

FREEWAT

Free and Open Source Software Tools for Water Resource Management

EU HORIZON 2020 Project

FREE and Open Source Software Tools for WATer Resource Management

FREEWAT User Manual

Volume 3

Water management and crop-growth modeling

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This version is confidential, only for FREEWAT Project Partners



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FOREWORD

FREEWAT is an HORIZON 2020 project financed by the EU Commission under the call WATER INNOVATION: BOOSTING ITS VALUE FOR EUROPE. FREEWAT main result is an open source and public domain GIS-integrated modeling environment for the simulation of water quantity and quality in surface water and groundwater with an integrated water management and planning module. Specific objectives of the FREEWAT project are: to coordinate previous EU and national funded research to integrate existing software modules for water management in a single environment into the GIS-based FREEWAT platform and to support the FREEWAT application in an innovative participatory approach, gathering technical staff and relevant stakeholders in designing scenarios for the proper application of water policies.
The open source characteristics of the platform allow to consider this an initiative "ad includendum", as further research institutions, private developers etc. may contribute to the platform development. Capabilities integrated in FREEWAT are:

- a dedicated module for water management and planning;
- a whole module for calibration, uncertainty and sensitivity analysis;
- a module for solute transport in the unsaturated zone;
- a module for crop growth and rural water management;
- a module dedicated to time-series processing to support advanced model calibration;
- tools for dealing with groundwater quality issues;
- tools for the analysis, interpretation and visualization of hydrogeological data.

FREEWAT Development has received funding from the following projects:

1. Hydrological part has been developed starting from a former project, named SID&GRID, funded by Regione Toscana through EU POR-FSE 2007-2013 (sidgrid.isti.cnr.it).
2. Porting of SID&GRID under QGIS has been performed through funds provided by Regione Toscana to Scuola Superiore S.Anna - Project Evoluzione del sistema open source SID&GRID di elaborazione dei dati geografici vettoriali e raster per il porting negli ambienti QGIS e Spatialite in uso presso la Regione Toscana (CIG: ZA50E4058A)
3. Saturated zone solute transport simulation capability has been developed within the EU FP7-ENV-2013-WATER-INNO-DEMO MARSOL. MARSOL project receives funding from the European Union's Seventh Framework Programme for Research, Technological Development and Demonstration under grant agreement n. 619120 (www.marsol.eu)
4. The previous codes have been integrated into FREEWAT under development within EU H2020 project FREEWAT - Free and Open Source Software Tools for Water Resource Management. FREEWAT project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 642224 (www.freewat.eu)
This User Manual provides guidelines to properly install and use the FREEWAT plugin.

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Capabilities of the FREEWAT platform were tested either by the developers group and by Project Partners. However, future applications of the platform may reveal errors and drawbacks not detected to date. Users are kindly requested to notify any error in both platform and User Manual. Please send this info to: rudy.rossetto@sssup.it

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Abstract

This Volume describes the workflow which has to be followed to set up and run a water management scenario. Sustainable water management, with particular attention to conjunctive use of ground- and surface-water in rural areas, is accomplished in FREEWAT by having implemented the *Farm Process* (Schmid et al., 2006; Schmid and Hanson, 2009), integrated within *MODFLOW - One-Water Hydrologic Flow Model* (*MODFLOW-OWHM*; Hanson et al., 2014).

The creation and set up of a new hydrologic model, as described in Volume 1, is required.

In Chapter 1, the steps needed to set up a water management scenario are described. First of all, the User has to define limits of "farms" or water units, i.e., basic units of water consumption, for which several properties need to be assigned:

- the on-farm efficiency (OFE; i.e., the evaporative losses from irrigation);
- some economic parameters related to surface- and ground-water costs (e.g., for delivery);
- surface- and ground-water allotments;
- some parameters need to be specified if surface-water transfer from several kinds of sources without conveyance (non-routed deliveries) is simulated.

A further source of surface-water supply, fully routed and/or semi-routed deliveries can be specified connecting a farm to the main channel (e.g., a river) and/or to a secondary channel connected to the main one through a diversion point. A connection between a farm and a surface channel can be represented defining a pipeline from the farm to a specific reach (i.e., grid cell) of a stream segment, the latter simulated through the *SFR* (Stream-Flow Routing) MODFLOW Package (refer to Chapter 6 in Volume 1).

Farm wells can be introduced as well, namely wells delivering groundwater to a certain water unit to satisfy its demand. A maximum capacity must be defined for them, all over the simulation period.

The demand of each water unit is related to the amount of water needed by the crops for transpiration. To determine such demand, one or more crop types must be specified for each water unit and related properties must be assigned for each crop type.

The User must also specify soil types over the domain and assign a value of capillary fringe for each soil type, in order to evaluate root uptake by each crop.

Finally, precipitation and potential evapotranspiration need to be assigned as climate-related data.

Chapters 2 and 3 deal with simulation run options and visualization of water management scenario results.

The implementation of *MODFLOW-OWHM* within the GIS-based *FREEWAT* platform constitutes a relevant advantage, as the *Farm Process* module dynamically links the demand, supply, and related change in aquifer-system storage and the supply and demand components integrating the groundwater-flow budget calculated by *MODFLOW-2005*.

CHAPTER 1

Setting up a water management model

The simulation of a water management scenario requires creating and setting up a new hydrological model, as described in Chapters 3 to 6, in Volume 1.

As stated in section 2.2 in Volume 1, the User will first define the spatial discretization of the aquifer system under exam in the horizontal and vertical planes i.e., creating the horizontal grid and the model layers. The properties of each model layer will be then edited to represent top and bottom surfaces of each hydrostratigraphic unit and the related hydraulic properties. To do so, specific tools integrated in the FREEWAT platform (*Copy from Vector layer* and *Copy from Raster layer*) can be adopted to facilitate the use of shapefiles and/or raster files. The time discretization must be specified as well, through the definition of discrete stress periods (SPs) and time-steps to cover the whole period of simulation. Boundary conditions and source/sink terms will be finally specified through the *MODFLOW Boundary Conditions* sub-menus.

The hydrological model must then be run through the **Run Model** interface (**Groundwater Flow** tab), in order to create into the working folder the *MODFLOW* input files.

Once the groundwater flow model is set-up and run, building a water management scenario requires following the steps reported below.

First of all, the *farms* (i.e., basic units of water consumptions, hereinafter referred to as *Water Demand Units*) must be defined, assigning a farm ID at each grid cell.

Each farm requires specification of some properties, in particular:

- the *on-farm efficiency* (*OFE*; i.e., the evaporative losses from irrigation);
- some economic parameters related to surface- and ground-water costs (e.g., for delivery);
- surface- and ground-water allotments;
- some parameters need to be specified if surface-water transfer from several kinds of sources without conveyance (*non-routed deliveries*) is simulated.

As a further source of surface-water supply, *semi-routed deliveries* can be specified connecting a farm to the main channel (e.g., a river) and/or to a secondary channel connected to the main one through a diversion point. A connection between a farm and a surface channel can be represented defining a *pipeline* from the farm to a specific reach (i.e., grid cell) of a stream segment, the latter simulated through the SFR Package (see chapter 6, in Volume 1).

Farm wells can be introduced as well, namely wells delivering groundwater to a certain farm to satisfy its demand. A maximum capacity must be defined for them, all over the simulation period.

The demand of each farm is related to the amount of water needed by the crops for transpiration. To determine such demand, one or more *crop types* must be specified for each farm, assigning a crop ID at each grid cell.

Each crop then requires specification of the following properties:

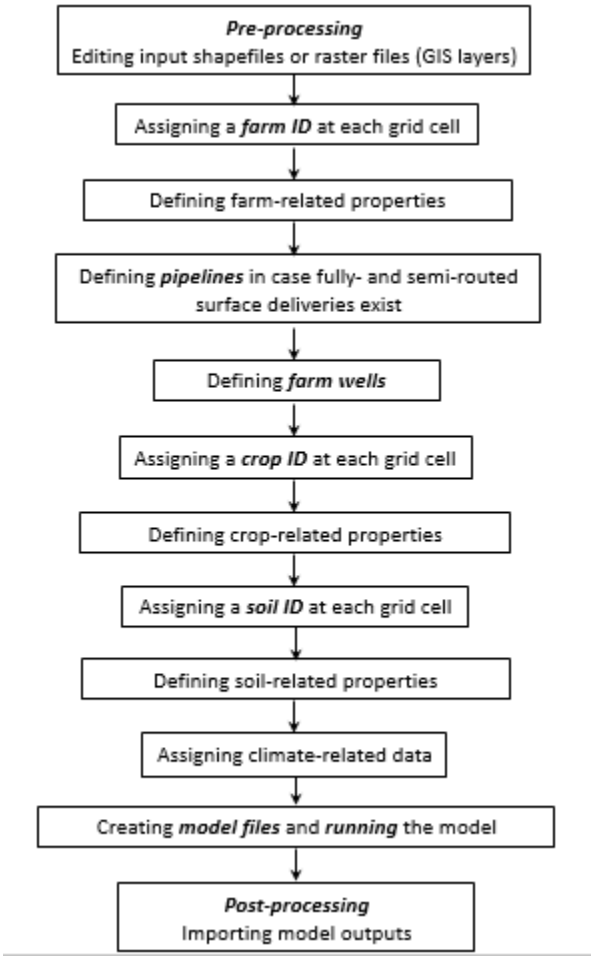
- transpiratory fraction;

- evaporative fractions related to precipitation and irrigation;
- fractions of inefficiency losses to surface-water related to precipitation and irrigation;
- depth of the root zone (*ROOT*), used to define crop transpiration as a result of groundwater level changes;
- crop coefficient (*Kc*), used to calculate crop evapotranspiration (*ETc*) as a product of *Kc* and the potential evapotranspiration;
- market price per crop;
- coefficients of crop-specific Water-Production Function (i.e., yield vs. crop evapotranspiration).

The User must also specify *soil types* over the domain, assigning a soil ID at each grid cell.

For each soil type, a value for *capillary fringe* must then be specified to evaluate root uptake by each crop.

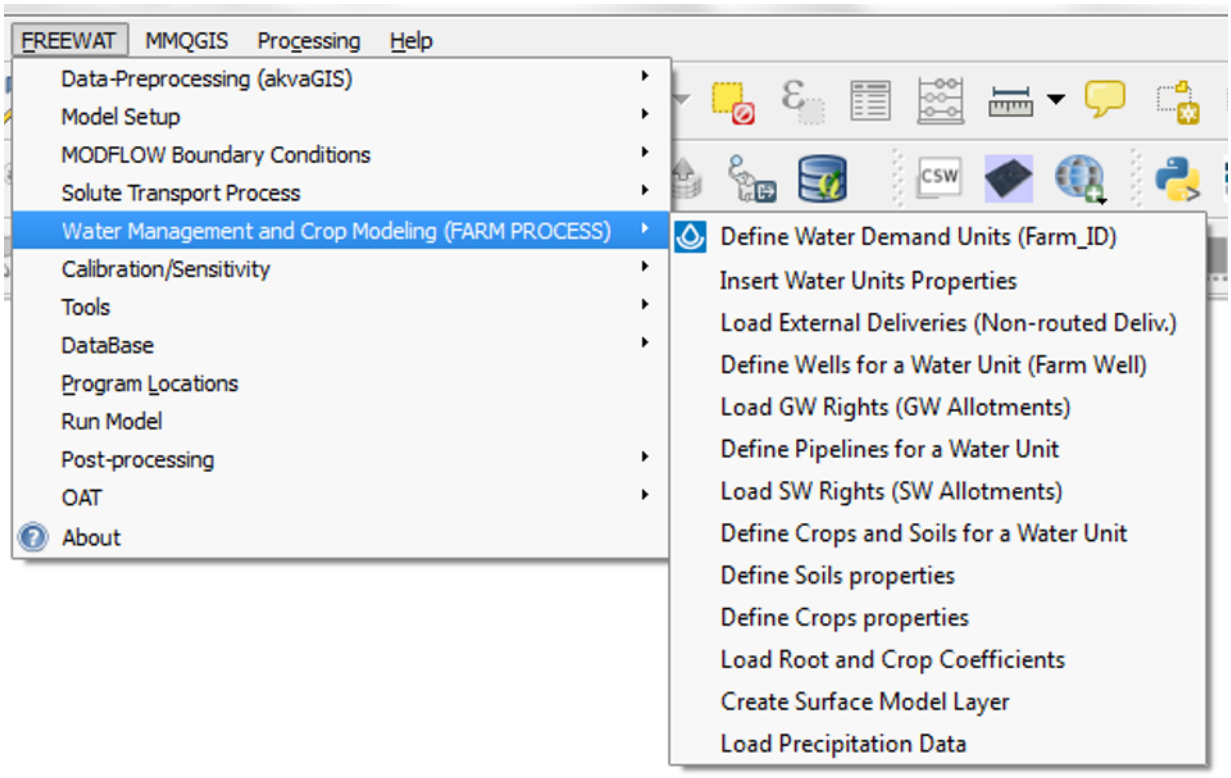
Finally, *precipitation* and *potential evapotranspiration* need to be assigned as climate-related data at each SP all over the simulation.



Setting up a water management scenario

A water management scenario can be created through the following menu:

FREEWAT -> Water Management and Crop Modeling (FARM PROCESS).

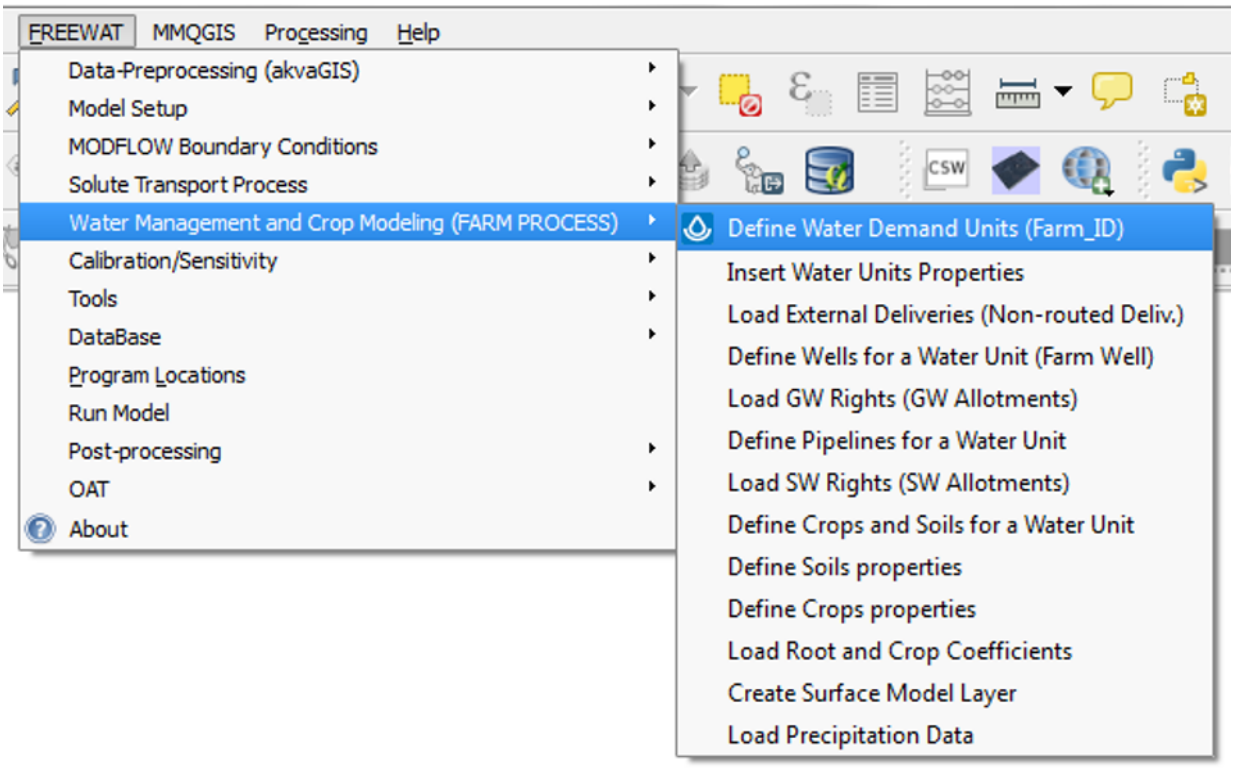


Defining Water Demand Units

Water Demand Units must be defined, assigning a specific ID (*Farm ID*) at each grid cell.

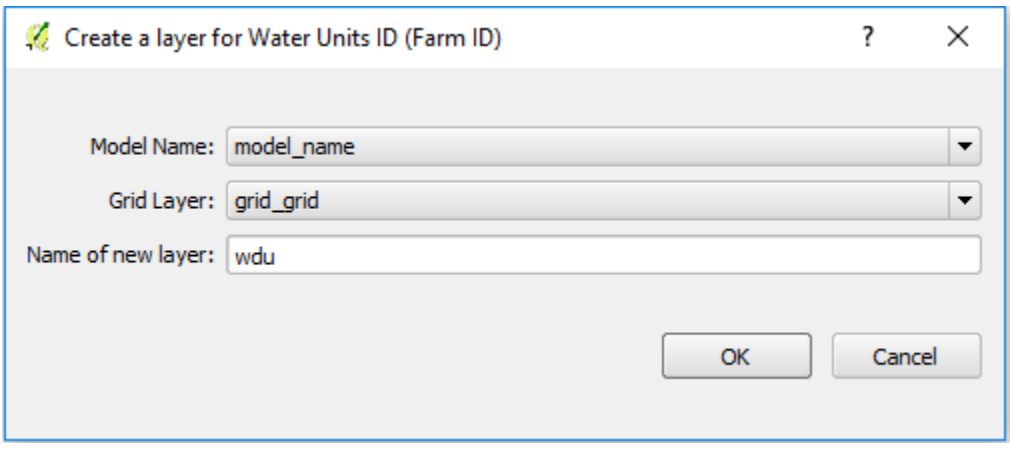
Water Demand Units (WDUs) can be defined through the following menu:

FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Define Water Demand Units (Farm_ID).



In the **Create a layer for Water Units ID (Farm ID)** window, the following data are required:

- *Model Name*: name of the hydrological model;
- *Grid Layer*: grid MDO;
- *Name of new layer*: name of the MDO which has to be created, containing information about the spatial distribution of WDUs.



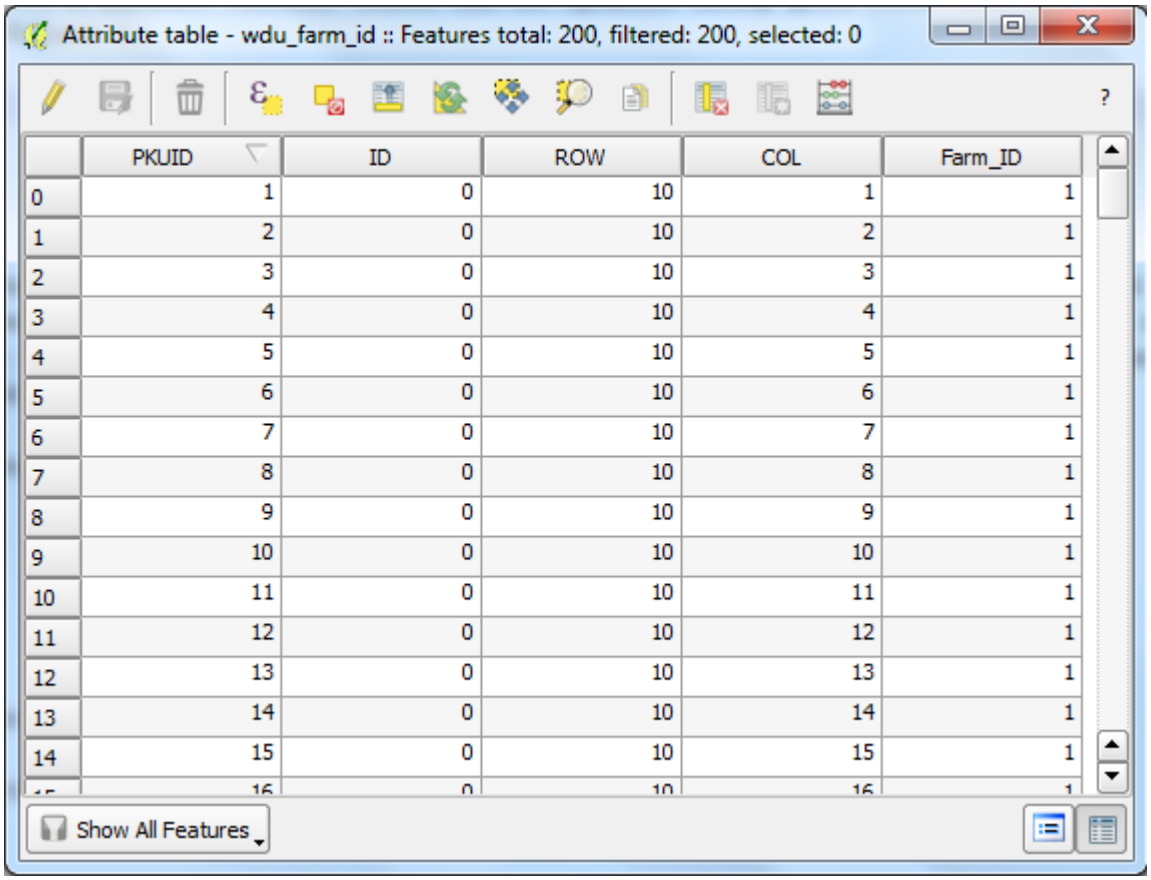
A new MDO, named *wdu_farm_id*, is created, stored within the model DB and loaded in the Layers Panel.

