Dynamic versus static representations of land use change in SWAT

P.D. Wagner, S. Murty B., B. Narasimhan, S. Kumar, N. Fohrer, P. Fiener

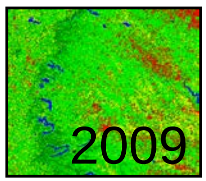
1. Motivation

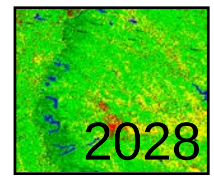
Static Delta-Approach to derive impacts of land use change on water resources

Hydrologic Model

Model run A | **Model run B**

2009-2028





Mean water balance A | **Mean water balance B**

Difference of water balance components
Mean impact of land use change

Result: long-term average, dynamics are not represented

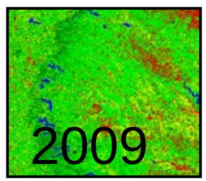
=> Integration of dynamic land use change in a hydrologic model (possible in SWAT since 2010)

1. Motivation

Integration of dynamic land use change*

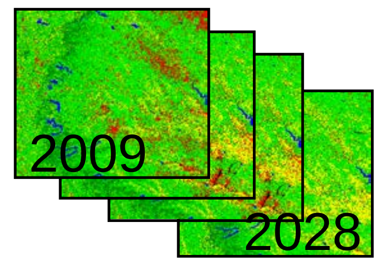
Hydrologic model

Model run A



2009-2028

Model run B



Water balance without LUC

Water balance with LUC

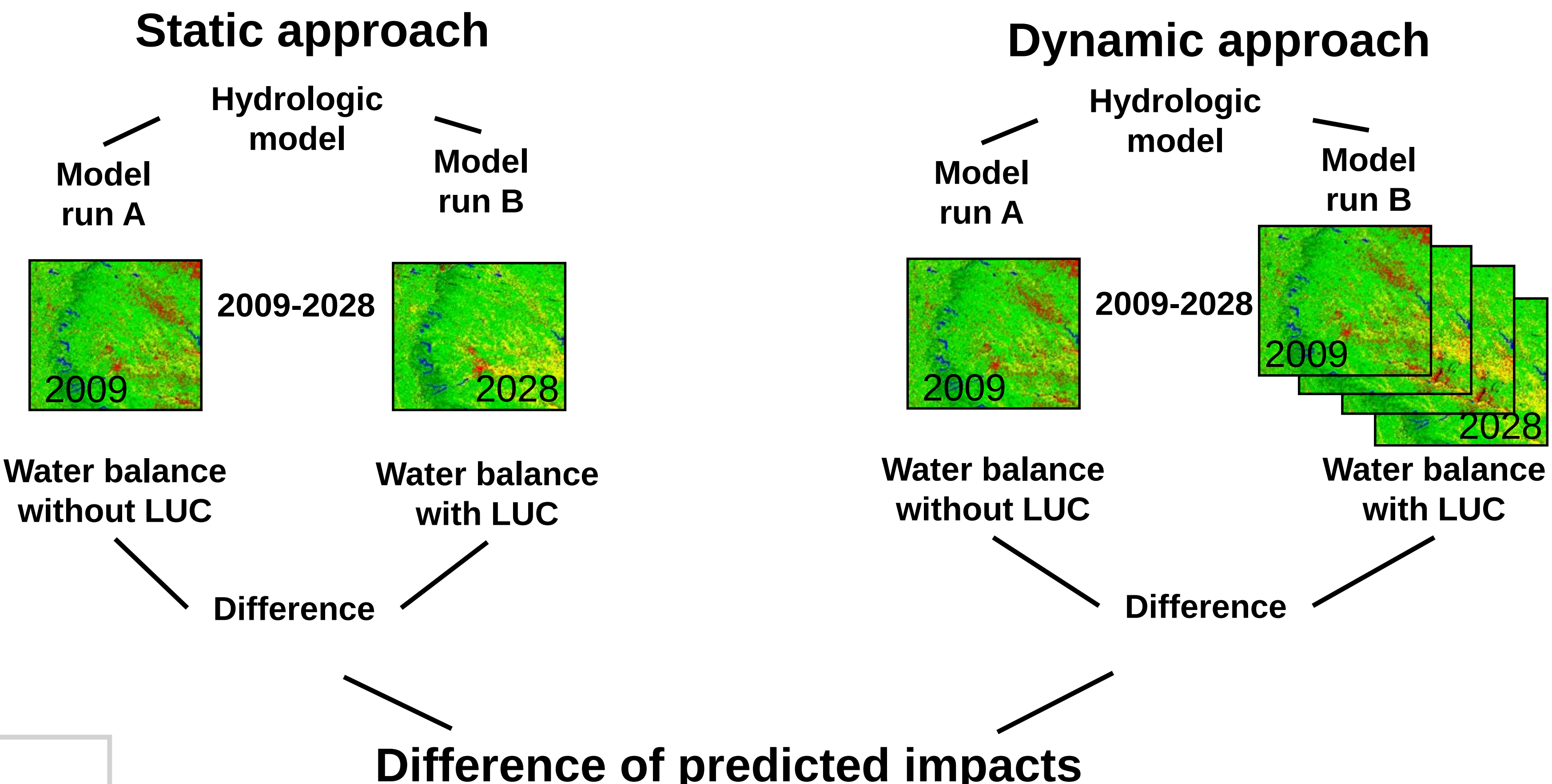
Difference of water balance components

Temporally differentiated impacts of land use change

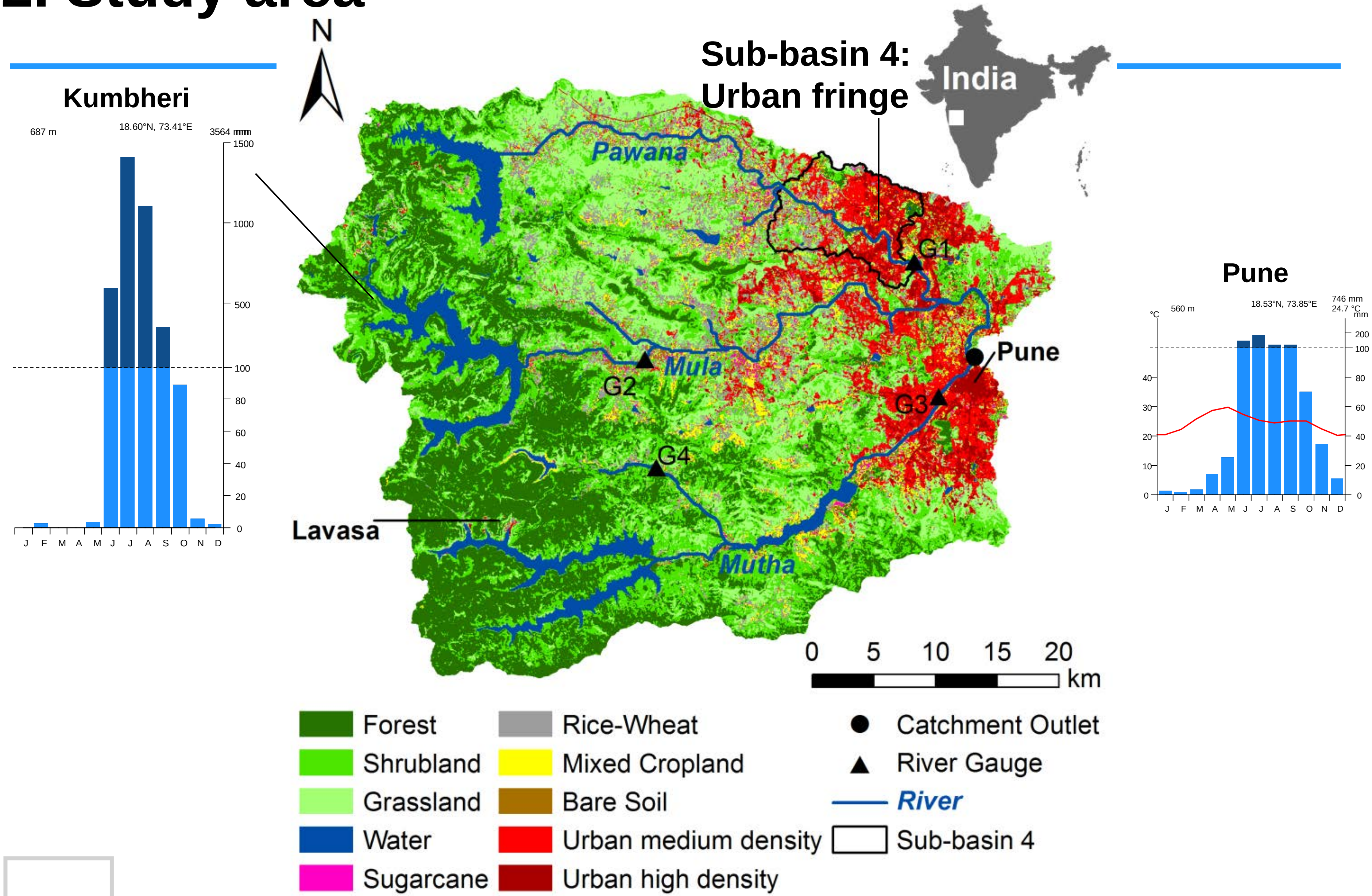
***Wagner, P.D., S. Murty Bhallamudi, B. Narasimhan, L.N. Kantakumar, K.P. Sudheer, S. Kumar, K. Schneider, P. Fiener, 2016.** Dynamic integration of land use changes in a hydrologic assessment of a rapidly developing Indian catchment. *Science of the Total Environment*, 539: 153-164.

