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ENVIRONMENTAL DISPOSAL OF BRINE FROM REVESRE OSMOSIS DESALINATION PLANTS

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Abstract

Technologies used in water desalination are accompanied by adverse environmental effects. There are several effects to be considered in desalination plants, such as the use of the land, the groundwater, the marine environment, noise pollution and the use of energy. The objectives of this study is the determination of the environmental impacts of Rejected brine in Reverse Osmosis desalination plants, according to the site visits to RO plants in Egypt and the analysis conducted with regards to the brine disposal impacts and thus propose the best solution for impacts handling according to the Egyptian conditions to reach finally to an environmentally friendly desalination plant.

Key words: Desalination, Reverse osmosis, Desalination environmental impacts, Brine rejection

INTRODUCTION

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.

In comparison to all desalination techniques, Reverse Osmosis (RO) is relatively new, with successful commercialization occurring in the early 1970s. Reverse Osmosis has become a system used in desalination and major technological advancements have been made in within this field all over the world especially in Middle East. In Egypt RO desalination is becoming more and more commercialized and increasing the spectrum of suitable and possible applications for it, as Egypt is encouraging, not only the public sector but also the private sector, to apply modern technologies for desalination. **[1]**

The main problem while studying desalination techniques is the environmental aspects, Reverse Osmosis desalination plant is accompanied by adverse environmental effects. Some of these environmental effects are considered to be negative impacts to the surrounding environment such as contaminating underground aquifers – if exists – and threatening marine life organisms.

Concentrate discharge is one of the principal features of planning a desalination plant regardless of location and type. Concentrate disposal considerations include potential environmental impacts, permitting requirements, concentrate water quality, receiving water quality, costs of disposal system, public perception and awareness, and other site-specific issues. **[2].**

MATERIALS AND METHODS

This study is divided into two parts, the first part is the theoretical part which determines the data collection phase including the literature review and studying of the negative impacts accompanied by RO plants construction and operation. The second part is the practical part which includes the site visits to different RO plants in Egypt and the analysis conducted to raw water, rejected brine and final product water.

A. THEORITICAL

The theoretical part is related to the following tasks:

- Data collection for Reverse osmosis desalination plants including process description, countries applying those plants, plants' components and factors affecting those components.
- Highlight the negative environmental impacts resulting from construction and operation of the RO plants
- Illustrate applications and methods used for minimizing impacts resulting from construction and operation of RO plants

B. PRACTICAL

The practical part is related to the following tasks:

- Prepare a plan for field visits to several RO plants in Egypt to cover all the regions that use RO plants
- The six proposed plants are covering RO plants along the Red sea like Hurghada, Sharm El sheikh, Al Quseir and Ras Ghareb and along the Mediterranean sea like RO plants in marsa matrouh and El Saloum
- Analysis have been conducted for each plant on the negative environmental impacts like raw water, rejected brine and final product water
- Study the results of pollutants measured and make assessment on their negative impacts on the environment.
- Illustrate methods used to mitigate the negative impacts according to the Egyptian conditions.
- Provide the optimum solution for minimizing the negative impacts
- Illustrate the regulating laws concerning the environment in Egypt **[3]**

RESULTS

PLANTS EFFLUENTS ANALYSIS RESULTS

The field analysis includes the following measurements, the measurements for saline water covers:

- Raw Water
- Pre – treated water
- Rejected brine water

ANALYSIS RESULTS SUMMARY

Raw water vs rejected brine

PH Analysis

Table (1) Field results of PH values in Raw & Brine water

Type	Ras Ghareb	Quseir	Marsa Matrouh	Saloum	Sharm El Sheikh	Hurghada	Marsa Alam
Raw	**7.8**	**7.3**	**7.8**	**7.8**	**7.35**	**7.22**	**6.98**
Brine	**7.85**	**7.4**	**7.84**	**7.82**	**7.48**	**7.56**	**7.35**

