Effect of Water Quality on Infiltration Rates from the Ponding Method of Managed Aquifer Recharge: A Case Study from Ban Nong Na, Phitsanulok, Thailand

Suwanchai Nadee[1,3]*, Vidhaya Trelo-ges[1,3], Paul Pavelic[2], Kriengsak Srisuk[3]
[1]*Department of Land Resources and Environment, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand*
[2] *International Water Management Institute, Vientiane, Lao PDR*
[3]*Groundwater Research Center, Faculty of Technology, KhonKaenUniversity, KhonKaen, Thailand*

Abstract

The shallow groundwater in Bangrakum District, PhitsanulokProvince, situated within the Lower Yom River Basin, Thailand has been heavily pumped for growing rice all year round. During the past decade static water levels within the gravel, sand and silt aquifers have decreased to critical depths of up to ten meters below the ground surface. Ponding method of Managed Aquifer Recharge (MAR) is being trialed as solution to groundwater depletion of the area. The infiltration test was conducted in Ban Nong Na sub-watershed consisting of recharge pond A with bottom area of 660 m^2 and using synthetic filter sheets at the bottom and pond B with bottom area of 600 m^2 and not using synthetic filter sheets. The objectives of this study are to investigate effect of water quality to infiltration rates and efficiency of synthetic filter sheets in the field scale. The test under constant head conditions over a period of 30 days. The turbidity of raw water was ranging of 12 to 287 NTU (average turbidity of 89.9 NTU). Infiltrated water was calculated by water budget equation and total volume infiltrated water of pond A and B during the experiment were 4,884 and 3,953 m^3 respectively Averaged infiltration rates of pond A and B were 0.26 and 0.22 meter per day respectively. The infiltration rates of pond A and B could be categorized into 4 stages, namely; stage 1: the infiltration rate increases, stage 2: the infiltration rate rapidly decreases stage 3: the infiltration rate decreases; and stage 4: the infiltration rate gradually decreases. The last stage (stage 4) of the infiltration readings indicate the approach of the clogging of the pond bottom. Using and not using synthetic filter sheets at the bottom of the pond show very small difference in infiltration rate of 0.04 m/d. The turbidity of the infiltration water should be limited to less than 50 NTU. Further field experiment is needed over longer periods to provide firmer assurance on the water quality requirements for MAR.

Key words: water quality/ infiltration/ field experiment/ ponding method/ Lower Yom River Basin

1. Introduction

A field experiment consisting of infiltration tests via the ponding method of recharge was conducted at Ban Nong Na, located in Bangrakum District, Phitsanulok Province. The study area is situated in the Lower Yom River Basin where the shallow groundwater has been heavily pumped for growing rice all year round. Within the past ten years or so, static water levels in the alluvial fan deposits that consist of gravel, sand and silts have steadily decreased from about one to ten meters below the ground surface, placing enormous constraints on the lift irrigation systems employed by farmers. The objectives of this study are to investigate effect of water quality to infiltration rates and efficiency of synthetic filter sheets in the field at the pilot scale (1,260 m^2).

Clogging is one of the most critical factors affecting infiltration performance (Pavelic et al., 2007; Wu et al., 2007; Liu et al., 2003) and therefore the technical

*Corresponding author
E-mail: suwanchai_nadee@yahoo.com

and economic viability of MAR. Clogging may be defined as the reduction of the available pore volume of a porous media due to a range of physical, biological and chemical processes. Consequently, the immediate effect of clogging is to reduce the intrinsic permeability of a system, leading to a drop in infiltration rates in the case of surface ponding (Perez-Paricio and Carrera, 1999). The maximum infiltration rate is generally observed at the beginning of an infiltration test and decreases over time such asthe infiltration capacity have reached 20.3% of the original value (Mousavi and Rezai, 1999) and the infiltration rate decreased to 0.07 m/d (Izbicki et al., 2008). The poorer the source water quality, the faster and more extensive the reduction in infiltration rate (Nadee et al., 2010), as illustrated in Figure 1. The challenge here is define the appropriate quality of source (recharge) water to achieve viable rates of infiltration over the long term.

