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Potential Impact of Climate Change on Area Affected by Waterlogging and Saline Groundwater and Ecohydrology Management in Northeast Thailand

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Abstract

Modeling approach was employed to predict potential impact of climate change on waterlogging and salinity distribution with the ecohydrology options for land management under the projected climate conditions in Huai Khamriam subwatershed in the northeastern region, Thailand. The prediction was simulated using the variable density groundwater model SEAWAT supported with recharge estimation model HELP3 under the projected weather data from PRECIS RCM scenario A2. As the result of the higher precipitation simulated by PRECIS RCM scenario A2, the predicted groundwater recharge was likely to be higher in the middle of this century onward. The areas affected by shallow saline groundwater were found to increase with the climate change scenario as well as for the base case. Based on scenario simulation, climate change did not have substantial impact on salinity distribution, but it was significant impact to the expansion of waterlogging areas. Management option using ecohydrology simulation approach was performed to reduce the recharge water to groundwater system, which consequently minimizes the impact of the higher precipitation in the future. The results indicated that establishment of the fast growing tree integrated with the shallow groundwater interception in the recharge areas could reduce the expansion of waterlogging and salinised areas under the climate change condition.

Keywords: climate change; salinity; waterlogging; ecohydrology approach

1. Introduction

The Maha Sarakham Formation consisting of the naturally occurring halite and the secondary deposits of salt in unconsolidated materials is identified as a source of salt in the northeast region, Thailand. However, salt dispersion or salinization due to human activities has been recognized since early as the 1980s (Arunin, 1984). The main human activity is deforestation that alters water balance of groundwater system in the region. Changing in groundwater recharge and raising water table in the saline source areas make the area in northeast region dramatically expanding on waterlogging and salinisation. About 75% of the salt affected land in this region is used for rainfed rice cultivation and 1.5% is regarded as wasteland (Arunin, 1992), of which such affected land are being the most vulnerable area for climate change.

Currently, the climate change has been coming up as the global and natural issues. Climate for mainland Southeast Asia was projected for the period of year 2010 - 2099. The simulation was conducted under the PRECIS (Providing Regional Climates for Impacts Studies) regional climate model with Global Circulation Model (GCM) ECHAM4 dataset as initial and boundary conditions. The simulation covered the Intergovernmental Panel on Climate Change (IPCC) emission scenarios A2 and B2 (IPCC 2000). The projection presented an evident trend of increasing precipitation from the middle of the century onward, especially in the areas near Mekong River as well as the southern region (Chinvanno *et al.*, 2009). Increasing precipitation, thus increase the groundwater recharge, would expand waterlogging and saline soil areas, which further affect land availability for agriculture and food production. That is the motivation of this research study on the specific subwatershed area

2. Materials and Methods

2.1. Study Area

Huai Khamrian subwatershed, covering an area of approximately 154 km^2 (Fig.1), represented as a typical feature of the salt affected area was selected as the pilot study area. It is existed by an undulating topography covered with various salinisation levels. Land is covered by the agricultural areas, whereas the main

