



Development of groundwater management system in Thorthongdaeng Irrigation Project of Thailand

Tuantan Kitpaisalsakul^{1,*}, Phatcharasak Arlai¹

¹Faculty of Engineering and Industrial Technology, Phetchaburi Rajabhat University, Thailand

Abstract

Thorthongdaeng irrigation project is water storage pond type, located in the upper central region of Thailand. It was found that there was groundwater pumping during the period that the surface water resource is insufficient in the dry seasons. However, the development of groundwater management system for estimating groundwater quantities in various scenarios does not exist for the irrigation project. This study was done to develop the groundwater management system containing the groundwater modeling and monitoring. The groundwater pumping test data was analyzed to determine the hydraulic conductivity, transmissivity and storativity. The groundwater model was calibrated, verified and applied to estimate the annual groundwater use, potential and recharge in the dry, normal and wet years, within the 3 aquifer layers and the 3 irrigation zones. The average annual potential groundwater of 171 million cu.m. was nearly 3 times more than the average annual groundwater uses of 66.5 million cu.m. The average annual groundwater recharge of 64 million cu.m. was almost equal to the annual groundwater uses of 65 million cu.m. However, there should be caution in using and monitoring groundwater in the irrigation zone 1 and zone 2 due to the groundwater use exceeding the groundwater recharge. The groundwater levels in Khampaengphet province had the trend to be rather constant while the groundwater levels in Sukhothai province and Phitsanulok province had the trend to decrease. The groundwater management criteria and the measures to manage the groundwater appropriately and sustainably were set up and presented.

Keywords: Groundwater management, Groundwater modeling, Groundwater monitoring, Thorthongdaeng irrigation project

Article history: Received 30 June 2026, Revised 10 July 2026, Accepted 25 July 2026

1. Introduction

Thorthongdaeng irrigation project is water storage pond type, receiving water from Ping river to the agricultural areas in the provinces of Khampaengphet, Sukhothai and Phitsanulok. It was found that in this region there was groundwater pumping to be water reserve to every water use sector such as comsumptive use, industrial use and agricultural use particularly during the period that the surface water resource from the irrigation water or storage pond was insufficient in the dry seasons. However, there is no development of groundwater management system for estimating groundwater quantities in various scenarios in this irrigation project. This situation causes unable to estimate the

groundwater quantity with reliability and manage the groundwater according to the water years [1-2]. The groundwater management system will be an important tool to estimate and manage the groundwater to be conjunctive use with the surface water appropriately [3-5].

Chulalongkorn University [3] studied the development of groundwater management system to improve conjunctive use water management system in the upper central region of Thailand covering 6 provinces. The groundwater model was developed using MODFLOW simulating 2 aquifer layers and applied to determine the groundwater use, potential and recharge. It was found that the groundwater use was less than the potential groundwater but exceeded the groundwater recharge from the rain and river within the

*Corresponding author; e-mail: Tuantan.kit@mail.pbru.ac.th

study area, however receiving from the net boundary inflow from the surrounding region to avoid the water shortage. For the proportion of conjunctive use of annual surface water and groundwater uses, the total annual volume for all 6 provinces equals to 16,816 million cu.m., dividing into the surface water uses at 95.49% and the groundwater at 4.51%. Nevertheless, the groundwater plays a crucial role where the surface water is inadequate to meet the demand and help to reduce damage to crop production due to the water shortage.

Chulalongkorn University [4] studied the development of groundwater management system for planning improvement to improve conjunctive use water management system in the north of lower central region of Thailand covering 7 provinces. The groundwater model was developed using MODFLOW simulating 4 aquifer layers. The groundwater model was calibrated, verified and applied to determine the groundwater use, potential and recharge in the water years classified to be dry, normal and wet years. From the study results, the average annual groundwater use, potential and recharge were 440, 804 and 544 million cu.m. respectively, indicating the sufficiency of groundwater. In supplying water to the 7 provinces, the annual water supplies from surface water and groundwater amount to 7,344 and 470 million cu.m. respectively, totaling 7,814 million cu.m. On the proportion of the average annual water use type in the 7 provinces, the water uses mainly are the surface water at 94.37%, much more than the groundwater at 5.63%.

This study had the objectives to develop a groundwater management system containing groundwater modeling and monitoring in the Thorthongdaeng irrigation project, mainly receiving and using the surface water but also using the groundwater when the surface water was insufficient [5]. The groundwater model was developed and applied to estimate the groundwater use, potential and recharge to investigate the sufficiency of groundwater in the irrigation areas. The trends of the groundwater levels in the 3 provinces were investigated. In addition, the objectives include the groundwater management criteria and the recommended measures to manage the groundwater appropriately and sustainably.