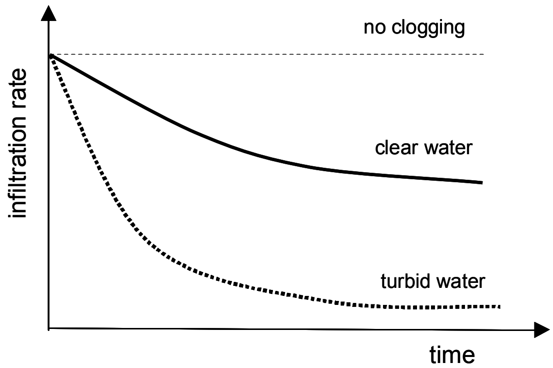

Figure 1 Conceptual illustration of infiltration and clogging with clear and turbid source water quality

2. Methodology

2.1 Study area

The pilot site is located at Ban Nong Na, Bangrakum District, Phitsanulok Province, Lower Yom River Basin, Thailand (Figure 2). Climate data for the study area collected from Phitsanulok Province station during year 2000 – 2010 indicate a mean temperature of 28 ^{o}C, relative humidity of 70 %, wind speed of 1.37 knots and annual pan evaporation of 1,504 mm. Annual rainfall analyzed from four rainfall stations at Bangrakham, Sai Ngam, Lan Krabue and Sam Ngam Districts determined from the Thiessen method is 1,286 mm.

The shallow aquifer of the pilot site consists of gravel, sand and silt with varying thickness of10 – 15 meters and underlain by a clay layer of 2 –5 meters thick. The deep aquifer of coarses and is located below clay stratum found at varying depths of 15 –20 meters from groundsurface. The deep aquifer consists of medium to coarse grained sand and gravel alternated with clay.

The construction site is underlain by a shallow aquifer of fine to coarse grained sand with the thickness of 12-15 meters interlayering with 1-5 meters clay stratum as shown in Figure 3.Physical properties of upper and lower sand of shallow aquifer are distinguishable from their different grain sizes distribution. The effective grain size (d_{50}) and coefficient of uniformity (C_u) of upper sand and lower sand are 0.34 and 0.49 mm and 2.14 and 2.19 for the upper sand and lower sand respectively. Hydraulic properties of the shallow aquifers were determined by pumping tests indicate values of transitivity between 2,050 to 3,600 m^2/day and specific storage between $8.4x10^{-4}$ to $1.3x10^{-2}$.

The component of the recharge systems consisting of raw water diversion system, raw water quality treatment system, site office and monitoring system, and recharge rate measuring system (Figure 4).

1) Raw water diversion system consists of a concrete weir with water controlling gate capable of raising the maximum water level to 1.5 meters. The water inlet to the system features a rectangular concrete culvert capable of regulating the flux rate by gravity between 1 to 200 cubic meters per hour.

2) Raw water quality treatment system consist of 4 constructed wetlands, namely, constructed wetlands A, B, C, and D with areas of 1237, 975, 992, and 813 square meters, respectively. The floor of each constructed wetland has a standard operating level of 0.3 meter and is capable of storing water up to a level of 0.6 meter. Local, hardy and fast growing hydrophilic plants such as canna and triangular papyrus were planted within the constructed wetlands. The embankments were lined with geotextile and covered with vetiver grass to protect against erosion.

3) The recharge ponds A and B (Figure 4) have ground surface areas of 1,250 and 1,160 square meters and bottom floor areas of 660 and 600 square meters, respectively. The depths of the ponds A and B are 2.66 and 2.75 meters with the maximum storage capacity at the storage level of 2 meters of 1,830 and 1,690 cubic meters, respectively. The side slope of the ponds were designed at 1.5:1 to ensure slope stability.The base of the ponds were covered with a filter sand layer (d_{50}=0.33 mm) 0.5 meter thick, and the side walls were lined with synthetic filtering blankets to control erosion. Pond A using synthetic filter sheets at the bottom for trap sediment and pond B not using synthetic filter sheets.

