IJESMR
International Journal OF Engineering Sciences & Management Research

OPTIMIZATION MODEL FOR WATER DESALINATION BRINE DISPOSAL

Ismail, M.T.[*1], El Nadi, M.H.A.[2], Wahb, E.S.A.[3], Nasr, N.A.H.4
[*1] PhD student, Faculty of Eng., Ain Shams University, Cairo, EGYPT
[2] Professor of Sanitary & Environmental Eng., Faculty of Eng., Ain Shams University, Cairo, EGYPT
[3]Associate Professor of Sanitary Eng., Faculty of Eng., Ain Shams University, Cairo, EGYPT

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

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 affects 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 (Consultant’s 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 that reaches results in a short time.

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.

INTRODUCTION
Desalination, desalting, desalinization, refers to a water treatment process that removes salt from water. Desalination can be done in a number of ways, but the result is always the same .Fresh water is produced from Brackish or in sea water [1].

The world installed capacity consist mainly of the multi-stage flash distillation and Reverse Osmosis (RO) process, these two process make up about 86 % of the total capacity .the remaining 14% is made up of the multiple effect, electrode analysis,& vapor compress method .while the minor process mounted is less than 1% [2].

Desalination produces two streams of water. One, the product water, is fresh water. The other is concentrate water containing salts and any un-reacted pre-treatment chemicals (Brine), if the latter is used. The salinity and chemical composition of the concentrate stream will vary with the type of desalting plant, the feed water composition, and how the desalting plant is operated.

There are a variety of methods that are used for concentrate management. The most common methods of concentrate disposal include (i) Surface water Discharge, (ii) Ground water Discharge, (iii) Wastewater treatment plant, and (iv) Concentration / Evaporation.

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.

ISSN 2349-6193
Impact Factor (PIF): 2.243

IJESMR

International Journal OF Engineering Sciences & Management Research

BRINE DISPOSAL METHODS

There are many brine disposal alternatives being used or investigated these days, the most common used methods are:

Evaporation Pond Disposal

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 . The principal environmental concern associated with evaporation pond disposal is pond leakage, which may result in subsequent underground aquifer contamination. Evaporation ponds are relatively easy to construct, while requiring low maintenance and little operator attention compared to mechanical systems.

Sea water disposal

Brine is transported through an outfall pipe and discharged directly into the ocean or estuary from the end of the pipe when natural mixing is available. In seawater desalination the concentrate is denser then seawater and diffusers that accelerate the diffusion and mixing process are used. Plants in the Middle East generally use this type of discharge.

Deep well injection

Deep well injection is presently the most common technique used for brine disposal in Egypt. Injection wells may vary in depth from a minimum of 100 m from sea level up to few hundred meters, depending on geological characteristics of the selected site. The injection of brine water to deep underground formations can provide a disposal alternative where none was previously available. Potential environmental impacts of deep well injection include the potential degradation of useful groundwater aquifers, the alteration of deep geologic formations and increasing soil salinity which might affect crops.

MODEL APPLICATION

INTRODUCTION TO THE MODEL, OBJECTIVES AND TARGET

Mathematical modeling is the process of creating a mathematical representation of some phenomenon in order to gain a better understanding of that phenomenon. A mathematical model can be defined as a representation of the essential aspects of an existing system (or a system to be constructed) that presents knowledge of that system in usable form. Mathematical models typically contain three distinct types of quantities: output variables, input variables, and parameters (formulas). Output variables give the model solution. The choice of what to specify as input variables and what to specify as parameters is somewhat arbitrary and often model dependent. Input variables characterize a single physical problem while parameters determine the context or setting of the physical problem.

This section will provide an overall comprehensive description on the model, starting from model target, objectives, and benefits then identifying users and profile that can use the model and benefit from the outcomes, and finally providing a full description on all parts of the model.

The model's main objective is to assist decision makers (Consultant's or Government authorities) in the selection of an optimum brine disposal method applying applicable, environmentally friendly and cost effective methods, through a user friendly interface that reaches results in a very short time depending on users inputs

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, based on the user inputs, 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

IJESMR
International Journal OF Engineering Sciences & Management Research

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 BENEFITS & VALUE PROPOSITION

