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ISSUES OF GROUNDWATER- SALTWATER INTERACTION IN COASTAL AQUIFER

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1.0 Introduction

More than 70% of Population lives in coastal areas, wherein Groundwater is important source of freshwater. In coastal areas, due to indiscriminate groundwater it faces development of contamination from intrusion of saltwater from the sea. The economic cost of such a threat turning into a reality can be high, especially in regions that are heavily dependent on coastal Aquifers for water supply.

2.0 Coastal Hydrogeologic Conditions

A coastal Aquifer has complex hydrogeologic conditions compared to inland aquifers. It may be represented by an unconfined, confined and island aquifer. In other cases, the hydrogeologic setting may be that of a multi-layer aquifer system. In either case, the aquifer system has a sea front so that there is a direct contact between continental fresh water and marine saltwater. Besides slight difference between viscosities between the two fluids, there exist a density change that depends mainly on salinity differences. Under natural undisturbed conditions, sea water hydraulic gradients exist in the aquifer with fresh water discharge into the sea. The heavier salt water flows in from the sea and a wedge-shaped body of salt water develops beneath the lighter freshwater, with the freshwater thickness decreasing from the wedge toe towards the sea. The freshwater interface is stationary under steady state conditions with its shape and position determined by the freshwater head and gradient. A groundwater development take place, inland changes in discharge or recharge occur that modify the flow within the fresh water region, inducing a corresponding movement of the interface. A reduction in freshwater flow, due to overdraft, causes the interface to move inland and results in the intrusion of saltwater into the aquifer. Conversely, the interface retreats following an increase in freshwater flow. The extent of intrusion is governed by groundwater recharge to the aquifer, hydrogeology of the region and the manner and degree of ground water development. Thus, in areas where as consequences of intrusion, freshwater is underlain by the saltwater interface, freshwater needs to be tapped by the installing partially penetrating wells. However, merely keeping the well screen above the interface cannot ensure the success of a well. This is because of a localized rise of the interface below the well as the pumping concerns. The upconed interface may reach a steady state below the well screen provided the pumping discharge does not extent certain threshold. The interface rises and encroaches upon the well screen as the threshold is exceeded. Thus, the pumping duration must be restricted if design well discharge exceeds the threshold. As the pumping is discontinued, the upconed interface starts settling down and may reach back its

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original pre-pumping position after a certain period. The next pumping spell may commence.

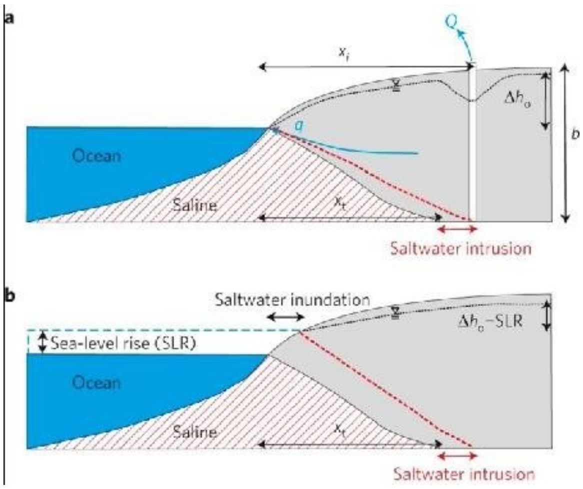

Fig 1. Development of saltwater in costal aquifer (a) Pre-development scenario with raised water table (b) Post development scenario with lowered water table.

3.0 Formation of Transition Zone

Seawater intrusion occurs mainly on account of saltwater transport by advection and hydrodynamic dispersion. Due to hydrodynamic dispersion, the zone of contact between freshwater and saltwater takes the form of a transition zone across the salt concentration and hence density of water varies from that of seawater (1025 kg/m3) to that of freshwater (1000 kg/m3). In the transition zone the diluted salt water, being lighter than original sweater, rises and moves seaward, causing salt water from the sea to flow towards the transition zone. This induces a cyclic flow of saltwater from the floor of the sea to the transition zone and finally back to the sea.

In some instances, the transition zone is thin, a few meters or less, but in other situations it can attain a thickness of more than a hundred meters, especially in highly non-homogeneous formations like limestone aquifers. In non-homogeneous highly permeable materials, with small fresh water flow, the top of the transition zone can reach the water table. Moreover, the thickness of transition zone is not constant, and may expand or contract in accordance with a succession of low and high rides and wet and dry periods.

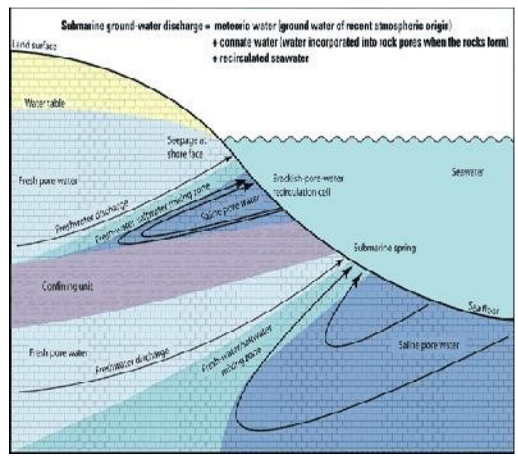

Fig 2. Zone of Transition in a coastal Aquifer

The salinity of groundwater generally increases with depth. However, in a multiaquifer system each aquifer my have its freshwater zone and the underlying saline zone. As such, fresh groundwater may occur below saline groundwater. Also, the freshwater may be stagnant fossil groundwater or water that is getting recharge in the uplands.

