DISCUSSION PAPER

GROUNDWATER IN THE MEKONG DELTA

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MEKONG WATER DIALOGUES

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MINISTRY FOR FOREIGN AFFAIRS OF FINLAND

1. Introduction

Groundwater provides valuable services to the Mekong Delta. These include the supply of drinking water to millions and the prevention of salt water intrusion. Yet this resource is effectively invisible and consequently ignored by policy makers. This paper looks at groundwater conditions and trends in the Vietnamese portion of the delta. It argues that the extensive hydrological manipulation of the delta, particularly through the construction of dykes that separate the river network from the floodplain and the unregulated extraction of groundwater has severe economic, environmental, and social impacts.

2. Background

The Mekong Delta covers 50,000 sq. km of fertile alluvial plain extending from Kratie in central Cambodia to Viet Nam's East Sea. The Vietnamese portion of the delta is home to over 18 million people and makes a substantial contribution to the national GDP, including half of Viet Nam's rice production and almost 100% of its rice exports.

Since the reunification of Viet Nam in 1975, and particularly since the mid-1990s, rice production in the Mekong Delta has been intensified. Average annual yields now exceed 5 tons/hectare. This transformation has involved draining large areas of wetlands and using increasingly sophisticated water control projects that have significantly altered the hydrology and flooding patterns of the delta (Do, 2007; Hashimoto, 2001; White, 2002).

The extensive hydrological manipulation of the delta has directly impacted groundwater, caused by the disruptions of natural flood regimes and aquifer recharge, and the effects of agrochemical use on aquifer water quality. Groundwater extraction has increased rapidly and declining groundwater levels now pose an immediate threat to drinking water supplies, farming systems, and livelihoods in the delta.

3. Groundwater of the delta

From a management perspective, the Mekong Delta can be described as having five main aquifers named after the following geological units: (*qh*) Holocene; (*qp2-3*) Upper-Middle Pleistocene; (*qp1*) Lower Pleistocene; (*m4*) Pliocene; and (*m3*) Upper Miocene.

Figure 1 is a cross section of the delta showing the vertical distribution of these water-bearing layers in relation to the surface of the delta. The yellow layers labeled *qh* to *m3* are termed aquifers because they have physical properties that allow for the storage and flow of water between the grains of sediment. The blue layers represent largely impermeable units, such as clay and silt that impede the flow of water between aquifers. Water trapped beneath impermeable layers may become pressurised by the weight of water entering above it. When tapped by wells, water stored in these aquifers will rise up the well under pressure to a certain elevation, or water level within the well. This is referred to as the groundwater level in this paper.

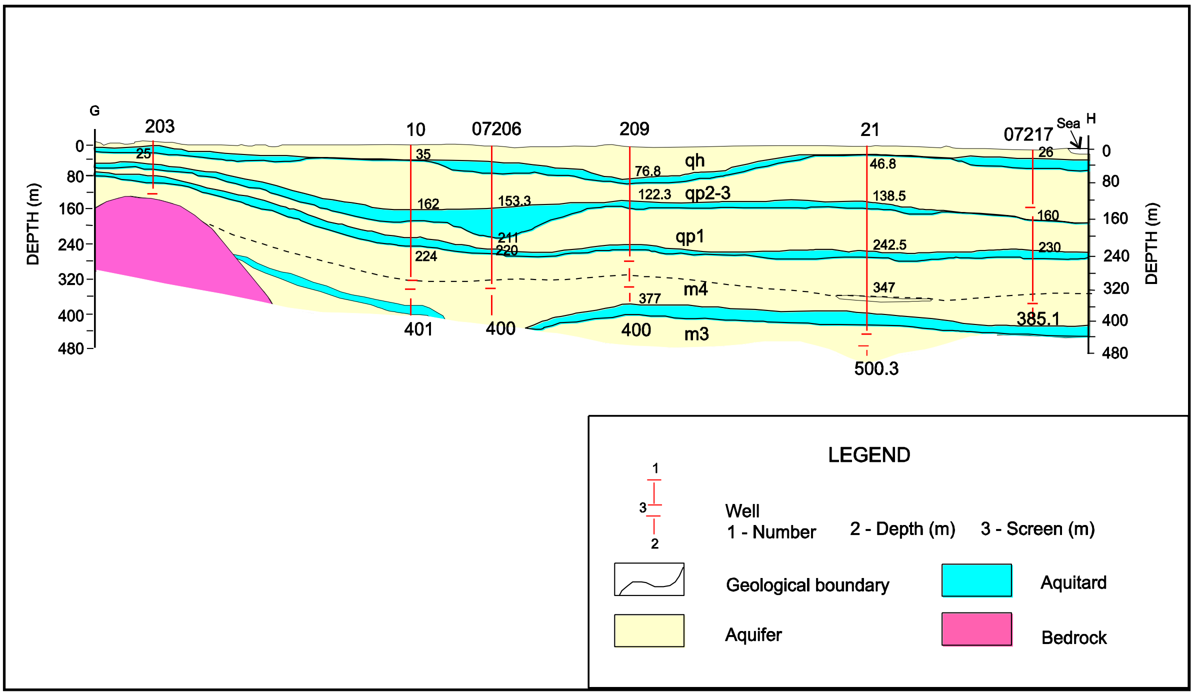


Figure 1. Cross section of the Mekong Delta roughly following the path of the Bassac River (*Ghassemi & Brennan, 2000)*

Near surface aquifer

The overlying Holocene aquifer (*qh* in Figure 1) occurs across most of the delta. Water generally flows from north to south, essentially draining to the rivers, canals, wetlands, and coast. From a water supply perspective, quality and yield from this aquifer are generally poor in Viet Nam with high salinity, high levels of pollutants, and some areas of extremely low pH as a result of the exposure and oxidization of acid sulphate soils, particularly in the Plain of Reeds and the Ca Mau Peninsula (Hung et al., 2000; Hashimoto, 2001; Quyen, 2005; Phuc, 2008).From an ecosystem and livelihoods perspective, this aquifer is very important, as it directly interacts with vegetation, farming systems, and the wet and dry season water regimes of the delta.

Deeper confined aquifers

The deeper confined aquifers in Viet Nam are large-scale reserves of water with varying yield and quality (Phuc, 2008). These aquifers are the Upper-Middle Pleistocene, Lower Pleistocene, Pliocene and Miocene (*qp2-3, q1, m4,* and *m3* respectively in Figure 1). Water quality is best in the Pleistocene and Pliocene layers but varies markedly by location and aquifer.