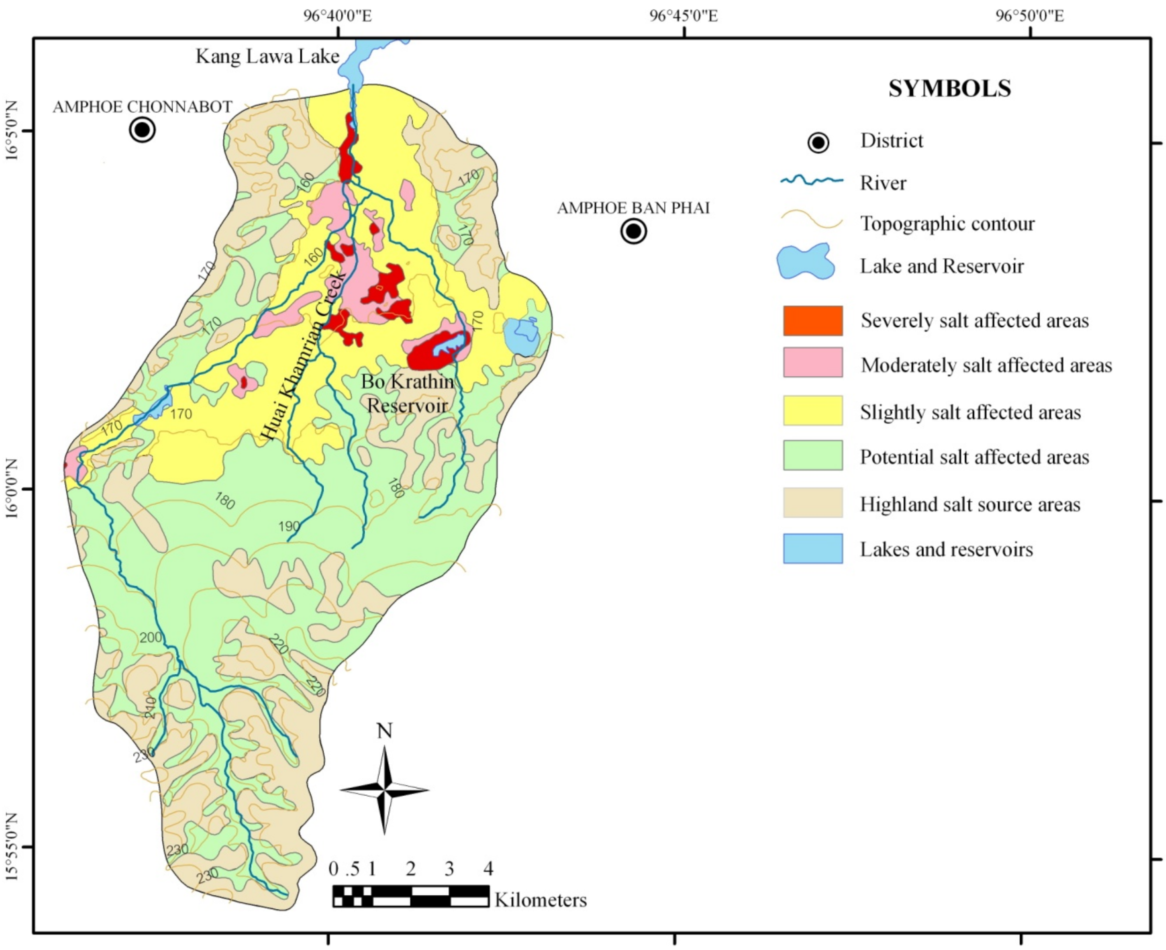


Figure 1. Location and salt affected areas in Huai Khamrian subwatershed (LDD, 2002)

products are rice, sugarcane and cassava. The rainfed rice field covers 64% of the subwatershed, located in the lowland at central and the northern parts. Huai Khamrian Creek, the main natural drainage system in the study area, flows from the south to the north. During the dry season, water quality of the creek is mildly brackish with electrical conductivities of up to 1,500 µS/cm and becomes fresh to slightly brackish in rainy season. Surface water and groundwater salinity had been monitored during November 2003 to March 2004 by measuring electrical conductivity over the area, the high electrical conductivity of 10,000-100,000 µS/cm in the discharge area or along the central floodplain of the Creek. The watershed is underlain by siltstone and sandstone aquifer of the Upper Phu Thok unit with the thickness of 30-250 m and claystone of the Lower Phu Thok unit is underlain by the rock salt layers of the Maha Sarakham unit. Water level measurements from the year 2003 (Fig. 2) shows the high hydraulic heads existed in the south, west and east, but the relatively low hydraulic heads existed in the central and north (Srisuk *et al*., 2007). Groundwater flows originate near the boundary of the subwatershed, particularly in the southwest, south and southeast and tend towards the central region within the Upper Phu Thok unit. The highly salt affected area with salt crust at the ground surface is evident over more than 50% of the discharge areas in the north part near Kang Lawa Lake. The slightly and moderately salt affected areas occur at the mid reach of the small tributaries of Huai Khamrian Creek and the areas around Bo Krathin reservoir (Fig. 2).

2.2. Methodology

Potential impact of climate change on areas affected by waterlogging and shallow saline groundwater was evaluated using the variable density groundwater model SEAWAT version 4 (Langevin *et al*., 2008) supported with recharge estimates derived from the hydrologic model HELP3 (Schroeder et al., 1994). The weather data from the (RCM) PRECIS model downscaled from Max Planck Institute for Meteorology (MPI) GCM model (ECHAM4), a high emission scenario (SRES-A2) from the collaboration between Southeast Asia START Regional Center and ESRI (Thailand), was used as the input data for the recharge estimation using HELP3 model. Result from the recharge model estimation was assigned into a groundwater flow and salt transport model to predict the movement of the