The Attribute Table of such MDO may contain several records, according to the number of grid cells, and the following fields:

- *PKUID*: database primary key (it must not be modified);
- *ID*: database primary key (it must not be modified);

- *ROW*: row number of a grid cell;
- *COL*: column number of a grid cell;
- *Farm_ID*: integer ID assigned at each grid cell to identify a certain WDU.

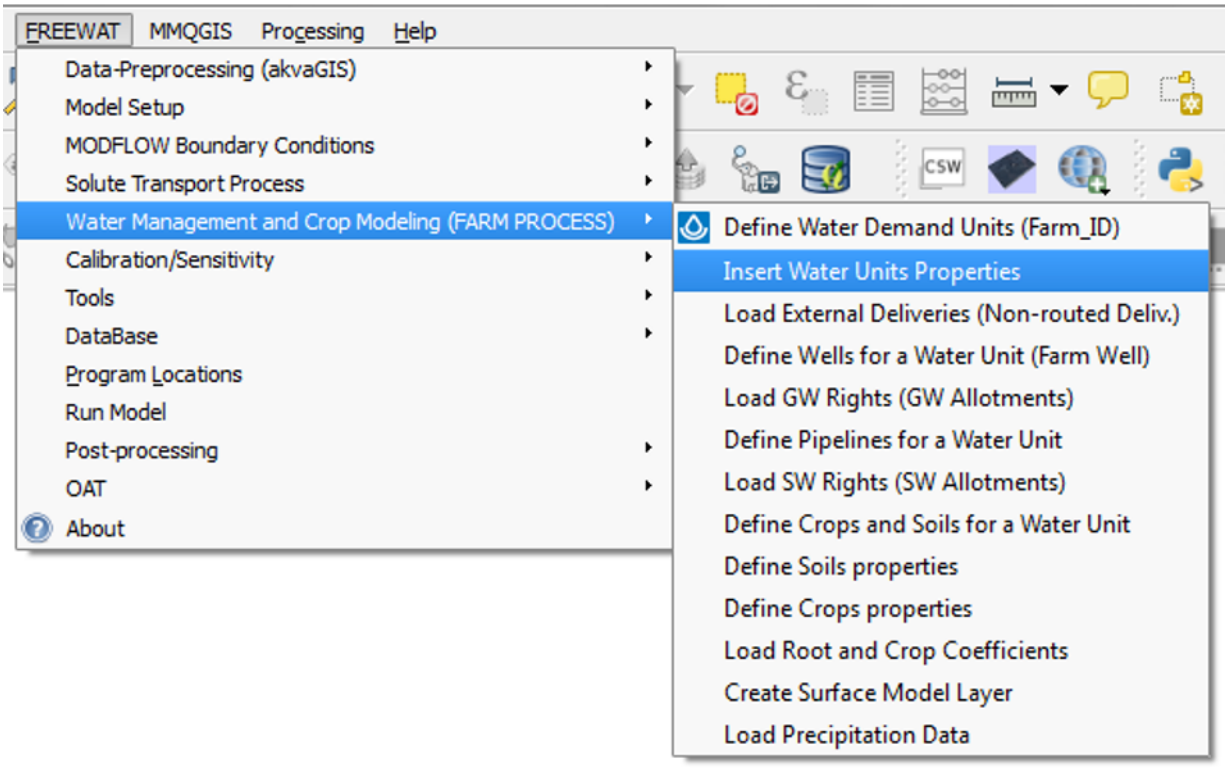
The field *Farm_ID* is filled with a default value, which can be updated using QGIS selection and editing tools described in Chapter 5, in Volume 1.



	PKUID	ID	ROW	COL	Farm_ID
0	1	0	10	1	1
1	2	0	10	2	1
2	3	0	10	3	1
3	4	0	10	4	1
4	5	0	10	5	1
5	6	0	10	6	1
6	7	0	10	7	1
7	8	0	10	8	1
8	9	0	10	9	1
9	10	0	10	10	1
10	11	0	10	11	1
11	12	0	10	12	1
12	13	0	10	13	1
13	14	0	10	14	1
14	15	0	10	15	1

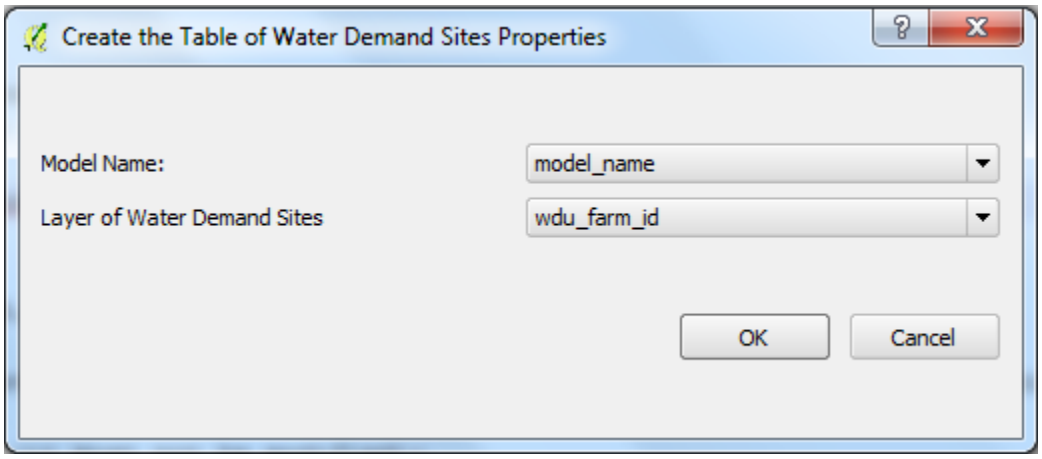
Once defined the spatial distribution of WDUs, some WDU-related data must be assigned to each of them. To do so, the following menu must be used:

FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Insert Water Units Properties.



In the **Create the table of Water Demand Sites Properties** window, the following data are required:

- *Model Name*: name of the hydrological model;
- *Layer of Water Demand Sites*: name of the wdu MDO just created.



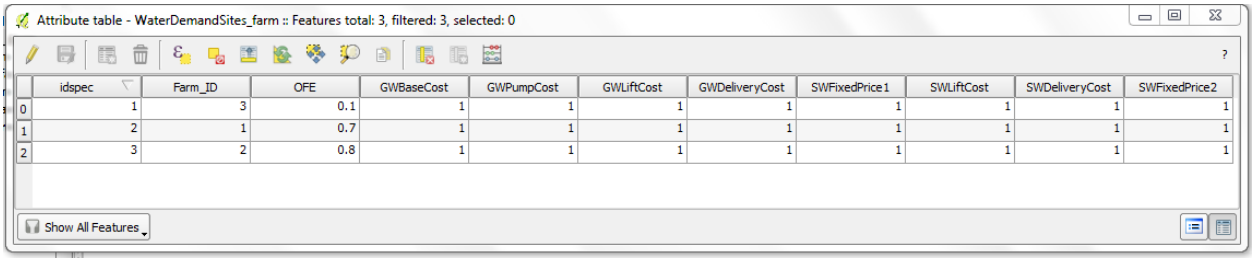
A new table, named *WaterDemandSites_model_name*, is created, stored within the model DB and loaded in the Layers Panel.

Such table contains as much records as the number of WDUs defined, with the following fields:

- *idspec*: database primary key (it must not be modified);
- *Farm_ID*: integer ID assigned to identify WDUs;
- *OFE*: real number defining On-Farm Efficiency ($0 < OFE <= 1$);
- *GWBaseCost*: groundwater base maintenance costs per unit volume [$\$/L^3$];

- *GWPumpCost*: groundwater costs for pumping in well per unit volume, per unit lift [$\$/(L^3 * L)$];
- *GWLiftCost*: groundwater costs for vertical lift from well to cell per unit volume, per unit lift [$\$/(L^3 * L)$];
- *GWDeliveryCost*: groundwater delivery costs per unit volume, per unit distance [$\$/(L^3 * L)$];
- *SWFixedPrice1*: fixed price of (semi-)routed surface water per unit volume [$\$/L^3$];
- *SWLiftCost*: costs for vertical lift of (semi-)routed surface water from reach to cell per unit volume, per unit lift [$\$/(L^3 * L)$];
- *SWDeliveryCost*: delivery costs of (semi-)routed surface water per unit volume, per unit distance [$\$/(L^3 * L)$];
- *SWFixedPrice2*: fixed price of non-routed surface water per unit volume [$\$/L^3$];

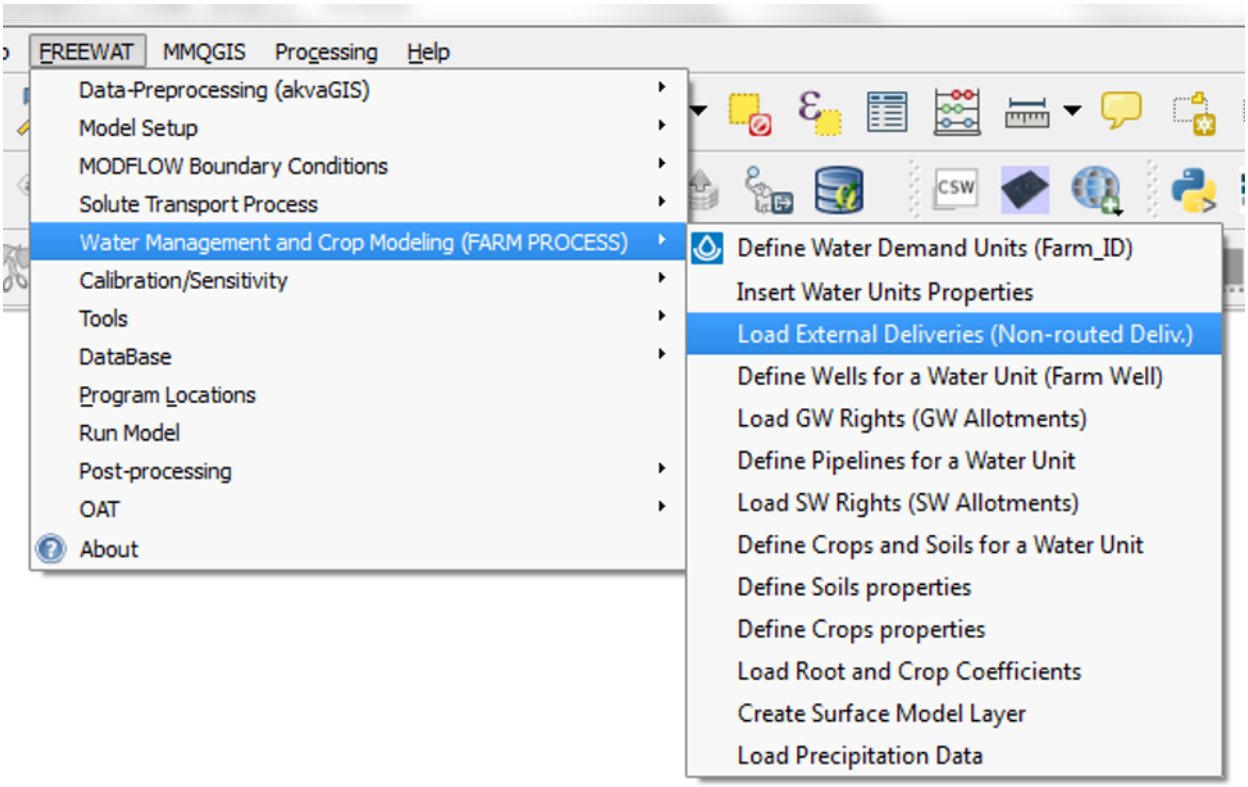
The fields *OFE* through *SWFixedPrice2* are filled with default values, which can be updated using QGIS selection and editing tools described in Chapter 5, in Volume 1.



	idspec	Farm_ID	OFE	GWBaseCost	GWPumpCost	GWLiftCost	GWDeliveryCost	SWFixedPrice1	SWLiftCost	SWDeliveryCost	SWFixedPrice2
0	1	3	0.1	1	1	1	1	1	1	1	1
1	2	1	0.7	1	1	1	1	1	1	1	1
2	3	2	0.8	1	1	1	1	1	1	1	1

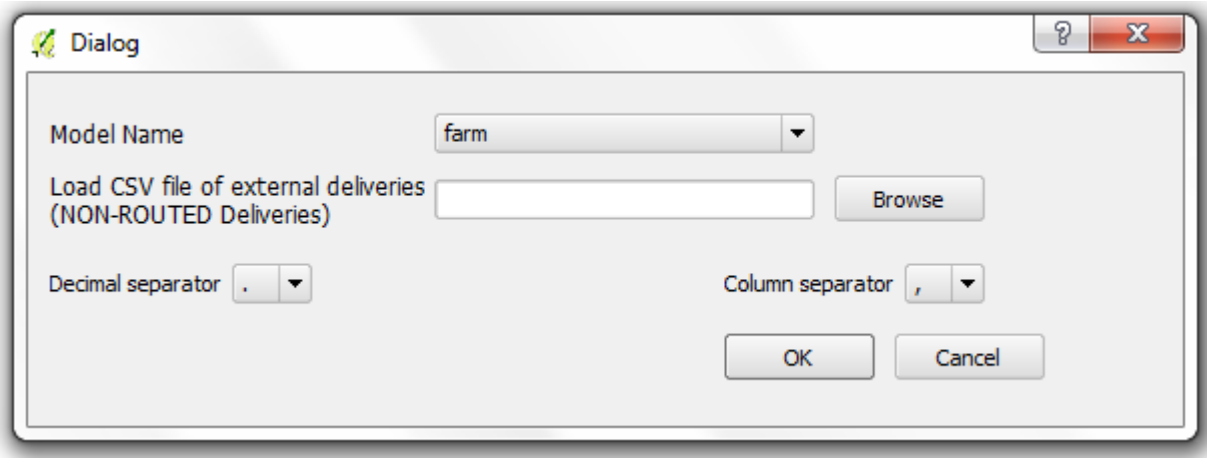
Defining External Deliveries (Non-routed Deliveries)

If (at least) one WDU is linked to a non-routed delivery (i.e. any kind of source without conveyance), it is necessary to load a table containing information on amount and type of these deliveries, for each WDU and for each stress period. This is done from the menu: *FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Load External Deliveries (Non-routed Deliv.)*

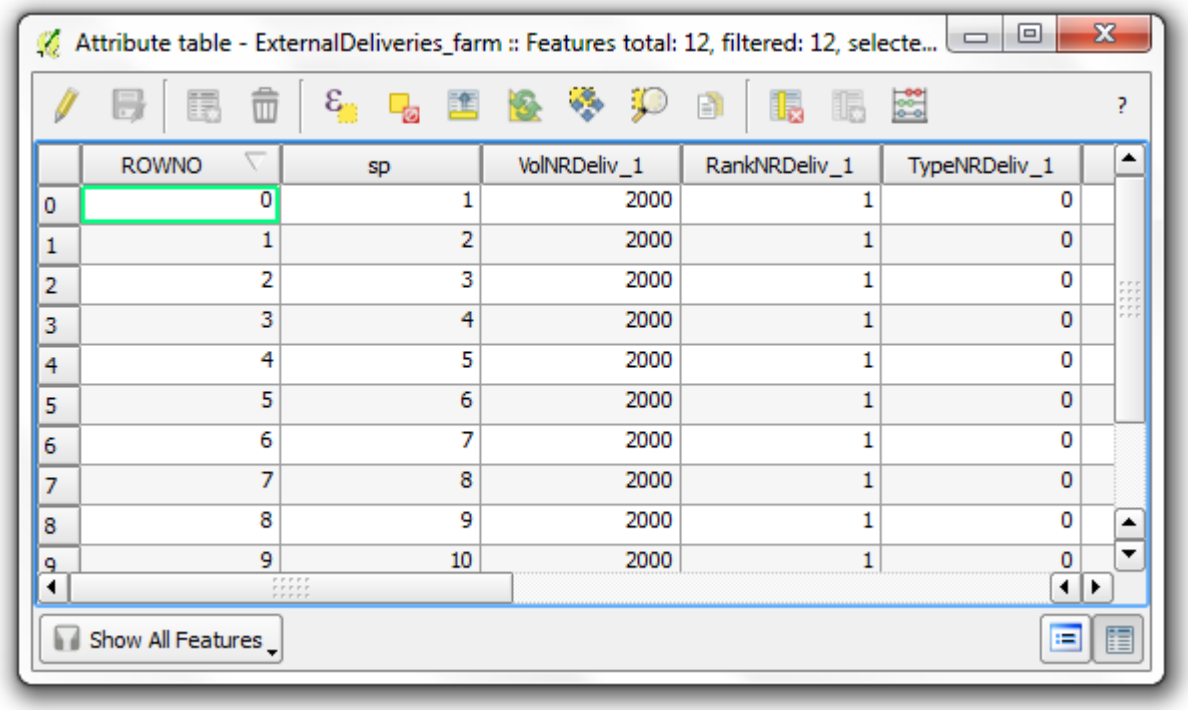


In the window, the following data are required:

- *Model Name*: name of the hydrological model;
- The csv file in which non-routed deliveries (for each WDU and for each stress period) are reported. For the User's convenience, a template for this file is included within the sub-folder folder *csv_templates*, under the main plugin's folder.



A new table named *ExternalDeliveries* is created within the model DB and loaded in the Layers Panel. This table appears as in the picture below:



	ROWNO	sp	VolNRDeliv_1	RankNRDeliv_1	TypeNRDeliv_1
0	0	1	2000	1	0
1	1	2	2000	1	0
2	2	3	2000	1	0
3	3	4	2000	1	0
4	4	5	2000	1	0
5	5	6	2000	1	0
6	6	7	2000	1	0
7	7	8	2000	1	0
8	8	9	2000	1	0
9	9	10	2000	1	0

where the fields have the following meaning:

- *ROWNO*‘: database index (it must not be modified);
- *sp*: stress period number;

while the following three fields are repeated according to the number of WDUs implemented (*n* refers to the WDU’s ID):

- *VolNRDeliv_n*: volume of non-routed delivery to WDU number *n*, for the current stress period [L^3];
- *RankNRDeliv_n*: rank of the non-routed delivery;
- *TypeNRDeliv_n*: type of non-routed delivery (three options are available: *0* if only the amount needed to meet the farm’s demand is used; *1* if the total amount available is used and possible surplus is discharged into farm’s head gate reach; *2* if the total amount available is used and possible surplus is discharged into farm wells).

