ISRAEL AS A MODEL FOR ENVIRONMENTALLY RESPONSIBLE DESALINATION

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ABSTRACT

As global warming and increasing water scarcity progressively affect more and more regions of the planet, interest in the use of seawater desalination as an alternative source of water is increasing.

Together with the increase in the need for, and interest in desalination, there is a corresponding increase in the level of concern and confusion regarding the environmental impact of this solution. While many countries facing water shortages due to climate conditions discuss the pros and cons of seawater desalination in confusion, their water reservoirs are being depleted to levels that prevent economic development in various fields, e.g. agriculture and industry, as well as a regular supply of water for basic human needs.

Israel is located in a semi-arid climate zone with over 60% of the land being desert. The 70 years since the establishment of the State of Israel have seen rapid growth in the population with the influx of immigrants, while the natural water sources have remained limited, thus endangering the supply of fresh water for the population.

In 1999, the Israeli government initiated a long-term SWRO desalination program, aimed to meet the growing demand for Israel's scarce water resources, and to mitigate the drought conditions prevalent since the mid-1990s. The plan includes the erection of seven mega size seawater desalination plants by 2025, along the 200 km Mediterranean coast. Five desalination plants are already in operation, supplying 600M m^3/year of potable water – representing 75% of the country's domestic water consumption. The 6th plant (Sorek B) is expected to start operation during 2023; while the 7^{th} plant (Western Galilee) is in the final tendering stage. The capacity of these two plants will provide an additional 300M m3/year of potable water, in total representing almost 100% of the national domestic consumption. In addition, the statutory process by the Government has begun for an additional 200M m3/year plant in Emek Hefer.

The Israel Master plan has been successfully implemented since the outset. The regulator defines clear rules to manage the implementation of desalination with a holistic approach, including statutory, financial, socio-economic and environmental impacts. The establishment of responsible regulations plays a major role in the State's national effort to overcome the water crisis, and assures the preservation of the country's precious marine and coastal environment.

This paper reviews the responsible implementation of the environmental regulations, created with the purpose of ensuring that the supply of desalinated water is sustainable, available, and reliable, in the required quantities, locations and qualities; while also ensuring preservation of the marine environment during the construction and operation of the mega desalination plants along the Mediterranean cost of Israel.

The paper is aimed at decision makers in countries suffering from drought, and summarizes the environmental regulatory and permits policy, provides details and samples of monitoring reports, and expert conclusions on the actual marine and coastal environment.

Spoiler 20 years of responsible desalination demonstrate the legitimacy of seawater as an alternative water source that can co-exist in harmony with the environment.

Keywords: desalination, environment, regulations, policy, monitoring, marine environment

I. INTRODUCTION

1.1 Desalination in Israel

Israel is a small state and presents to the world via the country's only coastline. All its seawater desalination plants were built along this strip of the Mediterranean coast, for a length of approximately 200 km in which the miracle of production of some 80% of Israel's potable water takes place. The desalination plants along the Israel coastline are among the largest operating plants worldwide, which firmly positions Israel as an expert on the subject of effluent discharge in general, and its impact on the environment in particular. The plant effluent generated during the desalination process is also discharged along this same strip of coast, therefore it is necessary to ensure that all relevant regulation is in place to ensure that this unique and precious state asset will not be harmed or negatively impacted.

Contracts between the State of Israel and the Private Companies for the erection of the desalination plants are based on BOT agreements, i.e., concession for the construction, operation, and maintenance the plants. In most cases, the Concessionaire is responsible for planning, financing, building, operating and maintaining the facility for a period of 27 years and 9 months starting from date of signature (NTP). At the end of this period, the project is transferred to the State at no cost. The O&M phase is 24 years and 11 months, starting from PPTO.

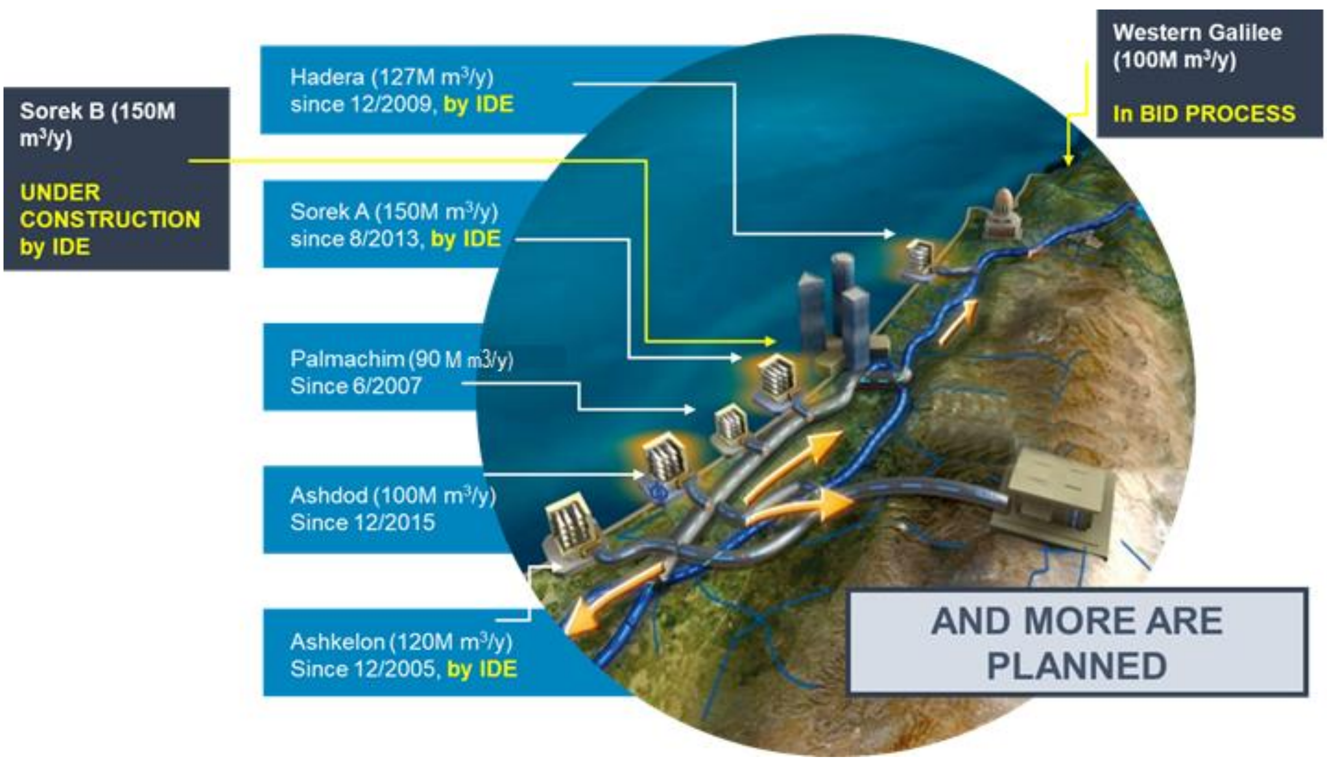

Figure 1: Mega Size Desalination Plants along the Israel Coastline

Table 1 presents the basic parameters for each of the desalination plants.

