Geophysics at Australia’s Desalination Plants

Robert Whiteley
Coffey Geotechnics
9/12 Mars Rd., Lane Cove West,NSW 2066
Bob_Whiteley@coffey.com

SUMMARY

In recent years major coastal desalination plants have been constructed at various locations around Australia. Engineering geophysics has contributed to the successful completion of these major projects. During 2009-10 two of Australia’ largest desalination plants with a combined capacity of 370Megalitres/day (upgradable to 670Ml/day) were commissioned in Sydney, NSW and at the Gold Coast, Queensland at a total cost of approximately $A2.5 billion.

Case studies at these desalination plants discuss aspects of the land, borehole and marine geophysical technologies that were applied during the feasibility and design phases of these projects. These technologies were used to investigate geotechnical conditions at the proposed plant sites and along the land and marine sections of the sea-water intake and brine outlet tunnels.

These studies had a significant impact on the geotechnical risk assessments and the final design of these desalination plants and involved the use of electromagnetic, gravity and seismic methods.

The case studies demonstrate the value of appropriate geophysics to large civil engineering projects.

Key words: desalination, geophysics, magnetics, gravity, seismic, marine

INTRODUCTION

During the first decade of the 21st century severe water shortages were experienced in Australian cities due to the combination of prolonged drought and increased human demand from an expanding urban population. These factors and perceptions of a rapidly drying climate led to the construction of major coastal desalination plants designed to supplement dam supply. Two of the largest desalination plants were recently completed at Kurnell near Sydney, NSW and at Tugun on the Gold Coast, Qld. at a combined cost of some $A2.5 billion (Fig.1).

Case studies, involving aspects of the land and marine geophysical investigations that were undertaken at these desalination plant sites and along the saltwater intake and brine outlets tunnels during the feasibility and design stages of these major civil engineering projects are discussed.

Sydney Desalination Plant

This plant is located at Kurnell on the southern side of Botany Bay near Captain Cook’s historic landing place. The geotechnical aspects of this project are discussed by Sarabia and Waddell (2010).

Figure1. Australian Desalination sites, 2013 (Hoang, 2009).

Fig. 2 shows the as-built planof the plant site and intake and outlet tunnels. The plant site (Fig. 2) is about 45 Ha in size,

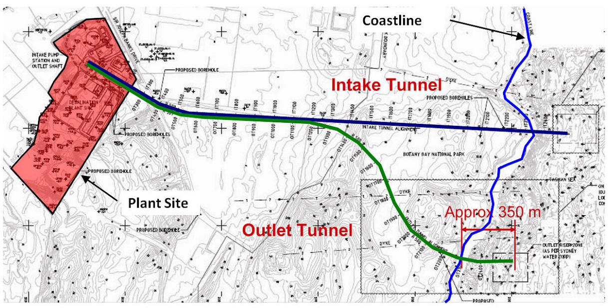

Figure 2. As-built plan of the Sydney Desalination Plant.

With ground levels generally 3 to 5m above mean sea level. Initial drilling revealed highly irregular bedrock of Hawkesbury Sandstone but further investigations were hampered by a wetland, a protected bat colony and heaps of dumped fill material intended earlier industrial development.

Previous gravity surveys in Sydney (Whiteley, 2005) have demonstrated a substantial density contrast between the sandy sediments and Hawkesbury Sandstone. Consequently, a detailed gravity survey of the plant site area was selected as the most eco-friendly option for mapping the bedrock surface. This defined a significant palaeochannel extending to about

20m to 25m depth showed that generally much shallower rock at about 3 to 6m depth extended over the northern third of the site. The plant design was modified to allow construction in the shallower bedrock area to reduce piled foundation cost, however, rapidly deepening bedrock beyond the plant site forced re-design of the tunnel entries to the plant.

The intake and outlet tunnels have a diameter of about 3m, are about 2.5 km long (Fig. 1) and extend to the coast beneath the Royal National Park with increasing depth. They connect to the sea via vertical shafts and seafloor structures, called risers, located about 300m offshore. The land height along the alignments increases from the plant site to about 20 to 30m above sea level at the coastal cliffs. At the risers, the seafloor is about 25m below the sea surface and the tunnels are about 20 below the sea floor. Geological mapping with the National Park was restricted to walking tracks but was of limited value due to dune sand cover and low scrubby vegetation. Some of the dunes were up to 17m high. Mapping along the cliff line identified at least four east-west trending dykes (Dykes 2 to 5). These were deeply weathered and no igneous material was actually observed as is common in the Sydney region (Rickwood, 1985). Their inferred widths were from 0.5 to 4.3m. Three of these dykes were considered to pose a significant geotechnical risk to tunnelling due to the deep weathering and potential for high groundwater inflows during construction. A ground magnetic survey was not permitted in the National Park but an airborne magnetic survey was undertaken. This was only partially successful as only the thickest dyke (Dyke 3) was detected, however, it did result in a re-alignment of the intake tunnel to avoid intersecting this dyke. The outlet tunnel could not avoid intersecting at least two of these inferred dykes (Dykes 4 and 5).