1. Objective

What is the impact of using dynamic land use information as compared to using static land use information?



2. Study area



Kumbheri
687 m
18.60°N, 73.41°E
3564 mm
Pune
560 m
18.53°N, 73.85°E
746 mm
24.7 °C
N
Sub-basin 4:
Urban fringe
India
Pawana
Mula
Mutha
Pune
Lavasa
G1
G2
G3
G4
0 5 10 15 20 km
Forest
Shrubland
Grassland
Water
Sugarcane
Rice-Wheat
Mixed Cropland
Bare Soil
Urban medium density
Urban high density
Catchment Outlet
River Gauge
River
Sub-basin 4

3. Materials & Methods

Land use scenario 2009 to 2028

- Land use model SLEUTH extrapolates trends from the past
- Development plan of new „hill station“ city Lavasa in the Western Ghats

Hydrologic model SWAT

- SWAT-Model-Runs from 2009 to 2028
    - with annual land use updates
    - compared to model runs with static land use information

Model Validation*

- Land use model: ROC urban 80%; deviations < 3% per land use class
- Hydrologic model: Nash-Sutcliffe efficiencies of 0.67 and 0.68

=> Both models show reasonable performance

***Wagner, P.D., S. Murty Bhallamudi, B. Narasimhan, L.N. Kantakumar, K.P. Sudheer, S. Kumar, K. Schneider, P. Fiener, 2016.**
Dynamic integration of land use changes in a hydrologic assessment of a rapidly developing Indian catchment.
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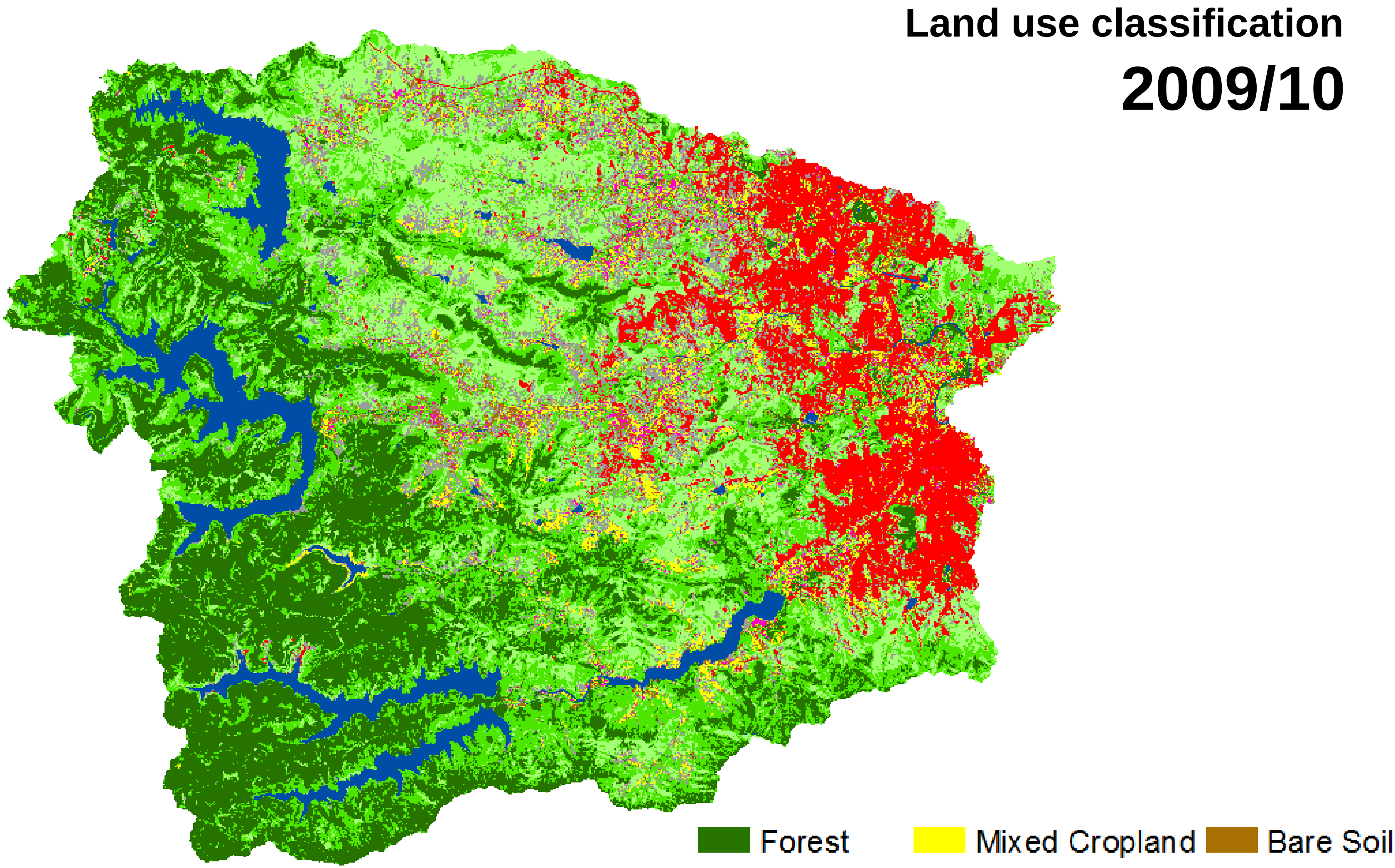
3. Land Use Scenario

Projected Land use change between 2009 and 2028

Land use	Catchment	Sub-basin 4 (urban fringe)	Sub-basin 24 (Lavasa)
Forest	-0.3%	-0.8%	-8.3%
Shrubland	-2.6%	-2.9%	-3.4%
Grassland	-1.4%	-5.4%	-0.3%
Cropland	-3.6%	-14.0%	-0.3%
Water	0.0%	0.0%	0.0%
Urban medium density	+6.0%	+15.6%	+9.7%
Urban high density	+1.9%	+7.5%	+2.5%

