GWHAT

Documentation

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GWHAT Documentation Contributors

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User Documentation

GWHAT (Ground-Water Hydrograph Analysis Toolbox) is a free, open source, and cross-platform interactive computer program whose main focus is the interpretation of observation well hydrographs. It is written in the Python 3 programming language and is currently maintained and developed by Jean-Sébastien Gosselin at INRS. The source code and a stand-alone executable for the Windows platform are available free of charge for download on GitHub.

If you encounter any problems or errors during program execution, have any questions, or have suggestions on how to improve GWHAT, please contact Jean-Sébastien Gosselin at jean-sebastien.gosselin@ete.inrs.ca.

Getting Started

1.1 Installing GWHAT on a Windows system

First of all, the latest binary distribution of GWHAT, packaged as a zip archive, must be downloaded from the project Releases[1] page on GitHub. Then the content of the zip archive needs to be extracted in a directory with `Write`[2] permission. This will result in a directory containing a folder named `GWHAT`, which contains several files including a file named **`gwhat.exe`**. GWHAT can then be started simply by double clicking on this file, no installation is required.

The installation directory will also contain a folder named `Projects`, where all input and output files used and created by GWHAT are stored by default. This folder includes a project example with samples of input and output files to test and learn the various features of the program.

Note: Please help GWHAT by reporting bugs or proposing new features in our Issues Tracker[3] on GitHub.

1.2 Updating GWHAT on a Windows system

It is possible to check if updates are available for GWHAT by clicking on the button *Check for Updates* in the *About GWHAT* window, which can be accessed by clicking on the ⓘ icon as shown in Fig. 1.1.

To update GWHAT to a newer version, the latest binary distribution of the software, packaged as a zip archive, needs first to be downloaded from the project Releases page on GitHub. Then, in the directory where GWHAT was installed, the folder named `GWHAT` needs to be replaced manually with the one that is included in the zip archive that was just downloaded. The new version of GWHAT can then be started simply by clicking on the **`gwhat.exe`**, located in the new `GWHAT` folder.

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[1] https://github.com/jnsebgosselin/gwhat/releases/latest
[2] Permits adding of files and subfolders (https://msdn.microsoft.com/en-us/library/bb727008.aspx).
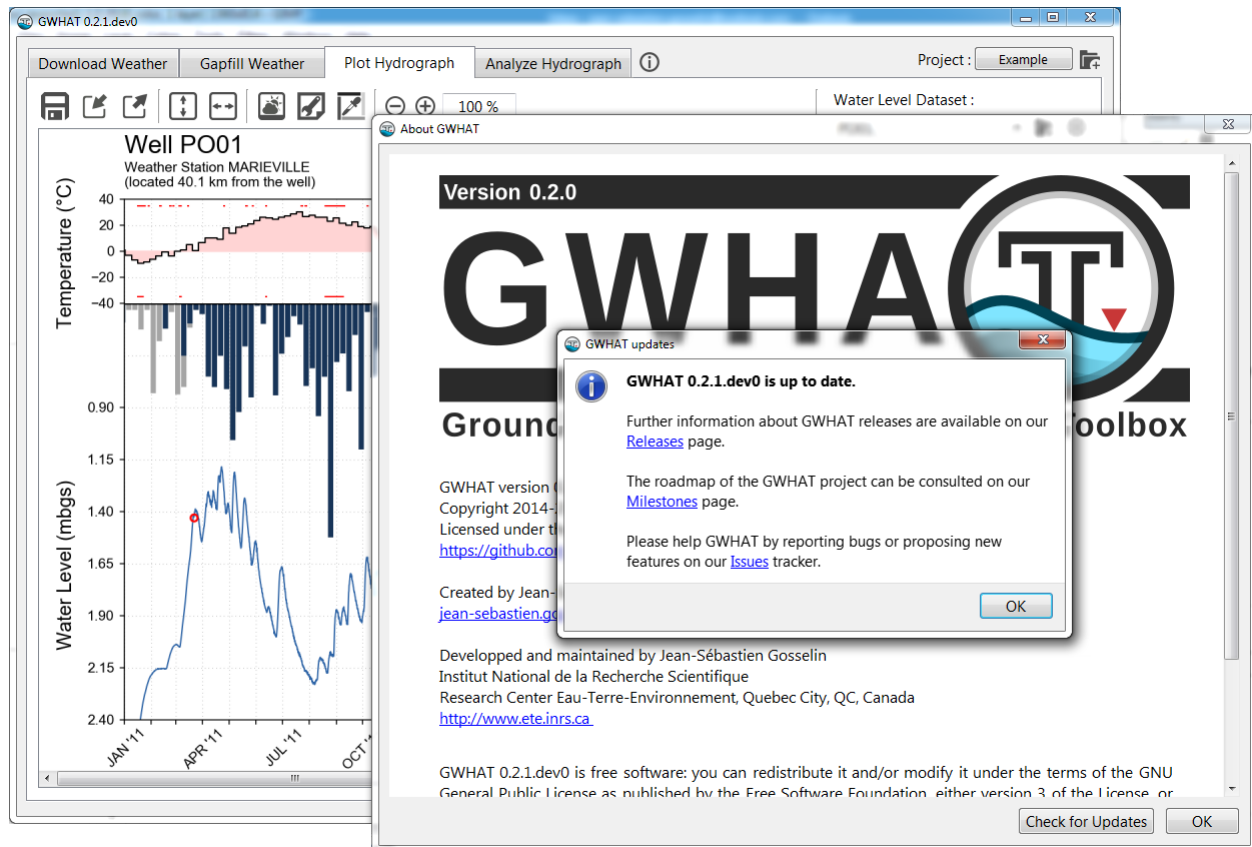[3] https://github.com/jnsebgosselin/gwhat/issues

Fig. 1.1: Presentation of the tool to check if updates are available for GWHAT.

1.3 Running GWHAT from the source files

Binary distribution are currently produced only for Windows systems. However, GWHAT can run on Windows, Linux, or macOS computer operating systems directly from the source files.

Project Management in GWHAT

This document shows how to create, open and manage existing projects in GWHAT. Data are managed in GWHAT by project. This means that all input and output files relative to a particular project are stored in a common folder, hereafter referred to as the *project folder*. This file management system allows to easily backup or copy the data related to a particular project since all the files are saved at the same location.

Only one project at a time can be opened per instance of GWHAT. The title of the currently opened project is displayed on a button located in the *project toolbar* as shown in Fig. 2.1. The project named *Example* is opened by default the first time GWHAT is started. This project includes samples of files to test the different features of GWHAT.
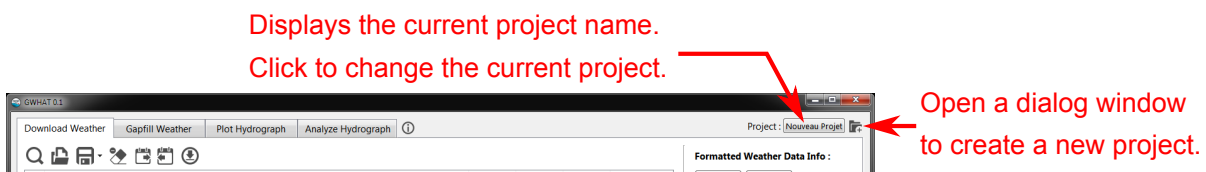

Fig. 2.1: Presentation of the project toolbar in GWHAT.

2.1 Creating a new project

New projects are created by clicking on the ⬛ icon located on the *project toolbar* (see Fig. 2.1). This opens a dialog window (see Fig. **??**) where information about the project can be entered such as its title, author, and location coordinates.

Clicking on the button *Save* will create a new project folder (named after the project's title) and a file with a `gwt` extension where the information related to the project are saved. The directory where the `project folder` is created can be changed by clicking the ⬛ icon. The content and format of the project folder and project file (`*.gwt`) are described in more details, respectively, in Section 2.3 and Section 2.4.

Fig. 2.1 image with annotations:
- General project information.
- Project location coordinates.
- Click to change the directory where the new *project folder* will be created.
- Directory where the new *project folder* will be created.
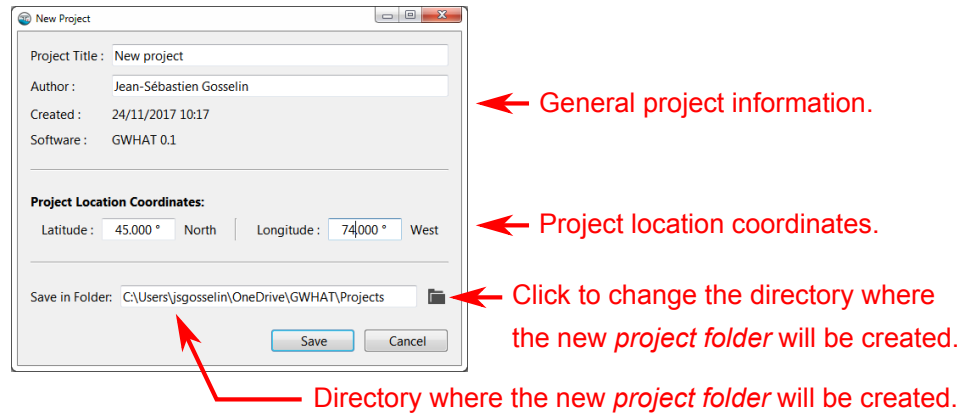
2.2 Opening an existing project

Clicking on the button where is displayed the currently opened project title on the project toolbar (see Fig. 2.1) opens a dialog window where an existing project file (`.gwt`) can be selected and opened.

The path to the project folder is stored in a relative format in GWHAT. This means that if the location of the project folder is changed relative the executable of the software (**gwhat.exe**), GWHAT will need to be redirected to the new location of the project by repeating the procedure described above.
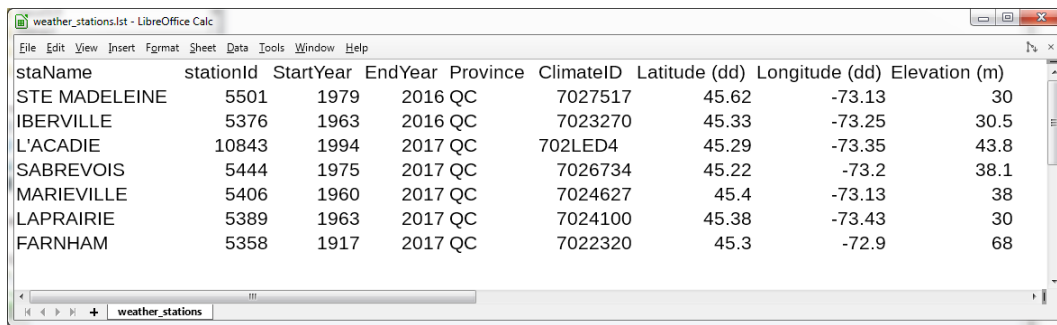
2.3 Project Folders

This section describes in details the content of project folders, where are stored all input and output files relative to a particular project. An example of a project folder files organization is presented in Fig. 2.2.

Fig. 2.2: Example of a project folder files organization.

The file with the `gwt` extension is a binary file where are saved the metadata related to the project (e.g. project title, author, creation date, etc.). It is also where are saved all the input and output data related to the plotting and interpretation of hydrographs, including the estimation of recharge. The format and structure of these files are described in more details in Section 2.4.

The file with the `lst` extension is a csv file containing a list of weather stations from the Canadian Daily Climate Database (CDCD). These files can be created with the tools presented in Section 4. An exemple of weather station list is presented in Fig. 2.3.

Fig. 2.3: Example of a `.lst` file containing a list of climate stations.

The file `waterlvl_manual_measurements.xls` contains the manual water-level measurements from field visits that are used when plotting the hydrophraph as explained in Section 6.

The folder `Meteo` contains all input and output data relative to the downloading, formatting, and the creation of gapless daily weather records. It contains three sub-folders named respectively `Raw`, `Input`, and `Output`.

