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SURFACE WATER AND PHREATIC AQUIFER INTERACTION IN FLOODPLAIN WITH PADDY FIELD IN THAILAND

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Abstract: - The interaction of surface water and phreatic aquifer in floodplain with paddy field was studied. A case study in the lower part of the Yom River in Phichit Province, Thailand was selected to research from 2001 to 2003. The numerical model for conjunctive surface and groundwater flow using alternating direction implicit was developed as a case study. The estimation of hydrological components in water budget which observed from field recorded and experiments were used as the input dataset, calibration and verification the model. Those included the estimation of crop evapotranspiration and effective rainfall; surface runoff; and infiltration. Moreover, the observations of inundated depths by flood as well as groundwater recorded were used for model verification. The results of computed water tables from the model were used to compare with the observed data and agreed with R^2 approx. 0.9995.

Key-Words: - Surface water, phreatic aquifer, floodplain, paddy field, and recharge.

1 Introduction

In large floodplain with rain-fed paddy field particular in Thailand, the interaction of surface water and groundwater is very interesting study. The fluctuation of groundwater during wet season and dry season is always change by amount of recharge and groundwater withdrawal. The evidence was shown in most of rain-fed in floodplain particular for the Yom River Basin in Thailand which land suits for growing rice due to fertile of alluvium soil. Uncontrolled water consuming for paddy was over withdrawal from the shallow groundwater and other surface water sources lead continuously drawdown of water table and hardly to recover.

Previous research had tried to recover groundwater in this area by using spreading basin and deep-well injection methods according to the feasibility study by Public Works Department (DPW) since 1998. However, the study using 3-dimensional mathematical simulation model (MODFLOW) was lack of field data of boring logs and groundwater recorded and no floodwater. The constant of aquifer characteristics: transmissivity coefficient, recharge rate, conductance, and leakage coefficient were used as input data in such model, respectively. The number of tube-wells for groundwater withdrawal was increasing by the rate of 2.5% per year resulted drawdown of water table of 12 m in the next 20 years was reported. The report also suggested more conducting a field experiment of hydrological parameters, geological phenomenon, and their behaviors involved in floodplain [1].

2 Materials and Methods

This research focused the field experiments and continuously observation involved in groundwater recharge and surface water fluctuation particular by infiltration from floodwater. Those included the installation of automatically devices and the construction of in-situ soil log profiles from 22-bore wells which used to continuously observe groundwater level, flood depth, and river stage recorded [1]. The results of water cycle in this study had reached the water balance for the demand and supply of groundwater. Infiltration is an important process with an effect on recharge to both streams and aquifer which is necessary to use in the study of surface water and groundwater interaction using the empirical formula resulted by field experiment. Evapotranspiration (*ET*) is important loss from ground by plant which can be estimated using climatically data and combined based on Penman-Monteith's (P-M) [2]. However, there was none of the study of surface and phreatic aquifer in floodplain using long event of field experiments and observation yet. This study presented the interaction of surface water and groundwater in phreatic aquifer induced by flood in floodplain with paddy field through the model.

2.1 Study Area

The study area was located on floodplain of the Yom River in Phichit Province, Thailand (Figure 1). The types of landforms are floodplain and low river terrace with the slope less than 1 %. The inner zone for studying conjunctive surface water and groundwater in floodplain was around 153 km^2 while the outer zone for study upstream runoff was around 1698 km^2. There were 2-RID (Royal Irrigation Department)'s gauging stations (Y17 and Y5) between upstream end and downstream end with a river reach of 71.8 km. A river stage (Dlog) was located at midstream of the Yom River which used for this research.

Lowland paddy field in the inner zone of study area (40 km^2) is normally inundated by floodwater along 11-observation wells (OW$_s$) name P3, P5, P7, P8, P9, P10, P12, P20, P21, P22, and P24. The topography of the inner zone (153 km^2) was described by average slope of 0.00014, ground surface level at +32.89 m above mean sea-level (MSL), and 3-local streams name Phairob, Nongkla, and Dongsualuang (Figure 2). Most of land-uses in this area are paddy field (89.6%), residence including upland crops and orchards (7.4%), and water bodies and bare-land (3.0%), respectively. Its geomorphology conformed by shallow clay and silt at topsoil layer, and deep sand in lower layer as considered as phreatic aquifer with average effective porosity (n_e) of 0.083 resulted by in-situ tests [1].

