Overview of Different Approaches Simulating the Long Term Response to Climate Change and Coastal Effluents in the Arabian Gulf

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Presentation Outline

• Introduction
• Field measurements in the Gulf
• Simple approaches
• Extensive approaches
• Proposed net evaporation equivalent approach
• Conclusions
Introduction

• Evaluating the long-term variability of the seawater's salinity and temperature among other ambient conditions due to climate change is a limiting economical and operational factor in planning the design of new and expansion of desalination plants.

• This need is amplified in the Arabian Gulf due to the natural arid climate and anthropogenic stresses related to urban growth, energy exploration and on-going coastal developments.

• A robust method is needed to evaluate the future seawater quality state considering the scarcity and limited access to monitoring data.
Introduction - Climate Change

• Climate change described as the persistent change of the mean state of climate for an extended period typically decades or longer has been observed globally at a rate of 0.1°C/decade since 1950 (IPCC, 2007).

• Using a 100 year satellite-based measurements indicated a linear increase of temperature by 0.63 °C/decade and an insignificant decrease in precipitation (Nasrallah and Balling, 1996)

• Arabian Peninsula mean annual temperature (Dubai) showing an increasing rate of 0.81°C/decade (Al-Sarmi and Washington 2011).

• Analysis of mean temperatures from over the Kingdom of Saudi Arabia (1960 to 2010) conducted by the Met Office Hadley Centre in 2011 (UKMO, 2011) has shown an increased trend of 0.41 °C/decade in summer and 0.16 °C/decade in the winter.
Introduction – Coastal effluents

• Seawater temperature and salinity in the AG are affected by coastal effluents
  ➢ Desalination, over 20 Mm³/day (IDA, 2012)
  ➢ Power generation, over 800,000 MWhr (eia.gov, 2010) (160Mm3/day)
  ➢ Oil industry, over 26 Mbbl/day (eia.gov, 2010) (156Mm3/day)

• All sectors have planned expansions
• All sectors are using the shallow coastal waters as source and sink
• Lack of long-term Gulf-wide sustainability perspective
Field measurements in the Gulf

• “Probably no other body of water of comparable size and economic importance is so under investigated” (Reynolds, 1993).

• Direct oceanographic observations are very sparse and limited in time and space and access to actual raw data is very strict.

• Changes are so rapid, temperature and salinity changes in restricted water flows along the coast, as well as by climate warming is a growing concern.

• Assessment studies conducted using either field sampling or modelling are mostly qualitative and of local fashion in which the superimposing effects of multiple coastal effluents and trans-boundary effects are not distinguished nor considered.
Simplified Approaches
(Gross assessment)

• The discussed approaches are considered as important starting point to indicate the potential impacts of desalination discharges

• Produce only gross evaluation

• not very useful for planning or impacts studies when the evaluation of temporal changes are needed for a specific location

• There is a need for a more sophisticated approach to address these requirements.
## Simplified Approaches (Gross assessment)

<table>
<thead>
<tr>
<th>Approach</th>
<th>Considerations</th>
<th>assessing</th>
<th>Findings</th>
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<tr>
<td>Purnama et al., (2005); AlBarwani et al., (2009)</td>
<td>Simplified Mathematical model</td>
<td>• the incoming flow from the ocean, • the freshwater input at the head, • the losses due to evaporation and • the seawater intake by the desalination plant</td>
<td>Increase of salinity due to desalination</td>
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<tr>
<td>Bashitialshaaer et al., (2011)</td>
<td>Simplified Mathematical model</td>
<td>• statistics of projected population • brine and wastewater discharge until 2050 • without considering the climate change factor.</td>
<td>Increase of salinity due to desalination</td>
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<td>Saif Uddin et al., (2011)</td>
<td>observational data collected in Kuwait-Desalination plant expansion</td>
<td>• measurements taken between 1st January 2007 to 31st March 2009</td>
<td>Increase of salinity due to desalination</td>
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<tr>
<td>Nunes vas (2012)</td>
<td>Statistical analysis of long-term observations spanning 27 years- Australia</td>
<td>• Desalination brine • Climate change projection</td>
<td>Increase of salinity due to desalination and Climate change</td>
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Extensive Approaches
(Numerical Modeling)

• The AG has a complex bathymetry, variable seasonal circulation, thermal stratification and different controlling advection mechanisms (Reynolds, 1993).

