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REPORT ON CUSTOMIZED TRAINING ON GROUNDWATER MODELING FOR THE ASPIRED TEAM AND STAKEHOLDERS

March 2018

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Advanced Science & Partnerships for Integrated Resource Development

REPORT ON THE CUSTOMIZED TRAINING ON GROUNDWATER MODELING FOR THE ASPIRED TEAM AND STAKEHOLDERS

March 2018

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Prepared for:

United States Agency for International Development
Armenia Mission
1 American Avenue
Yerevan 0082, Armenia

Prepared by:

ME&A
4300 Montgomery Ave.
Suite 103
Bethesda, MD 20814
Tel: +1 301 652 4334
Fax: +1 301.652.3733
http://www.meandahq.com/

Armenian Branch of ME&A
105/1 Teryan St., Suite 204,
Yerevan 0009
Republic of Armenia
Tel. +374 10 514 315
Fax: +374 10 514 317
Email: aspired@engl.com

DISCLAIMER

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LIST OF ACRONYMS

ASPIRED	Advanced Science and Partnerships for Integrated Resource Development
AHGW	Arc Hydro Groundwater
ATC	Agribusiness Teaching Center
AUA	American University of Armenia
DEM	Digital Elevation Model
EMIC	Environmental Monitoring and Information Center
ESRI	Environmental Systems Research Institute
GOA	Government of Armenia
GIS	Geographic Information System
GMS	Groundwater Modeling System
ICARE	International Center for Agribusiness Research and Education
MNP	Ministry of Nature Protection
NGO	Non-Governmental Organization
SNCO	State Non-Commercial Organization
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WRMA	Water Resources Management Agency

Project Report on Customized Training on Groundwater Modelling for the ASPIRED Team and Stakeholders

15-19 January, 2018

Yerevan, Armenia

Background Information

The Advanced Science, Technology, Innovation and Partnerships for Integrated Resource Development (ASPIRED) Project assists the Government of Armenia (GOA) in improving management of groundwater resources in the Ararat Valley through the use of science, technology, innovation and partnership initiatives. Works aimed at developing and calibrating decision support tools that generate hydrological, hydrogeological data are implemented to this end. These tools will be used by stakeholders to inform decision making process on sustainable use of groundwater resources of strategic importance. ASPIRED is funded by the United States Agency for International Development (USAID) Armenia and implemented by the ME&A.

To enhance the skills of the ASPIRED technical team and selected representatives of the key government agencies, academia and non-governmental organization (NGO) in developing a three-dimensional (3D) model and numeric groundwater flow model of the Ararat artesian basin, ASPIRED used services of the Aquaveo company to design and deliver hands-on training course on application of Arc Hydro Groundwater (AHGW) tools and Groundwater Modeling System (GMS), which is a standalone graphical user interface developed by Aquaveo for creating and running MODFLOW model. This course builds on the GIS training for beginners conducted by the ASPIRED GIS specialist for the MNP staff in December 2017. Aquaveo was selected as a uniquely qualified company for providing training program and distance coaching services customized to the needs of the ASPIRED team and Armenian stakeholders in modeling groundwater aquifers and flows in the Ararat Valley.

Aquaveo is a US-based company and responsible for development, distribution, training, and technical support for the Arc Hydro Groundwater (AHGW), GMS and GIS data models and tools. Aquaveo provides training and consulting services in the field of water resource engineering, hydraulics, and hydrologic engineering. Aquaveo had conducted over 25 training courses in the use of AHGW, GMS and MODFLOW all over the United States and internationally. These courses have been provided as on-site training to various government and private entities.

Aquaveo has ongoing software development and consulting contracts with federal and local government agencies, such as the US Army Corps of Engineers, the US Federal Highway Administration, Los Angeles County, the US Geological Survey (USGS), the US Department of Energy, and the US Environmental Protection Agency (USEPA).

Aquaveo has a partnership agreement with Environmental Systems Research Institute (ESRI) to develop ArcGIS-based groundwater solutions, which is of high relevance to the ASPIRED needs. It includes the development and maintenance of the Arc Hydro Groundwater (AHGW) data model and an associated suite of tools, development of an extension to AHGW called the MODFLOW data model that is used to store an entire MODFLOW simulation inside an ArcGIS database. This makes it possible to perform spatial queries and run geo-processing tools directly on the MODFLOW data. It also provides the capability to develop custom workflows to automate repetitive tasks associated with groundwater modeling, including many of the tasks involved in the groundwater well permitting. These enhancements reduce error frequency and significantly reduce turnaround time for each analysis.