2. Materials and Methods

2.1 Study Area

Thorthongdaeng irrigation project is located mainly in Khampaengphet province in the upper central region of Thailand. The irrigation project is the water storage pond type, receiving water from Ping river to the agricultural areas in the provinces of Khampaengphet, Sukhothai and Phitsanulok through the flow system of natural channels having water control structures along the channels. The project receives water through the water control gates at the entrance of Thorthongdaeng channel, supplying water to the irrigation areas of 883.85 sq.km. as shown in Figure 1. The irrigation project area is divided into 3 irrigation zones, zone 1 in the north (green), zone 2 in the east (yellow) and zone 3 in the south (red).

2.2 Groundwater Wells

The number of groundwater wells in the study area was referred from the data base collected by the Department of groundwater resources in the year 2019. The number of pumping groundwater wells amounted to 1,679 wells divided into 646 public wells and 1,033 private wells. The number of observation groundwater wells amounted to 18 wells divided into 9 recorder wells and 9 non recorder wells.

2.3 Methodology

The methodology contains the following steps.

- 1) Collect data such as meteorology, hydrology, geology, hydrogeology, groundwater level and use data.
- 2) Survey and install automatic groundwater monitoring and recording system.
- 3) Develop groundwater model using MODFLOW.
- 4) Apply the groundwater model to estimate the annual groundwater use, potential and recharge.
- 5) Set up the groundwater management criteria and the measures to manage the groundwater.

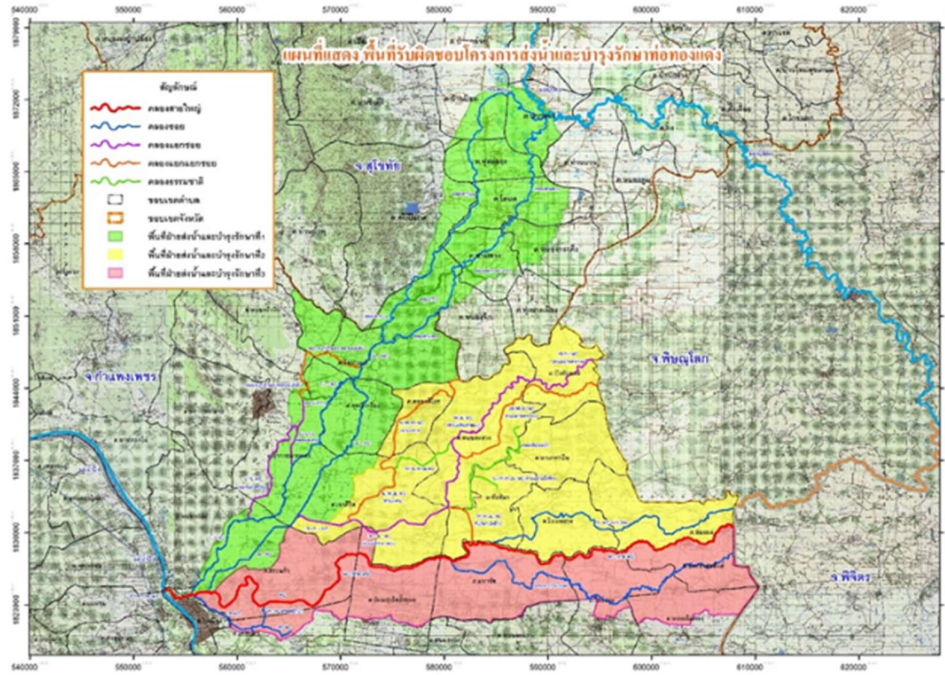


Figure 1. Thorthongdaeng Irrigation Project of Thailand.

2.4 Groundwater Flow Theory

The Darcy equation explains the groundwater flowing through the porous media as shown in Eq. (1).

$$V = -K \frac{\Delta h}{\Delta l} \quad (1)$$

Where V = flow velocity (LT^{-1})

K = hydraulic conductivity (LT^{-1})

Δh = difference in hydraulic head (L)

Δl = distance along flow direction (L)

The general groundwater flow equation, derived from the conservation of mass (continuity equation) and Darcy equation, describes how water moves through porous media. The governing equation for transient (time-dependent) 3D flow in a heterogeneous, anisotropic medium is explained in the partial differential equation for the case of 3D flow as shown in Eq. (2). The numerical method by implicit finite difference is applied to solve the

groundwater flow equation in the form of system equation.

$$\frac{\partial}{\partial x} \left(K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_{zz} \frac{\partial h}{\partial z} \right) - W = S_s \frac{\partial h}{\partial t} \quad (2)$$

Where h = hydraulic head or groundwater level (L).

K_{xx} , K_{yy} and K_{zz} = hydraulic conductivity in x , y and z directions (LT^{-1}).