The folder `Raw` is where are saved the daily weather data files once they have been downloaded from the CDCD as described in Section 4.1. All the files downloaded for a same station are saved within a common folder, named after the name of the station and its climate ID. For example, in Fig. 2.2, the data file `eng-daily-01011980-12311980.csv`, which contains weather data from the station *Marieville* for the year 1980, is saved in a folder named `MARIEVILLE (7024627)`, where the number in parentheses is the climate ID of the station.

The folder `Input` is where are saved by default the formatted weather data files generated from the raw data files. The csv files are named by default after the name of the station, its climate ID, and the first and last year of the data record. This folder is also the default location used by the tool to fill the gaps in daily weather data records to look for input weather data files as described in Section 5.1.

The folder `Output` is where the gapless weather time-series are saved in csv files with the extension `.out`. The files with the extension `.log` are csv files that contain detailed information about the missing daily weather values that were estimated to fill the gaps in the weather datasets. The files with the extension `.err` contains a time-series of estimated weather values that were produced with a crossvalidation re-sampling technique. These estimated values can be used to evaluate the accuracy of the method. The file `weather_datasets_summary.log` is a csv file that contains a summary of all the weather data files that are saved in the `Input` folder.

The folder `Water Levels` is the preferred location where the water level datasets related to a same project should be stored. These files can be either in a csv, xls or xlsx file format.

2.4 Project Files

Data Management in GWHAT

3.1 Importing Data

Time series of water level and weather data must first be imported in GWHAT before groundwater hydrographs can be plotted or analyzed. The format in which the data must be saved, so that they can be imported successfully, is described in Section 3.2.

Importing water level and weather datasets in GWHAT is done by clicking on one of the ⬚ icons that are located in the *Water Level Dataset* or in the *Weather Dataset* section of the tabs *Plot Hydrograph* or *Analyze Hydrograph* (see Fig. 3.1). This opens a window named *Import Dataset* (shown in Fig. 3.2), where a valid water level or weather data file can be imported.

Selecting a water levels or weather data file from the *Import Dataset* window (shown in Fig. 3.2) is done by clicking on the ⬚ icon. After a valid data file has been selected, the information relative to the climate or piezometric station is displayed in the section *Dataset info* of the *Import Dataset* window. This information is read from the header of the selected data file. Missing or wrong info can be entered or corrected from *Import Dataset* window before importing the dataset by clicking on the button *Import*. The dataset is then added to the *project file* and is referenced in the list of imported water level or weather datasets (see Fig. 3.1) by the name that was entered in the field *Dataset name*.

Important: A valid dataset name is at least one charater long and can't contain any of the following special characters: \ / : * ? " < > |

3.2 Input data files format

This section describes the format in which daily weather and water level datasets must be saved so that they can be imported in GWHAT as described in Section 3.1. GWHAT includes a tool to download and automatically save daily weather data from the Canadian Daily Climate Database[1] in the appropriate format (see Section 4). Moreover, GWHAT provides an automated, robust, and efficient tool to fill the gaps in daily weather data records that is presented

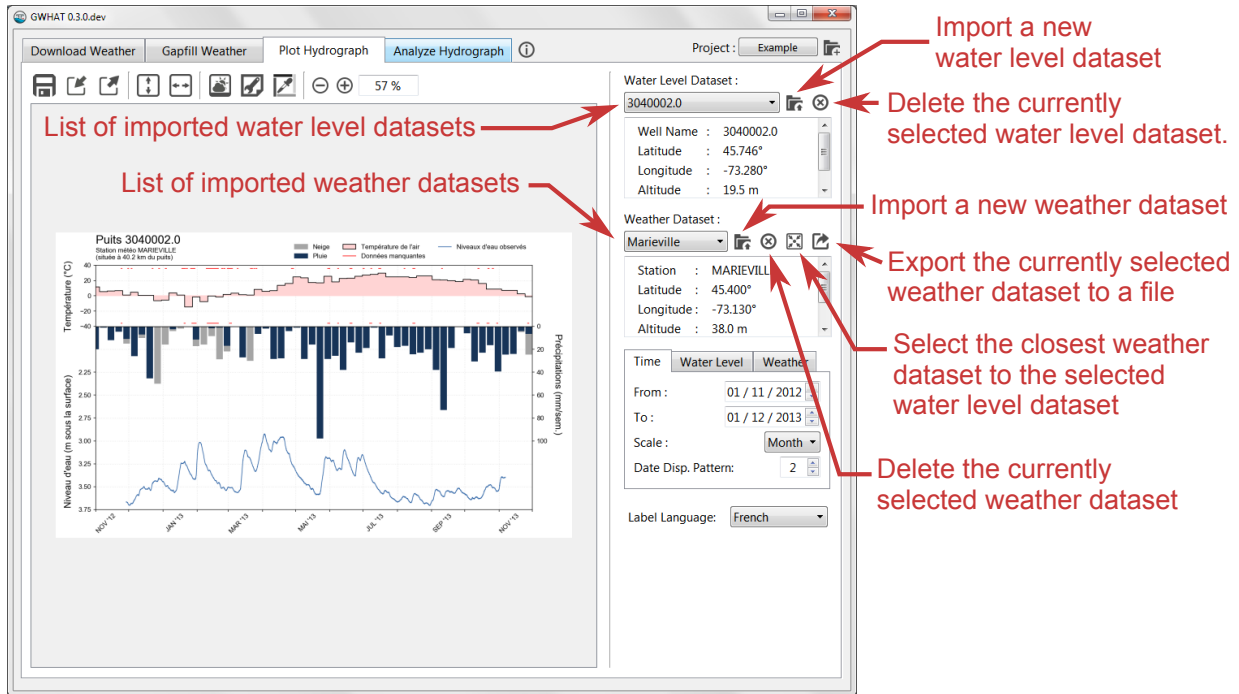---

[1] http://climate.weather.gc.ca/

Fig. 3.1: Presentation of the panel to manage water levels and weather datasets.

in Section 5. There is currently no tool in GWHAT to automatically download and format groundwater levels time series. However, these data can be downloaded free of charge for the province of Quebec from the Groundwater Monitoring Network of Quebec[2] and for several Canadian provinces from the Groundwater Information Network (GIN)[3].

3.2.1 Weather data files

GWHAT can read weather data saved in comma-separated values (csv) or tab-separated values (tsv) text files with UTF-8 encoding. An example of correctly formatted data file is presented in Fig. 3.3.

The file header contains information about the station name, province, latitude, longitude, elevation and climate identifier. The dataset is composed of daily maximum, minimum, and mean air temperature in °C and total precipitation in mm. NAN (not a number) values must be entered where data are missing. Data must also be in chronological order, but do not need to be continuous over time. That is, missing blocks of data (e.g., several days, months or years) can be completely omitted in the time series.

Note: Preferably, the gaps in the daily weather records must have been filled before importing them. Otherwise, a value of 0 is assumed for days where precipitation is missing and the missing values for air temperature are evaluated by linear interpolation. GWHAT provides an automated, robust, and efficient tool to fill the gaps in daily weather data records that is presented in Section 5.

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[2] http://www.mddelcc.gouv.qc.ca/eau/piezo/
[3] http://gin.gw-info.net/service/api_ngwds:gin2/en/gin.html
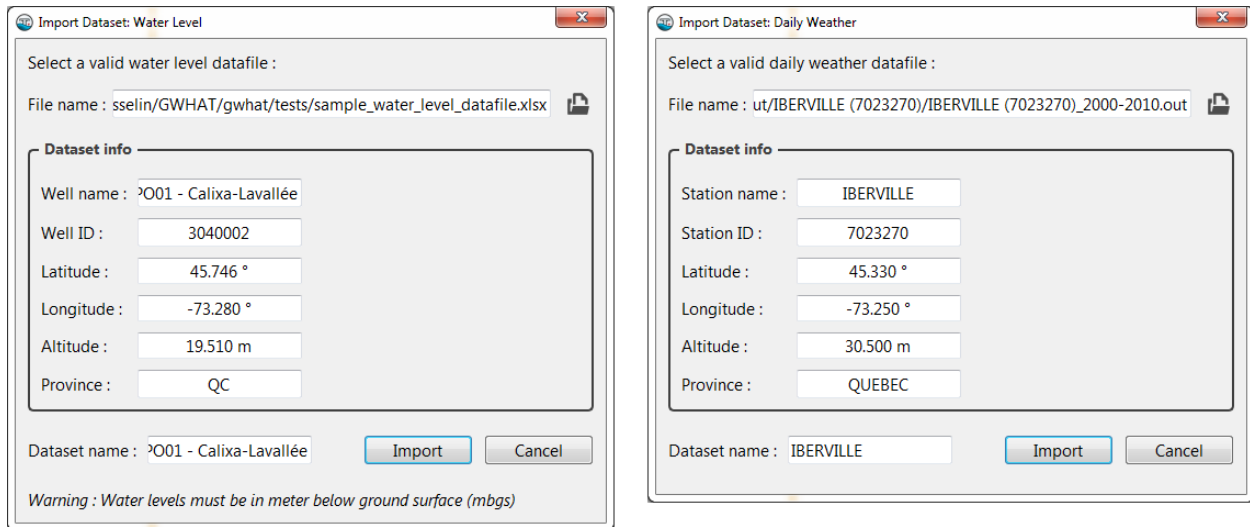
Fig. 3.2: Presentation of the *Import Dataset* windows to import water levels (to the left) and weather (to the right) data files.

Fig. 3.3: Example of a correctly formatted weather data file.

3.2.2 Water level data files

GWHAT can read water level data from either coma-separated text files (`csv`) encoded in UTF-8 or from an Excel spreadsheet (`xls` or `xlsx`). An example of correctly formatted water level data file is presented in Fig. 3.4. This file is also available in the folder of the project example that is distributed with GWHAT (see Section 1.1).

The file header contains information about the well name, identifier, province, latitude, longitude, and elevation. The data must be saved in chronological order. The first column of the data must contain the time in excel numeric format. The second column must contain the water level, given in metres below the ground surface. The third and fourth columns correspond, respectively, to the barometric pressure and the Earth tides. The use of barometric pressure and the Earth tides data will be discussed in more details in Section 9.

Important: Water levels must be in metres below the ground surface. The name of the labels of the header and of the data columns (e.g., Well Name, Well ID, Date) must be respected for the program to read the content of the file correctly.

Fig. 3.4: Example of a correctly formatted water level data file. This file is available in the folder of the project example that is distributed with GWHAT.

3.3 Exporting Data

It is possible to export the currently selected weather dataset to a coma-separated text file (with UTF-8 encoding) or an Excel spreadsheet (xls or xlsx) by clicking on the ⬈ icon as shown in Fig. 3.5. The dataset can be exported in a daily, monthly or yearly format. Note that the export of water level datasets is currently not available in GWHAT.
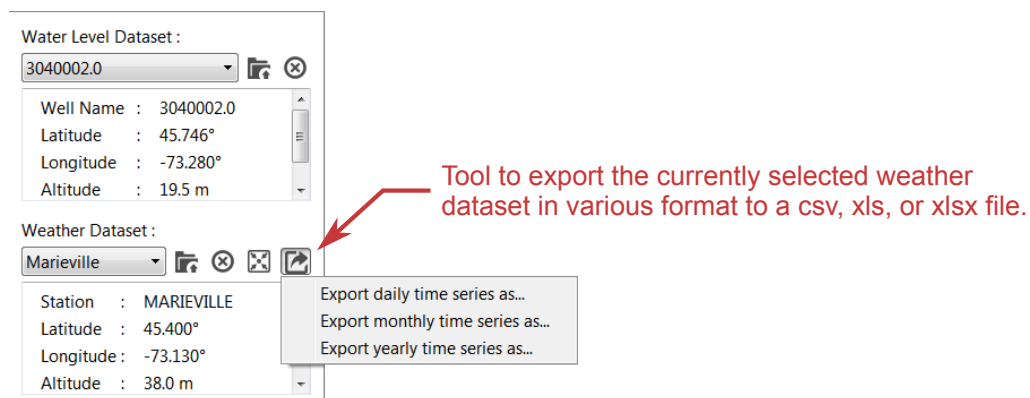

Fig. 3.5: Tool to export weather datasets in a daily, monthly, or yearly format to a csv, xls, or xlsx file.

