Desalination 249 (2009) 1088–1098

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Methodologies for abstraction from coastal aquifers for supplying desalination plants in the south-east of Spain

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ARTICLE INFO

Article history:
Accepted 16 June 2009
Available online 7 October 2009

Keywords:
Desalination plants
Coastal aquifers
Vertical and horizontal drilling

ABSTRACT

Supplying seawater to desalination plants using boreholes or drains can be less expensive than direct water intakes, since the silt density index (SDI) tends to be much lower. This approach is dependent on the presence of coastal aquifers with good hydraulic connection to the sea. Moreover, conventional boreholes are not suitable for pumping water on a long-term basis, since seawater is very aggressive. Hence, this type of abstraction requires the application of special technologies, from borehole location to borehole lining and special operations. These include the selection of the most appropriate drilling method, which depends on the lithology to be penetrated and its structure. This study focuses on Horizontal Directional Drilling (HDD), which encompasses very advanced technology. Various examples of work done in south-eastern Spain are described, along with the keys to their success.

1. Introduction

The Mediterranean coast of south-eastern Spain enjoys moderate temperatures and many sunny days, features that contribute to the fact that people want to live here all year round and to the development of highly profitable agriculture. These factors have led to a continual increase in the demand for water, which has frequently led to overexploitation of the coastal aquifers, to the extent that the abstractions have even had to be abandoned due to salinization.

Amongst the options for palliating the growing scarcity of water is reutilisation of treated wastewaters and desalination of seawater, as well as maximisation of water saving and use optimisation. The latter alternative has a long tradition in other parts of Spain, particularly in the Canary and Balearic Islands, and it is common practice over the arid regions of the Mediterranean, from Malta to Cyprus, Israel, Libya and Tunisia. Meanwhile, Saudi Arabia, the Arab Emirates and other countries in the region – the large oil producers – use desalination, and in some cases they have even assessed the possibility of using desalinated water for artificial recharge, specifically in Kuwait [1].

For medium-sized desalination plants, it can be less costly to extract seawater from boreholes or drains than to provide direct seawater intakes, since coastal boreholes extract water with very low SDI and organic content. The SDI (Silt Density Index) is a measure of the fouling capacity of water in reverse osmosis systems. The procedure for measuring SDI determines the drop in flow over a 47 mm diameter membrane with a pore size of 0.45 µm. The reduction in flow is represented as between 1 and 100 U. Rapid clogging indicates an elevated content of the colloidal and fine fractions. To avoid the fouling of the reverse osmosis membranes, the water supplied to the plant must be as clean as possible. An SDI value of no more than 5, together with a low organic content, is acceptable and reduces the need for pre-treatment. Moreover, this option can contribute to a wiser use of the coastal aquifers, since it considerably reduces the risk of seawater intrusion by creating a negative barrier that impedes the advance of the saline wedge. For large desalination plants, the use of coastal boreholes for water intakes is less competitive [2–4].

The objectives of this article, apart from highlighting the importance of considering this alternative water resource in coastal areas, are to describe practical geological and hydrogeological criteria for improving abstraction. In addition, it details the main problems that can arise, both in terms of selecting borehole locations and in planning the monitoring systems over the life of the exploitation. Finally, the intake systems of a number of seawater desalination plants in the Almeria and Alicante provinces of SE Spain are described.

2. General practical considerations for the location of boreholes

From a geological standpoint, the stratigraphic, sedimentological, tectonic and neotectonic characteristics need to be taken into account for the stretch of the coast in question. There must be a hydraulic connection between the coastal terrain and the sea. Of special interest are aquifers with intergranular porosity, given that these will filter the abstracted water better. The ideal strata are coarse-grained gravels and sands. The most suitable deposits are those with greater intrinsic

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doi:10.1016/j.desal.2009.06.046

permeability, which arise from shallow seas, ancient beaches, coastal dunes, reefs, fan- and alluvial deltas.

Fissured and fractured strata can deliver higher rates of flow, especially along open fractures; although they do permit the passage of organic material and suspended particles (high SDI). Something similar is true of karstic aquifers, which usually exhibit very high flows, especially when different sea levels have presided over the last few hundred thousand years, as in the case of the Mediterranean [5,6], since eustatic variations have favoured karstification. In such cases, it is advisable to place the boreholes in the fracture zones perpendicular to the coastline, in synclinal axes or in anticlinal crests.

In zones such as south-eastern Spain, where there is neotectonic activity, there is a need to analyse the dominant fracture orientations, so that the "open" fractures – the normal faults and joints – can be penetrated.

It is highly advisable to do a hydrogeological study prior to sinking the boreholes. The area chosen for the hydrogeological investigation should not be restricted to the vicinity of the boreholes, but widened to include the entire aquifer in order to understand how it operates hydrodynamically. Other issues also have to be considered, including legal aspects, maritime–terrestrial demarcations, possible aquifer overexploitation and the presence of regulated aquifer protection zones.

