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National Hydrology Research Institute
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NHRI RESEARCH PROGRAM

Summaries of Activities and Progress
in 1980-81

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FOREWORD

This report is a compilation of brief summaries of activities and progress for those NHRI research studies that were active during 1980-81. We plan to issue a similar report annually for distribution internally within IWD, primarily for the information and use of the Water Research Advisory Committee. Succeeding issues will be put together towards the end of the calendar year and issued early in the new year.

Summary of Activities and Progress in 1980-81

Study No. SI 67-4

Peyto/Yoho Glacier Hydrology

G.J. Young

The basic monitoring of glaciology and meteorology at Peyto Glacier continued. The monitoring of the discharge on four streams in the vicinity continued very successfully. This year the basic monitoring program was contracted out to P.G. Johnson of Ottawa University. Two student assistants have now been trained in techniques and they will be undertaking Master degree projects as well as the basic monitoring program in 1981. This system of contracting out is proving very successful and useful in these times of economic constraint.

No new projects were initiated on Peyto Glacier this year, but a concentrated effort was made to have previous studies written up. A summary paper on mass balance 1966-78 has been accepted by Arctic and Alpine Research; a paper on shortwave radiation on Peyto was presented at the Eastern Snow Conference and two more papers are well on their way to completion; a paper on the effect of debris cover on ablation was presented at Geilo, Norway, and is accepted for Annals of Glaciology and another paper on debris cover has been submitted to Journal of Glaciology; papers on water chemistry are in preparation; a Master's thesis on katabatic winds was completed and a paper from this work is soon to be submitted for publication; a Master's thesis on snow density and a Ph.D. thesis on glacier/climate relationships are currently under way.

Summary of Activities and Progress in 1980-81

Study No. SI 67-15

Snow and Ice Information and Data Systems

C.S.L. Ommanney

A general information file has been assembled for all aspects of the Stikine/Iskut glacier inventory - aerial photographs, maps, references, the hydrology and glacier information. A base map of the two major basins has been compiled and drafted. A study of the glacier-dammed lakes in the region was completed, under contract, by M. Perchanok. Glacier inventory work maps for 5 basins have been compiled.

A detailed glacier inventory of southeastern Ellesmere Island has been completed in a cooperative program with the Geographisches Institut, ETH-Zürich, by Pavel Kraus. The results of this project are to be used to determine the freshwater inflow to the North Water polynya. A total of 731 glaciers were identified, mapped and digitized. In another cooperative project on Ellesmere Island, the glaciers of Borup Fiord have been inventoried by Dr. Lorenz King of the University of Heidelberg.

Work on the glacier inventory of Glacier National Park was suspended during 1980/81 due to problems in the metric conversion routine within the digitizer data reduction program. This problem is now being investigated by the Computer and Applied Statistics Directorate. Work was also suspended on the Glacier Atlas of Canada pending completion of the Columbia Icefield map.

Glacier inventory work maps were made available to both federal mapping agencies for the purposes of checking glaciological information. One set was provided to the National Atlas of Canada to be used as the basis for a new Glacier Map of Canada and for the identification of calving glaciers.

A composite tape of western Canadian glacier inventory data was prepared and shipped to the University of British Columbia for use in a study on the nature and distribution of surging glaciers.

Information on, and delineation of, more than 150 glaciers was provided to various Provincial and Territorial name boards as well as to Parks Canada. The application of a glacier name is now checked in the files of this Study prior to official approval. Many other requests for glaciological information were received from national and international agencies as well as from the private sector.

Work continued on the preparation of a National Hydrology Research Institute display which will be shown at selected scientific symposia and which will inform the public about the activities of the Institute.

Annual reports on various glaciological activities were prepared for the Canadian Geophysical Bulletin, the International Glaciological Society and the Working Group on Ice. Some special projects were carried out in connection with the work of the Advisory Committee on Glaciological and Alpine Nomenclature.

Summary of Activities and Progress in 1981-82

Study No. GW 68-8

Potential Evaporation - Significance and Measurement

F. Morton

Final revisions were made to the latest version of areal evapotranspiration and lake evaporation model.

The areal evapotranspiration model was evaluated further using water budget data for river basins in Africa, Australia and New Zealand.

A technique was developed for summarizing and illustrating the seasonal water budget of river basins.

The computer programs for the areal evapotranspiration and lake evaporation models were documented in NHRI Paper No. 12.

A paper was prepared which documents the theoretical basis and supporting evidence for the concept of the complementary relationship between areal and potential evapotranspiration and its superiority to currently used alternatives in providing realistic independent estimates of areal evapotranspiration and lake evaporation from routine climatological observations. The paper has been submitted for publication.

Studies were initiated to take into account the effects of subsurface heat storage changes on lake evaporation.

Assistance was provided to Alberta Environment in the application of the areal evapotranspiration and lake evaporation model.

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Study No. GW 71-1

Hydrogeology, Fraser Valley

E.C. Halstead

During the year, activities relating to this project included some field work and collection of water samples, together with the preparation in part of the final report and maps. Approximately 800 water quality analyses are stored in NAQUADAT and programs are presently being initiated to process these data for inclusion in the report.

H.M. Liebscher was involved during a large part of the year as a consultant to the Geological Survey of Canada, providing expertise and supervision of a program at Coldstream Ranch, near Vernon, B.C. where a flowing artesian well was brought under control.

Appraisals of ground water development projects were provided for Agriculture Canada at research stations at Agassiz and Clearbrook, B.C., for Indian and Northern Affairs at Chehalis, Nitinat Valley, Chilko Lake, Anahim and Cannim Indian Reserves; and for Provincial Parks Branch, at Peace Arch Park, Blaine border crossing where a test hole was drilled 1,112 feet. Contaminant studies included an EPS referral in connection with the Elbow Lake, near Harrison Mills, diesel oil spill. There was consultation as well with Langley Municipality and Provincial Health Engineering concerning a contaminated well on 13th Avenue and the installation of piezometers and evaluation of hydrogeology in the vicinity of Langley landfill on 272 Street.

Requests from consultants, municipal engineers, well drillers and land owners averaged 40 per month.

Summary of Activities and Progress in 1980-81

Study No. SI 73-12

Water Management of Glacierized Basins

O. Mokievsky-Zubok

Several glaciers in British Columbia were studied and their winter, summer and mass balances for the period from the fall of 1979 to the fall of 1980 were measured. The data were processed and balance values determined for each glacier. Meteorological stations at glaciological camps were maintained and data collected for the purpose of assessing glacier response to climatic changes. Albedo studies were conducted by S. Fogarasi on a glacier in the Iskut River basin.

Net glacier runoff contributions to the flow regimes of downsteam rivers were estimated.

Consultations were held with B.C. Hydro officials on the application of glaciological data to operational and forecast models for large reservoirs (Hydrology Section - Burnaby) and in the planning of power dam construction (Hydroelectric Design Division - Vancouver).

Locations susceptible to glacier outburst floods (jokulhlaups) were investigated and ice-dammed lakes observed to establish the periodicity of sudden discharges of the lakes affecting areas under study and for some understanding of the processes leading to jokulhlaups.

Reports on glaciological activities in connection with joint projects have been written and submitted to B.C. Hydro offices in Vancouver and Burnaby, and to the IWD, Pacific and Yukon Regional office. A paper on runoff estimation from Sentinel Glacier, B.C. is in preparation. A contract report on glacier-dammed lakes in the Stikine and Iskut River basins has been received from M. Perchanok.

Guidance and assistance was given to the Geography Department, Simon Fraser University, in organizing a Glacial Hydrology field course for graduate students and professionals on Place Glacier, taught by G. Østrem.

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Study No. SI 73-13

Hydrologic Studies, Mackenzie Delta Region, NWT

J.C. Anderson

Field studies continued in the eastern Mackenzie Delta region in 1980, on behalf of the Northern Roads Environmental Working Group, DINA. At three basins in the taiga zone south of Inuvik, and seven basins in the tundra zone between Inuvik and Tuktoyaktuk, data were collected on one or more of the following variables:

1. Culvert ice accumulation thickness;
2. Late winter snowpack water equivalent;
3. Field season precipitation;
4. Air temperature; and
5. Discharge.

Surveys of culvert icings were conducted in the taiga zone in March, May and September. During the May field trip, the following additional work was performed: snow surveys, installation of precipitation gauges and thermographs, and installation of water level recorders. The principal investigator was not on location during the spring flood event, but arrangements were made with cooperating agencies (e.g. Water Survey of Canada) to obtain the necessary streamflow data.

Data analysis is not yet complete, but it is apparent that the 1980 spring flood was a major one in the region, comparable with that of 1977 on account of high snowpack water equivalents. As data records lengthen, (e.g. nine years at Boot Creek), more meaningful statistical analyses (such as flood frequency analysis) can be undertaken.

A brief progress report was submitted to DINA in July 1980, and a complete report on the year's activities will be prepared in the near future. This study is funded by DINA, and current intentions are to continue it.

Summary of Activities and Progress in 1980-81

Study No. HR 74-2

Northern Ground Water and Engineering Problems

R.O. van Everdingen

Manuscript HR 80-2, "Morphology, hydrology and hydrochemistry of karst in permafrost terrain near Great Bear Lake, NWT, was completed and edited and page proofs have been corrected. It will be published in the NHRI Paper Series.

Illustrations and tables for the final paper on the Bear Rock frost blisters have been prepared.

Films were retrieved from 12 time-lapse cameras installed in September 1979 at 8 icing sites along the Alaska Highway; they have been processed and printed and 3 of the films have been "read" for a report on the site at km 1817.5.