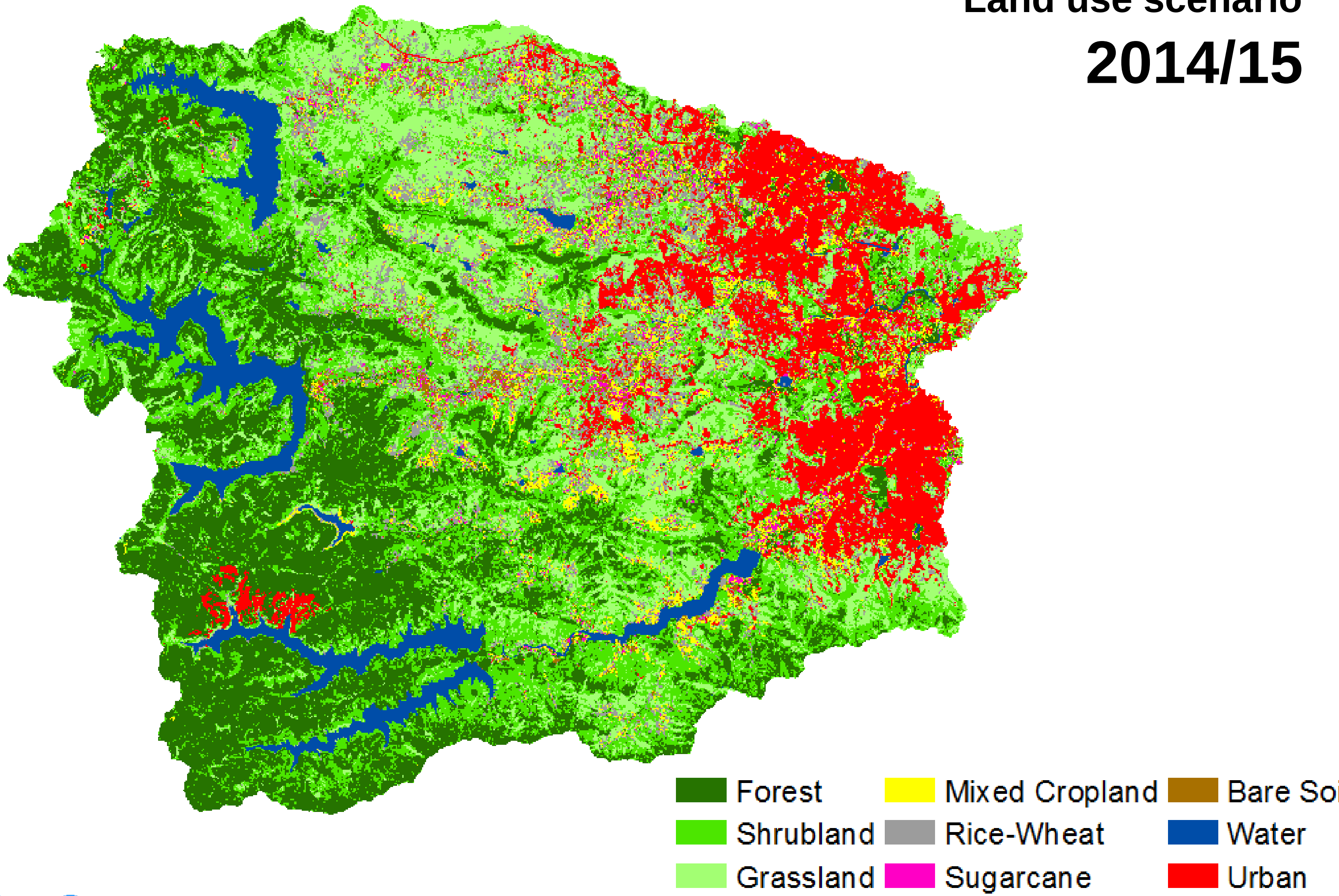
3. Land Use Scenario



3. Land Use Scenario

Land use scenario

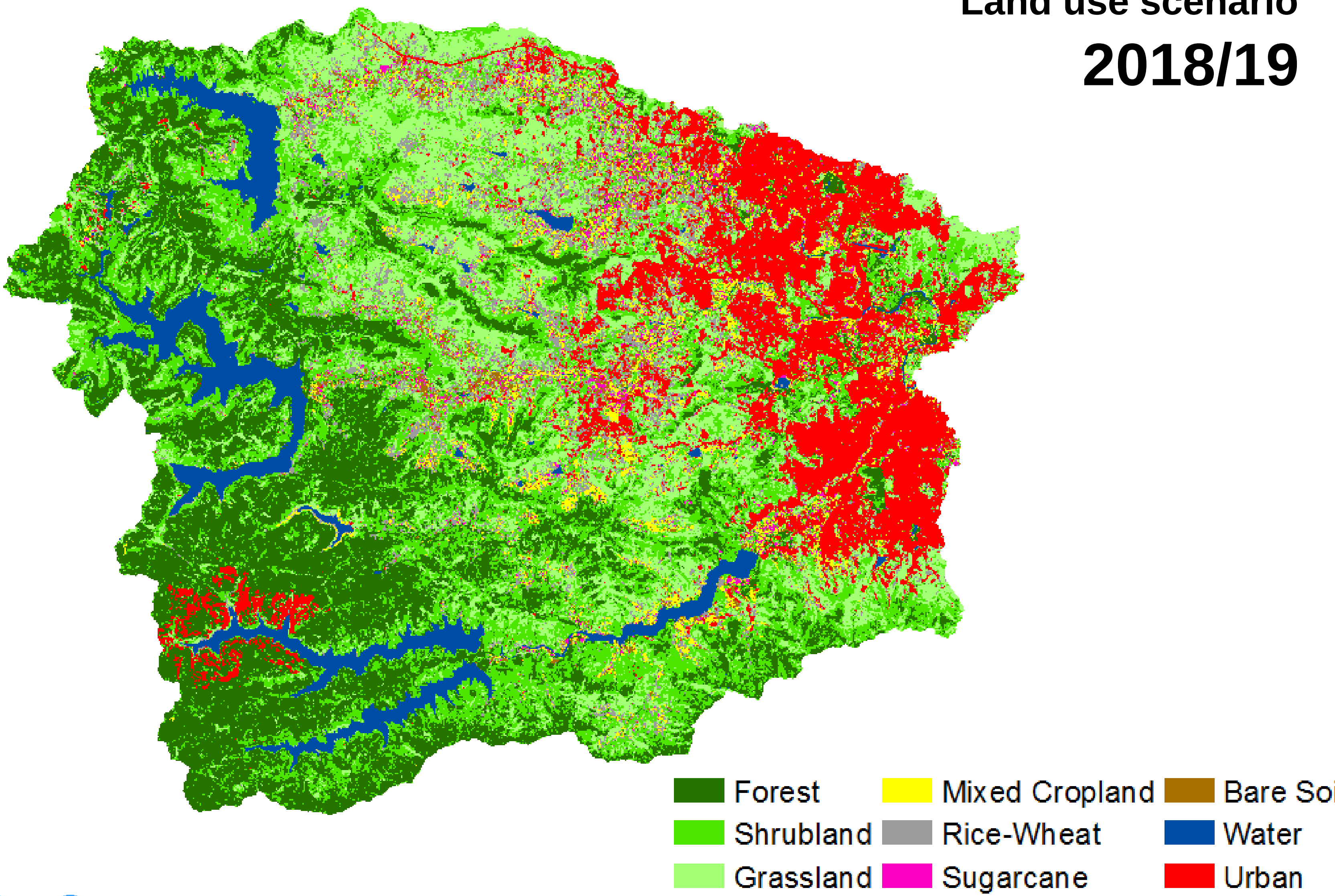
2014/15



3. Land Use Scenario

Land use scenario

2018/19



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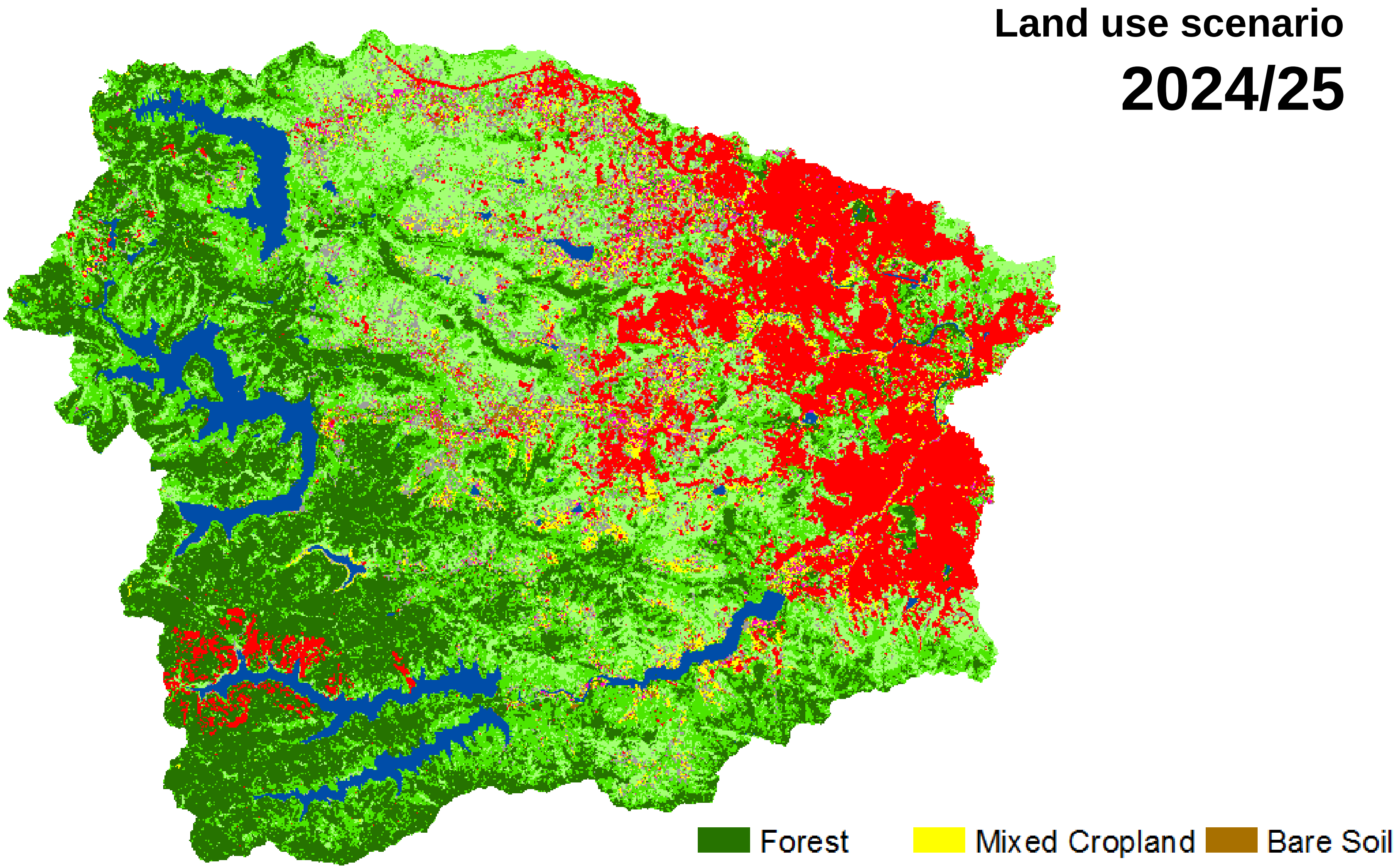
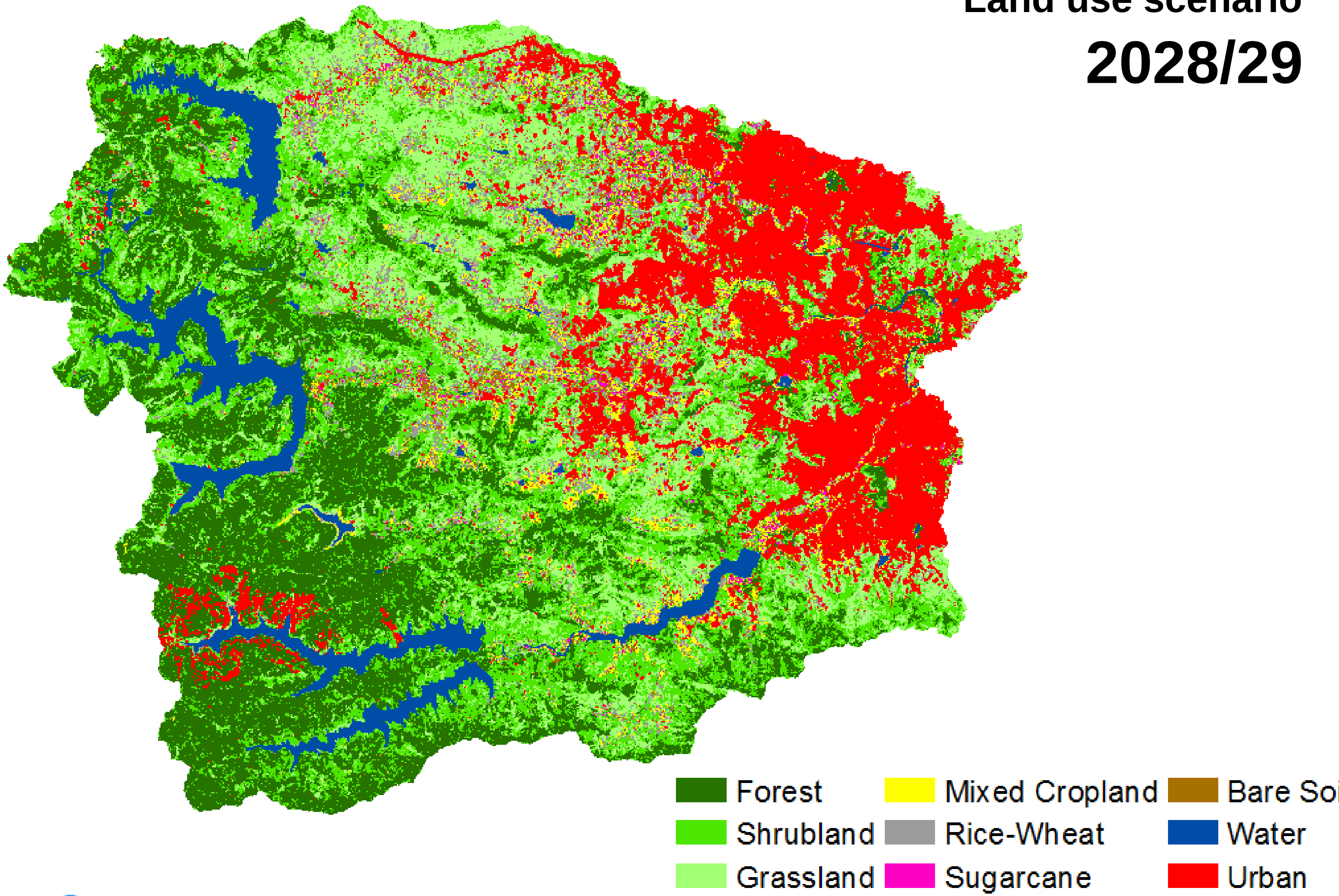


