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Full Length Research Paper

Optimum Solution for El Doha Water Desalination Brine Disposal in Kuwait

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Abstract

Water desalination processes have contributed to a better standard of living in a number of countries during the second half of the 20th century, following an increase in water demand for drinking purposes as well as industrial and agricultural uses. Desalination process produces two streams of water, one is the product fresh water, and the other is concentrate water containing salts and any un-reacted pre-treatment chemicals (Brine). Brine is considered to be one of the main environmental aspects that affect the surrounding environment during disposal. There are a variety of methods that are used for brine disposal / management. The most common methods include (i) Surface water Discharge, (ii) Ground water Discharge, (iii) Evaporation ponds. The availability of the disposal alternative is mostly site-specific. Therefore, the most suitable disposal methods from an environmental and economic perspective have to be evaluated on a site-specific basis .The aim of this study is to develop a mathematical model, named "Brine disposal decision support system" (BDDSS). The model's main objective is to assist decision makers (Consultants or Government authorities) in the selection of an optimum brine disposal solution applying applicable, environmentally friendly and cost effective methods, through a user friendly interface. The BDDSS model can be applied to any desalination plant to obtain the optimum brine disposal solution, by providing three scenarios for brine disposal, after performing a compilation of all inputs provided by the user, then start comparison among the three alternatives and select the optimum solution / alternative through an evaluation matrix based on the cost / environmental of each disposal alternative. The optimum solution provided is the one achieving lowest cost and lowest negative environmental impact. In order to observe the benefits of applying the BDDSS model on desalination plants, a live run has been conducted on an existing desalination plant in Kuwait bay. The reason for selecting this case is that there is severe impact on the surrounding environment as a result of extensive brine disposal from Doha desalination plants to Kuwait bay. This case study will show results obtained before and after applying the model.

Keywords: Water Desalination, Wastewater in Desalination plants, Environmental impact for brine disposal.

INTRODUCTION TO THE BDDSS MODEL

MODEL OBJECTIVE AND TARGET

The model's objective is to assist decision makers reaching a quick and integrated decision in selecting the optimum brine disposal method.
The Model aims to achieve three main targets:

a. Applicable Brine disposal methods.

Among the different models allocated for brine disposal, selection has been made for three common methods widely used in the region and worldwide. The three models are sea disposal, deep well injection and disposing into evaporation ponds.

b. Cost effectiveness

The model provide analysis for the estimate cost of the three disposal models, depending on the recent prices obtained from suppliers, and contractors being benchmarked as well with similar projects executed. and assist in decision making for selecting the optimum method to be used for brine disposal from the economic aspect to achieve the value for money.

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c. Environmentally friendly

Besides providing the applicable methods for brine disposal as shown above, the model also apply the environmental measures that mitigate the negative impact on the surrounding environment for each method mentioned, to achieve finally an applicable cost effective and environmentally friendly method.

Model Application

Applying the BDDSS model on the existing plant will provide different scenarios for brine disposal. The model will suggest three disposal scenarios for brine disposal.

- Sea disposal (the current case of this study, but after applying certain measures to make it environmentally friendly).
- Disposing brine to evaporation pond.
- Disposing brine through injection wells.

The model will provide the environmental solution to minimize negative impacts on the surrounding environment for each method and calculate the design criteria for each method. The model will also calculate the estimated budget for each scenario.

After taking the environmental and site considerations into account, the model will provide the optimum solution. The optimum solution provided is the one achieving lowest cost and lowest negative environmental impact(Ismail et al., 2015), Figure 1.

Case Study

The study area

Kuwait Bay is a semi-enclosed bay with area of 740 Km^2 and water volume of 5.4 Km3, the average water depth of the bay is 7.2 m and it is characterized by weak currents and water stagnation, and tends to deposit water pollution in large amounts. It is known for its shallows and tidal flat formed by mud, sand and rock which are full of various ecosystems. On the other hand, some areas of this tidal flat have been damaged due to intensive coastal development in the last two decades, excessive run off of treated and untreated sewage, and continuous flow of brine water with high temperature and high salinity from four desalination and power plants, Subyiah is located in the north, Doha East and Doha West on its south western part and Shuwaikh power and desalination plant in the south. Figure 2.

Current state of the existing desalination plant

As mentioned above the Kuwait Bay is a semi-enclosed bay, having some areas of the been damaged due to continuous flow of brine water with high temperature and high salinity from four desalination and power plants.

Taking Doha desalination plant as an example, the desalination plant dispose brine directly into the sea through an outfall structure. And no initial dilution is done, and thus the surrounding area adjacent to the shore is subjected to high salinity.

Analysis have been conducted to the Kuwait bay, specially focused on Doha desalination plant, and it was concluded that the brine increased the salinity of bay water by average 16ppt at the disposal point and the effect of this increase dispersed through the bay gradually to distances varied between 550m in winter and 3500m in summer with diversion to north part during most period and the effect of wastewater disposal from El Shuwaikh Port and the coming water from Khor Sabyiah prevents the pollution motion to east and south of the bay, (Al Fadhli et al., 2011).

Generally, the continuity of brine disposal to the bay will increase the bay water temperature and Salinity by 10% every 3 years that may cause a very noticeable change during the coming years to the bay environment and its ecology (Sultan Al Fadhli NS, 2011).

