Groundwater Potential of Heterogeneous Unconsolidated Aquifers in the Chiang Mai Basin, Northern Thailand

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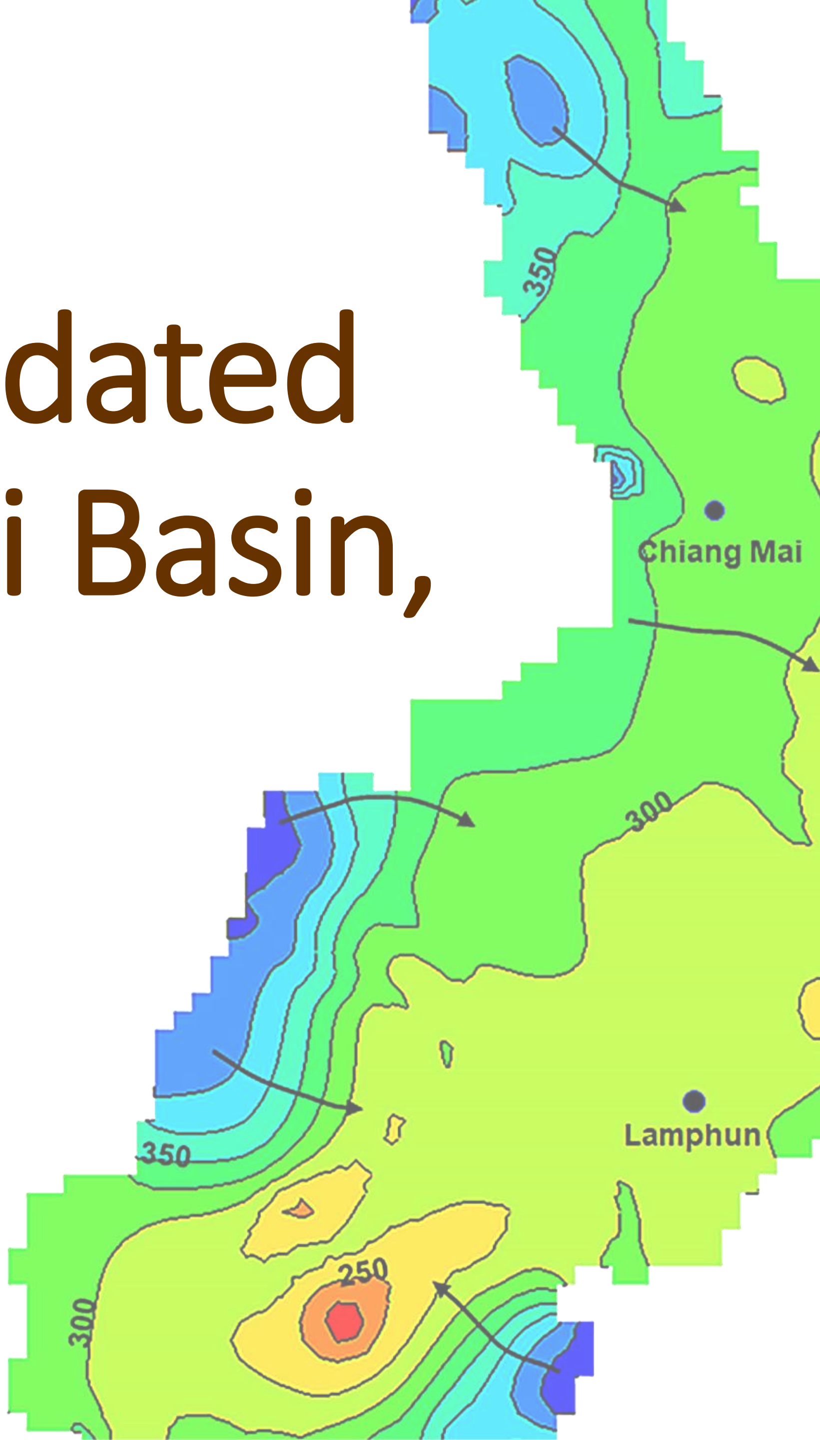

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Evaluation of Groundwater Potential and Safe Yield of Heterogeneous Unconsolidated Aquifers in Chiang Mai Basin, Northern Thailand

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Abstract: Chiang Mai basin has an escalating population growth resulting in high demand for water consumption. Lack of surface water supply in most parts of the basin gives rise to the increasing use of groundwater which leads to a continuous decline in groundwater level in the past decades. This study is the first long-term groundwater monitoring and modeling study that aims at developing a transient, regional groundwater flow model of heterogeneous unconsolidated aquifers based on the MODFLOW program. Long-term groundwater monitoring data from 49 piezometers were used in model calibration and validation. The pilot points technique was used to account for the spatial variability of hydrogeologic parameters of heterogeneous aquifers. The simulation results and statistics showed that most sensitive and significant model parameters were spatially variable hydraulic conductivities and recharge rates. The Chiang Mai basin's unconsolidated aquifers do not have high potential. The water table and/or potentiometric surface in the southeast and southwest areas of Chiang Mai city were continuously decreasing with no sign of recovery indicating critical groundwater condition and careful management must be considered. Safe yield calculation, based on a 2-m average drawdown threshold, suggested that unconsolidated aquifers of the Chiang Mai basin can sustain overall abstraction rates up to 51.2 Mm^3/y or approximately 214% of the current extraction rates.

Keywords: Chiang Mai groundwater basin; MODFLOW; groundwater model; groundwater recharge; groundwater potential

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Outline

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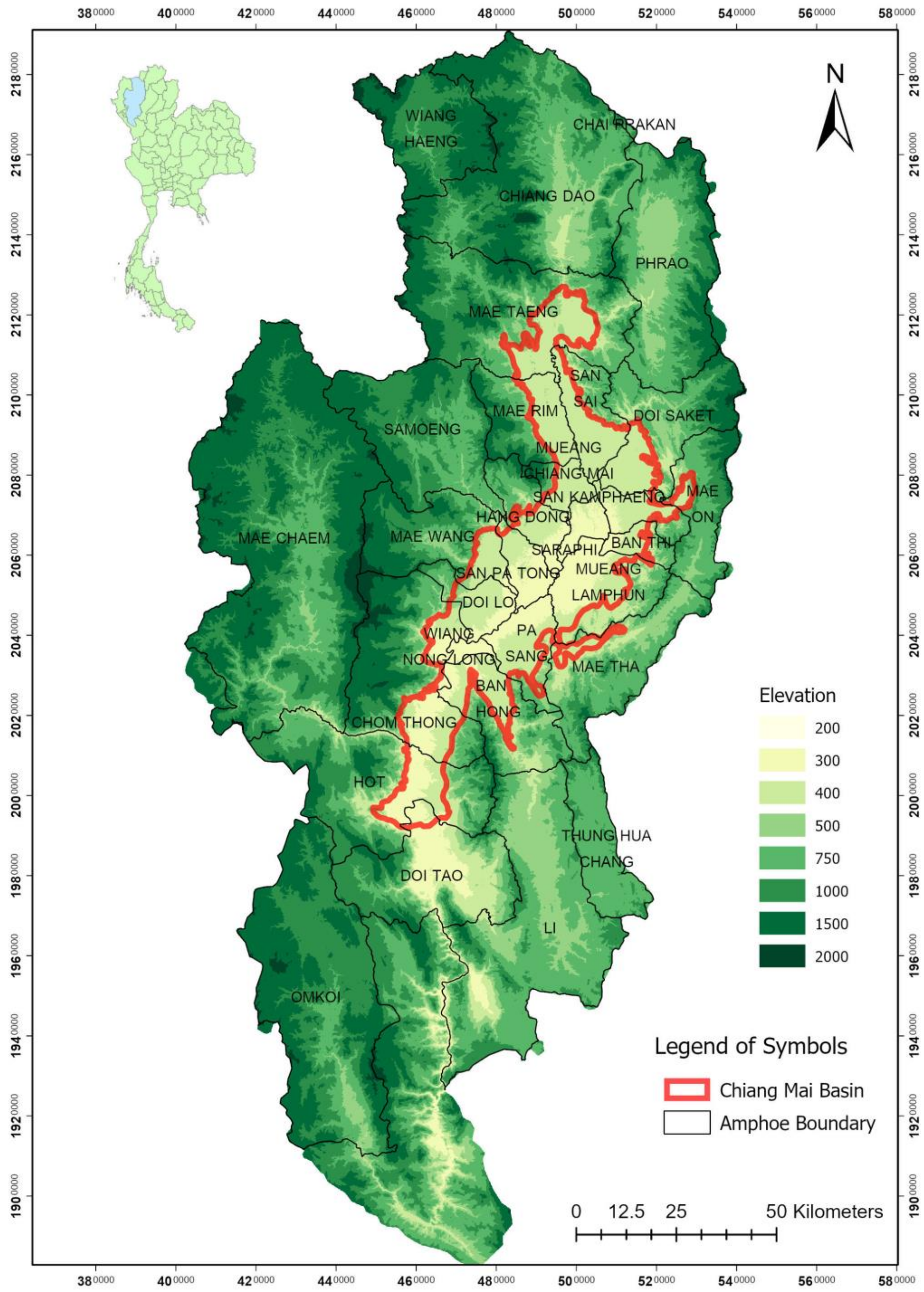
- Conclusions



