Water, Life and Civilisation

Climate, Environment and Society in the Jordan Valley

Water, Life and Civilisation provides a unique interdisciplinary study of the relationships between climate, hydrology and human society from 20,000 years ago to 100 years into the future. At the heart of the book is a series of case studies that integrate climate and hydrological modelling with palaeoenvironmental and archaeological evidence to generate new insights into the Neolithic, Bronze Age and Classical periods in the Jordan Valley. The volume not only develops our understanding of this most critical region, but provides a new approach and new methods that can be utilised for exploring the relationships between climate, hydrology and human society in arid and semi-arid regions throughout the world.

This volume describes how state-of-the-art models can simulate the past, present and future climates of the Near East, reviews and provides new evidence for environmental change from geological deposits, builds hydrological models for the River Jordan and associated wadis and explains how present-day urban and rural communities manage their water supply. It demonstrates how the theories and methods of meteorology, hydrology, geology, human geography and archaeology can be integrated to generate new insights into not only the past, from the hunter-gatherers of the Pleistocene to classical civilisation, but also the present and future. As such, it is an invaluable reference for researchers and advanced students concerned with the impacts of climate change and hydrology on human society, especially in the Near East.

STEVEN MITHEN is Professor of Early Prehistory and Pro-Vice Chancellor for International and External Engagement at the University of Reading. Having originally studied at the Slade School for Fine Art, he has a BA degree in Archaeology (Sheffield University), an MSc in Biological Computation (York University) and a PhD in Archaeology (Cambridge University). He was appointed a lecturer at the University of Reading in 1992, where he has since served as Head of the School of Human and Environmental Sciences (2003–2008) and Dean of the Faculty of Science (2008–2010) prior to his present appointment as a Pro-Vice Chancellor. He directs archaeological fieldwork projects in western Scotland, where he is attempting to reconstruct Mesolithic settlement patterns, and in southern Jordan where he is excavating the early Neolithic village of WF16 in Wadi Faynan. In addition to such archaeological research, he has sought to develop interdisciplinary approaches to the past by integrating archaeology with theories and methods from the environmental and cognitive sciences. He is the author of several books including *The Prehistory of the Mind* (1996), *After the Ice* (2003), *The Singing Neanderthals* (2005) and *To the Islands* (2010), and editor of *The Early Prehistory of Wadi Faynan* (2007, with Bill Finlayson) and *Hunter-Gatherer Landscape Archaeology* (2000). Steven Mithen was elected as a Fellow of the British Academy in 2003.

EMILY BLACK is a senior research fellow at the University of Reading. After completing a BA in Natural Sciences at the University of Cambridge and a DPhil in Andean tectonics at the University of Oxford, in 2000 she was appointed a post-doctoral research fellow at the Climate Division of the National Centre for Atmospheric Science. In 2005, she took up the post of project manager of the Water, Life and Civilisation project. She has published widely in the scientific literature on a variety of topics, including Middle East climate change, African rainfall variability and seasonal forecasting.

INTERNATIONAL HYDROLOGY SERIES

The **International Hydrological Programme** (IHP) was established by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1975 as the successor to the International Hydrological Decade. The long-term goal of the IHP is to advance our understanding of processes occurring in the water cycle and to integrate this knowledge into water resources management. The IHP is the only UN science and educational programme in the field of water resources, and one of its outputs has been a steady stream of technical and information documents aimed at water specialists and decision-makers.

The **International Hydrology Series** has been developed by the IHP in collaboration with Cambridge University Press as a major collection of research monographs, synthesis volumes, and graduate texts on the subject of water. Authoritative and international in scope, the various books within the series all contribute to the aims of the IHP in improving scientific and technical knowledge of freshwater processes, in providing research know-how and in stimulating the responsible management of water resources.

EDITORIAL ADVISORY BOARD
Secretary to the Advisory Board
Dr Michael Bonell *Division of Water Science, UNESCO, I rue Miollis, Paris 75732, France*

Members of the Advisory Board
Professor B. P. F. Braga Jr *Centro Technológica de Hidráulica, São Paulo, Brazil*
Professor G. Dagan *Faculty of Engineering, Tel, Aviv University, Israel*
Dr J. Khouri *Water Resources Division, Arab Centre for Studies of Arid Zones and Dry Lands, Damascus, Syria*
Dr G. Leavesley *US Geological Survey, Water Resources Division, Denver Federal Center, Colorado, USA*
Dr E. Morris *Scott Polar Research Institute, Cambridge, UK*
Professor L. Oyebande *Department of Geography and Planning, University of Lagos, Nigeria*
Professor S. Sorooshian *Department of Civil and Environmental Engineering, University of California, Irvine, California, USA*
Professor K. Takeuchi *Department of Civil and Environmental Engineering, Yamanashi University, Japan*
Professor D. E. Walling *Department of Geography, University of Exeter, UK*
Professor I. White *Centre for Resource and Environmental Studies, Australian National University, Canberra, Australia*

TITLES IN PRINT IN THIS SERIES

M. Bonell, M. M. Hufschmidt and J. S Gladwell *Hydrology and Water Management in the Humid Tropics: Hydrological Research Issues and Strategies for Water Management*
Z. W. Kundzewicz *New Uncertainty Concepts in Hydrology and Water Resources*
R. A. Feddes *Space and Time Scale Variability and Interdependencies in Hydrological Processes*
J. Gibert, J. Mathieu and F. Fournier *Groundwater/Surface Water Ecotones: Biological and Hydrological Interactions and Management Options*
G. Dagan and S. Neuman *Subsurface Flow and Transport: A Stochastic Approach*
J. C. van Dam *Impacts of Climate Change and Climate Variability on Hydrological Regimes*
D. P. Loucks and J. S. Gladwell *Sustainability Criteria for Water Resource Systems*
J. J. Bogardi and Z. W. Kundzewicz *Risk, Reliability, Uncertainty, and Robustness of Water Resource Systems*
G. Kaser and H. Osmaston *Tropical Glaciers*
I. A. Shiklomanov and J. C. Rodda *World Water Resources at the Beginning of the Twenty-First Century*
A. S. Issar *Climate Changes during the Holocene and their Impact on Hydrological Systems*
M. Bonell and L. A. Bruijnzeel *Forests, Water and People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water Management*
F. Ghassemi and I. White *Inter-Basin Water Transfer: Case Studies from Australia, United States, Canada, China and India*
K. D. W. Nandalal and J. J. Bogardi *Dynamic Programming Based Operation of Reservoirs: Applicability and Limits*
H. S. Wheater, S. Sorooshian and K.D. Sharma *Hydrological Modelling in Arid and Semi-Arid Areas*
J. Delli Priscoli and A. T. Wolf *Managing and Transforming Water Conflicts*
H. S. Wheater, S. A. Mathias and X. Li *Groundwater Modelling in Arid and Semi-Arid Areas*
L. A. Bruijnzeel, F. N. Scatena and L. S. Hamilton *Tropical Montane Cloud Forests*
S. Mithen and E. Black *Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley*

Water, Life and Civilisation

Climate, Environment and Society in the Jordan Valley

Edited by Steven Mithen and Emily Black

University of Reading

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore,
São Paulo, Delhi, Dubai, Tokyo, Mexico City

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521769570

© Steven Mithen and Emily Black 2011

This publication is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without
the written permission of Cambridge University Press.

First published 2011

Printed in the United Kingdom at the University Press, Cambridge

A catalogue record for this publication is available from the British Library

Library of Congress Cataloging-in-Publication Data

Water, life & civilisation : climate, environment, and society in the Jordan Valley / edited by Steven Mithen and Emily Black.
p. cm. – (International hydrology series)
Includes bibliographical references and index.
ISBN 978-0-521-76957-0 (Hardback)
1. Hydrology–Jordan River Watershed. 2. Water-supply–Jordan River Watershed–History. 3. Jordan River Watershed–Antiquities. 4. Water and civilization. 5. Climate and civilization. I. Mithen, Steven J. II. Black, Emily. III. Title: Water, life, and civilisation.
GB791.W384 2011
551.48095694–dc22 2010028679

ISBN 978-0-521-76957-0 Hardback

Cambridge University Press has no responsibility for the persistence or
accuracy of URLs for external or third-party internet websites referred to
in this publication, and does not guarantee that any content on such
websites is, or will remain, accurate or appropriate.

Bruce Sellwood recording a section of the Lisan Marl for the Water, Life and Civilisation project, 2006.

This volume is dedicated to Professor Bruce Sellwood (1947–2007).

Bruce was a pioneer of integrating palaeoclimatic modelling and geological research. He was an inspirational figure within the Water, Life and Civilisation Project and has been sorely missed by his colleagues for both his academic contributions and bonhomie.

© in this web service Cambridge University Press

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

Contents

List of figures *page* ix
List of tables xxii
List of contributors xxiv
Acknowledgements xxvii

1 Introduction: an interdisciplinary approach to Water, Life and Civilisation 1
Steven Mithen and Emily Black

Part I Past, present and future climate 11

2 The present-day climate of the Middle East 13
Emily Black, Brian Hoskins, Julia Slingo and David Brayshaw

3 Past climates of the Middle East 25
David Brayshaw, Emily Black, Brian Hoskins and Julia Slingo

4 Future climate of the Middle East 51
Emily Black, David Brayshaw, Julia Slingo and Brian Hoskins

5 Connecting climate and hydrological models for impacts studies 63
Emily Black

Part II The palaeoenvironmental record 69

6 A review of palaeoclimates and palaeoenvironments in the Levant and Eastern Mediterranean from 25,000 to 5,000 years BP: setting the environmental background for the evolution of human civilisation 71
Stuart Robinson, Stuart Black, Bruce Sellwood and Paul J. Valdes

7 Palaeoenvironments of the southern Levant 5,000 BP to present: linking the geological and archaeological records 94
Claire Rambeau and Stuart Black

8 Using proxy data, historical climate data and climate models to investigate aridification during the Holocene 105
Emily Black, David Brayshaw, Stuart Black and Claire Rambeau

9 Palaeoenvironmental and limnological reconstruction of Lake Lisan and the Dead Sea 113
Stuart Black, Stuart Robinson, Richard Fitton, Rachel Goodship, Claire Rambeau and Bruce Sellwood

Part III Hydrological studies of the Jordan Valley 129

10 The impacts of climate change on rainfall-runoff in the upper River Jordan: methodology and first projections 131
Andrew Wade, Emily Black, Nicola Flynn and Paul Whitehead

11 Modelling Dead Sea levels and rainfall: past, present and future 147
Paul Whitehead, Dan Butterfield, Emily Black and David Plinston

12 The hydrology of the Wadi Faynan 157
Andrew Wade, Paul Holmes, Mohammed El Bastawesy, Sam Smith, Emily Black and Steven Mithen

13 Future projections of water availability in a semi-arid region of the eastern Mediterranean: a case study of Wadi Hasa, Jordan 175
Andrew Wade, Ron Manley, Emily Black, Joshua Guest, Sameeh Al Nuimat and Khalil Jamjoum

Part IV Human settlement, climate change, hydrology and water management 189

14 The archaeology of water management in the Jordan Valley from the Epipalaeolithic to the Nabataean, 21,000 BP (19,000 BC) to AD 106 191
Bill Finlayson, Jaimie Lovell, Sam Smith and Steven Mithen

© in this web service Cambridge University Press

15 From global climate change to local impact in Wadi Faynan, southern Jordan: ten millennia of human settlement in its hydrological context 218
Sam Smith, Andrew Wade, Emily Black, David Brayshaw, Claire Rambeau and Steven Mithen