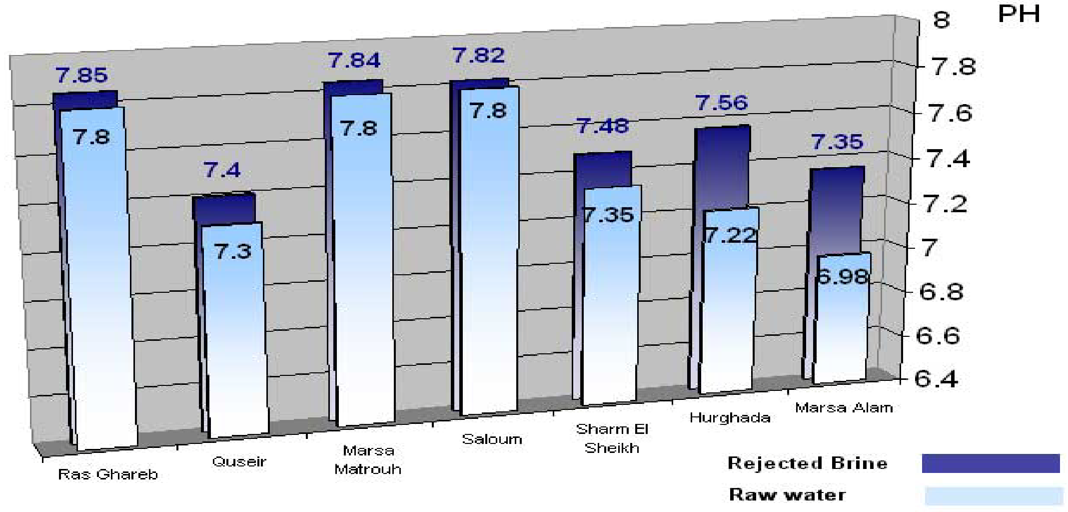

Fig (1) Graph of results of PH values in Raw & Brine water

From the above result it is obvious that the PH value in the rejected brine is more than the PH value in raw water, but with small difference

Conductivity Analysis

Table (2) Field results of Conductivity values in Raw & Brine water

Type	Ras Ghareb	Quseir	Marsa Matrouh	Saloum	Sharm El Sheikh	Hurghada	Marsa Alam
Raw	**24400**	**68000**	**21700**	**49600**	**64800**	**49200**	**60800**
Brine	**37500**	**104780**	**33324**	**76135**	**99132**	**75400**	**84500**

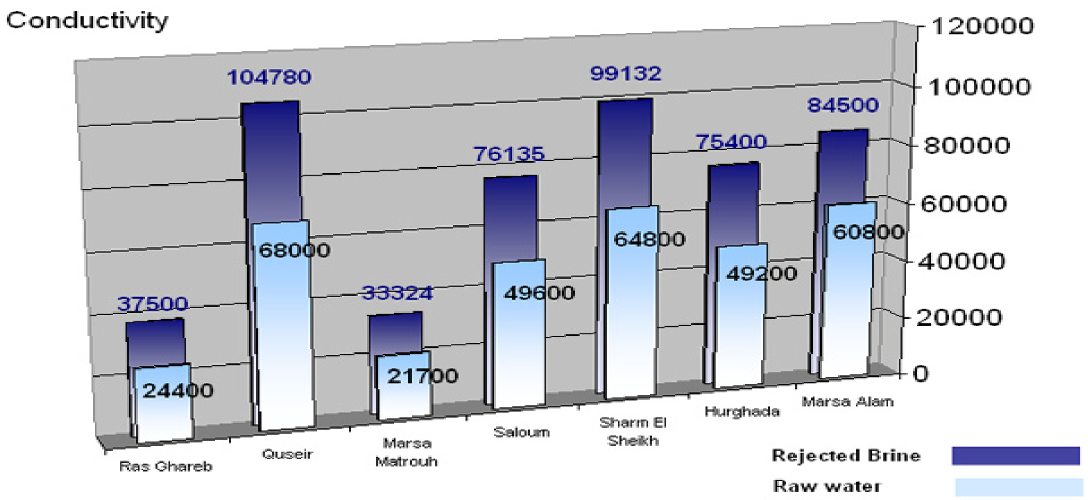

Fig (2) Graph of results of Conductivity values in Raw & Brine water

From the above result it is obvious that conductivity value in the rejected brine is more than the conductivity value in raw water, specially in the Red sea.

