	ERTS [PHOTOS (15-7-51)]
42	Mancha Creek (2)	ERTS [PHOTOS (15-7-51)]
43	Old Crow River, headwaters	ERTS
44	Sheenjek River tributary	ERTS
45	Sheenjek River (4)	ERTS
46	Egaksrak River (5)	ERTS
47	Achilik River and tributaries (10)	ERTS
48	Okerokovik Creek	ERTS
49	South of Kaktovik	ERTS
50	Egaksrak River delta	ERTS

NORTHERN GROUNDWATER AND ENGINEERING PROBLEMS RELATED TO GROUNDWATER FLOW

Project No. HR 74-2
R.O. van Everdingen*

Groundwater Data Maps

A series of groundwater maps is being prepared for release into open file, for the Environmental-Social Program Northern Pipelines, Task Force on Northern Oil Development. The maps show spring locations, major winter open water, and locations of icings. Notes to accompany the maps give short descriptions of the occurrences, dates of observation and sampling, where applicable, and available data on water temperature, total-dissolved-solids content, dissolved-oxygen content, pH and discharge rate. Ice thicknesses and areas are listed for some of the icings.

The information for the maps was obtained from a variety of sources, including: Northern Engineering Services Co. Ltd., and Aquatic Environments Ltd. (both consultants for northern pipeline study groups); Canada Department of Public Works, Edmonton; Department of Indian Affairs and Northern Development, Yellowknife and Whitehorse; published and unpublished reports (Brandon, 1965; van Everdingen, 1974); field observations during the period 1972 - 1974; airphoto interpretation; and study of ERTS imagery for the period between August 1972 and May 1974.

By January, 1975 the following 18 maps had received approval for release: Camsell Bend (95 J), Dehadinni River (95 N), Wrigley (95 O), Fort Norman (96 C), Norman Wells (96 E), Mahony Lake (96 F), Sans Sault Rapids (106 H), Fort Good Hope (106 I), Fort McPherson (106 M), Arctic Red River (106 N), Travaillant Lake (106 O), Canot Lake (106 P), Eagle River (116 I), Bell River (116 P), Blow River (117 A), Davidson Mountains (117 B), Demarcation Point (117 C), and Herschel Island (117 D). Other map sheets that may be included in the series are Trail River (106 L), Porcupine River (116 J/K) and Old Crow (116 N/O).

REFERENCES

Brandon, L.V., 1965, Groundwater hydrology and water supply in the district of Mackenzie, Yukon Territory, and adjoining parts of British Columbia: Geol. Survey Canada Paper 64-39, 102 p.

van Everdingen, R.O., 1974, Groundwater in permafrost regions of Canada: NRC/IHD Permafrost Hydrology Symposium, Calgary.

* Hydrology Research Division, Calgary

GOWN - DOCUMENTATION

Project No. HR 74-3

G. Grove*

The objective of this project is to provide a complete set of documentation including system documentation, program documentation, user documentation and operator documentation for the GOWN system. Initially effort will be concentrated on the seven programs comprising the data storage system. These programs are:

1) well log card to tape

2) well log edit

3) well log update

4) well data card to tape

5) well data edit

6) well data update

7) dictionary create and update

Previous work on this project which was initiated at the beginning of the 1974/75 fiscal year includes:

1) some very elementary narrative documentation for the programs in the data storage system;

2) flowcharts for the programs in the data storage system.

A number of instances of inefficient or generally confusing coding have been discovered as a result of the detailed investigation of program operation required for the purposes of documentation. Where possible, minor changes in coding are being made to remove these inefficiencies and general rearrangement of sections of coding are being made in the programs to improve their readability. Therefore, a useful by-product of the documentation process is an improvement in efficiency and readability of the programs.

At present a draft copy of the program documentation for the well log card to tape and well log edit programs have been completed. It is planned to publish the documentation in the form of a manual in a loose-leaf binder. Selected pages from this manual can then be updated periodically as required.

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* Hydrology Research Division, Ottawa

GOWN-RETRIEVAL

Project No. HR 74-4
G. Gora*

The GOWN data storage and retrieval system stores and processes physical and scientific groundwater well data. These data are stored on three master files, namely the WELLLØG, WELLDATA and HYDROGRAPH files. Previously each retrieval and calculation run required a complete serial processing of one of these master files. However, changes have been made to remove this restriction and retrieved subfiles can now be passed through the CALCULATION PHASE of the system any number of times after the initial retrieval from the master file. This facility will now allow the user to retrieve data for a general geographic area, for example, and use this new data file in the execution of more detailed retrievals.

The present CALCULATION PHASE prepares retrieved data solely for plotting computer generated hydrogeological contour maps. Programs are being redesigned and rewritten to meet anticipated requirements for adding computer subroutines for new applications as they are needed. It is hoped that these new programs will facilitate user processing and execution as much as possible.

Four programs are being written to allow users to employ their ingenuity in designing their own programs and routines to use retrieved GOWN data. These programs are:

(1) An <u>edit/update program</u> for adding records to a keyword dictionary.

(2) A <u>translate program</u> to translate user requests. This program will define to the COBOL program generator [see (3) - below] the instructions and groups of instructions to be generated in COBOL format.

(3) A <u>COBOL program generator</u> for generating a unique COBOL program to select and reformat data in uniformity with user requests.

(4) A <u>data and control card merge program</u> to merge retrieved well data with user control cards prior to execution of a specific user application.

Reference is made to these programs in the CALCULATION PHASE redesign flowchart (Fig. 74.4.1). The codes P1 through P4 in this figure refer directly to the above programs.

