INSTRUMENTATION AS A TOOL FOR EFFECTIVE AND EFFICIENT WATER MANAGEMENT

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ABSTRACT:

For devising, implementing, monitoring and reviewing the effectiveness of the plans for reduction in water consumption, conservation and regeneration of fresh water reserves it is essential to comprehensively map, measure and monitor the extent and quality of both sub soil aquifers and surface fresh water resources. This in itself is a gigantic task given the sheer number of sites and number of parameters to be monitored. Using sensors and back end computers networked using cellular phone network for data collection reduces the manpower requirement and cost drastically. Automatic analysis of the collected data and publication of the results in the form of graphs and tables to geographically dispersed stake holders in real time is a great advantage. X for monitoring water quality only relevant parameters which are expected to exceed safety threshold should be monitored to reduce overall project cost.

1. INTRODUCTION

With each passing year we are faced with the grim reality of ever depleting fresh water resources due to a variety of reasons like over exploitation for human use, high degree of pollution, drying up or depletion of sources of recharge such as glaciers and run off of rainwater without percolating in ground. Depletion in fresh water reserves is going to make life extremely difficult for our future generations.

For devising, implementing, monitoring and reviewing the effectiveness of the plans for reduction in water consumption, conservation, preservation and improvement of water quality and regeneration of fresh water reserves, it is essential to comprehensively map, measure and monitor the extent and quality of both sub soil aquifers and surface fresh water reservoirs, streams as well as sources of charging like rainfall.

An effective and extensive fresh water extent and quality monitoring plan spread over the length and breadth of the country is both an expensive proposition and a logistic nightmare due to the sheer number of sampling sites that will include many remote locations and the large trained manpower required to collect and send the data to designated central locations. it is also essential that the huge amount of collected data is meaningfully analysed and timely presented to all stake holders who may be located at dispersed locations throughout the country.

A properly designed and executed instrumentation plan can go a long way in reducing total monitoring costs, increase the quality and reliability of collected data, reduce manpower requirement, automatically analyse the collected data and present them in relevant tabular or graphical forms and make it available to authorised users, located anywhere in the world, simultaneously over the internet with least possible time delay consistent with user requirement.

Automated monitoring from a central location provides a great advantage to monitoring and regulatory bodies and authorities. The data from remote locations can not only be monitored in near real time, but it also eliminates any chance of human error in recording data, and the actual data cannot be intentionally or unintentionally modified by any person.

The discussion in this paper is limited to the most economical instrumentation and telemetry solutions available that can cater to the need of users interested in state or country wide monitoring from a central location.

2. ESSENTIAL INSTRUMENTATION USED FOR MONITORING GROUND WATER

The most frequently specified parameter for water table measurement is depth of water table from the surface at any location. This is inadequate if data from neighbouring locations need to be correlated. In such situations, and in general also, it is advisable to determine the water table in terms of elevation from Mean Sea Level (MSL) as topographic variations in borehole locations will introduce errors if water table is reported in terms of depth from ground surface.

For monitoring the water table at any location either an abandoned bore hole is used or if a bore hole is not available a fresh borehole may be drilled that goes down to some depth below the water table. The boreholes are generally lined with casing to avoid borehole collapse and casing sections passing through aquifers are replaced with highly permeable filter sections.

The most common method of measuring the elevation of water table is to employ a water pressure sensor. A pressure sensor is also known as a piezometer in geotechnical engineering. The pressure sensor is installed lower than the lowest expected ground water table elevation. The pressure sensor measures the water level (called head) above the location of the measuring diaphragm of the pressure sensor using the relationship that pressure is equivalent to 10 KPa for every 1 m or 1000 mm of water column for pure water with a specific gravity of 1.00. 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. Brackish water found in boreholes in coastal areas often have a specific gravity as high as 1.1 that will introduce an error of 10% in the measured value if the specific gravity correction is not applied.

