# APPENDIX 4 : SAT & MAR monitoring, and model for performance evaluation from EviBAN D2.1, June 2023

## 5.1. SYSTEM MONITORING DEVICE (SMD) AND THE ENVIRONMENTAL MONITORING INTERFACE (EMI)

SMD (Subsurface Monitoring Device) is an automatic geophysical tool installed in a piezometer used to constantly record water's electrical conductivity along the aquifer's vertical axis. It provides a real-time picture of the position and evolution of the saltwater intrusion. In costal environments, the saltwater intrusion can penetrate several kilometres inland after a drop in the piezometric level caused by excessive pumping and/or droughts. If uncontrolled, this phenomenon can compromise the region's drinking water supply and economic activity.

The SMD includes a cable loaded with electrodes which is deployed in a borehole and provides a profile of the resistivity of the rock formation around the borehole. A surface data acquisition box injects a known current between electrodes and measures the induced potential difference between two other electrodes (Figure 1). Bulk resistivity is obtained using Ohm's law, corrected by a geometric factor. This process is repeated from the top to the bottom of the electrode cable, allowing the measurement of bulk resistivity profiles. Bulk resistivity, which is affected by the water salinity, porosity, and rock type, is converted into EC of the liquid, using the Waxman–Smits equation. This conversion considers the formation factor (F), and the surface conductivity term (Cs), which are determined using a reduced set of logging measurements (gamma ray, resistivity and sonic for porosity).

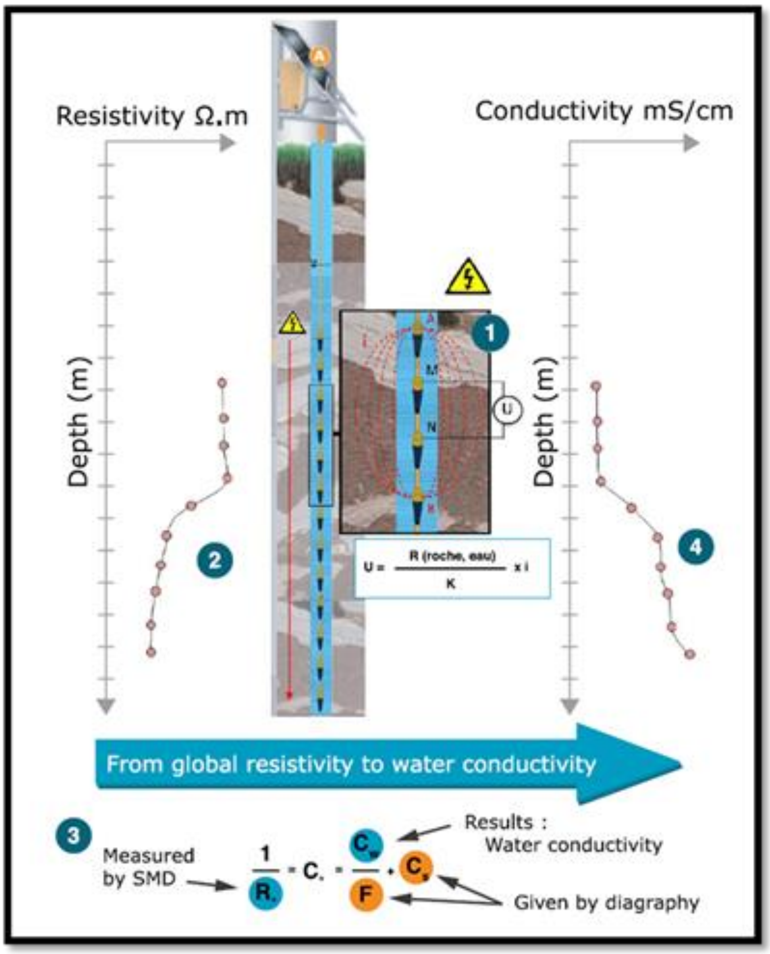


*Figure 1: the SMD principle: (1) Current (i) between two electrodes (A and B) measure the induced potential difference between two other electrodes (M and N). According to Ohm's law corrected by a geometric factor, bulk resistivity (R) is thus obtained (U =R (formation, pore) * (i)/k. U is the tension (Volt) and K the formation factor (2) This process is repeated from the top of the electrodes cable to its*