It will be necessary to create three new files in conjunction

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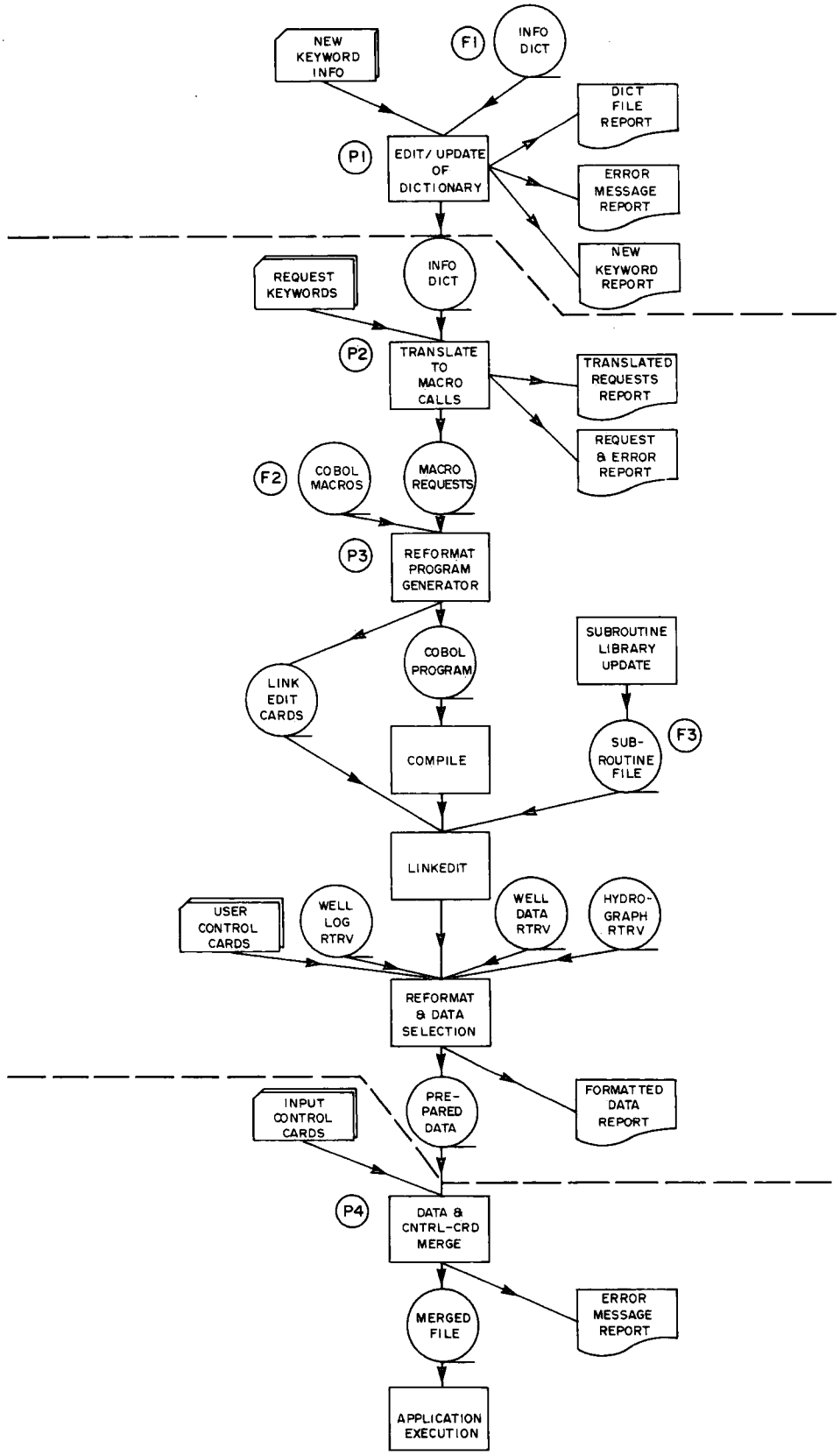

Figure 74.4.1. Calculation phase redesign.

with the design of these new programs. These are described below.

(1) A keyword dictionary file containing all the necessary information on existing user application keywords. Each record on this file will contain an identifying application name, and the names of the subroutines it uses, as well as the necessary master file names and the data fields that are required in executing the specific application. The edit/update of this dictionary will be done when required and is not part of the CALCULATION PHASE execution.

(2) A "library" of COBOL language instructions and groups of instructions used in generating the unique COBOL data selection program.

(3) A "library" of user subroutines which will be updated each time a new application routine is written requiring GOWN data as its input.

These files are shown on the flowchart (Fig. 74.4.1) as F1, F2 and F3.

The general flow of data through the CALCULATION PHASE of the GOWN system will be as follows:

(1) The user will specify an application name or keyword as card input into the translate program (P2). The translate program will in turn use the keyword dictionary file to obtain all parameter information for this keyword and will output a file containing request names for COBOL statements or groups of statements.

(2) The reformat program generator (P3) will then use this file with the COBOL instruction library (F2) in generating the unique COBOL program.

(3) This COBOL program will be compiled and executed and will function in reformatting and selecting data from a subfile that has been previously retrieved from the GOWN master file.

(4) Subroutines oriented to the specific application will be called by and linked in with the generated program before execution.

(5) On execution of the generated COBOL program the user will receive a formatted report of retrieved records which have been processed.

(6) If further processing is required, such as the plotting of contour maps, the user will have the option of receiving a prepared data file from the executed reformat program.

(7) Prior to processing this file any further, the prepared data file may be input into a data and control card merge program (P4) in order to prepare the data in proper formats for further processing.

It is hoped that the GOWN CALCULATION PHASE redesign and rewrite will open new channels to the GOWN user in executing new and varied applications in the future.

GENERALIZED HYDROLOGIC MODEL FOR STREAMFLOW SIMULATION

Project No. HR 74-5

S.Y. Shiau*

INTRODUCTION OF THE SYSTEM LOGIC

The model was originally developed by Burnash and Ferral (1971). It is based on a system of percolation, soil moisture storage, drainage, and evapotranspiration characteristics. The system expresses the basin as a set of storages of determinable capacities which hold water temporarily and which gradually recede as their contents are diminished by vertical percolation, evapotranspiration and lateral drainages (Fig. 74.5.1). The definition of system parameters is achieved by establishing a soil moisture computation which allows the determination of basin streamflow from basin precipitation. Effective moisture storage capacities in the soil profile are estimated, not by sampling of the soil profile, but by inference from the precipitation and discharge records. The equations and formulations used allow a preliminary evaluation of many of the system parameters from streamflow records and other observable characteristics of the watershed.

The basin is considered to comprise two basic areas, 1) a permeable portion which produces runoff when rainfall or snowmelt rates are sufficiently heavy and 2) an impervious portion which produces direct runoff from any rain or effective melt. It should be noted that the impervious portion does not have to be a constant area in this model. It has been observed in many basins that coincidental with the filling of the tension water storages, an increasing fraction of the basin may assume impervious characteristics. This fraction, in addition to the PerManent IMPervious area (PMIMP), provides a useful representation of the filling of small reservoirs, marshes, and temporary seepage outflow areas which achieve impervious characteristics as the soil mantle becomes wetter. It is defined as the ADditional IMPervious area (ADIMP) in this model.

In the permeable portion of the basin, the model identifies an initial soil moisture storage as Upper Zone Tension Water (UZTW) which must be totally filled before moisture becomes available to enter other storages. Tension water represents that water which is closely bound to soil particles and is constantly depleted by evapotranspiration. Upper Zone Tension Water Maximum storage (UZTWM) represents that volume of water which would be required under dry conditions to meet all interception requirements and to provide sufficient moisture to the upper soil mantle so that percolation to deeper zones and, sometimes, horizontal drainage can begin. When UZTWM has been filled, excess moisture is temporarily

