NATIONAL CENTRAL UNIVERSITY
Graduate Institute of Applied Geology

Assessment of future climate change impacts on streamflow and groundwater by hydrological modeling in the Choushui River Alluvial Fan, Taiwan

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Taoyuan, October 7

Introduction

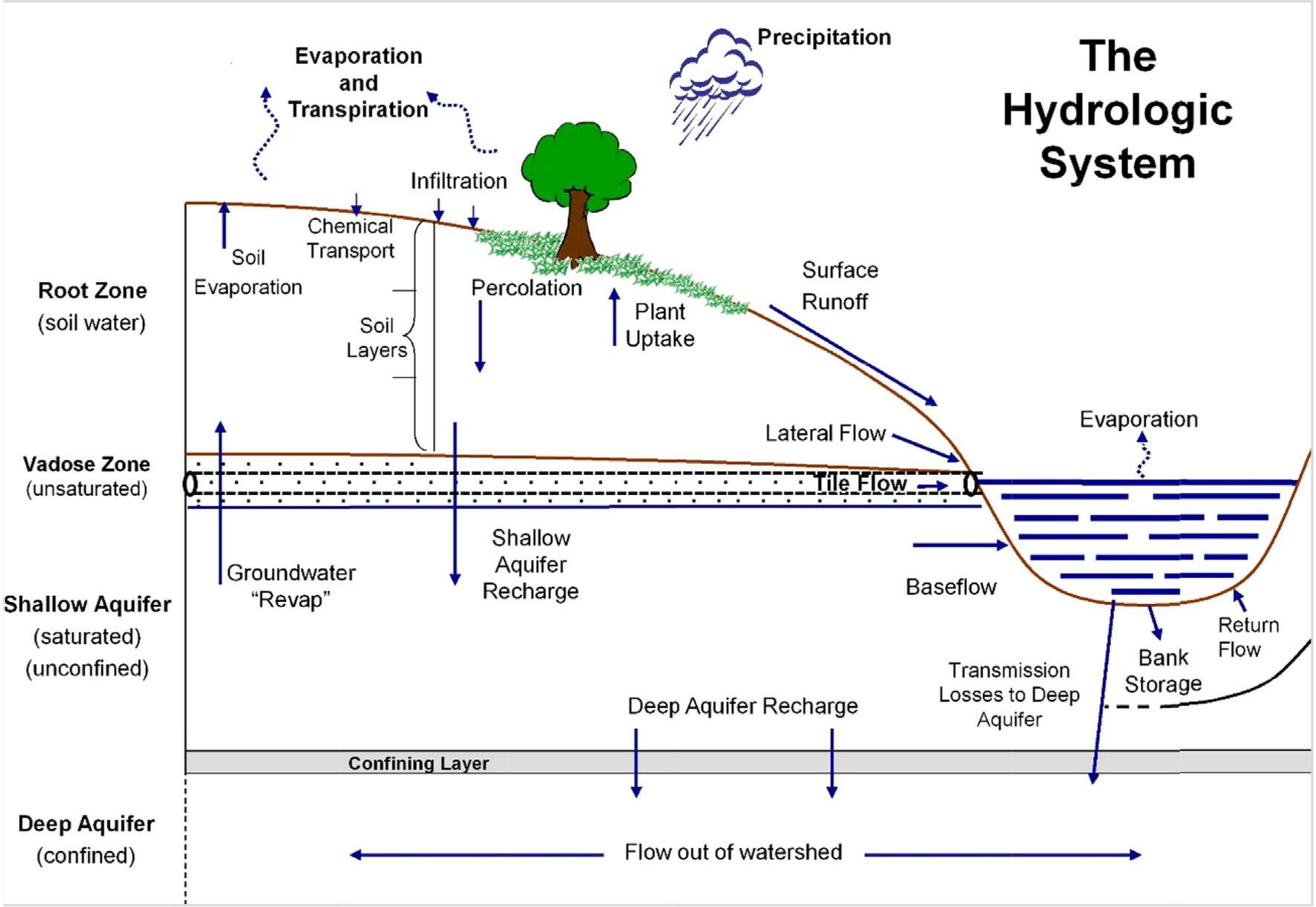


Figure 1. Schematic of the hydrologic cycle simulation processes (*Neitsch et al., 2011*)

The **hydrologic cycle** (*Fig. 1*) as simulated base on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{lat} - Q_{gw})$$

Introduction/motivation

Introduction:

The **interaction** between groundwater (GW) and surface water (SW) is an **important** aspect of the water cycle. The management or use of one of them often impacts the availability and temporal patterns of another. Besides, the assessment on the **impact of climate change** on GW recharge is a challenge in hydrological researches because substantial doubts still remain, particularly in arid and semi-arid regions (David et al. 2014).

The Soil and Water Assessment Tool (SWAT) (Gassman et al. 2007; and Neitsch et al. 2011) is a physical based semi-distributed catchment-scale hydrological model. It simulates the surface runoff and GW dynamics, management practices or climate change on water quantity at different geographical locations and scales.

The MODFLOW–NWT (a Newton–Raphson formulation for MODFLOW-2005)(Niswonger et al. 2011), which improves the solution of unconfined groundwater-flow problems simulates groundwater flow processes and all associated sources and sinks on time steps.

Motivation

This study applies the coupled SWAT-MODFLOW models to **estimate streamflow discharge, GW recharge, and water exchange between GW and SW** in the Choushui River Alluvial Fan, Taiwan. The research assesses **the impact of climate change scenarios** influence **on GW recharge in the future.**

Study area: Choushui River Alluvial Fan, Taiwan

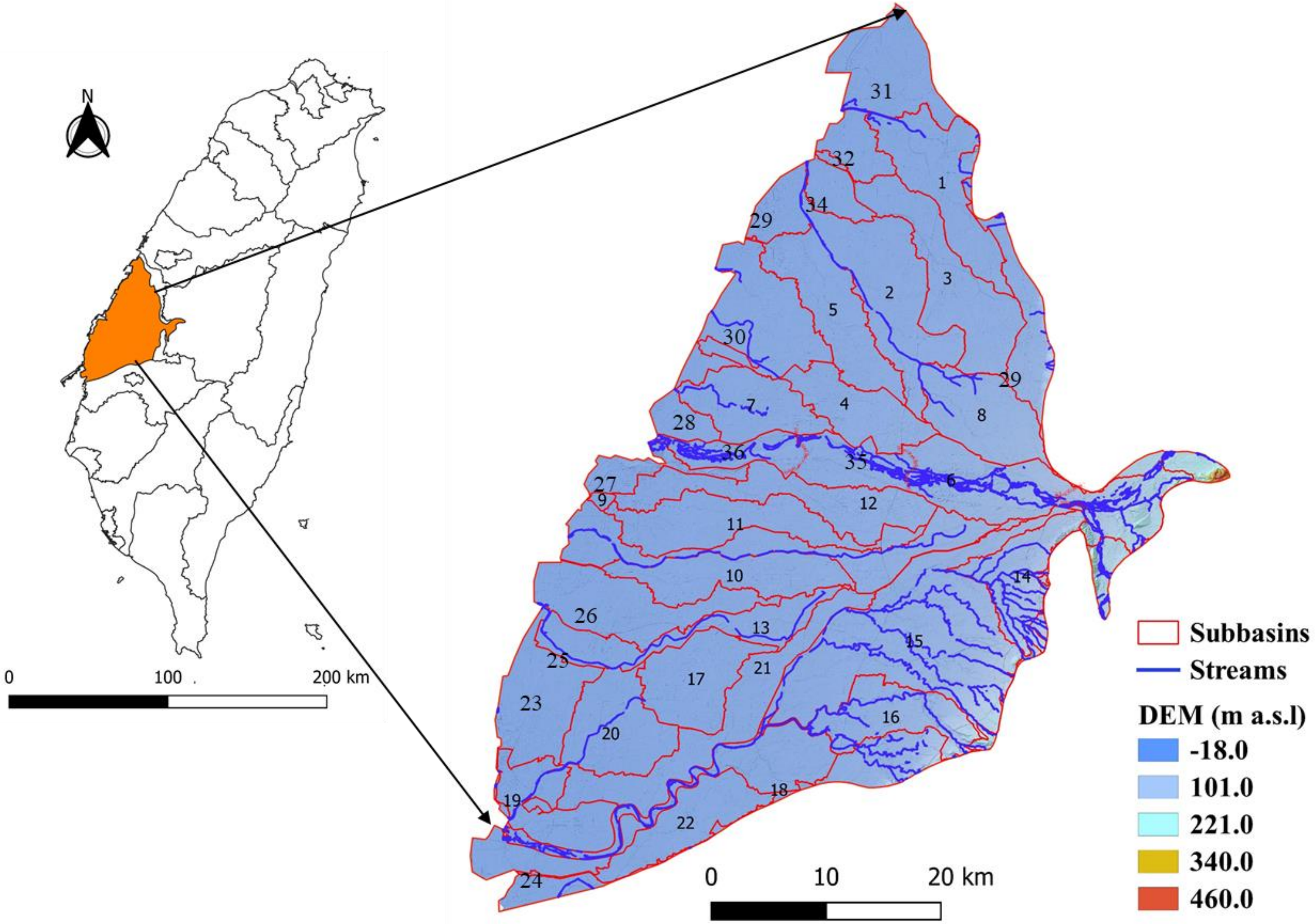


Figure 2a. Location of the Choushui River alluvial fan (colorful area), and the delineation in SWAT model.

Choushui River Alluvial Fan is located in the central-west of Taiwan (***Figure 2a***), which is the downstream part of Choushui River watershed and occupies most area of Chang-Hua County (north of Choushui River) and Yun-Lin County (south of Choushui River).

Materials and methods

Model set-up — SWAT-MODFLOW models set-up

Using the QSWAT3 interface 2020, MODFLOW-NWT, and QSWATMOD linkage files for a SWAT-MODFLOW

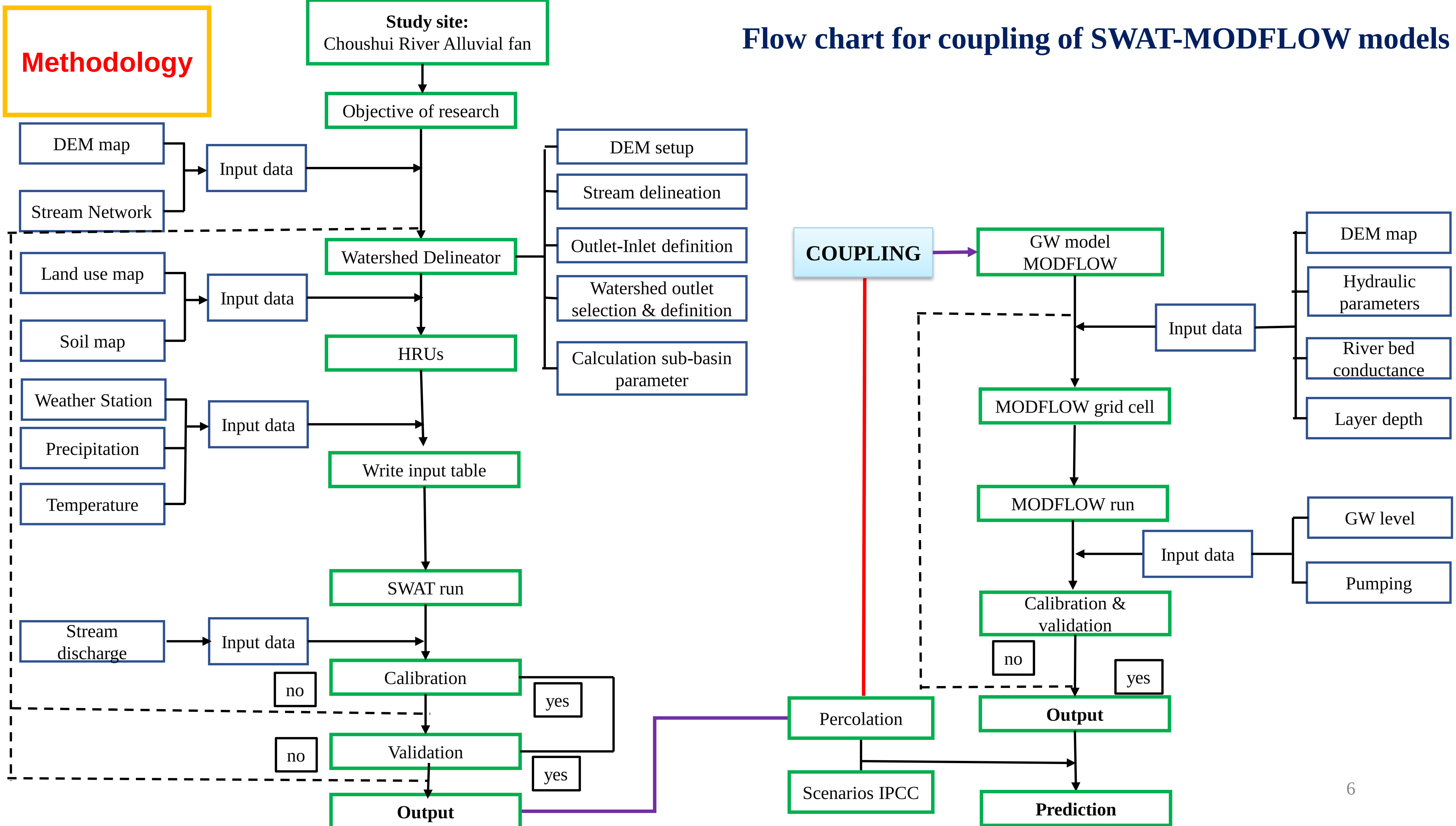
Table 1: Data sources used for the SWAT-MODFLOW models

