MANAGING SALTWATER INTRUSION IN A POORLY-CONSTRAINED ARID AQUIFER, UTILIZING ISOTOPE AND GEOCHEMISTRY, NORTH WESTERN COAST, EGYPT

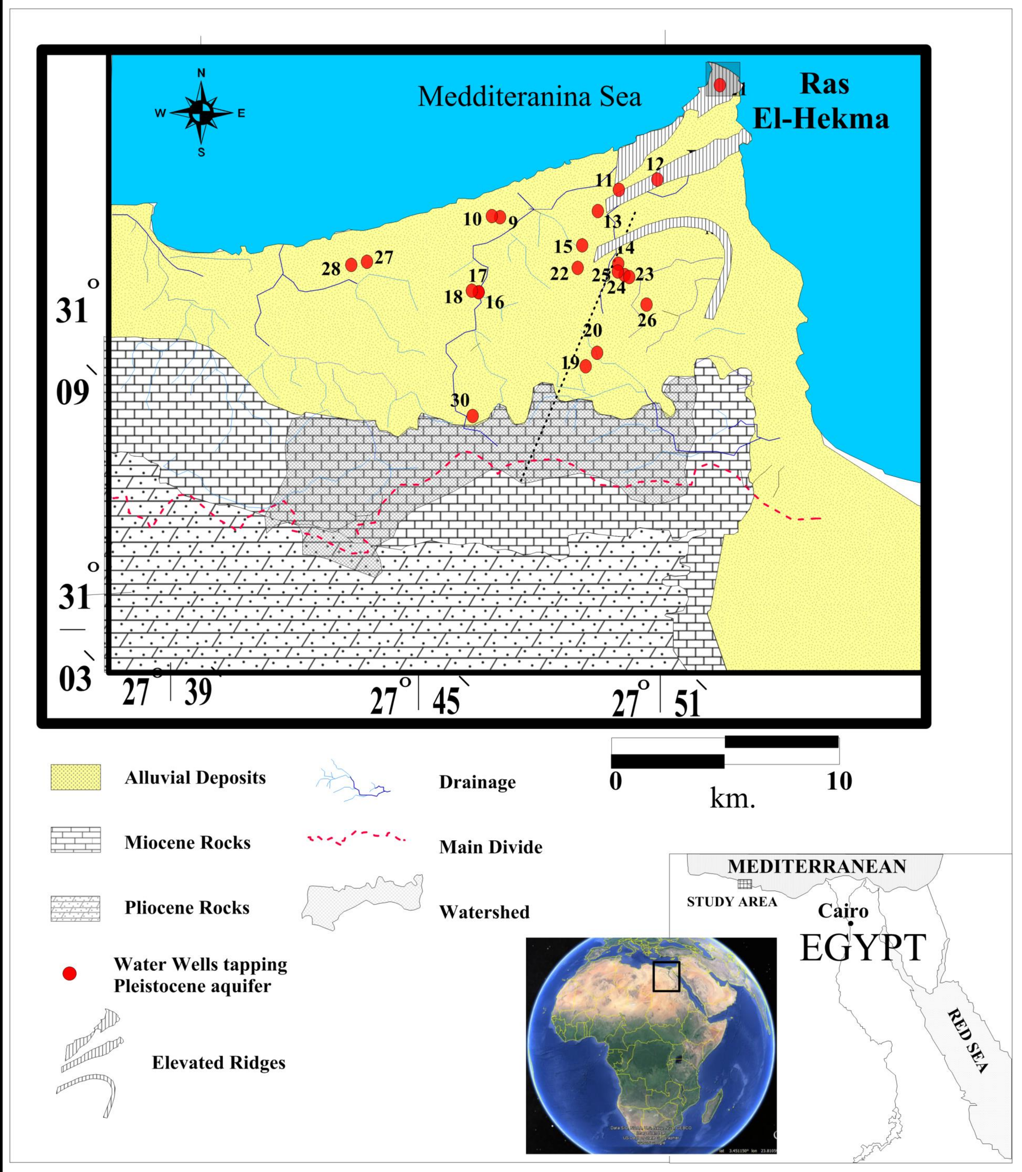
EISSA. MUSTAFA[1,2,3], SHOUKAR-STASH. ORFAN[1,2], PARKER. BETH[1], DE-DREUZY. JEAN-RAYNALD[4]

