ALL_WATER_gw
Version 1.1.1

Software for

Groundwater Resources Management Optimization (GWRMO)

USER GUIDE

BY
DR. ISSAM NOUIRI

June 2011

Content

1. Introduction

ALL_WATER_gw is a tool designed to optimize the management of groundwater in a planning area. It is developed by Dr. Issam NOUIRI with the support of a technical cooperation project between the Federal Institute for Geosciences and Natural Resources (BGR) and the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD). It can be requested directly from the author (inouiri@yahoo.fr) or downloaded from the ACSAD-BGR project web sites (http://www.acsad-bgr.org) and is free of charge. This first public version can be considered as a starting point of a long term work projected by the developer. Case study application reports and comments, about the software or its user guide, are welcome to improve this contribution.

ALL_WATER_gw considers four objectives in the problem formulation: i) the demand satisfaction, ii) the minimization of the maximal drawdown in aquifer water table, iii) the minimization of the unit cost of water supply, over a planning period and iv) the quality (salinity) satisfaction. Wells maximal pumping rate and drawdowns as well as pipes transfer capacities are also taken in consideration in the proposed problem formulation, as hydraulic constraints. Appendix 3 presents more details about the optimization problem formulation.

To re-constitute the hydraulic system from WEAP, MODFLOW and the linkage shape file, the proposed tool performs three steps, before the start of the groundwater management optimization. In the first step, ***ALL_WATER_gw*** reads the variable values of all the demand sites, the water sources and the transmission links from the WEAP Area. The second step is to read the linkage between demand sites and the active well cells from the linkage shape file. The third step allows the reading of the main characteristics of the MODFLOW model. Theses steps are grouped in the first screen of ***ALL_WATER_gw***.

After the preparation of the required data and the definition of the objectives and their weights, the constraints, the genetic algorithm parameters and the parameters of the convergence criteria, the ***ALL_WATER_gw*** tool uses a Multi-Objective Genetic Algorithm (MOGA) to optimize the management of the groundwater.

As output, ***ALL_WATER_gw*** displays statistics of the optimal solutions determined and the performances of each simulated optimal solution and creates “csv-files” required by WEAP to simulate the optimized scenario.

The details of each of the cited steps are described in the present user guide.

2. Software compatibility and installation

2.1 Compatibility

ALL_WATER_gw is programmed by the VB6 programming language. It can be installed on any personal computer (PC) providing the operation system Windows XP, Windows Vista or Windows 7. The installation package contains all the required components. The present version of ***ALL_WATER_gw*** is compatible with the WEAP version 3.0004 or later, capable to produce an aggregated MODFLOW model for each of the studied scenarios.

The present version of ***ALL_WATER_gw*** supports MODFLOW 2000, also used by WEAP. In some steps of the ***ALL_WATER_gw*** run, MS Excel is used. Excel versions up to 2010 are successfully tested. Please be sure that this software is installed on your PC. When using ***ALL_WATER_gw*** it is recommended to save and close Excel applications to save PC memory and to overcome conflicts.

The ***ALL_WATER_gw*** user interface is optimized for a screen resolution of 1280 x 800 pixels. For screen resolutions lower than 1024 x 768 pixels, it is not possible to display the entire interface of

ALL_WATER_gw. To overcome such problem, ***ALL_WATER_gw*** interfaces are designed to be adjusted by user depending on the PC screen size and resolution.

2.2 Installation

To start the installation of **ALL_WATER_gw**, the user has to execute the installation package, named '*Setup.exe*'.

The installation step will optionally create shortcuts to the software in the Windows Start Menu, the task bar and on the desktop. In addition, it creates an installation folder called: "**ALL_WATER**" under the default path: (e.g. "**C:\Program Files**"), which can be changed by the user.

In the "ALL_WATER" folder, it will be copied the executable program (*ALL_WATER_gw.exe*), the required files for the dynamic graph displaying (RMChart.ocx, RMChart.dll and RMChart.oca) and the VB6 library (VB6.dll). These files are also copied in the "system32" folder in the Windows directory (c:\windows\system32) when using Windows XP or Windows Vista and in the "SysWOW64" folder in the Windows directory (c:\windows\SysWOW64) when using Windows 7. These files are automatically registered when installing the software. If the windows error "Run-time error 339" is displayed when starting ***ALL_WATER_gw***, the (*.ocx) and (*.dll) files have to be registered by user using the command prompt window. One of the following commands has to be executed with administration rights:

- When using Windows XP or Windows Vista: "regsvr32 c:\windows\system32\rmchart.ocx".
- When using Windows 7: "regsvr32 c:\windows\SysWOW64\rmchart.ocx".

A PDF copy of the user guide (ALL_WATER_gw user guide.pdf) is also saved in the ***ALL_WATER_gw*** installation folder. A shortcut to this file is displayed in the Windows Start Menu under the application shortcut.

The files of two WEAP Areas (Opt_2010_12_Test01_WEAP_3_wells.zip and Opt_test_03__MF_2wells-IN.zip) will be copied in the installation folder of ***ALL_WATER_gw***. The first example is a simple case without MODFLOW model. The second one is an example with MODFLOW model. User can use theses examples to perform the first optimization applications.

In addition, a shortcut of the "Uninstall" package will be displayed in the Windows Start Menu, allowing uninstall the software if needed.

***Note**: If a previous version of **ALL_WATER_gw** software is installed in the PC, user has to uninstall it before installing the new version.*

3. Requirements for the WEAP Areas

In order to use ***ALL_WATER_gw*** for groundwater management optimization, in the framework of WEAP_MODFLOW DSS, it is needed to respect next requirements:

3.1. Minimum numbers of Water Sources, Demand Sites and Transmission links

The ***ALL_WATER_gw*** tool needs at least two Water Sources and one Demand Site in the WEAP Area to perform an optimization run. In addition, one of the Demand Sites has to be supplied at least by two Water Sources through two Transmission links.

3.2. Data requirements

Water demands have to be filled in by user for all Demand Sites. The two option allowed by WEAP can be used:

- Specify yearly demand and monthly variation,
- Specify monthly demand.

While ***ALL_WATER_gw*** tool is capable to generate default values for Water Sources and Transmission links to perform optimization runs, it is highly recommended to fill in all the data in the WEAP Area. In particular, user has to fill in the variable “Maximum Flow Volume” of each of the Transmission links with realistic values in order to restrict the calculation time.

To perform optimization considering the cost reduction objective function, it is required to fill in the Cost variables of the Water Sources and/or the Transmission links. In particular, the variables:

- Capital Costs,
- Variable Operating Costs,
- Fixed Operating Costs.

To optimize the groundwater management considering the quality satisfaction objective function, user has to add a new quality variable using the “General/Water Quality Constituents” menu. The new variable has to be called “Salinity”. Three quality variables will be created by WEAP for each of the Demand Sites: “Salinity Inflow”, “Salinity Intensity” and “Salinity Concentration”. Real values of the “Salinity Inflow” have to be filled in for demand sites. For each of the Water Sources, a new variable called “Salinity Concentration” will be also created by WEAP. User has to fill in the values to perform quality satisfaction optimization.

3.3. Units requirements

ALL_WATER_gw computes objective functions using variables of Water Sources, Demand Sites and Transmission links. Thus, it is required to use the same units for water volumes (ex. m^3), for costs (ex. $) and for salinity (ex. g/l).

3.4. Update of WEAP results

After each input data modification in the WEAP Area, a new WEAP run is required to get updated inputs for ***ALL_WATER_gw***. A simple click on the result view icon of WEAP can perform this step before starting data acquisition by ***ALL_WATER_gw***.

4. Presentation of the “*ALL_WATER_gw*” software

4.1. General presentation of the user interface

The ***ALL_WATER_gw*** Graphical User Interface (GUI) is formed by three main screens. The first one is reserved to read in the hydraulic system from WEAP Area, from the linkage shape file and the MODFLOW model. The second screen allows the user to choose the optimization objectives and constraints, to fix the genetic algorithm parameters, to assign weights to the objectives, to choose the parameters of the convergence criteria and to run the optimization. The optimization progress is also displayed in this screen with a PARETO front and the fourth objectives functions evolution. The third screen is designed to display statistics of all found optimal solutions and to propose three characteristic ones. This screen allows the user to evaluate specific optimal solution and to save solutions.

When ***ALL_WATER_gw*** is started, a welcome screen is displayed to provide information about the tool.

Figure 1: The welcome screen of ***ALL_WATER_gw*** software.

The "START" button allows the user to access to the first screen of the GUI, as presented in the figure below:

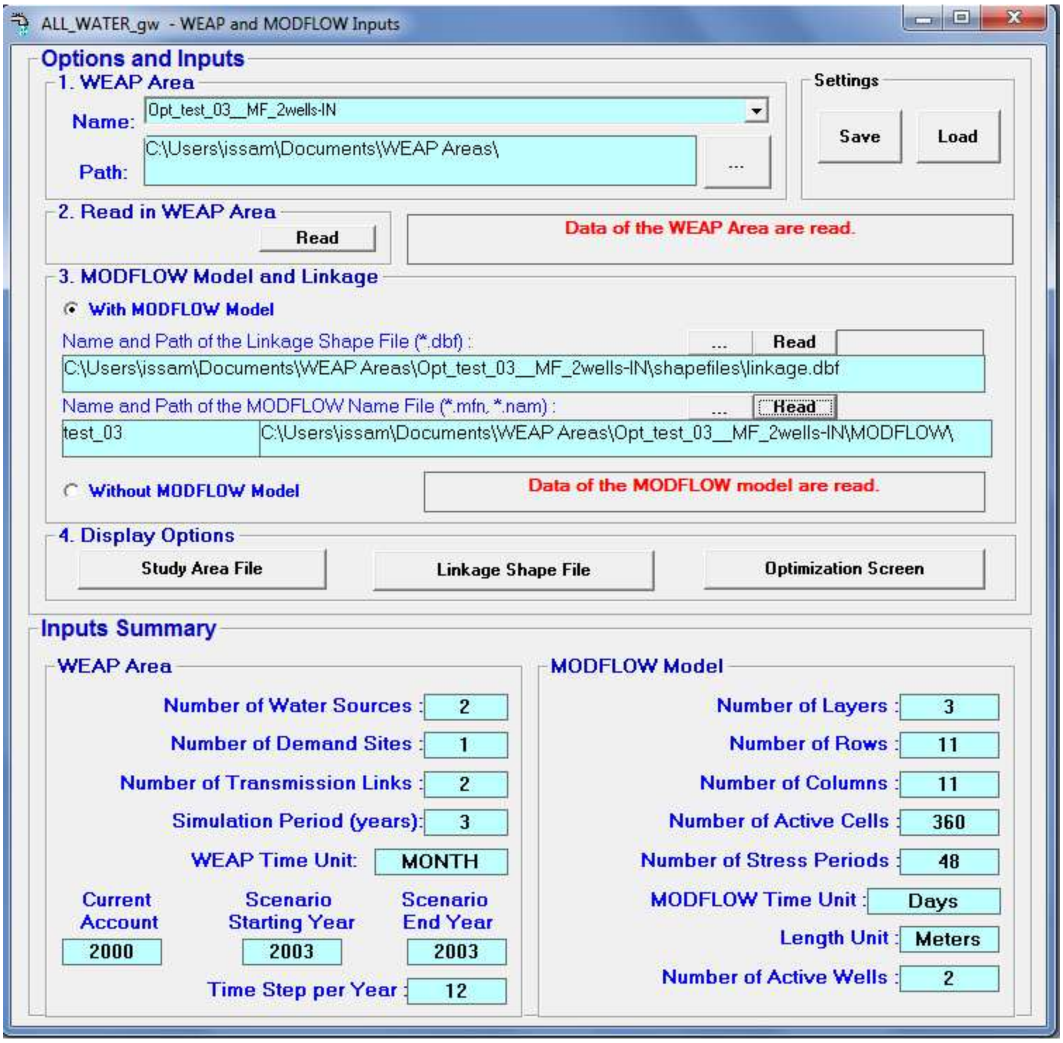


Figure 2: Graphical User Interface of ***ALL_WATER_gw*** for data inputs.

When the input data step is completed, the optimization screen can be displayed using the bottom "Optimization Screen", as presented in the next figure:

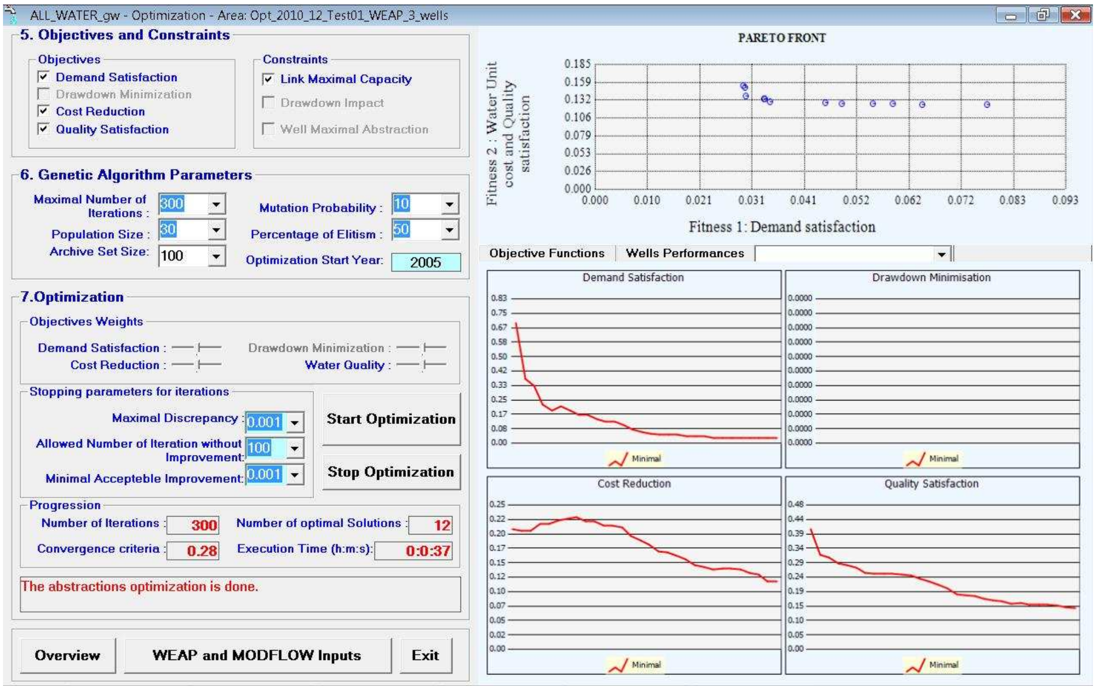


Figure 3: Optimization Interface of ***ALL_WATER_gw***.

The third screen of ***ALL_WATER_gw*** is an "Overview" of the obtained results, presented in the next figure:

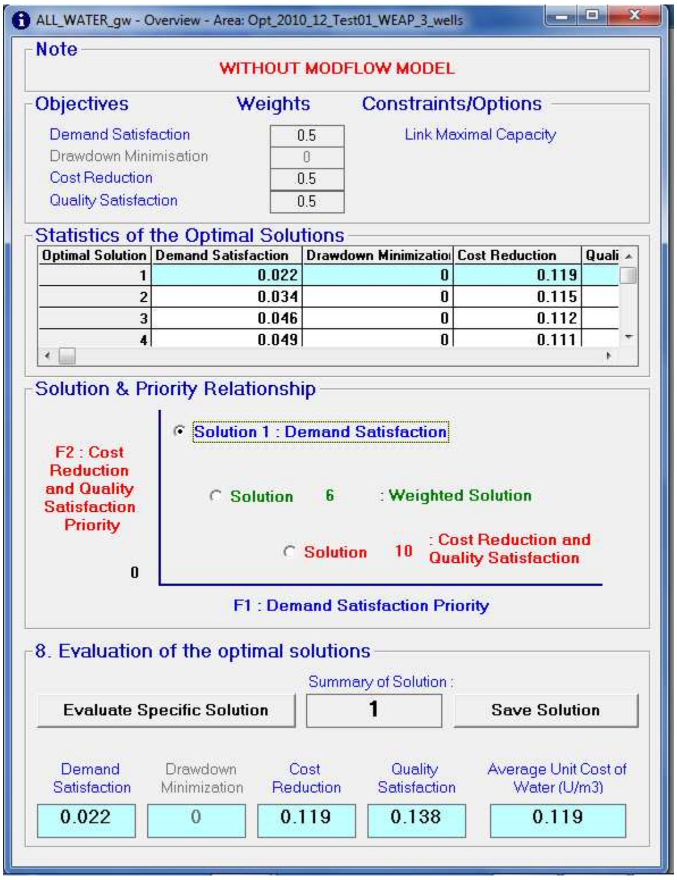


Figure 4: Overview Interface of ***ALL_WATER_gw***.

Next paragraphs explain the steps from the data preparation to the results displaying in detail.