Table 1: Desalination Plant Parameters

Plant	Product Capacity [Mm^3/year]	Start of Operation	Outfall Type
Ashkelon	120	2005	Discharge in tidal zone after mixing with power station cooling water
Palmachim	90	2007	Submerged marine outfall
Ashdod	100	2015	Submerged marine outfall
Hadera	127	2010	Discharge in tidal zone after mixing with power station cooling water
Sorek A	150	2013	Submerged marine outfall

Based on Table 1, the total desalinated water produced per year is 595 Mm^3/year and the amount of effluent discharged to the sea from the operating plants is also expected to be close to 600 Mm^3/year. This is a significant volume of effluent, which could be expected to have an impact on the marine environment. However, proper handling, according to the environmental requirements, has proven that this is not the case, and the impact to the marine environment is, in fact, negligible. Moreover, theoretical studies and practical operation have shown that desalination plants and the marine environment can – and do - co-exist in perfect harmony, if constructed and operated accordingly. .

1.2 The Technology

All the seawater desalination plants operating in Israel are based on RO technology.

As part of the process, the seawater that is pumped from the sea intake to the plant, and ultimately to the country's potable water network, makes its way through various treatment steps. The heart of the plant is the RO section in which the actual desalination process takes place, using Reverse Osmosis (RO) technology. Prior to the membrane treatment area, the seawater is pretreated to render it fit for the RO process by the removal of dissolved solids and other contaminants. The RO desalination process is followed by a post-treatment phase where additives are added to the water in order to ensure that the water is indeed suitable for human consumption.

Figure 2 shows the stages in a typical RO desalination plant, from intake to the potable water reservoir.

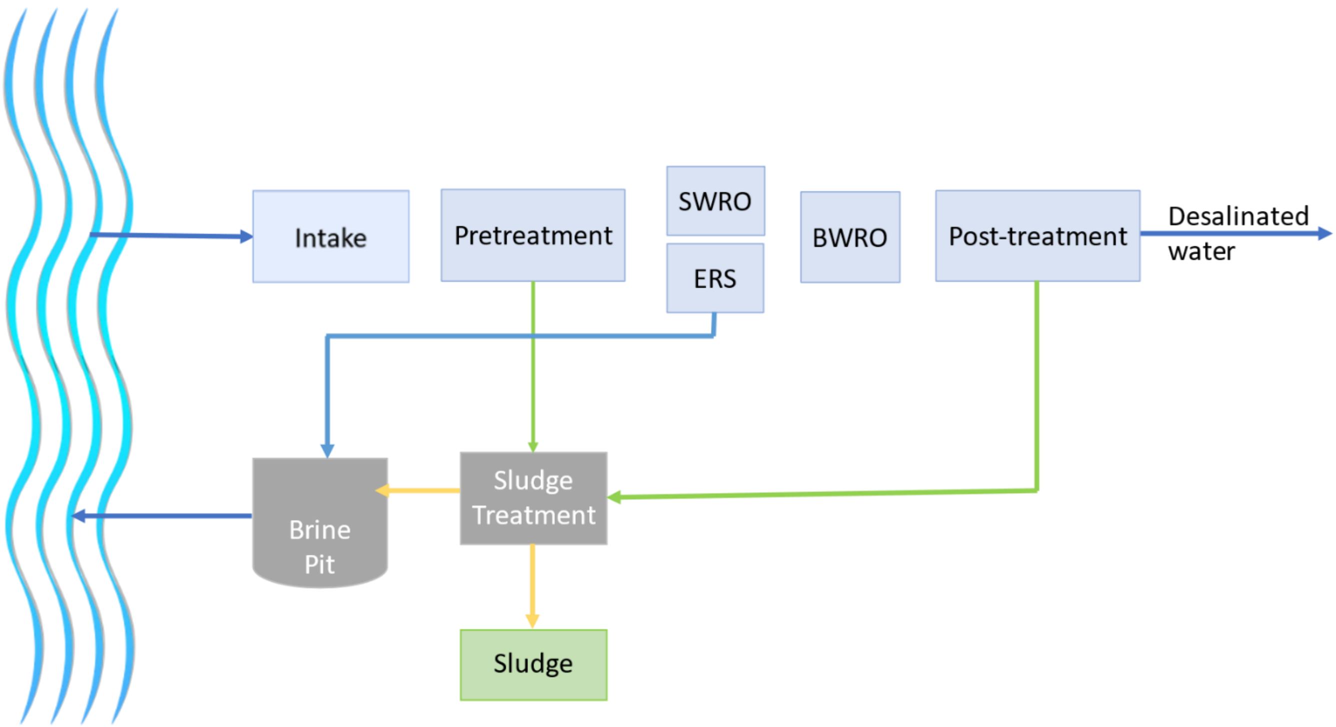

Figure 2: Process Stages in a typical SWRO Desalination Plant

1.3 Environmental Aspects

While the Ministry of Environmental Protection welcomed the establishment of desalination facilities, considering this an important national goal, it also provides suitable and strict environmental policies for proper management of the variety of environmental challenges expected due to the construction and operation of desalination facilities.

While the main challenge is clearly to ensure the preservation of the marine environment, there are many other aspects not discussed in this paper. Among these, there are also environmental aspects that have improved as a result of the implementation of the use of the high quality desalinated water in domestic environments. For example, in Israel, the hardness of the water from aquifers, etc. poses a real challenge due to scaling in pipes and machines, and the use of the higher quality water from desalination reduces this risk. Further, scaling is significantly reduced in sun collectors, resulting in longer life span for these. Due to the reduction of chlorides in general, the detrimental impact to the soil and crops is also reduced, with a resulting benefit to agricultural use.

In addition to the above, it is important to remember that increasing the scope of desalination means reducing the utilization of the natural resources. The Sea of Galilee and the aquifers are being restored, and more water flows in the springs and streams improving their quality.

The establishment of responsible regulations plays a major role in the State's national effort to overcome the water crisis, and assures the preservation of the country's precious marine and coastal environment.

This paper reviews the responsible implementation of the environmental regulations, which ensure preservation of the marine environment during, and after the construction, as well as during the operation of all the mega desalination plants along the Mediterranean cost of Israel.

The paper is aimed at decision makers in countries suffering from drought, and summarizes the environmental regulatory and permits policy, provides details and samples of monitoring reports, and expert conclusions on the actual marine and coastal environment.

II. REGULATORS AND REGULATIONS

2.1 Regulators

All aspects of desalination plant construction and operation in Israel are governed by three official bodies:

- **The Water Desalination Authority, the official Israel Government** contracting agent responsible for agreements between the parties. A great part of the success of desalination in a region (country/state) lies with the relationship between the off-taker and the project company/operator. A well-organized contractual arrangement leads to a good allocation of risk between the parties, and the expectations moving forward, and enables the proper design and operation. The more experienced a region is, the better this works.