1- G360 Group, Center of Applied Groundwater Research, University of Guelph, ON, Canada
2- IT2 Isotope Trace technologies Inc., Waterloo ON, Canada
3- Desert Research Center, Hydrogeochemistry Dept. Matariya, Cairo, Egypt
4- Rennes-1 University, Hydrology Department

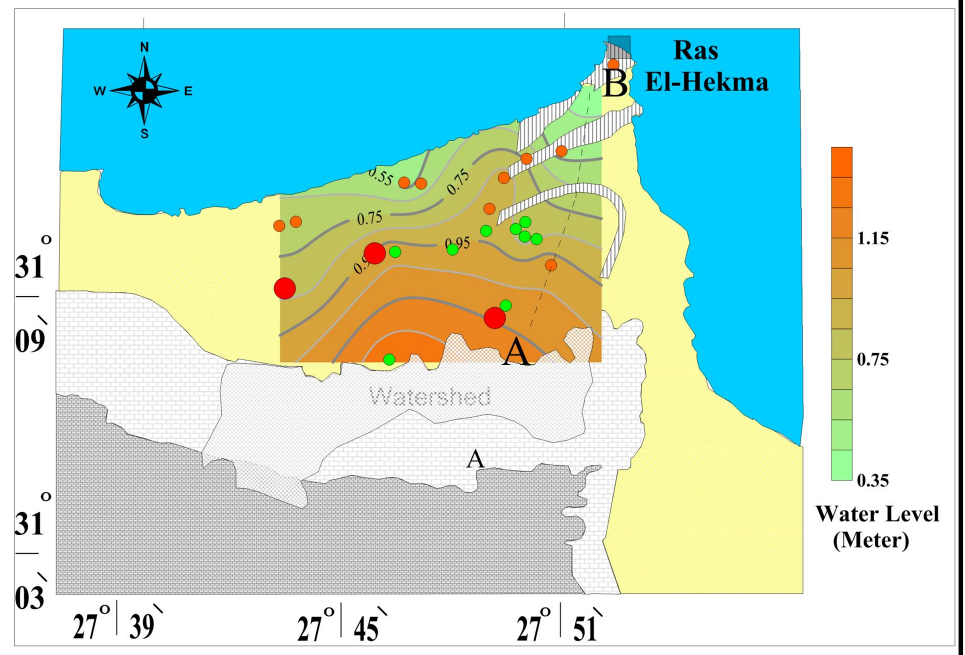
1. Abstract

Ras El Hekma is located on the northwestern coast of Egypt as a triangular headland inside the Mediterranean. The scarcity of rainfall and high pumping rates degraded groundwater quality in the main water-supply wells. Saltwater intrusion is the major concern in coastal aquifers around the world explicitly in arid regions, where recharge is limited and groundwater withdrawals is the main source for potable water. In such arid areas, groundwater is being pumped from the aquifer that is hydraulically connected with the sea, causing lateral movement of seawater toward land and up-coning of the underlying saline water toward the pumping wells. In Ras El Hekma area, the groundwater occurs in the fractured limestone aquifer of Miocene age and a friable O-Olitic limestone aquifer of Pleistocene age, where structure settings, dissected elongated ridges as well as sequent local depressions act as barriers and favorable recharge sites for groundwater entrapments. Water chemistry, stable isotopes ($\delta^{18}O$ and δ^2H), and multi isotope tracers were utilized to estimate the percent of seawater mixing in groundwater and the source of recharge for different aquifers. An analytical model for seawater intrusion was used to predict the extent of seawater intrusion along the coast, to determine the optimal pumping rates and to evaluate the recharge source for the coastal unconfined Pleistocene aquifer. Steady flow in an isotropic and homogeneous medium with a sharp interface between the freshwater and seawater wedge is assumed. The seawater-freshwater interface was determined through the explicit equations assuming fuzzy and globally distributions of total pumping and recharge rates in the entire region. The conservative mass balance equation and the historical records of water level, groundwater salinity and conservative ions were used for model calibration. The models estimate average annual groundwater recharge and seawater intrusion along the coast for different pumping scenarios.

