Impact of Brine Disposal from EMU Desalination Plant on Seawater Composition

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Abstract

This study deals with the desalination plant at the Eastern Mediterranean University (Cyprus) and its environmental impact. The reverse osmosis plant produces normally 42m^3/hr potable water from 120m^3/hr feed. The feed concentration reaches up to 36,000ppm TDS, while an approximate amount of 73.8m^3/hr is led out from a pipe of 10inches diameter with a concentration of about 56,000ppm and the permeate 400ppm of potable water. A maximum brine discharge concentration of about 74,180ppm TDS was recorded close to the outlet. During brine disposal an increase in salinity in the coastal zone is observed. To overcome the potential impact of brine disposal and facilitate an optimal operation in the coastal and marine environment, the basis for a solution strategy was developed.

Due to the high salt concentration in the brine disposal to return the sea, impacts on the environment can result from the brine discharge, which contains some chemicals used in the desalination process that may affect the coastal areas and the marine ecosystem negatively. Many plants use biocides such as chlorine to clean pipes or to pre-treat the water. These chemicals should be removed before the brine is released to the ocean, which is not always the case.

A part of this study started 10 days after the plant had been fully stopped, in other words the plant had zero discharge to the sea during the analysis period when repairs took place. Based on measurements during this period, comparisons could be made between full-capacity brine discharge and non-working plant. The pipeline of the brine discharge into the sea was located in shallow water, and the measurement depth in front of the pipe outlet was 30 cm and the average depth in the investigated region was about 2.5m. Corresponding data were taken during operation of the reverse osmosis plant as well. Finally, a simple two-dimensional mathematical model of the discharge and an evaluation of the effect of the brine disposal on the marine chemistry was developed.

I. INTRODUCTION

1.1 General

With population growth and the recent several year long droughts contributing, concerns about water scarcity have emerged causing several communities and researchers to propose construction of desalination plants. Because virtually all seawater desalination plants will be located in the coastal zone, the construction and operation of the facilities generally will have to adopt to strict environmental protection rules for costal zones and other legislative issues related to desalination discharge. The legal demand on desalination plants vary however between countries. More knowledge of how brine discharge affects recipients is needed.

As a case study, the effects of brine disposal from a desalination plant of the Eastern Mediterranean University (EMU) were investigated in detail and a comparison was made with some other desalination plants. During brine disposal the increase in salinity within the coastal water was significant. To overcome this potential impact of the brine disposal on the coastal and marine environment during operation, the basis a solution strategy was developed. A part of this study started 10 days after the plant had been fully stopped, in another words, the plant had (zero) discharge to the sea during the analysis period because of repair. Therefore, it was a good opportunity to determine the time for the coastal area where the brine was discharged to reach the normal conditions of the seawater.

II. DESALINATION AND BRINE DISPOSAL IMPACTS

2.1 Desalination Plants

Desalination, the process of removing salt, other minerals, or chemical compounds from impure water, has provided a limited source of potable water especially in the Middle East countries (e.g. Libya, United Arab Emirates, Oman, Saudi Arabia, and Cyprus). The water from the sea, ocean, and Gulf resources is used for the desalination plant input to provide potable water to coastal and island communities whose ground and/or surface water supplies have been reduced or eliminated. Water shortages may be the result of events such as droughts, contamination, salt water intrusion, or limited water sources, even after water conservation methods have been implemented. Thus, desalination has received increasing attention in drought years when water supplies become greatly threatened or diminished. The conventional desalination methods are mainly based on physical separation processes that use seawater having a brine concentration of 4,000–35,000 ppm [1].

2.2 Desalination Plants Worldwide

Until April 2004, the total desalination capacity of RO-plants was close to 3,500,000 MGD ($16x10^9$ m^3/d), which is half of the entire desalination capacity worldwide. Membrane desalination is the fastest growing technology, and it is expected to become the prevalent desalination technology for the 21st century. Table 1 provides summary information on the global production of desalinated water by plant capacity and desalting process [2].

Unit Capacity (m^3/day)	Capacity MCM/d	Capacity MGD	Number of plants	Capacity RO %
100-500	22.57	4,965	12,433	39.1
500-4,000	21.36	4,699	6,436	37.9
4,000-60,000	14.48	3,186	1,311	25.7
Total	58.41	12,850	20,180	35.3

Table 1: Summary of worldwide desalination plant capacity [2]

2.3 Waste Discharges from Desalination Plants

The major parameters of water discharged from the desalination plants mainly depend on the desalination technology used; the quality of the intake water; the quality of water produced; and the pretreatment processes, cleaning and washing of some parts, and RO membrane storage. In general, discharges from desalination plants may have the following types of potentially adverse constituents and qualities [3]:

- High salt concentrations discharged to the coast;
- Turbidity levels above those of receiving waters;
- Different type of chemicals from pretreatment processes of the input;
- Chemicals used to preserve the RO membranes.

Salt concentrations may be reduced by mixing brines with other discharges, such as wastewater; yet, this mixing may also cause sewage contaminants and other particulates to aggregate in particles of different sizes than they would otherwise. This effect influences rates of sedimentation, and is highly important for determining the well-being of benthic organisms that may be buried or burdened by an increase in deposition of unstable and/or finely suspended materials. If the particles are smaller and stay in suspension, they could interfere with transference of light in the ocean, which would diminish the productivity of kelp beds and phytoplankton. In addition, redistribution of trace metals and nutritionist (e.g., iron, ammonia, and phosphates) could change the phytoplankton community to one that is unappetizing to fish and may also be toxic (for example, by increasing the possibility or prolonging the occurrence of a "red tide" condition) [4].

2.4 Brine Discharge and Hydraulic Effects

The desalination process creates brine with salinities higher than naturally found in coastal waters of Cyprus and in greater volumes than the freshwater produced. Disposal of brine into coastal waters is an economical option for the desalination projects if legally allowed. After discharge, dense brine water flows below the less-dense ambient water to form a stratified cap over the bottom sediment. Typically, it is not the quantity of salt discharged that causes a problem; it is the mixing rate and the brine's fate prior to complete mixing that determines impacts. If natural forces of plume flow, wind mixing and tidal currents are slow to mix the brine with the overlying water, biogeochemical processes in the sediment may deplete the available dissolved oxygen near the bottom, causing hypoxic (low oxygen) conditions that harm aquatic life [5,6].