16 Palaeoenvironmental reconstruction at Beidha, southern Jordan (*c.* 18,000–8,500 BP): Implications for human occupation during the Natufian and Pre-Pottery Neolithic 245
Claire Rambeau, Bill Finlayson, Sam Smith, Stuart Black, Robyn Inglis and Stuart Robinson

17 The influence of water on Chalcolithic and Early Bronze Age settlement patterns in the southern Levant 269
Jaimie Lovell and Andrew Bradley

18 Modelling water resources and climate change at the Bronze Age site of Jawa in northern Jordan: a new approach utilising stochastic simulation techniques 289
Paul Whitehead, Sam Smith and Andrew Wade

19 A millennium of rainfall, settlement and water management at Humayma, southern Jordan, *c.* 2,050–1,150 BP (100 BC to AD 800) 302
Rebecca Foote, Andrew Wade, Mohammed El Bastawesy, John Peter Oleson and Steven Mithen

Part V Palaeoeconomies and developing archaeological methodologies 335

20 The reconstruction of diet and environment in ancient Jordan by carbon and nitrogen stable isotope analysis of human and animal remains 337
Michela Sandias

21 Irrigation and phytolith formation: an experimental study 347
Emma Jenkins, Khalil Jamjoum and Sameeh Al Nuimat

22 An investigation into the archaeological application of carbon stable isotope analysis used to establish crop water availability: solutions and ways forward 373
Helen Stokes, Gundula Müldner and Emma Jenkins

23 Past plant use in Jordan as revealed by archaeological and ethnoarchaeological phytolith signatures 381
Emma Jenkins, Ambroise Baker and Sarah Elliott

Part VI Society, economy and water today 401

24 Current water demands and future strategies under changing climatic conditions 403
Stephen Nortcliff, Emily Black and Robert Potter

25 Water reuse for irrigated agriculture in Jordan: soil sustainability, perceptions and management 415
Gemma Carr

26 Social equity issues and water supply under conditions of 'water stress': a study of low- and high-income households in Greater Amman, Jordan 429
Khadija Darmame and Robert Potter

27 The role of water and land management policies in contemporary socio-economic development in Wadi Faynan 442
Khadija Darmame, Stephen Nortcliff and Robert Potter

28 Political discourses and public narratives on water supply issues in Amman, Jordan 455
Khadija Darmame and Robert Potter

Part VII Conclusions 467

29 Overview and reflections: 20,000 years of water and human settlement in the southern Levant 469
Steven Mithen and Emily Black

Index 481

Colour plates appear between pages 196 and 197.

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

Figures

1.1 Disciplinary aims and interdisciplinary interactions of the Water, Life and Civilisation Project. *page* 4
1.2 Hierarchical modelling from global circulation models to socio-economic impacts (courtesy of David Viner). See colour plate section. 5
1.3 The geographical scope of the climate modelling within the Water, Life and Civilisation project and the case study region, indicating the key research localities. 6
1.4 Water, Life and Civilisation team members during an orientation visit to Jordan in October 2004, here seen at the Iron Age tell of Deir ‘Alla. See colour plate section. 7
2.1 Location of rain gauges. Top: Global Historical Climate Network (GHCN) gauges within Europe, Middle East and North Africa. Bottom: gauge data within the Middle East. Circles indicate GHCN monthly data; diamonds are gauges from the World Meteorological Organisation Global Summary of the Day (GSOD; daily data of very variable quality); stars are stations with daily data, provided by the Israeli Meteorological Service. 15
2.2 Mean climate over the Mediterranean. From top to bottom: December–February total precipitation; December–February SLP; December–February track density. See colour plate section. 17
2.3 Seasonal cycle in various rainfall statistics for the stations shown in the map to the right. The *x*-axis gives the month and the *y*-axis the statistic in question. The error bars represent the inter-annual standard deviation from one of the stations. All rainfall units are millimetres. From top to bottom, the statistics are: total monthly rainfall; mean number of rainy days in the month; mean rain per rainy day; mean maximum daily rainfall in the month; probability of rain given rain the day before (upper group of curves) and probability of rain given no rain the day before (lower group of curves). 18
2.4 Annual total rainfall in Jordan and Israel superposed on the orography. The contours are based on the data from the gauges shown in Figure 2.1. The dashed contours are sketched from published sources (US Geological Survey, 2006) because we were unable to obtain suitable quality data in eastern Jordan. See colour plate section. 19
2.5 Mean correlation versus mean distance apart for rainfall stations within Jordan and Israel. The solid line is cross-correlations between all stations; the dotted line is cross-correlations between grid squares of the same latitude, and the dashed line represents cross-correlations between grid squares of the same longitude. 19
2.6 Composite daily anomalies during the four GWL regimes that favour rainfall most strongly (WA, SWA, SWZ and NWZ – abbreviations defined in Table 2.1). Left set: daily rainfall anomaly composites over the Mediterranean (box shown on the top right plot); right set: daily SLP anomaly composites over the Mediterranean and Atlantic. See colour plate section. 20
2.7 Composites of precipitation, track density and SLP during January based on the five wettest and driest Januaries in a box with minimum longitude 34°, maximum longitude 36°, minimum latitude 31°, maximum latitude 33°. See colour plate section. 21
2.8 Histograms of rainfall total for the box defined in Figure 2.7 for positive and negative phases of the NAO, EAWR, East Atlantic pattern and for warm and cold Niño sea surface temperature (SST) anomalies. Negative phases or cold SSTs are shown by no shading and positive phases or warm SSTs by grey shading. 21
3.1 The forcings used to drive the global and regional models. (a) Greenhouse gas concentrations. (b) The annual cycle of insolation at the top of the atmosphere in experiment PREIND (units W m^{-2}). (c) The anomaly in the annual cycle of top of atmosphere (TOA) insolation applied to experiment 6kaBP (units W m^{-2}). (d) Annual mean insolation anomalies at the top of the atmosphere in each of the time-slice experiments (units W m^{-2}). 27
3.2 (a) The area of land surface modifications over North Africa and the Arabian Peninsula in the ‘Wet Sahara’ (WS) experiments (+ shows grid points that are converted from mostly desert to uniform savannah/shrubland and × are converted to open water).

© in this web service Cambridge University Press

(b) Imposed land ice-sheet changes between experiments 8kaBP and PREIND (shading shows the change in surface height, in metres). (c) Ocean heat flux convergence in experiments PRESDAY – 6kaBP ($W\ m^{-2}$). (d) Ocean heat flux convergence anomaly applied to experiment 8kaBP ($W\ m^{-2}$). (e) Sea surface temperature (SST) difference between experiments 8kaBP and 8kaBPNOICE (shading, °C) and sea ice difference (contours at 5% and 30%) for June–August. (f) As (e), but for December–February. 28

3.3 The seasonal distribution of precipitation over the Mediterranean. (a) GPCC dataset (June–September). (b) GPCC dataset (December–February). (c) As (a) but from the regional model in experiment PRESDAY. (d) As (b) but from the regional model in experiment PRESDAY. (e) As (a) but using the ERA-40 dataset. (f) As (b) but using the ERA-40 dataset. Units mm day^{-1}. In (a) and (b) missing data areas are blacked out. In (c) to (f), black squares mark the regions where GPCC data are missing. 31

3.4 Annual mean SAT and precipitation during the pre-industrial period. The top row panels show (a) SAT (°C) in experiment PRESDAY, and (b) the difference (°C) found in experiment PREIND (i.e. PREIND – PRESDAY). The middle row panels show results from the global model where (c) is the precipitation in experiment PRESDAY (mm day^{-1}) and (d) is the fractional difference (%) found in experiment PREIND (i.e. [PREIND – PRESDAY] × 100/PRESDAY). The bottom row (e, f) is identical to the middle row but uses downscaled data from the regional model. For the difference plots (b, d, f), areas where the differences are statistically significant at (b) 99%, (d) 90% and (f) 70% confidence are indicated by black crosses. Areas of extremely low precipitation (less than 0.2 mm day^{-1}) in experiment PRESDAY are blacked out in the difference plots. See colour plate section. 32

3.5 Hemisphere average SAT differences. (a) Northern Hemisphere average SAT change relative to experiment PREIND (°C). Data points from the time-slice experiments are marked by crosses, and data points from experiment 8kaBPNOICE are marked by triangles (experiment PRESDAY is shown at time $= -0.2$ kaBP). (b) As (a) but for Southern Hemisphere. 33

3.6 Changes in SAT across the Holocene time-slice integrations. (a) Annual mean SAT change (experiment 6kaBP – PREIND, °C). Panels (b) and (c) are as (a), but for boreal summer and winter seasons, respectively. (d) The change in the strength of the seasonal cycle of SAT between experiment 6kaBP and PREIND (the strength of the cycle is defined as the maximum monthly mean SAT minus the minimum monthly mean SAT, units °C). (e) Boreal winter SAT change (6kaBP – PREIND, colours, °C) in the regional model and lower tropospheric winds (850 hPa) in experiment PREIND (arrows, units $m\ s^{-1}$). (f) As (e) but for boreal summer. In panels (b) to (d), areas where the changes are statistically significant at the 90% level are marked with black crosses. See colour plate section. 34

3.7 The annual cycle of zonal mean SAT anomalies in experiment 6kaBP relative to experiment PREIND. (a–c) Zonal mean SAT anomaly including (a) both ocean and land points, (b) land points only, and (c) ocean points only (units °C). (d) Outgoing longwave radiation anomalies at the top of the atmosphere (boreal summer, for experiment 6kaBP – PREIND, units $W\ m^{-2}$). For (a) to (c) contours are at ±0.25, 0.5, 1, 2 °C. 36

3.8 The lower tropospheric circulation, as given by the 850 hPa streamfunction. (a) Experiment PREIND during December–February. (b) Difference between experiments 6kaBP and PREIND during December–February; shaded areas indicate negative values. (c) As (a) but for June–September. (d) As (b) but for June–September. The circulation is along streamlines and is cyclonic (anticlockwise) around negative values. The contour interval is the same in (a) and (c), and is four times greater than that in (b) and (d). 38

3.9 Differences in boreal summer precipitation across the Holocene time-slice integrations. The top row shows the precipitation in experiment PREIND (units mm day^{-1}) using data from (a) the global model and (b) the regional model. The middle row shows the fractional change in precipitation (units %) in experiment 6kaBP relative to experiment PREIND (i.e. [6kaBP – PREIND] × 100/PREIND), using data from (c) the global model and (d) the regional model. Panel (e) is similar to (c) but for experiment 8kaBP-WS. Panel (f) shows the fractional precipitation changes averaged over the SAHEL box (in the global model, as marked in panels (a) and (c)) and the CAUCUS box (in the regional model, as marked in panels (b) and (d)) in the time-slice experiments. Data points from the time-slice experiments are marked by × symbols whereas the + symbols mark data points from experiments 6kaBP-WS and 8kaBP-WS and triangles mark data points from experiment 8kaBPNOICE (experiment PRESDAY is shown at time $= -0.2$ kaBP). In panels (c) to (e), areas where the changes are statistically significant at the 90% level are marked with black crosses. Areas of extremely low precipitation (less than 0.2 mm day^{-1} for the global model and

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

0.05 mm day^{-1} in the regional model) in experiment PREIND are blacked out in panels (b) to (e). See colour plate section. 39

