RITE GEOSYSTEMS

ENCARDIO RITE METASENSING FOR MEGA STRUCTURES

APPLICATION NOTE

MONITORING GROUNDWATER LEVEL AND PIEZOMETRIC PRESSURE

1 INTRODUCTION

Groundwater is a critically important global resource. It requires careful monitoring, protection and management. Monitoring of groundwater level and its recharge has become a mandatory requirement at several places all over the world. For efficient water management, continuous monitoring of groundwater level and pore pressure is crucial. Reliable and accurate groundwater data is required, well in time, to assess groundwater conditions. However, the monitoring task becomes gigantic and expensive when the number of sites to be monitored increases. Automated real-time monitoring systems are best solution. Encardio-rite offers advanced integrated solutions for the same.

2 WHY MONITOR GROUNDWATER

Water beneath the earth surface needs to be monitored for two reasons:

- Groundwater table mapping for Hydrology
- Groundwater level and pore water pressure variation measurement as part of geotechnical monitoring during construction of large civil engineering projects.

Groundwater measurements can be made using different types of instruments. Choosing the right type of instruments depends on factor such as reason for monitoring, accuracy of the measurement and the type of pumping activity. Encardio-rite offers both vibrating wire and mechanical type of groundwater monitoring instrumentation for groundwater level monitoring & pore pressure variation monitoring at any construction site, as well as for groundwater table mapping across a wide geographic area.

Our automated groundwater monitoring systems are extensively used for long term continuous monitoring and stand alone installations. A variety of solutions are available ranging from unattended maintenance free monitoring of a few boreholes at construction site to state-wide monitoring of hundreds of boreholes at remote locations from a central location.

Parameters generally monitored are:

- Pore pressure & groundwater level at construction site
- Groundwater table mapping
- Water temperature
- Rainfall to co-relate water table variation with rainfall

Encardio-rite offers following products to monitor various above mentioned parameters:

1. Real-time monitoring:
   - Automatic water level monitoring system (EWLR-101) consisting of piezometer and datalogger
   - Piezometer (EPP-30V) to monitor pore pressure
   - Rain gage (ERG-200) to monitor rain fall
   - Digital dataloggers (ESDL-30) with GSM/GPRS or RF transmission facility.
   - Integrated software and web data management service (WDMS) to provide the data at client's fingertips, with instant alarms to stakeholders
2. Manual monitoring
   - Casagrande piezometer (EPP-10) for monitoring pore pressure
   - Open standpipe (EPP-10SP) for monitoring of water level
   - Dipmeter or water level sounder

In this application note we will be discussing the near real-time monitoring systems.

3 PORE PRESSURE & GROUNDWATER LEVEL MONITORING (GEOTECHNICAL)

3.1 Pore water pressure & water level

Large civil engineering projects or infrastructures like high rise buildings, tunnels, dams, etc. requires measurement of pore water pressure as an integral part of geotechnical monitoring services. The pressure experienced by water contained in pores of earth materials, concrete structures or rock is generally called pore water pressure also called piezometric pressure. The main purpose to study pore pressure is to determine the level and flow pattern of groundwater.

The level in the ground at which the pore pressure is zero (equal to atmospheric) is defined as the water table or phreatic surface. Groundwater extraction by pumping is quite common in construction activities like deep excavation of high rise buildings or underground car parks, tunnels, subways, underground stations and dams. While, it is important to dewater during excavation such that construction activity shall be smoothly and safely carried out, it is equally important to monitor the groundwater level. The monitoring is done prior to any drilling of wells and during dewatering activities.

Groundwater extraction impacts the amount of groundwater stored in an aquifer and the rate at which it recharge and refills. It may lower the water table of the area. Not only this, the groundwater extraction may increase chances of ground movement/ settlement to fill the empty spaces left behind. This can result in damaging the construction area as well as local communities. Thus, groundwater monitoring is crucial to protect the local community and to ensure safe construction progress.

