



FREEWAT

Free and Open Source Software Tools for Water Resource Management
EU HORIZON 2020 Project

FREEWAT

FREE and open source software tools for
WATER resource management

Training material final version

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Abstract

This report describes the main features of the final version of the training material produced during the duration of the H2020 FREEWAT project. It consists in a set of lectures, tutorials and exercises prepared to demonstrate the FREEWAT platform capabilities. Previous versions of this training material have been delivered for performing Task 3.1. *Preliminary training* and Task 3.2. *Training the trainers*, in the framework of the Work Package 3 Capacity building. Further information on these activities can be found in Deliverable 3.3. The present version of the Training material has been finalised taking into account the various suggestions provided by the trainers and the trainees that participated in the aforementioned Tasks. All the training material is in English.

This report includes a set of Annexes detailing the training material for each of the developed FREEWAT modules. They are:

- Annex_A_self_training
 - Annex_A.1_gw_modeling
 - Annex_A.2_GGIS_GGMN
 - Annex_A.3_background_stampriet_aquifer
- Annex_B_akvaGIS
- Annex_C_calibration
- Annex_D_unsat_solute_transport
- Annex_E_vadose_transport
- Annex_F_heat_transport
- Annex_G_sw_intrusion
- Annex_H_particle_tracking
- Annex_I_rural_water_management
- Annex_J_lake_package
- Annex_K_OAT

A LINKEDIN User Group (EU H2020 FREEWAT) was created to build a FREEWAT Community of Users, and to date about 680 individuals are enrolled. FREEWAT LINKEDIN User Groups exist now also in Turkish, Ukrainian, Italian and Spanish. A FREEWAT User Group, conceived as a Q&A forum, a place where any user can post questions on FREEWAT usage and application, or reporting potential bugs, was created at the address:

https://groups.google.com/forum/?utm_medium=email&utm_source=footer#!forum/freewat-users-group

All the training material can be downloaded for free by registering at the website address: <http://www.freewat.eu/download-information>

1 Introduction

The present Deliverable provides a set of lectures, tutorials and exercises for the different modules of the FREEWAT platform.

This training material (including dedicated data files to run exercises) has been initially prepared to be distributed for testing and improving the knowledge of all the platform capabilities. Initial training material was designed for performing preliminary training activities included in *Task 3.1. Preliminary training*. This material included two MODFLOW lectures and three tutorials (with dedicated datasets) for dealing with the hydrological part of the platform. They were delivered starting from October 2015 to project partners, in order to allow them to gain confidence on the software instruments. Conversely from what stated in the Grant Agreement – Annex 1 Description of Action (Part A), distribution of training material prepared by IGRAC (related to the Global Groundwater Information System, GGIS, and Global Groundwater Monitoring Network, GGMM, web portals) was anticipated and shared with partners during Task 3.1 activities, instead of Task 3.2. Further training material was then developed on the remaining FREEWAT platform capabilities. Moreover, as far as the African context, a lecture about the background and current situation of the Stampriet aquifer based on the Governance of Groundwater Resources in Transboundary Aquifer (GGRETA) was prepared by UNESCO. This material has been extensively tested during the courses held in Task 3.2 *Training the trainers* at the premises of each case study partner (SSSA, UNESCO, METCENAS, AMALTEA, RT, IEI, ERU, NTUA/AMD, INHGA, PRN, UTARTU, TSNUK, BUGS, and IST-SUPSI). Training material was prepared by the FREEWAT STEERING group (SSSA, TEA, TUDA, IDAEA-CSIC) and IGRAC and IST-SUPSI.

The training material aims at helping the Users of the FREEWAT platform to test its capabilities for targeting water resource management issues. The training material has been improved in quality during the training phases (Task 3.1 and 3.2), according to the different suggestions provided by the trainers and the trainees who attended the aforementioned courses. The training material includes handouts and data for testing the different capabilities of the FREEWAT platform:

- Self-training tutorials (including two MODFLOW lectures, three exercises on groundwater flow modeling, two lectures about the GGIS and GGMM web portals, and a lecture about modeling of the Stampriet aquifer);
- AkvaGIS tutorial (for hydrochemical and hydrogeological analysis and interpretation);
- Calibration tutorial;
- tutorial on Solute Transport in the Unsaturated Zone using the USB module;
- tutorial on Solute Transport in the Unsaturated Zone using the UZT Package;
- Heat Transport tutorial;

- Saltwater Intrusion tutorial;
- Particle Tracking tutorial;
- tutorial on Water Resource Management in Rural Environment;
- Lake Package tutorial;
- Observation Analysis Tool (OAT) tutorial.