  Also, the state/country oversees all aspects of the impacts of a plant. For example, the planning authority can take into consideration the environmental expected effects of the construction of a desalination plant, but also the negative consequences of long lasting drought and lack of water in the country, and direct the project regulatory environment in a holistic way.

  The water authority leads the Annual production plan for each plant, and follows up on the water quality including Process Performance monitoring and energy and chemicals consumptions.

- **The Ministry of Health,** responsible for raw and product water quality, monitored via
  - Daily laboratory sampling
  - Chemistry and microbiological analysis
  - Annual report
  - Laboratories authorized by the Ministry of Health
  - On-site laboratory certified by Ministry of health

- **Ministry of Environmental Protection**, which governs discharge quality and quantities, and impacts on the environment during construction and operation, and is responsible for issuing the respective Licensee permits.

One of the main objectives of the Ministry of Environmental Protection policy is the prevention of harm to the marine environment. This includes:

- Identifying the risks of sea pollution as a result of plant activity, possible mitigation measures to prevent and reduce pollution, pollutants that might be released in any situation, including emergency situations and periodic cleanings, as well as estimates of concentrations and daily and annual loads.
  - Monitoring the impact of the concentrated discharge water on water quality, from aspects such as heavy metals, antiscalants, biological pollution, toxicity, thermal effect, disinfectants, and other specific parameters that this effluent may contain due to the location of the desalination plant.
  - Steps to minimize/prevent any possible impact on the marine and coastal environment.
  - Reduction of the quantity of solids discharged to the sea from rinsing of filters, requires that the water be treated based on a technology of separating solids and their removal to an authorized site. The solids should have a moisture content of at least 25% solids and a concentration of dissolved solids (TDS) of less than 6% (60 grams of TDS/kg Dry Solids).
  - Minimizing the amount of phosphorus discharged into the sea.
  - Minimizing the quantity of suspended solids discharged into the sea from limestone washing, to which end the limestone wash water discharged into the sea should be treated to limit the concentration of suspended solids (TSS) to an average of 3.5 mg/l and a maximum of 10 mgl, the turbidity to an average of 15 mg/l and a maximum of 30 NTU prior to discharge, mixing with the concentrate water, and into the sea.
  - It is forbidden to discharge organic substances into the sea, including water from periodic membrane cleaning (CIP).

2.2 Regulatory Requirements

2.2.1 Preliminary environmental Survey (at the bid stage)

Environmental issues of possible concern are divided into those expected during the construction and operation stages, with the operation stage further sub-divided into marine impacts, and impacts on the terrestrial environment and atmosphere (Lokiec, 2013).

In order to address these concerns, as part of the bid stage proposal, the proposing companies are required to submit a detailed survey on all environmental aspects of the project, including mitigation practices, and possible solutions.

During the construction stage, possible impacts during the earth and construction works include alteration of the natural terrain, impacts of construction wastes and excess soil, soil and groundwater pollution (fuels, oils, etc.), air pollution (fugitive dust emission), noise emission, and damage to antiquities. Marine works during the construction stage raise the following concerns: alteration of the seabed, Sediment resuspension (impacts on marine water quality and ecology) and oil pollution.

Potential impacts on the **terrestrial environment and atmosphere during the operation stage** include:

- Alteration of the coastal environment and obstruction of free passage along the seashore (onshore pipelines and pumping station)

- Emission of greenhouse gases and air pollutants (power generation)
- Noise emission (pumping station and main plant)
- Interference from lighting (main plant)
- Accidental spillage or leakage of hazardous chemicals (main plant – storage and handling of chemicals)
- Solid waste and sanitary sewage (main plant [used containers, maintenance works waste, office waste)
- Aesthetic impacts (landscape and natural scenery (all inland structures)

Potential impacts on the **marine environment** during the **operation stage** include:

- Habitat alteration and changes in sediment transport (Intake & outfall systems (piping))
- Entrainment and impingement of marine biota (Intake system [suction heads])
- Debris pollution (from intake screening) - intake system (screening system)
- Biological effects of residual chlorine and chlorination by-products (concentrate outfall RO Brine)
- Effects of residual chemicals (iron hydroxide, metals, antiscalants, membrane cleaning chemicals)
- Particulate matter in the effluent (effluent outfall [process streams])

The way to address the above concerns related to the marine environment is by proper dispersion of the discharged effluent, and correct handling of the residual chemicals and particulate matter in the effluent by sludge treatment.

This preliminary survey during the bid process has a high point grade of almost 10% during the evaluation of each proposal, and aims to reflect the bidder's environmental approach.

2.2.2 Outfall Aspects

The design aspects of intakes and outfalls have been explained in detailed in the literature. (Missimer, 2018; Voutchkov, 2011)**.**

The main challenges associated with selecting the most appropriate location for desalination plant's marine outfall discharge are:

- Finding an area devoid of endangered species and stressed marine habitats;
- Identifying a location with strong marine currents that allows quick and effective dissipation of the concentrate discharge;
- Avoiding areas with frequent naval vessel traffic, which could damage the outfall facility and change mixing patterns; and
- Identifying a discharge location as close as possible to the shoreline, in order to minimize outfall construction expenditures, without compromising the intake water quality.

Figure 3: Near Shore Discharge - Hadera Desalination Plant

An Environmental Impact Assessment (EIA) is performed during the planning stages of the plants. This includes, inter alia, modeling of the brine dispersion, and pre-construction marine surveys. Modeling, to optimize the outfall design to achieve maximum dilution by certified research entities.

Near field simulations are usually performed with the UM3 model from the Visual Plume package developed by the United States Environmental Protection Agency (EPA), and the far-field simulations are performed with the CAMERI3D/HD-ST model. [Kress,2020]

The main issues addressed during the EIA include:

- Evaluation of discharge dispersion and recirculation of the discharge plume to the plant intake;
- Evaluation of the potential for whole effluent toxicity of the discharge;
- Assessment whether the discharge water quality meets the quantitative and qualitative effluent water quality standards applicable to the point of discharge;
- Establishment of the marine organism salinity tolerance threshold for the site-specific conditions of the discharge location and outfall configuration, in order to design the outfall for dilution that meets this threshold within a short distance from the point of discharge.