TDS Analysis

Table (3) Field results of TDS values in Raw & Brine water

Type	Ras Ghareb	Quseir	Marsa Matrouh	Saloum	Sharm El Sheikh	Hurghada	Marsa Alam
Raw	16200	45800	14500	34300	43600	34500	42010
Brine	24890	70338	22300	52760	66900	55383	67216

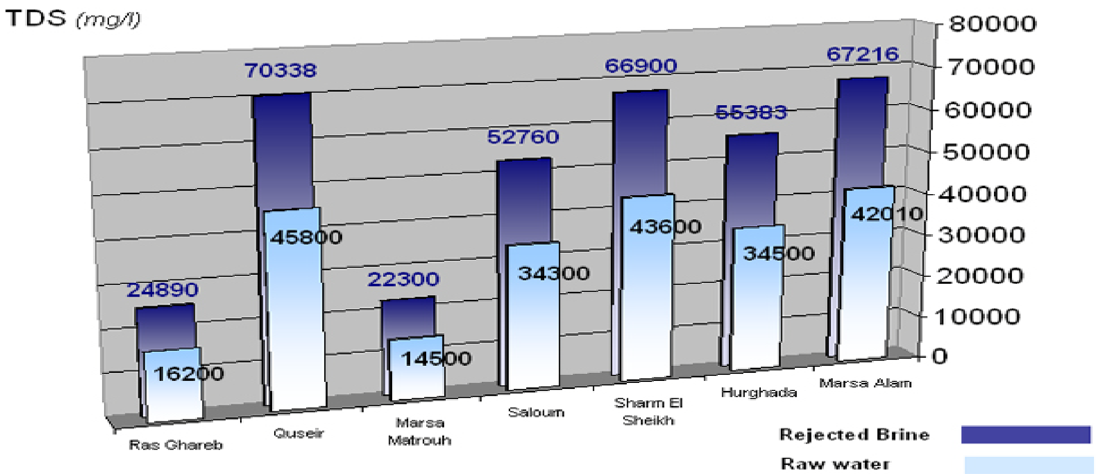

Fig (3) Graph of results of TDS values in Raw & Brine water

From the above result it is obvious that the TDS value in the rejected brine is more than the PDS value in raw water, especially in the Red sea. **[3]**

DISCUSSION

Technologies used in water desalination are accompanied by adverse environmental effects. The main negative effects to be considered in desalination plants is the groundwater, the marine environment, To protect and preserve the environment, most countries turned to assess the environment impacts produced by desalination plants. Seawater desalination plants are located by the shoreline, to supply desalted water to the population of the main cities and other uses. The construction of both the desalination plants and all the required infrastructure in coastal areas affects the local environment. The impact on groundwater is due to the seawater pipes leaks which could contaminate the aquifers.

The high salt concentration in the brine (TDS of brine ranges from 22,000 mg/l up to 70,000 mg/l) and several chemical products used in the desalination process are returned to the sea. Most impacts on the marine environment arise as a consequence of the brine discharge. Analysis have been made on the environmental problems of seawater reverse osmosis desalination plants, focusing on some case studies, and describing the major pollutants and their environmental impacts, which is the waste Disposal impact, classified to:

- Brine surface discharge
- Brine evaporation ponds
- Brine deep well injection

The majority of impacts can however be effectively mitigated through the use of current environmental protection measures and careful planning.

From all above site visits, it's obvious that the negative impacts, regarding brine disposal, can be classified as follows:

WASTE DISPOSAL TO SEA

Only 28% of the plants dispose brine by a long pipe into the sea, the main impact is due to the discharge of the concentrated brine to the sea, and its magnitude depends on environmental and hydro geological factors characteristic of the sea: waves, currents, depth of the water column etc. These factors would determine the extent of the mixing of the brines and therefore the geographical range of the impact.
The brine returned to the sea, would form a plume of highly saline seawater, the plume would sink to the sea floor as it constitutes a hyper saline layer which sinks towards the sea bed due to its greater density and its effects would extend over a range of hundreds of meters.

