Evaluation of watershed responses to multiple natural disturbance and anthropogenic activities in the Chenyulan Watershed, Taiwan

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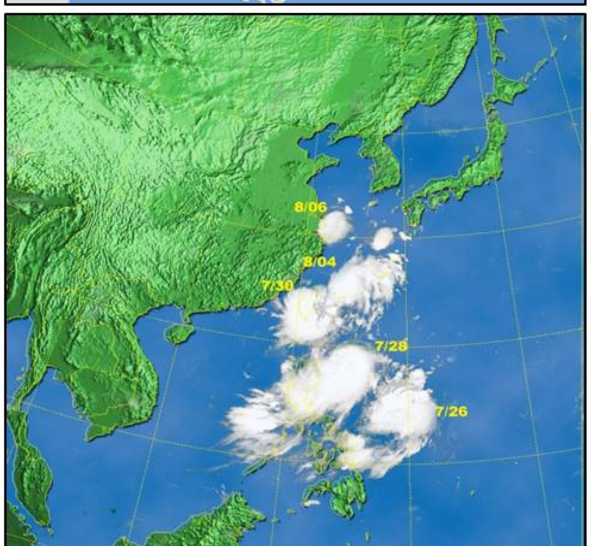
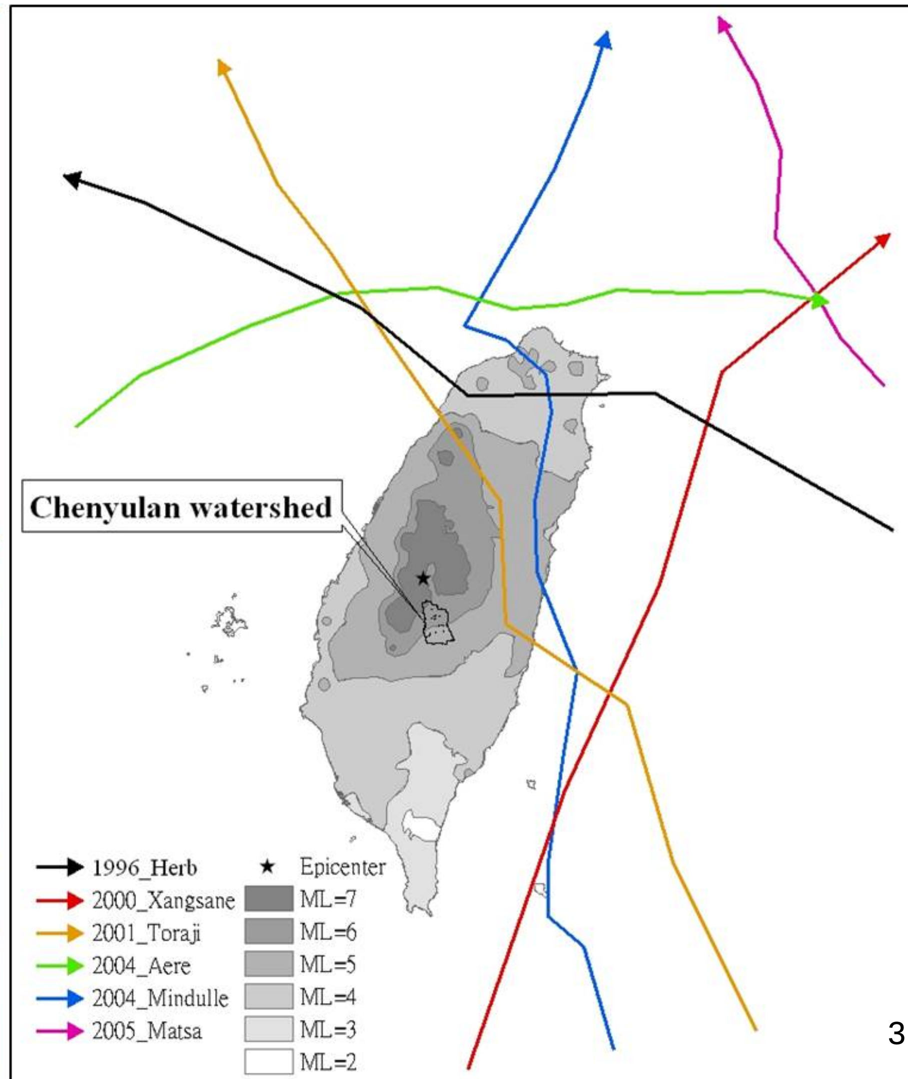
Introduction

- Land use and climate change are both important drivers for ecosystem degradation
- Human-driven land use changes, such as deforestation and urbanization, reduce ecosystem resilience to disasters
- The impacts of climate change include global warming and the increasing frequency of extreme weather events such as storms, flood, and drought
  - **How large physical disturbances influence hydrological regime and components?**

Study area: Chenyulan watershed

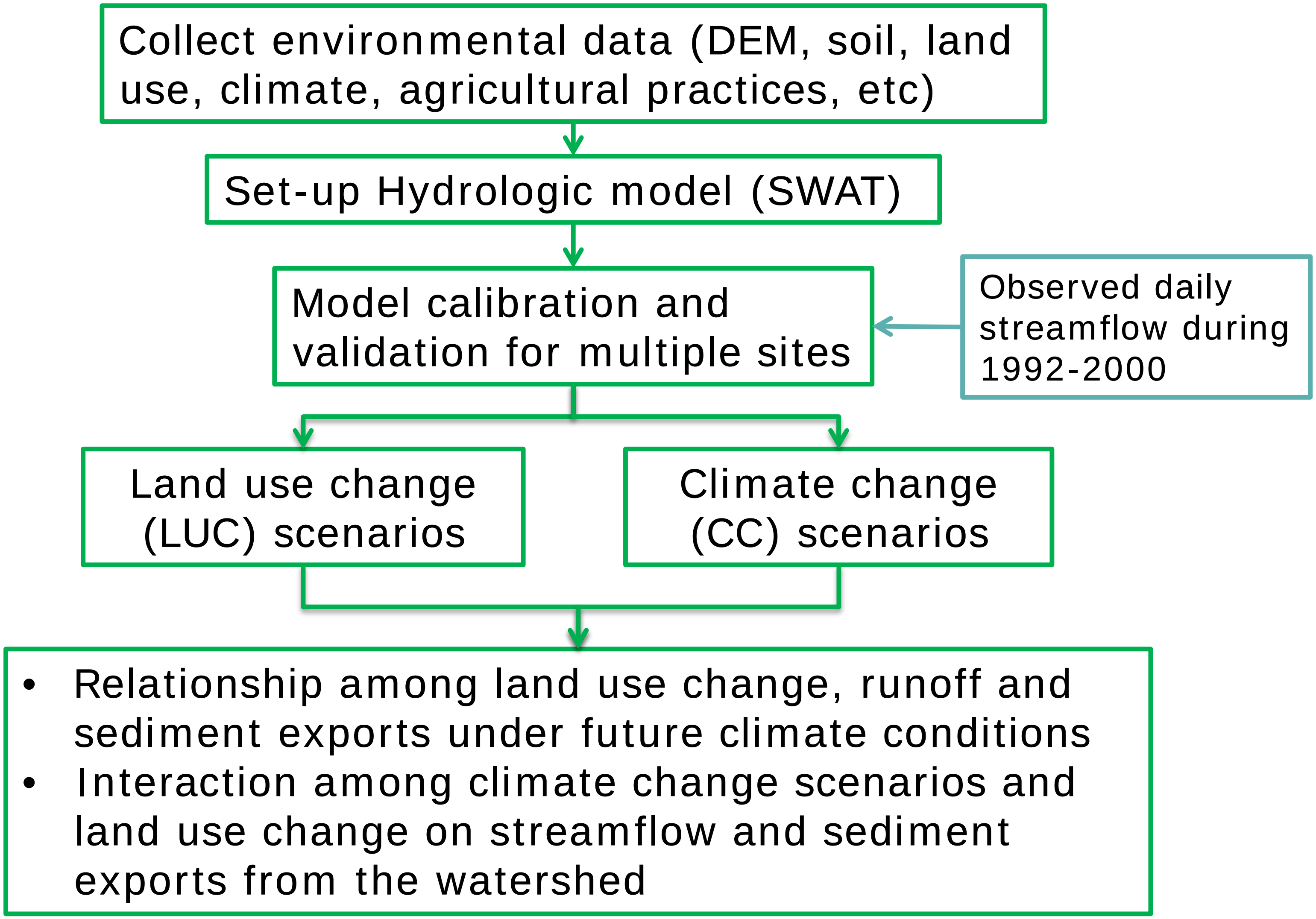




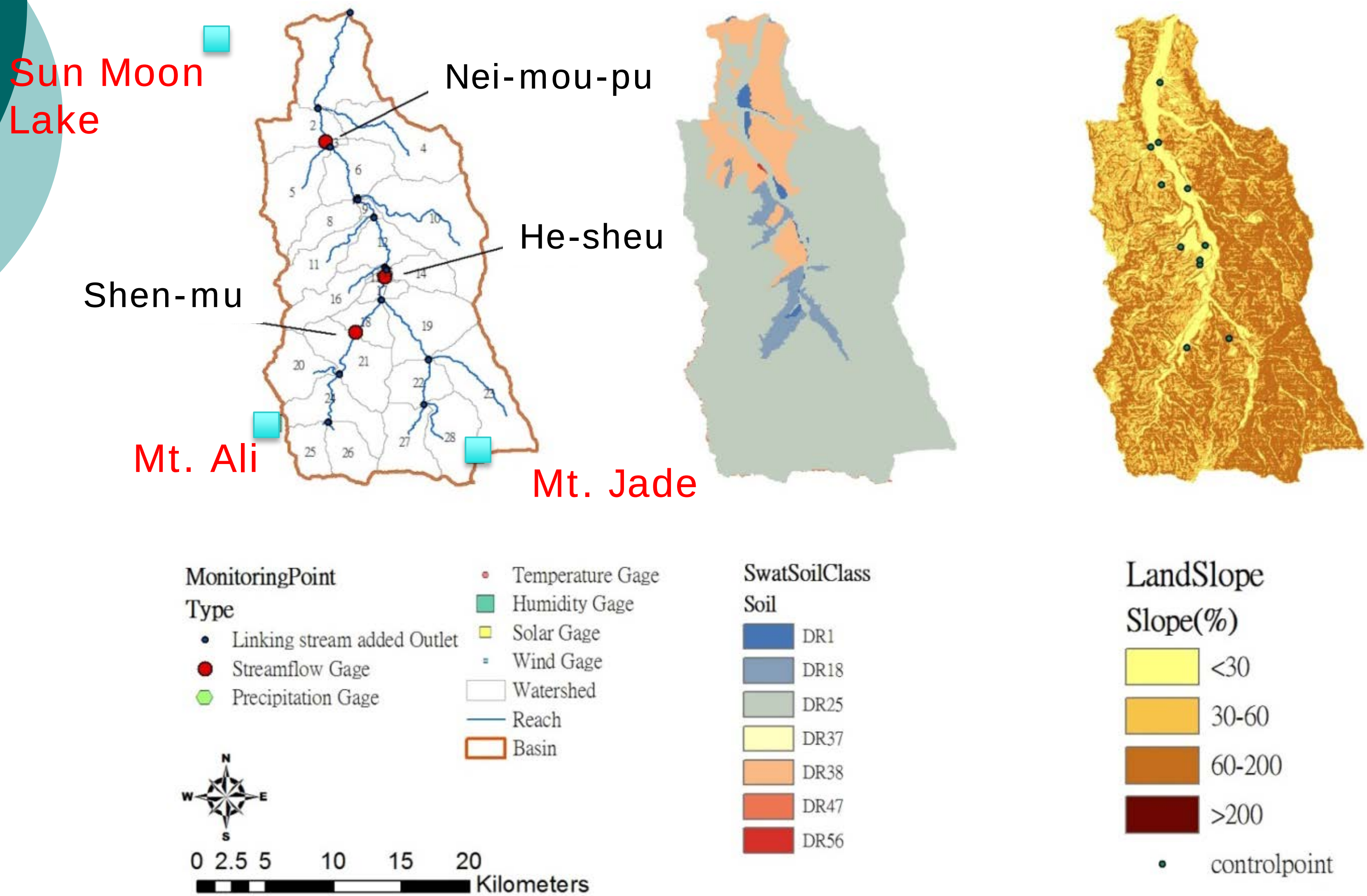
Objectives

- Evaluate the sensitivities of SWAT parameters when land use update function is activated or not.
- Quantify the individual impacts of land use change induced by disasters and anthropogenic activities on ecosystem services (water yield and sediment concentration)
- Evaluate the combined impacts of land use and climate change on the Chenyulan watershed, Taiwan, which has been suffering typhoons during summer and especially one big earthquake in 1999.
- Develop an integrated plan including ecosystem service management, land use management, and climate change adaptation to increase the resilience of the ecosystem in the Chenyulan watershed.