S_s = specific storage (L^{-1}), representing water released per unit change in head

W = volumetric flux per unit volume as sources or sinks of water (recharge or pumping) (T^{-1})

t = time (T)

2.5 Groundwater Monitoring

The automatic groundwater monitoring and recording systems were installed at 9 locations at the existing groundwater observation wells as shown in Figures 2 and 3. The groundwater level measuring system through wireless system contains

- 1) sensor is located at the bottom or the specific depth within the well, measuring the groundwater level and sending the water level signal to the controller unit.

2) controller unit receives data from the sensor, processes and presents the result,

sends the data through the wireless network to the cloud system for data storage.

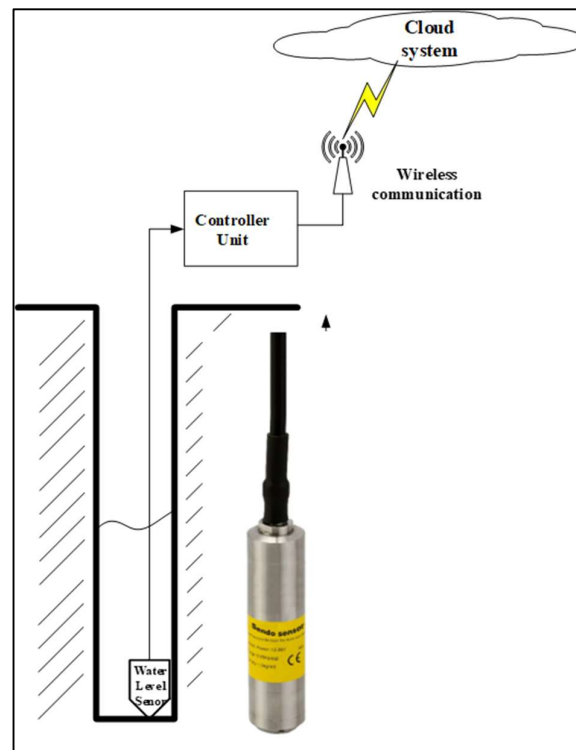


Figure 2. Function of automatic groundwater monitoring and recording system.



Figure 3. Installation of an automatic groundwater monitoring and recording system.

The principle of water level measurement of the groundwater level sensor is shown in Eq. (3).

$$P = P_0 + \rho gh \quad (3)$$

Where P = pressure on the sensor

P_0 = atmospheric pressure

ρ = density of liquid

h = depth of sensor related to water level

2.6 Groundwater Modeling

The groundwater model was developed containing 3 aquifer layers. The first, second

and third aquifer layers are in the depths below the ground surface of 10-40 m, 40-100 m and more than 100 m, respectively. Each aquifer layer was divided into a large number of grids or units of calculation area covering the study area. Each unit was rectangular shape with the small size of 0.5 km * 0.5 km. as shown in Figure 4.

The boundary conditions of the groundwater model was set up based on the hydrogeological data on the cross sections. The model was calibrated in the steady state flow in the dry season in the year 2010 to calibrate the hydraulic conductivity (K). The model was calibrated in the transient state flow during the years 2011 -2016 to calibrate the transmissivity (T) and storativity (S). The model was verified by comparing the computed groundwater levels in the transient state flow to the observed data during the years 2017 -2020.

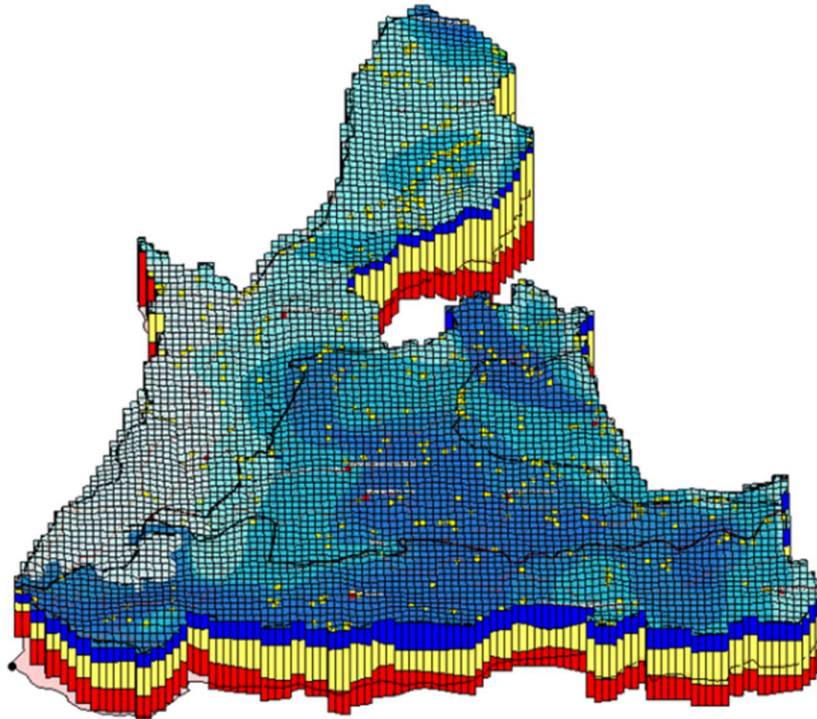
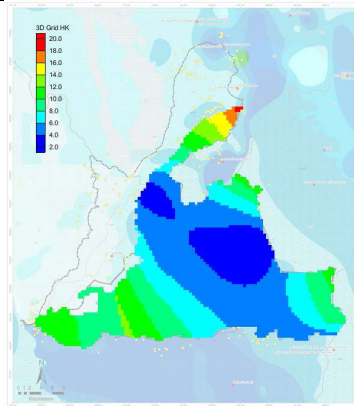


