Examples

version 3.0

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DiSAA – Department of Agricultural and Environmental Sciences

University of Milan

IdrAgra Example - version 2.0

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Disclaimer

The dataset provided in these examples is used exclusively for training purposes. All Data used for this analysis is fake.

Requirements

To run this example, the user needs:

1. the latest version of the IdragraTools plugin installed on its own QGIS environment
2. a few experiences with QGIS interface and some basic knowledge about Geographic Information System
3. ~~the Matlab runtime version 9.9 (R2020b) correctly installed~~ Actually, no more required
4. a copy of the sample dataset available from www.idragra.unimi.it
5. a copy of the IdrAgra user manual by your side, available from www.idragra.unimi.it
6. a big mug of coffee [optional].

Conventions

The following conventions are used in the text:

The symbol → represents flow through menu items

In the text, menu items are in **bold** while attribute names are in *italic*.

This is a warning

This is a hint

Example 1: net crop irrigation needs estimation

Aims

In this example, we will show how to prepare input data for an IdrAgra simulation and how to perform simulation in NEED mode for an irrigation district, to assess the crop irrigation needs considering pedological, land use and meteorological variability, but without considering the efficiencies of the irrigation methods and of the distribution network, i.e. what we will call the “net crop irrigation need-field”.

Study area

The study area is represented by an irrigation district of about 2000 ha of which 1652 ha are for agriculture use (Figure 1). The district has a single main water source, which diverts water from the Blue river.

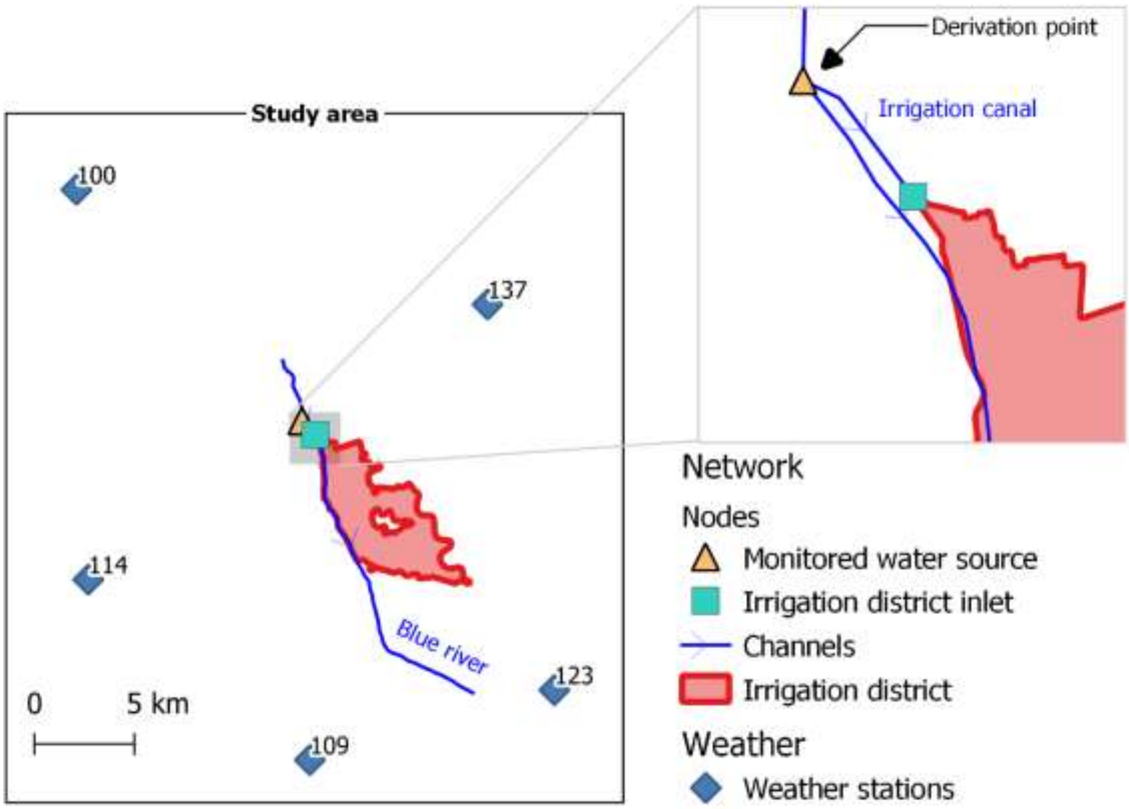


Figure 1. Study area and diversion point from the Blue river

Downstream of the diversion point, the water is conveyed and distributed to the fields through a dense network of unlined open ditches. In this example, the district will be considered as a single Irrigation Unit.

Land use

The district is mainly cultivated with fodder crops, where maize and grass are predominant. Figure 2 shows the land use in years 2005 and 2006, that were used in the simulations.

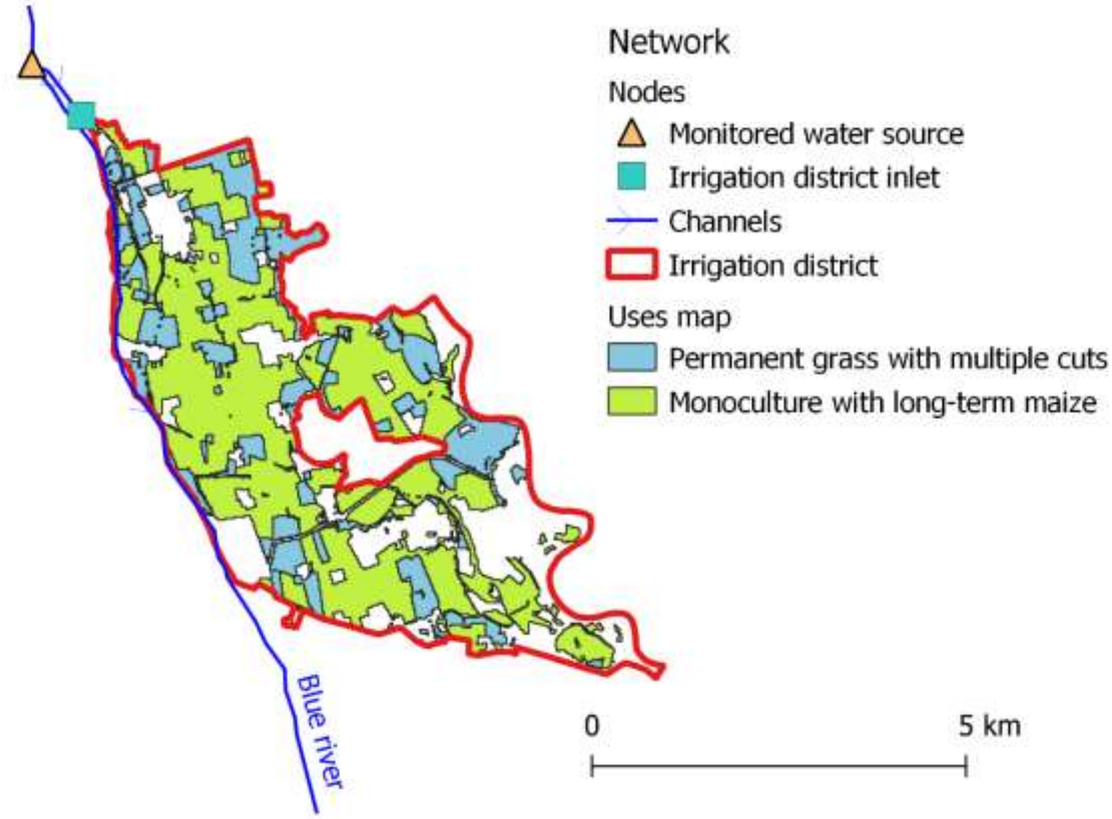


Figure 2. Land use in the study area

Soils

The soil types distribution is available from the regional geographic information services. Eight pedological units are included in the study area (Figure 3) and for each of them the pedological and physico–chemical characteristics of a soil profile are available. The soil hydraulic parameters were derived for each horizon of each of these profiles by applying the Rawls and Barkensiek Pedo-Transfer Function[1] (see Table 1).

[1] Rawls, W.J., and D.L. Brakensiek. 1985. Prediction of soil water properties for hydrologic modeling. p. 293–299. In E.B. Jones and T.J.Ward (ed.) Proc. Symp.Watershed Management in the Eighties, Denver, CO. 30 Apr.–1 May 1985. Am. Soc. Civil Eng., New York

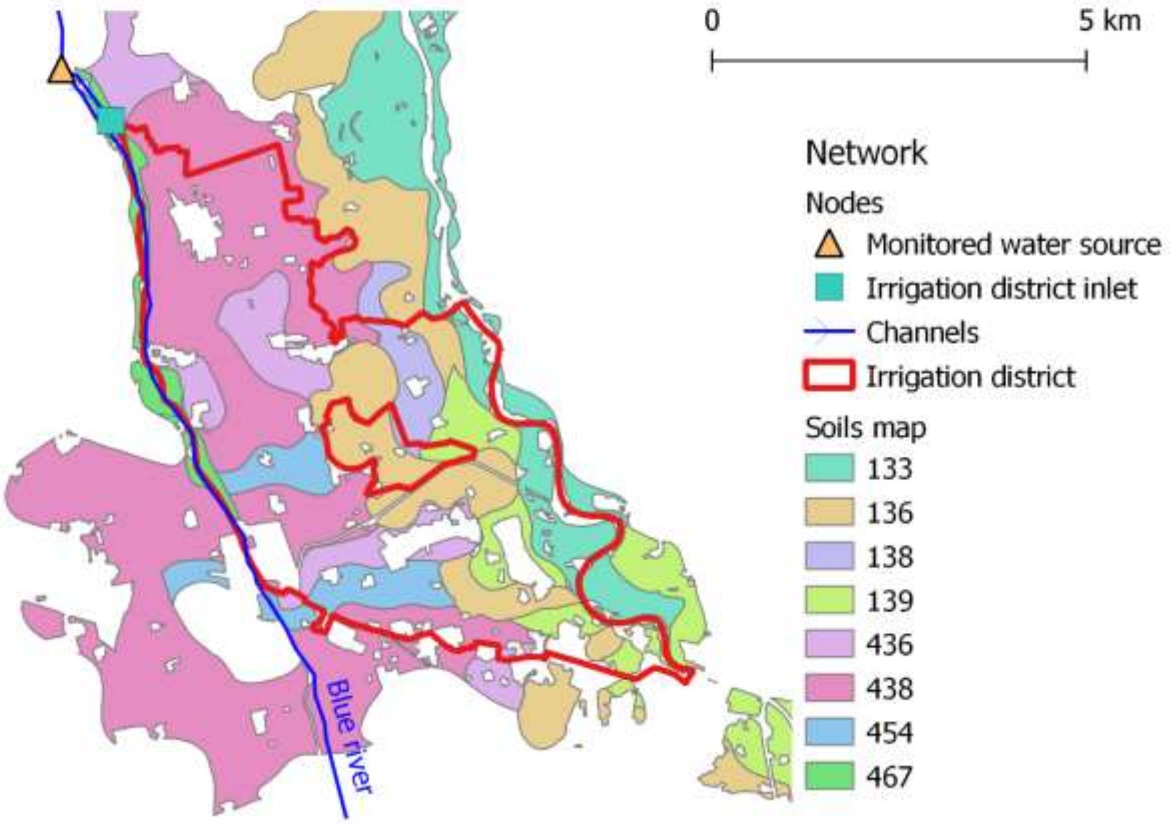


Figure 3: soil map distribution in the study area; colors indicate the different pedological units.

Table 1: hydraulic characteristics of each soil profile used in the example (Ksat: hydraulic conductivity at saturation, Theta FC: soil water content at field capacity, Theta WP: soil water content at wilting point, Theta R: residual soil water content, Theta SAT: soil water content at saturation, texture classes: 1:sand, 2:Loamy sand, 3:sandy loam, 4:loam, 5:silt loam, 6:silt, 7:sandy clay loam, 8: clay loam, 9: silty clay loam, 10: sandy clay, 11: silty clay, 12:clay).

Soil ID	Max depth (cm)	Ksat (cm/h)	Theta FC (-)	Theta WP (-)	Theta R (-)	Theta SAT (-)	texture class
133	7	2.401	0.304	0.115	0.05	0.633	5
133	18	19.59	0.164	0.058	0.043	0.467	3
133	201	42.301	0.129	0.042	0.032	0.461	1
136	35	20.433	0.329	0.074	0.02	0.792	3
136	201	47.059	0.142	0.039	0.025	0.564	1
138	40	7.728	0.233	0.059	0.027	0.552	3
138	150	0.279	0.356	0.119	0.055	0.499	5
138	201	5.401	0.211	0.072	0.048	0.472	3
139	39	3.272	0.279	0.103	0.061	0.529	4
139	100	1.848	0.25	0.102	0.068	0.459	4
139	201	28.294	0.123	0.044	0.036	0.413	1
436	40	5.723	0.222	0.077	0.035	0.576	5
436	80	6.751	0.239	0.116	0.08	0.507	3
436	100	18.983	0.194	0.076	0.054	0.507	3
436	120	22.764	0.136	0.06	0.051	0.406	1

436	155	30.763	0.108	0.049	0.041	0.412	1
436	201	28.73	0.106	0.044	0.037	0.417	1
438	55	9.144	0.208	0.06	0.034	0.519	3
438	90	10.076	0.224	0.125	0.096	0.431	3
438	160	25.117	0.123	0.064	0.055	0.406	1
438	201	0.083	0.369	0.171	0.085	0.477	9
454	50	2.994	0.253	0.097	0.054	0.542	4
454	80	2.048	0.317	0.137	0.07	0.624	5
454	105	0.33	0.41	0.192	0.102	0.578	5
454	155	0.907	0.332	0.139	0.073	0.57	5
454	201	1.018	0.317	0.116	0.054	0.57	5
467	40	8.984	0.201	0.062	0.031	0.549	3
467	60	6.889	0.177	0.07	0.049	0.459	3
467	140	3.356	0.225	0.079	0.047	0.499	3
467	201	38.718	0.098	0.046	0.039	0.43	1

Weather stations

A dataset of 5 agro-meteorological station is available for the region where the district lies (Figure 1).

For each weather station, the daily timeseries of the following variables were collected for the simulation period: maximum temperature, minimum temperature, precipitation, maximum relative humidity, minimum relative humidity, wind at 10 m above the ground and the solar radiation.

For example, Figure 4 shows the pattern of temperature and precipitation over the simulation period for weather station 100. It can be noticed that in the year 2005, the crop season was very hot and relatively dry (202mm in 2005 compared to 395mm in 2006); in late June and July of the first year, an intense heat wave hit the district, when the maximum temperatures were above 35°C for several days. In the year 2006 the summer temperatures were lower, never reaching 35°C.

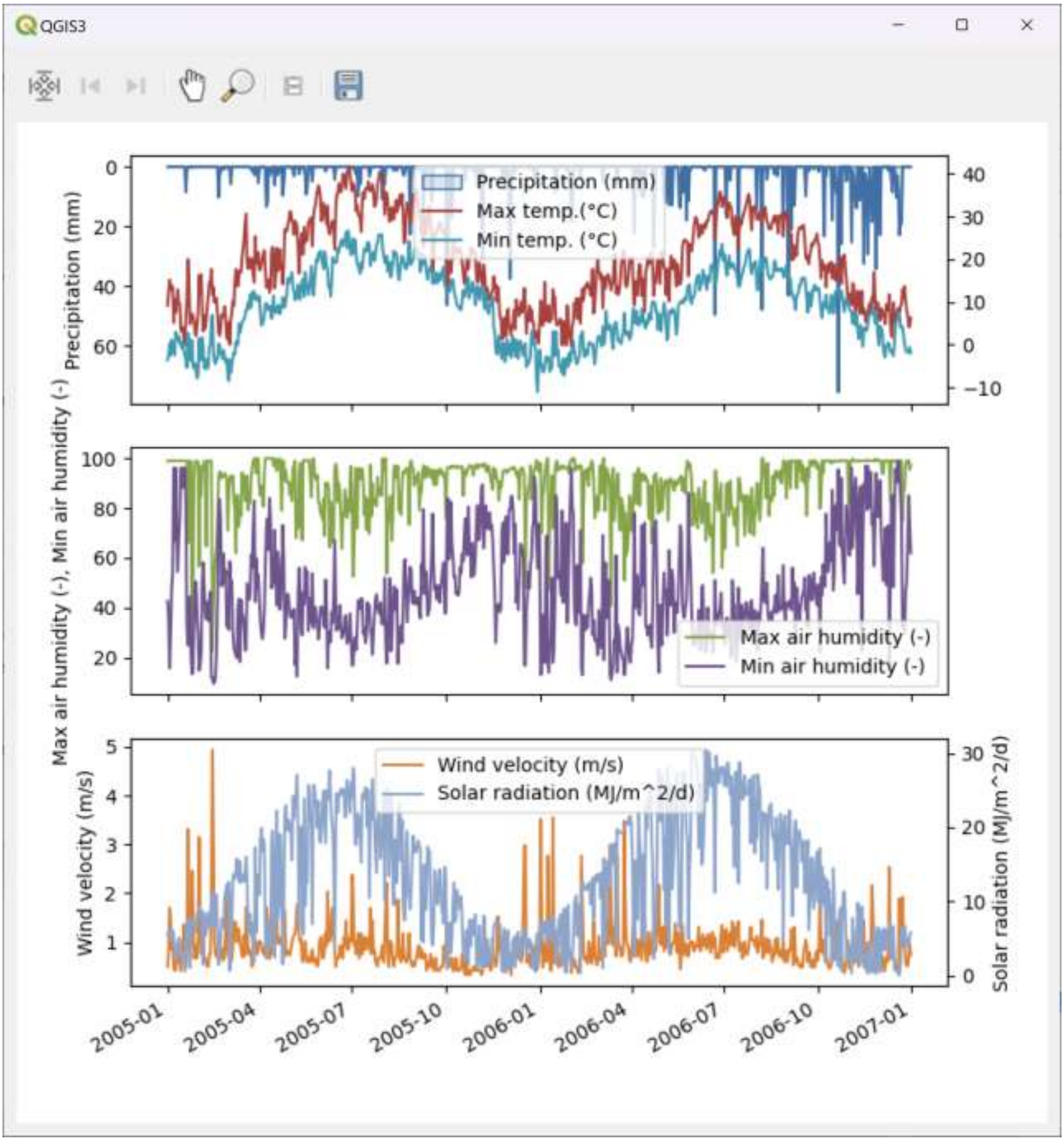


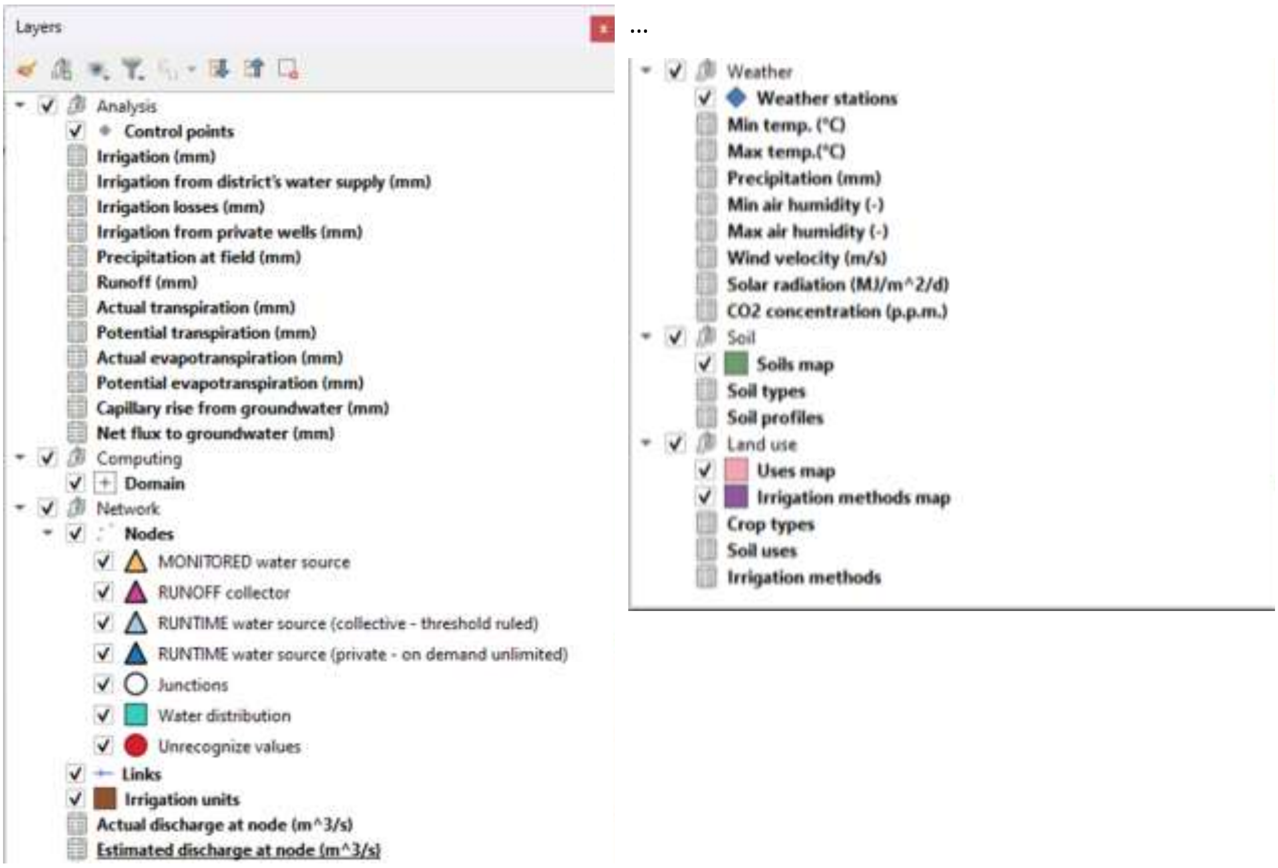
Figure 4: daily meteorological time series for weather station 100.

