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Control and management of brine disposal for inland desalination plants

Arina Shulman*, Inbal David, Elena Gelman, Menahem Priel

Mekorot — National Water Co., PO Box 20128, Tel-Aviv 61201, Israel
Tel. +972 (3) 6230604; Mobile +972 (50) 2173491; Fax +972 (3) 6230864; email: ashulman@mekorot.co.il

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ABSTRACT

Desalination is a solution for a range of water supply problems. A higher recovery rate is an important goal because it increases production and improves cost effectiveness. As the recovery ratio increases, however, the concentration of dissolved ions in the brine becomes high enough to form scaling caused by precipitation of super-saturated salts. These precipitates might form a scale not only on membranes' surfaces but also in the brine disposal line. In order to prevent scale formation, special antiscalants are added to the reverse osmosis feed. It is important to emphasize that antiscalants only delay the onset of precipitation, resulting in possible scale precipitation in long outlet pipes. In addition to the tendency of scaling, brine disposal can be a serious environmental concern that needs to be studied and considered when building a desalination plant. Marine brine disposal can cause three possible hazards: precipitation on the pipe walls, soil and marine contamination. Since 2004, Mekorot has exclusively operated and maintained a unique 30-km long brine disposal pipeline to the Mediterranean Sea with the required permission from the Ministry of Environmental Protection. The pipe is used to dispose brine streams from the Gat and Granot BWRO desalination plants, which are located in southwestern Israel near the city of Ashkelon. A brine disposal pipe was developed by Mekorot as part of a coastal aquifer rehabilitation project and was chosen as the most economic solution for these two plants. A few years ago, an experimental system was run to obtain the design parameters for preventing scale deposition from a concentrate solution. Through the design of optimal operation of brine pipes, we prevent soil contamination and avoid scale deposition from concentrate solutions from both desalination plants. This paper reviews the management and control of the brine disposal pipe, including early scale detection, as well as the standard and special monitoring programs for the long brine disposal pipe at Mekorot.

Keywords: Desalination; Aquifer rehabilitation; Brine; Scaling; Antiscalants; Monitoring programs

1. Introduction

Reverse osmosis (RO) desalination is a process that removes salts and other dissolved solids from salt water. The RO process can remove total organic carbon (TOC), precursors to disinfection by-products. Reverse osmosis membranes are also very effective in removing microorganisms; such as protozoa *Cryptosporidium* and *Giardia*, bacteria and viruses [1,2].

One of the issues to be solved considering RO desalination plants is the generation of concentrate effluent (brine), whose environmental impacts has to be considered and studied.

The main conventional brine disposal methods for brackish water reverse osmosis (BWRO) are: surface and sewer discharge, deep well injection, and evaporation

* Corresponding author.

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ponds [3–7]. Ocean disposal is the most cost effective method, and is therefore almost exclusively used wherever practical, mainly for desalination plants near the sea [8,9]. However alternative methods have to be considered for inland remote locations [10]. The most suitable disposal method from environmental and economical aspects has to be evaluated site-specifically. For example, brine discharge to open land will salinize the soil and groundwater, and will significantly damage numerous crops. Evaporation ponds, which only work well in arid areas, require large tracts of land and are consequently an expensive option. Therefore, marine brine disposal from inland desalination plants is permitted when a suitable land alternative does not exist and/or the brine does not contain pollutants which can harm the marine environment.

Operating at high recovery rate in RO desalination is an important goal because it increases production and improves cost effectiveness. As the recovery ratio increases, however, the concentration of dissolved ions in the brine becomes high enough to form scaling caused by precipitation of super-saturated salts, such as calcium carbonate ($CaCO_3$), calcium sulfate ($CaSO_4$), calcium fluoride (CaF_2), barium sulfate ($BaSO_4$), strontium sulfate ($SrSO_4$), magnesium hydroxide ($Mg(OH)_2$) and silicates (SiO_2) [11–14]. These precipitates might form a scale not only on membranes' surfaces but also on pipe walls in the brine disposal line. Scale precipitation along a pipe tens kilometers long is probably irreversible, and it is therefore obviously easier to invest in preventing the scale formation, rather than wasting efforts in removing scaling. In order to prevent scale formation, special antiscalants are added. It is important to emphasize that antiscalants only delay the onset of precipitation, resulting in possible scale precipitation in long outlet pipes and probably causes CO_2 emissions as well [13].

In addition to scaling tendency, marine brine disposal can cause other possible hazards, such as soil and marine contamination.

The Mediterranean Sea, as the receiving water body of the brine, is oligotrophic and therefore sensitive to the addition of organic matter or nutrients, such as nitrogen and phosphates, which effect eutrification. Their impact depends on their concentration and total loads. Silica enrichment may also change algae diatoms composition that directly contribute to the large fish populations in coastal zones, and which require nutrients nitrogen, phosphorus and silicon for their photosynthesis. Regions with substantial natural silica inputs can tolerate larger sewage inputs of nitrogen and phosphorus before undesirable eutrophication effects occur [15,16].

Non-metal equipment and stainless steel are typically used in RO plants. Sometimes, however, trace metals can originate from underground water. The RO brine may therefore contain traces of iron, nickel, chromium, molybdenum and other metals, but contamination levels are generally low. Heavy metals tend to clump in suspended material and finally in sediments, so that areas of restricted water exchange and soft bottom habitats can be affected by heavy metal accumulation. Many benthic invertebrates feed on this suspended or deposited material, with the risk that metals accumulate in their bodies and are passed on to higher trophic levels. It is therefore recommended to set limits for heavy metal concentrations in brine discharges.