3.10 Differences in boreal winter precipitation across the Holocene time-slice integrations using the global model. (a) Experiment PREIND (units mm day^{-1}). (b) The fractional change in precipitation (units %) in experiment 6kaBP relative to experiment PREIND (i.e. [6kaBP – PREIND] × 100/PREIND). (c) As (b) but for experiment 8kaBP. (d) As (b) but for experiment 8kaBPNOICE. (e) As (b) but for Early Holocene experiments (8kaBP + 10kaBP + 12kaBP) minus the Late Holocene experiments (2kaBP + 4kaBP + 6kaBP). Panel (f) shows the fractional precipitation changes averaged over the boxes marked in panels (a) to (e). Data points from the time-slice experiments are marked by × symbols whereas triangles mark data points from experiment 8kaBPNOICE (experiment PRESDAY is shown at time = −0.2 kaBP). In panels (b) to (e), areas where the changes are statistically significant at the 90% level are marked with black crosses. Areas of extremely low precipitation (less than 0.2 mm day^{-1}) in experiment PREIND are blacked out in panels (c) and (d). See colour plate section. 41

3.11 Differences in boreal winter storm tracks across the Holocene time-slice integrations using the global model. (a) The storm track in experiment PREIND (units of storms per month passing through a 5° spherical cap). (b) Storm track difference (expt 6kaBP – PREIND). (c) As (b) but for experiment 8kaBP. (d) As (b) but for experiment 8kaBPNOICE. (e) As (b) but for Early Holocene experiments (8kaBP + 10kaBP + 12kaBP) minus the Late Holocene experiments (2kaBP + 4kaBP + 6kaBP). (f) The fractional storm track changes averaged over the boxes marked in panels (a) to (e). Data points from the time-slice experiments are marked by × symbols (experiment PRESDAY is not shown). In panels (b) to (e), areas where the differences are statistically significant at the 90% level are marked with black crosses, and areas of high orography (in excess of 1,200 m) are blacked out. Thick black contours in (b) to (e) show the 10 storms per month contour from experiment PREIND. Prior to display, the storm track diagnostics have been smoothed to improve readability. 42

3.12 The upper and lower tropospheric σ (the susceptibility of the mean state to weather system growth, as described in Section 3.2.7). (a) Values of σ in experiment PREIND (units s^{-1}) at 925 hPa. (b) As (a) but for 400 hPa. (c) Difference in σ between experiments 6kaBP and PREIND at 925 hPa. (c) As (b) but at 400 hPa. (e) As (c) but for experiment 8kaBP. (f) As (d) but for experiment 8kaBP. Data are only shown for the Northern Hemisphere extratropics and the contours have been lightly smoothed to improve readability. 43

3.13 Differences in boreal winter precipitation across the Holocene time-slice integrations from the regional model. (a) Experiment PREIND (units mm day^{-1}). (b) The fractional change in precipitation (units %) in experiment 6kaBP relative to experiment PREIND (i.e. [6kaBP – PREIND] × 100/PREIND). (c) As (b) but for experiment 8kaBP. (d) As (b) but for experiment 8kaBPNOICE. (e) as (b) but for early Holocene experiments (8kaBP + 10kaBP + 12kaBP) minus the late Holocene experiments (2kaBP + 4kaBP + 6kaBP). (f) The fractional precipitation changes averaged over the boxes marked in panels (a) to (e). Data points from the time-slice experiments are marked by × symbols, whereas triangles mark data points from experiment 8kaBPNOICE (experiment PRESDAY is shown at time −0.2 kaBP). In panels (b) to (e), areas where the differences are statistically significant at the 90% level are marked with black crosses. Areas of extremely low precipitation (less than 0.2 mm day^{-1}) in experiment PREIND are blacked out in panels (c) and (d). See colour plate section. 45

3.14 Differences in the boreal winter storm tracks across the Holocene time-slice integrations using the regional model. (a) The storm track in experiment PREIND (units of storms per month passing through a 5° spherical cap). (b) Storm track difference (expt 6kaBP – PREIND). (c) As (b) but for experiment 8kaBP. (d) As (b) but for experiment 8kaBPNOICE. (e) As (b) but for the average of the Early Holocene experiments (8kaBP + 10kaBP + 12kaBP) minus that for the Late Holocene experiments (2kaBP + 4kaBP + 6kaBP). (f) The fractional storm track differences averaged over the box marked in panels (a) to (e). Data points from the time-slice experiments are marked by × symbols (experiment PRESDAY is not shown). In panels (b) to (e), areas where the changes are statistically significant at the 90% level are marked with black crosses and areas of high orography (in excess of 1,200 m) are greyed out. Thick black contours in (b) to (e) show the 10 storms per month contour from experiment PREIND. The storm tracking analysis is performed on a coarse grid (hence the extremely coarse orographic features shown), and prior to display here the storm track diagnostics have been further smoothed to improve readability. 46

4.1 Model domains and modelled and observed topography. Top: model grid points (dots) on the model topography for the large domain. Bottom left: small domain (Middle East only) used for the ensembles. Bottom right: observed

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

topography for the eastern Mediterranean and Middle East. Topography is given in metres above sea level for all the plots. See colour plate section. 53
4.2 Left set of panels: seasonal cycles in various statistics of the weather for eight stations (black lines), and the regional climate model baseline ensemble (grey shaded area indicates the ensemble range). The *x*-axis gives the month and the *y*-axis gives the mean rainfall statistic during that month. From top to bottom the statistics are: mean total monthly rainfall, mean total number of rainy days, mean rain per rainy day, mean maximum monthly rainfall, monthly mean probability of rain given no rain the day before, monthly mean probability of rain given rain the day before. Rainfall is given in millimetres for all the plots. Right panel: the location of the stations and the RCM time-series box. The crosses indicate RCM grid points. 54
4.3 Seasonal cycle in precipitation change under an A2 scenario by 2070–2100. Significance at the 95% level is shown by a dot in the grid square. Top set: monthly mean absolute change in rainfall (mm) over the whole of the Mediterranean under an A2 scenario. Bottom set: monthly mean percentage change in rainfall (%) over the East Mediterranean only. See colour plate section. 55
4.4 Change in the January climate (temperature, precipitation, sea-level pressure and 850 mb track density) over the Mediterranean under an A2 scenario by 2070–2100. See colour plate section. 56
4.5 Change in daily rainfall probabilities. Significance at the 95% level is indicated by a dot within the grid square. Top row, left panel: absolute change in the probability of rain given no rain the day before; right: absolute change in the probability of rain given rain the day before. Bottom row: as above but for percentage changes for the southeast part of the region only. See colour plate section. 57
4.6 Left set of panels: seasonal cycles in various statistics of the weather for the baseline ensemble (light grey polygon); the A2 ensemble (dark grey polygon) and the B2 integration (dashed line) for the box shown in Figure 4.2. The *x*-axis gives the month and the *y*-axis gives the mean rainfall statistic during that month. From top to bottom the statistics are: mean total monthly rainfall, mean total number of rainy days, mean rain per rainy day, mean maximum monthly rainfall, monthly mean probability of rain given no rain the day before, monthly mean probability of rain given rain the day before. Rainfall is given in millimetres for all the plots. Right set of panels: difference in ensemble means between the A2 scenario integration and the baseline integration for the statistics shown on the left. Filled bars indicate significance at the 95% level. 58
4.7 Percentage change in January precipitation under an A2 scenario by 2070–2100 for eight IPCC models. The model name abbreviations on the plots are: CSIRO Mark 3.0 (csmk3); GFDL CM 2.0 AOGCM (gfcm20); HadCM3 (hadcm3); IPSL CM4 (ipcm4); MRI-CGCM2.3.2 (mrcgcm);NCAR CCSM3 (nccsm); GFDL CM 2.1 AOGCM (gfcm21); MIMR MIROC3.2 (medium resolution). See colour plate section. 59
4.8 Top: mean percentage change in January precipitation predicted under an A2 scenario for 2070–2100 for the IPCC models shown in Figure 4.7; middle: mean percentage change in January precipitation predicted under a B1 scenario for 2070–2100 for the IPCC models shown in Figure 4.7. Bottom: difference in the mean percentage change between the A2 and B1 (B1 – A2). See colour plate section. 60
5.1 Location of gauges referred to in the chapter superposed on the topography. The inset map shows the location of the main map. Crosses are the locations of the stations provided by the Israeli Meteorological Service. The star is Tafilah and the circles are monthly data used in Chapters 12 and 13 and referred to here. 65
5.2 Seasonal cycles of rainfall statistics for the observations (black line), the weather generator based on observed statistics (dashed line) and the weather generator based on the predicted statistics (grey line). Top left: rainfall probabilities (upper lines are PRR and lower lines are PDR); bottom left: rainfall amount fractional frequency histogram; right: rainfall totals (mm day^{-1}). 66
5.3 Quantile–quantile plot of observed versus simulated rainfall amounts for a single gamma distribution (filled circles) and for spliced gamma/extreme value distribution (open circles). The line represents a $y = x$ function on which the circles would lie if the theoretical distribution perfectly matched the observations. 66
6.1 Map of the eastern Mediterranean and Levant region showing the locality of major features and sites discussed in the text. 1: Ghab Valley; 2: Hula Basin; 3: Peqiin Cave; 4: Israeli coastal plain; 5: Ma'ale Efrayim Cave; 6: Soreq Cave; 7: Jerusalem West Cave; 8: Wadi Faynan; 9: Ocean Drilling Program (ODP) Site 967; 10: site of core M44–1-KL83; 11: site of core GeoB5804–4; 12: site of core GeoB5844–2. Map produced with GMT (http://gmt.soest.hawaii.edu/). 72
6.2 Reconstructed air temperatures from the GISP 2 ice core in Greenland (after Alley, 2000). The timing and duration of the Last Glacial Maximum (LGM) is the

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

same as the 'LGM Chronozone Level 1' as defined by Mix *et al*. (2001). 72

6.3 Climate model outputs for the LGM and the present day. (A) Present-day winter (DJF) precipitation (precipitation in mm per day); (B) LGM winter (DJF) precipitation; (C) present-day summer (JJA) precipitation; (D) LGM summer (JJA) precipitation; (E) present-day annual precipitation; (F) LGM annual precipitation; (G) LGM winter (DJF) snowfall (snowfall in mm per day); (H) LGM summer (JJA) snowfall. Note that panel H is blank because there is no snowfall in summer. 74

6.4 Climate model outputs for the LGM and present day. (A) Present-day winter (DJF) temperature (°C); (B) LGM winter (DJF) temperature; (C) present-day summer (JJA) temperature; (D) LGM summer (JJA) temperature; (E) present-day average annual temperature; (F) LGM average annual temperature; (G) LGM annual average precipitation minus evaporation in mm day^{-1}; (H) LGM annual average wind strength (in m s^{-1}) and vectors. See colour plate section. 74

6.5 Compilation of lake level curves for Lake Lisan/the Dead Sea and Lake Tiberias. (A) Frumkin *et al.* (1994); (B) Neev and Emery (1995); (C) Landman *et al.* (2000); (D) timing of massive salt deposition (Yechieli *et al*., (1993); Neev and Emery (1967); there is some uncertainty regarding the exact age of the sediments, hence the dashed line. Shading of the YD here indicates the range of the two best dates); (E) Bartov *et al.* (2002, 2003); (F) Hazan *et al.* (2004). EHWP = Early Holocene Wet Phase; YD = Younger Dryas; H1 = Heinrich Event 1; LGM = Last Glacial Maximum; H2 = Heinrich Event 2. 75

6.6 An integrated, schematic lake level curve (solid black line) for the Lake Lisan/Dead Sea based upon various studies. This curve is designed primarily to illustrate lake level trends over time for ease of comparison with other proxy data. For the period 25 to 13 cal. ka BP the integrated curve is an approximate average of Neev and Emery (1995), Bartov *et al.* (2002, 2003) and Landmann *et al.* (2002). From 13 to 9 cal. ka BP we have used the data from Neev and Emery (1967), Begin *et al.* (1985), Yechieli *et al.* (1993) and Stein (2001) which suggest a major lake level fall between 13 and 11 cal. ka BP. From 9 cal. ka BP onwards we have followed the study of Frumkin *et al.* (1994). 76

