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Surface water and groundwater interaction patterns via groundwater model –case study in Plaichumphol Irrigation Project-

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Outlines

I. Introduction
II. Objectives
III. Study area condition
IV. Methodology, equations used
V. Results
VI. Conclusions

I. Introduction

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- In the last decades, water demand has increased due to the rapid development in economy in Thailand.
- Because of the spatial and temporal distribution of rainfall and insufficient water storage, groundwater has played an important role for agricultural productivity in Plaichumphol Irrigation Project area (PIP).
- In Plaichumphol Irrigation Project area, the farmer used GW 0.39MCM/day (0.2MCM in dry season and 0.18MCM in wet season) (Werapol. B., 2007)
- These amount are not enough for their cultivation in this area.
- In order to better groundwater management in this area, the study aimed to understand interaction mechanism in the study area and compare the model's interaction parameters with field observed data.
- Groundwater model was developed from 1993-2003 (Aye. P.P, 2018) and this model was used to determine the interaction mechanism.

II. Objectives

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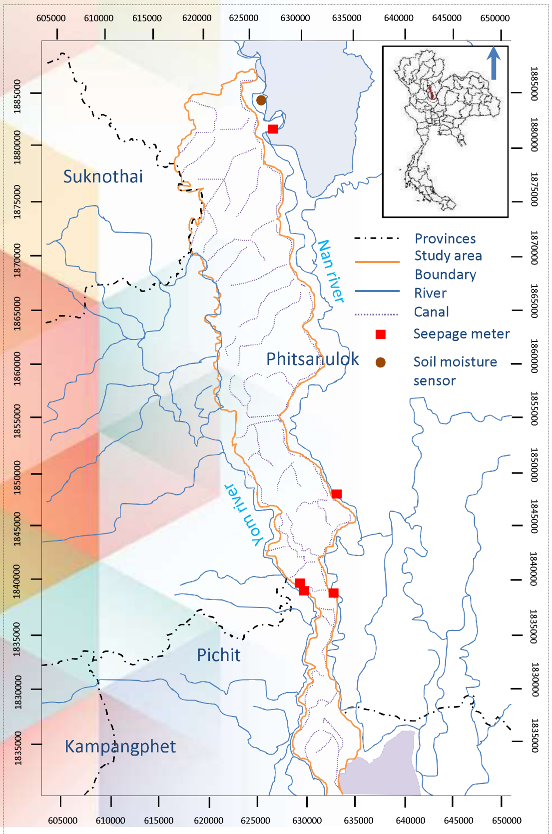
The main objective

- to understand the surface water and groundwater interaction mechanism (volume and patterns) via development of local groundwater model

The specific objectives;

1. to develop soil moisture sensor system to determine land recharge coefficient and land recharge rate,
2. to determine river conductance via field measurements
3. to determine surface and groundwater interaction patterns via groundwater model.

III. Study area



Plaichumphol Irrigation (Local area)
(Source; PIP, 2008)

- Plaichumphol Irrigation Project area
- Located in Phitsanuok province, the lower northern region of Thailand
- Total project area is 436sq.km
- The irrigated area is 338sq.km
- Nan river in the east
- Yom river in the west
- Elevation is 40-60m.MSL