More information about the Aquaveo is available at https://www.aquaveo.com/**.**

Content of the Training Program

Content of the training program was elaborated by the Aquaveo experts, in close coordination with the ASPIRED team. The topics, modeling and other tools proposed by Aquaveo were customized to needs of the ASPIRED for modeling the Ararat artesian basin, and covered the following topics:

- Introduction to geodatabases and the Arc Hydro Groundwater data model
- Building and customizing an Arc Hydro Groundwater geodatabase
- Working with wells and time series data and creating water level maps using the Groundwater Analyst tools
- Introduction to the MODFLOW model
- Introduction to the use of GMS to develop MODLFOW models.
- Learn how to use Model Builder to automate workflows
- Managing and visualizing borehole data (vertical, non-vertical)
- Building 3D hydrogeologic models with Subsurface Analyst tools
- Creating 2D cross sections in ArcMap
- Learn how groundwater models can be viewed in Arc Map to aid decision-making.

The training course was designed in a way that it consisted of various lessons related to AHGW and MODFLOW topics, presented by the trainer to the trainees with information related to the particular topic. The presentations included discussion led by the trainer to check participants understanding of the topic, as well as answer any questions session. Most presentations were followed by a workshop with hands-on exercise that gave participants an opportunity to use the software to apply the features of the software presented in the lesson. Agenda of the training course is presented in Annex A.

Temporary license codes for the software were provided by Aquaveo to allow participants to use the software during the training and 3 weeks after the training. The software was

installed on the computers of the training venue – GIS lab of the American University of Armenia (AUA) by the ASPIRED team.

Digital copies of the training course manual, consisting of power point presentations, exercise instructions and tutorials were sent to the ASPIRED team, and the ASPIRED team prepared training handouts for the participants with the Armenian translation of the presentations, and the tutorial. Both printed and electronic versions of the handouts were provided to all the participants, and interested stakeholders can get copies of the handouts from the ASPIRED office.

Proceedings

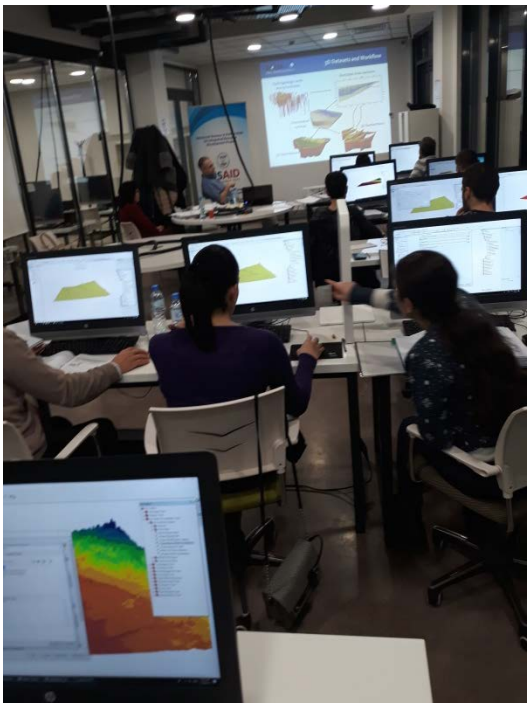
The training course on stratigraphic and groundwater modeling with AHGW, GMS and MODFLOW took place on January 15-19, 2018, in the GIS lab of the AUA. It was conducted by Alan Lemon, software engineer, who is the lead developer of AHGW and member of the GMS development team. Alan has years of experience developing groundwater modeling software and teaching. He has also been involved in several consulting projects using GMS to model groundwater systems.

