Feasibility Study for Raw Water Supply to a Proposed Reverse Osmosis Plant on New Providence Island, Bahamas

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ABSTRACT
A hydrogeological investigation was conducted to study the feasibility of raw water supply to a proposed reverse osmosis (RO) plant on New Providence Island, Bahamas. The study included field investigation and development of a SEAWAT model. After calibration, the model was used to evaluate the long-term water quality changes due to different withdrawal scenarios. Both wellfield and lake withdrawals were considered. The results indicate the raw water total dissolved solids (TDS) concentration would increase quickly due to vertical migration of salt from below. There is no significant difference to the simulated water quality changes between well or lake withdrawals.

INTRODUCTION
Reverse osmosis (RO) water treatment facilities in the Bahamas typically use wells tapping seawater as the raw water supply. To reduce treatment costs for a site on New Providence Island, a hydrogeological investigation was conducted on a man-made lake containing brackish water and on the surrounding shallow groundwater system. The investigation included test drilling, aquifer testing, water sampling and analysis, and groundwater modeling. A 3-D SEAWAT model was developed. The model was calibrated and used to evaluate various scenarios of withdrawals from wells and a man-made lake as an alternate source of raw water.

SITE HYDROGEOLOGY AND FIELD INVESTIGATION
The project site is located at the western portion of New Providence Island (Figure 1). Five boreholes were drilled to depths up to 30 m below land surface near the 0.05 km^2 man-made lake to obtain groundwater quality data and for hydraulic testing purposes. Field data indicate that the Lucayan Formation of Pleistocene age underlies a thin veneer of sandy soil at the site. The upper 5 m of sediments consists primarily of white to light gray limestone. The limestone from 5 to 10 m is harder, more porous, and more permeable than the shallower unit. The limestone from 10 to 30 m is hard, well indurated, and generally, has a high apparent porosity and permeability. However, dense limestone layers with low apparent porosity and permeability are also present and provide a degree of separation between the zones with high permeability.

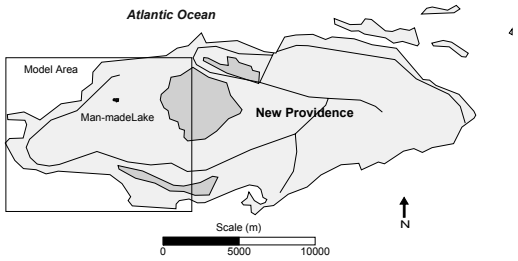

Figure 1. Location of Study Area

The lake was reportedly excavated between 1994 and 1997. The depth of the lake varies from approximately 3 to 5 m and averages about 4 m. Water quality within the lake is relatively uniform. The average dissolved chloride and TDS concentrations of two samples obtained from the lake during January 2007 were 2,040 mg/l and 4,150 mg/l, respectively. Wells with depths of greater than 30 m on the island are known to produce water with TDS concentrations of approximately 34,000 mg/l or greater (seawater quality). Less saline groundwater exists at shallower depths. In the site area, the shallow groundwater was density-stratified with TDS values ranging from less than 1,000 mg/l near the land surface to about 30,000 mg/l at a depth of 30 m. Slug tests and constant rate pump tests were conducted at various depth intervals. The hydraulic conductivity calculated from these tests ranged from 3.54 to 597 m/day. The ratio of horizontal to vertical hydraulic conductivity was estimated to vary from 10:1 to 100:1.

DEVELOPMENT OF SEAWAT MODEL

SEAWAT is a computer program that couples two popular groundwater modeling codes MODFLOW (McDonald and Harbaugh, 1988) and MT3DMS (Zheng and Wang, 1998) for simulation of flow with variable density (Guo and Langevin, 2002). For this project, SEAWAT-2000 (Langevin et al., 2004) was used. Only a portion of the island was modeled. The model consisted of 110 rows and 160 columns with a uniform grid spacing of 80 m. The model had eight flat layers. Information on these layers including the layer thickness and hydraulic parameters, is shown in Table 1. A constant head (zero m) and concentration boundary (35,000 mg/l) was specified along the coastline in the model in all layers. Along the northern and eastern edges of the model, constant concentration boundaries were specified to simulate the potential mass flux entering the model through dispersion. The values specified for these constant concentration boundaries were consistent with the values of initial concentrations for each layer (Table 1). The inland area of layer 8 was specified as a constant concentration with a value of 32,000 mg/l based on measured data. No-flow boundary conditions were specified along the northern and eastern edges of the model in layers 1 through 7 since they are located approximately along the hydrologic divides on the island.

Table 1: Model Layers and Hydraulic Parameters

Layer	Thickness (m)	Initial TDS (mg/l)	Kh (m/day)	Sy
1	3.66	2300	3.66	0.1
2	0.91	2300	3.66	0.1
3	1.52	2650	0.61	0.2
4	1.52	2800	60.96	0.2
5	1.52	2800	152.40	0.25
6	10.67	8000	152.40	0.25
7	6.10	15000	304.80	0.3
8	4.57	32000	304.80	0.3

The model was calibrated to the TDS concentration of the lake. The current TDS concentration in the lake is approximately 4,150 mg/l. It was assumed that the aquifer has the same water quality as it was 10 years ago, and the initial TDS concentration in the lake was the same as the surrounding aquifer, 2,300 mg/l, when the lake was excavated. It was also assumed that the salt in the lake was only coming from the surrounding aquifer and that increases in salinity were due to evaporative concentration of solutes in the lake.