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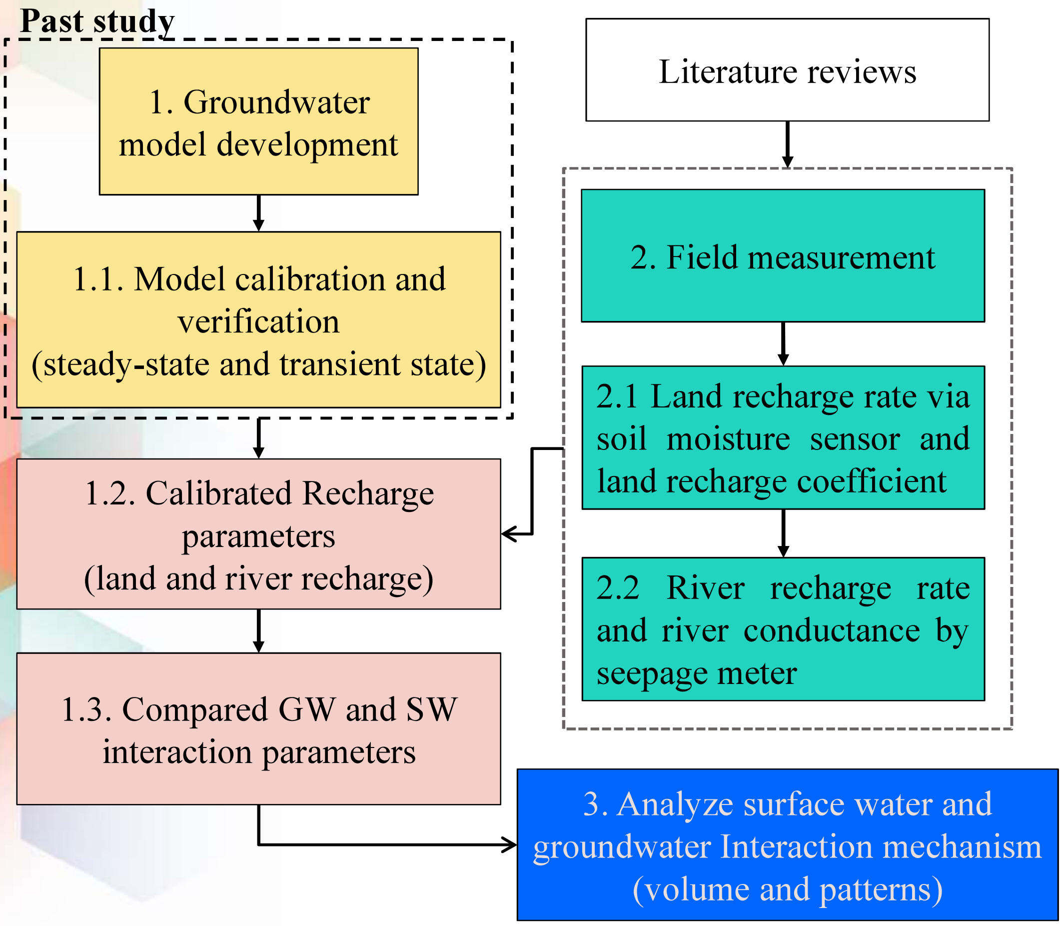
IV. Methodology



Equation used

1. Land recharge rate analysis

- The van Genuchten–Mualem model (Mualem,1976) was used to describe the soil water retention, $\theta(h)$, and the hydraulic conductivity, $K(h)$, and effective saturation S_e, curves are given by

One-dimensional soil water flow model

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}\left(K(h)\frac{\partial h}{\partial z}\right)+\frac{\partial}{\partial z}(K(h))$$

$$\theta(h)=\begin{cases}\theta_r+\dfrac{\theta_s-\theta_r}{[1-|\alpha h|^n]^m} & h<0\\ \theta_s & h\geq 0\end{cases}$$

Where,

- θ is the volumetric water content,
- K is the hydraulic conductivity (LT-1),
- h is the pressure head(L)
- t is the time (T) and
- z is the vertical ordinate (L)
- θ_r denote the residual water content
- θ_s denote the saturated water content
- α is the inverse of the air-entry value (or bubbling pressure)
- n is a pore-size distribution index

1.1 Land recharge coefficient

Land recharge coefficient (k) can be approximated by using the following equation.

R/P = k(P-ET)/P

- R = recharge rate (cm/day)
- P = precipitation (cm/day)
- ET = evapotranspiration (cm/day)
- k = land recharge coefficient

Equation used

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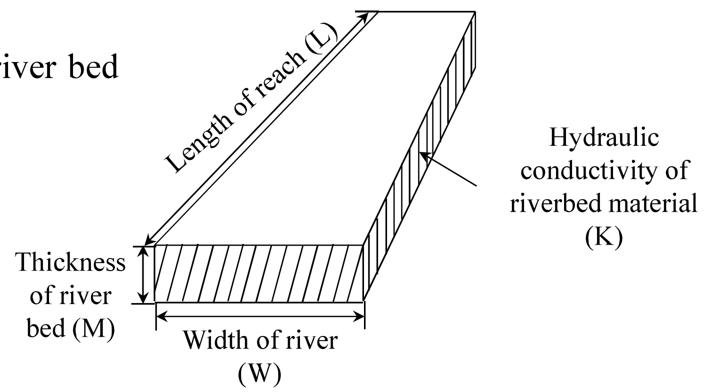
2. River conductance (C_{riv})

