Research article

Assessment of the Groundwater Quantity Resulting from Artificial Recharge by Ponds at Ban Nong Na, Phitsanulok Province, Thailand

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Abstract Ban Nong Na Phitsanulok Province, has been facing continuous groundwater level decreases, from 1-2 m below ground surface in the past 25 years to 7-8 m in the present due to overexploitation for irrigation. This area was selected as a pilot site to construct and conduct the recharge experiment. The objective of this research is to quantify groundwater mound resulting from the recharge experiment using MODFLOW2000. Two recharge ponds A and B, which have an area of 660 and 600 m^2, respectively, were constructed in the selected site of the study area. The experiment duration was July to November, 2010 using raw water with turbidity less than 100 NTU. The total recharge amount is 25,797 m^3. The results showed that under the experiment conditions the designed recharge pond can provide a moderately good analysis of the recharge water. The mounding results of the simulations were compared with the field observation; both were found to be compatible. After 5 days of the fifth test, the maximum rise of the mound was 3.33 m and covers an area of approximately 6,000 m^2.

Keywords artificial recharge, groundwater mound, Phitsanulok

INTRODUCTION

The Groundwater Research Center (GWRC), Khon Kaen University, was invited by the Department of Groundwater Resources (DGR), Ministry of Natural Resources and Environment, to conduct the research on “Pilot Study and Experiment on Managed Aquifer Recharge Using Ponding System in the Lower North Region River Basin, Phitsanulok, Sukhothai, and Pichit Provinces” to test the feasibility of using artificial groundwater recharge to reverse the declining trend. The project duration was between April 2009 and April 2011. The project area was identified from the Lower North Region River Basin areas of about 21,300 km^2 covering the areas of Phitsanulok, Sukhothai, and Pichit Provinces using a zooming-in technique ultimately focusing in on the Ban Nong Na pilot area of approximately 4.12 km^2, and a construction site for the artificial recharge pond system of about 0.01 km^2. Ban Nong Na pilot project area is suitable for the construction site of recharge pond system because it fits various suitability indices such as; (i) hydrogeological suitability, which include thin top clay layer of less than 3 m thick, thick shallow strata (10-15 m) of sands and gravels with good continuity of strata; (ii) there are about 100 agricultural wells for target water user; (iii) suitable distance from raw surface water source; (iv) availability of electricity and access road; and (v) availability of land and good cooperation from local people and local organization (DGR, 2011). Uppasit et al (2011) described the site characterization for the ponding recharge system at Ban Nong Na and used the finite difference groundwater flow model, MODFLOW2000, (Harbergh et al, 2000) in order to assess the groundwater flow and groundwater balance.

The objective of this study is to quantify the groundwater mound resulting from the recharge experiment using numerical modeling technique in the study area.

STUDY AREA

General description

The study area covers Ban Nong Na, Tambon Nong Kula, Amphoe Bang Rakham, Phitsanulok Province. Topographic elevations range between 43-50 meters above mean sea level (m amsl). Low elevations are found in the central and northern part and to the southeast of the study area which are mainly dominated by paddy fields. High elevations are found in the southwestern part, where landuse is mainly dominated by villages and sugarcane fields. Soil types of the study area consist of loamy sand, clay, and loamy clay (Fig. 1). Important sources of surface water are Klong Lan Ba and a drainage canal. Klong Lan Ba is located in the northern part of the study area and flows from West to East with a total catchment area of 30.38 km^2. The canal is used to drain water from paddy fields. It flows from west through the central part, and drains into Klong Lan Ba in northern part with a catchment area of 6.54 km^2. Average runoff of the drainage canal is about 0.75 million (M) m^3/y. Surface water quality is good and with no contamination of chemical fertilizers under the standard of notification of the national environmental board No. 8. Surface water turbidity frequently exceeded the “recharging waste water into groundwater wells regulation” of 50 NTU established by the Ministry of Industry, Thailand. Manganese concentration ranges from 5-8 mg/L (the standard is 1 mg/L; DGR, 2011). The water of the canal is used to recharge the aquifer using the pond system.

