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Optimizing desalinated sea water blending with other sources to meet magnesium requirements for potable and irrigation waters

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ABSTRACT

Sea water desalination provides fresh water that typically lacks minerals essential to human health and to agricultural productivity. Thus the rising proportion of desalinated sea water consumed by both the domestic and agricultural sectors constitutes a public health risk. Research on low-magnesium water irrigation showed that crops developed magnesium deficiency symptoms that could lead to plant death, and tomato yields were reduced by 10–15%. The World Health Organization (WHO) reported on a relationship between sudden cardiac death rates and magnesium intake deficits. An optimization model, developed and tested to provide recommendations for Water Distribution System (WDS) quality control in terms of meeting optimal water quality requirements, was run in computational experiments based on an actual regional WDS. The expected magnesium deficit due to the operation of a large Sea Water Desalination Plant (SWDP) was simulated, and an optimal operation policy, in which remineralization at the SWDP was combined with blending desalinated and natural water to achieve the required quality, was generated. The effects of remineralization costs and WDS physical layout on the optimal policy were examined by sensitivity analysis. As part of the sensitivity blending natural and desalinated water near the treatment plants will be feasible up to 16.2 US cents/m^3, considering all expenses. Additional chemical injection was used to meet quality criteria when blending was not feasible.

1. Introduction

Large investments are being made to close the gap between water supply and demand (World Water Assessment Program, 2009). The reduction of water loss in the distribution system, the control and reuse of runoff water, wastewater reclamation, cloud seeding, and desalination of saline and/or sea water constitute a promising battery of methods to supply future water quantity demands. Worldwide, the loss of water (e.g., leaks, malfunctions) from water distribution systems is estimated at 30% (Feldman, 2009; EPA, 2010). Surface runoff can be utilized if the proper infrastructure, such as highway and urban drainage systems, dams, and other water harvesting systems, are in place (Meirovich et al., 1998). Cloud

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seeding can be implemented to enhance precipitation for runoff generation and aquifer recharge (Guo et al., 2006). Treated wastewater represents a reliable and uniform water supply that simultaneously solves water shortage and wastewater disposal problems (Oron et al., 1999).

Desalination enables the exploitation of non-potable, saline or brackish water to produce high quality potable waters, independent of rainfall, droughts, and other natural phenomena related to irregular water supplies. Approximately 75 million people worldwide obtain their potable water from desalination plants, and that number is due to increase with the continuous growth in the demand for water. Major desalination technologies are based on evaporation methods (e.g., multi stage flash process and multi effect distillation), Electro Dialysis (ED), and Reverse Osmosis (RO), the last of which is responsible for 43.5% of the global desalination capacity (Crittenden et al., 2005; Al-Subaie, 2007).

In Saudi Arabia, desalinated water provides approximately 50% of the drinking water (Al-Sahlawi, 1999). In Israel, 32% of the domestic water consumed is obtained via sea water desalination, and that proportion is due to increase to 75% by the year 2025 (www.water.gov.il). Cyprus currently answers 63% of its water demand with desalinated sea water [based on population size, consumption per capita, and desalination capacity (http://www.fao.org/nr/water/aquastat)].

1.1. *Desalinated water mineral deficiencies and the risk imposed on human health and agricultural production*

Despite the apparent benefits of using desalination to produce a reliable potable water source, its deficiencies in nutrients required for both humans and agricultural plants is a cause for concern and should generate further research (WHO, 2005; Yirmiyahu et al., 2007). Such deficiencies in minerals critical to human and agricultural plant growth may have substantial adverse effects on both human health and agricultural productivity.

The link between the consumption of water with a low mineral content and human health has been investigated for at least half a century, as summarized in the World Health Organization's (WHO) guidelines for nutrients in drinking water (2005). Certain nutrients – e.g., calcium, magnesium, fluoride, sodium, iron, copper, selenium and potassium – have been investigated for the potentially adverse health effects people whose water supply is mineral deficient may suffer. Among the nutrients, calcium and magnesium have been studied more thoroughly due to the protective roles they play in the human body. A primary skeletal structural constituent, calcium is also important for various main physical functions. Because it causes decreases in bone mass and mineral content, a calcium deficiency translates into an increased risk of fractures. Deficiencies in magnesium, which is essential in physiological processes such as mineralization and skeletal development, cardiac excitability and vascular tone, contractility, reactivity, and growth, can contribute to the pathophysiology of hypertension. Convincing findings of the relationship between sudden cardiac death and deficits in magnesium intake have been presented (WHO, 2005; Almoznino-Sarafian, 2009). Another study found that a 1-mg/L increment in drinking water magnesium content reduced the risk of acute myocardial infarction by 4.9% (Kousa et al., 2006). Minerals in drinking water tend to be present as free ions, making them more readily absorbed than when presented in food. However, because the modern diet often fails to supply sufficient levels of basic minerals and microelements (23% of the adult American population suffers from hypomagnesaemia, (Bruno and Rhian, 2007)), even the relatively low intake of these elements in drinking water may play an important protective role. For instance, the daily consumption of 2 L of water rich in magnesium (40 mg/L) will provide about 25% of an adult's total requirement. But compared to the relatively immediate effect, in terms of plant growth and productivity, of magnesium-deficient irrigation on crops, the impact on human health of regular exposure to low-magnesium water is delayed. The ultimate consequences, however, are no less dire, and therefore, the minimum concentration of magnesium in water required for human health is around 10 mg/L, assuming that drinking water demand per capita is around 5 L/day (Sontia and Touyz, 2007; Almoznino-Sarafian et al., 2009).

The replacement in agriculture of natural with desalinated water exposes the plants to growth-limitations factors (Yermiyahu et al., 2007; Bruno and Rhian, 2007). Thus a calcium deficiency may harm the development of terminal buds and of root apical tips (Yermiyahu et al., 2007). Magnesium is vital to the photosynthesis and protein synthesis operations of plants. Irrigation with low-magnesium-content water (10 mg/L) resulted in a decrease in leaf magnesium and chlorophyll contents, and the fruit produced was lacking in the basic nutrients like magnesium, calcium and sulfate, therefore warranting the need for additional fertilization (Birnhack and Lahav, 2007). Thus, the shift from natural to desalinated water irrigation may have significant effects on plant health and hence, on productivity. Calcium's interactions with other nutrients when they are deficient drops about 10–15%, also affecting plant productivity (Alarcon et al., 1999). Sulfate deficiency can reduce plant dry weight, photosynthetic rate, chlorophyll content, and total number of fruits (Assaf, 1994). Hence, the amount of daily magnesium required for agriculture irrigation is around 24 mg/L, assuming a water demand per common crop in the Middle-East region varies between 6000 and 10,000 mm/ha.

In the agricultural areas adjacent to a newly operating Sea Water Desalination Plant (SWDP) in Ashkelon (Israel), crop irrigation has shifted from natural to desalinated water, resulting in magnesium deficiency symptoms appearing in the irrigated crops. Further research into the effect of demineralized water irrigation showed that crops irrigated with low-magnesium content water responded with significant reductions in yield quality and quantity (Yermiyahu et al., 2007). Moreover, irrigating with water that contained high calcium to magnesium ratio resulted in crops with magnesium deficiency symptoms (Yermiyahu et al., 2007).

1.2. *Mineral deficient water scenarios*

Mineral deficiencies in fresh water occur under two major scenarios: a constant supply of low-mineral content water or a supply comprising irregular water quality. When the SWDP is the sole or primary water source in the region, adjacent water consumers will receive low-mineral content water