Applying the BDDSS model on the existing desalination plant

As mentioned earlier, applying the BDDSS model on the existing plant will provide different scenarios for brine disposal as follows:

a. Sea disposal alternative (scenario I – current scenario for existing plant)

a1 Current state for brine disposal

The current situation shows disposing brine directly to the shore line without any initial dilution, result in wider brine dispersion and increase on negative impact on the sorrounding envorpnemnt . The figures below (3,4) show the difference between the existing system used in the current state and the new approach adopted for brine disposal to seawater.

a2 Suggested scenario by BDDSS model:

In order to minimize environmental impacts on the surrounding environment, the model has taken certain steps, those steps include :

- Rejected water is initially diluted by seawater before discharging into the pipe
- Brine discharge / Effluent point is made through a long pipe under sea surface
- Diffusers are added at the end of the rejection pipe to enhance dilution and increase dispersion

The solution adopted by the model achieve the following benefits :

- Disposing brine through outfall pipe protects the shoreline from being exposed to brine plumes which affect the sea activity at the shore
- Adding diffusers to the end of the discharge pipe

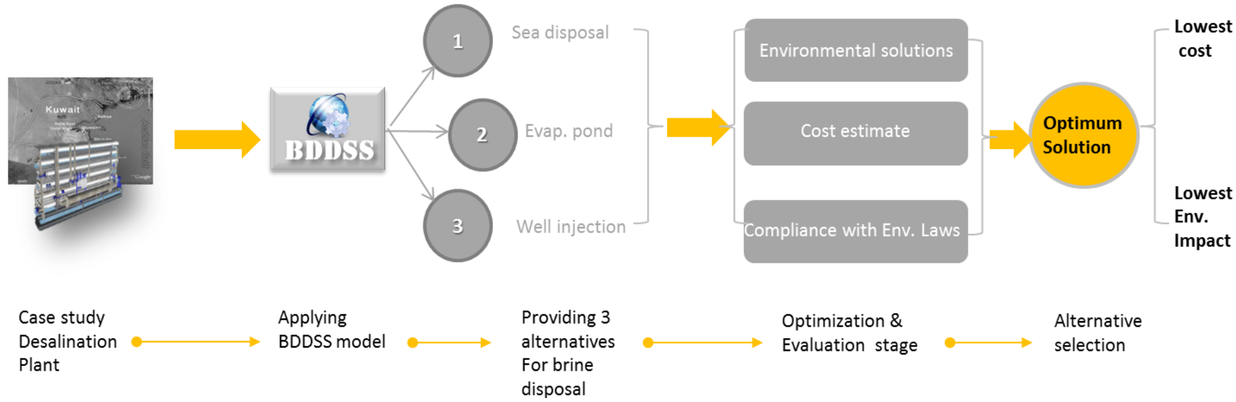

Figure 1. Methodology for applying the BDDSS model(Ismail et al., 2015).