Research flow

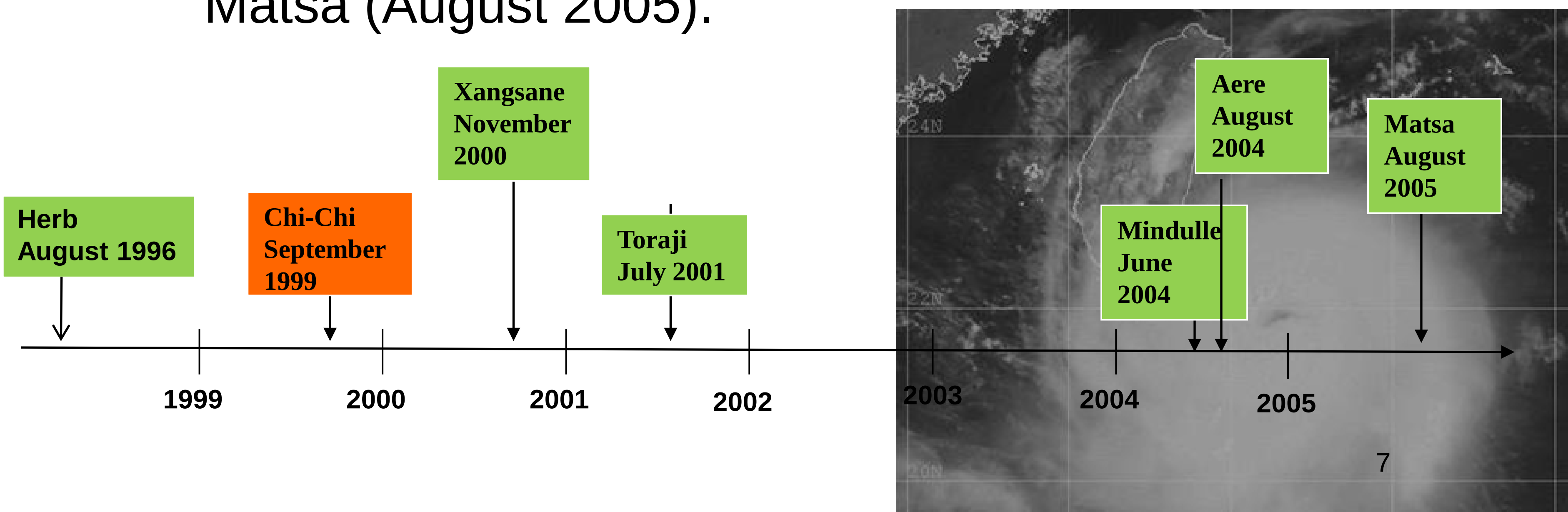


Distribution of subbasins, discharge and weather stations, soil and slope

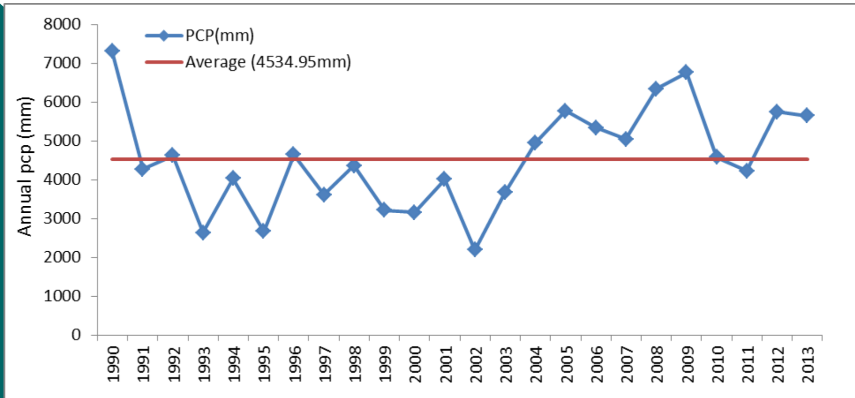


Changes of Ecosystem Services induced by large disturbances

- During 1996–2005, large disturbances in the following sequence impacted central Taiwan: (1) typhoon Herb (August 1996); (2) the Chi-Chi earthquake (September 1999); (3) typhoon Xangsane (November 2000); (4) typhoon Toraji (July 2001); (4) typhoon Mindulle (June, 2004); (5) typhoon Aere (August 2004) and (6) typhoon Matsa (August 2005).



Stn530 (Mt. Ali)



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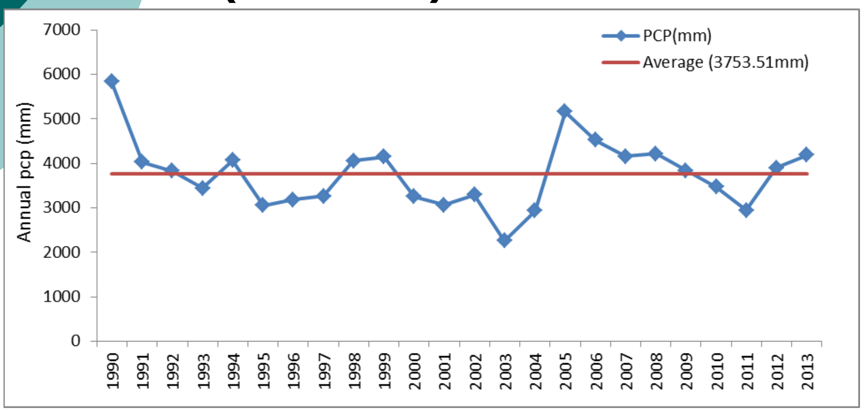
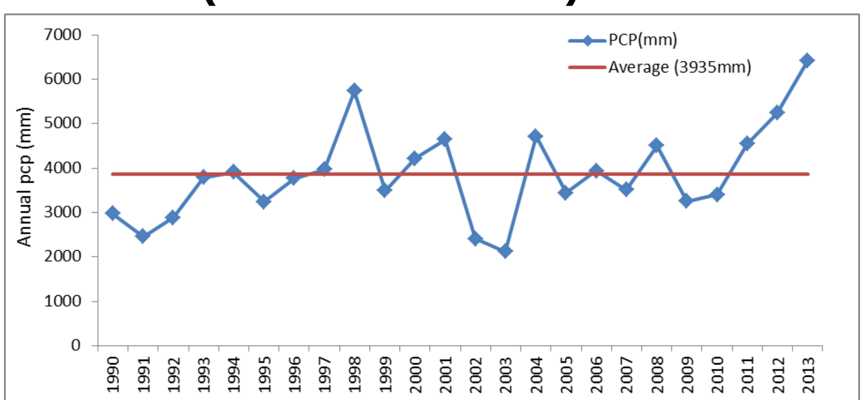


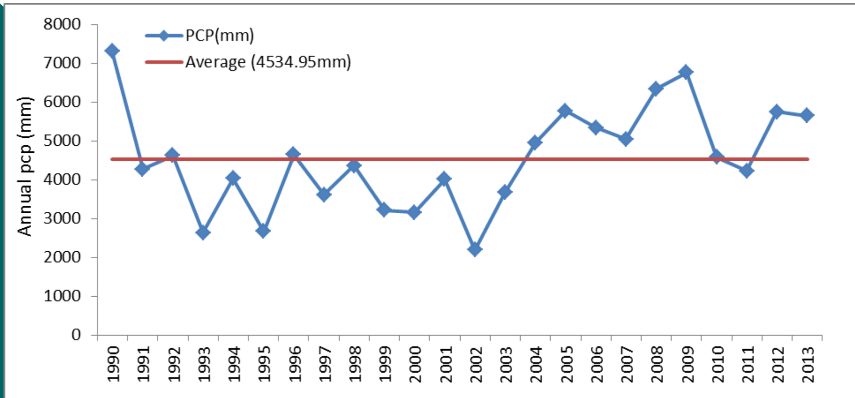
Stn650 (Sun moon Lake)



Historical (1990-2015) annual precipitation

Rain gage	Mt. Ali		
Rank	Year/Typhoon Name		Total rainfall (mm)
1	2009	MORAKOT	3059.5
2	1996	HERB	1987
3	2008	SINLAKU	1457.7
4	1963	GLORIA	1433.5
5	2005	HAITANG	1215.5
6	1990	YANCY	1194
7	2004	MINDULLE	1181.5
8	1966	TESS	1104.6
9	2007	KROSA	1093
10	1960	SHIRLEY	1091.2

Stn530 (Mt. Ali)



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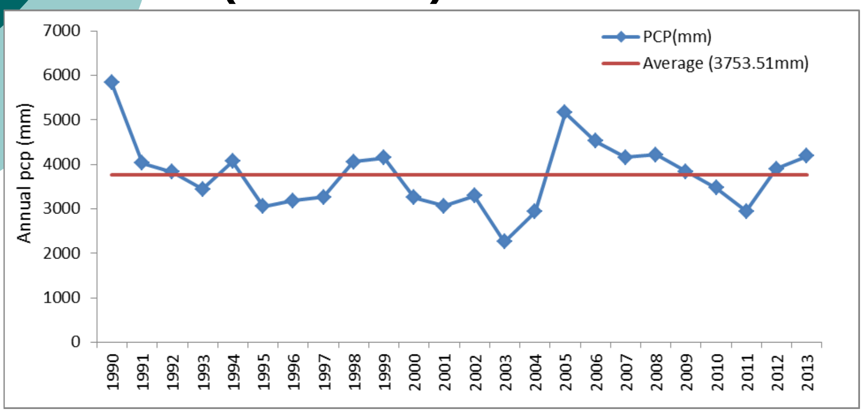

