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New and innovative sea water intake system for the desalination plant at San Pedro del Pinatar

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Abstract

This paper deals with a new sea water intake system which can be used in large desalination plants as it presents numerous advantages over vertical costal wells.

Keythemes: Desalination plants; Sea water intake; Horizontal drains and targeted horizontal drilling

1. Introduction

The desalination plant at San Pedro del Pinatar, also know as the "Nuevo Canal de Cartagena," is located to the north of the Mar Menor (Minor Sea), just next to the road that links San Pedro with El Mojón (Figs. 1 and 2) This road is the dividing line between the provinces of Alicante and Murcia.

The area in which the desalination plant is located presents some challenging environmental conditions. As you will note from Figs. 3 to 4. the terrain of the plant is enclosed on both sides: on one side by the Regional Park and the sandy areas of San Pedro del Pinatar, and on the other side by the brackish water desalination plant which treats the drainage zone of the irrigation area of the "Campo de Cartagena." In addition, the marine area is designated as a protected zone ("LIC prioritario" – Franja Litoral Sumergida de la Región de Murcía) due to the presence of sea grass as can be seen in Fig. 5.

2. Properties of the desalination plant

The most important properties of the desalination plant are set out in Table 1. The diagram

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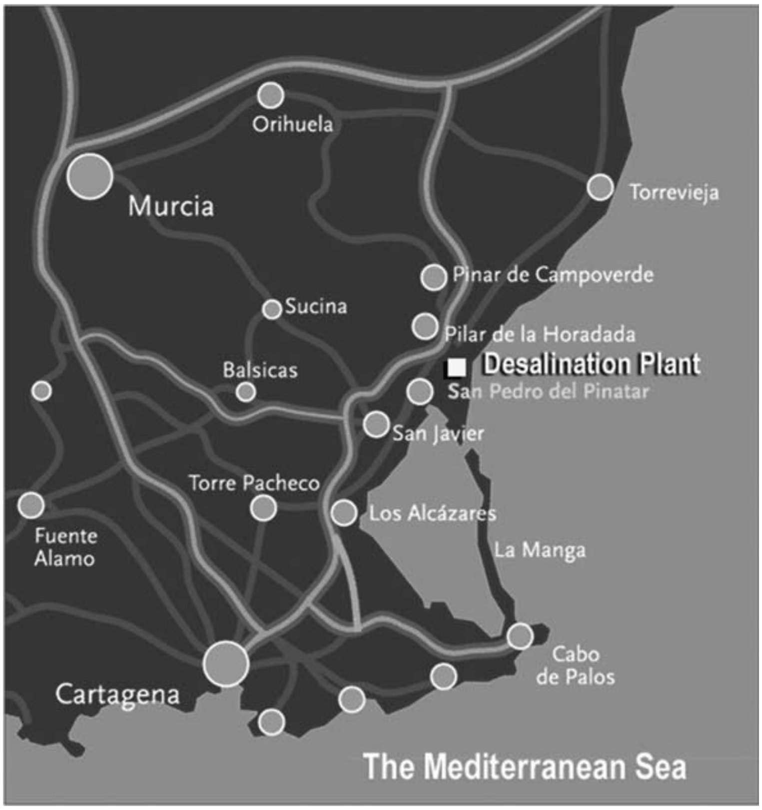

Fig. 1. Location of the desalination plant.

of the process is detailed in Fig. 6 and a plan of the plant is explained in Fig. 7. Although this desalination plant is conventional from many points of view: dosages of chemical reagents, pre-treatment, and energy recovery systems, it has 3 very distinct features.

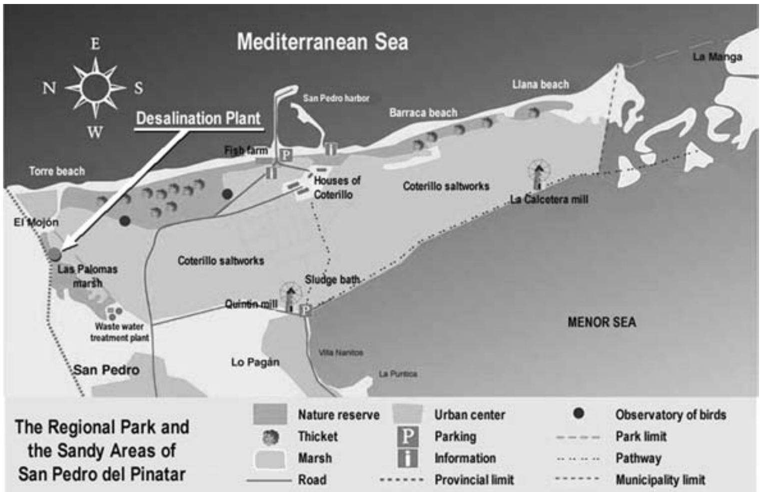

Fig. 2. Location of the municipal district of San Pedro del Pinatar.

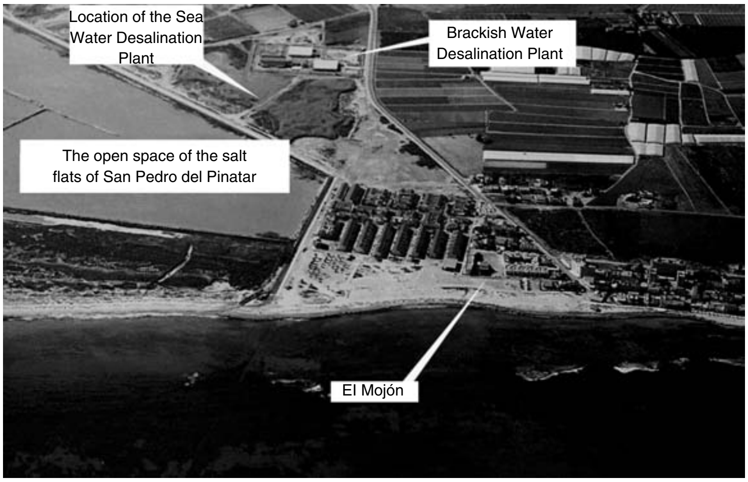

Fig. 3. Overview of area surrounding the desalination plant.