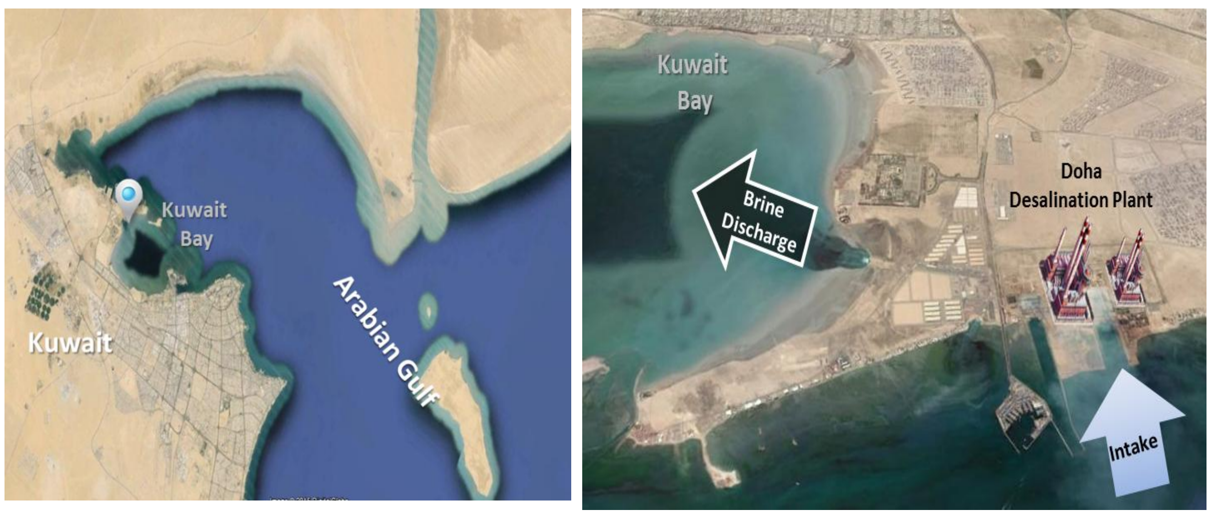

Figure 2. Case study Location / Kuwait bay

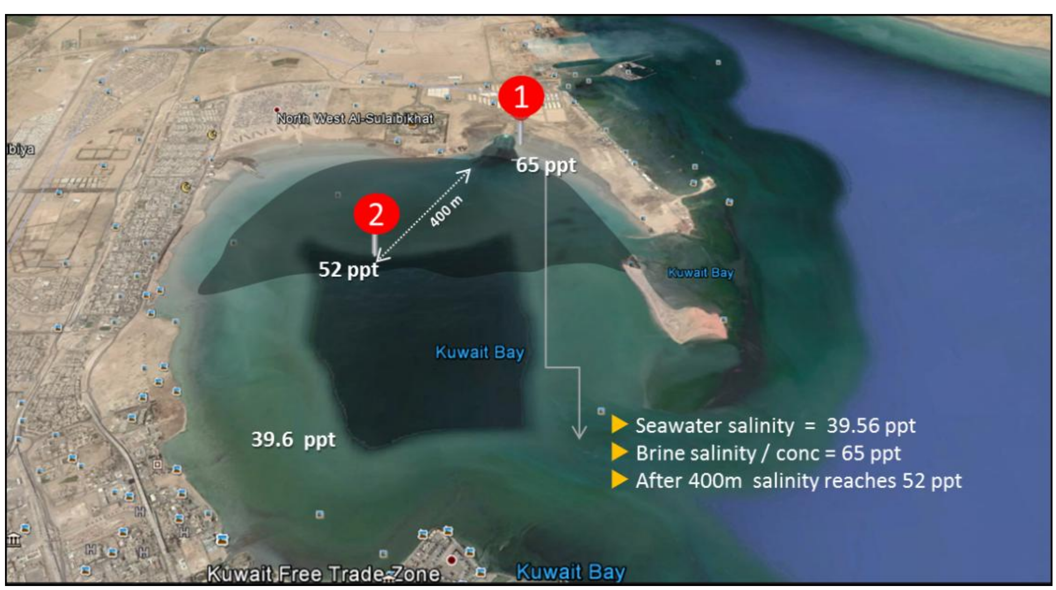

Figure 3. Existing brine disposal method for Kuwait bay

Figure 4. Suggested solution for brine disposal method for Kuwait bay

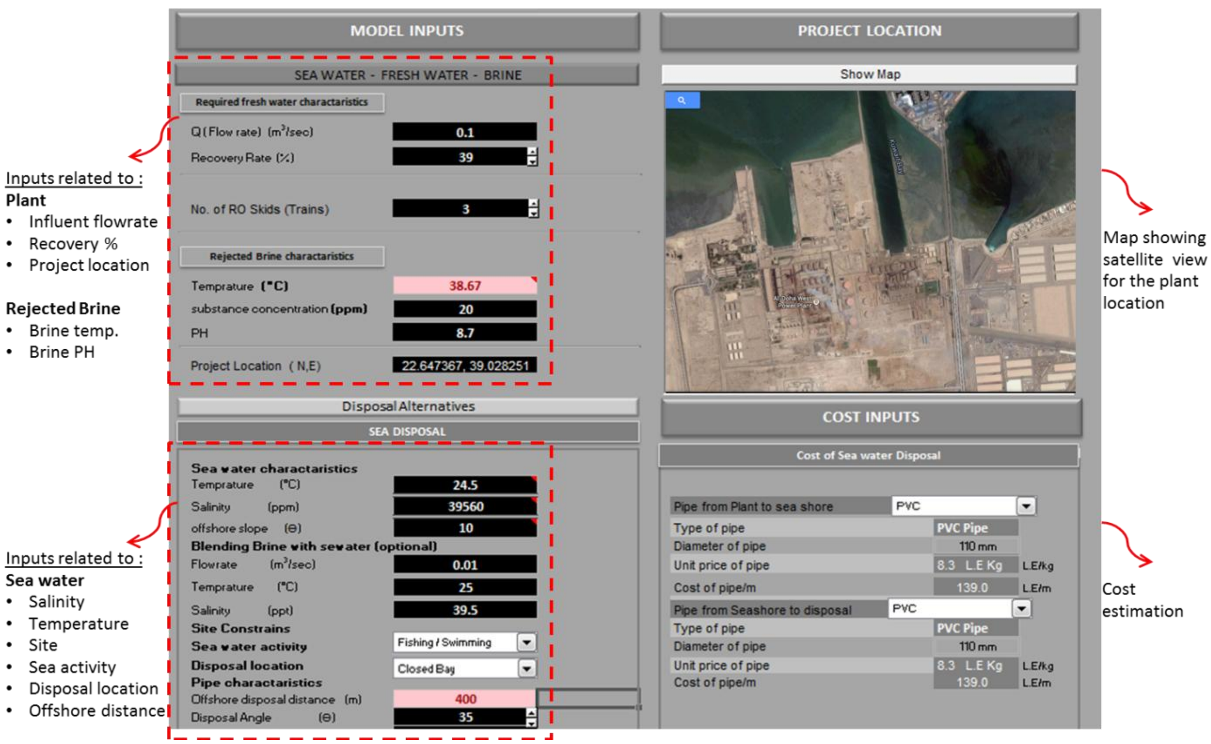

Figure 5. Model's snapshot illustrating inputs fed to the model related to sea water disposal alternative

maintain well dispersion of brine plume into sea water body to minimize plume effect on marine organisms

Based on the inputs provided by the user, the model starts compiling the parameters obtained from data collected in relation to ambient conditions using the formulas and charts embedded within the model to come up with the requested design parameters.

The figure (5) above shows a model's snapshot illustrating inputs fed to the model related to the plant, seawater ambient conditions, and blending options made for initial dilution, in addition to plant land use like seawater activity and disposal location.

The model's inputs includes the following parameters :

Desalination plant datas:
- No. of RO Skids
- Recovery rate (r)
- Influent Flow Rate (Q drink)
- Brine Flow rate
- Brine Temperature (Tdesal)
- Brine PH

Water and Brine Analysis, as:
- TDS readings for influent
- effluent and;

- brine

Inputs related to sea water disposal

- sea water salinity (Salo) (0 -160 ppt)
- sea water temperature (To) (10-180 oC)
- Port openings (n)
- land and soil characteristics
- sea water navigation status

The model compiles the inputs along with the formulas embed within to come up with the appropriate solution for brine discharge in seas water.

