Urban Groundwater Management and Sustainability

Edited by

John H. Tellam, Michael O. Rivett
and Rauf G. Israfilov

NATO Science Series

IV. Earth and Environmental Sciences – Vol. 74

Urban Groundwater Management and Sustainability

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Series IV: Earth and Environmental Sciences – Vol. 74

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edited by

John H. Tellam
Earth Sciences, School of Geography, Earth and Environmental Sciences,
University of Birmingham, U.K.

Michael O. Rivett
Earth Sciences, School of Geography, Earth and Environmental Sciences,
University of Birmingham, U.K.

and

Rauf G. Israfilov
Geology Institute, Azerbaijan National Academy of Sciences,
Baku, Azerbaijan

Technical Editor

Liam G. Herringshaw
Earth Sciences, School of Geography, Earth and Environmental Sciences,
University of Birmingham, U.K.

Springer

Published in cooperation with NATO Public Diplomacy Division

Proceedings of the NATO Advanced Study Institute on
Management and Sustainable Development of Urban Groundwater Systems
Baku, Azerbaijan
6 – 15 August 2004

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN-10 1-4020-5174-3 (PB)
ISBN-13 978-1-4020-5174-6 (PB)
ISBN-10 1-4020-5173-5 (HB)
ISBN-13 978-1-4020-5173-9 (HB)
ISBN-10 1-4020-5175-1 (e-book)
ISBN-13 978-1-4020-5175-3 (e-book)

Published by Springer,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

www.springer.com

Printed on acid-free paper

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PREFACE

With increasing awareness of environmental issues and the rapid expansion of urbanized areas, interest in urban groundwater has developed greatly over the last two decades. A number of meetings have been held on urban groundwater issues, for example the International Association of Hydrogeologists (IAH) Congress in 1997 (Chilton et al., 1997), and the urban groundwater session of the Geological Congress of 2004. The IAH has a commission on Urban Hydrogeology, and UNESCO has an Urban Water Management focal area under its IHP VI programme. Concomitantly, there has been a great interest in the wider development of the concepts of sustainability (e.g. Hiscock et al., 2002), including as applied to urban systems. It was in this context that a NATO Advanced Studies Institute (ASI) was held in Baku, Azerbaijan, in August 2004, following a very successful NATO Advanced Research Workshop at the same venue in 2001 (Howard and Israfilov, 2001). The ASI brought together, over a period of 10 days, a very diverse group of researchers from a wide range of countries interested in the whole gamut of urban groundwater issues. The aim was to share experiences and ideas, and to explore the commonality of urban groundwater problems, working towards methods for managing urban hydrological systems in ways that would minimize adverse impacts. This book is one product of the meeting. It covers all the main aspects of urban groundwater issues, from flow systems, through chemical and biological contamination, to engineering and socio-economic impacts, with evidence being drawn from many different countries and hydrogeological/socio-economic environments. It also includes, importantly, overviews which demonstrate how the different processes and impacts coexist and interact within any one city system.

We would like to thank NATO, and in particular Dr Alain Jubier and Dr Deniz Beten, for support and funding of both the ASI and the book. In the running of the ASI, the ‘Baku team’ and the staff of the Geology Institute of the Azerbaijan National Academy of Sciences provided much needed infrastructural support. We would particularly like to recognize the contributions of Rafig Hanifazade and Tofig Rashidov. The book would not have been possible without the extremely able editing of Dr Liam Herringshaw. Our publishers were very understanding, and in particular we would like to thank Mrs Wil Bruins for her support. Vanessa Chesterton and Kevin Burkhill undertook much of the metadata compilation and re-drafting of figures. Finally, we would like to thank all the contributors for their interesting ideas and lively discussions during the ASI, and later for their helpful response to our many editing queries.

Chilton, P.J. et al. (eds), 1997. *Groundwater in the Urban Environment, Vol. 1*. A.A. Balkema, Rotterdam, 682pp.

Hiscock, K.M., Rivett, M.O., Davison, R.M. (eds), 2002. *Sustainable groundwater development*. Geological Society, London, Special Publication 193, 352pp.

Howard, K.W.F., and Israfilov, I.G. (eds), 2001. *Current problems of hydrogeology in urban areas, urban agglomerates and industrial centres*. NATO Science Series IV: Earth and Environmental Sciences, Vol.8, Kluwer Academic Publishers, Dordrecht, 500 pp.

