UNIVERSITAT POLITÈCNICA DE VALÈNCIA

iiama Instituto de Ingeniería del Agua y Medio Ambiente

RISTEKDIKTI

THE IMPACT OF LAND USE CHANGES ON SOIL EROSION AND SEDIMENT CYCLE USING DISTRIBUTED MODELING IN A TROPICAL WATERSHED IN INDONESIA

By:

Shantosa Y. Siswanto and Félix Francés

Research Group of Hydrological and Environmental Modelling (GIMHA)
Research Institute of Water and Environmental Engineering (IIAMA)
Universitat Politècnica de València, Spain

Background

Tropical Rainforest Watershed

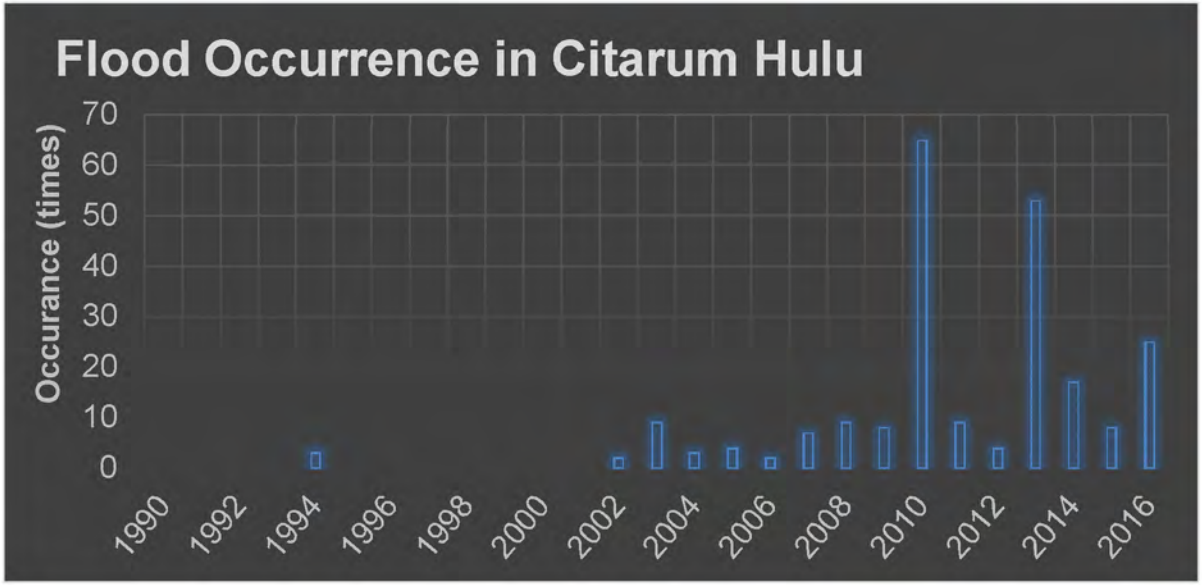
- High precipitation amounts
- Dry and rainy seasons

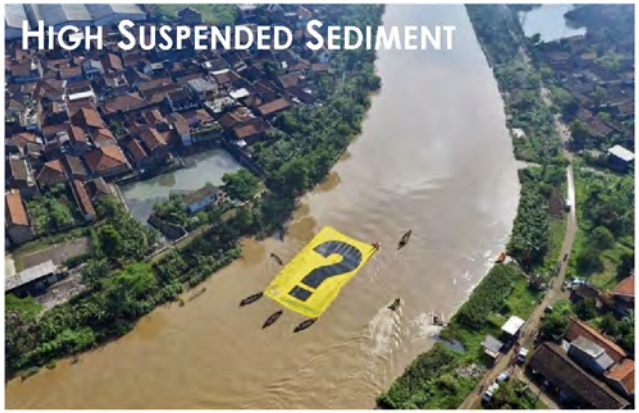
Significant Land Cover Changes

- Increasing population
- Improper implementation of land regulation

Unpredicted Effect : water scarcity, flood, erosion, sedimentation

Unpredicted effect





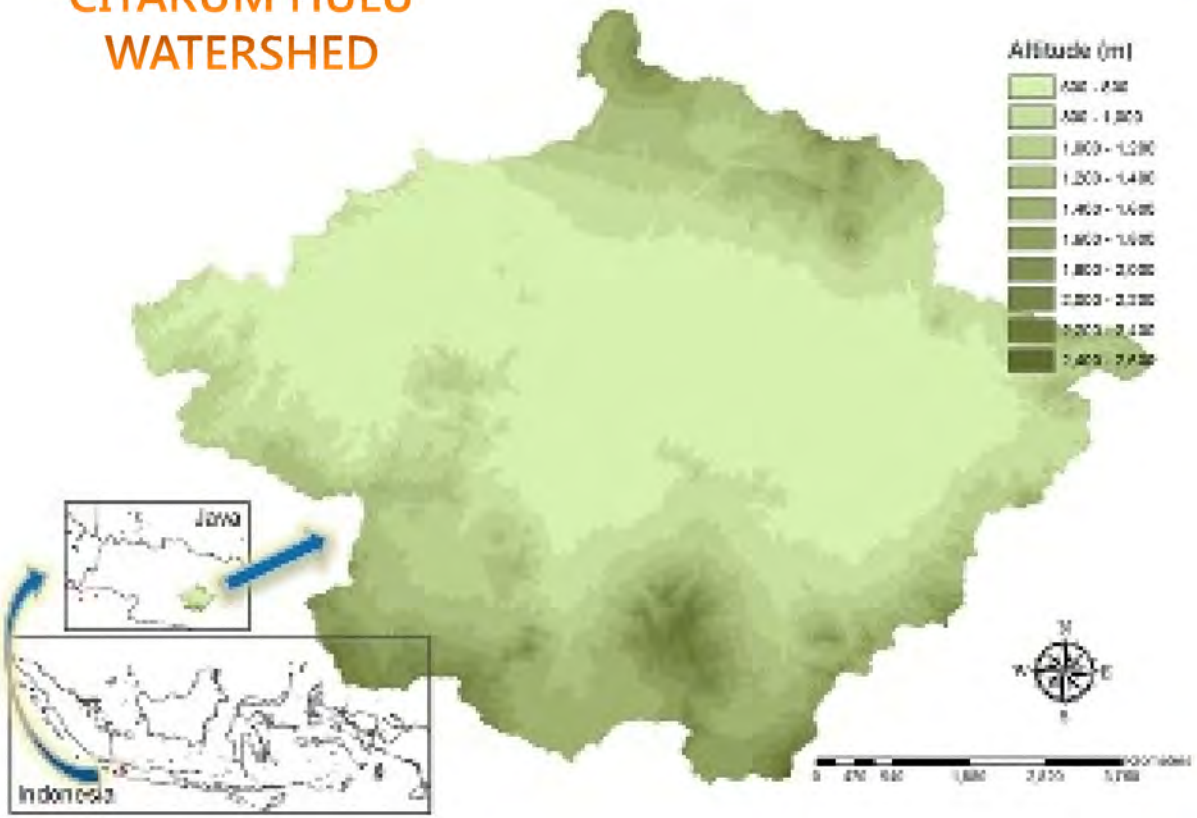
iiama

The Impact of Land Use Changes on Soil Erosion and Sediment Cycle
Using Distributed Modeling in a Tropical Watershed in Indonesia