Perform the IdrAgra simulation

Each IdrAgra simulation consists of a four-step process: 1. Build the study area dataset 2. Set up the simulation parameters 3. Run CropCoef and IdrAgra and 4. Analyse and post-process of the simulation results. These steps can be performed using a variety of software tools (e.g., GIS, spreadsheets, programming platforms, etc.), but using the IdrAgraTools plugin greatly facilitates the operations. In fact, IdrAgraTools offers a unique environment where all the simulation steps can be carried out in a guided form, as illustrated in the next sections.

Build the study area dataset

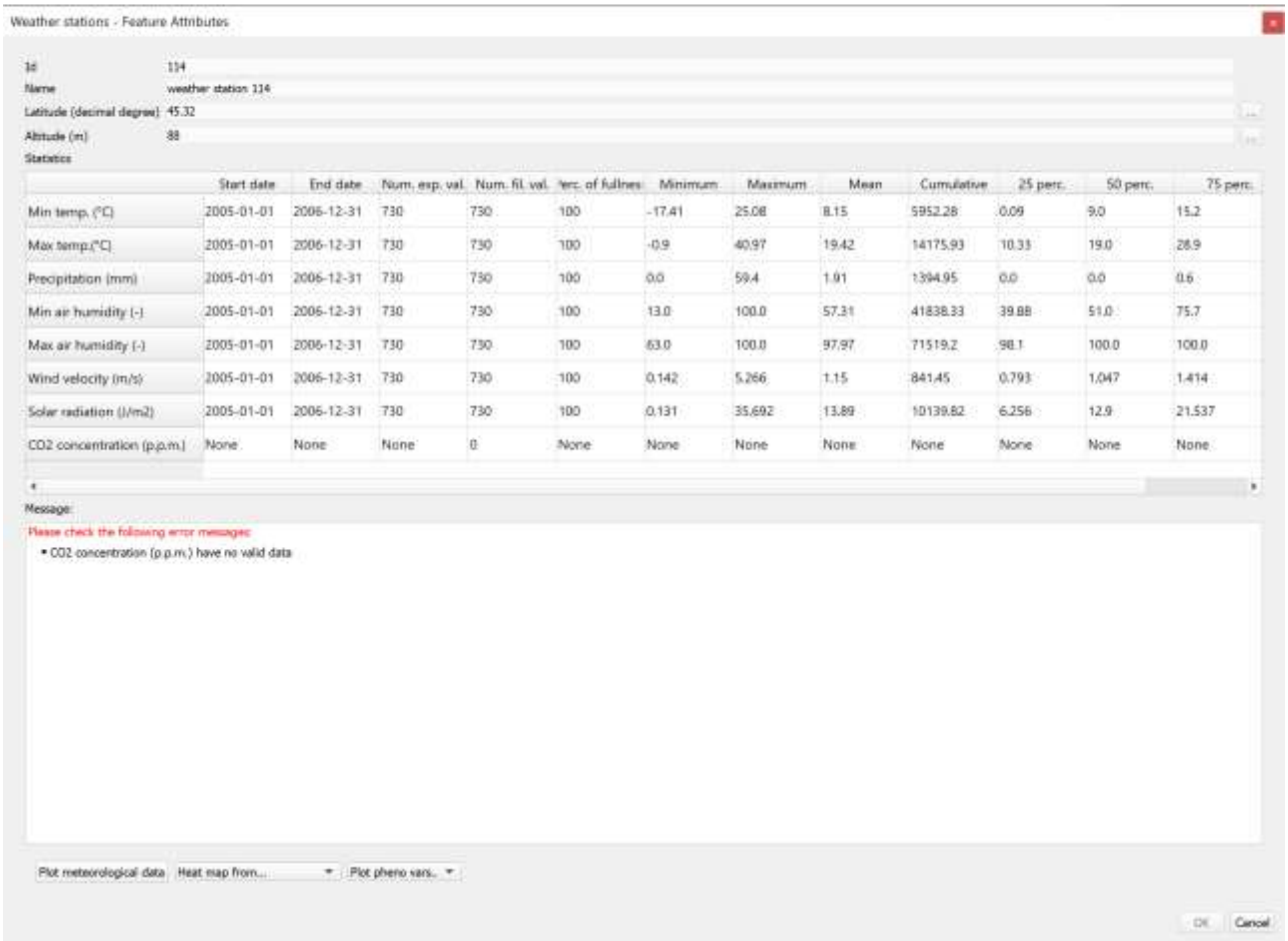
All the data and information required by this example is contained in the file example1_DATA.gpkg. Figure 5 shows the list of the layers loaded in the QGIS project.



follow ...

Figure 5: table of contents of the dataset provided for example 1.

The dataset contains information about the meteorological conditions (both weather stations locations and timeseries of meteorological variables). Five weather stations are implemented in this dataset, identified by unique IDs (100, 109,114,123,137). Connected to each of them, time series of meteorological variables for two years are provided. To check the completeness of the time series of a specific weather station, switch on the attribute form dialog (Figure 6) both from the attribute table or the identify tool inside QGIS.


Weather stations - Feature Attributes

Id 114
Name weather station 114
Latitude (decimal degree) 45.32
Altitude (m) 88
Statistics

	Start date	End date	Num. exp. val.	Num. fil. val.	'erc. of fullnes	Minimum	Maximum	Mean	Cumulative	25 perc.	50 perc.	75 perc.
Min temp. (°C)	2005-01-01	2006-12-31	730	730	100	-17.41	25.08	8.15	5952.28	0.09	9.0	15.2
Max temp.(°C)	2005-01-01	2006-12-31	730	730	100	-0.9	40.97	19.42	14175.93	10.33	19.0	28.9
Precipitation (mm)	2005-01-01	2006-12-31	730	730	100	0.0	59.4	1.91	1394.95	0.0	0.0	0.6
Min air humidity (-)	2005-01-01	2006-12-31	730	730	100	13.0	100.0	57.31	41838.33	39.88	51.0	75.7
Max air humidity (-)	2005-01-01	2006-12-31	730	730	100	63.0	100.0	97.97	71519.2	98.1	100.0	100.0
Wind velocity (m/s)	2005-01-01	2006-12-31	730	730	100	0.142	5.266	1.15	841.45	0.793	1.047	1.414
Solar radiation (J/m2)	2005-01-01	2006-12-31	730	730	100	0.131	35.692	13.89	10139.82	6.256	12.9	21.537
CO2 concentration (p.p.m.)	None	None	None	0	None	None	None	None	None	None	None	None

Message:
Please check the following error messages:
• CO2 concentration (p.p.m.) have no valid data

Plot meteorological data | Heat map from... | Plot pheno vars..
OK | Cancel

Figure 6: attribute form view for the selected weather station.

Meteorological time series, except for CO_2 concentration, must be completely filled by meaningful data for the whole simulation period (missing data will always be treated as zeros)

Meteorological time series could be of different length in the database but simulation period must be complete.

Search for the "form view mode" button in the lower right side of the attribute table of QGIS if the dialog form doesn't appear

Soil maps and hydrological characteristics are implemented from the data provided by the regional pedological service and contained in the layer "Soil map" and in the tables "Soil types" and "Soil profiles" (Figure 7). Notice that the maximum layer depth of the soil profile (*maxdepth* attribute) must be in meters and that the soil map does not need to exactly fit the edges of the irrigation district, although a largely predominant overlap is highly recommended.

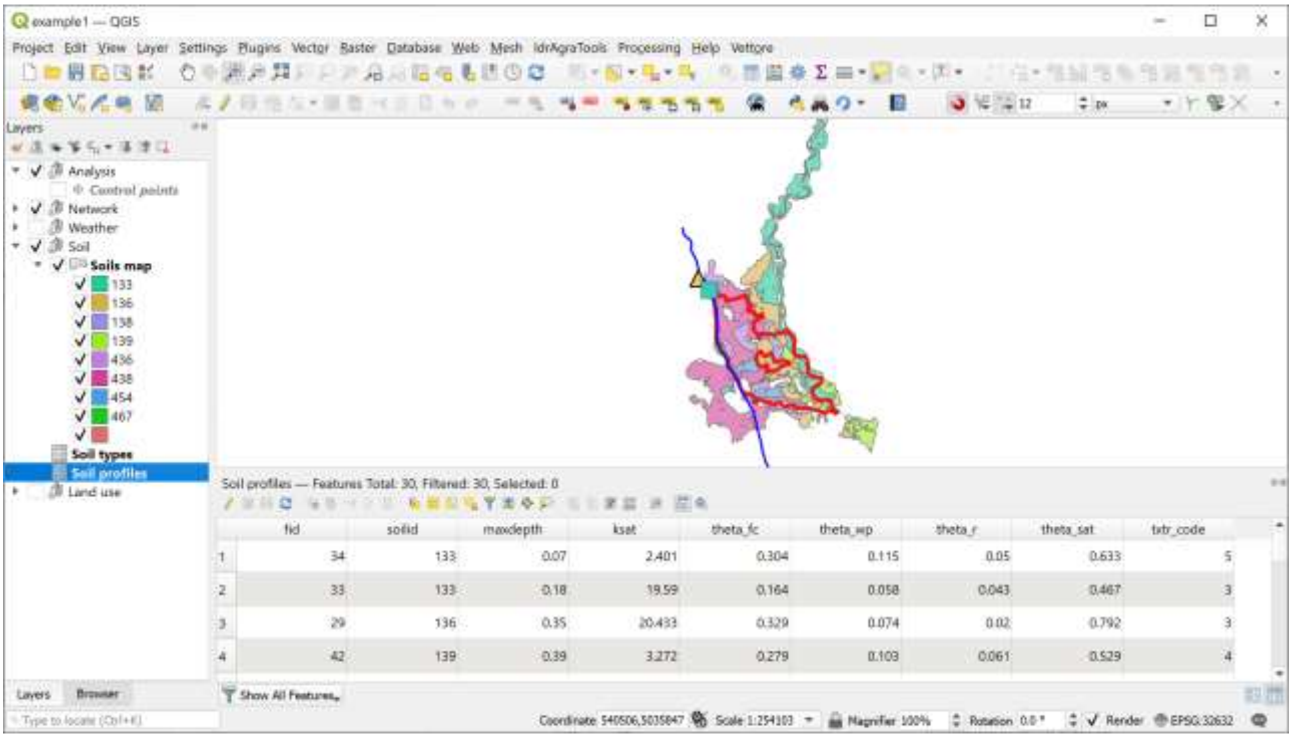


Figure 7: QGIS project interface with soil map visible and profile table opened.

Land use map is also provided from the regional service. Two main land uses are identified in the irrigation district (permanent grass and maize). Each land use is defined in the Soil uses table and each crop is parametrized in the Crop types table. Also in this case, use the form view option to see the complete description of the parameter.

In order to calculate water needs at crops scale, a theoretical, "perfect" irrigation method without losses, called "No losses irrigation", was defined and the irrigation method maps was updated consequently.

"No losses irrigation" method has identification code equal to 5, all stress coefficients (*k_stress* e *k_stresswell*) are set to 1, irrigation efficiency is set to 1 and all other loss parameters (for percolation and tailwaters) are set to zero.

At the same time, the *extid* of the irrigation map is set to 5 to match the code of "No losses irrigation" method (Figure 8). Moreover, the Internal distribution efficiency (*distr_eff* in the Irrigation units table) is set to 1 (i.e. all the water is used for irrigation).

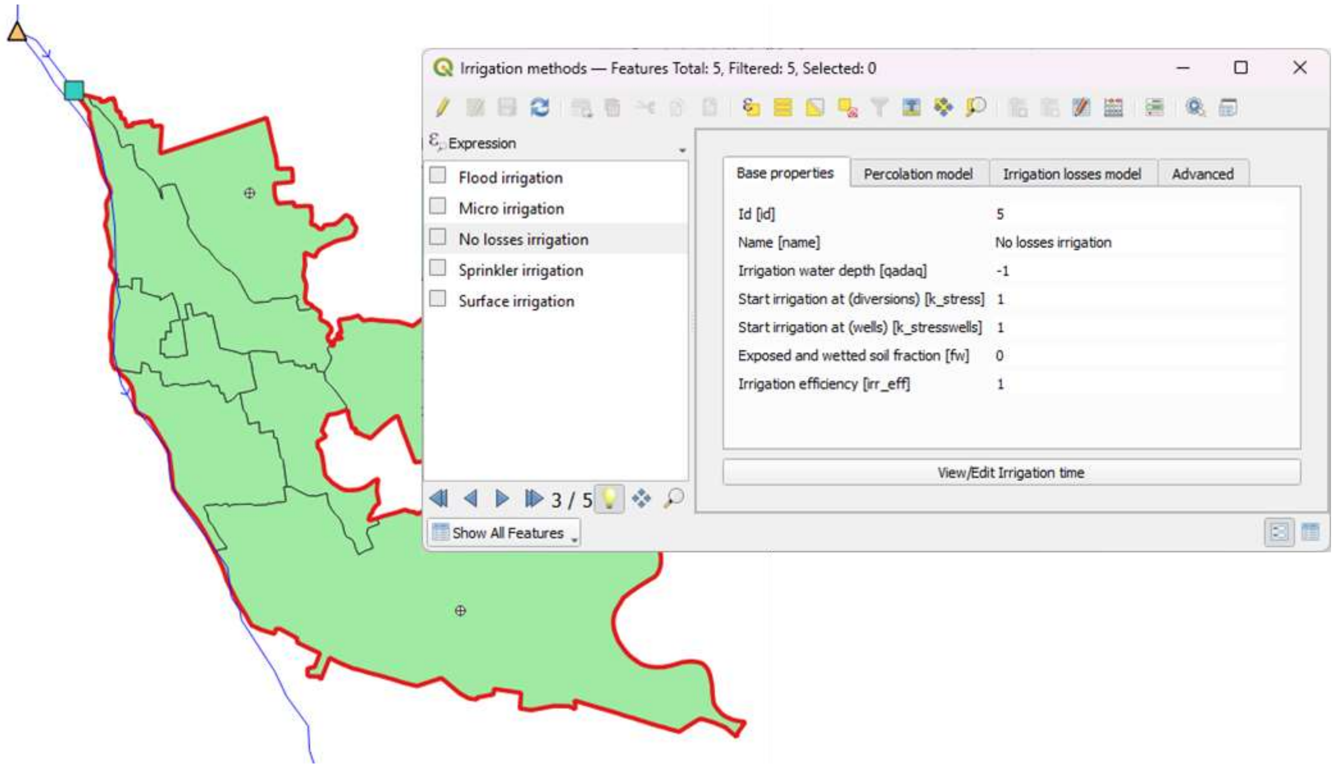


Figure 8: irrigation method is set to "No losses irrigation" in all the irrigation district.

Use the QGIS field calculator tool to convert all the (selected) values of the field extid to the desired code.

Elevation model is not necessary for this example and all the study area is supposed to be completely flat (slope is set to the minimum value in the simulation option: set it to zero!).

The capillary rise effect is also considered negligible, as the water table is supposed to be far from the root zone in this example.

Set up simulation and export dataset

The next step is to setup the simulation. To do that, select the Set simulation option from **IdAgraTools → IdrAgra** (Figure 9).

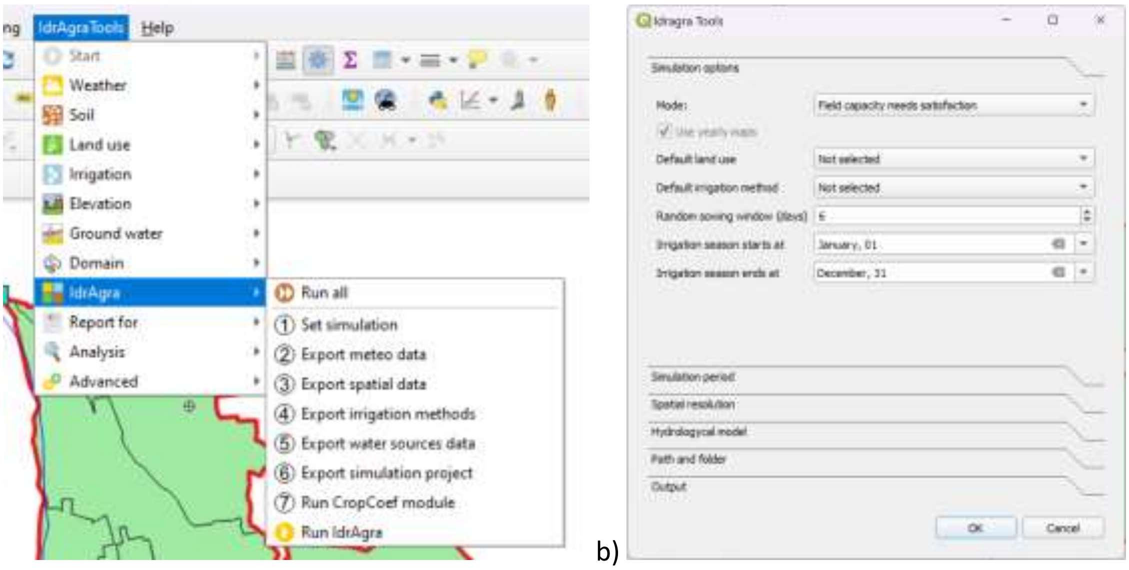


Figure 9: set simulation menu selection (a) and setup simulation form (b).