PARTICIPANTS AND CONTRIBUTORS

Ruslan Ch. AGAMIRZAYEV
Ministry of Ecology and Natural Resources, Balajar, Natavan st. 16, Az-1117, Baku,
AZERBAIJAN

Ramil A. ALEKPEROV
Ministry of Ecology and Natural Resources, Balajar, Natavan st. 16, Az-1117, Baku,
AZERBAIJAN

F. Sh. ALIYEV (now deceased)
Institute of Geology, National Academy of Sciences, H.Javid Av. 29A, Baku-AZ1143,
AZERBAIJAN

F. ARAL
Department of Civil Engineering, Engineering Faculty, Trakya University, 59860, Çorlu, Tekirdağ,
TURKEY

M. A. ASADOV
Institute of Water Problems, Tbilisi av, 69a, 370012, Baku,
AZERBAIJAN

F. S. ASKEROV
BP Oil Company, Baku,
AZERBAIJAN

Sukru ASLAN
Cumhuriyet University, Department of Environmental Engineering, 58140, Sivas,
TURKEY

Onder AYYILDIZ
Geological Engineering Department, Engineering and Architecture Faculty, Çanakkale Onsekiz Mart University, 17100 Canakkale,
TURKEY

Alper BABA
Geological Engineering Department, Engineering and Architecture Faculty, Çanakkale Onsekiz Mart University, 17100, Canakkale,
TURKEY

Marianne BJORKENES
Dept. of Plant and Environmental Sciences, Agricultural University of Norway, Box 5003, 1432 Ås,
NORWAY

Nikolai BOBYLEV
St. Petersburg State Polytechnic University,
RUSSIA

G. BUACHIDZE
Institute of Hydrogeology and Engineering Geology, Georgian Academy of Sciences, 31Rustaveli Ave, 380008, Tbilisi,
GEORGIA

G. BUNTEBARTH
Geophysikalisch-Technisches Büro, Burgstaetter Str. 6, D-38678 Clausthal-Zellerfeld,
GERMANY

Antonio CHAMBEL
Department of Geosciences, University of Évora, Apartado 94, 7002-554, Évora,
PORTUGAL

T. CHELIDZE
Institute of Geophysics, Aleksidze Str. 1, 0193, Tbilisi,
GEORGIA

D. CHUTKERASHVILI
Institute of Hydrogeology and Engineering Geology, Academy of Sciences, Tbilisi,
GEORGIA

Aidan A. CRONIN
Robens Centre for Public and Environmental Health, The University of Surrey, Guildford, GU2 7XH,
UK

Thibault DATRY
University Claude Bernard - Lyon 1 - Bat. Forel (403), UMR CNRS 5023, 43 Bd du 11 Novembre 1918, F-69622 Villeurbanne Cedex,
FRANCE

Jorge DUQUE
Department of Geology, Faculty of Sciences, University of Lisbon, Edifício C2, Campo Grande, Lisbon,
PORTUGAL

Matthias EISWIRTH (now deceased)
Department of Applied Geology, University of Karlsruhe,
GERMANY

Fred ELLERY
University of Natal, Durban,
SOUTH AFRICA

Anita ERŐSS
Dept. of Applied and Environmental Geology, Institute of Geography and Earth Sciences, Eötvös Loránd University, Pázmány P. sétány 1/c, 1117, Budapest, HUNGARY

Michael J. FRIEDEL
Department of Water Resources Science, University of Minnesota, 55108, St Paul, Minnesota,
USA

Daniel GALATCHI
Ovidius University, Department of Ecology and Environmental Protection, Mamaia Boulevard 124, 900241, Constanta - 3,
ROMANIA

Gocha GELASHVILI
Institute of Hydrogeology and Engineering Geology, Academy of Sciences, 31Rustaveli Ave, 380008, Tbilisi,
GEORGIA

Janine GIBERT
University Claude Bernard - Lyon 1 - Bat. Forel (403), UMR CNRS 5023, 43 Bd du 11 Novembre 1918, F-69622 Villeurbanne Cedex,
FRANCE

