Natural Resources Canada
Ressources naturelles Canada

EARTH SCIENCES SECTOR
GENERAL INFORMATION PRODUCT 8

Groundwater discharge in the Humber River watershed

Hinton, M J; Russell, H A J; Bowen, G S; Ahad, J M E

1998

Originally released as: Groundwater discharge in the Humber River watershed, Hinton, M J; Russell, H A J; Bowen, G S; Ahad, J M E; in, Proceedings of the groundwater in a watershed context symposium; Piggott, A R (ed.); 1998; pages 213-220 (GSC Cont.# 1998115)

Canada

Groundwater Discharge in the Humber River Watershed

Marc J. Hinton[1], *Hazen A.J. Russell*[2], *Gary S. Bowen*[3], *and Jason M.E. Ahad*[4]

[1] Terrain Sciences Division, Geological Survey of Canada

[2] Department of Earth Sciences, University of Ottawa

[3] Science and Technology Branch, Ontario Ministry of the Environment

[4] Department of Geology, University of Toronto

Abstract

The Humber River watershed drains approximately 900 km^2 of urban, suburban and rural land within the Greater Toronto Area. Stream baseflow surveys were conducted to locate major areas of groundwater discharge within the watershed. This case study demonstrates potential uses of baseflow surveys for watershed studies and management.

Major groundwater discharge zones are located throughout much of the northwestern portion of the watershed where the Oak Ridges Moraine forms the largest surficial aquifer. This portion of the watershed accounted for approximately one third of total stream baseflow discharge. Localized groundwater discharge zones sustain most of the stream baseflow in the West and East Humber River watersheds. These discharge zones often are associated with shallow buried sand deposits that crop out along the stream. Surface and subsurface geological data suggest that these discharge zones are hydraulically connected with the Oak Ridges Moraine. Water chemistry surveys allow elemental fluxes from different portions of the watershed to be compared. Isotopic data suggest that leakage of municipal water drawn from Lake Ontario contributed to stream baseflow in urban areas but could not be estimated accurately.

Introduction

Groundwater discharge, the movement of water from the saturated zone in the ground to the ground surface, has important ecological functions. It sustains stream baseflow and saturation in wetlands, maintains specific habitats for aquatic ecosystems, and provides nutrients to these ecosystems. Groundwater discharge also has important social and economic roles including recreation, irrigation, fish farming, water supply, effluent receiver and dilution of contaminants. The importance of these uses are highlighted by the large number of the region's recreational areas that border water, and the economic impact of many activities such as sport fishing. Sometimes the social, economic and ecological roles are not compatible and there is a need for water management to provide a balance between competing uses and the natural functions of water that will ensure sustainable use of the resource.

Since groundwater discharge quantity and quality are influenced by land use, water management also involves land use management. As a result, the issue of groundwater discharge and stream baseflow are increasingly influencing land use and management practices. As this issue grows in importance, it is necessary to ensure that all those involved in watershed management have the necessary data on which to make informed decisions. Baseflow surveys can provide watershed managers with useful data to help make these decisions.

This paper provides an overview of baseflow survey results in the Humber River watershed.

These surveys have provided detailed information on: 1) the spatial and 2) temporal patterns of groundwater discharge within the watershed, 3) the relationship between groundwater discharge and geology, and 4) water chemistry in different portions of the watershed.

Study Area

The Humber River watershed is located on the northwestern shore of Lake Ontario with its headwaters on the Niagara Cuesta and the Oak Ridges Moraine. The watershed includes significant tributary subwatersheds, including Cold Creek, East Humber River, West Humber River, and Black Creek (Figure 1). Elevations in the watershed range from 75 masl at Lake Ontario to 480 m on the Niagara Cuesta (Figure 2). The topography is varied within the watershed; steep slopes and hummocky topography are found in the northern portion of the watershed (particularly northwestern), whereas the central portion of the watershed is relatively flat. The Humber River is incised in the central and lower portions of the watershed. The three most extensive surficial geological units in the watershed are mostly silt, sand and gravel of the Oak Ridges Moraine (ORM, 19%), overlying silty Halton Till (50%), and glacial lake silt and clay (12%) (Sharpe *et al.*, 1997, Figure 2). Detailed lithofacies descriptions of the ORM (Russell *et al.*, 1998) indicate that it is best modeled as a subaqueous-fan. Land use is variable in the watershed ranging from predominantly rural land use in the headwaters, towards suburban and urban land uses in Toronto. Black Creek and the lower Humber River are the most urbanized areas.