The coming section illustrates the benefits of the model, and how it integrates several tasks done by different entities / consultants in few steps, some of the model benefits are illustrated as follows:

i. Integration of services
- The model integrates identifying applicable water disposal solutions, applying environmental mitigation measures and check compliance with the regulatory / and environmentally aspects together
- In addition to above, the model also achieve value for money for optimum disposal method, by assisting decision makers reaching the most economic benefits of each disposal method

ii. Acting as consortium of experts
The model can act as an expert on the following tasks:
- Water Expert
  It can provide a robust applicable method for brine disposal alternatives including design details for each method as:
  - Sea disposal
  - Well injection
  - Pond
- Cost Expert
  The model can act as a cost engineer / expert in estimating budget/ costs for all disposal options identified above, assisting decision makers in verifying the value for money for the optimum method to be used
- Environmental Expert

The model also can act as an Environmental expert, to ensure compliance of each disposal model with all relevant laws & regulations

The model's interface is considered to be a user friendly interface, as it is supported by auto assisting aiding tools that that provide the users with smart illustrations and hints on the screen that guide the users during entering the input data

The interface is also supported by indicative sketches that show all data and outcomes on the corresponding diagrams

Thus the smart interface with the auto aiding tools save time to reach results, as well as avoid boring of seeing just numbers and figures

MODEL USERS & PROFILES

The model addresses a wide range of users starting from an owner of a project who needs to know the optimum solution having the minimum cost and complies with the regulations in order to get the necessary approvals, moving forward to a government entity who wants to check the compliance of the desalination plant to the laws and regulations and ensure it followed the right approach to dispose the brine. Finally the model addresses also the consultant who might be hired by the previous users mentioned above to study the different alternatives for brine disposal as per each entities objective.

The model is designed to address the different requirements of the three identified users; this can be addressed in the next section:

I. Project owner: the Project owner requires hiring a consultant / Water Expert & Environmental expert to design the desalination plant and suggest possible solutions for brine disposal that can achieve minimum

ISSN 2349-6193
Impact Factor (PIF): 2.243
IJESMR
International Journal OF Engineering Sciences & Management Research

cost (VFM) and to be complying with the Environmental regulations in order to obtain approval and permits from the local authorities

II. The Government entity : the government entity requires hiring a consultant / Water Expert & Environmental expert to design the desalination plant and suggest possible solutions for brine disposal that is complying with the Environmental regulations and shall not be threatening the surrounding environment

III. The Consultant: two types of experts / consultants shall be on board as follows:
- A Water Expert to design possible solutions for brine disposal including:
  - Sea disposal
  - Well injection
  - Evaporation ponds
- A Water / cost expert to estimate the budget / cost required for each disposal method
- Environmental Expert to assess negative impacts born by each disposal method, in addition apply methods that decrease negative environmental impacts and ensure compliance of the suggested methods with the applicable laws and regulations

All of the three users can use the model directly without depending on one another, thus reaching out quick comprehensive solutions, saving time and money

STRUCTURE OF THE MODEL

Like any analytical model, this model consists of inputs, outputs and formulas that convert the input data into real outputs that achieve a defined target

The figure below shows the model three sections inputs, formulas and outputs

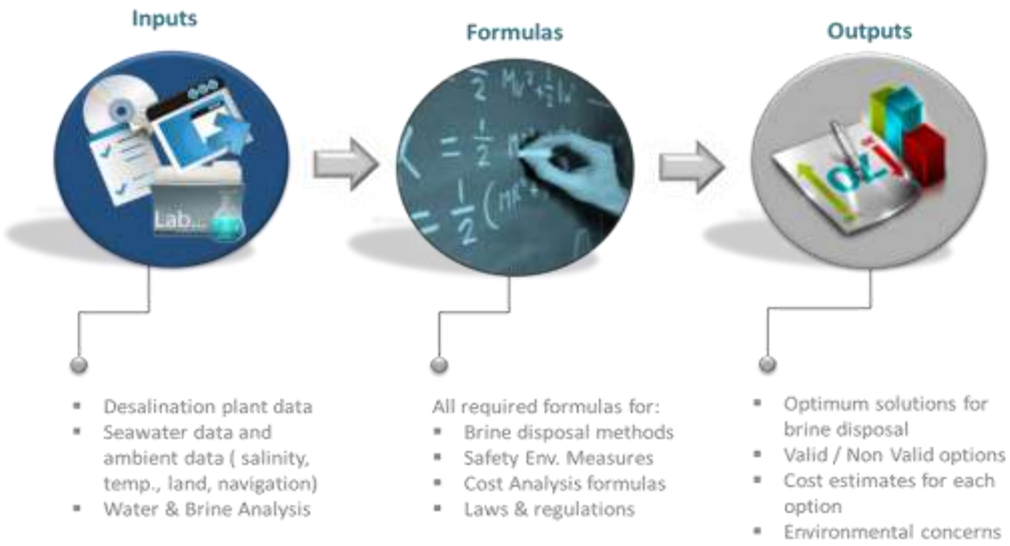

Fig (1) Model Structure

In the next section a detailed description on the three main sections of the model supported by real snapshots from the model