Downloading Daily Weather Data

This document shows how to search, download, and format daily climate data from the Canadian Daily Climate Database (CDCD)[1] using the download weather data tool of GWHAT available under the tab *Download Weather* shown in Fig. 4.1.

4.1 Downloading weather data

Daily weather data can be downloaded automatically for one or more stations at a time simply by selecting them in the table shown in Fig. 4.2 and by clicking on the ⊕ icon in the toolbar.

Climate stations can be added to the table either by selecting an existing list of stations from a file by clicking on the 🖿 icon or by using the *Weather Stations Browser* (see Fig. 4.4) that is accessible by clicking on the 🔍 icon. Climate stations can be removed from the table by selecting them and clicking on the ✥ icon. The list of stations can be exported to a CSV (comma-separated values) file by clicking on the 🖫 icon, so that it can be directly loaded in successive sessions of GWHAT.

When clicking on the ⊕ icon, daily weather data are downloaded between the *From Year* and *To Year* values specified for each selected station and the results are saved as csv files in the Raw folder of the current project. The downloading process can be stopped at any time by clicking on the ❌ icon that appears in the toolbar as soon as a downloading task is started. Weather data for a given station will not be downloaded for the years for which a data file already exist in the Raw folder. Finally, the *From Year* and *To Year* values can be set individually for each station or for all stations at once using the 🗓 and 🗓 icons as shown in Fig. 4.3.

4.2 Searching for weather data

The *Weather Stations Browser* shown in Fig. 4.4 provides a graphical interface to the CDCD, which contains daily data for air temperature and precipitation dating back to 1840 to the present for more than 8000 stations distributed across Canada. The list of stations can be filtered in the browser by proximity, provinces, or/and the number and the range of years for which data are available at each station. For example, Fig. 4.4 shows all stations with at least 10

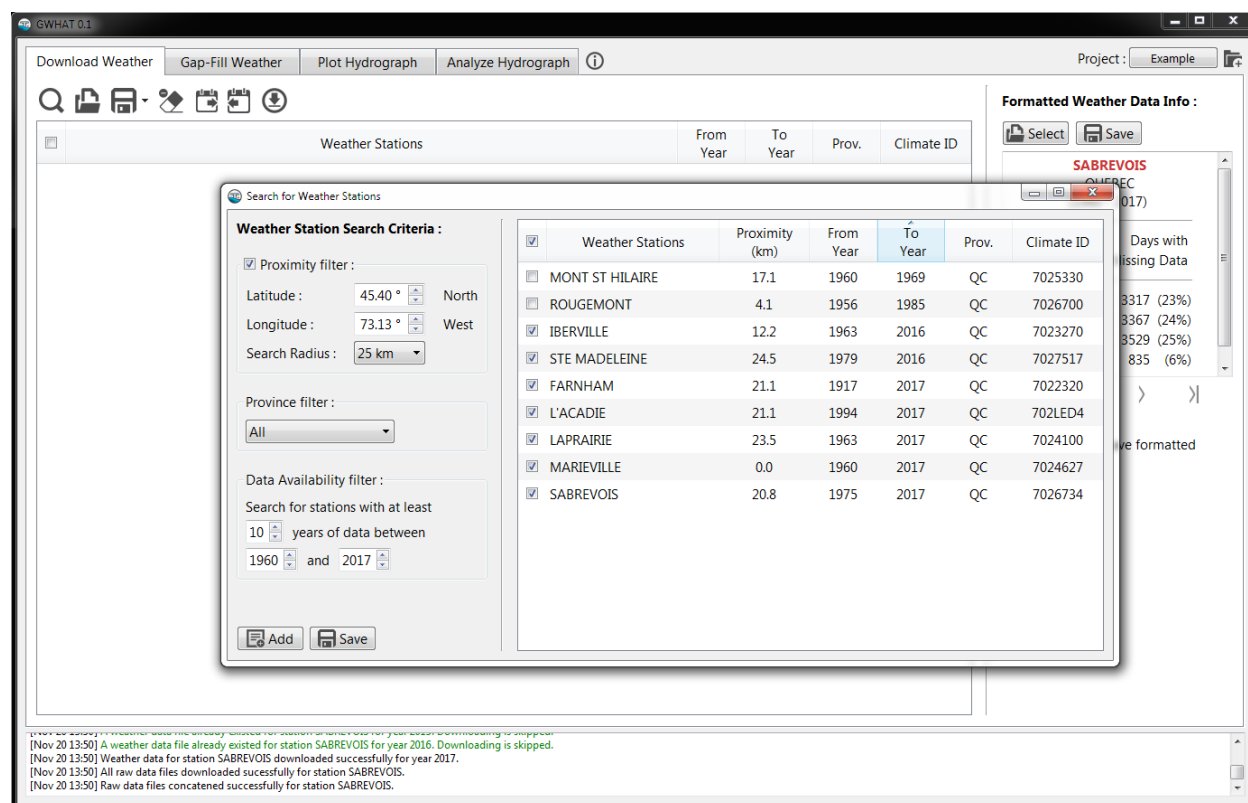---

[1] http://climate.weather.gc.ca/

Fig. 4.1: Presentation of the download weather data tool of GWHAT available under the *Download Weather* tab.

years of available data between 1960 and 2018 that are located less than 25 kilometres away from the specified lat/lon coordinates.

The list of stations displayed in the table can be exported to an Excel or csv file by clicking on the button 🖫 *Save*. Stations can be added from the *Weather Stations Browser* to the table displayed in the *Download Weather* tab (see Fig. 4.2) by checking them in the table and clicking on the button 🖻 *Add*.

The first time that the *Weather Stations Browser* is opened after installing GWHAT, a database of the available climate stations in the CDCD is downloaded from the ECCC (Environment and Climate Change Canada) server. The database is then saved in the installation directory of GWHAT (see Section 1.1). The local copy of the climate station database can be updated whenever by fetching it again from the ECCC server by clicking on the button ⊕ *Fetch*.

4.3 Formatting the weather datafiles

After all data have been successfully downloaded for a given weather station, GWHAT automatically displays information about the number and the proportion of days with missing data in the the right-side panel of the *Download Weather* tab (see Fig. 4.5). It is possible to navigate through the information of all the datasets that were downloaded over the course of a given session by using the left-right arrows located at the bottom of the panel.

By default, GWHAT saves the formatted data automatically in a single csv (comma-separated values) file in the `Input` folder of the current project folder. Details about the format of the csv files in which the data are saved are provided in Section 3.2.1. It is possible to prevent GWHAT from automatically saving the formatted data by unchecking the *Automatically save formatted weather data* option located at the bottom of the formating tool. The formatted data can be manually saved afterwards by clicking on the button 🖫 *Save*.
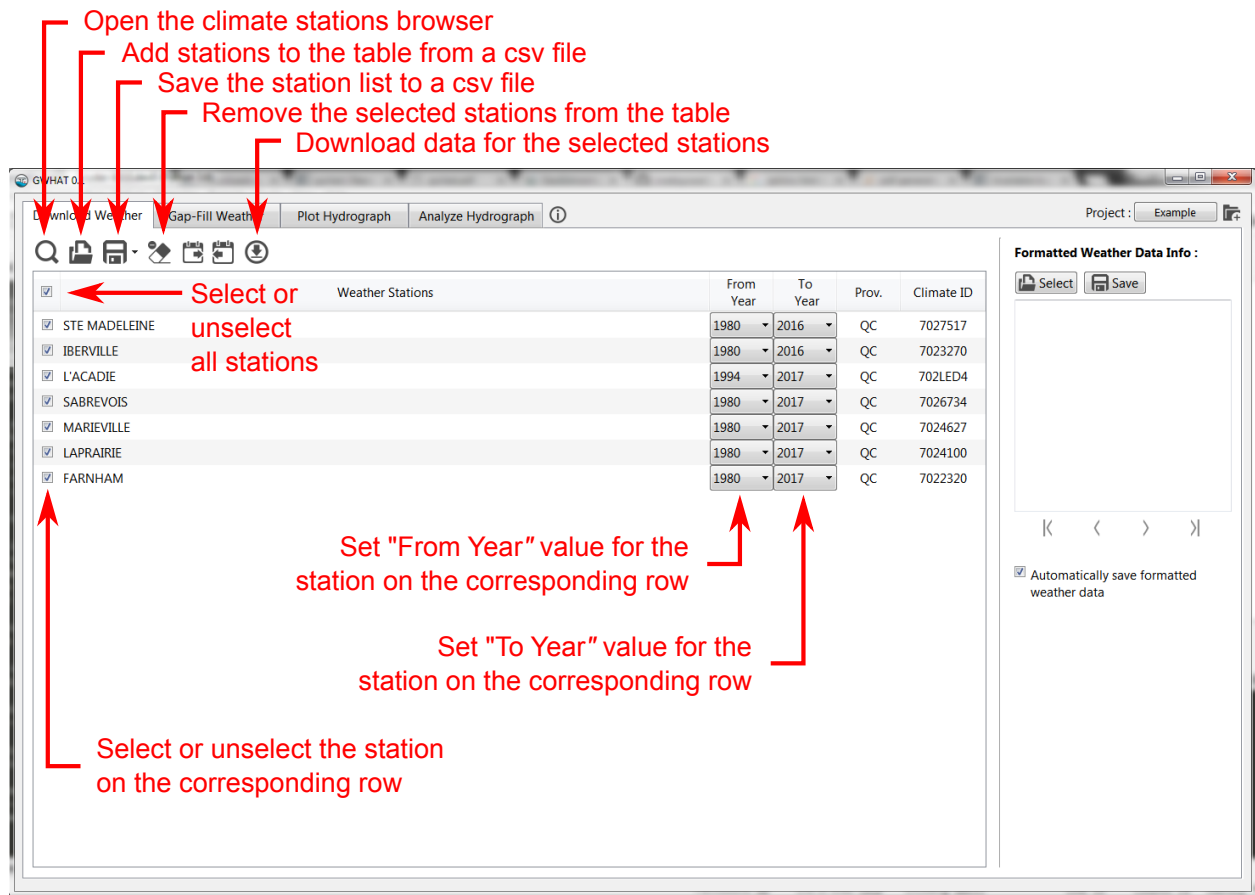
Fig. 4.2: Tool to download and format daily weather data from the online CDCD (Canadian Daily Climate Database).

Moreover, previously downloaded raw weather data files, which are saved automatically in the `Raw` folder, can be opened and formated at any times by clicking on the button ⬒ *Select* at the top of the panel. The formatted data can then be saved manually by clicking on the button ⬛ *Save* or automatically if the *Automatically save formatted weather data* option is checked.

Set "From Year" value for all the stations
Set "To Year" value for all the stations
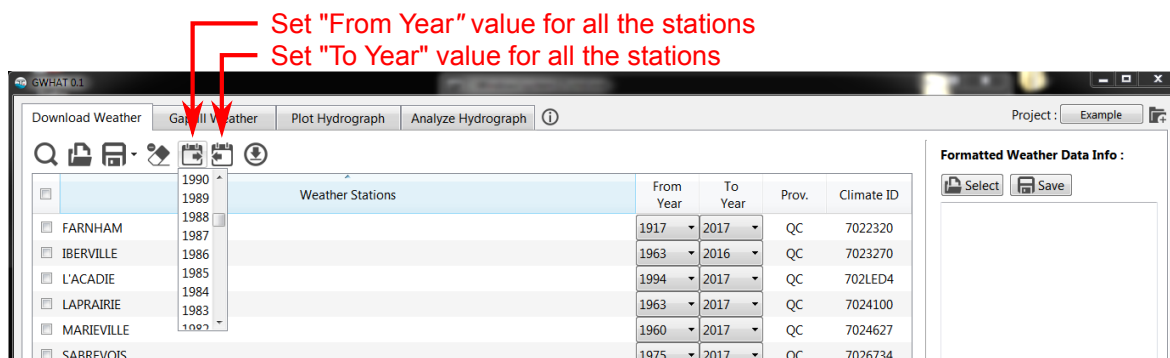
Fig. 4.3: Set the *From Year* and *To Year* values for all stations at once.

