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Software tools for sustainable water resources management: the GIS-integrated FREEWAT platform

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ABSTRACT

This paper aims at presenting the open source and public domain FREEWAT platform capabilities for water resource management, including: (i) pre-processing modules to facilitate the preparation of input data, (ii) modelling tools for the analysis of several processes aimed at supporting water resource management, and (iii) post-processing tools to present results.

The FREEWAT platform is based on open source solutions to perform an integrated coupling between the QGIS desktop software, surface and subsurface model engines, mostly based on fully distributed and numerically-based codes developed by the USGS, and other software applications, and the SpatiaLite spatial database. The development of the FREEWAT platform was supported by the main needs and priorities expressed by relevant stakeholders from the water sector involved in the early stage of the project.

Extensive testing on the platform is still going on and training material and six User Manuals were prepared to disseminate its use as a standard software for managing surface/sub-surface water quantity and quality dynamics under demand-driven and supply-constrained conditions. The testing phase also includes demonstration of the platform capabilities on 14 case studies at European scale and beyond, to address specific water management issues. Nine of them are devoted to the application of EU water-related Directives, while the others address water management issues in the rural environment under the requirements of EU and/or national/local regulations. Beyond software testing, this demonstration is thought as an experiment on involving stakeholders in the formation of water plans yet during the technical phase of the analysis.

KEYWORDS: FREEWAT, QGIS, FOSS, rural water management, MODFLOW, conjunctive use of surface- and ground-water

INTRODUCTION

Simulation techniques along with tools for geospatial data analysis may contribute to proper management of widespread conjunctive use of surface- and ground-water resources, also to avoid conflicts among different users and maintenance of agro-ecosystems (Rossetto et al., 2013). As such, the development of innovative software tools for water management issues is of paramount importance, also in view of a proper application of the EU Water Framework Directive (EU, 2000) and other water related directives.

FREEWAT (FREE and open source software tools for WATer resource management; Rossetto et al., 2015) is a EU HORIZON 2020 project aiming at promoting the application of EU water-related Directives by: i) developing a dedicated free and open-source platform GIS-integrated solution for planning and management of surface- and ground-water resources, ii) performing extensive capacity building activities, and finally iii) applying the developed platform to 14 case studies along with a dedicated participatory approach.

The development of the FREEWAT platform was supported by the result of a survey performed in the first phase of the project to draw up an evaluation grid for modules to be integrated in the developing FREEWAT platform, by intersecting needs/priorities related to water management issues and availability of software tools to address such issues. Questionnaires were distributed to 14 case study FREEWAT project partners and several stakeholders, from research institutions, governmental authorities, geoenvironmental companies and river basin authorities in EU and non-EU Countries. Identified priorities refer to management of water in the rural environment (including management of agrochemicals) and tools and methods for sustainable management of ground-water in terms of quality and quantity. Several needs are then related directly or indirectly to conjunctive use of surface- and ground-water management, and interaction between ground-water/surface-water bodies. Needs and priorities were also linked to related specific EU Directives and Regulations. Priorities were then addressed during the development phase of the FREEWAT platform

FREEWAT CAPABILITIES

The FREEWAT platform is at present a large QGIS (QGIS Development Team, 2009) plugin, allowing to couple the power of GIS geo-processing and post-processing tools in spatial data analysis with that of process-based simulation models (mostly benefitting from codes of the USGS family; Fig. 1). As such, the FREEWAT platform is conceived as a canvas, where several codes for the simulation of the hydro-

logical cycle, hydrochemical or economic-social processes, are integrated in the QGIS desktop. Input and output data is managed through the SpatiaLite (SpatiaLite Development Team, 2011) Data Base Management System. Up to now, the FREEWAT platform includes 6 modules for data pre-processing and model implementation (Fig. 2).

The AkvaGIS module provides several tools for the analysis and interpretation of hydrochemical and hydrogeological data. The capabilities of the AkvaGIS module span from plots and statistics related to hydrochemical data for ground-water quality assessment to interpretation of hydrogeological data and generation of thematic maps for implementation of conceptual models.

