Assessments of Groundwater–Surface Water Connectivity for the Lower Yom and Nan Rivers

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Abstract—*This study outlined the first-time assessments of groundwater–surface water connectivity for the Lower Yom and Nan Rivers. The direct measurements of exchange fluxes using seepage meters were carried out. The diurnal flow directions between groundwater and surface water were then investigated based on thermal conditions in streambeds (8-m depth within the sediment). The study's findings exhibited seasonal influxes and effluxes (-4.32 to 163 cm/day for the Lower Nan and -1.90 to 198 cm/day for the Lower Yom) of surface water associated with groundwater. In addition, the rapid thermal responses (approximately 1.5 degree Celsius) in the streambed due to high rates of infiltration were diurnally evident. The groundwater–surface water interactions are essential for laying the foundations of conjunctive water management approach. Better understandings of the groundwater–surface water connectivity would help enhancing integrated water resource planning and management at the river basin level in order to achieve the efficiency of agricultural production, economic equality, and environmental sustainability.*

Keywords—groundwater connectivity; exchange fluxes; seepage meters; infiltration; conjunctive water management.

I. INTRODUCTION

This study illustrated the first-time assessments of groundwater–surface water connectivity for the Lower Yom and Nan Rivers. The direct measurements of exchange fluxes using seepage meters were carried out. The diurnal flow directions between groundwater and surface water were then investigated based on thermal conditions in streambeds at 8-m depth within the sediment. The groundwater-surface water interactions are essential for laying the foundations of conjunctive water management approach. Better understandings of the groundwater-surface water connectivity would help enhancing integrated water resource planning and management at the river basin level in order to achieve the efficiency of agricultural production, economic equality, and environmental sustainability.

II. MATERIALS AND METHODS

A. Monitoring sites

Ten monitoring sites of seepage fluxes were chosen from the total Lower Yom and Nan River Basin areas (Figure 1). The Y6-L (Gravelly Sandy Clay) and DR2.8Y-L (Sand Bar) were located at the left side of Yom River in Si Satchanalai District (Sukhothai Province) and Bangkratum District (Phitsanulok). The DR2.8Y-R (Sand Bar) was located at the right side of Yom River in Bangkratum District (Phitsanulok). The N60-L (Sand Bar) and N67-L (Loamy Sand) were located at the left side of Nan River in Tron District (Uttaradit Province) and Chum Saeng District (Nakhon Sawan Province). The N60-R (Loamy Sand), N27A-R (Clay), WTRN-R (Clay), DR2.8N-R (Clay), and N67-R (Clay) were located at the right side of Nan River in Tron District (Uttaradit Province), Phrom Phiram District (Phitsanulok), Mueang Phitsanulok District (Phitsanulok), Bangkratum District (Phitsanulok), and Chum Saeng District (Nakhon Sawan Province), respectively. These 262 exchange flux measurements were conducted during October 2017 to April 2018.