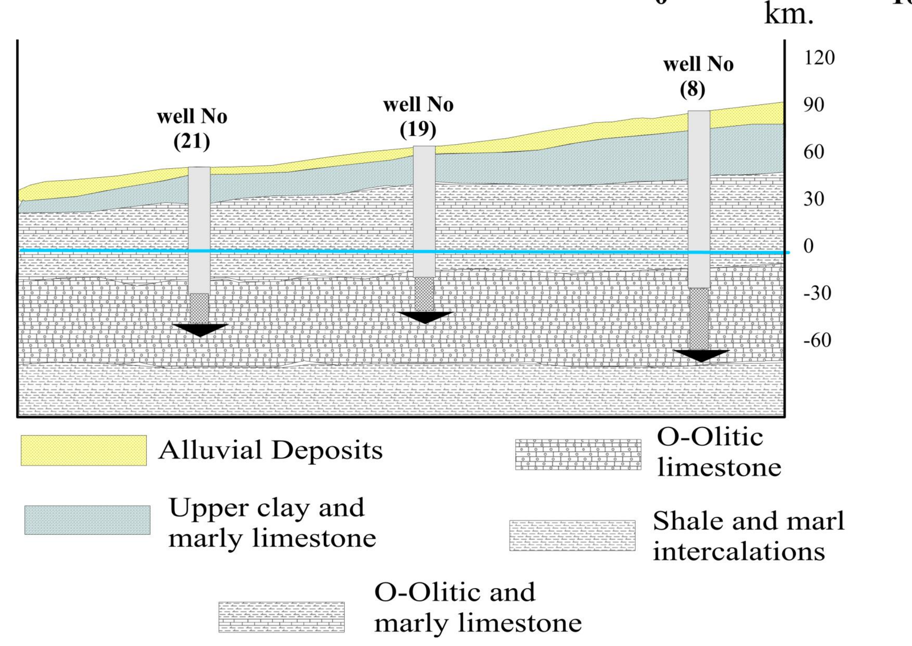
2. Site Descriptions



Well location sites tapping Pleistocene aquifer, Ras El-Hekma Area



Groundwater Flow Map



Subsurface Cross Section N-S

3. Methodology

The groundwater geochemistry, isotopic results were utilized to develop an analytical model using Starck Assumption (Strack, 1976 and Mantoglou 2003). The models were calibrated using groundwater level changes and salinity variation. The models estimate average annual groundwater recharge and simulate seawater intrusion along the coast for different pumping scenarios.

4. Governing Equations

$$\mathbf{SWMI} = a\,x\,\frac{C(Na)}{T(Na)} + b\,x\,\frac{C(Mg)}{T(Mg)} + c\,x\,\frac{C(SO4)}{T(SO4)} + d\,x\,\frac{C(Cl)}{T(Cl)}$$ (Park, 2005)

$$\frac{\delta}{\delta x}\left(kh_f\frac{\delta h_f}{\delta x}\right) + \frac{\delta}{\delta y}\left(kh_f\frac{\delta h_f}{\delta y}\right) + N - Q = 0$$ Zone 1

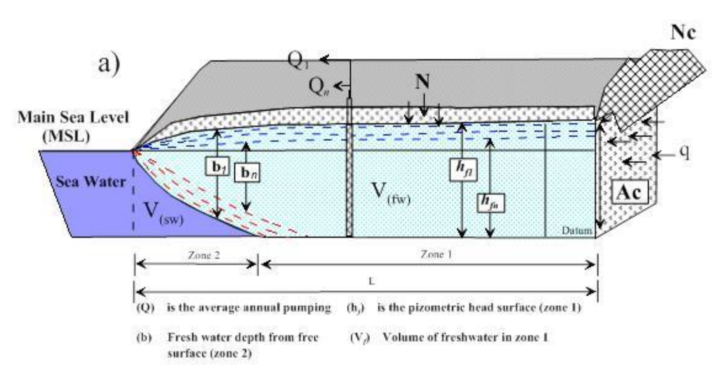
$$\frac{\delta}{\delta x}\left(kb\frac{\delta h_f}{\delta x}\right) + \frac{\delta}{\delta y}\left(kb\frac{\delta h_f}{\delta y}\right) + N - Q = 0$$ Zone 2

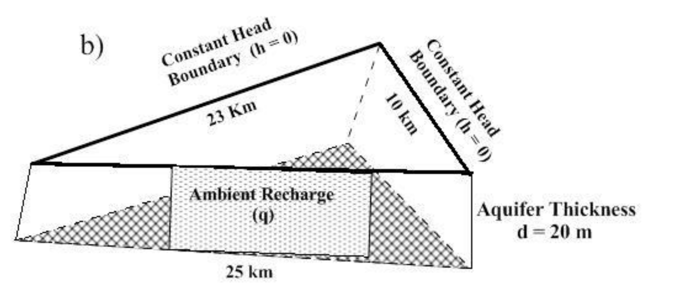
$$\frac{\delta}{\delta x}\left(k\frac{\delta\phi}{\delta x}\right) + \frac{\delta}{\delta y}\left(k\frac{\delta\phi}{\delta y}\right) + N - Q = 0$$ Smoothly over Zone 1 and Zone 2 (Strack 1976 and Mantoglous 2003)