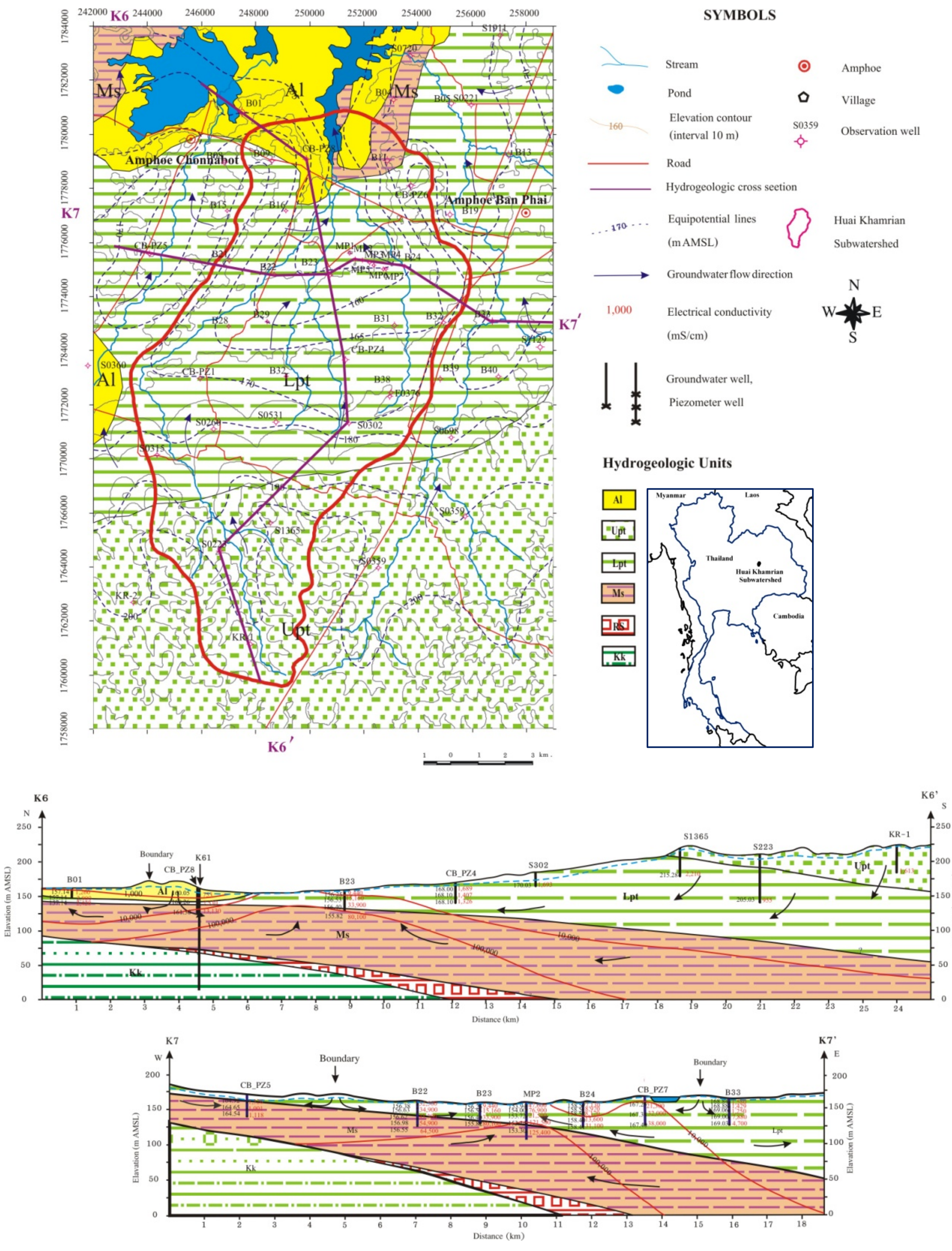
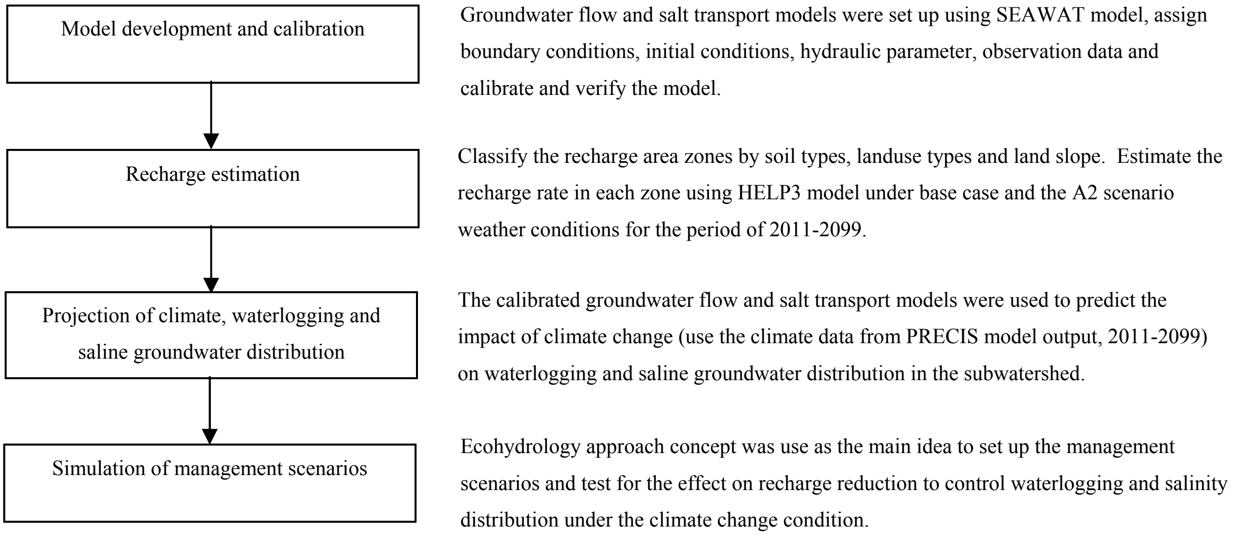


Figure 2. Hydrogeological map and cross sections of Huai Khamrian Subwatershed (Srisuk *et al*., 2007)

saline groundwater boundary compared to the simulation with the historical base case scenario (Figs. 3-4). The impact of future climate change on waterlogging and salinity distribution in the watershed was determined under the means of areal distribution of water table depth and saline groundwater extension areas under the results from the prediction result at the time of the middle and the end of this century. The range of adaptation scenarios under the principal of ecohydrology were tested for suitability of the adaptation options.



Groundwater flow and salt transport models were set up using SEAWAT model, assign boundary conditions, initial conditions, hydraulic parameter, observation data and calibrate and verify the model.

Classify the recharge area zones by soil types, landuse types and land slope. Estimate the recharge rate in each zone using HELP3 model under base case and the A2 scenario weather conditions for the period of 2011-2099.

The calibrated groundwater flow and salt transport models were used to predict the impact of climate change (use the climate data from PRECIS model output, 2011-2099) on waterlogging and saline groundwater distribution in the subwatershed.

Ecohydrology approach concept was use as the main idea to set up the management scenarios and test for the effect on recharge reduction to control waterlogging and salinity distribution under the climate change condition.

