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CHAPTER 2
REVIEW OF LITERATURE

2.1. Groundwater Flow

The chronicle of groundwater flow study begin when Darcy (1856) stated the relationship between the gradient of the piezometric head and the macroscopic velocity of a fluid in a porous medium as vs = -k (dh/ds). Theis (1936) stated the analogy between the hydrologic conditions in a confined aquifer and the thermal conditions of heat diffusion in a solid. Theis pointed out the significance of the storage coefficient, S, to the transient behavior of aquifer that was not fully appreciated at that time. Cooper & Jacob (1946) presented an alternative by plotting the results on a semi-log graph to obtain a straight line relationship between drawdown and time, and deducing the aquifer parameters (T, S) from the slope and intercepts of this straight line. Boulton (1955) introduced the concept of "delayed yield from storage" above the piozemetric surface. Hantush (1960) proposed a modified theory in which the yield from the clay storage was taken into account while the piezometric head in the unpumped aquifer remained constant, and the effect of yield from clay storage was presented in terms of another dimensionless parameter. Hantush (1967) later considered the case that piezometric heads in both aquifers were allowed to drop while the yield from clay storage was neglected. Boulton & Streltsova (1975) described the further theory to take into account the effects of the compressibility and anisotropy of the aquifer, partial penetration of the pumping well and saturated-unsaturated zones above the water table. Neuman (1975) described another approach to the same problem of an unconfined aquifer, in which the physical explanation of Boulton's parameter. Freeze and Cherry (1979) indicate that a change in head will produce a change in density of fluid and compaction of porous media, and the volume of water produced for a unit head decline is S_s, the specific storage.

2.2. Groundwater Modeling

The groundwater flow model is a tool to analyzing flow and solute-transport in groundwater system. The groundwater model has been evolving since the early nineteen century. Hele-Shaw (1896) studied about immiscible fluids with different densities; for example, as encountered in salt-water intrusion. Two liquids with different densities are used to simulate the fresh and salt water. Schwille (1988), stated scale models using sand tanks have been used to study the movement of dense, nonaqueous phase liquids, both above and below the water table. Conrad et al. (1992) have built etched glass micro models in which pore-scale movement of residual organic liquids trapped in an aquifer can be studied under microscopic magnification. Walton (1984) introduced application on analytical flow model to simulate the flow of water to well and streams. Javendel, Doughty & Tsang (1984) described the analytical flow model can be used for the heat and mass transport in the groundwater. Anderson and Woessner (1992) presented an overview of applied groundwater flow and advective transport modeling. Zheng & Bennett (1995) described an overview o the theory and practice of contaminant transport modeling. Fleck and Vroblesky (1996) described the application of a three-dimensional groundwater flow model to a coastal plain system in the northern-eastern US.

2.3. Groundwater Balance

Lee (1915) introduce concept of safe yield. The term of safe yield was regarded as the amount of water that could be pumped regularly and permanently without dangerous depletion of the storage reserve. Meinzer (1923) added the safe yield concept with necessary factor such as economics of groundwater development. Theis (1940) emphatical stated that the safe yield of a ground water basin was not the long-term recharge to the groundwater. He clearly demonstrated that under natural conditions, recharge was equal to discharge and that any artificial discharge via wells would result in disequilibrium in the system. Conkling (1946) proposed the safe yield concept include a protection of the quality of the existing store of groundwater. Banks (1953) proposed the safe yield concept with a protection of existing legal rights and potential environmental degradation. Kazmann (1956) proposed the term on safe yield on the grounds that it does not take into account the interrelationship of groundwater and surface water and may preclude the development of the storage functions of an aquifer. Collins (1972) studied about the groundwater development can reduce stream flow and, as consequent, lower lake levels and dry wetlands. Peters (1972) proposed a basic principle of ground water development is that by withdrawing water from an aquifer, some of the natural discharge may be made available for use. Bouwer (1977) stated that ground-water withdrawals have been linked to subsidence of the land surface. This result in land-surface cracking and damage to structure, highways, pipelines, dams and tunnels. Fetter (1977) mention that the effects of groundwater withdrawal not only in the physical phenomena but also environmental impacts include ecological, economical, social, cultural and political values. Bredehoeft (1997) points out that what are doing in developing a ground-water resource is capturing part of the natural discharge of the system. Thus, the important factor in determining the safe yield of a ground-water system is determining how much of the natural discharge can be captured.

2.4. Groundwater Research in Thailand

Many researches about groundwater have been conducted in Bangkok area. During 1972 to 1973, the Department of Mineral Resources (DMR) conducted an experimental artificial recharge test at the Thai German Agricultural Training Center, Bangpoon, Pathum Thani province (Ramnarong, 1975). The site was located close to the Bang Luang Rak Canal, a tributary of the Chao Phraya river. They used injection well method for groundwater recharge. Result of the recharge experiments showed that the disposal of floodwater into the Bangkok aquifer was achieved at an injection rate of more than 880 gpm or 200 m^3/hour.

According to AIT (1978), the land surface is subsiding at a rate of more than 10 cm./year at some place, and more than 5 cm/year over a considerable area. The land surface subsidence has consequently caused several social, economic and technical problems.

Since 1987, Public Works Department (PWD) has been carrying out an experimental recharge project at Bang Rong Kong Kao, Tambon Buak Kang, Amphoe San Kampang, Changwat Chiang Mai. Two different recharge facilities were constructed: one is a surface water recharge system, and the other is a rainwater recharge system. However, the piezomentric levels observed since 1987 indicated no clear effect of recharge and groundwater.