3. Land Use Scenario

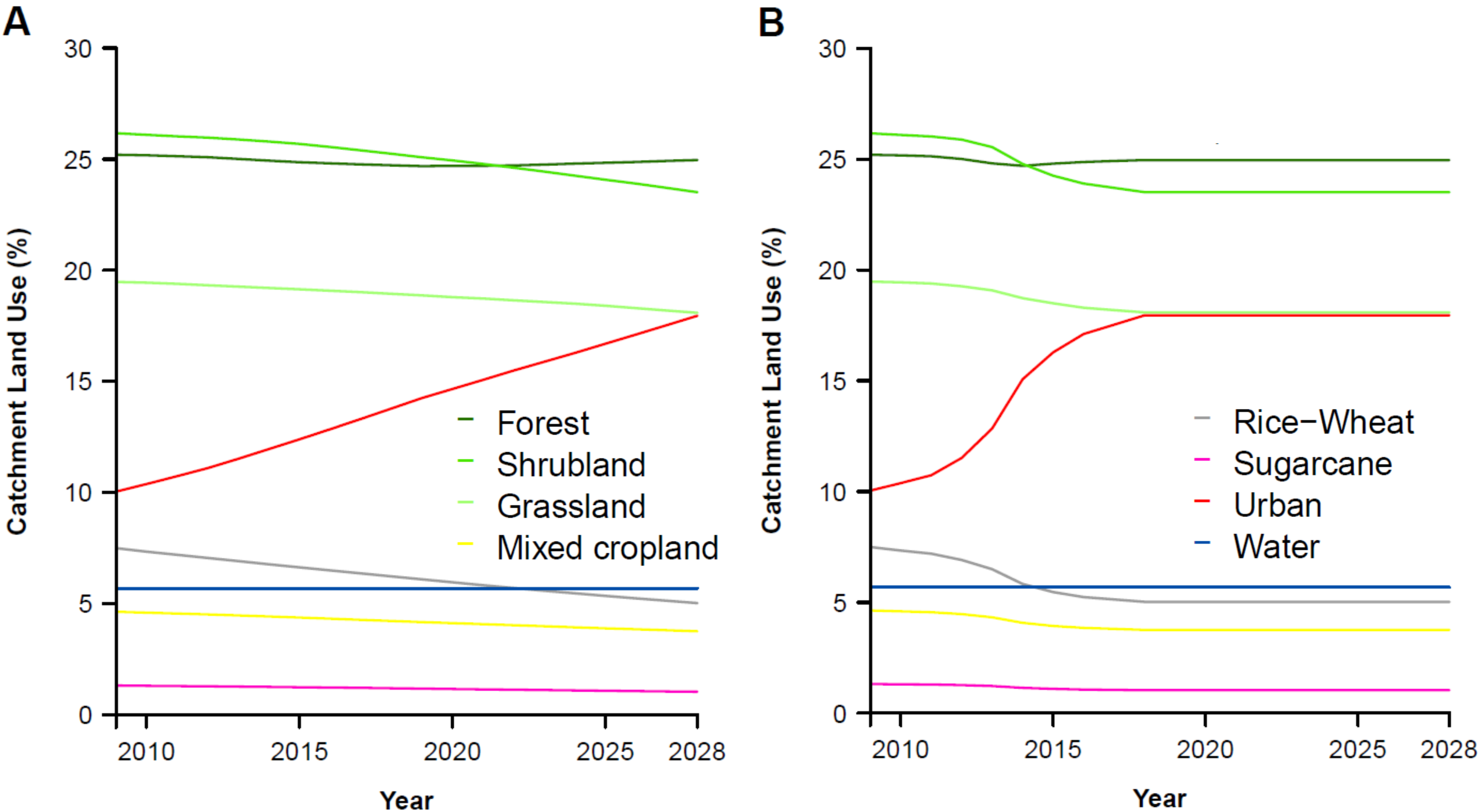
Land use scenario

2028/29



3. Land Use Scenarios

linear



3. Model runs

Land use representation	Land use scenario	Model run abbreviation
Static (2009/2010)	-	LU09
Static (2028/2029)	-	LU28
Dynamic (time step 1 yr)	linear	LU1S1
Dynamic (time step 1 yr)	non-linear	LU1S2
Dynamic (time step 3 yrs)	non-linear	LU3S2
Dynamic (time step 5 yrs)	non-linear	LU5S2
Dynamic (time step 9 yrs)	non-linear	LU9S2