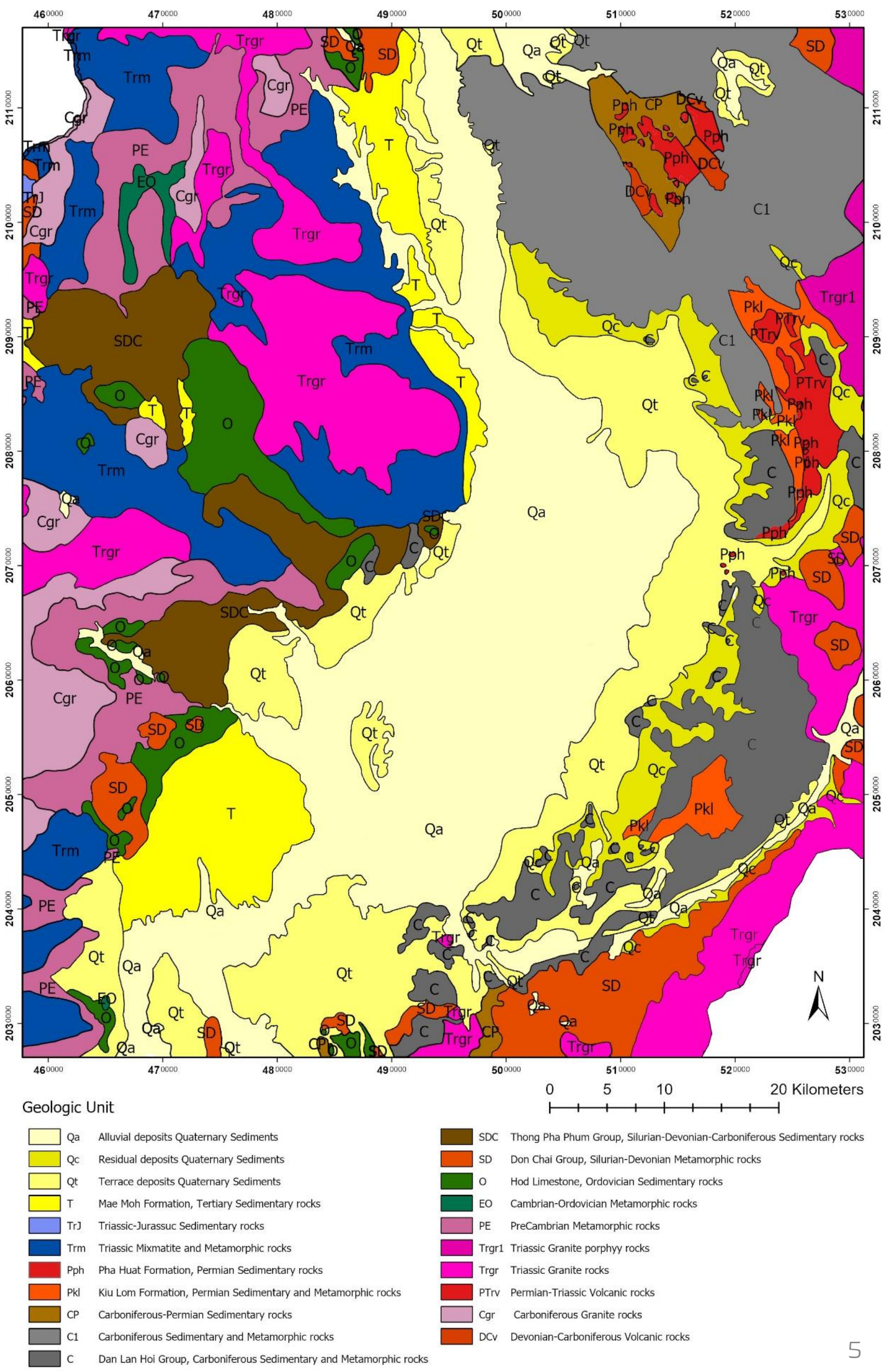
Chiang Mai Basin

The Chiang Mai basin is one of the largest sedimentary basins in Northern Thailand. It is an elongated intermontane and structurally controlled basin. The basin covers an area of semi-consolidated to unconsolidated sediments of approximately 2,800 square kilometers of Chiang Mai and Lamphun provinces.

The inner basin is relatively flat with elevations varying from around 280 - 335 meters (amsl.).

The Chiang Mai basin formed under an extensional tectonic regime similar to other basins in Northern Thailand, between the late Cretaceous and the early Tertiary (Polachan and Sattayarak, 1989)

The mountainous areas surrounding the basin are made up of Precambrian to Permian sedimentary rocks (DMR, 2007).

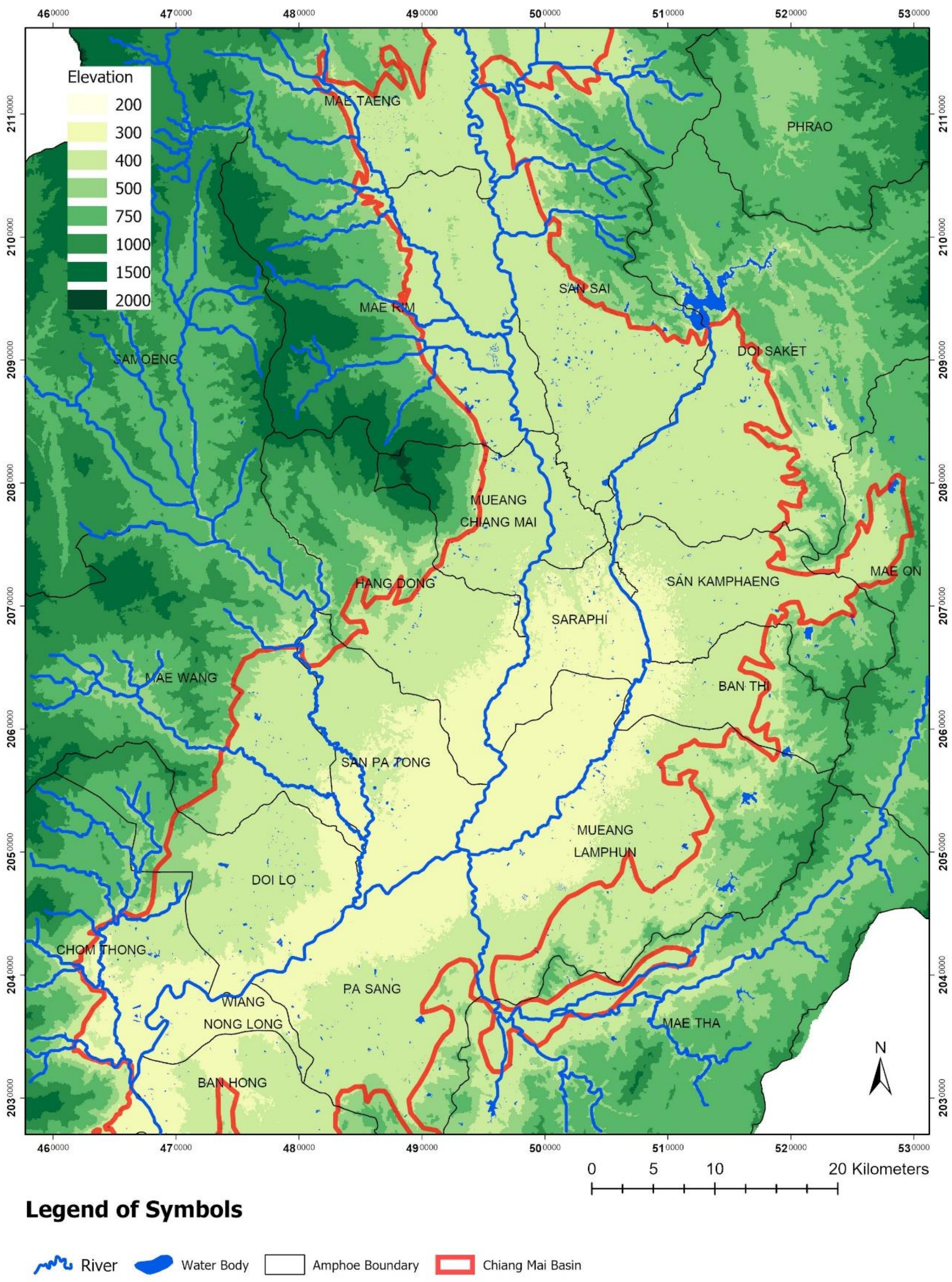


Geologic map of Chiang Mai basin (modified from DMR, 2007)

Province	Forecasted Groundwater Demand								
	Domestic Use (Mm^3/yr)			Industrial Use (Mm^3/yr)			Agricultural Use (Mm^3/yr)		
	Year 2009	Year 2014	Year 2019	Year 2009	Year 2014	Year 2019	Year 2009	Year 2014	Year 2019
Chiang Mai	51.77	52.90	53.82	12.66	14.00	15.13	29.83	31.35	32.95
Lamphun	24.31	24.62	24.77	6.68	7.38	8.19	29.79	31.31	32.90
Total	76.08	77.52	78.58	19.34	21.38	23.32	59.62	62.66	65.85

Forecasted groundwater demand of Chiang Mai and Lamphun provinces (DGR, 2010)

Outside the municipal areas, people still mainly rely upon the availability of groundwater for domestic, industrial, and agricultural uses. Based on the increasing of population trend, increasing of uncontrolled domestic, agricultural, and industrial groundwater usage can cause a decline in groundwater storage and associated hydraulic heads.



Main rivers:

Ping river, Mae Kuang river

Annual precipitation:

approximately 1,200 mm (1989 – 2018)

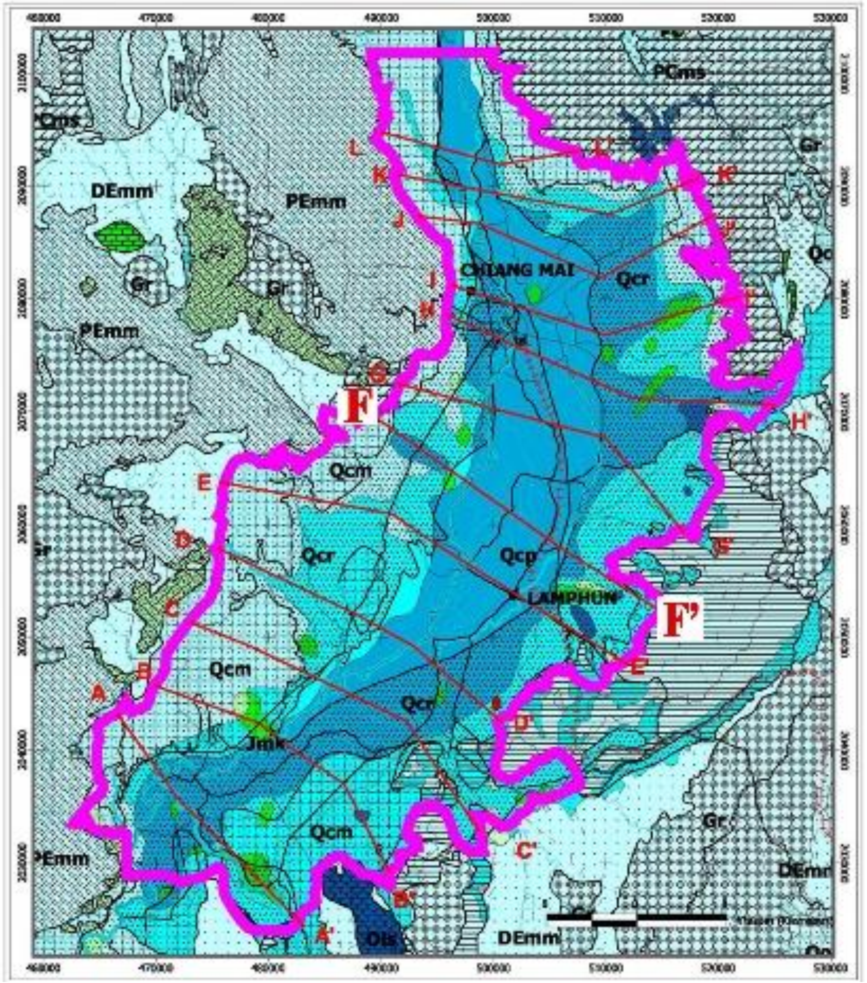
Rainy season:

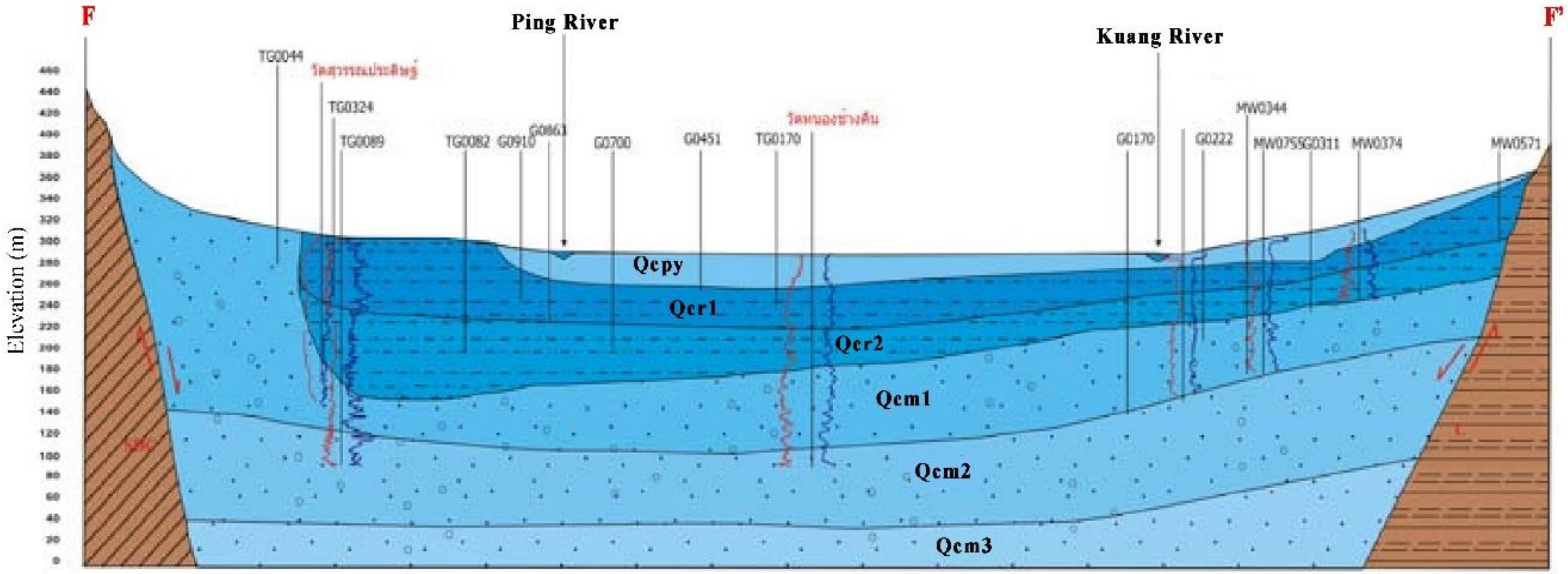
June – October

Groundwater recharge period:

July – September (DGR, 2005)

- Chao Phraya Aquifers (Qfd/Qcpy)
  - alluvial sediments on the flood plain area
- Chiang Rai Aquifers (Qa/Qcr)
  - younger terrace deposits
- Chiang Mai Aquifers (Qth/Qcm)
  - older terrace deposits

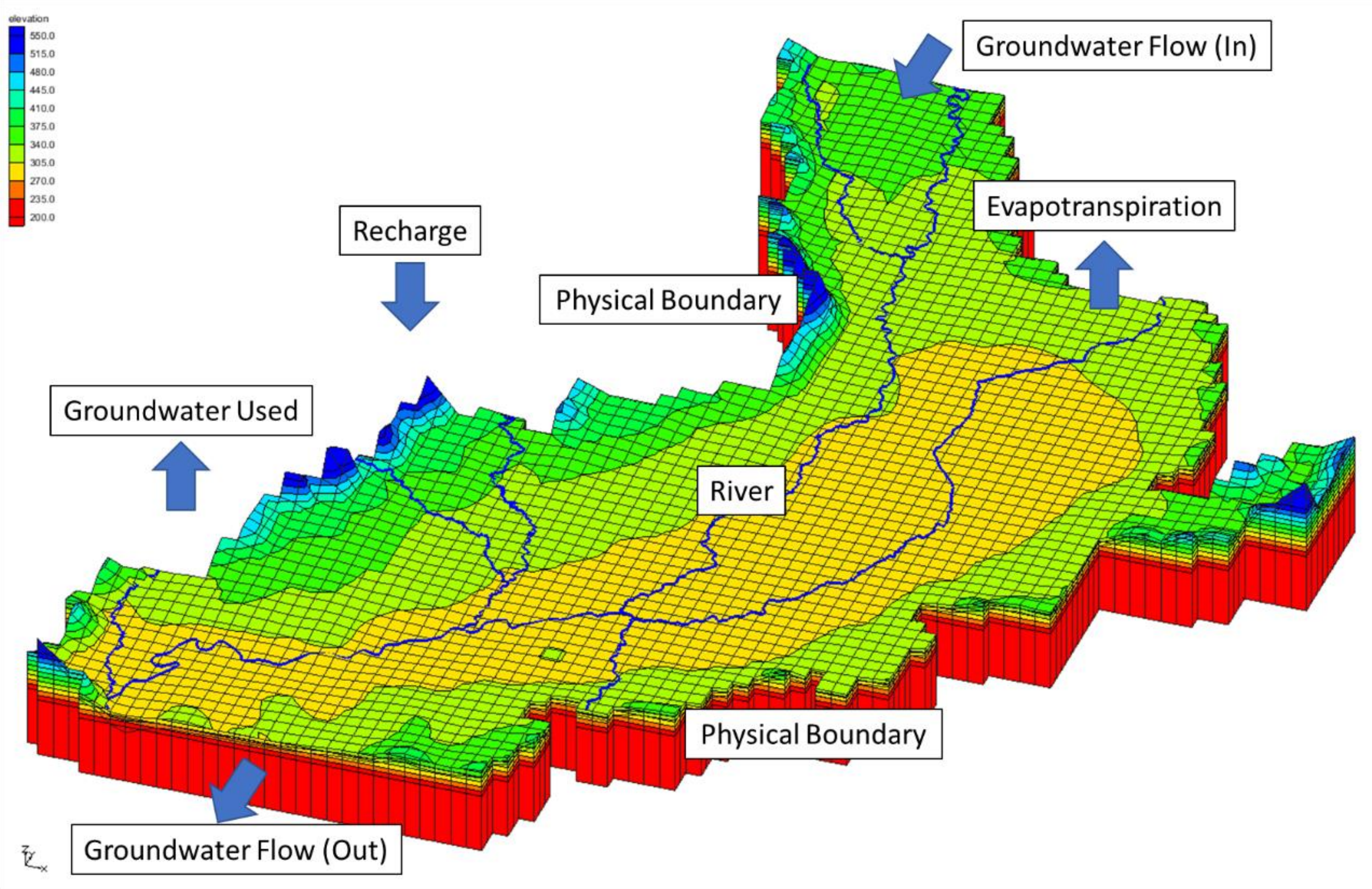


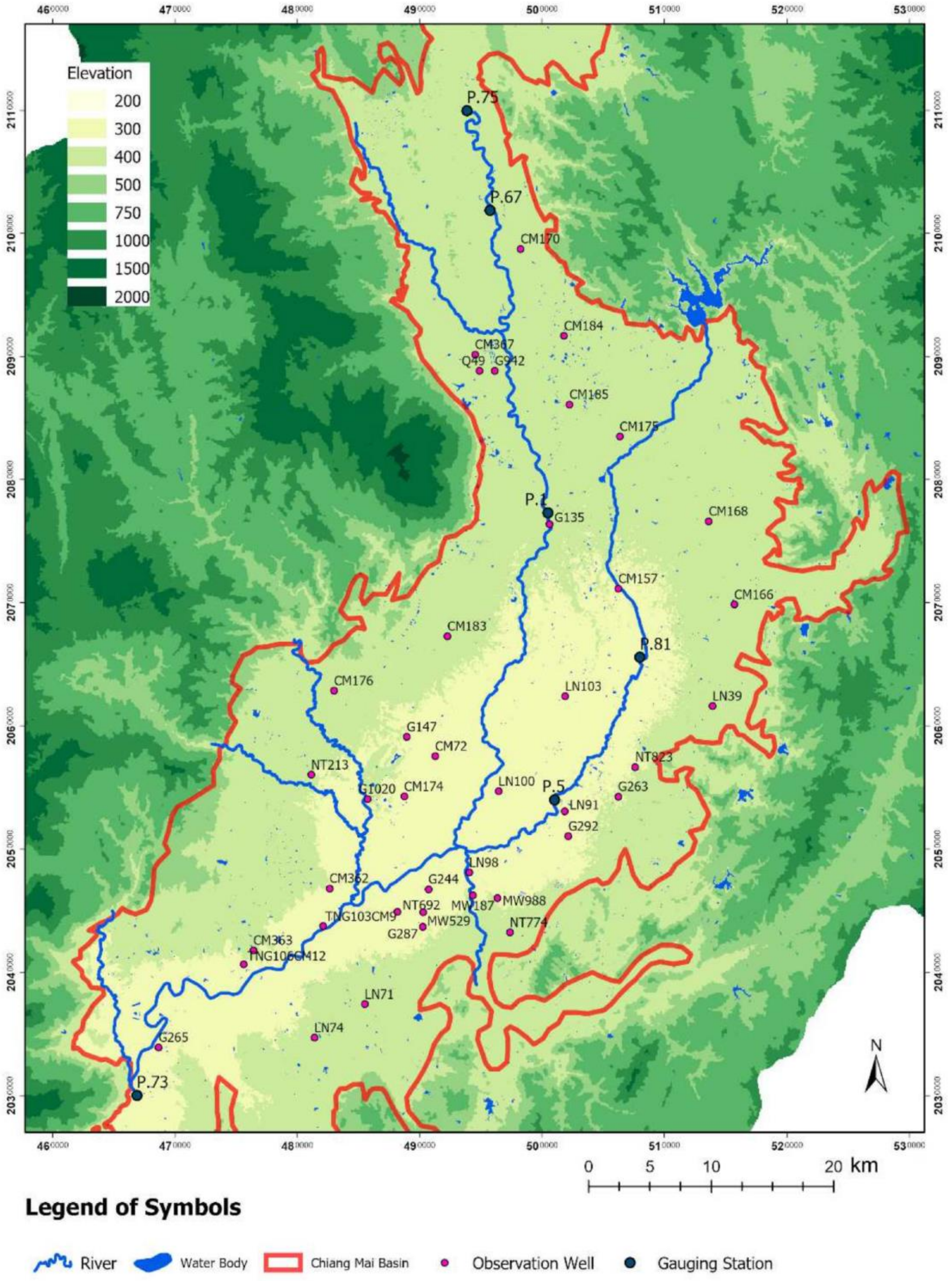


Hydrologic cross-section of the Chiang Mai basin (DGR, 2008)