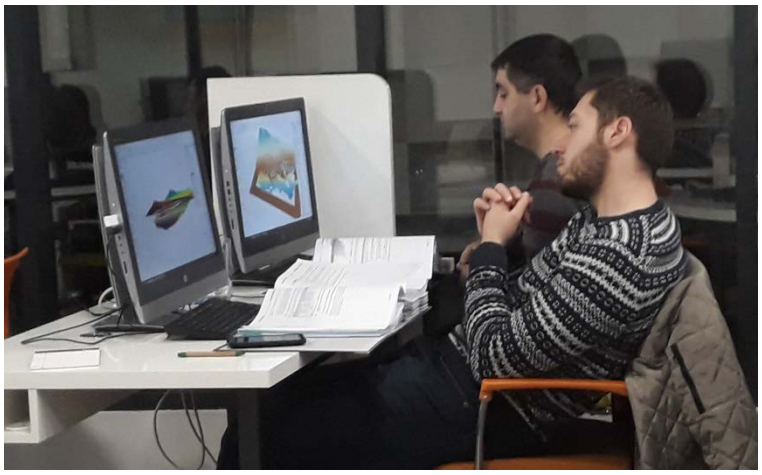
One of the lead developers of the AHGW introduces groundwater modeling software to the Armenian professionals.

Ten professionals, representing the ASPIRED Project, Environmental Impact Monitoring and Information Center and Water Resources Management Agency of the Ministry of Nature Protection, Acopian Center for the Environment of the AUA, International Agribusiness Teaching Center/ of the National Agrarian University, Yerevan State University, and the

Institute of Geological Sciences of the National Academy of Sciences of Armenia. List of the trainees is presented in Annex B.

During the four days of the training course, modern software applications for hydrogeologic modeling were presented to the participants, such as AHGW tools, GMS and MODFLOW. Presentations were combined with practical exercises, and training participants learned how to build and customize an AHGW geodatabase, import data, produce maps of temporal data such as water levels and water quality, manage and visualize borehole data, build 3D hydrogeologic models inside ArcGIS including construction of 2D and 3D cross sections and volume models, and import, edit, visualize, and create workflows with MODFLOW models inside ArcGIS.





Trainees apply knowledge gained on software features in exercise

The last, fifth day of the training was devoted to practical exercise on creating a preliminary simple model of the Ararat Valley, using presented tools and input data available in the ASPIRED Project. Particularly, cross-sections and 3D volumes of the main hydrogeological units in the Ararat Valley using ArcHydro Groundwater Tools were generated, and a sample model of groundwater flow for the first confined layer in the Ararat Valley groundwater basin using the GMS and MODFLOW tools were created by the training participants. The GIS layers on the thicknesses of the 9 hydrogeological units created by the USGS as a part of the study on Hydrogeological Framework of the Ararat Basin, as well as the 30-meter DEM raster image of the Ararat Valley were used as input data for generation of the 3D volumes under the AHGW Tools. For construction of a sample groundwater flow model under the GMS software, the lithological structure data collected during the inventory for more than 2800 wells in the Ararat Valley were used. The preliminary simple model created by the training participants will be used as a starting point for modeling the aquifers of the Ararat artesian basin.

Trainees work on the developing the preliminary simple model for the Ararat Valley

Post-training activities

A training evaluation report was prepared by Alan Lemon, which also provides recommendations on the next steps of development, calibration and testing of the groundwater model for the Ararat Valley, and software needs. It is presented in Annex C.

Following the recommendations made by A. Lemon on the software needs for modeling Ararat Valley groundwater resources, ME&A purchased three sets of the licenses and software activation keys for the AHGW, GMS and MODFLOW. These will be used by the ASPIRED, EMIC and WRMA during development of the groundwater model for the Ararat Valley.

Starting in April 2018, the Aquaveo consultants team will be providing post-training distance coaching to the ASPIRED team and stakeholders in the process of developing and calibrating groundwater model for the Ararat Valley. This coaching will be provided via tele-conferencing. This will allow Aquaveo to share screens with ASPIRED personnel while discussing questions or challenges.

Annex A: Training Agenda

Stratigraphic and Groundwater Modeling with AHGW, GMS, and MODFLOW Training Course

