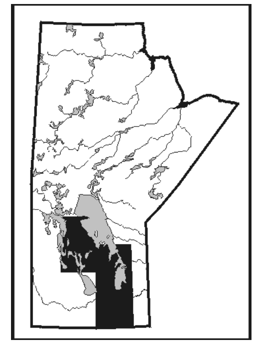
GS-29 HYDROGEOLOGY AND HYDROGEOCHEMISTRY OF THE RED RIVER VALLEY/ INTERLAKE REGION OF MANITOBA (NTS 62H, 62I, 62O, 62P and 63B)



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SUMMARY

The 750,000 people of the eastern Red River Valley and southern Interlake regions of Manitoba rely heavily on groundwater to supply municipal, industrial, agricultural, and rural residential use. This water is drawn from thousands of wells, most of which utilize two aquifers formed in Ordovician sedimentary rocks, a near-surface fractured and paleokarst-enhanced carbonate aquifer, and a deeper sandstone aquifer that directly overlies the Precambrian basement. Probable Pleistocene subglacial recharge in these rocks is supplemented by modern recharge, most notably from the Sandilands glaciofluvial complex east of Winnipeg. Discharge from these aquifers provides base flow to rivers and streams, and maintains water levels in wetlands that support wildlife habitat. Groundwater use in the region is constrained by Williston Basin saline waters that form an unstable interface with fresh groundwater along the Red River.

In order to facilitate sustainable groundwater-reliant economic development in the region, to protect existing utilization, and to co-ordinate management across the international boundary, enhanced knowledge of the dynamics of this groundwater system is required. A multi-agency effort to obtain this knowledge therefore is underway under the auspices of the Geological Survey of Canada Hydrogeology Program, that brings together work by Geological Survey of Canada (GSC), Manitoba Water Resources Branch (MWRB), Manitoba Geological Services Branch (MGSB), the University of Manitoba (U of M), Queens University, University of Waterloo and University of Ottawa.

The work entails field and laboratory investigations that deal with the physical hydrogeology and hydrogeochemistry of the freshwater-bearing portions of the Paleozoic rock aquifers in southeastern Manitoba and the southern Interlake. Work is addressing recharge of freshwater to the system, as well as encroachment of saline waters from the sedimentary basin to the west.

INTRODUCTION

The Prairie region of Canada increasingly is dependent on groundwater as a source of water supply for municipal, industrial, agricultural, and rural residential use. In Manitoba, major groundwater developments are underway at Brandon and Selkirk, and exploration has been carried out for a groundwater supply that would offset the current reliance of the City of Winnipeg on a single pipeline from Lake of the Woods. Agricultural water consumption is expanding rapidly due to growth in the livestock industry stimulated by changes to rail subsidies. Further economic developments, particularly in the agricultural sector, will be facilitated if adequate groundwater supplies can be confirmed.

Sustainable development of these water resources requires, however, that withdrawals not result in excessive drawdown that result in loss of supplies, unacceptable modification of natural systems such as streams and wetlands that exist in harmony with current conditions, or degradation of surface water or groundwater quality. Management under this principle will require an enhanced knowledge of controls on the groundwater system, including locations, mechanisms and rates of recharge and discharge, means of aquifer protection, the rate and direction of groundwater flow, properties of aquifers, as well as the spatial distribution and character of mechanisms governing groundwater chemistry.

The largest and most heavily utilized groundwater source in Manitoba are aquifers formed in Ordovician sedimentary rocks, on the eastern flank of the Williston Basin that extend from the Red River Valley/Interlake region northwest to Saskatchewan. Most wells in this area draw water from a near-surface fractured and paleokarst-enhanced carbonate aquifer (Figure GS-29-1), but many also tap the deeper Winnipeg Formation sandstone aquifer that rests directly on the Precambrian basement. In addition to consumption, groundwater in these aquifers is utilized for heating and cooling systems for major hotels, apartment complexes, and industrial facilities in Winnipeg. Discharge from these aquifers also provides base flow to rivers and streams, and maintains water levels in wetlands that provide wildlife habitat.

The movement of fresh groundwaters through these aquifers is broadly understood in southern Manitoba, although management in this intensely developed area would be greatly enhanced by a more detailed knowledge. The hydrogeology of the northern extent of the aquifers is poorly understood, however, including areas where mineral exploration beneath the Paleozoic cover is being undertaken. Should mineral development occur in these areas, a much more detailed understanding of the regional hydrogeology will be needed to evaluate potential mining impacts on the hydrogeology.

The most important source of recharge to these bedrock aquifers is thought to be the Sandilands glaciofluvial complex, east of Winnipeg (Figure GS-29-1). This area has, however, been evaluated as a water supply for Winnipeg, and the impact such development would have on recharge is unknown. In the southern Interlake, recharge to the carbonate aquifer is thought to be concentrated in areas where the aquifer lies close to surface. These recharge areas are very sensitive to contamination, but are currently under considerable development pressure from an expanding livestock industry. It has been suggested that freshwater in the sandstone aquifer of the Interlake is a non-renewable resource and resulted from Pleistocene subglacial recharge (Betcher, 1986), although this model has not been tested against current understanding of the Laurentide Ice Sheet/Williston Basin system. In order to clarify sustainable yield, information about the rate and spatial distribution of recharge is urgently required.

Groundwaters are fresh east of the Red River and in the Interlake, but saline Williston Basin waters to the west, that form a mobile interface with fresh waters along the river (Figure GS-29-1), are a major impediment to development, including prevention of a livestock industry in the western Red River Valley. In some areas, discharge of brackish waters has resulted in soil salinization and resultant economic impacts on farming. A more thorough understanding of the interplay between the brackish groundwaters to the west and the fresh waters to the east is needed. Overuse of fresh groundwaters, or reduction in recharge caused by changed land use practices, may have caused the observed eastward movement of the saline waters, with serious consequences for current groundwater users.

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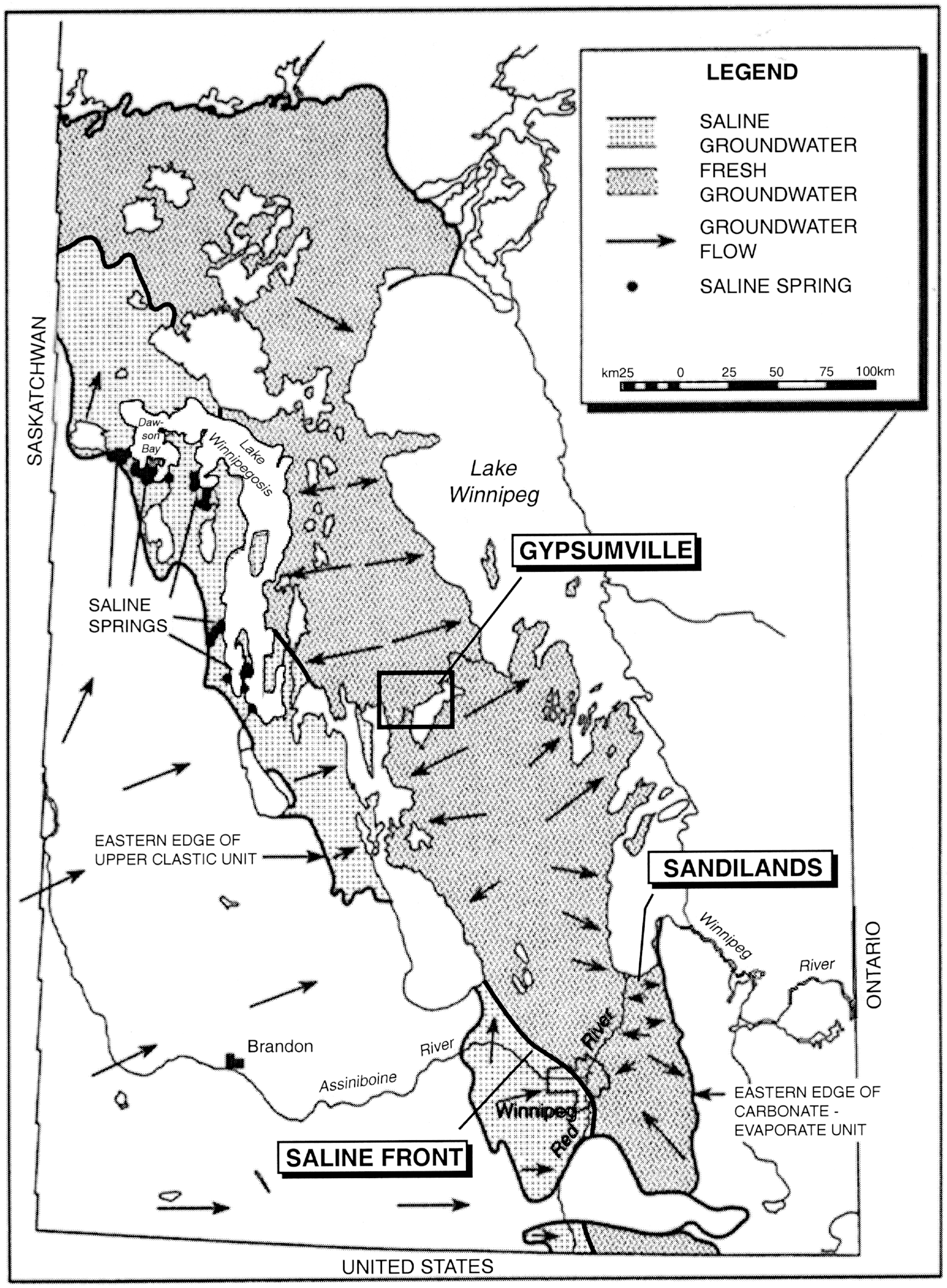

