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Institute for Natural Resources Conservation

Evaluation of land use, land management and soil conservation strategies to reduce non-point source pollution loads in the Three Gorges Region, China

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Photo: A. Strehmel

YANGTZE PROJECT

YANGTZE-GEO
2009 - 2015

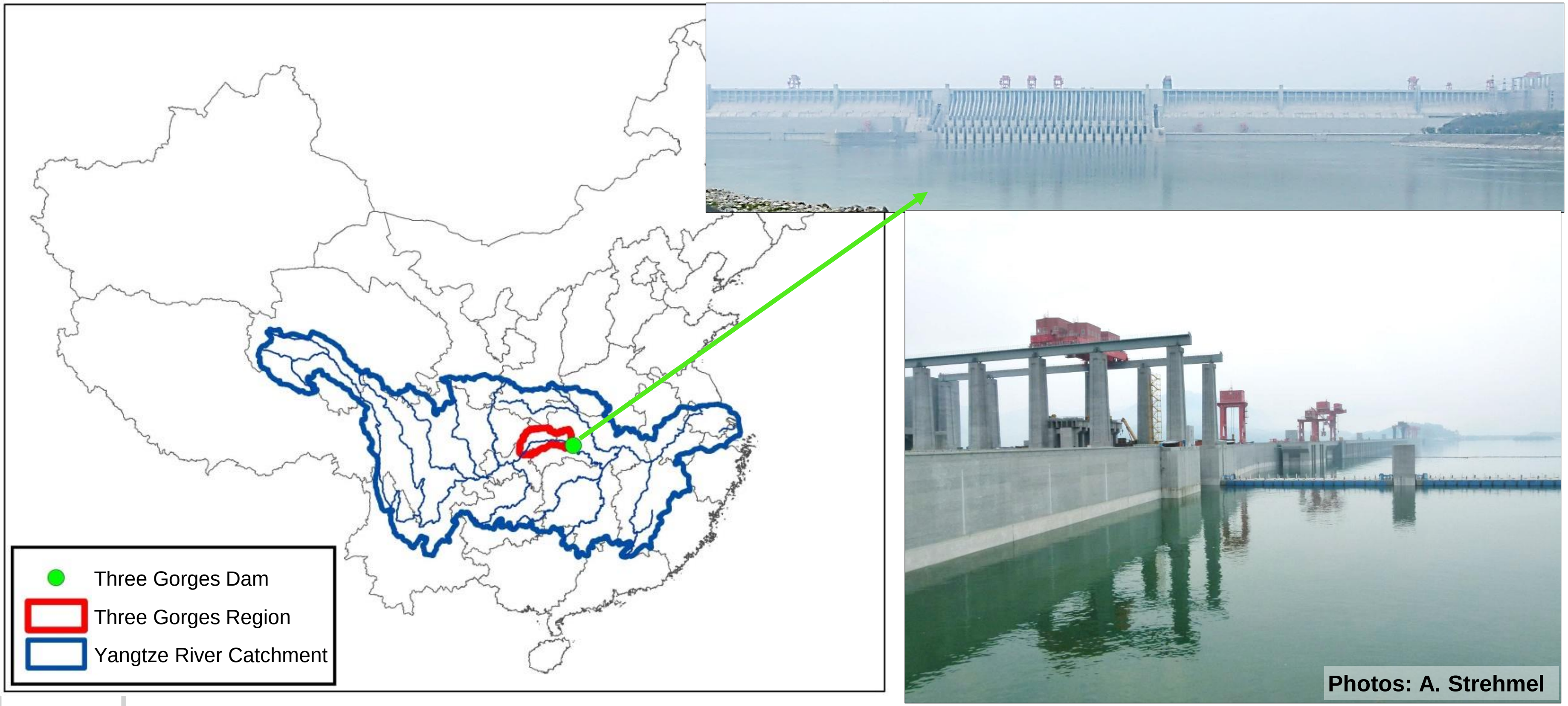
Land use change, erosion, mass movements and diffuse matter inputs in the Three Gorges Region

Erosion Tübingen	Landslides Erlangen	Landslide Monitoring DMT Essen	Diffuse Matter Inputs Kiel	Remote Sensing Trier
Assessment and analysis of soil erosion	Assessment and analysis of landslides	Assessment of mass movements using geo-monitoring techniques	Analysis of sediment and phosphorus inputs using SWAT and HEC-RAS	Classification of land use and land use change assessment

Aim:
Analysis of land use change, risk assessment of mass movements, soil erosion and diffuse inputs to rivers

The Three Gorges Dam in China

- Impoundment of the Yangtze River in central China
- Major land use changes in the Three Gorges Region (TGR) upstream of the dam due to resettlements



Soil Erosion in the TGR

- High soil erosion due to mountainous terrain
- Reclamation of agricultural land on steep slopes
- Lack of experience in establishing and maintaining soil conservation measures
- **Consequence: High sediment loads in rivers and streams, especially during strong rainfall events**

Phosphorus Displacement

- Phosphorus easily adsorbed to soil particles
- Phosphorus as limiting factor for the aquatic ecosystem of the Three Gorges Reservoir
- Low flow velocities in the tributary valleys
  → accumulation of phosphorus
  → eutrophication
- **Eutrophication and algae blooms endanger the aquatic ecosystem of the reservoir**