The inner area is normally affected by flood occupies by 50 % of the total area which caused by over-bank flow from the Yom River during rainy season and damaging some paddy yield. In contrast during the drought after flood, lack of surface water for crops consuming can be seen.

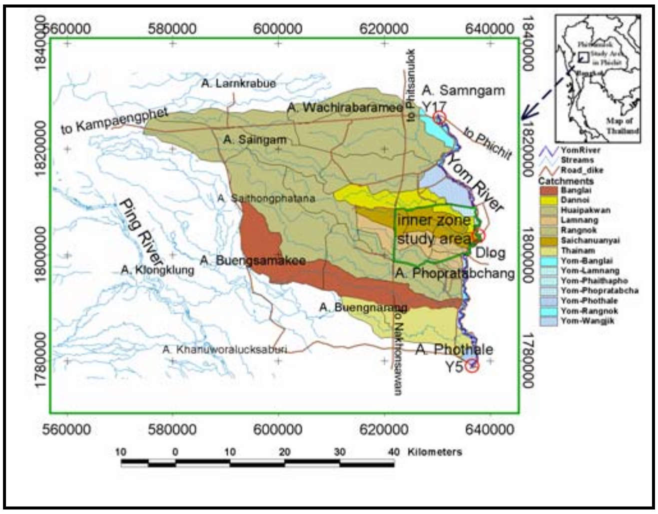

Fig.1 Location of study area.

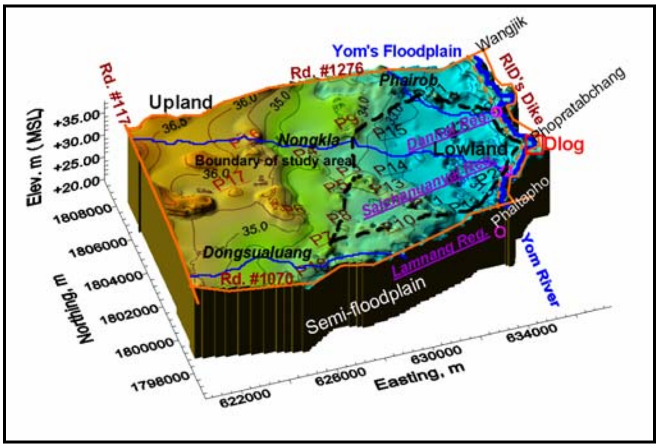

Fig.2 The inner zone and inundated floodplain.

2.2 Water Budget Model

The statistical hydrology particular regression analysis was used for analyzing and fitting those hydrological components in water budget model as shown in Figure 3.

Surface hydrological components (Figure 3) included infiltration (I), evapotranspiration (ET), rainfall (P), stream-flows (Q_{in} and Q_{out}), and inundated extensive on floodplain by the change of flood storage (ΔS).

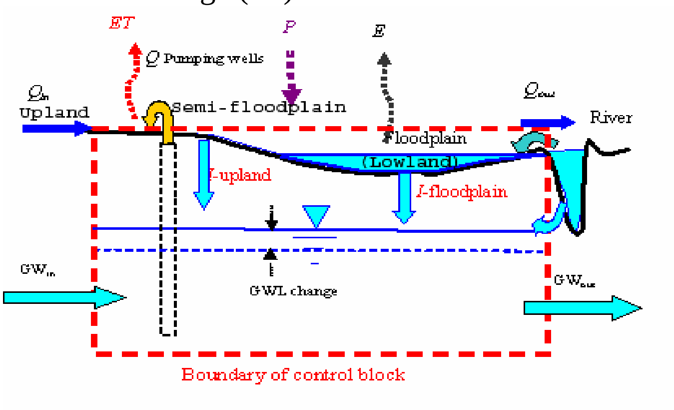

Fig.3 The water budget model.

It can categorize into the cases of none-flood (upland), partially flood (semi-floodplain), and completely flood (lowland-floodplain), respectively. In case of inundation, infiltration can be considered as saturated hydraulic conductivity (K) with varied by flood depth. The amount of surface flux to the ground will be considered as seepage rate: A_c which might be K/H (saturation case) or F/H (unsaturated case) whereas F is field infiltration results in unsaturated condition. Therefore, the amount of vertical flux can be estimated using ponding depth (H) and A_c. Therefore, continuity equation for the computing of infiltration flux over a period (t) will be budgeted by using those surface hydrological components subtraction. The lower one is also applied for the computing of groundwater balance using control boundaries.

