SALINITY INTRUSION - ITS CHARACTERISTICS AND IMPACT - CASES IN THE ASIA PACIFIC REGION

DR. GREGORY SHAHANE DE COSTA, Open Polytechnic of New Zealand
86, Wyndrum Av., Lower Hutt, Wellington, New Zealand. shahanedecosta@yahoo.com

PROF. TOSHIHARU KOJIRI, DPRI, Kyoto University, Japan.
Gokasho, Uji, Kyoto, 611-0011, Japan. tkojiri@wrcs.dpri.kyoto-u.ac.jp

ASSOC. PROF. MARK PORTER, University of Southern Queensland, Australia
Faculty of Engineering, USQ, Toowoomba 4350 Australia. porter@usq.edu.au

ABSTRACT –

Anthropogenic impacts on hydro-geological systems can result in long term harm and the degradation of the resource if they are not adequately managed. While this is well known, and witnessed around the world, management options to prevent increasing damage to the surrounding environment are being developed on an individual site basis. Salinity intrusion with the eventual degradation of both land and water quality is one of the most common examples of this type of problem. This paper presents our observations and analyses of salinity intrusion at selected areas in the Asia Pacific region, namely in New Zealand, Australia, Japan and Sri Lanka. It discusses the characteristics of each site and analyzes the impacts on the environment. It also presents the management practices used to mitigate the resulting damage on the environment at each site.

1. INTRODUCTION

A rapidly growing human population with its attendant needs for water, food and fiber supplies has resulted in global exploitation of available water and land resources. The constant pressure on available land and water has led to the development of many marginal resources. Heavy financial investment is taking place to allow these resources to be exploited. The environmental consequences of developing and overexploiting such systems can be major unless they are carefully managed. Salinity intrusion in fresh water supplies and the eventual degradation of both the land and water resources is one example of these consequences.

In many instances of salinity intrusion local ecological systems have adapted to the phenomenon through the development of salt tolerant vegetation and animal species. In other cases salinity intrusion has been blamed for the loss of fresh water, aquatic plant species and fresh water oysters as well as the corrosion of infrastructure. If predictions of sea level rises from global warming are fulfilled, the number of cases of salinity intrusion will be exacerbated in the future.

This paper describes a number of selected cases of salinity intrusion in the Asia Pacific region, namely in New Zealand, Australia, Japan and Sri Lanka. It presents our analyzes of each case and its impact on our environment.

2. CASE OF THE WAIWHETU AQUIFER NEW ZEALAND

The Waiwhetu aquifer is located beneath the city of Wellington and extents from the Hutt Valley well into Wellington harbour. Greater Wellington extracts 40% of it's water requirements from ground water aquifers. We analysed the water quality at three well locations (Somes Island, Petone and Seaview) to establish the degree of intrusion which has already occurred in this aquifer. The variation of Conductivity and Total Dissolved Solids at each of these points are shown below. Table 1 presents summary statistics of the main water quality parameters measured at these sites, and the predicted values in the future if past trends are continued.

Figure 1 – Variation of Conductivity (Jun 93–Sep01)

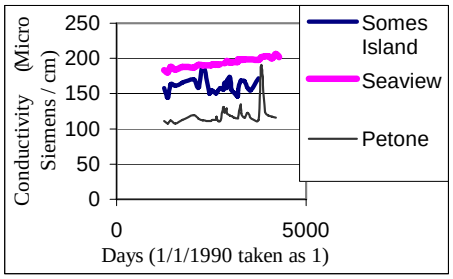

Figure 2 -Variation of Total Dissolved solids (Jun 93–Sep 01)

