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Adelaide Desalination Plant outfall diffuser performance validation

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ABSTRACT

Desalination has come to the fore in Australia as a means of "water proofing" Australian coastal cities against drought. The construction of large desalination plants along Australia's coastline has generated considerable public debate, which has required plant operators to provide assurance that the protection of the local environment is a strong core value in the developments. The dispersion of the saline concentrate reject from these plants has been the focus of numerous modelling and monitoring studies, as rapid dilution is required to minimise potential impacts to the local marine environment from high salinity concentrations. The plant is designed to produce potable water at different rates dependent upon the city's demand at different times of the year. This variable flow creates a challenge as the velocity of the saline discharge being dispersed through the outfall can dramatically change, influencing dilution. The Adelaide Desalination Plant utilises duckbill valves to rapidly disperse the saline concentrate waste stream into the local marine environment. The results to date have shown that this novel engineering solution has increased the dispersion of the saline waste at low flows, protecting the local marine environment from the adverse effects of concentrated salt water.

Keywords: Environment; Desalination; Brine; Discharge

1. Introduction

In December 2007, the South Australian Government announced the Adelaide Desalination Project (Fig. 1) as part of a major investment in securing water supplies for the State as a result of many years of severe drought.

The construction of the Adelaide Desalination Plant (ADP) commenced in early 2009 and was completed in December 2012. The plant was designed and constructed by AdelaideAqua D&C Consortium, a conglomerate composed of McConnell Dowell, Abigroup and ACCIONA Agua.

The plant is operated by AdelaideAqua Pty Ltd, a joint venture between ACCIONA Agua and TRILITY, who have a contract to operate and maintain the plant over the next 20 years. Since the plant has become fully operational, it has supplied over 17 GL of drinking water to the city of Adelaide.

The ADP incorporates a high level of operational flexibility with nominal daily production rates from 30

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Fig. 1. Adelaide desalination plant.

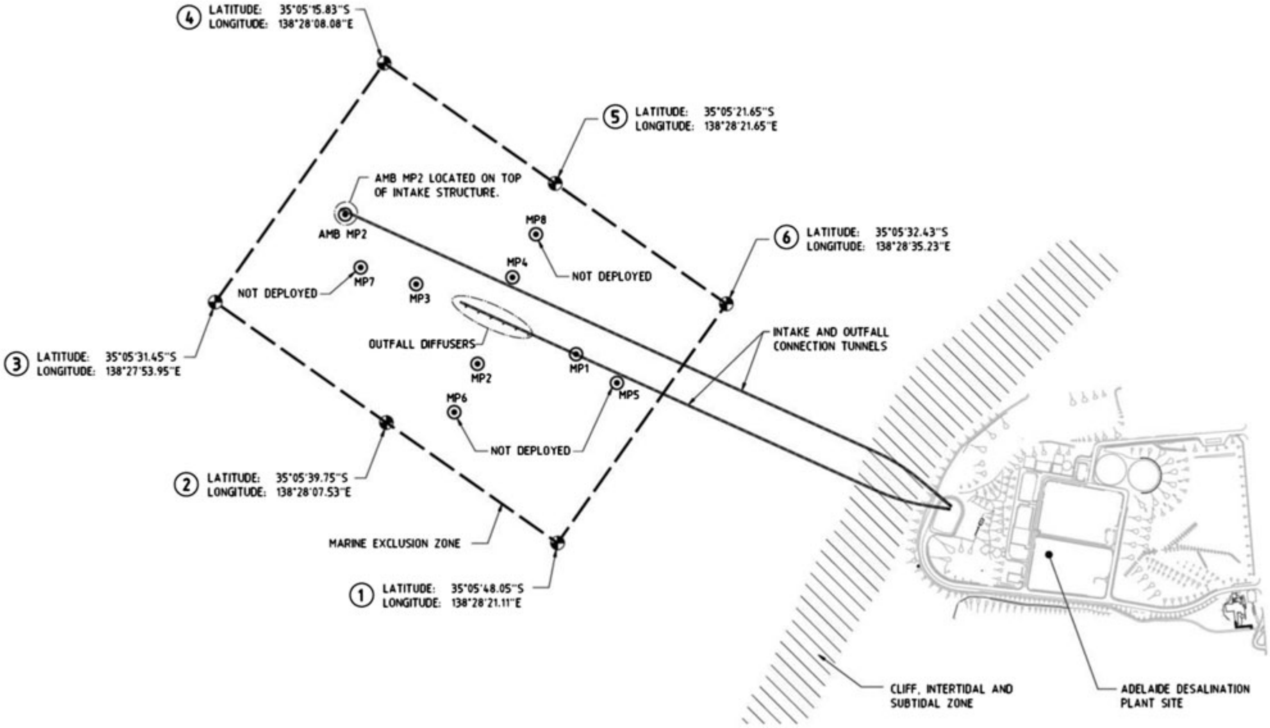

Fig. 2. The Adelaide desalination intake and outfall tunnels, diffuser and intake structure and monitoring points (MP1–8), in relation to the plant.

to 300 ML/d in 15 ML/d increments. The plant was designed to deliver 300 MLD of drinking water to the city, which is approximately 50% of Adelaide's current drinking water requirements.

Environmentally, the ADP has one of the lowest carbon footprints of any desalination plant in the world. The plant is supplied with renewable energy with energy consumption optimised by sustainable design initiatives such as turbines and solar cells.

There were number of key environmental drivers for the project other than reducing the carbon footprint. During the environmental impact assessment process, a number of commitments were made to the community in regards to protecting the local terrestrial and marine environment. One of these commitments was the rapid dispersion of the saline waste stream to minimise any potential impacts to local marine fauna and flora in the region.

The outfall system consists of a 1.2-km long tunnel terminating in six risers, each with a rosette of four duckbill valves. Duckbill valves were incorporated into the diffuser design to assist in the rapid dispersion of the saline concentrate generated from the desalination process into the marine environment. This novel engineering solution has dramatically increased the effectiveness of the outfall, particularly at low flow rates.

The ADP uses real-time salinity instruments on the seafloor to monitor the performance of the dispersion of the saline waste stream from the outfall. These sensors are linked to acoustic modems that transmit the salinity data to the plant via a wireless telemetry system. The South Australian Environment Protection Authority (EPA) stipulated as part of licence conditions to operate that plant with the salinity concentration 100 m from the outfall should be less than 1.3 ppt (24 h rolling average) above natural background concentrations.