The Observation Analysis Tool (OAT) is a pre-processing tool to provide the user with enhanced time-series processing capabilities, in view of an increasing establishment of diffuse, online and real-time monitoring networks. OAT is designed to facilitate the import, analysis and visualization of time-series data and the use of these data to support model construction and advanced model calibration.

Groundwater flow simulation in aquifers may be performed using MODFLOW-2005 (Harbaugh, 2005), a physically-based, spatially distributed code developed by USGS, which simulates the groundwater flow dynamics in the saturated and unsaturated zones. Flow associated to wells, areal recharge, evapotranspiration, drains, and surface water bodies, can be simulated through specific MODFLOW Packages, among which the Lake Package (Merritt & Konikow, 2000) is worth of mention for the simulation of lake-aquifer interaction.

In FREEWAT, the hydrological model can be coupled with a solute transport model, to simulate multi-species advective-dispersive transport, in the saturated zone, using MT3DMS (Zheng & Wang, 1999). The possibility to simulate 1D solute transport within the unsaturated zone is achieved so far by the USB module. The integration in FREEWAT of the code SEAWAT (Langevin et al., 2007) allows to simulate viscosity- and density-dependent flows. Such capabilities are particularly relevant to approach seawater intrusion processes or to assess geothermal plants at low and medium enthalpy.

Water resource management is accomplished by integrating MODFLOW-OWHM (One-Water Hydrologic Flow Model; Hanson et al., 2014). Within it, the Farm Process allows to dynamically simulate demand and supply components of water use for basic units of water consumption. A fully-coupled, integrated hydrologic model is so obtained, with estimation of water allocations from conjunctively used surface- and ground-water. Rural water management may be then performed by defining "farms" and providing rules for water supply.

The UCODE_2014 (Poeter et al., 2014) is implemented to perform sensitivity analysis and parameter estimation is based on and aims at improving the model fit, by reducing the gap between model-simulated heads and flows and the observed data. To accomplish this task, several statistics can be used to evaluate model construction and to select parameters to be estimated through an inverse, regression method based on the evaluation of an objective function.

PLATFORM TESTING AND APPLICATION

The development of the platform included testing of the above-mentioned pre-processing and simulation modules. To this purpose a set of tutorials and six User Manuals were prepared to disseminate its use as a standard software for managing surface/sub-surface water quantity and quality dynamics. Tutorials and handouts include: 1) tutorials about the application of MODFLOW-2005 to simulate the groundwater dynamics, 2) lectures reporting the basic concepts of MODFLOW, 3) tutorials and handouts for each of the aforementioned modules.

Training the Trainers activities were run in 14 countries. These courses were intended: 1) to demonstrate all the platform capabilities and its potential application to each case study, 2) to serve as testing phase as functionalities implementation was completed, and 3) to serve as the basis for building capacities at national level in further phases of this project. About 100 persons from 60 institutions (from Europe, Africa and US) were trained. during the courses, several suggestions and feedbacks were collected. They have been taken into account for the release of the present FREEWAT version 0.1 (July 31st 2016).

The FREEWAT platform is now applied to fourteen case studies in EU and non-EU Countries, to address specific water management issues. Such case studies may be divided in two clusters (Fig. 3):

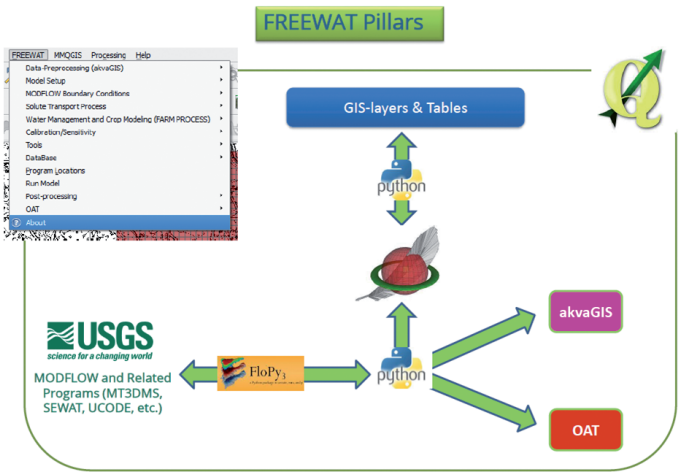

Fig. 1 - FREEWAT platform pillars.

