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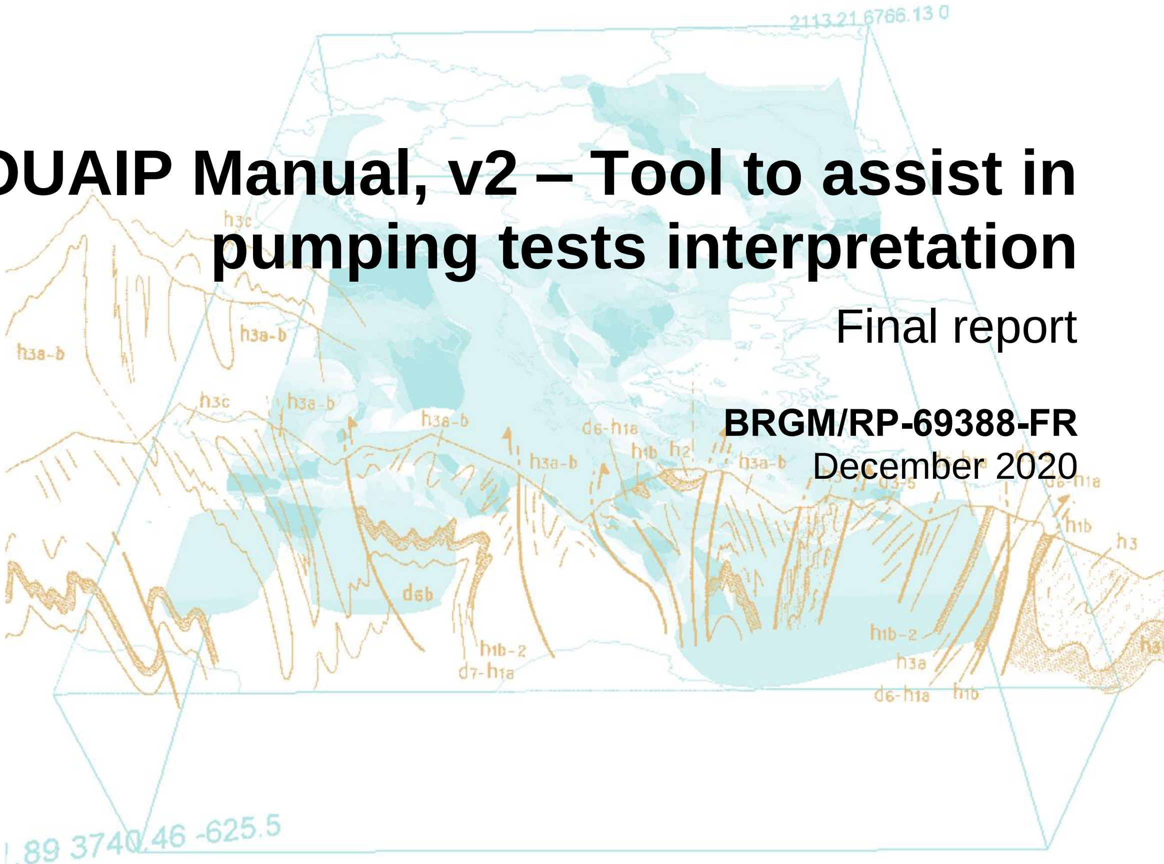
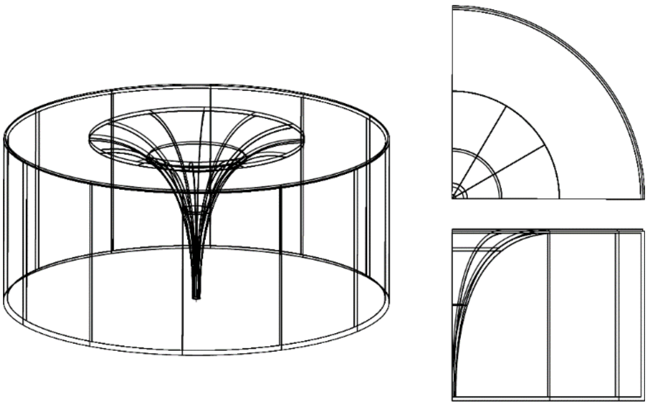


OUAIP Manual, v2 – Tool to assist in pumping tests interpretation

Final report

BRGM/RP-69388-FR

December 2020



Géosciences pour une Terre durable

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OUAIP Manual, v2 – Tool to assist in pumping tests interpretation

Final report

BRGM/RP-69388-FR

December 2020

T. KLINKA, A. GUTIERREZ
With collaboration from
J. ELSASS, B. LETAT

Verifier:	**Approver:**
Name: Benoît DEWANDEL	Name: Pascal AUDIGANE
Position: Hydrogeologist	Position: D3E/GDR Manager
Date: 10/12/2018	Date: 17/01/2019
Signature:	Signature:

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Download the report from this address: http://infoterre.brgm.fr/rapports/RP-69388-FR.pdf

Summary

Interpretation of pumping test has benefited the development of methods and analytical solutions which can determine hydrodynamic characteristics of well pumping and pumped aquifers since the middle of the twentieth Century. These methods have been written into IT tools since the 1980s, using increasingly complex mathematical solutions.

OUAIP software (Outil d'Aide à l'Interprétation des Pompages d'essai [Tool to assist pumping tests interpretation]) is a continuation of ISAPE software (BRGM). This was developed from internal financing sources in VBA.NET language, and placed online on the BRGM site (www.brgm.fr\logiciels). Version 2 provides some improvements as compared to the previous version (1.9.4): corrections to display bugs, ability to place several characteristic graphs on the same graph, deletion of the licence number and improvements to the operating manual.

The manual presents the software set up, basic principles and describes the different menus. A majority of the manual is dedicated to applications examples using real data sets provided with the software.

The OUAIP software is free and collaborative. Users can contribute to its improvement by adding analytical formulas in different languages. It is offered in French and English at this time.

Although it has been subjected to large number of tests, version 2.3, to which this manual refers, is probably not free of errors and bugs. Any problems can be noted and sent to ouaip@brgm.fr.

The tool is distributed for free in order to offer a service to the hydrogeologist community. The BRGM does not warranty results, and cannot be held liable in the case of a dispute.

Summary

List of illustrations

1. Introduction

1.1. WHAT IS OUAIP?

OUAIP (called “WEP”) is an acronym for **Ou**til d’**A**ide à l’**I**nterprétation des **P**ompages d’essai [Tool to assist in pumping tests interpretation].

OUAIP

It is a software developed by BRGM (Groundwater Division), distributed for free and designed to interpret hydrogeological pumping test, such as:

- Step-drawdown test (non continuous);
- Aquifer test (long duration tests at constant or variable flow);
- It also provides predictive simulation of the change in the level of groundwater subjected to constant or variable pumping (Illustration 1).

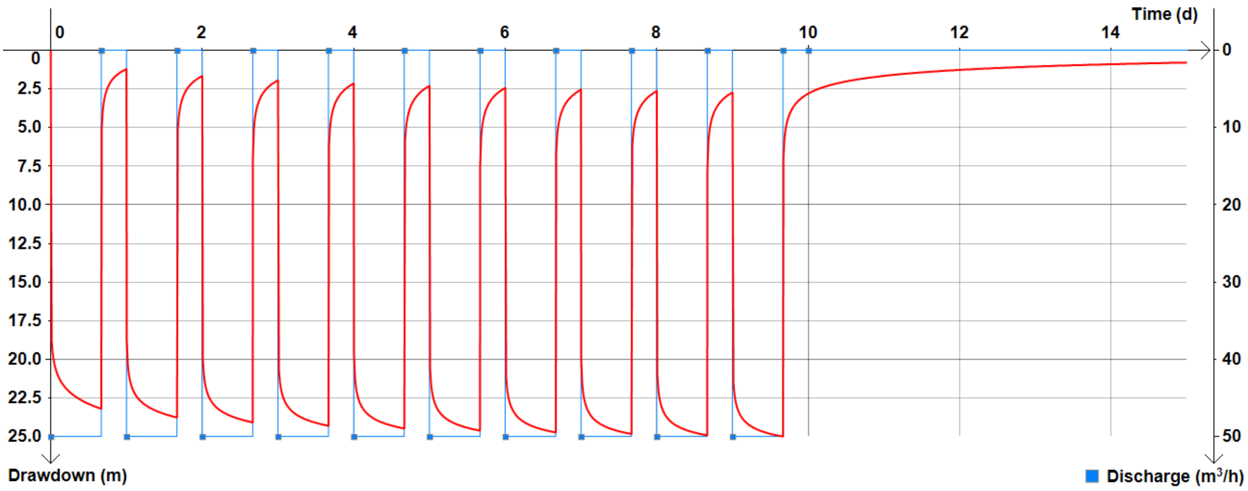


Illustration 1 : Example of predictive simulation of a drawdown at the straight line of a pumping well 16/24 hours for 10 days. In blue: pumping schedule, in red, modelled draw-down

OUAIP software and this manual can be downloaded from: http://ouaip.brgm.fr or from https://www.brgm.eu/software

One only need fill in an online form and give a valid email address in order to download it. Contrary to version 1.9.4, OUAIP v2 (and later versions) does not require a OUAIP user code. It can be installed without any conditions on one or more computers, training centre or company.

The goal of this manual is to succinctly present operating OUAIP using ten tutorials which cover the main functions of the software.

These are:

- Interpretation of step-drawdown test;
- Interpretation of aquifer test (long duration test with constant or variable flow) using four different analytical solutions;
- Predictive simulation of drawdowns of groundwater level on the basis of hydrodynamic properties of the aquifer and hydraulic properties of the well.

Illustration 7 shows the OUAIP invitation screen. Three functional modules are offered to the user, from top to bottom:

- (1) A mode to interpret step-drawdown tests in order to characterise well performance (quadratic head loss, critical discharge if needed);
- (2) A mode to interpret aquifer tests, which determine the transmissivity and storage coefficient of the aquifer using level and discharge measurements performed at the well or at piezometers during pumping and recovery phases;
- (3) A dynamic level simulation mode which consists of predictively calculating the change in water level induced in pumping well and/or at a nearby piezometer with a determined pumping schedule, more or less complex.

At the time of this version, this manual is primarily based on OUAIP version 2.3, dated 06/01/2021. Some versions of the software, graphic interface or some functions could have slightly changed since then.

You can use the following citation when citing your OUAIP usage:

KLINKA T., GUTIERREZ A. (2020) – OUAIP Manual, v2 – Tool to assist pumping tests interpretation. Final report. BRGM/RP-69388-FR, 132 p., 127 ill.

Please notify us if you have found a bug at: **ouaip@brgm.fr**. Do not forget to provide screenshots, your Windows version as well as the OUAIP file used to create the fault in your comments.

You can also use the form at “Contact us” on our web page.

Training: the success of a pumping test depends first on the quality of the pumping performed (experimental protocol). You can train yourself in implementation and interpretation of pumping test with OUAIP at BRGM in Orleans, France. Please check the following link:

https://www.brgm.eu/key-roles/training/continuing-professional-training

Custom training can also be provided on request.

1.2. OBJECTIVES OF OUAIP SOFTWARE

OUAIP was inspired by ISAPE software (semi-automatic interpretation of pumping test) developed at BRGM at the end of the 1980s, based in particular on the work by Philippe Leblanc (1987). He uses the principles listed below.

Interpretation of pumping test starts with the choice of a theoretical flow scheme which is as close as possible to the real case being examined (aquifer type, type of medium, geometry, etc.).

This choice can call on future versions of diagnostic techniques using logarithmic derivatives for drawdown to validate chosen theoretical scheme(s) or to select graph sections related to them (Bourdet, 2002; Renard et al., 2009). The “drawdown derivatives” module has not yet been incorporated in the OUAIP tool (planned for v3).

Gaps between this theoretical scheme and reality are due to heterogeneity in the medium (nature, thickness) which alter the model’s representation of reality, but also perturbations due to several origins in which impacts can be superimposed:

- Effects related to the aquifer’s environment which can cause movements in the groundwater not related to pumping (tides, atmospheric pressure, interference with other pumping) which makes it necessary to filter or correct the raw data,
- Effects linked to the pumping well itself, related to the drilling (wellbore storage effect, head losses, skin effects, partial penetration, backflow effects),
- Effects related to implementing the pumping test (pumping rate variation) and those related to the monitoring quality (measurement accuracy, device drift) which are the responsibility of, and rely on the care of the operator.

The goal of OUAIP software is to provide hydrogeologists with a tool which can take into account cumulative pumping **effects calculated using a theoretical scheme (analytical solution), as well as perturbations at the pumping well and variations in pumping rate.**

In practice, OUAIP pictures the theoretical change in water level (or drawdown) in a pumping well or in a piezometer using hydrodynamic parameters entered by the operator. The operator graphically compares these with observations and attempts to minimise gaps between the theoretical graph and measured drawdown. Although it is always possible to adjust the parameters automatically, the ‘philosophy’ of semi-automatic interpretation is to successively approach through trial and error desired hydrodynamic parameters (generally transmissivity “T” and the storage coefficient “S”) in plausible range values within the hydrogeological context of the test. As is the case with many models, many solutions can approach an equivalent result, but not all are necessarily realistic. **Automatic adjustment must therefore be carefully framed by the operator** (using semi-automatic adjustment). That is why, although non-specialists will find it sufficiently easy to use to obtain a satisfactory result in many cases, the OUAIP tool should not be used if one does not possess hydrogeology expertise.

1.3. OUAIP FUNCTIONALITIES, V2.3

Version 2.3 offers the following functions for current OUAIP users as compared to OUAIP version 1.9.4:

- OUAIP installation doesn't require a user code;
- One can simultaneously compare several well tests with the same interface (experimental data and interpretations);
- One can modify default units used by the analytical solutions;
- Publishing PDF and HTML interpretation reports was improved;
- Graphic displays (arithmetic, semi-logarithmic and log-log) were improved;
- It's now possible to import water level depth instead of drawdown;
- English translation was improved;
- The manual gives additional details on advanced OUAIP functions;
- An English-language manual is available (this one);

1.4. INSTALLATION

Required configuration

- OUAIP is only available on the Windows operating system. It has been tested with Windows XP, Windows Vista, Windows 7, Windows 8 and Windows 10.
- OUAIP is not available yet on Linux or Mac operating systems.

Installation

After downloading OUAIP from: http://www.brgm.fr/ouaip you will have a ZIP folder which name is the latest available OUAIP version. At the time of writing this manual, the present version is:

- OUAIP-v2.3.zip

Extract the file from the ZIP folder to install OUAIP. Right click on the OUAIP-v2.3.ZIP file. A contextual menu will give the option “Extract all...” (Illustration 2), then click on “extract” (Illustration 3) to extract to your hard disc.

We do not recommend installing OUAIP on a network, although this can be done.

NB: If you do not have a program to extract the OUAIP folder, or your Windows version doesn't allow it, you can download the free and Open Source program 7-Zip.

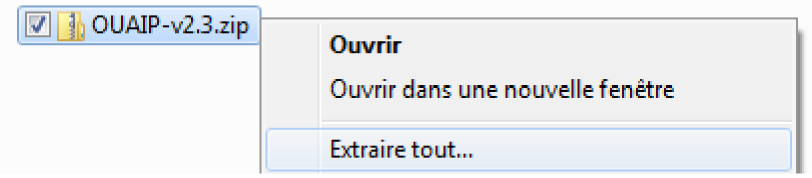


Illustration 2 : Extracting the OUAIP ZIP folder

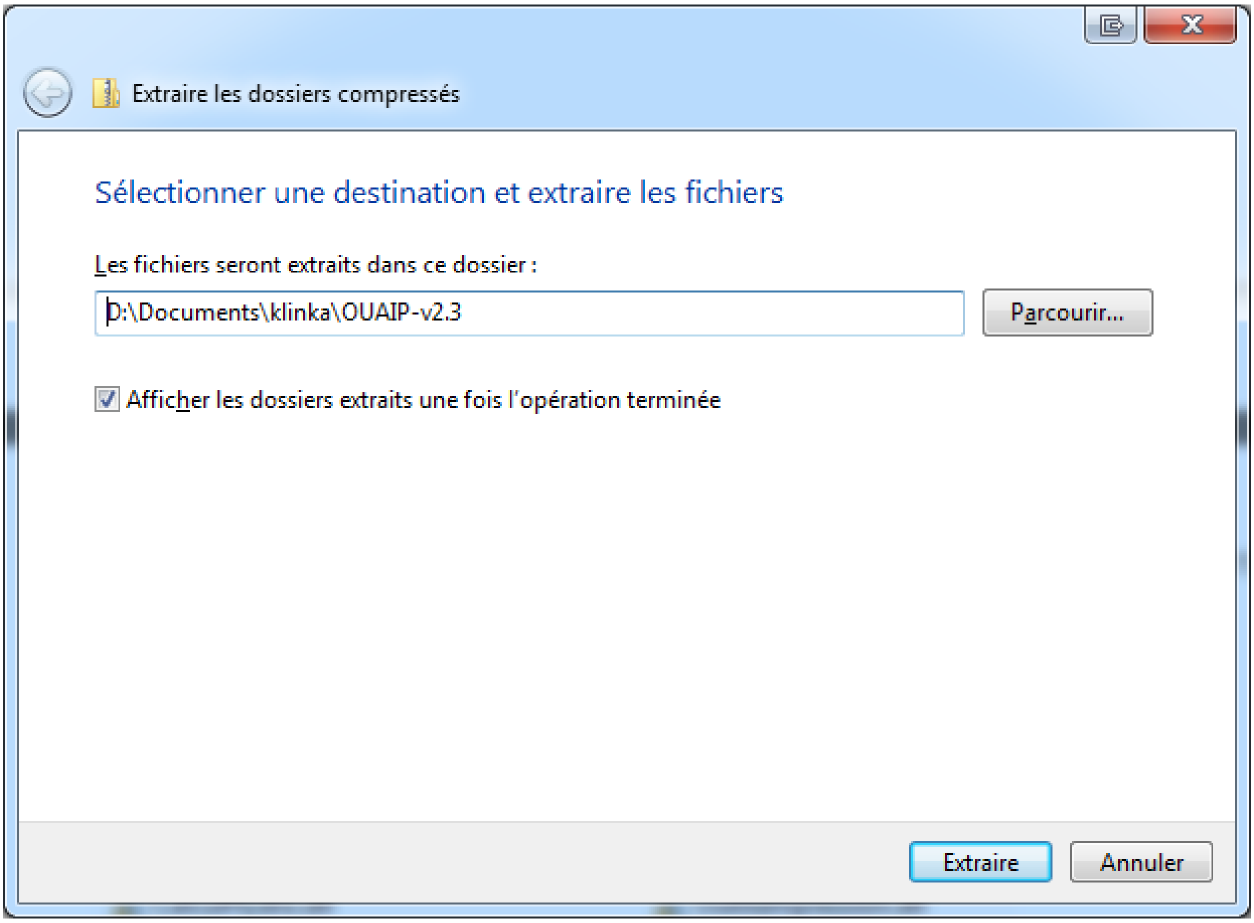


Illustration 3 : Procedure to extract the OUAIP ZIP folder

Once the extraction is completed, a OUAIP directory will show the name of the installed version was created, for example **OUAIP v2.3**. This folder contains the following files (Illustration 4):

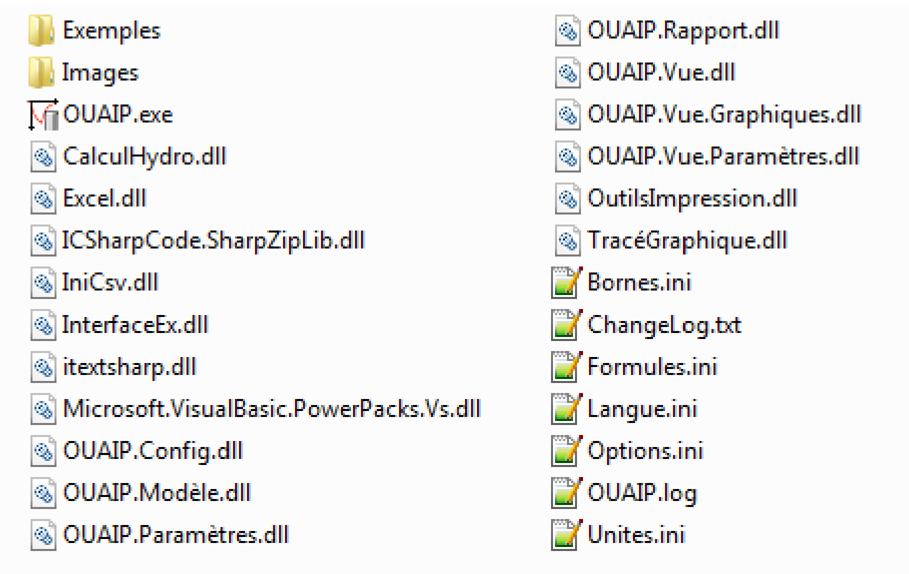


Illustration 4 : Tree and directory contents of the OUAIP directory

You can install OUAIP on several computers (training room, IT room).

Start OUAIP

Simply press **OUAIP.exe** to start OUAIP. The prompt is launched when OUAIP starts (Illustration 7). The first time OUAIP executes, the software proposes automatic connection to OUAIP data file extensions (project: *.ouaipp, *.ouaipi, *.ouaips) with the software. Just double-click on a OUAIP data file to start the software without being prompted. Note that you can execute several OUAIP programs simultaneously on the same computer.

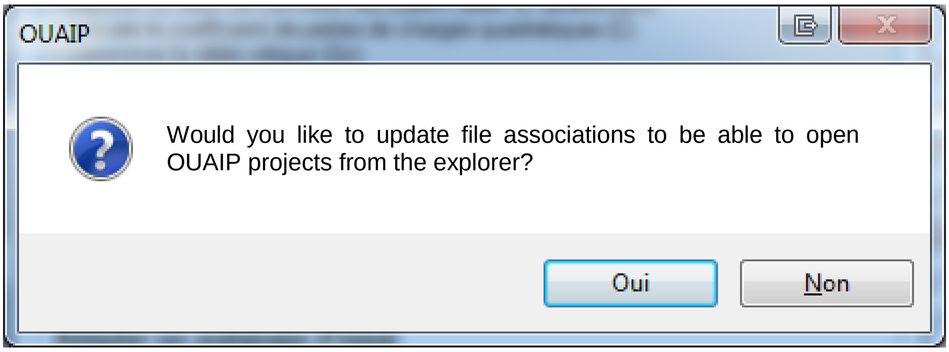


Illustration 5: At first start-up, OUAIP will associate the project files (.ouaipp, *.ouaipi, *.ouaips) to the OUAIP.exe program.*

OUAIP project files

OUAIP saves files with the following three extensions depending upon your user mode in order to save your work/project:

- *.ouaip**p**: **p**uits [well] interpretation module (step-drawdown test);
- *.ouaip**i**: **i**nterpretation module of an aquifer test (long duration test);
- *.ouaip**s**: **s**imulation module for pumping test;

Simply click on one of the files with these extensions to launch OUAIP in the appropriate mode.

Keyboard shortcuts

OUAIP uses several keyboard shortcuts. A list of shortcuts is shown in Chapter “4 OUAIP graphic interface“. By hovering over an icon with your mouse, its use as well as its keyboard shortcut appear (Illustration 6).

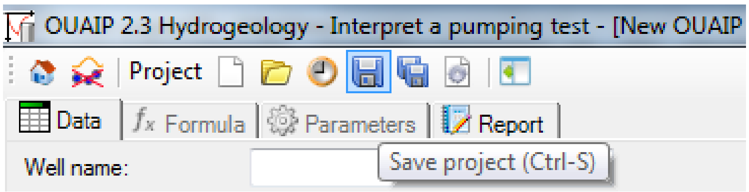


Illustration 6 : Showing keyboard shortcuts by passing the mouse over icons

1.5. PRESENTATION OF OUAIP SOFTWARE

1.5.1. OUAIP invitation

When running OUAIP, the prompt appears and proposes three modules, logically from top to bottom:

- Module to interpret a step-drawdown test (SDT) using the Jacob method (1947). This module evaluates linear and quadratic head losses in the pumping well, possibly critical discharge.
- Module for aquifer test (long duration test: LDT) interpretation. This module evaluates aquifer hydrodynamic characteristics, possibly taking into account, for example, quadratic load losses found during the SDT.
- Module for temporary simulation of drawdown in an aquifer subject to a pumping schedule in which the hydrodynamic (aquifer) and hydraulic (well) properties were evaluated beforehand.

These three modules are presented for detailed handling in tutorials in Chapter “5 Use example“.

These three modules correspond to operations and analyses to implement to determine operating discharge using the recommendations of the French standard (AFNOR NF-X-10-999) of August 2014. These operations are as follows:

- Determination of critical discharge by performing a step-drawdown test and choice of aquifer test discharge (module 1),
- Interpretation of an aquifer test, determining a conceptual scheme and hydrodynamic parameters (module 2),
- Operating simulation and optimisation of operating discharge using given parameters (module 3).

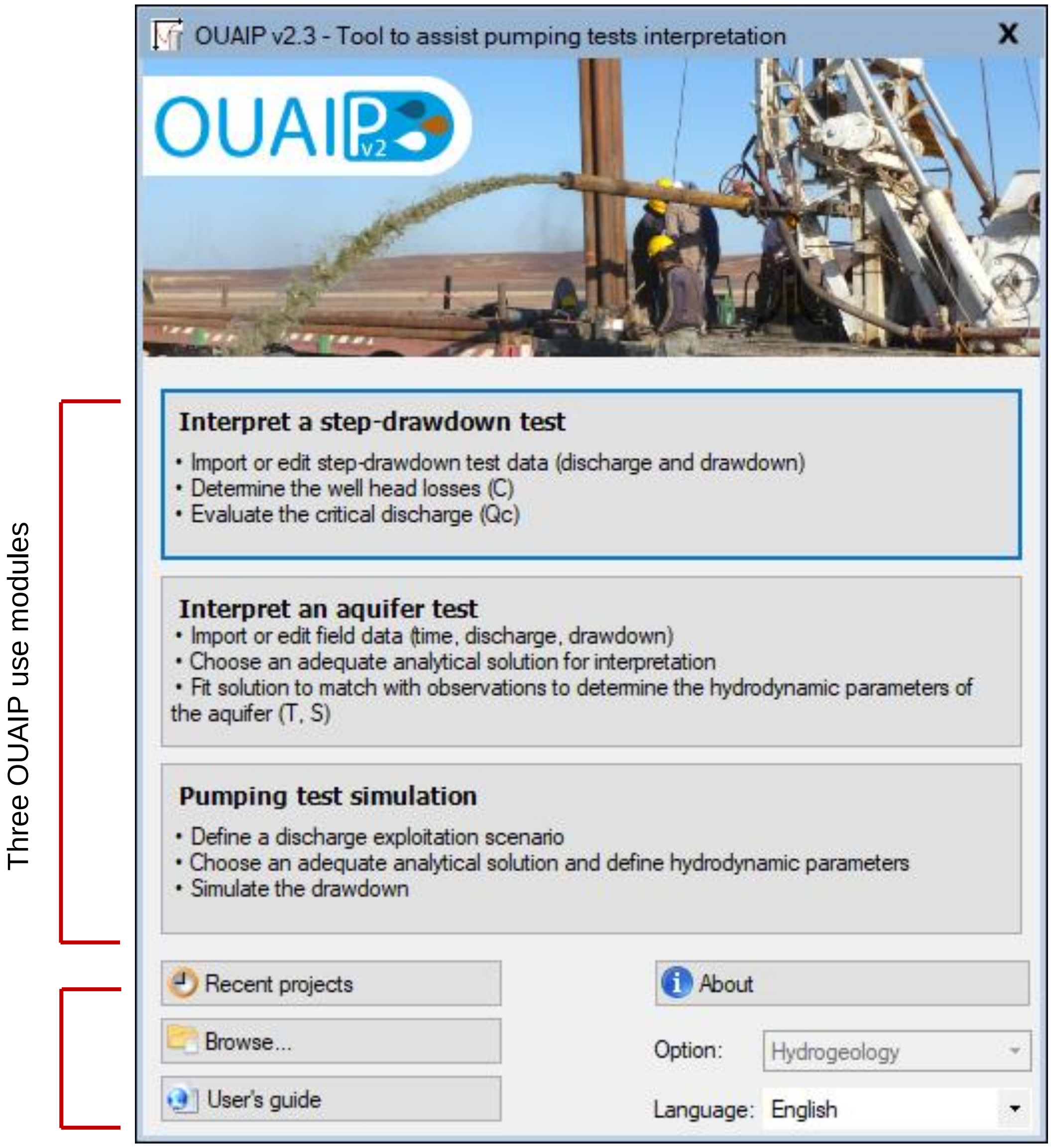
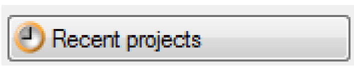


Illustration 7 : Launch OUAIP v2.3

Several buttons are available on the lower portion of the OUAIP launch screen:

- 

Recent projects (Illustration 8): rapidly shows a list of files which you have recently created or used, which you can directly load into OUAIP without having to go through your tree structure.

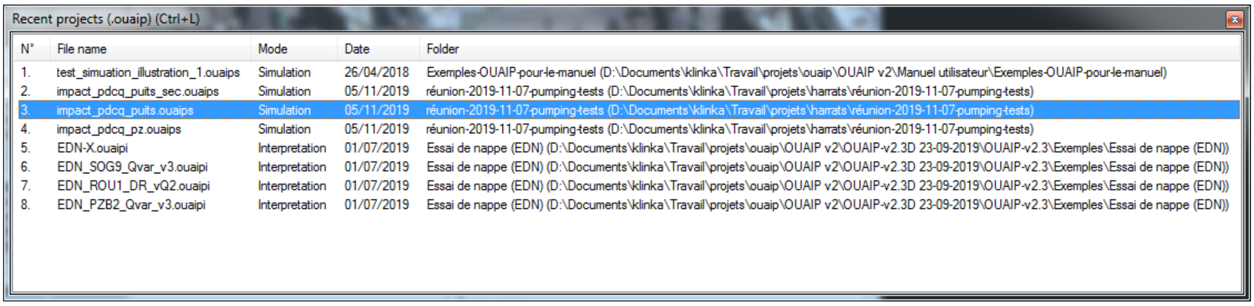


Illustration 8 : Recent OUAIP projects

- 

Browse (Illustration 9): displays a Windows Explorer window to open up a OUAIP project (extension file *.ouaipp, *.ouaipi, *.ouaips)

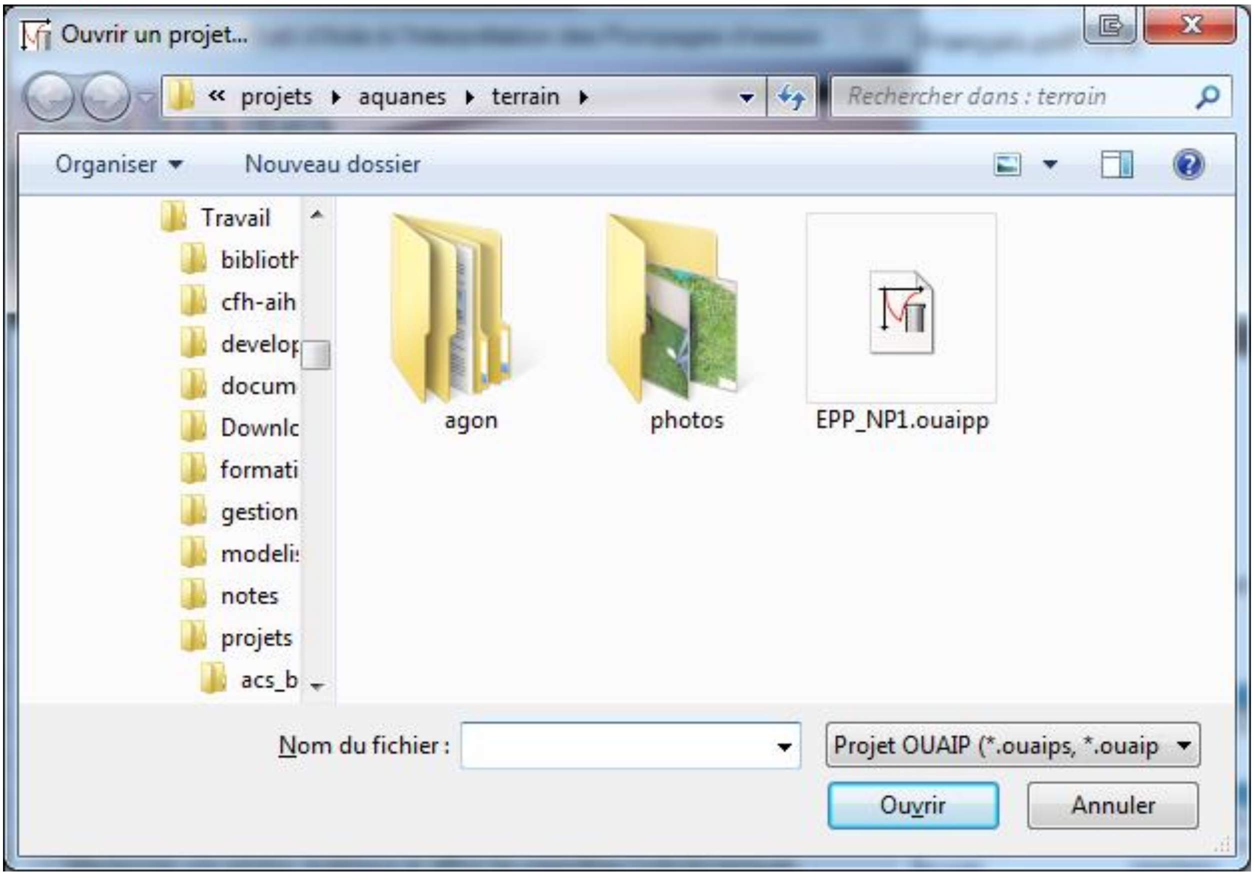
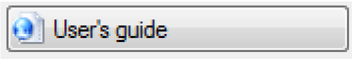


Illustration 9 : OUAIP browsing window

- 

User manual: open this user manual in PDF format. This is found on your OUAIP set-up directory (RP-69388-FR.pdf). This BRGM report is also available at the following: http://infoterre.brgm.fr/rapports/RP-69388-FR.pdf

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About (Illustration 10): displays a window with information about the current installed OUAIP version. Clicking on the version number shows a text file with changes in OUAIP depending upon the version.

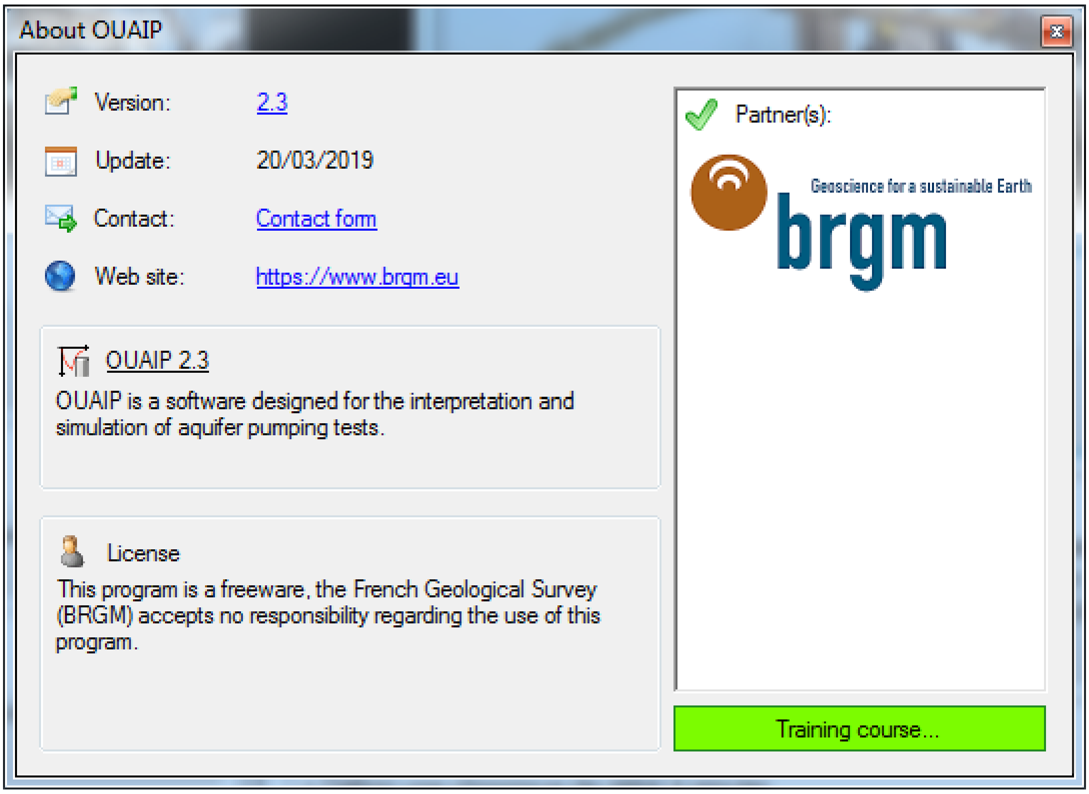


Illustration 10 : "About OUAIP" window

- Option: this is a mode which is currently deactivated. It allows using OUAIP either in the "hydrogeology" mode, or for "geothermal" applications to take into account density changes in "hot" water related to viscosity, temperature and mineral contents of the water. By default, only the hydrogeology option is accessible to the public at present.

- Language: OUAIP is offered in French and English. If you are interested, you can translate OUAIP into another language to benefit the community. This point is described in Chapter "4.5.5 Langue.ini".

1.5.2. Graphics interface

OUAIP's graphic interfaces is organised in two separate sections, in the "interpretation" mode a Step-drawdown test or an aquifer test, and the "simulation" mode (Illustration 11):

- The **left section** (framed in **green**) allows data entry. It is structured in tabs, which are progressively used from left to right;
- The **right section** (framed in **red**) is used for **real-time graphics,** resulting from data entry and parameters;
- The top left part (in **purple**) is the tool bar, which can save or load a project.

The black arrows indicate the four zones which can be re-sized by the user using the mouse to adjust the software ergonomics at one's workstation.

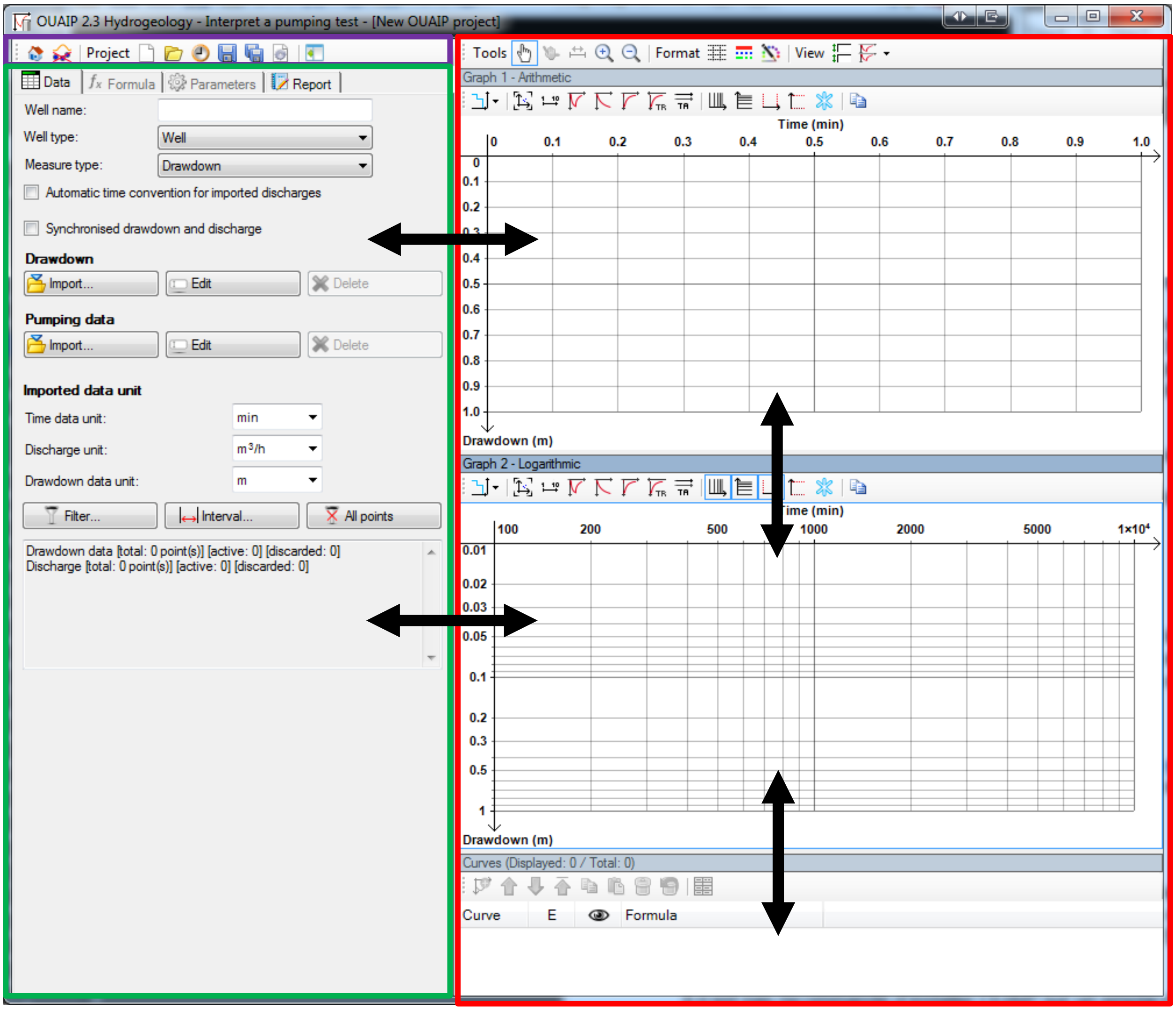


Illustration 11: OUAIP's general interface (the arrows indicate where one can resize various windows)

2. Principles

2.1. INTERPRETATION OF A STEP-DRAWDOWN TEST (SDT)

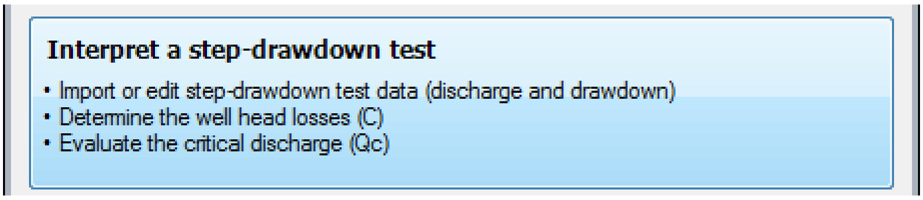
The first OUAIP module is dedicated to interpreting SDT.

The goal of SDT is to evaluate hydraulic characteristics related to the well (drilling) by a series of short-duration steps, generally with increasing discharge rates.

This type of test generally reveals the appearance of flooding problems from the aquifer water during drilling. These are related to head losses called “quadratic” because they evolve in proportion to the square of the discharge rate. These are generated by a turbulent flow that generally occurs at the filter screen entrance or nearby. In a pumping well, it is absolutely required to avoid the appearance of this type of flow which generates physical (particle entrainment) and chemical (oxidation) problems and have a significant financial impact (pump and borehole wear, higher energy costs).

The well's characteristic curve helps to determine a critical discharge rate with respect to the quadratic head loss criterion. OUAIP determines head losses in the well, and offers a critical discharge determination related to head losses. The method, which follows the French standard AFNOR X10-999, is described for the most part in the BRGM/RP-65683 report (online).

If it is compatible with the technical and hydrogeological log of the borehole, the position of the pump and its capacity, the discharge thus determined is generally that which is used for the aquifer test (long duration pumping test). On the other hand, this must not be confused with optimal operational pumping rate which uses other criteria than head losses in the well; this requires an operational simulation (see the OUAIP simulation module).



Interpretation principles

The proposed interpretation for automatic determination of the critical discharge differs from the Porchet method which determines an inflection point on the characteristic curve in a more or less subjective way. OUAIP offers a more rigorous method which is based on linear and quadratic head loss calculations (Illustration 12) using the Jacob method. In any case, this automatic method requires that the user regards it in a critical manner.

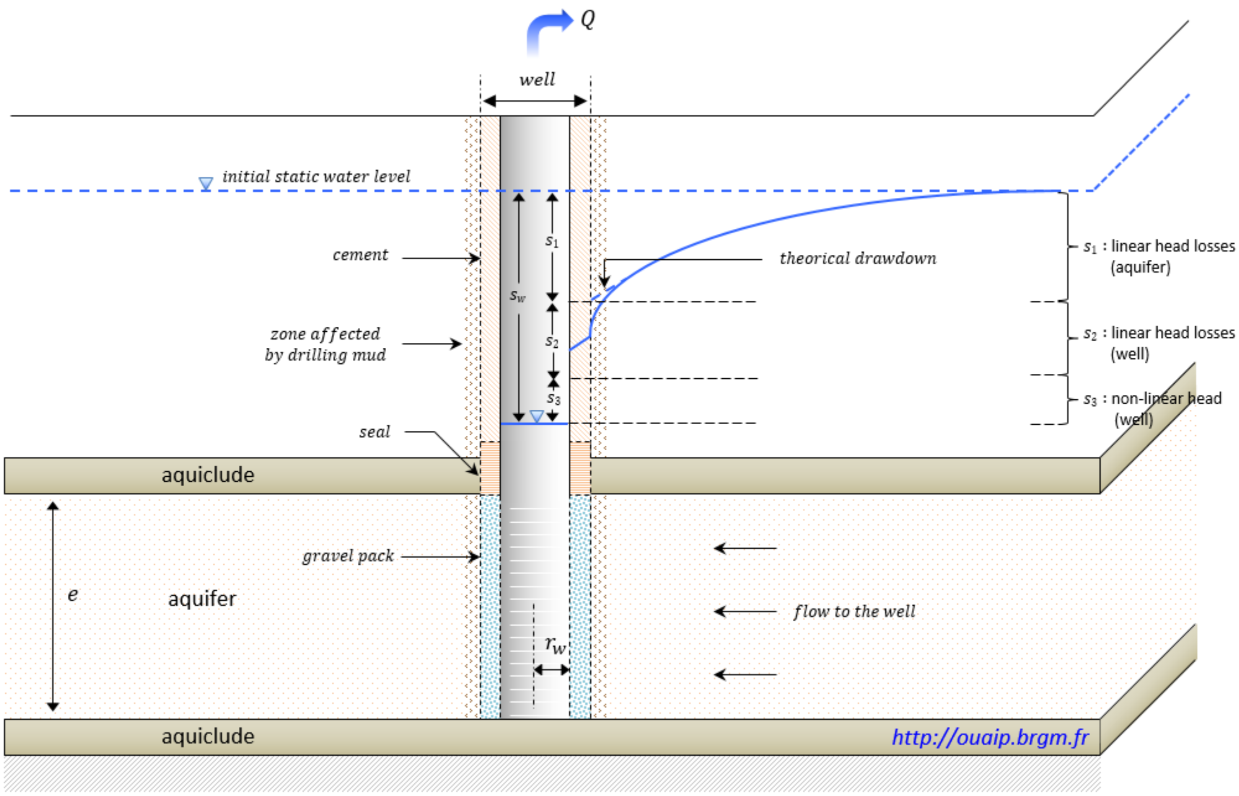


Illustration 12 : Simplified diagram for head losses in a well and the aquifer

Jacob estimates in a fairly schematic way the total drawdown (s_{total} ; s_w Illustration 12) measured in a pumping operation is the sum of a draw-down which depends upon the aquifer's hydrodynamic properties (s_{aqui} ; s_1 Illustration 12) and additional drawdown caused by the installed equipment and the immediate neighbouring of the well (s_{equip} ; s_1+s_2 Illustration 12).

$$s_{total} = s_{aqui} + s_{equip}$$

Due to the increase in water velocity near the well, the first term, s_{aqui} is generally a linear function of the well discharge (Darcy flow conditions in which the flows are pictured by parallel flow lines) while the second term includes an amount proportional to the square of the discharge (head losses are therefore quadratic). In this case, flow is turbulent rather than laminar. Thus, Jacob (1947) wrote the following formula:

$$s_{total} = BQ + CQ^2$$

Where B is the linear head loss coefficient and C is the quadratic head loss coefficient. Thus, the term BQ, represents the laminar flow section and the term CQ^2 represents the turbulent flow section of the groundwater flow mobilized by the pumping.