4.2. Data reading and input file preparation

To guide the user of the ***ALL_WATER_gw*** software, the main steps where the user has to interact with the tool are numbered from 1 to 8. Each of them is exposed next.

4.2.1. STEP 1: Selection of the WEAP Area

The first step in using ***ALL_WATER_gw*** is to specify the name of the WEAP Area that has to be optimized for water management. In the present version of the ***ALL_WATER_gw***, it is considered that each WEAP Area is saved in a folder with the same name as the area. When starting, ***ALL_WATER_gw*** proposes a help by loading all the WEAP Area names to the user interface:

Figure 5: Dialog box asking to load the names of all WEAP Areas.

If the user chooses this option, ***ALL_WATER_gw*** performs this option. The WEAP software has to be started before. The user can then choose a WEAP Area from a list, provided by the combo box, as depicted in the following figure.

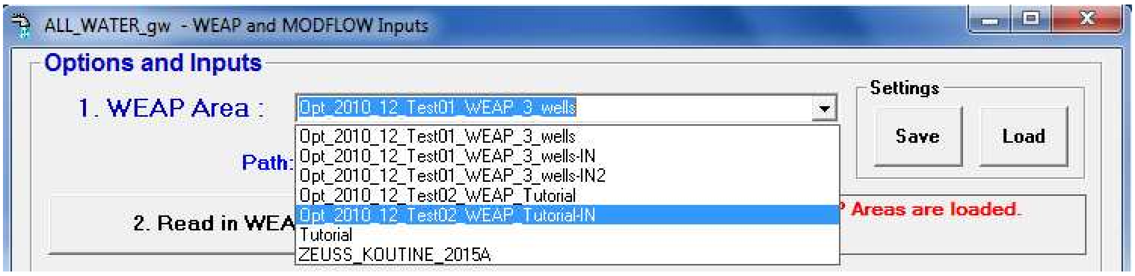


Figure 6: List of WEAP Area names loaded in the user interface.

If the automatic loading option of the WEAP Areas names is not chosen by the user, a dialog box invites the user to browse for the folder of the desired WEAP Area:

Figure 7: Dialog box asking to browse over the PC and to select the folder of the WEAP Area.

If the user doesn't accept also this option, by clicking on the "Cancel" button of the previous dialog box, ***ALL_WATER_gw*** informs the user that it is not possible to continue if the path and the name of the WEAP Area are not chosen. Thus, the user has to type in the required fields: the WEAP Area name and its path.

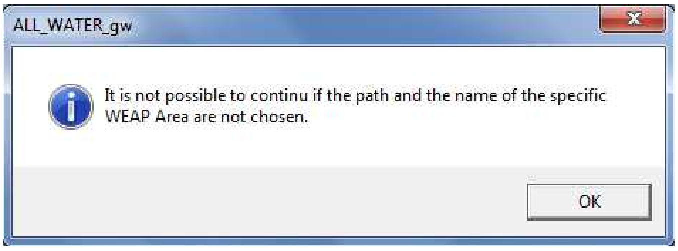


Figure 8: Dialog box asking the user to provide the required information.

If the tool is used the first time, the user has to select the WEAP Area by one of the two options.

Note: *If WEAP hasn't be started in the background automatically, it is required to start WEAP before the next step. The WEAP results have to be up-to-date. You can check this by changing to the "Results" view within WEAP.*

4.2.2. STEP 2: Read in a WEAP Area

After the selection of the name of the WEAP Area in the list box of the step 1, and by clicking on the command button named "*Read in WEAP Area*", ***ALL_WATER_gw*** will perform necessary verifications to ensure runs without bugs.

First, ***ALL_WATER_gw*** activates the selected area and verifies the version of the installed WEAP application. When the WEAP version 3.0004 (or later) is used, ***ALL_WATER_gw*** reads the names of all the WEAP Areas saved on the user PC, their respective directories and the WEAP default path. The default path is displayed in the "Options and Inputs" part of the user interface. A dialog box invites the user to confirm or to change the path:

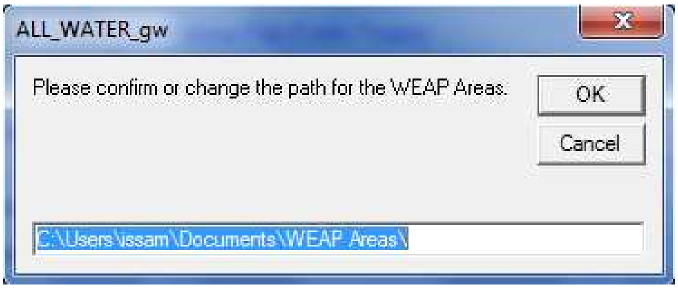


Figure 9: Message box for path confirmation.

Secondly, if the optimization input files, created by ALL_WATER_gw, exist already, a message box will ask if the user want to create new files for the selected area:

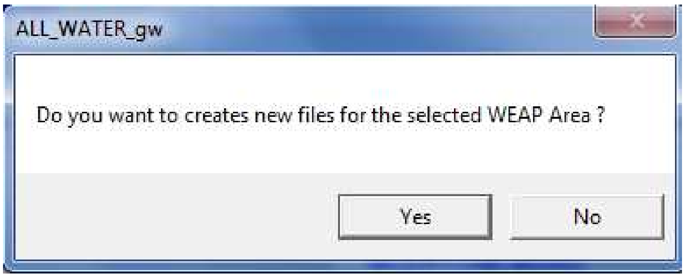


Figure 10: Read in WEAP Area - Confirmation.

If the user wants to use optimization files prepared by former ***ALL_WATER_gw*** runs, he should select “No”,

The present version of ***ALL_WATER_gw*** requires a scenario named “Reference” in the WEAP Area. This scenario is used to read variable values of the WEAP branches. The user has also to introduce, by dialog box, the starting year of the optimization: First year of the period to be optimized, as presented in next figure:

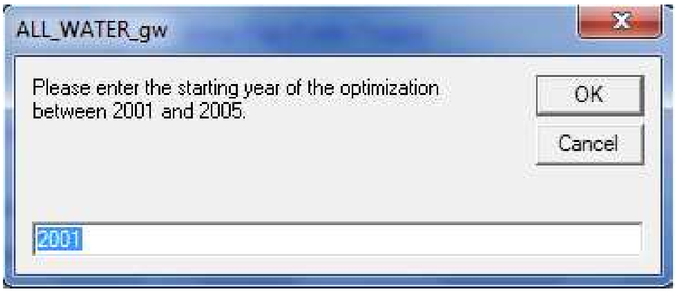


Figure 11: Read in WEAP Area – Starting year of the optimization.

ALL_WATER_gw creates a folder named “OPTIMIZATION”, if it doesn’t already exists, within the study area folder. This folder is used to save all files created before the optimization. At this moment, ***ALL_WATER_gw*** starts reading all variables in the WEAP Area branches. Nine files will be created: Four text files and five Excel files, as listed in the next figure:

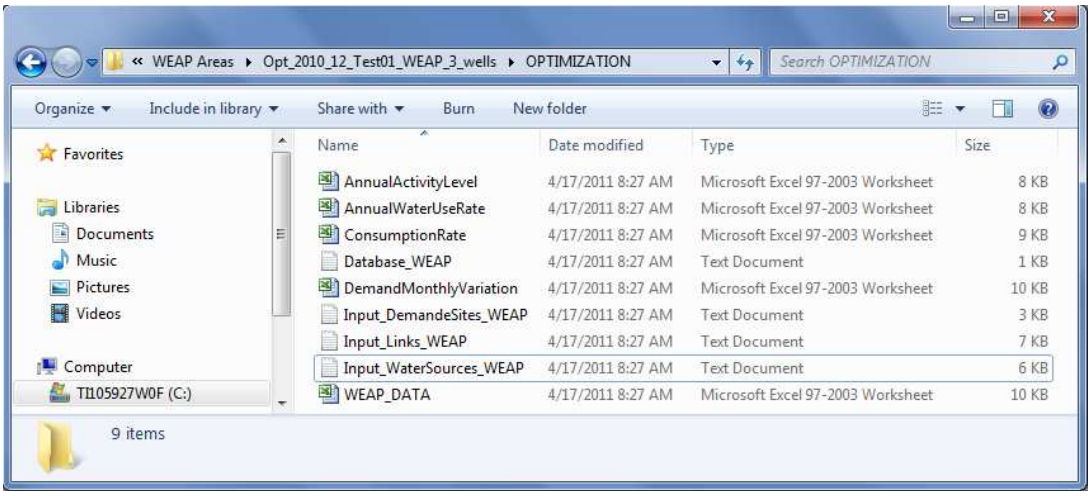


Figure 12: Output files created by ***ALL_WATER_gw*** in step 2.

The “WEAP_DATA.xls” file contains the branches and the variables of the study area read from WEAP. The files “AnnualActivityLevel.xls”, “DemandMonthlyVariation.xls”, “AnnualWaterUseRate.xls” and “ConsumptionRate.xls” summarize the consumption properties of the demand site nodes of the WEAP schematic. The information in the previous files is taken from WEAP, without modification. If the water demand is defined within WEAP by “Specify monthly demand” method, theses files will be also created and will contain the data introduced by user.

The text files created in the present step describe the demand sites (Input_DemandSites_WEAP.txt), the water sources (Input_WaterSources_WEAP.txt) and the linkage between sources and demand sites (Input_Links_WEAP.txt). The file: “Database_WEAP.txt” summarizes the numbers of demand sites, water sources and transmission links, the time parameters (length of the study period, initial, present and last time steps, the number of time steps and the time unit) and the ID of the WEAP reference scenario.

A list of all the created files is presented in appendix 1. Their formats are described and examples are presented in the appendix 2.

When ***ALL_WATER_gw*** is running a red text message is always displayed, describing what the software is doing. The mouse pointer will be changed to the waiting appearance. If this step has succeeded, the message: "*Data of the study area are read*" is shown and the mouse pointer returns to the default appearance.

At the end of this step, ***ALL_WATER_gw*** asks the user, by message box, to edit or not the created demand sites file "Input_DemandSites_WEAP.txt":

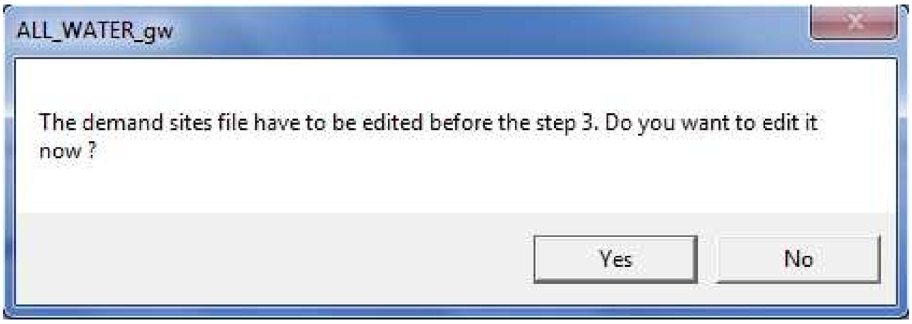


Figure 13: Message box asking to edit or not the demand sites input file.

Indeed, when demand sites have not to be considered by the optimization, it is possible to assign that to ***ALL_WATER_gw*** by the value of a demand site parameter called "ChoiceD", as presented in the next figure:

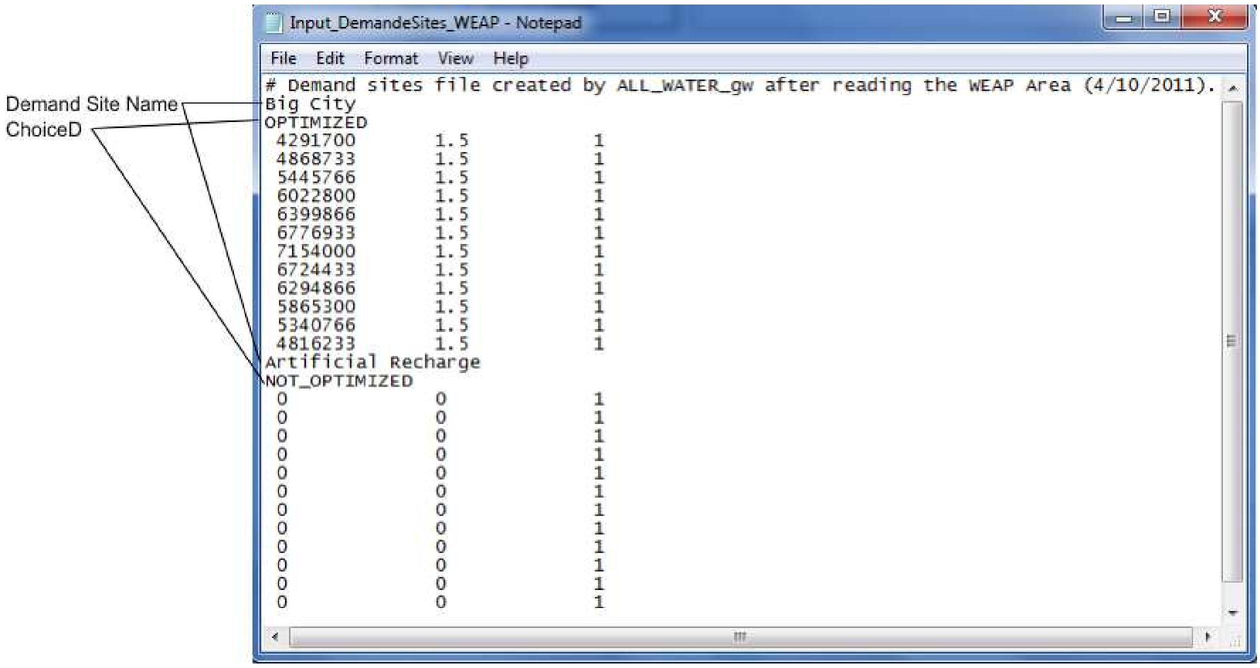


Figure 14: Demand sites input file created by ***ALL_WATER_gw***.

The default values of the "ChoiceD" parameter are "OPTIMIZED", when the water demand is positive, and "NOT_OPTIMIZED", when the water demand is equal zero. The user has to modify the default proposed values according to the optimization objectives. This option allows the user flexibility to optimize the groundwater management while considering specific demand sites. It is also useful when demand sites are used to simulate natural water demand, as evaporation and recharge, and have not to be optimized.

4.2.3. STEP 3: Read in the linkage shape file and the MODFLOW model and editing the ALL_WATER_gw well file

There are two options in this step:

If there is no MODFLOW model, the user has to activate the option “Without MODFLOW Model”. In this case only transmission link flows can be considered and optimized. This action will create four new files for demand sites, water sources and transmission links, with the suffix “*_Opt”. This option is the default one when the WEAP Area is read in. Four new files for demand sites, water sources and transmission links will be created, as in the first option. Next figure shows the names of the files created by ALL_WATER_gw up to here:

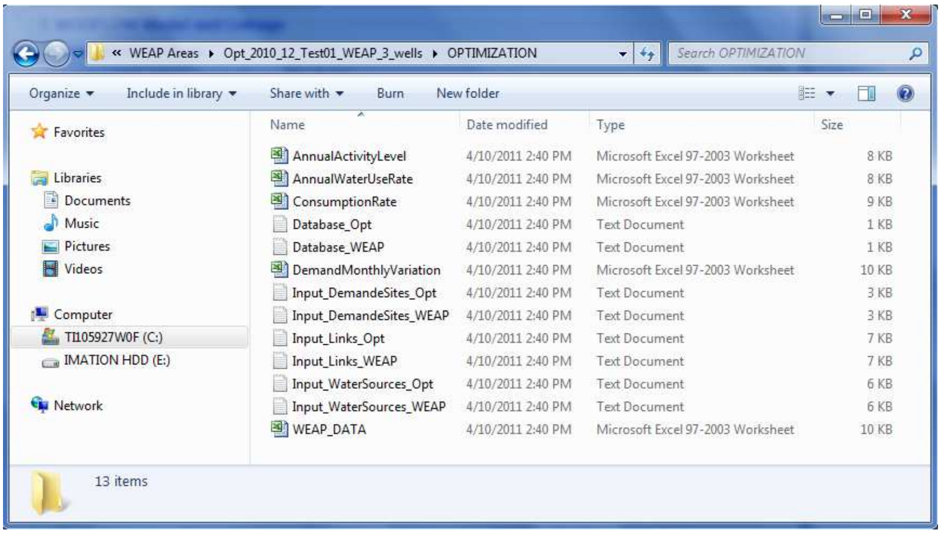


Figure 15: Output files created by ***ALL_WATER_gw*** up to the end of step 3, if there is no MODFLOW model.

If there is a MODFLOW model linked to the WEAP Area, the user has to activate first the option “With MODFLOW Model”. In this case, the abstractions at each well can be optimized. In the second step, the names and the paths of the linkage shape file (*.dbf) and of the MODFLOW name file (*.nam, *.mfn) have to be introduced.