Input data

Model	Data Type	Frequency/resolution	Source
SWAT	DEM	30×30m	Academia Sinica, 2019
	Soil map	30×30 m	Taiwan SSURGO database, 2020
	Land-use	1000× 1000m	USGS global land use, 2019
	Climate data	Daily	The Taiwan Climate Change Projection Information and Adaptation Knowledge Platform (TCCIP)
	River runoff	Daily	Water Resources Agency, Ministry of Economic Affairs
MODFLOW	Storativity	-	Water Resources Agency, Ministry of Economic Affairs
	Aquifer thickness	-	
	Hydraulic conductivity	-	

Methodology

Flow chart for coupling of SWAT-MODFLOW models



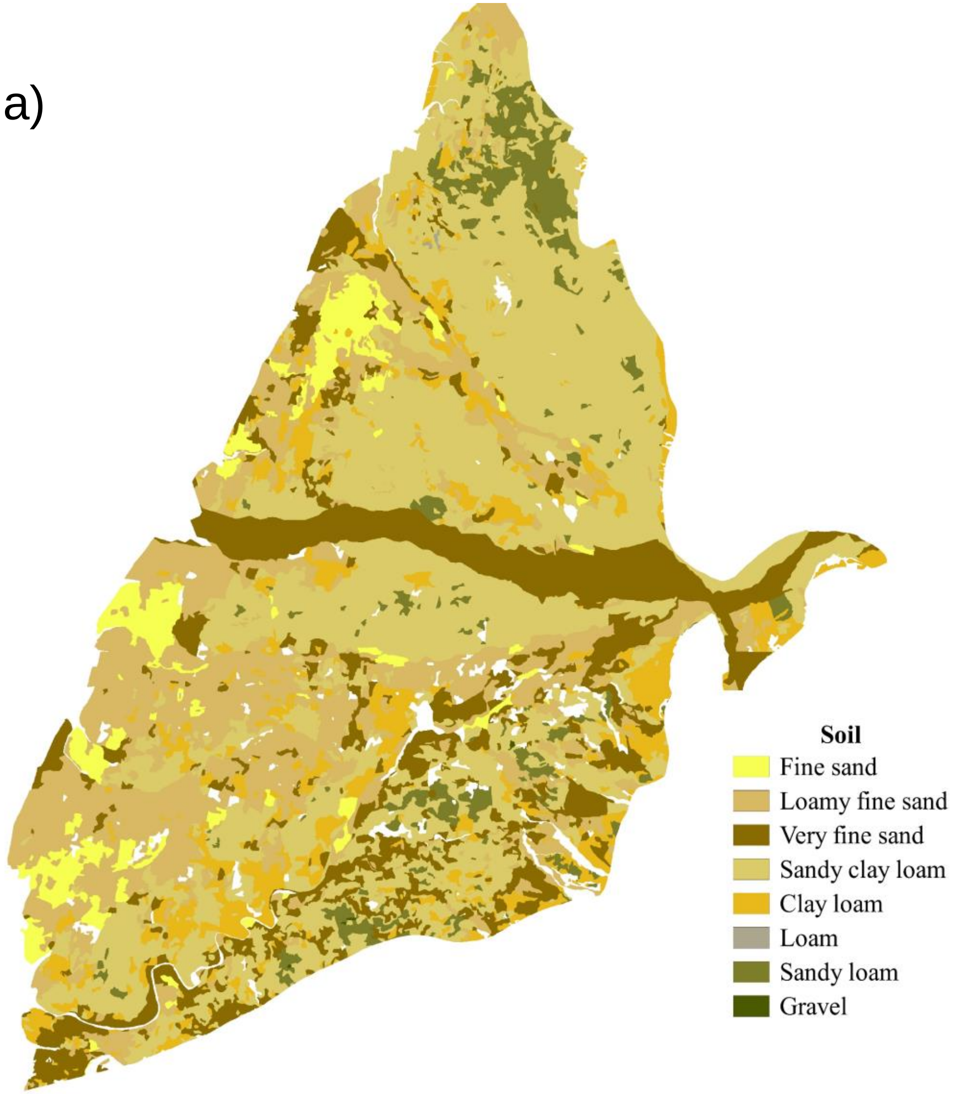
Materials and methods

Model set-up

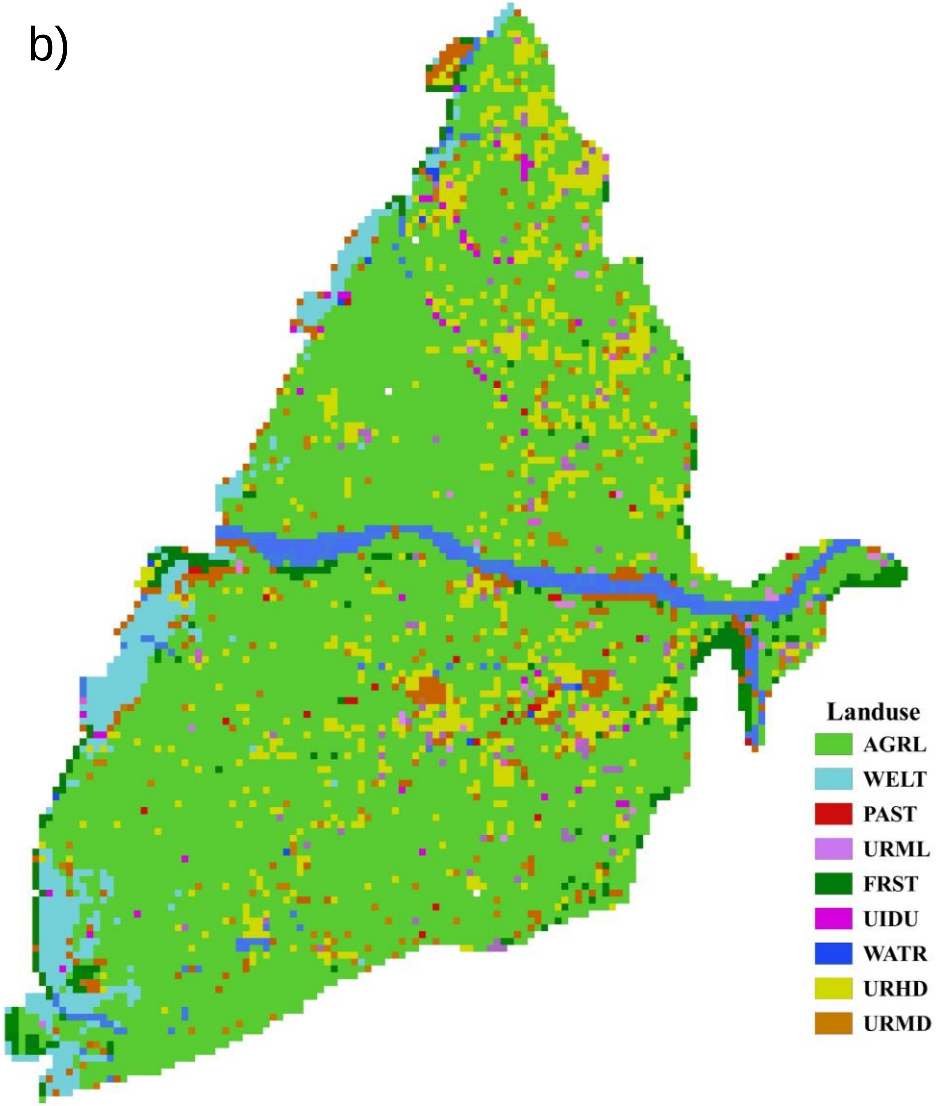
SWAT model set-up

Figure 3. The distribution and proportion of each (a) soil type and (b) land use after reclassification for HRU definition in SWAT

a)



b)



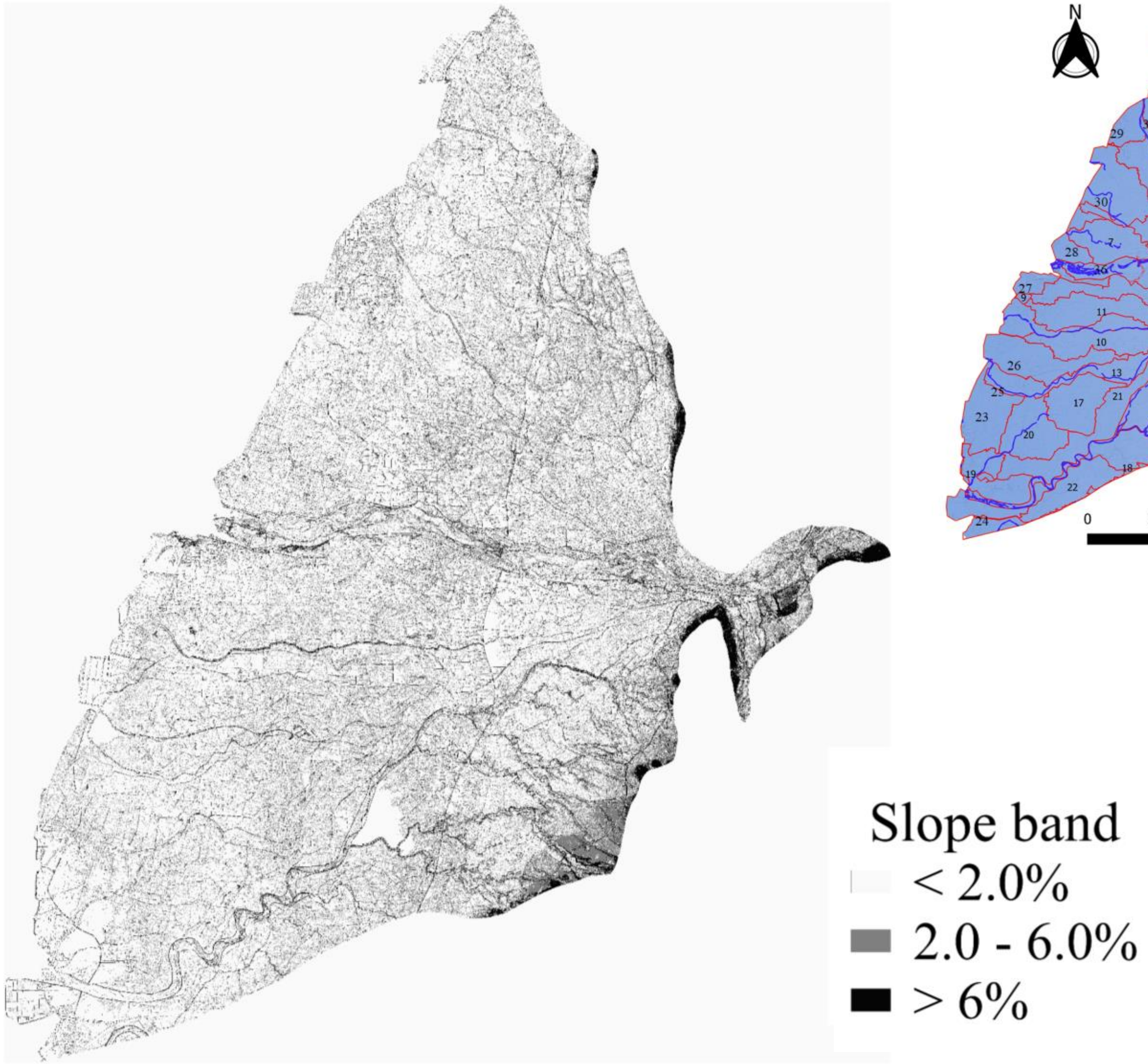
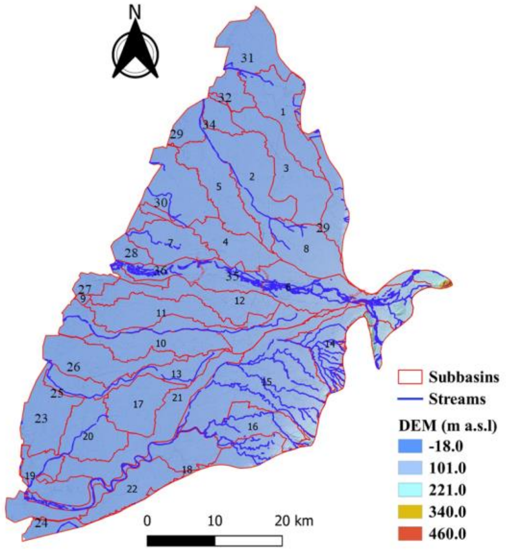
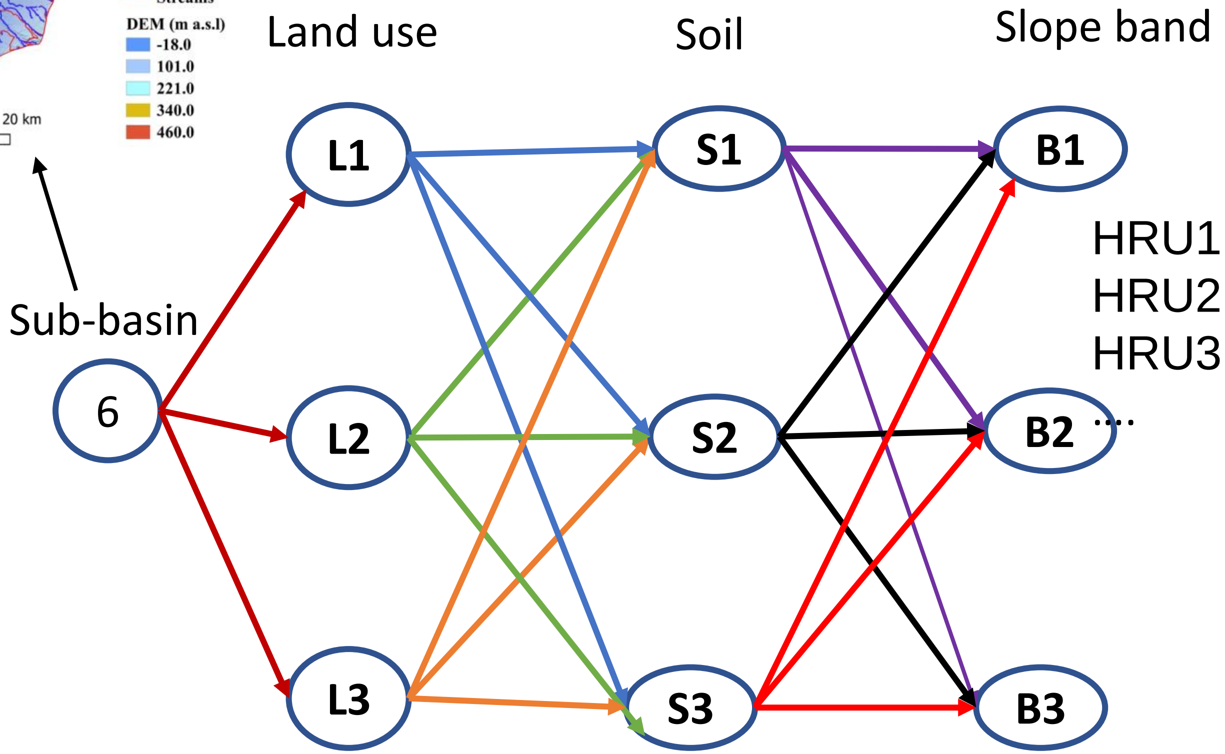


