# Environmental Geology of Urban Areas

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## SUMMARY

This paper is the first in a series that will appear in future issues of *Geoscience Canada*. All 39 papers will be published in one volume by the Geological Association of Canada. The text is primarily intended to be a source of readings for senior undergraduate and graduate students. Many of the papers are state-of-the art summaries and will also be essential reading for professional environmental geologists already working in urban areas. The future well-being of urban society is reliant on an informed and proactive citizenry and it is hoped that the lay reader, urban planner, and business person can also learn something of the environmental geological problems associated with urban areas. For this reason, an extensive glossary of commonly used terms is provided. The book will be an aid to the teaching of academic courses and also be of practical use. Above all, we hope it will inform, interest and stimulate the reader.

## RÉSUMÉ

Cet article est le premier d'une série à paraître dans les prochains numéros de *Geoscience Canada*. Réunis en un seul volume, ces 39 articles seront publiés ensuite par l'Association géologique du Canada. Il s'agit d'abord d'un ouvrage de référence à l'intention des finissants et des diplômeés. Dans plusieurs cas, il s'agit d'articles de synthèse sur l'état actuelle des connaissances, et à ce titre, ils constituent des références obligées pour les professionnels à l'oeuvre dans le milieu de l'écogéologie. Dans la mesure où le bon fonctionnement des sociétés urbanisées dépend du niveau d'information et de l'attitude proactive de leurs populations, nous aimons croire que le profane, l'urbaniste, et les gens d'affaire pourront y puiser des connaissances sur les problèmes écogéologiques en milieu urbain. C'est pourquoi cet ouvrage comprendra un glossaire important des termes les plus courants. Ce livre sera à la fois une référence pour des cours universitaires et pour les praticiens de l'écogéologie urbaine. Nous espérons surtout qu'il sera une source d'information, et qu'il stimulera l'intérêt du lecteur.

## ENVIRONMENTAL GEOLOGY

Geology has a long record as an academic discipline, and geologists play a key role in society. However, in recent years the focus of geological applications has broadened. Environmental geology has emerged as a distinct field, and traditional discipline boundaries have dissolved. There have been major changes in employer needs and job markets.

Environmental geology can be formally defined as the application of geological science to practical issues relating to human activity (Chan *et al.*, 1987; Dunlap *et al.*, 1992; National Research Council, 1993, 1994; Montgomery, 1994; Innes Lumsden, 1994; Figs. 1, 2). The central characteristic that distinguishes environmental geologists is their strongly interdisciplinary approach, drawing on such areas as chemistry, physics, biology and, increasingly, economics, urban planning, and the law. This is reflected in changing curricula in universities and in the integration of geology with other disciplines formerly taught as separate entities. A training rooted only in geology is no longer sufficient and there is now increasing emphasis on wider systems approaches to education and training (what has been called "earth system science"; National Research Council, 1993).

## URBAN GROWTH AND ENVIRONMENTAL DEGRADATION: A FOCUS FOR ENVIRONMENTAL GEOLOGY

On a global scale, the combined forces of urbanization and a rapidly expanding chemical industry have been responsible for great improvements in the quality of life over the last 150 years. Ironically, these same forces now threaten the global environment. Urban areas are widely characterized by intense and often unregulated industrial activity, rapid and poorly planned growth, the fragmentation of natural habitats, and the degradation of surface and ground waters by a wide range of chemical contaminants.

More than 70% of the world's population now lives in urban areas and there are more than 20 so-called "supercities," each containing more than 10% of their respective national populations. Examples include Mexico City (31% of national population), Buenos Aires (42%), Cairo (36%), and Sao Paulo (17%; Turner *et al.*, 1990; United Nations Population Fund, 1991). Whereas the growth of cities is the engine of the world economy and generates enormous social benefits, most global environmental problems of the late 20th century can be linked directly to the massive transfers of resources and

**Geology**: The study of planet Earth

**Environment**: The sum of all the features and conditions surrounding an organism that may influence it

**Environmental Geology**: Since planet Earth provides the fundamental physical environment for organisms, then all of geology can be regarded as environmental geology. However, the term is increasingly restricted to:

- Understanding geologic processes as they relate directly to human activities
- Identifying constraints imposed on human activities by geologic processes, availability of resources, and disposal of wastes

**Figure 1** *Definition of environmental geology (after Montgomery, 1994).*

waste products required by large cities. Terms such as "urbanization," "economic imbalance," and "environmentally unsustainable" are becoming synonomous (Tabibzadeh *et al.*, 1989; Stren *et al.*, 1992; Socolow *et al.*, 1994; Drakakis-Smith, 1995).

