Contents

Foreword xvii

Introduction 1

1 Overview 4

Oil, Water, Climate, and Population: An Interactive System of Immense Complexity 4 Coupled Unsustainable Use of Energy and Water Resources 5 Role of Population and Economic Development in Oil and Water Use 5 Effects of Energy Demand and Use on Global Warming 6 Climate Change Can Exacerbate Water Scarcity Oil and Water Resource Issues Share Many Features 7 Exhaustion of Easily Accessible Resources Realization of Finiteness of Resources and New Strategies 8 Value of Efficiency Improvement 8 Oil and Water Security Concerns Poor Management of Oil and Water Resources 9 Aging Infrastructure and Magnitude of the Needed Investments 10 Urgency and Window of Opportunity 10 Major Differences in Oil and Water Resources Issues Strong Leadership Needed 12

2 Carbon Dioxide Emissions, Global Warming, and Water Resources 14

Introduction 14
Carbon Dioxide Emissions 15
Increasing Carbon Dioxide Concentration in the Atmosphere due to
Human Activities 16

Earth's CO ₂ Concentration and Temperature 19 Understanding the Present by Looking at the Past 19 Relationship between Past CO ₂ Concentration and Temperature 19 Earth Temperature Observations: Global Warming 20 Temperature: Observations and Proxy Data 20 Understanding Earth's Temperature Maintenance and Change 22 Earth Radiation Budget and Temperature 22 Increased Greenhouse Effect 24 Feedbacks 24 Earth's Climate 26 Role of the Ocean on Climate 26 Deep Ocean Circulation and Climate 27 Main Climate Effects of Global Warming 28 Snow, Ice Extent, Oceanic Heat Content, and Sea Level 28 Impact on Water Cycle, Precipitation, El Niño, and Winds 30
Future Carbon Dioxide Emissions 31
Future Climate: Climate Models 31
Predicted Impacts on Water Resources 33
Conclusion 35
Population, Environmental Impacts, and Climate Change 36
Introduction 36
Current Population Projections and Characteristics of Future Population 37
Factors Influencing Population Predictions 40
Fertility 42
Mortality 43
Migration 44
Tools for Analyzing Demographic Changes 44
Demographic Transition Model 44
Population Pyramid 45
Uncertainty of Demographic Projections 45
Geographic and Age Distribution of Population 46
Population Concentration in Urban Areas 46
Population Concentration in Coastal Regions 47
An Aging Population 50
Development, Global Energy Use, and Demography 51
Population, Water, and Climate Change 51
Population Growth, Resources Use, and Vulnerability to
Climate Change 52
Per Capita Emissions Trends 53
Other Human Impacts on the Global Carbon Balance and
Greenhouse Gases 55

Integrating Population Considerations into Climate Change Solutions 56
Population and Emissions Limitation Agreements 56
"Climate Refugees" 56
Conclusion 57

4 Carbon Cycle and the Human Impact 59

Introduction Carbon and the Carbon Cycle 60 Carbon Exchanges Affecting Atmospheric CO₂ Concentration Exchange between Rocks and the Atmosphere Biotic Fluxes: Photosynthesis and Respiration Phytoplankton Photosynthesis 67 Net Carbon Uptake: Carbon Sinks Land as a Carbon Sink The Ocean as a Carbon Sink 72 Partitioning Carbon Sinks between Land and Ocean 73 Examples of Natural and Anthropogenic Impacts on the Carbon Cycle Land-Use Change: Deforestation and Agricultural Practices CO₂ Fertilization and Nutrient Deposition Fires 77 Fossil Fuel Burning and the Carbon Cycle 78

Coupling between the Carbon Cycle and Climate: Carbon-Climate Feedback 78

Conclusion 79

5 Peak Oil, Energy, Water, and Climate 81

Introduction The Concept of Peak Oil 82 Conventional and Unconventional Oil Reserves 85 Why Production and Reserve Estimates Differ 87 Consumption 88 Estimating Peak Oil 90 Oil Production, Distribution, and Use 93 Energy Consumption Needed for Oil Production Water Used in Oil Production 94 Oil Production and Greenhouse Gas Emissions 94 Oil Transport and Water Pollution Potential Consequences of Peak Oil 95 Peak Oil and Energy Policy Choices Peak Oil and Market Economies Peak Oil and Climate 97 Conclusion 99