Conceptual Model

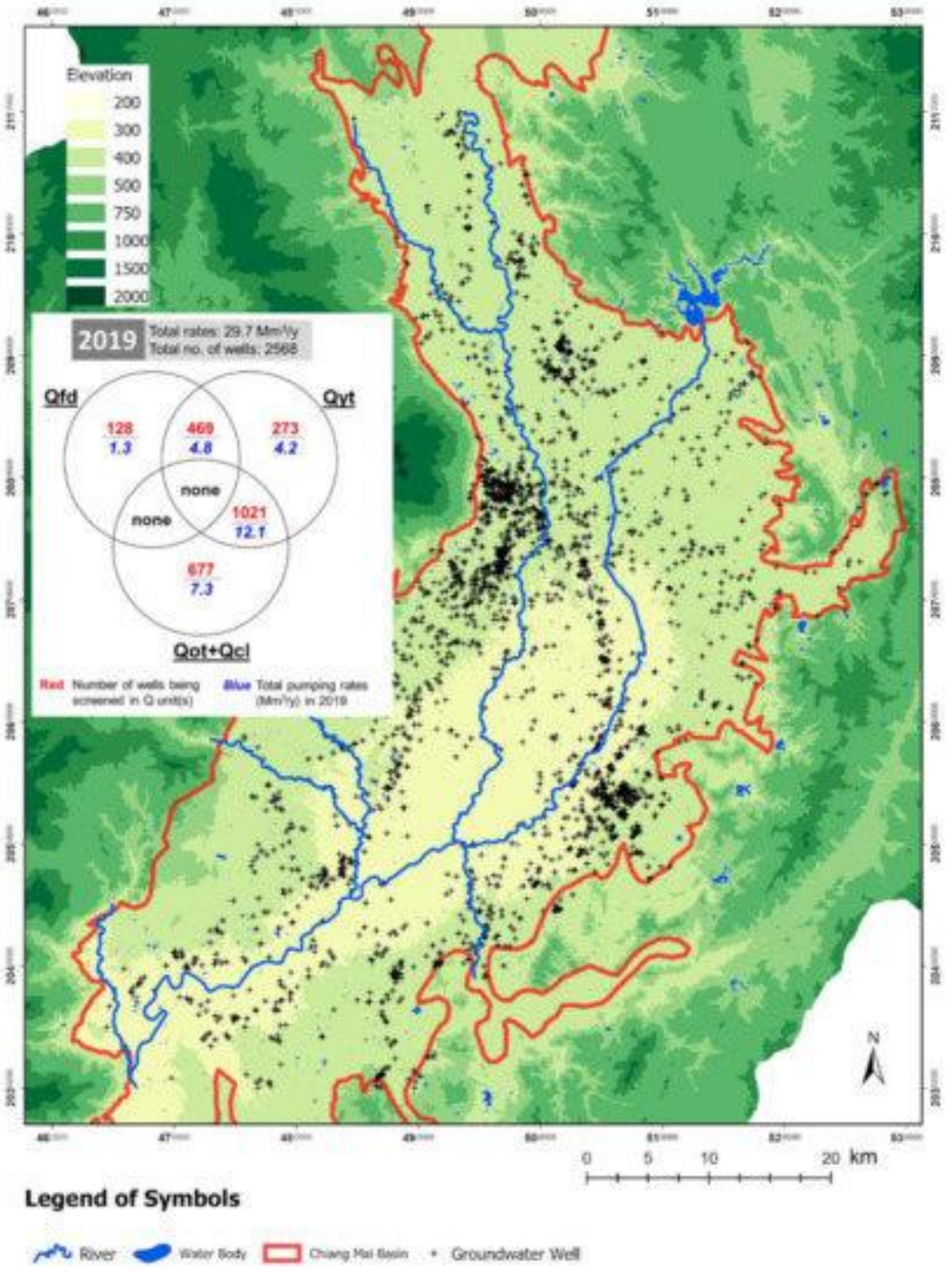
Hydrostratigraphic Units	K (m/d)
Floodplain	0.015-0.78
Low Terrace	0.035-0.3
High Terrace	0.043-1.73
Semi- to Consolidated Aquifer	0.12-13.5





Transient hydraulic head data used for the initial conditions and model calibration were obtained from field measurements (2006-2015) from 49 DGR's monitoring wells of various depths (DGR, 2013).

Baseflow data, also used as flow observations in model calibration, was estimated using baseflow separation analyses of hydrograph data obtained from RID's gauging stations of main rivers.



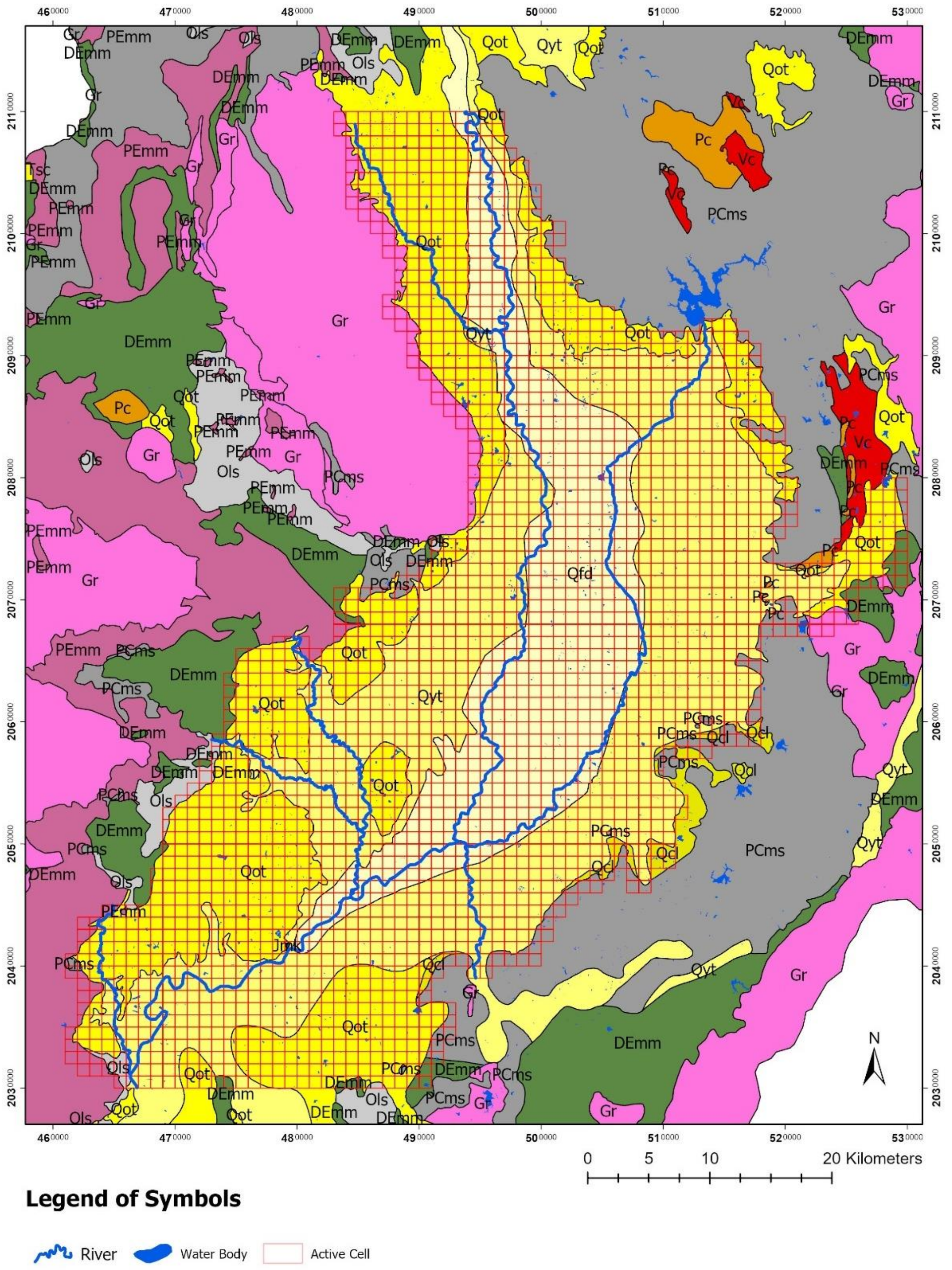
There are several active groundwater wells in the Chiang Mai basin which have been used for domestic, agricultural, and industrial purposes (approximately 2500 wells).

These wells as well as their extraction rates are obtained from DGR's database and will be input into the model.

Numerical Model

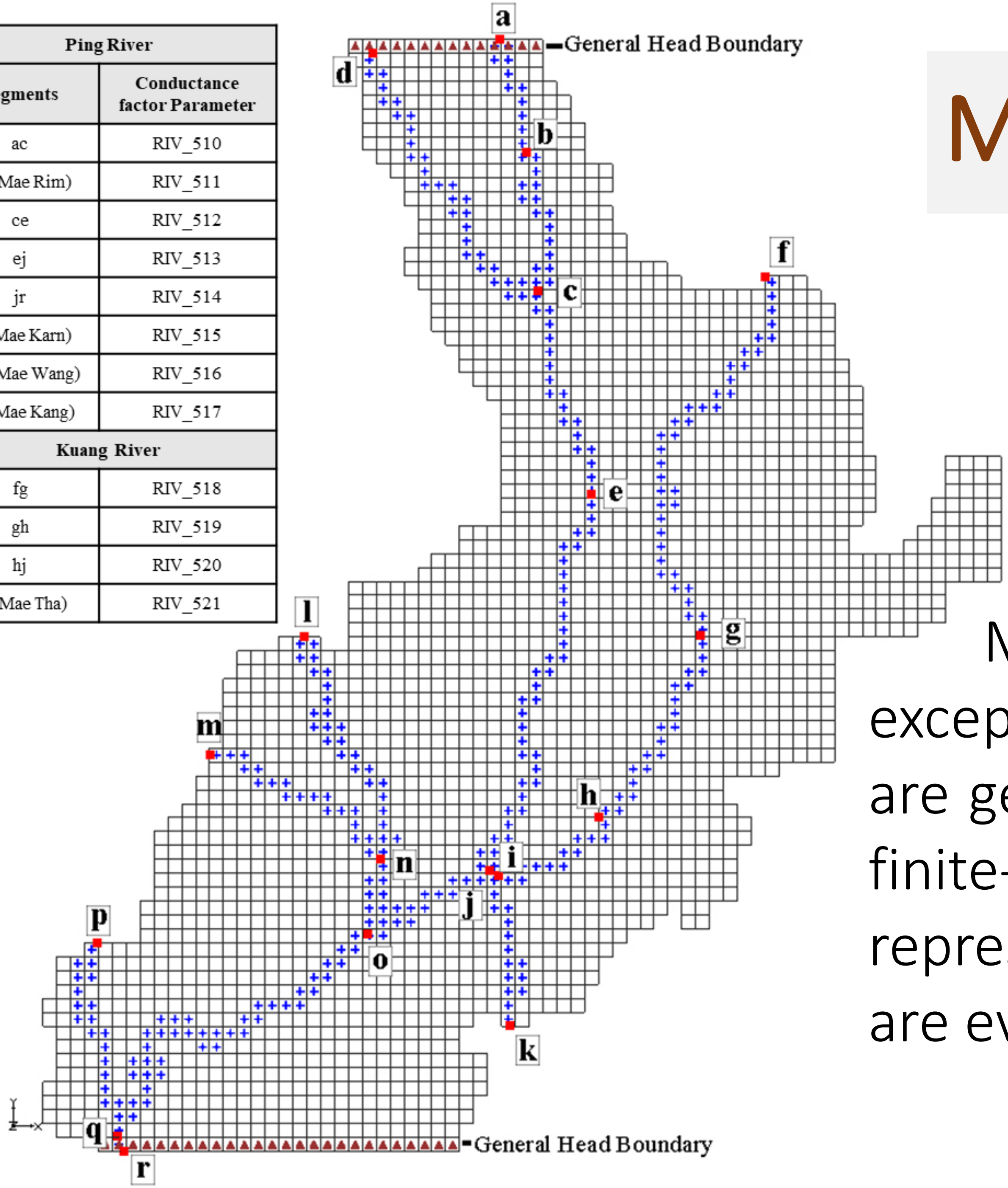
The 3-D numerical model of the Chiang Mai basin

- cover 2,490 km^2
- uniform grid size of $1,000 \times 1,000$ m^2
- 71 columns, 80 rows, and 4 layers



Model Boundary Condition

Ping River	
Segments	Conductance factor Parameter
ac	RIV_510
dc (Mae Rim)	RIV_511
ce	RIV_512
ej	RIV_513
jr	RIV_514
lo (Mae Karn)	RIV_515
mn (Mae Wang)	RIV_516
pq (Mae Kang)	RIV_517
Kuang River	
fg	RIV_518
gh	RIV_519
hj	RIV_520
ki (Mae Tha)	RIV_521