Note: In a water management problem, the User might need to introduce some *non-rural* water demand for a WDU, like domestic water consumption, for instance.

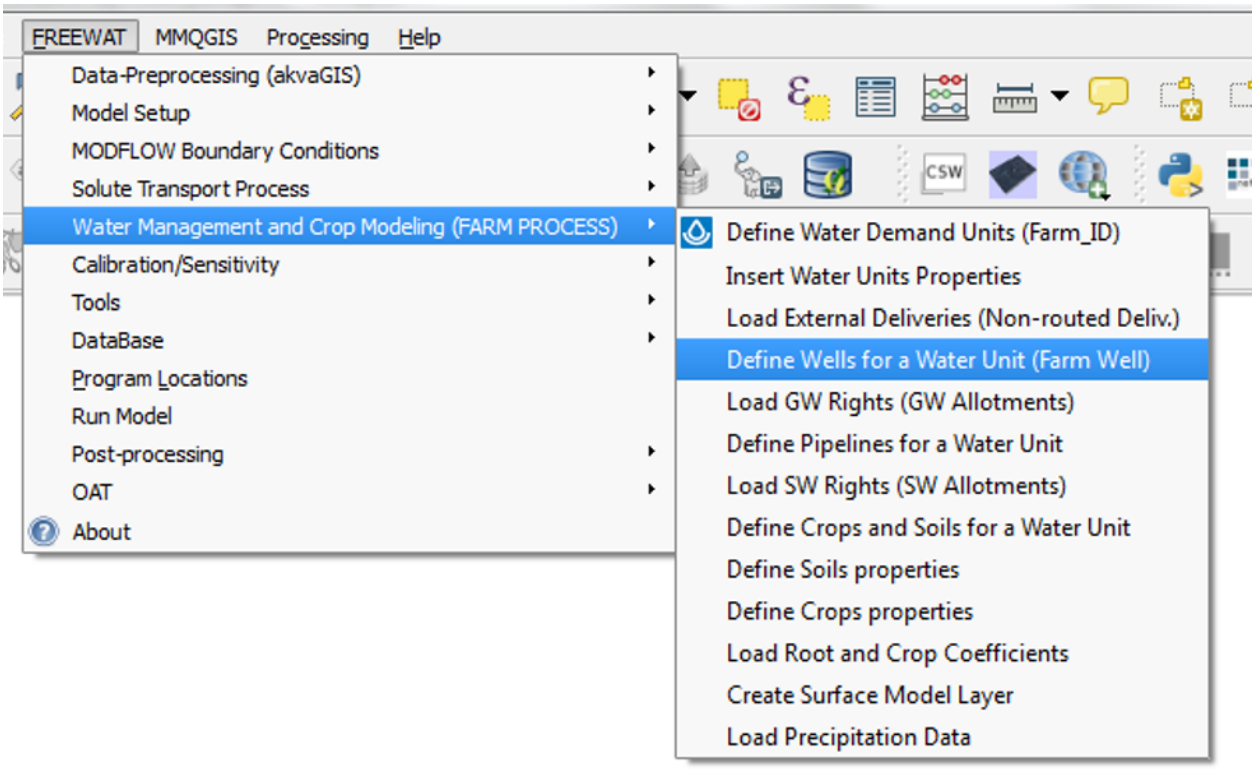
This can be represented by imposing a negative volume, namely a negative value for *VolNRDeliv* variable. If for the current stress period a WDU has several positive and/or negative values of non-routed deliveries, the User has here to assign as *VolNRDeliv* the algebraic sum of them

Defining farm wells

Then, it is necessary to define wells supplying groundwater to satisfy the demand of the WDUs just defined (farm wells).

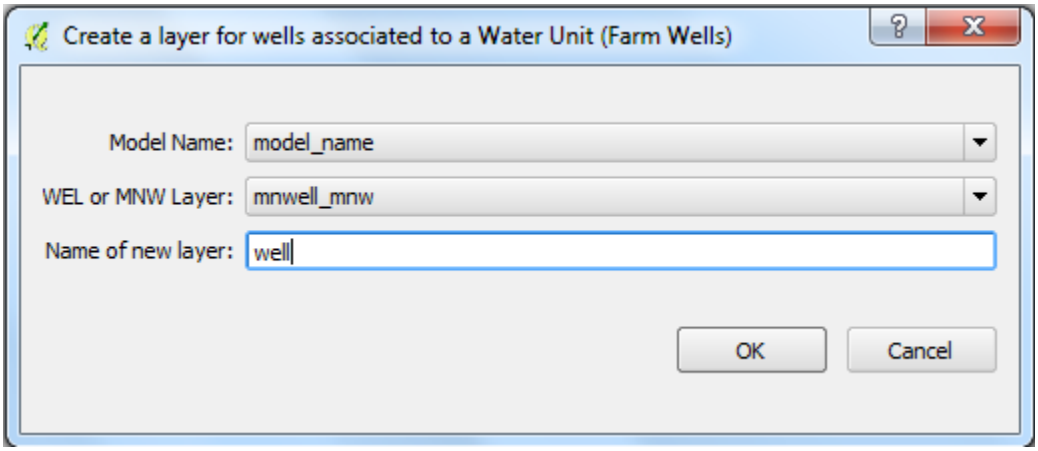
Farm wells can be defined through the following menu:

FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Define Wells for a Water Unit (Farm Well).



In the **Create a layer for wells associated to a Water Unit (Farm Wells)** window, the following data are required:

- *Model Name*: name of the hydrological model;
- *WEL or MNW Layer*: wel or mnw MDO previously created when setting the hydrological model (see Chapter 6, in Volume 1); by using this menu, each well or multi-node well is defined as a farm well;
- *Name of new layer*: name of the MDO which has to be created, containing information about location of farm wells.



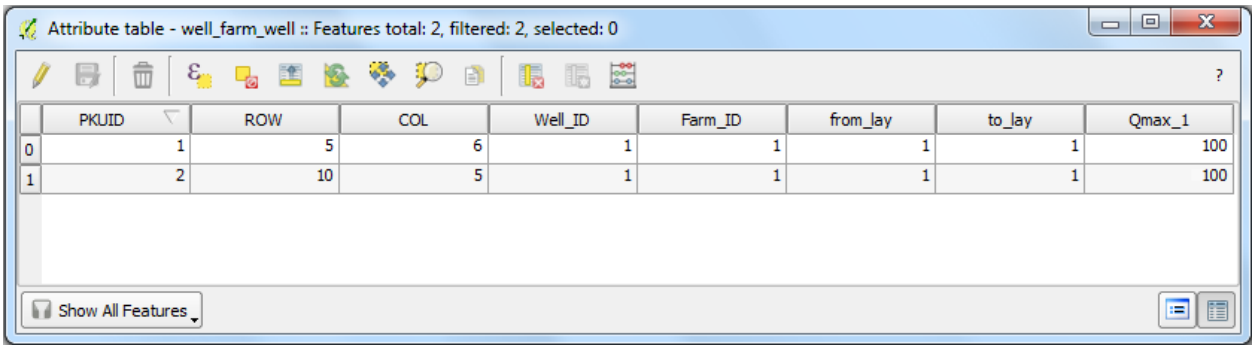
A new MDO, named *well_farm_well*, is created, stored within the model DB and loaded in the Layers Panel.

The Attribute Table of such MDO may contain several records, according to the number of grid cells where this boundary condition is assigned, and the following fields:

- *PKUID*: database primary key (it must not be modified);
- *ID*: database primary key (it must not be modified);

- *ROW*: row number of a grid cell;
- *COL*: column number of a grid cell;
- *Well_ID*: farm well ID;
- *Farm_ID*: WDU ID to which the farm well is related;
- *from_lay*: number of the uppermost layer where the farm well is active;
- *to_lay*: number of the deepest layer where the farm well is active;
- the following field is repeated according to the number of SPs implemented (*n* refers to the number of a SP):
  - *Qmax_n*: maximum well capacity $[L^3/T]$ during the *n*-th SP (a positive value must be specified).

The fields *Well_ID*, *Farm_ID* and *Qmax_n* are filled with default values, which can be updated using QGIS selection and editing tools described in Chapter 5, in Volume 1.

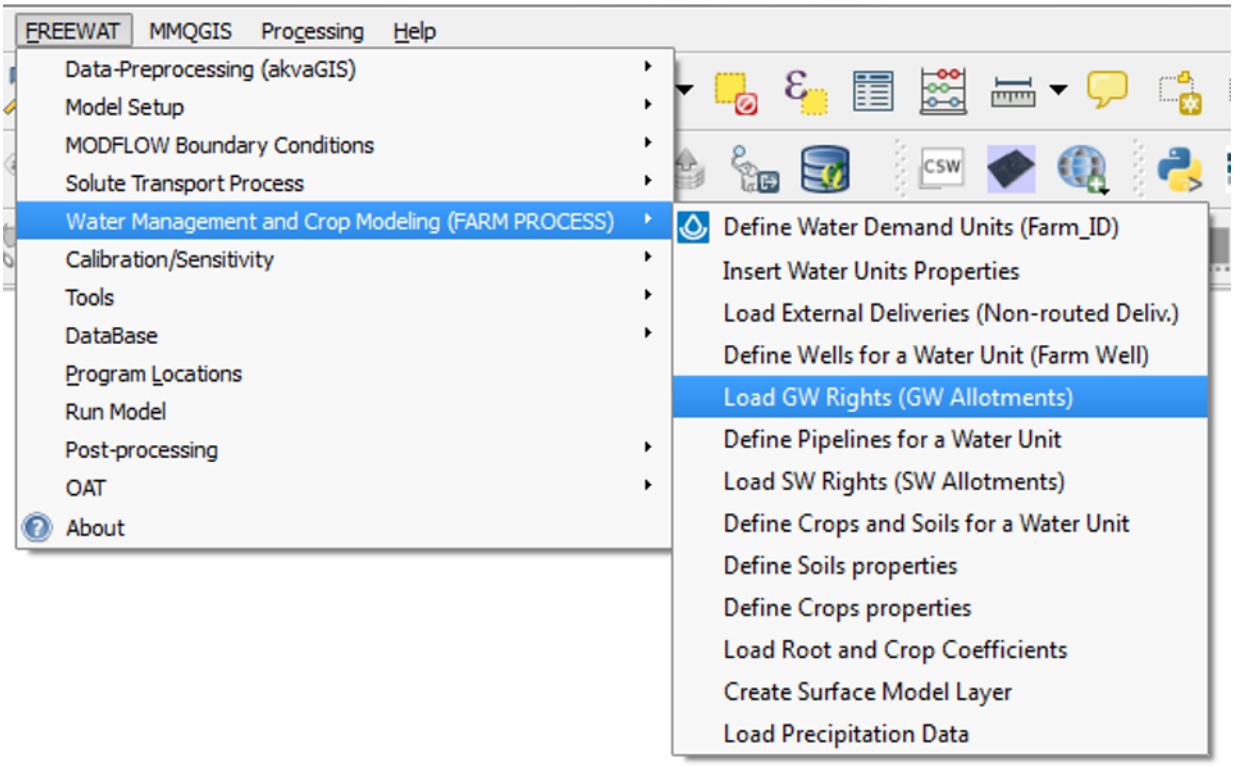


	PKUID	ROW	COL	Well_ID	Farm_ID	from_lay	to_lay	Qmax_1
0	1	5	6	1	1	1	1	100
1	2	10	5	1	1	1	1	100

Defining Groundwater Allotments

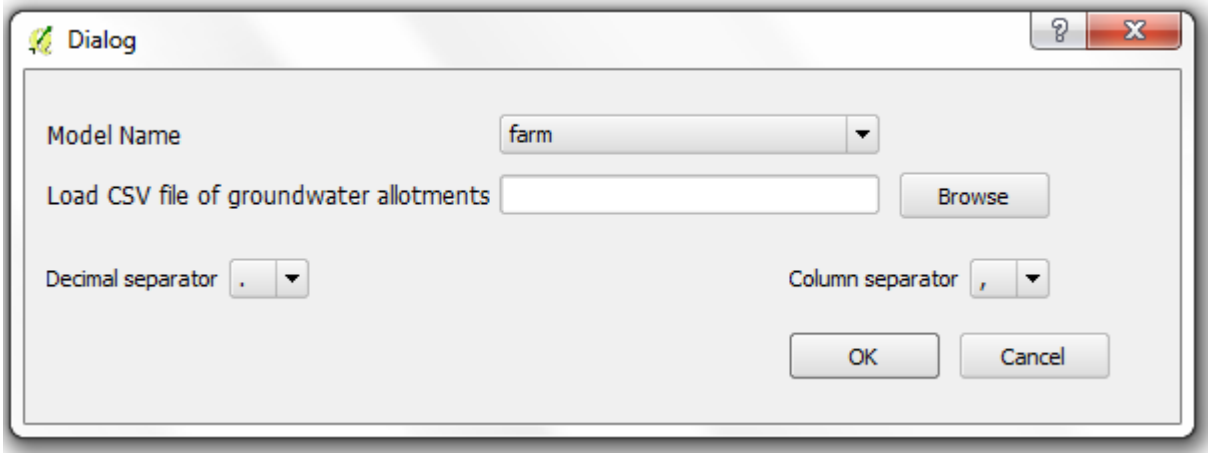
The User might need to set constraints (rights) on groundwater pumping, related to one or more WDUs, which are called *groundwater allotments* in MODFLOW-OWHM code. As stated above, each WDU's well has an own pumping limit defined; however, the groundwater allotment imposes a limit to the overall amount of water volume pumped by each WDU (in a specific stress period). This feature can be activated by defining groundwater rights, through the menu:

FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Load GW Rights (GW Allotments).

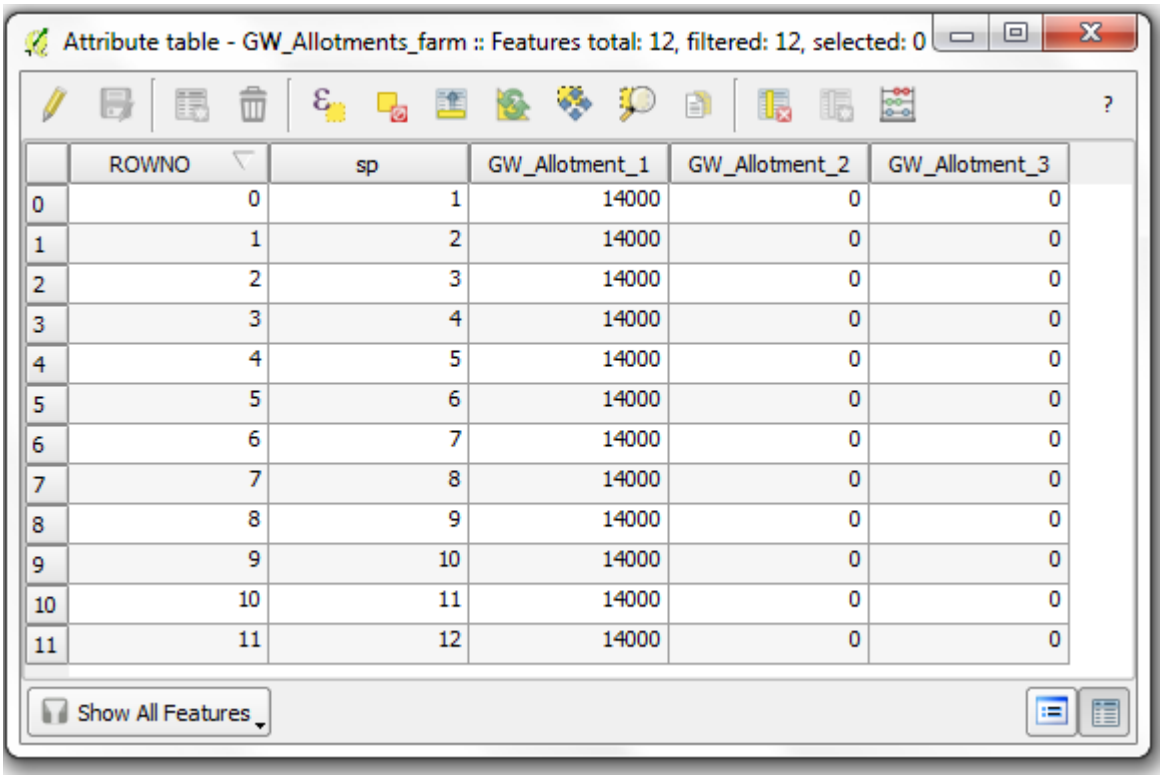


In the window, the following data are required:

- *Model Name*: name of the hydrological model;
- The csv file in which groundwater rights (for each WDU and for each stress period) are reported. For the User's convenience, a template for this file is included within the sub-folder folder *csv_templates*, under the main plugin's folder.



A new table named *GW_Allotments* is created within the model DB and loaded in the Layers Panel. This table appears as in the picture below:



	ROWNO	sp	GW_Allotment_1	GW_Allotment_2	GW_Allotment_3
0	0	1	14000	0	0
1	1	2	14000	0	0
2	2	3	14000	0	0
3	3	4	14000	0	0
4	4	5	14000	0	0
5	5	6	14000	0	0
6	6	7	14000	0	0
7	7	8	14000	0	0
8	8	9	14000	0	0
9	9	10	14000	0	0
10	10	11	14000	0	0
11	11	12	14000	0	0

where the fields have the following meaning:

- *ROWNO*': database index (it must not be modified);
- *sp*: stress period number;

while the following field is repeated according to the number of WDUs implemented (*n* refers to the WDU's ID):

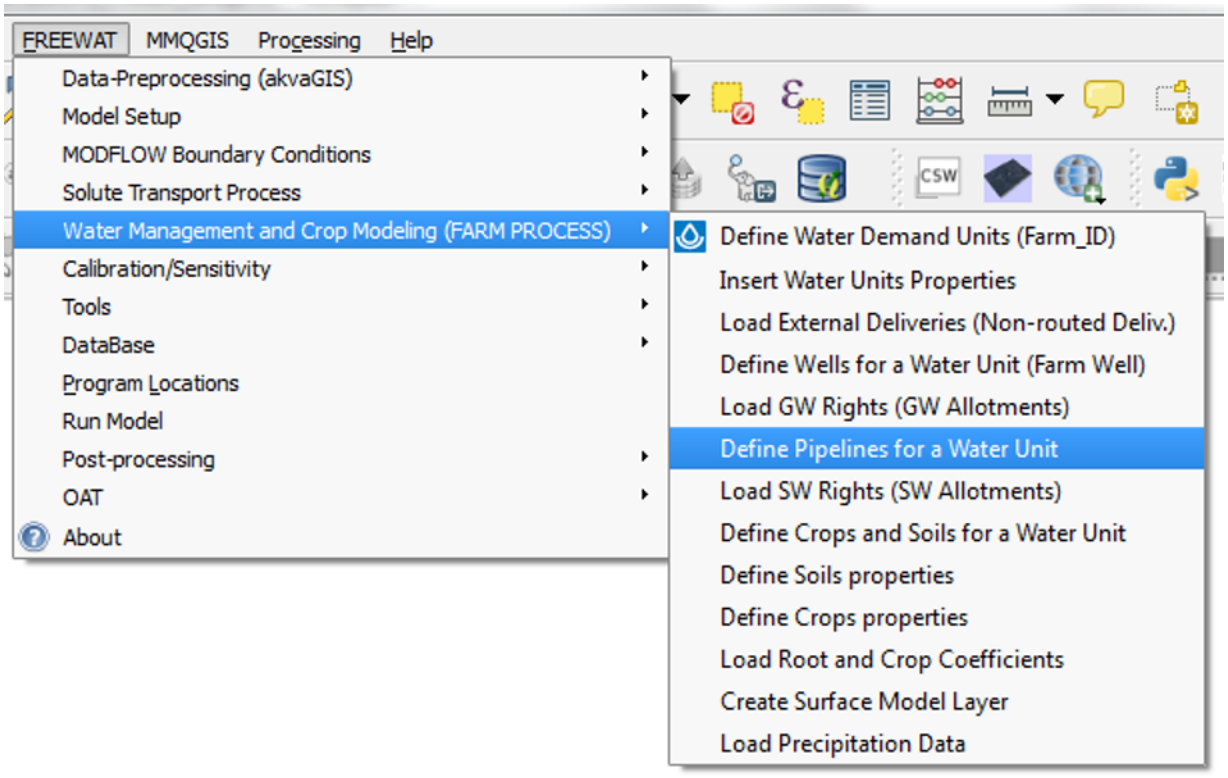
- *GW_allotment_n*: groundwater allotment for WDU number *n*, for the current stress period $[L^3/T]$: It represents a maximum pumping limit for a particular WDU's total allowable pumping. That is the sum of all the farm wells rates specified for a WDU are reduced evenly to equal *GW_allotment* if they exceed it.

