SW-GW interaction study and its application to Groundwater modeling

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I. INTRODUCITON

1.1 Background Problem

- In the last decades, water demand has increased due to the rapid development in economy in Thailand.
- As many irrigation projects in Upper Central Plain are not capable to provide sufficient amount of water to farmers (RID, 2007).
- 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).
- The average GW use in normal water year is 134.4 MCM/year with 40% and 60% to the wet and dry season (Werapol et al., 2003)
- The farmers used GW about 715 MCM/year for agriculture in Upper Central Plain area (Chokchai et al, 2007).
- In Plaichumphol Irrigation Project area, the farmer used GW143.6MCM/year (74MCM in dry and 69MCM in wet) (Werapol. B., 2007)
- These amount are not enough for their cultivation in this area

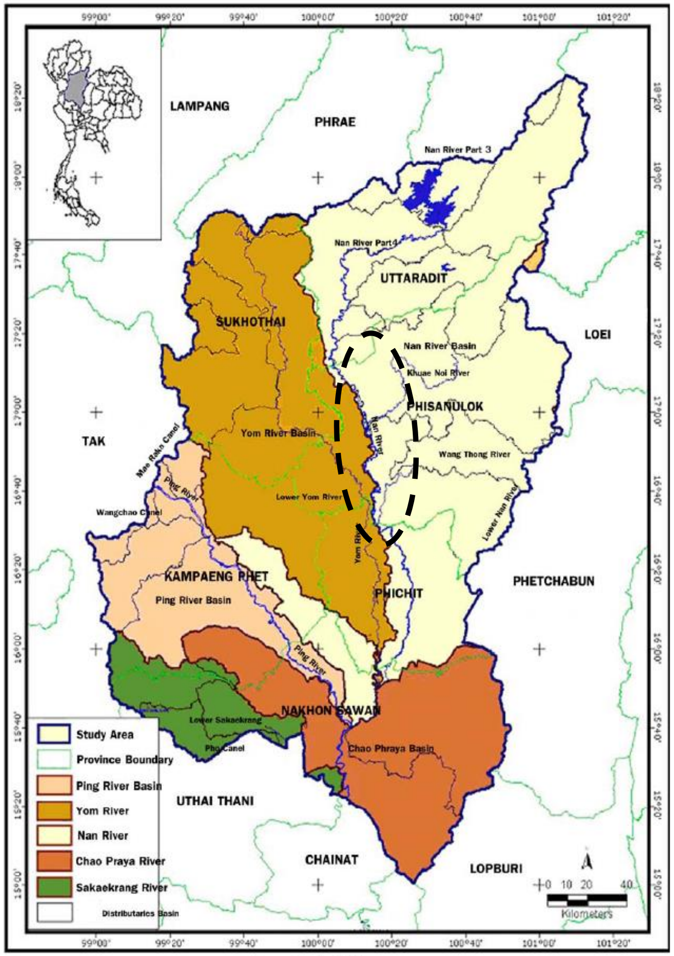
1.2 Research Significance

- **Dominant parameters for gw simulation (interaction parameters)**
- **Field measurements with sensor installation**
- **Parameter determination (with soil type, rainfall intensity)**
- **Application to gw modelling to find flow budget**
- **Interaction pattern and volume (mechanism)**
- **Application to climate change impact assessment in future study.**

II. STUDY AREA CONDITIONS

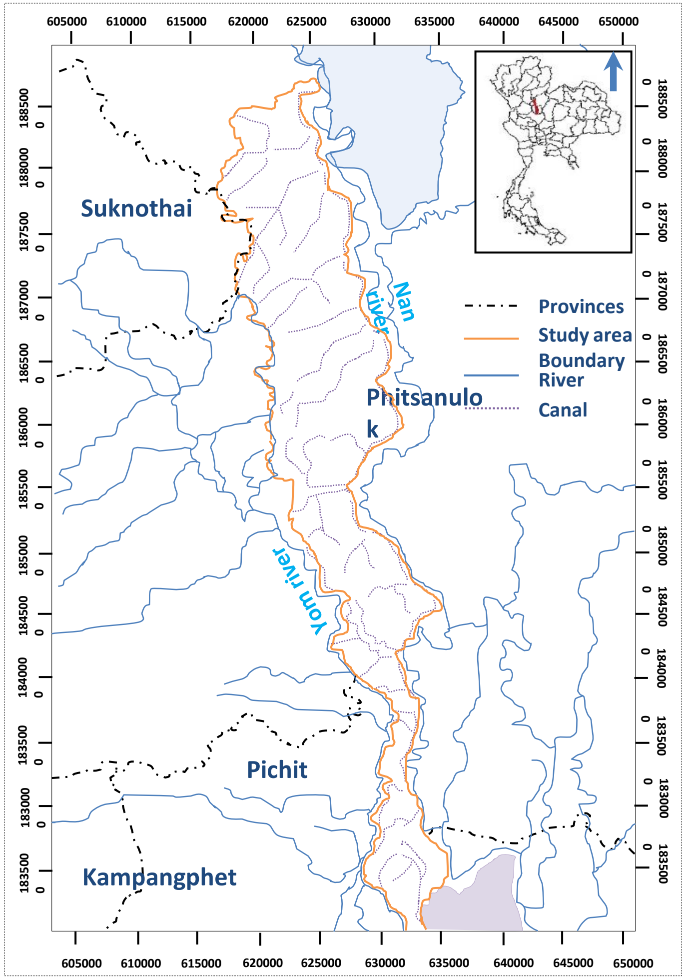
Study area

- This study used the regional area (Upper Central Plain) and the local area (Plaichumphol Irrigation Project, PIP) to understand flow budget and groundwater and surface water interaction mechanism.



Upper Central Plain (Regional area)
(Source; Koontanakulvong S. et al., 2006)

Regional area	47,986 km^2
Local area	436km^2
Irrigation Area	338km^2
Main rivers	Nan and Yom



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

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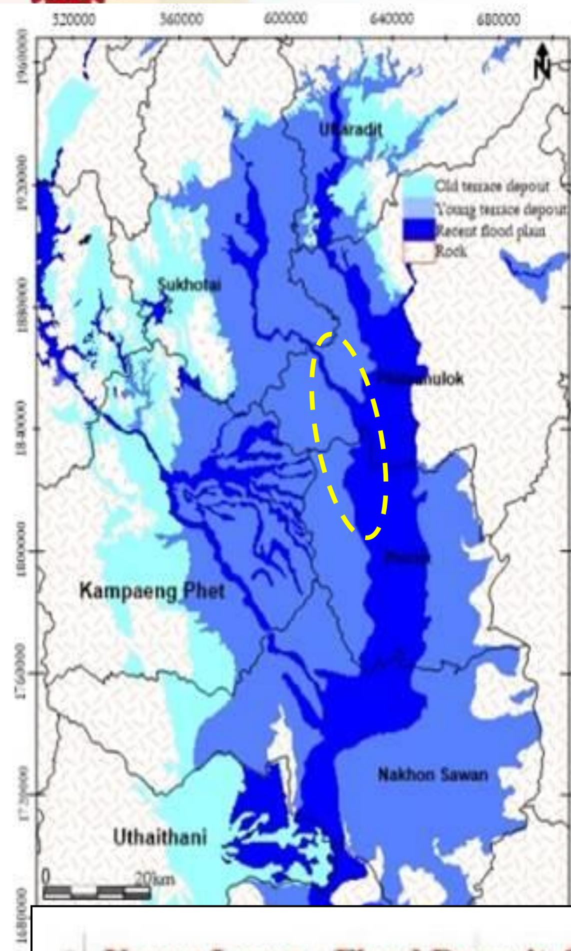
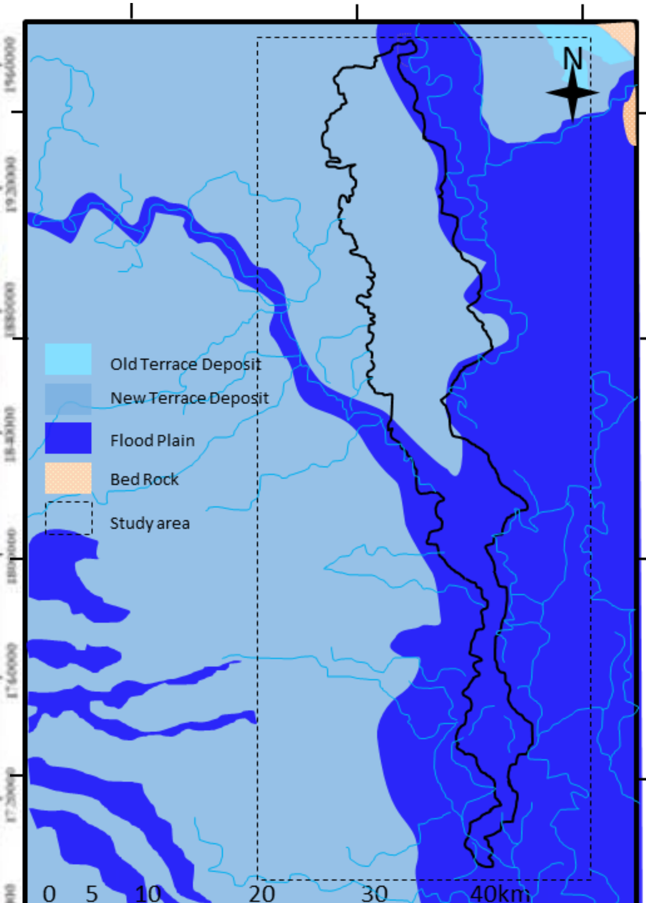
Aquifer Characteristics





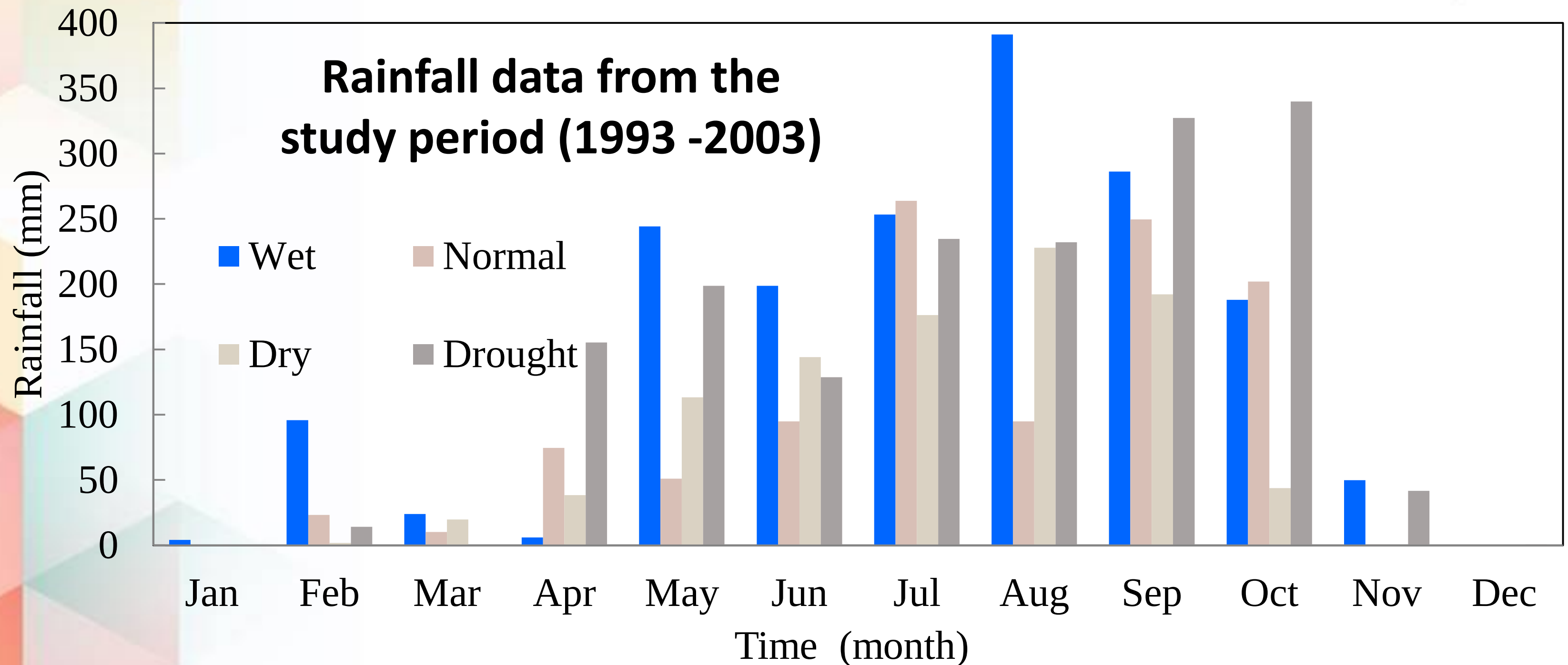
High Terrace Deposit

Low Terrace Deposit

Recent Flood Plain Deposit

(Source: Werapol B., 2006)

