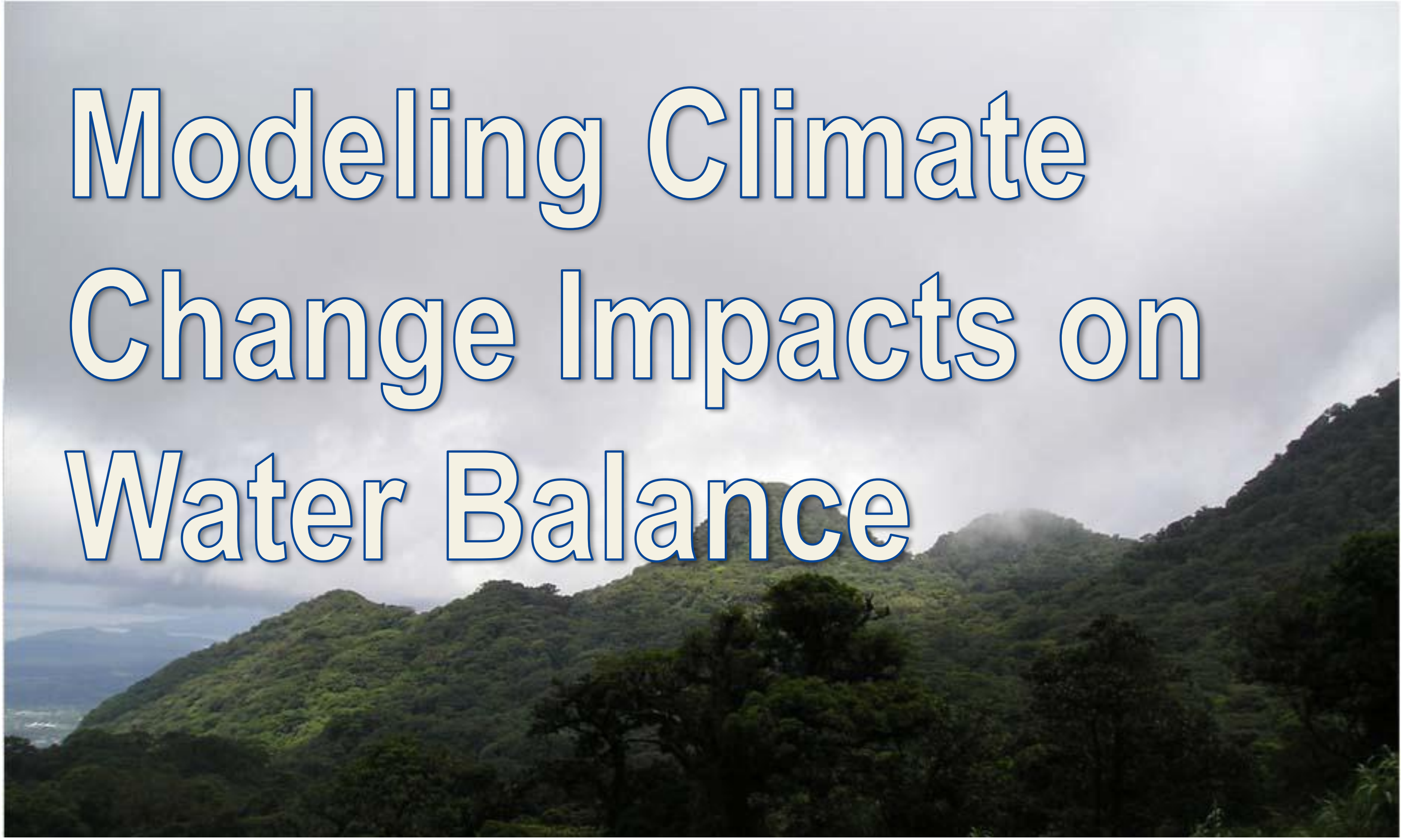
Modeling Climate Change Impacts on Water Balance



Edwin A. Combalicer

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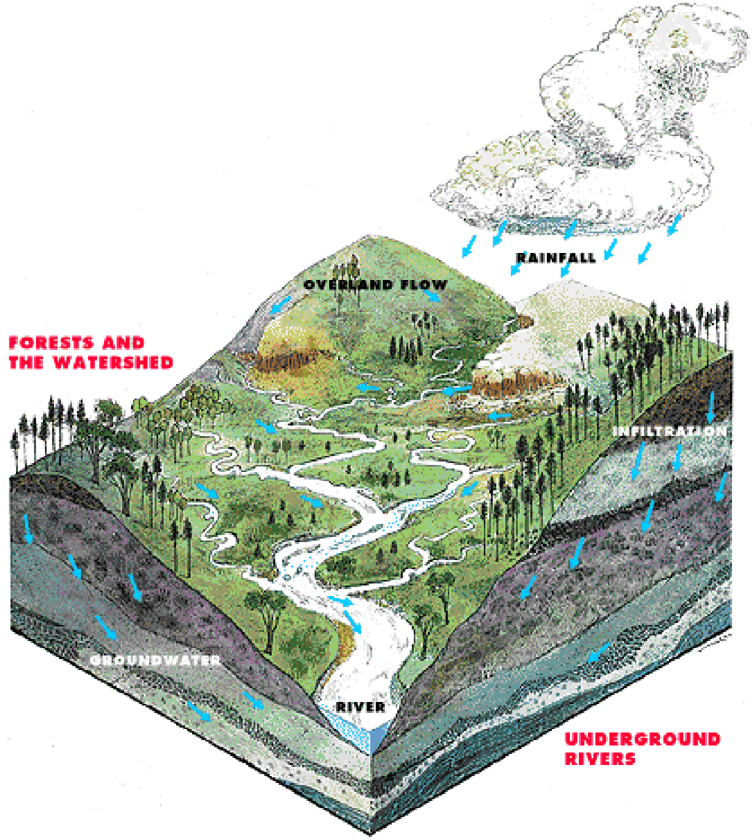
Contents

What is modeling?

…distinguished from other types of public performance…



'Modeling'

… the use of models, including prototypes, simulators, and stimulators, either statically or over time…

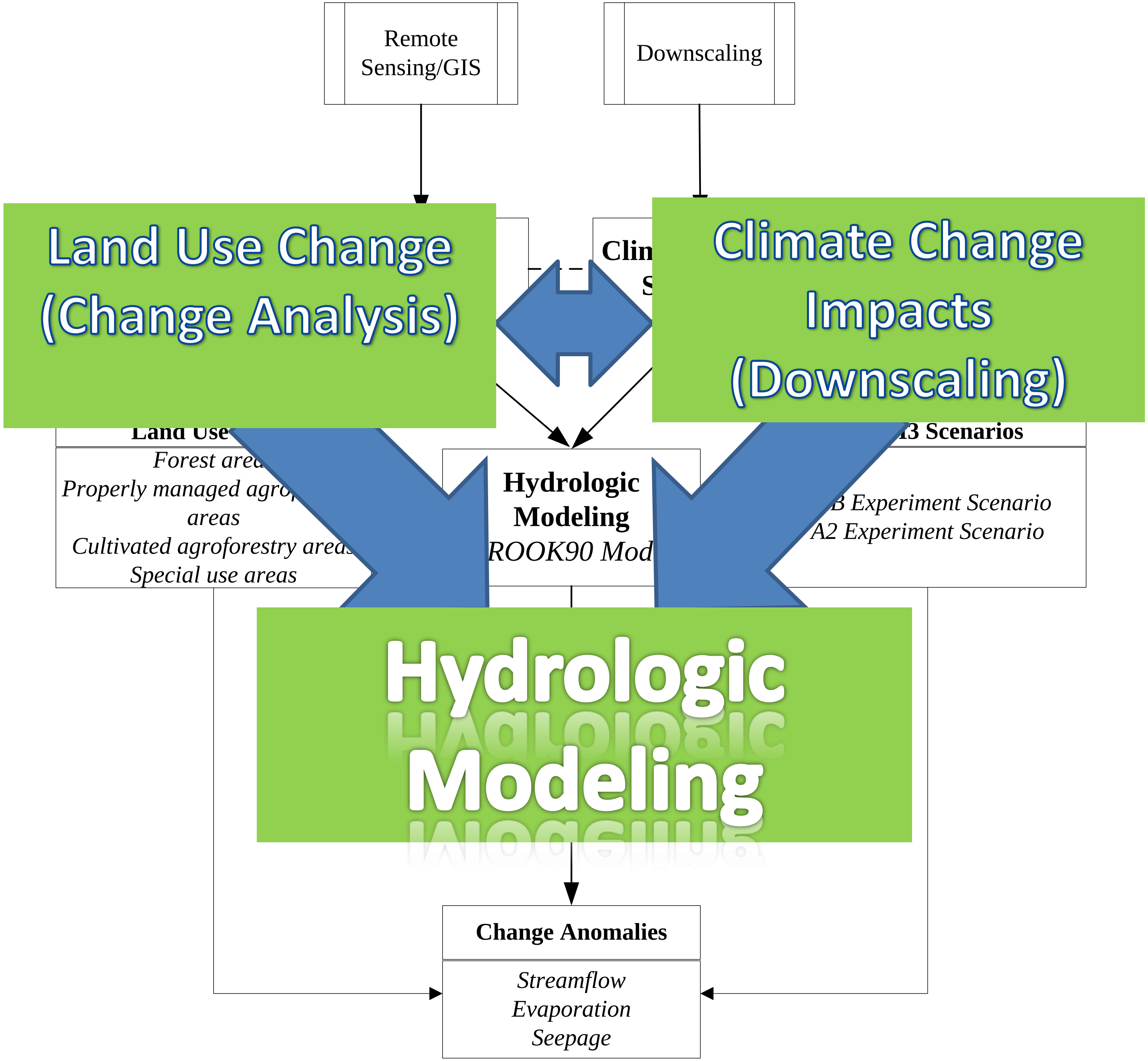
Why modeling?

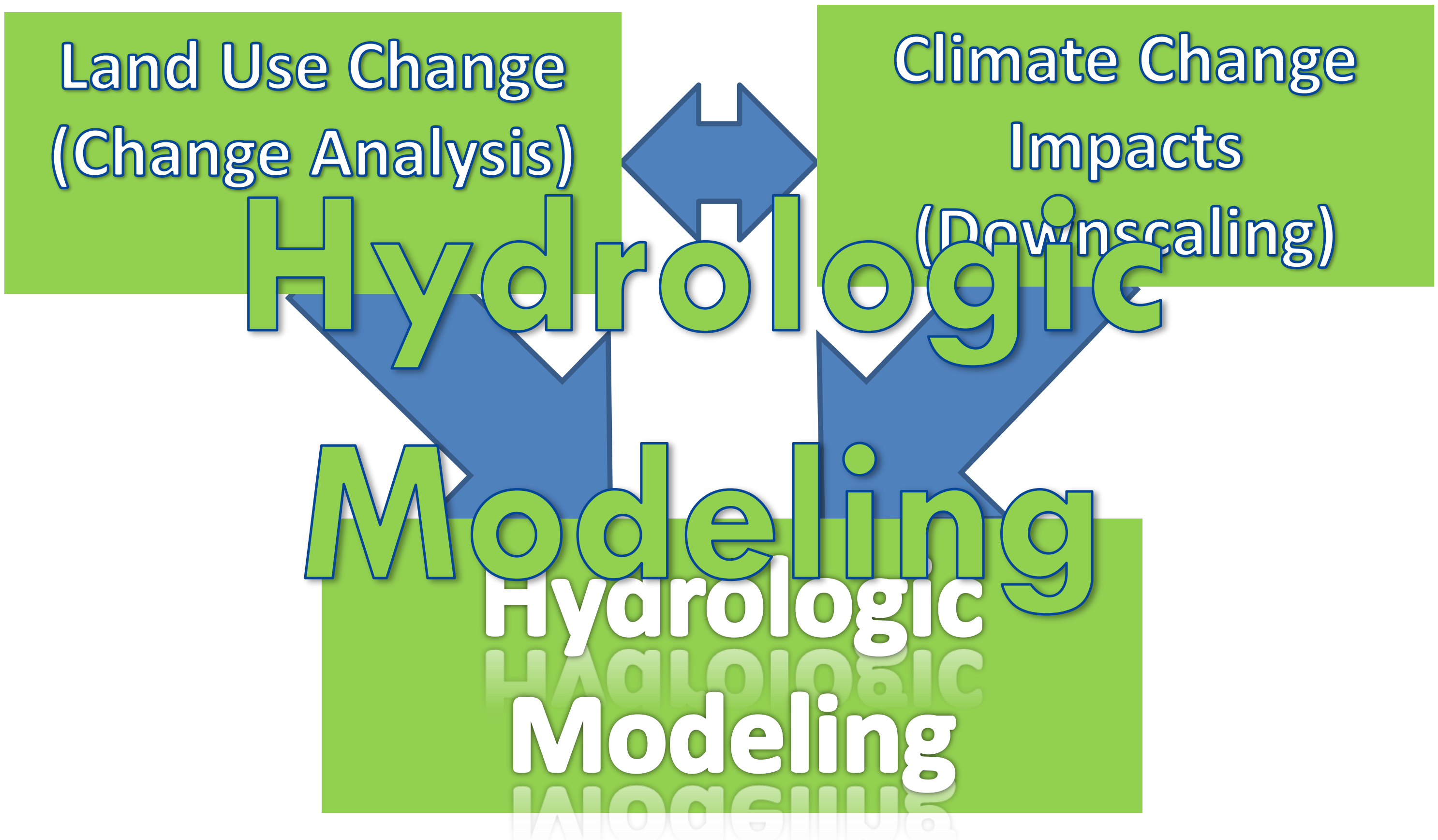
- Cheaper and safer than conducting experiments
- Even more realistic than traditional experiments
- Often be conducted faster than real time.

In hydrologic perspective:

- simplified and conceptual representations of a part of the hydrologic cycle

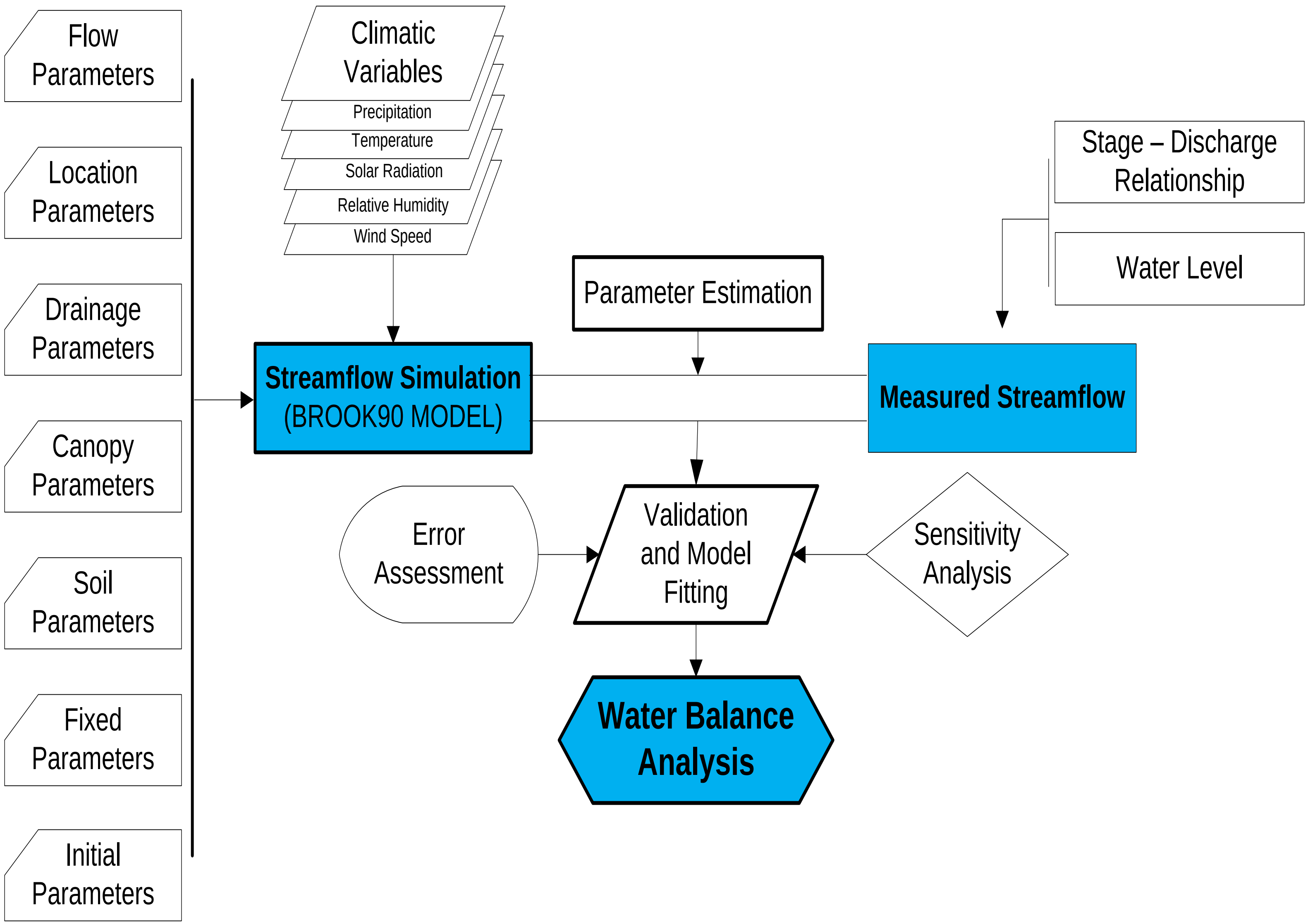
- hydrologic models: deterministic and scholastic


Remote Sensing/GIS
Downscaling
Land Use Change (Change Analysis)
Climate Change Impacts (Downscaling)
Land Use
Forest area
Properly managed agro
areas
Cultivated agroforestry areas
Special use areas
Hydrologic Modeling
ROOK90 Mod
B Experiment Scenario
A2 Experiment Scenario
3 Scenarios
Hydrologic Modeling
Change Anomalies
Streamflow
Evaporation
Seepage