To perform the NEED simulation, select **Field capacity needs satisfaction**. For the aim of the example, irrigation period starts from the first day of year and runs till the last one. The simulation period covers two years (2005-2006). The cell size in the **Spatial resolution** tab is 250 m, approximately the average size of the irrigated plots in the area. The simulation domain extension includes the irrigation district edge. Outputs are produced for all the simulation period with a seven-day time step.

It is not required that the simulation domain extension covers the entire dataset extension. The user can select a sub area if necessary

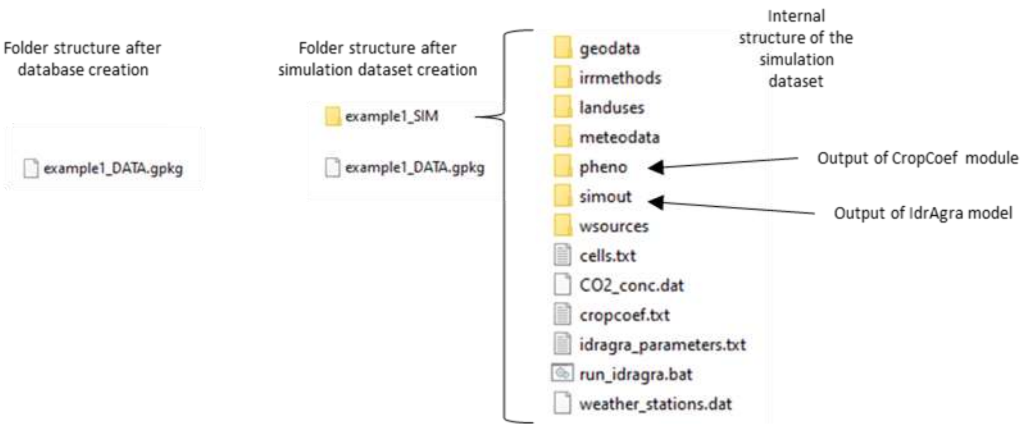


Figure 10: folder structure after the creation of the dataset and simulation execution.

In order to export the complete simulation dataset inside the QGIS project path (Figure 10) the following steps must be followed (see Figure 9a):

- **Export meteo data**: all files and folders necessary to define weather stations position and timeseries are created;
- **Export spatial data**: all the maps of spatially distributed parameters are created;
- **Export irrigation methods**: all the file necessary defining the characteristics of the irrigation methods are created;
- **Export water sources data**: the water sources file (not required for the selected simulation mode, skipped) is created;
- **Export simulation project**: IdrAgra parameters file (e.g. idragra_parameters.txt) and executable file (run_idragra.bat) are prepared.

Perform simulation

Performing a simulation is quite easy: simply select **Run CropCoef module** and **Run simulation** from **IdrAgraTools → IdrAgra**. The simulation requires few minutes. Please control messages (infos, warnings and errors) from the IdrAgraTools progress dialog (Figure 11).

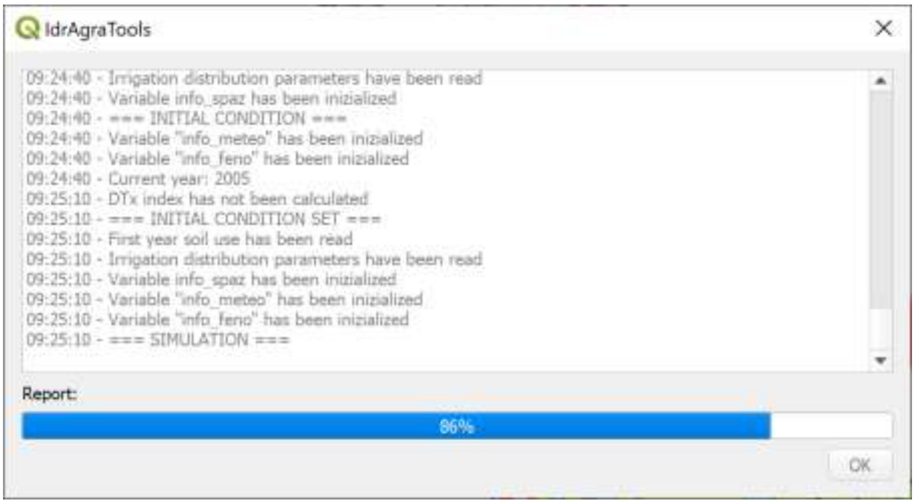


Figure 11: IdrAgraTools progress dialog.

Simulation results, both from CropCoef module and IdrAgra, are saved in the output folders showed in Figure 10, defined in the simulation parameter dialog.

Check paths to executables in the executable tab from the setup simulation form

Changes in the dataset require repeating the dataset exportation processes

Select Run all option to perform all the simulation steps at one time

Alternatively, the user can run the simulation directly from run_idragra.bat from the command shell, outside the QGIS session. This way gives more control on the simulation process.

Analyse outputs

Maps of the weekly values of the net crop irrigation needs at the field scale computed by the IdrAgra simulation can be created using the tool called **Grouped statistics** under **IdrAgraTools → Analysis** (Figure 12a).

To perform the task, select the irrigation variable, the irrigation units as query edge, the attribute field that defines homogeneous areas (not important in this case because the study area is an unique polygon) and the function to apply (in the case we calculate the average value of NIN-F).

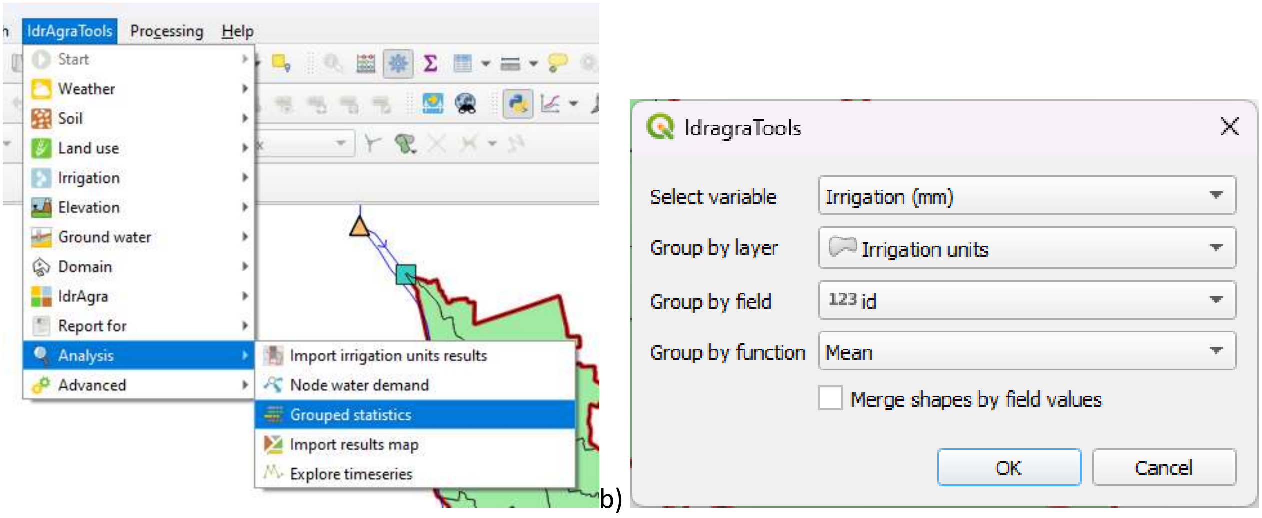
a)  b)

Figure 12: example use of Grouped statistics tool.

Process result is a new layer, named as "Irrigation (mm) Mean by Irrigation units and id" (i.e. selected variable + function + border polygon + aggregation field). Notice that the resulting layer is populated with repeated copies of the same polygon overlapped (Figure 13). Each copy is connected to a single attribute record. Each record is composed by the date of the last day of the output step (*timestamp*), the identifier of the selected edge (*wsid*), the result of the aggregation function (*recval*) and the count of elements inside the edge polygon (*count*).

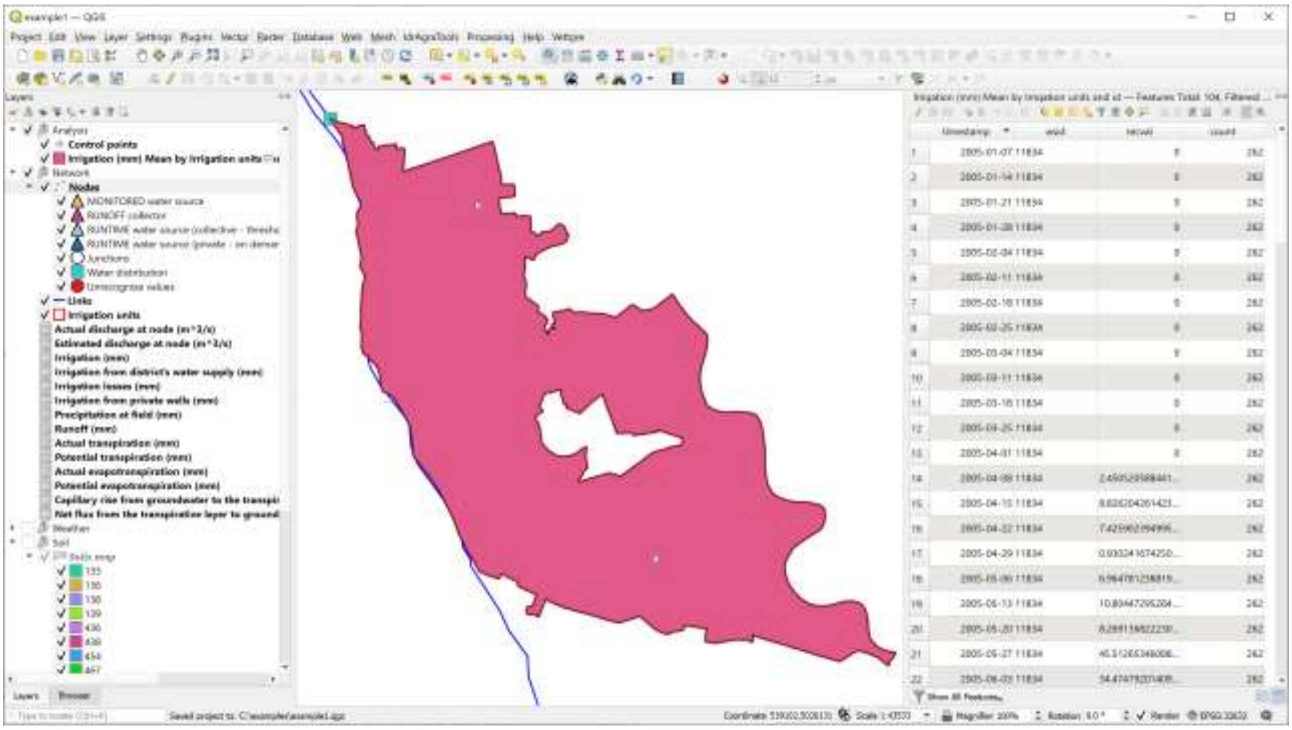


Figure 13: result from the aggregation function.

In this example, the layer reports the date every seven days from the first day of simulation and the average NIN-F values over the entire reference area (irrigation district, Figure 13).

Using other tools provided by QGIS (e.g. Basic statistics for fields from Processing, Figure 14), the user can calculate the spatially averaged value of the seasonal water needs of the irrigation district for the two years of the simulation, obtaining 471 mm and 394 mm for the first and second (cooler) year, respectively.

Figure 14: sample use of Basic statistics for fields algorithm

Statistics maps are saved as temporary layers and they will deleted on closing QGIS. Save on your HD the most relevant results.

Statistics map table are formatted in order to use Temporal controller panel from QGIS

Conclusion

This example shows how to perform the NEED mode simulation with IdrAgra in order to calculate the net crop irrigation needs at the field scale, considering negligible the losses due to water distribution and irrigation methods. It also illustrates how to access and analyse the simulation results using the QGIS – IdrAgraTools functions. Although all the input data can be prepared with different tools and IdrAgra model can be run as a separate process, the IdrAgraTools option helps the user to rapidly perform common tasks, from dataset building to results analysis.

More functionalities of IdrAgra and of IdrAgra Tools will be illustrated in following examples.

Example 2: gross crop irrigation needs at the field and district scale

Aims

In this example, we will show how to prepare input data for IdrAgra simulation and how to perform simulation in NEED mode for an irrigation district, considering irrigation methods and distribution network efficiency, i.e. how to compute the gross crop irrigation needs at the field and at the district scales.

Study area

The study area is the same of example 1, but more information about the irrigation methods and the irrigation distribution network are provided.

Irrigation water supply

The main source of irrigation water of the district is a diversion from the Blue river, 1 km upstream from the district inlet. A flow meter is located on the primary canal, close to the diversion section. For each year, the diversion starts on April 1st and ends the on September30th. The flow data have a daily resolution (Figure 15). The year 2005 was characterized by lower flows, due to a severe hydrological drought in the Blue river basin, with peak value of only 2.1 m^3/s. Instead in 2006 hydrological conditions were more favourable and the diverted flow could reach the licensed value of 3.75 m^3/s.

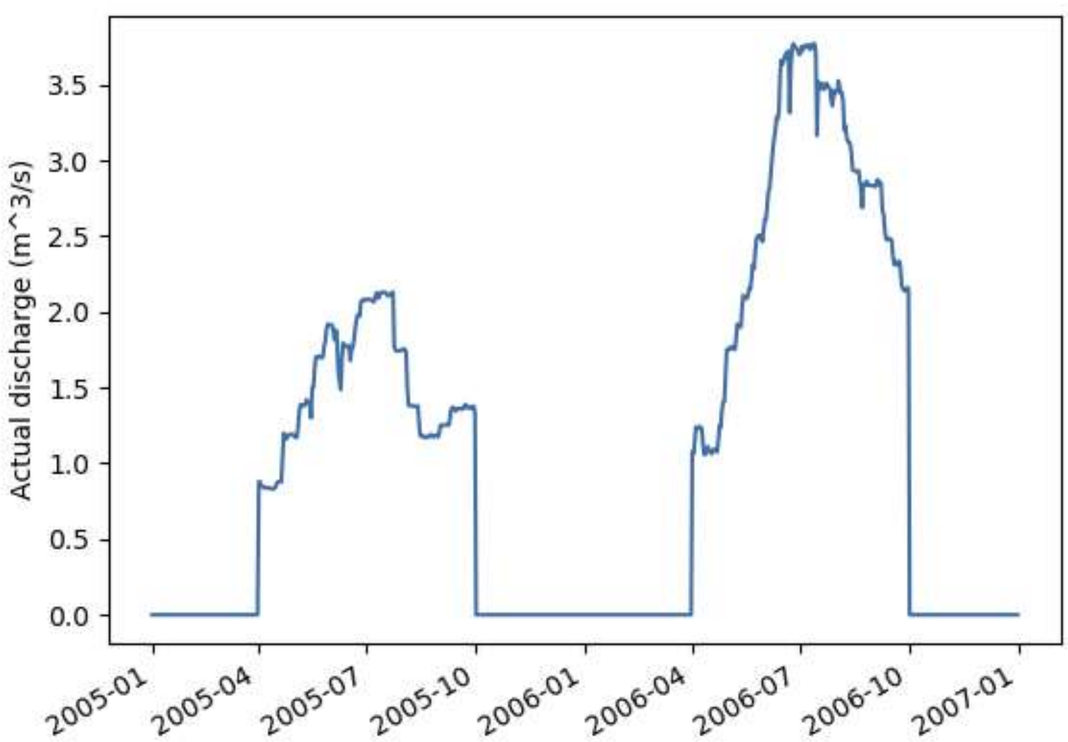


Figure 15. Flow diverted from the Blue river for irrigation supply in the study area

Given the characteristics of the irrigation canals of the district, seepage losses occur along the path from the district inlet to the individual fields; the local irrigation agency provided an estimated value of the seepage loss of 25% of the flow at the district inlet.

Field irrigation methods

The actual irrigation method is border irrigation in the upper part of the irrigation district, while sprinklers are used in the lower part (Figure 16).

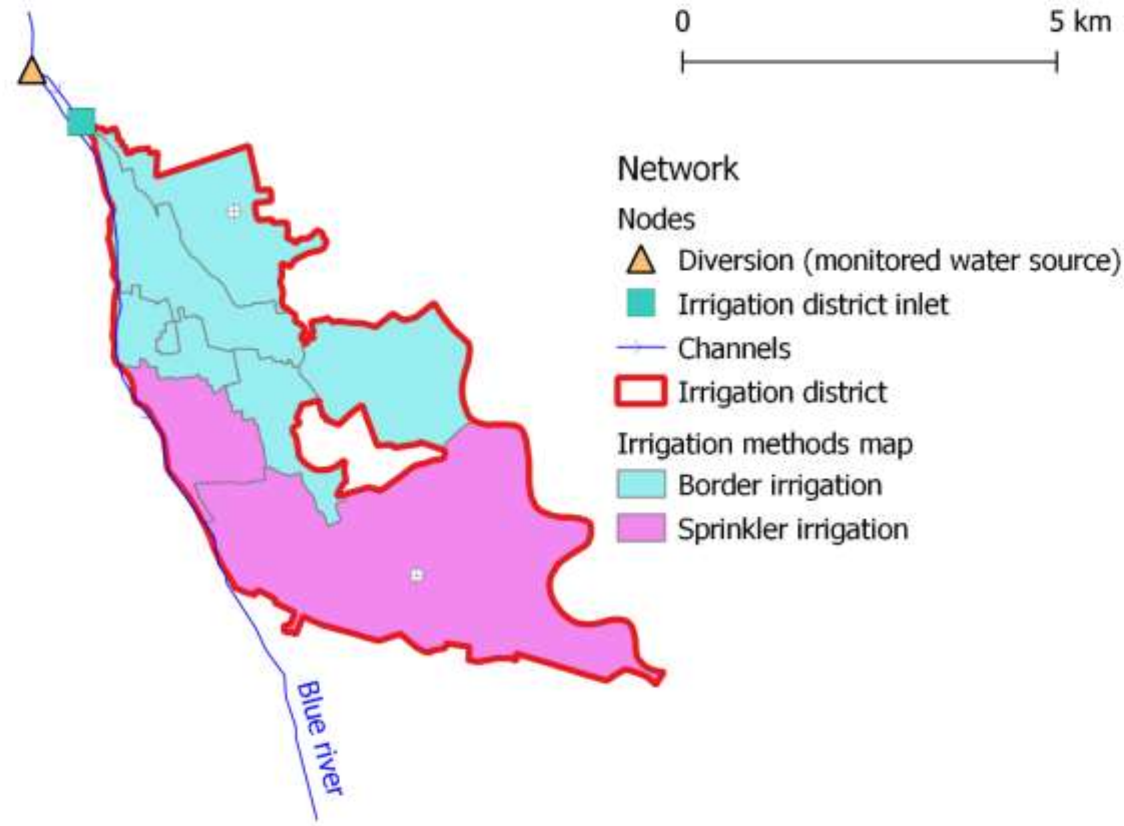


Figure 16. Irrigation methods over the irrigation district.

