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Innovative Method for Saltwater Intrusion Control

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Abstract

Salt water intrusion is the migration of saltwater into freshwater aquifers under the influence of groundwater development (Freeze and Cherry, 1979). The most detrimental effect that ground water depletion causes lowering of water table. Another problem due to saltwater intrusion is changing saltwater freshwater interface. Methods for controlling intrusion vary widely depending on the source of the saline water, the extent of intrusion, local geology, water use and economic factors. The proposed methodology to control saltwater intrusion is (ADR) Abstraction, Desalination and Recharge. The proposed methodology interplays between the major parameters of the system to control saltwater intrusion. These parameters include the soil/aquifer properties, the well locations, the well depths, the rates and the relation between the abstraction and recharge rates which depends on the recovery rate and the salinity degree. It is capable of completely preventing saltwater intrusion because it increases the volume of fresh groundwater and decreases the volume of saltwater, while considering economical aspects, environmental impact and sustainable development of water resources.

Keywords : Salt water intrusion, ADR methodology, Biscayne aquifer

Introduction

Most of the coastal regions rely on groundwater as their main source of fresh water for domestic, industrial and agricultural purposes. In professional way: Salt water intrusion is the migration of saltwater into freshwater aquifers under the influence of groundwater development (Freeze and Cherry, 1979). Most often, it is caused by ground-water pumping from coastal wells, or from construction of navigation channels or oil field canals. A major factor that drives the intrusion process is the density difference. The salt water intrusion process has a significant role in water management in coastal region. It is because a small fraction of the intruded salt can increase the salinity level of an impacted aquifer. Therefore, the location of the interface between the freshwater and saltwater, commonly known as the saltwater wedge, should be carefully managed in coastal areas to avoid an unexpected contamination of drinking water reserves. Saltwater intrusion occurs in virtually all coastal aquifers, where they are in hydraulic continuity with seawater. Saltwater intrusion into freshwater aquifers is also influenced by factors such as tidal fluctuations, long-term climate and sea level changes, fractures in coastal rock formations and seasonal changes in evaporation and recharge rates. (4)

Saltwater Intrusion (SWI) is a major problem in coastal regions all over the world. The intrusion of saline water in groundwater is considered a special category of pollution, making groundwater unsuitable for human, industry and irrigation uses. SWI reduces the freshwater storage in coastal aquifers and in extreme cases can result in abandonment of freshwater supply wells if concentration of dissolved salts exceeds drinking water standard. Seawater intrusion increases salt concentration in groundwater which places limitations on its uses. Therefore, efficient control of seawater intrusion is very important to protect groundwater resources from depletion. Therefore saltwater intrusion should be prevented or at least controlled to protect groundwater resources. Methods for controlling intrusion vary widely depending on the source of the saline water, the extent of intrusion, local geology, water use and economic factors. There are several methods for reducing the impact of saltwater intrusion, including modification of the pumping pattern, direct artificial recharge at land surface, the use of injection and/or extraction wells, and the installation of a subsurface barrier (Todd, 2005). An innovative methodology, ADR (Abstraction, Desalination and Recharge), is used to control SWI in coastal aquifers. This methodology aims to overcome all or at least most of the limitations of the previous methods. ADR consists of three steps; abstraction of brackish water from the saline zone, desalination of the abstracted brackish water using reverse osmosis (RO) treatment process and recharge of the treated water into the aquifer.