OUAIP makes it possible to use the generalised formula (Rorabaugh, 1953) in which the “n” exponent can be different (between 1.5 and 3.5, Lennox, 1966), although it is generally near 2.

$$s_{total} = BQ + CQ^n$$

On the basis of this flow conceptualisation, OUAIP determines critical discharge as the flow rate which shall not be exceeded to maintain flows which are primarily laminar around the entry to the well. This point is defined for:

$$BQ = CQ^n$$

This is the point called linear and quadratic “head loss equality.” Selecting this determination method and the graph will show critical discharge and corresponding drawdown.

Important comment:

There are cases where the **equality of head losses does not apply** because there are cases where Jacob’s concept does not correspond to reality:

- This is the case for very highly permeable media (karst media in particular, fractured medium): quadratic head losses “explode” due to the very high flow velocities which already exist in fractures or karst channels;
- If the exponent is not equal to 2, the conceptual scheme is probably different than Jacob’s simple scheme.

The user must therefore manually determine (in clicking on the curve with the mouse) the critical discharge using his own criteria. In addition, if the straight line of the specific drawdown shows a break or inflection in the linear trend, one might suspect a significant modification of the flow conditions in the well.

OUAIP uses the international system by default as head loss units. B is in s/m^2 and C in s^2/m^5. The choice of these units means that one can handle these figures without decimals. In any case, one can modify the proposed units by default.

2.2. ANALYTICAL SOLUTIONS TO INTERPRET AQUIFER TESTS OR TO SIMULATE PUMPING TESTS

OUAIP’s second and third modules are dedicated respectively to:

- Interpreting pump tests with a goal of determining tested aquifer characteristics in the pumping environment: hydrodynamic parameters, geometry, and various observations on the behaviour of the groundwater under pumping.
- Pumping simulation with the goal of determining operating flow rates or the effect of pumping on groundwater at any given place.

OUAIP currently integrates four analytical solutions described below. These methods are available to interpret groundwater tests and simulation modes. One can add additional analytical solutions in OUAIP. Refer to Chapter “4.5.2 Formules.ini“. Illustration 13 presents a summary of the characteristics of analytical solutions as well as available additional effects:

		Interpretation			List effects				
Analytical solution	Variable flow	Well	Piezometer(s)	Partial penetration	Boudaries conditions	Quadratic head losses	Skin effect	Wellbore storage effect	No return check valve effect
Theis (1935)	✓	✓	✓	✗	✓	✓	✓	✓	✓
Papadopulos-Cooper (1967)	✓	✓	✓	✗	✓	✓	✓	✓	✓
Hantush (1964)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Gringarten-Witherspoon (1972)	✓	✓	✓	✗	✓	✓	✓	✓	✓

Illustration 13: Summary of OUAIP's analytical solutions and additional available effects

2.2.1. Theis solution (1935)

Theis' solution (1935) simulates confined (or unconfined) groundwater under transient state conditions for a full penetration well or a piezometer (Illustration 14). This solution can also be used in the case of unconfined aquifer under the condition that the drawdown of the groundwater is low, so the Dupuits hypotheses are not altered (in practice, Theis can be used if the drawdown in the aquifer near the well does not exceed 1/3 of the tapped thickness).

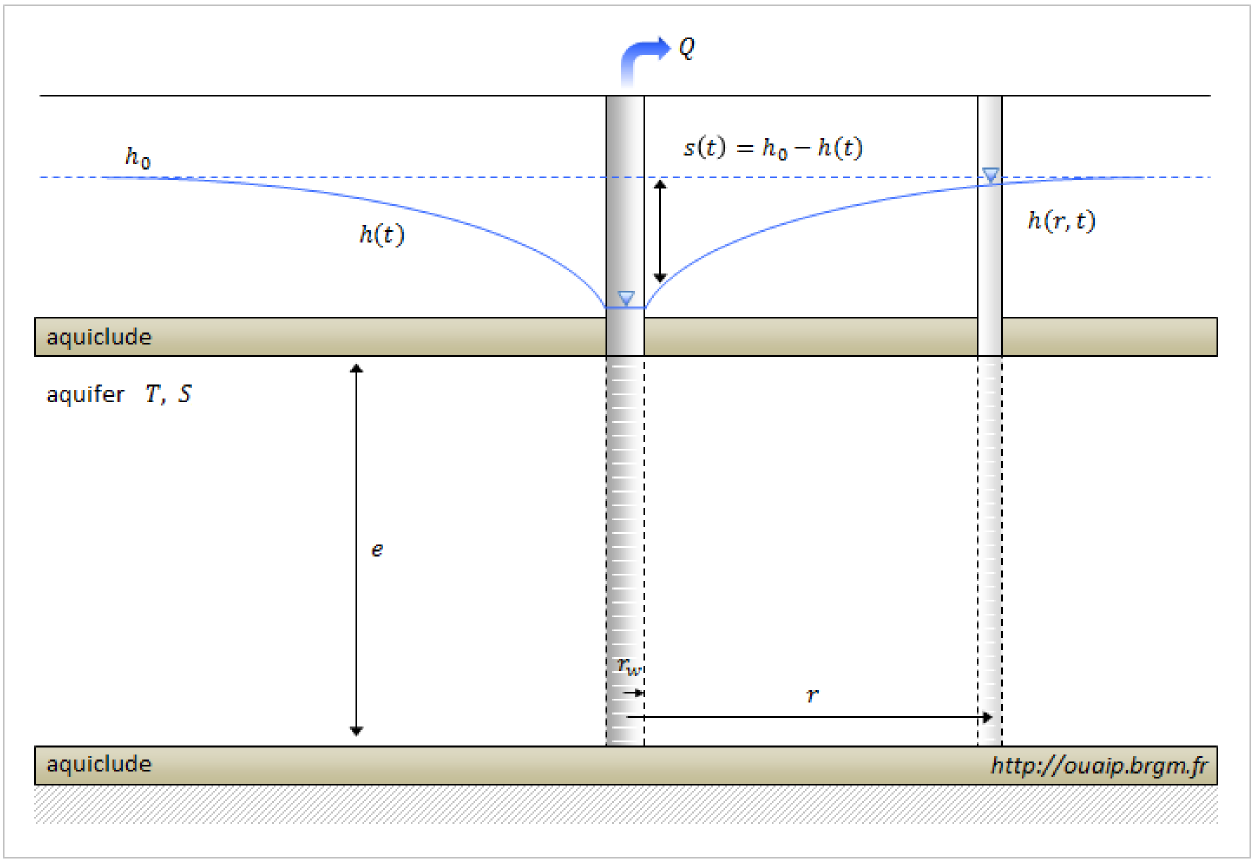


Illustration 14: Diagram of the Theis solution configuration

Formula

$$s(r,t) = \frac{Q}{4\pi T}\int_u^\infty \frac{1}{y} exp(-y)\, dy = \frac{Q}{4\pi T} W\left(\frac{r^2 S}{4Tt}\right)$$

With:

- s(r,t): drawdown, function of the distance to the centre of the well and the pumping time [L],
- Q: flow rate (discharge) [L3/T],
- T: Aquifer transmissivity [L2/T],
- S: Aquifer storage coefficient [-],
- r: observation radius (distance to the well or radius of the well if the drawdown measurements are done there) [L],
- t: Pumping time [T].

In posing $u = \frac{r^2 S}{4Tt}$, the Theis formula becomes $s(r,t) = \frac{Q}{4\pi T} W(u)$

W(u) is the Theis function.

Assumptions

Type of aquifer:

- Confined groundwater;
- Homogeneous groundwater, isotropic, infinite lateral extension and constant thickness.

Type of well:

- full penetration well (well radius negligible and total penetration);
- Piezometer.

Application conditions:

- transient state;
- Dupuits assumptions: the flows to the well are horizontal.

Available effects: boundary effect, quadratic head losses, skin effect, wellbore storage effect, backflow effect.

Parameters in the pumping well solution:

- T (in m^2/s): aquifer transmissivity;
- S (without units): aquifer storage coefficient;
- r (in m): distance between the pumping well and the measure of the dynamic level. r is equivalent to the well radius (screens, borehole) for a measure at the pumping well.

At the piezometer:

- r (in m): distance between the pumping well and the measure of the dynamic level. r is equivalent to the well-piezometer horizontal distance.

Reference:

- *Theis, C.V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, Am. Geophys. Union Trans., vol. 16, pp. 519-524.*

2.2.2. Papadopulos-Cooper solution (1967)

If the pumping well is of a large diameter, the assumption of a negligible radius of the full penetration well in the Theis solution is no longer valid. Papadopulos-Cooper's solution for Confined groundwater under transient state conditions for a full penetration well of a large diameter or a piezometer with a wellbore storage effect (Illustration 15). This solution can also be used for the case of unconfined water tables under the same conditions as the Theis solution. Note that taking into account the wellbore storage effect of the well can also be done with the Theis solution (and other OUAIP solutions) using solutions giving a very good approximation (Blasingame et al., 1991).

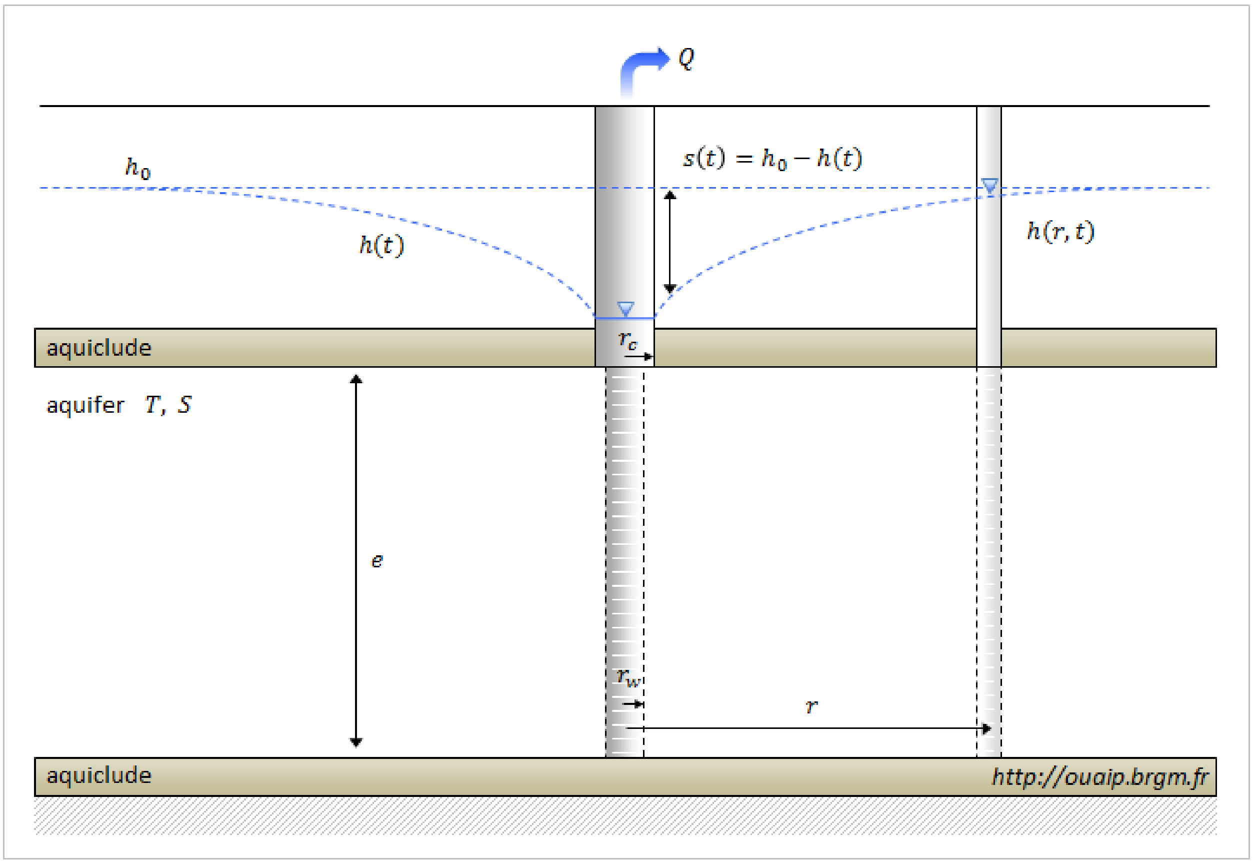


Illustration 15: Diagram of the Papadopulos-Cooper solution configuration

Formula

Analogous to the problem of heat flux, the authors established that the Laplace transform of the drawdown, with *p* being the transformation parameter, can be calculated by:

$$\bar{s}(p) = \frac{QK_0(qr)}{\pi p[r_c^2 pK_0(qr_w)+2r_w TqK_1(qr_w)]} \text{ where } q = \sqrt{\frac{pS}{T}}$$

r Is the distance to the well, r_w is the well radius, r_c is the radius of a full tube in which the water level fluctuates and K_0 and K_1 are Bessel functions modified by the second type and order 0 and 1.

The drawdown s(t) is obtained by the inverse Laplace transform of this function.

Assumptions

Type of aquifer:

- Confined aquifer;
- Homogeneous groundwater, isotropic, infinite lateral extension and constant thickness.

Type of well:

- Well capturing all the thickness of the aquifer;
- Piezometer.

Application conditions:

- Transient state conditions;
- Dupuits assumptions: the flow to the well is horizontal.

Available effects: boundary effect, quadratic head losses, skin effect, backflow effect.

Parameters in the pumping well solution:

- T (in m^2/s): aquifer transmissivity;
- S (without units): aquifer storage coefficient;
- r_c (in m): radius of the casing section (not screened)
- r_w (in m): radius in the screened section

NB: the indices c and w respectively designate the words **c**asing and **w**ell

If the interpretation is performed on piezometer measurements, the well to piezometer distance must be considered:

- r (in m): distance between the pumping well and the piezometer

Reference:

- *Papadopulos, I.S. and H.H. Cooper, 1967. Drawdown in a well of large diameter, Water Resources Research, vol. 3, no. 1, pp. 241-244.*
- *Blasingame T.A., Johnston J.L., Lee W.J., Raghavan R., 1991. Advances in the use of convolution methods in well test analysis. Soc. Petr. Eng., SPE 21826, presented at the SPE Rocky Mountain Regional symposium, Denver, Colorado, 15-17 April.*

2.2.3. Hantush-Jacob solution (1955)

The Hantush-Jacob solution (1955) simulates the drawdown of semi-confined aquifer fed by an overlaying water table (or underlying) through a semi-permeable layer or aquitard (Illustration 16). In this solution, the stock of water in the surface aquifer (overlying the aquitard) is supposed to be infinite, and therefore its level does not vary during the test. Thus, this solution can be applied in the case that the level of the water in the surface aquifer does not vary significantly during the test.

The flow of water passing through the aquitard is constant and vertical. The curve is similar to the Theis curve at the start of pumping. Then the influence of leakage is manifested by a stabilisation of the drawdown.

Hantush (1961) proposed a method to take into account partial penetration of the well in the aquifer. This is implemented in the software.

Formula

Drawdown calculation s(r,t), with r the distance to the well (full penetration well):

$$s(r,t) = \frac{Q}{4\pi T}\int_{u}^{\infty}\frac{1}{y}exp\left(-y-\frac{r^2}{4L^2y}\right)dy = \frac{Q}{4\pi T}W\left(u,\frac{r}{L}\right)$$

With:

- $u = \frac{r^2 S}{4Tt}$
- T: the aquifer transmissivity [L2/T],
- S: the aquifer storage coefficient [-],
- t: the time [T],
- r: distance to the well [L],
- Q: the pumping rate (constant) [L3/T],
- $L = \sqrt{Te'/K'}$: the leakage factor [L],
- K' Is e': related to permeability [L/T] and thickness of the aquitard [L],
- $W\left(u,\frac{r}{L}\right)$: is called the Hantush-Jacob function.

Assumptions

Type of aquifer:
- Semi-confined water table;
- Homogeneous aquifer, anisotropic (vertical anisotropy in the case of is partial penetration), with an infinite dimension and constant thickness;
- Effect of leakage through a semi-permeable layer (aquitard);
- The storage coefficient of the aquitard is negligible;
- The head in the underlying groundwater remains constant (no variation due to pumping).

Type of well:
- full penetration well or well with partial penetration (incomplete well);
- full penetration piezometer or piezometer with partial penetration (incomplete well);

Application conditions:
- Transient state conditions;
- Vertical flow in the aquitard.

Available effects: boundary effect, quadratic head losses, skin effect, wellbore storage effect, backflow effect.

Solution parameters in OUAIP:

At the pumping well:

- T (in m^2/s): aquifer transmissivity;
- S (without units): aquifer storage coefficient;
- L (in m): leakage factor, which is $L = \sqrt{\frac{T * e'}{K'}}$;
- e’ (in m): thickness of the aquitard;
- K’ (m/s): aquitard permeability;

On the piezometer:

- r (in m): distance between the pumping well and a measure of the dynamic level. r is equivalent to the well to piezometer distance for a measurement at a piezometer.

Solution with partial well penetration:

$$s(x,y,t) = \frac{Q}{4\pi T} \mathrm{f}\left(u_r, \frac{r}{B_r} \frac{r}{B}, \frac{d}{B}, \frac{l}{B}, \frac{z}{B}\right) = \frac{Q}{4\pi T}\left\{\mathrm{W}\left(u_r, \frac{r}{B_r}\right) + \mathrm{f_S}\left(u_r, \frac{r}{B_r}, \frac{r}{B}, \frac{d}{B}, \frac{l}{B}, \frac{z}{B}\right)\right\}$$

$$\mathrm{f_S}\left(u_r, \frac{r}{B_r}, \frac{r}{B}, \frac{d}{B}, \frac{l}{B}, \frac{z}{B}\right) = \frac{2B}{\pi(l-d)} \sum_{i=1}^{\infty} \left\{ \begin{array}{l} \frac{1}{i}\left[\sin\left(i\pi \frac{l}{B}\right) - \sin\left(i\pi \frac{d}{B}\right)\right] \\ \cos\left(i\pi \frac{z}{B}\right) W\left(u_r, \sqrt{\left(\frac{r}{B_r}\right)^2 + \frac{k_z}{k_h}\left(i\pi \frac{r}{B}\right)^2}\right) \end{array} \right\}$$

$$u_r = u_{rw} = \frac{r_w^{\,2} S}{4Tt} \qquad B_r = \frac{T}{k'/e'}$$

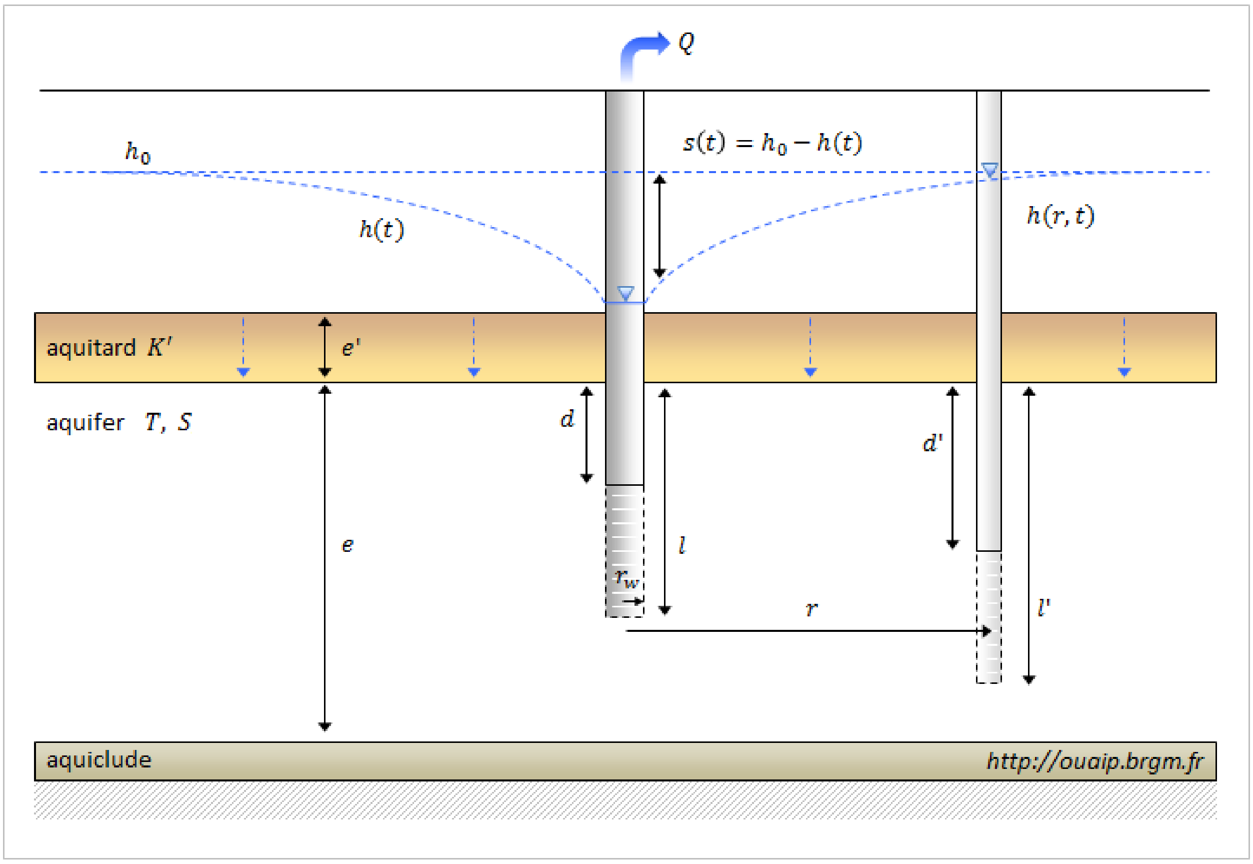


Illustration 16 : Diagram of the Hantush solution configuration

Reference:

- *Hantush, M.S., 1964. Hydraulics of wells, in: Advances in Hydroscience, V.T. Chow (editor), Academic Press, New York, pp. 281-442.Hantush, M.S. and C.E. Jacob, 1955. Non-steady radial flow in an infinite leaky aquifer, Am. Geophys. Union Trans., vol. 36, pp. 95-100.*

2.2.4. Gringarten-Witherspoon solution (1972)

The Gringarten-Witherspoon solution (1972) simulates pumping in a unique vertical fracture intercepting all of a confined aquifer under transient state conditions. The well is situated in the middle of the fracture (Illustration 16). The flow in the fracture is uniform in the proposed solution. This solution can also be used for the case of unconfined water table if the drawdown is low compared to the thickness of the aquifer.

After some pumping time, the flow is pseudo-radial (as with Theis), but the presence of the fracture gives a larger radius of action to the well in the axis of the fracture.

One considers that the fracture does not induce significant wellbore storage effect (however, in any case, such an effect, if observed, can be taken into account (Illustration 13). The fracture has a practically infinite permeability compared to that of the aquifer, and negligible thickness compared to the thickness of the aquifer. Under these conditions during pumping, the level will lower very rapidly in the fracture, inducing flow from the aquifer toward the fracture. Gringarten et al. (1974) proposed a more general solution with a piezometer.

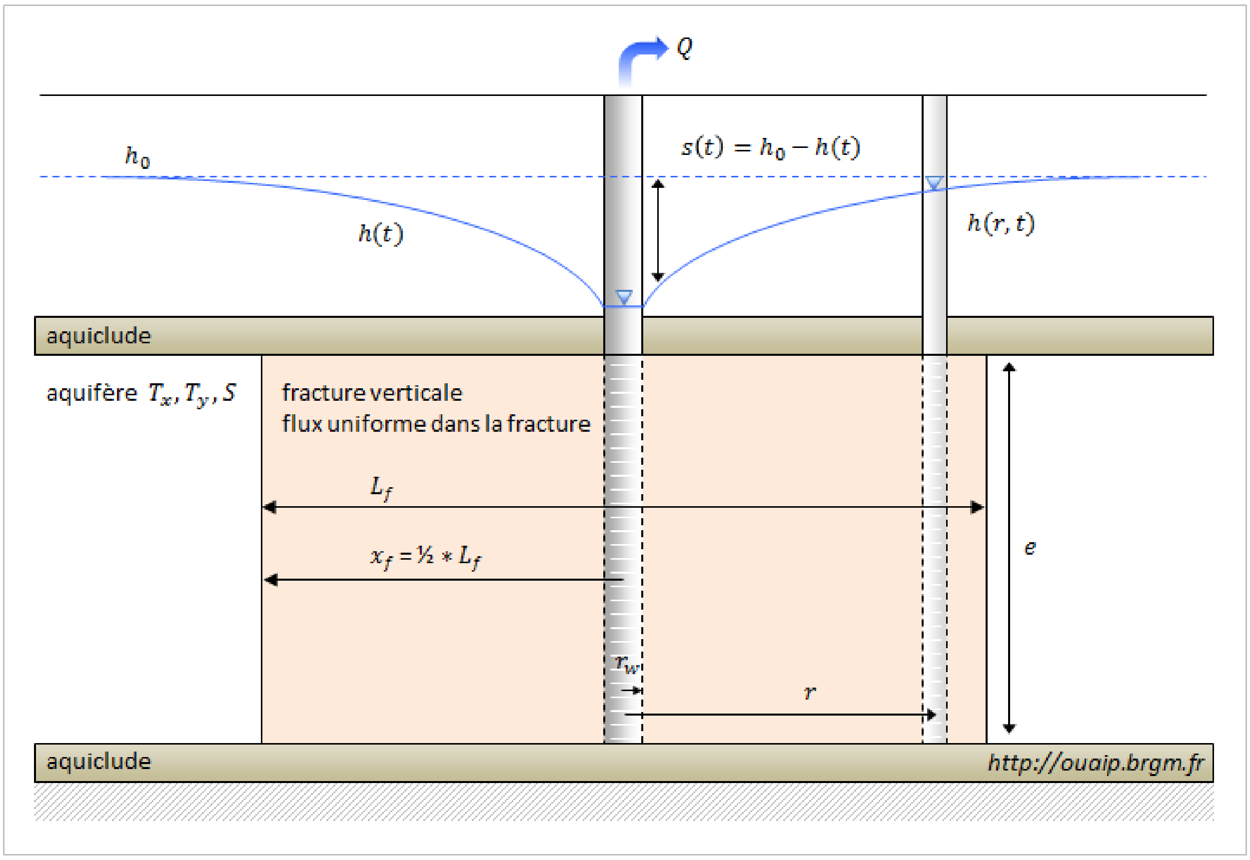


Illustration 17: Diagram of the Gringarten-Witherspoon solution configuration

Formula

In the pumping well, the formula is as follows:

$$s = \frac{Q}{4\pi\sqrt{T_x T_y}}\left(2\sqrt{\pi t_d}\,\mathrm{erf}\left(\frac{1}{2\sqrt{t_d}}\right) + W\left(\frac{1}{4t_d}\right)\right)$$

With:

- $t_d = \frac{T_x t}{x_f^2 S}$

Where:

- T_x: is horizontal transmissivity in the axis of the fracture [L2/T],
- T_y: is horizontal permeability in the axis perpendicular to the fracture [L2/T],
- S: is storage coefficient [-],
- x_f: is the half-length of the fracture [L].

The formula is a bit more complicated at the piezometer. This introduces:

- r: the distance between the piezometer and the pumping well.
- x and y: the position of the piezometer, considering that the pumping well is at the centre of the reference system and the x-axis coincides with the axis of the fracture. One therefore has $x^2 + y^2 = r^2$

$$s = \frac{Q}{2\pi\sqrt{T_x T_y}}\int_0^{t_d} \exp\left(-\frac{y_d^2}{4\tau}\right).\left[\mathrm{erf}\left(\frac{1 - x_d}{2\sqrt{\tau}}\right) - \mathrm{erf}\left(\frac{1 + x_d}{2\sqrt{\tau}}\right)\right].\frac{d\tau}{4\sqrt{\tau/\pi}}$$

Where $x_d = \frac{x}{x_f}$ and $y_d = \frac{y}{x_f}$

Gringarten's solutions consider anisotropy of the aquifer's transmissivity expressed by the ratio $\frac{T_y}{T_x}$. According to the author, the method can analyse a fractured aquifer as an "equivalent porous medium, homogeneous and anisotropic with a single vertical fracture with much greater permeability intersecting the pumping wells." The OUAIP tool introduces equivalent transmissivity $T = (T_x T_y)^{0,5}$ with an anisotrope coefficient $\frac{T_y}{T_x}$

Assumptions

Type of aquifer:

- Confined aquifer;
- Anisotropic aquifer, infinite lateral extension and constant thickness;
- Only one vertical fracture centred on the wells;
- The fracture is limited to the aquifer and passes through it entirely;
- The fracture has infinite permeability, zero storage and zero thickness;

No leakage with this solution.

Type of well:
- Full penetration well: negligible radius and total penetration (relative, because the fracture must cut through the entire aquifer, not necessarily the pumping well).
- Piezometer, defined by x and y ($y \neq 0$).

Application conditions:
- Transient state conditions;
- Horizontal flows;

Available effects: boundary effect, quadratic head losses, skin effect, wellbore storage effect, backflow effect.

Solution parameters in OUAIP:

- T (in m^2/s): aquifer transmissivity;
- S (without units): aquifer storage coefficient;
- T_y/T_x (without units): anisotropic coefficient of transmissivity, T_y being horizontal transmissivity perpendicular to the fracture and T_x the horizontal transmissivity in the axis of the fracture;
- x_f (in m): half-length of the fracture (or L_f the length of the fracture: $x_f = L_f / 2$) ;
- One need not define the radius of the well to use this solution. At the well, the equation does not depend on this parameter. The fracture has very high permeability, considered to be infinite, compared to that of the aquifer. The drawdown within it is nearly the same. The proposed solution is also the best approximation for a fracture with infinite permeability.

At the piezometer:

- x_{piezo} (in m): projection of the piezometer on the axis of the fracture;
- y_{piezo} (in m): projection of the piezometer perpendicular to the axis of the fracture.
- NB: by default, for all solutions, the pumping well is centred at x=0 (m), y=0 (m).

Reference:

- *Gringarten, A.C. and P.A. Witherspoon, 1972. A method of analysing pump test data from fractured aquifers, Int. Soc. Rock Mechanics and Int. Assoc. Eng. Geol., Proc. Symp. Rock Mechanics, Stuttgart, vol. 3-B, pp. 1-9.*
- *Gringarten, A.C., Ramey, H.J., Jr. and R. Raghavan, 1974. Unsteady-state pressure distributions created by a well with single infinite-conductivity vertical fracture, SPE Journal (August 1974), pp. 347-360.*

2.3. DESCRIPTION OF ADDITIONAL EFFECTS

In a general manner, in order to calculate theoretical drawdown at the well or at a piezometer, whatever the mathematical solution used, OUAIP makes it possible to take into account various disruptive effects presented below in Illustration 18:

Effet	Well	Piezometer
Wellbore storage effect	✓	
Backflow effect	✓	
Skin effect	✓	
Quadratic head losses	✓	
Boundary conditions (constant head, no flow)	✓	✓

Illustration 18 : Taking effects into account

2.3.1. Wellbore storage effect

A wellbore storage effect is found if the pumping well contains a non-negligible volume of water. Under these conditions, in effect, a part of the pumped water comes from removing the stored water from storage in the well without transiting through the aquifer. At first, the drawdown measured is found to be reduced as compared to that which would be observed without the wellbore storage effect. After pumping stops, the inverse phenomenon produces and the recovery is slowed by the filling of the well.

This effect is specific to pumping wells. It is more marked if the diameter of the well is large, the drawdown significant and the aquifer not very transmissive. For rigour, the diameters of the technical design of the borehole are needed to calculate the wellbore storage effect (especially the diameters of the casing or the drilling (if the casings are screened or not cemented) related to the groundwater drawdown. OUAIP introduces one variable called “radius of the wellbore storage effect”.

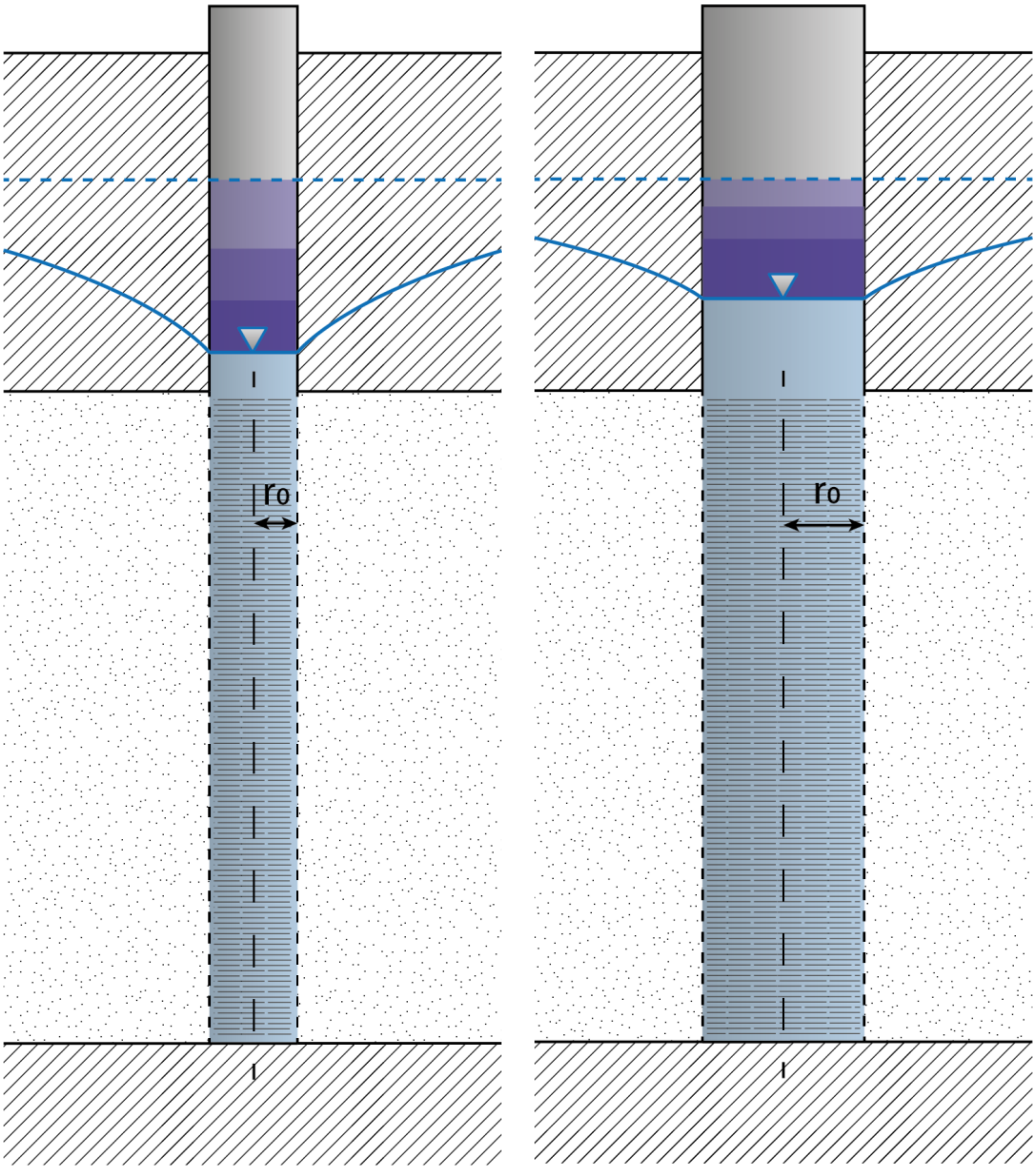


Illustration 19: Diagram of the wellbore storage effect incidence in a pumping well

OUAIP can perform a calculation of the wellbore storage effect on the column if its radius is given (Illustration 20). Blasingame's approximation is used:

$$s_{Dw} = s_D\left(1 - Exp\left(-\frac{t_D}{s_D C_D}\right)\right) \quad \text{and} \quad C_D = \frac{r_c^{\,2}}{2Sr^2}$$

Where:

- s_{Dw}: draw-down of an analytical solution with the wellbore storage effect,
- s_D: draw-down of an analytical solution (without dimension),
- t_D: time (without dimension),
- C_D: wellbore storage effect (without dimension),
- r_c: radius of the wellbore storage effect (m),
- S: storage coefficient (without dimension),
- r: radius of the well (m).

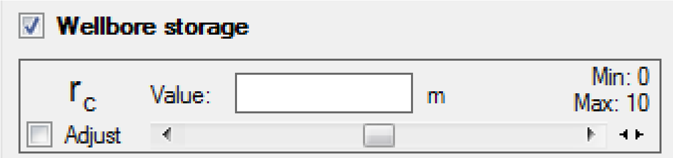


Illustration 20 : rc parameter of the wellbore storage effect

2.3.2. Backflow effect

This effect results from the absence or malfunction of the check valve at the bottom of the rising main of a pump. In this context, in effect, the rising main backflows into the well as soon as the pump stops, which is equivalent to reinjection of a parasitic flow rate Q_{cor}.

In order to simulate the backflow effect, one must provide the rising main diameter to OUAIP (d_v, in m), the height of the rising main (h_v, in m), as well as a “Backflow coefficient” (K_v in m²/s). The latter represents a degree of opening in the rising main. It is difficult to evaluate and varies between 0 (sealed valve) and infinite (no valve, maximum opening). A fourth, optional parameter is the backflow time (t_v in s), which corresponds to the duration of water's free fall at height h_v. If this is not specified, then $t_v = \frac{\pi r^2}{Kv}$. See § 4.4.6 for the calculation's precision.

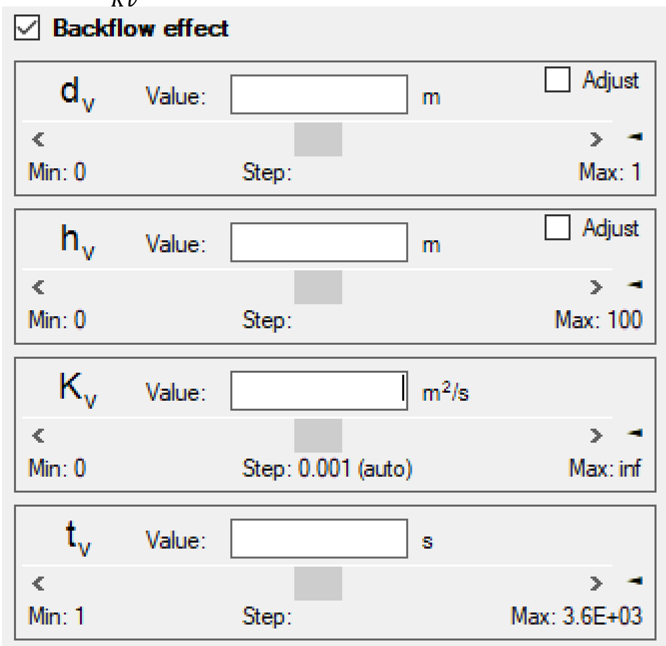


Illustration 21: Backflow effect parameters

2.3.3. Skin effect

The skin effect (W_{skin}, without units, Illustration 23) corresponds to singular head losses (linear) through the walls of a well- in case of clogging by the residual “cake” (Illustration 22) left by the drilling mud or, on the other hand, increased permeability induced by fissures in the medium - natural or resulting from decompression of the soil by the borehole.

The range of values [-2 ; +40] offered by the skin coefficient can translate significant skin effects for the most common ratios (permeability of the aquifer formation (K_f) / zone permeability to the skin effect (K_s)):

- Skin is positive if K_f / K_s > 1 (from 10 to 100 for a clogged well);
- Skin is negative if K_f / K_s < 1 (from 10^{-2} to 10^{-5} if there is a peripheral fissure zone);

The skin effect is an additional drawdown which is calculated as follows:

$$s = skin * \left(\frac{Q}{2\pi T}\right) \qquad avec \qquad skin = \left(\frac{K}{K_s - 1}\right) \ln\left[\frac{(r_0 + es)}{r_0}\right]$$

Where:

- Q: pumping flow rate (m^3/s),
- skin: skin effect parameter (without units),
- K: permeability of the aquifer formation (m/s),
- K_s: permeability of the skin effect zone (m/s),
- r_0: well radius (m),
- es: thickness of the skin effect zone (m),
- s: additional drawdown (or not) due to the skin effect (m).

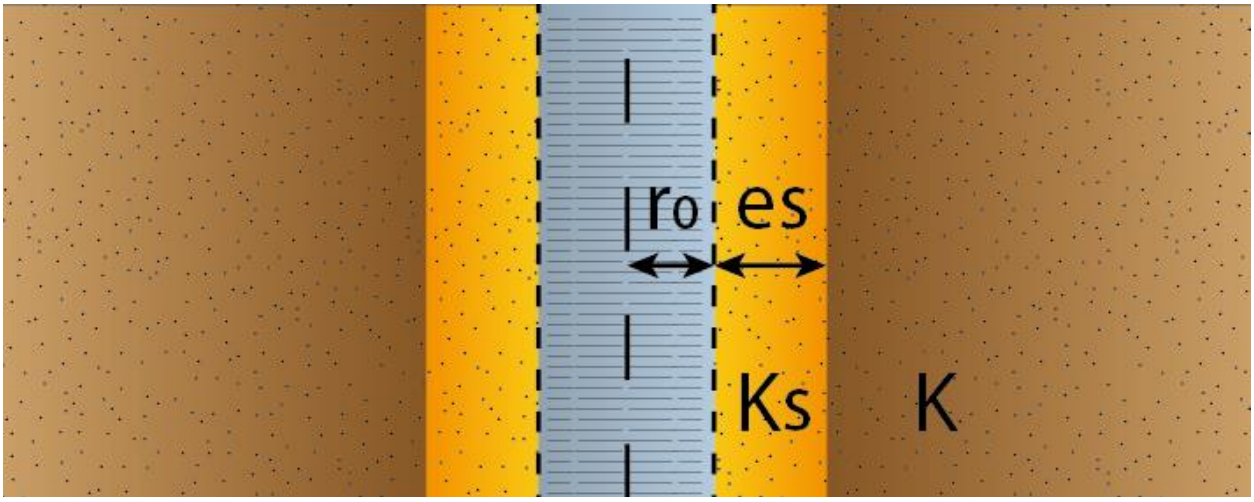


Illustration 22: Skin effect diagram

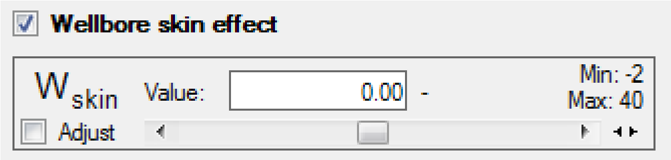


Illustration 23: Skin effect

2.3.4. Quadratic head losses

Quadratic head losses are only found in pumping wells. These are generated by the well equipment, more specifically by the turbulence effects near the well, screens and casings.

Quadratic head losses have two origins:

- The passage of water into the gravel pack and through the slots of the screens (singular losses),
- Turbulent flow in the tubing, from the well screens to the pump screens.

As indicated by their name, quadratic head losses are proportional to the square of flow rate, or $s = C.Q^2$, where:

- s: additional drawdown due to quadratic head losses [L];
- Q: flow rate pumped in the well [L^3/T];
- C: quadratic head loss coefficient [T^2/L^5];

This term is added to the calculated drawdown.

One must undertake a specific pumping test called a step-drawdown test to evaluate quadratic head losses in a pumping well. This type of test consists of performing intermittent pumping at several flow rate, usually between 3 and 5 steps, (separated by a recovery step). As a general rule, it is desirable that all test phases, pumping and recovery, last the same amount of time.

OUAIP can take into account quadratic head losses in either directly entering the C coefficient (Illustration 24) or in expressing the value of the observed head loss for a given flow rate (Illustration 25, an automatic calculation of the quadratic head loss coefficient).

