Effect of Desalination Discharges on Coastal Environments

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Saline Water Desalination Research Institute (SWDRI)
Outline

- Theme
- Overview
- About SWCC
- Some impacts of the environment on desalination plants
- Effect of discharges on coastal environments
• The brine discharged from SWCC’s plants has a benign or (at worst) minimal impact on the marine coastal environment.

• However, the plants themselves are subject to severe impacts from adjacent water and surrounding air environments.
Much publicity is devoted to the negative effect of desalination plants on the environment. This claim is rarely supported by experimental evidence. On the contrary, operation of plants is often jeopardized by problems arising from surrounding environments.
The Saline Water Conversion Corporation (SWCC)

• SWCC is a Government Agency of the Kingdom of Saudi Arabia, responsible for the production of desalinated water.

• ≈60% of freshwater requirement of the Kingdom is met from seawater desalination plants on the shores of the Red Sea and Arabian Gulf.
Production Capacity

- Present capacity of SWCC is ≈3 millions M$^3$ per day of desalinated water produced from 26 plants at 15 sites: 12 sites on the Red Sea and 3 sites on the Arabian Gulf.
- Additional 1.25 millions M$^3$ are being added from new plants.
- Additionally, 74000 MWH of power are also generated by the SWCC plants, with 2400 to be added from new plants.
The Research Institute is tasked with the responsibility of environmental assessment and corrective remedies.

- SWCC also established environment committees in the East and West coasts with environmental personnel in each plant for on-site monitoring.

SWCC needs a clean source water to feed its plants. Therefore, SWCC has great interest in keeping clean environment and has dealt with this issue seriously. As a consequence:
Size of Feed and Discharged Water

The product water constitutes only a small fraction of the feed water withdrawn from the sea for desalination.

The larger fraction, a huge quantity of water, is returned to sea in the form of brine reject.

– For example: the Jubail plants withdraw 400,000 m$^3$ of seawater/hour.

– Of this quantity, 340,000 m$^3$/hour is discharged back into the sea.
IMPACT

• SWCC plants could affect and in turn be affected by the environment.

• The impact involves air and coastal water environments.
Some impacts of environment on Desalination plants include:

- Marine shells clogging intake structures and impeding water flow and heat transfer.
- Seasonal water currents and tide bringing suspended matter and creating filtration problems.
- Dust storms fertilizing coastal water creating algal blooms and associated die offs and filtration problems.
- The nagging problems of membrane fouling.
Effect of Discharges on Coastal Environments
Intake and Discharge System of Jubail plants

$S_1$ sampling station from open sea, $S_2$ from Intake bay, $S_3$ from discharge site
## Physico-chemical parameters

### Distribution of major seawater quality parameters during different seasons in the near-shore waters of Jubail Desalination and Power Plants

