Software tool for sensors management and off-line data validation

User manual for Evohe 2013.2
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User manual for Evohe 2013.2
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This report is:
PU = Public
Summary

The EVOHE software is developed in PREPARED to implement and make accessible for all users metrological methods for sensors calibration, uncertainty assessment and off-line data validation for time series collected in urban water systems. These methods are presented in D3.1.5, D3.1.6 and D3.3.1.

This deliverable is the user manual of the EVOHE software version 2013.2.

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Sensor management – Data validation – Uncertainties
Monitoring of sewer systems

User Manual

Version 2013.2

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Evohé has been developed by the LGCIE (Laboratory of Civil and Environmental Engineering) at INSA Lyon from the experience acquired since 1999-2000 in the OTHU project (Field Observatory on Urban Hydrology – www.othu.org).

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Partenaires du développement / Development partners
Les partenaires suivants ont contribué au développement d’Evohé, notamment en participant à la définition des spécifications et aux tests des versions préliminaires :

The following partners contributed to the development of Evohé, especially by participating in the definition of specifications and testing preliminary versions:

Alyotech, Chambéry Métropole, Grand Lyon, Safège.

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The following persons contributed, with various levels of involvement since 1999-2000, to the conceptualisation and to the research and informatics works which led to the development of Evohé:

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### How to use this manual

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Introduction

**What is the purpose of EVOHE?**

In order to comply with legal obligations (French decrees dated 1994 and 2007 on monitoring of urban sewer systems) and to promote the implementation of permanent diagnosis by practitioners, the LGCIE (Laboratory of Civil and Environmental Engineering) at INSA Lyon has developed a software aiming to evaluate automatically and reliably flow rates, volumes and pollutants loads transferred in sewer systems and discharged into aquatic environment. Based on the OTHU experience (Field Observatory on Urban Hydrology – www.othu.org), EVOHE allows processing and validating of long time series in urban hydrology. It contains many functions in a unified tool, from raw data acquisition by sensors to the validation of corrected data. Many functions are available: automatic calculation and selection of sensor calibration, raw data correction, uncertainty assessment, new numerical regression methods accounting for uncertainties in all variables, algorithms and parametric tests for data validation, filling gaps in time series, etc. EVOHE delivers results which can be directly used to create regulatory monitoring reports. EVOHE offers powerful calculation tools which generate great time savings for the user.

**Software structure**

The EVOHE software structure has been designed to facilitate the handling and the processing of large data sets. The main concept (see figure below) is based on successive steps for correction, prevalidation, validation, completion and processing of continuous time series measured in sewer systems equipped with on line sensors.

**What means Evohe?**

In ancient Greek, Evohe means « Courage, my son ». These words were pronounced by Zeus to encourage his son Dionysus for his fighting against the Giants. The expression has been used later on by the Bacchantes, the nursing nymphs of Dionysus, to remember his victory against the Giants.
Installation and characteristics of EVOHE

Minimum computer requirements

Operating system: Windows XP/7
Random access memory (RAM): 2 GB
Hard disk space: 21 MB for EVOHE + 760 MB for Matlab MCR
Minimum screen resolution: 1024x768
Processor: Double Core
USB port for protection key
CD-ROM drive
Internet access for online documentation

EVOHE is developed with Matlab which is a language specialised for numerical computation.
In order to use Matlab applications, it is required to previously install the « Matlab Compiler Runtime » (MCR).
This is why two types of installations exist: the first one includes the MCR, the second one installs only EVOHE and runs faster.

Remark: for the MCR installation, you should work in a session with the administrator rights.

Step by step installation

- Run the file setup_evohe_2013_2_system.exe to start the installation with system files.
- Run the file setup_evohe_2013_2.exe to start the installation/update.
- Enter the EVOHE installation directory: the default installation directory is c:\EVOHE 2013.2
- You can choose the location and the name of the “Start” shortcut.
- By ticking the option « Create an icon on the desktop », a shortcut for EVOHE will be created on your desktop.
- After the reminder of your preferences, click on “Install”.
- A progress bar indicates the progress of the installation. At the end of the installation, if you have selected the option including the MCR, its installation start automatically by unzipping the MCR install file.
- Follows the steps and accept the Matlab licence.
- Enter the MCR installation directory: the default installation directory is c:\program files/MATLAB/MATLAB Compiler Runtime.
- After the reminder of your preferences, click on “Install”.
- A progress bar indicates the progress of the installation.
- Click on “Finish”.
- Click on “Terminate”.