6.7 Palaeoclimate of the Israeli coastal plain, as interpreted from palaeosols (Gvirtzman and Wieder, 2001). Black dots show position of age model tiepoints. S1 = Sapropel 1, B-A = Bølling–Allerød; other abbreviations as in Figure 6.5. 77

6.8 Palynology of the Hula Basin (Baruch and Bottema, 1991) and the Ghab Valley (Niklewski and van Zeist, 1970) with the proposed chronostratigraphy of Rossignol-Strick (1995). Horizontal axes in %; in the left-hand figure, the percentage for each taxon refers to concentration of that pollen taxon with respect to total 'Arboreal pollen+non-arboreal pollen'. In the right-hand figure, the percentage scale refers to the relative proportions of 'trees + shrubs' and 'Chenopodiaceae+*Artemisia*'. 78

6.9 Speleothem stable-isotope data (Bar-Matthews *et al*., 2003; Vaks *et al*., 2003) and reconstructed air temperatures (McGarry *et al*., 2004). 80

6.10 Gastropod oxygen isotope data from the Negev Desert (Goodfriend, 1991). 82

6.11 (A) Foraminiferal LGM annual, summer and winter SST reconstructions (Hayes *et al*., 2005), calculated using an artificial neural network (ANN). (B) Temperature anomalies for annual, summer and winter SSTs during the LGM, compared with modern-day values (Hayes *et al*., 2005). Anomaly values were calculated by subtracting modern-day SSTs from the glacial values. The black dots represent the sites of the cores from which the LGM data were obtained. This figure is a reproduction of part of Figure 9 in Hayes *et al.* (2005). See colour plate section. 83

6.12 Compilation of eastern Mediterranean Sea palaeoclimatic records from Site 967 (Emeis *et al*., 1998, 2000, 2003) and MD84–461 (Fontugne and Calvert, 1992). The 'δ^{18}O/p.s.u. value' is a coefficient used in the calculation of SSS that relates salinity and $\delta^{18}O_{seawater}$ (see Emeis *et al*., 2000 for more details). 84

6.13 Compilation of northern Red Sea palaeoclimatic records (Arz *et al*., 2003a, b; core names defined therein). 84

6.14 Compilation of terrestrial and marine palaeoclimatic proxy data for the Levant and eastern Mediterranean. Also shown is the ice-core record from GISP2 (Greenland). References: 1: Alley (2000); 2: see Figure 6.6; 3: Bar-Matthews *et al.* (2003); 4: Arz *et al.* (2003a); 5: Emeis *et al.* (2000, 2003); 6: Gvirtzman and Wieder (2001); 7: Rossignol-Strick (1995); 8: Magaritz (1986), Goodfriend and Magaritz (1988); 9: Magaritz and Heller (1980); Goodfriend (1990, 1991, 1999); 10: Reeder *et al.* (2002). 86

6.15 Summary of climatic conditions at the LGM (A), peak of the Bølling–Allerød warm phase (B), the Younger Dryas (C) and during the early Holocene/S1 (D). Turbidite data from Reeder *et al.* (2002); alkenone SSTs and SSS data from Emeis *et al.* (2000, 2003) and Arz *et al.* (2003a, b); speleothem data from Bar-Matthews *et al.* (1997, 1999, 2000, 2003), Frumkin *et al.* (1999b, 2000), Vaks *et al.* (2003) and McGarry *et al.* (2004); pollen data from

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

Niklewski and van Zeist (1970), Baruch and Bottema (1991) and Rossignol-Strick (1995); lake levels from Figure 6.6 (this study); LGM annual SSTs calculated from foraminiferal assemblages taken from Hayes *et al.* (2005); early Holocene SSS values are from Kallel *et al.* (1997a); Israeli coastal plain palaeosol data from Gvirtzman and Wieder (2001); Negev data from Magaritz (1986), Goodfriend and Magaritz (1988); Goodfriend, (1999); southern Jordan fluvial data from McLaren *et al.* (2004). T = temperature (all in °C), S = salinity, P = precipitation, NAP = non-arboreal pollen, AP = arboreal pollen, Maps drawn with GMT (http://gmt.soest.hawaii.edu/). Coastlines do not account for any changes in sea level or sedimentation. 87

7.1 Location of the different localities and regions presented in the text. (A) Map of the southern Levant and mean annual rainfall (from EXACT 1998). 1 – Hula Basin (Baruch and Bottema, 1999; Cappers *et al.*, 1998; Rosen, 2007). 2 – Upper Galilee caves (Issar, 2003). 3 – Ma'ale Efrayim Cave (Vaks *et al.*, 2003). 4 – Soreq Cave (Bar-Matthews and Ayalon, 2004; Bar-Matthews *et al.*, 1998, 1999, 2003). 5 – Israeli coastal plain (Gvirtzman & Wieder, 2001). 6 – Wadi Faynan (Hunt *et al.*, 2004, 2007; McLaren *et al.*, 2004; Grattan *et al.*, 2007). 7 – Elat shorelines (Shaked *et al.*, 2002). 8 – Wadi Muqat (Abboud, 2000). 9 – Cores GA 112–110 (Schilman *et al.*, 2001a,b). 10 – Jordan Valley (Hourani and Courty, 1997). 11 – Northern Negev Desert (Goodfriend, 1991, 1999). 12 – Southern Negev (Amit *et al.*, 2007). 13 – Qa'el-Jafr Basin (Davies, 2005). 14 – Central Negev Highlands (Rosen *et al.*, 2005; Avni *et al.*, 2006). 15 – Birkat Ram Lake, Golan Heights (Schwab *et al.*, 2004). 16 – Wadi ash-Shallalah (Cordova, 2008). 17 – Wadi al-Wala and the Madaba-Dhiban plateau (Cordova *et al.*, 2005; Cordova, 2008). 18 – Tel Lachish (Rosen, 1986). 19 – Nahal Qanah Cave (Frumkin *et al.*, 1999a). 20 – Nahal Zin, Negev (Greenbaum *et al.*, 2000). (B) Map of the Dead Sea area. 96

7.2 Compilation of several proxies for the middle to late Holocene in the southern Levant. Red and blue bars (see colour plate section) show interpreted climate fluctuations (wetter/drier conditions). Archaeological periods from Rosen (2007). Dead Sea levels: 1 – Frumkin and Elitzur (2002). 2 – Klinger *et al.* (2003). 3 – Enzel *et al.* (2003). 4 – Bookman *et al.* (2004). 5 – Migowski *et al.* (2006). (A) Dead Sea levels in 1997 (Migowski *et al.*, 2006). Lake Kinneret levels: 6 – Hazan *et al.* (2005). Calculated rainfall: 7 – From the Soreq cave record; Bar-Matthews and Ayalon (2004). (B) Present-day mean annual rainfall in Soreq area. 8 – From tamarisk wood, Mount Sedom cave; Frumkin *et al.* (2009). (C) Present-day mean annual rainfall at Mount Sedom. 9 – Climatic change from pollen indicators according to Neumann *et al.* (2007). Our synthesis is presented at the bottom of the figure. See colour plate section. 97

8.1 Summary of rainfall signal from the proxy data for the Middle East and Europe described in the text. Pluses indicate higher rainfall and minuses lower rainfall during the early Holocene as compared with the early/mid-Holocene. 108

8.2 Comparison between the observed and modelled climate. Top set, left: GPCC precipitation for the whole Mediterranean (top) and for the Middle East only (bottom); right: RCM precipitation for the whole Mediterranean (top) and for the Middle East only (bottom). Bottom set, left: NCEP reanalysis temperature for the whole Mediterranean (top) and for the Middle East only (bottom); right: RCM temperature for the whole Mediterranean (top) and for the Middle East only (bottom). See colour plate section. 109

8.3 Comparison of modelled and observed track densities (in number of tracks per month per 5 degree spherical cap). Left: mean January track density in the reanalysis. Right: mean January track density in the RCM large-domain baseline scenario. Both figures are based on tracking of features in the 850 mb vorticity field. See colour plate section. 110

8.4 Modelled changes in October–March precipitation (top, in mm) and December–February track density (bottom, in number of tracks per month per 5 degree spherical cap for (from left to right) late Holocene minus early Holocene; future (2070–2100) – present (1961–1990); and driest years – wettest years from 1948–1999. See colour plate section. 110

9.1 Map showing the initial extent of Lake Lisan and present-day Dead Sea (after Stein *et al.*, 2009). Inset shows the structural setting for the region. 113

9.2 Map showing the location of sites 1–4 sampled within this study. 114

9.3 Photograph showing the Lake Lisan Grey Unit and White Unit on the East side of the Jordan Valley. 116

9.4 The U-decay series chain. 117

9.5 The Th-decay series chain. 117

9.6 Compilation figure of previously published lake level data from Lisan sediments, predominately from the west side of the Jordan Valley together with information from this study coming from the east side. 118

9.7 Site 4 used in this study. Inset shows stromatolite in cross-section, with intercalated gravels above and fine-grained sediments below. 123

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

9.8 Site 1. Inset shows laminated bands of aragonite (white) and grey (silicate-rich) units. 123
9.9 Site 3. Inset shows detailed layers of the sediments with annual bands. 124
9.10 The data presented in this chapter (black circles) together with the elevation/age data from Enzel *et al.* (2003) (grey squares). 124
10.1 A schematic map of the upper River Jordan. 133
10.2 An overview of the modelling framework. 137
10.3 Modelled and observed daily mean flows in the Jordan river at Obstacle Bridge from 1 October 1988 to 30 September 1993. 138
10.4 The relationship between monthly mean flow and monthly mean rainfall for different values of PDR. Top: monthly mean flow plotted against monthly mean rainfall. High PDR are filled circles and low PDR are unfilled circles. Bottom: histograms of flow for different ranges of monthly total rainfall for high PDR (filled bars) and low PDR (unfilled bars). The ranges are given on the figure. 140
10.5 The relationship between monthly mean flow and monthly mean rainfall for different values of PRR. Top: monthly mean flow plotted against monthly mean rainfall. High PRR are shaded circles and low PRR are unfilled circles. Bottom: histograms of flow for different ranges of monthly total rainfall for high PRR (shaded bars) and low PRR (unfilled bars). The ranges are given on the figure. 141
10.6 Flow duration curves for each of the sensitivity studies compared with the flow duration curve for the generated time-series based on the observed statistics of the weather (sensitivity studies labelled on the figure). 142
10.7 Comparison between the flow duration curves for halving PRR and halving PDR. The right-hand figure is a zoom of the high flow region of the left-hand figure, which shows all the data. 142
10.8 Projected changes in the monthly rainfall totals at Degania Bet, Israel, from the HadRM3 and weather generator models for 2070–2100 under the SRES A2 scenario. 143
10.9 Modelled daily mean flows in the Jordan river at Obstacle Bridge for control (1961–1990) and scenario (2071–2100) periods. 144
11.1 Map Showing the Dead Sea catchment area, with Lake Kinneret in the north. 148
11.2 A GIS representation of the digital terrain of the Jordan Valley and the Dead Sea. 148
11.3 Estimates of changing Dead Sea levels over the past 25,000 years (Enzel *et al.,* 2003 – upper graph; Black *et al.*, Chapter 9 of this volume – lower graph). 148
11.4 Dead Sea hypsometric curves showing relationships between sea elevation, surface area and volume. 149
11.5 The shoreline of the Dead Sea reconstructed for four different depths. The 170 m depth equates to that at the Last Glacial Maximum, which occurred at approximately 20 cal. ka BP based on the palaeoenvironmental evidence summarised in Robinson *et al.* (2006). 150
11.6 Dead Sea elevations from 1860 to 2009, showing rapid decline since the 1960s. 150
11.7 Jerusalem rainfall from 1846 to 1996. 152
11.8 Regression of Dead Sea level change against Jerusalem rainfall for the period 1860–1960 using decadal averages. 152
11.9 Observed and modelled Dead Sea levels 1860–1960. 152
11.10 Extension of the observed and modelled data to include the recent period of abstraction and sea level decline. 152
11.11 Predicted simulation of the levels to 2050 assuming continued abstraction from the River Jordan. 153
11.12 Predicted sea levels in the future assuming climate change for eight future realisations without the effects of abstraction, and two climate change scenarios that do include the abstraction. 154
11.13 The effects on Dead Sea elevations assuming a major water transfer from either the Red Sea or the Mediterranean Sea into the Dead Sea. Shown are three water transfer rates of 1,690, 1,900 and 2,150 million m^3 per year for the years 2020 to 2040, and then transfer rates falling to match the water abstraction rate of 800 million m^3 per year. 154
11.14 Estimated rainfall over the past 9,000 years based on the Enzel *et al.* (2003) Dead Sea elevations. 155
11.15 Estimated rainfall over the period 8–250 ka BP based on the Black *et al.* (Chapter 9, this volume) Dead Sea elevations. 155
12.1 A schematic map of the Wadi Faynan, its major tributaries and settlements. PPNB, Pre-Pottery Neolithic B. 158
12.2 The geology of the Wadi Faynan area. Source Geological Map of Jordan 1:250,000, prepared by F. Bender, Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover 1968 [Sheet: Aqaba-Ma'an and Amman]. Reproduced with permission. Not to scale. © Bundesanstalt für Geowissenschaften und Rohstoffe. See colour plate section. 161
12.3 A geological cross-section made 5 km to the north of the Wadi Faynan. Source: Geological Map of Jordan 1:250,000, prepared by F. Bender, Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover 1968 [Sheet: Aqaba-Ma'an and Amman]. Reproduced with permission. Not to scale. © Bundesanstalt für Geowissenschaften und Rohstoffe. See colour plate section. 162