- River conductance is defined by river bed materials and slope

$$C_{riv}=\frac{KLW}{M}$$



2.1. River recharge coefficient

- The coefficient of streambed conductance (C_{riv}) is estimated from

$$Q_{riv}=C_{riv}\times(h_{riv}-h)$$

- Q_{riv} is taken as positive if it is directed into the aquifer,
- h_{riv} is the water level (stage) in the river (m),
- h is the head of groundwater (m)

Equation used

3. Interaction Mechanism

3. 1 Water balance analysis

- to check the water storage inflow into the aquifer and outflow from the aquifer

$$I - O = \Delta W / \Delta t$$

Where,

- I = inflow (m^3/day) during time Δt
- O = outflow (m^3/day) during time Δt
- W = change in water volume (m^3)

3. 2 River recharge (loss and gain)

- to check the flow between river and aquifer in up/ mid /down streams

$$\sum_{i=1}^{n} Q = \sum_{i=1}^{n}(Qup - Qdown)$$

Where,

- Q = River loss or gain
- Q_{up} = River discharge in upstream
- Q_{down} = River discharge in downstream

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Field measurement

1. Land recharge

Purpose

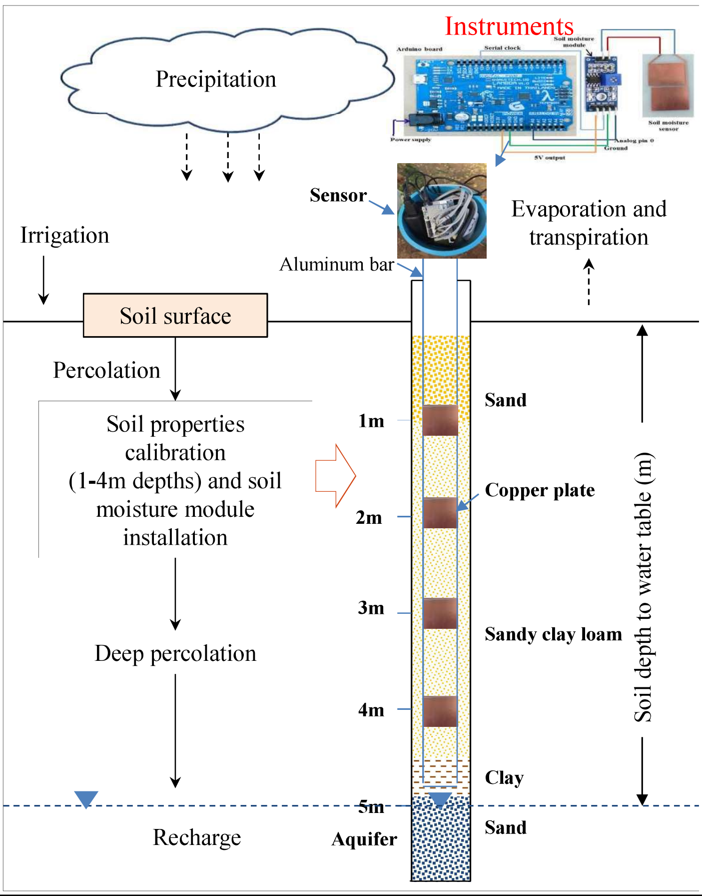
- to determine land recharge rate and land recharge coefficient via soil moisture sensor

Location

- The experiment site was located in the Rice Water Use Experimental Station 2 of Royal Irrigation Department in Phitsanulok Province