Zone # 1 $\quad \phi = \frac{1}{2}\,[h_f^2 - (1+\delta)\,d] \quad h_f = \sqrt{2\phi + (1+\delta)d^2}\,\delta \quad \phi \geq \left(\frac{\gamma(\gamma+1)}{2}\right)d^2$

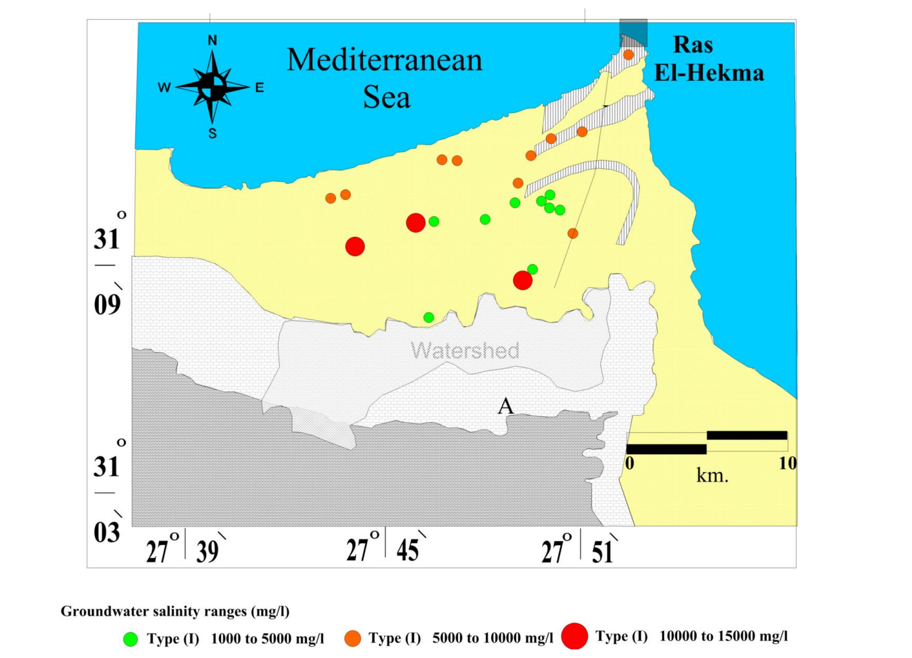
Zone # 2 $\quad \phi\,\frac{(1+\delta)}{2\delta}\,[(h_f - d)^2] \quad h_f = \sqrt{\frac{2\delta\phi}{(1+\delta)}} + d \quad 0 > \phi \leq \left(\frac{\gamma(\gamma+1)}{2}\right)$