The full scale measurement range of the pressure sensor is chosen to be just larger than the maximum expected variation of water table at that location. This allows the level of water table to be monitored with highest possible resolution and accuracy.

If the water table in the long term does go below the lowest expected water table elevation the pressure sensor can be further lowered down in the borehole and the new position used for subsequent elevation calculations.

For automatic logging of height of water column above the pressure sensor some kind of datalogger is required. In most cases the datalogger sits at the top of the borehole and the pressure sensor is suspended down inside the water through a non stretch cable that carries both power for the sensor from the datalogger and signal from the sensor below to the datalogger above.

The pressure sensors that have a measuring range of 30 metres water column (mwc) or less are sensitive enough to be affected by variation in atmospheric pressure. The daily variation in atmospheric pressure can typically be up to 40 mm water column (mmwc) and over a period of time can be typically be around 150 mmwc. If measurement accuracy in the range of few millimeters is required then a gauge pressure sensor is employed. A gauge pressure sensor has one side of its pressure measurement diaphragm open to atmosphere to differentially compensate for the change in atmospheric pressure. When gauge pressure sensors are used the pressure sensor is suspended from the datalogger using a special cable that has a built in capillary tubing to connect the interior space of the pressure sensor to the air at atmospheric pressure at ground level.

For pressure sensors with a measuring range of over 50 mwc the effect of change in atmospheric pressure is much less than the accuracy rating of the pressure sensor so generally gauge pressure sensors are not used for measurement ranges over 50 mwc.

Figure 1 A typical water level sensor (bottom) connected with signal cable to the datalogger with cellular phone telemetry module (top) for installation inside boreholes.

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 behaviour is called temperature drift. The effect is more pronounced in lower cost sensors than premium grade sensors which are quite expensive. However, for ground water monitoring applications the temperature drift is not much relevant as for ground water at a depth of more than 10 metres the change in temperature is typically found to be less than 1ºC over a whole year. Versions of pressure sensors are also available with temperature sensor built in so that the same sensor can measure both pressure and temperature if required.

The measuring range, accuracy class and temperature drift figures of the pressure sensor should be carefully specified as over specifying increases the total cost of the instrumentation many folds. Considering that more than a few hundred to a thousand boreholes may need to be monitored in each state the cost escalation is very significant if the sensor performance is over specified. For ground water monitoring where in all but a few locations the water temperature remains between 0 to 50ºC and variation in water level due to change in atmospheric pressure is typically of the order of 40 mm in a day, specifying pressure sensors with much extended operating temperature range or mm level accuracy only increases the cost of instrumentation without any corresponding increase in the quality or usability of logged data.

A variation of pressure sensor is available with an integral conductivity sensor. These types of sensors are known as CTD (conductivity, temperature, depth) sensors. The conductivity measurement gives a measure of salinity of the water from which the density of the water can be calculated. The calculated value of density can then be used to correct the pressure sensor reading to give the actual height of the water head over the pressure sensor. This kind of sensor is indispensable in areas where the salinity of the ground water varies with time, as the varying salinity would introduce error in water level (or depth) measurement due to the changing specific gravity of the water.

This figure shows a typical datalogger suitable for use with borehole water level sensors. The narrow cylindrical housing allows the datalogger to be installed at ground level inside a borehole for protection from vandalism. The pressure sensor is connected to the datalogger with the help of a non-stretch cable that carries power to the sensor and sensor output signal back to the datalogger. Often a telemetry module is also installed inside the datalogger cap. Dataloggers and telemetry units are discussed in more detail later in this paper.

Compared to water level measurement, water quality measurement sensors for unattended automatic measurement are very expensive. The pollution level of ground water changes relatively very slowly, so a manual sampling and lab test method conducted once every few weeks may be sufficient to effectively monitor the water quality at a particular location. Online instrumentation for ground water quality may be prohibitively expensive without much attendant benefit if the parameter being monitored takes months to show significant change.