MODEL INPUTS

The model's input includes the following parameters:
- Desalination plant data such as :
  - No. of RO Skids
  - Recovery rate *(r)*
  - Influent Flow Rate (Q_{drink})
  - Brine Flow rate
  - Brine Temperature (T_{desal})

ISSN 2349-6193
Impact Factor (PIF): 2.243

IJESMR

International Journal OF Engineering Sciences & Management Research

  - Brine PH

- Water & Brine Analysis, as:
  - TDS readings for both influent, effluent and brine

- Inputs related to disposal alternatives, are shown as follows:

a. Inputs related to sea water disposal	b. Inputs related to deep well injection	c. Inputs related to evaporation pond disposal
▪ sea water salinity ▪ sea water temperature ▪ Bottom slope ▪ Discharge angle ▪ land & soil characteristics ▪ sea water navigation status	▪ Well Depth ▪ Number of Wells ▪ Well Diameter	▪ Conversion factor of fresh brine ▪ CF – Contingency factor ▪ Standard evaporation rate ▪ Available area ▪ Agriculture land around site ▪ Pond depth ▪ Free board ▪ Plant slopes ▪ Ponds dikes ▪ Dikes high ▪ Pond liners type

The model then compiles the inputs with the formulas embed within to come up with the appropriate solutions for brine discharge

The figures below show real snapshots of the model illustrating the inputs parameters for the three disposal alternatives that the user has to enter based on the real data on site