• Numerical modeling provides a useful tool to address and evaluate the long-term superimposed effects of multiple release from coastal desalination plants.

• Climate models are the only available tool to satisfactorily estimate different future rates of climate change (Samuelsson, 2010), and

• The hydrodynamic models are able to simulate future water quality accounting for a changing climate (Perroud et al., 2009).
Extensive approaches
(Numerical modeling)

• Numerical models are powerful tools but are not capable of providing meaningful and reliable information unless competent field measurements in space and time are used for their setup and validation.
• The higher the degree of model sophistication the more extensive data and field measurements are needed.
• Issues related to data availability and exchange in the Gulf region has limited the advancement of scientific research and understanding in this important water body.
• There is a crucial need to fill the gap of knowledge of the long-term impacts of coastal effluents in the AG and to arrive to a well-reasoned evaluation using available data resources.
# Extensive approaches  
(Numerical modeling)

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<tr>
<th>Approach</th>
<th>Description</th>
<th>Consideration</th>
<th>Data requirement</th>
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<tr>
<td>Far field modeling approach</td>
<td>transport and dispersion is dominated by ambient flow conditions – single model</td>
<td>Hydrostatic only</td>
<td>Boundary forcing, Weather forcing, Discharge salinity, Discharge temperature</td>
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<tr>
<td>Far field and particle tracking approach</td>
<td>Transport model using Hydrodynamics from the far field – two models</td>
<td>Transport based on HD</td>
<td>Boundary forcing, Weather forcing, Water quality</td>
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<td>One-way coupling of Near-Field and Far-Field approach</td>
<td>Near field changes are used as input for the far field – two models</td>
<td>Non-hydrostatic in the near field “One-way coupling”</td>
<td>Boundary forcing, Weather forcing, Diffuser release properties</td>
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<tr>
<td>Continuous coupling Near-Field and Far-Field approach</td>
<td>interchangeable effect between near field and far field – two models simultaneous simulation</td>
<td>Non-hydrostatic in the near field “Dynamic and online coupling”</td>
<td>Boundary forcing, Weather forcing, Diffuser release properties</td>
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</table>
Net Evaporation Equivalent Approach

• The proposed method benefits from the recent findings of Nunes-Vaz (2012) showing that the mean salinity of the North Spencer Gulf (inverse estuary) varies predictably and consistently with the effects of net freshwater loss (evaporation).

• The AG owns similar environmental setup allowing the adaptation of the same concept.

• The net evaporation (NE) concept is considered as a proxy to assess the long-term variability of seawater salinity and temperature in the AG using hydrodynamic modeling.
Net evaporation equivalent approach

- The total Net Evaporation (NE) used in the hydrodynamic model is computed based on freshwater losses of the considered processes using the following formulae:

\[ NE = Eb + Ec + Ed + Ee - P \]

- Eb is the background evaporation from the calibration phase;
- Ec is projected evaporation due to climate change;
- Ed is evaporation due to desalination;
- Ee is evaporation due to industrial effluents; and
- P is precipitation.
Estimating Ec

- Dalton law of evaporation is used to calculate the surface evaporation due to climate change using global climate models (GCM) temperature projections.
- As the GCM output does not include projections for the seawater temperature, a correlation factor is produced between the current measured values of seawater temperature and air temperature.
- The projected GCM air temperature is then substituted in the developed correlation to produce the projected seawater temperature needed to conclude the evaporation calculations with the Dalton’s law.
- Analysis of long-term climatological records from coastal weather stations until 2012 in the AG showed insignificant changes of relative humidity and wind speed.
- For the evaporation calculations, annual average constant values for Relative humidity (RH) and wind speed ($U_{10}$) are assumed sufficiently correct for the projection period.
Estimating Ed

• Inventory data of desalination capacity in the AG from the IDA and GWI (2012) is used.

