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# Conjunctive Surface Runoff and Groundwater Management in Salinity Soils

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***Abstract*—**This research was conducted in the Lower Namkam Irrigation Project situated in the Namkam River Basin in Thailand. Degradation of groundwater quality in some areas is caused by saline soil spots beneath ground surface. However, the tail regulated gate structure on the Namkam River, a lateral stream of the Mekong River. It is aimed for maintaining water level in the river at +137.5 to +138.5 m (MSL) and flow to the irrigation canals based on a gravity system since July 2009. It might leach some saline soil spots from underground to soil surface if lack of understanding of the conjunctive surface water and groundwater behaviors. This research has been conducted by continuously the observing of both shallow and deep groundwater level and quality from existing observation wells. The simulation of surface water was carried out using a hydrologic modeling system (HEC-HMS) to compute the ungauged side flow catchments as the lateral flows for the river system model (HEC-RAS). The constant water levels in the upstream of the operated gate caused a slight rising up of shallow groundwater level when compared to the water table. However, the groundwater levels in the confined aquifers remained less impacted than in the shallow aquifers but groundwater levels in late of wet season in some wells were higher than the phreatic surface. This causes salinization of the groundwater at the soil surface and might affect some crops. This research aims for the balance of water stage in the river and efficient groundwater utilization in this area.

***Keywords*—**Surface water, groundwater observation, irrigation, water balance.

## I. Introduction

THE Namkam River, one of the Mekong River's tributaries, is located in Sakhon Nakhon and Nakhon Phanom provinces in Northeast region of Thailand with a catchment area of 3440 square kilometers ($km^2$) as shown in Fig. 1. The study area, the Lower Namkam Basin in Nakhon Phanom Province covers an area of 1570 $km^2$. Apart of this area located in Na Kae, Renu Nakhon, and That Phanom districts was chosen for study with emphasize on floods and groundwater levels change. The Lam Nam Kam (Namkam) is the main river used as the water source for agriculture in this area, but there is a high variation of flow between rainy and dry season. The direction of water flow is from the west in Sakhon Nakhon to the east and meets the Mekong River in Nakhon Phanom. The Nam Bang (Nambang) is the largest lateral river of the Namkam which flows from the north in Pla Pak district to the south in Renu Nakhon and Na Kae districts.

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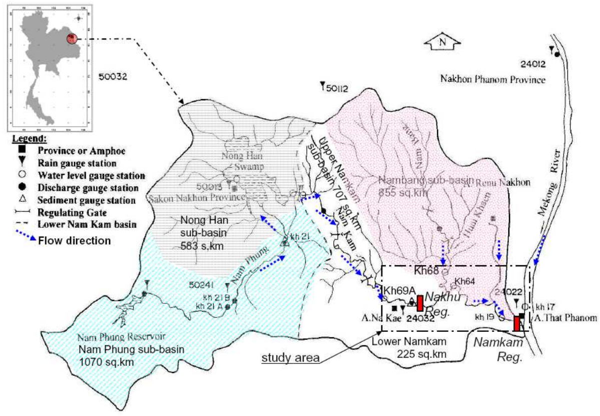


Fig. 1 Map of study area in the Namkam River Basin, hydrological observation stations, and regulated-structures in study area

The major existing water resources development projects in this basin include a big dam, a lake and 5-regulated structures. The Nam Phung Dam (with a storage capacity of 155.8 million cubic meters: MCM) and the Nong Han Lake (266.9 MCM) are operated for downstream water utilization and flood control. Suratsawadee is a gate structure designed release water from the Nong Han Lake to the Namkam River before flowing to the Mekong River via 4-regulated structures : Nongbueng (97 km), Nakham (71 km), Nakhu (46 km) and Namkam (1.7 km). The proposed maintaining of water level in the Namkam river upstream of the tail gate will be operated at +137.5 to +138.5 m (above mean sea level: MSL) which aim for inundated irrigation of paddy field since July 2009. However, the irrigation systems are not finished yet [1, 2].