The following potential coastal zone impacts should be considered in evaluating proposals for the desalination plants:

- Impacts to the marine environment from continuous discharges of hazardous chemicals from brine disposal;
- Impacts to commercial fishing and navigation during construction of intakes and outfalls and during operation;
- Interference with public access and recreation from pipelines, wells or other structures;
- Noise from pumps during operation;
- Impacts on the desalination process from pollution near the intake pipes;
- Use of landfill disposal space for solid waste disposal.

2.5 Environmental Acceptance

To develop an environmentally acceptable project, the developer needs to address the latest issues of desalination plant technology while taking into consideration the sustainable development principles. In such cases, the national and public authorities should be encouraged to consider sustainable development in the early stages of the planning process (e.g., site selection, plant capacity, and brine discharge).

2.6 Chemical Analysis of Brines from Reverse Osmosis Plants

Brines are not just concentrated seawater. All desalination plants use chlorine or other biocides, which are hazardous to the coastline environment and this is known as pre-treatment processes. Moreover, in case if the plant is shut down for any reason some chemicals (usually sodium bisulfite) will be used to protect membrane. These chemicals should be treated before discharge to the sea, to reduce any potential effects. Due to these chemicals, some fish like Larval fish that feed on the phytoplankton could be forced beyond nearshore waters, where they may not survive. The concentration of major ions in the brine appears logically to be proportional to those measured in the input. The study of chemical analysis for the brine, input, potable water, and water from evaporation ponds (or bores) were determined from both United Arab Emirates and Sultanate of Oman [7]. Table 2 provides feed-water and brine disposal for the chemical characteristics data to selected small-scale desalination plants in Oman and UAE. These data were obtained from a single sampling of water and brine from various (RO) desalination plants during field visits.

Chemical Parameter	**Name of the plant**						**Omani plant**	
	Qidfa I		**Qidfa II**		**Jabal al-Dhana**		**Esherjah**	
	Feed	Brine	Feed	Brine	Feed	Brine	Feed	Brine
Calcium (ppm)	464	617	533	730	636	760	490	841
Magnesium (ppm)	1640	2150	1620	2240	2140	2660	1,100	1,900
Sodium (ppm)	11,900	15,100	12,200	15,800	14,200	17,700	8,630	14,800
Chloride (ppm)	23149	30,540	23,484	32,004	27,098	34,839	15,868	24,062
Sulfate (ppm)	2787	3931	3181	4500	3121	4602	4,104	6,139
E.C (µS/cm)	55,700	73,300	56,130	78,000	65,900	81,100	41,900	61,100
TDS (ppm)	40,592	53,177	41,661	56,158	47,940	61,587	48,510	--
Potassium (ppm)	574.0	767.0	581.0	805.0	661.0	950.0	631	--

Table 2: Chemical characteristics of feed-water and brine disposal of Oman and UAE plants [7]

III BRINE DISCHARGE STUDIES

3.1 Studies of Salinity Changes in Recipients

Some researchers have studied and reported the effect of brine discharge from desalination plants.
Perez and Quesada [8] provided a study of the brine discharge of the Gran Canaria desalination plant. Their samples were taken in front of the brine discharge outfalls, at the bottom, intermediate and surface level, about 20m from the outfalls. As seen from the data, the initial dilution of the brine over the first few meters was high and it continued almost uniformly through the whole column of the water.

The brine concentration decreased from a salinity of 75.1 (discharge salinity in psu) to a salinity of 38.4 at the seabed and 37.0 on the surface. At a location about hundred meters away, the salinity of the sampled water was very near to the normal values for the seawater of the area, that is, in summer it is around 37 practical salinity units (psu). The theoretical studies indicated that the brine tends to gather at the bottom, once it stops being affected by the effects of the discharged jet and it reaches a balance with the surrounding environment according to the density conditions [8].

Another example was obtained from Javea desalination plant which is located at the Mediterranean coast in Spain [9]. Highest salinities were located inside the Channel of the Fontana and in the proximities of the outlet. The salinities of the superficial water ranged between 37.3 and 43.5 psu, at the bottom between 37.4 and 42.3 psu, and in the interstitial water between 37.4 and 39.9 psu. These tendencies required in the samplings carried out during the 2004. In summer similar influence areas were obtained while in winter the dilution was very high and a certain increment of salinity was only observed in the internal part of the channel [9].

Surface salinity could be homogenous around the brine discharge pipe with no clear trend at any position. The dilution close to the discharge took place rapidly, but an increased salinity could be found far from the outlet. It was possible to observe an increase higher than 0.5psu above an average salinity in the area up to 4km from the discharge. These results and conclusions were found after three surveys of the Alicante desalination plant during February, April, and August 2004 [10].

IV THE EMU PLANT

4.1 Study Area

The Mediterranean Sea covers an area of 2.5 million square kilometers (km^2), excluding the Black Sea, and has an average depth of about 1500 m. As a sea it is rather unique in that it is almost completely surrounded by land: Europe to the north, Africa to the south, and Asia Minor to the east. During winter time, a combination of cold air temperature and mixing of the surface water due to storms destroys the thermo-cline [11]. The EMU's plant is located at the coast of Cyprus. It is one example of a Mediterranean Sea Island where seawater is used for desalination due to lack of sufficient groundwater supply within the country.

The Eastern Mediterranean University is the oldest and the largest university in Cyprus with over 13,500 students, including dormitories with a capacity of 4,500 students and more than 2,000 staff. The University is located in a campus stretching over an area of 2,000,000m^2, near the city of Famagusta. Within the campus area, 154,000m^2 of green areas exist with over 60,000 trees.

For a considerably period of time, the University had been supplied with insufficient amounts of water from the Famagusta Municipality. The municipal water carries a level of salt (TDS) that is too high both for indoor uses and for irrigation purposes. This insufficient amount of water was supplemented by water obtained from wells belonging to the University and/or water purchased from external sources.

However, these sources of water were usually unreliable due to frequent droughts in the Island, as well as generally having poor quality. At present, daily water needs for the University is determined to be 2,000m^3 and 1,200m^3 of this amount is currently supplied from the Municipality, while the rest is obtained from a desalination plant belonging to the University, which operates through the principle of reverse osmosis (RO). The desalination plant was built in 1998 and has a capacity of 1000 m^3/day (location shown in Figure 1). At present the University plans to increase the capacity of this plant to meet the increase in the number of student to a total amount of 3,000m^3/day [12].

