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NATIONAL STATUS REPORT ON HYDROGEOLOGICAL RESEARCH, 1988/89

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MANAGEMENT PERSPECTIVE

This status report on hydrogeological research in Canada summarizes the work of the main research groups across Canada. It pays particular attention to the emerging field of flow through fractured rocks and to the work of groups in Alberta and at the Waterloo Centre for Groundwater Research. It was requested by the Associate Committee on Hydrology of NRCC.

PERSPECTIVE GESTION

Le rapport sur l'état de la recherche hydrogéologique au Canada, commandé par le Comité associé d'hydrologie du CNRC, livre une description sommaire des travaux des principaux groupes de recherche qui oeuvrent dans l'ensemble du territoire. Il porte une attention particulière à un domaine de recherche qui se fait jour, l'écoulement au travers des roches fissurées, et sur les travaux exécutés par des groupes de l'Alberta et au Centre de recherches sur les eaux souterraines de Waterloo.

INTRODUCTION

During the past year, considerable progress has been reported by Canadian hydrogeologists in their research into such topics as flow through fractured media and the development and testing of pesticide transport models. This paper reviews research done by the major hydrogeological R&D groups across the country.

FLOW THROUGH FRACTURED MEDIA

Research on fractured rock hydrogeology is centred at the Universities of British Columbia (UBC), Waterloo and Memorial, and at the National Water Research Institute (NWRI) of Environment Canada.

John Gale of Memorial University, St. John's, Newfoundland, is continuing his work on the flow properties of fractured rock with a new focus on chemical migration processes. In a study of regional groundwater flow around an abandoned ore mine near Stripa, Sweden, using a 3-D model, it was found that model predictions of groundwater transit times were much less than actual transit times determined from chemical-isotropic data. Simulation on a more local scale of groundwater inflow to the mine openings was also conducted by Rouleau of the University of Quebec and Gale using fracture mapping data collected underground. In a laboratory and numerical study of mass transport at fracture intersections, Robinson and Gale found that mixing at these

intersections may play a smaller role than previously anticipated in diluting contaminant concentration.

In a field study of groundwater flow and mass transport conducted in a single fracture in fractured shale by Kent Novakowski of NWRI and John Cherry at the Waterloo study site at Clarkson, Ontario, it was determined that, due to the remarkably different results obtained from hydraulic tests versus tracer experiments with respect to fracture permeability, a new conceptual model for relating fracture permeability to groundwater velocity is required. Other results from this study of Novakowski and Cherry have lead to the development of new methods for the analysis of pumping tests affected by wellbore storage and skin effects and a generalized computational package for the interpretation of pulse interference tests conducted in fractured rock.

Les Smith at the University of British Columbia is studying large-scale processes related to groundwater flow in mountainous terrain. In a modeling study combining thermal and hydrogeological data, Woodbury and Smith found that simultaneous inversion of these combined data provide a significant advantage over the case where only hydrogeological data is employed in the inverse problem. In a related modeling study, the controlling factors which influence groundwater flow in mountainous terrain were investigated by Forster and Smith. Results suggest that water table elevation is the most sensitive indicator of the factors controlling groundwater flow.

HYDROGEOLOGICAL RESEARCH IN ALBERTA

Alberta has a long history of hydrogeological research. Many of the basic concepts of groundwater flow and hydrochemical patterns in shallow groundwater flow systems originated due to research undertaken at the Alberta Research Council during the early 1960's by Meyboom, Farvolden, Toth, Lennox, and Le Breton. Alberta continues to have strong groundwater research programs at both the Alberta Research Council (ARC) and at the University of Alberta (UA).

Within the ARC, research is being undertaken by two groups: the Basin Analysis Group and the Terrain Sciences Group. The four hydrogeologists comprising the Basin Analysis Group focus upon (1) the hydrogeology of flow systems in deep sedimentary basins and (2) environmental effects of disposal of liquid wastes via deep wells. During 1988, this group completed an analysis of the effects of deep well disposal at Cold Lake, and are currently developing a numerical model to simulate pressure build-up at the Swan Hills Facility of the Alberta Special Waste Management Corp. Additional projects are designed to investigate the hydrogeology of sedimentary rocks in the Peace River Basin and geochemistry of the formation waters.

The Terrain Sciences Group consists of two research hydrogeologists whose research focuses upon the conservation of soil and shallow groundwaters. Specifically, their projects include soil salinity, strip mine reclamation, hyrdaulic properties of aquitards and petroleum drilling induced wastes. Much of the research undertaken by both

groups has been published as ARC reports and in conference proceedings.

