Groundwater in Urban Development

Assessing Management Needs and Formulating Policy Strategies

Stephen Foster
Adrian Lawrence
Brian Morris

The World Bank
Washington, D.C.
Stephen Foster is assistant director of the British Geological Survey, visiting professor of contaminant hydrogeology at the University of London, and chair of the International Association of Hydrogeologists: Burdon Commission on Developing Nations. Adrian Lawrence and Brian Morris are principal hydrogeologists at the British Geological Survey, Nottingham.

Library of Congress Cataloging-in-Publication Data
Foster, Stephen S. D.
Groundwater in urban development: assessing management needs and formulating policy strategies / Stephen S. D. Foster, Adrian R. Lawrence, Brian L. Morris.
p. cm.—(World Bank technical paper; no. 390)
ISBN 0-8213-4072-7
TD327.F67 1997
333.9'0415'091724—dc21 97-41737
CIP
Contents

Foreword .............................................................................................................................. v
Acknowledgments .............................................................................................................. vii
Abstract ............................................................................................................................. ix
Executive Summary .......................................................................................................... xi

1. Interdependence of Groundwater and Urbanization ....................................................... 1
   Subsurface Dimensions of Urban Development .............................................................. 1
   Stages and Patterns of Urban Evolution ......................................................................... 3
   Inter-Related and Conflicting Processes ........................................................................ 5
   Urban Groundwater in Hydrogeological Context .......................................................... 6

2. Analysis of Urban Hydrogeological Processes ............................................................... 11
   Urban Influences on Groundwater Recharge and Quality .............................................. 11
   Effects of Uncontrolled Groundwater Abstraction ....................................................... 22

3. Urban Groundwater Management Issues ...................................................................... 27
   Analysis from Different Perspectives .......................................................................... 27
   Evolution of Problems ................................................................................................... 30
   Underlying Causes of Management Problems .............................................................. 34

4. Improving Groundwater Resource Management ......................................................... 39
   Institutional Framework and Social Dimension ............................................................. 39
   Technical Management Objectives and Targets ........................................................... 40
   Achieving Management Targets .................................................................................. 40
   The Way Forward: Political Realism and Practical Steps .............................................. 52

References and Bibliography ............................................................................................. 55

Boxes
1.1 Groundwater Occurrence ............................................................................................ 9
1.2 Groundwater Flow Systems ....................................................................................... 10
2.1 Urban Groundwater Contamination by Canal Seepage—Hat Yai, Thailand ................ 15
2.2 Groundwater Contamination by Pathogens—Merida, Mexico ..................................... 19
2.3 Downward Leakage of Contamination Induced by Pumping—Santa Cruz, Bolivia ....... 20
3.1 Separation of Water Supply and Wastewater Disposal in Vulnerable Aquifers—Merida, Mexico ........................................... 29
3.2 Deep Groundwater Quality Degradation Induced by Pumping—Hat Yai, Thailand ...... 32
3.3 Industrial Wastewater Reuse for Irrigation: Problems and Potential Solutions—León, Guanajuato, Mexico ...................................................... 33
3.4 The Problem of Unregulated Private Abstraction—Bangkok, Thailand ......................... 35
3.5 Long-Term Groundwater Quality Threat Posed by On-Site Sanitation in an Arid-Zone, Urban Environment—Sana’a, Yemen .................................................. 38
4.1 Reduction of Urban Groundwater Abstraction in a Command Economy to Control Land Subsidence—Tianjin, China ................................................................. 42
Table of Contents

Groundwater in Urban Development

4.2 Conjunctive Use of Water Resources: Worth More than the Sum of the Parts ........................................... 45
4.3 Regulatory and Economic Instruments to Reduce Groundwater Abstraction—
Jakarta, Indonesia .................................................................................................................. 47
4.4 Complementary Relation between Public and Private Groundwater Abstraction—
Santa Cruz, Bolivia .............................................................................................................. 48
4.5 Proactive Response to Excessive Groundwater Abstraction—Querétaro, Mexico ......................... 49
4.6 Protection Zones for Periurban Groundwater Sources—Bridgetown, Barbados ................................. 54

Figures
1.1 Interaction of Groundwater Supply and Wastewater Disposal in a City Overlying a Shallow Aquifer ....................................................................... 1
1.2 Evolution of Water Supply and Wastewater Disposal for a Typical City Underlain by a Shallow Aquifer .................................................................................. 4
1.3 Population Growth and Water Demand in the Mexico City Metropolitan Area ................... 5
2.1 Hydrological Equivalent Rates of Circulation in Water Supply Mains in Urban Areas ............... 13
2.2 Potential Range of Subsurface Infiltration Caused by Urbanization ............................................. 17
2.3 Processes that Promote Contaminant Attenuation in Groundwater Systems ....................... 22
2.4 Evolution of Groundwater Quality Problems in a Typical Coastal, Alluvial Aquifer System following Rapid Urbanization .............................................. 26
3.1 Interaction between Urban Services and Facilities through the Underlying Groundwater System ........................................................................ 27
3.2 Urban Evolution from the Perspective of Groundwater Resources ......................................... 31

Tables
ES.1 Groundwater-Using Cities Considered in Assessing Management Needs and Formulating Policy Strategies ................................................................. xii
1.1 Balancing Initial Benefits and Long-Term Costs in the Urban Use of the Subsurface Environment ........................................................................ 2
1.2 Characteristics of Principal Urban Hydrogeological Environments ........................................ 7
2.1 Impacts of Urban Processes on Infiltration to Groundwater ...................................................... 11
2.2 Sources of Aquifer Recharge in Urban Areas and Their Implications for Groundwater Quality ..................................................................................... 12
2.3 Classification of Groundwater Quality Problems ................................................................. 18
2.4 Hydrogeological Environments and Their Associated Groundwater Pollution Vulnerability ...................................................................................... 23
2.5 Summary of Activities that Might Generate a Subsurface Contaminant Load ......................... 24
2.6 Susceptibility of Hydrogeological Environments to Adverse Side-Effects During Uncontrolled Exploitation ..................................................................... 25
3.1 Urban Groundwater Problems and Management Requirements ...................................... 36
4.1 Urban Groundwater Supply Management: Objectives, Problems, and Mitigation Measures ........................................................................................................ 41
4.2 Practical Steps toward Defining and Promoting an Urban Groundwater Resources Management Policy ................................................................. 53