All hydrological components can be measured and observed from the field experiments, continuous observation of river stage and phreatic level, as well as flood extent estimation using topographic map. Field infiltration testing can be fitted by using the empirical Kostiakov's model [3],[4],[5]. The Penman-Monteith's (P-M) equation can be used to estimate reference evapotranspiration (ET_o), and crop evapotranspiration (ET_c=K_c* ET_o) with crop coefficients (K_c) [2] in none-flood and partially flood zones. Since, most of floodplain suits for rice cultivation particular in Thailand, the actual amount of water requirement for paddy (V_c) should include water for land preparation period (W_{Lp}) with land preparation area (A_{Lp}) and activities period (T_{Lp}), growth period (T), and growth area (A_g) as shown in flow chart (Figure 4). However, during inundated period, ET can be considered as only evaporation (E). The amount of water for land preparation of 150-250 mm per 3-8 weeks and percolation of 1-3 mm/d per 90-100 days of paddy growing stage were reported, respectively [6].

To estimate Q_{in} and Q_{out}, which the area is located in ungauged catchments and can be applied by the synthetic hydrograph using basin characteristics and discharge formula of water flow structures, respectively [7].

2.3 Surface Water and Groundwater Model

Flow chart in Figure 4 is used for studying conjunctive surface water and groundwater in floodplain with paddy field. Amount of flux resulted by infiltration and percolation in groundwater budget will move downward to subsoil beneath ground surface with some part store in subsoil and the remaining part go to phreatic aquifer. Therefore, the regional change of water tables can be computed using existing fluxes as recharge, lateral groundwater inflow and outflow, leakage of groundwater to the lower aquifer, and amount of groundwater withdrawal during growing seasons as discharge, respectively. The lateral groundwater flow can be computed using Darcy's equation using known water tables inside and outside boundaries and length between those observation wells along the boundaries [1].

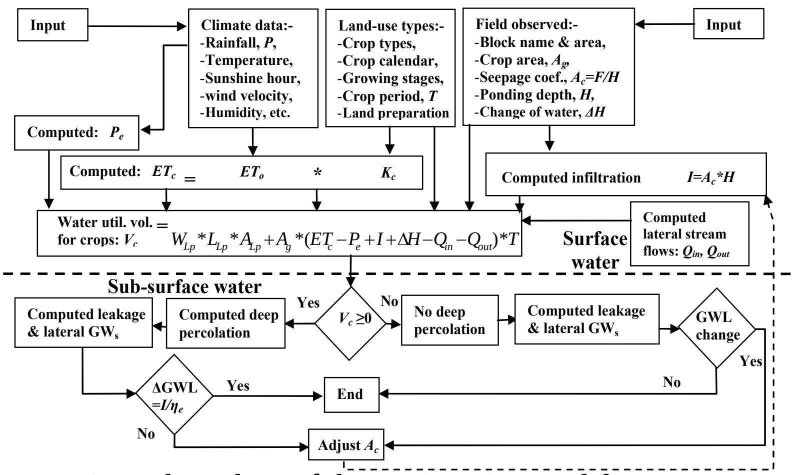

Fig.4 Flow chart of the conjunctive model.

The applied alternating direction implicit (ADI) [8] which was used for the solution of implicit finite difference of groundwater flow below ground during inundated as the flow chart in Figure 5.

