

Contents

<i>Preface</i>	v
<i>About the Authors</i>	vii

Chapter 1. Complexity Science: From Reductionism to Holism	1
1.1 Basic Concepts	1
1.1.1 Complexity science is an extension and development of systems science and is “the science of the 21st century”	1
1.1.2 Systems and complex systems, elements and environments, structures and functions	4
1.1.3 Complexity science, nonlinearity and uncertainty, random theory	10
1.2 Main Features of Complexity Science	15
1.2.1 Nonlinearity	16
1.2.2 Uncertainty	18
1.2.3 Self-organization	18
1.2.4 Emergence	19
1.3 Key Research Methods of Complexity Science	21
1.3.1 Theoretical analysis	21
1.3.2 Models	21
1.3.3 Numerical calculation and simulation	25
1.4 Complexity Science and Earth System Science	31

1.4.1	Research theory and knowledge basis of earth system science	31
1.4.2	Needs and history of the transition of traditional earth science to earth system science	38
Chapter 2. Complexity of the Groundwater System and Its Influencing Factors		43
2.1	Groundwater System — Open and Complex Giant System	43
2.1.1	Complexity of runoff pattern	44
2.1.2	Complexity of the runoff process	45
2.1.3	Complexity of system boundaries	48
2.1.4	Temporal complexity of system	50
2.2	Complexity of Medium Space	52
2.2.1	Complex geology	53
2.2.2	Complexity of climate and landscape	57
2.2.3	Interaction of earth system structures	61
2.3	Complexity of Hydrodynamic Field	62
2.3.1	Influence of medium structure complexity on hydrodynamic field	62
2.3.2	Influence of heterogeneity on hydrodynamic field	65
2.3.3	Complexity of external factors	67
2.4	Complexity of Hydrochemical Fields	72
2.4.1	Coupling factors of media and dynamic field . .	74
2.4.2	Biogeochemical processes	76
2.4.3	Human activities	78
2.5	Stress Field and Thermal Field of Groundwater System	81
2.5.1	The complexity of the stress field	81
2.5.2	Complexity of thermal field	84
2.5.3	Coupling of stress field and thermal field	88
Chapter 3. Uncertainty of Groundwater System Observation and Forecast		91
3.1	Parameter Uncertainty	91
3.1.1	Spatial-temporal variability of media field and hydrodynamic field	91

3.1.2	Multi-process coupling of hydrochemical field	99
3.2	Observation Scale and Uncertainty	107
3.2.1	Up-down scaling and scale conversion	107
3.2.2	Application scope and uncertainty analysis of the scale conversion model	113
3.3	Simulation Uncertainty	114
3.3.1	Defects of the concept model	119
3.3.2	Calculation errors of mathematical models	123
Chapter 4.	The Complexity of Groundwater Systems: Scientific Research Methods	131
4.1	Characterization of Functional Complexity of the Groundwater System	131
4.1.1	Groundwater order parameter	131
4.1.2	System order degree	132
4.1.3	Groundwater function and its grade	138
4.2	Theory of Dissipative Structure	140
4.2.1	Theory of dissipative structure	141
4.2.2	Dissipative structure in the evolution of groundwater systems	142
4.3	Characterization of Uncertainty in Groundwater System	145
4.3.1	Uncertainty of groundwater systems	145
4.3.2	Random uncertainty method	146
4.3.3	Fuzzy uncertainty method	153
4.3.4	Grey system theory method (GST)	155
4.3.5	Unknown theory methods	157
4.3.6	Multi-standard decision analysis (MCDA) technology based on geographic information system (GIS)	158
4.3.7	Bayes theory	163
Chapter 5.	Research Examples	165
5.1	Research Cases Based on Theoretical Analysis of Complexity Science	165
5.1.1	Application of dissipative structure theory to analyze of groundwater system evolution, taking Hengshui City as an example	165

5.1.2	Complexity analysis of groundwater buried depth sequence based on sample entropy	171
5.1.3	Complexity diagnosis of regional groundwater resources system based on fractal dimension of time series and artificial fish swarm algorithm	176
5.1.4	Dynamic characteristics of groundwater system in the lower Yellow River based on nonlinear system theory	187
5.1.5	Complexity measurement of groundwater system in urbanization region based on permutation entropy	191
5.2	Case Study Based on Model and Numerical Simulation	198
5.2.1	Multi-dimensional dynamic system model of groundwater resources in karst area, taking Zaozhuang City as an example	198
5.2.2	Regional groundwater system complexity measurement and its impact on model prediction accuracy	203
5.2.3	Effects of research complexity on uncertainty in modeling of groundwater flow	214
5.2.4	Variable model simulation of groundwater flow in the glacial aquifer system in northeastern Wisconsin	228

<i>References</i>	247
-------------------	-----

<i>Index</i>	273
--------------	-----