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Saltwater Intrusion Techniques

Table: 1 Saltwater Intrusion Techniques [7]

SrNo	Name of Techniques	Description	Advantages	Disadvantages
1	Reduction of Pumping Rates	* Public Awareness *Recycling & reuse of water	*Reduction of abstraction rate	*Private Stackholders *Temporary Solution
2	Relocation of Pumping Wells	*Movement of wells in more inland position *SUTRA used to decide best location of well	*Decrease the occurrence of Upconing of saltwater (Abd-Elhamid and Javadi, 2008).	*Costly *Temporary solution *Obstruction in relocation
3	Use of Subsurface Barriers	*Reduce the permeability of aquifer *Sheet piling, cement grout, or chemical grout	*Reduce the intrusion of saline water	*Not efficient for deep aquifers (Abd-Elhamid and Javadi, 2008). *Costly
4	Natural Recharge	*Constructing dams and weirs to prevent the runoff from flowing to the sea.	Prevent the runoff to flow directly to the sea	*Depends on the soil properties *Take Long time *Unsuitable for confined and deep aquifers.
5	Artificial Recharge	*Increase the groundwater levels, using surface spread for unconfined aquifers and recharge wells for confined aquifers.	Increase the groundwater storage	*Ineffective in the areas where excessive groundwater pumping occurs *Occupies a large area
6	Abstraction of Saline Water	*Reduce the volume of saltwater by extracting brackish water from the aquifer and returning to the sea.	*Decreases the volume of saline water *Protects pumping wells from upconing.	*Disposal of the saline water *Affect the marine life in these areas, fishing and tourism activities

The Proposed Methodology to Control Saltwater Intrusion (ADR)

The proposed methodology Abstraction, Desalination and Recharge (ADR) consists of three steps: [2]

i. (A): Abstraction of brackish water from the saline zone using abstraction wells.
ii. (D): Desalinate the abstracted brackish water using RO treatment process; and
iii. (R): Recharge of the treated water using recharge wells into the aquifers.

The proposed methodology interplays between the major parameters of the system to control saltwater intrusion. These parameters include the soil/aquifer properties, the well locations (L1, L2, and L), the well depths (d1, d2, d), the rates (QA, QR, QP) and the relation between the abstraction and recharge rates which depends on the recovery rate and the salinity degree. The objectives of these management scenarios include minimizing the total construction and operation cost, minimizing salt concentrations in the aquifer and determining the optimal depths, locations and abstraction/recharge rates.

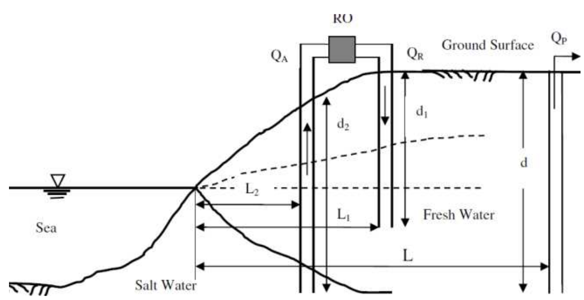

Fig : 1 Abstraction, desalination and recharge methodology

The proposed methodology considers:

1. The relationship between abstraction and recharge rates; QA and QR ,
2. The locations of abstraction and recharge wells; LA and LR ,
3. The depths of abstraction and recharge wells; DA and DR ,
4. The aquifer properties,
5. Construction and operation costs,
6. Environmental impacts, and
7. Climate changes, sea level rise and their effects on saltwater intrusion.

Benefits of ADR Technology

This method is a combination of two methods; abstraction of saline water and recharge of fresh water in addition to desalination of abstracted water and treatment to be ready for recharge or domestic use. It combines the advantages of these three steps as:

The first step: Abstraction of brackish water helps to reduce the saline water volume in the aquifer and reduce the intrusion of saltwater.

The second step: Desalination of abstracted brackish water using RO treatment process aims to produce fresh water from brackish water for recharge. This step is very important to produce freshwater in the areas where freshwater is scarce.

The third step: Recharge of treated water aims to increase the fresh groundwater volume to prevent the intrusion of saltwater.

