



## Introduction to the AnAqSim Instructional Series

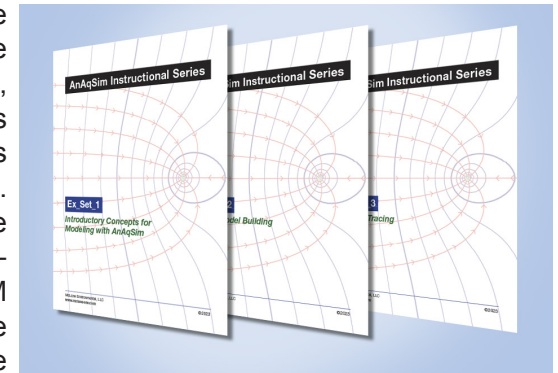
The *flexAEM*<sup>™</sup> System is designed to introduce you to the power, accuracy and ease of use of the analytic element method (AEM) approach to groundwater modeling using AnAqSim AEM modeling software.

Tutorials and software tools have been developed to lead you step-by-step through the process of building and running groundwater models for problems that cover the range from simple single-layer steady-state models to complex multi-layer transient simulations for well field water supply projects, geotechnical drain and dewatering problems, or groundwater remediation system design. For advanced applications, AnAqSim can simulate saltwater interface movement, and model calibration can be automated using powerful PEST parameter estimation software.

The *flexAEM*<sup>™</sup> System also includes a Remediation Calculator Toolkit of over a dozen simple pre-packaged calculators to design, or evaluate the performance of, ground-water remediation systems consisting of wells, trenches, slurry walls, caps, and other components. These calculators allow groundwater scientists and engineers to rapidly assess groundwater flow patterns and velocities, pumping or infiltration aquifer stresses, capture zones and discharge rates for remediation system designs.

### *flexAEM*<sup>™</sup> Tutorials: AnAqSim Instructional Series

*flexAEM*<sup>™</sup> tutorials, available for download and purchase from the *flexAEM.com* website, consist of exercise packages containing self-paced lessons and hands-on tutorial booklets. The training materials provide a gradual and thorough introduction to the concepts of AEM groundwater modeling, and the features and application of the AnAqSim software.



Lessons are included that outline basic concepts required to properly apply AnAqSim. These concepts lead into a series of hands-on tutorials, with each tutorial focusing on the use of a particular AnAqSim feature, or exploring one or more methods for representing a common hydrologic feature using the AnAqSim set of analytic elements.

The tutorials are also designed to teach a variety of groundwater modeling techniques and “best practices.” While presented within the context of the tutorial step-by-step AnAqSim instructions, the concepts and techniques learned in the *flexAEM*<sup>™</sup> training series can be applied in any groundwater project using any selected modeling software.

The *flexAEM*<sup>™</sup> AnAqSim Instructional Series consists of 15 packages of exercises. Set 1 is a FREE introduction to groundwater modeling, and Set 2 is a FREE introduction to AEM modeling with AnAqSim that contains a combination of introductory lecture slides and hands-on exercises that should get you well on your way to building Analytic Element Method groundwater models. Sets 3 through 15 introduce AnAqSim model building concepts and techniques, in-depth discussions of AnAqSim software features, and links to other software that can enhance and facilitate your modeling projects.

## Set 1: Introductory Concepts for Modeling with AnAqSim

This free set of lectures introduces you to the basics of groundwater modeling (aquifer hydraulics concepts, and common model applications for environmental and engineering project work) and then provides an overview of Analytic Element Method (AEM) modeling and the key features of AnAqSim (sub-domain method; radial basis functions for multi-layer and transient simulations; how its solutions compare with MODFLOW; etc.). No hands-on modeling is performed in this series; and it is not necessary to download or purchase AnAqSim to begin exploring its capabilities. Once you have familiarized yourself with the basics, you can move on to the other exercise sets, which focus on a particular concepts and applications of the many features and capabilities AnAqSim has to offer.