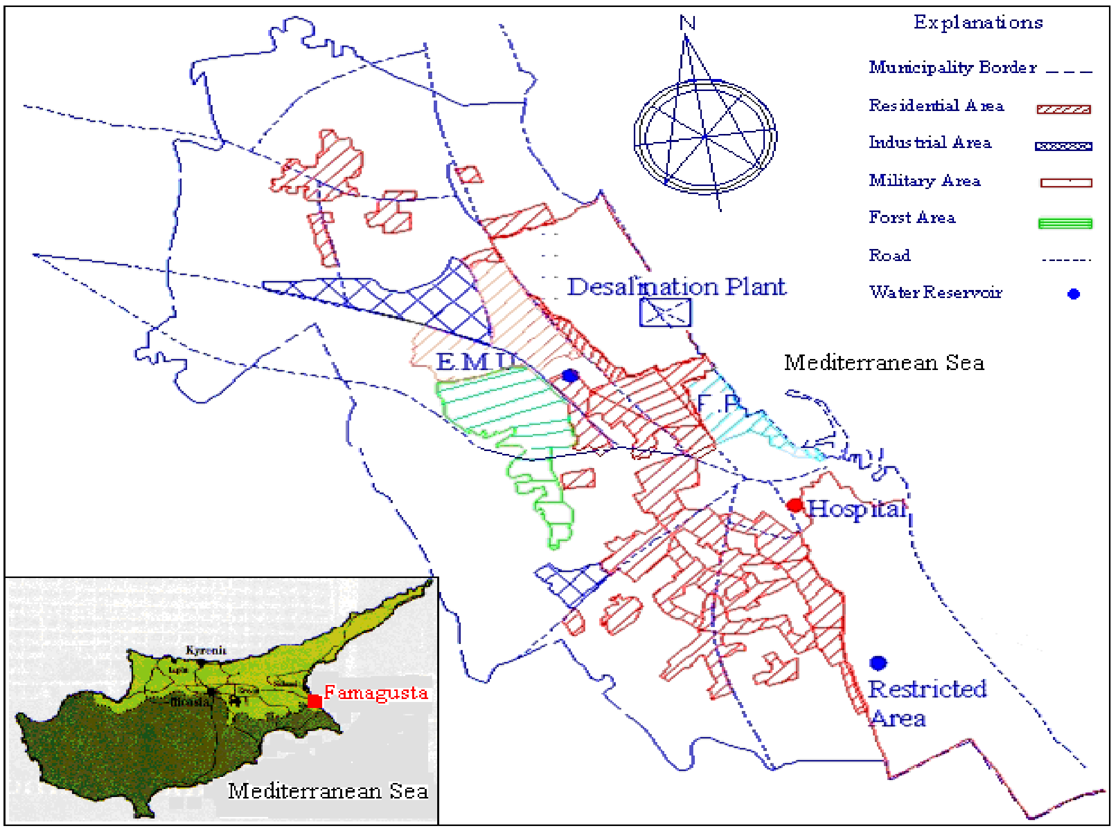


Figure 1: Desalination plant location in Famagusta city, North Cyprus

4.2 In and Output of EMU Desalination Plant

The RO-system utilized in the EMU desalination plant is fed with 115.83m^3/hr seawater obtained from three parallel pipes 30m from the coastline at an average depth of 15m. The seawater contains 36,000-40,000ppm as TDS. To save membrane life, around 36.3% of the feed water is obtained as permitted output (permeate) and the remaining amount is considered to be waste discharge (brine disposal). In this way, 42 m^3 of seawater per hour is released as a high quality output (EMU desalination plant produces water quality of less than 400ppm (TDS), which can be used for drinking water), while an approximate amount of 73.8m^3/hr is led out of the system as a brine with salt concentration of about 56,000ppm TDS [12].

V. METHODOLOGY AND SAMPLING

In this study some chemical and other factors have been analyzed as a function of the brine disposal from the desalination plant. Some of the analytical results from the beginning of the study period are presented in Table 3 (Ca, Mg, Cl, SO_4, Na, pH, K, Electrical Conductivity, Alkalinity, and TDS).

Picture 1: Taking samples and recording on them

The sampling locations were assigned with respect to an x and y axis; x is the location of each point towards seawater and perpendicular to the coastline and y is the location assigned parallel to the coastline. The sampled parameters are important for fish life and coastline environmental impact. The laboratory analysis of this study was carried out by the State Laboratory of North Cyprus.

Samples were collected in the vicinity of the brine discharge outlet. One sampling point was located directly in front of the outlet (pipe outlet system) with the purpose of determining the initial concentration of the brine and the discharge at the surface of shallow seawater.

The other positions from where the samples were collected were determined by fixing steel bars with exact dimensions using measurements in y and x coordinates and extending a rope for each to ensure that during each sampling day having the same points in the field would be used in the aimed area as shown in Figure 2.

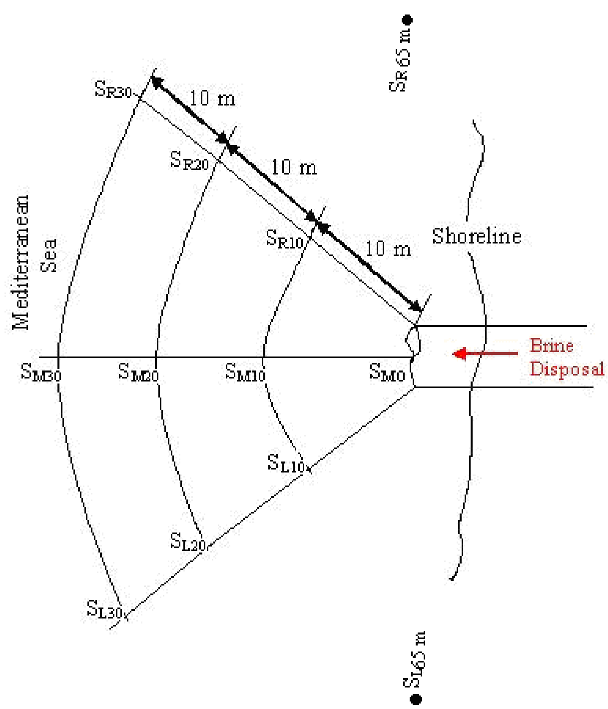
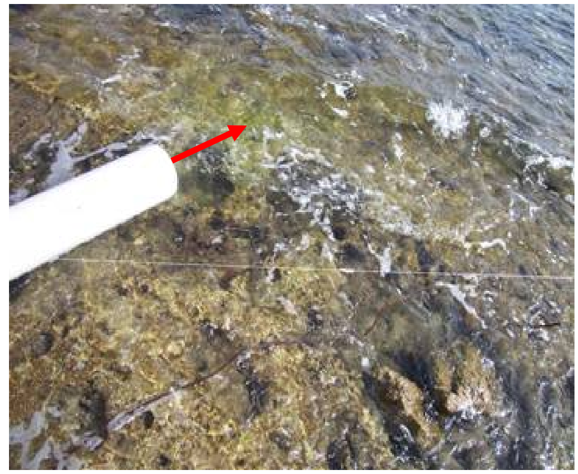


Figure 2: Outlet from desalination plant and sampling positions

The following is a description of the sampling points and how they are denoted:

- Two reference points were selected taking into consideration the ecological status and the bathing areas 65m away from the pipe outlet to the right and left to compare the results of the analysis (denoted as S_{R65m} and S_{L65m}).