Figure 4. Map of slope band after the definition in SWAT



Hydrologic Response Units (HRUs)



Materials and methods

Weather data processing

The data created follow database structure

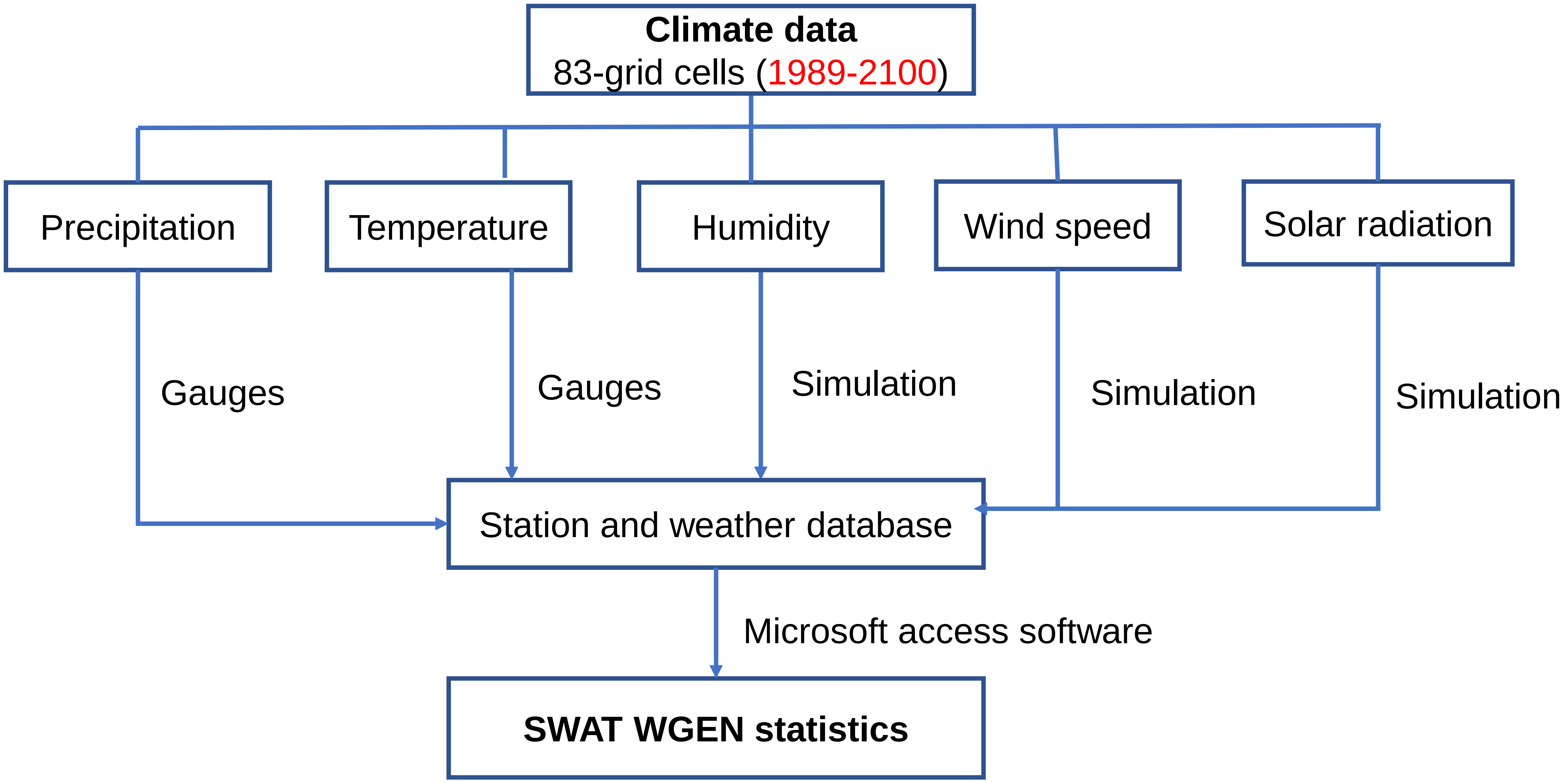
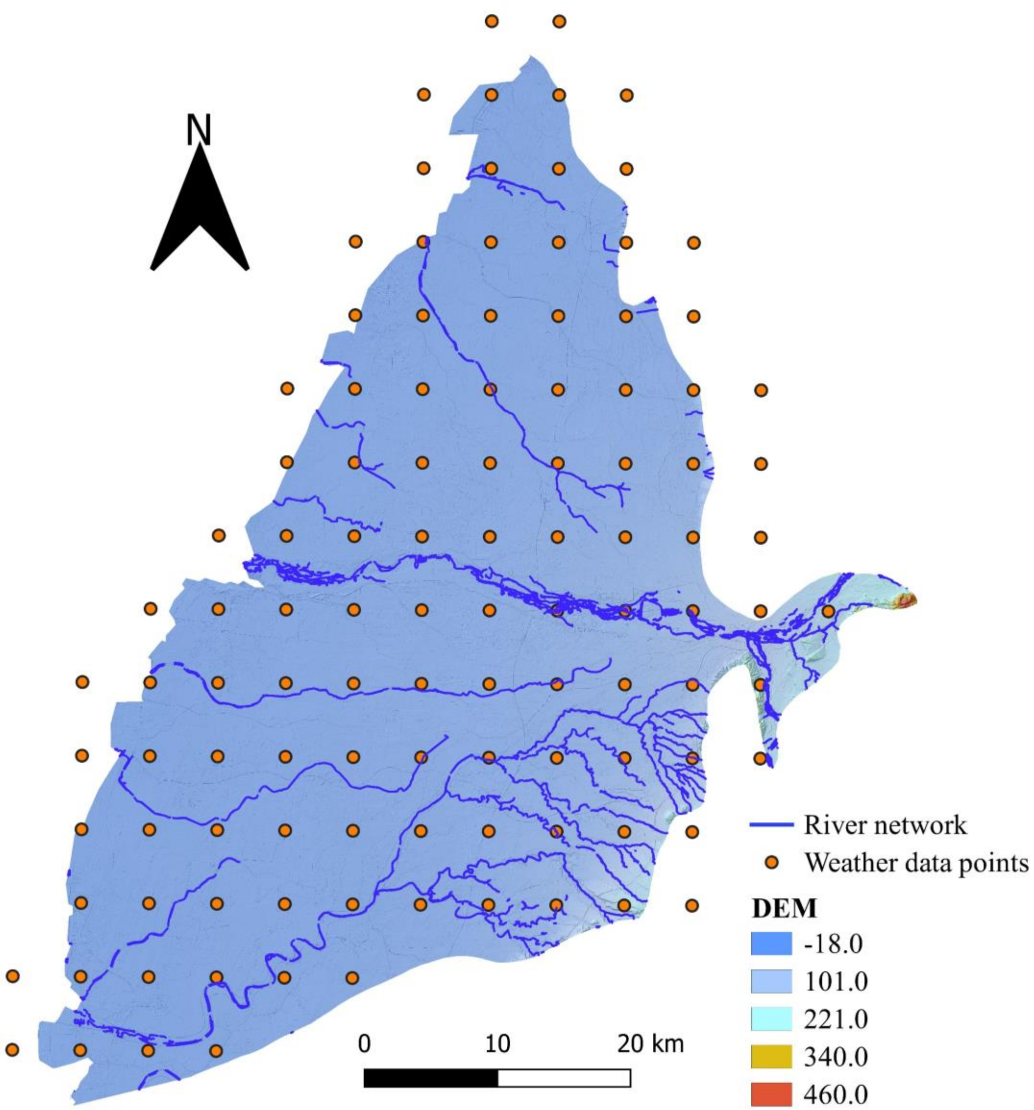


