

Wen-Hsing Chiang

3D-Groundwater Modeling with PMWIN

A Simulation System
for Modeling Groundwater Flow
and Transport Processes

Second Edition
With 242 Figures and 23 Tables

 Springer

Contents

1	Introduction	1
1.1	MODFLOW	1
1.2	MODFLOW Related Codes	2
1.3	Processing Modflow Pro	4
1.4	<i>PMWIN Pro</i> and Environmental Data Management System	6
1.5	Compatibility Issues	7
2	Modeling Environment	9
2.1	The Grid Editor	10
2.2	The Data Editor	15
2.2.1	The Cell-by-Cell Input Method	18
2.2.2	The Polygon Input Method	19
2.2.3	The Polyline Input Method	21
2.2.4	Specifying Data for Transient Simulations	22
2.3	The File Menu	23
2.3.1	New Model	23
2.3.2	Open Model	23
2.3.3	Convert Model	23
2.3.4	Preferences	24
2.3.5	Save Plot As	28
2.3.6	Print Plot	28
2.3.7	Animation	29
2.4	The Grid Menu	29
2.4.1	Mesh Size	29
2.4.2	Layer Property	30
2.4.3	Cell Status	33
2.4.3.1	IBOUND (MODFLOW)	33
2.4.3.2	ICBUND (MT3D/MT3DMS)	34
2.4.4	Top of Layers (TOP)	34
2.4.5	Bottom of Layers (BOT)	35
2.5	The Parameters Menu	35

2.5.1	Time	35
2.5.2	Initial & Prescribed Hydraulic Heads	38
2.5.3	Horizontal Hydraulic Conductivity and Transmissivity	38
2.5.4	Horizontal Anisotropy	39
2.5.5	Vertical Leakance and Vertical Hydraulic Conductivity	39
2.5.6	Vertical Anisotropy and Vertical Hydraulic Conductivity ...	39
2.5.7	Effective Porosity	39
2.5.8	Specific Storage, Storage Coefficient and Specific Yield	40
2.5.9	Bulk Density	41
2.5.9.1	Layer by Layer	41
2.5.9.2	Cell by Cell	41
2.6	The Models Menu	41
2.6.1	MODFLOW	41
2.6.1.1	MODFLOW Flow Packages Density	41
2.6.1.2	MODFLOW Flow Packages Drain	42
2.6.1.3	MODFLOW Flow Packages Evapotranspiration	43
2.6.1.4	MODFLOW Flow Packages General-Head Boundary	45
2.6.1.5	MODFLOW Flow Packages Horizontal-Flow Barrier	46
2.6.1.6	MODFLOW Flow Packages Interbed Storage ..	47
2.6.1.7	MODFLOW Flow Packages Recharge	49
2.6.1.8	MODFLOW Flow Packages Reservoir	50
2.6.1.9	MODFLOW Flow Packages River	53
2.6.1.10	MODFLOW Flow Packages Streamflow-Routing	55
2.6.1.11	MODFLOW Flow Packages Time-Variant Specified-Head	59
2.6.1.12	MODFLOW Flow Packages Well	60
2.6.1.13	MODFLOW Flow Packages Wetting Capability	61
2.6.1.14	MODFLOW Solvers	63
2.6.1.15	MODFLOW Head Observations	71
2.6.1.16	MODFLOW Drawdown Observations	74
2.6.1.17	MODFLOW Subsidence Observations	74
2.6.1.18	MODFLOW Compaction Observations	75
2.6.1.19	MODFLOW Output Control	75
2.6.1.20	MODFLOW Run	77
2.6.1.21	MODFLOW View	79
2.6.2	MOC3D	85
2.6.2.1	MOC3D Subgrid	85
2.6.2.2	MOC3D Initial Concentration	85
2.6.2.3	MOC3D Advection	85
2.6.2.4	MOC3D Dispersion & Chemical Reaction	87
2.6.2.5	MOC3D Strong/Weak Flag	89
2.6.2.6	MOC3D Observation Wells	90
2.6.2.7	MOC3D Sink/Source Concentration	90