Figure 3. Procedural diagram representing the modeling approach

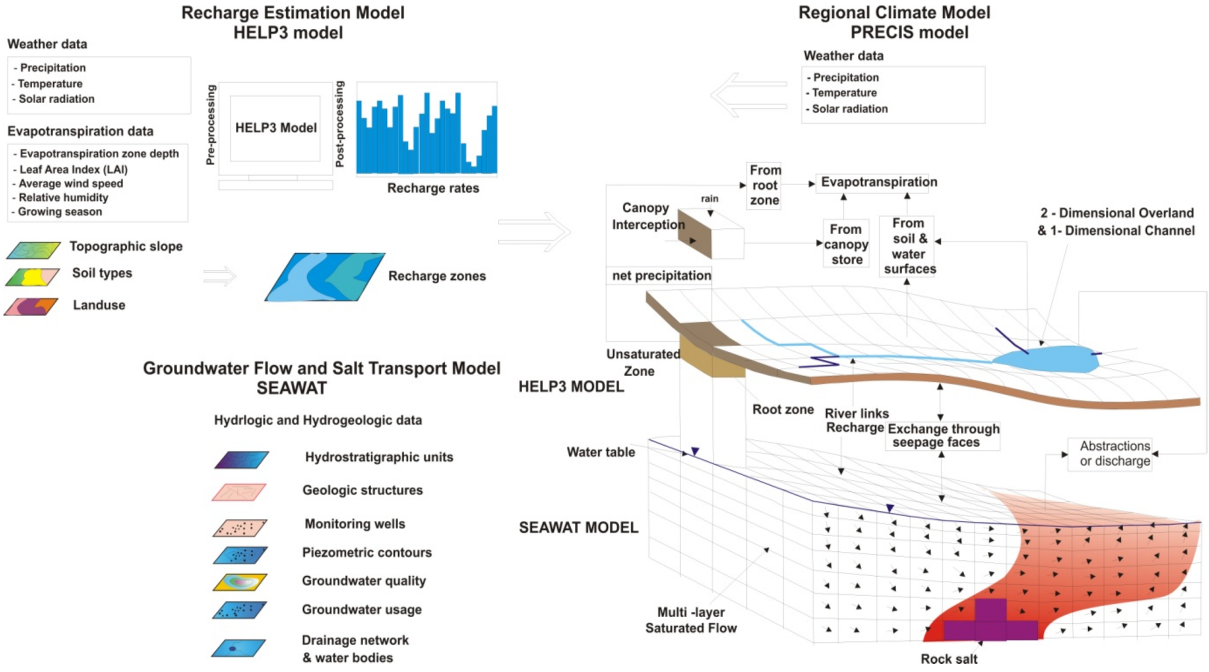


Figure 4. Structural diagram of the modeling approach and required data

2.2.1. Recharge estimation

Groundwater recharge depends on the rainfall intensity, temperature and ground surface cover. Whereas the recharge water is subjected to various processes such as interception, evaporation and surface runoff. The Hydrologic Evaluation of Landfill Performance (HELP) computer program (Schroeder *et al.*, 1994) is a quasi-two-dimensional model, deterministic water routing model for computing water balances. It simulates the daily movement of water into the ground, and accounts for precipitation in any form, surface storage, runoff, evapotranspiration, vegetative interception and growth, unsaturated flow, and temperature effects. The required input parameters for the model are shown in Table 1. HELP model has been extensively tested by its developers (Peyton and Schroeder 1988; Schroeder *et al.*, 1994) and also been compared with Richards' equation based approaches as well as field results under various conditions (Fleenor and King, 1995; Woyshner and Yanful, 1995; Khire *et al.*, 1997; Chammas *et al.*, 1999; Berger, 2000; Gogolev, 2002; Risser *et al.*, 2005). It has been used to estimate the impact of climate change on spatial varying groundwater recharge rate (Jyrkama *et al.*, 2002; Allen *et al.*, 2004; Scibek and Allen, 2006; Jyrkama and Sykes, 2007). HELP3 was chosen to cooperate with SEAWAT because it can simulate all of the important processes in the hydrologic cycle at each recharge zone. The recharge rate was used as the boundary conditions for groundwater simulation in the watershed scale.

The recharge zones in the solute transport groundwater SEAWAT model were classified by land use, soil type, and ground surface slope. The soil profile survey was conducted to design the soil columns in the HELP3 model. Seven recharge zones were assigned in the groundwater model. The result from HELP3 was used as input for each zone in SEAWAT model (Fig. 4).

2.2.2. Groundwater simulation

The groundwater model area was identified by the boundary of Huai Khamrian subwatershed and was divided into three groups of aquifers. The siltstone and sandstone aquifer of the Upper Phu Thok unit with a thickness of 30-250 meters and claystone of the Lower

Table 1. Required HELP3 input data (modified from Jyrkama and Sykes 2007)

