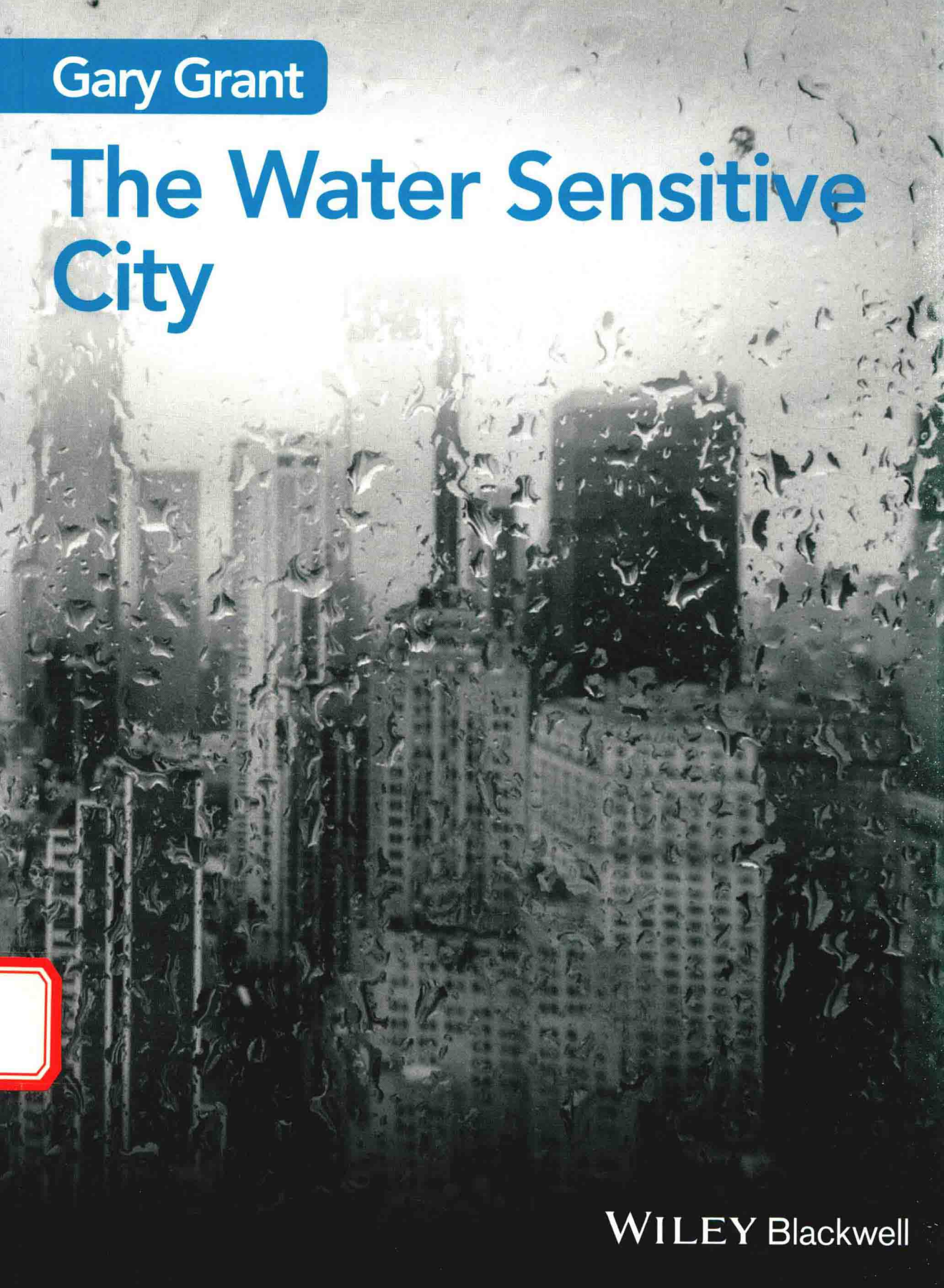




Gary Grant

The Water Sensitive City



WILEY Blackwell

The Water Sensitive City

Gary Grant

WILEY Blackwell

This edition first published 2016
© 2016 by John Wiley & Sons, Ltd

Registered Office

John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex,
PO19 8SQ, United Kingdom.