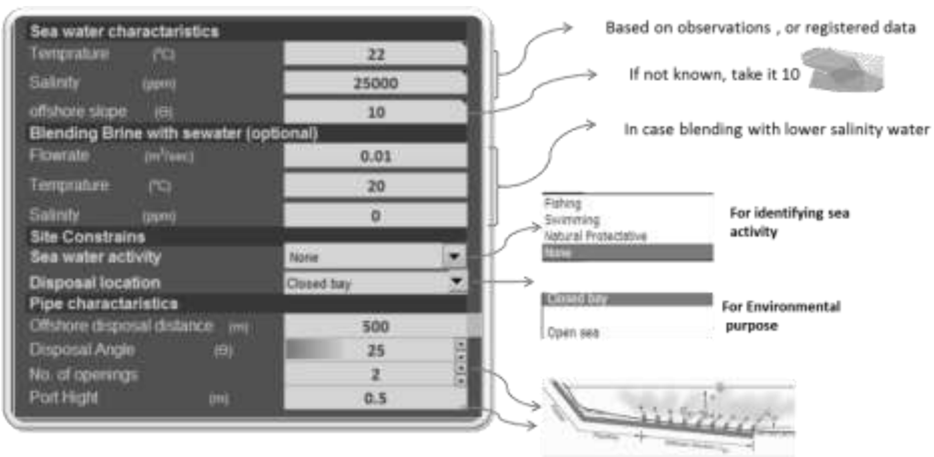

Fig (2) Model snapshot – inputs related to seawater disposal

ISSN 2349-6193
Impact Factor (PIF): 2.243

IJESMR

International Journal OF Engineering Sciences & Management Research

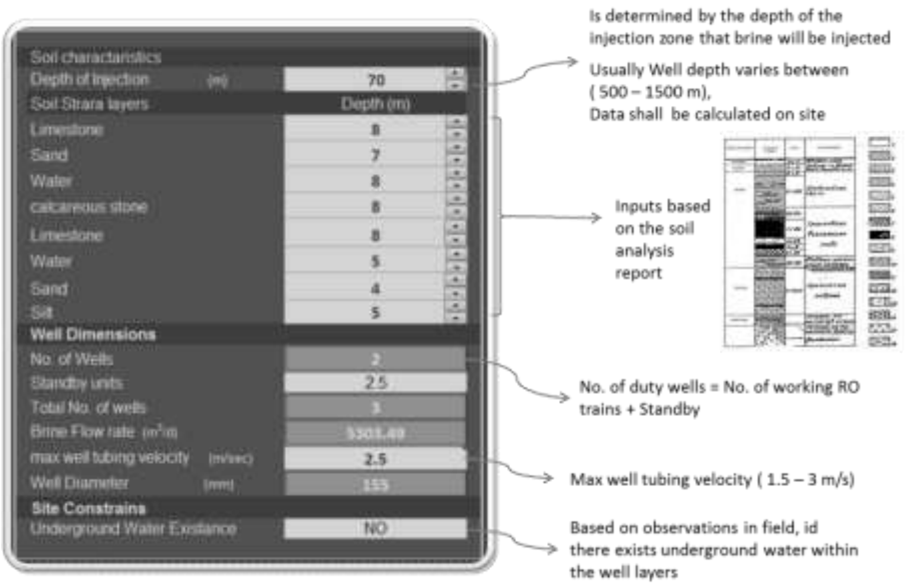

Fig (3) Model snapshot – inputs related to well injection

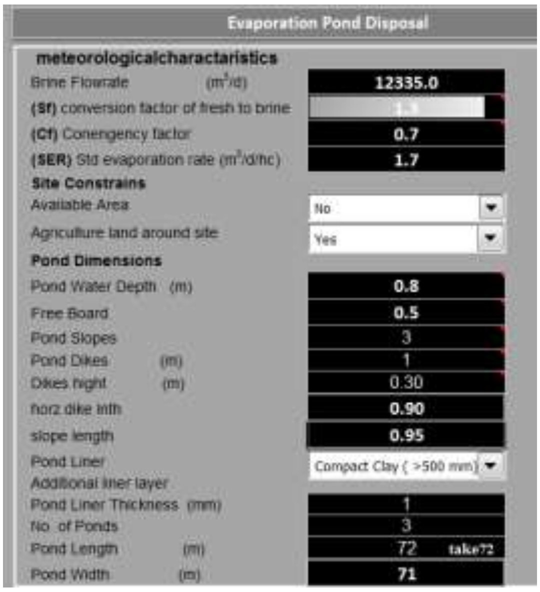

Fig (4) Model snapshot – inputs related to evaporation pond

MODEL FORMULAS

The formula section includes all the required formulas to convert the data inputs to a comprehensive outputs, it includes all the design principles and equations applied for each disposal method. In the next sections, a detailed explanation of the Formulas applied to the three disposal methods is provided.

After feeding the model with all the desalination plant data required by the model as illustrated in the previous section (Model inputs), also information related to the three disposal alternative is fed to the model to enable the model to analyze those data and estimate the discharge parameters.

Formulas related to Sea water disposal

Once the plant design has been drafted, and the model is fed by the Influent Flow Rate, Recovery rate, initial brine effluent characteristics should be computed. The next section includes a description for a simple calculator to compute effluent characteristics in comparison with ambient conditions.

ISSN 2349-6193
Impact Factor (PIF): 2.243

IJESMR
International Journal OF Engineering Sciences & Management Research

The model design is based on Microsoft excel software; a spreadsheet was developed for the estimation of effluent flow rates and their characteristics of a RO desalination plant. The procedure is based on a technical note "Improved Discharge configurations for Brine Effluents from Desalination Plants" by Jerika (2006).

The density calculator is based on El-Dessouky and Ettouny (2002) **[3]** and is valid for salinities between 0 to 160 ppt and temperatures between 10 to 100 °C at pressures of p = 1 atm. The density correlation is given by:

$$\rho = (A1F1 + A2F2 + A3F3 + A4F4) \cdot 10^3 \ [kg/m^3]$$

Results are the final effluent flow rate, the effluent temperature and salinity, and the resulting density and viscosity and substance concentrations. In addition the calculator computes the buoyant acceleration defined as go' = g (ρo - ρa)/ρo with g = earth acceleration, ρo = effluent density at discharge point, ρa = ambient density. The buoyant acceleration is a measure for density induced motions. The effluent is positively buoyant for positive go' and negatively buoyant (sinking down) for negative go'.

Estimation for the jet properties: After calculation of density & viscosity, the required design of the outfall (geometry) and its characteristics (discharge velocity Uo, momentum flux Mo, length scales LQ & 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)

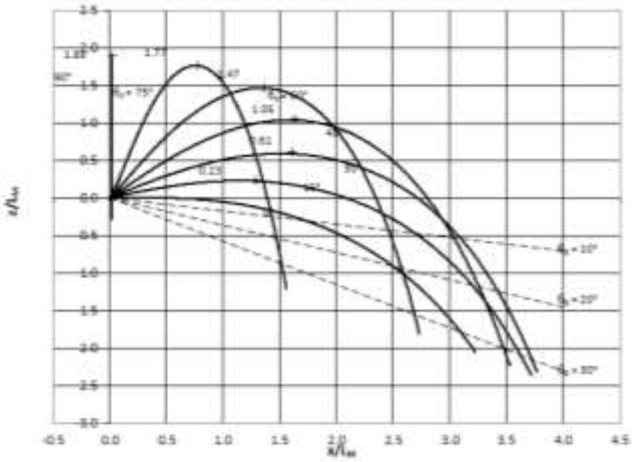

Fig (5) Jet trajectories for variable offshore slope

Formulas related to well injection disposal
To properly design and install a deep well injection facility, a complete geologic and geochemical analysis of the reservoir formation is required. Before drilling any injection well, a careful assessment of geological condition must be conducted in order to determine the depth, location, and thickness of a suitable porous aquifer reservoir, as well as determining its permeability.