This paper is separated into sections; the first provides details on how the telemetry system works; and the second section discusses how local tidal currents influence mixing and the performance of the duckbill valves in dispersing the saline concentrate around the outfall.

2. Method

There are four monitoring points (MP1–4) deployed at 100 m from the outfall diffusers (Fig. 2) to measure, record and transmit salinity data to ensure dilution requirements are met at all times as required by EPA licence conditions [1]. Initially, there were an additional four monitoring points (MP5–8), located 200 m from the diffusers, but these were decommissioned after verifying diffuser performance. The ambient monitoring point (AMB MP2), measuring background salinity concentrations, is located on the top of the intake structure, 1.5 km offshore. Seawater depth around the diffuser varies between 17 and 18 m. The intake structure is located in 20 m of water, with the ambient monitoring point located at a depth of 10 m. The distance between the intake and the outfall is 300 m.

One Acoustic Doppler Current Profiler (ADCP) instrument is located at the same location of monitoring point 2 (MP2) to measure local water current velocities.

The salinity sensors are composed of two main components: a frame located on the sea floor at 16–20 m depth and a marine communication buoy located at the sea surface. The frame (Fig. 3) is constructed from

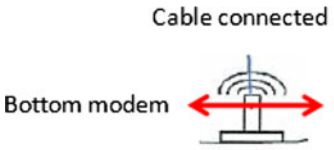

Fig. 3. Frame.

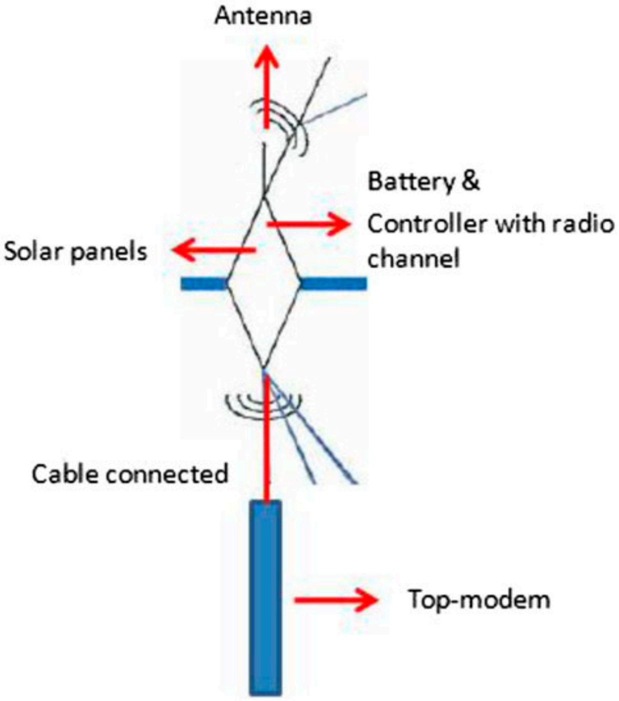

Fig. 4. Platform.

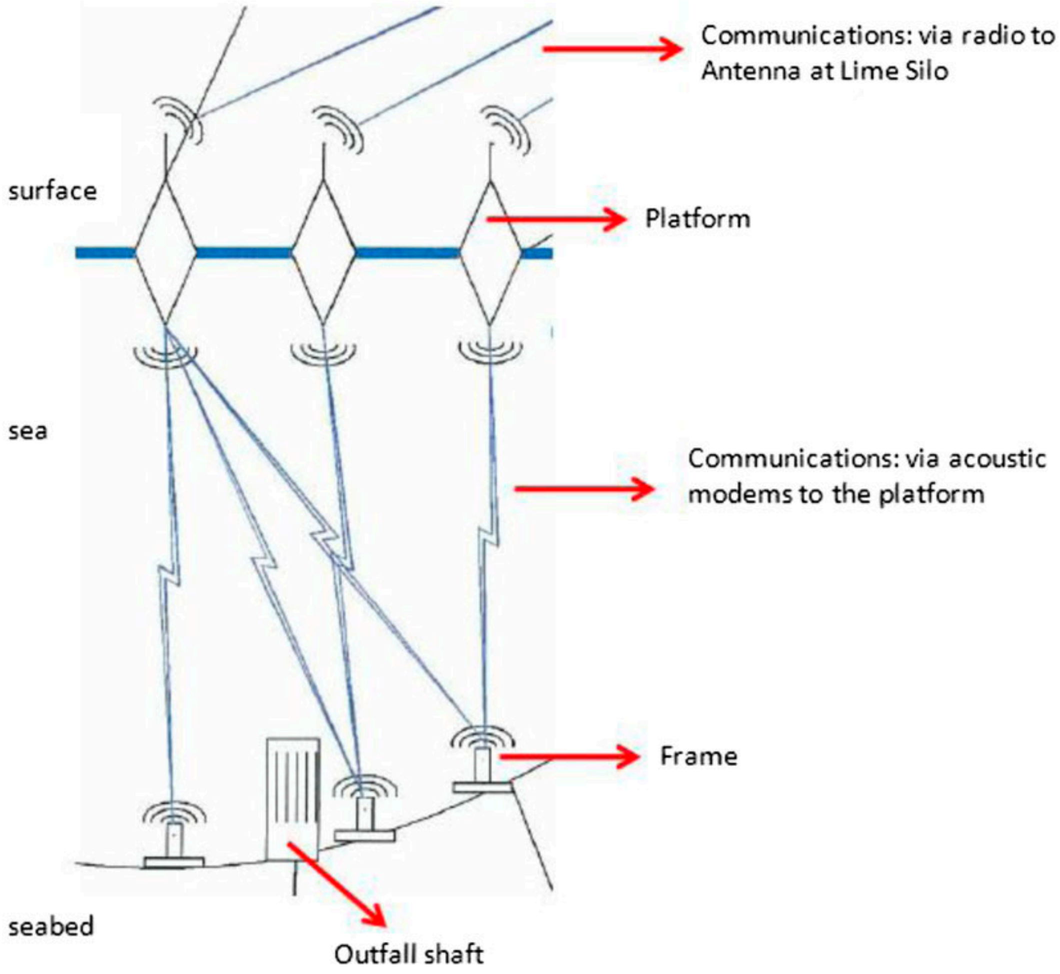

Fig. 5. Communications in between frame and platform.

stainless steel, which supports a CTD (conductivity/temperature/depth) sensor cable connected to a bottom modem. The marine communication buoy (Fig. 4) provides communication to land via a bidirectional modem connected to a controller with radio and antenna, powered by a battery that is charged during the day by two solar panels.