Figure GS-29-1: Extent of the fresh-groundwater-bearing and saline-groundwater-bearing outcrop of the carbonate aquifer, with location of major project elements (after Betcher et al., 1995).

Hence there is a need to more clearly define regional factors that govern the long-term capacity, sensitivity, and dynamics of Winnipeg-region groundwater systems. Research on the topic will provide benefits to the 750,000 people of the region by helping to protect existing groundwater utilization, to facilitate sustainable development of groundwater resources through intensified management and public education, to identify opportunities for new groundwater development, and to co-ordinate management across the international boundary.

Surveys under the project are addressing both the physical flow field and hydrogeochemistry of the fresh water-bearing rock aquifers. External controls and boundary conditions to the exploited and exploitable aquifers are being examined by characterizing recharge, as well as the dynamic balance between the fresh groundwaters to the east and saline waters to the west. Modelling on two spatial/temporal scales was initiated at the outset of the project in order to set priorities for field work and test hypotheses. Finite difference modelling conducted at GSC Calgary and the University of Alberta includes work on a 1000-km/10,000 year scale, to understand the sedimentary basin/ice sheet system that has dictated the current state of the aquifers. At the University of Manitoba, finite element modelling is utilizing a 100-km/100 year scale in order to construct a groundwater flow model directly applicable to management issues in the study area. Modelling studies will guide the field projects, field results will be fed back to the model, and a series of iterations will lead to a potential management tool.

Pilot activity for the project, including regional EM transects (Hyde et al., in preparation), water sampling, surveys in Lake Winnipeg, and database syntheses, were carried out in 1996 and 1997. The 1998 field season was the first of three years of intensive field effort. Final outputs will be released in 2001/2002. The work is now structured as several inter-related projects that include Sandilands recharge, hydrogeology of Lake Agassiz clay, regional hydrogeochemistry, the multidisciplinary Gypsumville project, the saline front, and modelling.

PREVIOUS RESEARCH

Syntheses of the hydrogeology of the region have been prepared by Saskatchewan-Nelson Basin Board (1972), Rutulis (1984b; 1986; 1987), Lennox et al. (1988), and Betcher et al. (1995). Examples of early investigations in the area are the work of Upham (1895) and Johnston (1934). Work on the hydrogeology of the Williston Basin includes publications by Downey (1984), Dinwiddie and Downey (1986), Young (1992), Bachu and Hitchon (1996), and Burrus et al. (1996). Work on the carbonate aquifer includes that of Grice (1964), Render (1965a; 1971), Ford (1983), and Betcher et al. (1992). Research on the underlying Winnipeg Formation sandstone aquifer has been conducted by Betcher (1986c). An example of analyses of aquifers in glacial sediments is the work of Cherry et al. (1971), and work on the stratigraphy of these sediments includes that of Teller (1976) as well as Teller and Fenton (1980). A summary of springs in southern Manitoba was published by Rutulis (1985), while an example of research on surface water/groundwater interaction is a thesis on the Shoal Lakes by Goff (1971). Work on the groundwater response to a major earthquake was published by Scott and Render (1964). The hydrogeology of the Precambrian rocks to the east of the study area has been discussed by Davison and Kozak (1984), Davison (1984), and Farvolden et al. (1988). Work on the hydrogeology and engineering geology of the City of Winnipeg area includes the writings of Render (1965b; 1965; 1970), Whitehead et al. (1969), Render and Fritz (1975), Baracos et al. (1983), and Baracos and Kingerski (1998).

Summaries of the hydrogeology of NTS 1:250,000 map areas have been done for the Winnipeg area (Little, 1980), the Selkirk area (Betcher, 1986b), the Kenora area (Betcher, 1986a), the Neepawa area (Betcher, 1989), the Dauphin Lake area (Betcher, 1987), and the Hecla area (Betcher, 1983). Groundwater reports for areas such as rural municipalities and planning districts within the study area include those by Charron (1961; 1965; 1967; 1974), Rutulis (1975; 1978a; 1978b; 1979; 1981a; 1981b; 1981c; 1981d; 1982a; 1982b; 1982c; 1982d; 1984a) International Roseau River Engineering Board (1975), Lebedin (1978), and Gray (1988).

Work on hydrogeochemistry and isotopic studies has been reported by Charron (1969), Render and Fritz (1973), Fritz et al. (1974), Beck and Brown (1985), and Betcher et al. (1988). Investigations dealing with saline waters include work by Hyde et al. (in preparation), Charron (1962), Meyboom et al. (1966), van Everdingen (1968), van Everdingen (1971), Betcher (1984), and McKillop et al. (1992). A regional water quality survey covering the southern Interlake was published by Betcher (1997). Research on the hydrogeology of fine-grained sediments, including tills and clay, includes work published by Day (1977), Cherry and Smith (1990), Remenda et al. (1994), Pach (1994). Regional hydrogeochemical surveys of the Interlake in support of mineral exploration and regional geology have been conducted by McRitchie (1989; 1994; 1995; 1996; 1997) and by McRitchie and Kaszycki (1997).

SANDILANDS RECHARGE

Recharge to the bedrock aquifers of the Red River Valley from the uplands of the Sandilands glaciofluvial complex (Figure GS-29-1) will determine the long-term sustainable groundwater yield in southeastern Manitoba, a critical factor in this populous, developing area. Effort under the project therefore is being directed at quantification and characterization of the rate and distribution of recharge to the sediments, hydrostratigraphy of the sediments, groundwater flow in the sediments, hydrogeochemical evolution of Sandilands recharge, and transfer of water to the underlying rock aquifers. This work will support modelling that will be used to evaluate the supply and water quality impacts of current and future groundwater development.

Recharge rates are being estimated, and distribution of transfers to the rock aquifers better determined, based on both direct physical means, by employing test drilling, sampling, and measurement of rates of flow, as well as indirect geochemical and modelling methods, in order to obtain uncertain but independent estimates. Physical methods include analyses of water balances and observations from several new multiple-level piezometer installations. The application of thermal methods also is being evaluated. Geochemical analyses of soil water and piezometer samples include dating of groundwater by CFC and tritium analyses, measurement of the depth distribution of conservative ions in groundwater solutions in the soil profile and comparison to concentrations found in precipitation, and following conservative tracers in the vadose zone. Analyses of stable isotopes of oxygen and hydrogen on archived samples collected from private wells completed in surficial and bedrock aquifers in southeastern Manitoba are being used to determine the distribution of Pleistocene groundwaters.