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Study area

CITARUM HULU WATERSHED



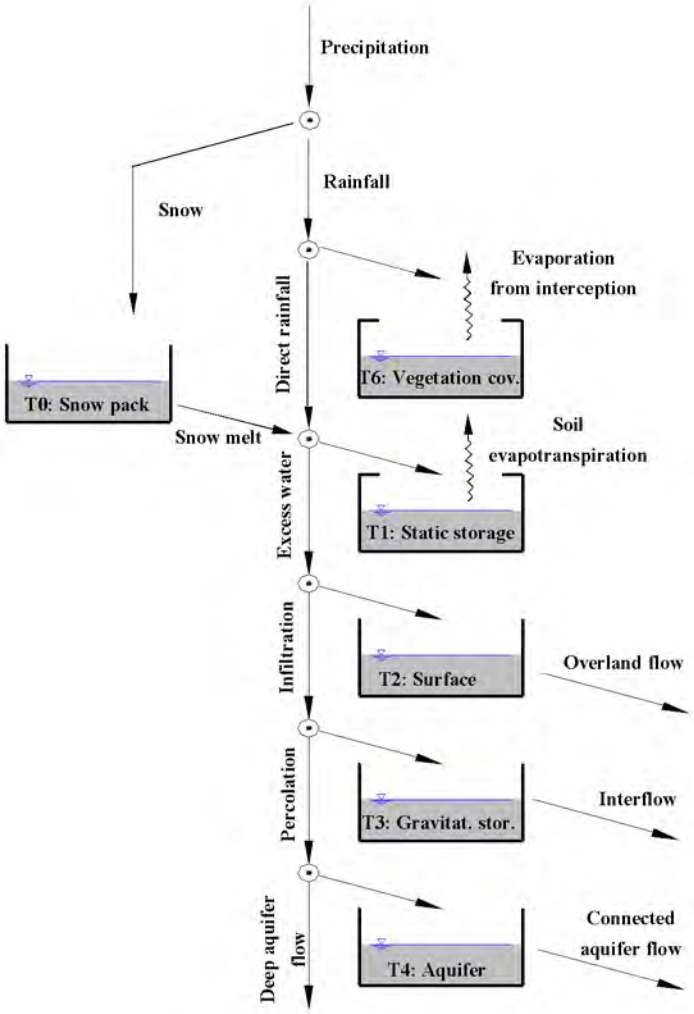
- Upper part of Citarum Watershed
- Area : 2316 Km^2
- Population : 6 million
- Rainfall: 1840 mm/year
- Mean annual Temperature : 25.6 °C
- Altitude
  - Highest : 2600m
  - Lowest : 600 m

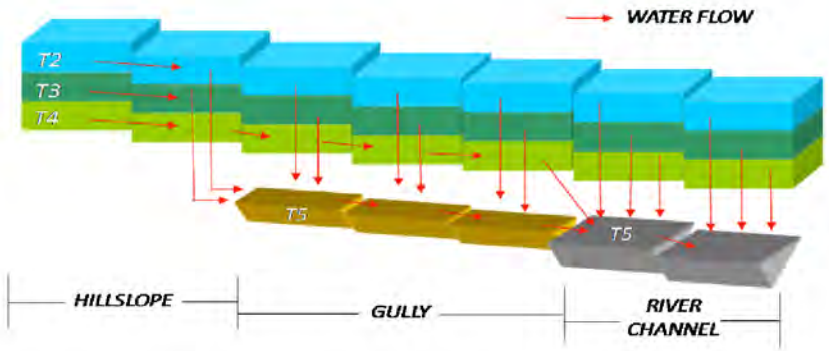
urban and industrial water supply (875 million m^3) and hydroelectricity production (5.000 Giga watts)

Objectives

- ✓ Analyze historical land cover changes
- ✓ Analyze the impact of historical changes and future scenarios of land cover on water, flood, erosion and sediment cycles

TETIS model



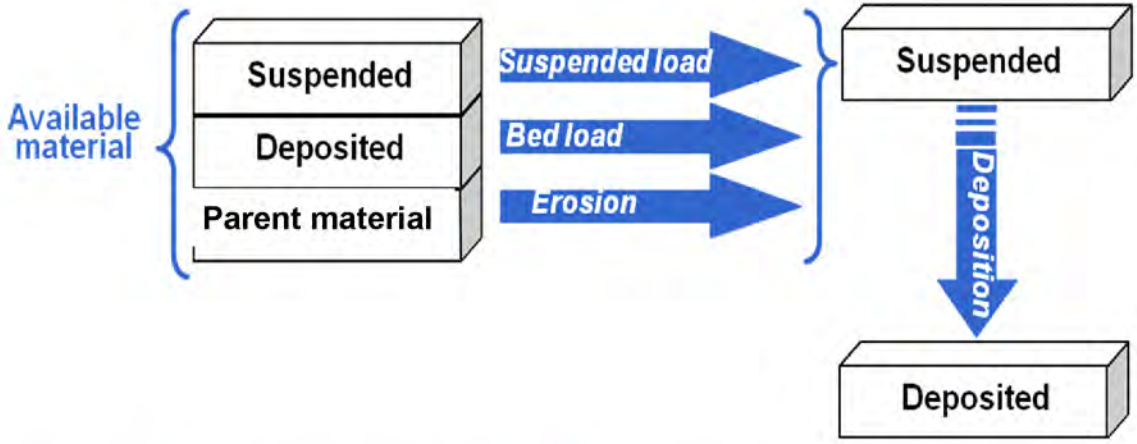


Hydrological sub-model (Frances et al., 2007)