During dry season, there is insufficient surface water for the cultivated areas. Therefore, many shallow groundwater tube-wells have been drilled and pumped as the water supply system for irrigation and drinking purposes. Observations of groundwater quality in this area reported that there are some problems of groundwater salinity which might affect water quality for irrigation purposes [1, 3]. The geological map shows thick layers of mudstone, shale, and siltstone inter-bedded with rock salt which significant influence groundwater salinity as shown in Fig. 2 and Fig. 3 [3, 4, 5]. The research reported in this paper was undertaken to analyze the relationship of river water stages, and groundwater change from the observation data after the downstream gate has been operated as for further management of efficient conjunctive surface and ground waters utilization.

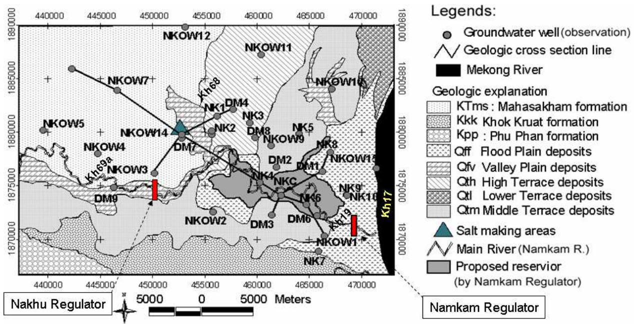


Fig. 2 Map of the interpreted geological explanations, cross-sectional lines, and the location of observation wells in the study area [3]

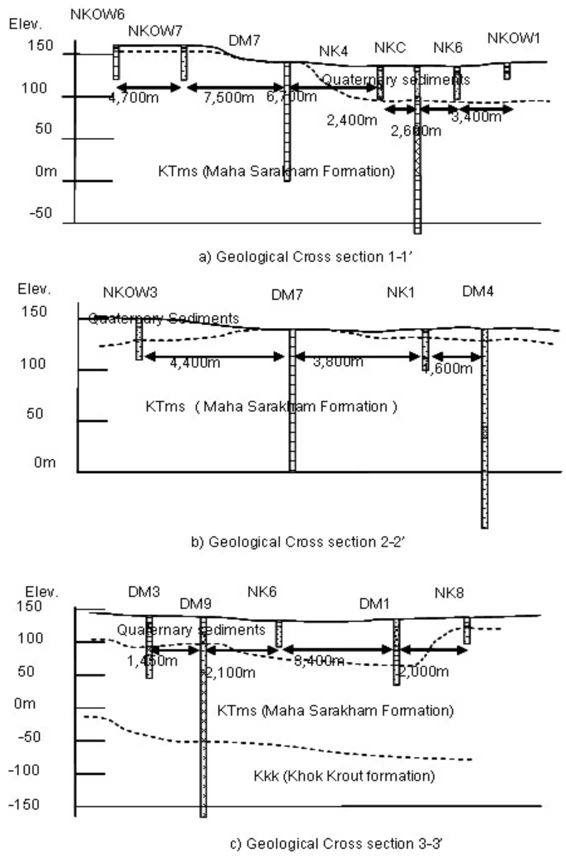


Fig. 3 Cross-sectional profiles of geological maps from log data [4]