Figure 6. The framework for weather database

Materials and methods

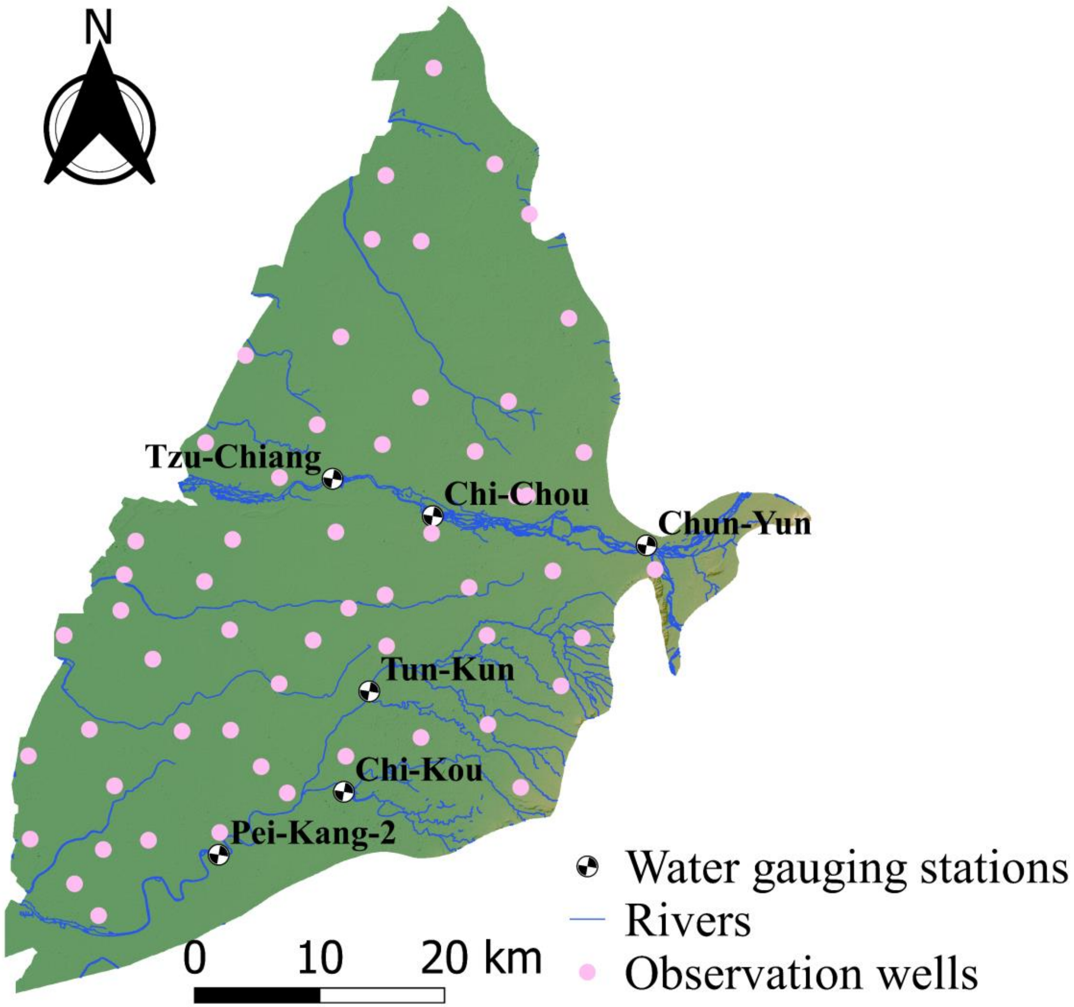


Future climate data with **five-kilometer** spatial resolution, provided by TCCIP, were selected to accommodate the future climatic conditions of catchment features.

Figure 5. Location of the grid cells weather data (100 years in each points) in whole study area

Model calibration for SW-GW

SWAT-CUP V5.1.6.2 (2019): It is enables sensitivity analysis, calibration, validation, and uncertainty analysis of a SWAT model. The PEST utilized to adjust MODFLOW-NWT parameters.



溪州大橋_Chi-Chou
自強大橋_Tzu-Chiang
北港(2)_Pei-Kang
土庫大橋_Tun-Kun

Figure 6. Bridge and wells stations on Choushui River Alluvial chosen for checking model performance.

Materials and methods

Model set-up

MODFLOW model set-up

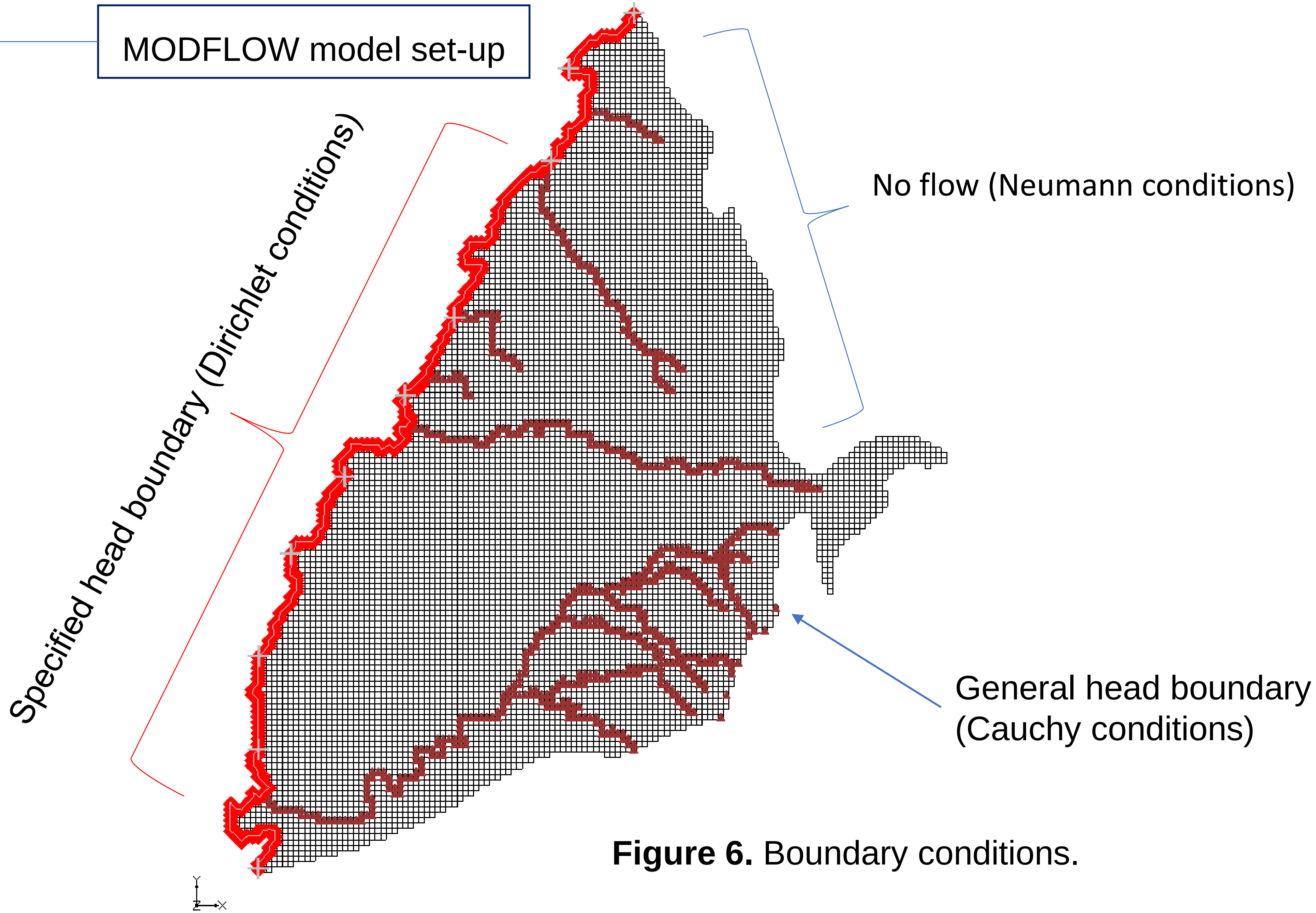
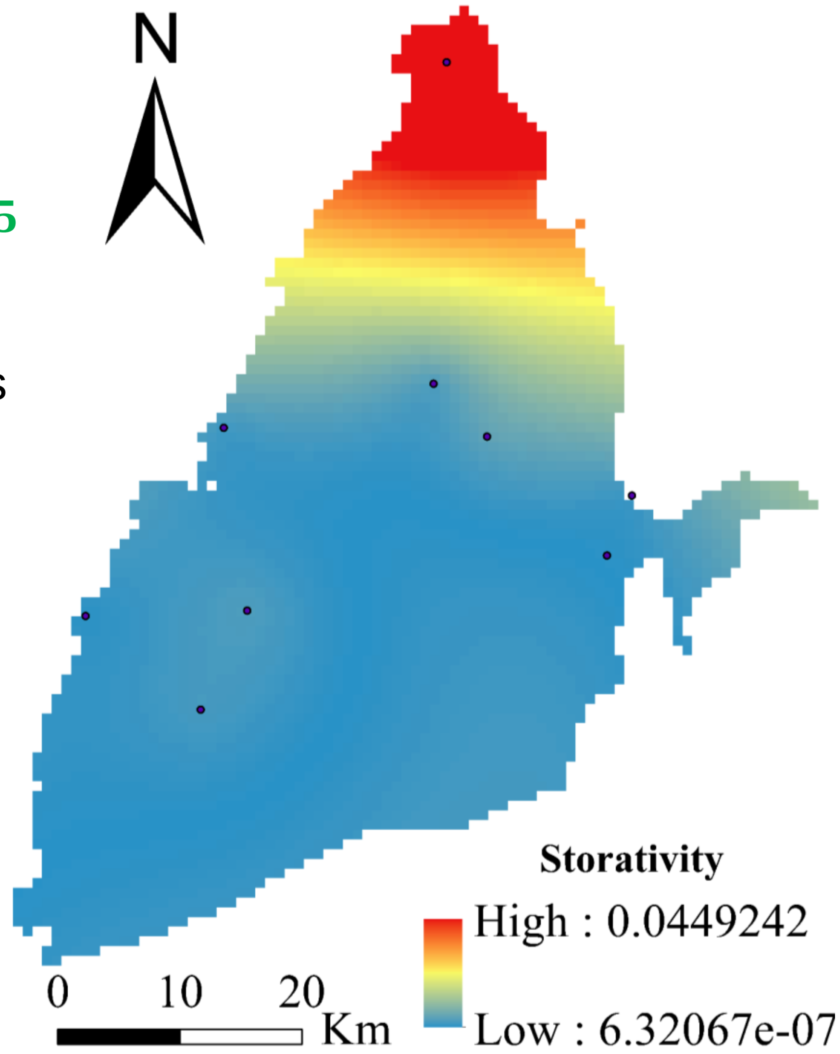


Figure 6. Boundary conditions.

Preparing before calibrate MODFLOW

Time step period 2003-2025

2003-2004: having initial head for calibrate periods
2005-2011: calibration
2012-2017: validation



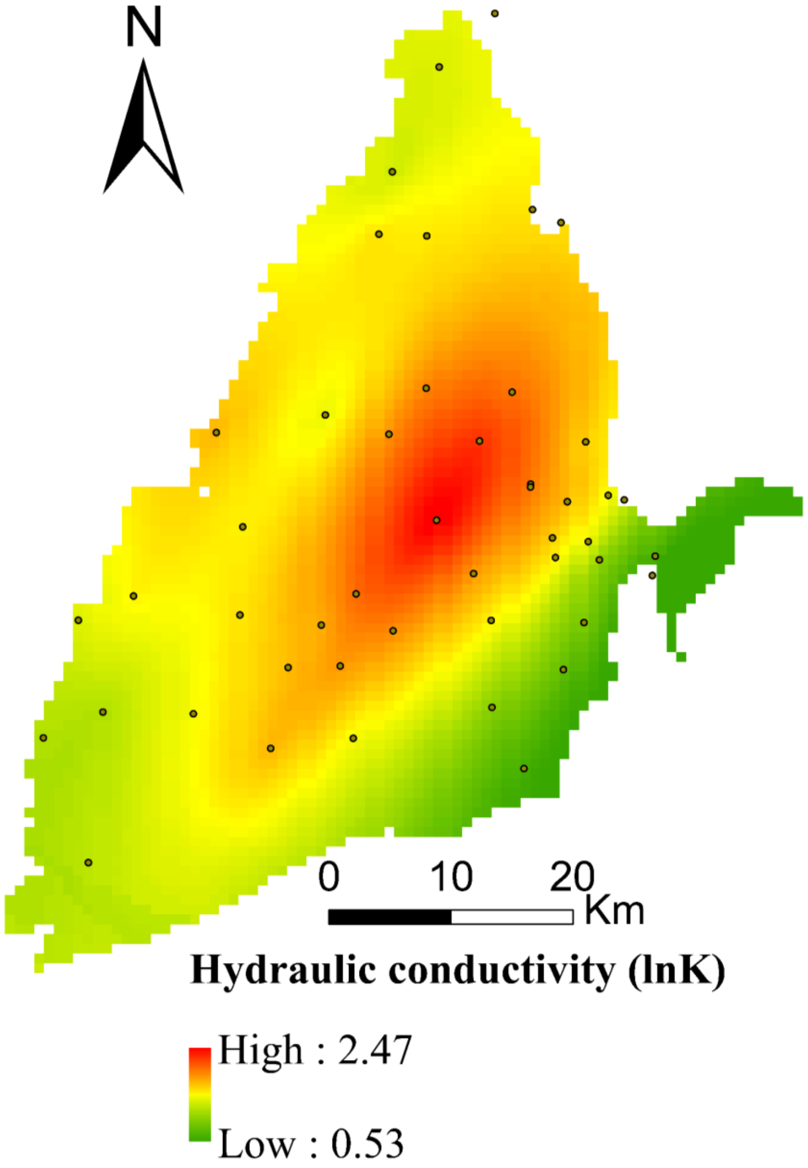


Figure 7. Interpolation storativity and hydraulic conductivity by kriging method

GCM datasets for climate risk assessment

What is climate change?