- Samples were collected in the open sea separated with a distance of 10m between each point, with a sampling period of 15 days; the samples were collected following three radial lines starting from the discharge point with a separation from midline of about 45° each.
- Samples taken on the left hand side were denoted (S_{L10}, S_{L20} and S_{L30}), on the right hand side (S_{R10}, $S_{R20,}$ and S_{R30}) and along the middle points (S_{MO}, S_{M10}, S_{M20}, and S_{M20}).



Picture 2: Brine disposal pipeline towards the sea

Table 3 presents both the overall average of zero-capacity discharge versus full-capacity discharge to compare some of the chemical variation with respect to time. As seen in (Picture 1), samples were collected and recorded twice a month trying to find calm weather each time. During most of the sampling the weather was good but during one sampling event it was windy with marked wave action along the coastline that may have affected some of the data. The pipeline of the brine discharge towards the sea and the depth conditions are shown in (Picture 2). The depth close to the pipe outlet was about 30cm and the average depth in the investigated shore area was 2.5m.

Sample name	Coordinates		Concentrations, ppm						El. Cond. µS/cm
	X (m)	Y (m)	TDS	Ca	Mg	Cl	Na	SO_4	EC
M_{0m}	0	0	38,360	480	1,458	22,720	11,800	862	52,800
M_{10}	0	10	38,020	520	1,397	23,075	11,800	211	46,500
M_{20}	0	20	38,350	500	1,390	22,720	11,800	740	45,400
M_{30}	0	30	38,610	500	1,519	23,075	11,800	672	48,600
R_{10}	7,07	7,07	38,570	480	1,480	22,543	11,800	1,102	43,000
R_{20}	14,14	14,14	38,480	480	1,495	22,898	11,800	767	48,700
R_{30}	21,21	21,21	38,600	460	1,519	22,720	11,800	1,056	46,500
R_{65}	65	0	40,200	440	1,568	22,010	11,800	3,217	51,000
L_{10}	-7,07	7,07	40,790	520	1,384	22,543	12,600	2,098	47,800
L_{20}	-14,14	14,14	39,060	480	1,593	22,72	11,800	1,080	51,900
L_{30}	-21,21	21,21	38,620	520	1,507	23,075	11,800	671	43,800
L_{65}	-65	0	38,560	500	1,519	23,075	11,800	647	49,500

Table 3: Sampling results at the beginning of the study, 2nd March 2005

	Full Capacity Brine Discharge						Zero Capacity Brine Discharge					
	TDS ppt	EC mS/cm	Ca ppt	Mg ppt	Cl ppt	Na ppt	TDS ppt	EC mS/cm	Ca ppt	Mg ppt	Cl ppt	Na ppt
M_{0m}	74.18	83.4	0.84	2.438	34.26	22.40	41.72	50.46	0.51	1.613	23.90	12.73
M_{10}	58.77	62.5	0.64	1.678	24.85	18.00	41.06	47.03	0.52	1.568	23.64	12.57
M_{20}	51.82	60.9	0.58	1.495	23.96	16.00	40.69	50.35	0.51	1.561	23.02	12.37
M_{30}	52.58	60.5	0.62	1.580	23.25	16.00	41.72	47.47	0.53	1.615	24.02	12.73
R_{10}	56.41	61.4	0.58	1.605	23.96	17.40	42.37	50.54	0.51	1.591	24.32	13.00
R_{20}	52.08	60.9	0.50	1.776	25.92	16.00	41.08	49.53	0.51	1.591	23.34	12.50
R_{30}	53.46	61.0	0.54	1.617	23.43	16.40	41.54	48.79	0.51	1.587	23.55	12.67
R_{65}	50.90	60.3	0.46	1.568	24.14	16.00	41.87	52.17	0.49	1.574	23.61	12.77
L_{10}	52.26	59.8	0.62	1.470	22.72	15.60	41.90	47.80	0.51	1.542	23.70	12.87
L_{20}	51.58	60.2	0.60	1.470	22.54	15.80	42.53	52.08	0.52	1.599	23.84	13.00
L_{30}	49.65	60.4	0.54	1.752	22.72	14.80	41.43	50.41	0.51	1.511	23.52	12.77
L_{65}	49.93	60.1	0.48	1.580	22.37	15.20	42.42	50.27	0.52	1.615	24.08	12.97
R_{100}	50.90	60.3	0.46	1.568	24.14	16.00						
L_{100}	52.29	59.9	0.44	1.654	21.48	15.80						

Table 4: The average of zero-capacity discharge (2nd March 2005-18th May 2005) versus full-capacity discharge at October, 19 2006

VI. MATHEMATICAL MODELING

6.1 Theoretical Formulation

A mathematical model was developed of the brine discharge and its spreading in the nearshore based on simple jet theory. It was assumed that the conditions were uniform through the water column and that the discharge behaved like a plane jet that expanded primarily due to entrainment of ambient water at the sides. Some distance away from the discharge point the assumption of vertical uniformity will clearly be violated and the brine will spread as a gravity current along the bottom, but observations in the study area indicated that the conditions did not vary significantly through the water column. Friction along the bottom was also neglected in the model discussed here.

