Open Source for Water Management: including capabilities of MODFLOW-OWHM in the FREEWAT GIS modelling environment

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Abstract:

FREEWAT is an ongoing GIS environment to serve as pre- and post-processor for running simulations of surface-/groundwater interaction, with the possibility to activate several features accounting for the different water stresses. This paper reports the capability related to address water resource management problems, by activating management tools available in the MODFLOW-OWHM code. The latter is integrated in FREEWAT, which appears as composite plugin of the well-know QGIS software (QGIS, 2016). Therefore, all the necessary pre- and post-process procedures can be run effectively within QGIS, also in conjunction with the several tools for GIS analysis already included in QGIS. It turns out a simple and intuitive user interface to manage the simulation of complex problem in which the mutual interaction among surface waters, groundwaters and anthropic water demand/supply terms can be handled. The development phase of such tools is already at an advanced stage, while next work will be focused on producing real-world applications to serve as tutorial for interest Users.

Introduction:

FREEWAT is an HORIZON 2020 project financed by the EU Commission, aiming at promoting water resource management by simplifying the application of the Water Framework Directive and other EU water related Directives (Rossetto et al., 2015). FREEWAT main result will be an open source and public domain GIS integrated modelling environment for the simulation of water quantity and quality in surface water and groundwater with an integrated water management and planning module, the latter being the topic described in this paper. The FREEWAT modelling environment is implemented as a plugin of the open source software QGIS as a desktop interface, it takes advantage of Spatialite as a geodatabase management system and FloPy (Bakker et. al., 2016) as reference python library to connect with hydrological codes, particularly MODFLOW-2005 (Harbaugh, 2005).

Background:

FREEWAT includes capabilities to address water resource management. The specific goal is to exploit the output of a numerical simulation to solve problems of water delivery control and optimization.

Conjunctive use of water is the joint usage and management of surface- and groundwater resources to meet required water demand and minimize potential damage to the quantity or quality of the resource. To get an effective representation of conjunctive use of surface and subsurface water, it is necessary to integrate simulation methods for subsurface, surface, and urban and agricultural water-demand computations. Furthermore, these models have to take into account the cases where there is not enough water supply to meet the total water demand, and propose possible management strategies.

To simulate water management, FREEWAT applies of the MODFLOW-OWHM (Hanson et al., 2014), which can be used also to include the specific computation of water demand coming from rural environments and crops acreage. This approach has been tested in several water management applications, as documented in Faunt (2009) and Hansons et al. (2010), for instance. It allows an effective planning of long-term water resources uses and management of short-term water resources allocation.

Method:

Water Demand Units

The basic concept in MODFLOW-OWHM is the Water Demand Unit (WDU), namely any "entity" consuming water (urban zone, industrial zone, farms, rural areas, natural vegetation areas, etc.). At each WDU the User can associate one or more source/sink of water (i.e. demand or supply terms), varying in time. At the end of the simulation, a specific budget for each WDU is produced in addition to the global budget for the entire model. A WDU is a model sub-region, made by a cluster of cells of the first model layer (top layer). Thus, the whole grid is classified in one or more WDU by assign to each cell a WDU ID.

Terms of Water Demand and Supply

For each WDU, a total water demand is input or computed, with the possibility to account of several ways for defining different terms of water demand, namely:

- Crops water demand (in case of agricultural areas or natural vegetation areas are modeled). This demand is computed as ET representing the target crop consumptive use to meet. Defining such water demand term is essential whenever an agricultural/irrigation problem is addressed. However, the entity "crop" can represent not only real crops, but also any land-use type (urban environment, water bodies, etc.) which are defined as "virtual crops" (Hanson et al., 2014).
- Municipal and industrial urban water demand is user-specified as "negative supplies" (specified as non-routed deliveries, see later on).
- The Total Delivery Requirement is defined as the portion of crop demand that is not met by precipitation and uptake from groundwater, increased by the inefficiency losses from irrigation.

For each WDU, for each stress period, the code attempts to satisfy the Total Delivery Requirement with one or more delivery terms, according to the following ranking:

- 1st priority by water transfer to/from a WDU from several kinds of sources, without simulating the process of conveyance.
- 2nd priority by water transfer to/from a WDU through a streamflow-routing network or specifying diversion points from the main channel. The streamflow-routing network is simulated through the SFR package in MODFLOW (Niswonger and Prudic, 2010).
- 3rd priority: ground-water pumping (wells) necessary to satisfy the total delivery requirement.