Desalination of seawater has a lot of problems such as; high cost, high pollution (mainly carbon emission), and the large area of land that is required for plants and the disposal of the brine. Desalinating brackish water is a good alternative to seawater desalination, because the salinity of brackish water is about one-third of the seawater salinity. Therefore, brackish water can be desalinated at a lower cost than sea water. The cost of desalting brackish water is about one-third of the cost of desalting sea water. Several methods can be used for desalination but RO has been selected as a method for desalting brackish water, because it has many advantages; it requires simple equipments, low energy, low cost and lower environmental impact. [(5)]

Limitation of ADR Technology

ADR has shown to be the most effective method, in practice, there might be exceptional cases in which other methods could prove more efficient. For example, in cases where the transition zone is close to the sea, the ADR methodology may not be effective. This is mainly because the desalination may involve water with very high salinity which could increase desalination costs. In this case, abstraction of saline water and disposal to the sea could be more cost effective. Also, if sufficient source of freshwater is available in the area, recharge of fresh water could be more efficient.

Comparison between Three Management Model

Hypothetical Case Study:

The objective function for the three models is to minimize the total cost associated with well locations, depths and abstraction/recharge rates and treatment. Comparison between total costs, salt concentration in the aquifer and abstraction/recharge rates for the three management models for hypothetical case study are presented in Figure: 2.

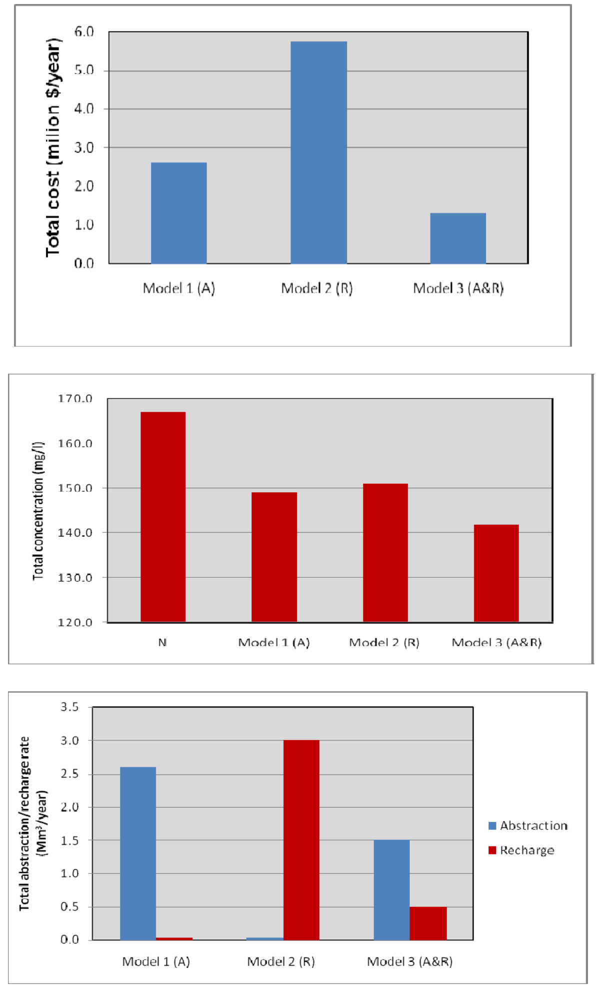

Fig: 2 Comparison of three models for hypothetical case study

From fig.(2) it can be concluded that: using recharge wells alone has reduced the total salt concentration in the aquifer from 167 where no management model is used (N) to151(mg/l) through recharging 3 (Mm3/year) of fresh water at a cost of $5.72 million/year. Using abstraction wells alone reduced the salt concentration to 149 (mg/l) through abstracting 2.6 (Mm3/year) of saline water at cost of $2.62 million per year. However, using a combination of abstraction, and recharge (ADR) reduced salt concentration to 142 (mg/l) through abstraction of 1.5 (Mm3/year) of saline water and recharge of 0.5 (Mm3/year) with cost of $1.32 million/year. [(6)]

For Real World Case Study: (Biscayne aquifer, Florida, USA)