Climate change refers to long-term shifts in temperatures and weather patterns. These changes may be natural. however, since 1800s, human activities has been the main driver primarily d factories, cars, etc. → Produced heat-trapping gases. (*definition from Unitec*

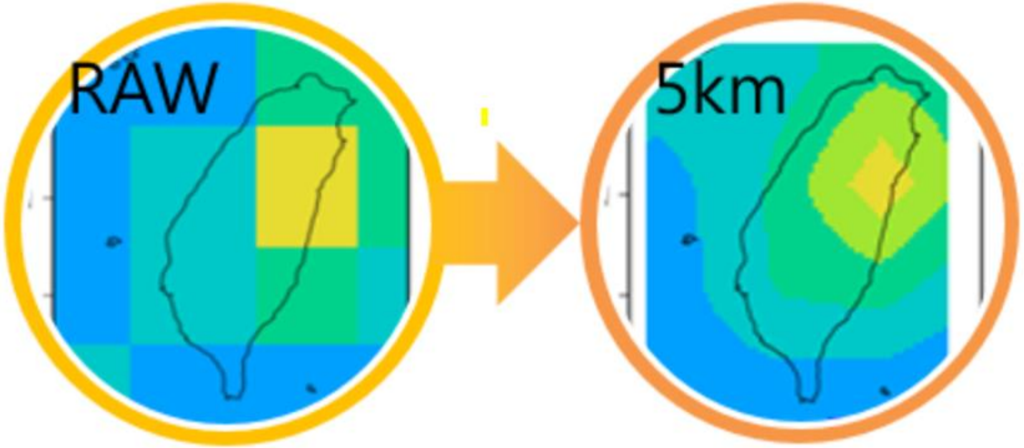
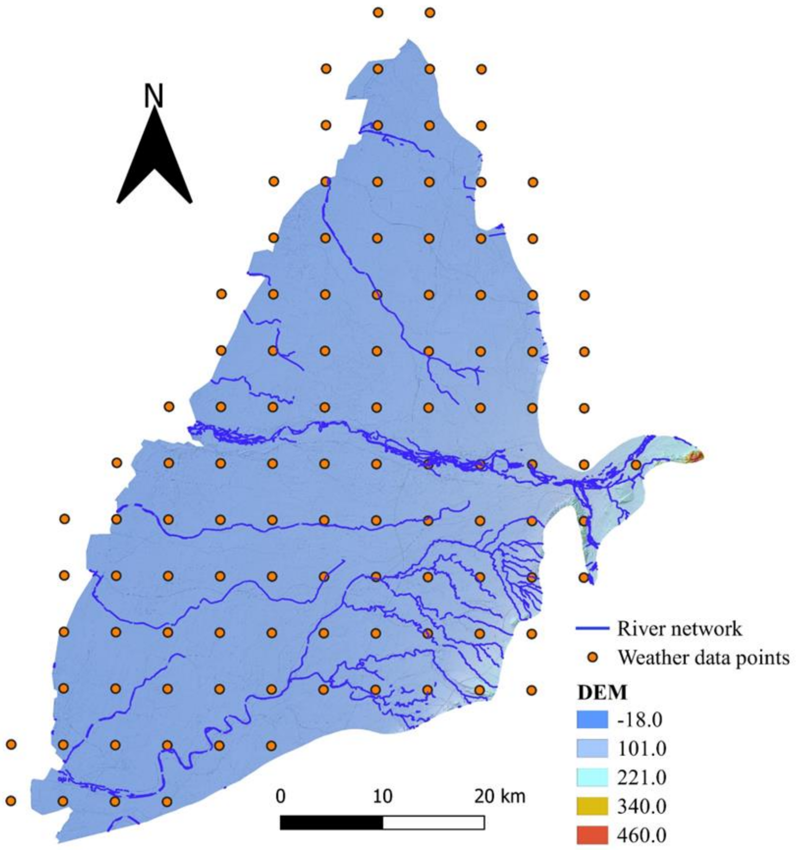


Figure 8. AR5 Global Raw data resolution model with "bilinear interpolation method" to increase resolution 5km



→ Across all Representative Concentration Pathways (RCPs), global mean temperature is projected to rise by 0.3 to 4.8 °C by the late-21st century

Results and discussion/ **Calibrate streamflow**

Downstream of Choushui river: Average monthly streamflow out of reach during time step (m^3/s).

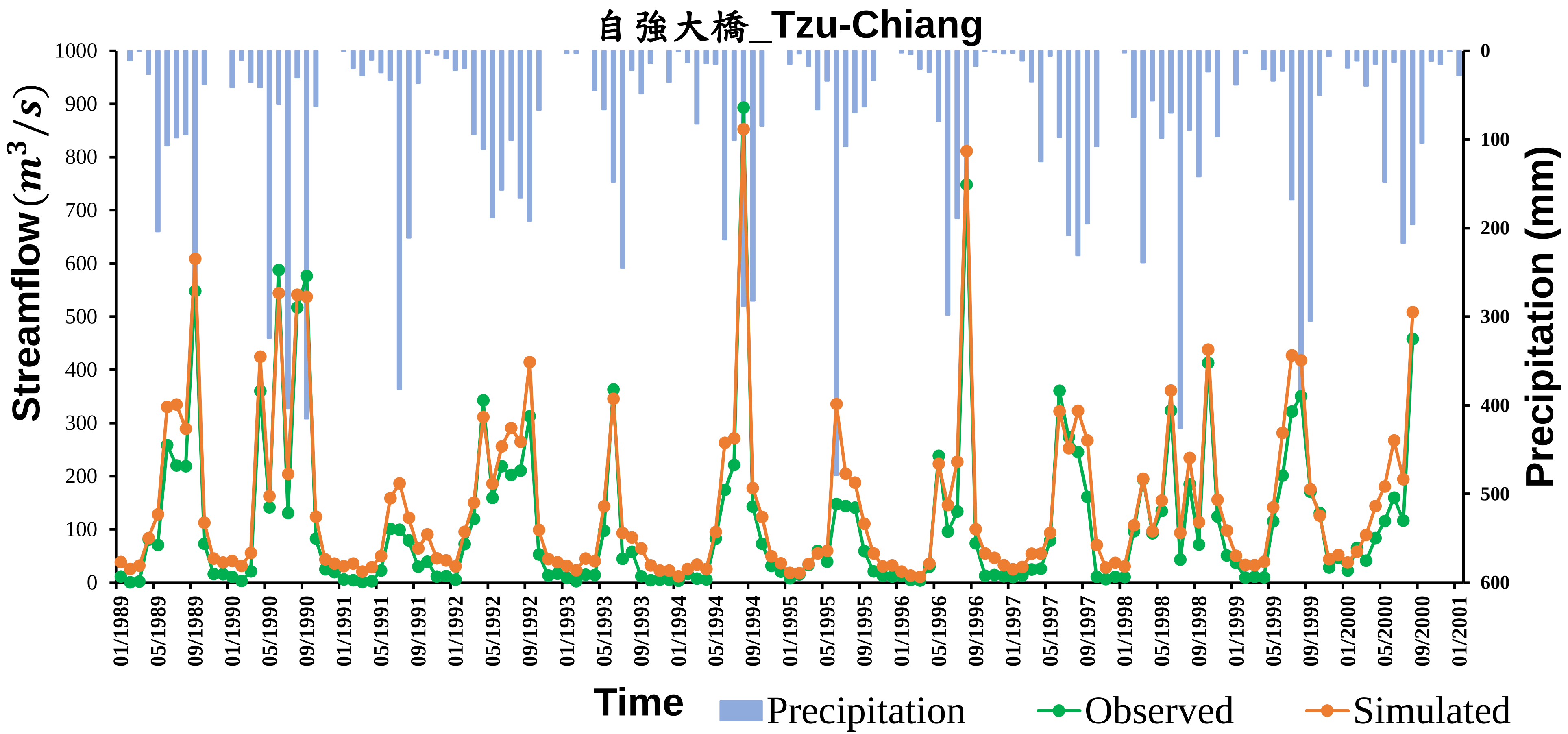


Figure 9. Observed and best simulated monthly streamflow at the outlets of Tzu-Chiang bridge during the calibration period (1989–1994) and validation period (1995-2000)

SWAT model	Pearson correlation coefficient	RMSE	R^2	Pbias	NSE
Calibration	0.979	2.742	0.959	-0.003	0.942
Validation	0.971	1.194	0.943	-0.131	0.866

Results and discussion

Another Downstream of Choushui river: Average monthly streamflow out of reach during time step (m^3/s).

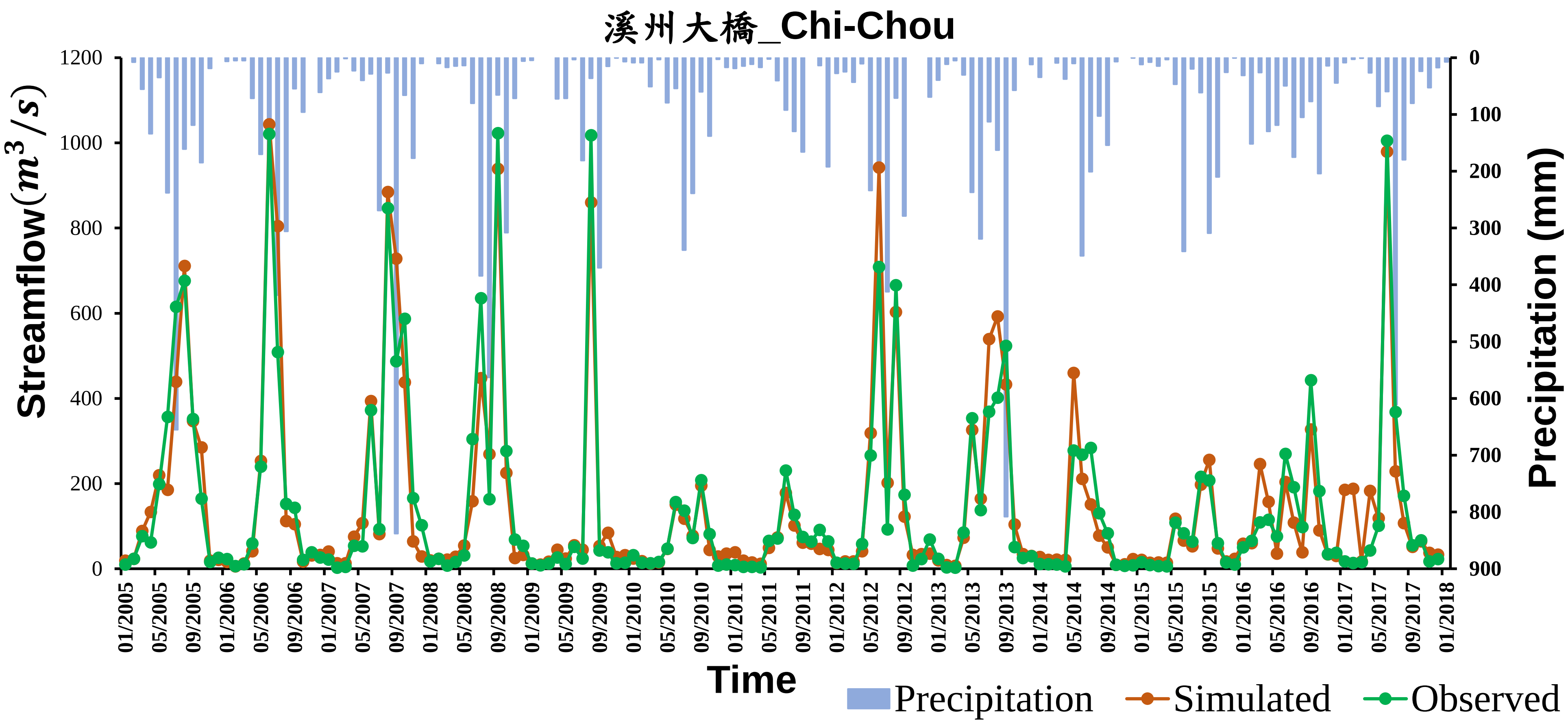


Figure 10. Hydrographs of precipitation, observed and best simulated monthly streamflow at the outlets of Chi-Chou Bridge during the calibration period (2005–2011) and validation period (2012-2017)

SWAT model	Pearson correlation coefficient	RMSE	R^2	Pbias	NSE
Calibration	0.959	0.020	0.920	-0.001	0.920
Validation	0.930	0.114	0.865	0.010	0.846