The following parameters are considered to be the main aspects for designing the injection:

a. Well Depth

- Is determined by the depth of the injection zone that brine will be injected
- Data of the target hydro geological formation shall be available first
- Determination of the depth and capacity of the deep confined aquifer

Usually Well depth varies between (500 – 1500 m), to be calculated on site based on the geological study made and soil analysis report.

b. Number of Wells

- No. of wells is determined as a function of the RO plant operation pattern (RO membrane skids / trains)
- Usually total No. of duty discharge wells are designed to match the No. of RO trains
- There are standby units of discharge capacity of (20-30%), to work during maintenance

Therefore, No. of duty wells = No. of working RO trains + Standby

ISSN 2349-6193
Impact Factor (PIF): 2.243

IJESMR
International Journal OF Engineering Sciences & Management Research

c. Well Diameter

Well diameter is a function depending on:

- Max well tubing velocity (1.5 – 3 m/s)
- Total max concentrate discharge flow rate
- Total No. of duty wells

The chart below used to obtain the sizing of the well (well diameter) using the inputs mentioned earlier

So, depending on the discharge capacity and the tubing velocity, the well diameter shall be obtained

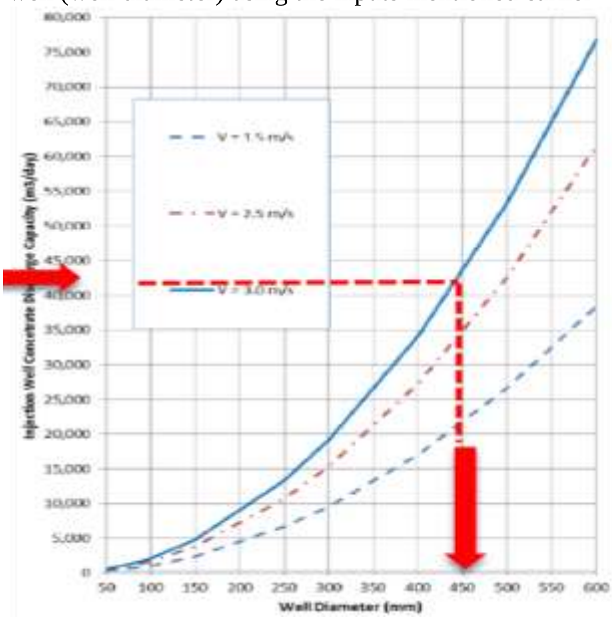

Fig (6) illustration for getting well diameter using max tubing velocity and injection discharge

a. Well Casing

Casing is a term that refers to tubular material extending from the surface to some depth in the well. It is installed to accommodate the sealing of the well, to stabilize the walls of the borehole, or to allow the installation of screen or liner . At least two types of casing are often found. Surface casing is installed a short distance (to the first impermeable strata or minimum of 18 ft, (6 m according to many codes) from the surface to a depth sufficient to allow the installation of the surface seal (usually cement grout) between the surface casing and the well bore.

Formulas related to the evaporation pond disposal

Most ponds are designed in square or rectangular shapes, the following parameters are considered for pond design:

1 Ponds dimensions

– Pond Depth

Optimum pond depth in terms of evaporation rate is approximately 2 ft (0.5 in, 0.6m), but often deeper 8 to 16 ft (2.5 to 5.0 in) ponds are used in order to reduce their construction costs and to accommodate salt accumulation at the bottom of the ponds, as well as to provide for accumulation of water from precipitation and for contingency water storage.

– Pond Dikes

The perimeter of the evaporation ponds is surrounded by earthen dikes. The dikes are typically compacted earthen structures with slope of 2:1 to 4:1 and 12 to 20 ft (4 to 6 in) wide road on the top. Dike height usually varies between 5 to 12 ft (1.5 in and 4 m).

– Pond Area

The evaporation pond surface area is primarily function of the evaporation rate, which in turn is determined by local climate conditions.