Parameter	Units [a]	Constraints
Daily precipitation	mm/day	≥0
Daily mean temperature	^{O}C	-
Daily incoming solar radiation	MJ/m^2	≥0
Average annual wind speed	km/hour	≥0
1st quarter relative humidity	%	≥0 and ≤100
2nd quarter relative humidity	%	≥0 and ≤100
3rd quarter relative humidity	%	≥0 and ≤100
4th quarter relative humidity	%	≥0 and ≤100
Growing season start day	Julian date	≥0 and ≤365
Growing season end day	Julian date	≥0 and ≤365
Evaporative zone depth	cm	>0 and ≤total column depth
Leaf area index (LAI)	–	≥0 (insensitive to values >5.0)
Curve number (CN)	–	≥0 and ≤100
Soil layer depth	cm	≤total column depth
Soil texture	–	–
Total porosity (Ø)	vol/vol	>FC and ≤1
Field capacity (FC)	vol/vol	>WP and <Ø
Wilting point (WP)	vol/vol	>0 and <FC
Saturated hydraulic conductivity (K_S)	cm/s	>0
Initial volumetric soil water content (□)	vol/vol	≥0 and ≤1
Optional parameters		
Mean monthly precipitation [b]	mm/month	≥0
Normal mean monthly temperature [b]	^{O}C	–
Latitude [b]	degrees	≥ -90 and ≤90
Surface slope [c]	%	≥0
Slope length [c]	m	≥0

[a] All units can also be specified in imperial units.
[b] Required for synthetic weather generation.
[c] Required for automatic CN estimation.

Table 2. Flow and mass transport parameters used in SEAWAT simulation

Hydrogeologic Units	Parameters				
	Horizontal hydraulic conductivity, Kh (m/s)	Vertical hydraulic conductivity, Kv (m/s)	Specific storage, Ss (L/m)	Specific yield, Sy (-)	Longitudinal Dispersivity, Dl (m)
Alluvium (Al)	1.1x10^{-7}-1.1x10^{-5}	1.1x10^{-8}-1.1x10^{-6}	1.8x10^{-3}	0.01-0.16	500
Upper Phutok (Upt)	2.4x10^{-5}-2.1x10^{-4}	8.1x10^{-6}-7.3x10^{-5}	4.3x10^{-3}	0.24-0.36	400
Lower Phutok (Lpt)	3.7 x10^{-7}-4.8x10^{-6}	3.4 x10^{-8}-4.8x10^{-7}	5.0x10^{-5}	0.22-0.31	100
Maha Sarakham (Ms)	9.4x10^{-8}-1.2x10^{-7}	9.4x10^{-9}-1.2x10^{-8}	1.0x10^{-6}	0.01-0.12	300

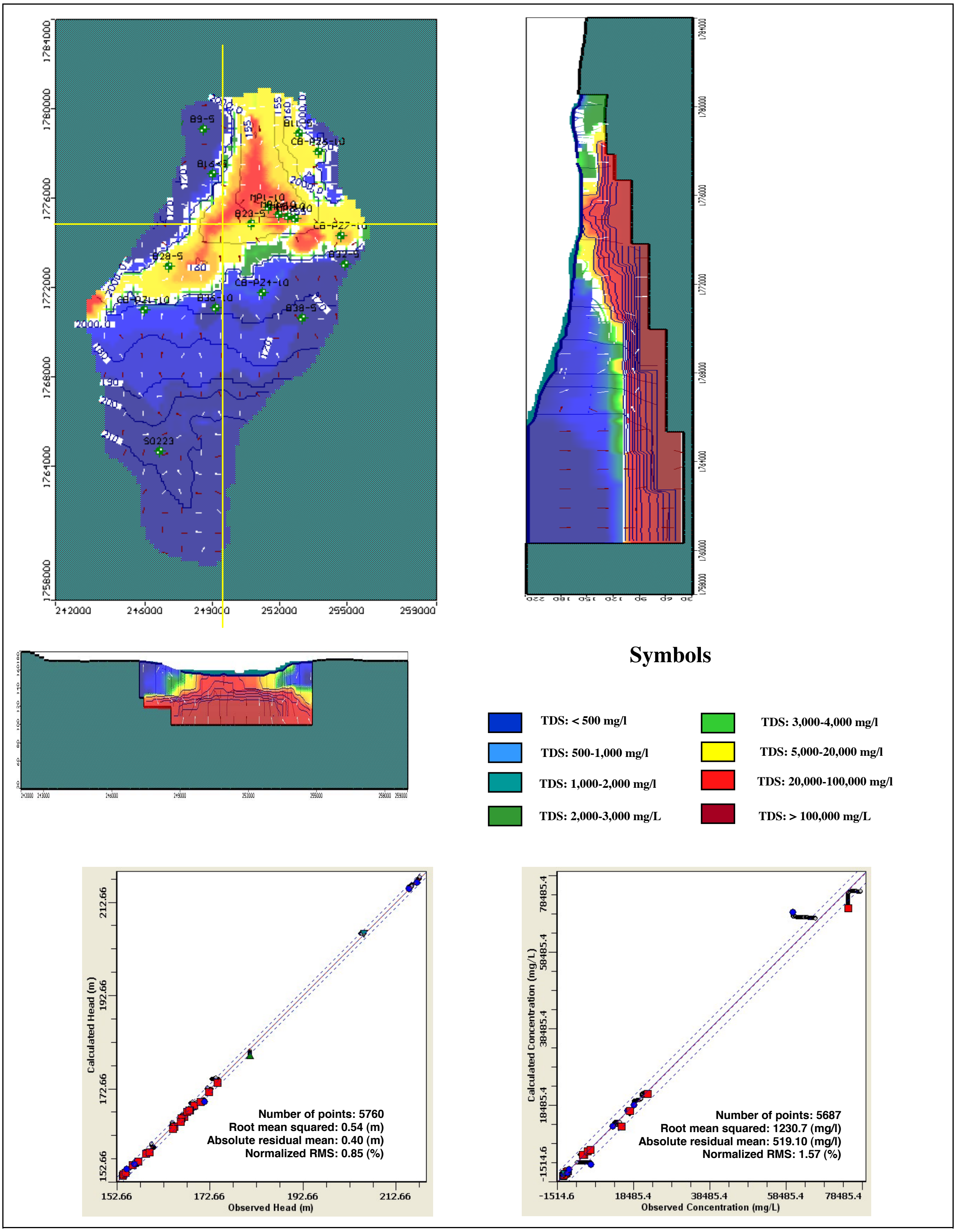
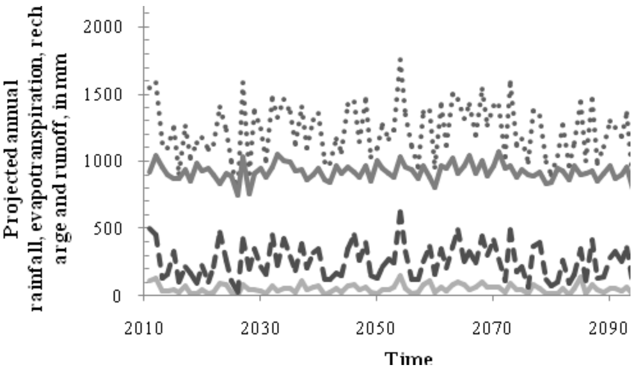