Climate



Climate Parameter	Monthly average data
Temperature (°C)	23.4-30.7
Wind Velocity (knot)	0.9-2.1
Evaporation (mm)	109.8-186.8
Humidity (%)	61-86
Precipitation (mm)	107.7-152.4

3. Objectives and scope of the study

Objectives

The main objective

- **to analysis the mechanism of surface water and groundwater interaction**

The specific objectives;

1. **To determine surface and ground water interaction parameters via field measurement,**
2. **to determine the surface water and groundwater interaction parameters used in local groundwater model in the study area and compared with field measurement data,**
3. **to analyse interaction volume and pattern by applying gw modeling.**

Scope of the study

1. Interaction

- In the study, we focused one two main aspects of interaction between surface water and groundwater.
- Firstly, the flow of groundwater support rainfall (land recharge) and secondly the flow from rivers to groundwater (river recharge).
- It is primarily determined by the relationship between surface water and groundwater levels.

Scope of the study

2. Mechanism

- **In addition, the mechanism of interactions between groundwater and surface water (GW–SW) as affect recharge–discharge processes which change in volume and direction in space (up, mid, downstream) and time (water year and water season) of interactions.**

Scope of study

3. Tools used

- Interaction field measurements

  Land recharge with soil moisture sensor (Arduino),

  HYDRUS-1D software package for data analysis

  River recharge (Seepage meter, river conductance)

- Regional and Local GW model

  Groundwater modeling system (GMS)

  (boundary conditions for LGM,

  interaction parameter, flow budget, interaction mechanism from LGM)

Scope of the study

4. Time period

- **Field measurements (to compare the parameters with the model parameters)**

  Land recharge (August 2017 - Feb 2018)

  River recharge (23 - 28 January 2018)

  River water level (April 2016 - Feb 2018) (to check the river recharge parameter)

- **Regional Model (boundary conditions for local model) (1993-2003)**

  River water level, recharge rate (monthly)

  Pumping rate, observed water level (seasonal)

  Calibration and verification (seasonal)

- **Local model (to understand the mechanism)**

  Interaction parameters estimation from model result (1993-2003)

  Interaction mechanism analysis from model result (1993-2003)

Scope of study

5. Data used

- The study is based on secondary and primary data collection.
- Field observation for land recharge was done in September 2017 for soil moisture monitoring test and seepage flux in January 2018.

No.	Data	Source	Description
1	Topography	Thai Military Map Department (2003)	Map scale 1:50,000
2	Monthly Rainfall data	Thai Meteorological Department and Royal Irrigation Department (1993-2003)	Digital files
3	Monthly Evaporation	Thai Meteorological Department (2017)	Digital files
4	The man stream	Thai Meteorological Department	Digital files
5	Result of Pumping Test and Groundwater Parameter	Conjunctive use project on the upper Chao Phraya basin and Groundwater Department (1993-2003) (259 wells)	Digital files

Scope of study

5. Data used (cont.)

No.	Data	Source	Description
6	Observation wells (38 wells)	Plaichumphol Irrigation Project (PIP) (1998-2008) (2016-2018)	Digital files Self-measuring
7	Well level(MSL)	Plaichumphol Irrigation Project (PIP) (2016-2018)	Self-measuring
8	River stage	8stations (1998-2016) from RID	Digital files
		5 stations (2016-2018)	Self-measuring
9	Soil sample	4 samples (2017)	Self-measuring
10	Soil moisture	5 stations	Self-measuring
11	Seepage measurement	7 stations	Self-measuring

4. Literature reviews

4.1 Land recharge analysis

There are vary commonly methods using to estimate natural ground water recharge since 1960s.

1. **Soil water balance model**
2. **Zero flux plane method**
3. **The inverse modeling technique**
4. **Groundwater level fluctuation method**
5. **A hybrid water fluctuation**
6. **One-dimensional soil water flow model**

- **Soil water balance method is facing difficult task in runoff and evapotranspiration in regional scale**
- **Zero flux plane method is challenge on determine zero flux plane depth under saturated condition**
- **Hybrid water fluctuation method and Ground water level fluctuation method are facing special storage and steady recharge estimation**
- **Chemical/ radioactive method get problems of mixing of water of different origins, then can use as evaluation process under clear the mechanism of groundwater recharge.**
- **One-dimensional soil water flow model is the popular methods to estimate land recharge in point scale. If statistic application, this method can provide land recharge function for regional scale**

4.1.1 Soil moisture

Soil moisture is a significant parameter in the atmospheric water cycle of land and atmosphere interaction (Raju,2017).

Lu et al. (2010) estimated the groundwater recharge at five representative sites to investigate the effects of irrigation and water table depth on groundwater recharge. A one-dimensional unsaturated flow model (HYDRUS-1D) was used to calibrate field data of climate, soil moisture, and groundwater level.

4.1.1 Soil moisture (cont.)

Kojima et al. (2016) developed a low-cost soil moisture profile probe using thin-film capacitors and a capacitive touch integrated circuit. The developed sensor captured dynamic changes in soil moisture at different depth, with a period required after sensor installation for the contact between capacitors and soil to down. The results showed that the influence of the individual sensor differences, however, the developed sensor could detect large differences and the different magnitude of changes in soil moisture. They suggested that the developed sensor made more affordable to farmers as it requires low financial investment and it can utilized for decision making in irrigation.

4.1.1 Soil moisture (cont.)

Yong Li et al. (2017) studied the modelling of soil water regime and water balance in a transplanted rice field experiment with reduced irrigation and evaluated using HYDRUS-1D model. Measured and simulated results indicated that water percolation was the main path of water losses from the transplanted rice fields, and suggested that long and high standing water increased water percolation.

4.1.2 Deep percolation

Deep percolation is the flowing of soil moisture by gravity below the effective of root zone. It is important factor in filling of groundwater and design of surface drainage. Deep percolation plays a crucial role in studies of artificial nutrition of pastures and catchment basins and designing of drains. There are four methods available for estimation or measuring the deep percolation:

1. **water balance method**
2. **method of concurrent measurement**
3. **chloride mass balance modelling**
4. **Darcian flux**

4.1.2 Deep percolation (cont.)

Allison et al. (1994) stated that when soil water flux is calculated at such a depth in the profile that no further extraction by roots occurs, then the flux will be equal to groundwater recharge. To estimate groundwater recharge, deep percolation must be monitored below the root zone where it would be constant. The root zone of cotton was estimated to extend from 0-0.8m and deep percolation was calculated below this depth so that groundwater recharge could be estimated. Estimates of deep percolation were obtained at a depth of 2.0m using the water balance and water content were collected to this depth. (Slavich *et al.*,1995)

4.2 Seepage meter

Numerous methods have been used to assess streambed seepage, including differential gauging, seepage meters, shallow piezometers, and tracer injection experiments

Lee et al. (1978) studied a field exercise on groundwater flow using seepage meters and mini- piezometers. They described the use of two simple inexpensive devices that enable students to measure the flow of groundwater and to demonstrate for themselves some of the basic principles of hydrogeology. The devices are known as the miniature piezometer and the seepage meter. Seepage meters and miniature piezometers are inserted in the sediment of shallow areas in lakes, estuaries, or streams, a few hours; the devices can be installed, monitored, and removed. Information on the direction and rate of groundwater flow can be obtained.

4.2 Seepage meter (cont.)

Lee et al. (1979) designed a seepage meter consisting of one end of a 55-gaon (208 liters) steel rum that is fitted with a sample of pot and a plastic collection bag. The drum forms a chamber which is inserted open end down into the sediment water seeping through the sediment will displace water trapped in the chamber forcing it up through the port into the top plastic bag. The change in volume of water in the bag over a measured time interval provides the flux measurement.

4.3 Previous study in Upper Central Plain and Plaichumphol Irrigation Project area

Koontanakulvong et al. (2003) used MODFLOW model to summarise the groundwater model methodology and determine the parameter application to the complex groundwater system with limited data constraint of the North part of Lower Central Plain, Thailand. Calibrated model provided acceptable results and they provided flow characteristics, water balance of inflow-outflow, recharge can be used as a groundwater management planning. However, they suggested that the more accurate model needs more reliable input parameters on both method and data. Better estimations of the parameter are still required.

4.3 Previous study in Upper Central Plain and Plaichumphol Irrigation Project area (cont.)

Chokchai et al. (2015) applied MODFLOW using the bias corrected MRI-GCM data to mitigate the drought and as an adaption to climate change in the Plaichumphol Irrigation Project, in the Nan Basin, Thailand. They investigated relationship of recharge rate with climate condition (temperature), to assess the impact on groundwater recharge in the Upper Central Plain. assessed the impact on GW recharge in this area. They found that the recharge decrease and GW level decrease in both near and far future.

4.3 Previous study in Upper Central Plain and Plaichumphol Irrigation Project area (cont.)

Chokchai et al. (2017) used MODFLOW to understand the flow budget and conjunctive use pattern of surface water and groundwater mechanism under climate change scenario in the regional scale. Their study showed that the average land recharge was 0.9 MCM in wet season and 0.01MCM in dry season. The river recharge were different from land recharge, it recharged to aquifer is 0.77MCM/day in wet season but it received water from aquifer is -1.54 MCM/day in dry season. The average groundwater pumpage was very high in dry season, i.e., 2.0 MCM/day.

4.4 Parameter estimation

Logan, J., (1964) studied the transmissibility from routine production tests of water wells. He estimated the transmissibility (T) from the results of routine pumping tests of water well when only discharge (Q), drown (ΔS) and aquifer thickness (m) for confined conditions. A value for the quantity log was established and the logarithm of their ration are not vary a great deal.

The estimated transmissivity ranges from is reasonable.

4.4 Parameter estimation (cont.)

Xiaohui Lu et al. (2010) studied groundwater recharge at five representative sites in the Hebei Plain, China. Recharge is estimated using empirical equation by multiplying the precipitation rate by an empirical recharge rate. HYDRUS-1D software package was used to simulated 1D vertical flow using field data of climate, soil moisture, and groundwater levels. The average recharge rate is 4.4cm/day for sandy clay.

4.4 Parameter estimation (cont.)

Tuan et al. (2018) studied groundwater and river interaction parameter estimation in Saigon River, Vietnam to analysis the interaction between river recharge and groundwater reserve. Groundwater modelling system was applied to simulate conductance calibration, water balance and river recharge. The calibrated river conductance range from 0.1 to 4.9m/d. Their result for groundwater modelling, hydraulic conductivity estimation of riverbed can be applied for future groundwater modelling.