$$\phi_{toe} = \left(\frac{\delta(\delta+1}{2}\right)d^2$$

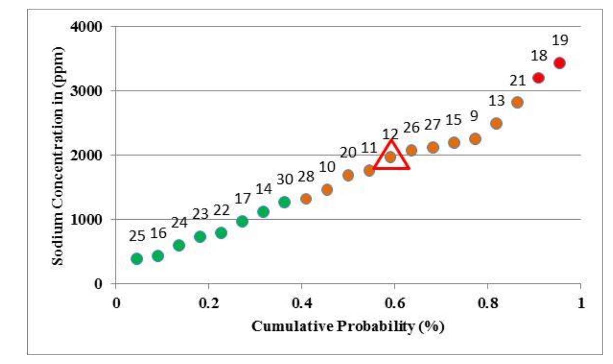


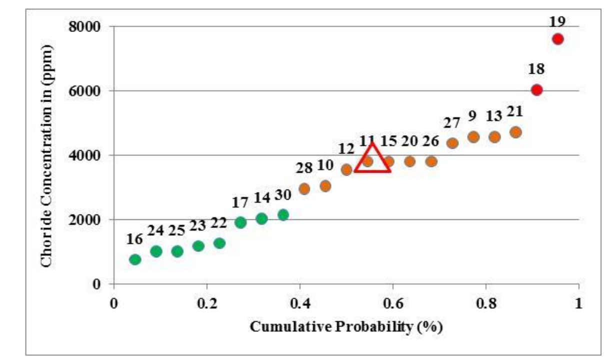


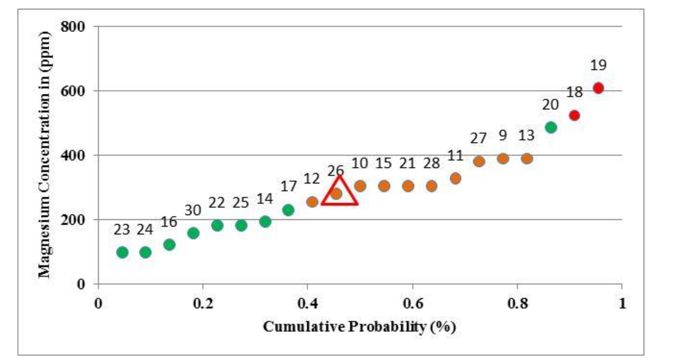
5. Geochemistry, Isotopes and Seawater Mixing Indicators