Methods

Two types of surveys were conducted: stream discharge and stream water chemistry. Baseflow surveys were conducted in August 1995 and August 1996 during low summer baseflow conditions following several days of dry weather. Under these conditions, stream baseflow is maintained predominantly by groundwater discharge with the exception of stored surface water in impoundments such as the Claireville Dam. Stream baseflow surveys consisted of measuring stream discharge at several locations in a short time (Figure 1). Since the watershed is large, the

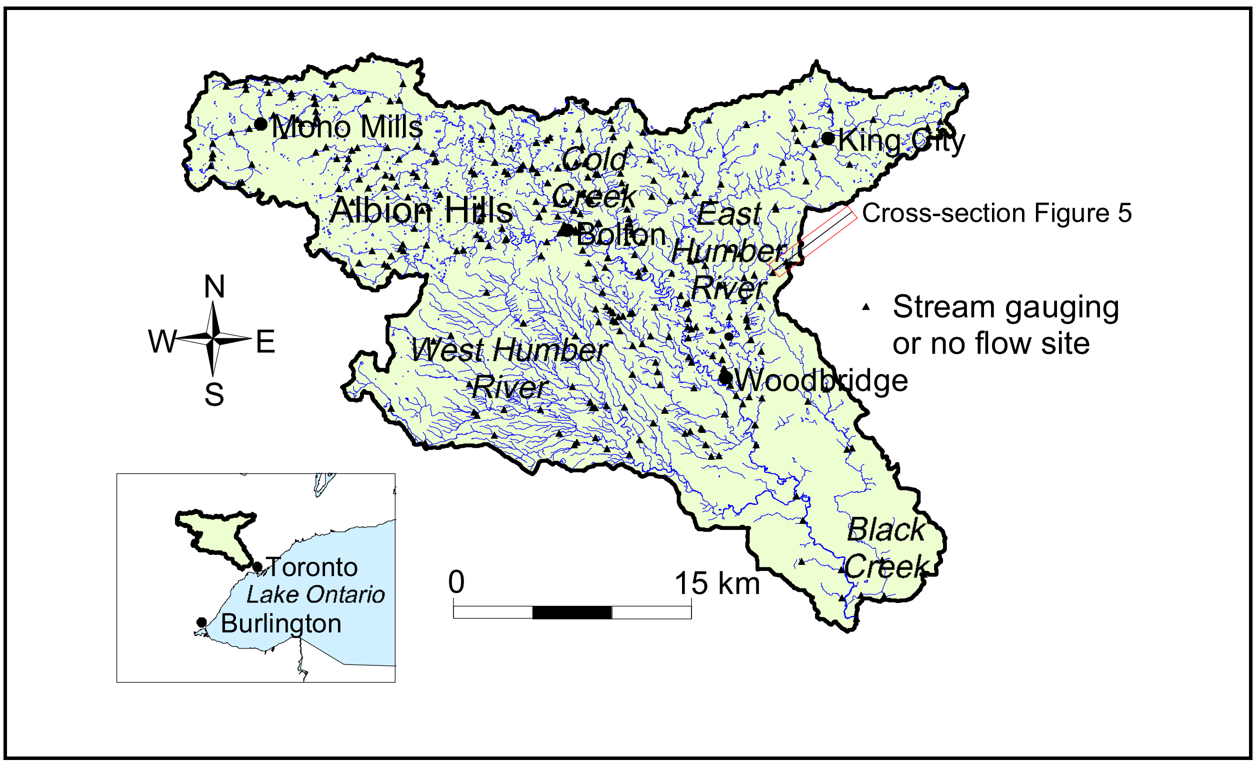

Figure 1: The Humber River Watershed, Stream Network and Stream Gauging or No Flow Sites