Study period

- Daily (108days) measured soil moisture data in the field at 1-4m depths



Data analysis

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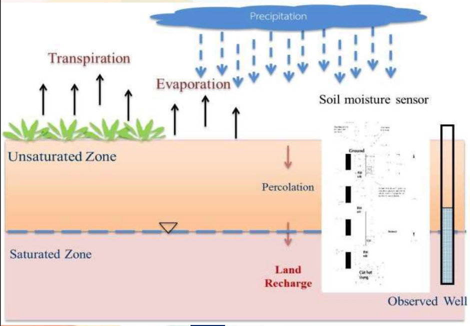
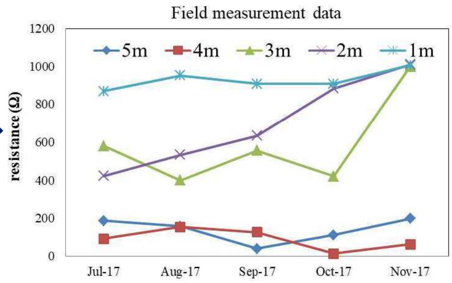
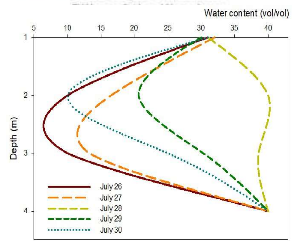
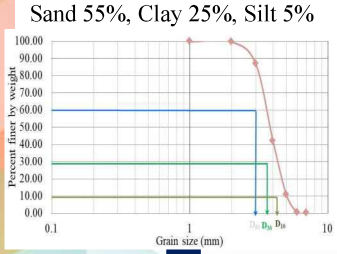


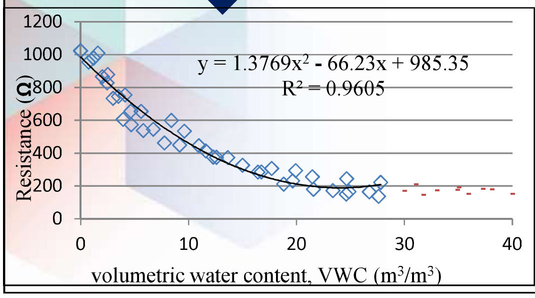




- Sandy clay loam (0-3m)
- Sandy clay(3-4m)

Sand 55%, Clay 25%, Silt 5%

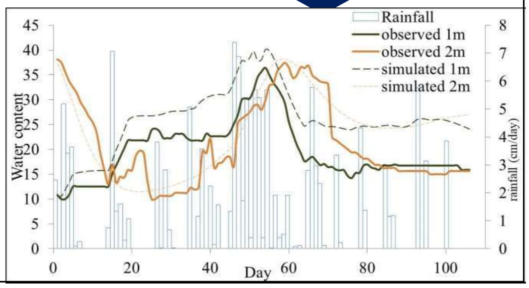




Calibrated soil hydraulic parameters

Materials	θ_r	θ_s	α	n	Ks	λ
S_{cl} (0m)	0.1	0.4	0.18	1.5	4	0.5
S_{cl} (1m)	0.095	0.41	0.11	4.2	8	0.5
S_{cl} (2m)	0.095	0.41	0.09	5.2	7.5	0.5
S_{cl} (3m)	0.095	0.41	0.08	5.1	5.5	0.5
S_c (4m)	0.095	0.41	0.11	3.4	3	0.5

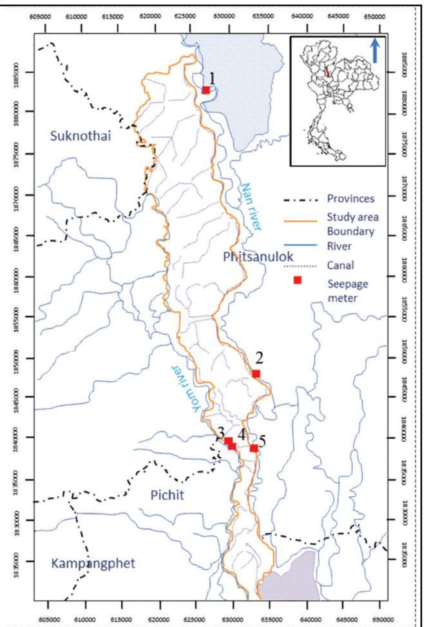
- HYDRUS-1D
- Input parameters
  - Rainfall
  - Evaporation
  - Transpiration
  - Groundwater level



Field methods

2. River conductance

- to know discharge and recharge from river seepage to analysis interaction mechanism



- ➢ Inject the steel ring (seepage meters) into the river bed.
- ➢ Measure the initial water discharge while the steel ring is injecting into the river bed.