Three equations govern the evolution of the jet, that is, conservation of water flow, momentum flux, and flux of the constituent of interest, expressed as, respectively (compare with [13]),

$$\frac{d}{dx}\left(\sqrt{\pi}u_m hb\right) = 2\alpha h u_m \tag{1}$$

$$\frac{d}{dx}\left(\sqrt{\frac{\pi}{2}}\rho u_m^2 hb\right) = 0 \tag{2}$$

$$\frac{d}{dx}\left(\frac{\sqrt{1+\lambda^2}}{\lambda}\sqrt{\pi}\left(c_m - c_a\right)u_m hb\right) = 0 \tag{3}$$

where u is the velocity, b the width, c the concentration, h the water depth, x a coordinate pointing offshore, ρ a representative density, α an entrainment coefficient, λ an empirical coefficient relating the spread of concentration and velocity in the jet (λ=1.2), and subscripts m and a denote conditions at the centerline and in the ambient, respectively. In the derivation of equations 1-3, self-similar profiles were assumed for the velocity and concentration following a Gaussian distribution yielding $u(x,y) = u_m(x)\exp\left(-\left(y/b(x)\right)^2\right)$ and $c(x,y) - c_a = \left(c_m(x) - c_a\right)\exp\left(-\left(y/b_T(x)\right)^2\right)$, where y is an alongshore coordinate and b_T the width of the concentration profile. The equations will not be valid until some distance downstream the discharge point where the initial top-hat distributions have been transformed to Gaussians shapes. It was assumed in the present study that the first sampling point was sufficiently far from the pipe exit to fulfill the conditions for self-similarity.

Solving Eqs. 1 and 2 yields the evolution of the centerline velocity,

$$u_m = \left(\frac{1}{u_o^2} + 2\sqrt{2}\alpha \frac{\rho}{M_o} \int_0^x h(x)dx \right)^{-1/2} \quad (4)$$

where u_o is the velocity and M_o the momentum flux (conserved during jet evolution) at x=0. The solution is valid for an arbitrary variation in the bottom elevation assuming constant conditions alongshore. The centerline concentration of a constituent is given by,

$$c_m - c_a = \left(c_{mo} - c_a\right)\left(1 + 2\sqrt{2}\alpha \frac{\rho u_o^2}{M_o} \int_0^x h(x)dx \right)^{-1/2} \quad (5)$$

where c_{mo} is the centerline concentration at x=0.

6.2 Comparison with Field Measurements

The measurements along the centerline of the brine discharge were compared with the theoretical solution given by Eq. 5. A plane-sloping bottom profile according to $h(x) = h_o + mx$ was assumed, where h_o is the water depth at the first measurement point (M_o) and m the bottom slope (h_o=0.3 m and m=0.073; $\int_0^x h(x)dx = h_o x + mx^2/2$). The entrainment coefficient was set to α=0.054 following [13], the flow at the pipe exit was Q=73.8 m^3/hr=0.0205 m^3/s, and the diameter D=0.254 m. The momentum flux was estimated from $M_o = \rho U^2 \pi D^2/4$, where $U = 4Q/\pi D^2$.

Only one parameter was difficult to specify in the solution, namely u_o, which is the velocity at x=0 corresponding to the centerline velocity at point M_o. The exit velocity at the pipe is assumed to follow a top-hat distribution and the centerline velocity for a Gaussian distribution that would produce the same flow rate and momentum flux is $u_{mp} = \sqrt{2}U$. However, because point M_o is located some distance downstream the pipe exit and the transition of the profile from a top-hat to a Gaussian is complex and might not have taken place completely, a calibration coefficient was introduced to modify the value of the velocity at x=0 according to $u_o = C_v u_{mp}$. A value of $C_v = 0.5$ was applied in all calculations.

The measured concentration in point M_o was used as input value in Eq. 5 and the ambient concentration was set as the average between points R_{65} and L_{65}.

Figure 3 displays the results of a comparison between calculated and measured concentrations for the studied constituents. In general good agreement is obtained between the simple model and the measurements, although over- or under-prediction is observed depending on the particular constituent studied.

This is a study of the first desalination plant that was built in Northern Cyprus belonging to the Eastern Mediterranean University for distilling seawater. Due to new development their must be improved control of this facilities in order to know the effects of the discharge and to minimize any type of environmental impact. The plant is not big nor is the discharge, compared with typical municipal desalination plants. Still the recipient has an increased salinity for 10-20 m from the discharge pipe outlet. Possibly could this be minimized by using more outlets and/or longer pipelines towards the sea. Changing the direction of the brine discharge could also minimize the impact on the coastline.