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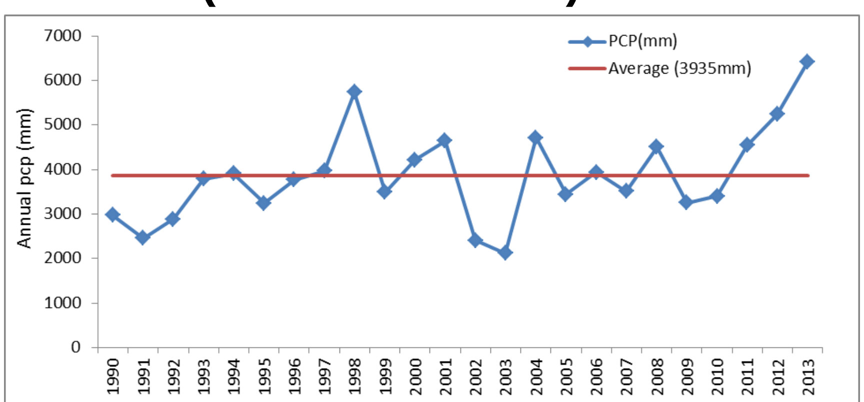
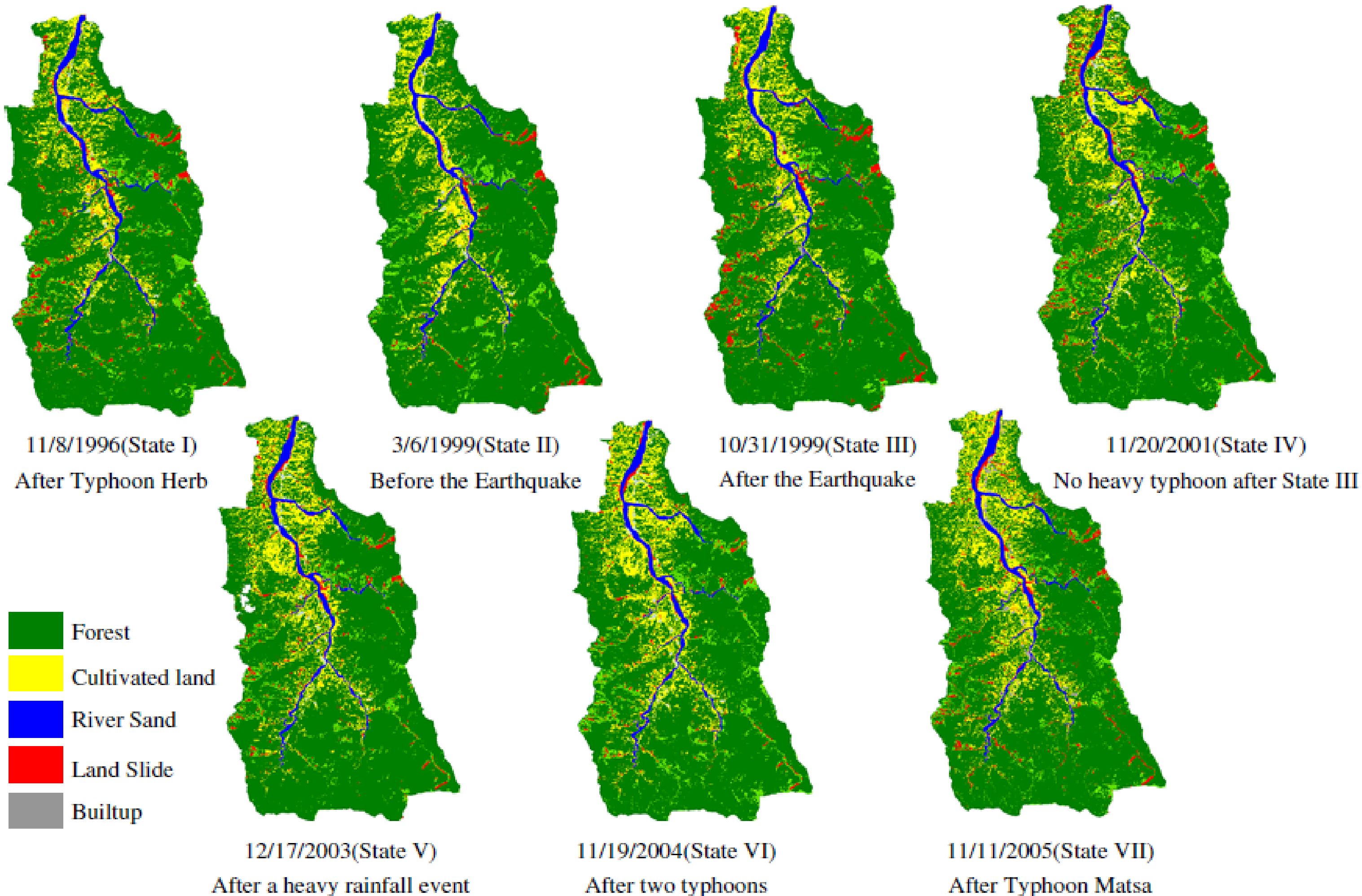


Historical (1990-2015) annual precipitation

Rain gage	Mt. Jade		
Rank	Year/Typhoon Name		Total rainfall (mm)
1	2009	MORAKOT	2160.8
2	2005	HAITANG	1144.5
3	2008	SINLAKU	881.5
4	1990	YANCY	718.5
5	1996	HERB	710.5
6	2004	MINDULLE	702.6
7	1963	GLORIA	696.5
8	2004	AERE	651.5
9	2005	MATSA	635.5
10	1989	SARAH	595.4

Landscape change during 1996-2005



Hydrologic model: SWAT

- Version SWAT2012_rev635
- 28 subbasins and 2448 HRUs
- Calibration procedure: OAT sensitivity analysis → Multi-site calibration by SWAT-CUP
- Evaluate the climate change and land use change impact on streamflow and sediment export.

Scenario matrix

- Climate change (CC) impact: sim2 – sim4
- Land use change (LUC) impact: sim4 - sim3
- LUC + CC impact: sim2 – sim3

Climate change (CC) scenario

	Land use change (LUC) scenario	
	LU2001 CONSTANT	LU2001-2200
2 GCMs * 4 RCPs	1	2
Future Baseline	3	4

LUC+CC –

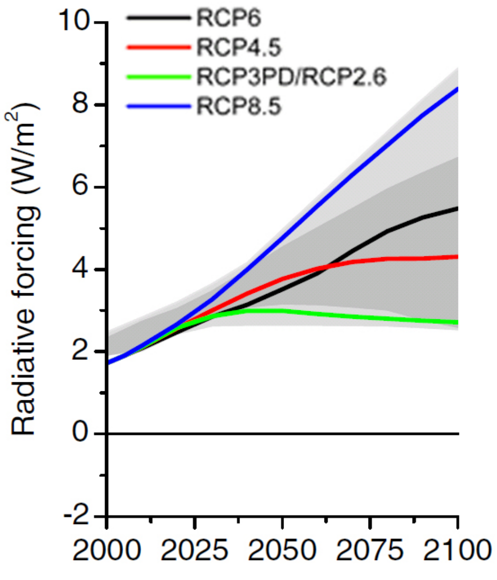
CC –

LUC –

Selection of GCM

- A total of 20 GCMs were first evaluated for their suitability of representing the characteristics of seasonal change in this study area.
- Coefficient of determination (R^2) > 0.8: Compared with the historical average monthly precipitation.

- Final selected GCMs (CCSM4, MRI-CGCM3) combined with Representative Concentration Path (RCP): RCP2.6, 4.5, 6, 8.5
- Simulation for near future climate change scenarios: 2020-2039
- Integrated climate and hydrological model (TaiWAP) generates 200 years of data to represent the characteristics of near future climate change

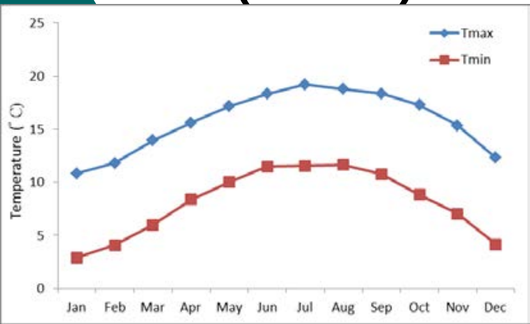


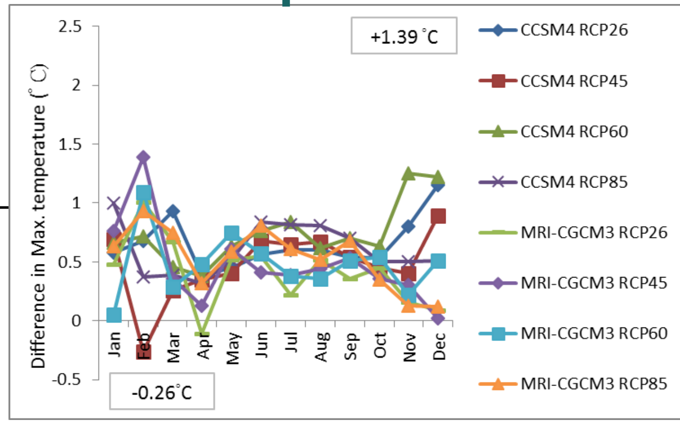
Source: http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html

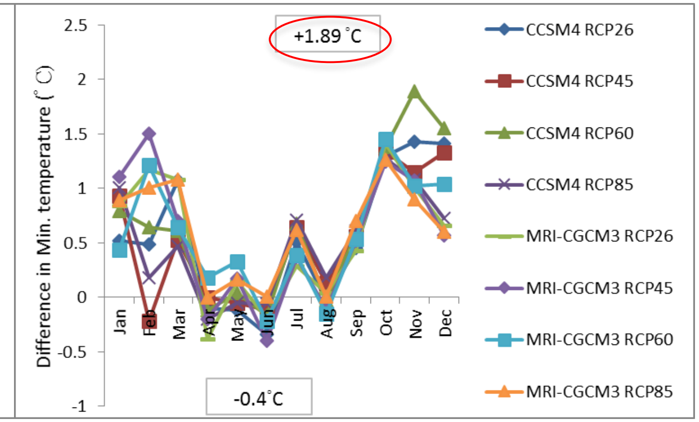
Comparison of historical and CC scenarios: min. & max. temperature

Historical Temperature (1990-2013)

Stn530 (Mt. Ali)







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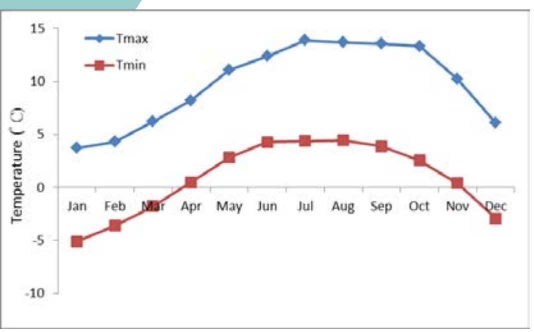
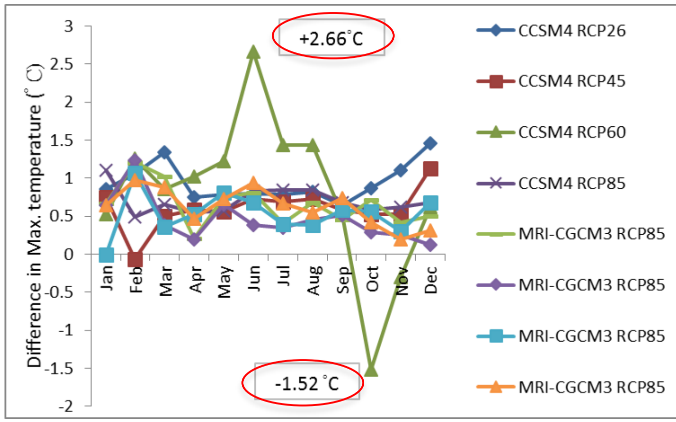
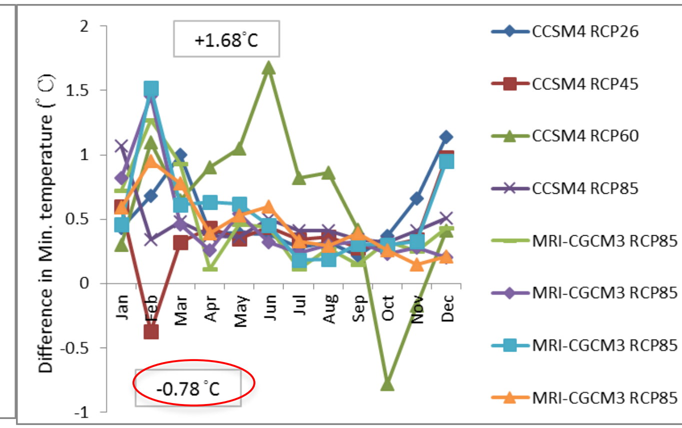
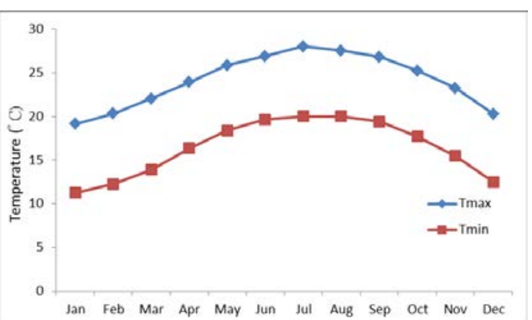
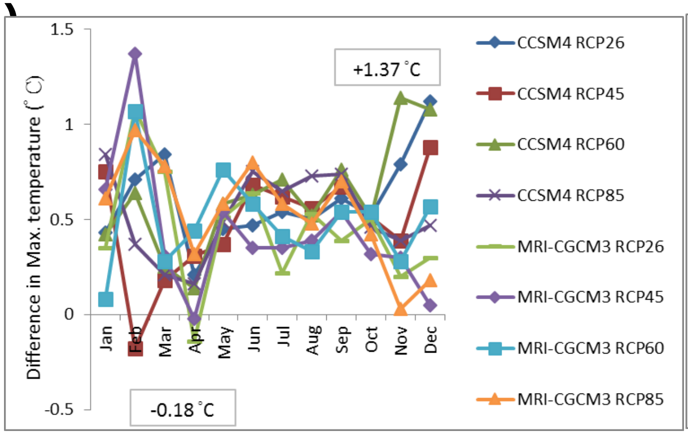