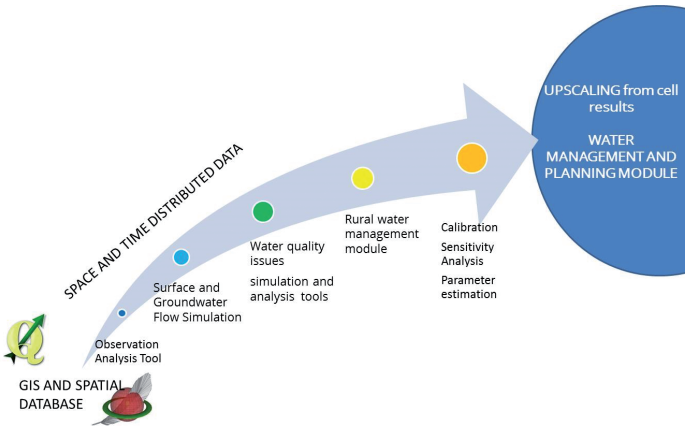

Fig. 2 - FREEWAT platform architecture.

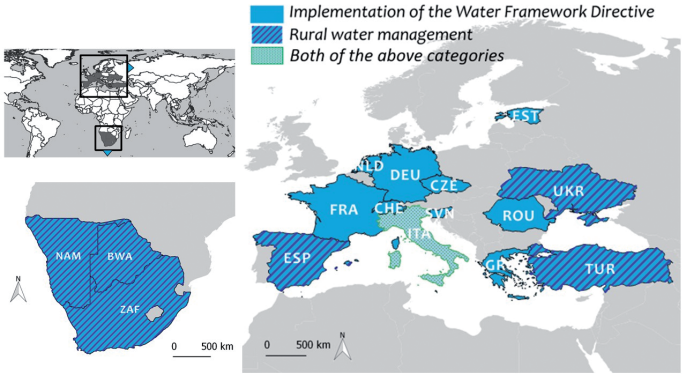

Fig. 3 - Main topic and geographical setting of the 14 case studies where the FREEWAT platform is under testing and application.

- nine case studies (eight in EU Countries and one in Switzerland) are specifically focused on the application of the Water Framework Directive, Ground Water Directive and other water-related Directives on selected issues. Links to the application of EU water related directives are established, in example, by testing the feasibility of measures foreseen by the programmes of measures that each basin authority has set for achieving the environmental objectives of the Water Framework Directive cost-effectively. Among these, the following topics are dealt with: seawater intrusion processes, groundwater pumping zones allocation, transboundary water bodies, groundwater dependant ecosystems;
- five case studies (two in EU Countries, one in Ukraine, one in Turkey and one in Africa) are devoted to address water management issues in the rural environment under the requirements of the EU and/or national/local regulations. Issues dealt with in these case studies are about reducing water consumption in irrigation areas, reducing nitrates pollution of groundwater.

At each case study the technical part will be run conjunctively and at the same time with the participatory approach. Seven Focus Group meetings on the use of software in water management and the application of the FREEWAT approach are run at each case study. This will constitute a large experiment on involving stakeholders in the formation of water plans yet during the technical phase.

CONCLUSIONS

The development of an open source and public domain, GIS-integrated, fully distributed and numerically-based suite dedicated to water management may constitute an advancement in the water resource management sector. The efforts run in the HORIZON 2020 FREEWAT project, at European scale and beyond, strongly push towards this direction.

The FREEWAT platform is designed for water authorities and public/private companies to build a high informative and dynamically growing representation of hydrologic systems, taking into account the large amount of data nowadays available. The FREEWAT platform unites the power of GIS geo-processing and post-processing tools (including management and visualisation) for the analysis of spatial data to that of simulation software. In this way, the use of third-party software and, i.e., data redundancy and data-broken flows is avoided.

This constitutes the chance for public authorities to build a high informative and dynamically growing representation of a hydrologic system (i.e., river basin) where performing data storage and planning analysis.

Policy makers may benefit from its application following the proposed participatory approach to perform scientifically and technically sounding decision-making.

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