According to AIT (1981) during 1979 until 1980, groundwater in Bangkok area has been pumping approximated from well inventory to be over 1 million m^3/day. The present rate of groundwater pumping is excessive and caused the drop in piezometric level in various depth zones from the original free flow artesian condition in the 1950's to lower than 40 meters below the ground surface at present. The rate of drop is now about 2.5 m/year. In critical areas the level of drop is now about 2.5 m/year. In critical areas the level approaches even 50 meters below the ground surface.

In 1982, Wijemunige Piyasena had carried out the research work "Rehabilitation of a Depleted Aquifer System Through Artificial Recharge Application to Bangkok" to investigate about aspects of artificial recharge scheme for Bangkok. Bangkok region consists of several confined aquifers-the first three layers (vis. Bangkok, Phra Pradaeng and Nakhon Luang aquifers) lie within the top 200 meters, and the fourth layer (Nonthaburi aquifer) begins to appear at or above 200 meters. In some places, these aquifers may be hydraulically connected or separated by very thin clay layers. Records show that groundwater withdrawals by private consumers are increasing at an alarming rate, especially from the Nakhon Luang aquifer. Surface water recharge method can be used for rehabilitation of Bangkok aquifer. The Nakhon Luang and Phra Pradaeng aquifers have to be recharged probably through injection wells since they are at greater depths, but the topmost Bangkok aquifer can be recharged through deep canals or large diameter gravity fed wells in area where it is located at shallow depths. Dredging of the Chao Phraya riverbed over some stretches may also help to recharge the Bangkok aquifer. Optimum recharge locations and rates depend on the pattern of groundwater withdrawal, the length of recharging period, the initial piezometric head distribution in aquifers, and the specified piezometric head gain. Thus, before the start of any future recharge program, the optimum values should be reestimated.

Bunrayong Somwung (1990) investigated the rapid decline of the piezometric level of the Bangkok aquifer resulted in the land subsidence. The subsidence becomes more serious especially in the eastern area of Bangkok. The area surrounding of Ramkamhank Rd., Pattanakarn Rd. & Srinakarind Rd. has subsided more than 10 centimeters per year. Due to the land subsidence in this area, problems concerning the gravity drain of flooded water, the negative skin frictions and the differential settlement of the building have occurred. Such differences may be related to the variation of the permeability value "K" caused by the subsidence of the aquifer and the over pumping of wells with large discharge.

Department of Mineral Resources (1998), conducted a research to investigate the feasibility of using surface water to artificially recharge Bangkok's problem aquifers. The transmisivity values at the selected site for the Bangkok Aquifer and the Nakhon Luang aquifer are 100 square meters per day and 1,000 square meters per day, respectively. According to the three modelling scenarios at recharging rates range between 200-600 m^3/day for Bangkok aquifer and 3,000 – 5,000 m^3/day for Nakhon Luang aquifer. It can be concluded that the transmisivity values are feasible for recharging at the rate of 500 and 3,500 m^3/day, which are the rate within the range of the models. The selected site's artificial recharge operation will be supplied with raw water from an irrigation canal, namely Khlong Khud Mai, which is a part of the Phraya Banlue Irrigation System under the authority of the Royal Irrigation Department. The availability of water is assessed as sufficient for the pilot scheme operation. Water quality from the Klong Khud Mai, though it did not meet the drinking water standard, is considered good quality. Laboratory testing results on water samples taken at the site and related canals revealed acceptable values on all key parameters. Treatment of water to meet legal requirements can be accomplished. The recommended treatment for the injection water is carried out using wetlands in combination with sedimentation, chemical dosing, and disinfections. From the modelling results, it can be concluded that the requirement set by the DMR's TOR to recharge the Bangkok aquifer and the Nakhon Luang aquifer at the total rate of not less than 400 m^3/day is feasible. The modelling result reveals that the upper Bangkok aquifer being recharged at the rate of 400 m^3/day will reach steady stage within 1,980 days with resulted maximum head rise of 1.85 meters. For the Nakhon Luang aquifer, at the recharge rate of 4,000 m^3/day, steady stage will be reached within 800 days, with maximum head rise of 1.85 meters. Radius of influence for the two-recharged aquifer is 4,400 and 4,800 meters, respectively.

A.R. Lawrence et all (2000) reported in Hat Yai, Southern Thailand, seepage of urban wastewaters has produced substantial deterioration in the quality of the shallow groundwater directly beneath the city. For this reason, the majority of the potable water supply is obtained from groundwater in deeper semi-confined aquifers 30-50 meters below the surface. However, downward leakage of shallow groundwater from beneath the city is a significant component of recharge to the deeper aquifer, which has long-term implications for water quality. Results from cored boreholes and shallow nested piezometers are presented. The combination of high organic content of the urban recharge and the shallow depth to the water table has produced strongly reducing conditions in the upper layer and the mobilization of arsenic. A simple analytical model shows that time scales for downward leakage, from the surface through the upper aquitard to the semi-confined aquifer, are of the order of several decades.

Benoit Laplante and Craig Meisner (2001) revealed that industrial Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS) emissions is heavily concentrated in the Central region of Thailand, and in a small number of provinces in the country: Samut Prakharn, Samut Sakhon, Chonburi, Rayong, Chiang Mai, Nakhon Ratchasima, and Songkhla. The results clearly demonstrate that industrial BOD and TSS emissions are accounted for by a very limited number of industrial sectors. Across regions and provinces, typically 4 or 5 industrial sectors account for more than 80% of total releases of industrial BOD and TSS emissions. These sectors are iron and steel, pulp, paper and paperboard, distilled spirits, dairy products, sugar factories and refineries, fish products, industrial chemicals except fertilizer, and nonferrous metals. Across regions and provinces, industrial plants located in industrial estates contribute only a small percentage of industrial emissions of BOD and TSS. The results obtained in this paper thus suggest that focusing effort and resources on a very limited number of industrial sectors can obtain significant reductions in water pollution.