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# Impact Assessment Of Organic Contamination On Intake Quality Of Coastal Desalination Plants Using Fate Transport Modeling

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# IMPACT ASSESSMENT OF ORGANIC CONTAMINATION ON INTAKE QUALITY OF COASTAL DESALINATION PLANTS USING FATE TRANSPORT MODELING

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Intake water of coastal desalination plants may be subjected to different types of organic pollutants originated from different sources including nearby effluents, loading/unloading of offshore stations, and/or accidental oil spills in the nearby marine water. In United Arab Emirates (UAE), many of such desalination plants are located along one coast hosting desalination plants, refineries and other coastal facilities while many oil tankers are loaded/unloaded from nearby offshore stations. A number of organic pollutants are generated from these sources and can potentially threaten the quality of intake seawater of the nearby desalination plants. This paper assesses the impacts of two selected organic pollutants; Phenol and PCB-180 (HeptachloroBiphenyl) originated in the coastal water of an industrial coastal basin located in UAE via modeling of their transport from different respective sources to the intake of a nearby thermal desalination plant. A number of parameters involved in the transport processes were determined from lab experiments while most other parameters were estimated from a numerical sensitivity study. The model results depict contour maps of dissolved concentrations of the two pollutants for three different wind conditions in summer and winter. While most of the simulated considered scenarios reflect insignificant impacts on the intake quality of the desalination plant, hazardous levels of migrated phenol are found to impact the intake quality and potentially the produced desalinated water under certain loading conditions and when north western winds are dominant. The obtained results and observations constitute useful information for the desalination plants' operators and allow them to adapt appropriate contingency measures seeking the best quality of target produced distillate.

## INTRODUCTION

The coastal ecosystem of the UAE may experience environmental threats due to the oil and petrochemical activities undergoing along the coastal line. The limited knowledge on the marine biogeochemistry in the Arabian Gulf and on the vulnerability of marine lives to the oil-related activities does constrain the exploration of such threats. Of particular concern are the presence of oil refineries near the desalination plants in some sites of the UAE and the potential impact of transported organic pollutants from the effluents of such refineries to the intakes of the desalination plants. The impact of organic pollutants formed at the intake of a desalination plant in the UAE has been assessed given the major chlorination practiced at such intakes [1]. A major finding was the contribution of bromoform and phenol formed at the intake to the

bromoform formed in the final distillate produced from the thermal desalination plant. The current study assesses the transport of two organic compounds; phenol and PCB180, to the intake location of a desalination plant in an industrial coastal basin in the UAE as shown in Figure 1. The two compounds are generated from a refinery and three loading offshore mooring stations (Single Point Mooring or SPM) with different loading conditions.

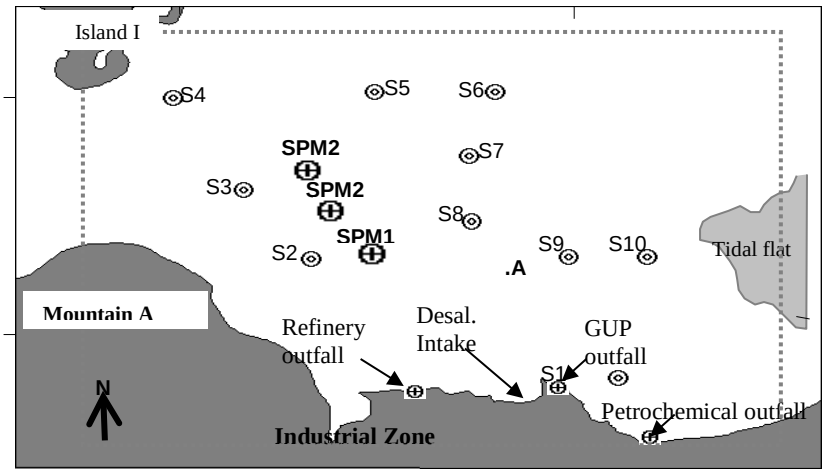


Figure 1. Application Site of the Coastal Industrial Basin

The transport of any compounds in seawater is governed by the hydrodynamic and environmental conditions prevailing in the ambient coastal water. Tidal effects, currents, winds, temperature, and density can all contribute to the varying dynamic and circulation patterns that affect the transport process. Moreover, the abundance of marine organisms in the seawater in either suspended or settled form can also affect the residual transported pollutants in seawater. Therefore, hydrodynamic as well as ecological modeling of the coastal application area represents a major task before conducting a comprehensive fate transport study in marine water. Such results have been obtained from other relevant studies [2 & 3].