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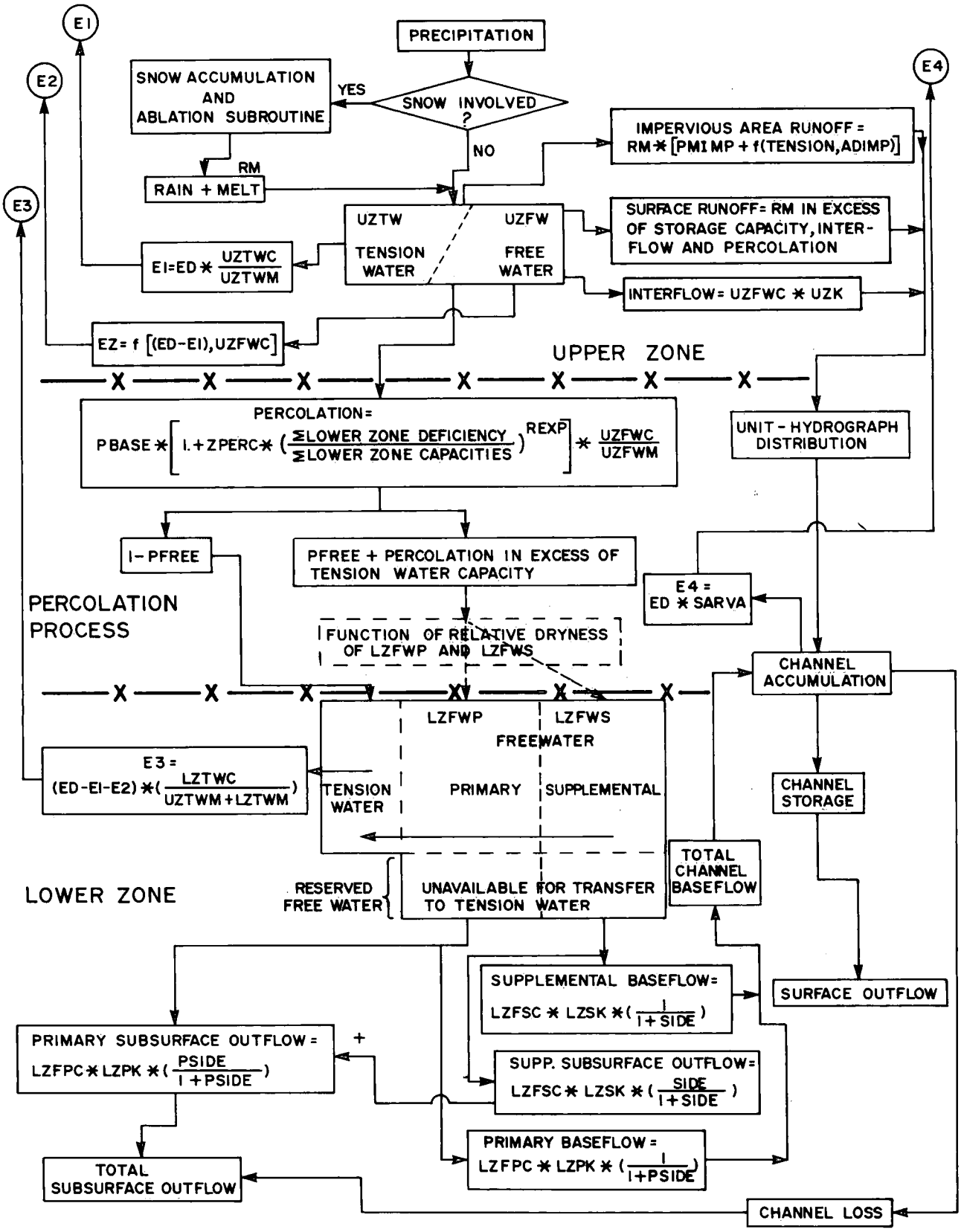

Figure 74.5.1. Schematic representation of the streamflow simulation system logic.

accumulated in Upper Zone Free Water storage (UZFW). Free water is that water which is not bound to soil particles. It is free to percolate to deeper storages and to move laterally as interflow in response to the gravitational and pressure forces. UZFW also is depleted by evapotranspiration when the tension water can not satisfy the evapotranspiration demand.

Interflow is proportional to the free water content after percolation. The rate of vertical drainage, i.e. the percolation to deeper soils, is controlled both by the content of UZFW and the deficiency of the lower zone moisture storages. The preferred path for moisture in UZFW is considered to be downward as percolation. Interflow occurs only when the rate of precipitation exceeds the percolation rate. When the precipitation rate exceeds the combined rates of percolation and maximum interflow drainage, then the UZFW storage is filled completely and the excess precipitation will result in surface runoff. Under this system, surface runoff is a highly rate-dependent volume with the rate of runoff being determined by the rate of precipitation and the degree of dryness of the different storages.

The Lower Zone Tension Water storage (LZTW) is that volume of moisture in the lower zone soil which will be claimed by dry soil particles when moisture from a wetting front reaches that depth. It is the difference between that water held against gravity after wetting and that remaining after plant roots have extracted all that they are capable of withdrawing. It should be realized that it represents that volume of water which will be tapped by existing plants during prolonged dry periods. The two Lower Zone Free Water storages, Primary (LZFWP) and Supplemental (LZFWS) represent those volumes of water which are available for drainage as baseflow and/or subsurface outflow. These storages fill simultaneously from percolated water and drain independently at different rates, giving a variable groundwater recession.

The mechanics of transfer from upper zone to lower zones is based upon the computation of the lower zone percolation demand. When the lower zone is saturated, the percolation demand is at its minimum and is equal to the saturated lower zone drainage rate. This rate is computed as the sum of the products of the two lower zone free water capacities and their respective drainage rates, and is defined as PBASE. However, it is evident that following dry periods much higher rates of percolation may occur. Assuming that the percolation demand reaches its maximum when the lower zone storage content is at the minimum, the maximum percolation demand can then be defined as

$$\text{Max. Percolation Demand} = \text{PBASE}\ (1 + Z)$$

where Z is the necessary multiple to increase the percolation demand from the minimum, PBASE, to the maximum.

Further assuming that the change in lower zone percolation demand is exponentially related to the lower zone moisture deficiency, then the percolation demanded by the lower zone can be stated as:

$$\text{Lower Zone Percolation Demand} = \text{PBASE}\ (1 + Z(\Sigma(\text{Lower Zone Moisture Deficiency}))^{\text{REXP}})$$

where REXP is the exponent which defines the curvature in the percolation curve with changes in the lower zone moisture deficiency.

The actual percolation must, however, also be controlled by the supply of available water in the upper zone free water storage, hence:

$$\text{Percolation} = \text{Lower Zone Percolation Demand} \left(\frac{\text{UZFW Content}}{\text{UZFW Capacity}}\right)$$

The observed characteristics of the motion of moisture through the soil profile such as those reported by Hanks et al. (1969) and Green et al. (1970) have been incorporated in the design of this percolation mechanism. It allows a close parallel to the formation and transmission characteristics of the wetting front in the soil profile.

Generally, the percolated water tends to satisfy the tension water deficiency first. However, variations in soil conditions and rainfall or snowmelt rates over a drainage basin cause variation from the normal condition. The effect of these variations is approximated in the model by diverting a fraction of the percolated water into free water storages before tension water deficiency is fully satisfied. The water made available to the free water storages is distributed between the primary and supplemental storages in response to their relative deficiencies.

The use of three free water components - one upper and two lower zones - allows the generation of a wide variety of recessions and is generally consistent with observed streamflow characteristics.

If the natural boundary conditions should require all applied moisture to leave the basin, either at the gauging point or through evapotranspiration, then these soil moisture divisions would be adequate to describe the disposition of liquid water applied at the soil surface. However, subsurface drainage bypasses the gauging site in many basins. In order to approximate this effect within a particular basin, it is assumed that those soils which do not drain to the stream channel within the basin have the same basic drainage characteristics as those soils which drain to the stream channel. Thus the capacities of lower zone free water storages providing such subsurface flows can be expressed as a fraction of the apparent lower zone free water storage capacities derived from the stream channel outflow hydrographs. This fraction is defined as SIDE in the model.

Evaporation from the area covered by surface water or phreatophyte vegetation is computed at the potential rate. Over other portions of the soil mantle, evapotranspiration varies with both the demand and the content and distribution of tension water storages. As the soil mantle dries from evapotranspiration, moisture is withdrawn from the upper zone at the potential rate multiplied by the proportional loading of the upper zone tension water storage. In the lower zone, evapotranspiration is calculated by the unmet demand times the ratio of the lower zone tension water content to tension water capacity. If evapotranspiration should occur at such a rate that the ratio of contents to capacities for available free water exceeds the ratio of content to capacity of tension water, then water is transferred from free to tension water and the relative loadings balanced in order to maintain a moisture profile that is logically

consistent. Depending upon basin conditions, some fraction of the lower zone free water is considered to be below the root zone and therefore is unavailable for such transfers. This fraction is expressed as RSERV in the model.