Editorial Offices

9600 Garsington Road, Oxford, OX4 2DQ, United Kingdom.
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom.

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com/wiley-blackwell.

The right of the author to be identified as the author of this work has been asserted in accordance with the UK Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book.

Limit of Liability/Disclaimer of Warranty: While the publisher and author(s) have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. It is sold on the understanding that the publisher is not engaged in rendering professional services and neither the publisher nor the author shall be liable for damages arising herefrom. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

Library of Congress Cataloging-in-Publication data applied for

ISBN: 9781118897669

A catalogue record for this book is available from the British Library.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Set in 10/12.5pt Avenir by SPi Global, Pondicherry, India
Printed and bound in Singapore by Markono Print Media Pte Ltd

About the Author

Gary Grant is a Chartered Environmentalist, Fellow of the Chartered Institute of Ecology and Environmental Management, thesis tutor at the Bartlett Faculty of the Built Environment, University College London and Director of the Green Infrastructure Consultancy (formerly the Green Roof Consultancy). In 2006 he wrote *Green Roofs and Facades* published by BRE Press and in 2012, *Ecosystem Services Come to Town – Greening Cities by Working with Nature*, published by Wiley-Blackwell. From 2006 to 2009 he was a director of EDAW and then AECOM Design + Planning, where he worked on large-scale planning projects including the London 2012 Olympic Park, the Bedford Valley River Park, the Whitehill-Bordon eco-town, Education City, Qatar and Saadiyat Island, Abu Dhabi. More recently, with the Green Infrastructure Consultancy, he has been working on planning and design, including green infrastructure networks for cities, green roofs, living walls and rain gardens.

Acknowledgement

I would like to thank my wife Sue for her support and understanding during the writing of this book.

Contents

<i>About the Author</i>	xiii
<i>Acknowledgement</i>	xv
1. Water and Cities	1
The Molecule	1
Blue Planet	1
A Global Water Cycle	2
Terrain and Water	2
Seasons and Cycles	4
Variations in Rainfall	4
Changing Climates	5
Atmospheric Carbon Dioxide	5
Fossil Fuels and Growth	6
The Ancients and Water	6
Dams	7
Limits	7
Sanitation	9
Pollution	9
Urban Drainage	10
Potable Water	12
Waste	12
Rainwater Harvesting	13
Recycling	14
Biodiversity	14
Restoration	15
The Future	16
Privatization and Regulation	16
Coordination and Cooperation	17
Towards a Better Future	18
2. A Brief History of Water Supply and Sanitation	19
Genesis	19
Bronze Age	20
The First Aqueducts	20
Nineveh	21
The Nile	21
The Minoans	22
Qanats	22

Pompeii	23
Byzantium	24
Yucatan	24
The Incas	25
Qi	26
Lijiang	26
Medieval and Early Modern Europe	26
Early Victorian Period	27
Germ Theory	27
The Great Stink	28
Modern Sewers and Sewage Treatment	28
Sewage Treatment Refined	29
Standards for Sewage Treatment	29
Birmingham Corporation Water Act 1892	30
Los Angeles and the Owens Valley	30
3. Demand	33
Basic Needs	33
Personal Consumption	34
Water Footprint	35
Dependency	36
China	36
Germany	36
India	37
Indonesia	37
Spain	38
United Kingdom	38
Water Footprint of Products	38
Meat	39
Vegetable Crops	39
Power Plants	40
Steel	41
Mining, Oil and Gas	42
When Will Water Consumption Peak?	42
4. Supply	43
The Roof of the World	43
Mountains	44
Forests	45
Reservoirs	46
Impacts of Dams	46
Lowland Rivers	47
Licensing Abstraction	48
Aquifers	48
Nitrate	49
Overabstraction	49