The figures (6,7) below illustrate snapshots of the model's outputs related to effluent characteristics and effluent system Also the model calculates the jet properties for the disposal plume, disposed through the effluent pipe.

a3 Cost of sea water disposal alternative

The model calculates the cost of supply and installation of the disposal pipes based on the type of pipe selected by the user (uPVC / HDPE).

The cost estimated based on recent quotations from the local market multiplied by factor (for construction under sea water) in addition to the cost of diffusers. The model calculates the cost of pipe discharge system to be 1,541,663 L.E

a4 Environmental considerations for sea water disposal

The model ensures compliance with the requirements of the relevant environmental laws and regulations.

Commonly, regulators require that Environmental Impact Assessment for any project must contains a mathematical simulation for the impact of the proposed project structure on marine stability.

Also some regulators require a hydrodynamic model, in cases where the projects contain end-of-pipes, they require an output result from a dispersion model. This model simulates the dispersion of effluent discharged to the water body and gives a figure of its concentrations at a certain location after an interval of time.

Accordingly the BDDSS model takes into consideration all aspects related to brine effluent and jet characteristics, the model results include the following:

The final effluent flow rate, the effluent temperature, salinity and the resulting density and viscosity and substance concentrations. After calculation of density and viscosity, the required design of the outfall (geometry) and its characteristics (discharge velocity Uo, momentum flux Mo, length scales LQ and LM are calculated for a discharge into a stagnant water body.

The properties of the negatively buoyant jet are estimated (Dilution S, maximum level of rise Z_{max}, X_{max} , impingement point Z_i, X_i) and recommendation for the outfall location is given (distance) - results are as illustrated in Figure (7)

The model takes into account that there must be enough distance between the intake and discharge points (more than 0.2 km distance) to avoid or minimize risks of feed water deterioration. The disposal of brine by pipeline should, therefore, be sufficiently far out into the sea—about 0.5 km depending on the marine life and the coral reefs.

The outfall system includes buried ultra-polyvinyl chloride (UPVC) pipe from the desalination plant to the shore .The remaining part of the pipe from offshore to the outfall point (offshore pipe) is recommended to be high- density PE, with a special covering, laid down on/or embedded in the seabed. At the end of the outfall pipe, a distributor head (diffusers) is fitted to discharge the brine water over a wide area. Figure 8

As shown above, the model requests to enter the current situation of the sea activity (no activity / fishing or swimming activity / natural protective)

Also the model provide query whether the disposal location is a closed bay or open sea. As it will be taken into consideration while evaluating the environmental impact.

Based on the inputs provided above, the desalination plant is located in a closed bay (Kuwait bay) where there are fishing activities as well as adjacent entertainment and residential activities (like Kuwait entertainment city). Accordingly, the model referred back to the environmental laws and regulations and mentioned that the alternative of disposing brine into the sea is valid but have environmental concerns. But however the alternative is valid, the existence of a closed bay as well as activities adjacent to the plant will affect the environmental evaluation of this alternative.

b. Evaporation pond disposal alternative (scenario II)

b.1 Suggested solution for brine disposal through evaporation ponds

Based on previous studies, disposal of brine into an evaporation pond seems to be the solution that have the minimum environmental impacts on the surrounding environment, because there is no direct contact with seawater or underground aquifer, providing that the pond is lined very well to avoid negative environmental impacts.

So, in order to minimize environmental impacts on the surrounding environment, the model has taken certain steps as follows:

First, the model has to provide an applicable alternative solution for brine disposal. And by checking the site location, it has been noticed that the site area has enough land space to construct evaporation ponds. Also there are existing ponds in the site area.

Based on that, the solution of having an evaporation pond as an alternative for brine disposal is valid. See figure (9,10) below

Second step, based on the flow rate of the rejected effluent, and the given formula for calculating the pond area, the model can calculate the following parameters:

- Pond Area
- Pond Length

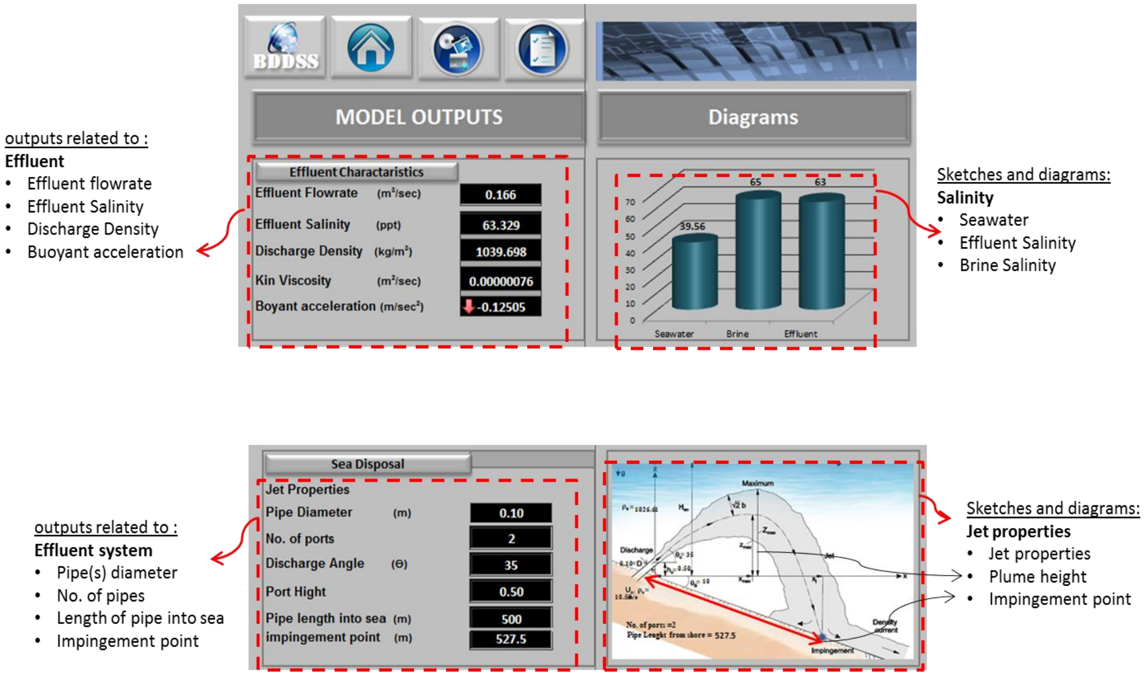

Figure 6. Model's snapshot illustrating outputs of the model related to sea water disposal alternative