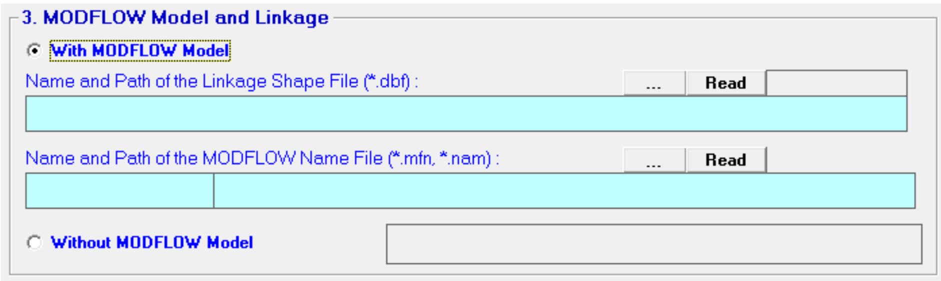


Figure 16: Reading of the Linkage shape file and the MODFLOW model.

NOTE: *In this step, the name file of the original MODFLOW model is required and not one of those, created by WEAP.*

Use the browse buttons (…) to select these files. ***ALL_WATER_gw*** will fill in the respective fields. Dialog boxes will be displayed to help user to select files and to fill in the required fields.

The first browse button allows the user to select the linkage shape file. The WEAP Area folder is displayed as a default.

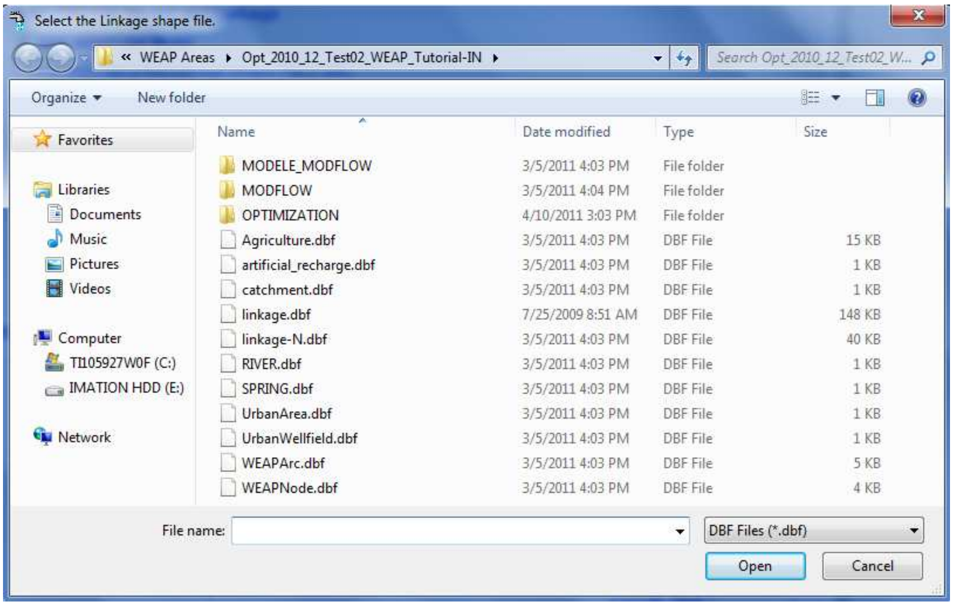


Figure 17: Dialog box to browse for the linkage shape file.

Click on the buttons “Read” to start reading separately the linkage shape file and the MODFLOW model. A red text message displays what ***ALL_WATER_gw*** is doing. In addition, a status bar informs about the progress of the linkage shape file reading. New files for demand sites, water sources, transmission links and summary data, with the suffix “_Opt_MF” will be created.

A click on the second browse buttons activate the dialog box designed to browse for the MODFLOW name file and to fill in the respective fields:

Figure 18: Dialog box to browse for the MODFLOW name file.

As preparation for the optimization step, ***ALL_WATER_gw*** creates in this step a text file of the active well properties, called: ***ALL_WATER_gw*** well file. This file should be edited by the user manually. If this file already exists in the OPTIMIZATION folder, a message box asks the user if he want to create a new one:

Figure 19: Dialog box asking to create the ***ALL_WATER_gw*** well file**.**

The ***ALL_WATER_gw*** well file has the following structure:

***ALL_WATER_gw* well file**

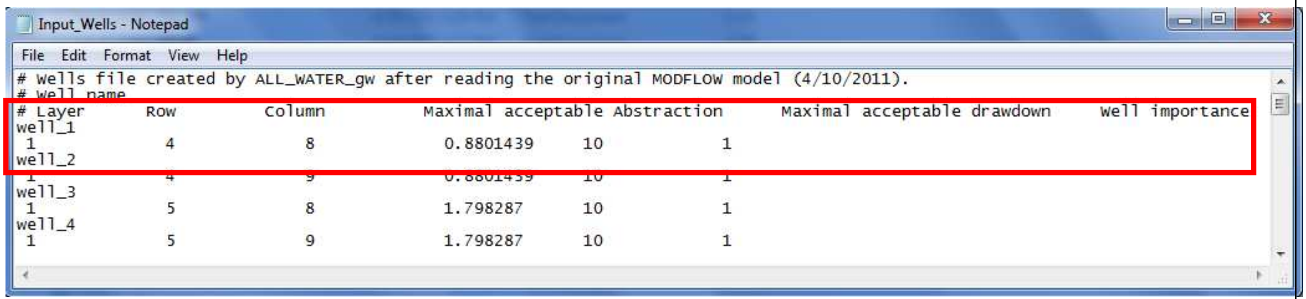


Figure 20: Example of well input file, as automatically created by ***ALL_WATER_gw.***

For each well present in the MODFLOW well file two lines are reserved: The first one contains the well name (eg. "well_1"). The second line is formed by six columns:

column 1: well layer;

column 2: well row;

column 3: well column;

column 4: maximal pumping rate, with the unit as in the MODFLOW well file (m^3/s in the demonstration example); default: highest value observed over the study period in each well

column 5: maximal cell drawdown (m); default value: 10;

column 6: well importance parameter; default value: 1.The importance parameter describes the priority of drawdown minimization at each well. A value of 1 means highest priority for the drawdown minimization at the concerning well in comparison to the other wells. The importance parameter for less important wells takes values greater than 1. The user has the task to compare the importance of the optimized wells and to choose an importance parameter for each of them;

The user has to modify the maximal pumping rate, the maximal drawdown and the importance parameters for each well, according to the data availability and his experience, before the optimization step.

If all needed files are read in successfully, the red text displays the message: "*Data of the linkage shape file and the MODFLOW model are read*".

Next figure presents the first ***ALL_WATER_gw*** screen with the summary of a test study area. For the demonstration example, there are 2 water sources, 1 demand sites and 2 transmission links. The simulation period (3 years), the current account year (2000), the scenario starting year (2001) and the end year (2003) as well as the number of time steps per year (12) are displayed in the "Inputs Summary" part of the GUI. In addition, the inputs summary of the MODFLOW model is presented: For this demonstration example, there are 3 layer, 11 rows, 11 columns, 360 active cells and 48 stress periods. The time unit of the MODFLOW model is "Days" and the length unit is "Meters". There are 2 active wells in the MODFLOW model.

The only basic data required by ***ALL_WATER_gw*** to ensure the first four steps are the name of the WEAP Area and the names and paths of the linkage shape file and of the original MODFLOW name file. The parameters presented in the "Inputs Summary" frame within the user interface are the result of the communication performed between ***ALL_WATER_gw*** and WEAP as well as the reading of the linkage and the MODFLOW files.

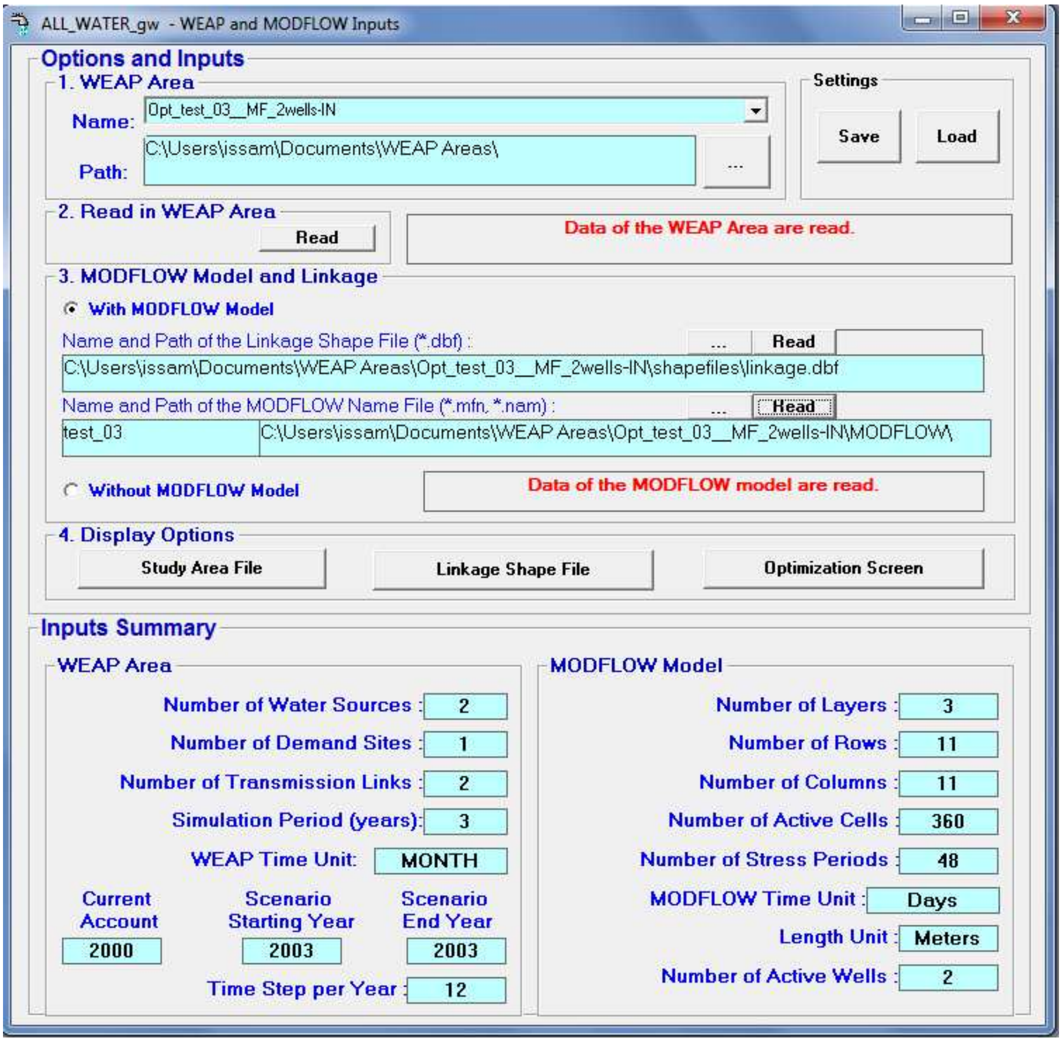


Figure 21: Display of the inputs summary of the WEAP Area and the MODFLOW model in the user interface of ***ALL_WATER_gw.***

At the end of the step 3, the final files are created, which will be used as inputs for the optimization step. Next figure lists the files created in step 3, in addition to the files created in step 2:

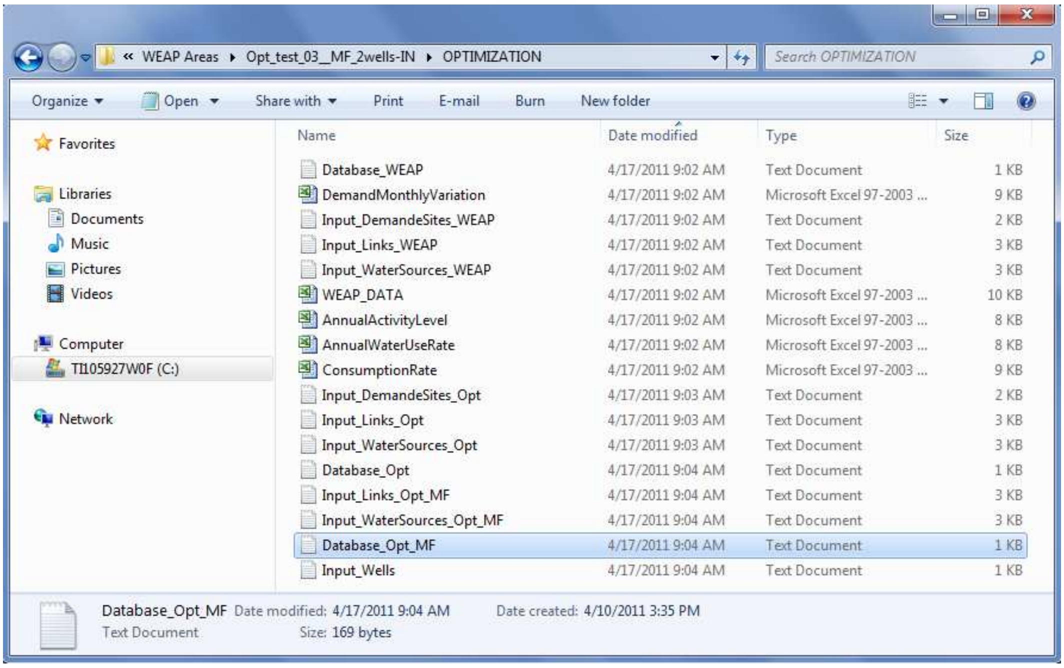


Figure 22: Output files created by ***ALL_WATER_gw*** up to the end of step 3, if there is a MODFLOW model.

The text files describe the demand sites, the water sources, the links and data summary, as in step 2, and constitute the inputs for the optimization step. You can see that their names are similar to those created in step 2. The suffix is changed to "_Opt", if there is no MODFLOW model. The suffix is changed to "_Opt_MF", if there is a MODFLOW model linked to the WEAP Area. In addition, the file "Input_Wells.txt" details the well data.

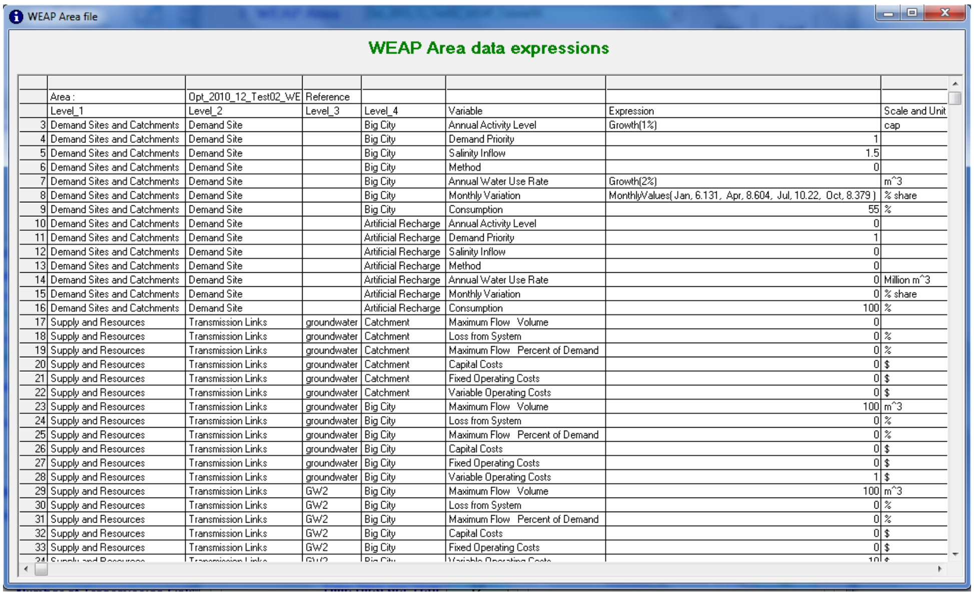
At this point, the user can check for the input data and those generated by the ***ALL_WATER_gw*** software. If all the files are conformal to their standard structure (see appendix), it is possible to display the optimization screen by activating the button named "*Optimization screen*" in the display option section (step 4).

4.2.4. STEP 4: Display options

ALL_WATER_gw allows the displaying of the data expression of the WEAP Area and the linkage shape file, by clicking on command buttons. This step allows also the activation of the optimization screen.

Figure 23: Display option of step 4.