The installation is completed.
**Characteristics of the software**

The EVOHE software is a single license. It should be installed on the computer of each user. There are two types of users:

- The manager (reading/writing mode): he/she can read, create, modify and delete a base and create new users (the protection key is required).
- The consultant (reading mode only): he/she can read and extract data, but cannot modify the content of a base.

Without the protection key, the default mode of the EVOHE software is in the consultant mode: one can only read existing bases and extract data.

With the purchase of the EVOHE license, a login and a password are given.

*Remark: when launching EVOHE, it is possible to create new users with their logins and passwords. If the protection key is recognised, you will need your login and your password to launch EVOHE.*
Step by step user manual

Creation of a base
- Define sensors, calibrate sensors and define their maintenance
- Import data
- Define measurement cross sections
- Define a measurement site and its associated sensors

Data correction

Data prevalidation

Data validation

Application of functions

Application of tools for data treatment and processing

Export data
When the software is launched, it is possible to create a new base (« New base ») or to open an existing base (« Open a base »).

At any time, modifications of a base can be saved by clicking « Save a base ».

A base includes: sensors, measurement sections and sites. Any sensor or section can be connected to several sites, depending on the user’s needs. As shown on the example in the left figure, the sensor C2 is connected to sites S1 and S3.

For a proper use of the software, the following recommendations are very important:
- Import raw data as .csv files with the structure shown on the left page. Dates shall be with written with the customised format "dd /mm/yyyy HH:MM:SS".
- The decimal separator is the point . (and not the comma ,).
- Apply the standard and SI units shown below.

**Variable** | **Unit**
---|---
Rainfall intensity | mm/h
Water level | m
Flow rate | m³/s
Conductivity | µs/cm
Flow velocity | m/s
Turbidity | FAU ou NTU
Temperature | °C
Diameter or any other length | m
Median particle diameter $d_{50}$ | µm
Manning-Strickler coefficient $K_{MS}$ | m¹/³/s
Sediment depth | m
Wet section | m²
Free surface width, wet perimeter | m
Concentration | mg/L

**IMPORTANT REMARK:**
It is highly recommended to work systematically with the universal time UT and not with legal time.
This allows avoiding problems with days of 23 h or 25 h at each change of time in spring and autumn.
Sensors maybe:

- real ones, installed in measurement sites.
- Virtual ones, their data resulting either from computations or from modelling.
Management of sensors

Information and data to provide:

- Name of the new sensor
- Measured variable: water level, flow velocity, conductivity, temperature, etc. It is possible to add new variables with their respective SI units.
- Type of sensor: real sensor to be calibrated, real sensor but with no possible calibration, virtual sensor.
- Settings: offset (shift from zero, most frequently for water level sensors above invert), empirical uncertainty linked to local measurement conditions
- Durations between maintenance or calibration operations
- Prevalidation thresholds: sensor measurement range (provided by the manufacturer) et empirical thresholds determined locally for a given sensor
- GPS or SIG coordinates of the sensor
- Link to a photo, a manual (pdf format) or to any other document related to a sensor

Remarks:

- The empirical uncertainty is assessed from the user expertise, for each sensor and each measurement site. For a water level sensor in a sewer, one may set for example $u(h) = 0.0075 \text{ m}$, for a standard Doppler sensor $u(U) = 0.05 \text{ m/s}$, for a conductivity sensor in homogeneous flow $u(\text{conductivity}) = 0$, and for $u(\text{turbidity})$ between 5 and 10 % of the measured value (OTHU experience).
- Settings written in red characters are mandatory.
Sensor calibration

This action is essential for all sensors declared as a real sensor to be calibrated. The calibration includes 3 steps:

- **Selection of sensor**
- **Importing the calibration file** with the following format: date of calibration, standard values $x_i$, associated standard uncertainties $u(x_i)$ and the $n$ measured values $y_{ij}$ to $y_{in}$ for each standard value $x_i$.
- **Choice of the type of calibration**
  - Ordinary regression: three polynomial functions with order 1, 2 and 3 are systematically estimated by means of the ordinary least squares method. The most appropriate polynomial function is selected according to a Fisher variance test and to a gradient analysis. This method is recommended for most frequent cases.
  - Williamson regression: three polynomial functions with order 1, 2 and 3 are systematically estimated by means of the Williamson weighted least squares method to account for uncertainties in all variables, based on $N \geq 2$ Monte-Carlo simulations. This method is recommended if i) standard uncertainties $u(x_i)$ in standard values $x_i$ are not negligible compared to standard uncertainties in measured values $y_{ij}$, or ii) the variance of the $y_{ij}$ values is very high. The Williamson regression method needs a rather long computation time.

After calibration, the most appropriate polynomial function is shown in a box with a green frame line, containing the values of the coefficients of the function and their standard uncertainties. The user may decide to change the proposed polynomial function.