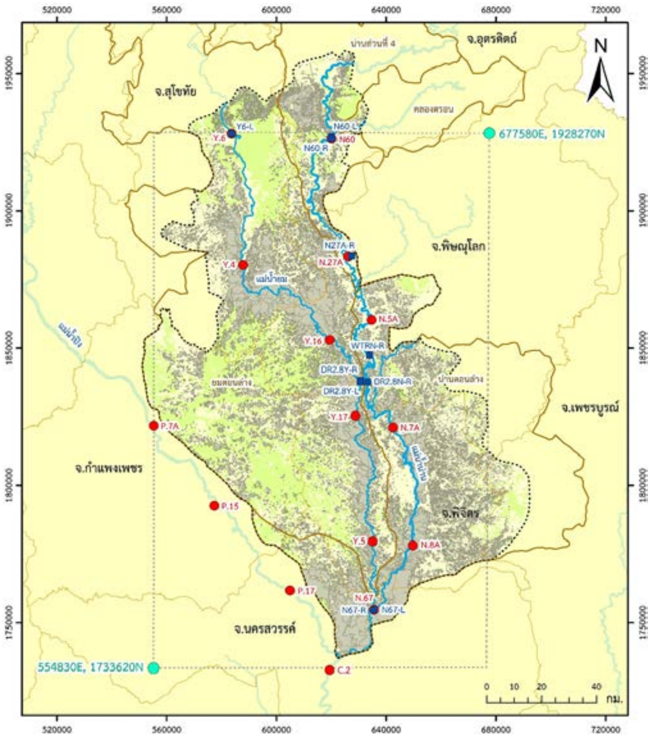

Figure 1. Monitoring sites of seepage fluxes.

B. *Seepage meters*

This cylindrical seepage meter was developed based on [1 & 2]. The seepage meter was made from the stainless steel with the 30-cm height, and its diameter is 57 cm. There are two valves in the meter. The first valve is for releasing air inside the meter, and the second valve is for letting the water out (Figure 2). The black hose (1-cm diameter and 1-m length) is used to connect the second valve with the plastic box. This plastic box contains the plastic bag for storing the water which comes out of the second valve. In addition, the box will not allow the flowing river water to directly contact with the plastic bag. This would prevent the excessive stored water in the plastic bag. The seepage meter is normally placed on the riverbed with 10-cm depth. After getting rid of the air inside the meter, each measurement then begins [3].

Figure 2. Seepage meter components.

C. *Exchange Flux Determination*

By recording the water volume contained in the bag at the times of emplacement and removal, the volumetric seepage flux is computed by

$$Q=\frac{V_{t2}-V_{t1}}{t_2-t_1} \qquad (1)$$

where V_{t1} is the volume contained in the bag at the start of the measurement period (cm^3), V_{t2} is the volume in the bag at the end of the measurement period, and t_1 and t_2 are the times at the start and end of the measurement period (day). Dividing the volumetric seepage flux by the area of seepage cylinder (0.25 x π x 57^2 = 2,553 cm^2) gives seepage flux in length per time (cm/day) [3] as

$$q=\frac{Q}{A} \qquad (2)$$

D. *Streamflow Information*

There are relevant 3 hydrological monitoring sites for the Yom River (i.e., Y6, Y16, and Y17), and 5 hydrological monitoring sites for the Nan River (i.e., N5A, N7A, N27A, N60, and N67) from Thai Royal Irrigation Department [hydro-2.rid.go.th and hydro-5.rid.go.th]. Selected monthly streamflow during the year 2017-2018 (based on seepage monitoring months in Figure 1) are exhibited in Table 1. One example of cross-sectional schematic for Y6 is illustrated in Figure 3.

Table 1. Selected monthly streamflow during the year 2017-2018 based on seepage monitoring months.

Monitoring Months	Hydrological Monitoring Sites							
	Y6	Y16	Y17	N5A	N7A	N27A	N60	N67
October 2017	860							
November 2017							139	
December 2017		58.0	236					
January 2018				662	708	634		770
February 2018	27.1							
April 2018	7.33							

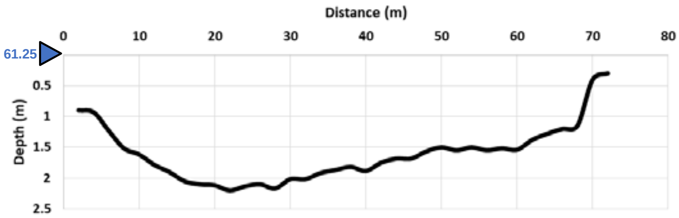

Figure 3. A cross-sectional schematic of Y6 (April 2018).

E. *Streambed thermal measurements*

The DR2.8Y-L and DR2.8N-R were selected to install the 8-m and 6-inch PVC wells, and Lutron (TM-1947SD) Temperature Data Loggers (Figure 4 and Table 2). Both thermocouple probes were then placed at the riverbed surface outside the well and 8-m depth inside the well. The temperature measurements were carried out during July 2018.