Perform the IdrAgra simulation

Most of the necessary steps to run IdrAgra simulation have been already presented in Example 1, only the additional information needed for this new simulation are provided in the following.

Build the study area dataset

The irrigation distribution network is defined by links (i.e. canals paths) and nodes (i.e. canal junctions, delivery points, …). In our case, two of the nodes are the monitored section and the inlet to the irrigation district and are connected with a single segment (i.e. link). This element is necessary to define the proper flow sequence between nodes and the distribution efficiency. The diversion node is also linked to the measured discharge time series (Figure 17).

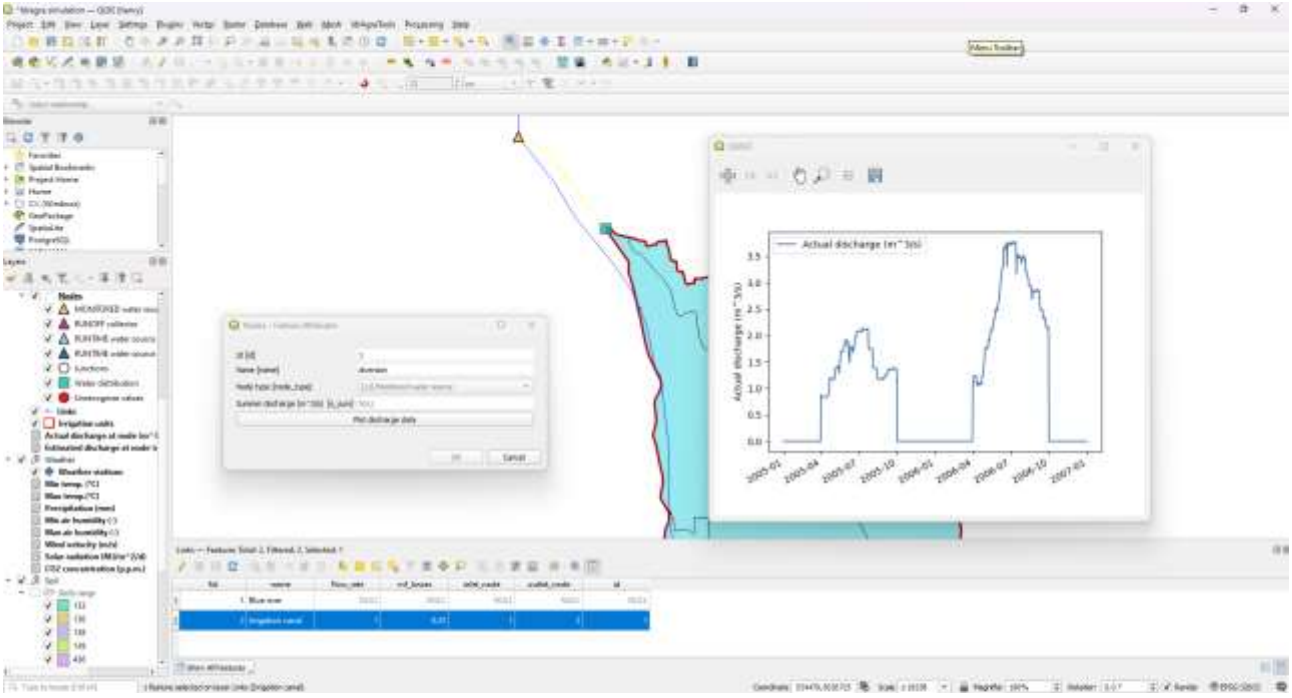


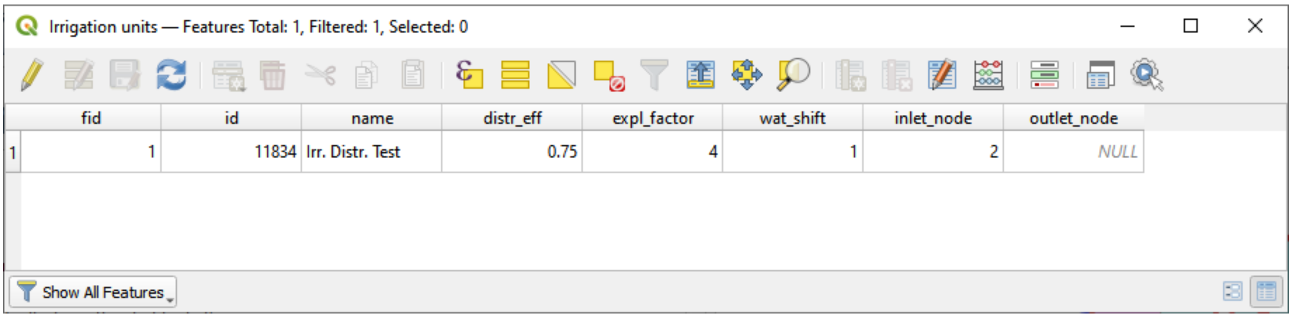
Figure 17: water distribution network. Highlighted link is the irrigation canal that connects node 1 (diversion) to node 2 (irrigation district inlet). Diversion node is a monitored water source and recorded discharge is plotted in the chart window.

To take into account the effect of seepage, the infiltration losses attribute in the links layer (*inf_losses*, Figure 17) is set to 0.25.

Recorded flow data are stored in the Actual discharge at node (m^3/s) table.

Defining the links network is an advanced feature of IdrAgraTools while it is not mandatory for IdrAgra simulation. It is useful when mixed water sources are present.

To take into account the overall efficiency of the internal distribution network (that is not necessary to be defined with geometrical elements in the database), the *distr_eff* attribute (Figure 17) is set to 0.75 (i.e. 1-0.25). Finally, the exploration factor (*expl_factor*) is set to 4. This last factor, together with the daily irrigation supply, determines the number of cells that could be potentially irrigated in each day. Finally, the *inlet_node* set to 2 defines that the identification code of the water source node (Figure 18).



fid	id	name	distr_eff	expl_factor	wat_shift	inlet_node	outlet_node
1	11834	Irr. Distr. Test	0.75	4	1	2	NULL

Figure 18: irrigation unit attribute table.

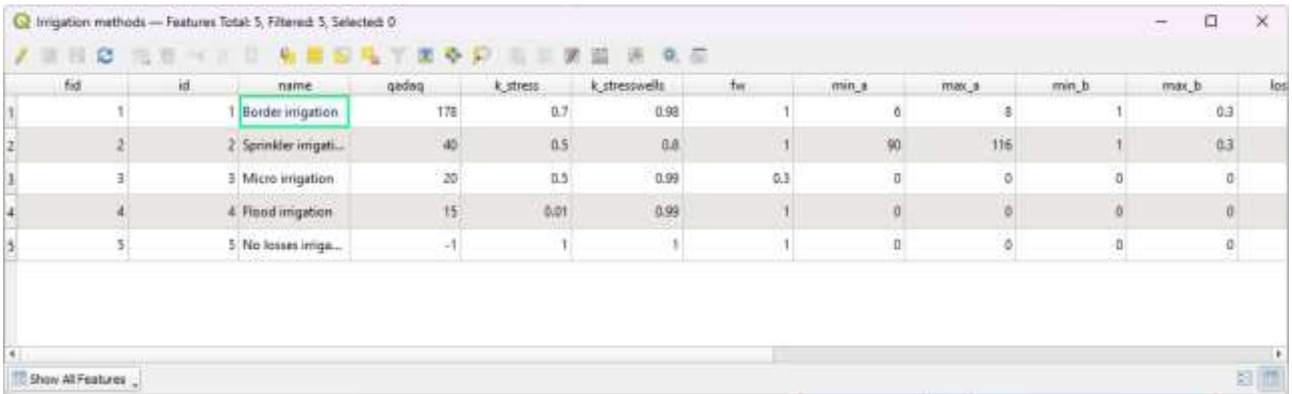
***Wat_shift* parameter is not used in the current version of IdrAgra**

Use the QGIS form view option in the QGIS attribute table view to see attributes in a more explanatory way

Use the QGIS form view also in the QGIS identifier tool to the attributes of single elements in the map

Use the QGIS form view also shares advanced tools for querying the dataset

Irrigation methods are defined by the attributes showed in Figure 19. A fixed water volume (expressed as irrigation depth, *qadaq*) is set to 178 mm and 40 mm respectively for Border irrigation and Sprinkler irrigation. Also the stress coefficient (*k_stress*) varies between the two methods as all the percolation and irrigation losses coefficients (see the IdrAgra Technical Manual for details about their meanings and use).



fid	id	name	qadaq	k_stress	k_stresswells	fw	min_a	max_a	min_b	max_b
1	1	Border irrigation	178	0.7	0.98	1	6	8	1	0.3
2	2	Sprinkler irrigati...	40	0.5	0.8	1	90	116	1	0.3
3	3	Micro irrigation	20	0.5	0.99	0.3	0	0	0	0
4	4	Flood irrigation	15	0.01	0.99	1	0	0	0	0
5	5	No losses irriga...	-1	1	1	1	0	0	0	0

Figure 19: irrigation method parameters used in the simulation (some not relevant attributes are hidden).

Finally, field slope is set to zero and capillary rise is assumed to be negligible.

Set up simulation and export dataset

The procedure is the same as for exercise 1. The only difference is the selection of the simulation mode and the irrigation period (from the 1st April to the 30th September).

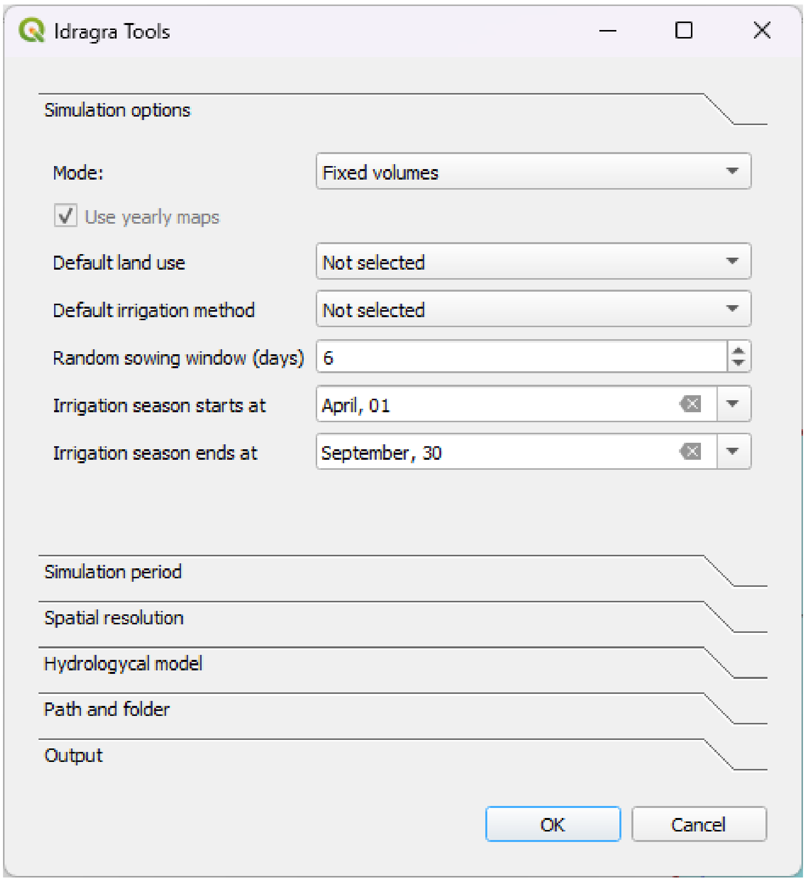


Figure 20: IdrAgra simulation parameters dialog.

Perform simulation

The procedure is the same as for the exercise 1.

Analyse outputs

The user can be interested in extraction of the 1) total yearly water demand for irrigation at irrigation district scale and 2) calculate the water demand at source. The first task can be resolved with the procedure presented in Example 1. For the second task, IdrAgraTools provides a specific function.

Calculate total irrigation demand at district scale

Water demand maps are created using the tool called **Grouped statistics** under **IdrAgraTools → Analysis** (Figure 12a). Using "Basic statistics for fields" from QGIS Processing interface, the average of the seasonal gross irrigation needs at the district scale is calculated: 1181 mm for the first year and 1022 mm for the second year (obviously higher than example 1 due to loss accounting).

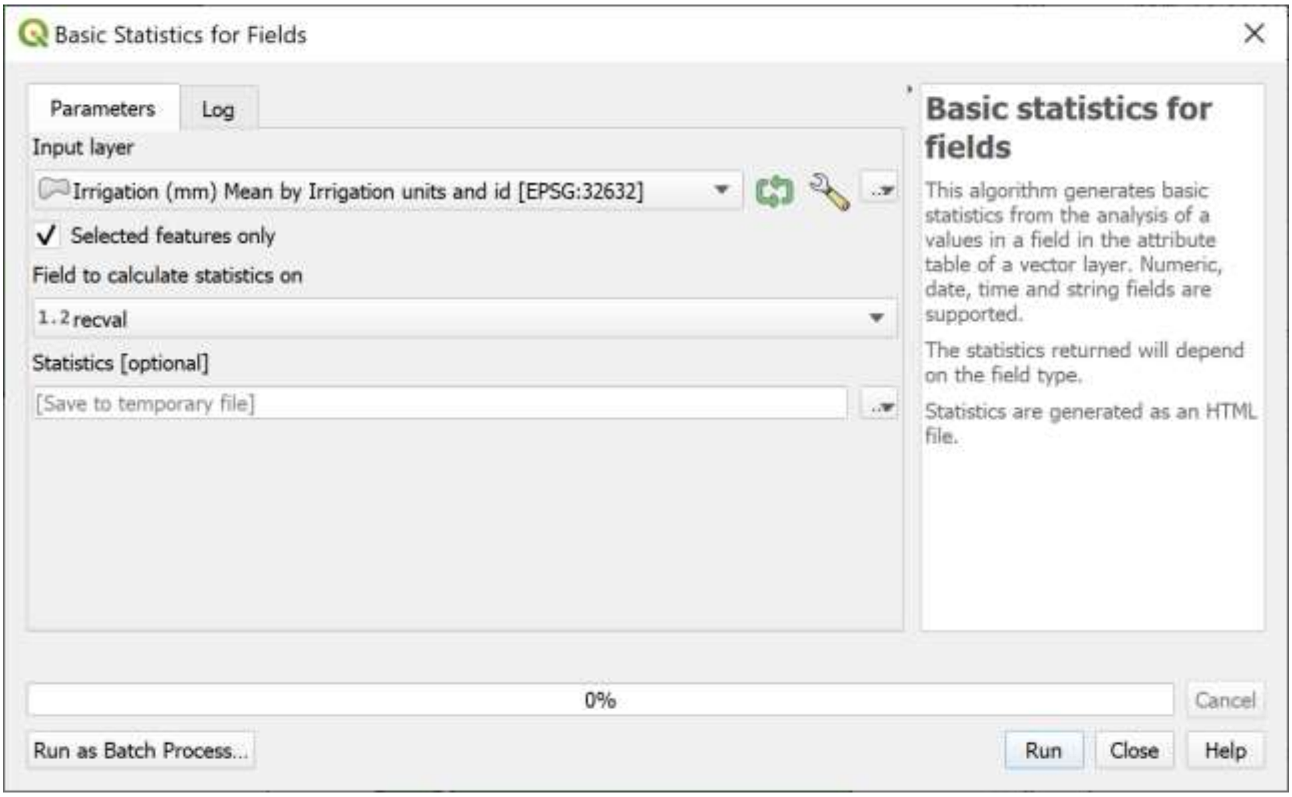


Figure 21: sample use of Basic statistics for fields algorithm

Calculate water demand at source

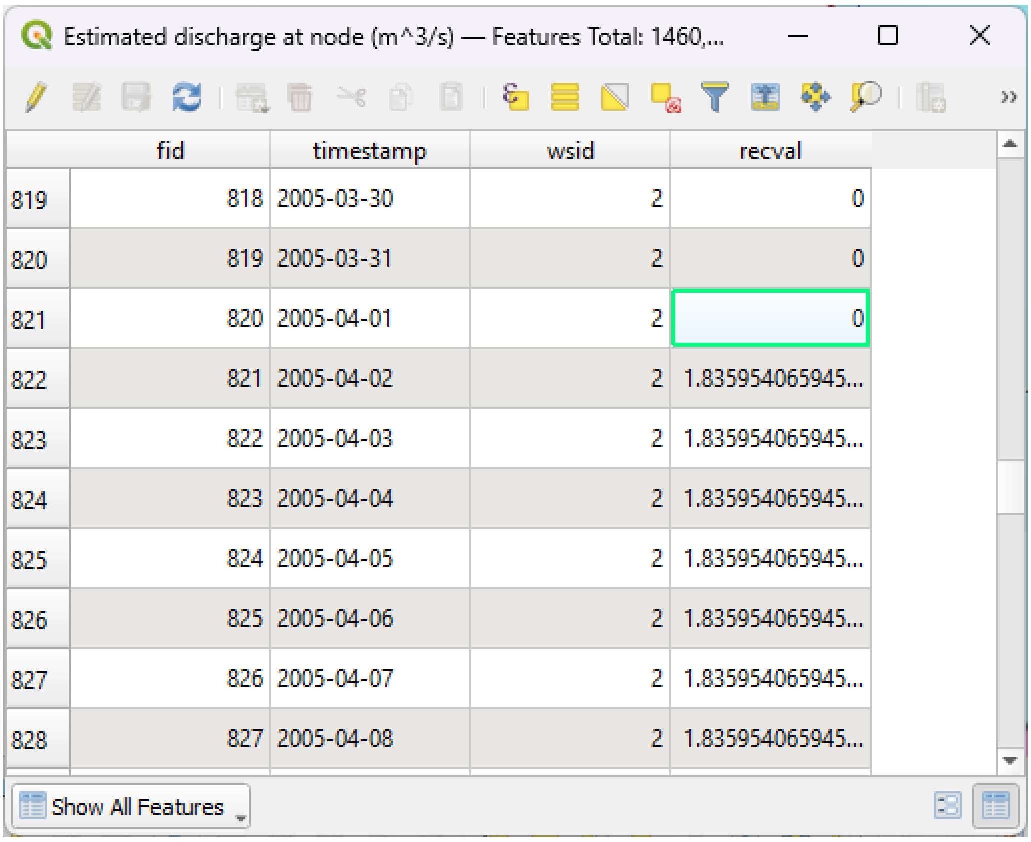
To calculate water demand at the source, the irrigation network with at least one node has to be defined. In our case, two nodes (district inlet and source) are connected with a link.

To perform this task, simply select **Node water demand** from **IdrAgraTools → Analysis** (Figure 12a). At the end of the process, the calculated flow are inserted in the Estimated discharge at node (m^3/s) table (Figure 22).

To make a comparison between actual and estimated water discharges at diversion node, the user can make a plot using the **Explore timeseries** tool under **IdrAgraTools → Analysis** (Figure 12a).

Figure 23 shows a screenshot of the **Data manager** tool: a plot with estimated and measured discharges at node 1 – diversion is generated for the whole simulation period. Notice that the plotted values are the discharge values averaged over the time interval defined by the user in the simulation settings (weekly interval in this example). Estimated discharges are higher than measured ones in the first simulation year while are similar to observed in the second.