Desalination	50
Reverse Osmosis	50
Impacts of Desalination	51
High Cost of Desalination	51
Rainwater Harvesting	51
Pressure and Pumps	52
Pipework	52
Reliant on Rain	53
5. Climate Change and Water	55
Climate Changes	55
The Greenhouse Effect	55
Callendar	56
Keeling	57
Atmosphere and Oceans	57
Details of the Carbon Cycle	57
The IPCC	58
Stern and the Financial Crisis	58
400 ppm Breached	59
Two Degrees	59
Sea Level Rises	60
Coastal Cities	61
Warmer Seas	62
Ice	62
Feedback Loops	62
Ocean Chemistry	63
Snowmelt	63
Models and Projections	65
Summer Storms	66
Heat Waves	66
Drought	66
6. Microclimate	69
Climate	69
Microclimate	69
City Microclimates	70
Urban Heat-Island Effect	70
Smog	70
Solving the Air-Pollution Problem	71
Cooler Roofs	72
Living Walls	73
Trees Cool Streets	74
Parks	75
Quality of Green Space	75
Locating Trees	76
Water Bodies	76

Rivers	76
Heat-Related Deaths	77
Energy Savings	78
An Overwhelming Case	79
7. Ecosystem Approach	81
The Great Acceleration	81
The Convention on Biological Diversity	81
Ecosystem Approach	82
Ecosystems	82
Principles of the Ecosystem Approach	83
Operational Guidance	85
Ecosystem Approach and the Water-Sensitive City	87
Impacts and Responsibilities	88
Limits	88
City-Scale Planning	89
The City Spectrum	89
Ecosystem Services	89
Valuation of Ecosystem Services	90
Supporting Services	91
Regulating Services	91
Provisioning Services	91
Cultural Services	92
Economics and Ecosystems	92
8. Rivers and Coasts	95
The Source	95
A River of Life	95
Transport Revolution	96
Regeneration	96
Water Quality and Regeneration	97
The Idea Spreads	97
A More Natural Approach	98
River Restoration and Urban Regeneration	99
Greening the River Wall	99
Coastal Cities	100
Beach Life	101
Fun in the Sun	101
The Front Line	102
An Uncertain Future	103
9. Near-Natural Drainage	105
Rain-Garden Origins	105
Scotland Takes Up the Challenge	106
England & Wales	106
Working with Nature	106
Management Train	107

Source Control	108
Green Roofs	108
Holding Water on the Roof	109
Rain Gardens	110
The Idea Spreads	111
Other Permeable Load-Bearing Surfaces	112
Underground Voids	113
Trees and Water	114
Stockholm Tree Pits	115
Conveyance	115
Rills	116
Ponds	116
Detention Ponds	116
Attenuation Ponds	117
Floating Wetlands	117
Larger Water Bodies	118
Make Space for Water	119
10. Reduce	121
A Worthwhile Effort	121
Reduce Leaks	121
Monitor	122
Check for Leaks	123
Less Flush	123
Toilets are Not for Trash	123
Composting Toilets	124
Showers	124
Washing Machines	124
Dishwashers	125
Garden Irrigation	125
The Workplace	126
Behaviour Change	126
Heating, Ventilation and Air Conditioning	126
Vehicle Washing	127
Urban Farming and Recycled Water	128
Diet and Water	128
Soft Drinks	128
Clothing	129
Reduction Targets	129
11. Collect	131
Reduce Reliance on Abstraction	131
When Sealed Surfaces are Useful	131
Rainwater Harvesting	132
How Rainwater is Tainted	132
First Flush	133

Novel Methods	133
Filters and Tanks	134
Siting a Tank	134
Materials	135
Treating Rainwater	135
Sizing Tanks	136
City Centre Rainwater Harvesting	137
Potsdamer Platz	137
District Collection	138
Singapore Wants Every Drop	138
Legal Problems	139
Dew	140
Lanzarote	140
Air Wells	140
Lightweight Fog Catchers	141
Foil Collectors	141
Biomimicry: Desert Beetle	142
Potential in Towns	142
Condensate	142
Collecting Alone is Insufficient	143
12. Recycle	145
Huge Potential	145
Treated Wastewater	146
The Big Dry	146
Greywater	146
Treating Greywater	147
Microbes and Membranes	148
Regulations	148
Standards	149
German Pioneers	150
Jordan	150
Domestic Greywater Recycling	151
13. Water Quality	153
Nature Cleans	153
Safe to Drink?	153
Microbes	154
Which Pathogens to Monitor?	156
Bacteria	156
Protozoa	157
Treatment	157
Chemical Contaminants	159
Nitrates	159
Pharmaceutical Contaminants	161
Radioactive Substances	161
Smell and Taste	161