5. Methodology and Theories used

5.1 Methodology

1. Field measurements on land recharge and river interaction
2. Secondly, regional groundwater model (RGM) was developed to be used as boundary conditions for local groundwater model (LGM)
3. Thirdly, to understand the interaction mechanism more precisely, local groundwater model was developed with parameters from field measurements
4. Finally, the surface water and groundwater interaction mechanism (volume and pattern) were analysed from flow budget of local groundwater model

5.2 Theories used

1. Recharge parameter estimation by field measurement
   - Deep percolation rate (HYDRUS-1D)
   - River hydraulic conductance
2. Interaction mechanism
   - Land recharge
   - River loss and gain
3. Groundwater flow model (GMS)
   - Parameter estimation
   - Empirical formula (Transmissivity (T) estimation, specific capacity (Sc)
   - Geostatistics methods (Hydraulic conductivity (K),

5.3 Recharge parameter estimation via field

1. Land recharge analysis

One-dimensional soil water flow model

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K(h)\frac{\partial h}{\partial z}\right) + \frac{\partial}{\partial z}(K(h)) \qquad [6]$$

HYDRUS-1D Simulation

$$\theta(h)=\begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{[1-|\alpha h|^n]^m} & h<0 \\ \theta_s & h\geq 0 \end{cases} \qquad [6.1]$$

$$K(h)=K_s S_e^{1/2}\left[1-(1-S_e^{1/m})^m\right]^2 \qquad [6.2]$$

$$S_e=\frac{\theta-\theta_r}{\theta_s-\theta_r} \qquad [6.3]$$

- 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
- K_s is the saturated hydraulic conductivity
- α is the inverse of the air-entry value (or bubbling pressure)
- n is a pore-size distribution index
- S_e is the effective water content

5.3 Recharge parameter estimation via field (cont.)

2. River recharge (the flow between river and aquifer, Q_{riv})

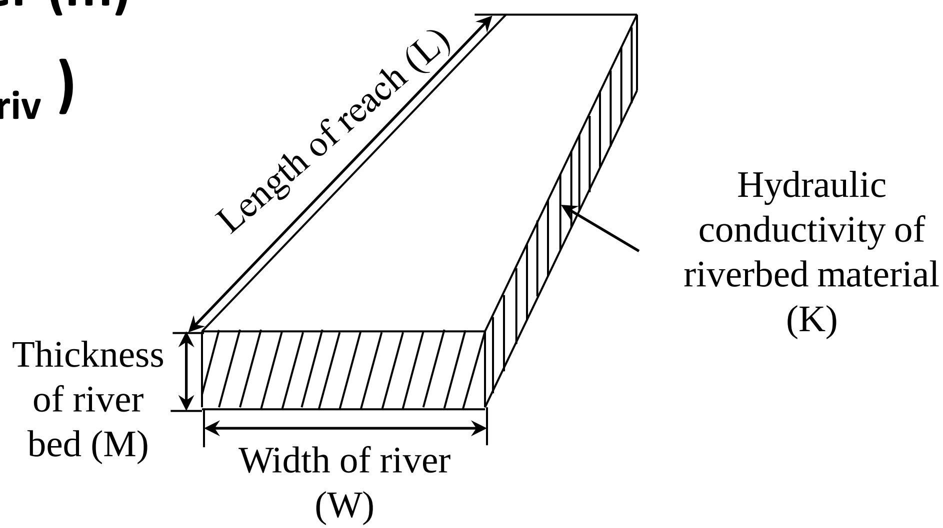
- **The coefficient of streambed conductance (C_{riv}) is estimated from :**

  $$Q_{riv} = C_{riv} \times (h_{riv} - h) \quad [7]$$

- **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)**

3. River hydraulic conductance (C_{riv})

$$C_{riv} = \frac{KLW}{M} \quad [8]$$



5.4 Interaction Mechanism

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1. River recharge (loss and gain)

- River Loss and Gain Equation

$$\sum_{i=1}^{n} Q = \sum_{i=1}^{n} (Qup - Qdown) \qquad [9]$$

Where,

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

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

6. RESULTS

6.1 Field measurement data

6.1.1 Deep percolation estimation via Soil moisture sensor

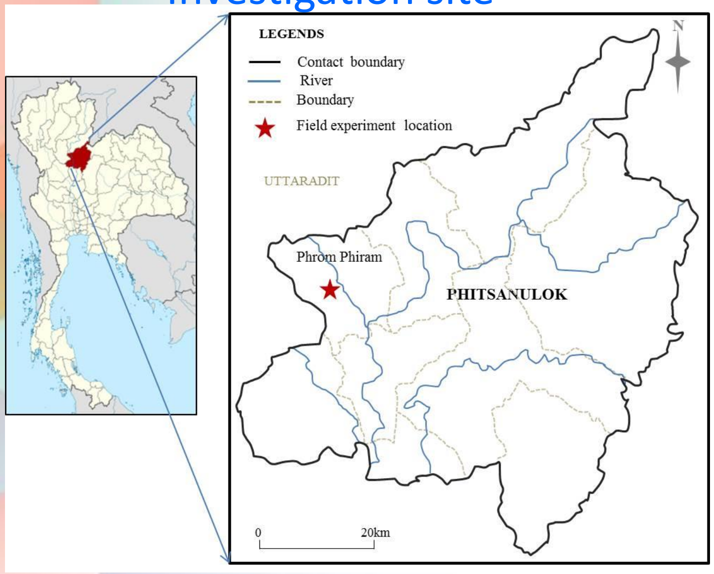
Purpose

•to understand deep percolation (land recharge) characteristic in the unsaturated zone for developing groundwater modelling

Study period

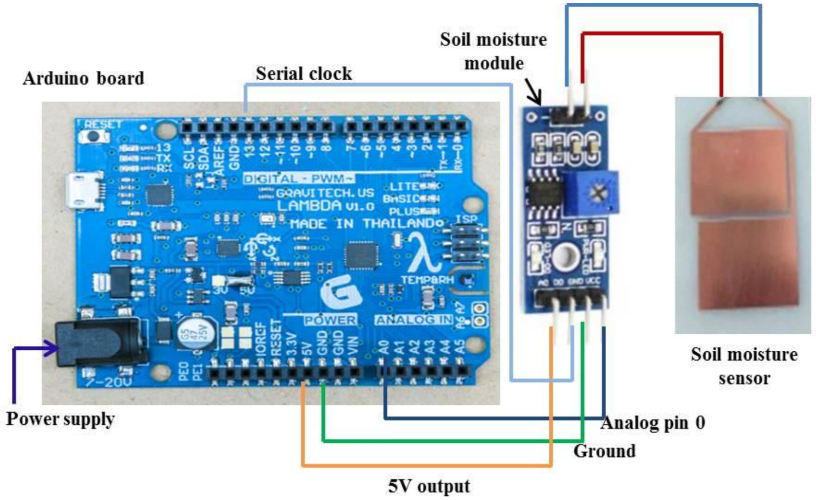
•August 2017 - Feb 2018 (108 days)

Investigation site



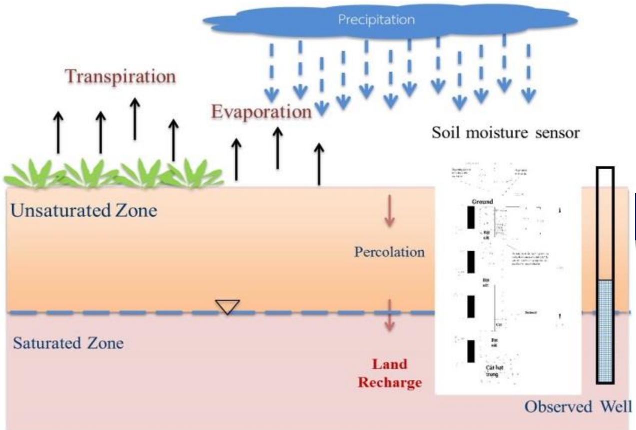
- Royal Irrigation Department (RID), Phom Piram District
- 20×25sq.m

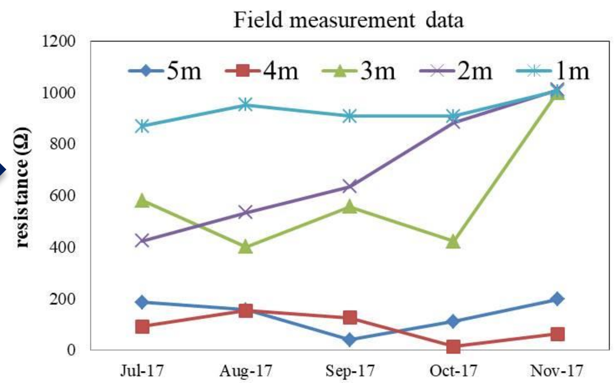
Instruments

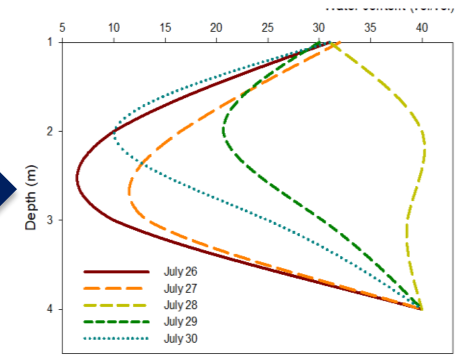


1. Arduino board (electrical resistance)
2. Soil moisture module
3. Soil moisture sensor

Data analysis

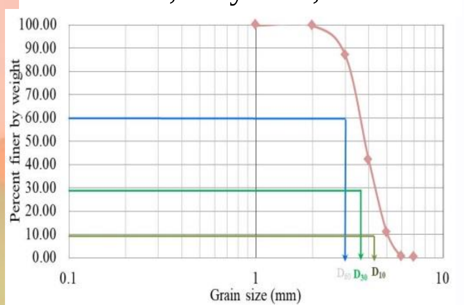


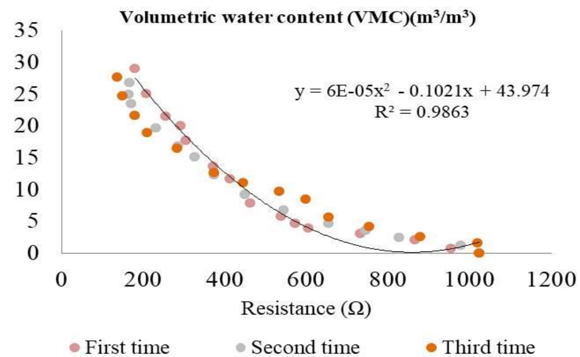




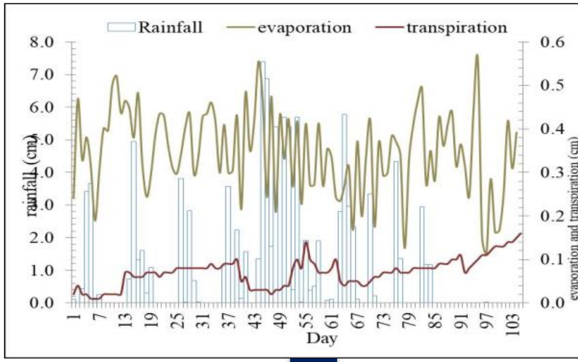
- Sandy clay loam (0-3m)
- Sandy clay(3-4m)