Photo: A. Strehmel


Photo: X. Jiang

Research Question

Current Situation in the TGR

Agricultural Management

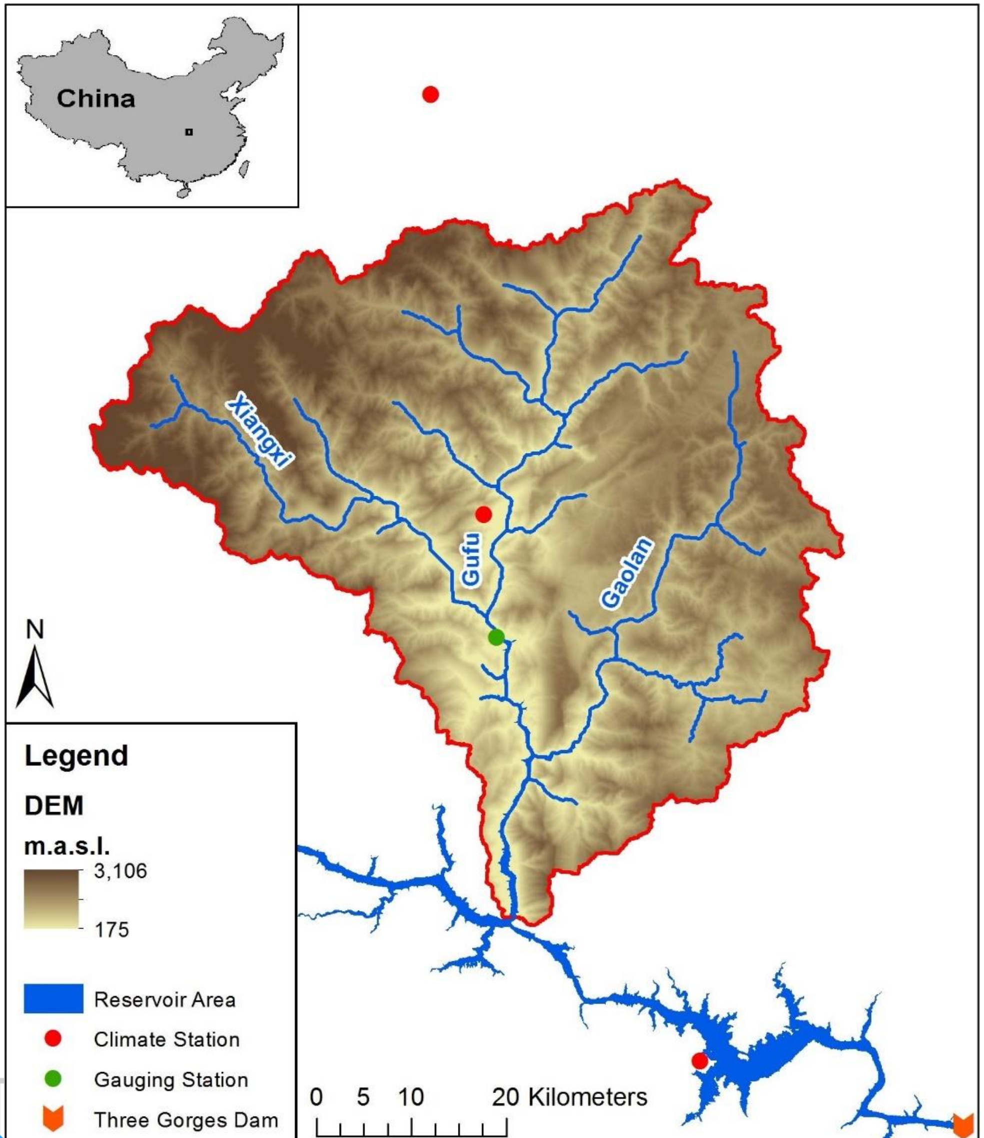
Soil Conservation Measures (Terraces)

What are suitable management strategies to reduce diffuse sediment and phosphorus pollution?