- Developed in TU of Valencia since 1994 (version 8.3.0 on the web)
- Distributed Hydrological Model represented by tank for each characteristic
- Physically-based parameter
- Distinction between slope, gully and channel cells
- **Integral** model: water resources, floods, sediments, dynamic vegetation, N-C cycle

TETIS model: hillslope erosion

- 3 additional tanks



- Balance between water **transport capacity** and sediment availability
- Hillslope transport capacity: modified Kilinc – Richardson equation (Julien, 1995)

$$Q_h = \frac{1}{\gamma_s} W \alpha S_o^{1.66} \left(\frac{Q}{W}\right)^{2.035} \frac{K}{0.15} C P$$

Input data

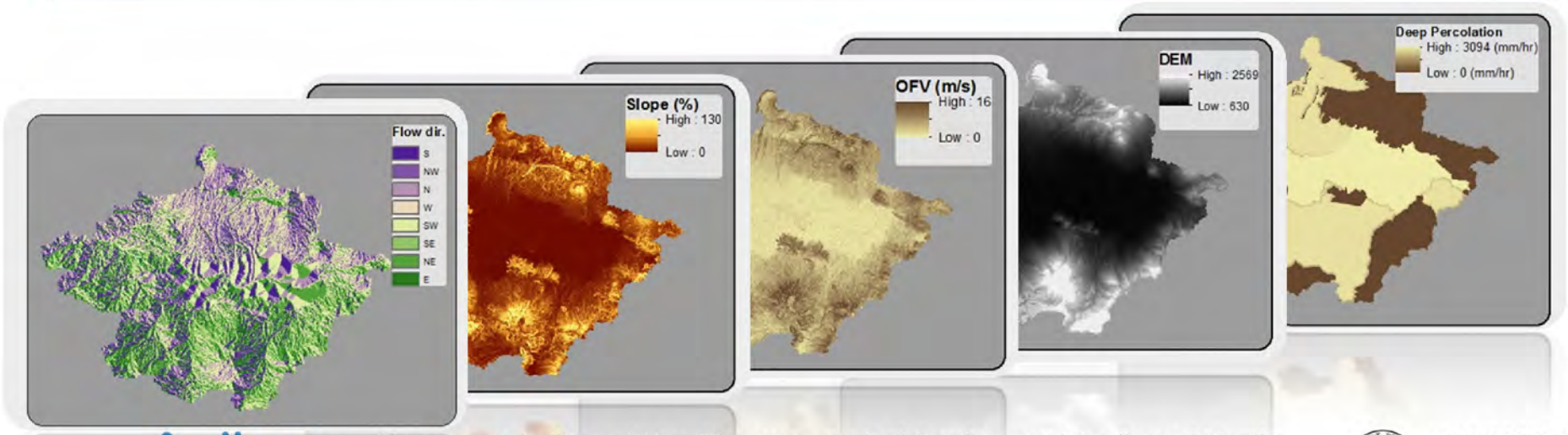
Hydro meteorological & sediment

- Daily time step
- 1985-2014
- Precipitation (38 stations)
- Temperature (10 stations) Potential Evapotranspiration based on Hargreaves
- Discharge (19 stations)
- Sediment in reservoir: 29 years of bathymetries

Input data

Spatial information and parameter maps

> DEM from USGS with 90 m resolution to produce 90 m unit pixel - Slope - Flow direction - Accumulated cells - Overland flow velocity	> Geological map - Hydraulic conductivity of the aquifer



Input data

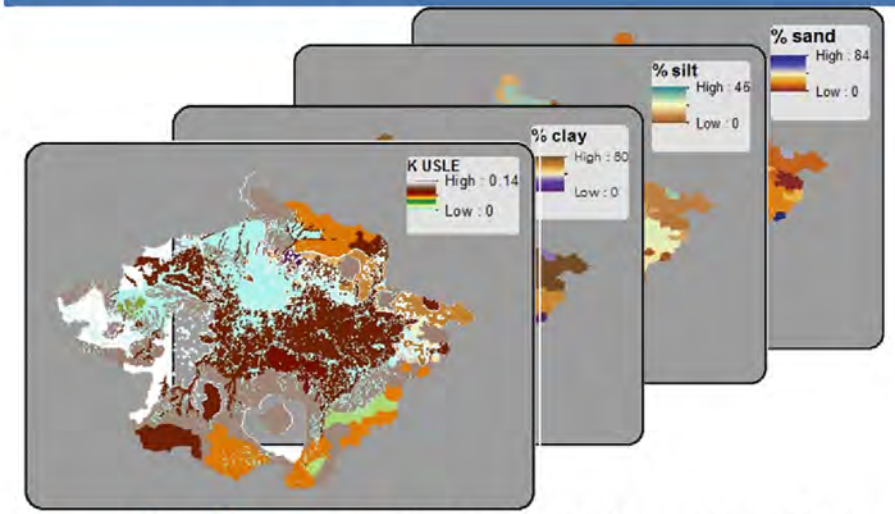
Spatial information and parameter maps

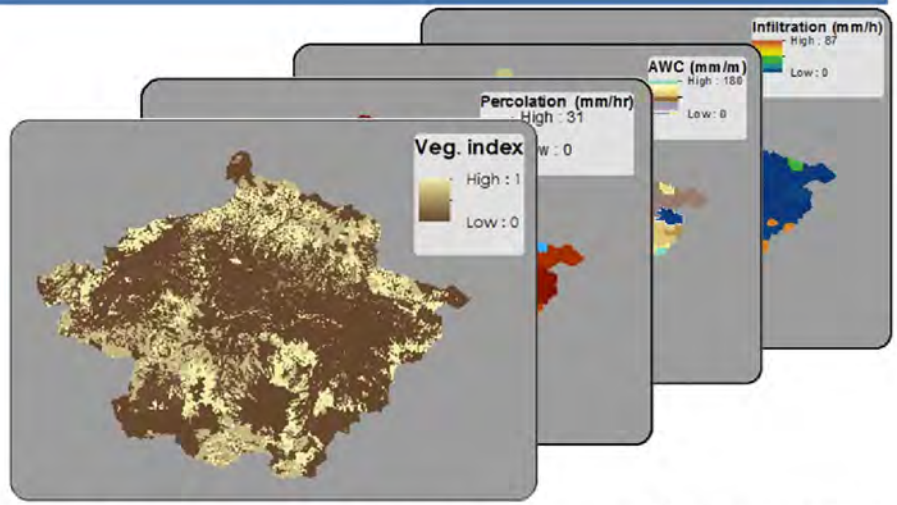
> Soil Survey of 77 soil profile and sample based on soil unit map