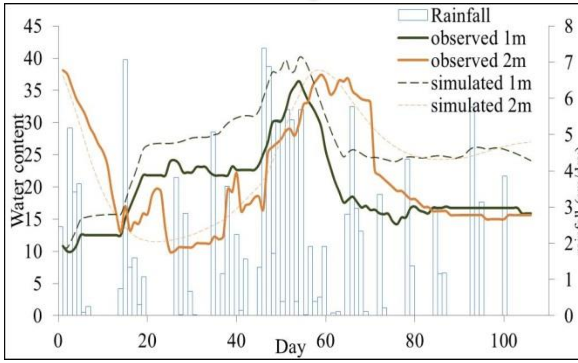
Sand 55%, Clay 25%, Silt 5%





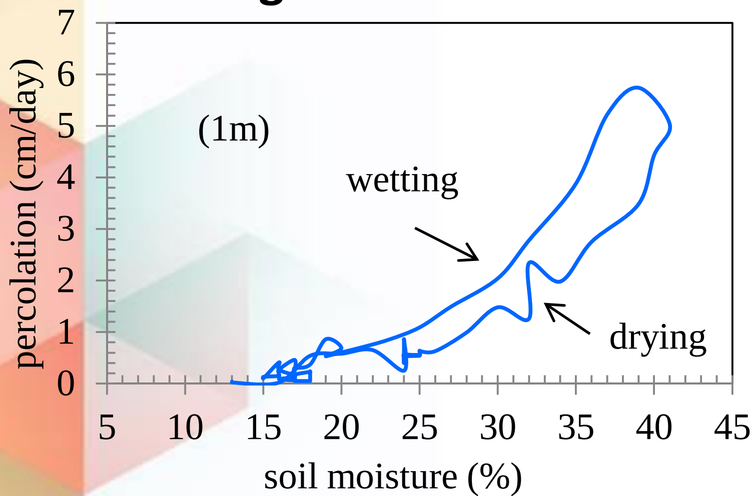
- **Daily measure (106days)**
- **1-4m depth**
- **HYDRUS-1D**
- **Input parameters**
  - **Rainfall**
  - **Evaporation**
  - **Transpiration**
  - **Groundwater level**

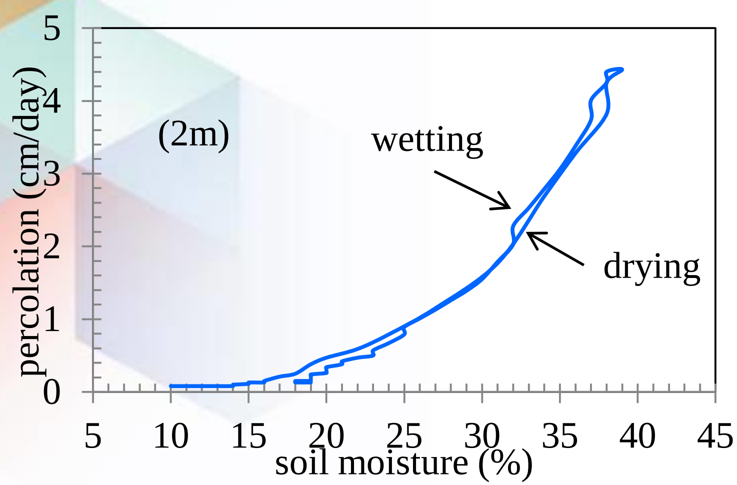




Percolation characteristics

- two different curves during wetting and drying stages of soil due to the evaporation and transpiration from soil storage.
- the daily deep percolation from 1m depth to 2m depth is almost in one curve both in the wetting and drying stages due to the effect of no evaporation to water storage in the soil.





Soil moisture	Percolation rate (cm/d) 1m	Deep Percolation rate (cm/d) 2m
Saturated (41%)	5.07	4.4
Field capacity (17-25%)	0.86	0.79
Wilting point (17%)	0.02	0.15

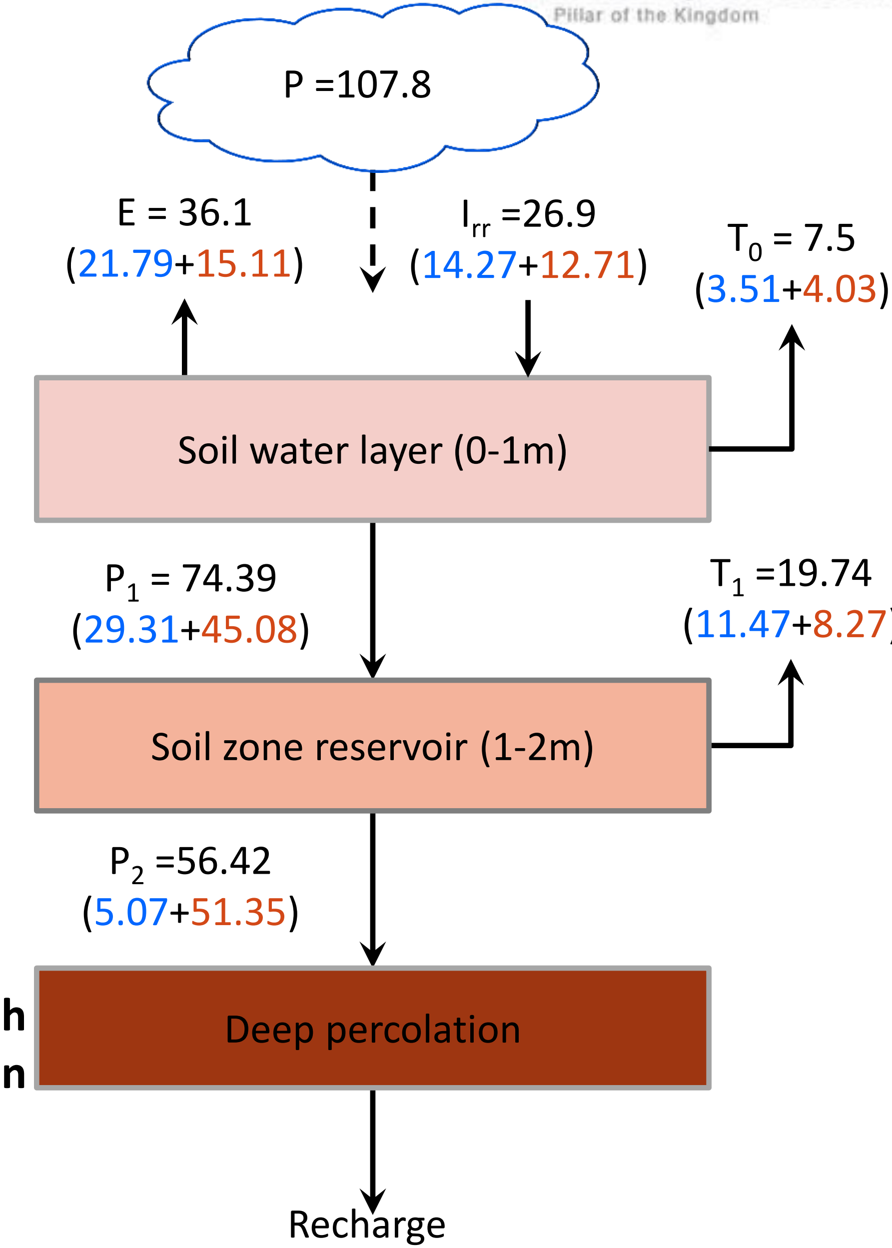
Reference: Groundwater recharge could be estimated at a depth of 2.0m of estimated deep percolation. (Allison et al., 1994))

Water balance of percolation system

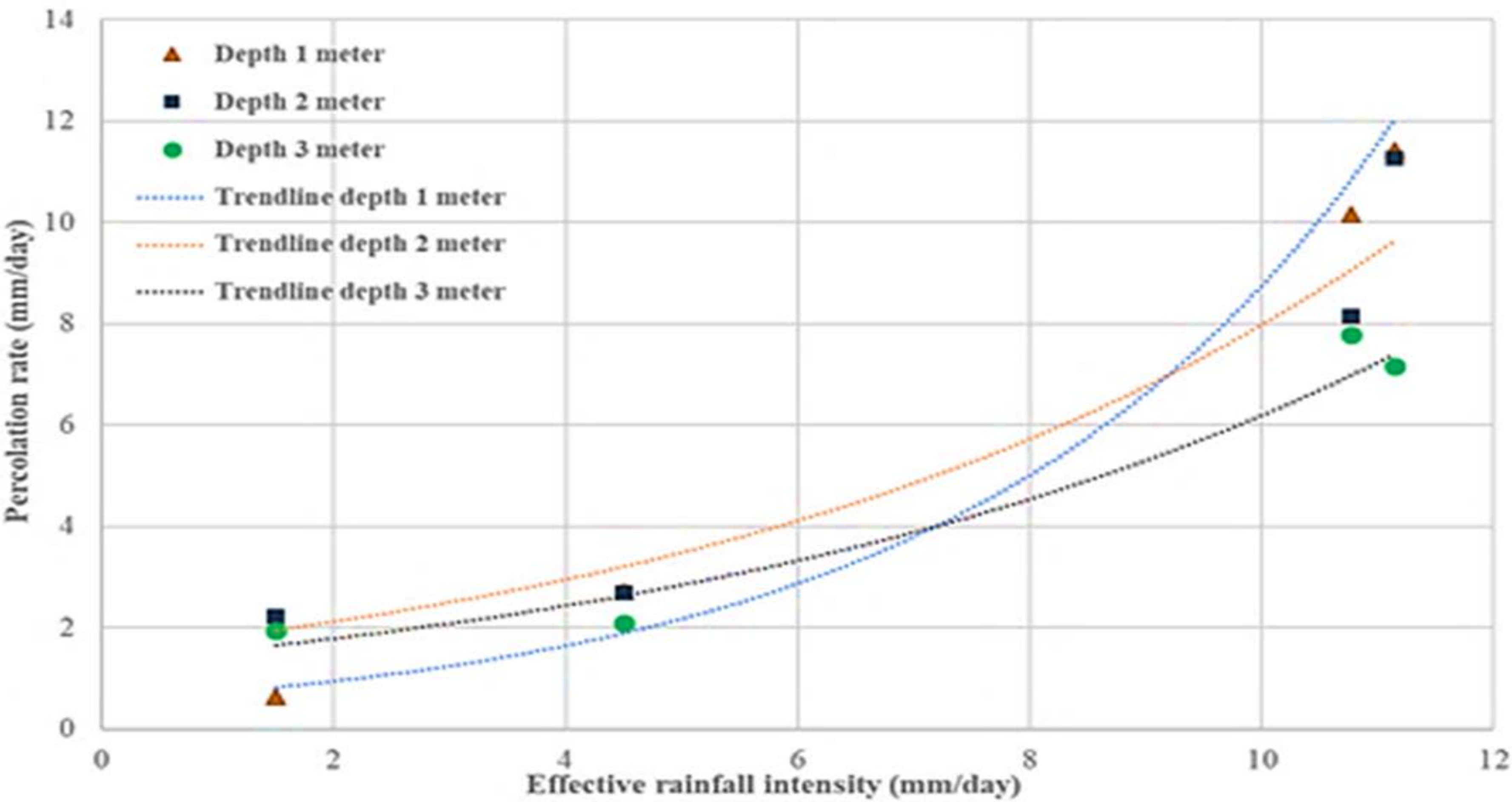
- Input-output of each component for water balance analysis of both wetting, drying processes (in bracket)

Average recharge rate (mm/day)	
Xiaohui Lu et al., 2011	5.5
Chokchai. S. et al., 2017	3.8
Present study (deep percolation rate)	5.2