Select or unselect all stations

Filter stations
by proximity

Filter stations
by province

Filter stations by
data availability

Add the selected stations
to the table of the
download weather tool

Save the station table to an Excel or CSV file

Update the station database by fetching it again
from the ECCC ftp server

Select or unselect the station
on the corresponding row

Fig. 4.4: Presentation of the *Weather Stations Browser*.

Open and format raw weather datafiles from disk.

Save the formated dataset to a csv file.

Info about the number and ratio
of missing data in the dataset.

Navigate through the formatted datasets.

Option to automatically save the formatted data after
raw data have been downloaded or opened from disk.
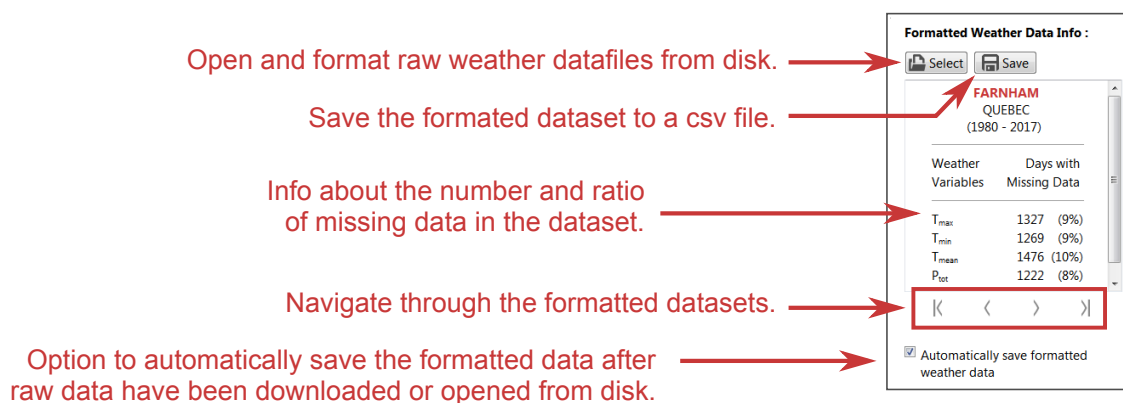
Fig. 4.5: Presentation of the tool to format raw weather datafiles located in the right panel of the *Download Weather* tab.

Gapfilling Daily Weather Data

GWHAT provides an automated, robust, and efficient method to fill the gaps in daily weather data records. In addition, uncertainties of the estimated missing values can be automatically assessed with a cross-validation resampling technique. This document shows how to fill the gaps in daily weather records using the gapfilling weather data tool of GWHAT available under the tab *Gapfill Weather* shown in Fig. 5.1.

Fig. 5.1: Presentation of the *gapfill weather data* tool of GWHAT available under the tab *Gapfill Weather*.

5.1 Loading the weather data files

When starting GWHAT or when a new project is selected, the content of the *Input folder* is automatically scanned for valid weather data files that respect the format described in Section 3.2.1.

The restuls are displayed in a list located under *Fill data for weather station* section as as shown in Fig. 5.2. The list of weather datasets can be refreshed at any times by clicking on the ⟳ icon. This needs to be done if new datafiles are added or deleted manually from the `Input` folder, outside of GWHAT. Datasets can be removed from the list by selecting them and clicking on the ⊗ icon. Doing so also removes the corresponding data file from the `Input` folder.

A summary of the number of days with missing data for each dataset is also produced and displayed under *Missing Data Overview* tab of the display area.
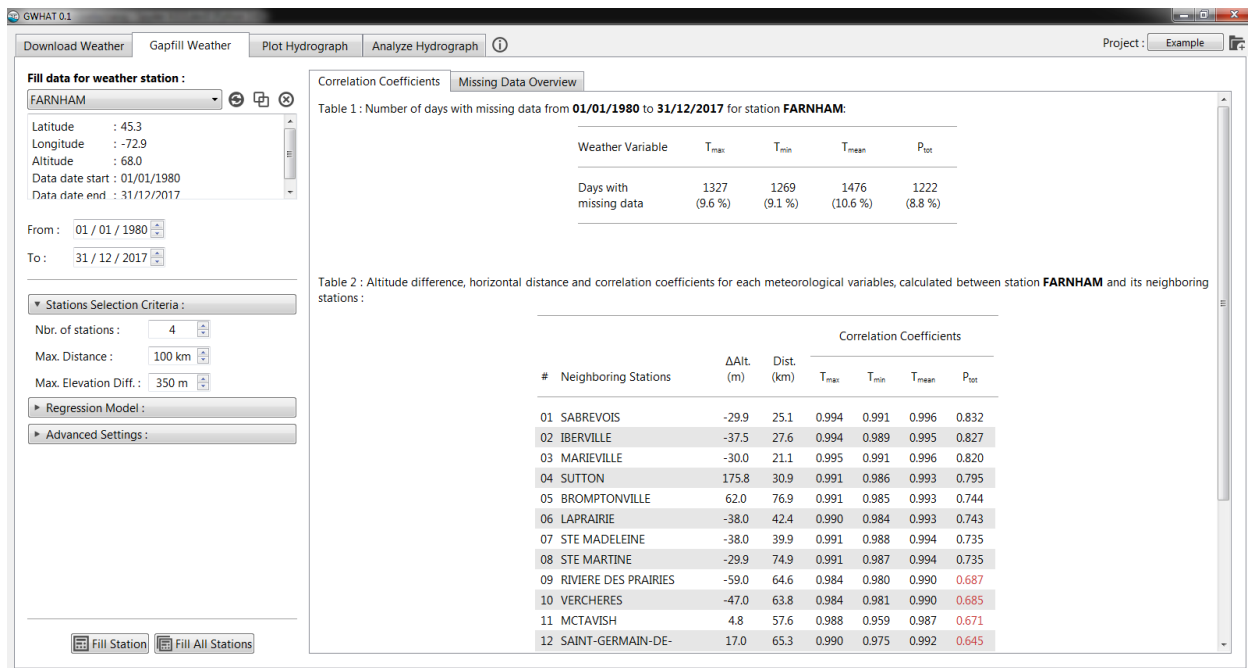
Fig. 5.2: Presentation of the *gapfill weather data* tool of GWHAT available under the tab *Gapfill Weather*.

5.2 Merging two weather data files

Sometimes, more than one daily weather dataset is available at a same location. Often, this happens when a new climate station is installed in a location where a station was operating in the past, but was later removed (due to governmental budget cuts for example). This results in two datasets for which the data are mutually exclusive in time. In that case, it is beneficial to merge these two mutually exclusive datasets into a single dataset that spans over a longer period of time. This can be done mannually by manipulating the files located in the `Input` folder or by using the tool available in GWHAT by clicking on the ⧉ icon (see Fig. 5.3).

Note: Datasets that are mutually exclusive in time can results in problems when filling the gaps in daily weather records. So it is always a good practice to reduce the occurence of the situation described above in the input weather datafiles before trying to fill the gaps in the data.

Fig. 5.3: Presentation of the tool to merge two daily weather records together.

5.3 Filling the gaps in the data

The first step is to select the dataset for which missing values need to be filled. This is done from the drop-down list located under the *Fill data for station section* shown in Fig. 5.2. Under this list are displayed information about the currently selected weather station.

It is also possible to define the period for which the data of the selected station will be filled by editing the date fields located next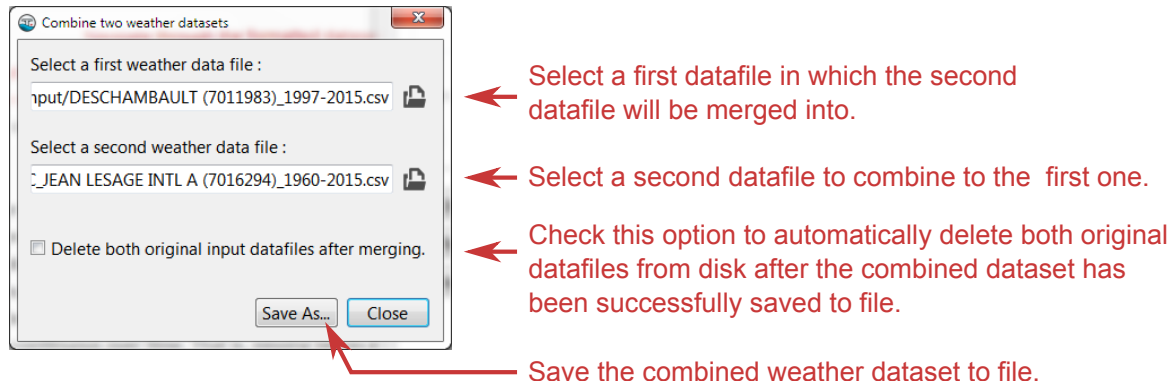 to the *From* and *To* labels. By default, dates are set as the first and the last date for which data are available for any of the stations of the list.

The method used to estimate the missing data for the selected weather station consists in the generation of a multiple linear regression (MLR) model, using synchronous data from the neighboring stations. The neighboring stations used to generate the MLR model are selected based on the correlation coefficients computed between their data and those of the selected weather station. The values of these coefficients are automatically calculated when a new weather station is selected from the dropdown list and the results are displayed in the table located under the *Correlation Coefficients* tab. Among the selected neighboring stations, the ones with the highest correlation coefficients have more weight in the model than those with weak correlation coefficients. As a guidance for the user, correlation coefficients that fall below a value of 0.7 are shown in red in the table. There are several settings that can be used to control the selection of the neighboring stations, the generation of the MLR model, and the outputs of the gapfilling procedure. An overview of these settings is presented below in Section 5.5.

Once the parameters have been set to the desired values, the automated procedure to fill the gaps in the dataset of the selected climate station can be started by clicking the button 🖩 *Fill*. It is also possible to fill the gaps of all the datasets of the *Fill data for weather station* dropdown list in batch by clicking on the button 🖩 *Fill All Stations*. The parameters used in the gapfilling procedure will then be the same for all the stations.

5.4 Output files

Once the process to fill the gaps is completed for a station, the resulting gapless daily weather dataset is automatically saved in a csv file with a `.out` extension in the `Output` folder. Detailed information about the format of the `.out` files are provided in Section 3.2.1. The `.out` file is named after the weather station name, climate ID, and first and last year of the dataset. For example, the resulting output file for the station *FARNHAM* in Fig. 5.2 would be `FARNHAM (7022320)_1980-2017.out`.

Detailed information about the estimated values that were used to fill the gaps in the data series (e.g., parameter values used in the method, uncertainty of the estimated values, simultaneous data at neighboring stations used for the estimations) are also saved in an accompanying file with a `.log` extension. A histogram showing the yearly and

monthly weather normals, calculated from the gapless data series is also produced and saved in a pdf format. An example is presented in Fig. 5.4.

Additional outputs are produced when the option *Full Error Analysis* is checked in the *Advanced Settings* (see Section 5.5.3). These outputs are described in more details in Section 5.6.
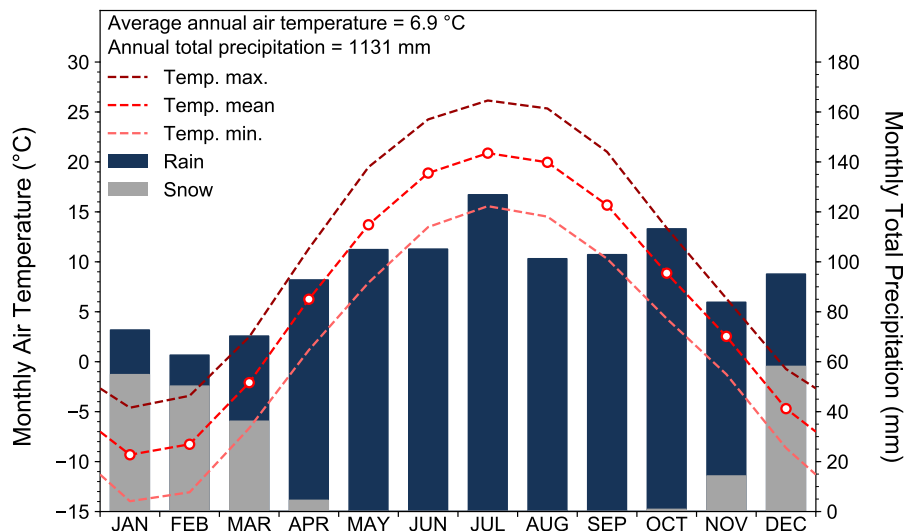

Fig. 5.4: Example of a histogram generated by GWHAT showing the yearly and monthly weather normals for the climate station *MARIEVILLE*.