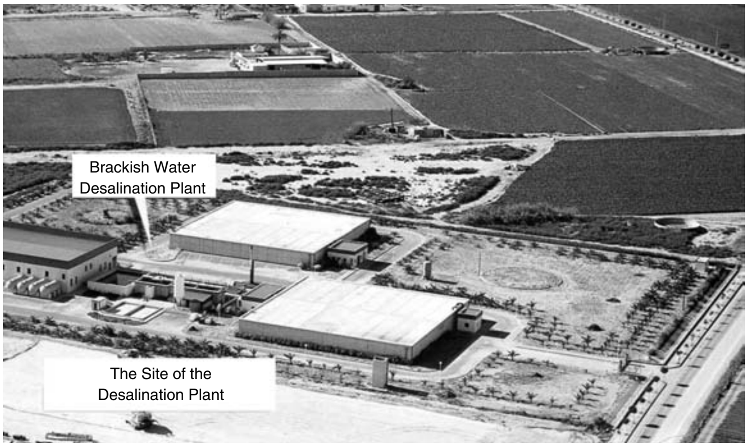

Fig. 4. Brackish water desalination plant and the surrounding area.

Fig. 5. The Sea Grass (Posidonia oceanica) on the sea beds surrounding the desalination plant.

Table 1
General information about the Desalination Plant

Aspect of Plant	Initial situation	Following enlargement
Volume of water desalinated (m3 / day)	65000	85000
Annual volume of water produced (hm3)	23,0	30,2
Method of water intake	Horizontal Drains	Horizontal Drains
Number of production lines	9	10
Volume of each line (m3 / day)	7,225	8,500
Work conversion rate (%)	45	53
Energy recovery system	Pelton Turbine	Pelton Turbine
Disposal system for waste brine	Underwater dispersal using diffusers	Underwater dispersal using diffusers
Height of the Desalination Plant above sea water (m)	4,00	4,00
Height of the desalinated water outlet above sea water (m)	86,00	86,00
Power (MVA)	30,00	30,00
Specific energy consumption (kWh / m3)	4,25	4,25

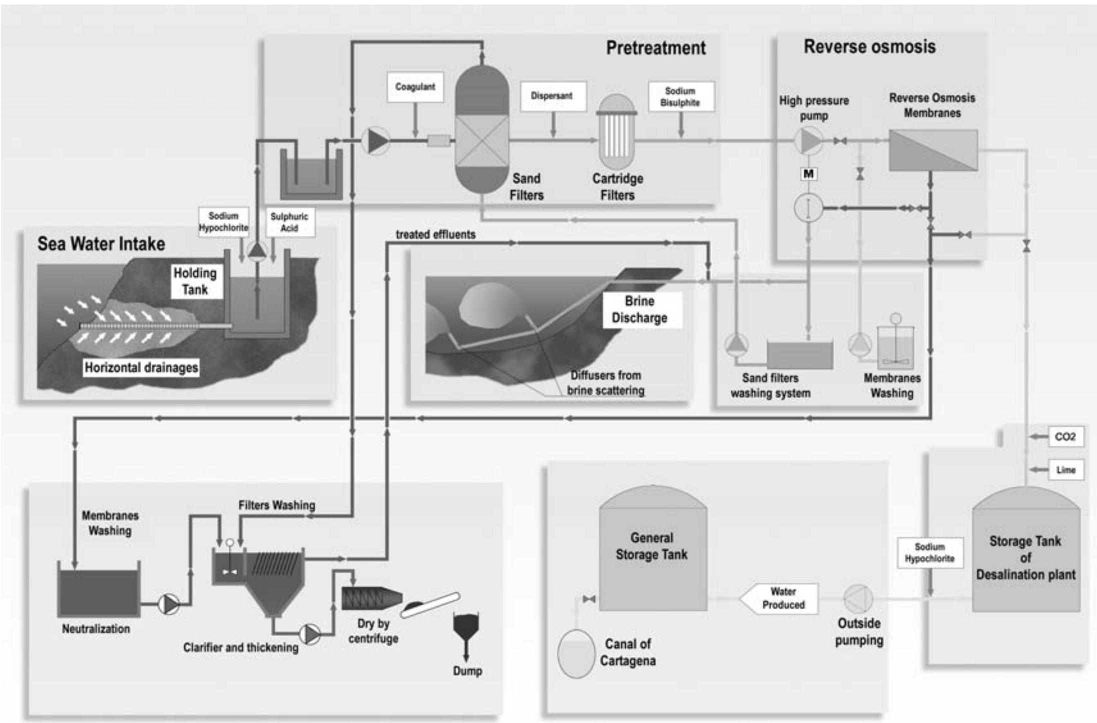

Fig. 6. Diagram of the process.