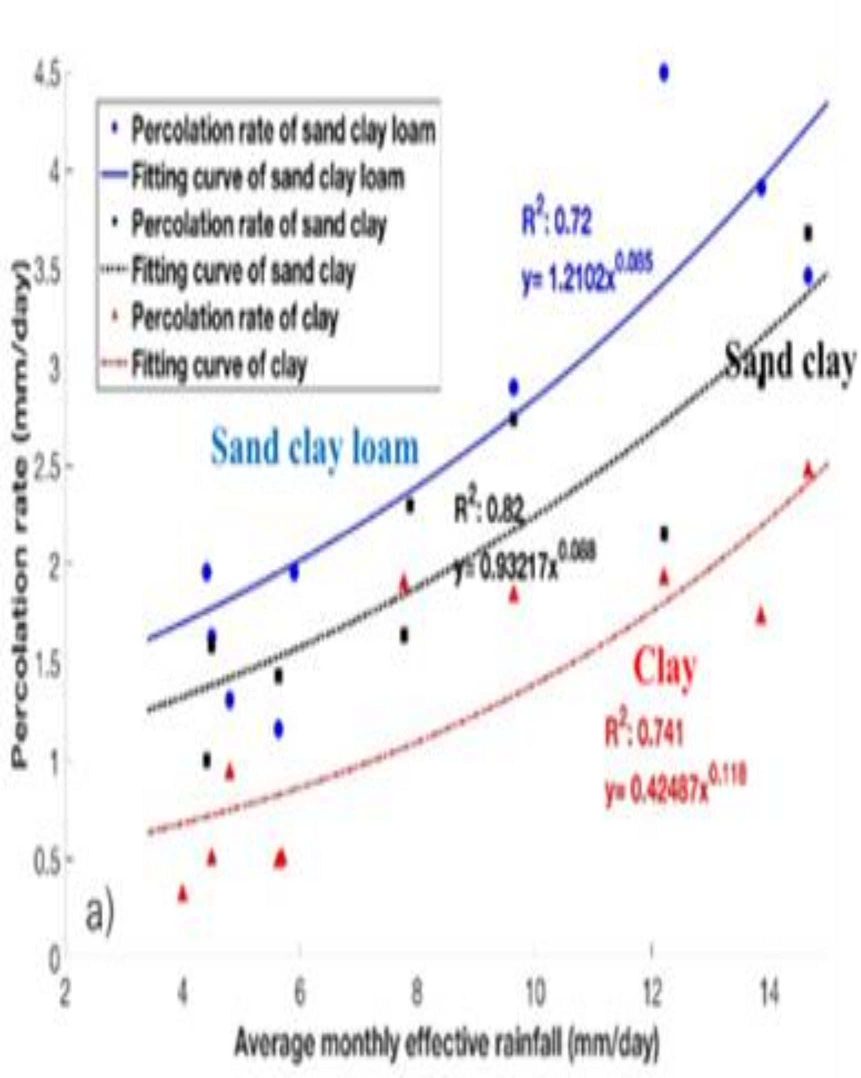
Remarks: the results provided to estimate both irrigation demand and groundwater recharge in GW modelling.



Recharge coefficient



Vietnam case



6.1 Field measurement data

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6.1.2 River conductance estimation via Seepage meter measurement

Purpose

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

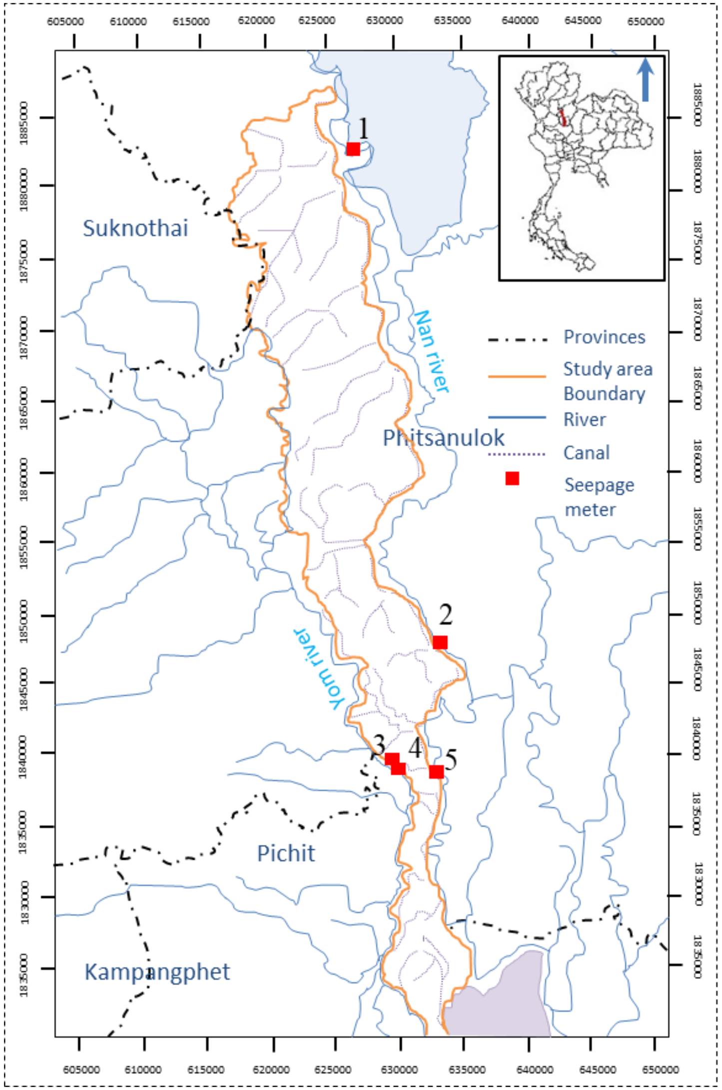
•to compare and check the local groundwater model (flux).

Location

•the flux discharge from groundwater to river was measured at 5 stations along the rivers.

- 2 stations (Yom river)
- 3 stations (Nan river)

•The test was processed at right river bank and main channel river bed.



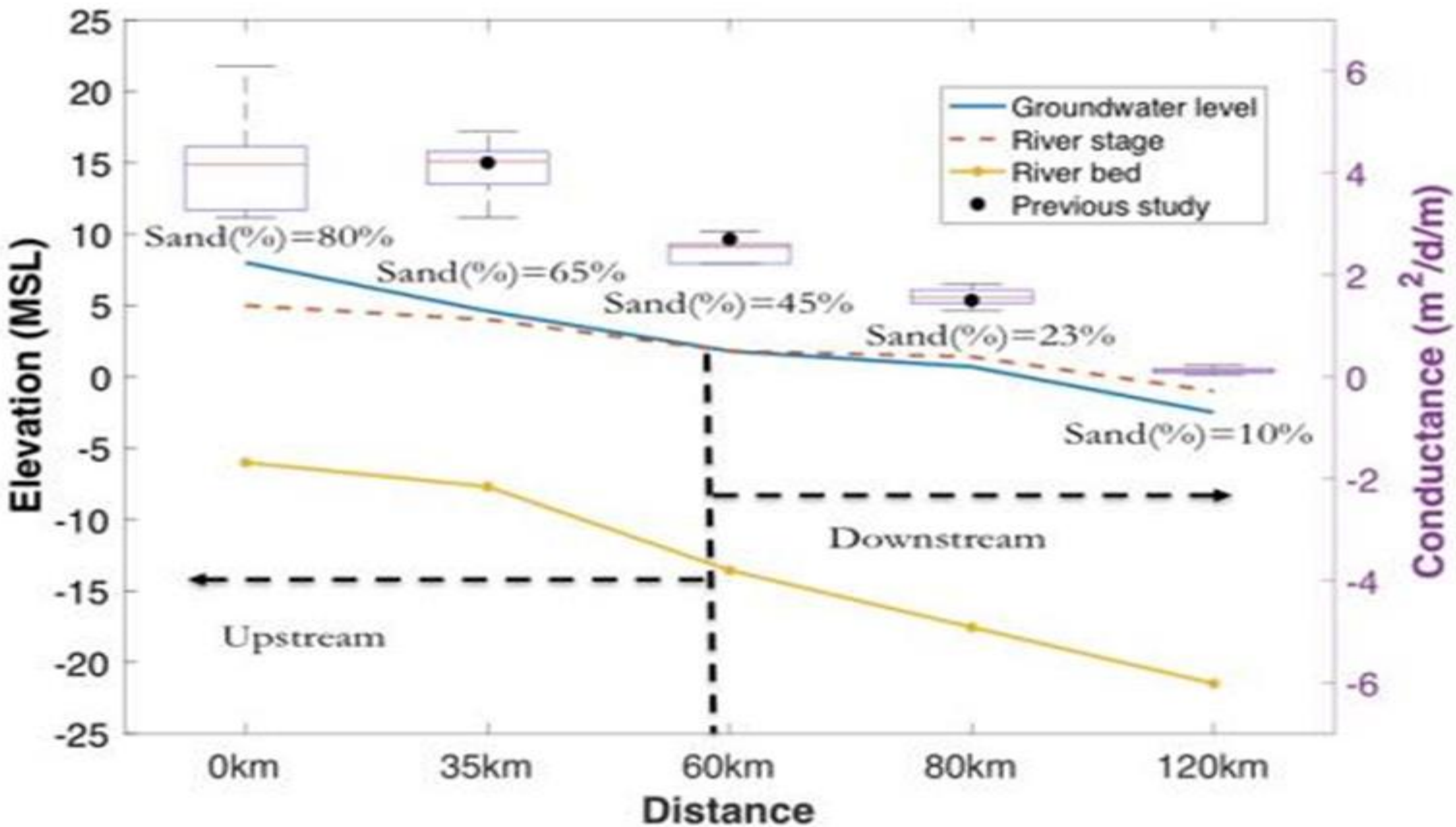
Study period

- 23 - 28 January 2018

Table 5.10 Seepage meter measured data

River bed material			hydraulic conductivity (m/d)	Conductance (m^2/d)	Seepage (m/d)	Hydraulic conductivity (Todd et al. (1976))
Yom River	mid	sand	0.27	7.18	0.40	0.2
	down	sand	0.18	6.30	0.33	0.2
Nan River	up	silt	0.14	5.70	0.17	0.08
	mid	silt	0.13	5.50	0.10	0.08
	down	clay	0.04	4.80	0.08	0.002

Vietnam case



6.1.3 Compared the results from model with field results

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Deep percolation rate

•Deep percolation is defined by soil zone

•The maximum deep percolation rate is 4.43cm/day for sandy clay loam soil type quite closed to the field measured data and is also in the range with (Xiaohui Lu, 2010).