The CTD sensor is connected to the bottom modem which provides the ability to acoustically communicate and transmit salinity and temperature data to the top modem. The surface modem relays acoustic commands to the bottom modem and radio frequency modulated data to the marine monitoring server located at the desalination plant through the antenna at the Lime Silo at the plant (Fig. 5).

The transmitted information by telemetry is then processed in the marine monitoring server, processed the information received and transferred to the SCADA programme via optical fibre. Fig. 6 shows the completed arrangement of the ADP marine monitoring communication system.

2.1. Salinity calculation

The CDT sensors measure electrical conductivity and temperature (depth is approximately constant), and this information is translated into salinity (expressed in parts per thousand as per EPA licence requirements) using the equations below[1]:

$$\mathrm{TDS}\,[\mathrm{mg/L}] = 0.548 \times \mathrm{EC} + 2.2 \times 10^{-6} \times \mathrm{EC}^2 - 2.06 \times 10^{-12} \times \mathrm{EC}^3 \qquad (1)$$

$$\mathrm{TDS}\,[\mathrm{ppt}] = \mathrm{TDS}\,[\mathrm{mg/L}]/1{,}026\,[\mathrm{g/L}] \qquad (2)$$

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[1] Developed by the Australian Water Quality Centre.

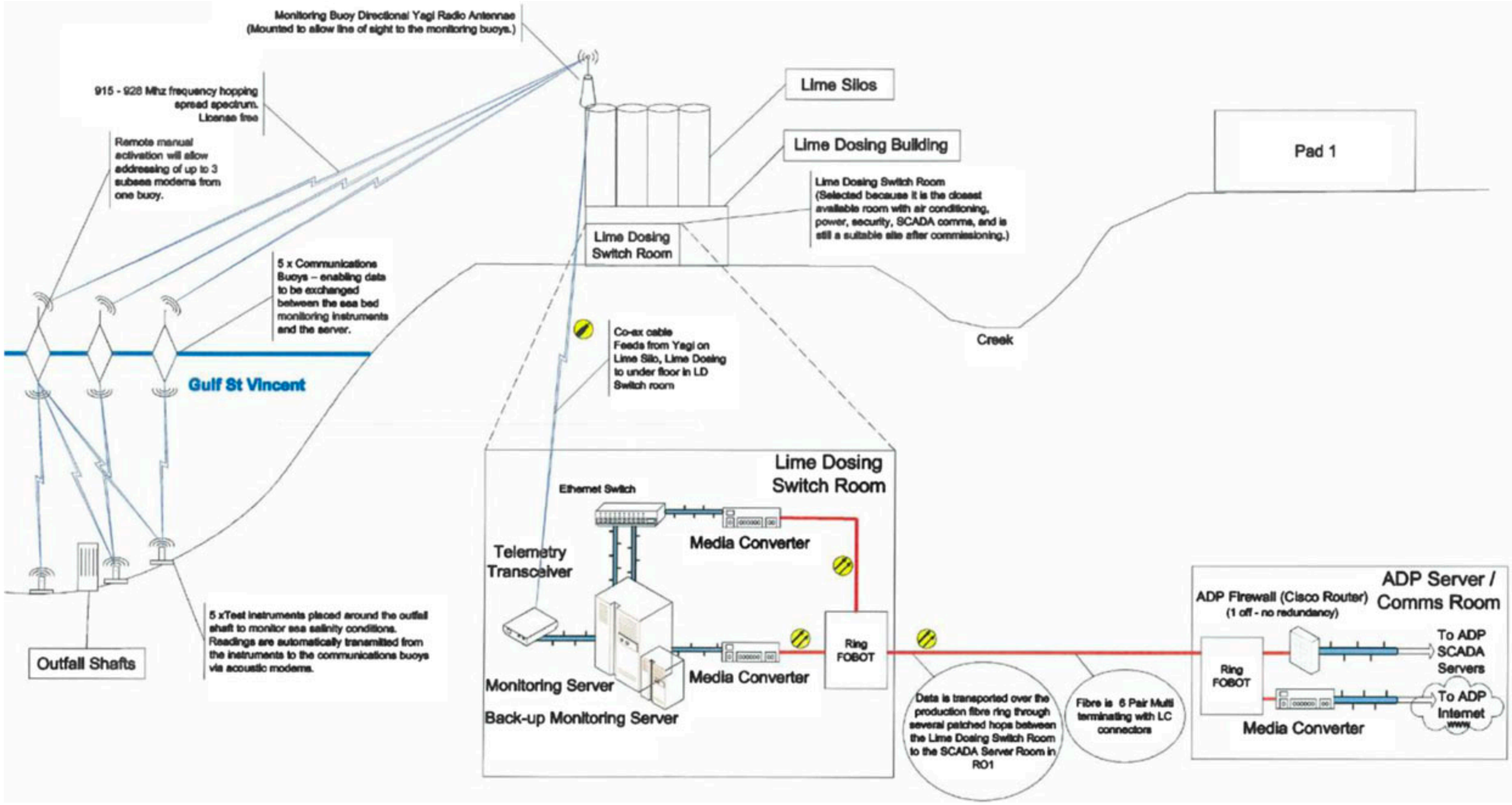

Fig. 6. ADP marine monitoring communications.

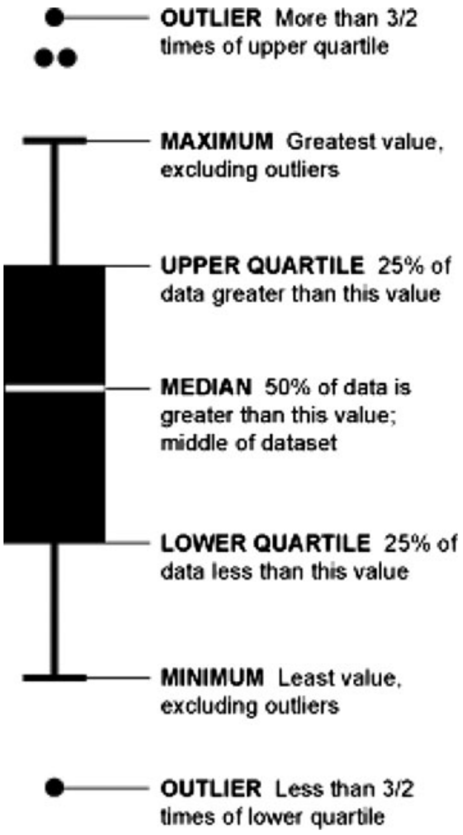

Fig. 7. Box plot.

where EC is the electrical conductivity normalised at 25°C in μS/cm.

