Available online at www.sciencedirect.com

ScienceDirect

Applied Mathematical Modelling 31 (2007) 2347–2354

APPLIED MATHEMATICAL MODELLING

www.elsevier.com/locate/apm

Sensitivity of hypersaline Arabian Gulf to seawater desalination plants ☆

Ronald Smith [a,*], Anton Purnama [b], H.H. Al-Barwani [b]

[a] *Department of Mathematical Sciences, Loughborough University, Loughborough LE11 3TU, UK*

[b] *Department of Mathematics and Statistics, Sultan Qaboos University, College of Science, P.O. Box 36, Al-Khod 123, Muscat, Oman*

Received 1 August 2004; received in revised form 1 November 2005; accepted 6 September 2006
Available online 2 January 2007

Abstract

Due to the hot, arid nature of its bordering lands, seawater in the Arabian Gulf can have significant evaporation rates leading to hypersaline conditions. If additional desalination plants were to operate along its coast, then the extraction of desalinated water and returned brine waste stream into the Gulf would increase the salinity. This paper uses a tidally and cross-sectionally averaged mathematical model that reveals multiplicative dependence of the salinity on factors associated with river flow, evaporation rates and each of the desalination plants. Present-day desalinated water production rates are in the linear regime, but hypersalinity has exponential sensitivity to the position and volumetric rate of desalinated water extraction.

PACS: 92.10.Sx; 92.10.Mr

Keywords: Arabian Gulf; Hypersaline; Seawater desalination

1. Introduction

Rapid industrial development and population growth in the arid Arabian Gulf countries of Kuwait, Saudi Arabia, Bahrain, Qatar and the United Arab Emirates (UAE), had led to a large and growing need for freshwater. Desalination of seawater is a reliable solution for that vital need. Therefore, the construction of more seawater desalination plants along the coast of the Gulf is to be expected. The total production capacity of all desalination plants in the Arabian Gulf countries was estimated [1] at 5.075 million m^3 of water per day, which accounts for more than 58% of the world's desalting plants' capacities. The world's largest seawater

☆ This work was supported by the Sultan Qaboos University Internal Grant IG/SCI/DOMS/05/07. We are grateful to Mr. Mohammed Al-Washahi, AES Barka, Oman, for information on desalination plants in the Arabian Gulf, and to the referee for suggesting that we quantify the sensitivity of the salinity predictions.
* Corresponding author.
E-mail addresses: ron.smith@lboro.ac.uk (R. Smith), antonp@squ.edu.om (A. Purnama), hamdi@squ.edu.om (H.H. Al-Barwani).

0307-904X/$ - see front matter © 2006 Published by Elsevier Inc.
doi:10.1016/j.apm.2006.09.010

desalination plant with a production capacity of more than 1 million m^3 of water per day started to operate in 1983 at Al Jubail on the coast of Saudi Arabia (150 km NW of the island of Bahrain). The removal of water from seawater also produces brine, containing salt concentrations up to 2.5 times of the seawater salinity, to be disposed of into the Arabian Gulf through an outfall. In total, the desalination plants built along the west coast of the Gulf are discharging their brine waste stream in excess of 3.4 million m^3 per day.

The Arabian Gulf is a shallow marginal semi-enclosed sea situated in the northern-eastern Arabian Sea, with mean depth at only 35 m [2] and less than 100 m in depth over its entire extent (see Fig. 1). It covers an area of about 240,000 km^2, with 1000 km in length and breadths ranging from 185 km to 340 km. The main topographic features are a deep channel on its north-east side off the coast of Iran, and shallow areas on the west side off the coasts of Kuwait, Saudi Arabia, Qatar and the UAE. The Arabian Gulf is connected to the Gulf of Oman via the narrow Strait of Hormuz, which is constricted to 56 km wide at its narrowest point by the Musandam peninsula. At the Strait of Hormuz the deep-water channel is at the southern side with the shallower water along the coast of Iran.

The Arabian Gulf is located between latitudes 24°N and 30°N (see Fig. 1). In those latitudes, descending dry air produces arid conditions and is where most of the Earth's deserts are located. The mean annual net evaporation rate for the Arabian Gulf is equivalent to the sea surface lowering at a rate of 1.5 m/yr [3]. By contrast, the freshwater inflows from the Tigris, Euphrates and Karun at the delta of the Shatt al Arab are only equivalent to a 0.2 m/yr rate of rise. The Gulf acts as an inverted estuary with salinity greater than the Arabian Sea e.g. salinity values exceeding 40 ppt (parts per thousand) around the island of Bahrain, and the coasts of Qatar and the UAE [4,3,2]. Dense, saline water formed by evaporation tends to sink, and eventually flows around the tip of the Musandam peninsula through the deepest part of the Strait of Hormuz into the Gulf of Oman. Along the shallower coast of Iran, there is a replacement surface inflow with the salinity 37.5 ppt [5].

The occurrence of net evaporation rate and high salinity is commonly associated with warm and dry summer conditions [6]. It may be expected to weaken as the net evaporation rate reduces during winter [7]. However, in the Arabian Gulf, the hypersaline conditions are persistent through out the winter as shown in Fig. 3 of Brewer and Dyrssen [3], and Fig. 9 of Reynolds [2].

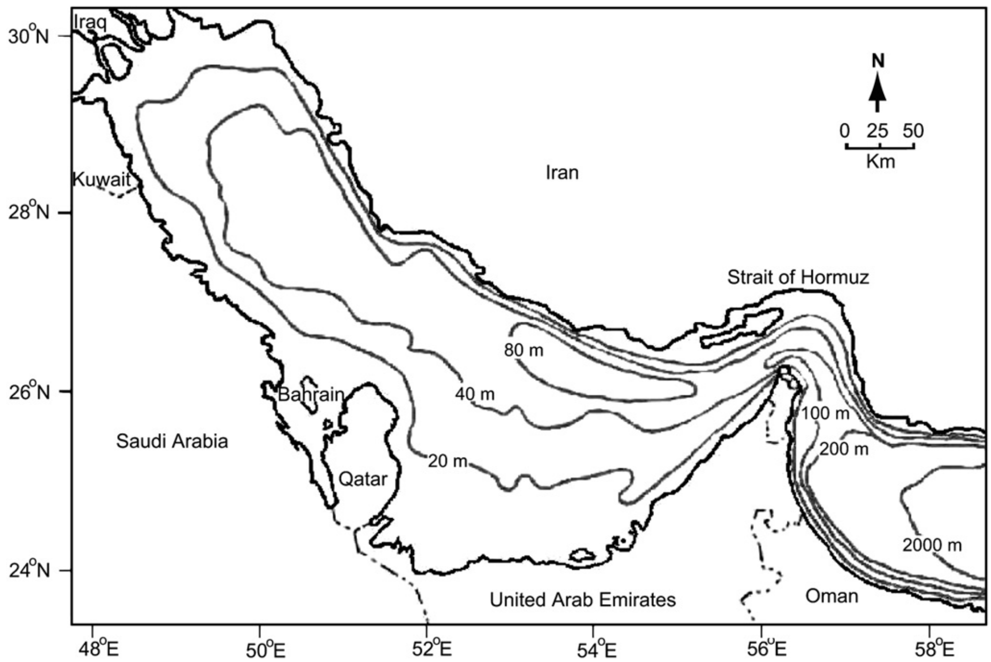

Fig. 1. Depth-contour map of the Arabian Gulf.