REQUIREMENTS AND CONSIDERATIONS FOR EFFECTIVE SIMULATION

The simulation of streamflow requires more then just modelling the hydrologic characteristics of the basin. It also requires a snowmelt and/or precipitation model which will process the available input data into a form which reasonably represents the effective moisture input to the basin. It further requires an evapotranspiration model to obtain a reasonable estimate of the basin evapotranspiration demand. Indeed, an effective simulation of streamflow must be predicated upon an effective simulation of all significant components in the hydrologic cycle. The primary components involved in such a simulation are: 1) a determination of effective basin precipitation and/or snowmelt, 2) a determination of basin evapotranspiration demand and 3) the determination of basin characteristics for the generation of streamflow.

The water balance characteristics of this system make it necessary that the precipitation estimate be as true as possible. Definition of basin precipitation is a complex problem that has not been resolved for areas where precipitation reports are sparse. Even where precipitation gauges provide apparently adequate areal coverage, the gauges themselves are frequently inadequate in their ability to "catch" true rainfall -- not to mention their ability to "catch" true snowfall. The presence of snow further complicates the problem in determining the effective moisture input to the basin. When snow is involved, an effective snow accumulation and ablation model is necessary before an effective simulation of streamflow is possible.

Inasmuch as evapotranspiration may be the dominant use of the moisture supplied by precipitation or melt, and since it is one of the most difficult processes to evaluate in hydrologic analysis, evapotranspiration is frequently a principal source of error in streamflow simulation. In many areas more moisture is lost through evapotranspiration than is discharged by the streams. Potential evapotranspiration often exceeds precipitation on an annual basis, thus streamflow may result only from concentration of precipitation and/or snowmelt. Due to the significance of evapotranspiration to the streamflow simulation, it is necessary to obtain a reasonable estimate of the basin evapotranspiration demand. The modified Penman method (Shiau and Davar, 1973) has been utilized to estimate the potential evapotranspiration at a point, such as at a meteorological site in or near the basin. The topographic parameters such as elevation, exposure, slope and aspect over the basin are then compared to the same parameters at that point at which the potential evapotranspiration has been calculated. The average basin evapotranspiration demand is then estimated on the basis of this comparison.

The third element in a hydrologic analysis is the evaluation

of basin characteristics. The ability to evaluate basin characteristics on the basis of observed streamflow records is restricted by the types of data available in a particular basin, the length of record, and the basin experience during the period of record. If the surface basin boundaries and the subsurface boundaries coincide, if the basin operates as a closed system with all precipitation returned as either streamflow or evapotranspiration with no subsurface losses, and if the data field covers a complete range of hydrologic events, then a close approximation of basin characteristics can be derived from observed hydrograph data. The range of hydrologic events required for such an analysis extends from an extreme drought which leaves the basin in a parched condition to that heavy rain or melt event which fully saturates the soil mantle and produces a runoff regime of maximum efficiency. If these data are available, concurrent with a reasonably accurate precipitation record which has been effectively adjusted for snow, then the basin hydrographs will allow a reasonably direct determination of basin characteristics. In the more usual cases in which the data field does not meet these requirements, the direct approximation of basin characteristics becomes more difficult to derive. In any event one should examine carefully the available data and define as many basin characteristics as is possible from direct analysis of the hydrograph.

Following the initial determination of the values required for simulation, a number of trial runs for short time periods that include both very high and very low discharges should be attempted. Major deviations between computed and observed discharges should be analyzed and the response of the model components evaluated to justify the adjustments of the parameter values. Subsequent simulations should then be attempted for the total record period with the same rational approach. Generally, a reasonably successful simulation can be achieved and the parameter values defined for the subject basin at this stage. The automatic optimization techniques may then be utilized to achieve a polished analysis. Generally, only a limited number of parameters need to be modified by the optimization process. Automatic optimization techniques applied at too early a stage are likely to generate compensating changes among interrelated variables, which result in curve fitting rather than rational solution.

PROGRAM ORGANIZATION AND FUNCTIONS

A program library has been created for the streamflow simulation system. The library is maintained on disk file and backed up by tape and punch card files. Individual programs or combination of programs and subroutines can readily be called upon from the program library to perform various functions such as 1) the creation, update and retrieval of the basin data files, 2) simulation of snow accumulation and ablation to generate the rain plus melt data, 3) calculation of basin evapotranspiration demand, 4) model calibration and streamflow simulation, etc.

The basin data file is an Index-Sequential file which can be

retrieved either randomly or sequentially. The floating point file key system simplifies the organization of the data file and greatly increases the efficiency of the simulation processes.

Fig. 74.5.2 shows the program organization and functions. The functions of individual programs and various subroutines are explained below.

Program QCHECK

Provides a check against many of the common key punching errors before loading the data card decks onto the basin data file.

Program DBLMASS

To help locate precipitation data errors and isolate precipitation station location changes. The output consists of the cumulative double mass relationships for each station compared to the other stations. An annual ratio of catch is also provided. Changes in slope of the cumulative ratios, or scatter in the annual ratios, are suggestive of data inconsistencies which may require resolution before simulation is practical.

Program DISTRIP

To distribute accumulated precipitation values such as those obtained from Sacramento Storage Gauges, those due to malfunctioning of recording gauge timers, etc. into daily precipitation. DISTRIP uses daily precipitation records from reference stations where the distribution pattern is considered the same as the subject station. The program also produces a punched card deck of the distributed daily precipitation. It can also store this distributed data onto the basin data file directly if desired.

Subroutine IMPRV

To replace any erroneous data which may exist on the basin data file. Also to update the basin data file when new data become available.

Program QLØGSM

To plot discharge hydrograph (semilogarithmic plot) - the output of QLØGSM is used to analyze the free water volumes, their drainage characteristics, and other basin characteristics such as the impervious area, the upper zone tension water volume, etc. The results of this analysis are used as the initial values for the model calibration. QLØGSM utilizes files created by Program DALØAD.