Due to concerns about soil and marine contamination and possible precipitation in pipelines, management and control of the brine disposal pipeline are required.

2. Discussion

2.1. Process description

The quality of coastal groundwater in Israel is harmed by natural and anthropogenic salinization, such as overpumping.

The major goals in aquifer rehabilitation are salinization prevention of the aquifer as a whole by pumping the saline water and desalination, production of high-quality water and initiating a long-term process of cleaning the salted zone.

Mekorot Company established BWRO desalination plants Gat (daily capacity 4,200 m^3) and Granot (daily capacity 9,000 m^3) as the first phase of future total daily capacity of 100,000 m^3 that include the third future desalination plant Lahat (under construction). The plants are located in southwestern Israel near the city of Ashkelon.

Both desalination plants were constructed to operate in a wide range of recovery ratios, ranging between 80% and 88%, with a currently brine flow of 130 m^3/h (R = 80%). The RO plants have two desalination stages with an inter booster pump for flux adjustment.

2.2. Brine disposal pipeline description

Since 2004, Mekorot has exclusively operated and maintained a unique brine disposal pipeline to the Mediterranean Sea. A brine disposal pipe was chosen as the best solution due to the high cost of land in central Israel and the Mediterranean zone climate with a typical high relative humidity of 40–80%. The operation and maintenance of the brine disposal pipeline comply with Ministry of Environmental Protection regulations.

The pipe, which is about 30 km long, is used to dispose brine streams from Mekorot's Gat and Granot BWRO desalination plants, as well as from the future plant at Lahat. The future daily capacities of RO desalination plants Granot (after extension) and Lahat are 54,200 m^3 and 45,200 m^3, respectively. Therefore, brine disposal pipeline is designed to transfer flow up to 1,000 m^3/h in comparison to 130 m^3/h currently.

The brine from these plants is combined with the vast brine stream from VID's (IDE Technologies, Veolia

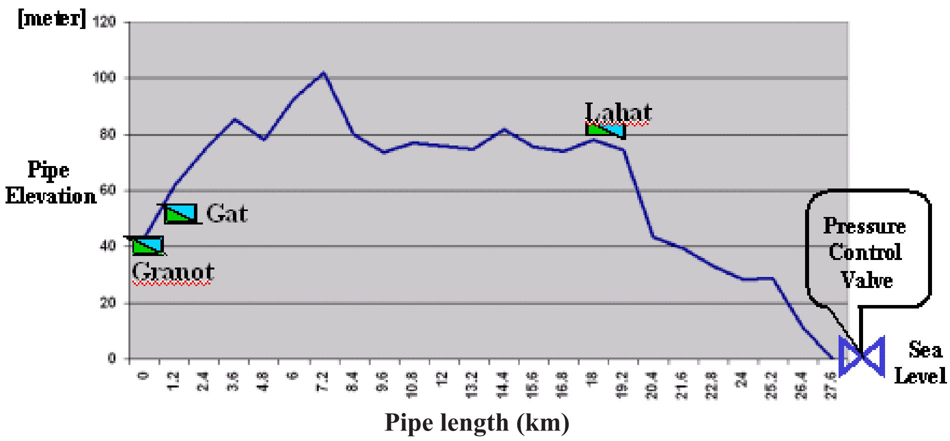

Fig. 1. A topographic section of the brine line and the desalination plants.

and Dankner-Ellern Infrastructure) SWRO desalination plant at Ashkelon, resulting in a combined outlet stream of brine to the sea.

A topographic section of the brine line and the desalination plants are illustrated in Fig. 1.

The brine disposal parameters for the brine pipeline design were achieved through flow simulation [13]. The parameters examined in the experiment were the scaling potential and the antiscalant concentrations. The main conclusions for design, operation and maintenance were as follows:

- It is important to ensure full pipe flow in order to prevent CO_2 emissions, which induces a pH increase and initiates precipitation.
- Control of LSI. The Langelier Saturation Index used to predict the calcium carbonate stability of water; that is, whether water will precipitate, dissolve, or be in equilibrium with calcium carbonate. LSI values must be kept under 2 along the pipe.
- Defined pH and antiscalant dosage that should be kept along the pipe at a concentration level of 50 ppm antiscalant with pH of 7.2 (at 88% recovery).

Mekorot monitors the brine disposal line to avoid solid precipitation, including early scale detection, as well as the standard and special monitoring programs for the long brine disposal pipe.

The brine disposal pipeline is very long and immersed in the ground so if scaling will be formed it will be very difficult to locate it and to implement a cleaning procedure.

Fig. 2 illustrates the brine pipeline and the desalination plants location, on the local map.

There are sampling points along the brine disposal line:

1. Granot station — inlet of Granot's brine to the pipe;
2. Gat station — inlet of Gat's brine to the pipe;

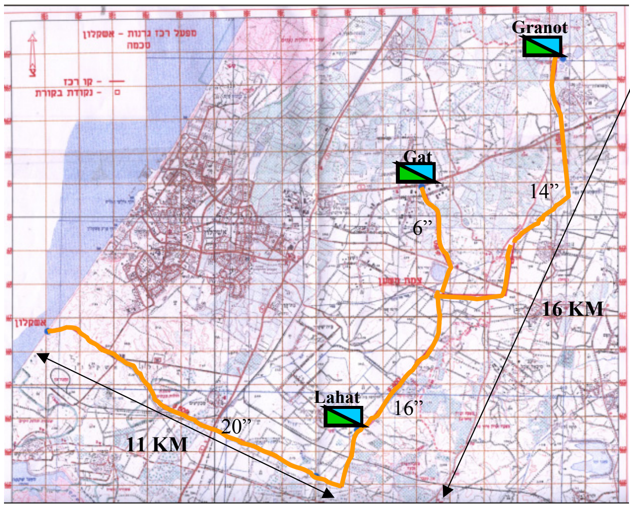

Fig. 2. Location of the brine pipeline and the desalination plants.

