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Two Case Studies of Geophysical Delineation of Salt Water Intrusion in Yemen: Wadi Hadramaut and the Tuban And Abyan Deltas

Paul Bauman[1], Richard Kellett[1], Gilein Steensma[1], Christine Cadman[1], Paul Hardisty[2], and Jane Dottridge[2]

[1]Komex International Ltd., Canada
[2]Komex International Ltd., England

ABSTRACT

Wadi Hadramaut and the Tuban and Abyan deltas are traditionally two of the most important agricultural areas in Yemen. In 2001 and 2002, as part of sustainable resource management programs being carried out in each region under the cooperative sponsorship of UNDP, and the governments of the Netherlands and Yemen, a program of geophysical characterisation of salt water intrusion was carried out. The geophysical survey results were integrated into groundwater modelling, a groundwater quality study, and the design of a rehabilitation program for the groundwater quality monitoring network. Remote sensing data was essential in extrapolating 2-D geophysical interpretations into the 3-D regional geologic interpretations required for groundwater modeling.

The project area in Wadi Hadramaut is 100 km long and 15 km wide (1500 km2) and follows the main part of the wadi (valley). This part of the wadi is more than 50 km from the ocean. Groundwater is heavily utilized for irrigation and domestic use. Although the three aquifers in the main valley of Wadi Hadramaut (alluvium, conglomerate and Mukalla sandstone) are in general hydraulic continuity, they do not behave as a single unconfined aquifer, but as a stratified aquifer system comprising layers with distinct hydraulic properties. Water is drawn largely from the Mukalla sandstone. Water quality in the Mukalla is generally very good. However, since the rapid growth in the number of boreholes and in total abstraction since 1990 (149 Mm3/year in 1990 to 248 Mm3/year in 2001), high salinity water has begun to leak into the principal aquifer. The source of this salt water was unknown. As part of the groundwater investigation to understand the mechanisms of salt water intrusion, 32 km of two dimentsional (2-D) electrical resistivity surveys to depths of between 200 m and 400 m were carried out. Twenty boreholes were geophysically logged. A well inventory covering 3083 wells and boreholes was completed. It was determined that the source of high salinity water was downward leakage from localized saline aquifers in overlying alluvium and conglomerate aquifers.

The Tuban and Abyan Deltas cover approximately 700 km2 and 650 km2, respectively. The geophysical surveys showed that in the Tuban Delta, three layers are indentifiable, Quaternary alluvium underlain by cemented alluvium on the bedrock. In the Abyan Delta, three layers are also indentifiable, Quaternary alluvium underlain by fractured sandstone on the bedrock. The upper two layers in each area are in general hydraulic continuity, behaving as a single unconfined aquifer, with some local semi-confined conditions. Sea water intrusion has heavily impacted well fields in both deltas. 33.6 km of 2-D electrical resistivity surveys were carried out with the objective of mapping the salt water intrusion fronts. 11 boreholes were geophysically logged in order to improve detailed vertical characterization. Another 134 km of 2-D geoelectrical sections were created from the reprocessing of previously collected 1-D resisitivty sounding data. The sea water intrusion front in the Abyan delta was geophysically mapped as far as 15 km inland. The sea water intrusion front in the Tuban delta was mapped 10 km inland. Predictive modeling was carried out. A sea water intrusion mitigation strategy has been proposed.

The geophysical mapping program was particularly innovative and effective. 2.4 kilometer 2-D resistivity spreads were employed. A modern automated multielectrode address system with 80 live electrodes at any one time was used. Local Yemeni staff from the National Water Resources Authority (NWRA), already very familiar with 1-D resistivity soundings, were quickly trained in the techniques of 2-D acquisition. Production techniques were optimised to where greater than 4 kilometers of data could be collected and processed daily, imaging to a depth of 400 m. Technical advances allowed large scale resistivity surveys to be carried out with the production efficiency and depths of investigation more typical of seismic reflection surveys. Borehole conductivity and gamma logging in available boreholes provided "truthing" to the interpretations of 2-D geoelectrical inversions as well as baseline logs for future monitoring of salt water intrusion fronts. The large extent of the areas investigated, the great expense of drilling and sampling a significant number of monitoring wells, and the critical nature of the groundwater degradation combined to make geophysical surveys an essential element in mapping and understanding salt water intrusion.

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Corresponding author:

Paul Bauman, Komex International Ltd., Suite 100, 4500 16th Avenue N.W., Calgary, Alberta, Canada T3B 0M6
Telephone (403)-247-0200
Fax: (403) 247-4811
Email: pbauman@calgary.komex.com