Figure 4. View 3D groundwater modeling of 3 aquifer layers with grid cells.

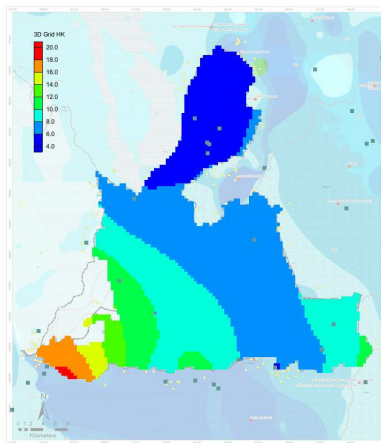
The data of groundwater pumping tests of 147 wells was used to determine the hydraulic conductivity distribution [5]. Table 1 shows the hydraulic conductivity (K), the transmissivity (T) and storativity (S) from the model calibration. Figure 5 shows the hydraulic conductivity distribution in each aquifer layer using Kriging interpolation. In the groundwater modeling using MODFLOW, HK stands for horizontal hydraulic conductivity. Figure 6 shows the comparison between the observed and simulated groundwater levels from the groundwater model verification.

Table 1. Hydraulic parameters of groundwater model.

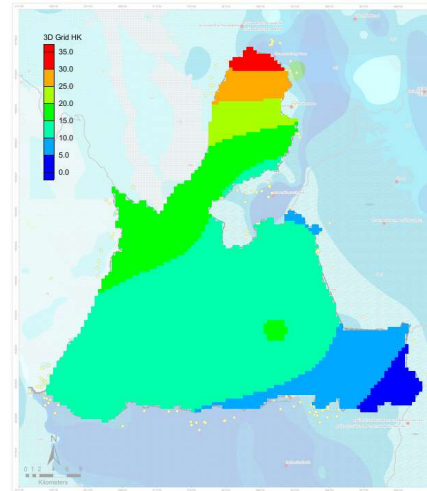
Parameter	Min	Max
hydraulic conductivity (K) m/d	0.0216	704
transmissivity(T) m ² /d	0.173	2,820
storativity (S)	2.93X10 ⁻⁶	0.584



aquifer layer 1



aquifer layer 2



aquifer layer 3

Figure 5. Hydraulic conductivity distribution.

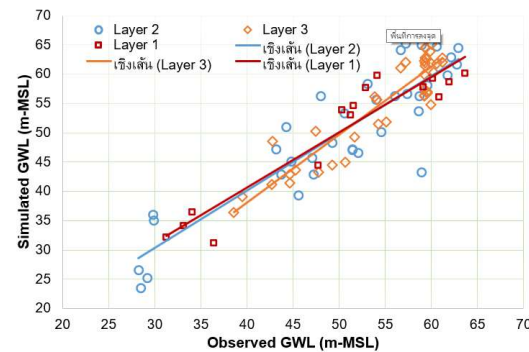


Figure 6. Comparison between observed and simulated groundwater levels during years 2017-2020.

2.7 Water Year Classification

The water years were classified to be the dry, normal and wet years according to the analysis of annual rainfall depth (P) data for 30 years. The dry year had $P < 1,000$ mm/year, the normal year had $P = 1,000$ -1,400 mm/year and the wet year had $P > 1,400$ mm/year.

3. Result and Discussion

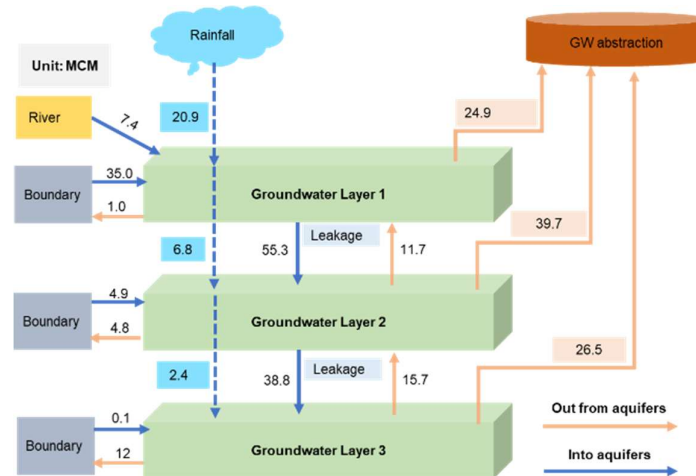
3.1 Groundwater Simulation Results

The groundwater model was applied to simulate the groundwater conditions in Thorthongdaeng irrigation project during the years 2010 – 2020.