Piezometric pressure at any depth is generally equal to the groundwater level around it, but it is not necessary that it always happens so. In rock enclosed aquifers, the pore water pressure may be different from the surrounding groundwater level/ table. Take the example of a water spring. The water pressure in the aquifer connected to the spring makes the water flow out to the ground; whereas one may have to dig a few meters away from the spring to find water.

3.2 How piezometer can be used to measure pore water pressure and groundwater table?

Vibrating wire piezometer is widely used to monitor pore water pressure and groundwater level. Different types of piezometers are available to suit specific application and project requirements.

As a general rule, when piezometers are sealed within the soil (in borehole, concrete or embankment), they respond only to the changes of the pore water pressure at a local zone around itself and not to the groundwater pressures at other elevations. The piezometer in this case provides significant quantitative data on the magnitude and distribution of pore pressure and its variations with time that helps to understand ground behaviour before-during-after construction.

However, when the piezometers are not sealed (installed in an open observation well), they respond to the changes of groundwater pressure throughout their installed depth. Thus, it monitors the groundwater level/table at installed location.

Model EPP-30V vibrating wire piezometer

Model EPP-40V vibrating wire piezometer

The piezometer is used for following main monitoring purposes:

- Effect of water in pores of soil or rock to reduce load bearing capacity of soil or rock. Effect is more pronounced with higher pore water pressure leading eventually in some cases to total failure of load bearing capacity of the soil.
- Determine level and flow pattern of groundwater
- Determine flow pattern of water in earth/rock fill & concrete dams and their foundations and to delineate the phreatic line.
- Provides basic data for design improvement that will promote safer and more economical design and construction.
- Proper evaluation of pore pressure also helps in monitoring the soil behaviour after construction and indicates potentially dangerous conditions that may adversely affect the stability of the structure, its foundation and appurtenant.

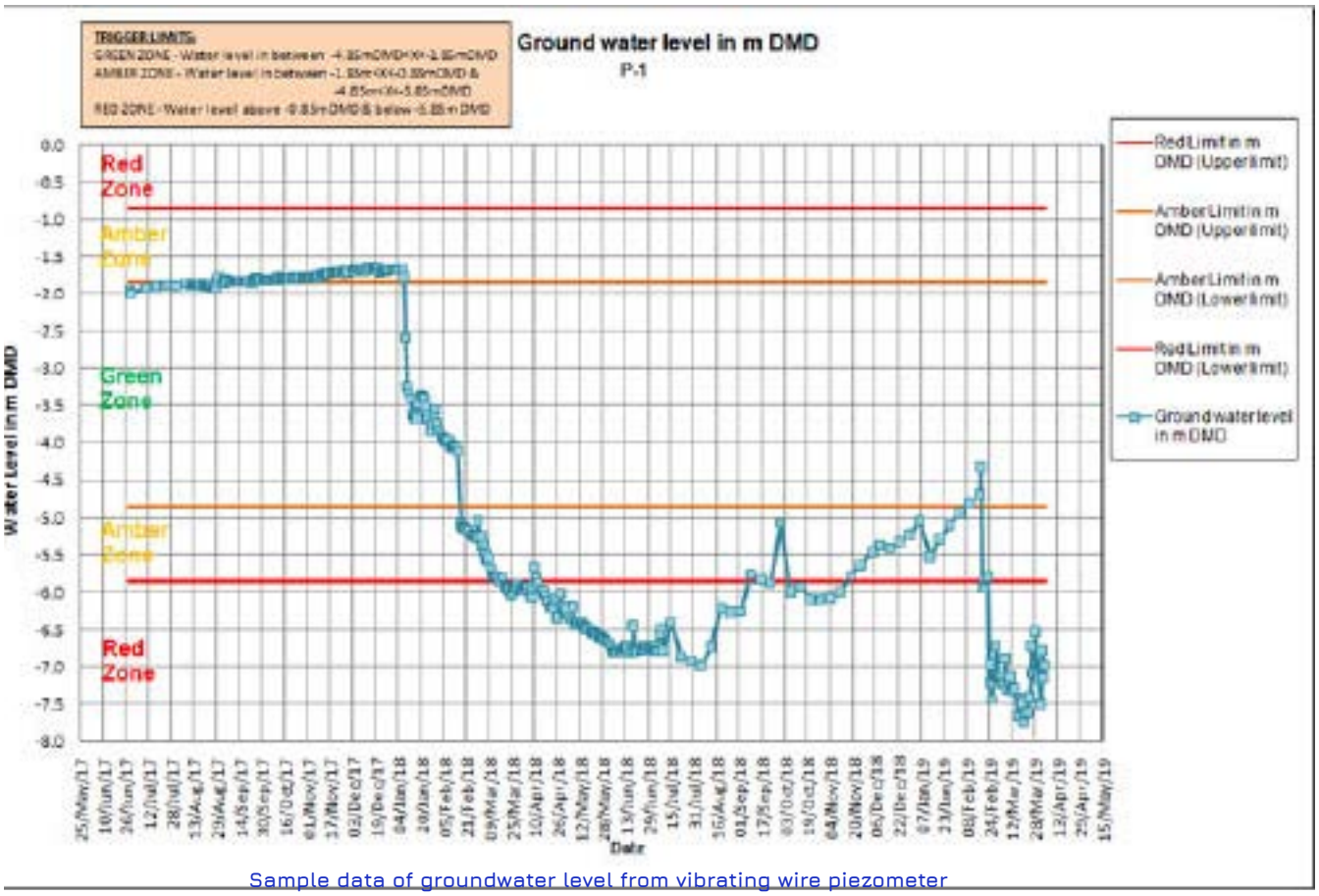
Piezometers installed with dataloggers at different construction sites