*bottom allowing the measurement of bulk resistivity profiles. (3) According to the Waxman–Smits equation, bulk resistivity is converted in to ECw20. This conversion needs to know the formation factor (F), and the surface conductivity term (Cs), which are determined using a reduced set of logging measurement (gamma ray, resistivity and sonic for porosity). (4) Finally, ECw20 profiles are obtained. The ECw20 profiles are corrected from borehole effect and normalized in temperature.*

The electrodes are made of a cupro-aluminium allowing reduction of the corrosion process. The energizing power was 12 V (battery or solar type), with the possibility of being plugged to the mains.

The radial resolution in the SMD is 40% to 50% of the spacing between electrodes, namely: For 1 m spacing, the radial resolution is 40–50 cm. Accordingly, the measured resistivity mostly represents salinity of groundwater outside the well, avoiding the well vertical flow effect.

The data is transferred by telecommunication and may be visible on an internet interface the Environmental Monitoring Interface (EMI). Online software platform (using an Internet browser), the EMI has been developed to collate and display information about the aquifer. It includes full description of water dynamics and has specific tools for salt-water intrusion data management. Current and historic data are available 24/7.

Each SMD installed on the site is connected to a secure extranet where data can be downloaded and visualized.

EMI application is based on two identities:

- A database where all the data coming from sensors installed in different sites is stored. Different processes to import data are available (several format files, API…)
- A web application allowing viewing and processing data

EMI can accept and integrate data from every monitoring tools already installed on the well field (whatever the tool and the manufacturing), such as flow meters, water level sensors, water quality sensors, pluviometers, ...

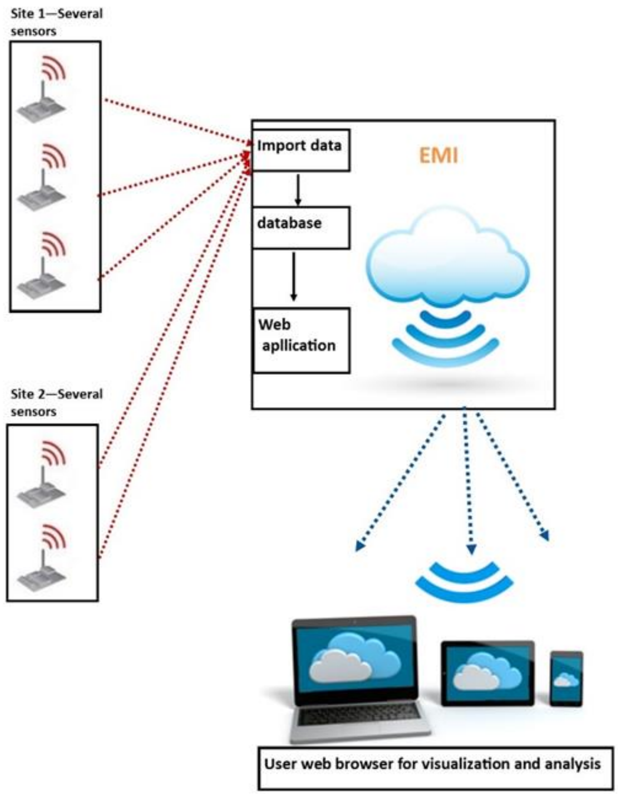


*Figure: 2 EMI architecture*

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To enable accessing to the data online, an interface has been developed allowing to:

- viewing data on graphs (value parameter versus time)
- processing the data
  - calculate hydrogeological parameters
  - have statistics on data
  - interpolate the data on 3D graphs
- export, if necessary, a large sample of preformatted data in order to use it in other programs
- setting alerts and thresholds on some parameters (water level…)

EMI organization is based on tree architecture. For each defined site, several monitoring stations can be associated; and for each station, several sensors with several measured parameters can be defined.