Hydrogeology

Detailed hydrogeological characteristics of the study area were obtained from the field investigation. Forty seven wells were drilled and installed in the main directions of groundwater flow since June, 2009 to explore geology, and monitor the groundwater level and quality. These include 32 wells for shallow depths of less than 15 m and 15 wells for depths greater than 15 m. Uppasit et al (2011) described the hydrogeology of the study area, underlain by alluvial fan deposits (Qaf) consisting of sand, gravel and clay; and flood plain deposits (Qff) composed of sand and gravel (Fig. 2). The area is overlain with clay layer of varying thickness of 0-3 m. Shallow aquifers deposited at the depth of 6 to 20 m below ground level. Thin clay layer of 2 to 7 m separates the shallow and deeper aquifers. The deep aquifer consists of gravelly sand and is found at 17-27 m depth (Fig. 3). The shallow aquifer has a transmissivity (T), hydraulic conductivity (K), and storativity (S) of 2,000-3,400 m^2/d, 2.43x10^{-3} - 3.90x10^{-3} m/s, and 0.001-0.090, respectively. The deep aquifer has T and S values of 30-150 m^2/d, and 0.001-0.040, respectively. The main groundwater moves from the southern part area with a head of 38.5-39 m amsl to the northern part area with a head of 36-36.50 m amsl (Fig.2). Shallow groundwater depths range from 7-9 m below the ground surface. The groundwater recharge of the study area is about 6 to 21% of annual rainfall (1,300 mm). The groundwater balance study using mathematical groundwater model simulations in the study area showed that the total groundwater recharge rates, use and deficit are about 1.2, 1.5 and 0.23 Mm^3/y, respectively. Groundwater level in the current condition showed a declination of 0.25 m/y.