Results and discussion

Upstream of Pei-kang river

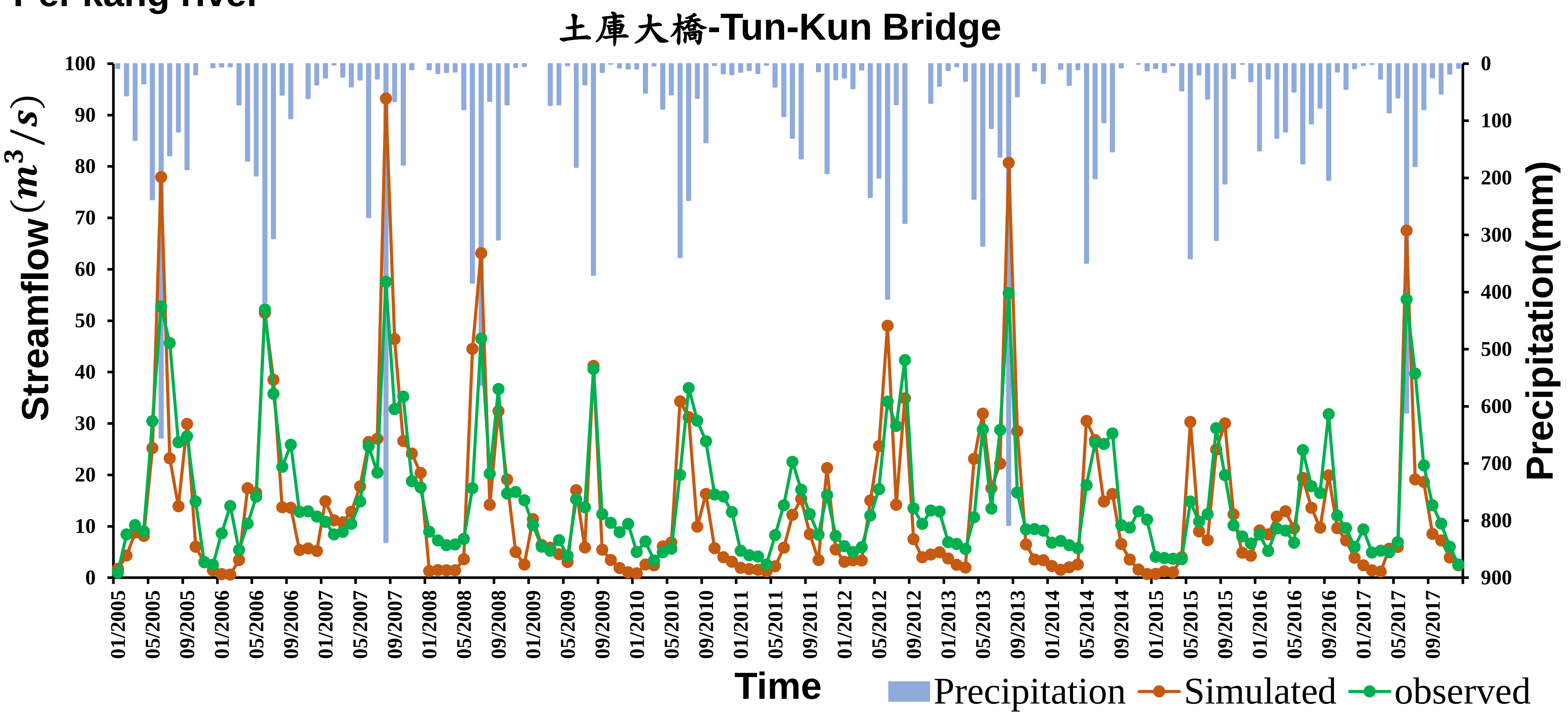


Figure 11. Hydrographs of precipitation, observed and best simulated monthly streamflow at the outlets of Tun-Kun Bridge during the calibration period (2005–2011) and validation period (2012-2017)

SWAT model	Pearson correlation coefficient	RMSE	R^2	Pbias	NSE
Calibration	0.865	0.354	0.749	0.289	0.549
Validation	0.857	0.056	0.734	-0.029	0.469

Results and discussion

Downstream of Pei-kang river

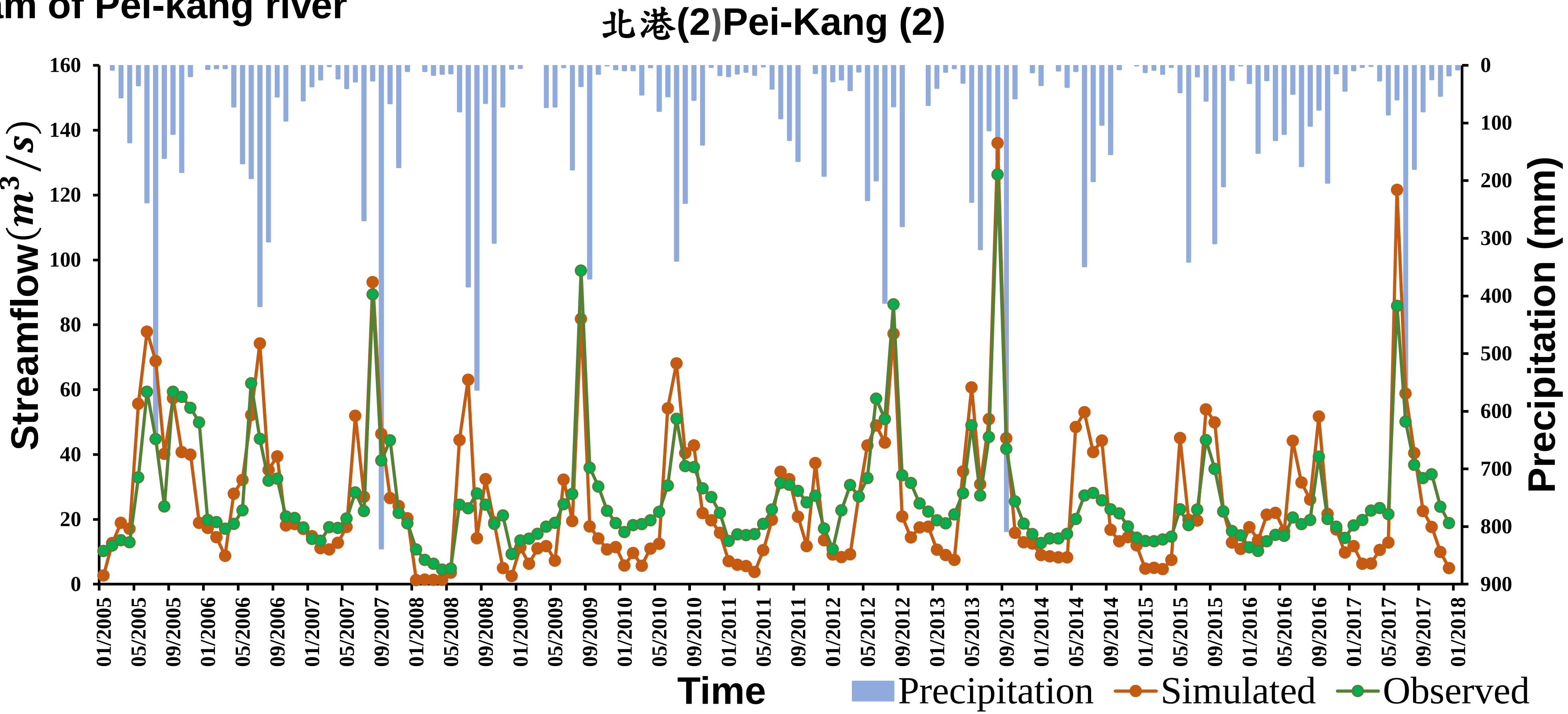


Figure 12. Hydrographs of precipitation, observed and best simulated monthly streamflow at the outlets of Pei-Kang (2) Bridge during the calibration period (2005–2011) and validation period (2012-2017)

SWAT model	Pearson correlation coefficient	RMSE	R^2	Pbias	NSE
Calibration	0.865	0.354	0.749	0.289	0.549
Validation	0.857	0.605	0.679	0.181	0.548

(a)

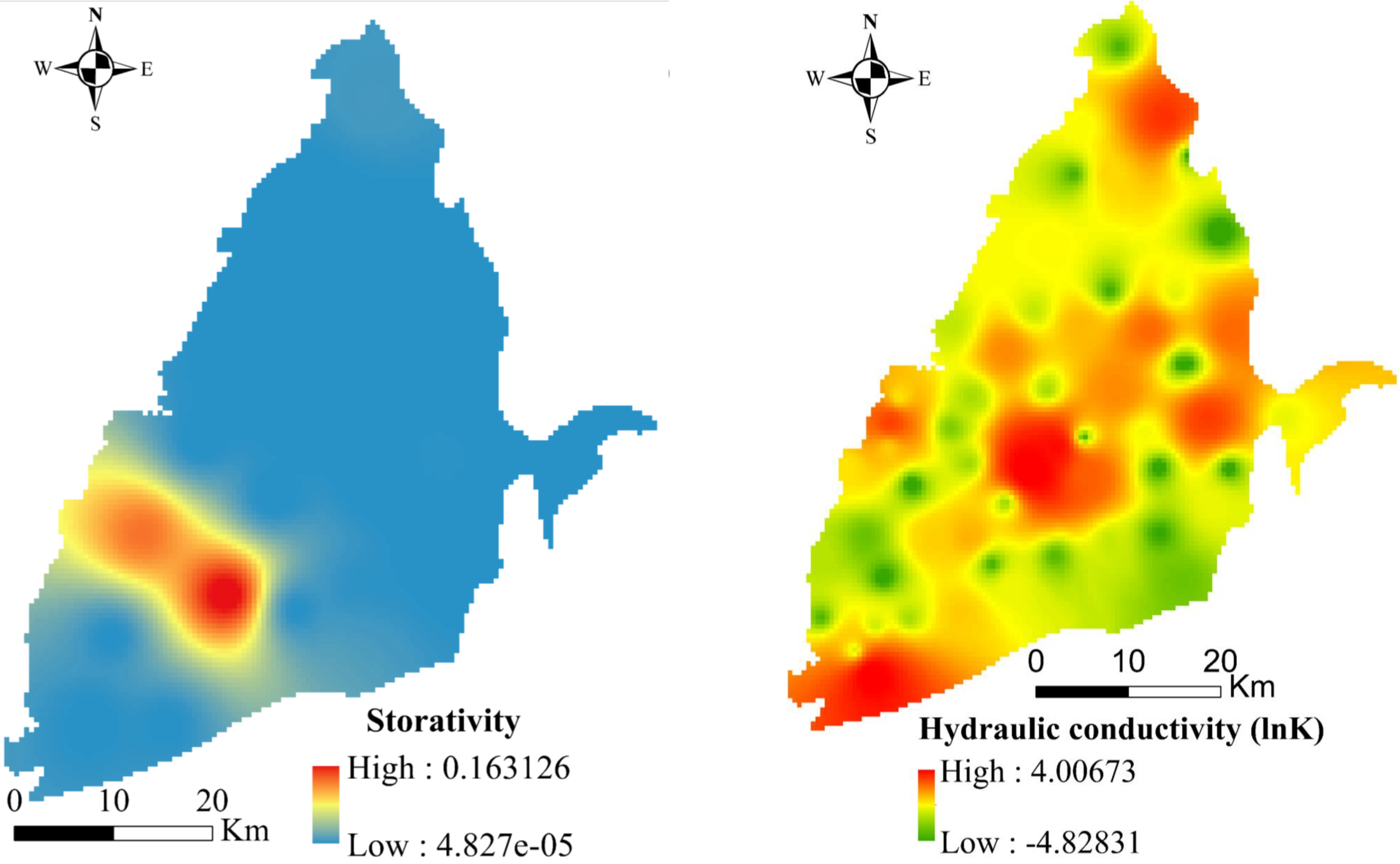


Figure 14: The distribution of storativity and hydraulic conductivity after calibrated