3.3 How to install piezometer to measure pore water pressure and groundwater table?

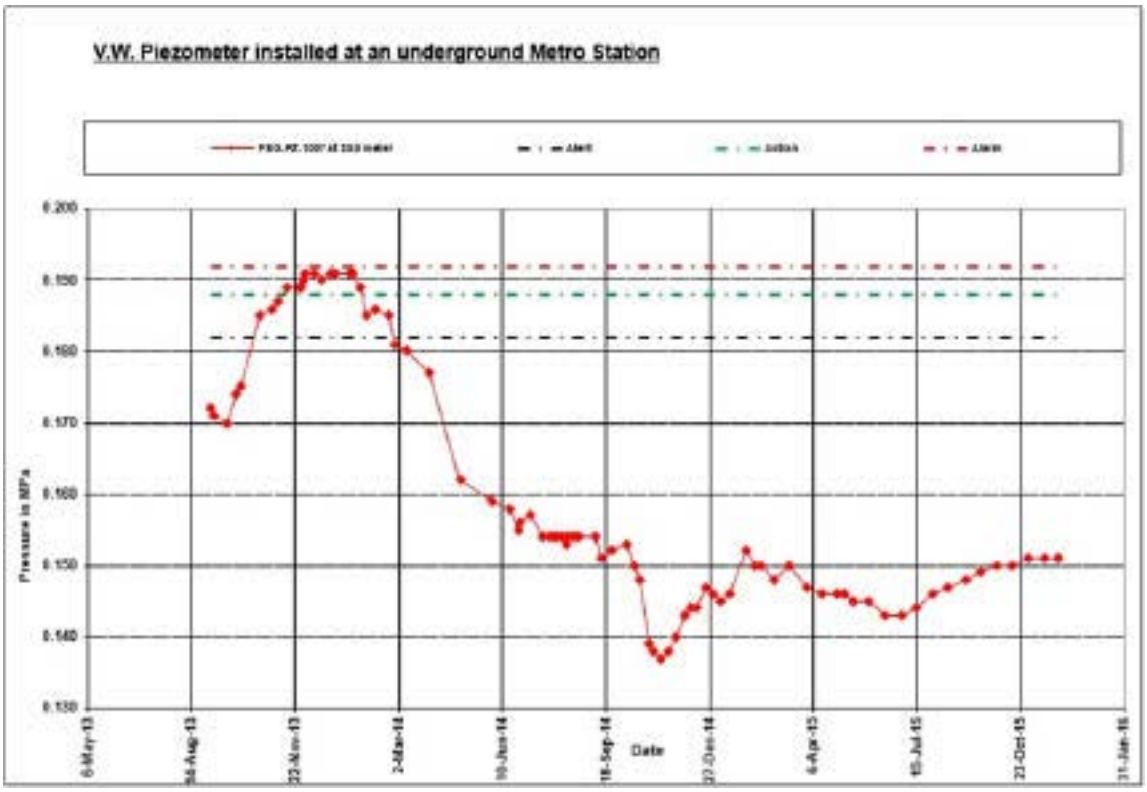
To monitor the groundwater level, piezometer is suspended inside any observation well with a perforated pipe sections at the bottom. The pressure of the groundwater pushes water into and up the standpipe until the level of water inside the standpipe is equivalent to the surrounding groundwater level. The piezometer inside the standpipe measures the water level head over it and provides the water level data. Both model EPP-30V and model EPP-40V are used for water level monitoring. However, model EPP-40V are used more often owing to its slim size that can easily go inside a less diameter borehole.

