Contents

	Preface	
1	**Introduction: The soil as a reactor between the earth´s atmosphere and the subsurface**	**1**
2	**Mechanical composition of mineral soils**	**2**
2.1	Soil texture	2
2.1.1	Mechanical analysis	2
2.1.2	Grain size distribution	3
2.1.3	Textural classes	7
2.2	Soil structure	8
3	**Basic parameters of bulk soil**	**9**
3.1	Macroscopic approach	9
3.2	Soil as a three-phase system	9
3.3	Standard values of bulk density	14
4	**Soil water balance in the field**	**16**
4.1	Water balance equation	16
4.1.1	Precipitation	17
4.1.2	Surface runoff	19
4.1.3	Evapotranspiration	19
4.1.4	A first approximation to real evapotranspiration and groundwater recharge	23
4.1.5	Simplified approach to drainage and capillary rise	24
4.1.6	The soil water storage term	26
4.2	Measurement of soil water content in the field	27
4.3	Simulation of water storage in soil	29
4.3.1	Spreadsheet model of soil water storage (see Appendix, files "Simulations.xls" or "Simulations.sxc")	30
4.3.2	Simple multi-layer soil water balance simulation model (see Appendix, files "Swb")	31
5	**Energy status of water in soil**	**33**
5.1	Total potential of soil water	33
5.2	Gravitational potential	35
5.3	Solute potential	36
5.4	Tensiometer pressure potential	38
5.4.1	Air pressure potential	38
5.4.2	Overburden potential	38
5.4.3	Hydrostatic pressure potential	39
5.4.4	Wetness and matrix potential	39
5.5	Soil water potential related to flow phenomena	40
5.6	Soil water potential and vapor pressure	43
5.7	Measurement of soil water potential	43
6	**Water retention in soil**	**46**
6.1	Capillary tubes	46
6.2	Soil water retention curve	48

6.2.1	Fundamentals	48
6.2.2	Differential water capacity, air entry point, and residual water content	50
6.2.3	Pore size distribution	51
6.2.4	Effect of temperature on pressure head	52
6.2.5	Hysteresis	52
6.3	Mathematical functions representing the water retention curve	53
6.3.1	Introduction	53
6.3.2	The Brooks and Corey model	54
6.3.3	The van Genuchten model	56
6.3.4	Multi-porosity models	58
6.4	Obtaining soil water retention data	59
6.4.1	Field measurements	59
6.4.2	Laboratory methods	60
6.4.3	Estimation of soil water retention from non-hydraulic soil properties	63
7	**Flow of water through saturated soil**	**64**
7.0	Introduction	64
7.1	Flow through capillary tubes	64
7.2	Darcy´s law	65
7.3	Steady-state flow of water in saturated soil	68
7.4	Saturated soil hydraulic conductivity	70
7.4.1	Specific permeability	70
7.4.2	Estimation of saturated hydraulic conductivity	71
7.4.2.1	Laboratory measurements	71
7.4.2.2	Field methods	73
7.4.2.3	Statistical data processing	74
7.4.2.4	Criticism and conclusions	74
7.4.2.5	Prediction of saturated soil hydraulic conductivity	75
7.4.2.6	Flow of water through saturated layered soil	76
8	**Groundwater flow**	**80**
8.1	Comment	80
8.2	Some basic terms of groundwater hydrology	80
8.3	Groundwater flow net	81
8.4	Aquifer	82
8.4.1	Hydraulic properties	82
8.4.2	Confined aquifer	84
8.5	Groundwater recharge and groundwater balance	85
8.6	Steady-state groundwater flow	87
8.6.1	One-dimensional flow	87
8.6.1.1	Introduction	87
8.6.1.2	Groundwater flow equation	89
8.6.2	Steady-state groundwater flow toward wells	92
8.7	Groundwater flow: The general case	93
8.8	Closing remarks	95
9	**Flow through unsaturatd rigid soil**	**96**
9.1	Fundamentals	96
9.2	Steady-state flow	97
9.3	Transient flow	99