© in this web service Cambridge University Press www.cambridge.org

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

12.4 A subset of the Landsat image of the Wadi Faynan area acquired on 08 March 2002. 162
12.5 This picture was taken just to the south of the Jebel Hamrat al Fidan and shows how a farmer has tapped the groundwater held close to the surface by the granitic barrier by digging a network of trenches to expose the water. The water is pumped from the trench and used to irrigate fields of watermelon. 162
12.6 Rainfall patterns (isohyets) in the region of the Wadi Faynan (marked by the circle). Source: Department of Civil Aviation, Jerusalem, 1937–38. 165
12.7 Sample site locations in the Wadi Faynan from the 2006, 2007 and 2008 field seasons. 167
12.8 A conceptual model of the key water stores and pathways in the Wadi Faynan. Precipitation on the limestone and plateau soils in the upper reaches is likely to be the key aquifer recharge mechanism. The water will flow laterally through the limestone and sandstones until it emerges at a contact point between the two or at a contact between the sandstone and the aplite-granite. Re-infiltration (transmission loss) occurs as the water flows along the channel network. The Jebel Hamrat al Fidan forces the water to return close to the surface. Base map source: Geological Map of Jordan 1:250,000, prepared by Geological Survey of Germany, Hannover 1968 (Sheet: Aqaba-Ma’an). Reproduced with permission. Not to scale. See colour plate section. 168
12.9 The flow duration curve based on the flows simulated in the Wadi Faynan over the period 1937 to 1973. The Pitman model was applied to simulate flows in the Wadi Faynan to a point on the channel network adjacent to the ancient field-system immediately downstream of the Ghuwayr–Dana confluence. The highest simulated flow of 98 $m^3 s^{-1}$ occurred in response to a mean daily rainfall-event of 90 mm. 170
13.1 A schematic map of the southern Ghors which includes the Wadi Hasa. 176
13.2 The modelling framework used to simulate the rainfall-runoff response in the Wadi Hasa catchment. 180
13.3 Observed and simulated mean monthly flows in the Wadi Hasa at (a) Tannur and (b) Safi. Simulated flows are shown for the calibration and scenario climate conditions. 183
13.4 Observed versus simulated (calibration period) mean monthly flows in the Wadi Hasa at (a) Tannur and (b) Safi. 183
13.5 Observed and simulated flow-duration curves for the Wadi Hasa at (a) Tannur and (b) Safi. Simulated flows are shown for the calibration (1923–2002) and scenario climate conditions. 184
13.6 Observed and simulated mean monthly flows, averaged over the 80-year simulation period, in the Wadi Hasa at (a) Tannur and (b) Safi. Simulated flows are shown for the calibration (1923–2002) and scenario climate conditions where both precipitation and PET are adjusted and where precipitation alone is adjusted (Scenario ΔP) for the model simulations of flow at Safi. 186
14.1 Map of the study region showing Epipalaeolithic and Pre-Pottery Neolithic A sites referred to in the text. 193
14.2 Map of the study region showing Pre-Pottery Neolithic B and Pottery Neolithic sites referred to in the text. 194
14.3 Map of the study region showing Bronze Age, Iron Age and Nabataean sites referred to in the text. 194
14.4 Massive concentration of chipped stone at Kharaneh IV, Wadi Jilat (© B. Finlayson), marked by the roughly oval, darkened area immediately in front of and next to the two figures. 194
14.5 Remnants of a brushwood hut at Ohalo II, showing location adjacent to Lake Tiberias (Kinneret) (© S. Mithen). 195
14.6 Extensive use of pisé and mud plaster at the Pre-Pottery Neolithic A settlement of WF16, Wadi Faynan, showing excavations of April 2009 (© S. Mithen). 196
14.7 Experimental PPNB buildings at Beidha (© B. Finlayson). 196
14.8 Archaeological remains of the Pre-Pottery Neolithic B ‘mega-site’ of Basta (© S. Mithen). 197
14.9 Archaeological remains of the Pre-Pottery Neolithic B site of Ba’ja, located within a steep-sided siq (© S. Mithen). 198
14.10 Excavation at the Pottery Neolithic settlement Sha’ar Hagolan (© Y. Garfinkel). 199
14.11 Cross-section of the Pottery Neolithic well at Sha’ar Hagolan (© Y. Garfinkel). 200
14.12 Plan of the Pottery Neolithic B settlement at Wadi Abu Tulayha, showing the relationship between the settlement structures, the barrage and the proposed cistern (Str M, W-III) (© S. Fujii). 202
14.13 The Pre-Pottery B ‘outpost’ settlement at Wadi Abu Tulayha (© S. Fujii). 203
14.14 The proposed Pre-Pottery Neolithic B barrage in Wadi Abu Tulayha (© S. Fujii). 203
14.15 The proposed Pre-Pottery Neolithic B barrage in Wadi Ruweishid (© S. Fujii). 204
14.16 Interior of the proposed Pre-Pottery Neolithic B cistern in Wadi Abu Tulayha (© S. Fujii). 204
14.17 Excavation of a remnant of a terrace wall in the vicinity of the Pottery Neolithic settlement of and projected extent of wall ‘Dhra (© B. Finlayson). 205

CAMBRIDGE

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

14.18 Reconstruction of Pottery Neolithic cultivation plots supported by terrace walls at ‘Dhra (© B. Finlayson). 206
14.19 Khirbet Zeraqoun, in the northern highlands of Jordan (© S. Mithen). 207
14.20 Tell Handaquq and the Wadi Sarar (© S. Mithen). 208
14.21 Iron Age Tell Deir Allah, looking across the Jordan Valley where water canals were built to supply the settlement (© S. Mithen). 211
14.22 Aqueduct at Humayma (© R. Foote). 212
14.23 Cistern at Humayma with an arched roof (scale provided by Dr Claire Rambeau) (© R. Foote). 213
14.24 Nabataean water channel in the siq at Petra (© S. Mithen). 213
15.1 Location of Wadi Faynan catchment in relation to Khirbet Faynan and present-day precipitation isohyets (mm yr^{-1}). 220
15.2 Contemporary Bedouin dam in Wadi Ghuwayr, used to help channel water into plastic pipes for transport to fields to west. 220
15.3 Contemporary Bedouin reservoir in Wadi Faynan. The water here is drawn from groundwater flow in the Wadi Ghuwayr using plastic pipes (as shown in Figure 15.2). 220
15.4 Schematic representation of present-day vegetation cover in Wadi Faynan catchment (after Palmer *et al*., 2007, figure 2.11). 221
15.5 Map of main archaeological sites discussed in this chapter in relation to modern settlements and principal wadi systems. 222
15.6 PPN sites in Wadi Faynan. (a) PPNA WF16; (b) PPNB Ghuwayr 1. 223
15.7 Schematic representation of EBA water harvesting system in Wadi Faynan (WF 1628) showing several cross-wadi walls and check dams built to deflect surface runoff onto surrounding landscape (after Barker *et al*., 2007b, figure 8.24). 223
15.8 WF4 field-system looking northwest. 223
15.9 Mean annual rainfall at Tafilah for each time slice against 0 ka (control) mean. 225
15.10 Mean monthly rainfall amounts for each time slice and control experiments. 226
15.11 Comparison of palaeo-rainfall estimates used in this study with those derived from Soreq Cave sequence. 227
15.12 Summary of mean daily flow rates for each month of time-slice and control experiments. Infiltration rate is 8 mm per day for all time slices. 231
15.13 Schematic diagram of Wadi Faynan showing the potential impact of changes in vegetation on hydrological processes. (a) Present day. Infiltration is limited to areas of colluvium, small areas of vegetation and soil cover in upper catchment (coloured grey), and the (saturated) wadi channel. The majority of the wadi comprises bare, rocky slopes and gravel terraces with very low infiltration rates, which induce high runoff. (b) Early Holocene. Dense vegetation cover and increased soil cover in the wadi system increases areas of infiltration (coloured grey). This increases potential percolation in upper catchment and reduces surface runoff generation. 231
15.14 Comparison of monthly flows for 12 ka BP time slice under different infiltration scenarios. 233
15.15 Comparison of flow duration curves for 12 ka BP simulation under high and low infiltration scenarios. 233
15.16 Comparison of monthly flows for 6 ka BP time slice under different infiltration scenarios. 233
15.17 Comparison of monthly flows for 2 ka BP time slice under different infiltration scenarios. 234
15.18 Comparison of monthly flows for each time slice and 0 ka BP (control) simulations under infiltration scenarios proposed for the Holocene. The key indicates time; infiltration rate. 234
15.19 Palaeo-rainfall (bars) and palaeo-flows (line) for Holocene scenarios and 0 ka (control) simulations for Wadi Faynan. 235
15.20 Summary of monthly flows for proposed early Holocene (12–8 ka BP) and 0 ka BP (control) simulations. The key indicates time; infiltration rate. 236
15.21 Summary of monthly flows for proposed mid-Holocene (6–4 ka BP) and 0 ka BP (control) simulations. The key indicates time; infiltration rate. 236
15.22 Summary of monthly flows for proposed late Holocene (4, 2 and 0 ka BP (control)) simulations. The key indicates time; infiltration rate. 237
15.23 Present-day cultivation in the WF4 field-system, irrigated using groundwater flow captured by plastic pipes in Wadi Ghuwayr (see Figures 15.2 and 15.3). 240
16.1 Map of the southern Levant showing average annual rainfall (modified from EXACT, 1998) and the location of the study area. 246
16.2 Schematic map showing the surroundings of the archaeological site of Beidha. The letters A to E refer to the locations from which the panoramic pictures presented in Figure 16.3 were taken. 247
16.3 (A) Panoramic view from the site, looking southwest. (B) View of ancient gravel terraces, looking south-southwest. Robyn Inglis for scale. (C) View from the site on the tufa section and the dunes, looking southwest. (D) View from a sandstone outcrop on the