- Static storage
- Infiltration capacity
- Percolation capacity
- Available water content
- Texture
- Erodibility (K USLE)

> Land use map

- Potential Evapotranspiration
- Vegetation index
- Interception
- Maximum root depth
- C USLE



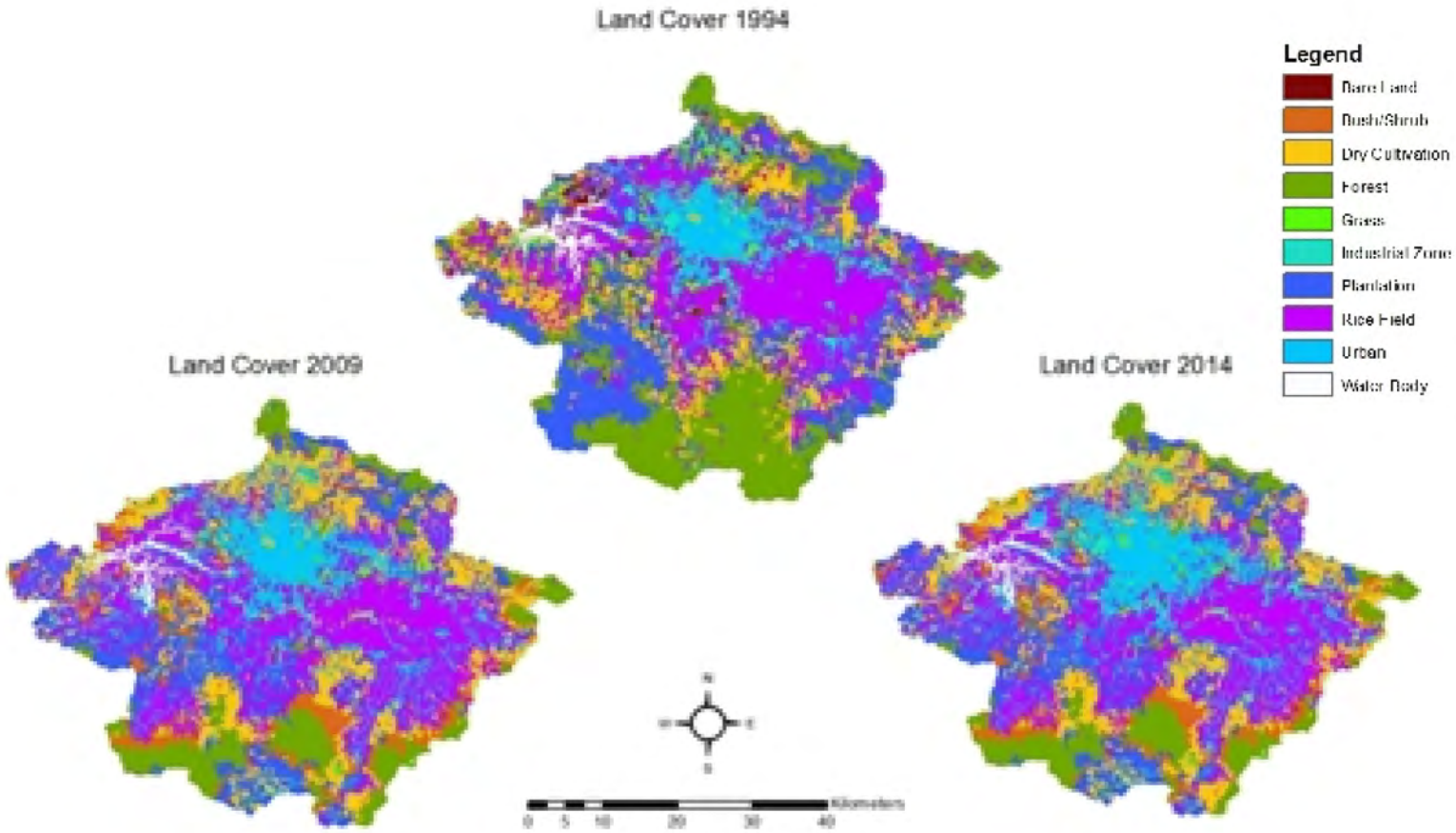


iiama

The Impact of Land Use Changes on Soil Erosion and Sediment Cycle Using Distributed Modeling in a Tropical Watershed in Indonesia