Instead, Figure 24 shows the estimated discharges at the two nodes of the network (1 – diversion and 2 – irrigation district inlet) for a selected time period (irrigation season of the first year). Flows at node 2 are lower than those at node 1 because the losses along the connecting link (i.e. canal losses).



	fid	timestamp	wsid	recval
819	818	2005-03-30	2	0
820	819	2005-03-31	2	0
821	820	2005-04-01	2	0
822	821	2005-04-02	2	1.835954065945...
823	822	2005-04-03	2	1.835954065945...
824	823	2005-04-04	2	1.835954065945...
825	824	2005-04-05	2	1.835954065945...
826	825	2005-04-06	2	1.835954065945...
827	826	2005-04-07	2	1.835954065945...
828	827	2005-04-08	2	1.835954065945...

Figure 22: calculated discharge table.

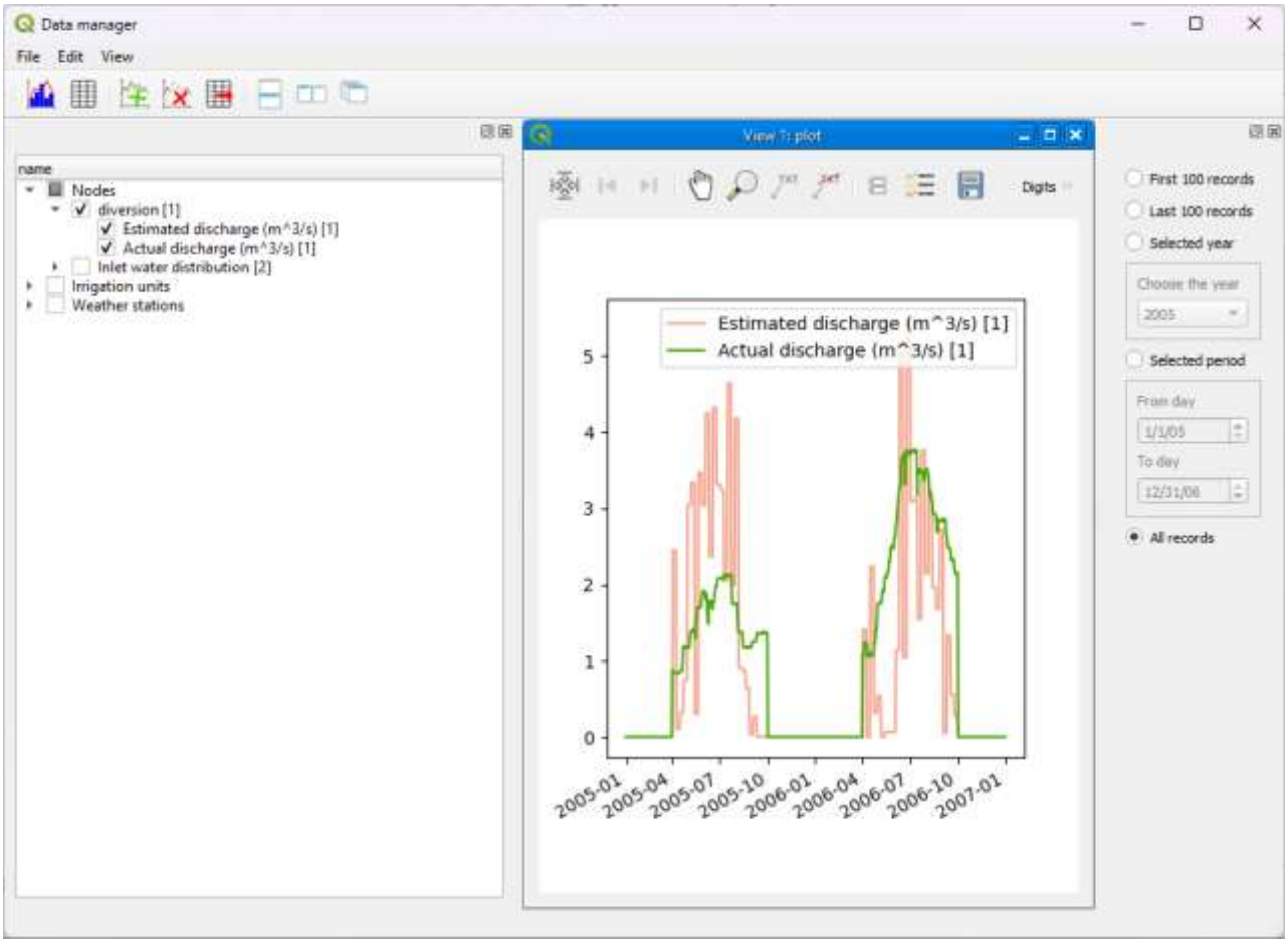


Figure 23: comparison between actual and estimated discharges at node 1-diversion for the second irrigation season.

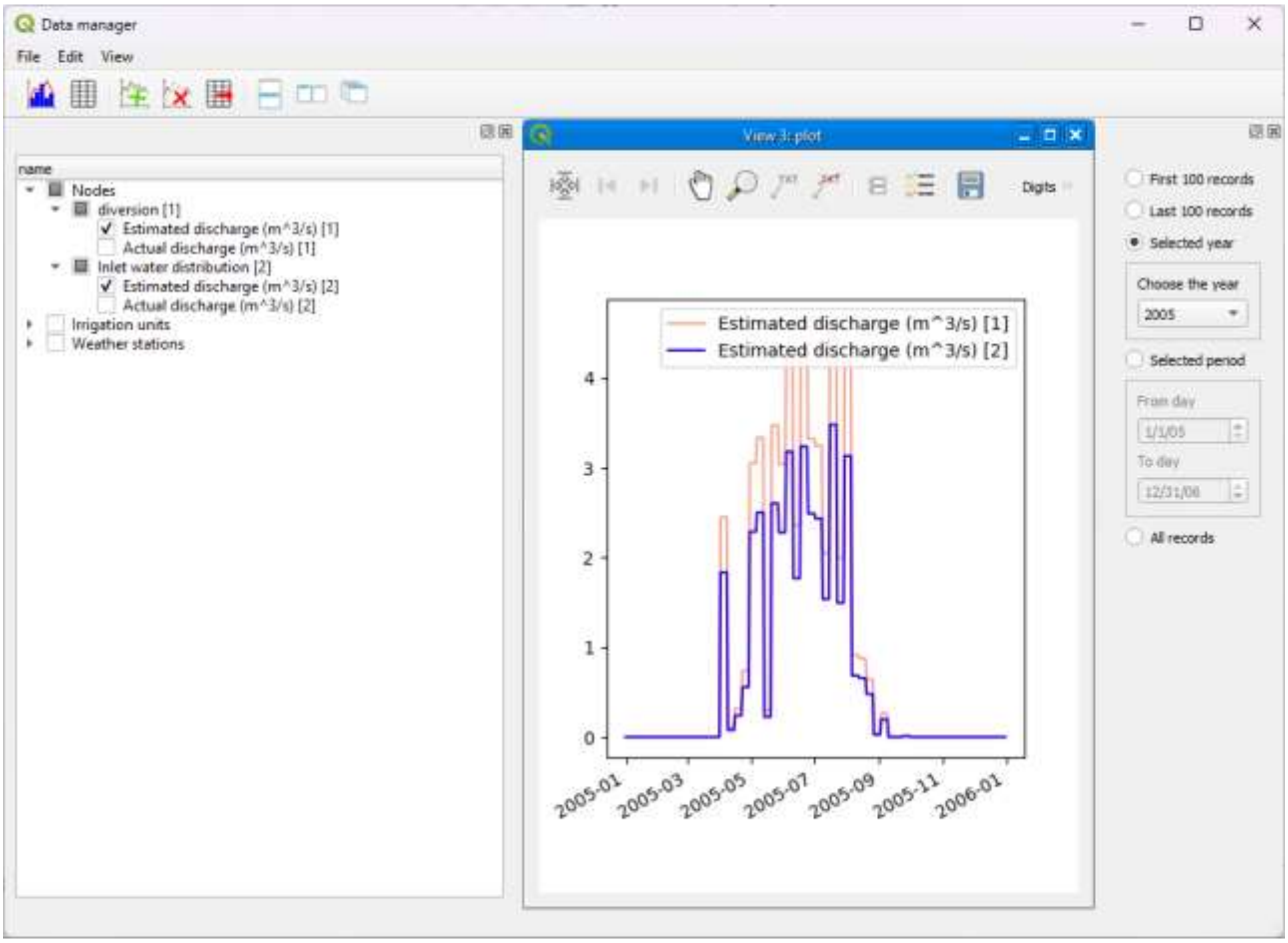


Figure 24: comparison between estimated discharges at node 1 - diversion and node 2 – irrigation district inlet.

Calculated discharges are always in cubic meters per seconds.

Calculated discharges are averaged along the time step set in the simulation parameters.

Use the Data manager to explore all the time series stored in the database, both in graph and tabular mode.

Conclusion

This example showed how to calculate the gross irrigation water needs at the field and district scales and compare the latter with monitored flows, if available. IdrAgra permits to account for the characteristics of the different irrigation methods, for the conveyance losses in the main canals (links) and for the overall seepage losses in the distribution network of the minor ditches (not defined by geometrical elements) and, with the use of the IdrAgraTools, it allows to “walk” across the distribution scheme (nodes and links) to see the estimated flows at each node of the network.

Example 3: assessing the actual use of monitored irrigation supply in a district

Aims

In this example, we will show how to prepare input data for IdrAgra simulation and how to perform simulation in USE mode for an irrigation district considering irrigation methods and distribution network efficiency.

Study area

The study area is the same of example 1 and all the characteristics have been already presented in example 1 (land use, soils type, weather data) and example 2 (irrigation methods and water availability). The timeseries of measured discharge supplied to the area is used in this example.

Perform the IdrAgra simulation

Most of the necessary steps to run IdrAgra simulation have been already presented in examples 1 and 2. In addition, two control points (i.e., individual irrigated cells) are defined to produce localized simulation results (useful for checking purpose or comparison): 1. Maize cell, border irrigated on middle range infiltration properties in the upper part of the irrigation district and 2. Permanent grass cell, sprinklers irrigated on very high infiltration rate in the lower part of the irrigation district (Figure 25).

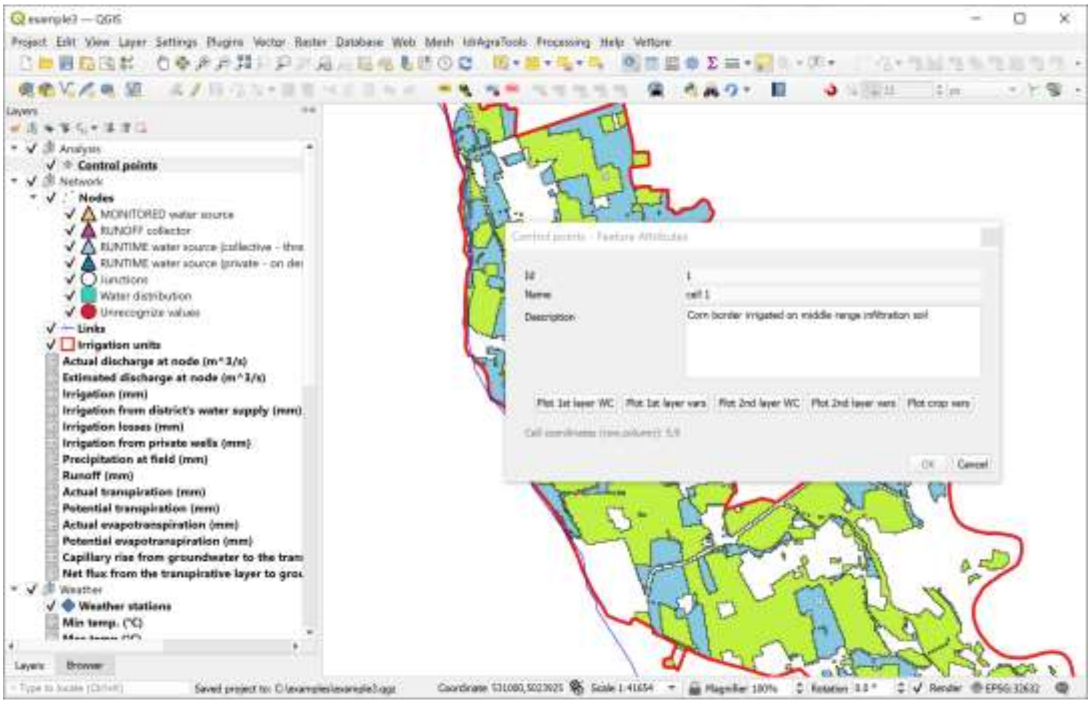


Figure 25: control points position and attribute form.

Add control points to the view with the QGIS editing procedure:

1. select the Control points layer and start editing mode

2. add as many points as you want

3. compile the form or the table attributes with the id, name and description of the points

Set up simulation and export dataset

The procedure is the same of exercises 1 and 2. The only difference is about the selection of the simulation mode "Consumptions".

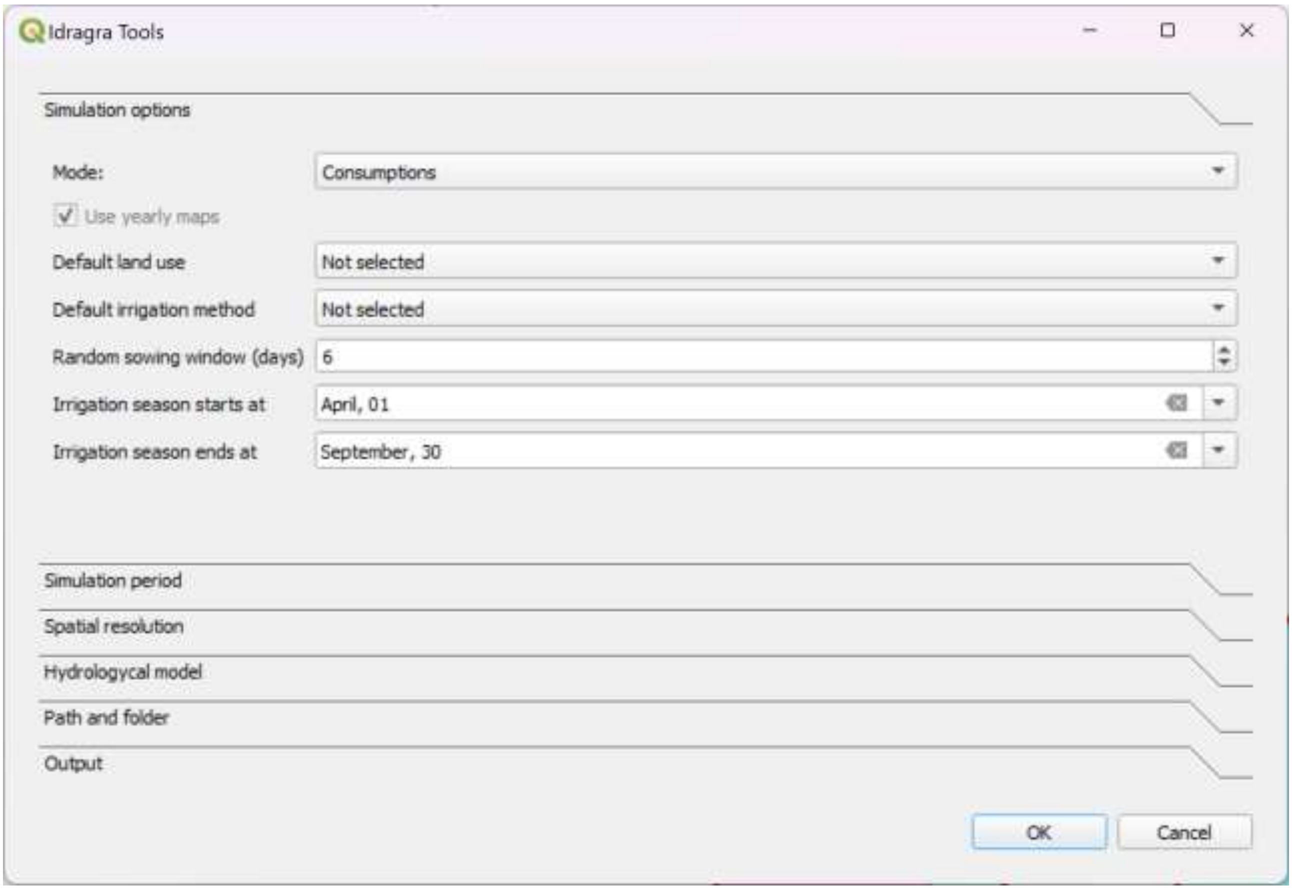


Figure 26: IdrAgra simulation parameters dialog for Consumptions – USE mode.

Perform simulation

The procedure is the same as for exercise 1.

Analyse outputs

The user can be interested in the 1) comparison of the total water consumption at source and measured discharges and 2) analysing water balance results at control points. The first task can be resolved with the procedure presented in Example 2. For the second task, IdrAgraTools shares a specific function.

Compare total water consumption at source and measured discharge

To calculate the water demand at source, perform **Node water demand** function and build the plot in the **Data manager** tool. Figure 23 shows the result of comparison. Estimated discharges at monitored node are quite closed to the measured ones. Small differences exist due to the discretization of the simulation results (7-days step) and the distribution criteria (part of daily water volume is saved, if available, for the following irrigation day in IdrAgra). At the same time, the comparison reveals that part of the water volume during the cooler year is not required by irrigation at the beginning and the end of the irrigation season, while most of it is used in the first, drier, year.

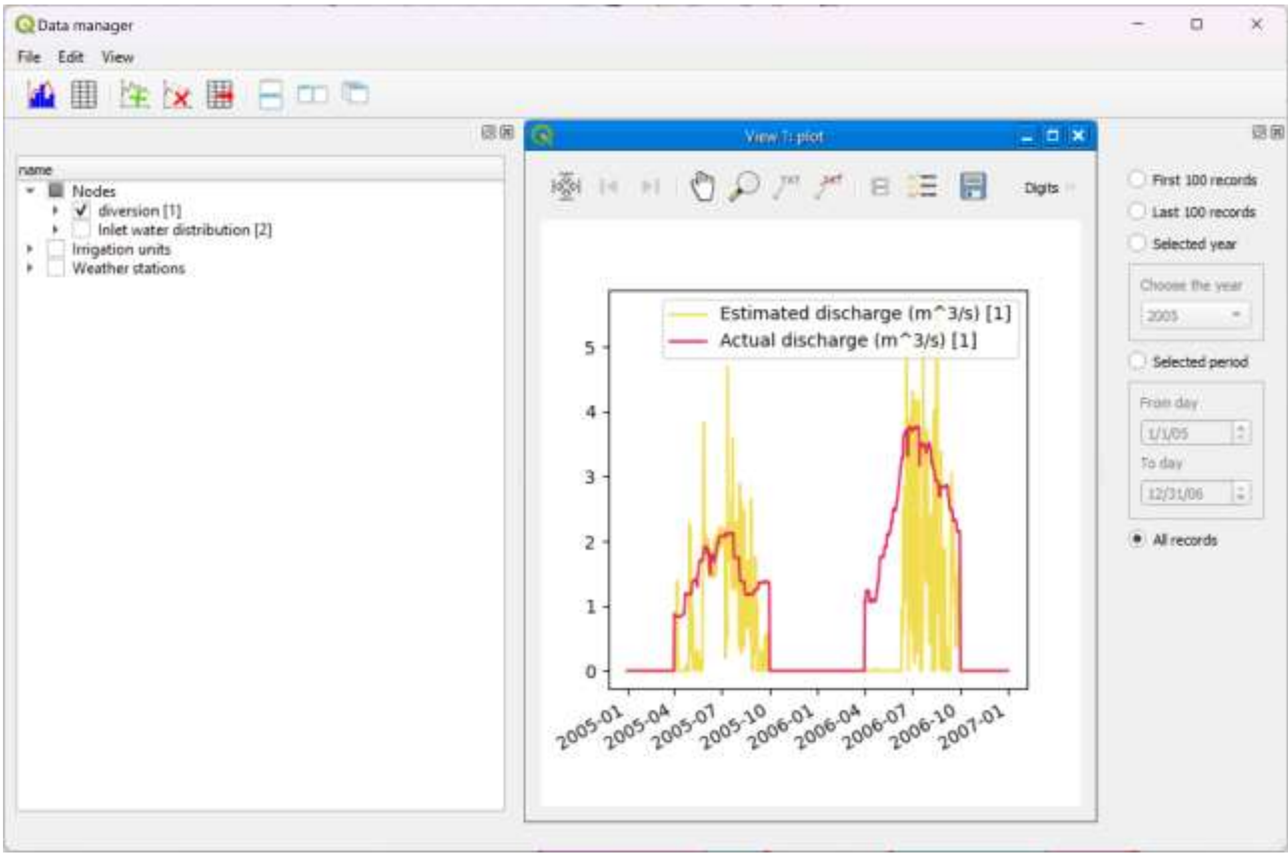


Figure 27: comparison between actual and estimated discharges at node 1 - diversion for all the entire simulation period.