- ➢ Connect with the plastic box by black cable (150cm) from steel ring to plastic box.
- ➢ Measure flux discharge to bag in 10-15 minutes.

- ➢ Then, measure the discharge by time (15min, 15min, 20min) for near bank and same as far from bank
- ➢ Noted the water volume discharge by time (15min, 15min, 20min)

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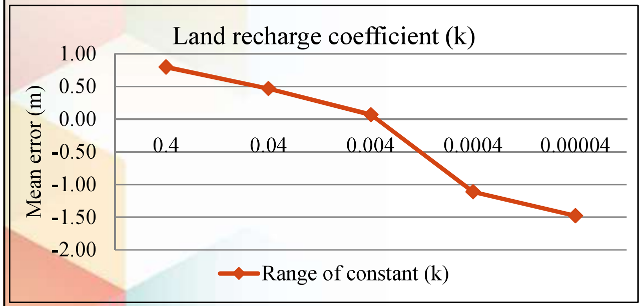
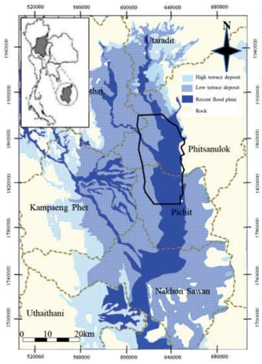
V. Results

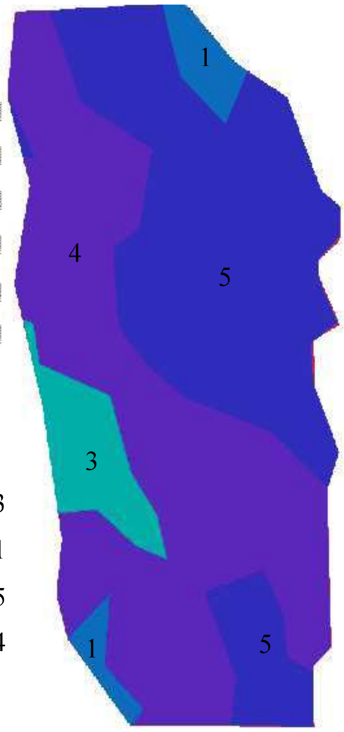
1. Land recharge analysis by soil types



Past (Gw model study)	Calibrated	Field measurement
0.003- 0.009	0.004	0.001- 0.003

Soil zone	Soil type	Recharge rate (Past GW model study)	Calibrated recharge rate (cm/d)
3	Sand	12	5.7
1	Sandy clay	9.8	4.6
5	Sandy clay loam	6.2	3.5
4	Clay	7.3	2.9





Soil zone 3
Soil zone 1
Soil zone 5
Soil zone 4

The field measured data is 4.43cm/day in sand clay loam.

Reference; Recharge rate in sandy clay is 4.4cm/day (Xiaohui Lu,2010)

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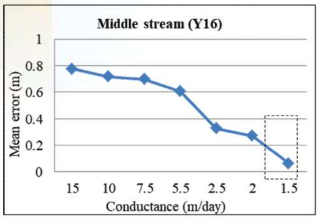
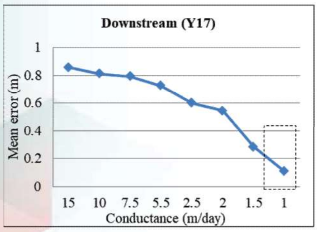
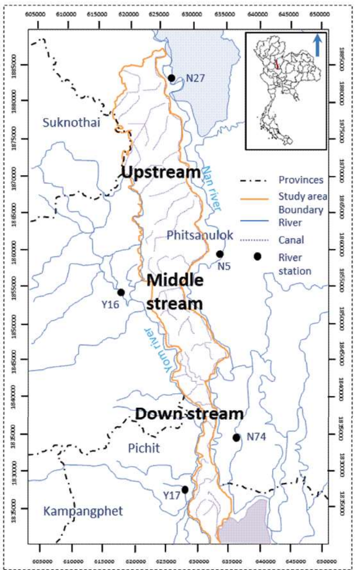
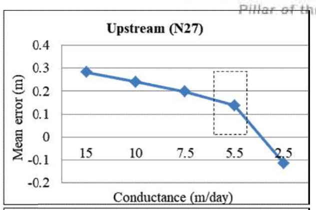
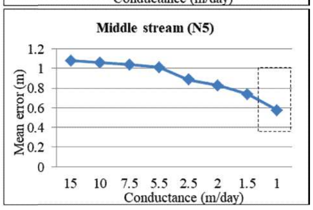
2. River conductance by river bed materials and slope