3. Lahat station — several kilometers after merger of the two brine streams from both desalination plants;
4. Ashkelon station — marine brine disposal.

2.3. *The monitoring programs*

2.3.1. *The standard monitoring program*

The standard monitoring program includes several types of monitoring: online control, measurement and sampling every three days, once a week and once a month. The detailed standard monitoring program is as follows:

1. Online monitoring:
   - Flow capacity at the Ashkelon station;
   - Antiscalant injection control;
   - Turbidity and pH at the Ashkelon station;

- Nitrate (as N) monitoring at the Ashkelon station.

2. Monitoring once every three days:
   - Electrical conductivity measuring at the Ashkelon station.
3. Weekly monitoring. The following parameters are monitored and sampled at the Ashkelon, Lahat, Gat and Granot stations:
   - Turbidity, electrical conductivity, pH and temperature measuring;
   - Alkalinity, calcium, silica (as Si) and nitrates (as N) sampling.
4. Monthly monitoring at the Ashkelon station:
   - Total phosphorous TP and phosphate PO4-P sampling;
   - TDS sampling;
   - TSS sampling;
   - Nitrogen components such as total nitrogen TN, nitrogen KJELDAHL TKN, ammonium NH_4-N and nitrite NO_2-N sampling;
5. Once every six month:
   - Sea sediment analysis: heavy metals (Cu, Cr, Cd, Pb, Ni, Zn, Hg, Fe, Pb, V) and TOC.

2.3.2. The special monitoring program

The special monitoring program is important because it compares expected and measured values at the Lahat and Ashkelon stations.

The theoretical values are calculated one and two days after the brine emerges from the Gat and Granot desalination plants in Lahat and Ashkelon stations, respectively.

The main purpose of this program is to detect whether scaling is occurred in the pipe. A difference between the expected and measured values suggests that some precipitation has occurred in the pipe.

The special monitoring program is as follows: pH, temperature, turbidity, electrical conductivity measuring and alkalinity, calcium, silica, nitrates and phosphorous samples are taken on a daily basis during two weeks period twice a year in all sampling locations.

In addition to the two monitoring programs, the "control pits" (inspection holes in the pipeline) for scaling monitoring in the pipeline are also inspected.

2.3.3. Monitoring for soil contamination prevention

Monitoring of the disposal line to prevent soil contamination by leakage of the brine to the soil includes the following points:

1. Online flow capacity measuring.
2. Online pressure measuring.
3. Weekly visual inspection along the pipe route.

2.4. Prevention of marine contamination

Mekorot's disposal of the brine complies with Ministry of Environmental Protection regulations. Mekorot provides a monthly operational report. The environmental impact of marine brine disposal is mainly marine disturbance in the outlet zone of the pipeline, due to the high salinity and chemical constituents in the brine.

Detailed below (Table 1) are the discharge quality levels provided by the Ministry of Environmental Protection for the BWRO desalination plants Gat and Granot in 2010.

2.5. Results from the special monitoring program 2009

Background monitoring from Granot and Gat desalination plants was implemented in 2005, after commissioning the facilities in late 2004. Monitoring has subsequently been implemented twice a year. The first special monitoring program implementation was started in January 2005.

It is important to reiterate the importance of the special monitoring program because it compares expected and measured values at the Lahat and Ashkelon stations.

Figs. 3–13 summarize the results from the special monitoring program performed in 2009. Both desalination plants have been operated at 80% recovery ratio.

The following parameters were measured in the brine samples: turbidity, electrical conductivity, temperature,

Table 1
Discharge quality levels provided by the Ministry of Environmental Protection in 2010

Parameter	Maximum concentration
Suspended solids 105°C (TSS), mg/L	15
Turbidity, NTU	15
TOC, mg/L	10
pH	9.0 > pH < 6.5
Total P[1] (temporary value)	6 mg/L 15 ton/y
NO_3-N[2] (temporary value)	63 mg/L (R = 80%) 110 mg/L (R = 88%) 341[3] ton/y
Appearance	Clear, without color and odor at all time

[1]Total P reduction goal: 0.5 mg/L (mean) and 1 mg/L (max). The technical aspects are tested by running antiscalants without phosphorous at a pilot plant. The objective is to replace polyphosphate antiscalants with environmentally friendly antiscalants.
[2]NO_3-N reduction goal: 5 mg/L (mean) and 8 mg/L (max). The technical-economic aspects should be tested by running a pilot plant for the denitrification technology.
[3]Annual loads discharge quality standards in 2010 is much higher than in 2009. The reason is the addition of brine disposal from two future planned desalination plants at Lahat and the new unit of Granot, which will begin discharging brine to the pipeline in the summer of 2010.

pH, calcium, total alkalinity, LSI, silica, nitrates and phosphorus.