The standard deviations of the measured values $y_{ij}$ are also displayed. It allows the user to choose between two options for the following uncertainty assessment: either a constant standard deviation for the whole measurement range (a scalar value, by default equal to the highest measured variance, but possibly modified by the user), or a set of standard deviations for various intervals along the measurement range (a matrix of values to be defined by the user) if a more detailed approach is needed.

Button for the visualisation of the polynomial functions with order 1, 2, 3 and of the standard deviation measured for each standard value.
When importing data, it is possible to correct them immediately for real sensor to be calibrated by choosing the option « Correct the data automatically », but only if the sensor has been previously calibrated. If no calibration has been done, a warning message is displayed. For real sensor which cannot be calibrated of for virtual sensors, no automatic correction can be applied automatically during import.

When importing data, it is also possible to prevalidate them immediately for real sensors by choosing the option « Prevalidate the data automatically », but only if a prevalidation parameters set exists for this sensor. If no parameters set has been defined, a warning message is displayed.

Remarks:

✓ When a time series has been imported, it is possible to import other time series for the same sensor. EVOHE checks if there are already imported data for the same dates and times. In this case, a warning message is displayed and asks the user to choose « Keep previous values » or « Replace by new values ».

✓ It is possible to delete data sets attached to a sensor: select the sensor, click on the data set and delete it.

For each sensor, time series with constant time step has to be imported. Select a sensor in the list and click on the button « Import a data set ».

For the chosen sensor, a data file has to be selected (its time step is read from the two first lines by EVOHE and is displayed for information but cannot be changed by the user).

Button for the visualisation of the time series.
Multiple import

It is possible, from a unique .csv file, to import simultaneously data for several sensors. The method is in principle similar to the previous one for one sensor. It is simply requested to indicate the corresponding sensor for each column of the .csv file (for example, sensor T1 → column CR-Vi-4 in the .csv file). Once the association is done, click on the green arrow in the centre to add this combination to the list on the right side. This list can be modified as much as necessary until the user confirms its choices.

To go further...

It is also possible to schedule the import, editing and prevalidation of data. To do this, click "Sensor" in the menu bar tab and choose to import from a database or a file.
This function is essential for monitoring the sensors over time. It provides information leading to remove values known to be invalid as recorded during the sensor maintenance.

If this is not done, unrepresentative values will be stored in the time series, which may lead to erroneous results.

Each maintenance of a sensor must be declared, specifying the date and time of start and end and the description of the intervention (menu “Type of maintenance” dropdown).
Section Module

Creation and management of measurement sections

To define a measurement section (scrolling list of possible geometries: circular, rectangular, trapezoidal or other to be defined by the user).

Setting of parameters to apply the Manning-Strickler formula:
- \( K_{MS} \): Strickler roughness coefficient (m\(^{1/3}\)s\(^{-1}\))
- \( d_{50} \): median diameter of particles (\(\mu m\)) in sewer sediments are present on the pipe invert
- Pipe invert slope (m/m)

To import data sets defining a section.

Three types of files can be imported according to specific needs:
- Couples of points \( h_i \) (water depth, in m) and \( S_i \) (wet section, in m\(^2\)) to estimate the flow rate by a relation \( Q = SU \);
- Couples of points \( h_i \) (water depth, in m) and \( L_i \) (free surface width, in m) to estimate the flow by the Manning-Strickler formula with accounting for the possible presence of sewer sediments;
- Couples of points \( h_i \) (water depth, in m) and \( P_i \) (wet perimeter, in m) to estimate the flow by the Manning-Strickler formula with accounting for the possible presence of sewer sediments.

The file should contain a high density of points around significant changes in section geometry in order to establish an accurate approximation function (angles, thresholds, dry weather channels, sidewalks...).

To establish a unique or composed optimised approximation function from the imported data sets.

After having selected a section, the user choses the regression to be applied to the imported data set. He/she indicates if the approximation function should intercept the zero or not.

The software displays the tentative approximation functions \( S_m = f(h) \) or \( L_m = f(h) \) or \( P_m = f(h) \) determined from both the imported data sets and the number of threshold points defined by the user in order to establish an optimised function, with the corresponding 95 % confidence intervals.
Site Module

*Creation and management of sites with associated sensors and sections.*
This module is essential for data processing (Correction, Prevalidation, Validation: CPV).
Management of sites

For each site, the user defines a list of associated sensors, created previously in the module « Management of sensors », and associates one or more sections.