Land recharge

Soil zone	Soil type	Calibrated recharge rate (cm/d)
1	Sandy clay	4.9
3	Sand	6.1
4	Clay	3.1
5	Sandy clay loam	3.7

River conductance

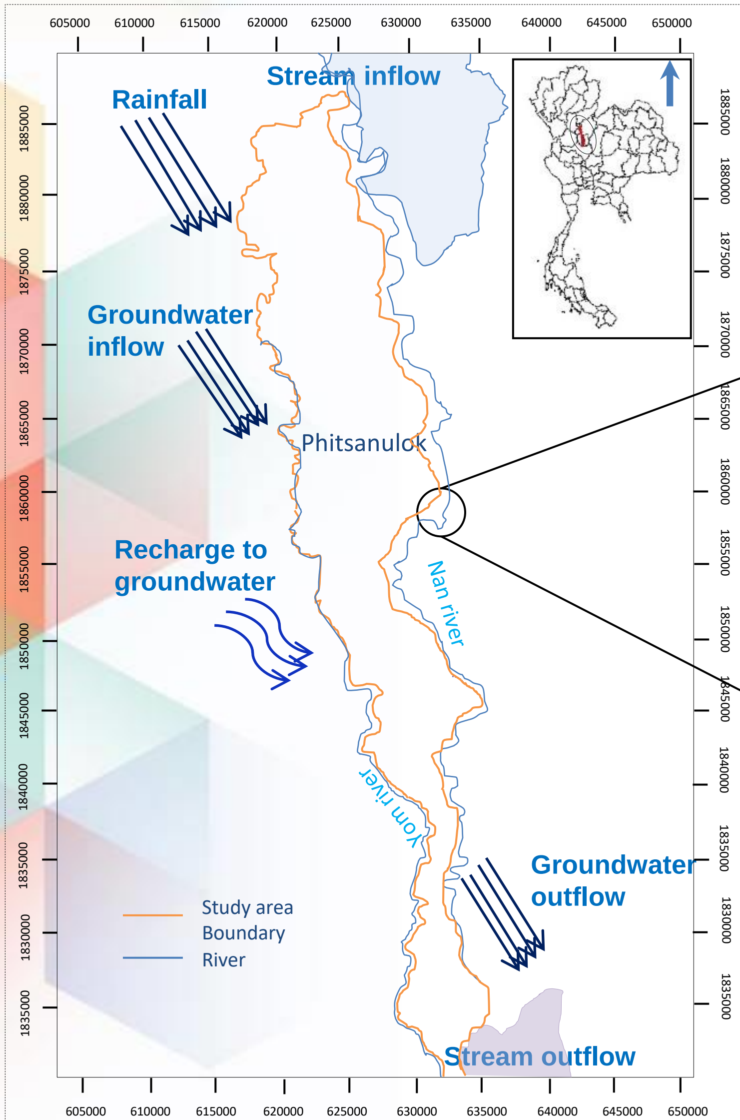
•River conductance is defined by river bed materials and slope

•The calibrated conductivities show smaller values than those of field measured data. (because the field measurements were done in dry season (January 17) and at near bank locations.)

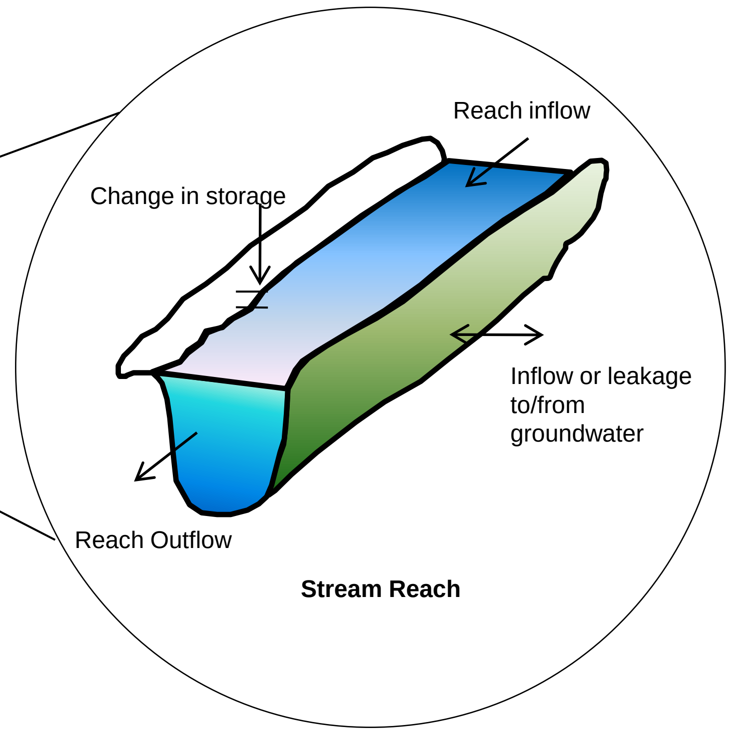
Stream	Bed material	Conductance		Previous study		Field measurement
		Nan River	Yom River	Nan	Yom	
Upstream	sand	5.5	-	2.2		7.8
Mid-stream	sandy clay	0.5	1.5	2.1	1.2	5.7
Downstream	clay	1.0	1.0	2.0	1.9	4.8

6.2 Interaction mechanism

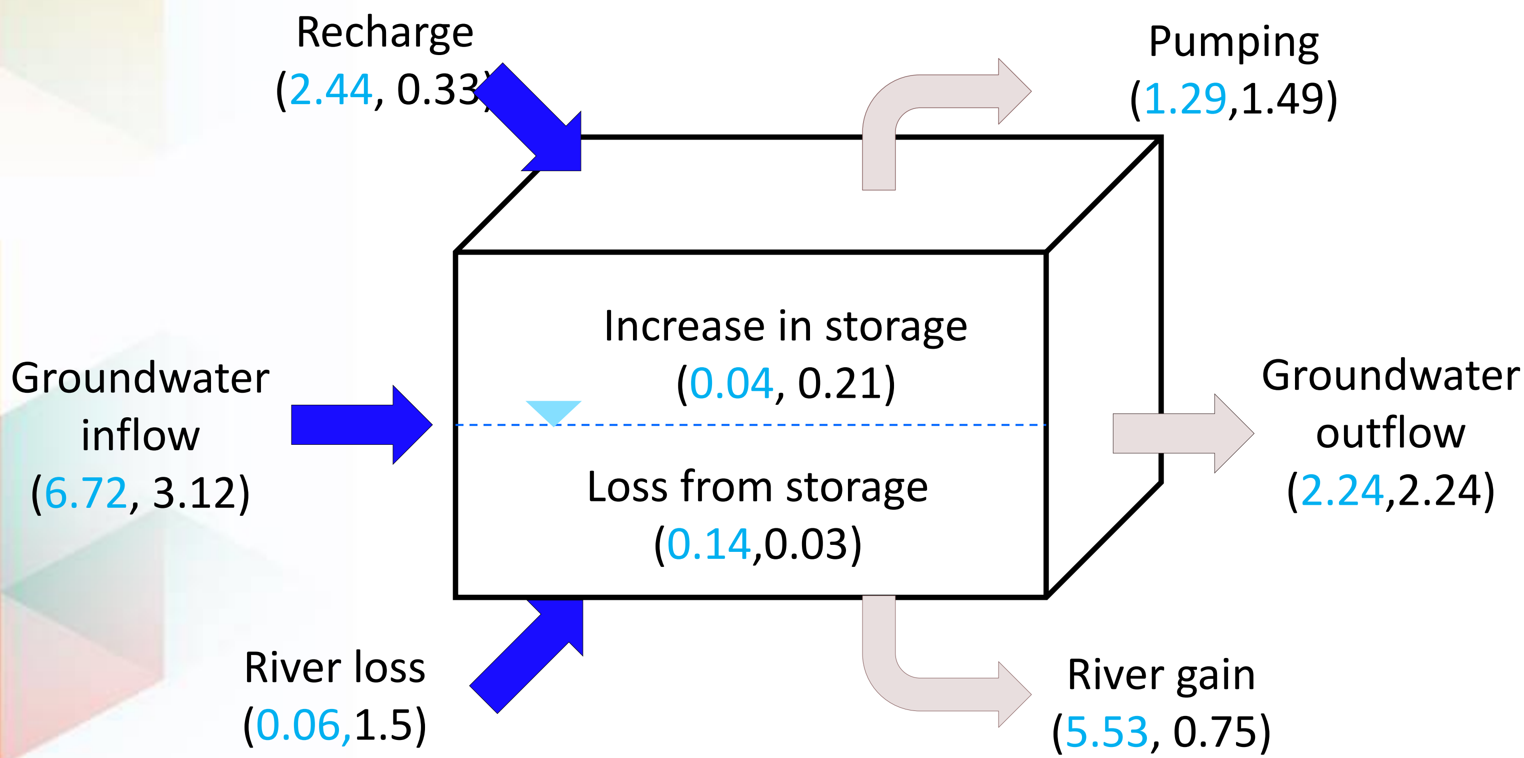
- The surface water and groundwater interaction mechanism was analysed from flow budget of local groundwater model and river loss and gain regime.