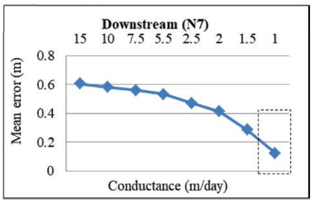












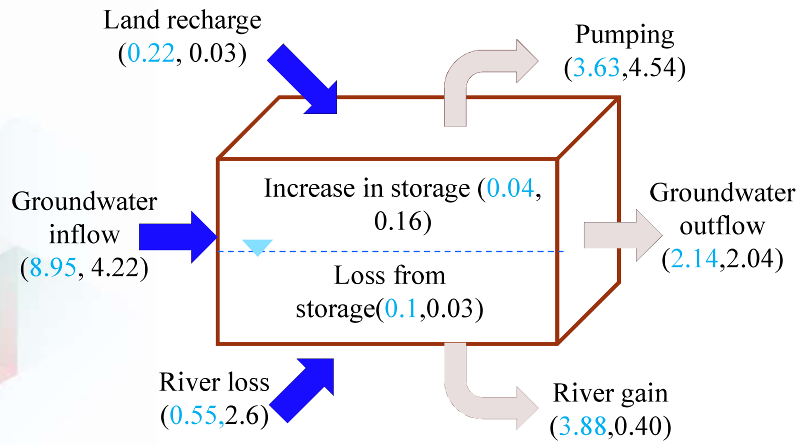
Stream	Bed material	Past study		Present study		Field measurement	
		Nan River	Yom River	Nan River	Yom River	Nan River	Yom River
Upstream	sand	2.2		5.5	-	7.8	-
Mid-stream	sandy clay	2.1	1.2	1.0	1.5	5.7	5.5
Downstream	clay	2.0	1.9	1.0	1.0	4.8	4.4

Reference: hydraulic conductance range from 0.1-4.9m/d in Saigon River (Tuan. P.V, 2018)

3. Interaction mechanism

- The surface water and groundwater interaction mechanism was analysed from flow budget of groundwater model and river loss and gain regime.

3.1 Annual groundwater flow budget



Blue refers wet season
Black refers dry season
unit: MCM/day

Annual	Boundary inflow	River loss	Land recharge	Storage in
Average of total	13.17	3.15	0.25	0.19
Annual	Boundary outflow	River gain	Pumping	Storage out
Average total	4.18	4.28	8.18	0.13
Annual Net	+8.99	-1.13	-7. 93	+0.06

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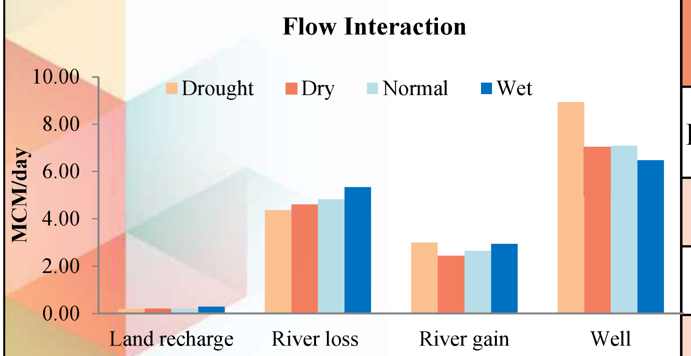
3. 2. Interaction volume by water year, unit: MCM/day

- The water year is defined by Bhumibol and Sirikit reservoirs storage on January 1st.