SWAT Modelling Approach

Evaluation of Agricultural Best Management Practices

Study Area: The Xiangxi (香溪) catchment

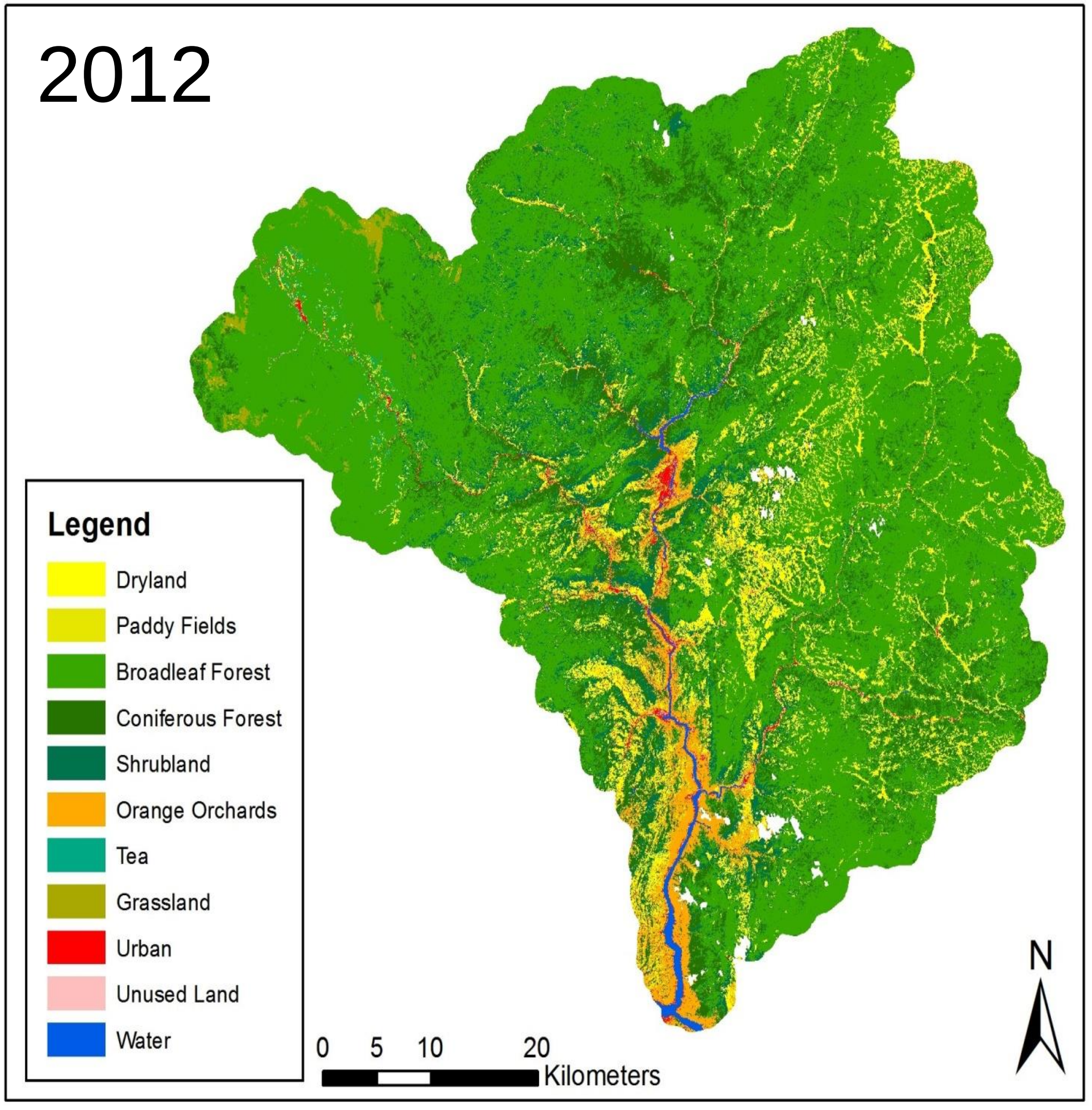


Area: ca. 3.200 km²

Average slope: 24°

Length of Xiangxi River: 94 km

Land Use of the Xiangxi Catchment



- Forest: 75%
- Cropland: 10%
- Shrubland: 8%
- Orange orchards: 4%
- Rest: 3%
- Terraces as most important soil conser-vation measure

Source: Buzzo (2013)
Maximum-likelihood classification of Rapid-Eye imagery (RapidEye, 2012)

Current Situation in the TGR

Agricultural Management

Soil Conservation Measures (Terraces)

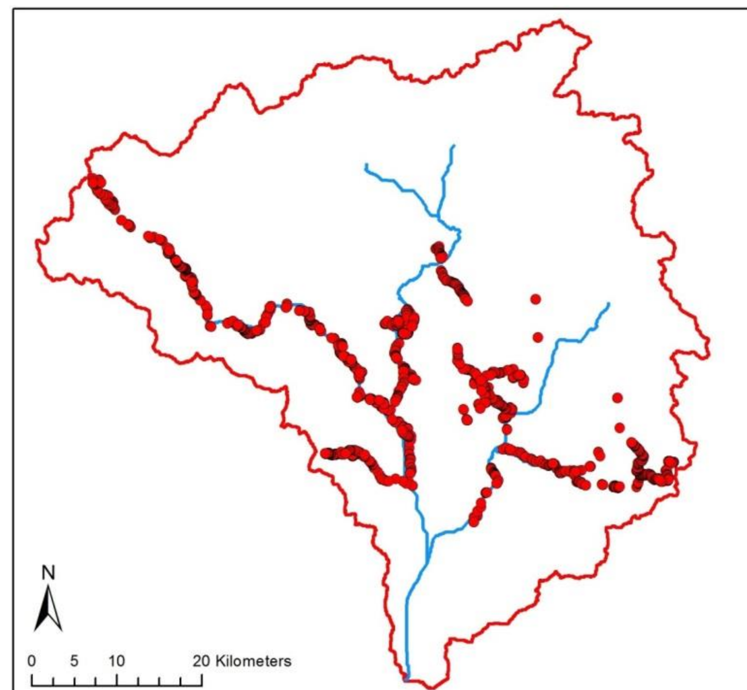
Dynamics of non-point source pollution? (Total Phosphorus)

- **What is the current situation?**
- **How to implement these information in SWAT?**

Field Mapping – Spring 2013

Geo-referenced photos using a GPS-equipped camera:

- mostly from the car along the main rivers and valleys
- also on some high plateaus
- in total 2,500 geo-tagged photos



Farmer Interviews – Spring 2013

- in total 15 semi-standardized interviews with farmers
- in different agricultural zones of the catchment
- Questions on: - Seeding and harvesting times
  - Crop rotations
  - Yields
  - Fertilizer use: when? what? how much?


