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

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## INTRODUCTION

The interaction between groundwater (GW) and surface water (SW) is an important aspect of water cycle. The assessment of climate change impact on groundwater recharge is a challenge in hydrological researches because substantial doubts still remain, particularly in arid and semi-arid regions (Pulido-Velazquez et al., 2018).

The **Soil and Water Assessment Tool** (SWAT) (Gassman et al., 2007; Neitsch et al., 2011) simulates the surface runoff and groundwater dynamics, management practices or climate change on water quantity at different geographical locations and scales. **Future climate** data with **five-kilometer spatial resolution**, provided by TCCIP, were selected to accommodate the future climatic conditions of catchment features.

The **MODFLOW–NWT** (a Newton–Raphson formulation for MODFLOW-2005)(Niswonger et al., 2011) was used as a **SWAT sub-routine**, simulating groundwater flow processes and all associated sources and sinks on time steps in order to improve the solution of unconfined groundwater-flow problems.

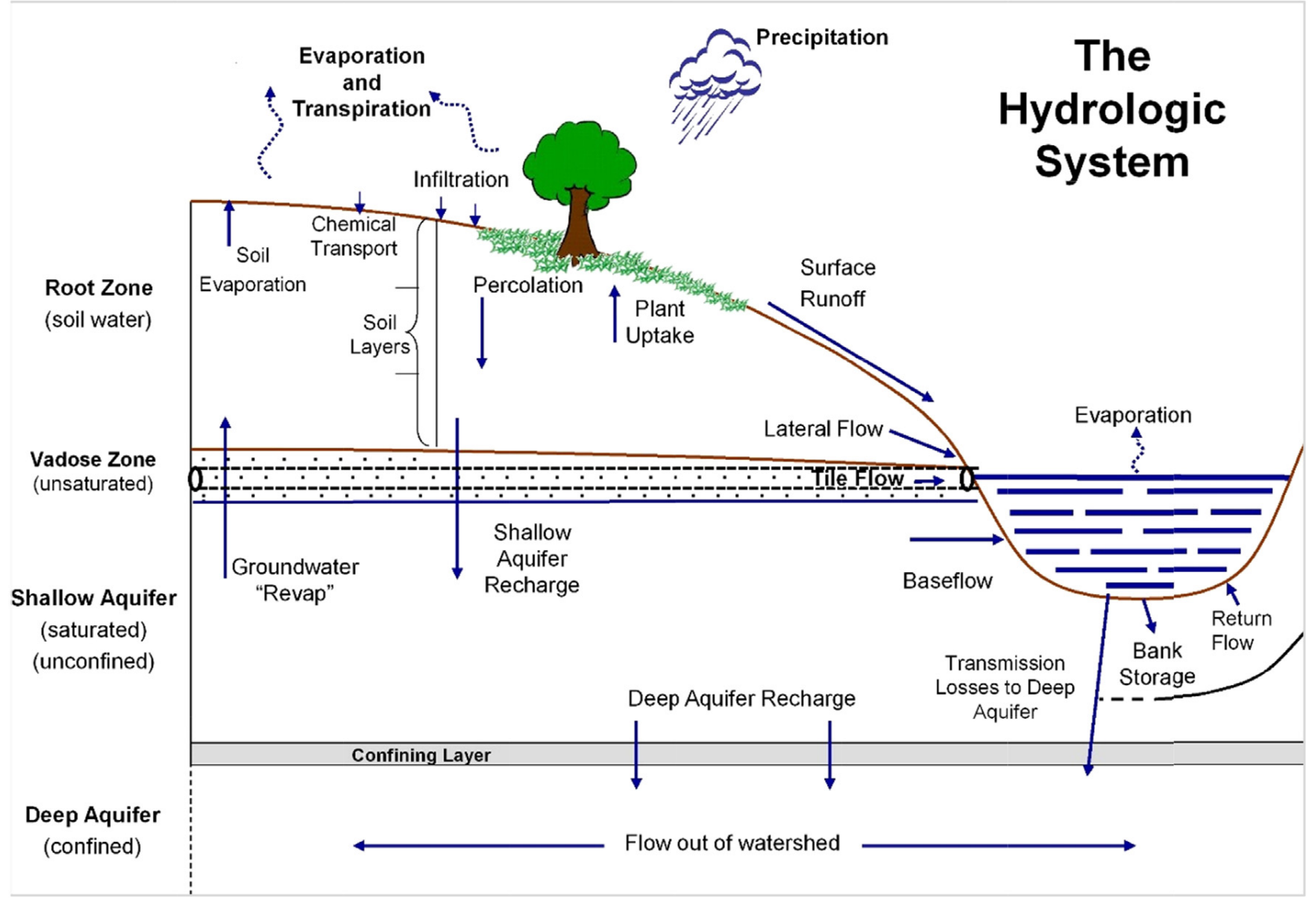


*Fig. 1 Schematic of the hydrologic cycle simulation processes (Neitsch et al., 2011)*