Work on this topic is being directed by M. Hinton of the Terrain Sciences Division (TSD) of GSC and by A. Cherry and I. Clark of University of Ottawa, with one of the key objectives of current work being to validate the chlorofluorocarbon (CFC) method of groundwater age dating in Manitoba. Field activities for 1998 focused on Bedford Ridge, site of the highest elevations in southeastern Manitoba. Sixteen shallow piezometers that range in depth from 3 to 27m were installed in five nests of three, plus one single piezometer. All piezometers were bail tested and sampled for CFC, ^{3}He, ^{3}H, and full water chemistry. A temperature cable was installed to obtain automated measurements of temperature profiles to a depth of 20 m. Stream baseflow was gauged on several streams that drain this topographic high, and forty-seven stream and groundwater chemistry samples were collected over the Bedford Ridge region. This sampling will contribute to compilation of hydrogeochemical data for regional groundwaters from shallow and deep Quaternary aquifers, as well the carbonate and sandstone aquifers.

Drilling results obtained during summer 1998 suggest that thick, uniform fine to medium sand within the core of the Bedford Ridge is conducive to high groundwater recharge rates. Occurrences of thin, near-surface till deposits may, however, reduce recharge rates on the periphery of the ridge. Baseflow discharge in streams is low, indicating that groundwater discharge is a small component of the local water budget. Dissolved oxygen levels determined in the piezometer nests show that groundwater can become quickly reduced below the water table. The regional sampling demonstrated that the deep aquifers also have reduced waters.

Plans for further research in the Sandilands include: 1) installation of deep piezometer nests extending to bedrock in order to determine groundwater flow to bedrock aquifers; 2) measurement of a CFC profile to further validate the method in Manitoba; 3) expansion of CFC recharge estimates and hydrochemical surveys to a larger area within the Sandilands; and 4) the investigation of groundwater recharge through wetland areas that surround the Sandilands. This research will aid in sustainable long-term planning of groundwater resources in southeastern Manitoba through the determination of aquifer replenishment rates and accurate boundary conditions for regional hydrogeological models.

HYDROGEOLOGY OF LAKE AGASSIZ CLAY

Recharge of meteoric precipitation to the groundwater table is a poorly understood phenomenon, especially in clayey sediments such as the Lake Agassiz deposits of the Red River Valley (Remenda et al., 1994). These deposits blanket the important aquifers of the region, and exert some control on their behaviour. Where the clays are unfractured, they provide a measure of protection for drinking water supplies. Elucidation of the hydrogeological properties of these materials, both fractured and unfractured, therefore is required in order to obtain a better understanding of regional hydrogeology.

Research on this topic is being directed by V. Remenda and S. Ryan of Queen's University, as well as by T. Edwards and J. Birks of University of Waterloo, and is being conducted with partial support from the GSC Hydrogeology Program. The objectives of the work are to elucidate the spatial and temporal variability of recharge, as well as to investigate the relationship between stable isotope composition of precipitation and shallow groundwater.

During the summer of 1998, field investigations were undertaken at three sites. At two sites near Winnipeg, one between St. Adolphe and St. Norbert and the other at Glenlea, the dominant mode of migration is by fracture flow. At a third site, near the International Border, 2 km north of Emerson, the dominant mode of migration is by diffusion. Field activities included collection of core, installation of both piezometers in the groundwater zone and tensiometers in the unsaturated zone for hydraulic measurements and water sampling, and in situ monitoring of water content, temperature, and induced infiltration. Laboratory activities will include isotopic and geochemical analyses, core logging and squeezing, and geotechnical index tests.

REGIONAL HYDROGEOCHEMISTRY

Compilation of a regional hydrogeochemical database has been an ongoing activity in recent decades of the MWRB and MGSB. Participants in the GSC program are contributing to the ongoing development of this database. Hydrogeochemical mapping based on this database will support the development of groundwater flow models, will provide an independent estimate of recharge, will clarify the origin of hydrogeochemical anomalies, and will better map the interface between fresh and saline groundwaters. These maps will be used to provide geochemical indications of the locations of groundwater recharge and discharge areas and flow system development. They will also indicate where significant geochemical anomalies exist that may provide important information on the origin and movement of groundwaters. The position of the fresh water-saline water boundary and the geochemical transitions that are associated with this boundary, from both the fresh water and saline water sides, will also be presented.

The MWRB database, which has been built over several decades, consists of two major groupings of data. One is a digital record of water analyses from about 350 provincial monitoring wells, that in many cases include annual or biannual samples that extend over the past three decades. Analyses typically are for major ions (Ca, Mg, Na, K, Cl, SO_4 and HCO_3), minor ions such as F, nitrate, Fe, Mn, as well as variables such as pH, conductivity, total dissolved solids (tds), and temperature. The second database, only recently digitized as a result of support from Agriculture Canada, includes analyses of from private wells, regional surveys, and local investigations carried out by MWRB. The analyses had previously been stored in a card file stored by section, township and range. These analyses range from limited tests such as conductivity and iron to more complete analyses that include metals and isotopes. The current structure of the database readily permits viewing of one well or analysis, but, at present, broader interpretation of, for example, the chemistry for a group of wells or wells completed into a particular aquifer are not readily done. Data are made available to external users, with locations generalized to prevent direct association of analyses to specific wells. Verification of the recently digitized records is ongoing. For example, there are problems with entry of nitrate-NO_3 values as nitrate-N values, with variables being entered into the wrong columns, and with errors in placement of less than or greater than symbols. Enhanced query and mapping capabilities will increase error-recognition capabilities. Conversion of computing systems has resulted in a two-year backlog of new analyses. Efforts also are underway to capture past project-related data, as well as data acquired by past activity of other agencies. Long-term efforts also are being directed to enhanced well location accuracy. The hydrogeochemical data has been gathered over decades, so collection and analytical methods have varied.

Work by S. Grasby and W. McDougall of GSC Calgary, in co-operation with R. Betcher of MWRB, has included compilation of pre-existing data for the carbonate aquifer, into a single database that has been: 1) culled for poor quality and/or incomplete analyses; 2) screened for inconsistencies and duplication of data, and 3) calculated UTM and Latitude/Longitude co-ordinates for all wells. These data have then been used to produce preliminary regional maps of groundwater chemistry in preparation for release of this database in a GSC/MWRB Open File. The culling procedure was used to identify suspect analyses due, for example, to drilling mud contamination.

New sampling under the GSC program has permitted application of more sensitive analytical methods, with analysis being co-ordinated by the Mineral Resources Division (MRD) of GSC. For example, a helicopter-supported survey in summer 1997 permitted new sampling along the eastern escarpment of the Central Interlake, an area in which several tufa mound springs occur (McRitchie and Kaszycki, 1997). A systems approach is being used to develop an understanding of the origin, mixing, and flow of waters, and interactions both within and between recharge and discharge areas. In order to elucidate mixing patterns, residence times, and flow path characteristics, waters are analyzed for ultra low trace constituents, including rare earth elements, using a newly developed ionic chelation enrichment technique, as well as for a selection of isotopes (^{18}O, ^{2}H, ^{13}C, $^{10}B/^{11}B$, ^{34}S, ^{3}H). Hydrogeochemical modelling will be used to further constrain the origin(s), mixing, and flow characteristics of these groundwaters.

An updated protocol has been implemented by team members to address the issues of sample container types, labelling, filtration, preservation, quality assurance/quality control (QA/QC), and in-field analysis. With the exception of some specialized isotope analyses, all samples are being collected in high-density polyethylene bottles. Separate leached bottles are being used for cations and anions. A 60-ml sample is used, unless additional tests or chelation extraction methods are to be used, in which case a 125 ml or 250 ml bottle is used for the cation sample. The leached bottles are used for both the cation and anion samples where as unleached bottles are used for isotope samples. The bottles are filled so that a positive meniscus is formed at the top, and the cap is screwed down tightly. All reasonable precautions are taken to avoid introduction of contamination to the bottle during sampling, especially the cap. No metal jewellery is worn during sampling and sample preparation. Radium watch dials are avoided to prevent influence on tritium results.