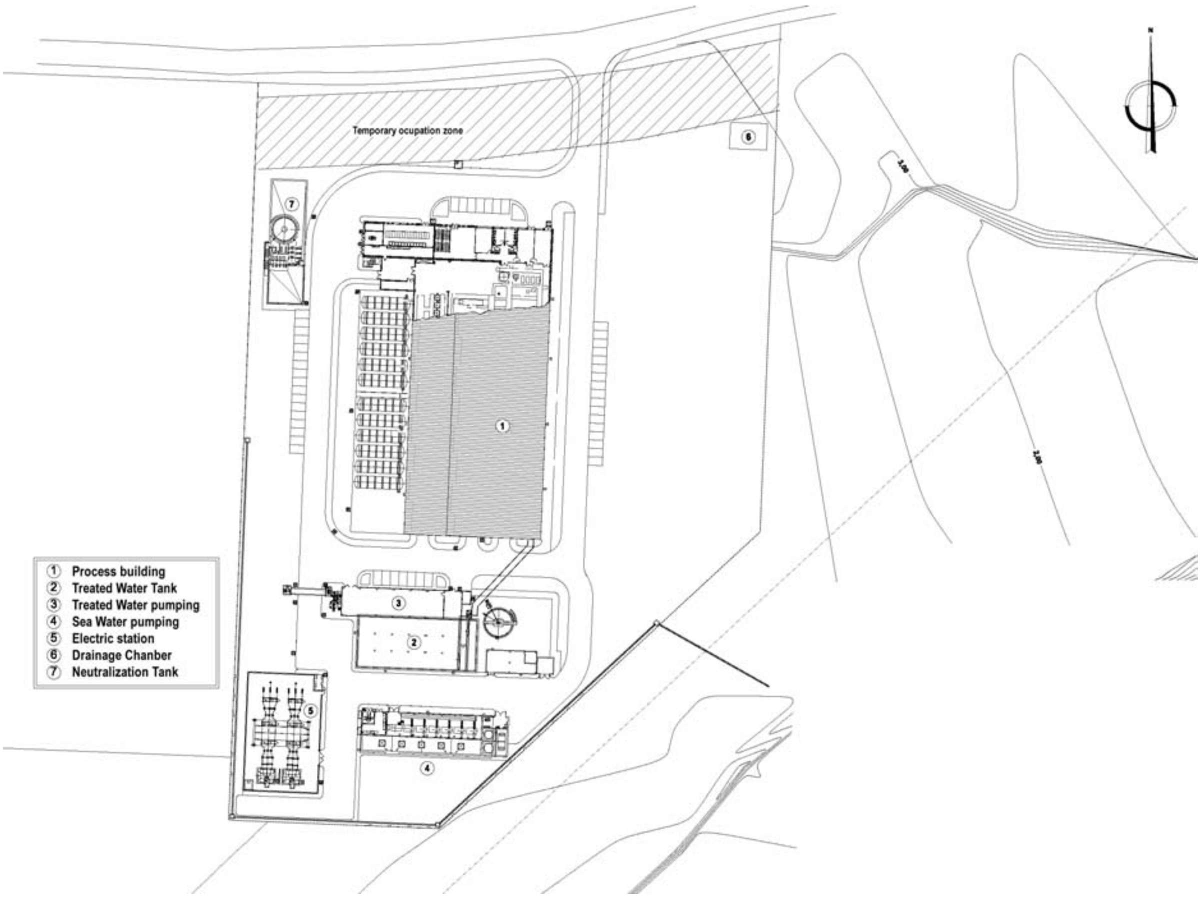

Fig. 7. Plan of the Desalination Plant.

- Future enlargement.
- The disposal of the brine waste product.
- The sea water intake.

These 3 elements will be expanded on forthwith :

2.1. Future enlargement

Currently the desalination plant has 9 production lines which use Pelton Turbines as the energy recovery system. Each production line produces 7225 m^3/day with a conversion rate of 45%. The structure of the plant was built to allow the integration of a new production line bringing the total number to 10.

The membranes trains, the supply pipes, the discharge pipes etc have all been designed so that the conversion rate of the plant in the future can be increased to 53%. To achieve this conversion rate, the only change that would need to be made would be to install a second level of membranes in the aforementioned frameworks, to be supplied by an additional corresponding booster pump.

With this increase in capacity, each line is capable of producing 8500 m^3/day and the output of the plant would exceed 85,000 m^3/day.

2.2. The disposal of the waste brine product

The Governing Body of the Environment Department for the Murcía region stated in their directive on the "Environmental Impact" regarding the technical requirements for the desalination plant, that in order to protect the fields of sea grass in the brine outlet area, that the disposal of the brine waste product must occur at a depth greater than 4.69 m. This restriction means that the disposal of the brine takes place beyond the boundary of the sea grass fields, and is sufficiently far away that the fragile sea grass, which is very sensitive to changes in its environment, is not affected by the hyper-salinity of the waste brine.

2.3. The sea water intake

In the same directive on the "Environmental Impact" for the desalination plant, it was stressed that in terms of the sea water intake for the plant, that under no circumstances could water be taken from the aquifers of the "Campo de Cartagena" nor from the Wetlands of the Protected Natural Area of "las Salinas y Arenales de San Pedro del Pinatar." Furthermore, it was emphasized that it must be proved that all the water intake should come from the sea and not negatively impact on the aforementioned areas.

In light of the problems which occurred with the sea water intake during the development of the project, a new and innovative sea water intake system for desalination plants was designed which will be expanded upon forthwith.

3. Water intake backround

3.1. Water intake method as proposed in project

Based on the available hydrological information about the zone, it had been planned that the sea water would be taken in through vertical wells, dug through the land on which the desalination plant is located. The project then planned that the water would feed into the water intake holding tank before being pumped by self feeding pumps to the pre-treatment phase.

In order to investigate the possibilities of the exploitation of the aquifers in the area, the hydraulic dynamics between the aquifers and the sea, and thus the possibility of using the planned sea water intake method, investigative drilling was carried out to a depth of 169 m at Pinatar I, the location of which is marked by no. 1 in Fig. 8.

The Lithological column revealed in this investigation is summarised in Table 2.

Through the investigative drilling results, the existence of the 2 types of hydro-geological formations were revealed, as summarised in Table 3.

Table 4 shows the aquifer levels within the first formation described above which is composed of clay interspersed with gravel, sands, travertines and marl.

The second formation is composed of alternate layers of greyish marl and very malleable clay lime which cannot be exploited hydro-geologically due to the lack of permeability within the structure.

The resistance levels of the water (the opposite of conductivity) found down to a depth of 32 m were constant. These levels then reduced between a depth of 32 and 48 m, at which depth the registered values approached the resistance levels of sea water.