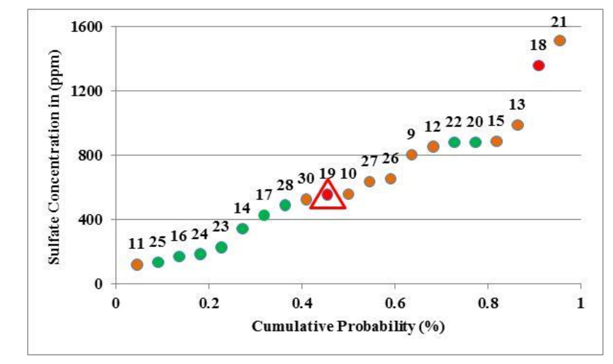


Distribution of groundwater Salinity in the study area

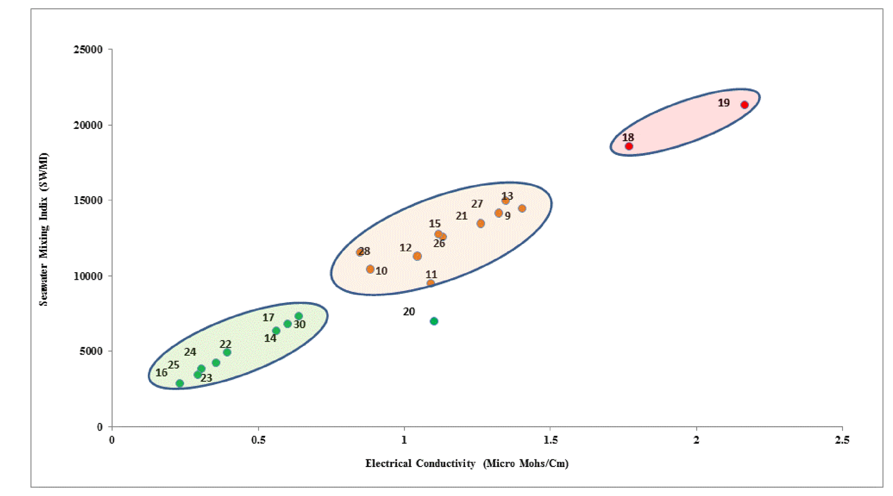




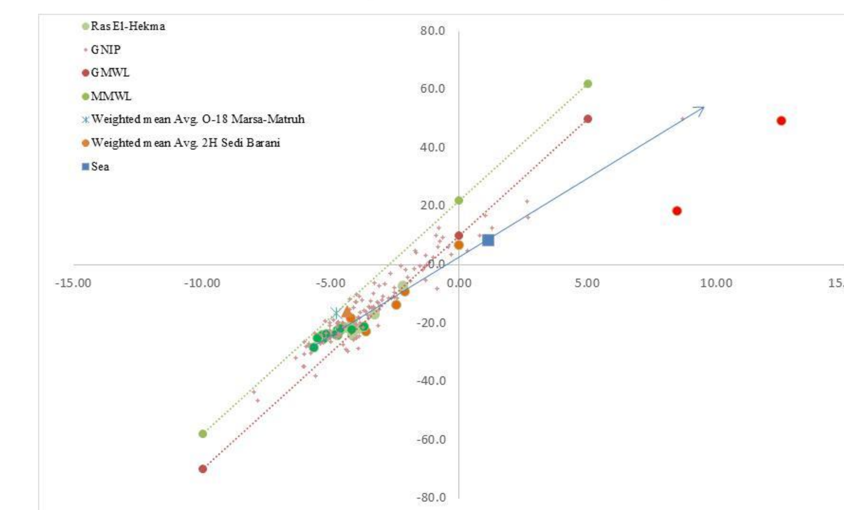




Cumulative probability curves for Mg, Na, SO_4 and Cl ions in groundwater

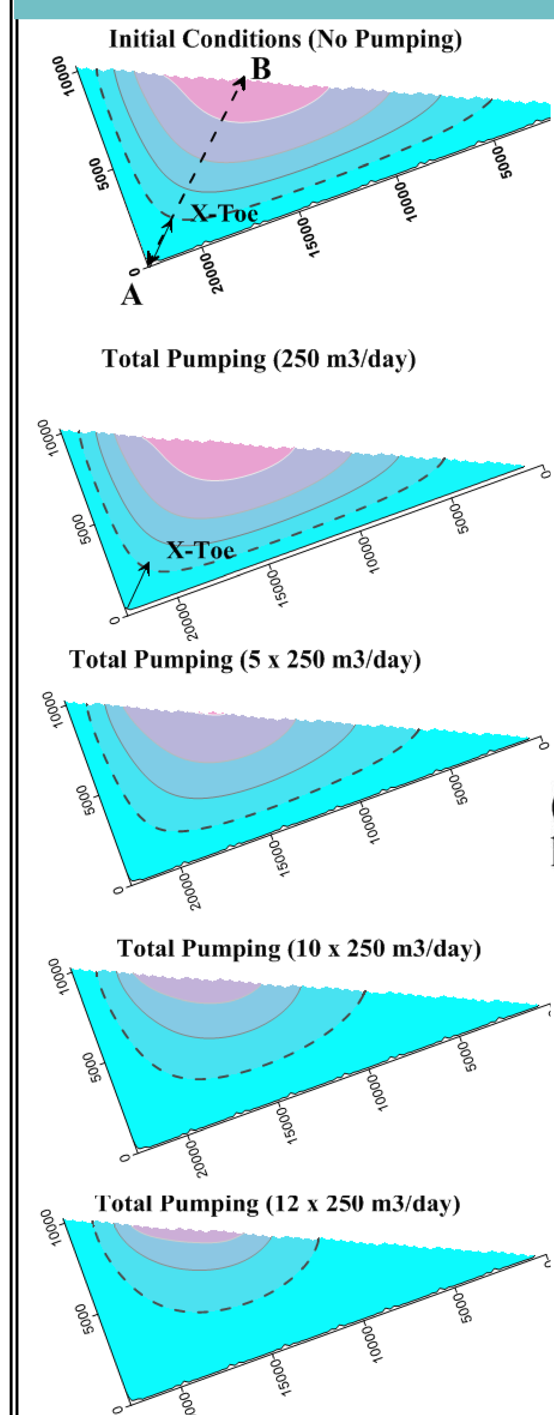


Estimated SMWI for groundwater samples in Ras El-Hekma

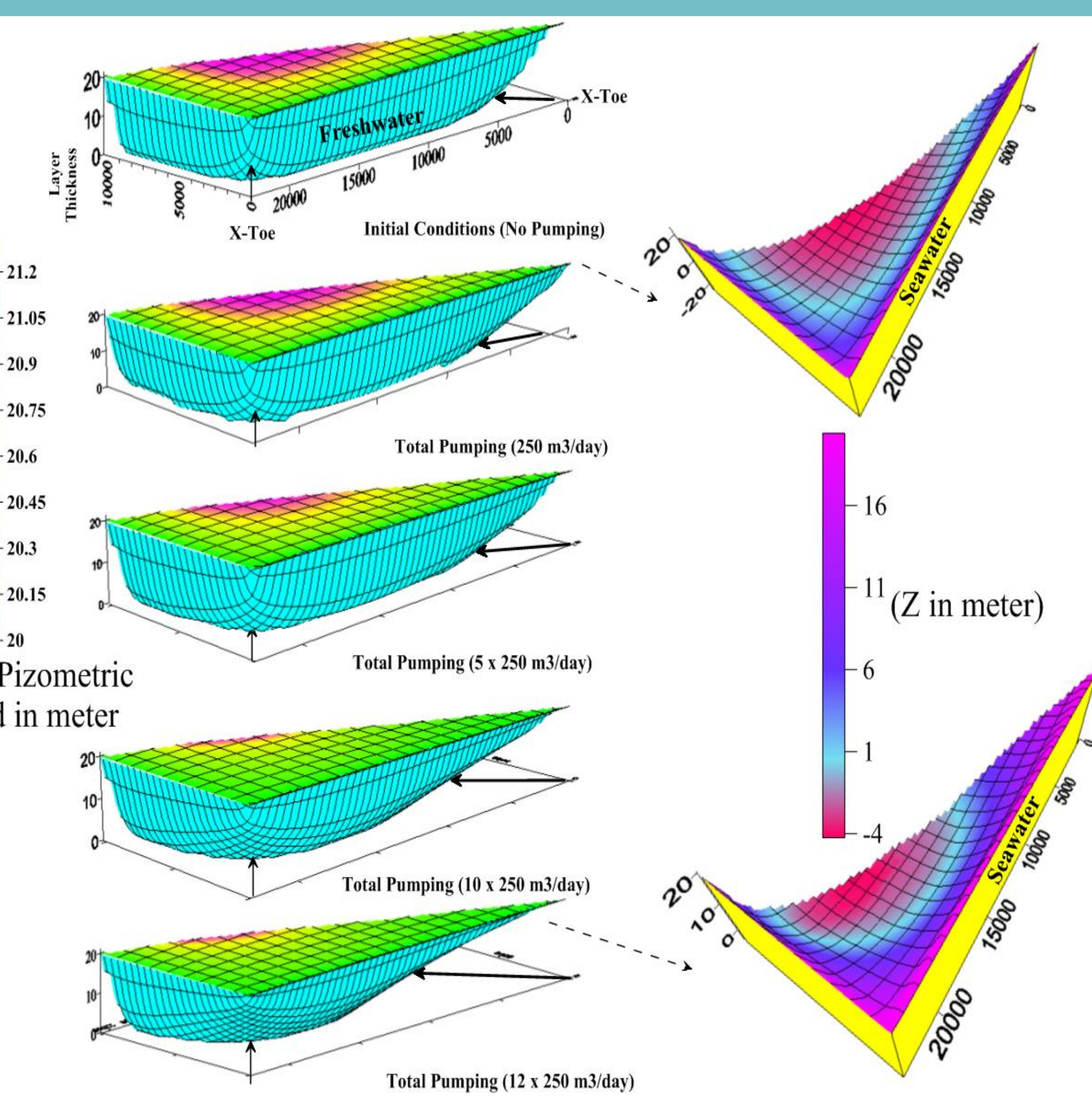


Estimated SWMII for groundwater samples in Ras El-Hekma

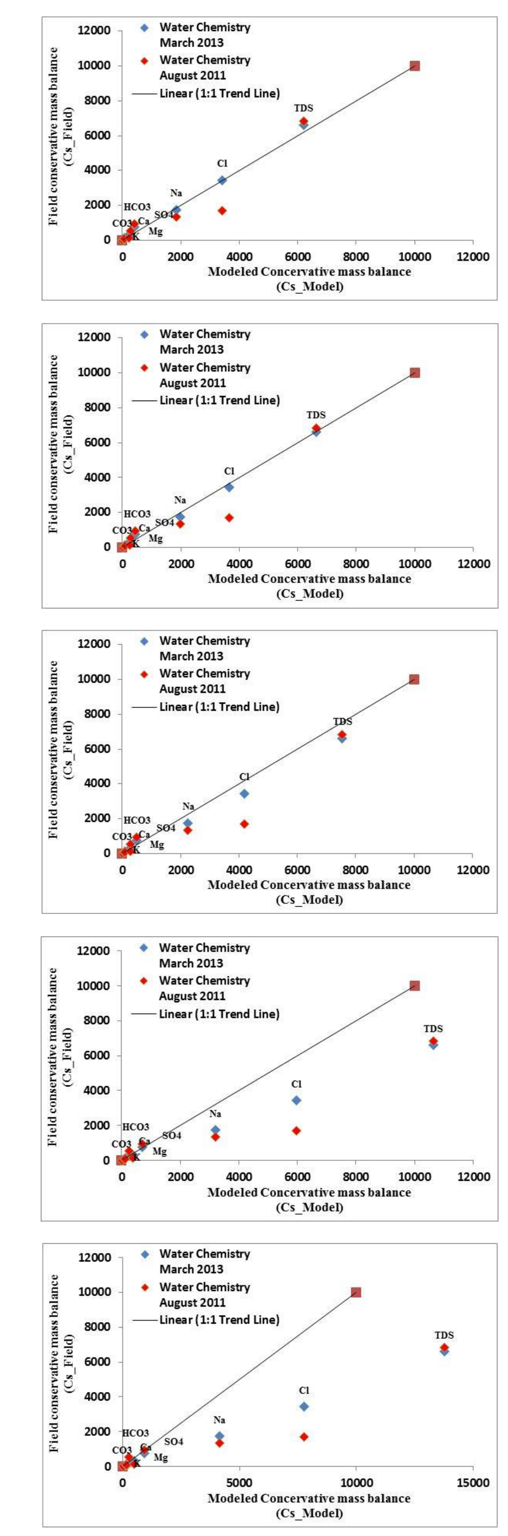
6. Groundwater Flow Model



Theta Contour map and X-toe under different pumping rates



Volume of Freshwater and Seawater with different pumping rates



Inverse calibration for groundwater flow model with pumping rates using historical groundwater salinity records