site and the Seyl Aqlat, looking north-northwest. (E) View from a sandstone outcrop on the alluvial plain and the present-day bed of the Wadi el-Ghurab. Looking southeast. Picture credits: C. Rambeau and R. Inglis, May 2006. 248
16.4 Chronological framework at Beidha. Dates marked by triangles: this study. Black lines: data from Byrd (1989, 2005), recalibrated. 249
16.5 Schematic succession of sedimentary layers at the site section, as illustrated in Figures 16.2 and 16.3, and location of the levels from which new radiocarbon dates have been obtained. 250
16.6 Spring carbonate (tufa) sequence, U-series dates and average sedimentation rates. Italic numbers refer to dates obtained on one sub-sample only; other dates were obtained with the isochron technique on multi sub-samples. Numbers 1–6 relate to sedimentation rates as calculated in Table 16.3. 256
16.7 Granulometry analysis from the site section and other sediments from the valley. 259
16.8 Oxygen stable isotope curves for the tufa (left) and site (right) sections. Grey highlights refer to times of occupation at the archaeological site (Natufian and Neolithic). White dots in the tufa section correspond to isotopic compositions potentially influenced by disequilibrium effects (e.g. evaporation). 260
16.9 Oxygen and carbon isotopic composition and covariation (trend lines) for the site and tufa sections at Beidha. Evaporation/disequilibrium trend from Andrews (2006). The black box contains the samples that may be considered independent from disequilibrium effects. 261
16.10 Comparison between the Soreq isotopic record (left; modified from Bar-Matthews *et al*., 1999) and the Beidha spring-carbonate record (right; this study). Open dots correspond to samples from the Beidha record that show potential disequilibrium effects (e.g. evaporation). Light grey highlights indicate the probable time of the Younger Dryas (YD). 264
17.1 Southern Levant showing drainage basins and survey coverage, with the North Rift Basin and North Dead Sea Basin indicated. oPt refers to occupied Palestine territory. 272
17.2 Cost distance maps and site locations for the three time periods: (a) Chalcolithic, (b) EBI, (c) EBA. Top left, to permanent sites; top right to routes; bottom left, to springs; bottom right, to wadi. 274
17.3 Cost distance against altitude for wadi, site, route and spring for the three altitudinal sectors and three time periods. (a) North Rift Basin; (b) North Dead Sea Basin. Best fit lines represent the general trends in each sector. Altitudinal sectors, <−200 m, 200 m to 300 m and >300 m. CHL, Chalcolithic. 279
17.4 Cost distance pairs, site v. route, site v. spring, route v. spring and wadi v. spring regression plots for the three altitudinal sectors and three time periods. The first variable is on the horizontal axis, second on the vertical, dotted line shows line of equal value. (a) North Rift Basin; (b) North Dead Sea Basin. 282
18.1 Location map of Jawa showing catchment of Wadi Rajil with rainfall isohyets (rainfall data represent average annual rainfall 1931–1960). Source: NRA Jordan. Rajil catchment after Helms (1981). 290
18.2 Detail of the Wadi Rajil, storage ponds and Jawa. (After Helms, 1981 p. 157.) 291
18.3 Long-term changes in rainfall and temperature from the HadSM3 GCM, compared with Dead Sea levels (after Frumkin *et al*., 2001) and palaeo-rainfall estimates derived from analyses of Soreq isotope sequence (after Bar-Matthews *et al*., 2003). 297
18.4 Sustainable population levels at Jawa with varying water storage volumes for (a) high, (b) medium and (c) low rainfall scenarios. 298
18.5 Sustainable population levels as a function of pond storage under a range of rainfall conditions. 299
18.6 Percentage population failure at Jawa as a function of rainfall. 299
19.1 Location of Humayma in the hyper-arid zone of southern Jordan. 303
19.2 Site plan of the Humayma settlement centre (S. Fraser, courtesy J. P. Oleson) and aerial photograph of the site, looking north (courtesy D. Kennedy). 304
19.3 Humayma environs showing locations of pertinent hydraulic structures surveyed in the Humayma Hydraulic Survey. See colour plate section. 306
19.4 Reservoir at Humayma. (after modern restoration, originally covered; Courtesy E. De Bruijn). 306
19.5 Covered reservoir at Humayma (R. Foote). 306
19.6 Section of the aqueduct at Humayma (J. P. Oleson). 307
19.7 Terraced hillside at Humayma (J. P. Oleson). 308
19.8 Aerial photograph of the area north and east of the Humayma Settlement Centre (coustesy D. Kennedy archive, 26.002). 308
19.9 The Wadi Yitm catchment in southern Jordan (M. El Bastawesy). 314
19.10 The badlands at Humayma (R. Foote). 315
19.11 WorldView 1 Panchromatic satellite image from Eurimage, Jordania WV01 taken in 2008, showing the Wadi Amghar, the palaeo northern Wadi Qalkha tributary head waters, the badlands, the present-day northern Wadi Qalkha catchment headwaters and northern part of the Humayma settlement centre. 316

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

19.12 The interpolated path of the aqueduct between the surveyed points (turquoise circles) (M. El Bastawesy and R. Foote). See colour plate section. 317
19.13 Digital elevation models, comparing palaeo- and present-day northern Qalkha sub-catchment elevations and wadi pathways. Present-day, left; palaeo, right panel (M. El Bastawesy). 318
19.14 Details of 1926 (left) and 2008 (right) photos, comparing part of the badlands (after M. El Bastawesy). 318
19.15 Details of 1926 and 2008 photos, comparing a section of the Wadi Amghar. The fine lines sketch as it was in 1926 (after M. El Bastawesy). 319
19.16 Schematic diagram of the Humayma water balance model (A. Wade). 320
20.1 Map of Jordan indicating the sites mentioned in the text. 338
20.2 Mean isotopic values (±1 standard deviation) for humans and domestic animals from Pella. Figures in parentheses indicate number of individuals. Abbreviations: MB/LB = Middle Bronze/Late Bronze; LR/Byz = Late Roman/Byzantine. 342
20.3 Mean isotopic values (±1 standard deviation) for humans and domestic animals from Ya‘amūn. Figures in parentheses indicate number of individuals. Abbreviations: MB/LB = Middle Bronze and Late Bronze; LR/Byz = Late Roman/Byzantine. 342
20.4 Mean isotopic values (±1 standard deviation) for humans from Gerasa (seventh century AD), Pella (third–fourth centuries AD), Ya‘amūn (Late Roman/Byzantine); Yajūz (Byzantine) and Sa‘ad (Late Roman/Byzantine) in the north of Jordan. 343
21.1 Map showing location of crop growing sites. 351
21.2 Irrigation and evaporation (both in mm) by crop development stage. Crop development stages (given on the *x* axis) follow the Food and Agricultural Organisation convention of Initial (Init.), Crop development (Dev.), Mid-Season (Mid.) and Late. Late barley and late wheat are shown separately, reflecting differences in their development. DA, Deir ‘Alla; KS, Khirbet as Samra; RA, Ramtha. 353
21.3 Harvesting barley at Khirbet as Samra after the third growing season. 355
21.4 (A) Well silicified conjoined phytolith. (B) Poorly silicified conjoined phytolith. 357
21.5 Extractable silicon from soil samples taken before and after experimentation. 358
21.6 Crop yield for wheat. 359
21.7 Crop yield for barley. 360
21.8 Weight percent of phytoliths to original plant matter processed for wheat. 361
21.9 Weight percent of phytoliths to original plant matter processed for barley. 362
21.10 Correlation between non-irrigated barley and rainfall. 363
21.11 Correlation between mean weight percent of phytoliths and levels of extractable silicon. 363
21.12 (A) Single dendritic long cell. (B) Single cork-silica cell. 363
21.13 Comparison of the percent of cork-silica cells and dendritic long cells for the wheat samples. 363
21.14 Comparison of cork-silica cells and dendritic long cells for the barley samples. 364
21.15 Comparison of well silicified to poorly silicified conjoined forms from the wheat samples. 364
21.16 Comparison of well silicified to poorly silicified conjoined forms from the barley samples. 366
21.17 Percent of conjoined cells in the wheat samples for all sites, years and irrigation regimes. 368
21.18 Percent of conjoined cells in the barley samples for all sites, years and irrigation regimes. 369
22.1 Flowchart illustrating the different environmental parameters determining the carbon stable isotope composition ($\delta^{13}C$) of C_3 plants (for references, see text). 375
22.2 Location of crop growing stations in Jordan used in the WLC experiments (map reproduced from Fig. 1 of Mithen *et al*., 2008). Khirbet as Samra N 32° 08′, E 36° 09′, 564 m asl, Ramtha N 32° 33′, E 32° 36′, 510 m asl and Deir ‘Alla N 32° 13′, E 35° 37′, 234 m bsl. Altitudes were obtained from the Google Earth database and were checked against OS maps (Ordnance Survey 1949a and b and 1950). 377
22.3 Graph showing mean Δ (‰) values for each irrigation regime at the three sites with trendlines fitted by polynomial regression. 377
23.1 Map of Jordan showing location of sites. 381
23.2 (A) Juma in front of his winter tent. (B) Inside the public part of the tent. (C) Inside the domestic area of the tent. (D) Um Ibrahim (Juma’s wife) cooking bread on the domestic hearth. 388
23.3 Images of the main single-celled phytolith morphotypes identified: (A) irregular shaped dicotyledon (platey) from Tell esh-Shuna; (B) polyhedral shaped psilate from Tell Wadi Feinan; (C) trapeziform psilate from Tell esh-Shuna; (D) bilobate from WF16; (E) rondel from Tell esh-Shuna; (F) siliceous aggregate (usually bright orange) from Tell esh-Shuna; (G) globular echinate (date palm) from Tell esh-Shuna; (H) elongate dendriform from Tell esh-Shuna; (I) trapeziform crenate from Tell esh-Shuna; (J) globular echinate (date palm) from Tell Wadi Feinan; (K) elongate psilate from WF16. 391
23.4 Images showing conjoined phytoliths. (A) Elongate dendriform and short cells formed in a wheat husk from Tell esh-Shuna; (B) conjoined parallepipedal bulliforms from Tell-esh Shuna; (C) conjoined elongate sinouate