Defining pipelines

Surface water supply to a WDU or flow of water away from any WDU can be simulated as non-routed surface water, or as conveyance from diversions or to drainage canals with the SFR Package (see Chapter 6, in Volume 1). The simulation of surface water conveyance to and from WDUs can include any combination of fully-routed and semi-routed transfers that, in turn, can represent a variety of conveyance mechanisms from natural rivers to man-made pipelines.

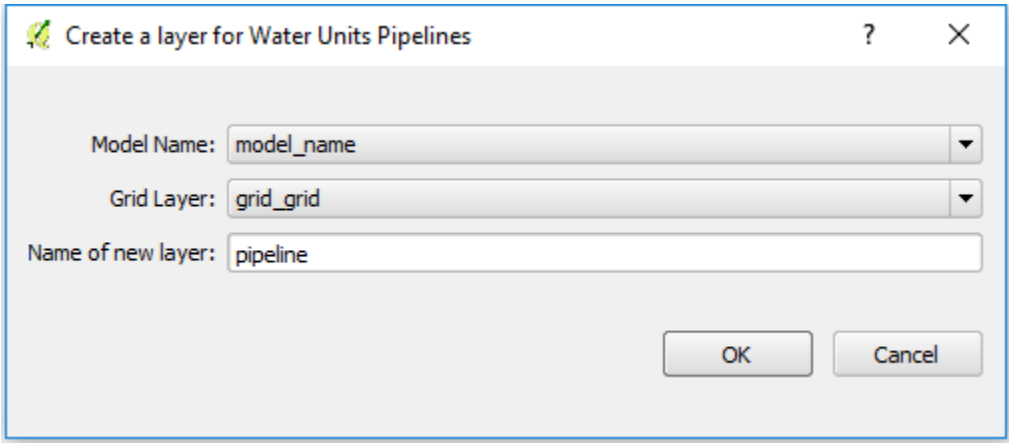
Pipelines can be defined through the following menu:

FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Define Pipelines for a Water Unit.



In the **Create a layer for Water Units Pipelines** window, the following data are required:

- *Model Name*: name of the hydrological model;
- *Grid Layer*: grid MDO;
- *Name of new layer*: name of the MDO which has to be created, containing information about the location of pipelines.



A new MDO, named *pipeline_div*, is created, stored within the model DB and loaded in the Layers Panel.

The Attribute Table of such MDO may contain several records, according to the number of stream reaches where the pipelines are located, and the following fields:

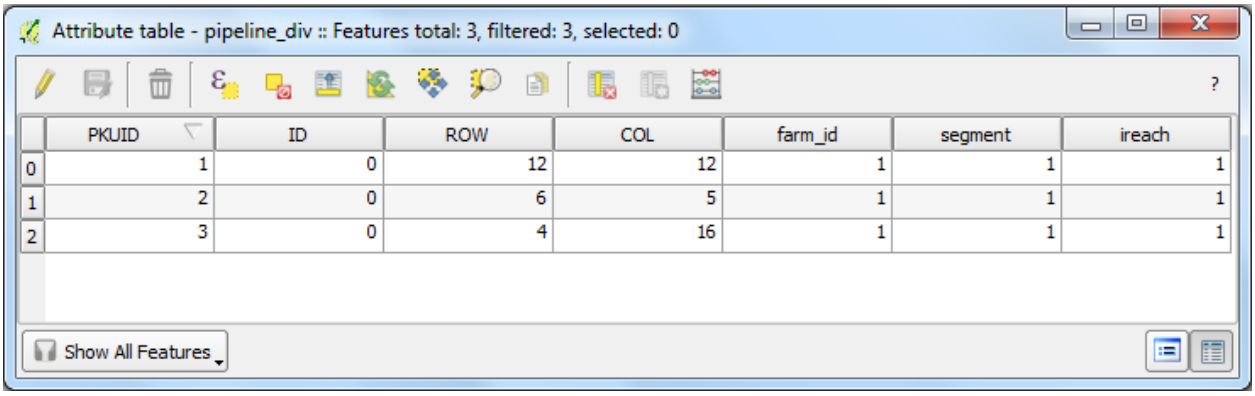
- *PKUID*: database primary key (it must not be modified);
- *ID*: database primary key (it must not be modified);

- *ROW*: row number of a grid cell;
- *COL*: column number of a grid cell;
- *farm_id*: integer ID of the WDU to which each pipeline is connected;
- *segment*: segment number of the stream to which each pipeline is connected (variable *seg_id* in SFR; see Chapter 6, in Volume 1);
- *ireach*: cell ID of the stream reach to which each pipeline is connected (variable *ireach* in SFR; see Chapter 6, in Volume 1).

The fields *farm_id*, *segment* and *ireach* are filled with default values, which can be updated using QGIS selection and editing tools described in Chapter 5, in Volume 1.

Note: In the current version, the possibility to intersect stream reaches by using linear shapefiles with pipeline profiles is not yet implemented. Therefore, grid cells corresponding to stream reaches where pipelines are connected must be prior selected.

Note: In the next version, the fields *segment* and *ireach* will be automatically updated with information included in the sfr MDO (see Chapter 6, in Volume 1).

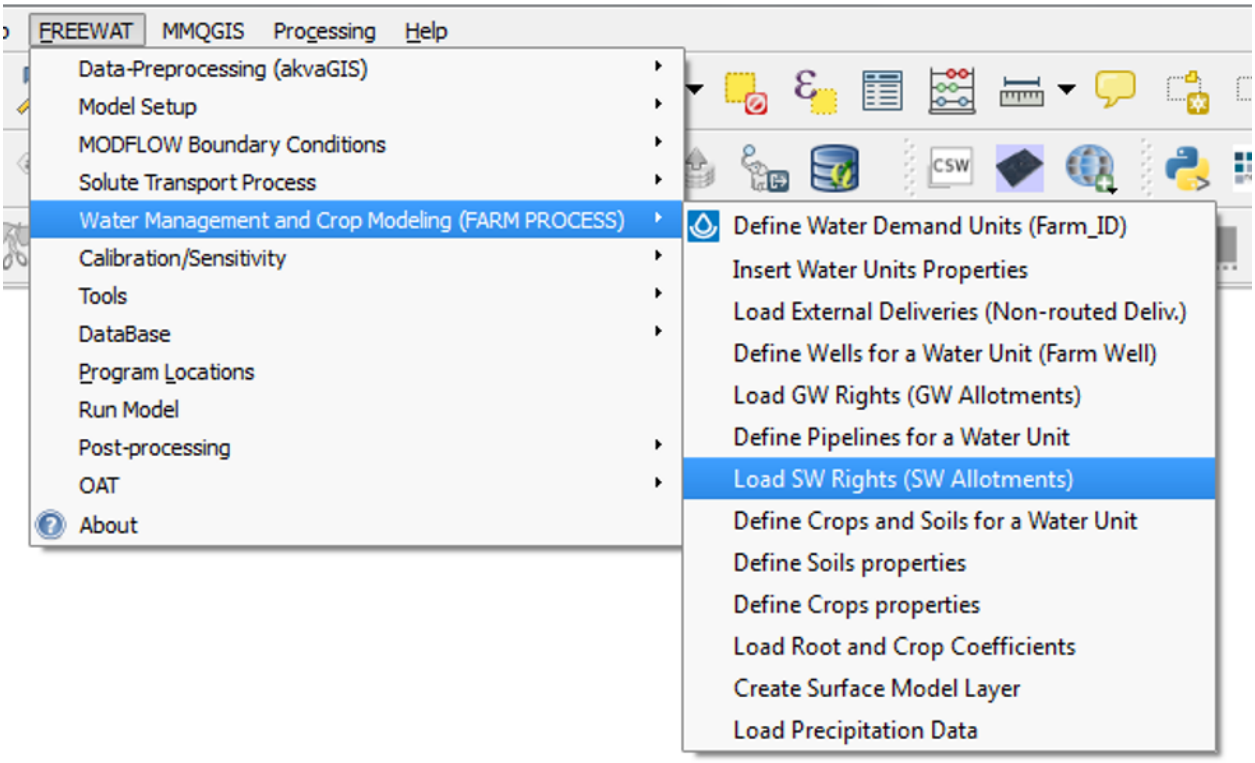


	PKUID	ID	ROW	COL	farm_id	segment	ireach
0	1	0	12	12	1	1	1
1	2	0	6	5	1	1	1
2	3	0	4	16	1	1	1

Defining Surface-water rights

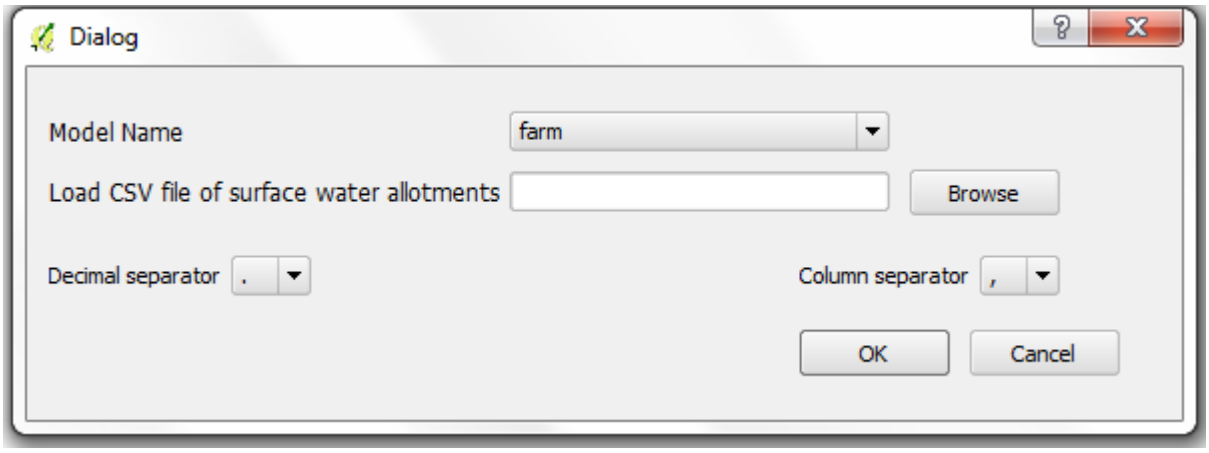
Once the surface-water deliveries are set, the User might need to set water rights call on usage of these water amount, related to one or more WDUs, which are referred to *surface-water allotments* in MODFLOW-OWHM code. Therefore, in a specific stress period, a WDU can claim a certain amount of water to be delivered through the pipelines above defined: this represetns a target value, but also an upper limit, for each WDU. This feature can be activated by defining surface-water rights, through the menu:

FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Load SW Rights (SW Allotments).

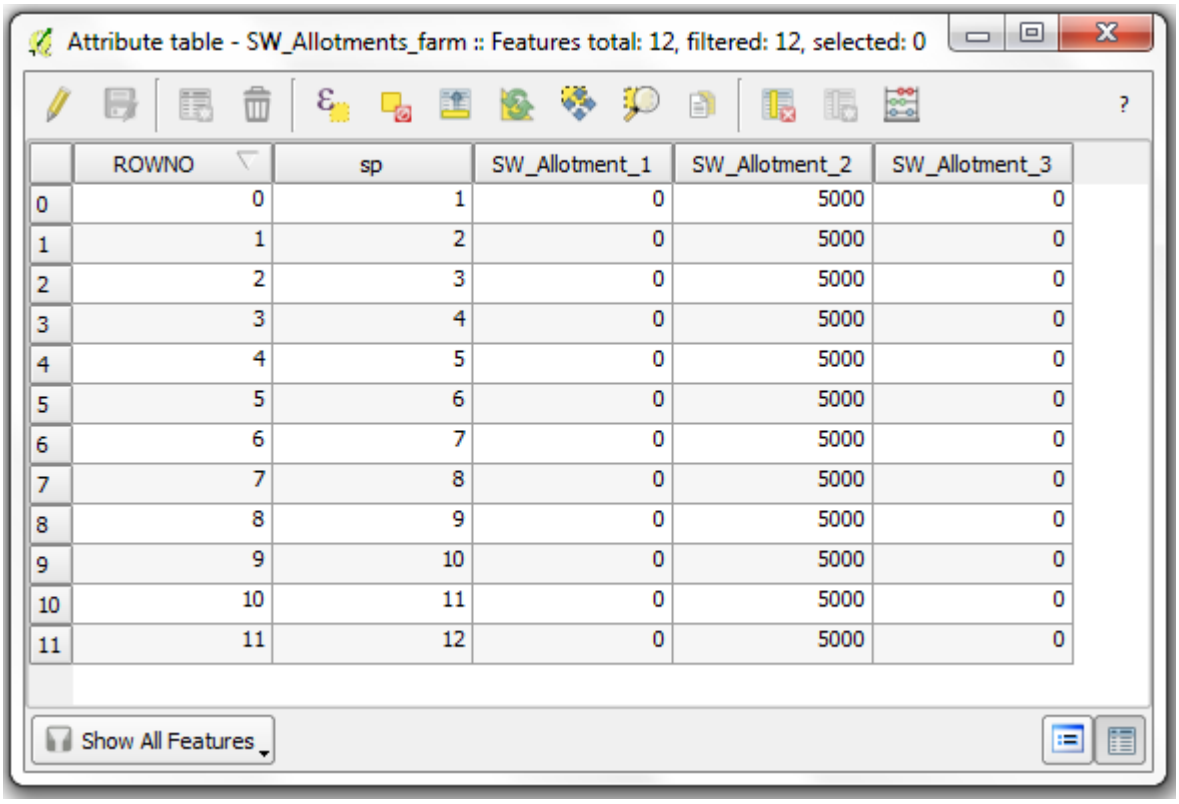


In the window, the following data are required:

- *Model Name*: name of the hydrological model;
- The csv file in which surface-water rights (for each WDU and for each stress period) are reported. For the User's convenience, a template for this file is included within the sub-folder folder *csv_templates*, under the main plugin's folder.



A new table named *SW_Allotments* is created within the model DB and loaded in the Layers Panel. This table appears as in the picture below:



	ROWNO	sp	SW_Allotment_1	SW_Allotment_2	SW_Allotment_3
0	0	1	0	5000	0
1	1	2	0	5000	0
2	2	3	0	5000	0
3	3	4	0	5000	0
4	4	5	0	5000	0
5	5	6	0	5000	0
6	6	7	0	5000	0
7	7	8	0	5000	0
8	8	9	0	5000	0
9	9	10	0	5000	0
10	10	11	0	5000	0
11	11	12	0	5000	0

where the fields have the following meaning:

- *ROWNO*‘: database index (it must not be modified);
- *sp*: stress period number;

while the following field is repeated according to the number of WDUs implemented (*n* refers to the WDU’s ID):

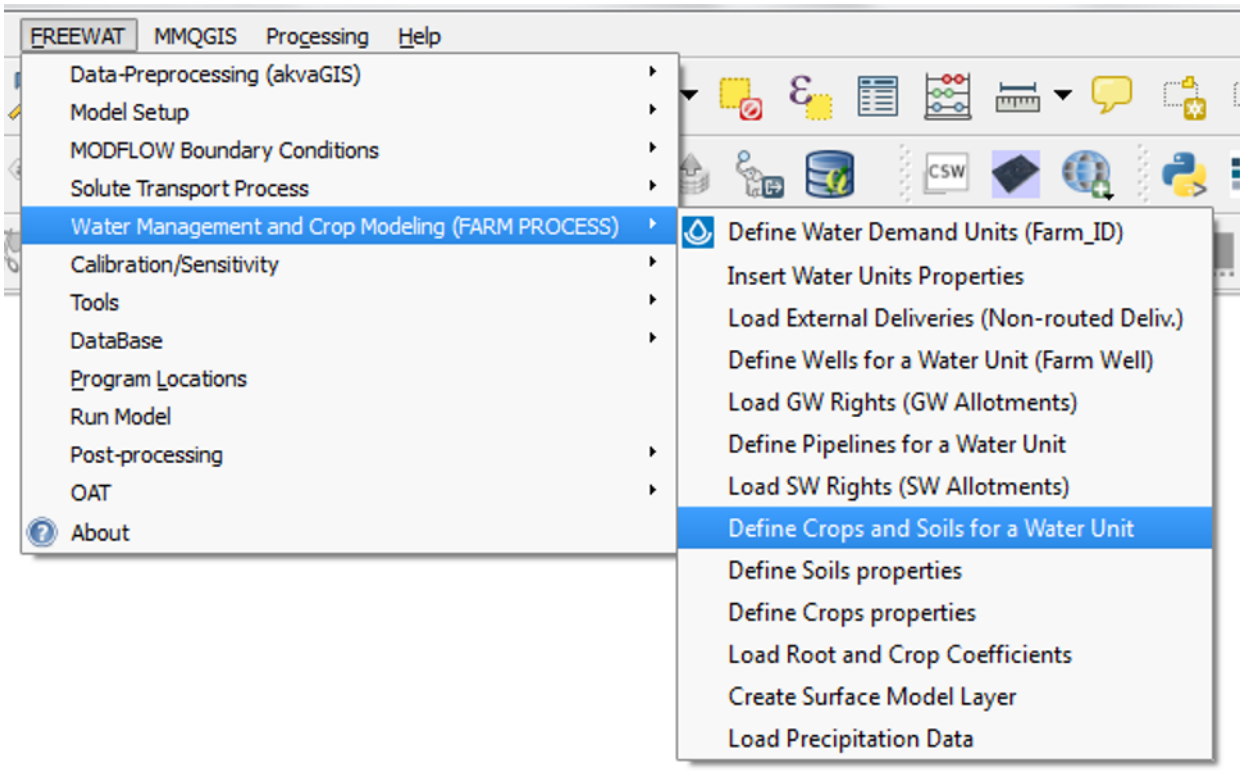
- *SW_allotment_n*: surface-water water allotment for WDU number *n*, for the current stress period [L^3/T].

Defining crops and soils

As a further step, crops and soils types must be defined, assigning a specific ID (Crop ID and Soil ID, respectively) at each grid cell.

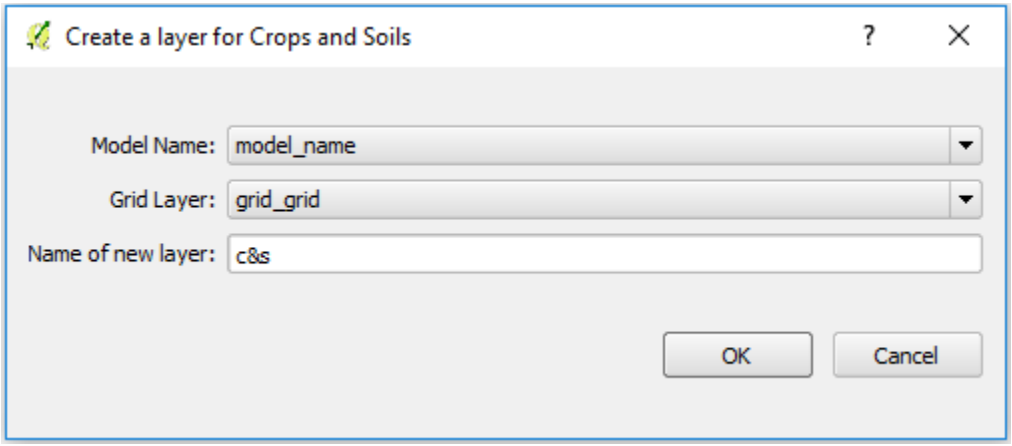
Crops and *soils types* can be defined through the following menu:

FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Define Crops and Soils for a Water Unit.