To measure the piezometer pressure or the pore water pressure, the piezometer is installed at a required depth inside a borehole by fully grout method (sealed). The annular spacing between the sensor and the borehole is sealed with cement grout, thus ensuring that the piezometric pressure is monitored only at the depth at which the porous tip is installed. Grouting is done by fully grouted method as the piezometer require very little volume of water to register a change in pore water pressure, thus resulting in a fast response time.

Model EPP-30V vibrating wire piezometers are suitable for embedment for long term monitoring. Special manufacturing techniques ensure insignificant zero drift. Each piezometer has in inbuilt thermistor for temperature readings. The coefficient of thermal expansion of the wire used in all vibrating wire sensors is 11.5 ppm per °C. It is almost the same as that of the steel surface to which it is attached and therefore normally no correction is required to be made for temperature variations.



Sample data of groundwater level from vibrating wire piezometer



Sample data from vibrating wire piezometer

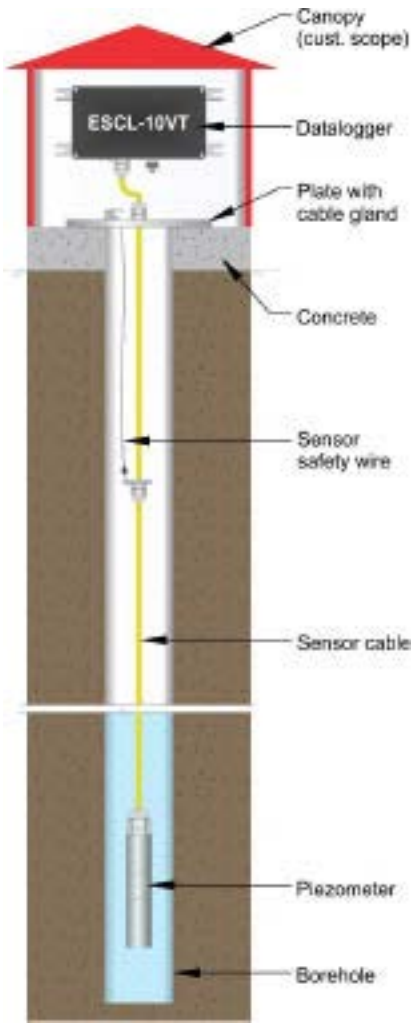
4 GROUNDWATER TABLE MAPPING (HYDROLOGY)

The learning of the distribution and movement of groundwater is called hydrogeology also called groundwater hydrology. Groundwater table monitoring is an essential element in any environment information system. Based on groundwater monitoring data, information is noted and many results can be oriented. Constant monitoring provides the necessary data inputs for our smart environment and is basically the basis of the decision for climate change.

4.1 How to monitor groundwater table

Water level measurements from observation wells are the principal source of information. To monitor water level at a particular location, either an existing well/borehole is used or a borehole is drilled down to the aquifer that contributes most to the water table. A casing pipe is installed in the borehole to prevent the borehole wall from collapsing. At the level of the aquifer, a highly porous filter is provided at the lower end of the casing pipe.