In September 1980, 8 cameras were installed at 4 icing sites.

In March, 4 continuous ice cores were obtained from 3 icings; one was used for ice-fabric analysis, the other 3 for isotope analyses (^{2}H, ^{3}H, ^{18}O); one ground-ice sample was collected for isotope analysis.

In March and September, 3 precipitation samples (1 rain, 2 snow) were collected for isotope analysis.

In March, May and September, 38 water samples were collected for chemical and isotope analyses.

In March and September, surveys were carried out to determine ice thickness distribution at the site at km 1817.5.

In September, a number of small dye tracer tests were run at Mines Creek, to investigate whether at that time the stream was influent or effluent.

In September, 2 water samples were collected from Takhini Hot Spring for isotope analysis, following a meeting of the Technical Committee, Yukon Territorial Water Board, where an application for a geothermal lease was discussed.

Two water samples were collected from a pond and a spring at a pingo site on the old Dawson road; a core of ice-rich frozen ground was collected from the valley alluvium nearby (with H.M. French and W. Pollard, University of Ottawa, and F.A. Michel, University of Waterloo).

Three water samples were collected from springs in North Fork Pass, for chemical and isotope analyses; a core of overburden and frost blister ice was obtained from one of the 1979-1980 frost blisters at this site, for isotope analysis (with H.M. French, W. Pollard and F.A. Michel).

Electrical resistance frost gauges, developed under this project, are now being used to monitor permafrost at a uranium tailings disposal site in Northern Saskatchewan; such gauges are also being considered for use along the Alaska portion of the Alaska Highway Gas Pipeline.

The time-lapse photography system is being considered for use at a thaw-settlement test site along the Yukon portion of the same pipeline.

Summaries of Activities and Progress in 1980-81

Study No. HR 74-6

Hydrogeology of the National Capital Region

R.L. Herr

The results of the chemical analyses have been computerized and plotted on Schoeller and Piper diagrams to give some indication of the types of waters encountered in the National Capital Region.

The well information and field data have been plotted on 1:50,000 scale maps. These will be plotted on 1:100,000 scale maps which will be a more reasonable size. The report for this project is being written.

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Study No. HR 74-8

Geophysical Survey - Strait of Canso

H.M. Elliott

The pressure of commitments to bring the AECL-purchased borehole acoustic televiewer to operational status and to provide geophysical backup for LRTAP studies in the Haliburton Highlands (Study No. GW 80-3) and in the Turkey Lakes watershed (Study No. GW 80-5) interfered with progress in this study. The sequence of malfunctions encountered with the televiewer was such that it was finally turned over to the electrical and mechanical shops at AECL, Chalk River for repair and remodelling. LRTAP geophysical studies are reported on under Study No. GW 80-4.

Summary of Activities and Progress in 1980-81

Study No. HR 75-1

Contaminant Hydrogeochemistry

R.E. Jackson

This report marks the conclusion of project HR 75-1 on the hydrogeochemical processes affecting radionuclide migration in a fluvial-sand aquifer at the Chalk River Nuclear Laboratories, 200 km northwest of Ottawa. A major report on this study was written in 1979 (Jackson and Inch, 1980); however field, laboratory and theoretical analysis conducted since that time have added considerably to our understanding of (1) the pH and E_H controlling processes within the aquifer, and (2) the identity of the radionuclide adsorbents. Manuscripts on both of these topics will be submitted for external publication during 1981. The following summary statements may be made:

1. The aquifer system is a fine-grained sand ($K \sim 10^{-3}$cm/s) composed of quartz and plagioclase (70% of all grains) with minor chlorite, hornblende, muscovite, K-feldspar, magnetite and biotite (partially altered to vermiculite), and trace amounts of calcite, organic matter and hydrous oxides of Al, Fe and Mn. Acid-neutralization capacity measurements and X-ray diffractograms suggest that acid precipitation recharging the aquifer undergoes a two step neutralization process involving an initial adsorption step, mainly onto feldspars and micas, and a subsequent irreversible neutralization step involving biotite alteration to vermiculite and carbonate-mineral dissolution. During migration through deep confined parts of the aquifer, ground waters attain equilibrium with calcite.

2. A thermodynamically based redox model of a closed-oxidant system satisfactorily accounts for the sequential reduction of dissolved oxygen, ferric oxides and sulfate in the aquifer by the oxidation of dissolved organic carbon and (for oxygen only) ferrous iron. Because of the problem of using Pt electrodes in natural waters, it is recommended that E^H measurements be supplemented with dissolved oxygen and sulfide measurements.

3. Distribution coefficients for the radionuclides ^{90}Sr and ^{137}Cs, which were disposed of into the aquifer in the period 1952-55, are of the order of $K_d^{Sr} \sim 10$ ml/g and $K_d^{Cs} \sim 100$ ml/g. Most ($\sim$80%) of the ^{90}Sr is exchangeable with 0.1 M $SrCl_2$, whereas less than one half of adsorbed ^{137}Cs is exchangeable with 0.5 M $CaCl_2$. Most of the nonexchangeable ^{90}Sr is extractable with acidified hydroxylamine hydrochloride, the amount desorbed being strongly correlated with extractable Al, Fe and Mn. On a grain-for-grain basis, vermiculite is the strongest adsorbent; however, due to their abundance, most ^{90}Sr is adsorbed to feldspar (generally sericitized) minerals.

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Study No. HR 75-2

Hydrogeology of Excavations and Impoundments

K.U. Weyer

Research work for the project was nearly dormant in 1978, 1979 and 1980, because of involvement in assessment of Environmental Impact Statements. This involvement, however, also led to the preparation of two publications and several unpublished reports. A paper on ground water flow near mining sites in the high Arctic is in preparation.

List of reports and publications during 1980-81:

1. Weyer, K.U. and J.A. Vonhof, 1980. Water quality? - A discussion of "The effects of surface mining of coal on water quality near Grande Cache, Alberta", by D.A. Hackbarth. Canadian Journal of Earth Sciences, Vol. 17 (7), 952-955.

2. Weyer, K.U., 1980. Organic and inorganic sources for sulfate ions dissolved in water from spoil dumps of a coal mine in Alberta and associated biochemical oxidation processes. 25 pages, 3 figures.

3. Weyer, K.U., 1980. Review of the 1979 Environmental Baseline Studies in the area of the future McLean Lake Uranium mine, Northern Saskatchewan. 5 pages.

4. Weyer, K.U., 1980. Regional groundwater flow in the area of the Cluff Lake Uranium mine, deduced from regional maps of topography, geology, aeromagnetics and gravimetrics. 16 pages, 8 figures.

5. Weyer, K.U. and S.A. Zaidi, 1980. A review of geohydrological data for the area of the Cluff Lake Uranium mine reported by AMOK Ltd. 43 pages, 8 figures.

5. Weyer, K.U., 1980. Use of the "Sub-aerial technique" for the disposal of uranium tailings in Northern Saskatchewan, 12 pages.

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Study No. HR 75-5

Hydrothermal Effects Near Arctic Streams

A. Wankiewicz

The thermal regime and ground water conditions are being investigated beneath rivers which freeze to their bed in areas of continuous permafrost. Ground temperature data collected over a two-year period at river sites on Melville Island and near Inuvik, NWT are being input to a digital file, corrected for calibration error and compared with theoretical thermal profiles. The surface heat transfer is determined by both thermal flows at the solid ice surface in winter and the river temperature regime in summer.

To extend the river temperature record, the longitudinal temperature variability along a meandering river channel was calculated using Jobson's numerical river temperature model. It was concluded that the mixing length for thermal transients along a river channel varies from 500 km during spring flood to 1 km (one pool length in a pool and riffle sequence) at low flow for the rivers investigated.

A selection of finite difference ground water models was reviewed (Outcalt surface climate simulator, Harlan 2D transient conduction-correction model, Pickens ground water quality model, and the Gemmix parabolic numerical procedure) to determine a suitable procedure for mapping the hydrothermal pattern beneath an intermittent inner channel. Because of the complex linkage between the river stage, channel ice formation (surface ice and aufeis) and the ground water thermal and fluid fluxes, it was concluded that further experience was required in modelling selected key interactions to establish simplifying approximations permitting a more comprehensive simulation. The Outcalt surface climate simulator, which includes an implicit finite difference procedure for calculating thermal profiles, was selected for comparison with the field measurements because of its simplicity and the Division's previous experience with its use.

A problem with modelling seasonal ground temperature profiles is the requirement that an initial profile be input to the simulation program. Calculation shows that the approach to equilibrium at depth is very slow so that the long-term equilibrium temperature profile should be used as the initial profile. Surface temperature residuals were calculated for heat exchange by both black-body radiation and forced convection. It was concluded that the second year of a two-year simulation of daily temperature profiles could be used to a high degree of accuracy as the initial profile for a detailed seasonal ground temperature simulation.

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Study No. HRO 75-1

Hydrogeology, Richmond Landfill - Richmond, B.C.

H.M. Liebscher

A high percentage of an estimated annual 750,000 tons of domestic, commercial and industrial waste generated in the Vancouver metropolitan area are disposed of at peat bog landfills lying near or on the Fraser River delta. Test holes either within or peripheral to these landfills indicate similar geological and hydrological environments.

As a result of resident complaints in the vicinity of federally owned Richmond Landfill Site, the Federal Activities Pollution Abatement Group of the Environmental Protection Service initiated an environmental assessment study of this property. In August 1975, engineers of this group requested assistance from the Hydrology Research Division in determining site hydrogeology. Field studies including geological mapping, test drilling, piezometer installation, slug tests, and monitoring surface and subsurface waters commenced late in 1975.