In general, water in the confined aquifers is held under pressure and water levels in wells are near, or above, ground surface in both wet and dry seasons. An exception is the southwest corner of the Ca Mau Peninsula where as a result of excessive extraction, water pressure has dropped and water levels are now well below mean sea level in all aquifers (see map in Figure 6)(Hung et al., 2000;Phuc, 2008).

Water source and groundwater flow

All aquifers in the delta acquire their water (recharge) from rainfall, primarily through the infiltration of water from rivers, lakes, wetlands, and floodplains. After this process, water flows between the grains of rock and sediment under the same basic principle as water in a river; from an area of high pressure (hydraulic head)[1] to lower pressure. In comparison to a river, water moves very slowly in an aquifer at perhaps only a few meters per year. Nonetheless, large volumes move through the ground from where water enters an aquifer (recharge zone) to where it leaves the aquifer (discharge zone), usually at a low lying water body such as a river, wetland, lake, or ocean.

The relationship between recharge and discharge is often dynamic and seasonal. For example, during the wet season in the Mekong Delta, floodwaters may have a higher hydraulic head[1] (caused by increased water elevation of the swollen river), and consequently water will move from the floodwaters into the aquifer system (recharge).In the dry season when river levels are low, water will gradually flow from the aquifer system into the rivers, wetlands, and coastal zone (discharge).

Figure 2a shows the mechanism of wet season overbank flooding recharging an unconfined aquifer. Figure 2b shows the reverse: water returning back to the river during the dry season. In reality, overbank flow is stored in wetlands and lakes where it can slowly infiltrate into the soil through root zones and into aquifers to maintain groundwater levels.

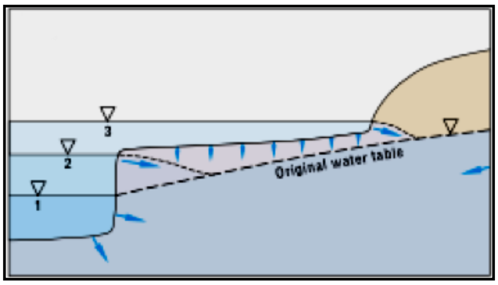
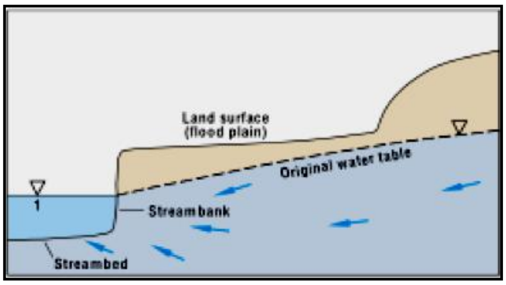


Figure 2a. Recharge during wet season flooding(Winter et al., 1998)



2b. Water returning to the river during the dry season (Winter et al., 1998)

Important recharge areas for Vietnam’s aquifers

The overlying Holocene aquifer is recharged from rainfall infiltration and surface water across most of the delta. The recharge mechanism of the confined aquifers, however, is largely unknown. Deeper aquifers such as the lower Pliocence and Miocene (*m3* in Figure 1) do not occur near the land surface (Deltares, 2011) and may be disconnected from any surface recharge containing only stored ancient water or “fossil water”. The Upper Pliocene aquifer contains fresh water and pressures that indicate water actively enters the aquifer where the aquifer sediments are exposed to the surface in elevated areas of Cambodia

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[1] Hydraulic head (or piezometric head) is an indicator of the total energy available to move groundwater through an aquifer. It is measured by the height to which a column of water will stand above a reference point such as mean sea level. Because hydraulic head represents the energy of water, groundwater flows from locations of high hydraulic head to locations of low hydraulic head.

(Deltares, 2011).

For the upper and upper-middle Pleistocene aquifers it is likely that the primary recharge areas are where the aquifer is exposed to wetlands and river channels in the upper portion of the Vietnamese delta (Hung et al., 2000, Phuc, 2008).Figure 3shows that the Pleistocene aquifers (*qp2-3* and *qp1* in Figure 1) occur near the surface in small areas in Kien Giang and significantly the Plain of Reeds, where large natural wetlands have now been converted to agricultural land.