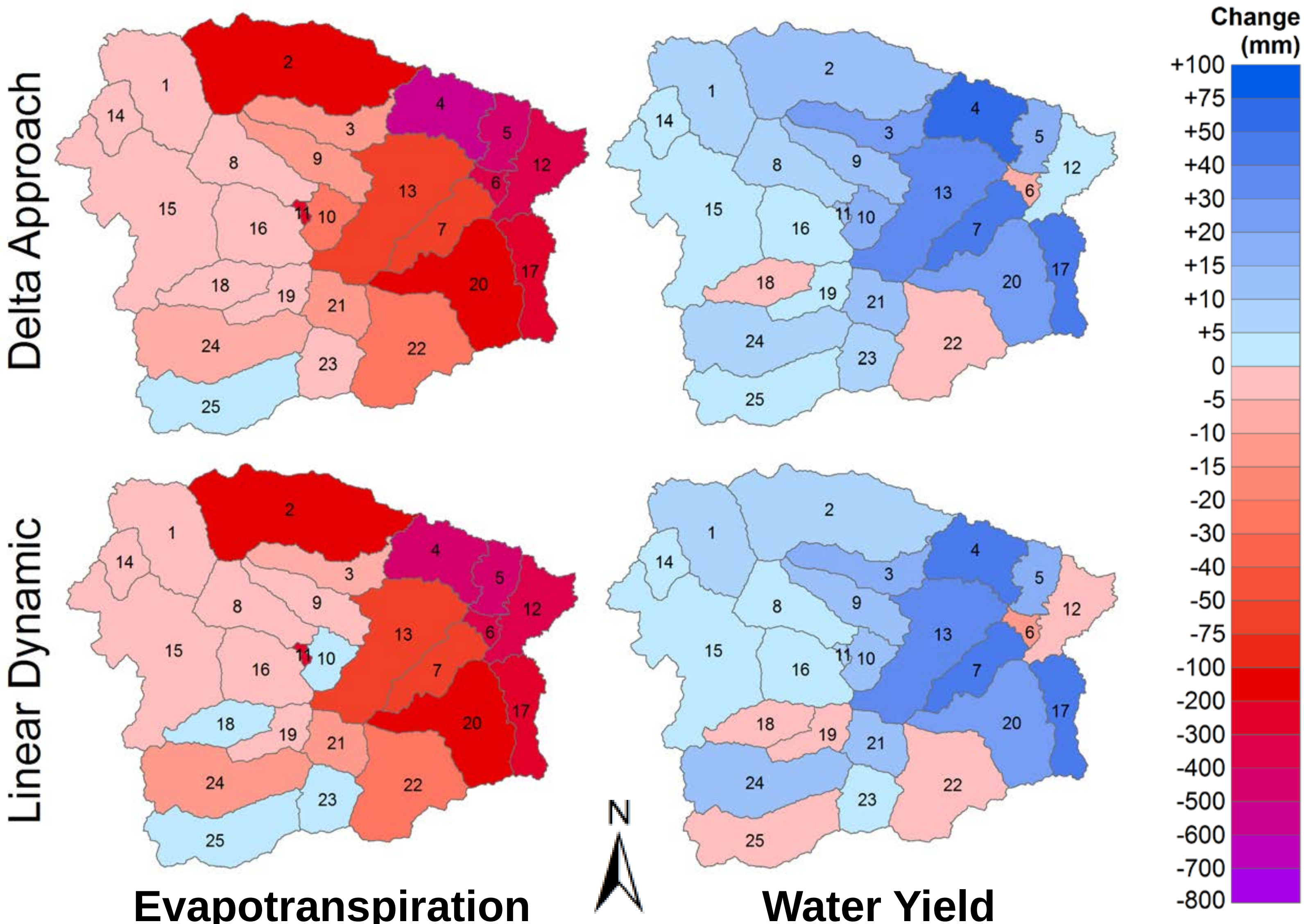
3. Land use change impact assessment

$$Delta\ Change = \frac{V(LU28) - V(LU09)}{2}$$

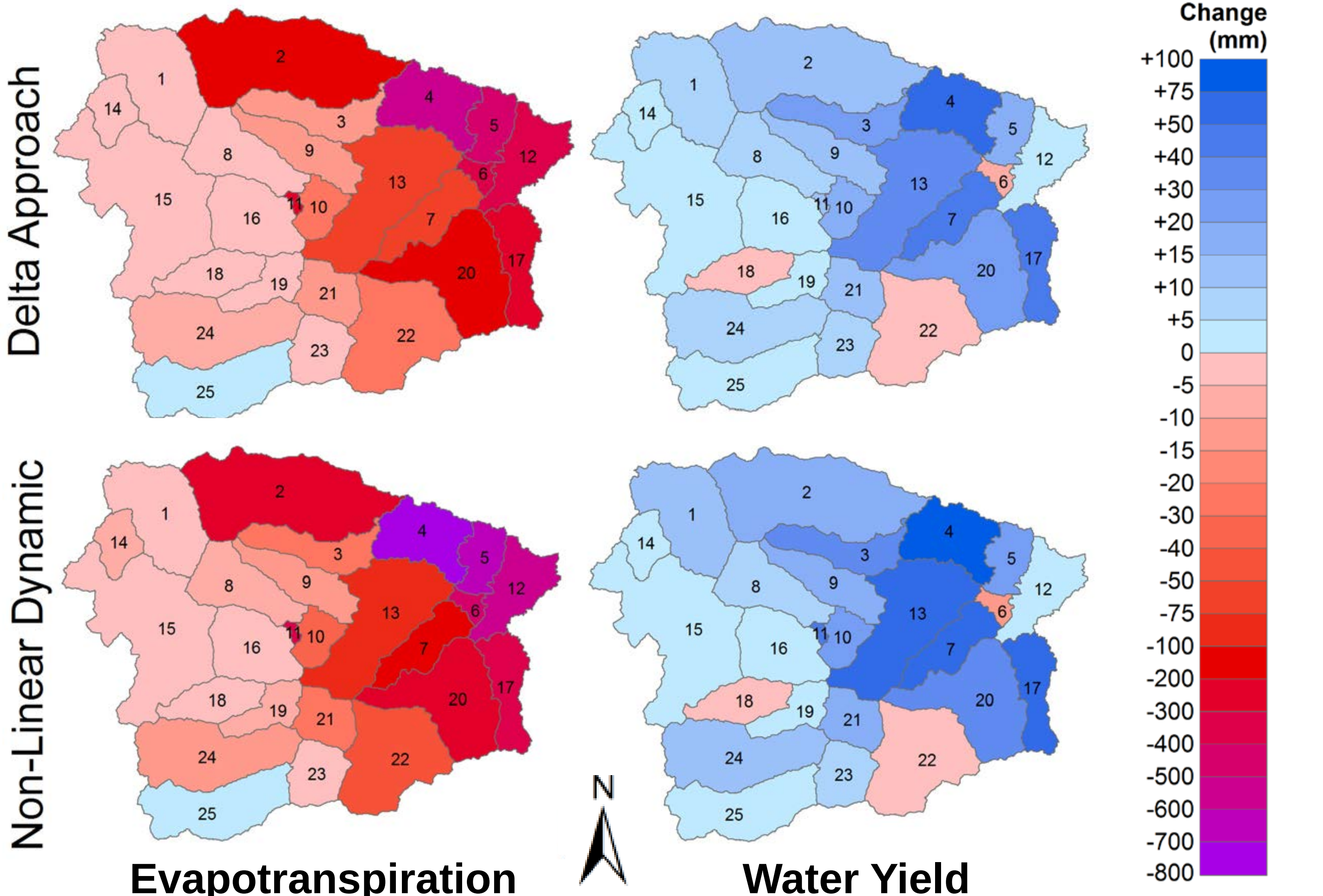
$$Dynamic\ Change = \sum_{i=2009}^{2028} \left[V(LUi) - V(LU09) \right]$$

where $V(LU28), V(LU09), V(LUi)$ are the cumulative values of a water balance component V for the model runs $LU28$, $LU09$, and LUi (for the period between the annual land use updates i), respectively