Figure 5. Simulated groundwater flow and salinity distribution for current situation and calibration results

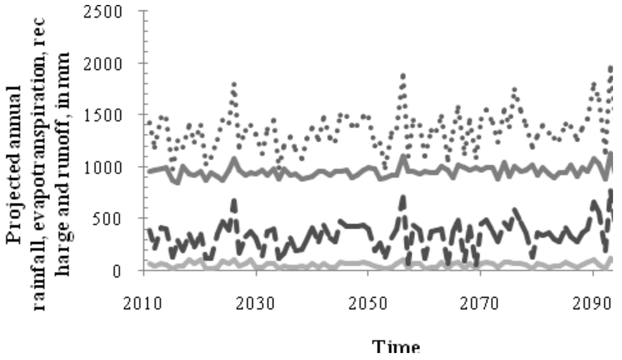
Phu Thok unit is underlain by the rock salt layers of the Maha Sarakham unit that was treated as a no flow boundary. The range of flow and mass transport input parameters including the vertical and horizontal hydraulic conductivity, specific yield and dispersivity of the simulated aquifers were drawn from the previous field studies (Srisuk, 1994; Srisuk, 1995; Srisuk *et al*., 1999) as summarized in Table 2. The lateral boundaries of subwatershed were treated as no flow as well as the bottom boundary. The model was designed as a finite difference grid with a spatial resolution of 200m x 200m. The model layers were separated into 10 layers, each 10-15 m thick, between the altitudes of the topography to the lowest layer of 30 m above mean sea level (AMSL). The drainage system was applied with the river package. Initial condition was created by 102 observed well data in November 2003. The constant concentration of total dissolved solids of 100,000 mg/L was assigned at the lowest boundary to represent the rock salt layer underlying the subwatershed.

The transient state simulation was calibrated using 28 observation wells which were monitored for water level and salinity on 4 occasions between November 2003 and March 2004 (Fig. 5). The model was verified with 17 observation well data monitored in the year 2010.

Sensitivity analyses of the HELP3, SEAWAT models parameters and boundary conditions were performed to indicate which parameters most affect the models. HELP3 runs were carried out to investigate the recharge estimation sensitivity. It indicated that the precipitation was the most sensitive parameter for recharge estimation. Sensitivity analysis of groundwater flow and transport model indicated that recharge rates and hydraulic conductivity were the most sensitive parameters.



(a) Base case



(b) Scenario A2

┈┈┈┈ Rainfall
—— Evapotranspiration
- - - - Recharge
—— Runoff

Figure 6 Projected annual rainfall, evapotranspiration, runoff and estimated groundwater recharge from 2011 to 2099 for (a) base case, (b) and scenarios A2 in recharge zone 1

3. Results

3.1. Climate change scenarios

The longest meteorological records of Khon Kaen station (Thai Meteorological Department (TMD), unpublished) situated about 35 km northward of the study area indicated an average annual rainfall of 1,216 mm over the period of 1960-2010. The records present an increasing trend of rainfall from 1,191.5 mm/year (1960-1990) to 1,208.0 mm/year (1991-2000) and 1,301.2 mm/year (2001-2010). The increasing trend of an average temperature was from 27.1°C (1960-1990) to 27.4°C (1991-2010).

The projected base case scenario weather data during 2011-2099 was generated by the weather generator based on 30 years weather records at Khon Kean station. The generated base case weather data was used as the input data for HELP3 model and SEAWAT model simulations. From PRECIS A2 scenario output, the studied subwatershed area was predicted to have a significant higher rainfall and temperature than the baseline period of 1978-2010 of which an average annual rainfall is approximately 1,600 mm/year at the last decade of the century. The projected average temperature of scenarios A2 presents an increasing trend. At the end of the century the average temperature is approximately 31°C. Average recharge rates in the recharge zones increase in scenarios A2 related to the base case. Fig. 6 presents the projected annual rainfall evapotranspiration, runoff and groundwater recharge for scenarios A2 in recharge zone 1. The significant increasing trend of recharge rate is shown in scenario A2 in the period of 2080-2099.