2.6.2.8	MOC3D	Output Control	91
2.6.2.9	MOC3D	Concentration Observation	92
2.6.2.10	MOC3D	Run	92
2.6.2.11	MOC3D	View	93
2.6.3	MT3D		93
2.6.3.1	MT3D	Initial Concentration	93
2.6.3.2	MT3D	Advection	94
2.6.3.3	MT3D	Dispersion	98
2.6.3.4	MT3D	Chemical Reaction Layer by Layer	99
2.6.3.5	MT3D	Chemical Reaction Cell by Cell	101
2.6.3.6	MT3D	Sink/Source Concentration	101
2.6.3.7	MT3D	Concentration Observations	102
2.6.3.8	MT3D	Output Control	103
2.6.3.9	MT3D	Run	104
2.6.3.10	MT3D	View	105
2.6.4	MT3DMS		106
2.6.4.1	MT3DMS	Reaction Definition	107
2.6.4.2	MT3DMS	Initial Concentration	108
2.6.4.3	MT3DMS	Advection	109
2.6.4.4	MT3DMS	Dispersion	110
2.6.4.5	MT3DMS	Chemical Reaction	110
2.6.4.6	MT3DMS	Sink/Source Concentration	113
2.6.4.7	MT3DMS	Mass-Loading Rate	114
2.6.4.8	MT3DMS	Solver GCG	114
2.6.4.9	MT3DMS	Concentration Observations	115
2.6.4.10	MT3DMS	Output Control	115
2.6.4.11	MT3DMS	Run	115
2.6.4.12	MT3DMS	View	116
2.6.5	RT3D		117
2.6.5.1	RT3D	Reaction Definition	117
2.6.5.2	RT3D	Initial Concentration	119
2.6.5.3	RT3D	Advection	119
2.6.5.4	RT3D	Dispersion	119
2.6.5.5	RT3D	Sorption Layer by Layer	119
2.6.5.6	RT3D	Sorption Cell by Cell	120
2.6.5.7	RT3D	Reaction Parameters Spatially Constant	120
2.6.5.8	RT3D	Sink/Source Concentration	120
2.6.5.9	RT3D	Concentration Observations	121
2.6.5.10	RT3D	Output Control	121
2.6.5.11	RT3D	Run	121
2.6.5.12	RT3D	View	122
2.6.6	MODFLOW-2000 (Parameter Estimation)		123
2.6.6.1	MODFLOW-2000 (Parameter Estimation)	Parameter List	124

2.6.6.2	MODFLOW-2000 (Parameter Estimation) Head Observations	129
2.6.6.3	MODFLOW-2000 (Parameter Estimation) Flow Observations	130
2.6.6.4	MODFLOW-2000 (Parameter Estimation) Run ..	132
2.6.6.5	MODFLOW-2000 (Parameter Estimation) View ..	135
2.6.7	PEST (Parameter Estimation)	137
2.6.7.1	PEST (Parameter Estimation) Parameter List	139
2.6.7.2	PEST (Parameter Estimation) Head Observations	148
2.6.7.3	PEST (Parameter Estimation) Flow Observations	148
2.6.7.4	PEST (Parameter Estimation) Run	149
2.6.7.5	PEST (Parameter Estimation) View	150
2.6.8	UCODE (Parameter Estimation)	152
2.6.8.1	UCODE (Parameter Estimation) Parameter List ..	153
2.6.8.2	UCODE (Parameter Estimation) Head Observations	157
2.6.8.3	UCODE (Parameter Estimation) Drawdown Observations	158
2.6.8.4	UCODE (Parameter Estimation) Run	158
2.6.8.5	UCODE (Parameter Estimation) View	159
2.6.9	PMPATH (Advective Transport)	160
2.7	The Tools Menu	161
2.7.1	Digitizer	161
2.7.2	The Field Interpolator	162
2.7.2.1	Interpolation Methods for Irregularly Spaced Data	162
2.7.2.2	Using the Field Interpolator	162
2.7.3	The Field Generator	166
2.7.4	2D Visualization	168
2.7.5	3D Visualization	169
2.7.6	Results Extractor	170
2.7.7	Water Budget	171
2.8	The Value Menu	173
2.8.1	Matrix	173
2.8.2	Reset Matrix	175
2.8.3	Polygons	176
2.8.4	Points	176
2.8.5	Search and Modify	176
2.8.6	Import Results	177
2.8.7	Import Package	178
2.9	The Options Menu	178
2.9.1	Map	178
2.9.2	Environment	181