<table>
<thead>
<tr>
<th>Parameters/Seasons</th>
<th>Intake Bay</th>
<th>Open Sea</th>
<th>Outfall Mixing Bay</th>
<th>Recovery Zone (1 Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sea surface temperature (0°C)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>17.90 ± 0.85</td>
<td>17.80 ± 1.06</td>
<td>27.30 ± 2.47</td>
<td>20.50 ± 4.95</td>
</tr>
<tr>
<td>Spring</td>
<td>24.42 ± 5.10</td>
<td>24.00 ± 4.09</td>
<td>33.08 ± 4.06</td>
<td>25.91 ± 5.59</td>
</tr>
<tr>
<td>Summer</td>
<td>30.25 ± 0.35</td>
<td>30.75 ± 1.06</td>
<td>37.25 ± 0.35</td>
<td>34.38 ± 3.71</td>
</tr>
<tr>
<td>Fall</td>
<td>27.00 ± 1.41</td>
<td>27.00 ± 1.41</td>
<td>34.50 ± 0.71</td>
<td>30.00 ± 2.82</td>
</tr>
<tr>
<td><strong>Conductivity (Milli siemens/cm)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>57.28 ± 4.70</td>
<td>57.58 ± 5.90</td>
<td>67.33 ± 1.23</td>
<td>60.15 ± 6.15</td>
</tr>
<tr>
<td>Spring</td>
<td>58.83 ± 1.33</td>
<td>59.56 ± 3.11</td>
<td>65.55 ± 2.65</td>
<td>61.21 ± 1.62</td>
</tr>
<tr>
<td>Summer</td>
<td>63.85 ± 1.77</td>
<td>63.73 ± 1.66</td>
<td>69.53 ± 2.65</td>
<td>68.58 ± 3.57</td>
</tr>
<tr>
<td>Fall</td>
<td>61.15 ± 1.49</td>
<td>61.60 ± 0.00</td>
<td>67.40 ± 4.53</td>
<td>64.43 ± 1.66</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>8.36 ± 0.00</td>
<td>8.38 ± 0.02</td>
<td>8.39 ± 0.02</td>
<td>8.39 ± 0.00</td>
</tr>
<tr>
<td>Spring</td>
<td>8.29 ± 0.06</td>
<td>8.31 ± 0.06</td>
<td>8.32 ± 0.05</td>
<td>8.31 ± 0.05</td>
</tr>
<tr>
<td>Summer</td>
<td>8.34 ± 0.06</td>
<td>8.35 ± 0.06</td>
<td>8.34 ± 0.04</td>
<td>8.34 ± 0.06</td>
</tr>
<tr>
<td>Fall</td>
<td>8.60 ± 0.22</td>
<td>8.61 ± 0.21</td>
<td>8.63 ± 0.24</td>
<td>8.67 ± 0.17</td>
</tr>
<tr>
<td><strong>Dissolved Oxygen (mg/L)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>6.88 ± 0.56</td>
<td>6.98 ± 0.41</td>
<td>6.36 ± 0.61</td>
<td>6.65 ± 0.00</td>
</tr>
<tr>
<td>Spring</td>
<td>6.66 ± 0.52</td>
<td>6.85 ± 0.79</td>
<td>6.18 ± 0.49</td>
<td>6.27 ± 0.54</td>
</tr>
<tr>
<td>Summer</td>
<td>5.24 ± 0.68</td>
<td>5.46 ± 0.27</td>
<td>5.34 ± 0.44</td>
<td>5.17 ± 0.29</td>
</tr>
<tr>
<td>Fall</td>
<td>5.22 ± 1.09</td>
<td>4.89 ± 0.69</td>
<td>4.86 ± 0.45</td>
<td>5.17 ± 0.00</td>
</tr>
</tbody>
</table>
Temperature profile at Jubail plants at 500, 1000 and 2000m from intake and discharge sites.

- Temperature stabilizes at 500-1000m beyond the discharge point
# Effect of Discharges on Primary Productivity in Terms of Chlorophyll

<table>
<thead>
<tr>
<th>Location</th>
<th>Chlorophyll Concentration (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Discharge site</td>
</tr>
<tr>
<td>Jubail (depth ~4m)</td>
<td>0.50</td>
</tr>
<tr>
<td>Jeddah (depth 30m)</td>
<td>*0.51</td>
</tr>
</tbody>
</table>

**Note:** At Jubail normal primary production regained at 500m from discharge site.

At Jeddah discharge site is more productive than open sea.
## Plankton groups and numbers in Jubail and Jeddah Coasts

<table>
<thead>
<tr>
<th>Group</th>
<th>Location : Jubail</th>
<th>Jeddah</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open sea(^1)</td>
<td>Intake bay(^2)</td>
</tr>
<tr>
<td>A. Phytoplankton (cell/m(^3))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diatoms</td>
<td>3.42 x 10(^5)</td>
<td>2.14 x 10(^5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dinoflagellates</td>
<td>4.29 x 10(^4)</td>
<td>2.71 x 10(^4)</td>
</tr>
<tr>
<td>Blue-green bacteria</td>
<td>6.84 x 10(^5)</td>
<td>1.39 x 10(^5)</td>
</tr>
<tr>
<td>B. Zooplankton (No./m(^3))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protozoa</td>
<td>4.93 x 10(^3)</td>
<td>5.93 x 10(^3)</td>
</tr>
<tr>
<td>Coelenterates</td>
<td>1.59 x 10(^3)</td>
<td>1.85 x 10(^3)</td>
</tr>
<tr>
<td>Nematodes</td>
<td>2.19 x 10(^3)</td>
<td>1.06 x 10(^3)</td>
</tr>
<tr>
<td>Annelida</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Mollusca</td>
<td>2.75 x 10(^3)</td>
<td>5.5 x 10(^2)</td>
</tr>
<tr>
<td>Crustaceans</td>
<td>4.41 x 10(^4)</td>
<td>7.52 x 10(^4)</td>
</tr>
<tr>
<td>Echinodermes</td>
<td>1.25 x 10(^3)</td>
<td>12</td>
</tr>
<tr>
<td>Chordata</td>
<td>4.09 x 10(^4)</td>
<td>8.70 x 10(^4)</td>
</tr>
<tr>
<td>(fish eggs, fish larvae and tunicates)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Notes on Plankton