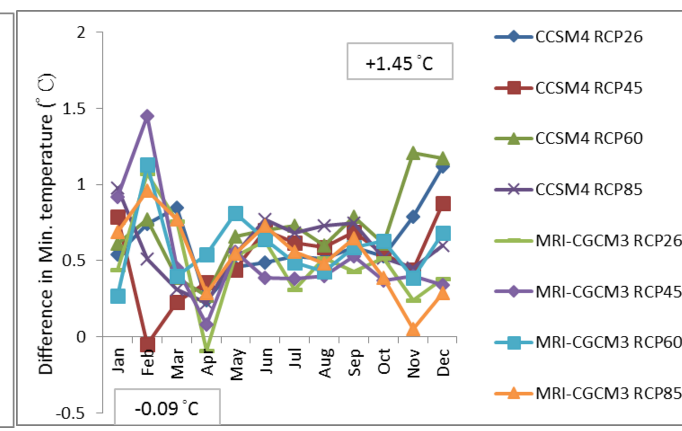




Stn650 (Sun moon Lake)

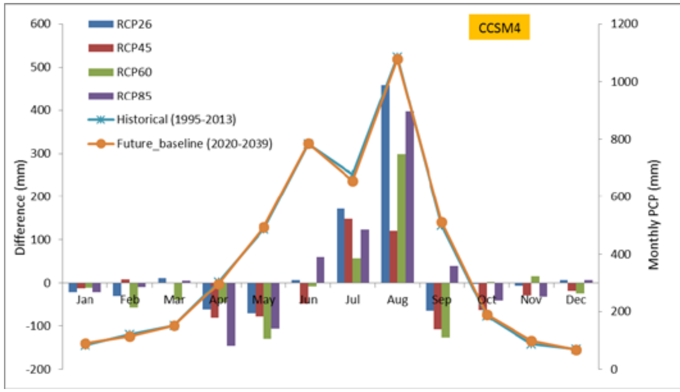


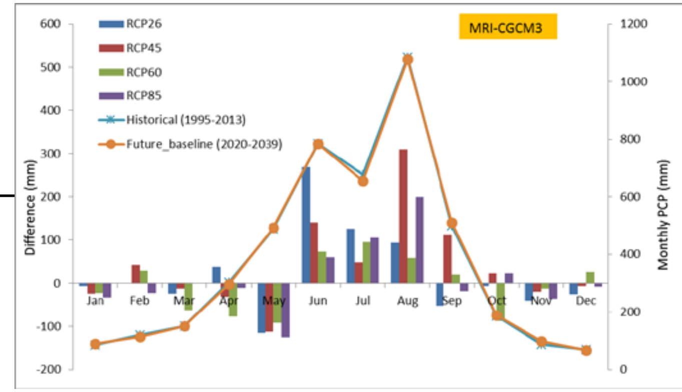




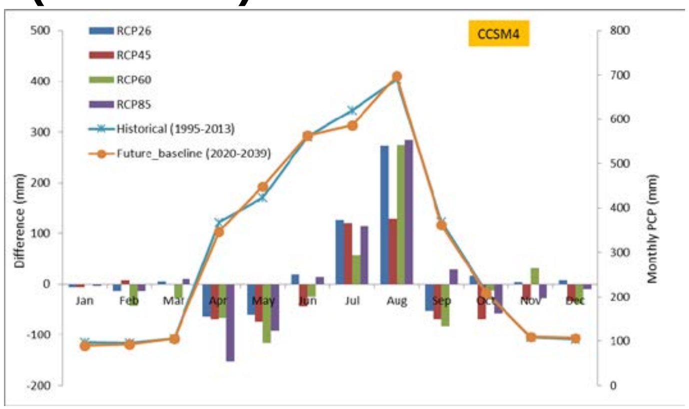
Comparison of historical and CC scenarios: monthly precipitation

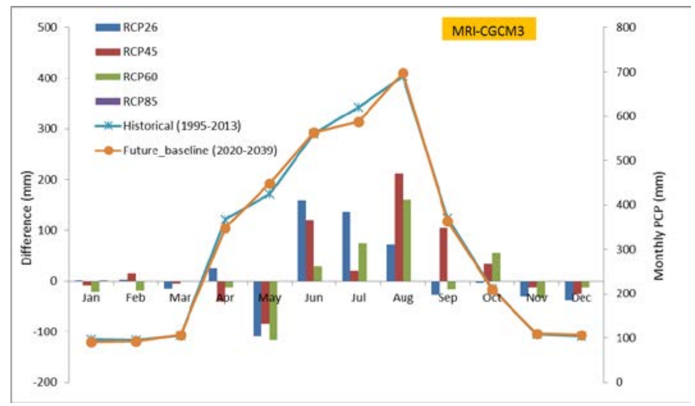
Stn530 (Mt. Ali)





Stn550 (Mt. Jade)





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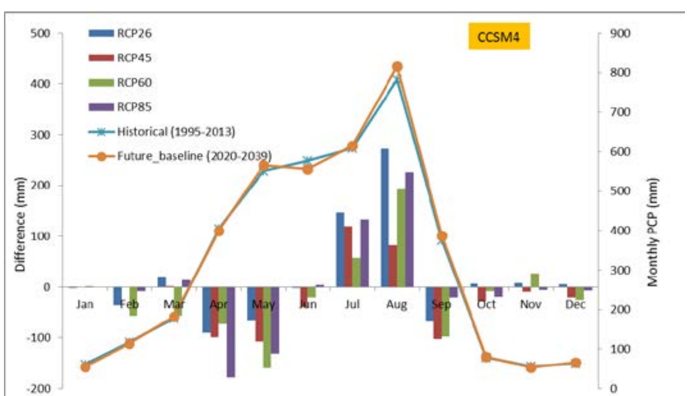
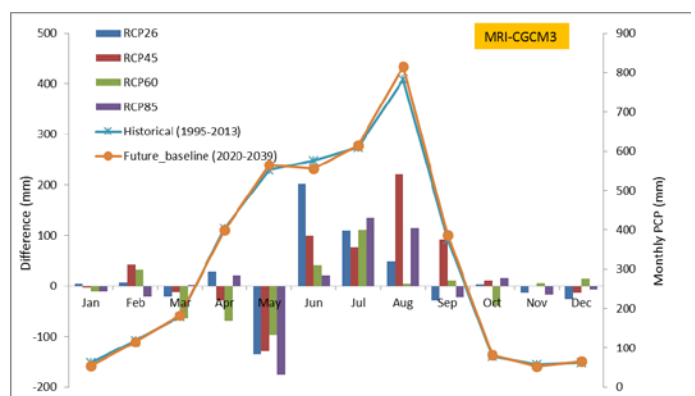




Historical land use change & Future land use change scenarios

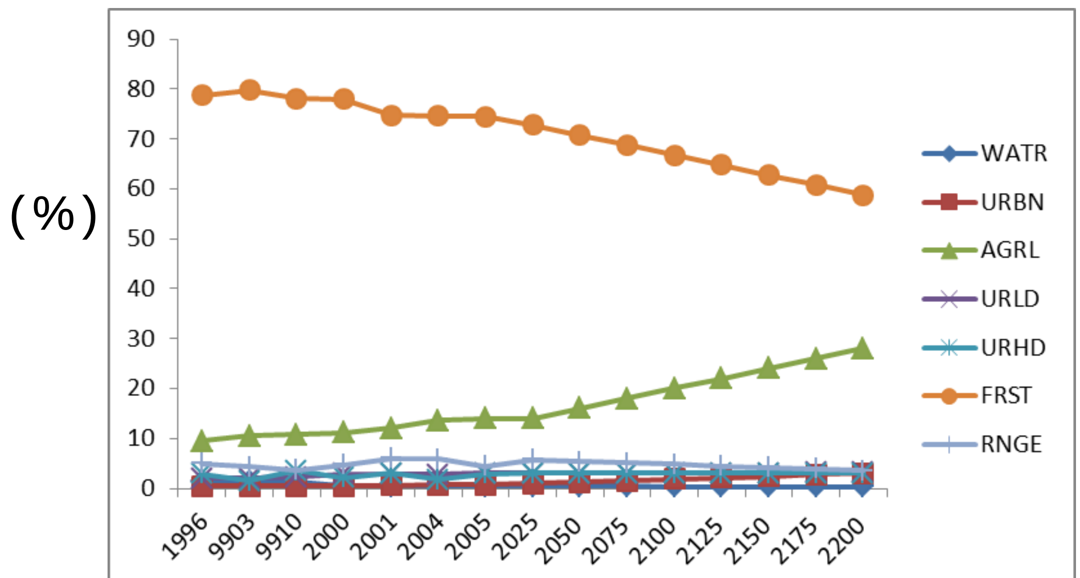
- Historical land use change (1996-2005)

Watershed area: 44880.96 ha

%\Year	1996	9903	9910	2000	2001	2004	2005
WATR	1.37	1.50	1.21	0.53	0.48	0.65	0.46
URBN	0.42	0.46	0.50	0.52	0.63	0.67	0.76
AGRL	9.54	10.47	10.82	11.16	12.03	13.60	14.05
URLD	2.05	1.98	2.21	2.91	2.97	2.81	2.98
URHD	2.95	1.52	3.51	2.17	3.10	1.73	2.89
FRST	78.69	79.79	78.12	77.99	74.78	74.67	74.45
RNGE	4.98	4.29	3.63	4.73	6.00	5.87	4.40
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Future land use change scenarios (2001-2200)

Landuse (%)	25-year difference (%)	area (ha)	Year								
			2001	2025	2050	2075	2100	2125	2150	2175	2200
WATR	-0.02	-8.98	0.48	0.46	0.44	0.42	0.4	0.38	0.36	0.34	0.32
URBN	0.30	134.64	0.63	0.93	1.23	1.53	1.83	2.13	2.43	2.73	3.03
AGRL	2.00	897.62	12.03	14.03	16.03	18.03	20.03	22.03	24.03	26.03	28.03
URLD	0.02	8.98	2.97	2.99	3.01	3.03	3.05	3.07	3.09	3.11	3.13
URHD	0.00	0.00	3.10	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
FRST	-2.00	-897.62	74.78	72.78	70.78	68.78	66.78	64.78	62.78	60.78	58.78
RNGE	-0.30	-134.64	6.00	5.7	5.4	5.1	4.8	4.5	4.2	3.9	3.6
	0.00	0.00	100.00	100	100	100	100	100	100	100	100



Results (1/4): Calibration with/without the land use update function

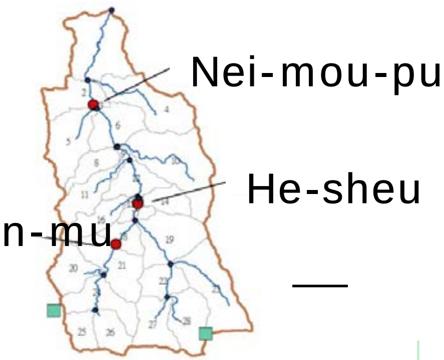
- Several hydrologic parameters could be overfitting when not activating the land use update function in SWAT

Parameter	Method	Range	Fitted value (with landuse update)	Fitted value (without landuse update)
CH_K2	v	93~273, 53~151, 30~82	275.38, 72.50, 50.71	276.32, 72.94, 50.71
CN2	r	-20%~20%	-15.9%, -18.8%, -13.9%	-19.1%, -16.6%, -3.5%
GW_DELAY	v	10~150	67.26, 53.16, 153.98	77.03, 30.59, 141.52
GWQMN	v	0~500	82.13	31.40
GW_REVAP	v	0.02~0.2	0.09685	0.05923
RCHRG_DP	v	0~1	0.97163	0.98525
ESCO	v	0.01~0.95	0.395344	0.061994
EPCO	v	0.01~0.95	0.591625	0.5518
CH_N2	r	-20%~20%	12.8%	11.0%
OV_N	r	-20%~20%	14.3%	15.1%
SOL_AWC	r	-50%~50%	-17.2%	-22.3%
CANMX	v	0~500	470.73	412.20
REVAPMN	v	0~500	228.90	264.39
SURLAG	v	0~5	1.54	2.88