Figure 7 presents the groundwater balance in the year 2020. Each aquifer layer gained inflow from the rainfall and river recharge and lost as outflow from the groundwater abstraction. The boundary flows were both inflow and outflow in each aquifer. The leakage flows between each pair of the two aquifer layers had the flow direction both downward and upward. The flows had the flow direction from the higher piezometric head to the lower piezometric head.

Figure 8 presents the annual groundwater abstraction or uses in the 3 irrigation zones during the years 2010-2020, varying widely in the range of 30-90 MCM.

Table 2 and Figure 9 present the average annual groundwater abstraction in the 3 irrigation zones and 3 water years. It is seen that every zone had almost equal groundwater abstraction volume in each of the water years. The groundwater use in the dry years was more than the groundwater uses in the normal and wet years. Classified according to the aquifer layers, the average annual groundwater uses were 17, 29 and 19 million cu.m. in the first, second and third aquifer layers respectively. The groundwater use from the second aquifer layer was more than the groundwater uses from the first and third aquifer layers.



(unit : MCM)

Figure 7. Groundwater balance in 3 aquifer layers in year 2020.

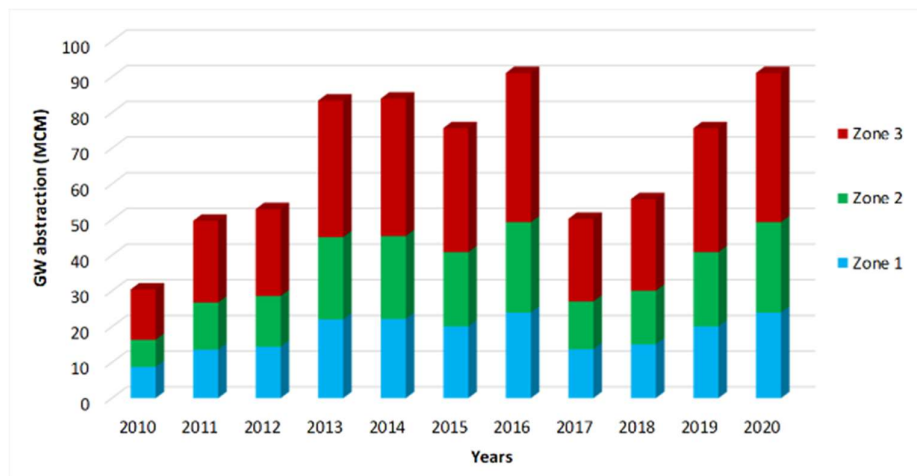


Figure 8. Annual groundwater abstraction during years 2010-2020.

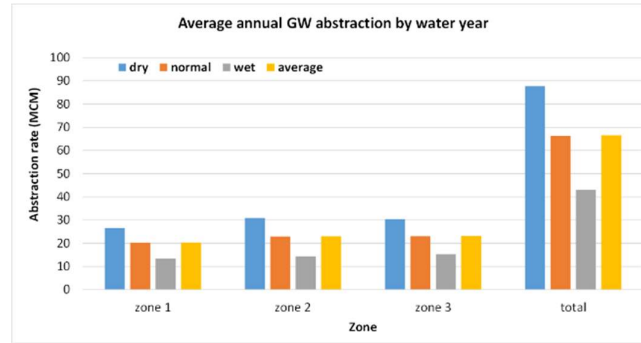


Figure 9. Average annual groundwater abstraction in irrigation zones and water years.

Figure 10 presents the relationship between the seasonal groundwater abstraction and the groundwater level at the seasonal end in the 3 irrigation zones. This relationship is useful

to estimate the seasonal groundwater abstraction to be used in the groundwater management.