4) The field office cabin and control system consists of an office, meeting room, electric control system, and amenities.

5) Climate monitoring system consists of automatic rainfall measuring device and class A evaporation pan for evaporation measurement.

6) Surface water level measuring system consists of water quantity measuring tool using sharp edge rectangular concrete weir installed at 6 locations and water level measuring staff gauges installed at 7 locations.

7) Groundwater level and groundwater quality monitoring system is comprised of a network of 47 observation wells installed at depths greater and less than 15 meters in the near vicinity of the recharge ponds. The recharge evaluation system consists of recharge evaluation and assessment of constructed wetland performance and system maintenance.

2.2 Field experiment

The field experiment consists of two main components: 1) measurement of physical and hydraulic properties of the porous media in both the unsaturated and saturated zones, and 2) infiltration testing under 2 meters constant head conditions.
Infiltration (R) was calculated from the water budget equation as given in equation (1):

$$R = P + I - E \pm (\Delta S/\Delta t) \qquad (1)$$

where P is precipitation, I is water inflow to the pond, E is evaporation, S is water storage in the pond and t is the elapsed time.

Precipitation was measured from automatic recorder every ten minutes; evaporation was measured from class A pan daily, water inflow to the ponds and water storage in the ponds were measured every three hours.

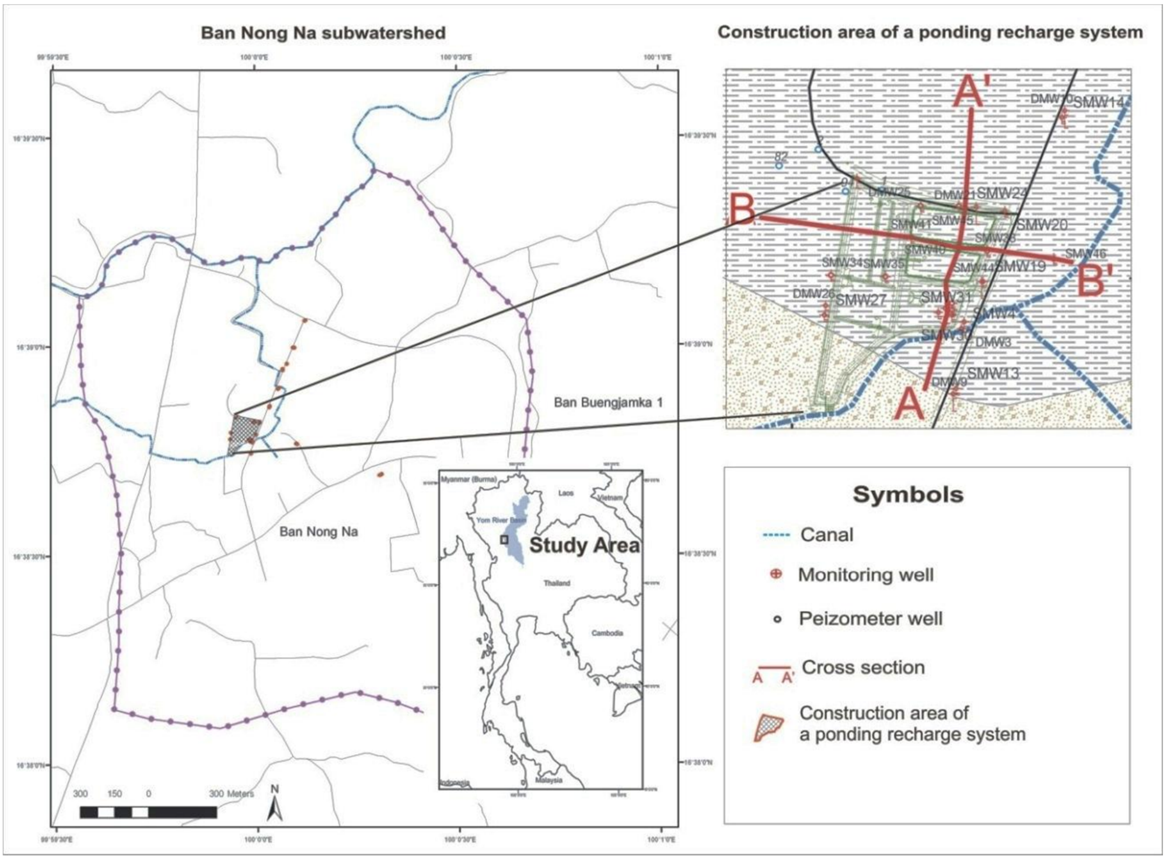

Figure 2 Location of the study area (Modified from Department of Groundwater Resources, 2011)

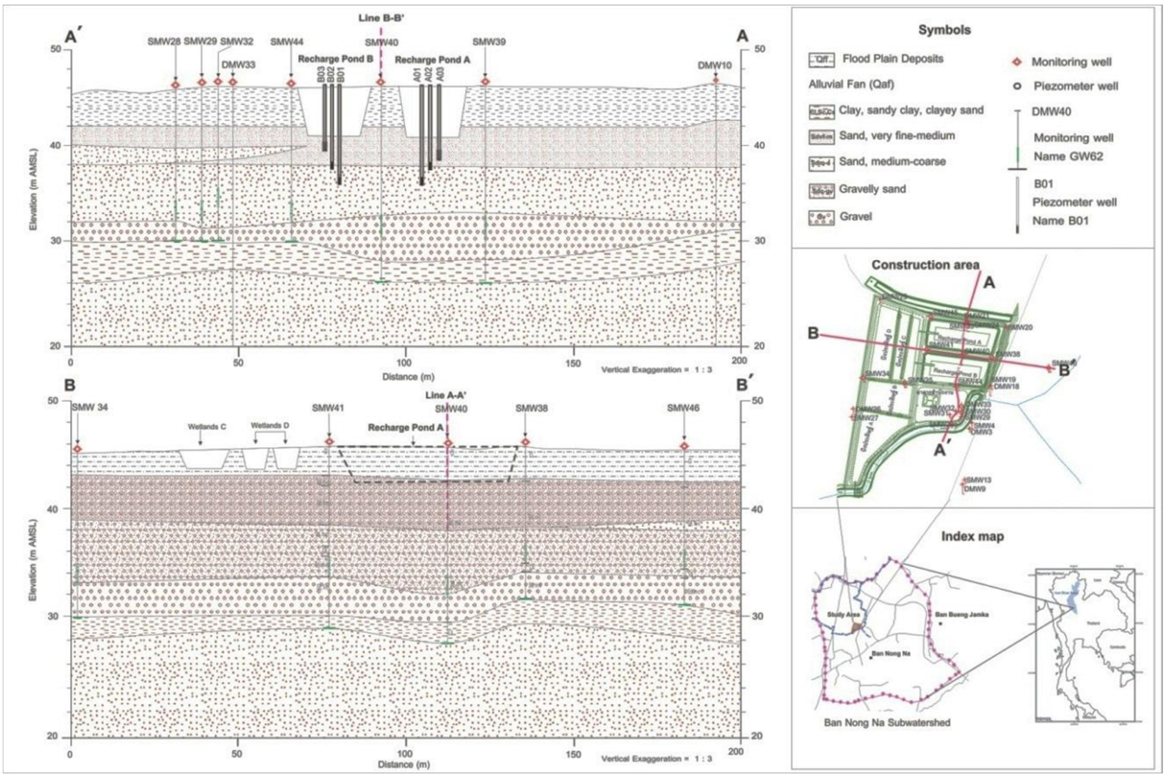

Figure 3 Cross section of the study area (Modified from Department of Groundwater Resources, 2011)

Figure 4 Components of the ponding system including four constructed wetlands for pretreatment and two recharge basins (Department of Groundwater Resources, 2011)

3. Results and discussion

The field experiment was carried out during the period from October 23 to November 24, 2010. Total rainfall and pan evaporation during this period were 47.0 and 125.0 mm respectively.