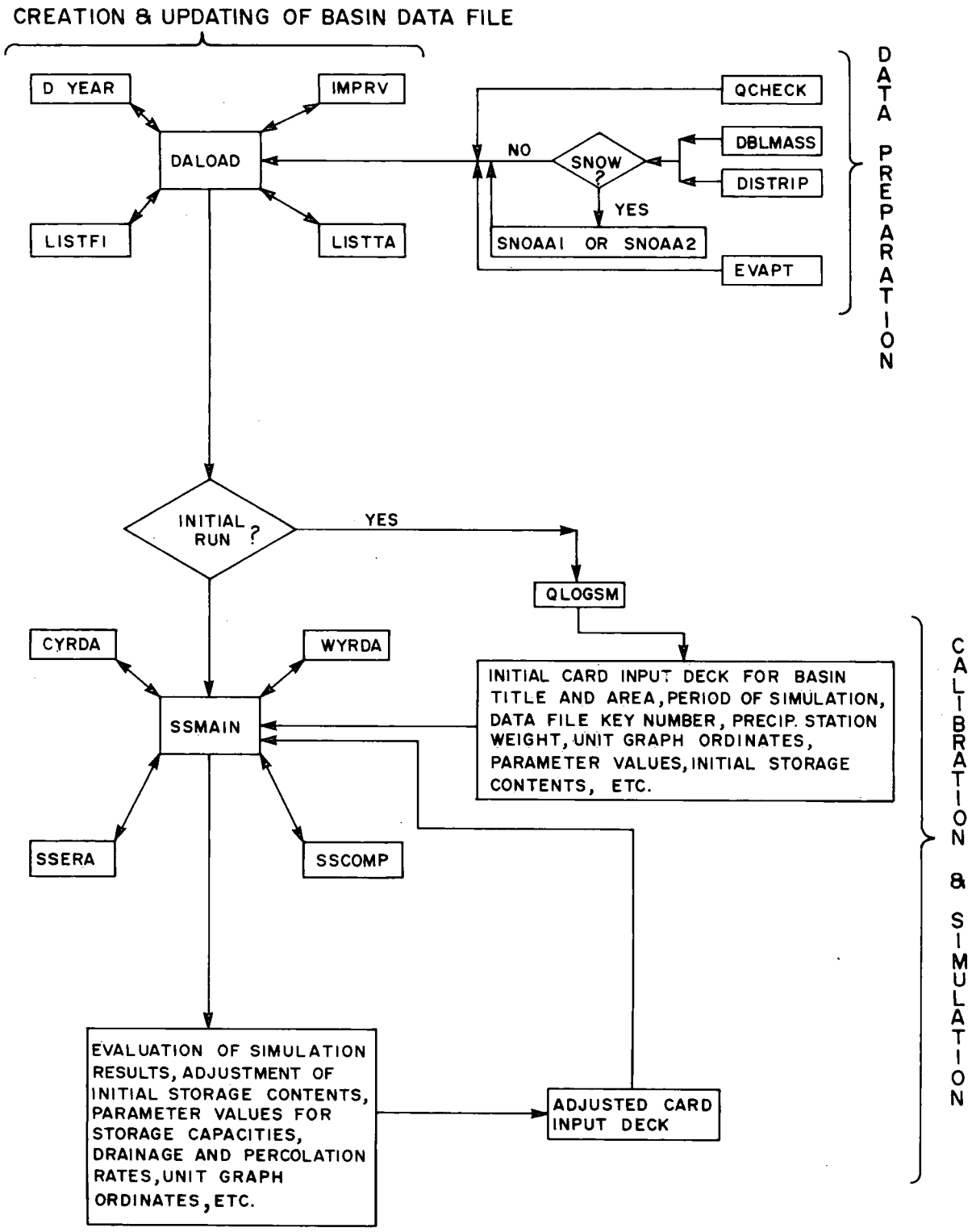

Figure 74.5.2. System programs organization and their functions.

Program SNØAA1

To simulate snow pack conditions to reproduce snow pack reports from an occasionally read snow course or to generate snow pack approximations (daily rain plus melt data decks) for remote areas from real data sources. Precipitation and maximum-minimum temperature data stored on the basin data file are used to generate the snow pack simulation.

Program SNØAA2

Performs the same functions as SNØAA1 but, in addition to the daily precipitation and maximum-minimum temperature data, SNØAA2 also utilizes daily bright sunshine data to calculate the net shortwave and longwave exchange on the snow pack for the computation of the radiational melt. SNØAA2 also takes into account the forest cover in the calculation of the heat budget by utilizing the relationships developed by the U.S. Corps of Engineers (1955) between forest transmission and insolation.

Program SSMAIN

SSMAIN is the main controlling program for the calibration and simulation operation. It utilizes the basin data files created by DALØAD and requires subroutines SSCØMP, SSERA and WYRDA (for water year analysis) or CYRDA (for calendar year analysis). SSMAIN performs various functions such as 1) selection of options for a particular run, 2) unit hydrograph distribution of runoff, 3) incorporation of the Layered Muskingum routine, 4) error analysis of simulated flows including monthly and annual water balance errors, etc. SSMAIN produces output such as 1) plots of daily simulated vs. observed discharge together with corresponding precipitation or rain plus melt data, 2) listing of daily storage contents and runoff components, 3) plot of groundwater component, 4) results of error analysis, 5) monthly and annual water balance summary, etc.

Subroutine SSCØMP

SSCØMP is the heart of the simulation system. It contains most of the concepts required for soil moisture and runoff determinations and provides SSMAIN with the computed results such as storage volumes, runoff and evapotranspiration components, etc.

Subroutine SSERA

To perform error analysis of the simulated flow. It can perform this analysis for 3-day and 5-day volumes if desired.

Subroutine WYRDA

To unload data from the basin data file and arrange on a water year

basis. It can also utilize selected station weights to calculate weighted mean basin precipitation, rain plus melt, temperature, etc.

Subroutine CYRDA

Perform the same functions as WYRDA except on a calendar year basis.

Program EVAPT

EVAPT applies the modified Penman method for potential evapotranspiration calculation. It has an option to incorporate the evaporation pattern developed for a mountainous basin to estimate the mean basin potential evapotranspiration. The topographic parameters used in the development of the evaporation pattern for a particular mountainous basin are elevation, slope, aspect and exposure.

Program DALØAD

To load precipitation, rain plus melt, temperature, evaporation, discharge, sunshine, radiation and other data from card decks on to the basin data file (disk file) for the preparation of model calibration and simulation. File organization is index-sequential and can be processed randomly or sequentially. Utilizes Control Data Corporation Record Manager program for file creation and file processing. Each record unit contains one year of daily data and requires 367 words (6 PRU) of storage space.

Subroutine DYEAR

A routine to determine day of year of the first and last days of each month. Leap year is taken care of by the parameter NADD.

Subroutine LISTFI

To list the contents of basin data file stored on disk for the purpose of checking.

Subroutine LISTTA

To tabulate the basin hydro-meteorological data stored on disk file for the purpose of presentation. Also to perform simple calculations such as monthly and annual totals and means over specified record periods, etc.

APPLICATION

The streamflow simulation system has been applied on Trapping Creek basin and Perch Lake basin with encouraging results. These applications are described under Project Nos. GW 71-4 and HRO 74-2 in this volume, respectively.

The system requires further testing on basins of various sizes located in different physiographic and climatologic regions. The system further requires modification and improvements by way of system subroutines to make use of the new research results on various hydrologic processes such as snowmelt, evapotranspiration, percolation mechanisms, etc. For more effective simulation and to help understand the functions of the simulation system, a sensitivity analysis of the various system parameters is desired. To facilitate the implementation and practical application of the system, the documentation of the system programs and subroutines is necessary and is in progress.

REFERENCES

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Green, D.W., Dabri, H., Weinang, C.F., and Prill, R., 1970, Numerical modeling of unsaturated groundwater flow and comparison of the model to a field experiment: Water Resour. Res. 6, 3, 862-874.

Hanks, R.J., Klute, A.,and Brester, E., 1969, A numerical method for estimating infiltration, redistribution, drainage, and evaporation of water from soil: Water Resour. Res. 5, 5, 1064-1069.

Shiau, S.Y.,and Davar, K.S.,1973, Modified Penman method for potential evapotranspiration from forest regions: Jour. Hyrol. 18, 349-365.

