Management of Land Subsidence in Bangkok

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1 Introduction

Land subsidence due to excessive groundwater withdrawal is one of the most urgent environmental problems facing Bangkok Metropolis and its vicinities. Prolonged flooding, salt water encroachment, groundwater quality deterioration, damage to building foundations, roads, bridges etc. are some of the adverse consequences of the groundwater over-exploitation and the resulting land subsidence. In this study, numerical model along with the application of stochastic process and Monte Carlo simulation has been developed to predict the subsidence caused by excessive groundwater extraction. Results of the analysis, then, can be considered as information for management of groundwater usage in Bangkok area.

2 Land Subsidence Problem in Bangkok

The water-bearing formations of Bangkok consist mainly of sand and gravel with minor clay lenses. They can be zoned into 8 principal artesian aquifers within 550 m depth. Deep groundwater extraction in Bangkok started in the early 1900s, but not until the early 1950s that large-scale extraction from the aquifer system began due to rapid economic growth of the city and lack of tap water supply. Daily pumping rate was recorded at 0.65 million m^3 in 1975 and rapidly jumped to 1.2 million m^3 in 1980. The chronicle of the groundwater extraction in Bangkok and surrounding provincial suburbs during the last 50 years is shown in Fig.1. The record showed that groundwater extraction in Bangkok Metropolis has continued to increase over the period from 1950 to 2000.

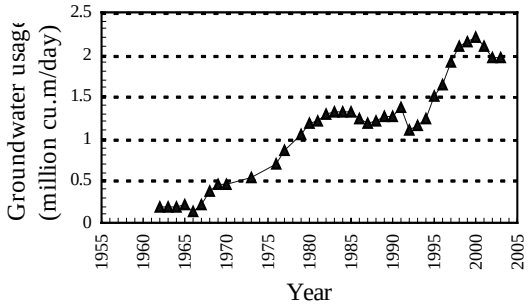

Fig.1 Chronological record of groundwater extraction rate

According to the previous studies by [1] to [3], the extensive pumping in the 1970-1980s led to significant drawdown in piezometric head up to 40-50 m in the exploited aquifers. Furthermore, by 1998, the maximum drawdown increased by additional 20 m after 1981. The comprehensive research study made by the Asian Institute of Technology [4] clearly confirmed that excessive pumping of groundwater from a large number of deep wells sunk into the aquifers underneath the city was the most predominant factor that cause widespread land subsidence problem of the city. The piezometric decline led to compression of the aquifer system, which manifested as widespread land subsidence. According to the record, the largest magnitude of subsidence over a 54-year period (1933-1987) was 1.60 m in the worst affected area of the city [1]. Moreover, it subsequently increased to 2.05 m in 2002. In central Bangkok where groundwater pumping did not exist after the late 1980s, the subsidence still continued at a rate of 5 to 10 mm/year (in 2002). To provide an effective plan for management of land subsidence, analysis of land subsidence due to groundwater extraction needs to be performed.

3 Groundwater Flow Modeling

In order to analyze the land subsidence by means of consolidation theory, groundwater levels or piezometric heads in each aquifer have to be analyzed at first. In this study, the modular finite difference groundwater flow model (MODFLOW) was chosen to model 3-dimensional ground-water flow in the Bangkok Metropolis and its vicinity. The model was divided into 10 layers based on the hydro-geological classification. The structure of the 3-D model is given in Fig.2. Appropriate boundary conditions were specified for numerical calculation based on hydrogeological information.

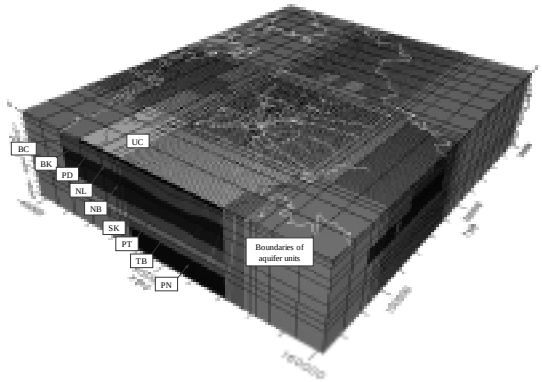

Fig.2 Comparison of stress-strain relationship between the results from 1-D compression test and simulation

Groundwater pumpage is one of the most important parameters for the simulation. The historical pumpage data were used for the model calibration. Then the future piezometric levels could be predicted by using the calibrated simulation model. The future pumpage was prepared as input to the model by the method described in subsequent section. The groundwater flow analysis can then be performed which yields the predicted future groundwater drawdown in each aquifer. Consequently, the predicted land subsidence based on 1-D consolidation can be evaluated.

