

GLOBAL CHANGE AND ITS EFFECT ON COASTAL WATER RESOURCES – CASES OF THE ASIA PACIFIC REGION

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Abstract

While global change is directly affecting water resources, it is also well known that 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 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. Due to increase in demand for fresh water resources, ground water is being exploited, and coastal ground water systems hydraulically connected to the ocean necessarily has to cope with salinity intrusion. 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 India. It discusses the characteristics of each site, simulates some sites using state of the art software, 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.

Keywords – Salinity intrusion

1. INTRODUCTION

The most significant impact of global change is its effect on water resources. A United Nations report has warned that, coastal degradation will put at risk ecosystems which support over half the world's economies, unless coastal management strategies are implemented. It goes on to say that "terminal" disaster looms in many coastal areas unless "unless we introduce much more effective management immediately." "Coastal marine ecosystems have declined progressively in recent times due to the increase in human populations and their accompanying development of coastal regions. This, accompanied by increasing climate change, is putting enormous pressure on the coastal ecosystems" say the authors of the report. "By 2050, 91% of the world's coastlines will have been impacted by development," It says that, "We believe that use of scientific and traditional knowledge, together with better understanding of the economic value of healthy coastal ecosystems, can help change the political discourse that eventually determines societal pressures. Although the situation is dire, there is reason for hope. Our understanding of the ecological functioning of the coastal ocean is quite good, and we have a basic kit of useful management tools at our disposal."

Coastal aquifers are important sources of water in coastal regions. As population density in many coastal areas increased, need for fresh water also increased. Along with the population, industrial and agricultural growths in these areas accelerate the exploitation of groundwater. Over exploitation of groundwater from coastal aquifers may result in intrusion of saltwater in the aquifer. This is mainly due to excess withdrawal of groundwater compared to the recharge rate, and unplanned pumping locations and pumping patterns. Saltwater intrusion often results in loss of fresh potable water, loss of water for irrigation, increase in soil salinity etc. This results in even possible relocation of inhabitants from villages due to non-availability of productive soils and drinking water effectively changing the catchments characteristics including its socio economic characteristics.

On the whole, contamination of coastal aquifers may lead to serious consequences on environment, ecology and economy of that region. This research endeavours to investigate changes in coastal zones caused by salinity intrusion, and first, would assess and predict the long term salinity intrusion situation, and then, simulate aquifer variations, and thereafter develop a model that would facilitate the policy makers to take optimal decisions with multiple objectives to manage the changes occurring in coastal zones.

2. CASE STUDIES

2.1 Whaiwetu aquifer, Wellington New Zealand

There are three principal groundwater areas in the Wellington region: Lower Hutt Valley, Kapiti Coast and the Wairarapa Valley. Secondary groundwater areas include: Upper Hutt, Mangaroa Valley, Wainuiomata Valley and Sections of the Eastern Wairarapa Coastline. Aquifers in all of these areas are found in unconsolidated alluvial, aeolian, and beach sediments of varying grain size. Minor aquifers are also found in limestone and fractured greywacke in some areas of the region.