Analyse water balance results at control points

By clicking on one control point in the map with the QGIS Identify features tool, if the form view is enabled, the dialog of Figure 28 is showed. The dialog shows attributes from the selected control point and it shares some plotting functions:

Plot 1st layer WC: it shows daily soil water content of the first (evaporative) layer respect to wilting point and field capacity (Figure 29)

Plot 1st layer vars: it shows daily water height (volume) of the first (evaporative) layer of the main water balance fluxes (Figure 29)

Plot 2nd layer WC: it shows daily soil water content of the second (transpirative) layer respect to wilting point and field capacity (Figure 30)

Plot 2nd layer vars: it shows daily water height (volume) of the second (transpirative) layer of the main water balance fluxes (Figure 30)

Plot Irrigation Events: it shows irrigation events and soil water content of the 2nd layer (Figure 31)

Plot crop vars: it shows daily variation of the main crop variables (Figure 32).

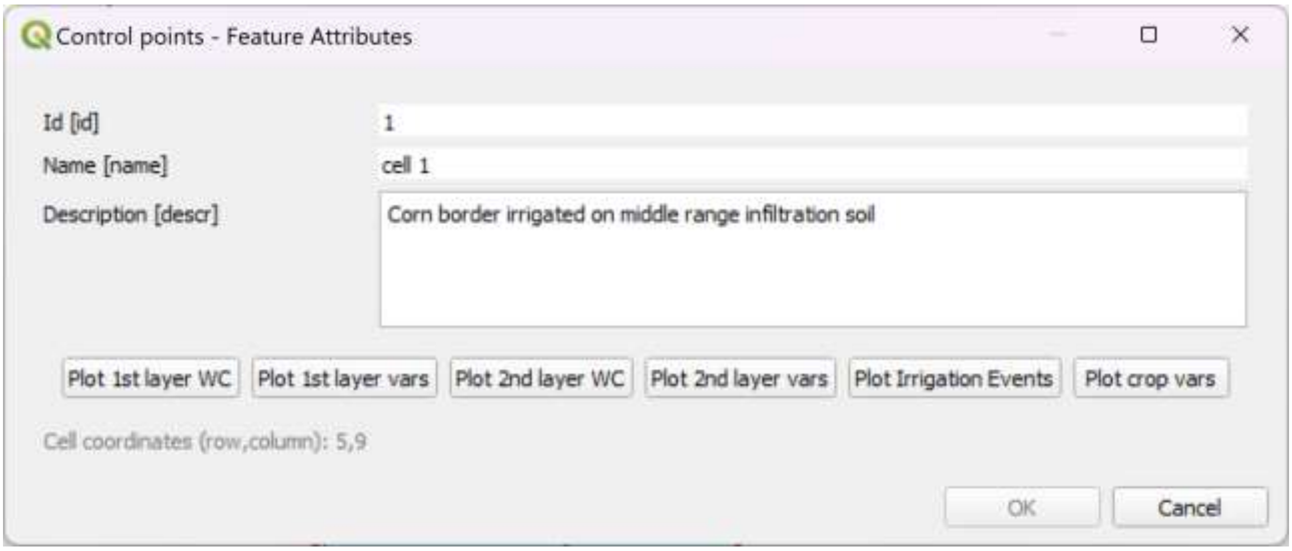


Figure 28: attribute form view from QGIS Identify features tool.

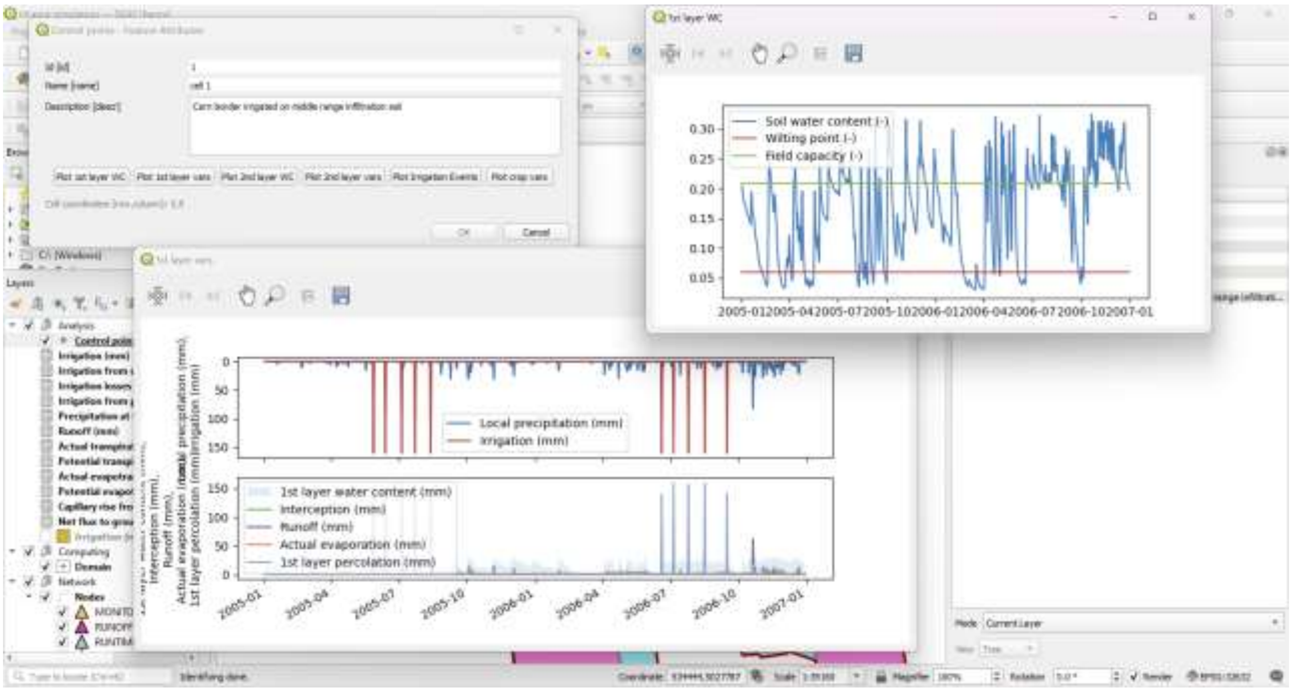


Figure 29: 1st (evaporative) layer plots (water content and water balance variables).

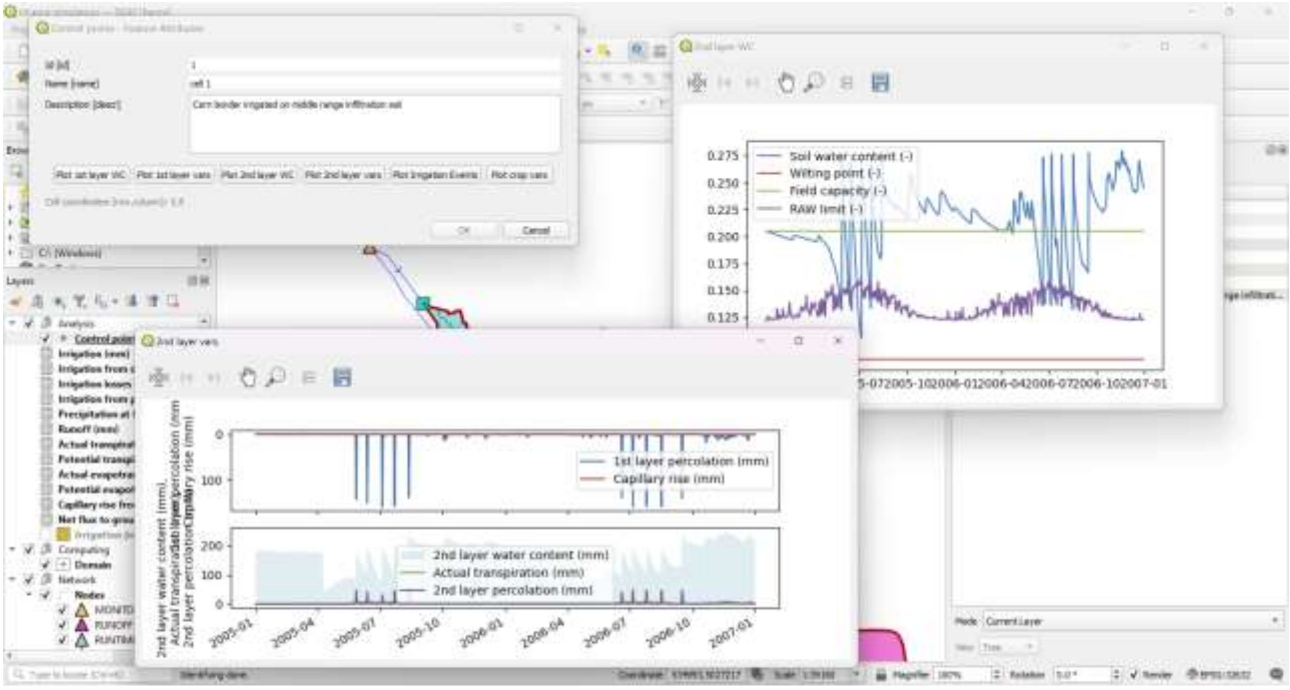


Figure 30: 2nd (transpirative) layer plots (water content and water balance variables).

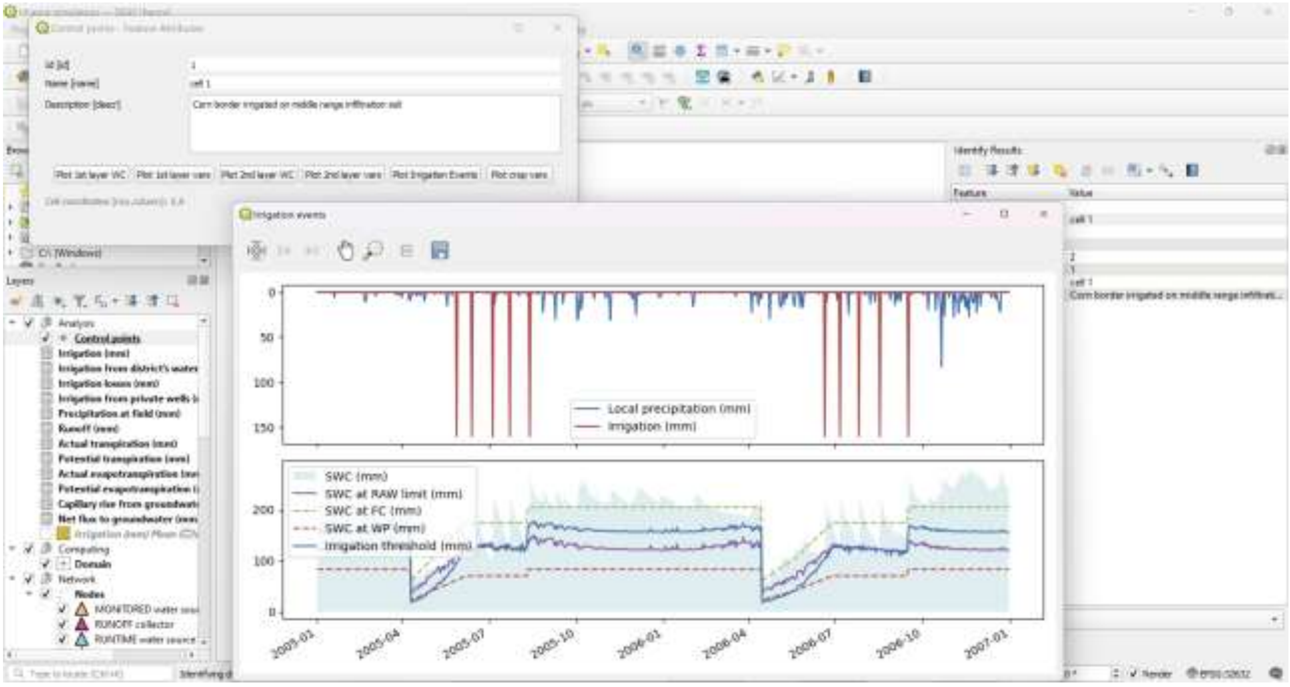


Figure 31: irrigation events and soil water content.

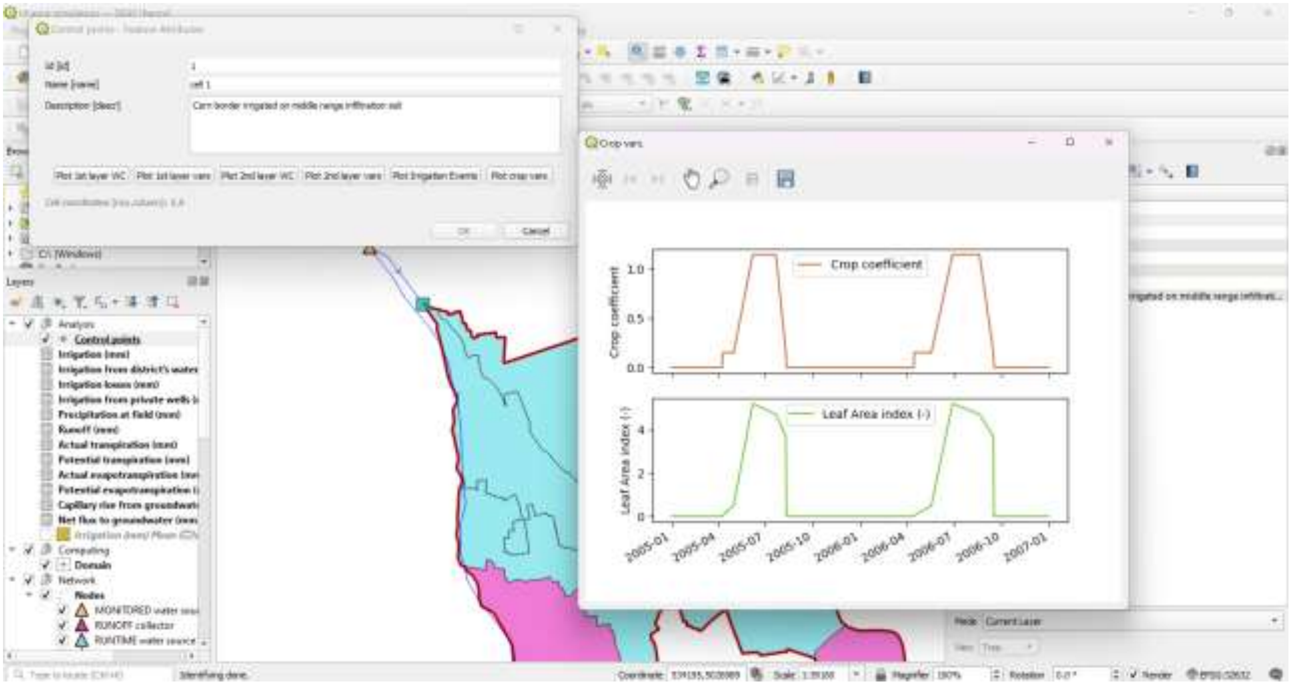


Figure 32: crop variables plot from control point form view.

Control point plots are generate directly from IdrAgra outputs (i.e. data are not imported in the database)

Data used in the plots are extracted directly from the original IdrAgra output file for the selected control point. The user is free to use the same file in its own analysis framework.

You can access directly to the data, searching the file named YYYY_cell_R_C.csv in the output path where YYYY is the year of simulation, R and C are respectively the row and the column of the control point in the simulation matrix

One-based row and column values are shown in the Control points form view accessible by clicking on the chosen point by QGIS Identify Features tool.

Conclusion

This example shows how the diverted water supplied to an irrigated area is actually used within the area, accounting for the efficiency of the irrigation methods and the losses along distribution network. This example also demonstrates how to easily access to and analyse the simulation outputs at the control points.

Example 4: assessing the actual use of monitored irrigation supply and estimating the additional uptake from a runtime source (well field) in a district

Aims

In this example, we will show how to prepare input data for IdrAgra simulation and how to perform simulation in USE mode for an irrigation district served by a monitored diversion (the same of example 2) and where a well field can provide additional supply when the diverted flow is insufficient. Remember that in IdrAgra RUNTIME sources are sources where the daily uptake is not fixed *a priori*, but depends on the conditions of the area which is supplied by the source itself, computed runtime by IdrAgra

Study area

The study area is the same of example 1 but a collective well source is added to the existing diversion in order to meet crop water requirements as the diverted flow is reduced by half.

Collective wells

A well field was installed by the local irrigation agency in order to complement the water supply from the Blue river diversion during drought periods, pumping up to 1.5 m^3/s of water into the main irrigation channel. Pumps activation is regulated by average water needs inside the district expressed by the activation thresholds and flow ratio as reported in Table 2. Activation thresholds are calculated as the complementary of the amount of water necessary to restore the Readily Available Water, RAW, of the irrigation unit.

Table 2: activation thresholds and flow rate ratio table for the public well plan (RAW = Readily Available Water).

Average water need	Activation threshold	Flow rate ratio
10 % of RAW	0.9	0.5
20 % of RAW	0.8	0.7
50 % of RAW	0.5	0.9

Perform the IdrAgra simulation

Most of the necessary steps to run IdrAgra simulation have been already presented in Example 1, 2 and 3. Following some additional information about the process to include one (or more) wells plan(s) in the simulation.

Add pumping plan to the dataset

Pumping plan is inserted in the database as node element of type “RUNTIME water source (collective - threshold ruled)”. Start editing mode of the layer “Nodes” and insert a new point. Assign to the new elements the attributes as reported in Figure 33. Add a new element to the Links layer to connect the node of the collective well field with those named “Inlet water distribution”. Pay attention to the direction of the line and, in particular, the correct order of inlet and outlet nodes. Finally, assign flow rate equal to 1 and zero losses (Figure 34).