The volume of water inflow during the experiment of pond A and B were 6,323 and 5,050 m^3 respectively and total volume of water inflow during the experiment was 11,373 m^3.

The volume of water infiltrated during the experiment of pond A and B was 4,884 and 3,953 m^3 respectively and total volume of water infiltrated during the experiment was 8,837 m^3 as shown in Figure 5.

a) Pond A

b) Pond B

Figure 5 Pond A (a) and B (b) when filled with water during the field experiment

Water quality was measured every three hours and raw water turbidity ranged from 12 to 287 NTU (average of 89.9 NTU) as shown in Figure 6. The average water level in pond A and B were 1.57 and 1.73 m above (meter above bottom) respectively as shown in Figure 7.

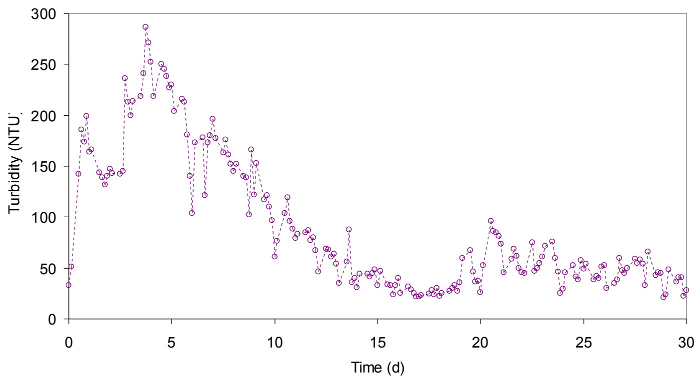

Figure 6 Raw water turbidity from the field experiment

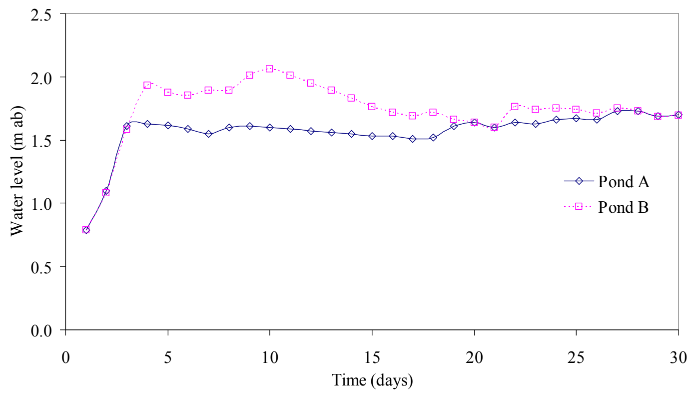

Figure 7 Water level of pond A and B during the field experiment

3.1 Infiltration characteristics

Infiltration characteristics during the field experiment of pond A could be categorized into 4 distinct stages (Table 1 and Figure 8), namely; stage 1: the infiltration rate increases (days 1 –3) from 0.66 to 1.14 meter per day; stage 2: the infiltration rate rapidly decreases (days 4–7) from 1.13 to 0.23 meter per day; stage 3: the infiltration rate decreases (days 8–11) from 0.22 to 0.14 meter per day; and stage 4: the infiltration rate slowly decreases (days 12– 30) from 0.13 to 0.05 meter per day. The last stage (stage 4) of the infiltration readings indicate the approach of the clogging of the pond bottom.

Infiltration characteristics during the field experiment of pond B could be categorized into 4 distinct stages (Table 2 and Figure 8), namely; stage 1: the infiltration rate increases (days 1 – 4) from 0.14 to 0.79 meter per day; stage 2: the infiltration rate rapidly decreases (days 5 – 8) from 0.78 to 0.28 meter per day; stage 3: the infiltration rate decreases (days 9 – 15) from 0.27 to 0.16 meter per day; and stage 4: the infiltration rate slowly decreases (days 16 – 30) from 0.15 to 0.07 meter per day. The last stage (stage 4) of the infiltration readings indicate the approach of the clogging of the pond bottom.