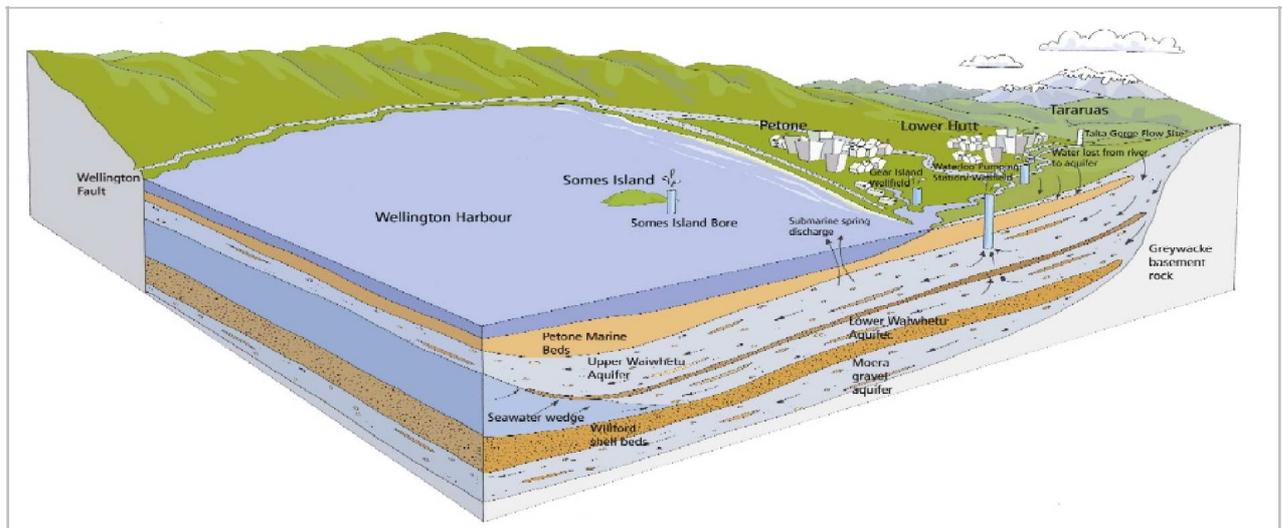


Figure 1. Lower Hutt Groundwater System, Source: Wellington Regional Council Report.

2.1.1 Long term variations

The Waiwhetu aquifer is located beneath the Hutt Valley and extends well into the Wellington harbour. Greater Wellington extracts 40% of its water requirements from ground water. The risk of salinity intrusion is emphasized by the level of abstraction from the Waiwhetu aquifer, estimated to be as 80 to 90% of the total through flow. The variation of Conductivity and Total Dissolved Solids for the points Somes Island, Petone and Seaview are shown in Figures 1 and 2.

Figure 2 – Variation of Conductivity (Jun 93–Sep01)

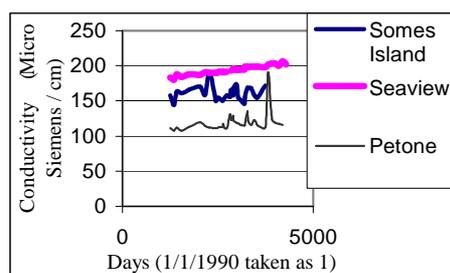


Figure 3 -Variation of Total Dissolved solids (Jun 93–Sep 01)

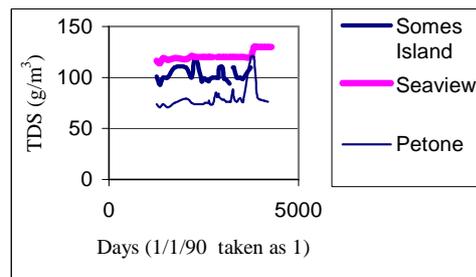


Table – 1 Variation and Forecast at Seaview

	Present Values	Average Values	Slope% (Gradient)	Coefficient of Correlation	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

It can be seen that there is a very high correlation for all these factors with time. 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 of, the variation of these factors and particularly conductivity, being positive and high indicates that there is a continuous rise in these factors. The regression results can be extrapolated to indicate that, the Conductivity of the water at Seaview will cross the threshold from fresh into the medium saline category by the year 2025. Analysis of Somes Island and Petone reveal that there is no significant correlation between either conductivity or TDS and time at Somes Island. The aquifer cap in and around Seaview could be thinner, or fractured to allow saline water intrusion to take place. As it was clear that the aquifer is susceptible to salinity intrusion detail investigation was performed and presented as follows. Here, PMWIN has been adopted to develop a three dimensional model in the study area. The model is used to understand the ground water movement and the risk of saltwater intrusion. Based on resulted conditions, the paper highlights some of the possible approaches to use for enhancing the sustainability of ground-water resources.

2.1.2 Simulating Monitoring and Management of Seawater Intrusion

PMWIN model package is used to test different assumptions on how the system may develop in the future. Since the future is uncertain, some assumptions about the evolution of the main source/sink terms need to be made resulting in different future scenarios. The complete set of scenarios provides a wide insight into the long term sustainability of existing pumping rates under different conditions. Furthermore, they provide information about where and which additional corrective measures are needed. Many corrective measures can be considered. Basically, they can be grouped into: reduction of groundwater pumping; increase of recharge; relocation of pumping wells; and in the case of coastal aquifers, additional engineering solutions to restore groundwater quality (e.g. hydraulic barriers).

2.1.3 Control of the water abstraction

Control of abstraction to manage the levels recommended by different studies is the traditional method to control seawater intrusion in Waiwhetu Aquifer. The new model has a more detailed layer structure and re-designed boundaries. The information and analysis on the aquifer system has been used to review the critical level for hydraulic heads on the aquifer. Donaldson, I.G. and Campbell, Cussins and Phreatos studying the aquifer's flow under different stresses calculated a critical level for hydraulic heads on the aquifer. Based on the results, control of abstraction to manage the levels was recommended.