Please, notice that a detailed explanation of the different capabilities of the present FREEWAT version platform can be found in the Reference Manual (Volume 0) and in the six User Manuals (Volumes 1 to 6) as presented in Deliverable 2.9.

A LINKEDIN User Group (EU H2020 FREEWAT) was created to build a community of Users and Developers, and to date about 680 individuals are enrolled. FREEWAT LINKEDIN User Groups exist now also in Turkish, Ukrainian, Italian and Spanish.

A FREEWAT User Group was created at the address:

https://groups.google.com/forum/?utm_medium=email&utm_source=footer#!forum/freewat-users-group

The Group is conceived as a Q&A forum, a place where any user can post questions on FREEWAT usage and application, or reporting potential bugs.

2 Short descriptions of the tutorials

This Section provides a short presentation of the training material.

2.1 Self-training

Material for Self-training activities was mainly assembled taking stock from existing tutorials dealing with the hydrological part of the platform (already developed in the SID&GRID project and then modified during its porting in QGIS). They were reassembled, translated in English and presented to be compatible with the FREEWAT platform capabilities. In addition to that, two MODFLOW lectures were prepared. Also, as stated before, training material prepared by IGRAC (related to the Global Groundwater Information System, GGIS, and Global Groundwater Monitoring Network, GGMN, web portals) was distributed during Task 3.1 activities. At the beginning of the Self-training activities, partners were asked to reinforce their GIS capabilities using the QGIS desktop software (within which the FREEWAT platform is integrated) by performing the exercises provided in the QGIS User Manual (https://docs.qgis.org/2.2/en/docs/user_manual/).

2.1.1 Tutorial 0

The "*Modelling groundwater flow using FREEWAT – Tutorial 0*" teaches the use of some MODFLOW Packages for the simulation of pumping wells, distributed recharge and the hydraulic contact between a river and an aquifer system. The CHD MODFLOW Package is used as well to define specific boundary conditions. The tutorial is divided in two parts. The first part deals with definition of the conceptual model for the investigated hydrodynamic system and model setting during the first two Stress Periods. The second part deals with definition of the model setting during Stress Periods 3 and 4 and post-processing and analysis of the model budget. Model results are presented and discussed.

2.1.2 Tutorial 1

The "*Modelling groundwater flow using FREEWAT – Tutorial 1*" teaches the use of some MODFLOW Packages for the simulation of pumping wells, distributed recharge and evapotranspiration and the hydraulic contact between a river and a drain and an aquifer system. The CHD, WEL and GHB MODFLOW Packages are used as well to define specific boundary conditions. The tutorial is divided in two parts. The first part deals with definition of the conceptual model for the investigated hydrodynamic system and setting of the model geometry. The second part deals with definition of the above mentioned sink/source terms and boundary conditions and post-processing and analysis of the model budget. The concept introduced above is demonstrated taking into account a groundwater flow model

of the western part of the Lucca plain (Tuscany, Italy). Model results are presented and discussed.

2.1.3 Tutorial 2

The "*Modelling groundwater flow using FREEWAT – Tutorial 2*" teaches the use of some MODFLOW Packages for the simulation of pumping wells, distributed recharge and the hydraulic contact between a river and a drain and an aquifer system. The GHB and WEL MODFLOW Packages are used as well to define specific boundary conditions. The tutorial is divided in two parts. The first part deals with definition of the conceptual model for the investigated hydrodynamic system and setting of the model geometry. The second part deals with definition of the above mentioned sink/source terms and boundary conditions and post-processing and analysis of the model budget. The concept introduced above are demonstrated taking into account a groundwater flow model in the peri-urban area of Sant'Alessio, north of Lucca (Tuscany, Italy), for the simulation of an Induced RiverBank Filtration MAR (Managed Aquifer Recharge) scheme. Model results are presented and discussed.