The site overview can be used to locate the monitoring tools connected to EMI.

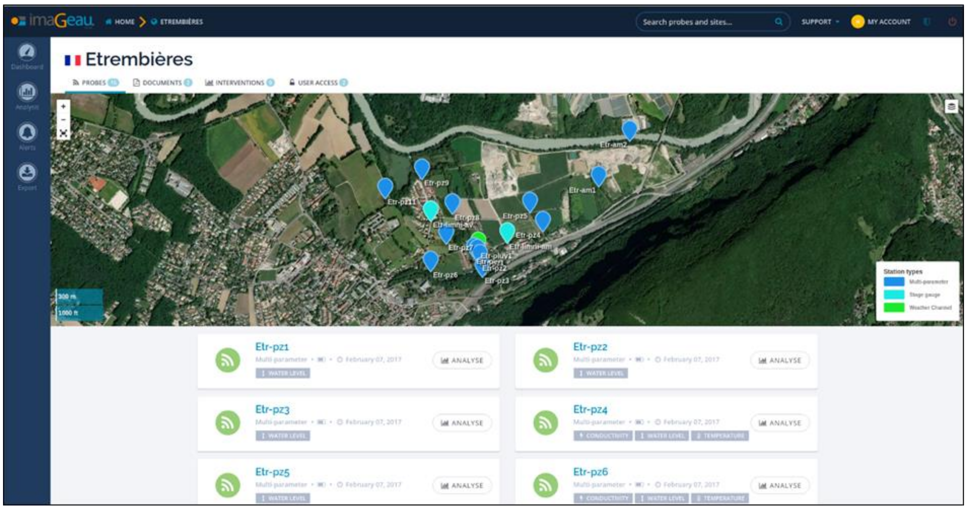


*Figure 3: Site overview with different monitoring stations (dark blue: multi-parameters sensors (Cw, water level T°); light green: rain gauge; blue: water level sensor)*

This organization allows having all the data associated to the same site in a same place in order to visualise and analyse it with different process. For example, on a site with several boreholes equipped with water level elevation sensors, all the water level elevation curves can be plotted on the same graph. If a rain gauge is installed on the site, the water level can be plotted in front of this rain gauge allowing having data cross-correlation.

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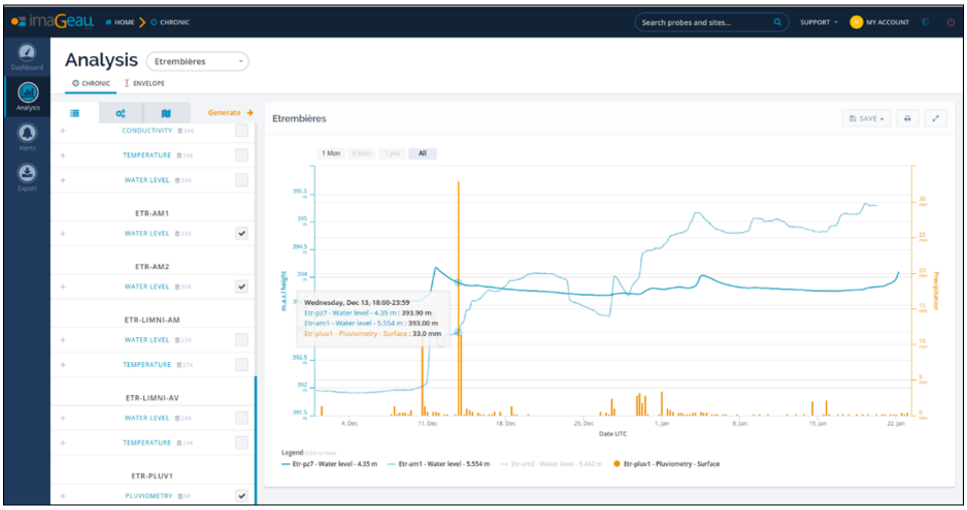


*Figure 4: Site overview with different monitoring stations (dark blue: multi-parameters sensors (Cw, water level T°); light blue: rain gauge; green: water level sensor)*