The waterlogging areas (water table shallower than 4 m) were predicted to have significantly impact from climate change under scenario A2. The much higher precipitation and recharge rates in scenario A2 compared to the base case will drive the water level in the shallow aquifer as shown in Table 3 and Fig. 7.

The prediction results show that various climate change scenarios will not cause significantly different impacts on the extent of saline groundwater areas (groundwater salinity higher than 2,000 mg/L). The impact of the higher recharge rates is most evident during the last 20 years of the century, when the saline shallow groundwater areas expand to cover the area of 46.83% in scenario A2 (Table 3 and Fig. 7).

Table 3. Percentage of the area affected by waterlogging and shallow saline groundwater under current and the projected scenarios in 2050 and 2099

Scenarios	% of the area with groundwater salinity ≥2,000 mg/L		% of the area with water table depth ≤ 4 m	
	Base case	Scenario A2	Base case	Scenario A2
2010	32.91	32.91	69.19	69.19
2050	39.65	39.87	86.50	92.05
2099	46.52	46.83	86.70	94.33

3.2. Ecohydrology Management Simulations

In this study ecohydrology approach (Zalewski, 2000) which integrates biological measures with the necessary engineering solutions was selected as a main idea for set up the management scenarios to control water table based on simulation results under the high precipitation projected climate scenario. The models were simulated with alternative scenarios of ecohydrology approach which integrates agro-forestry and drainage practices to reduce recharge water from precipitation in the subwatersheds under four management scenarios; I. no management option, II. planting *deep-root growing tree* in the recharge areas, III. installation of shallow wells to intercept fresh groundwater for irrigation in the recharge areas, and IV. combination of scenarios II and III.

Plantation of deep-root growing tree in the recharge areas does not show the significant reduction of saline groundwater areas, but presents more impact on reduction of waterlogging area of about 5% in the year of 2050 and 2% of the total watershed area compared to the base case in the year of 2099 (Table 4). Installation of shallow wells in the recharge areas does not show the significant impact on reduction of saline groundwater and waterlogging areas. In scenario IV, combination of deep-root growing tree (scenario II) and installation of shallow pump in the recharge area (scenario III) can reduce the impact of climate change on waterlogging expansion but do not have any significant difference from the result of scenario II.

4. Conclusions and Recommendations

Based on the recharge prediction, groundwater recharge was higher in the middle and the end of this century. The projected climate change results in the higher precipitation over the Huai Khamrian subwatershed in the periods of 2011-2050 and 2051-2099 under IPCC SRES A2, that cause higher groundwater recharge. The extension of shallow saline groundwater areas were found in the model results of climate change scenario as well as the result from the base case. The prediction results indicate that climate change do not have substantial impact on salinity distribution in the subwatershed, but there is more significant impact on expansion of waterlogging areas for A2 climate change scenario.

Simulation on the management option using ecohydrology approach was carried out to find the possible adaptation options in salinity environment and reduce the extension of salt affected areas in the future. The results from various scenarios present that agro-forestry option in the recharge areas can reduce the impact of climate change on waterlogging and salinity distribution around 2-5% of total area compared to the projection under the climate change scenario A2. Due to the high uncertainty of climate change projections, the comprehensive intervention of waterlogging and salinity including reforestation, enhancing drainage efficiency, improving soil texture and fertility and introducing salt tolerant paddy rice are very important to be implemented.

Table 4. Percentage of the area affected by waterlogging and shallow saline groundwater under management options simulation in 2050 and 2099

Scenarios	% of the area with groundwater salinity ≥2,000 mg/L				% of the area with water table depth ≤ 4 m			
	I	II	III	IIII	I	II	III	IIII
2010	32.91	32.91	32.91	32.91	69.19	69.19	69.19	69.19
2050	39.87	39.48	39.63	39.31	92.05	86.96	91.57	86.58
2099	46.83	46.05	46.26	46.05	94.33	92.54	94.29	92.40