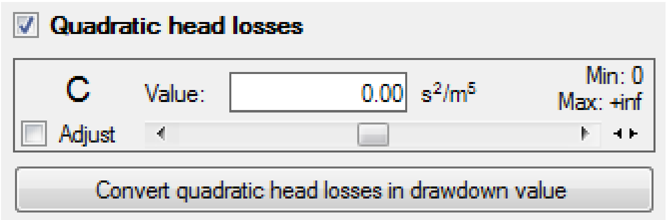


Illustration 24 : Quadratic head loss parameter

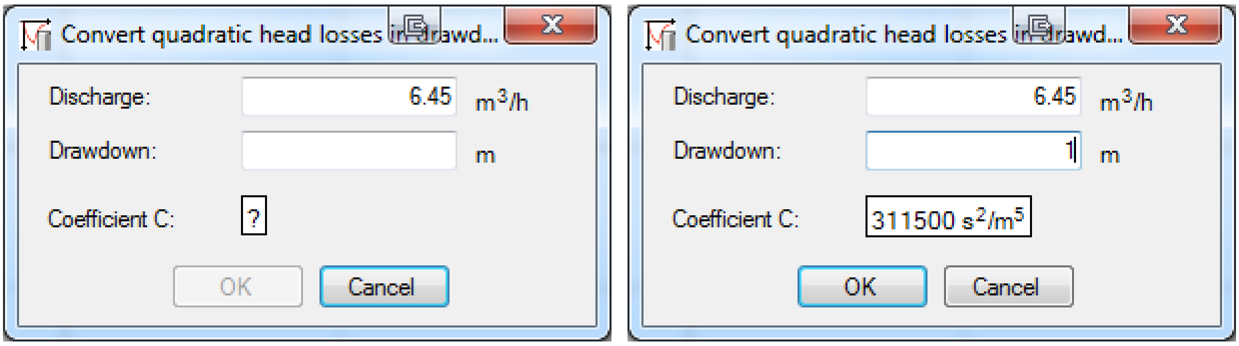


Illustration 25: Calculation of quadratic head losses through the head loss (drawdown in m) for a given flow rate

2.3.5. Boundary effects (recharge, impermeable barrier)

OUAIP can simulate two types of rectilinear boundaries (Illustration 26):
- Recharge boundary (line source at constant head);
- The impermeable barrier boundary (no flow).

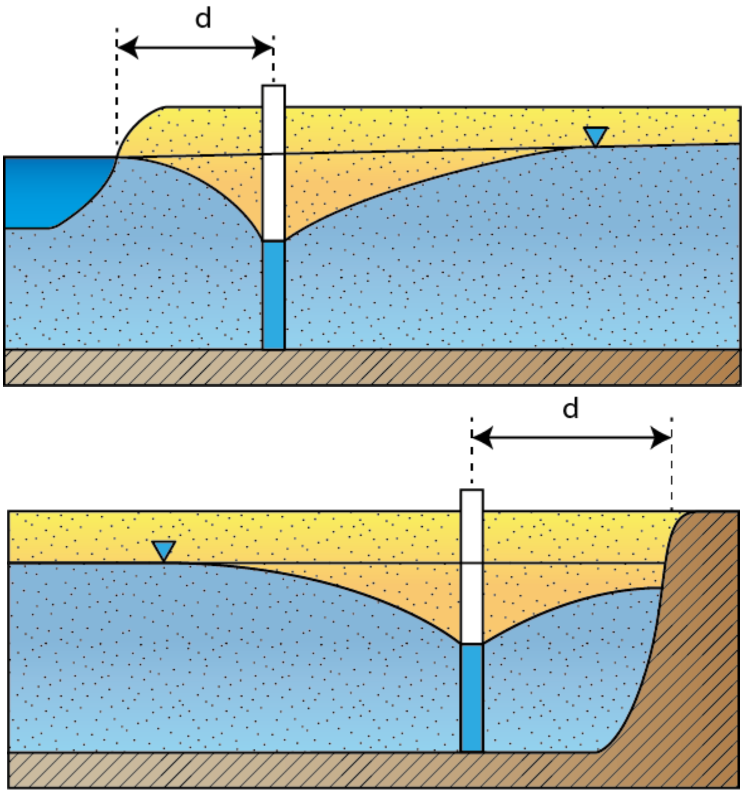


Illustration 26: Diagram of the effect of a constant head boundary (on top) and a no flow boundary (on the bottom) on the draw-down cone

The boundaries are defined in an orthonormal frame (Illustration 27) where:

- The pumping well is centred at X = 0 m and Y = 0 m;
- The piezometer has X and Y coordinates so that $X^2 + Y^2 = R_{obs}^2$. By default, the piezometer is on the X axis, or the alpha angle to the Y axis = 90°. If alpha = 0°, the piezometer is aligned with the Y axis Y (Illustration 28 and Illustration 29).
- The boundaries are parallel to the axis of the abscissa:
    - L1, the first boundary, has a positive ordinate Y > 0;
    - L2, the second boundary, has a negative ordinate Y < 0;

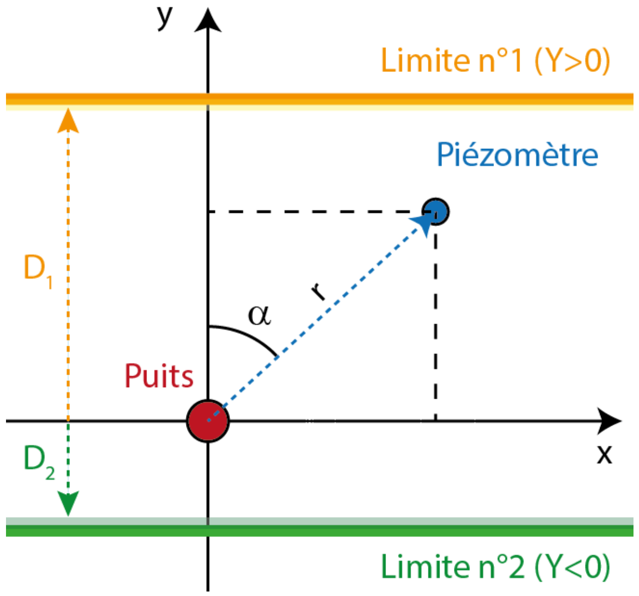


Illustration 27: Diagram of the definition of boundaries in an orthonormal marker

Each boundary is either tight (impermeable barrier), or recharged, or absent (that is without a specific role: aquifer with an infinite extension).

OUAIP takes the boundaries into account in simulating the presence of an image at a distance 2d of the pumping well (where d is the distance from the well to the boundary). The drawdowns which can be imputed to real wells and image wells are added; this is the superposition principle.

The boundaries are located in indicating (Illustration 28 and Illustration 29):

- Either the distance d separating the pumping well from the boundary;
- Or the influence time t at the pumping well: t is the moment when the drawdown s induced by the image well situated at a distance of 2d from the pumping well begins to reach it.

t and d can be evaluated in applying the Jacob approximation:

- $s = \frac{Q}{4\,\pi\,T} \log\left(\frac{2.25\,T\,t}{4\,d^2 S}\right)$
- Posing: $\frac{2.25\,T\,t}{4\,d^2\,S} = 1$
- it comes: $t = \frac{4\,d^2\,S}{2.25\,T}$
- That is: $d^2 = \frac{2.25\,T\,t}{4\,S}$

In OUAIP, in order to calculate the time from which the drawdown reaches the boundary using the Theis solution, one obtains (Bourdarot, 1996):

- $d = 2\sqrt{\frac{T\,t}{S}}$
- $t = \frac{d^2 S}{4\,T}$

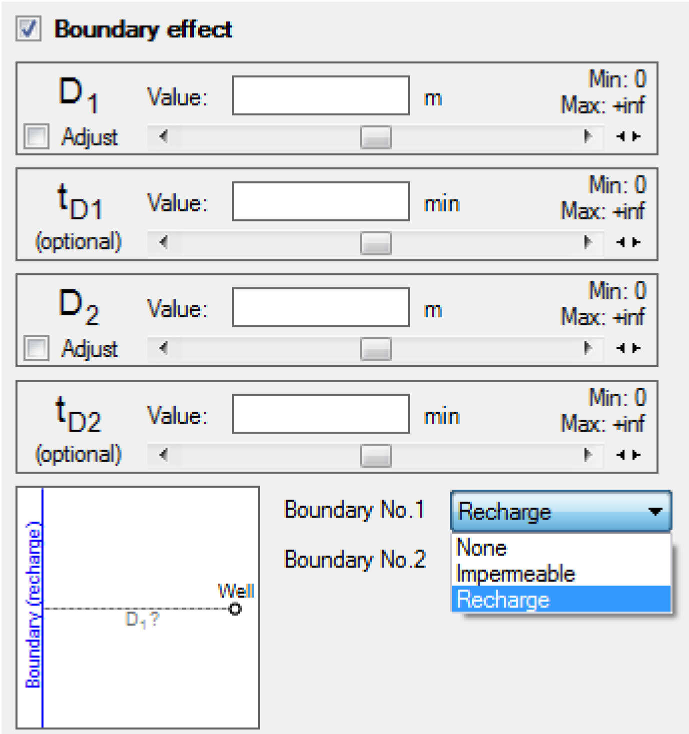


Illustration 28 : Parameters of the well boundary effect (click on the diagram to enlarge it)

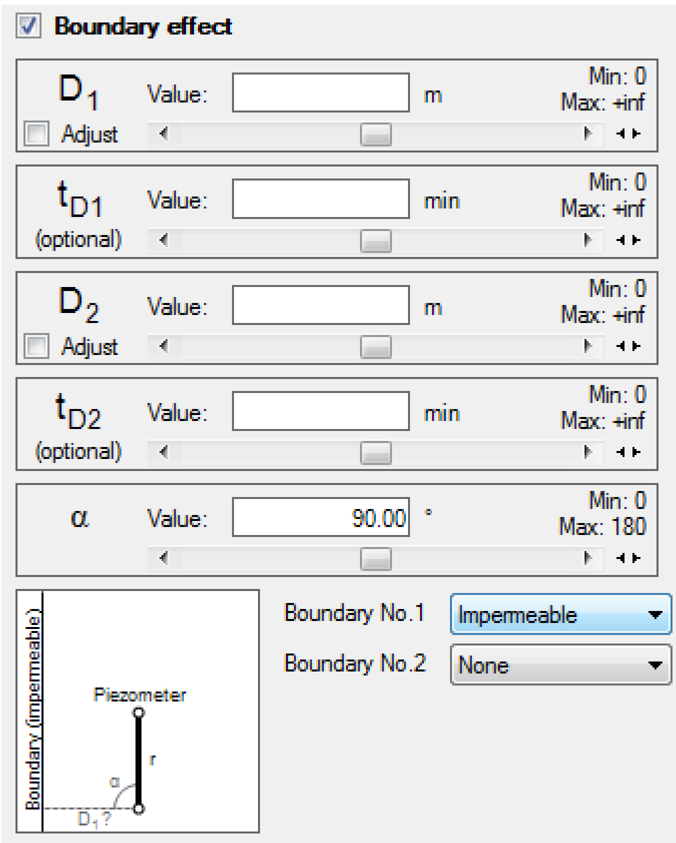


Illustration 29 : Parameters of the boundary effects at the piezometer (clickable diagram)

3. First quick use of OUAIP

This very short chapter aims to show examples of using OUAIP in only a few minutes using projects already done, in modifying the parameters as needed. This is primarily to familiarise yourself with the OUAIP interface. The chapter “5 Use example“ presents details of how to create a project, to import or enter your data, to interpret a test or simulate pumping and to write a report. Project examples can be found in the OUAIP file tree.

Below, folders are splitted between “Step-drawdown test”, “Aquifer Test” and “Simulation”.

OUAIP-2.3\Tutorials

Tutorial No. 1 - Step-drawdown test
Tutorial No. 2 - Step-drawdown test
Tutorial No. 3 - Step-drawdown test
Tutorial No. 4 - Step-drawdown test
Tutorial No. 5 - Aquifer test - Theis
Tutorial No. 6 - Aquifer test - Papadopulos-Cooper
Tutorial No. 7 - Aquifer test - Hantush-Jacob
Tutorial No. 8 - Aquifer test - Gringarten
Tutorial No. 9 - Simulation
Tutorial No. 10 - Simulation and optimisation

3.1. INTERPRET A STEP-DRAWDOWN TEST

You can test and open the following *.**ouaipp** project files:

Tutorial No. 1 - Step-drawdown test\Step-drawdown test - Tutorial No. 1 Solution.ouaipp

Tutorial No. 2 - Step-drawdown test\Step-drawdown test - Tutorial No. 2 Solution.ouaipp

Tutorial No. 3 - Step-drawdown test\Solution\1. TF1 - 2010 - Solution (and 7 other *.ouaipp files)

Tutorial No. 4 - Step-drawdown test\Step-drawdown test - Tutorial No. 4 Exercise.ouaipp

3.2. INTERPRET AN AQUIFER TEST

You can test and open the following *.**ouaipi** project files:

Tutorial No. 5 - Aquifer test - Theis\Aquifer test - Tutorial solution No. 5.ouaipi

Tutorial No. 6 - Aquifer test - Papadopulos-Cooper\ Aquifer test - Tutorial solution No. 6.ouaipi

Tutorial No. 7 - Aquifer test - Hantush-Jacob\ Aquifer test - Tutorial solution No. 7.ouaipi

Tutorial No. 8 - Aquifer test - Gringarten\ Aquifer test - Tutorial solution No. 8.ouaipi

3.3. SIMULATE A PUMPING TEST

You can test and open the following *.**ouaips** project file:

Tutorial No. 9 – Simulation\Pumping simulation - Tutorial No. 7 Solution.ouaips

Tutorial No. 10 – Simulation\Pumping simulation - Tutorial No. 10 Solution.ouaips

4. OUAIP graphic interface

4.1. INPUT INTERFACE: TABS

OUAIP is organised in the form of tabs (there are no scrolling menus) which one logically uses from left to right. They can enter data. The graphs then instantly translate the result of the data entered. There are 3 or 4 tabs depending upon the OUAIP mode:

- In the Step-Drawdown Test (SDT) interpretation mode (Illustration 30), the “formula” tab is absent because only one method is used to interpret a SDT by steps of discharge which are not continuous (Jacob method, 1947).

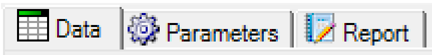


Illustration 30: Tabs for the interpretation mode for a well test

- In the interpretation mode for an Aquifer Test (long duration test) or simulation of pumping test (Illustration 31), the tab “formula” appears in these two modules, allowing the user to choose between the available analytical solutions.

Illustration 31: Interpretation mode tabs for an aquifer test or to simulate pumping tests

4.1.1. Data tab

For the interpretation mode for a well test

The data tab is presented below (Illustration 32). It is recommended to identify the well by its name to start your project (its identification number, for example), the name of the well will then be used in the interpretation report.

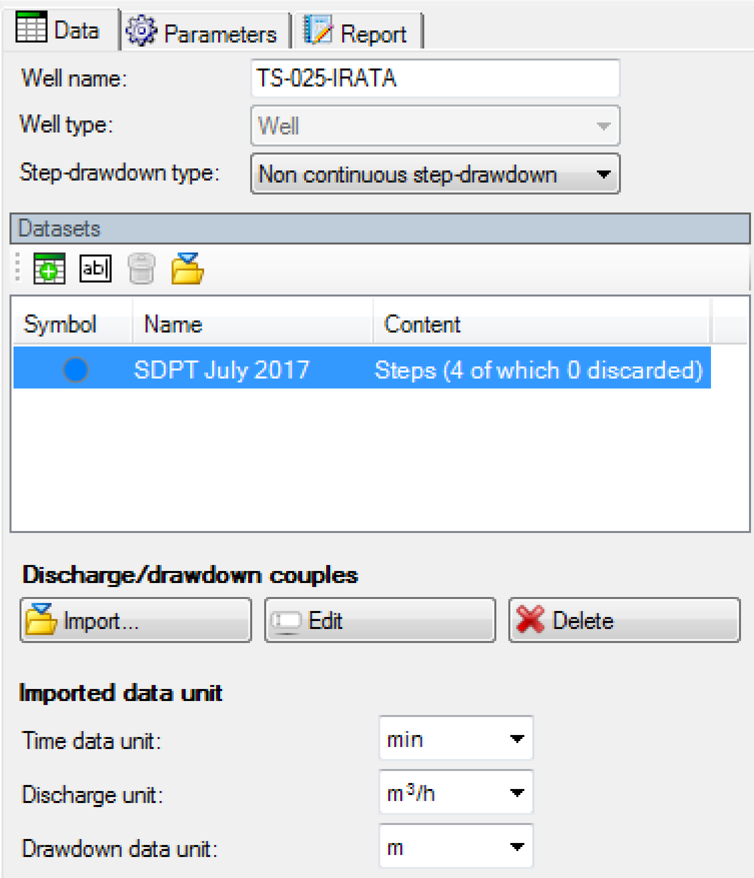


Illustration 32: Data tab in the interpretation mode for a well test

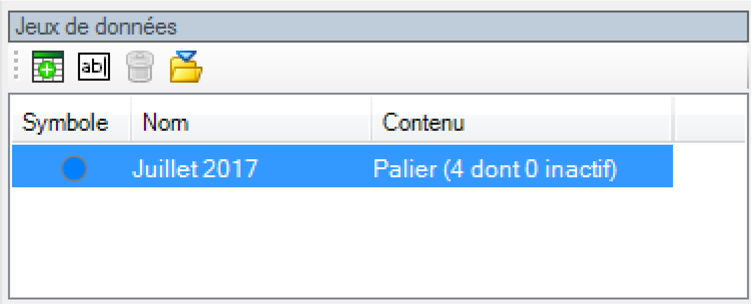
The **type of well** does not vary because a well test is by definition performed on a pumping well (in opposition to a piezometer).

The **type of pumping**, for information only (the information will be written in the pumping report) gives information on how the SDT was performed:

- Indeterminate (if the source data are not accessible or are unknown);
- "Continuous step-drawdown," in this case, one must use the Bierschenk (1963) method to get the corrected drawdown before interpreting the test;
- "Non continuous step-drawdown," OUAIP implements an ad-hoc method (called the Jacob method) to interpret this type of well testing.

Refer to the BRGM/RP-65683 report (Gutierrez, 2016) for more information on step-drawdown tests, on line at: http://infoterre.brgm.fr/rapports//RP-65683-FR.pdf

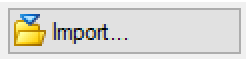
In the "datasets" box, one can enter one or more SDTs if one would like to compare SDTs performed over time, for example. Each dataset can be associated with one or more interpretations. On the other hand, one interpretation is only connected to one dataset.



The dataset box icons can:

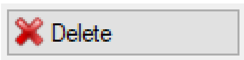
-  Add a dataset (discharge rate and draw-down connected);
-  Rename a dataset;
-  Erase a dataset;
-  Import a *.ouaipp file to add a new, pre-existing dataset.

Two methods can be used to integrate your corresponding pumping rate and drawdown data:

- 

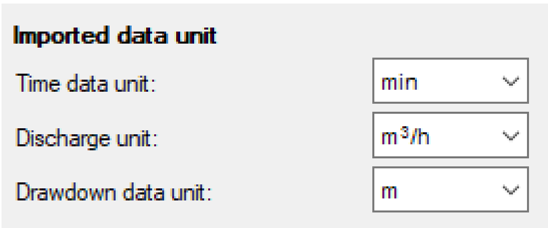
Import a file containing the pairs of pumping rates and drawdowns for an identical pumping period of time. The type of files read are CSV, TXT, XLS or XLSX. The data must be organised in a table and the headers should contain the name of the column and its units. Examples of CSV files are shown in the OUAIP directory: \Données
- 

"Enter/edit" copy/paste your data from a spreadsheet or enter the data manually. Use the Ctrl+V shortcut in the OUAIP spreadsheet to paste the copied data. One can also modify the data units for pumping rate and drawdown.



"Erase" erases the dataset in OUAIP.

The "imported data units" box can monitor and modify the units of imported data.



For the aquifer test interpretation mode

The data tab is presented below (Illustration 33). It is recommended to identify the well by its name to start your project or its identification number, the name of the well will then be used in the interpretation report.

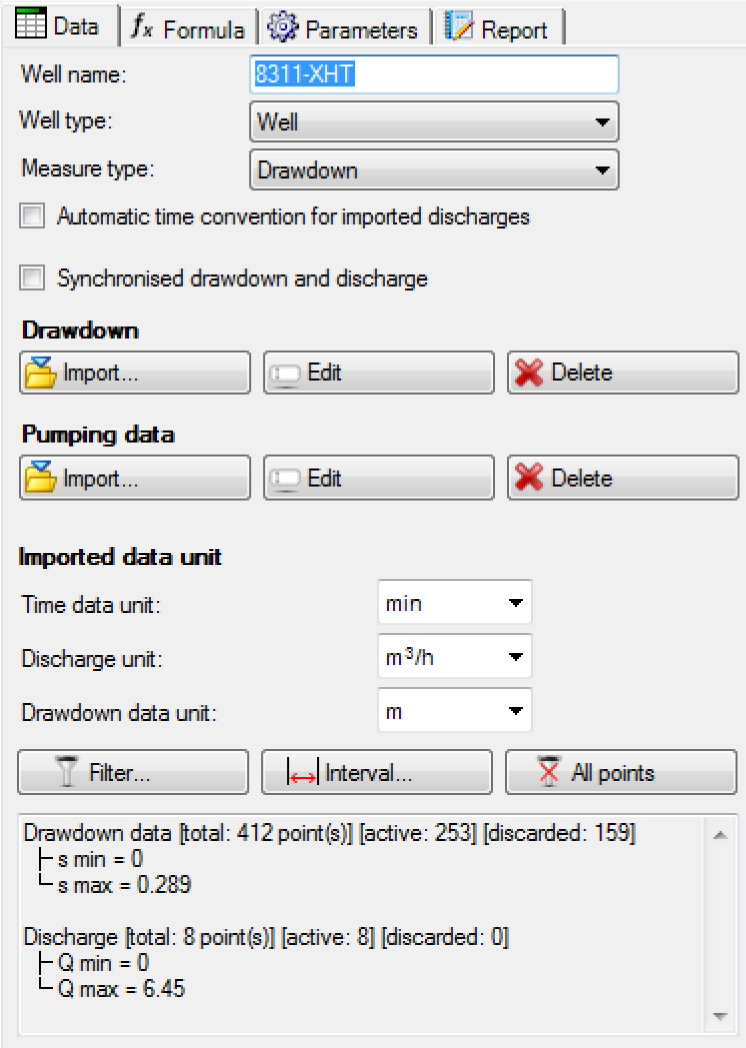


Illustration 33: Data tab (in the interpretation mode for an aquifer test)

The type of well corresponds to the well in which the drawdown or the water level depth measurements were computed/made:

- If the measurement was done in the pumping well, choose: **Well**
- If the measurement was done in the monitoring well, choose: **Piezometer**

NB: The analytical solutions available for choice depend on the type of well.

Types of measurements corresponds to the type of measures done/imported:

- If this is a water depth measured comparatively with measurement reference point, choose: **Depth.** If this option is chosen, the "**Depth of the initial static level: (m/reference)**" appears. Once this parameter is entered, OUAIP automatically calculates the resulting drawdown. Note that the depth of the static or dynamic level is counted positively downwards. So, if the depth of the water level is 5 m/reference (i.e. below the reading benchmark), write 5.
- If this is directly a calculated drawdown (dynamic level less the static level before the start of the test), choose: **Drawdown** This choice is presented by default. The user must calculate the drawdown beforehand.

NB: OUAIP always displays drawdown.

If a dynamic level measurement is performed, there is no ambiguity. The measurement corresponds to the date on which it was done.

On the other hand, to express pumping rate, there can be ambiguity:

- Either the measurement refers to the start of a pumping step (the pumping rate is Y from X minutes)
- Or the measurement refers to the end of the pumping step (flow rate Y up to X minutes)

If this is imported, OUAIP can pose the question to remove ambiguity (Illustration 34).

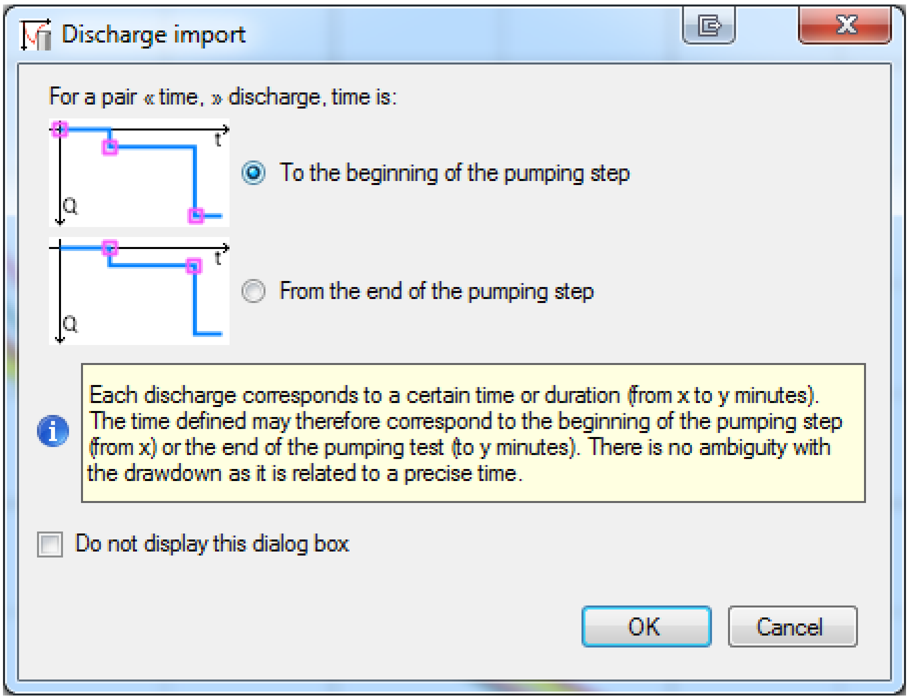
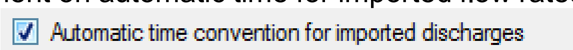
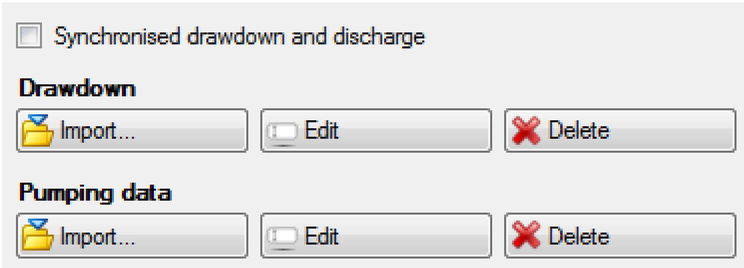


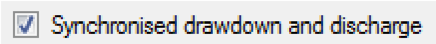
Illustration 34: Time agreement for variable flow rates

If the “agreement on automatic time for imported flow rates” box is checked, OUAIP does not ask this question 

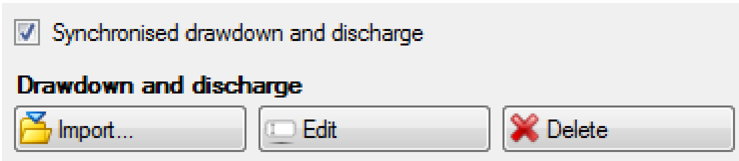
In all cases, one should increase the frequency of measurements if the flow rate varies. Take care to keep the values framing these variations when creating a data file. For example, at the end of pumping, the last measure is done just before switching off the pump, and the first immediately after.

OUAIP makes it possible to enter or import flow rates and drawdowns in a simultaneous fashion (time, drawdown, flow rate) or separately (time, flow rate) and (time, drawdown). By default, it is assumed that the drawdown data and the flow rates were done at different times (non-synchronised data): following this, one can enter/import/copy-paste the drawdown and flow rate data from a spreadsheet in an independent manner.



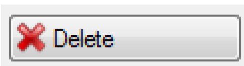
If, on the other hand, the drawdown and flow rate data have been systematically measured at the same time, check the box: 

In this case, the drawdown, flow rate and time are imported or entered for the times in common:



In all cases, two methods can integrate your data into OUAIP:

- **"Import" *via* a file**: importing data (time and drawdown, time and pumping rate or time for drawdown and pumping rate) can be done using the "import" button. The type of files read are CSV, TXT, XLS or XLSX. The data must be organised in a table and the headers should contain the name of the column and its units. Examples of CSV files are shown in the OUAIP directory: \Données
- **"Enter/edit" using copy-paste** from a spreadsheet (Illustration 35): click on "enter/edit." Use the Ctrl+V shortcut in the window to paste the data into the OUAIP spreadsheet. One can also modify data units at this time.



"Erase" erases the data in OUAIP.

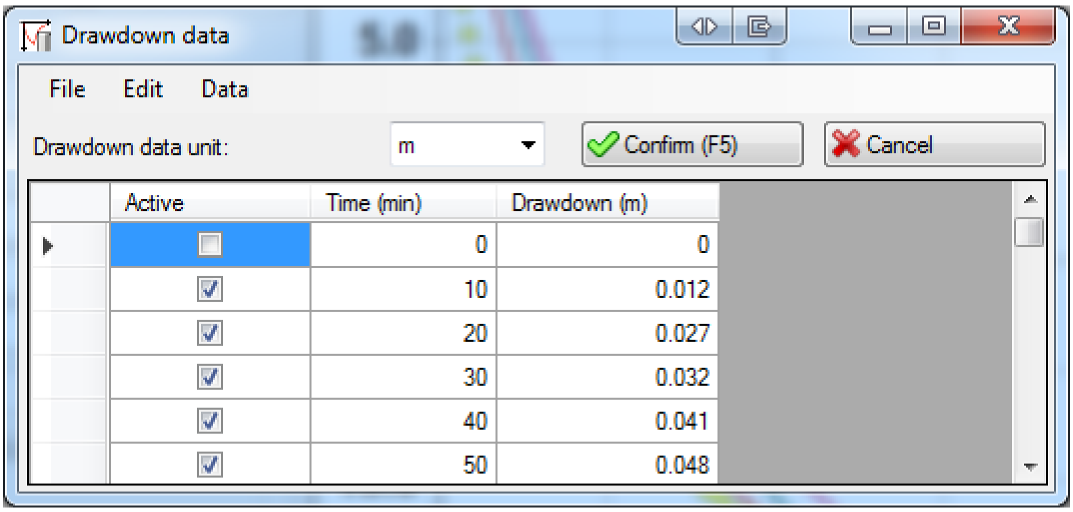


Illustration 35: Window to enter and edit data

One can define or modify the “imported data units” (time, drawdown, pumping rate) in a box provided for this (Illustration 36):

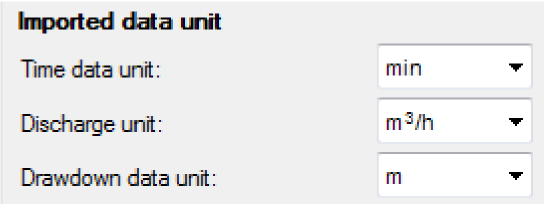
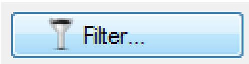


Illustration 36: Data units imported into OUAIP

NB: In the case that, despite the extent of the proposed units, you cannot find the unit you need (especially for English flow rate units), we have provided the user the ability to add new units for time, drawdown and pumping rates. This point is described in the “4.5.4 Unites.ini” section.

The following buttons can:



Filter (Illustration 37) the data (in order to lighten the graph or to create efficient optimisation) as a function of time, draw-down, discharge or depending upon all these parameters (choose “all conditions required must be met for the same point”). One can check “hide the filtered points” to make the graph lighter.

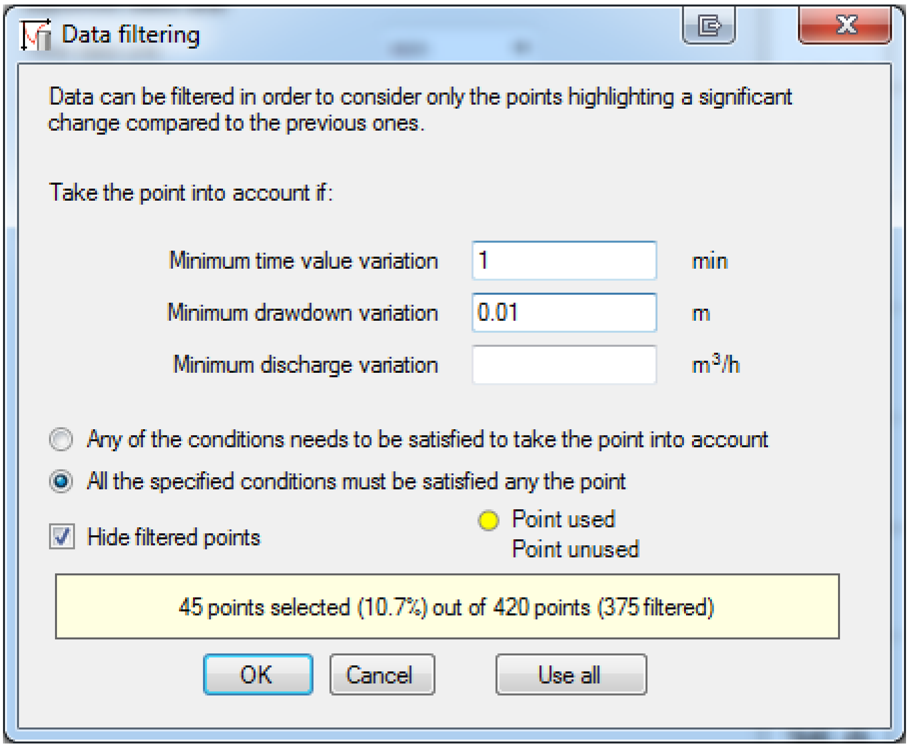
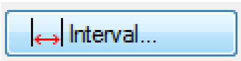


Illustration 37: Filtering time, draw-down and pumping rate data

NB: If the data come from an automatic acquisition device with a high and regular frequency, it is advised to filter the file before importing it into OUAIP. One file with thousands of points becomes very hard to manage and slows down calculations.

In fact, OUAIP filtering does not erase the filtered data. Filtering in OUAIP does not significantly accelerate calculations.

One can use OUAIP's intelligent filter to create a data file on which one can work. One must use the table on a bar graph for this (see 4.3.4) to export the filtered experimental data, then import this new file.



Select a time interval (Illustration 38) in which the data are to be considered, the data outside the interval are hidden. During optimisation process, fitting will be done using the displayed data only (called "active" in the enter/edit box).

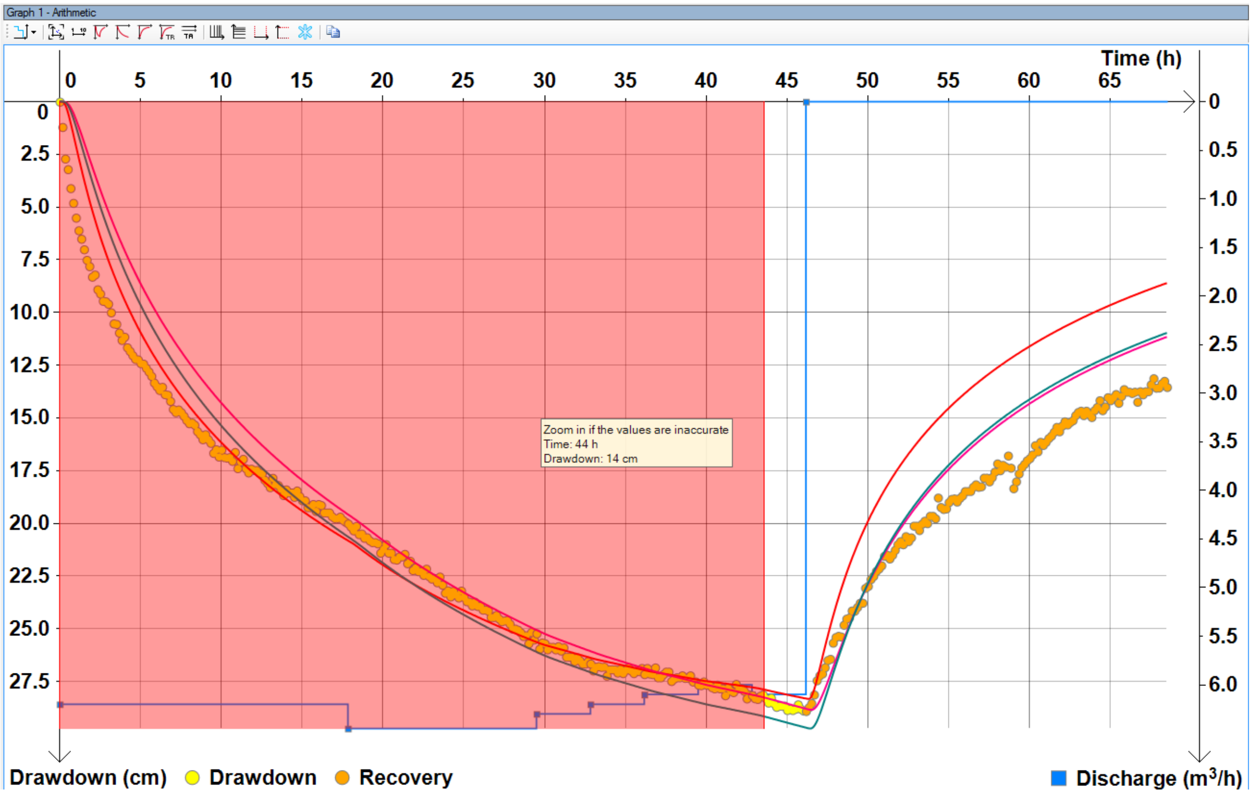
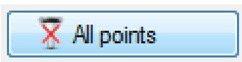


Illustration 38: Select a draw-down interval (in red)



Cancel filter, make all data visible (active).

Finally, the box in the lower part of the tab (Illustration 39) shows the number of imported data, active and inactive (by filtering or selection by interval) as well as the minimum and maximum value.

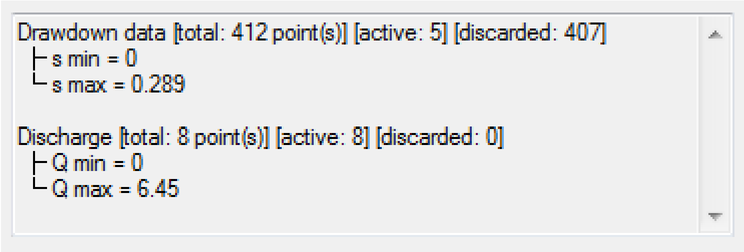


Illustration 39: Summary information on the imported data

Pumping test simulation mode

The only difference between the simulation mode and the mode for interpretation of an aquifer test is the fact that the simulation mode, by definition, does not have measured data (drawdown). Only pumping rates are defined by the user in order to then make the “formula” tab active (Illustration 40).

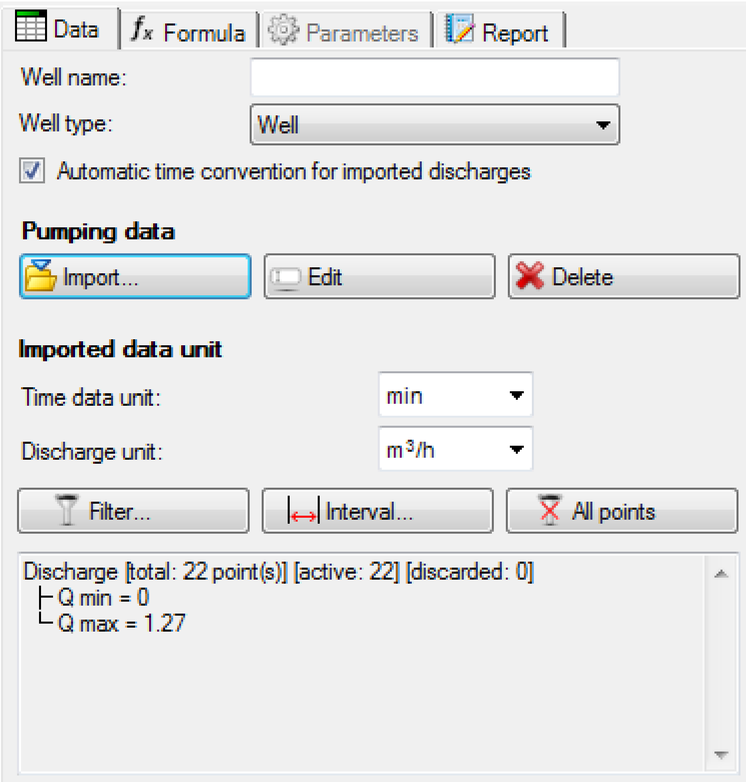


Illustration 40: Data tab (in pumping test simulation mode)

4.1.2. Formula tab

Step-drawdown test mode

There is no “formula” tab (Illustration 30) in this mode, given that the only solution used to interpret a well test by flow sections of unconnected flow rates is the so-called Jacob method (1947), or its derivative version (Rorabaugh, 1953).

Aquifer test mode

The “formula” tab can select an analytical solution to interpret the aquifer test (Illustration 41).

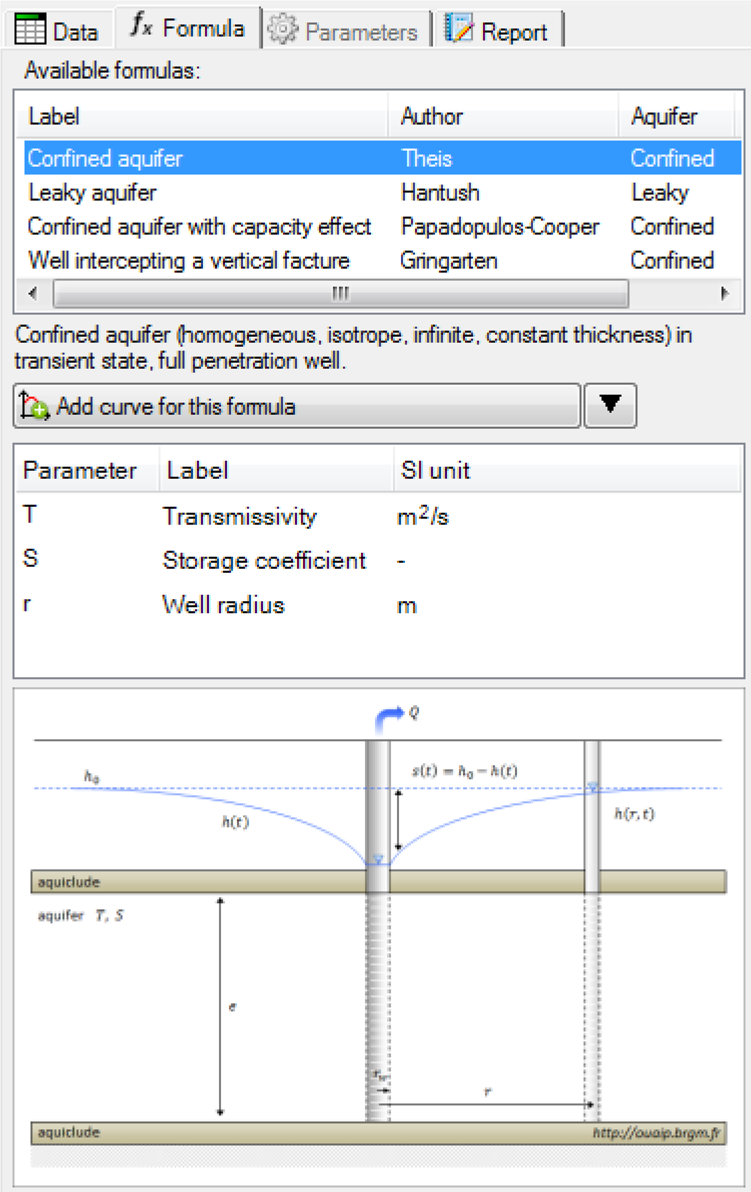
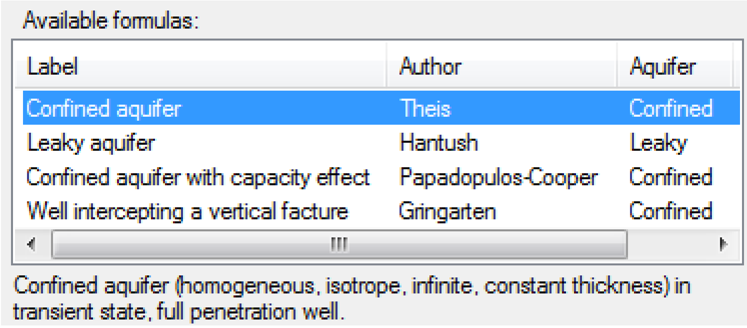
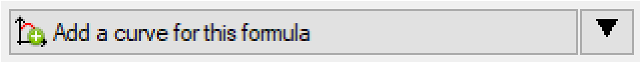


Illustration 41: Formula tab

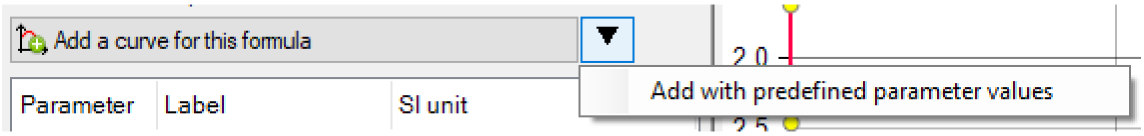
Each proposed solution includes different conceptual assumptions about the medium (porous medium, fractured medium), the configuration of the well (full penetration well, incomplete well) as well as the different disruptive effects which could be present. These assumptions are shown in Chapter “2 Principles“.



The button “add a curve with this formula” leads the user to input and adjust parameters in the following tab (“parameters” tab becomes active once the curve has been added) allowing the drawing of a new theoretical curve.



It is also possible to add a curve with parameters by default by clicking on the bottom arrow:



If a solution is selected, the hydrodynamic parameters needed for its adjustment, its units and symbols are synthesised (Illustration 42). A conceptual diagram of the system is also presented.

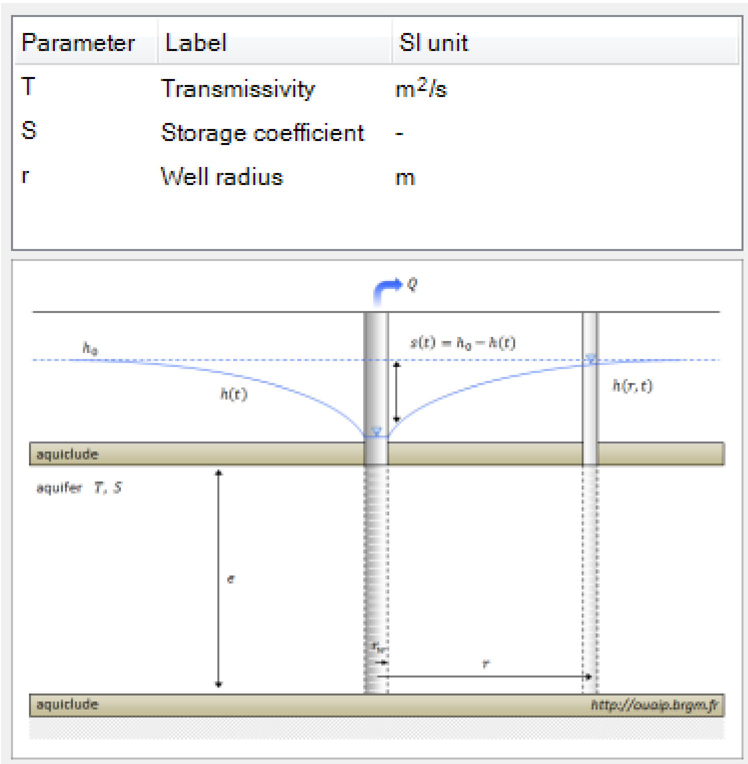


Illustration 42: Description of the analytical solution parameters and the associated conceptual diagram.

