

Pump/Recharge Rate Affects Saltwater Intrusion

Groundwater Monitoring, Management and Conservation Keep Saltwater Intrusion Under Control

Freshwater-Saltwater Interactions

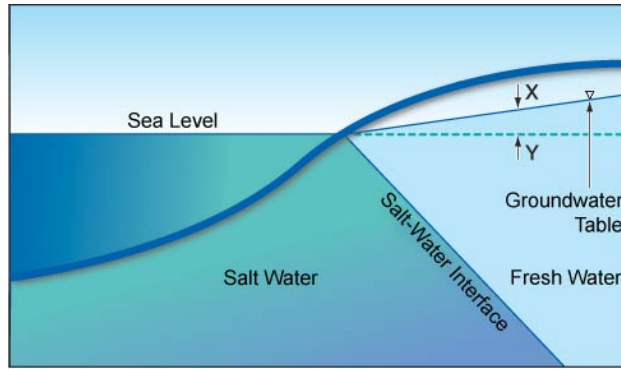
Saltwater intrusion is a major concern commonly found in coastal aquifers around the world. Saltwater intrusion is the induced flow of seawater into freshwater aquifers primarily caused by groundwater development near the coast. Where groundwater is being pumped from aquifers that are in hydraulic connection with the sea, induced gradients may cause the migration of salt water from the sea toward a well, making the freshwater well unusable.

Because fresh water is less dense than salt water it floats on top. The boundary between salt water and fresh water is not distinct; the zone of dispersion, transition zone, or salt-water interface is brackish with salt water and fresh water mixing.

Under normal conditions fresh water flows from inland aquifers and recharge areas to coastal discharge areas to the sea. In general, groundwater flows from areas with higher groundwater levels (hydraulic head) to areas with lower groundwater levels. This natural movement of fresh water towards the sea prevents salt water from entering freshwater coastal aquifers (Barlow, 2003).

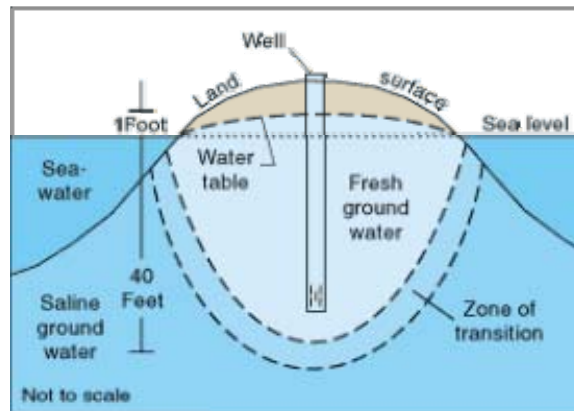
Groundwater pumping/development can decrease the amount of fresh water flowing towards the coastal discharge areas, allowing salt water to be drawn into the fresh water zones of coastal aquifers. Therefore, the amount of fresh water stored in the aquifers is decreased (Barlow, 2003).

The Ghyben-Herzberg Relation assumes, under hydrostatic conditions, the weight of a unit column of freshwater extending from the water table to the salt-water interface is balanced by a unit column of salt water extending from sea level to that same point on the interface. Also, for every unit of groundwater above sea level there are 40 units of fresh water below sea level.



X= Groundwater Level Y= Sea Water Level

Salt-water interface in an unconfined coastal aquifer according to the Ghyben-Herzberg relation.



Freshwater aquifer in an island setting. Note that the freshwater depth (40 feet) links to the 1 ft height of the groundwater table above the surrounding sea level.

This analysis assumes hydrostatic conditions in a homogeneous, unconfined coastal aquifer. According to this relation, if the water table in an unconfined coastal aquifer is lowered by 1 m, the salt-water interface will rise 40 m.

Generally, saltwater intrusion into coastal aquifers is caused by two mechanisms:

- **Lateral encroachment from the ocean due to excessive water withdrawals from coastal aquifers, or**
- **Upward movement from deeper saline zones due to upconing near coastal discharge/pumping wells.**

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. Recharge rates can also be lowered in areas with increased urbanization and thus impervious surfaces. Intrusion has

also occurred in areas because of water levels being lowered by the construction of drainage canals (Barlow, 2003).

Intrusion Occurrence

Incidents of saltwater intrusion have been detected as early as 1845 on Long Island, New York. Intrusion occurs in coastal aquifers worldwide, and is a growing issue in areas including North Africa, the Middle East, the Mediterranean, China, Mexico, and most notably, the Atlantic and Gulf Coasts of the United States, and Southern California. The increased use of groundwater has caused the salt-water interface to move inland and closer to the ground surface along much of the U.S. Atlantic Coast, as well as Southern California.

Los Angeles Area Aquifers

One third of the fresh water supply for the greater Los Angeles area comes from local groundwater sources. Over 10 million residents of L.A. County rely on these sources (Edwards and Evans, 2002). Because of rapid population growth, by the 1920's the overall flow of groundwater had reversed, leading to seawater entering some of the Los Angeles Basin coastal aquifers. In the 1950's three injection/barrier wells were installed in an attempt to stop the seawater from intruding. With such complex hydrogeology on the coast, these barriers were only partially effective. Current studies are attempting to map and understand the overall hydrogeology of the area, and efforts towards alternative solutions, such as desalination, are underway.