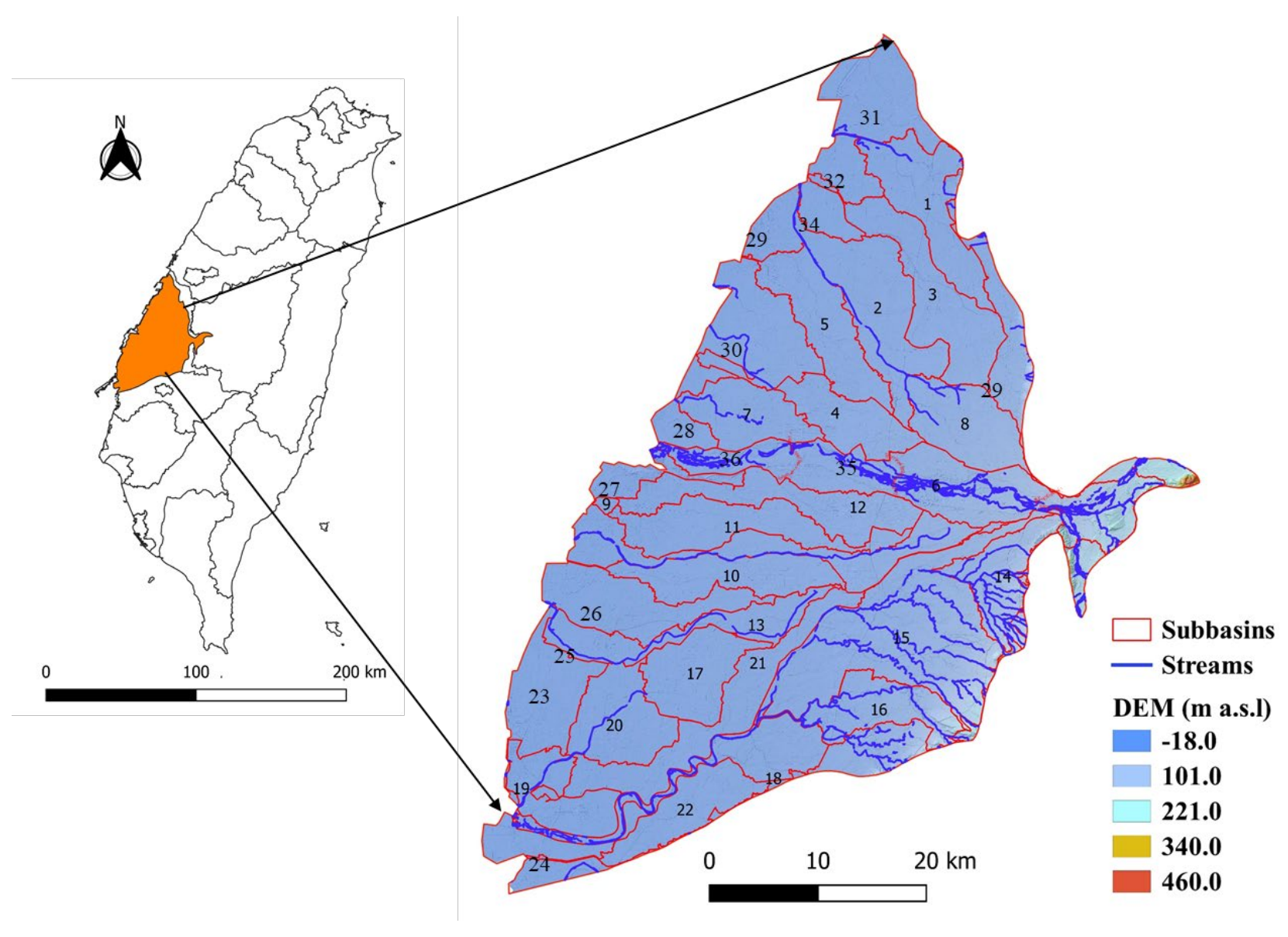


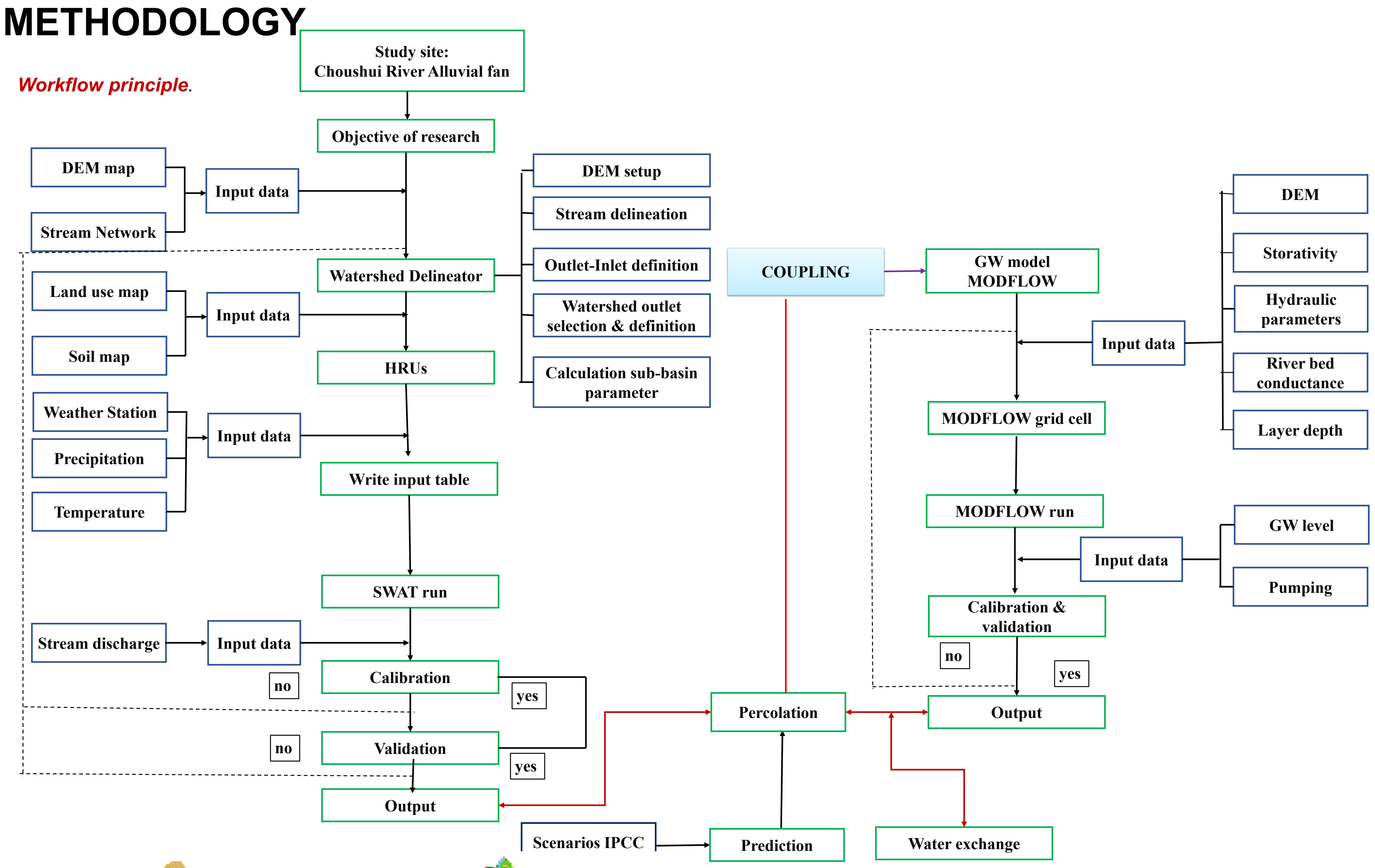
*Fig. 2 Location of the Choushui River Alluvial Fan (CRAF), and the delineation in SWAT model.*

## OBJECTIVE

This study were to apply the **coupled** SWAT-MODFLOW models to estimate **streamflow discharge, percolation, 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.

## METHODOLOGY

*Workflow principle.*


Study site: Choushui River Alluvial fan
Objective of research
DEM map
Stream Network
Input data
DEM setup
Stream delineation
Outlet-Inlet definition
Watershed outlet selection & definition
Calculation sub-basin parameter
Watershed Delineator
Land use map
Soil map
Input data
HRUs
Weather Station
Precipitation
Temperature
Input data
Write input table
SWAT run
Stream discharge
Input data
Calibration
no
yes
Validation
no
yes
Output
Scenarios IPCC
Prediction
Percolation
Water exchange
COUPLING
GW model MODFLOW
Input data
DEM
Storativity
Hydraulic parameters
River bed conductance
Layer depth
MODFLOW grid cell
MODFLOW run
Input data
GW level
Pumping
Calibration & validation
no
yes
Output