Photo: G. Buzzo


Photo: A. Strehmel

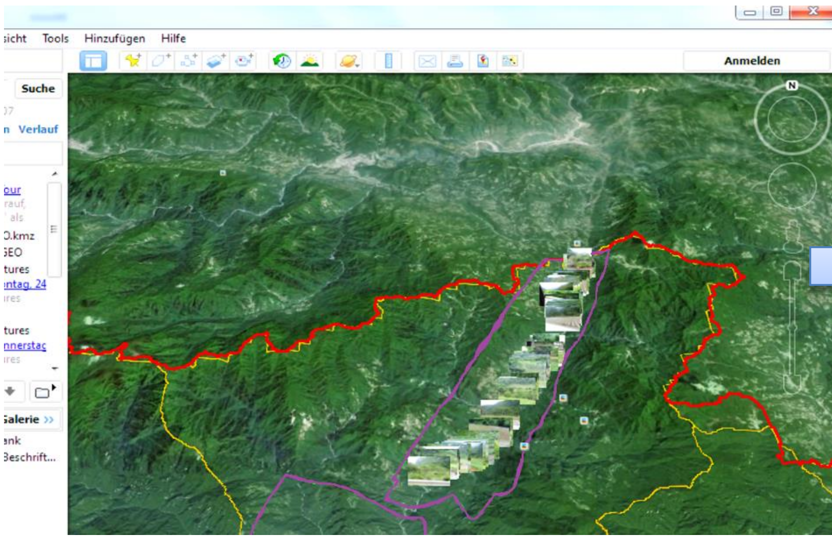

Photo: G. Buzzo

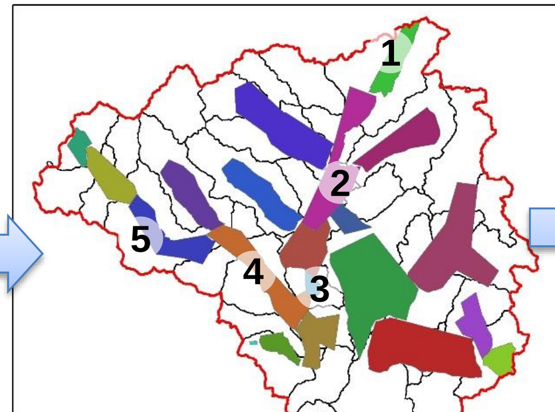
Daily Total Phosphorus Sampling

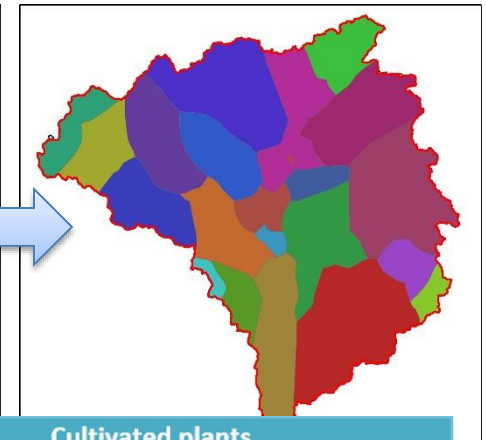
Goal: Establish an idea on seasonal phosphorus dynamics in the Xiangxi catchment

Implementation of Agricultural Management

- Analysis of the geo-referenced photos from the field campaigns
- Derivation of sub-areas with uniform cultivation patterns





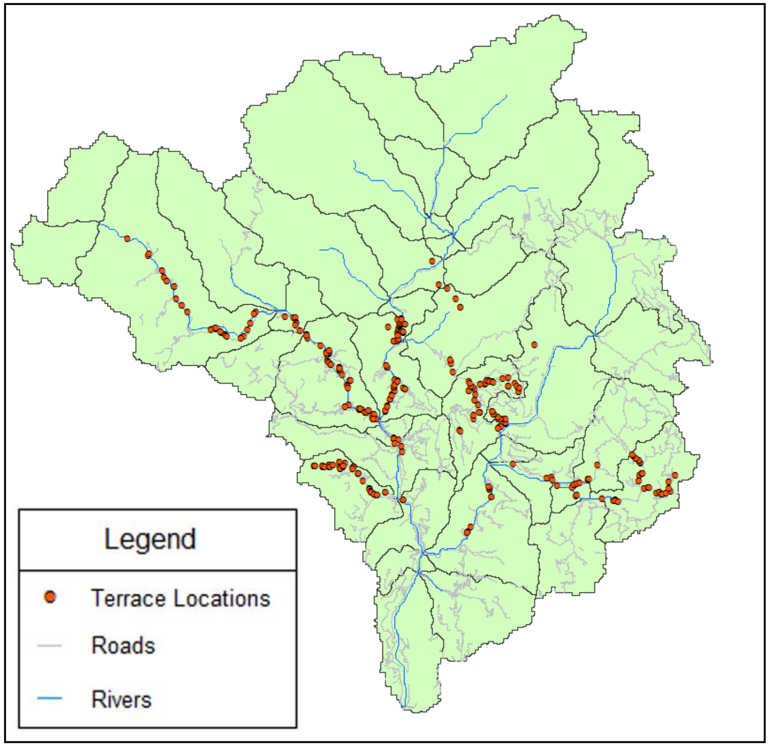


Data from farmer interviews to parameterize the land management

Subarea	Date of observations	Cultivated plants
1	17.05.2013	80% rape-corn; 10% walnut; 5% potato; 5% others (wheat, pumpkin, tomato, beans)
2	17.05.2013	55% rape-corn; 20% rice; 15% potato; 5% wheat; 5% other (sweet potato)
3	18.05.2013	55% rape-corn; 20% potato; 25% others (tomato, cabbage, sweet potato)
4	18.05./20.05.2013	85% rape-corn; 5% potato; 10% others (sweet potato, cabbage, tomato)
5	20.05/23.05.2013	50% tea; 22 % rape-corn; 20% potato; 5% tobacco;