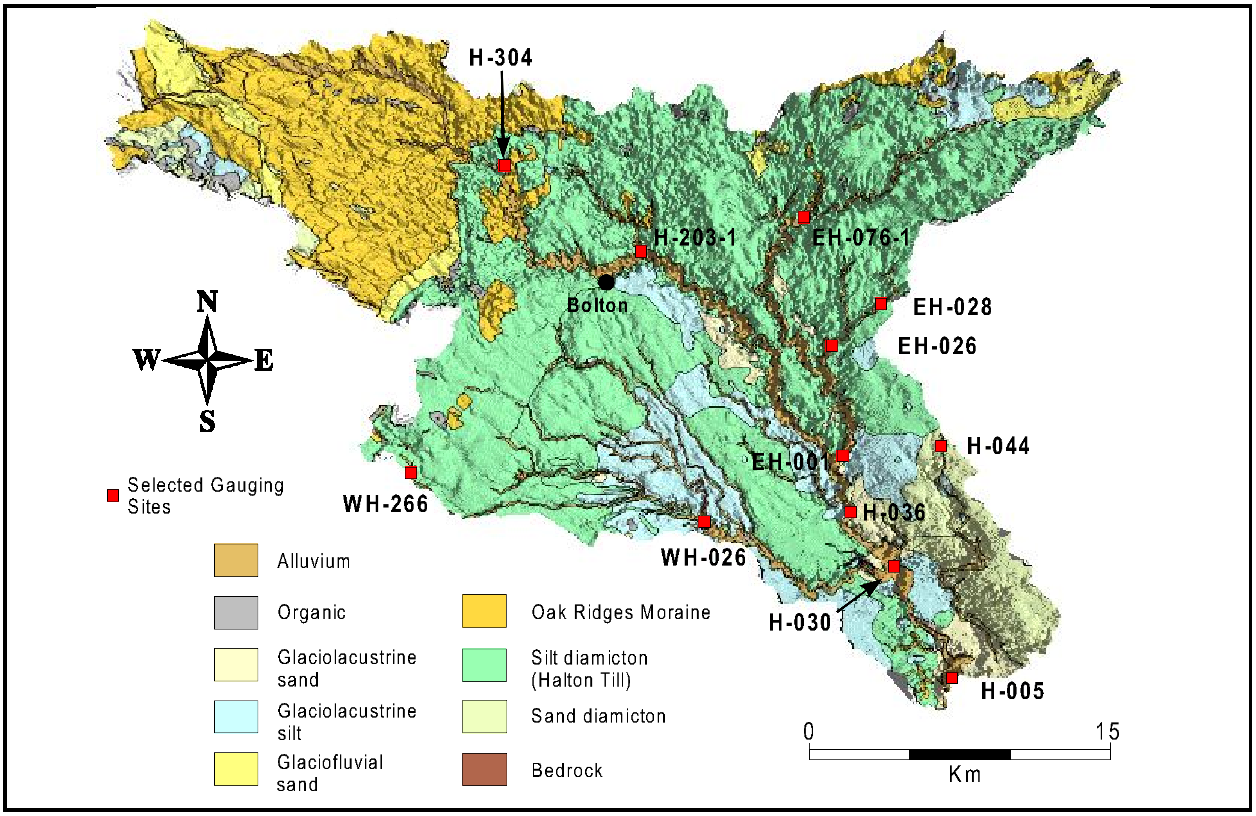

Figure 2: Surficial Geology Drape on a Digital Elevation Model. Note distinct landscape textural patterns and spatial and geological associations (Sharpe *et al.*, 1997; Kenny, 1998)

baseflow discharge survey was carried out as a series of surveys on individual subcatchments. Stream discharge was measured using standard velocity-area techniques (Rantz *et al.*, 1982) using Price AA and mini flowmeters, or floats on very shallow streams, and bucket measurements (volume/time) on waterfalls (usually at culverts). Prior reconnaissance surveys located suitable gauging sites and dry or almost dry (< 0.25 l/s) stream segments (Hinton, 1997). Measurements of stream discharge had a relative error of approximately 5%. Consequently, absolute errors increase downstream with an increase in stream discharge so that the most reliable determinations of net discharge are in upstream areas where the relative increases in discharge are highest.