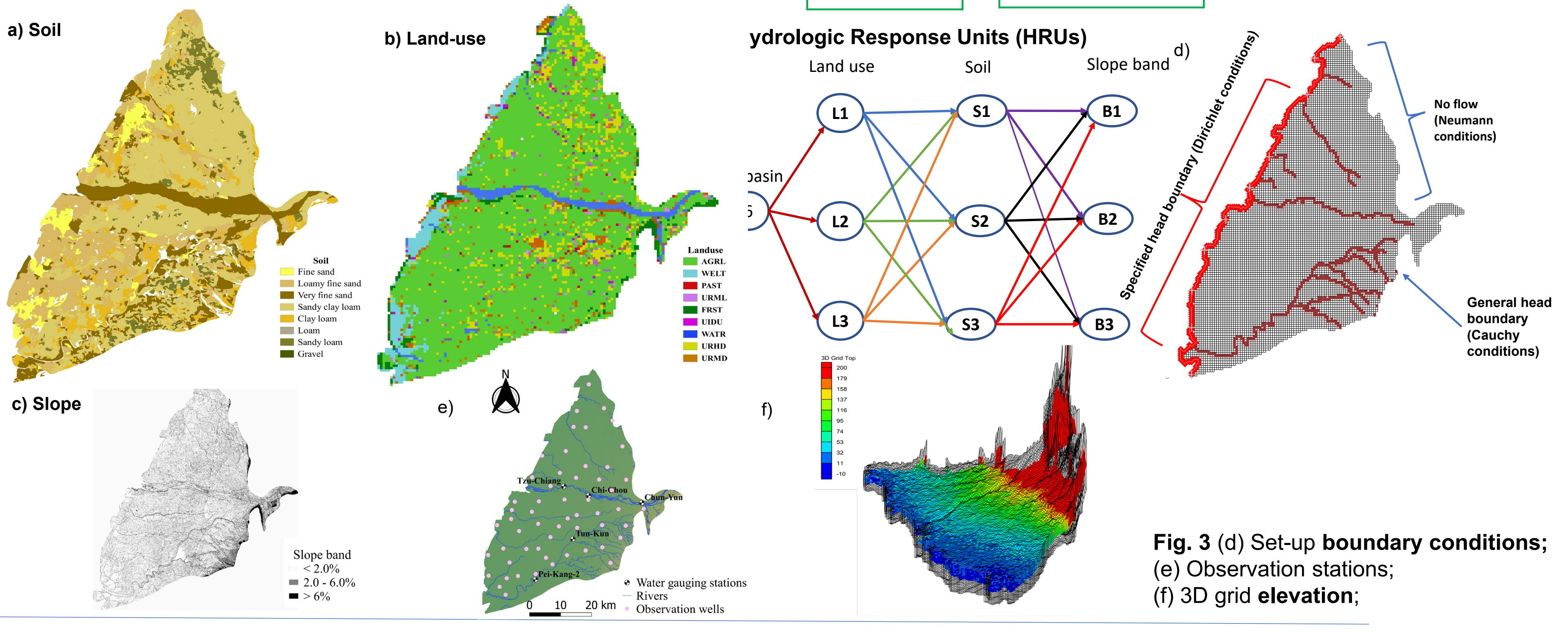


**Fig. 3** (d) Set-up **boundary conditions;** (e) Observation stations; (f) 3D grid **elevation**;

## RESULTS

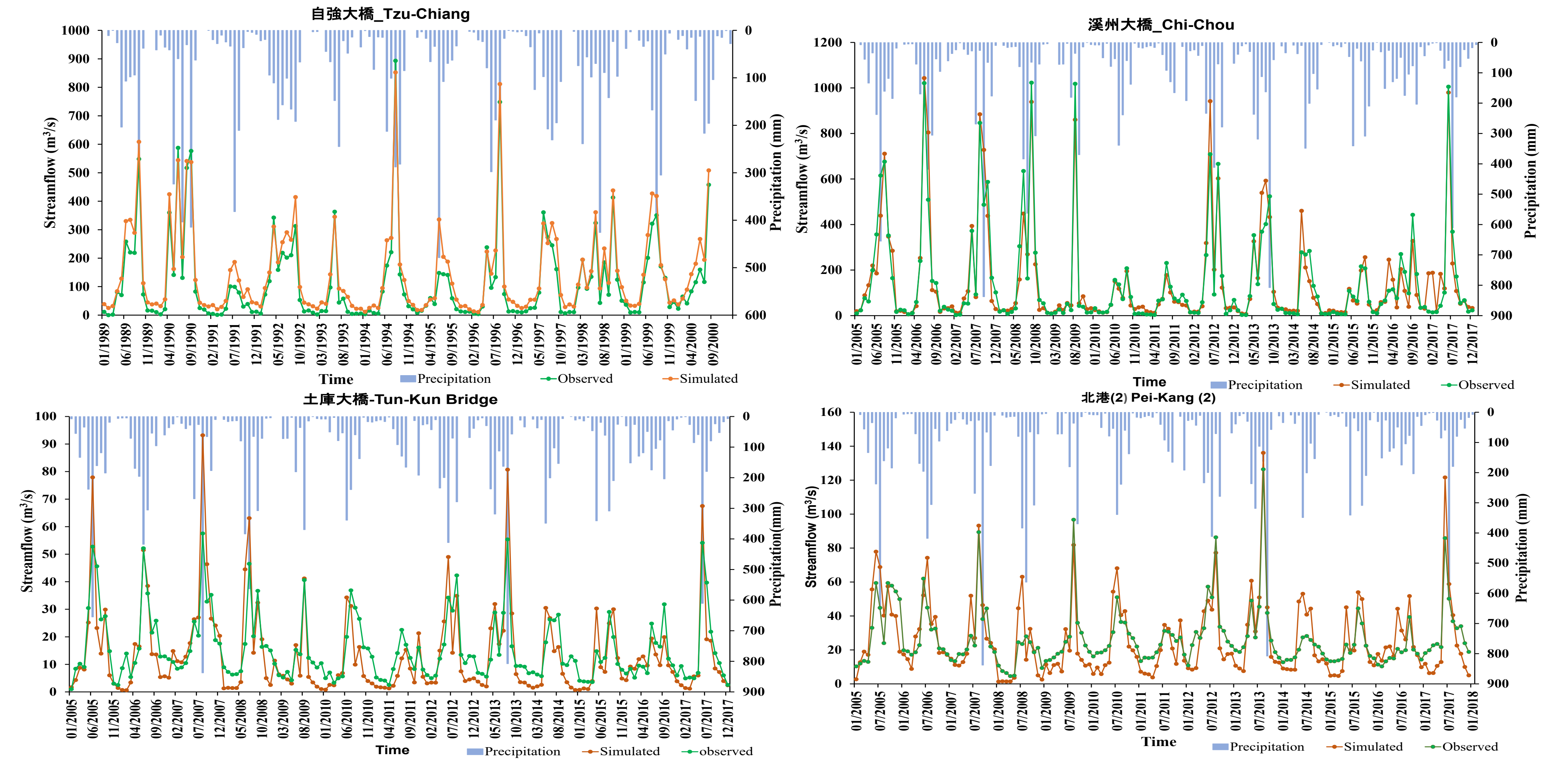


*Fig. 4 Hydrographs of **precipitation, observed and the best-fit monthly streamflow** at the outlet of Tzu-Chiang bridge during the calibration period (1989-1994) and validation period (1995-2000). The outlets of Chi-Chou, Tun-Kun, Pei-Kang Bridges during the **calibration** period (2005-2011) and **validation** period (2012-2017).*

**Table 1** Performance of the statistical indices for monthly runoff at the outlets of sub-basins during the **calibration** (2005-2011) and **validation** (2012-2017, ***bold in brackets***) periods with SWAT-CUP calibration.

| Outlets | Pearson correlation coefficient | RMSE (m) | $R^2$ | $P_{bias}$ | NSE |
|---|---|---|---|---|---|
| Tzu-Chiang | 0.979(**0.971**) | 2.742(**1.194**) | 0.959(**0.943**) | -0.003(**-0.131**) | 0.942(**0.866**) |
| Chi-Chou | 0.959(**0.930**) | 0.020(**0.114**) | 0.920(**0.865**) | -0.001(**0.010**) | 0.920(**0.846**) |
| Tun-Kun | 0.865(**0.857**) | 0.354(**0.056**) | 0.749(**0.734**) | 0.289(**-0.029**) | 0.549(**0.469**) |
| Pei-Kang | 0.865(**0.857**) | 0.354(**0.605**) | 0.749(**0.679**) | 0.289(**0.181**) | 0.549(**0.548**) |