2.2.3 Management of the Plant Residual Chemicals and Particulate Matter

Although recent years have seen a significant reduction the chemicals used in the desalination process, some usage of chemicals is inevitable. This includes:

- Ferric Salts: as a coagulant additive for enhancement of filtration process. Most of the iron-hydroxide formed in the process and accumulated in the filters is removed by backwash water, and further removed in the backwash sludge treatment stage. The use of coagulants has been significantly reduced in most existing plants in Israel and almost eliminated in some.
- Antiscalants for the different RO stages: to inhibit scaling of sparingly soluble salts. Antiscalants used are based on Poly-Phosphonates or other substances previously proven successful in RO processes, as well as harmless to the marine environment. The final antiscalant is concentrated in the RO brine stream and discharged to the sea.
- Caustic Soda and Sulfuric Acid/CO2: for pH adjustment in the different stages of RO treatment. Mainly for the final remineralization process, with insignificant impact on the final effluent discharged to the sea.
- Flocculant (polymer): to help flocculation of particulate matter during treatment of the filters backwash and the limestone reactor washings. The flocculant is incorporated into the sludge formed in the sludge treatment process.
- CO2, Limestone, Lime Water, Sodium Hypochlorite and Caustic Soda for rehardening, pH adjustment and final disinfection of product water. Most of the chemicals are incorporated into the final product water and any remaining calcite particles removed during the backwash process of the reactors are treated and converted to sludge in the sludge treatment stage.
- Membrane cleaning and preservation chemicals: Caustic Soda and Hydrochloric Acid, are used only few times in a year, and are neutralized prior to discharge into the brine stream.

All chemicals used in the desalination plants comply with the requirements of the Ministry of Health for the treatment of drinking water.

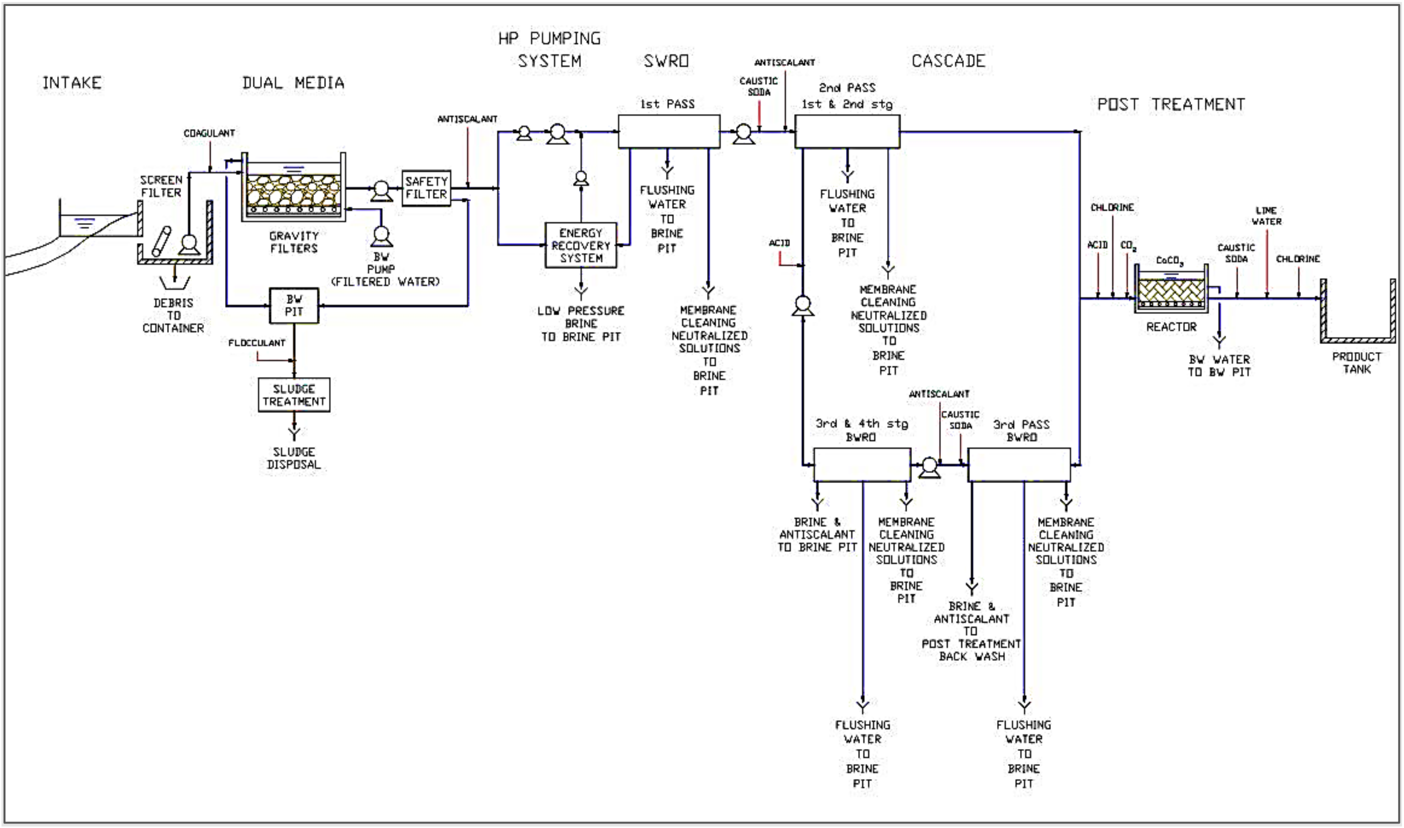

Figure 4: Typical Chemicals used in the desalination plants

2.3 Operation Reports

The Ministry of Environmental Protection defines very clear requirements for effluent discharge from the desalination facility.

All effluent discharge needs to comply with the Discharge Permit given to the plant, which needs to apply for a License Permit that has to be reissued every 1-5 years.

In addition, the following reports are required:

- Daily and online reports and weekly spot sampling
    - Automatic report every 15 minutes including discharge quality data from online sensors
    - Automatic SMS messages during times of water quality parameters deviation from standard
    - Full water chemistry analysis every two weeks
- Monthly Report.for each stream to the sea - RO brine, filter backwash, limestone wash, CIP solutions and overflows. The report includes quality analysis (by lab), quantities, deviations from standard and trend
- Annual report includes all the above, as well as
    - Yearly report of the turbidity of the discharge water – trends and causes of turbidity, actions for reducing turbidity

- Quarterly report for discharge fee calculation and payment – flow, Phosphorous, Nitrogen, BOD and TSS loads
- Yearly report for metals and nutrients discharge loads to sea due to the use of chemicals in the process
- PRTR (Pollutant Release and Transfer Register)
- Permit for use and storage of chemicals
- Marine monitoring
- Others

Figure 5 shows an example of a typical monthly report according to the requirements of the Ministry of Environmental Protection.