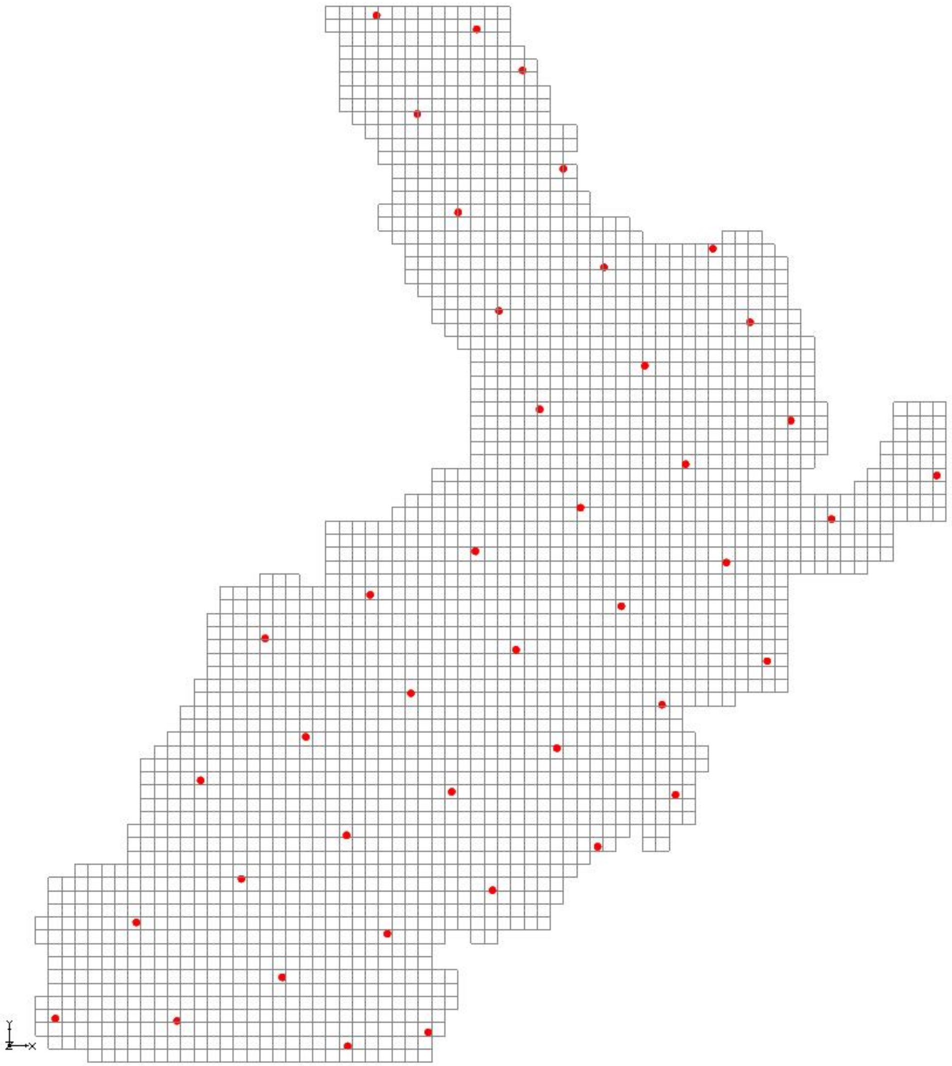


Most boundaries are physical boundary except for northern and southern boundaries are general-head cells. Rivers mapped to the finite-difference grid. All the top layer cells represent two more boundary types which are evapotranspiration and recharge.

Model Calibration

Parameter types		Symbol	Initial Values	Note
Hydraulic conductivity	Qfd	HK1	0.015-0.78 m/d	Pilot points[1]
	Qyt	HK2	0.035-0.3 m/d	Pilot points[1]
	Qot	HK3	0.043-1.73 m/d	Pilot points[1]
	Semi-Consolidated Aquifer	HK4	0.12-13.5 m/d	Pilot points[1]
Storage coefficient[2]	Qfd	SS1 SY1	0.0166-0.2996	Pilot points[1]
	Qyt	SS2 SY2	0.01532-0.02047	Pilot points[1]
	Qot	SS3 SY3	0.01703-0.0328	Pilot points[1]
	Semi-Consolidated Aquifer	SS4	0.000015-0.0002	Pilot points[1]
Vertical anisotropy	All units	VANI	0.1	-
Recharge rate	-	RCH	90 mm/yr	Pilot points[1]
Max ET rate	-	EVT	50 mm/yr	Pilot points[1]
North and South GHB	-	GHB	0.25 m^2/m/d	-
River-bed conductance factor	Ping	RIV_510 to RIV_517	0.25 m^2/m/d	-
	Mae Kuang	RIV_518 to RIV_521	0.25 m^2/m/d	-

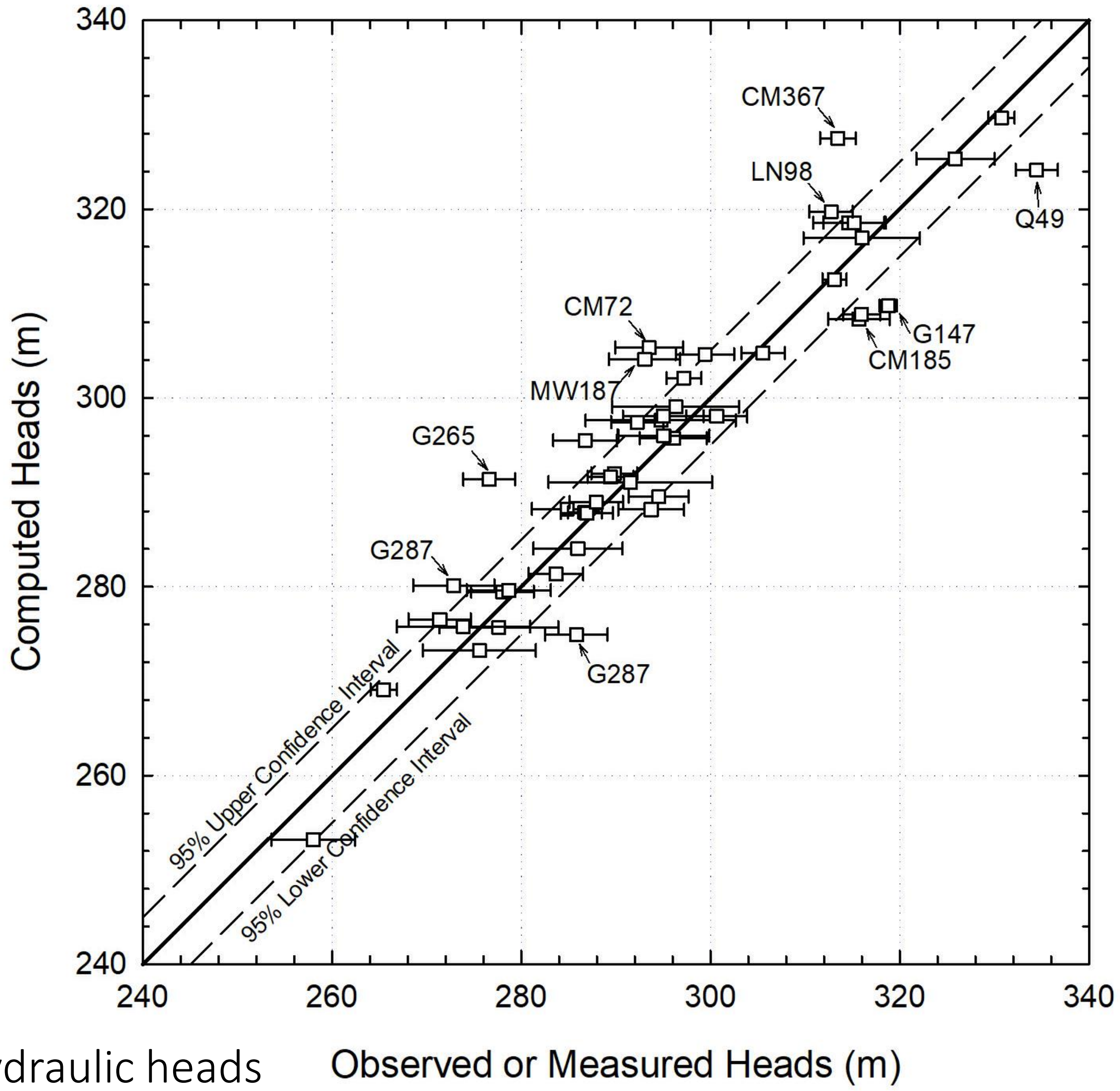
[1]Pilot points allow parameter values to vary spatially (i.e. heterogeneous or non-uniform)



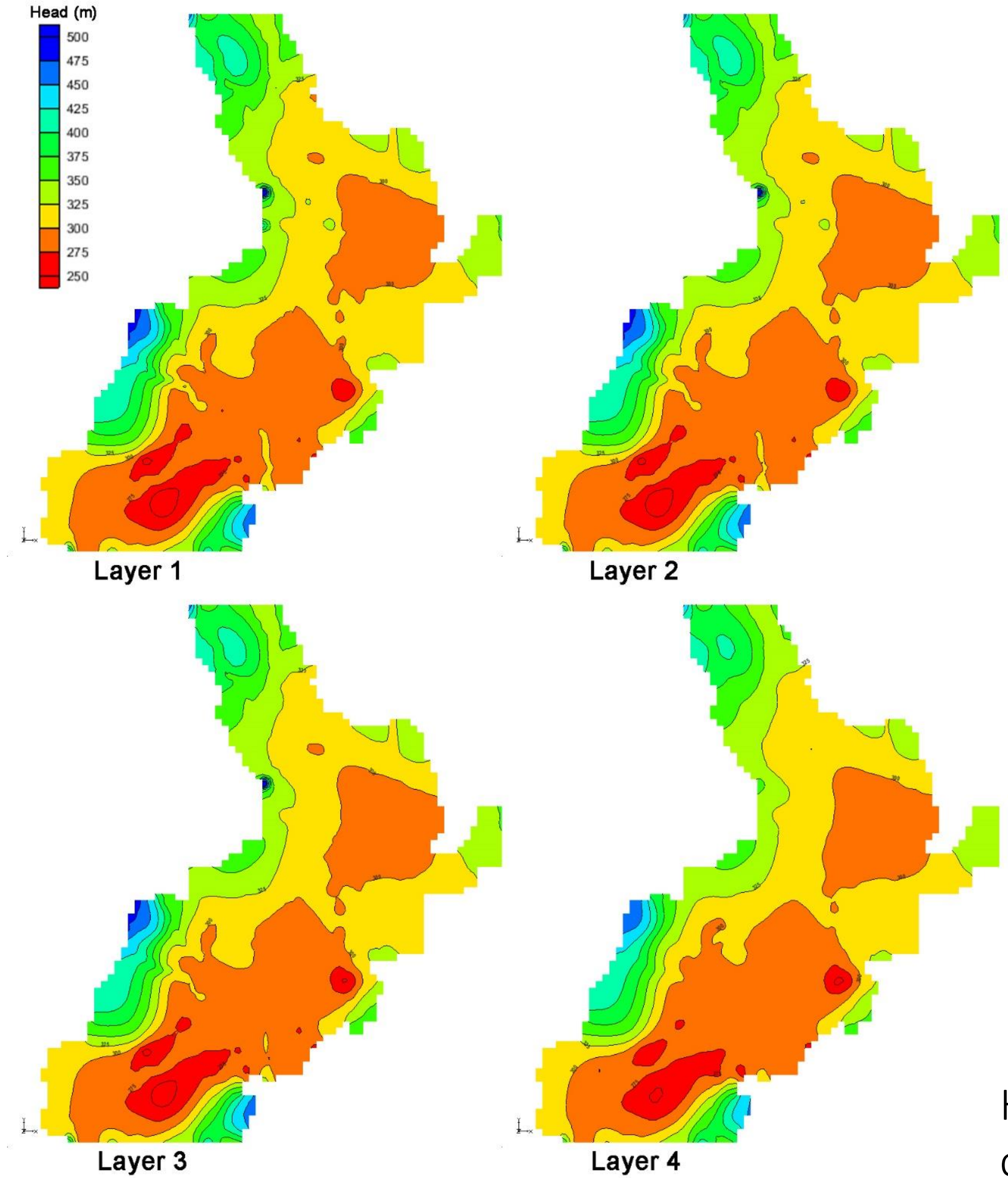
Results

Steady-state simulations

Groundwater flow model of the unconsolidated aquifer system was setup and simulated using MODFLOW program and the model was then calibrated with the aid of PEST program.