Once the solution parameters are entered, the theoretical curve is designed in the graphics area. The “list of graphs” box, situated at the bottom right underneath the graphs area, can add other graphs in order to compare other sets of parameters or other analytical solutions. The tool bar for the list of graphs is presented in Chapter “4.3.4 Curve tool bar“.

Pumping test simulation mode

The “formula” tab is identical at all points to the interpretation mode for an aquifer test.

4.1.3. Parameters tab

The “parameters” tab only becomes active under certain conditions:

- in the ‘interpretation of a well test’ mode, the data in the test must have been entered;
- in the ‘interpretation of an aquifer test’ mode, one analytical solution must have been chosen and added;
- in the ‘simulation of a pumping test’ mode, one analytical solution must have been chosen and added;

Step-Drawdown Test mode

The “parameters” tab (Illustration 44) enters and adjusts the coefficients for linear (B) and quadratic (C) head losses as well as the exponent “n”, by default defined as 2. Above these parameters, a graph shows the significance of the characteristic graph. One can expand the graph by clicking on it.

Options to modify parameters, units, terminals and adjustments are similar whatever the OUAIP mode. In order to avoid any repetition, these are described completely in the following section “in the interpretation mode for an aquifer test.”

The box “resolution of critical discharge” calculates, if this method is justified, the equality point between linear and quadratic head losses (following the French AFNOR NF-X-10-999 standard) or to manually define a critical discharge and to calculate the corresponding or inverse quadratic drawdown. It is also possible not to add anything if determining the critical discharge is impossible.

Depending upon the case, critical discharge and associated drawdown are displayed on the characteristic graph curve (Illustration 43).

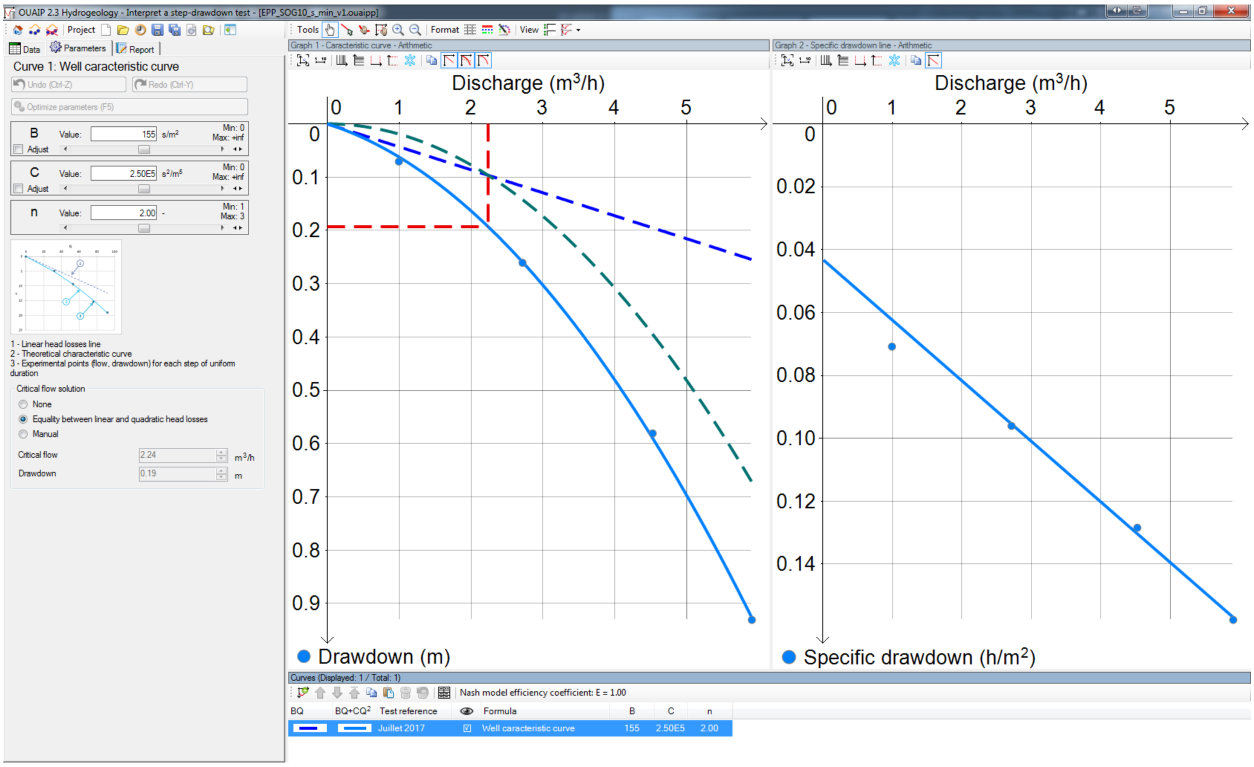


Illustration 43 : Calculation of a critical discharge as per OUAIP

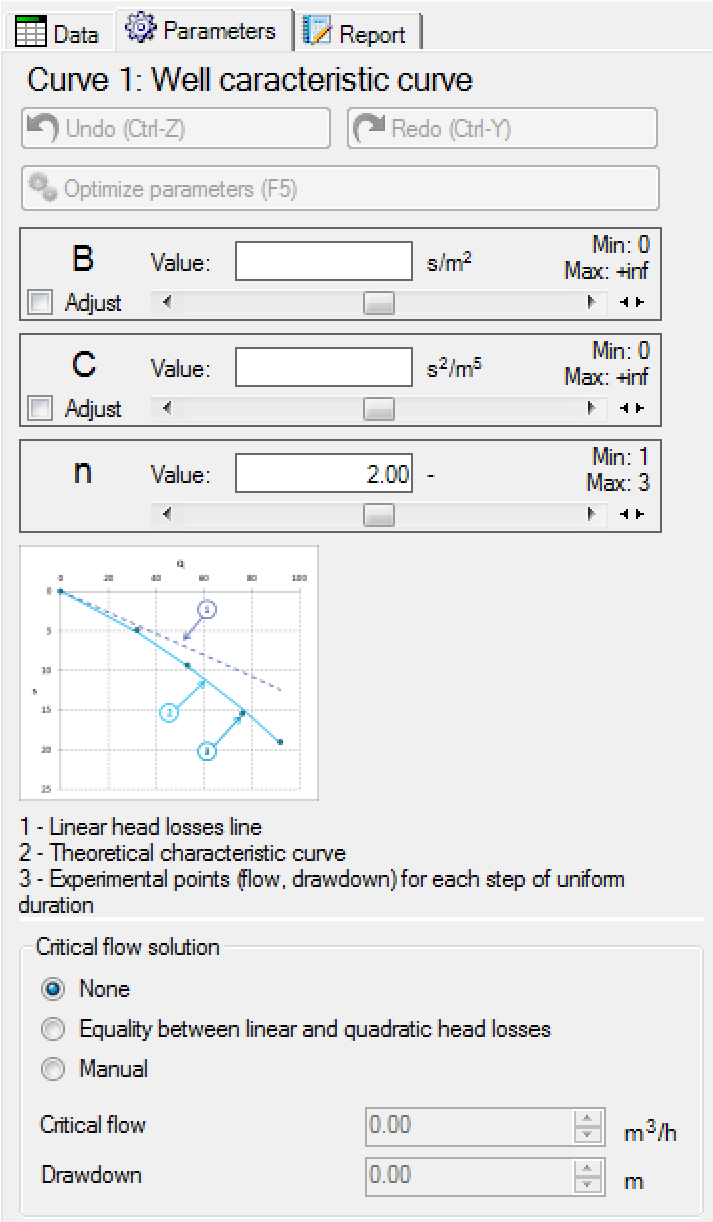


Illustration 44 : Parameters tab for interpretation of step-drawdown test

Aquifer test interpretation mode

In the aquifer test interpretation mode, the "parameters" tab allows entering the parameters for the chosen analytical solution as well as additional effects (Illustration 45).

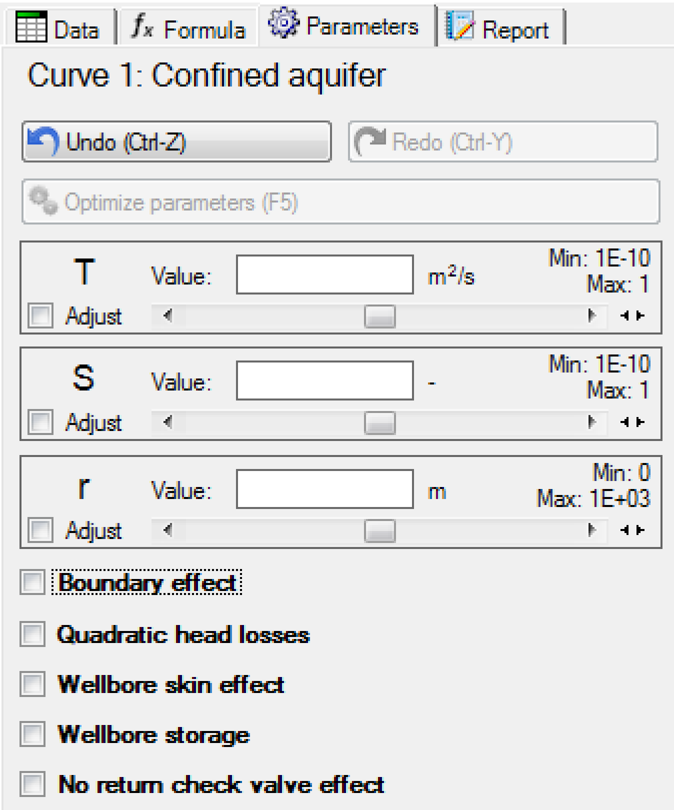


Illustration 45 : Parameters tab in the interpretation mode for an aquifer test

A tool tip shows the name by hovering over a parameter symbol. The parameter digital values can be entered in the following way:

- 1.25E-5 or 1,25e-5
- 0.0000125 or 0,0000125
- The comma or period decimal separator depends upon the configuration of your operating system. OUAIP automatically chooses your system's separator by default by pressing on "," or "." .

After entering a value, the horizontal scroll can be used to vary the initial value of the parameter. In order to vary the parameter in different ways and, more quickly, combine the use of the Ctrl or Shift key while moving the horizontal scroll to the left (decrease the value) or to the right (increase the value).

If the mouse points to the right of the scroll on " < > ", a note is indicated on the modification of the parameters (Illustration 46).

Note that the presentation of parameters has been changed from the OUAIP version 1.9.3, in this report the previous fashion is shown and the new one is described below (Illustration 46).

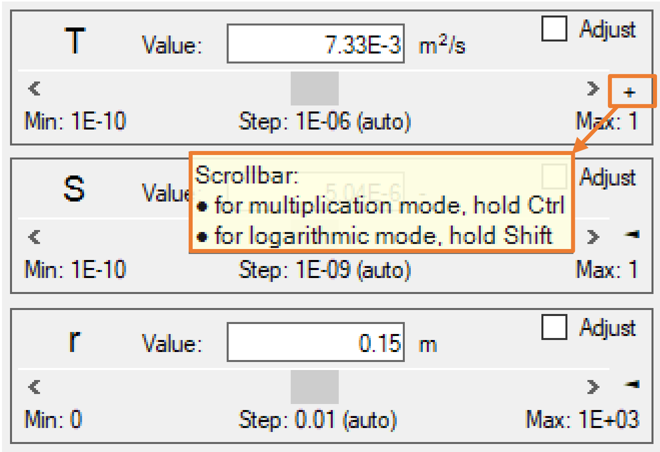


Illustration 46 : Modification of the parameters using the Ctrl or Shift keyboard shortcuts

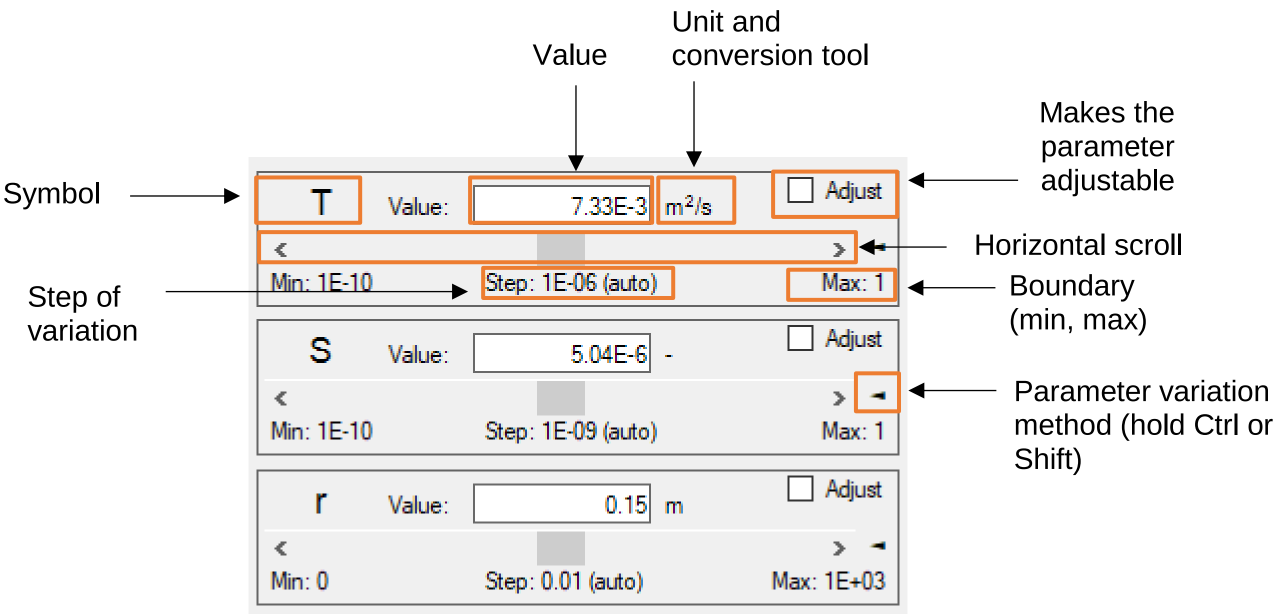


Illustration 47 : Description of the parameters in the Theis solution

A left click on the unit provides (Illustration 48):

- Makes a conversion (Illustration 49) without modifying the unit.
- Changes a parameter's unit by default.

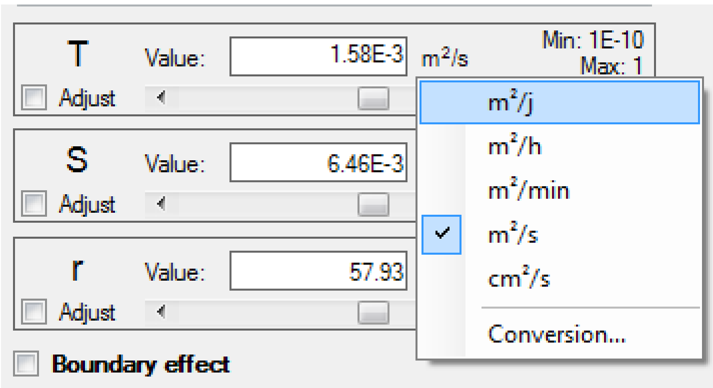


Illustration 48 : Unit scroll menu.

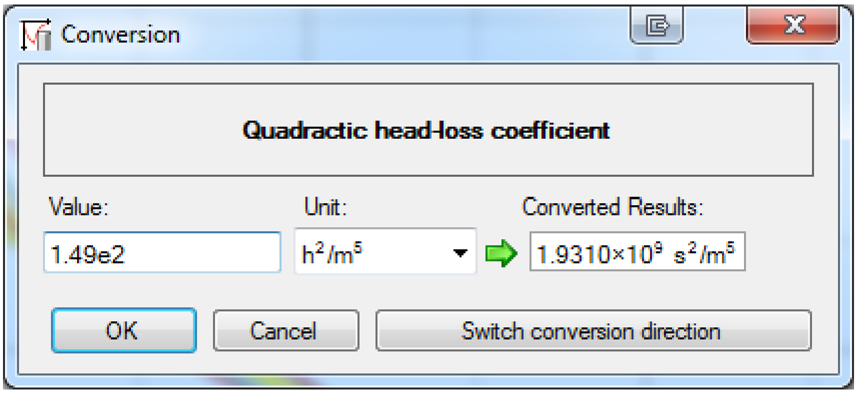


Illustration 49 : Use the OUAIP unit converter

By clicking on the boundaries of a parameter (Illustration 47, represented by Min: 1E-10 Max: 1), one can modify the minimum and maximum value ranges which the parameter can use to limit the field of possible solutions (Illustration 50):

- Relative boundaries: the min and max boundaries correspond to a percent of the entered parameter (do not exceed 100%).
- Fixed boundaries: these are boundaries chosen by OUAIP by default. The user can modify the minimum and maximum value of the parameter.
- Automatic boundaries

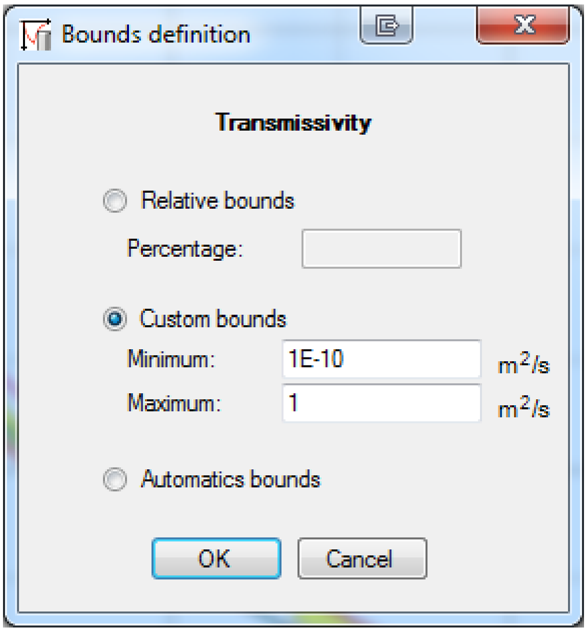


Illustration 50 : Parameter boundaries (transmissivity)

In pumping test simulation mode

In a simulation mode of a pumping test, the available parameters for the simulation are by definition the same as in the aquifer test mode (Illustration 51).

In any case, an additional function was added to the list of effects. This is the “Discharge optimisation” (Illustration 52).

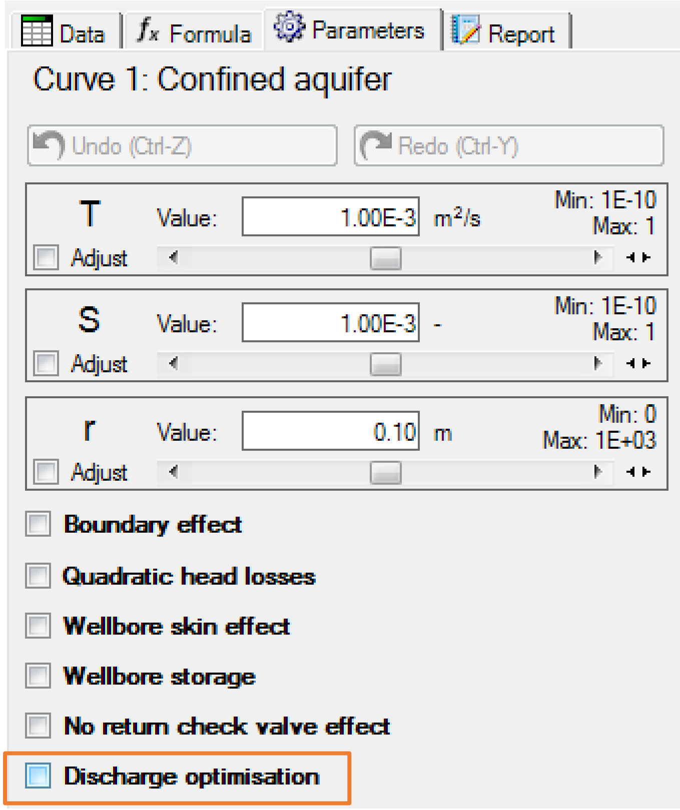


Illustration 51 : Parameters tab in pumping test simulation mode

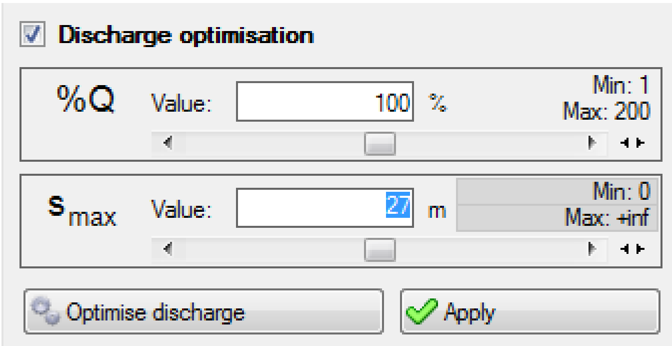
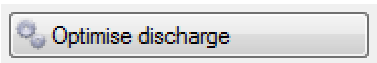


Illustration 52 : Optimisation function tab in pumping test simulation mode

This function can define maximum drawdown (s_{max}) which one wishes not to exceed (or which one would like to achieve) in the context of a pumping test simulation.



The "Optimise discharge" button calculates the pumping rate necessary to reach this maximum drawdown. A flow rate value must be defined prior to achieve this. Modification of the flow rate which is to be applied to respect s_{max} is indicated in %Q (percent of nominal flow rate). This modification is global. Optimisation is relevant to test a sole flow rate (continuous or non-continuous pumping), thus defining an operating regime.

Then click on "apply" to enable OUAIP to modify the initial pumping rate data.

It's also possible to directly modify the %Q field to simulate the effect of an increase or decrease in flow rate on the draw-down **(by default, the boundaries of the %Q parameter are 1% to 200%). It is, of course, recommended to modify these boundaries depending upon your needs.**

NB: It is recommended to end the pumping rate series by indicating an end to the pumping (pumping rate equals zero). If not, OUAIP considers that the pumping is infinite, which can produce unrealistic results. In practice, a simulation of operating pumping rates is done over a hydrological cycle, a period of low water, an irrigation period, etc.

4.1.4. Report tab

Step-Drawdown Test mode

The “Report” tab (Illustration 55) allows entering information about the test to complement the writing of the report.

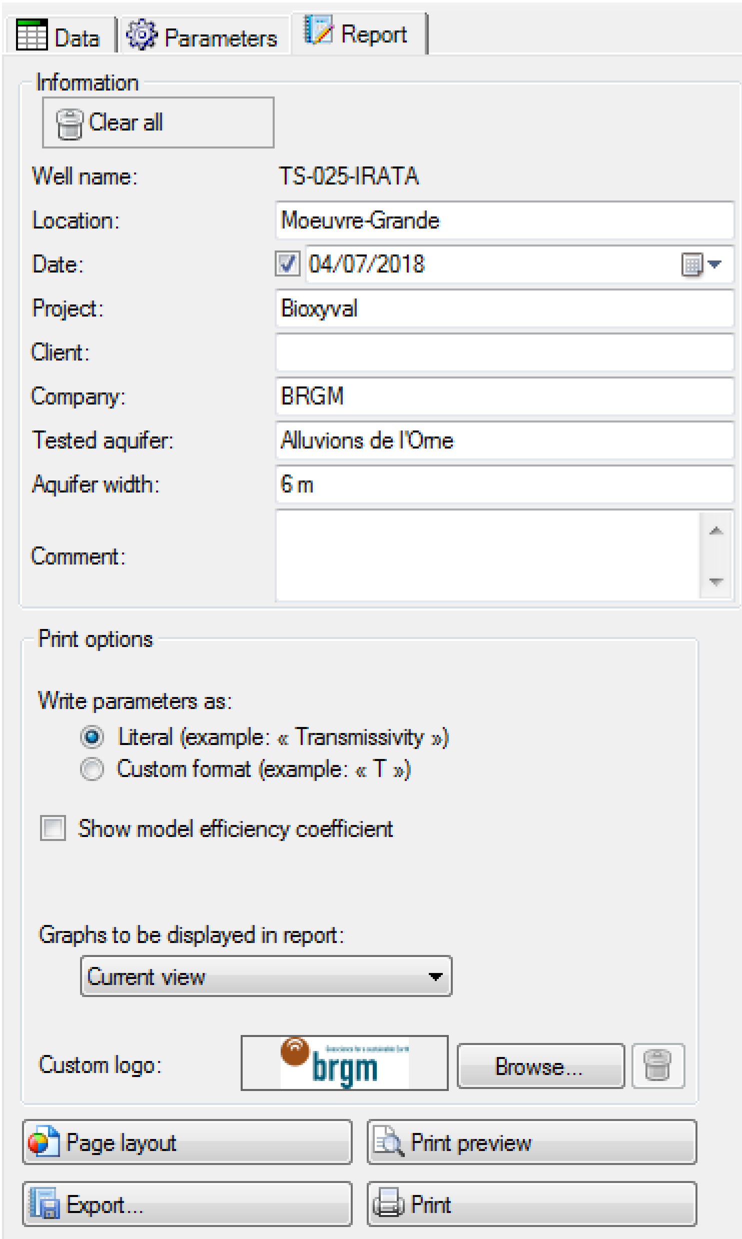
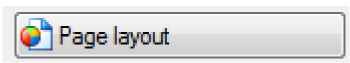


Illustration 53 : Report tab in the interpretation mode for a step-drawdown test

One has the following printing options:

- Choose a literal formatting of the hydrodynamic parameters : (Transmissivity) or concise (T),
- Display or hide the Nash adjustment coefficient (E),
- Choose one or more graphs (graphs no. 1, no. 2) to display in the report,
- Define a custom logo which will appear on the report.

The buttons on the bottom:

- 

Choose the format and layout of the print-out;

- 

To export the report in PDF and/or HTML format;
- 

To open a preview before printing the report;
- 

To print the report.

“Export” (Illustration 54) proposes the following options:

- Choose the destination of the exported files. It is recommended to create a sub-directory to avoid mixing report files with others;
- Choose to export in PDF and/or HTML formats.
- Define Graphic resolution
- Define File margins

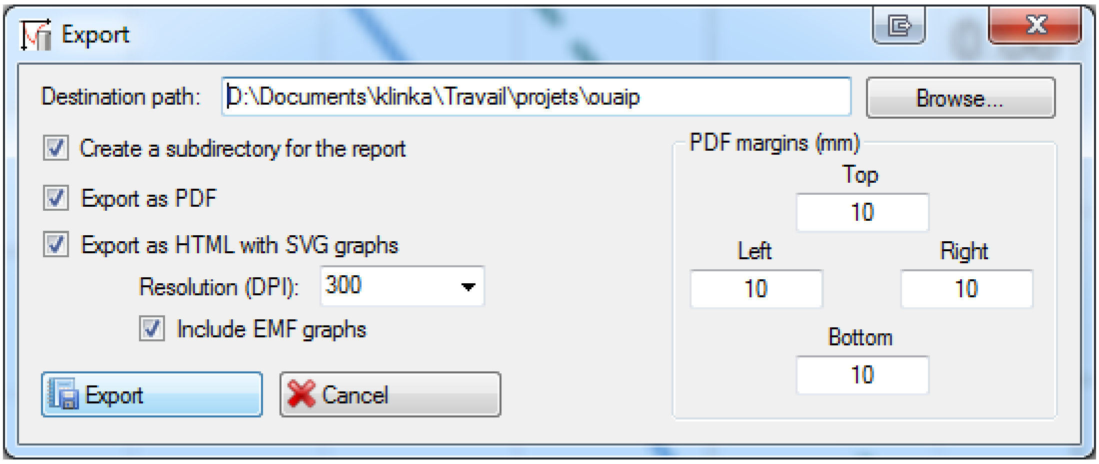
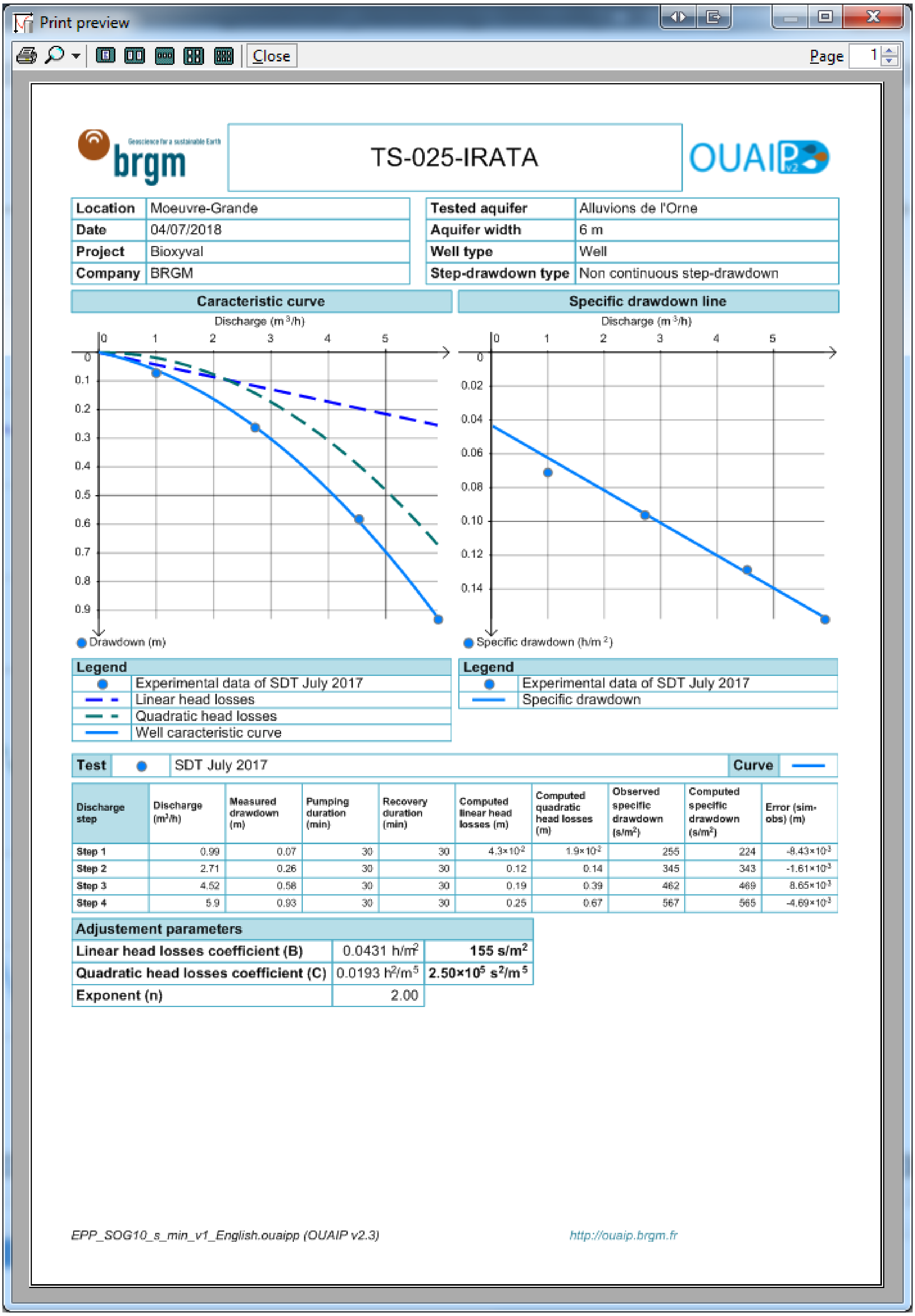


Illustration 54: Export window for reports in PDF and/or HTML



Location	Moeuvre-Grande	**Tested aquifer**	Alluvions de l'Orne
Date	04/07/2018	**Aquifer width**	6 m
Project	Bioxyval	**Well type**	Well
Company	BRGM	**Step-drawdown type**	Non continuous step-drawdown

Test SDT July 2017 **Curve**

Discharge step	Discharge (m^3/h)	Measured drawdown (m)	Pumping duration (min)	Recovery duration (min)	Computed linear head losses (m)	Computed quadratic head losses (m)	Observed specific drawdown (s/m^2)	Computed specific drawdown (s/m^2)	Error (sim-obs) (m)
Step 1	0.99	0.07	30	30	4.3×10^{-2}	1.9×10^{-2}	255	224	-8.43×10^{-3}
Step 2	2.71	0.26	30	30	0.12	0.14	345	343	-1.61×10^{-3}
Step 3	4.52	0.58	30	30	0.19	0.39	462	469	8.65×10^{-3}
Step 4	5.9	0.93	30	30	0.25	0.67	567	565	-4.69×10^{-3}

Adjustement parameters		
Linear head losses coefficient (B)	0.0431 h/m^2	**155 s/m^2**
Quadratic head losses coefficient (C)	0.0193 h^2/m^5	**2.50×10^5 s^2/m^5**
Exponent (n)	2.00	

Illustration 55 : Preview before printing the report

Aquifer test interpretation mode.

In the interpretation mode for an aquifer test (Illustration 56), two additional options can display filtered points and include test data tables in the report.

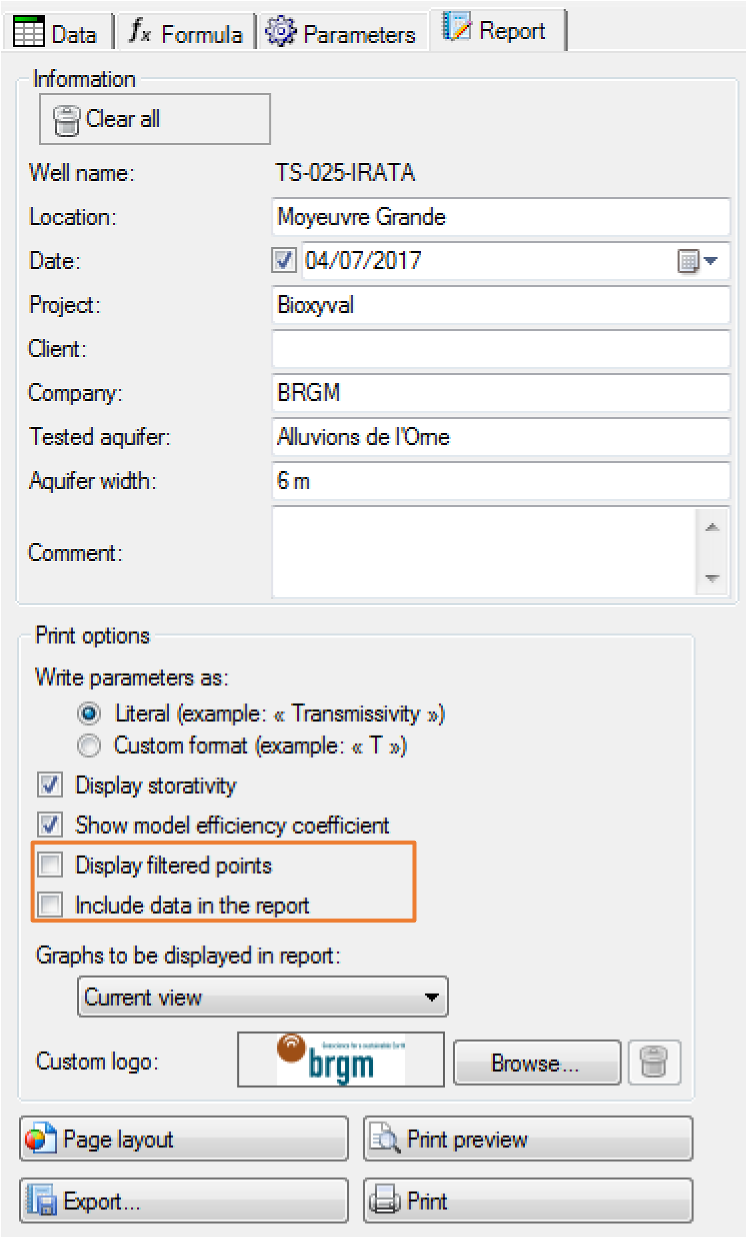


Illustration 56: Report tab in the interpretation mode for an aquifer test

Pumping test simulation mode

The “report” tab is identical at all points to the aquifer test interpretation mode.

4.2. RESULTS IN REAL-TIME: GRAPHS

Graphs can visualise in real time the calibration obtained depending upon the parameters entered.

For the interpretation mode for a Step-Drawdown Test

Two graphs are needed to complete the interpretation (Illustration 57). Graph no. 1 shows the characteristic graph of the test, that is:

- Experimental data: pumping rate and corresponding drawdown for identical pumping durations;
- The characteristic curve resulting from interpretation, corresponding to the total head loss, i.e. the sum of linear and quadratic head losses;

It is possible to display the linear and quadratic head loss curves separately.

Graph no. 2 shows the specific drawdown interpretation, with:

- Experimental data: pumping rate and corresponding specific drawdown
- The straight line of specific drawdowns resulting from interpretation.

This graph allows, in particular, to adjust the following coefficients:

- The linear head loss B (ordinate at the origin) and
- The quadratic head loss C (slope to the right).

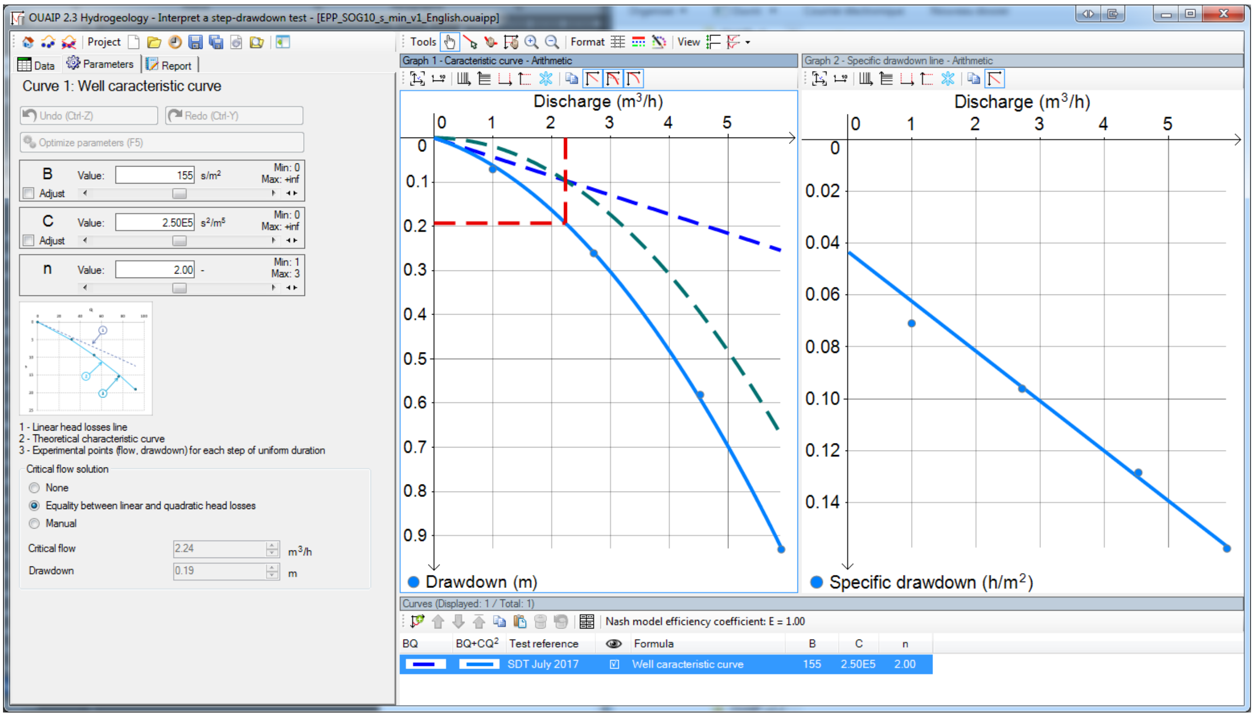


Illustration 57: Graphics displayed in the interpretation mode for a well test

Aquifer test interpretation mode

Two graphs, superimposed vertically, can be displayed to perform an interpretation of an aquifer test (Illustration 58), by default, only one graph is displayed when OUAIP starts. One only need click on the separation bar at the bottom of graph no. 1 to enlarge graph no. 2. A double click on this separation optimises sharing of the graph window.

The graphs present:

- The measured pumping rate;
- The measured drawdown;
- The simulated analytical solution(s).

The graphs can be customised, and one can modify the axes' scale (arithmetic or logarithmic or semi-log) using the graph tool bar described in Chapter "4.3.3 Graph tool bar".

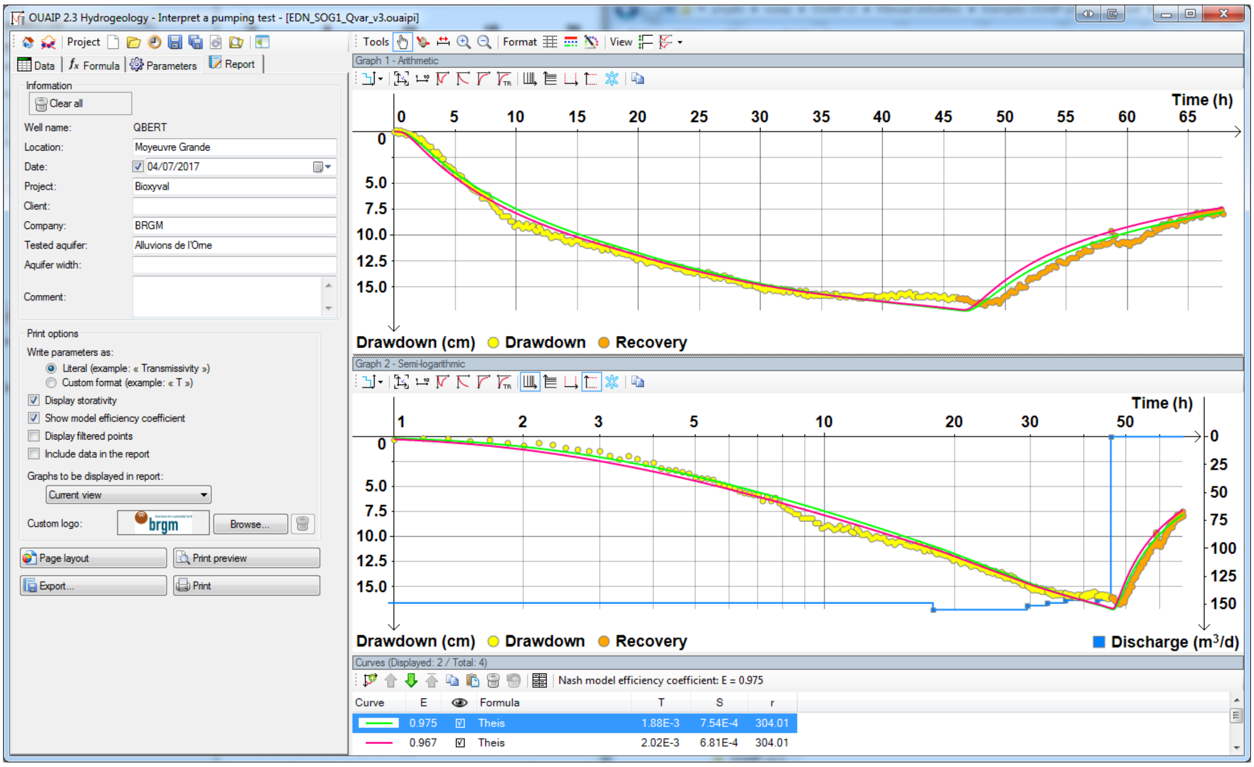


Illustration 58: Graphs displayed in the interpretation mode for an aquifer test

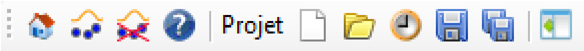
Pumping test simulation mode

In pumping test simulation mode, the graphs are identical to the aquifer test interpretation mode except that, by definition, there is no measured drawdown.

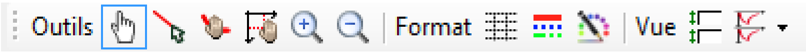
4.3. THE TOOL BAR

The four OUAIP tool bars are shown separately in the interface:

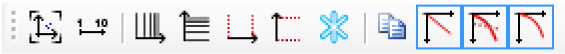
- the “**project**” tool bar, which is at the top left of the interface:



- the “**adjustment**” tool bar, at the right, below the graphs:



- the “**graph**” tool bar, situated below each graph:


(interpretation mode for a step-drawdown test)


(interpretation mode for an aquifer test)

- the “curve” tool bar, situated below the curve list:

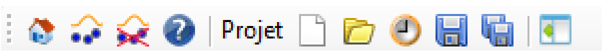
Note that the contents of the tool bars change depending upon the OUAIP mod (step-drawdown test, groundwater test, simulation).

4.3.1. Project tool bar

The project tool bar is presented on all OUAIP modules (Illustration 59).

In the interpretation mode for an aquifer test, after having created your interpretation, an additional icon in the tool bar permits moving directly to the simulation mode of a pumping test while preserving all interpretation parameters (therefore, one need not re-enter these data).

This (icon) option can be accessed during interpretation of a step-drawdown test or simulation of a pumping test.



: Interpretation mode for a step-drawdown test

: Interpretation mode for an aquifer test

: Pumping test simulation mode

Illustration 59: Project tool bar

These icons respectively from left to right:

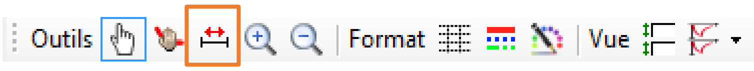
- Return to the OUAIP invitation (Ctrl+Q);
- Switch to the “Simulation” mode while keeping current parameters (quadratic head losses, for example);
- Switch to the “Simulation” mode while keeping current parameters (quadratic head losses, for example);
- Open the OUAIP manual (F1)
- Create a new project (Ctrl+N);
- Open a project (Ctrl+O);
- Save the project (Ctrl+S);
- Save the project under (Ctrl+E);
- Display the list of projects recently opened (Ctrl+L);
- Partially hide the left pane to maximise the graphics size (Alt+R).