A	B	C	D	E	F	Y	Z	AE	AF	AJ	AK	AO	AP	AS	AT	AX	AY	BC	BD	BH	BI
מי רכז	מי רכז	מי גלם	מי רכז	מי גלם	מי גלם	מי רכז	מי רכז	מי רכז	מי גלם	מי רכז	מי גלם	מי רכז	מי גלם	מי רכז	מי גלם	מי רכז	מי גלם	מי רכז	מי גלם	מי רכז	מי גלם
Date	מספר תעודה	מספר תעודה	Time	Time	Time	Turbidity (lab)	Turbidity (on-line)	TOC	TOC	TSS	TSS	TDS	TDS	Turbidity	Turbidity	NH_4-N	NH_4-N	TKN	TKN	NO_3-N	NO_3-N
אופן דיגום				שעת דיגום בדיקת חטף לבדיקת אימות		אימות	אימות	מורכב	מורכב	מורכב	מורכב	מורכב	מורכב	מורכב	מורכב	מורכב	מורכב			מורכב	מורכב
אמות מידה						ממוצע של 15NTU ומקסימום 30NTU ל 4% מהזמן	ממוצע של 15NTU ומקסימום 30NTU ל 4% מהזמן			Max 15NTU											
dd/mm/yyyy						[NTU]	[NTU]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[NTU]	[NTU]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
07/03/2019	552833	552822	15:00	15:00	14:00	1.87	2.01	0.96	1.46	1.3	3	80,400	45,520	1.14	0.85	0.0200	0.0402			0.077	0.015
20/03/2019	549074	549063			11:30	2.98	2.88														
21/03/2019	556226	556196	15:00	15:00				0.56	1.84	1	1	70,000	43,520	0.81	0.46	0.0656	0.0283			0.215	0.028
02/04/2019	14925	14924	15:00	15:00	15:00	0.51	0.44	2	2	10	10	73,405	41,020	7.8	0.72	0.0902	0.1192			0.074	0.006
18/04/2019	17917	17916	12:00	12:00	11:20	0.45	0.48	2	2	10	10	68,560	42,000	0.43	0.31	0.1001	0.0577			0.068	0.011
06/05/2019	575265	575291	15:00	15:00	15:00	0.39	0.45	0.51	0.5	2	1	78,280	44,900	0.94	0.76	0.0963	0.075			0.116	0.010
22/05/2019	575216	575294	15:00	15:00	15:00	2.86	2.79	0.62	0.5	7.3	2.3	81,460	45,620	2.79	0.29	0.1125	0.0489			0.084	0.020
06/06/2019	575258	575293	11:00	11:00	15:00	2.04	1.65	0.8	0.51	29	4.7	79,900	45,710	7.8	0.52						
20/06/2019	577156	577160			11:45	2.26	2.73	0.94	0.83	1	1	78,880	44,590	0.42	0.22						
04/07/2019	586138	586120	15:00	15:00	15:00	0.86	0.74	1.28	0.83	3.3	1	79,600	45,400	0.35	0.26						
21/07/2019	58485	589340	12:00	12:00	15:00	1.11	0.98	0.91	0.73	1	1	77,600	44,960	0.80	0.40						
08/08/2019	596805	596709	11:00	11:00	11:00	1.09	1.0	1.12	0.84	1	1	79,320	45,560	0.91	0.25						
22/08/2019	601632	601778	13:00	13:00	13:00	0.93	0.87	1.04	1	1	1	82,500	45,900	1.29	0.29						

Figure 5: Typical Desalination Plant Monthly Report

2.3.1 Marine Monitoring Reports- Marine Surveys

As part of the brine discharge permitting process, the plants are required to conduct biannual compliance monitoring surveys to assess the effects of brine discharge on the receiving marine environment, and report the findings to the Ministry of Environmental Protection. Results are compared to those of previous years to evaluate environmental impacts and changes as a result of the plants' activity.

The goal of this studies is to characterize the spatial and temporal distribution of the brine plume during real operations, as opposed to modeling results, and determine its impact on seawater and sediments quality and on the biota.

The monitoring reports are submitted in Hebrew and are publicly available on the web site of the Ministry of Environmental Protection.

The Environmental Impact Assessment (EIA) serves as a reference against which to estimate the impact of the plants during long term operation.

The specific aims of these marine surveys are:

- To determine the actual variability of the brine dispersion,
- To compare the field and modeling results, providing necessary true ground data for modeling improvement, and
- To monitor the following parameters to ensure compliance with regulations:
    - Seawater (physical, chemical and biological tests) – to be performed twice a year, in the spring (April-May) and in the fall (September-October). Various parameters are tested from the list of parameters, according to the requirements of the Sea and Coastal Division: BOD, TSS, TOC as C, TDS, chlorides, turbidity, pH, MBAS, free chlorine, temperature, chlorophyll, nitrate as N, Ammoniacal nitrogen as N, nitrogen as N, phosphorus as P, ICP, Hg, GCMS organic substances. The concentrations are also measures in seawater outside the area of discharge influence on the marine environment (open seawater - background).
    - Sedimentological - The monitoring is carried out using accepted sampling methods of sediment from the bottom of the sea between the coastline and a water depth determined in the detailed monitoring plan. Granulometry of sediments and metals presence on sediment are measured.
    - Biological – In fauna population

The marine surveys use a sampling scheme comprised of a number of planned stations for discrete seawater sampling, and additional stations to follow the spatial dispersion of the brine plume for each plant. The number and location of these additional stations are based on the actual brine dispersion pattern encountered during the preliminary and bi-annual surveys.

The complex requirements to be complied with by plant operators, although time-consuming and requiring dedication and investment, are the key to successful desalination plant operation while preserving the marine environment. This has been shown to allow sustainable desalination for 17 years of operation of the Ashkelon desalination plant, as shown below.