Geologically the landfill lies on the south east corner of Greater Lulu Island Peat Bog and partly on a former distributary channel of the Fraser River. Results from test drilling indicate that the bog portion of the landfill is underlain by three stratigraphic units. These units are (1) 30 to 37 m of silty sand overlain by (2) 1 to 7 m of silty organic clay which in turn is overlain by (3) 0 to 5 m of compressed peat. The former distributary channel consists of 0 to over 11 m fine to coarse sands overlain by 1 m floodplain silty clays. Refuse is generally spread in three separate lifts which includes a basal industrial mattress later overlain with two putrescible lifts. Thicknesses of the lifts vary from 2 to 5 m and they are generally separated by 10 to 30 cm dredged silty sand.

Surface and ground water chemical analyses, slug tests and hydrographs of 23 piezometers installed in the lower two units and in the refuse indicate no downward leachate migration through the silty clay unit into the deltaic silty sand.

Most leachate generated on site is collected in an integrated landfill ditch system where it flows directly either into adjoining properties, the Fraser River, or the municipal ditch system.

Ditch excavations in 1977 into and through the former distributary channel silty clays resulted in leachate migration and contamination of alluvial sands. This has resulted in formation of an oscillating leachate plume in the former channel which hydrologically responds directly to the tidal stages of the river. This ditch has recently been filled and a diversion ditch excavated through the bog portion of the landfill. With existing data this appears to have checked leachate loss at the north east corner. Recent data indicate that the oscillating plume now contains less total dissolved material than one year ago. This most likely is due to diffusion, ion exchange, absorption, biodegradation and other attenuation mechanisms.

A number of diverse factors lead to significant recharge at the landfill. These include: high tides, high discharge rates of the Fraser River, compaction of the peats, winter precipitation and on-site dredging operations. The heterogeneous nature of the refuse and the diurnal tidal influence of the Fraser River results in a highly variable concentrated leachate being discharged into the receiving environment.

Most information on the landfill study has been gathered and a final report is in various stages of completion.

This project was dormant for most of the fiscal year due to the principal investigator's involvements at the flowing GSC well in Coldstream and in subsurface contaminant studies in Langley, B.C. Richmond Landfill study and final report should be completed by the end of the forthcoming fiscal year.

Summary of Activities and Progress in 1980-81

Study No. HR 76-2

Ground Water Investigations in the Pine Point Region

K.U. Weyer

Field work in the Pine Point area was continued with hydrogeochemical sampling at open pits and in the wider area. Detailed hydrochemical observations were made at the K77 pump tests. Together with the Microbiology Labs of EPS, Edmonton, samples for sulphur bacteria were taken during the K77 pump tests and in the general area and subsequently analyzed.

Three gauging stations and one time-lapse camera observation site were operated and the data analyzed.

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Study No. SI 77-1

Computer Programming and Support

J.E. Glynn

The EDP report on computer usage in the Snow and Ice Division (FY 79-80) was completed and submitted to the Computing and Applied Statistics Directorate.

A programme to compute river ice flow velocity from digitized aerial photographs was completed for E.J. Langham. The programme has now been documented as well.

Work was performed for V. Klemes on some mathematical properties of stochastic rainfall-runoff relationships. The particular class of relationships considered involved a power law storage-runoff function. A report on some of the properties of the model in continuous and discrete time is currently in preparation.

Summary of Activities and Progress in 1980-81

Study No. SI 77-2

Airborne Sensing and Measurement of River Discharge during Spring Ice Break-up

D.A. Sherstone

Stereophotogrammetric techniques were employed with high accuracy aerial photography in order to map surface water velocities at test sites on the Mackenzie River, by plotting the displacement of river ice debris in successive photos. Having obtained the distribution of surface velocities across a river section, discharge could be estimated if the cross sectional river profile were known. A discussion of this technique and its results formed the basis of a Master's thesis, which was completed in 1980.

Summary of Activities and Progress in 1980-81

Study No. HR 77-2

Arsenic Contamination of Ground Water in the Maritimes

D. Bottomley

Field and laboratory activities for this project were completed in the 1980 fiscal year and a paper presenting the results of this study in detail is in progress. The following points summarize the main findings of this study:

1. The occurrence of arsenic in ground water in the Carboniferous volcanic formations of southwestern New Brunswick appears to be a result of natural rock-water interactions. The arsenic in the rock is associated with magnetite and its iron-oxide alteration products.

2. The occurrence of arsenic in the ground water of the Meguma Group of Nova Scotia is attributable to two factors:

   (a) natural oxidation of in-situ arsenopyrite which is in the quartz veins that were the hosts for the gold mineralization, and

   (b) recharge of surface waters which have oxidized arsenopyrite associated with tailing materials. Some of this material has been subsequently used for fill and even to line some dug wells.

Arsenic contamination of ground waters in both areas can be expected to remain widespread. Outside of the mining districts in Nova Scotia, the instances of arsenic contamination will depend on whether the ground water has been in contact with the major arsenic-bearing minerals.

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Study No. HR 77-3

Stochastic Rainfall - Runoff Relations

V. Klemes

The problem of response of a nonlinear system to stochastic input was studied with the aid of recently improved Box-Jenkins techniques (Hipel and McLeod, Water Resources Research, 1979) and was found intractable. The technique is able to discriminate between different nonlinear models neither in the identification stage nor in the diagnostic checking stage. The same difficulty (of insufficient discriminatory power) has been encountered in connection with other techniques (linear approximation, nonlinear transition matrices). Results including a discussion of (1) convergence problem encountered in a simulation approach, (2) nonseparability of model and parameter uncertainty, and (3) irregular properties of output residuals have been reported in the invited paper for the Mississippi Rainfall-Runoff Symposium.

J. Glynn has been approached for advice on some mathematical problems related to the nonlinear response and encouraged to work on explicit solutions for output parameters. The cooperation has been very successful in that he was able to obtain some original results on negatively skewed runoff which will be submitted for publication.

The problem of nonlinearity is acknowledged to be a difficult one and no adequate theory is so far available. The situation was summarized by the famous Australian mathematician P.A.P. Moran as follows: ..."It is clear that nonlinearity is an all pervading problem and here we are confronted, if not with a brick wall, at any rate with a hill of rapidly increasing slope. Nearly all work done on time series has been from the point of view of spectral analysis which is a linear theory and not invariant under nonlinear transformations....Thus many questions remain unanswered" (Moran, Proc. Int. Congress Math. Vancouver, 1974).

Summary of Activities and Progress in 1980-81

Study No. HR 77-4

Snowmelt Infiltration and Runoff

A. Wankiewicz

The activities in this project consisted of application of previous theoretical work to support of the microwave remote sensing field study HR 78-8. A literature review produced typical soil moisture parameters for modelling the expected winter hydrologic behaviour of sand, silt, clay and loam soils, as well as the unfrozen water content as a function of ground temperature. Tables of dielectric constant and loss tangent were calculated for both soil and snow as functions of density, liquid water content and porous medium structure. Snowpack liquid water context profiles were calculated for the range of snow irrigation application rates planned for the snow treatment plots at the Ottawa Central Experimental Farm. The effects of antecedent rain/melt rate conditions were included in the calculation. These studies show that large-scale artificial snow treatments would be a valuable research tool for investigating the hydraulics of rain-on-snow events in addition to providing radar targets for study HR 78-8.

Because of time constraints related to the emphasis placed on the activities outlined above, a planned paper on the Perch Lake infiltration study was delayed and will be written in 1981-82.

Summary of Activities and Progress in 1980-81

Study No. HR 77-5

Trace Elements in Ground Water

L.M. Johnston

Investigation of the temporal variations in ground water chemistry in three piezometers (HA1, 08, KN2) in the lower Perch Lake Basin was completed in October 1980. These piezometers are slotted and screened over the bottom 0.6 m. Samples were usually collected monthly and analyzed for temperature, electrode potential, pH, conductivity, dissolved oxygen, alkalinity, NO_3^-, SO_4^{2-}, Cl^-, Na^+, Ca^{2+}, Mg^{2+}, K^+, SiO_2, Fe_T, Mn_T, Cu^{2+}, Ni^{2+}, Co^{2+}, Pb^{2+}, Al_T . (Where T refers to all valence states). Samples were taken daily or weekly during the spring melt. Three years of data are available and variations are evident in alkalinity, dissolved oxygen, SiO_2, Fe_T, and platinum electrode potential at all stations. Variations in SO_4^{2-} and pH were common at most stations and there were extreme variations in conductivity, Na^+, and Cl^- at station HA1.

Monthly sampling of a multilevel piezometer (HA2-HA7) (sampling point every 0.5 m) near HA1 in a recharge area is continuing. Temporal variations similar to those at HA1 were observed but addition of the vertical dimension has increased their complexity, especially for conductivity, dissolved oxygen, pH, and electrode potential.

Four conventional piezometers (LJ1-LJ4) installed near A Disposal Area confirmed the consistently low pH ($\sim$5) and high conductivities (500-900 μ Siemens/cm) of ground waters in the area. A multilevel piezometer (LJ5) allowed assessment of the vertical variations in pH and conductivity in this area. Core samples, recovered during drilling, are being analyzed for chemistry and mineral content to assess the matrix through which the ground water is flowing.

A preliminary assessment of the water in fifteen existing piezometers was made on the east side of Perch Lake (sub-basin #3, Barry, 1975). The waters from two previously identified cross sections (Killey, 1977 and McNaughton, 1975) were analyzed for the same variables as those listed in the first study. Large variations in most parameters occurred in these fifteen piezometers. Monthly sampling is being undertaken at three sites for a one-year period.