## PHYSICAL AND ECOLOGICAL MODELING RESULTS

A three dimensional rectangular grid model (COSMOS) was applied to resolve the flow field and temperature-salinity dynamics of the industrial coastal basin [1]. A survey campaign was carried out to support the modeling study, involving measurements of tide, current, temperature, and salinity. Investigation was done for two meteorologically extreme conditions, i.e. summer and winter. An excellent agreement between the measured and simulated tides was evident while a reasonable agreement between the measured and simulated currents was noticed. The water industrial discharges tend to elevate the temperature and salinity of the water near the eastern shoreline. This water mass propagated towards north under the influence of gravity. The model study did also show that the western flux develops an anticlockwise circulation in the study basin.

EUTROP model [4] is an ecological model coupled with a hydrological model (COSMOS) and used in simulating the lower trophic level of the coastal basin. One set of model parameters

was identified for both the summer and the winter seasons based on the obtained water quality and ecological data. Outputs of time-dependent compartments and time-average vertical distributions of selected compartments were obtained. The coastal basin is characterized as HNLC (High nutrients-low chlorophyll) and the food web system is mainly dominated by zooplankton grazing on phyto and picoplankton. Summer outputs indicated that phytoplankton and picoplankton concentrations are slightly higher near the shore as a result of industrial discharges containing high nutrients. Zooplankton biomass was found lower, however, in the shallow coastal region. Winter outputs reflect an overall slow decreasing trend of phytoplankton and zooplankton biomass.

**FATE TRANSPORT MODEL**

FATE3D is a chemical model that predicts the transport and transformation of the pollutants in the aquatic system, being coupled with resolved flow hydrodynamics. The model simulates chemical stability between organic matter in an estuarine ecosystem and pure chemical substances dissolved into the water. The chemicals, existing in both dissolved and adsorbed forms in the water column, are transported by the tidal current, and settle on the bottom sediment with suspended particulates. The dynamics of the micro-pollutants are resolved using an unsteady mass balance equation that provides the change of a concentration over a known time step in a compartment within a water column or a sediment layer. The flow filed becomes available from a hydrodynamic model (COSMOS), and the suspended particulates such as phytoplankton cells and detritus are predicted by means of an ecosystem model (EUTROP).

**TRANSPORT MODEL PARAMETER ESTIMATION**

The fate transport model parameters required to simulate the two selected pollutants are associated with three major environmental processes; degradation, partitioning, and volatilization. Degradation includes biodegradation and photo-degradation. The fate model FATE3D handles the degradation of pollutants in marine water considering half-life parameter at zero temperature (DO) in addition to the effect of prevailing temperature considering an exponential relation. Portioning is modeled in FAT3D using a proportionality characteristic constant of the chemical (K $^{o}$C) representing the extent of its sorption to the solid particulates present in marine water. Volatilization from marine water is simulated considering a volatilization rate constant ($sec^{-1}$).

In summary the FATE3D model parameters involve nine parameters; (1) apparent biodegradation rate at 0.0 $^{o}$C, (2) sea surface photolysis rate, (3) photolysis parameters (four sub-parameters), (4) apparent degradation in sediments, (5) sinking rate, (6) partition coefficient, (7) adsorption coefficient, (8) volatilization rate, and (9) carbon/organic suspended solids parameter. Such parameters (Table 1) were identified using two approaches. The first approach was a sensitivity analysis with the help of numerical simulations considering extreme values of common ranges of each parameter. The second approach was carrying out laboratory experiments to estimate the critical parameters, proposed from the sensitivity tests, for the considered pollutants.