2.2. Data quality

The period of time presented in the graphs goes from October 2012 until December 2013, covering the most active period for commissioning and operation of the plant.

All available data were reviewed to ensure only quality data is considered, ruling out any data which, due to calibration issues or other significant uncertainties, were not deemed reliable.

3. Salinity

The data analysis covers all production scenarios, from 0 to 300 ML/d.

In order to minimise errors that could lead to misinterpretation of data, box plots have been used for each of the four monitoring points. Those graphs do not show 24-h rolling average data to minimise data manipulation and increase the number of data points as much as possible. This is a conservative approach from the point of view of assessing saline concentrate dilution.

The salinity data used have been extracted directly from the CTD to eliminate any data loss during communication to the desalination plant.

The advantage of this method against a comparison with the ambient salinity is that it reduces the uncertainties associated with ambient measurements (including possible effects associated with saline concentrate influencing the ambient concentrations). The data available during periods of no production are shown in the box plots and can be interpreted as ambient salinity.

Fig. 7 explains the box plot graphs.

The box plots presented in this report show the average value as a diamond. Outliers are represented as crosses and extreme outliers (more/less than three times the upper/lower quartile) are represented as circles.

A pink band with the same width as interquartile range (difference between the upper and lower quartiles) at zero production, but raised +1.3 ppt, has been overlayed to the box plots to give an idea of the diffuser performance. Also, a red dashed line has been drawn at 1.3 ppt over the average salinity at zero production. These are not indicators of compliance, but are rather tools to help analyse the data.

The period covered by each graph is shown at the top-right corner of the figure and the total number of days in which the data are considered representative are shown in the bottom-right corner.

Maximum production has been achieved several times during this period, including times of low current velocities (a local phenomenon called a dodge or neap tide; with minimal rise and fall over the course of 2 d). Those data have been included in the analysis.

Fig. 8 shows the box plot for monitoring point 1 located east of the outfall diffusers.

The first point to consider is the small size of the boxes (low interquartile range) indicating that the salinity variations at any given production are not large. Under all production scenarios, the interquartile range remains well below the red band and so do the averages below the dashed line.

Considering the marine topography in the area (marine floor depth increases as we go further offshore), this monitoring point is not likely to be effected by the denser saline concentrate plume.

Fig. 9 shows the box plot for monitoring point 2 located south of the outfall diffusers.

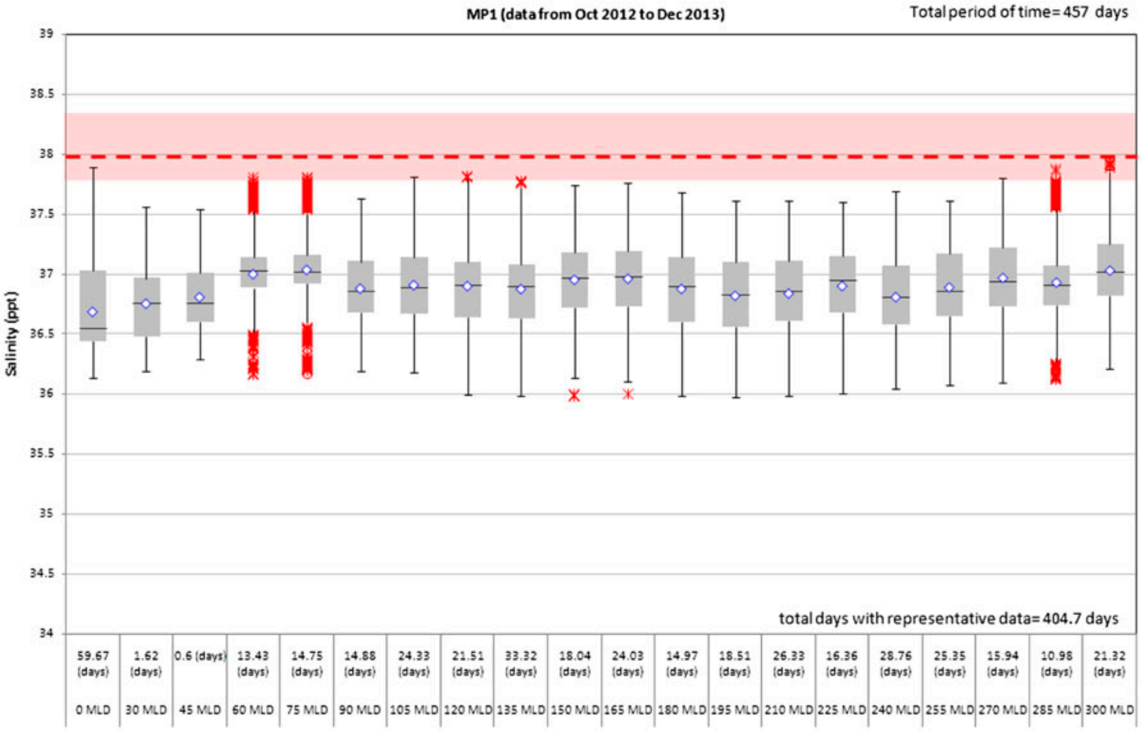

Fig. 8. Monitoring point 1.