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Killey, R.W., 1977. Carbon geochemistry of an unconfined aquifer-lake system on the Canadian Shield. Unpublished MSc. Thesis. Waterloo University, Waterloo, Ontario, 110 p.

McNaughton, D.C., 1975. A hydrogeological, geochemical and isotopic study of an uncontaminated flow system, Perch Lake Basin, Ontario. Unpublished MSc. Thesis. Waterloo University, Waterloo, Ontario, 95 p. plus figures.

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Study No. SI 78-1

Suspended Sediment: Liard River Basin Spring Flood

B.J. Grey

This was the third year of a three year study to investigate the suspended sediment regimes and sediment transport of the Muskwa and Fort Nelson Rivers as they relate to that of the Liard River. In 1980, field work to collect sediment samples was undertaken prior to break-up (March), during the spring break-up flood (April-May) and during the early summer period (June-July) at sites on the Muskwa, Fort Nelson and Liard Rivers.

Data gathered in 1980 were analyzed, and the results confirmed preliminary findings of the 1979 field season. Among these findings are the following:

1. The Liard is a major sediment source for the Mackenzie;
2. The Muskwa-Fort Nelson system is a major contributor of suspended sediment to the Liard;
3. Suspended sediment concentrations and loads are typically higher during summer rainfall floods than during spring snowmelt floods on the Muskwa and Fort Nelson since rainfall floods are usually much greater in volume on those rivers.

These and other findings have been presented in a summary report prepared for the Mackenzie River Basin Committee, and this study has now ended.

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Study No. SI 78-2

River Ice Break-up: Liard River Basin Spring Flood

D.A. Sherstone

In this, the third year of a three year study, the progress and character of river ice break-up in the Liard Basin was again monitored. By means of aerial photography and ground-based study, break-up was followed on the Fort Nelson River below Fort Nelson, and on the Liard River below Nelson Forks. (Break-up was also monitored downstream on the Mackenzie River, toward Norman Wells). Field work was also undertaken at selected locations in March to obtain ice thickness measurements prior to break-up, and in July to obtain channel profile data at some ice-jam sites.

The aerial photography and field data were examined and analyzed and a summary report prepared in which the 1980 information was compared with that obtained in the two previous years. Major findings include the following:

1. The Fort Nelson River breaks up earlier than the Liard and acts to initiate break-up on the Liard below Nelson Forks;
2. Ice jams occur and recur at numerous sites along the Fort Nelson and lower Liard Rivers; and
3. Backwater effects caused by jamming on the Fort Nelson and Liard were not as great as those observed in past years on the Mackenzie River.

This study has now ended.

Summary of Activities and Progress in 1980-81

Study No. SI 78-4

Thermal IR Remote Sensing of Columbia Icefield

A.C.D. Terroux

Study of the imagery obtained in 1977, aided by a contract completed by E.J. McLaren Consultants, Ltd., shows that it is possible to differentiate surface temperatures using isotherms with temperature intervals of less than 1°C, and that all snow and ice covered areas except glacial margins and the Columbia Glacier are at temperatures below -0.8°C. Part of the imagery is being used as a cover for the new Columbia Icefield map being produced by Inland Waters Directorate and Parks Canada. Comparison of the thermal data with data at several spectral bands in the photographic spectral region is continuing.

Summary of Activities and Progress in 1980-81

Study No. SI 78-5

Thermal Infrared and Photography, Liard River Basin, NWT

A.C.D. Terroux

Thermal infrared imagery acquired in July 1979 over selected Liard River and Fort Nelson River confluences was examined and found to lack in thermal discrimination, partly because of the lateness of season yielding reduced thermal contrast. A number of tributaries to the Liard were imaged again on June 14, 1980 with greater success. At the same time colour aerial photography was acquired using the Beech G-18 aircraft chartered by the Polar Continental Shelf Project. Many of the data from these flights have been processed and photographs have been printed.

Interpretation of the imagery is under way and charts of surface mixing are being prepared for the seven sites imaged in 1980. Comparison of the three years of data (1978-80) will form the basis for reports to the Mackenzie River Basin Committee. This study will terminate with these reports.

Summary of Activities and Progress in 1980-81

Study No. SI 78-6

River Ice Jams: Mechanisms, Processes and Distribution

D.A. Sherstone

Field work conducted for the Liard River Basin river ice break-up study (see SI 78-2) provided input to this study as follows:

1. Ice thickness measurements at selected jam sites (March 1980);
2. Break-up observations on the Liard and upper Mackenzie Rivers (April-May);
3. Collection of river channel profile data at selected ice jam sites (July).

Observations on ice jams on the Liard River form a part of the final summary report on the three-year Liard spring flood study that is now being prepared for the Mackenzie River Basin Committee. The principal investigator has left NHRI. In addition, airphoto support (the Beechcraft) provided by Polar Continental Shelf Project has been terminated by mutual agreement, and funding from DINA for the Liard study ended in 1980-81. Thus, unless renewed interest and financial support are forthcoming, these studies in the Liard River basin are now complete.

Summary of Activities and Progress in 1980-81

Study No. HR 78-1

Hydrologic Nonstationarity and Streamflow Control

V. Klemes

The project was completed, results summarized in a paper "Long-memory flow models in reservoir analysis: what is their practical value?" (co-authored with Sricanthan and McMahon), which has been accepted for publication in Water Resources Research.

The main results have been (1) a demonstration of an impossibility to find objective criteria to distinguish long memory from short memory of the annual streamflow process on the basis of records of a typical length (about 30 years), and (2) a demonstration of a practical irrelevance of such a difference from the point of reservoir design (the difference is quantitatively smaller than the noise in the design characteristics commonly employed).

Summary of Activities and Progress in 1980-81

Study No. HR 78-2

Hydrogeology of Bedrock Aquifers

G. Grove

During the fiscal year it was decided to limit the hydrodynamic study and preparation of the piezometric maps for the Mississippian formations to one field area covering approximately one township of Manitoba. Although some data to 1967 are available in Ottawa, most of the data exist in paper files with the Manitoba Department of Natural Resources. Therefore, rather than getting involved in a large-scale transcription of all data from the Manitoba files, it was decided to test the techniques being used in this study on a smaller area first. Some work has been done on the compilation of the data in Ottawa before visiting the Manitoba government, but very little progress has been made on this project because of the involvement of the principal investigator in other projects.

Summary of Activities and Progress in 1980-81

Study No. HR 78-4

Arsenic Contamination of Ground Water in Ontario

L.M. Johnston

Due to problems experienced in the drilling phase of the project, not all piezometers have been installed to date. A tentative date of June 30 has been agreed upon for installation of the remaining sampling sites. At this time ground water samples will be taken for preliminary analyses for major and trace element content, in particular As^{III}, As^{V}, Fe_T and Mn_T. Soil samples collected during the drilling operation will be prepared for chemical analyses.

Summary of Activities and Progress in 1980-81

Study No. HR 78-5

Streamflow Forecasts Based on Basin Storage

F. Morton

There has been no progress on this study since the initial feasibility investigation because of the lack of technical assistance. Supervision of the research of a Ph.D. student at the University of Ottawa was initiated late in 1980 in the hope that he will be able to develop the techniques needed for realistic streamflow forecasts.

Summary of Activities and Progress in 1980-81

Study No. HR 78-6

Ground Water Contamination by Waste Water Effluent and Sludge

B.W. Graham

The main thrust of the 1980 field work was directed towards taking a suite of samples and cores at the Gloucester rapid infiltration site to study geochemical pathways, looking closely at the attenuation of heavy metals and organics.

Multilevel samplers and piezometers installed in September 1979 were sampled during the summer and fall of 1980 for major and trace elements, organics and environmental isotopes. The major element analyses were performed in the NHRI Booth Street laboratories; the organics were analyzed at MOE Rexdale laboratory; and the isotopes were analyzed at the University of Waterloo.

During September and October 1980, six locations were cored with a Parsons' cohesionless sediment sampler using a 15 cm hollow stem auger. Aluminum core tubes, 5 cm OD and 150 cm long were driven into the sand with the hammer of the drilling rig. A total of 10 cores was recovered, cut into 25 cm sections, capped, and stored at 4°C. The mineralogy and chemical composition of the material will be analyzed shortly. Interstitial water has been centrifuged from a few samples to date, and will also be analyzed in the near future.

Following coring at three sites, 10 cm ID PVC wells with 3 m of slotted screen were installed and pump tested. These are to be used for tracer studies in the future. Piezometers, 5 cm OD PVC, were installed in the other core holes.

The geochemical methods developed, the instrumentation installed, and the results obtained are now to be incorporated into a coordinated study of the hydrogeochemistry of toxic contaminants at the Gloucester Special-Waste Disposal Site by the federal government, provincial government and universities. The proposal is before the Toxic Waste Management Committee for funding at the present time.

The literature review of "Ground water contamination by waste water effluent and sludge" is being stored on tape at the same time as it is being printed by the word processor. Yearly updates of the material will be made.

A report on the new methodologies developed by the Contaminant Ground Water Section for evaluating contamination in shallow ground water systems will be completed by May 31, 1981.