Topics covered in our Set 1 Introductory Concepts package include:

- Aquifer recharge, flow and discharge
- Basic equations of groundwater flow
- Concept of hydraulic head
- Using head to map groundwater flow patterns
- Darcy's Law of groundwater flow
- Types of subsurface models
- Typical model applications
- Process of groundwater modeling
- Benefits of groundwater modeling
- Analytic Element Method (AEM) modeling
- AnAqSim concepts and features
- AnAqSim comparison with MODFLOW

The Free Set 1 Lecture Materials provide valuable information that will get you ready to apply the Analytic Element Method of groundwater flow modeling using AnAqSim!

## Set 2: Simple Model Building

This free introduction to the dozens of tutorials in the AnAqSim Instructional Series has been designed to get you started modeling using the Analytic Element Method today! Our introductory training package includes exercises and lessons that are intended to familiarize users with the AEM method using the AnAqSim modeling software, establish good modeling practices, and provide detailed instruction on how to build simple models and perform commonly used groundwater modeling analyses.

Topics covered in our Set 2 Simple Model Building include:

- Simple introductory Hello World type example
- Defining external boundaries for your model
- Setting up a model
- Adding a pumping well
- Tracing flow pathlines (single layer model)
- Modeling aquifers with isotropic and anisotropic hydraulic conductivity
- Adding model sources (inflow) and sinks (outflow)
- Simple hydraulic head contouring (drawdown features; mounding features)

The Free Set 2 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.

### Set 3: Pathline Tracing

Pathline tracing for flow through the aquifer, and to and from hydraulic features like wells, trenches and streams, is one of the most important tools that the analyst can apply to groundwater model simulation results. Pathline tracing analyses allow for evaluation of horizontal and vertical flow paths, velocities of groundwater movement, exchange of groundwater from one vertical layer to another, and termination of flow at a discharge feature.

Topics covered in Set 3 Pathline Tracing package include:

- Basic pathline tracing
- Setting starting pathline locations in a model
- Implementing proper pathline control settings
- Use of pathline tracing to delineate the area contributing recharge to a well
- Stepwise use of different pathline techniques
- The power of applying AnAqSim's built-in feature to identify captured pathlines
- Several hands-on pathline tracing exercises

The Set 3 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.

### Set 4: Aquifer Boundaries and Geometry

The Sub-Domain method used in AnAqSim differs from some other AEM methods in that the analyst is required to specify an outer boundary condition on the aquifer domain. The exercises in Set 4 of the AnAqSim Instructional Series describe the three main types of external boundaries and how to apply them. Methods are also presented for moving beyond a horizontal flat aquifer base model to a model that employs a sloping or undulating impermeable base (e.g. bedrock surface).

Topics covered in the Set 4 Aquifer Boundaries and Geometry package include:

- Common specified head and specified flow boundaries
- Third-type (general head boundary "GHB" type) boundaries
- Setting up a model with a sloping aquifer base
- Setting up a model with a structurally controlled aquifer base

The Set 4 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.

## Set 5: Heterogeneities

AnAqSim is based on the sub-domain analytic method. This provides AnAqSim with one its key strengths: the ability to easily include heterogeneities (sub-domains or zones) of different types within the overall regional aquifer domain. These zones can be set with different aquifer properties, different recharge rates, etc. Higher hydraulic conductivity zones cause a convergence of regional flow, while lower permeability heterogeneities cause divergence of regional flow as it moves through and around the zone. Rules for digitizing and specifying the order of vertices along boundaries of various types are presented.

Topics covered in the Set 5 Exercise Package include:

- Basic introduction on how to create sub-domain heterogeneities.
- Rules for digitizing heterogeneity boundaries of different types
- Embedding high hydraulic conductivity zones in an aquifer model
- Embedding low hydraulic conductivity zones in an aquifer model
- Using pathlines to examine changes in flow patterns for each zone type

The Set 5 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.