Spatial Distribution of Groundwater Discharge

Most groundwater springs and discharge zones occur in the northwestern portion of the watershed along the edge of the Niagara Escarpment and throughout the Albion Hills (Figure 3). Groundwater discharge from this area (H-304, Figure 2) accounted for 34% of the total stream baseflow discharge in the Humber River (2,400 l/s at H-005).

The baseflow discharge surveys indicate that groundwater does not discharge uniformly across the watershed but rather is concentrated in specific areas. Whereas groundwater discharge zones occur throughout much of the northwestern area, large discharge zones are limited to localized areas in the remainder of the watershed (Figure 3). In the West Humber River, there is only one discharge zone in excess of 15 l/s (WH-266). In the East Humber River, there are important discharge zones near sites EH-076-1 and EH-028 (Figure 2).

There also were increases in stream baseflow within urban areas of the watershed. Stream baseflow increased along the East Humber River in Woodbridge (EH-001), along the lower Humber

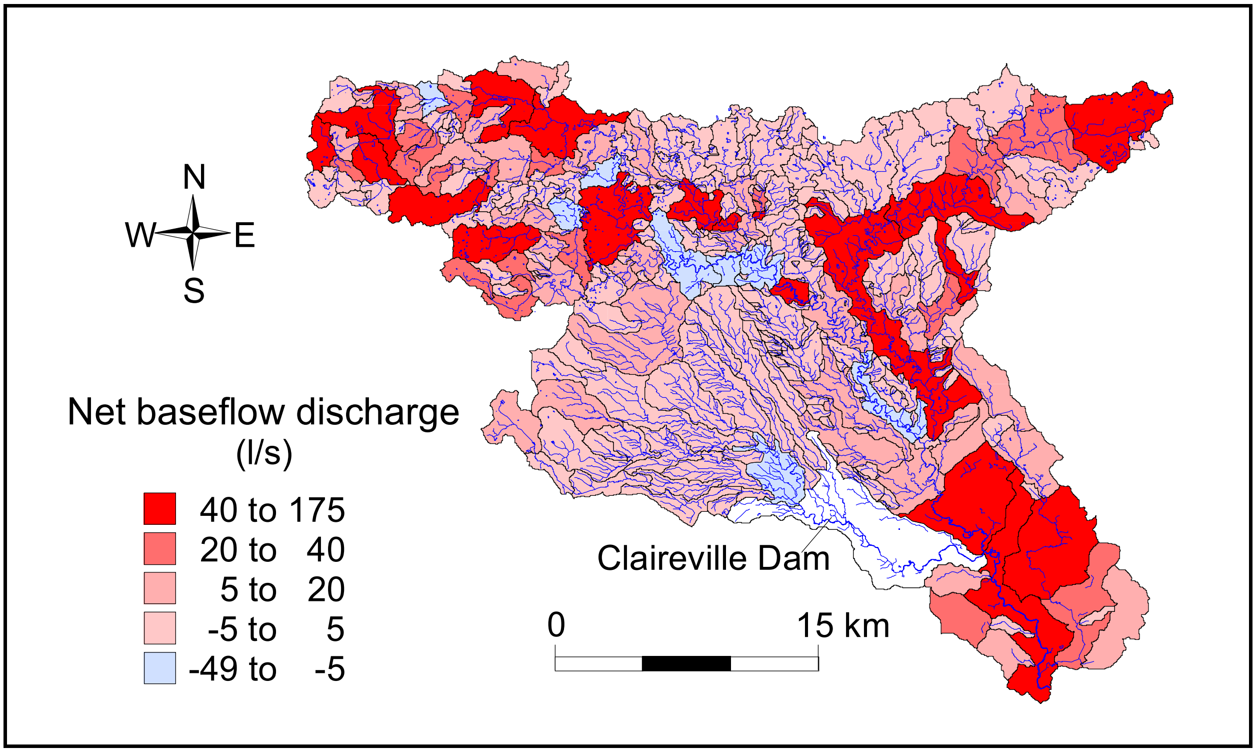

Figure 3: Net Baseflow Discharge, mid-August 1996

River downstream of Woodbridge (H-036) and along the Black Creek downstream of H-044. Some of this increase occurs as drainage from culverts into the rivers; however, the baseflow discharge surveys alone could not distinguish between flow which originates as groundwater discharge, urban discharge into culverts or from leakage of urban waterworks.

Temporal Variations in the Stream Baseflow Patterns