Measured (observed) vs. model simulated (computed) hydraulic heads after steady-state model calibration



Water budget for steady-state simulation

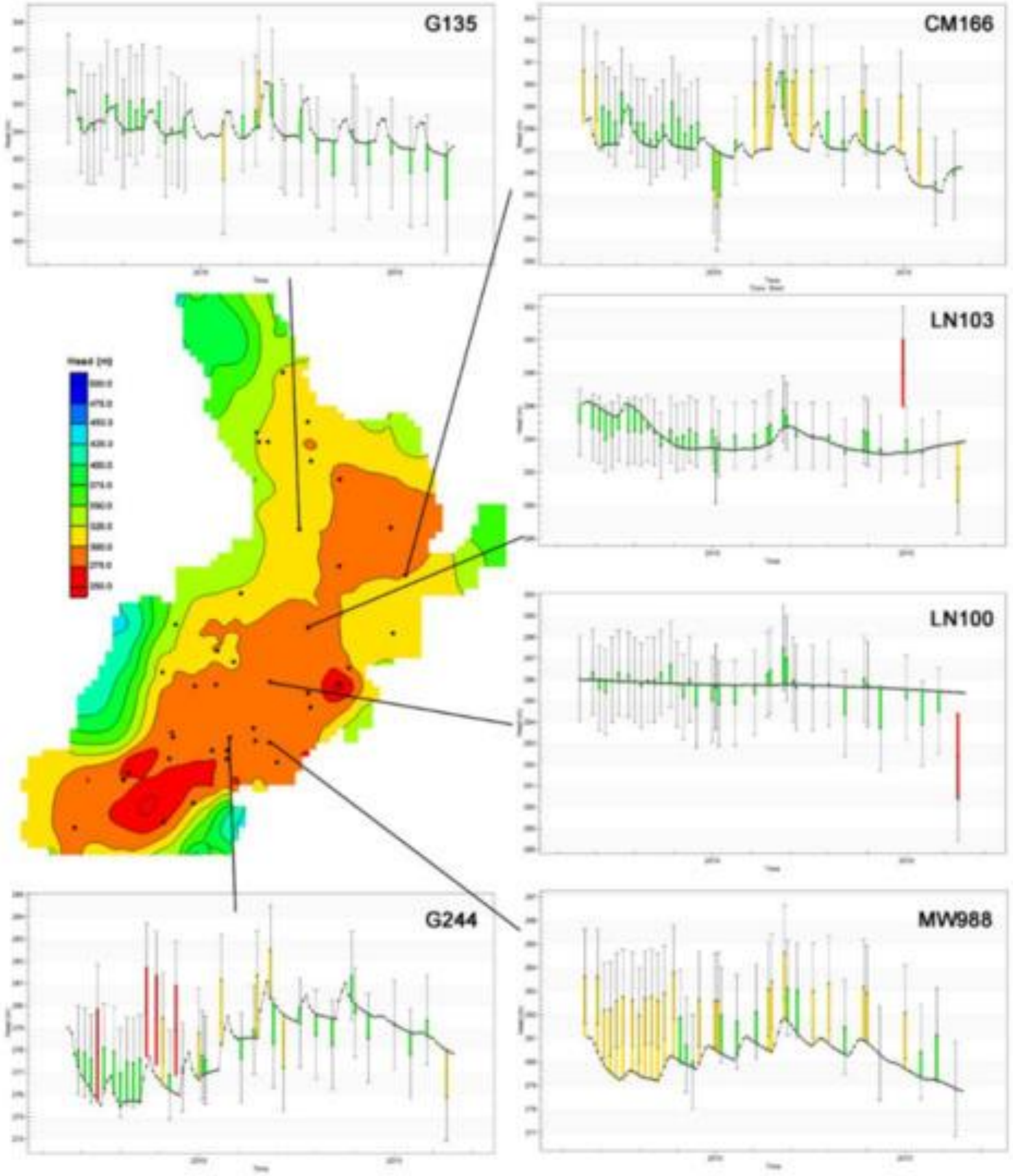
	Inflow (Mm^3/yr)	Outflow (Mm^3/yr)
Aquifer storage	-	-
Recharge	140.69	-
Evapotranspiration	-	109.28
Pumping wells	-	63.61
General Head Boundary	55.27	0.15
Rivers	12.68	35.61
Total (Mm^3/yr)	**208.65**	**208.65**

Hydraulic head contours after steady-state model calibration for Layer 1 (top) to Layer 4 (bottom)

Results

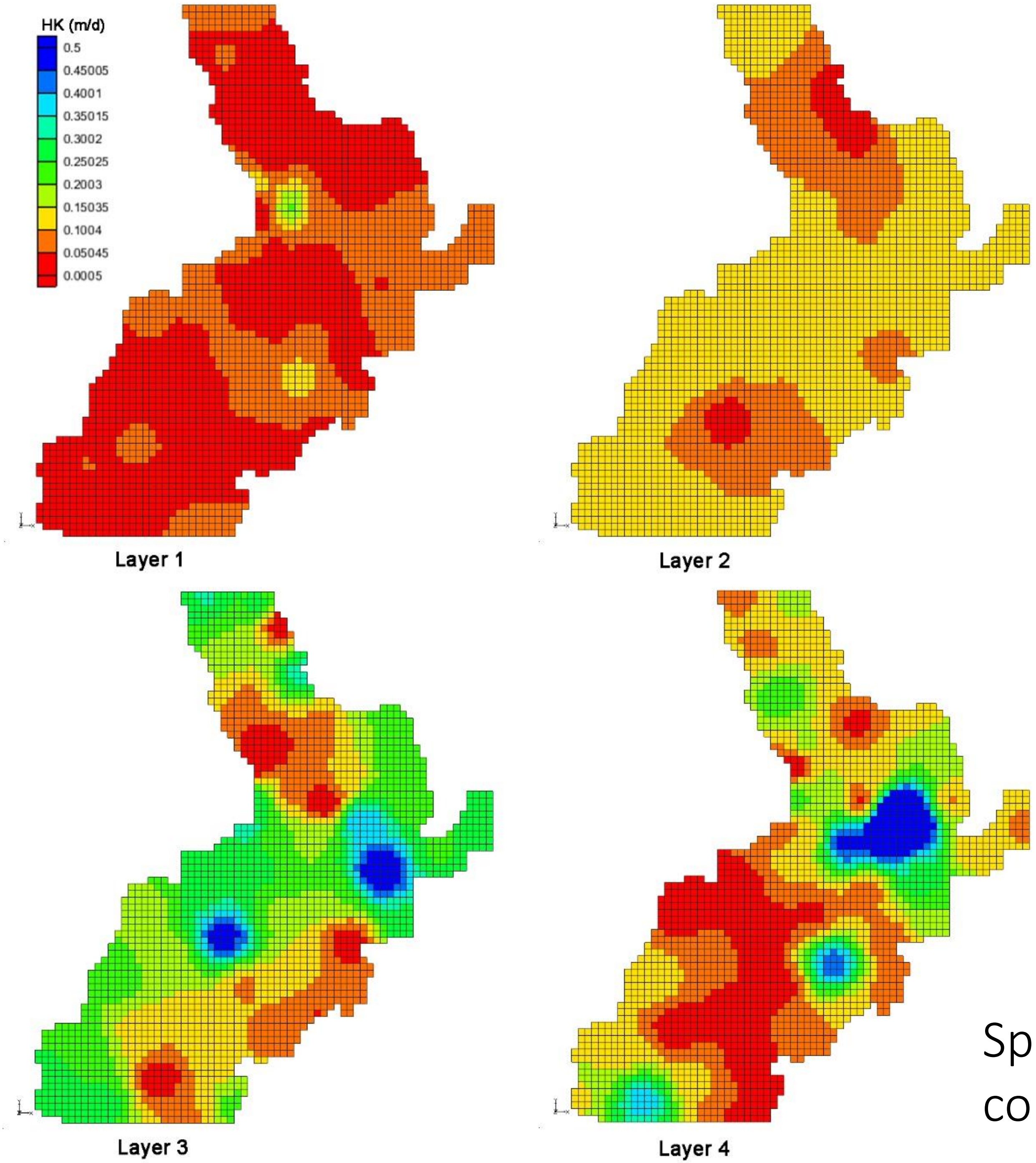
Transient simulations

The aim of the transient was to reproduce observed water level in time series. The calibrated model form steady-state condition was used as a starting point of transient simulation