6 Oil Consumption and CO₂ Emissions from Transportation 100

Introduction 100

Present and Future Global Oil Consumption 10

Oil Consumption by the Transportation Sector 103

CO₂ Emissions by the Transportation Sector 104

Gasoline Consumption Standards 105

Crude Oil and Gasoline Prices 109

Private Car Ownership Trends 111

Distillates and Oil Use by Other Transportation Vehicles 113

Reducing CO₂ Emissions from Transportation 114

Government Regulatory Actions 114

Raising Fuel Economy Standards 114

Establishing Environmental Regulations 115

Increasing Fuel Taxes 116

Establishing Tradable Fuel Economy Credits 116

Offering Technology Incentives 117

Reducing Traffic Congestion and Average Annual Mileage Driven 117

Developing Rapid and Carbon-Light Mass Transit Systems 118

The Case of Air Transportation 118

Marine Transportation 119

CO₂ Impacts and Related Emissions Costs 120

The Role of the Public: Influence of Personal Behavior 120

Conclusion 121

7 Oil, Economy, Power, and Conflicts 123

Introduction 123

Oil Consumption, Economics, and Politics 123

The Geopolitics of Oil 127

Oil Prices and Financial Markets 127

Petroleum-Rich Economies 130

Oil Security 133

China's Geopolitical Outlook Regarding Oil 134

Impact of Climate on Oil Production and Price 135

Conclusion 137

8 Energy Alternatives and Their Connection to Water

and Climate 138

Introduction 138

Coal 140

Natural Gas 143

Nuclear Energy 147

Wind Energy 151

Solar Energy 154

Hydrogen Cells 155 Hydroelectric Power 159 Biomass: Ethanol 160 Geothermal Energy 162 Conclusion 164