Standards	162
United States	162
Europe	162
China	163
Clean Water Act	163
Water Framework Directive	164
Earlier Legislation	165
The Struggle for Compliance	165
Nonpoint Source Pollution	165
Dust in the Streets	166
Urban Runoff	166
A Continuing Problem	166
14. Future Water-Sensitive Cities	169
Waste Not	169
Measure	170
Water Collection	170
Recycling and Cooling	170
Smart Plumbing	171
Water and Power	171
Water and Roofs	172
Water and Walls	173
Blue-Green Infrastructure	173
Making Room	175
A More Permeable City	175
Green Streets	175
Street Life	175
Sparkling Streets	177
Urban Food Revolution	177
Urban Farms	177
Agricultural Reform	178
Relax and Play	178
Swimming and Boating	178
Encounters with Nature	179
Rediscovering Urban Waterways	179
A Greener Looking City	180
Living with Climate Change	180
Tough Decisions	181
Younger and Wiser	181
Hope	182
<i>Useful Resources</i>	183
<i>Notes</i>	191
<i>Index</i>	207

1. Water and Cities

The Molecule

Water is remarkable. It is an odourless, tasteless and transparent molecule. Consisting of two hydrogen atoms bonded to a single oxygen atom, with each water molecule weakly connected to its neighbour, water is a relatively sticky liquid, with a high boiling point compared to other species of molecule of a similar atomic mass. Liquid water forms a solvent, solute and reactant that channels life. As far as we know, biological reactions do not occur in the absence of water. Barring new supplies delivered in the form of comets (an extremely infrequent occurrence fortunately), the amount of water on earth remains constant.¹

Blue Planet

We inhabit a watery blue planet. When viewed from space, the oceans give our only home its blue colour. Earth is predominantly blue, but also white – with the white caps of the polar ice and the swirling white clouds organized into weather systems. Water, whether seen by astronauts, or viewed by the earthbound, may appear to be abundant, however it constitutes, in effect, a thin film on the surface of the planet. If the water of the earth, all 1.386 million cubic kilometres of it, were to be put into a single drop, it would create a sphere only 1384 km in diameter. To put this in context, the diameter of the earth is 12,742 km.

The Water Sensitive City, First Edition. Gary Grant.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.

For a sense of scale, compare a marble (equivalent to the volume of all the water of the earth) with a basketball (equivalent to the volume of the earth). The saltwater of the oceans makes up 96.5% of the total reservoir of water, the rest being groundwater, vapour, rivers, lakes and ice. Most freshwater, about 24 million cubic kilometres of it, is locked up in glaciers and ice caps. 10.5 million cubic kilometres of freshwater occurs as groundwater, with less than 200,000 km³ of water in lakes, rivers and wetlands. Readily available liquid freshwater in rivers and lakes totals 93,113 km³ and could be contained in a sphere just 56.2 km in diameter.² Only about 2.5% of the earth's water is suitable for human consumption without some kind of treatment. Water is ubiquitous in the biosphere; yet clean, safe, drinkable, freshwater is a relatively scarce resource.

A Global Water Cycle

Water moves and changes state as part of a perpetual planetary hydrological cycle. Radiation from the sun, striking the earth as it revolves, heats seas, lakes, soil and vegetation, causing water to evaporate. The sun also drives plant transpiration, the process whereby water passes through plants and exits via the leaves. As night turns to day and parts of the earth turn to face the sun, the warming water vapour forms into clouds. These clouds then move through the atmosphere in a process known as advection. When the temperature of the air falls, as it meets colder air, or as it cools when it rises, the water in clouds condenses and falls as rain, sleet or snow. As day turns to night and the dark side of the earth cools, dew may form (often the only source of water for the denizens of the desert). Where snow falls onto ice caps and glaciers it may accumulate and be sequestered for millennia. Spring melt, by contrast may come from snow that has lain for no more than a few days, weeks or months. Rain falls back to the oceans or onto the land. It may be intercepted by vegetation, never reaching the ground, or may infiltrate into the soil. Surplus rainfall forms surface or underground flows, entering lakes, streams and rivers, with the latter usually reaching the oceans. Where soil is saturated or frozen, or where soil or rocks are impermeable, rainfall will form runoff and enter water courses. In locations where the geological conditions are suitable, where the rocks are permeable, water replenishes aquifers, where in some cases, like the water of the ice caps, it may remain for millennia – the so-called fossil waters.³