Schematic illustration for evaluating stream-aquifer interaction

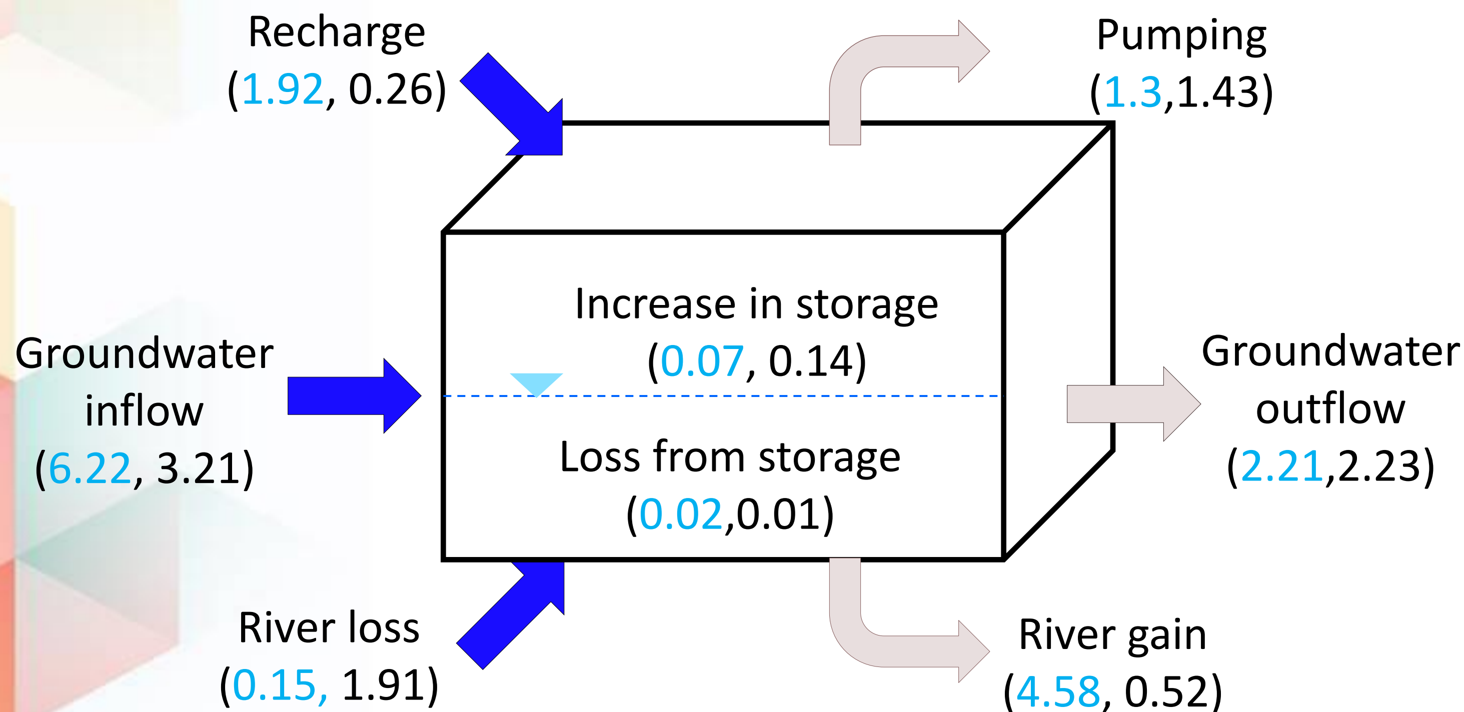


6.2.1. Annual groundwater flow budget , unit: MCM/day



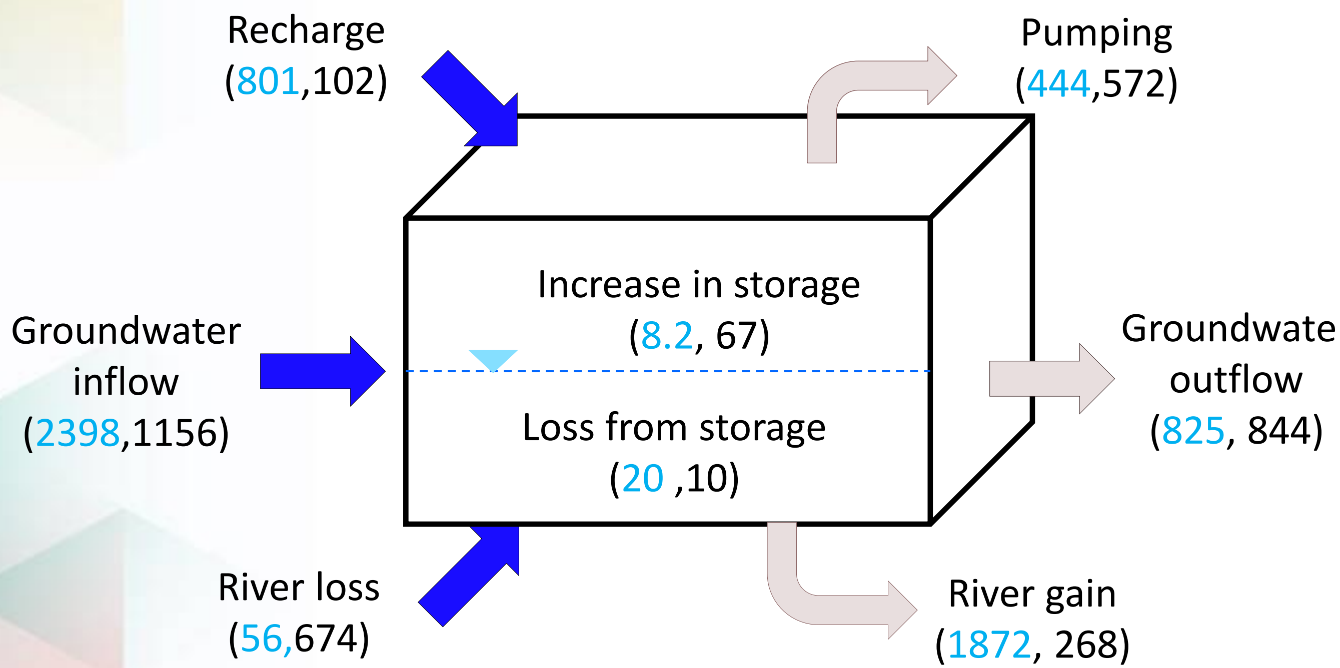
Annual	Boundary inflow	River loss	Recharge	Storage in
Average	9.8	1.6	2.8	0.2
Annual	Boundary outflow	River gain	Pumping	Storage out
Average	4.5	6.3	2.8	0.2

6.2.2 Seasonal groundwater flow budget, unit: MCM/day



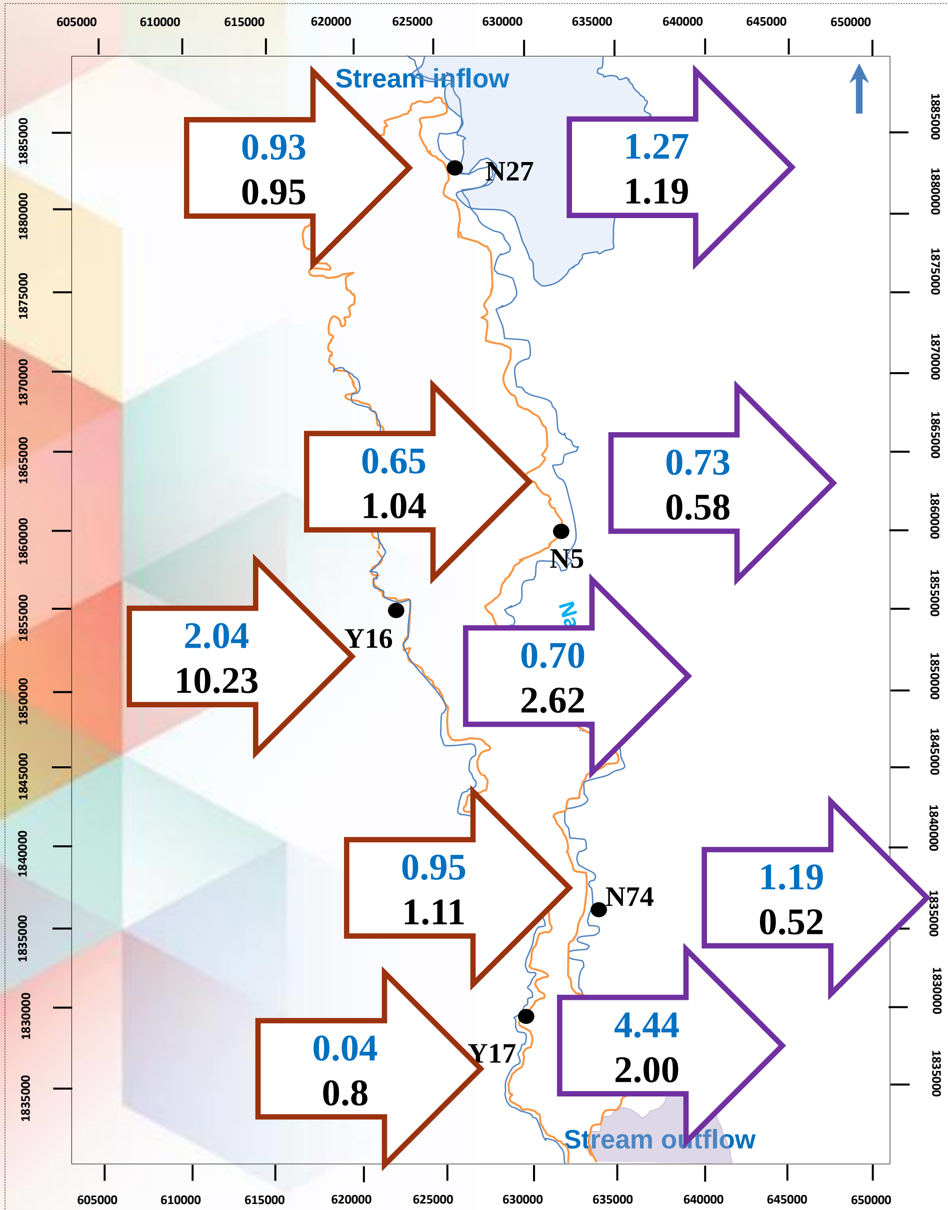
Seasonal	Boundary inflow	River loss	Recharge	Storage in
Average	8.9	2.1	2.2	0.2
Seasonal	Boundary outflow	River gain	Pumping	Storage out
Average	4.5	5.1	2.8	0.03

6.2.3 Seasonal groundwater flow budget, unit: MCM/year



Net	Inflow	River loss	Recharge	Storage in
Drought	3734	683	880	66
Dry	3873	664	993	77
Normal	3270	752	796	77
Wet	3340	821	945	84
Net	**Outflow**	**River gain**	**Pumping**	**Storage out**
Drought	1756	2161	1099	22
Dry	1726	2595	898	62
Normal	1646	1862	1033	11
Wet	1551	1942	1037	26

6.2.4 Interactions of groundwater and river by locations, unit:(MCM/day)



River loss to aquifer

Aquifer loss to river

Blue refers to wet season

Black refers to dry season

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Water Resources Study for Strategic Water Management in Nan River Basin

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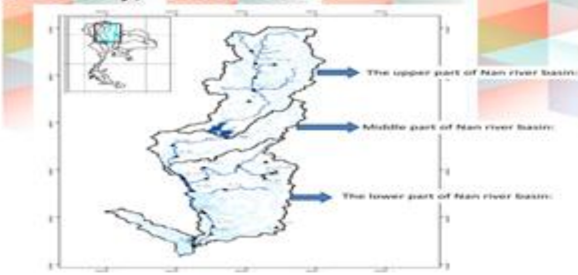
1. Introduction

- The Nan River Basin is one of the basins that has experienced water shortage and flooding problems. Water shortage has occurred in many irrigation projects even though there is a large reservoir, the SIRIKIT dam, to store water for use during a dry season. The upper of SIRIKIT dam is the critical area to study the impact of land use change and deforestation affect towards runoff.
- Land use in the upper watershed of Nan Basin had changed dramatically due to the increasing population and agricultural growth in the past decade.
- Forest area changed to agriculture and after that the agricultural area was transformed residential areas.



2. Study area

The Nan river basin is located in the northern region of Thailand with the total catchment area of 34,331sq.km The basin originated from Nan Province.

Rainfall

Rainfall data from 76 rainfall gagging stations were used to analyze the average annual rainfall in Nan river basin and its vicinity area varies between 759.6 – 2,200.6 mm/year, the maximum average annual rainfall depth is 2,200 mm/year at the station code 28164 (Doi Phuka station, Amphoe Pua) and minimum average annual depth is 759.6 mm/year at the station code 090901(Ban Chai Daen Station). Overall average annual rainfall for the project and vicinity areas is 1,260.0 mm/year.

Streamflow

The mean annual streamflow in Nan river basin is 12,199.60 MCM/year with average annual specific yield is 11.33 lps/sq.km. The Nam Pad sub-river basin has a low figure of 5.08 lps/sq.km, and the Nam Wa sub-river basin has a highest figure of 27.68 lps/sq.km.

3. Strategic issues in Nan River basin

From the review and meeting with communities in the basin, the strategic issues in the Nan River basin are summarized as follows.

The upper part of the basin:
- Decrease in runoff cause by decreasing forest area in upper section of upper Nan river basin, War sub river basin, Yao 2nd sub river basin and 3rd section of Nan sub basin
- Flash flood
- The water deficit for agricultural use especially in Nam Samun and Nam Haeng sub river basin

Middle part of Nan river basin:
- Flash flood in Pad and 4th section of Nan sub basin
- Water deficit in dry season in Khlong Tron and Nam Pad sub river basin.

Lower part of Nan river basin:
- The appropriated releasing rule of Sirikit Dam for irrigation water demand
- Model for water management in the rainy season
- Warning system, retention area

4. Objective

The purposes of the research are to assess the risk due to the future change and to provide solutions for the key strategic issues of the Nan River basin which in this poster the water deficit issue is focused.

5.Approach and methods used

The analysis was performed by simulating options of water management using the following data and tools:

- short and seasonal rainfall forecast,
- the relationship between forested area and runoff in the sub-basin,
- rainfall-runoff model,
- water balance model,
- reservoir operation rule via water balance model,
- groundwater flow model,
- the simulation and analysis of water management for water situation under existing and climate change conditions,
- options for water management strategies in the basin such as dam operation rule curve, conjunctive use of surface water and groundwater under climate change and deforestation scenarios.

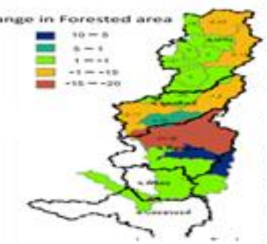
6. Analysis results

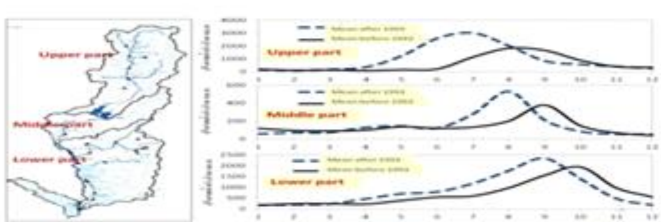
6.1 Deforestation effect

The study of rainfall and runoff in the upper Nan river basin is to analyse the relationship of rainfall, runoff and the percentage of forested area. Four sub-basin with different percentage of forest area were selected to investigate the runoff difference via field measurements. The forest area change was analysed from the satellite map and change in forest area in percentage can be drawn in the map.