In the **Create a layer for Crops and Soils** window, the following data are required:

- *Model Name*: name of the hydrological model;
- *Grid Layer*: grid MDO;
- *Name of new layer*: name of the MDO which has to be created, containing information about the spatial distribution of crops and soils types.



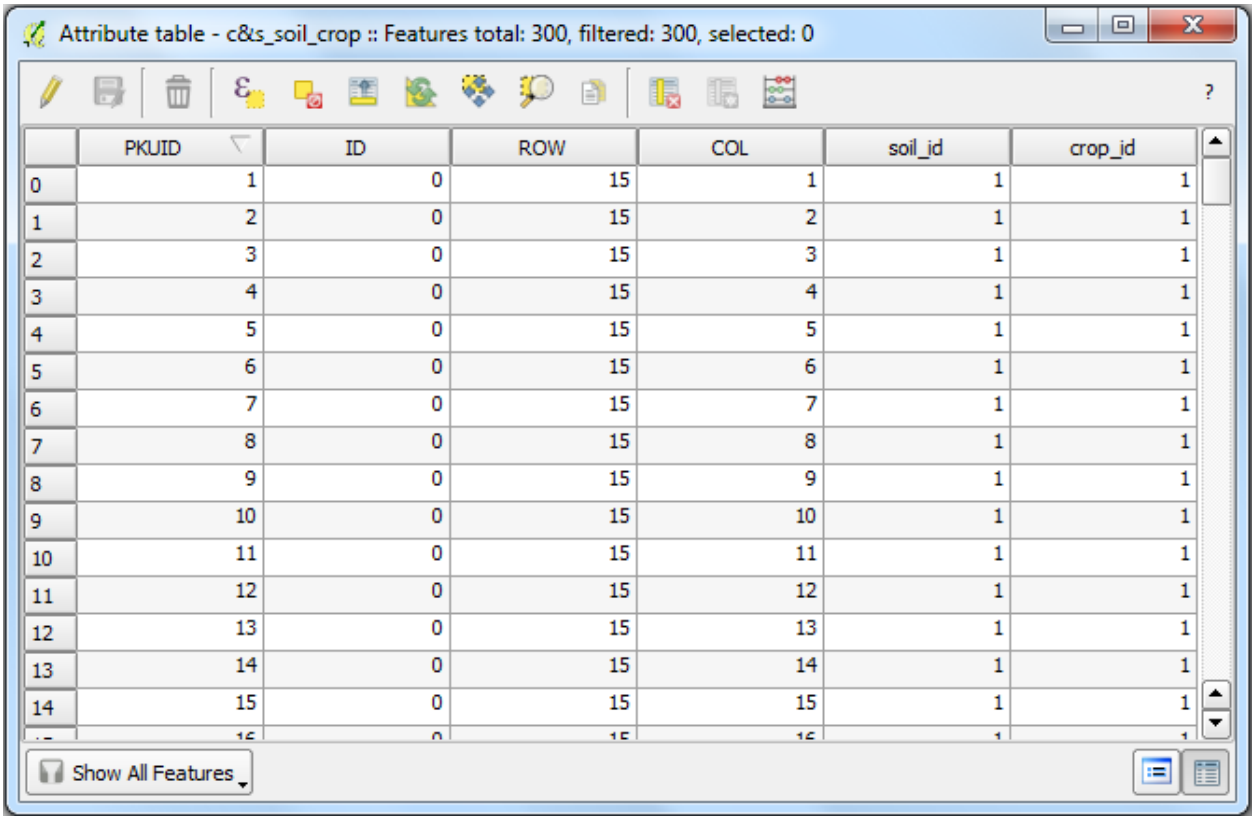
A new MDO, named *c&s_soil_crop*, is created, stored within the model DB and loaded in the Layers Panel.

The Attribute Table of such MDO may contain several records, according to the number of grid cells, and the following fields:

- *PKUID*: database primary key (it must not be modified);
- *ID*: database primary key (it must not be modified);

- *ROW*: row number of a grid cell;
- *COL*: column number of a grid cell;
- *soil_id*: integer ID assigned at each grid cell to identify the soils types;
- *crop_id*: integer ID assigned at each grid cell to identify the crops types.

The fields *soil_id* and *crop_id* are filled with default values, which can be updated using QGIS selection and editing tools described in Chapter 5, in Volume 1.



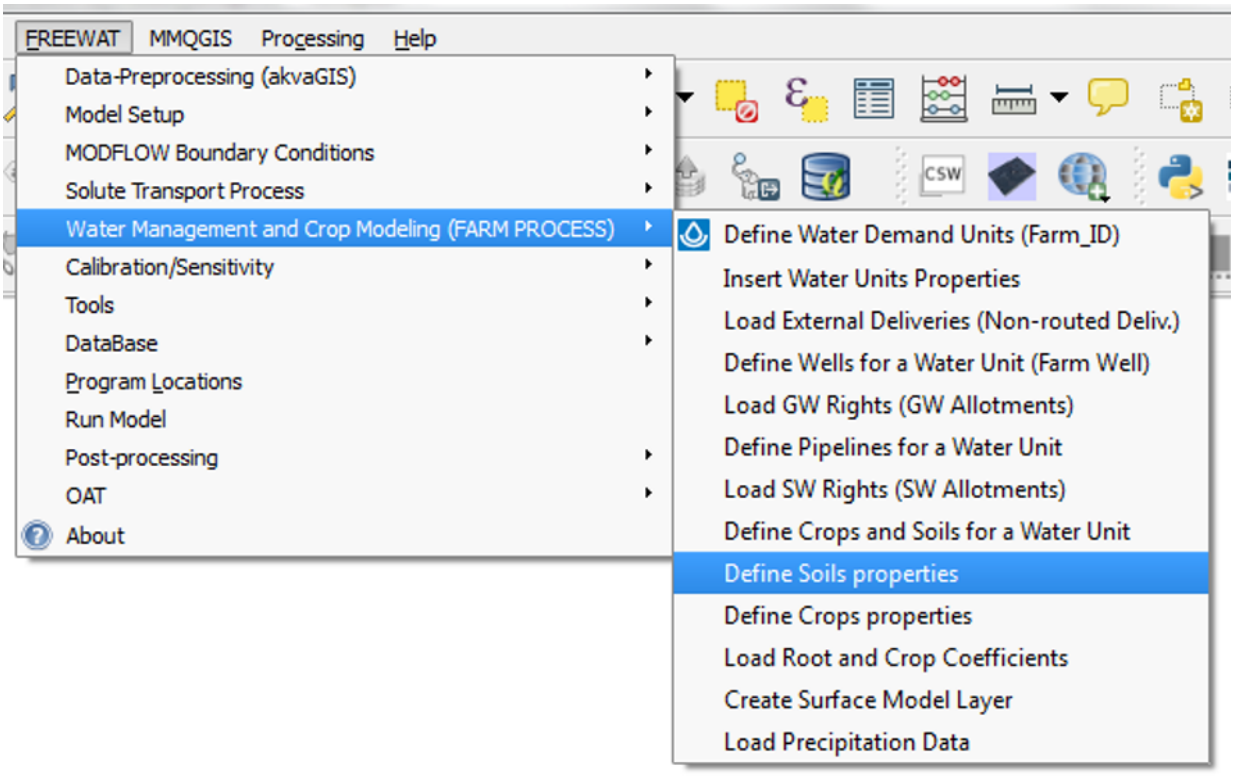
	PKUID	ID	ROW	COL	soil_id	crop_id
0	1	0	15	1	1	1
1	2	0	15	2	1	1
2	3	0	15	3	1	1
3	4	0	15	4	1	1
4	5	0	15	5	1	1
5	6	0	15	6	1	1
6	7	0	15	7	1	1
7	8	0	15	8	1	1
8	9	0	15	9	1	1
9	10	0	15	10	1	1
10	11	0	15	11	1	1
11	12	0	15	12	1	1
12	13	0	15	13	1	1
13	14	0	15	14	1	1
14	15	0	15	15	1	1

Soils properties

Once defined the spatial distribution of soils types, some soil-related data must be assigned to each of them.

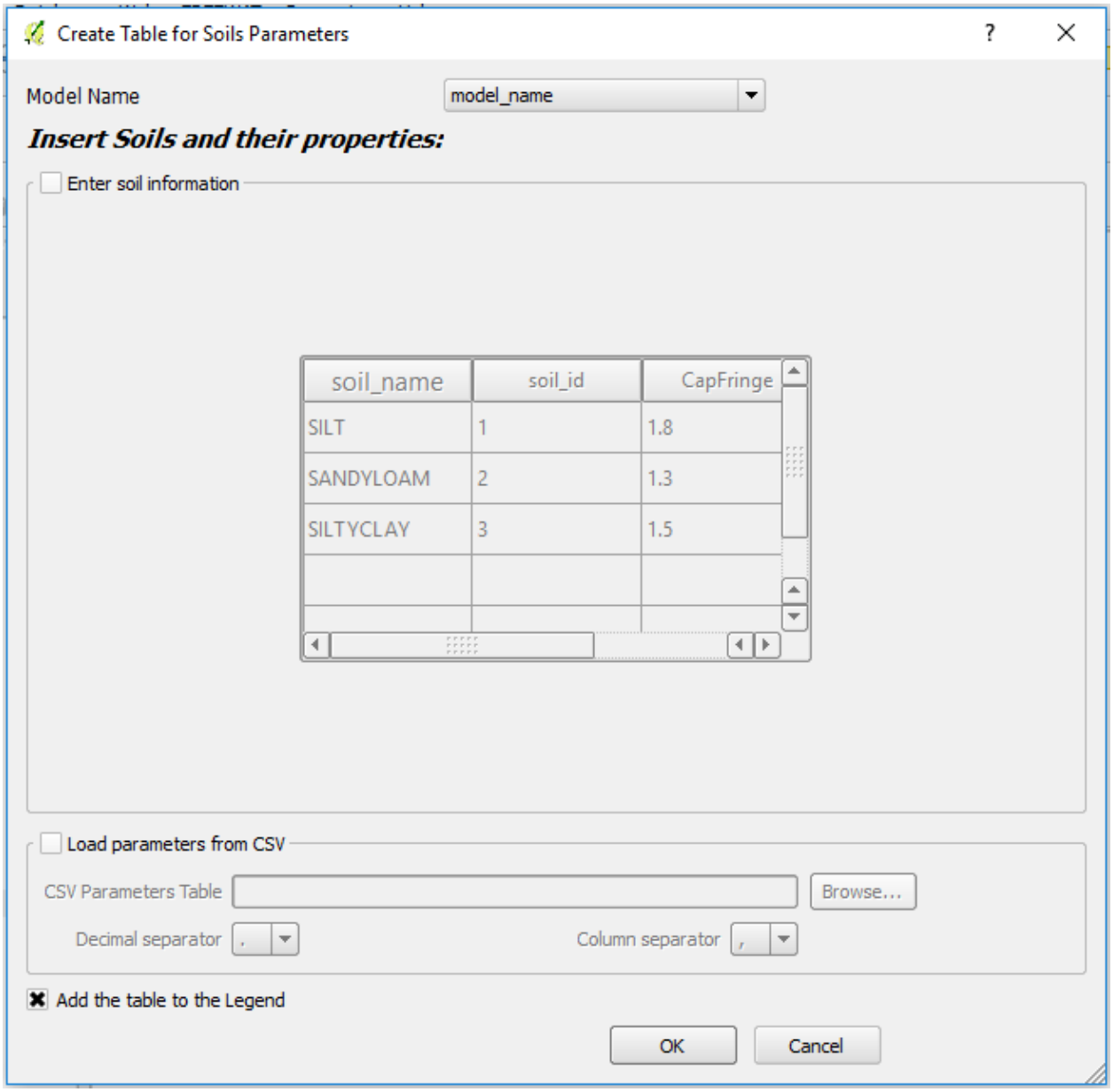
To define *soils properties*, the following menu must be used:

FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Define Soils properties.



In the **Create Table for Soils Parameters** window, the following data are required:

- *Model Name*: name of the hydrological model;
- if *Enter soil information* is checked, the User can fill manually the table with all the necessary parameters to be assigned to each soil type;
- if *Load parameters from CSV* is checked, the User can load a csv file containing parameters to be assigned to each soil type, using the *Browse...* button (field *CSV Parameters Table*). In this case, the User must define the *Decimal separator* and *Column separator* used in the csv file loaded;
- if *Add the table to the Legend* is checked, a table containing the soils properties assigned is loaded in the Layers Panel.



The required soils properties are the following:

- *soil_name*: name assigned to each soil type;
- *soil_ID*: integer ID assigned to each soil type;
- *CapFringe*: depth of the capillary fringe [L] for each soil type.

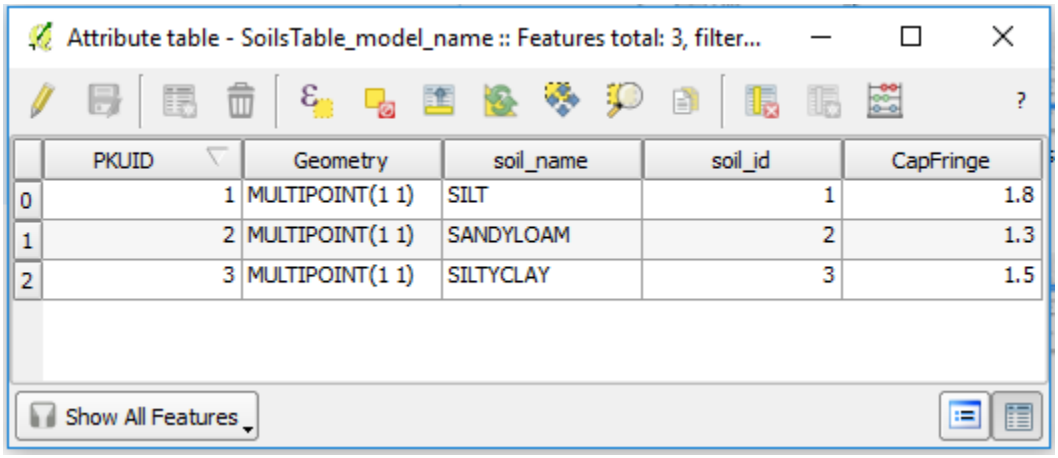
If loaded, the csv file must follow this structure.

Note: If *Enter soil information* is checked, the table already contains three soils types (*SANDYLOAM*, *SILT* and *SILTYCLAY*) with proper values for *CapFringe* (refer to example problem 1 in Schmid et al., 2006). Such soils types are those for which linear approximation of transpiration uptake with changing groundwater levels were derived and embedded within the Farm Process code (Schmid et al., 2006). In the current version, the User can edit the field *CapFringe*, but **not** *soil_id*, as the code identifies each soil type by a specific soil_id.

A new table named *SoilsTable_model_name* is created and loaded in the Layers Panel. It may contain several records, according to the number of soils types defined, and the following fields:

- *PKUID*: database primary key (it must not be modified);
- *Geometry*: ???;
- *soil_name*: name assigned to each soil type;
- *soil_id*: integer ID assigned to each soil type;
- *CapFringe*: depth of the capillary fringe [L] for each soil type.

Note: Such table is filled with values previously assigned in the **Create Table for Soils Parameters** window, but it can be edited later on, if necessary.



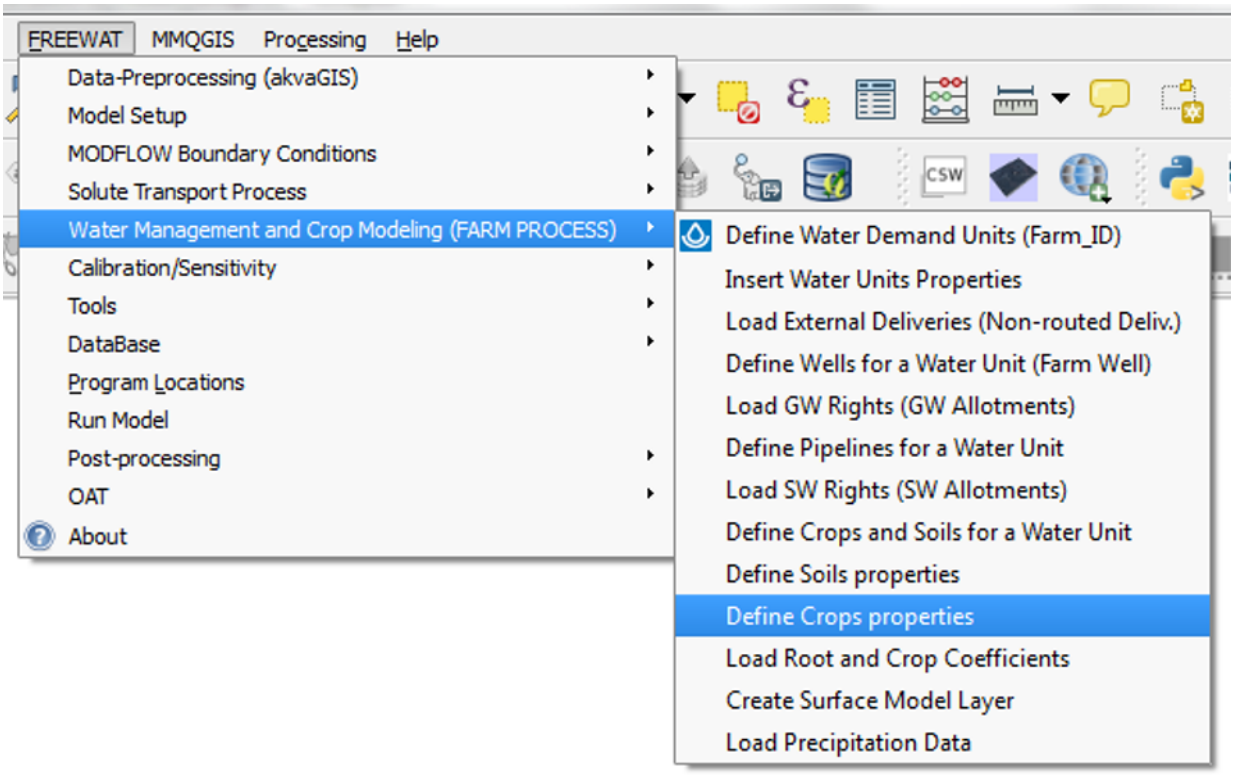
	PKUID	Geometry	soil_name	soil_id	CapFringe
0	1	MULTIPOINT(1 1)	SILT	1	1.8
1	2	MULTIPOINT(1 1)	SANDYLOAM	2	1.3
2	3	MULTIPOINT(1 1)	SILTYCLAY	3	1.5

Crops properties

As done for soils types, some crop-related data must be assigned to each crop type.