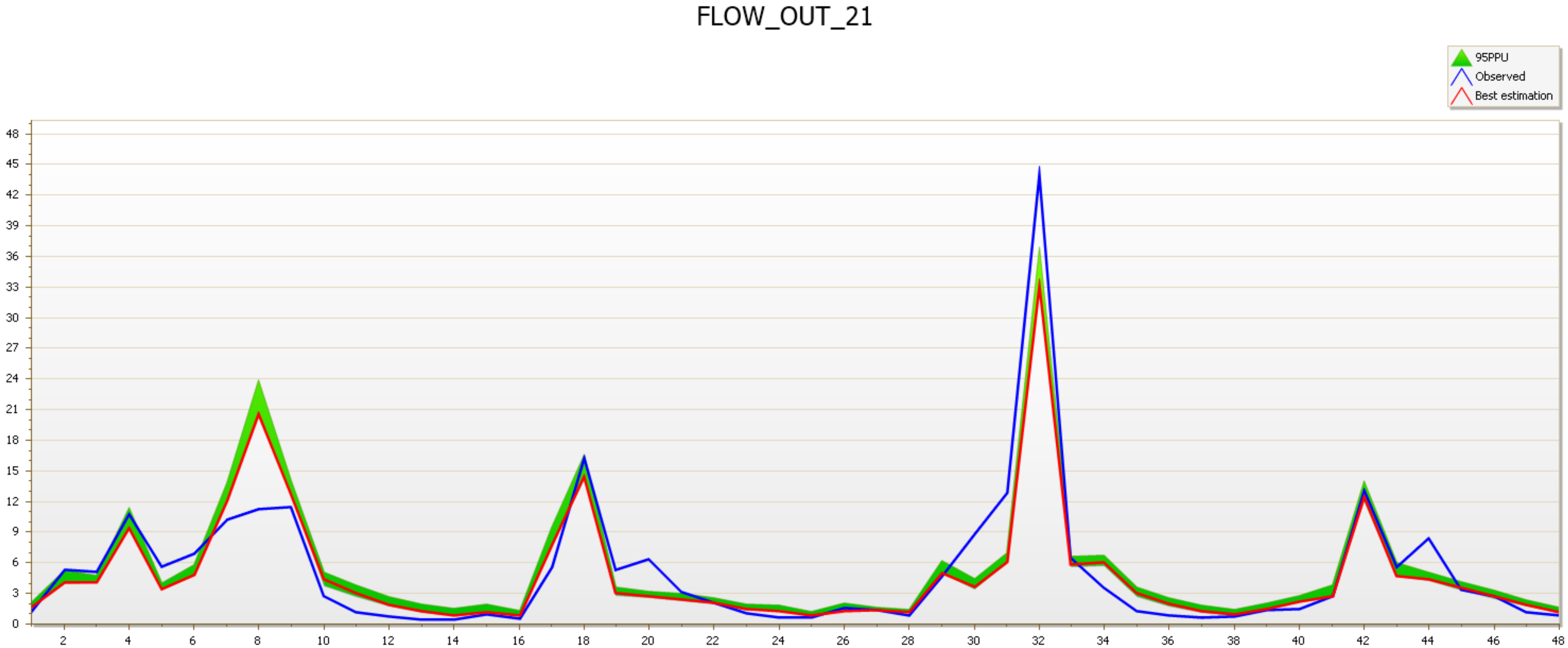
Results (2/4): Model Performance

- With LU update function, we simulated monthly streamflow for 1990-2000 (2 year warm-up)
- SWAT model performed well for monthly flow simulation
- Calibration (1992-1995) for 3 gages
  - R^2 (0.66~0.86)
  - NSE (0.65~0.85)
  - PBIAS (-10.7%~5.6%)
- Validation (1997-2000) for 1 gage
  - R^2 (0.59)
  - NSE (0.3)
  - PBIAS (-14%)

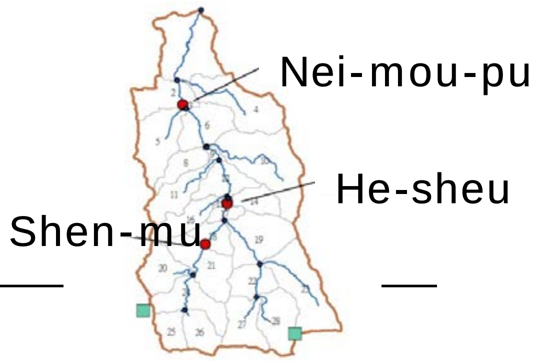
Calibration (1992-1995)



station	R2	NSE	PBIAS	Mean_sim	Mean_obs	StdDev_Sim	StdDev_Obs
FLOW_OUT_3 (Nei-mou-pu)	0.78	0.77	-10.7	22.25	20.1	24	25.76
FLOW_OUT_17 (He-sehu)	0.66	0.65	4.5	12.95	13.56	13.26	18.58
FLOW_OUT_21 (Shen-mu)	0.86	0.85	5.6	4.91	5.21	5.89	7.07

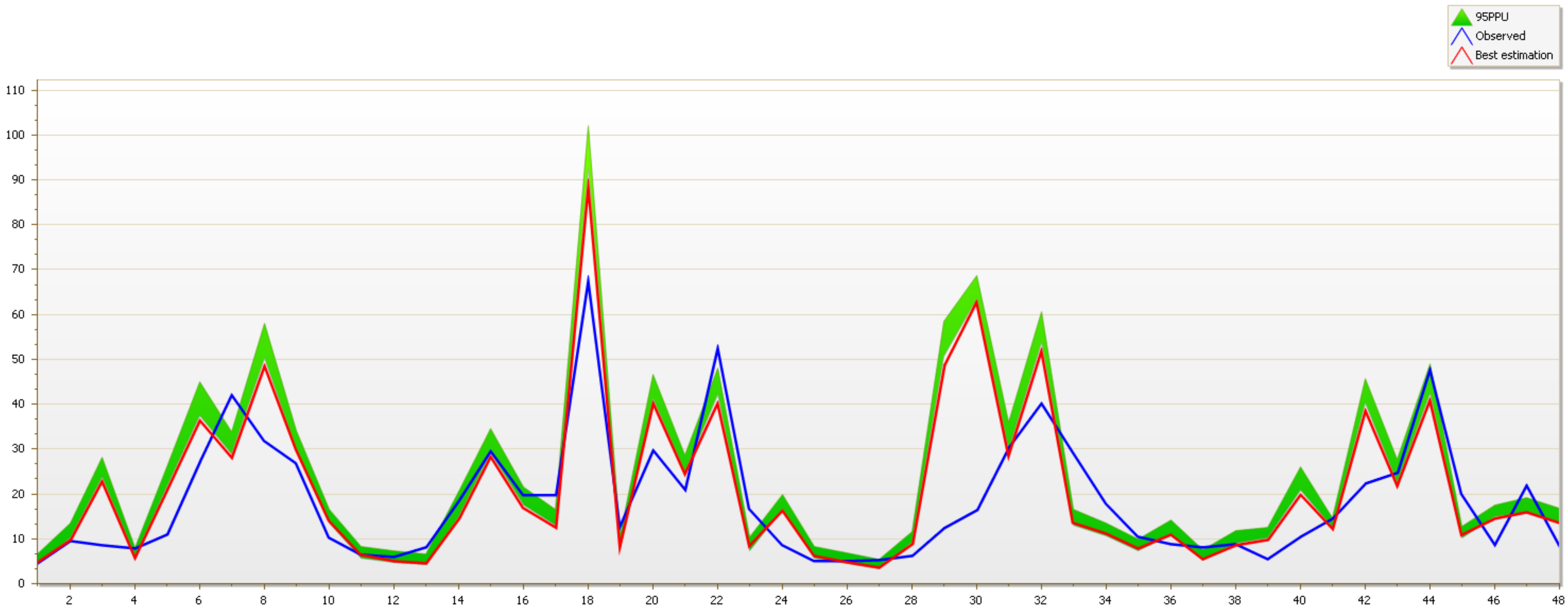


Validation (1997-2000)



station	R2	NSE	PBIAS	Mean_sim	Mean_obs	StdDev_Sim	StdDev_Obs
FLOW_OUT_3 (Nei-mou-pu)	0.59	0.3	-14	21.32	18.7	17.73	13.85