White self-sticking labels are attached to the bottle, and the sample number written with a permanent marker. The written label is covered with transparent tape prior to filling the bottle. A numbering system has been adopted as follows: M981001-C = cation sample (unfiltered), M981001-FC (filtered); M981001-A = anion sample (unfiltered), M981001-FA (filtered); M981001-C13 = ^{13}C isotope sample; M981001-O/H = ^{18}O/D isotope sample; M981001-H3 = tritium sample; M981001-S34 = sulphur isotope sample; and additional suffixes for specialized analyses. In the case of precipitate or stream/lake sediment samples, the same number is used for both the water and the sediment.

Whether or not the sample is filtered has been based on the sampling conditions and the objectives of the work. In some cases, filtering has not been done where elements such as Fe, Al, and Mn, that may be in colloidal form, are important to interpretation. In all cases, samples that are to be filtered are passed through a 0.45 μM filter. Regardless of the type of filter medium used, a small volume of sample is passed through the filter before collecting the sample to be analyzed, to allow chemical equilibration with the filter medium, as well as to minimize contamination from the filter. Both disposable cartridge filters and mountable filter papers on a vacuum container system are being used. The vacuum container system is used to filter large volumes of water and when field conditions do not place constraints on time spent on site. The system is rinsed after use with deionized (DI) water and also rinsed once with a portion of the filtered sample.

Cation samples are preserved with approximately 1% by volume ultrapure nitric acid. Cation and anion samples are kept cool before shipping. Isotope samples are kept cool and dark. Isotope samples are preserved according to Clark/Fritz procedure, with the exception that HgCl is used instead of Na-azide for preservation of ^{13}C. For acid additions the following amounts are added according to bottle size: 0.5 ml to 60 ml bottle; 1.5 ml to a 125 ml bottle; 2.5 ml to a 250 ml bottle. For ^{18}O/D a separate 60-ml unleached bottle is used. For ^{13}C, glass Boston bottles with septums are used, with a small amount of HgCl added to kill biological activity. For tritium, an unleached 250 or 500 ml bottle is filled completely. For ^{34}S, the Clark/Fritz protocol is used. The acidified sample may also be used for B isotopes. Upon shipping, arrangements are made to ensure cold storage upon arrival. A sample listing in the boxes using the appropriate coding is included in the shipment, as are a printed and/or digital report of conductivity and pH values for each sample.

Instruments are calibrated with standards each morning, and are checked during the day as required. Calibration of pH to two decimal places is not attempted, although the second decimal place is recorded. At a minimum, samples are analyzed for pH and conductivity, but DO and temperature also are recorded where possible. Eh measurements are needed in some cases, and calibration is ensured given the impact of these values on geochemical modelling. Backup instruments for each parameter are maintained in the field and on call from laboratories in Ottawa and Winnipeg.

In order to ensure internal data consistency, a duplicate sample is taken within every batch of 20 samples, with consecutive numbers used for this procedure, and a set of bottles is left empty, to be used for a blank or standard inserted in the lab, within every batch of 40 samples. Samples are submitted on a strict time schedule, to permit preparation and analysis as a single batch. Following analysis, data are inspected for QA/QC and ion balances before being released to individual members of the team. In certain cases, some samples may require re-analysis.

Regional surveys in the northern Interlake (McRitchie, 1989; 1994; 1995; 1996; 1997; McRitchie and Kaszycki, 1997) have shown that there are two main groups of groundwaters in the region. One group represents Ca-Mg-HCO_3 groundwaters associated with the Paleozoic carbonate formation. The second group consists of Ca-Mg-

SO_4-HCO_3 waters that represent mixing of groundwaters associated with evaporite sequences and those of the first group. The second group is also highly anomalous in B and Sr. The most likely source of the evaporite component in the second group is the Permo-Jurassic evaporite formations of the St. Martin's crypto-structure. Within the first group, there is a localized set of groundwaters strongly anomalous in F, Mo, Fe, and Sr that suggests groundwater input into the carbonate sequence aquifers of waters associated with either the Precambrian basement or the Winnipeg Formation sandstone. These anomalous fluoride groundwaters are significant since they occur as spring upwellings topographically high on the Silurian stratigraphy.

In addition to regional hydrogeochemical investigations, it is planned that at least one area will be chosen for more comprehensive analysis. The first such site is the area of unique groundwater geochemical development around Gypsumville, where extremely high fluoride concentrations have been known for some time. Additional potential sites for focussed analysis include areas of anomalously poor groundwater quality west of the Red River, just north of Winnipeg and in the Dugald area. These are areas of rapid suburban development, with most houses dependent on individual wells. If the poor quality groundwaters in these areas are shown to result from leakage from the overlying clayey sediments, this may influence the amount of local drawdown that should be allowed to develop. A larger drawdown cone may result in increased influx of poor quality groundwater from the clays and further deterioration of water quality.

REGIONAL PHYSICAL HYDROGEOLOGY

Work to address physical hydrogeology of the bedrock aquifers is directed by A. Desbarats of MRD. The research, on both the carbonate and sandstone aquifers, includes aquifer geology, groundwater flow rates, origin and distribution of groundwater flow, and groundwater age dating. In the carbonate aquifer, water flows through a karst-enhanced network of fractures, joints and bedding planes. In the sandstone aquifer, pumping and leakage through abandoned wells open to the carbonate aquifer substantially exceed recharge to this aquifer. Studies of flow rates and water quality near the saline front in the sandstone will help clarify this water balance. Field surveys and remote sensing are used to map springs in the Interlake, to clarify the interaction between the local, shallow, karst-hosted groundwater flow system and the deeper regional flow system as it reaches the up-dip limit of the Paleozoic sequence. Study of the shallow, karst-hosted freshwater system will contribute to an understanding of the dynamics that control the location of the freshwater-saltwater interface. Together with estimates of recharge and discharge rates, and water balance calculations, this information will allow an assessment of the feasibility of expansion of commercial and domestic water supplies. Contingent on adequate funding levels, a series of deep boreholes will be drilled to the Precambrian basement and will be completed as multiple-level piezometers in the Winnipeg Formation, and in units such as the Fort Garry Member of the Red River Formation and productive zones within the Stonewall and Interlake groups. These piezometers will be used to determine the head and vertical head gradient between permeable units. The shallow groundwater flow system is being investigated at springs using data loggers that continuously monitor water levels, discharge rates, temperature and conductivity in selected boreholes and springs. Tracer tests may be considered for identifying fast groundwater flow paths in the karst horizon.

THE GYPSUMVILLE PROJECT

Physical hydrogeology

The Gypsumville study area (Figure GS-29-1), about 200 km north of Winnipeg, includes the Rural Municipality of Grahamdale north of the Dauphin River, as well as the Lake St-Martin, Little Saskatchewan and Fairford Indian Reservations, including their lands to the south of the Dauphin River. In this area, the simple regional stratigraphy is disrupted by a large impact structure filled with Permian impact breccia, as well as Jurassic redbeds and evaporites. Uplifted Precambrian basement also is present on the east flank of the structure. These rocks impart high fluorine content, hardness and salinity, so water quality is extremely poor to non-potable in many wells. Furthermore, the complex stratigraphy within the impact structure, and the karstification of the evaporites, has created complex groundwater flow patterns, in which construction of usable wells is difficult. Aboriginal and agricultural communities in the area are entirely dependent on groundwater for their domestic and livestock needs. Poor water quality imposes hardship and health risks on all inhabitants, particularly the most disadvantaged. Hydrogeological studies that may alleviate the groundwater supply problem are welcomed by these communities, as demonstrated by the favourable reception from area residents to the fieldwork carried out during the 1998 field season.