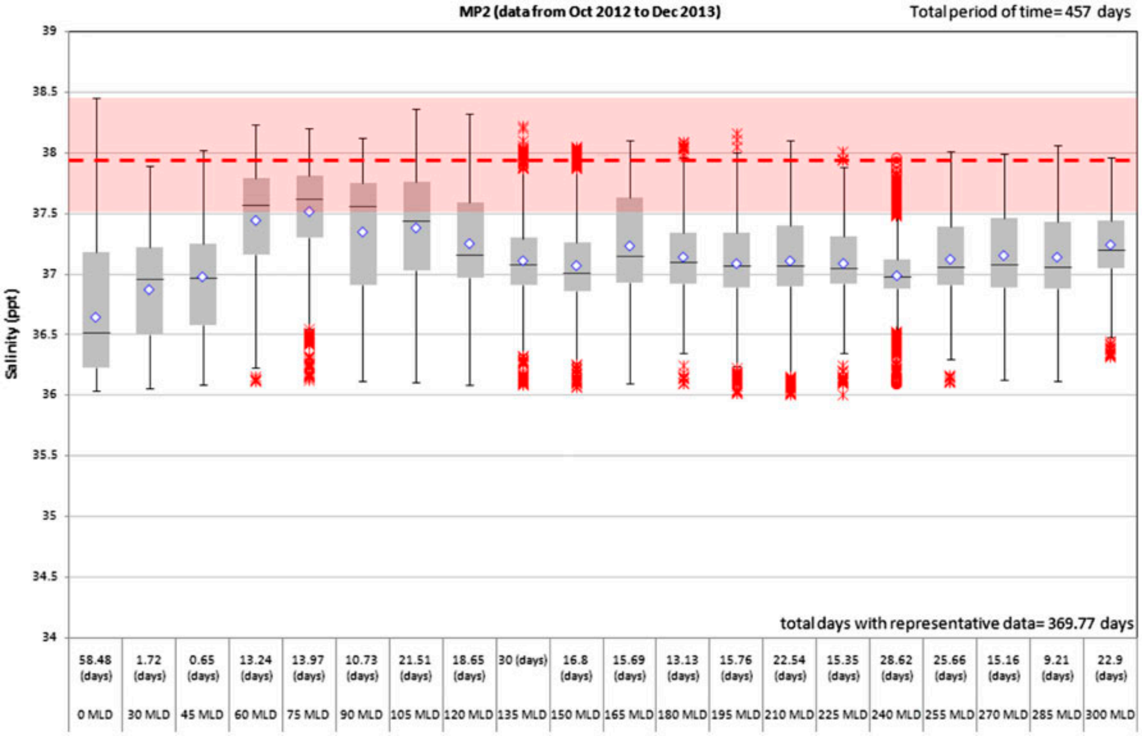

Fig. 9. Monitoring point 2.

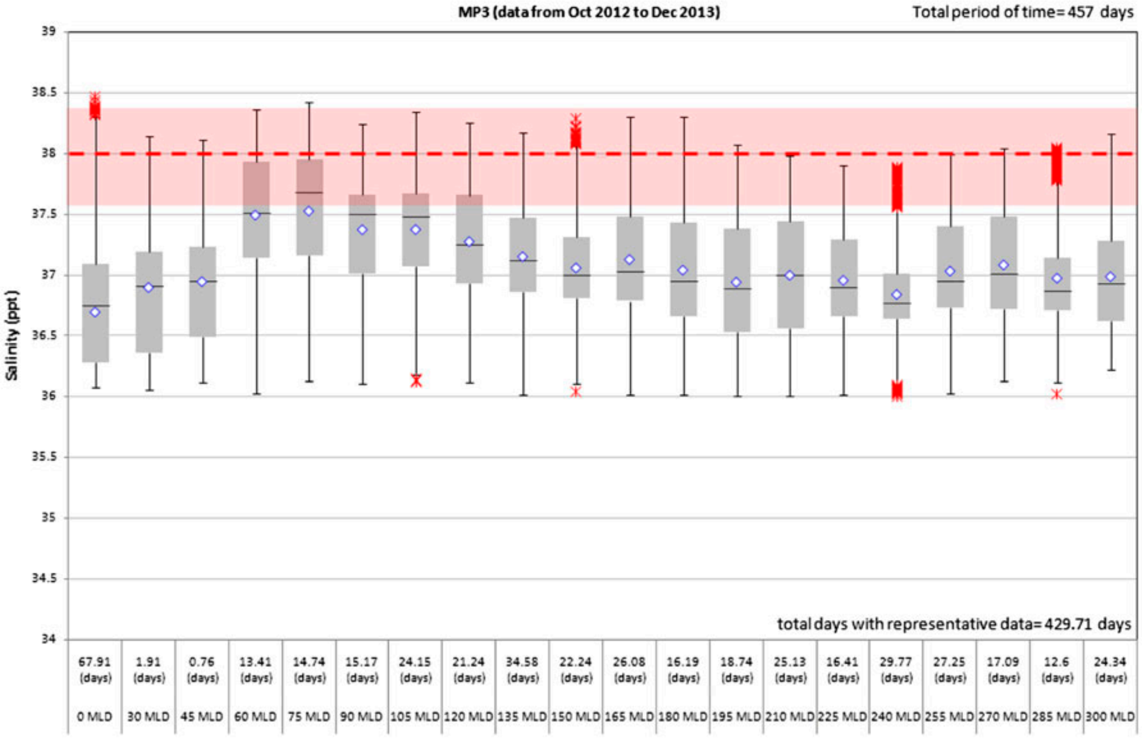

Fig. 10. Monitoring point 3.

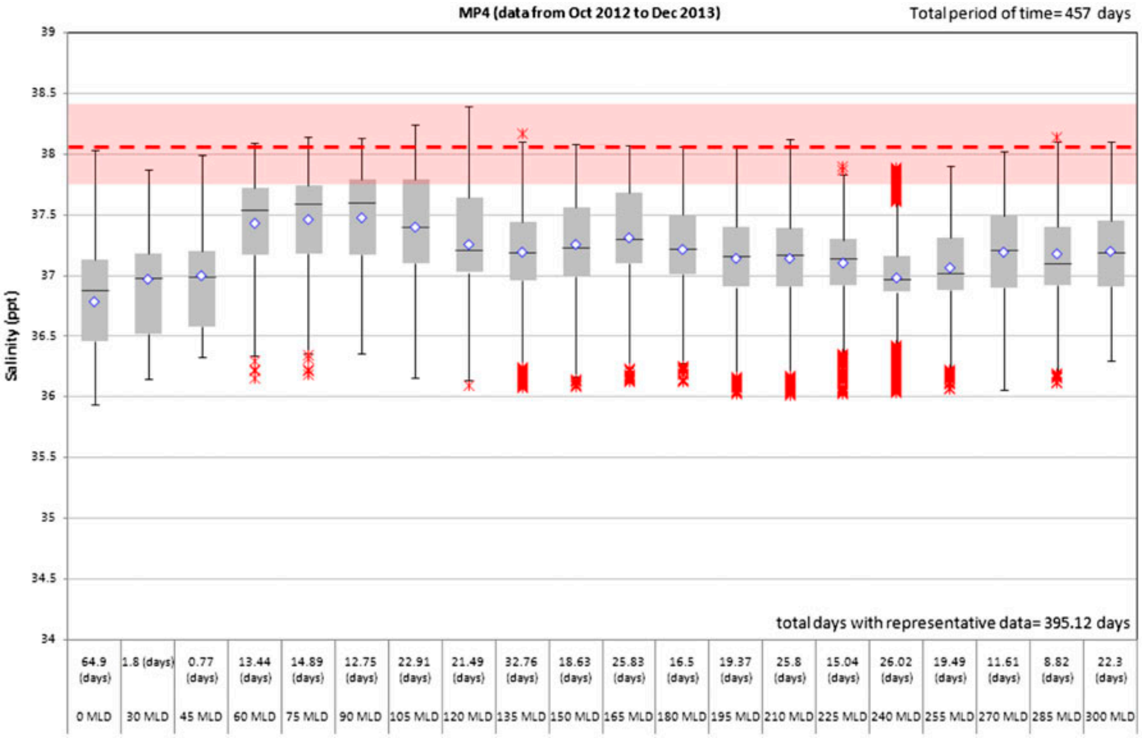

Fig. 11. Monitoring point 4.