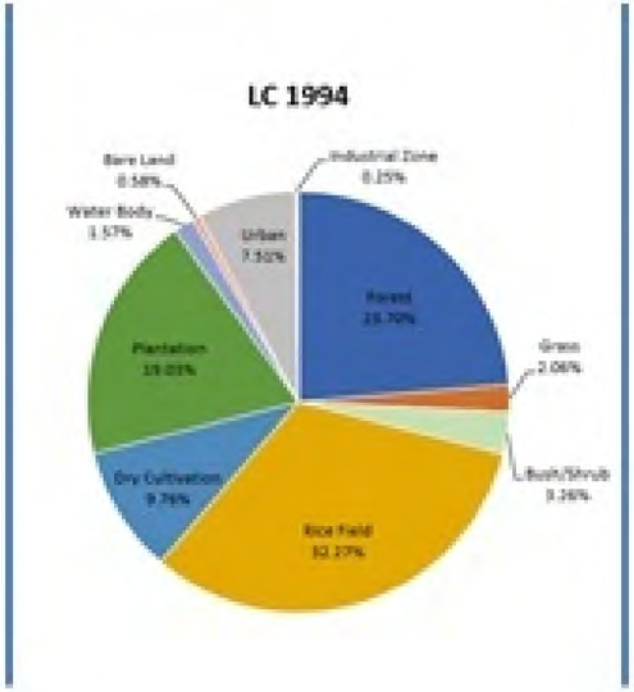
UNIVERSITAT POLITÈCNICA DE VALÈNCIA

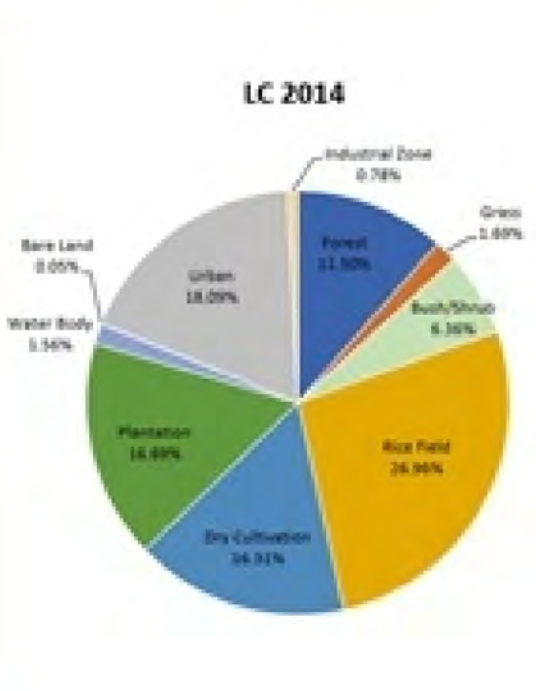
Comparison of historical LC



Historical land covers

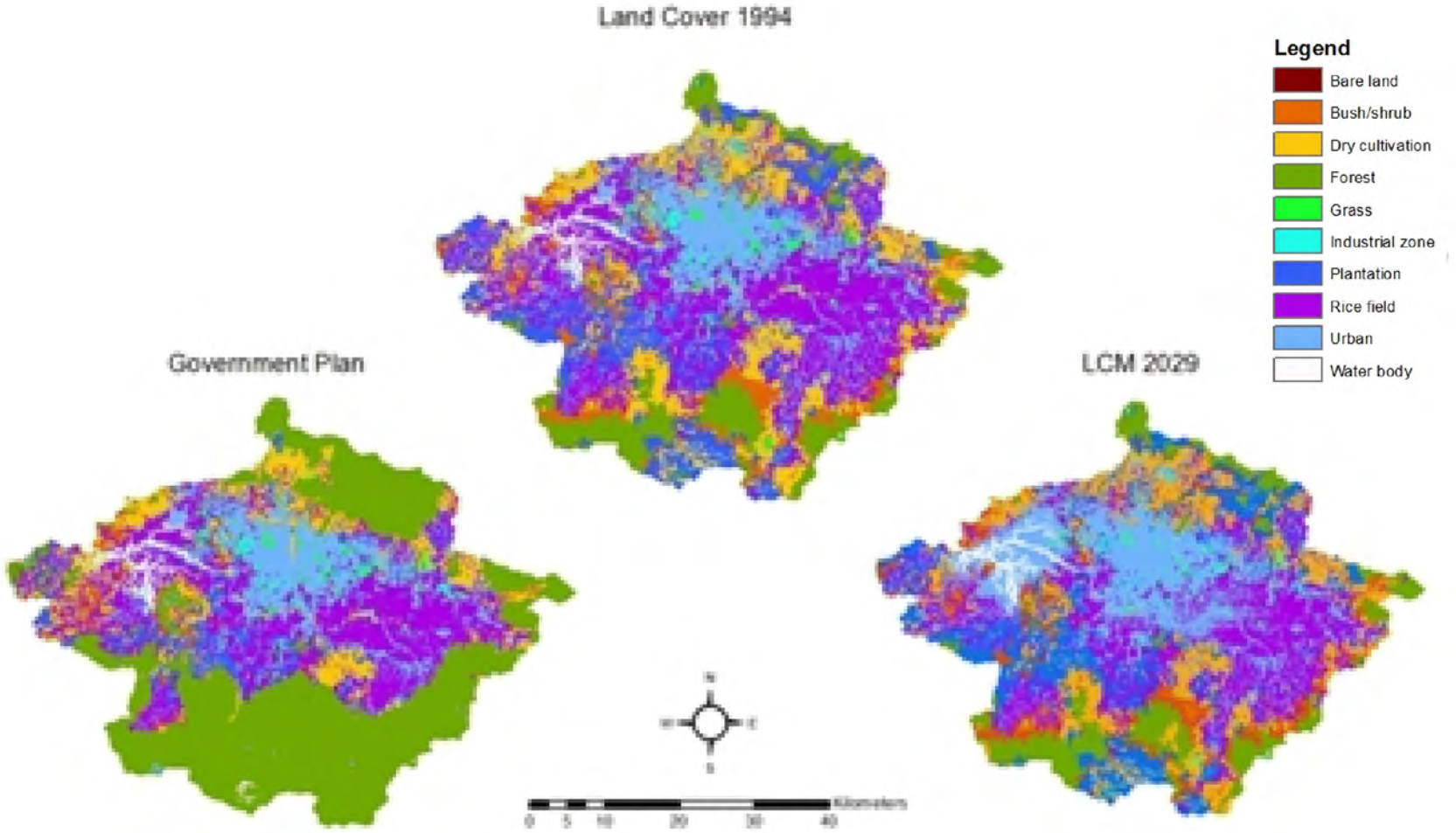
LC	Change (%)
Forest	-51
Grass	-18
Bush/Shrub	95
Rice Field	-16
Dry Cultivation	67
Plantation	-12
Water Body	-1
Bare Land	-91
Urban	141
Industrial	213
TOTAL	2,316





- Increasing of rice field, urban area and dry cultivation due to increasing of population
- Reduction forest due to increasing of population and improper policy of land usage
- Forest with conservation status also disturbed

Comparison of 2 scenarios



iiama

The Impact of Land Use Changes on Soil Erosion and Sediment Cycle
Using Distributed Modeling in a Tropical Watershed in Indonesia

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Methodology

Calibration

- Hydrology
  - LC 2009
  - Hydro Meteorological (HM) data 2008-2010
- Sediment sub model
  - Trapped sed. 2009

Validation

- Hydrology
  - LC 1994, HM data 1994-1996
  - LC 2014, HM data 2012-2014
- Sediment
  - yearly 2008-2012