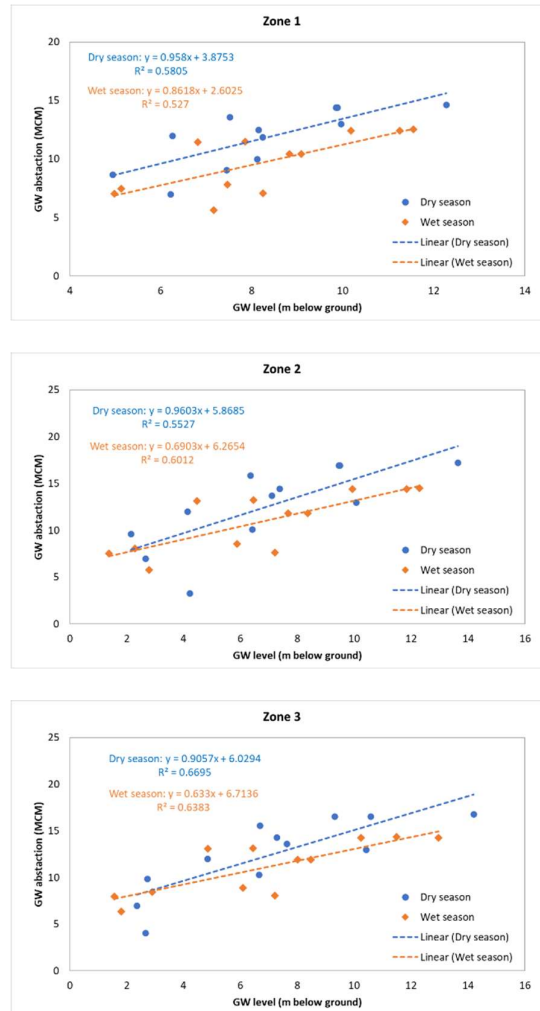


Figure 10. Seasonal groundwater abstraction and groundwater level at seasonal end.

Table 3 and Figure 11 present the average annual potential groundwater in the 3 irrigation zones and 3 water years. The zone 2 and zone 3 have almost equal potential groundwater and more than the zone 1 in each of the water years. Table 4 presents the average

annual potential groundwater in the 3 aquifer layers and 3 water years. The aquifer layer 2 has the most potential groundwater while the aquifer layer 1 and layer 3 have almost equal potential groundwater.

Table 3. Average annual potential groundwater in irrigation zones and water years.

water year	potential groundwater (million cu.m./year)			
	zone 1	zone 2	zone 3	Total
dry	34	51	49	134
normal	43	64	66	173
wet	49	77	80	206
average	42	64	65	171

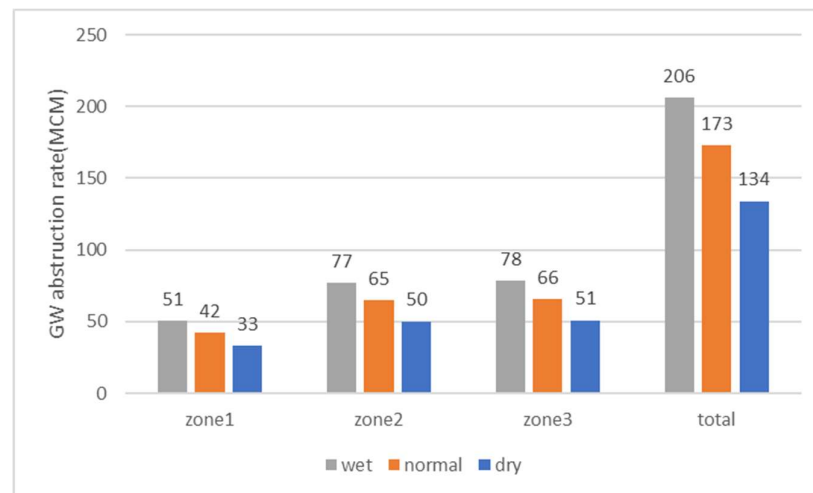


Figure 11. Average annual potential groundwater in irrigation zones and water years.

Table 4. Average annual potential groundwater in aquifer layers and water years.

water year	potential groundwater (million cu.m./year)		
	layer 1	layer 2	layer 3
dry	35	59	39
normal	46	76	51
wet	54	90	60
average	45	75	50

Table 5 presents the average annual groundwater recharge in the 3 irrigation zones and 3 water years. The groundwater recharge depended on the rainfall amount and the soil moisture content in the study area and years. The groundwater recharge was highest in the wet year, followed by the dry year and the normal year, respectively. The groundwater recharge was very high in the zone 3 but very

low in the zone 1 and zone 2. Therefore, there should be caution in using and monitoring groundwater in the irrigation zone 1 and zone 2 due to the groundwater use exceeding the groundwater recharge. Classified according to the aquifer layers, the average annual groundwater recharge volumes were 44, 15 and 5 million cu.m. in the first, second and third aquifer layers respectively. The groundwater

recharge in the first aquifer layer, close to the ground surface receiving directly rain recharge, **Table 5.** Average annual groundwater recharge in irrigation zones and water years.

was much more than the groundwater recharge in the second and third aquifer layers.

water year	groundwater recharge (million cu.m./year)			
	zone 1	zone 2	zone 3	Total
dry	5.9	18.2	45.2	69.3
normal	3.8	4.4	49.1	57.3
wet	4.1	0.6	68.3	73.0
average	4.6	7.2	52.7	64.5

Table 6 presents the comparison between average annual groundwater use, potential and recharge covering the 3 irrigation

zones in 3 water years and average of all water years 2010-2020.