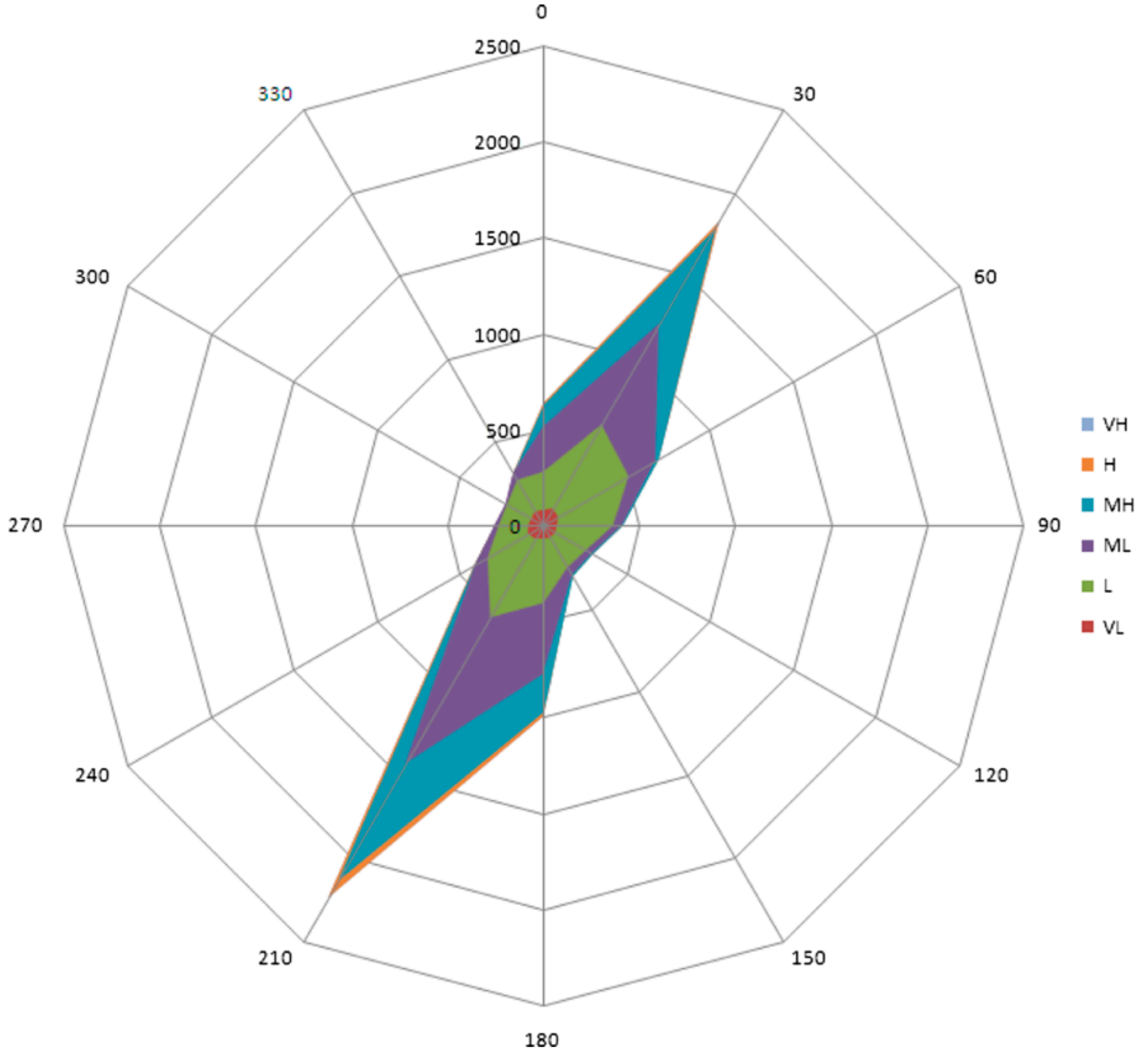

Fig. 12. Currents.

Table 1
Current velocities in the region of the ADP outfall

Name	Minimum velocity (mm/s)	Maximum velocity (mm/s)
Very high (VH)	335	–
High (H)	268	334
Medium high (MH)	201	267
Medium low (ML)	134	200
Low (L)	67	133
Very low (VL)	0	66

The interquartile ranges are noticeably larger than those in MP1, indicating high variations in salinity even when the plant is not operational.

Overall results indicate good dilution of the saline concentrate reject; there are excursions outside the red band, and average salinities remain below the dashed line.

It is worth considering that this monitoring point is located south of the diffusers, and currents normally in the discharge area tend to move in a north/south