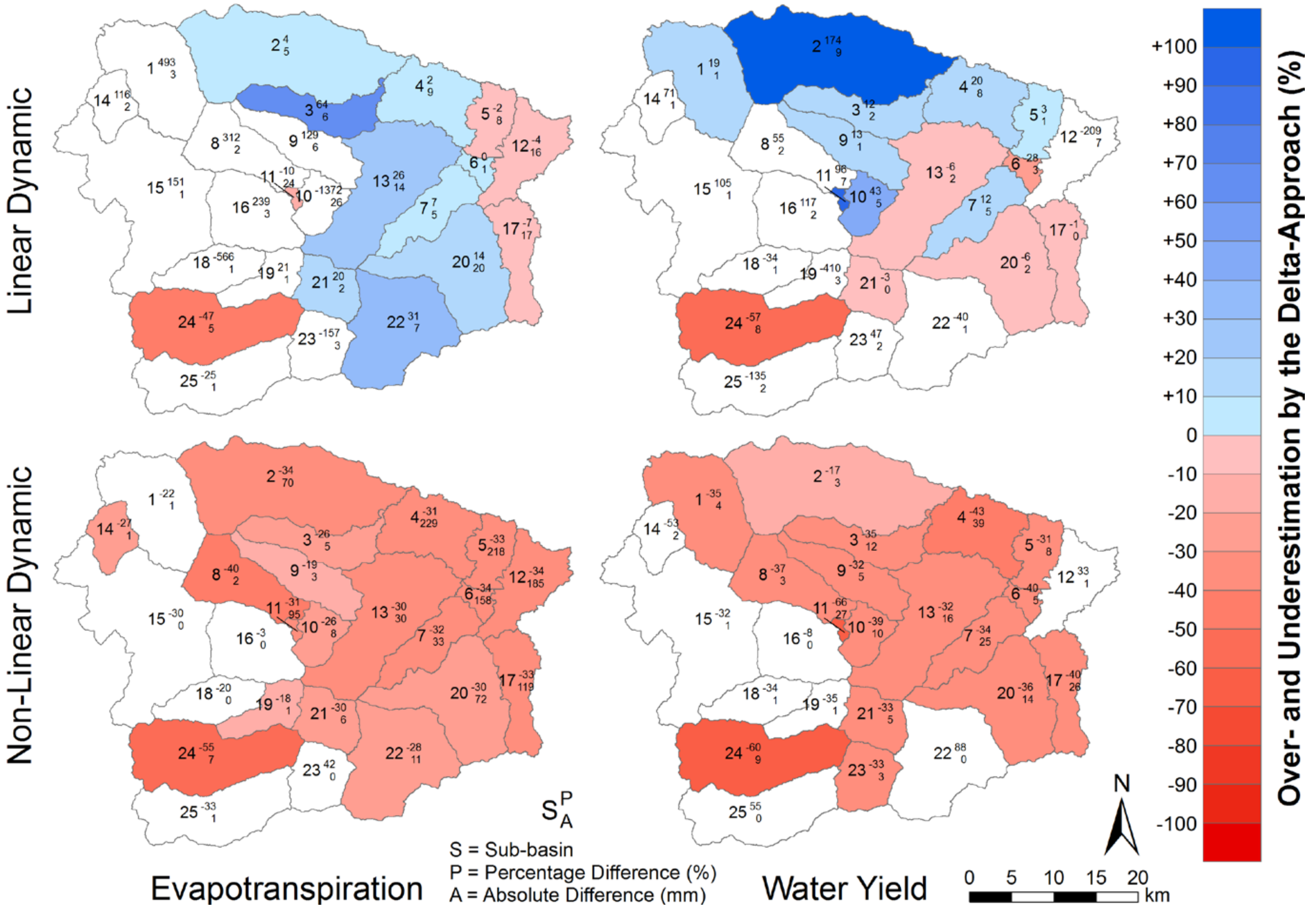
4. Cumulative land use change impacts



4. Cumulative land use change impacts



5. Approximation by the Delta-Approach



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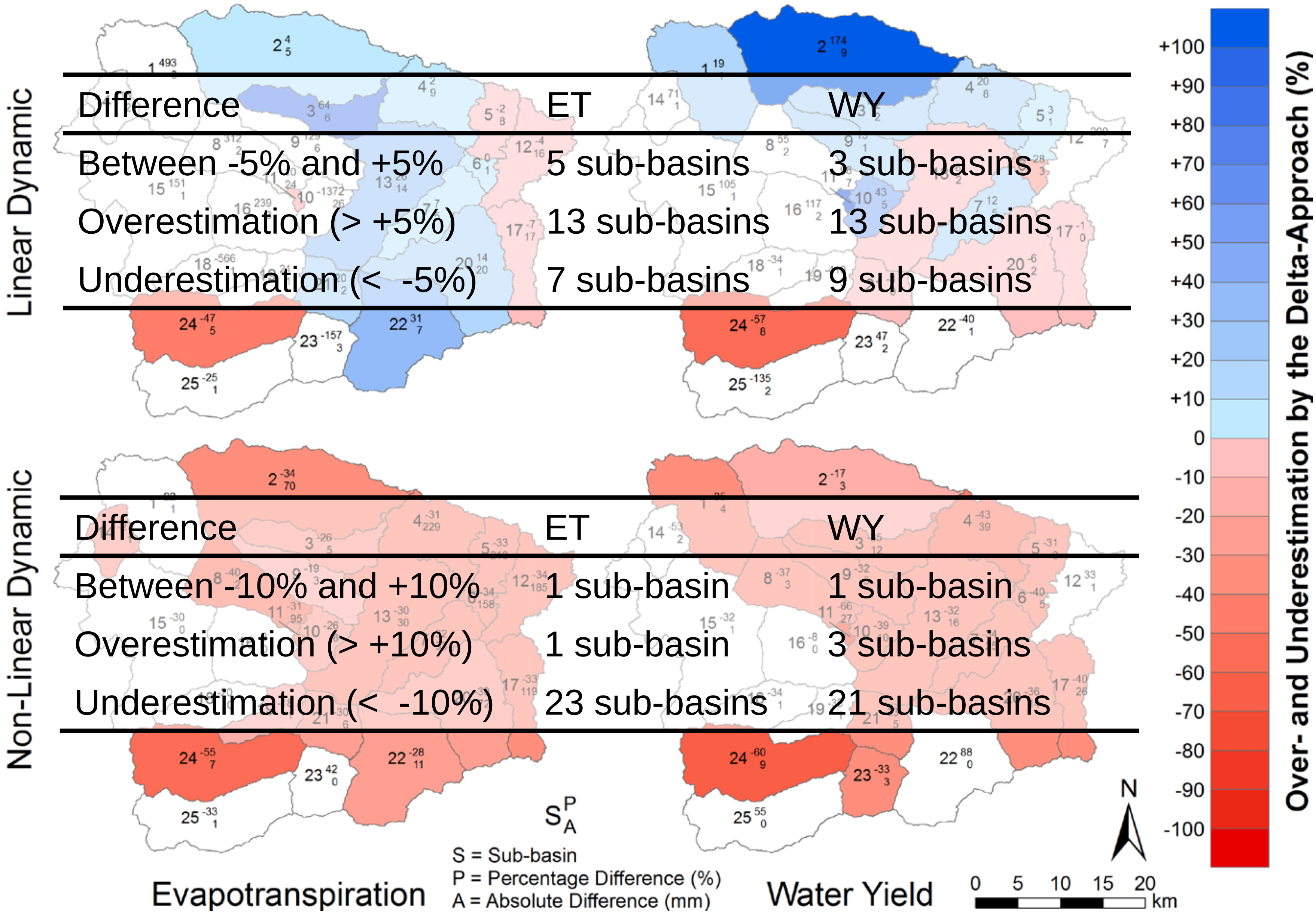


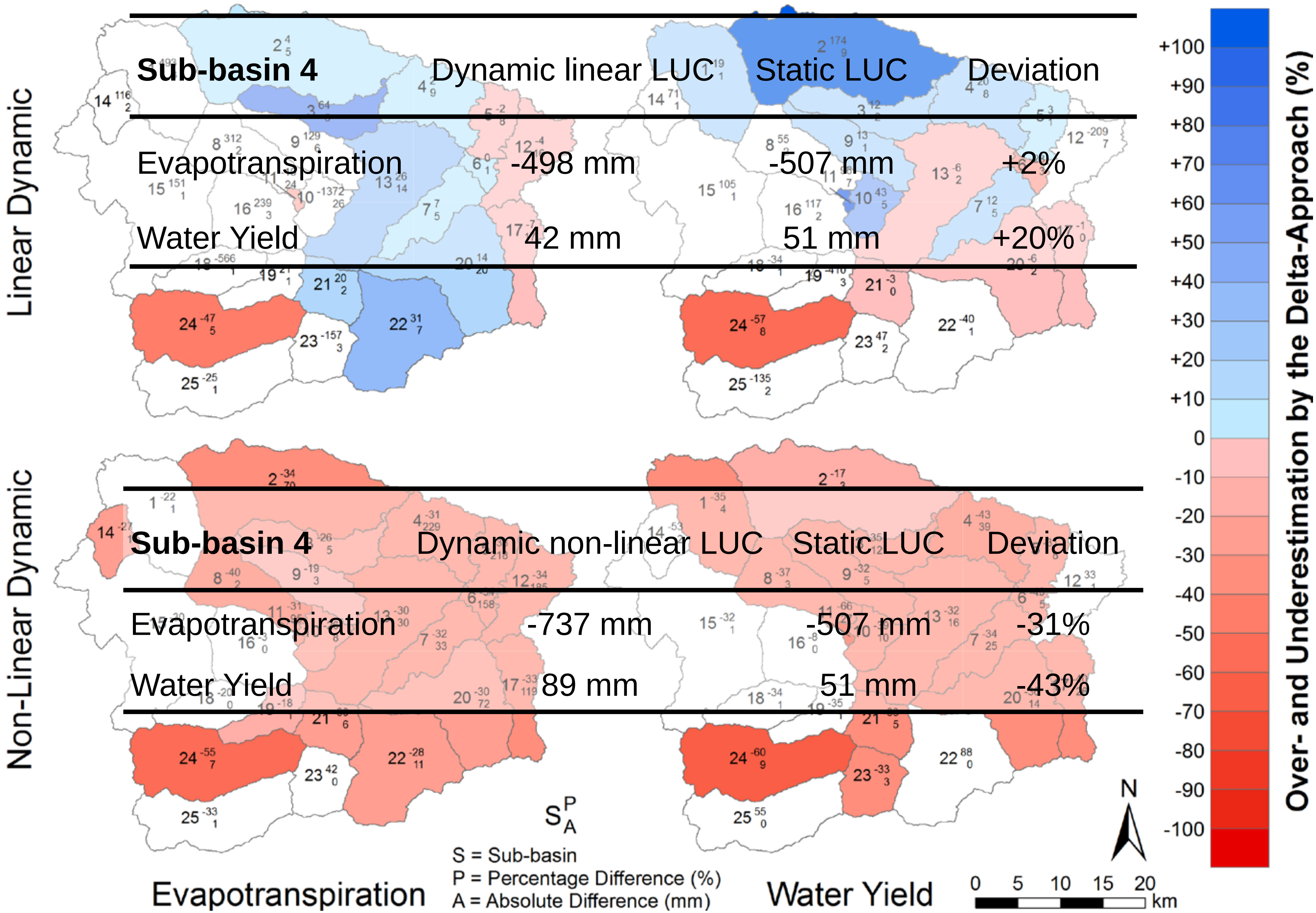
Difference	ET	WY
Between -5% and +5%	5 sub-basins	3 sub-basins
Overestimation (> +5%)	13 sub-basins	13 sub-basins
Underestimation (< -5%)	7 sub-basins	9 sub-basins