The objectives of the work are to develop a detailed understanding of groundwater flow patterns in the Gypsumville area, from recharge to discharge, including a model for interaction of shallow redbed and karst-hosted groundwater flow systems and the deeper regional system at the up-dip limit of the Paleozoic sequence. This physical hydrogeological information will support concurrent hydrogeochemical investigations in the area. These new and detailed physical hydrogeological measurements will be contributed to the MWRB database. Driller's logs compiled by MWRB are used to develop a hydrostratigraphic model that may guide water well drilling. The work will assist groundwater availability assessments, and will improve understanding of groundwater fate on the northeast margin of the Williston Basin.

Work completed during 1998 included acquisition of background literature and database material, geological and hydrogeological reconnaissance of the study area, community liaison, search for suitable abandoned wells for siting data logging equipment, fabrication of surface infrastructure and protection for data logging equipment, and field calibration and deployment of six multiparameter data loggers at sites scattered over the study area. A new TROLL MP-8000 multiparameter data logger was sited in a 67-m well located ~2 km north of Gypsumville and 0.5 km east of the old gypsum quarry. The well intersects 25 m of gypsum and is screened in redbed sands and calcareous shales. Numerous karstic sinkholes occur in the vicinity of the well. Water level, conductivity, pH and temperature were measured hourly from June 28th to August 25th, 1998 (Figure GS-29-2). Groundwater levels declined during this period by 4 m and conductivities show a corresponding increase. Recharge from rainfall early in the summer probably caused the initial decrease in conductivity. Values for pH were generally stable at around 8.3 for most of the summer, except in late June when a sharp increase briefly reached almost 11, perhaps due to flushing of karstic conduits after rainfall. Groundwater temperature over the summer was remarkably stable at around 5°C. Data loggers sited in August will provide precipitation and barometric pressure data in addition to water levels and conductivities in other wells scattered over the study area.

Future plans call for remote sensing to be used to identify spatial distribution of karstic features that may control groundwater flow. Phreatic/piezometric water levels will be surveyed in accessible wells, and six water-level monitoring stations will be established to assess temporal variability of groundwater characteristics. Geostatistical mapping of piezometric surfaces and hydrogeochemical dispersal plumes will be conducted, and drilling of one or two deep wells in order to assess groundwater conditions in the regional Paleozoic aquifers is planned.

Hydrogeochemistry

Work on the hydrogeochemistry of groundwaters in the Gypsumville area (Figure GS-29-1) is being directed by D.Boyle and M. Leybourne of MRD. The principal objective of the work is to obtain a geochemical characterization of Paleozoic aquifers in the Interlake generally, and more specifically the Jurassic evaporite aquifer at Gypsumville. The study is addressing processes that affect water quality and water composition in the Gypsumville area, and will use hydrogeochemical and stable isotopic techniques to help define groundwater flow paths, in support of work on physical hydrology. There are serious issues of water quality for residents of the Gypsumville area. Previous work in the area has demonstrated that groundwaters have elevated fluoride contents. Most Gypsumville residents do not drink local well waters. In addition, sampling conducted during the summer of 1998 has shown that many sites have elevated conductivity, as an approximate measure of total dissolved solids, well above potable levels (Figures GS-29-3 and 4). Thus, there are local sources of enhanced groundwater salinity that are unrelated to eastward migration of the saline front.

The site is in the Lake St. Martin meteorite impact structure, where hydrology is both formation and fracture controlled, and groundwaters interact with a complex geology that results in compositions potentially detrimental to public health. From the sparse data available,

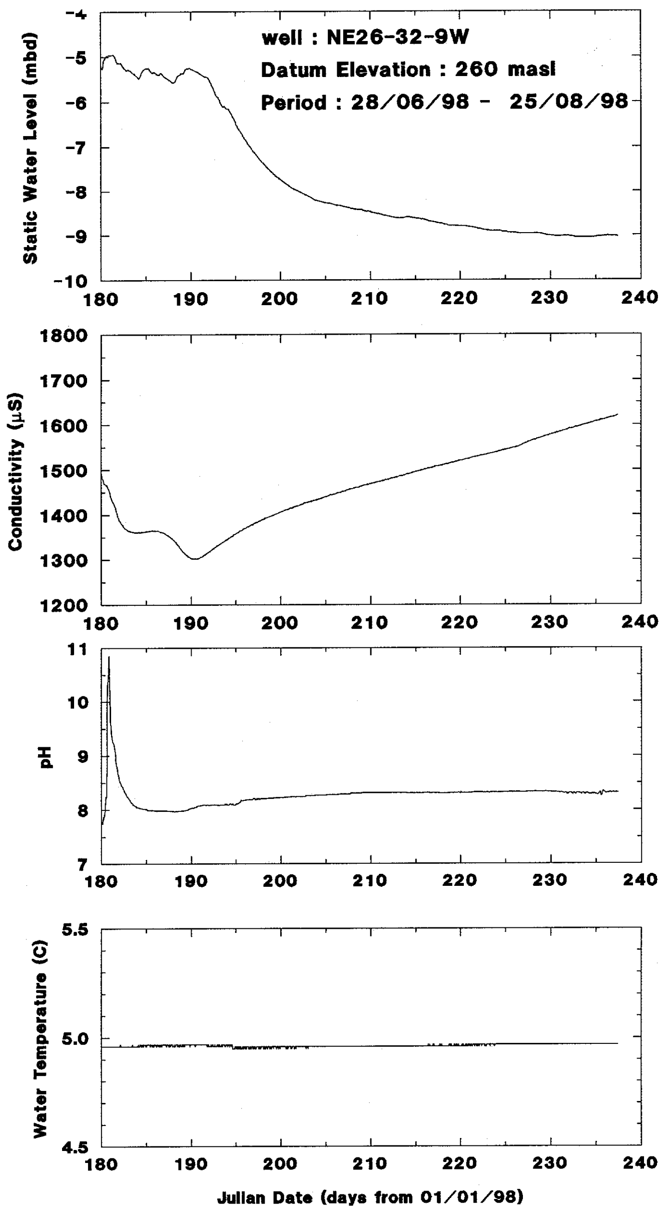

Figure GS-29-2: Hourly data for a well near Gypsumville.

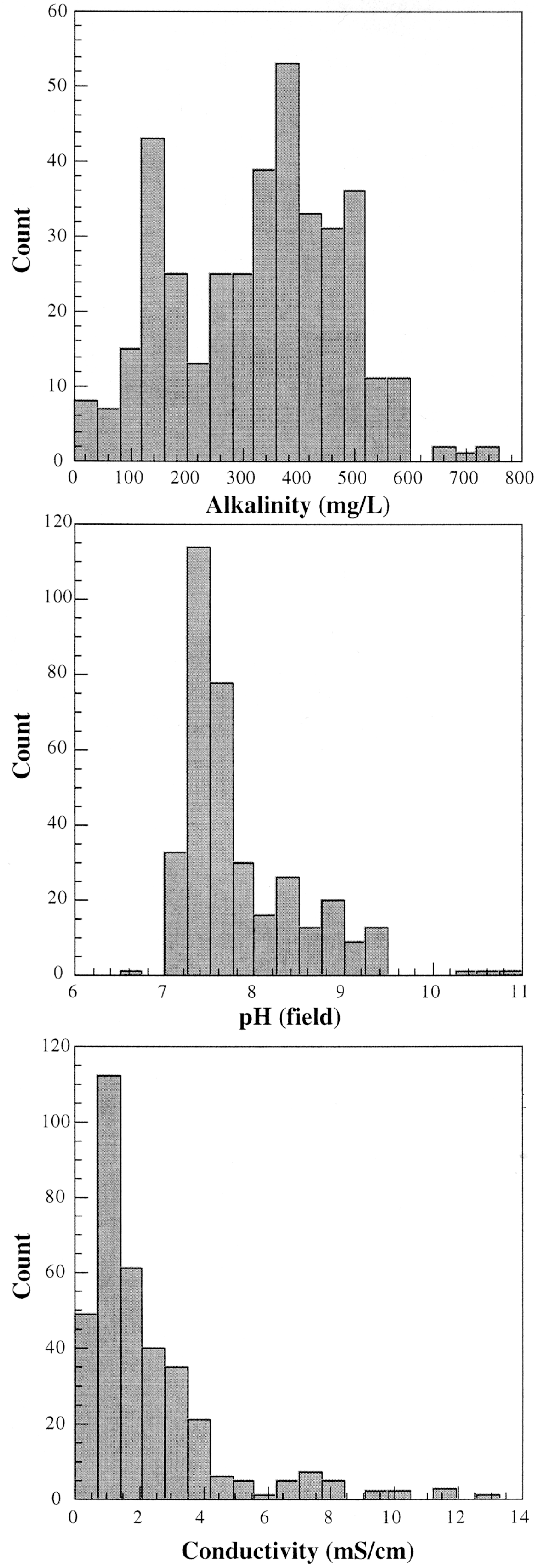

Figure GS-29-3: Histograms of alkalinity, pH and conductivity for groundwaters collected in the Gypsumville area in 1998.