Figure 4. Streambed thermal measurement sites.

Table 2. Riverbed information for thermal measurement sites

Site Code	Well Depth (m)									
	1	2	3	4	5	6	7	8	9	10
DR2.8Y-L	Sand					Clay		Sand		
DR2.8N-R	Clay								Sand	

III. Results and Discussion

A. *Exchange fluxes*

Most observed exchange fluxes had positive values, and there were decreasing tendencies towards the drier season (-4.32-163 cm/day for the Lower Nan and -1.90-198 cm/day for the Lower Yom) (Figures 5 and 6). These would indicate the flow direction from the groundwater into the river. The higher fluxes were observed while the seepage meter were placed closer to the river bank. Sometimes when a rice farmer pumped the groundwater from the well next to the river for irrigating the paddy field, negative flux with fluctuated values were evident. Exchange fluxes, obtained from the monitoring site closed to the municipal area, were fluctuated.

The median influx (Groundwater Discharge) for the Lower Yom River were generally found to be ~1.5 times higher than that for the Lower Nan River. Upper areas of the Lower Yom River had the greater amount of groundwater discharge than lower areas. Upper areas of the Lower Nan River had the lesser amount of groundwater discharge than lower areas.

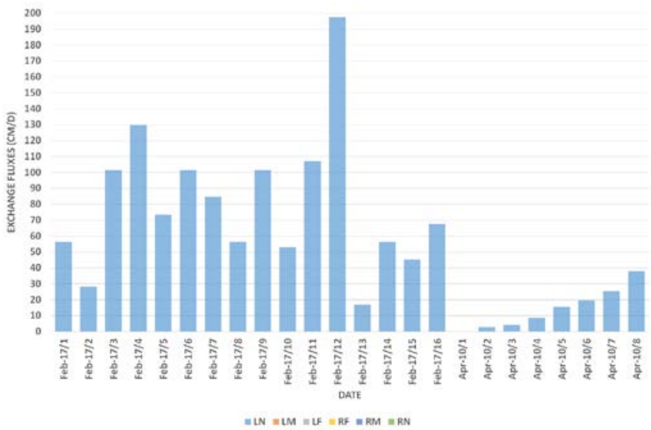

Figure 5. Exchange fluxes observed from Y6 (February and April, 2018).

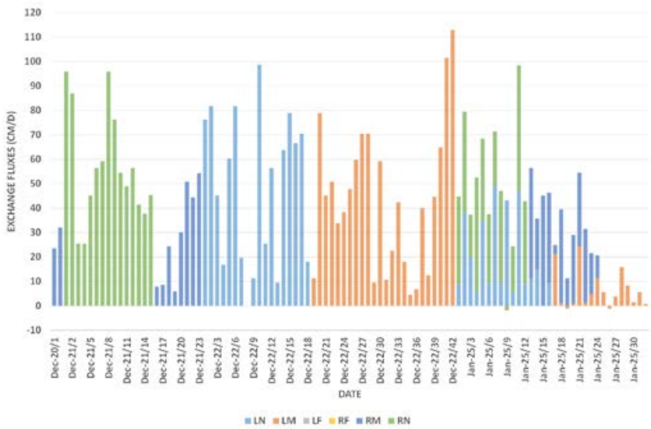

Figure 6. Exchange fluxes observed from DR2.8Y (December 2017 and January 2018).

B. Streambed thermal conditions

Higher streambed thermal variations at the 8-m depth and sediment surface were found at site DR2.8N-R. The clay layer of riverbed at the 8-m depth could be able to maintain the water temperature, while the sand layer could not. Both temperatures (Figures 7 and 8) were higher from 7 am to 3 pm (peaks). The temperatures then decreased and returned to the original stage around 8-10 pm.