Summary of Activities and Progress in 1980-81

Study No. HR 78-7

Dispersion of Solutes in Ground Water Flow Systems

J.F. Pickens

The importance of ground water sampling scale on determining the magnitude of longitudinal dispersivity in a sandy stratified aquifer has been investigated using laboratory column and field tracer tests. The field investigations, which were conducted at Chalk River Nuclear Laboratories, included two single-well injection-withdrawal tracer tests using ^{131}I and a two-well recirculating withdrawal-injection tracer test using ^{51}Cr-EDTA (ethylene diamine tetracetic acid) complex. The tracer movement within the aquifer was monitored in great detail with multilevel point-sampling instrumentation. A constant value for dispersivity of 0.7 cm was found to be representative (and independent of travel distance) at the scale of an individual level within the aquifer. A dispersivity of 0.035 cm was determined from laboratory column tracer tests as a representative laboratory-scale value for sand from the field site. The scale effect observed between the laboratory dispersivity and the dispersivity from individual levels in the aquifer is caused by the greater inhomogeneity of the aquifer (e.g. laminations within individual layers) and the averaging caused by the ground water sampling system. Full-aquifer dispersivities of 3 and 9 cm obtained from the single-well tests indicate a scale effect with the value obtained being dependent mainly on the effect of transverse migration of tracer between the layers and the total injection volume. The full-aquifer dispersivity of 50 cm from the two-well test is scale-dependent, controlled by the distance between the injection and withdrawal wells (8 m) and hydraulic conductivity distribution in the aquifer. Scale-dependent full-aquifer dispersivity expressions were derived relating dispersivity to the statistical properties of a stratified geologic system where the hydraulic conductivity distribution is normal, log-normal or arbitrary. In the developed expressions, dispersivity is a linear function of the mean travel distance. Proportionality constants ranged from 0.041 to 0.256 for the hydraulic conductivity distributions obtained from the field tracer tests.

An approach for handling scale-dependent dispersion using a finite-element (linear triangular) solute transport model was developed. Dispersivity is allowed to vary temporally as a function of the mean travel distance of the solute from an input source. The model was applied successfully to the results of several tracer tests reported in the literature that have exhibited a scale effect. For systems that exhibit a constant (assymptotic) dispersivity at large times or mean travel distances, the importance of scale dependent dispersion at early times or short travel distances was shown to be minimal in long-term predictions of solute transport.

Emphasis on the investigation of the migration of solutes has shifted from advection and mechanical dispersion to diffusion. A literature review on the measurement of solute diffusion coefficients in porous media has been completed. Laboratory diffusion experiments are being organized.

Publications:

Pickens, J.F. and G.E. Grisak, 1981. Scale-dependent dispersion in a stratified granular aquifer. Accepted for publication in Water Resources Research.

Pickens, J.F. and G.E. Grisak, 1981. Modelling of scale-dependent dispersion in hydrogeologic systems. Submitted for publication in Water Resources Research.

Pickens, J.F., J.A. Cherry, R.M. Coupland, G.E. Grisak and W.F. Merritt, 1981. A multilevel device for ground water sampling. Ground Water Monitoring Review, Vol. 1, (in press).

Gleddie, G.D., 1980. Experimental methods to determine diffusion coefficients in saturated porous media. Prepared as a University of Waterloo cooperative work-term report, 38 p.

Summary of Activities and Progress in 1980-81

Study No. HR 78-8

River Basin Moisture Measurement

A. Wankiewicz

Microwave signals emitted by natural snow packs depend on the physical properties of the snow cover and underlying soil. The MIT random scattering model for three layer media was programmed on the CDC computer and microwave brightness temperatures were calculated for selected values of electromagnetic, snow and soil parameters: frequency, solarization, sensor observation angle, dielectric constant and loss factor for both snow and soil layer, and thickness of the snow layer. To interpret the EM properties in terms of hydrologic variables, a random sphere model was constructed of the ice and water phases in the snow pack. Microwave brightness temperatures were then calculated for a number of typical combinations of snow density, water equivalent, soil texture, snow and soil temperature, snow liquid water content, and rain/melt rates. The results are presented in a paper given at the Fall AGU meeting in December.

A field experiment was designed to determine the feasibility of managing snow pack properties on a scale large enough to be detected by airborne synthetic aperture radar. Seven one-acre sites were selected on the Central Experimental Farm for treatment by (1) selective snow cover removal, (2) artificial spraying of the snow cover, and (3) depth control by snow fencing. This research approach is patterned after the method used to assess remote sensing procedures for agricultural crop detection and inventory by means of specially treated agronomy plots. Snow removal on February 6 resulted in a snow cover only 5.2 cm deep, in contrast to 25 cm depth on the control plot. The transition zone between plots was gradual and averaged 4 m in width. Detailed measurements were made of snow density and basal ice thickness over the plots. Snow irrigation tests were successfully carried out using a commercial water truck with 0.4 cm of water applied over a one-acre plot. Spraying variability and snow pack flow patterns were recorded in both initially dry and wet snow using a rain gauge network and dye tracers. The snow fence produced both a 12 m wide accumulation up to 70 cm deep and an adjacent 30 m depletion zone 5 cm deep. Due to an unseasonal thaw, only the snow fence leeward drifts were present during the airborne X and L band radar overflights of February 21. The digital radar tapes are processed to produce higher resolution images of the dark snow fence "lineations" observable in the real-time "quick-look" images. The field tests demonstrate the feasibility of the snow pack treatments planned for the airborne tests planned for winter of 1981-82.

Summary of Activities and Progress in 1980-81

Study Nos. HR 78-10, HR 78-11

Hydraulic Testing and Radionuclide Transport - Fractured Rock

C.C. Davison

Single and multiple borehole physical hydrogeologic field methods have been developed in the borehole array (CR6, CR7 and CR8) at the Chalk River Nuclear Laboratories (CRNL) site during FY 1978/79/80. During these programs, a great deal of detailed information was obtained regarding the ground water conditions which exist at the site. Three additional boreholes (CR10, CR11 and CR12) were drilled, logged and surveyed at the CRNL site during FY 1980 to provide comprehensive radial network of five boreholes, which at 100 m depth are within a radius of 35 m from the central borehole, CR6. Many hydrogeologic measurements were made in these new boreholes during FY 1980 to evaluate the three dimensional distribution of specific fracture zones within the rock mass. These included: pumping tests of the entire boreholes, bottom hole drill stem tests, ground water sampling, fluid injection tests and between-hole pressure pulse interference tests. A between hole NaI-labelled ground water tracer experiment was performed in a set of fractures which are interconnected between boreholes CR6 and CR7. The chemical break-through data have been compared with hydraulic information which was obtained from independent between-hole pressure interference experiments. Multilevel pvc casing strings were installed in CR7 and CR8 during FY 1980. These casings allow pressures to be determined more or less simultaneously at various depth intervals in the rock mass. The casings also permit water samples to be extracted from numerous fractures at different isolated depth intervals in the rock mass.

Reports which document all of the FY 1978 and 1979 physical hydrogeologic studies at CRNL and Whiteshell Nuclear Research Establishment (WNRE) have been completed. Separate scientific papers which discuss the between-hole chemical tracer experiment and the drill stem testing procedures are being prepared for journal submission. A joint research paper with S. Keys and F. Paillet of the USGS Denver is currently in preparation. This latter paper will discuss the hydrologic and geologic interpretation of various geophysical logs run in the boreholes at WNRE and CRNL.

Summary of Activities and Progress in 1980-81

Study No. HR 78-13

Hydrogeochemical Assessment of Crystalline Terrain

D.J. Bottomley

Hydrogeochemical sampling was conducted at Whiteshell Nuclear Research Establishment (WNRE) during the summer of 1980. Several technical deficiencies were encountered with the cable reel containing the 1100 m, 7 cm diameter umbilical cable. These problems resulted in long periods of "down" time while the cable reel was in the WNRE machine shop being upgraded. Other problem areas identified were related to the effects of hydraulic pressure on the operation of the downhole pump and the downhole sensors.

In spite of these problems, very saline ground water samples were collected in borehole WN4 from depths below 450 m ($Cl \sim 10,000\ mg.L^{-1}$). Isotopic analyses (under contract and not yet received), in conjunction with the complete WNRE chemical analyses should assist in the evaluation of the origin of this water.

In the fall, a 600 m air drilled hole for future hydrogeochemical research was constructed at CRNL. Westbay multilevel ported casing was installed in the borehole in December 1980. This borehole will be the focus for most of the NHRI hydrogeochemical activities in fiscal years 1981 and 1982.

Summary of Activities and Progress in 1980-81

Study No. SI 79-1

Photogrammetric Applications to Glacier Research and Water Supply from Glacierized Basins

K.C. Arnold

Terrestrial Photogrammetry, Athabasca Glacier, 1979

The August photography (end of melt season) was worked up as part of IWD's Water Resources Branch ongoing surveys. Arrangements are being made for compilation of the June photography.

Aerial Surveys, Athabasca Glacier, 1980

Aerial photography was successfully flown at the beginning and end of the melt season. The associated ground control was improved, targetted and the targets removed (being in a National Park). The photography is of good quality and the targets are clear.

The necessary check points, for measurement of ice melt in the conventional manner, were set out on the glacier. Movement over the year August 1979 to August 1980 was measured and within-season movement should allow the slip portion of glacier movement to be estimated.

Early in January 1981 an estimate was obtained for working up the aerial photography by the orthophoto technique. The proposed work includes the preparation of digital terrain models from the June and September photography: 1:5,000 orthophotos of the glacier, and 1:2,500 enlargements of the snout area. At the snout the recession between the June and September surveys is plainly evident.

Summary of Activities and Progress in 1980-81

Study No. SI 79-2

Mechanical Properties of Ice and Permafrost

S.J. Jones

Laboratory testing has continued throughout the year on polycrystalline ice, single crystal ice, and frozen sand. The project on the confined compressive strength of polycrystalline ice was completed and a paper was accepted by the Journal of Glaciology.