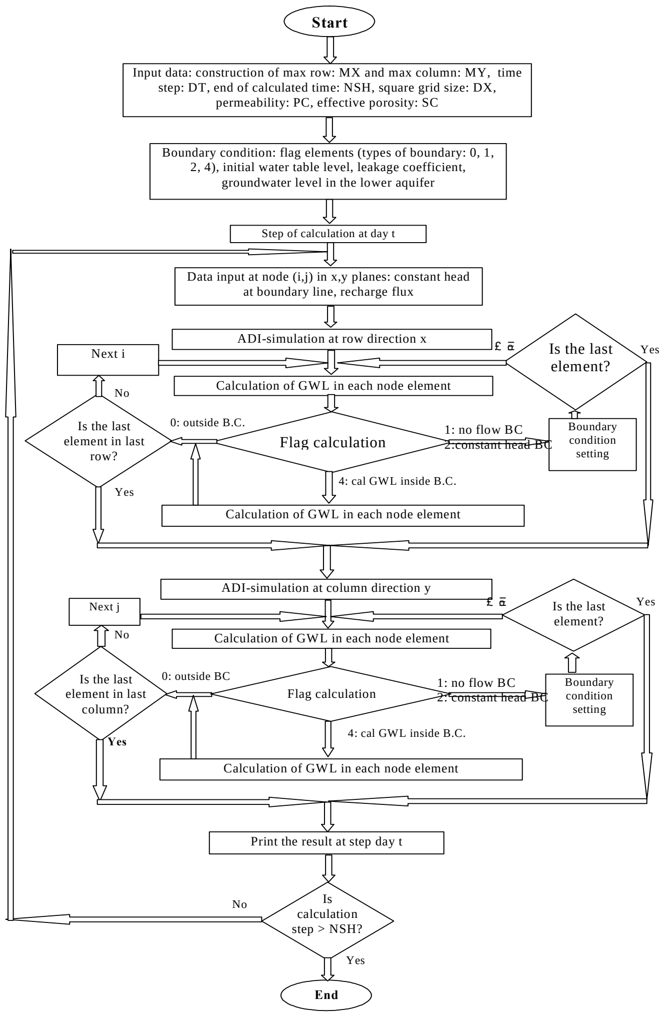

Fig.5 Flowchart of conjunctive model simulation.

The systematized model includes square-grids, boundaries, and number of rows, columns (i,j). For the given boundary conditions (B.C.) are 0: outside boundary, 1: no flow, 2: constant head of GWL, and 4: GWL computation inside B.C., respectively. The others are given time step (DT) and time of calculation at ending phase (NSH).

The process of calculation in Figure 5 starts with initial condition: GWL and computed recharge flux at every grid points on the first time of flood. Then ADI processes to calculate surface flux from given A_c and further to compute water storage in ground and aquifer, leakage flux to the lower aquifer, and the change of groundwater level (GWL), respectively. The solution of groundwater flow for the next time step using ADI will be processed to the direction of rows and columns as the iteration numbers with given boundaries and initial conditions. The output of calculated GWL will be compared to the observed GWL in order to test how effectiveness of the model and model verification.

3 Results and Discussion

The inundated depths caused by flood in floodplain were measured of 0.02-0.08 m and 0.2-3.0 m during growth season and flood period (Figure 6), respectively.

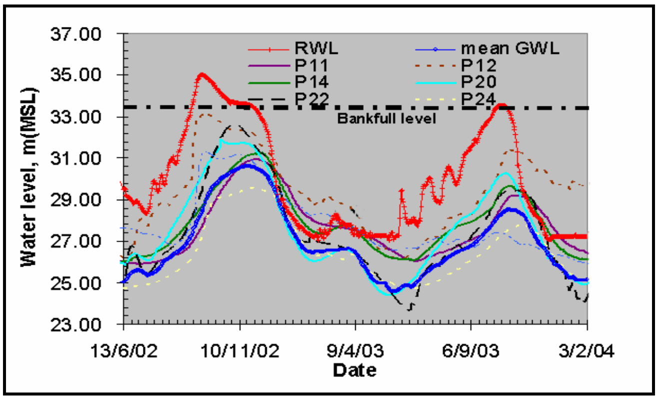

Fig.6 GWL and river stage (RWL) in 2002-2003.

The investigation of a local percolation with 49-spots during the examination of filed infiltration was expressed distribution of seepage (A_c) as shown in Table 1 and Figure 7.

Table 1 Infiltrations, seepage, and hydraulic conductivities at each observation wells.

OW's name	*A* [km^2]	Elevation [m(MSL)]	*F* [mm/d]	A_c [mm/d/m]	*K* [mm/d]
P03	4.23	33.72	12.4	30.9	2.1
P07	0.62	33.67	0.1	9.6	0.003
P08	3.96	33.82	2.8	10.9	0.6
P09	3.35	34.07	0.9	9.8	0.04
P10	3.67	33.45	13.2	14.5	4.9
P11	3.70	33.16	3.9	4.3	0.9
P12	2.25	32.12	3.9	37.6	0.7
P13	3.18	33.54	3.5	4.7	1.5
P14	4.35	32.74	3.9	51.1	0.9
P15	4.82	32.57	7.6	23.7	2.2
P20	3.65	31.62	2.8	4.7	1.6
P21	2.81	32.19	9.7	14.8	2.7
P22	2.29	32.08	0.3	6.3	0.02
P23	5.92	32.16	1.0	2.8	0.04
P24	1.56	32.37	0.3	6.3	0.02

The model's shape of the inner area of 72 km^2 (10x7.2) as shown in Figure 7 with grids sizing of 200x200 m were drawn by 51 columns, and 37 rows as cell (i,j) from the left to right hand side.