• The distribution of the major plankton groups are similar in feed and discharge zones

• Only Echinoderms seem to be impacted by the brine discharge, and reasons other than brine may contribute to their scarce presence in the brine discharge area e.g. impingement and entrainment

• The major groups of phyto- and zooplankton could form a healthy base of food chains in feed and discharge water zones.
## Concentration of nutrients at Jubail and Jeddah

<table>
<thead>
<tr>
<th>Nutrient (µg/l)</th>
<th>Jubail Open sea</th>
<th>Intake bay</th>
<th>Discharge site</th>
<th>Jeddah Open sea</th>
<th>Discharge site</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Inorganic nutrients (µg/l)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Ammonia -N</td>
<td>1.7 – 8.9</td>
<td>0.8 – 8.5</td>
<td>0.5 – 0.7</td>
<td>1.4 – 4.6</td>
<td>1.7 – 3.5</td>
</tr>
<tr>
<td>2. Nitrite -N</td>
<td>0.5 – 1.4</td>
<td>0.2 – 3.0</td>
<td>0.05 – 0.1</td>
<td>0.02 – 0.2</td>
<td>0.03 – 0.2</td>
</tr>
<tr>
<td>3. Nitrate-N</td>
<td>1.4 – 6.0</td>
<td>1.6 – 5.3</td>
<td>0.5 – 2.0</td>
<td>0.5 – 0.9</td>
<td>0.2 – 1.2</td>
</tr>
<tr>
<td>4. Phosphate-P</td>
<td>1.7 – 6.5</td>
<td>1.9 – 4.6</td>
<td>0.2 – 0.3</td>
<td>0.03 – 0.2</td>
<td>0.1 – 0.3</td>
</tr>
<tr>
<td>5. Silicate –S</td>
<td>BDL – 0.1</td>
<td>BDL – 0.1</td>
<td>BDL</td>
<td>BDL</td>
<td>BDL</td>
</tr>
<tr>
<td><strong>B. Organic nutrients (mg/l)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Dissolved sugars</td>
<td>0.5 – 0.8</td>
<td>0.9 – 1.5</td>
<td>3.9 – 5.0</td>
<td>0.34 – 0.42</td>
<td>0.17 – 0.25</td>
</tr>
<tr>
<td>2. Dissolved nitrogen</td>
<td>0.2 – 0.3</td>
<td>1.5 – 2.1</td>
<td>4.9 – 6.1</td>
<td>0.02 – 0.05</td>
<td>0.02 – 0.03</td>
</tr>
<tr>
<td>3. TOC</td>
<td>2.1 – 2.6</td>
<td>1.6 – 2.4</td>
<td>2.9 – 3.5</td>
<td>1.9 – 2.9</td>
<td>1.9 – 2.9</td>
</tr>
</tbody>
</table>

BDL = Below detection limit

Increased organic matter in discharge due to organic decomposition by chlorine
## Metals in the Coastal Waters of Jubail and Jeddah

<table>
<thead>
<tr>
<th>Trace Metal ¹</th>
<th>Concentration (µg/l)</th>
<th>Jubail</th>
<th>Jeddah</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open sea</td>
<td>Intake bay</td>
<td>Discharge site</td>
</tr>
<tr>
<td>1. Iron</td>
<td>0.34 – 5.86</td>
<td>0.45 – 6.20</td>
<td>0.6 – 7.0</td>
</tr>
<tr>
<td>2. Nickel</td>
<td>0.16 – 1.40</td>
<td>0.25 – 1.40</td>
<td>0.25 – 1.50</td>
</tr>
<tr>
<td>3. Copper</td>
<td>0.35 – 2.60</td>
<td>0.65 – 3.70</td>
<td>0.6 – 4.0</td>
</tr>
<tr>
<td>4. Chromium</td>
<td>0.60 – 0.20</td>
<td>0.00 – 0.17</td>
<td>0.00 – 0.05</td>
</tr>
</tbody>
</table>