Water Year	Reservoir storage (MCM)
Drought	<4,200
Dry	4,200-8,500
Normal	8,500-12,500
Wet	>12,500



Water y					
Land recharge	0.20	0.22	0.22	0.30	0.24
River loss	4.37	4.62	4.83	5.35	4.79
River gain	3.01	2.46	2.66	2.95	2.77
Well	8.92	7.03	7.10	6.48	7.38

- Well abstraction increased from 6.4 – 8.9MCM, river discharge increase rapidly 4.3 -5.3MCM
- Groundwater discharge (river gain) decreased from 2.4 – 3.0MCM
- Land recharge seem not to effect to the flow interaction
- River recharge plays major role to balance the groundwater accumulation in this area

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3.3. Aquifer gain (River loss) and Aquifer loss (river gain), by locations

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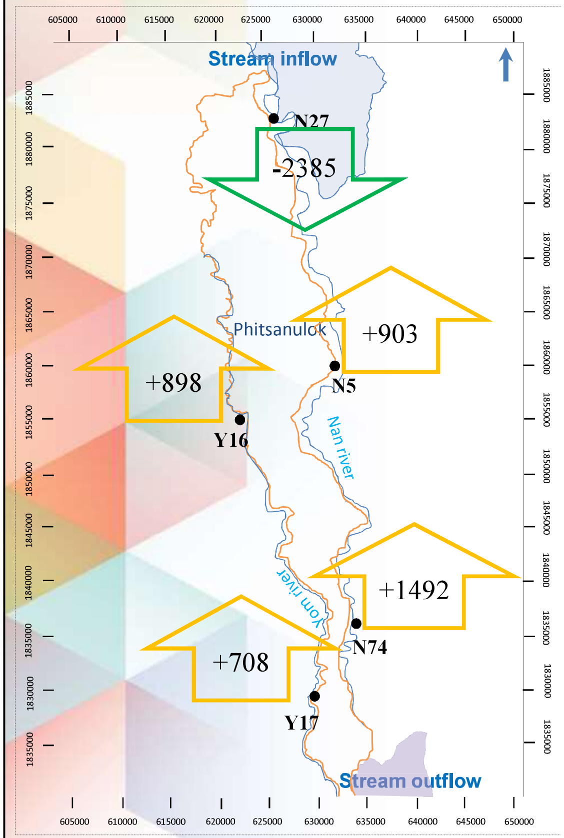
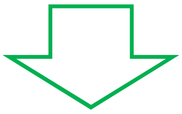
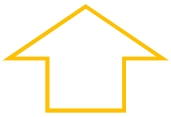



Aquifer loss to river (river gain)


Aquifer gain from river (river loss)

Remarks: Calculated Loss and Gain by months in three stations in Nan River and two stations in Yom River separately.

unit: m^3/day

Nan river	Upstream	Midstream	Downstream
Aquifer gain	+1,243.20	+1276.29	2200.53
Aquifer loss	-3,628.59	-373.07	-708.62
Net	-2,385.39	+903.22	+1,491.91

Yom River	Midstream	Downstream
Aquifer gain	+1,058.06	+785.24
Aquifer loss	-160.20	-76.45
Net	+897.86	+708.9

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Conclusions

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1. Land recharge rate and land recharge coefficient

Estimated the interaction parameter and compared with the model results

- Soil moisture sensor system was developed and installed to monitor the field soil moisture content for 108 days to understand deep percolation (recharge).

Land recharge	Past (Gw model study)	Present study (Calibrated)	Field measurement
coefficient	0.003- 0.009	0.004	0.001- 0.003
Rate (cm/day)	6.2 - 12	2.9-5.7	4.43

2. River conductance

- The seepage meter was used to estimate the river conductance values based on the river bed materials and slope.

Unit m/day	Past model study	Present study	Field measurement
Nan River	2.2-2.0	5.5 – 1.0	7.8 – 4.8
Yom River	1.9-1.2	1.5 – 1.0	5.5 – 4.4

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3. Interaction volume and patterns

- Estimated the interaction mechanism via water budget by time (water year/season) and by space (river upstream, mid-stream, downstream and land recharge by soil types)

Unit MCM/day	Wet	Dry	Total
Land recharge	0.22	0.03	0.25
Aquifer gain (River loss)	0.55	3.15	3.70
Aquifer loss (River gain)	3.88	0.40	4.28
Well	3.63	4.54	8.17
Boundary	8.95	4.22	14.17

- According to river loss and gain, Nan river loss to the aquifer 2,385m/day and water store in the midstream 903m/day and aquifer gain the water 1,491m/day in downstream and aquifer loss to the Yom river 897-708m/day from midstream to downstream.