## II. MATERIALS AND METHODS

The recorded daily data of rainfall and river stages (WSL) along the Namkam River, the Nam Bang River and the Mekong River, conducted by the RID, the Department of Water Resources (DWR) and Thailand Meteorology Department (TMD) were used in this study. This study used daily stage and discharge records in the river stations namely : Kh69a (57.3 km), Nakhu regulator (49.0 km), Namkam regulator (1.7 km) and Kh17 (0.0 km) which measured from the river mouth in That Phanom and Na Kae districts as shown in Fig. 1 and Fig. 2, respectively. The aerial rainfall based on Thiessen polygons was applied to generate from point rainfall to aerial rainfall. The most side-flows of the river are ungauged catchments; therefore a hydrologic modeling system : HEC-HMS [6] using daily rainfall recorded at Kh17 was applied as the uniform lateral inflow based on Snyder's synthetic hydrograph [7] for each specific reaches in the river system model : HEC-RAS [8] from 2009 to 2011. The hydrological and river analysis map shows in Fig. 4, whereas Reach-1 to Reach-4 is the Namkam River at each modeling portions. The gauging stations namely : Upper and Nabua are located at upstream and a lateral stream which meet main stream at Pakbang village for the calibration of hydrological parameters i.e. peak coefficients ($C_p$), peak lags ($t_p$), and loss rates etc. The remaining lateral inflows of the Namkam are ungauged catchments namely : Namseong, Bang, Nongdu, and Kudcan (north catchments), and A1, A2, and A3 (south catchments) which were modeled using those hydrological parameters. Initial transposing unit hygrograph's parameters for Mekong sub-basins in Thailand [9] were applied for HEC-HMS's Snyder transformed model shown in (1) and (2). Finally, the hydrological parameters from model optimization are presented and fitted with observed data for gauged catchments. The upstream and downstream regulated gates are located at the end portion of Reach-1 and Reach-4 (H.reg or Namkam Reg. in Fig. 1) before the outlet to the Mekong River, respectively.

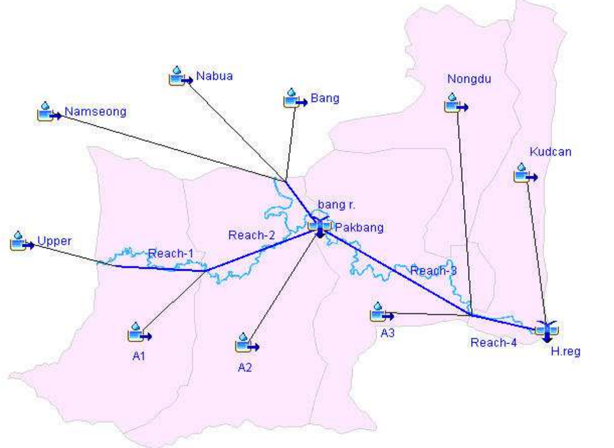


Fig. 4 Map of using HEC-HMS and HEC-RAS models

$$t_p = 0.75 C_t (LL_c)^{0.3} \text{ and } Q_p = 2.78 C_p A / t_{IR} \quad (1)$$

$$t_p = C_t [LL_c / S^{0.5}]^n \quad (2)$$

whereas : $L$, $L_c$ are channel and mid stream lengths in km, $S$ is the channel slope, $A$ is catchment's area in km$^2$, $t_p$, $t_{IR}$ are basin lag and adjust duration in hr, $Q_p$ is peak discharge in m$^3$/s, $C_t$ and $n$ are basin coefficient and exponent values with the 0.2837 and 0.3979 for this regional study, respectively.

The river analysis model using existing 51-cross sectional profiles with length step of 1.1 km, and 2-regulating structures at km46 and km1.7 were modeled shown in Fig. 5.