## Set 6: Hydraulic Features – Linear

Exercises in Set 6 of the AnAqSim Instructional Series describe how AnAqSim can be applied to simulate aquifers with linear (long and narrow) hydraulic and hydrologic features. Line elements deployed perpendicular to regional flow can represent no-flow or slightly leaky hydraulic barriers like slurry walls or sheetpile walls. Dug trenches can be simulated using line elements (specified head or specified flux), but they can also be modeled as a separate long narrow domain containing high-permeability material. These exercises compare the application and results for each approach to modeling a trench. In addition, exercises in this set explore techniques to incorporate certain geologic features into a bedrock aquifer model, including long linear features such as transmissive fault zones and networks of linear features like interconnected fractures.

Topics covered in the Set 6 Exercise Package include:

- Linear barriers to flow (no-flow and leaky)
- Line element representation of a collector trench
- Domain representation of a collector trench
- Adding a long transmissive fault feature
- Modeling flow in bedrock aquifer with fracture features

The Set 6 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.

## Set 7: Hydraulic Features – Areal

AnAqSim provides numerous methods for including areal hydraulic features in an aquifer model. These features may be part of the aquifer (e.g. an area at the aquifer's surface where water is added by recharge or lost to evapotranspiration (ET)) or they may represent a surface water feature that is hydraulically connected to the aquifer (e.g. a wetland, pond or lagoon). Recharge or ET may be easily applied as a domain area in which the top flux is set at a different value than the surrounding regional aquifer (greater for recharge; lesser for ET). Discharge from the aquifer to a pond or wetland area can be represented by an array of spatially-variable area sinks (SVAS) radial basis points with head values set at the water level in the pond or wetland. In addition, groundwater flow out of the aquifer, into and through a shallow pond, and then back into the aquifer can be represented using a small domain set to a very high hydraulic conductivity value (which represents no resistance to flow).

Topics covered in the Set 7 Exercise Package include:

- Discharge to a pond / wetland using a head-dependent flux domain
- Areal recharge to the aquifer (e.g. spray irrigation) using increased specified recharge
- Pond / lagoon recharge to the aquifer using increased specified recharge
- Pond or lagoon defined using a domain with specified head boundary
- Flow through pond created using a high hydraulic conductivity domain

The Set 7 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.

## Set 8: Streams and Rivers

For simple model representations of streams or rivers two types of line elements may be used. If the seepage flow from the aquifer to the stream segment is known (e.g. via stream gaging) a specified line element may be used. More commonly a specified line element is set to represent the stream stage, and that controls the aquifer water level at the stream. For a better representation of the hydraulic interaction between the aquifer and a stream or river, AnAqSim provides a special river element that allows the analyst to specify the surface water stage and the conductance of the bed material, which allows AnAqSim to calculate the flow from the aquifer to (or out of) the stream. This set of exercises presents information on how to include streams and stream networks in an AnAqSim model using specified head line elements, and how those stream elements may be joined to a lake domain feature. They also describe how to improve on the simple stream representation by using the AnAqSim river element. Use of Analysis Tools to examine head and hydraulic flow to a stream element is also presented.

Topics covered in the Set 8 Exercise Package include:

- Adding a stream to a watershed model
- Adding a tributary line element to form a simple stream network
- Parameters that define a river element and how to add the element to a model
- Analysis Tools for examination of the hydraulics surrounding a stream element
- Proper methods for joining a stream line element to a lake domain

The Set 8 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.

## Set 9: Multiple Layers

The Set 9 Exercise Package introduces an important new area of AnAqSim's capabilities: development of multiple layer groundwater flow models. Exercises included in Exercise Set 9 demonstrate multi-layer model construction for the simulation of vertical aquifer flow, flow to wells with multiple screened intervals, and accurate representation of 3-D flow in stream-lake confluence areas.