In order to try and resolve conflicting literature reports concerning the effect of grain size on the strength of ice, we started a series of mechanical tests on random polycrystalline ice of different grain sizes. Preliminary results, which are contained in a letter to the editor of the Journal of Glaciology, show that at $10^{o}C$ grain size has very little effect on the unconfined strength, measured at a strain-rate of $5.5 \times 10^{-4} s^{-1}$. A large number of tests will have to be conducted, however, before a quantitative relationship between grain size and strength is determined.

Our work on the mechanical properties of frozen sand continues, in cooperation with the permafrost group of the Division of Building Research, NRC. The confined compressive strength of fully saturated sand has been reported in the Journal of Glaciology (and at the 4th Canadian Permafrost Conference) and we are now studying the effect of varying the amount of sand. We have started work on a 25% sand/ice mixture and later we hope to produce samples containing 10% and 50% sand.

As a result of a National Science Foundation workshop on the mechanical properties of ice in which I participated in Boulder, Colorado in March 1979, a review of current knowledge and priorities for future research was published in Cold Regions Science & Technology.

Summary of Activities and Progress in 1980-81

Study No. SI 79-3

Ice Core-Climate Change Study

G. Holdsworth

A comprehensive paper was written on the mode of formation of large icebergs, based on simulations done with the computer model developed (Study No. SI 77-1) over the last five years. A second paper is in preparation dealing with the general dynamics of Erebus Glacier Tongue (for presentation at an international conference in September 1981).

The paper dealing with the Mt. Logan ice core-proxy climate data results was completed, but it was deemed worthwhile to defer publication until longer time series are available, so that more sophisticated spectral analyses can be performed on the data. This should be possible by mid/late 1981 depending on the integrity of certain laboratories towards meeting promised schedules. A second paper dealing more with the geophysical aspects of the Mt. Logan study should be ready for submission to a journal in 1981.

The field operation on Mt. Logan, by far the major commitment this year, was carried out with encouraging results. The new core drill was tested and tuned before attempting three holes of depth 46, 62, and 103 m at site on Mt. Logan at 5340 m altitude. This particular operation inherently suffers from considerable risk and represents inefficient use of time. The drill and 75 m of the deep core had to be abandoned at the site due to adverse weather and snow conditions. These must be retrieved in 1981. Processing of the upper sections of core took place at the temporary facility set up in Whitehorse (AES). Delay in completing facilities in Calgary has required this arrangement.

The ice core processing "laboratory" in Calgary is not yet operational due to a delay in delivering of chest freezers, in rewiring circuits and in installing alarms for safe operation. Space has not been released as expected, to conveniently work on large quantities of samples; therefore in the meantime processing will continue to be done in Whitehorse.

Summary of Activities and Progress in 1980-81

Study No. SI 79-4

Hydrology of the Mountain Snowpack

R.I. Perla

The main progress during the past year has been in two experimental areas.

New techniques were developed for rapid sectioning and photographing of snow specimens. The techniques involve filling the snow with water insoluble, supercooled liquids. The temperature of the specimen is lowered until the above liquid freezes. The specimen is then microtomed, polished, and stained. These techniques will be published in the Journal of Glaciology. We originally developed these techniques so that we could quantitatively describe changes in snow texture, and in particular to help us describe metamorphism; however, the techniques may have applications for describing the interaction of snow with radar and microwaves (remote sensing).

Laboratory experiments for controlling snow metamorphism were designed, constructed, tested, and put into operation. These experiments involve transporting snow from our field station, sectioning and photographing as above, and then exposing the specimens to a temperature gradient. After approximately 100 hours, the specimen is sectioned and photographed.

Summary of Activities and Progress in 1980-81

Study No. SI 79-5

Simulation of Alpine Runoff

J.M. Power

A revised and updated version of the UBC watershed model was obtained from B.C. Hydro and converted for use on the EMR computer system. Goldstream River and Stitt Creek hourly flow data (1973-1977) were obtained and converted to UBC model format. Hourly temperature and precipitation data for three adjacent meteorological stations (Glacier Rogers Pass, Blue River North and Revelstoke Airport), for the period 1973-1978, were obtained from B.C. Hydro and placed on file on the EMR system. Maps (1:50,000) of the Goldstream basin were obtained and from them a square grid data base containing information on terrain types, elevations, and outline of the basin area was constructed. These data were analyzed to produce necessary inputs to the UBC model, such as total area, forest area, glacier cover, mean elevation etc., for each of eleven elevation bands. The UBC model was then calibrated for the Stitt Creek basin for the period 1973-1976.

Flow data for the three stream gauges within the Kicking Horse River basin are currently being digitized from original charts in preparation for modelling of the streamflow in the basin.

Summary of Activities and Progress in 1980-81

Study No. SI 79-6

Time Domain Reflectrometry Study of Snow and Ground Water

Harry Gross

A probe design suitable for ground freezing and moisture content measurement has been established. Along with the probe, computational methods for data reduction and a suitable computer programme are available.

Various models of dielectric mixtures have been studied and their influence on probe response illustrated. This is a new approach to the problem of studying soil moisture content and changes due to freezing. Most other investigators assume the response to depend on surface adsorption of water reducing the mobility of the molecule and giving an ice-like response. The models investigated suggest that the shape of the solid components present, along with their orientation, can influence the behaviour in a similar fashion.

A report is now under review.

The system is available for field use.

Summary of Activities and Progress in 1980-81

Study No. SI 79-7

Working Group on Glacier Runoff

G.J. Young

During the first year of its existence the Working Group on Prediction of Runoff from Glacierized Areas has concentrated most of its efforts into establishing an organization and preparing a scheme of activities for the future. The group now comprises 20 members; this is a larger number than was originally envisaged, but necessary to accommodate all opinions.

The first meeting was held at Geilo, Norway from August 23-26, 1980. Half of the members were able to attend this meeting and much useful discussion took place. The most important decisions made at the meeting are as follows:

1. The name of the group should be "The Working Group on Prediction of Runoff from Glacierized Areas". This reflects the concern of many group members that glaciers should be viewed in the context of overall alpine hydrology.

2. A Bibliography on Runoff from Glacierized Areas should be compiled and published in 1981. The details of what should be included and a timetable for implementation were agreed upon. Many regional bibliographies have been completed and this task is well under way.

3. A text on "Techniques for Prediction of Runoff from Glacierized Areas" should be compiled and published by July 1982, to coincide with the IAHS/ICSI Symposium on High Mountain Hydrology in Exeter, England. This will be primarily a descriptive summary of what data collection and analysis techniques are currently being used. It should form a good basis for the compilation of further texts in the future.

4. The Working Group should try to make a strong contribution to the IAHS/ICSI Symposium in Exeter.

5. Every effort should be made to involve members from Himalayan and Andean countries more fully. It was very apparent at the Geilo meeting that these members were not represented. With this aim in mind, it was thought very important that a small workshop be held in 1981 (probably September) in a Himalayan country with the aim of bringing together the concerns and opinions of members from that area.

It is hoped that the Working Group has set itself realistic tasks to be accomplished within realistic deadlines. Successful completion of the Bibliography and Text on Predictive Techniques will require considerable hard work and cooperation from all WG members. The group has more than enough to keep itself busy until mid-1982. At that time decisions can be made on possible future activities which may include bringing together the latest theoretical (rather than practically oriented) knowledge on the hydrology of glacierized areas, or a series of casebook studies to illustrate particular types of projects concerning glacier runoff.

Summary of Activities and Progress in 1980-81

Study No. SI 79-8

Gamma Ray Snow Surveys

J.E. Glynn

A gamma ray snow survey of Southern Ontario was carried out in March 1980 for the Ontario Ministry of Natural Resources and Parks Canada. The program initially called for two snow surveys to be performed in March but, due to a lack of snow, the second survey at the end of the month was cancelled. Analysis of the data was hampered by variability in soil moisture and lack of an adequate number of soil samples along several lines.

Work on an operational manual for gamma ray snow surveying is proceeding. The calibration procedure has been documented already in the form of a paper entitled "A Calibration Procedure for Airborne Gamma Ray Snow Surveys" presented at the Western Snow Conference. The computer programs required for data processing of the data have been internally documented and the instructions for taking soil moisture measurements and laboratory calculation of soil moisture have been documented. The preparation of the reports is behind schedule.

The gamma ray snow survey in Saskatchewan, scheduled initially for February-March of 1981, has been cancelled due to a lack of snow. This also forced the cancellation of the Trent-Severn survey planned for the same time.

Summary of Activities and Progress in 1980-81

Study No. HR 79-2

Hydrogeological Observations of a Deep Geothermal Borehole

R.L. Herr

During March 1980, a three-day pump test was conducted with water levels measured by NHRI-supplied transducers, recorders and associated equipment.

The original recorder house that was destroyed has been replaced by a more durable shelter. At the present time we are still waiting for the University to have power extended to the site. This power is required for the operation of the pressure transducer and associated recorder.

Summary of Activities and Progress in 1980-81

Study No. HR 79-3

Chloride 36 Content of Selected Canadian Aquifers

D.J. Bottomley

Ground water samples from several aquifers in Western Canada were selected for determination of their Cl 36 content by linear accelerator techniques. Aliquots of these samples were also analyzed for major ions and tritium. A purification technique (suggested by H. Bently, University of Arizona) to remove interferences from minute amounts of ^{36}S was followed during chloride extraction from the ground water. The technique involves adding "pure" ^{32}S (from Oak Ridge Nuclear Laboratories) to dilute the ^{36}S content.