Sylvi HALDORSEN
Dept. of Plant and Environmental Sciences, Agricultural University of Norway, Box 5003, 1432 Ås,
NORWAY

Inka HELD
Department of Applied Geology, University of Karlsruhe,
GERMANY

E. Zia HOSSEINIPOUR
DHI Water and Environment, 311 South Brevard Ave., 33606, Tampa, Florida,
USA

Heinz HÖTZL
Department of Applied Geology, University of Karlsruhe,
GERMANY

Ken W. F. HOWARD
Groundwater Research Group, University of Toronto at Scarborough, 1265 Military Trail, M1C 1A4, Toronto, Ontario,
CANADA

T. IASHVILI
Institute of Hydrogeology and Engineering Geology, Academy of Sciences, 31Rustaveli Ave, 380008, Tbilisi,
GEORGIA

Aydin IBRAHIMOV
Department of Geography, Faculty of Art and Literature, University of Çanakkale Onsekiz Mart, 17100, Çanakkale,
TURKEY

Mehriban M. ISMAILOVA
Hydrogeology Department, Azerbaijan State Oil Academy, 20 Azadlig Ave, Az 1001, Baku,
AZERBAIJAN

Rauf G. ISRAFILOV
Geology Institute, National Academy of Sciences, H.Javid Av. 29A, Baku AZ1143,
AZERBAIJAN

Yu. H. ISRAFILOV
Institute of Water Problems, Tbilisi av 69a, 370012, Baku,
AZERBAIJAN

E. JOYCE
Robens Centre for Public and Environmental Health, The University of Surrey, Guildford GU2 7XH,
UK

Olga A. KARIMOVA
Water Problems Institute, Russian Academy of Sciences, 3 Gubkina str. GSP-1, 119991, Moscow,
RUSSIA

Bruce KELBE
University of Zululand,
SOUTH AFRICA

Detlef KLAFFKE
The International Association of Hydrogeologists, Heedheide 8, 58553, Halver,
GERMANY

Talat KOC
Department of Geography, Faculty of Art and Literature, University of Çanakkale Onsekiz Mart 17100, Çanakkale
TURKEY

Danila KUZNETSOV
Geolink Consulting
Warshavskoe shosse 39a, Moscow,
RUSSIA

Judit MÁDL-SZŐNYI
Dept. of Applied and Environmental Geology, Institute of Geography and Earth Sciences, Eötvös Loránd University, Pázmány P. sétány 1/c, 1117 Budapest,
HUNGARY

M. Manuel MADEIRA
SULPLANO, R. da Sfuap A/E, Laranjeiro, 2890-510 Almada,
PORTUGAL

Florian MALARD
University Claude Bernard - Lyon 1 - Bat. Forel (403), UMR CNRS 5023, 43 Bd du 11 Novembre 1918, F-69622 Villeurbanne Cedex,
FRANCE

Ramez Yu. MAMMEDOV
Institute of Hydraulic Design, Landau str. 16, AZ1073, Baku,
AZERBAIJAN

M. MAMMADOVA
Baku State University, 23 Zaid Khalilov street, AZ1073, Baku,
AZERBAIJAN

Augustin MARIA
CERNA - ENSMP, Ecole Nationale Supérieure des Mines de Paris, 60 Bd St Michel, 75006, Paris,
FRANCE

G. MELIKADZE
Seismohydrogeodynamic Research Centre, Mosashvili Str. 24, 0162, Tbilisi,
GEORGIA

Andrea MINDSZENTY
Dept. of Applied and Environmental Geology, Institute of Geography and Earth Sciences, Eötvös Loránd University, Pázmány P. sétány 1/c, 1117 Budapest,
HUNGARY

Jan MULDER
Dept. of Plant and Environmental Sciences, Agricultural University of Norway, Box 5003, 1432 Ås,
NORWAY

Imre MÜLLER
Dept. of Applied and Environmental Geology, Institute of Geography and Earth Sciences, Eötvös Loránd University, Pázmány P. sétány 1/c, 1117 Budapest,
HUNGARY

Kirami ÖLGEN
Department of Geography, Ege University, Bornova-Izmir 35100,
TURKEY

Atakan ONGEN
Department of Environmental Engineering, Engineering Faculty, Trakya University, 59860, Çorlu, Tekirdağ,
TURKEY