Terrain and Water

Topography, geology and biomes⁴ have strong influences over where water collects and flows. High ground stimulates clouds to produce

rainfall as the clouds are pushed upwards into colder air by prevailing winds. The leeward sides of mountains may receive less rainfall and are therefore said to fall within rain shadows. The land divides along watersheds into river basins or catchments, where rain and snow melt feed particular river systems, forests and wetlands. Small catchments have small rivers and cannot support large settlements by themselves. Large rivers, like the Nile, Indus, Tigris, Euphrates and Yellow River, carry silt that was the foundation of agricultural systems that supported the first cities and civilizations. Humans continue to modify the water cycle and those modifications have been increasing in extent and intensity, particularly since the middle of the twentieth century. There are particular problems with those places where people are exploiting the upper parts of catchments, intercepting or diverting freshwater that would otherwise supply communities downstream, a problem that is predicted to lead to an increase in conflict and even warfare between nations.⁵ In addition, poor management practices, for example, deforestation in the upper reaches of river basins or an overreliance on piped drainage, can also lead to flooding and pollution problems downstream. Integrated catchment (river basin) management is frequently and quite rightly promoted as best practice but is usually applied in an inadequate and unsatisfactory way because of administrative and political divisions, conflicting private and public interests

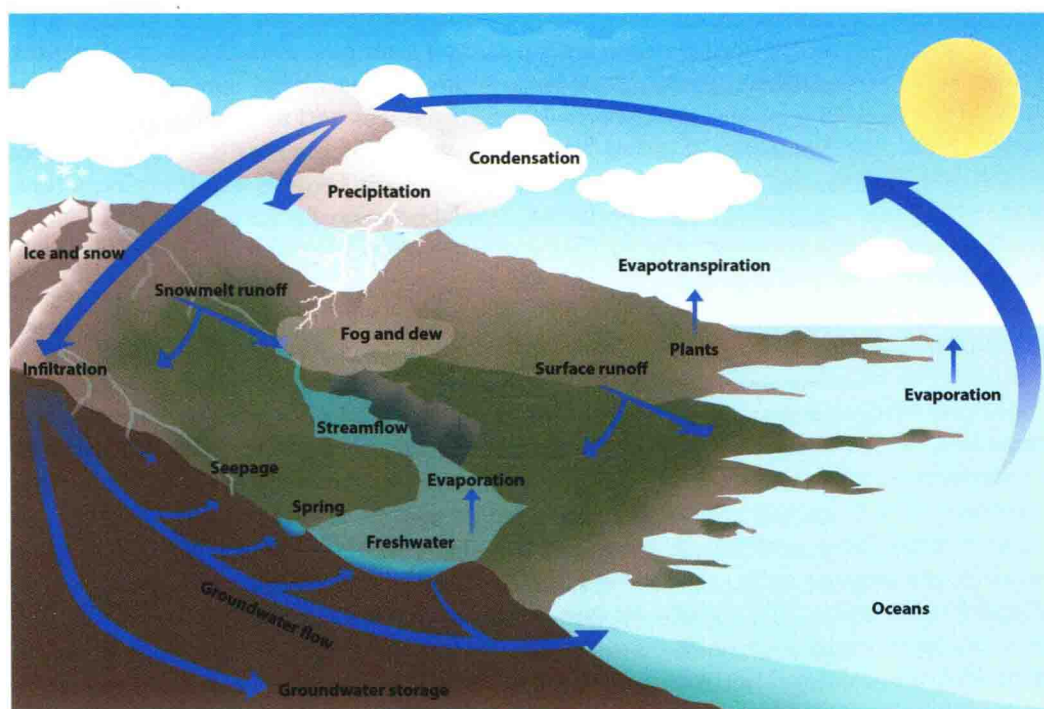


Figure 1.1 The water cycle. Based on an original by USGS. Illustration by Marianna Magklara.

or just plain ignorance. Watersheds (also known as river basins or catchments) would make the ideal administrative boundaries, but catchments frequently traverse administrative, political and even national boundaries, making comprehensive integrated catchment management plans difficult to agree and implement.