The extracted Cl (as Ag Cl) was sent to the University of Toronto for compression into micropellets suitable for sputtering. The samples were scheduled for analyses at the University of Rochester in October 1980. However a major machine accident resulted in the run being aborted and rescheduling of the analyses still remains to be finalized. Results of that run will indicate how successfully the ^{36}S problem has been met and should provide an indication of the areal variation in ^{36}Cl content of relatively young (with respect to the 3×10^5 yr. half life of ^{36}Cl) shallow ground water in Western Canada.

Summary of Activities and Progress in 1980-81

Study No. HR 79-4

Effects of Land Use Changes on Evapotranspiration

F.I. Morton

Humicells were installed at six stations and hygrothermographs at four stations in Spring Creek Basin. Sunshine recorders were installed at Grande Prairie and Sturgeon Heights.

Humicells were installed at three stations in Kernen Farm, University of Saskatchewan.

Summary of Activities and Progress in 1980-81

Study No. HR 79-6

Linking a Ground Water Model to a Surface Square Grid Model

A. Vandenberg

Of the four steps of the work plan, the first three have been completed: (1) a model has been formulated, programmed and tested which simulates the water table elevation of an unconfined aquifer under pumping or recharging stresses. The nonlinearity of the differential equation for unconfined ground water flow could adequately be handled by an iterative procedure within each time step. (2) The existing flow model for a confined leaky aquifer has been modified to conform with the square grid set-up of the surface water model; it has amongst other things provided for separate subprograms for input and output of variable data such as recharge and pumping rates, making the program more flexible. (3) A completely new program, DUBBLE, has been designed to handle the linking between surface water and ground water; to this end the concept of a double aquifer system of a water table aquifer and a confined aquifer has been developed. The two aquifers are linked by a resistive bed. Linking with the surface water model can now be achieved by translating the amount of recharge into an equivalent rise of the water table by means of an assigned porosity. Routing of the ground water through the unconfined aquifer, the resistive bed and the confined aquifer is thereby completely determined. Needless to say, the amount of recharge from precipitation through the unsaturated zone to the water table is still a very important and virtually unknown quantity.

The actual linking of the two programs so far has had little progress, but WPM (J.J. Brown) hopes to have a revised surface water model ready within a short time. Messrs. Brown and Vandenberg will then give the final product their total attention.

Reports completed:

Vandenberg, A., 1980. Program DUBBLE. Simulation of water table and piezometric head variation in a system of a water table and a confined aquifer connected by a leaky bed, 23 pp.

This report documents the program and analyzes two special cases of application.

Summary of Activities and Progress in 1980-81

Study No. HR 79-7

Relationship Between Mean Daily and Peak Flow

B. Sangal

This study is nearing completion. Methodology has been developed to estimate the ratio of peak flow to mean daily flow based on time of peak, shape of the hydrograph and base length. Analysis suggests that the completed ratios are random variables. Therefore, a frequency analysis of ratios for records exceeding 10 years or more will soon be carried out. A report on this project will be published by June 1981.

Summary of Activities and Progress in 1980-81

Study No. HR 79-8

A Comparative Study of Various Methods of Estimating Potential and Actual Evapotranspiration

B. Sangal

This study is progressing well. Required climatological data have been collected. The basic purpose of this study is to show that predictable relationships exist among the estimates made by various methods of estimating potential evapotranspiration. It is, therefore, unnecessary to apply more complex methods such as Budyko's, Penman's etc. when estimates of these methods can be made through simpler techniques such as the Thornthwaite method or similar temperature functions. Computer programs for large scale use are now available. This study is scheduled to be completed during 1981.

Summary of Activities and Progress in 1980-81

Study No. HR 79-9

Study of a Ground Water Contamination Problem in Newfoundland

A. Vandenberg

During 1980, A. Vandenberg visited the disposal site and the general area with J. Robinson (Nfld.). The province has installed 10 piezometers in the disposal site, which are monitored regularly for chemical composition and height of the water table. Permeability has been estimated at all piezometers by means of slug tests.

Results so far indicate that leachate from the waste accumulated to date has travelled approximately 300 feet down gradient.

A mathematical model of water table aquifer flow has been prepared, extensively tested and documented; during a two-week period Messrs. Vandenberg and Robinson have adapted the model for use at the IBM computer at St. John's. As a result, Mr. Robinson is now fully conversant with the model.

However, no actual data from the test site (recharge, measured head) have as yet been used to run or even calibrate the model. On the trial runs, so far, estimates of permeability have been averaged for input to the model. There is still a good deal of "trial and error" work to be done before the model can be considered as a reasonable replica of the hydrogeology of the disposal site.

Summary of Activities and Progress in 1980-81

Study No. SI 80-1

Lake Regimes, Mackenzie Delta, NWT

J.C. Anderson

This was the first year of a study designed to investigate the water level regimes of a variety of lakes in the Mackenzie Delta, in order to provide baseline information for the assessment of the potential impact of increased flow regulation on the Mackenzie River and Delta. A major objective is to compare water level fluctuations in "open" lakes (those with a direct low water connection to a delta channel with those in "closed" lakes (those connected to a channel only at flood stage, if ever).

In August 1980, with the assistance of Mr. C.P. Lewis, Inuvik Scientific Resource Centre, one set of open and closed lakes was selected for a pilot study in the middle Delta zone, near Reindeer Station. The advantage of this site was that bench marks, imbedded in permafrost, were already in place from a former study conducted by Mr. Lewis. At the open lake, the closed lake, and the channel into the open lake, series of overlapping staff gauges were installed to cover water level variation of up to four or five meters. All staffs were tied into the benchmark system. Also at each site, stands were erected for time-lapse camera systems that will be used to photograph the staff gauges and thus obtain water level records. The time-lapse camera systems are currently being assembled and are scheduled for installation at the lake sites in April 1981. Should this initial phase of the study succeed, similar sites are planned for the upper and outer Delta, where levee heights are higher and lower, respectively, than those in the middle Delta.

Summary of Activities and Progress in 1980-81

Study No. SI 80-2

Ice Regime of Lower Mackenzie River and Mackenzie Delta

A.C.D. Terroux and D.A. Sherstone

Measurement of the maximum thickness of ice was accomplished at 30 locations in the Mackenzie Delta during a period from April 15-25, 1980 at sites along three transects chosen for aerial photography during the spring break-up. These sites were subsequently photographed throughout the break-up period in late May and early June. In addition, break-up on the lower Mackenzie River was monitored and photographed in the reach from Fort Norman to Fort Good Hope.

Mackenzie Delta freeze-up was monitored and photographed with 35 mm camera equipment during October and early November, although persistent low cloud conditions made this task difficult. Water temperatures during this period were measured from the ferries at Arctic Red River and Fort MacPherson until freeze-up.

Some aerial photography and all the 35 mm photography have been examined and charted. A preliminary report for the Mackenzie River Basin Committee is in preparation. Planning is under way for the second year of this five year project.

Summary of Activities and Progress in 1980-81

Study No. SI 80-4

Stream Flow Velocities by Autocorrelation

E.J. Langham

The work on this study has been completed and no follow-up work is contemplated at this time. The results are being written up and will be presented at the meeting on Port and Ocean Engineering under Arctic Conditions (POAC) to be held in Quebec City in June 1981.

The tests were done on two pairs of aerial photographs taken over the Liard River during Spring break-up 1977. The main conclusions were that the velocity profile across the Liard could be calculated within 3-4% of the measured flow velocities. This is about the same accuracy as that attained using conventional photogrammetric procedures on the same data. The method could have wide applications but to be used operationally would require dedicated hardware. Whether this is worth doing depends on the interest of operational agencies. A promising use of the technique would be the mapping of ice movement in the Arctic but this would require further scientific work, among other things to extend the method to a two dimensional map of velocity vectors.

Summary of Activities and Progress in 1980-81

Study No. SI 80-5

Dielectric Properties of Contaminated Ice

G.P. Johari

Laboratory measurements of the effect of physical and chemical impurities on the dielectric loss and permittivity of ice were initiated. Several sets of measurements indicate that dissolved gases such as nitrogen and oxygen in polycrystalline ice increase the attenuation and dielectric loss but decrease the permittivity at MHz frequencies. The work on this subject using many different samples and over a wide range of frequencies and temperatures will be continued.

Ice clathrates (a form of naturally occurring but molecularly different ice), which contain various types of dissolved impurities including natural gas, were studied by computer modelling of their dielectric properties using the crystal structure data. A comparison with the measured dielectric properties showed an incomplete disorder of orientation of water molecules in the clathrates. The results of this study were accepted for publication in the Journal of Chemical Physics in their January 15, 1981 issue.

Summary of Activities and Progress in 1980-81

Study No. SI 80-6

Investigation of Utility of X and L Band Synthetic Aperture Radar (SAR) for Mapping Snow Conditions

E.J. Langham

Arrangements were made for an experiment to be conducted in the second week of February 1981 at sites on the Central Experimental Farm, Ottawa. This was a follow-up to work done as part of the SURSAT programme. The SURSAT experiment was only partially successful because the SAR data acquired was incomplete. Field preparations were made but a prolonged melt period preceding the date scheduled for the experiment removed almost all the snow from the area. The result was that, while valuable experience was obtained in experimental procedures, no useful data was obtained on the radar imaging of snow. The experiment will be repeated in winter 1981-82 as part of the RADARSAT programme.

Summary of Activities and Progress in 1980-81

Study No. SI 80-7

Hydroclimatological Studies on Western Canadian Glaciers

S. Fogarasi

During 1980 two computer programs calculating daily direct and global radiation values along a grid network have been tested for Sentinel Glacier under clear sky conditions.