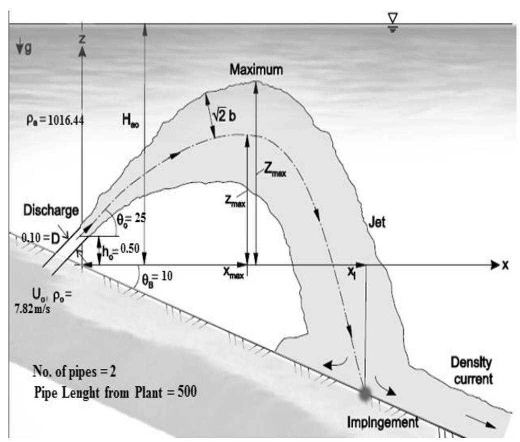

Figure 7. Model's snapshot illustrating jet properties for the rejected brine plume

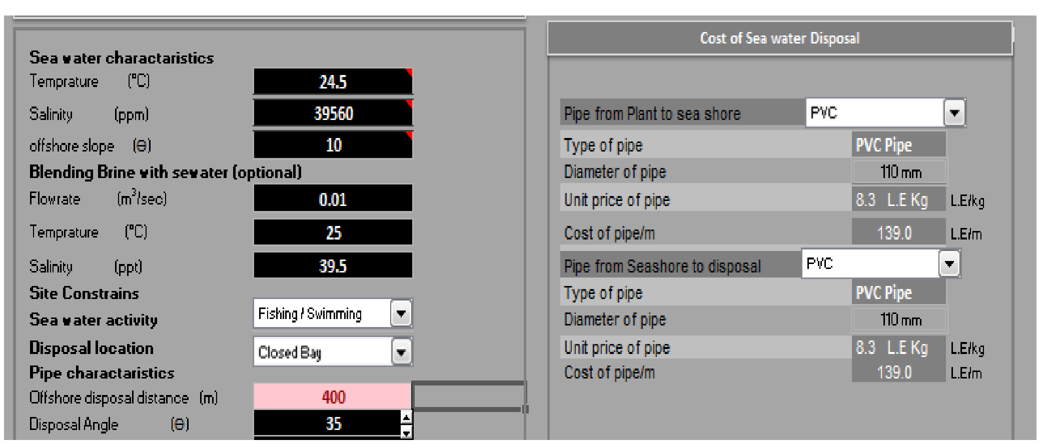

Figure 8. Model's snapshot illustrating inputs to seawater disposal alternative related to sea water activity and disposal location situation

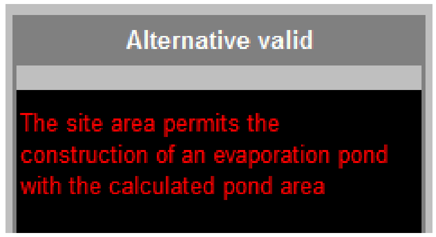

Figure 9. Model's snapshot showing that the alternative is valid due to availability of space at the site

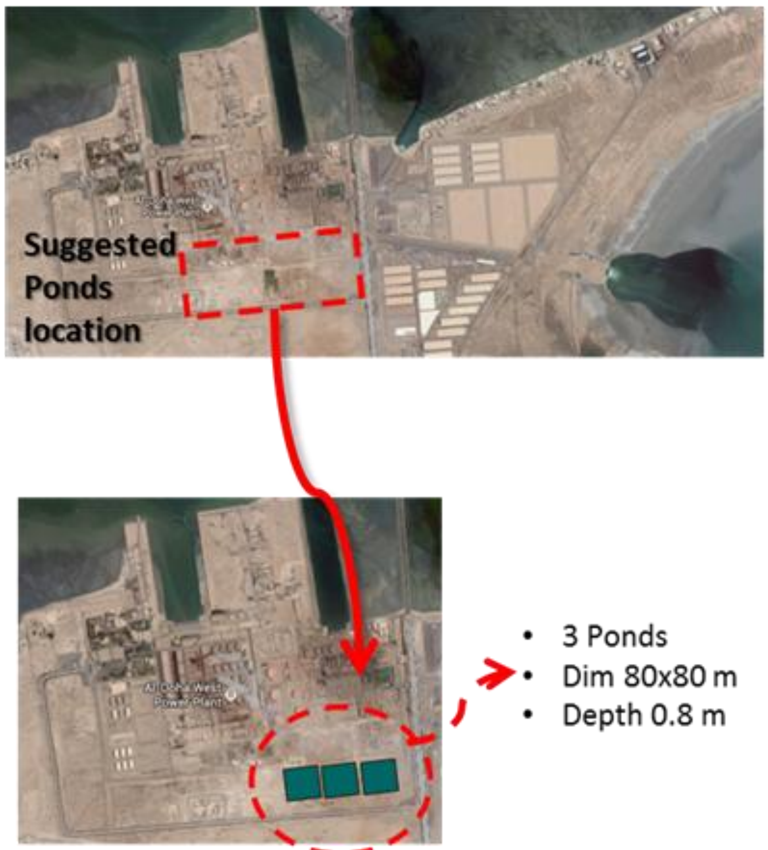

Figure 10. Diagram showing the availability of land in the site area

- Pond Width
- Upper and Lower length
- Base and Side areas
- Pond Volume

Those parameters can be described as pond characteristics, and are shown on the following diagram (a snapshot of the model is shown in Figure 11).