5.5 Setting the parameters

This section describe the various parameters that can be set to control the selection of the neighboring stations, the generation of the MLR model, and the outputs of the gapfilling procedure.

5.5.1 Stations Selection Criteria

A MLR model is generated for each day for which a data is missing in the dataset of the selected station. This is done because the number of neighboring stations with available data can vary in time. Therefore, for a given date with missing data in the dataset of the selected station, the neighboring stations are selected in decreasing order of their correlation coefficients. Neighboring stations that also have a missing data at this particular date are excluded from the selection process.

The maximum number of station that are selected for the generation of the MLR model can be specified with the parameter *Nbr. of stations*, located under the *Stations Selection Criteria* section shown in Fig. 5.5. The number of neighboring station that is selected by default is 4. If for a given date, all the neighboring stations have missing data synchronously with the selected station, a nan value is kept in the dataset at this particular date.

Moreover, the correlation between the data of two stations generally decreases as the distance and the altitude difference between them increase. Therefore, the parameters *Max. Distance* and *Max. Elevation Diff.* allow to specify thresholds for the distance and altitude difference. Neighboring stations exceeding either one of these thresholds will not be used to fill the gaps in the dataset of the selected station. The default values for the distance and altitude difference are set to 100 km and 350 m, respectively, based on values found in the literature (Simolo et al., 2010; Tronci et al., 1986; Xia et al., 1999). The horizontal distances and elevation differences calculated between the selected station and its neighbors are shown in the table to the right, alongside the correlation coefficients. The values that exceed their corresponding threshold are shown in red.

Fig. 5.5: Parameters that can be set to control the selection of the neighboring stations in the gapfilling procedure.

5.5.2 Regression Model

It is possible to select whether the MLR model is generated using a Ordinary Least Squares (OLS) or a Least Absolute Deviations (LAD) criteria from the *Regression Model* section shown in Fig. 5.6. A regression based on a LAD is more robust to outliers than a regression based on a OLS, but is more expensive in computation time.

Fig. 5.6: Parameters to control the criteria used to generate the MLR model.

5.5.3 Advanced Settings

It is possible to automatically estimate and add the daily Potential Evapotranspiration (PET) to the output data file (`.out`) produced at the end of the gapfilling procedure of the selected station. This option is enabled by checking the *Add PET to data file* option in the section *Advanced Settings* shown in Fig. 5.7. The daily PET is estimated with a method adapted from Thornthwaite (1948), using the daily mean air temperature time series of the selected station. Alternatively, it is possible to add manually the PET retrospectively to an existing `.out` file by clicking on the icon.

The *Full Error Analysis* option can be checked to perform a cross-validation resampling analysis during the gapfilling procedure. The results from this analysis can be used afterward to estimate the accuracy of the method. This option is discussed in more details in Section 5.6.

Finally, the format (pdf or svg) and the language (English or French) of the figures that are automatically produced by GWHAT after a dataset has been sucessfully gapfilled (see Fig. 5.4 and Fig. 5.8) can be selected from the *Figure output format* and *Figure labels language* menus.

5.6 Uncertainty Assessment

By default, each time a new MLR model is generated to estimate a missing value in the dataset of the selected station, the model is also used to predict the values in the dataset that are not missing. The accuracy of the MLR model is then approximated by computing a Root-Mean-Square Error (RMSE) between the values estimated with the model and the respective non-missing observations in the dataset of the selected station. The RMSE thus calculated is saved, along with the estimated value, in the `.log` file.

Fig. 5.7: Advanced parameters of the gapfilling procedure.

When the *Full Error Analysis* option in the *Advanced Settings* section is checked, GWHAT will also perform a cross-validation resampling procedure to estimate the accuracy of the model, in addition to fill the gaps in the dataset. More specifically, the procedure consists in estimating alternately a weather data value for each day of the selected station's dataset, even for days for which data are not missing.

When a value for every day of the dataset has thus been estimated, the estimated values are saved in the `Output` folder as a csv file with a `.err`, along with the `.log` and `.out` files as described in Section 5.3. The accuracy of the method can then be estimated by computing the RMSE between the estimated weather data and the respective non-missing observations in the original dataset of the selected station.

In addition various graphs are automatically generated by GWHAT to the performance of the method and saved in a pdf format. These graphs consist of scaterplots comparing the estimated and measured daily weather data and a plot comparing the probability density function of the original and the estimated daily precipitation series. Example of these graphs are presented in Fig. 5.8.
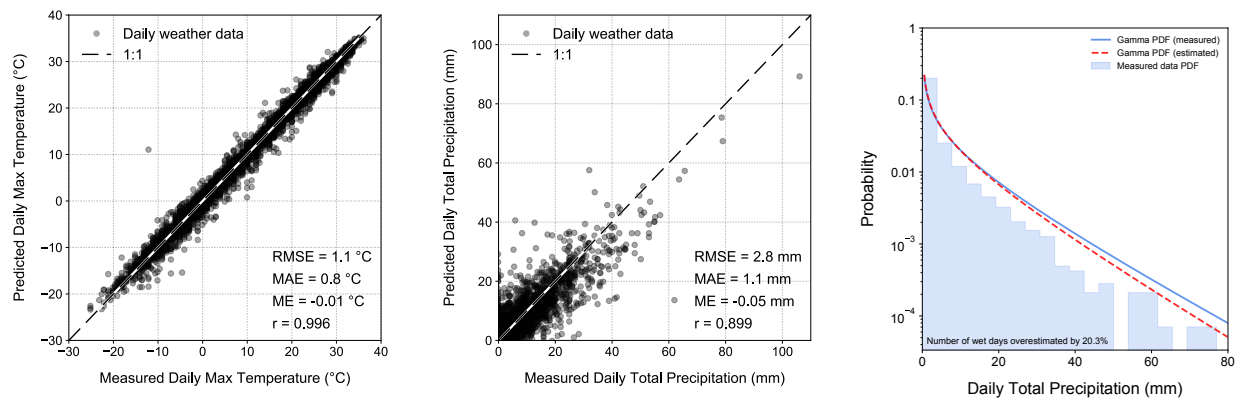

Fig. 5.8: Graphs that are automatically generated by GWHAT allowing to assess the performance of the method to fill the gaps in daily weather data records accurately.

Note: Checking the *Full Error Analysis* option will increase the computation time of the gap filling procedure, especially if the least absolute deviation regression model is selected, but can provide interesting insights on the performance of the procedure for the specific datasets used for a project.

Plotting the Hydrographs

This document shows how to produce publication quality figures of well hydrographs in GWHAT using the tools available under the tab *Plot Hydrograph* shown in Fig. 6.1. For detailed information on how to import the weather and water level data in GWHAT, please consult Section 3.
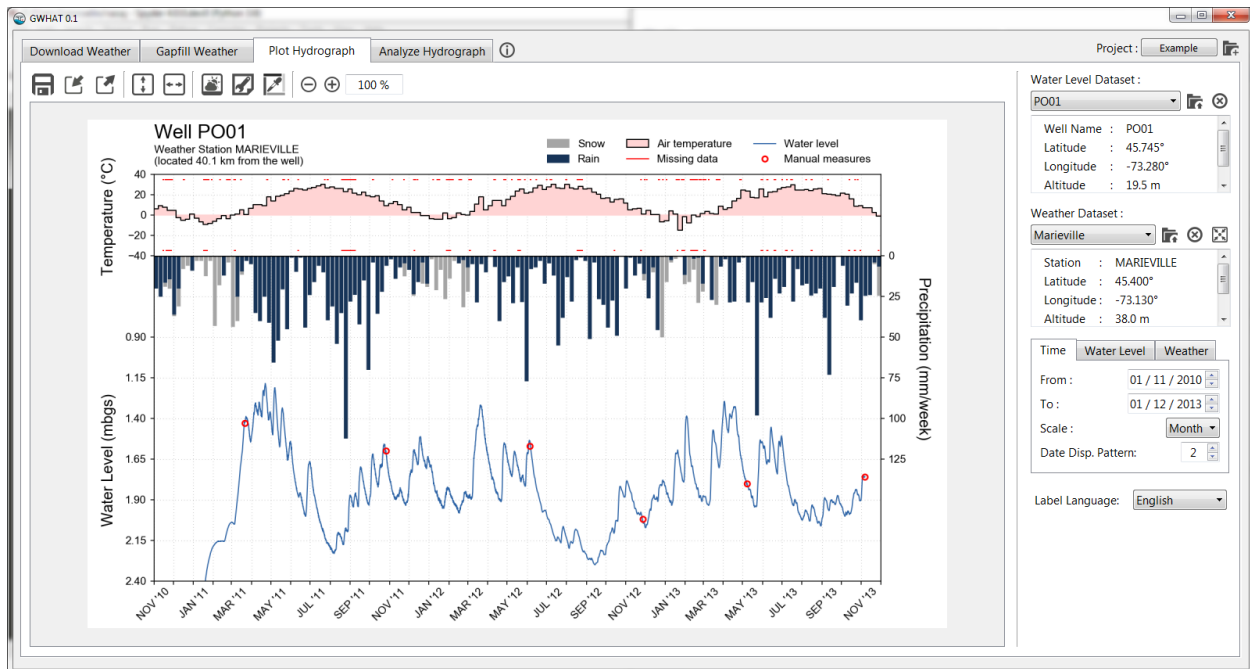

Fig. 6.1: Presentation of the tool to plot hydrographs in GWHAT under the *Plot Hydrograph* tab.

The tab *Plot Hydrograph* consists mainly of an editor to produce a graph showing the groundwater level time series in relation to weather conditions. As shown in Fig. 6.2, the editor consists of a toolbar, the panel *Input data* (documented in Section 3), the panel *Axes settings*, and a canvas where the hydrograph figure is shown.

A figure of the hydrograph is produced as soon as a water level dataset have been selected in the *Input data* panel.

It is possible to zoom the figure canvas in or out by pressing the ⊕ or ⊖ icon or by rotating the mouse wheel while holdind the `Ctrl` key.

Various parameters are available to customize the layout of the hydrograph:

- Several options are available to customize the size and visibility of the components of the hydrograph in the *Page and Figure Setup* window, which is accessible by clicking on the ▨ icon. This is covered in more details in Section 6.2.

- The color of most of the elements that are plotted in the hydrograph can be configured in the *Colors Palette Setup* window, which is accessible by clicking on the ▨ icon. This is covered in more details in Section 6.4.

- The axis of the graph can be configured in the *Axes settings* panel. This is covered in more details in Section 6.3. In addition, the ⟷ and ⇕ icons can be clicked at any time to, respectively, fit the time and water level axis automatically to the data.

- The ▨ icon is used to access the *Weather Averages* window where are displayed the yearly and monthly normals of the weather dataset. This is covered in more details in Section 7.