The most common source of recharge for subsoil aquifers is rain water. Tipping bucket rain gauges provide an accurate measurement of the amount of rainfall at a particular location. Tipping bucket rain gauges can be easily integrated with dataloggers for automation. In practice the datalogger detects the cumulative value of rainfall over each hour and also calculates the total rainfall over 24 hours. The daily rainfall reading is reset to zero at 12:00 AM each night.

Rain gauges are installed in the open and subject to direct sunlight and weather. Rain gauges with plastic, resin or aluminium construction tend to crack or corrode within a few years especially in hot, humid weather and strong sunlight conditions as in tropical countries like India. For remote locations, where frequent maintenance or replacement is expensive, heavy duty rain gauges with stainless steel housing should be specified as they can work for decades without degradation and turn out to be more economical in the long run.

Correlation of rainfall data with change in ground water table gives a valuable qualitative insight about the magnitude of percolation of rainwater in the aquifer being monitored and any change in rate of percolation taking place over time.

The dataloggers used for ground water monitoring applications allow the datalogger to function unattended for up to ten years from a set of lithium primary cell battery making them suitable for deployment at remote sites where frequent battery replacement could be a logistic problem.

For monitoring at very remote or difficult to approach sites where users can afford to collect data at intervals of many months the large internal memory of the dataloggers allow years of data to be stored inside the data logger till it is collected.

For accessing the data stored in the dataloggers users will have to go to each datalogger periodically and download the data from the dataloggers to a laptop computer or a smart mobile phone running android operating system.

If the laptop computer has an internet dongle, or in the case of mobile phone if a GSM/GPRS cellular network is available, the downloaded data can be sent to a central pc over the cellular phone network without having the user to physically visit the central office to submit the data.

3. ESSENTIAL INSTRUMENTATION USED FOR MONITORING SURFACE WATER

Surface fresh water bodies that need to be monitored include streams, rivers, reservoirs formed due to natural or manmade dams across rivers, other lakes or manmade reservoirs, and often canals or channels discharging into or off taking water from other water bodies. Water level sensors gives no idea of either the change in volume of the water body or the volume flow rate.

V-notch weirs together with water level sensors can be used to measure volume of water flowing through the smaller channels with uniform rectangular cross section. In wider open channels or canals a combination of water level and flow measurement system can be used to calculate the volume of water flowing through the canal. Monitoring the volume of water being carried by a river is more complex as a river has a very non-uniform and changing cross section (due to erosion and silting) and requires more sophisticated measuring systems.

The measured value of flow and level is generally logged by a datalogger at predetermined intervals. The measurement and reporting time for surface water parameter measurement has to be comparatively faster than that required for ground water monitoring as the field conditions can change at a very fast rate when compared to sub soil water parameters. In some cases update rates of 1 hour or less may have to be employed.

Rain gauges are also an important parameter for surface water monitoring but for effective correlation of rainfall with change in volume of water bodies, a large array of rain gauges in catchment areas is required. Rain gauges do require a higher degree of maintenance and have to be periodically cleared of dust and debris like bird droppings and leaves etc. and so should be installed at more approachable sites. The rainfall data can be automatically transmitted to a remote server using cellular network.

WATER QUALITY MONITORING

Water quality monitoring should also be an integral part of most water conservation program to monitor pollution due to human activities or over exploitation. Online monitoring of water quality allows the pollution level of water at remote locations to be monitored continuously in near real time from a central location and requires very little skilled or unskilled manpower.

Pollutants can be of many types including heavy metals, pesticides, oils and greases, other inorganic or organic chemicals, biological agents and thermal, such as discharge of hot water from power generating stations.

Many of the polluting agents of interest can now be measured with the help of low maintenance small size electronic sensors. Most of the currently available sensors are able to monitor only a few types of pollutants. A cluster of sensors that can measure a range of pollutants with a datalogger can be set up at each remote monitoring site and the data collected through a low power datalogger. The sensors and the datalogger can be powered from small solar panel based battery backed power supply.