Difference	ET	WY
Between -10% and +10%	1 sub-basin	1 sub-basin
Overestimation (> +10%)	1 sub-basin	3 sub-basins
Underestimation (< -10%)	23 sub-basins	21 sub-basins

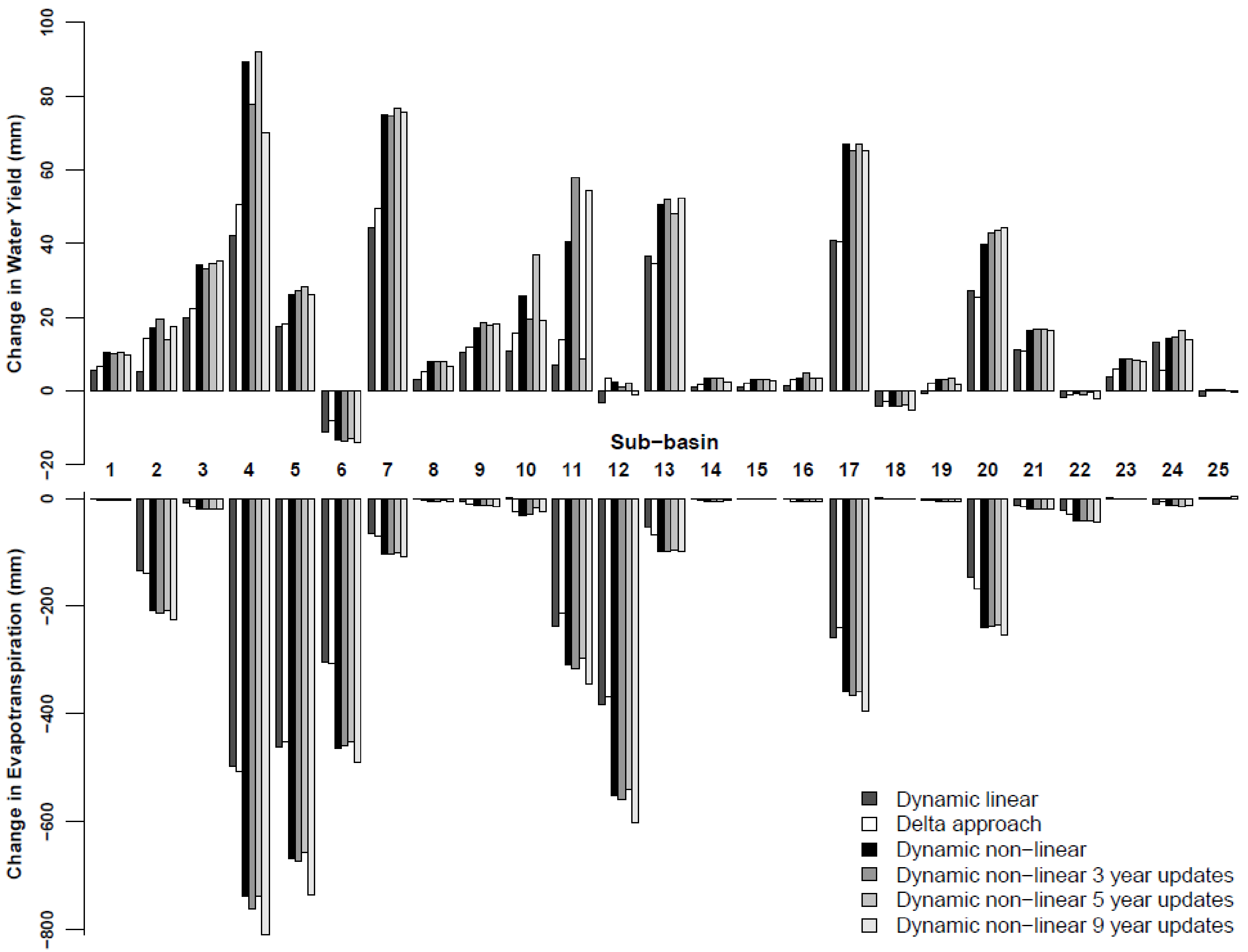
5. Approximation by the Delta-Approach

Sub-basin 4	Dynamic linear LUC	Static LUC	Deviation
Evapotranspiration	-498 mm	-507 mm	+2%
Water Yield	42 mm	51 mm	+20%

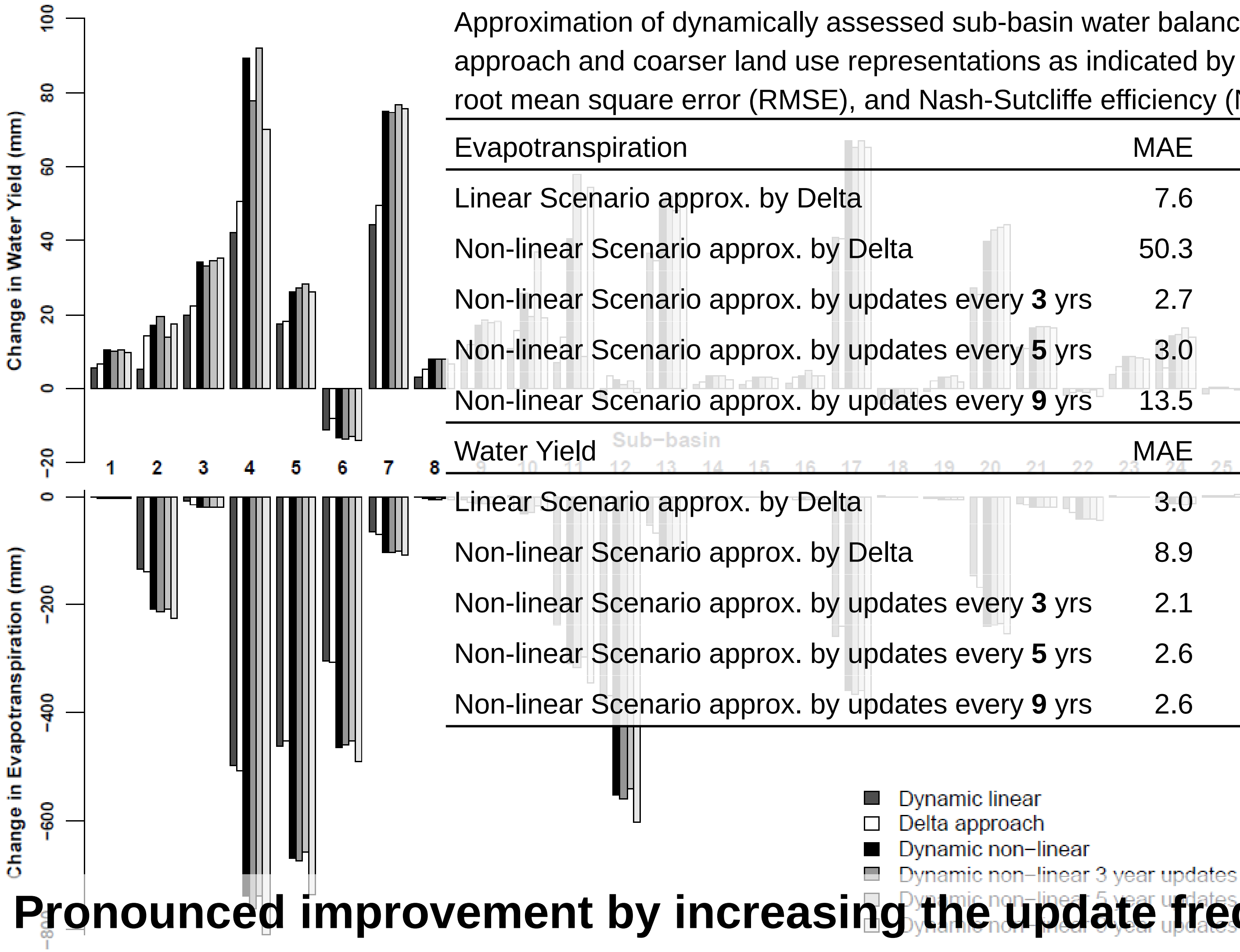
Sub-basin 4	Dynamic non-linear LUC	Static LUC	Deviation
Evapotranspiration	-737 mm	-507 mm	-31%
Water Yield	89 mm	51 mm	-43%



6. Land use update frequency



6. Land use update frequency



Approximation of dynamically assessed sub-basin water balance changes by the delta approach and coarser land use representations as indicated by mean absolute error (MAE), root mean square error (RMSE), and Nash-Sutcliffe efficiency (NSE).