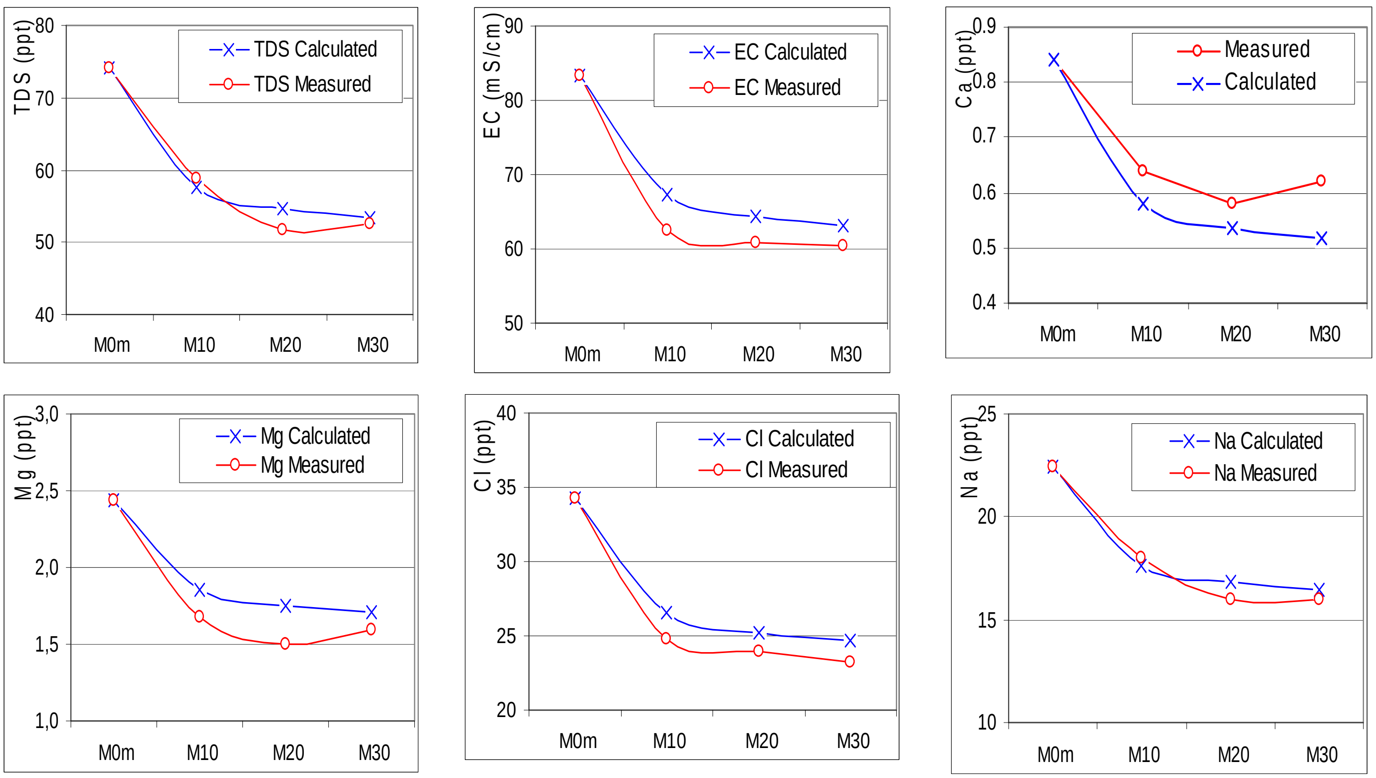


Figure 3: Comparison between calculated and measured spatial evolution of the concentration along the centerline of a brine discharge for different constituents

VII. RESULTS AND RECOMMENDATIONS

Since the starting up of the desalination plant and the brine discharge to the coastline, no study was carried out concerning the dispersion and dilution of the discharged water, but most of the analyses were performed during no-discharge conditions. Therefore, these data were suitable to analyze the brine disposal as well to be able to define the environmental impact that may be present in the area. As mentioned above, the analysis was carried for the period between the 2nd of March 2005 and the 18th May 2005 at the time the plant had been stopped for repair (zero-brine discharge). Subsequently, another sampling test was carried out when the plant was working full capacity (full-capacity brine discharge) in order to compare between both analyses.

In order of getting a real representation of the salinities variations in the space an interpretation of the data campaign was made using the kriging technique. Some of the samples varied significantly due to the influence of the seasonal effect in the hydrodynamic conditions and climatic changes (e.g. wind speed, wave force, rainfall, and evaporation).

In these campaigns, the samples have been taken from twelve different stations homogeneously distributed surrounding the brine discharge and each of the sampling point was positioned with a rigid steel bar (accuracy of ±0.5m around the point). The samples were analyzed in the State Laboratory of Northern Cyprus (Governmental) with an accuracy of (±5%). As seen in (Figure 4) the concentrations at the most distant sampling points of Total Dissolved Solid, Calcium, Magnesium, Sodium and Electrical Conductivity indicate that the normal seawater characteristics are reached. The (TDS) average of reject brine area with no-discharge period show a low degree of variability ranging from (38,000-43,000 ppm).

In general, higher concentrations are recorded closer to the outlet, whereas they are quite uniformly distributed in the rest of the study area. Thus, it was observed that the total concentration of the effluent takes place over a short distance which could be explained by the initial dilution of the brine discharge before and after the desalination plant using the seawater for intake and return. When working and non-working periods are compared, it has been observed that the Total Dissolved Solid (TDS) and Electrical Conductivity (EC) both significantly differ during the two periods as shown in (Figure 4a and b). In the case of Calcium (Ca) and Magnesium (Mg) only the point close to the outlet displays higher concentrations and the rest is quite similar (Figure 4c and d). For the Chloride (Cl) and Sodium (Na) the same behaviour as in the two cases above was observed at the outlet (Figure 4e and f).

Considering the improvement in desalination technology, attention must be given to evaluate desalination from environmental, technical, and economical perspective. The two-dimensional spatial distribution of various chemicals for both, a) full-capacity brine discharge and b) an average results for zero-capacity brine discharge are presented in (Figures 5a and b). It may be observed how some of the chemicals mix after being discharged from the outfall (Figure 5a) with higher concentrations around the outlet pipe and minimum values about 30m away. In (Figure 5b) uniformly distributed concentrations occur all over the period for most of the tested chemicals, which means the stable conditions could be possible for small scale plant after three months. Also this indicates that when the desalination plant have (zero) brine disposal for a period of three months or more, there could be a good chance for refreshing the seawater at the area where the brine was discharged.