Third step, and in order to minimize environmental impacts of brine, the pond shall be lined. Accordingly, the model calculates the required liner dimensions based upon the pond dimensions and liner overlap sizes needed , the user can also adjust the overlap factor – if needed – according to the type of liner or it can be left as 10% from each side length.

The model present the alternative outputs on a diagram showing the pond slopes, dike length and water depth. Also the diagram shows the selected liner type illustrating the cross section for the pond with selected liner type. Taking into consideration that this diagram is changed by changing the liner type .

b.2 Cost of evaporation pond disposal alternative

The model calculates the cost of disposing brine to evaporation ponds based on the design parameters. The cost breakdown is presented as follows:

- Cost of earthworks for pond construction, and that include all the CAPEX needed to construct the pond including labor costs, excavation and filling
- Cost of pond liner, depending on the type of liner selected

The total cost for constructing the pond and applying the

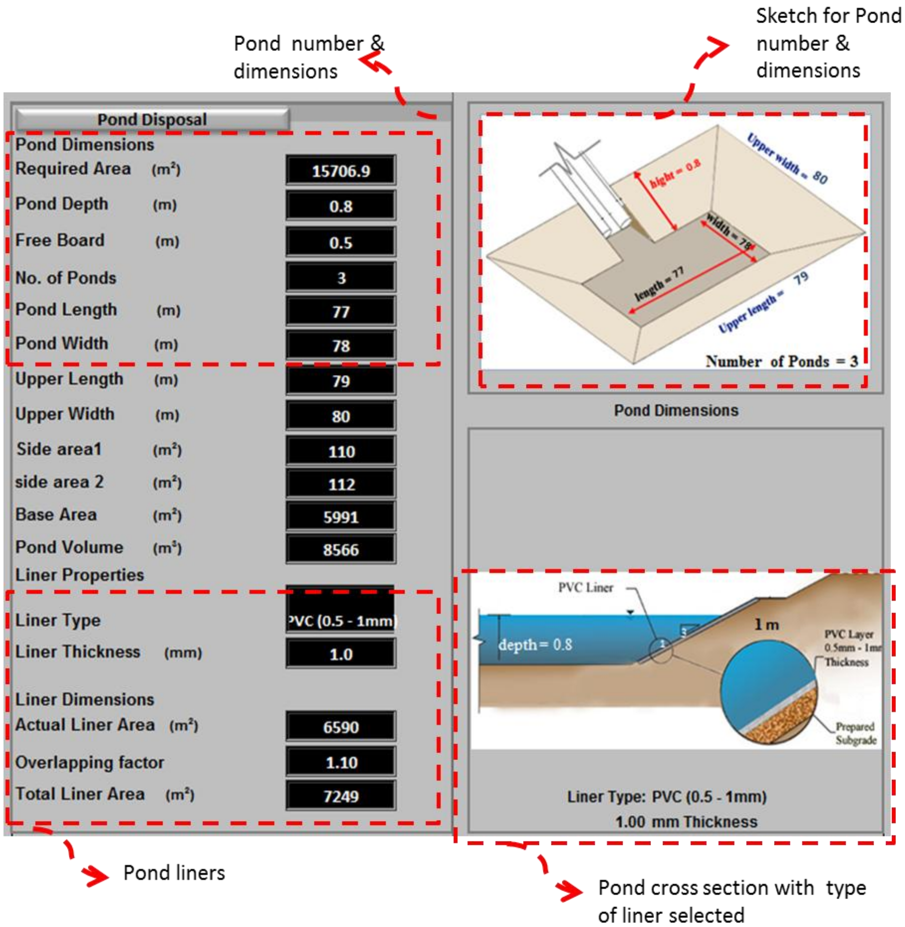

Figure 11. Model's snapshot showing the evaporation pond disposal output

liner is 1,408,519 L.E

b.3 Environmental considerations for evaporation pond disposal

Also the model take into consideration the environmental laws and regulation related to the evaporation ponds disposal method.

The environmental concerns related to evaporation ponds are classified as follows :

- The risk of contamination of water aquifers through upward or lateral migration of waste fluids;
- The risk of increasing the salinity of soil for the surrounding agriculture areas near the plant, due to seepage / infiltration of brine.
- Possibilities of contamination increase in case the soil layers are permeable

Based on those risks, the model provides query on each of those parameters by checking the status of each.

Based on the inputs provide by the user the site location doesn't have agriculture land adjacent to the pond's location, also the soil layers don't include fresh water aquifer in the zone. In addition, the soil layers at the location is non permeable soil.

Accordingly, the environmental risks associated with the evaporation pond disposal will have minimal impacts on the surrounding environment. That will be taken into consideration during final evaluation of the optimum solution.

c. Well injection disposal alternative (scenario)

c.1 Suggested solution for brine disposal through deep well injection

Based on the inputs provided by the user, the model starts compiling the parameters obtained from soil analysis reports using the formulas and charts embedded within the model to come up with the requested design parameters, as shown in figure (12).

