12 HYDROGEOPHYSICAL CASE STUDIES AT THE REGIONAL SCALE

MARK GOLDMAN1, HAIM GVIRTZMAN2, MAX MEJU3, and VLADIMIR SHTIVELMAN1

1Geophysical Institute of Israel, Israel
2Hebrew University of Jerusalem, Israel
3Lancaster University, UK

12.1. Introduction

12.1.1 GENERAL BACKGROUND

Geophysical methods are widely applied in both local and regional hydrogeological investigations. Examples of local hydrogeophysical studies will be given in the next two chapters of this book. In this chapter, several original, mostly unpublished case histories showing regional hydrogeophysical applications will be presented.

Typical regional-scale hydrogeophysical investigations are characterized by the specific dimensions of the study area (x and y), varying from several kilometers to several tens of kilometers; and by the depth to the target (z), varying from several tens of meters to several hundred meters. In some special cases, x and y can be on the order of hundreds of kilometers, and the depth to the target may exceed a few kilometers.

All major exploration geophysical methods are employed in these regional hydrogeophysical studies, although some of them have a limited application because of insufficient penetration depth (such as ground-penetrating radar) or a low sensitivity to major hydrogeophysical parameters of the target (such as magnetic methods). The main methods applied in the overwhelming majority of regional hydrogeophysical investigations are electrical/electromagnetic (EM) and seismic methods. Electrical and seismic regional surveys are carried out using ground-based techniques, whereas electromagnetic (as well as gravitational, magnetic, and radiometric) methods are applied in both surface and airborne modifications.

Based on the sensitivity of the methods to measured (or more precisely, interpreted) physical parameters, each geophysical technique has specific applications for which it is best suited. For example, seawater intrusions are most accurately delineated by electrical methods, particularly by EM methods, owing to the very close relationship that exists between the interpreted electrical/EM resistivity and groundwater salinities. Because of the temporal variability of the target, electrical/EM methods are also frequently applied to monitoring seawater intrusion and similar hydrogeological targets. In addition, some geometrical parameters of the aquifer—such as overall thickness, intercalation of aquiferous portions and aquicludes/aquitards—are successfully detected by seismic methods, as well by electrical/EM and gravitational methods.
In some cases, the combined application of relevant geophysical techniques may significantly increase the reliability and accuracy of regional hydrogeophysical surveys. This usually happens when the individual geophysical methods supplement each other with respect to different hydrogeological properties of the target. For example, the combined application of nuclear magnetic resonance (NMR) and transient electromagnetic (TEM) methods in the Mediterranean and Dead Sea coastal aquifers of Israel enabled us to quantitatively estimate the amount of fresh groundwater within the aquifers (Legchenko et al., 1998). This estimation became possible because NMR and TEM are very efficient in detecting two supplementary properties of the target, namely the depth to the water table and the water content within the aquifer (with NMR) and the depth to freshwater/seawater interface (with TEM).

Although the primary objective of regional hydrogeophysical surveys is mapping the largely geometrical features of hydrogeological targets, several attempts (admittedly less successful) have been made to investigate hydraulic/hydrological properties of aquifers, such as porosity, transmissivity, hydraulic conductivity, and clay content. We believe that local hydrogeophysical investigations (see Chapters 13 and 14 of this volume) are more suitable for solving this problem. Regional hydrogeophysical studies, such as those discussed in this chapter, can provide important information regarding the geometry of a specific hydrogeological target, as well as the necessary boundary conditions for more detailed local hydrogeophysical investigations.

12.1.2 SELECTED GEOPHYSICAL TECHNIQUES

Electrical (particularly DC resistivity) methods have been widely used to image the resistivity structure of near-surface targets (i.e., within a few tens of meters of the ground surface), owing to their ease of operation and low equipment cost (see Chapter 5 of this volume). In some environments, however, these methods are difficult or impossible to use for delineating deep targets, since they require large array dimensions in relation to the maximum depth at which useful information can be obtained (about 5–6 times the target depth of interest). The problem is particularly severe in the case of multidimensional resistivity imaging techniques, which require a large number of electrodes to be involved in the measurements. On the other hand, 1-D resistivity soundings that sample great depths usually deal with significant lateral resistivity variations, thus leading to essential problems in data interpretation. Controlled-source electromagnetic (EM) techniques, which play an important role in shallow-depth conductivity mapping (see Chapter 6), have limited frequency bandwidth and hence relatively poor depth sounding capability (e.g., Meju et al., 2001).

The methods most suitable for deep soundings are the transient (TEM) or time-domain electromagnetic (TDEM) and various magnetotelluric (MT) techniques, including audio-magnetotelluric (AMT) and controlled-source audio-magnetotelluric (CSAMT). These EM methods are particularly appropriate for hydrogeophysical studies in arid and semi-arid regions (see Bazinet and Legault, 1986; Meju, 2002). Note that EM methods can be combined with electrical methods for improved subsurface mapping (see Chapter 6 of this volume). The TEM method is particularly suitable for the