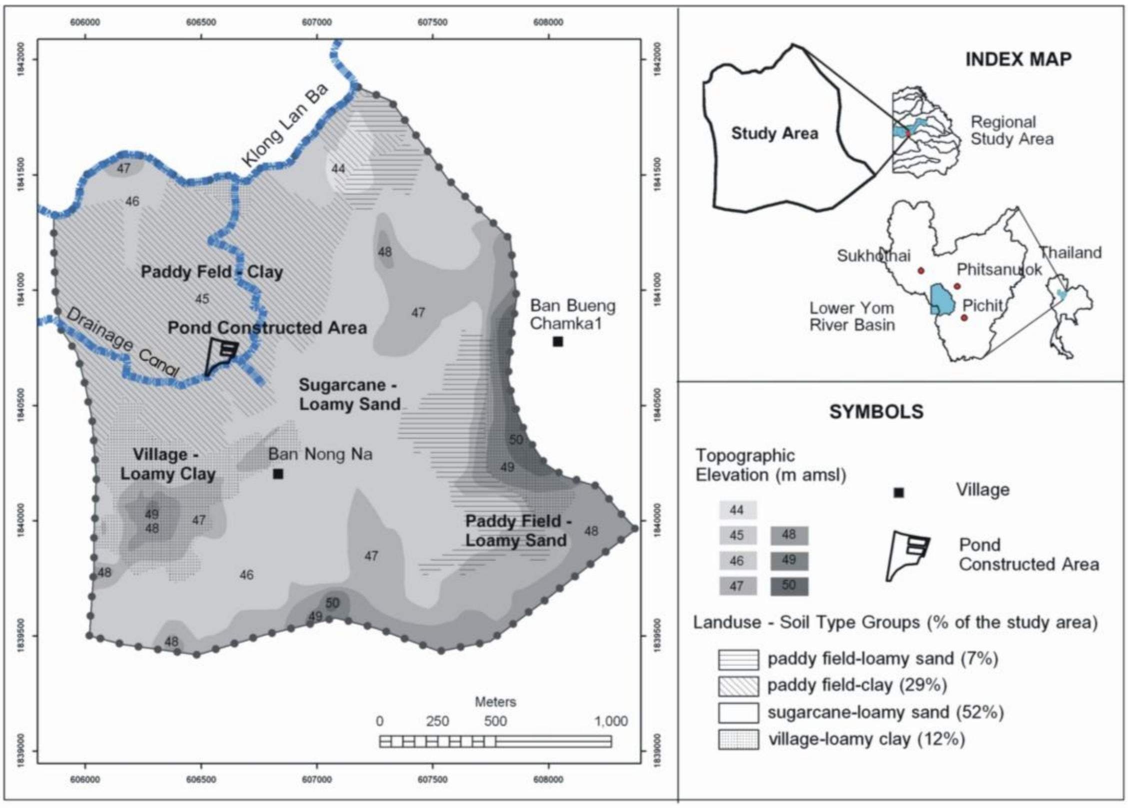


Fig. 1 Map of the study area showing topography and landuse

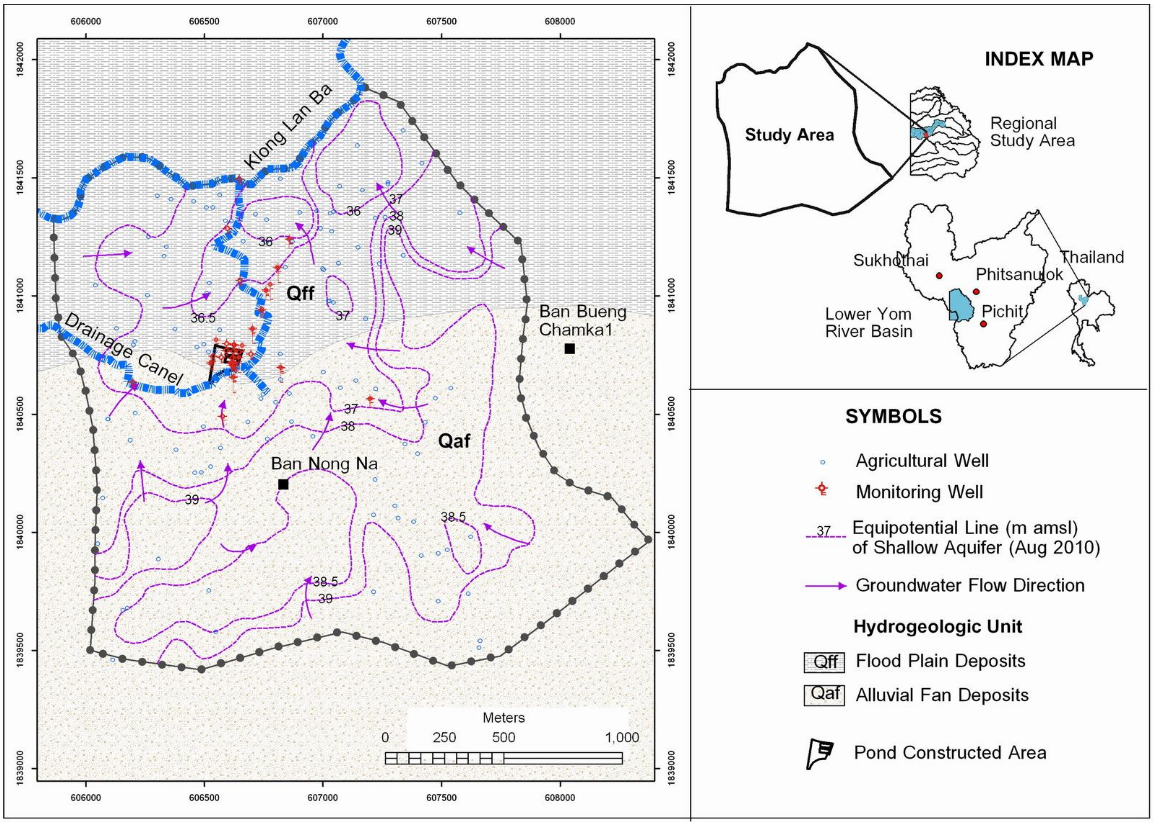


Fig. 2 Hydrogeological map of the study area

The thirty nine groundwater samples from the groundwater wells were monitored prior and during the recharge experiments and analyzed for physicals, chemicals, and toxic elements following the standard of characteristics discharged into deep wells of the Notification of the Ministry of Industry, No. 5 B.E. 2521 (1978) and analyzed for volatile organic compounds, heavy metals, and pesticides following the groundwater quality standards of the Notification of the National Environmental Board No. 20, B.E. 2543 (2000). It was indicated that the samples are of good quality and do not show signs of contamination from fertilizers or pesticides (DGR, 2011).

METHODOLOGY

The methods used in this paper consist of (1) data compilation including climate, physiography, hydrology and hydrogeology from the literature review and field investigation of DGR (2011) and Uppasit et al (2011); (2) recharge pond experiment, groundwater level and quality monitoring; and (3) numerical modeling of groundwater flow, balance and mound prior and resulting from the recharge experiment.

Recharge pond system and experiments

The recharge pond system was constructed in the central part of the study area closely to the drainage canal (Fig. 3). The construction site consists of two main systems; four constructed wetlands for raw water quality treatment, and two recharge ponds. The constructed recharge ponds A and B have ground surface areas of 1,250 and 1,160 m^2 and the bottom floor areas of 660 and 600 m^2, respectively. The depths of the ponds A and B are 2.66 and 2.75 m with the maximum storage capacity at the storage level of 2 m of 1,830 and 1,690 m^3, respectively. The side slope of the ponds was designed at 1.5:1 to ensure slope stability. The bottom floor of the ponds were covered with filter sand layer of 0.5 m thick and the side walls and bottom floors were lined with synthetic filtering blankets for sediments filtering and protection of erosion (DGR, 2011).