2.5.1. Turbidity

Turbidity data were measured along the brine pipeline (Fig. 3). The measurements were taken during March and November 2009. Fig. 3 shows that turbidity values were stable along the brine pipeline and were well below 1 NTU. If precipitation inception occurs, then an increase in brine turbidity is observed.

In addition, turbidity values at the Ashkelon and Lahat stations were not lower than the turbidity values at the outlet of Gat and Granot stations. Therefore, the probability of scale forming in the brine pipeline was slim.

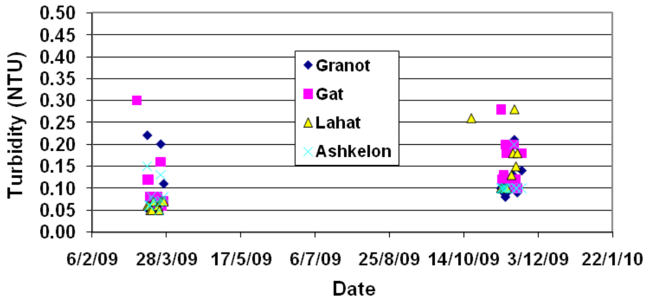

Fig. 3. Turbidity along the brine pipeline (March, November 2009).

2.5.2. pH

Fig. 4 illustrates the pH values of the two special monitoring programs conducted in March and November 2009 along the brine pipeline.

The pH values in the brine from the Gat Desalination Plant were higher than pH values in the brine from the Granot Desalination Plant because of acid addition in the feed water in Granot Desalination Plant.

The pH ranged from 7.4 to 7.5 at the Ashkelon station.

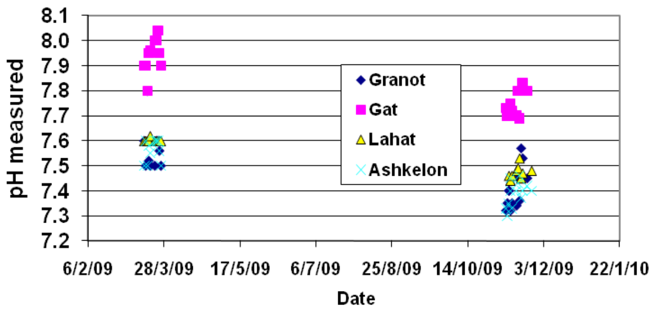

Fig. 4. pH values along the brine pipeline (March, November 2009).

2.5.3. Langelier saturation index (LSI)

Fig. 5 illustrates the LSI values of the two special monitoring programs conducted in March and November 2009 along the brine pipeline.

The LSI values in the brine from the Gat Desalination Plant (about 2) were higher than LSI values in the brine from the Granot Desalination Plant (about 1.5–1.6). This result was expected, because LSI values depend on pH values. As pH rises, a greater LSI value is obtained.

The use of antiscalant at both desalination plants enabled operation with LSI of 1.8–2.1 in the pipe. Antiscalants adsorb onto formed crystals or associate/complex with incipient nuclei (or crystals) and these phenomena govern the inhibition of scale formation. In this situation the crystals never grow to a size or concentration sufficient to fall out of suspension. The antiscalant used in both desalination plants is effective in controlling carbonate, sulfate, fluoride and silica scaling.

The antiscalants only delay the onset of precipitation, resulting in possible scale precipitation in long outlet pipes.

Saturation pH depends on calcium, alkalinity and TDS concentrations. Therefore, if the concentrations of calcium, alkalinity and TDS increases as a result of recovery increase, it will be necessary to automatically decrease the pH values of the brine streams.

Currently, when recovery of both desalination plants

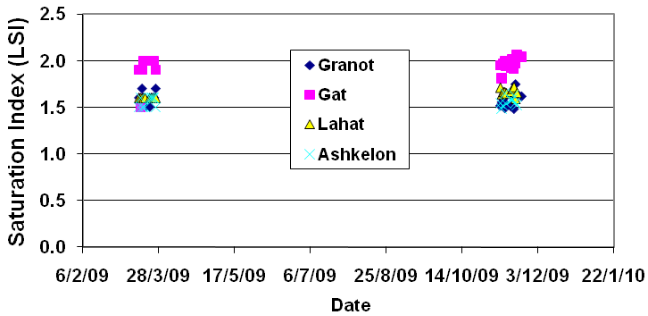

Fig. 5. LSI values along the brine pipeline (March, November 2009).

is 80% there is no danger in operation with the pH values that were shown above (Section 2.6.2).

The LSI values of 1.5–1.6 at the Ashkelon station were similar to LSI values from Granot Desalination Plant. The capacity of the Granot Desalination Plant is much higher than capacity of the Gat Desalination Plant, therefore Granot has higher impact on LSI value along the brine pipeline after the two streams merge.

Consequently, the probability of scale forming in the brine pipeline in terms of LSI was slim.

2.5.4. Alkalinity

The pH range of both brine streams is between 7 and 8, therefore the total alkalinity is practically equal to the bicarbonate alkalinity.

The overall chemical reaction involved in precipitation of $CaCO_3$ from a supersaturated solution is:

$$Ca^{2+} + 2HCO_3^- \Leftrightarrow CaCO_3(s)\downarrow + CO_2 + H_2O \quad (1)$$

If precipitation inception occurs, then a sharp drop in total alkalinity is observed.

Fig. 6 illustrates the total alkalinity of the two special monitoring programs conducted in March and November 2009 along the brine pipeline.