Table 6. Average annual groundwater use, potential and recharge in water years.

water year	annual groundwater (million cu.m./year)		
	ground water use	potential	recharge
dry	87.7	134	69.3
normal	66.2	173	57.3
wet	43.0	206	73.0
average	66.5	171	64.5

Figure 12 presents the observed and simulated groundwater levels at Khampaengphet province during the years 2008-2020 [5]. In each year, the groundwater levels varied significantly in the range of 45-54

m due to groundwater pumping in dry season and recharge from rain in wet season. The trend of the groundwater levels, on the average during the study years, was rather constant, not changing.

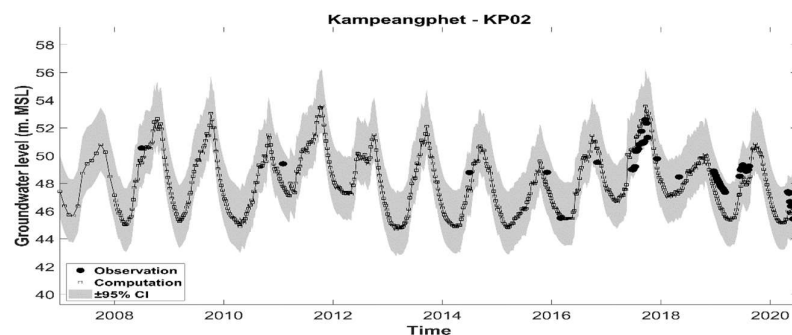


Figure 12. Observed and simulated groundwater levels at Kampeangphet province during years 2008-2020.

Figure 13 presents the observed and simulated groundwater levels at Sukhothai province during the years 2008-2020 [5]. In each year, the groundwater levels varied significantly in the range of 32-45 in the year 2008 and changing to the range of 25-36 m in

the year 2020. The groundwater levels had the trend of decreasing evidently with respect to time during the study years. This result indicated that the groundwater use exceeded the groundwater recharge significantly, thus

requiring to reduce the groundwater use to recover the groundwater level.

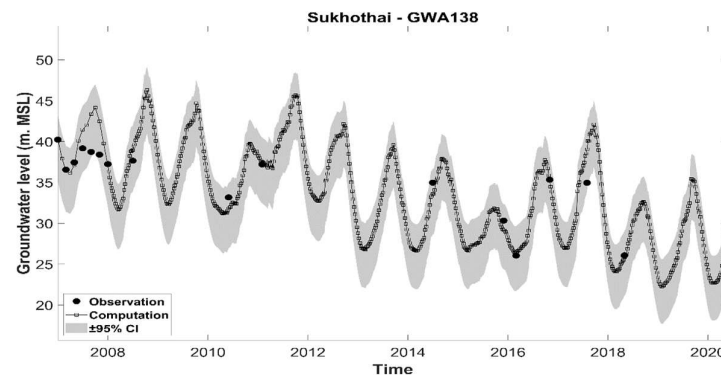


Figure 13. Observed and simulated groundwater levels at Sukhothai province during years 2008-2020.

Figure 14 presents the observed and simulated groundwater levels at Phitsanulok province during the years 2008-2020 [5]. In each year, the groundwater levels varied significantly in the range of 27-38 in the year 2008 and changing to the range of 18-33 m in the year 2020. The groundwater levels had the

trend of decreasing evidently with respect to time during the study years. This result indicated that the groundwater use exceeded the groundwater recharge significantly, thus requiring to reduce the groundwater use to recover the groundwater level.

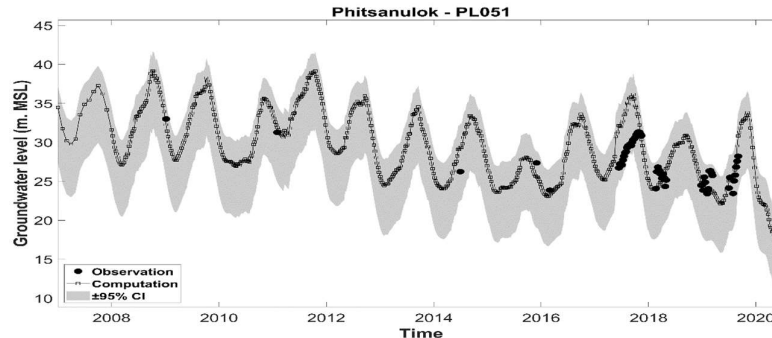


Figure 14. Observed and simulated groundwater levels at Phitsanulok province during years 2008-2020.