2 Pond area calculation formula

IJESMR
International Journal OF Engineering Sciences & Management Research

$A_p = (Q_{conc} \times S_f) / (C_f \times SER)$

Where:

- A_p = Active evaporation pond area (ha)
- Q_{conc} is = Concentrate flow rate (m^3/day)
- SER = Standard evaporation rate of fresh water m3/day.ha
- S_f = Factor of conversion of fresh water Evaporation rate to concentrate evaporation rate , and typically has a value between (1.2-1.3)
- Cf = Contingency factor (taken 70% , i.e: 0.7)

Based upon the previous stated criteria, the model allows the user to input the following parameters:

- Pond water depth (taken between 0.25 – 1.5 m)
- Free board (taken between 0.2 – 0.6 m)
- Pond Slopes (taken between 2:1 – 4:1)
- Pond Dikes (taken between 1-3 m)

Then the model calculates the slope length accordingly

MODEL OUTPUTS

Based on the inputs provided by the user, the model starts compiling the parameters obtained from data collected in relation to desalination plant and ambient conditions using the formulas and charts embedded within the model to come up with the requested design parameters. The outcomes of the model are represented in the form of dashboards and diagrams providing all the required data at a glance, those diagrams are shown in the following figures:

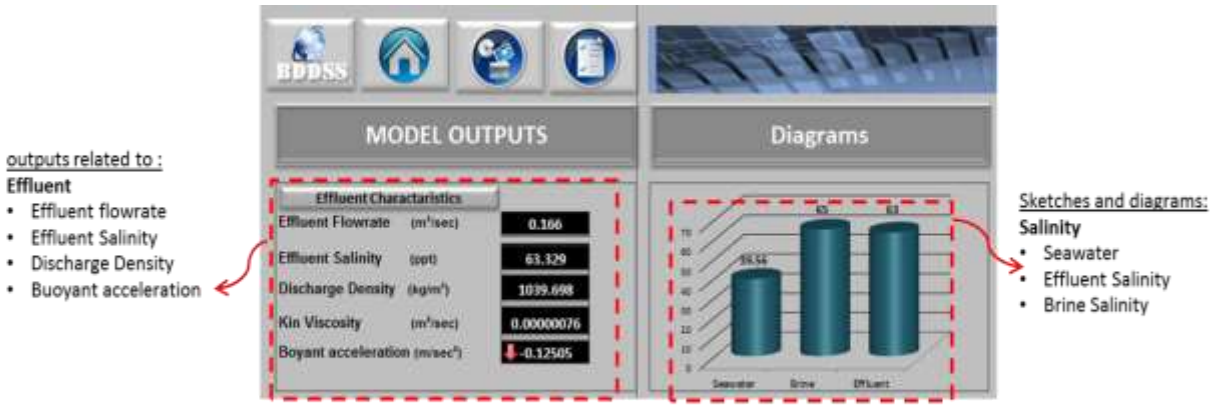

Fig (7) Model snapshot – outputs related to sea water disposal effluent & ambient conditions

The figure (7) above shows a real snapshot of the model illustrating outcomes of the ambient characteristics. While figure below (8) shows outcomes related to jet properties for sea water brine disposal.

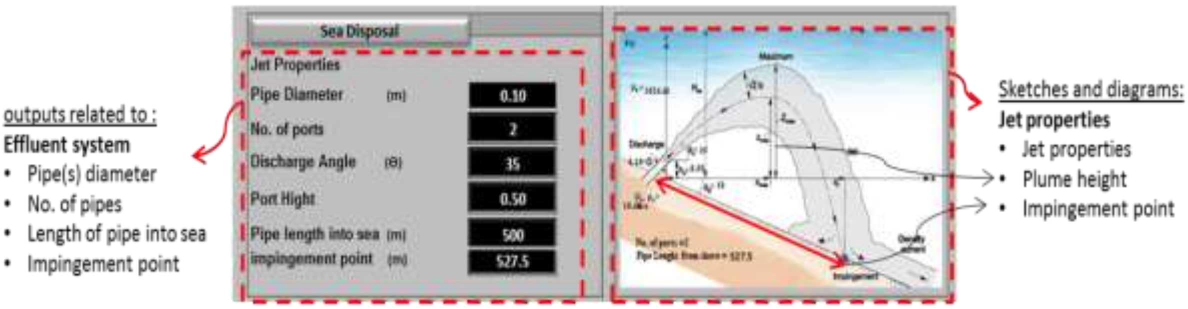

Fig (8) Model snapshot – outputs related to sea water disposal piping and jet properties