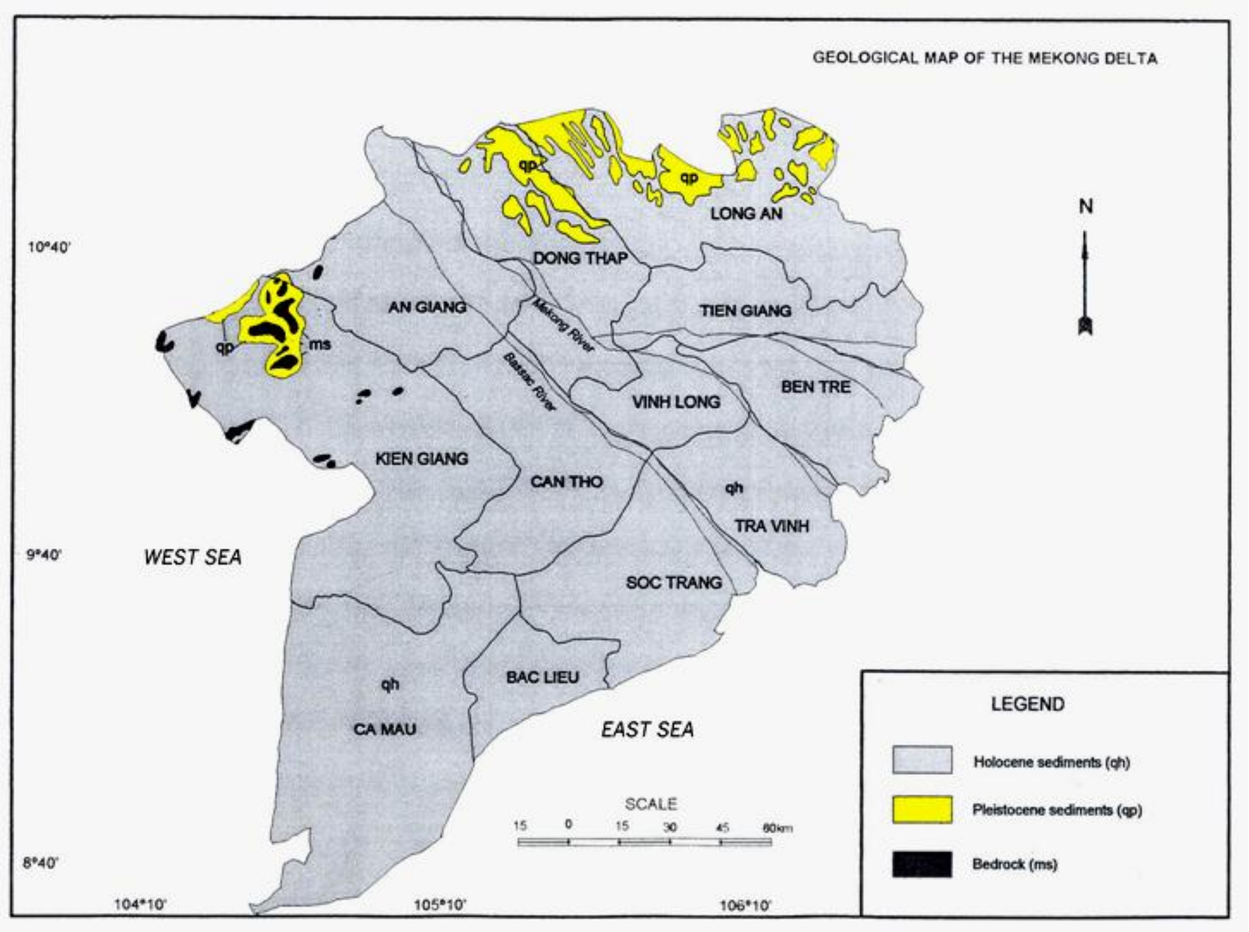

Figure 3. Geological map of the Mekong Delta showing the underlying Pliocene units (*qp*) outcrop in the Plain of Reeds and Kien Giang (Hung et al., 2000).

4. Groundwater use in the delta

Groundwater in the Mekong Delta supplies water for domestic use, urban water supply, irrigation, aquaculture, and industrial sites. About 4.5 million people depend upon groundwater for drinking (Ghassemi and Brennan, 2000).For example, a survey conducted in 2002 by the Can Tho Department of Agricultural and Rural Development found 24 per cent of the population of Can Tho, the largest city in the delta, used groundwater for domestic use. This proportion is much higher in rural and coastal areas where residents have great difficulty accessing fresh water during the dry season due to saline and/or polluted canal water (Danh, 2008).

Surface water, such as that found in rivers, lakes and dams, is the main source of water for irrigation. However, dry season irrigation using groundwater is expected to increase in both Viet Nam and Cambodia (Eastham et al., 2008; Phuc, 2008; IDE Cambodia, 2009).

Groundwater is accessed via dug wells, small-scale household tube-wells, or medium and large-scale central supply wells that were dug as part of the Rural Clean Water Supply Program (Stolpe, 2008; UNICEF, 1996, CERWASS, 2011).In 2007, it was estimated there was 465,000 groundwater wells in the delta that removed a total of 1,229,000 m^3/day (DWRPIS, 2009).Figure 4 shows the estimated total number of wells and extraction volume by province in Viet Nam; it should be noted that estimates vary significantly amongst available publications.

The Division for Water Resources Planning and Investigation (DWRPIS, 2009) found that 60 per cent of wells access the Pleistocene aquifers of the delta (*qp2-3* and *qp1* in Figure 1) and that most water supply projects for domestic and industrial water supply use this aquifer.

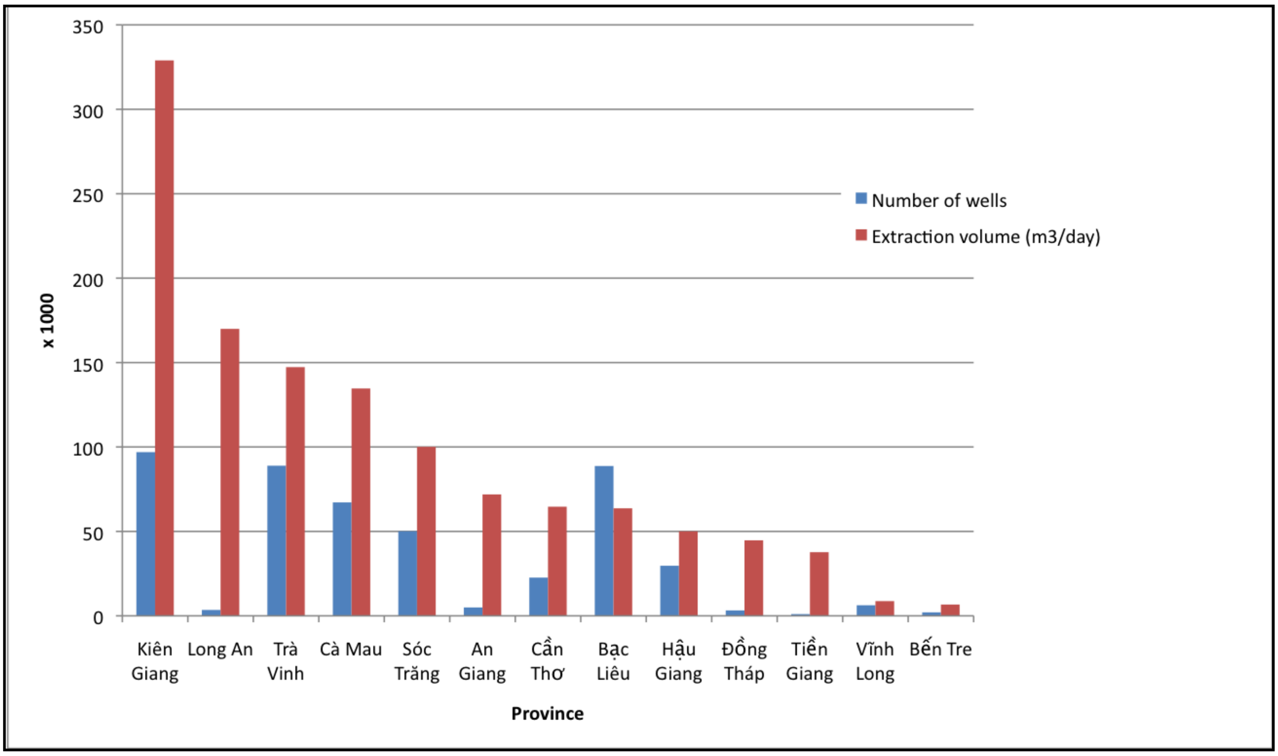

Figure 4. Number of wells and extraction volume by province in Viet Nam within the Mekong Delta (DWRPIS, 2009).