Table 1. Kinetic Parameters used in FATE3D to model the two organic compounds

| **Parameter** | **Phenol** | **PCB-180** |
|---|---|---|
| Apparent biodegradation rate at $^{o}$C (DPIO in sec$^{-1}$)[1] | 2.005E-7 | 3.50E-9 |
| Sea surface Photolysis rate (PIDG$_o$ in sec$^{-1}$) [2] | 1.145E-6 | 3.50E-9 |
| Photolysis Parameters (AK, BK, CK, and CCLA)[3] | 0.21, 0.00880, 0.0, 15.3 | 0.21, 0.00880, 0.0, 15.3 |
| Apparent degradation in sediments (BPIO in sec$^{-1}$)[4] | 7.17E-8 | 3.50E-9 |
| Sinking rate (cm/s) [5] | 2.0E-4, 0.0, 1.0E-4, 1.0E-4 | 2.0E-4, 0.0, 1.0E-4, 1.0E-4 |
| Partition Coefficient (L/µg)[6] | 1.41E-8 | 7.94E-3 |
| Adsorption rate (sec$^{-1}$) [7] | 2.0E-5, 2.0E-5, 1.0E-5, 0.0 | 2.0E-5, 2.0E-5, 1.0E-5, 0.0 |
| Volatilization rate (sec$^{-1}$) [8] | 9.0E-8 | 3.0E-9 |
| Carbon/organic SS (gC/dry-g) | 0.4 | 0.4 |

[1]As per the biodegradation rate in water $\lambda_{wat} = DPIO * \exp(DTP.T).\frac{DO}{DDOI + DO}$ where DTP and DDOI are taken as 0.069 and 3.0 mg/l, respectively

[2]As per the photolysis equation PIDG$_z$ = PIDG$_o$ e$^{(-k.z)}$ and k is determined as follows:

[3] k = AK + BK . Chla + CK . (Phyto/CCLA)$^{2/3}$

[4] As per the biodegradation rate in sediment $\lambda_{sed} = BPIO * \exp(BTP.T).\frac{DO}{BDOI + DO}$ where BTP and BDOI are taken as 0.069 and 3.0 mg/l, respectively

[5] Given rates for phytoplankton, picoplankton, zooplankton, and detritus

[6]As per the equation $K_{OC} = [C_{SS} . 100]/ (C_c . C_W)$

[7] Given rates for phytoplankton, picoplankton, zooplankton, and detritus

[8] Spatially uniform volatilization rate

## FATE TRANSPORT MODELING SCENARIOS AND RESULTS

While continuous release of chemicals from the refinery effluent was considered in all simulations, the release from the SPMs was considered continuous from the nearest SPM and intermittent from the two distant ones. Such intermittent release was tailored to reflect the times of arrival and disappearance of the modeled chemicals from these points to the desalination plant intake. So, the release from these SPMs started after one week from the onset of simulation and continued for one day only. Considering the maximum potential levels of the two considered pollutants prevailing in the area, Phenol concentrations of 1.0 and 2.0 mg/l and PCB180 concentrations of 1.0 and 2.0 µg/l were released from the refinery and SPMs, respectively. The volumetric flow rates at the SPMs were assumed to be identical to that of the refinery effluent; that is about 350,000 m$^3$/day. Three wind conditions were considered in the study, western, northwestern, and northern wind. Simulation results are presented here.

Phenol: Figure 2 shows the time variation of dissolved phenol in summer as a result of continuous discharge of refinery waste for three wind directions. The plot reveals that the concentration varies in a diurnal way in accordance with the water level variation (peaking up with low tide and down with high tide). Same observation is seen with the cyclic behavior of the dissolved levels in agreement with the tidal cycle. The maximum level is observed during the minimum tide occurring during the neap tide, close to days 8, 22, etc. While the western wind affects most of the shoreline area with levels above 2.0 µg/l, the northern wind tends to have

wider influence in the central basin. The average dissolved concentrations at the intake varies from 2.5 to 4.0 µg/l with the maximum value generated with the western wind. This indicates that on the average, about 0.3% of the original released dosage at the source (refinery) develops at the intake. This increases to 0.4% in case of western wind. Figure 3 shows a time series profile for three release scenarios associated with the most prevailing northwestern wind. These scenarios are explained here as follows:

- Scenario I: No SPM Scenario: Continuous release from the refinery only
- Scenario II: Nearest SPM scenario: Continuous release from refinery and nearest SPM
- Scenario III: Regulated SPMs: Continuous release from refinery and nearest SPM in addition to intermittent release from the two furthest SPMs

The results show that the release from the nearest SPM increases the level of dissolved Phenol at the intake from an average of 3.0 to 6.0 µg/l. Also, the release from the next SPM increases the detected level to 8.0 µg/l (yellow color noticed near day 7) while the furthest SPM increases it to 9.5 µg/l only (yellow color noticed close to day 8). The two-week cyclic variation of detected level at the intake does not occur for the second and third scenarios. This can be attributed to the fact that pollutant transport here takes place in deep water that is less affected by the water level fluctuations. In other word, observed fluctuation of dissolved concentration is apparent only if the transport happens in shallow water as with the first scenario. Similar plots for the same above scenarios but for western wind (not shown here) shows that while the nearest SPM increases the detected level at the intake from 3.5 to 5.0 µg/l only, the next SPM increases that level to 9.0 µg/l and the furthest SPM adds nothing to that level. This indicates that the western wind flushes the phenol released form the SPMs away from the intake and eventually weakens their contribution in comparison with the northwestern wind situation.

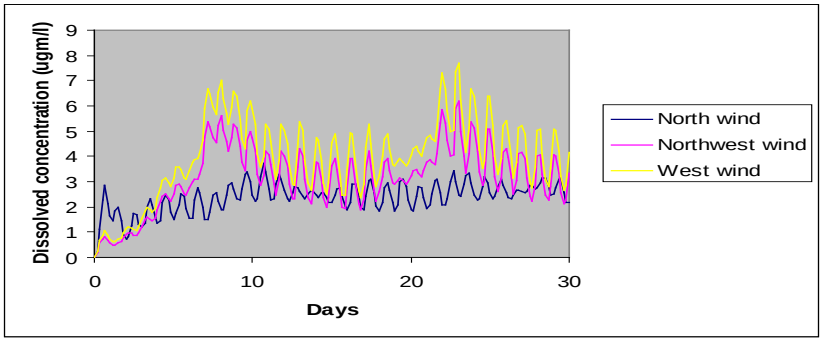


Figure 2. Daily variation of Dissolved phenol in summer for Scenario I

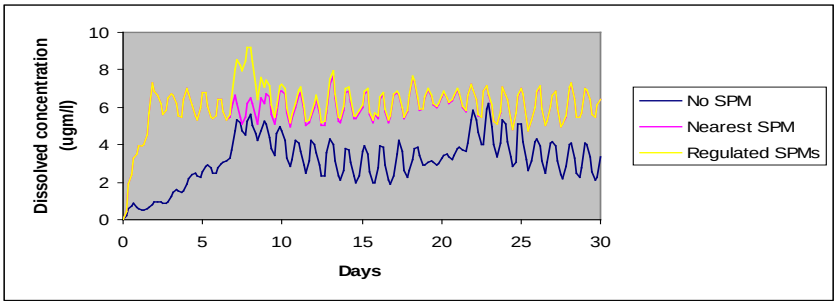


Figure 3. Daily variation of dissolved phenol in summer for three Scenarios (northwest wind)

The simulated distribution of Phenol after 30 days of discharge from the refinery outfall in winter shows that the currents profile in case of west wind tends to rotate the plume of phenol up at the southern eastern side. The average dissolved concentration at the intake varies from 1.0 to 6.0 µg/l with the maximum level associated with the western wind as before. The detected range is generally larger than that of the summer season as a result of less biodegradation losses occurring with the lower winter temperatures. However, the average level in case of northern wind was less than that of summer apparently due to the reversed current direction in that case.

The time series profiles for the same three release scenarios discussed above for the three wind directions show that the nearest SPM scenario increases the average detected level at the intake from 5.0 to 6.0 µg/l. The next SPM increases it to 7.0 µg/l and the furthest increase it to 8.0 µg/l. It is noticed that the detected level is larger than the summer case if release is from the refinery only (compare 5.0 µg/l now to 3.0 µg/l in summer) while the level is either the same or less when the release happens from the SPMs (compare 7.0 µg/l now to 7.5 µg/l for release from the next SPM and 8.0 now to 9.5 µg/l for release from the furthest SPM). The contribution of SPM to the detected level is even less in case of western wind. The reason as mentioned earlier is related to current profile that tends to rotate up in case of northwest and west winds flushing away the chemicals released from the SPMs.