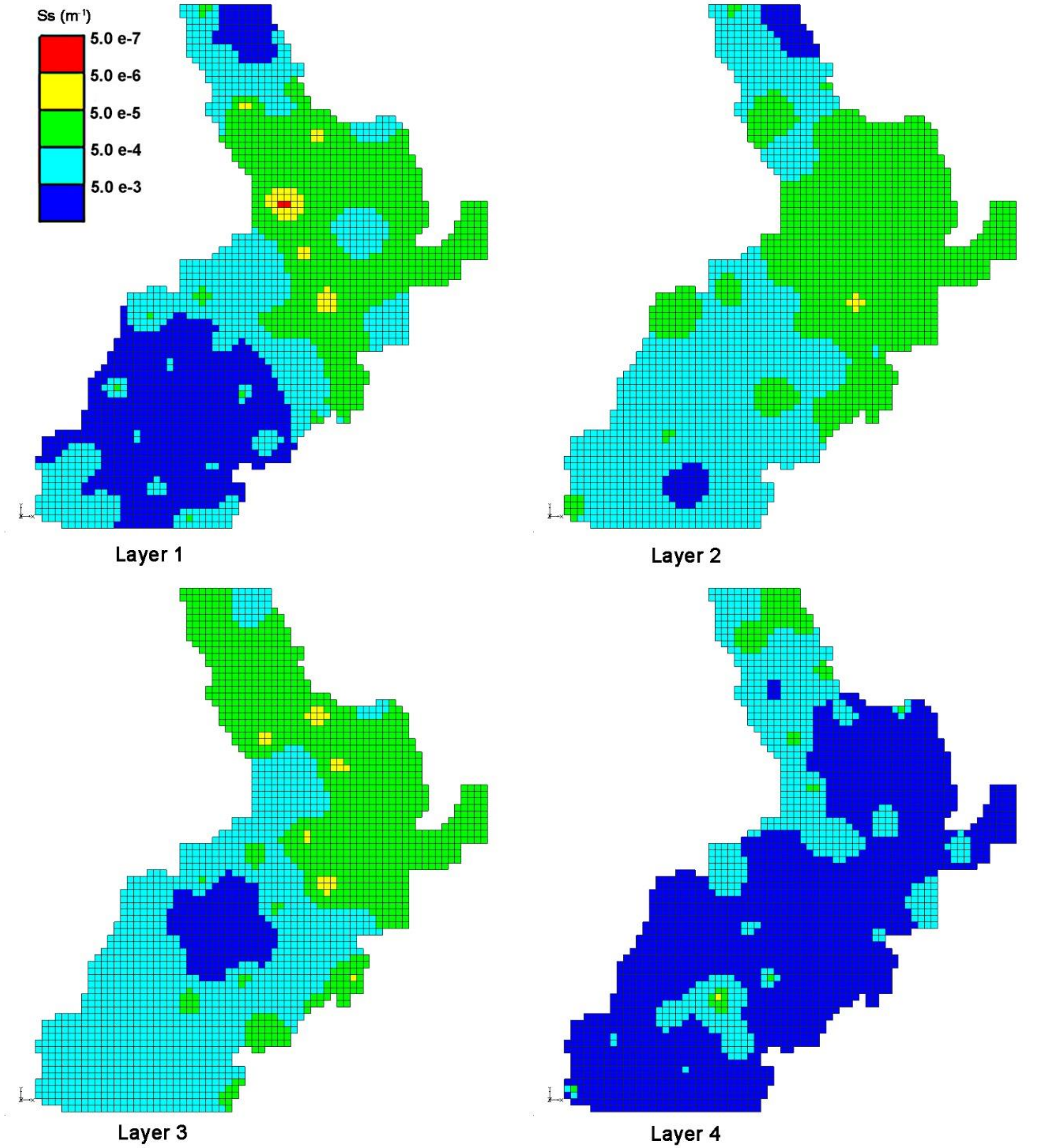


Examples of transient hydraulic heads between modeled and observed heads.

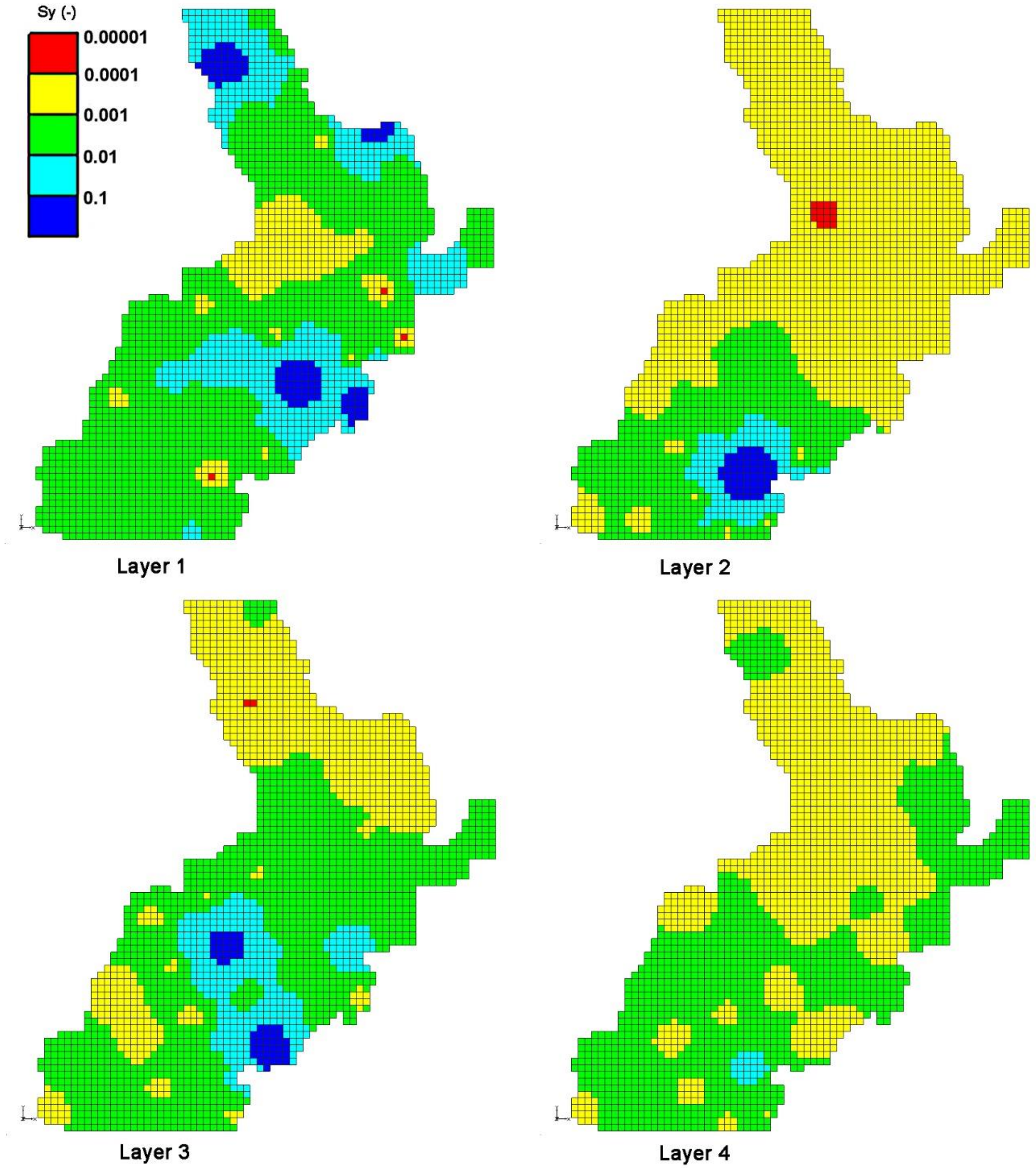
The Chiang Mai aquifer systems are highly heterogeneous.



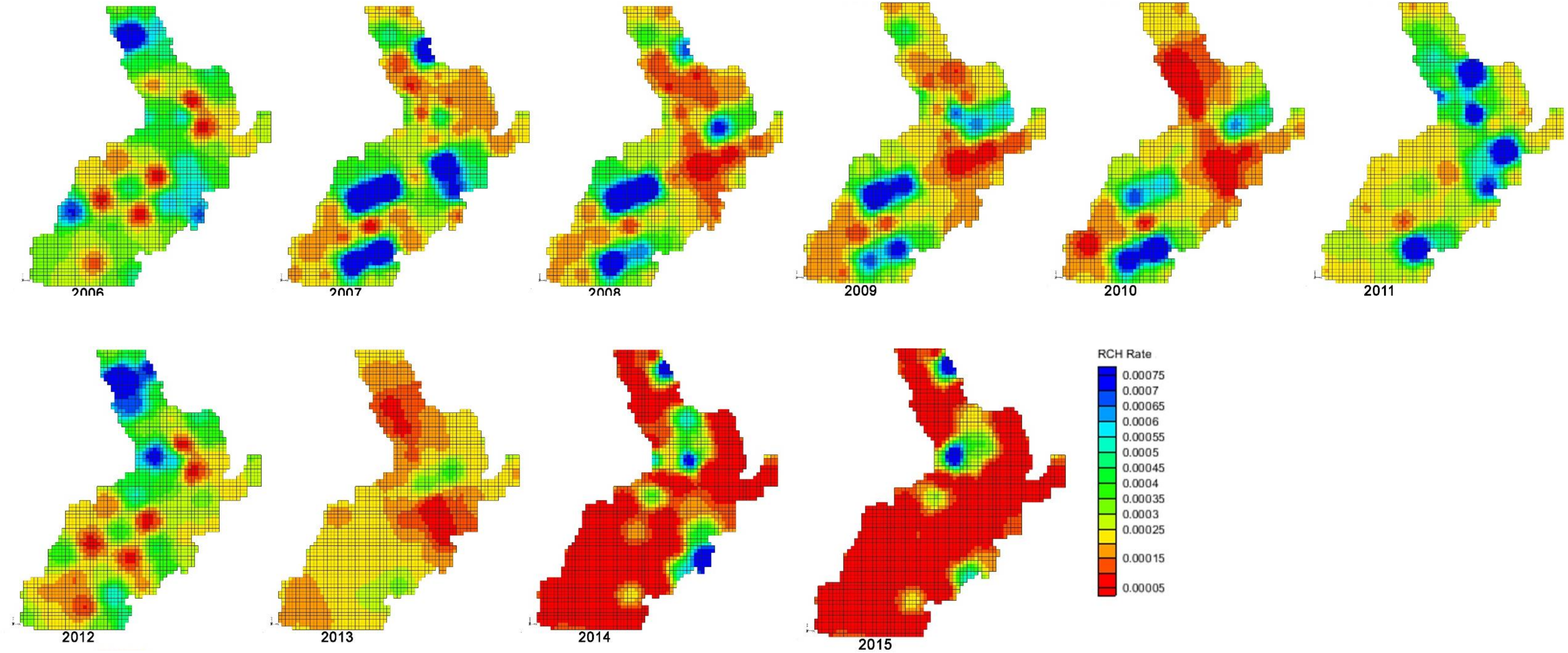
Spatial distribution of hydraulic conductivities after model calibration



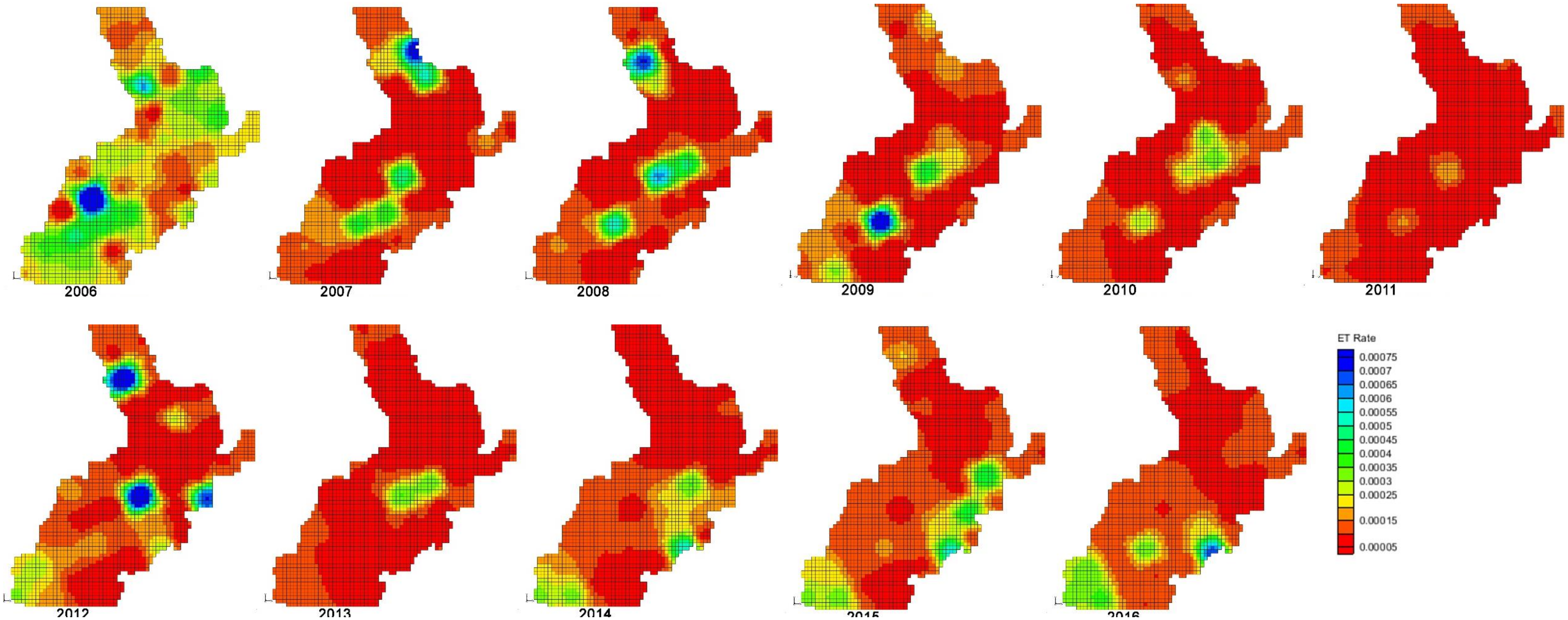
Spatial distribution of specific storage after model calibration