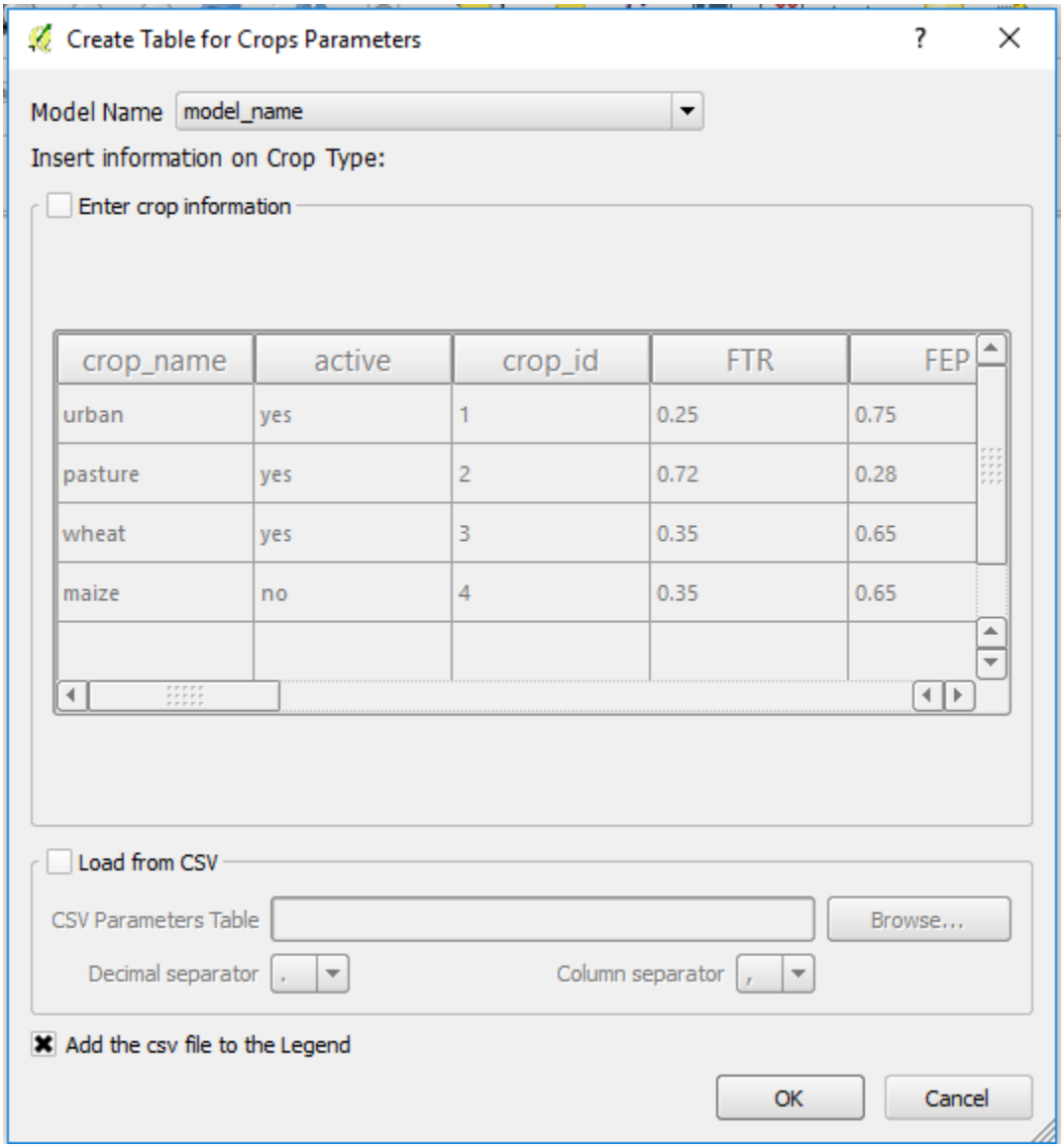
To define *crops properties*, the following menu must be used:

FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Define Crops properties.



In the **Create Table for Crops Parameters** window, the following data are required:

- *Model Name*: name of the hydrological model;
- if *Enter crop information* is checked, the User can fill manually the table with all the necessary parameters to be assigned to each crop type;
- if *Load parameters from CSV* is checked, the User can load a csv file containing parameters to be assigned to each crop type, using the *Browse...* button (field *CSV Parameters Table*). In this case, the User must define the *Decimal separator* and *Column separator* used in the csv file loaded;
- if *Add the table to the Legend* is checked, a table containing the crops properties assigned is loaded in the Layers Panel.



The required crops properties are the following:

- *crop_name*: name of the crop type for which the following data are available;
- *active*: two option are avaiable, *yes* if a crop type is used, *no* if not;
- *crop_id*: crop type identity (to be filled with ID values assigned in the soil_crop MDO);
- *FTR*: transpiratory fraction of consumptive use ($0 <= FTR <= 1$);
- *FEP*: evaporative fraction of consumptive use related to precipitation ($0 <= FEP <= 1$);
- *FEI*: evaporative fraction of consumptive use related to irrigation ($0 <= FEI <= 1$);
- *FIESWP*: fraction of inefficiency losses to surface-water related to precipitation ($0 <= FIESWP <= 1$);
- *FIESWI*: fraction of inefficiency losses to surface-water related to irrigation ($0 <= FIESWI <= 1$);
- *PSI1*: negative (partially saturated) or positive (saturated or submerged) value of pressure head, at which root uptake becomes zero due to anoxia or high pressure [L];

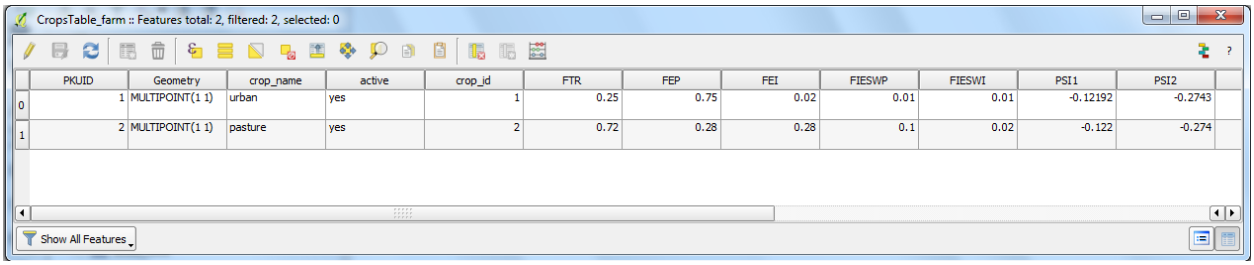
- *PSI2*; negative or positive values of pressure head, at which root uptake is at maximum and from which uptake decreases with rising pressure head due to anoxia [L];
- *PSI3*: negative pressure head, at which root uptake is at maximum and from which uptake decreases with falling pressure head due to wilting [L];
- *PSI4*: negative pressure head, at which root uptake becomes zero due to wilting [L];
- *NONIRR*: non-irrigation flag (if *1*, crop type is not irrigated);
- *IFALLOW*: two options are available, *1* if crop type is fallowed, *0* if not;
- *WPFSlope* and *WPFInt*: slope and intercept of crop-specific water-production function (yield vs. ETc-act; refer to Schmid et al., 2006);
- *CropPrice*: market-price per crop [value/weight].

Note: If *Enter soil information* is checked, the table already contains four crop types (*urban*, *pasture*, *wheat* and *maize*) with proper values for fields *root* through *IFALLOW* (Allen et al., 1998; Faunt, 2009; Miller et al., 2001). The User can edit all fields, along with the field *crop_id*, but should pay attention to be coherent with crop IDs used in the soil_crop MDO.

A new table named *CropsTable_model_name* is created and loaded in the Layers Panel. It may contain several records, according to the number of crops types defined (field *active*: yes), and the following fields:

- *PKUID*: database primary key (it must not be modified);
- *Geometry*: a fake field (it must not be modified);
- *crop_name*: name of the active crop type;
- *active*: two option are available, *yes* if a crop type is used, *no* if not;
- *crop_id*: integer ID assigned to each crop type;
- *ftr*: transpiratory fraction of consumptive use;
- *fep*: evaporative fraction of consumptive use related to precipitation;
- *fei*: evaporative fraction of consumptive use related to irrigation;
- *fieswp*: fraction of inefficiency losses to surface-water related to precipitation;
- *fieswi*: fraction of inefficiency losses to surface-water related to irrigation;
- *psi1*: negative (partially saturated) or positive (saturated or submerged) value of pressure head, at which root uptake becomes zero due to anoxia or high pressure [L];
- *psi2*; negative or positive values of pressure head, at which root uptake is at maximum and from which uptake decreases with rising pressure head due to anoxia [L];
- *psi3*: negative pressure head, at which root uptake is at maximum and from which uptake decreases with falling pressure head due to wilting [L];
- *psi4*: negative pressure head, at which root uptake becomes zero due to wilting [L];
- *NONIRR*: non-irrigation flag;
- *IFALLOW*: fallow flag;
- *WPFSlope* and *WPFInt*: slope and intercept of crop-specific water-production function;
- *CropPrice*: market-price per crop [value/weight].

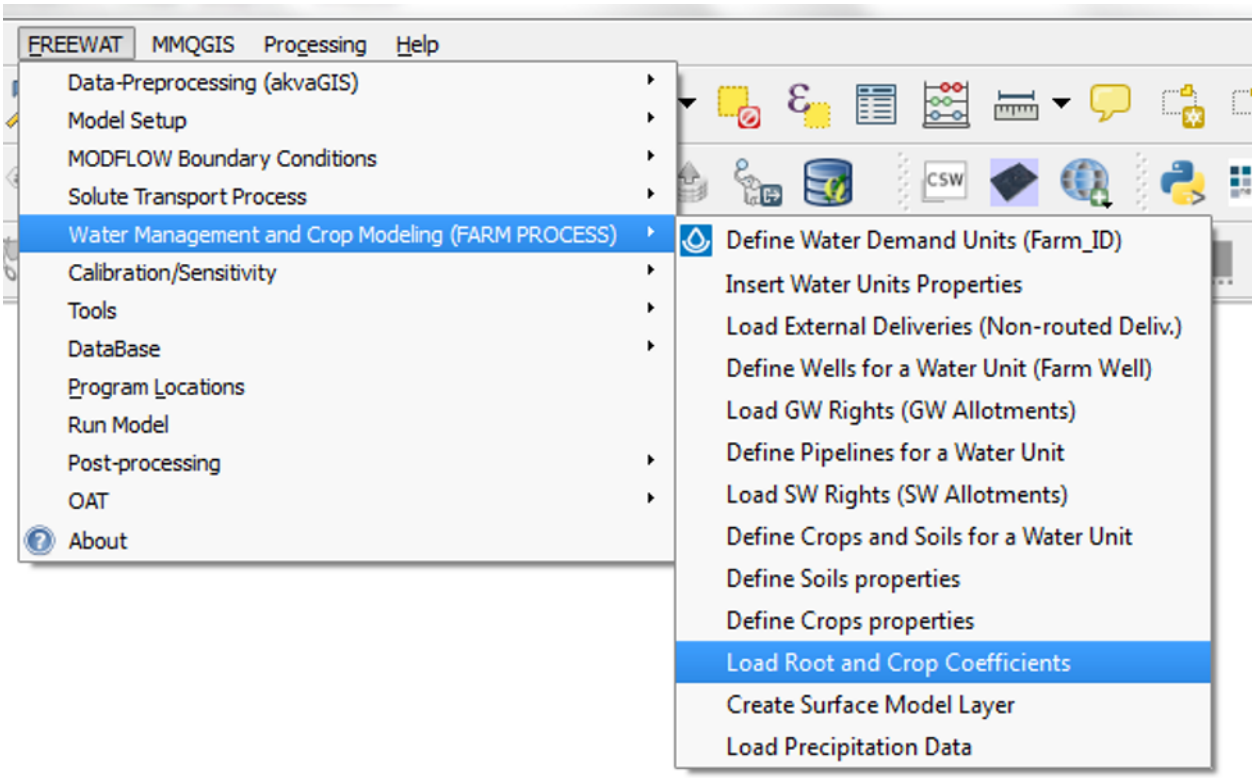
Note: Such table is filled with values previously assigned in the **Create Table for Crops Parameters** window, but it can be edited later on, if necessary.



The depth of the root zone (*ROOT*) and crop coefficients (K_c) must be defined as well for each crop type and for each SP.

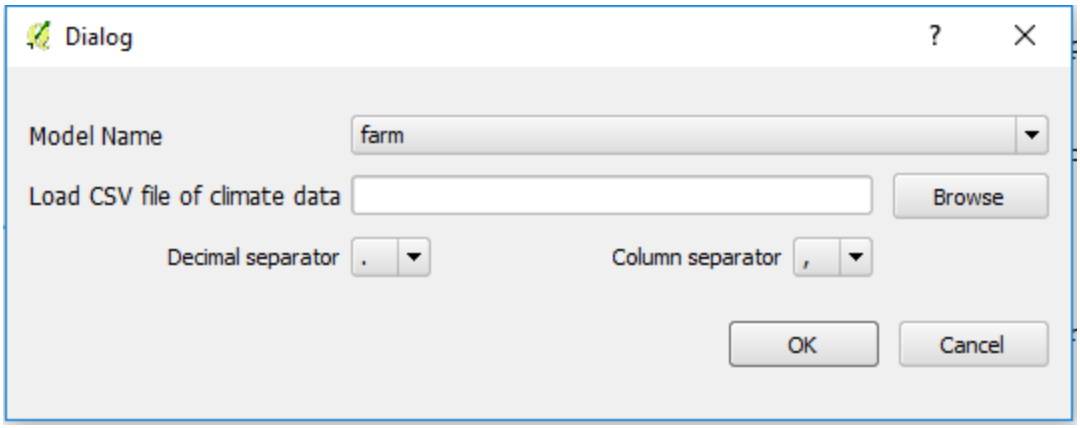
To assign values for *ROOT* and K_c, the following menu must be used:

FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Load Root and Crop Coefficients.



In the **Load Root and Crop Coefficients** window, the following data are required:

- *Model Name*: name of the hydrological model;
- a CSV file with values of *ROOT* and K_c for each crop type and for each SP (*Load CSV file of ROOT* and K_c). In this case, the user must define the *Decimal separator* and *Column separator* used in the csv file loaded.



The csv file must have the following structure:

kc_root.csv

```
1  sp,kc_1,kc_2,kc_3,root_1,root_2,root_3
2  1,0.75,0.96,0.6,0.61,1.22,1.61
3  2,0.75,1.2,0.75,0.61,1.22,1.61
4  3,0.96,1.2,0.96,0.61,1.22,1.61
5  4,1.09,1.2,1.09,0.61,1.22,1.61
6  5,1.09,0.175,1.09,0.61,1.22,1.61
7  6,1.09,0.175,1.09,0.61,1.22,1.61
8  7,1.09,0.175,1.09,0.61,1.22,1.61
9  8,1.09,0.175,1.09,0.61,1.22,1.61
10 9,1.09,0.175,1.09,0.61,1.22,1.61
11 10,0.75,0.175,0.75,0.61,1.22,1.61
12 11,0.75,0.23,0.27,0.61,1.22,1.61
13 12,0.75,0.35,0.27,0.61,1.22,1.61
```

Ln : 14 Col : 1 Sel : 0 | 0 Dos\Windows UTF-8 INS

A new table named *CropCoefficients_model_name* is created and loaded in the Layers Panel. It may contain several records, according to the number of SPs, and the following fields:

- *ROWNO*: database primary key (it must not be modified);
- *sp*: progressive ID of each SP;
- the following fields are repeated according to the number of crop types (*n* refers to a certain crop type):
  - *kc_n*: crop coefficient for the *n*-th crop type;
  - *root_n*: depth of the root zone [L] for the *n*-th crop type.

Note: Such table is filled with values previously assigned in the **Load Root and Crop Coefficients** window, but it can be edited later on, if necessary.

Attribute table - CropCoefficients_model_name :: Features total: 12, filtered: 12, selected: 0

	ROWNO	sp	kc_1	kc_2	kc_3	root_1	root_2	root_3
0	0	1	0.75	0.175	0.6	0.61	1.83	1.61
1	1	2	0.75	0.175	0.75	0.61	1.83	1.61
2	2	3	0.96	0.53	0.96	0.61	1.83	1.61
3	3	4	1.09	0.67	1.09	0.61	1.83	1.61
4	4	5	1.09	0.8	1.09	0.61	1.83	1.61
5	5	6	1.09	0.84	1.09	0.61	1.83	1.61
6	6	7	1.09	0.84	1.09	0.61	1.83	1.61
7	7	8	1.09	0.84	1.09	0.61	1.83	1.61
8	8	9	1.09	0.84	1.09	0.61	1.83	1.61
9	9	10	0.75	0.81	0.75	0.61	1.83	1.61
10	10	11	0.75	0.55	0.27	0.61	1.83	1.61
11	11	12	0.75	0.175	0.27	0.61	1.83	1.61

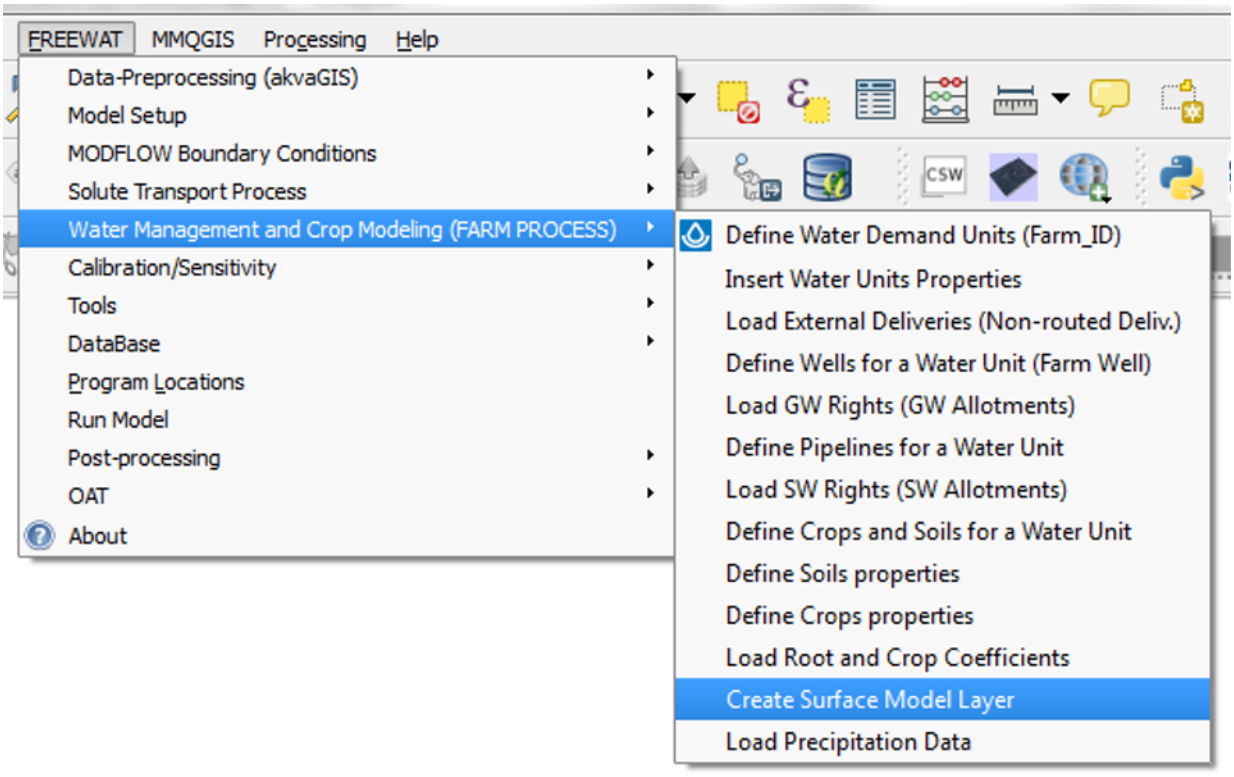
Show All Features

Climate data

The last step consists in defining climate-related data i.e., reference evapotranspiration and precipitation.