FLOW_OUT_3

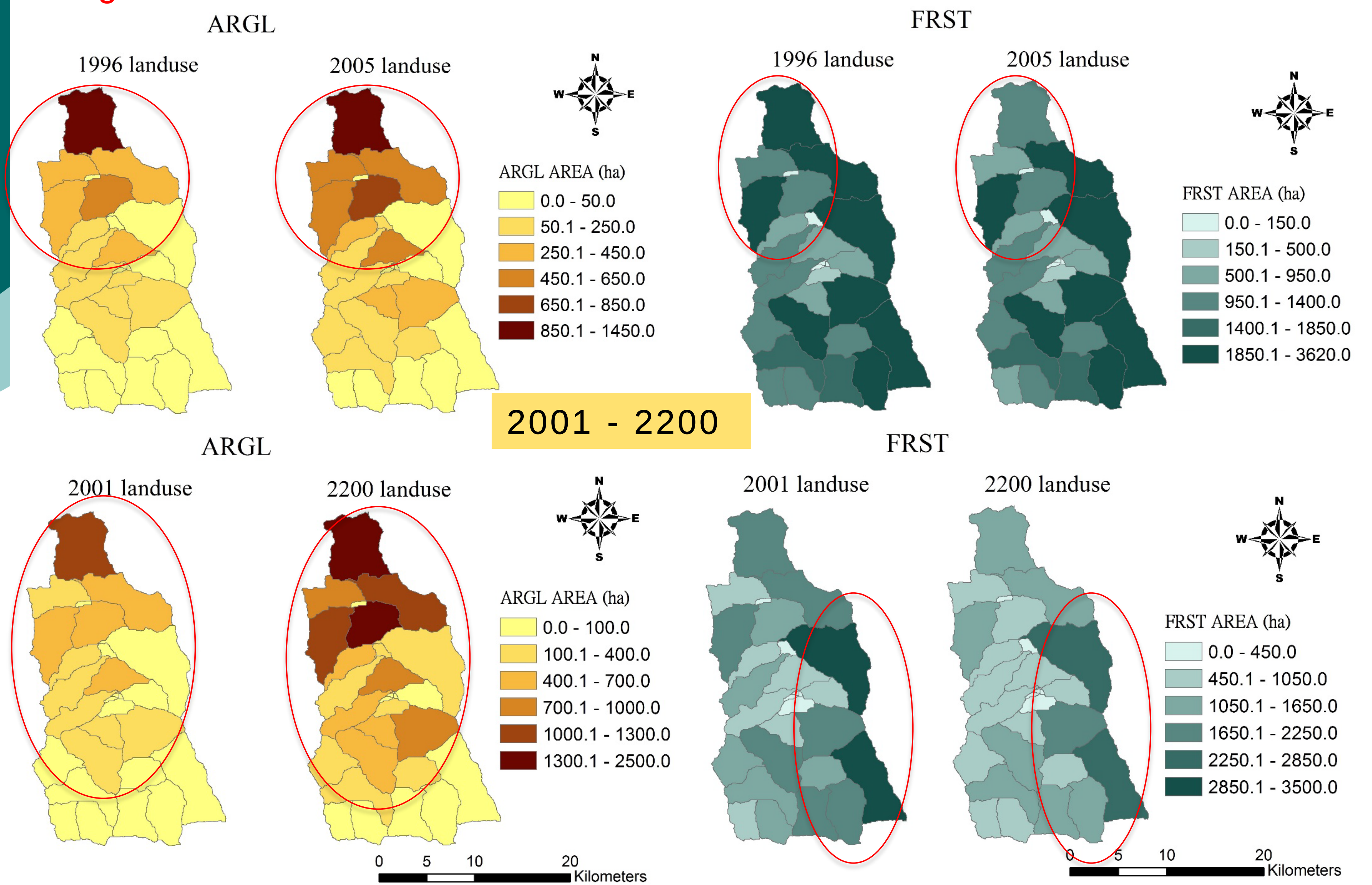


Results (3/4): LU impact on hydrologic cycle & sediment export

Agriculture increased

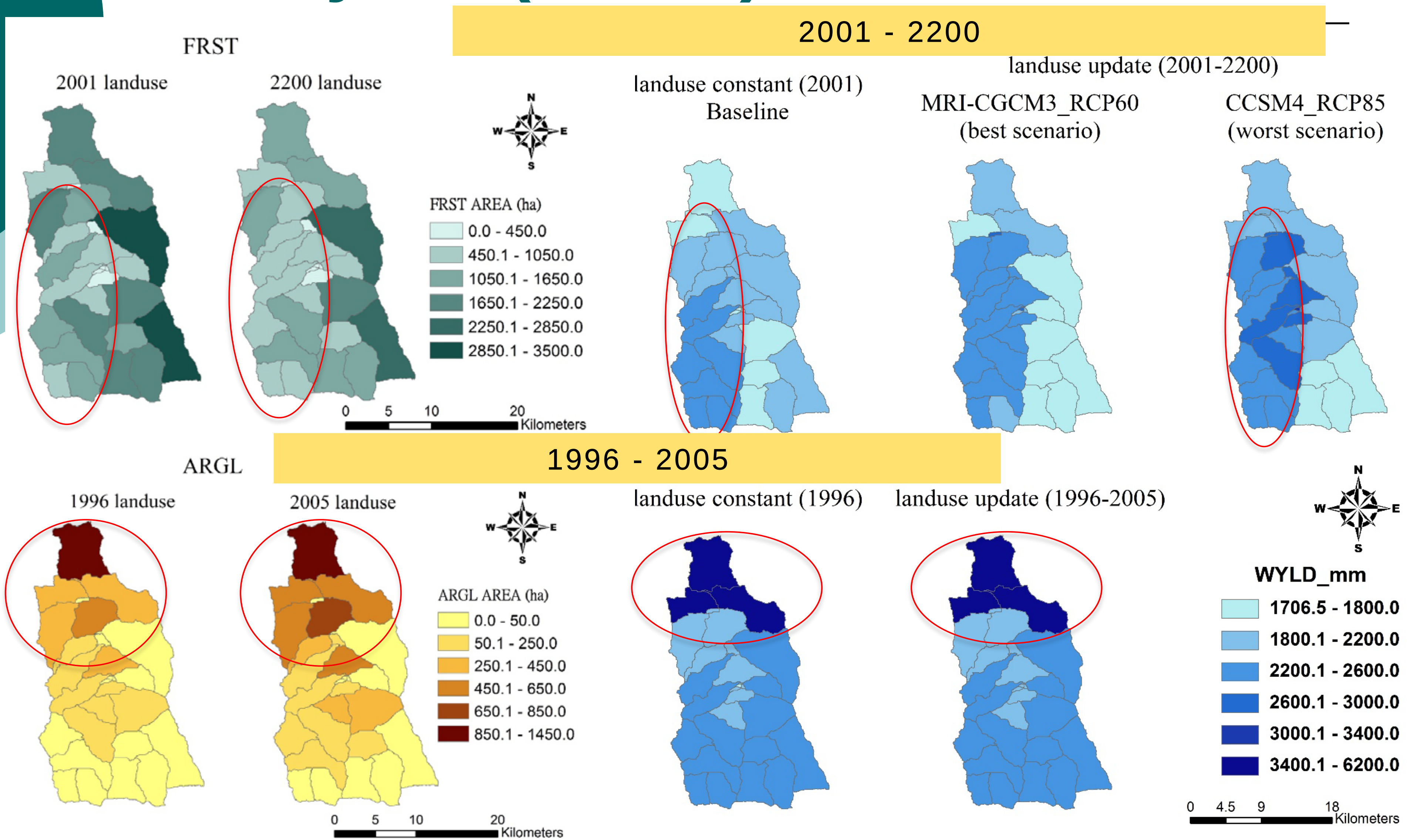
1996 - 2005

Forest decreased



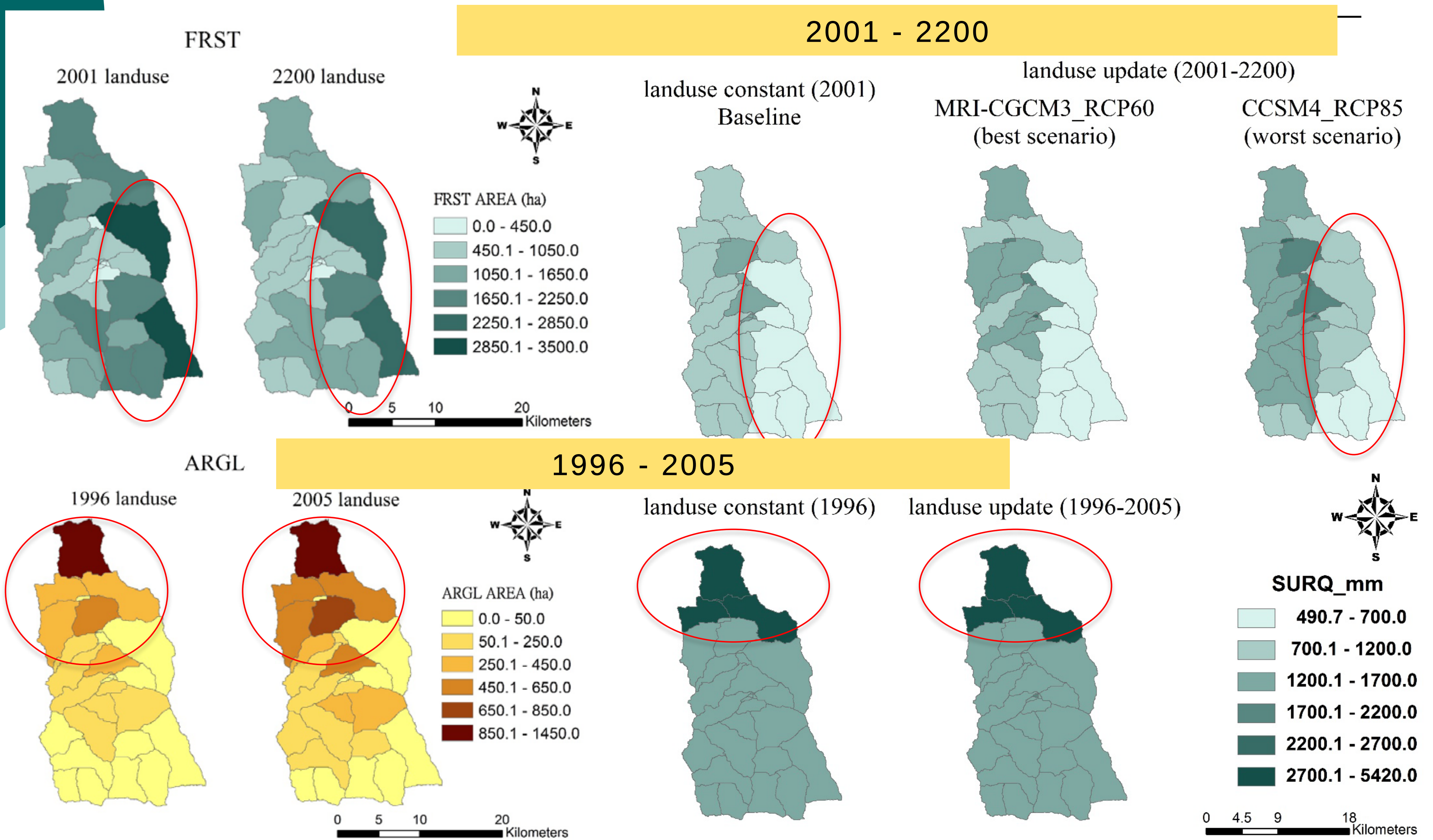
LU impact on water yield (WYLD)

FRST decreases → WYLD & SURQ increase
AGRL increases → WYLD & SURQ increase



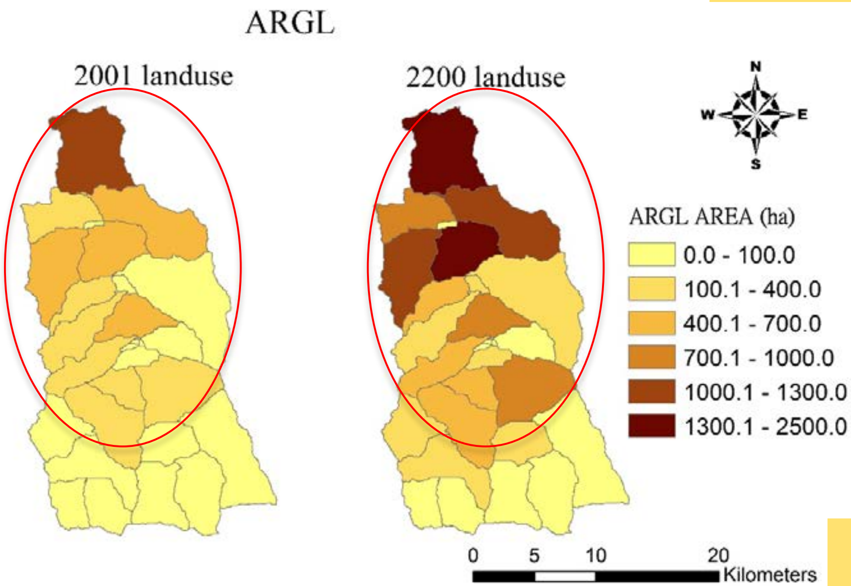
LU impact on surface runoff (SURQ)

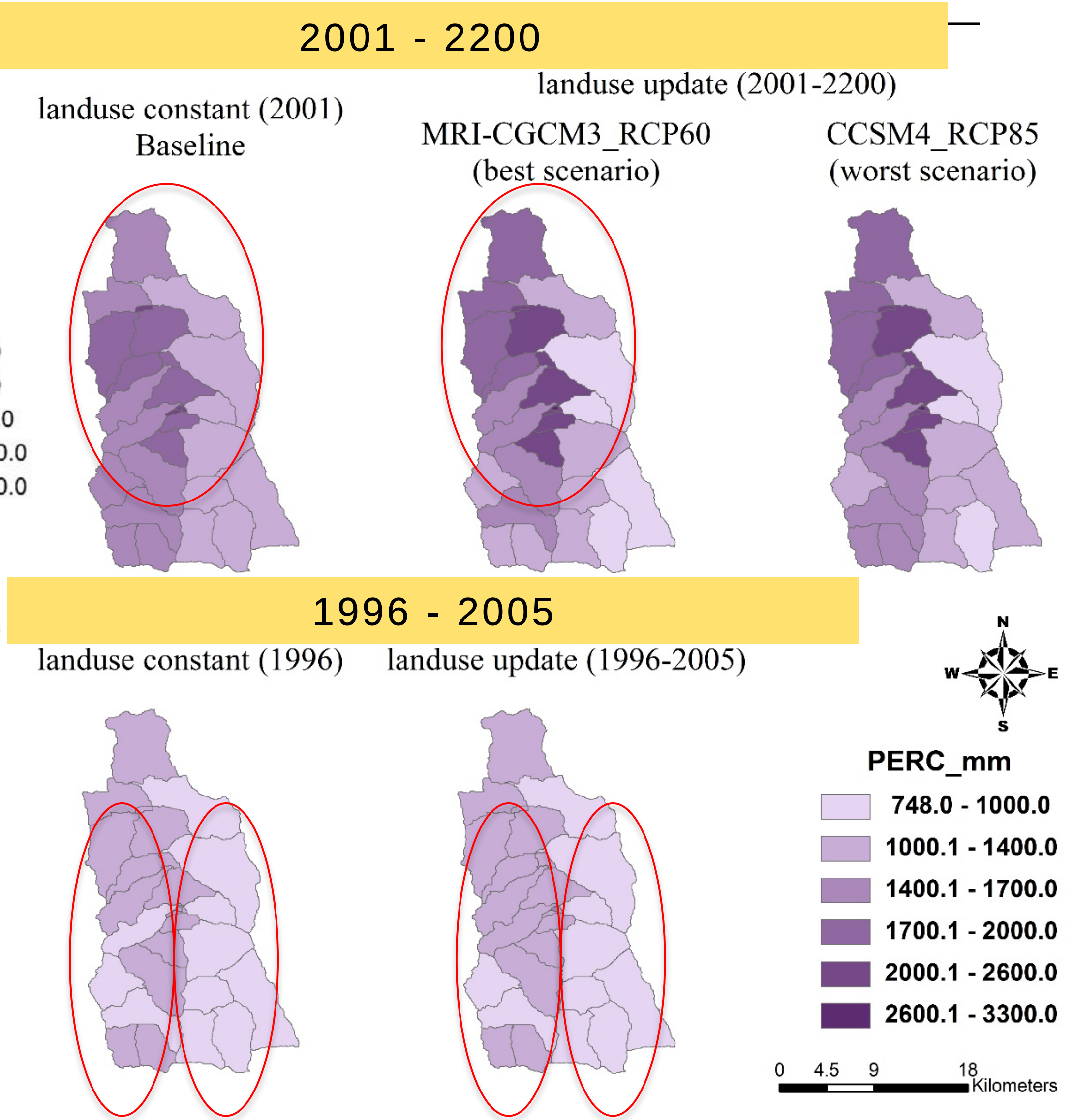
FRST decreases → WYLD & SURQ increase
AGRL increases → WYLD & SURQ increase