4 Prediction of Future Groundwater Extraction

The stochastic process was used to predict the trend and

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variation of future groundwater pumpage based on historical data. From the available data, groundwater pumpage had a trend to increase linearly with time due to the increasing water demand. Therefore, the linear constant coefficients stochastic differential equation was applied to model the stochastic process of groundwater pumpage. The groundwater pumpage increment, *dQ*, can be expressed as

$$dQ = m \cdot dt + \sigma \cdot dW \quad (1)$$

where m is trend component, σ is volatility component, *dt* is time increment and *dW* is Wiener's increment. The Wiener's increment obeys the Wiener process, which is normally distributed with its variance growing proportionally to the time interval and can be expressed as

$$dW = \varepsilon_t \cdot (dt)^{1/2} \quad (2)$$

where ε_t is the standard normal distribution, N(0,1).

Monte Carlo simulation was then performed to obtain the distribution of the groundwater pumpage, which is used as input parameters in the numerical model.

5 Risk of Land Subsidence

The probability distribution of land subsidence could be obtained through Monte Carlo simulation with a number of realizations as described in previous section. It is obvious that more subsidence leads to higher risk against flooding and results in more loss due to flooding. In order to evaluate the risk of land subsidence against flooding, the flood mitigation measures have to be taken into consideration and the criteria related to the occurrence of flood have to be established. Vital efforts have been made to mitigate flood damage in the study area through the construction of dam reservoirs, dikes and pump stations. For the most recent project, a flood barrier along both banks of main river, Chao Praya River, had been constructed to protect the urban area from flooding. The freeboard of 0.50 m was provided to account for the effect of future land subsidence. According to the design of flood barrier, land subsidence of more than 0.50 m can be considered as the criterion of flood occurrence. The distribution of land subsidence in the central of Bangkok during critical period for high risk of flooding was shown in Fig.3.

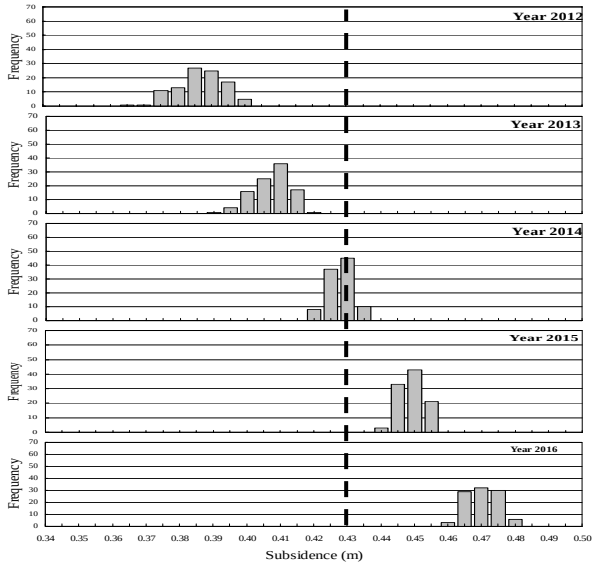

Fig.3 Distribution of land subsidence in Bangkok during 2012-2016

According to the exceedance probability of land subsidence, it can be pointed out that flood risk increases significantly during 2012 to 2016.

6 Mitigation of Land Subsidence in Bangkok

To cope with subsidence problem, the government had conducted some measures to mitigate the risk due to future land subsidence. Artificial recharge to aquifers through wells had been studied in 2000 and yielded promising results. However, due to its very high investment and operation cost, the project has not yet been approved for its actual implementation [5]. Although, the mitigation measures employed in the past were ineffective, the strict measures adopted recently have resulted in a marked drop of groundwater usage and rebound of subsidence at few locations. The measures comprise a pricing policy on ground water fee, expansions of tap water supply, and strict enforcement of groundwater laws.

7 Conclusions and Suggestions

In this study, the problem of land subsidence due to excessive groundwater pumping in urban areas was stressed. The Bangkok Metropolis and its vicinity were focused as the study area, and the problems caused by land subsidence were mentioned. The relationship between groundwater with-drawal, piezometric drawdown and compression of aquifer system was described as the main cause of land subsidence. 3-D finite different model was developed as a tool in analysis of groundwater flow and land subsidence. Stochastic methods to model the uncertainties associated with groundwater flow and land subsidence analysis were introduced, particularly the uncertainty in future groundwater pumpage. The variation in groundwater drawdown and land subsidence was assessed and the methodology to evaluate the risk of land subsidence against flooding was also proposed. From the results, land subsidence in Bangkok would continue with no sign of termination if the groundwater had still been abstracted increasingly. The ultimate solution is to install and expand treatment facilities for surface water sources and distributing networks to cover the entire Bangkok Metropolis, and the adoption of a pricing scheme of groundwater tariff to persuade the users to revert to piped water supply. The strict measures adopted recently have resulted in a marked drop of groundwater usage and rebound of subsidence at few locations. However, nowadays, this unsolved man-made geo-environmental hazard still faces Bangkok.

8 References

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