Usually brine is disposed by more than one pipe and on different levels to avoid concentrating brine into one point, the pipes are HDPE as to resist corrosion, and thus reduce leakage and impacting the marine environment. Also pipes are extended for about 300 – 400 meters horizontally into the sea to avoid shore pollution, and going downwards from 50 – 60 meters.
Also pipes may contain nozzles at the end to disperse brine and avoid concentration in one point.

Sometimes brine are mixed with effluent water coming out from a beach well, then pumped put o the sea, thus make some dilution for brine water before disposing into sea, and this is considered to be a solution for minimizing negative impacts from directing brine into the sea.

WASTE DISPOSAL TO INJECTION WELL

Only 57% of the above mentioned plants dispose brine into injection wells without dilution, accordingly the brine raise the salinity of the seawater, also introduce chemicals and hazardous wastes to marine life in case of disposing to sea, or contaminating underground water in case of disposing into injection wells.

Injection wells varies in their depths starting from 40 m to 70 meters and the most common concern in all the above mentioned plants is that the difference in level between the injection well and the beach intake well is around 10 m, and sometimes the distance between them doesn’t exceed 300 or 400 meters, so this may cause contamination of the intake well by the brine that is injected in the injection well.

Considerations must be taken to reduce the negative impacts of brine on the underground water, like injecting brine into porous rock or sand formations below the ground surface. The well is generally called a 'deep well' because the proposed injection occurs beneath the lowermost underground source of usable water. Any porous and permeable rock formation such as sandstone can act as a disposal reservoir for the injection liquid brines that contains undesirable level of solution may cause problems due to the undesirable introduction of solids into the near well bore region.

Potential environmental impacts of deep well injection include the potential degradation of useful groundwater aquifers, the alteration of deep geologic formations by increasing subsurface fluid pressures in the vicinity of the injection wells and potentially inducing subsurface fracturing and seism city.

Contamination of potable water supplies may occur (in case of the existence of an aquifer) either by lateral migration of acid wastes to existing unplugged dry holes or producing wells , or by vertical migration through the subsurface aquifer due to mechanical failure or geological fault line shifting .

Perhaps the most dramatic risk of geological faulting associated with deep well injection is the potential for stimulation of earthquakes in certain seismic areas.

Also these brines may become contaminated with certain heavy metals, these heavy metals may precipitate as oxides or hydroxides which damage the formation of water in the aquifer, if the pretreatment residuals are not treated and they are mixed directly with brine. **[3]**

WASTE DISPOSAL TO EVAPORATION POND

One plant disposes brine into an evaporation pond, it 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.

Improper disposal has the potential for polluting the groundwater resources and can have a profound impact on subsurface soil properties. Seepage from brine cause groundwater contamination of the source well and results as an increase in hardness of the groundwater. High salt contents in reject effluent with elevated levels of sodium, chloride, and boron can reduce plants and soil productivity and also increase the risk of salinization. Additional impacts include increasing irrigation and rain water run off, poor aeration and reduce leaching of salts from root zone because of poor permeability.

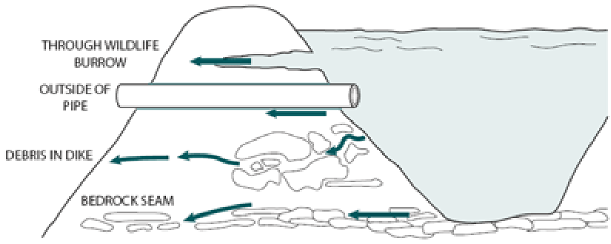

Figure (4) Causes of ponds leaking [4]

Heavy metals and inorganic compounds build up in the soil and groundwater resources may cause long term health problems

All current installations are lined with polyethylene or various other polymeric sheets. Liner installation must be carried out with care since sealing of joints is critical in order to prevent leakage. see figure (4)
Double lining is strongly recommended with leakage sensing probes installed between layers of pond lining.

Therefore there is a need for careful environmental monitoring of potential pond leakage, since a variety of toxic chemicals generated in plant operation (including chemicals used in membrane cleaning and pretreatment) may pose a potential risk for contamination of ground water aquifers. **[3]**

ENVIRONMENTAL PROBLEMS SOULTIONS

SOLUTIONS USED FOR DIRECT DISCHARGE

The effects of brine disposal into sea can be mitigated by adequate dispersal and mixing of concentrated brine wastes. On occasion, brine flows are mixed with other fresh or waste water flows, such as power plant cooling water discharges, to dilute them before discharge.