Topics covered in the Set 9 Exercise Package include:

- Creating multiple-layer models
- Multiple layer model with pumping well
- Multiple layer model with river line element
- Multiple layer model with river domain
- Stream joining a lake domain boundary
- Stream joining a lake with 3-D flow and discharge
- Flow patterns near a stream joining a multi-layer lake feature

The Set 9 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.

## Set 10: Streams and Rivers

Recommended for more advanced users, the Set 10 Exercise Package provides instruction on how to create, and analyze results for, transient groundwater flow models. AnAqSim allows the user to first create a steady-state flow model and to include desired data recording locations (e.g. for transient hydrographs). It is then simple to convert that model to transient mode, run it, and analyze the stored results. This exercise set presents that process, including the important step of properly specifying the number and spacing of SVAS radial basis points that allow the transient aquifer simulation to release water from storage as heads are lowered by pumping (or take water into aquifer storage for an injection scenario).

Topics covered in the Set 10 Exercise Package include:

- Creating transient models (e.g. adding a transient pumping well)
- The process of moving from a steady-state model (for initial conditions) to a corresponding transient model (to simulate and store transient response)
- Specifying time periods (stress periods), and the number and time-spacing of time steps within each period
- Specifying SVAS radial basis functions for release from (or flow to) storage
- Checking the adequacy of SVAS point spacing
- Analysis of transient model output data
- Use of hydrograph plots (both pre-set and "on the fly")
- Contouring of selected time step heads
- Transient pathline tracing

The Set 10 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.



## Set 11: Model Calibration

Calibration of a groundwater flow model — adjusting model parameters to achieve an acceptable match to measured field conditions — is often an important step in a model application. AnAqSim facilitates model calibration via a set of built-in tools that allow the analyst to enter the location and head value for site observation points, run the simulation, and then calculate, plot, and write out the calibration residuals (model head at each observation point minus measured head).

Topics covered in the Set 11 Exercise Package include:

- Introduction to concepts and terminology of groundwater flow model calibration
- Description of AnAqSim calibration setup methods and inputs
- Discussion of calibration residual charting, mapping, and output
- Hands-on exercise that demonstrates the AnAqSim calibration process and results

The Set 11 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.

## Set 12: Saltwater Interface Modeling

The Set 12 Exercise Package focuses on the fresh-salt water interface modeling capabilities of AnAqSim including instruction on basic interface hydraulics concepts, and exercises that explore the flow of a freshwater aquifer in the presence of a dense saltwater boundary.

Topics covered in the Set 12 Exercise Package include:

- The Ghyben-Herzberg principle that governs the depth and configuration of the freshwater-saltwater interface in AnAqSim
- The “sharp interface” approach applied in analytic element modeling as a representation of the salt-to-fresh transition zone in natural aquifers
- Methods for setting up single layer and multi-layer interface models
- The fully-penetrating well assumption applied in simple AEM interface models compared with the more accurate multi-layer partially penetrating well conditions that can be applied in AnAqSim
- Vertical saltwater interface upconing beneath a shallow water supply well
- Lateral saltwater intrusion in response to pumping near a coastal boundary
- The effect of different coastal boundary condition settings on models incorporating several different coastal boundary conditions are developed to examine the effects on the simulated groundwater discharge zone at the coast

The Set 12 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.

## Set 13: AnAqSim Tools, Tips, and Techniques

The Set 13 Exercise Package provides introductions to a wide range of AnAqSim built-in tools that can be used for model development and analysis of model results. Import a basemap to guide digitizing of site features to guide the model development; modify AnAqSim's graphic output (contours, pathlines, and flow vectors) using the View Manager to prepare report-ready graphics; learn how to use the various analysis tools to inspect and evaluate model results, including the model inspector tool and charting and plotting features; and export model data for evaluation in other programs.

