GEF-IWCAM Project Experience Note # 2

TITLE

Using Multi-Electrode Electricity Resistivity (MER) to measure aquifer capacity and threats.

PROJECT TITLE

Rehabilitation and Management of the Basseterre Valley as a Protection Measure for the Underlying Aquifer in Saint Kitts.

PROJECT DESCRIPTION

The Integrated Watershed and Coastal Areas Management (IWCAM) demonstration project of the Basseterre Valley Watershed (BVW) proposed to demonstrate the proper management and protection of a critical aquifer and well-field through a parallel process of mitigating threats from contaminants; on-the-ground protection through specific management activities; and improved user-resource management through the establishment of a management regime in the form of a national park or other similar management system.

Basseterre valley, which is immediately adjacent to its capital, Basseterre, houses the aquifer which supplies 60% of the water supply to the country’s capital. It produces approximately 2.5 million gallons of the daily national water consumption of 4 million gallons per day (gpd). There is need to address the growing threat of pollutants and contaminants to the aquifer (both actual and potential), as several factors have and continue to pose a major threat to the
water quality. These threats include intensive use of pesticides and fertilizers for the large agricultural practices in the Valley; sewage and disposal associated with recent commercial, industrial and housing programmes; storm water runoff along major roads traversing the aquifer and leading to an unprecedented increase in the loadings of nitrates and phosphates; and over-extraction from this water source compounded by new demands from real estate developments and new golf courses.

The aim of this demonstration project was to identify the impacts from these activities, both actual and potential, and to develop alternate strategies and incentives to reverse these impacts.

The approach adopted by the Project Management Unit (PMU), as a priority activity, was to contract a firm to conduct a hydro-geological feasibility analysis to identify the threats to the groundwater resource base. This was done using a technique called Multi-Electrode Electricity Resistivity (MER), a geophysical method of mapping the subsurface geology by creating a vacuum arc which is an electric current discharge between pairs of electrodes. This is a preferred technique over drilling which is time consuming, labour intensive, exorbitant in cost and does not allow for determination of the base of the aquifer.

**DESCRIPTION OF ISSUES**

The Basseterre Valley Aquifer is an unconfined coastal aquifer. The location of the well-field on a peninsula surrounded by salt water makes delineation of the fresh/salt water interface critical for appropriate long-term water supply use. The aquifer is recharged directly by rainfall, and has a defined zone of capture and volume.

The main challenge of pumping water from an unconfined aquifer is the balance between water withdrawn via pumping versus the recharge rate. Excessive pumping rates or extended pumping in a given area can cause dewatering of the aquifer, pump cavitation, well collapse, and saltwater intrusion. However, with the proper well-field configuration, well pumping schedule, well-field management,
and appropriate monitoring system, coastal aquifers can be developed to provide a long-term source of potable water.

Traditionally, aquifer parameters were determined by drilling multiple holes and installing monitoring wells.

RESULTS AND LEARNING FROM EXPERIENCE

Project Results
Several issues were elucidated in the feasibility analysis conducted using the MER methodology. Firstly, the existing well-field is currently operating at full capacity to meet existing demands, and salt water underlies the entire well-field area. This is resulting in long term mining of the groundwater from the Basseterre Valley Aquifer, which is causing intrusion of saline waters into the aquifer from three different directions. Additionally, the existing distribution of wells is not ideal according to the groundwater modeling scenarios where declines of water levels will result ultimately in seawater entering most of the wells. Compounding the situation, global warming is projected to increase the rate of sea level rise resulting in saltwater intrusion within 20 years according to some predictions about the rate of glacial collapse and associated sea level rise.

Multi-Electrode Electricity Resistivity (MER)
MER is a geophysical method of mapping the subsurface geology by creating a vacuum arc which is an electric current discharge between pairs of electrodes. It is the technique used in the hydro-geological evaluation of the BVA to map the aquifer. This is a preferred technique over drilling which is time consuming, labour intensive, exorbitant in cost and does not allow for determination of the base of the aquifer. Traditionally, aquifer parameters were determined by drilling multiple holes and installing monitoring wells. MER was used to delineate:
1. The thickness and distribution of sediments throughout the aquifer;
2. Zones of increased porosity (areas where water can flow more easily);
3. Zones of possible contamination; and,
4. The fresh/salt water interface (freshwater floats on seawater because seawater is about one-fortieth more dense than freshwater).
Geophysical techniques such as MER measure the differences in resistivity of earth materials. Resistivity is the property of a material to resist the flow of electrical current. Electric current is introduced into the ground using pairs of electrodes and then the electrical fields that flow through the various layers of earth in the subsurface are observed. The electrodes are typically arranged in a linear array (called a “transect”).