5. Management of groundwater use in the Viet Nam delta

Up to 2011 water resource planning in Viet Nam focuses on surface water resources with relatively minor consideration of groundwater and groundwater resource protection(Phuc, 2008).According to the 1999 Law on Water Resources, permits are required for groundwater supply units and industrial wells. The implementation of these regulations is the responsibility of local authorities, but their capacity is considered low (Danh, 2008; Phuc, 2008; IUCN, 2010) and enforcement is inconsistent. For example, Danh (2007) found that of the 406 industrial wells in Can Tho, only 33 (8.13 per cent) were licensed. Construction standards are also cited as poor without adequate prevention of cross-contamination and pollution between aquifers or the surface (Phuc, 2008).

Recognition of dwindling supplies and deteriorating quality has led the Vietnamese government to issue Decision 2065in November 2010. Decision 2065 approves water supply planning in the key economic zones of the delta and includes step-by-step reductions in groundwater use, with cessation of groundwater exploitation in key zones by 2020.

6. Problems with groundwater in the delta: issues and consequences

Investigation and monitoring of the delta's aquifers over the last 30 years shows two major trends:

1. Decline in groundwater levels in parts of the delta caused by a reduction in the volume of water in the aquifer system from extensive drainage, exploitation, and the interception of recharge waters.
2. Decline in groundwater quality caused by urban, industrial, and rural pollutants, and the concentration of natural contaminants and salt water intrusion caused by excessive pumping of groundwater reserves.

Groundwater levels

Water monitoring in the major aquifers reveals water level declines far in excess of natural variability. Figure 5 illustrates that groundwater levels in Ca Mau have fallen by as much as 10 m since 1995.

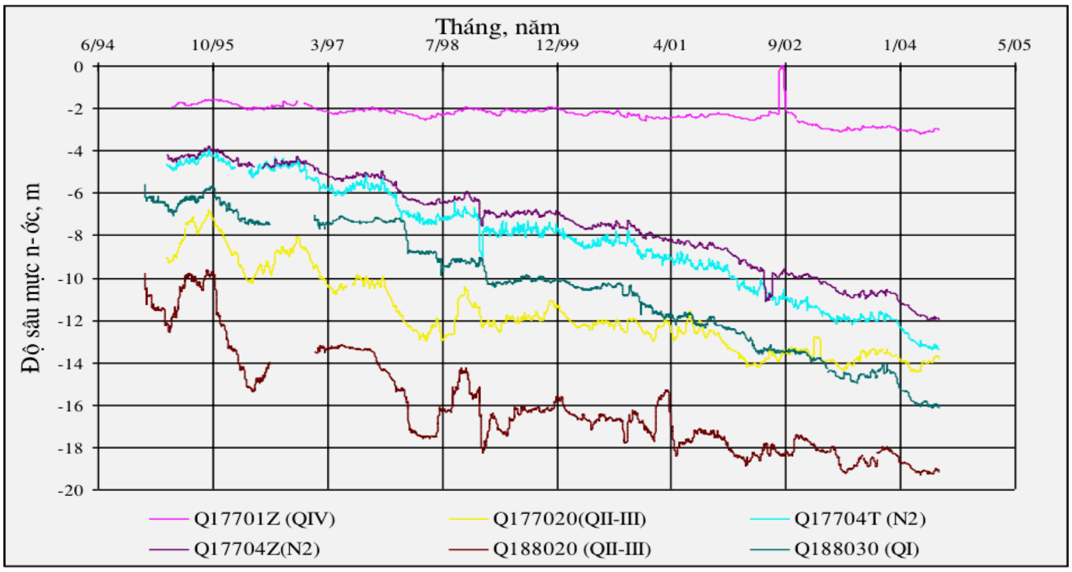

Figure 5. Observed aquifer water level variation in the Ca Mau Peninsula 1995-2004 (Phuc 2008).

The area of concentrated extraction in Cau Mau province is shown in Figure 6. The coloured lines represent the level of water in a well, relative to the mean sea level (i.e., the hydraulic head of water in the confined aquifer). The arrows show the consequent direction of groundwater flow toward the area of low pressure caused by excessive extraction. Changes in the direction of groundwater flow have caused seawater to enter the aquifer in coastal areas (Phuc, 2008, DWRPIS, 2009).