The model simulations showed a noticeable effect of seawater intrusion for the dry period.

Assuming that the recharge is zero (aquifer recharge only from river bed seepage, no recharge from raining or other sources), after five years period with constant abstractions of 15000, 25000 and 50000 mc/day for each of the wells, the results show a considerable advance of the seawater intrusion.

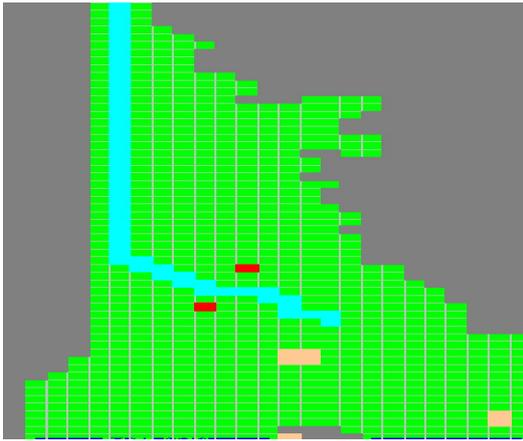


Figure 4. Seawater intrusion.
No abstraction, no recharge.

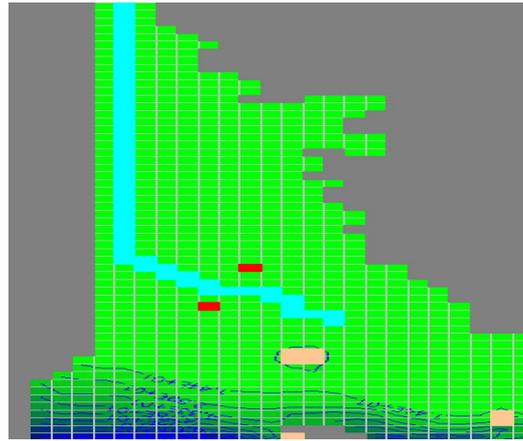


Figure 5. Seawater Intrusion.
15000mc/day each well. No recharge.

Blue line is sea water location, green zone is fresh water zone

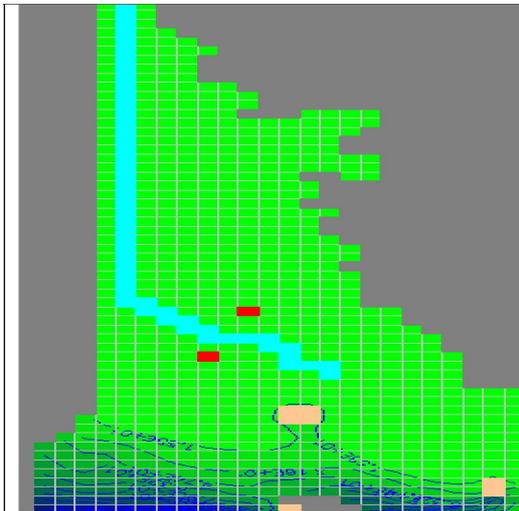


Figure 6. Seawater intrusion.

25000mc/day each well. No recharge.
Blue line is the seawater location.
green zone is freshwater zone

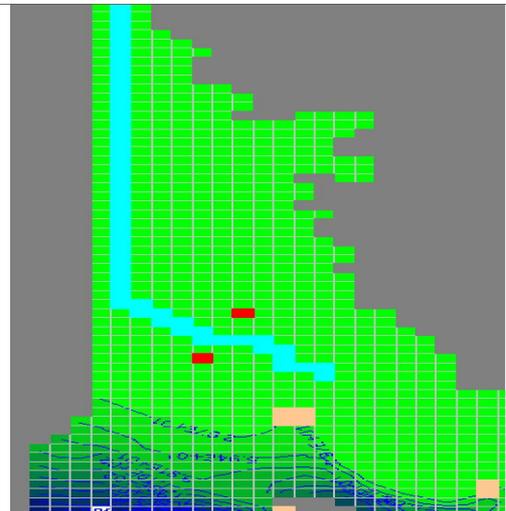


Figure 7. Seawater intrusion.