The alkalinity in the brine from the Gat Desalination Plant (about 1400 mg/L as $CaCO_3$) was higher than alkalinity in the brine from the Granot Desalination Plant (about 1300 mg/L as $CaCO_3$). An alkalinity decline was not observed in either special monitoring program.

Figs. 7a and 7b illustrate the theoretical and actual alkalinity values at the Ashkelon and Lahat stations of the two special monitoring programs.

The alkalinity measured at the Ashkelon and Lahat stations (1300–1320 mg/L) were compatible with the calculated theoretical alkalinity, as can be seen in Figs. 7a and 7b, respectively.

The calculation assumption:

1. The calculation of the theoretical concentration of alkalinity at the Ashkelon station is based on two days after brine discharge from both desalination plants. The actual retention time of the two brine streams is 42.8 and 32.6 h from Granot to Ashkelon and from Gat to Ashkelon, respectively.
2. The calculation of the theoretical concentration of alkalinity at the Lahat station is based on one day after brine discharge from both desalination plants. The actual retention time of the two brine streams is 12.8 and 2.6 h from Granot to Lahat and from Gat to Lahat, respectively.

2.5.5 Calcium, Ca^{2+} concentration

Fig. 8 illustrates the calcium concentration of the two special monitoring programs conducted in March and November 2009 along the brine pipeline.

If precipitation inception occurred then a sharp drop in calcium concentration is observed.

The calcium concentration in the brine from the Gat Desalination Plant (about 400 mg/L as $CaCO_3$) was lower than calcium concentration in the brine from the Granot Desalination Plant (about 500–550 mg/L as $CaCO_3$). A calcium concentration decline was not observed in either special monitoring program.

Figs. 9a and 9b illustrate the theoretical and actual calcium concentrations at the Ashkelon and Lahat stations of the two special monitoring programs conducted in March and November 2009 along the brine pipeline.

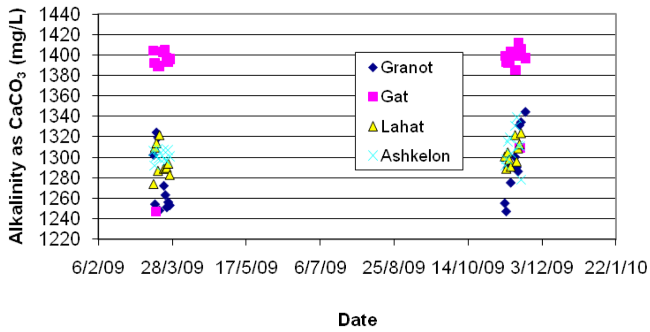

Fig. 6. Alkalinity along the brine pipeline (March, November 2009).

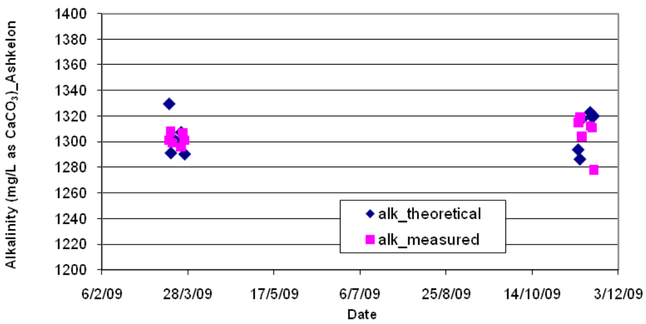

Fig. 7a. Theoretical and measured alkalinity at the Ashkelon station (March, November 2009).

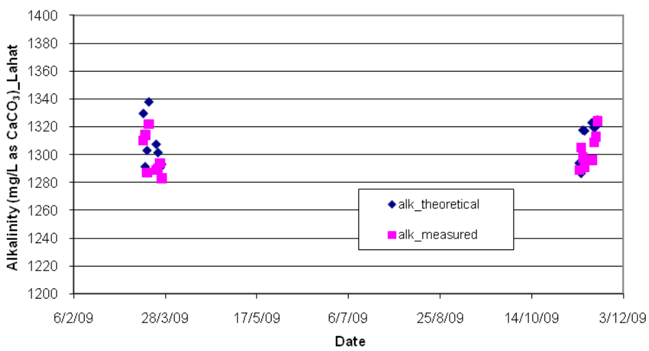

Fig. 7b. Theoretical and measured alkalinity at the Lahat station (March, November 2009).

The calcium concentrations (500–550 mg/L) measured at the Ashkelon and Lahat stations were compatible with the calculated theoretical calcium concentration with small deviations, as can be seen in Figs. 9a and 9b, respectively. The reason for deviation is shown in Section 2.5.4.

In conclusion, there was no $CaCO_3$ precipitation.

2.5.6. Silica concentration

Fig. 10 illustrates the silica (Si as SiO_2) concentration of

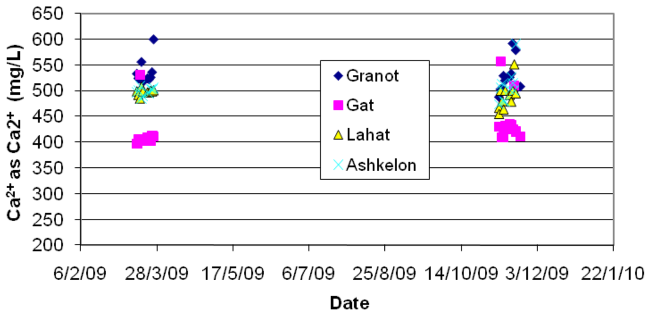

Fig. 8. Calcium concentration along the brine pipeline (March, November 2009).