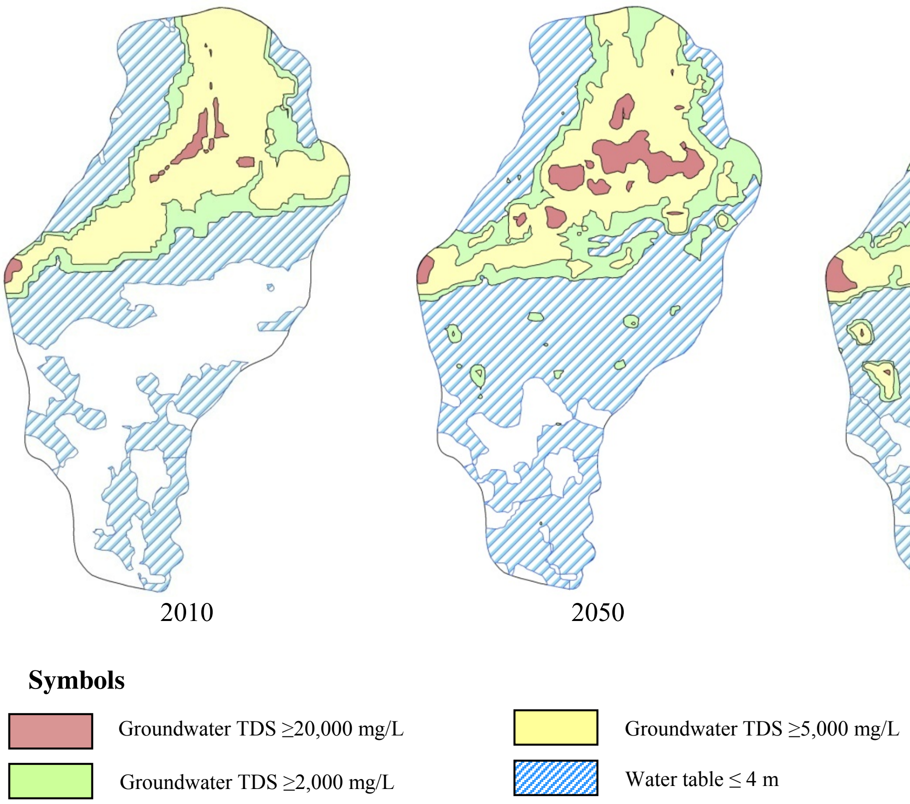


Figure 7. Waterlogging and saline groundwater areas for climate scenario A2 projection

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References

Allen DM, Mackie DC, Wei M. Groundwater and climate change: a sensitivity analysis for the Grand Forks aquifer, southern British Columbia, Canada. Hydrogeology Journal 2004; 12: 270-90.

Arunin S. Characteristic and management of salt-affected soils in the northeast of Thailand. Ecology and Management of problem Soil in Asia, Taiwan: Food and Fertilizer Technology Center for the Asian and Pacific Region, (FFTC Book Series no. 27) 1984.

Arunin S. Strategies for utilizing salt affected lands in Thailand. In Proceedings of the International Symposium on Strategies for Utilizing Salt Affected Lands, Bangkok, 17-25 February 1992: Department of Land Development, Ministry of Agriculture and Cooperatives. 1992; 26-37.

Berger K. Validation of the hydrologic evaluation of landfill performance (HELP) model for simulating the water balance of cover systems. Environmental Geology 2000; 39(11): 1261-74.

Chammas GA, Geddis M, McCaulou DR. A comparison of two models for simulating the water balance of soil covers under semi-arid conditions. In: Proceedings of the National Meeting of the American Society for Surface Mining and Reclamation 1999; 2: 688-95.

Chinvanno S, Laung-Aram V, Sangmanee C, Thanakitmetavut J. Future Climate Projection for Thailand and Mainland Southeast Asia Using PRECIS and ECHAM4 Climate Models, Southeast Asia START Regional Center Technical Report 18. 2009.

Fleenor WE, King IP. Identifying limitations on use of the HELP model. In: Dunn RJ, Singh UP (Eds.), Landfill Closures. Environmental Protection and Land Recovery. ASCE, Geotechnical Special Publication 1995; 53: 121-38.

Gogolev MI. Assessing groundwater recharge with two unsaturated zone modeling technologies. Environmental Geology 2002; 42: 248-58.

IPCC. Emissions Scenarios. *In*: A Special Report of Working Group II of the Intergovernmental Panel on Climate Change (IPCC). (*Eds*: Nakicenovic N, Swart R.), Cambridge University Press, Cambridge, UK. 2000.

Jyrkama MI, Sykes JF, Normani SD. Recharge estimation for transient ground water modeling. Ground Water 2002; 40(6): 638-48.

Jyrkama MI, Sykes JF. The impact of climate change on spatially varying groundwater recharge in the grand river watershed (Ontario). Journal of Hydrology 2007; 338(3-4): 237-50.

Khire MV, Benson CH, Bosscher PJ. Water balance modeling of earthen final covers. Journal of Geotechnical and Geoenvironmental Engineering 1997; 123: 744-54.

Langevin CD, Thorne DT Jr, Dausman AM, Sukop MC, Guo W. SEAWAT Version 4: A Computer Program for Simulation of Multi-Species Solute and Heat Transport: U.S. Geological Survey Techniques and Methods Book 6, Chapter A22, 2008.

LDD. Soil salinity map of Khon Kaen Province, Land Development Department (LDD), Bangkok, Thailand. 2002.

Peyton RL, Schroeder PR. Field verification of HELP model for landfills. Journal of Environmental Engineering 1988; 114(2): 247-69.

Risser DW, Gburek WJ, Folmar, GJ. Comparison of methods for estimating ground-water recharge and base flow at a small watershed underlain by fractured bedrock in the Eastern United States. US Geological Survey Scientific Investigations Report 2005-5038. 2005.

Schroeder PR, Dozier TS, Zappi PA, McEnroe BM, Sjostrom JW, Peyton RL. The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3, EPA/600/R-94/168b, U.S. Environmental Protection Agency Office of Research and Development, Washington, DC. 1994.

Scibek J, Allen DM. Modeled impact of predicted climate change on recharge and groundwater level. Water Resources Research 2006; 42(11): 1-18.

Srisuk K, Nadee S, Uppasit S, Cotanont T, Saraphirom P. Lowering of groundwater level for controlling salinity distribution in Huai Khamrian Subwatershed, Ban Phai District, Khon Kaen Province, Northeast, Thailand. International Conference on Agricultural, Food and Biological Engineering and Post harvest/Production Technology, Sofitel Raja Orchid Hotel, Khon Kaen, Thailand, 2007.

Woyshner MR, Yanful EK. Modelling and field measurements of water percolation through an experimental soil cover on mine tailings. Canadian Geotechnical Journal 1995; 32(4): 601-09.

Zalewski M. Ecohydrology - the scientific background to use ecosystem properties as management tools toward sustainability of water resources. Ecological Engineering 2000; 16(1): 1-8.

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