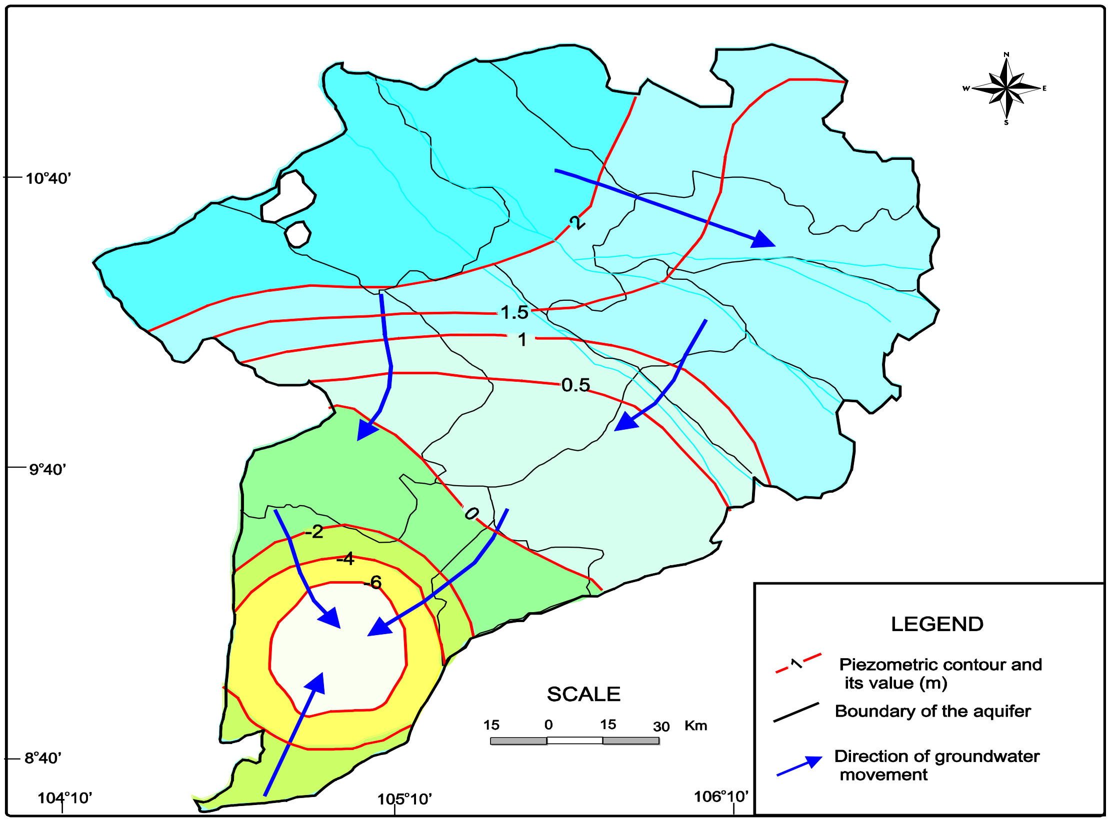

Figure 6. Piezometric map of the Upper-Middle Pleistocene aquifer in the 1995 rainy season (Hung et al., 2000).

Groundwater quality

In many urban and industrial areas, the exposed Holocene aquifer is heavily polluted with microbial and inorganic pollutants and considered unfit for drinking water purposes (Tuan, 2004; Danh, 2008). Some areas of the Upper Pleistocene layers around Can Tho also show high levels of pollution (Quyen, 2005).Several studies have shown widespread low-level arsenic contamination originating mainly from natural sources, both in shallow aquifers (0-5 m in depth) and in aquifers at 100-120 m (Stanger, 2005; Bang et al., 2008; Sampson, 2008; Hoang et al., 2010).

Saline and brackish groundwater is widespread in the delta and in many areas fresh and saline water tend to mix both within and between aquifer layers. The salty water is mostly derived from when the delta was forming in a marine environment during past interglacial periods when sea levels were higher than present day (Deltares, 2011).

In the western and northern parts of the delta, groundwater is predominately fresh where salt water has, over millennia, been flushed from the system. In coastal areas groundwater is generally saline, both naturally and because of salt water intrusion caused by excessive pumping to serve the fresh water supply demands of the surrounding communities[2](Phuc, 2008; Hung et al., 2000).

7. Drivers

Groundwater levels

The major factors driving a decline in groundwater levels can be explained by supply and demand.

A dense population and agricultural based economy has resulted in a high **demand** for fresh water. Where the demand for fresh water is high and the supply of clean surface water is low, significant exploitation of groundwater resources is occurring. Such areas include the salt-water-affected areas of Ca Mau, Soc Trang and Kien Giang, and urban areas such as Can Tho and Ho Chi Minh City.

On the **supply** side of the equation, large-scale conversion of wetlands for agricultural production has led to a dramatically altered hydrology (Hashimoto, 2001; Hung et al., 2000; White, 2002), which has altered the recharge pattern of the delta's aquifers (the amount of water entering the aquifer).Winter et al. (1998) explains how draining wetlands increases the volume of runoff, reducing the amount of groundwater recharge and increasing the frequency of downstream flooding. Water resources management since the 1990s has further affected supply through the construction of dykes and creation of polders that have blocked the natural water flow and reduced groundwater recharge. This is especially significant for the Vietnamese section of the Plain of Reeds where important recharge areas exist for the heavily used Pleistocene aquifers.

Groundwater level declines to date are most likely a combination of both processes: reduced supply and increased extraction. If this imbalance between water in and water out continues, it will lead to further declines in groundwater supply.

Groundwater quality

The major factors driving a decline in the quality of groundwater in the delta are a combination of:

- Poor environmental practices in the delta contributing to surface and aquifer pollution.
- Over-exploitation inducing sea water intrusion, mixing and concentration of contaminants.
- Poor well construction that creates a direct pathway for inferior quality aquifer water and surface pollutants to mix with otherwise good quality groundwater layers.

8. What does this mean for the delta?

Declining water quality and water levels in parts of the delta are well documented. However, the linkages with ecosystem health, farming systems, and livelihoods are less understood. Essential services provided by the system of aquifers throughout the Mekong Delta are discussed below in the context of declining groundwater levels and quality.

Water for life and the economy

One of the critical functions of groundwater aquifers is the storage and retention of water for domestic, industrial, and agricultural use, including a primary buffer against the impacts of climate variability and drought (FAO, 2003; Bergkamp, 2006).Groundwater is widely available and groundwater development has been an effective tool for poverty reduction across the globe.

Economic development and livelihoods: Maintaining sustainable water levels increases confidence of user access, encouraging development of the resource (Goesch et al., 2007).By contrast, falling water levels discourages investment and increases pumping and access costs, and can lead to the eventual loss of water supply and the collapse of groundwater-dependent businesses. For example, declining groundwater levels in some areas of India has led to the collapse of local economies and loss of drinking water supplies (Shah, 2002).

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[2] In Soc Trang, Vung Tau and Ho Chi Minh City some coastal fresh water supply works have suspended operations as a result of salt water intrusion (Phuc, 2008).

Social equity: As groundwater levels decline, those who can afford to drill and pump at depth have primary access and control over the water, thus increasing inequality. For example, poor farming communities can suffer when dry season levels fall below the capacity of surface suction pumps (IDE Cambodia, 2009).

Health and water quality: The unconfined Holocene aquifer is considered largely unusable in many parts of the delta (Tuan, 2004; Quyen, 2005; Danh, 2008).Confined aquifers in the delta are also vulnerable to contamination by salt, arsenic, pesticides and nitrates. Poor well construction and over extraction can concentrate contaminants and people who access and drink contaminated groundwater can suffer serious health affects (Dasgupta et al*.*, 2005; Sampson, 2008; Ravenscroft, 2009).