4.3.2. Adjustment tool bar

The adjustment tool bar allows to modify fitting between simulated theoretical curve and experimental data as well as to modify the appearance of the graphs. It varies depending upon OUAIP use:

- Interpretation mode for a step-drawdown test:

- Interpretation mode for an aquifer test:



From left to right for icons specific to the step-drawdown test interpretation mode:

- Move to the graph (M);
- Draws the adjustment line of the specific draw-downs (right graph);
- Adjust the analytical solution parameters (L) by manually moving the curve. In order to do this, at least one parameter must have the “adjust” box checked. This is a very practical option which allows to adjust interactively the theoretical curve instead of manually modifying the solution parameters.
- Move the critical discharge value;

Common to the modules “interpretation of an aquifer test” and “simulation of pumping test”:

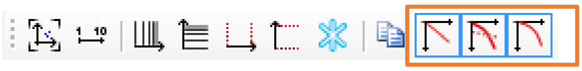
- Selects an experimental data interval (I) in order to make an automatic adjustment solely on the selected data;

From left to right, the icons which are common to the three modules:

- Zoom on the graph (the use of the mouse scroll wheel can be used as well as the plus (+) and minus (-) buttons on the number pad);
- Reduce the zoom on the graph. Trick: Holding the **Ctrl** button at the same time as the scroll wheel provides zooming/dezooming on the time axis only without modifying or dilating the drawdown axis;
- Display/hide the grid (G);
- Change the line style (thickness, colour, type of characteristic) (K);
- Change the points style (draw-down, flow rate) (P);
- Equalise the height of graphs 1 and 2 (Alt+D);
- Save/load a view for a current project (position and scale of the graph).

4.3.3. Graph tool bar

The “graph” tool bar modifies a graph’s appearance. In the interpretation mode for a step-drawdown test, on graph 1, “Characteristic curve”:

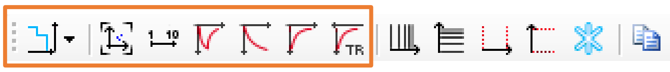


- Display/hide the straight line of the linear head losses;
- Display/hide the curve of the quadratic head losses;
- Display/hide the straight-line theoretic characteristic (sum of linear and quadratic head losses).

In the interpretation mode for a step-drawdown test, on graph 2, “straight line of specific drawdowns”:

- Display/hide the straight line of the specific drawdowns.

For the interpretation mode for an aquifer test:



- Display the flow rate axis / do not display the flow rate axis;

- Adjust the graph zoom (original or “home”);
- Adjust the scale to logarithmic cycles;
- Display the drawdown and recovery phases;
- Display the drawdown phase only;
- Display the recovery phase only;
- Display the recovery in reduced time;
- Arithmetic or logarithmic abscissa axis scale;
- Arithmetic or logarithmic ordinate axis scale;
- Freeze the abscissa. This freezes the time axis, in normal time the time axis adjusts automatically to a certain percent of the recovery for an adjustment to parameters or a simulation, for example;
- Freeze the ordinate. This allows to freeze the drawdown axis which otherwise automatically adjusts to simulated drawdowns. This is useful during curve fitting;
- Completely freezes the graph (Xmin, Xmax, Ymin, Ymax invariants);
- Copy the graph to the clipboard (Ctrl-C).

4.3.4. Curve tool bar

The “curve” tool bar, located in the lower part of the interface screen at the level of the list of curves allows to duplicate, erase and organise the simulated curves and extract data (simulation or experimental):

Illustration 60: Curve tool bar

The following functions are available:

- Add a new curve (analytical solution) in duplicating the selected curve (Ctrl+A) ;
- Move a curve forward (modify the order of the curve’s display);
- Lower a curve ;
- Move a curve to the top of the list (first position);
- Copy the hydrodynamic parameters of a curve (Ctrl+C);
- Paste the hydrodynamic parameters of a curve to another one (Ctrl+V);
- Delete a curve (Delete) ;
- Cancel deletion of a curve;
- **Data table**: generate and export simulated digital data (useful to display the data in another spreadsheet such as Excel or OpenOffice) and to compare them with experimental data.

Export theoretical and experimental data

The  Table function on the “curve” tool bar exports theoretical data **<u>for the current selected curve</u>** and experimental data (Illustration 61).

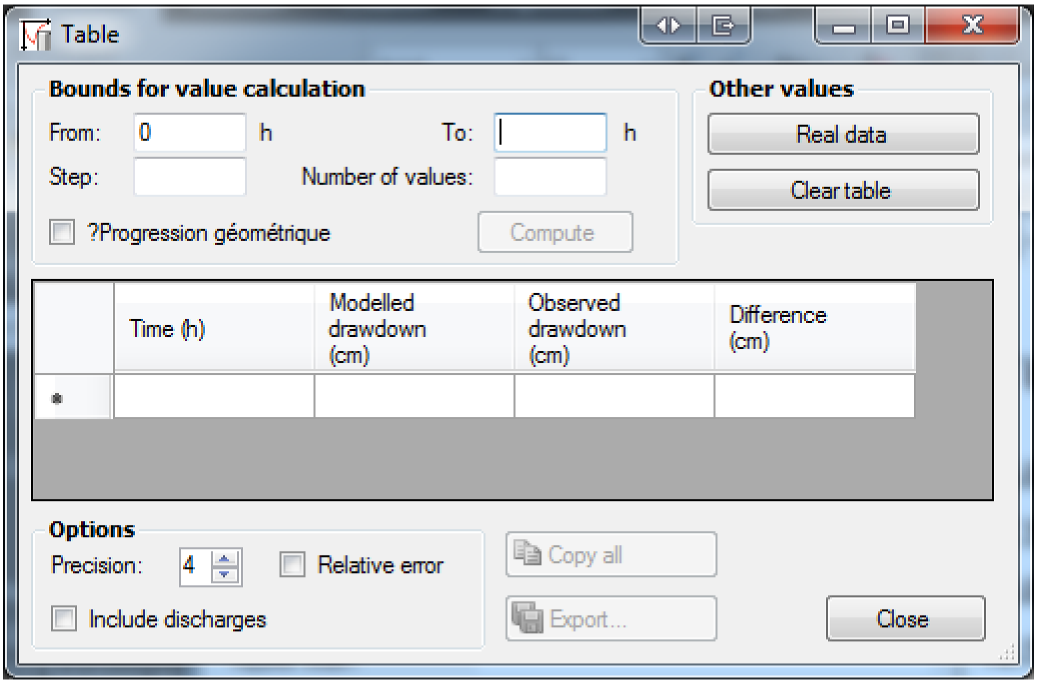
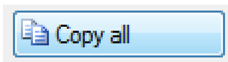
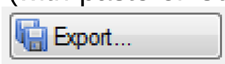


Illustration 61: Value table

To do this, one must enter the desired minimum (From) and maximum (To) time to export the data as well as the step to discretise time. The resulting number of values will be automatically calculated.

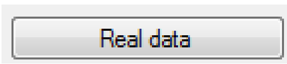
Note that the units of time, drawdown and flow rate in the “table” corresponds to the units in the graph. You can therefore modify the graph units in order to modify the export units without having to modify the units in the imported data.

You need only to click on “Compute” to calculate the values, then on “Copy all” 

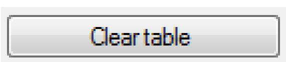
to copy the data to memory and paste them into a spreadsheet (with paste or Ctrl+V). One can directly export the value table to a CSV or TXT file with “Export” 

.

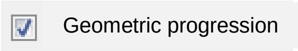
One can also define the “number of values” desired so that OUAIP automatically calculates the appropriate step.

The “Real data” button 

exports simulated data at the time when the experimental data exist.

Click on “Clear table” to erase the value table 

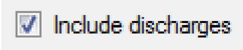
.

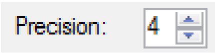
The “geometric progression” option 

calculates an adaptive time step since the drawdown is not a linear time function (it varies strongly at the beginning, then more and more slowly).

The value table presents the following columns by default:

- Data time;
- Drawdown calculated by the selected curve (analytical solution);
- Measured drawdown (experimental data);
- Difference, corresponding to the absolute difference between the measured and calculated drawdown.
- One can calculate a relative error (in %) by checking “relative error” 

. This is the absolute difference between the measured and calculated drawdown divided by the measured drawdown, expressed as a percentage.
- One can add a column to export the flow rates by checking “include the flow rates” 

The precision option 

modifies the number of decimals (from 2 to 8) after the comma/period in the table’s columns.

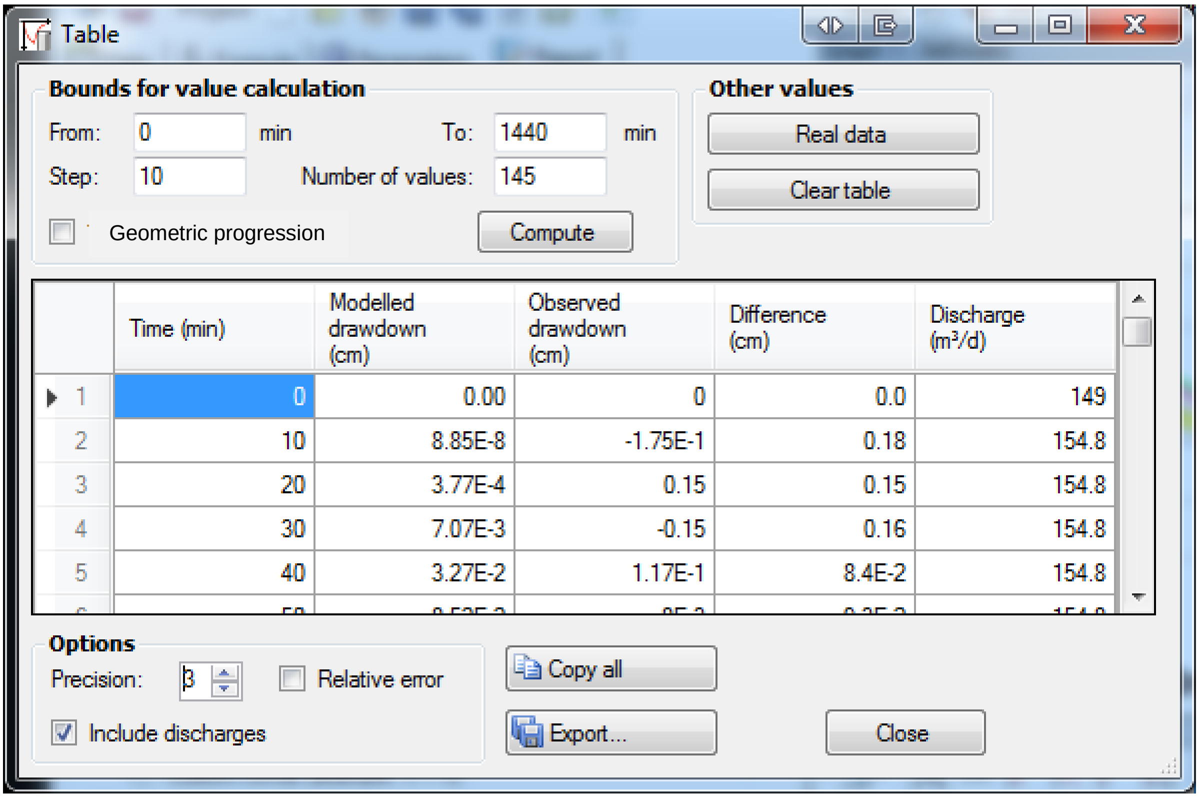


Illustration 62: Value table - Example of value calculations

4.4. GRAPH OPTIONS

The OUAIP interface offers two customisable graph windows (Illustration 63). The idea is to allow the user to simultaneously display the drawdown in an arithmetic scale on a graph and with a semi-log scale on another in order to improve visualisation and the scale of the data on different time scales.

Right click on the graph to be modified to access graph options. A contextual menu will appear. Choose “graph” to access “graph options” (Illustration 64).

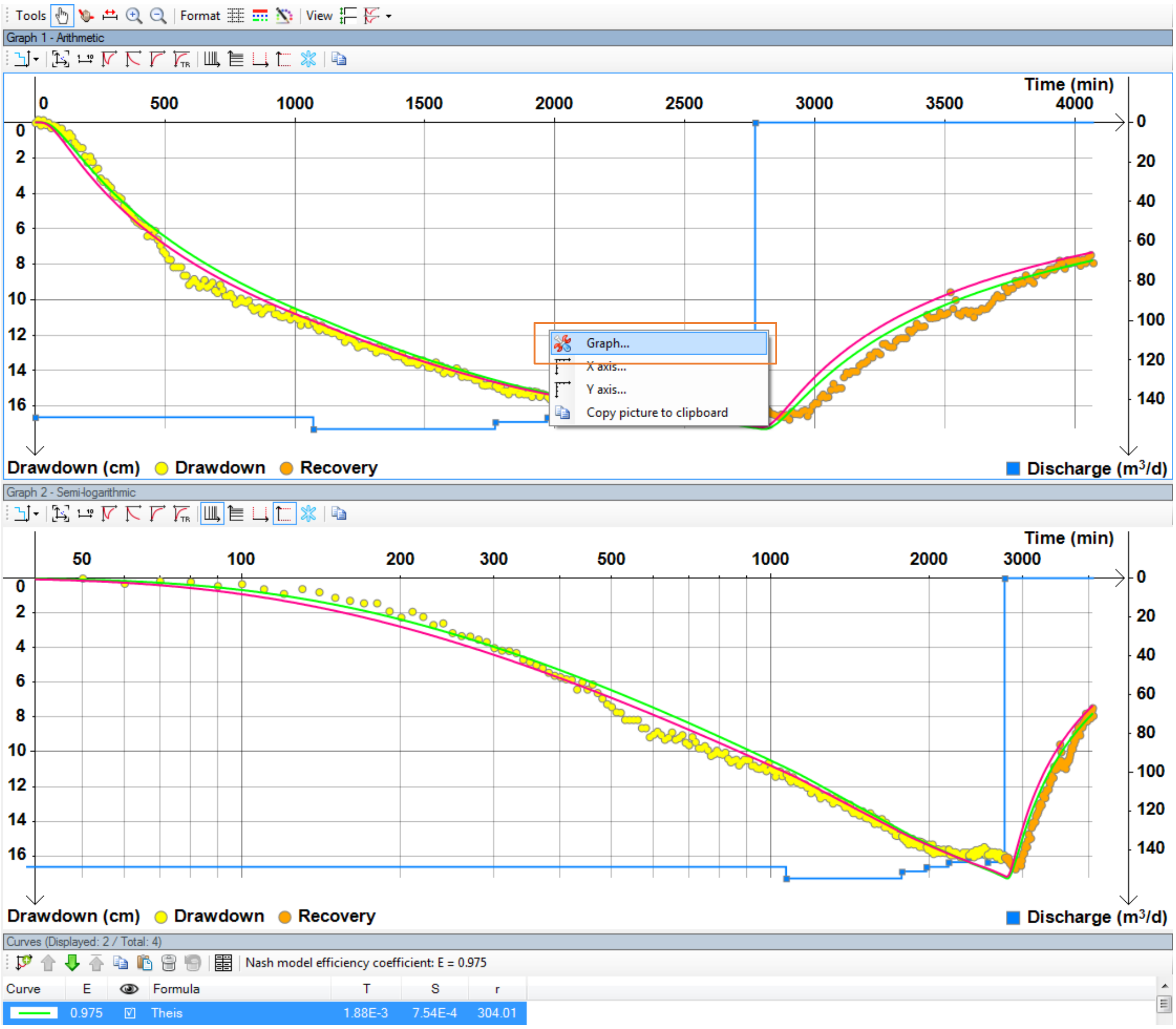


Illustration 63: OUAIP graphs and graph options

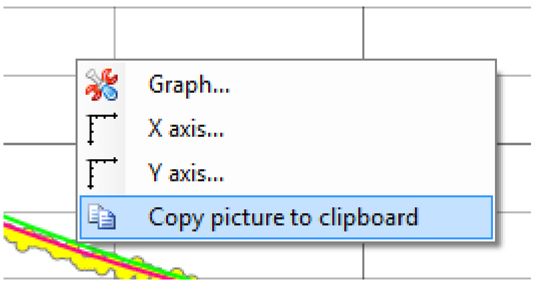


Illustration 64: Contextual graph menu using a right click

The “graph options” window (Illustration 65) offers several tabs, described below.

4.4.1. General tab

The “general” tab (Illustration 65) can **modify the graph units independently of the imported data units.** As an example, if the time/flow rate data are imported in minutes and m3/hour, you can display the time as hours and the flow rates as m3/day without modifying the original data units.

The horizontal and/or vertical grid can be displayed or hidden, as well as the main graduations (and secondary graduation in a logarithmic scale).

The “freeze the graph” option blocks the X and Y axes in the graph (invariant minimum and maximum). This is useful if the user would like to modify the parameters of a solution but would not like the window to automatically adjust to scale changes.

One can display or hide the graph values by moving the mouse over the graph.

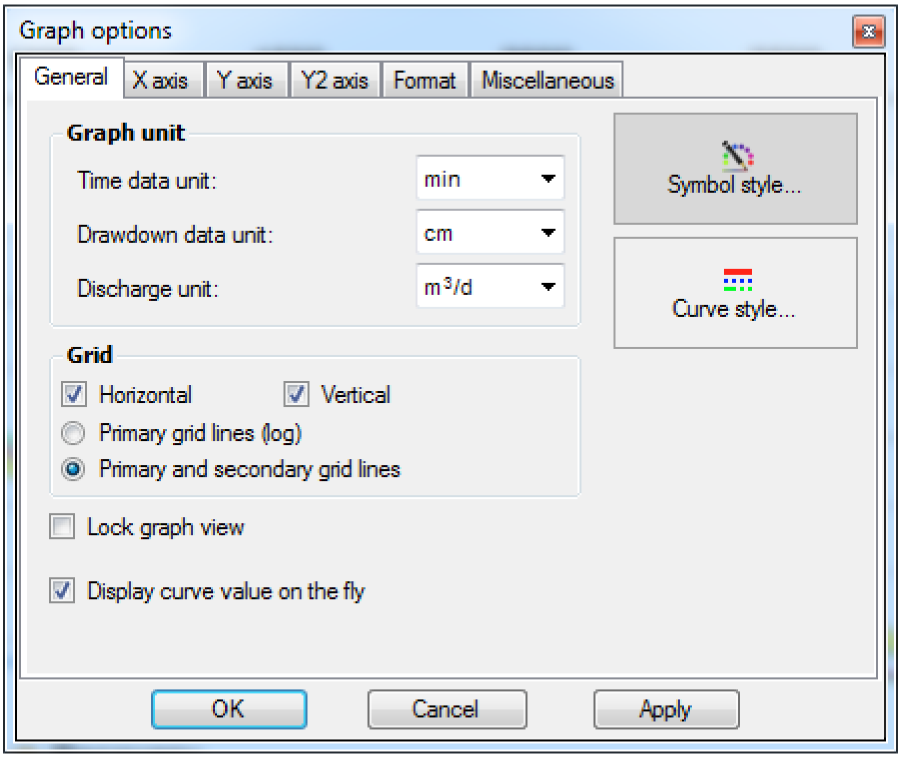


Illustration 65: Graph options window - general tab

The style (colour, size and shape) of the points (imported data: flow rate, drawdown) can be modified as shown in Illustration 66:

- One can join the experimental points with a curve (drawdown, pumping rate) *via* “Display curve”;
- It is possible to display the analytical solution(s) above the experimental points to facilitate the setting “above the theoretical curve”.

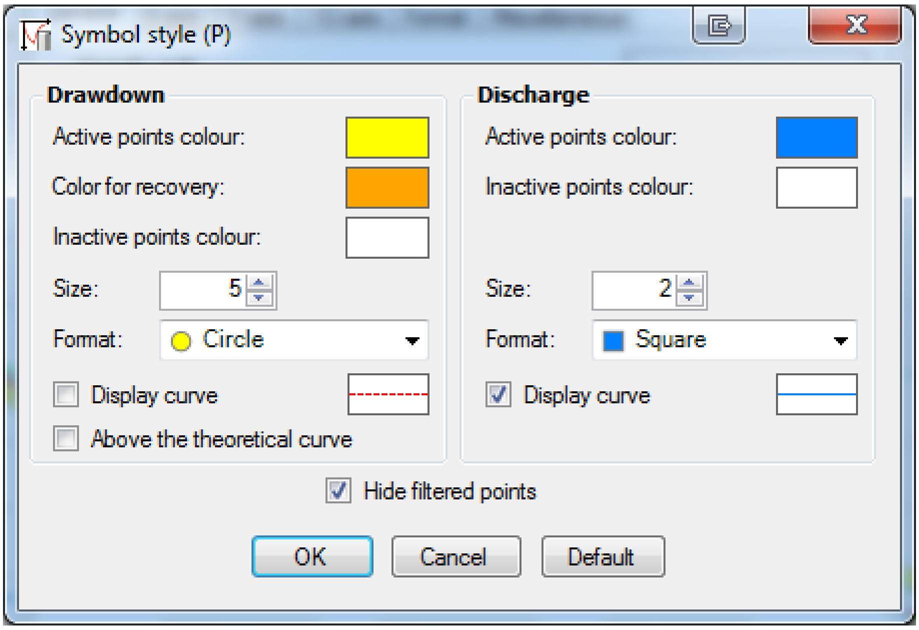


Illustration 66: Point style window

The style (thickness and colour) of the curves (simulated/measured drawdown, simulated/measured flow rate) can be modified as shown in Illustration 67:

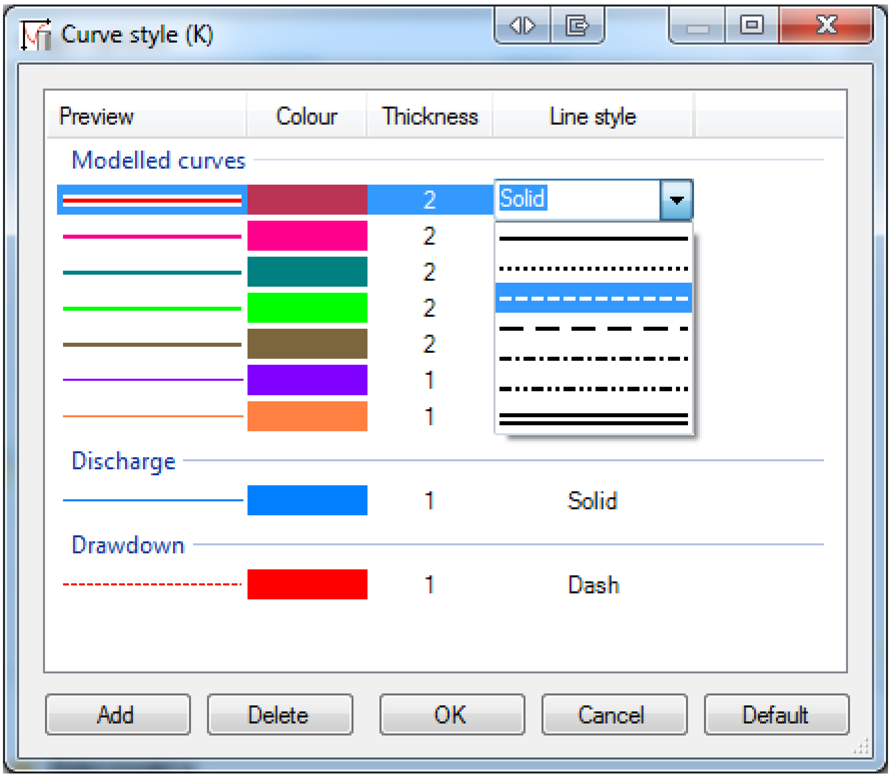


Illustration 67: Curve style window

4.4.2. X-axis tab

The X-axis tab (Illustration 68) defines one or more minimum and maximum boundaries for the horizontal axis if “Custom limits” are selected. If the “automatic” option is checked, the boundaries adjust automatically.

One can modify the “graduation step” on the axis by entering the desired value. If the graduation steps are too small, OUAIP automatically defines the steps (one cannot reduce below a certain step size).

One can centre the X-axis legend on the graph.

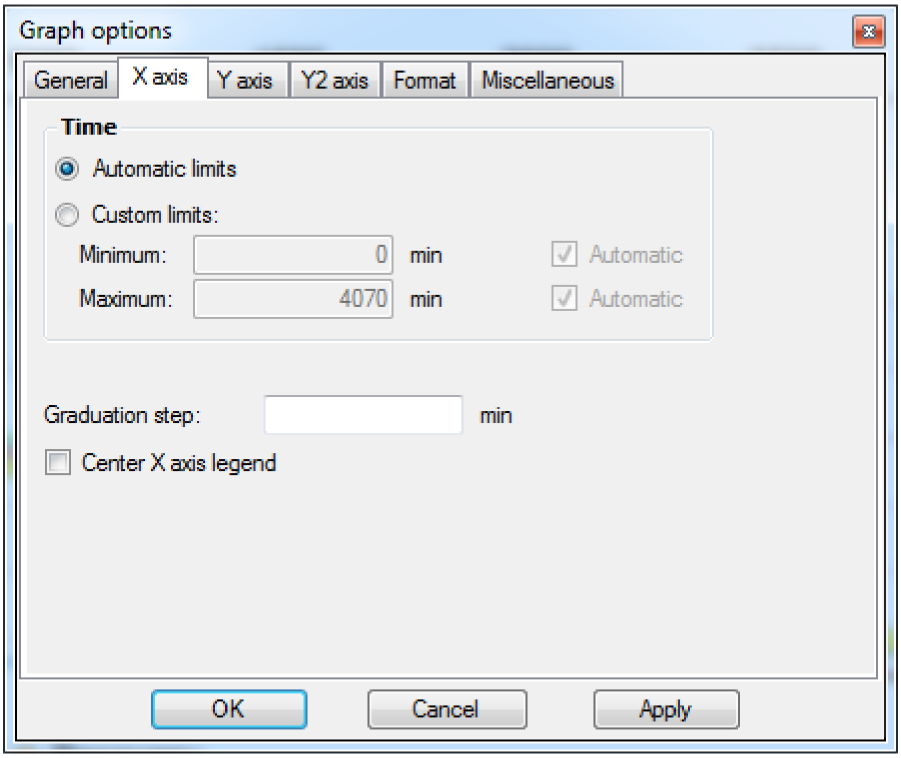


Illustration 68: Graph options - X-axis

4.4.3. Y-axis tab

The Y-axis tab (Illustration 69) offers the same options as the X-axis tab. However, one can reverse the drawdown axis order. By convention, it is presented positively downward (the drawdown increases downwards), which represents the natural evolution of the dynamic level (as one pumps, the level lowers).

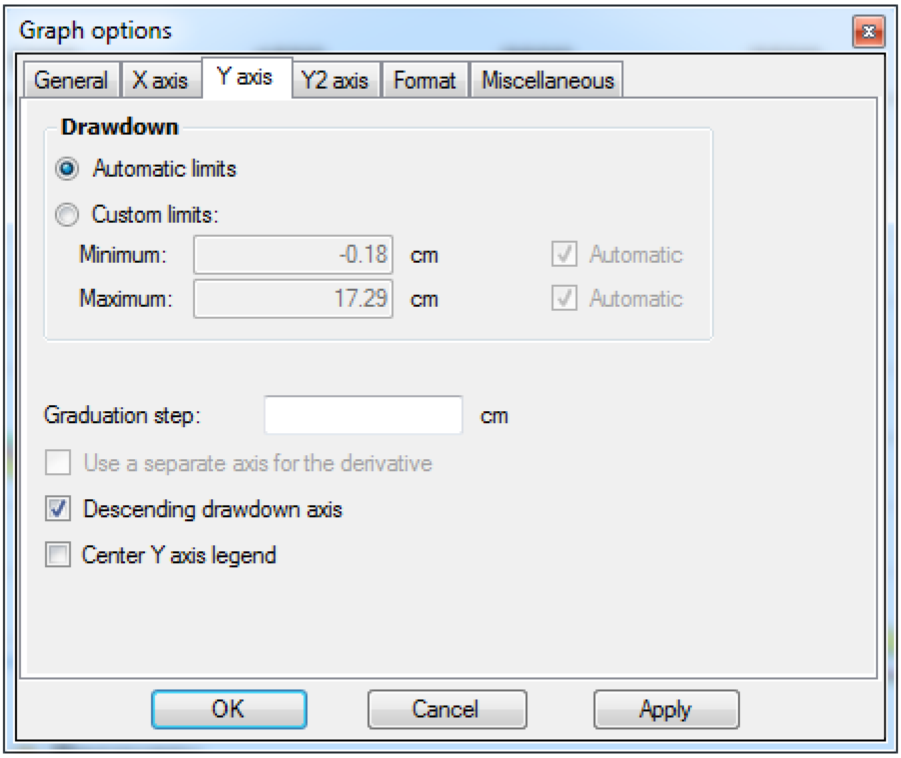


Illustration 69: Y-axis window

4.4.4. Y2-axis tab

The Y2-axis tab (Illustration 70), specific to pumping rate, has the same function as the X-axis and Y-axis tab.

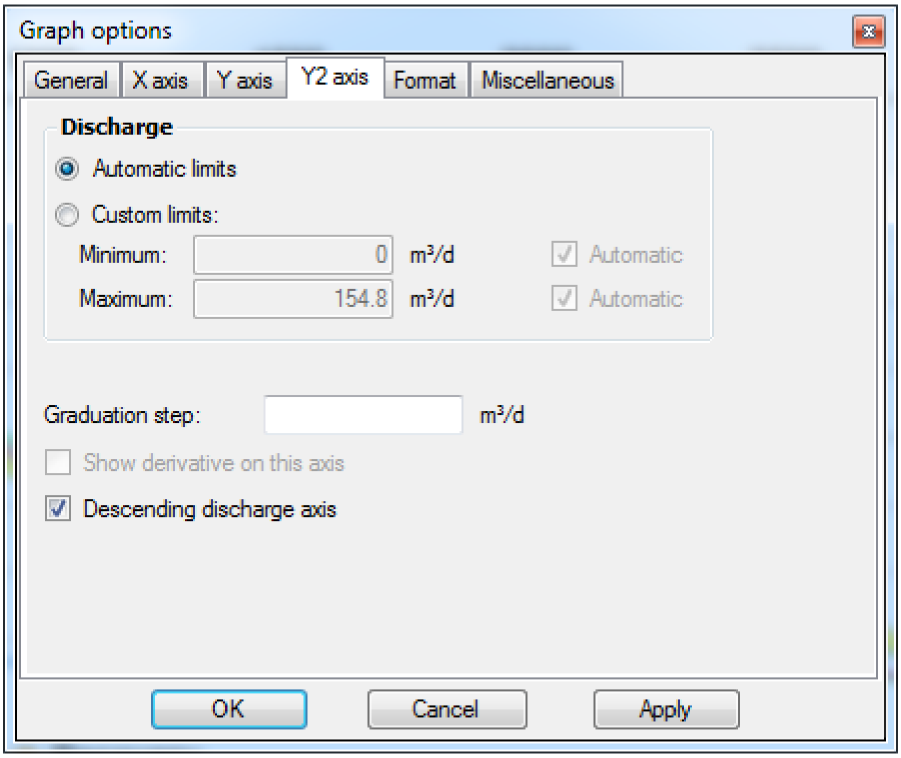


Illustration 70: Y2-axis tab

4.4.5. Format tab

The format tab below in Illustration 71 modifies a graph's appearance from the point of view of the font used (Illustration 72), the colour (Illustration 73), the size as well as the background colour of the graph (dark colour to work in a low-light environment) as well as the colour of the grid.

One can also monitor the label format (normal: time, drawdown or abbreviated: t and s), the X and Y axes as well as the format of the axis numbers (use of exponential notation using a value threshold).

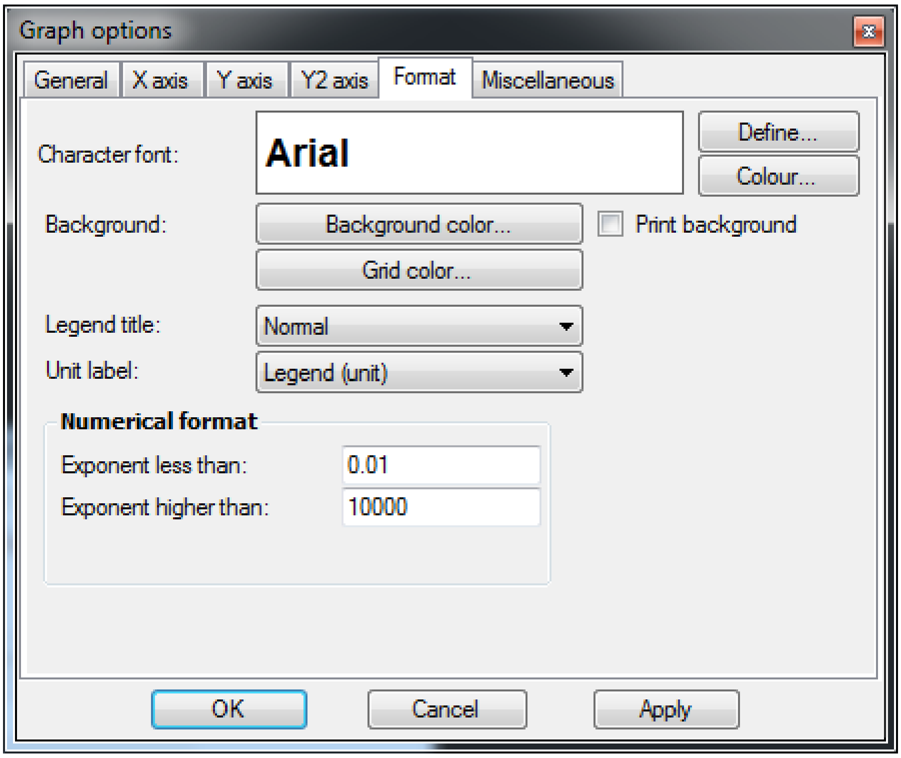


Illustration 71: Format window

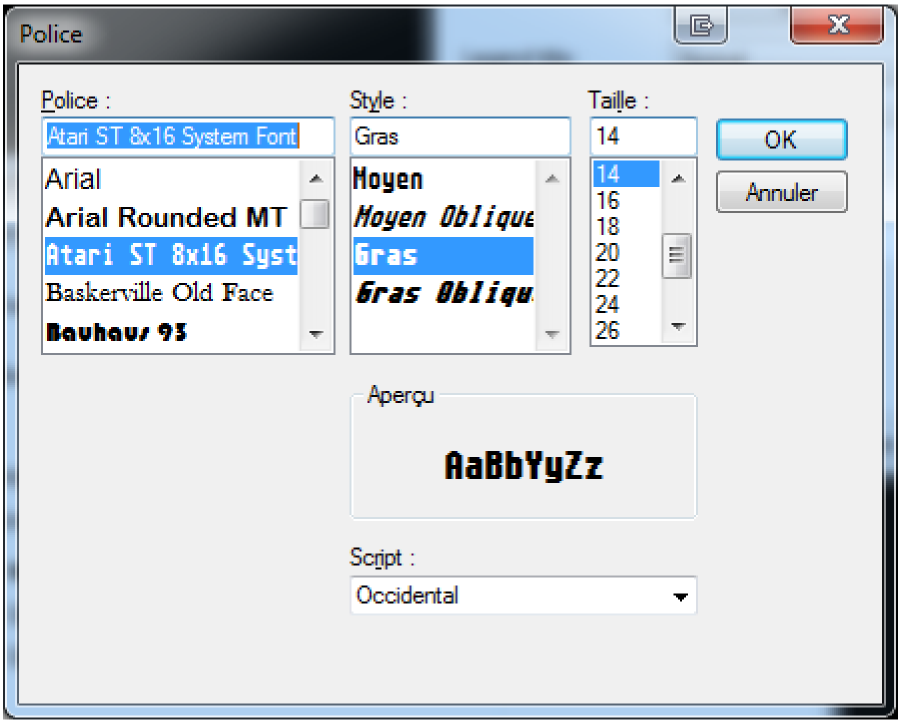


Illustration 72: Define window ... (the font)

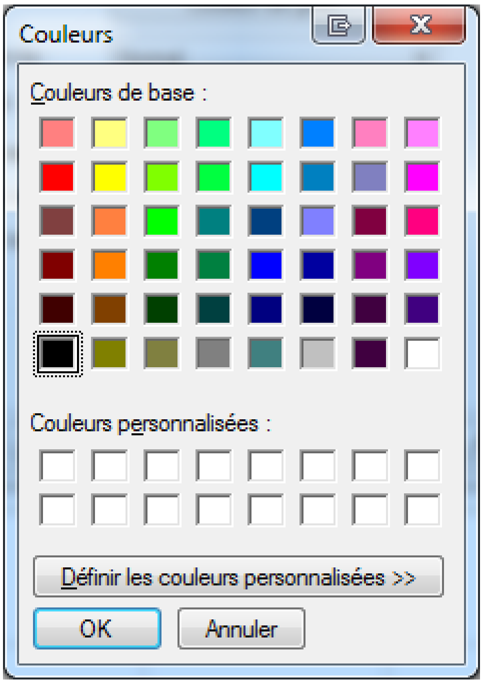


Illustration 73: Colour window

4.4.6. Miscellaneous tab

The “miscellaneous” tab (Illustration 74) modifies:

- The default size of the graphs copied to the clipboard (size factor equal to 2 by default, or two times the current size of the graph);
- The maximum display time by default of a recovery curve (93% of recovery by default, 100% being infinity);
- Precision for the backflow effect (described in “2.3.2 Backflow effect“) which adjusts the calculation of this effect if needed;

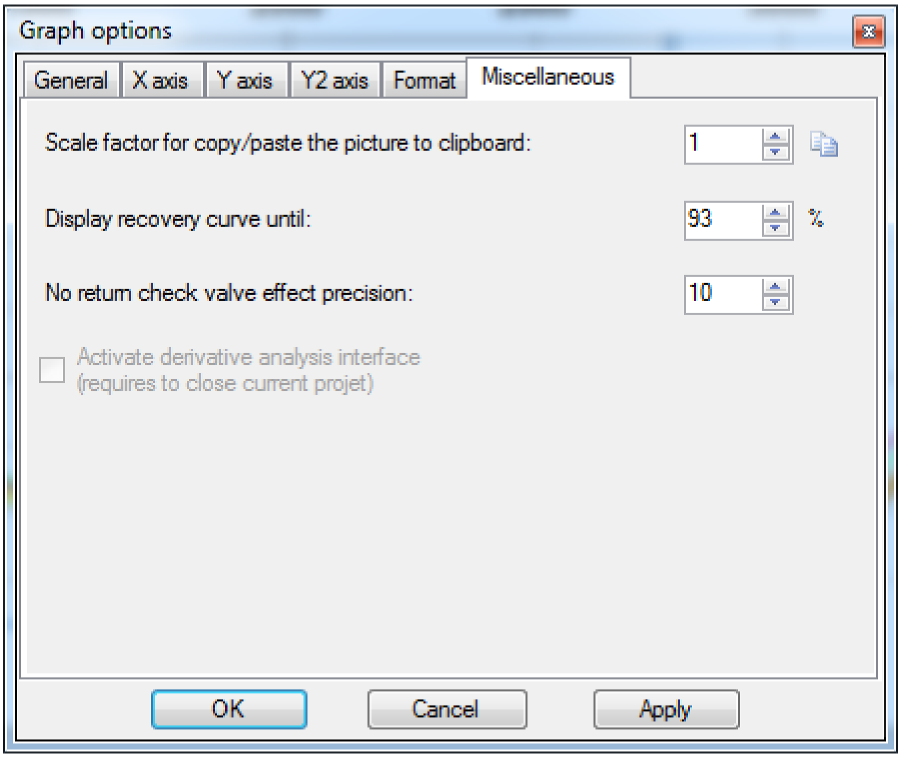


Illustration 74: Miscellaneous window

4.5. ADVANCED OUAIP FUNCTIONS - *.INI FILES

Advanced OUAIP options are accessible by modifying some *.ini files which are found in the OUAIP directory (Illustration 75).

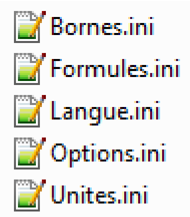


*Illustration 75: *.ini files in the OUAIP directory*

The goal is to provide user modification of software to enrich functionality. Modifying these files is detailed in this chapter. These are the following files:

- Options.ini : modifies the OUAIP interface options;
- Formules.ini (formulas) : adds new analytical solutions to OUAIP ;
- Bornes.ini (boundaries) : modifies the default boundaries for OUAIP parameters;
- Unites.ini (units) : modifies/adds new units to OUAIP;
- Langue.ini (language) : modifies OUAIP translation into other languages ;

In order to modify *.ini files, use a text file editor such as Notepad in Windows or an advanced text editor, such as Notepad++, which can be downloaded free of charge at: https://notepad-plus-plus.org/

*.ini files are organised in a section which is between brackets [**Section**] in each parameter section and their values are specified in the following way: **Parameter=Value**

The use of semi-colons ";" allows for comments entries.

4.5.1. Options.ini

The Options.ini file can modify some OUAIP parameters as well as its interface; only the parameters which the user can modify are described.

4.5.2. Formules.ini (formulas)

The formulas.ini defines the **Analytical Solutions** (written as "**AS**" below) currently implemented in OUAIP as well as to add other solutions. This consists of the following sections:

- [Général] : defines the IS units of the graph axes;
- [Attributs] : defines the AS attributes;
- [Paramètres] : defines the AS parameters (symbols, translation, expression, if they can be adjusted with optimisation);
- [Expressions] : defines some unit conversions
- [TheisCaptive] : Theis solution
- Then the following ASs

As an example, the Theis solution:
`[TheisCaptive]` // Unique name of the solution

`NuméroSolution=1` // Unique solution number
`Attributs=Confined aquifer` // Attributes of the solution
`Libellé=Confined groundwater` // Name of the solution in OUAIP in French
`Libellé.English=Confined aquifer` // Name of the solution in English
`Libellé.Espagnol=Acuifero confinado` // Name of the solution in Spanish (language not currently available in OUAIP)
`Formule=Q/(4*Pi*T)*W(Pow(r,2)*S/(4*T*t))` // AS mathematical expression
`EffetsInaccessibles=PartialPenetration` // Effects which are not available for this SA
`Auteur=Theis` // Name of the AS author
`Valid|Hydro=yes` // Filter to show or hide the SA in OUAIP hydrogeology
`Valid|Geothermie=yes` // Filter to show or hide the AS in OUAIP geothermal
`Description=Confined groundwater (homogeneous, isotrope, infinite, constant thickness) in temporary regime, full penetration well.` // Literal description of the AS in OUAIP
`Description.English=Confined aquifer (homogeneous, isotrope, infinite, constant thickness) in transient state, full penetration well.` // Literal description of the AS in OUAIP in English

In order to add a new solution, close OUAIP. It is recommended to copy and paste the section of a solution, then to modify the parameter-associated values. Some parameters are unique and may not coexist in duplicates in the formulas.ini file. These are:

- [NameOfTheSolution]: unique, with no spaces or special characters;
- NuméroSolution=X : unique, start at 20, for example;

Note that some AS's exist in the formulas.ini, but are not visible in OUAIP. This is normal. These solutions are not totally validated in a digital manner (in this case, they are annotated “Valide|Hydro=Non”).

4.5.3. Bornes.ini (boundaries)

If one can modify the boundaries (Illustration 76) by default in an OUAIP project, these are re-initialised each time that a new project is created. The Bornes.ini file makes it possible to durably modify the default boundaries in OUAIP for analytical solution parameters.

For example, for the Theis solution for wells, the boundaries are in Illustration 76 at the right of each parameter *via* “Min: “ and “Max : “.

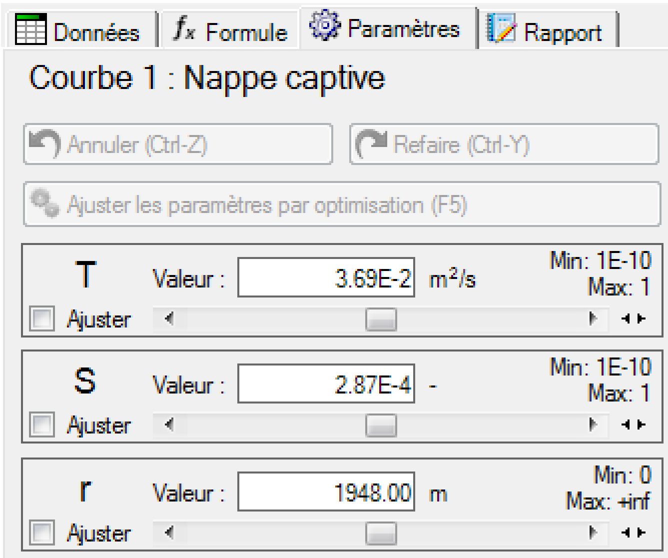


Illustration 76: Definition of boundaries

In the Bornes.ini file, [default] establishes the boundaries. For example:
`S|Hydro=1e-10;1` // S corresponds to the storage coefficient, the vertical bar “|”followed by Hydro indicates that this parameter addresses OUAIP's hydrogeology version. The min and max boundaries are separated by a semi-colon “;”.
`S|Geothermie=1e-16;1e-4`// Corresponds to the storage coefficient of the Geothermal versión of OUAIP (in preparation)
`S.Format=0.00E0` // Corresponds to the display format of the parameter in the entry field
`T|Hydro=1e-10;1` // T corresponds to transmissivity, the vertical bar “|” indicates that this parameter addresses OUAIP's hydrogeology version. The min and max boundaries are separated by a semi-colon “;”.
`T|Geothermie=1e-12;1`

The following syntaxes for boundaries are available:

- **Pourcent%** : signifies that there are no fixed boundaries, but this is initially relative to the defined value, the percentage value indicates the parameter’s margin of variation;
- **Pourcent%+** : same definition, but the value must remain positive (therefore in the sense of an increase in value);
- **min**;**max** : signifies that the value must be between min and max ;
- **min**;**max**;**default** : same meaning, but there is a specified default value.