As the distance between the electrodes is increased, more data on subsurface resistivity from successively greater depths can be achieved. MER is a useful technique in groundwater hydrology because each type of earth material (sand, clay, rock etc.) exhibits a different resistivity. Also, the resistivity of earth materials is very sensitive to water content. In turn, the resistivity of water changes as its salt content increases.

**Learning from the experience**

The MER technique identified three units in the Basseterre Valley Aquifer:

- **Unit I**: A high resistivity unit of dry sands, clayey sands and volcanic rock. Unit I was an average thickness of 5.5 meters.

- **Unit II**: A layer of intermixed sand, clay and rock similar to Unit I but its resistivity signature is different due to partial saturation with water. Unit II is approximately 14 meters thick.

- **Unit III**: A unit of gravels, coarse sands and boulder rocks which is the water storage unit of the aquifer system. This unit begins at about mean sea level and has an average thickness of about 22 meters. The lower part of Unit III exhibits markedly lower resistivity material that represents the saltwater saturated part of the aquifer. This contact of the high resistivity fresh water aquifer with the very low resistivity of the salt water at the base of Unit III marks the fresh/salt water interface across the entire area.

Analyses of water samples were taken from ten supply wells and three surface water sites to evaluate potential contaminant levels in the supply wells, observe salinity and total dissolved solids (TDS) levels that may be related to salt water intrusion. Several production wells (Conaree, Ponds 2 and 1-48) exhibited elevated TDS concentrations that are up to twice as high relative to other supply
wells sampled. Historical data show that there is a clear increase over time in both the chloride levels (data not shown) and TDS levels (Figure 5) in the majority of the wells. These temporal relationships indicate that over time, the pumping within the Basseterre well field has resulted in increasing trends of TDS and chloride, potentially indicating gradual saltwater intrusion. Furthermore, these trends directly correlate to the decline in static water levels across the valley from 1976-2009.

Perhaps the most useful revelation, for the purposes of the GEF-IWCAM Project, was a noted trend of declining static water levels observed in the Basseterre well-field. This decline ranges from 1.5 to 2+ feet according to available data extending back into the 1970’s. The decline in water levels appears to have accelerated between 1999 and 2009 with an increase in groundwater withdrawals. Continued water extraction from the aquifer will lead to increased areas of salt water intrusion and declining potable water quality within the well-field. Three zones of salt water intrusion have already been identified in the well-field area by the MER mapping. (OET, 2009. Executive Summary)

**REPLICATION**

The conditions for replication of good practice or lessons learnt are often dependent on the local conditions that facilitate this. Aquifers are not uncommon in SIDS and are increasingly perceived as an important source of potential potable water. The technology revealed by this project to measure the parameters of these groundwater sources is of tremendous value to SIDS desirous of expanding access to and production capacity of potable water. Further, SIDSs are most vulnerable to sea-level rise and the MER technology can also be used in determining salt water intrusion.

MER provided a wealth of new information about the aquifer in the Basseterre Valley, at a reasonable cost and without the boring of holes. Each hour of mapping using MER is equivalent to 56 boreholes. The results of the MER analysis of the BVA has proven to be an excellent method for delineating the upper parts of the aquifer as well as the depth and variations between fresh and
salt water. It also provided information about the salt and fresh water interface and the implications for long-term pumping or water extraction.

Information from MER transects is also incredibly useful in terms of managing pumping levels in the aquifer and understanding the likelihood of salt water intrusion in the future especially with the likely impacts of climate change and sea level rise. Together with water level and water quality monitoring, an assessment of the likelihood of saltwater intrusion can be made. Moreover, the use of the MER methodology now allows aquifer managers to determine the thickness and distribution of sediments throughout the aquifer; determining areas of greater or lesser porosity so as to determine where water may flow more easily; as well as delineating zones of contamination which is critical for determining extraction points.

**SIGNIFICANCE TO GEF-IWCAM**

The GEF–IWCAM approach is a strategy that incorporates watershed and coastal areas management in achieving improved overall watershed management objectives. The strategy covers coastal area management and biological diversity conservation; tourism development policy and planning; protection of water supplies; and land and marine-based sources of pollution.

The MER technology is directly related to protection of water supplies as it allows for delineation of parameters as well as determining threats to groundwater quality. It is also relevant for tourism policy and planning, as the Caribbean is the most dependent region in the world on tourism, and a reliable supply of potable water is a major determinant for tourism investment.

The GEF-IWCAM approach is strengthened by this experience as it demonstrates the interconnectivity of coastal saline water resources to fresh ground water resources and how this interface may be managed. It also provides inexpensive and time sensitive information which is so critical for development planning particularly for the fast emerging tourism industry.