Different viewing/analysis tools are available in order to better analyse the data. Depending on the sensor type, different analyses are available. For single point sensor (i.e., water level sensor, quality sensor…), data can be plotted with:

- "Temporal Chronic": Used to view environmental data changes in graph form. Up to ten curves can be added to the graph and multiple parameters can be viewed through linked graphs.
- “Envelop”: used to plot actual data relative to historic data (i.e., mean to see the evolution of the water level relative to anterior years)

When multiple parameters are measured at the same measurement station, it is possible to display them simultaneously on superimposed graphs with the same timescales. The browser's cursor can be used to directly compare different parameters at the same "T time."


*Figure 5: Muti-parameters curves displaying on the same graph with different colours and scales depending on the parameter (black: T°, blue: conductivity, orange: water level)*

For multi-points sensors (i.e., SMD), in addition, other analyses are available:

- "Interpolation": Used to interpolate multi-point data in order to create temporary iso-value maps, example: display the map of water conductivity changes over the whole aquifer block over a one-year period,
- "Log": Used to view multi-point data in the form of a profile at a given date or over a given time interval,

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- "Saltwater intrusion interface": In the case of a conductivity profile measured using imaGeau systems (SMD), the saltwater intrusion interface can be used to follow over time the depth of an interface defined by the user, e.g.: change in depth of the fresh water/salt water interface (limit 5000 µS/cm). If multiple conductivity sensors are measuring changes over the entire vertical of a piezometer, it is useful to track the evolution of the depth of the interface between two masses of water of differing salinities. In the case of saltwater intrusion tracking, the depth of the saltwater intrusion (freshwater/saltwater interface) is an essential parameter for understanding the evolution of the saltwater intrusion.

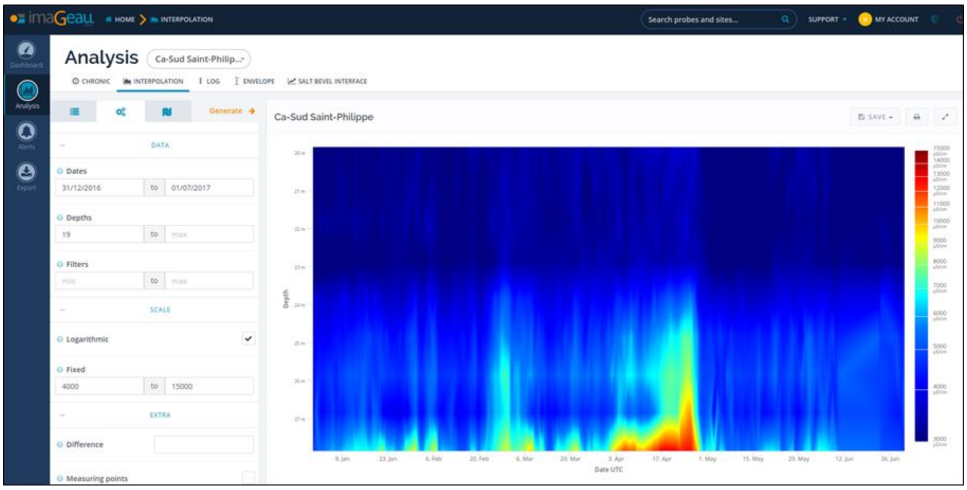


*Figure 6: 3D interpolation generated from multi point data over vertical and time, example of SMD monitoring a salt water intrusion*

### 5.1.1. Objectives

In case of aquifer recharge, the SMD monitoring allows to determine the impact of the recharge in terms of water quality and potential benefit of this recharge to struggle against the saltwater intrusion.

### 5.1.2. Interest for MAR-SAT systems

Analysis of conductivity acquired by SMD tools at various locations, at different depth during several years provides a new perspective on the impact of wastewater spreading on saltwater intrusion. The implementation of the SMD technologies in the EviBAN project provides evidence of the potential benefit of MAR practices and management to a larger scale of aquifer recharge, particularly in coastal areas to struggle saltwater intrusion.