2.1.4 MODFLOW lectures

Two MODFLOW lectures are provided ("*Modelling groundwater flow with MODFLOW: an introduction*" and "*Introduction to MODFLOW Packages*"). They present a brief summary of theory on groundwater hydrology with the goal of demonstrating the main characteristic and the basic concepts of MODFLOW. Extensive references and web-links are provided to facilitate the Users who are new to the application of MODFLOW and MODFLOW-related softwares. Most of the boundary conditions and flow packages are described. Finally, information on how to run MODFLOW is included.

2.1.5 GGIS-GGMN

Training material for the utilization of GGIS (Global Groundwater Information System) and GGMN (Global Groundwater Monitoring Network) has been prepared by IGRAC to be used in Workpackage 3 of the FREEWAT project. These two GIS-platforms, which are also web-based and open source, were developed to help sharing information and knowledge world-wide, necessary for the sustainable use and management of the groundwater resources. The training material contains an overview of the main functionalities of GGIS and GGMN and few exercises to allow professionals to understand how these platforms work. It also contains an exercise on the interaction between GGMN and QGIS. The main goal of this material is to present GGIS and GGMN to the FREEWAT Core Technical Groups (see Deliverable 3.1) and to disseminate these tools among potential Users.

2.1.6 Background on the Stampriet aquifer

The lecture "*Development of the Stampriet Transboundary Aquifer System (STAS) numerical model*" is available. It deals with providing an overview about the state of the art of the research activities conducted on the Stampriet Transboundary Aquifer System (STAS), in southern Africa. Some general information on the STAS area is reported (e.g., about climate, land use, landscapes). These are integrated by the conceptual model of the Stampriet aquifer system and by results and information retrieved from the GGRETA (Governance of Groundwater Resources in Transboundary Aquifers) project.

2.2 AkvaGIS (Hydrochemical and Hydrogeological Analysis Tools)

Tutorials and handouts are available to introduce the main capabilities of AkvaGIS. This module provides different instruments to analyze and interpret the hydrochemical and hydrogeological data.

To achieve this goal, different lectures and practical examples explain step by step all the actions and commands needed for: (1) entering hydrochemical and hydrogeological data into the AkvaGIS database, (2) visualizing, analyzing and interpreting the hydrochemical data, e.g. obtaining ionic balance calculations, chemical time-series analysis, correlation of chemical parameters, and calculation of various common hydrogeochemical diagrams (e.g., Stiff diagram), (3) generating maps of the spatial distributions of parameters and thematic maps for the parameters measured in the queried area and classified according to the threshold approach established by a given guideline (e.g., the WFD), (4) analyzing and visualizing different hydrogeological measurements, such as water level, for generating contour maps (e.g., piezometric maps).

2.3 Calibration

Training material related to sensitivity analysis and calibration teaches the use of the MODFLOW Observation packages (HOB and RVOB) as well as the capabilities of the implemented UCODE_2014 code for sensitivity analysis and calibration within the FREEWAT modelling platform. This includes:

- a lecture ("*UCODE_2014 in FREEWAT Model Sensitivity Analysis, Data Assessment, Calibration, and Uncertainty Evaluation – Lecture*") introducing the concepts and importance of model sensitivity analysis and calibration; it is explained how UCODE_2014 works and which statistics are calculated;

- an exercise ("*Model Sensitivity Analysis, Data Assessment, and Calibration – Tutorial*") showing how to perform sensitivity analysis, data assessment and calibration in FREEWAT and how to visualize the outputs. These capabilities are explained using an example groundwater model.

2.4 Solute Transport in the Unsaturated Zone using the USB module

The general aim of the "*Tutorial on solute transport: estimating the effect of sources in the unsaturated zone*" is to introduce some capabilities of the GIS-integrated FREEWAT platform devoted to solute transport in the unsaturated zone. To achieve this goal, the free and open source code MT3DMS is used jointly with MODFLOW. The specific objective is to show how the User can apply the tool USB (*Unsaturated Solute Balance*), integrated in FREEWAT, to estimate the effect of a prescribed source of contaminant (or tracer, in general), released at the ground surface. Due to rainwater infiltration, this contaminant can infiltrate through the vadose zone driven by vertical groundwater flow simulated by the UZF MODFLOW Packages, and eventually reaches the aquifer, where it spreads according to advective-dispersive mechanisms.