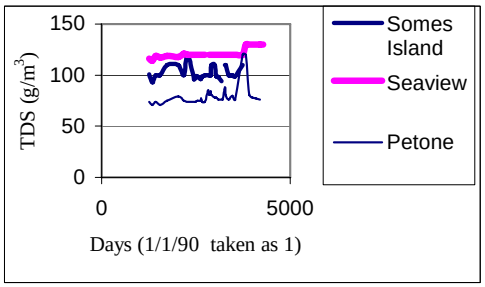

Table – 1 Variation and Forecast at Seaview

	Present Values	Average Values	Slope% (Gradient)	Correlation Coefficient	Forecast 1/1/2010	Forecast 1/1/2025
Conductivity	202	195.61	0.75	0.94	229.6	270.6
Total Dissolved Solids	130	122.73	0.54	0.83	147.3	176.9
Cl	19	17.42	0.09	0.85	21.6	26.8
Na	18	17.62	0.05	0.75	20.0	22.8
Hardness	55	49.81	0.34	0.77	65.4	84.3

Table 1 shows that there is a very high correlation with time for all the measured quality factors. In the case of conductivity it is as high as 0.94, giving an r^2 (square of the Pearson product moment correlation coefficient) value of 0.88. The gradient represents the trend of the regression line with time, and it indicates that all values are increasing. The conductivity gradient is particularly high, indicating a relatively rapid change with time. The regression results indicate that the Conductivity of the water at Seaview will change from fresh into the medium saline (250 Micro Siemens / cm) category by the year 2025.

Analysis of Somes Island and Petone water quality data revealed no significant correlation between either conductivity or TDS and time, De Costa et. al., (2003). The changes occurring in and around Seaview could be the result of a number of possible processes. The aquifer cap in at this location could be thinner, or fractured, allowing saline water to enter the aquifer. Alternatively there could be active submarine springs in and around Seaview facilitating a localized influx of saline water into the aquifer. Similar characteristics to Seaview were observed at the Petone location, although the rate of change is less.

The analyses made of the Waiwhetu aquifer suggested that there is considerable dependency as well as stress on the aquifer and it has the potential to degenerate in quality and cross the threshold category limit of saline water unless properly managed.

3. CASE OF THE BUNDABERG AQUIFER AUSTRALIA

Bundaberg is a regional centre on the coast of Queensland, 360 km north of the state capital, Brisbane. The Bundaberg aquifer provides a major water supply for domestic consumption and irrigation. The aquifer is located under the Burnett and Elliott river systems and is hydraulically connected to the ocean. It is known to have suffered saline intrusion from the sea over many years, exacerbated by over pumping for irrigation purposes. The State Government has constructed an extensive surface irrigation scheme to reduce the pressure on the aquifer, and pumping of groundwater is now regulated by license. The variation in conductivity between 1/1/90 and 7/8/2002 at four wells in the Elliott head area of the Bundaberg ground water system is presented in Figure 3, while Table 2 shows the summary statistics for this parameter over a line of pumped wells.

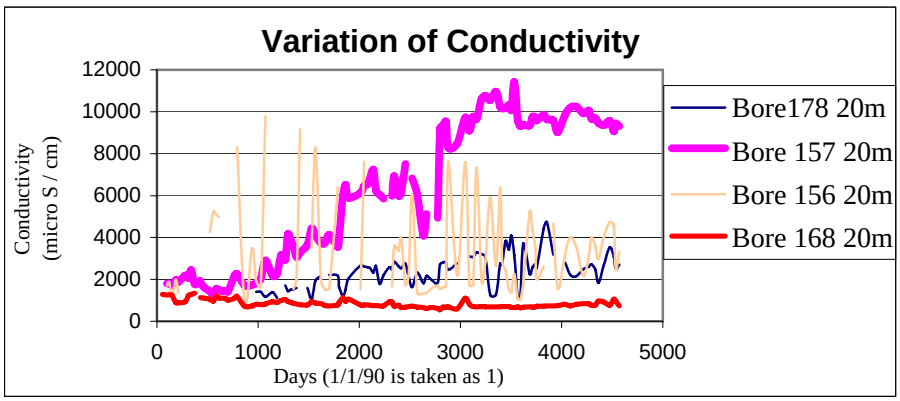

Figure 3 - Conductivity at Elliot Heads

Table – 2 Variation of Conductivity at Elliott Heads.