These results pointed to two possible conclusions:

- That the fresh water/sea water interface was situated at a depth of about 30–35 m
- That due to the lack of vertical movement of currents inside the drilling well, that the water has separated into layers, with the salt water (the most dense) at the bottom

Table 2
Lithological column revealed through investigative drilling at Pinatar I

Depth (m)	Lithological Properties	Depth (m)	Lithological Properties
0 - 9	Muddy Yellow Sands	73 - 80	Green - blue Marl
9 - 10	Reddish Clay	80 - 82	Muddy green - blue Marl
10 - 15	Compact travertines with secondary dissolved porosity of white ochre colour	82 - 85	Green - blue Marl
15 - 19	Reddish Ochre Clay	85 - 88	Muddy green - blue Marl
19 - 20	White Ochre calcarenite with primary compacted porosity	88 - 90	Green - blue Marl
20 - 23	Coarse sand and ochre gravel without interspersed clay, composed of pebbles of limestone, calcarenites and quartzite	90 - 94	Muddy green - blue Marl
23 - 31	Reddish Clay	91 - 104	Green - blue Marl
31 - 34	White ochre Marl	104 - 106	Darker green - blue Marl
34 - 36	Compacted white ochre travertines	106 - 118	Green - blue Marl
36 - 40	Compact travertines with secondary dissolved porosity of light brown colour	118 - 120	Muddy green - blue Marl
40 - 42	Light brown Marl	120 - 122	Green - blue Marl
42 - 45	Reddish brown Marl	122 - 124	Muddy green - blue Marl
45 - 48	Light brown Marl	124 - 143	Green - blue Marl
58 - 64	Green - blue Marl	143 - 146	Muddy green - blue Marl
64 - 71	Muddy green - blue Marl	146 - 166	Green - blue Marl
71 - 73	Light brown Marl	166 - 169	Muddy green - blue Marl

of the well, and the fresh water towards the top.

To resolve the uncertainty, a new drilling investigation was launched, known as Pinatar II, this time to a depth of 74 m and shown by position 2 in Fig. 8. The lithological column from this drilling is shown in Table 5.

It was concluded that there were 2 aquifers within the 50 m deep quaternary sediment layer:

- Down to a depth of 16 m: unconfined.
- Between 30 and 43 m: confined and made up of travertines.

In light of this information and taking into account temperature readings and fluid resistance, the project team concluded that the filtration area of the well was located between a depth of 32 and 42 m.

During the appraisal of the drain, water conductivity at 25 °C varied between 8000 and 9200 μS/cm, stabilising around the 9200 μS/cm level which clearly indicated that the water was not coming from the sea.

In addition it was observed over time that whilst the volume of water extracted was increasing, the levels of $Cl^-/HCO^-{}_3$ and Na^+/Ca^{++} in the pumped water were also

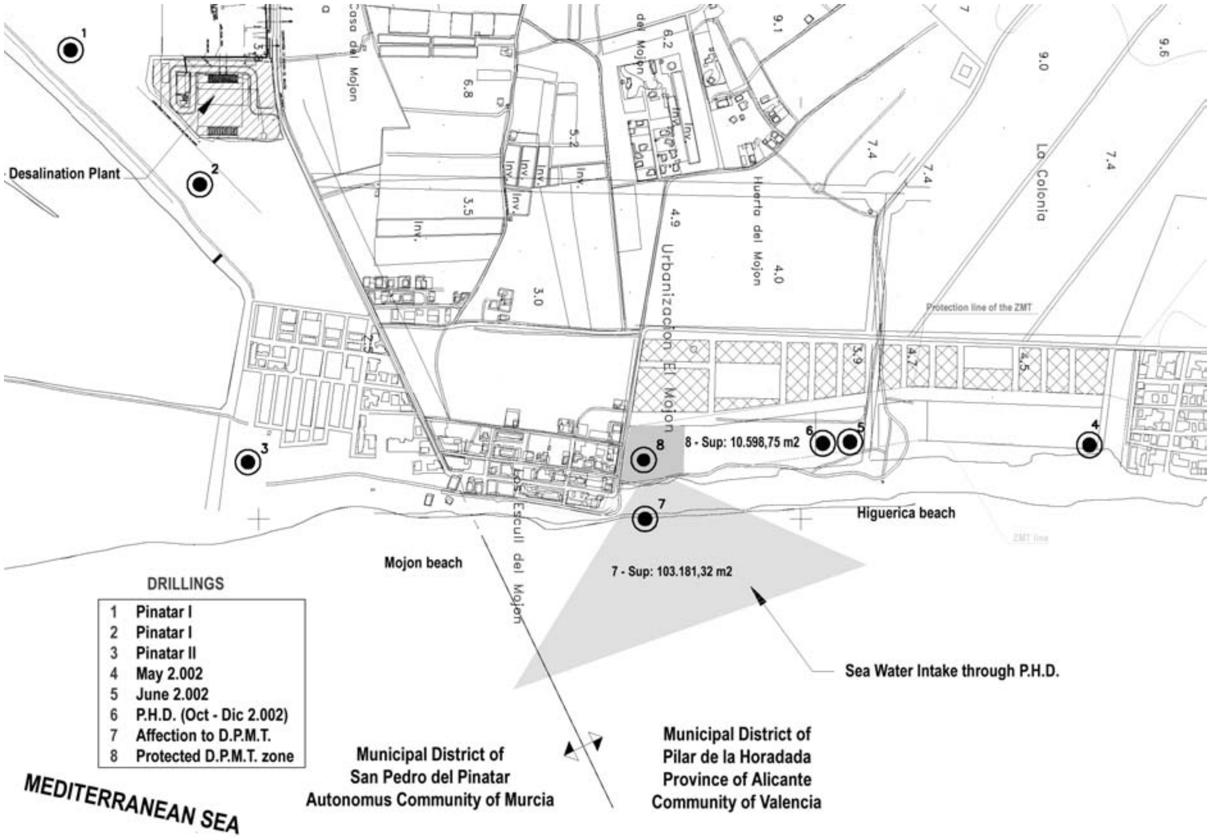

Fig. 8. Plan of the locations of the various drilling investigations.

Table 3
Hydro-geological formations

Formation	Depth	Type
1	0 - 42	Quarternary Sediments
2	42 - 169	Tertiary Miocene Sediments

increasing, however they were still very far from the natural levels found in sea water.

Everything seemed to point towards the fact that although there was a direct connection with the sea, the hydraulic gradient generated by the pump was not strong enough for the sea water to penetrate the ground and thus towards the intake zone. Given that the Pinatar II Well was located 700 m from the coast line, it was evident that the sea water/fresh water interface must be closer towards the coast line and not further inland, as is illustrated in Fig. 9.