2.5 Solute Transport in the Unsaturated Zone using the UZT Package

The aim of the exercise "*Tutorial on solute transport through the vadose zone*" is to estimate the effect of a prescribed source of contaminant (or tracer, in general), released at the ground surface. Due to rainwater infiltration, this contaminant can infiltrate through the vadose zone, eventually reaching the aquifer, where it will spread according to advective-dispersive mechanisms. In particular, such a situation refers to a decommissioning area, where a soil contamination is detected. The complete removal of this contamination source took 90 days. The final goal is to assess that the contaminant plume (due to the pollutant leaching) did not spread to an adjacent area, which is going to host a new building block, whose construction will commence within 1 year. This simulation is done applying the UZT (Unsaturated Zone Transport) Package of the code MT3D-USGS, integrated in FREEWAT.

2.6 Heat Transport

The general aim of the "*Tutorial on heat transport*" is to introduce FREEWAT capabilities devoted to simulate heat transport in the subsurface. In particular, the exercise aims at investigating the effect of injecting warm water (25°C) in the aquifer, the latter having an initial temperature of 5°C. The numerical model is required to investigate how the injection/pumping cycle affects the thermal status of the aquifer, and if the effect of a

low-conductivity zone present in the site is enough to prevent the thermal “contamination” of the pumping well. This simulation shows the capability of using the MT3DMS code to study problems of heat transport in the saturated zone.

2.7 Saltwater Intrusion

The “*Simulating saltwater intrusion in coastal aquifers*” tutorial aims at introducing capabilities of the FREEWAT platform for the simulation of saltwater intrusion in coastal aquifers. To this scope, the exercise is inspired to a real case study located in the lower Cornia plain (central Italy), where the focus is on a coastal aquifer which has been overexploited during the past decades for drinking, irrigation and industrial purposes. A simplified version of a groundwater flow model developed within the LIFE REWAT project (www.liferewat.eu) is provided to be imported in QGIS. This sets the stage for further implementation of transport packages to simulated saltwater intrusion through the coast. The SEAWAT code is run to achieve this objective and the occurrence of saltwater intrusion is assessed at different depths.

2.8 Particle Tracking

The goal of the “*Tutorial on particle tracking*” is to introduce the application of the MODPATH code to run particle tracking simulations. In particular, the exercise deals with an area with a groundwater pumping station for drinking water supply connected to an established groundwater recharge system. The latter needs to be optimized to prevent groundwater contamination (particularly from the city center). The general aim of this tutorial is to present the use of MODPATH to estimate: (i) the location of the watershed divide in the eastern part of the model domain; (ii) the wells capture zone at the pumping station. Each one of these objectives is related to contamination zones (existing or potential) present in this area.

2.9 Water Resource Management in Rural Environment

The “*Simulating water management in agricultural catchments*” tutorial teaches the use of the Farm Process module integrated in MODFLOW-OWHM for the simulation of the conjunctive use of ground- and surface-water for water management purposes.

The tutorial is divided in two parts. The first part deals with definition of the conceptual model for the investigated hydrodynamic system and the import of an existing database with the groundwater flow model already set-up. The second part deals with the building of the water management scenario and post-processing and analysis of the model budget.

A lecture ("*Simulation Tools for Water Resource Management and Water Consumption Assessment in Rural Environment*") is further available to provide the basic concepts of the Farm Process in dealing with conjunctive use of ground- and surface-water.

2.10 Lake Package

The "*Lake Package*" tutorial teaches the use of the Lake MODFLOW Package within the FREEWAT modelling platform. In the first part, the tutorial introduces the concepts of the Lake Package and it describes the data input required to set up a model where large surface water bodies (i.e., lakes) are present. The second part introduces the conceptual model used for implementing the practical exercise and then guides the Users with a step by step approach through the creation and running of the model which includes 3 lakes. Finally, the model results are analyzed and discussed.