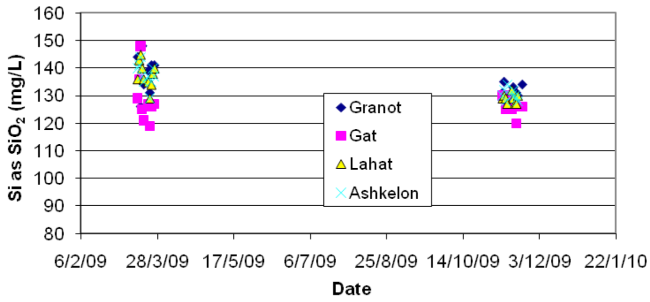

Fig. 10. Silica (as SiO_2) concentration along the brine pipeline (March, November 2009).

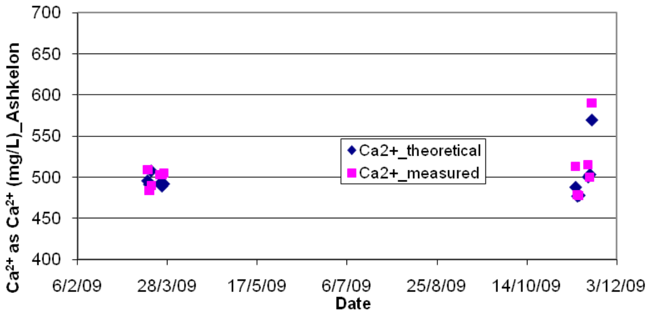

Fig. 9a. Theoretical and measured calcium at the Ashkelon station (March, November 2009).

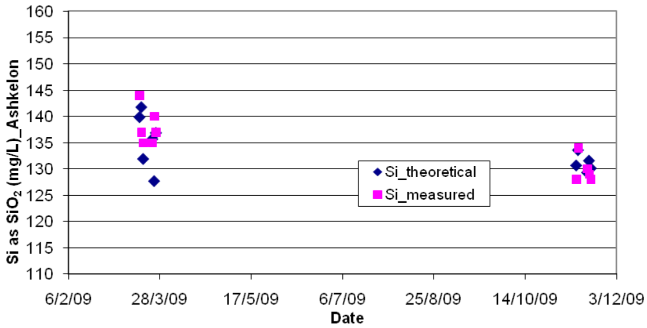

Fig. 11a. Theoretical and measured silica concentration at the Ashkelon station (March, November 2009).

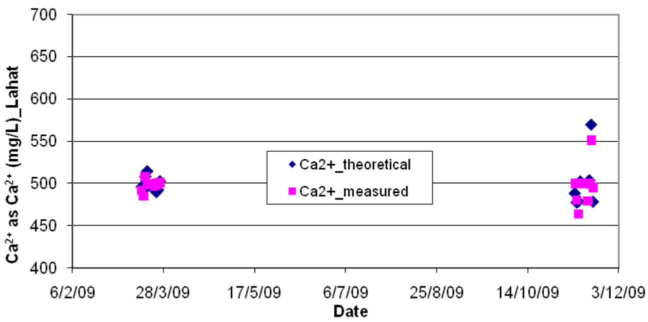

Fig. 9b. Theoretical and measured calcium at the Lahat station (March, November 2009).

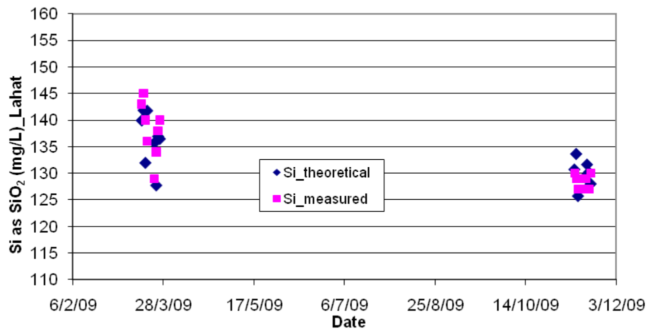

Fig. 11b. Theoretical and measured silica concentration at the Lahat station (March, November 2009).

the two special monitoring programs conducted in March and November 2009 along the brine pipeline.

The silica concentration in the brine from the Gat Desalination Plant is similar to silica concentration in the brine from the Granot Desalination Plant (about 125–150 mg/L as SiO_2).

Figs. 11a and 11b illustrate the theoretical and actual silica concentrations at the Ashkelon and Lahat stations of the two special monitoring programs conducted in March and November 2009 along the brine pipeline.

The silica concentrations (125–145 mg/L) that measured at the Ashkelon and Lahat stations were compatible with the calculated theoretical silica concentration with small deviations, as shown in Figs. 11a and 11b, respectively. The reason for deviation is shown in Section 2.5.4.

The conclusion is that there was no scaling of silica.

2.5.7. Total phosphorus

Antiscalants, which are added to inhibit the formation of scale precipitates and salt deposits, belong to different chemical groups. Commonly used antiscalants are polyphosphates, phosphonates, or carboxylic-rich polymers such as polyacrylic acid and polymaleic acid.

Scale control at the Granot and Gat desalination plants is carried out by dosage of a phosphonate-based antiscalant. Phosphonates are widely used in desalination as scale and corrosion inhibitors and iron sequestrates. In membrane system, they act as "super-threshold" agents.

The total phosphorus concentration is routinely sampled only at the Ashkelon station.

Fig. 12 illustrates the total phosporous (as P) concentration of the two special monitoring programs conducted in March and November 2009 along the brine pipeline.