¹These metals are normally associated with corrosion
- No difference between source and discharge waters
ND = Not detected
Toxic Effects of Brine Discharge

• Cumulative findings of our research show that the brine discharged from SWCC’s plants has a benign or (at worst) minimal impact on marine coastal environment.
• Still there are claims that effluents are potentially harmful to coastal environment.
• A direct way to address these concerns involves exposing selected marine organisms to brine discharge, measuring their biological response and assessing any deviation from norm.
Toxic Effects of Brine Discharge

- We assessed the comparative in vitro toxicity of water from the discharge site of Jubail compared to feed water using artemia cysts and a bioluminescent bacterium.

RESULTS:
- No difference in the hatching and survival of larval artemia.
- No difference in emission of light by the bioluminescent bacterium.
## Brine Shrimp Hatching and Larval Mortality Rates

<table>
<thead>
<tr>
<th>Source water</th>
<th>Hatching Rate (%)</th>
<th>Larval Mortality Rates (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>24h</td>
</tr>
<tr>
<td>Discharge</td>
<td>≥ 98</td>
<td>None</td>
</tr>
<tr>
<td>Feed</td>
<td>≥ 98</td>
<td>None</td>
</tr>
</tbody>
</table>

<sup>a,b</sup> Means with same letter superscript are not different (n = 50, ANOVA and t-test, P=0.05)

No difference in hatching rate or larvae survival between discharge and feed waters
Stages in Brine Shrimp Life Cycle

Cysts and Hatching Larvae  Larva  Adult
## Inhibition of Bacteria Bioluminescence

<table>
<thead>
<tr>
<th>Source</th>
<th>% Inhibition</th>
<th>Difference*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open seawater</td>
<td>8.2 ± 5.3</td>
<td>Control</td>
</tr>
<tr>
<td>Intake bay</td>
<td>9.9 ± 5.8</td>
<td>Not Significant</td>
</tr>
<tr>
<td>Discharge site</td>
<td>9.7 ± 4.9</td>
<td>Not Significant</td>
</tr>
<tr>
<td>Feed water + Antifoam</td>
<td>9.0 ± 5.1</td>
<td>Not significant</td>
</tr>
<tr>
<td>Feed water + Antiscalant</td>
<td>10.4 ± 5.9</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

*(n=10, ANOVA and t-test, P=0.05)*
Luminescent bacteria
Reasons for Benign Effects of Discharge

1. Inherent mitigating design

• The discharge channel of Jubail plants is designed such that it dissipates temperature.
• The channel is ~1.5 Km long and is cascading to the discharge point with strong mixing and air contact that reduce temperature and replenish Oxygen.
• The added volume of cooling water in the discharge also helps in diluting chemical additives and salinity.
2. Dilution Effect

- Significant and immediate dilution by cooling water (heat rejection)
Dilution Effect of Cooling Water

Total intake (ex: Jubail) 12 (≈ 12 millions m\(^3\)/day)
Cooling (heat rejection) 9
Product 1
Reject 2
Brine discharge 11
Assume salinity 40‰
2/3 of make-up is rejected
1/3 product

Salinity of rejected portion of make-up is \(\frac{3}{2} \times 40 = 60\)‰
Salinity of 9 parts cooling is 40‰

\[
\text{Final Salinity} = \frac{2}{11} \times 60 + \frac{9}{11} \times 40 = 10.9 + 32.7 = 43.6
\]

\[\therefore \text{Salinity increases by only } 3.6\%\text{ or } 9\%\]
CONCLUSIONS

• An environmental database has been established for the Arabian Gulf and Red Sea coastal and open sea waters opposite the SWCC Jubail and Jeddah desalination and power plants.

• The data clearly show that the brine discharged from SWCC’s plants has a benign or (at worst) minimal impact on the marine coastal environment.

• Desalination plants should not be falsely implicated in any negative impact upon coastal water environments. Any report about coastal water pollution from the desalination plants should be interpreted with caution.
Thank You