3.2. Alternative water intake areas

Given the results of the previous investigations, it became clear that the sea water could

Table 4
Aquifer levels within the first formation

Level	Depth	Properties
I	10 - 15	Compact travertines with secondary porosity
II	19 - 20	Compacted fine grain calcarenites
III	20 - 23	Sands and pebbles without interspersed clay
IV	34 - 40	Compact travertines with secondary porosity

not be taken from under the grounds of the desalination plant, and so a decision was taken to move the water intake wells closer to the shore line, carrying out a new drilling investigation only 100 m from the sea shore. This well was named Pinatar III and shown by no. 3 in Fig. 8.

The water collected from this well during the survey recorded a conductivity level ranging from 42,000 μS/cm in the initial stages to 45,000 μS/cm towards the end of the investigation. Analysis of the water showed that it was still not seawater, although it was clearly coming from the zone where sea water mixed with

Table 5
Lithological column revealed through investigative drilling at Pinatar II

Depth (m)	Lithological Properties
0 - 5	Muddy Yellow Sands
5 - 9	White Clay
9 - 14	Pebbles and sand with gravel made up of limestone, calcarenites and quartzites...etc of ochre colour without any interspersed clay
14 - 16	White Marly Limstone Rock
16 - 18	Red Ochre Clay
18 - 21	Redish Clay
21 - 25	Red Ochre Clay
25 - 30	White Ochre Clay
30 - 34	Compact travertines with secondary dissolved porosity, compacted micro-crystals of white ochre colour
34 - 40	Greyish, porous compacted travertines and micro-crystals
40 - 43	Very compacted travertines with no porosity
43 - 45	White Marly Limstone Rock
45 - 54	Brown Clay
54 - 74	Green - blue Marl

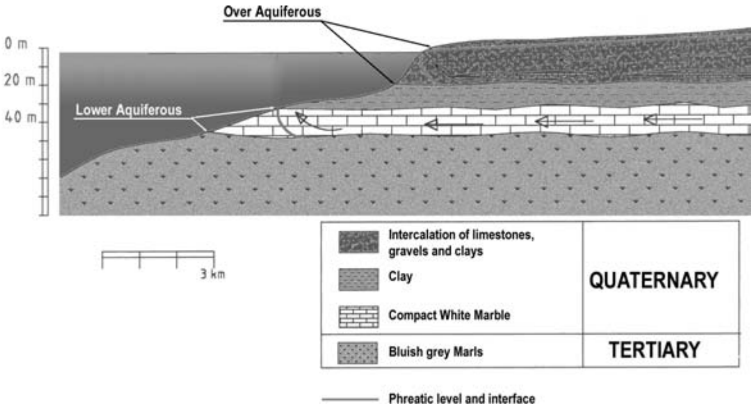

Fig. 9. Hydro-geological schematic of the area.

water from the lower aquifer. Unfortunately the capacity of the well was very low (12 l/s with a depression of 32.91 m) which meant that further development of this well as a potential water intake position was halted.

It was thought that the only way to create a sea water intake which complied with the conditions set out in the Environmental Impact Directive, was to locate the wells in an area of high permeability near to the shore line so that the hydraulic gradient created by the pump would distort the interface in the water intake zone, as is illustrated in Fig. 10.

In order to further this theory, an investigation marked by position 4 in Fig. 8 was carried out. As can be observed, the well was excavated on the right hand boundary at the mouth of a water outlet. The results obtained showed that the water from this well came from the mixing zone. The same results were again obtained from investigation 5 in Fig. 8, which was located very close to the sea, in the middle of Higuerica beach.

Following all these tests and investigations, the project team reached the conclusion that the lower aquifer was exerting a strong influence over the whole area, acting as a channel that drained off fresh water into the sea, preventing the intake of sea water. It became clear that the interface between the aquifer water and the sea water was located further into the body of the sea, meaning that if the water intake method was to be via vertical wells, it would be impossible to comply with the Environmental Impact Directive.

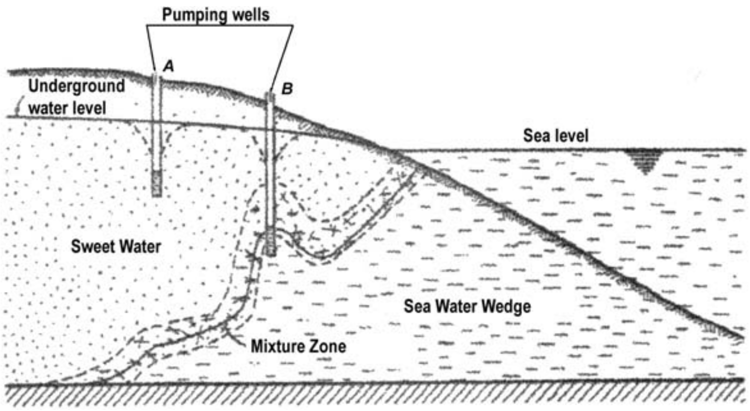

Fig. 10. Schematic of the interface distortion due to the sea water intake.

3.3. The development of a new water intake method

Following the aforementioned challenges presented in the search to come up with a suitable water intake method, the project team arrived at the conclusion that there were only 2 ways in which sea water could be collected from the area:

- Return to the open intake method, with the inevitable problems and consequences caused by the beds of sea grass surrounding the intake area.
- To take water which has filtered through the ground, however to take it from the sea beyond the limit of the interface.

The presence of the cracked calcarenites which appear at the edge of the beach and descend into the sea forming sandbanks, persuaded us to design an original water intake system.

4. New water intake system

4.1. The basic concept

The essential concept of the design was to collect sea water filtered through existing fissures in the upper calcarenites. Given that the sandbanks were essentially acting as a type of underwater, unconfined aquifer on the sea bed which was in direct contact with the sea, the project team considered that the pumping system would create a very large depression, which would ultimately be strong enough to ensure that the water intake came from the sea and not the mixing area between the sea water and fresh water.

Given that the calcarenites were not very thick (around 10 m in depth) the only possible way to extract the 2000 l/s of sea water required to supply the desalination plant was to drill a horizontal well, not a vertical one, as is illustrated in the schematic in Fig. 11. Similarly to vertical wells, the filtration zone would be located in the productive area of the fissured calcarenites, and the rest of the pipe would remain closed.