Although stream baseflow discharge was much higher in 1996 than in 1995 (1,800 l/s vs. 1,000 l/s at site H-030), the relative proportions of stream discharge from different watershed areas remained relatively constant for the two surveys (Figure 4 A)). Similarly, the long-term median August baseflow from Water Survey of Canada (WSC) gauging stations (Cummins Cockburn Ltd., 1990) generally show similar proportions of discharge to the baseflow surveys (Figure 4 B)). These results suggest that a single stream baseflow survey can provide a reasonable estimate of the spatial distribution of groundwater discharge.

One exception to the constant spatial pattern of stream baseflow discharge is the East Humber River where the proportion of baseflow in 1996 exceeded those of other years (Figure 4). Between August 13 and 26, 1996, stream baseflow in the East Humber River (EH-001) decreased by 45%. During a similar period, net discharge remained nearly unchanged near sites EH-076-1 (+14%) and EH-028 (0.0%) but decreased dramatically in the headwaters (-89%) and lower portions (-69%) of the East Humber River. This difference suggests that groundwater flow contributing to baseflow in the headwater areas is likely very shallow and is influenced by increasing drought whereas discharge areas near sites EH-076-1 and EH-028 have more constant discharge that are maintained by deeper groundwater flow.

Geological Controls on Groundwater Discharge

Groundwater discharge is closely correlated with the surficial geology map units. Most groundwater discharge areas are associated with the deposits of the ORM whereas very little discharge