- To raise groundwater level, boundary is mainly important effect and river recharge is semi-important effect in this area.
- The river recharges in the upstream in wet year through aquifer and filled back to river again in the mid and downstream reaches.
- These findings can be used for future groundwater planning and management in the area.

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ACKNOWLEDGMENTS

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References

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1. W.Bejranonda, S. Koontanakulvong, and C. Suthidhummajit, "Groundwater modelling for conjunctive use patterns investigation in the upper Central Plain of Thailand," in *International smposium-Aquifers Systems Management-30th May-1st June 206*Dijon, France, 2006, pp. 161-174.
2. W. Bejranonda, M. Koch, and S. Koontanakulvong, "Surface water and groundwater dynamic interaction models as guiding tools for optimal conjunctive water use policies in the central plain of Thailand," *Environmental earth sciences,* vol. 70, no. 5, pp. 2079-2086, 2013.
3. C. Suthidhummajit, S.. Koontanakulvong, "The Role of Groundwater to Mitigate the Drought and as an Adaptation to Climate Change in the Phitsanulok Irrigation Projrct, in the Nan Basin,Thailnd," *jurnalteknologi,utm.my,* vol. 76, no. 15, pp. 89-95, 2015.
4. W.Bejranonda, S. Koontanakulvong, and C. Suthidhummajit, "Study of the Interaction between Streamflow and Groundwater toward the Conjunctive use Management: a Case Study in an Irrigation Project," 1st NPRU Academic Conference, Oct. Annals, 2008, pp. 59-67
5. P. P. Aye and S. Koontanalulvong, " Hydrogeological parameter distribution estimation by Geostatistical methods in Regional Groundwater Modeling in the Upper Central Plain, Thailand", IJCIET, vol 9, no. 3, March 2018, pp. 313-322.
6. P. P. Aye, S. Koontanakulvong and T.T. Long, " Deep percolation characterisitcs via field soil moisture sensors: case study in Phitsanulok, Thailand", Taiwan Water Conservancy, vol 67, no. 1, March, 2019, pp. 1-10.
7. J. Šimůnek, M. T. van Genuchten, and a. M. Šejna, "The HYDRUS-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variable-saturated media," in HYDRUS softeare series 1, University of California Riversitd, USA, 2005.
8. Y. Mualem, "A new model for predicting the hydraulic conductivity of unsaturated porous media," *Water Resources Research,* vol. 12, no. 3, pp. 513-522, June, 1976.
9. M.G. McDonald and W.A. Harbaugh, "A modular three-dimensional finite difference groundwater flow model," U.S.Geological Survey, Open file report, pp. 83-875, 1988.
10. D.R Lee and J.A. Cherry, A field exercise on groundwater flow using seepage meters and mini-piexometers,Journal of Geological Education, vol. 27,no1, pp. 6-10, 1978.
11. M. J. Xiaohui Lu, Martinus Th. van Genuchten, Binggo Wang, "Groundwater Recharge at FIve Representative Sites in the Hebei Plain, China," *National Ground Water Association,* vol. 49, no. 2, pp. 286-294, 2010 2010.
12. R. A. Schincariol and J. D. McNeil, "Errors with small volume elastic seepage meter bags," *Ground water,* vol. 40, no. 6, pp. 649-651, 2002.
13. W. R. S. R. Unit, "The impact of Climate Change on Irrigation Systems and Adaptation Measuers (Plaichumphol Irrigation Project case study),"pp. 301, 2010.
14. T.V.Pham and S. Koontanakulvong "Groundwater and River Interaction Parameter Estimation in Saigon River, Vietnam," *Engineering Journal,* vol. 22, no. 1, pp. 257-267, 31/Jan/2018 2018.
15. S. Koontanakulvong, C. Suthidhummajit, "Flow budget and conjunctive use pattern of groundwater system under climate change in Upper Central Plain, Thailand," in *THA 2017 International Conference on —Water Management and Climate Change Towards Asia's Water-Energy-Food Nexus*, Bangkok, Thailand, 2017, pp. 186-191.

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Q&A

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