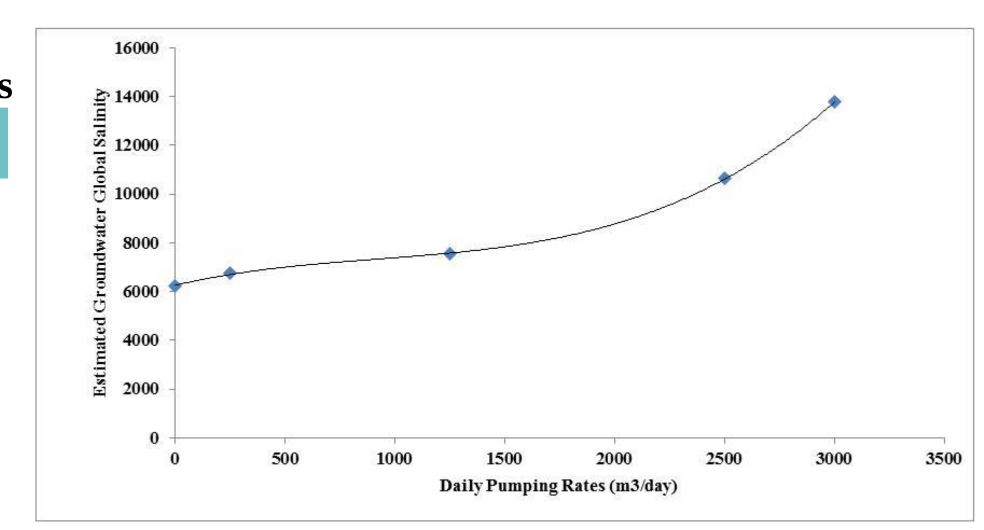
7. Conclusion and Recommendation

1- The results lead to a better understanding of aquifer salinization due to seawater intrusion at the coast, and leaching of aquifer matrix leads to deterioration of groundwater quality.

2- The global groundwater salinity has been estimate with different pumping rates where, the recommended amount of daily pumping should not exceed 250 m3/day.

3- According to the isotopic results obtained from the IT2 Isotope Trace technologies Inc Lab., sites 18 and 19 should be investigated to determine the reasons for high evaporations at these sites.

4- The result of the analytical model shows a transgression of seawater inland and along the coast. The model and isotope results recommend a decrease in pumping to the drilled wells in order to avoid further seawater intrusion along the coast and upwelling of deep saline groundwater.



Estimated global groundwater salinity with different pumping rates

8. References

Mantoglou, A. (2005) Pumping management of coastal aquifers using analytical models of saltwater intrusion. *Water Resour. Res.*, *39*, doi:10.1029/2002WR001891.

Park, S., Yun, S., Chae, G., Yoo, I., Shin, K., Heo, C., Lee, S. (2005). Regional hydrochemicalstudy on salinization of coastal aquifers, western coastal area of South Korea.Journal of Hydrology 313, 182–194.

Strack, O. D. L. (1976), A single-potential solution for regional interface problems in coastal aquifers, *Water Resour. Res.*, *12*, 1165–1174, doi:10.1029/WR012i006p01165.