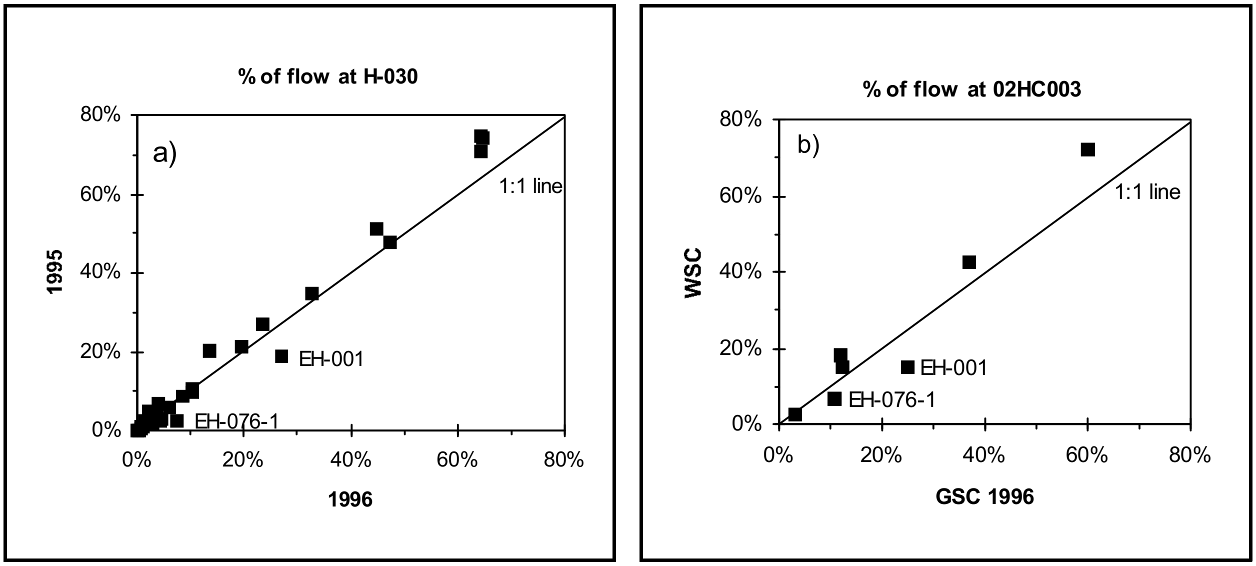

Figure 4: Proportions of Baseflow Discharge at Individual Sites at Different Times, A) 1995 and 1996 Surveys, B) 1996 and Long-term Water Survey of Canada Gauging Stations

occurs in areas of exposed Halton Till. This result is most clearly demonstrated by comparing the baseflow discharge of 36 l/s in the West Humber River (at site WH-026) where 91% of the contributing area (145 km^2) is Halton Till and glacial lake deposits, to the baseflow discharge of 790 l/s in the upper Humber River (at site H-304) where 77% of the contributing area (160 km^2) is glacial deposits of the ORM. Furthermore, most of the discharge in the West Humber River is associated with small outcrops of ORM (3% of the contributing area).

Groundwater discharge provides insight into hydraulic connections of buried sediments. Along river valleys, small sand and gravel outcrops frequently are associated with localized high discharge. Geological cross-sections of borehole data support the hypothesis based on discharge data that these small, seemingly isolated, outcrops are connected to the ORM (Figure 5). Southwest of King City, continuously cored boreholes indicate the moraine is dominated by a rhythmic succession of silt and fine sand (K ~ 10^{-5} to 10^{-7} m/s) with an irregular, isolated occurrence of sharp based, medium-coarse sand to gravel beds (K ~ 10^{-4} m/s) of 0.5 to 2 m thickness (IWA, 1994). To sustain the high baseflow discharge at EH-026 (87 l/s) requires hydraulic conductivities of at least 10^{-4} m/s. Therefore, these high groundwater discharge zones are sustained by flow through coarse channelized beds within the finer silt-fine sand sequence of a distal subaqueous fan environment. Other examples of localized groundwater discharge areas in the watershed include Cold Creek (H-203-1), and the East Humber River near site EH-076-1. These areas are particularly significant because stream baseflow from surrounding areas is low.

Baseflow Water Chemistry Surveys

Baseflow water chemistry surveys can provide insight into spatial sources of contaminants (Bowen and Hinton, 1998). When combined with baseflow gauging results, chemical concentrations also can be used to compare baseflow elemental fluxes from different portions of the watershed and isolate areas of potential concern. For example, nearly one third of the baseflow flux of chloride is discharged from Black Creek. This flux is almost equal to the combined flux of chloride from the upper Humber River and East Humber River portions of the watershed.

Analysis of the isotopic composition (^2H and ^{18}O) of baseflow was conducted to distinguish between natural sources of groundwater discharge and urban water sources. Lake Ontario water is