The layout for the currently selected water level dataset can be saved by clicking on the ⬈ icon. The previously saved layout can be loaded back for the currently selected water level dataset by clicking on the ⬉ icon. Finally, the hydrograph can be saved in a `pdf`, `svg` or `png` format by clicking on the 🖫 icon.
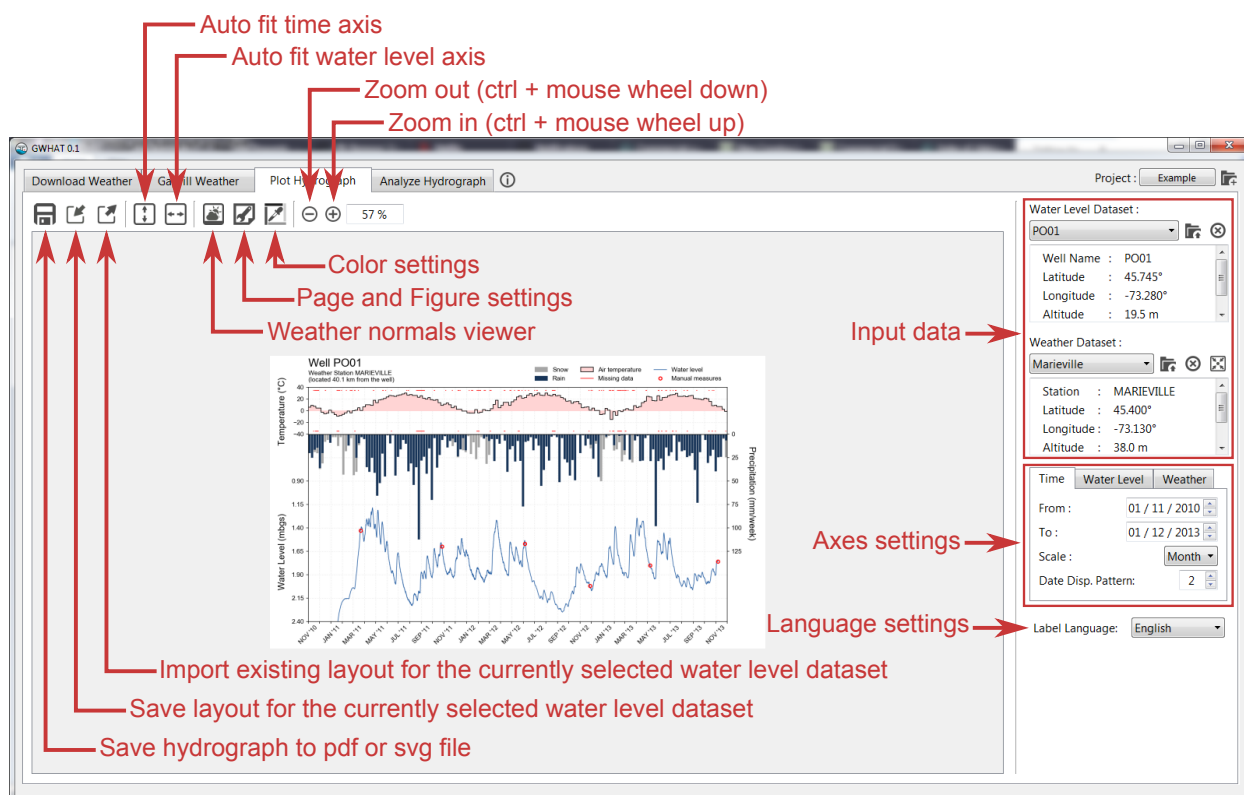

Fig. 6.2: Presentation of the editor to produce publication quality figures of well hydrographs that is available in the tab *Plot Hydrograph* of GWHAT.

6.1 Components of the Hydrograph

Fig. 6.3 presents the various elements of the hydrograph. Each of these are discussed in more details below.
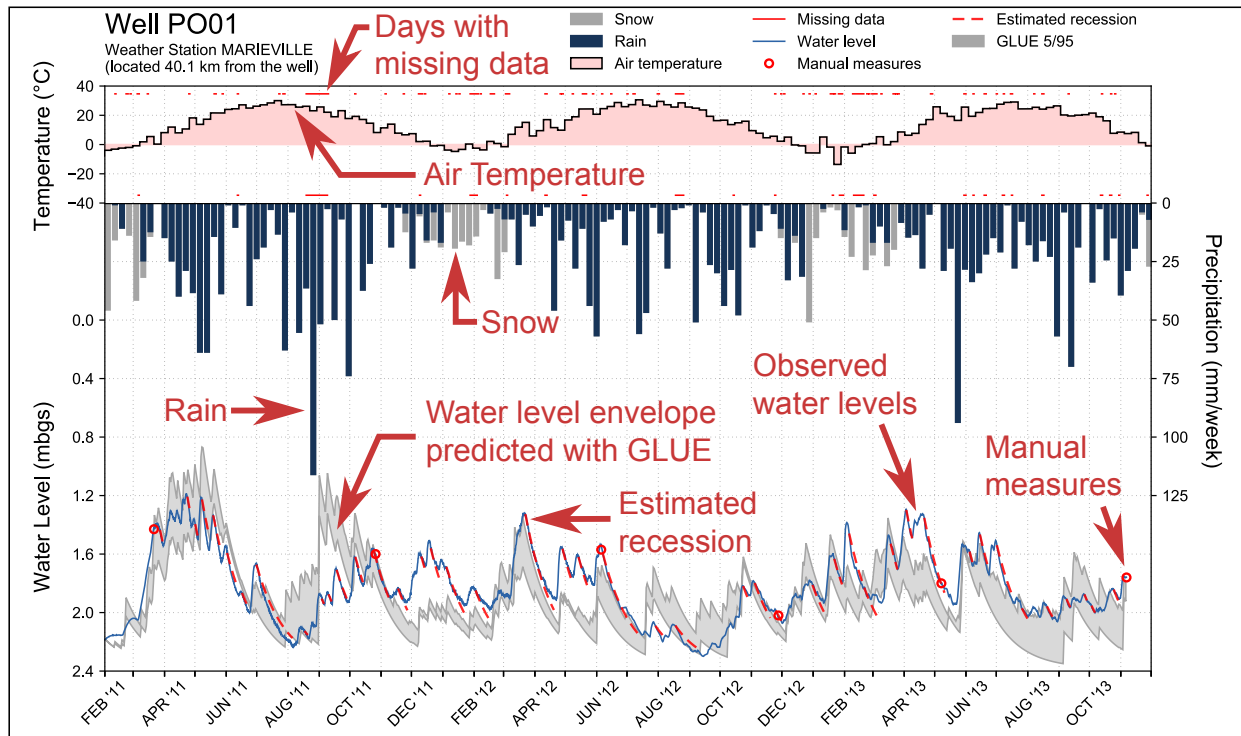

Fig. 6.3: Identification of the components of the hydrograph.

6.1.1 Observed water levels

The observed water levels are plotted on the bottom part of the hydrograph. By default, groundwater levels are represented by a continuous line that connects to all available data.

It is possible to ensure that the continuous line is not drawn over periods where data is missing by marking the missing period in the water level time series with at least one `nan` value before importing the water level dataset in GWHAT. For example, in Fig. 6.4, water levels were missing for the whole of 2012. A `nan` was thus added in the time series at one time during this period to avoid a line to be plotted between the 31/12/2011 and the 01/01/2013.

As shown in Fig. 6.5, it is also possible to show the trend of the water level by setting the option *Water Level Trend* to *On* in the *Page and Figure Setup* window (see Section 6.2). The actual observed data are then plotted under the trend line as a scatter plot. The trend line is computed using a moving average window of 30 days.

6.1.2 Weather data

Mean air temperature is plotted in the top part of the graph. The area between 0ºC and the observed temperature is colored by default to highlight the periods when air temperature is below the freezing point of water. Mean air temperature can be plotted on a daily, weekly, or monthly basis. This can be changed from the *Axes settings* panel as discussed in Section 6.3.
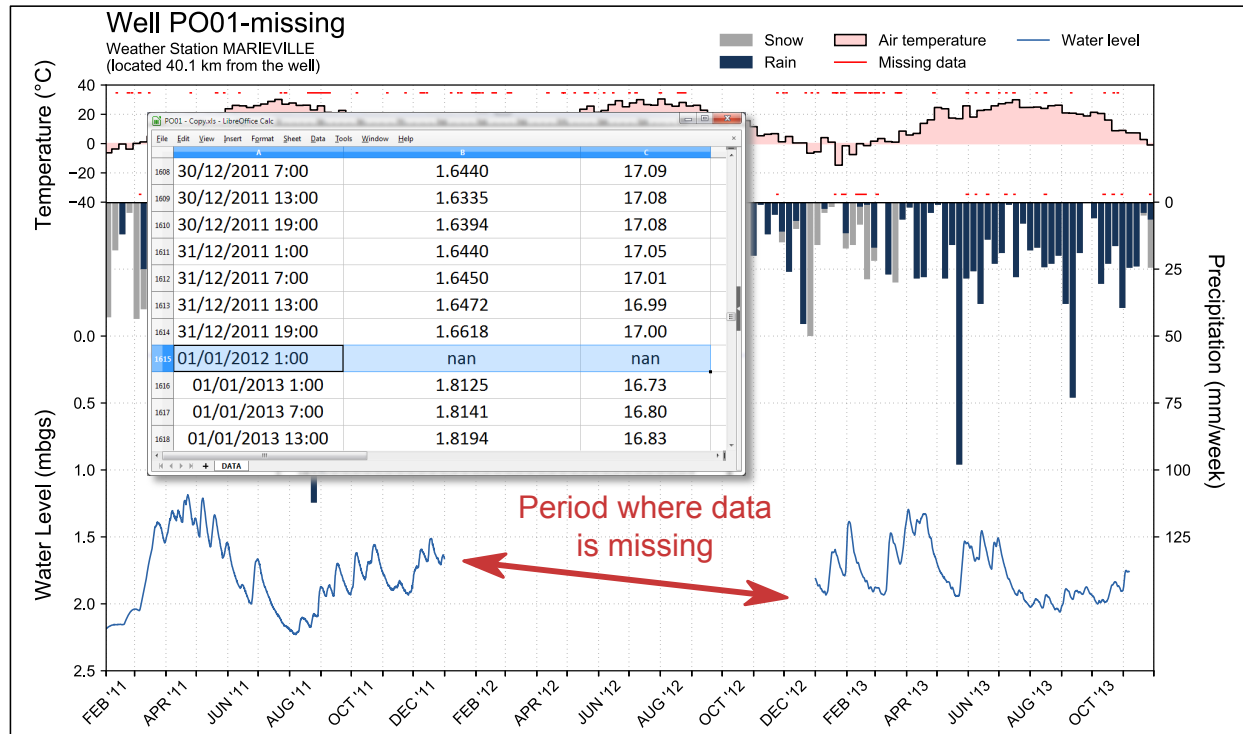
Fig. 6.4: Example of an hydrogaph with an extended period of time for which data is missing.

Cumulative precipitation, as rain and snow, is plotted in the bottom part of the hydrograph along with the water level data. For a given day, precipitation is assumed to fall as snow if the mean air temperature for that day is below 0ºC and as rain otherwise. As for air temperature, cumulative precipitation can be plotted on a daily, weekly, or monthly basis.

As shown in Fig. 6.5, it is possible to plot the water level data alone, without the mean air temperature and cumulative precipitation, by setting the *Weather Data* component to *Off* in the *Page and Figure Setup* window.

6.1.3 Missing weather data

The `Missing data` component is used to mark where daily air temperature and precipitation were estimated due to missing data in the dataset. This information is read when importing a dataset in GWHAT (see Section 3.1) from the `.log` file that is produced automatically when gap filling daily weather records with the tool presented in Section 5.

Note: If no `.log` exists when importing a daily weather datafile in GWHAT, `Missing data` markers won't be plotted on the hydrograph, even if data are missing in the daily weather dataset.

6.1.4 Water level manual measurements

Water levels measured manually during field visits can also be plotted on the hydrograph. This provides a quick and easy way to visually validate the automated measurements acquired with a water-level data logger.