Results and discussion

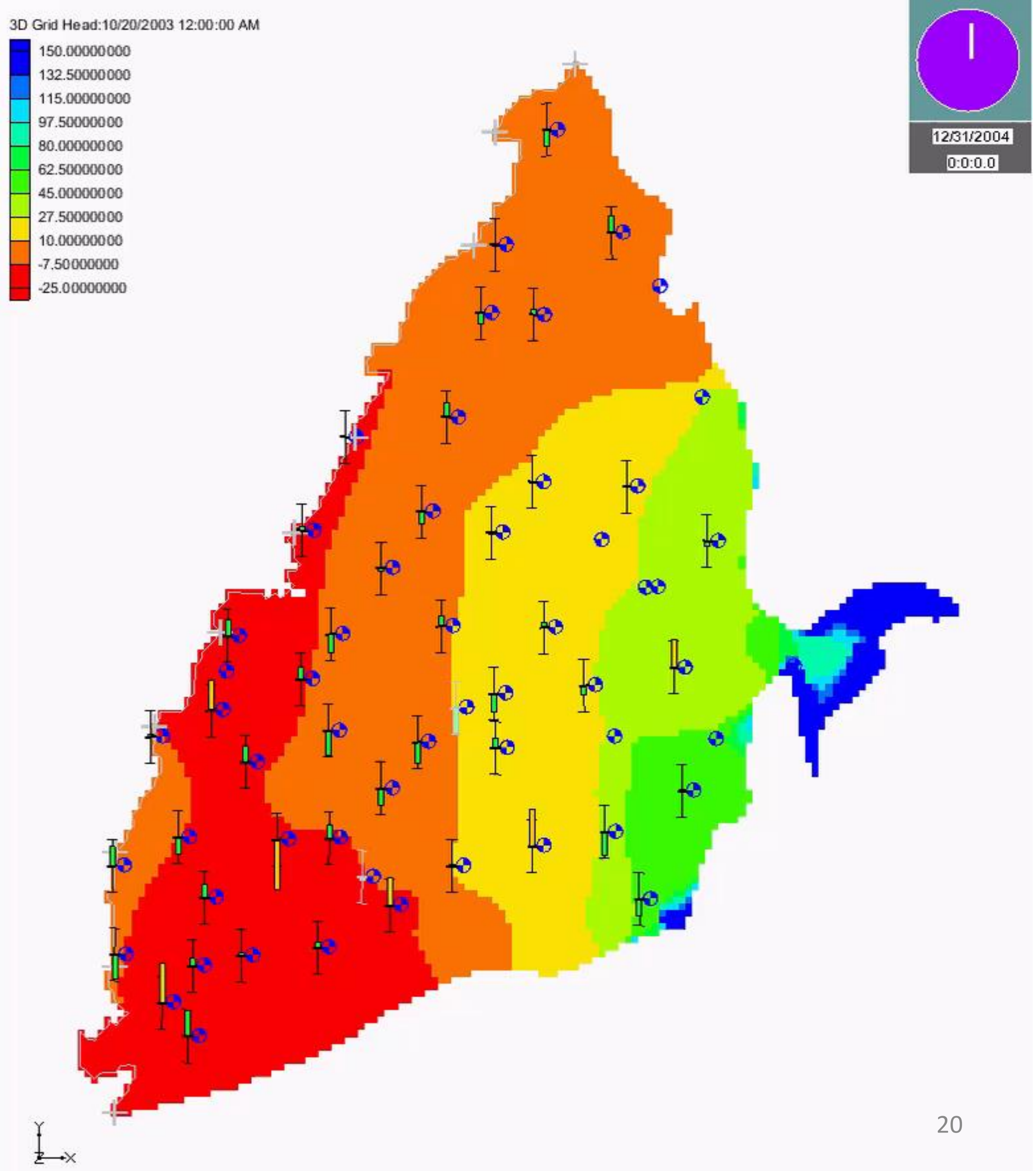
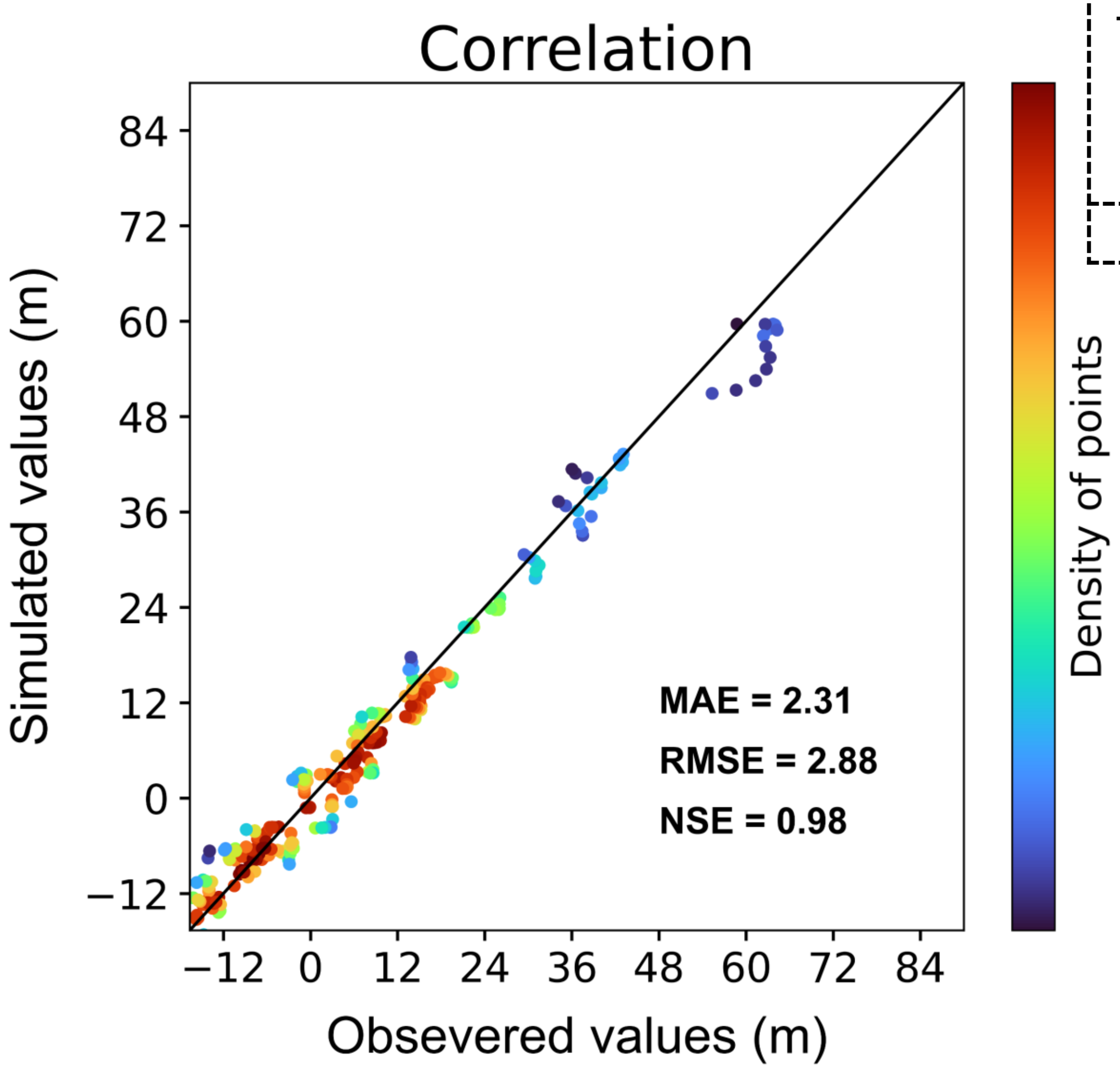


Figure 15. Visualization of the proximity of the observed and simulated heads of layer-1 by the calibrated transient MODFLOW-NWT

Results and discussion

The statistics for the calibrated MODFLOW performance



During the calibration period (2005–2011)

The number of observed heads	NSE (Nash–Sutcliffe efficiency coefficients)	M_{AE}(mean absolute error, meters)	R_{MSE}(root mean squared error, meters)
62	0.98	2.31	2.88

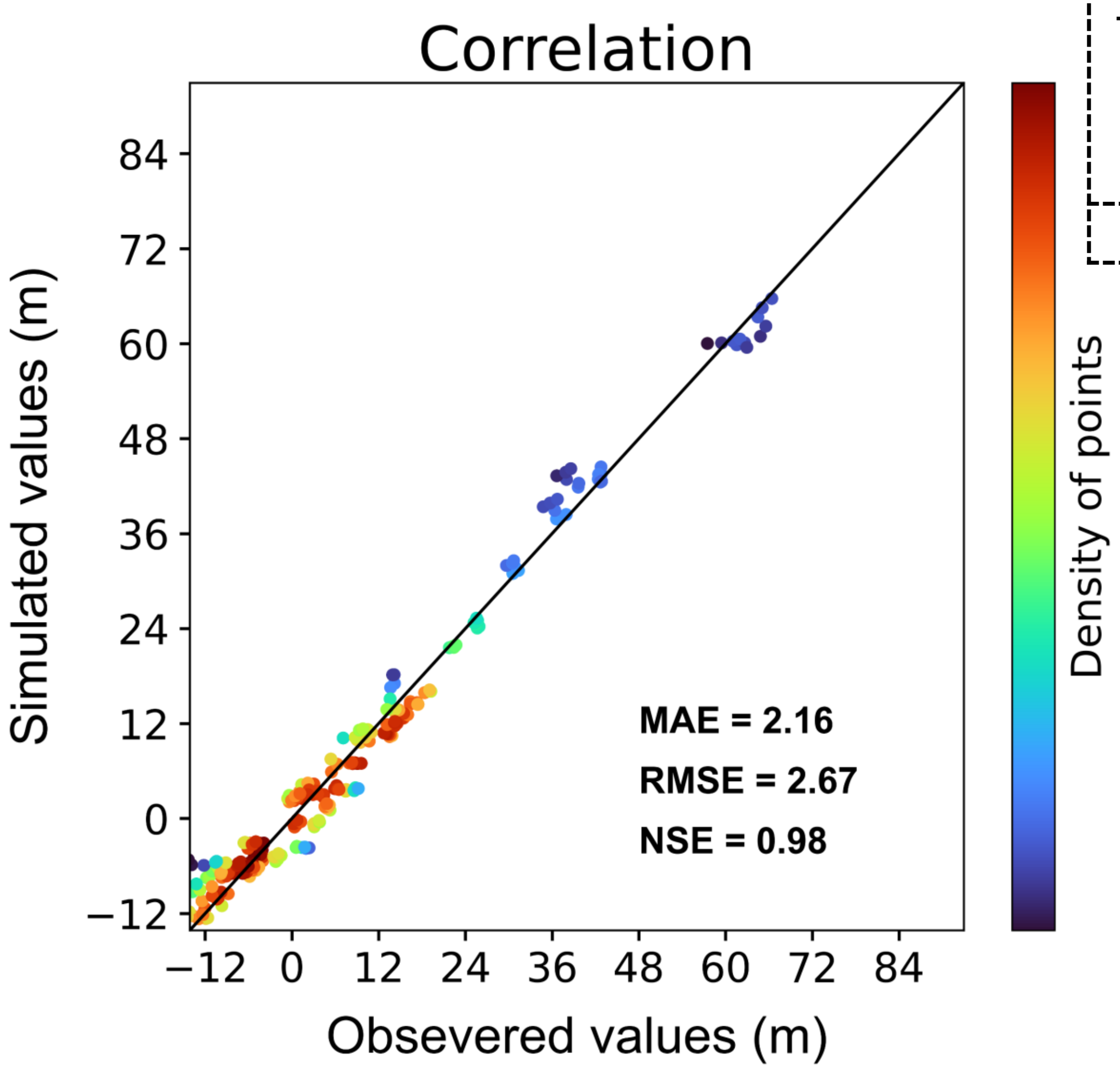
⟶ **The modified calibrated MODFLOW model was satisfactory and suitable as a basis for coupling to SWAT in transient mode.**

Results and discussion

The statistics for the validated MODFLOW performance

The validation period (2012-2017)

The number of observed heads	NSE (Nash–Sutcliffe efficiency coefficients)	M_{AE}(mean absolute error, meters)	R_{MSE}(root mean squared error, meters)
62	0.98	2.16	2.67



⟶ **The modified validated MODFLOW model was aslo satisfactory and suitable as a basis for coupling to SWAT in transient mode.**