Seasons and Cycles

The 23.5° tilt of the earth's axis results in the northern hemisphere being more exposed to the sun from May to July and the southern hemisphere being more exposed to the sun from November to January. These annual changes bring the colder and wetter weather of winter to temperate regions and the wet (monsoon) seasons in the tropics. There is a larger landmass and therefore more plant biomass in the northern hemisphere, which means that the global atmospheric carbon dioxide concentration fluctuates, falling during the northern summer as plants grow and absorb carbon dioxide and increasing again through the northern winter as plant growth slows and, in some cases, halts. The current overall trend of atmospheric carbon dioxide concentration, of course, is up – largely the result of the burning of fossil fuels. The oceans play a key role in modifying the climate because they absorb and store heat. Ocean temperatures affect atmospheric temperatures, oceans currents and wind and the Pacific Ocean, which is the largest ocean by far, has the strongest impact of global weather patterns, as demonstrated by the El Nino phenomenon, which causes floods and drought across the Americas and as far afield as Australia, Southeast Asia and Africa.⁶ Seasonal effects mean that rainfall in most parts of the world is uneven, with many regions experiencing intense rainfall for short periods followed by extended dry spells.

Variations in Rainfall

The amount of rain that falls varies considerably from region to region and place to place. For example, the heaviest rains of more than 11,000mm per year occur where monsoon clouds meet the Kharsi Hills on the slopes of the eastern Himalayas in north-east India. Vancouver, on the rainy northwest Pacific coast of North America, enjoys more than 1100mm of rainfall per year. London, England, to the surprise of many, is relatively dry, receiving only 600mm of precipitation per year and Cairo, the capital of Egypt, receives just 25mm of rainfall each year.⁷ Rainfall patterns can be unpredictable. Even places noted for their reliable rainy season, like Ecuador for example, can suffer drought. In 2009, during an El Nino event, that country suffered its worst drought for 40 years.⁸ As a result of the drought, reservoirs dried up, leading to water shortages in the cities, however much of the news

at the time was dominated by stories of power blackouts, caused because of the lack of water to drive the turbines of the country's hydroelectric power stations.⁹

Changing Climates

As climate changes, so does the water cycle; 25,000 years ago, during the last ice age, sea levels were 120m lower than at present, with more water locked up in the polar ice caps and mountain glaciers. The Ice Age climate of that time was drier and rainfall was lower overall than it is at present. Rainforests shrank in size and deserts and grasslands expanded.¹⁰ As global temperatures warmed after the end of the last Ice Age, the atmosphere increased its capacity to hold water vapour, in turn changing weather patterns, which then allowed both tropical and temperate forests to expand in area. Anthropogenic (man-made) climate change is accelerating the process of warming, with the ice caps and mountain glaciers shrinking still further and sea levels rising. The atmosphere is predicted to carry even more water, bringing more unsettled weather with heavier downpours, more powerful storms and longer droughts. (Read more on climate and climate change in Chapter 5.)

Atmospheric Carbon Dioxide

There has been increase in atmospheric carbon dioxide caused by deforestation, agricultural intensification and expansion and, more recently, the burning of fossil fuels (an increase from 280 parts per million in the year 1800 to 400 parts per million in 2015).¹¹ This has had indirect effects on the water cycle but there have also been direct impacts. Deforestation, which usually leads to the creation of new pastures or croplands, tends to dry out soils and the landscape as a whole. Following deforestation, there are increases in surface runoff and therefore overall reductions in the volume of water evaporated and reductions in quantities of ground water. Regional patterns of cloud formation, and therefore rainfall, also change. Once denuded of forest vegetation, soils lose some of their organic matter and associated capacity to store water. The problem is further exacerbated as wetlands are also drained to create farmland. Then the farmland itself is drained. When this occurs, organic matter is oxidized and carbon dioxide is released into the atmosphere. Where crops, which require large quantities of water, are introduced, irrigation often becomes necessary, resulting in the unsustainable exploitation of groundwater or overabstraction of water from rivers. Globally, around 70% of the water abstracted from rivers, wells and boreholes is used for agriculture.¹² Lake-fed rivers (like, for example, the Aral Sea) shrink or may disappear altogether as the result of abstraction of water for agricultural