9 The Water Cycle and Global Warming 168

Introduction 168

Water Cycle and the Water Budget 169

Elements of the Water Cycle 170

Evaporation, Condensation, and Precipitation 170

Land Surface Hydrology 175

Snow and Ice 177

Water Cycle and Climate 177

Water Vapor Greenhouse Effect 177

Clouds and Climate 177

Precipitation and Climate 178

Evapotranspiration and Climate 180

Snow/Ice and Climate 180

Weathering Effect of Water and Climate 181

Predicted Changes in the Water Cycle 181

Predictive Abilities of Climate Models 181

Changes in Water Vapor and Clouds 182

Precipitation 183

Evaporation 183

Changes in the Land Water Budget 185

Other Effects of Human Activities on the Water Cycle 186

Conclusion 186

10 Fresh Water Availability, Sanitation Deficit, and Water Usage: Connection to Energy and Global Warming 187

Introduction 187

Global Distribution of Fresh Water Availability 189

Sanitation Deficit 189

The Water-Sanitation Gap 189

Lack of Sanitation: Poverty Link 191
The Future of Sanitation 191

Cities and Water 192

Water Usage: Global Inequality and Irrigation Needs 194

Global Inequality 194 Irrigation Needs 194

Future of Irrigation: Where Will the Water Come From? 196

Ecosystem Needs 198

Blue and Green Water 199

Overview and Definition 199

Water Returning to the Atmosphere, Green Water Needs, and Blue Water Waste 199

Energy and Water Connection 200

Energy Needs for Irrigation and Crops Water Delivery 200

Energy for Water Supply, Sanitation, and Wastewater Treatment 201

Water for Energy Generation 201

Water Availability and Global Warming 202

Overall Trends 202

Managing Water in a Changing Climate 202

Water Needs of Alternative Energy Sources 203

Conclusion 204

11 Rivers, Lakes, Aquifers, and Dams: Relation to Energy and Climate 205

Introduction 205

Surface Water 205

Rivers and Streams 206

Lakes 208

Wetlands 209

Groundwater 210

Fresh Water Ecosystem 211

Ecosystem Functions 211

Human Pressures on Ecosystems 212

Dams 213

Major Functions of Dams 213

Environmental Effects of Dams 214

Dam Silting 216

Dams and Greenhouse Gas Emissions 217

Social Impacts 218

Potential Effects of Global Warming on Dams, Rivers, and Lakes 218

Conclusion 221

12 Water Contamination, Energy, and Climate 222

Introduction 222

Water Pollution and Water Quality 223

Water Contaminants 223

Sources of Water Contamination 226

Agriculture 226

Fertilizer Contamination 226

Irrigation-Induced Salinization and Waterlogging 229

Livestock Pollution 229

Accumulation of Agriculture Contaminants in Enclosed Basins 230
Industrial Contamination 230
Domestic Household Contamination 231
Deposition from the Atmosphere 231
Groundwater Contamination 232
Infiltration Contamination 232
Saltwater Intrusion 235
Urban Water Contamination and Water Cycle Modification 235
Water Resources Management and Waste Treatment 237
Water Resources Management 237
Wastewater Treatment 238
Effects of Water Pollution on Health 241
Changes in Precipitation Patterns and Water Contamination 242
Conclusion 243
Geopolitics of Water and the International Situation 245
Introduction 245
Water Rights and Water Regimes 246
Definition of Water Rights 246
Water Rights and Security 248
Water Regimes 248
Transboundary Waters 248
Hydrological Interdependence 248
Transboundary Water Governance Challenges 249
International Water Rights 250
Water Allocation 250
International Water Laws 251
Delimitation of International Boundaries 252
Roots and Types of Water Conflicts 252
Potential for Cooperation around Water Resources 253
Water and Poverty 255
Two-Way Relationship 255
Public Finance, Access, and Price 255
Conditions for Empowerment 257
Women and Water 257
Development and Environmental Protection: Water in the Middle 258
UN Millennium Development Goals, Millennium Project
and Water, and Others 258
The World Bank and Water 259
Nongovernmental Organizations 259
World Water Forum 259
Opposition to Large-Scale Water Initiatives 260
Opposition to Huge Dams 260
Privatization of Water and Water Systems 261

13

Water Value, Price, and Cost 263
Integrated Water Resource Management 265
Water Security and Water as a Human Right 265
Water Security 265
Water as a Human Right 266
Water Rights and Climate Change 267
Conclusion 268

14 Water Alternatives 270

Introduction 270 Water Saving 271

Water Conservation and Efficiency 271

Water Distribution Infrastructure Maintenance, Repair, and Replacement 272

Water Productivity Increase: "More Crop per Drop" 273

Raising Irrigation Water Efficiency and Productivity 273

Rainwater Harvesting 274

Water Diversions and Transfer among Basins 276

Technological Solutions 276

Water Trading and the Concept of Virtual Water 277

Water Trading 277

Virtual Water 280

Land-Use Change for Increased Rainfed Agriculture 281

Desalination 282

Desalination Process and Technology 282

Desalinated Water Production 283

Energy Needs of Desalination 283

Cost of Desalinated Water 284

Environmental Impacts and Health Risks 284

Conclusion 286

15 Global Climate Change: Observations, Modeling, and Predictions 288

Introduction 288

Present Observational Evidence of Climate Change 289

Global Temperature Changes 289

Change in Temperature Extremes 290

Stratospheric Cooling 290

Polar Amplification of Anthropogenic Warming 290

Changes in Hurricanes and Oceans 291

Hurricanes 291

Storage of Heat in the Oceans 292

Ocean Salinity and Density in a Warmer Climate 293

```
Forcings, Radiative Forcing, and Climate Sensitivity
     Forcings 294
     Radiative Forcing 296
     Climate Sensitivity 296
   Future Climate Change 298
     Tools 298
     Predicted Changes under Various Scenarios 300
   Natural Variability and Anthropogenic Effects 302
     Climate Oscillations 303
     Monsoons
               306
   Climate Inertia and Abrupt Climate Change 307
     Climate Inertia 307
     Abrupt Climate Change 307
   Conclusion 308
16 Energy and Water Challenges and Solutions in a Changing
   Climate Framework: Commonality, Differences,
   and Connections
                      310
   Introduction 310
   Time Frame for Action 312
     Population 312
     Energy 313
     Water 313
     Climate 314
   The Scope of the Challenge
     Energy and Climate 314
     Water 316
     Electricity Production 317
       Clean Coal 317
       Natural Gas 317
       Solar and Wind Power 318
       Nuclear Power 318
     Improved Water Management 318
       Resource and Demand Management 319
       Addressing Urbanization Issues 319
       Water Treatment and Reuse
       Development of Indicators of Global Water Trends 320
   Common Characteristics of Solutions 320
     Efficiency and Conservation
       Energy Savings in the Building Sector
       Transport Sector Energy Savings
       Irrigation Water Savings 321
       Urban Water Savings 322
```

Changes in Sea Level 293

Adaptation to Change 322

Technology Breakthroughs and Research and Development (R&D)

Programs 323

Addressing Externalities 324

Assigning a Cost to Emitting CO₂ 324

Assigning a Cost to Water 324

Respect for the Environment 325

Reasonable Use of Resources 325

Environmental Ethics 325

Sustainability 326

Addressing Needs of Future Generations 327

Intergenerational Equity 327

Climate Discounting across Generation versus the Precautionary

Principle 328

Empowerment and Education in Support of Poverty Eradication 329

Education and Adaptability to Change 330

The Security Issue 330

Conflict versus Cooperation 331

Massive Infrastructure and Research and Development

Investments Needed 331

Leadership and Behavior Changes 331

Final Thoughts 335

References 337

Index 345