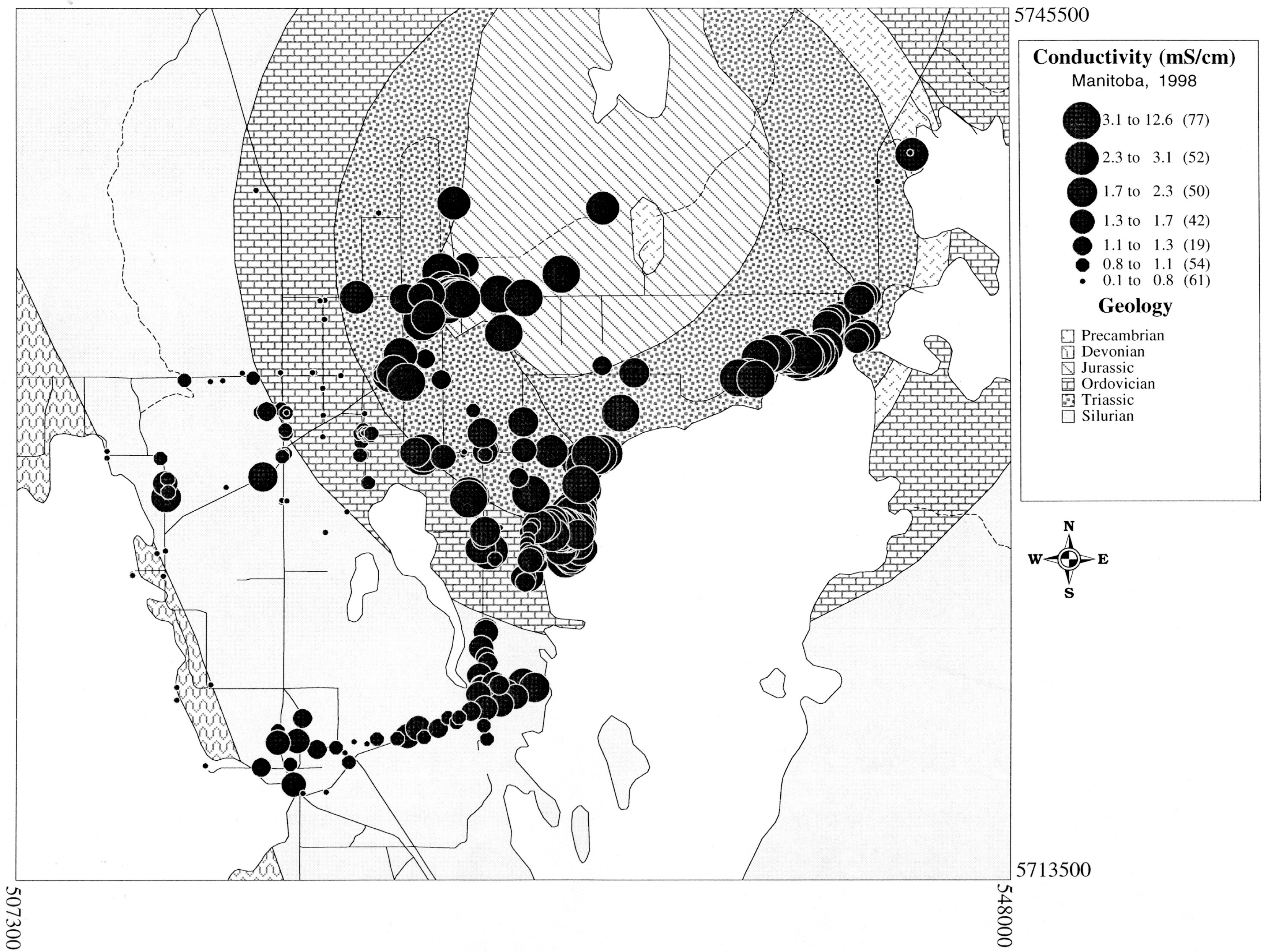

Figure GS-29-4: Spatial distribution of groundwater conductivity with respect to the major lithologies in the Gypsumville study area.

considerable base exchange with the enclosing geology can be recognized. There are about 300 accessible boreholes, with logs, available for more detailed sampling. Understanding of hydrogeochemistry of the groundwaters will allow a better understanding of local and regional groundwater flow and allow the mapping of areas where further development of domestic groundwater supplies should be avoided. The geology of the study area is complex due to an inferred impact event at around 220 Ma. Precambrian basement rocks occur on the eastern side of the study area, overlain by Paleozoic sedimentary and carbonate units. Triassic rocks of the St. Martin complex include microbreccias and trachyandesites (inferred meltrock) and are overlain by Jurassic redbeds and gypsum/anhydrite deposits (Figures GS-29-4 to 6). Thus, there is potential for a great diversity of water types and this is borne out by field analyses of pH and conductivity (Figures GS-29-4 and 5), and potential flow paths.

During summer 1998, 384 samples of well waters and stream waters were collected for major cation and anion analyses, as well as trace and ultra-trace metal contents. Waters at 103 sites were sampled for stable isotope analyses, including $\delta^{13}C$, $\delta^{18}O$, δD, and $\delta^{34}S$. A subset will also be analyzed for Sr isotopes, to aid interpretations of water-rock reactions and groundwater sources. Parameters measured in the field included pH, conductivity, Eh, dissolved oxygen and temperature. Over 100 rock samples were collected from drill core for geochemical, stable isotope, and radiogenic isotopic analyses, as well as analyses meant to determine cation exchange capacity, to better understand water-rock reactions.

On the basis of field analyses, including alkalinity determinations, it is observed that groundwaters in the study area range from low conductivity fresh waters in the west and south, to brackish waters with conductivities as high as 12.6 mS/cm around the town of Gypsumville, as well as the Little Saskatchewan and Lake St. Martin Reserves (Figure GS-29-4). Groundwater pH values are above neutral and range to elevated values exceeding 9 (Figures GS-29-3 and 5). High pH waters occur around the Little Saskatchewan and Lake St. Martin Reserves. Groundwaters from the Lake St. Martin Reserve have generally low alkalinity, despite high pH and conductivities. This suggests that the anions in these waters are dominated by sulphate or chloride and could indicate either local flow of sulphate-bearing waters from the Gypsumville area or a deeper, more regional groundwater flow system bearing chloride. The highest alkalinities occur in groundwaters from the Little Saskatchewan Reserve (Figure GS-29-6).

The Gypsumville hydrogeochemistry project is linked to a study of the physical hydrology in the same area being conducted by A. Desbarats. This work also complements regional sampling conducted by McRitchie and Kaszycki (1997), who noted elevated sulphate contents in springs east of Gypsumville.