4.0 Groundwater Development issues in Coastal Aquifers

The position of the fresh-salt water interface in a coastal aquifer is essentially determined by the rate of outflow to sea. Any increase in the development would lead to reduction of the outflow rate and

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hence landwards and upward movements of the interface. This may have the following implication.

a) The interface may encroach upon the screens of a few wells leading to their failure.

b) For other wells, the initial cushion between the well screen and the interface may get reduced leading to reduced discharge/pumping duration resulting in reduced well yield. Thus, in order to ensure a sustainable groundwater development pattern in coastal aquifer, groundwater development may need to be planned both at the regional scale and at the localized scale. Planning the regional scale will ensure a deep enough and short enough freshwater-saltwater interfaces. While planning at the localized scale will imply the design of wells and pumping schedule to ensure salt free pumped water.

5.0 Regional Development Issues

Regional scale problem pertains to a large area in which the interface gradually moves upward and/or in inland direction. The large-scale movement of the interface is caused by a large-scale modification of the outflow rate. Recognizing that the outflow rate in each hydrogeological scenario is determined by the recharge /Pumping pattern, planning t the regional scale can be conceptualized as designing such a regional pumping/recharge pattern, which keeps the interface between the freshwater and salt water at pre-assigned large depth.

5.1 Regional Mathematical Model

To solve the problem of saltwater intrusion at regional scale various alternative strategies may be employed. These include:

(i) Modification of pumping /recharge patterns
(ii) Construction of Physical Barriers.
(iii) Installation of Injection Barriers and /or extraction barriers. Tapping alternative aquifers etc., In order to gauge the feasibility of strategy and its relative effectiveness, a prior knowledge of the immediate and long-term response of the coastal aquifer to the stress is vital. This can be accomplished by mathematical modeling of the coastal aquifer system. A mathematical model of a coastal aquifer essentially involves a coupled solution of the differential equations governing flow and mass transport. In practice, some assumption my made for simplifying the mathematics without sacrificing the predictive capability model.

Presence of transition zone makes the mathematical modeling of saltwater intrusion a complex task, since it involves simulation of flow with variable density. To reduce the mathematical complexity of the problem an assumption can be made regarding the presence of the transition zone itself. If the thickness of this zone is small, relative to the thickness of the aquifer, then it is assumed, for the purpose of analysis, that freshwater-saltwater are immiscible fluids separated by a sharp interface instead of the disperse interface. Therefore, mathematical modeling of saltwater interface can be attempted using models based on either of the following approaches.

- Sharp Interface Approach
- Miscible Transport Approach

In this study, advective Transport of saltwater interface modeling using sharp interface Approach is explained.

5.2 Sharp Interface Approach

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6.0 General Methodology

The sharp interface models require simultaneous solution of freshwater and saltwater interface flow equation coupled by boundary conditions that specific discharge and pressure must be equal on either side of the sharp interface.

The equation of flow in the freshwater region is

d/dx (Kxf dhf/dx) + d/dy(Kyf dhf/dx)+ d/dz (Kzf dhf/dz)+Qr = Ssf dhf/dt (1)

and for saltwater region it is d/dx (Kxs dhs/dx) + d/dy(Kys dhs/dy)+ d/dz (Kzs dhs/dz)+Qr = Sss dhs/dt (2)

where h- hydraulic head; Kx, Ky, Kz = hydraulic conductivity in x, y and z direction; Ss=Specific storage; Q= source/Sink term and subscripts f and s refer to fresh water and saltwater respectively. The solution of Equations (1) and (2) yields the spatial distributions of the freshwater (hf) and the saltwater head (hs) at the steady state. The corresponding position and shape of the interface is then obtained using the equation

Z =[ɣ s/(ɣ s - ɣ f)]hs - [ɣ f/(ɣ s- ɣ f)]hf

Where Z= elevation of interface; ɣ s and ɣ f = specific weight of salt and freshwater respectively.

6.1 Local Planning Issues

Planning t localized scale primarily deals with well design and pumping schedules. Given the required discharge, the pre-pumping position of the interface and the maximum permissible salt concentration on the pumped water, duration of a single pumping spell and the necessary rest period between two successive spells. The permissible limit of saltwater concentration in pumped water may be stipulated based upon its specific utilization like drinking, irrigation or industrial.

Summary

For designing wells /operation schedules in coastal aquifers, mathematical models permitting simulation of upconing/salt concentration in pumped water is required. As in regional planning models, there are two types of models like sharp interface and miscible transport models re used. Implementations of above any one is involving tradeoff in one from or the other. Therefore, the selection of a technique from amongst the alternative solutions should be based on a thorough analysis of competing alternatives in an organized and comprehensive manner. In Decision making process the economic, environmentl, social, technical, and other such issues of the coastal area under groundwater development should be given adequate consideration.

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