Blindly monitoring for all possible types of pollutants is not economically or technically feasible. A careful study of the present level of pollutants in the water at that site should be carried out first. An assessment of potential activity around that site should also be carried out to identify any potential pollutant that can rise to alarming level in future. Once the parameters are identified a set of sensors suitable for measurement of the identified parameters can be installed together with a suitable datalogger and power supply at that site.

Many of the water quality parameters of interest can be measured using different techniques. However, the different methods often give from slightly different to significantly different results for the same sample. Also the sensor for a particular parameter may give an inaccurate value in the presence of some other particular parameter. The data from the installed sensors should be periodically correlated with measurement done on water samples, from the same site, in a lab.

Selection of water quality parameter sensors is a more involved exercise. Sometimes different types of sensors using different principle may be available for measuring the same parameter. The various tradeoffs and advantages/disadvantages of competing sensor types should be carefully evaluated before making a selection. The type of service is also important as there may be different sensor models for use in still and flowing water. Similarly sensor model for drinking water would be different from sensor used for industrial effluent for the same parameter type. Finally the sensor measurement range and operating temperature range should be chosen with care. Electronic sensors for online systems often have some means for cleaning the sensor inlet periodically.

Electronic water quality parameter measurement sensors require a datalogger for recording the sensor readings. The sensor output should be compatible with the input of the datalogger chosen for the whole sensor cluster.

USING TELEMETRY SYSTEM FOR REMOTE DATA COLLECTION

The sheer number of locations that need to be monitored to effectively map and monitor the ground water resources makes the job of reliably collecting the data from these locations and sending them to a central location a gigantic task in itself. Besides being expensive it creates a logistic nightmare for organizations entrusted with the job.

The ubiquitous cellular phone network now a days seem to be present at all parts of the country wherever a sizeable group of people are living. The cellular network can be leveraged to collect data economically and in real time from the dataloggers that are used to collect data from the water quality monitoring sensors and rain gauges.

A number of commercially available dataloggers these days have an inbuilt gsm/gprs cellular phone modem that allows the datalogger to send data over the cellular phone network to a remote pc at a central office located anywhere in the world. The dataloggers are programmed to wake up every day at a set time and send the data collected over the past one day to the remote pc. Though the dataloggers can be programmed to send data more frequently if required, the power consumption goes up and the batteries get exhausted much faster.

In one of the commercially available dataloggers if the parameters are measured every 4 hours and transmitted over the cellular phone network once a day the battery supplying power to the datalogger would last a little over 5 years. If the data is required more frequently the battery change interval tends to be much shorter.

WEB DATA PRESENTATION

Using suitable commercially available software the data collected by the remote pc can be automatically formatted as different types of graphs and tables and published over the internet. Any authorised user can log onto the web server remotely over the internet from anywhere around the world to see the graphs and reports in real time.