Water for prevention of land subsidence

By definition, groundwater is water held between the interstitial (pore) spaces in rock, sediment, and soil. This water provides a vital but invisible service by physically supporting the soil and sediment structure, contributing to the volume of the substrate. When extraction or drainage removes this water, accelerated compaction of the sediment can occur and lead to land subsidence (Syvitski, 2008).For example, compaction in the Chao Phraya Delta in Thailand has ranged from 50 to 150 mm/year as a result of groundwater withdrawal (Saito, Y et al., 2007; USGS, 2009).

Aquifer compaction as a result of regional groundwater level decline is a particularly serious risk in the Mekong Delta given the low lying topography and threat of sea level rise. A global comparison found that the Mekong Delta is currently sinking by as much as 6mm per year primarily as a result of groundwater extraction, overwhelming the rates of sea level rise (Syvitski et al., 2009).The Ministry of Natural Resources and Environment (MONRE) web site also reports the unchecked use of bores has caused localised land subsidence and pollution problems in the delta.The end result will be increased vulnerability to natural disasters and climate change.

Water for acid sulfate soils

Over 40 per cent of the soils in the Mekong Delta are affected by, or have the potential to be affected by acidity (Hashimoto et al., 2001).These are called acid sulfate soils (ASS).The main characteristic of ASS is their potential to develop high levels of acidity upon exposure to oxygen.

Oxidation of this soil type can be induced by groundwater pumping, drainage, or groundwater interception. For example, large-scale conversion of wetlands into agricultural land in the Plain of Reeds has significantly increased the relative proportion of acidic soils in the delta, by draining the subsurface aquifers and exposing vulnerable soils to oxygen (Hashimoto, 2001).Maintaining natural flood processes and aquifer water levels inhibits oxidation of the potential ASS layers, thereby maintaining soil pH within acceptable ranges for vegetation growth and reducing acid drainage to canals.

Water for river flow

Within the hydrological cycle, groundwater serves the function of storing water in aquifers and subsequently releasing water slowly to sustain river flows, springs, and wetlands (Morris et al., 2003).This function is particularly important during the long dry season of the delta where it provides water for dry season irrigation and the maintenance of natural ecosystems. Minimum flow volumes in rivers are required to support ecosystem processes, fish life-cycles, and maintain a host of environmental services. A minimum level of flow is also required to impede saltwater intrusion, flush pollutants from the system, and minimize bank erosion caused by undercutting.

The extraction of groundwater can reduce discharge volumes in the dry season to rivers, canals, and wetlands. Where aquifer water levels drop significantly, the surface water body may begin to lose water to the aquifer system rather than gaining from it, thereby reducing river flow further and increasing competition between irrigation supplies and environmental flow requirements. Globally, there are numerous examples of the consequences of ignoring the connection between surface water and groundwater and being forced to live with reduced river flows[3].

Water for wetlands

Groundwater naturally interacts with areas of low lying land where permanent wetlands tend to develop. Wetlands provide habitat for fish breeding, buffer flood events by absorbing huge quantities of excess water, and offer natural water cleansing functions (Poff et al., 1997; Opperman et al., 2009).Surface waters in the Mekong Delta tend be contaminated by agricultural and urban pollutants. The dense vegetation of wetlands create a natural water treatment system where sediment and contaminates settle out, plants absorb excess nitrate and phosphorous from agricultural areas, and waste products of humans and animals can be biologically neutralized. The cleaner water discharging from a wetland may then pass into another waterway or percolate into the ground and recharge groundwater supplies with better quality water (Figure 7).

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[3] For an example of documented river connection issues and conflicts see; Halaniak, 2003; Boulton, 2006; Evans, 2007 and Sophocleous, 2010.

Wetlands often depend upon groundwater to maintain ecosystems during the dry season and where groundwater levels drop below the historic norms, wetlands can dry out(SKM, 2001; RAMSAR, 2005;).Likewise, Coastal mangroves depend on groundwater inflows to regulate salinity around the plant root systems and associated faunal assemblages (Susilo, 2004; Susilo, 2008; Susilo et al., 2005, Mazda and Ikeda, 2006).Significant changes in groundwater flow could affect coastal wetlands, thereby undermining coastal rehabilitation efforts. Mangroves protect against storm events and sea level rise, sequester and store large amounts of carbon (Donato, 2011) and are breeding grounds for marine ecosystems and fisheries (Graaf, 1998).

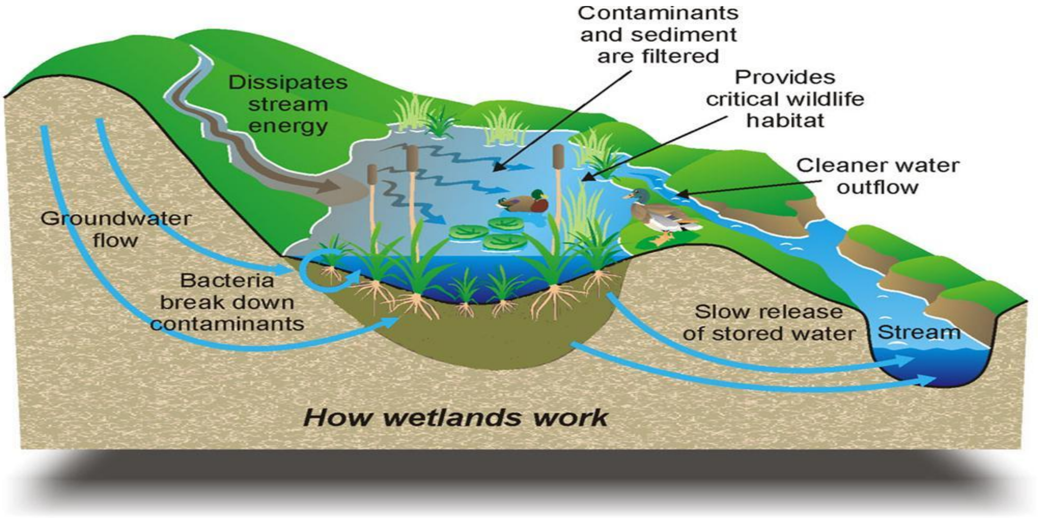

Figure 7. How wetlands work: blue arrows indicate groundwater flow into and out of wetlands; this relationship is dynamic and seasonal depending on climate and water levels (Greenerloudon, 2008).

9. Conclusions

The natural flood regime of the Mekong River contributes considerable quantities of water to the delta's aquifers every year[4].This allows for the annual storage and use of large quantities of water for multiple purposes. Over-exploitation and the contamination of aquifers by pollution, however, threaten the viability of this extremely valuable resource.