2.11 Observation Analysis Tool (OAT)

The "*Observation Analysis Tool (OAT)*" tutorial foresees the introduction of the theory and concepts used to design the OAT library and the execution of practical exercises conceived to demonstrate such module. The exercises show how to add, manage, process and compare time-series using the FREEWAT OAT interface. Data filling, stress period statistics, calculation of stream segment recharges, data resampling, calculation of river baseflow are only some of the processing capabilities that are explored analysing precipitation, discharge and head observation time-series.

3 Deviations from Work Plan

No significant deviations from the Grant Agreement have been envisioned. Conversely from what stated in the Grant Agreement –Annex 1 Description of Action (Part A), distribution of training material prepared by IGRAC (related to the Global Groundwater Information System, GGIS) was anticipated, and instead than in Task 3.2 it was shared with partners during Task 3.1 activities.

The Deliverable is enriched with Tutorials not foreseen in the GA, such as one additional tutorial on unsaturated zone flow modelling, one tutorial on heat transport in aquifers and one tutorial on particle tracking.

4 Conclusions

The present report describes the main features of the final version of the training material, a set of lectures, tutorials and exercises prepared to demonstrate the FREEWAT platform capabilities. This training material has been used in initial form for performing Task 3.1 *Preliminary training* and Task 3.2 *Training the trainers*, in the framework of the WP3 Capacity building. Suggestions provided by the trainers and the trainees who attended the aforementioned training activities helped in improving the quality of the material.

A set of Annexes, including training material for each of the developed FREEWAT modules, completes the Deliverable. A wide set of tutorials and handouts has been produced. These have been made freely available through the FREEWAT website since April 2017 (hence 6 months prior the end of the project), along with the up-to-date version of the FREEWAT plugin. The training material has been used in courses run within the Task 3.3 activities.

This material constitutes now a solid basis to allow FREEWAT exploitation at EU scale and beyond, as also described in Deliverable 3.3.

Please, notice that a detailed explanation of the different capabilities of the present FREEWAT version platform can be found in the Reference Manual (Volume 0) and in the six User Manuals (Volumes 1 to 6) as presented in Deliverable 2.9.

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Document History

- 28.07.2016 Release of v1.0 for Steering Group revision
- 29.07.2016 Release of v2.0 major revision following Steering Group suggestions
- 30.07.2016 Release of v2.1 formatting
- 31.07.2016 Release of v2.2 inclusion of tutorial list and conclusions
- 31.07.2016 Release of v2.3 minor revisions prior to deliverable submission
- 31.01.2017 Release of v2.4 Modified according to PO's and Reviewers' comments
- 03.02.2017 Release of v3.0 for deliverable submission
- 30.09.2017 Release of v3.1 Including tutorials on UZT package, heat transport and particle tracking
- 04.10.2017 Release of v3.2 Including tutorial on saltwater intrusion
- 18.10.2017 Release of final version v3.3 after Coordinator's review

Appendix A Self-training

Material related to Task 3.1 *Preliminary training* (also known as *Self-training* by project partners) can be found in the folder **Annex_A_self_training**. This includes the following folders:

Annex_A.1_gw_modeling

The latter includes material related to basic groundwater modeling concepts, in particular two MODFLOW lectures (folder *MODFLOW_lectures*) and three tutorials (folders *tutorial_0*, *tutorial_1* and *tutorial_2*).

The folder *MODFLOW_lectures* includes the following files:

- an introduction about the MODFLOW capabilities is reported in the "*Modelling groundwater flow with MODFLOW: an introduction*" lecture (file *MODFLOW_lecture_1_v1.3.pdf*);
- conceptualization of MODFLOW Packages is reported in the "*Introduction to MODFLOW Packages*" lecture (file *MODFLOW_lecture_2_v1.3.pdf*).