	Present Values	Average Values	Slope% (Gradient)	Correlation Coefficient	Forecast 1/1/2010	1/1/2025
Well 156	3302	3447	0.22	-0.13	2395(n/a)	1187(n/a)
Well 178	2708	2375	0.41	0.55	4241	6511
Well 157	9308	6130	2.35	0.94	17,953	30862
Well 168	734	843	0.086	-0.64	387	0

The correlation coefficient for the conductivity against time at all wells except number 156 is reasonably high. Well 157 has the highest correlation value of 0.94. Well 156 is closest to the ocean and is very susceptible to tidal influences, while 157 is inland by about 1.3km. Well 168 is further inland by about 1.2km; and its results are influenced by the fresh groundwater flows, which explains its decreasing conductivity. It is thought that the rising conductivity in Wells 157 and 178 could be due to two factors: (a) intrusion from the Elliott River (there is a tidal flat nearby); or (b) the aquifer in the vicinity of 157 is more clayey and thus responds more slowly to changes than does a more permeable aquifer. At this location the conductivity values are decreasing and although the water is saline it should reach the fresh potable water range in the near future. Its decreasing salinity may be caused due to inland flow, the greater distance to the coast and the effect of stringent water management practices employed in this region.

Our analysis of the Bundaberg aquifer confirms that the Governments management system appears to have stabilised the aquifer. We conclude that it is possible to manage saline water intrusion. If the aquifer is managed well, not only will the degree of intrusion be reduced but also the recovery of ground water quality is possible.

4. CASES OF SALINITY INTRUSION IN JAPAN

Ogawara lake is located in the north of Japan's main island Honshu. Ishikawa et. al. (2001) indicate that the lake has suffered intermittent salinity intrusion during particular periods. The lake is hydraulically connected to the sea by the 6 km long Takase river. During the summer months a saline tidal wedge intrudes into the lake resulting in a duplex flow pattern. The upper layer of low salinity water flows towards the lake exit while the bottom layer of high salinity flows in the opposite direction. This flow pattern is driven by the balance between effective gravity towards the centre of the lake and the pressure gradient towards the exit. Clams used for a Japanese soup (Miso) grow in this lake. They require a certain degree of salinity for breeding. As indicated by Ishikawa et. al. (2001) the dynamic balance of flows facilitates higher salinity in shallower areas and favorable conditions for breeding the clams. This is a positive outcome of salinity intrusion.

Tsuruta et. al. (2000) demonstrate that salinity intrusion in this lake is controlled by meteorological factors such as atmospheric pressure, wind drift, varying river inflows caused by rainfall and snow melt as well as by tidal influences. Any environmental impact analysis, even of channel improvement works, must allow for the stochastic nature of these processes. This indicates the difficulty in analyzing the impact of any intervention on this hydrological system.

Working on the Gono river in the Shimane prefecture, Tokuoka et. al. (2000) demonstrated that the fresh - saline water interface between adjacent subsurface aquifer systems was positively correlated with the movement of the fresh-saline water interface in the surface river system. This finding establishes the connection between surface and groundwater systems and implies that utmost care must be taken in any intervention of the overall hydro geological system. Any intervention in either system could impact on both surface and groundwater resources.

Another complementary study was done by Tsumi et. al. (2001) in the western part of Fukouka city. They demonstrated that salinity intrusion in coastal aquifers was highly sensitive to direct recharge of rain water and irrigation water in the catchment lowlands but remained low in the high lands. Surface development work such as construction on low lands would result in reduced seepage and so heavily impact on salinity intrusion in coastal aquifers. In addition, systems used to irrigate and drain water in low lands were found to express varying sensitivities to salinity intrusion. The impact of such activity on high lands is much less. Therefore the location of surface development work, including irrigation and drainage systems, as well as the works them selves play a major role in controlling salinity intrusion.