To display the data expressions of the WEAP Area, click on the button "Study Area File". Next screen will be displayed:



WEAP Area file

WEAP Area data expressions

	Area :	Opt_2010_12_Test02_WE	Reference				
	Level_1	Level_2	Level_3	Level_4	Variable	Expression	Scale and Unit
3	Demand Sites and Catchments	Demand Site		Big City	Annual Activity Level	Growth(1%)	cap
4	Demand Sites and Catchments	Demand Site		Big City	Demand Priority	1	
5	Demand Sites and Catchments	Demand Site		Big City	Salinity Inflow	1.5	
6	Demand Sites and Catchments	Demand Site		Big City	Method	0	
7	Demand Sites and Catchments	Demand Site		Big City	Annual Water Use Rate	Growth(2%)	m^3
8	Demand Sites and Catchments	Demand Site		Big City	Monthly Variation	MonthlyValues(Jan, 6.131, Apr, 8.604, Jul, 10.22, Oct, 8.379)	% share
9	Demand Sites and Catchments	Demand Site		Big City	Consumption	55	%
10	Demand Sites and Catchments	Demand Site		Artificial Recharge	Annual Activity Level	0	
11	Demand Sites and Catchments	Demand Site		Artificial Recharge	Demand Priority	1	
12	Demand Sites and Catchments	Demand Site		Artificial Recharge	Salinity Inflow	0	
13	Demand Sites and Catchments	Demand Site		Artificial Recharge	Method	0	
14	Demand Sites and Catchments	Demand Site		Artificial Recharge	Annual Water Use Rate	0	Million m^3
15	Demand Sites and Catchments	Demand Site		Artificial Recharge	Monthly Variation	0	% share
16	Demand Sites and Catchments	Demand Site		Artificial Recharge	Consumption	100	%
17	Supply and Resources	Transmission Links	groundwater	Catchment	Maximum Flow Volume	0	
18	Supply and Resources	Transmission Links	groundwater	Catchment	Loss from System	0	%
19	Supply and Resources	Transmission Links	groundwater	Catchment	Maximum Flow Percent of Demand	0	%
20	Supply and Resources	Transmission Links	groundwater	Catchment	Capital Costs	0	$
21	Supply and Resources	Transmission Links	groundwater	Catchment	Fixed Operating Costs	0	$
22	Supply and Resources	Transmission Links	groundwater	Catchment	Variable Operating Costs	0	$
23	Supply and Resources	Transmission Links	groundwater	Big City	Maximum Flow Volume	100	m^3
24	Supply and Resources	Transmission Links	groundwater	Big City	Loss from System	0	%
25	Supply and Resources	Transmission Links	groundwater	Big City	Maximum Flow Percent of Demand	0	%
26	Supply and Resources	Transmission Links	groundwater	Big City	Capital Costs	0	$
27	Supply and Resources	Transmission Links	groundwater	Big City	Fixed Operating Costs	0	$
28	Supply and Resources	Transmission Links	groundwater	Big City	Variable Operating Costs	1	$
29	Supply and Resources	Transmission Links	GW2	Big City	Maximum Flow Volume	100	m^3
30	Supply and Resources	Transmission Links	GW2	Big City	Loss from System	0	%
31	Supply and Resources	Transmission Links	GW2	Big City	Maximum Flow Percent of Demand	0	%
32	Supply and Resources	Transmission Links	GW2	Big City	Capital Costs	0	$
33	Supply and Resources	Transmission Links	GW2	Big City	Fixed Operating Costs	0	$

Figure 24: WEAP Area data expressions screen.

To display the linkage shape file, use the command button "Linkage Shape File":

Linkage Shape file

Linkage Shape file data

	MF_ROW	MF_COL	MF_RC	CATCHMEN	LANDUSE	GROUNDW/	RIVER	DEMAND1	DEMAND2	AREA_M2	AREA_HA	BND_L1	BND_L2	BND_L3	STD_L1	STD_L2	STD_L3
1	1	1	01-01			gw_01				8264.46	0.826446	1	1	1	250	250	250
2	1	2	01-02			gw_01				8264.46	0.826446	1	1	1	250	250	250
3	1	3	01-03			gw_01				8264.46	0.826446	1	1	1	250	250	250
4	1	4	01-04			gw_01				8264.46	0.826446	1	1	1	250	250	250
5	1	5	01-05			gw_01				8264.46	0.826446	1	1	1	250	250	250
6	1	6	01-06			gw_01				8264.46	0.826446	1	1	1	250	250	250
7	1	7	01-07			gw_01				8264.46	0.826446	1	1	1	250	250	250
8	1	8	01-08			gw_01				8264.46	0.826446	1	1	1	250	250	250
9	1	9	01-09			gw_01				8264.46	0.826446	1	1	1	250	250	250
10	1	10	01-10			gw_01				8264.46	0.826446	1	1	1	250	250	250
11	1	11	01-11			gw_01				8264.46	0.826446	1	1	1	250	250	250
12	2	1	02-01			gw_01				8264.46	0.826446	1	1	1	250	250	250
13	2	2	02-02			gw_01		demand_01		8264.46	0.826446	1	1	1	250	250	250
14	2	3	02-03			gw_01				8264.46	0.826446	1	1	1	250	250	250
15	2	4	02-04			gw_01				8264.46	0.826446	1	1	1	250	250	250
16	2	5	02-05			gw_01				8264.46	0.826446	1	1	1	250	250	250
17	2	6	02-06			gw_01				8264.46	0.826446	1	1	1	250	250	250
18	2	7	02-07			gw_01				8264.46	0.826446	1	1	1	250	250	250
19	2	8	02-08			gw_01				8264.46	0.826446	1	1	1	250	250	250
20	2	9	02-09			gw_01				8264.46	0.826446	1	1	1	250	250	250
21	2	10	02-10			gw_01				8264.46	0.826446	1	1	1	250	250	250
22	2	11	02-11			gw_01				8264.46	0.826446	1	1	1	250	250	250
23	3	1	03-01			gw_01				8264.46	0.826446	1	1	1	250	250	250
24	3	2	03-02			gw_01				8264.46	0.826446	1	1	1	250	250	250
25	3	3	03-03			gw_01				8264.46	0.826446	1	1	1	250	250	250
26	3	4	03-04			gw_01				8264.46	0.826446	1	1	1	250	250	250
27	3	5	03-05			gw_01				8264.46	0.826446	1	1	1	250	250	250
28	3	6	03-06			gw_01				8264.46	0.826446	1	1	1	250	250	250
29	3	7	03-07			gw_01				8264.46	0.826446	1	1	1	250	250	250
30	3	8	03-08			gw_01				8264.46	0.826446	1	1	1	250	250	250
31	3	9	03-09			gw_01				8264.46	0.826446	1	1	1	250	250	250
32	3	10	03-10			gw_01				8264.46	0.826446	1	1	1	250	250	250

Figure 25: Linkage shape file data screen.

This option can be performed only if the linkage shape file is already read in (step 3). If not, ***ALL_WATER_gw*** asks the user, by dialog box, to read in the linkage shape file before.

When the data reading, by ***ALL_WATER_gw***, and verification, by user, are performed, it is possible to activate the optimization screen by the command button "Optimization Screen". A verification of the existence of the required files for the next step is performed by ***ALL_WATER_gw***. A message box informs the user about the verification result.

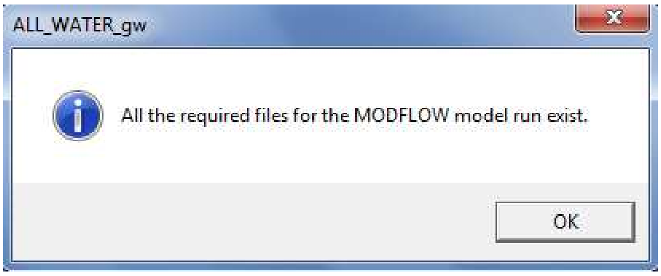


Figure 26: Message box to confirm the existence of required files for MODFLOW run.

4.3. Optimization of the groundwater management

4.3.1. STEP 5: Choice of the objectives and the constraints and editing input files for optimization

4.3.1.1 Choice of the objectives and the constraints.

There are two default situations of the optimization screen. The first one when there is no MODFLOW model for the study area. In this case, the drawdown objective (Drawdown Minimization), the constraints of maximal abstraction (Well Maximal Abstraction) and the maximal cell drawdown (Drawdown Impact) will not be activated.

When there is a MODFLOW model, and the data are read in (step 3), the optimization screen proposes to optimize the water management taking in consideration all the objectives and all the constraints, as shown in the next figure:

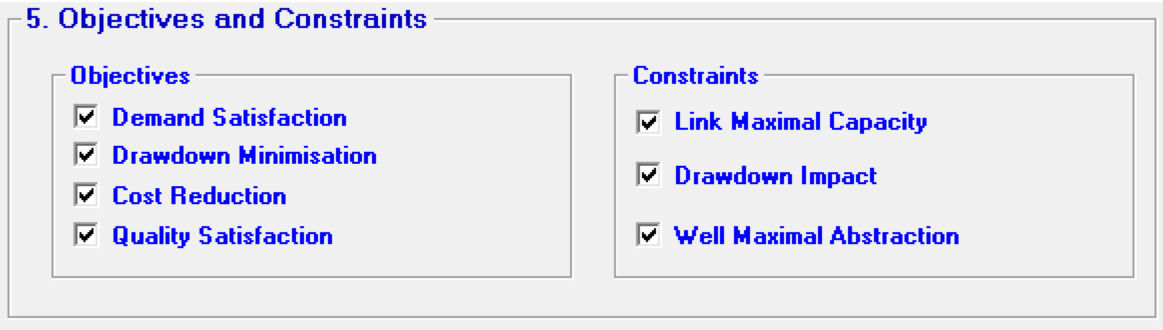
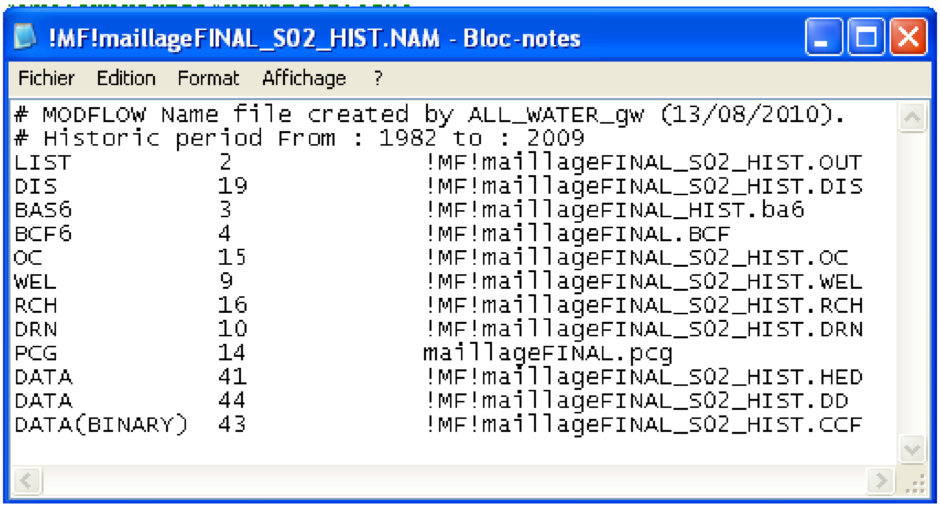


Figure 27: Choice of the objectives and the constraints in step 5 (optimization screen).

In this step, the user can choose the interesting objectives and the associated constraints by activating and deactivating the respective check boxes.

4.3.1.3 Automatic editing of MODFLOW name files

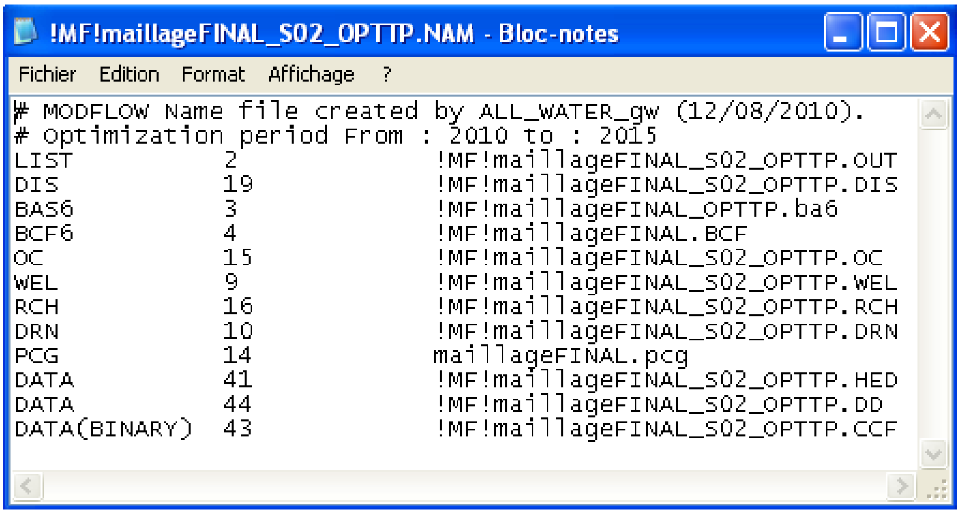
In order to ensure the success of the MODFLOW model simulation, two MODFLOW name files are required. The first one is for the running of the historic period of the model. The second one is for the future period, which is subject of the optimization process. ***ALL_WATER_gw*** is capable to edit these two files automatically. The user has the responsibility to verify and to update them, if necessary. Next figure presents an example of a MODFLOW name file of the historic period, created by ***ALL_WATER_gw***:




```
# MODFLOW Name file created by ALL_WATER_gw (13/08/2010).
# Historic period From : 1982 to : 2009
LIST           2            !MF!maillageFINAL_S02_HIST.OUT
DIS            19           !MF!maillageFINAL_S02_HIST.DIS
BAS6           3            !MF!maillageFINAL_HIST.ba6
BCF6           4            !MF!maillageFINAL.BCF
OC             15           !MF!maillageFINAL_S02_HIST.OC
WEL            9            !MF!maillageFINAL_S02_HIST.WEL
RCH            16           !MF!maillageFINAL_S02_HIST.RCH
DRN            10           !MF!maillageFINAL_S02_HIST.DRN
PCG            14           maillageFINAL.pcg
DATA           41           !MF!maillageFINAL_S02_HIST.HED
DATA           44           !MF!maillageFINAL_S02_HIST.DD
DATA(BINARY)   43           !MF!maillageFINAL_S02_HIST.CCF
```

Figure 28: MODFLOW name file for the historic period created by ***ALL_WATER_gw***.

ALL_WATER_gw will read all the MODFLOW files and modify them according to the optimization period. The results of the simulation of the historic period are used as initial heads for the optimized period.



```
!MF!maillageFINAL_S02_OPTTP.NAM - Bloc-notes
Fichier Edition Format Affichage ?
# MODFLOW Name file created by ALL_WATER_gw (12/08/2010).
# Optimization period From : 2010 to : 2015
LIST           2          !MF!maillageFINAL_S02_OPTTP.OUT
DIS            19         !MF!maillageFINAL_S02_OPTTP.DIS
BAS6           3          !MF!maillageFINAL_OPTTP.ba6
BCF6           4          !MF!maillageFINAL.BCF
OC             15         !MF!maillageFINAL_S02_OPTTP.OC
WEL            9          !MF!maillageFINAL_S02_OPTTP.WEL
RCH            16         !MF!maillageFINAL_S02_OPTTP.RCH
DRN            10         !MF!maillageFINAL_S02_OPTTP.DRN
PCG            14         maillageFINAL.pcg
DATA           41         !MF!maillageFINAL_S02_OPTTP.HED
DATA           44         !MF!maillageFINAL_S02_OPTTP.DD
DATA(BINARY)   43         !MF!maillageFINAL_S02_OPTTP.CCF
```

Figure 29: MODFLOW name file for the optimized period created by ***ALL_WATER_gw***.

All the input and output files used by MODFLOW are saved beneath the default windows “TEMP” path. Therein, a subfolder is automatically created by ***ALL_WATER_gw,*** having the name of the WEAP Area.

4.3.2. STEP 6: Choice of the Genetic Algorithm parameters

Next the genetic algorithm (GA) parameters have to be defined. The following figure lists these parameters and their defaults values:

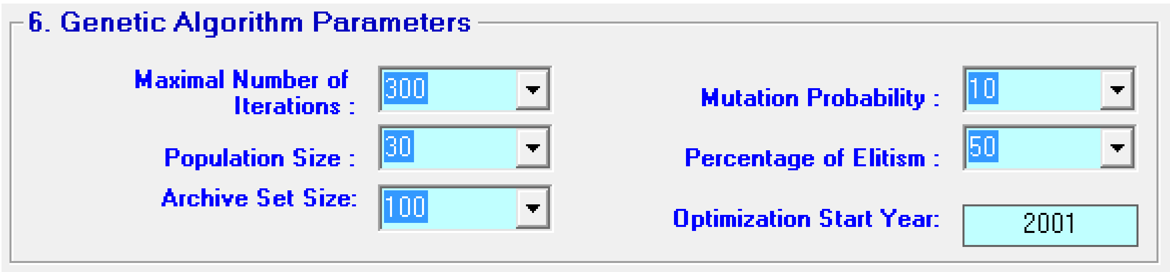


Figure 30: Choose of the GA parameters values in step 6, in the optimization screen.

It is not possible to explain in detail on this document the meaning of each parameter of the GA but the user can find a guideline to choose the acceptable values here. For further details about GA concepts, parameters meaning and determination the user could refer to the references cited in the following paragraph.