Land Use Change
(Change Analysis)
Climate Change
Impacts
(Downscaling)
Hydrologic
Modeling
Hydrologic
Modeling

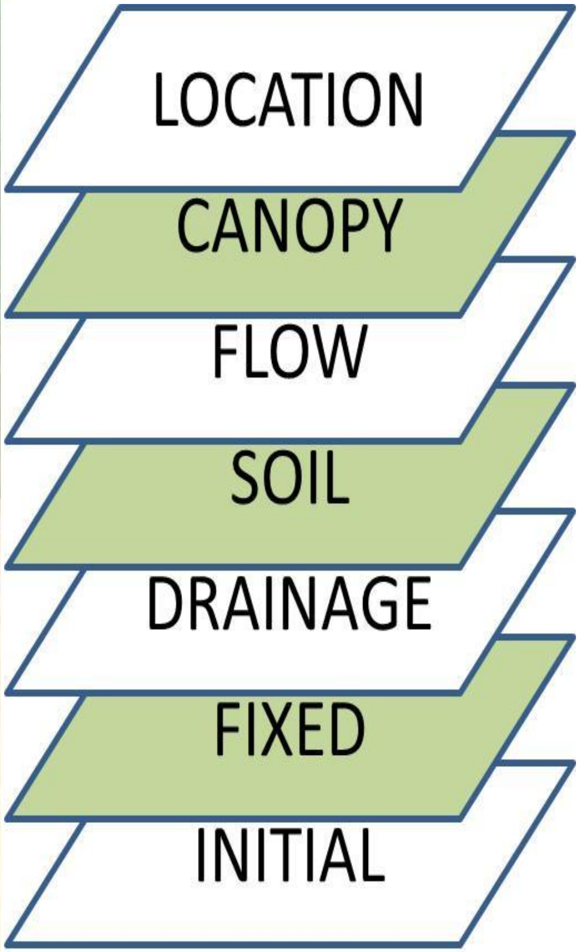
The BROOK90 Model

Federer et al., 2002



The water balance is expressed as:

P = EVAP + FLOW + SEEP



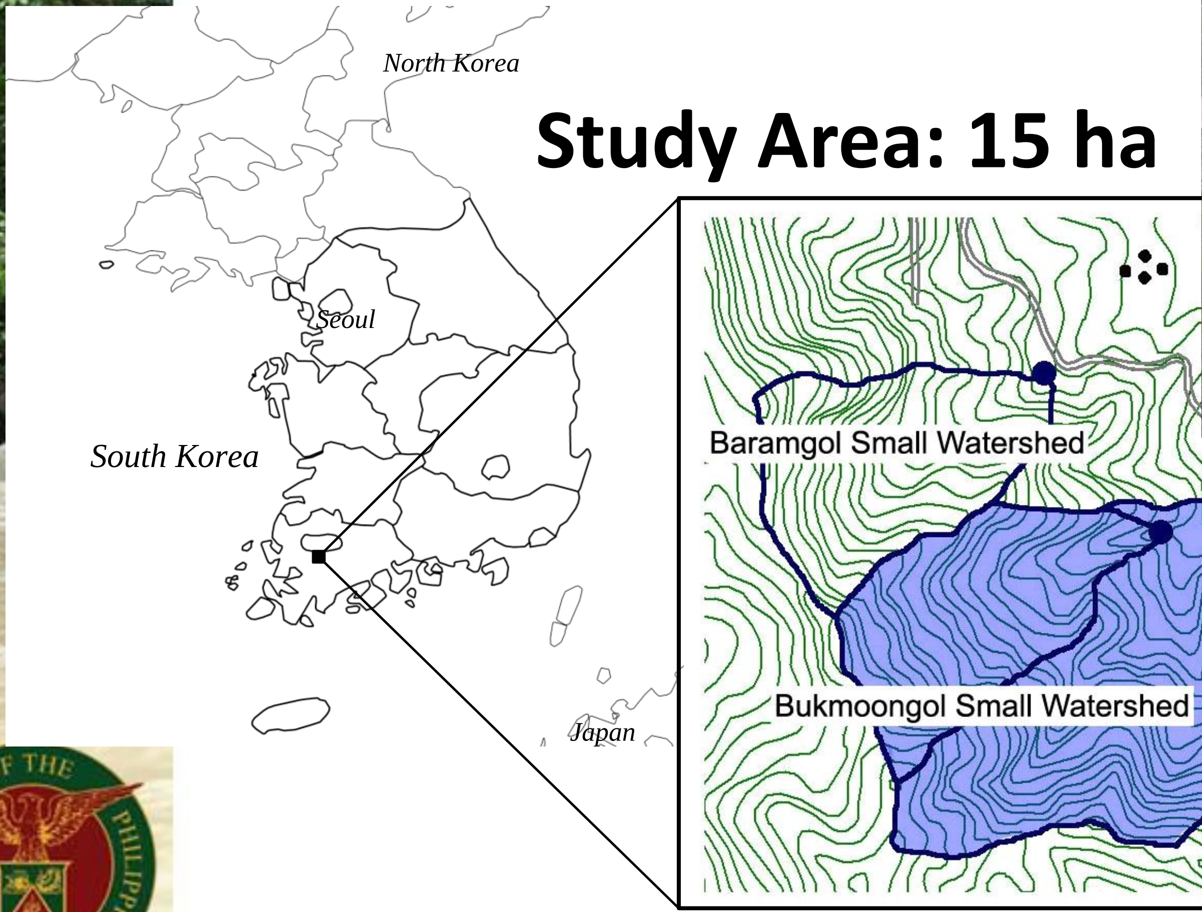
- **Evaporation:** *evaporation of intercepted rain and snow, snow and soil evaporation, and transpiration*
- **Streamflow:** *source area flow …and first-order groundwater storage*
- **Seepage:** *groundwater storage, fraction of groundwater storage…, and groundwater discharge…*

Applications…

- Grassland, temperate evergreen and deciduous forests (Federer, 2002),
- Monoculture conifer stands into mixed or pure deciduous (Armbruster *et al.*, 2004),
- Cultivated land (Wahren *et al.*, 2007),
- Silver fir-beech forest (Vilhar *et al.*, 2006),
- Mixed Norway spruce and European beech (Jost *et al.*, 2005),
- Mixed coniferous forest (Combalicer *et al.*, 2008)
- Tropical forest watershed (Combalicer *et al.*, 2010)

The mixed coniferous watershed

Study Area: 15 ha



Site Conditions

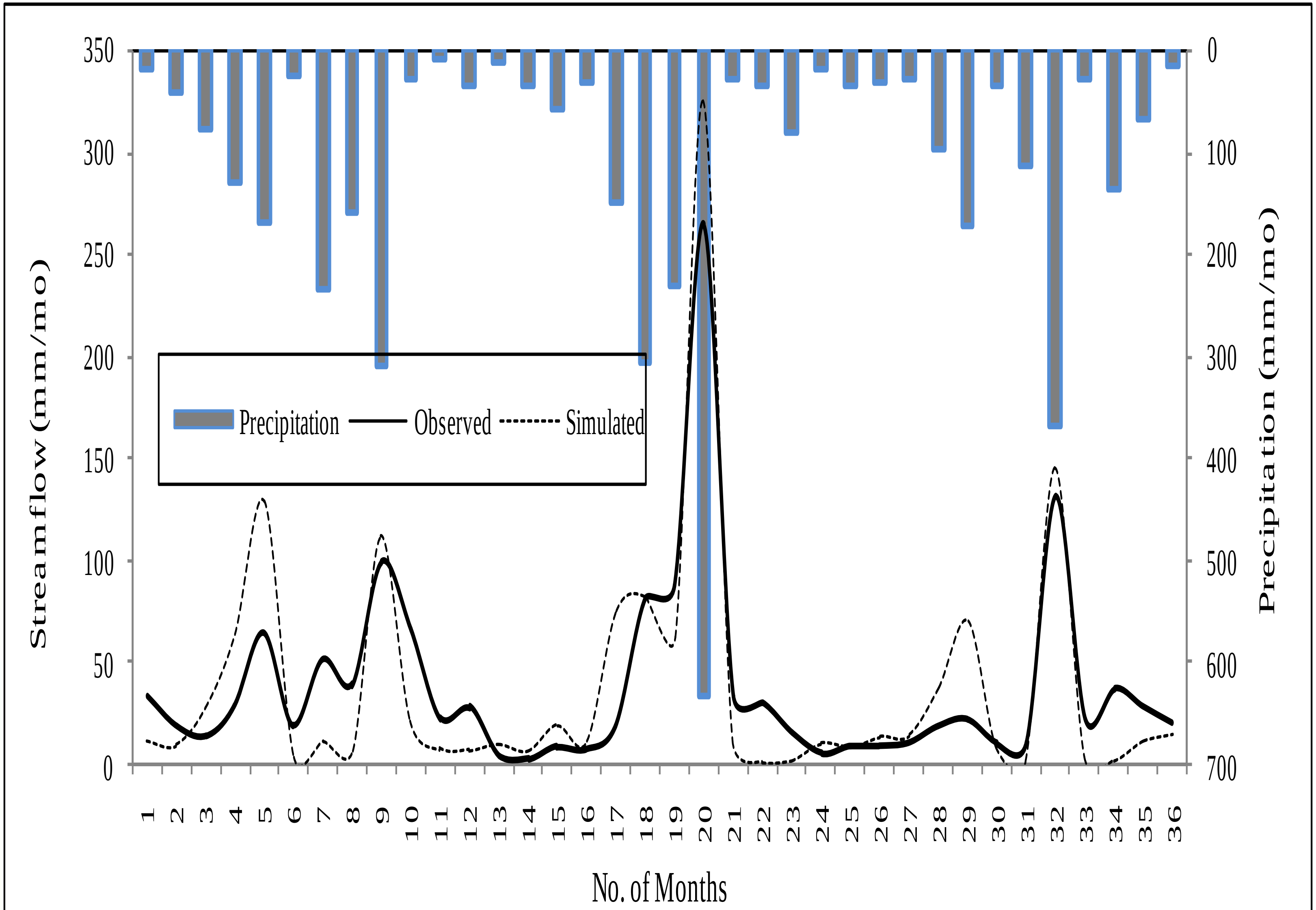
- …a temperate mixed forest of pine and deciduous trees…
- Soil… loam to clay loam in texture
- Temperature: -15.4 °C in winter (January), 30.7 °C in summer (August)
- Precipitation: 1374 mm

Canopy Parameters Evaluation

Parameters	Description	Values from literatures	Range of Values	Final Value
ALB	Albedo (f)	0.25[a] 0.09-0.15[b] 0.10 -0.20[c]	0.1 – 0.3	**0.18**
ALBSN	Surface reflectivity without and with snow on the ground (f)	0.15[a]	0.1 – 0.9	**0.23**
KSNVP	Multiplier to reduce snow evaporation, arbitrary (f)	-	0.2 – 2.0	**0.3**
Z0G	Ground surface roughness (m)	1.5[d]	≥ 0.001	**0.02**
MAXHT	Maximum canopy height for the year (m)	-	> 0.01	**25**
MAXLAI	Maximum projected LAI for the year (m^2 / m^2)	10.20[e] 7.8[e] 5.91[f]	>0.00001	**6.0**
MXRTLN	Maximum length of fine roots per unit ground area (m / m^2)	3000[h] 3500[g]	1700 - 11000	**3500**
MXKPL	Maximum plant conductivity ($mm\ d^{-1}\ MPa^{-1}$)	8[g,h]	5 - 30	**15**
FXYLEM	Fraction of the internal plant resistance to water flow that is in the xylem (f)	0.5[h]	0 – 0.99	**0.6**
CS	Ratio of projected stem area index (SAI) to HEIGHT (f)	0.035[h]	≥ 0	**0.035**
PSICR	Minimum plant leaf water potential (MPa)	-2.0[h]	-1.5 to -3.0	**-2.0**
GLMAX	Maximum leaf conductance (cm/s)	2.0[i] *0.53*[g]	0.2 - 2.0	**0.53**
LWIDTH	Average leaf width (m)	-	> 0.01	**0.05**
CR	Extinction coefficient for photosynthetically-active radiation in the canopy (f)	0.6[g]	0.5 – 0.7	**0.6**

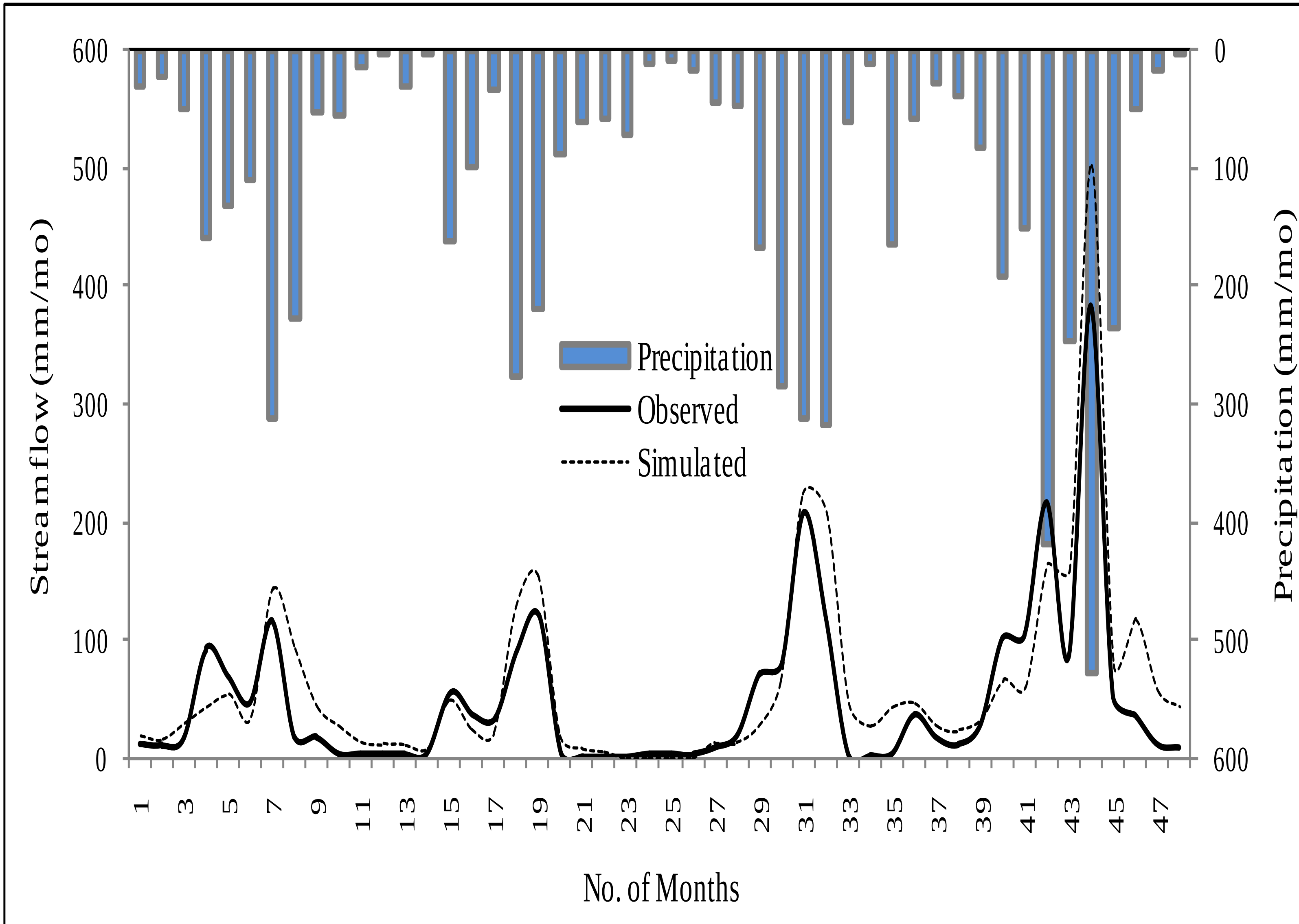
[a] *Ito & Oikawa (2002)*
[b] *http://en.wikipedia.org/wiki/Albedo#Trees*
[c] *http://scienceworld.wolfram.com/physics/Albedo.html*
[d] *Oh (1999)*
[e] *Luo et al. (2002)*
[f] *Scurlock (2001)*
[g] *Federer et al. (1996)*
[h] *Federer (2002)*
[i] *Harris et al. (2004)*

Calibration



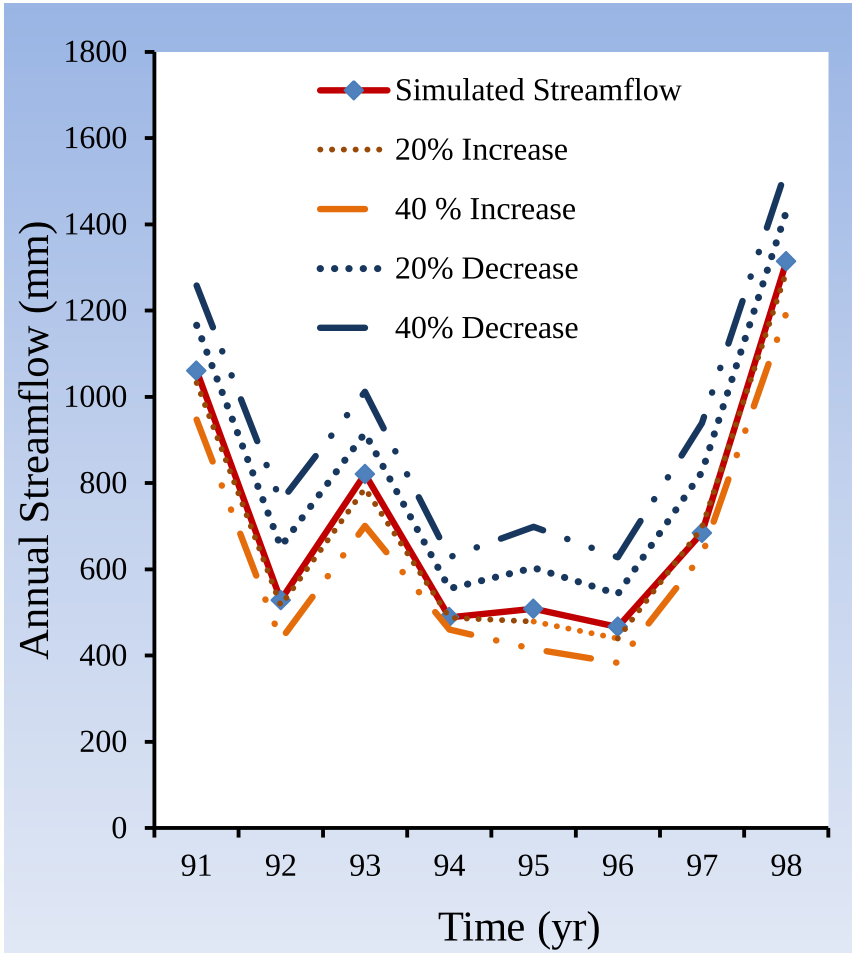
Results

Validation



Precipitation
Observed
Simulated
Streamflow (mm/mo)
Precipitation (mm/mo)
No. of Months
0
100
200
300
400
500
600
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47