Whereas geologists have a long history of working in cities alongside engineers (*e.g.*, Legget, 1973), the artificial, built landscapes of urban areas have, by and large, been seen seen as "poor places to do geology" (Walton, 1982). Despite a wealth of subsurface geological and hydrogeological data in urban areas, there has been little effort to systematically collect and consolidate such information by government agencies; mining and other resource-based projects in the far north have traditionally taken precedence over the environmental needs of the immediate south. This situation is rapidly changing in the face of heightened public concern with urban environmental and health issues and is reflected in new planning legislation and land use regulations.

The principal environmental geological concerns in urban areas centre on the provision of adequate drinking water, waste disposal, soil and landscape degradation, and the increasing vulnerability of densely populated urban areas to geological hazards and environmental disasters. Environmental geologists working on such problems are, in the main, employed by the environmental-consulting sector. There is increasing interest by private companies and financial institutions (particularly insurance and banking) concerned with the safety of investments arising from litigation over contaminated properties or geological hazards, and the need for clients to recognize and comply with environmental regulations.

Concern with the sustainability and viability of urban environments is promoting collaboration between environmental geologists, planners, legislators and workers in public health. This interdisciplinary approach has spawned several new journals, such as *Environmental Geology* (Springer), *Environmental & Engineering Geoscience* (Geological Society of America and Association of Engineering Geologists), *Environmental Modelling and Assessment* (Baltzer Science Publishers), *Journal of Environmental Planning and Management* (Carfax Publishing), and *Environment and Urbanization* (International Institute for Environment and Development). In addition to the established journals serving specific areas such as ground water, planning and public health, these new journals provide a forum for environmental geological studies of urban areas and avenues for collaboration between scientists and policy makers. 1991 saw the formation of the International Working Group on Urban Geology, with its primary focus the improvement of communication between environmental geologists and city planners (*Urban Geology News*, 1995).

Growing recognition of the importance of environmental geology, and the need for an increased body of professionals, is reflected in new programs in universities and colleges and the availability of textbooks (*e.g.*, Keller, 1992; Montgomery, 1994; Pipkin, 1994; Murck *et al.*, 1996). Their use to a Canadian audience is strictly limited however, because most of their contents focus on American experience emphasizing the clean-up projects funded by the United States Environmental Protection Agency Superfund. Published case examples of the wide range of everyday urban environmental geology investigations being undertaken in Canadian urban communities are still relatively few and found mostly in the "grey literature" of government and private-sector reports.

**Scope of Environmental Geology**

1) Understanding and managing earth processes
2) Providing sufficient resources *e.g.*, water, minerals and fuels; coping with hazards *e.g.*, soil erosion, ground and surface water contamination, improper mining and waste disposal practices
3) Avoiding excessive disturbance and pollution of geological environments *e.g.*, soil erosion, ground and surface water contamination, improper mining and waste disposal practices
4) Anticipating and adjusting to environmental and global changes
5) Ensuring long-term viability of society as it relates to public heath/safety and geologic processes
6) Providing reliable technical information for environmental decision making
7) Ensuring a sufficient number of well-qualified professionals
8) Effective collaboration with other sciences
9) Public education

**Figure 2** *Scope of environmental geology.*

## OBJECTIVES OF *ENVIRONMENTAL GEOLOGY OF URBANIZED AREAS*

The principal objective of this new volume is to provide case examples of environmental geological investigations in Canadian urban areas. Despite a picture postcard image of vast tracts of wilderness, the country is, in fact, heavily urbanized. Statistics Canada (1994) defines an urban area as a community with a total population of more than 1000 persons and having a density of at least 400 persons per square kilometre. In 1871, 19% of the nation's population lived in an urban area. This figure had risen to 76% a century later. The latest available (1991) figure is 76.6%, which is close to the proportion of the world's population currently identified as urban (74%). Illustrative figures for other countries are 74.1% for the United States, 76.9% for Japan, 85.5% for Australia, 21.4% for China, 83.9% for Sweden, and 72.6% for Mexico.