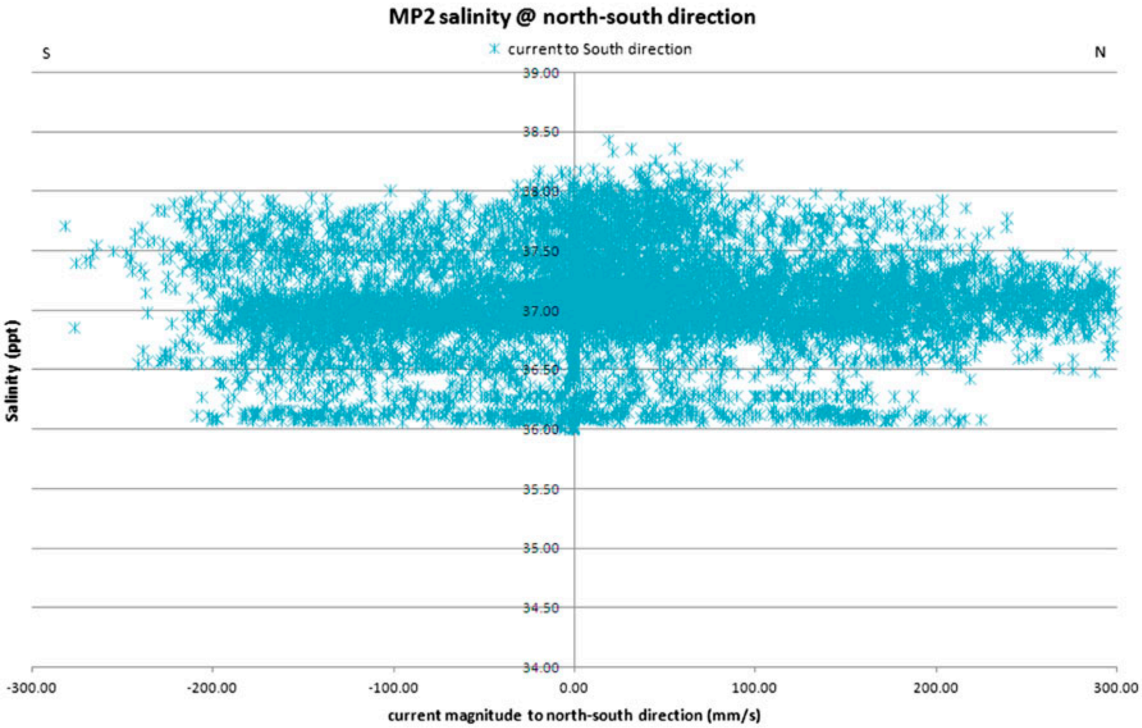

Fig. 13. MP2 salinity vs. current (N–S).

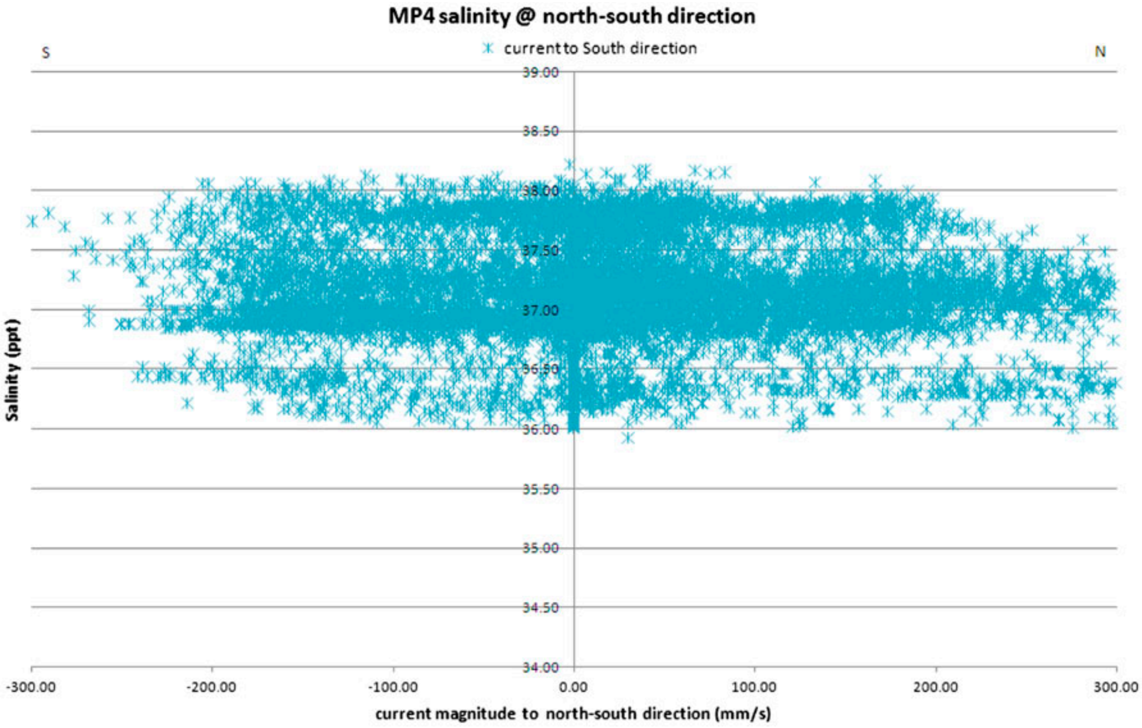

Fig. 14. MP4 salinity vs. current (N–S).

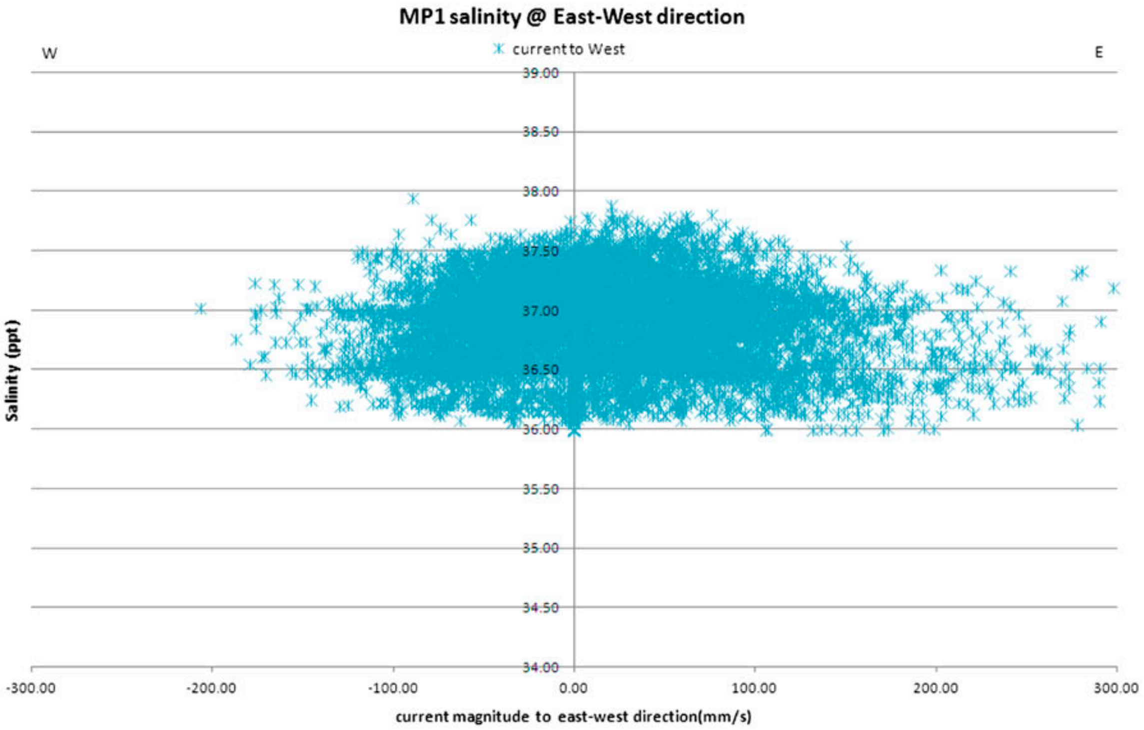

Fig. 15. MP1 salinity vs. current (E–W).