In sitting the boreholes, it is advisable to give preference to coastal aquifers that show evidence of marine intrusion, since any problems arising will undoubtedly have fewer social repercussions in these boreholes than in other, more balanced aquifers. In addition, boreholes showing signs of marine intrusion guarantee that there is a hydraulic link between the seawater and the continental groundwater.

As a general rule, the boreholes need to be located as close as possible to the coastline (30–50 m), to ensure that seawater is intercepted and to avoid salination of other boreholes further inland.

Geophysical surveys can provide good auxiliary information when deciding where the production boreholes are to be located. Seismic reflection methods are the most suitable, though they are also the most costly. Among the electrical methods, the electromagnetic ones give sufficient resolution in the saturated zone of the continental groundwater, since they can determine the fresh water–seawater contact with great accuracy because of the marked contrast between the two types of water, provided the contact is relatively shallow [7,8]. However, they have less resolution within the saltwater saturated zone because there is little contrast in resistivity.

Electrical Resistivity Tomography (ERT) can also provide reasonable resolution [9]. This measures apparent resistivity using a large number of current and potential electrodes. The data are then processed using mathematical inversion algorithms to obtain to "real" Resistivity–Depth image that can be interpreted vertically as well as horizontally (2D). The results are spectacular in homogeneous detritic aquifers, since the zones of highest transmissivity – which are those saturated in seawater – exhibit the lowest resistivity (0.2 to 5 Ω m).

In addition to recording profiles parallel to the coast, marine electrical tomographs can also be constructed. First, a general sweep is made in open sea by means of a silicone cable with graphite electrodes, which is towed behind the boat and which has flotation buoys attached. Then, specific profiles are recorded in the most promising areas but this time the cable is held over the seabed. The electrodes are held 5 m apart. Quantitative interpretation of such profiles is much improved if the lithology is known from an existing borehole.

Geophysical down-hole logs are also needed to accurately define the sections to be lined. The gamma ray log usually gives best resolution, as it differentiates well the clayey sections from the non-clayey ones.

3. Drilling methods

The choice of drilling technique is highly relevant, since it determines the duration of the exercise, the quality of the termination and the kind of problems that might occur during drilling. In general, any method that can drill diameters exceeding 600 mm will be sufficient, so long as it is rapid, clean, and accurate in terms of the lithological profile extracted, and ensures adequate stability of the walls of the borehole.

3.1. Percussion

This technique generally puts no limit on diameter. Nevertheless, it comes with certain drawbacks that seriously limit its applicability. In the first place it is slow, and a 100 m borehole takes 30 to 50 days to drill, provided that no additional problems occur. For instance, in the case of detritic aquifers, problems can arise due to wall descaling or collapse. The solution to this usually involves using auxiliary casing. This brings further difficulty since the diameter is reduced each time, unless the additional casing can be extricated once drilling is finished, though normally this is not an option. If it is not removed and it is intended to insert screens *in situ*, the result is usually inadequate since proper dimensioning of the slots cannot be achieved. Percussion drilling also has the problem common to nearly all drilling techniques, of appropriately assigning the samples to their correct depth. For this reason it is necessary to do a well log before inserting the well lining.

With respect to fissured, carbonate or cohesive detritic rocks (sandstones and conglomerates), it has to be said that the preferred system is percussion, since descaling problems do not arise, although the problems of slowness persist.

3.2. Direct circulation drilling

Direct circulation drilling using bentonite muds is a very fast technique, though its biggest problems arise from the incorrect removal of the mud or cake. This forms on the borehole walls and serves to bind the walls together to prevent collapse; however, its retention diminishes the productivity of the well. It is useful to remember that part of the drilling will occur in a medium saturated by briny or salt water, with a composition close to or equal to that of seawater. As a result, conventional drilling muds tend to be problematical; usually the difficulties subside as the density of the mud increases. They limit the passage of water into the borehole and make it more difficult to eliminate the side-wall mud cake, with the consequent loss of productivity in the borehole. Nor is the problem of the loss of solubility eliminated. Consequently, specific muds must be used for salt waters [10,11]. There is always the option of employing degradable muds which, although they are more expensive, are eventually eliminated naturally.

The advantage of direct circulation drilling over other drilling methods is that considerable depths can be achieved. However, in the case of small drilling rigs, since drilling diameters of 600 mm may not be achievable, it is not possible to insert the correct lining or gravel pack. This means that when the pumping equipment is installed, it does not fit very well and presumably, this results in pronounced head losses. The main problem is assigning the lithology of the strata being penetrated and, although a core sample can be extracted at any time, this is very expensive.

Nevertheless, rotary drilling, being a sophisticated technique, allows more autonomy and facilities for allied operations, such as the placement of screens, gravel packs, grouting and final cleaning, etc.

3.3. Reverse circulation rotary drilling

Reverse circulation rotary drilling is traditionally considered to be the optimum method for drilling loose material. It commands other advantages, such as the ability to drill large-diameter wells rapidly and, above all, cleanly — especially if water is used as the drilling fluid. Some of the difficulties that arise even with this procedure derive from the fact that drilling rarely proceeds using just water, though the