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HYDROGEOLOGICAL APPLICATIONS OF ERTS IMAGERY IN THE PRECAMBRIAN SHIELD

Project No. HR 74-7
J.E. Charron*

The objectives of the project are:

1. To evaluate the usefulness of ERTS imagery in identifying and locating water-bearing zones in the Canadian Shield.

2. To characterize ERTS features of hydrogeological significance in terms of such parameters as orientation, density, distribution and pattern.

3. To relate these parameters to predictability of groundwater occurrence and yield.

The study will be carried out in a selected area of the Canadian Shield lying to the north and northeast of Ottawa for which good clear ERTS imagery generally unobstructed by clouds is available. The field and analytical procedures will initially be based on the discussion and conclusions given by D.P. Gold, R.R. Parizek and S.A. Alexander in a paper presented at the 1973 Symposium on Significant Results obtained from the Earth Resources Technology Satellite-I.

The principal investigator has already conducted some preliminary studies on correlation of ERTS imagery with the hydrogeology of two other areas in Canada: the Winnipeg area of Manitoba and the interstream area between the Ottawa and St. Lawrence Rivers and between Ottawa and Montreal. He has had extensive field experience in these two areas. Interpretation of the imagery for these two examples has been reported on at three meetings in 1974: (1) Ontario Surveyors Convention, Toronto; (2) UN-FAO Remote Sensing Seminar, Cairo; and (3) Royal Geological and Mining Society, Amsterdam. A short report is being written on the ERTS interpretation for these two areas.

Field studies in the Precambrian area north of Ottawa will begin in the summer of 1975. A preliminary evaluation of the results will be made during 1975-76, so that a decision can be taken concerning the value of continuing this study into succeeding years.

REFERENCES

Charron, J.E., 1969, Hydrochemical interpretation of groundwater movement in the Red River Valley, Manitoba: Inland Waters Branch, Sci. Series 2, 31 p.

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* Hydrology Research Division, Ottawa

_____, 1975, A study of groundwater flow in Russell County, Ontario: Inland Waters Directorate, Tech. Bull. (in press).

_____, Hydrogeological applications of ERTS satellite imagery: Proc. UN/FAO Seminar on Remote Sensing, Cairo, Egypt, 1974 (in press).

GEOPHYSICAL SURVEY
STRAIT OF CANSO AREA, N.S.

Project No. HR 74-8

H.M. Elliott*

This project was undertaken as part of the collaboration between the Nova Scotia Department of the Environment and Environment Canada initially established in 1973 for a similar study on Sable Island, N.S.

The groundwork for the commitment of Hydrology Research staff and equipment was worked out between Mr. Terry Hennigar for the provincial department and Dr. H. L. Lazreg for the federal.

The objective of the project is to investigate the application of surface resistivity techniques to determine: (1) depth to water table, (2) stratigraphy and (3) indications of water quality.

Since the known geology of the area consisted of sand through clay till, gravel, or sand over shale, siltstone, or sandstone it was expected that there would be difficulty differentiating between lithologic units and especially in determining the depth to the water table. A preliminary survey was therefore conducted at several sites where the Nova Scotia department had good drill-hole information on the geology. Unfortunately, there was little or no corresponding information on depth to the water table. This survey was done during the last week of September and the first two weeks of October 1974. The survey consisted of six soundings of the Schlumberger type and six soundings of the Wenner type, one of each at each of six sites.

Interpretation of the soundings has been in progress since mid-November. Using standard curve-matching methods, five Wenner and five Schlumberger soundings have been interpreted, computer-verified and refined. The critical phase of the initial study, comparison of the drill-hole data and interpreted soundings, was just getting under way in January 1975. From the early stages of this comparison, it is evident that the Wenner array is distinctly more sensitive to near surface disturbances of the electric field than the Schlumberger array. This result was anticipated and is in agreement with theory.

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GEOPHYSICAL STUDIES IN THE FREDERICTON - OROMOCTO AREA

Project No. HR 74-9

K.B.S. Burke* and H.G. Tejirian*

This study is being done for the Hydrology Research Division under contract. Its objectives are: (1) to investigate the extent, origin and significance of inland saline waters in the Fredericton - Oromocto area of New Brunswick and (2) to delineate the dip and structure of the resistant basement and the hydrostratigraphy of the overlying Carboniferous rocks.

Field studies began in the summer of 1974. They included 21 vertical electrical soundings (resistivity method) and 55 gravity stations. A number of saline water samples were also collected. A preliminary quantitative evaluation of the resistivity data has been carried out and a progress report prepared on the summer's field work.

REFERENCES

Tejirian, Haig G., 1974, Field report summer, 1974: Univ. of New Brunswick, Dept. of Geology, unpubl. internal rept., 33 p.

* Department of Geology, University of New Brunswick

KENORA LAKES STUDY, FISHERIES RESEARCH BOARD

Project No. GWO 69-2

J.A. Cherry*

This project was initiated in response to a request by the Freshwater Institute in Winnipeg to participate in an interdisciplinary study of artificial eutrophication of Rawson Lake. The Hydrology Research Division was asked to provide a detailed understanding of the mechanisms of groundwater inflow into the lake and also to provide a network of piezometers to determine the quantity and quality of the inflow. Arrangements were made for the study to be carried out under contract. The contract was originally awarded to the University of Manitoba and went subsequently with the principal investigator to the University of Waterloo.

The field studies have included test drilling programs, a seismic survey by the Geological Survey of Canada, the installation of a large number of piezometers and water wells, and the collection of many water samples from wells, piezometers, springs, seeps and streams. Soils and surficial deposits were mapped and a number of aquifer tests carried out.

Progress reports have been prepared regularly and the studies have also provided the scientific data required for two M.Sc. theses. The last and most important unresolved question connected with the study was the reliable estimation of hydraulic conductivity for the surficial deposits. There was a possible order-of-magnitude uncertainty in this parameter at one time but this was removed as a result of the final drilling and testing program carried out in 1973. The hydraulic conductivity values were definitely established thereby to be low enough to make groundwater inflow into Rawson Lake probably less than 2 per cent of total inflow.

With the acceptance by the university of the two M.Sc. theses, this study is now complete.

REFERENCES

Bottomley, D.J., 1974, Sources of stream flow and dissolved constituents in a small Precambrian Shield watershed [Unpubl. M.Sc. thesis]: Univ. Waterloo, 118 pages.

Kennedy, K.G., 1974, The hydrology and hydrochemistry of a small Precambrian Shield watershed [Unpubl. M.Sc. thesis]: Univ. Waterloo, 248 pages.

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GROUNDWATER REGIME
CENTRAL RESEARCH FOREST

Project No. GWO 69-3

R.L. Herr*

The objective of this study has been to determine the direction of groundwater movement and the magnitude of the annual water table fluctuation throughout the Central Research Forest of the Federal Forest Management Institute. This study was undertaken at the request of the Manager, Central Research Forest.

Field studies began in 1969 and included test drilling and the installation of piezometers and shallow observation wells. A number of continuous water level recorders (Stevens Type F) were installed on the shallow observation wells and weekly water level readings were taken on the observation wells and on the piezometers. Some conductivity measurements were made on the shallow observation wells.

The hydrographs for the period of approximately two years, November 1969 to October 1971, have been accumulated for retention by the Division. The recorders are currently installed on some wells and continuous records are being collected. These later records are retained in the files of the Central Research Forest Institute.