This new method of water intake has a great advantage over vertical wells, which is that if the capacity produced is insufficient due to lack of water intake, or if the water collected has come from the mixing zone, then the money spent on the project will not be wasted as the end of the pipe can easily be opened and converted into an open water intake system.

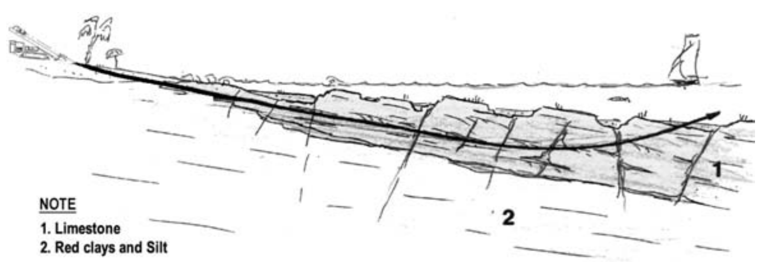

Fig. 11 Diagram showing the new water intake system.

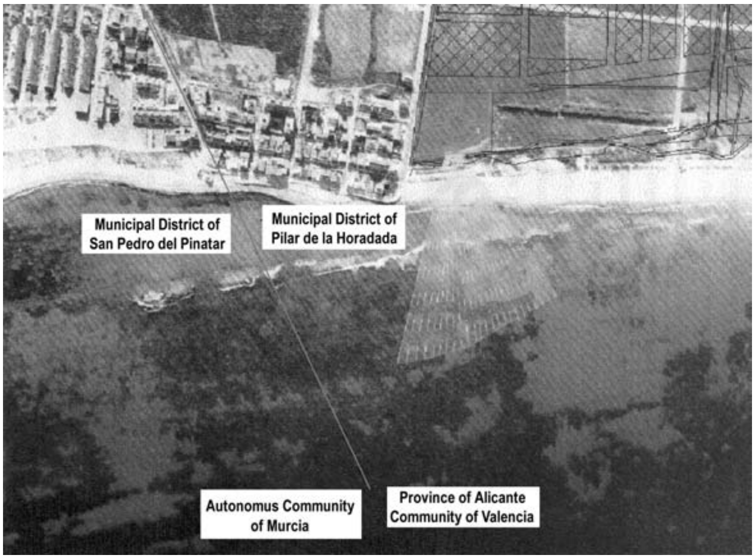

Fig. 12. Overview of the water intake zone.

In order to ensure a water intake of high quality, the drain should be located in the lower part of the calcarenite which will ensure a sufficient thickness of ground for the water to filter through.

The technique chosen to perform this type of water intake is "directed horizontal drilling" (PHD – Perforación horizontal dirigida) which allowed the project to overcome all the aforementioned conditions and challenges.

4.2. Geology and bathymetry

Once the decision on the method of water intake had been taken, the next step was to decide on the location of the intake, so that a geological investigation could be launched in addition to a study into the bathymetry of the zone.

Following a study of three possible sites, the project team decided that the best solution would be to locate the water intake at the south end of the Higuerica beach, on the

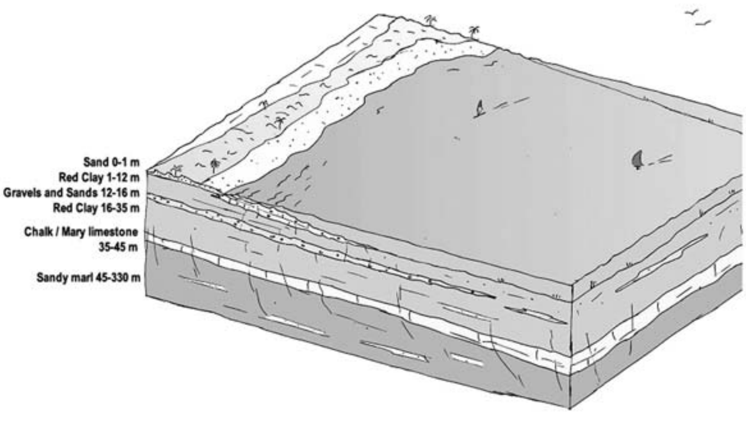

Fig. 13. Schematic of the geology of the water intake zone.

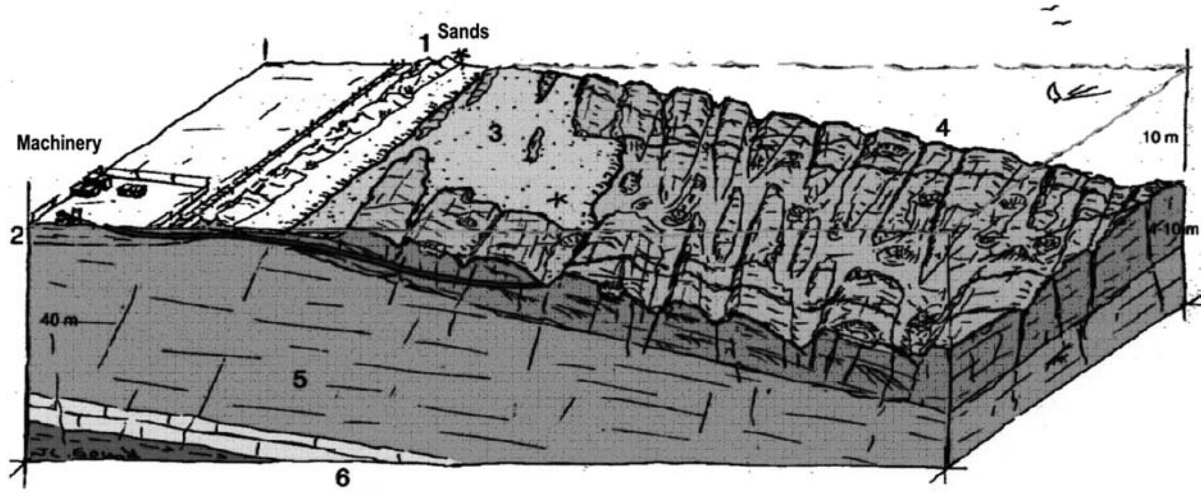

Fig. 14. The geological and bathymetric composition of the water intake zone.

land belonging to the municipal district of Pilar de la Horadada, as is illustrated in Fig. 12.