The twenty two shallow groundwater wells situated along the major groundwater flow direction were installed to monitor the water level fluctuation during experimental of artificial recharge. The recharge pond experiment was made 5 times for 55 days during July to November 2010, the recharge vary from 3,953-4,439 m^3 using surface water with the average turbidities varying from 27.2 to 89.9 NTU. The total recharged water is 25,797 m^3 as shown in Table 1 (DGR, 2011). During the longest experiment of 30 days in the fifth test, the groundwater level underneath the recharge ponds rises to the highest level of 3.33 m from normal immediately after 5 days of artificial recharge operation and after that gradually lowers to normal level (Fig. 3). The groundwater flows from the recharge pond area to the surrounding region and the north with average flow velocity of 0.07 m/day. The results of the physical, chemical and biochemical groundwater quality monitoring show no indications of groundwater quality changes (DGR, 2011).

Groundwater numerical modeling

The simulation area is 2.6 km in width and 2.7 km in length. The size of the grid cells increase from 5 m x 5 m at the recharge pond area to 20 m x 20 m at the remainder of the model. The model height ranges from 0-50 m amsl. Model was divided into three layers; shallow aquifer, deep aquifer, and confining layer. For the shallow aquifer, the southern side was selected as groundwater divided boundary, eastern and western boundaries as parallel with groundwater flow line, and northern side set as river boundary. For the deep aquifer, western and eastern sides are designed as prescribed flux, and southern and northern boundaries as parallel with groundwater flow line. Ponds A and B were assigned as recharge boundaries.

