

groundwater modeling

Using GEOGRAPHICAL
INFORMATION SYSTEMS

GEORGE F. PINDER

Contents

Preface

xi

1 Flow Modeling

1

1.1 Introduction / 1

1.2 Areal Extent of a Model / 9

1.3 Hydrological Boundaries to the Model / 22

1.4 Compilation of Geological Information / 23

1.4.1 Unconsolidated Environments / 27

1.4.2 Consolidated Rocks / 31

1.4.3 Metamorphic Rocks / 32

1.4.4 Igneous Rocks / 33

1.4.5 Representation of Geological Units / 35

1.5 Compilation of Hydrological Information / 50

1.5.1 Geohydrological Parameters / 51

1.5.2 Boundary Conditions / 52

1.5.3 Stresses / 53

1.6 Water-Table Condition / 54

1.6.1 Near-Surface Aquifer Zone / 54

1.6.2 Sharp-Interface Approximation of the Water Table / 57

1.6.3 Variably Saturated Water-Table Formulation / 57

1.6.4 Comparison of the Sharp-Interface and Variably Saturated Formulations / 59

1.7 Physical Dimensions of the Model / 62

1.7.1 Vertical Integration of the Flow Equation / 64

1.7.2 Free-Surface Condition / 66

1.8 Model Size / 68

1.9 Model Discretization / 69

1.9.1 Finite-Difference Approximations / 69

1.9.2 Finite-Element Approximations / 70

1.9.3 Two-Space Dimensional Approximations / 70

1.10 Finite-Difference Approximation to the Flow Equation / 72

1.10.1 Model Boundary Conditions / 75

1.10.2 Model Initial Conditions / 75

1.11 Finite-Element Approximation to the Flow Equation / 76

1.11.1 Boundary Conditions / 79

1.11.2 Initial Conditions / 81

1.12 Parameters / 86

1.13 Fractured and Cavernous Media / 87

1.14 Model Stresses / 93

1.14.1 Well Discharge or Recharge / 95

1.14.2 Rainfall / 96

1.14.3 Multiple Stress Periods / 96

1.15 Finite-Element Mesh / 98

1.16 Simulation / 102

1.16.1 Solution Algorithm / 102

1.16.2 Bandwidth / 111

1.16.3 Running PTC / 112

1.17 Output / 115

1.18 Calibration / 121

1.18.1 Model Building Guidelines / 121

1.18.2 Model Evaluation Guidelines / 124

1.18.3 Additional Data-Collection and Model Development Guidelines / 125

1.18.4 Uncertainty-Evaluation Guidelines / 126

1.18.5 Some Rules of Thumb / 127

- 1.19 Production Runs / 129
- 1.20 Summary / 129
- References / 129

2 Transport Modeling

133

- 2.1 Compilation of Water-Quality Information / 134
- 2.2 Physical Dimensions / 135
- 2.3 Model Size / 136
- 2.4 Transport Equation / 137
 - 2.4.1 Equilibrium or Adsorption Isotherms / 137
 - 2.4.2 Mass Flux / 139
 - 2.4.3 Example of Retardation / 140
- 2.5 Chemical Reactions / 141
- 2.6 Model Boundary Conditions / 143
- 2.7 Finite-Element Approximation / 150
- 2.8 Boundary Conditions / 157
 - 2.8.1 First-Type Boundary Condition / 157
 - 2.8.2 Second-Type Boundary Condition / 157
 - 2.8.3 Third-Type Boundary Condition / 157
- 2.9 Initial Conditions / 157
- 2.10 Model Parameters / 158
- 2.11 Model Stresses / 160
- 2.12 Running the Model / 160
- 2.13 Output / 162
- 2.14 Calibration / 163
- 2.15 Production Runs / 165
- 2.16 Summary / 167
- References / 167

3 Finite-Element versus Finite-Difference Simulation

169

- 3.1 Elementary Application / 169
 - 3.1.1 Groundwater Flow / 169
 - 3.1.2 Groundwater Transport / 201
- 3.2 Comparison of Methods / 211
 - 3.2.1 Graphical User Interfaces / 211

3.2.2	Model Formulation and Implementation /	212
3.2.3	Groundwater Flow /	216
3.2.4	Groundwater Transport /	220
3.3	Summary /	221