To do so, the manual measurements must be saved in a csv or xls/xlsx file named `water_level_measurements` in the `Water Levels` folder (see Section 2.3). An example is shown in Fig. 6.6 below. The first column corresponds
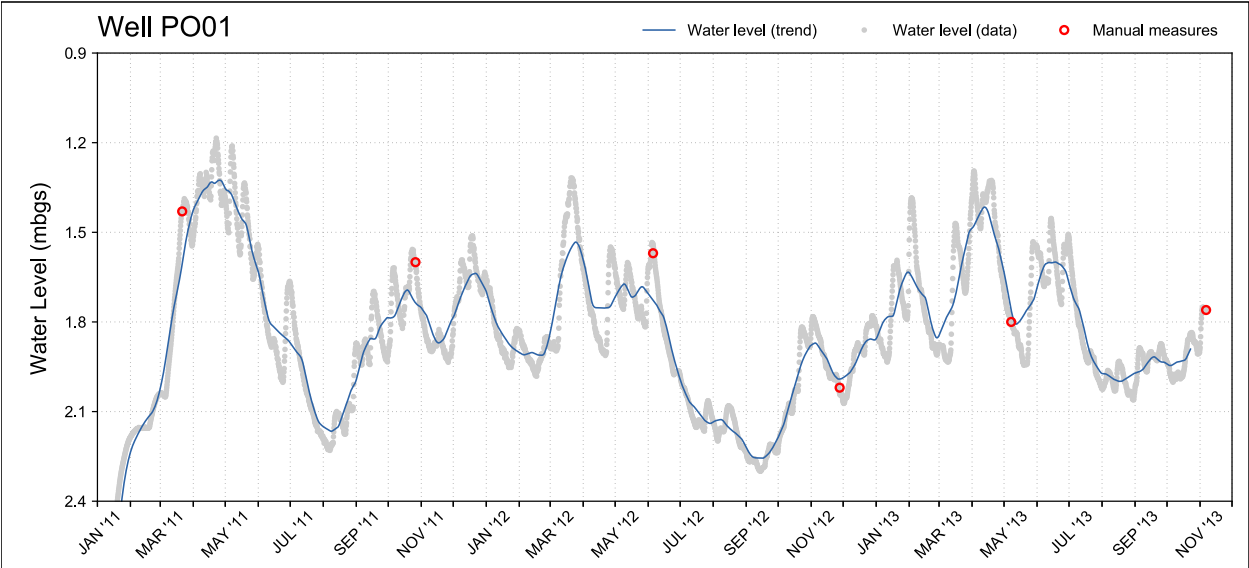
Fig. 6.5: Example of a hydrograph where the trend of the water level is shown as a continuous blue line along with the real observations plotted as a series of light gray dots.

to the name of the observation wells (see *Section 3.1*), the second column is the dates entered in *Excel numeric date format*, and the last column corresponds to the manual measurements, in metres below the ground surface.

Fig. 6.6: Example of a `water_level_measurements` file.

Note: A `water_level_measurements` file is created in a csv format by default by GWHAT the first time a project is created. If desired, this file can be converted to a xsl or xslx format. Note that if more than one file named `water_level_measurements` exists in the folder `Water Levels`, but with different extension, GWHAT will always read the data from the csv file by default.

6.1.5 Water level envelope predicted with GLUE

Water levels predicted by optimizing a quasi-two-dimensional hydrologic model with the GLUE (Generalized Likelihood Uncertainty Estimation) methodology at the 05/95 uncertainty level can be plotted on the hydrograph once groundwater recharge have been evaluated with the tool presented in Section 10.

As for many other elements of the hydrograph, the plotting of the GLUE predicted water level envelope can be turned on or off in the *Page and Figure Setup* window.

6.2 Page and figure settings

Several options are available to customize the size and visibility of the various components of the hydrograph in the *Page and Figure Setup* window, which is accessible by clicking on the ⬛ icon (see Fig. 6.2). The *Page and Figure Setup* window is shown in Fig. 6.7, along with an annoted figure where are presented the various components of the hydrograph layout that can be configured from this dialog.
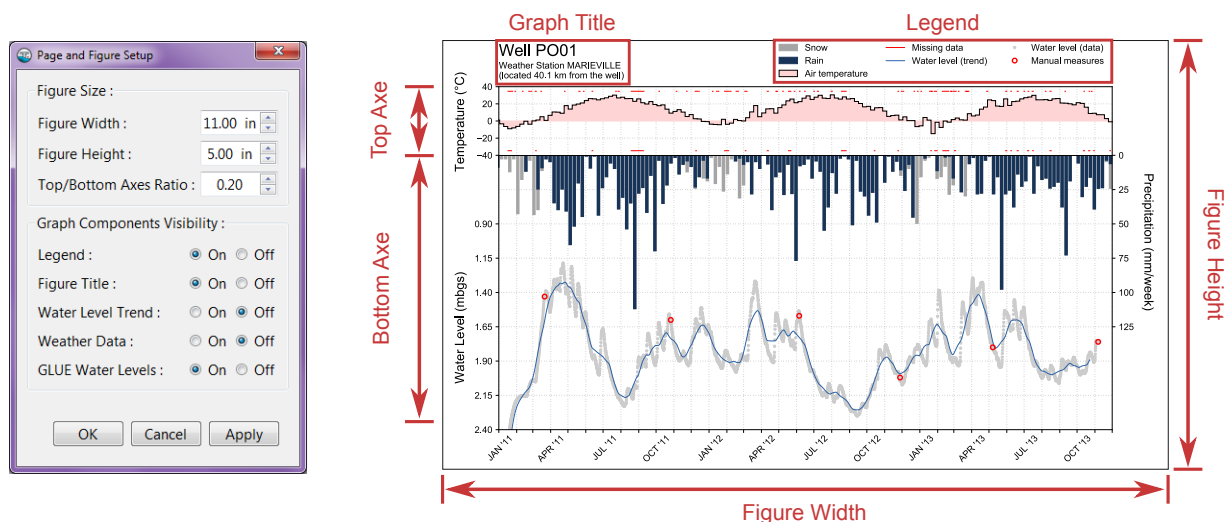

Fig. 6.7: Presentation of the components of the hydrograph for which the size or the visibility can be configured in the *Page and Figure Setup* window.

6.3 Axis settings

The scale and range of the axes for time, water level, and weather data can be configured from the *Axes settings* panel, located on the right side of the hydrograph editor. The options that are available for each axis are presented in Fig. **??**. The hydrograph is updated automatically when a value is changed in the *Axes settings* panel.

6.3.1 Time axis

The range of the time axis can be changed by setting the *From* and *To* dates. The *Scale* of the time axis can be set to *monthly* or *yearly*. The *Date Disp. Pattern* setting allows to define the interval with which the tick labels of the time axis are plotted. Four different cases with different values of the *Scale* and The *Date Disp. Pattern* settings are presented in Fig. **??**.

* WL Maximum = WL Minimum - (Grid Divisions x WL Scale) when datum is the ground surface
WL Maximum = WL Minimum + (Grid Divisions x WL Scale) when datum is the sea level

6.3.2 Water levels axis

The *Minimum* setting of corresponds to the value at the bottom of the water level axis. The *Grid Divisions* value corresponds to the number of intervals in which the water level axis is divided as shown on Fig. **??**. The *Datum* of reference of the water level axis can be set to either `Ground Surface` or `Sea Level`.

The value at the top of the water level axis is calculated from the values specified in *Minimum*, *Scale*, and *Grid Divisions*. The equation that is used in the calculation, which depends on the *Datum* that is selected, is presented at the bottom of Fig. **??**.

6.3.3 Weather axis

Only the scale of the axis for the precipitation is configurable through the *Precip. Scale* setting. The minimum value for precipitation is always set to 0 and the range of the axis depends on the value specified for the setting *Precip. Scale* and *Grid Divisions* in the water level axis settings.

As discussed in Section 6.1.2, the *Resampling* setting is used to set the time scale on which mean air temperature and

cumulative precipitation are plotted on the graph.

6.4 Color Settings

The color of several components of the hydrograph can be changed from the *Colors Palette Setup* window, which is accessible by clicking on the ☑ icon (see Fig. 6.2). The *Colors Palette Setup* window and the components of the hydrograph for which the color can be changed are both shown in Fig. 6.8. A new color can be selected for a given component of the hydrograph by clicking on its corresponding colored square in the *Colors Palette Setup* window and by clicking on the *OK* or *Apply* button.
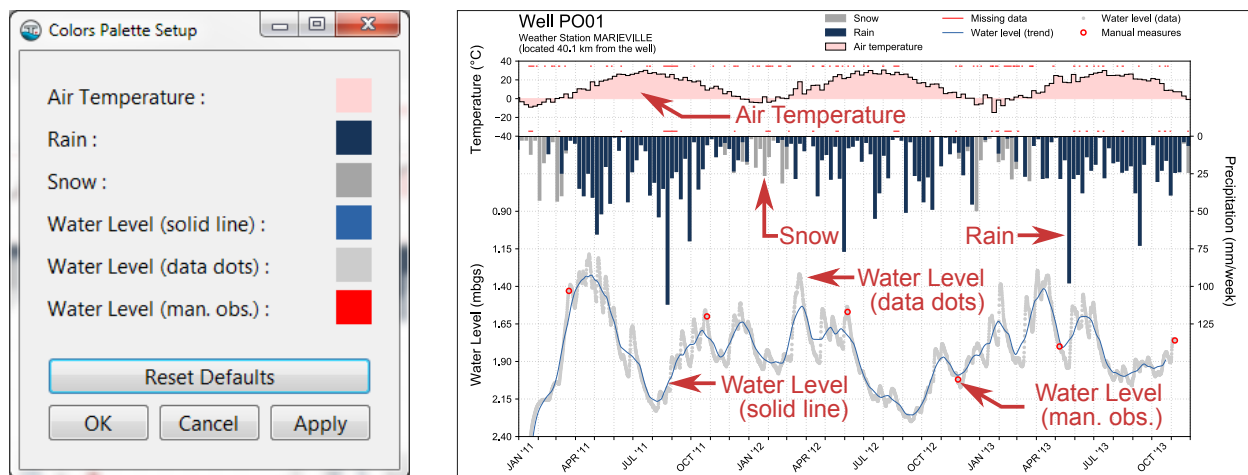