Marine geophysical investigations of the offshore region were also undertaken. These were also difficult due to boulders on the sea floor near the coast line and frequent rough sea conditions. The results of a deep tow, high resolution, marine magnetic survey with the inferred dyke locations from the coastal mapping are shown in Fig. 3.

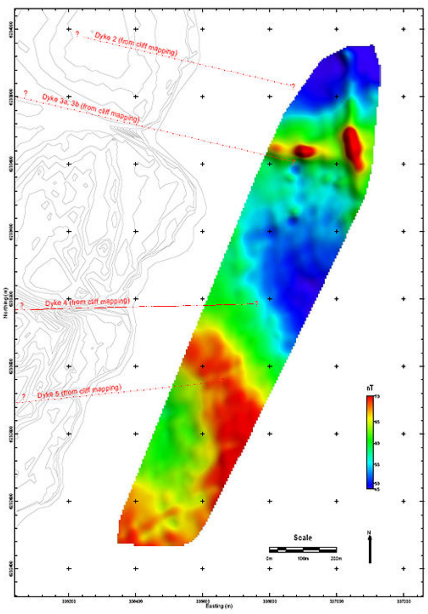

Figure 3. High resolution marine magnetic results.

These clearly show the offshore extension of Dyke 3 (labelled 3a and 3b in Fig. 3) that is actually two dykes in close proximity with a total width of 7.4m. The north-south trending feature near Dyke 3 is presumably associated with a previously unknown dyke. Within the vicinity of Dykes 4 and 5 the situation is less clear as no discrete magnetic anomaly can be associated with either. Regardless of this, higher magnetic values over much of this region indicate the presence of significant magnetic materials possibly in the form of sills and narrow dyke swarms. Several inclined boreholes were drilled at the coast line in the vicinity of Dyke 5 where it was to be intersected by the intake tunnel. These encountered the chilled margins of indurated sandstone, moderately to highly weathered basalt and shear zones about 40m below sea level. This dyke was 1.3 to 2.7m wide and borehole acoustic imaging indicated that it strikes at about 160^0M and dips at about 70^0 to 85^0. Although Dyke 4 was not drilled the confirmation of Dyke 5 allowed the orientation of the intake tunnel to be modified to intersect both dykes at right-angles to reduce tunnelling risks. The intake riser location was also altered to place it with the area of lower magnetic field intensity, i.e. the green region on Figure 3, to the south of Dyke 5. The intake tunnel intersected both dykes at the predicted locations without incident.

The Sydney Desalination Plant was completed and commissioned in 2010.

Gold Coast Desalination Plant

This desalination plant is sited on an old domestic landfill adjacent to Coolanagatta Airport, Tugun about 75 km south of Brisbane (Fig. 4). Concept design proposed shallow intake and outlet tunnels along the same alignment from the plant site to the coast then diverging alignments in the sea extended eastward to a minimum water depth of 20m.

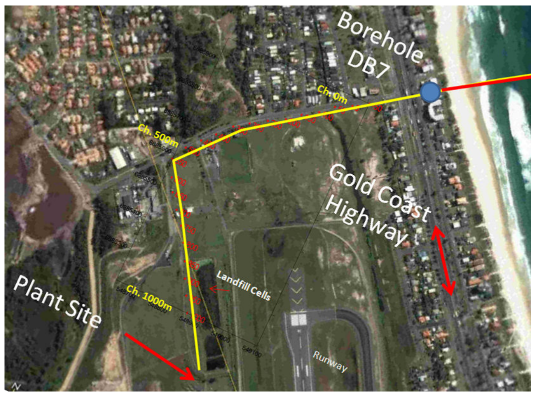

Figure 4. Location of the Gold Coast Desalination Plant.