January 15-19, 2018

Yerevan, Armenia

40 Marshal Baghramyan Avenue, #002 Computer Lab

Daily Schedule

DAY 1 – *COURSE INTRODUCTION/AHGW INTRODUCTION & GROUNDWATER ANALYST*

Time	Activity	Topic
9:00 – 10:00	ASPIRED Team Presentation	Presentation of Ararat Valley model and modeling objectives
10:00 – 11:00	Presentation	Course and Project Objectives 1- Introduction Introductory remarks Getting acquainted 2 - Intro to Geodatabases
11:00 –11:15	**Break**	
11:15 - 12:00	Presentation	3 - Overview of AHGW Data Model
12:00 – 1:00	Installations/ Workshop	Install AHGW 3.0 Workshop 1 - Building an AHGW geodatabase
1:00 – 2:00	**Lunch**	
2:00 – 3:00	Presentation	4 - Well & Time Series Data Aquifer feature class Well feature class Aquifers and Wells Surface water-Groundwater Time series tables and types Raster series Intro to Groundwater Analyst Import Wizard Make Time series Statistics Tool HydroIDs
3:00 – 4:15	Workshop	Workshop 2 - Well and Time series tutorial (AHGW tutorial, skip section 15)
4:15 – 4:30	**Break**	
4:30 – 5:00	Presentation	5 - Introduction to Model Builder
5:00 – 6:00	Workshop	Workshop 3 - Build model with Make Time Series Stat, Interpolation, & Add to Raster Series Create Animation

DAY 2 – AHGW SUBSURFACE ANALYST/GMS SUBSURFACE CHARACTERIZATION

Time	Activity	AHGW Topic	GMS Topic
9:00 – 9:45	Presentation	6 - Working with Borehole data	6b - 2D Geostatistics MODFLOW – Interpolating Layer Elevations
9:45 - 10:15	Workshop	Workshop 4 - Working with Borehole Data Tutorial *Optional – Workshop 5 – Working with Non-Vertical Borehole Data*	Workshop 4b - Defining Layer Data
10:15 – 10:45	Presentation	7 - Hydrostratigraphy component	
10:45 – 11:00	**Break**		
11:00 – 11:30	Workshop	Workshop 6 - Creating Georasters	
11:30 – 12:15	Presentation	8 - Building 3D models (Geosections & Geovolumes) GeoSection and GeoVolume	8b – Site Characterization via Horizons Horizons -> Solids Horizons -> HUF
12:15 – 1:00	Workshop	Workshop 7 - Building 3D Models with the Horizons Method Tutorial	Workshop 7b – Horizons Tutorial
1:00 – 2:00	**Lunch**		
2:00 – 2:30	Presentation	9 - XS2D Component XS2D Local Coordinate System \ Data Frame XS2D Feature Classes XS2D Catalog XS2D Wizard	9b - Site Characterization Borehole data User-defined cross-sections
2:30 – 3:45	Workshop	Workshop 8 - Creating 2D Cross Sections XS2D Wizard Editing cross sections GeoSection→XS2D XS2D -> GeoSection	Workshop 8b - Cross section Tutorial
3:45 – 4:00	**Break**		
4:00 – 4:15	Presentation	10 - Well Construction data Feature classes Model builder	
4:15 – 5 :00	Workshop	Workshop 9 - Well Construction data tutorial	
5:00 – 5:15	Presentation	11 - XS2D Images	
5:15 – 6:00	Workshop	Workshop 10 - XS2D Images	

DAY 3 – *GMS AND MODFLOW INTRODUCTION*

Time	Activity	Topic
9:00 - 9:30	Presentation	12 - GMS Introduction
9:30 – 10:15	Presentation	13 - Groundwater Modeling Concepts Conceptual Model Development, Boundary Conditions 2D vs. 3D, Steady State vs. Transient Parsimony, Code Selection, Model Calibration, Prediction
10:15 – 10:45	Presentation	14 - Modeling Case Studies
10:45 – 11:00	**Break**	

Time	Activity	Topic
11:00 – 12:00	Presentation	15 - MODFLOW – Part I Overview Basic, BCF-LPF-HUF-UPW, RCH, WEL, DRN Conductance
12:00 – 1:00	Workshop	Workshop 11 - MODFLOW - Grid Approach Workshop #1
1:00 - 2:00	**Lunch**	
2:00 –2:30	Presentation	16 - MODFLOW – Part II RIV, STR, SFR, GHB, HFB, EVT, ETS, MNW, UZF, DRT
2:30 – 3:30	Workshop	Workshop 12 - MODFLOW - Grid Approach Workshop #2
3:30 – 3:45	**Break**	
3:45 – 4:45	Presentation	17 - MODFLOW – Part III File formats, Importing models – ascii, VM, GW Vistas, PMWIN Exporting native text, Solvers Trouble shooting MODFLOW models MODFLOW – USG
4:45 – 6:00	Workshop	Workshop 13 (a or b) - MODFLOW – Importing, trouble shooting