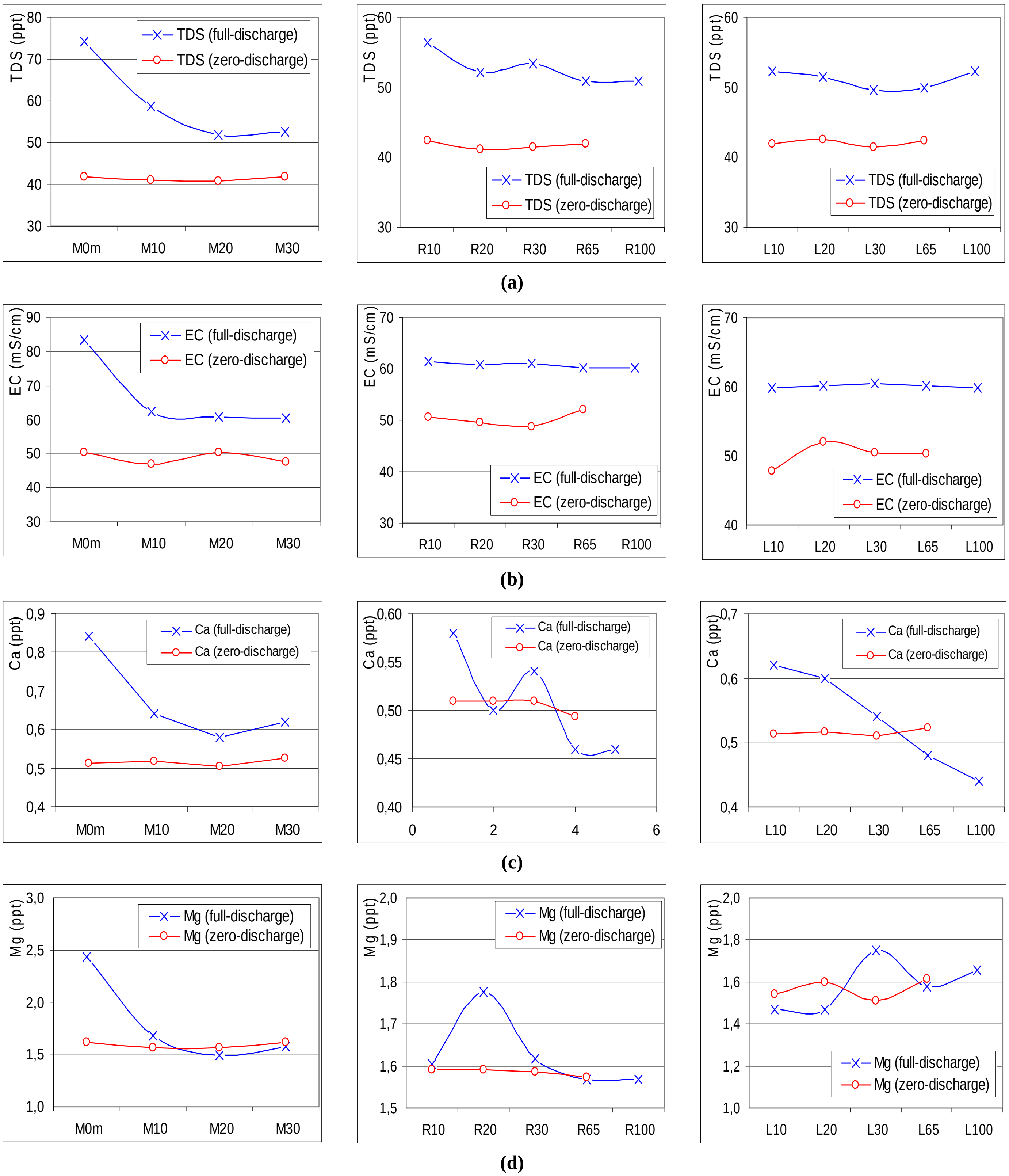
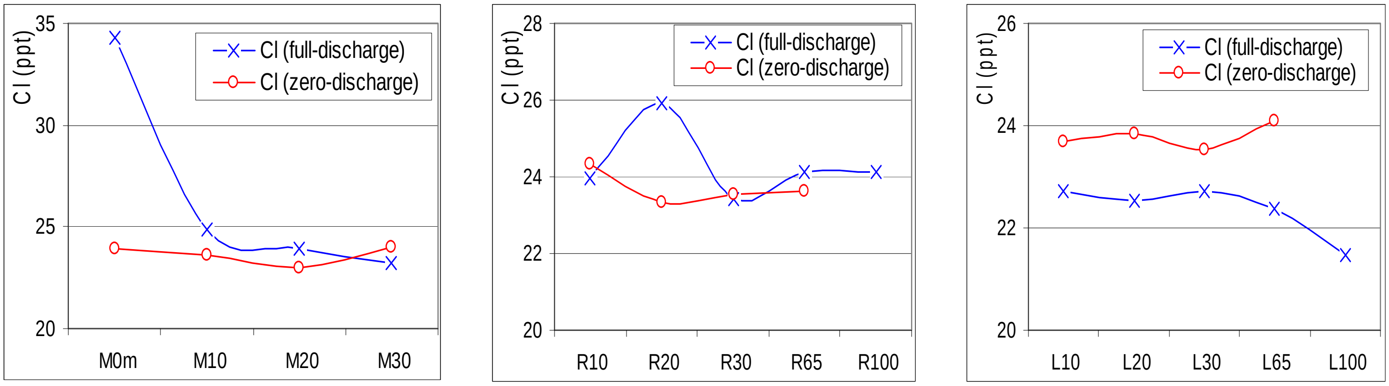
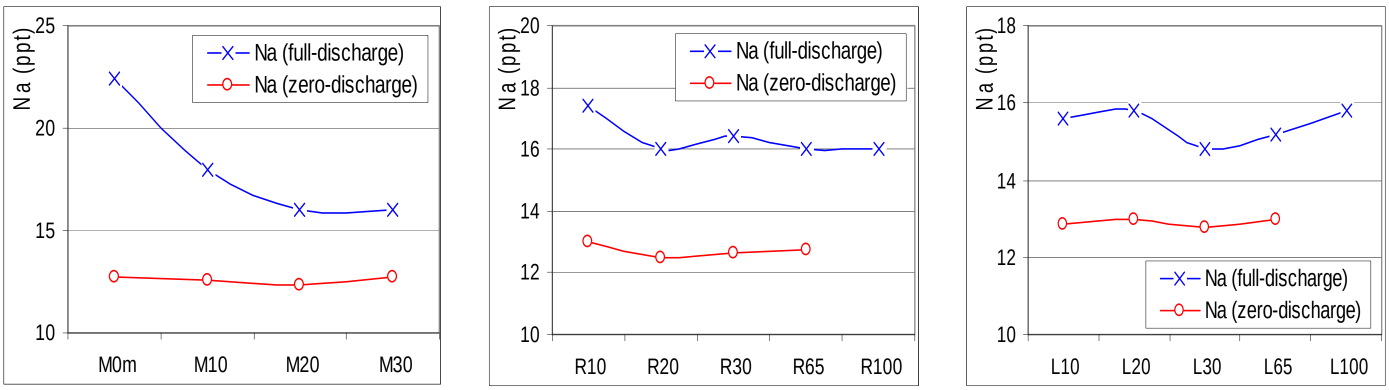


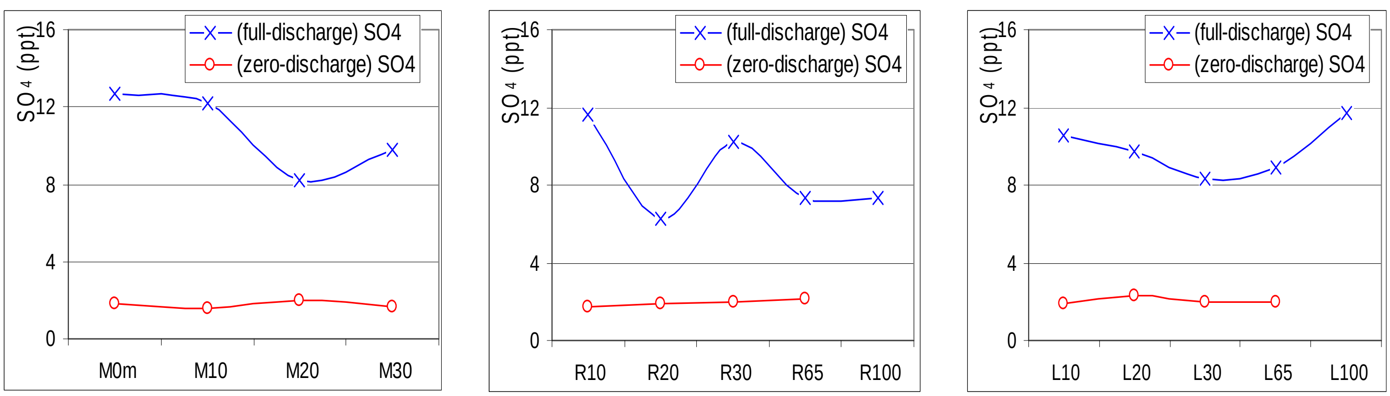
Figure 4: Comparison between full-capacity brine discharge and the average of zero brine discharge between 2nd March 2005-18th May 2005 with respect to location