© in this web service Cambridge University Press

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

from a reed stem from Juma's summer tent; (D) elongate dendriform and short cells formed in a barley husk from Humayma; (E) elongate dendriform and short cells formed in a barley husk from Tell esh-Shuna; (F) conjoined elongate sinouate from a reed stem from Ghuwayr 1; (G) bilobates from Tell Wadi Feinan; (H) sinuous long cells from Ghuwayr 1; (I) elongate dendriform and short cells formed in a wheat husk from Juma's summer tent; (J) jigsaw puzzle from Tell esh-Shuna. 392
23.5 Weight percent of phytoliths by context category and chronological period. 393
23.6 Water availability index showing percentage of long-cell phytoliths relative to the sum of short and long cells by context category. 394
23.7 Woody material index showing percent of siliceous aggregates by context category. 394
23.8 Plot of two first axes of the PCA showing the taxonomic origin of the phytolith types. The individual vectors (phytolith types) are unlabelled for clarity reasons. 394
23.9 Plot of two first axes of the PCA showing the archaeological samples (used for the analysis) and the ethnoarchaeological samples (passively plotted) (JT, Juma's tent). 394
23.10 Plot of two first axes of the PCA highlighting the samples from fields and channel. 395
23.11 Plot of two first axes of the PCA highlighting the affinities of hearth and other fire-related contexts. 395
23.12 Plot of two first axes of the PCA showing the chronological patterns. 397
24.1 The general geography of Jordan. 404
24.2 Rainfall distribution in Jordan (Source: Ministry of Environment, 2006). 405
24.3 Jordan's surface water resources (Source: Ministry of Environment, 2006). 408
24.4 Jordan's groundwater resources (Source: Ministry of Environment, 2006). 409
24.5 Top left: percentage change in annual total rainfall predicted for 2070–2100 under an A2 emissions scenario. Top right: seasonal cycle in total rainfall in the box shown on the top left figure, for a group of model integrations for a present-day climate (dark grey polygon); a 2070–2100 A2 scenario climate (pale grey polygon) and a single B2 scenario model integration (line). Bottom left: observed annual total precipitation (based on the publicly available GPCC gridded dataset). Bottom right: percentage changes in annual total rainfall under an A2 scenario projected on to the observed present-day totals. See colour plate section. 412
25.1 Schematic diagram and corresponding map of the pathway of water reuse in northwest Jordan. 417
25.2 Map of northwest Jordan showing the locations of soil sampling and farmer interviews. 418
25.3 Nutrient inputs and nutrient requirements of barley at the research sites (nutrient uptake of barley is based on data from Cooke, 1982). 420
25.4 Salinity of the saturation extract (ECe) from Ramtha after one and two years of irrigation with reclaimed water (error bars give standard error from the mean). 421
25.5 Salinity of the saturation extract (ECe) from Khirbet as Samra after one and two years of irrigation with reclaimed water (error bars give standard error from the mean). 421
25.6 Salinity of the saturation extract (ECe) from sites irrigated with reclaimed water for extensive periods of time (error bars give standard error from the mean). 422
25.7 Leaching methods and timings of leaching described by farmers irrigating with reclaimed water in the Jordan Valley. 423
25.8 Modelled scenario of leaching timings on the Cl concentration in the soil solution at Deir Alla. 424
26.1 Water charges in Amman, Jordan and a selection of other cities in the MENA region. Exchange rates in 2004 (from Magiera *et al*., 2006). 430
26.2 The Greater Amman urban region: general location map (revised and adapted from Lavergne, 2004). 431
26.3 The social areas of Greater Amman and the residential areas sampled for the household interviews. 433
26.4 Typical roof-top storage tanks on a property in the northwestern suburbs of Amman. 435
26.5 Income-related variations in water storage capacity among the interview respondents. Each of the 25 high-income and low-income respondents is represented by a vertical bar. 436
26.6 Typical water delivery tanker in Greater Amman, Jordan. 437
27.1 Rainfall distribution and water resources in Jordan and location of the study area. Adapted from Darmame (2006). 444
27.2 The regional and national context of the Faynan and Qurayqira villages. 444
27.3 The typical small dwelling provided by the government in Faynan village. 444
27.4 The tent: place of traditional hospitality and shrubs on the 1 dunum plot. 445
27.5 The everyday challenges of water access for the Al-Azazma tribe. 445
27.6 A young girl bringing back water from Wadi Ghuwayr for cooking. 445
27.7 Land use in Faynan and Qurayqira villages. 445

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

27.8 Rudimentary dam in Wadi Ghuwayr to collect water prior to transfer through pipes for irrigation. 447
27.9 Water storage basin near the farm for irrigation. 448
27.10 Watermelons immediately prior to harvest in the Faynan area. 450
27.11 Watermelons being packed on to trucks in Faynan for transport north to Amman and for export. 450
28.1 In a country area of the southern Amman Governorate, people use water directly from the piped network. 457
28.2 An illegal connection from the principal pipe of the network, southern Amman Governorate. 457
28.3 The service area of LEMA. From Darmame (2006). 459
28.4 The total supply duration (hours per week) in Greater Amman, summer 2006. Source: LEMA Company, personal communication, Anmar 2007. See colour plate section. 460
28.5 Supply duration (hours per week) in Greater Amman by geographical sector, January 2003 to August 2006. 461

© in this web service Cambridge University Press

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

Tables

1.1 Water, Life and Civilisation: project members. *page* 5
2.1 The 15 most common GWL regimes and their relationship to Jordan Valley rainfall and large-scale modes of variability. 20
2.2 Distribution of rainfall quintiles for NAO-positive and NAO-negative years. 22
3.1 The experimental configuration. 29
3.2 Summary of the changes in the time-slice experiments (expressed relative to the pre-industrial control run). 48
9.1 Uranium series ages for samples analysed as part of this study. 122
10.1 A summary of rainfall and flow data collated for the application of the hydrological models to simulate the flows in the upper River Jordan. 135
10.2 The mean monthly minimum and maximum near-surface air temperatures observed at Ramtha, Jordan and those simulated by the HadRM3P regional climate model during a control run (1961–1990) and for the A2 scenario (2071–2100). 143
11.1 Mean rainfall and Dead Sea levels for the period 1860–1960. 150
12.1 Baseflow measurements in the Wadi Ghuwayr made during the 2006, 2007 and 2008 field seasons. 166
12.2 Peak floods in the Wadi Ghuwayr and the Wadi Dana estimated using open-channel techniques. 171
12.3 Surface and groundwater flow statistics for the Wadi Faynan generated by running the Pitman hydrological model with modified rainfall inputs and/or a modified infiltration rate parameter. 171
13.1 Meteorological data collated for the hydrological study of the Wadi Hasa. 179
13.2 Delta change values calculated at four precipitation and two near-surface air temperature measurement stations to compare daily mean precipitation ratios and temperature differences between the HadRM3P modelled control period (1961–1990) and the A2 scenario period (2071–2100). 185
15.1 Summary of synthetic Tafilah rainfall series for time slices (results of 100-year simulation). 225
15.2 Synthetic monthly mean rainfall (mm per month) at Tafileh for each time slice (mean of 100-year total). 226
15.3 Comparison of palaeo-rainfall estimates. 227
15.4 Summary of results from Hunt *et al.* (2007) (table 12) showing changing patterns of Holocene vegetation in Wadi Faynan. 229
15.5 Summaries of simulated wadi flows under changing precipitation scenarios. 231
15.6 Summaries of simulated wadi flows under changing precipitation and infiltration scenarios. 232
15.7 Comparison of simulated median groundwater flows between first and last decade of simulations, for 12 ka scenarios (8 mm hr^{-1}, 100 mm hr^{-1}) and 0 ka (control) period. 232
15.8 Infiltration rates and rainfall values used in proposed simulation of Holocene evolution of Wadi Faynan. 234
15.9 Summary of proposed wadi flows for Holocene Wadi Faynan. 234
16.1 All radiocarbon dates from Beidha. 249
16.2 Uranium-series dates from the tufa series. 257
16.3 Sedimentation rates calculated for various intervals of the tufa section. 260
17.1 Number of sites and average altitude for the North Dead Sea Basin for all sectors and time periods (includes all survey data, sites may be listed in more than one column). 277
17.2 Number of sites and average altitude for the North Rift Basin for all sectors and time periods (includes all survey data, sites may be listed in more than one column). 277
17.3 Statistics of cost distance values for the North Rift Basin for all sectors and time periods (single time period data). 278
17.4 Statistics of cost distance values for the North Dead Sea Basin for all sectors and time periods (single time period data). 278

© in this web service Cambridge University Press www.cambridge.org

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

18.1 Distribution types and characteristics for key parameters used in the Monte Carlo Analysis for the high rainfall condition. 296
19.1 Humayma water storage features, divided by sub-catchment. 309
19.2 Catchment characteristics of the four sub-catchments used in the model-based water balance assessment rendered in present-day and proposed historic areas. 320
19.3 Summary of the parameter distributions used in the model simulations. 321
19.4 Estimates of the storage capacity available in the cisterns, reservoirs and created pools throughout the Humayma catchment. 323
19.5 Estimates of the surface area of the uncovered cisterns, reservoirs and created pools throughout the Humayma catchment. 324
19.6 The modelled mean and median populations at Humayma and modelled runoff for a succession of rainfall and water management scenarios. 327
21.1 Description of crop growing sites. 352
21.2 Amount of applied irrigation by crop, year and growing site. 352
21.3 Selected water quality parameters for reclaimed water from the crop growing stations based on samples collected in the field and available data. 354
21.4 Record of plots covered with mesh. 355
21.5 Soil physical and chemical properties at the crop growing stations. 356
21.6 Methodology used for analysis of extractable silicon. 357
21.7 Dry ashing methodology employed for extracting phytoliths from modern plants. 357
21.8 Absolute numbers of well silicified and poorly silicified conjoined phytoliths counted with standard deviations from the wheat samples (all standard deviations were calculated using the STDEV function in Excel 2007). 365
21.9 Absolute numbers of well silicified and poorly silicified conjoined phytoliths counted with standard deviations from the barley samples. 367
22.1 Table showing mean Δ values in ‰. 378
23.1 Chronology of the sites studied. 386
23.2 Taxa present by chronological period. 393
23.3 Single-cell phytoliths by family and subfamily for the various context categories. 396
24.1 Climatic classification according to rainfall distribution. 405
24.2 Sources of water used by sectors in Jordan in 2000 (million cubic metres, MCM). 406
24.3 Jordan water use (MCM) by sector according to the Ministry of Water and Irrigation. 407
25.1 Water quality parameters at Khirbet as Samra, Ramtha and Deir Alla based on data determined through water sampling and published data. 420
25.2 Comparison between the average ECe in the root zone (10–40 cm depth) of soil irrigated to 100% and 120% of the crop water demand for two years. 422
26.1 Socio-demographic profile of the respondent households. 433
26.2 Distribution of respondent households by income group. 433
26.3 Occupational categories of the heads of households included in the sample. 434
26.4 Residential profiles of the respondent households. 434
26.5 Distribution of respondent households by size of dwelling. 434
26.6 Household water supply from the public network. 434
26.7 Average household water storage capacity by income group. 435
26.8 Respondent households by water storage capacity. 435
26.9 Household water consumption and cost levels. 436
26.10 Method of payment of water bill. 437
26.11 Details of the use of networked water by households. 437
26.12 Gendered aspects of the management of water within households. 438
26.13 The use made of collected rainwater by households. 438
26.14 Awareness of selected water tariff issues. 439
26.15 Variations in household satisfaction levels with the water sector as a whole. 439
26.16 Overall household satisfaction score with the water sector by income group. 439
26.17 Satisfaction with different aspects of the water supply system. 440
26.18 Perceived improvement in the water supply system since privatisation in 1999. 440
26.19 Priority accorded to water supply issues by households. 440
28.1 Selected performance indicators concerning urban water and sanitation utilities in selected cities of the MENA region, 2004. 458
28.2 Targets set in the LEMA contract for the reduction of unaccounted for water (UFW) and water supply improvements. 460
28.3 Proportion of water subscribers in Greater Amman by total duration of water supply per week during summer 2006. 461

© in this web service Cambridge University Press

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

Contributors

Ambroise Baker
Long-Term Ecology Laboratory,
School of Geography and the Environment,
University of Oxford,
Oxford, OX1 3QY, UK

Emily Black
Department of Meteorology,
University of Reading,
Earley Gate, PO Box 243,
Reading, RG6 6BB, UK

Stuart Black
Department of Archaeology,
School of Human and Environmental Sciences,
University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

Andrew V. Bradley
Department of Geography,
University of Leicester,
University Road,
Leicester, LE1 7RH, UK

David Brayshaw
Department of Meteorology,
University of Reading,
Earley Gate, PO Box 243,
Reading, RG6 6BB, UK

Dan Butterfield
Water Resource Associates,
PO Box 838, Wallingford OX10 9XA, UK

Gemma Carr
Centre for Water Resource Systems,
Vienna University of Technology,
Karlsplatz 13/222, A-1040 Vienna,
Austria