By similarity to the evolution theory of Darwin, GA evolves population of individuals (solutions), using genetic operators: Selection, crossover and mutation (Back et al., 2000; Goldberg, 1991). An evolution strategy is generally associated. This iterative process is stopped in case of evolution stagnation or when the maximal number of generation is reached (Dreo et al., 2003). In GA, problem solutions are represented as chromosomes formed by a set of genes. Each gene represents a bit that must be filled by a decision variable value, in its definition interval. Initially, genes and chromosomes are randomly created (in the research space). Next, an intelligent research process will combine solutions (crossover) and modify randomly some bits values (mutation) to improve the population performance and to identify the set of non-dominated solutions. For multi-objective optimization, Goldberg (1991) recommended the use of the PARETO optimality concept to compare solutions, and to select the non-dominated ones.

The first parameter is the number of iterations (N_{pop}) that the GA has to perform before stopping the computation. The use of a higher number of N_{pop} will lead to better solutions. But this will consume more memory of the personal computer (PC) and the optimization will take more time. For simple cases, 150 iterations can be enough. For very complicated cases, more iterations are necessary to converge to the best solutions. The exact number has to be identified case by case.

There is a direct relationship between the number of water sources, the number of demand sites, the number of links and the number of time steps to be optimized and the complexity of the problem and then the required N_{pop}. If the case study presents many water sources, demand sites, links and additionally, the optimized period is long, the GA has to identify a high number of decision variables: well abstractions in our case. Thus, many of crossovers and mutations and consequently, a lot of iterations are needed. For example, the optimization of the abstraction from two wells to supply only one demand site for one time step can be considered as a simple case study: 2 decisions variables (bits). It requires a low number of iterations (eg. 50). The optimization of the abstraction from 10 wells to satisfy only one demand site for one time step is a more complicated case: 10 decision variables (bits). The problem resolution will require more iterations. For the last case, when the abstraction have to be optimized for 12 time steps, the number of decision variable (bits) will be equal 120 (10 x 12) and the required number of iterations have to be increased to converge to optimal solutions.

The second GA parameter is the population size (T_{pop}). Just as the parameter "number of iterations", higher values lead to higher accuracy but higher computational effort. A population size of more then 20 and less then 100 can be adopted for any case study. The choice depends on the PC performances and on N_{pop}.

The archive size is the maximal number of optimal solutions that the GA has to find. If this number is reached before to reach the N_{pop}, the GA will stop the computation. Usually, the GA has to perform all the iterations requested (N_{pop}) before filling the archive set. If this is not the case, the user has to increase this number. The default value of 100 can be kept as starting value for any case study.

The mutation probability (p_m) is a parameter that defines the number of genes (bits) where the mutation will be operated, in each iteration. The values of these bits will be randomly changed in their definition interval. The "p_m" value is usually between 1 and 10 %. The user has to find the most adequate value for his case study. An example: If the number of bits in the population is equal 1200 (10 solutions, each have 120 bits) and p_m is equal 5 %, the values of 60 bits will be changed randomly in each iteration.

The percentage of elitism (p_e) defines the number of optimal solutions copied from the previous population to the population under building. Highest values (more than 50 %) push the GA to quick converge. Lowest values (less than 10 %) don't guarantee the GA convergence. Usually values between 10 and 30 % are used. For example, if T_{pop} is equal 20 and p_e is equal 30 %, each new population created by the GA will include 6 optimal solutions (20 x 0.3), if they exist in the archive set. If this number does not exist, all the identified optimal solutions (less then 6 for the example) will be copied in the new population.

The last parameter defines the optimization start year. The default value displayed in the section 6 has been introduced by the user in step 3.

4.3.3. STEP 7: Start the optimization

To allow flexibility for managers and decision makers, it is allowed in step 7 to choose a weight for each of the four optimization objectives by using four sliders. The value of the weight indicates the importance of the objective in the optimization. For important objective, the user has to choose a great weight, near 100. For less important objective, just choose less weight. If the user wants to eliminate one objective from the optimization, he has just to choose a weight equal zero. The next figure shows how each of the sliders can be used to define the respective objective weight:

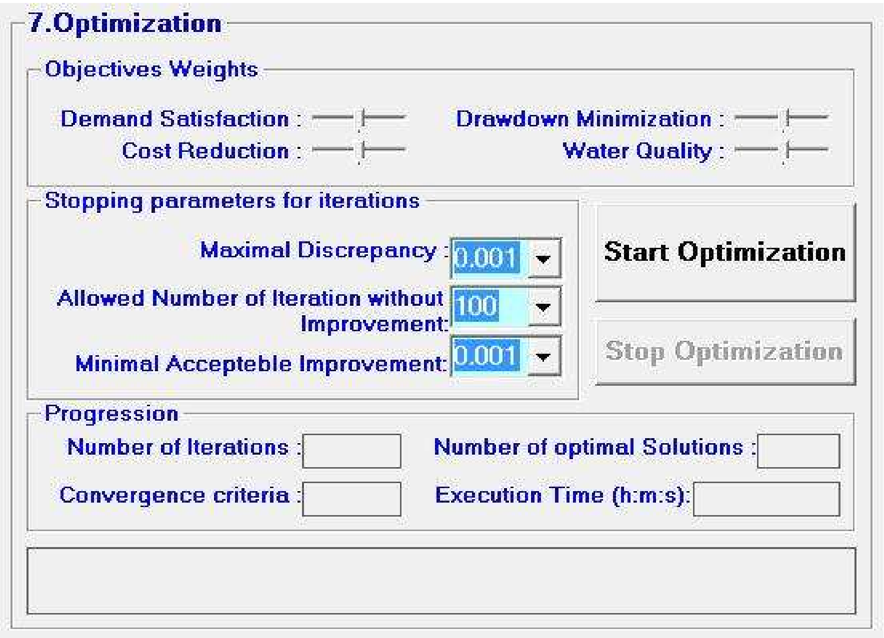


Figure 31: Choice of the objectives weights and the convergence parameters.

Please note that the optimization objectives are grouped by pair to compute the two fitness functions "fitness 1" and "fitness 2", used to evaluate solutions by the GA. The "Demand Satisfaction" and the "Drawdown Impact" objectives form the function "fitness 1". The "Cost Reduction" and the "Quality Satisfaction" objectives form the function "fitness 2". Therefore, it is not allowed to choose weights equal zero for both of the coupled objectives, used to compute the same fitness function. If the user chooses this option a dialog box will appear and invite him to change his choice.

In addition to the maximal number of iterations, ***ALL_WATER_gw*** uses a Convergence Criterion. In order to define the accuracy of the optimization result, a "Discrepancy" is defined as the sum of the fourth objective functions. Figure 31 presents in the second frame from the top the three stopping parameters used to control the iteration process. Four criteria for stopping the iteration optimization are considered: 1) the maximal number of iterations is reached; 2) the archive set size is reached; 3) the Discrepancy falls below a user defined value (convergence is reached and the accuracy is sufficient), 4) the Discrepancy does not change over a user defined number of iterations (convergence is reached).

The following parameters have to be defined by the user to control the iteration:

- The "Maximal Discrepancy": This parameter is the maximal acceptable value of the Discrepancy. If the Discrepancy is equal or less than the chosen value, the iteration process will be stopped,
- The "Allowed Number of Iteration without Improvement": The iteration process will be stopped, if no improvement of the Discrepancy parameter can be reached for the defined number of iterations.

- The “Minimal Acceptable Improvement”: The minimal difference between the Discrepancy parameters on iterations separated by the parameter “Allowed number of iterations without improvement”.

The optimization can be started by clicking on the command button named “Start Optimization”. If there is a MODFLOW model, ***ALL_WATER_gw*** asks the user to confirm or change the default path of the temporary optimization folder, proposing the “Temp” folder (eg. “C:\Documents and Settings\Issam\Local Settings\Temp”).

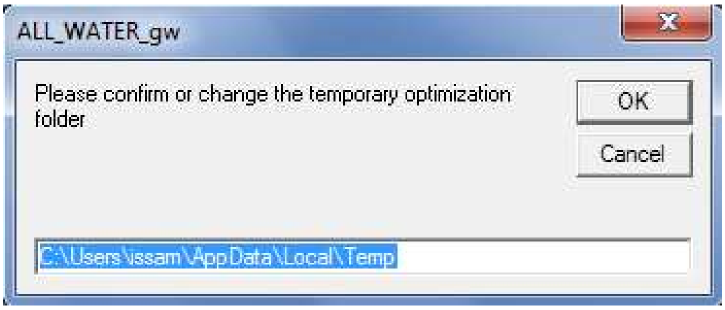


Figure 32: Validation of the path of the temporary optimization folder.

All the MODFLOW simulations will be done in the folder having the same name as the WEAP Area under the previous path. By clicking OK the optimization process starts. ***ALL_WATER_gw*** will perform two steps: first, it will crate and run a MODFLOW model for the historic period: Start year – Present year. Secondly, ***ALL_WATER_gw*** will start the abstractions optimization.

When the optimization is in progress, the optimization interface will display a dynamic chart showing the optimal solutions found during the iterations: the PARETO FRONT. The red text message will change to characterize the progression. The number of iterations, the number of optimal solutions founded, the convergence criteria and the execution time will be displayed in the “Progression” frame of step 7.

It is possible for user to pause or stop the optimization process using the command button “Stop Optimization”.

The MODFLOW model execution time depends essentially on the number of active cells and on the number of time steps. For the example used in this user guide, a MODFLOW run for the whole model (360 active cells) takes about 1 second using a standard PC (Processor Single core *Centrino* - 512 MB RAM).

To compute the objectives functions and to identify the optimal solutions for the studied case study, the same PC takes about 2 seconds (1 s for MODFLOW execution and 1 s for GA computing). Thus, for a population with 10 solutions, each of the iterations will consume about 20 s. The optimization step takes about 200 s (3.3 min), 2000 s (33.3 min) and 20000 s (5.5 hours) for 10, 100 and 1000 iterations, respectively. Please note that these performances are given as examples. The real computational time depends on the present hardware and software layout of the PC and available free memory when the optimization is started.

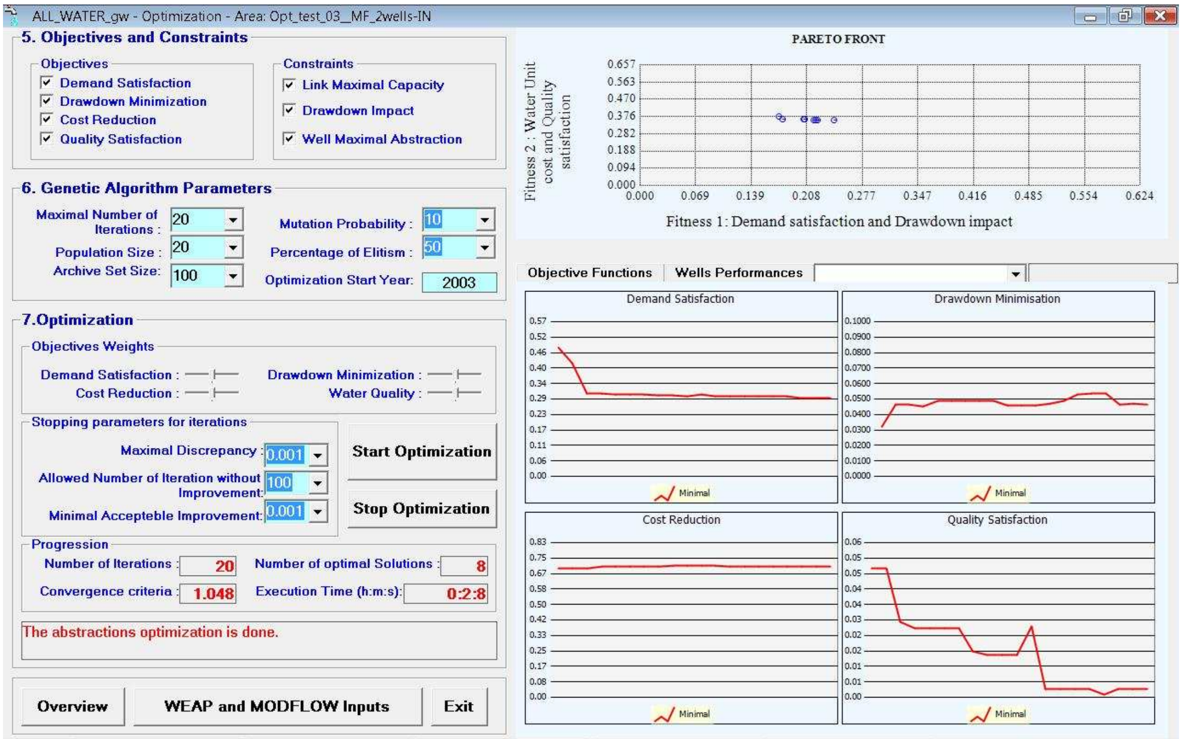


Figure 33: User interface during the optimization.

When the optimization is completed, the user has three options, that can be activated by command buttons in the lower left part of the optimization screen, as shown in next figure:

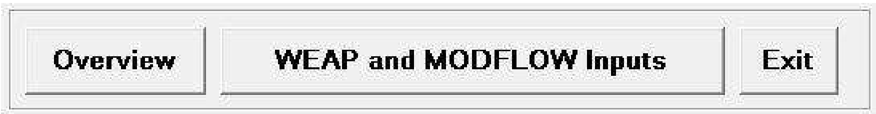


Figure 34: User interface during the optimization is in progress.

The first option is to display the “Overview” user interface, by clicking on the button “Overview”. Next figure is an overview interface example.

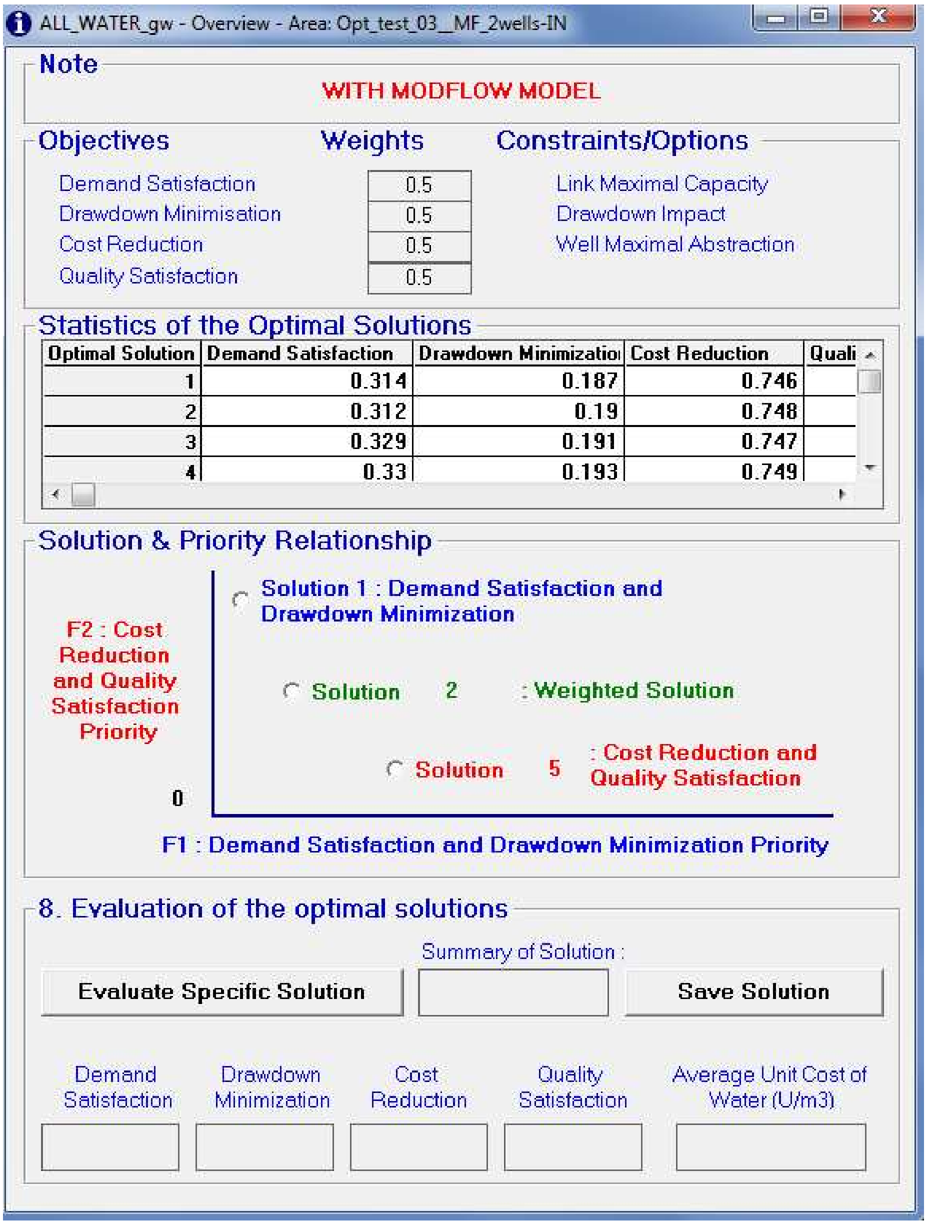


Figure 35: Overview User Interface.