Current development policy fails to recognize the delta as an integrated system with linkages between groundwater and surface hydrology, farming systems, and environmental health. In particular the construction of dykes that separate the river network from the natural floodplain is a policy which carries substantial risk. The delta could follow a similar path as other great deltas of the world, where land subsidence, degraded ecosystems, increased salinization of aquifers, reductions in river flow, and a loss in drinking water supply have had huge negative social impacts[5].

In the Mekong Delta, the sustainable use of groundwater is still an achievable goal. Solutions that will benefit groundwater supplies align with best floodplain management practices that are needed to address other pressing issues in the delta, such as flood control and sustainability of soil fertility. Opperman et al. (2009) demonstrates how reconnecting rivers to their natural floodplain provides multiple benefits such as groundwater recharge, flood risk reduction, increases in production of floodplain goods and services, and greater resiliency to climate change. In addition, aquifer storage and recovery techniques have yet to be assessed, and planned surface water supply infrastructure may reduce over-pumping. It is vital that policy makers recognize the services provided by a healthy groundwater system and intervene to manage both the supply and demand aspects of groundwater in the delta.

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[4] Volumetric estimates of dynamic reserves (annual recharge volumes) are included in Phuc, 2008, and DWPIS, 2009. Phuc, 2008 notes a list of assumptions and issues related to the accurate calculation of dynamic reserves.

[5] For examples of consequences please see Shah, 2002; Morris et al., 2003, Zekster et al., 2005; Evans 2007, Sophocleous, 2010.

References

Bang, S., Thi, H. H., Kim K. W., Nguyen, M. H., & Dang, D. M. (2008). *Arsenic-Contaminated Groundwater in the Mekong River Delta of Vietnam.* Proceedings of the International Symposia on Geoscience Resources and Environments of Asian Terranes (GREAT 2008), 4th IGCP 516, and 5th APSEG; *November 24-26, 2008, Bangkok, Thailand*

Bergkamp G., Cross K. (2006). *Groundwater and Ecosystem Services: towards their sustainable use.* International Symposium on Groundwater Sustainability (ISGWAS). Gland: IUCN (International Union for the Conservation of Nature).

CERWASS (2011) website - http://www.cerwass.org.vn/English/index_e.htm

Can Tho Department of Agriculture and Rural Development (DARD). 2002. *Division of Water Resource Management.* Internal Annual Report.

Donato D.C, Kauffman J.B. , Murdiyarso D., Kurniant S., Stidham M., Kanninen M. (2011). *Mangroves among the most carbon-rich forests in the tropics.* Nature Geoscience. DOI: 10.1038/NGEO1123

Danh, V. T. (2008). *Household Switching Behavior In The Use Of Groundwater in The Mekong Delta, Vietnam.* Cantho University, School of Economics and Business Administration. Cantho city, Vietnam: Economy and Environment Program for Southeast Asia (EEPSEA).

Dasgupta S., Meisner C., Wheeler D., Nhan Thi Lam, Khuc Xuyen. (2005). *Pesticide poisoning of farm workers: Implications of blood test results from Vietnam*. World Bank Policy Research Working Paper 3624, June 2005.

Deltares. 2011. *MEKONG DELTA WATER RESOURCES ASSESSMENT STUDIES.* Vietnam-Netherlands Mekong Delta Masterplan project, January 2011.

Division for Water Resources Planning & Investigation for the South of Vietnam (DWRPIS). (2009). *ĐỊA CHẤT THUỶ VĂN VÀ TÀI NGUYÊN NƯỚC NGẦM ĐBSCL, Đặc điểm nguồn nước ngầm***.** Unpublished reports by Southern Hydrogeological and Engineering Geological Division, 2009.

Do T. N. (2007). *Impacts of dykes on wetland values in Vietnam's Mekong Delta: a case study in the Plain of Reeds.* Crawford School of Economics and Government, ANU. Economy and Environment Program for Southeast Asia.

Eastham J., Mpelasoka F., Mainuddin M., Ticehurst C., Dyce P., Hodgson G., Ali R., Kirby M. (2008). *Mekong River Basin Water Resources Assessment: Impacts of Climate Change.* CSIRO: Water for a Healthy Country National Research Flagship.

Evans R. (2007). *The Impact of Groundwater Use on Australia's Rivers Exploring the technical, management and policy challenge.* Land & Water Australia.

Food and Agriculture Organization of the United Nations (FAO). (2003) *Groundwater management. The search for practical approaches.* Water Reports 25. Food and Agriculture Organization of the United Nations. Rome, Italy.

Ghassemi F, Brennan D. (2000). *'Resource profile subproject: Summary Report.' An evaluation of the sustainability of the farming systems in the brackish water region of the Mekong Delta.* ACIAR Project, Canberra.

Goesch T., Hone S., Gooday P. (2007). *Groundwater Management: Efficiency and Sustainability.* ABARE Research Report 07.8, Canberra, March.

GoV. Prime Minister. (2010). *Decision No: 2065/QĐ-TTg, APPROVAL FOR WATER SUPPLY PLANNING IN CENTRAL KEY ECONOMIC ZONES IN MEKONG DELTA BY 2020*,12 November 2010.

Graaf G.J., Xuan T.T. (1998). *Extensive shrimp farming, mangrove clearance and marine fisheries in the southern provinces of Vietnam*. Mangroves and Salt Marshes: Volume 2, Number 3, pp159 -166.

Greenerloudon. (2008). Image sourced from website. http://greenerloudoun.wordpress.com/land/

Hoang T.H., Bang S., Kim K.W., Nguyen M.H., Dang D.M. (2010). *Arsenic in groundwater and sediment in the Mekong River delta, Vietnam.* Environmental Pollution, Volume 158, Issue 8, August 2010, Pages 2648-2658.

Hashimoto, T. (2001). *Environmental Issues and Recent Infrastructure Development in the Mekong Delta: Review, Analysis and Recommendations with Particular Reference to Large-scale Water Control Projects and the Development of Coastal Areas .* Australian Mekong Resource Centre. University of Sydney.

Hung D.T., Bang N.H., Giang P.V., Ghassemi F. (2000). *An evaluation of the sustainability of farming systems in the brackish water region of the Mekong Delta: availability and quality of groundwater* *resources.* Department of Geology and Minerals, Division of Hydrogeology and Engineering Geology for the South, Ho Chi Minh City & ACIAR, ANU, Canberra.