Simulation

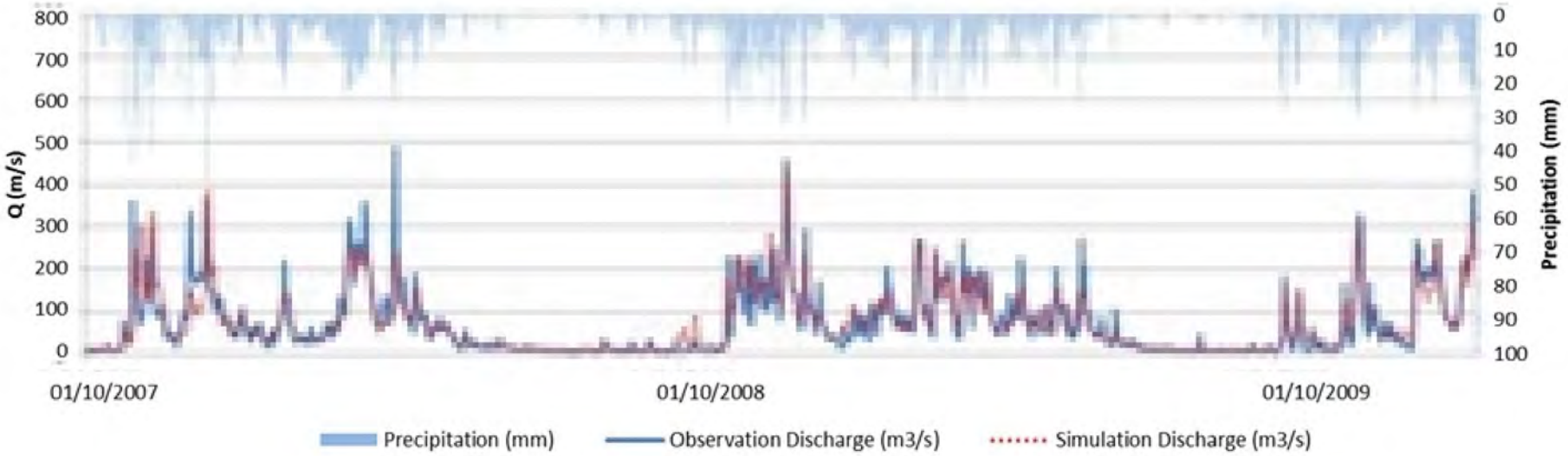
- **HM data1985-2014**
- **Miller equation and Brune's Curve-TE**
- LC 1994
- LC 2014
- Government plan scenario
- Land Change Modeler (2029) scen

Parameters depending on Land Cover:
1. Veg. Coefficient
2. Static storage cap.
3. Infiltration cap.
4. Interception

Analysis

- Water Balance
- Floods
- Erosion
- Reservoir sedimentation

Model implementation



Calibration → NSE = 0.71

Validation → 2014 land cover with 2012 to 2014 data, NSE = 0.52

1994 land cover with 1994 to 1996 data NSE = 0.54

Volume sediment error : 2%

Historical Water Balances

Flow	1994		2014	
	Amount (mm)	%	Amount (mm)	%
Infiltration	548	29.72	582	31.52
Percolation	223	12.09	250	13.56
Evapotranspiration	997	**54.06**	875	**47.42**
Overland flow	298	**16.17**	388	**21.03**
Interflow	321	17.44	328	17.78
Connected Aquifer Flow	221	11.95	248	13.42
Water Yield	841	**45.56**	964	**52.22**

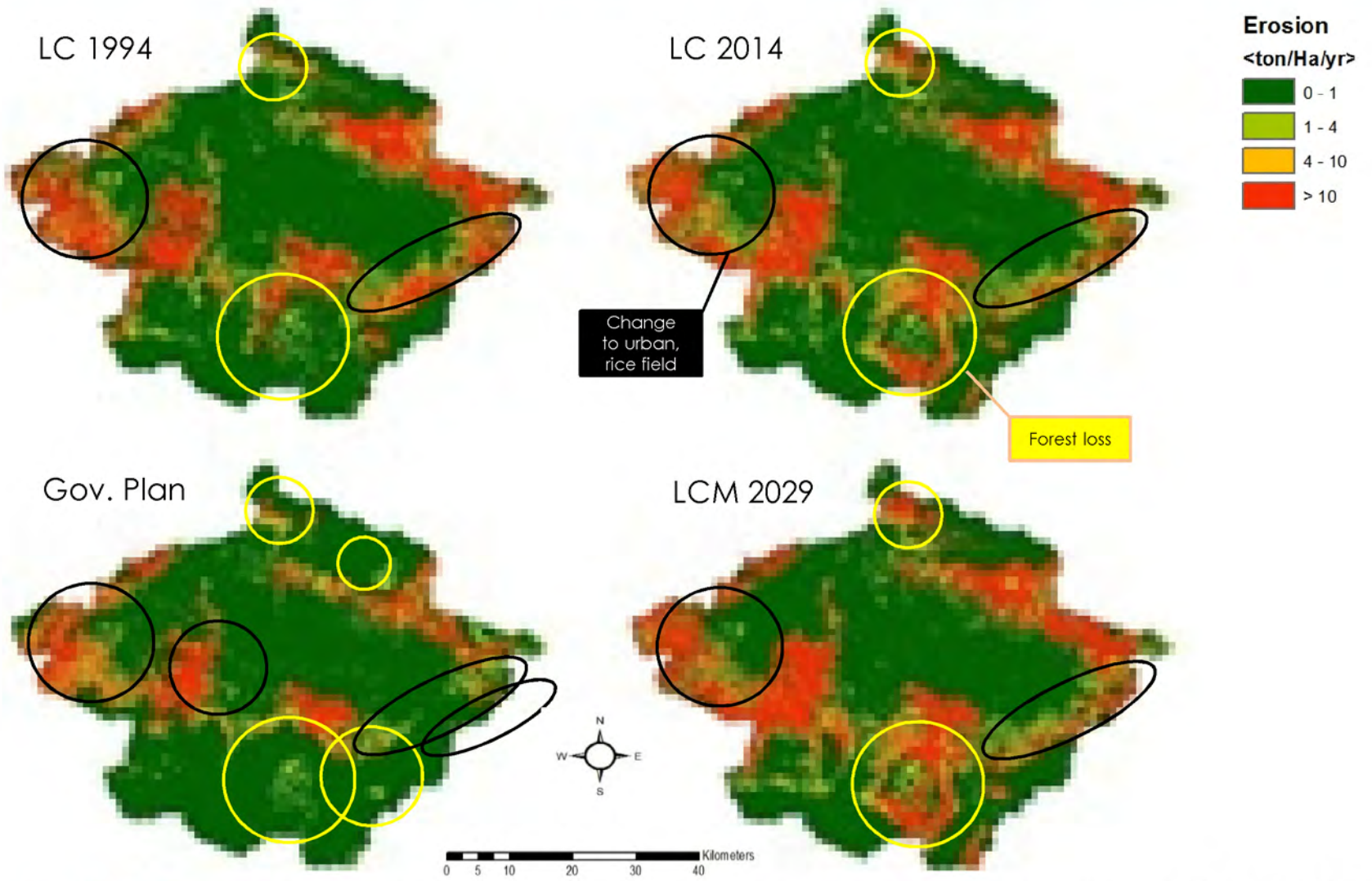
- Evapotranspiration is decreasing along with the decreasing of forest area
- Higher overland flow because of lower evapotranspiration => flood hazard increase
- Result : higher water yield