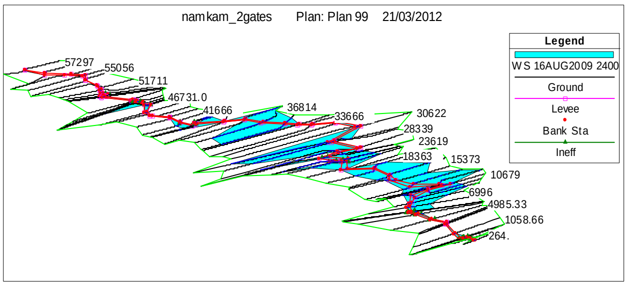

Fig. 5 Plan view of the Namkam geometry in HEC-RAS model

The upstream boundary condition at km57 was discharge which releases from Nam Phung Dam, Nong Han Lake, and upstream of the Namkam river. A big later inflow to the Namkam is the Nambang River where meets at km34 from river mouth. The remaining side-flows were used as uniform lateral inflows to Namkam. Thus, WSL for each section was computed based on previous calibrated roughness coefficients in years 2005 to 2007 [10, 11]. This WSL will be used to compare observed groundwater levels (GWL). Flood level above ground surface level (NGL) will be used as the head for estimating seepage flow as direct recharge to the unconfined aquifer. The main crop for study water requirement in this basin is paddy of 88% of total land use which estimated using climatologically data and CROPWAT program [12] and modified in weekly basis. The amount of water for paddy use covered land preparation of 270 mm/2weeks, percolation of 3 mm/d, and evapotranspiration using Penman-Monteith include delivery losses which is total water of 14200 $m^3$/ha/year [2].

The existing GWL recorded from each observation wells : NK2, NK3, NK8, NKOW14 and DM6 located in both unconfined and confined aquifers. The electric conductivity (EC) from DM6, NKOW14 and NK3 were observed and analyze according to the fluctuated of daily RWL.

## III. Results and Discussion

The optimization of gauged hydrological parameters : $C_p$, $t_p$ in HEC-HMS and result of 3-year observed rainfall and comparison between simulated and observed flow to Upper and Nabua were shown in Table 1. Daily record of rainfall in 2009, 2010, and 2011 (Fig. 8) was used as input in the model with average annually rainfall at Kh17 of 1203, 1333, and 1843 mm, respectively. The WSL during flood periods (1 July-31October) in 2009 to 2011 (Fig. 8) were used as boundary conditions in HEC-RAS model. The roughness coefficients in HEC-RAS ranged from 0.025 to 0.05 for main channel, and 0.06 to 0.09 for flood plain. The example results of maximum flood for each year were summarized in Table 2 with plan view of maximum flood in 2009 shown in Fig. 5, profiles and plan view of maximum flood in 2011 were shown in Fig. 9 and Fig. 10. Daily WSL in Namkam resulted by amount of rainfall and influenced from backwater effect from the change of water stages in Mekong River. The averaged WSL in years 2009-2011 was higher than 2006-2008 because there has no tail gate operated in previous time yet.

TABLE I
Hydrological Parameters for Each Sub-Basin in HEC-HMS

| Sub-basin | Area, $km^2$ | $L$, km | $L_c$, km | $S$ | $t_p$, hr | $C_p$ | Infiltration, mm/hr |
|---|---|---|---|---|---|---|---|
| Upper* | 2204 | 128 | 64 | 0.0013 | 48 | 0.1 | 1.2 |
| Namseong | 135 | 30 | 15 | 0.0014 | 12 | 0.3 | 0.1 |
| Bang | 120 | 22 | 11 | 0.0014 | 9 | 0.3 | 0.1 |
| Nabua* | 443 | 50 | 25 | 0.0009 | 12 | 0.2 | 0.05 |
| Nongdu | 85 | 20 | 10 | 0.0007 | 4 | 0.25 | 0.5 |
| A1 | 119 | 14 | 7 | 0.0139 | 4 | 0.25 | 0.5 |
| A2 | 140 | 15 | 7.5 | 0.0039 | 4 | 0.25 | 0.5 |
| A3 | 120 | 13 | 6.5 | 0.0072 | 4 | 0.25 | 0.5 |
| Kudcan | 73.5 | 24 | 12 | 0.0003 | 12 | 0.4 | 0.2 |