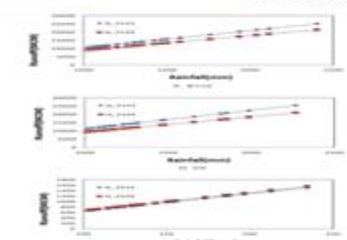
The runoff hydrograph affected from the deforestation was investigated and it was found that the peak and timing of the hydrograph (before 1993 with much forest) is lower and slower than the hydrograph (after 1993 with less forest)

The runoff yield can be seen from the ratio of rainfall-runoff. The study of the changes in the ratio of rainfall- runoff which consider the change in forest area by using the land use map between the year 2000 and 2006 .By calculating the ratio of runoff-rainfall and comparing the difference in this ratio, the change of the ratio in the upper part, the middle part and lower part of Nan river basin are 10%-20%, 10%-15% and more than20%, respectively. The change of this ratio relate to the change in forested area, inversely. By using this ratio to construct the curve of rainfall-runoff between in 2000 and in 2006 for all parts of Nan river basin It was found that in the upper part of Nan river basin, in annual and wet season, the rainfall and runoff decreased 20% and in dry season decreased 5%. It concludes that the volume of runoff which generate by the same rainfall, is decreasing 15% when the forested area decreased.

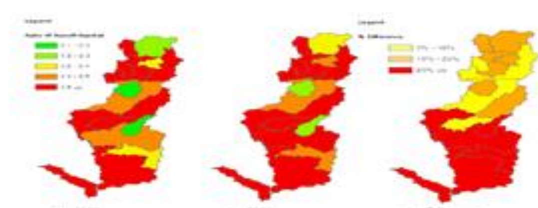




Hydrograph pattern before and after 1993



Rainfall- runoff in 2000 and 2006, upper part of Nan river basin



Ratio of Runoff-Rainfall and the change between in 2000 and 2006

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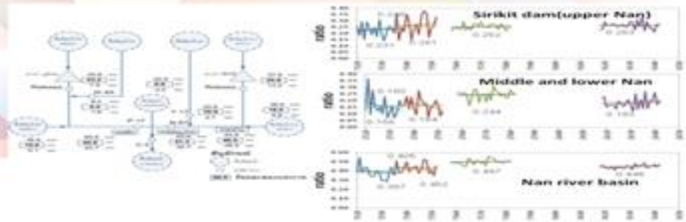
6.2 Role of water from Nan Basin to the Central Plain

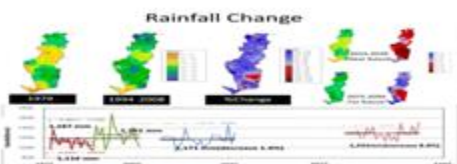
From the study of 30 years of runoff from the sub basins north of Nakhonsawan province shows that the Nan Basin accounts for 40.5% of flow in the Central Plain and both Nan and Yom basins account for 51.3%. The Sirikit Dam accounts for 24.6% of flow in the Central Plain and 16% of flow in the sub basins in the lower reach of the reservoir. This means the importance of Nan River Basin to the central plain water security.



6.3 Climate Change

Precipitation change: the study shows that there was a decreasing trend in precipitation between year 1979 and 1993 at a rate of 9.68 mm/year. In year 1994, precipitation increased and between year 1994 and 2008 there was a decreasing trend at a rate of 2.61 mm/year. In the near future (year 2015-2039) and the far future (year 2075-2099), it has been found that precipitation will increase at rates of 1.82 mm/year and 2.22 mm/year respectively. In conclusion, precipitation in the near future will decrease compare to the present and will increase to the amount close to that of the present in the far future.

Impacts on runoff: land use and precipitation are important factors in runoff change. It has been found that the land use and precipitation changes in the Nan Basin result in increase in the runoff coefficients and decrease in a time period for rain to become runoff. As a result, the increase in runoff in a rainy season intensified floods, and the decrease in runoff in a dry season intensified water shortage. When precipitation was included in the consideration, annual precipitation had a decreasing trend and precipitation increased in a rainy season but decreased in a dry season intensifying flood and more water shortage problems.



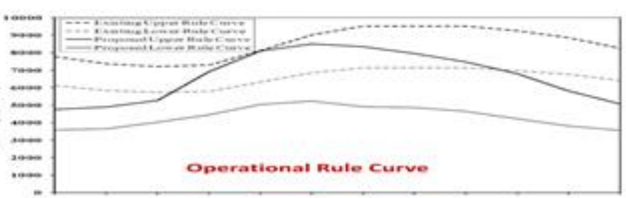
Summary of runoff change in each part of river basin

7. Mitigation results

7.1 Rule curve adjustment

For the analysis of water release rules from Sirikit Dam, it can be considered from the patterns of reservoir release. The improvement is to analyse the pattern in more detail and set release ratio on each patterns. The release rules can be determined from the proportion between the monthly release and effective storage corresponding to water year. The release ratio can be classified based on the effective storage of the water year and probability which is classified into five levels i.e. higher (Probability >= 0.9) high (0.9 > Probability >= 0.7) medium (0.7 > Probability > 0.3) low (0.3 >= Probability > 0.1) and lower (Probability <= 0.1), respectively. The simulated storage obtained from the reservoir water balance model can be used to formulate new reservoir operation by setting the lower rule curve at the probability of 0.2 and upper rule curve at the probability of 0.8 in each month.

The improvement of release ratio can reduce the flood water better but can not reduce water deficit totally. The further reduction of water deficit should be considered with irrigation water allocation rules to match demand (cultivation area) and supply (dam storage).



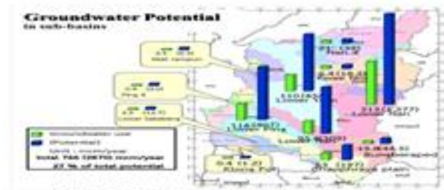
7.2 Reforestation

Thai Government had a policy to increase forest area in the Nan Basin about 20 %. The question arise that if the reforestation scheme success, what will be the impact to water deficit. By increasing forest area approximately 20% (to have forested area as in 2000), we can use the previous rainfall-runoff ratio to estimate the runoff. With the estimated runoff, water deficit will decrease to 27 percentage compared with present water deficit volume and by adjusting rule curve of Sirikit Dam, the water deficit will decrease to 44 percentage.

7.3 Conjunctive use

From the field survey and data collection, the ratio of groundwater and surface water use for agriculture sector was 19:50 in Nan river basin, the farmer pumped the groundwater 3 time, 19 hrs. per time and 6 times, 21 hrs. per time in wet season and dry season, respectively.

When applied MODFLOW model(Koontanakulvong S., et,al.2013) and used the above ratio to simulate the groundwater flow, it was found that in the past, the groundwater usage in the upper central plain (Lower Part of Nan Basin) was 766 MCM/year and in the irrigation area, the groundwater use was 30-90 MCM/year. Using the groundwater model to estimate the groundwater potential in the upper central plain with the condition of groundwater level not lower than 15 m, the groundwater potential will be 2,873 MCNM/year, and in the Lower Nan river basin, the groundwater potential will be 180 MCM/year in the irrigation area.



Ground water use and potential in the lower Nan Basin

7.4 Overall assessment

In summary, the key strategic solutions are to increase forest area in the upper Nan basin and adjusting the release rules from Sirikit Dam. These two measures will help to alleviate the problem of water deficit for the entire Nan basin in both near and far futures. If the forest area increases, the water deficit will decrease 27%. And if the release rule from Sirikit Dam is adjusted , the water deficit will decrease 44%. When combining both measures, the irrigation water deficit will decrease 54%. And when apply the conjunctive use approach, it will decrease deficit to nearly 0. In the risk curves for near future and far future conditions, they show that the risk of irrigation water deficit will decrease and the deficit will remain at the probability less than 0.1.

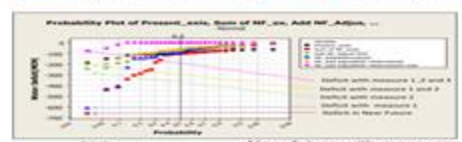
The results of strategic water resources management

Rule Curve		Existing			Purpose		
Land use	Climate	Present (MCM)	Near future (%)	Far future (%)	Present (MCM)	Near future (%)	Far future (%)
Forest area	existing	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	decrease	-	[illegible]	[illegible]	-	[illegible]	[illegible]
	increase	-	[illegible]	[illegible]	-	[illegible]	[illegible]

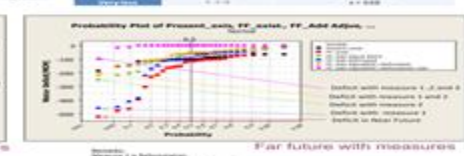
Released Pattern of Rule Curve

Dry Season	Probability	Effective Storage (MCM)
High	[illegible]	[illegible]
Normal	[illegible]	[illegible]
Less	[illegible]	[illegible]
Very less	[illegible]	[illegible]

Wet Season	Probability	Effective Storage (MCM)
High	[illegible]	[illegible]
Normal	[illegible]	[illegible]
Less	[illegible]	[illegible]
Very less	[illegible]	[illegible]



Near future with measures



Far future with measures

Probability distribution of irrigation water deficit in Present, Near future, Far future periods with proposed measures

Acknowledgement

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7. CONCLUSTIONS

7.1 Field measurement and comparison with values from local groundwater model

- 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)
- Estimated land recharge based on soil types
  - field measurement is 4.43cm/day for sandy clay loam soil type and
  - Model values are 3.7cm/day for sandy clay and 4.9cm/day for sandy clay loam.
- The seepage meter was used to analysis the river flux in local model
- Estimated the river conductance values based on the river bed materials and slope
  - The up, mid and downstream values of Nan River are 5.5, 0.5, and 1.0 and mid-stream and downstream of Yom river are 1.5 and 1.0 respectively.
  - The up, mid and downstream river conductances have values of 7.8, 5.7, 4.8 from field measurement.

7.2 Interaction mechanism from flow budget

- 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)
- Land recharge to the aquifer 2.09, 2.45, 1.92, 2.32MCM/day, (drought, normal and wet year) in wet season.
- **Land recharge** to aquifer 847MCM (wet season) and 99MCM (dry season) in wet year.
- In normal year, land recharge 701MCM (wet season) but 95MCM (dry season).
- It means that the precipitation is the main factor for land recharge during 81% of the annual rain in rainy season and less than 19% in dry season.
- **River loss** to the aquifer about 668MCM in dry and 2262MCM give back from aquifer in dry season.
- Well pump out from the aquifer 496, 277, 511 and 493MCM in dry, drought, normal and wet year in wet season and 602, 621, 522, 544MCM in dry season.
- According to river loss and gain (Nan river), river loss from upstream to downstream is 0.95MCM to 0.65MCM in dry season.
- However, the river gain the water from upstream to downstream is 1.27MCM to 1.19MCM in dry season.
- Yom river loss (upstream) 0.23MCM and gain (downstream) 2.62MCM in dry season.

7.3 Application to GW modeling

- Estimated recharge parameters by field measurement were compared with the estimated parameter from model result and needed more study/data on soil type and rainfall pattern effects.
- Volume of river loss and gain in the rivers were estimated from river conductance and the values are smaller than the model figures which needed more field survey data.
- To raise groundwater level, river recharge has mainly important effect in this area in dry season and land recharge is important in wet season. The river recharges in the upstream through aquifer and filled back to river again in the mid and downstream reaches.
- These findings were used for groundwater impact assessment from climate change and groundwater management to mitigate water shortage in the Nan River Basin area during dry years.

8. Acknowledgement

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    - **Royal Irrigation Department (RID)**
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    - **Mr. Tuan Pham Van**

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