Net recharge was applied to the inland area in the model. For the lake, it was assumed that the lake loses water by net evaporation. A series of model simulations were made using different combinations of recharge/ET rates. Figure 2 shows the results of model simulation with different net recharge/net evaporation rates. The results indicate 12.7 cm/yr recharge over the land area and a 12.7 cm/yr net ET rate at the lake would give the closest TDS concentration to the values actually measured in the lake.

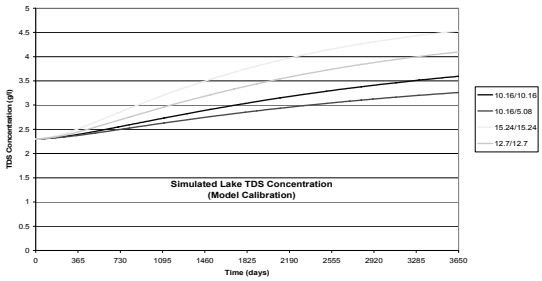

Figure 2. Model Calibration (Values are Recharge/ET Rates in cm/yr)

EVALUATION OF WITHDRAWAL SCENARIOS

A total of seven scenarios were evaluated. All of the scenarios were run for 10 years from the base conditions. Three options were evaluated: (a) withdrawals from the lake; (b) withdrawals from four wells; and (c) withdrawals from seven wells. The results of the groundwater modeling indicate that continuous raw water pumpage at a rate of 3,785 m^3/day (1.0 MGD) from the lake would result in a TDS increase from approximately 4,200 mg/l to 13,200 mg/l over a 10-year period (Figure 3). Continuous pumpage at the same rate from a series of shallow wells constructed near the lake resulted in a predicted TDS change from approximately 2,000 mg/l to 12,400 mg/l during the same stress period. The simulated increase in raw water salinity is relatively rapid with the majority of the TDS changes occurring within the first year of pumpage and then leveling off. It seems that withdrawal from wells is slightly better than lake withdrawal in terms of water quality. This is likely due to the fact that some of the wells would capture some fresher water from the up-gradient direction.

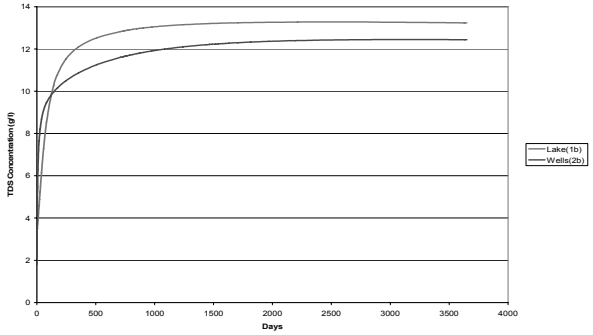

Figure 3. Simulated TDS Concentration of Raw Water

SUMMARY

A hydrogeological investigation, including field testing and modeling, was conducted for a site on New Providence Island, Bahamas to study the feasibility of raw water supply development from a man-made lake and/or wells for a proposed RO plant. Use of brackish raw water will economically allow the recovery efficiencies to be higher and cause the permeate water quality to be better than that obtained using seawater throughout the life-cycle of the plant. The brackish

source of water would produce the most energy efficient RO plant design based on the raw water available for use. Use of wells, rather than the lake water, would result in lower pre-treatment costs for the facility. Since the water will be used for irrigation, there may be some seasonal blending opportunities to further reduce the overall water production cost.

A SEAWAT model was developed as a tool to assess the water quality changes under different withdrawal scenarios. The projected 10-year brackish raw water TDS concentration between 12,400 and 13,200 mg/l is roughly one-third of normal seawater.
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REFERENCES

Guo, W**.** and C.D. Langevin. 2002. User's guide to SEAWAT: A computer program for simulation of three-dimensional variable-density ground-water flow, *U.S. Geological Survey TWRI Book 6, Chapter 7*, 79 p.

Harbaugh A.W, E.R. Banta, M.C. Hill, and M.G. McDonald. 2000. MODFLOW-2000, the U.S. Geological Survey modular ground-water model-User guide to modularization concepts and the groundwater flow process. *U.S Geological Survey Open-File Report* 00–92.

Langevin, C.D., W. B. Shoemaker, and W. Guo. 2003. MODLFOW-2000, the U. S. Geological Survey Modular Ground-water Model- Documentation of the SEAWAT-2000 Version with the Variable-Density Flow Process (VDF) and the Integrated MT3DMS Transport Process (IMT), *U.S. Geological Survey Open-File Report 03-426*, Tallahassee, Florida.43 p.

McDonald M.G., and A.W. Harbaugh. 1988. A Modular Three-Dimensional Finite-Difference Ground-Water flow Model. *U.S. Geological Survey Open-File Report* 83-875.

Zheng, C., and P.P. Wang. 1999. MT3DMS-A modular three-dimensional multispecies transport model for simulation of advection, dispersion and chemical reactions of contaminants in ground-water systems: Documentation and user's guide: U.S. Army Corps of Engineers Contract Report SERDP-99-1.

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