There were possibilities that the losing river occurs from 7 am to 3 pm, and the gaining river occurs from 3 pm to the equilibrium state around 8-10 pm at night. In addition, the rapid thermal responses (approximately 1.5 degree Celsius) in the streambed due to high rates of infiltration [4 & 5] during 7-10 am were diurnally evident.

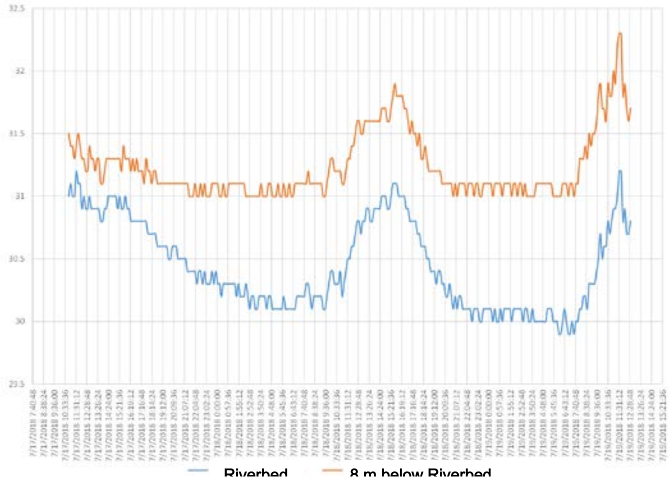

Figure 7. Riverbed thermal conditions at DR2.8Y-L.

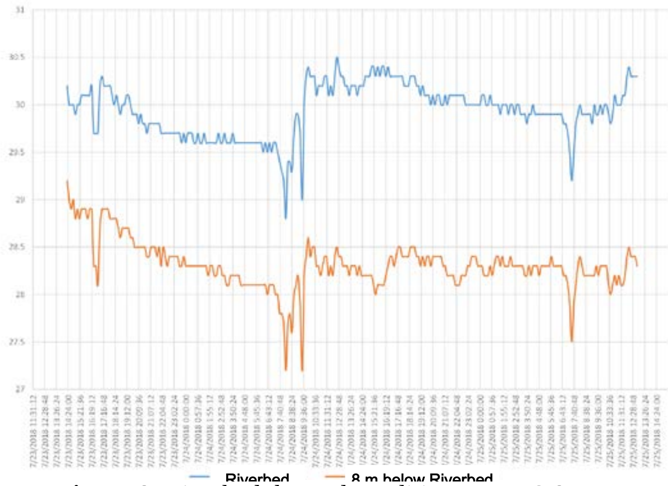

Figure 8. Riverbed thermal conditions at DR2.8N-R.

C. Conjunctive Water Management

Inquires to the local farmers indicate that the shallow groundwater is conjunctively used for irrigating their paddy fields. Due to the lower groundwater table, wells with lowering pumping machines are normally evident in the area. These wells are also dangerous for routine maintenance. The major reason for the lower groundwater table is that the groundwater use has exceeded the natural replenishment of groundwater. The conjunctive water management with new and/or exiting recharge facilities (e.g., dug wells and irrigated canals) could be an option.

IV. CONCLUSIONS

On the basis of this work, we draw the following conclusions:

1. The cylindrical seepage meter is well applied for direct measurement of exchange flux. This is demonstrated for the Lower Yom and Nan Rivers during October 2017 to April 2018.

2. Exchange fluxes of -4.32 to 163 cm/day for the Lower Nan and -1.90 to 198 cm/day for the Lower Yom exhibit similar decreasing tendencies towards the drier season.

3. The groundwater has discharged into the Lower Yom River ~1.5 times higher than the Lower Nan River.

4. The rapid thermal responses in the streambed are due to high rates of infiltration (High Groundwater Recharge in the Morning). The exchange direction could then vary throughout the day (Groundwater Discharge in the Late Afternoon and Evening).

5. The conjunctive water management approach may be taken into consideration in the use of new and/or existing facilities for recharging the groundwater due to imbalance of groundwater use and natural replenishment.

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