Geophysical surveys were completed along the land section of the tunnel alignments shown in Fig. 4 to determine the extent of the landfill and to provide information on the bedrock. This involved EM 31 profiling, seismic refraction and MASW. Fig. 5 shows EM31 profile and the interpreted P-wave and S-wave velocity sections obtained from Ch. 1000 to Ch. 500m (Fig. 4). A single borehole (BHT3) near Ch. 950m penetrated waste sands and weathered arenite of the Neranleigh-Fernvale Group at about 29m depth (P-wave velocity ~ 2800 m/s). The higher bulk ground conductivities and very low S-waves obtained over the landfill extended to about Ch. 700m, about 150m to the north of the visible landfill cells (Fig. 4) indicating significantly more waste was present at the site than was anticipated. The P-wave velocity section also shows an irregular bedrock surface that is most clearly evident in higher velocities at depth from Ch. 500 to 700m (Fig. 5). This suggested that shallow tunnelling might encounter variable bedrock conditions. On this section the water-table is indicated by the 1500m/s velocity contour near its normal depth of about 5m at Ch. 500m. This velocity contour is depressed below the landfill as a result groundwater pumping used to control leachate in the putresible waste.

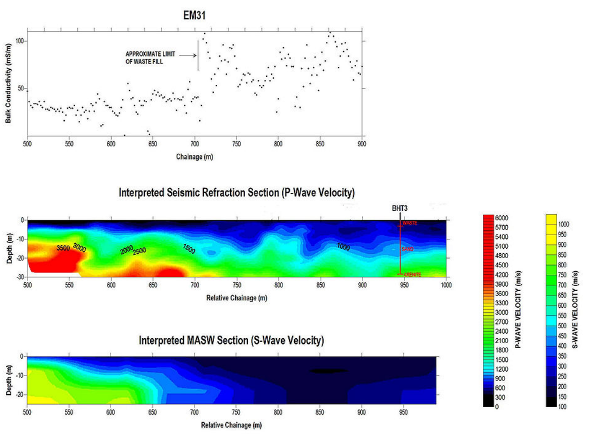

Figure 5. EM31 results and interpreted seismic sections along the tunnel alignment.

Following abandonment of the shallow tunnelling option the deep rock option was investigated with borehole (DB7, Fig. 4) that was drilled adjacent to the beachfront. In order to extend the information from this borehole beneath the beach and beyond the surf zone where drilling was not permitted surface-to-borehole seismic imaging using transmission tomography was undertaken (Whiteley, 2000). A hydrophone array was deployed along the length of this borehole and small explosive charges in holes, augered to the water table, were initiated at successive intervals along the beach to the low tide line. Beyond this a towed airgun source in a weighted sled was deployed through the wave zone to a distance of over 200m from the borehole. The P-wave seismic image that was obtained is shown in Fig. 6. The interpreted weathered and fresh rock interfaces are identified by the dashed red and black lines respectively at approximately the same levels as weathered and fresh argillite/arenite was encountered in the borehole.

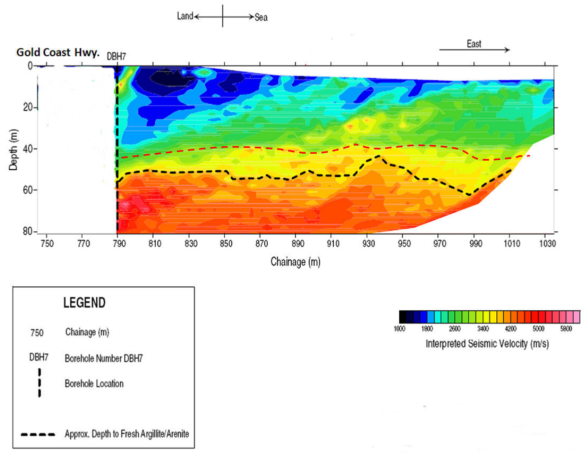

Figure 6. Surface-borehole seismic image from DBH7.

Bathymetric, side-scan sonar, marine magnetic and Boomer reflection surveys were also completed in the area offshore section of the intake and outlet tunnels. Fig. 7 shows an interpreted reflection section near the centreline of these tunnels over a length of about 2.6 km from surf zone. The actual length of the tunnelled section was only about 50% of this distance. This shows an easterly sloping seafloor and extent of the recent sand wedge from the surf zone. Beneath this are a series of disturbed sandy and clayey sediments presumably deposited on a relatively flat rock platform of

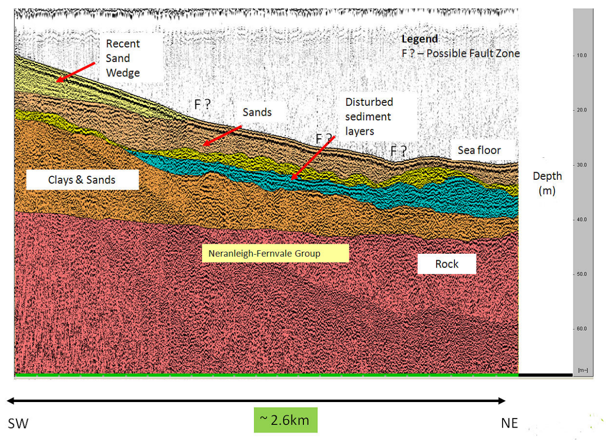

Figure 7. Interpreted Boomer reflection section.