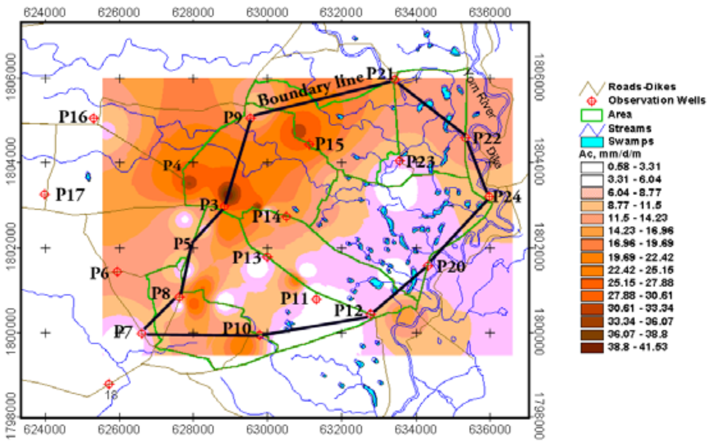

Fig.7 Aerial view of A_c and area of testing model.

The surface flux in the inner zone resulting from infiltration in 2001-2003 is summarized in Table 2. It is clear that the rising of groundwater level in this area is mainly resulted by flood. However, minimum GWL is moving drawdown during dry season by mean of a lot of groundwater use for crop has been over withdrawn than groundwater yield. The recharge during flood period in wet season, and ponding water in paddy field during dry season was averaged to 70-75 %, and 25-30%, respectively.

Table 2 Recharge flux through ground to aquifer during flood using existing A_c.

Item (each year)	2001	2002	2003
Avg. RWL, m(MSL)	32.13	32.51	31.50
Av. NGL, m(MSL)	30.30	30.30	30.30
Ponding period, day	129	118	63
Flood area, km^2	22.0	29.5	12.0
Avg. flood depth, m	1.83	2.21	1.20
Avg. A_c, mm/d/m	16.245	16.245	16.245
surface flux, mm	3848.28	4247.9	1225.78
flux volume (MCM)	84.66	125.31	14.71

The calculated daily GWL and observed data in 2002 and 2003 were compared and fitted by using linear regression analysis and found average R^2 of 0.9995 (Figure 8). The examples of computed and observed GWL on 24 September 2002 and on 24 October 2003 were presented by different types as contour-lines of computed and observed groundwater level (Figure 9).

The calculated of groundwater flow were flux by infiltration of 9.0 and 3.8, recharge flux of 4.3 and 1.2, leakage of 1.7 and 0.9, stored in subsoil of 4.7 and 2.6, and stored in aquifer of 2.6 and 0.3 mm/d, in 2002 and in 2003, respectively. Most result of recharge in 2002 was greater than 2003 due to the higher magnitude and longer period of flood.