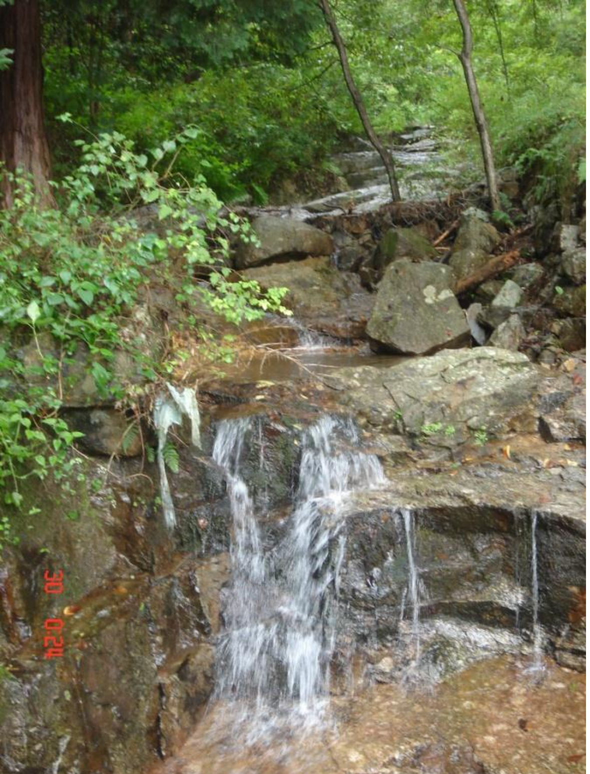
Sensitivity

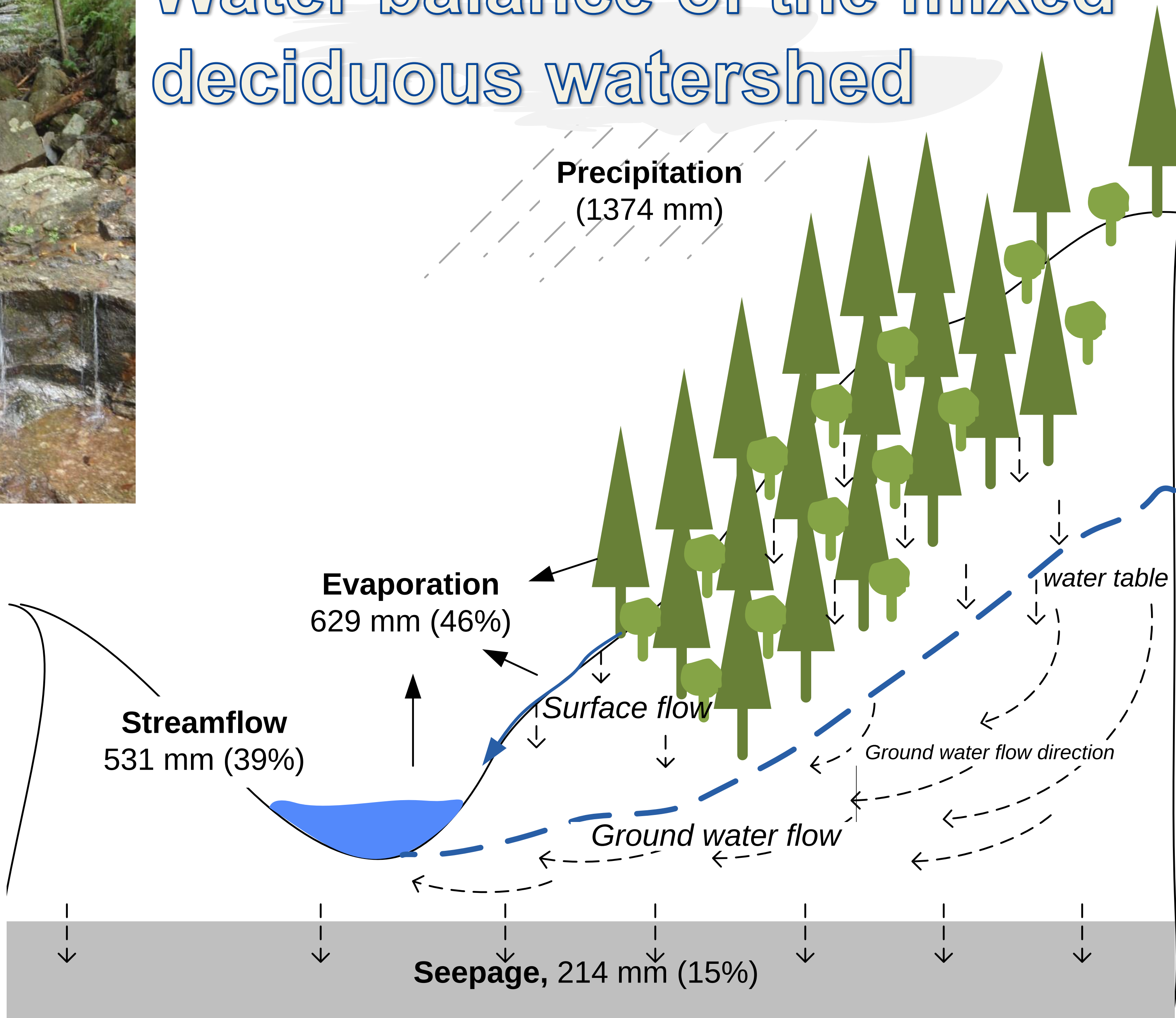


…most sensitive to:

- *canopy height,*
- *leaf area index,*
- *maximum plant conductivity,*
- *maximum length of fine roots*
- *maximum leaf conductance,*
- *avg. leaf width*

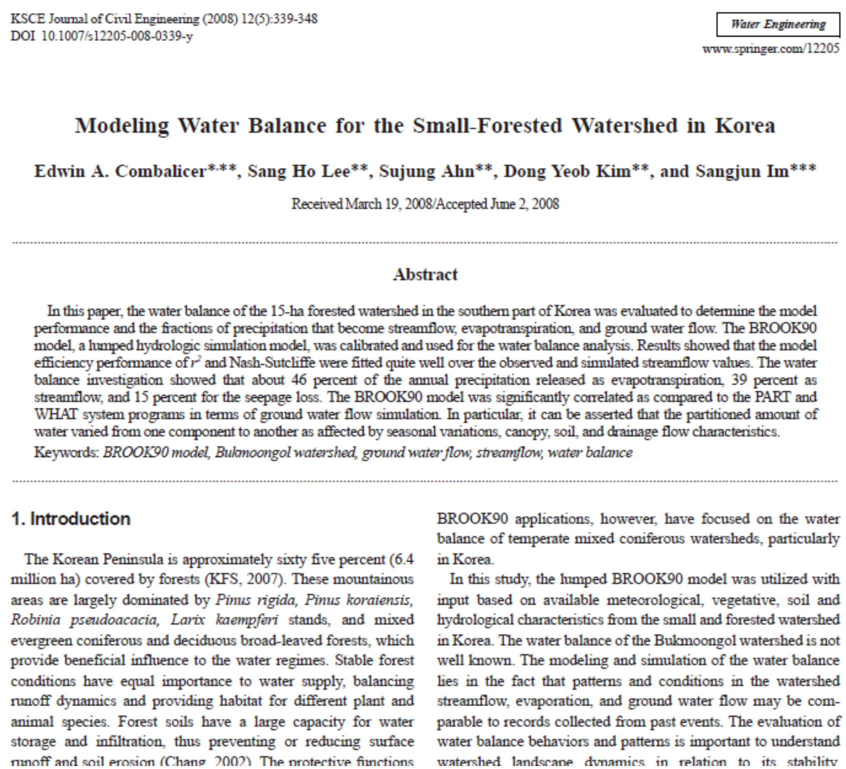
Water balance of the mixed deciduous watershed





Water Budget of the Pine/Coniferous Forest

For further details:



KSCE Journal of Civil Engineering (2008) 12(5):339-348
DOI 10.1007/s12205-008-0339-y

Water Engineering

www.springer.com/12205

Modeling Water Balance for the Small-Forested Watershed in Korea

Edwin A. Combalicer*,**, Sang Ho Lee**, Sujung Ahn**, Dong Yeob Kim**, and Sangjun Im***

Received March 19, 2008/Accepted June 2, 2008

Abstract

In this paper, the water balance of the 15-ha forested watershed in the southern part of Korea was evaluated to determine the model performance and the fractions of precipitation that become streamflow, evapotranspiration, and ground water flow. The BROOK90 model, a lumped hydrologic simulation model, was calibrated and used for the water balance analysis. Results showed that the model efficiency performance of r^2 and Nash-Sutcliffe were fitted quite well over the observed and simulated streamflow values. The water balance investigation showed that about 46 percent of the annual precipitation released as evapotranspiration, 39 percent as streamflow, and 15 percent for the seepage loss. The BROOK90 model was significantly correlated as compared to the PART and WHAT system programs in terms of ground water flow simulation. In particular, it can be asserted that the partitioned amount of water varied from one component to another as affected by seasonal variations, canopy, soil, and drainage flow characteristics.

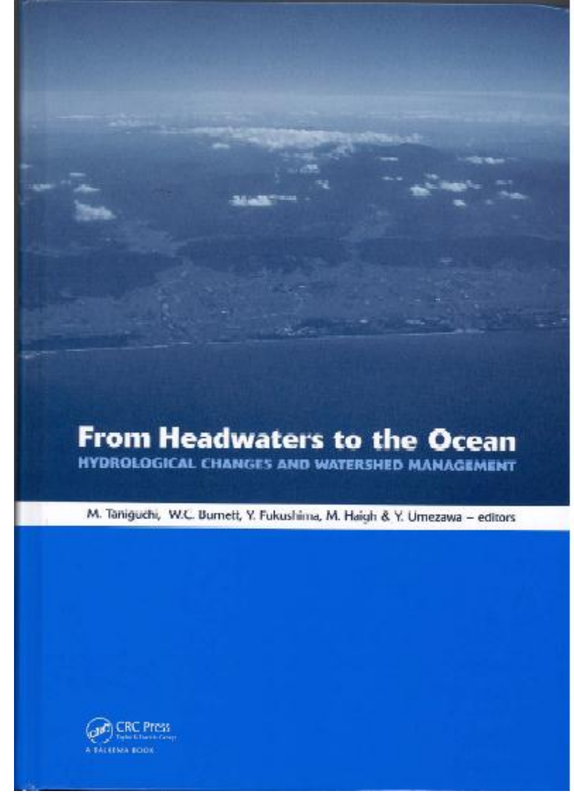
Keywords: *BROOK90 model, Bukmoongol watershed, ground water flow, streamflow, water balance*

1. Introduction

The Korean Peninsula is approximately sixty five percent (6.4 million ha) covered by forests (KFS, 2007). These mountainous areas are largely dominated by *Pinus rigida, Pinus koraiensis, Robinia pseudoacacia, Larix kaempferi* stands, and mixed evergreen coniferous and deciduous broad-leaved forests, which provide beneficial influence to the water regimes. Stable forest conditions have equal importance to water supply, balancing runoff dynamics and providing habitat for different plant and animal species. Forest soils have a large capacity for water storage and infiltration, thus preventing or reducing surface runoff and soil erosion (Chang, 2002). The protective functions

BROOK90 applications, however, have focused on the water balance of temperate mixed coniferous watersheds, particularly in Korea.

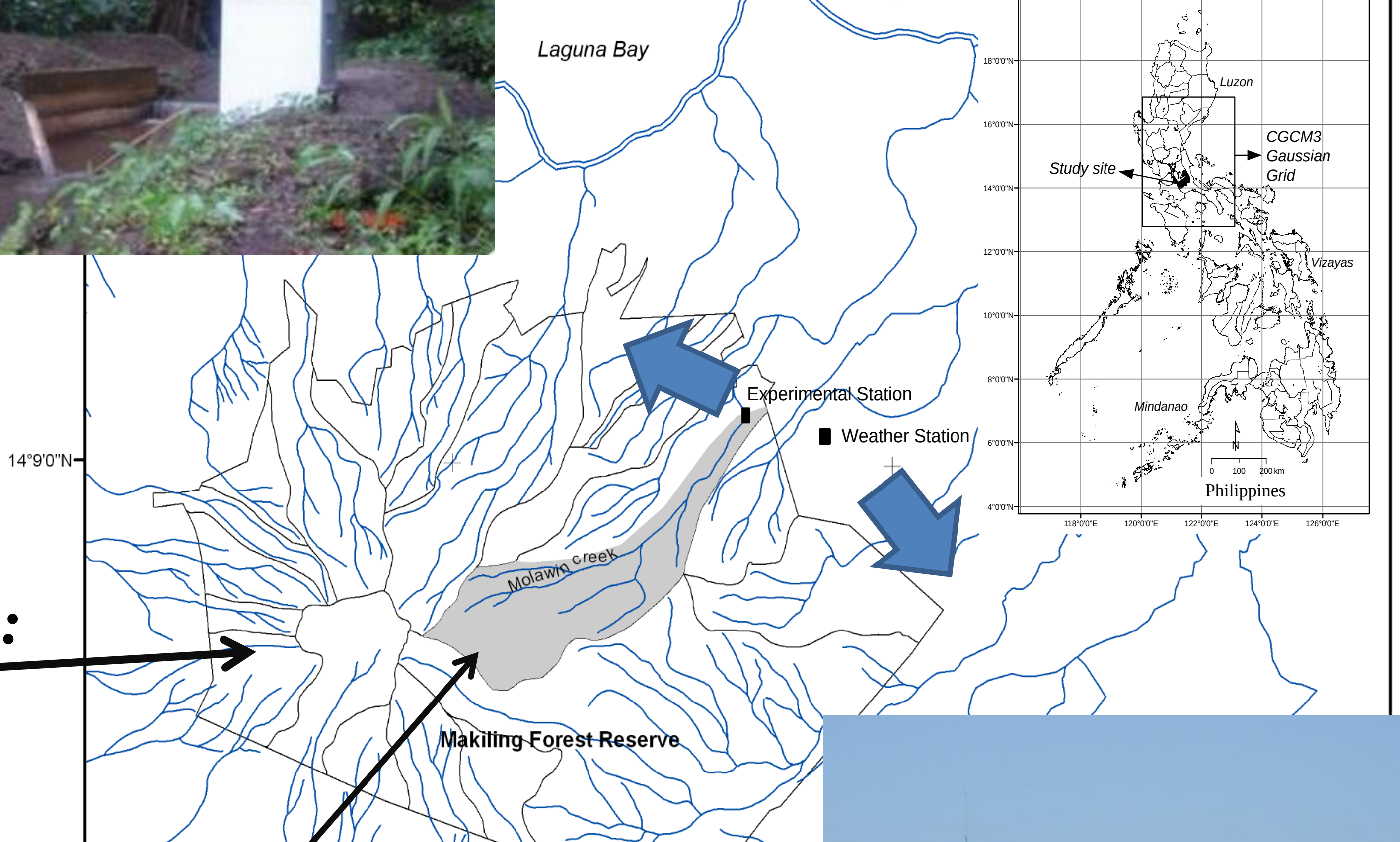
In this study, the lumped BROOK90 model was utilized with input based on available meteorological, vegetative, soil and hydrological characteristics from the small and forested watershed in Korea. The water balance of the Bukmoongol watershed is not well known. The modeling and simulation of the water balance lies in the fact that patterns and conditions in the watershed streamflow, evaporation, and ground water flow may be comparable to records collected from past events. The evaluation of water balance behaviors and patterns is important to understand watershed landscape dynamics in relation to its stability



1. **Combalicer, E.A.**, Lee, S.H., Ahn, S., Kim, D.Y. and Im, S. 2008. Modeling the water balance for the small-forested watershed in Korea. *KSCE Journal of Civil Engineering* 12(5): 339-348.

2. **Combalicer, E.A.**, Lee, S.H., Ahn, S., Kim, D.Y. and Im, S. *Simulating water balance of the small-forested watershed using BROOK90 model.* From headwaters to the ocean: Hydrological changes and management. Taniguchi, M. Burnett, W.C., Fukushima, Y., Haigh, M. and Umezawa, Y. (eds). Taylor and Francis Group, London, UK. 181-186p. 2009.