China's Imbalance

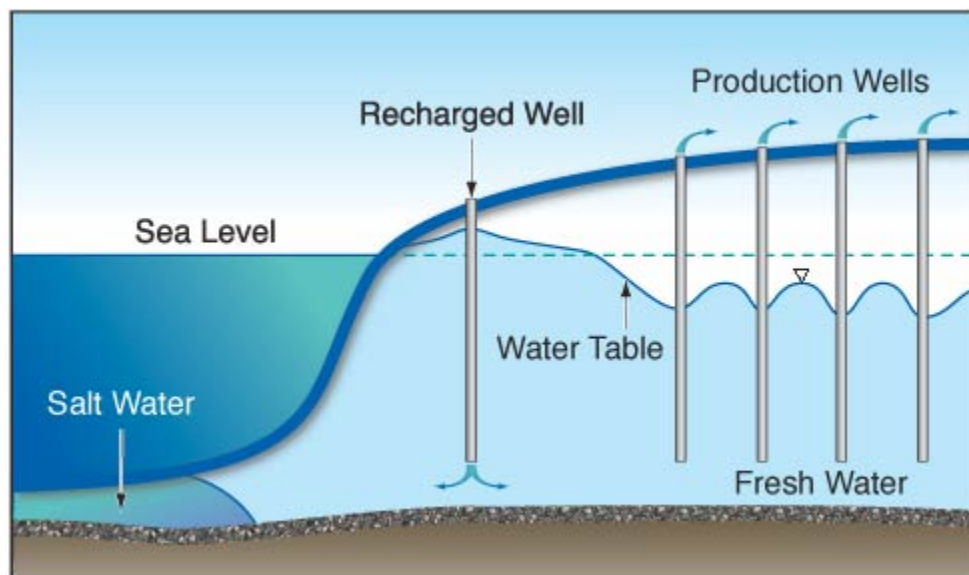
Since the early 1960's, the coastal aquifers of China have been studied for saltwater intrusion. With a transition zone of 1.5 to 6.0 km, and an aquifer area of more than 580 km², the increasing extension of saltwater intrusion is a major concern in this area. A study conducted in the City of Laizhou in 1971, and in the City of Longkou in 1979, illustrated that excessive pumping of the groundwater in these areas had caused saltwater intrusion. In 1979, the saltwater intrusion area covered 16 km². By 1989, the saltwater intrusion area became a continuous zone covering an area of 238 km² in Laizhou. In the 1970's, the saltwater intrusion area in the southwestern part of the study area increased by 4 km² each year. In the early 1980's, this number increased to 11.1 km², and after the mid-1980's to 30 km². This rapid increase reinforces the need for proper monitoring and controlling methods for saltwater intrusion.

Controlling and Managing Saltwater Intrusion

One key to controlling saltwater intrusion is to maintain the proper balance between water being pumped from an aquifer and the amount of water recharging it. Constant monitoring of the salt-water interface is necessary in determining the proper management technique. In the past, many communities who came across a saltwater intrusion problem simply set up new production wells further inland. This only complicated the issue.

Since then, various methods have been employed to help alleviate the concerns of saltwater intrusion. Efforts towards the promotion of water conservation, and restricting withdrawals from coastal aquifers have been the focus in many areas. Using alternative freshwater sources has also been encouraged. Ocean water desalination plants are showing up in coastal regions around the world.

Where there are no other options for fresh water, efforts to maintain groundwater levels by ponding surface water and stormwater runoff, or using river water to recharge the groundwater table have been successfully implemented. Aquifer Storage and Recovery (ASR) systems can help restore aquifers that have experienced long-term declines in water levels due to over-pumping.



Deep recharge well creates groundwater ridge.

Other methods to control saltwater intrusion, such as using deep recharge wells, have also been successful. These wells create a high potentiometric surface, which allows for the pumping of groundwater below sea level landward of a groundwater ridge created. In some instances, barrier wells have been set up near the shore to pump out salt water and recharge a fresh water gradient toward the sea.

In all of these cases, hydrologic studies and water quality monitoring are essential to help better understand the movement and interaction of fresh water and salt water in the subsurface, and determine the best method to manage saltwater intrusion. Potentiometric surface mapping of an aquifer can provide important information determining the direction of groundwater flow within a confined aquifer. Plotting water level elevations on

a map and contouring the results determines this. The contoured surface is known as the potentiometric surface, which is actually a map of the hydraulic head in the aquifer.

Monitoring well networks allow continuous observation of the saltwater interface, after management strategies have been put in place. This provides early warnings of saltwater intrusion and tracks the effectiveness of the strategy. Overall, proper groundwater monitoring techniques and groundwater management, combined with groundwater conservation are needed to keep saltwater intrusion under control, and ensure fresh water supplies are sustained for future generations.