Constraints on water supply

FREEWAT's User has the possibility to specify, for each WDU, surface- or groundwater allotments, to represent water-rights. Allocation constraints representing water-rights hierarchies can be imposed as surface-water allotments. Furthermore, the simulation of a groundwater allotment for each WDU is also possible. Each allotment can represent any kind of physical or governance limit, such as a groundwater right or a transboundary operating agreement. Within a WDU, groundwater allotments refer to the entire WDU. In the meantime, for each well associated to a WDU, the User imposes a maximum for the pumping rate. This is an additional option to impose specific water rights to a single WDU, but associated to a specific location.

Optimization algorithms in case of Deficit Scenario

Once the water demand and supply have been computed (for each stress period), taking into account possible constraints on surface- or groundwater delivery, the code compares the two terms Demand and Supply.
If Demand is greater than Supply, than that WDU is in a deficit scenario. In this case, the code allows estimating optimal distributions of supply components to cope with this deficit

Implementation in FREEWAT

Water management capabilities of FREEWAT can be applied once the hydrological model (say the standard MODFLOW model) has been set up and run. Then, the User can proceed to input the information needed to run management tools in MODFLOW-OWHM. More in detail, the following steps are needed:

1. Defining the classification of the model domain in WDUs
2. Setting the properties for each WDUs (efficiency, water delivery costs, water allotments, etc.)
3. Linking the model wells (if any) to WDUs, including for each of them a maximum value for the pumping rate.
4. Linking pipeline diversions to WDUs (if any): this procedure defines the semi-routed water delivery associated with selected WDUs.
5. Defining soils and crops distribution on the top model grid.
6. Defining soils properties, for each soil defined in the previous step: capillary fringe value.
7. Defining crops properties, for each crop defined in the previous step, such as irrigation and ET losses efficiency coefficients, profits from crop production, crop coefficient, root depth, etc.
8. Setting precipitation and reference evapotranspiration data
9. Selecting model options and run the model (*Fig. 3*)

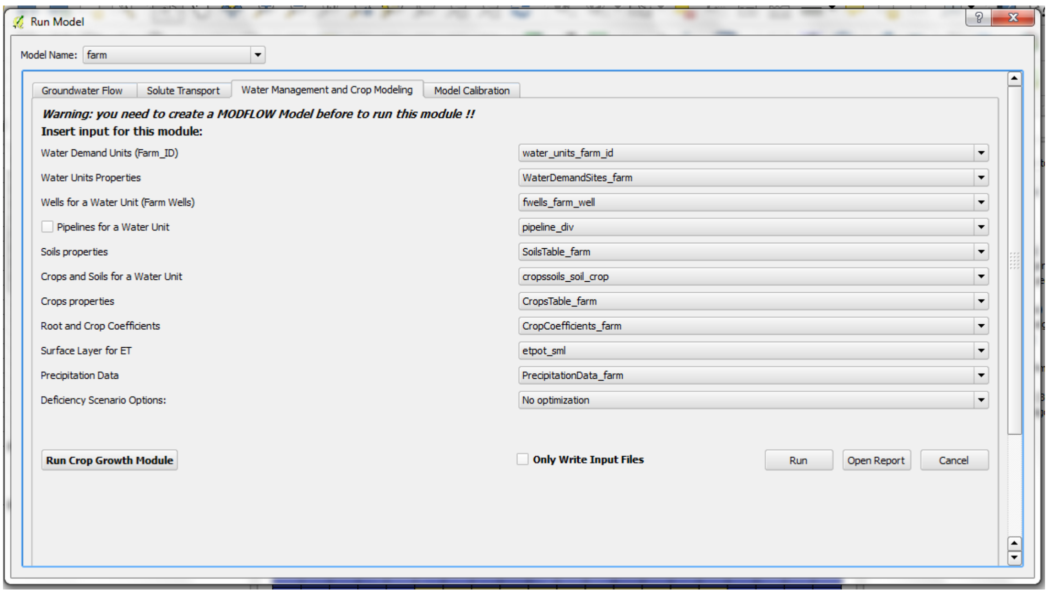

Figure 3: Screen shot of the GUI to run the Water Management capabilities in FREEWAT

10. Analyzing the WDUs budget by plotting results printed in MODFLOW-OWHM output files (*FREEWAT > Post-processing > Plot budgets for Water Unit*).

Conclusions

Including a water management module in FREEWAT modeling platform added a great value to the platform itself: as in fact, the powerful GIS desktop software QGIS could be used as interface to run water management tools belonging to a unique modeling framework for water resource management. Such simulation tools are based on the well-known and worldwide tested code MODFLOW-OWHM, guarantee a good scientifically accuracy to the modeling platform.

Acknowledgements:

This paper is presented within the framework of the project FREEWAT, which has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n. 642224.

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