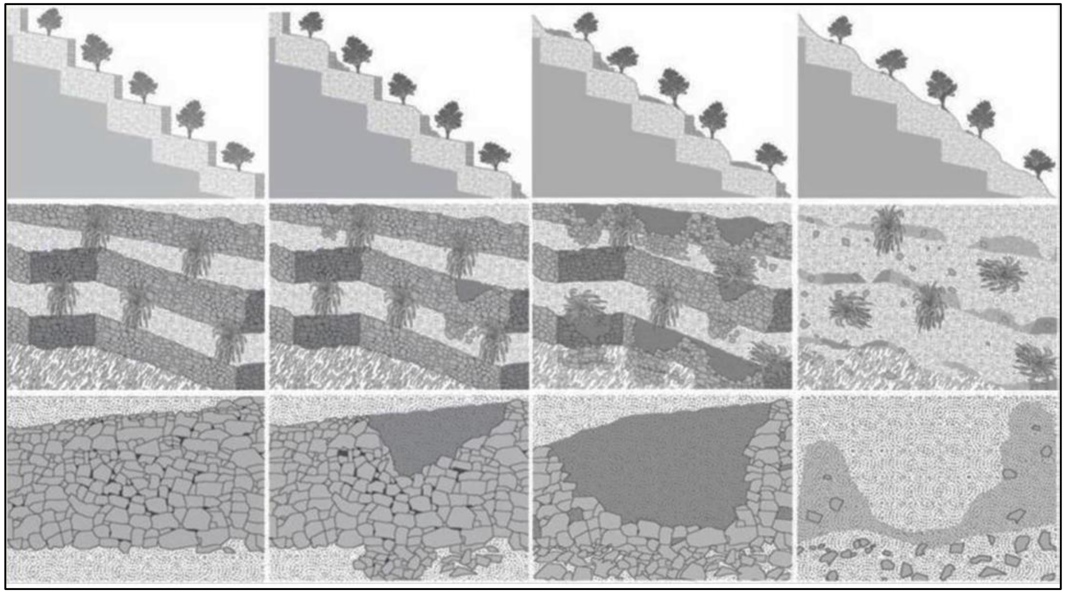
Terrace Condition Mapping

Terrace mapping:
420 terraces for analysis



Classification of terrace conditions:

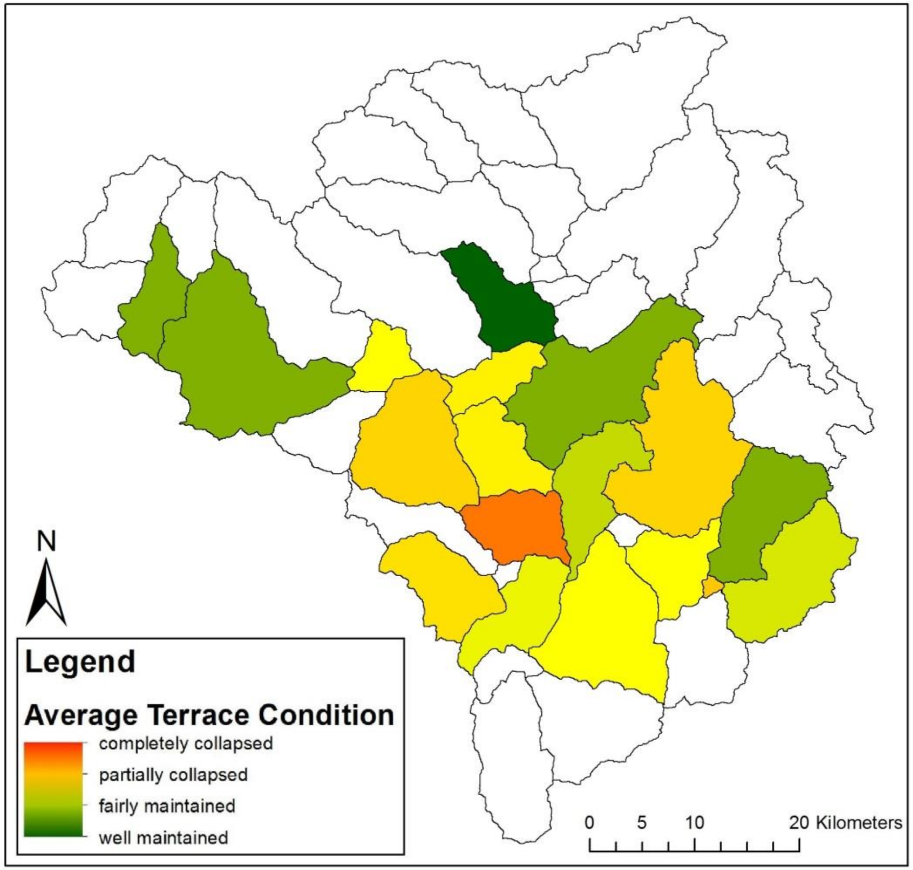
1	2	3	4
Well maintained	Fairly maintained	partially collapsed	completely collapsed



after Schönbrodt-Stitt et al., 2013

Goal: Determination of the average terrace condition per subbasin

Terrace Condition Field Data



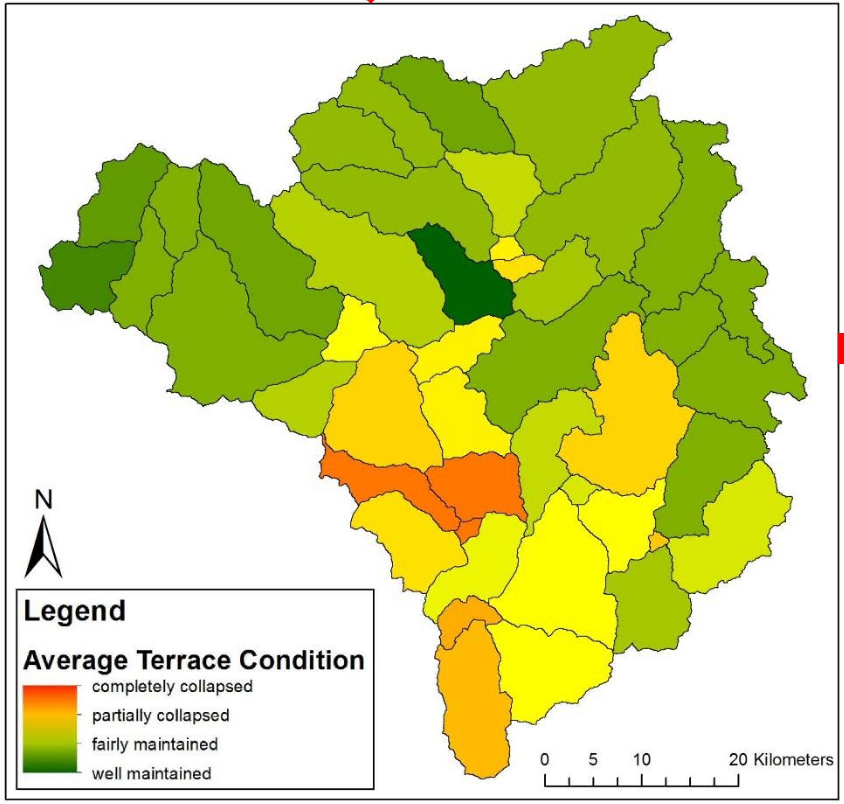
How to extrapolate the information on the whole catchment?