Hydrogeological research at the UA is being conducted under the direction of two professors of geology: Dr. J. Toth and Dr. F.W. Schwartz. Dr. Toth's research programme is oriented towards petroleum hydrogeology, which is the relationship of petroleum migration and deposition to regional groundwater flow systems. Field studies conducted during 1988 documented (1) that the regional potentiometric field is distorted due to highly permeable lenticular bodies at the Buck Lake Field, (2) that gas accumulations are associated with highly saline formation water north of the Deep Basin, and (3) sour gas accumulations in the Lloydminster Area can be correlated to surface hydrogeological features in the discharge areas of regional flow systems but not in the recharge zones. These studies show that the application of hydrogeological methods can aid in the exploration for petroleum reservoirs. Current field studies focus on the petroleum hydrogeology of the Red Earth and Manning Fields in Alberta, and the Upper Rhine Graben in Europe. In addition, numerical simulations, using a multiphase flow model, are being conducted to analyse the migration and entrapment of petroleum in highly permeable lenticular bodies.

Dr. Schwartz's research interest lies in the field of contaminant hydrogeology, and his research focused on five topics during 1988. First was the development and application of an expert system for

groundwater contamination. This system has gained a great deal of attention from people working in the field who do not have expertise in mass transport modeling or designing a monitoring strategy. A second area of research is a numerical analysis of mass transport in fractured media. A model utilizing a continuum approach was developed and application of the model showed that dispersion in non-idealized fracture networks is too complex to be represented by the approach of de Josselin and de Jong. A third study showed that diffusion of isotopically enriched water from the confining aquitards control the chemical and isotopic patterns in the Milk River Formation, Alberta. A final research project used a sand-tank model to examine how layers with varying hydraulic conductivities influence the dispersion of dense NPL's and light NAPL's (non-aqueous phae liquids) due to gravity flow versus fluid density flow. Unfortunately for groundwater research in Canada, Dr. Schwartz has recently left Alberta to take a position at Ohio State University.

HYDROGEOLOGICAL R&D AT NHRI

Results of the first research projects conducted at the new National Hydrological Research Institute of Environment Canada in Saskatoon are now appearing in print. Of particular interest are the results from the indoor aquifer test facility and from NHRI's long term work on the acidification of groundwater. Both projects have been led by Dr. L.M. Johnston.

The construction phase of the Facility for Indoor Aquifer Testing (FIAT) has been completed, and it is now operational. In consists of five major subsystems: the tank body, solid/liquid sampling ports, soil moisture/groundwater collection system, precipitation simulator, and the drain/groundwater table manipulation system. Preliminary tests, using de-ionized water, indicate that all systems are functioning and water samples can be retrieved from all depths. The initial geochemical results show a concentration profile developing which can be moved within the soil column by adjusting precipitation application rates and groundwater pumping rates. Preliminary tracer experiments show that the FIAT's instrumentation functioned well and performed as designed.

A digital model has been constructed for the simulation of the vertical movement of soil moisture through an unsaturated bed of Atmospheric Fluidized Bed Combustion (AFBC) solid waste within the FIAT, underlain and overlain by sandy soil. The model is based on a finite difference solution to Richard's equation and features:

1) an iterative routine for the calculation of flow between adjacent elements, when the elements are soil-physically dissimilar, and
2) a self-adjusting time step.

Investigations into the modification of the effects of acid precipitation by water-mineral interactions were continued at the Turkey Lakes Watershed, Ontario. The groundwater flow system has been divided into: a rapid flow in the surficial, highly permeable zone, characterized by low carbonate content and short residence time; and, slow flow in the deeper less permeable zone with higher carbonate content and longer residence time. Water chemistry in the former is largely determined by precipitation chemistry, while in the latter by the buffering effect of the soil.

In the shallow regime, short-term pH depressions are observed in response to acid loadings such as from spring melt. The higher concentration of K^+ may be due to increased weathering of aluminum-silicate minerals, especially K-feldspar, during precipitation events. The trace carbonates in the soil cannot offset the increased acidity. The surficial sediments (0-20 cm) were depleted in K-feldspar but had significant aluminum-silicate alteration products. Deeper sediments (20-40 cm) had more K-feldspar. Equilibrium speciation studies using WATEQ suggest increasing saturation of the aluminum-silicate and carbonate minerals with depth.

THE WATERLOO CENTRE FOR GROUNDWATER RESEARCH

The Waterloo Centre for Groundwater Research was established in 1988, with funding of $1.6 million per year provided through the Centres of Excellence Fund of the Province of Ontario. Formation of

the Centre represents a major commitment to water science in Ontario and a significant stimulus to groundwater research in particular. Centre funding is being used primarily to support new faculty positions, for funding of support staff and for other infrastructure support. Support for specific research projects will come primarily from industrial and government sources. Principal Investigators of the Centre include the groundwater group within the Earth Sciences Department, as well as individuals from Biology, Civil Engineering, Chemistry and Urban and Regional Planning.

Some of the research projects associated with the Centre's director, Dr. R.W. Gillham, are described below:

(a) Sorption of Organic Contaminants on Sampling Well Materials

Bias caused by sampling procedures is an important consideration in sampling groundwater for trace organics. In this study, potential bias caused by sorption onto sampling materials was examined. Results showed significant uptake of several organics, on polymer materials. Of particular importance, uptake on PVC was less than on PTFE. Flexible tubing materials showed the greatest uptake. The mechanism of uptake was shown to be molecular diffusion.