In Ontario and Quebec, the most populous provinces in Canada, the present-day urban population accounts for 81.8% and 77.6%, respectively, of the provincial totals (Statistics Canada, 1994). The provinces of British Columbia and Alberta also have relatively high proportions of urban residents (80.4% and 79.8%, respectively) compared with the global average. Only New

Brunswick, Prince Edward Island and the Northwest Territories have fewer urban residents compared to those living in rural areas. Close to one-third of the national population of Canada (28,118,000 as of 1991), is now concentrated in three emerging supercities, Vancouver, Toronto and Montreal, all clustered along the United States border.

Canadian developments parallel the global transfer of population from rural to urban areas. But, contrary to the global trend for the development of sick cities, Canada has a well-deserved image of having one of the best-housed populations in the world. Our cities are safe and vital, and there is considerable interest in the Canadian experience of regulating, preventing and dealing with urban environmental geological problems. The environmental sector is a major employer of university and college graduates; in 1994 some 55% of geology graduates across North America found employment in the environmental sector. In the province of Ontario alone, the sector employs more than 38,000 people, working for 2200 companies, and generates $3.5 billion annual revenue for the province, much of which comes from the export of environmental expertise and technologies outside Canada (Canadian Environmental Directory, 1994/5). For comparison, the provincial mining industry employs 25,000 people and generates some $2.5 billion in revenues.

## THEMES

Most of the papers in the book focus on environmental geology problems in the heavily urbanized core of central Canada, in Ontario. These are intended to provide important case examples for comparison with other urban communities across the nation.

### Environmental Geology of Urban Areas

The first theme establishes the general scope of environmental geology of urban areas. Nick Eyles describes the environmental geological setting of the Greater Toronto Area, the largest urban complex in Canada, containing 16% of the national population. The contamination of ground and surface waters from a wide range of point and non-point sources, the remediation of contaminated industrial sites, and the legacy left by improper disposal of a wide range and large volume of municipal, industrial and nuclear wastes are the principal issues and are common to most urban areas in southern Canada.

Urbanization north of 60° latitude presents a rather different set of challenges. Because of cold conditions that persist year round, more than 50% of Canada is underlain by some form of permanently frozen ground (permafrost), and this has historically impeded northern development. About 50,000 Canadians live on permafrost. The major problems associated with urban development in permafrost terrains are reviewed by Hugh French and relate to the ease with which permafrost is made unstable when disturbed by construction. Because of unique ground-water conditions in permafrost areas, the provision of water to urban communities is a major challenge and a constraint to future growth.

### Ground-water Contamination

Ground-water contamination in urban settings is the second and major theme of the volume. Most urban centres are faced with an increasing demand for responsible environmental policies regarding the safety of drinking-water supplies. Ken Howard identifies the principal global sources of contaminants in urban areas and, in a subsequent paper with Steve Livingstone, shows how to conduct a quantitative assessment of the potential impact of such sources. Stanley Feenstra highlights the widespread problem of contamination by chlorinated solvents emanating from the dry-cleaning industry. In addition, there are approximately 200,000 underground fuel storage tanks in Canada, of which between 20,000 and 40,000 are estimated to leak. Ground-water contamination by hydrocarbons from such tanks is reviewed by Jean Pierre François and Hugh Molyneux; this widespread problem is also touched upon by several other papers in later sections of the book. Ken Howard and Janet Haynes identify the serious environmental impacts of the widespread Canadian practice of using salt as a road de-icing chemical in winter.

### Ground-water Resource Evaluation and Protection

Resolving the sources of contamination of urban ground waters goes hand in hand with ground-water resource evaluation and protection. In mid-continent North America, about 110 million people live within the area directly affected by Pleistocene glaciations. Aquifers within complex successions of glacial sediments are a significant source of municipal drinking water for many communities. In southern Ontario, the largest aquifer system within the Toronto-centred region occurs within the Oak Ridges Moraine, which is threatened by urban development. An overview paper by Ken Howard and his colleagues Nick Eyles, Phil Smart, Joe Boyce, Rick Gerber, Sean Salvatori and Mike Doughty describes the formation and geology of the moraine and gives the broader context for a detailed paper by Rick Gerber and Ken Howard on quantitative evaluation of the moraine's ground-water resources. The need for proactive legislation to prevent contamination of ground-water resources by restricting land uses in the vicinity of municipal wells (wellhead protection) is an emerging issue in municipal planning, nation wide. Steve Livingstone, Thomas Franz and Nilson Guiguer review the types of information that are required to carry out wellhead protection and demonstrate the application of two-dimensional and three-dimensional computer modelling.