50000mc/day each well. No recharge
Blue line is the seawater location.
green zone is freshwater zone

2.1.4 Recharging the Aquifers

This investigation deals with artificial recharging of the unconfined part of the aquifer. Natural replenishment of aquifers occurs very slowly. Therefore, withdrawal of groundwater at a rate greater than the natural replenishment rate causes declining of groundwater level, which may lead to decreased water supply, contamination of fresh water by intrusion of pollutant water from nearby sources, seawater intrusion into the aquifer of coastal areas, etc. Artificial recharge may be defined as an augmentation of surface water into aquifers by some artificially planned operation. Possible adverse effects of the excess recharging may lead to the growth of water table near the ground surface and causes several types of environmental problems, such as water logging, soil salinity, and may affect natural aquifer storage and recovery systems. If the recharge is increased to 400mm/years, the seawater intrusion is less significant for the abstraction of 15000, 25000mc/day but considerable for 50000 mc/day.

2.2 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 suffer some intrusion from the sea. The State Government has constructed an extensive surface irrigation scheme to reduce the pressure on the aquifer, and pumping of groundwater is controlled 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.

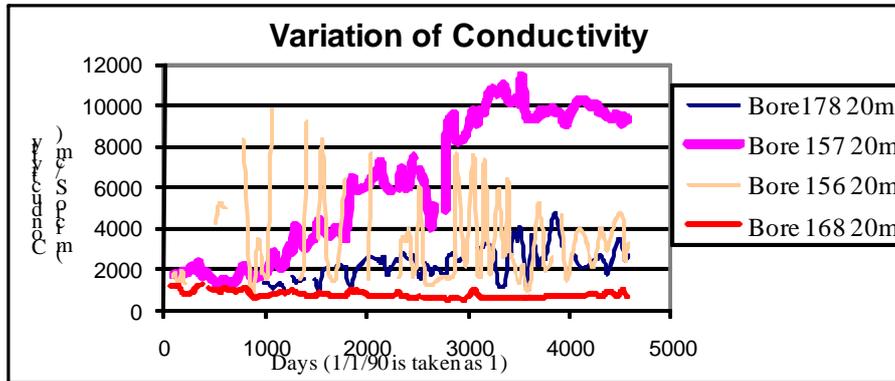


Figure 8 - Conductivity at Elliot Heads

Table – 2 Variation of Conductivity at Elliott Heads.

	Present Values	Average Values	Slope% (Gradient)	Coefficient of Correlation	Forecast 1/1/2010	Forecast 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 coefficient of correlation for all the wells, except number 156 is reasonably high. Well 157 has the highest correlation value of 0.94, giving an r^2 value of 0.88. Well 156 is closest to the ocean and is very susceptible to the external variation of tides, while 157 is inland by about 1.3km. Well 168 is further inland by 1.1-1.2km; its results are influenced by freshwater flow from inland to the ocean, which explains the decreasing conductivity. It is thought that the rising conductivity in 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 a highly permeable aquifer, say at 156. Well 168 furthest from the coast is associated with an 18 m thick aquifer. Its conductivity values are decreasing and should reach the fresh potable water range in the near future. Its decreasing salinity may be caused due to inland flow, the greater proximity to the coast and the effect of stringent water management practices employed in this region. The analysis of the Bundaberg aquifer suggests 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 the ground water quality is possible.

2.3 Andhra Pradesh India

In the state of Andhra Pradesh, saltwater intrusion is widespread in the Delta regions of the eastern coast. Cities/towns affected by deteriorating groundwater quality due to increase in salinity are Vijayawada, Guntur, Tenali, and south regions of the Krishna River. This study area is known for large amount of groundwater withdrawals for agriculture and aquaculture. The increasing salinity in the explored groundwater aquifers is a matter of concern. A 3-D, transient, density dependent, finite element based flow and transport simulation model is implemented for the selected area in Nellore District, in Andhra Pradesh, India. This area is extensively utilizing pumped water from the underlying aquifers for agricultural, domestic and aqua cultural uses. The simulation model is

calibrated using observed head and concentration data. The calibrated model is then utilized for evaluating the impact of adapting few pumping strategies for controlling the saltwater intrusion process.

The geographical location of study area is show below. The study area falls under alluvium soil type. These soils comprises of admixtures of sand, silt and clay in various proportions. The quartz pebbles are invariably encountered at different depths in almost all places in alluvial areas. It is generally light brown to pale gray and sandy in nature. The thickness of coastal alluvium is very large as evident from the exploratory wells drilled by Central Ground Water Board (CGWB) in this area. Bedrock was not encountered even at drilling depths ranging from 250 to 500 m.