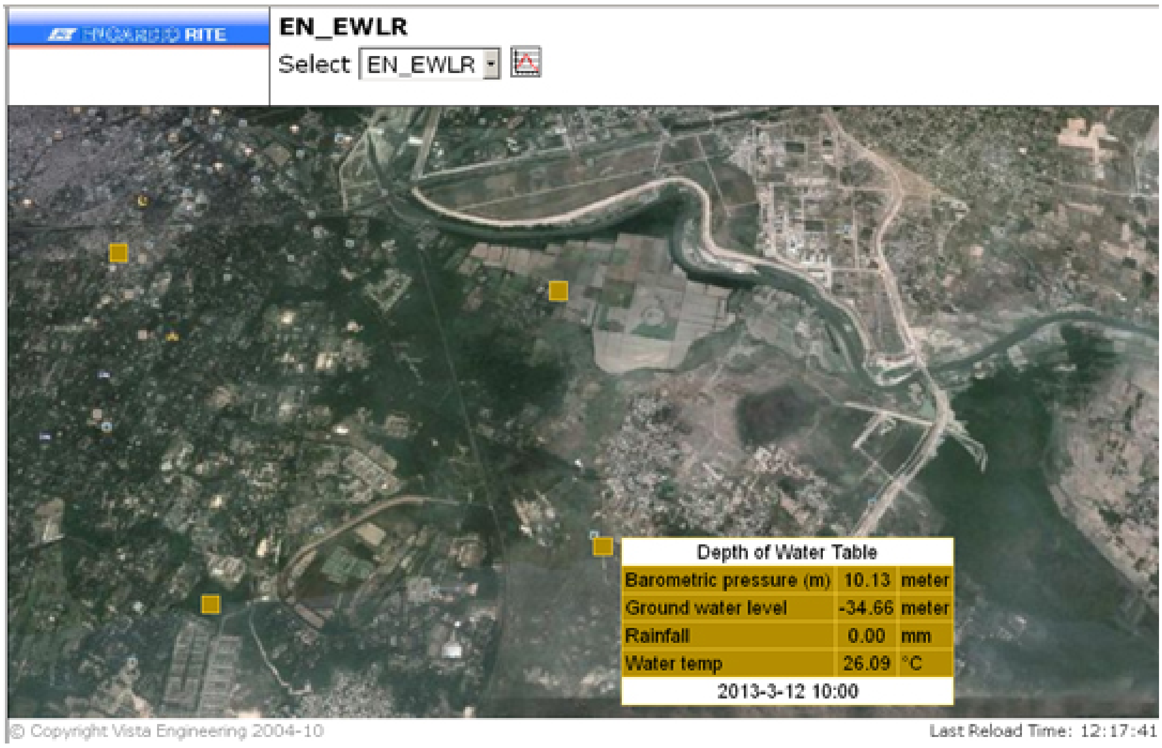

Figure 2 A web map showing locations of ground water sensor locations

An authorised user can log on to the server using any of the more popular web browsers (e.g. Microsoft Internet Explorer or Google Chrome etc.). The system presents the user with a log on screen where the user enters his login credentials like user name and password. Once the system verifies the user credentials it allows the user to access data for which the user has permission.

After successful logon, an user is presented with a map or diagram of the area of his interest with the locations of the installed sensors marked on the map or diagram. If the user hovers the pointer over these points, a table pops showing the value of the measured parameter and the last update time. Any alert condition is signaled with a red marker. If the user clicks the table a new view opens showing the change in parameter value with time in graphical form. Fig 2 shows a typical web map with the locations of boreholes being monitored marked as small square dots. Clicking on one of the dots brings up a screen that shows the value of the parameter like barometric pressure, ground water table depth, rainfall during the last hour and the temperature of water in a table adjacent to the marker.

The user has the choice to view the data in the form of graph or table. In graph view the user can select the time period for which the data is to be plotted and can scroll the time axis in any time increment, starting from one day to many months both in the forward and backward direction as long as data is available. The pages are preformatted and the graphs are generally composite graphs that show the relevant parameters together on a single graph. For example, a graph may show water level, temperature and conductivity on the same graph. If a rain gauge is also installed at that location it can also show the daily and cumulative rainfall recorded by the rain gauge.