Jarl ØVSTEDAL
Oslo Airport, P.O. Box 100, 2061 Gardermoen,
NORWAY

Sh. PASHAYEVA
Geology Institute, National Academy of Sciences, H.Javid ave. 29[a], AZ1143, Baku,
AZERBAIJAN

S. PEDLEY
Robens Centre for Public and Environmental Health, The University of Surrey,
Guildford GU2 7XH,
UK

Sh. PETRIASHVILI
Institute of Hydrogeology and Engineering Geology, Academy of Sciences, 31
Rustaveli Ave, 380008, Tbilisi,
GEORGIA

Shammy PURI
Scott Wilson Kirkpatrick, The Brook House, Drayton Rd, Dorchester on Thames,
OX10 7PJ Oxon,
UK
(Now at Puri Resources International – Sustainable Solutions)

Nizamidin R. RAHIMOV
Central Asian Research Institute for Irrigation (SANIIRI), Karasu-4/11, Tashkent
700187,
UZBEKISTAN

T. M. RASHIDOV
Geology Institute, National Academy of Sciences, H.Javid av. 29a, AZ1143, Baku,
AZERBAIJAN

Michael RIVETT
Earth Sciences, School of Geography, Earth and Environmental Sciences,
University of Birmingham, Birmingham B15 2TT,
UK

Liliya M. ROGACHEVSKAYA
Water Problems Institute, Russian Academy of Sciences, Gubkina str., 3, 119991,
Moscow,
RUSSIA

Tanya ROMANENKO
Scott Wilson Kirkpatrick, The Brook House, Drayton Rd, Dorchester on Thames,
OX10 7PJ Oxon,
UK

Mark ROSS
Dept. of Civil and Environmental Engineering, University of South Florida, 4202 E. Fowler Ave., Tampa, Florida, 33620,
USA

J. RUEEDI
Robens Centre for Public and Environmental Health, The University of Surrey, Guildford GU2 7XH,
UK

Rustam R. SAIDOV
"SUGORISH" Research Centre, Karasu-4/11, Tashkent 700187, (UMRP),
UZBEKISTAN

Bernd SCHREIBER
Dresden University of Technology, Institute of Water Chemistry, 01062 Dresden,
GERMANY

John TELLAM
Earth Sciences, School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham B15 2TT,
UK

T. TEVZADZE
Institute of Hydrogeology and Engineering Geology, Academy of Sciences, 31Rustaveli Ave, 380008, Tbilisi,
GEORGIA

Esra TINMAZ
Department of Environmental Engineering, Engineering Faculty, Trakya University, 59860, Çorlu, Tekirdağ,
TURKEY

Kenneth TROUT
University of South Florida, Dept. of Civil and Environmental Engineering, 4202 E. Fowler Ave., 33620, Tampa, Florida,
USA

Aysen TURKMAN
Department of Environmental Engineering, Dokuz Eylul University, 35160 Buca Izmir,
TURKEY

Sh. USMANOV
SPA SANIIRI, Karasu-4/11, 700187, Tashkent,
UZBEKISTAN

Kai WEGERICH
Irrigation and Water Engineering Group, Wageningen University, Nieuwe Kanaal 11, 6709 PA, Wageningen,
THE NETHERLANDS

Bente WEJDEN
Oslo Lufthavn AS, P.O.Box 100, 2061, Gardermoen,
NORWAY

Rachel WHITE
Earth Sciences, School of Geography, Earth and Environmental Sciences,
University of Birmingham, Birmingham B15 2TT,
UK

Leif WOLF
Department of Applied Geology, University of Karlsruhe,
GERMANY

Sh. YAKUBOV
SPA SANIIRI, Karasu-4/11, 700187, Tashkent,
UZBEKISTAN

Sh. YUSUPOV
Central Asian Research Institute for Irrigation (SANIIRI), Karasu-4/11, Tashkent 700187,
UZBEKISTAN

Ucha ZVIADADZE
Department of Hydrogeology and Engineering Geology, Georgian Technical University, 1 Cavchavadze Ave, Tbilisi, 380028,
GEORGIA

SECTION I:

INTRODUCTION

TOWARDS MANAGEMENT AND SUSTAINABLE DEVELOPMENT OF URBAN GROUNDWATER SYSTEMS

An Introduction

John H. Tellam[1], Michael O. Rivett[1], and Rauf G. Israfilov[2]
[1]Earth Sciences, School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham B15 2TT, UK; [2]Geology Institute, Azerbaijan National Academy of Sciences

Abstract: Urbanization modifies underlying groundwater systems. This may lead to adverse hydrological, water quality, geotechnical, or socio-economic effects, jeopardizing sustainability. To avoid these effects, management is required irrespective of whether the groundwater is to be used or not. This management must be based on a sound technical understanding of the interacting processes involved. The papers in the present volume explore the state of this understanding in the context of a wide range of countries, climates, and geologies.

Key words: importance of urban groundwater; flow; chemical water quality; biological water quality; remediation; engineering; socio-economic issues; water balance.

1. THE IMPORTANCE OF URBAN GROUNDWATER

Urbanization modifies local hydrology, often extensively. Water and chemical fluxes are changed in both surface and groundwater systems, often to the detriment of the environment and water usability.

Changes in land cover will often reduce recharge amounts and change recharge distributions. Recharge will be supplemented by leakage from water pipelines and sewers, discharges onto ground surface, and increased

J.H. Tellam et al. (eds.), Urban Groundwater Management and Sustainability, 1–9.

infiltration from surface water bodies. Groundwater abstraction will lower piezometric surfaces and reduce flows from the system. These changes in water balance will cause changes in solute fluxes: chemical fluxes will also be affected by dissolution from modified ('contaminated') land.

Depending on which factors dominate, possible implications of these changes include: reduced well and river yields; increased flood hazard; deterioration in quality of groundwater; salinization; poor quality baseflow; migration of polluted urban groundwater into surrounding rural areas; increased ground instability; and increased social conflict.

For a city to be hydrologically sustainable, an equilibrium needs to be established which is acceptable for drainage, flooding, waste disposal, and water supply. Such an equilibrium is unlikely to be established without active management intervention. Even if groundwater is not required for use, an increasingly unusual case, there are still potentially serious consequences of not managing the system actively: inaction has consequences. This is evident from the continuing impacts past un-managed development has had on both water levels and water quality in many cities, as exemplified by the papers in Section II of this volume.

Management of the interacting surface/groundwater system, considering both quantity and quality whilst satisfying other constraints of the built environment, is not a trivial undertaking. It is made more difficult by the transient nature and marked heterogeneity of urban development. Some forecasts suggest that urban populations will double by 2050 (Foster et al., 1999), and climate change will add further pressures: the development of management techniques is therefore urgently needed.

2. THE MAIN TECHNICAL HURDLES

Urban aquifers are hydrogeologically distinctive in at least the following respects:

- the density and heterogeneity of wells and pollution sources in space and time;
- the presence of structures such as sewers, fill material, foundations, pipelines, and various types of ground cover;
- the presence of chemicals such as synthetic industrial organic compounds (and any arising cocktails);
- the concentration of human-associated biological contaminants; and
- the socio-economic structures impacted by water-related issues.

Much remains to be learnt about how to quantify each of these components. However, the most difficult problem is how to integrate all the interacting hydraulic, chemical, biological, and socio-economic systems.

3. THIS VOLUME

The ultimate aim of urban groundwater studies is to develop the sound theoretical understanding necessary to develop management techniques which will deliver sustainability. This volume outlines the current state of understanding across the main areas of the subject, using both review and focused, specific-issue papers. The studies represented come from many different countries, including some for which the English language literature is sparse. This international diversity and the comprehensive range of urban groundwater issues covered are key features of the book. Although each city is unique, it is clear that many of the urban groundwater problems faced are common to many countries. As such, lessons learnt in, e.g., Azerbaijan may well be relevant in, e.g., Portugal, and *vice versa*.

The remainder of the book is divided into eight sections. Section II sets the scene with a series of case studies dealing with regional overviews. Sections III to VIII cover the following issues: flow; chemical water quality; biological water quality; remediation; engineering; and socio-economics. These areas are briefly outlined below.

4. IMPACTS ON GROUNDWATER FLOW: SECTION III

Flow issues include: recharge estimation; flow pattern assessment; integrated flow modelling; and characterizing the hydraulic behaviour of urban-specific structures. The latter includes the effects of foundations, tunnels, and any other buried structure, and the effects of fill material.