• In order to capture the local impacts of desalination plant discharge, Ed of each desalination plant can be introduced at the plant location as a point-inflow or using the domain decomposition feature (in Delft3D-Flow software) with 1:10 grid reduction (i.e. 500 meters for a 5km grid regional model) and the in-out discharge feature at the sub-domain file.

• The evaporation equivalent is quantified based on the capacity and the recovery ratio of each plant.

• For salinity changes, the recovery ratio is considered as 1:4, 1:3, and 1:2 for the MSF, MED, and the RO respectively.
Estimating Ee

- The industrial effluents impacts involving the use of seawater for cooling and other production processes are quantified as fresh evaporation-equivalent based on the process involved.

- The U.S. Department of Energy report (USDE, 2006) and the technical report of EPRI, (2002a) provides data on the range of water consumed (evaporated) for the energy and thermoelectric power plants operations.

- The reported values are used to estimate the collective total evaporation based on the statistics of published quantities of oil, natural gas and electricity in the AG countries.

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<td>Water evaporation due to energy and thermoelectric operations (Source: USDE, 2006; EPRI, 2002a) a.</td>
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<table>
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<tr>
<th>Energy</th>
<th>(Gal/MMBTU)</th>
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<tbody>
<tr>
<td>Refining</td>
<td>8–30</td>
</tr>
<tr>
<td>Petroleum extraction</td>
<td>0–3</td>
</tr>
<tr>
<td>Natural gas extraction and processing</td>
<td>3–4</td>
</tr>
<tr>
<td>Thermoelectric power plants</td>
<td></td>
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<tr>
<td>Natural gas (open loop cooling)</td>
<td></td>
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<tr>
<td>Natural gas (closed loop tower)</td>
<td>180 for every 230 withdrawal</td>
</tr>
<tr>
<td>Nuclear steam (once through)</td>
<td>720 for every 800–1100 withdrawal</td>
</tr>
<tr>
<td>Nuclear steam (cooling tower)</td>
<td>400 for every 25,000–60,000</td>
</tr>
</tbody>
</table>

1 barrel = 42 U.S. gallons = 5.8 MMBtu (based on U.S. production, 2011).
1 cubic foot NG = 0.001023 MMBtu (based on U.S. consumption, 2011).
Conversion base: 1 gallon = 0.00454609 m³.

a (MMBTU = Million Metric British Thermal Unit).
CONCLUSIONS

• Seawater desalination is the only reliable source to secure the vast and ever increasing needs for freshwater supplies in the Gulf region.
• Discharges from coastal plants represent a concern in the long run when the combined effects of multiple sources are considered simultaneously especially in the shallow low flushing regions where most desalination plants are situated.
• The issue of increased salinity and temperature is further accelerated with the superimposed impacts of climate change.
• Simplified gross mathematical estimates of the AG response to desalination brine effluents showed their potential effect on the physical water quality conditions.
• Numerical modeling resolves the hydrodynamic field and produces the spatial and temporal distribution estimates of salinity and temperature needed to develop better understanding of the near-shore response to coastal effluents and climate change.
CONCLUSIONS (continued)

• The lack of field measurements in the AG limits the usefulness of the highly sophisticated modeling approaches.

• The presented approach represents a systematic innovative approach to evaluate the anticipated long-term changes in the seawater salinity and temperature under the stresses of projected climate change and multiple sources of industrial effluents using statistical correlation and hydrodynamic simulation in an integrated regional scale and considering the lack of effluents measurements in the AG.

• A major advantage of the proposed methodology is its utilization of the readily available measurements of weather data to project the long-term changes in the seawater conditions by which the need for unavailable or inaccessible field measurements is minimal.
Ongoing Work

• Long-term HD simulation of the AG considering all coastal effluents considering different growing-demand scenarios and climate change
• Salinity and temperature are simulated and validated with a number of historical referenced records
• Future projection of salinity and temperature at all observation coastal sites
• Results are used to suggest the most suitable desalination technologies at different sites for the considered scenarios at 2020, 2050, and 2080
Main Outputs

Long-term unit costs of different desalination technologies for all desalination plants in the AG as impacted by long-term projected demands and ambient temperature and salinities (using decision support matrix: seeking expert feedback!)
QUESTIONS?