PCB-180: As per the kinetic relations for PCB-180 described earlier (Table 1), PCB-180 experiences much less biodegradation and volatilization when compared to Phenolic compounds. However, it owns a much higher partition coefficient causing its rapid depletion due to increased adsorption by organic carbon in the water column. The simulated distribution of PCB-180 after 30 days of discharge from the refinery outfall in summer for different winds shows that the plume sweeps along the shoreline in case of west wind and stretches up in case of north wind (Figure 4). However, the wind direction does not have a tangible effect on the small trace levels detected at the intake. Although of the small levels detected, they were still increasing arriving no equilibrium after the one month simulation time (Figure 5). Such non equilibrium is related to its low degradability in water and in sediment as well. The portion partitioned in the water column keeps flowing with the continuous supply from the refinery showing no decline or equilibrium as it used to happen in case of largely-degradable Phenols.

An average of 0.0005 µg/l is detected at the intake indicating a 0.05 % of the original released dosage at the source (refinery) develops at the intake. While the nearest SPM increases the detected level at the intake to 0.0009 and 0.0007 for the northwest and west winds, respectively, the next and furthest SPMs contribute nothing to that level.

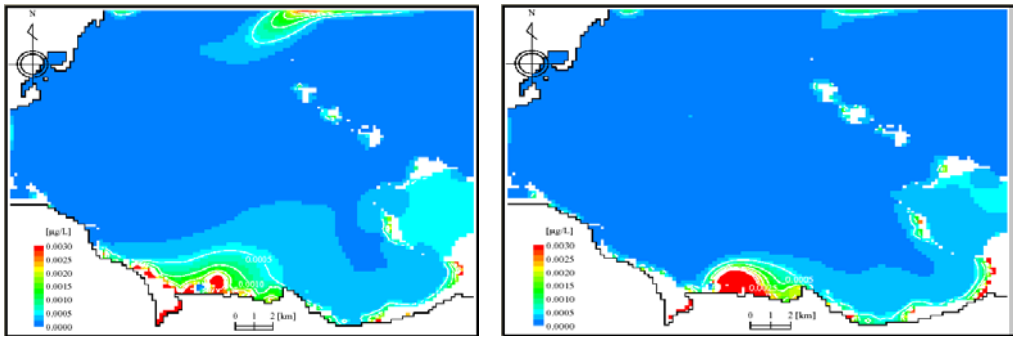

Figure 4. Summer distribution of PCB-180 for Scenario I (north & west winds)

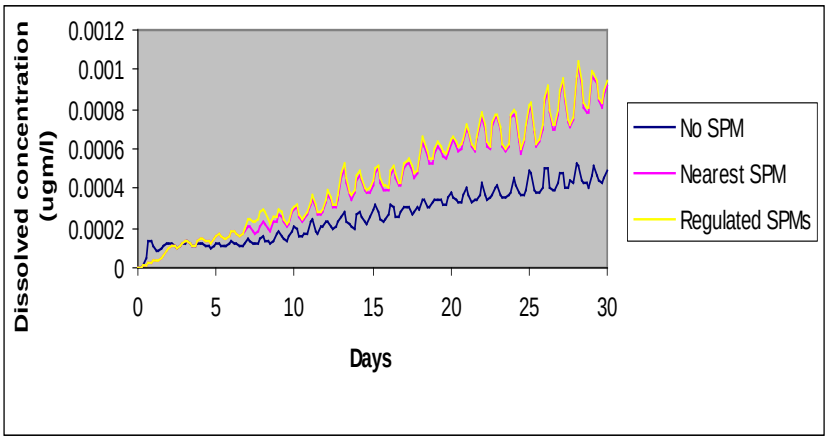


Figure 5. Dissolved phenol variations in summer for three Scenarios (northwest wind)

For the winter results, higher levels are reported in this case. A maximum of 0.001 µg/l results for the west wind; that is double the level detected during the summer. The nearest SPM increases the detected level at the intake to 0.0015 for both northwest and west winds with the nearest and furthest SPMs contribute nothing in both the northwest and west winds.