The characteristic increase in recharge during stage 1 at the start of a recharge cycle is caused by an increasing saturation and gradual removal of residual air from beneath the pond (Perez-Paricio and Carrera, 1999).

Table 1 Infiltration characteristics during the field experiment of pond A

Stage	Date	Avg. Turbidity (NTU)	Water inflow (m^3)	Infiltration rate (m/d)
1	1-3	159	3,091	0.66 – 1.14
2	4-7	207	1,243	1.13– 0.23
3	8-11	126	488	0.22 – 0.14
4	12-30	47	1,501	0.13 – 0.05
Average		89.9		0.26
Total			6,323	

Table 2 Infiltration characteristics during the field experiment of pond B

Stage	Date	Avg. Turbidity (NTU)	Water inflow (m^3)	Infiltration rate (m/d)
1	1-4	181	2,490	0.14 – 0.79
2	5-8	186	857	0.78 – 0.28
3	9-15	82	802	0.27 – 0.16
4	16-30	44	901	0.15 – 0.07
Average		89.9		0.22
Total			5,050	

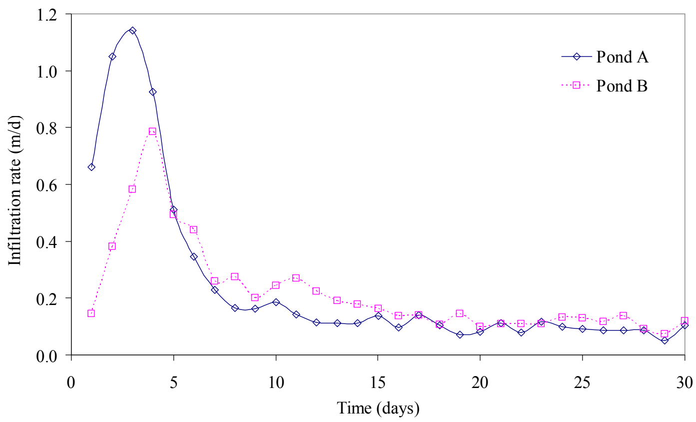

Figure 8 Infiltration rate changes of pond A and B during the field experiment

3.2 Sediment loadings

Sediment loadings within the pond were calculated from the turbidity level and flux of raw water pond. Suspended solids (SS, mg/L) is approximately 0.8timesof the turbidity (NTU) (Nadee et al., 2011). Suspended solids inputs of pond A for stages 1 to 4 approximately range from 337.6 to 51.5 kg and the total SS input 723.7 kg (Table 3 and Figure 9). SS inputs of pond B for stages 1 to 4 approximately range from 372.8 to 31.0 kg and the total SS input 597.2 kg (Table 4 and Figure 9).

Table 3 Sediment loadings in pond A

Stage	Date	SS (kg)	Accumulated SS (kg)	Percent
1	1-3	337.6	337.6	54.94
2	4-7	223.6	621.2	30.90
3	8-11	51.0	672.2	7.05
4	12-30	51.5	723.7	7.11
	Total	723.7		100.00

Table 4 Sediment loadings in pond B

Stage	Date	SS(kg)	Accumulated SS (kg)	Percent
1	1-4	372.8	372.8	62.43
2	5-8	129.8	502.6	21.72
3	9-15	63.6	566.2	10.66
4	16-30	31.0	597.2	5.19
	Total	597.2		100.00