### Surface-water Contamination

Ground water is only one element of the urban hydrological cycle and the fourth theme of the volume is that of surface-water contamination. This is a problem associated with all urban areas and arises from the flushing of contaminants deposited on urban streets and other built surfaces into nearby waterbodies. Miron Berezowsky reviews the history of using constructed wetlands to assist in remediation of surface-water quality and provides examples of their use in controlling urban storm runoff and mine drainage waters. Given the historic dominance of a resource-based economy in Canada, the management and treatment of waste waters derived from either acidic or basic mine tailings is a major concern in many urban communities. Andréa Bolduc, Marc Lafléche and Louise Talbot describe the geochemical impacts on surface waters caused by basic mine drainage at Montauban, Quebec. Nelson Belzile, Douglas Goldsack, Stephanie Maki and Andrew McDonald describe the Sudbury urban area of Ontario where highly acidic surface waters are the legacy of a long history of nickel mining and smelting and where some 35,000 tonnes of sulphide-rich tailings continue to be dumped every day.

**Urban Waterfronts**

Many environmental geologists are particularly concerned with urban waterfronts with their long history of industrial use and contamination from urban-impacted surface waters, sewage and contaminated ground water. John Coakley and Alena Mudroch describe case examples of contaminated harbours in the Great Lakes and St. Lawrence regions and argue that assessment and design of waste-water management systems is highly dependant upon knowledge of sediment transport and deposition. Hamilton Harbour, at the western end of Lake Ontario, has been identified as one of over 40 severely affected areas in the Great Lakes basin. Ken Versteeg, Bill Morris and Norm Rukavina identify and map the impact of the iron and steel industry on sediment quality in the harbour, using magnetic properties of contaminated sediment. Gordon Fader and Dale Buckley review a long history of waste-water management problems in Halifax Harbour, Nova Scotia where bottom sediments affected by sewage now contain the highest levels of metal contamination anywhere recorded in Canada. These workers similarly conclude that knowledge of geological processes is fundamental to remediation and management of contaminated waterfronts and harbours.

Rising sea and lake levels result in significant erosion problems along urban shorelines, requiring costly, ongoing remediation. However, the construction of hardened, artificial shorelines has to be balanced with the competing need to preserve areas of natural habitat and public recreation. These issues are illustrated by Rob Nairn and Nigel Cowie using the heavily urbanized Scarborough waterfront area of Lake Ontario, near Toronto. Bruce Hart and Vaughn Barrie describe the offshore environmental geology of the Fraser Delta in the Vancouver area of British Columbia, paying particular attention to the hazard posed by submarine landsliding caused by earthquakes, together with debris and wastes left by previous industrial activity.

**Urban Waste Management**

Problems of urban waste management are common to all urban areas worldwide. Nick Eyles and Joe Boyce review geological constraints on municipal waste management practices in southern Ontario that, hitherto, have focussed on disposing of wastes in the ground (landfills). An historical perspective by Richard Anderson reminds us that waste management is not a new problem in the Toronto area, and further, that the number and location of historic dumps is not at all well known. Modern landfills are highly engineered structures designed to protect underlying ground waters from contaminants that are leached from the waste pile; a guide to detailed siting and design requirements is presented by Kerry Rowe and Mike Fraser. Detailed studies of the geology of waste sites are essential; Laurence Andriashek, David Thompson and Reed Jackson show how an understanding of geological complexity arising from glacially deformed substrates below the municipal landfill at Edmonton, Alberta, is necessary to understand the site's hydrogeology. Leachate migration away from landfills sited in former quarries along the Niagara Escarpment, near the city of Hamilton, Ontario, is documented by Jean Birks and Carolyn Eyles. Landfills also produce voluminous amounts of methane gas; the isotopic and geochemical characteristics of landfill methane are established by Steve Desrocher and Barbara Sherwood Lollar and compared with background methane sourced from glacial sediments and bedrock. All of the above papers provide case studies that can assist investigations elsewhere.