The aquifer system on Izena island in northern Okinawa prefecture is the main source of water for domestic and agricultural consumption. It has to be exploited to support the needs of the island and it is imperative that the water quality be maintained. Therefore exploitation of this resource has to take place in a sustainable manner. A study done by Ru et. al., (2001) found that the saline – fresh water interface is moving upstream. Current management practice results in the formation of large cones of depression due to continuous abstraction. Even though large percentage of the fresh water flow passes through the system in to the ocean, the reverse gradient at the cones of depression causes the saline - fresh water interface to migrate and it is gradually contaminating the aquifer. This problem could be mitigated by construction of impervious subsurface dams at appropriate locations in the aquifer. The barriers would increase the speed of recharge of the aquifer by reducing the radial flows, and also impede the upward

movement of the saline/ fresh water interface. Therefore it could be said that, the important criteria in a hydro geological sense is not the degree of exploitation of aquifers, but the equilibrium of the aquifers. This can only be achieved by naturally maintaining hydraulic gradients and by means of active intervention such as the use of impervious subsurface dams.

5. CASES OF SALINITY INTRUSION IN SRI LANKA.

Incidences of salinity intrusion to both land and water are prevalent in Sri Lanka. The land area affected by salinity is estimated to be 18,000 to 45,000 Ha, De Alwis et. al. (1972). Soil salinity is observed in the dry zone, inland, and in low lying areas. The problem is particularly significant in new irrigation schemes such as at Mahaweli. Evaporation of water following irrigation application concentrates its salinity, particularly in the dry zone of Sri Lanka. However it has been observed that repeated application of water on soils with good drainage can subsequently reduce soil salinity levels.

Kuruppuarachchi (1995) observed a high Chloride content of well water in high agricultural activity locations in Kalpitiya, The ground water system in the Jaffna peninsula is also very susceptive to salinity intrusion because of its arid nature. Continuous application of high rates of fertilizer and improper drainage both contribute to the higher levels of salinity in the ground water system. Further human impacts on groundwater in Sri Lanka are seen in the dredging of river sand from the river bed of the Kelani Ganga, one of Colombo`s main sources of water supply. The dredging has given rise to sea water intrusions in the river at particular times of the year.

These examples show that intervention processes can degrade soil and water resource quality. The application of irrigation water can give rise to higher levels of soil salinity and eventually increasing salinity in the ground water system. Human activity on our soil and water resources as irrigation, fertilization and dredging must be managed in a sustainable manner and only undertaken after the potential impact on salinity intrusion of water resources has been assessed.

6. SUMMARY AND CONCLUSION

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Our analysis of the Waiwhetu aquifer indicates that the level of abstractions has resulted in stress on the water resource and it could become saline in the future unless the system is well managed. The Bundaberg analysis indicates that implementation of aquifer management practices can indeed prevent the degeneration of the aquifer over a long period of time. It is not only possible to prevent degradation by saline intrusion, but also to facilitate the recovery of water quality even to the point of eventually yielding potable water.

The Ogawara river case shows that there can be positive aspects of salinity intrusion. In this case the breeding of clams in the high salinity areas is taking advantage of this natural phenomenon. It also indicates that numerous complexities that exist in salinity intrusion. The Gonokawa case reveals that surface and aquifer water systems are correlated and so care is required, as any intervention in either the surface or the aquifer water systems could impact on both aspects of the hydro-geological system. The Kitakyushu situation shows how the location of surface development work such as irrigation and drainage systems within the surface system,

can play a major role in salinity intrusion of coastal aquifers.
The North Okinawa Island aquifer system illustrates how the degree of exploitation of aquifers is not necessarily as important as achieving sustainability of the hydro-geological system by naturally maintaining hydraulic gradients and sometimes by actively creating impervious subsurface barriers.

The examples described from Sri Lanka illustrate how apparently unrelated interventions such as the application of irrigation water may also give rise to higher levels of soil salinity which eventually finds its way to the ground water system. We emphasize that impacts on soil and water resources of human activity such as irrigation, fertilization or dredging must be assessed with reference to the immerging issue of salinity intrusion. Finally, we conclude that care must be taken in all human activity impacting on the hydro-geological system. Any intervention process can result in fresh or degraded water quality depending on how well the process is managed.

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