The folder *tutorial_0* includes the following sub-folders and files:

- a demonstration of the capabilities of the MODFLOW RIV, WEL, RCH and CHD Packages is reported in the "*Modelling groundwater flow using FREEWAT – Tutorial 0 – Part A*" and "*Modelling groundwater flow using FREEWAT – Tutorial 0 – Part B*" tutorials (files *tutorial_0_part_a_v2.5.pdf* and *tutorial_0_part_b_v2.5.pdf*);
- *input_data* sub-folder contains files needed to perform the "*Modelling groundwater flow using FREEWAT – Tutorial 0 – Part A*" and "*Modelling groundwater flow using FREEWAT – Tutorial 0 – Part B*" tutorials;
- *bin* sub-folder:
 - *mf2005.exe* is the MODFLOW-2005 executable needed to run the simulation scenarios set in the "*Modelling groundwater flow using FREEWAT – Tutorial 0 – Part A*" and "*Modelling groundwater flow using FREEWAT – Tutorial 0 – Part B*" tutorials.

The folder *tutorial_1* includes the following sub-folders and files:

- a demonstration of the capabilities of the MODFLOW RIV, DRN, WEL, RCH, EVT, GHB and CHD Packages is reported in the "*Modelling groundwater flow using FREEWAT – Tutorial 1 – Part A*" and "*Modelling groundwater flow using FREEWAT – Tutorial 1 – Part B*" tutorials (files *tutorial_1_part_a_v2.5.pdf* and *tutorial_1_part_b_v2.5.pdf*);

- **input_data** sub-folder contains files needed to perform the "*Modelling groundwater flow using FREEWAT – Tutorial 1 – Part A*" and "*Modelling groundwater flow using FREEWAT – Tutorial 1 – Part B*" tutorials;
- **bin** sub-folder:
 - **mf2005.exe** is the MODFLOW-2005 executable needed to run the simulation scenario set in the "*Modelling groundwater flow using FREEWAT – Tutorial 1 – Part A*" and "*Modelling groundwater flow using FREEWAT – Tutorial 1 – Part B*" tutorials.

The folder **tutorial_2** includes the following sub-folders and files:

- a demonstration of the capabilities of the MODFLOW RIV, DRN, WEL, RCH, GHB and CHD Packages and the Zone Budget is reported in the "*Modelling groundwater flow using FREEWAT – Tutorial 2 – Part A*" and "*Modelling groundwater flow using FREEWAT – Tutorial 2 – Part B*" tutorials (files **tutorial_2_part_a_v2.4.pdf** and **tutorial_2_part_b_v2.4.pdf**);
- **input_data** sub-folder contains files needed to perform the "*Modelling groundwater flow using FREEWAT – Tutorial 2 – Part A*" and "*Modelling groundwater flow using FREEWAT – Tutorial 2 – Part B*" tutorials;
- **bin** sub-folder;
 - **mf2005.exe** and **zonbud.exe** are the MODFLOW-2005 and Zone Budget executables needed to run the simulation scenarios set in the "*Modelling groundwater flow using FREEWAT – Tutorial 2 – Part A*" and "*Modelling groundwater flow using FREEWAT – Tutorial 2 – Part B*" tutorials.

Annex_A.2_GGIS_GGMN

The latter includes the folder **GGIS-GGMN**, where two lectures about the GGIS and GGMN platforms can be found (files **GGIS_GGMN_handouts_v.2.pdf** and **GGIS_GGMN_training.pdf**).

Annex_A.3_background_stampriet_aquifer

The latter includes the pdf file **background_stampriet_aquifer.pdf**, providing an overview about the state of the art of the research activities conducted on the Stampriet Transboundary Aquifer System (STAS), in southern Africa.

Appendix B AkvaGIS (Hydrochemical and Hydrogeological Analysis Tools)

Material related to the AkvaGIS module can be found in the following folder:

Annex_B_akvaGIS

The latter includes the following sub-folders and files:

- **Lecture_1** sub-folder
 - an introduction about the AkvaGIS module is reported in the "*AkvaGIS*" lecture (file *Lecture1_v6.pdf*);
- **Lecture_2** sub-folder
 - a demonstration of the hydrochemical analysis tools is reported in the "*AkvaGIS Hydrochemical Tools*" tutorial (file *Lecture2_v6.pdf*);
 - *akvaGIS.sqlite* is an sqlite file needed to perform the "*AkvaGIS Hydrochemical Tools*" tutorial;
 - **Ex4.1** and **Ex4.2** sub-folders contain csv files needed to perform the "*AkvaGIS Hydrochemical Tools*" tutorial;
- **Lecture_3** sub-folder
 - a demonstration of the hydrogeological analysis tools is reported in the "*AkvaGIS Hydrogeological Tools*" tutorial (file *Lecture3_v6.pdf*);
 - **Ex1** sub-folder contains csv files needed to perform the "*AkvaGIS Hydrogeological Tools*" tutorial.