SALINE INTERFACE

A major issue in the greater Winnipeg region is the potential for over-development of fresh groundwater resources that would result in the eastward migration of saline waters. For example, migration of the saline front occurred during dewatering operations associated with construction of the Red River Floodway in the late 1960's. After dewatering ceased, the front slowly receded, although salinity in the impacted area has not yet returned to earlier levels. The salt-water front has also advanced eastward and northward beneath the City of Winnipeg as a result of groundwater development over the past hundred years. More recently, a gradual eastward movement has occurred along the Red River south of Winnipeg as a result of water supply development. Salinization is a particular concern in these areas, where communities and an expanding rural residential population all heavily depend on the carbonate aquifer for water supplies. The saline front in the sandstone aquifer lies farther east than in the overlying carbonate. This has resulted in upward movement of saline water into overlying fresh aquifers, where karst channels have been eroded through the carbonates and into the underlying sandstones. Salt waters have also intruded into the fresh water portion of the carbonate aquifer through abandoned open wells. There is also concern that the long-term decline in sandstone aquifer water levels will eventually result in eastward and southward migration of the saline front into areas where the aquifer has been developed for water supply.

Research under the project therefore has identified an enhanced understanding of the saline front as a high priority. Investigations of the interaction between fresh and saline groundwaters and the stability of the saline front will facilitate enhanced management of these major issues. The initial work has included compilation of existing data, new sampling, and field measurement of conductivity in water wells, to establish the current position and concentration gradient of the interface and provide a baseline for future monitoring. Sampling of saline waters down-dip from their eastern limit to the dense brines in southwestern Manitoba will permit analysis of major, minor and trace dissolved constituents, as well as the stable isotopes of O and H, S and O in sulphate and C in the bicarbonate. The stable isotope results will provide information on the origin, and in some instances the age, of saline groundwaters in the basin. Isotopic concentrations will also be used as natural tracers in mixing models and indicate the role of biochemical reactions in regulation of groundwater chemistry. Installation of new monitoring wells and piezometers across the water quality boundaries in both bedrock aquifers in southeastern Manitoba is planned, to examine short- and long-term migration of the boundaries, and to relate these changes to small and large scale changes to the aquifers induced, for instance, by local groundwater development, long term groundwater level changes, seasonal and longer weather fluctuations, and changes in stage of rivers, including major floods. An experiment that would involve installation of a pumping well near one of these monitoring nests and observing impacts from controlled groundwater abstraction is also being considered. Each monitoring location will consist of at least three separate piezometers completed at different depths and instrumented to record water level and fluid conductivity. Archived cores from the carbonate aquifer, and additional cores collected during the drilling of the monitoring wells, will be examined with respect to indications of diagenetic changes between fresh and saline porewaters. This information will be analysed with the help of geochemical models of rock/water interactions and may lead to an understanding of paleo-movements of the fresh water-saline water boundary, and hence the stability of the boundary.

Fieldwork by MWRB during summer 1998 was directed at increasing the accuracy with which wells are mapped, and measurement of conductivity in these wells, along the saline front from the south Perimeter Highway to the US border and from the Red River east to a conductivity of 1000 uS. This work is documenting the current location of the fresh water/salt water front in the carbonate aquifer.

Work by S. Grasby of GSC Calgary, including new sampling and field measurement of conductivity in water wells, also is contributing to mapping the current position and gradient of the interface and to providing a baseline for future monitoring. Samples are analysed for major, minor and trace dissolved constituents, as well as the stable isotopes of O and H, S and O in the sulphate and C in the bicarbonate. The stable isotopes provide information on the origin, and in some instances the age, of groundwaters in the basin. Saline springs along Lake Winnipegosis were sampled to provide information on the geochemistry of the saline waters in the deeper parts of the basin. Future work will include development of geochemical models for water/rock interactions, possibly allowing definition of diagenetic signatures in the host rock that would indicate the paleo-position and hence stability, of the fresh water-saline water boundary. Examination of archived cores from the carbonate aquifer, and additional cores collected during the drilling of the monitoring wells.

WILLISTON BASIN MODELLING

The study area is located at the eastern margin of the Williston Basin. Aquifers in this sedimentary basin convey water a thousand km from recharge sites in the US to the base of the Manitoba escarpment (Bachu and Hichon, 1996; Burrus et al., 1996), where saline waters are discharged, producing the greatest development constraint and management hazard in the region. Furthermore, the current state of the aquifers in the study area are to a large degree related to linkage of the Williston Basin to the subglacial environment during the last glaciation. For example, it has been suggested that freshwater in the sandstone aquifer of the Interlake is subglacial recharge (Betcher, 1986), although this model has not been tested against current understanding of the Williston/Laurentide system. It therefore is crucial for successful completion of the project for a Williston/Laurentide model to be constructed that takes into account current knowledge of Williston Basin hydrogeology, of the geometry and thermal regime of the Laurentide Ice Sheet, of glacial isostatic vertical adjustments, and significant tectonic vertical adjustments if any. Plans call for a two-dimensional finite-difference model that will

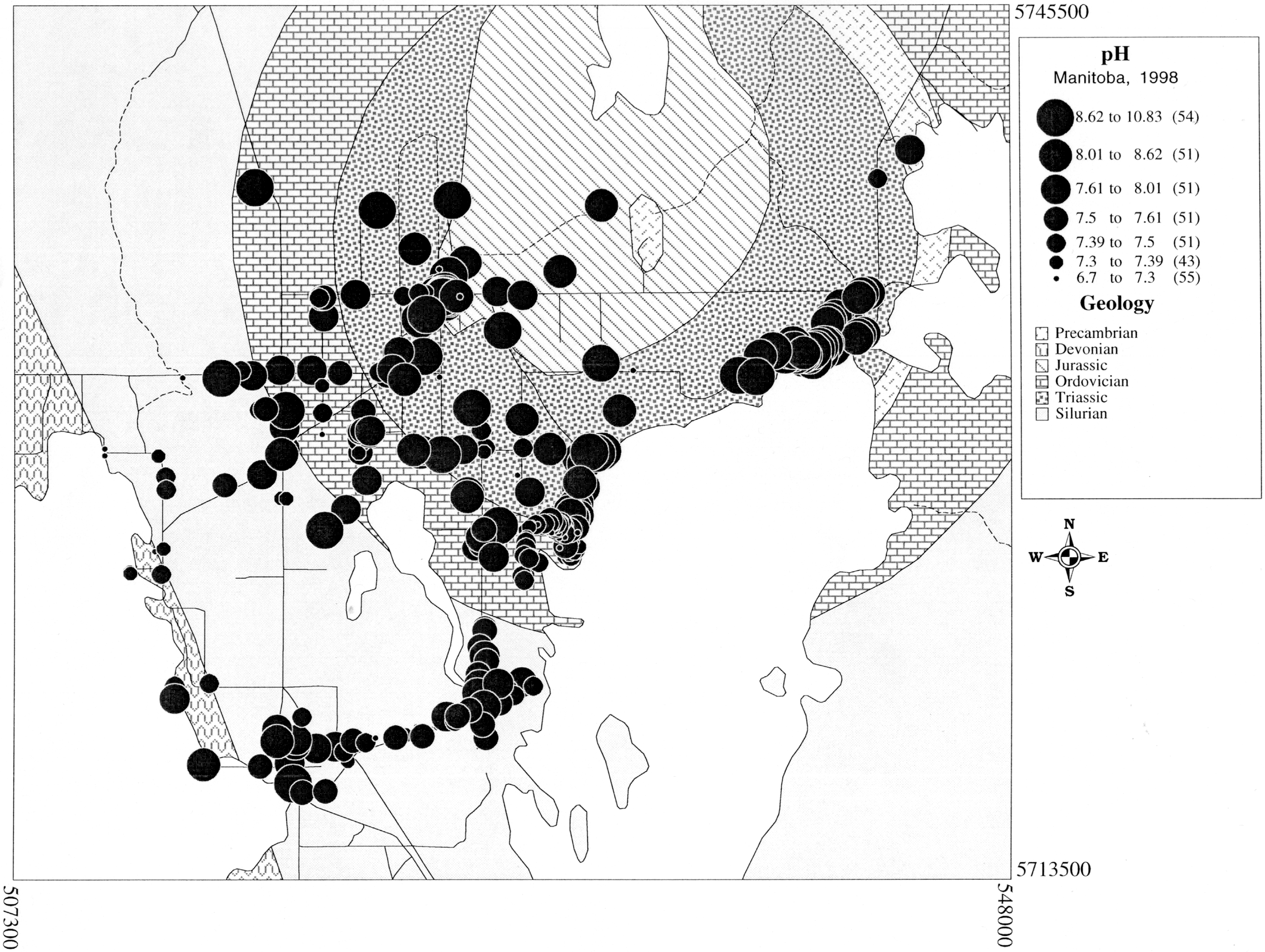

Figure GS-29-5: *Spatial distribution of groundwater pH with respect to the major lithologies in the Gypsumville study area.*