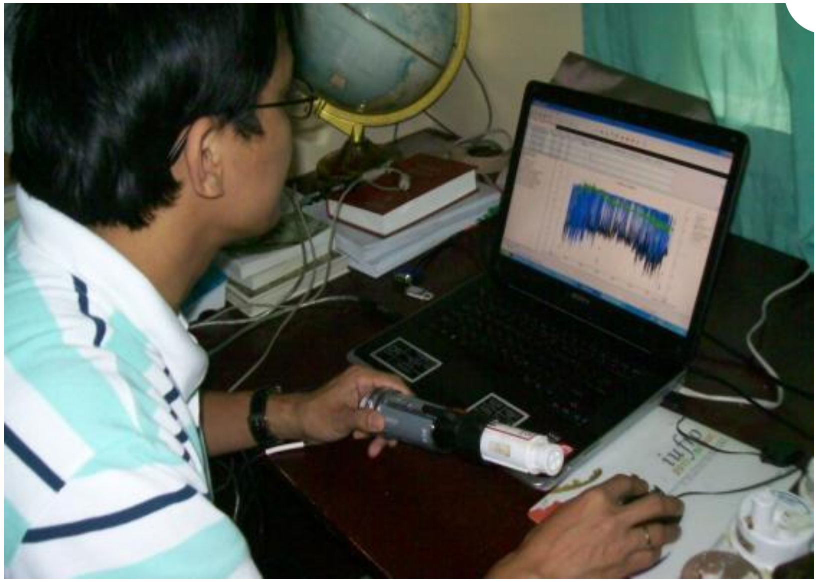
The Makiling Forest Reserve



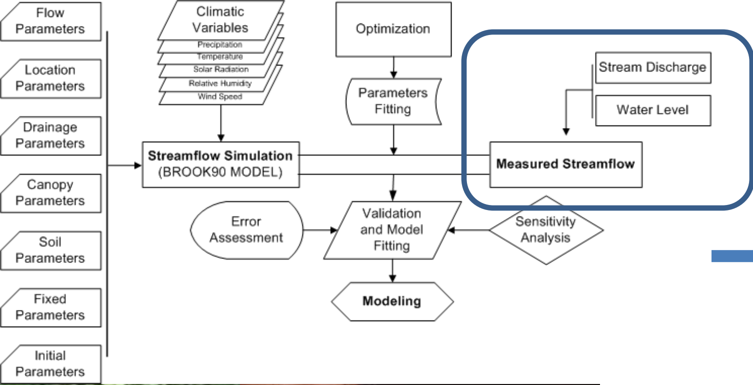
MFR Area:
4,346 ha

Molawin watershed area: 377 ha

Data collection…6-yr data



UNIVERSITY OF THE PHILIPPINES 1908



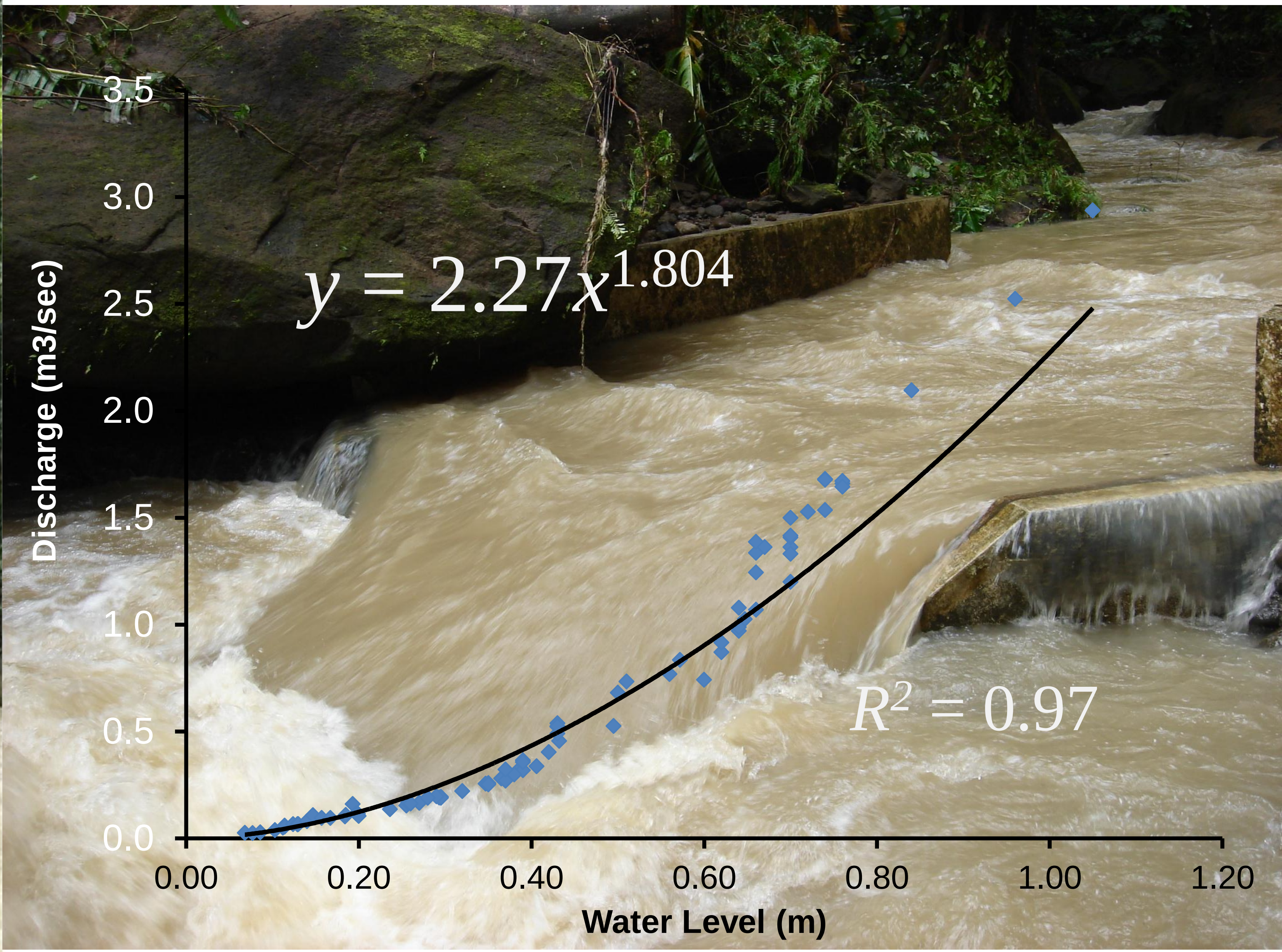
Measured Streamflow

Discharge: f(Area, Velocity)

Water Level: OTT Thalimedes

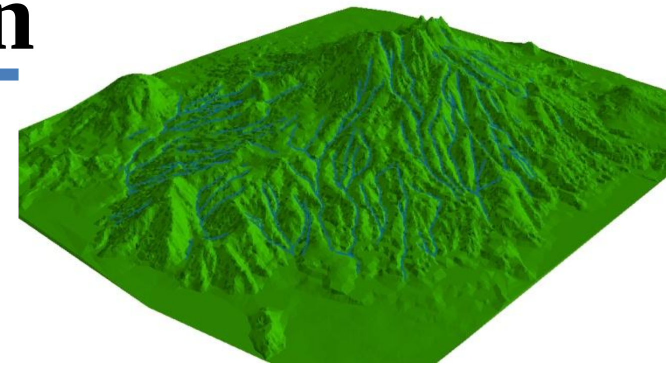
Water Velocity

- digital flow probe
- water levels



Rating curve of the forest watershed

Parameter estimation

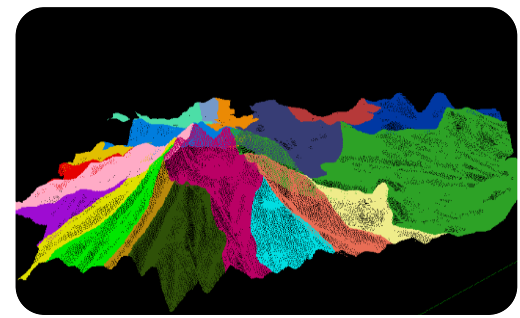


Flow variables

- *Based on geomorphological characteristics of the watershed…*

Canopy variables

- *from published documents, direct observations and remote sensing data*



Soil variables

- *Field survey*
- *Samples were collected from soil layers*
- *Empirical Eqn: Clapp and Hornberger (1978), and Saxton (2006)*

Model's Performance

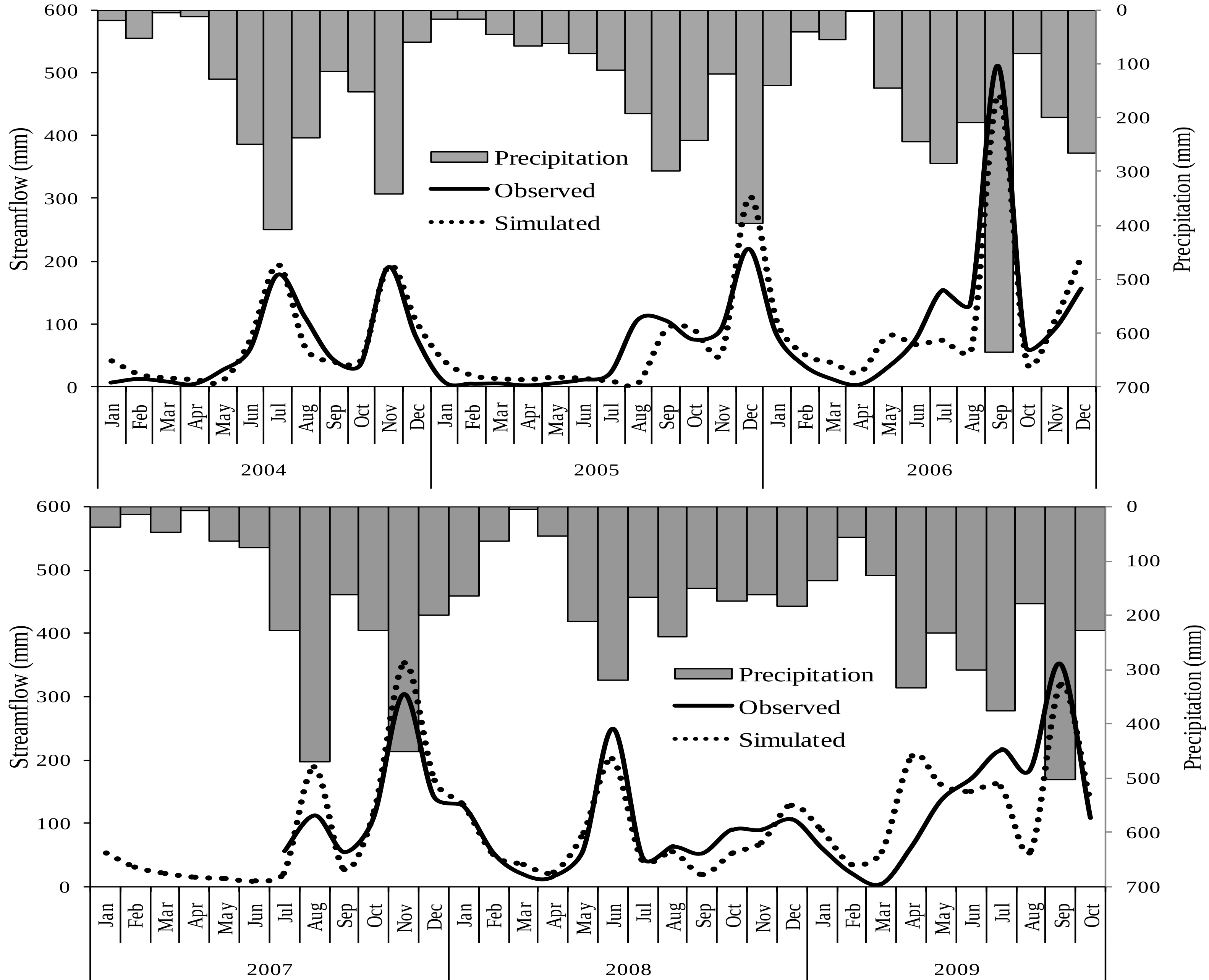
Hydrologic modeling: BROOK90

Measured vs. simulated streamflow

Efficiency Criteria (BROOK90):

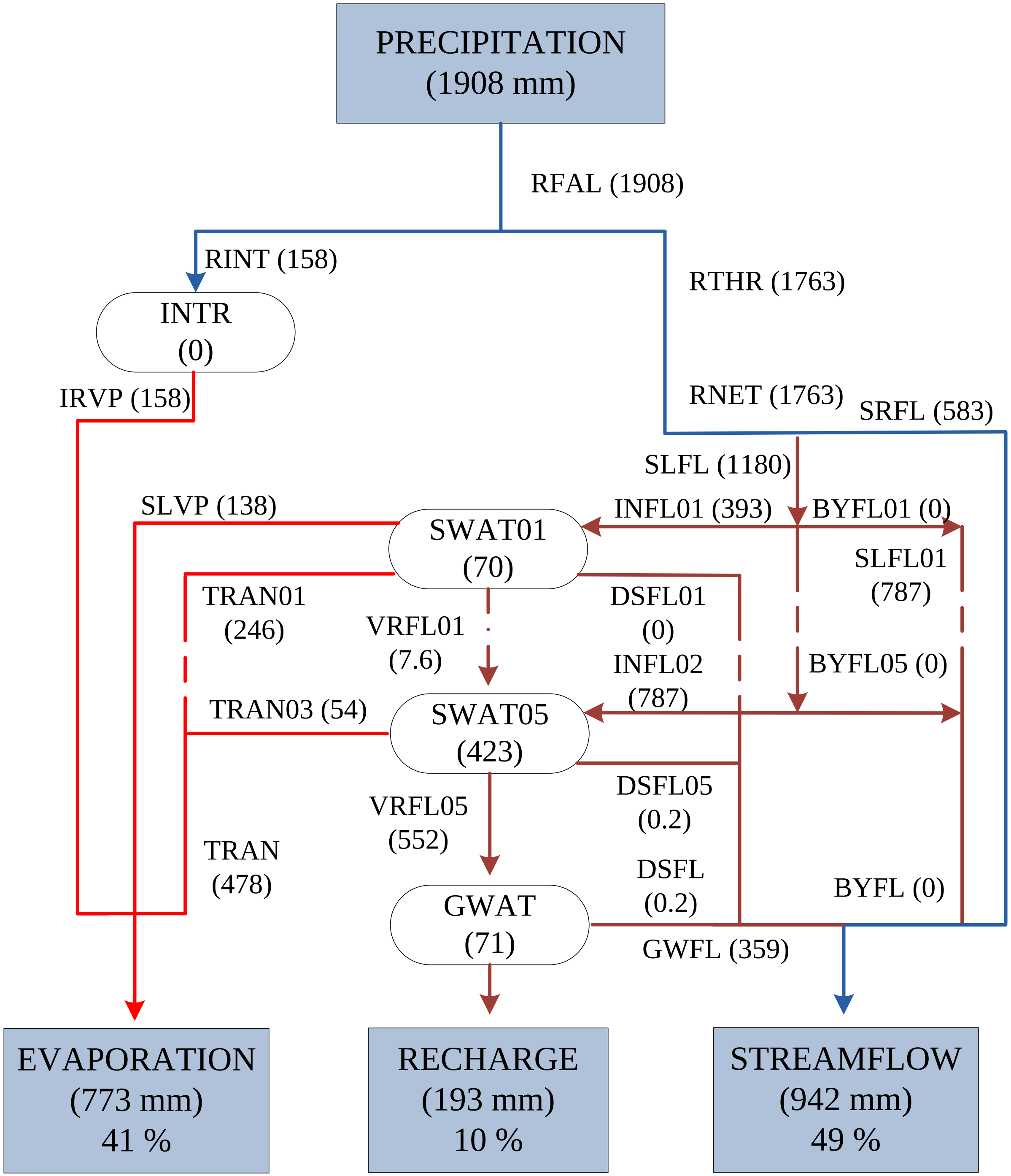
- Coefficient of Determination (R^2)
- Nash-Sutcliffe Coefficient (E)
- Root Mean Square Error (RMSE)
- Mean Absolute Relative Error (MARE)

Hydrologic Modeling



Streamflow simulations for the forest watershed during calibration (a) and validation (b) periods

Illustrative distribution and partitioning of different hydrologic processes (2004-2009)



Comparison of annual estimates for various hydrologic processes in different tropical rainforest watersheds.