Fig. 6.8: Presentation of the *Colors Palette Setup* and identification on the hydrograph of the components for which the color can be changed.
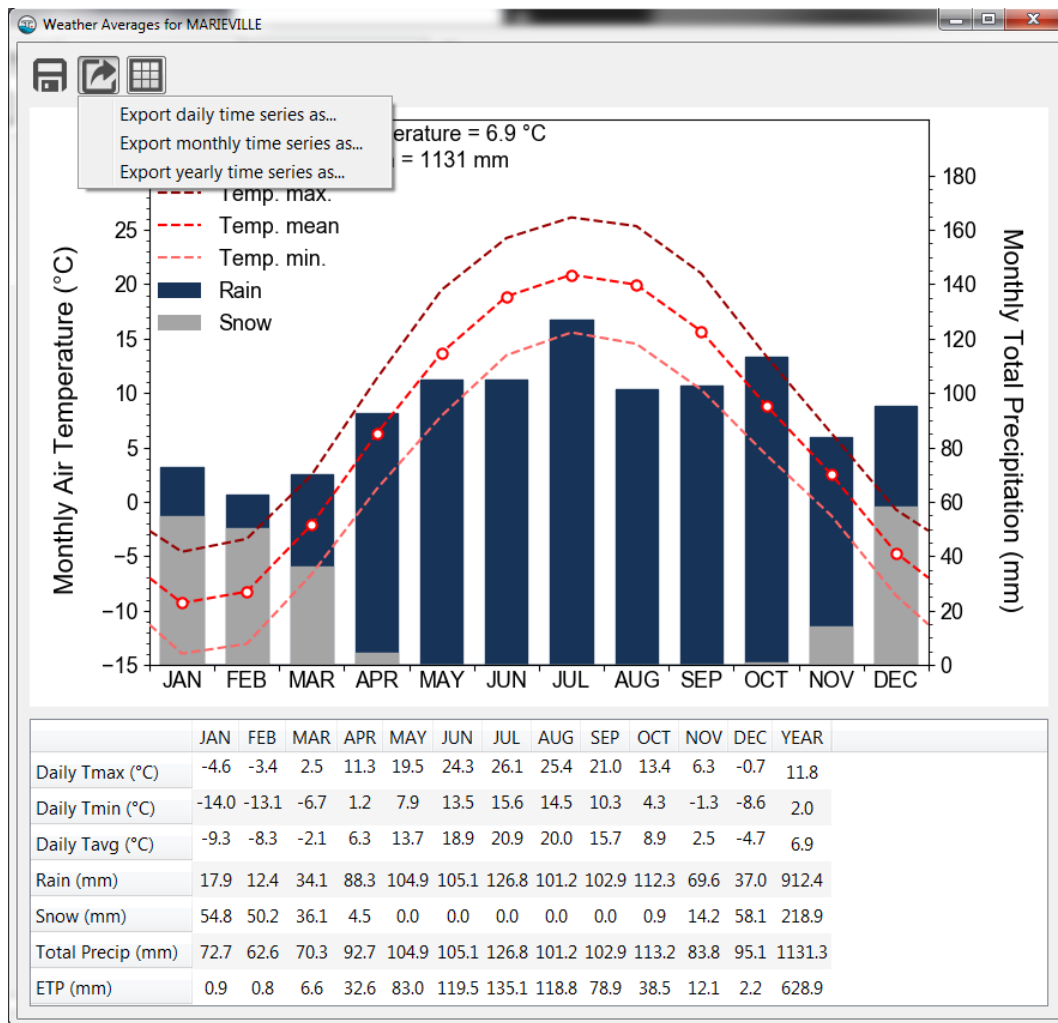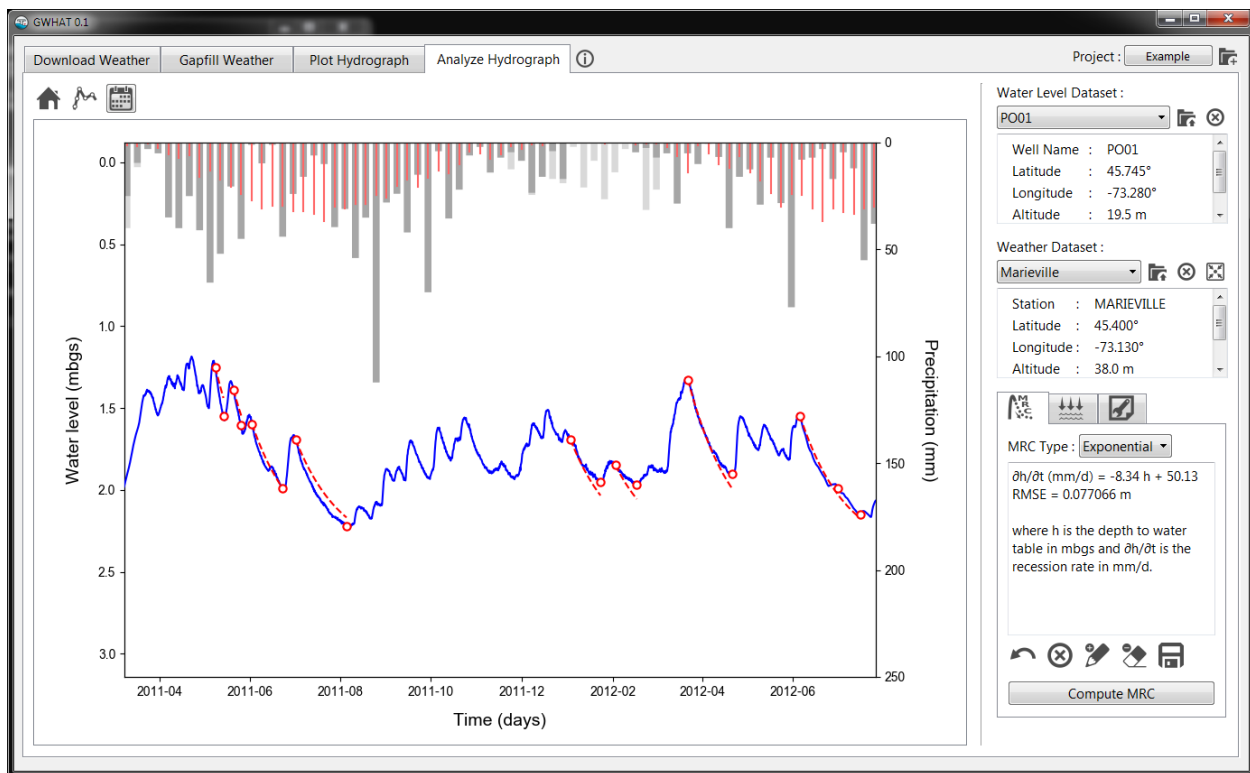
CHAPTER 7

Weather Normals Vizualisation

Fig. 7.1: Presentation of the weather normals viewer.

CHAPTER 8

Modelling the Recession

Computing the Well Barometric Response Function
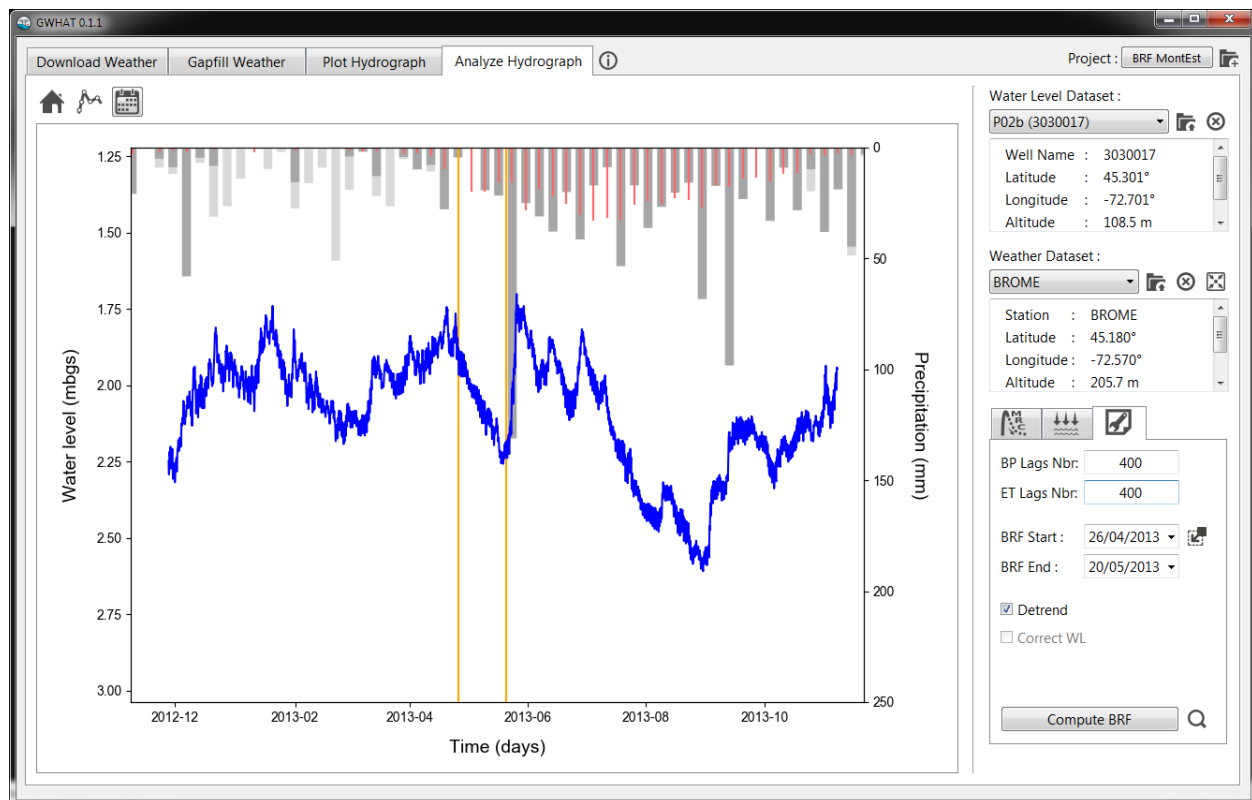

Fig. 9.1: Presentation of the interface to the KGS Barometric Response Function Software to compute the barometric response function of a well.

Estimating Groundwater Recharge
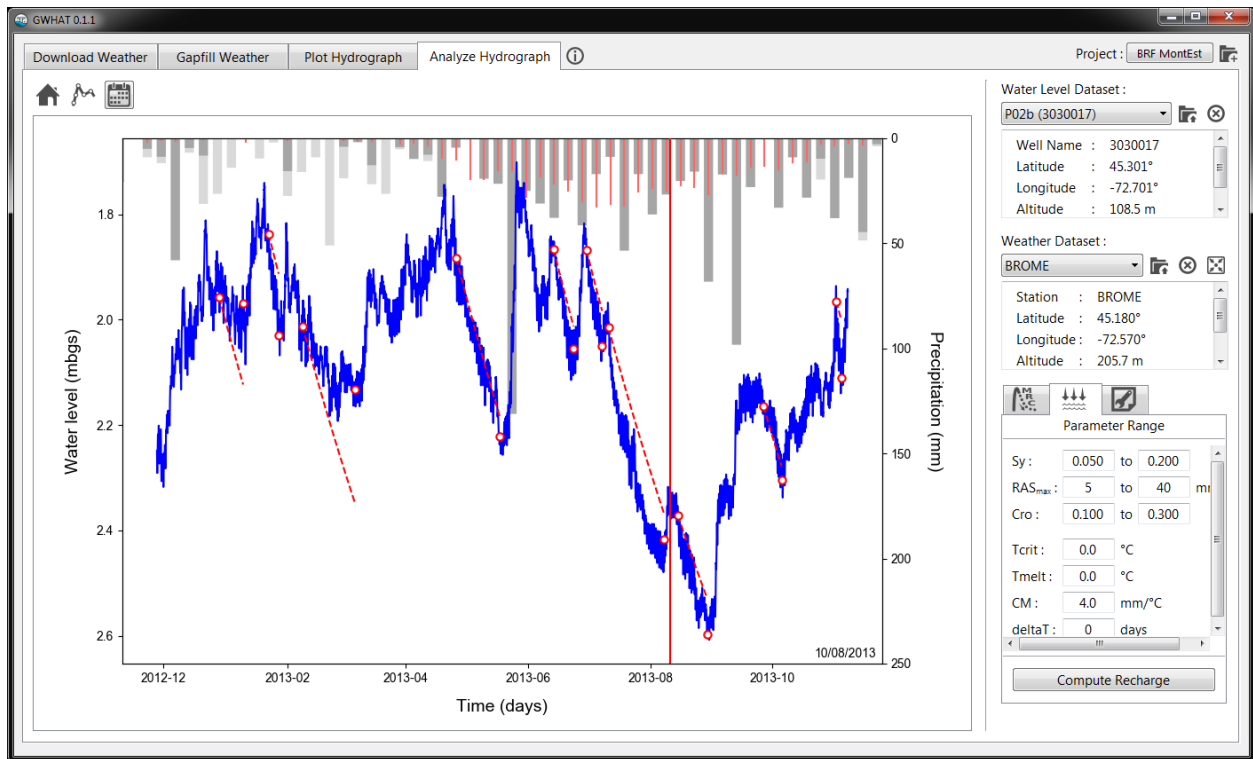

Fig. 10.1: Presentation of the tool to evaluate ground-water recharge in GWHAT available under the tab *Analyze Hydrograph*.

About GWHAT

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11.2 Contributors

GWHAT and this documentation have seen many revisions over the years as additional research has been completed. Contributing authors, listed in chronological order, include:

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11.3 Feedback

Please report bugs and feature requests on our Issue tracker or contact Jean-Sébastien Gosselin at jean-sebastien.gosselin@ete.inrs.ca.

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Glossary

Excel numeric date format Excel stores dates as sequential serial numbers, representing the number of days, in decimal format, since January 1, 1900. For example, January 1, 2008 6:00 AM is serial number 39448.25 because it is 39,447 days and 1/4 after January 1, 1900. Dates before January 1, 1900 is thus not supported by this format.

Input folder Folder where are saved by default the formatted weather data files generated from downloaded raw data files. This folder is also the default location where the tool to fill the gaps in daily weather data records look for input data files as described in Section 5.1.

Project file HDF5 binary file with a `gwt` extension where are saved the metadata related to the project (e.g. project title, author, creation date, etc.) and all the input and output data related to the plotting and interpretation of hydrographs, including the estimation of recharge. See Section 2.4 for more details.

Project folder Folder where are stored all input and output files relative to a particular project. See Section 2.3 for more details.

Raw folder Folder where are saved the daily weather data files once they have been downloaded from the CDCD as described in Section 4.1.

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