The overview informs the user about the optimization option in the “Note” frame in the top. The Objectives, weights and constraints chosen by user in steps 5, 6 and 7 are summarized in a second frame. The objectives functions of the optimal solutions found are displayed in the table “Statistics of the Optimal Solutions”, in the third frame. To simplify the decision when choosing a solution to save and/or to apply, it is presented a symbolic representation of the PARETO front in the frame “Solution & Priority Relationship”. Three optimal solutions are identified in the graph with different priorities:

- Demand Satisfaction and Drawdown Minimization,
- Weighted Solution,
- Cost Reduction and Quality Satisfaction.

The weighted solution is determined by ***ALL_WATER_gw*** by taking into account the user defined weights of the objective functions.

The second option is to return to the first GUI screen, by clicking the command button “WEAP and MODFLOW Inputs”. The third option is to quit the application by using the command button “Exit”.

4.3.4. STEP 8: Evaluation of the optimal solutions

After identifying optimal solutions for the studied problem, it is important for the user to analyze their performances before choosing. ***ALL_WATER_gw*** offers two options.

The first is to choose a solution, among the three optimal solutions displayed in the simplified PARETO graph, by activating the option box. The solution number will be automatically displayed in the field “Summary of Solution” in the frame “8. Evaluation of the optimal solutions”. In addition, the values of the fourth objective function and the “Average Unit Cost of Water” will be displayed in the lower part of the user interface. The selected solution will be marked by a red point in the PARETO graph and its row in the table “Statistics of the Optimal Solutions” will be highlighted, as presented in the next figure:

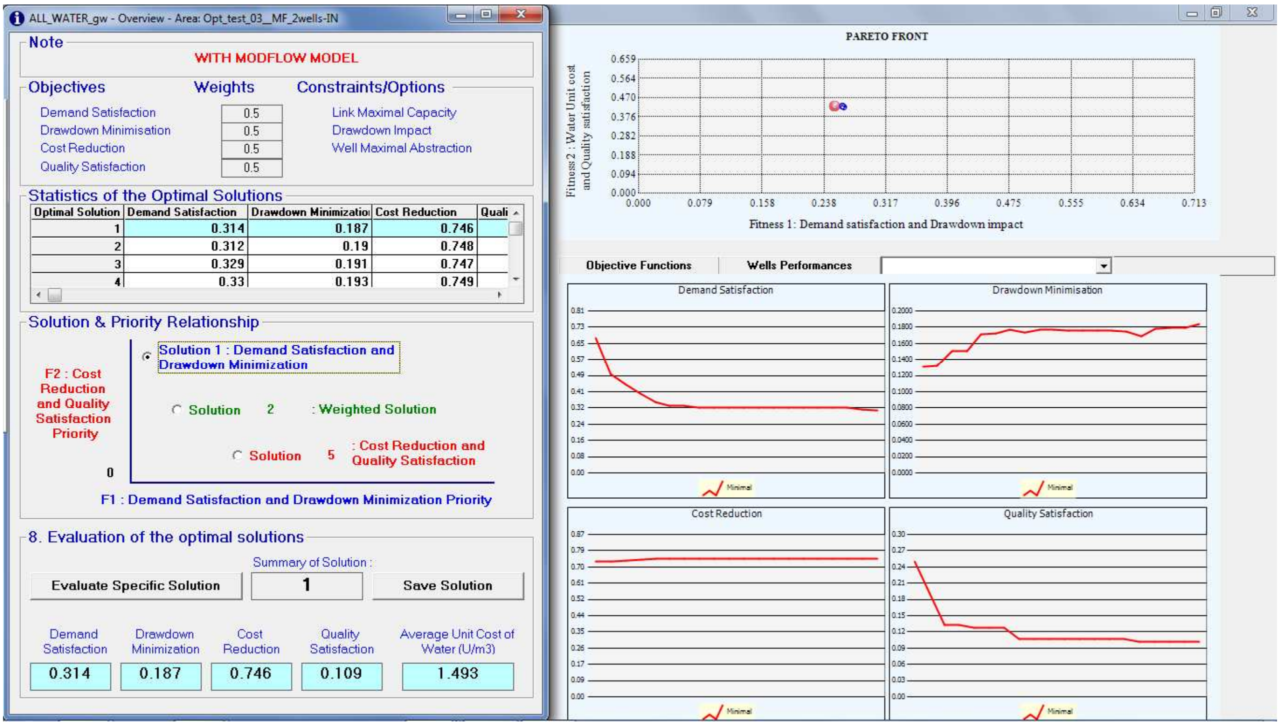


Figure 36: Solution evaluation in the optimization screen.

The second option is to use the command button “Evaluate Specific Solution” to choose any optimal solution by its number for evaluation. A message box asks the user to introduce the number of the solution to evaluate. The same results as described before will be displayed in the lower part of the user interface.

For each evaluated solution ***ALL_WATER_gw*** print all the output files, in the “OPTIMIZATION” folder, and run the MODFLOW model with the optimal pumping rates. Next figure shows the list of all input and output files at the end of the optimization. Examples are presented in the Appendix.

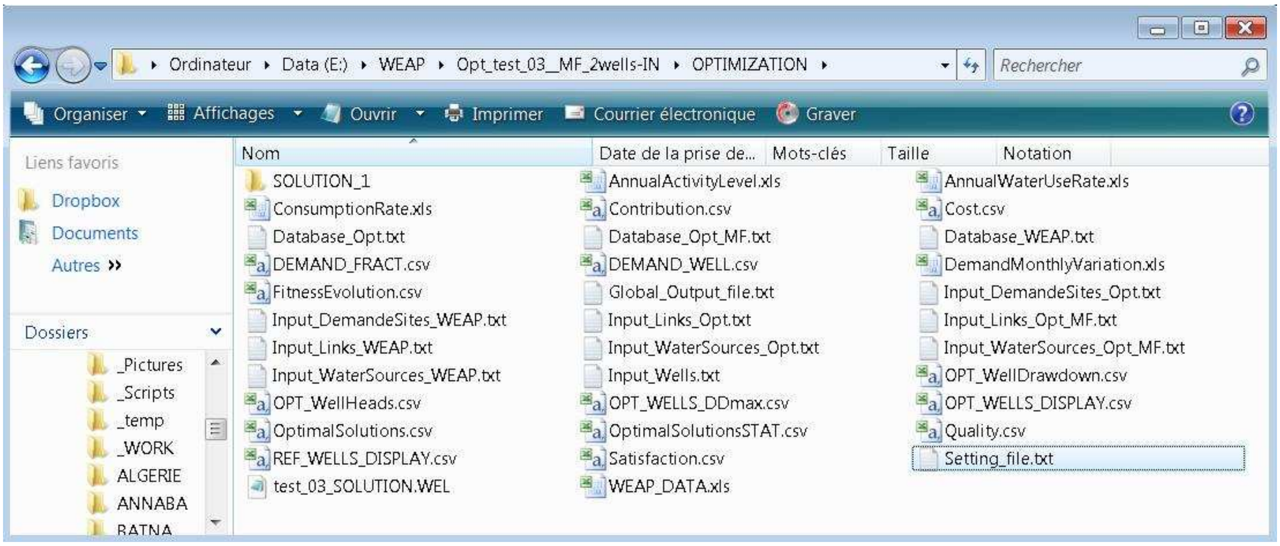


Figure 37: Input and output files in the folder "OPTIMIZATION" after the optimization step.

At the end of the optimization step seven "csv" files are created:

The first one (OptimalSolutions.csv) summarizes the optimal solutions founded. The "Contribution.csv" file presents the contribution of each of the water sources in the demands satisfaction. The "Cost.csv" file presents the unit cost of water for each of the optimal solutions identified by the optimization. The "DEMAND_FRACT.scv" file details the fraction of the demand covered by groundwater nodes for each demand site. The "DEMAND_WELL.csv" file details the volume of water supplied by wells for each demand site. The "Quality.csv" file presents the water quality in each of the demand sites. The "DemandSatisfaction.csv" file presents the percentage of satisfaction of each of the demand sites for all time steps.

In addition, a conformal MODFLOW well file named: "MODFLOW name file_SOLUTION.WEL" is created and saved in the OPTIMIZATION folder. For each of the active wells, it is saved the initial abstraction rates for the historic period and the optimized ones for the optimized period.

ALL_WATER_gw offers the possibility to display the optimal abstractions, the heads and the drawdown in the cell of each of the active wells. The user can select the name of the well among the list of all active wells in the combo box named "Well name". A click on the button "Well performance" displays the row and the column of the well and two graphs:

- OPTIMAL ABSTRACTIONS: Display the optimal abstraction of the chosen well for each time step,
- HEADS AND DRAWDOWNS: Displays the head and the drawdown modulation in the active well and the maximal drawdown.

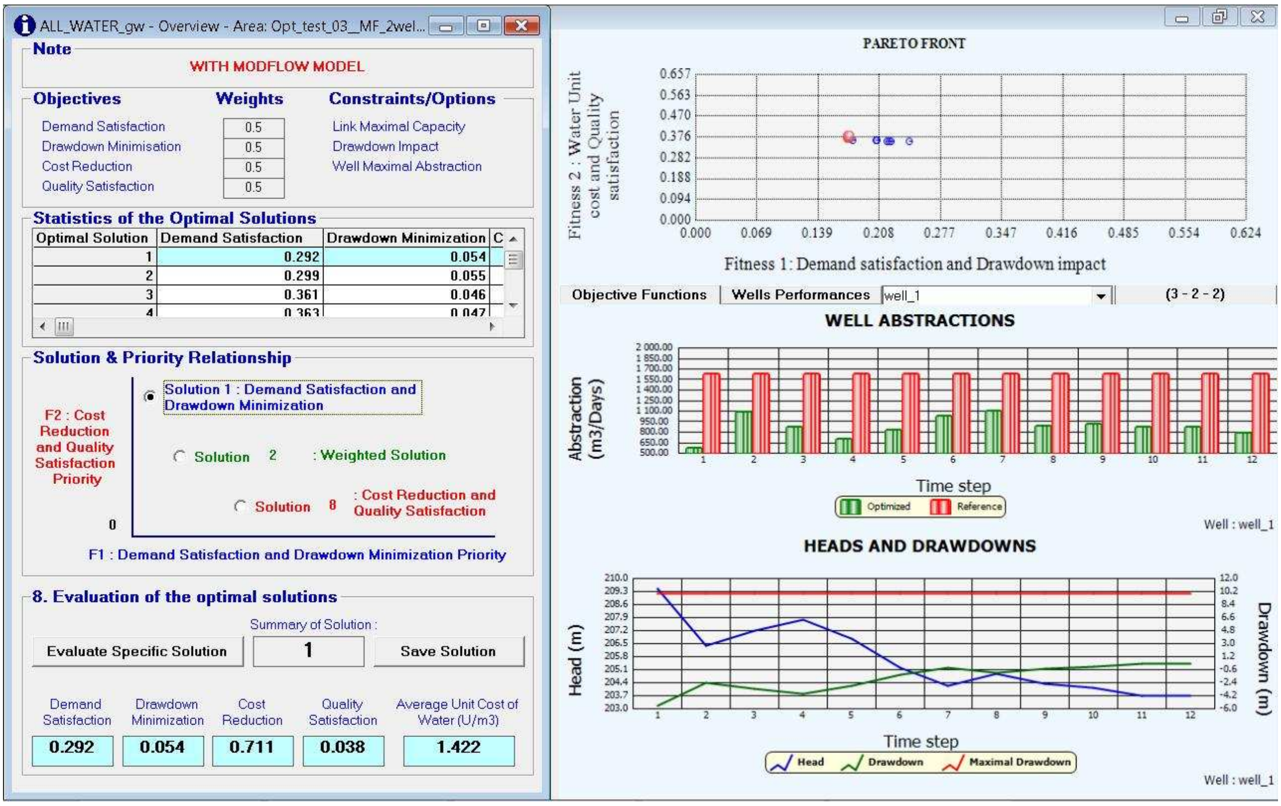


Figure 38: User interface with well performances after the optimization step.

The command button "Save Solution" allows the user to save selected optimal solutions, under the folder "OPTIMIZATION" created by ***ALL_WATER_gw***. To perform this step, it is required to enter, by input box, the ID of the optimization scenario in WEAP Area:

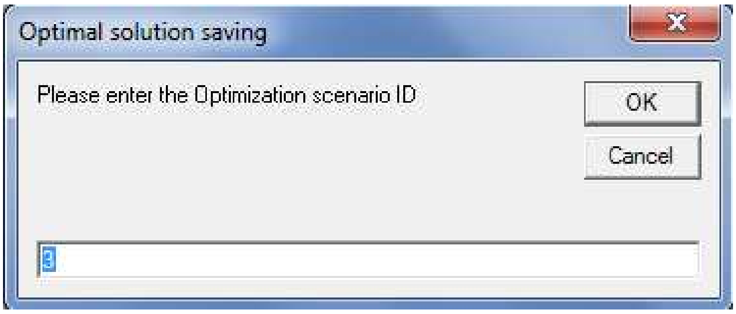


Figure 39: Input box to enter the ID of the optimization scenario.

A message box inform about the path and the folder name where the solution is saved:

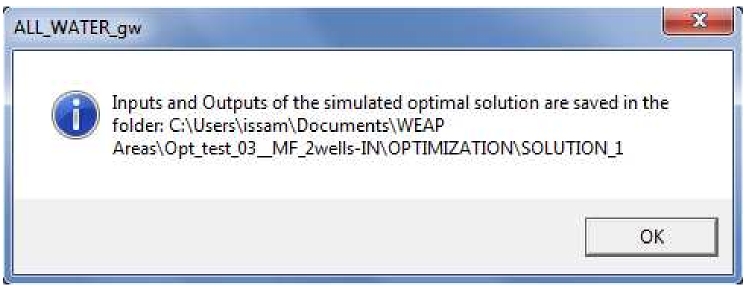


Figure 40: Message box to inform about the path and the folder name of the saved solution.

To save the settings used to get the characteristic optimal solutions, there is the possibility to create and save a setting file, called "Setting_file.txt". This file is placed in the OPTIMIZATION folder created by ***ALL_WATER_gw***. The button “Save” in the frame “Setting” of the first GUI allow this function.

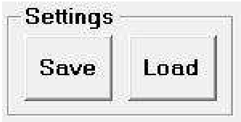


Figure 41: Setting frame in the first GUI of ***ALL_WATER_gw***.