The filter generally consists of a section of slotted pipe covered with geotextile to prevent soil particles from clogging the borehole. The level of water in such a borehole or well corresponds to the water table at that location. The water level is generally referenced to mean sea level and is known as the elevation of the water table.



Typical installation scheme for automatic groundwater monitoring system

4.2 Automatic groundwater monitoring system

Encardio-rite offers model EWLR-101 automatic water level monitoring systems. The system basically comprising of sensor and datalogger is installed in an observation well to monitor the water level variation in it. A typical system consists of following components:

- **Absolute pressure/Level sensor (model EPP-30V or EPP-40V)** suspended down the observation well, up to the required installation depth. It measure the ware columns above it i.e. height of the water columns above the pressure sensor.
- **Automatic datalogger (ESCL-10VT)** to record, store and transmit the data at required intervals, settable at even 5 seconds.
- **Interconnecting cable** from sensor to datalogger, with Kevlar strain wire
- **Temperature sensor** inside pressure sensor to measure water temperature
- **Barometric pressure** sensor inside datalogger to measure atmospheric pressure
- **GSM/GPRS modem** in the datalogger for data retrieval/transmission with telemetry

4.3 What are the factors that need to be compensated to get correct water level?

Modern pressure sensors and dataloggers allow water levels to be monitored at rapid rates and with excellent precision. While automated methods have the potential for reducing measurement errors, systematic errors may provide faulty estimates of the total head. Factors like atmospheric pressure, specific gravity of water, temperature drift can affect the measured total head of water column. These are thus compensated automatically by the online monitoring systems.

Barometric pressure effect

Changes in atmospheric pressure can cause groundwater levels to fluctuate. Atmospheric pressure is caused by the Earth's gravitational attraction of air in the atmosphere. The relationship between water level and barometric pressure is an inverse one. An increase in air pressure will cause water level in the well to fall and a decrease in air pressure will cause water level in the well to rise.

Till recently there was no better option and one had to live with the gauge pressure sensor, vented tube cable combination. However, with today's advanced technology it is possible to use absolute pressure sensor that responds to the total pressure. The atmospheric pressure is simultaneously measured by installing a barometric pressure sensor in each automatic water level monitoring system. Effect of barometric pressure can be corrected using a basic formula:

$$W0 = \frac{Ho - Bp}{\gamma}$$

Where H_o = the measured absolute hydraulic head obtained from pressure sensor

B_p = the measured barometric pressure obtained from barometric pressure sensor

γ = $\rho.g$ (specific gravity of water x acceleration of gravity); for pure water specific gravity of water is 1.

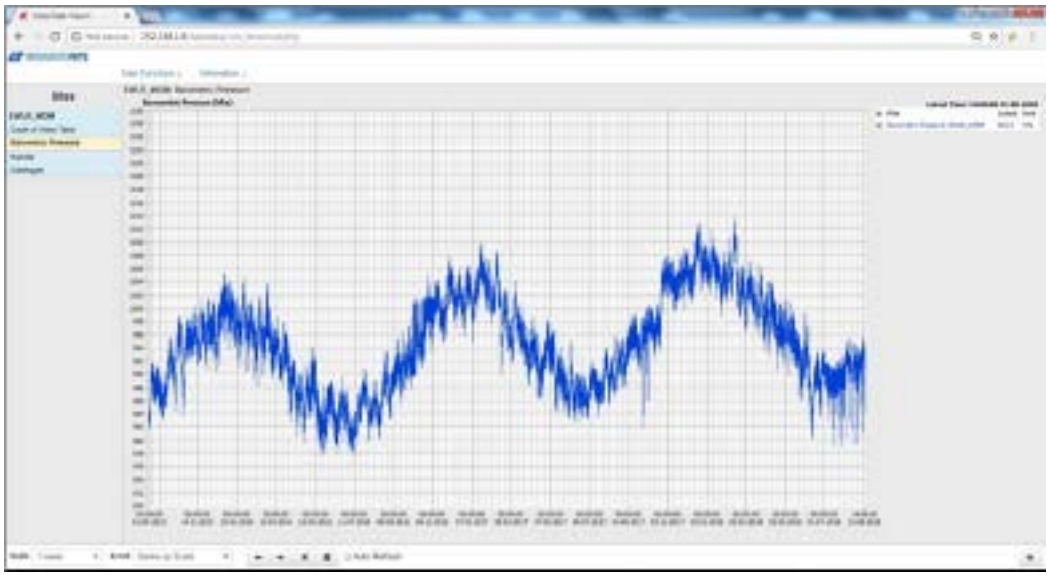


Figure 2 Variation in atmospheric pressure over a period of 3 year at a typical site in Lucknow