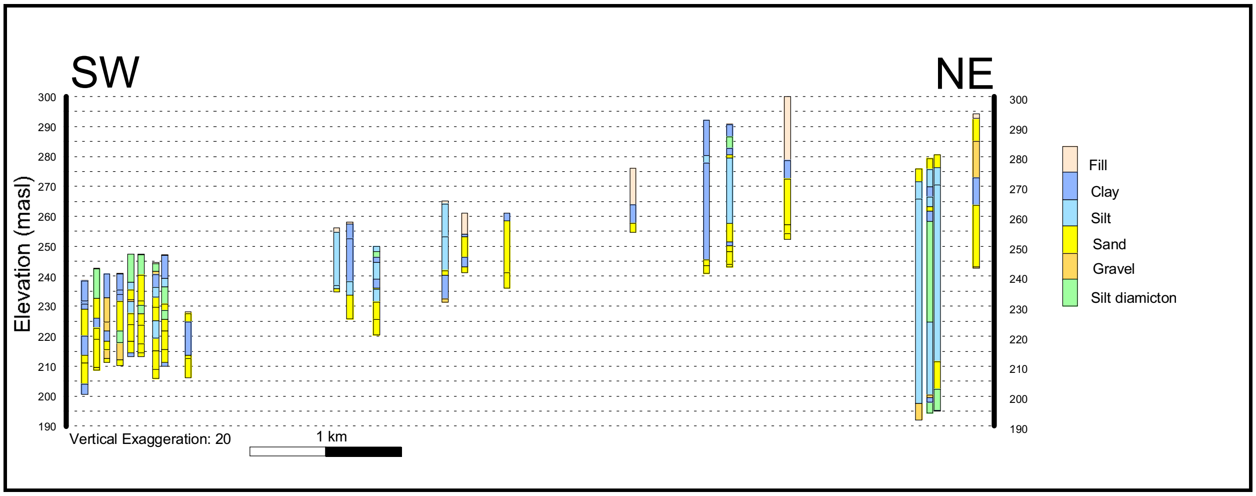

Figure 5: Geological Cross-section Near EH-028. Section Location Shown in Figure 1

the water supply for the urbanized southern part of the watershed. This water is subject to isotopic enrichment by evaporation. Stream baseflow generally shows a progressive downstream enrichment in ^{2}H and ^{18}O (Figure 6). Small tributary streams in urban areas have isotopic ratios most similar to Lake Ontario. A simple isotopic mixing between Lake Ontario water and upstream source areas suggests that urban streams have between 27 and 88% of Lake Ontario water and downstream sections of the main Humber could have as much as 30 to 49%. However, these values overestimate urban water contributions since isotopic enrichment of the source water also occurs within the river. In theory, one could solve an isotopic mass balance equation to determine the isotopic composition of the net increase to baseflow in the urban areas; however, the errors in the net discharge estimate preclude an accurate mass balance calculation.

Watershed Management Implications

While gauging stations provide invaluable discharge records over time, such data often are insufficient to address common local scale issues. As demonstrated for the Humber River watershed, groundwater discharge zones can be restricted to small areas. These local, high discharge areas should be managed carefully since an activity that occupies a small area could have a large impact on the watershed. With the understanding provided by baseflow surveys, limited resources can be targeted to protect key areas. Stream baseflow surveys provide useful and inexpensive data that can be used to address immediate watershed management issues (e.g., fish habitat), to provide historical data for monitoring purposes and for scientific study.

Acknowledgements

This study was jointly funded by the Geological Survey of Canada, the Ontario Ministry of the Environment and the Toronto and Region Conservation Authority. We greatly appreciate the help of Chris Kozuskanich, Costa Samaras, Derek Law, and Abe House in conducting the baseflow surveys. We thank the National Calibration Service of the National Water Research Institute which provided individually calibrated flow meters. Environment Canada supplied the wading rods.