DAY 4 – *GMS CONCEPTUAL MODEL APPROACH, CALIBRATION, AND TRANSPORT MODELING INTRODUCTION*

Time	Activity	Topic
9:00 – 9:45	Presentation	18 - GIS data Shapefiles, rasters, Projections
9:45 – 10:45	Presentation	19 - Working with Regional Models Base maps, Conceptual models, Conductance
10:45 – 11:00	**Break**	
11:00 – 12:15	Workshop	Workshop 14 (a, b, or c) – MODFLOW Conceptual Model Approach – pond, fault, lake (a), East Texas I (b), or East Texas II (c)
12:15 – 1:00	Presentation	20 - Model Calibration Importing Observation Well Data, Calibration basics, Point Observations, Flow Observations, Plotting calibration statistics
1:00 – 2:00	**Lunch**	
2:00 – 2:45	Workshop	Workshop 15 - Model Calibration Tutorial
2:45 – 3:00	**Break**	
3:00 – 3:45	Presentation	21 - Parameter Estimation with PEST Introduction to inverse modeling, Parameterization, Defining zones with key values, PEST options
3:45 – 4:30	Workshop	Workshop 16 - Automated Parameter Estimation Tutorial
	Take home calibration material	21a - Parameter Estimation – Pilot Points Presentation Workshop 17 - Pilot Points Tutorial
4:30 – 5:00	Presentation	22 - MODPATH Applications of Particle Tracking
5:00 – 6:00	Workshop	Workshop 18 - MODPATH Tutorial
	Take home transport modeling material	22a - Transport Modeling Concepts (Advection, Dispersion, Diffusion, Sorption, Decay) Presentation 22b - MT3DMS (Governing Equations, Packages) Presentation Workshop 19 (a and b) - MT3DMS Grid Approach Tutorial (a) and MT3DMS Conceptual Model Approach (b)

DAY 5 – GMS TRANSIENT MODELING, REVIEW, AND PROJECT WORK

Time	Activity	Topic
9:00 – 9:30	Presentation	23 - Transient MODFLOW Models
9:30 – 10:15	Workshop	Workshop 20 - Transient Tutorial
10:15 – 10:30	**Break**	
10:30 – 1:00	Project Work	Begin working on Ararat Valley model
1:00 – 2:00	**Lunch**	
2:00 – 3:30	Project Work	Begin working on Ararat Valley model
3:30 – 3:45	**Break**	
3:45 – 6:00	Project Work	Begin working on Ararat Valley model Discuss next steps

Annex B: List of Participants

Stratigraphic and Groundwater Modeling with AHGW, GMS, and MODFLOW Training Course

January 15-19, 2018

Yerevan, Armenia

40 Marshal Baghramyan Avenue, #002 Computer Lab

USAID ASPIRED Project		
1.	Benyamin Zakaryan	Hydrologist
2.	Aram Gevorgyan	Data Management Specialist
Ministry of Nature Protection of Armenia		
3.	Armine Hakobyan	Head of Hydrogeological Investigations and Monitoring Division, Environmental Monitoring and Information Center State non-commercial organization
4.	Harutyun Yeremyan	Head of Western Division of the National Network of Groundwater Monitoring, Environmental Monitoring and Information Center State non-commercial organization
5.	Gegham Muradyan	Head of Southern Division of the National Network of Groundwater Monitoring, Environmental Monitoring and Information Center State non-commercial organization
6.	Gayaneh Hovsepyan	Chief Specialist of the Water Resource Cadaster and Monitoring Division, Water Resources Management Agency
7.	Victoria Terteryan	Leading Specialist of the Water Use Permitting Division, Water Resources Management Agency
Academia and NGO		
8.	Aghavni Harutyunyan	GIS Specialist, GIS and Remote Sensing Lab, AUA Acopian Center for the Environment, AUA Center for Responsible Mining, American University of Armenia
9.	Avetiq Mnatsakanyan	Intern, International Agribusiness Teaching Center, Armenian National Agrarian University
10.	Artak Piloyan	Teaching GIS, Digital Cartography, Engineering Geomorphology, Yerevan State University
11.	Alexander Arakelyan	GIS Specialist, ERGIS NGO, Head of GIS Lab of Institute of Geological Sciences of the National Academy of Sciences of Armenia, Teaching GIS at the Digital Cartography, Engineering Geomorphology, Yerevan State University