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Optimal managing the coastal aquifer for seawater desalination and meeting nitrates level of drinking water

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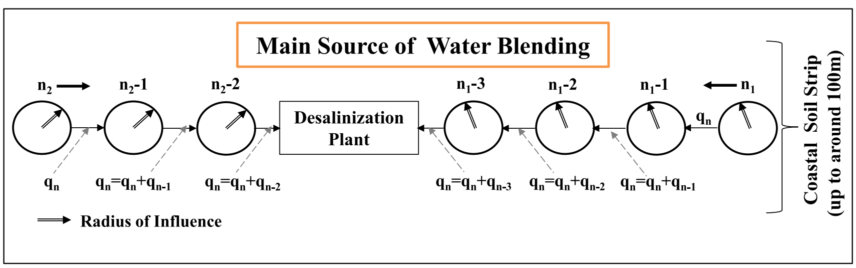
GRAPHICAL ABSTRACT



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ABSTRACT

Fouling remains one of the main issues related to membrane filtration during seawater desalination. The main acceptable methods are based on adding chemical reagents to the low quality waters that are going to be desalinated and/or adjusted to the membrane materials and the waters. This becomes a real issue when developing desalination plants for small communities, located along the sea shore. The approach adapted here is based on Coastal Soil Seawater Pumping (CSSP), with a pretreatment stage for the desalinated water. A management model was used for construction of main lines characterizing the system.

In this work, a management model for small and relatively isolated communities is presented. It allows the water authorities of urban areas located close to the sea to provide desalinated water for the benefit of their residents, primarily for drinking purposes. Water from local wells that contain relatively high nitrate (NO_3^-) levels will be blended with the desalinated waters that are produced and distributed along the seashore to reach acceptable levels of 50–70 mg/L nitrates this will replace the “killed” wells and revive wells with high nitrate contents.

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1. Introduction

Continuous population growth, along with intensive water withdrawal from aquifers, has increased water scarcity in many parts of the world, emphasizing the need for new sources of fresh [1]. Water has become a scarce commodity in many sectors around the world, primarily for agriculture [2–5]. Advanced processes and improved methods have been developed for producing new waters at reasonable prices.

Many parts of the world, primarily a large number of Mediterranean Countries, are suffering from water shortages [6]. Seawater desalination by Reverse Osmosis (RO) is an advanced method that allows production of new waters [7,8]. However, RO methods are strongly associated with membrane fouling, resulting in reductions in economic efficiency [9–11]. Current work focuses on managing the feasibility of suppling seawater to small desalination plants from wells that are located along the coastal soil strip [12,13]. It enables as well to reduce the pretreatment costs of large desalination plants. One of the main goals of the work is that it allows to blend desalinated seawater with other low quality wells' water that cannot be used for drinking purposes due to relatively high nitrates content [14,15]. The standard pretreatment expenses are assessed at 35%–45% of the total costs for conventional large scale desalination plants [4].

Desalinated seawater can be processed from shallow depth sea shore strip wells that contain very low nitrogen concentrations in the form of nitrate. It would be largely beneficial to dilute this desalinated water with local wells' waters that is currently unused due to high nitrate concentrations. However, there is a limit of using this approach with large scale desalination plants: there are constraints referring to the amount of water per time unit (hour) that can be extracted from one well along the sea shore, specifically in reference to its' depth and the radius of influence. This work focuses on small desalination plants that produce up to 10 million cubic meters per year.

2. Membrane technology

Membrane technology is gradually becoming an acceptable method for producing new fresh water, primarily for drinking purposes, but also for agricultural irrigation [14,16]. It is used mainly for producing new waters from seawater. However, one of the main problems in the design and operation of such advanced system is the membrane clogging due to fouling [17,18]. Contamination of seawater used for desalination includes fish, algae, different seaweeds, sand and various other elements. These contaminants and others will be filtered via the sandy soil aquifer located adjacent to the seashore [19,20] (Figs. 1 and 2).