The outputs of the well injection alternatives are presented as follows:

- Soil analysis preview (strata layers)

Visual illustration of the soil layers with their depths is shown in the following diagram, which enable the user to check the arrangement of the layer in line with the well characteristics

- Wells specifications

This section shows the design parameters of the

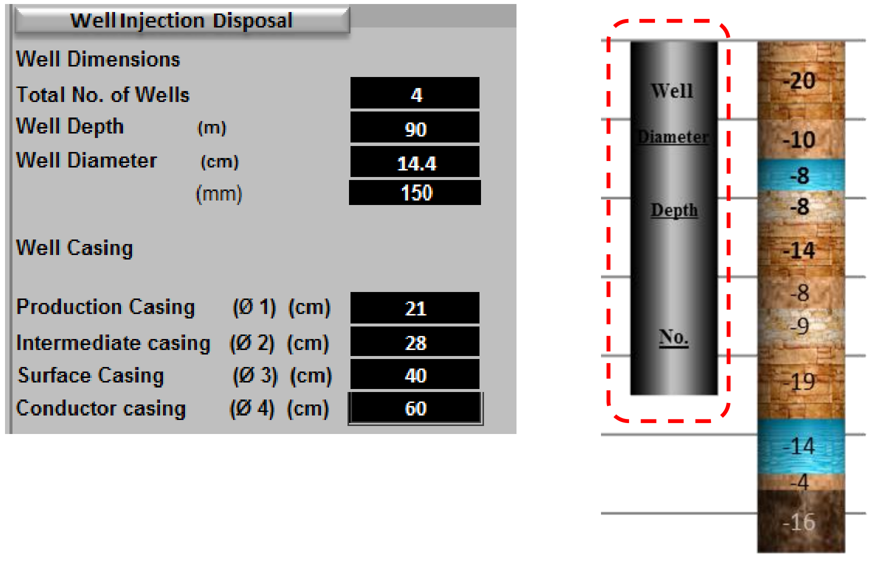

Figure 12. Model snapshot illustration for wells specification based on design criteria, as well as well casing diameters and depths

wells which define well specifications as follows

- Total No. of Wells
- Well Depth
- Well Diameter
- Standby units

In addition, visual illustration of the wells' characteristics is shown in the following figure (12), which enable the user to have a quick view on the well's characteristics in line with the soil layers

c.2 Cost of injection wells disposal alternative

The model calculates the cost of disposing brine to the injection wells based on the design parameters .

The cost breakdown is as follows:

- Cost of earthworks and drilling as well as pumps supply an d installation, and that include all the CAPEX needed to construct the well including labor costs, excavation and filling, testing and commissioning
- Cost of well casing, depending on the type of casing selected

The total cost for constructing the well and applying the casing is 658,325 L.E

c.3 Environmental considerations for evaporation pond disposal

The model takes into consideration the environmental laws and regulation related to the deep well injection disposal method.

The environmental concerns related to the well are similar to the ones related to the evaporation ponds are classified as follows:

The risk of contamination of water aquifers through upward or lateral migration of waste fluids;

- The risk of increasing the salinity of soil for the surrounding agriculture areas near the plant, due to seepage / infiltration of brine.
- Possibilities of contamination increase in case the soil layers are permeable

Based on the inputs provide by the user the site location doesn't have agriculture land adjacent to the well's location, also the soil layers don't include fresh water aquifer in the zone. In addition, the soil layers at the location is non permeable soil.

Accordingly, the environmental risks of the well disposal will have minimal impacts on the surrounding environment. That will be taken into consideration during final evaluation of the optimum solution.

However, precautions shall be taken by the model to ensure that the rejected brine will not disperse into soil layers, and that is done by installing well casing.

- Well Casing

As described above, casing is the major structural component of a well. Casing is needed to:

- Maintain borehole stability
- Prevent contamination of water sands
- Isolate water from producing formations
- Control well pressures during drilling, production, and work over operations

The model calculates the sizes of the cases needed as the cost of installing the casings

The figure 13 to the right illustrates a schematic diagram for types of wells casing with their respective diameters

RESULTS AND DISCUSSION

Model scenarios evaluation

In order to consolidate the final conclusion and obtain the optimum solution for brine disposal for our case, the model starts compiling all the results obtained from the three disposal alternatives in terms of:

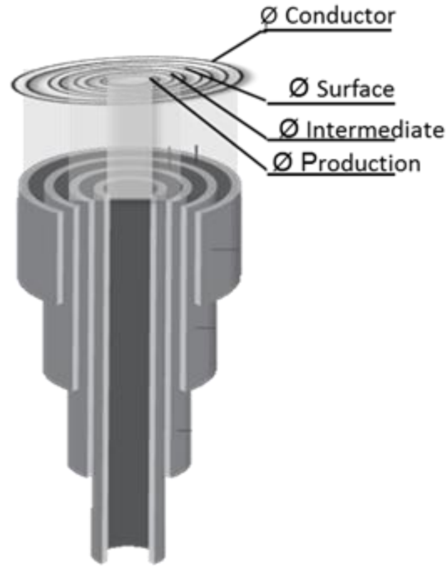

Figure 13. Model snapshot for well casing diameters and arrangements

Figure 14. Model snapshot for alternatives cost comparison

- Applicable disposal solutions
- Cost effectiveness
- Environmentally friendly solutions

First, in terms of the estimated cost for each disposal alternative, the model starts comparing among the three alternatives and choose the one that have the minimum cost. A visual illustration is made on a diagram. (see figure 14 above)

From the analysis, it is obvious that the well injection alternative has the minimum cost comparing to the other two alternatives.