Khadija Darmame
The French Institute of the Near East,
BP 830413,
Amman, 11183,
Jordan

Mohammed El Bastawesy
National Authority for Remote Sensing and Space Sciences,
Cairo, Egypt

Sarah Elliott
School of Human and Environmental Sciences,
University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

Bill Finlayson
Council for British Research in the Levant (CBRL),
10 Carlton House Terrace,
London,
SW1Y 5AH, UK

Richard Fitton
Talisman Energy Inc.,
Suite 3400, 888 – 3rd St Southwest,
Calgary,
Alberta, Canada

Nicola Flynn
School of Human and Environmental Sciences,
University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

Rebecca Foote
c/o School of Human and Environmental Sciences,
The University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

© in this web service Cambridge University Press

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

Rachel Goodship
School of Human and Environmental Sciences,
The University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

Joshua Guest
School of Human and Environmental Sciences,
The University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

Paul Holmes
School of Human and Environmental Sciences,
The University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

Brian Hoskins
Department of Meteorology,
University of Reading,
Earley Gate, PO Box 243,
Reading, RG6 6BB, UK

Robyn Inglis
Department of Archaeology,
University of Cambridge,
Downing Street,
Cambridge, CB2 3DZ, UK

Khalil Jamjoum
National Centre for Agricultural Research and Extension,
PO Box 639,
Baq'a 19381, Jordan

Emma Jenkins
School of Applied Sciences,
Bournemouth University,
Christchurch House,
Talbot Campus, Poole,
Dorset, BH12 5BB, UK

Jaimie L. Lovell
Council for British Research in the Levant (CBRL),
10 Carlton House Terrace,
London, SW1Y 5AH, UK

Ron Manley
Water Resource Associates Limited,
PO Box 838,
Wallingford, OX10 9XA, UK

Steven Mithen
University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB UK

Gundula Müldner
School of Human and Environmental Sciences,
The University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

Stephen Nortcliff
School of Human and Environmental Sciences,
The University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6DW, UK

Sameeh Al Nuimat
Permaculture Project,
CARE International – Jordan,
PO Box 950793 – Amman 11195,
Jordan

John Peter Oleson
Department of Greek and Roman Studies,
Box 3045, University of Victoria,
Victoria BC, V8W 2P3, Canada

David Plinston
Water Resource Associates,
PO Box 838,
Wallingford, OX10 9XA, UK

Robert B. Potter
School of Human and Environmental Sciences,
The University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

Claire Rambeau
c/o School of Human and Environmental Sciences,
The University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

Stuart Robinson
Department of Earth Sciences,
University College London,
Gower Street,
London, WC1E 6BT, UK

© in this web service Cambridge University Press

CAMBRIDGE

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

Michela Sandias
c/o School of Human and Environmental Sciences,
The University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

Bruce Sellwood
c/o School of Human and Environmental Sciences,
The University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

Julia Slingo
Department of Meteorology,
University of Reading,
Earley Gate, PO Box 243,
Reading, RG6 6BB, UK

Sam Smith
Department of Anthropology and Geography,
Oxford Brookes University,
Headington Campus,
Gipsy Lane,
Oxford, OX3 OBP, UK

Helen R. Stokes
Department of Archaeology,
University of York,
King's Manor,
York, Y01 7EP, UK

Paul J. Valdes
School of Geographical Sciences,
University of Bristol, University Road,
Bristol, BS8 1SS, UK

Andrew Wade
School of Human and Environmental Sciences,
The University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

Paul Whitehead
School of Human and Environmental Sciences,
The University of Reading,
Whiteknights, PO Box 227,
Reading, RG6 6AB, UK

© in this web service Cambridge University Press www.cambridge.org

Acknowledgements

The authors and editors are grateful to the Leverhulme Trust for generously funding the Water, Life and Civilisation (WLC) project (Grant no. F/00239/R), and thus enabling them to carry out the research described in this volume.

The majority of this research has been undertaken in Jordan and we are immensely grateful to the following for their support: Princess Sumaya bint Hassan, patron of the archaeological field work in Wadi Faynan undertaken by the Council for British Research in the Levant (CBRL) and its collaborators; Dr Abed al-Nabi Fardour (Director of National Centre for Agricultural Research and Technology Transfer, NCARTT), Khalil Jamjoum (NCARTT) and Sameeh Nuimat (Ministry of Agriculture), with regard to Chapters 12, 21, 22 and 24); Dr Fawwaz al-Khraysheh (Director General of the Department of Antiquities) for permission to undertake fieldwork in Wadi Faynan and at Jawa; Nasr Khasawneh and Mohammed al Zahran, who were the Department of Antiquities Representatives for fieldwork in Jawa and Wadi Faynan, respectively; Professor Dawud Al-Eisawi of the University of Jordan, for its ongoing collaboration regarding pollen analyses of the Dead Sea peaty deposits (sampled during the WLC project and still being analysed), and Sagida Abu-Seir (University of Jordan) for sample preparation and identification of the pollen species; Dr Mohammed Najjar (Council for British Research in the Levant) for advice and information regarding Chapters 12 and 13). Professor Zaid al-Sa'ad, Professor M. El-Najjar and Dr A. Al-Shorman (Institute of Archaeology and Anthropology of Yarmouk University Jordan), with regard to Chapter 20; and Dr L. Khalil (Department of Archaeology of the University of Jordan), for permission to sample skeletal remains for Chapter 20. With regard to the research concerning water issues in Jordan and especially with regard to present-day Amman (Chapters 24–28), we are grateful to: Professor Nasim Barham (University of Jordan); Dr Philipp Magiera (Team Leader, German Technical Cooperation/Ministry of Water and Irrigation, Improvement of the Steering Competence in the Water Sector Project) for consultations concerning the National Water Master Plan for Jordan; Dr Max Bobillier (Operations Director, LEMA/Ministry of Water) for discussions concerning upgrading the water network of Greater Amman; and staff of the Greater Amman Municipality GIS and Planning Departments for background information on urban planning and residential land issues in Greater Amman.

Equally valued have been the many residents of Jordan who generously gave up time to help with our research. We are especially grateful to those households in Greater Amman, and farmers in the Jordan Valley and Wadi Faynan who provided interviews as cited in Chapters 24, 26, 27 and 28 of this volume. The farmer interviews would not have been possible without the translation assistance from a number of individuals to whom we are grateful. The WLC archaeological and hydrological work in Wadi Faynan (Chapters 12, 14, 15) was only possible through the help and support provided by our friends in the local Bedouin communities, notably Abu Fawwaz, Abu Sael and Juma Ali Zanoon. We would also like to thank Juma Ali Zanoon for generously allowing the authors of Chapter 23 to take sediment samples from his tents, and to Haroun al-Amarat who provided translation. We are also grateful to the Maayah family from Madaba for their warm welcome to Claire Rambeau and support of her work in the vicinity of the Dead Sea region and Beidha.

We are grateful to the CBRL for providing administrative and logistical support, especially with regard to fieldwork in Jordan. We would particularly like to thank Professor Bill Finlayson, in his role as Director of the CBRL, for facilitating permits for archaeological and geological sampling of sites, and the Department of Antiquities of Jordan, for having awarded those permits.

We have benefited greatly from the support and advice of numerous other academics and bodies outside Jordan and our own University, to whom we are grateful: the Israeli Meteorological service for providing the daily data for rain stations along the Jordan River referred to in Chapters 2, 4, 5, 10 and 13; David Hassell, David Hein and Simon Wilson (Hadley Centre) for their invaluable assistance and advice on regional modelling, and for providing lateral boundary conditions as used in Chapter 4; Michael Vellinga (Hadley Centre) for providing the sea surface temperature data used to calibrate the slab ocean model in Chapter 3; Yuval Bartov (Colorado School of Mines), Stephen Calvert (University of British Columbia). Kay-Christian Emeis

© in this web service Cambridge University Press www.cambridge.org

Cambridge University Press
978-0-521-76957-0 - Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley
Edited by Steven Mithen and Emily Black
Frontmatter
More information

(Institute for Biogeochemistry and Marine Chemistry), Mebus Geyh (Nidersächsisches Landesamt für Bodenforschung) and Angela Hayes (University of Limerick) for contributing data to Chapter 6; Professor Fabrice Monna (University of Burgundy) for his help regarding the ongoing analyses of the Dead Sea peaty sediments; Frank Farquharson and Helen Houghton-Carr (Centre for Ecology and Hydrology, Wallingford) for allowing the authors of Chapter 12 access to hydrological records in their overseas archive; Steve Savage (Arizona State University) for allowing the authors of Chapter 17 access to the raw data of the JADIS database; Yehuda Dagan and the staff at the Israeli Antiquities Authority for discussing survey methodology in Israel with regard to Chapter 17; Paul Valdes (Bristol University) for access to the Bristol University BRIDGE Climate Change data for Chapter 18 and advice regarding palaeoclimate modelling; Professor J. Rose (University of Arkansas) for enabling access to skeletal remains for Chapter 20; Dr Stephen Bourke and Dr I. Kehrberg (University of Sydney) for advice regarding the analysis of skeletal remains from Jordan for Chapter 20; Dr Carol Palmer (CBRL) and Dr Mark Nesbitt (Kew Gardens) for advice on setting up the crop growing experiments described in Chapter 21; Dr Mohammed al-Najjar, Dr Douglas Baird (University of Liverpool), Graham Philip (University of Durham) and Alan Simmons (University of Nevada) for allowing the authors of Chapter 23 permission to sample their archaeological sites; Anson MacKay (University College London) for advice on using Canoco for Chapter 23.

We are grateful to Elsevier for allowing permission to republish a WLC paper from the *Quaternary Science Reviews* (2006, **25**: 1517–1541) as Chapter 6 of this volume. We acknowledge the support of Stuart Robinson by a Royal Society University Research Fellowship. With regard to our academic colleagues at the University of Reading, we would especially like to thank those who have advised on the climate modelling: Lois Steenman-Clark and Jeff Cole of NCAS-Climate for advice on high performance computing, and Kevin Hodges of ESSC and the University of Reading for giving permission for the authors of Chapters 2, 3 and 4 to use his storm tracking software, and providing support and advice; Charles Williams for useful discussion throughout the project and help with setting up the regional climate model; Tim Woollings and Paul Berrisford for their contributions to the analysis during the early part of WLC.

The project has been fortunate in having the support of clerical and technical staff from the University of Reading. We would especially like to thank Jane Burrell, the WLC project administrator, Chris Jones and Cheryl Foote (University of Reading), and Penny Wiggins and Nadja Qaisi (Council for British Research in the Levant) for administrative support. Tina Moriarty, John Jack and Emilie Grand-Clément prepared samples for the Beidha study (Chapter 16); Ian Thomas carried out the spatial analysis of water quality data described in Chapter 12, while Anne Dudley and Dave Thornley carried out the water sample analysis described in that chapter; Ambroise Baker, Sarah Elliott, Kim Carter and Geoff Warren processed the soil and water samples described in Chapter 21; Tina Moriarty and Paul Chatfield advised on the sample processing and statistics described in Chapter 22; Bruce Main set up the mathematical model described in Chapter 24; We are especially grateful to Sophie Lamb who helped to prepare all of the illustrations for this volume, and to our copy-editor Lindsay Nightingale.

Finally, we would like to thank the four academics who were our ‘critical friends’ throughout the project, attending our annual meetings and providing immensely constructive advice: Professor Richard Bradley (Archaeology, University of Reading), Professor Robert Gurney (Meteorology, University of Reading), Professor Neil Roberts (Physical Geography, Plymouth University) and Professor Tony Wilkinson (Archaeology, Durham University).

© in this web service Cambridge University Press