The recharge from rainfall and the pilot experiment was assigned using recharge boundary. Groundwater usage was simulated by the well package. The hydraulic property values are assigned based on the range of field hydrogeological testing results. The model was calibrated with the water level data both in prior and during the recharge experiment. In current condition, the water level data of 59 monitoring wells observed during monthly basis since December 2009 to November

2010. During the recharge test, water level data in daily basis of 22 monitoring wells were calibrated.

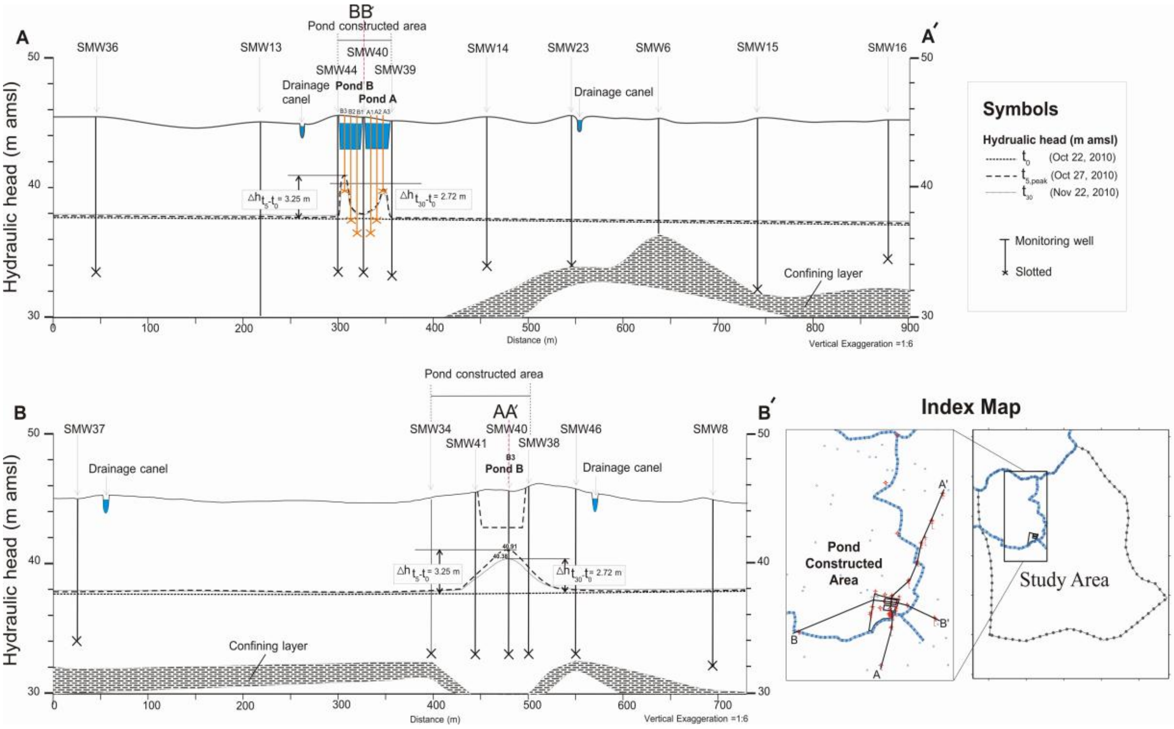


Fig. 3 Cross sections showing groundwater mound during the fifth experiment.

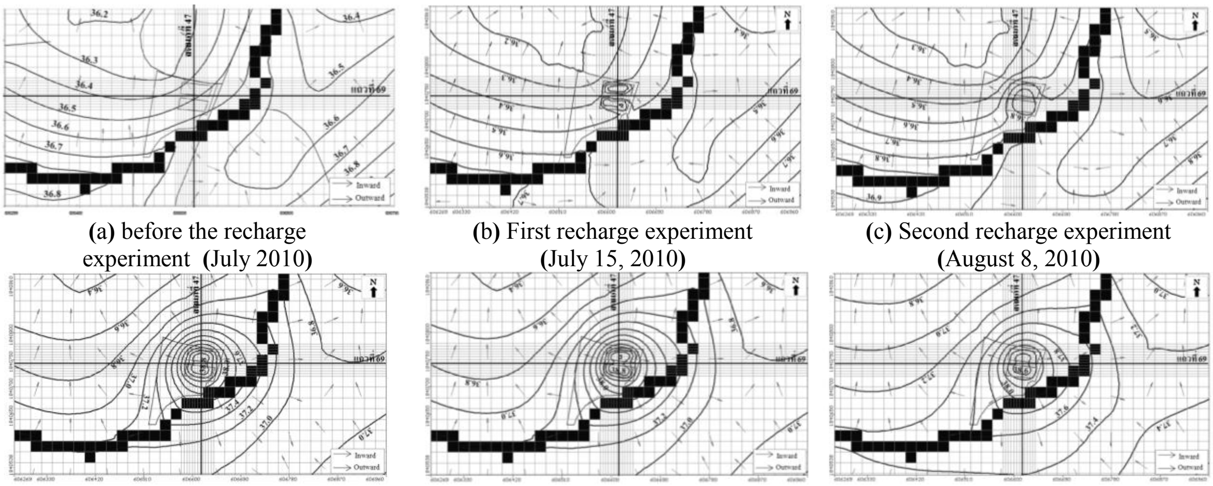
Table 1 Field data of the recharge pond experiment