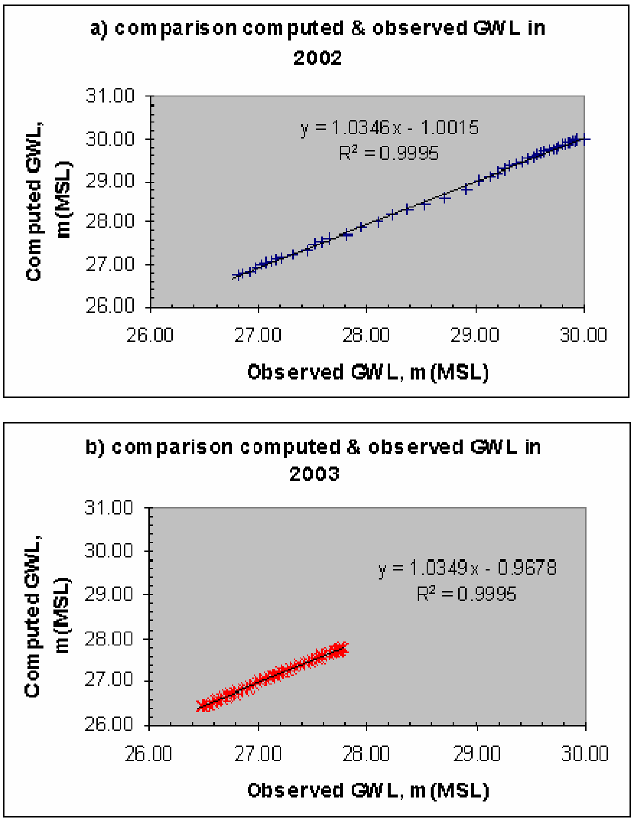

Fig.8 Comp. of cal. and obs. GWL in 2002-2003.

Table 3 Simulation results from the model.

Results	Year 2002	Year 2003
Ground surface flux, m^3	59,067,400	15,407,800
Recharge flux, m^3	28,238,999	4,857,139
Leakage to lower aquifer	11,229,448	3,634,858
Water stored in subsoil	30,828,401	10,550,661
Water stored in aquifer	17,009,551	1,222,280
Period of flood , days	91	57
Calculated GWL,m(MSL)	29.463	27.262
Observed GWL, m(MSL)	29.445	27.278
Dif. Cal. & observed, m	0.018	-0.016
Error cal. GWL, %	0.061	0.058
R^2 regression result	0.9995	0.9995

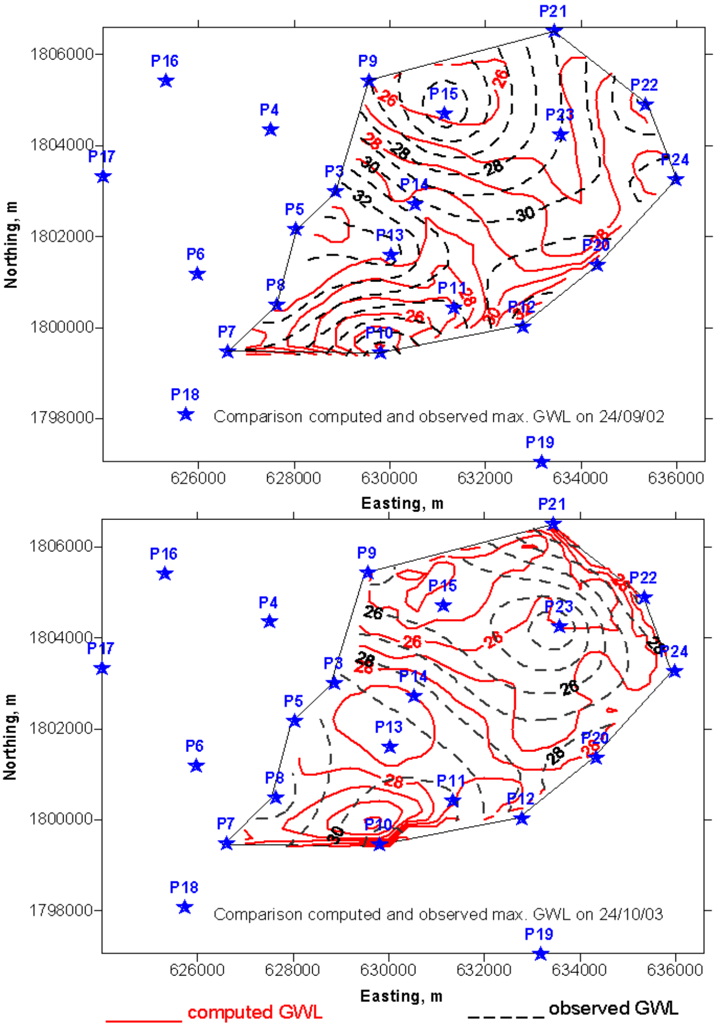

Fig.9 Comparison cal. and obs. daily GWL.

4 Conclusion

This study evaluated the situation of the effect of surface runoff to the change of groundwater level using field observation data in paddy field through developed conjunctive model. Infiltration flux during inundated period is the major effect to increase water table. However, trend of minimum water table slightly recessed year by year caused by the withdrawal of groundwater for farm crop consumption. The numerical solution using ADI was effectiveness and high accuracy enough which can apply to solve the problem of conjunctive surface water and groundwater in any country with floodplain conditions similar as Thailand.

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