Note * with gauging station

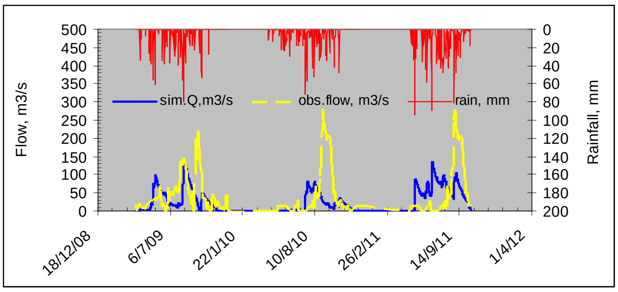

Fig. 6 Observed rainfalls, river flow and simulated flow of Upper

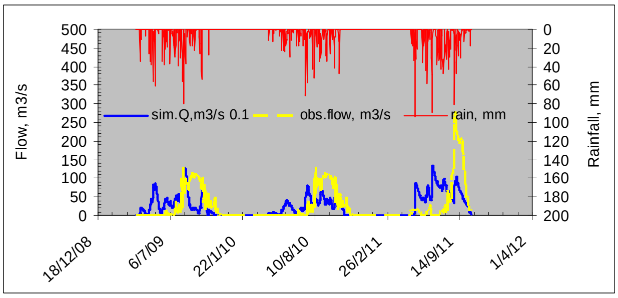

Fig. 7 Observed rainfalls, river flow and simulated flow of Nabua

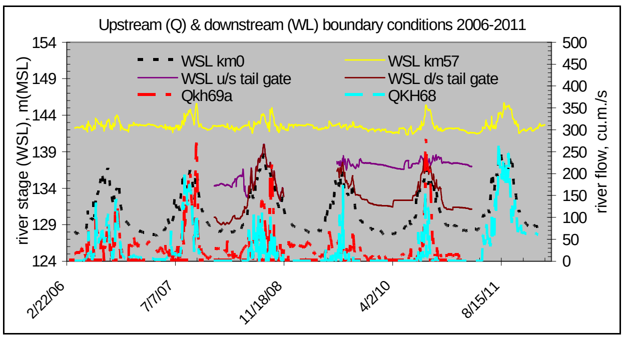

Fig. 8 WSL and river discharge in the Namkam River in 2006-2011

TABLE II
SUMMARY OF FLOOD INFORMATION IN YEARS 2009 TO 2011

| Year | Mean WSL, m(MSL) | Date of max WSL | Max WSL, m(MSL) | % flood area per study area | Inundated days |
|---|---|---|---|---|---|
| 2009 | 137.32 | 16 August | 138.93 | 3.63 | 22 |
| 2010 | 137.91 | 3 September | 139.71 | 9.55 | 61 |
| 2011 | 139.23 | 12 August | 140.59 | 16.25 | 90 |