Location	Hydrologic process						Source
	Rainfall (mm)	Flow (mm)	Interception loss (mm)	ET (mm)	TRAN (mm)	Seepage / Storage (mm)	
Molawin watershed, Philippines (2004-2009)	1908	942 (49%)	158 (8%)	773 (41%)	478 (25%)	193 (10%)	The present study
Forested watersheds in central Taiwan	2500	1300 (52%)	450 (18%)	1200 (48%)	650 (26%)		Cheng *et al.* (2002)
A rain forest region of eastern Amazonia, Brazil (1992-1993)	2706		406 (15%)	1350 (50%)			Klinge *et al.* (2001)
Lien-Hua-Chi watershed, central Taiwan (1990-1991)	2708		307 (11%)				Lu & Tang (1995)
Sapulut watershed, Malaysia (1991-1992)	2418 - 2222		504 – 473 (21%)				Kuraji (1996)
Sungai Jelai watershed, Peninsular, Malaysia (1973-1985)	2058	748 (36%)		1014 (49%)		296 (14%)	Mun (1987)
Janlappa nature reserve, West Java, Indonesia (1980-1981)	2833		595 (21%)	1481 (52%)	886 (31%)		Calder *et al.* (1986)

Tropical watersheds average losses of water are in the range of 36 – 52% for streamflow, 8 – 21% for interception, 41 – 52% equivalent to ET, 25 – 31% for transpiration, and 10 – 14% into a recharge

Journal of Tropical Forest Science 22(2): 155–169 (2010) *Combalicer EA et al.*

MODELLING HYDROLOGIC PROCESSES DISTRIBUTION IN A TROPICAL FOREST WATERSHED IN THE PHILIPPINES

EA Combalicer[1, *], RVO Cruz[2], SH Lee[1] & S Im[1, **]

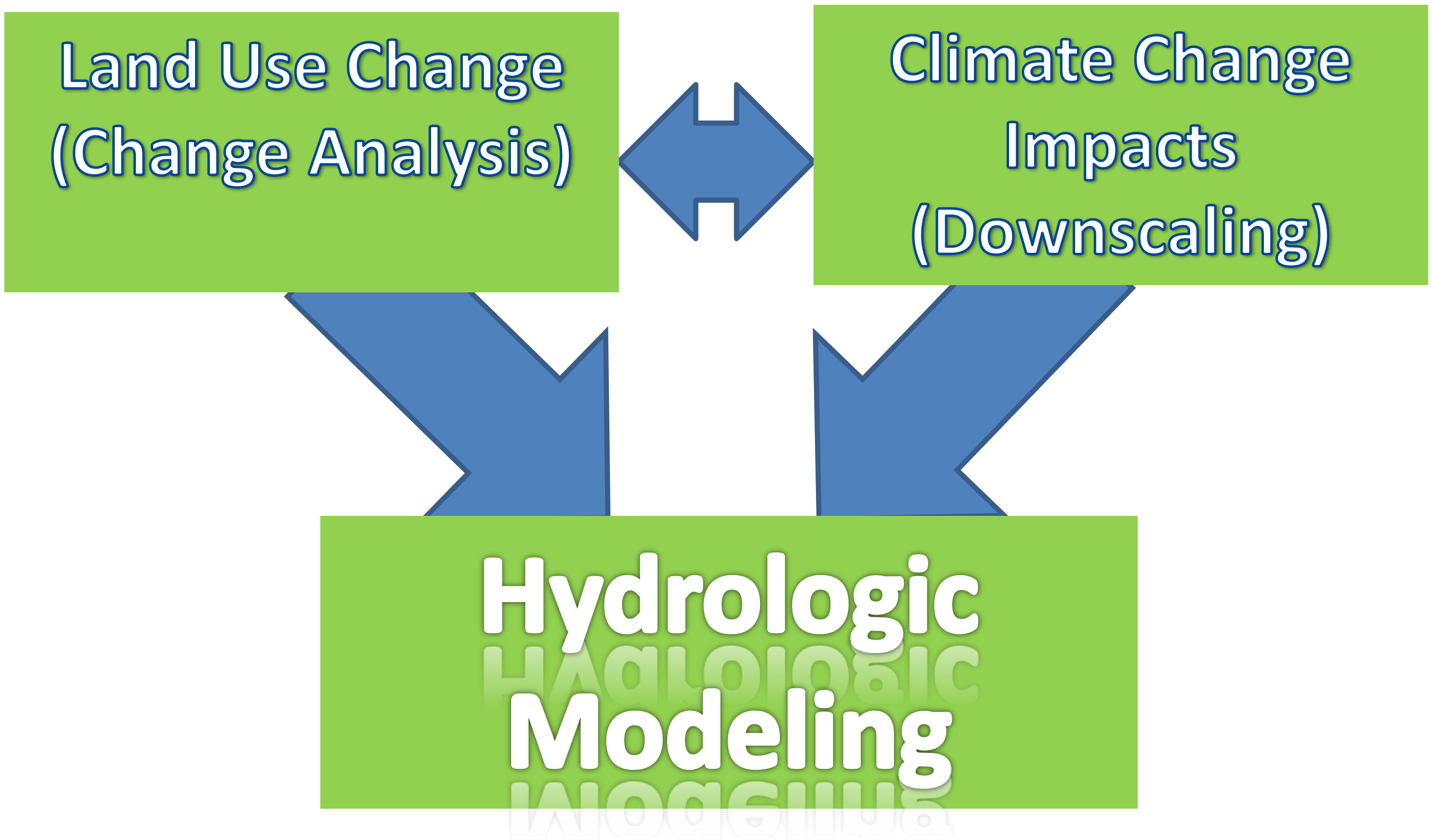
[1]*Department of Forest Sciences, College of Agriculture and Life Sciences, Research Institute for Agriculture and Life Sciences, Seoul National University, 599 Gwanak-ro, Gwanak-gu, Seoul, 151-921, Korea*
[2]*College of Forestry and Natural Resources, University of the Philippines Los Banos, College, Laguna, Philippines*

Received February 2009

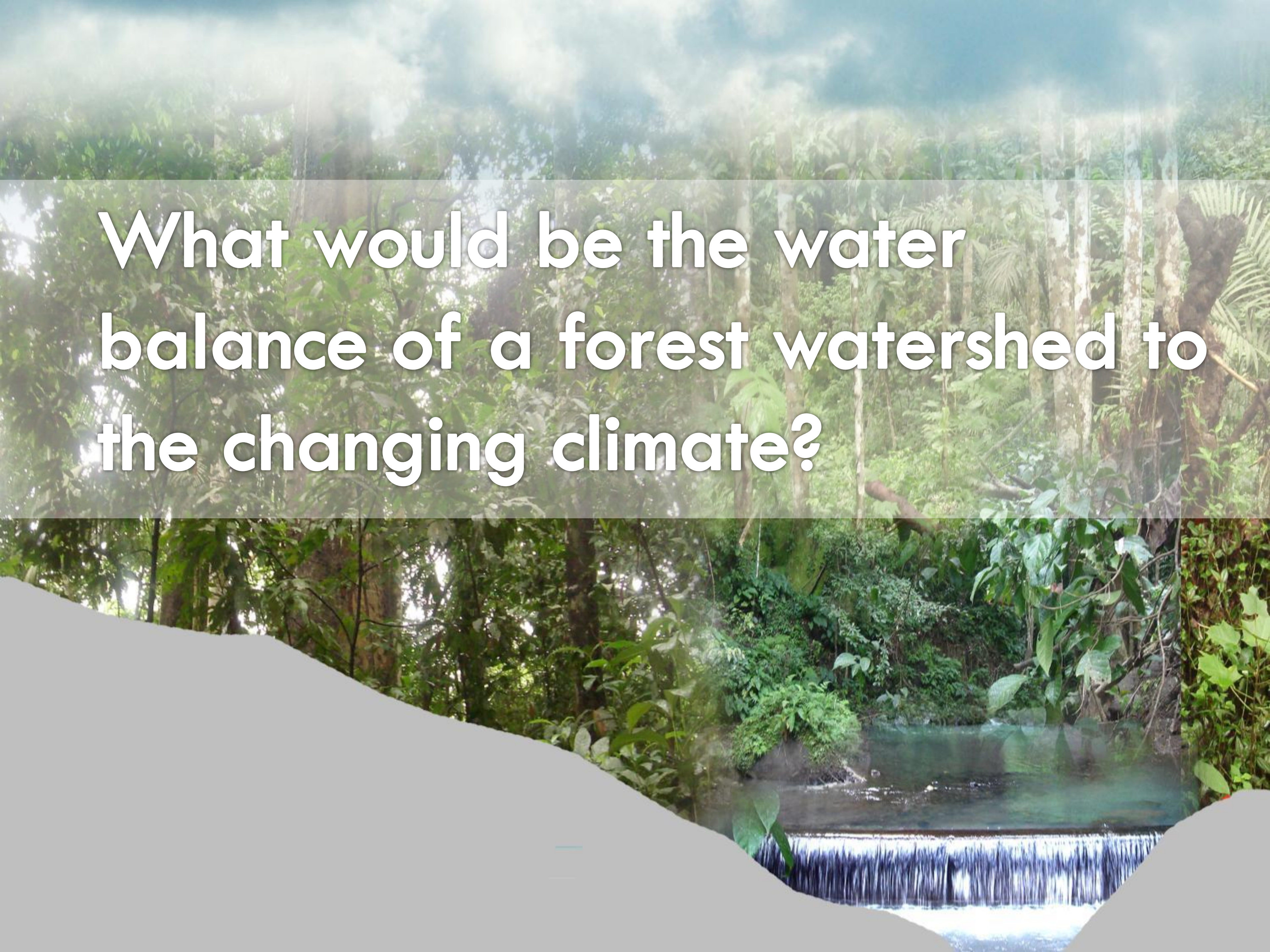
COMBALICER EA, CRUZ RVO, LEE SH & IM S. 2010. Modelling hydrologic processes distribution in a tropical forest watershed in the Philippines. Hydrologic modelling has become an indispensable tool and cost-effective process in understanding the movement of water loss in the Molawin rainforest watershed, Philippines. The study aimed to optimise the use of a lumped BROOK90 model and simulate the hydrologic processes distribution in a given watershed. The rating curve model was developed as a basis for hydrologic modelling. The model was calibrated at catchment scale to avoid subjectivity of various variable parameters by considering the topography, morphology, climate, soil and canopy characteristics. Five years of streamflow discharge measurements were considered for the model sensitivity analysis, calibration and validation. Results showed a good agreement between observed and simulated streamflows during calibration (r = 0.87 and E = 0.87) and validation (r = 0.84 and E = 0.81) periods. As a consequence, the major hydrologic processes distribution accounted for 41% of the precipitation that turned into evaporation, while 49% became streamflow and 10% remained in deep seepage loss. Overall, the distribution of hydrologic components is primarily reflected during pronounced seasonal variations and fluctuating patterns in precipitation.

Keywords: BROOK90 model, lumped model, Molawin watershed, precipitation partitioning, water loss

Availability: http://info.frim.gov.my/cfdocs/infocenter_application/jtfsonline/jtfs/v22n2/155-169.pdf

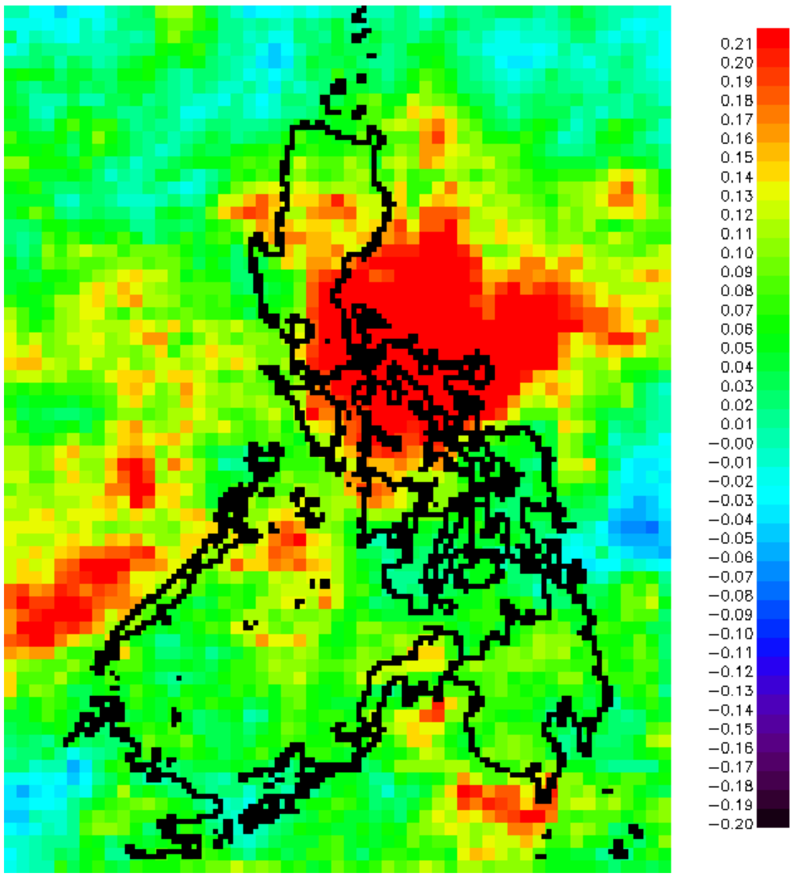

Land Use Change
(Change Analysis)
Climate Change
Impacts
(Downscaling)
Hydrologic
Modeling

What would be the water balance of a forest watershed to the changing climate?