It is possible to select simultaneously several sensors to be associated to a given site. For the following data processing, an active site must be defined. The user selects a line in the table « List of sites » and clicks on the button « Set as an active site ». The name of the active site is then displayed below the button and appears also in the main window.
It is possible to export data after they have been CPV processed.

Data can be exported with four different formats: .txt, .xls, CANOE importable format and SANDRE format. The .csv and .xls export files are structured as shown on the right side.

A data synthesis can also be provided (.doc, .pdf or .html format) (release 2014.1).
Functions Module

Data processing module (Correction, Prevalidation, Validation : CPV) and post-processing functions

General principle:
Each function converts lower case input data into one or more upper case output data.

For example, the function $hvQ$ converts water level $h$ and flow velocity $v$ into flow rate $Q$. 
Correction/Prevalidation/Validation
CPV processing

Before applying the CPV data processing, it is required to have previously applied the following steps: Management of sensors, Sensor calibration of sensors, Import data, Management of sites & Management of sections.

1. Name of active site = working site selected in Management of sites.

2. Time interval for data processing. By default, starting and ending dates correspond to the most extreme dates of all data of the site. If the user wishes to work with a shorter time interval (included in the initial maximum interval), he/she simply needs to change starting and ending dates by clicking on the left side buttons.

3. Table showing all available data sets, measured or calculated for all sensors associated to the active site. The percentages of data having been previously corrected, prevalidated and validated are indicated. They vary according to the progress of the CPV data processing. The type of calibration (if applicable) used for each sensor is also indicated.

4. Hide or display data sets which have been respectively corrected, prevalidated or validated.

5. Graph displaying the data time series. If data have been corrected, a second graph display corrected data with their 95 % confidence intervals.

6. Completely remove data sets.

7. Data processing blocks: Correction, Prevalidation and Validation (see below).

In order to apply one of the CPV data processing steps, the user must first select one or more lines in the table. For each data set, the steps must be applied in the following order: Correction \(\rightarrow\) Prevalidation \(\rightarrow\) Validation.
a) *Data correction*

This step can be applied jointly and automatically with [data import](#). It is possible to correct the same data set as many times as necessary simply by choosing the corresponding sensors and data sets.

If, among the data sets selected for correction, some of them have already been corrected, a warning message is displayed.

At the end of the correction the percentage of corrected data is updated in the [CPV monitoring table](#).

Data correction includes two parts:
1) The estimation of most likely true values determined by the inversed calibration function.
2) The estimation of standard uncertainties from both the sensor uncertainty observed during calibration and the local empirical uncertainty set by the user when a sensor is created.
b) Data prevalidation

This step automatically check the data to identify and wrong or outlier values. Each value receives a prevalidation mark:

1: accepted value  
2: doubtful value  
3: rejected value

The command « Setting » allows saving frequently applied prevalidation tests for easy later applications like a macro. It is possible to jump over the prevalidation step to apply directly the validation. But in this case, all data will be systematically classified as **doubtful**.

After having clicked on the « Prevalidation » button, the window shown on the left side is displayed. The name of the active site and the list of applied tests are shown with their brief description: **basic tests**, **expert tests**, and **user defined tests**.

*It is possible to modify the characteristics of the sensor used for the prevalidation tests;*

Once the tests are selected, the user should click on « Save and run tests »: he/she may name this set of tests which will later on be applicable like a user defined macro including a series of actions.

In case a predefined set of tests is selected, the corresponding individual tests appear with a tick on their respective lines.

After prevalidation is performed, a statistical synthesis is given by a series of graphs, both globally and for each individual test (see on the left side).
**Data prevalidation**

**Basic tests**

<table>
<thead>
<tr>
<th>Selection</th>
<th>Name</th>
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<tbody>
<tr>
<td>☐</td>
<td>Measurement range</td>
</tr>
<tr>
<td>☐</td>
<td>Last maintenance</td>
</tr>
<tr>
<td>☐</td>
<td>Dernier étalonnage</td>
</tr>
<tr>
<td>☐</td>
<td>Maintenance</td>
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<tr>
<td>☐</td>
<td>Most frequent range</td>
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<tr>
<td>☐</td>
<td>Gradient simple</td>
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<tr>
<td>☐</td>
<td>Direct comparison</td>
</tr>
</tbody>
</table>

**Test – Last calibration**: checking of the time elapsed since the last sensor calibration. If the last calibration is more recent than the maximum period allowed between two calibration, measured values are accepted and marked 1, else they are rejected and marked 3.

**Test – Maintenance**: for a given date and time the sensor is in maintenance, the measured values are rejected and marked 3, else they are accepted and marked 1.

**Test – Frequent range**: this is the range containing the most frequent measured values for a given site. For example, 95% of the measured pH values in a given site are between 6 and 8. A measured value outside this frequent range will be doubtful and marked 2 in prevalidation.