Evapotranspiration	MAE	RMSE	NSE
Linear Scenario approx. by Delta	7.6	10.6	0.995
Non-linear Scenario approx. by Delta	50.3	88.3	0.844
Non-linear Scenario approx. by updates every **3** yrs	2.7	5.6	0.999
Non-linear Scenario approx. by updates every **5** yrs	3.0	5.5	0.999
Non-linear Scenario approx. by updates every **9** yrs	13.5	25.0	0.988
Water Yield	**MAE**	**RMSE**	**NSE**
Linear Scenario approx. by Delta	3.0	4.0	0.931
Non-linear Scenario approx. by Delta	8.9	13.5	0.722
Non-linear Scenario approx. by updates every **3** yrs	2.1	4.5	0.969
Non-linear Scenario approx. by updates every **5** yrs	2.6	6.9	0.927
Non-linear Scenario approx. by updates every **9** yrs	2.6	5.1	0.960

Pronounced improvement by increasing the update frequency (5-9 years)

7. Conclusions

Dynamic land use integration yields more accurate predictions

- *Water yield and ET are either underestimated or overestimated by the static delta approach in most sub-basins for both scenarios*

Frequency of required land use information depends on the development rate of land use change

Non-linear land use change scenarios are hard to approximate with static land use change assessments

Land use information every five to nine years meant a pronounced improvement of prediction accuracy

- Necessity of continous land use monitoring in rapidly developing regions
- Use the SWAT land use update function

Thank you very much!

More details: Wagner et al. (2017): Comparing the effects of dynamic versus static representations of land use change in hydrologic impact assessments. *Environmental Modelling and Software*, accepted.

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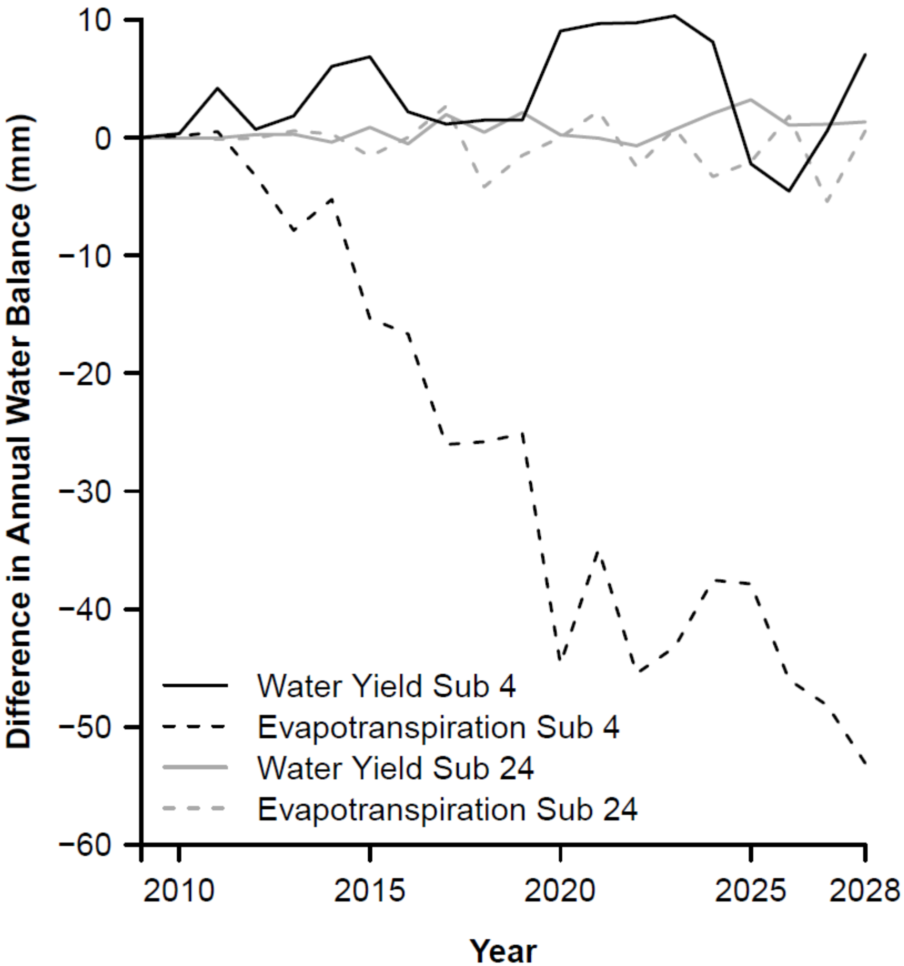
4. Land use change impacts

Annual impacts of land use change



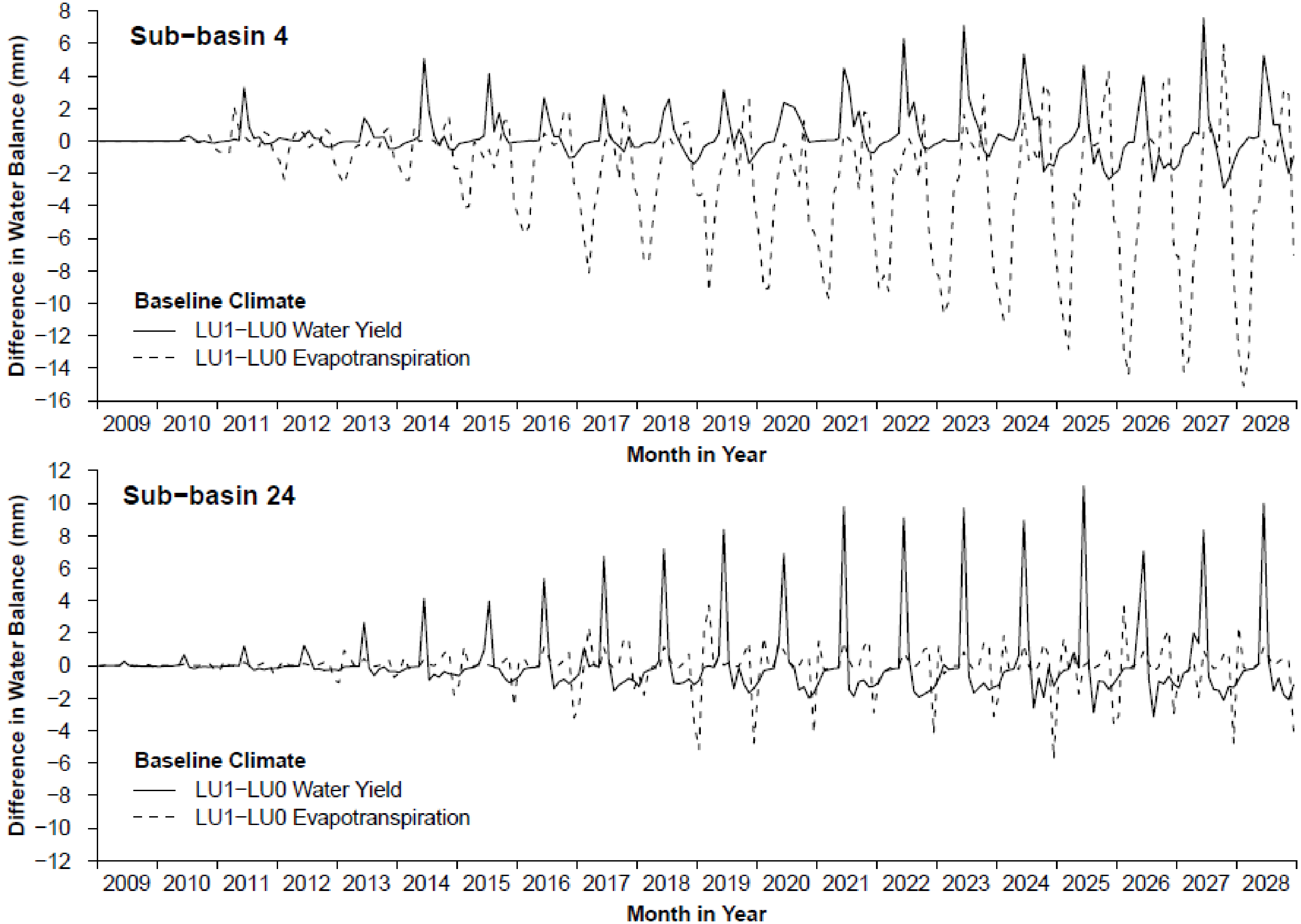
Sub-basin 4 (urban fringe):
- **Increase of water yield (surface sealing)**
- **Decrease of evapotranspiration (decrease of cropland)**

Sub-basin 24 (Lavasa):
- **Comparatively low impacts**

Source: Wagner, P.D., S. Murty Bhallamudi, B. Narasimhan, L.N. Kantakumar, K.P. Sudheer, S. Kumar, K. Schneider, P. Fiener, 2016. Dynamic integration of land use changes in a hydrologic assessment of a rapidly developing Indian catchment. *Science of the Total Environment*, 539: 153-164.

4. Land use change impacts

Impacts of land use change on the monthly time scale



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