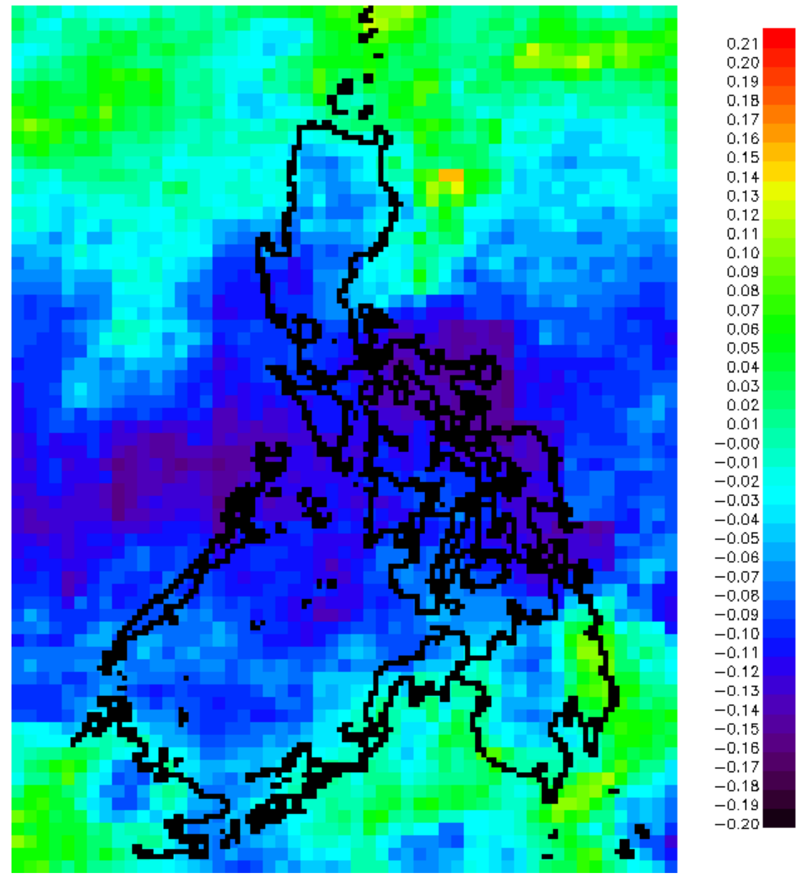


Rainfall Anomaly

Summer 2009

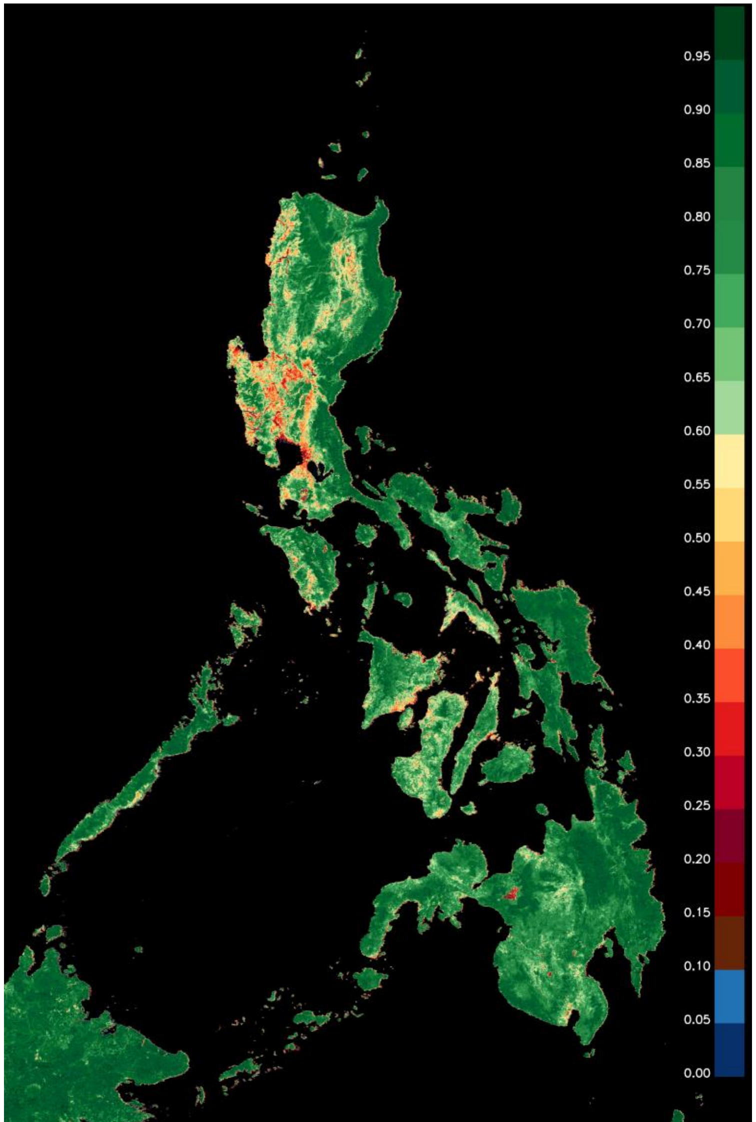


Summer 2010

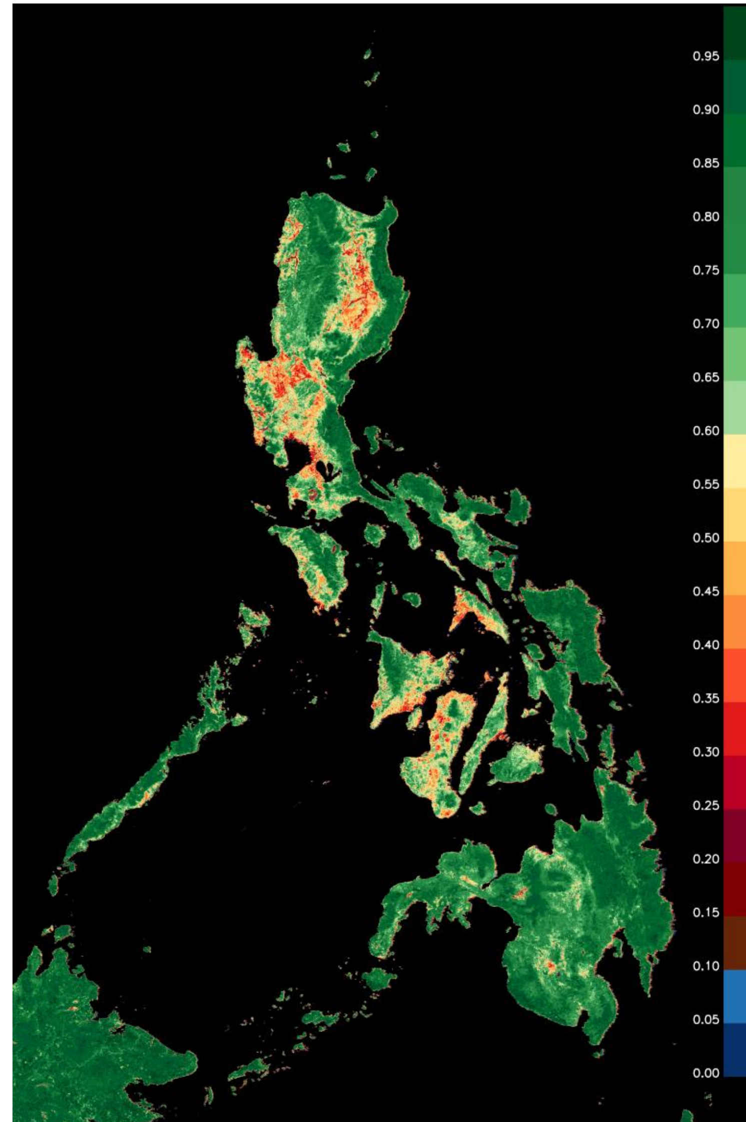


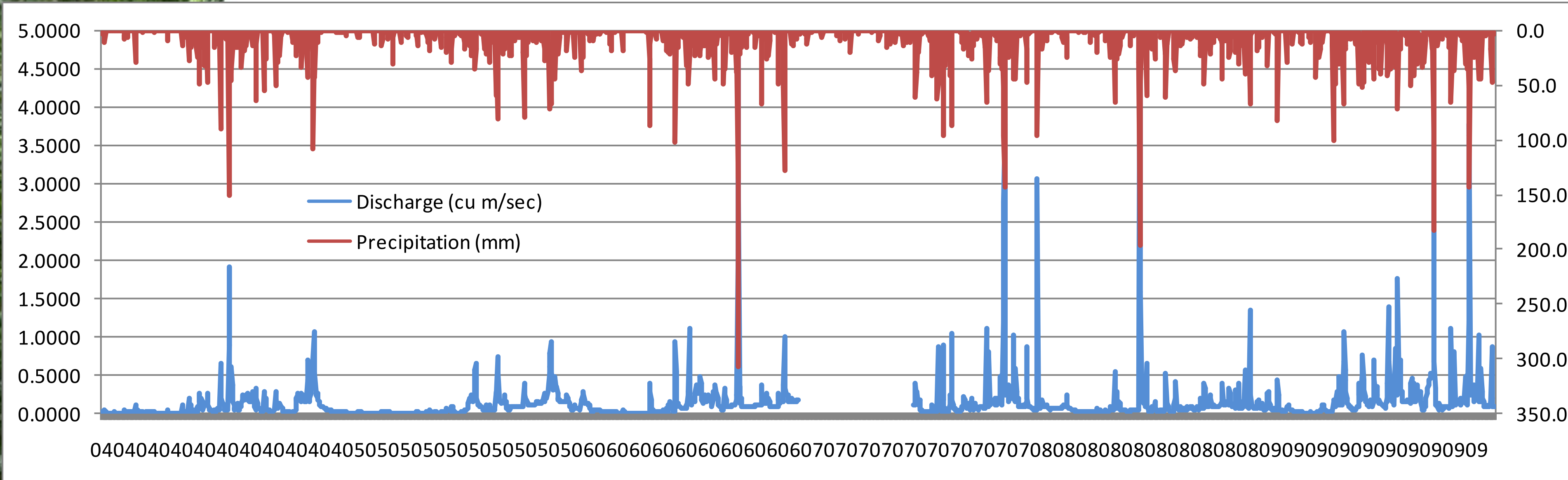
Vegetation Index

May 2002

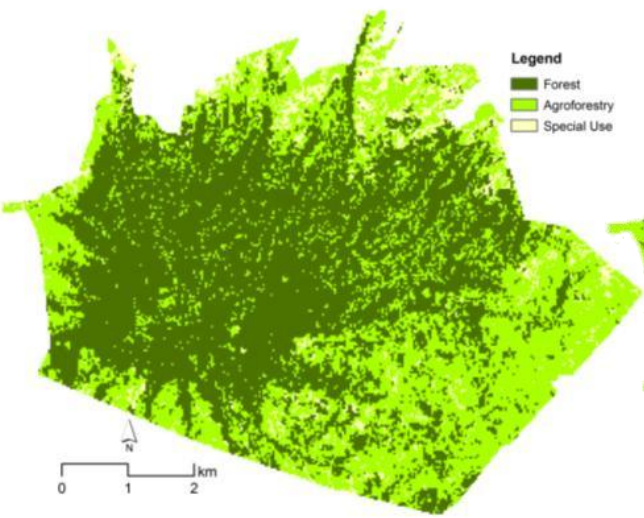


May 2010

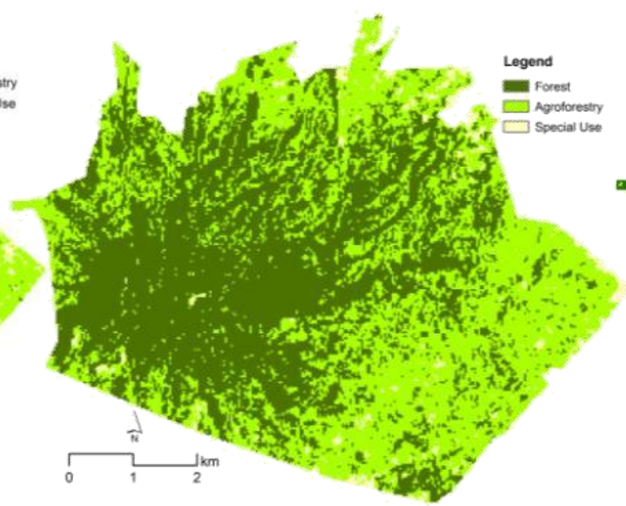




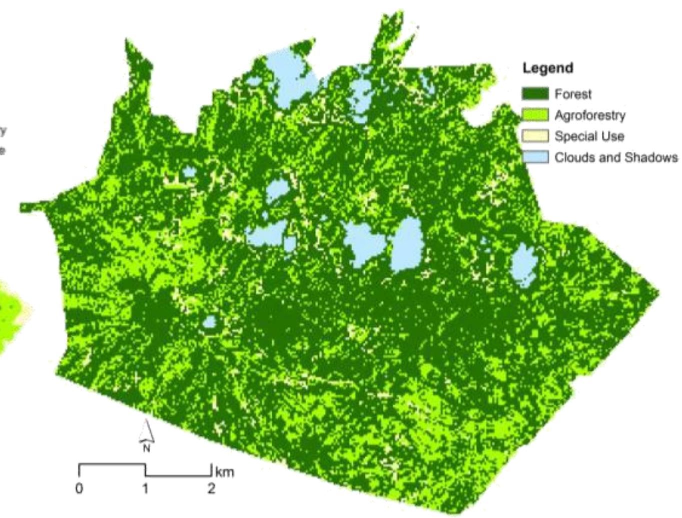
Mt. Makiling Forest Reserve



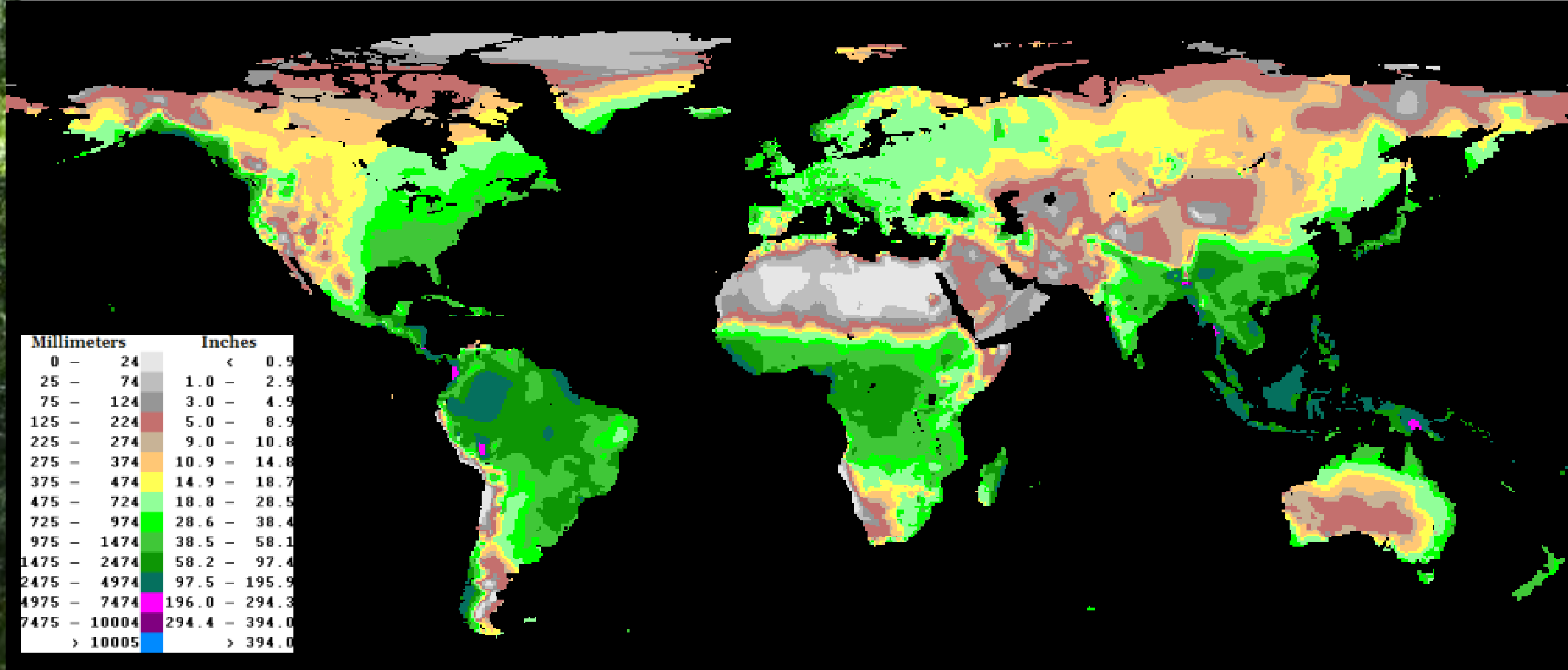
1993



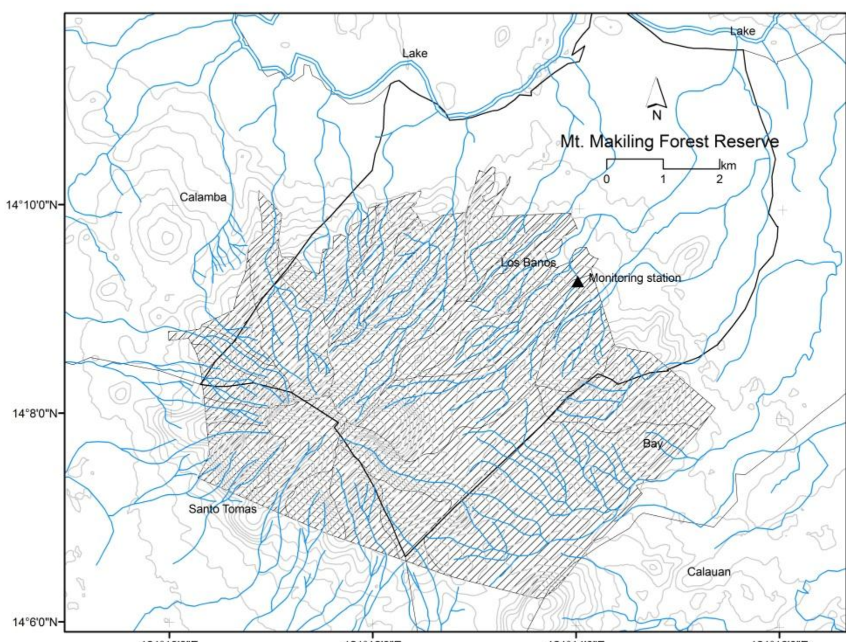
2002

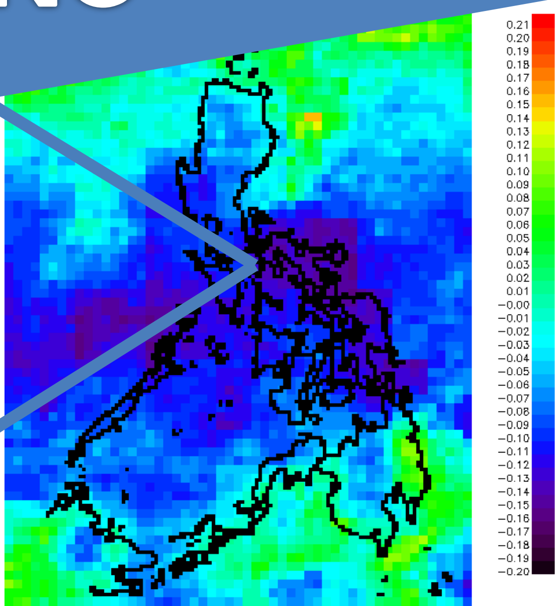


2008


Millimeters
Inches
0 – 24 < 0.9
25 – 74 1.0 – 2.9
75 – 124 3.0 – 4.9
125 – 224 5.0 – 8.9
225 – 274 9.0 – 10.8
275 – 374 10.9 – 14.8
375 – 474 14.9 – 18.7
475 – 724 18.8 – 28.5
725 – 974 28.6 – 38.4
975 – 1474 38.5 – 58.1
1475 – 2474 58.2 – 97.4
2475 – 4974 97.5 – 195.9
4975 – 7474 196.0 – 294.3
7475 – 10004 294.4 – 394.0
> 10005 > 394.0

ALING


Lake
Lake
N
Mt. Makiling Forest Reserve
0 1 2 km
Calamba
Los Baños
Monitoring station
Bay
Santo Tomas
Calauan
14°10'0"N
14°8'0"N
14°6'0"N
121°10'0"E
121°12'0"E
121°14'0"E
121°16'0"E


0.21
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
−0.00
−0.01
−0.02
−0.03
−0.04
−0.05
−0.06
−0.07
−0.08
−0.09
−0.10
−0.11
−0.12
−0.13
−0.14
−0.15
−0.16
−0.17
−0.18
−0.19
−0.20

Model: CGCM3 A2 -4 Experiment

(Flato *et al.*, 2005)

- 3rd Generation Coupled Global Climate Model (CGCM3)
- 4th member of the IPCC Fourth Assessment Report forcing scenario…
- …25 predictors
- Data access: http://gaia.ouranos.ca/DAI/predictors-e.html
- Predictor variables are supplied on a grid box: the study area grid box (33X - 21Y)

CGCM3 Scenarios…

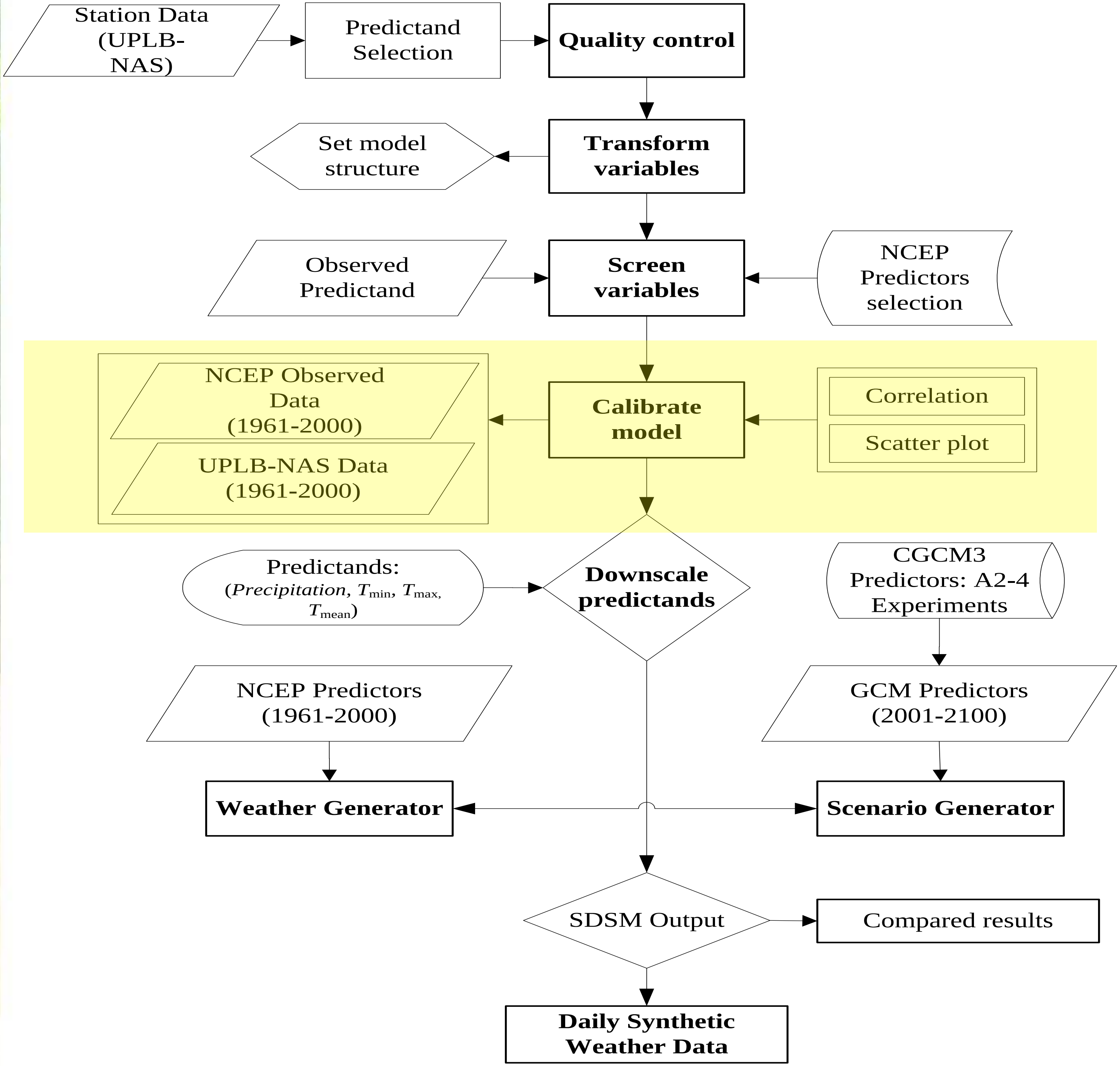
A1B

- Rapid economic growth
- Low pop'n growth
- Efficient technology

A2

- Low economic growth
- High pop'n growth
- Low technological change

Statistical DownScaling Model



Climate Change Impacts (Downscaling)