**Test – Simple gradient**: similar to the frequent range, but for gradient (i.e. first derivative) of the measured values.

**Test – Direct comparison**: this test compares two simultaneous time series, value by value, for both real and virtual sensors, by accounting for their respective standard uncertainties, and detects significantly diverging pairs of values which are then marked 2.

**Test – Physical range**: this test aims identifying any measured value outside the sensor measurement range. For example, a measured flow velocity of 5 m/s given by a sensor with a measurement range 0 – 2 m/s will be rejected and marked 3.

**Test – Last maintenance**: sewer systems are difficult and harsh environments where sensors become quickly dirty and fouled. Biofilm, grease or particles may disturb sensors and generate systematic errors or wrong measurements. It is thus necessary to do a maintenance (cleaning) with a period $T_e$ (in days). Values measured between the last maintenance and $T_e + 1$ later are accepted and marked 1; between $T_e + 1$ and $2T_e + 1$ days, they are doubtful and marked 2; beyond $2T_e + 1$ days after the last maintenance, they are rejected and marked 3.
Data prevalidation

**Expert tests**

<table>
<thead>
<tr>
<th>Selection</th>
<th>Nom</th>
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<tr>
<td></td>
<td>Variation rate</td>
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<tr>
<td></td>
<td>Material redundancy</td>
</tr>
<tr>
<td></td>
<td>Analytical redundancy</td>
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</table>

**Test - Variation rate:** the measured variable sometimes varies either abruptly or more gradually depending on specific circumstances (dry or wet weather conditions are typical examples). The test subtracts a filtered signal to the original signal: the mean of the residuals over a mobile time window should be zero; if this is the case, it indicates that an abnormal variation is observed. The corresponding values are marked 2.

**Test - Material redundancy:** Let us suppose two sensors measuring the same variable ion the same location. After correction, they should provide similar values, with differences compatible with their standard uncertainties. The difference between the two time series is used as a default indicator. If this difference is significantly different from zero, a defaults is detected. Without additional information, it is not possible to decide which sensor is wrong, and both values are marked 2.

**Test – Analytical redundancy:** similar to the above test, but between two correlated values (for example water level and flow velocity if there is no backwater effect, or measured and simulated flow rate, etc.).

**Test - User defined test:** this test is freely defined by the user according to his/her specific needs, based on values, standard uncertainties and marks of values.
Data validation

The user MUST have previously corrected and prevalidated data before starting this CPV step.

The final validation is done manual by the user. It concerns only doubtful values marked 2 after prevalidation. The values marked 3 (rejected) after prevalidation cannot be validated by the user.

The user shall either validate or reject the doubtful values by using the graphical tools to do that in a very simple way. To confirm his/her actions, he/she should click OK and close the window.

Data from several sensors can be displayed simultaneously to help the user to make decision by comparing time series. He/she should click « Active » for the selected sensor to allow validation. If not, and if only the “Displayed” box is ticked, data from this sensor are only displayed but cannot be validated.

It is possible to display data with both their uncertainties and their prevalidation marks in a floating table by clicking the button « D ».

Methods and tricks:

- By clicking on zoom -, and by clicking several times on the graphical validation window, one go back to the original graphs.
- To abandon the on-going validation and go back to the initial state, click on « Use the prevalidation marks ».
- The button « Results » allow pointing a given value in the graph. A white cross pointer appears and allows displaying the date, time and value of the pointed data.
- The filters allow displaying only doubtful data which are still not validated.
- To validate, click the button « Selection » and select an area containing doubtful values. Validate or reject all of them by clicking the « Validate » or the « Reject » buttons. Don’t forget to click « OK » to confirm your action.

Graphically, the progress of the CPV process is shown by clicking on the « Viewing » button in the CPV window, which displays:
1) The graph of raw values
2) The graph of corrected values with their 95 % confidence intervals
3) The graph of prevalidated values with their marks (1/2/3) appearing as a colour code
4) The graph of the validated values.
The following modules must be used only with previously validated data for various post-processing actions.

- **Calculation of flow rates**
- **Calculation of cumulated volumes**
- **Conversion of a surrogate signal into concentration**
- **Calculation of pollutant load from flow rate and concentration**
- **M(V) curves for a given pollutant**
- **Descriptive statistics of time series**
Toolbox module

Toolbox for post-processing treatment and analysis

- Replacement and filling
- Tipping bucket rain gauge
- Weighing rain gauge
- Dry weather / wet weather separator
- Correlation
- Changing time step
- Synchronising time steps
- Cloning
- Creation of virtual sensor