The user can also load these settings by selecting the name of the WEAP Area. A click on the command button “Load” in the same frame allows the selection of the setting file. Next figure is an example of loading saved settings:

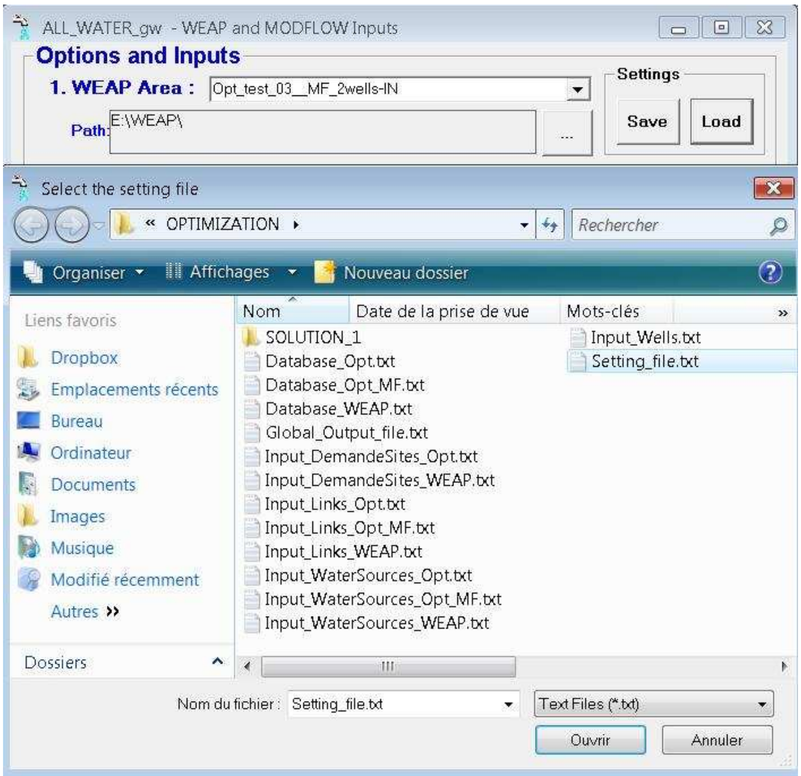
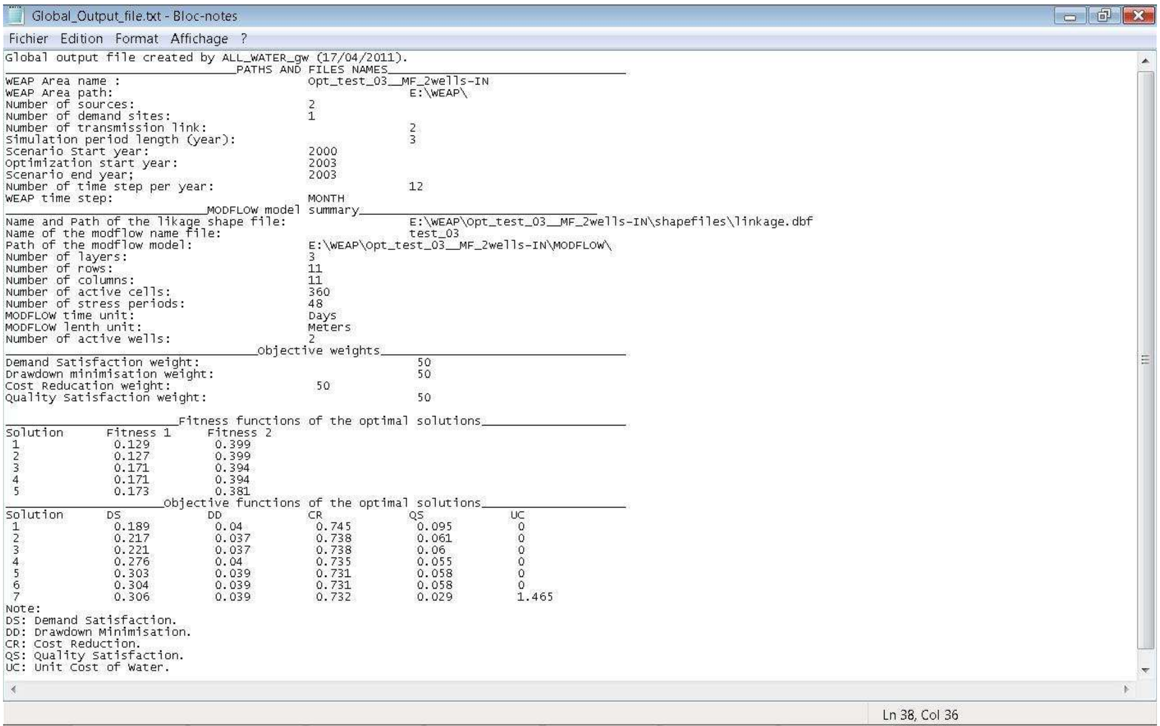


Figure 42: Example of loading a saved setting file.

At the end of each optimization run, a global output text file is created. This file summarizes the inputs and presents the performances of the optimal solutions. Next figure is an example:



```
Global output file created by ALL_WATER_gw (17/04/2011).
________________________________PATHS AND FILES NAMES_____________________________
WEAP Area name :                          opt_test_03__MF_2wells-IN
WEAP Area path:                                         E:\WEAP\
Number of sources:                        2
Number of demand sites:                   1
Number of transmission link:                            2
Simulation period length (year):                        3
Scenario Start year:                      2000
Optimization start year:                  2003
Scenario end year;                        2003
Number of time step per year:                           12
WEAP time step:                           MONTH
__________________________MODFLOW model summary___________________________
Name and Path of the likage shape file:                 E:\WEAP\opt_test_03__MF_2wells-IN\shapefiles\linkage.dbf
Name of the modflow name file:                          test_03
Path of the modflow model:                E:\WEAP\opt_test_03__MF_2wells-IN\MODFLOW\
Number of layers:                         3
Number of rows:                           11
Number of columns:                        11
Number of active cells:                   360
Number of stress periods:                 48
MODFLOW time unit:                        Days
MODFLOW lenth unit:                       Meters
Number of active wells:                   2
___________________________________objective weights_________________________________
Demand Satisfaction weight:                              50
Drawdown minimisation weight:                            50
Cost Reducation weight:                    50
Quality Satisfaction weight:                             50

_______________________Fitness functions of the optimal solutions____________________
Solution        Fitness 1      Fitness 2
 1               0.129          0.399
 2               0.127          0.399
 3               0.171          0.394
 4               0.171          0.394
 5               0.173          0.381
_____________________objective functions of the optimal solutions____________________
Solution        DS             DD             CR             QS             UC
 1               0.189          0.04           0.745          0.095          0
 2               0.217          0.037          0.738          0.061          0
 3               0.221          0.037          0.738          0.06           0
 4               0.276          0.04           0.735          0.055          0
 5               0.303          0.039          0.731          0.058          0
 6               0.304          0.039          0.731          0.058          0
 7               0.306          0.039          0.732          0.029          1.465
Note:
DS: Demand Satisfaction.
DD: Drawdown Minimisation.
CR: Cost Reduction.
QS: Quality Satisfaction.
UC: Unit Cost of Water.
```

Figure 43: Example of the Global output files after the optimization step.

4.4. Import of the optimized solution into WEAP

The output of the optimization can be easily integrated in the WEAP Area project. The steps to ensure this task are explained in the next paragraphs:

4.4.1. Creating an optimization scenario

The first step to visualize the optimization results in WEAP is to create a new scenario based on the "Reference" scenario, as shown in the next figure:

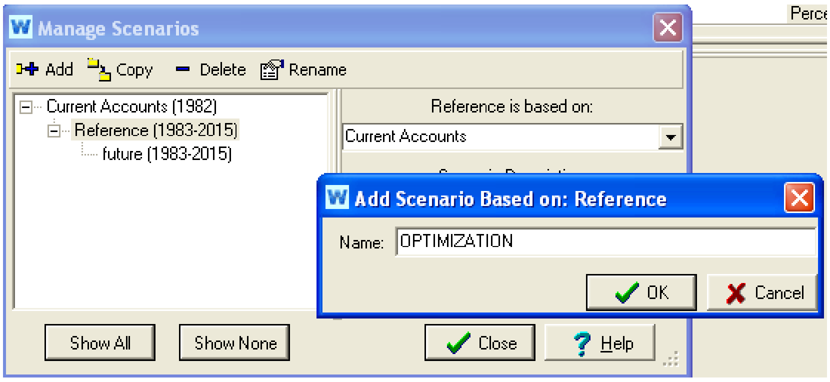


Figure 44: Adding a new scenario "OPTIMIZATION" based on the Reference scenario.

The new scenario will take all the existing data from the "Reference" scenario. The next figure presents the scenario tree after creating the OPTIMIZATION scenario:

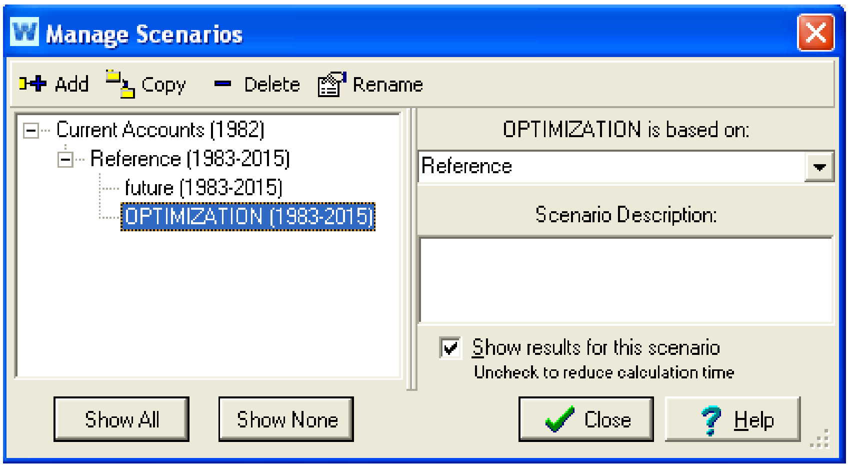


Figure 45: Scenario tree after creating the "OPTIMIZATION" scenario.

Note: This step has to be performed by the user inside WEAP.

4.4.2. Loading optimization data from ALL_WATER_gw outputs

The user has to load the optimization results from the "DEMAND_FRACT.csv" file to modify the variable "Maximum Flow Percent of Demand" in the branch "Transmission Links". To ensure this task, go to the data view and click on one of the transmission links. Press on the variable "Maximum Flow Percent of Demand" and choose "Expression Builder". The next dialog box appears:

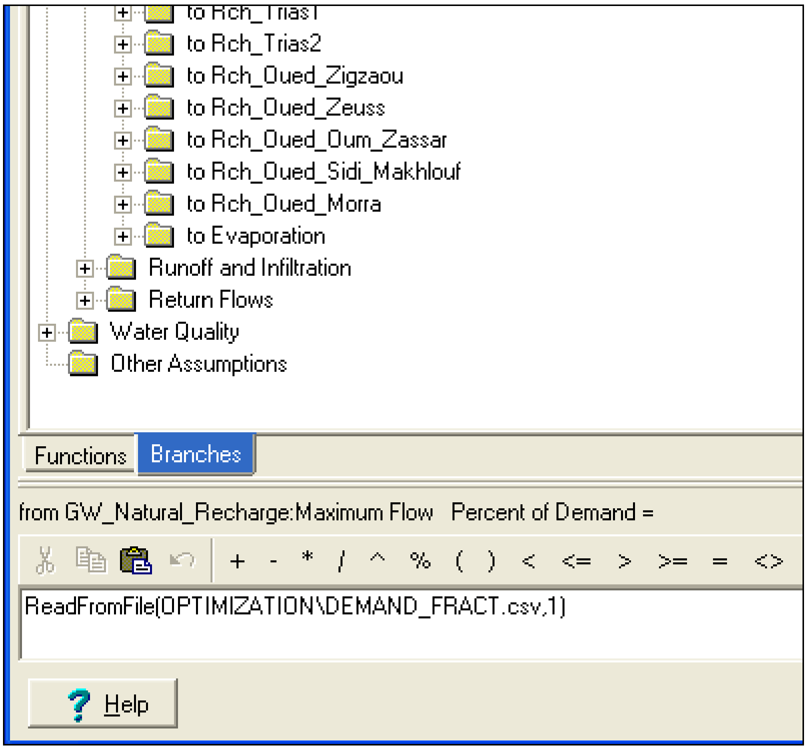
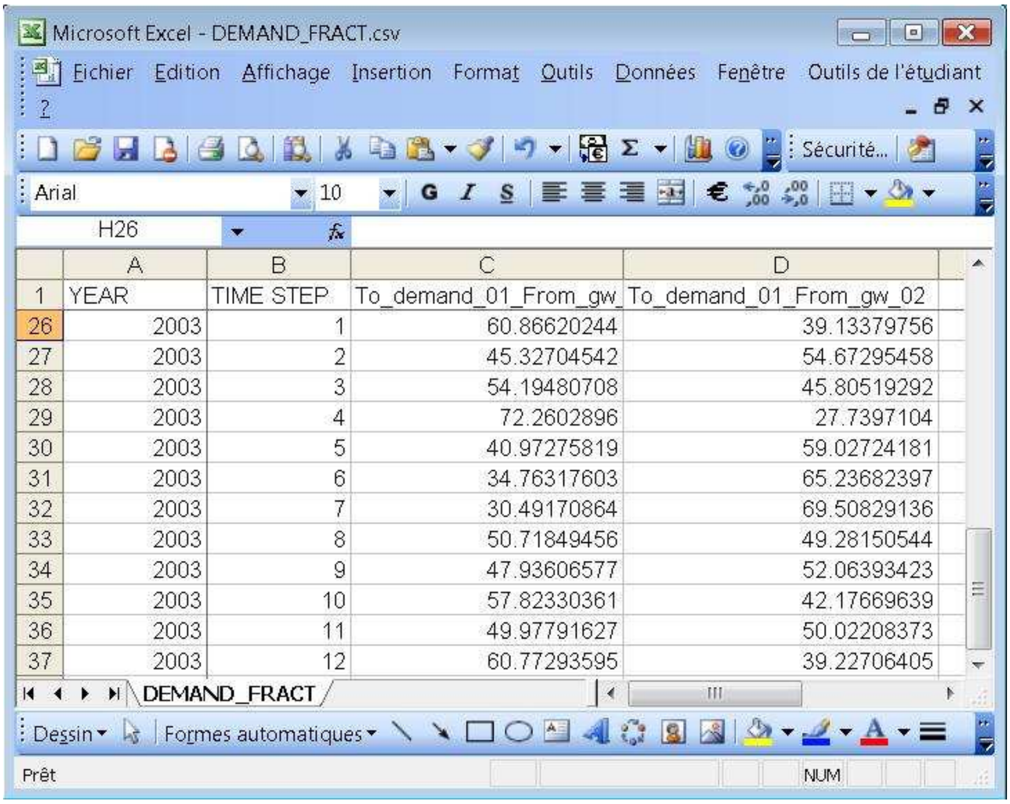


Figure 46: Dialog box of the WEAP expression builder to read on the ***ALL_WATER_gw*** output.

The user has to specify that this variable is read from a "csv" file, by adding its folder, its name (DEMAND_FRACT.csv) and the column corresponding to the transmission link. Next figure is an example of the DEMAND_FRACT.csv file:



	A	B	C	D
1	YEAR	TIME STEP	To_demand_01_From_gw	To_demand_01_From_gw_02
26	2003	1	60.86620244	39.13379756
27	2003	2	45.32704542	54.67295458
28	2003	3	54.19480708	45.80519292
29	2003	4	72.2602896	27.7397104
30	2003	5	40.97275819	59.02724181
31	2003	6	34.76317603	65.23682397
32	2003	7	30.49170864	69.50829136
33	2003	8	50.71849456	49.28150544
34	2003	9	47.93606577	52.06393423
35	2003	10	57.82330361	42.17669639
36	2003	11	49.97791627	50.02208373
37	2003	12	60.77293595	39.22706405

Figure 47: Example of the DEMAND_FRACT.csv output file.

***Note**: The columns "YEAR" and "TIME STEP", in the DEMAND_FRACT.csv file, have not to be considered when identifying the column number for each transmission link.*

4.4.3. Running WEAP and displaying results

To evaluate the optimization as a new scenario, click on the WEAP result view. A new run is necessary to display updated results.

Bibliographie

BACK T., FOGEL D. B., MICHALEWICZ T., 2000. Evolutionary Computation 1 : Basic algorithms and operators. *Institute of Physics Publishing*, United Kingdom.

DREO J., PETROWSKI A., SIARRY P, TAILLARD E., 2003. Métaheurestiques pour l'optimisation difficile : Recuit simulé, recherche avec tabous, algorithmes évolutionnaires et algorithmes génétiques, colonies de fourmis. Eyrolles, Paris.

Goldberg, D. E., 1991. Genetic Algorithms. Addison-Wesley.