Resistivity surveys were conducted in 1970 in the north and south valley of the Central Research Forest (Fig. 69.3.1). In the north valley a Schlumberger spacing of "AB = 20 metres" was employed, while in the south valley a Schlumberger spacing of "AB = 40 metres" was employed. The results of these two surveys have been compiled, plotted and contoured (Fig. 69.3.1).

The survey in the north valley indicates higher resistivity values along the northern, western and southern boundaries of the valley than in the central and eastern areas. From the survey in the south valley, the resistivity values are greatest along the northern and southern boundaries while lower values occur in the central area. The areas of low resistivity in both valleys are believed to be due to the upward discharge of deeper groundwaters high in chloride. The following additional observations also support the hypothesis.

During the field season of 1970 in the north valley near the eastern boundary adjacent to Anderson Road, a series of test holes were augered to a depth of two to three metres. These small holes were sampled and conductivity readings taken at various depths (Bik, Herr and Salm 1971).

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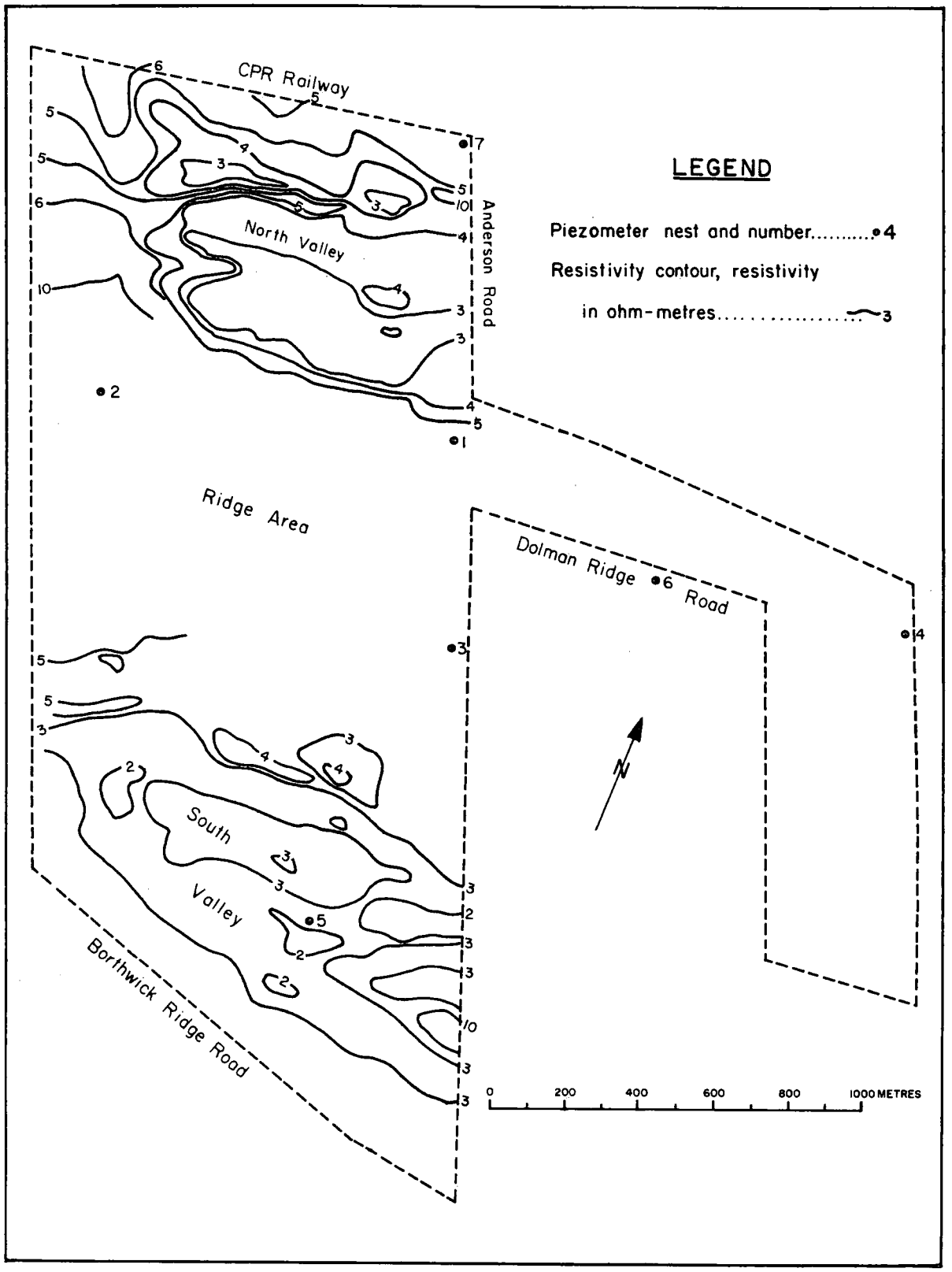

Figure 69.3.1. Sketch map of Central Research Forest.

The survey was conducted from the northern edge of the valley to the ridge on the southern boundary of the valley. It was observed that the conductivity values were low for approximately the first 300 metres from the northern boundary (CPR railway line). From 300 metres to 600 metres an increase in conductivity was observed followed by a decrease in conductivity from 600 metres to 800 metres.

In the southern valley at piezometer site No.5 (Fig. 69.3.1) an area of low resistivity occurs. This piezometer nest indicates an upward gradient with the deeper piezometer exhibiting artesian conditions.

The maps and results of these surveys are on file in the offices of the Hydrology Research Division of the Water Resources Branch in Ottawa.

REFERENCES

Bik, M.J.J., R.L. Herr and J. Salm, 1971, Saline groundwater, Central Research Forest, Ramsayville, Ontario: Geol. Survey Canada Paper 71-1, Part A, 149-154.

BENCHMARK BASIN PROGRAM

Project No. GWO 70-1
E.C. Halstead*

The role of the Hydrology Research Division in the Benchmark Basin program is to assist in the selection of suitable basins, to advise on the number and location of groundwater observation wells and piezometers and to assess network efficiency and scientific interpretation. The overall program is being co-ordinated by the Water Survey of Canada and the program was reviewed at a national committee meeting held in Toronto, May 7, 1974 and an interagency meeting held at Guelph, May 8, 1974. Although the program has been in operation for 7 years it has received low priority and not all basins have been selected. It was also brought to the attention of the National Committee that the present program may not meet hydrological benchmark basin objectives, that present instrumentation may be inadequate to provide basic hydrologic analyses and that data collected should be published annually. There has been no activity by the Hydrology Research Division in this program since the May 1974 meeting.

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HYDROGEOLOGICAL MAPS OF CANADA

Project No. GWO 71-1

R.L. Herr*

The objective of this project is to construct hydrogeological maps of Canada on a scale of 1:10,000,000 which will indicate the following:

1. Surficial hydrogeology showing the location and distribution of surficial aquifer materials, yields of wells, and water quality.

2. Bedrock hydrogeology showing location of bedrock aquifers, yields of wells, and water quality.

3. Observation wells showing location and purpose and whether well is for water table or piezometer measurements.

The Bedrock Aquifer, Surficial Aquifer and Observation Well maps have been completed, except for the marginal notes, and sent to the Secretariat of the IHD for drafting. These maps are a contribution to the IHD's Canadian Hydrological Atlas and were prepared at the request of the Canadian IHD Secretariat.