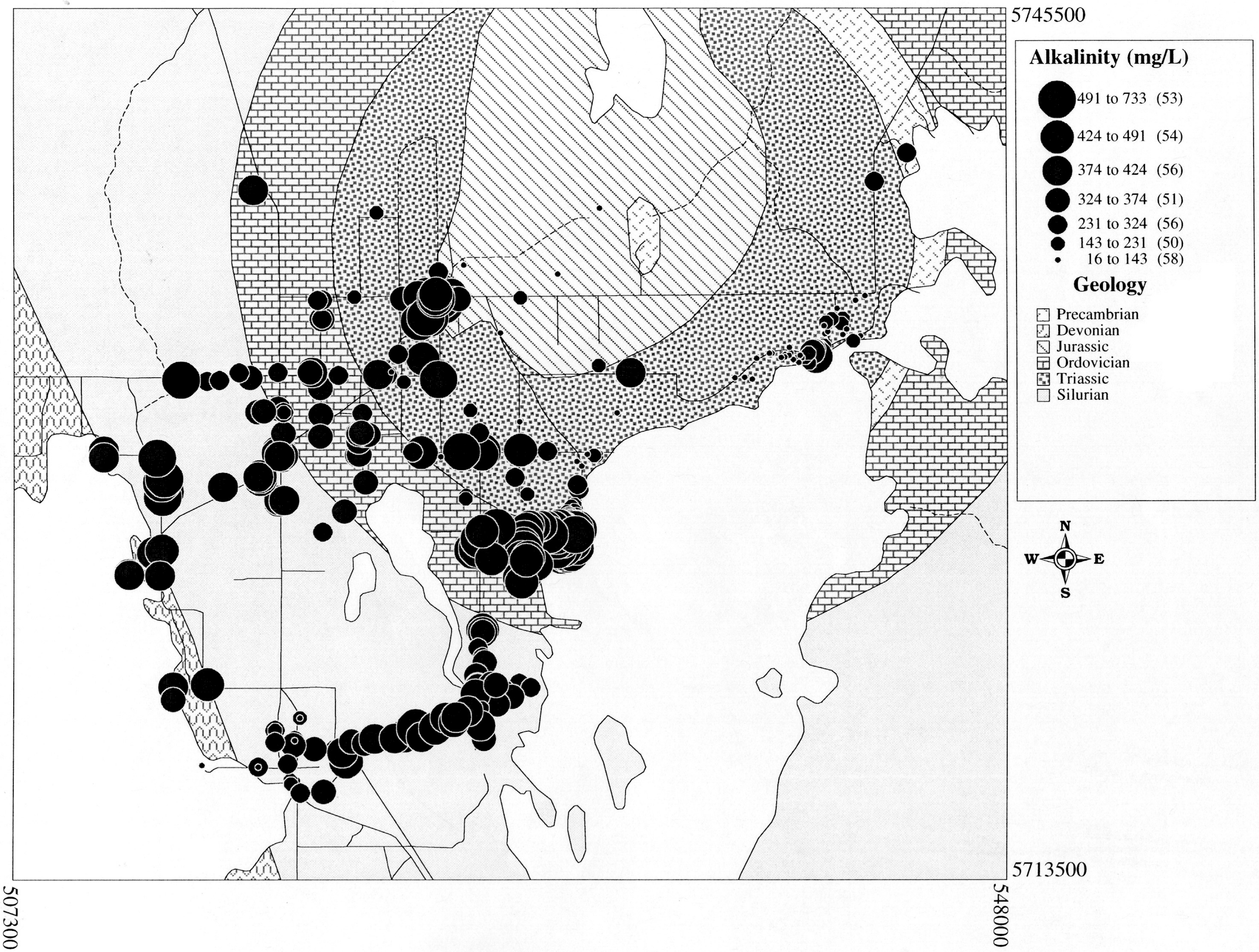

Figure GS-29-6: Spatial distribution of groundwater alkalinity with respect to the major lithologies in the Gypsumville study area.

address processes that govern the rate of flow, composition, and evolution of Williston saline waters. Integrated with the sedimentary basin model will be a simulation of the impacts of the Laurentide Ice Sheet, in order to assess the role of Pleistocene subglacial recharge on past and present groundwater systems. This work is being carried out in association with hydrocarbon-related modelling co-ordinated by GSC Calgary and the University or Alberta, incorporating effort by K. Osadetz, W. McDougall, S. Grasby, and Maowen Li of GSC Calgary, with contributions from elsewhere regarding subglacial conditions. Major contributions are made to this project by participants at several government agencies in Canada and the US, as well as at universities situated in North America to Australia and Israel.

MODELLING OF THE RED RIVER VALLEY/INTERLAKE SYSTEM

A key outcome of the project as a whole will be integration of available information in a manner that will allow enhanced predictions of the effects of groundwater development, such that current withdrawals may be managed, and potential for new development may be determined. 2D and 3D finite element modelling at the University of Manitoba, directed by A. Woodbury, will facilitate this objective, while also helping to set priorities for fieldwork and test hypotheses. The model will simulate flow in the rock aquifers and the sediments that control their recharge. Factors included will be flow from recharge to discharge areas, effects of withdrawals on groundwater levels and flow, migration of the saline front in response to groundwater development scenarios and natural variations in recharge, the fate of contaminants, impact of flowing wells, and inter-aquifer flow. The 3D geological model required for this groundwater modelling is being constructed at GSC Calgary as a joint hydrogeology/NATMAP initiative. This effort has necessitated a comprehensive upgrade of available drillhole databases.

The first phase of groundwater modelling, over the winter of 97/98, was undertaken as a post-doctoral project by Dr. D. Farrell in the Department of Civil and Geological Engineering at the University of Manitoba, and will now be carried forward by Ph.D. student P. Kennedy. The project involves evaluation of existing information and review of available models. Initially, a two-dimensional plan view finite element model is being developed. The model has the capability to simulate groundwater flow and mass transport in the bedrock aquifers as well as recharge and discharge. The impacts of groundwater withdrawals from the system by pumping are being simulated, as are the complexities of groundwater flow and mass transport near the fresh water-saline water boundary. This will lead to decisions as to the complexity and type of model that needs to be applied for subsequent phases, and whether to use an interconnected 2D plan view model, quasi-3D layered plan view, a series of 2D cross-sections, or a fully 3D model. Some of the outstanding issues to be resolved are coupling of temperature and salinity to groundwater flow, transient versus steady flow, location of the cross-sections, boundary conditions, and probabilistic vs. deterministic analysis.

Once the appropriate model has been chosen and development work carried out, calibration against existing information on water levels and water quality in the aquifers will be undertaken. Due to the number of variables, these initial simulations will be carried out as a sensitivity analysis to examine the effects of factors such as varying rates and locations of recharge/discharge, hydraulic interconnection between the aquifers, and seepage rates from the overlying unconsolidated materials. This work will force re-analyses and draw attention to priorities for field studies. Following calibration, the model will be applied to topics such as the effects of additional municipal withdrawals, the effects of inter-aquifer flow, the temporal stability of the fresh water-salt water front under various development scenarios, and impact of potential development scenarios such as dewatering for mine development.

The objective of the work is to develop an operational digital groundwater flow and mass transport model for the carbonate and sandstone aquifers of the Red River Valley/southern Interlake region. The model will include procedures for simulation of the impacts of groundwater developments that would allow water management and licensing decisions to be made with greater recognition of the complexity of the aquifer systems. Improved understanding of these groundwater systems will also support land use policy such as protection for critical recharge areas, further development of water level and water quality monitoring networks, and examination of groundwater contamination issues.

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