To define *reference evapotranspiration*, the following menu must be used:

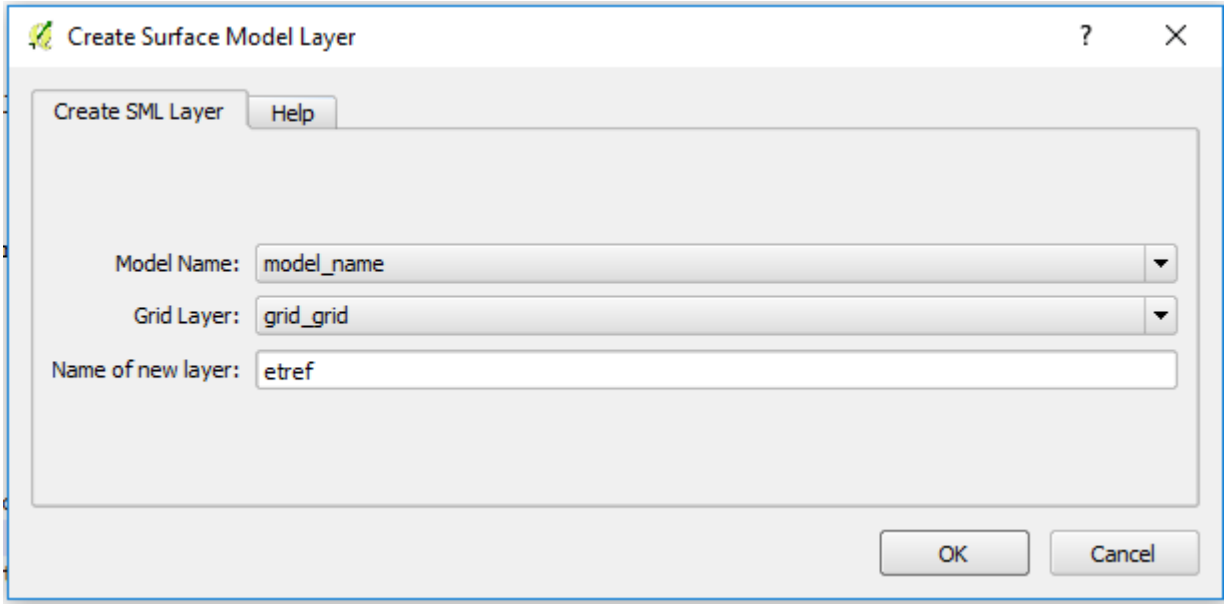
FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Create Surface Model Layer.



In the **Create Surface Model Layer** window, the following data are required:

- *Model Name*: name of the hydrological model;

- *Grid Layer*: grid MDO;
- *Name of new layer*: name of the sml MDO which has to be created.

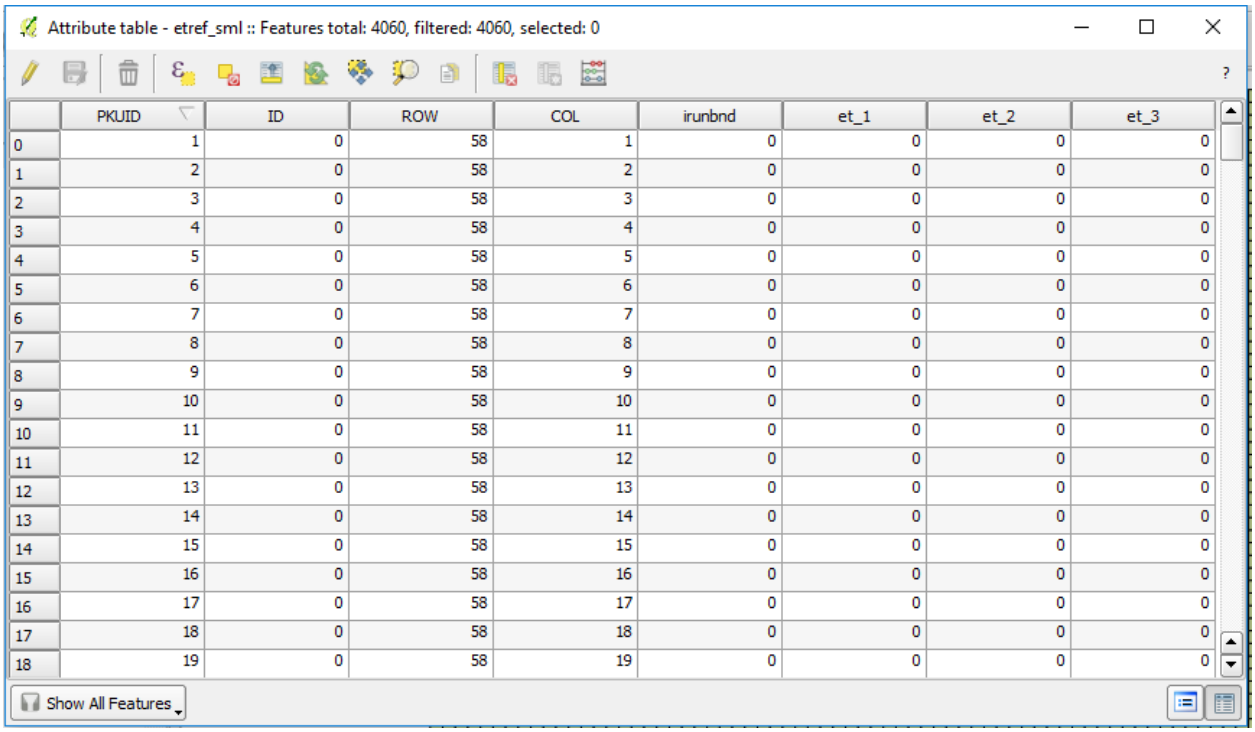


A new MDO, named *etref_sml*, is created, stored within the model DB and loaded in the Layers Panel.

The Attribute Table of such MDO may contain several records, according to the number of grid cells, and the following fields:

- *PKUID*: database primary key (it must not be modified);
- *ID*: database primary key (it must not be modified);
- *ROW*: row number of a grid cell;
- *COL*: column number of a grid cell;
- *irunbnd*: integer value used for UZF package part (not to be considered to the extent of this this manual);
- the following field is repeated according to the number of SPs implemented (*n* refers to the number of a SP):
  - *et_n*: reference evapotranspiration [L/T] during the *n*-th SP.

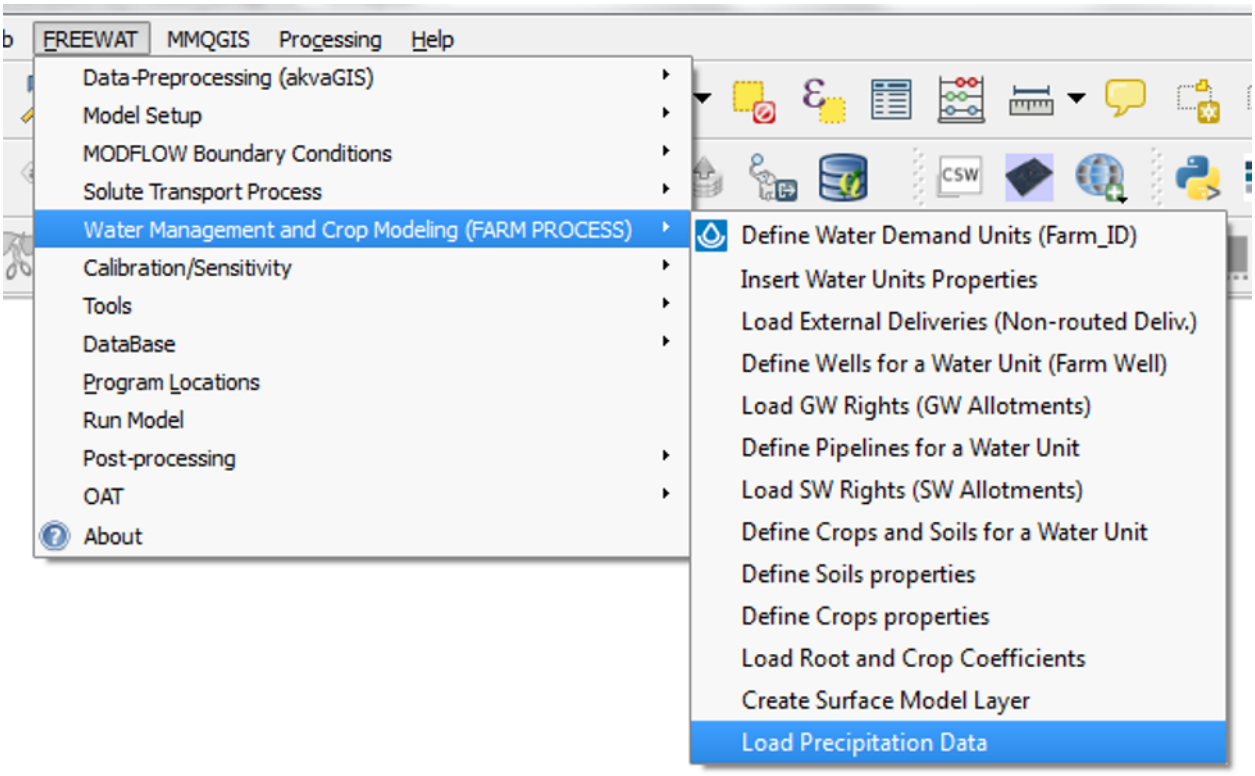
The fields *irunbnd* and *et_n* are filled with default values, which can be modified using QGIS selection and editing tools described in Chapter 5, in Volume 1.



	PKUID	ID	ROW	COL	irunbnd	et_1	et_2	et_3
0	1	0	58	1	0	0	0	0
1	2	0	58	2	0	0	0	0
2	3	0	58	3	0	0	0	0
3	4	0	58	4	0	0	0	0
4	5	0	58	5	0	0	0	0
5	6	0	58	6	0	0	0	0
6	7	0	58	7	0	0	0	0
7	8	0	58	8	0	0	0	0
8	9	0	58	9	0	0	0	0
9	10	0	58	10	0	0	0	0
10	11	0	58	11	0	0	0	0
11	12	0	58	12	0	0	0	0
12	13	0	58	13	0	0	0	0
13	14	0	58	14	0	0	0	0
14	15	0	58	15	0	0	0	0
15	16	0	58	16	0	0	0	0
16	17	0	58	17	0	0	0	0
17	18	0	58	18	0	0	0	0
18	19	0	58	19	0	0	0	0

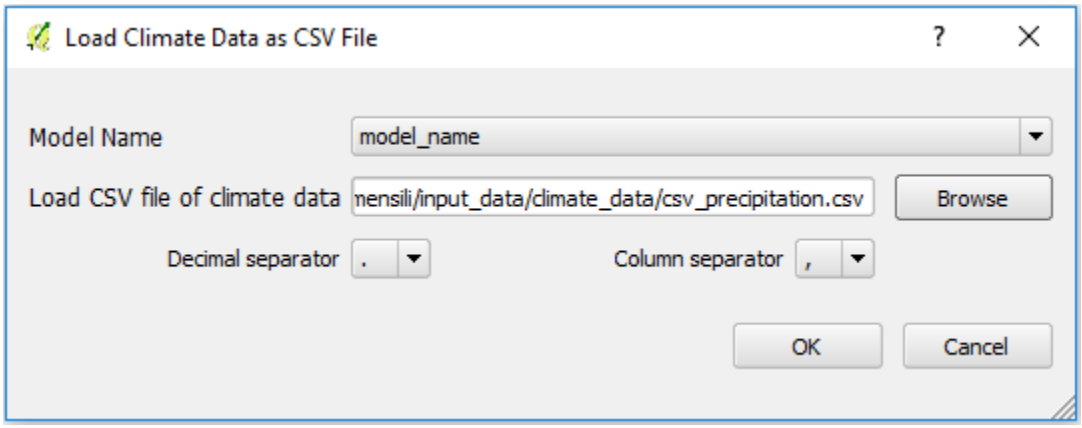
To define *precipitation*, the following menu must be used:

FREEWAT -> Water Management and Crop Modeling (FARM PROCESS) -> Load Precipitation Data.

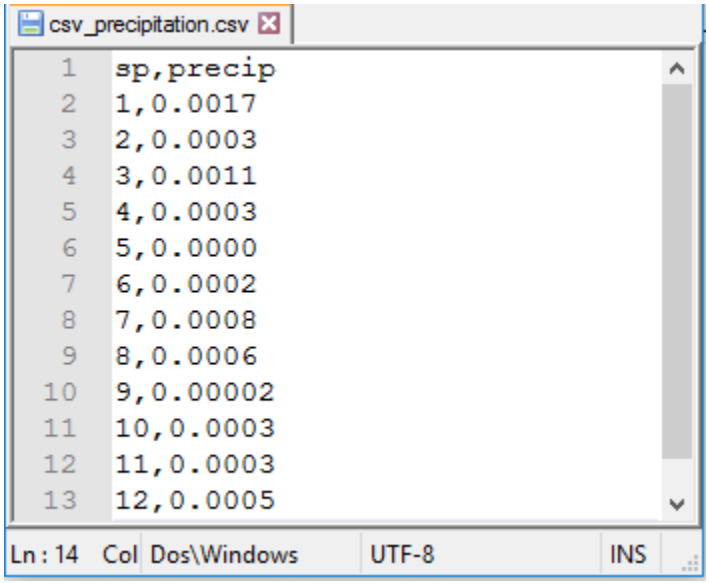


In the **Load Climate Data as CSV File** window, the following data are required:

- *Model Name*: name of the hydrological model;
- a CSV file with values of precipitation data for each SP (field *Load CSV file of climate data*). In this case, the user must define the *Decimal separator* and *Column separator* used in the csv file loaded.

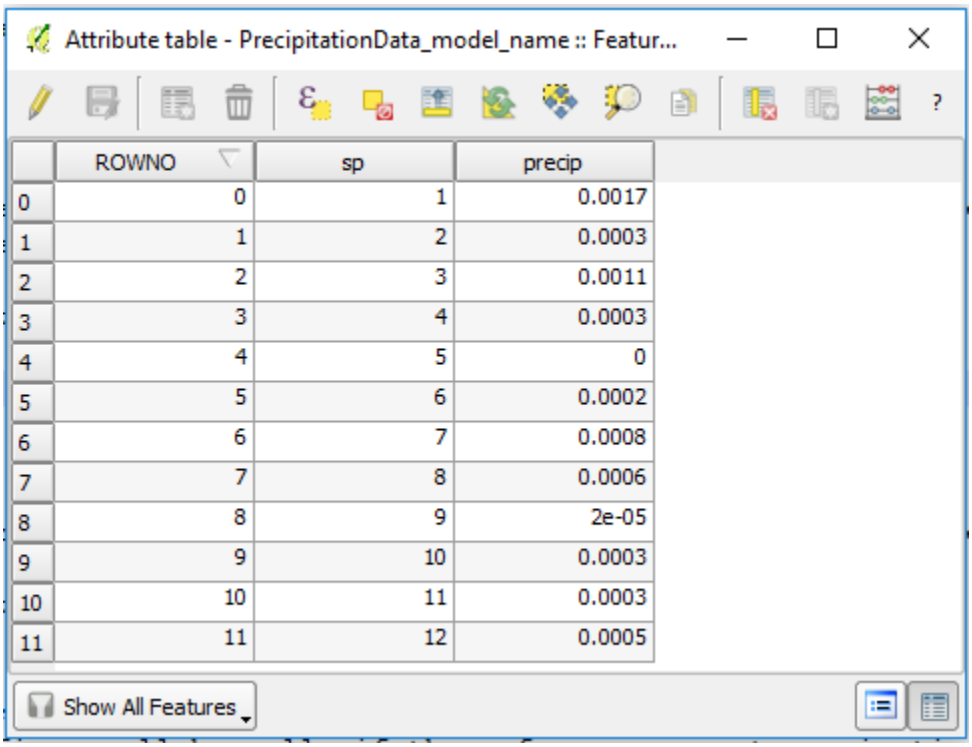


The csv file must have the following structure:



A new table, named *PrecipitationData_model_name*, is created, stored within the model DB and loaded in the Layers Panel. It may contain several records, according to the number of SPs, and the following fields:

- *ROWNO*: database primary key (it must not be modified);
- *sp*: progressive ID of each SP;
- *precip*: precipitation flux [L/T].



	ROWNO	sp	precip
0	0	1	0.0017
1	1	2	0.0003
2	2	3	0.0011
3	3	4	0.0003
4	4	5	0
5	5	6	0.0002
6	6	7	0.0008
7	7	8	0.0006
8	8	9	2e-05
9	9	10	0.0003
10	10	11	0.0003
11	11	12	0.0005

Limitations and Assumptions

The Farm Process implemented in the current version has the following main limitations and assumptions:

- spatial distribution of WDUs cannot vary throughout the simulation: that is, the assignment of WDU IDs is constant for the entire simulation;
- crop rotation is not allowed: that is, the assignment of Crop IDs is constant for the entire simulation;
- if included, non-routed deliveries are time-dependent (they are defined for each stress period), but for each WDU only one type of non-routed delivery can be set;
- if included, surface-water allotments are defined (for each WDU) as time-dependent (they are defined for each stress period). The scheme of *prior appropriation

option* is selected (*IALLOT* = 2). * if included, groundwater allotments are defined (for each WDU) as time-dependent (they are defined for each stress period).

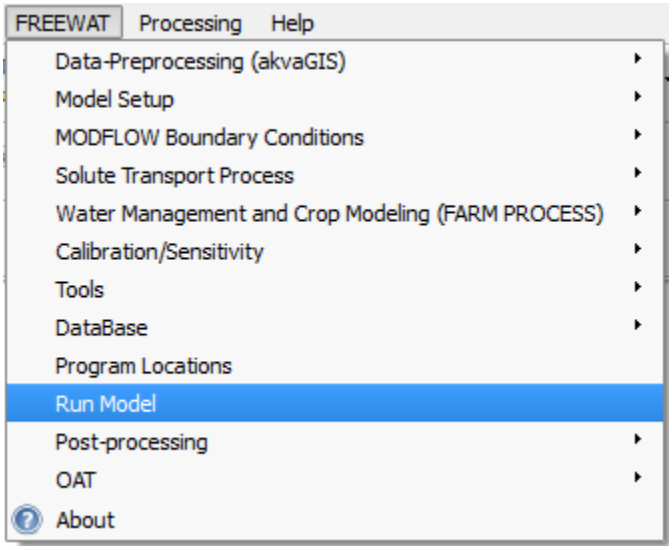
CHAPTER 2

Running a water management scenario

Once the water management scenario to be simulated is built, the executable of *MODFLOW-OWHM* must be loaded in the **Program Locations** window (details can be found in Chapter 7, in Volume 1).

Then, the model run can be performed through the following menu:

FREEWAT -> Run Model.



The processes which can be simulated are the following:

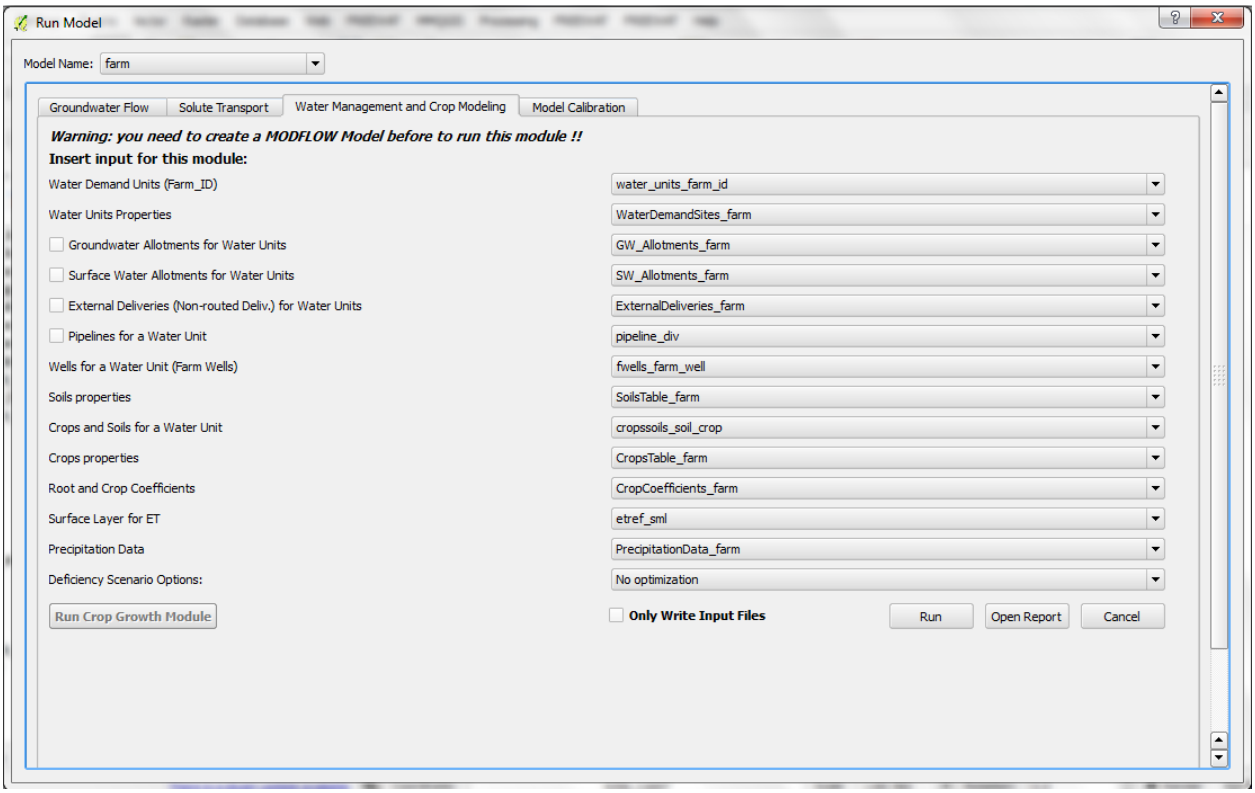
- **Groundwater Flow** (refer to Volume 1);
- **Solute Transport** (refer to Volume 2);
- **Water Management and Crop Modeling**;
- **Model Calibration** (refer to Volume 6).