3. Nitrates in drinking waters

Nitrates are soluble compounds in water and are well known pollutants of natural waters and groundwater. Nitrates are also well known for their toxicity effects, mainly on infants. Removal of the excess nitrates includes using nano SiO_2–FeOOH–Fe core–shell methods [21], applying hybrid ion exchange-catalyst processes [21], utilizing chemical procedures for removal of nitrate using aluminum-iron alloys [22], adding residual straw as a source of carbon to enhance the denitrification processes and implementing membrane technology [23]. In some areas the nitrate content is reaching values above maximum level (70 mg/L in Israel and 50 mg/L in Europe, according the European Standers) [24,25]. In these cases, when no means are taken to remove the excess nitrate from wells, they are just abandoned, or "killed".

However, there is another approach to tackle and solve the problem of excess of nitrate in wells along the seashore in regions under water shortage. The water from rich nitrate drinking wells can be blended with desalinated sea water, containing up to 0.5 mg/L nitrate [26–28]. Seawater can be improved via a Reverse-Osmosis (RO) processes and blended with the rich nitrates waters. The seawater, very close to the sea shore (width of seawater strip is up to 300 m) can be pumped from the shallow aquifer and mixed with the water from the "killed" wells. By pumping the seawater via the soils, adjacent to the sea, fouling of the RO membrane can be minimized and the water will be ready for desalination without an extra treatment stage. It will allow to revitalize those "killed" wells and to turn them into valuable sources of water supply for the community, primarily in water scarce regions.

The purpose of this paper is to present a management model allowing assessing the quality of seawater used for blending with the rich nitrate wells, and reach value of 50 mg/L nitrates. This approach is mainly important in water scarce regions.

4. Fouling control of membranes used for seawater desalination

Conventional pretreatment of seawater entering into a membrane plants includes mainly methods that are based on chemicals (coagulants and flocculants) that are added to the seawater and the removal of the large particles that are formed. This simultaneously improves the quality of the water that flows into the membrane system and prevents membrane deterioration [13]. The approach adapted in this work is to use the coastal soil strip as a "pretreatment filter". The coastal soil layer will filter the seawater subject to its' properties [13]. Periodically, the coastal soil layer will "gets a rest", allowing its' rehabilitation for the original hydraulic conductivity. The soil filter will be operated under continuous saturated conditions created at the sea shore [29]. The flow towards the wells will be maintained in accordance with the pumping intensity from the shallow layer along the coastal strip. The proposed pretreatment filtration scheme is described in Figs. 3 and 4.

According to the above concept, the pumping of seawater from the coastal strip has several advantages: (i) although the water is taken from the coastal aquifer, it has still to be treated due to its' salinity; (ii) pumping seawater from the coastal aquifer can reduce the risk of seawater intrusion into the land; (iii) desalinated tap water can be produced close to the sea, and; (iv) it is possible to mix the desalinated seawater with local waters, reducing the nitrate content of this water from existing wells. Commonly, the distance of the wells from the sea is up to 100 m and their depth is up to 100 m, depending mainly on soil properties [5].

Following are some factors that have to be considered for this type of seawater pretreatment system in the shallow layers along the sea shore: (i) the coastal aquifers can generate an approximate flow rate of 150 to 200 m^3/d (the cost of such a well is around US $ $0.65 \cdot 10^6$ to $0.70 \cdot 10^6$ per well); (ii) each well has a specific protection zone (based on the wells' capacity and surrounding soils) that has to be defined by

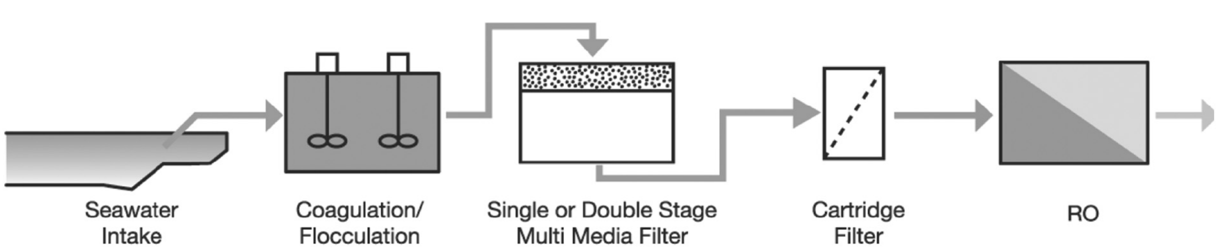

Fig. 1. Conventional pretreatment of water entering into a membrane system [18].