Urban recharge assessment is difficult. Low permeability cover promotes runoff. However, the cover will almost certainly be incomplete, encouraging focused recharge (Thomas and Tellam, 2006). In addition, cover may be modified to be permeable (SUDS: sustainable drainage systems). Evapotranspiration will be modified by the urban micro-climate and changes in the radiative properties of the cover material: if focused recharge occurs, evapotranspiration may be limited, and the frequently observed reduction in recharge rate during the hotter parts of the year may not be seen unless urban trees are present. Interflow in filled ground is extremely difficult to quantify. Leakage from water mains has often compensated for by the increase in runoff (e.g. Lerner, 1997), and leakage from canals can be so important that drainage wells are necessary (see Section VII). It is clear that new methods for determining recharge *in situ* would be particularly advantageous, and one such method is described in

Section III. The issue of uncertainty in modelling is also raised in the context of recharge estimation, but its salutary message should be considered in all aspects of assessment in urban hydrogeology.

If pollution risk is to be quantified, flow patterns need to be determined. This is particularly difficult in urban systems where, aside from the difficulties of estimating recharge, the history of pumping is typically complex in space and time. As shown in Section III, the well catchments need to be mapped all three space dimensions. Catchment shapes can become complex even in steady-state and certainly in unsteady-state. In most cases, detailed pumping histories are not available, and prediction becomes very uncertain.

Surface water and groundwater are part of the same system, yet it is much more usual to treat them separately. One reason is that integrated models are often difficult to develop, not least because of the differences in groundwater and surface water response times. However, progress is being made in this area, and an example of an integrated model run in real time to aid operational management is described in Section III.

5. IMPACTS ON CHEMICAL WATER QUALITY: SECTION IV

Many pollutant sources in urban areas are point sources and give rise to plumes which then move through the aquifer in paths often complicated by the time-variant nature of local abstractions. When sampled, often at pumping wells, the water is usually mixed, and may well have concentrations much lower than the maximum within the aquifer (e.g. Tellam and Thomas, 2002), thus making the interpretation of any *in situ* natural attenuation difficult.

In residential parts of a city, chemical pollutants may be limited to Cl, SO_4, and N species, with possibly some chlorination products (trihalomethanes) and occasionally other chemicals associated with minor spills. Cl and especially NO_3 may be associated in part with sewage pollution: presence will depend on the state/design of the sewerage system over time, and the residence time of the groundwater. In extreme cases, wastes could potentially transform the aquifer redox systems. However, in many cases industry will be a major cause of pollution, especially by synthetic organic compounds and inorganic pollutants (e.g. heavy metals, NH_4). The chemicals released will have varied over time as the industrial processes and land use changed (e.g. Lerner, 2003). Sources will vary from short-term, solute sources, to non aqueous phase liquid discharges which may act as sources for prolonged periods of time (Rivett et al., 2005).

Section IV includes examples of mainly residential and mainly industrial pollution from Portugal and the UK. But in addition, other papers provide reminders of a number of issues, including: the importance of recording the quality of the groundwaters before urbanization; pollution by less studied chemicals, including organic airport de-icers, pharmaceuticals, and actinides; the importance of urban landfills and city-adjacent agricultural areas; the presence of thermal waters in some cities; and the difficulty of predicting bypass pathways in systems as different as karstic limestones and clays.

6. IMPACTS ON BIOLOGICAL WATER QUALITY: SECTION V

Possible sources of microbiological pollution include human waste systems, animal wastes, food processing wastes, and waste water injection. Often it is assumed that groundwater contamination by bacteria and viruses in at least matrix-dominated systems can be dealt with in practice by use of 'setback' distances between potential sources and receptors. It is assumed that over this distance the microbes are inactivated by a variety of mechanisms, including predation, attachment to the rock, and breakdown. Recent evidence, summarized in Section V, in both developing and developed countries suggests that this may be a dangerous assumption, and interesting insights into apparently rapid virus movement and possibly extended times of viability are starting to emerge. Fractured systems have long been known to be vulnerable to microbiological pollution but, despite this, sometimes incidents involving groundwater transmission occur, even where management systems are in place: an important recent incident in Canada is described in Section V. Other papers compare microbe occurrence in countries with a range of waste-disposal practices.