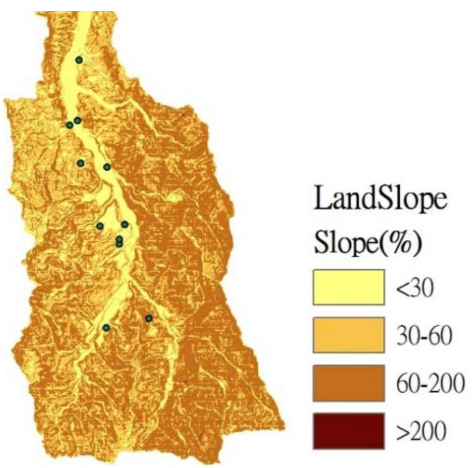


LU impact on percolation (PERC)

AGRL increases → PERC increases
Steeper slope → less PERC

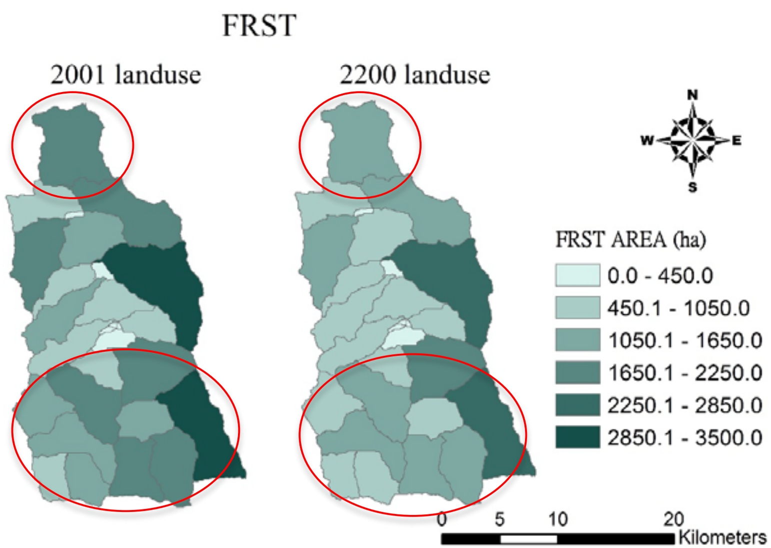




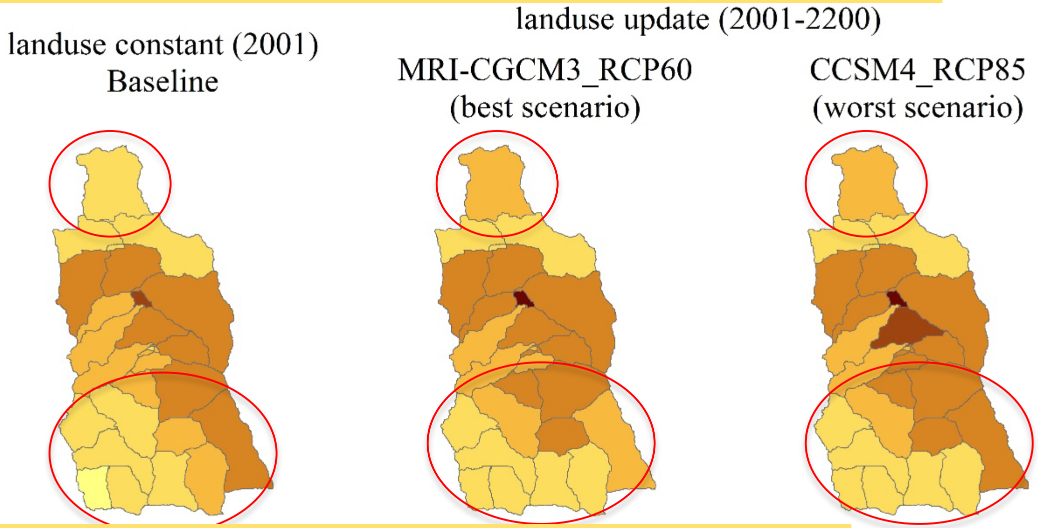


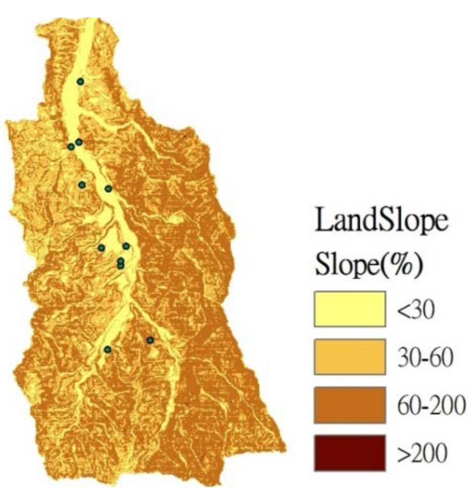
LU impact on sediment yield (SYLD)

FRST decreases → SYLD increases
Steeper slope → greater SYLD

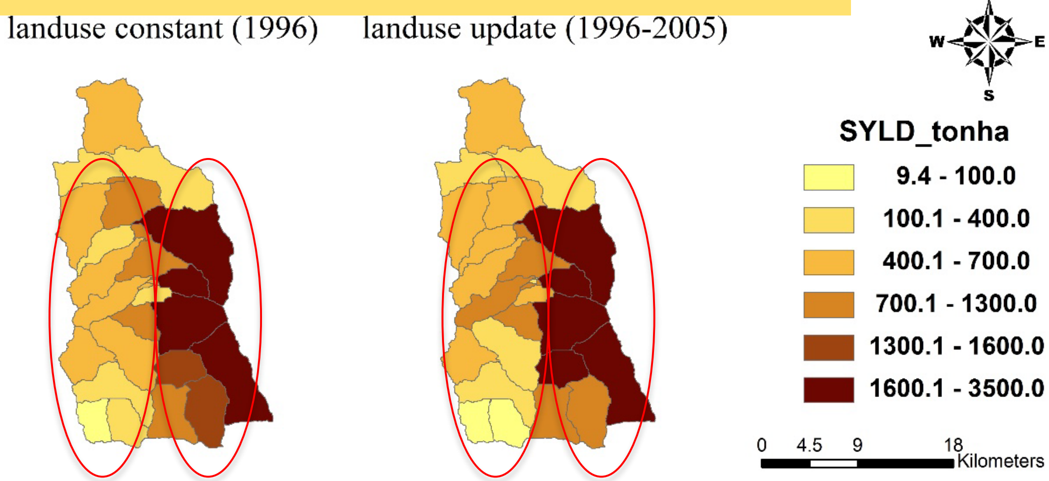


2001 - 2200





1996 - 2005

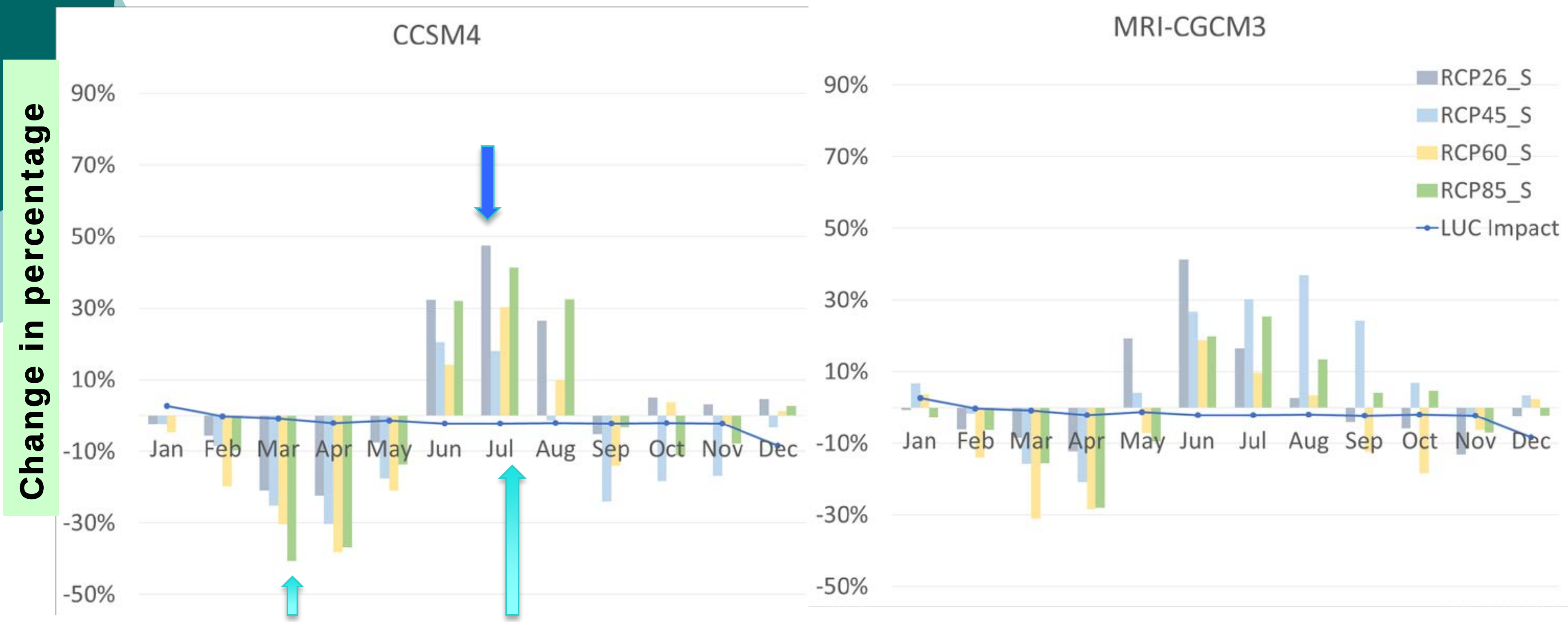


Results (4/4): Combined LUC + CC impact on streamflow

MON	LUC+CC impact (sim2 – sim3)								LUC impact (sim4 – sim3)
	CCSM4				MRI-CGCM3				
	RCP26_S	RCP45_S	RCP60_S	RCP85_S	RCP26_S	RCP45_S	RCP60_S	RCP85_S	
Jan	-0.02	-0.02	-0.05	0.00	-0.01	0.07	0.04	-0.03	0.03
Feb	-0.06	-0.09	-0.20	-0.10	-0.06	-0.02	-0.14	-0.06	0.00
Mar	-0.21	-0.25	-0.30	-0.41	-0.09	-0.16	-0.31	-0.16	-0.01
Apr	-0.22	-0.30	-0.38	-0.37	-0.12	-0.21	-0.28	-0.28	-0.02
May	-0.08	-0.18	-0.21	-0.14	0.19	0.04	-0.07	-0.09	-0.01
Jun	0.32	0.21	0.14	0.32	0.41	0.27	0.19	0.20	-0.02
Jul	0.47	0.18	0.30	0.41	0.16	0.30	0.10	0.25	-0.02
Aug	0.26	-0.01	0.10	0.33	0.03	0.37	0.03	0.13	-0.02
Sep	-0.05	-0.24	-0.14	-0.03	-0.04	0.24	-0.12	0.04	-0.02
Oct	0.05	-0.18	0.04	-0.11	-0.06	0.07	-0.18	0.05	-0.02
Nov	0.03	-0.17	-0.03	-0.08	-0.13	-0.03	-0.06	-0.07	-0.02
Dec	0.05	-0.03	0.01	0.03	-0.02	0.03	0.02	-0.02	-0.08