Where liquid disposal of concentrated brines is required this should involve adequate dilution, mixing and dispersal, should be restricted to areas of low biological sensitivity and should be subject to adequate monitoring regimes.

CURRENT SOLUTIONS USED FOR MINIMIZING THE IMPACTS OF BRINE DISPOSAL TO SEAWATER:

- Only 28% of the above mentioned plants use the technique of Mixing the effluent brine with raw water before discharging it into the sea, this can be achieved by two methods :
  - Mixing the effluent brine from the brine tank with the effluent water from a beach well (lower in salinity than brine) to achieve dilution. See figure (5)
  - Mixing the effluent brine with other waste flows prior to sea disposal. like dilution with a power stations cooling water or with municipal wastewater, and this reduce negative impacts by 30%.
- Also, 28% of the above mentioned plants use more than one pipe for disposing brine into the sea at different distances and at different levels to avoid concentration of brine in one location, and this reduce negative impacts by 15%.
- And 17% of the plants is applying a technique of making the last portion of the disposing pipe has punches (holes) (usually the last meter), as to avoid concentration of brine plume in one point and to achieve well disperse of brine in sea water, and this reduce negative impacts by 15%.

Fig (5) Mixing Brine with beach well for dilution [3]

SOLUTIONS USED FOR WELL INJECTION

Deep well injection is an alternative method for brine disposal provided that long-term operation can be maintained.

CURRENT SOLUTIONS USED FOR MINIMIZING THE IMPACTS OF WELL INJECTION

- None of the above mentioned plants dispose brine at depth more than 100 m, and this is considered to be a threaten to the underground aquifers and also the fossils underground.

CLASSES OF INJECTION WELLS

EPA defines an injection well as any bored, drilled or a driven shaft or a dug hole, where the depth is greater than the largest surface dimension that is used to discharge fluids underground
EPA classifies injection wells as five categories: Class I, II, III, IV,and V

- Class I wells

Class I wells are used to inject hazardous and non-hazardous wastes below the lowest underground source of drinking water . Injection occurs into deep, isolated rock formulations that are separated from the lowerest underground source of drinking water by layers of impermeable clay and rock. Class I injection wells are strictly regulated

- Class II wells

Class II injection wells are those wells associated with oil and gas industry. They include wells which brine is injected, see figure (10)
Example of fluids:

- High salinity brine
- Crude oil for storage
- Polymers , drilling fluids and muds

- Class III wells

Class III wells are wells that inject super-heated steam , water or other fluids into formations in order to extract minerals . the injected fluids are then pumped to the surface and the minerals in solution are extracted. Generally ., the fluid is treated and re-injected into the same formation.
Examples of fluids used in the solution mining of various minerals:

- Fresh water to extract salt (NaCl)
- Sodium bicarbonate to extract uranium salts
- Steam to extract sulphur
- Proprietary solutions to extract other minerals and metals

- Class IV wells

Class IV wells inject hazardous or radioactive waste into or above underground sources of drinking water.

- Class V wells

Class V wells are those wells which are used for the shallow "injection of non-hazardous fluids only. Some class V wells are technologically advanced wastewater systems used by industry, but most are "low-tech" wells, such as septic systems and cesspools.

ADDITIONAL SOLUTIONS FOR MINIMIZING THE IMPACTS OF WELL INJECTION

If the well injection is the only applicable solution, so it must follow the relevant regulations and follow the appropriate design and monitoring methods, EPA illustrates the construction standards for class II wells (which are considered for brine disposal) as follows:

- Construction standards for a disposal well

  Specifically, a disposal well's construction standards require three layers of casing to ensure groundwater is protected as follows:

  - The first protection layer is surface casing—a steel pipe that is encased in cement that reaches from the ground surface to below the deepest usable quality groundwater level. Surface casing acts as a protective sleeve through which deeper drilling occurs.
  - The second protection layer is the production casing—a pipe placed in the wellbore to the well's total depth and permanently cemented in place.
  - The third protection layer is the injection tubing string and packer that conducts the injected water down through the injection tubing string and production casing to perforations at the bottom of the well to inject the water into an underground formation. With this well construction, all three protection layers must fail at the same time to impact groundwater. See figure (6)
  - All new Class II wells shall be sited to inject into a formation that is separated from any USDW by a confining zone that is free from known open faults or fractures within the area of review
  - All Class II wells shall be cased and cemented to prevent movement of fluids into or between USDWs. Factors to be considered in setting requirements include injection zone depth, depth to bottom of all USDWs, estimated maximum and average injection pressure, lithology of injection and confining zones, and hole size.
  - At a minimum, all new Class II wells shall determine or calculate for the injection formation: 1) fluid pressure, 2) estimated fracture pressure, 3) physical and chemical characteristics of the injection zone.

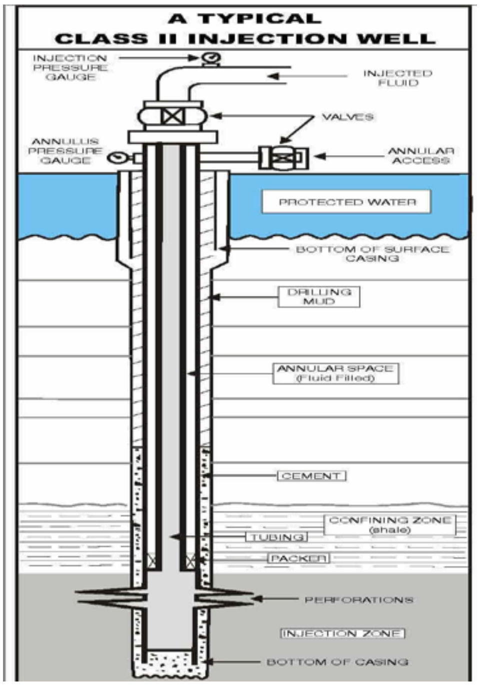

Figure (6) A Typical injection well [5]

SOLUTIONS USED FOR EVAPORATION PONDS WASTE DISPOSAL

The only principal environmental concern associated with evaporation pond disposal is pond leakage, which may result in subsequent aquifer contamination.

CURRENT SOLUTIONS USED FOR MINIMIZING THE IMPACTS OF POND DISPOSAL

One plant of the above mentioned plants disposes brine coming out from the high pressure pump into an evaporation pond.
Also the pond is lined by plastic sheets to prevent leakage, these sheets are covered by layers of sand and gravel which are being cleaned or totally changed according to the situation.

By applying these methods, negative impacts can be reduced by about 70% .

ADDITIONAL SOLUTIONS FOR MINIMIZING THE IMPACTS OF POND DISPOSAL

If more considerations are being applied, negative impacts can be reduced to reach 90% as follows:

- Installations are lined with polyethylene or various other polymeric sheets. Liner installation must be carried out with care since sealing of joints is critical in order to prevent leakage.
- Double lining is strongly recommended with leakage sensing probes installed between layers of pond lining. a primary liner consists of 2 mm thick HDPE, a leak detection and a collection system, and a secondary liner consists of 1.5 mm thick HDPE and is installed on a bedded layer of sand and gravel that can also function as a groundwater collection layer and leak detection system. figure (7)

- In the event that brine seepage is detected in the primary liner, the collecting pipe system below the liner and collection pump stations will return the brine to the pond