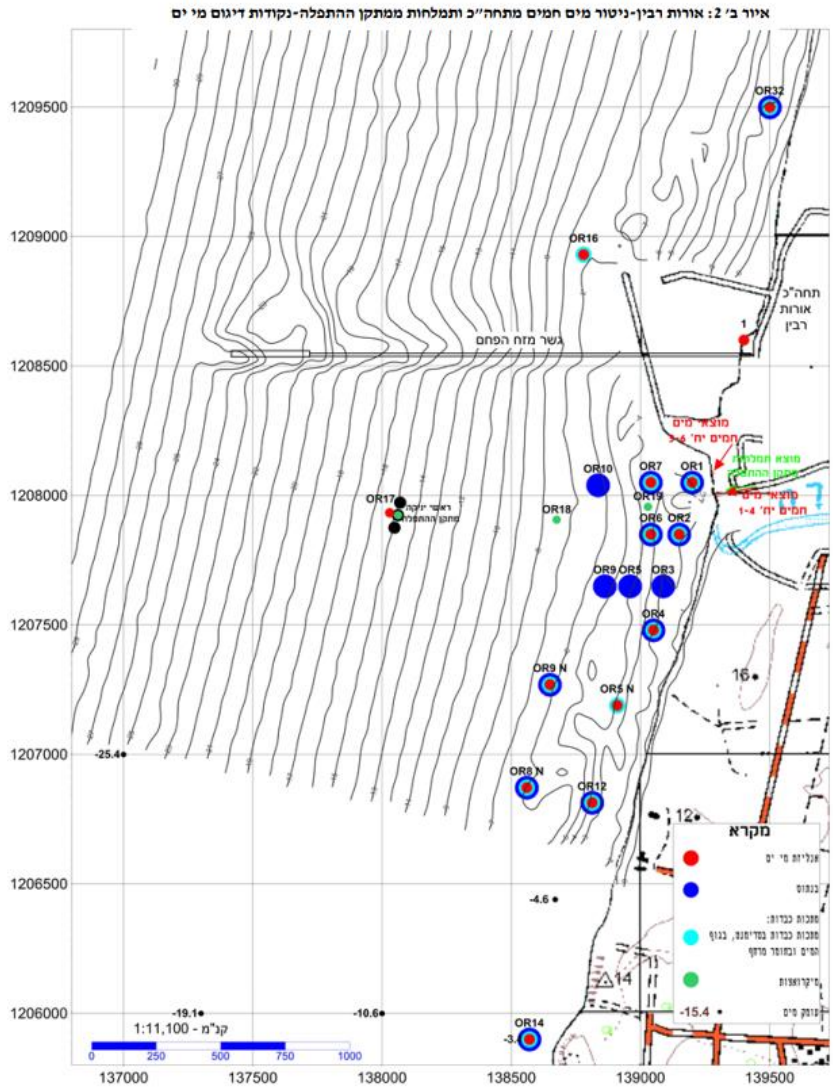

Figure 6: Sampling Points for the Hadera Desalination Plant

2.3.2 General Findings and Conclusion of Marine Surveys

As the Ministry of Environmental Protection strives to be transparent with regard to all reporting, these, and many other reports, can be found on the Ministry's website, at https://www.gov.il/he/departments/ministry_of_environmental_protection/govil-landing-page

Several researchers in various countries have studied the effects of desalination plant effluent discharge on the marine environment, and results across the board agree that there is no detrimental effect if the plants are constructed and operated in a environmental sustainable manner. The paper by Kress et al (2019), *Seawater quality at the brine discharge site from two mega size seawater reverse osmosis desalination plants in Israel (Eastern Mediterranean)* is of particular interest, both as it examines two of the plants along the Israeli Mediterranean coastline, and also because the data is recent. It can be seen in the paper that the effluent quality meets all the environmental requirements.

The conclusions and recommendations below have been extracted verbatim from the Marine surveys for the different desalination plants in Israel. This information is public and can be found in Hebrew at https://www.gov.il/he/departments/ministry_of_environmental_protection/govil-landing-page

Marine effluent from the following plants was monitored and submitted bi-annualy to Ministry of Environmental Protection since their first operation. The conclusions presented below are based on the latest reports available at the Environmental Protection office website: Hadera Desalination Plant and Orot Rabin Power Plant 2021;
Ashdod- 2022; Palmachim-Sorek1- 2022, Ashkelon- 2021.

The conclusions cited here relate only to the effluent from the desalination plants that was monitored, and not to other effluents from different sources mentioned in the same reports.

2.4 Marine Surveys Conclusions for the existing Seawater Desalination Plants

2.4.1 Hadera

The effluent of the Hadera desalination plant raises the salinity of the seawater in part of the monitoring area. The distribution of salinity in the monitoring area is determined by the extent of the mixing of the concentrate water of the desalination plant with the hot cooling water emitted from the Orot Rabin power plant, and the direction and strength of the natural winds and currents in the area.

Several conclusions emerge regarding the changes in the seawater quality in monitoring area in the last 8 years.

- In all the years, the area near the bottom with an excess **salinity** higher than 5% was found only in a limited area of less than **0.1 km^2**, except in the fall of 2021 when this area was about 3.0 km^2 due to the shutdown of one of the production units 1 - 4 of the power station.
- The results of the monitoring indicate that the concentrated water of the Hadera desalination plant,
  - Does not affect the turbidity and concentrations of **dissolved oxygen, suspended particles, heavy metals, and organic carbon** in the seawater in the monitoring area.
  - Does not affect significantly affect the concentrations of **nutrients** (except total organic phosphorus) in the monitoring area. The use of phosphonic antiscalants in the desalination plant does not contribute significant amounts of phosphate to the monitoring area (the biomass of algae) in the monitoring area
- The results of the multi-year monitoring findings
  - No effect of the effluent from the Hadera Desalination Plant in the **sediments** in the monitoring area related to the **concentrations of organic carbon and heavy metals (iron and trace metals**). This indicates that the iron and other metals that were discharged into the sea from the desalination plant during its years of operation did not accumulate in the sediments in the monitoring area, but were dispersed throughout the sea. These findings are an indication that, in general, particles originating from the desalination plant do not accumulate in the sediments.
  - A limited effect of the cooling water from the Orot Rabin power plant and the effluent from the desalination plant influenced the biotic species in the substrate of the monitoring area. In all the years of monitoring, the area of clear influence of the

cooling water and the effluent of the desalination plant on biotic species in the substrate (dilution of the number of individuals and species) was limited to a strip of shallow water (**up to a depth of 3 meters**) and a distance of about 15.0 - 25.0 km from the coast, and approximately 6.0 km south of the cooling water and effluent outfalls

- Recommendations: It is recommended to continue the same monitoring regime

2.4.2 Ashkelon

- The distribution of salinity in the monitoring area is determined by the extent of the mixing of the desalination plant effluent with the cooling water from the Rutenberg Power Plant, and the direction and strength of the winds and natural currents in the area.
- The effluent from the Ashkelon Desalination Plant increases the salinity of the seawater only in a part of the monitoring area. The salinity changes are smaller than the predictions of the effluent distribution model prepared prior to the start of operation of the desalination plant.

- The maximum excess **salinity** compared to the natural background near the seabed is found to be lower than 5% (about 2 salinity units), and it is usually limited to a distance of up to several meters from the common outfall.

- When the Rutenberg Power Station operates on a limited scale, the excess salinity can increase by additional ~2.5% (approximately 1 salinity unit), and can reach a distance of several kilometers from the source of the concentrate water.

- The effluent of the Ashkelon Desalination Plant does not affect the **turbidity** and concentrations of **dissolved oxygen, suspended matter, nutrients** (with the exception of total organic phosphorus) and organic carbon in the monitoring area.

- Concentrations of organic phosphorus in the seawater in the monitoring area (due to the use of phosphonic antiscalants): The additions of organic phosphorus do not contribute significant amounts of phosphorus to the monitoring area.

- The discharge of the cooling water from the Rutenberg and Dorad Power Plants into the sea, and of the concentrate water from the Ashkelon Desalination Plant, as well as the brackish water desalination facilities which belong to Mekorot, have no effect on the chlorophyll concentration (a measure of algae biomass) in the monitoring area. Over the years, abnormal chlorophyll concentrations have been measured in the monitoring area, probably due to the discharge of sewage from the Gaza strip to the sea (increased development of algae in the Gaza area, and their flow to the north due the sea currents).
- In terms of richness, distribution and frequency of the species of the different groups **of algae**, the results of the 2021 monitoring are not unusual relative to the findings in previous years, and the findings of other monitoring programs in nearby areas.
- The concentrations of the potentially toxic algae found in the monitoring area do not pose a danger, or indicate an effect of the effluent of the Ashkelon Desalination Plant

on the concentrations of **organic carbon and heavy metals** (iron and trace metals) in the sediments in the monitoring area.