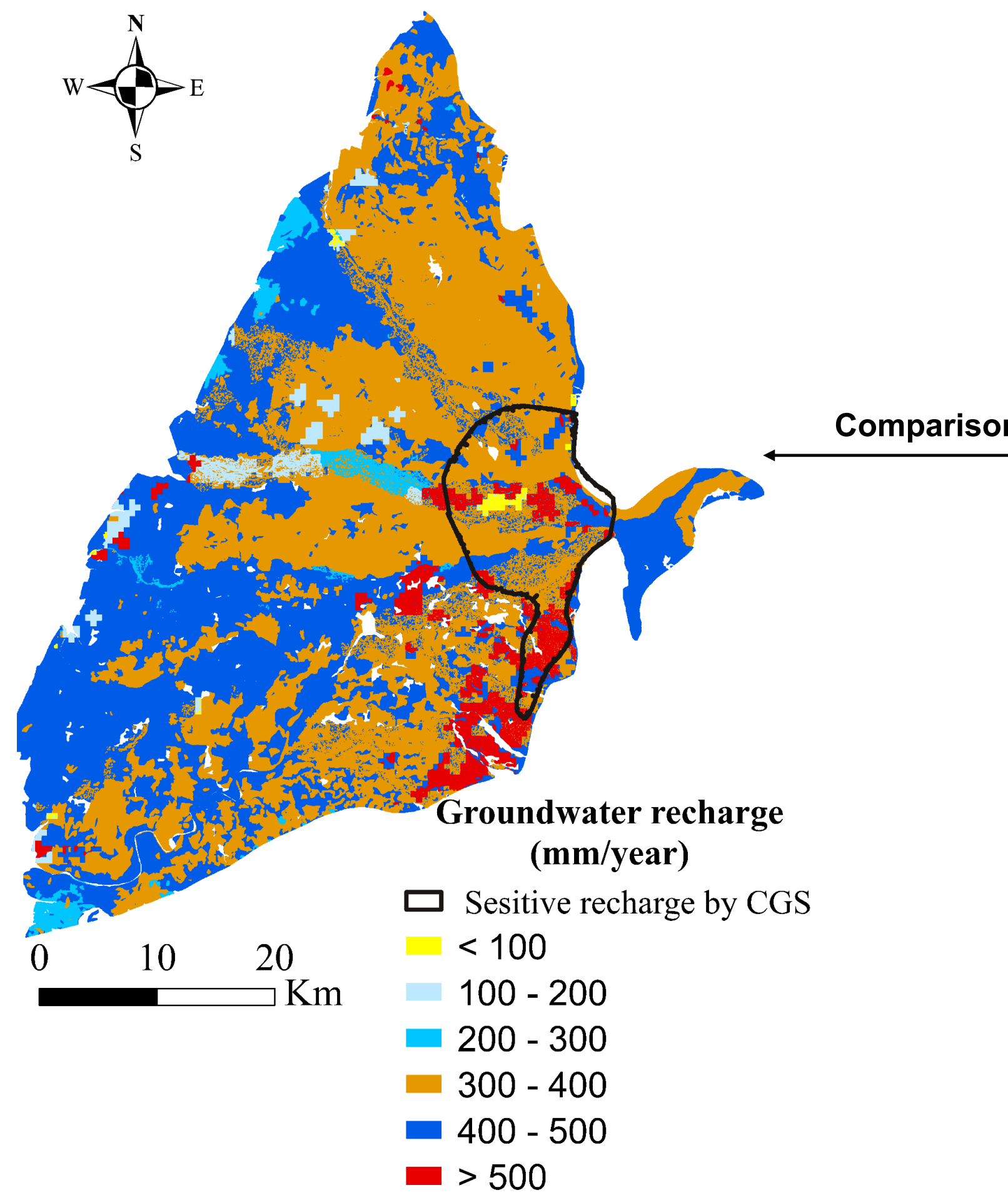


*Fig.7 Annual recharge rate in Choushui River Alluvial Fan.*

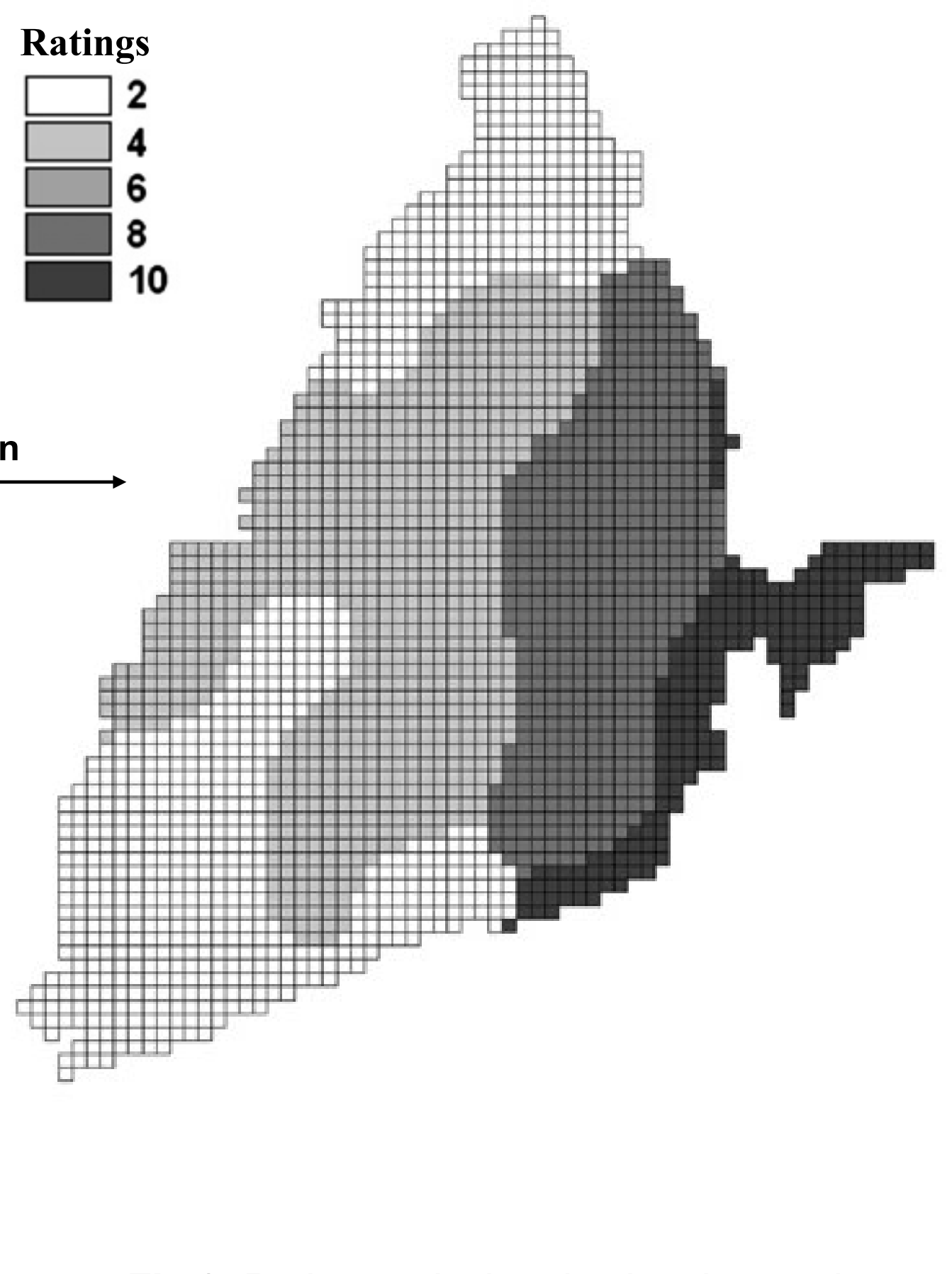


*Fig 8. Ratings calculated using the maximum estimation probability approach (Chen et al., 2013).*