SEI. 2010. Water Evaluation And Planning System (WEAP)

Appendix

Appendix 1: List of files created by ALL_WATER_gw

After reading the WEAP area:

- WEAP_DATA.xls : *WEAP Area data expression,*
- Input_DemandeSites_WEAP.txt : *Collection of all demand sites in the WEAP Area,*
- Input_WaterSources_WEAP.txt : *Collection of all the groundwater sources in the WEAP Area,*
- Input_Links_WEAP.txt : *Collection of the transmission links in the WEAP Area,*
- Database_WEAP.txt : *Summary of the WEAP Area,*
- DemandMonthlyVariation.xls : *The demand monthly variations of all the demand sites,*
- AnnualActivityLevel.xls : *The annual activity levels of all the demand sites,*
- AnnualWaterUseRate.xls : *The annual water use rates of all the demand sites,*
- ConsumptionRate.xls : *The consumption rates of all the demand sites,*

After editing the demand sites file:

- Input_DemandeSites_Opt.txt : *Collection of the demand sites to be optimized,*
- Input_WaterSources_ Opt.txt : *Collection of the groundwater sources to be optimized,*
- Input_Links_ Opt.txt : *Collection of the transmission links sources to be optimized,*
- Database_ Opt.txt: *Summary of the WEAP Area after editing.*

After reading the linkage shape file (if there is a MODFLOW model):

- Input_DemandeSites_Opt_MF.txt: *Collection of the demand sites to be optimized, after reading the linkage shape file,*
- Input_WaterSources_Opt_MF_.txt: *Collection of the groundwater sources to be optimized, after reading the linkage shape file,*
- Input_Links_Opt_MF.txt: *Collection of the transmission links sources to be optimized after reading the linkage shape file,*

After reading the MODFLOW model

- Input_Wells.txt : *Well file created by ALL_WATER_gw,*

When optimizing is in progress

- FitnessEvolution.csv: *Values of the objective function at each iteration,*
- OptimalSolutions.csv: *Values of the Fitness functions of the found optimal solutions,*
- MODFLOW files for the historic period (tmp folder),
- MODFLOW files for the optimized period (tmp folder);

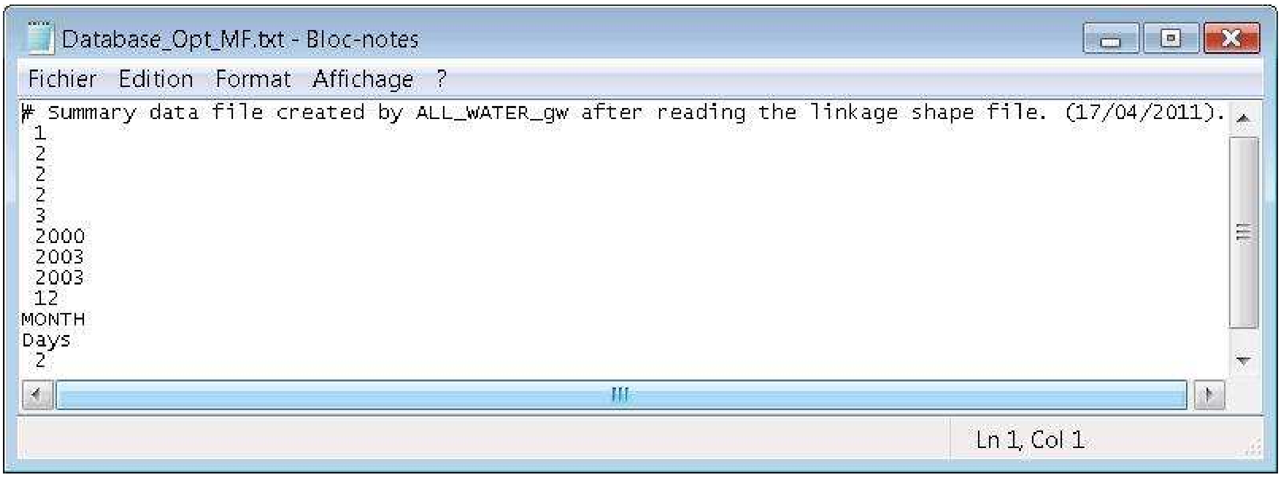
After optimization:

- Satisfaction.csv: *Temporal values of the demand satisfaction rates of the evaluated solution,*
- Quality.csv: *Temporal values of the water salinity in each of the optimized demand sites of the evaluated solution,*
- Cost.csv: *Temporal values of the unit water cost of the evaluated solution,*

- Contribution.csv : *Temporal values of the contribution percentage of each water source in the demand satisfaction,*
- DEMAND_FRACT.csv : *Demand percentage supplied by each water source to each demand site of the evaluated solution,*
- DEMAND_WELL.csv: *Wells Abstraction rates to each demand site of the evaluated solution,*
- * _SOLUTION.WEL: *WEAP/MODFLOW conformal well file with the optimal groundwater management.*
- OPT_WellDrawdown.csv: *Temporal cells drawdown values of the active wells of the optimal solution,*
- OPT_WellHeads.csv: *Temporal cells head values of the active wells of the optimal solution,*
- OPT_WELLS_DISPLAY.csv: *Temporal abstraction values of the active wells of the optimal solution,*
- REF_WELLS_DISPLAY.csv: *Temporal abstraction values of the active wells of the reference scenario.*
- Global_Output_file.txt: Output *text file summarizing the principal inputs and results.*

Appendix 2: Formats of files created by ALL_WATER_gw

- **Summary file**




```
# Summary data file created by ALL_WATER_gw after reading the linkage shape file. (17/04/2011).
 1
 2
 2
 2
 3
 2000
 2003
 2003
 12
MONTH
Days
 2
```

Figure 48: Standard structure of the Database.txt file.

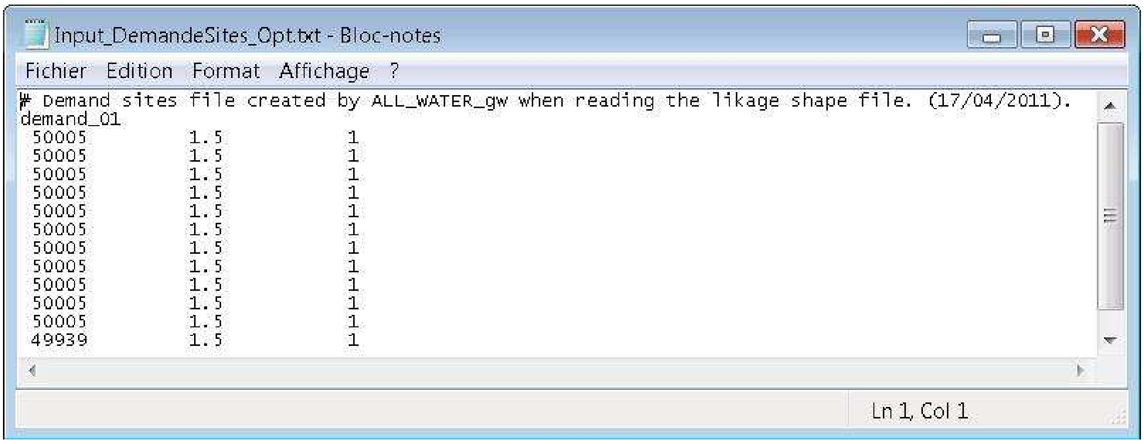
Line 1: Number of demand sites
Line 2: Number of water sources, ground water node
Line 3: Number of water sources, well
Line 4: Number of transfer Link
Line 5: Simulation period (Year)
Line 6: Start year
Line 7: End Year
Line 8: Start year of the optimization
Line 9: Number of time step by year
Line 10: WEAP Tine Unit
Line 11: MODFLOW time unit
Line 12: ID of the Reference scenario

- **Demand site file**

For each demand site i (Eg. Dom_Arram)

For each time step j

Water demand (i, j) Acceptable Salinity (d,j) Demand Priority(i)



```
# Demand sites file created by ALL_WATER_gw when reading the likage shape file. (17/04/2011).
demand_01
 50005          1.5           1
 50005          1.5           1
 50005          1.5           1
 50005          1.5           1
 50005          1.5           1
 50005          1.5           1
 50005          1.5           1
 50005          1.5           1
 50005          1.5           1
 50005          1.5           1
 50005          1.5           1
 49939          1.5           1
```

Figure 49: Standard structure of the Input_DemandSites_Opt.txt file.

- **Transmission links file**

For each water source s (MF_R_MF_C)

Groundwater node

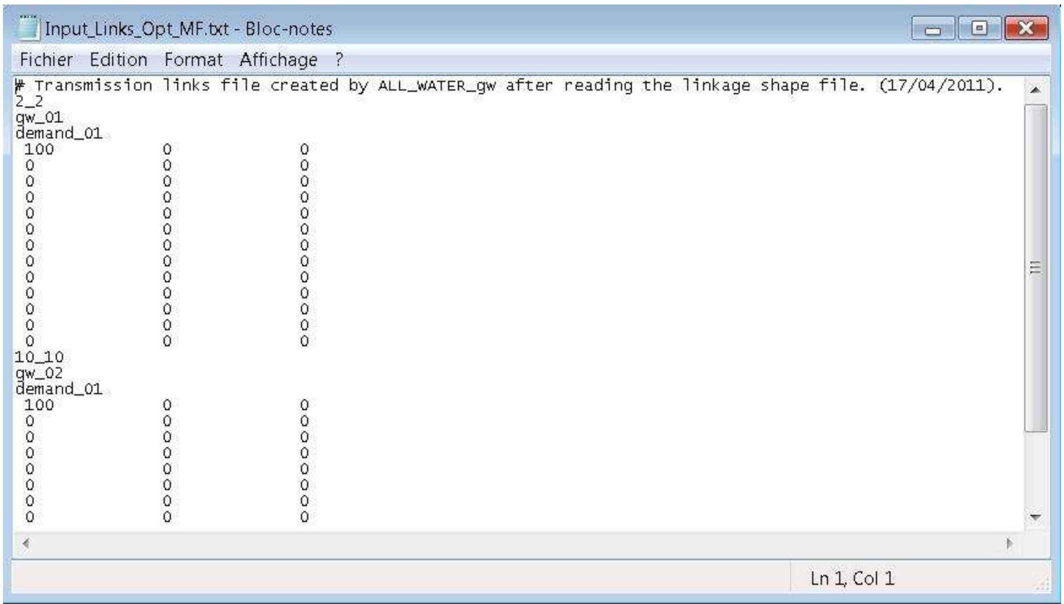
For each demand site i

Demand site (i)

Maximal supply (s, i) Maximal supply Percent of demand(s,i) Loss(s,i)

For each time step (t)

Capital Cost(t) Variable Operating Cost(t) Fixed Operating Cost(t)



```
# Transmission links file created by ALL_WATER_gw after reading the linkage shape file. (17/04/2011).
2_2
gw_01
demand_01
 100            0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
10_10
gw_02
demand_01
 100            0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
 0              0             0
```

Figure 50: Standard structure of the Input_Links.txt file.

- **Water source file**

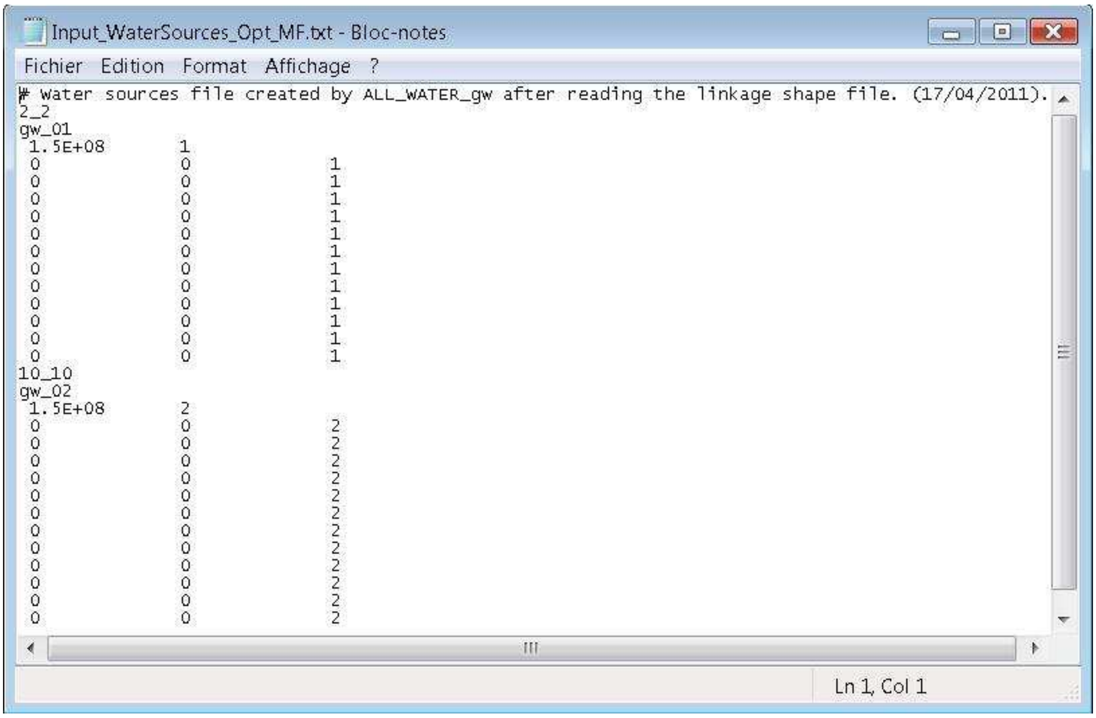
For each water source s (MF_R_MF_C)

Source (s)

Maximal pumping rate (s)   Water quality(s)

For each time step (t)

Capital Cost(t)   Variable Operating Cost(t)   Fixed Operating Cost(t)



```
Input_WaterSources_Opt_MF.txt - Bloc-notes
Fichier  Edition  Format  Affichage  ?
# water sources file created by ALL_WATER_gw after reading the linkage shape file. (17/04/2011).
2_2
gw_01
 1.5E+08      1
 0            0            1
 0            0            1
 0            0            1
 0            0            1
 0            0            1
 0            0            1
 0            0            1
 0            0            1
 0            0            1
 0            0            1
 0            0            1
 0            0            1
10_10
gw_02
 1.5E+08      2
 0            0            2
 0            0            2
 0            0            2
 0            0            2
 0            0            2
 0            0            2
 0            0            2
 0            0            2
 0            0            2
 0            0            2
 0            0            2
 0            0            2
Ln 1, Col 1
```

Figure 51: Standard structure of the Input_WaterSources_Opt_MF.txt file.

Appendix 3: Formulation of the optimization problem

Objectives functions

The fist objective of this problem is to satisfy the water demand of demand site "*d*" at every time step "*t*" in the optimization period. This objective can be expressed by the minimization of the function "f_{DS}" presented in next equation:

$$f_{DS} = Max\left[\left(\sum_{se=1}^{NSE_{max}} F_D(se,d,t) - D(d,t) \right) / D(d,t) \right] \quad d=1,\dots, ND_{max} \text{ and } t=\Delta t,\dots, T_{max}$$

Where "$F_D(se, d, t)$" is the abstraction from water source "se" to demand site "d" at time step "t"; "$D(d, t)$" is the water demand of the demand site "d" at time step "t"; "ND_{max}" is the maximal number of demand sites in the WEAP Area; "T_{max}" is the last time step in the optimization period; "Δt" is the time step.

The drawdown objective function evaluates the relative drawdown of the water head in the respective cells of the active wells, over the optimization period. The drawdown minimisation objective can be expressed by the minimisation of the function "f_{DD}" presented in next equation:

$$f_{DD} = Max(\frac{DWDW(c) \times VMaxDD(c)}{(Hi(c) - BOTM(c)) * I(c)}) \qquad c = 1, \ldots, N_{ac}$$

Where *DWDW(c)* is the water drawdown in the cell "*c*"; *VMaxDD(c)* is the violation of the maximal drawdown observed in the cell "*c*"; *Hi(c)* is the initial head in the cell "*c*"; *BOTM(c)* is the bottom of the cell "*c*"; "*I(c)*" is the importance of the cell "*c*" and "N_{ac}" is the number of the active cells.

The cost reduction objective function evaluates the average unit cost of water abstracted from water sources to demand sites over the optimization period. This objective can be reached by the minimisation of the function "f_C" presented in the next equation:

$$f_C = \frac{\sum_{t=\Delta t}^{T_{max}} \left[(\sum_{se=1}^{NSE_{max}} (\sum_{d=1}^{ND_{max}} F_D(se,d,t) \times (VOL(se,d,t) + VOS(se,t)) + FOL(se,d,t) + CCL(se,d,t)) + CCS(se,t) + FOS(se,t)) \right]}{\sum_{t=\Delta t}^{T_{max}} (\sum_{se=1}^{NSE_{max}} \sum_{d=1}^{ND_{max}} F_D(se,d,t)) \times T_{max} \times (CMaxS + CMaxL)}$$

Where "*VOL(se, d, t)*" is the variable operating cost of the transmission link between source "*se*" and demand site "*d*" at time step "*t*"; "*VOS(se, t)*" the variable operating cost of source "*se*" at time step "*t*"; "*FOL(se, d, t)*" the fixed operating cost of the transmission link between source "*se*" and demand site "*d*" at time step "*t*"; "*CCL(se, d, t)*" the capital cost of the transmission link between source "*se*" to demand site "*d*" at time step "*t*"; "*CCS(se, t)*" the capital cost of source "*se*" at time step "*t*"; "*FOS(se, t)*" the fixed operating cost of source "*se*" at time step "*t*"; "*CMaxS*" is the maximal variable operating cost of water sources; "*CMaxL*" is the maximal variable operating cost of transmission links.

The objective function evaluating the water quality is computed by the next equation. The quality satisfaction can be reached by the minimisation of the function "f_Q".

$$f_Q = Max(\frac{Qty(d,t) - Qa(d,t)}{Qa(d,t)}) \qquad d = 1, \ldots, N_{dmax} \text{ and } t = T_{act}, \ldots, T_{max} \qquad (4)$$

Where "*Qty(d, t)*" is the water salinity in demand site "*d*" at time step "*t*" and "*Qa(d, t)*" is the acceptable water salinity in the demand site "*d*" at time step "*t*".

Constraints

The maximal supply capacity from water source "*se*" to demand sites "*d*" is considered hydraulic constraints, expressed by the equations:

$$F_D(se,d,t) \le F_{max} D(se,d) \quad \forall\, se, \forall\, d \text{ and } \forall\, t$$

The maximal water abstractions from well constitutes the second hydraulic constraint.

$$Q(w,t) \le Q_{max}(w)$$

Where "*Q(w, t)*" is the abstraction from well "*w*" at time step "*t*" and "$Q_{max}(w)$" is the maximal acceptable abstraction from the well "*w*".

The maximal acceptable drawdown in each of the used wells is other constraints that have to be respected by any optimal solution.

$$DD(w,t) \le DD_{max}(w)$$

Where "*DD(w,t)*" is the drawdown in well "*w*" at time step "*t*" and "*DDmax(w)*" is the maximal acceptable drawdown in well "*w*".