- The metals discharged to the sea from the desalination plant do not accumulate The effect of the effluent from the desalination facilities on the biotic species within the substrate in the monitoring area (dilution of the number of individuals and species) was very limited, and limited to a strip of shallow water (up to a depth of about 5 m) that extended up to a distance of 8.0 km from the southwest to the sources of the warm and salty water, and 5.0 km from the beach.
- Recommendations: It is recommended to continue with the same monitoring regime

2.4.3 Palmachim and Sorek

- The effluent increases the salinity of the water in the monitoring area, especially near the seabed. The area of influence (defined as excess salinity of 1% , equivalent to 0.4 salinity units) is estimated to be at least 3 to 24 km^2, while the area varies according to the hydrographic conditions and the activity of the facilities before and during the sampling in the sea. Although an excess salinity variance of 0.4 units is within the range of the natural monthly/seasonal variation of salinity in the area, this is an indicative reference for delimiting the excess salinity related to the unaffected monitoring stations during sampling.
- When present, it was found that the area in which an excess salinity is higher than 5% is small, and is concentrated near the outlets of the effluent streams of the two plants.
- The effluent increases the **temperature** near the seabed by about 0.3-0.4^{o}C. The affected area is smaller than the area affected by the salinity.
- The brine from the Sorek facility is used as cooling water in the power plant IPP, causing an additional increase of up to 0.3 degrees in the temperature of the seawater at the Sorek outfall.
- No impact on the concentration of **chlorophyll** (an index of the biomass of microalgae) has been observed in the monitoring area till now.
- According to the results of the monitoring to date, there is no indication of an effect of the effluents on the **concentrations of suspended matter, nutrients (except for general organic phosphorus), organic substances, and metals in water** (dissolved and absorbed into a suspended substance).
- A correlation was found between the salinity of the effluents and organic phosphorus in the seawater, apparently from a source of phosphonate antiscalants used in the desalination process in the two facilities, and discharged to the sea with the effluent stream. At the same time, no deviations from the seawater standard values were found in all nutrients.
- The results of the monitoring to date show no effect of the effluent on the concentrations of organic carbon and heavy metals in the sediments.
- The totality of the biotic findings collected to date indicates the lack of impact of the effluent discharge in the entire monitoring area at a distance of 200m and more from the outfalls of the two desalination plants. The findings of the multi-year samplings at the monitoring stations, and in part within 200m area of the outlets, do not allow an unequivocal determination of the existence of any impact of the effluent in this area, inter

alia due to significant differences in the composition of the substrate found along the years (large presence of shells in some samples). Some of the findings indicate an effect of the effluent on the composition of the substrate, while others do not indicate such effects. In general, the results of the multi-year monitoring indicate a significant natural variation in the biotic within the substrate.

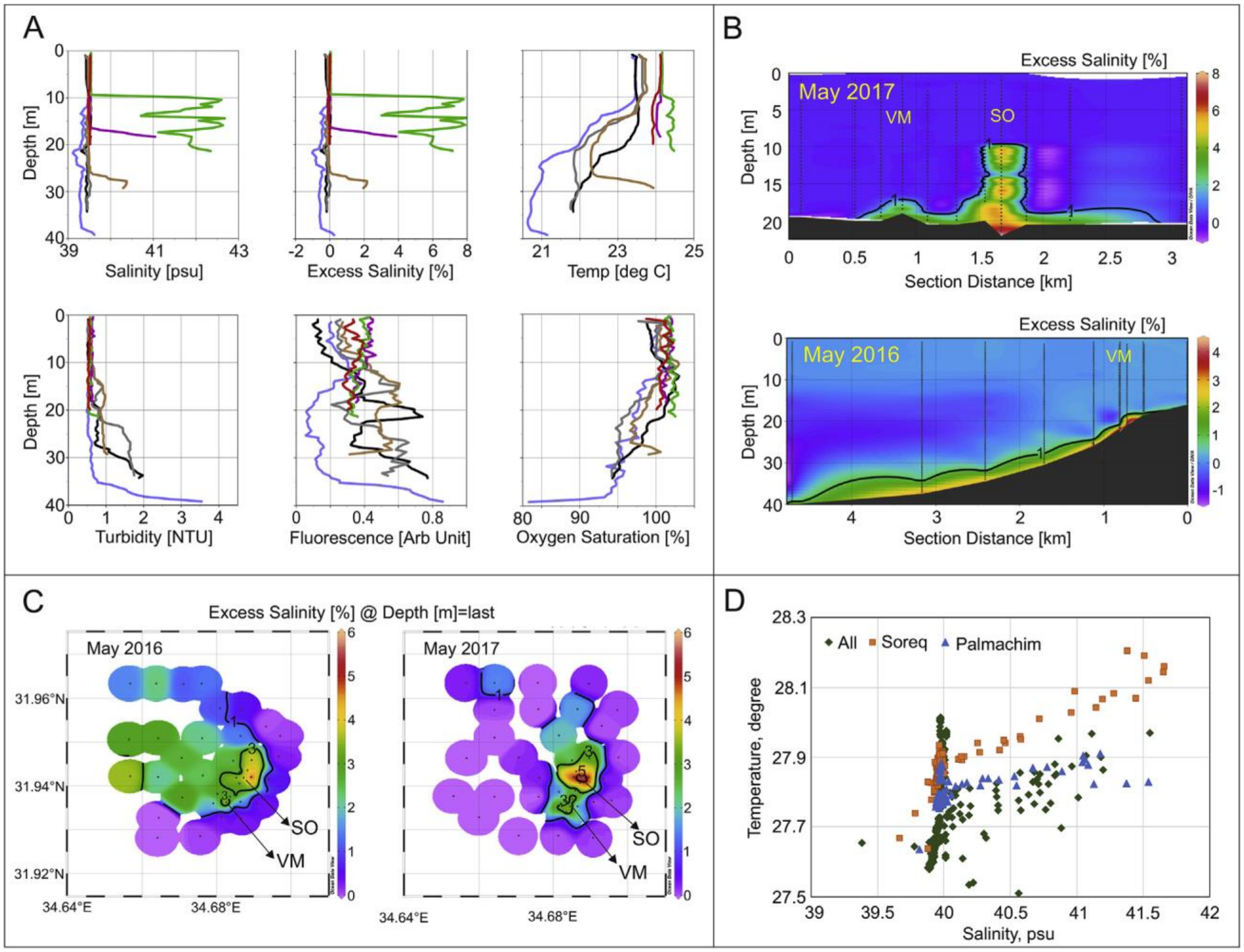

Figure 7: Depth profiles, depth sections, brine dispersion near the bottom and TS diagram at representative stations and surveys. (The Soreq and Palmachim outfalls are abbreviated as SO and VM respectively) (Kress et al., 2020)

A. Depth profiles of salinity, excess salinity, temperature, turbidity, fluorescence and dissolved oxygen saturation at selected stations (May 2017). SO and VM outfalls in green and purple, respectively; reference station in red. Other colors, typical stations.

B. Depth sections of excess salinity through the outfalls (May 2017) and westwards towards the open sea (May 2016).

C. Excess salinity in seawater near the seabed in May 2016 and 2017. Points denote the sampling stations (Fig. 1) and the right panel, the color coded scale of excess salinity.