Fig – 9 Location of the aquifer

Saltwater intrusion is already occurring in this area. This is mainly due to excess withdrawal of groundwater for domestic, agriculture and aquaculture uses. For the past 5 years the growth of aquaculture industries is very high, which requires huge amount of water. The only usable water source in this area is groundwater. The observation data by State Groundwater Department, Nellore suggest that water the table is going down every year. In addition to high pumping, there is no good amount of rains for the past 4 years (2001-2004). This further accelerates the groundwater deterioration. The only source of groundwater recharge is through rainfall. The data collected for this study area are briefly described below.

A 3D, transient, density dependent, finite element based flow and transport simulation model, FEMWATER is implemented for simulating the coupled flow and transport processes of saltwater intrusion in a coastal aquifer in Nellore district of Andhra Pradesh, India Available data for a selected study area of around 355 km² was collected from different agencies to be used as input data for implementing the numerical simulation model for the study area. Due to the scanty nature of available data and questionable reliability of all available data the best but subjective judgment was used in selecting the data for implementing the model.

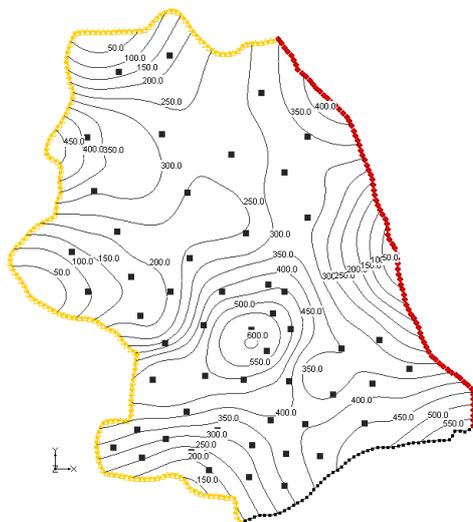


Fig. 10. Observed salt concentration contours July 2001

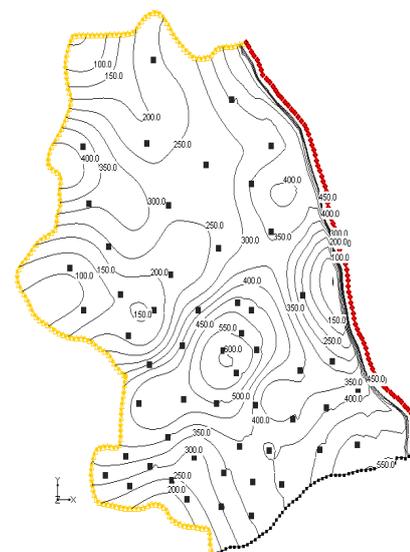


Fig 11. Simulated salt concentration contours July 2001

The numerical model was calibrated for two years time period, between July 2000 and July 2002, both in terms of hydraulic heads and salt concentration. The aquifer was considered heterogeneous in terms of vertical stratification. Both flow and transport are considered transient. Withdrawal from aquifer is estimated based on available data, and assuming an increasing trend over the period of calibration and validation. The calibrated simulation model was used to predict the saltwater transport scenario in the study area at future time periods. This predicted head and concentration values show the future saltwater intrusion patterns if the present trend of pumping continues. These results also show if the withdrawal rate continues to increase over time it may have detrimental effect on the salt concentration in the study area.

2.4 Salinity intrusion in Japan

The Ogawara lake, located in the north end of Japans main island Honshu, indicates salinity intrusion during particular periods, Ishikawa et. al., (2001). The lake is hydraulically connected to the sea by means of the Takase river which is 6 km long. During the summer months due to tidal effects sea water intrudes the lake and thereafter, the upper layer of low salinity flows towards the lake exit while the bottom layer of high salinity flows in the opposite direction, due to the balance between effective gravity towards the centre of the lake as well as the pressure gradient towards the exit.

Clams, which breed in this lake and used for a Japanese soup (Miso) require a certain degree of salinity for breeding. A dynamic balance which develops at certain locations facilitates sea water intrusion and higher salinity in shallower areas resulting in favourable conditions for breeding of clams. This is a positive implication of salinity intrusion caused by a natural phenomenon.

A study done by Tokuoka., et. al. (2000), on the Gono river in the Shimane prefecture indicates that the fresh - saline water interface of adjacent subsurface aquifer systems demonstrate good positive correlation to the movement of the fresh-saline water interface of the surface river system. This implies that utmost care must be taken in any intervention of the hydro geological system, as any intervention in either would impact on both the water systems.