Topics covered in the Set 13 Tools, Tips & Techniques Package include:

- Overview of the AnAqSim model building process
- Explanation of solver settings and checks parameters
- Direct inspection and editing of AnAqSim XML-format input files
- Use of model inspector tools
- Overview of Analysis Tools (lecture)
- Intro to Analysis Tools (hands-on)
- Working with AnAqSim input data grids
- Overview of View Manager features (lecture)
- Use of the View Manager (hands-on)
- AnAqSim digitizing tools
- Use of digital basemaps for model building and display of results
- Exporting model results
- Importing river element data from external Excel data set

The Set 13 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.

## Set 14: Using QGIS to Build AnAqSim Models

The Set 14 Exercise Package demonstrates the link between AnAqSim and QGIS, a powerful open-source software package that can be used as a graphical user interface for building and displaying AnAqSim models - - including the full interactive 3D display of AnAqSim pathlines. Exercises in Set 14 illustrate how QGIS and AnAqSim can exchange data and images to facilitate groundwater model construction and view and analyze model output.

Topics covered in the Set 14 QGIS Model Building Exercise Package include:

- An overview of QGIS, an open-source Geographic Information System software
- Using QGIS as a graphical pre- and post-processor to access web map services for basemaps
- Digitizing model features (e.g. watershed boundaries, geologic boundaries, etc.) in QGIS for import into AnAqSim
- Creating an AnAqSim river elevation data set by digitizing points on a basemap using QGIS
- Use of a custom *flexAEM* tool for importing digitized data into a standard XML-format AnAqSim input file to build a basic model framework
- Adding other required parameters to complete model construction
- Modifying the single-layer digitized model to include multiple layers
- Using QGIS with web map services for watershed hydrologic boundaries
- Exporting two and three-dimensional AnAqSim model results to QGIS for display and analysis

The Set 14 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.



## Set 15: AnAqSim and PEST

AnAqSim provides built-in tools for manual “trial and error” model calibration. Linking AnAqSim with the public domain PEST software creates a system for automated model calibration that takes the use of AnAqSim to the next level. AnAqSim is especially well-suited for PEST parameter estimation because of the general simple and gridless construction of the models, spatial accuracy provided by the analytic element solution technique, and computational efficiency in a method that requires scores or hundreds of iterative model runs to arrive at the final set of parameter values. This set of exercises begins with an overview of PEST with respect to its linking with AnAqSim. It then demonstrates the use of PEST to evaluate the uncertainty associated with selected model input parameters for a steady-state watershed model and a transient aquifer test model. The examples demonstrate the potential use of AnAqSim with PEST to guide field data collection and groundwater flow model calibration.

Topics covered in the Set 15 Exercise Package include:

- An overview of PEST (with respect to its linking with AnAqSim)
- Steady-state calibration of a simple site model with three aquifer zones
- Steady-state calibration of a simple site model with three aquifer zones and a stream
- Transient calibration of a transient pumping model of a regional aquifer to estimate aquifer hydraulic conductivity and storage
- Transient calibration of a transient pumping model of a regional aquifer with a zone of channel sand deposits to estimate hydraulic conductivity and storage properties for both the aquifer and the channel sands

The Set 15 Exercise Package contains instructional lessons, any necessary modeling input files, basemaps, etc; and a set of step-by-step completed AnAqSim files that you can load at any point if you want to check one of the exercise steps.

## Get Started Today!

Whether you want to explore the free tutorials or want to dive in deeper with some of the more advanced examples, *flexAEM*™ has the perfect place for you to start. Learn AEM modeling to complement your groundwater skill set, and add the ease, flexibility and power of an analytic model to your next groundwater project.

**Download a set of tutorials or sign up for a training course today!**

## Contact Us!

For more information on the *flexAEM*™ System of training, tools, and courses visit:

<http://www.flexAEM.com>

Or email Customer Service at:

[support@flexAEM.com](mailto:support@flexAEM.com)