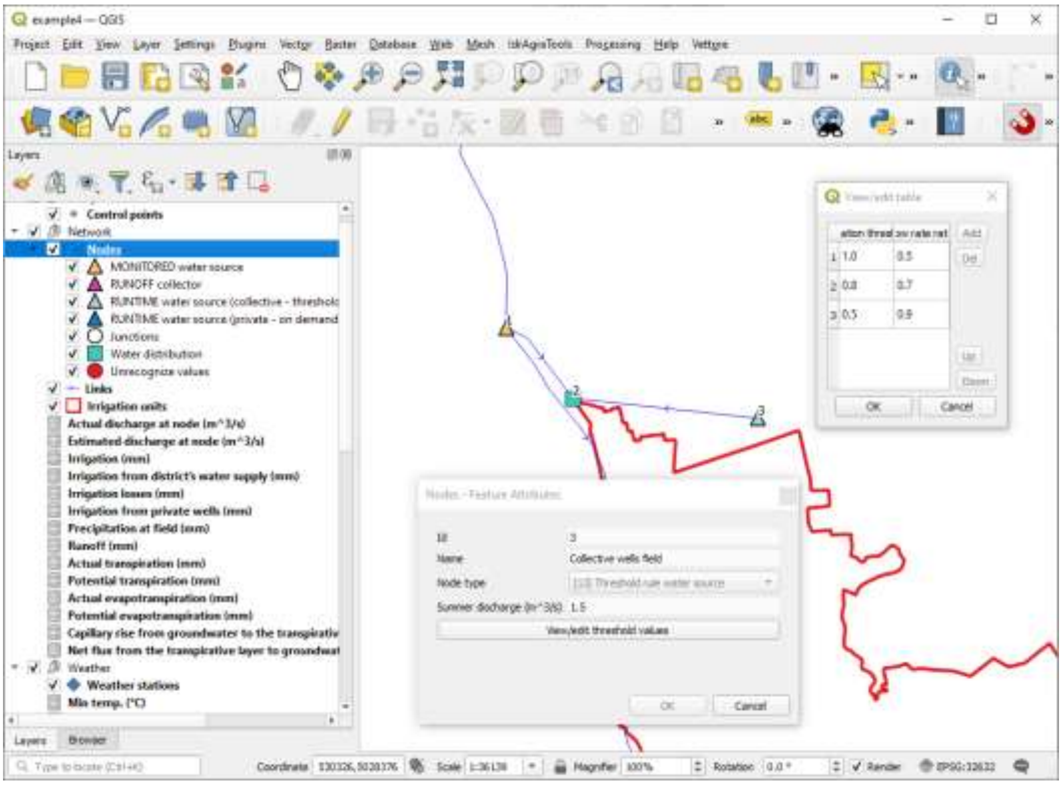


Figure 33: collective wells plan definition in the database.

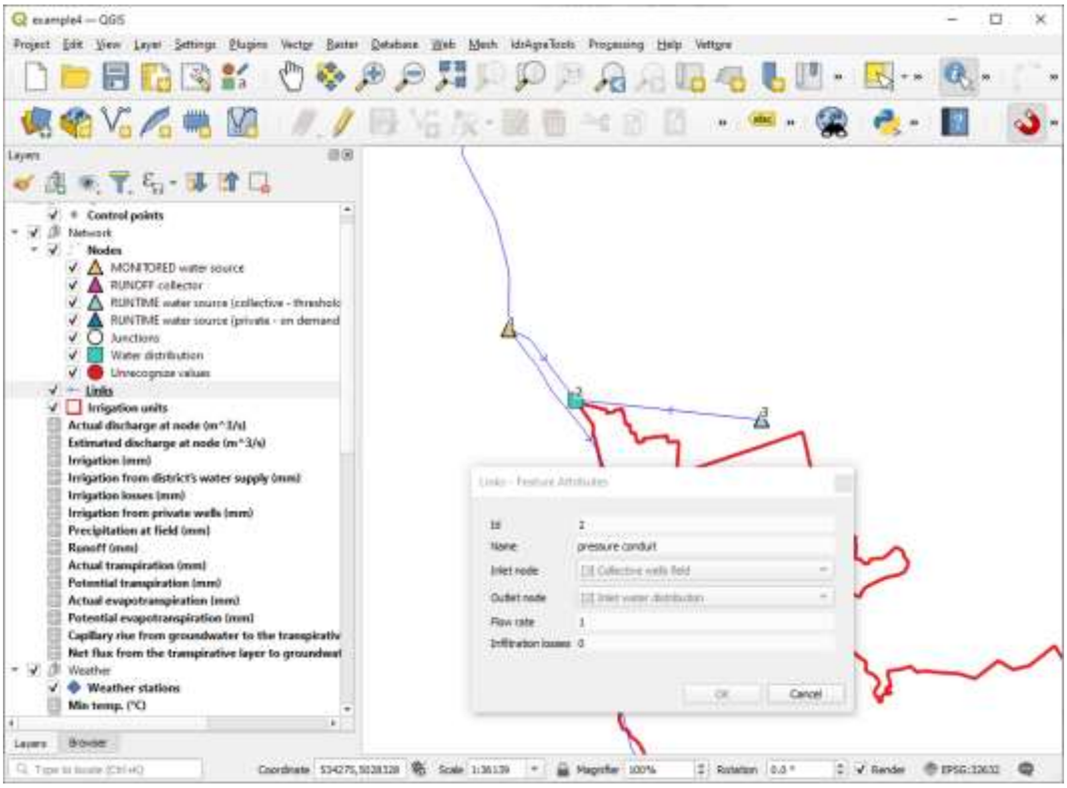


Figure 34: connection (link) between public wells node and water district inlet

Irrigation units can be connect to node of type “Water distribution” only.

Add as many water sources as you want to a single water distribution node in order to serve one or more irrigation units.

Unlimited water sources can be added as well to simulate private wells. Note that private wells are activated before collective ones.

Set up simulation and export dataset

The procedure is exactly the same as exercise 3. The only differences is related to the creation of water sources files: a new file named “3.txt” is added to the output folder and a new water source is added in the district file as shown in Figure 35.

a)

b)

Figure 35: water sources for the irrigation unit file (a) and collective wells field source - node id 3 - file (b)

Perform simulation

The procedure is the same of the exercise 1.

Analyse outputs

The user can be interested in the 1) exploration of the water demand at collective wells field source and 2) plot the actual evapotranspiration rate against the theoretical one for the entire water district.

Water demand at the collective well field

To perform this task, simply follow the procedure from Example 3: **IdrAgraTools → Analysis → Node water demand** (Figure 12a). At the end of the process, calculated flows are inserted in the Estimated discharge at node (m^3/s) table (Figure 22).

Figure 36 show the distribution of estimated discharges from the diversion and the collective well field along the two simulated years obtained through the **Data manager** tool. In this case, it's clear the contribution of the well field to the total water use in the district, in particular during the first simulation year when available volumes from diversion are lower than the crops needs. In the second year, wells are activated only at the beginning of the irrigation season and for a short period.

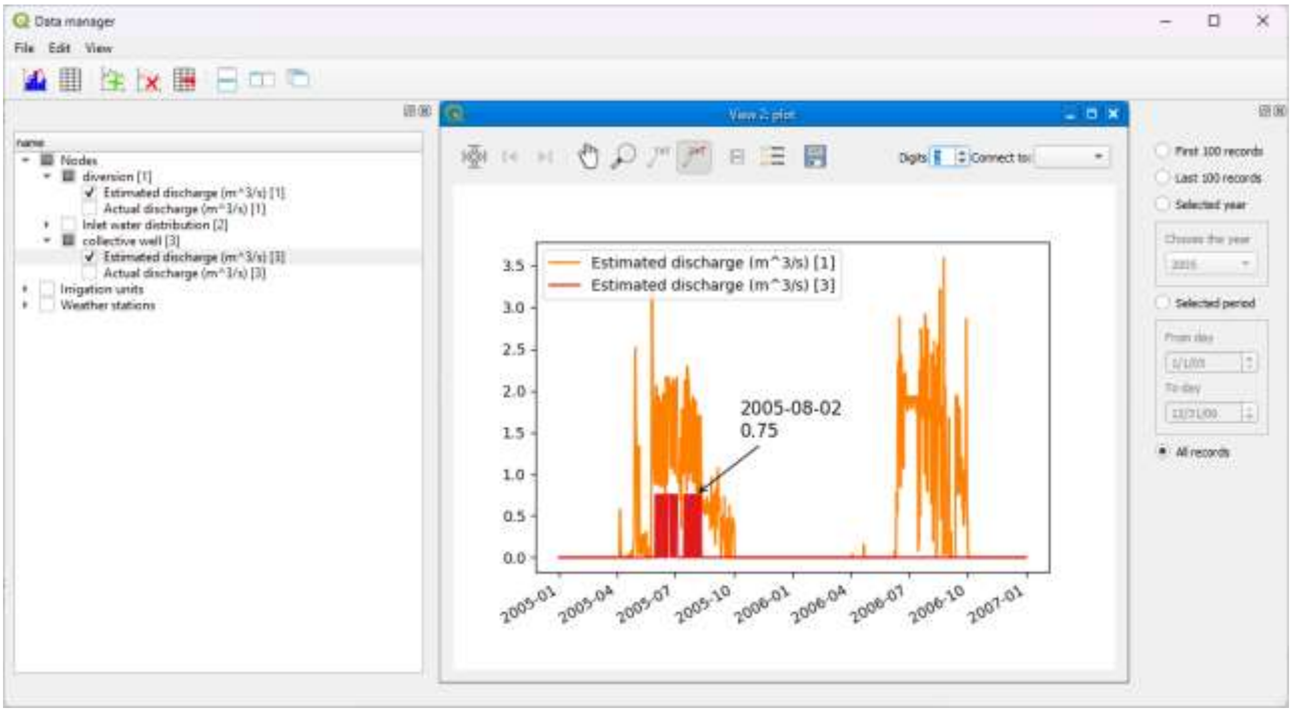


Figure 36: estimated discharges from diversion and collective well field.

Actual vs potential mean evapotranspiration rate

Through the command **IdrAgraTools → Analysis → Import irrigation units results** from (Figure 12a), the user can compute the average values of each variable produced as output by IdrAgra model. Importation results can be explored by the **Data manager** tool (Figure 37).

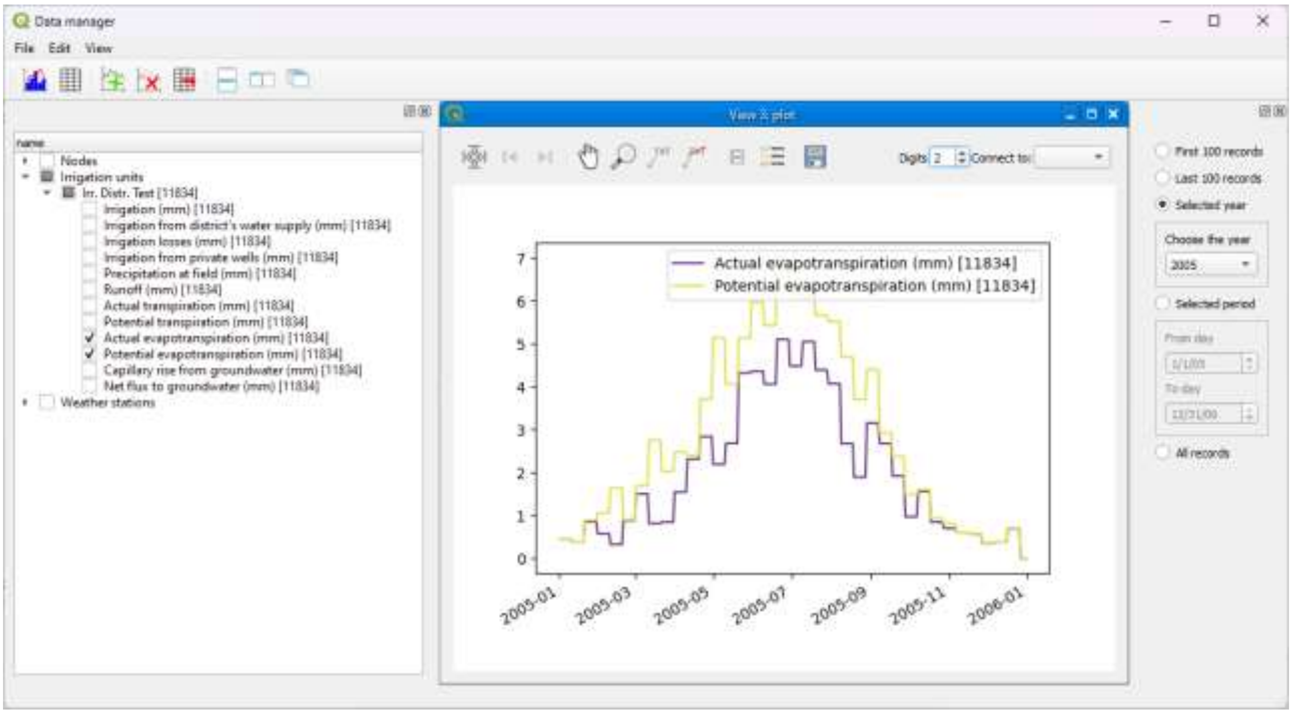


Figure 37: actual vs potential evapotranspiration of the irrigation unit.

Simulation results are always averaged for each irrigation units. If more control on the aggregation function to use is necessary, please consider the Grouped statistics option

The process can take a while according to the number of steps defined for the outputs

Conclusion

This example shows how to calculate water needs at a well field that is activated when the water supply from the main surface water diversion is not sufficient to satisfy the crop needs. It also shows how to calculate aggregate-averaged simulation results for each irrigation units and plot them.

Example 5: complete simulation scenario

Aims

In this example, we will show how to prepare input data for an IdrAgra simulation considering both the effect of topography and the presence of the water table. Additionally, this example shows how to take into account the amount of water that comes from runoff and becomes a source for the irrigation of the downstream district(s).

Study area

The study area is the same of example 1 but the irrigation unit is divided in two parts: the northern part irrigated by the already introduced diversion from the Blue river and collective well field and 2) the southern part, irrigated by the residual water coming from the northern part and private wells. The topography and the water table elevation of the entire area is also known. To make the required adjustments, follow the next steps.

Perform the IdrAgra simulation

Most of the necessary steps to run IdrAgra simulation have been already presented in the previous examples. Following the most relevant updates.

Edit irrigation network to fit new distribution system

With the editing tools provided by the QGIS framework, new nodes and links are added as shown in Figure 38. In particular, two new nodes of type "RUNOFF collector" (*node_type* = 12) and "RUNTIME water source (private - on demand unlimited)" (*node_type* = 14) are created (Table 3).

Table 3: list of nodes in the simulation dataset.

id	Name	Type of node	Notes
1	Diversion	11	See example 1
2	North water distributor	3	Called "Irrigation district inlet" in example 1
3	Well field	13	See example 4
4	Runoff collector	12	New in example 5
5	Private well	14	New in example 5
6	South water distributor	3	New in example 5

The new nodes are connected as shown in Figure 38 by a dummy link with no losses from the “RUNOFF collector” to the “South water distributor” node (*node_type* = 3) and a conduit with low losses (0.1 in fraction) from private wells to the “South water distributor” node.

The position of the geometrical elements could be fictitious and not represent the actual position of the object.

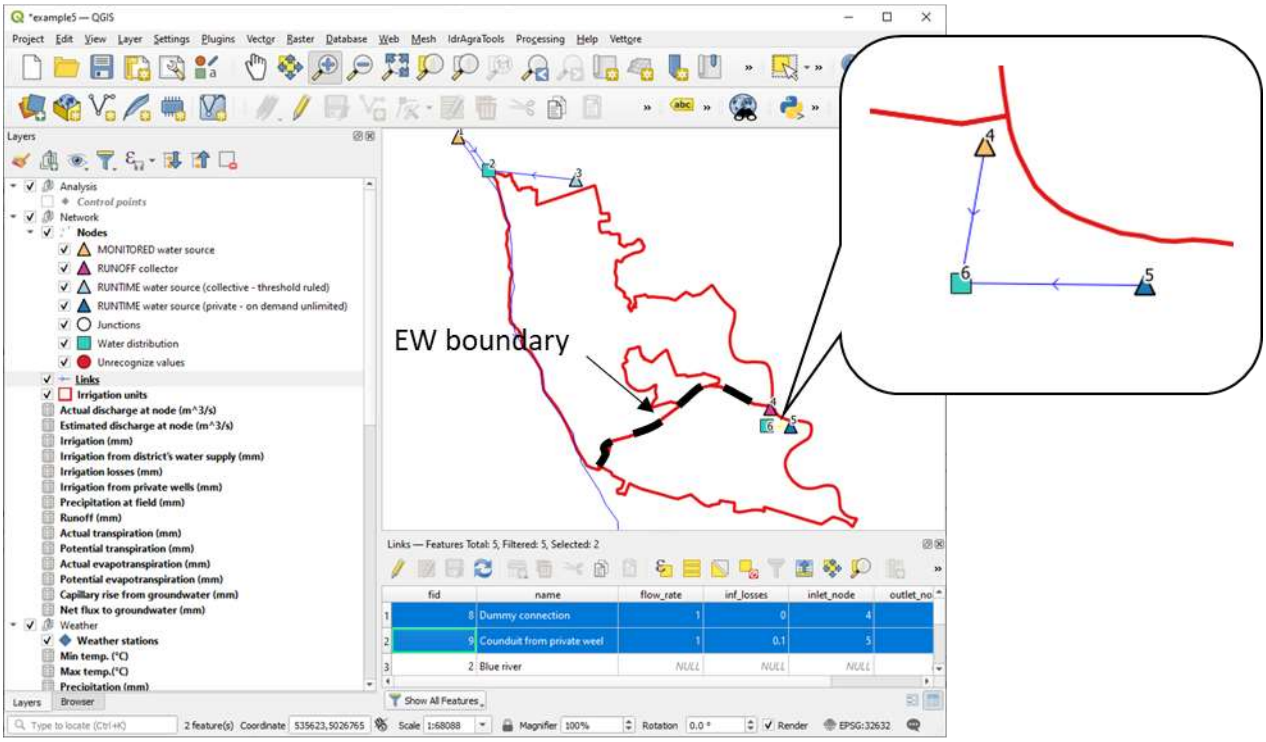


Figure 38: distribution map after network and irrigation units modification.

Also the irrigation units map was edited dividing in two part the existing irrigation unit: one to the North and one to the South of an hypothetical east-west boundary. The two new irrigation units have ids 1000 and 2000 respectively. Note that also the connection to the nodes of the network was modified accordingly: the outlet node of irrigation unit 1000 was set to the “Runoff collector” node (Figure 39a) while the inlet node of the irrigation unit 2000 was set to “South water distributor” (Figure 39b).