If there is an asterisk "*" at the end of min or max, this means that the value is excluded from the interval. Some examples of boundaries (P=any parameter):

- P=10% : the parameter can be adjusted to around 10% of its initial value;
- P=10%+ : the parameter is positive and can be adjusted to around +10% of its initial value;
- P=0*; : the parameter is exclusively positive;
- P=10;20 : the parameter is at or between 10 and 20 ;
- P=; : the parameter can be positive, negative or zero (no constraint);
- P= ;; 0 : : idem but its initial value is zero;
- P=5E-5;2E-3;1E-3 : the parameter is between $5x10^{-5}$ and $2x10^{-3}$, by default, it is $1x10^{-3}$.

As an example, to modify the minimum ($1x10^{-12}$) and maximum (1) boundaries of transmissivity in $1x10^{-8}$ and 0.1, simply modify as follows:

`T=1e-12;1` becomes `T=1e-8;0.1`

4.5.4. Unites.ini (units)

The file units.ini permits adding new units. It is made up of several sections depending upon the dimension of the units. For example:

- [Temps] ; (Time)
- [Débit] ; (Discharge)
- [Distance] ; (Length)
- [Transmissivité] ; (Transmissivity)
- Etc.

As an example, if you would like to add a new flow rate unit which is cubic feet per hour, or ft^3/h), do the following:

1) Check that the unit of distance, feet, exists in the [Distance] section, otherwise, add into the [Distance] section.

2) In the [Débit] (flow rate) section, write the correspondence between the new unit and a unit which has already been defined, or:

- `ft3/h=0.028316846 m3/h`

Suppose that you would like to add the unit 'kilometre' in the [Distance] section. You add:

- `km = 1000 m`

As an example, you want to add m^2/min as a unit of transmissivity. Enter it in the [Transmissivité] (transmissivity) section:

- `m2/min = 1440 m2/j`

4.5.5. Langue.ini (language)

The file language.ini modifies the translation of OUAIP. It includes two sections by default: [Fran**\x00e7**ais] (for French) and [English].

Each text displayed in OUAIP is in one of these two languages. Special characters are used to display some characters in French, such as **é** (coded \x00e9), **è** (\x00e8), **ç** (\x00e7), **à** (\x00e0), **ê** (\x00ea), etc.

For example, the import button is written in French (section [Fran**\x00e7**ais]) and in English (section [English]):

- Button_ImporterDonnees=Importer...
- Button_ImporterDonnees=Import...

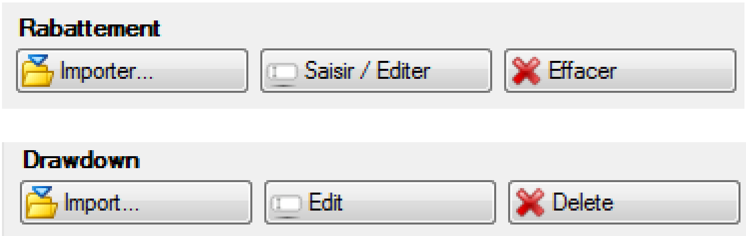


Illustration 77: Translating names

Modify a translation

OUAIP offers a graphic interface to modify the translation. When prompted in OUAIP, click on the current language and choose “Traduction…>” (translation) (Illustration 78).

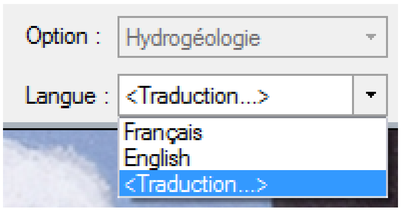


Illustration 78: System to translate OUAIP into other languages

The translation window filters names to be translated by category (buttons, questions posed to users, error messages, etc.). In order to modify a translation, click on the item to translate and enter it into the field at the top right.

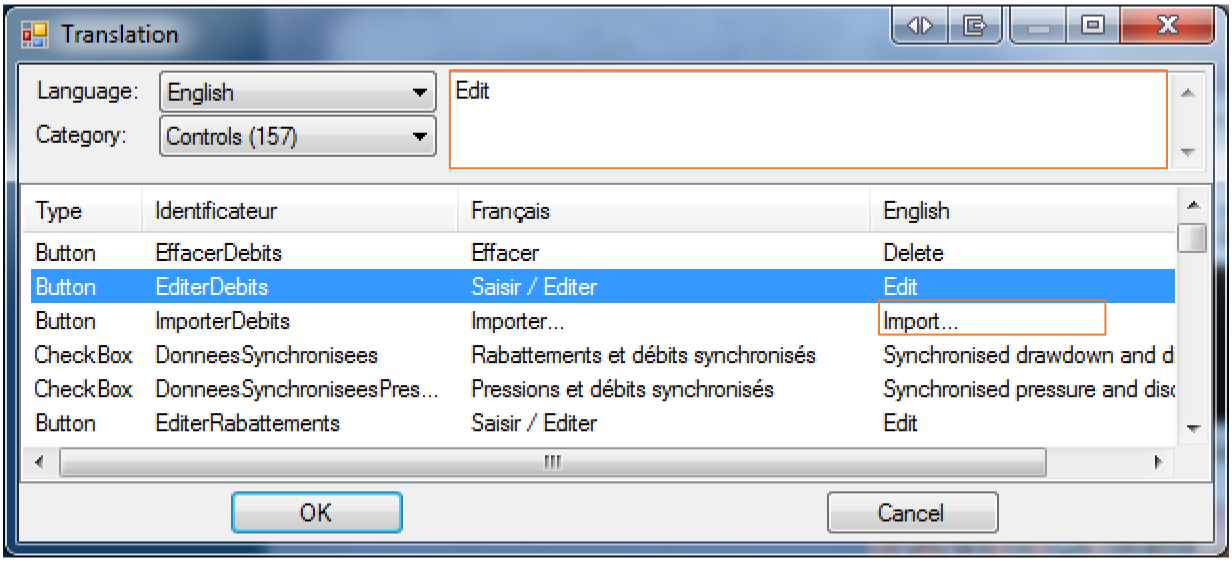


Illustration 79: OUAIP translation system

Add a language

In order to add a language, close OUAIP. In the language.ini, at the end of the file, add the section corresponding to the language. For example, in order to add the Spanish translation, add: [Spanish]

Start OUAIP. The new language will appear in the language menu (Illustration 80):

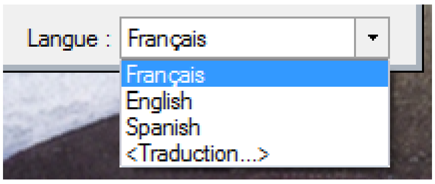


Illustration 80: Translation menu

Use the method presented above to translate names. You can help the OUAIP user community to benefit from your translation by sending it to us, and we will distribute it.

5. Use examples

5.1. INTERPRET A STEP-DRAWDOWN TEST

5.1.1. Tutorial No. 1 - Single interpretation

Context

The example used for this tutorial is linked to the public report: “Characterisation of hydrodynamic properties of alluvium in the Gravone river at Piataniccia, South Corsica.” This document is available for downloading (in French) in a PDF format on InfoTerre, ISBN/ISRN code: BRGM/RP-60905-FR.

The tested aquifer is unconfined of low thickness in the alluvium of the Gravone river.

The step-drawdown test consists of conducting 4 pumping steps on borehole F1. Each step (independent) includes at least one hour of pumping (at constant flow rate for the duration of a step) and at least one hour for recovery (stopping pumping).

The flow rate steps varied from 60 m^3/h to 120 m^3/h, with an increment on the order of 20 m^3/h between each one. Illustration 81 shows the evolution of the drawdown for each step.

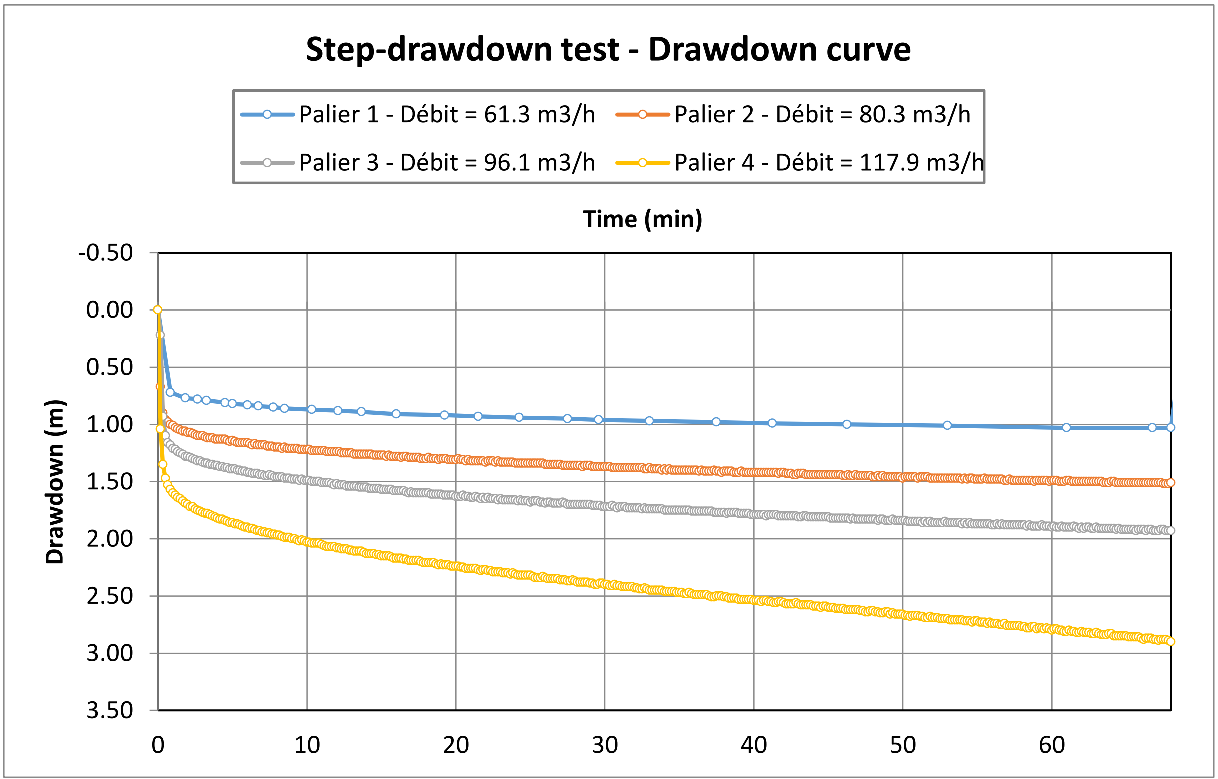


Illustration 81 : Change in draw-downs as a function of pumping flow rate

The results of the test (drawdown at the start of one hour of pumping as a function of flow rate) are summarised in Illustration 82 below:

Step	***Average pumping flow rate***	***Draw-down at t=1h***
no.	***(m3/h)***	***(m)***
1	61.12	0.96
2	78.81	1.42
3	96.06	1.95
4	117.63	2.78

Illustration 82: Summary of test data by section

Interpretation

Execute OUAIP and select “interpret a step-drawdown test”. The left part of the interface is used to enter input data. It consists of three tabs to use progressively from left to right (Illustration 83):

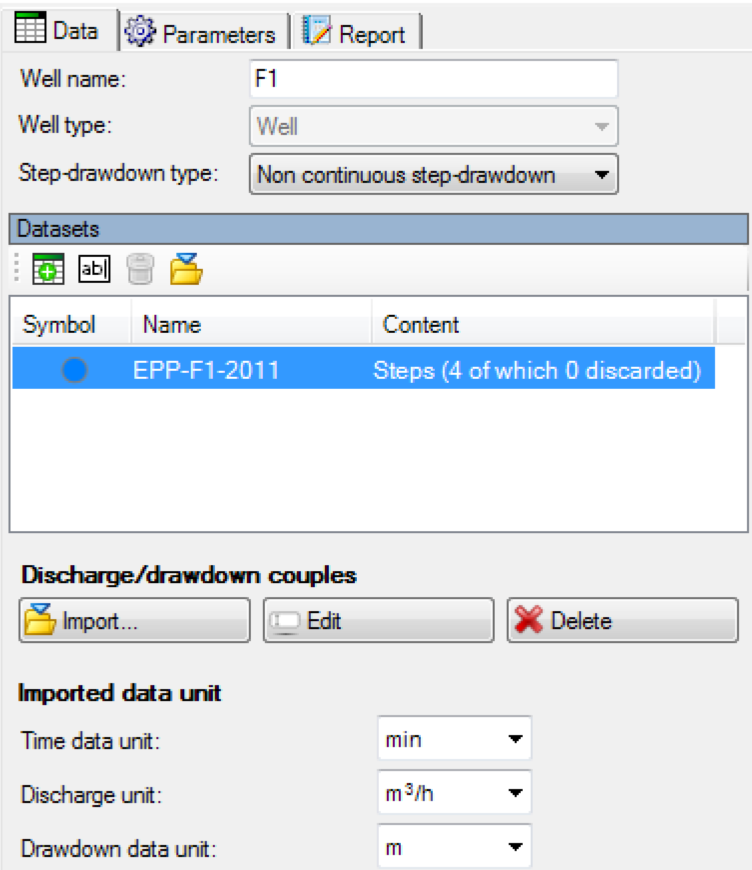


Illustration 83: Data tab

- Enter the name of the well, “F1.” It will be used in the interpretation report;
- Select “Non continuous step-drawdown”;
- Double-click on <no name> to define the name “SDT-F1-2011” of the dataset;
- Click on “enter/edit” to enter the corresponding flow rates and drawdowns from Illustration 82. You can directly copy-paste the digital data from Illustration 82, in selecting only lines and columns containing digital data, or else, to copy-paste the information from a

spreadsheet (see the “Step-drawdown test - Tutorial No. 1 Data.xlsx” file) in \Tutorials\Tutorial No. 1 - Step-drawdown test\) directly into the input table (Illustration 84).
- Verify the pumping rate units (m3/h) and the drawdown unit (m), then validate (F5);
- Optionally, you can enter the pumping and recovery durations for each step (in order to show this information in the report).

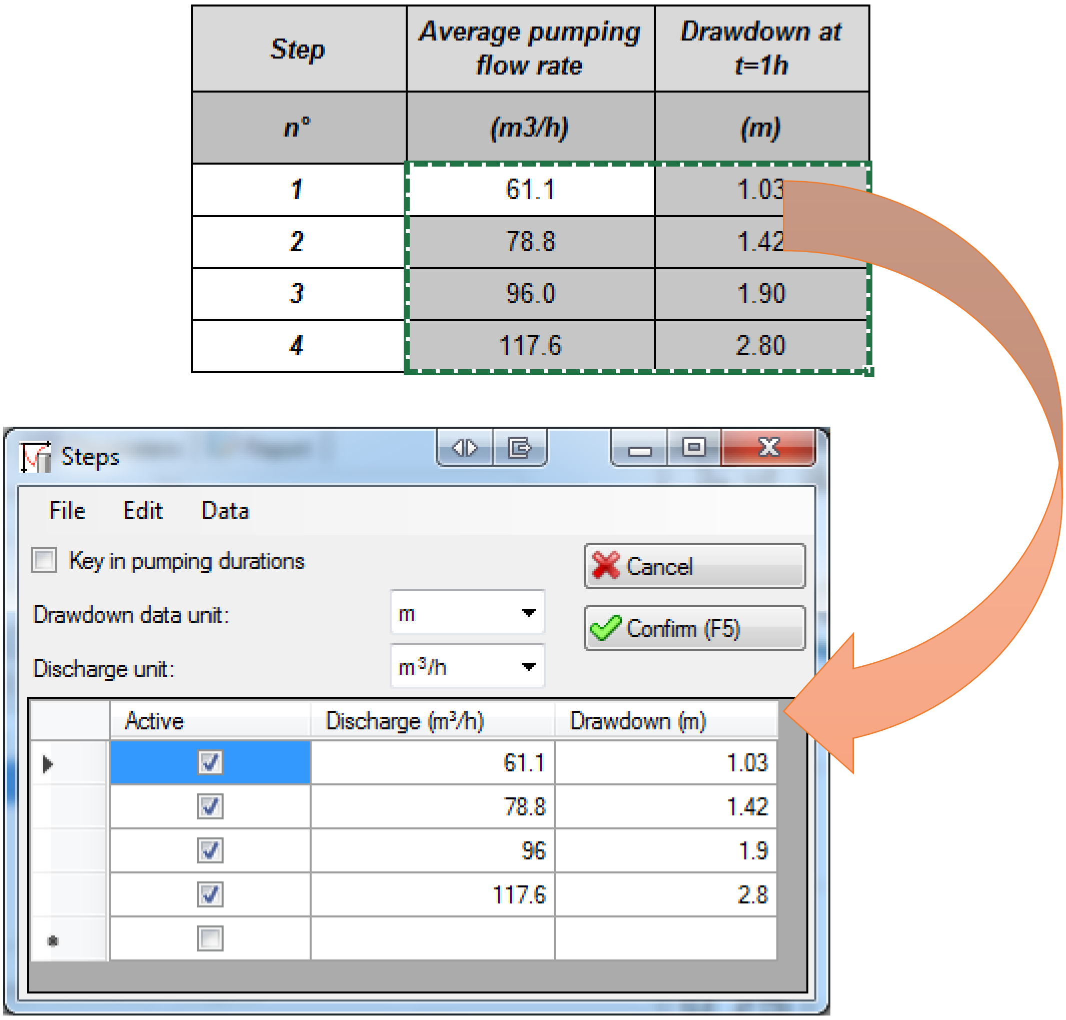


Illustration 84: Copy-paste the data from a spreadsheet to OUAIP

Once the data is validated, graph no. 1 “Characteristic curve” and no. 2 “straight line of the specific drawdowns” are updated, displaying the points (Illustration 85).

In most cases, the Characteristic curve equation is given as $BQ+CQ^2$ (Jacob), with s, the drawdown, Q, the pumping rate, B and C the linear and quadratic head loss coefficients. Thus, the right graph, which represents the specific drawdown s/Q as a function of pumping rate Q, will show aligned points. If not, unless in specific cases (exponent n different than 2), the non-aligned points invalidate the step-drawdown test. It could happen, for example, that the well development goes on during a step-drawdown test because the development phase was not concluded, or that clogging by fine particles occurs at the filter level following an excessive pumping rate. In these cases, the test cannot be correctly interpreted, and it must be redone in order to take into account the new drilling status, if applicable, after a new development phase.

Interpretation of a test by flow sections consists of determining the B and C parameters which respectively characterise linear and quadratic head losses (also called ‘singular’ head losses).

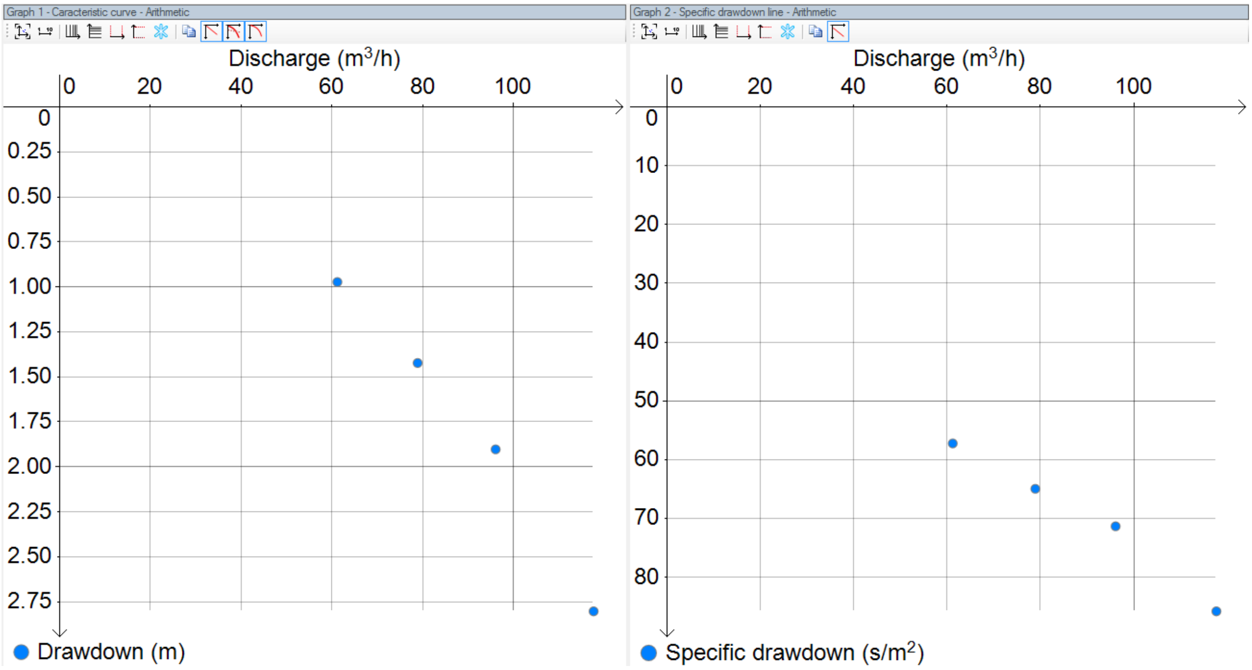


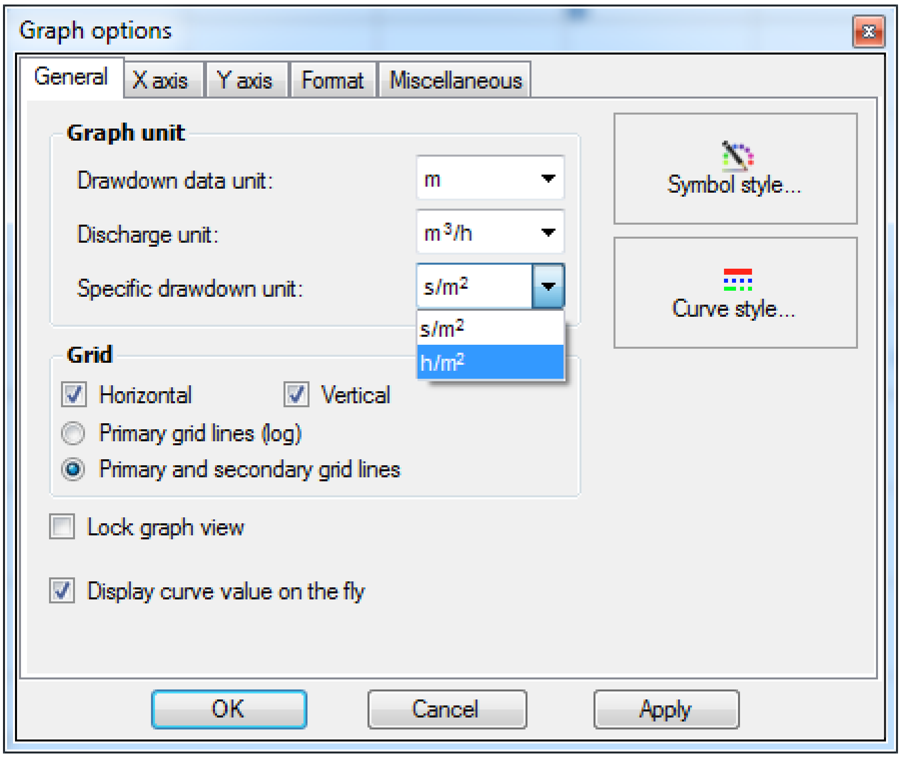
Illustration 85: Graphs with Characteristic curve and straight line of the specific drawdowns

Then click on the “parameters” tab to define the solution parameters. Start by adjusting “B”: the linear head loss coefficient this corresponds to extending the imaginary straight line passing through the graph points of the right-hand side graph, intercepting the axis of the s/Q ordinates.

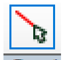
Express B in s/m² for better precision. In effect, the h/m² unit leads to using small values which are often rounded, while s/m² unit gives whole values which are easier to handle. In the same way, the C parameter is more relevant when it is expressed in S.I. units.

If units are not set this way, we therefore advise modifying the units in graph 2 by right clicking on the graph, in the menu, select the “graph” item in the “general” table, modify the “specific drawdown” unit from h/m² to s/m². One does not need to modify the flow rate unit (keep that which was used during the tests).

Alternatively, by left clicking on the “B” parameter unit, you can convert a value to another unit (for example, from s/m² to h/m² or vice versa). Modifying the unit impacts the graph. The use of a unit converter is presented in Chapter 4.1.3.



Then click on the “Adjust the zoom” button  (or press the “orig.” or “Home” on the keyboard) in order to update the graph display.

The approximate value for B can be estimated by projecting the straight line on the Y-axis passing through the graph points of specific drawdowns as a function of pumping rate (right graph). OUAIP offers a tool to trace this straight line. This is the button  “Trace the straight line for specific drawdowns.” This tool automatically places the value of B in the parameters tab (Illustration 87).

In the example of this tutorial: B = 25 s/m².

NB: the straight line traced here is temporary to help the user to find the best value of B with his visualisation. The figures can also be manually entered in the parameters tab.

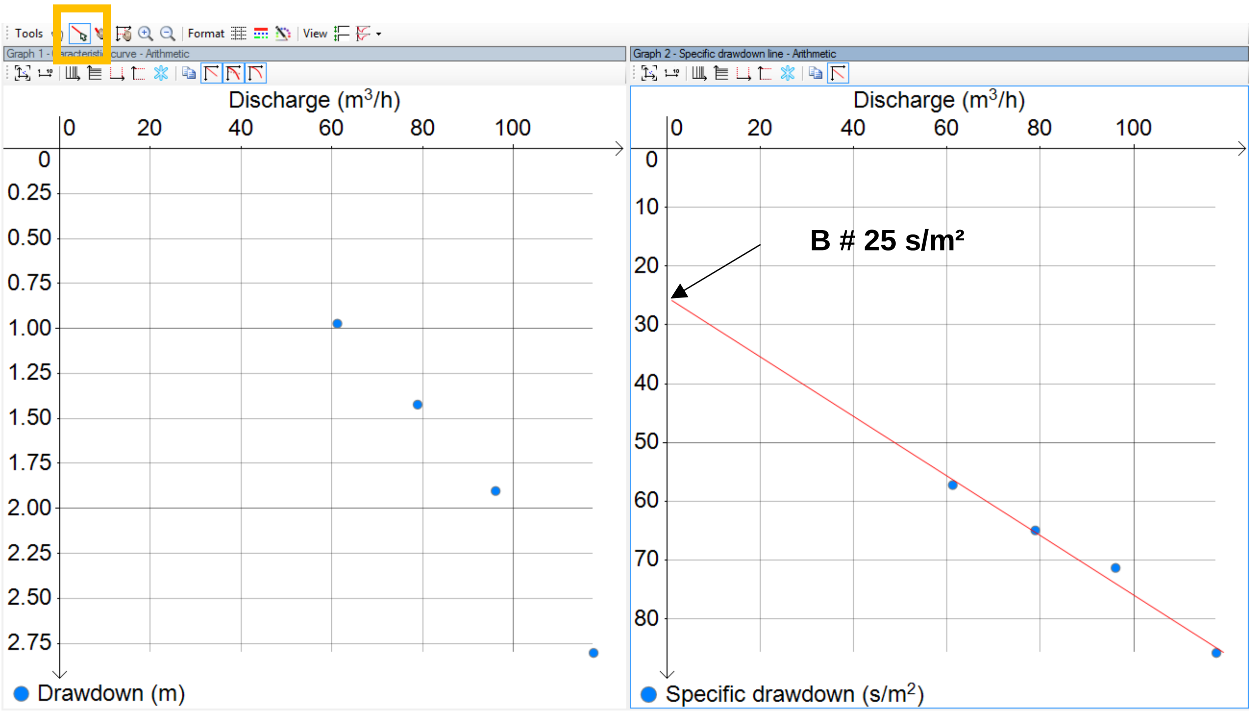


Illustration 86 : Manual tracing of the straight line for specific draw-downs.

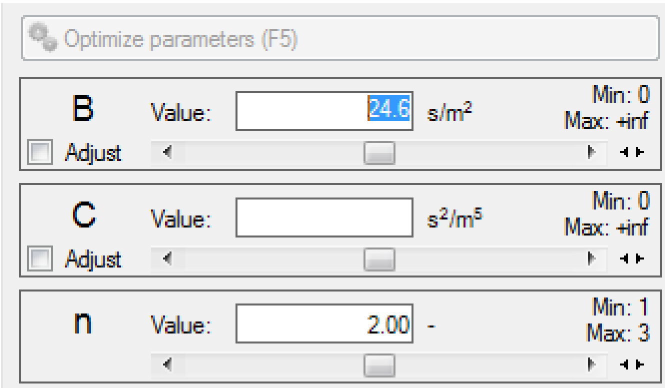
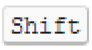


Illustration 87: Estimate of the linear head loss coefficient

Now enter the value for “C”: “Quadratic head loss parameter coefficient”. Keep the unit offered by default of s^2/m^5, set an initial value of 1000 s^2m^5. The value of the exponent equalling 2 remains unchanged. Now adjust the value of B and C parameters by using the horizontal scroll box, from left to right. When the scrolling arrives to the end, release the mouse button so that the scrolling recovers a central position, and restart the action (Illustration 89).

If you would like to vary the parameters by using the scroll boxes, OUAIP also offers two methods to vary the values considered for the parameter which allows the user to modify a parameter with greater or lesser precision.



: hold down the “shift” button (press “cap”) on the keyboard while moving the horizontal scrolling:

- To the left, the mantissa part is rounded to a whole number and decreased by 1. If the mantissa is less than 1, the exponent is decreased by 1, and so on;

- To the right, the mantissa is rounded to a whole number and increased by 1. If the mantissa is greater than 9, the exponent is increased by 1, and so on.

Example: Let's lower transmissivity T = 4.53×10^{-4} m²/s (press down the shift button + the up arrow on the left). It takes the following successive values: 4.0×10^{-4}, 3.0×10^{-4}, 2.0×10^{-4}, 1.0×10^{-4}, 9.0×10^{-5}, 8.0×10^{-5}, …

Ctrl : hold down the "ctrl" button on the keyboard while moving the horizontal scrolling:

- to the left (÷2, ÷2.5, ÷2). In this case, this action divides the current value by 2, then 2.5, then 2, and so on;
- to the right (x2, x2.5, x2). In this case, this action multiplies the current value by 2, then 2.5, then 2, and so on.

A tooltip reminds you of these tips when the user moves the mouse over the area indicated in red below (Illustration 88):

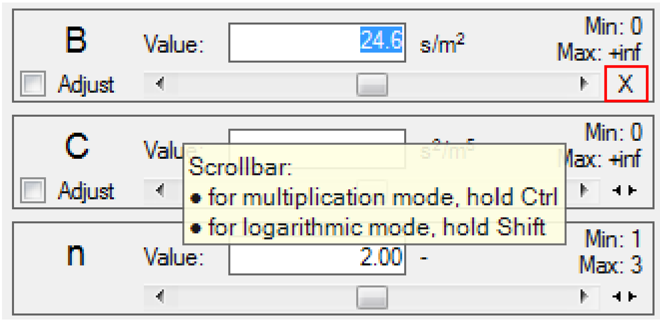


Illustration 88 : Info bubble to modify the parameters

Example: C = 1×10^{3} s^2/m^5 is raised (hold down Ctrl + right up arrow) and take the following successive values: 2.00×10^{3} (x2), 5×10^{3} (x2.5), 10.00×10^{3} (x2), 20.00×10^{3} (x2), 50×10^{3} (x2.5), …

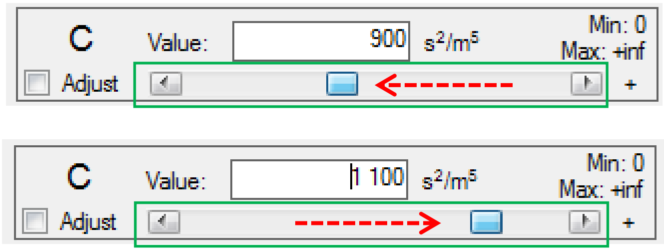


Illustration 89 : Modifying parameters

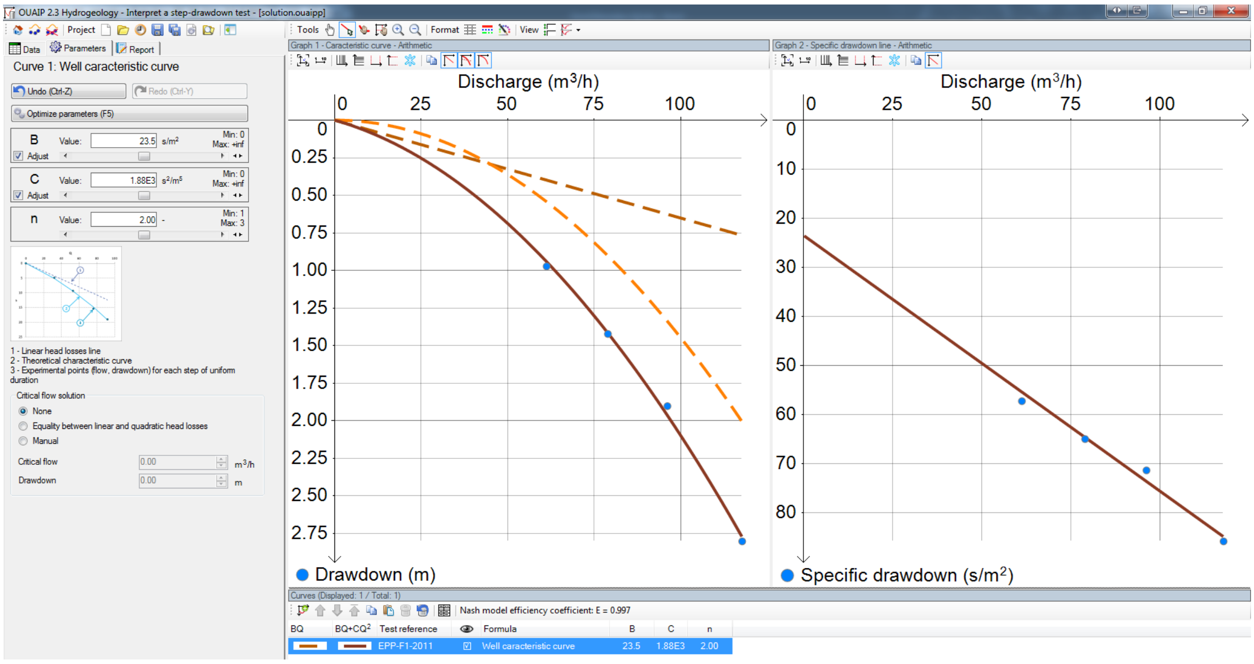
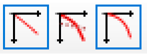


Illustration 90 : Result after calibration

After calibration, the B value is 24.6 s/m² and C = 1 8450 s²/m⁵ (Illustration 90).

With the  buttons on the graph toolbar on the left, one can display several curves:

- The Characteristic curve,
- The linear head loss line,
- The quadratic head loss curve.

Classically, one can display the Characteristic curve and the linear head loss line to reveal the “fall” of the head loss curve as compared to the linear head loss line.

Determining critical flow rate within the meaning of quadratic head losses can be done in one of two ways: either drawing all the curves (the critical point is therefore the intersection of the quadratic head loss curve and linear head loss line), or in ticking the button (left panel) “equal point of the linear and quadratic head loss coefficients”.

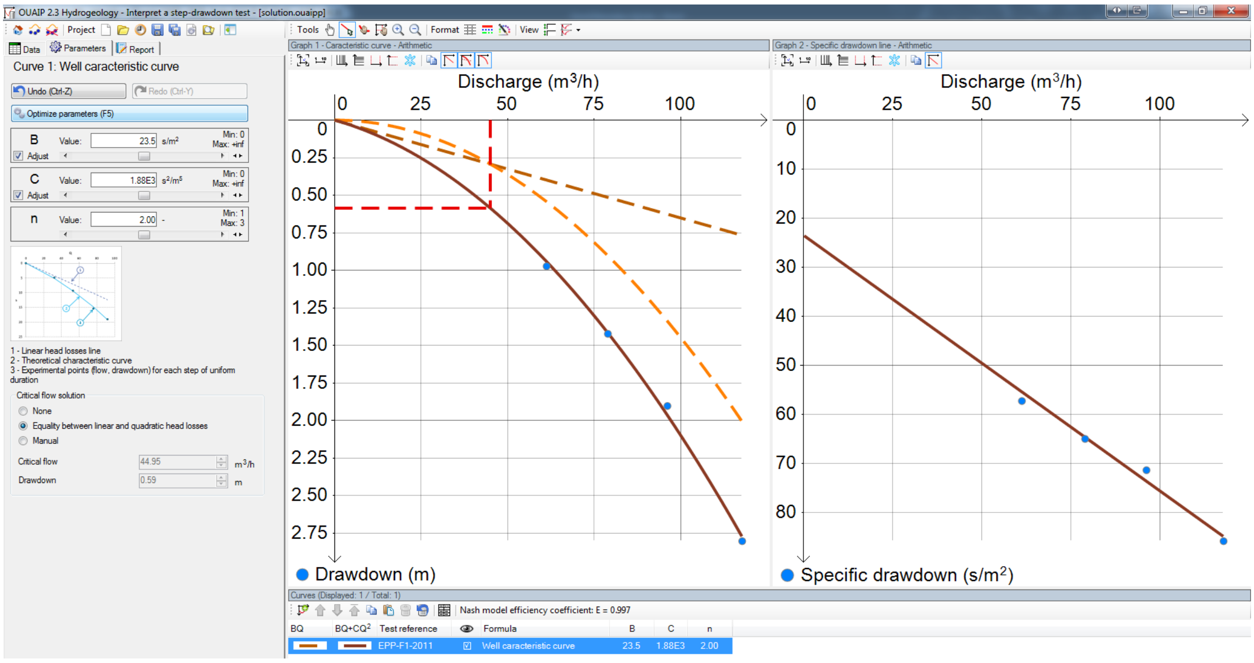


Illustration 91 : Determining critical flow rate

The report tab edits a summary report showing all the information from the test. Enter the contextual data for the test in order to show it in the report (Illustration 92):

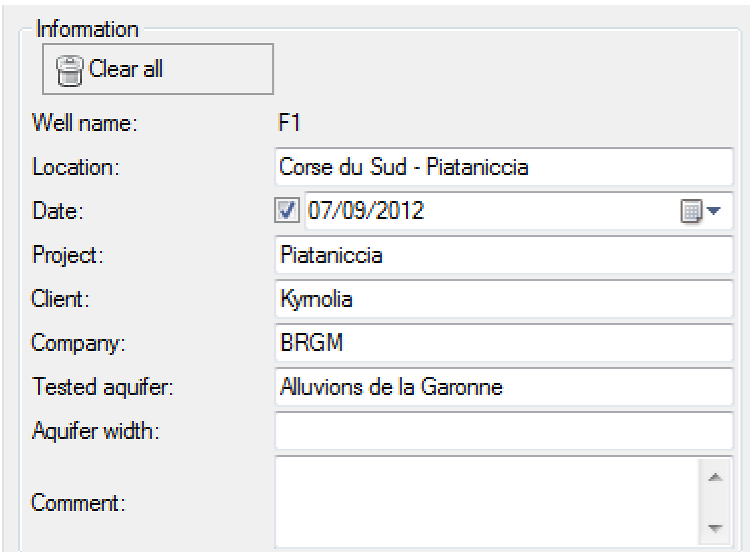


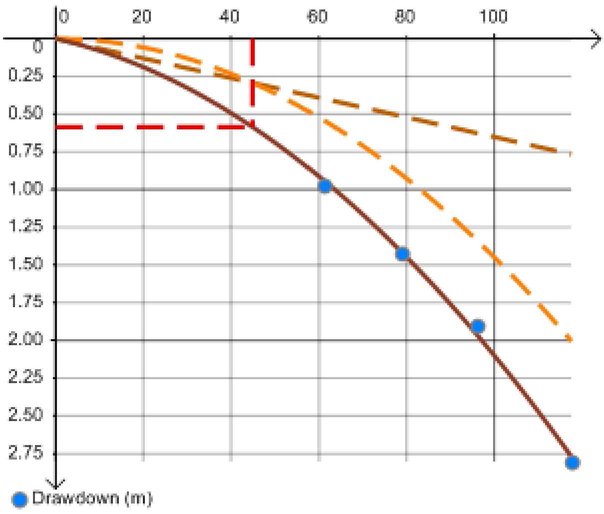
Illustration 92 : Report tab

The report can be exported in PDF or HTML format. The images and graphs are exported in a vector format (EMF for Word and SVG for the web). Illustration 93 below shows a sample report.

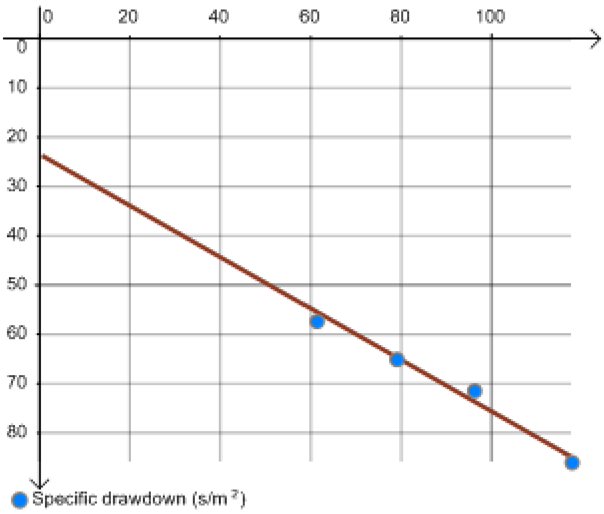
brgm	F1	OUAIP v2

Location	Corse du Sud - Piataniccia	Company	BRGM
Date	07/09/2012	Tested aquifer	Alluvions de la Garonne
Project	Piataniccia	Well type	Well
Client	Kyrnolia	Step-drawdown type	Non continuous step-drawdown

Caracteristic curve



Specific drawdown line



Legend	
	Critical flow
	Experimental data of EPP-F1-2011
	Linear head losses
	Quadratic head losses
	Well caracteristic curve

Legend	
	Experimental data of EPP-F1-2011
	Specific drawdown

Comment

Data after 1h of pumping, on original files + corrections

Test		EPP-F1-2011	Curve	

Discharge step	Discharge (m^3/h)	Measured drawdown (m)	Pumping duration (min)	Recovery duration (min)	Computed linear head losses (m)	Computed quadratic head losses (m)	Observed specific drawdown (s/m^2)	Computed specific drawdown (s/m^2)	Error (sim-obs) (m)
Step 1	61.1	0.97	-	-	0.4	0.54	57.2	55.3	-3.1×10^{2}
Step 2	78.8	1.42	-	-	0.51	0.9	64.9	64.6	-6.91×10^{3}
Step 3	96	1.9	-	-	0.63	1.3	71.3	73.5	6.08×10^{2}
Step 4	117.6	2.8	-	-	0.77	2	85.7	84.8	-2.99×10^{2}

Adjustement parameters		
Linear head losses coefficient (B)	0.00651 h/m^2	**23.5 s/m^2**
Quadratic head losses coefficient (C)	1.44×10^{-4} h^2/m^5	**1.88×10^{3} s^2/m^5**
Exponent (n)	2.00	

Critical flow	45 m^3/h

Corse-Gravone.ouaipp (OUAIP v2.3) *http://ouaip.brgm.fr*

Illustration 93: Interpretation report for a step-drawdown test

To finish, save your OUAIP project. It will take on the extension ouaip**p** ("**p**" for "**palier**" [step]). You can load the solution in opening the "Step-drawdown test - Tutorial No. 1 Solution.ouaipp" file to check your results.

5.1.2. Tutorial No. 2 - Compared interpretation

OUAIP v2 can enter and interpret several step-drawdown tests in the same OUAIP file, especially for comparisons. An example is placed in the OUAIP folder, in  \Tutorials\Tutorial No. 2 - Step-drawdown test\Step-drawdown test - Tutorial No. 2 Solution.ouaipp" file.

A first step-drawdown test for which the data has been entered "before acidification" is interpreted. The quadratic head loss coefficient is roughly 3900 s^2/m^5.

Following the first step-drawdown test, acidification was performed in order to improve the productivity of the borehole. One can now interpret the second step-drawdown test in order to evaluate if the well performance was improved.

In the "data" tab, click on the "add a dataset" icon (Illustration 94), enter the name of the "after acidification" dataset, then click on "enter/edit" and enter the values of the table below:

Step no.	Q (m3/h)	s (m)
1	60	2.95
2	120	6.95
3	180	12.05
4	240	18.25

The icons below provide, in order:

-  Adding a new dataset,
-  Renaming a dataset,
-  Erasing a dataset,
-  Importing a dataset or interpretation coming from a *.ouaipp file.

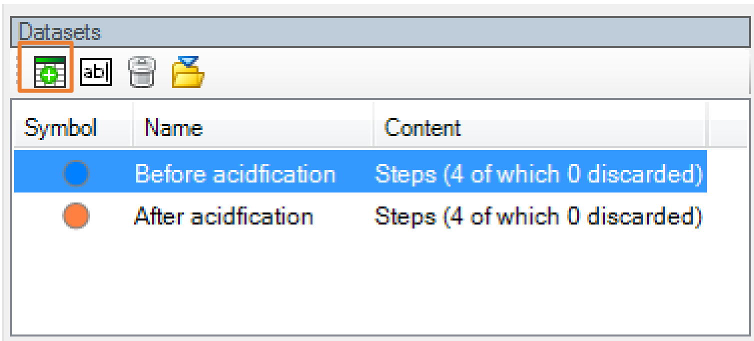


Illustration 94: Add a new dataset,

Then, in the list of curves, click on "duplicate the selected curve" in order to create a new interpretation. Then, in the "Test reference" column (Illustration 95), click on "before acidification" of the new curve to merge the "after acidification" dataset (Illustration 96).

In order to avoid temporarily overloading the graph, you can hide the first interpretation by clicking on the check box in the column with the symbol (Illustration 96).

