USING GEOPHYSICAL EXPLORATION TECHNIQUES TO MAP SHALLOW SEAWATER DEPTHS

AEM Bathymetry

Airborne Electro Magnetic Bathymetric (AEMB) mapping is useful in turbid and surf-zone waters where lidar systems are not fully effective. Coastal areas of hydrographic importance containing turbidity, shoals and channels have been surveyed. This article describes AEM systems, gives highlights from surveys in Sydney Harbour and mentions refinements that would improve bathymetric accuracy.

For several decades geophysicists have been using a transmitter loop fixed to an aircraft or towed by a helicopter to emit a magnetic field into the ground to search for mineral deposits. Currents thus induced in the ground generate a return magnetic field that can be detected by an airborne receiver system, and these signals can be interpreted in terms of layered-earth models to give conductivity and thickness of assumed one-dimensional layers forming sub-surface ground. This technique lends itself to measuring the thickness of a seawater layer above the seabed, and also for measuring thickness of sea ice. The Defence Science and Technology Organisation (DSTO) has undertaken several Airborne Electromagnetic (AEM) surveys in coastal areas to assess the effectiveness of this technique.

AEM Systems

Airborne Electromagnetic (AEM) systems use complex instrumentation and supporting software and operate in either time or frequency domain. The time-domain method uses a periodic pulsed current waveform and a receiver detects the return magnetic field induced by currents in the seawater and seabed whilst no transmitter current is present, known as the off-time period. Fixed-wing AEM systems usually operate in this mode. Frequency-domain systems use continuous sinusoidal current waveforms operating at a number of discrete frequencies to transmit magnetic fields into the seawater and seabed. Helicopter AEM systems usually operate in this mode, although recently a number of helicopter systems have been developed that operate in the time domain. All three types of systems have particular advantages and have been used by DSTO for AEMB surveys.

Helicopter Systems

Instrumentation consists of several transmitter-receiver coil pairs in a fixed geometry wherein each receiver coil has been tuned to its associated transmitter-coil frequency. The coil pairs, separated by 6 to 8m, are enclosed in a robust tube (â€˜birdâ€™) suspended about 30m below the helicopter and about 30 to 40m above sea-level (Figure 1). Survey measurements are recorded about every 3m. Frequencies range from about 350Hz to 100kHz. Lowering the operating frequency to about 350Hz gives better penetration in seawater, but use of a single low frequency may be unsuitable because a range of frequencies are usually required to get depth resolution.

Fixed-wing Systems

Fixed-wing TEM systems use a transmitter loop that spans the wingtips and front and rear extremities of the aircraft, with the receiver coil contained in a bird towed about 40 to 60m below, and 90 to 120m behind the aircraft. Survey altitude is about 120m and measurement spacing is approximately 12m. Swaying motion may lead to interpretation errors arising from unrecorded variations of bird attitude, offset and altitude. A combination of large loop area and high pulsed currents enables these systems to transmit stronger magnetic fields than do frequency-domain systems. The transmitter current waveform typically has a period of 40ms (25Hz), transmitting a magnetic field during a 4ms current pulse, followed by 16ms of off-time duration (no transmitter current). This half-cycle is then repeated with a current pulse of opposite polarity.

HoisTEM

One example of a helicopter time-domain AEM system is HoisTEM, developed in Australia by Normandy Mining Ltd, now Newmont Mining Inc. HoisTEM has been used in several DSTO surveys, including Sydney Harbour (Figure 2). The structure contains a 24m-diameter transmitter loop with an inner concentric loop as the receiver coil. This system operates at a 25Hz base frequency, similar to fixed-wing time-domain systems. Lowering the operating frequency for both time and frequency domain systems improves signal penetration through seawater but often introduces problems associated with electronic noise and system stability.

Water Depths from AEMB

Using numerical modelling and least-squares optimisation methods, the data is inverted to determine the parameters of the model that best fit the data. The model parameters consist of the thickness and electrical conductivity of horizontal layers (one-dimensional, 1D) that make up the seawater layer overlying the seabed. The seabed may consist of exposed bedrock or of several layers of marine sediment overlying bedrock. The other model parameter is transmitter height above seawater. Thus the data can be inverted to find depth of seawater, transmitter altitude, seawater conductivity and, in some cases, thickness and conductivity of marine sediment. Some model parameters can be measured directly and used to facilitate the inversion process; for example, seawater conductivity and height above seawater. Inversion of AEM data using two and three-dimensional models

(2D, 3D) is more time-consuming than 1D inversion but may prove more realistic in some circumstances, for example where narrow channels and large protruding rocks break up the seafloor topography. Generally, 1D models are suitable where the variation in seafloor topography does not change significantly within the measurement footprint, which is typically anywhere from tens of metres up to about 150m, depending on system and flying height. Objects smaller than the footprint may be detected if there is enough conductivity contrast between it and its host.

Sydney Harbour

Sydney Harbour is well suited for testing the AEM method for mapping water depth. (i) The seafloor topography is interesting and variable, including reefs, channels, islands and holes. (ii) There is a substantial database of accurate depth soundings from numerous multi-beam surveys. (iii) The waters can be quite turbid at times, and (iv) sediment composition and depth can be estimated from existing marine seismic recordings. Figure 3 shows the results of estimated water depths down to 32m, obtained from an AEM survey using the DIGHEM1 helicopter frequency-domain AEM system. The survey consisted of 21 parallel lines flown with a nominal spacing of 50m, each line being about 5.5km in length. The depths were obtained by inversion of data and then gridded to map the seafloor topography. Depths from acoustic soundings have been similarly gridded and are also shown in Figure 3 for comparison. Both images are displayed with the same vertical exaggeration and colour scale. A significant portion of this area, in seawater deeper than about 18m, is unsuitable for bathymetric mapping using airborne laser depth sounding because of water turbidity and poor reflections from the seafloor.

Time-Domain Survey

Figure 4 shows a profile of a conductivity depth section for a single line obtained by inversion of data. Here the water depth is obtained at the boundary where the conductivity changes from being highly conductive (greater than 3S/m) to resistive (less than about 0.1S/m). Figure 4 shows that the relatively small tide correction of 1.4m is important for water depths less than 22m at the time of survey. In this case, inverted sea depths from AEM data achieve sub-metre accuracy. At deeper depths the accuracy deteriorates as a result of instrument calibration errors. However, subsequent corrections involving data re-scaling to account for calibration errors suggest that accurate inverted water depths can be obtained to depths of about 55m.

Conclusions

AEMB surveys conducted in several locations have consistently shown that the technique can provide reliable water depths in shallow water. However, refinements involving both instrumentation and interpretation software are still needed. To date, AEM systems have not yet been optimised for marine surveying - a significant setback that means that the full potential of AEMB is not being realised. Reducing the lower range of operating frequencies and survey altitudes together with accurate measurements of the dynamic transmitter-receiver geometry during survey would be expected to lead to significant improvements in investigation depths, depth accuracy and the ability to discriminate between various sea bottom types.

Note by the editor

This article is a shortened version of the paper â€˜Airborne ElectroMagnetic Bathymetry Methods for Mapping Shallow Water Sea Depthsâ€™ published in the November 2004 issue of the International Hydrographic Review (IHR).