ISSN 2349-6193
Impact Factor (PIF): 2.243

IJESMR
International Journal OF Engineering Sciences & Management Research

- Pond Area
- Pond Length
- Pond Width
- Upper & Lower length
- Base & Side areas
- Pond Volume

Regarding the second alternative, evaporation pond disposal, and based on the flow rate of the rejected effluent, the user's opinion where there is an available land to accommodate the ponds or not, in addition to the given formula for calculating the pond area, the model will calculate the following parameters:

Also 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 illustrates 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. As shown in figure (9)

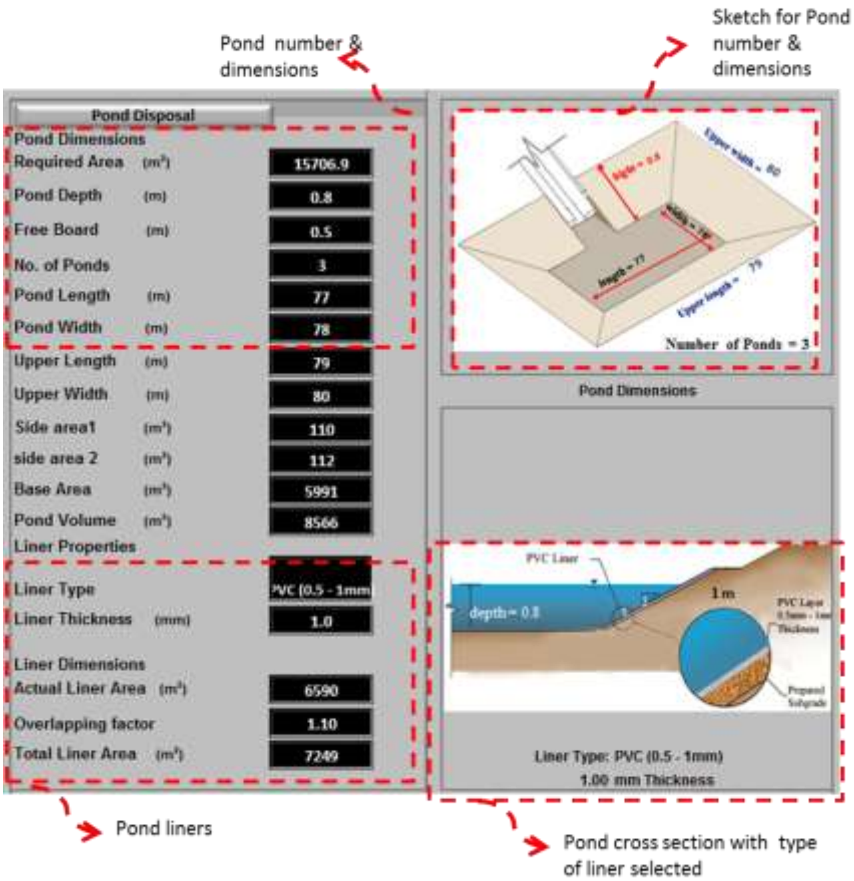

Fig (9) Fig Model snapshot – outputs related to ponds disposal

ISSN 2349-6193
Impact Factor (PIF): 2.243

IJESMR

International Journal OF Engineering Sciences & Management Research

The injection well disposal alternative is 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 wells which define well specifications as follows

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

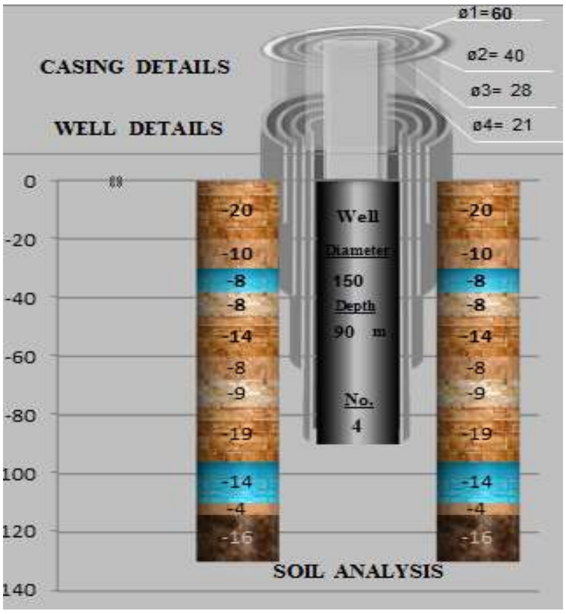

Fig (10) Model snapshot – outputs related to injection well disposal

RESULTS AND DISCUSSION

In order to consolidate the final conclusion and obtain the optimum solution for brine disposal for any desalination plant, the model starts compiling the outcomes & results obtained from the three disposal alternatives in terms of:

- Alternative applicability
- Cost effectiveness
- Environmentally friendly

First, in terms of the cost effectiveness, the model calculates the estimate cost for each applicable disposal alternative, then start comparing among the three alternatives and choose the one that have the minimum cost. And illustrates it visually on a diagram

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 alone.