In the **Water Management and Crop Modeling** tab, the following information is required:

- the wdu MDO must be selected from the dropdown menu corresponding to the field *Water Demand Units (Farm_ID)*;
- the table named *WaterDemandSites_model_name* must be selected from the dropdown menu corresponding to the field *Water Units Properties*;
- the farm well MDO must be selected from the dropdown menu corresponding to the field *Wells for a Water Unit (Farm Wells)*;

- if groundwater allotments exist, *Groundwater Allotments for Water Units* must be checked and the table named *GW_Allotments_model_name* must be selected from the dropdown menu;
- if surface-water allotments exist, *Surface-water Allotments for Water Units* must be checked and the table named *SW_Allotments_model_name* must be selected from the dropdown menu;
- if external deliveries exist, *External Deliveries (Non-routed Deliv.) for Water Units* must be checked and the table named *ExternalDeliveries_model_name* must be selected from the dropdown menu;
- if pipelines exist, *Pipelines for a Water Unit* must be checked and the corresponding div MDO must be selected from the dropdown menu;
- the table named *SoilsTable_model_name* must be selected from the dropdown menu corresponding to the field *Soils Properties*;
- the soil_crop MDO must be selected from the dropdown menu corresponding to the field *Crops and Soils for a Water Unit*;
- the table named *CropsTable_model_name* must be selected from the dropdown menu corresponding to the field *Crops Properties*;
- the table named *CropsCoefficients_model_name* must be selected from the dropdown menu corresponding to the field *Root and Crop Coefficients*;
- the sml MDO must be selected from the dropdown menu corresponding to the field *Surface Layer for ET*;
- the table named *PrecipitationData_model_name* must be selected from the dropdown menu corresponding to the field *Precipitation Data*;
- three options are available in the dropdown menu corresponding to the field *Deficiency Scenario Options*: *No optimization*; *Land/Crop use optimization* if the water use is optimized according to a crop ranking defined by the User; *Economic optimization* if the water use is optimized according to a balance between costs and benefits of each crop type.

Note: As stated in this tab, it is necessary to run the groundwater flow process (**Groundwater Flow** tab) **before** running the water management scenario.



Note: If the aim is to write only model files, without running the simulation, in the **Run Model** window the box *Only Write Input Files* must be checked before clicking the *Run* button.

Once the simulation is successfully terminated, the MODFLOW input file **Farm Process (.FMP)**, specific for the Farm Process module, is created and listed in the **model_name.nam** file.

Several additional input files are created as well in the folder **DATA_FMP**. They are identified by the filename extension **.in** and they are retrieved in the main **Farm Process (.FMP)** file.

The **model_name.list** file is created as well and can be open with any text editor or using the *Open Report* button in the **Run Model** window. Here, the aquifer water budget is complemented by farm-related budget terms (for details refer to Schmid et al., 2006).

Note: The button *Run Crop Growth Module* is not enabled in this version.

CHAPTER 3

Model output and post-processing

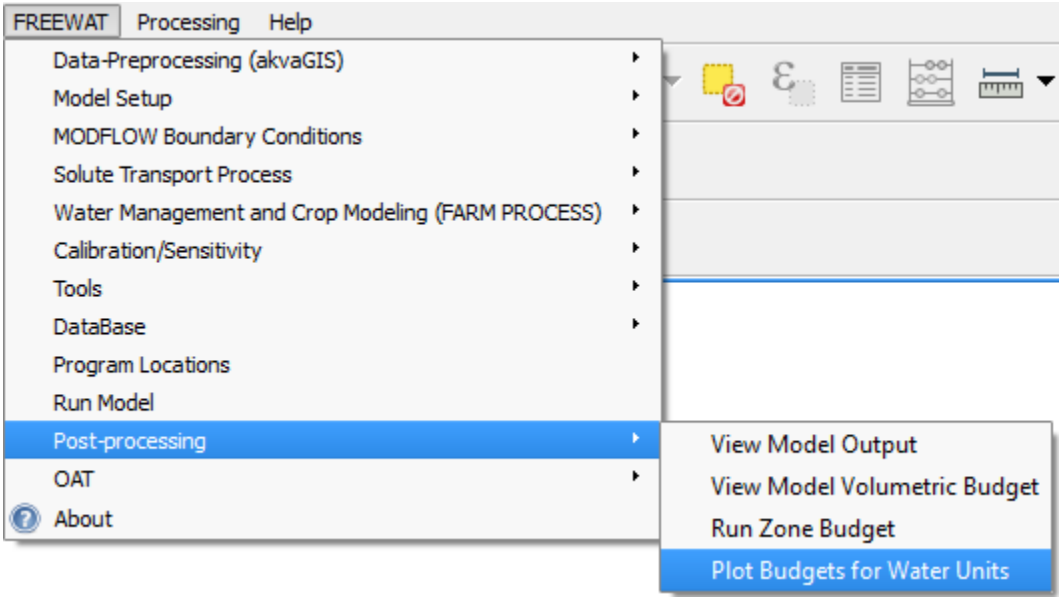
Besides the input files mentioned in Chapter 2, the following output files are also created in the working directory:

- **ET_ARRAY.OUT**: text file containing evapotranspiration distributions all over the grid and for each time-step;
- **FB_DETAILS.OUT**: text file containing information about the simulated Detailed Farm Budget components for each time-step;
- **FDS.OUT**: text file containing information about initial and final demand and supply flow rates, as a result of the application of a deficiency scenario and for each time-step;
- **FNRCH_ARRAY.OUT**: text file containing farm net recharge flow rates for each time-step;
- **FWELLS.OUT**: text file containing the simulated farm-well flow rates for each time-step.

Display model output

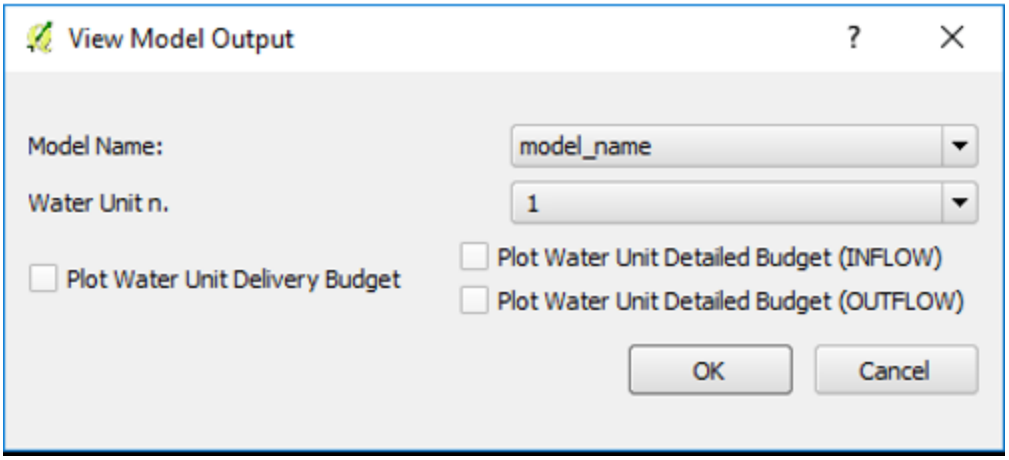
Once the model run has been successfully completed, some components of the farms' budget (files **FB_DETAILS.OUT** and **FDS.OUT**) can be displayed through the following menu:

FREEWAT -> Post-processing -> Plot Budgets for Water Units.

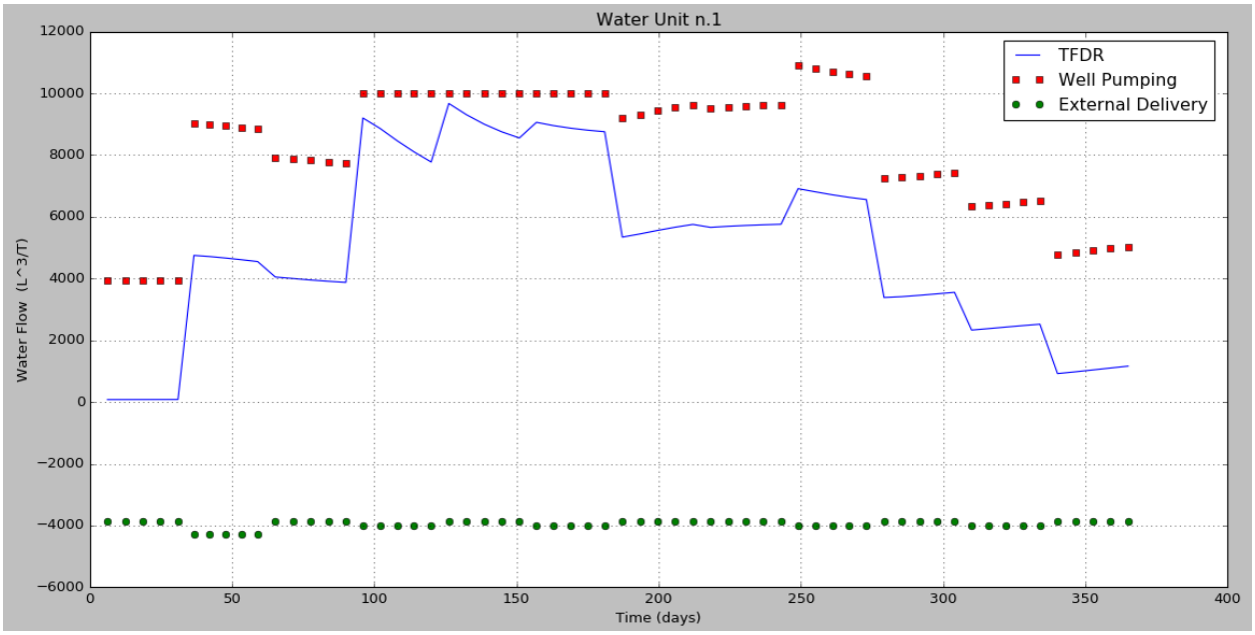


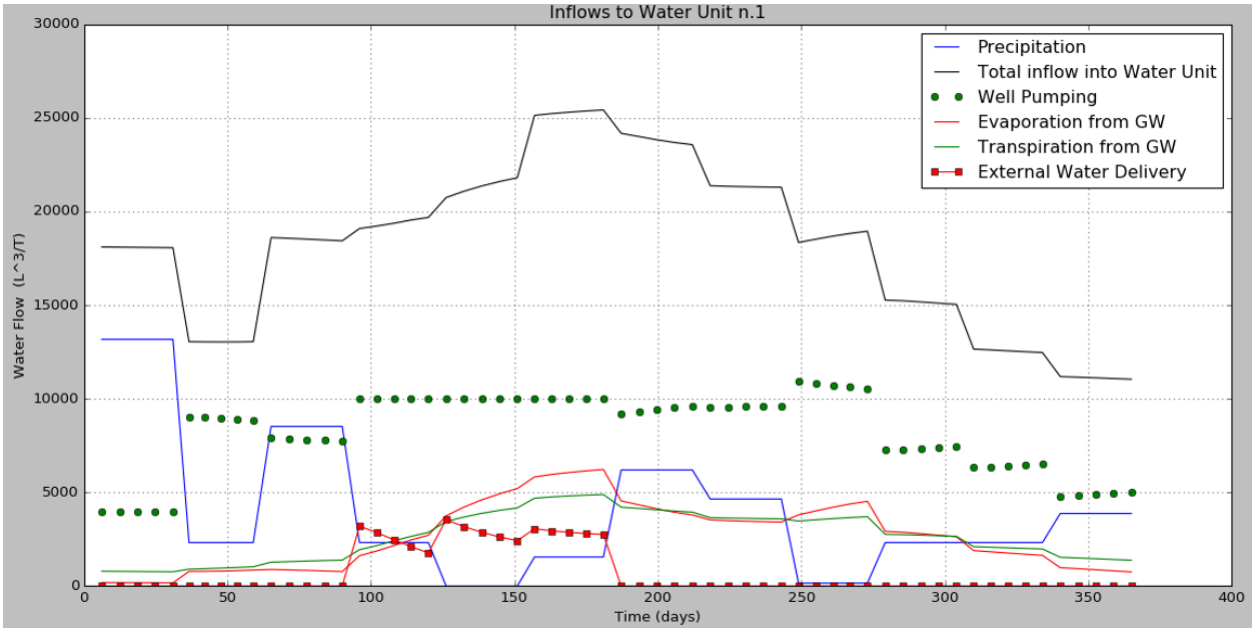
The following data are required in the **View Model Output** window:

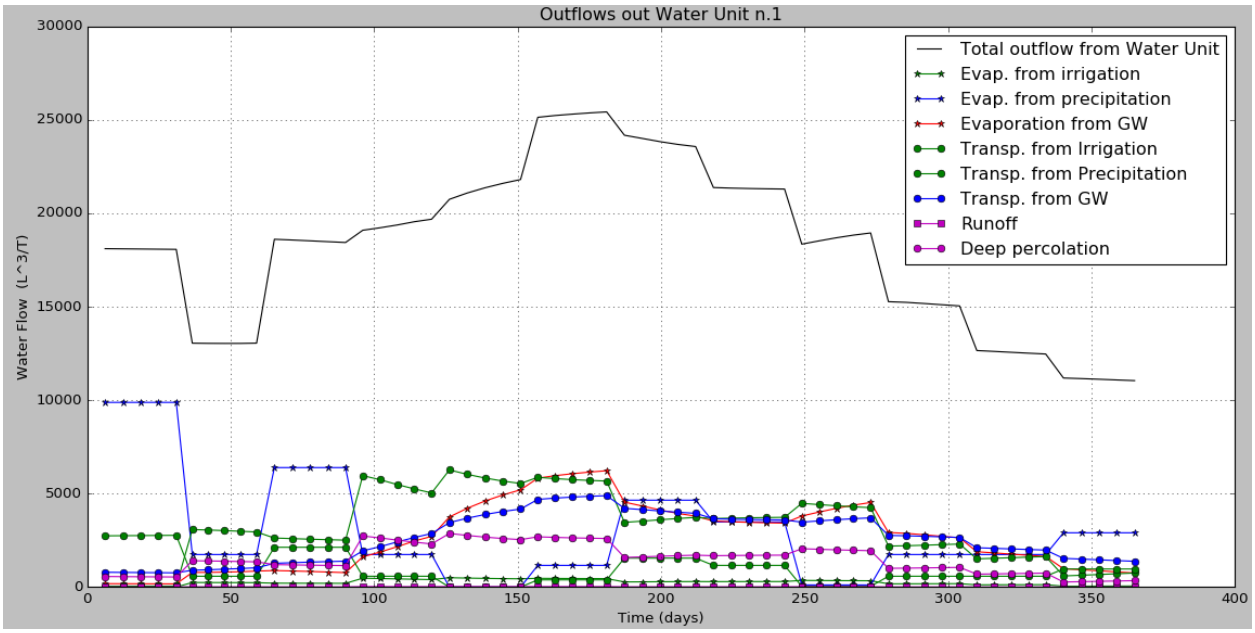
- *Model Name*: name of the hydrological model;
- *Water Unit n.*: id of the WDU for which the budget will be displayed;
- if *Plot Water Unit Delivery Budget* is checked, the following components of the **FB_DETAILS.OUT** and **FDS.OUT** files are represented:
  - ***TFDR*: Total Farm Delivery Requirement (i.e., the farm irrigation demand);**
    - *Well Pumping*: pumping rate from farm wells;
    - *External Delivery*: the amount of water needed to fully satisfy the *TFDR* and which must be derived from external sources;
- if *Plot Water Unit Detailed Budget (INFLOW)* is checked, the following components of the **FB_DETAILS.OUT** file are represented:
  - ***Precipitation*: the amount of water provided by precipitation;**
    - *Total inflow into Water Unit*: the amount of water provided by any available source (precipitation, root uptake, ground- and surface-water);
    - *Well Pumping*: pumping rate from farm wells;
    - *Evaporation from GW*;
    - *Transpiration from GW*;
    - *External Water Delivery*: the amount of water needed to fully satisfy the *TFDR* and which must be derived from external sources;
- if *Plot Water Unit Detailed Budget (OUTFLOW)* is checked, the following components of the **FB_DETAILS.OUT** file are represented:
  - *Total outflow from Water Unit*: the amount of water removed by evapotranspiration, runoff and deep percolation;
  - *Evap. from Irrigation*;
  - *Evap. from Precipitation*;
  - *Evaporation from GW*;
  - *Transp. from Irrigation*;
  - *Transp. from Precipitation*;
  - *Transp. from GW*;
  - *Runoff*;
  - *Deep percolation*.



For each plot, the time (in model time units) is displayed along the x axis and the water flow $[L^3/T]$ is displayed along the y axis.




Inflows to Water Unit n.1
Precipitation
Total inflow into Water Unit
Well Pumping
Evaporation from GW
Transpiration from GW
External Water Delivery
Water Flow (L^3/T)
Time (days)
0
5000
10000
15000
20000
25000
30000
0
50
100
150
200
250
300
350
400


Outflows out Water Unit n.1
Total outflow from Water Unit
Evap. from irrigation
Evap. from precipitation
Evaporation from GW
Transp. from Irrigation
Transp. from Precipitation
Transp. from GW
Runoff
Deep percolation
Water Flow (L^3/T)
Time (days)
0
5000
10000
15000
20000
25000
30000
0
50
100
150
200
250
300
350
400

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Harbaugh AW (2005). MODFLOW-2005, The U.S. Geological Survey Modular Ground-Water Model - the Ground-Water Flow Process. U.S. Geological Survey, Techniques and Methods 6?A16, 253 p.

Harbaugh AW, Banta ER, Hill MC, McDonald MG (2000). MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model ? User Guide to Modularization Concepts and the Ground-Water Flow Process. U.S. Geological Survey, Open-File Report 00-92, 130 p.

Miller P, Lanier W, Brandt S (2001). Using growing degree days to predict plant stages. Ag/Extension Communications Coordinator, Communications Services, Montana State University-Bozeman, Bozeman, MO.

Schmid W, Hanson RT, Maddock T, Leake SA (2006). User Guide for the Farm Process (FMP1) for the U.S. Geological Survey?s Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, MODFLOW-2000. U.S. Geological Survey, Techniques and Methods 6?A17, 140 p.

Schmid W and Hanson RT (2009). The Farm Process Version 2 (FMP2) for MODFLOW-2005 - Modifications and Upgrades to FMP1. U.S. Geological Survey, Techniques and Methods 6?A32, 116 p.

Release history

31/07/2016 release of vesion 0.1

15/10/2016 release of version 0.2

(new abstract inserted)

5/12/2016 release of version 0.3