Note : simulated WSL from km1.7 to km46, with study area of 390 $km^2$

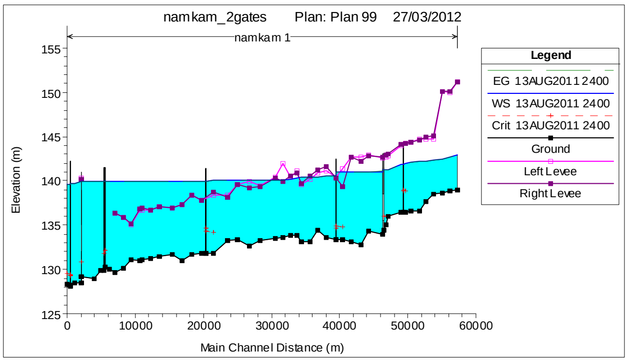


Fig. 9 Profile of max. flooded in the Namkam River on 13/08/2011

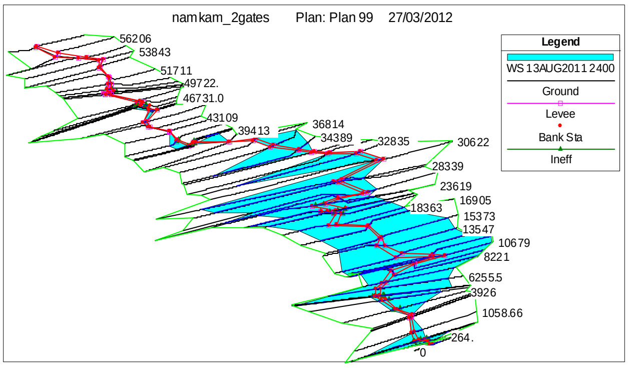


Fig. 10 Plan view of flooded area in the Namkam on 13/08/2011

The comparison of mean WSL in the river at each station in Fig. 8 and Fig. 9 were used to compare GWL at NK2, NK3, and DM6 shown in Fig. 11 and Fig. 12, respectively. The slight raising of GWL at DM6 and NK3 has been followed by the WSL in the Namkam. But NK2 is not much changed due to less water use for irrigation surrounding this well's area.

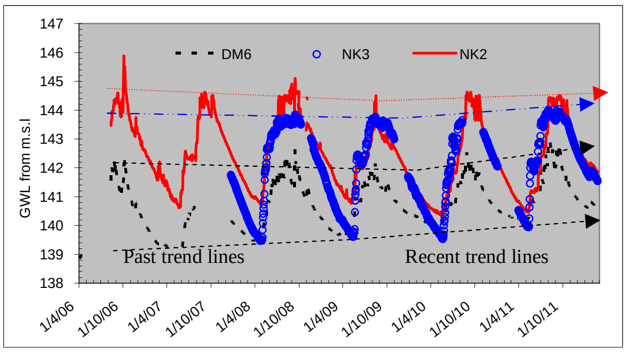


Fig. 11 GWL changes from observation wells in 2006-2011

The rising limbs of GWL result by high recharge from flooded water from gate control in wet season. The recession limbs of GWL are caused by high amounts of groundwater withdrawal during drought periods for crops and other consumptions. Both of the minimum GWL and maximum GWL are trended to be rising up from 2009 to 2011 followed by the rising of WSL in the Namkam River from the riverbed to the constant level with +137.5 to +138.5 m(MSL) after completed gate operation since 2009. The evidence showed the GWL in shallow aquifers i.e. at NK3 (in Fig. 11 and Fig. 12) slight rising up with the rate of 0.10 m per year. The reason causes to bring saline groundwater to soil surface if GWL becomes to NGL and cause saline soil at NGL and might affect some crops. The observations of GWL and electric conductivity (EC) at DM6 and NK3 in 2006-2011 (Fig. 12) showed the EC-values slight rising up with the rate of 10 and 240 mS/m per year, respectively.

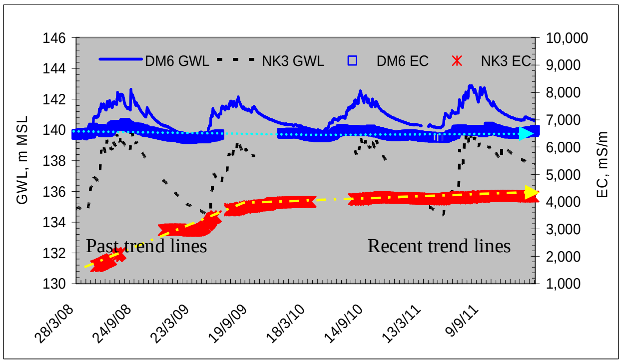


Fig. 12 GWL and EC-values at DM6 and NK3 in 2008 -2011

## IV. CONCLUSION

The results showed that both river levels (WSL) and groundwater levels (GWL) in recently after completed gate operation at downstream end of the Namkam River since 2009 have been rising compared to 2006-2008. The slight rising of saline groundwater is measured by mean of EC-value results by rising of GWL and WSL. Moreover, the backwater from tail gate operation and from the Mekong River to upstream of the Namkam River is caused to rising of GWL too. The tail gate operated in the Namkam River and the Nambang River should be carefully regulated with awareness of the dispersion of saline groundwater from some salt spots and other potential sources.

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