No.	Pond	Duration (days)	Recharged water Turbidity (NTU)	Artificial recharge (m^3)
1	B	Jul 13-15, 2010 (2)	52.6	814
2	A	Aug 3-8, 2010 (5)	27.2	4,439
	B			896
3	A	Aug 25-Sep 8, 2010 (14)	71.9	1,918
	B			4,157
4	A	Sep 19-23, 2010 (4)	65.5	2,835
	B			1,901
5	A	Oct 23-Nov 22, 2010 (30)	89.9	4,884
	B			3,953
Total		Jul 13-Nov 22, 2010 (55)		25,797

RESULTS AND DISSCUSSION

Groundwater flow pattern in natural condition shown that groundwater flows from the southern part of the study area or at Ban Nong Na with recharge rates of 6 to 21% of rainfall to the cone of depression area in the northern region nearby Klong Lan Ba and is characterized by low recharge rates of 3 to 5%. Groundwater heads surrounding the recharge ponds A and B were 36.70-36.30 m amsl (Fig. 4a). Groundwater balance during the recharge experiment can be summarized as the followings: the total recharges to the study area were 1.37 Mm^3 including the total of artificial recharge of 25,735 m^3, and seepage from the river was 0.17 Mm^3. The total annual draft through pumpage was 1.40 Mm^3. The subsurface horizontal inflows and outflows were 0.17 Mm^3. The result shows a deficit balance of 0.20 Mm^3. A continuous trend of groundwater decline of 0.22 m/y can be found for the study area. The mounding results of the numerical model simulations were compared with the field observation; both were found to be compatible with the Root Mean Square (RMS) of 0.48 m.

During the recharge experiment, it was found that groundwater mounded underneath the recharge ponds as shown in Fig. 4b and Fig. 4f. Groundwater flows from the central part of the mound to the surrounding area. The mound geometry that develops in the unconfined aquifer beneath the recharge ponds depends on several factors including the aquifer hydraulic properties, aquifer thickness, duration and quantity of the artificial recharge.



(a) before the recharge experiment (July 2010) | (b) First recharge experiment (July 15, 2010) | (c) Second recharge experiment (August 8, 2010)

(d) Third recharge experiment (September 7, 2010) | (e) Fourth recharge experiment (September 22, 2010) | (f) Fifth recharge experiment (November 22, 2010)

Fig. 4 Simulations of groundwater levels before and during the recharge pond experiment

CONCLUSIONS AND RECOMMENDATIONS

Groundwater recharge mound from the recharge experiment can be quantified using numerical modeling technique. It can provide a clarification of recharge mechanism, water balance, and mounding characteristics. Results from the simulations indicated that groundwater deficit in Ban Nong Na could be controlled by constructing an artificial recharge system in the highly abstraction of groundwater areas. Based on the results of pilot experiments, to keep the water table in Ban Nong Na area as the current condition, the volume of artificial recharge in this area have to be increased to not lower than 0.23 Mm^3/y, which indicated that more than 6 six recharge systems need to be implemented in this area.

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