(b) Remediation of Contaminated Groundwater by Surface Application

Soluble constituents of petroleum products represent a common and significant threat to groundwater quality. This study includes field and laboratory experiments to examine the feasibility of remediating

contaminated zones by removing the water and applying it to ground surface. Initial results indicate that biodegradation in the soil zone was effective in reducing benzene, toluene, ethylbenzene, and xylene to concentrations below detection.

(c) Stochastic Transport of Reactive Solutes

Considerable progress has been made concerning stochastic methods for predicting the transport of nonreactive solutes. The transport of reactive solutes raises additional questions, however. In particular, the transport and the mathematical formulation of the transport process may be very dependent on whether the reaction processes and the conductivity field are uncorrelated or are negatively correlated. The distribution of the K_d values for strontium has been determined in great detail in the Borden aquifer and the statistical character of the distribution has been determined. Numerical simulations are in progress.

(d) In Situ Measurement of Geochemical Parameters

Parameters such as retardation factors and rates of biochemical reactions are important parameters in predicting the fate and transport of many groundwater contaminants. Generally these processes are sensitive to the geochemical environment and thus it is preferable that they be measured in situ. In this study a column device was developed for making in situ measurements. It was demonstrated to be effective in measuring retardation factors for strontium and several

halogenated organic compounds, rates of denitrification and rates of biodegradation of monoaromatic hydrocarbons.

(e) Denitrification in Groundwater

Denitrification was shown to be an active process in areas of southern Ontario with shallow water tables, but of minor importance in areas with deep water tables. This study showed the occurrence of denitrification to be closely related to the transport of organic carbon from the soil zone to the water table.

(f) Response of Unconfined Aquifers

Detailed field monitoring showed, contrary to the accepted technology, that drainage from above the water table has a significant effect on the aquifer response to pumping. The results are being generalized through the application of a mathematical model.

In addition, a major R&D program led by Dr. John A. Cherry and funded by both industry and government is studying the physical and chemical processes controlling the fate of dense, non-aqueous liquids or DNAPLs, e.g., chlorinated solvents, in groundwater and the related topics of monitoring these contaminants and devising effective remediation schemes.

Vadose Zone Studies at the University of Guelph

The saturated and unsaturated hydraulic conductivities of soils have been measured by the research group of Dr. D.E. Elrick using a new permeater device known as the Guelph permeameter. The device has now been licensed for sale by Soilmoisture Equipment of Goleta, California. Preliminary tests indicated that the device can measure hydraulic conductivity values in clay as low as 10^{-9} m/s.

The Groundwater Contamination Project at NWRI

Studies of the hydrogeology of fractured rock (see above) and the chemical hydrogeology of hazardous waste sites continue to be the principal topics of research at NWRI. Drs. S. Lesage and R.E. Jackson noted that the organic contaminant present in greatest point quantity at the Gloucester Landfill, near Ottawa, was a trichloro-, trifluoro-ethane. Quite remarkably they discovered that this freon degraded by both dechlorination and defluorination mechanisms. Dr. A.S. Crowe began a study of the optimal decontamination of the Gloucester aquifer using a suite of flow, transport and optimization codes.

Radionuclide Transport Research at Chalk River

Hydrogeologists at the Chalk River Nuclear Laboratories (CRNL) have continued to study the transport and sorption of radionuclides in

the local flow systems on site. In a cooperative study with the U.S. Nuclear Regulatory Commission, CRNL hydrogeologists tested the reliability of a typical three dimensional, finite-element transport code, CFEST, to simulate radionuclide migration in a well-characterized porous media flow system. The model produced close matches between observed and computed hydraulic heads for simulations involving both complete and limited data sets. However, numerous simulations and adjustments were required before the model could reproduce the migration of an adsorbing radionuclide such as Sr-90.

Hydrogeological R&D in Quebec

The group of Prof. J.P. Villeneuve at INRS-EAU in Ste-Foy has continued to develop algorithms and codes addressing the issue of pesticide transport to the water table and the vulnerability of groundwaters to such contamination. At Laval University, the Geological Engineering group of Dr. Pierre Gelinas has been studying the migration and fate of DNAPLs at the hazardous waste site at Mercier. At MacDonald College, Dr. Shiv Prasher has been investigating the fate of atrazin applied to both sandy and clayey soils.

Research in the Maritimes

The Groundwater Studies Group at the University of New Brunswick (UNB) has focussed its research on the simulation of groundwater flow

in the Fredericton aquifer and on the simulation of aldicarb transport in the Prince Edward Island sandstone. The former study has lead to a detailed reappraisal of the hydrostratigraphy of this sand and gravel aquifer system. The latter study, done in cooperation with NWRI, has identified the inadvisability of applying aldicarb pesticides at Spring planting rather than plant emergence in June. Environment Canada's Atlantic Region group have continued to develop a site near Kentville, Nova Scotia, at which various pesticides might be tested to determine their leachability.