In the graphs shown above, a variation of 36 hPa or 367 mmWC was observed during a span of one year covering winters and summers. Over a period of years a variation of 500 mmWC has been documented at several places. In monsoon the barometric pressure is much more. One can therefore imagine the kind of impact it has on the accuracy of the monitored water table.

Specific Gravity effect

For water with dissolved solids, the specific gravity of water at that location has to be separately determined and a correction factor applied to the measured value to determine the water level. Brackish water in coastal areas often has a specific gravity as high as 1.1 and, therefore, requires a specific gravity correction to the measured value. This correction is easily done in the datalogger using formula

$$W1 = \frac{W_0}{S_g}$$

Where W_0 = water head after correcting barometric pressure obtained from formula above

S_g = specific gravity of water

Temperature effect

The output of the water pressure sensors are also affected to some degree by the change in the temperature of the water surrounding the pressure sensor. This behavior is called temperature drift. However, for groundwater monitoring applications the temperature drift is not much relevant as for groundwater at a depth of more than 10 m the change in temperature is typically found to be less than 1°C over a whole year. It can be observed in the hydrographs given above in case studies.

Final corrected water level plotted in hydrographs

The above calculations are made on the measured hydraulic head obtained from absolute pressure sensor. To obtain the water level or water table, following formula can be used:

$$W_L = G_e - (D_w - W_e)$$

Where G_e = elevation of ground surface (with respect to which measurement is made)

D_w = pressure sensor installation depth

W_e = water column above sensor installation location

Normally the water level sensors have a thermistor incorporated inside them for temperature compensation and the datalogger has a barometric pressure sensor fitted inside it, which measures atmospheric pressure.

Contouring water table

Contours of groundwater level, and of other related spatially varying quantities like aquifer characteristics, rainfall, etc., are required for a variety of computations aimed at the quantitative estimation of groundwater resources. When contouring water table in a vast area, it is a best practice to determine the water table in terms of elevation from Mean Sea Level (MSL). This is important as the topographic (ground surface level) variations in borehole locations will introduce errors if water table is reported in terms of depth from ground surface.

5 DATA COLLECTION AND PRESENTATION

Encardio-rite offers advanced dataloggers for automatic collection of data from installed sensors. We offer different types of dataloggers with multiple communication module options to suit different site requirements.

Model ESDL-30 is a compact datalogger suitable for digital sensors with SDI-12 serial interface output. A single datalogger can connect several digital sensors; it has 3 channels and can connect upto 160 sensors. One of the advantage of the datalogger is that only a single 3-core (6-core for longer distances) cable is required to interconnect all the sensors and the datalogger in a serial bus. Model ESCL-10VT datalogger is specially designed for groundwater level monitoring and has in-built barometric pressure sensor. It is a single channel datalogger that can connect one absolute pressure sensor with in-built temperature sensor along with one rain gage (if required). The datalogger automatically collects the readings from absolute pressure sensor, barometric pressure sensor and temperature sensor at desired intervals. The datalogger software calculates the pressure in terms of water column after correcting for the measured atmospheric pressure and water density. The datalogger software has features that allows the user to set the sensor calibration coefficients, recording intervals, datalogger or borehole code (identification tag numbers), sensor serial number, real time clock time, transmission time interval, etc. They are programmed to wake up at the set time and send the collected data to a remote PC/Server/Cloud. The data is stored together with the current date, time and battery voltage, as a data record in internal non-volatile memory of the datalogger. For both the dataloggers, a cellular network is required to transfer the data from the datalogger location to a central/cloudserver.