The data that was captured during the geological and bathymetric studies is displayed in the schematics in Figs. 13, 14.

4.3. The commissioning of the works

4.3.1. Drilling trajectory: As a result of the information obtained through the geological and bathymetric surveys, a proposed trajectory for each pipe was established, as is illustrated in Fig. 15. It must be noted that there are two factors which limit this type of drilling:

- The type of ground along the entire length of the horizontal bore hole.
- The minimum degree of curvature of the horizontal bore hole.

The ground through which the drilling takes place should be stable, and able to maintain its form even when bentonitic drilling mud is used.

The minimum degree of curvature of the bore hole depends on the diameter of the rods used which in turn depends on other factors: for example, the type and hardness of rock that needs to be tunnelled through and the length of the borehole.

4.3.2. Guidance system The drilling head is guided by a positioning system which sends a signal with information regarding its orientation to the operating machinery, through a cable with is located in the drilling rod. At the same time, a movable piece of machinery on the surface mobilises and controls the horizontal plane of the drilling head. The combination of both sets of information means that the required drilling trajectory is constantly monitored.

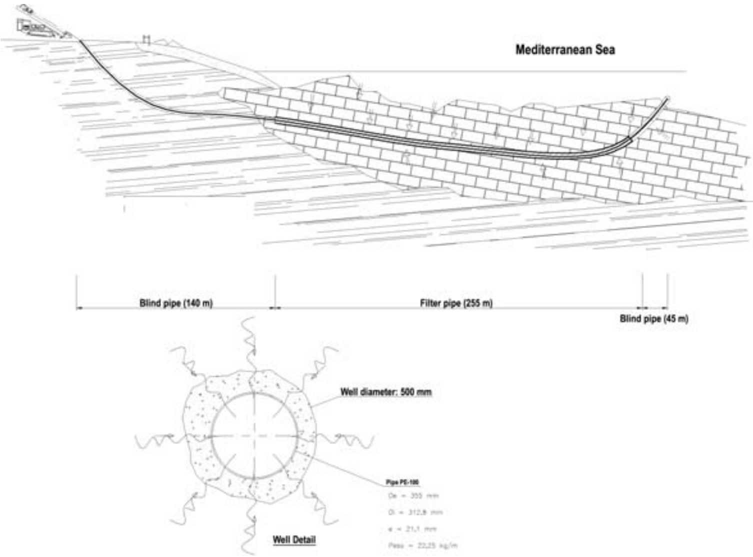

Fig. 15. The trajectory of a horizontal well.

4.3.3. Drilling machinery For this project the horizontal bore hole was drilled from the land, in the direction of the sea, through a drilling rod as shown in Fig. 16.

The end of the rod has a reinforced cutting tool as can be observed in Fig. 17 in order to cut away and drill into the earth. In order to excavate the earth, a combination of pressure and the activation the cutting heads was employed. Drilling mud was pumped into the bore hole in order to cool down the area, clean the cutting tool and stabilise the bore hole walls.

The drilling of each bore hole took place in two stages. The first stage consisted of a

Fig. 16. View of the drilling rod and machinery.

Fig. 17. Drill head.

pilot bore hole with a diameter of 250 mm which was drilled using pushing and rotary rods with diameters of 90 mm. Each rod is 5 m long and was inserted into the ground along the required trajectory by the drilling head machinery, so that once the rods had traced the required trajectory, they emerged in the sea as can be observed in Fig. 18.

Once the drill head had been removed, it was replaced by a backreamer which allowed the size of the opening to be increased to up to 500 mm. See Fig. 19.

The backreamer was then activated, turning and drilling along the required trajectory in the opposite direction from the pilot bore hole, as can be observed in the diagram in Fig. 20.

4.3.4. The geological information from each drilling hole It is essential to analyse the various types of ground through which the bore hole passes, in addition to their distances from the origin of the bore hole and the lithological profile of the area in order to determine the location of the layers that are able to act as filters. This means that the filtration casing can be installed in these layers, and the closed casing which seals the bore hole can be inserted into the other parts.

4.3.5. The positioning of the piping The piping is fed into the bore hole from the sea, and is directly connected to a backreamer which goes over the last stretch, so that when the drilling machine pulls it in, the backreamer cleans the tunnel that has previously been opened, whilst at the same time locating the piping inside the bore hole, as can been seen in Fig. 21.

This method of positioning the piping further guarantees the complete extraction of all detritus and silt, in addition to ensuring

Fig. 18. The drilling head emerging in the sea from the sea bed.

Fig. 19. Various backreamers.

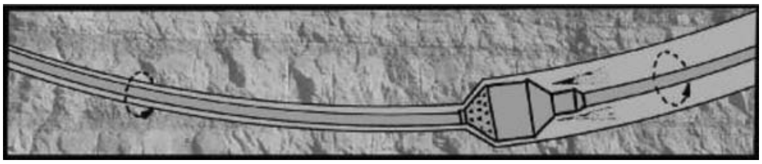

Fig. 20. Diagram of the movement of the backreamer.

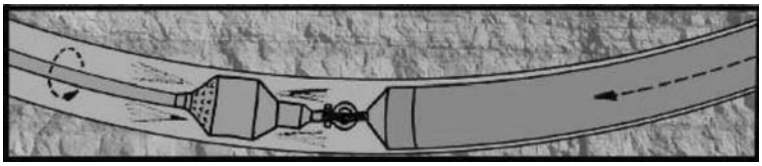

Fig. 21. Diagram of how the piping is put into position.

that these waste products are deposited on the land, as opposed to into the sea.

The front end of the piping is covered in a protective metal cone, as can be seen in Fig. 22 to facilitate its movement along the bore hole, preventing snagging.

The piping that is put into the bore hole is perforated along the length of the sections where the aquifer is considered to be active. Once the piping has emerged from the bore hole, its length is then adjusted so that just juts out over the area of the filtration zone within the bore hole.

4.3.6. Cleaning and cementation Once the piping has been inserted and set in its final position, it is vital to get rid of the drilling mud that the calcarenite will have picked up.