**Contaminated Substrates**

Many urban areas are characterized by contaminated substrates arising from historic landfilling of low-lying areas, to create new land for development, and unregulated industrial activity. Kim Bolton and Les Evans identify the sources and geochemistry of the principal inorganic and organic contaminants found in such sites. Many contaminated sites occur in downtown, inner-city locations that are now being rezoned and developed for residential and mixed-use purposes. Monica Campbell and her co-authors, Joan Campbell, Stephen McKenna, Scott MacRitchie and Miriam Diamond, show how development applications in contaminated areas in the city of Toronto are now being scrutinized from a public health perspective before being given approval to proceed. The intention is to identify the most appropriate clean-up technology that will not only protect the public during site remediation but ensure the health of future users.

**Geological Hazards**

The effects of geological hazards are magnified in densely populated urban areas. The natural release of radioactive radon gas in urban areas is a geologic hazard that has only recently been recognized and documented in the United States and Europe. Imshun Je argues that systematic data collection regarding background radon levels in Canadian urban communities is urgently required. This hazard has been compounded in many urban communities by the historic unregulated dumping of low-level radioactive wastes. John Clague provides an overview of the certain hazard facing the Greater Vancouver area as a consequence of large magnitude plate margin earthquakes produced where the North American tectonic plate is overriding the Pacific plate. Alex Mohajer points to a heightened risk of damaging earthquakes in the mid-continent Toronto area, hitherto regarded as geologically stable and risk free. There, mid-continent earthquakes (intraplate earthquakes) are produced by the reactivation of old geological structures deeply buried within the interior of the North American plate.

**Site Investigation, Remediation and Data Management Techniques**

Identification, assessment and remediation of many urban environmental geological problems is fundamentally dependent on site investigation, remediation and data management techniques. Identification of the subsurface geology of urban sites, where there has usually been a long history of site use and disturbance, is not straightforward. The traditional technique of drilling boreholes is expensive, provides data for a few (unrepresentative?) points only and can accelerate the migration of contaminants by physically disturbing the underlying substrate. In contrast, walk-over geophysical surveying techniques are rapid, non-invasive, inexpensive and, as a result, are being increasingly used to build a picture of what lies just below the surface of urban areas. John Scaife demonstrates the use of several of the more commonly used geophysical methods of site survey and assessment in urban areas. Joe Boyce and Berkant Koseoglu show how seismic reflection profiling provides an image of deeper geological strata. Significant progress has been made in adapting geophysical borehole logging techniques in use in the oil industry to ground-water resource investigations; these downhole techniques are demonstrated in the Kitchener-Waterloo region of Ontario by George Schneider, David Noble, Michael Lockhard and John Greenhouse.

Once characterized, the clean-up of contaminated urban sites requires the selection of an appropriate remedial technology from a very wide range of available techniques, many of which are new and untested. The wide array of possible remediation techniques is comprehensively reviewed by Paul Beck, paying particular attention to the advantages and disadvantages of each. Bioremediation, using bacteria, is a relatively new technology that is finding increasing application in urban areas. Paul Hubley, Andrew Panko and Doug Boocock describe the bioremediation of sites affected by petroleum contamination. Iqbal Noor shows how soil gas surveys are employed with the purpose of distinguishing background, naturally occurring hydrocarbons from petroleum products leaking from storage tanks.

"Data-rich but information-poor" describes an all too common situation where environmental geological data are scattered across different sources from where they cannot readily be retrieved and used. Much public money is often wasted recollecting or reformatting the same data. The field of computer-based Geoscientific Information Systems (GSIS) is rapidly evolving as a means of storing and presenting pictures of complex three-dimensional geological and environmental data. Nick Eyles, Mike Doughty, Kitty Brown and Derek Mack-Mumford describe the characteristics of the more commonly available systems and provide examples of their use in urban areas. Frank Kenny shows how satellite imagery can be used to map geology and land use on the rapidly changing urban fringe.

## Environmental Assessment Legislation

Today's environmental geologist needs to be part biologist, part chemist, part physicist, part computer technician, and increasingly, part lawyer. For the practising environmental geologist, environmental assessment legislation provides the framework for nearly all their activities, ranging from the collection of field samples, analytical techniques, analysis of data, to the reporting and dissemination of results and final decision making. These activities are commonly conducted under intense public, scientific and legal scrutiny. Existing regulations are complex and often not user-friendly to non-lawyers. Carolyn Eyles reviews the current federal and provincial environmental regulatory framework in Canada, emphasizing the system of legislation in place in Ontario. That province has the largest urban population and the most stringently implemented environmental legislation anywhere in the country.

A glossary of commonly used terms, a geologic time scale and units of measurement are provided as appendices.

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