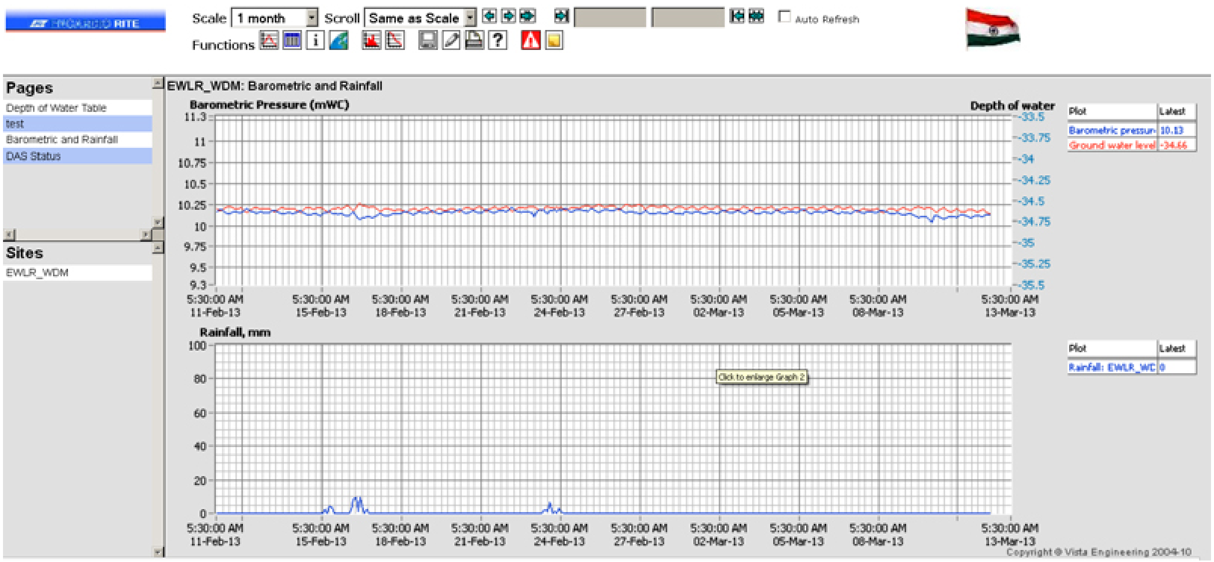

Figure 3 A typical screen shot showing variation in parameter as a graph

Fig 3 shows a typical screen shot showing the variation in barometric pressure, depth of water table and rain fall during each hour as a set of graph. The graph is showing data for 1 month but the time axis can be any value from 2 days to 1 year.

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.

The user organization has to maintain a server at the central monitoring office with a sufficiently broad band internet connection with static IP address. This server hosts the different software modules that are used to collect data from the field sensors at scheduled intervals, add them to the database on the server, prepare the graphs and tables in suitable pre designed formats and then publish them over the web for access by authorised users. The software suite also checks the integrity of the collected data and manages the security of the data in the database to prevent unauthorised access or modification.

If any organization does not have the necessary IT manpower and/or resources for maintaining a data centre, they can avail the services of specialized service providers who maintain suitable high reliability data centres and application specific back end processing software. Such services are now commercially available in India also at very economical rates and is recommended for all but the largest of organizations who already maintain their own data centres.

CONCLUSIONS

The type, range, resolution, accuracy and operating temperature range specification of all sensors in a particular instrumentation project should be consistent with actual requirement. Unnecessarily specifying higher performance grade sensors increases the cost of the whole project without any attendant benefit.

For water quality monitoring the parameters to be monitored should be decided carefully. Monitoring insignificant parameters will only increase the cost of instrumentation.

Sensors and dataloggers networked using cellular phone network together with back end application and web servers have the advantage of automatic data collection from a huge number of widely dispersed sensors and presenting the data to all stakeholders in real time at a very economical cost. Once configured and installed the system requires very little manpower for maintenance.

The choice of sensors, dataloggers, power supplies, telemetry systems, back end servers (central computers), database servers, custom application software etc. requires a lot of knowledge and field experience. Help should be taken from specialist turnkey instrumentation suppliers who have the expertise to design, configure, supply, install and manage (if required) such projects to find the most cost effective and economical arrangement.

Even when project owners do have the resources or the expertise to manage their own data centres it may be more economical and reliable to use the professional back end processing and web hosting services provided by companies providing such services.