Fig (11) Model snapshot for alternatives cost comparison

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.

ISSN 2349-6193
Impact Factor (PIF): 2.243

IJESMR
International Journal OF Engineering Sciences & Management Research

Accordingly, each of those concerns became a parameter that has 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)

Finally, reaching the target of applying the model on any desalination plant, 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 :

The optimum solution lies in the quadrant 1 (having the least cost and least environmental impact)

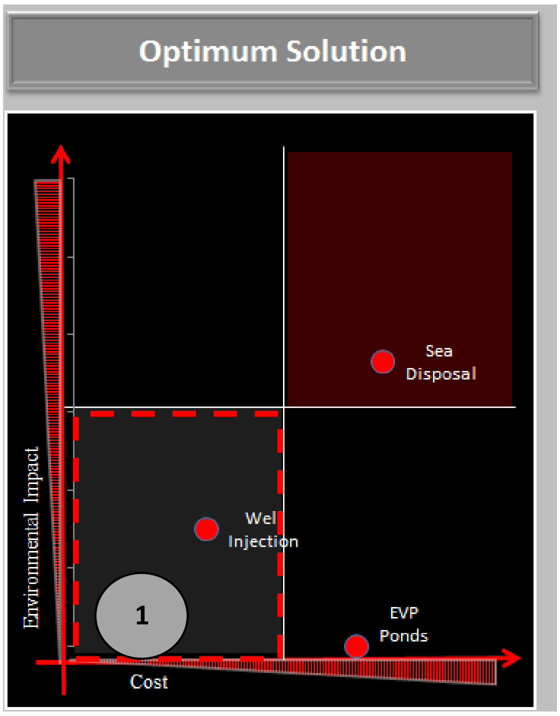

Fig (12) Model snapshot – evaluation matrix (Cost / Env. impact matrix)

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.

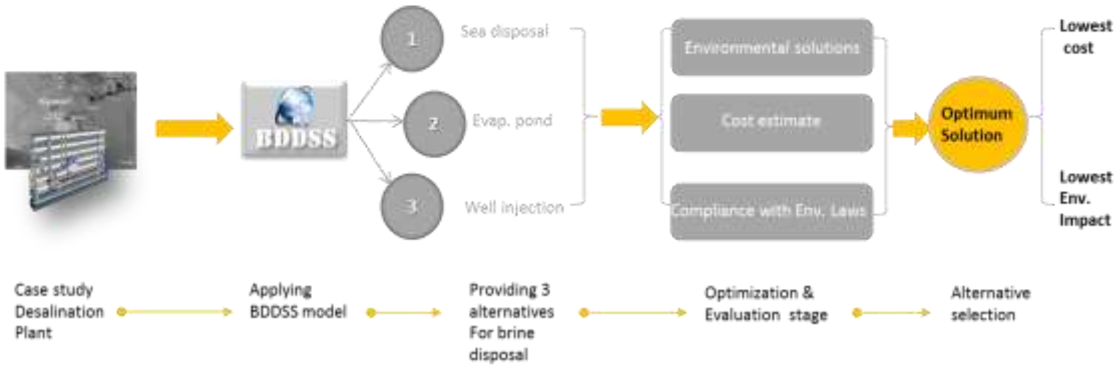

Fig (13) Methodology for applying the BDDSS model

The figure (13) above provide the methodology for applying the BDDSS model on any desalination plant
The BDDSS model will provide the following:

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

ISSN 2349-6193
Impact Factor (PIF): 2.243

IJESMR

International Journal OF Engineering Sciences & Management Research

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

REFERENCES

1. Abdel-Jawad, M., and M. Al-Tabtabaei, 1999, "**Impact of current power generation and water desalination activities on Kuwaiti marine environment.**", IDA World Congress on Desalination and Water Reuse, August 29 - September 3, San Diego, California, USA.
2. Abdel Moneam, M.T., 2008, " **Environmental Assessment of Reverse Osmosis Desalination Plants**.", M. Sc. Thesis, Public Works Dept., Faculty of Eng., Ain Shams Univ., Cairo, Egypt
3. El Dessouky, Elttouny (2002) "**Fundamentals of seawater desalination" Appendix A Thermodynamic properties**