Also, it worth saying that the sea disposal alternative – that supposed to have the minimum cost is almost near to the cost of the pond, and that is as a result of extending the effluent pipe to a length near 3000 m

Second, in terms of environmental impact, based on the environmental consideration mentioned above, the model evaluates each environmental concern on its own giving weights on each concern. These weights give an independent opinion depending on the evaluation of each concern.

Also the model takes into consideration the environmental laws and regulation related to each disposal method as follows:

(i) Disposing water to a closed bay will have more negative impact than disposing to an open sea (which

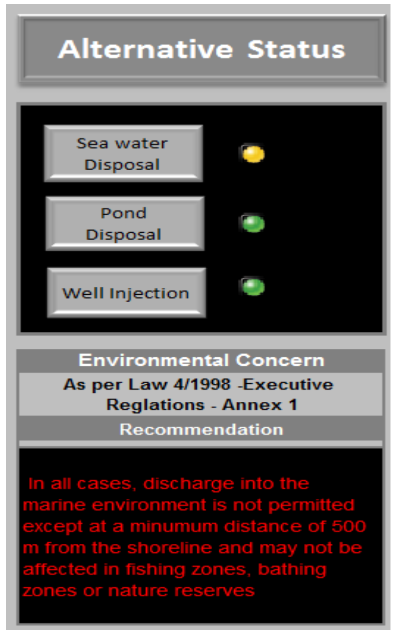

Figure 15. Model snapshot for three alternatives status and environmental concerns.

reflects our case study)

(i) For well injection and evaporation pond disposal, environmental concerns related to the soil are classified as follows:

- The risk of contamination of water aquifers through upward or lateral migration of waste fluids ; (there is no fresh aquifer in our case study)
- The risk of increasing the salinity of soil for the surrounding agriculture areas near the plant, due to seepage / infiltration of brine . (there is no adjacent agriculture land beside the well's location)
- Possibilities of contamination increase in case the soil layers are permeable (soil is not highly permeable)

Accordingly, each of those concerns became parameters that have a weight, depending on their existence. The result of the weights is illustrated on the graph indicating whether this alternative has negative environmental impact (far away from the origin) or has minimum impacts (near the origin)

Wherever there are more negative impacts the point moves across the Y axis upwards, and vice versa. The evaluation matrix is illustrated in figure (16)

So, the more the point moves towards the origin, the less the negative impact on the environment. The same procedure will be applied on both alternatives.

As mentioned above, each of those concerns became a parameter that have a weight, in our case, the model illustrates that the three disposal alternatives are valid from the applicability perspective, but the sea disposal include some environmental concerns – as discussed earlier.

The results are shown on a diagram figure 15 above highlighting the green lights to the applicable solution having no environmental concerns and the orange color of the alternative having environmental concerns

Finally, reaching the target of applying the model on our case study, after evaluating all the results and outcomes, calculating cost estimates for each disposal method. In addition to evaluating the environmental concerns for each alternatives the results were illustrated as follows:

a. Evaporation pond disposal :

- Lowest environmental impact
- Slight high cost estimate

b. sea water disposal :

- Highest environmental impact
- Highest cost estimate

c. well injection disposal :

- minimum environmental impact
- lowest cost estimate

CONCLUSION

Applying the "Brine disposal decision support system" (BDDSS) model on a desalination plant is considered to be an effective and quick tool for decision makers from Government side as well as consultants, to get a quick and integrated solution for one of the main aspects related to desalination process, which is brine disposal. This solution not only covers brine disposal techniques, but also takes into account the environmental considerations and cost factor as well.

The BDDSS model will provide the following: (Figure 16).

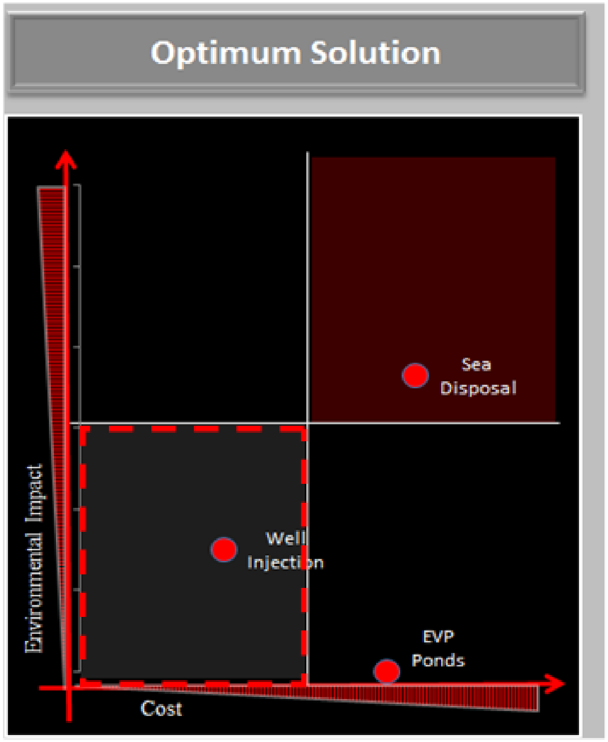

Figure 16. Model snapshot for decision matrix showing the optimum solution

(i) The complete methodology for brine disposal through three scenarios which are:

- Sea disposal
- Disposing brine to evaporation pond
- Disposing brine through injection wells

(ii) The environmental solutions to minimize negative impacts on the surrounding environment for each method and calculate the design criteria for each method
(iii) Environmental solutions are in compliance with the relevant laws and regulations
(iv) The estimated budget for each disposal scenario

After conducting all the above steps, the model will provide the optimum solution, through an evaluation matrix based on the cost / environmental of each disposal alternative. The optimum solution provided is the one achieving lowest cost and lowest negative environmental impact

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