**Table 2** Performance of the statistical indices for groundwater level during the **calibration** (2005-2011) and **validation** (2012-2017, in ***brackets***) periods by MODFLOW model

| 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 (0.98) | 2.31 (2.16) | 2.88 (2.67) |

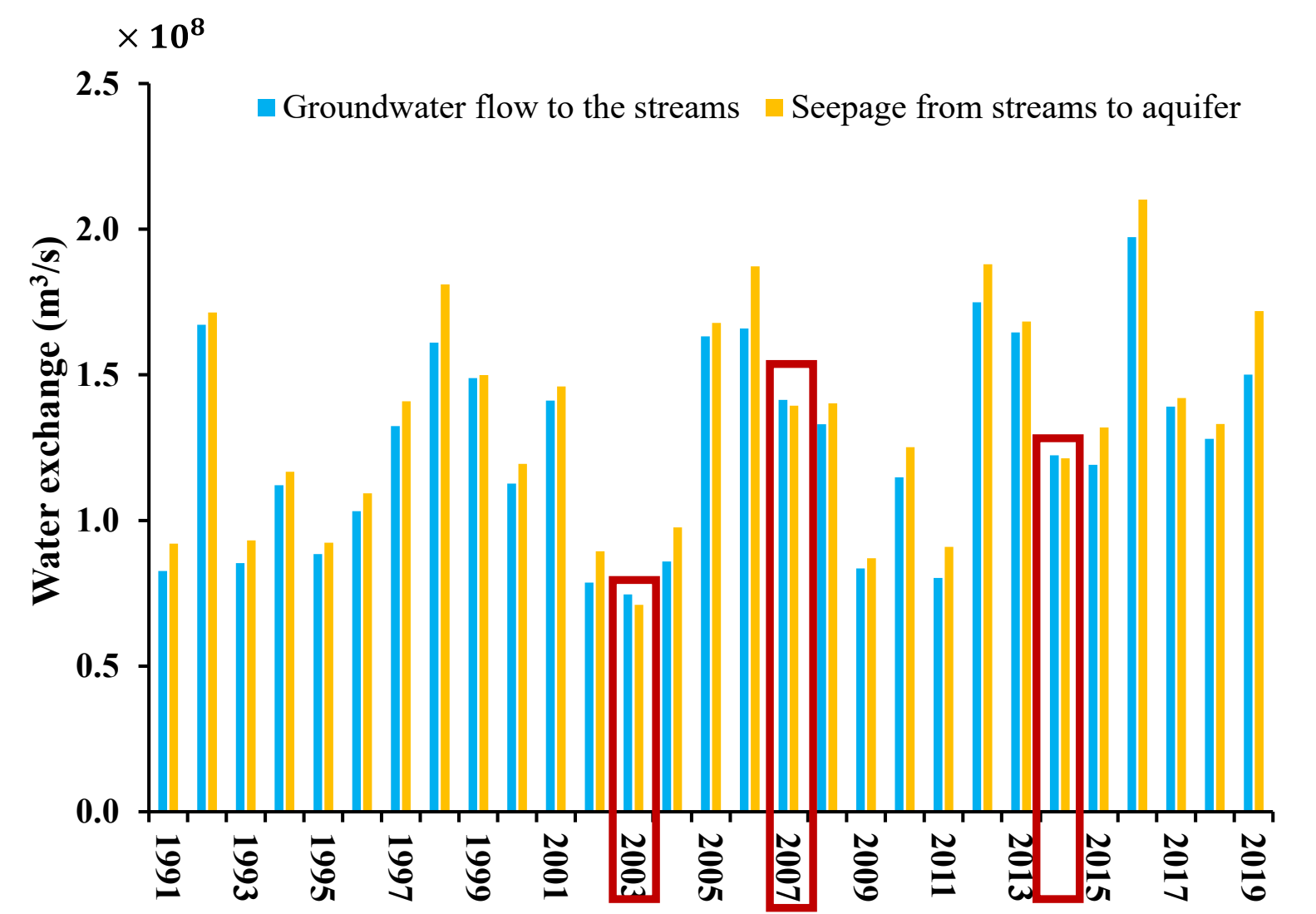


Fig. 5 The **water exchange** between stream and groundwater flow

### Climate change simulation

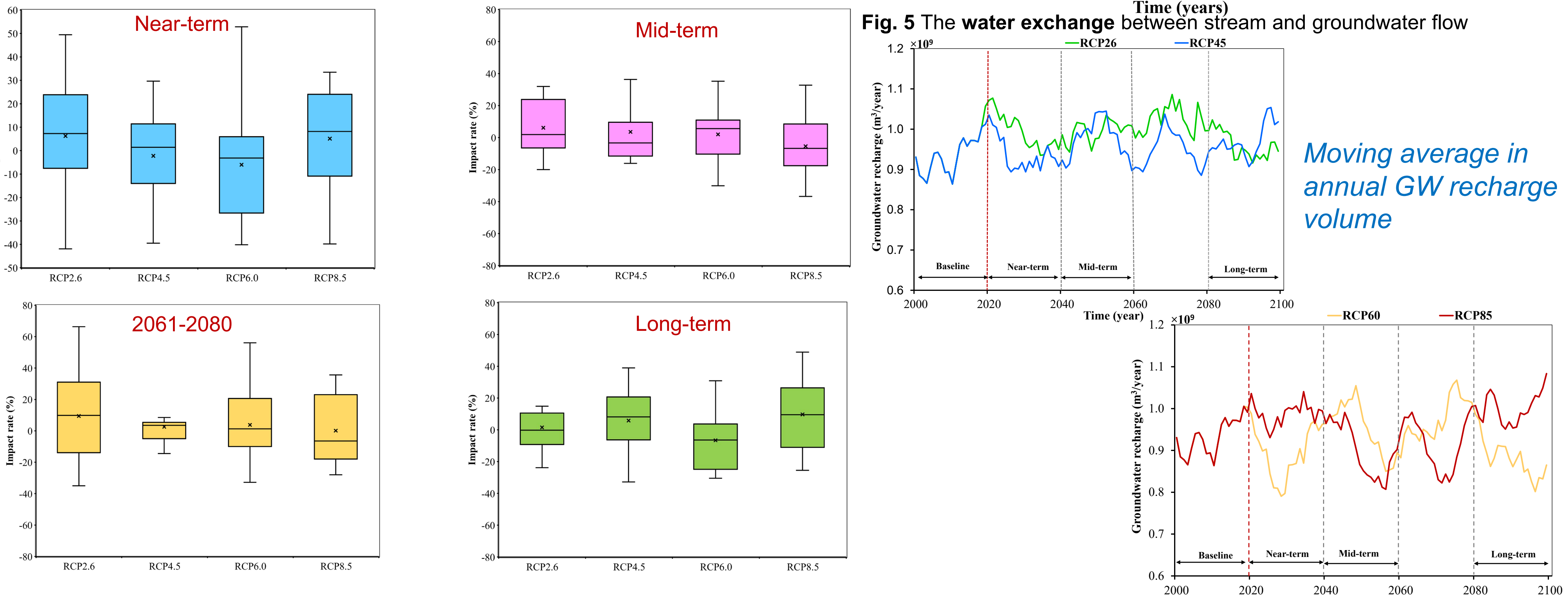


*Fig. 6 Change in annual **GW recharge volume** project MIROC5 against baseline under RCP2.6, RCP4.5, RCP6.0, and RCP 8.5 scenarios.*

## DISCUSSION

**Confidence in the calibrated** model was **enhanced** by **validation** through **generally good statistical performance** for the temporal pattern of streamflow and groundwater head, with the $R^2$, percent bias ($P_{bias}$), **RMSE**, Nash–Sutcliffe model efficiency coefficients **(NSE), mean absolute error**, which helps **achieve a reliable simulation** of the watershed responses.

The reflects of the concept for SWAT-MODFLOW GW recharge by a lumped module in individual sub-basins contribute to stream network as baseflow. With this simplified implementation of GW dynamics and water exchange between SW-GW (***Fig. 5***), the **spatiotemporal variability of GW recharge** for **near-term (2021-2040), mid-term (2041-2060), 2061-2080, & long-term period** was estimated under the baseline (***Fig. 7***) and **four representative concentration pathways** (RCPs) (***Fig. 6***).

## CONCLUSIONS

- The simulation results of both models (SWAT, MODFLOW) well fitted the temporal patterns of streamflow and GW head at the hydrology stations during the calibration and validation periods. This is a prerequisite step to apply the climate change scenarios to predict GW recharge in the future.
- During the dry years, the recharge rate seepage from the streams to the shallow aquifer was possible lower than the GW discharge to the streams.
- GW recharge mainly occurs in the proximal fan area, catching up some high potential recharge locations in previously delineated sensitive areas for GW recharge by Chen et al. (2013) and Central Geological Survey, Taiwan.
- According to the top-ranking GCM MIROC5 projections procedure for CRAF, the highest and lowest effect rates of climate change on GW recharge in the study region from the 2020s to the 2100s were RCP2.6 (66.36%, -41.92%), RCP4.5 (51.86%, -39.48%), RCP6.0 (56.11%, -40.13%), or RCP8.5 (48.93%, -39.85%). This suggests that even while GW recharge lies in complicated geological heterogeneity and soil profiles, the effects of climate change still substantially influence it. These findings help decision-makers and stakeholders devise sustainable water resource strategies.

## ACKNOWLEDGMENT

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