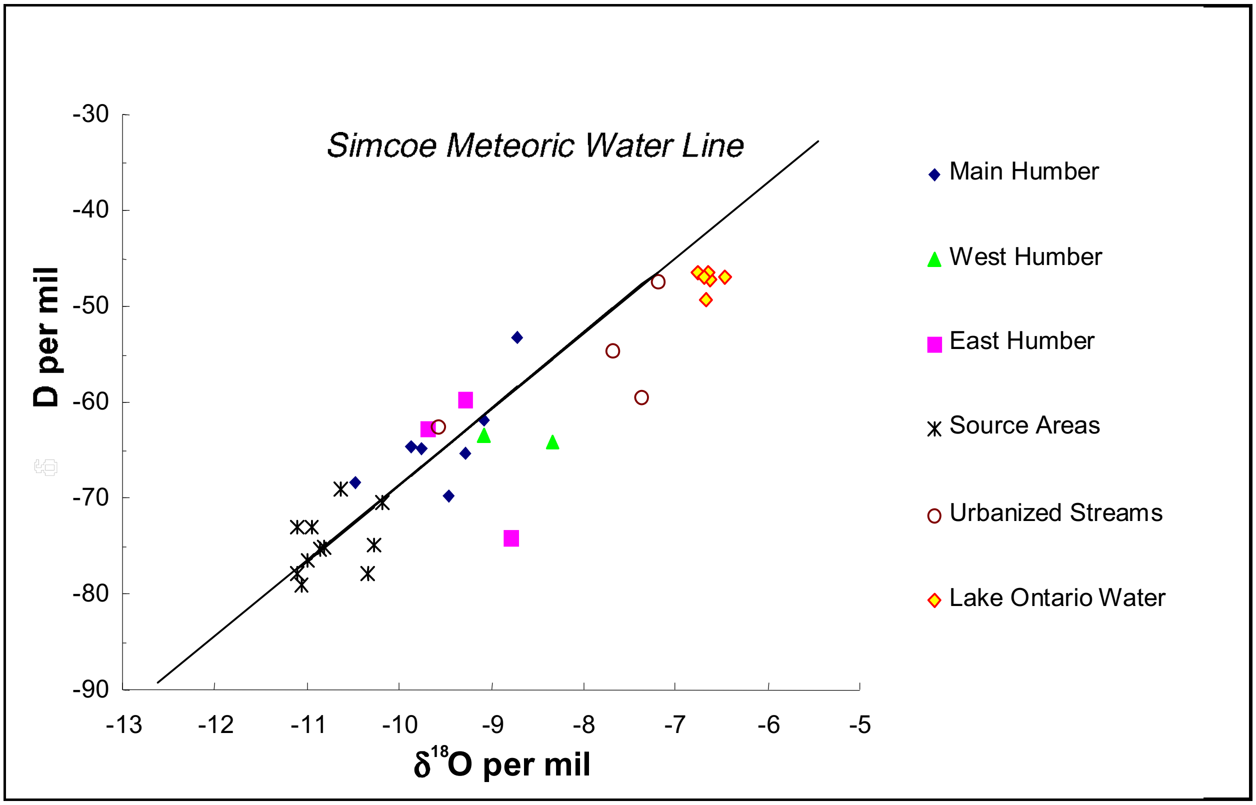

Figure 6: $\delta^{18}O$ vs. δD for Various Streams of the Humber River Watershed Plotted Along the Simcoe Meteoric Water Line

References

Bowen, G.S. and Hinton, M.J. 1998. The temporal and spatial impacts of road salt on streams draining the Greater Toronto Area. In Proceedings of the Groundwater in a Watershed Context Symposium, Burlington, Ontario. (These proceedings).

Cummins Cockburn Ltd. 1990. Low flow characteristics in Ontario. Appendix B: Central region. Prepared for Water Resources Branch, Ontario Ministry of the Environment.

Hinton, M.J. 1997. Groundwater discharge in the Humber River watershed: preliminary report. Prepared for the Metropolitan Toronto and Region Conservation Authority, 53p.

IWA (Interim Waste Authority). 1994. Detailed assessment of the Proposed site V4A. Appendix C: Geology/Hydrogeology.

Kenny, F. 1998: A chromostereo enhanced Digital Elevation Model of the Oak Ridges Moraine Area, southern Ontario. Geological Survey of Canada and Ministry of Natural Resources, Geological Survey of Canada Open File 3423, scale 1:200 000.

Rantz, S.E. and others. 1982. Measurement and computation of streamflow: volume 1. Measurement of stage and discharge. U.S. Geological Survey Water-Supply Paper 2175. Washington, D.C., 284p.

Russell, H.A.J., Sharpe, D.R. and Arnott, R.W.C. 1998: Sedimentology of the Oak Ridges Moraine, Humber River watershed, southern Ontario: a preliminary report. In Current Research 1998-C; Geological Survey of Canada, p 155-166.

Sharpe, D.R., Barnett, P.J., Brennand, T.A., Finley, D., Gorrell, G., Russell, H.A. and Stacey, P. 1997: Surficial geology of the Greater Toronto and Oak Ridges Moraine area, southern Ontario. Geological Survey of Canada, Open File 3062, scale 1:200 000.