Appendix C Calibration

Material related to the Calibration module can be found in the following folder:

Annex_C_calibration

The latter includes the following sub-folders and files:

- a demonstration of the sensitivity analysis and calibration tools is reported in the "*Model Sensitivity Analysis, Data Assessment, and Calibration - Tutorial*" tutorial (file *UCODE_Ex1_v3.0.pdf*);
- concepts and theory needed to perform properly the calibration training are described in "*UCODE_2014 in FREEWAT Model Sensitivity Analysis, Data Assessment, Calibration, and Uncertainty Evaluation - Lecture*" Lecture (file *UCODE_Lecture_v3.0.pdf*);
- *t1_ucode_tutorial* sub-folder:
 - *t1_ucode.sqlite* is an sqlite file needed to perform the "*Model Sensitivity Analysis, Data Assessment, and Calibration - Tutorial*" tutorial;
 - *input_data* sub-folder contains files needed to perform the "*Model Sensitivity Analysis, Data Assessment, and Calibration - Tutorial*" tutorial;
- *bin* sub-folder:
 - *mf2005.exe* and *ucode_2014.exe* are the MODFLOW-2005 and UCODE_2014 executables needed to run the simulation scenarios set in the "*Model Sensitivity Analysis, Data Assessment, and Calibration - Tutorial*" tutorial;

Appendix D Solute Transport in the Unsaturated Zone using the USB module

Material related to solute transport in the unsaturated zone using the USB module can be found in the following folder:

Annex_D_unsat_solute_transport

The latter includes the following sub-folders and files:

- an introduction about the MODFLOW UZF Package is reported in the "*Unsaturated-Zone Flow (UZF1) Package for Modeling Unsaturated Flow Between the Land Surface and the Water Table*" lecture (file *Unsaturated_Zone_Flow_UZF_Package_v4.pdf*);
- a demonstration of the tools for simulation of solute transport process is reported in the "*Tutorial on solute transport: estimating the effect of sources in the unsaturated zone*" tutorial (file *tutorial_unsat_solute_transport_v4.pdf*);
- *input_data* sub-folder contains files needed to perform the "*Tutorial on solute transport: estimating the effect of sources in the unsaturated zone*" tutorial;
- *bin* sub-folder:
 - *mf2005.exe* and *mt3dms5b.exe* are the MODFLOW-2005 and MT3DMS executables needed to run the simulation scenario set in the "*Tutorial on solute transport: estimating the effect of sources in the unsaturated zone*" tutorial.

Appendix E Solute Transport in the Unsaturated Zone using the UZT Package

Material related to solute transport in the unsaturated zone using the UZT Package can be found in the following folder:

Annex_E_vadose_transport

The latter includes the following sub-folders and files:

- a demonstration of the tools for simulation of solute transport process is reported in the "*Tutorial on solute transport through the vadose zone*" (file *tutorial_transport_in_vadose_zone_v4.pdf*);
- *vadose.sqlite* is an sqlite file needed to perform the "*Tutorial on solute transport through the vadose zone*";
- *input_data* sub-folder contains files needed to perform the "*Tutorial on solute transport through the vadose zone*";
- *bin* sub-folder:
 - *MODFLOW-NWT.exe* and *MODFLOW-NWT_64.exe* , *MT3D-USGS_32.exe* and *MT3D-USGS_64.exe* are the MODFLOW-NWT and MT3D-USGS executables needed to run the simulation scenario set in the "*Tutorial on solute transport through the vadose zone*".