In this instance, this process is carried out by the pipe flushing through a large quantity of water using 2 pumps; one which is self suctioning and pumps the water out at the end on the land, and the other which is underwater takes the water in from the end located in the sea.

Once the cleaning process has finished, the non productive areas of the bore hole, as well

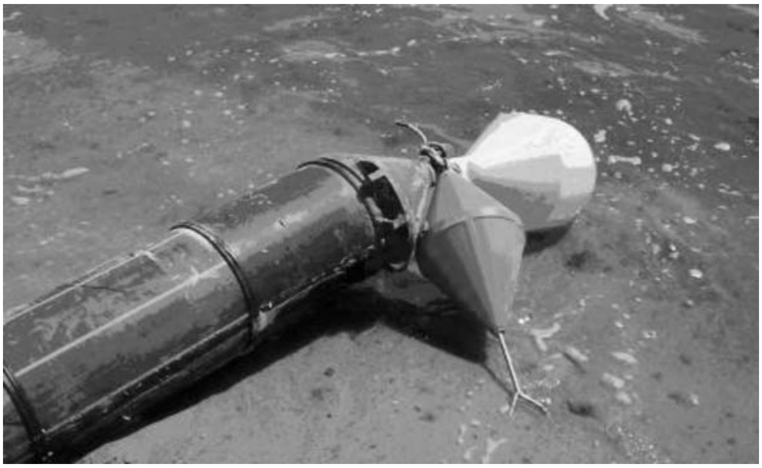

Fig. 22. The metal protection cone.

as the end that is located in the sea are sealed with sulphur resistant cement. The sea end of the bore hole is then sealed with a water resistant polyethylene cover, which marks the end of the construction of the bore hole.

4.4. Assessment of the drains

Once the construction of the drains was finished, each drain was then individually assessed, with a self suctioning pump, a precision vacuum measurer and an electromagnetic flow meter. During these tests, in addition to measuring the depression generated when the required capacity is pumped through, the provenance of the water is also checked to ensure that it is coming from the sea and not from the mixing zone.

In addition to checking the drains individually, trials were carried out to test up to three drains simultaneously to check the effects that the water extraction had on the overall capacity and on the depressions of the other two drains.

Due to the separation of the calcarenites in the area (the active filtration zone) and the slow speed of the filtration, no significant interaction was observed between the drains. The drains were easily able to produce 100 l/s with depressions of about 4 m.

4.5. The formation of the drains

This formation of the drains can be observed in Fig. 23. The fanned-out format of the drains means that the plant is able to work with a larger active filtration surface area. This element of the plant design, combined with the large amount of space between each of the drains means that the drains have very little effect on each other.

This technique allows the drains to be positioned in the minimum amount of space, resulting in the distance between the first and the final drain measuring less than 60 m.

5. Water intake tank

The aforementioned horizontal drains pump the water into a holding tank which is located some metres below sea level, using gravity to ensure that the water flows into this tank.

The holding tank is completely underground, and a small park with trees has been constructed on the roof of the tank which is just by the sea front promenade as can be seen in Fig. 24.

Fig. 23. The formation of the drains.

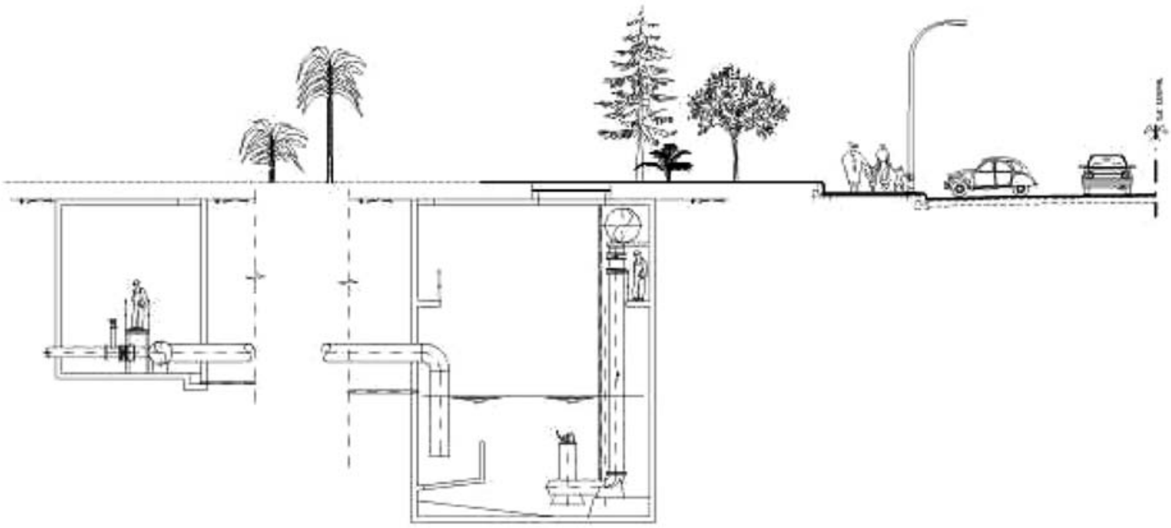

Fig. 24. Diagram of the holding tank.

6. Conclusion

For a large desalination plant with an output of approximately 100,000 m^3/day, the aforementioned water intake system presents numerous advantages over a plant using vertical wells. The most important advantages are:

- The filtration layer does not need to be large. A depth of between 6 and 10 m is sufficient.
- The capacity of each drain is greater than that of a vertical well, meaning that fewer wells are needed in total.
- In general, the filtration area of horizontal wells are larger than those of vertical wells leading to smaller depressions, meaning that the energy consumption of the plant is lower.
- If there is sufficient space between the individual wells, they have very little effect on each other. In addition, the space required by vertical wells for a plant of a similar size is far greater than the space taken up by horizontal wells, in spite of the need for the horizontal wells to be spaced apart.
- Unlike vertical wells, any investment in horizontal wells does not represent wasted money if the results are not satisfactory. It only requires a minimal investment to convert the drains into open intake wells if necessary.

The only disadvantage of this kind of water intake is that it cannot be constructed on all types of ground. The walls of the bore holes must be able to support the use of drilling mud without any danger of erosion.