The phosphorus concentration measured at the Ashkelon and Lahat stations was 1.0–1.1 mg/L. These values are much lower than the discharge quality phosphorus concentration of 6 mg/L mandated by the Ministry of Environmental Protection in 2010 (see Table 1 above). 2009 phosphorus values were different from the 2010 values: 2 mg/L (mean) and 4 mg/L (max) in 2009. The explanation for the increase in concentration of phosphorus is the introduction of brine from the new future plants at Granot (the second unit) and Lahat, mentioned in Section 2.4.

The results show that phosphorus concentration measured along the brine pipe was below the mandatory levels.

Phosphorous is frequently a limited nutrient in the marine environment, so the Ministry of Environmental Protection seeks to restict the use of antiscalants that include it as an ingrediant to prevent harm to the environment.

Since 2005, Mekorot has conducted research to test antiscalants without phosphorous. Since September 2009, Mekorot has been performing experiments for this purpose at a new RO pilot plant at the Granot site.

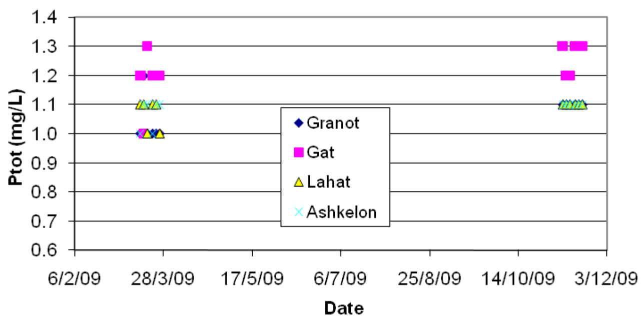

Fig. 12. The phosphorus concentration along the brine pipeline (March, November 2009).

2.5.8. Nitrates

The main cause of eutrophication is the strong inflow of nutrients to a body of water which causes the imbalance of the food chain that result in high levels of phytoplankton biomass in stratified water bodies, which can lead to algal blooms. The major consequence of eutrophication concerns the availability of oxygen.

Generally, phosphorus tends to be the limiting factor for phytoplankton in fresh waters. In large marine areas nitrogen is usually the limiting nutrient, especially in summer.

Fig. 13 illustrates nitrate concentration (as NO_3) of the two special monitoring programs conducted in March and November 2009 along the brine pipeline.

The nitrate concentration in the brine from the Gat Desalination Plant (about 170 mg/L as NO_3) was lower than nitrate concentration in the brine from the Granot Desalination Plant (about 210–230 mg/L as NO_3).

The nitrates concentration that measured at the Ashkelon and Lahat stations was 200-220 mg/L as NO_3 (between 45 and 50 mg/L as N).

These values are below the nitrate concentration level of 63 mg/L as N (R = 80%) mandated by the Ministry of Environmental Protection in 2010 (see Table 1 above).

The reduction target for nitrates is 5 mg/L (mean) and 8 mg/L (max). The technical-economic aspects of the nitrate removal procedure should be tested by running a pilot plant with brine from desalination plant.

2.6. Presentation data from the previous special monitoring programs

The data from special monitoring programs during 2007–2009 are summarized in Tables 2a–2d.

No changes were found in any of measured parameters in the special monitoring programs except for total phosphorous compared with the monitoring results in 2007, 2008 and 2009.

Higher concentrations of total phosphorous were measured in 2008–2009 compared with 2007 and previous years.

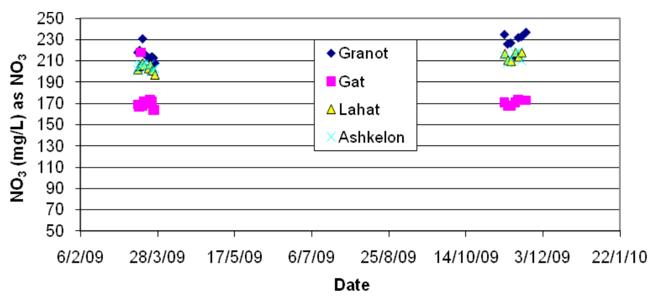

Fig. 13. The nitrates concentration along the brine pipeline (March, November 2009).

Table 2a
Turbidity and pH from special monitoring programs during 2007–2009

Special monitoring program date	Turbidity (NTU)				pH			
	Gat	Granot	Lahat	Ashkelon	Gat	Granot	Lahat	Ashkelon
17/06/07–28/06/07	<0.3	<0.3	<0.3	<0.3	7.7–7.9	7.3–7.7	7.4–7.6	7.4–7.5
09/03/08–20/03/08	<0.3	<0.3	<0.3	<0.3	7.7–7.9	7.3–7.7	7.4–7.6	7.4–7.5
14/09/08–25/09/08	<0.3	<0.3	<0.3	<0.3	7.7–7.9	7.3–7.7	7.4–7.6	7.4–7.5
15/03/09–26/03/09	<0.3	<0.3	<0.3	<0.3	7.8–8.0	7.5	7.6	7.5–7.6
08/11/09–19/11/09	<0.3	<0.3	<0.3	<0.3	7.7–7.8	7.3–7.5	7.5	7.3–7.5