Appendix F Heat Transport

Material related to heat transport simulation can be found in the following folder:

Annex_F_heat_transport

The latter includes the following sub-folders and files:

- a demonstration of the tools for simulation of heat transport is reported in the "*Tutorial on heat transport*" (file *tutorial_heat_transport_v2.pdf*);
- *input_data* sub-folder contains files needed to perform the "*Tutorial on heat transport*";
- *bin* sub-folder:
 - *mf2005.exe* and *mt3dms5b.exe* are the MODFLOW-2005 and MT3DMS executables needed to run the simulation scenario set in the "*Tutorial on heat transport*".

Appendix G Saltwater Intrusion

Material related to simulation of saltwater intrusion can be found in the following folder:

Annex_G_sw_intrusion

The latter includes the following sub-folders and files:

- a demonstration of the tools for simulation of the saltwater intrusion phenomenon is reported in the "*Simulating saltwater intrusion in coastal aquifers*" tutorial (file *tutorial_sw_v1.2.pdf*);
- ***sw.sqlite*** is an sqlite file needed to perform the "*Simulating saltwater intrusion in coastal aquifers*" tutorial;
- ***bin*** sub-folder:
 - ***mf2005.exe*** , ***swt_v4.exe*** and ***swt_v4x64.exe*** are the MODFLOW-2005 and SEAWAT executables needed to run the simulation scenario set in the "*Simulating saltwater intrusion in coastal aquifers*" tutorial.

Appendix H Particle Tracking

Material related to Particle Tracking module can be found in the following folder:

Annex_H_particle_tracking

The latter includes the following sub-folders and files:

- a demonstration of the tools for simulation of particle tracking is reported in the "*Tutorial on particle tracking*" (file *particle_tracking_tutorial_v2.pdf*);
- *particle_tracking.sqlite* is an sqlite file needed to perform the "*Tutorial on particle tracking*";
- *input_data* sub-folder contains files needed to perform the "*Tutorial on particle tracking*";
- *bin* sub-folder:
 - *mf2005.exe* and *mp6.exe* are the MODFLOW-2005 and MODPATH executables needed to run the simulation scenario set in the "*Tutorial on particle tracking*".

Appendix I Water Resource Management in Rural Environment

Material related to the Farm Process module can be found in the following folder:

Annex_I_rural_water_management

The latter includes the following sub-folders and files:

- an introduction to the water management capabilities in the rural environment using the Farm Process module is reported in the "*Simulation Tools for Water Resource Management and Water Consumption Assessment in Rural Environment*" lecture (file ***farm_theory_v2.1.pdf***);
- a demonstration of the tools for water management purposes is reported in the "*Simulating water management in agricultural catchments*" tutorial (file ***tutorial_farm_v3.2.pdf***);
- ***farm.sqlite*** is an sqlite file needed to perform the "*Simulating water management in agricultural catchments*" tutorial;
- ***input_data*** sub-folder contains files needed to perform the "*Simulating water management in agricultural catchments*" tutorial;
- ***bin*** sub-folder:
 - ***mf2005.exe*** , ***MF_OWHM_Win32.exe*** and ***MF_OWHM.exe*** are the MODFLOW-2005 and MODFLOW-OWHM executables needed to run the simulation scenario set in the "*Simulating water management in agricultural catchments*" tutorial.

Appendix J Lake Package

Material related to the MODFLOW LAK Package can be found in the following folder:

Annex_J_lake_package

The latter includes the following sub-folders and files:

- a demonstration of the capabilities of the MODFLOW LAK Package is reported in the "*Lake Package*" tutorial (file *Lake_tutorial_v1.9.pdf*);
- *input_data* sub-folder contains files needed to perform the "*Lake Package*" tutorial (it includes also the sqlite file *tlake.sqlite*);
- *bin* sub-folder:
 - *mf2005.exe* is the MODFLOW-2005 executable needed to run the simulation scenario set in the "*Lake Package*" tutorial.

Appendix K Observation Analysis Tool (OAT)

Material related to the OAT module can be found in the following folder:

Annex_K_OAT

The latter includes the following sub-folders and files:

- a demonstration of the capabilities of the OAT module is reported in the "*Observation Analysis Tool (OAT)*" tutorial (file *OAT_tutorial_v1.6.pdf*);
- *input_data* sub-folder contains files needed to perform the "*Observation Analysis Tool (OAT)*" tutorial.