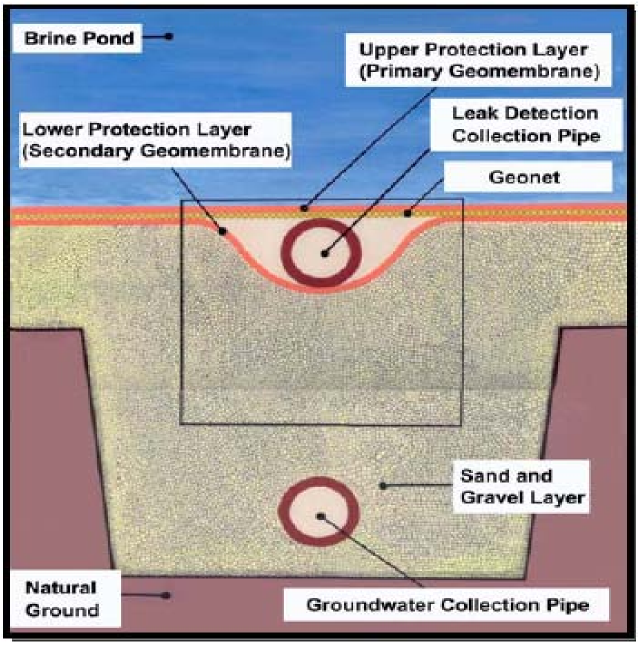

Figure (7) Ponds lining [6]

The groundwater sub-drain system installed below the brine pond secondary liner will be used to dewater the subsurface zones in order to maintain the underground water level , which will prevent any impact to the liner system. This sub-drain system can also be used as a leak detection pipe as well.

The HDPE liner at the tailings pile and brine pond is installed with double welled seams, so that the seam integrity can be tested and independent QA/QC program can be carried out to test and inspect the geo membrane materials during installation.

CONCLUSION

Technologies used in Reverse Osmosis desalination plants are accompanied by adverse environmental effects. There are several negative impacts shall be considered in construction and operation of desalination plants, such as the use of the land, the groundwater contamination, soil pollution, the marine environment pollution, noise pollution, air pollution and the use of energy. To protect and preserve environment, most countries turned to assess the environment impacts produced by desalination plants.

Accordingly, field visits have been conducted to several RO plants in Egypt to cover all the regions that use RO plants in Egypt, where 4 plants are located at the red sea in Hurghada, Sharm el sheikh, Al Qusir and Marsa Alam, as well as 2 plants are located at the Mediterranean sea in Marsa matrouh and Al Saloum. Analysis have to be done to stand upon the negative impacts to the surrounding environment.

From the visits to the RO plants in Egypt it has been found that brine disposal impacts occurs to the environment in the operation phase. During operation, the most important negative impact is the high salt concentration in the brine which also contains several chemical products used in the desalination process, it has been found that about 50% of the visited plants dispose brine directly to the sea without dilution and 50% of them dispose brine without treatment into injection wells where depths varied between 40 to 100m in depth, and very few plants dispose brine to evaporation ponds.

For minimizing impacts of the rejected brine, for surface discharge brine has to be diluted and then discharged through long pipes into the sea, and for injection wells, a very careful study has to be conducted prior injection to avoid contamination of underground water, whereas after studying of the impacts it has been found that the most optimum solution that have the minimal negative impacts on the environment is disposing brine into evaporation pond as well as it is the most economical method also, and it can be used commercially in extracting salt, providing applying the precautions during construction like the lining layer, sand and gravel as to prevent leakage to the soil.

RECOMMENDATIONS

Based on the study it is obvious that certain procedures shall be applied to minimize the negative impacts result from the operation of the RO plant, so in these recommendations best solutions will be illustrated for the negative impacts in order to reach to an environmentally friendly RO desalination plant.

It has been found that the best solution for brine disposal is the use of evaporation ponds, as it is considered to be the most feasible method as it has the minimum negative impacts on the environment, but it must follow some precautions as follows:

Installations are lined with polyethylene or various other polymeric sheets, and double lining is strongly recommended with leakage sensing probes installed between layers of pond lining. a primary liner consists of 2 mm thickness of HDPE, a leak detection and a collection system, and a secondary liner consists of 1.5 mm thick HDPE and is installed on a bedded layer of sand and gravel that can also function as a groundwater collection layer and leak detection system.

The specific regulations regarding disposal brine from inland desalination plants are lacking in many countries in the Gulf and the Middle East regions, specially in Egypt. The governments in these regions should formulate necessary rules and regulations to set limits and standards for the disposal of brine into sea or injection wells. It is also recommended that disposal systems should be monitored regularly. Finally There is a need for a comprehensive modeling and monitoring program, to determine expected impacts, short-term impacts and long term impacts before constructing the reverse osmosis plant to finally reach to an environmentally friendly Reverse Osmosis Desalination Plant.

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