D. Temperature vs Salinity (TS) diagram for the October 2018 survey. Orange squares - Soreq outfall and nearby stations; Blue triangles - Palmachim outfall and nearby stations; Green diamonds, other stations.

Recommendations

It is recommended to continue the monitoring in the area of the Palmachim and Sorek outlets in the existing format, with the exception of canceling the tests for oils and grease, and all hydrocarbons derived from petroleum. It is recommended to cancel these tests since the desalination process does not release these substances into the sea, and in all the samples in the monitoring area in the last five years, these were not detected in any sample.

2.4.4 Ashdod

Preliminary results of 2022

The highest excess in salinity found was 3.4 % at a distance of 750 m from the outfall outlet at a depth of 29 m. In the rest of the sampling stations, the excess salinity was lower than 1%.

Slight differences in **fluorescence, water turbidity, and oxygen saturation** near the bottom were observed in the monitoring area with slightly higher values in the deeper areas. These differences are natural, and are related to the thermocycling process in late spring-early summer (they do not show a statistical relationship for the distribution of the concentrated water in the area).

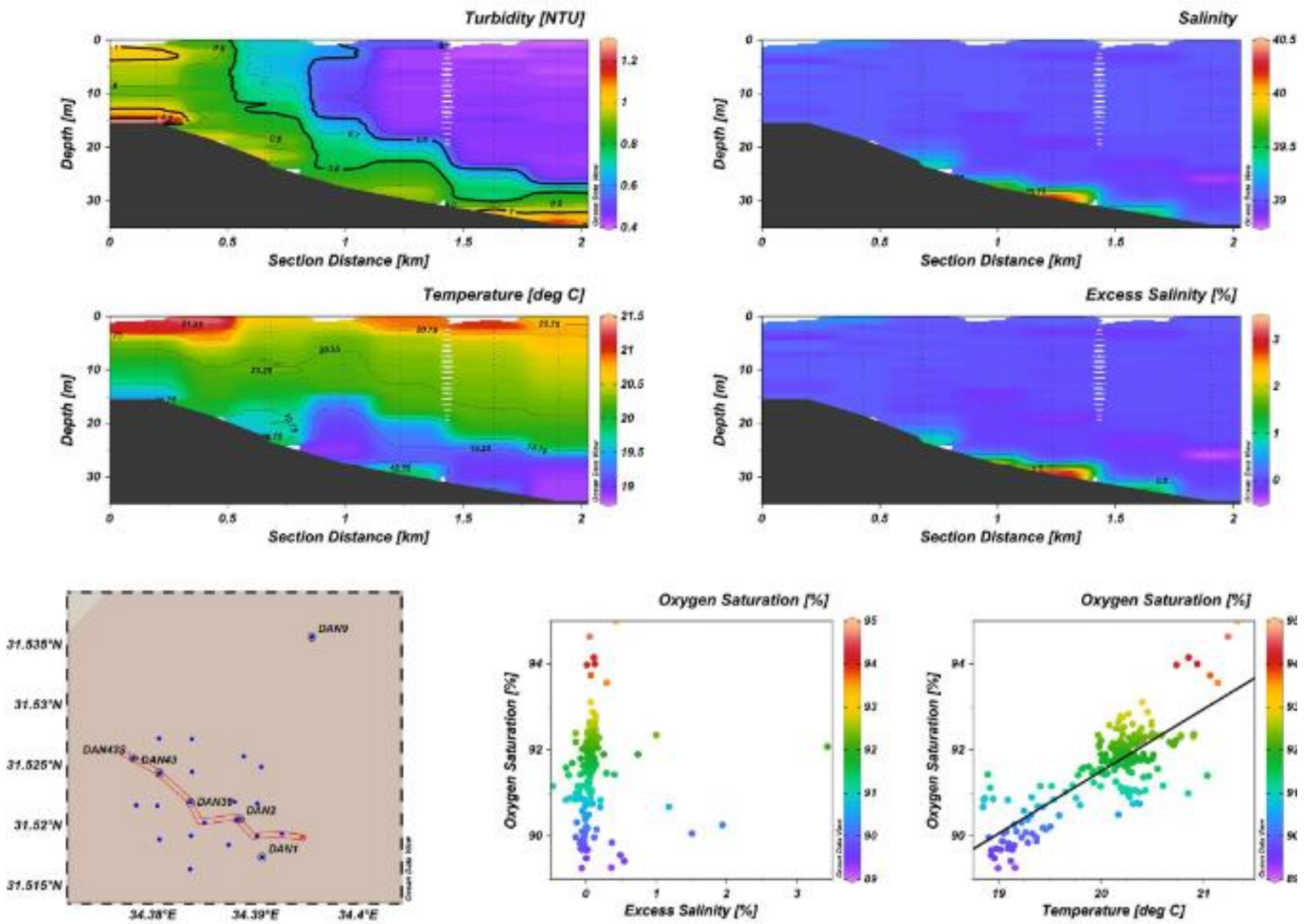

Figure 8: Sample from the Ashdod Desalination Plant Report (2022)

IV. CONCLUSIONS

Israel's largely arid climate and lack of natural water sources led the decision makers to look into the development of alternative water sources, and desalination was one of the key solutions to address this challenge. Over less than a decade, Israel moved from limited natural resources to water independence, with the production of almost 600 Mm^3/year resulting in a significant portion of the Country's drinking water supplied from mega size desalination plants. Israel's ability and technological readiness today to independently address the gaps in demand for water are exceptional on any international scale.

Desalination technology provides an important source for stabilizing the volatility of natural water, and makes it possible to reduce the gaps between water demand and supply, as well as improve the quality of the supplied water through management with water with a low salts concentration.

While the reliance on desalination plants for water production provides Israel with resilience, it also poses a challenge to the preservation of the vulnerable environmental sources due to the disposal of the plant effluent back to the sea.

Results of the continuous monitoring have clearly demonstrated the viability, economics and sustainability of the technology as a legitimate alternative source of drinking water for the State of Israel.

The success of the original master plan can be attributed to 3 main reasons

- The vision of decision makers that identified the need for this solution, and their obstinacy to implement it under totally uncertain conditions.
- The robust management base created to support the preparation, design and implementation of the first BOT contracts, new in this field, as well as realistic WPAs that allow long term engagement of both sides for the benefit of the State. The more experienced a region is, the better this works.
- Creation of a regulatory system, albeit complex and demanding, that allows the regulator to be in continuous control of the performance of the plants, and guarantee the compliance of the final desalinated water and the effluent discharged to the sea to fully comply with the stipulated quality, thus protecting the marine and coastal environments.

The efforts invested in the follow-up of the plants have given the green light for the progressive implementation of the 5 plants already in operation, the 6th under construction, and the 7th in the final tendering stage.

The impressive map of desalination along the Israeli Mediterranean coastline is testament to the success and sustainability of both the technology and its environmental management, and firmly positions Israel as a role model for the harmonious co-existence of desalination and the environment.

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