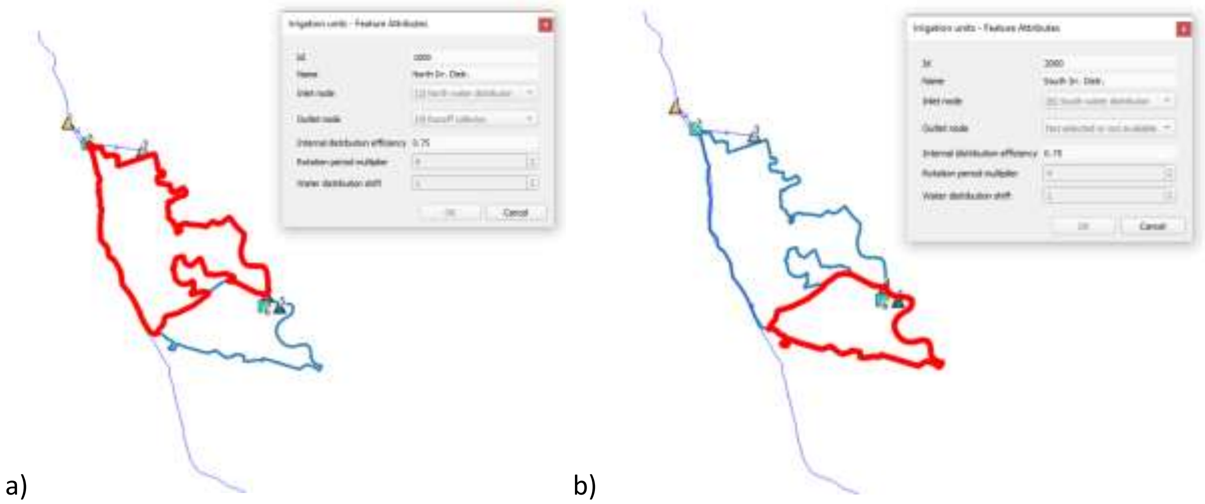


Figure 39: irrigation units map after editing (red line defines the selected element).

Add the elevation map to the project

Altimetry is managed as a raster map in the IdrAgraTools database. To add an existing elevation layer, use the command **Set/edit elevation** from the **Elevation** menu (Figure 41a). A new dialog opens (Figure 41b) and permits to the user to select or modify the source of the raster map (Figure 42Figure 41a). Once the raster layer is selected, the raster map is loaded into the project (Figure 42b) as a new layer under the "Elevation" group.

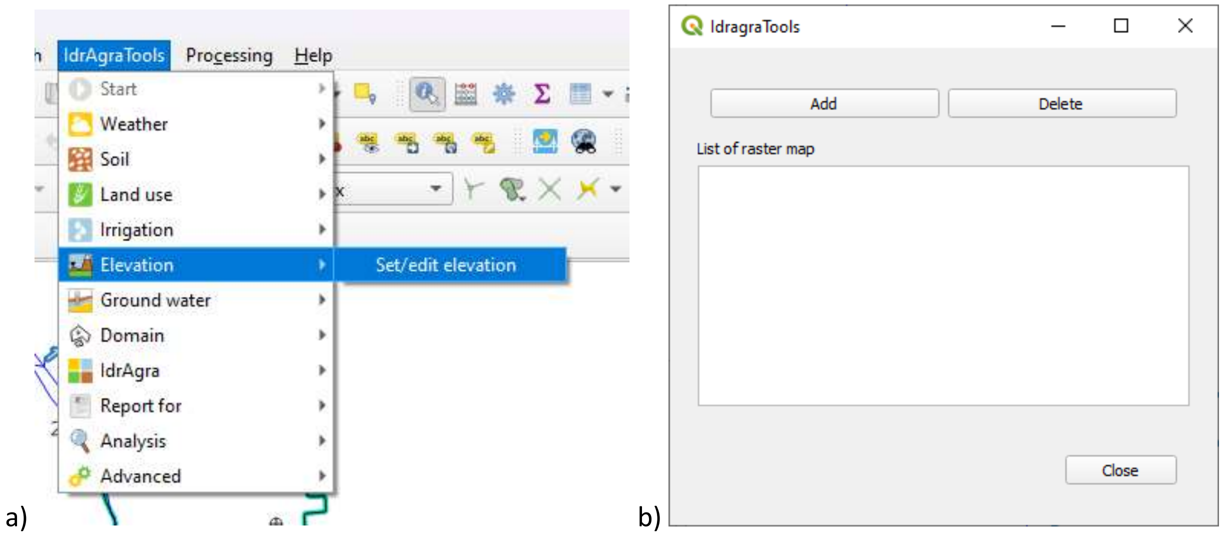


Figure 40: steps to follow in order to add an elevation map to the dataset a) menu option, b) empty list of available raster map

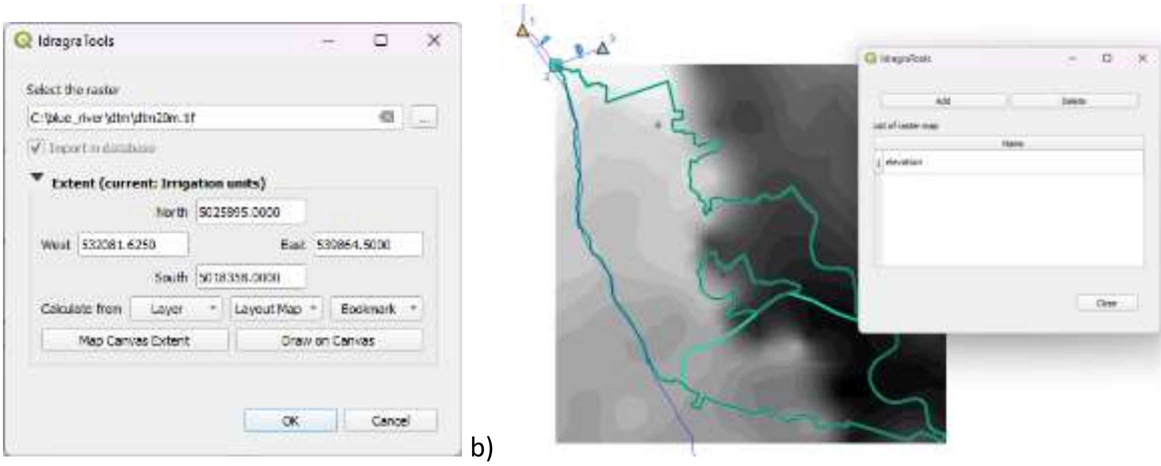


Figure 41: steps to follow in order to set up the elevation map a) select raster map dialog, b) raster map is correctly added to the project

The user can define only one elevation map for each dataset. If an elevation map is already loaded, it will be replaced by the new one once selected.

Raster map are made up of a matrix of pixels (also called cells), each containing a value that represents the conditions for the area covered by that cell (See https://docs.qgis.org/2.8/en/docs/gentle_gis_introduction/raster_data.html).

Elevation map can be loaded in the database as the path to the source file or as raw data. In the last case, original map is cropped according to the extension defined by the user.

Add water table map(s) to the project

Water table information can be added as raster map by the option **Set/edit water table** from the **Ground water** menu (Figure 42a). The procedure is similar to adding an elevation map but, the main difference is the possibility to add as many raster map as the user wants (Figure 43). In the case of the water table information, each raster map must mandatory be associated to a specific date (Figure 42b).

a) b)

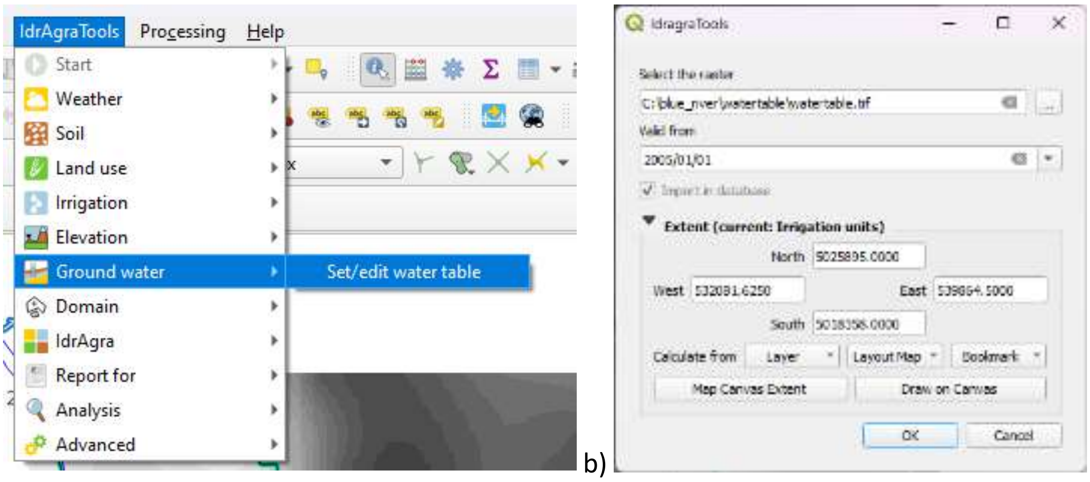


Figure 42: menu option to load water table into the project (a) and dialog where to assign water table date and extension (b)

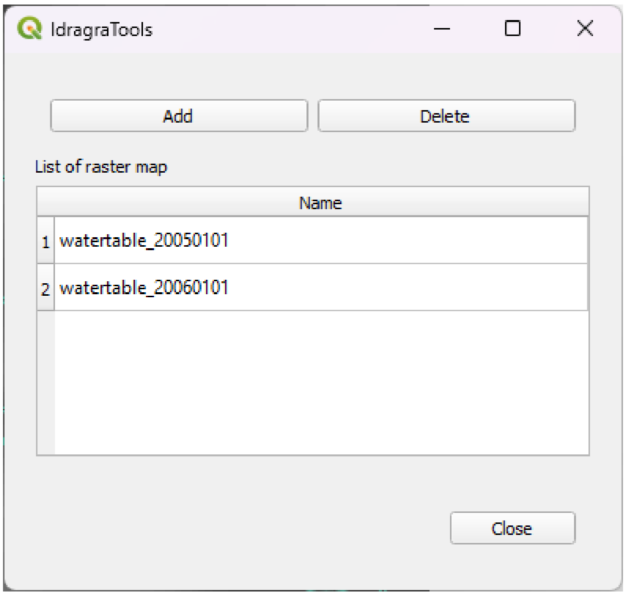


Figure 43: list of water table maps included into the project. Note that each map name includes the date.

Assign the date to the water table map is mandatory

The oldest water table map defines also the base condition at the beginning of the simulation.

Water table maps can change during the simulation period according to the date defined by the user. That permits, for example, to simulate water table variation along irrigation period.

Perform simulation

In this case the procedure required 3 steps:

1. run the IdrAgra simulation in USE mode as described in example 3. After the simulation is completed, calculate the "Node water demand" as in example 3.

2. copy all the records from the "Estimated discharge at node (m^3/s)" table that have the wsid value equal to the id of the "RUNOFF collector" node (id = 4 in the example) to the "Actual discharge at node (m^3/s)". In this way, a new time series of source discharge associated to the "RUNOFF collector" node is created.

3. run the option 5 "Export water sources data" and "Run IdrAgra" and analyze the final results as usual.

To select the necessary records from the table, use the "Select features using an expression" tool from the QGIS interface

Use copy/past features command from the QGIS interface to transfer the selected record. Past command is available only if the destination table is in editing mode

It is highly recommended to paste the record with the destination table not opened to make the operation faster

Analyse outputs

The user can be interested in the 1) display the water losses by deep percolation from each units and 2) compare the water availability from all the water sources.

Display the water losses by deep percolation from each irrigation units

To perform this task, run the **Import irrigation units results** option from the **Analysis** menu item. Then use the **Data manager** to see the imported data. Figure 44 shows the net fluxes to the groundwater table, i.e. the differences between percolation and capillary rise.

Except for the rainy period at the end of the second year, percolation processes are determined mainly by artificial water supplied from the diversion to the Northern irrigation unit. The Southern irrigation unit shows low losses due to percolation as most of the water is supplied by private wells that deliver only the amount of water strictly necessary to the crop. Also the distribution of more efficient irrigation methods (mainly sprinkler system) in the South part justifies low percolation losses.

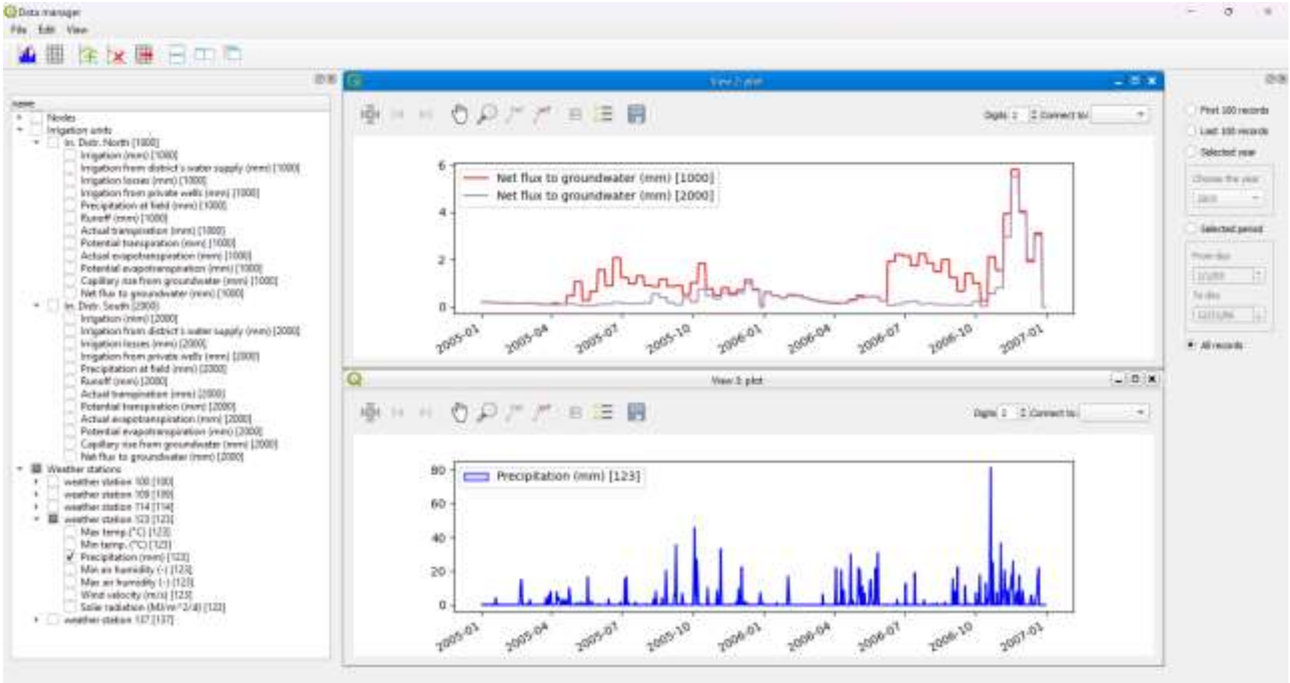


Figure 44: fluxes to the groundwater table for both the irrigation units.

Compare the water availability from all the water sources

Before continuing, it is necessary to modify the type of the "Runoff collector" node to "MONITORED water source" (*node_type* = 11) and set the outlet node of the Northern irrigation unit to empty. Then it is possible to calculate di flow distribution over the network. To do that, simply perform the **Node water demand** option from the **Analysis** menu.

A runoff collector node that is also a water source cause conflict when water distribution algorithm runs. To avoid that, simply change the type of node to MONITORED water source. In any case, the runoff volumes are saved in the "Actual discharge at node (m^3/s)" table

Water availability from each source can be easily compared using the **Data manager** tool (Figure 45). First at all, the actual discharge at diversion (node 1) and the estimated discharges from the collective well field (node 3) are plotted together. In a second window, estimated discharge from private wells (node 5) and the actual discharges from the RUNOFF collector (node 4) are represented.

Using the QGIS table query filter to select only the records in "Estimated discharge at node (m^3/s)" table that match the public well node id (number 3 in the example) and have the estimated values ("recval" field) greater than zero, the total number of collective well activation is obtained.

Comparing to the results from example 4, the activation of the collective well is reduced from 40 to 29 events. This is due to the reduced area of the irrigation unit served by the diversion and the contribution of the water table.

On the other hand, the water availability from the northern irrigation unit to the southern irrigation unit is lower and concentrated at the edge of the irrigation season for the first drier year (2005) while it is higher during the second year of simulation (Figure 45 lower plot).

The water supplied by the private well node (id = 5) varies during both the irrigation seasons of the two considered years (Figure 45 lower plot). The behaviour of node of type “RUNTIME water source (private - on demand unlimited)” drastically differs from “RUNTIME water source (collective - threshold ruled)” as it responds directly to the field water requirements (i.e. higher variability).

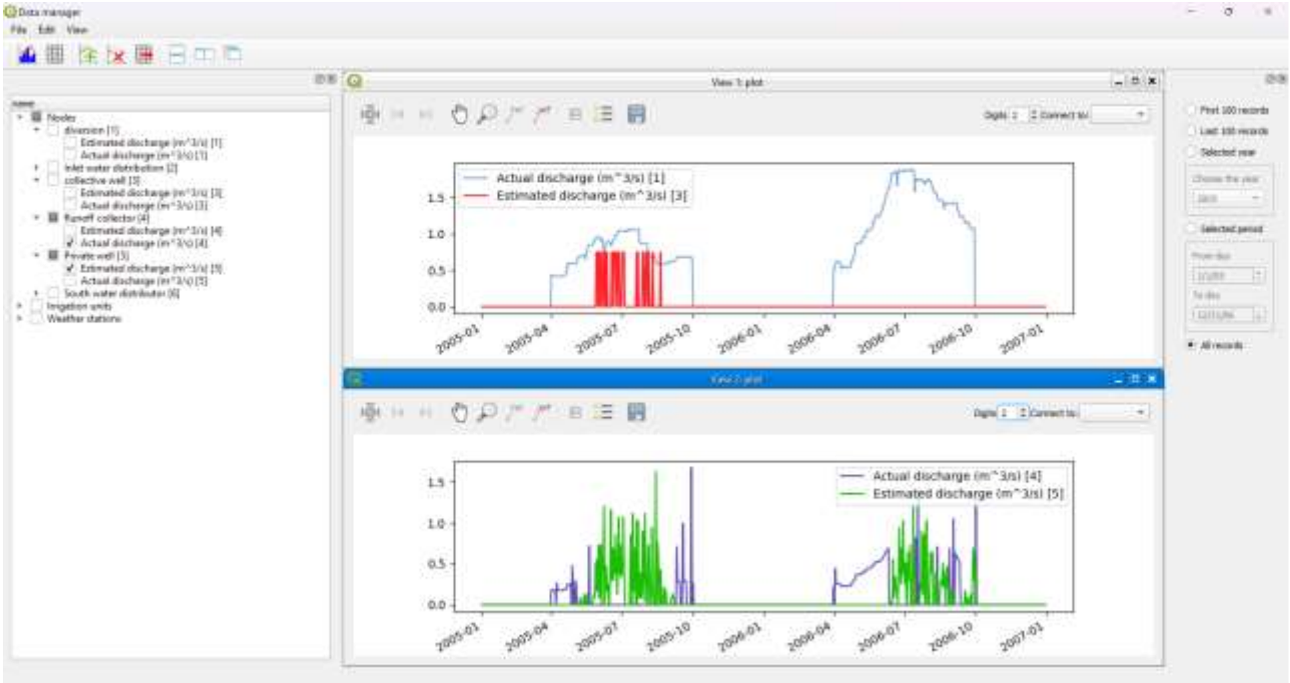


Figure 45: water availability for all the sources that serve the irrigation units.

Conclusion

This example shows how to perform a complex simulation with internal reuse and more accurate information about topography and groundwater level. It quite easy to include spatial continuous information through raster format file directly into the database. Then, with a double run procedure, the internal reuse of runoff discharges was simulated and results finally analysed.