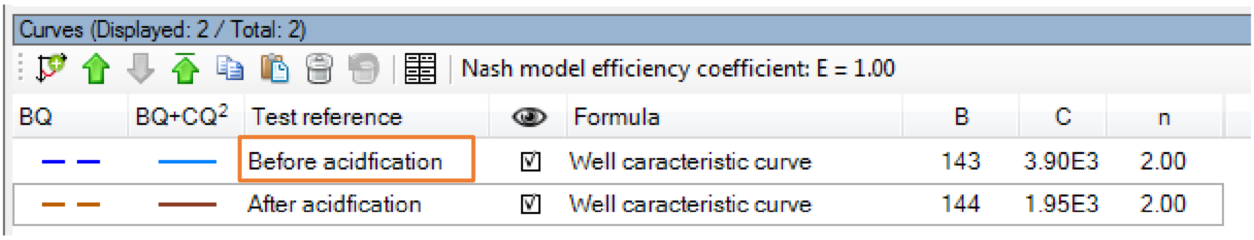


Illustration 95: List of curves and joining a dataset ("reference test" column)

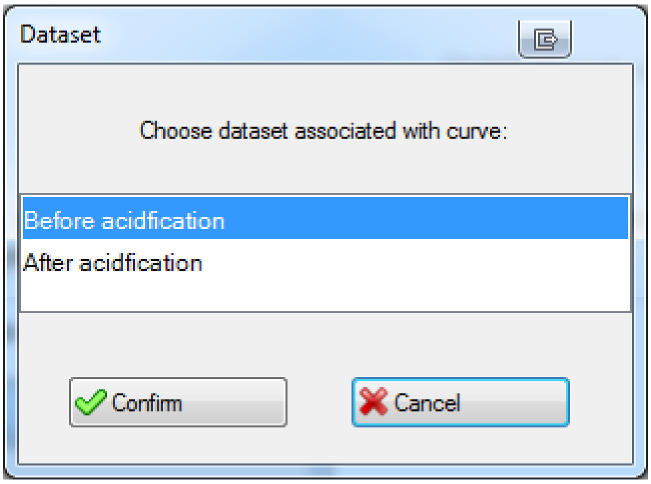


Illustration 96: Join a dataset

You can now proceed to the interpretation in the "parameters" tab. This confirms that C#1950 s^2/m^5. The wells' performance was improved after acidification, the quadratic head losses were lower. At 240 m^3/h, the quadratic head losses changed from 17.34 m to 8.67 m.

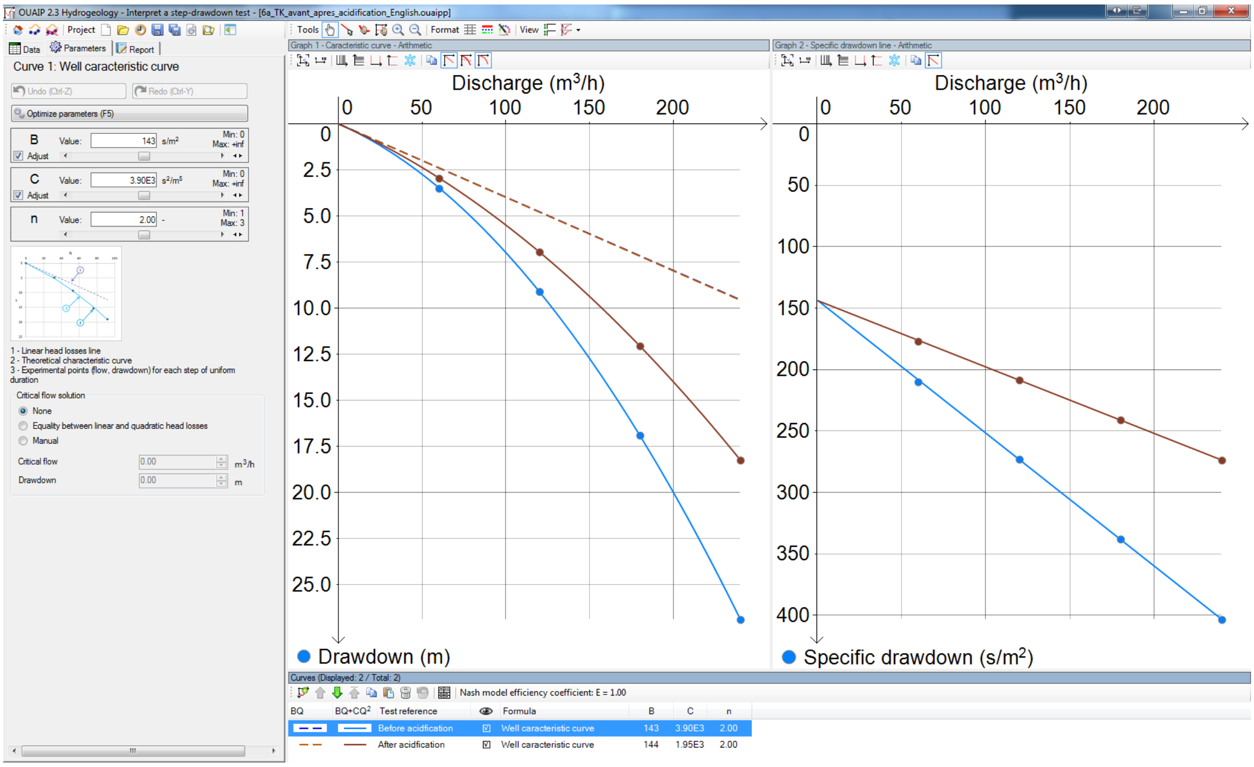


Illustration 97 : Comparison of the interpretations of two step-drawdown tests

5.1.3. Other tutorials

You can work on the following 9 datasets to interpret other step-drawdown tests in the folder:

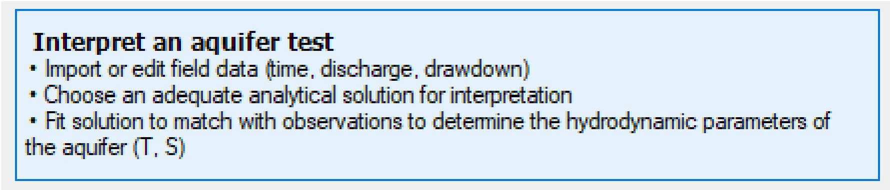
- Tutorial No. 3 - Step-drawdown test: this example offers 8 datasets for different well. Open the Excel file ("*.xls" or "*.xlsx"), import the "data" sheet containing the information (flow rate and drawdown column) by using copy-paste on the columns to the "enter/edit" window on the table. The "exercise" file includes the OUAIP files with the data already imported. The "solution" folder includes the *.ouaipp files with the solution.

The datasets presented in tutorial no. 3 are taken from the public report "Geological and hydrogeological monitoring of 3 reconnaissance drillings at the Tivoli site, Fort de France (Martinique), Final report," available for downloading , in French, in a PDF format on InfoTerre, ISBN/ISRN code: BRGM/RP-60339-FR.

- Tutorial No. 4 - Step-drawdown test: this example is extracted from the report: "Hydrogeological prospecting of the fractured basement of Bourg de Roura" BRGM/RP-67440-FR (on-line, in French). The detail of the drawdown calculations for each section is given for information in the file "Step-drawdown test - Tutorial No. 4 Data.xlsx." ("step-drawdown test" sheet). The "summary table" sheet summarises information needed for interpretation. The folder also containing the technical drilling section, the OUAIP project, its solution and the OUAIP interpretation report in PDF format.

5.2. INTERPRET AN AQUIFER TEST

The groundwater test's goal is to determine the aquifer's hydrodynamic parameters (transmissivity: T, storage coefficient: S) which forms the basis of hydrogeology calculations, such as those used to estimate the impact of pumping on the adjacent areas, designing protection perimeters, drying up of an excavation site or modelling groundwater. The groundwater test is longer than the test by flow sections in that it includes a significant aquifer volume (several hundreds of metres around the drilling).



5.2.1. Tutorial No. 5 - Theis solution (1936)

Context

The groundwater test consists of pumping in alluvial groundwater for a (short) duration of 2 hours. Monitoring is done by a piezometer 10 m away from the pumping well. The pumping well is complete, the saturated thickness is roughly 30 metres. The water level in the observation well was monitored during drawdown and recovery. The maximum measured drawdown is 0.3 m.

Interpretation

Launch OUAIP and select "interpret an aquifer test". The left part of the interface is used to enter starting data. It consists of four tabs to use progressively from left to right (Illustration 98):

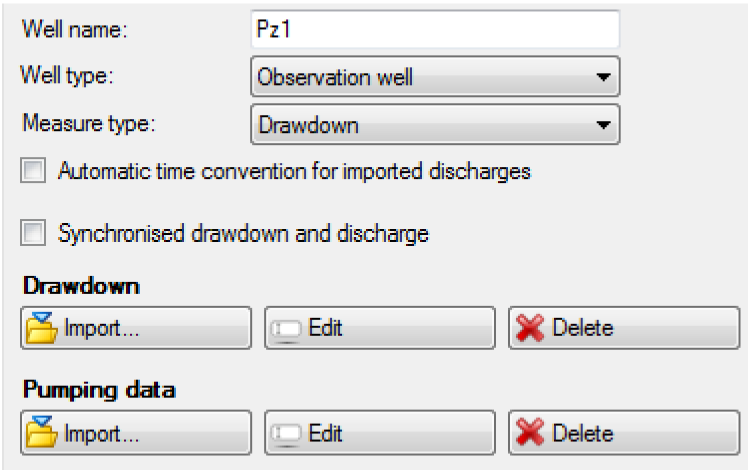


Illustration 98 : Data tab

In the "data" tab:

- Define the name of the well being monitored: "Pz1":
- In "type of well," select the type of well monitored: "Piezometer";

- If the draw-down data and the flow rate monitoring to be imported are synchronous, check the box “drawdown and flow rates synchronised” (by default, OUAIP considers them desynchronised);

“**Synchronous data”** means that the measurements of drawdown and flow rate were done at the same time. Thus, each line on the data table contains the information: time, drawdown and flow rate.

If the draw-down and flow rate were measured at different times (therefore independently), uncheck the box. Then one can enter the value with the time in a table, and the time and flow rate in another one.

- Click on “import,” then select the “Aquifer test - Tutorial No. 5 Data.csv” file in the directory “Tutorials**Tutorial No. 5 - Aquifer test - Theis”**. This file contains the time, drawdown and flow rate data, one line per measurement. The data can also be accessed in different formats (Aquifer test - Tutorial No. 5 Data.xlsx), however, OUAIP does not allow importing an Excel file. One must either copy the data from the Excel file into a text file (*.txt, *.csv), or copy-paste the data directly from Excel to the OUAIP spreadsheet;
- During loading of the file, the window below asks the user how the flow rates are to be taken into account (Illustration 99).Select the first option and click “OK”. If the pumping rate is not constant, it will be subdivided in pumping steps
    - By default, the time/flow rate pair corresponds to the start of the step,
    - Otherwise, the time/flow rate pair corresponds to the end of a step.

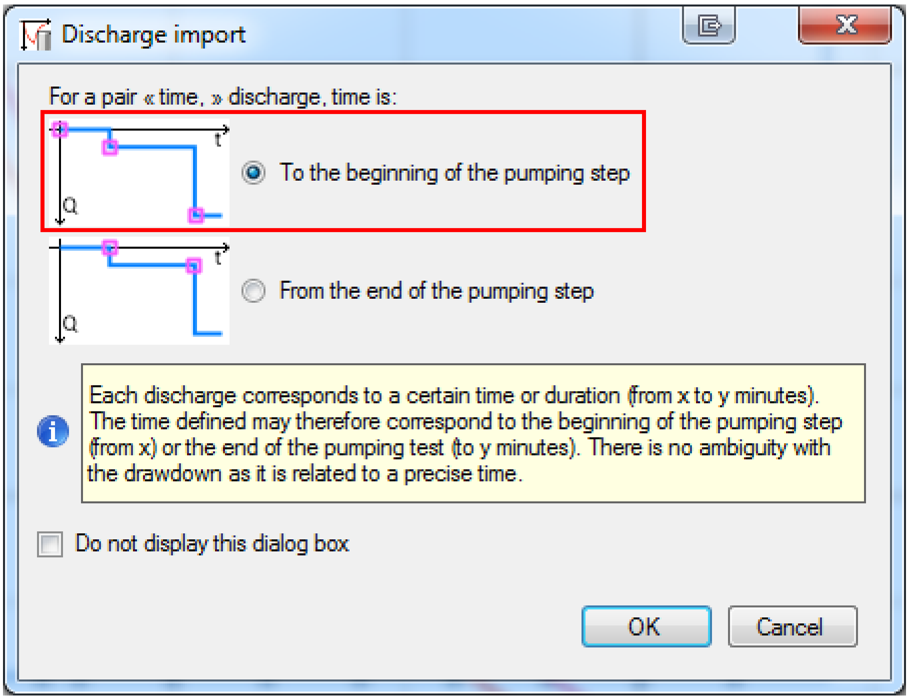


Illustration 99 : Importing flow rates

The “imported data units” insert allows you to modify the data units for time, drawdown and pumping rate. In this case, the units are specified in the imported *.csv file. OUAIP therefore automatically recognises them.

If there are a **lot of imported data** (drawdown, flow rate), it is recommended that you use the filtering options (Illustration 100) to simplify the history. Filtering makes it possible to dispense with data at times when they are stationary, and makes it possible to lighten the visualisation and to improve the efficiency of parameter optimisation procedures when used.

As an example, you may have recorded the data with a fine acquisition step (less than one minute), but in practice, only variations of drawdown are of interest for interpretation of the test. Filtering can therefore dispense with data that does not vary, and can improve execution speed to optimise parameters, in particular if a new file is created with filtered data. To do that, copy your filtered data in a spreadsheet, sort and keep only the active data, import again the data into OUAIP.

To the degree that the pumping rate does not vary much in your test, the history of the flow rate can be as simple as possible in order to improve calculation performance (the principle of superposition can drastically slow down some calculations and parameter optimisations).

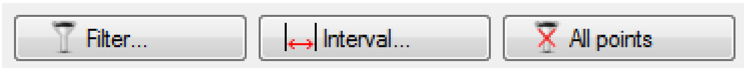


Illustration 100: Data filtering options

Click on “filtering” to select filtering method (Illustration 101). As an example, one can filter on condition if the drawdown varies of at least 0.01 m, which eliminates 11 measurement points (Illustration 102). The filtered points are not taken into account in the parameter optimisation process. The quantity of data during this test is not high. One can therefore click on “all the points” to again use all the available data.

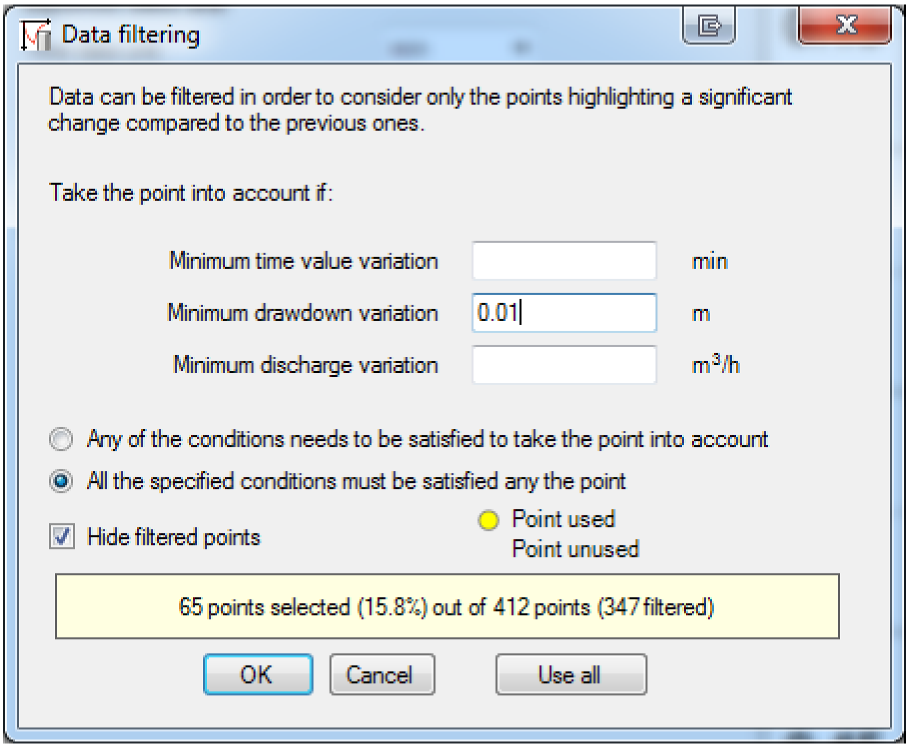


Illustration 101 : Filtering data (example on other big data set)

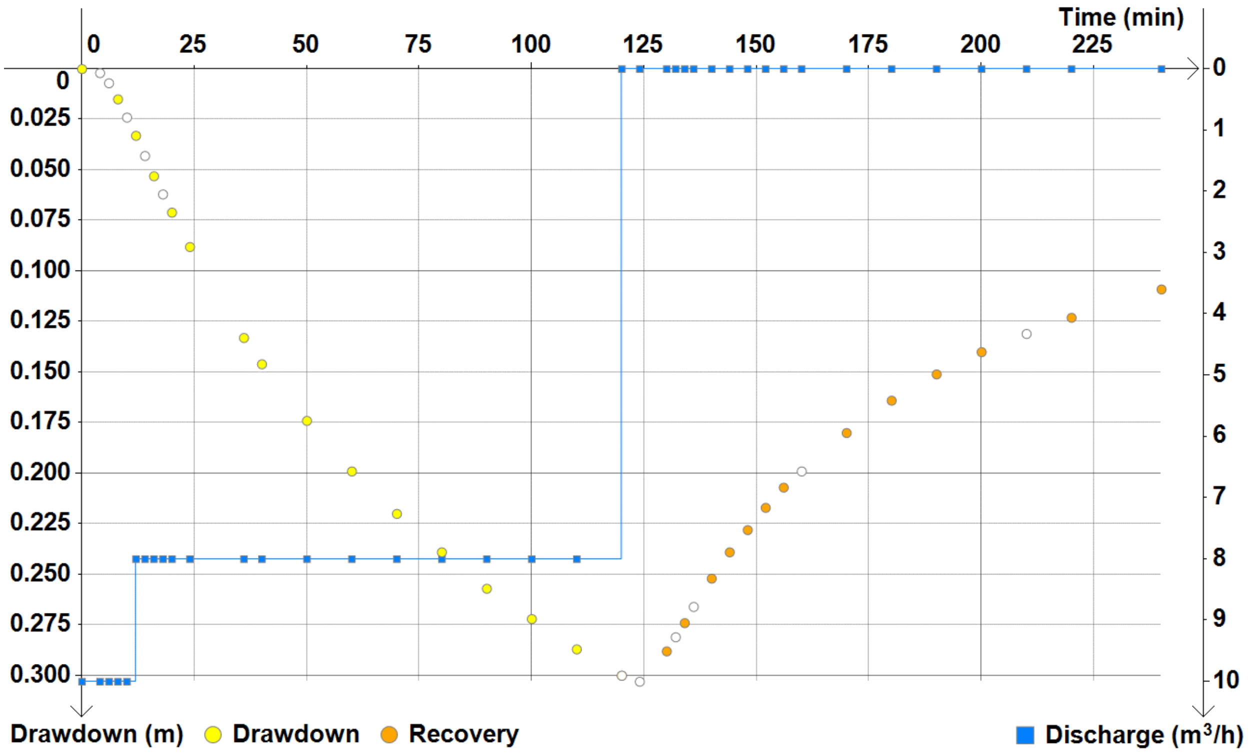


Illustration 102 : Consequence of filtering draw-down data (white points filtered)

Once the data are imported, the graph time, drawdown and pumping rate can confirm the presence of two pumping steps (blue lines, right axis pointed upward), a recovery (pumping rate zero) and the change in drawdown (drawdown yellow points, and recovery orange points, left axis pointing downward). The pumping rate change is slightly visible on the piezometer.

The different tool bars available, outlined in orange, are presented in Chapter “4.3 The tool bar.”

Note that you can display a second graph by clicking/stretching the area outlined in green to allow (Illustration 103):

- Displaying curves with another scale (semi-log or bi-log);
- Zooming on a part of the available data (drawdown, recovery);

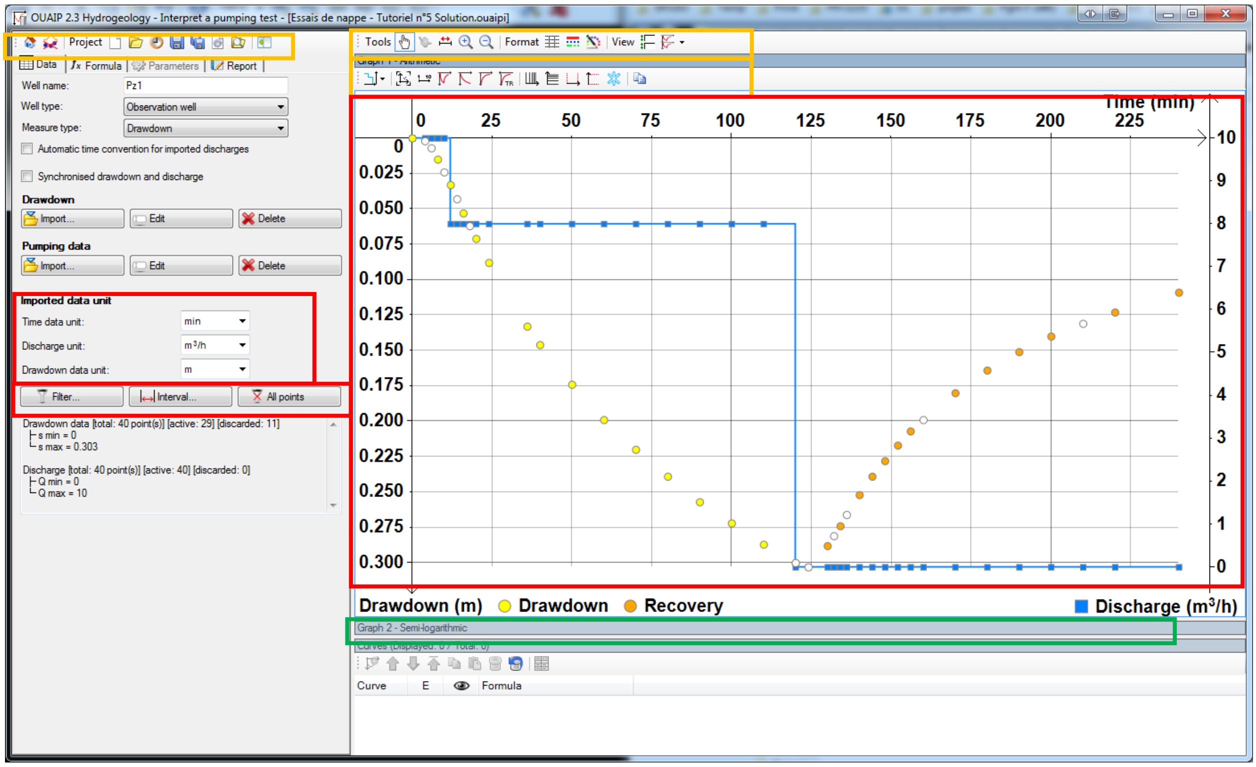


Illustration 103 : Direct data entering and visualisation

Use the OUAIP tool bar to save your project in *.ouaipi format ("i" for "interpretation").

Once the data are entered, you can see that the "formula" tab is now accessible (Illustration 104).

Illustration 104 : Activate the formula tab

In the "formula" tab, a list of analytical solutions using various groundwater and media typologies is offered. Select the Theis solution. For information, a diagram of the flow configuration will be displayed. Click on "add a curve with this formula" to interpret the test with this solution (Illustration 105).

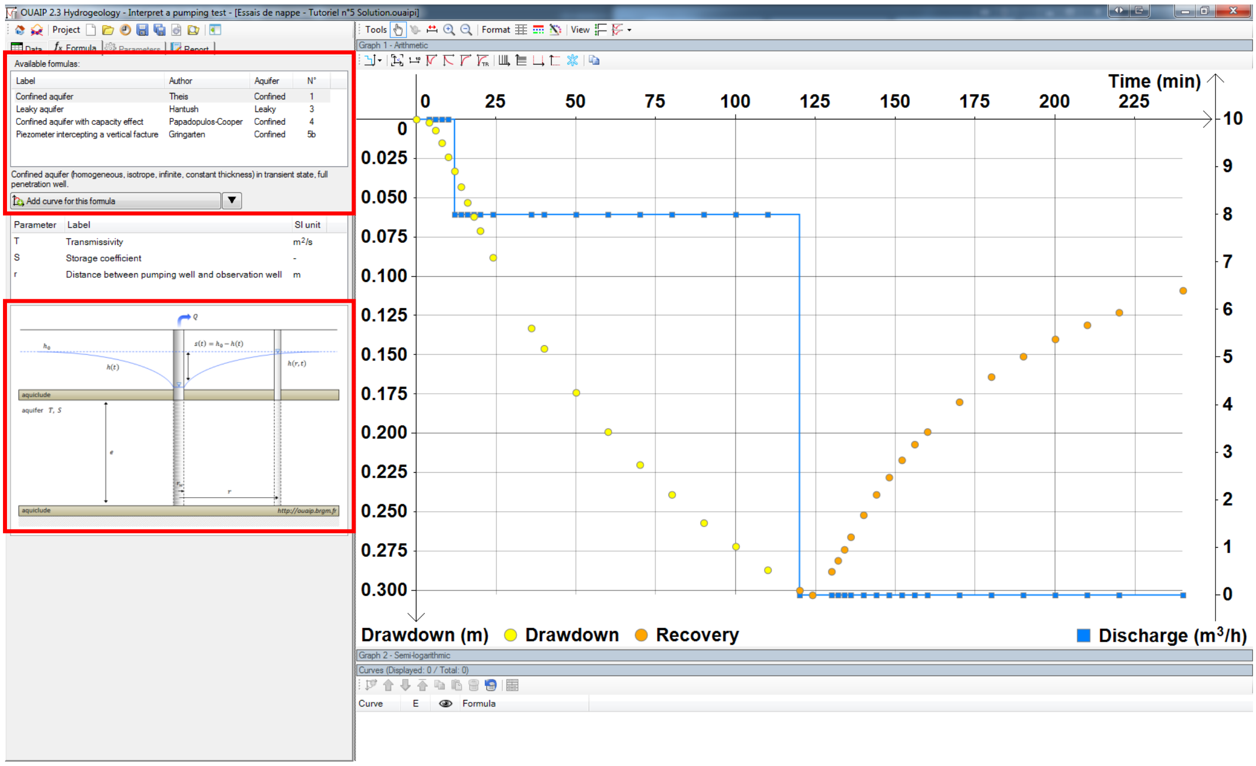


Illustration 105 : Formula tab

The “parameters” tab becomes accessible. Click on it. The page displays different parameters of the selected analytical solution. Initialise the parameters to be able to calculate and display the simulated curve (Illustration 106):

- Transmissivity: $5x10^{-3}$ m²/s (enter 5e-3)
- Storage coefficient: $1x10^{-2}$ (enter 1e-2)
- Distance from pumping well - observation point: 10 m

Once the parameters are entered, the simulated curve is calculated based on the specified pumping rates (Illustration 107). Using the horizontal up arrow, lower the transmissivity value to obtain a maximum drawdown of about 0.3 m. Then increase the storage in order to correctly represent the slope of the drawdown and the recovery, and finally lower the transmissivity again to complete the calibration (Illustration 108).

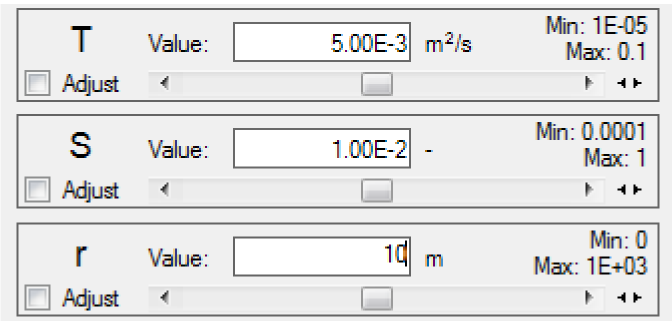


Illustration 106 : Modifying parameters

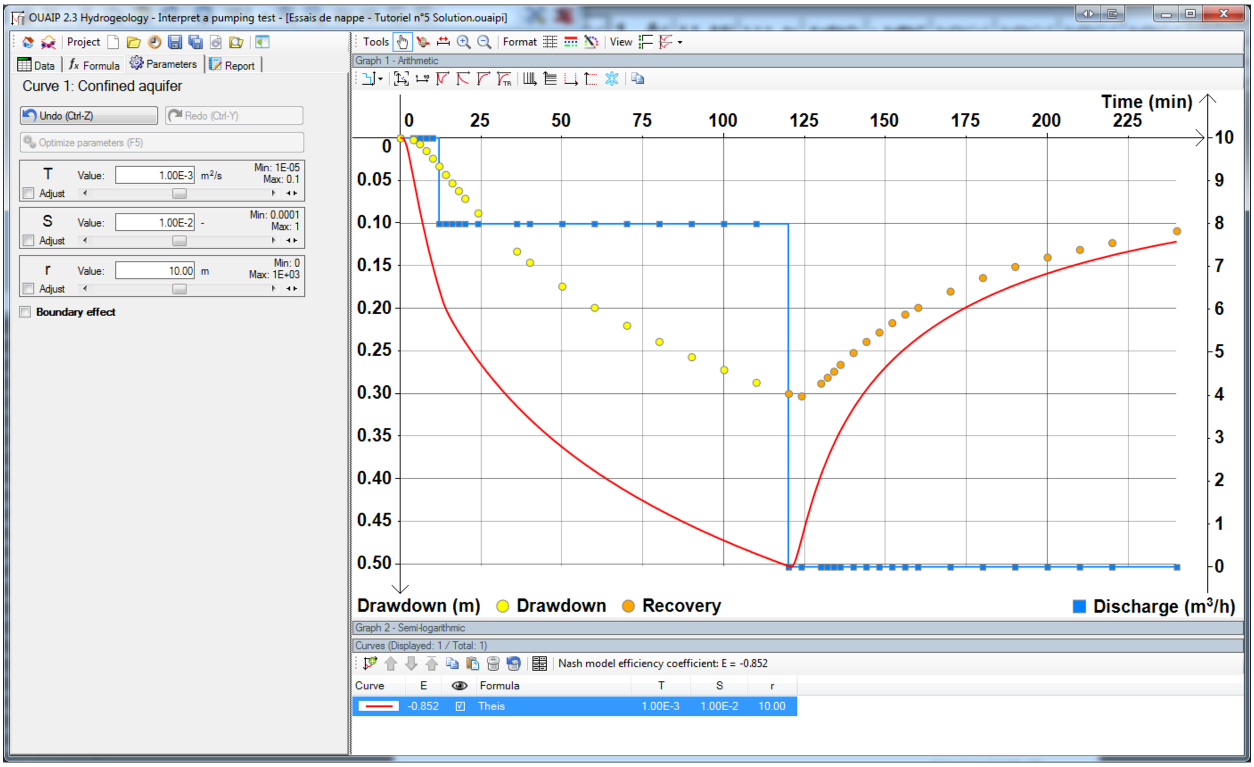


Illustration 107 : Initialising the parameters

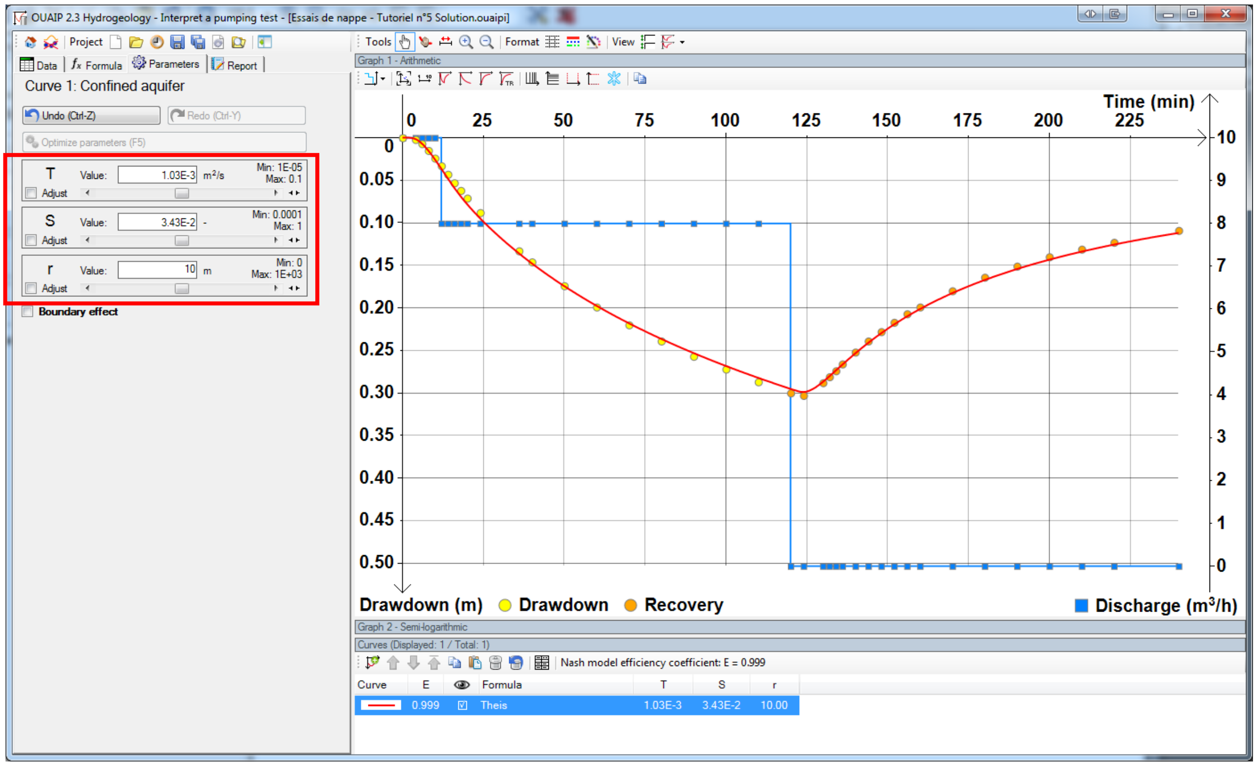


Illustration 108 : Adjusting the parameters

One can also adjust the hydrodynamic parameters by manually moving the curve. In order to do this:

- Check “adjust” on the parameter(s) that you would like to adjust (such as T);
- The  icon is now active in the adjustment tool bar. Select it;
- Then, click and hold on the curve with the mouse and move it horizontally and/or vertically. Note that the parameters are changed in real time;
- Uncheck T and then check S to restart the action. Although one can simultaneously adjust several parameters, we advise adjusting each parameter independently to better take into account the sensitivity of each one to the others. In addition, the calculation is thus faster, and adjusting the curve is more fluid.

You can also use automatic adjustment to complete the adjustment step. In order to do this, check “adjust” for the parameters you wish to optimise. Optimisation consists of minimising the gap between the observed drawdown data (measured) and the simulated drawdown.

The quality of calibration can be assessed:

- Either visually: the calibration is judged against the theoretical curve, which is more or less adjusted to the observation points for drawdown and/or recovery.
- Or you can use a mathematical criteria. The Nash-Sutcliffe adjustment coefficient can be found in the list of calculated curves (Illustration 111) and displayed for the selected curve. It is expressed by:

$$E = 1 - \frac{\sum_{i=1}^{n}\left(X_{obs}^{i} - X_{sim}^{i}\right)^2}{\sum_{i=1}^{n}\left(X_{obs}^{i} - \overline{X_{obs}}\right)^2}$$

This corresponds to the mean square deviation between the observation and the model divided by the variance of the observations. **Adjustment is better if the criterion trends to 1.**

Then define the parameter variation boundaries by clicking on the boundaries, outlined in red on the Illustration 109:

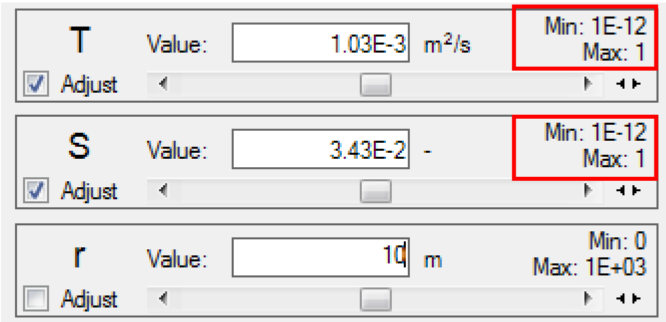


Illustration 109 : Modifying the parameter boundaries

Modify the boundaries set by default in order to constrain the range of values used during optimisation (Illustration 110):

- Minimum: 1×10^{-4} m²/s
- Maximum: 1×10^{-2} m²/s

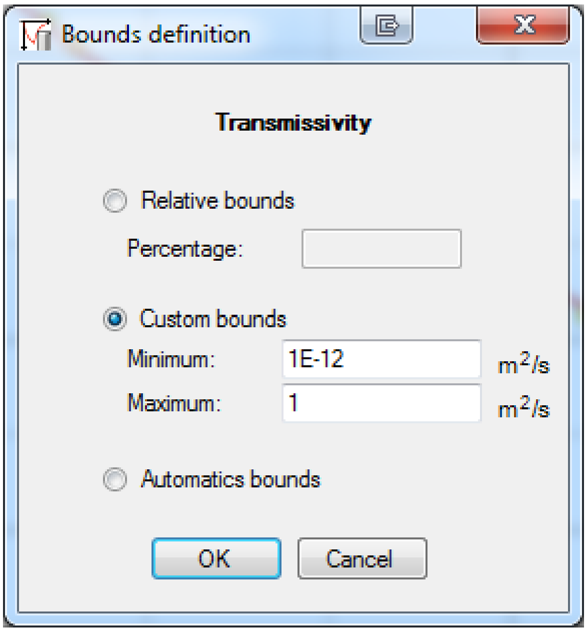


Illustration 110 : Definition of the parameter boundaries

Then, click on the "adjust the parameters by optimisation" button. By default, optimisation is done on all the data. If you would like to optimise the parameters only considering some of the points (recovery, for example), use the "Select an interval" icon and click one time to define the first point, and a second time to define the last point of the interval. Click again on "adjust the parameters with optimisation" to restart optimisation on this part of the curve.

You can test various parameter sets, or different formulas, in adding as many new curves as you wish (Illustration 111, Illustration 112).

OUAIP also permits adding disruptive effects (wellbore storage effect, backflow effect, skin effect, boundary effect) which are not present in this tutorial.

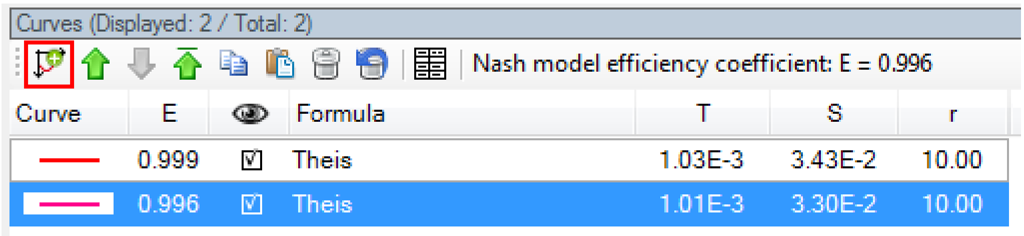


Illustration 111 : Add a new curve

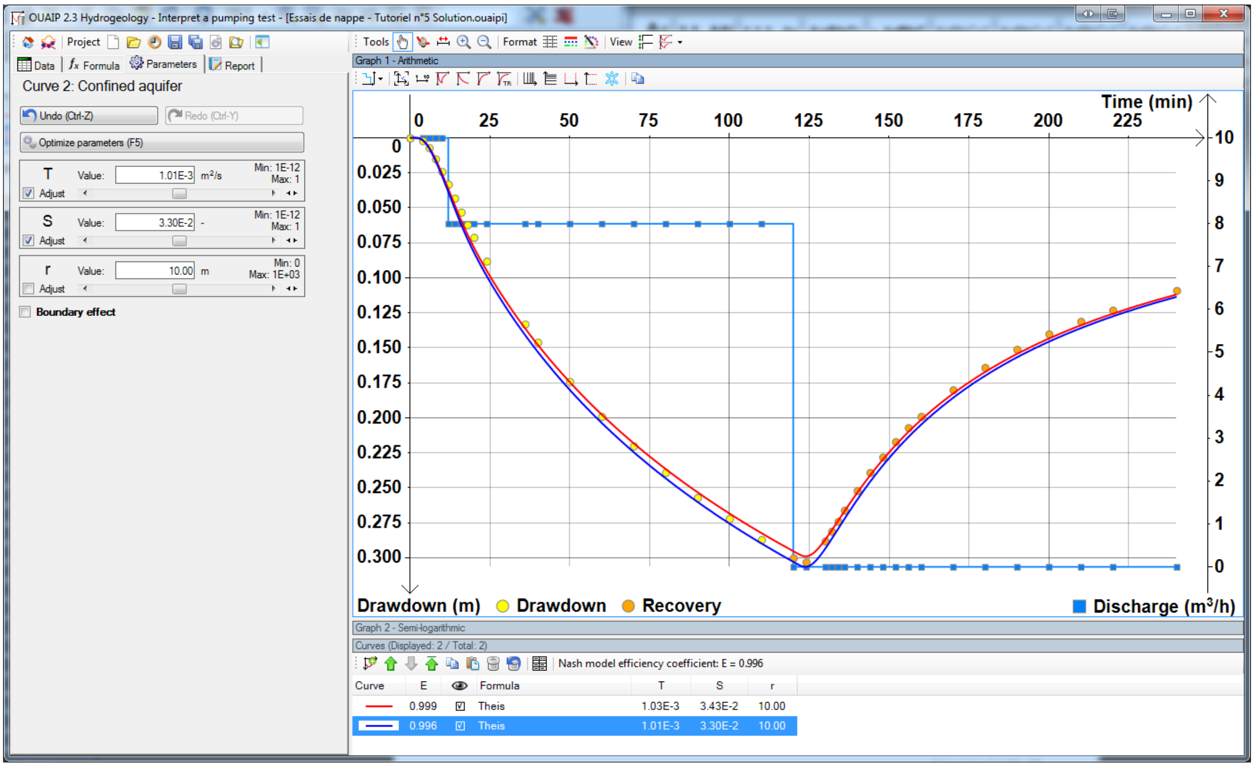


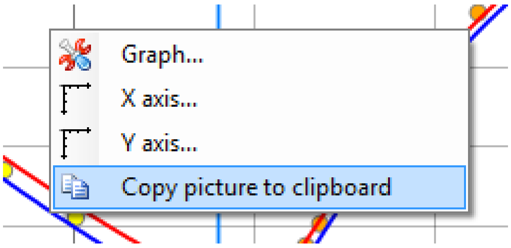
Illustration 112 : Adjust two curves

You can work on the following datasets to interpret the provided groundwater tests:

- Tutorial No. 5 - Aquifer test: interpretation with the Papadopulos solution;
- Tutorial No. 6 - Aquifer test: interpretation with the Hantush solution;

Save your OUAIP project by clicking on the “save” or “save at” icon. By default, the file name extension is written *.ouaipi (“**i**” for **i**nterpretation)

Note that you can copy graphs to paste them in a document using the classic combinations CTRL+C and CTRL+V (or right click on the graph: Copy the image).



The Report tab also presents summaries of results and allows editing a report in PDF and/or HTML.

5.2.2. Tutorial No. 6 - Papadopulos-Cooper solution (1967)

Context

The following pumping test was done in a large-diameter well (2.40 m) in a confined aquifer. The well is situated 26 m from a river. Interpretation of the step-drawdown test gives a quadratic head loss parameter coefficient equal to 351 s^2/m^5.

The test consists of pumping for 72 hours followed by recovery for 5 hours. The water level measurements were made in the pumping wells. The maximum measured drawdown is 4.03 m after 72 hours.

The pumping well is fully penetrating the aquifer. The Papadopulos-Cooper solution takes into account the wellbore storage effect induced by the large diameter of the well, which causes a delay in the evolution of the groundwater drawdown, a part of the pumped water being supplied at the beginning by the volume of water available in the well.

Interpretation

The procedure to interpret this test is similar to the previous one. In order to avoid redundancies, the reader can refer to the steps presented in Chapter “5.2.1 Tutorial No. 5 - Theis solution (1936)“.

Launch OUAIP and select “interpret an aquifer test”.

In the “data” tab:
- Define the name of the well being monitored: “F4”:
- In “type of well,” select the type of well monitored: “Well”;
- Select “drawdown” in “type of measurement”;
- The drawdown and discharge monitoring data to be imported are not synchronous. Verify that the “drawdown and discharge synchronised” box is not checked;
- In order to access the drawdown data and the monitoring of pumping rates, open the “Aquifer test - Tutorial No. 6 Data.xlsx” file in the folder “Tutorials\Tutorial No. 6 - Aquifer test - Papadopulos-Cooper”;
- In the Excel file, copy the time and drawdown columns (in the headers), then in OUAIP, click on “Edit” and paste the data in the table, then click on “confirm.” The graph will display the imported data. Check consistency between the data units and those offered by OUAIP.
- Do the same for pumping flow rate data.
- After these actions, you will have the following graph (Illustration 113):

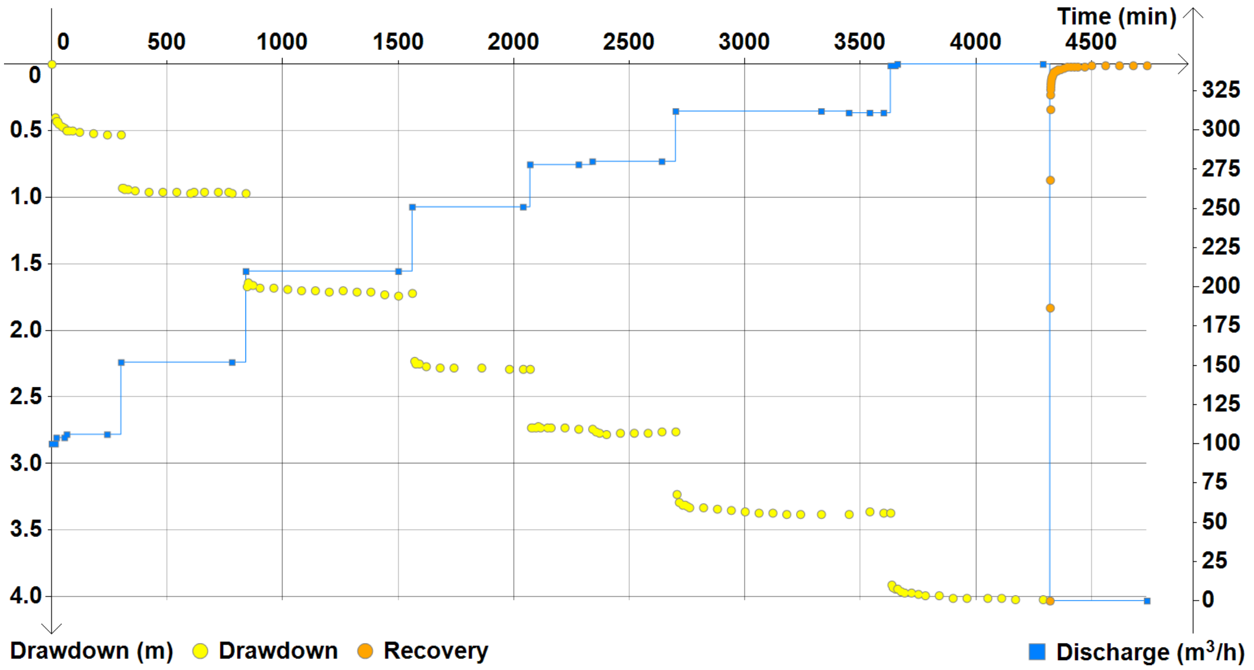


Illustration 113: Drawdown and pumping rate

Select the Papadopulos-Cooper solution in the “formula” tab, which will take into account wellbore storage effect for a large-diameter well, and click on “add a curve with this formula” to interpret the test with this solution.