Scenario Water Balances

Flow	2014		Government Plan		LCM 2029	
	Amount (mm)	%	Amount (mm)	%	Amount (mm)	%
Infiltration	582	31.52	490	26.58	859	46.54
Percolation	250	13.56	197	10.69	380	20.61
Evapotranspiration	875	**47.42**	1,018	**55.17**	489	**26.50**
Overland flow	388	**21.03**	335	**18.17**	497	**26.92**
Interflow	328	17.78	290	15.71	475	25.73
Connected Aquifer Flow	248	13.42	195	10.56	376	20.40
Water Yield	964	**52.22**	820	**44.44**	1,347	**72.99**

- ↑ ET of Gov. Plant due to ↑ forest area → ↓ overland flow => lower water yield
  => flood hazard, erosion, sedimentation decrease
- ↑ ET of LCM 2029 due to replacement of rice field by urban => ↑ overland flow
  => flood Hazard, erosion, sedimentation increase

Erosion rate comparison

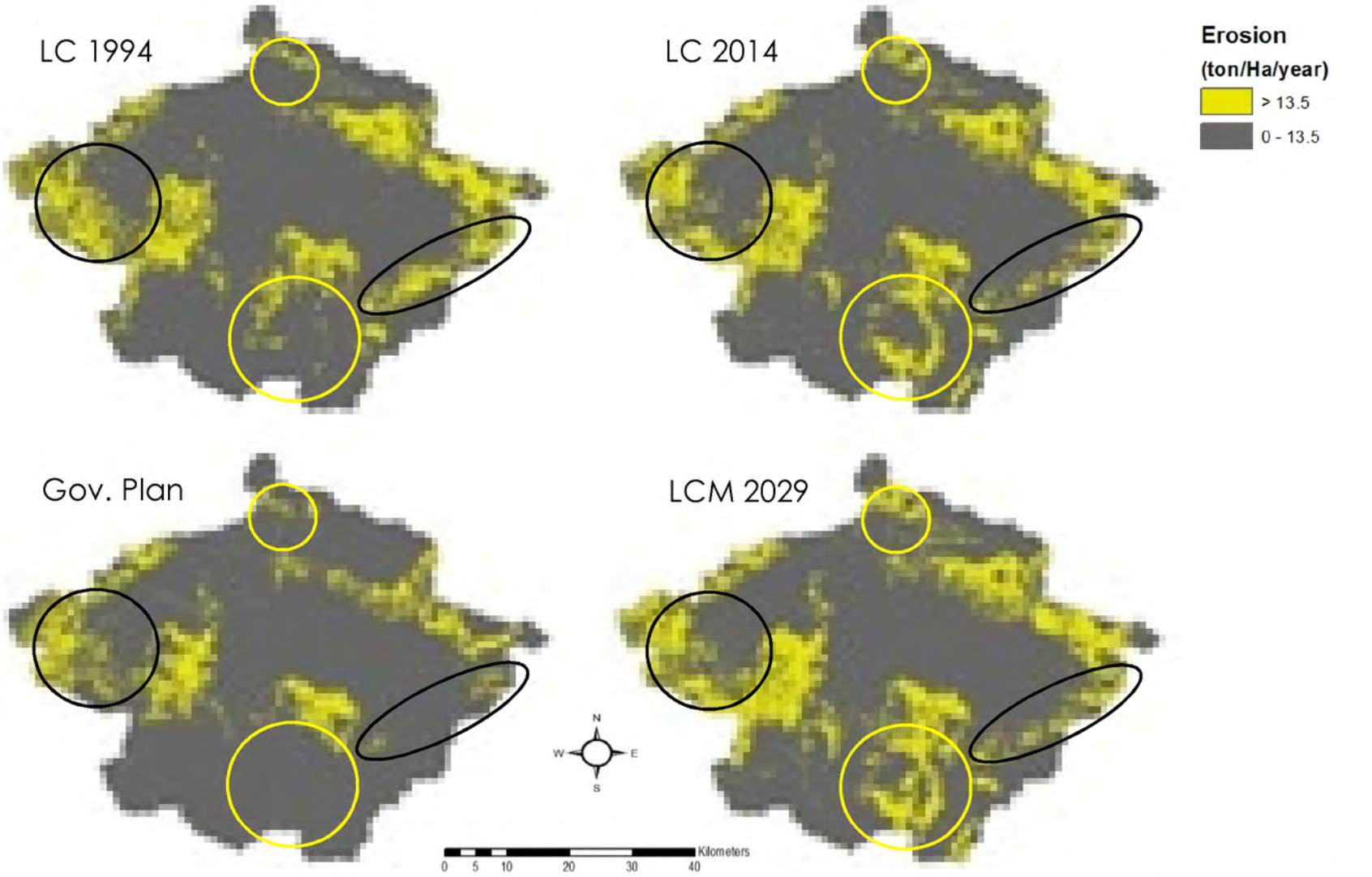


The Impact of Land Use Changes on Soil Erosion and Sediment Cycle Using Distributed Modeling in a Tropical Watershed in Indonesia

iiama

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Erosion rate comparison



iiama

The Impact of Land Use Changes on Soil Erosion and Sediment Cycle Using Distributed Modeling in a Tropical Watershed in Indonesia