Comparison groundwater recharge volume between RCPs with the baseline

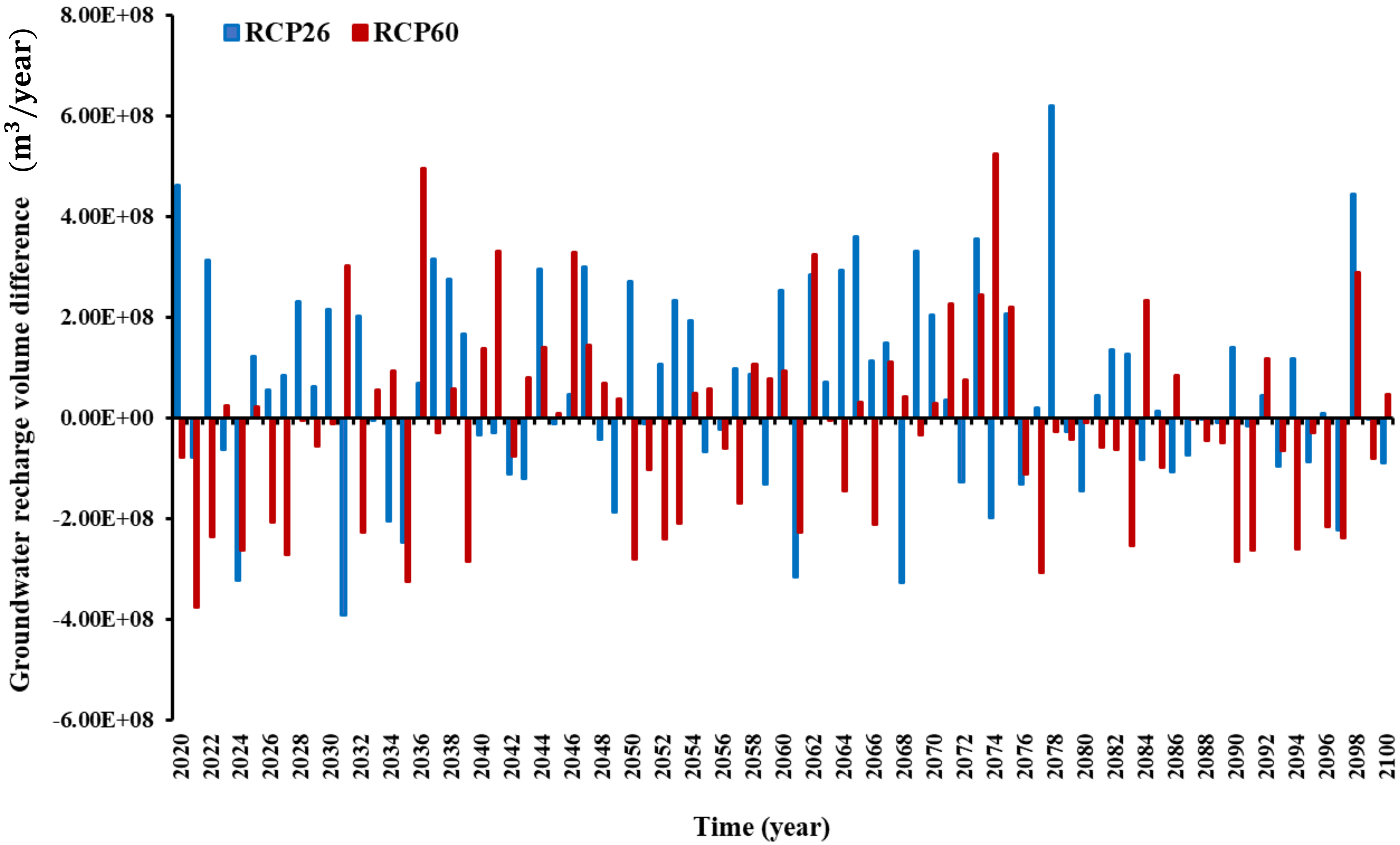


Figure 16: *Change in annual GW recharge volume project MIROC5 against baseline under RCP2.6 and RCP6.0 scenarios*

Comparison groundwater recharge volume between RCPs with the baseline

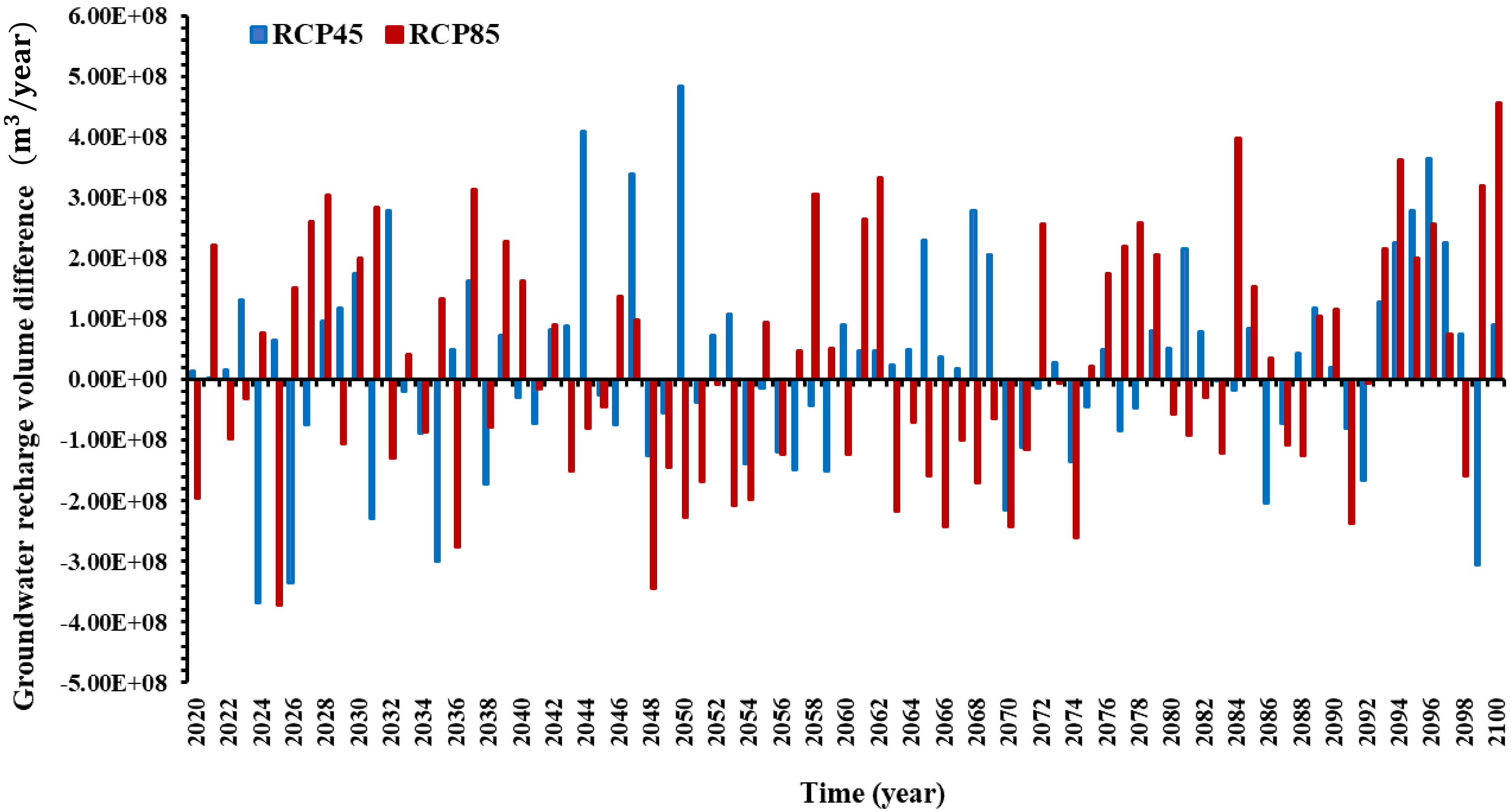


Figure 17: *Change in annual GW recharge volume project MIROC5 against baseline under RCP4.5 and RCP8.5 scenarios*

Conclusions

(1) Both models (SWAT, MODFLOW) simulated well fitted the temporal patterns of streamflow and groundwater head at the hydrology stations during the calibration and validation periods;

(2) The recharge mainly occurs in the top fan area, catching up some potential high recharge locations with previously delineated sensitive areas for GW recharge by Central Geological Survey, Taiwan.

(3) The climate change signal predominates the annual variability, resulting in a more pronounced pattern of greater recharge concentrated in fewer years. These findings help decision-makers and stakeholders devise sustainable water resource strategies;

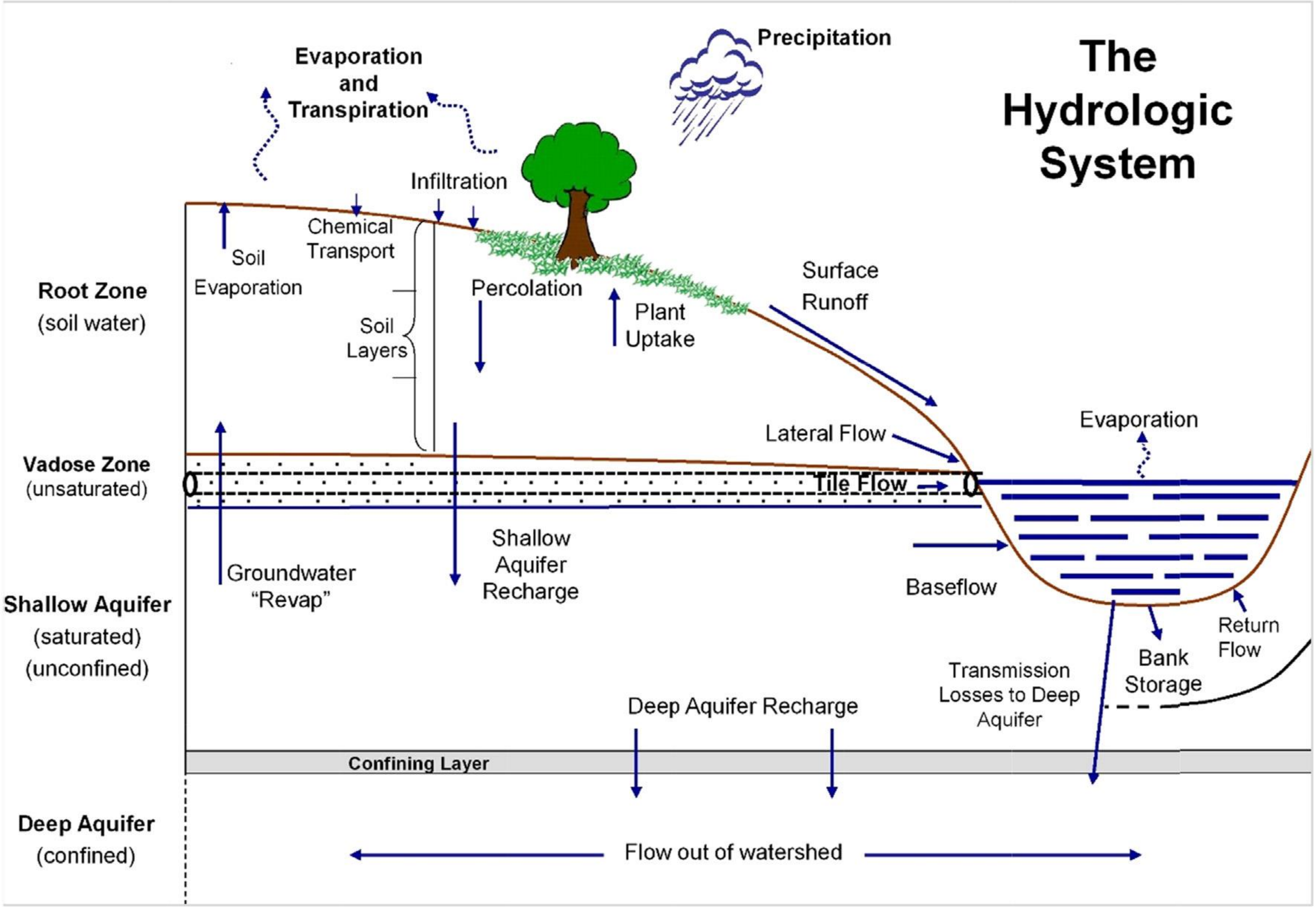
(4) The results demonstrate: properly calibrating surface water and groundwater recharge components of the water cycle is critical. This is also a prerequisite step to apply climate change scenarios to predict surface runoff and groundwater recharge in the future.

(5) The SWAT–MODFLOW would be a **valuable tool** for evaluating a wide variety of realistic scenarios in order to determine the most efficient and workable water resource management plans for replenishing the critically depleted SW and GW supplies.

Future work

(1) Estimation groundwater discharge to the stream and seepage from rivers to groundwater flow

→ Water exchange



Schematic of the hydrologic cycle simulation processes (*Neitsch et al., 2011*)

Thank you for your attention !

What are the RCPs?

RCP stands for 'Representative Concentration Pathway'. To understand how our climate may change in future, we need to predict how we will behave.

For example, will we continue to burn fossil fuels at an ever-increasing rate, or will we shift towards renewable energy?

Current emissions are tracking close to the RCP8.5 pathway

The RCPs try to capture these future trends. They make predictions of how concentrations of greenhouse gases in the atmosphere will change in future as a result of human activities.

The four RCPs range from very high (RCP8.5) through to very low (RCP2.6) future concentrations. The numerical values of the RCPs (2.6, 4.5, 6.0 and 8.5) refer to the concentrations in 2100.

2 °C increase in temperature is recognised as the threshold at which climate change becomes **dangerous**.

Effort to curb emissions	Energy generation	New technology	Transport	RCP	Temperature 2081–2100 (average increase relative to 1986-2005)	Sea level 2081–2100 (average rise relative to 1986-2005)	Extreme weather 2081–2100	Adaptation required
Low	Coal-fired power		Cars, trucks	RCP 8.5	3.7 °C	0.63 m	**Large** increase	High level at high cost
Medium	Mix		Mix	RCP 6.0	2.2 °C	0.48 m	**Moderate** increase	Medium level at medium cost
Medium	Renewable		Mix	RCP 4.5	1.8 °C	0.47 m	**Moderate** increase	Medium level at medium cost
High	Renewable	Emissions capture	Bicycles, public transport	RCP 2.6	1.0 °C	0.4 m	**Small** increase	Low level at low cost