The “parameters” tab becomes accessible, click on it. The page displays the various parameters of the selected analytical solution. Initialise the parameters to be able to display the simulated curve:

- Transmissivity T: $1x10^{-3}$ m^2/s ;
- Storage coefficient S: $1x10^{-3}$;
- Distance from pumping well - observation point r: 1.2 m ;
- Casing radius r_c: 1.2 m.

Add:

- The quadratic head loss parameter coefficient: 351 s^2/m^5 ;
- A boundary effect fed at a distance of 26 m.

Adjust T and S to correspond to the simulated curve with the observation points. You can also use the parameter functionality adjustment to optimise T then on S to approach the final solution (Illustration 114) : “Aquifer test - Tutorial No. 6 Solution.ouaipi” file ($T=7x10^{-2}$ m^2/s and $S=1x10^{-2}$).

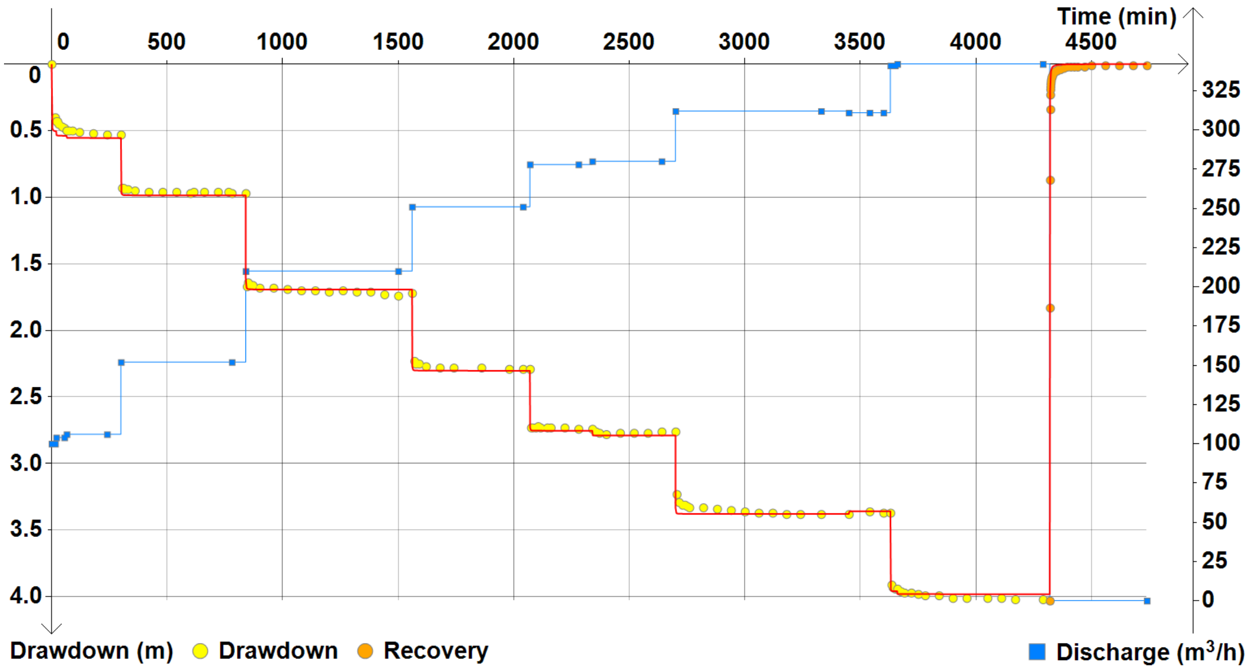


Illustration 114 : Simulated drawdown with the Papadopulos-Cooper solution (Recharge boundary effect and quadratic head losses)

5.2.3. Tutorial No. 7 - Hantush solution (1964)

Context

Kruseman and De Ridder (1990) presented data coming from a pumping test done in a confined aquifer near Dalem in the Netherlands. The aquifer was covered by an aquitard of a peaty nature, and located above a formation considered to be aquiclude. The interpretation of this test will be performed with the Hantush solution.

The tested well (M77) was pumped for 8 hours at a constant flow of 761 m^3/d (well diameter: 0.2 m). The drawdown was measured on a straight line by a piezometer which was 90 m from the pumping well. The data to be interpreted were corrected with the fluctuations of the tide and the partial penetration to the well. The aquifer's thickness is 40 m, the drawdown and flow rate data were asynchronous. The recovery was not monitored.

Interpretation

The path to interpret this test is similar to the previous ones. In order to avoid redundancies, the reader can refer to the steps presented in Chapter “5.2.1 Tutorial No. 5 - Theis solution (1936)“.

Launch OUAIP and select “interpret an aquifer test”.

In the “data” tab:
- Define the name of the well being monitored: “M77”:
- In “type of well,” select the type of well monitored: “Piezometer”;
- Select “draw-down” in “type of measurement”;
- The drawdown data and flow rate monitoring to be imported are asynchronous. Verify that the “draw-down and flow rates synchronised” box is not checked;
- In order to access the drawdown data and the monitoring of pumping flow rates, open the “Aquifer test - Tutorial No. 7 Data.xlsx” file in the folder “Tutorials\Tutorial No. 7 - Aquifer test - Hantush-Jacob”;
- In the Excel file, copy (Ctrl + C) the time and drawdown columns (in the headers), then in OUAIP, click on “enter/edit” and paste (Ctrl + V) the data, then click on “confirm.” The graph will update with the imported data.
- For pumping flow rate data, click on “enter/edit”, then define a flow rate of 761 **m^3/d** (select the unit **m^3/d**) of 0 at 479.52 minutes, and a zero flow rate after 479.52 minutes.
- After these actions, you will have the following graph (Illustration 113):

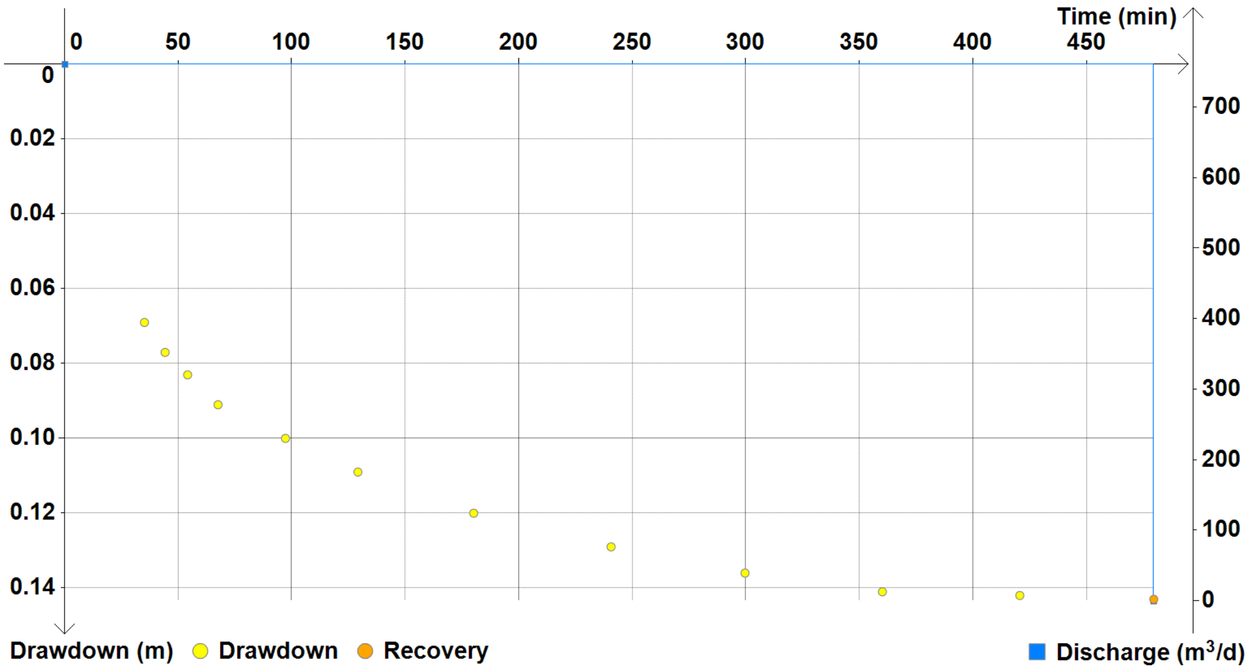


Illustration 115 : Draw-down and pumping flow rate

Select the Hantush solution in the “formula” tab, which will take into account the leakage effect of an overlying aquitard (and partial penetration of the pumping well or a piezometer), then click on “Add a curve for this formula” to interpret the test with this solution.

The “parameters” tab becomes accessible, click on it. The page displays different parameters of the selected analytical solution. Initialise the parameters to be able to display the simulated curve:

- Transmissivity T: $1x10^{-3}$ m²/s ;
- Storage coefficient S: $1x10^{-3}$;
- Distance from pumping wells - observation point r: 90 m ;
- Leakage parameter, click on the “+” to display the parameters which calculate the Leakage factor, $L = \sqrt{\frac{T*e'}{K'}}$ (m):
    - Let e’ be the thickness of the aquitard, e =1 m
    - Let K’ be the aquitard’s permeability, K’= $1x10^{-8}$ m/s
    - Then, L= 316.20 m

Successively adjust the transmissivity, then the storage coefficient to reproduce the shape of the curve, then adjust the aquitard’s permeability. One can directly vary the Leakage factor. The final parameters and result of calibration are following (Illustration 116):

- T = $1.92x10^{-2}$ m^2/s ;
- S = $1.79x10^{-3}$;
- L = 733.33 m
    - e’ = 1 m
    - K’ = $5.1x10^{-8}$ m/s

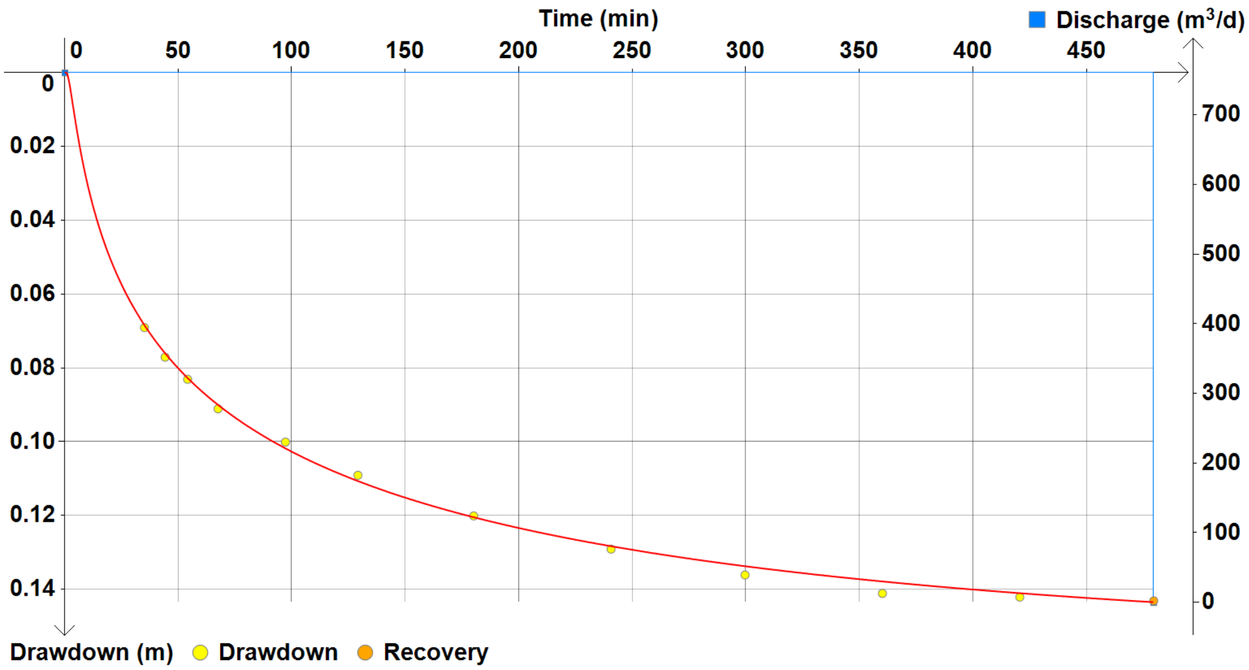


Illustration 116 : Adjustment of the Hantush analytical solution to the experimental data

5.2.4. Tutorial No. 8 - Gringarten-Witherspoon solution (1972)

Tutorial no. 8 on the Gringarten-Witherspoon solution is not implemented in this manual. It will be integrated in the next OUAIP version.

The reader can nevertheless refer to the BRGM report which refers to an example of interpretation:

> Klinka T., Vittecoq B., Arnaud L., Lhotelin M. (2011) Geological and hydrogeological monitoring of three reconnaissance drilling activities at the site of , Fort de France (Martinique). BRGM/RP-60339-FR report, 105 p., 48 ill. [on-line]

5.3. SIMULATE A PUMPING TEST

OUAIP provides temporary calculation of drawdowns induced by a history of any kind of pumping. The calculation can be performed using one or more analytical solutions using additional effects (to wells, piezometers, anywhere in the aquifer) which can impact the medium response. In general, the parameters used for simulation are those from the step-drawdown test related to the performance of the well and the aquifer test for the aquifer's hydrodynamic characteristics.

Pumping test simulation

- Define a discharge exploitation scenario
- Choose an adequate analytical solution and define hydrodynamic parameters
- Simulate the drawdown

Two examples are shown below. The first is a predictive simulation of the drawdowns. The second uses the optimisation function in order to adhere to a maximum drawdown criterion.

5.3.1. Tutorial no. 9 - Simulation of groundwater use

Context

This tutorial uses a case study from the public report:

- "Characterisation of alluvium hydrodynamic properties of Gravone river at the Piataniccia, Corsica site in the south." This document is available (in French) for downloading in a PDF format on InfoTerre, ISBN/ISRN code: BRGM/RP-60905-FR.

We propose to simulate public drinking water well exploitation the characteristics have been evaluated beforehand with a step-drawdown test and an aquifer test.

The scenario to simulate relates to the pumping of a well (F1). This scenario estimates the pumping rate on F1 (outside peak periods), in which production is 1000 m^3/d. The withdrawals are split by 12h/d for a period of 10 consecutive days. Several pumping rates were tested, including 60, 80, 100 and 120 m^3/h (respectively 720, 960, 1200 and 1440 m^3/d) with three scenarios:

- A constant head boundary(river),
- A constant head boundary (river) together with a no flow boundary (aquifer boundary),
- A no flow boundary (aquifer boundary).

The simulated drawdowns include quadratic head losses deduced from the step-drawdown tests (results presented in Illustration 90).

Simulation

Launch OUAIP and select "interpret an aquifer test". The left part of the interface is used to enter input data. It consists of four tabs to use progressively from left to right (Figure 1):

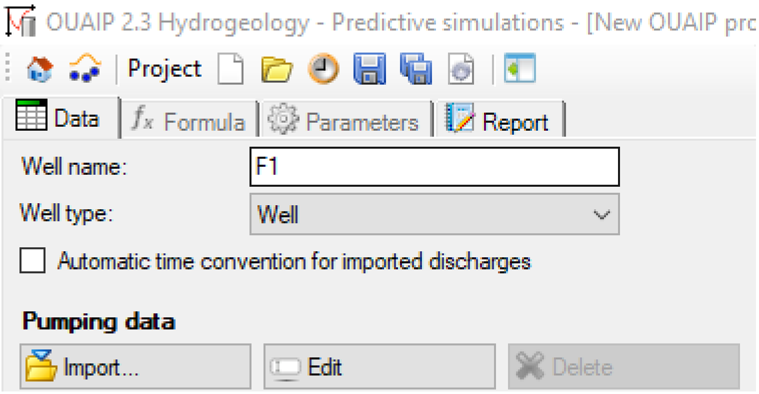


Figure 1 : Simulation mode tabs

In the “data” tab:

- Define the name of the well being monitored “F1”:
- In “Well type I,” select the type “Well” as F1 is an exploitation well;
- Click on “enter/edit” to generate the history of the pumping flow rates (Illustration 117) :

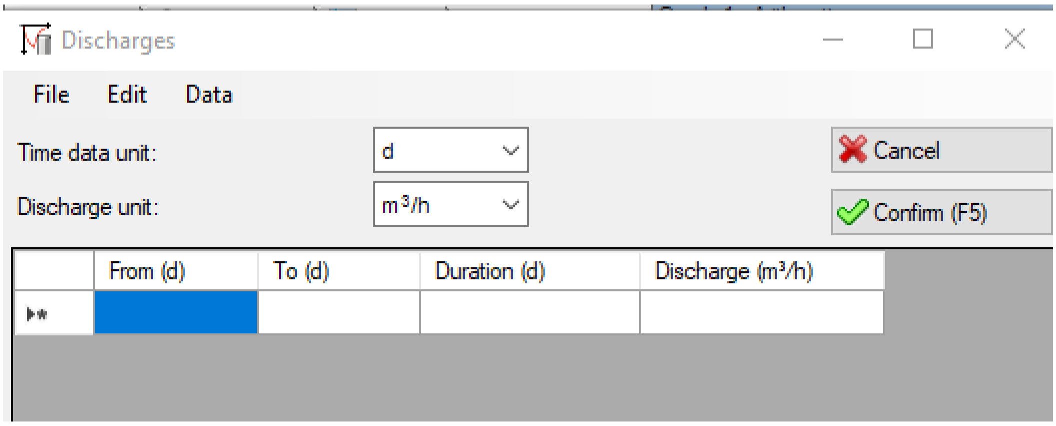


Illustration 117 : Enter/edit the pumping flow rates

- ○ Define the time units (d for days) and pumping discharge (m^3/h)
- ○ In order to define the pumping scenario of 12 hours of pumping per day during 10 days, we will define a history model then repeat it as many times as necessary (9 times);
- ○ For the first line, enter From 0 To 0.5 d (note that the duration is automatically completed by the difference in time between From and To and the corresponding flow rate of 60 m^3/h ;
- ○ For the second line, to indicate that the pump is stopped during 12 hours, enter From 0.5 To 1 d, flow rate 0 m^3/h (Illustration 117);
- ○ If a third line increments automatically, select it and erase it (Del key). Once these two flow sections are defined (2 lines), select the two lines then, in the “Edit” menu, click on “Repeat the selection by incrementing n times”, a window will appear asking the number of repetitions. (Illustration 120). Define 9 then click OK ;

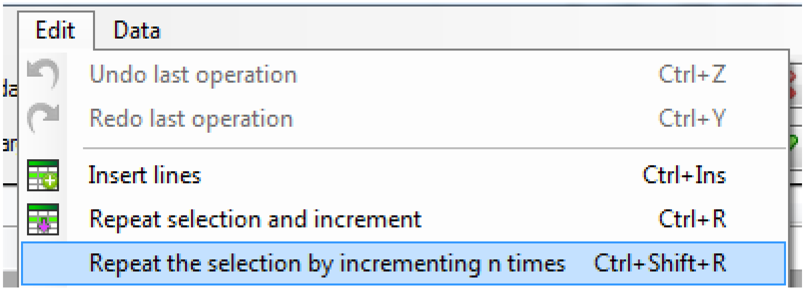


Illustration 118 : Write menu - repeat the selection by incrementing n times

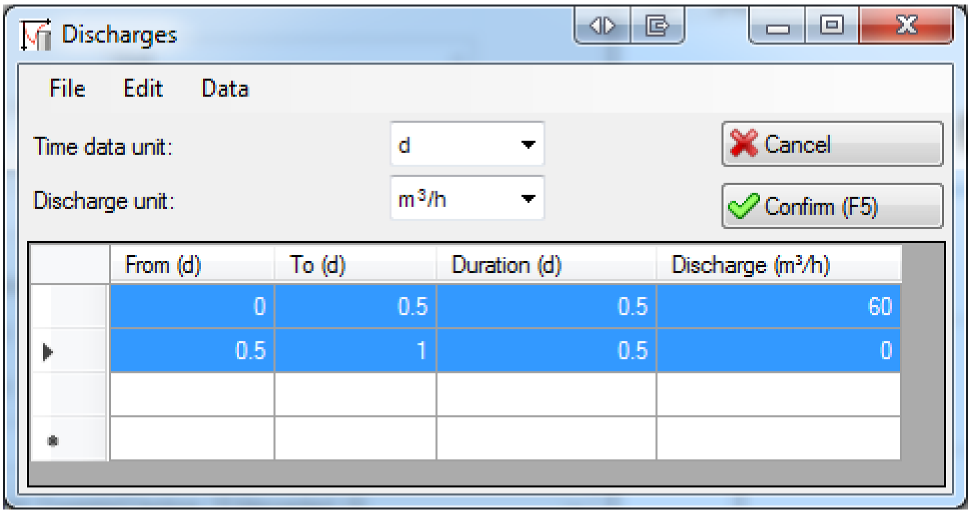


Illustration 119: Flow rate sections

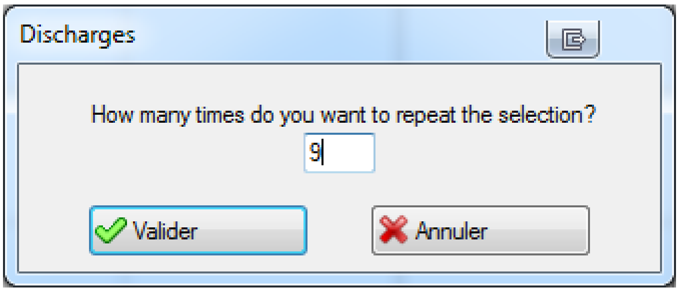


Illustration 120 : Repeat the flow rate sections

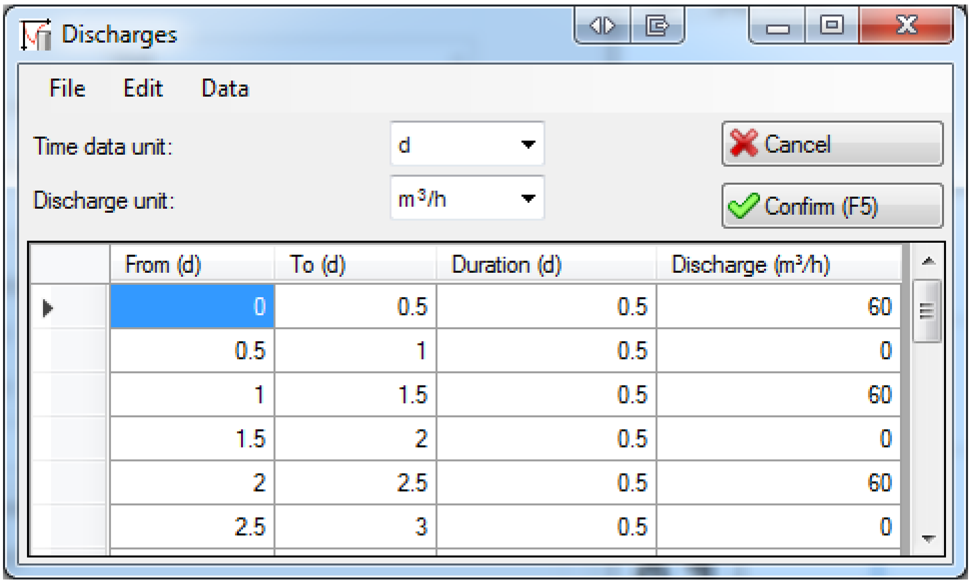


Illustration 121 : Generated pumping history

- Note that the flow rate table was completed 9 times on the basis of the selected model. Click on "Confirm" and verify the pumping history generated on the graphs (Illustration 121 and Illustration 122).

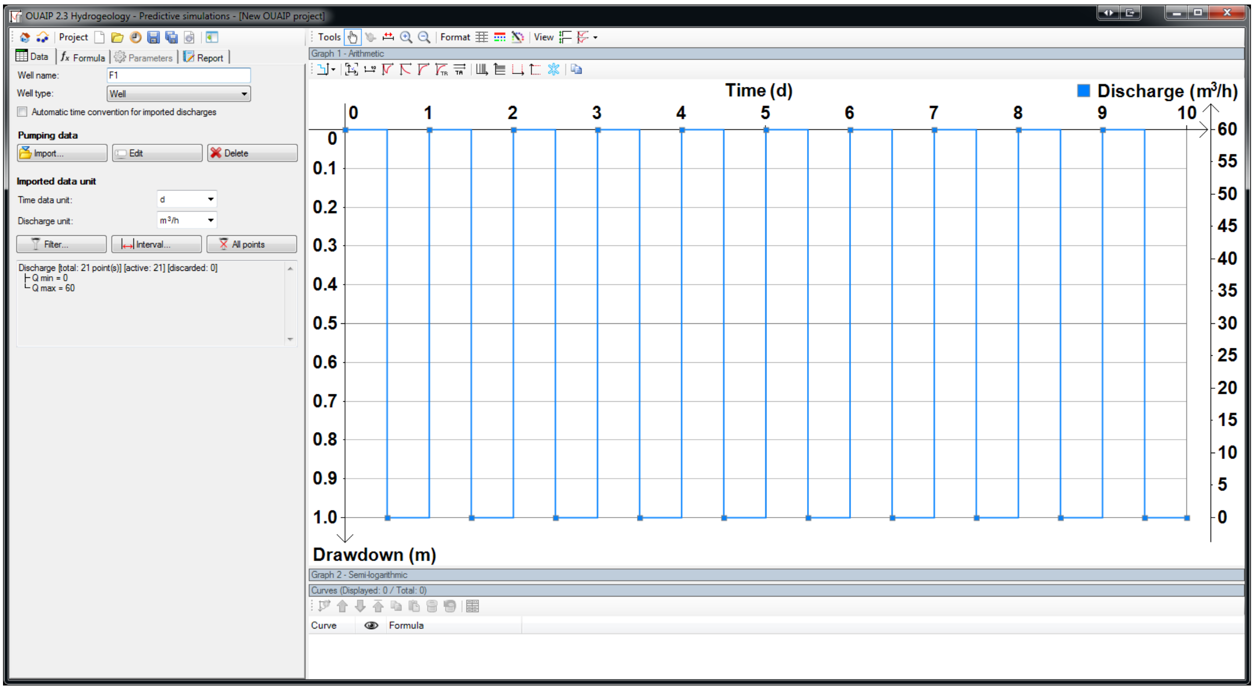


Illustration 122 : Visualisation of the pumping history

Once the flow rate history has been developed, click on the "formula" tab to select the "Theis" analytical solution (double click).

Define the hydrodynamic parameters:

- Transmissivity: 7.95×10^{-3} m²/s

- Storage coefficient: 4.79×10^{-2}
- Radius of the well: 0.1 m

Once the parameters are entered, the simulated curve will display. Check (under parameters):
- Quadratic head losses: 1 741 s^2/m^5
- Boundary effect:
  - Recharge boundary (Constant head): distance 60 m

Add a curve and modify the current recharge boundary into an impermeable boundary with the same distance.

Add another curve in defining an impermeable boundary and a recharge boundary (distances to both of 60 m). The current graph presents the change in drawdown curves using 3 contexts, with recharge boundary, impermeable boundary and with two equidistant boundaries on both opposite sides of the well (Illustration 123).

The maximum drawdown is about 3.35 m after 10 days of pumping at 60 m^3/h 12h/24 in considering an impermeable boundary at 60 m from the pumping well.

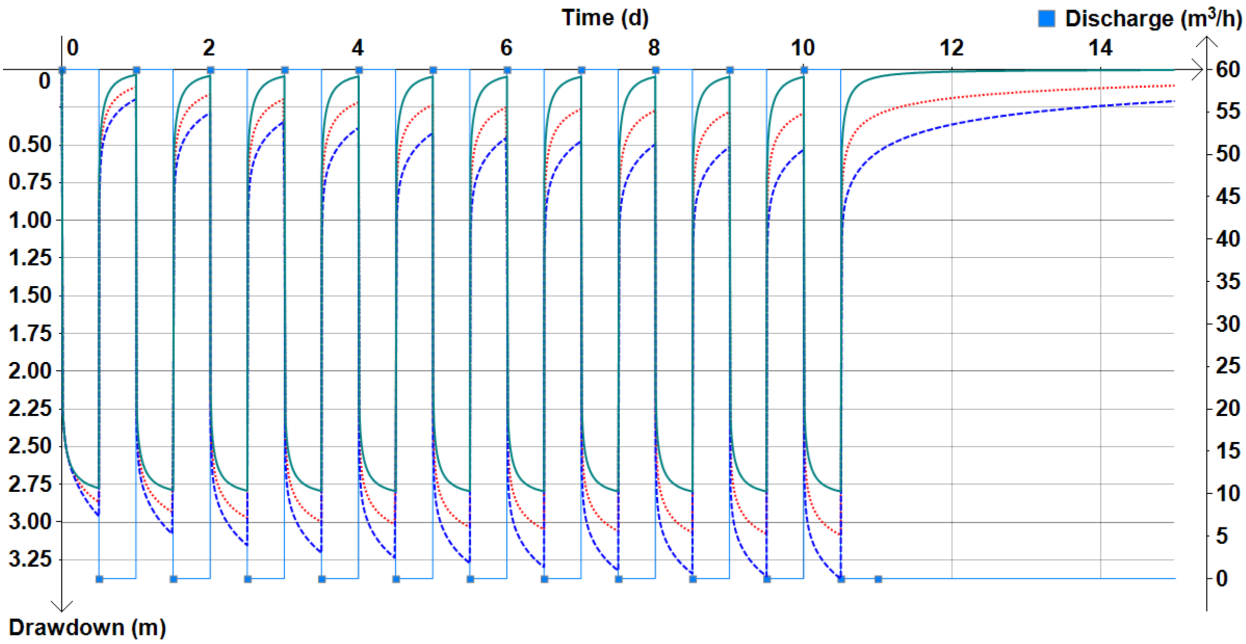


Illustration 123 : Simulated change in drawdowns as a function of different aquifer configurations

You can export digital values of the curve currently selected by clicking on the table  icon in the curves tool bar, on the lower part of the interface. Define the time boundaries for export, From 0 To 20 days, increment 0.05 d, then click on “Compute”. Use the button “Copy all” to export these data, and paste the values into a spreadsheet or export in the form of a *.csv file (Illustration 124).

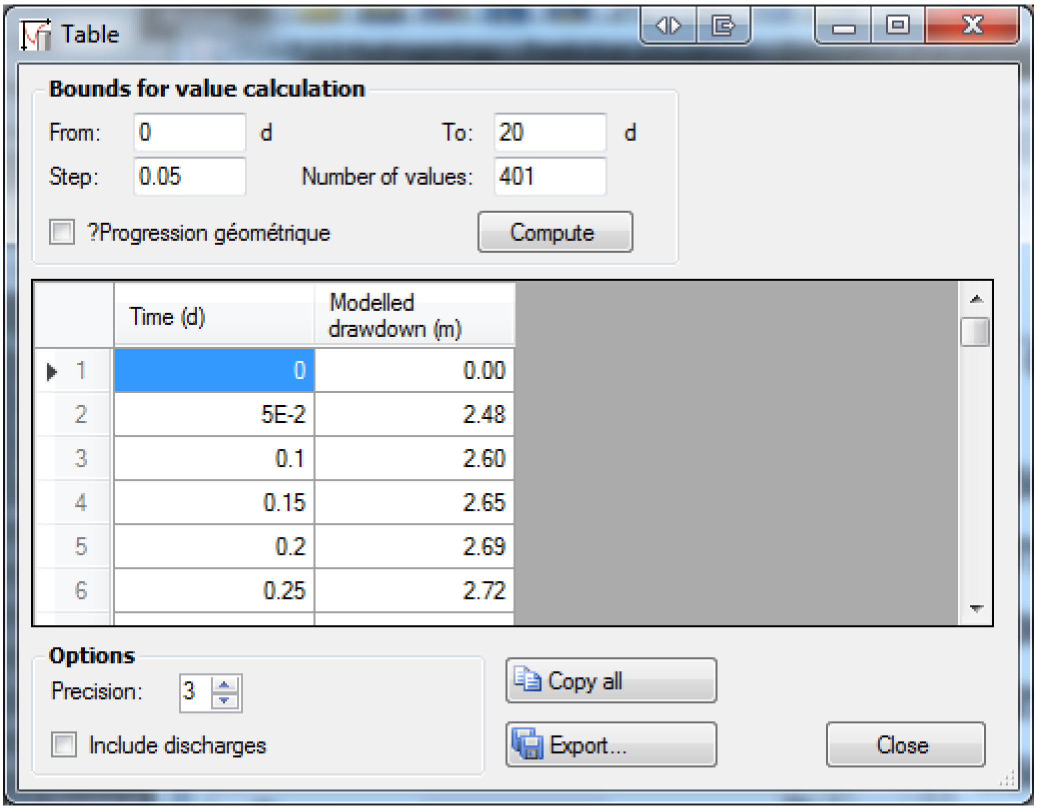


Illustration 124: Value table

Save your OUAIP project. By default, the file extension in OUAIP is *.ouaip**s** (“**s**” for “**s**imulation”).

You can work on the other simulation scenarios implemented in the report (flow rate: 80, 100 and 120 m^3/h, duration: 16h/24 in changing the pumping rates in order to adhere to the desired daily volume).

You can also simulate the drawdown induced by pumping in a monitoring piezometer which is 20 metres distant from the pumping well, for example.

5.3.2. Tutorial no. 10 - Optimisation of the pumping flow with a drawdown constraint

Objective: simulate 12h/d pumping for 1 year with flow rate optimisation

The example used for this tutorial is linked to the public report:

- “Hydrogeological prospecting of the fractured bedrock of Roura, French Guiana (December 2017) “. This document is available (in French) for downloading in a PDF format on InfoTerre, ISBN/ISRN code: BRGM/RP-67440-FR.

The section concerning pump testing is located from page 53 to page 83 of this report.

Following a step-drawdown test and an aquifer test, several exploitation scenarios (page 82) were tested. This tutorial consists of estimating the exploitation rate of the ROU1 well in the case of a use of 20 hours/day for a period of 30 consecutive days. The pumping rate shall respect the maximum admissible drawdown of 33 m (defined from constraints on the design of the well, pump location or water strike depth).

Start OUAIP in simulation mode, enter the name of the well, “ROU1”, choose “well” as the Well type. Then define the pumping history via the “edit” button:

- Change the time unit (hours) and check the discharge unit (m^3/h),
- Enter on the first line: From 0 (h) To 20 (h), the duration increments automatically, enter flow rate 10 (m^3/h)
- On the second line: From 20 (h) To 24 (h), simulate the stop of the pump: 0 (m^3/h).
- If a third line increments automatically, select it and erase it.
- Select the first two lines in the “Edit” menu, select “Repeat the selection in incrementing n times,” (or CTRL+SHIFT+R) the repetition value is 29 (in order to get 30 pumping cycles over 30 days).
- Finally, to facilitate the reading of the graph, right click on the graph window, select “graph”, in the “general” tab, choose the time data unit as “d” for days.
- In the X-axis tab, define graduation steps of 5 days.

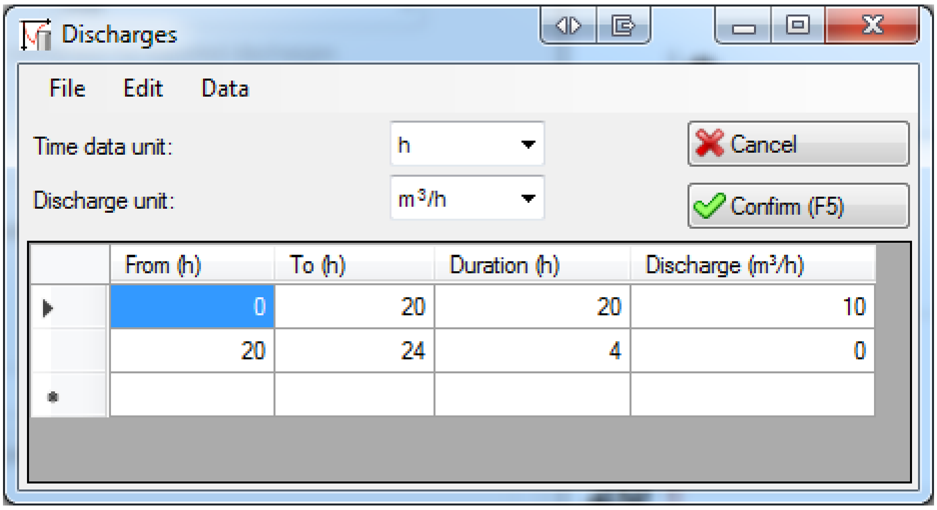


Illustration 125 : Enter the flow rate pattern to create the pumping timeseries of 30 days

In the “formula” tab:

- Select the Theis solution

In the “parameters” tab:

- T (m^2/s) = 3.87×10^{-5}
- S (-) = 1.42×10^{-3}
- r (m) = 0.11 (well radius)
- Add the quadratic head losses coefficient C (s^2/m^5) =1.85×10^{6}.

When these parameters are entered, the simulated drawdown is displayed. It goes down roughly to 104 m. We are looking for the pumping flow rate which shall give a maximum drawdown of 33 m. This will be a fraction of the current flow rate.

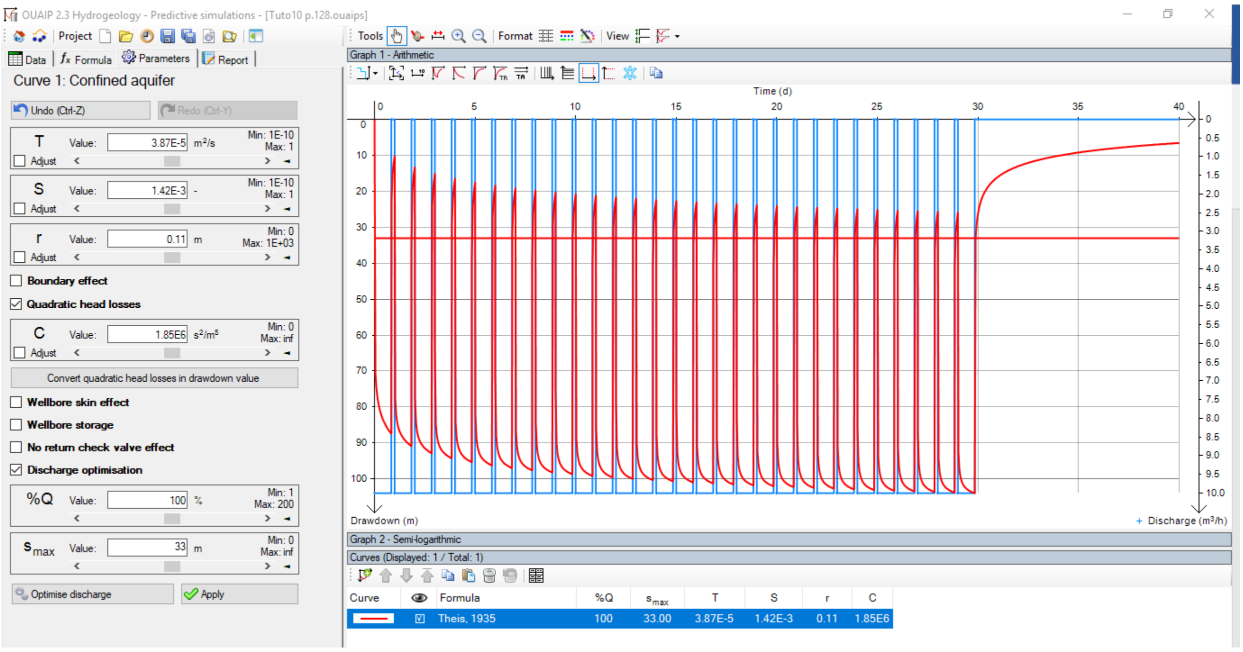


Illustration 126 : Pumping cycles, simulated drawdownand maximum desired drawdown (horizontal red line at s=33 m)

In order to identify this pumping rate, check the box "Discharge optimisation" under the hydrodynamic parameters and additional effects:

- s_{max} (m) corresponds to the maximal acceptable drawdown: enter 33;
- Then click on the button "Optimise discharge". The program displays the value of 35% in the box as a percentage of flow rate to use (%Q). In order to achieve a maximum drawdown of 33 m, one must keep 35% of the initially defined flow rate (or a 65% reduction in flow rate). Click on "apply" in order to apply this change in a definitive manner to the pumping history.
- One can also vary the %Q (by default from 1 to 200%) to instantly measure the impact of a change in flow rates, whether an increase or decrease, on drawdown.
- The optimisation function also works if one would like the pumping to induce a minimum drawdown on a well or on a piezometer remote from the pumping well.

If we return to the "data" tab in "Edit", we see the new pumping rate of 3.487 m^3/h corresponding to a reduction of 65% of the initially defined flow rate (10 m^3/h), Illustration 127.

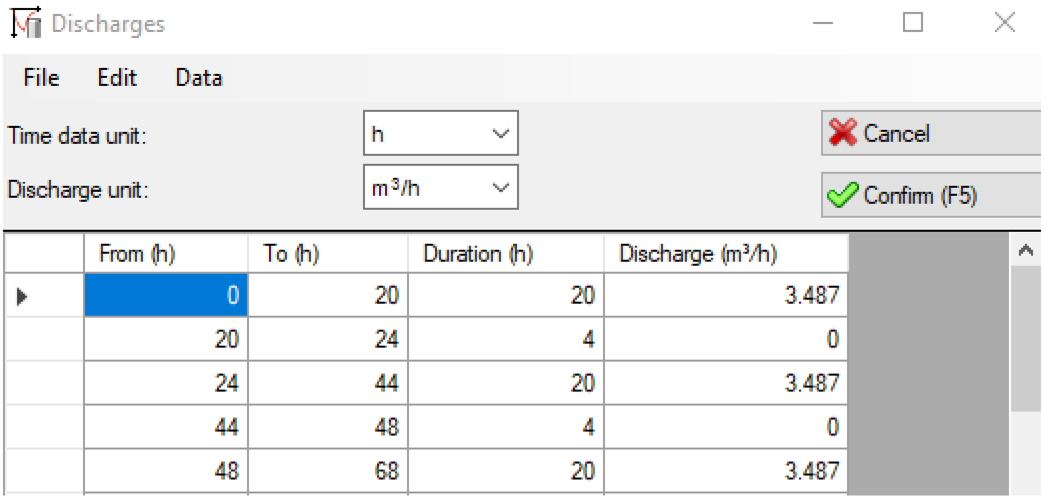


Illustration 127: Application of pumping rate optimisation

6. Conclusion and perspectives

OUAIP software, "Outil d'Aide à l'Interprétation des Pompages d'essai" AKA "Tool to assist pumping tests interpretation", has continued to evolve since its first version, distributed free of charge since May 2013. It is used by more than 5,000 users in France and abroad by the end of 2020. This new version of software offers compared interpretation of step-drawdown tests, improvement in the graphic interface and extended management of units. Publishing PDF and HTML interpretation reports was improved. The registration procedure was simplified.

Analytical solutions like those implemented in OUAIP[1] complement numerical groundwater modelling. For large watersheds where many boreholes are present, the use of meshed numerical models makes it possible to incorporate more complex aspects of reality than can be done by analytical solutions: stream geometry, aquifer geology, land use, aquifer recharging methods, etc., and to evaluate the phenomena related to pollutant transport.

However, the use of analytical solutions remains essential, as on the one hand, it can characterise the properties of aquifers which then is used as input into numerical modelling. On the other hand, these solutions can be used to make a first estimation of these impacts (the effect of pumping on other wells, for example). At smaller scale, at the level of a well or a wellfield, the data is for the most part insufficient to create a meshed numerical model, then leaving room for analytical solutions, both for the estimation of exploitation discharge for the wells, and for possible quantitative impacts on groundwater. Thus, whether at the scale of a well or at the scale of a large watershed, the use of these solutions is widespread. (Dewandel B., 2018).

This OUAIP v2 user manual brings together and covers the various functions which currently exist in the software. Its translation to English now assists its distribution and use abroad.

The goal of the tool remains the same: to improve interpretation of the results of different tests (step-drawdown test, aquifer test) in order to better characterise the aquifers and to simulate changes in the piezometric water level. The software will evolve in several ways in the future.

A version integrating a groundwater pumping impact module on the watercourse will implement a dozen new analytical solutions allowing the practising hydrogeologist to become familiar with "**river-groundwater**" exchange problems during pumping, and provide a series of adapted solutions which can calculate the flow rates taken from the river, or more generally on the surface waters.

A version dedicated to **geothermal** applications which takes into account the properties of water at high temperature, fluid viscosity, pressure, salinity, the ability to work under pressure and to evaluate the intrinsic permeability of a reservoir is under construction.

A version integrating diagnosis of pumping tests, based on analysis of drawdown derivatives and providing comparison to types of curves to identify the most appropriate analytical model, thus creating a better estimate of the hydrodynamic parameters is currently being validated.

New analytical solutions (media with double porosity, in particular) can be implemented in order to add to the interpretations related to specific cases. Users can also notify us of their needs and comments in using OUAIP at the following address: ouaip@brgm.fr

[1] See also BRGM's software offerings at http://www.brgm.fr/logiciels. This includes other tools based on analytical solutions, such as **TRAC** for tracer test interpretation or **Conexmin** for wells pumping next to a river.

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Géosciences pour une Terre durable
Centre scientifique et technique
Direction Eau, Environnement et Ecotechnologies
3, avenue Claude-Guillemin
BP 36009 – 45060 Orléans Cedex 2 – France – Tel. : 02 38 64 34 34
www.brgm.fr