Waste water injection is likely to become more popular as water resources become scarcer. Injected water will contain both microbial particles and potential nutrients, and care must be taken that the groundwater system is not degraded. A set of field experiments in a shallow sandy system, reported in Section V, shows that unsaturated zone thickness is critical if stimulation of groundwater bacterial populations is to be avoided. It also shows that such stimulation in turn affects the aquifer's indigenous invertebrate fauna.

7. REMEDIATION: SECTION VI

Section VI deals with remediation in the broadest sense of the term: aquifer protection; *in situ* remediation; and pumped water treatment. Prevention of pollutants entering an aquifer is generally the best approach, and, as indicated in one paper, in some cases waste treatment can even be potentially profitable. However, prevention is not always possible: there will always be cases where pollution occurs despite aquifer protection; in many aquifers there will be pollution present from times prior to the protection procedures being put in place; and in many cities it is simply not feasible to protect all the aquifer. In these cases, remediation can be considered, though often it will be an expensive option. There are many possibilities, from passive to vigorously interventionist, including monitored natural attenuation, permeable reactive barrier methods, pump-and-treat systems, and *in situ* chemical injection approaches. These are reviewed in Section VI from historical-, socio-economic-, and process-based perspectives. A final option is treatment at the point of use. This may involve simple procedures such as aeration or dilution, or rather more complex chemical treatments, an example of which is also described in detail in Section VI.

8. ENGINEERING IMPACTS: SECTION VII

There are numerous engineering impacts of urbanization, and many of these are covered in Section VII. Changes in water balance for an aquifer following urbanization can result in falling or rising water level depending on the relative changes in runoff, leakage, and abstraction. Falling water levels give rise to ground subsidence, especially in aquifer systems of alternating sands and clays. They can also result in the drying out and shrinking of soils or timber foundations, leading to subsidence of buildings. Rising water levels will result in greater pore pressures and hence lower effective stresses. In unfavourable cases, this will result in foundation collapse and landslide initiation. In extreme cases, seismic hazard may be increased. High water levels may result in salinization (through evaporation from the water table) and flooding, and require drainage systems to be installed. Another effect may be dissolution resulting in reduction of strength and building subsidence.

9. SOCIO-ECONOMIC IMPACTS: SECTION VIII

Even if all the technical problems were solved, success in sustainable development would still be contingent on finding satisfactory ways to implement any management strategies. In many countries, for example those of the European Union and North America, environmental legislation continues to be tightened. However, the experience summarized in the papers of Section VIII suggests that in many countries the situation is more complex, with governments unable and/or unwilling to enforce water control methods. This, and the sometimes inefficient performance of public water supply systems, has resulted in households taking more responsibility for developing their own supplies, often with an associated loss of central control over aquifer development. In other cases, this is not technically or economically feasible, and the population has to deal with low water availability. Often the key issue is to gain the agreement of the local populace, and non-governmental organizations are often heavily involved with raising awareness of water (and other) issues.

10. TOWARDS MANAGEMENT AND SUSTAINABLE DEVELOPMENT

The overall water and solute balances for an urban aquifer for a given time period can be expressed in the forms:

$$
\begin{aligned}
&P + L_s + L_f + D + SWI + GWI + AR \\
&- ET - RO - IS - Q - SWO - GWO - L_o = \Delta S
\end{aligned}
\tag{1}
$$

$$
\begin{aligned}
&F_{ET}PC_P + L_sC_s + L_fC_f + DC_D + SWIC_{SWI} + GWIC_{GWI} + ARC_{AR} + mdr \\
&- QC_{GW} - SWOC_{SWO} - GWOC_{GW} - L_oC_{GW} = V\Delta C_{GW}
\end{aligned}
\tag{2}
$$

where the symbols are as indicated in Table 1. All variables are functions of space and time, and many are not independent, being connected either directly (e.g. Q/GWI) or via socio-economic responses (e.g. if C_{GW} increases, Q may decrease). The problem faced in urban development is how to manipulate the balances represented by these equations so that abstraction, water levels, and water concentrations are optimized, i.e. do not give rise to unacceptable consequences (e.g. insufficient supply, flooding,