Datalogger with GSM/GPRS modem

RF datalogger with Gateway

In this end-to-end wireless datalogging system, the piezometer (vibrating wire or digital) is interfaced with the long-range, low-power wireless network through RF datalogger (also called node) that send recorded data to the gateway with utmost reliability. The gateway needs to be in line of sight of the RF datalogger. Gateway transmits the collected sensor data to the central/cloud server through cellular communication network.

We offer a choice of both the wireless technologies. Depending on site requirement, either any of the two, or a combination of the two technologies can be used.

RF datalogger (node) and Gateway

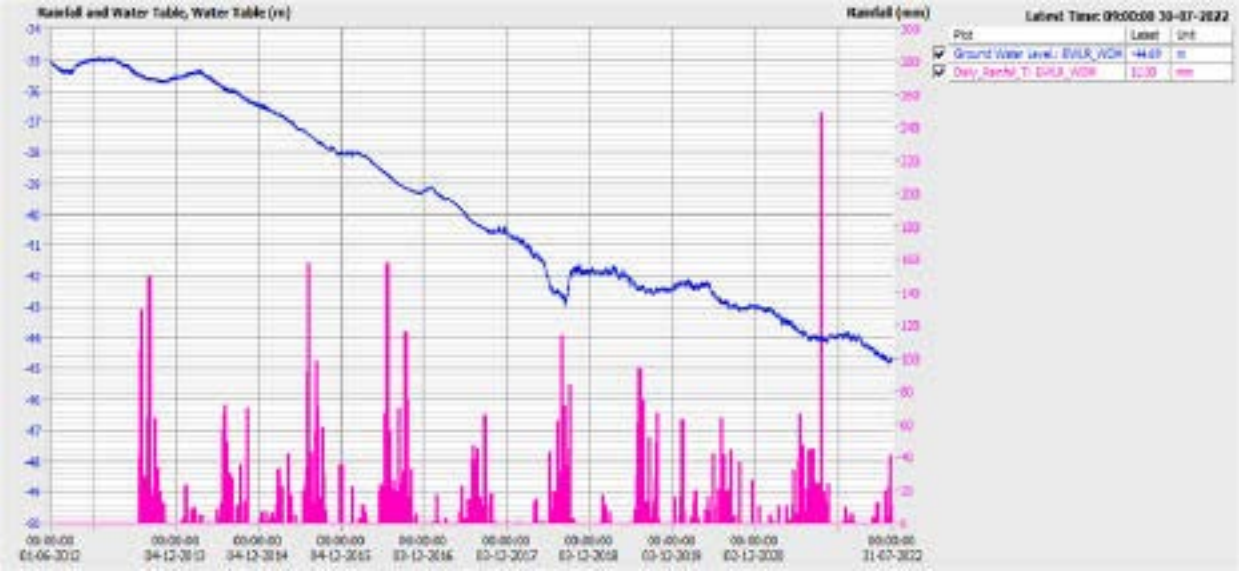
5.1 Database management system

Encardio-rite offers online database management software for retrieving data from dataloggers, archiving the retrieved data in a SQL database, processing the data and presenting the processed data in tabular and most suitable graphical forms for easy interpretation of logged data. The tables and graphs related to any site or sites can be accessed by authorized personnel from anywhere in the world.

No special software is needed for accessing the user sites as the information can be viewed using most standard and popular web browsers like Microsoft Internet Explorer, Mozilla Firefox, Google Chrome etc.

The data is generally displayed as composite graphs that show relevant parameters together on a single screen. For example, a graph may show water level and temperature on the same graph. If a rain gage is also installed at that location, it can also show the daily and cumulative rainfall recorded by the rain gage. This helps in correlating data with respect to different parameters easily.

The system also allows alarm limits to be set so that if any monitored parameter crosses the preset alarm limits an alarm is automatically triggered and suitable SMS or email alerts are sent to preset mobile phone numbers or email ids.



Online groundwater level and rainfall data from a factory in Lucknow. It is observed that water level increases a little after each monsoon. Yet it has recorded long-term water level decline with almost same amount of rainfall, due to extensive groundwater use.

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