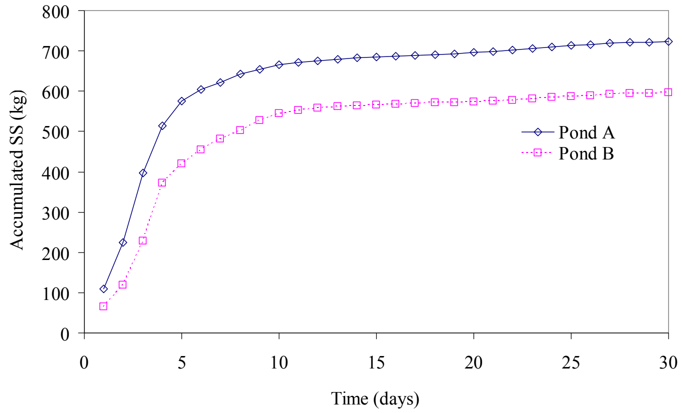

Figure 9 Accumulated SS in pond A and B during the field experiment

4. Conclusions and recommendations

The infiltration rates of pond A and B could be categorized into 4 stages, namely; stage 1: the infiltration rate increases, stage 2: the infiltration rate rapidly decreases stage 3: the infiltration rate decreases; and stage 4: the infiltration rate gradually decreases. The last stage (stage 4) of the infiltration readings indicate the approach of the clogging of the pond bottom. Suspended solids over the four stages ranged from 326.2 to 27.1 kg and the total SS loading into the recharge pond was 522.5 kg.

Using and not using synthetic filter sheets at the bottom of the pond show very small difference in infiltration rate of 0.04 m/d. The turbidity of the infiltration water should be limited to less than 50 NTU.

Further field experiment is needed over longer periods to provide firmer assurance on the water quality requirements for MAR.

5. Acknowledgment

Department of Groundwater Resources, Ministry of Natural Resources and Environment is acknowledged for financial support and the Groundwater Research Center, Faculty of Technology, KhonKaen University is acknowledged for data and technical support.

6. References

Department of Groundwater Resources (DGR). 2011. **Pilot Study and Experiment on Managed Aquifer Recharge Using Ponding System in the Lower North Region River Basin, Phitsanulok, Sukhothai, and Pichit Provinces**. KhonKean: KhonKaen University.

Izbicki, J.A., AL. Flint, C.L. Stamos. 2008. Artificial recharge through a thick, heterogenous unsaturated zone. **Ground Water** 46(3): 475-488.

Liu, C.W., Cheng, S.W., Yu, W.S., and Chen, S.K. 2003. Water infiltration rate in cracked paddy soil. **Geoderma** 117: 169–181.

Mousavi, S.F. and Rezai, V. 1999. Evaluation of scraping treatments to restore initial infiltration capacity of three artificial recharge projects in central Iran. **Hydrogeology Journal** 7: 490–500.

Nadee, S., Srisuk, K., Sarapirom, P., Pavelic P., and Uppasit, S. 2010. **Field and laboratory experiments to investigate infiltration processes and clogging effects from a ponding recharge system**

at Ban Nong Na, Bangrakum District, Phitsanulok Province, Lower Yom River Basin, Thailand. Proceedings of the 7th Annual International Symposium on Managed Aquifer Recharge (ISMAR). Abu Dhabi, UAE.

Nadee, S., Trelo-ges, V., Pavelic, P., and Srisuk, K. 2011. **Effect of turbid water on infiltration processes arising from the ponding method of Managed Aquifer Recharge: A case study from Ban Nong Na, Bang Rakam District, Phitsanulok Province**. Proceedings of the International Conference on Geology, Geotechnology, and Mineral Resources of INDO-CHINA (GEOINDO 2011). Khon Kaen, Thailand: Kosa Hotel.

Pavelic, P., Dillon, P.J., Barry, K.E., Vanderzalm, J.L., Correll, R.L. and Rinck-Pfeiffer, S.M. 2007. Water quality effects on clogging rates during reclaimed water ASR in carbonate aquifer. **Journal of Hydrology** 334: 1-16.

Pérez-Paricio, A. and Carrera, J. 1999. **Clogging Handbook**. EU Project on Artificial Recharge of Ground water. Contract ENV4-CT95-0071. Barcelona, Spain: Technical University of Catalonia.

Wu, J., Wu, Y, Lu, J. and Lee, L. 2007. Field investigations and laboratory simulation of clogging in Lixi dam of Jinduicheng, China. **Environ. Geol** 53: 387-397.