Unit: (100%) Change in Percentage

Results (4/4): Combined LUC + CC impact on streamflow



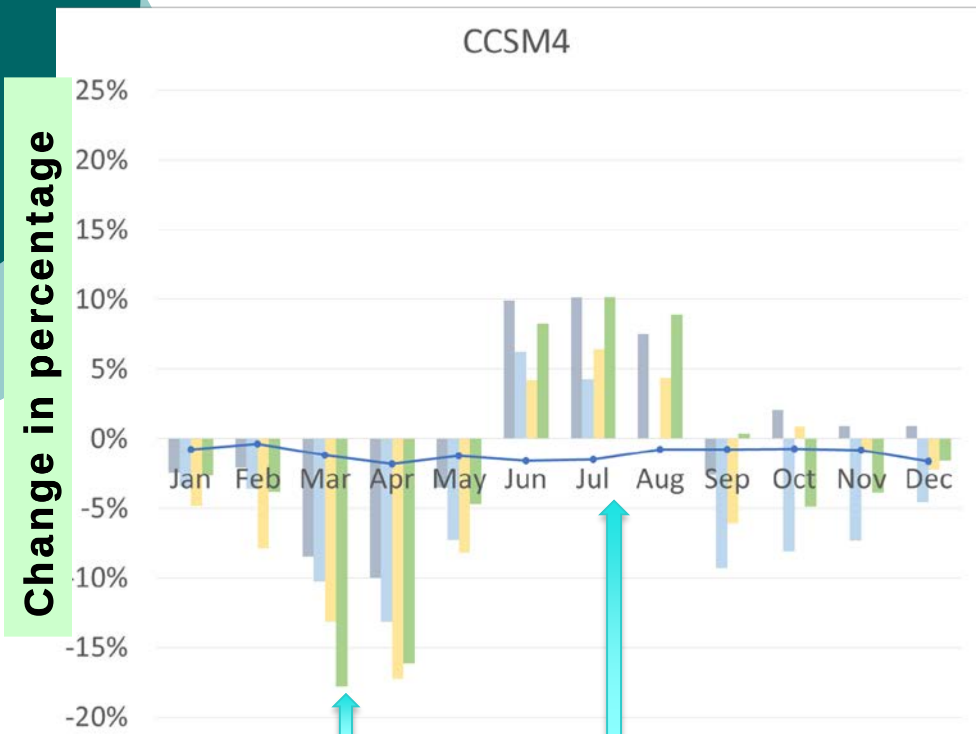
- CCSM4_RCP26 scenario would lead to highest streamflow in July
- CCSM4_RCP85 scenario has the greatest variation in monthly streamflow
- Land use change has relatively small impact on streamflow

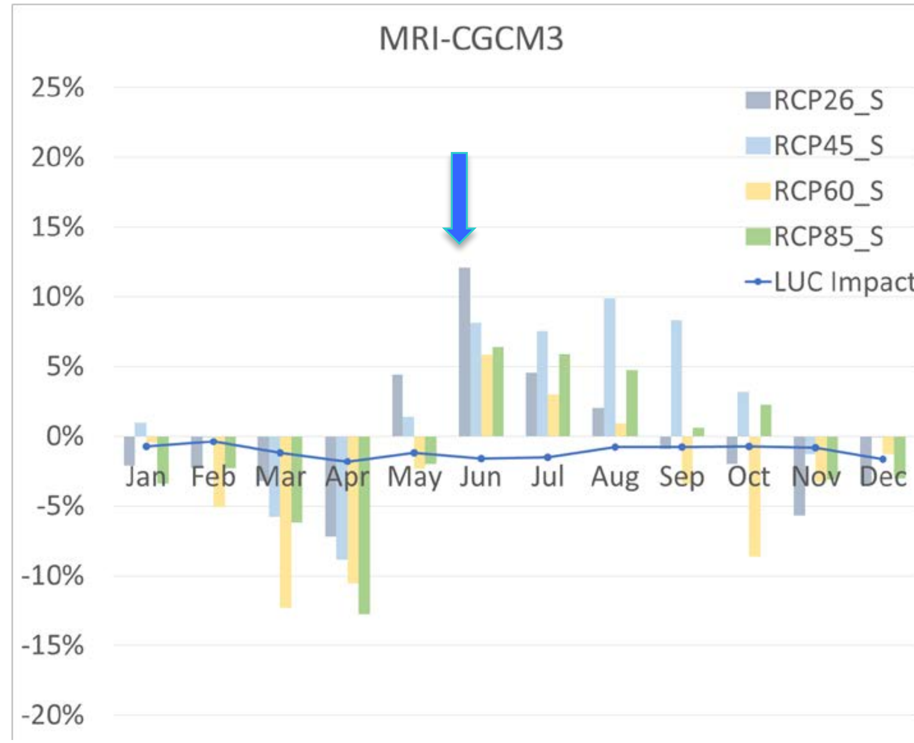
Results (4/4): Combined LUC + CC impact on sediment concentration

MON	LUC+CC impact (sim2 – sim3)								LUC impact (sim4 – sim3)
	CCSM4				MRI-CGCM3				
	RCP26_S	RCP45_S	RCP60_S	RCP85_S	RCP26_S	RCP45_S	RCP60_S	RCP85_S	
Jan	-0.02	-0.03	-0.05	-0.03	-0.02	0.01	0.00	-0.03	-0.01
Feb	-0.02	-0.04	-0.08	-0.04	-0.02	0.00	-0.05	-0.02	0.00
Mar	-0.08	-0.10	-0.13	-0.18	-0.03	-0.06	-0.12	-0.06	-0.01
Apr	-0.10	-0.13	-0.17	-0.16	-0.07	-0.09	-0.11	-0.13	-0.02
May	-0.04	-0.07	-0.08	-0.05	0.04	0.01	-0.02	-0.02	-0.01
Jun	0.10	0.06	0.04	0.08	0.12	0.08	0.06	0.06	-0.02
Jul	0.10	0.04	0.06	0.10	0.05	0.08	0.03	0.06	-0.02
Aug	0.08	0.00	0.04	0.09	0.02	0.10	0.01	0.05	-0.01
Sep	-0.03	-0.09	-0.06	0.00	-0.01	0.08	-0.03	0.01	-0.01
Oct	0.02	-0.08	0.01	-0.05	-0.02	0.03	-0.09	0.02	-0.01
Nov	0.01	-0.07	-0.01	-0.04	-0.06	-0.01	-0.03	-0.03	-0.01
Dec	0.01	-0.05	-0.02	-0.02	-0.03	0.00	-0.01	-0.03	-0.02

Unit: (100%) Change in Percentage

Results (4/4): Combined LUC + CC impact on sediment concentration





- MRI-CGCM3_RCP26 scenario would lead to highest sediment concentration in June
- Similar to streamflow, CCSM4_RCP85 has the greatest variation in sediment concentration
- Land use change has relatively small impact on sidementcon concentration

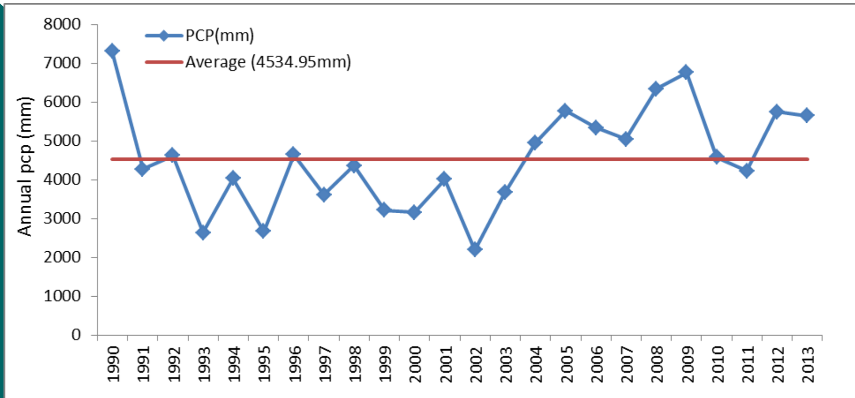
Conclusion

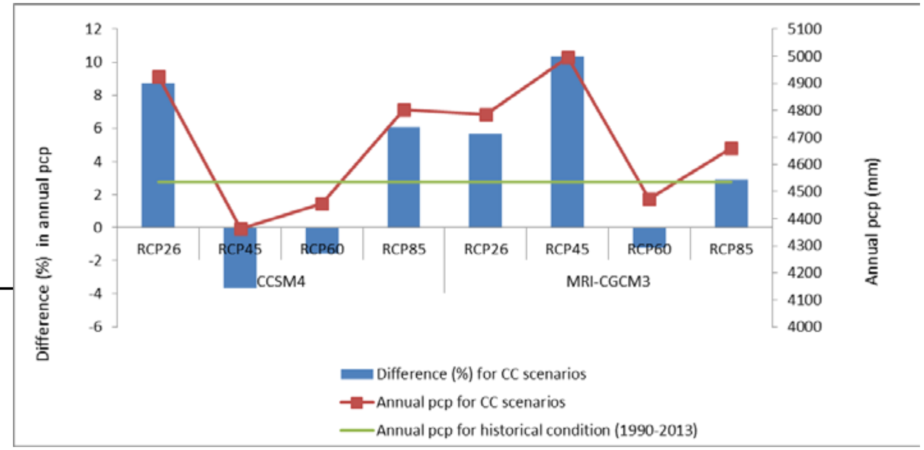
- Land use update function is suggested to activate for watersheds which have been experiencing landscape change.
- Most of the climate change scenarios resulted in higher precipitation in wet season (June - August), leading higher streamflow and sediment export.
- Change in forest and agricultural lands, and slope would significantly affect the hydrologic cycle (WYLD, SRUQ, PERC) and SYLD
- Based on the results, the subbasins that not only have great land use change but also are sensitive under future climate change conditions should be protected in watershed planning

Thank you!

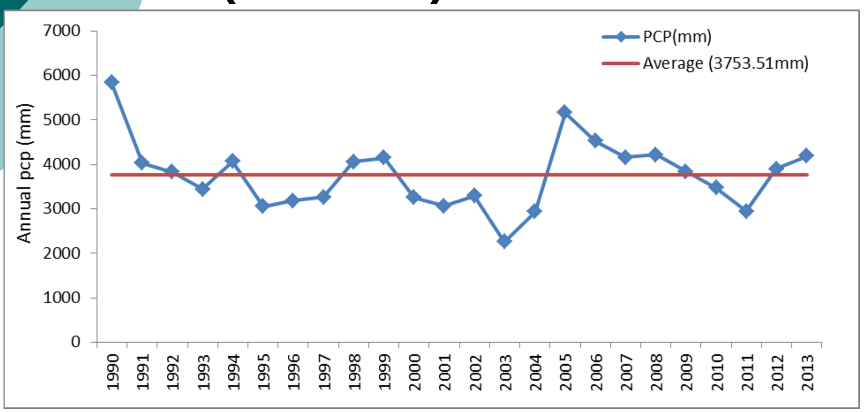
Questions?

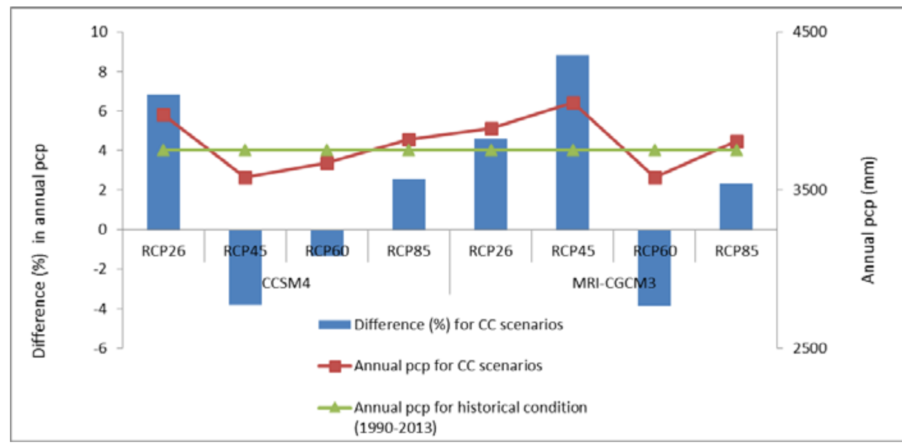
Stn530 (Mt. Ali)





Stn550 (Mt. Jade)





Stn650 (Sun moon Lake)