Neranleigh-Fernvale Group rocks. The disturbed sediments show evidence of slump structures and faults that may extend into the rock section. Figure 8 shows a reduced-to-the-pole

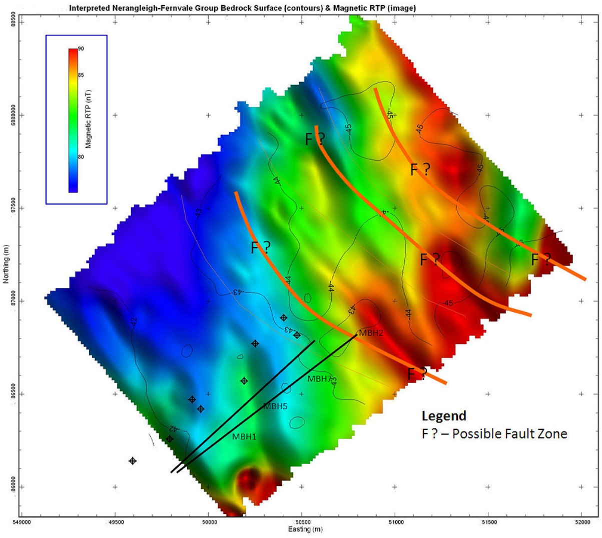

Figure 8. RTP Magnetics with rock level contours and interpreted faults from the marine seismic survey.

marine magnetic map with fresh rock contours and inferred major faults from the seismic interpretation. The locations of the intake and outlet pipes are also shown. The magnetic features observed occur mainly beyond the tunnels and appear to represent the combination NS trending magnetic rock units and narrower NW-SE trending narrower features possibly dykes. The correlation of these features with the inferred faults from the seismic interpretation is not strong but these generally trend in a NW-SE direction. There is one NS trending magnetic feature on Fig. 8 that crosses both tunnel alignments this was noted overwater borehole MBH5 was drilled in the area but did not encounter any igneous material.

The Gold Coast Desalination Plant was completed and commissioned in 2009.

CONCLUSIONS

The extensive geophysics that was completed at two of Australia's major desalination plants had a significant impact on design and final location of these facilities.

At the Sydney Desalination Plant, detailed gravity surveys of the environmentally sensitive plant site confirmed the presence of a deep paleochannel incising the highly irregular sandstone and delineated the areas of shallower bedrock on which the plant was eventually built, thereby significantly reducing foundation costs. Marine magnetic surveys that were completed close to the coastline identified dykes and sills that were considered major geotechnical hazards construction and assisted selection of the pipeline alignments and riser sites to reduce the associated tunnelling risks.

At the Gold Coast Desalination Plant land seismic refraction and MASW testing of the initially proposed shallow tunnel alignments showed that the buried waste was more extensive than previously believed and that variable ground water conditions and an irregular bedrock surface were present. This assisted the decision to investigate a deeper rock tunnel option that led to the drilling of a deep borehole near the beach and the extension of the information obtained in the hole beneath the surf zone using the surface-to-borehole seismic method. A marine reflection survey identified and essentially planar rock interface with some faulting and a single magnetic feature crossing the alignments was identified in the marine magnetic survey but no major impediments to rock tunnelling were identified.

These desalination plant projects were successfully constructed and commissioned during 2009-10 and are in operation.

REFERENCES

Hoang, M., Bolto, B., Haskard, C., Barron, O. Grey S., and Leslie, G. 2009. Desalination in Australia. CSIRO, 21p, ISSN 1835-095X.

Rickwood, P. C. 1985. Igneous intrusives in the Greater Sydney Region. In Engineering Geology of the Sydney Region, P. J. N. Pells (ed.), A. A. Balkema, 215-308, ISBN 90-6191-589-9.

Sarabia, D. and Waddell, P. 2010. Geotechnical conditions at Sydney Desalination Plant. Proc. GEO2010, Calgary, 1585-1591.

Whiteley, R. J. 2000. Seismic imaging of ground conditions from buried conduits and boreholes. Proc. Paris 2000 Petrophysics meets Geophysics, Paris, France, 6-8 Nov. 2000, paper B-15, EAGE ISBN 90-73781-15-9.

Whiteley, R. J. 2005. Gravity mapping and seismic imaging of large tunnel routes in Sydney Australia. In Near Surface Geophysics, D. K. Butler (ed,), Investigations in Geophysics 13, Soc. Explor. Geophys., Tulsa, Ch. 15, 503-512. ISBN 1-56080-130-1.