↓

Hydrologic Modeling

Model's Performance

Downscaling: SDSM

Observed predictands vs. simulated predictands

Efficiency Criteria (SDSM):

- *Coefficient of Determination (R^2)*
- *Nash-Sutcliffe Coefficient (E)*
- *Root Mean Square Error (RMSE)*
- *Mean Absolute Relative Error (MARE)*

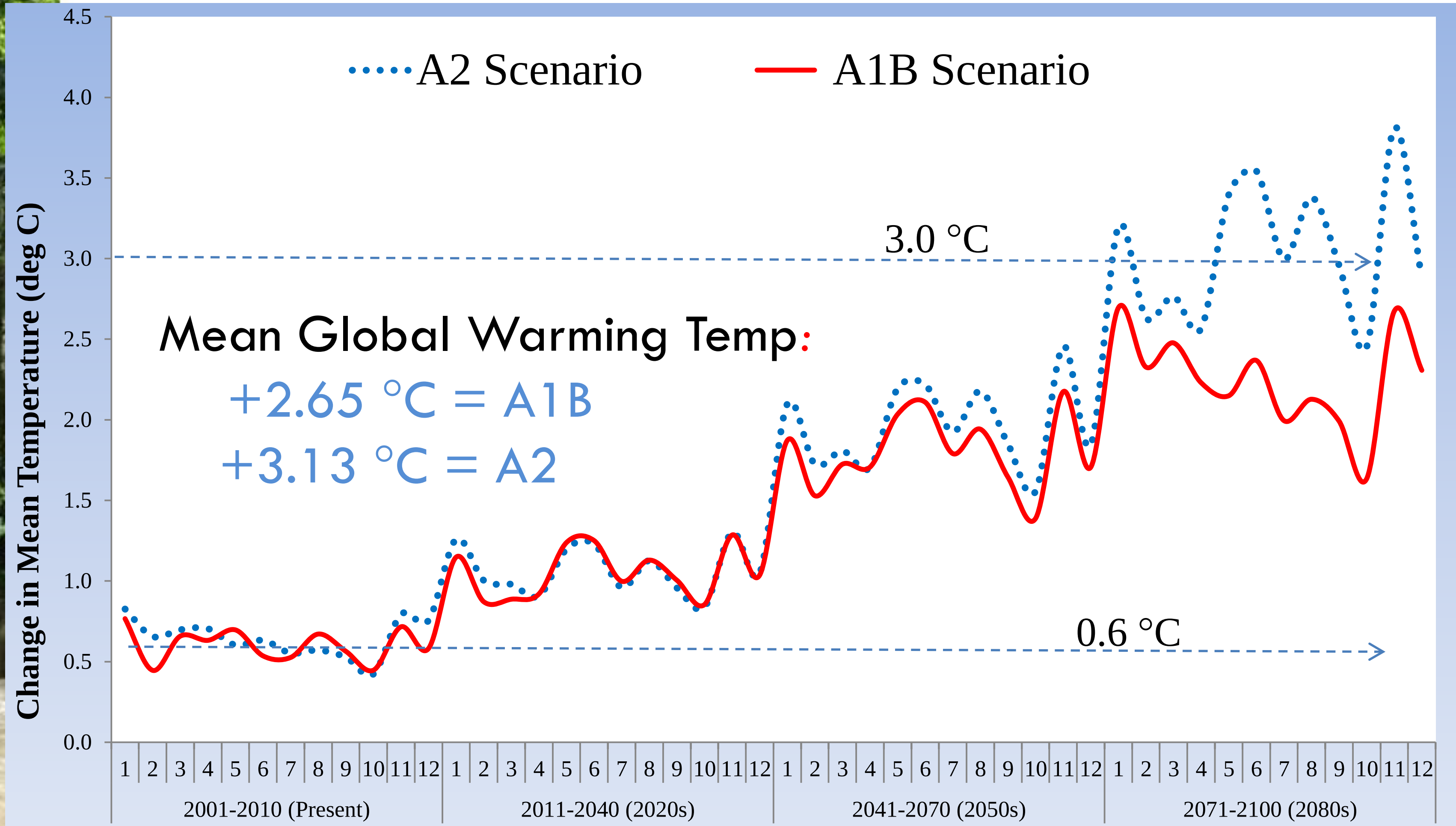
Selected predictors from NCEP and CGCM3 datasets with high monthly correlation

Predictors code	Description	Predictand		
		Precipitation	T_{max}	T_{min}
p__f	1000hPa Wind Speed	x	x	
p5_z	500hPa Vorticity		x	
p500	500hPa Geopotential	x	x	
p5th	500hPa Wind Direction	x		
p8_f	850hPa Wind Speed	x		
p850	850hPa Geopotential	x		
s500	500hPa Specific Humidity	x		
shum	1000hPa Specific Humidity		x	x
temp	Temperature at 2m	x	x	x

The SDMS performance for downscaling precipitation and temperatures using NCEP and CGMC3 predictors and observed predictands during calibration (1961-1990) and validation (1991-2000) periods

Performance criteria	Precipitation		*T*max		*T*min	
	Cal	Val	Cal	Val	Cal	Val
Predictors: NCEP						
R^2	0.94	0.89	1.00	0.97	1.00	0.98
E	0.90	0.89	1.00	0.77	1.00	0.87
RMSE	1.11	1.37	0.03	0.31	0.01	0.15
MARE	1.16	1.47	1.03	1.06	1.05	1.06
Predictors: CGCM3						
R^2	0.88	0.94	0.99	0.96	0.98	0.97
E	0.79	0.94	0.98	0.71	0.97	0.89
RMSE	1.51	1.01	0.20	0.37	0.14	0.21
MARE	1.15	1.40	1.03	1.06	1.04	1.06

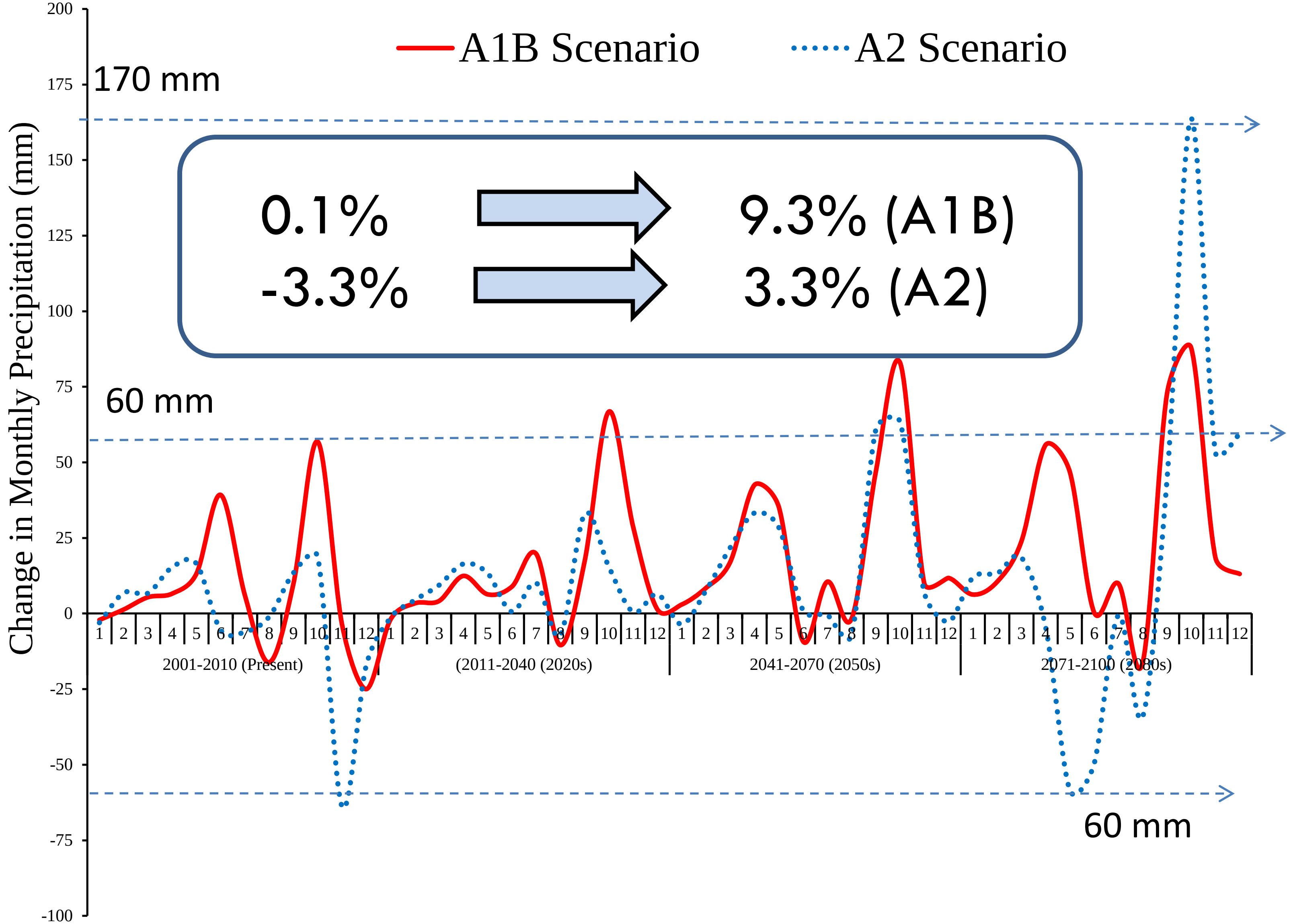
Downscaling ....Temperature



A1B	0.6 °C	1.1 °C	1.8 °C	2.2 °C
A2	0.6 °C	1.1 °C	2.0 °C	3.0 °C

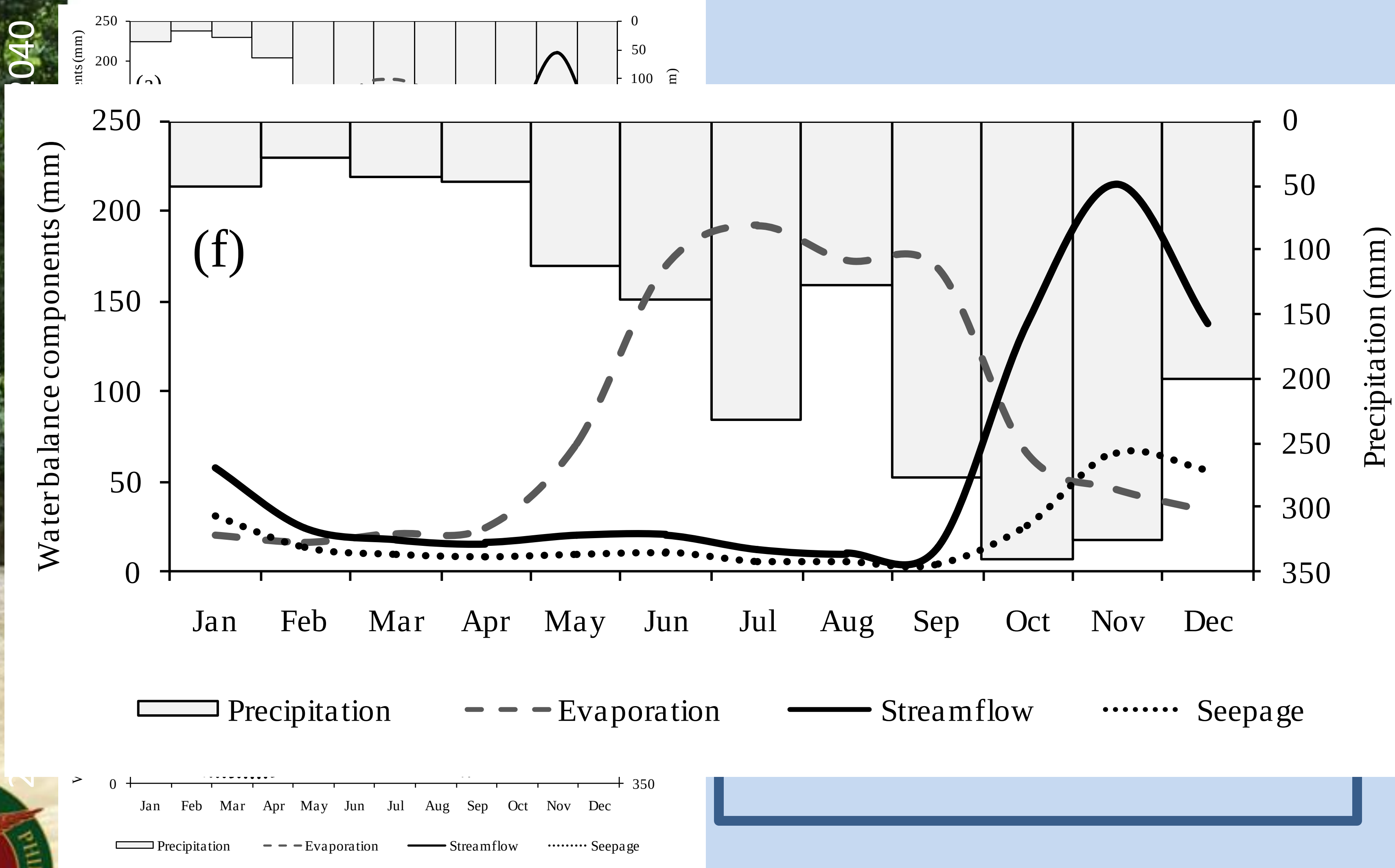
Change anomalies in temperature corresponding to two climate change scenarios in the study site

Downscaling ….Precipitation



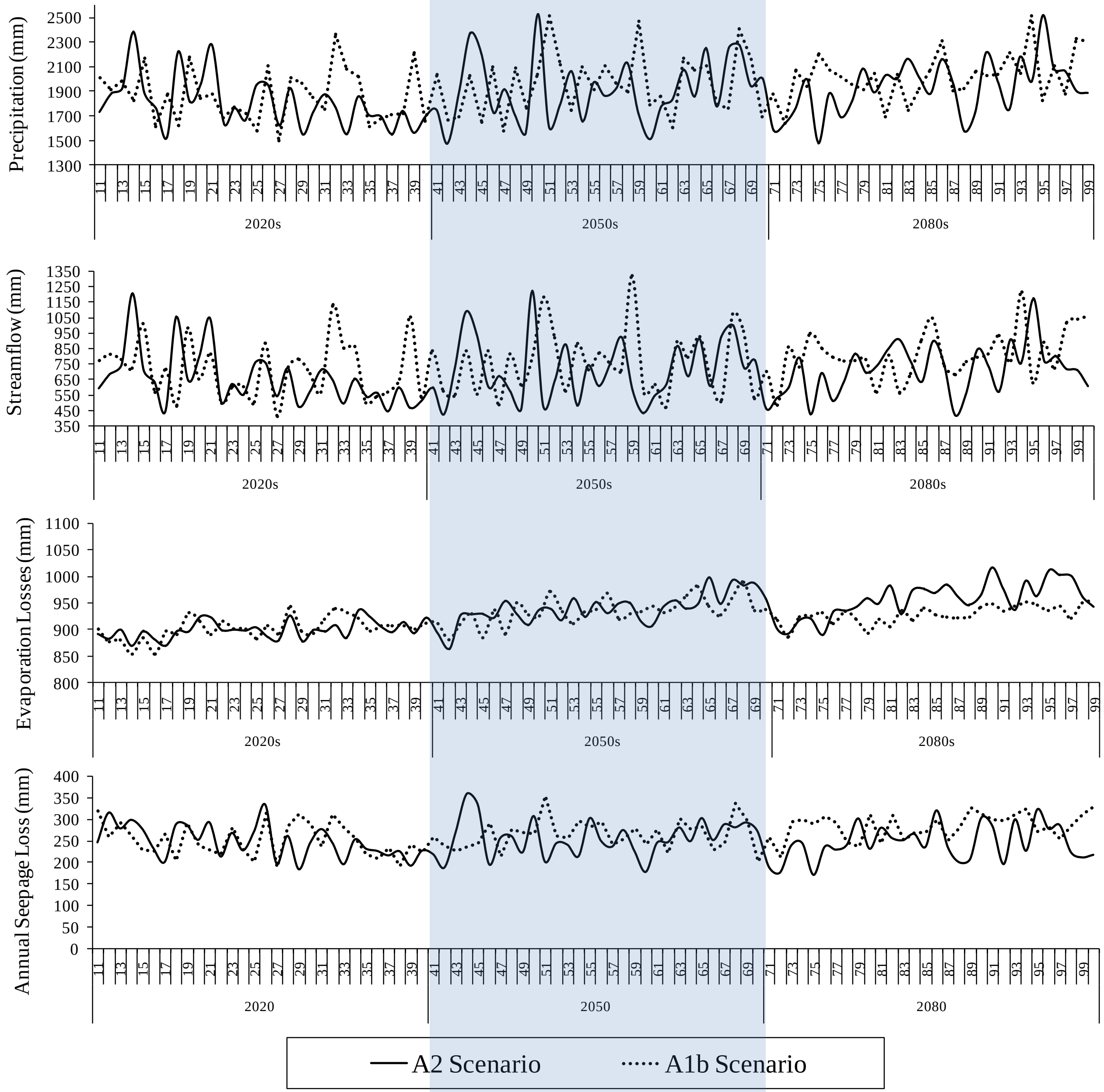
Change anomalies in monthly precipitation corresponding to A1B and A2 scenarios