(e)



(f)



(g)

Figure 4(cont'd): Comparison between full-capacity brine discharge and the average of zero brine discharge between 2nd March 2005-18th May 2005 with respect to location

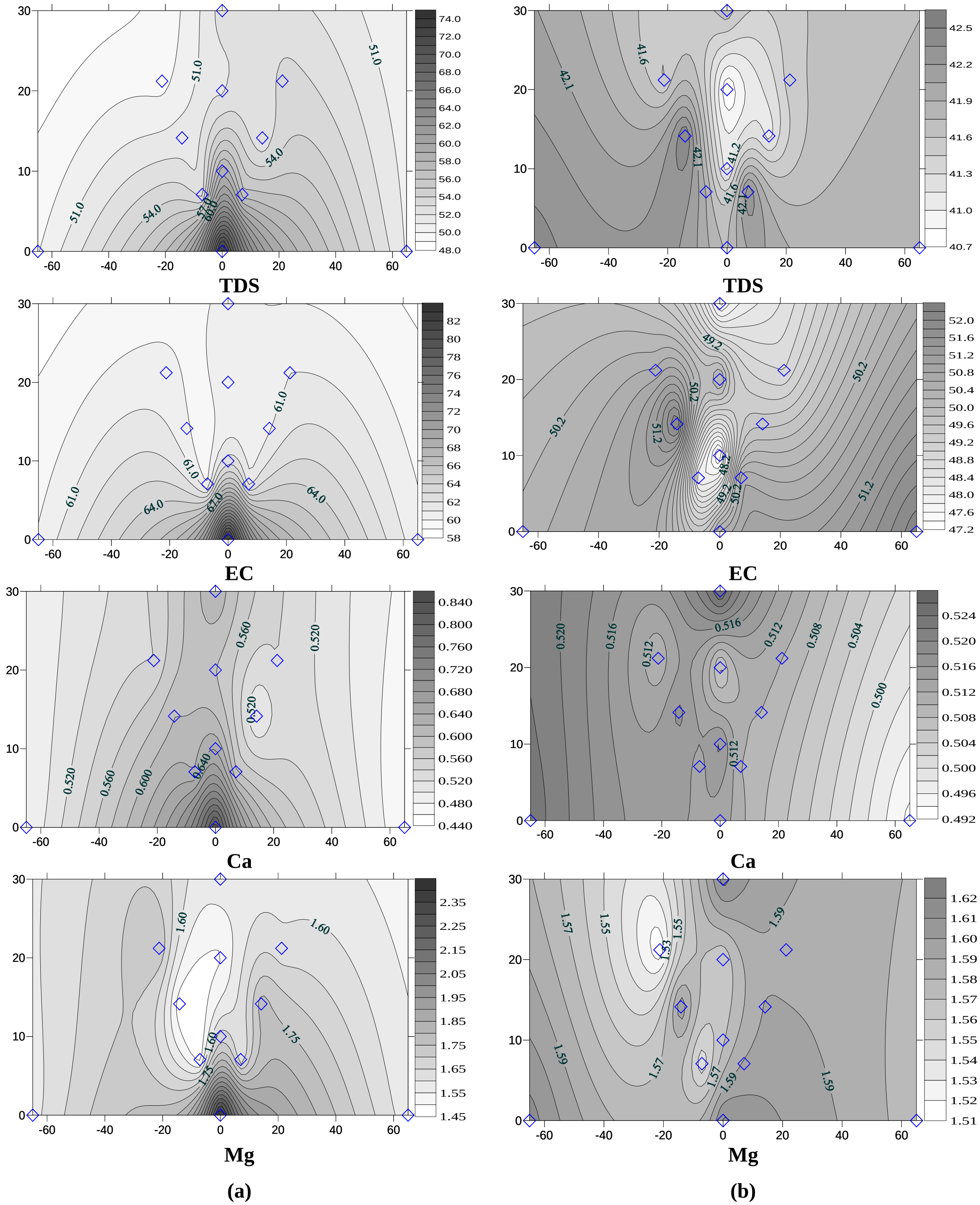


Figure 5: Two-dimensional spatial distribution of various chemicals: a) results for full-capacity brine discharge and b) an average results for zero-capacity brine discharge in between 2nd March 2005-18th May 2005

VIII. CONCLUSION

This is a study of the first desalination plant that was built in Northern Cyprus belonging to the Eastern Mediterranean University for distilling seawater. Due to new development their must be improved control of this facilities in order to know the behaviour of the discharge and to minimize any type of environmental impact. For that reason a sampling system should be established on site to measure during the operation of the desalination plant to observe the impacts on the coastline.

In this work it has been shown how the possible environmental impacts associated with the discharge of brine from a desalination plant can be minimized by means of planning more outlets or longer pipelines towards the sea. Changing the direction of the brine discharge could also minimize the impact on the coastline.

The general observations from this study is that preventing or reduce the coastal impact during the operational time of any plant (small or larger scale), due to the effect of brine discharge, can be considered necessary for future projects in the Mediterranean area or else where.

Coastal desalination plants discharge the brine waste containing high salt concentration directly into the sea. As shown above in (Figure 2) continuously discharging brine wastes directly to the coastline will result in salinity increases. Unfortunately, such increases in salinity will intensify, instead of improving, the critical problem of seawater intrusion into coastal groundwater aquifers.

Finally, in this case the impact of brine disposal operations on coastal and marine environments can be avoided by having more than one outfall (a series of outfalls) to the sea and this idea can be applied to the input as well idea to save membrane life.

IX. ACKNOWLEDGMENTS

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