Spatial distribution of specific yield after model calibration



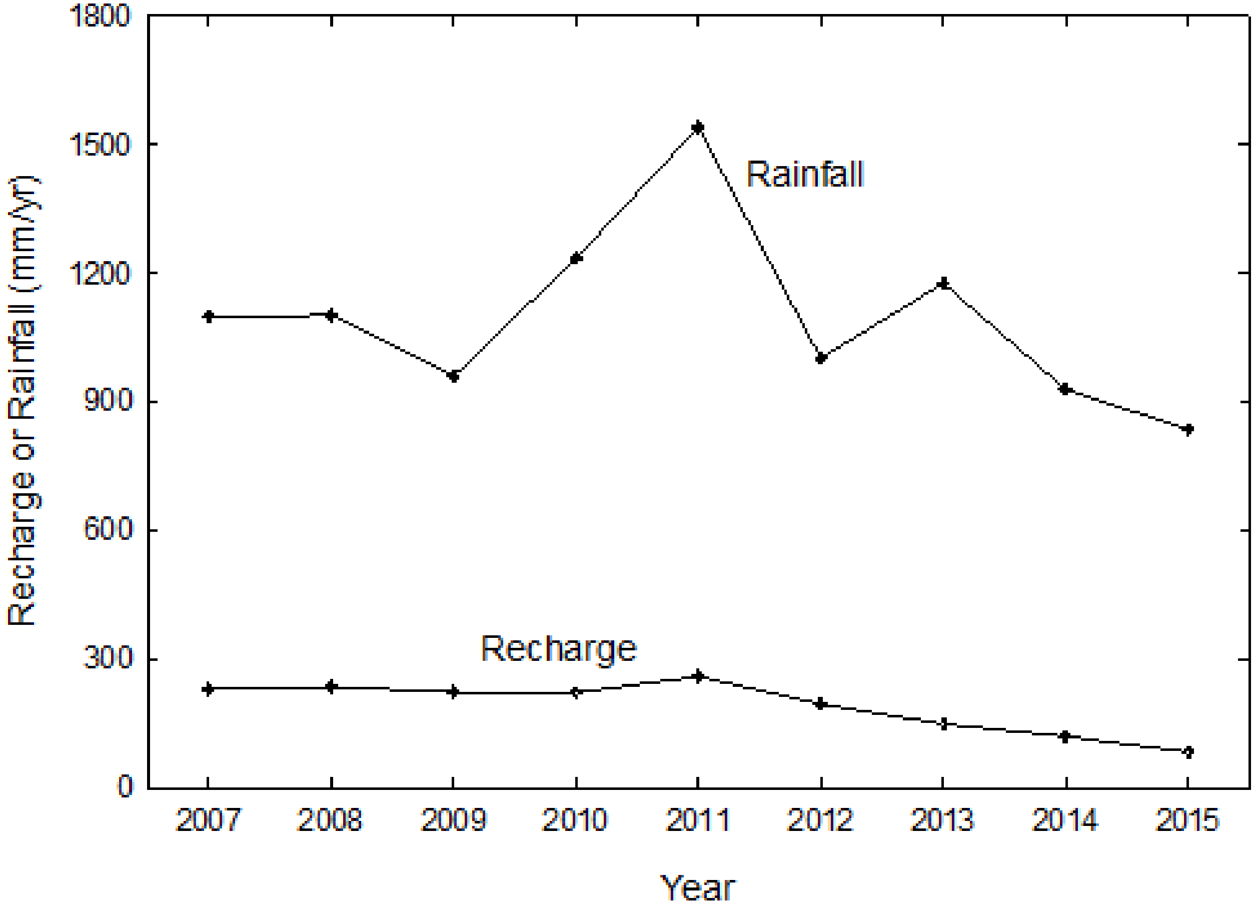
Spatial distribution of recharge (10-year duration) after model calibration



Spatial distribution of evapotranspiration (10-year duration) after model calibration

Implications of Climate Changes on Recharge Variability

Based on the water budget analysis from transient model, it was confirmed as it was speculated earlier that the values of natural recharges vary temporally and has strong dependency on precipitation pattern.



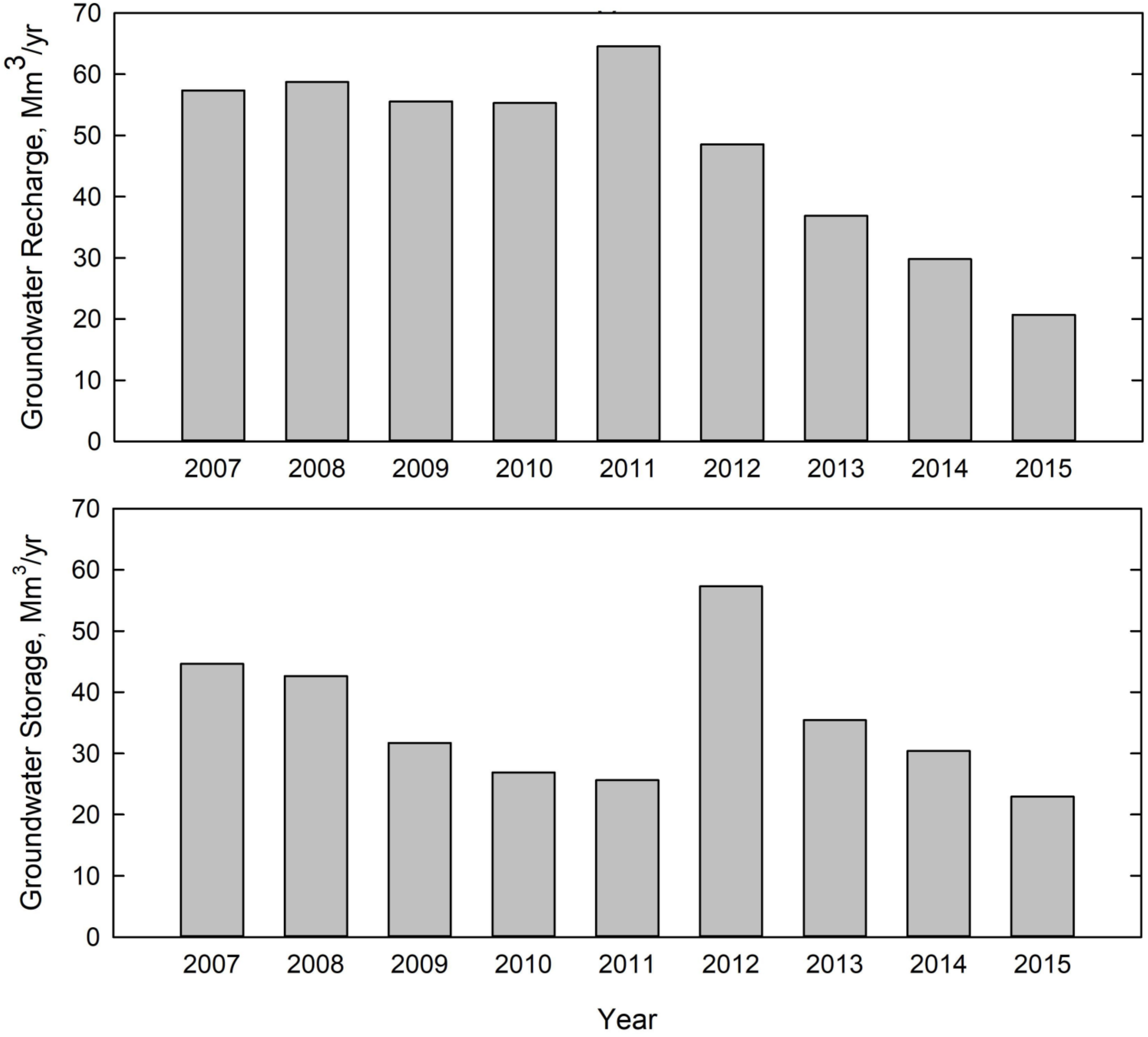
Variability of recharge over a period of 2007–2015 (from calibration)

Groundwater Potential of the Unconsolidated Aquifers

The hydraulic conductivities of the unconsolidated aquifers are in range of 10^{-3} to 10^{-1} m/d indicating poor to fair aquifer condition.

The specific yield varied from 10^{-2}-10^{-1} whereas specific storage shows a wider range 10^{-8}-10^{-4} m^{-1}. Values indicate that storativity of Qfd, Qyt and Qot aquifers of the Chiang Mai basin is generally lower than the normal range, so the groundwater potential is not in good condition.

From model, groundwater recharge and storage of the unconsolidated aquifers is declining. This is partly due to the lowering of annual precipitation. Groundwater potential is not in good condition.



Groundwater recharge and groundwater storage of the unconsolidated aquifers from 2007–2019

Groundwater Safe Yield

In this work, the safe yield is defined as the amount of extractable groundwater through pumping wells that may cause the drawdown, on average, to drop not more than the specified values.

Scenario	Targeted Average Drawdown (m)	Safe Yield or Pumping Rate of Qfd, Qyt, and Qot + Qcl Aquifers (Mm^3/y)	% Increase from Current Usage
Base Case	-	24.0 (2015)	-
Case 1	1.0	41.6	73
Case 2	2.0	51.2	114
Case 3	3.0	54.1	125
Case 4	4.0	54.9	129
Case 5	5.0	55.4	131

Conclusions

- Hydraulic heads in the north, east and west regions of the Chiang Mai basin were high and continuously decreased toward the center of the basin and groundwater discharged to Ping and Kuang rivers and flow southward
- In some areas, groundwater level dropped significantly below ground surface, especially in the central zone where groundwater abstraction was high due to agricultural, domestic, and industrial needs

Conclusions

- Natural recharges vary temporally and has strong dependency on precipitation pattern
- Some areas of the basin in under critical condition such as Mueang Lamphun, Pasang, Wiang Nong Long, and Doi Lo districts
- Safe yield calculation suggests that the basin can sustain abstraction rates up to 214% (51.2 Mm^3/yr for unconsolidated aquifers)

Conclusions

- Careful groundwater usage must be taken into consideration because groundwater storage is declining according to increasing groundwater usage and decreasing recharge. This observation is confirmed by a continuous decline in the hydraulic head which is indicated in long-term groundwater monitoring over the past fifteen years.

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