A study done by Tsumi et. al., (2001), in the western part of Fukouka city, demonstrates that the degree of sensitivity of salinity intrusion in coastal aquifers to direct recharge of rain water and irrigation water, is high in lowlands but low in high lands. Surface development work such as construction on low lands would result in reduced seepage and thereby impact on salinity intrusion in coastal aquifers. In addition, systems used to irrigate and drain water in low lands express varying sensitivities to salinity intrusion. The impact of such activity on high lands is much lesser. Therefore, not only surface development work, inclusive of irrigation and drainage systems, but also, their location within the surface system, plays a major role in salinity intrusion.

The aquifer system in the Izena Island in northern Okinawa prefecture is the main source of water for domestic and agricultural consumption. It has to be exploited to meet the needs of the island. As it is imperative that this aquifer continuously yield potable water, exploitation of this source has to take place in a sustainable manner. A study done by Ru et. al., (2001) indicates that, even though large percentage of fresh water flow through the system in to the ocean, the formation of large cones of depression due to continuous abstraction causes the upward journey of the saline - fresh water interface and the gradual contamination of the aquifer. This could be mitigated by construction of impervious subsurface dams at appropriate locations, which assists not only in the increase in speed of recharge of the aquifer by reducing the speed of outward flow, but also impedes the upward movement of the saline water fresh water interface.

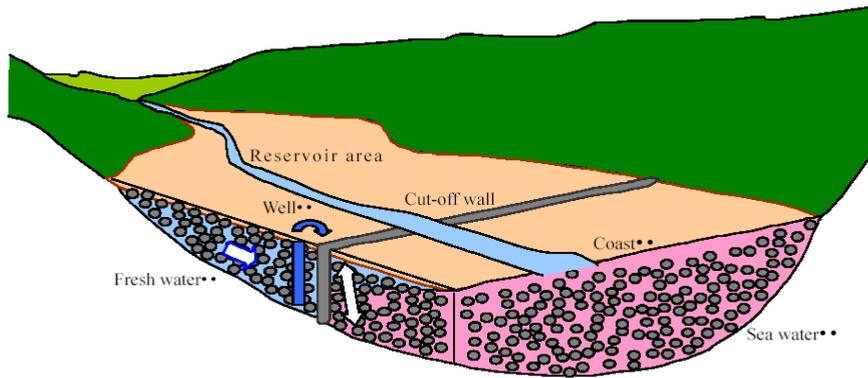


Fig – 12 Schematic diagram of underground dammed aquifer

3. SUMMARY AND CONCLUSION

The analysis of the Waiwhetu aquifer suggest that there is considerable dependency as well as stress on the aquifer and it has the potential to degenerate and cross the thresh hold category limit of saline water unless properly managed. The Bundaberg analysis indicates that implementation of aquifer management practices can prevent the degeneration of the aquifer over a long period of time. It is not only possible to prevent degradation, but also to facilitate the recovery of water quality even to the point of eventually yielding potable water. The Ogawara river and the breeding of clams in high salinity areas reveals a positive impact of salinity intrusion caused by a natural phenomenon. The Ogawara case also indicates that numerous complexities exist in salinity intrusion and the difficulty in analyzing the impact of intervention. The Gonokawa case reveals that surface and aquifer water systems are correlated and utmost care must be taken in intervention of the hydro geological system, as any intervention in either the surface or the aquifer water systems would impact on both the systems. From the Kitakyushu case it could be said that, not only surface development work inclusive of irrigation and drainage system, but also their location within the surface system, play a major role in salinity intrusion of coastal aquifers.

From the case of the North Okinawa Island aquifer system it could be concluded that, the important criteria in a hydro geological sense is not the degree of exploitation of aquifers, but the equilibrium of the aquifers and this could be achieved not only by naturally maintaining hydraulic gradients but also even by means of intervention such as creation of impervious subsurface dams.

This paper presents modelling of the Waiwhetu aquifer, and expresses the stresses under which the aquifer is subject to. PMWIN model has been used to simulate the aquifer, and some innovative scenarios have been investigated to identify possible solutions to reduce the risk of seawater intrusion.

The result of the simulations shows that the risk of sea water intrusion can not be reduced only by controlling the level of abstraction particularly if demand continues to increase and recharge decrease, but augmentation of recharge is a superior and viable alternative which facilitates abstraction as well. River banks, infiltration basins and injection wells have been simulated and the result show that the using a combination of different techniques abstraction could be maximized. The simulation studies show that abstraction can be double the actual current abstraction with no risk of seawater intrusion. Model Simulations indicate that implementation of aquifer management practices and varying methods to augment the recharge are alternatives that could be considered for the Waiwhetu aquifer if it is subject to higher abstraction levels, lower recharge and salinity intrusion.

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