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

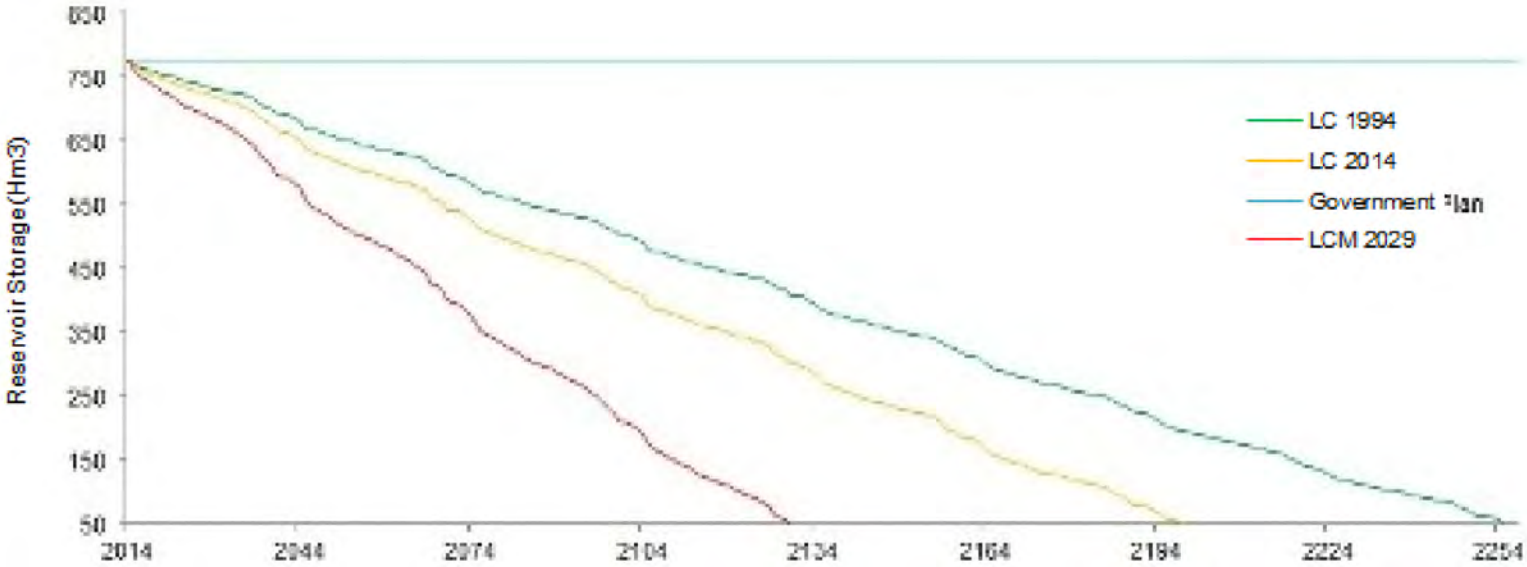
Flood quantile comparison

Return Period (year)	Discharge (m3/s)			
	1994	2014	Gov. Plan	LCM 2029
5	346.18	373.54	343.17	436.77

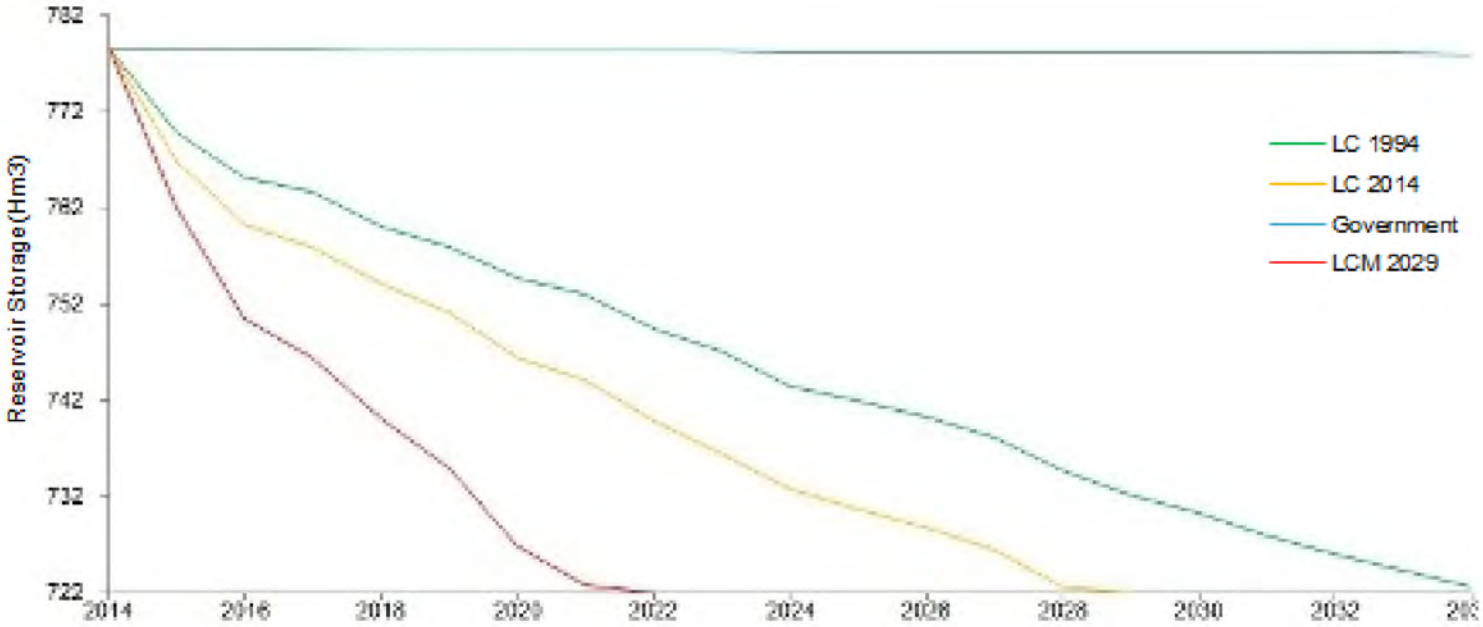
Return Period (year)	Percentage of discharge change (%)		
	1994 - 2014	2014 - Gov. Plan	2014 - LCM 2029
5	7.90	-8.13	16.14

Sediment comparison

	1994	2014	Gov. Plan	LCM 2029
Sediment yield	37 ton/Ha/yr	48 ton/Ha/yr	<1 ton/Ha/yr	77 ton/Ha/yr
Reservoir life time	239 yr	182 yr	Many years	113 yr



Hydropower station life time



"No hydropower in 8-20 years"

Conclusions

- The changes in the land cover are influencing the water cycle, erosion, floods and reservoir lifetime
- Lower forest percentage in 2014 compared to 1994 decrease evapotranspiration and increase overland flow (floods and sediments) and water yield
- Reforestation and proper land use planning (if possible!) is a positive way to solve the problem
- TETIS hydrological distributed model is a good tool to estimate the effect of land use changes on water, erosion and sediment cycles

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

iiama

RISTEKDIKTI