3.2 Groundwater Management Criteria

The groundwater management criteria to manage the groundwater appropriately and sustainably is set up as follows [3-5]

- 1) Specify groundwater to be water resource reserve to be used during the period that the surface water is insufficient to meet the water demand in order to reduce the damages to the crop production and other water use activities from water shortage.
- 2) Specify the available or potential groundwater based on the criteria that the groundwater depth does not exceed 20 m from the ground surface. This groundwater use limitation helps to prevent the loss of groundwater balance and recover the groundwater back to the normal level.
- 3) Use groundwater not exceeding the potential groundwater. Estimate the seasonal groundwater abstraction from the

graphs of relationship between seasonal groundwater abstraction and groundwater level developed for each province. Compare the groundwater abstraction to the potential groundwater in order to determine the sufficiency of groundwater.

- 4) Use groundwater not exceeding the groundwater recharge from rainfall, rivers and nearby aquifers in order to maintain the groundwater balance between the groundwater use and groundwater recharge, leading to sustainable groundwater use.

3.3 Recommended Measures

To achieve more efficient groundwater management, the following measures are recommended to be done [6].

- 1) Utilize the study results to be the database including the developed groundwater modeling and monitoring system at full capacity.
- 2) Install automatic groundwater measuring instruments covering the target region.
- 3) Install real time rainfall and river water level measuring instruments covering the target region.
- 4) Improve the model to simulate the interaction between groundwater and surface water.
- 5) Study research on groundwater recharge methods.
- 6) Develop and apply artificial groundwater storage such as groundwater bank.
- 7) Publish information and public warning in advance about groundwater crisis.

4. Conclusion

This study was done to develop groundwater management system for Thorthongdaeng irrigation project. The study results presented the groundwater management containing the groundwater well data, groundwater modeling and monitoring. The groundwater model was applied to estimate the groundwater use, potential and recharge according to each type of the 3 water years, the

3 aquifer layers and the 3 irrigation zones. For the whole irrigation zones, the average annual potential groundwater was nearly 3 times more than the average annual groundwater uses while the average annual groundwater recharge was almost equal to the annual groundwater uses, indicating the equilibrium or sustainable groundwater use condition. However, there should be caution in using and monitoring groundwater in the irrigation zone 1 and zone 2 due to very low groundwater recharge such that it is less than the groundwater use. The groundwater levels in Khampaengphet province had the trend to be rather constant while the groundwater levels in Sukhothai province and Phitsanulok province had the trend to decrease, requiring to reduce the groundwater use to recover the groundwater levels. The groundwater management criteria and the measures to manage groundwater appropriately and sustainably were set up and presented.

Considering the sufficiency of groundwater from this study and the previous studies [3-5], it was concluded that the groundwater use in the Thorthongdaeng irrigation project was sufficient in the zone 3 but had the risk of groundwater use exceeding the groundwater recharge in the irrigation zones 1 and 2. This study result indicates that the groundwater distribution in both groundwater use and recharge was different among the local scale areas as the irrigation zones 1 and 2 were vulnerable while the overall project-scale groundwater potential seemed adequate. Thus, the groundwater management should be considered in both the overall project-scale and the individual zone scale in order to prevent the excessive groundwater use and drawdown. The mitigation to solve the excessive groundwater drawdown is to reduce the groundwater use and increase the groundwater recharge to recover the groundwater level.

5. Acknowledgement

The authors would like to thank Thailand Science Research and Innovation council and National Research Council of Thailand for their research fund support, Chulalongkorn University for their research work support and Phetchaburi Rajabhat

University for their official support in writing and submitting this paper.

6. References

- [1] Department of Groundwater Resources, Project development of large groundwater resources using modern technology (riverbank filtration), Phase 1, Final Report: Feasibility study of large groundwater resources using modern technology, 2013.
- [2] Department of Groundwater Resources, Project study of drought and flood mitigation by groundwater recharge into upper region of Chao Phraya aquifer, Phase 2, Final Report: Feasibility study of drought and flood mitigation, 2013.
- [3] Chulalongkorn University, The development of groundwater management system to improve conjunctive use water management system, submitted to Thailand Science Research and Innovation Council and National Research Council of Thailand, 2020.
- [4] Chulalongkorn University, The development of groundwater management system for planning improvement to improve conjunctive use water management system in the north of lower central region, submitted to National Research Council of Thailand, 2021.
- [5] Chulalongkorn University, The assessing the groundwater potential and groundwater use for planning of conjunctive use water management system in Thorthongdaeng Operation and Maintenance Project, submitted to National Research Council of Thailand, 2022.
- [6] T. Kitpaisalsakul, P. Arlai, Development of groundwater management system for planning improvement to improve conjunctive water use in north of lower central region, Science and Technology in Society Forum (STS Forum) Japan-Thailand Symposium 2026, Bangkok, Thailand, 24-25 April 2026.
- [7] S. Punyawansiri, K. Chaengpui, B. Kwanyuen, Evaluation of water footprint of Phitsanulok-2 rice yield under alternate wetting and drying cultivation in dry season, *Interdisciplinary Research Review* 15(5) (2020) 32 – 37.