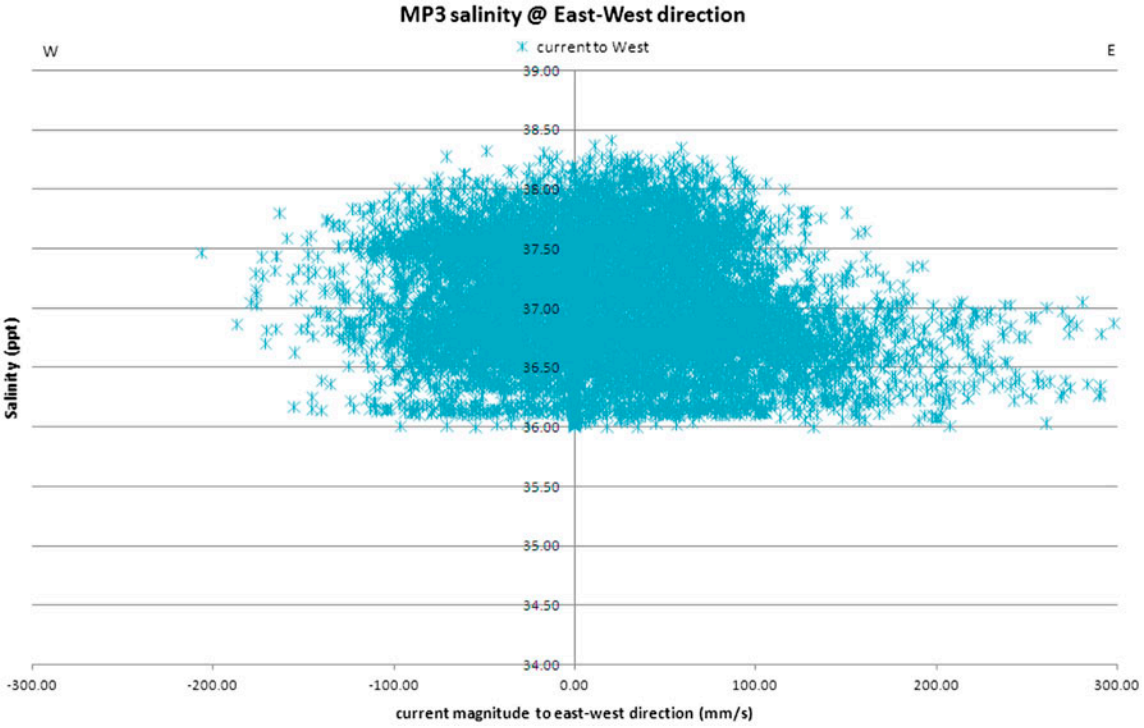

Fig. 16. MP3 salinity vs. current (E–W).

direction. The relationship between current and salinity will be discussed in the next section.

Fig. 10 shows the box plot for monitoring point 3 located west of the outfall diffusers.

This monitoring point should be, in theory, the most affected by the plant discharge due to its location, which is deeper and thus influenced by the denser saline concentrate plume migrating down the depth contour.

We observe a rapid increase in salinity from 45 to 60 ML/d, followed by a stabilisation with higher productions. There are no excursions outside the red band, not even with outliers, and the averages remain well below the dashed line.

This shows good diffuser performance based on a large pool of data collected over 15 months.

Fig. 11 shows the box plot for monitoring point 4 located north of the outfall diffusers.

Similar to monitoring points 2 and 3, we see an increase in salinity at low productions followed by a stabilisation with higher productions. There are no excursions outside the red band or the dashed line.

4. Currents

Current data were collected from an ADCP located at monitoring point 2 (MP2).

Fig. 12 and Table 1 describe the current's magnitude (in mm/s) and direction (0° being North) in the monitoring area.

Currents direction is predominantly north–south with magnitude generally between low and medium high (67–267 mm/s).

5. Salinity and currents

There are two monitoring points deployed in the north–south direction: MP2 (south) and MP4 (north); and another two in the east–west direction: MP1 (east) and MP3 (west).

To analyse the effect of currents on salinity and dispersion, the current velocity vector has been split into two perpendicular components (north–south and east–west) and only the relevant magnitude related to the monitoring point location has been used to derive the effect of currents in plume dispersion (Figs. 13–16).

The data show that there is no clear relationship between current speed or direction with diffuser performance.

6. Conclusions

The data gathered during commissioning and operation of the ADP confirm (as predicted) poor dilution at low flows. In monitoring points 2, 3 and 4, this effect can be seen from 45 to 105 ML/d.

This low-velocity effect disappears as flows increase with no substantial increase in salinity from 105 ML/d to approximately 240 ML/d in MP1, MP3 and MP4. This confirms the validity of the hydrodynamic modelling undertaken during the design phase of the project [2].

At the same time, as the velocity increases, the amount of saline concentrate being discharged into the environment also increases, and at a certain point, this effect starts to be more significant that the increase in mixing. Again, we can see this mostly in MP2, MP3 and MP4 data.

Comparing the average salinity with the ambient, the 1.3 ppt threshold specified in the EPA licence is never reached, and therefore the impact of the saline concentrate discharge on the marine environment is in the line with EPA requirements. This provides reassurance that the duckbill valves perform well since the discharge dilution does not affect the operability of the plant.

The effect of water currents in discharge dilution is too low to be detected. The monitoring points are located in within 100 m of the diffuser and we believe that this distance is not enough to see any difference.

Acknowledgements

Thanks to John Powell for helping us with all the marine buoys' servicing and troubleshooting, and also to Whyalla Divers for being ready everytime we needed them.

References

[1] Environmental Protective Authority of South Australia, EPA Licence 39143, AdelaideAqua Pty Ltd.

[2] Adelaide Desalination Plant—Outfall dilution modelling validation, Water Technol. (December 2012).