9.4	Solutions to flow equations	102
10	**Unsaturated soil hydraulic conductivity**	**105**
10.1	Introduction	105
10.2	Models of unsaturated soil hydraulic conductivity	106
10.2.1	Gardner's equations	106
10.2.2	The Burdine and Brooks and Corey theory	107
10.2.3	The Mualem and van Genuchten theories	109
10.3	Measurement of unsaturated hydraulic conductivity	112
10.3.1	Overall view	112
10.3.2	Steady-state evaporation or seepage	112
10.3.3	Steady-state infiltration field methods: The disc infiltrometer	115
10.3.4	Non-steady laboratory methods	117
10.3.5	Non-steady field methods	118
10.4	Prediction of unsaturatd hydraulic conductivity	122
10.4.1	Predictions based on soil water retention	122
10.4.2	Pedotransfer functions	122
10.4.3	Data bases	125
11	**Elementary soil hydrologic processes**	**128**
11.1	Introduction	128
11.2	Steady-state vertical flow: Capillary rise and constant flux infiltration	129
11.3	Infiltration	134
11.3.1	Introduction	134
11.3.2	Vertical infiltration under pressure head boundary condition	135
11.3.2.1	Philip's infiltration formula	137
11.3.2.2	Haverkamp's equation	139
11.3.2.3	The Green and Ampt method	140
11.3.3	Vertical infiltration under flux boundary condition	143
11.3.4	Complicating phenomena occurring in field situations	143
11.3.4.1	Crust-topped and layered soils	143
11.3.4.2	Fingering and preferential flow	145
11.3.5	Redistribution	145
11.3.6	Infiltration-based methods to estimate soil hydraulic properties	146
11.3.7	Two-dimensional, flux boundary condition infiltration from line and point sources	149
11.4	Internal drainage	151
11.4.1	Introduction	151
11.4.2	Internal drainage of groundwater-affected soils	152
11.4.3	Unit gradient drainage	155
11.4.4	The concept of field capacity	156
11.5	Drying of bare soil by evaporation	158
11.6	Soil hydrologic processes and Burgers' equation	159
12	**Coupled heat and water flow in soil**	**161**
12.1	Thermal properties of soil	161
12.2	Heat transport in soil	161
12.3	Non-isothermal flow of water through soil	162
12.4	Soil temperature changes in the field	164

13	**Solute transport in soil**	**166**
13.1	Introduction	166
13.2	Basic processes	166
13.2.1	Convection	166
13.2.2	Hydrodynamic dispersion	169
13.2.3	Diffusion	170
13.2.4	Total solute flux	172
13.3	Chemical reactions	173
13.3.1	Classification	173
13.3.2	Fast reactions (Classes I through III)	173
13.3.3	Slow reactions (Classes IV through VI)	176
13.4	Simplified approach to solute transport prediction	178
13.5	Convection-Dispersion Equation (CDE)	179
13.5.1	General problem	179
13.5.2	The simplified CDE and solutions	180
13.5.3	Breakthrough curves and solutions to the CDE	181
13.5.3.1	Experimental procedure and results	181
13.5.3.2	Analytical solutions to the CDE	183
13.5.4	Solute transport by groundwater flow	186
13.5.5	Non-equilibrium and the mobile-immobile concept	188
13.6	Parameter estimation	189
13.7	Stochastic descriptions of solute transport	190
14	**Solute management: Soil salinization**	**191**
14.1	Overview	191
14.2	Leaching requirement	193
14.3	Salt distribution in soil	194
14.3.1	Irrigation balances root water uptake	194
14.3.2	Irrigation on slowly permeable soils	196
14.4	The ultimate sink for soil salinity - the ocean	199
15	**Soil water and crops**	**200**
15.1	Soil moisture requirements	200
15.1.1	Optimal levels of plant available soil water	200
15.1.2	Deficit irrigation	202
15.2	Aeration	203
15.3	Soil mechanical properties	204
16	**Closing remarks**	**205**
16.1	Some general remarks on simulation models	205
16.2	Important issues not included in this book	206
References		**208**
Abbreviations		**216**
Glossary		**218**
Index		**227**