Hydrologic Responses

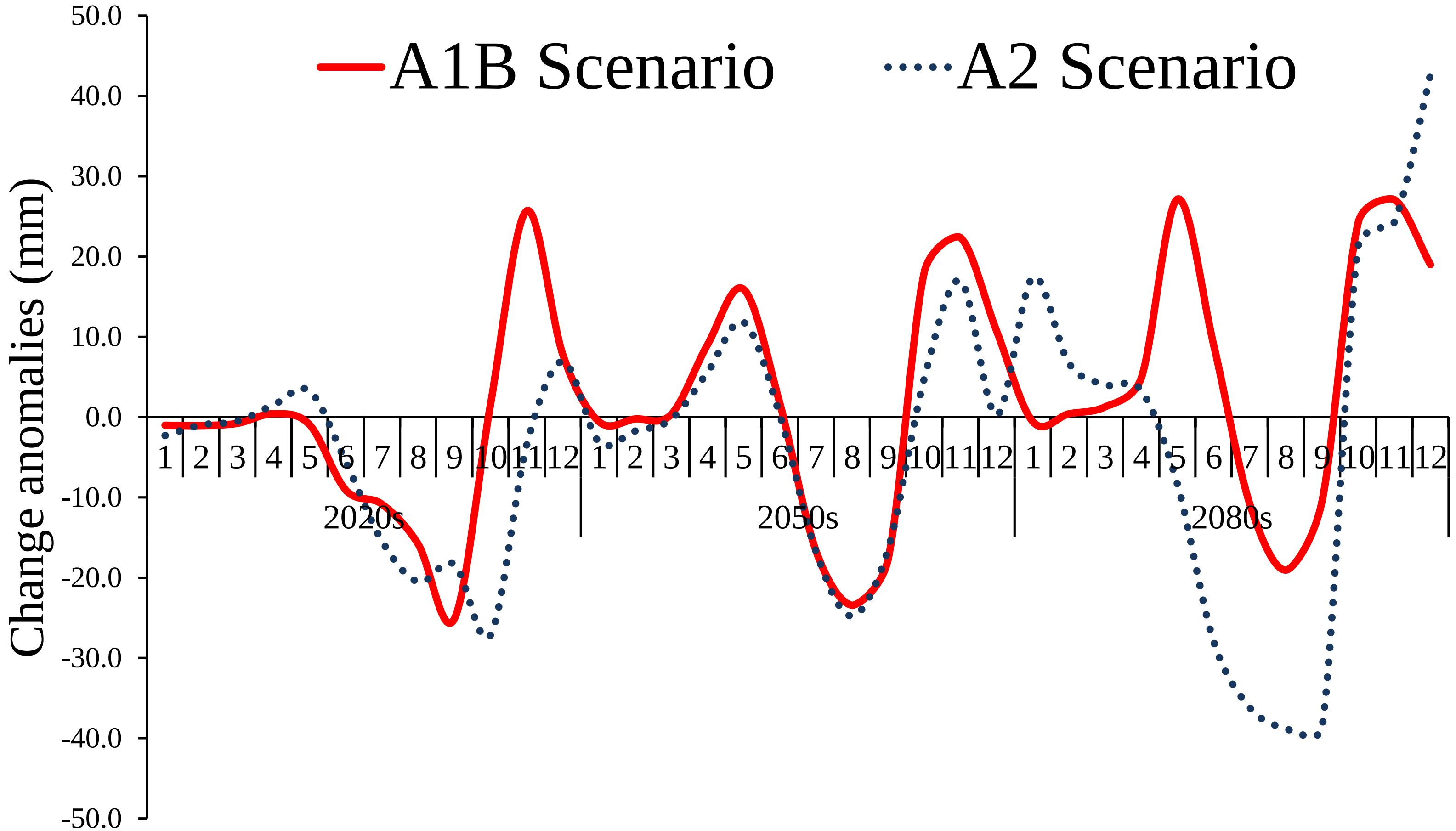


A1B Scenario

Hydrologic responses and trends under the two CGCM3 scenarios

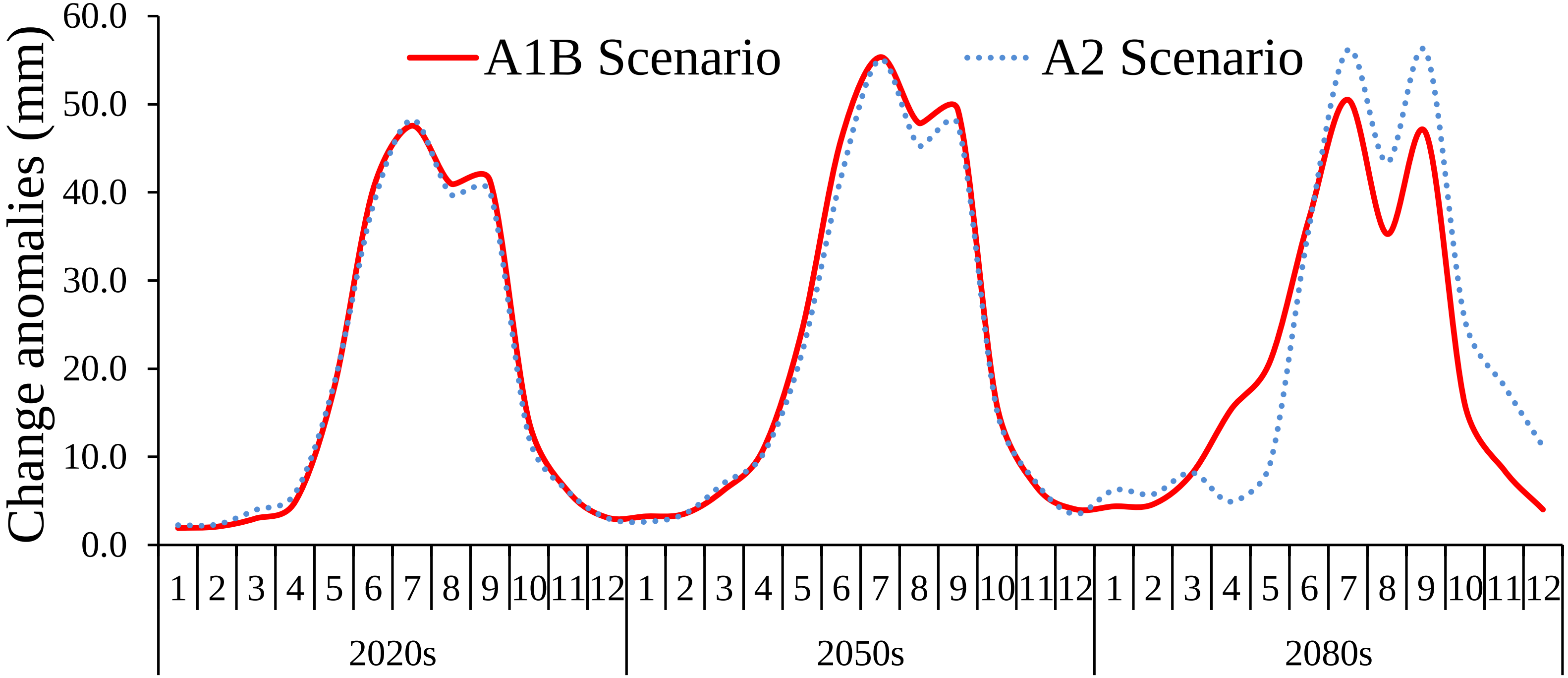


Streamflow

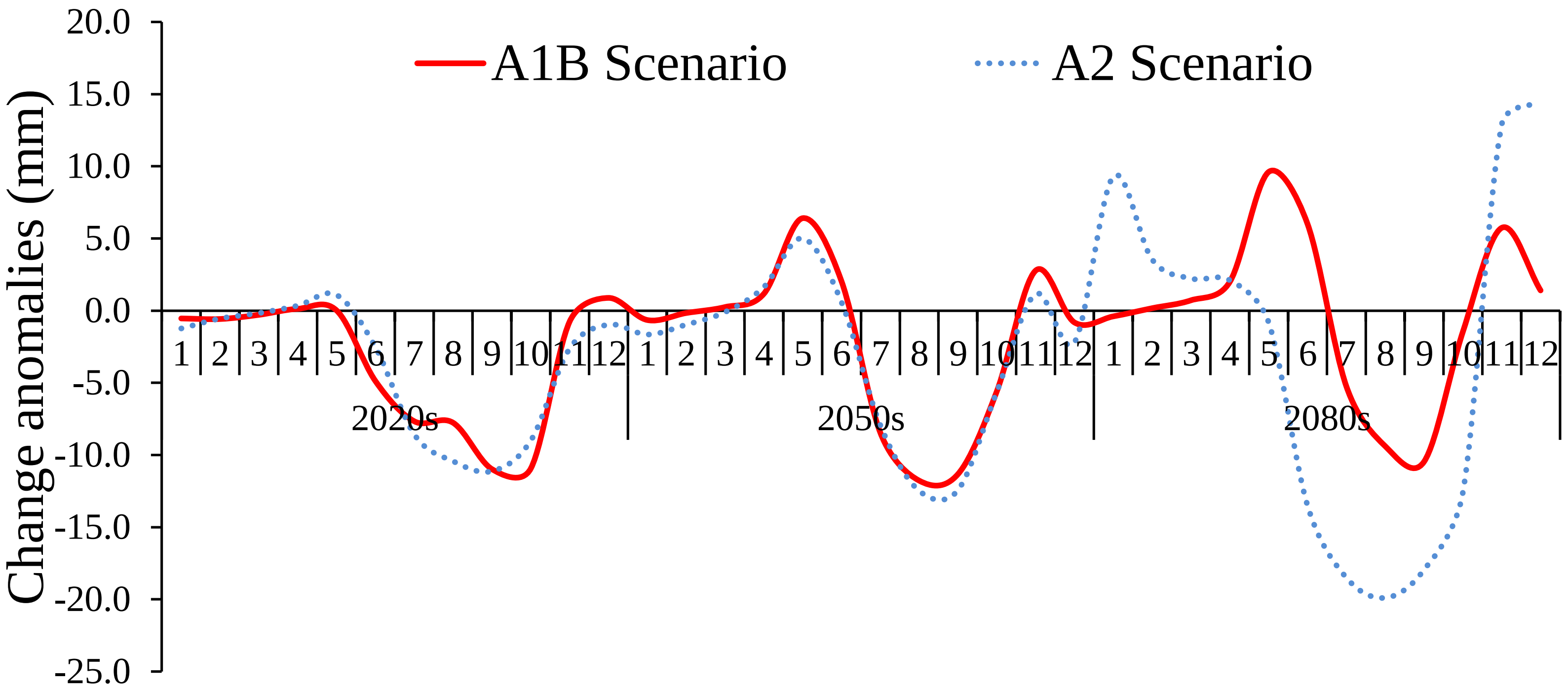


A1B Scenario
A2 Scenario
Change anomalies (mm)
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
2020s
2050s
2080s

Evaporation



Seepage



A1B Scenario
A2 Scenario
Change anomalies (mm)
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
2020s
2050s
2080s

Conclusions

Iteration of the BROOK90 model responded well

Disproportionate/ Fluctuating patterns and trends for the precipitation and temperature: *Longer dry season, and Extreme rainfalls*

Distribution of hydrologic processes: *subjected to change in land cover types, will be altered with disproportionate patterns and changes*

...the A2 scenario's findings... more damaging impacts of climate change than A1B scenario ...in 2080s

Assessing climate change impacts on water balance in the Mount Makiling forest, Philippines

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A statistical downscaling known for producing station-scale climate information from GCM output was preferred to evaluate the impacts of climate change within the *Mount Makiling* forest watershed, Philippines. The lumped hydrologic BROOK90 model was utilized for the water balance assessment of climate change impacts based on two scenarios (A1B and A2) from CGCM3 experiment. The annual precipitation change was estimated to be 0.1–9.3% increase for A1B scenario, and −3.3 to 3.3% decrease/increase for the A2 scenario. Difference in the mean temperature between the present and the 2080s were predicted to be 0.6–2.2°C and 0.6–3.0°C under A1B and A2 scenarios, respectively. The water balance showed that 42% of precipitation is converted into evaporation, 48% into streamflow, and 10% into deep seepage loss. The impacts of climate change on water balance reflected dramatic fluctuations in hydrologic events leading to high evaporation losses, and decrease in streamflow, while groundwater flow appeared unaffected. A study on the changes in monthly water balance provided insights into the hydrologic changes within the forest watershed system which can be used in mitigating the effects of climate change.

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Availability: http://www.ias.ac.in/jessci/jun2010/jess44.pdf

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Changes in the forest landscape of Mt. Makiling Forest Reserve, Philippines

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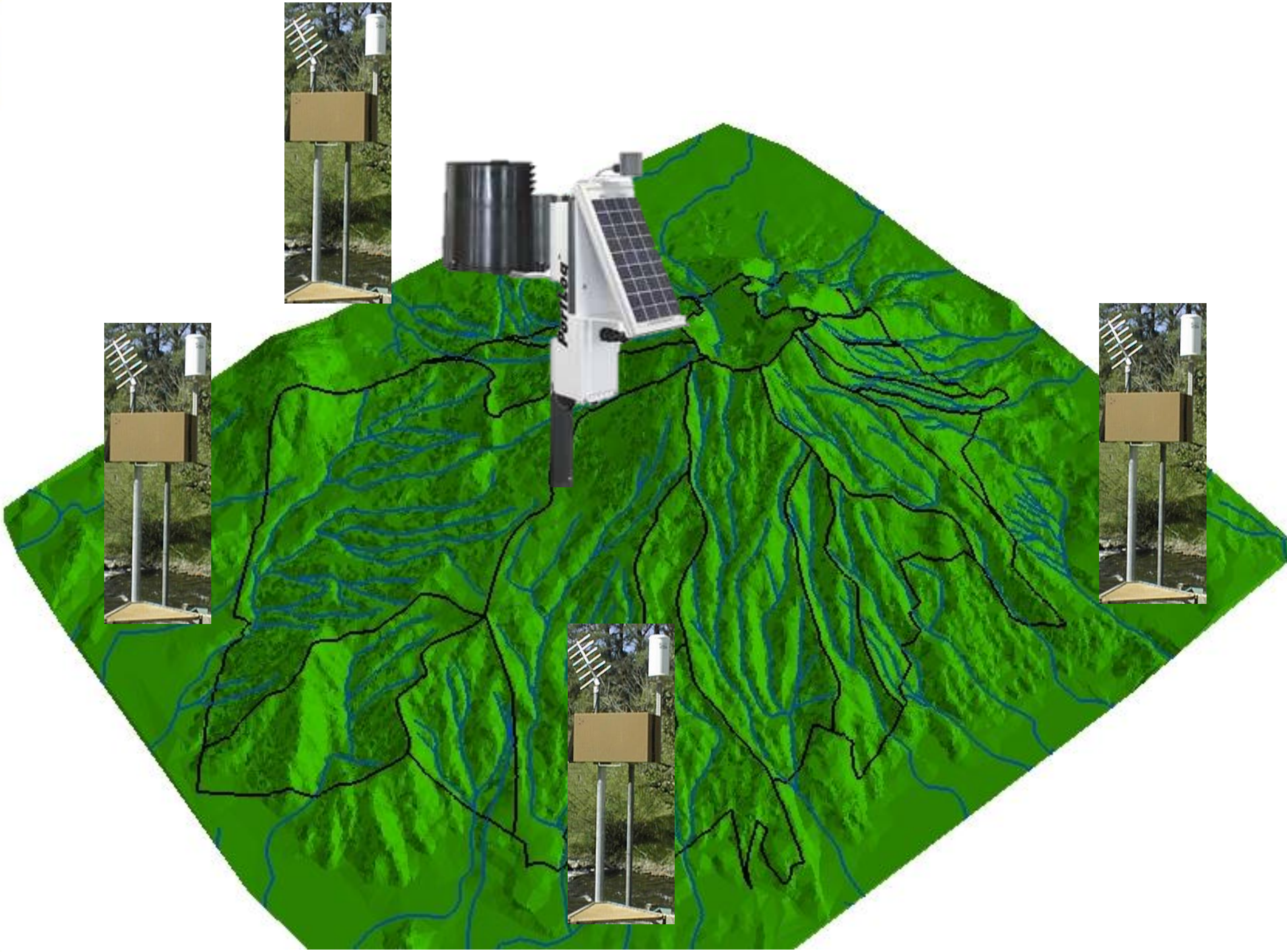
(*Received 5 July 2010; Accepted 4 March 2011*)

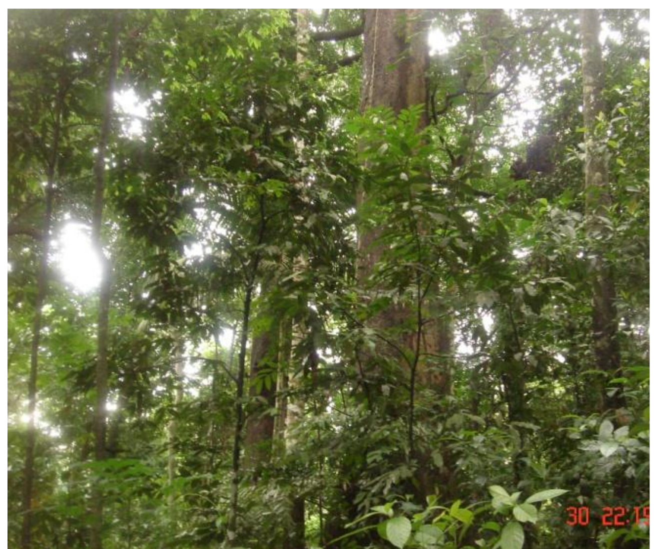
Changes in the forest landscape of Mt. Makiling Forest Reserve were evaluated given the three different time periods of remotely sensed datasets using ISOCLUST method. The classification explicitly figured out that the forest areas are persistent or still intact while spatially expanding the coverage from the area. The change analysis revealed that the spatial distribution of various land-cover categories was subjected to gain and loss based on the latest and previous remotely sensed data sets. High gains for forest areas and many losses on agroforestry areas were established at certain time spans. The land cover by category denotes a decrease of forest areas between 1993 and 2002, and eventually increases in line with the latest period. The increase in agroforestry areas was merely detected between 1993 and 2002 and subsequently reduced the possible expansion of its area coverage. A great deal of land cover can be perceived to the restoration efforts made in the study area. Applying NDVI in the segmentation process during the image classification demonstrated to be a constructive approach of classifying land cover types.

Keywords: change analysis; forest landscape; image classification; ISOCLUST; landscape transition; NDVI

Future Research



Thank You




MAKILINGWOOD