To investigate the breakdown of transported chemical in the coastal water among different mechanisms, a budget analysis was conducted for the two selected chemicals. Such analysis indicated that biodegradation represents the major losses for the transported Phenol (Figure 6). In case of PCB-180, major losses from the dissolved levels in the water column are related to the adsorption to picoplankton (Figure 7).

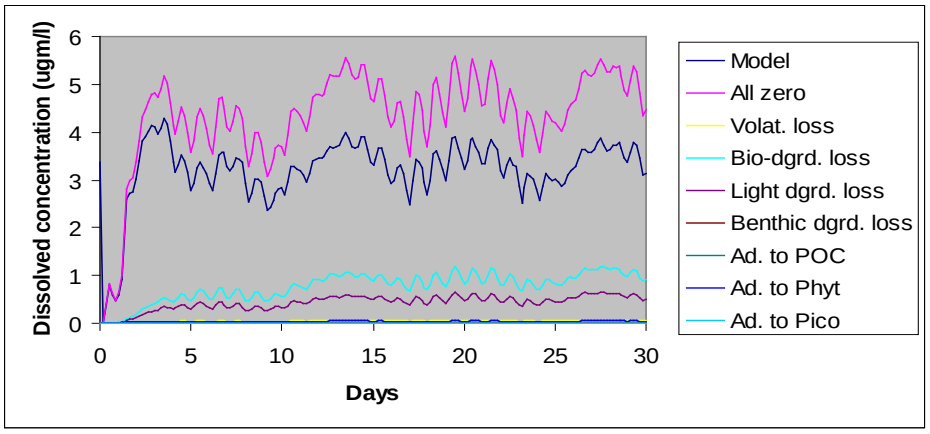


Figure 6. Breakdown of different processes upon the transported Phenol at point 1

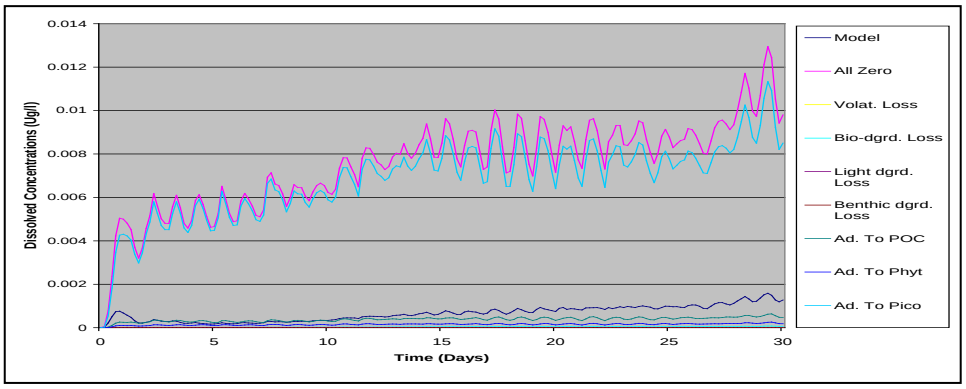


Figure 7. Breakdown of different processes upon the transported PCB180 at point 1

## CONCLUSIONS

The risk of refinery wastewater and other oil spillage is assessed in an industrial coastal basin in United Arab Emirates that has a desalination plant located along the basin coast besides an oil refinery and other several industrial facilities. This is done via simulating the fate transport of Phenol and PCB180 discharged from the refinery outfall and other offshore oil loading/unloading stations. The simulation results indicated that only the Phenol can have some risk at the desalination plant intake developed if a continuous load of phenol (1 ppm) is released from the oil-processing plant effluent along with the nearest Single Point Mooring (2 ppm) and when subjected to the common northwestern wind. The maximum risk is expected during the winter season and during the low-tide periods. Biodegradation was found to dominate the transport of phenol while adsorption to picoplankton dominates the transport of PCB180.

## ACKNOWLEDGMENT

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