A preliminary computer program has been written up for snow surface albedo predictions also for the same grid derived for Sentinel Glacier.

An albedo survey on Iskut River Glacier has been completed and these values will be incorporated in the net radiation program to be used in the Iskut River Glacier Energy budget study.

Summary of Activities and Progress in 1980-81

Study No. SI 80-8

Nimbus 7 Scanning Multichannel Microwave Radiometer Snow Experiment

E.J. Langham

This year has been devoted to organizing the experiment which is to take place in the province of Saskatchewan. Many agencies both in the U.S. and Canada supported the experiment through funding, personnel and equipment. Data collection for experiment was originally scheduled for the week of February 9-13, 1981 but was postponed for lack of snow . The same situation existed at the fall back date of March 9-13, 1981 and as a result the experiment was cancelled for the winter 1980-81. There is a strong interest in making a second attempt in winter 1981-82 but this possibility will depend on the availability of funds and the continued functioning of Nimbus 7. Both items will be investigated early in fiscal year 1981-82.

Summary of Activities and Progress in 1980-81

Study No. GW 80-3

LRTAP Related Ground Water Studies (Haliburton Highlands)

L.M. Johnston

A. Haliburton Highlands

Chemical analyses from a previously installed piezometer (7 m) are complete. While the upper sampling points appear to have been compromised by the drilling procedure, the lower points appear to provide a reliable chemical composition for the ground water in the basin. Stream and lake water samples have also been analyzed for the same variables (pH, Eh, spec. cond., alk., SO_4^{2-}, Cl^-, Si_T, Ca^{2+}, Mg^{2+}, Na^+, K^+, Fe_T, Mn_T, Cu, Pb, Zn, Co, Ni).

A geophysical survey was run in sub-basin No. 4 of the Harp Lake Study area. Overburden thickness ranged from 0 to 20 m within the basin and a suspected fault line was noted. A report has been prepared concerning this study.

Two 12 m multilevel samplers (7 points) were installed near the deepest section of this basin, as identified from the geophysical survey. These points have been sampled for cations, anions and trace elements and preliminary results are available. Further sampling will be undertaken for these variables and isotopes.

During a storm event (44 mm rain) samples were collected of the ground water, precipitation, and stream water. These samples were analyzed for O^{18}, deuterium, pH and specific conductance while 4-hour composite samples were measured for DIC, DOC, SO_4^{2-}, alkalinity and cations.

The interpretation of the isotopic analysis and stream hydrograph separation led to the conclusion that approximately 40% of the water in the stream during the storm was prestorm (ground) water. The implication is that the ground water contribution prevented the stream chemistry from reaching a level more closely resembling that of the rainfall chemistry. In particular, the pH only dropped from 6.2 to 5.5 while the measured rainfall pH was 3.9 but, in general, modification of other chemical parameters was also noted. A report is in preparation.

During this study, cooperation has been established between the groups at Ontario Ministry of Environment and National Hydrology Research Institute who are studying pollution resulting from long range transport of air borne contamination.

B. Kejimkujik Park

A site visit was made to Beaverskin and Pebblelogitch Lakes located in the Park. On the basis of this visit and the other available data, a report "LRTAP related ground water studies in Kejimkujik National Park" was prepared. This report included a suggested study plan for the lakes area as well as an estimate of the time required to complete the studies. A proposal, prepared by Water Planning and Management Branch, Environment Canada, has been reviewed. Cooperation will continue concerning any ground water studies undertaken in the area.

C. Lac LaFlamme Region

The ground water portion of this study will be carried out by a contractor. The contract was reviewed by NHRI in an effort to ensure compatibility with ground water studies in other areas.

Summary of Activities and Progress in 1980-81

Study No. GW 80-5

LRTAP Related Ground Water Studies (Turkey Lakes)

L.M. Johnston

A geophysical survey (electrical resistivity) was undertaken in selected areas. On the basis of airphoto interpretation, ten areas of potentially thick overburden were outlined. These features were investigated and cross sections prepared where feasible. Three areas of relatively thick (25-40 m) overburden were delineated while the remainder varied from ≈ 0-20 m. Several areas of potential ground water leakage into adjacent surface drainage basins or sub-basins were also determined. This implies that surface water basin boundaries and ground water basin boundaries may not be coincident. A report covering the interim results of this study has been prepared and is under review.

In one area of thick overburden (40 m), seven holes varying from 1.5 to 7.0 m were drilled and three multilevel ground water samplers (4-7 m) were installed. Several problems were encountered in penetrating the thick boulder and gravel sequence and several different drilling techniques were attempted. The results of these preliminary attempts using augers with a finger bit, diamond drill, and downhole hammer are being assessed. Based on equipment recommendations derived from this assessment, a contract for further drilling has been submitted. The piezometers installed during this drilling program, as well as the existing multilevel samplers, will then be sampled at regular intervals. The sampling and analysis of ground water seeps is continuing, mainly by staff at Sault Ste. Marie.

A preliminary reference list was prepared dealing with the interaction of atmospheric pollutants and ground water.

Summary of Activities and Progress in 1980-81

Study No. GW 80-4

Geophysical Survey, Acid Rain Project

H.M. Elliott

In May and June 1980, five weeks of geophysical field work to evaluate thickness was conducted in two areas: Harp Lake Basin, Huntsville, Ontario, and Turkey Lakes Basin, Algoma District, Ontario.

In the Harp Lake Basin, 23 electrical resistivity soundings using the Schlumberger array were done with three seismic refraction test soundings. These covered about 60% of the basin drainage area showing minimal overburden thickness in all but one sub-basin, which also showed a potential fault. That sub-basin has since been investigated and a significant ground water component to the outflow indicated.

In the Turkey Lakes basin, 67 Schlumberger array soundings and two seismic refraction test soundings were done over several selected areas. One faintly possible area where ground water flow could short-circuit the final weir was found and another area was located which appeared to have greater than 30 m of overburden in a channel extending along the major axis of a lake across the basin boundary towards a stream which feeds a different series of lakes.

Summary of Activities and Progress in 1980-81

Study No. SI 80-9

Runoff Estimation - Sentinel Glacier, B.C.

S. Fogarasi

Most of the glaciers in the Western Cordilleras are located in basins of great hydropower potential. Most of these glaciers have been neither surveyed nor studied glaciologically or hydrologically. Preliminary information on runoff conditions and related hydrologic processes would be of great importance to provincial agencies dealing with water planning problems. A small basin, Sentinel Glacier, within this region was selected for this preliminary analysis, mainly due to the availability of glaciological and climatological data collected over ten years.

These data were subjected to empirical eigenvector analysis to gain a better insight into the nature of data. Through this study an indication was found that the eigenvector with a high loading on melting-degree-days explained 46% of the total variance. Therefore, as a second step, the independent, orthonormal eigenvectors thus obtained were multiply regressed on runoff to see whether any meaningful relationship existed. This exercise, however, proved to be inconclusive. Some of these results were published internally in Scientific Series No. 95 (S. Fogarasi and O. Mokievsky-Zubok: 1978, Principal Components Analysis on Glacier-Climatological Data for Sentinel Glacier, B.C.).

In the light of this investigation, it was realized that the nature of data was such that another nonphysical method had to be tried. It had to be nonphysical because the available data from Sentinel Glacier would not be suitable in a physical model. Therefore, in cooperation with the "Computing and Applied Statistics Directorate" a purely statistical model (ARIMA Model) has been tried to show some of the relationships between runoff and other variables. These results are reported by P. Cohen, Jan. 1981, Project No. T421, "Forecasting Glacier Runoff".

The evaluation and the feasibility of the ARIMA model is being proposed here in this study.

Summary of Activities and Progress in 1980-81

Study No. GWO 81-5

Thermal Springs in Rocky Mountain National Parks

R.O. van Everdingen

Two submissions by consultants were reviewed; comments and suggestions were provided where appropriate.

A survey was run and a map prepared showing boundaries of the travertine deposit of the Cave-and-Basin springs, site of Parks Canada's proposed Centennial Centre in Banff National Park.

Water samples for isotope analyses (^{2}H, ^{3}H, ^{18}O) were collected from the five springs at the site.

Travertine samples for ^{14}C analysis were collected from the main cave (5) and from a smaller cave (3).

A secondary gypsum sample for ^{34}S analysis was collected from the small cave; bottom material was collected from the two Cave-and-Basin pools, for grainsize and mineral analyses, and for ^{34}S analysis of any gypsum present.

Twelve dye-tracer tests were carried out to detect secondary flow paths from the various spring sources through the travertine deposit and through the Cave-and-Basin Aquacourt plumbing.

Eleven series of discharge measurements were carried out to determine discharge rates from the five springs and distribution of the water through the system.

A report on the results of points 2 to 7 will be prepared for Parks Canada. A summary of spring discharge rates and the map of travertine deposit boundaries have already been submitted to the Western Region Office of Parks Canada.

At Miette in Jasper National Park, water samples for chemical analysis were collected from the three thermal springs.

Water samples for isotope analysis (^{2}H, ^{3}H, ^{18}O) were collected from Miette springs No. 1 and No. 3.

Samples of black deposit, corrosion residue and bedrock around the spring orifice were collected from spring No. 1, spring No. 2 and spring No. 3, respectively.

Two short reports on these last three investigations were prepared in July 1980 and submitted to Parks Canada.

a. Preliminary Report, July 8, 1980, 5 pages.

b. Recommendations for continuing measurements and considerations for redevelopment, July 21, 1980, 7 pages.

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