Table 2b
LSI and alkalinity from special monitoring programs during 2007–2009

Special monitoring program date	LSI				Alkalinity (mg/L) as $CaCO_3$			
	Gat	Granot	Lahat	Ashkelon	Gat	Granot	Lahat	Ashkelon
17/06/07–28/06/07	1.8–1.85	1.5–1.7	1.6–1.7	1.5–1.7	1400	1300	1300	1300
09/03/08–20/03/08	1.6–1.8	1.4–1.7	1.6	1.4–1.6	1400	1300	1300	1300
14/09/08–25/09/08	1.8–2.0	1.6–1.8	1.6–1.7	1.6–1.7	1400	1300	1300	1300
15/03/09–26/03/09	1.9–2.0	1.5–1.6	1.5–1.6	1.5–1.6	1400	1250–1300	1300	1300
08/11/09–19/11/09	1.9–2.0	1.5–1.6	1.5–1.6	1.5–1.6	1400	1250–1300	1300	1300

Table 2c
Calcium and silica concentrations from special monitoring programs during 2007–2009

Special monitoring program date	Ca (mg/L) as Ca^{2+}				Si (mg/L) as SiO_2			
	Gat	Granot	Lahat	Ashkelon	Gat	Granot	Lahat	Ashkelon
17/06/07–28/06/07	400–500	500–600	500–600	500–550	100–125	120–140	125–135	125–135
09/03/08–20/03/08	400–500	500–600	500–550	500–600	120–130	130–140	125–135	125–135
14/09/08–25/09/08	400–500	500–600	500–600	500–600	120–130	130–140	125–135	125–135
15/03/09–26/03/09	400–500	500–600	500	500	120–130	130–140	130–140	130–140
08/11/09–19/11/09	400–500	500–600	500	500	120–130	130–140	130	130

Table 2d
Total phosphorous and nitrates concentrations from special monitoring programs during 2007–2009

Special monitoring program date	Total phosphorus (mg/L) as P				Nitrates (mg/L) as NO_3			
	Gat	Granot	Lahat	Ashkelon	Gat	Granot	Lahat	Ashkelon
17/06/07–28/06/07	0.1–0.8	0.1–0.4	0.2–0.4	0.2–0.4	160–170	220–230	220–230	220–230
09/03/08–20/03/08	1.4–1.5	1.1	1.0–1.2	1.0–1.2	160–180	220–240	210–230	210–230
14/09/08–25/09/08	1.4–1.5	1.1	1.0–1.2	1.0–1.2	160–180	220–240	210–230	210–230
15/03/09–26/03/09	1.2–1.3	1.1	1.1	1.1	170	210–235	200–220	200–220
08/11/09–19/11/09	1.2–1.3	1.1	1.1	1.1	170	210–235	200–220	200–220

Table 3
Granot and Gat discharge brine concentration and load data 2007–2009

Year	RO desalination plants	Brine amount	Average chlorides concentration	Annual load of chlorides	Average silica as Si concentration	Annual load of silica as Si	Average nitrate as N concentration	Average load of nitrates as N	Average phosphorus as P concentration	Average load of phosphorus as P
		m^3/y	mg/L	ton	mg/L	ton	mg/L	ton	mg/L	ton
2007	Gat	245,961	2,187	538	56	14	37	9	0.44	0.11
	Granot	626,856	3,280	2,056	65	41	52	33	0.27	0.17
	Gat and Granot	872,817	2,963	2,594	62	55	48	42	0.32	0.28
2008	Gat	250,807	2,177	546	58	15	38	9	1.40	0.35
	Granot	784,021	3,185	2,497	65	51	51	40	1.10	0.86
	Gat and Granot	1,034,828	2,912	3,043	63	66	47	49	1.18	1.21
2008	Gat	283,650	2,200	624	58	17	39	11	1.25	0.35
	Granot	756,539	3,200	2,421	65	49	50	38	1.10	0.83
	Gat and Granot	1,040,189	2,929	3,045	63	65	47	49	1.14	1.19
2007–2009	Gat and Granot			8,682		186		140		2.68

Due to the fact that the same type and concentration of antiscalant were used throughout this period at both desalination plants, we suggest that the possible reason for the difference in total phosphorous concentration was a change in the phosphorous content in the antiscalant.

The concentration and loads of chlorides, silica, nitrates and phosphorous discharged in the brine of both desalination plants are given in Table 3.

Since the commissioning of Gat and Granot desalination plants, 8,682 tons of chloride and 186 tons of silica were removed from the aquifer in 2007–2009, as shown in Table 3. Removal of chlorides from groundwater was the primary goal in building these desalination plants: aquifer rehabilitation by removal of the saline layers of underground brackish water.

Nutrients concentration and loads are below the values mandated by the Ministry of Environmental Protection.

3. Summary

Since 2004, Mekorot has exclusively operated and maintained a unique 30-km long brine disposal pipeline from Gat and Granot BWRO desalination plants to the Mediterranean Sea, with permission of the Ministry of Environmental Protection. This paper demonstrated that nutrient concentrations and loads in the brine stream are below the mandated values.

Through optimal operation of brine pipes, Mekorot prevents soil contamination and avoids scale deposition from concentrate solutions of super-saturated $CaCO_3$. It is possible to maintain a high level of $CaCO_3$ supersaturation without any precipitation for a long retention time in the brine stream — about 40 h — by controlling the LSI index and by suitable antiscalant dosage in the feed.

Since the desalination plants startup, a large amount of chloride and silica have been removed from the aquifer, achieving a primary objective in establishing the Gat and Granot desalination plants, as the first phase of future desalination plants with a total daily capacity 100,000 m^3: aquifer rehabilitation by removing the saline layers of underground brackish water.

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