3	The Advective Transport Model PMPATH	187
3.1	The Semi-analytical Particle Tracking Method	188
3.1.1	Consideration of the display of the calculated pathlines	191
3.1.2	Consideration of the spatial discretization and water table layers	191
3.2	PMPATH Modeling Environment	192
3.2.1	Viewing Window and cross-section windows	192
3.2.2	Status bar	194
3.2.3	Tool bar	194
3.2.3.1	Open model	194
3.2.3.2	Set particle	195
3.2.3.3	Erase Particle	197
3.2.3.4	Zoom In	197
3.2.3.5	Zoom Out	197
3.2.3.6	Particle Color	198
3.2.3.7	Run Particles Backward	198
3.2.3.8	Run Particles Backward Step by Step	198
3.2.3.9	Stop Particle Tracking	198
3.2.3.10	Run Particles Forward Step by Step	198
3.2.3.11	Run Particles Forward	199
3.3	PMPATH Options Menu	199
3.3.1	Environment	199
3.3.2	Particle Tracking (Time)	203
3.3.3	Maps	207
3.4	PMPATH Output Files	208
3.4.1	Plots	208
3.4.2	Hydraulic Heads	209
3.4.3	Drawdowns	209
3.4.4	Flow Velocities	209
3.4.5	Particles	209
4	Tutorials	211
4.1	Your First Groundwater Model with <i>PMWIN Pro</i>	211
4.1.1	Overview of the Hypothetical Problem	211
4.1.2	Run a Steady-State Flow Simulation	213
4.1.2.1	Step 1: Create a New Model	213
4.1.2.2	Step 2: Assign Model Data	213
4.1.2.3	Step 3: Perform the Flow Simulation	221
4.1.2.4	Step 4: Check Simulation Results	222
4.1.2.5	Step 5: Calculate subregional water budget	223
4.1.2.6	Step 6: Produce Output	226
4.1.3	Simulation of Solute Transport	233
4.1.3.1	Perform Transport Simulation with MT3DMS	234
4.1.3.2	Perform Transport Simulation with MOC3D	241
4.1.4	Parameter Estimation	247