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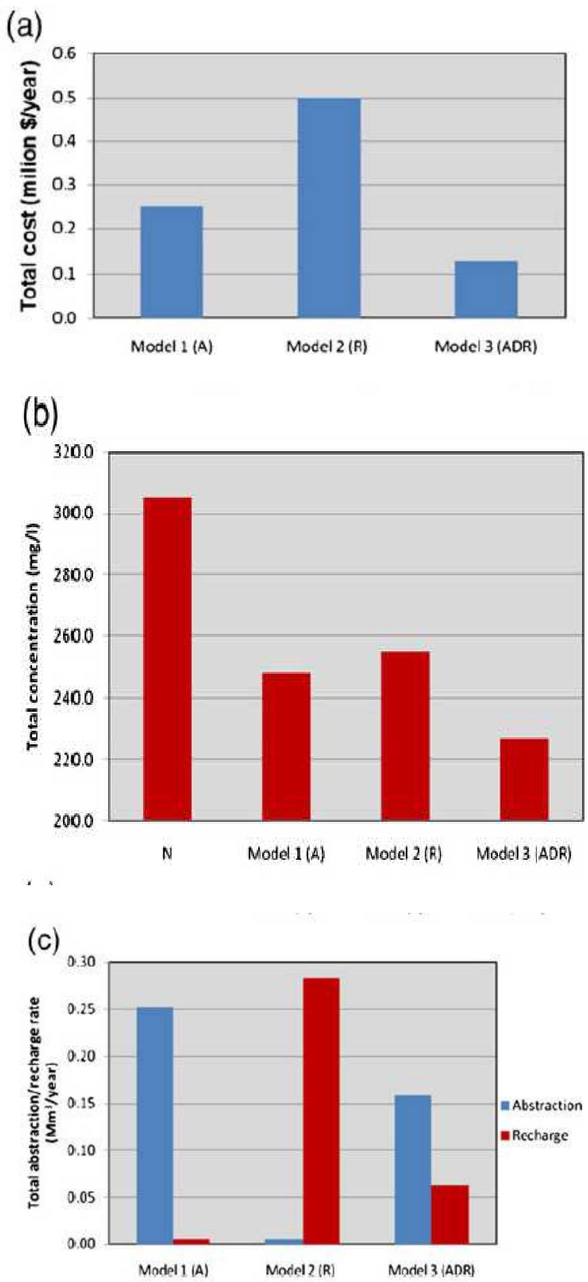

Fig : 3 Comparison of three models for real world case study

From Fig.(3) it can be seen that using the proposed ADR system in model 3 reduced salt concentration from 305 to 227 mg/l which is less than the amount of salt concentration achieved by model 1 (248 mg/l) or 2 (255 mg/l). Using ADR requires abstraction of 0.158 Mm3/year of saline water and recharge of 0.063 Mm3/year of fresh water which is less than the amount of water abstracted using model 1 (0.252 Mm3/year) or recharged using model (0.283 Mm3/year). It is also gives the least cost (US$0.13 million per year) compared with the cost for recharge (US$0.5 million per year) and abstraction (US$0.25 million per year) which represents 50% of the abstraction costs and 25% of the recharge costs. [6]

Conclusion

Seawater intrusion represents a great risk to groundwater resources in coastal areas as it raises the salinity to levels exceeding acceptable drinking water standards. Seawater intrusion is a major problem in the coastal regions all over the world that should be controlled to protect groundwater resources from depletion. The proposed methodology (ADR) is an attempt to overcome the limitations of previous technique. It is considered an economical solution and has less environmental impact because desalinating brackish water using RO treatment process involves lower energy consumption, lower cost, lower pollution and carbon emission as compared with conventional methods of sea water desalination and waste water treatment. From the comparison of the models , the total costs of ADR was about 50% less compared with the case of abstraction wells only and about 75% less in comparison with the case of using recharge wells only. It also provides fresh water for recharge using the treated brackish water. Finally the (ADR) technique is considered an efficient method to control saltwater intrusion. It is capable of completely preventing saltwater intrusion because it increases the volume of fresh groundwater and decreases the volume of saltwater, while considering economical aspects, environmental impact and sustainable development of water resources.

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