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* Hydrology Research Division, Ottawa

IMPACT OF NITRILOTRIACETIC ACID ON GROUNDWATER

Project No. GWO 71-3

D.W. Lawson*

This project was a Hydrology Research Division contribution to a broader IWD study of nitriloacetic acid (NTA) in the environment. The project objective was to arrive at some estimate of the NTA content of Canadian groundwaters. NTA is being substituted for phosphates in Canadian laundry detergents.

Various mechanisms whereby NTA could reach groundwater supplies were considered. The available evidence and some preliminary sampling suggested that the most likely route for introduction of NTA was via faulty septic systems. Groundwater monitoring for NTA was therefore set up in a small community (Finch, Ontario) where there had been a history of sanitary disposal problems of this type. Groundwater sampling was also carried out for comparison purposes at Stonewall, Manitoba and near Brandon, Manitoba. The geologic settings at Finch and Stonewall are similar (thin overburden over relatively impermeable bedrock) whereas the septic systems at Brandon overlie a shallow sand and gravel aquifer.

Groundwater supplies in Finch were randomly sampled in a door-to-door survey. They were analyzed for soluble PO_4 and for NTA. Coliform bacteria counts were provided from earlier surveys by local provincial health units.

The initial sampling in early 1972 gave NTA values of up to 250 ppb at Finch; one of the three groundwater samples from Stonewall also had a high NTA level - 290 ppb. Most of the Finch samples, however, had values below the detection limit (10 ppb), as did the second and third Stonewall samples. Detectable NTA tended to be associated with the presence of coliform bacteria; the mean NTA level for groundwater containing coliforms was about 50 ppb. Groundwater free of coliforms generally contained less than 10 ppb NTA.

Further sampling was carried out at Finch, Ontario on a monthly basis from September 1972 to February 1973 inclusive. During the first five months of this period, only a limited number of samples were collected from a few selected sites. In February, however, a complete set of 72 samples was taken. Sampling was also repeated at Stonewall, Manitoba with 29 samples being collected in October 1972 and again in February 1973. Results from the additional sampling - both at Finch and at Stonewall - were generally in complete contrast to the earlier findings: only four of the 72 samples collected during the February sampling showed detectable NTA; the highest value amongst these was 70 ppb. No NTA was detected in the Manitoba samples.

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A new sampling program was initiated later in 1973 at six sites: four of these were the four sites at which detectable NTA was found for the February sampling; the remaining two had had the highest reported NTA levels during the first major sampling period. The new sampling was continued on a monthly basis but only one location had detectable indications of NTA; this location yielded the unprecedented value of 3,900 ppb in August 1973. Daily sampling was conducted for a while at this location.

Further information on this project is contained on the Hydrology Research Division files. The study is also described in the reports listed below.

REFERENCES

Lawson, D.W., 1972, The NTA monitor program-groundwater: Inland Waters Directorate unpubl. internal rept., 19 p.

_____, 1973, Appendix 2: Progress Report No. 2: National NTA Monitoring Program, 17-19.

GENERALIZED HYDROLOGIC MODEL-PERCH LAKE BASIN

Project No. HRO 74-2

S.Y. Shiau*

A generalized hydrologic model for streamflow simulation (Project No. HR 74-5) has been applied to simulate the surface and groundwater inflows from six sub-basins into the Perch Lake. The Perch Lake basin is a very small research basin which comprises six sub-basins. The drainage areas of the sub-basins range from .13 (sub-basin No. 5) to 3.45 (sub-basin No. 2) square kilometers. The physiography varies from basically flat and swampy areas (No. 2) to rocky areas of high relief (Nos. 4 and 5). Further details describing the basin are given by Barry (1967), Barry and Merritt (1970), Kitchen (1971) and Slater (1974).

The period of calibration and simulation is from January 1969 to October 1973. The simulation is on a daily basis and is continuous. A snow accumulation and ablation routine has been utilized to simulate the snowpack water content and the effective rain plus melt for each of the sub-basins. The simulated daily rain plus melt rather than the daily precipitation data is used as the moisture input for calibration and flow simulation during snowmelt periods. The results of simulation indicate that the snowmelt routine is adequate for most of the melt periods. The results are particularly encouraging for the major melt events.

The activity of beaver at or near the gauging sites presents a special interpretation problem. Some observed peak flows that were impossible to simulate turned out to be "beaver peaks". The plot of simulated against observed hydrographs becomes an effective tool to detect "beaver peaks" on the discharge records.

The results show that sub-basins Nos. 4 and 5 generate the highest surface runoff per unit area - almost twice that generated from sub-basins Nos. 3 and B and about 70% higher than that from sub-basins Nos. 1 and 2. On the other hand, sub-basins Nos. 3 and B are most effective in providing groundwater inflow per unit area, whereas sub-basins Nos. 4 and 5 produce no groundwater inflow. Sub-basin No. 2 generates about 61% of the total groundwater inflow annually while sub-basins Nos. 1 and 3 contribute approximately 17% each with the balance coming from sub-basin B.

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The actual evapotranspiration used by the sub-basins as determined from the simulation results varies from 50% of the demand (sub-basin No. 5, 1971) to approximately 90% of the demand (sub-basin B, 1972).

Further details of the results regarding the simulation of surface and groundwater inflows to Perch Lake can be found in the "Perch Lake Evaporation Study Summary Report" to be published by the Environmental Research Branch of Atomic Energy of Canada Limited.

REFERENCES

Barry, P.J., 1967, Perch Lake evaporation study: Draft of progress report: Atomic Energy Can. Ltd., Internal Rept., Chalk River, Ont., 22 p.

Barry, P.J., and Merritt, W.F., 1970, The Perch Lake evaporation study: Symp. Uses of Isotopes in Hydrology, Vienna, paper SM-129/10.

Kitchen, B.W., 1970, Perch Lake evaporation study: Water Surv. Can. Internal Rept., 12 p.

Slater, J.E., 1974, Water Survey of Canada hydrometric program at Perch Lake: Water Surv. Can., Internal Rept., Guelph, Ontario. 13 p.

INVESTIGATION OF AN UNDERGROUND GASOLINE SPILL IN FLIN FLON, MANITOBA

Project No. HRO 74-3

J.A. Vonhof*

The objectives of this study are:

1. to delineate the shallow subsurface area contaminated with gasoline liquid and vapour,
2. to determine the source of the gasoline,
3. to define the stratigraphic framework, and
4. to suggest the best possible clean-up technology.

The first phase of a drilling program was conducted in early October 1974. The second phase began in December 1974. Preliminary interpretation of the data collected during September and October 1974 indicate that there is an area of at least 30,000 square feet contaminated with gasoline vapour and liquid.

This study is funded by the Environmental Protection Service.

* Hydrology Research Division, Calgary

HYDROGEOLOGY OF GROS MORNE AND KOUCHIBOUGUAC NATIONAL PARKS

Project No. HRO 74-4
R.L. Herr*

The objective of this project is to conduct a hydrogeological reconnaissance survey of Kouchibouguac National Park in New Brunswick and Gros Morne National Park in Newfoundland.

The author visited Kouchibouguac National Park August 5 to 9, 1974 and Gros Morne National Park, August 12 to 18, 1974. During these periods a reconnaissance survey was conducted and water samples collected from each area.

At the present time the literature is being reviewed and compilation and analysis of data are being undertaken. The final report is expected to be completed before the end of March 1975. At this time future work in the parks is not anticipated.

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