4.1.4.1	Parameter Estimation with PEST	249
4.1.4.2	Parameter Estimation with UCODE	253
4.1.5	Animation	255
4.2	Unconfined Aquifer System with Recharge	257
4.2.1	Overview of the Hypothetical Problem	257
4.2.2	Steady-state Flow Simulation	258
4.2.2.1	Step1: Create a New Model	258
4.2.2.2	Step2: Generate the Model Grid	258
4.2.2.3	Step 3: Refine the Model Grid	259
4.2.2.4	Step 4: Assign Model Data	260
4.2.2.5	Step 5: Perform steady-state flow simulation	265
4.2.2.6	Step 6: Extract and view results	265
4.2.3	Transient Flow Simulation	266
4.3	Aquifer System with River	270
4.3.1	Overview of the Hypothetical Problem	270
4.3.1.1	Step 1: Create a New Model	271
4.3.1.2	Step 2: Generate the Model Grid	271
4.3.1.3	Step 3: Refine the Model Grid	272
4.3.1.4	Step 4: Assign Model Data	273
4.3.1.5	Step 5: Perform steady-state flow simulation	279
4.3.1.6	Step 6: Extract and view results	279
5	Examples and Applications	283
5.1	Basic Flow Problems	283
5.1.1	Determination of Catchment Areas	283
5.1.2	Use of the General-Head Boundary Condition	287
5.1.3	Two-layer Aquifer System in which the Top layer Converts between Wet and Dry	289
5.1.4	Water-Table Mount resulting from Local Recharge	291
5.1.5	Perched Water Table	294
5.1.6	An Aquifer System with Irregular Recharge and a Stream ..	297
5.1.7	Flood in a River	300
5.1.8	Simulation of Lakes	303
5.2	EPA Instructional Problems	306
5.3	Parameter Estimation and Pumping Test	307
5.3.1	Basic Parameter Estimation Skill	307
5.3.2	Estimation of Pumping Rates	311
5.3.3	The Theis Solution – Transient Flow to a Well in a Confined Aquifer	314
5.3.4	The Hantush and Jacob Solution – Transient Flow to a Well in a Leaky Confined Aquifer	317
5.3.5	Parameter Estimation with MODFLOW-2000: Test Case 1 ..	320
5.3.6	Parameter Estimation with MODFLOW-2000: Test Case 2 ..	323
5.4	Geotechnical Problems	326
5.4.1	Inflow of Water into an Excavation Pit	326

5.4.2	Flow Net and Seepage under a Weir	328
5.4.3	Seepage Surface through a Dam	330
5.4.4	Cutoff Wall	334
5.4.5	Compaction and Subsidence	337
5.5	Solute Transport	340
5.5.1	One-dimensional Dispersive Transport	340
5.5.2	Two-dimensional Transport in a Uniform Flow Field	342
5.5.3	Monod Kinetics	345
5.5.4	Instantaneous Aerobic Biodegradation	347
5.5.5	First-Order Parent-Daughter Chain Reactions	349
5.5.6	Benchmark Problems and Application Examples from Literature	351
5.6	Miscellaneous Topics	353
5.6.1	Using the Field Interpolator	353
5.6.2	An Example of Stochastic Modeling	356
6	Supplementary Information	359
6.1	Limitation of <i>PMWIN Pro</i>	359
6.1.1	Data Editor	359
6.1.2	Boreholes and Observations	359
6.1.3	Digitizer	360
6.1.4	Field Interpolator	360
6.1.5	Field Generator	360
6.1.6	Water Budget Calculator	360
6.2	File Formats	360
6.2.1	ASCII Matrix File	360
6.2.2	Contour Table File	361
6.2.3	Grid Specification File	362
6.2.4	Line Map File	363
6.2.5	ASCII Time Parameter File	363
6.2.6	Head/Drawdown/Concentration Observation Files	364
6.2.6.1	Observation Boreholes File	365
6.2.6.2	Layer Proportions File	365
6.2.6.3	Observations File	365
6.2.6.4	Complete Information File	366
6.2.7	Flow Observation Files	367
6.2.7.1	Cell Group File	367
6.2.7.2	Flow Observations Data File	368
6.2.7.3	Complete Information File	368
6.2.8	Trace File	369
6.2.9	Polygon File	370
6.2.10	XYZ File	371
6.2.11	Pathline File	371
6.2.11.1	PMPATH Format	371
6.2.11.2	MODPATH Format	372

6.2.12	Particles File	372
6.3	Input Data Files of the supported Model.....	374
6.3.1	Name File	374
6.3.2	MODFLOW-88/96	376
6.3.3	MODFLOW-2000	377
6.3.4	MODPATH and MODPATH-PLOT (version 1.x).....	377
6.3.5	MODPATH and MODPATH-PLOT (version 3.x).....	378
6.3.6	MOC3D.....	378
6.3.7	MT3D	378
6.3.8	MT3DMS	378
6.3.9	RT3D	379
6.3.10	PEST	379
6.3.11	UCODE	380
6.3.12	Using MODPATH with <i>PMWIN Pro</i>	380
References		383
Index		391