IDE Cambodia. (2009). *Strategic Study of Groundwater Resources in Prey Veng and Svay Rieng (Phase 1) Final Report*. Rural Poverty Reduction Project, Seila Task Force Secretariat, IFAD Loan No: 623- KH, Phnom Penh.

IUCN (International Union for the Conservation of Nature) - Viet Nam. (2010*). Summary - Groundwater Issues and Knowledge in the Lower Mekong Basin - Information sharing session*, August 2010. Hanoi, Viet Nam: IUCN.

Mazda Y., Ikeda Y. (2006). *Behavior of the groundwater in a riverine-type mangrove forest.* Wetlands Ecology and Management: Volume 14, Number 6, 477-488, DOI: 10.1007/s11273-006-9000-z

Morris, B.L., Lawrence, A.R.L., Chilton, P.J.C., Adams, B., Calow, R.C., and Klinck, B.A. 2003. *Groundwater and its Susceptibility to Degradation: A Global Assessment of the Problem of Options for Management.* Early Warning and Assessment Report series, RS. 03-3. United Nations Environment Programme, Nairobi, Kenya.

NA. (1998). Law No. 08/1998/QH10 on Water Resources *(Enacted 1999).*

Opperman J.J., Galloway G.G., Fargione J., Mount J.F., Richter B.D., Secchi S. (2009). *Sustainable Floodplains Through Large-Scale Reconnection to Rivers.* Science: Vol. 326 no. 5959 pp. 1487-1488

Phuc, D. D. (2008). *General on Groundwater Resources.* Department of Water Resources Management. Hanoi: Water Sector Review Project.

Poff N.L, Allan J.D, Bain M.B., Karr J.R., Prestegaard K.L., Richter B.D.; Sparks R.E., Stromberg J.C. (1997). *The Natural Flow Regime.* BioScience, Vol. 47, No. 11: pp. 769-784.

Quyen, T. (2005). *Status-quo of Management and Using of Ground water in Can Tho City. Unpublished Bachelor Thesis.* Can Tho University. Viet Nam.

RAMSAR. (2005). *Guidelines for the management of groundwater to maintain wetland ecological character.* 9th Meeting of the Conference of the Parties to the Convention on Wetlands Kampala, Uganda, 8-1, November 2005.

Ravenscroft P., Brammer H. and Richards K. (2009) *Health Effects of Arsenic in Drinking Water and Food, in Arsenic Pollution: A Global Synthesis*. Wiley-Blackwell, Oxford, UK.

Saito, Y., Chaimanee, N., Jarupongsakul, T. & Syvitski, J. P. M. (2007). *Shrinking megadeltas in Asia: Sea-level rise and sediment reduction impacts from case study of the Chao Phraya Delta.* Inprint Newsletter of the IGBP/IHDP Land Ocean Interaction in the Coastal Zone 2007/2, 3–9.

Sampson, M.L., Bostick, B., Hannah C., Hagan, J.M., Shantz, A. (2008). *Arsenicosis in Cambodia: Case studies and policy response*, Applied Geochemistry: Nov2008, Vol. 23 Issue 11, p2976-2985.

Shah T. & Roy, A. D. (2002).*Socio-ecology of groundwater irrigation in India. Intensive Use of Groundwater: Challenges and Opportunities*. R. Llamas and E. Custodio. Lisse, A.A. Balkema: 307-335

SKM (2001), *Environmental Water Requirements of Groundwater Dependent Ecosystems.* 2001. Environmental Flows Initiative Technical Report Number 2, Commonwealth of Australia, Canberra.

Sophocleous MA (2010). *Review: groundwater management practices, challenges, and innovations in the High Plains aquifer, USA—lessons and recommended actions.* Hydrogeology Journal, 18: 559–575

Stanger G., Truong T.V., Ngoc K.S., Luyen T.V., Thanh T.T. (2005). *Arsenic in groundwaters of the Lower Mekong.* Environ Geochem Health, 27(4):341-57.

Stolpe H, Nuber T. (2008). *Challenges of the Groundwater Management in Can Tho City, Viet Nam.* Hannover: BGR- Symposium Sanitation and Groundwater Protection.

Susilo A. (2004). *Groundwater flow in arid tropical tidal wetlands and estuaries.* Ph.D. Thesis in the School of Mathematical and Physical Sciences, James Cook University, 152 pp.

Susilo A., Ridd P.V., Thomas S. (2005). *Comparison between tidally driven groundwater flow and flushing of animal burrows in tropical mangrove swamps*. Wetlands Ecology and Management: Volume 13, 377 – 388.

Susilo A. (2008). *Chapter 23 – Groundwater Flow Model in a Mangrove Forest. Groundwater for Sustainable Development Problems, Perspectives and Challenges*. Taylor & Francis 2008, Print ISBN: 978-0-415-40776-2, eBook ISBN: 978-0-203-89456-9, DOI: 10.1201/9780203894569.ch23

Syvitski, J. P.M. (2008). *Deltas ar risk.* Sustainability Science, Volume 3: 23-32.

Syvitski, J.P.M., Kettner, A.J., Overeem, I., Hutton, E.W.H., Hannon, M.T., Brakenridge, G.R., Day, J., Vörösmarty, C., Saito, Y., Giosan, L., and Nicholls R.J. (2009). *Sinking Deltas due to Human Activities.* Nature Geoscience, Vol 2, 681 - 686.

Tuan L. A. (2004*). An Overview of the Drinking Water Supply Situation in the Mekong River Delta, Viet Nam*. CanTho University, Viet Nam, College of Technology.

UNICEF. (1996). *Water and Sanitation Program YMW604.*

USGS. (2009). *Forecast Mekong: Navigating changing waters.* Multimedia. USGS National Wetlands Research Center

White I. (2002). *Water Management in the Mekong Delta: Changes, Conflicts and Opportunities*. UNESCO International Hydrological Programme - Technical Documents in Hydrology, No. 61.

Winter T.C., Harvey J.W., Franke O.L. and Alley W.M. (1998). *Ground water and surface water; a single resource.* USGS Circular 1139.US Geological Survey, Denver, Colorado.

Zekster I.S., Loaiciga H.A., Wolf J. (2005).*Environmental impacts of groundwater overdraft: selected case studies in the southwestern United States.* J Environ Geol 47(3): 396-404.