Idea:
Prediction of the average terrace condition in a subbasin by means of explanatory variables related to:

- Topography
- Land Use

Extrapolation of Terrace Conditions

$$TerraceCondition_{sub} = f\,(Elevation; Share\ of\ Cropped\ Dryland; Share\ of\ Orange\ Orchards)$$



Translation of terrace conditions into SWAT parameters (after Arabi et al., 2006):

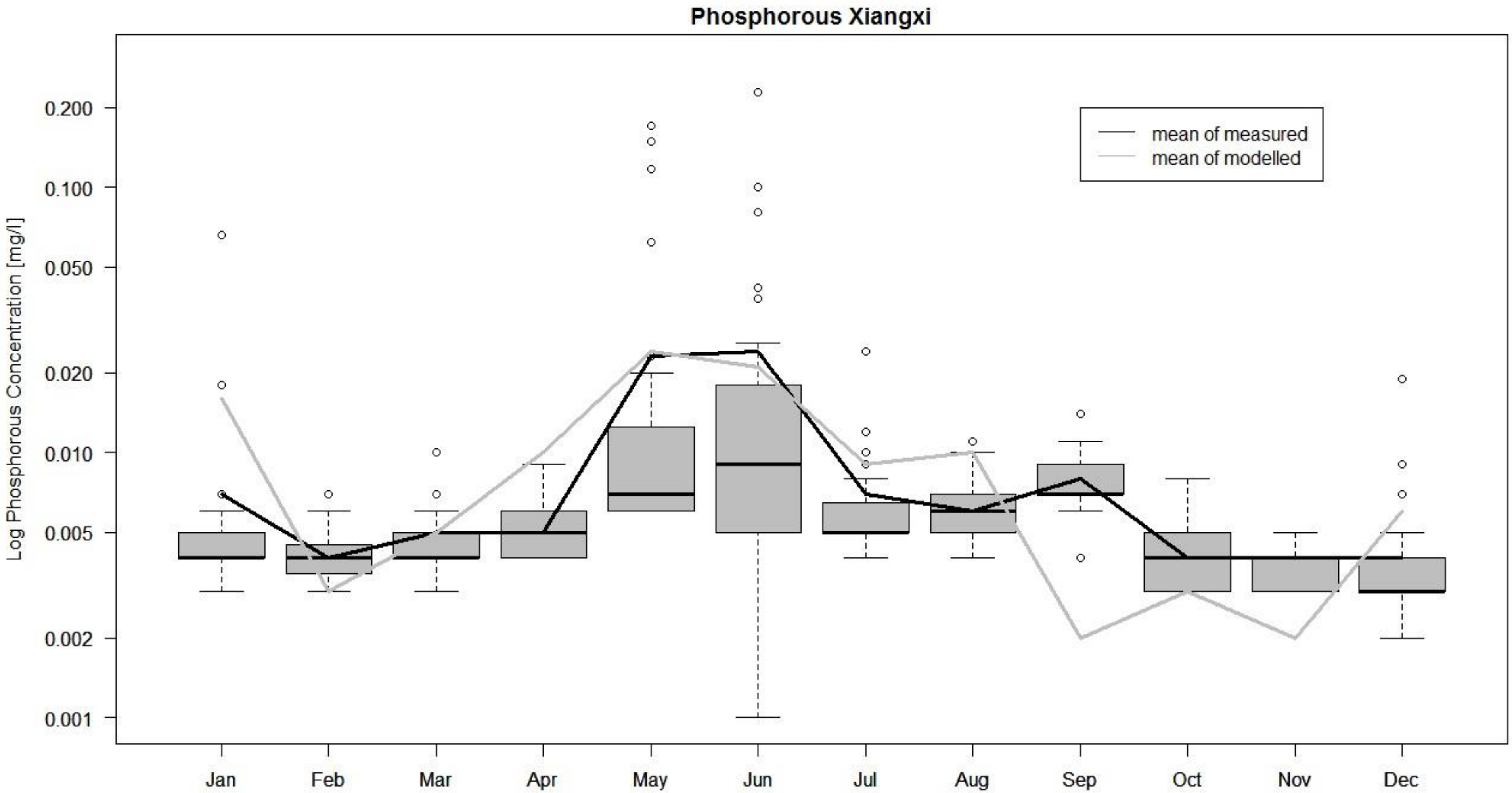
Terrace Condition	CN2 (add)	P_USLE (absolute)	Slope Length (relative)	Slope Length (steep)* (relative)
well maintained	-6	0.2	-40%	-20%
fairly maintained	-5	0.4	-30%	-15%
partially collapsed	-4	0.6	-20%	-10%
completely collapsed	-2	0.8	-10%	-5%
not terraced**	0	1.0	-0%	-0%

* steeper 50%
** only agricultural land steeper than 20% slope is terraced

Model Calibration & Validation

Calibration/Validation	Streamflow (daily)	Sediment (monthly)
Nash-Sutcliffe-Efficiency	0.69/0.70	0.81/0.51
Kling-Gupta-Efficiency	0.81/0.75	0.77/0.59

Validation of Phosphorus Dynamics



Scenario Definitions

Scenarios for phosphorus fertilizer use:

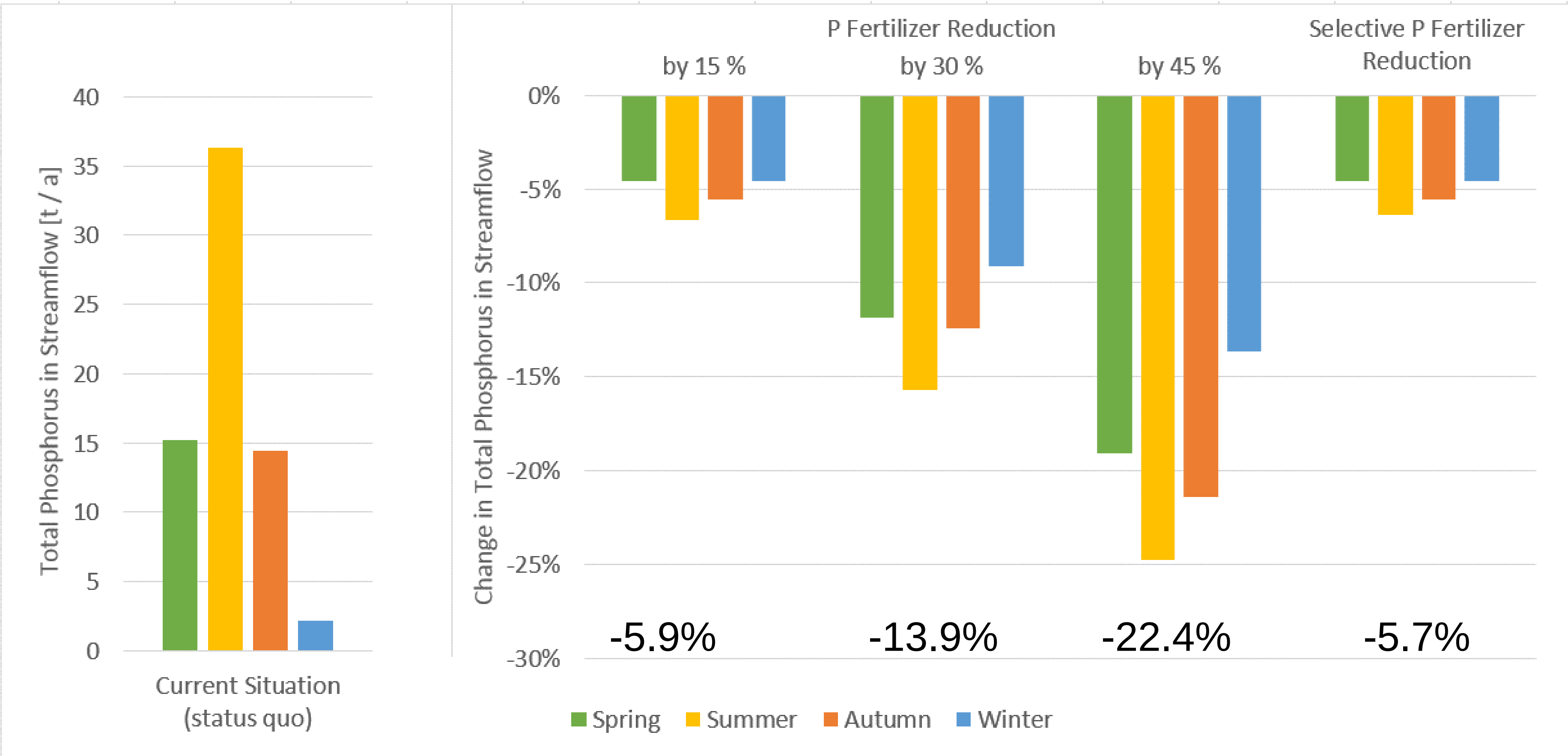
- Status quo: Current fertilizer usage scheme
- Phosphorus Application reduced by 15%
- Phosphorus Application reduced by 30%
- Phosphorus Application reduced by 45%
- Selective Reduction of Phosphorus Application

Definition: Reduction of phosphorus application, so that at least 90% of yield per crop rotation is retained

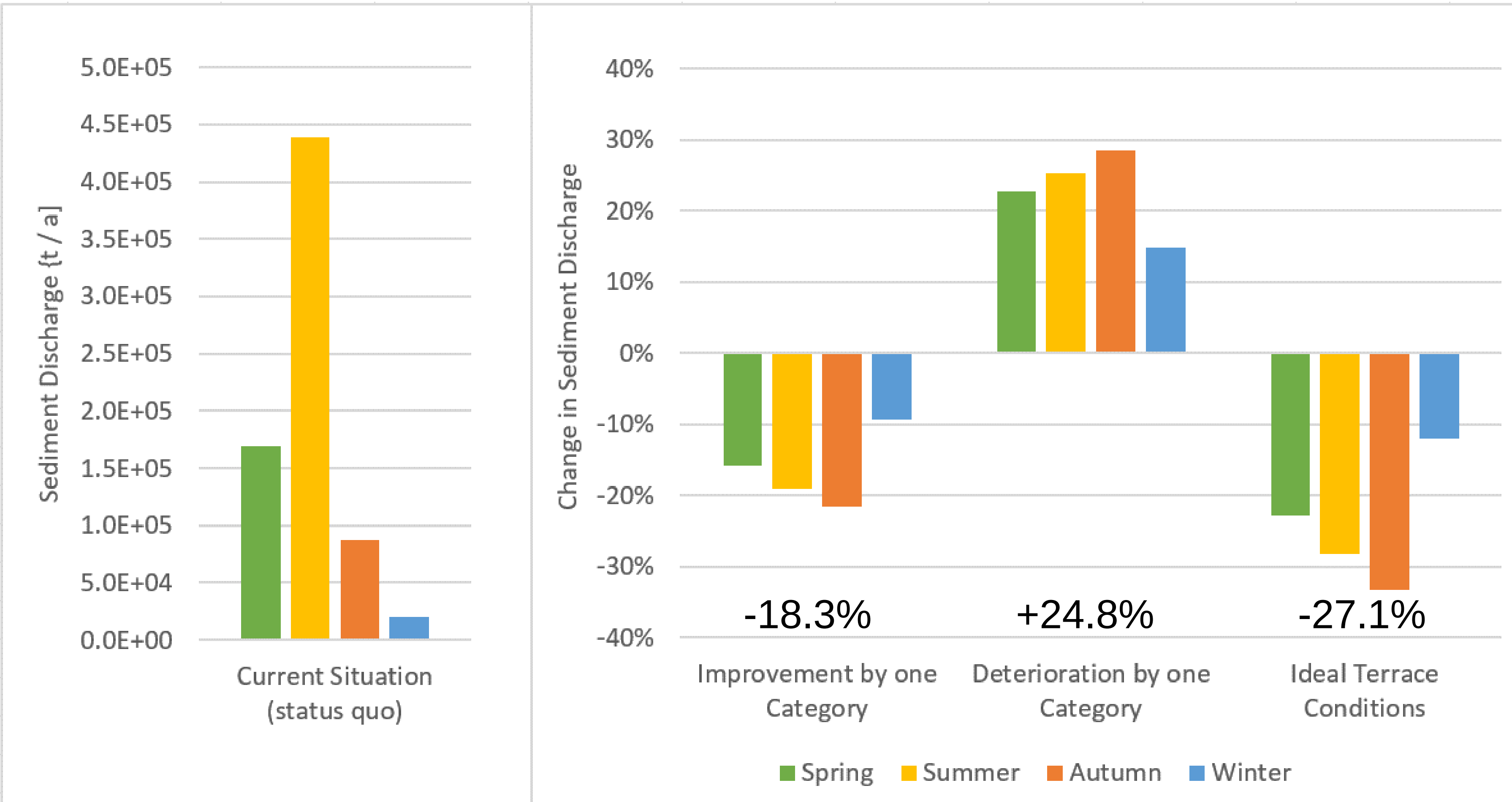
Scenarios for terrace conditions:

- Status quo: Current situation of terrace cond.
- Improvement of conditions by one category
- Deterioration of conditions by one category
- Catchment-wide well-maintained conditions

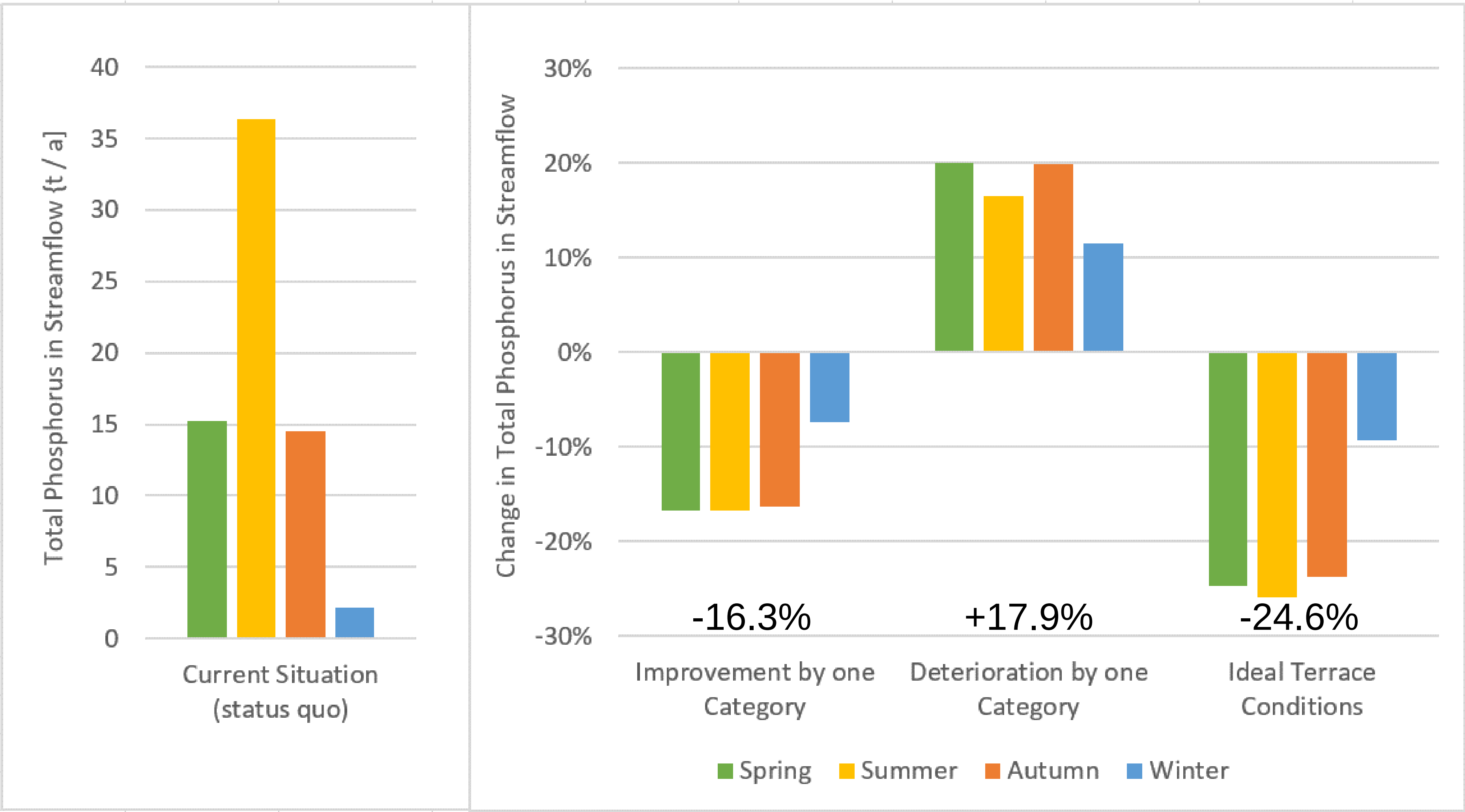
Phosphorus Fertilizer Reduction Scenarios



Adjustment of Terrace Conditions - Sediment

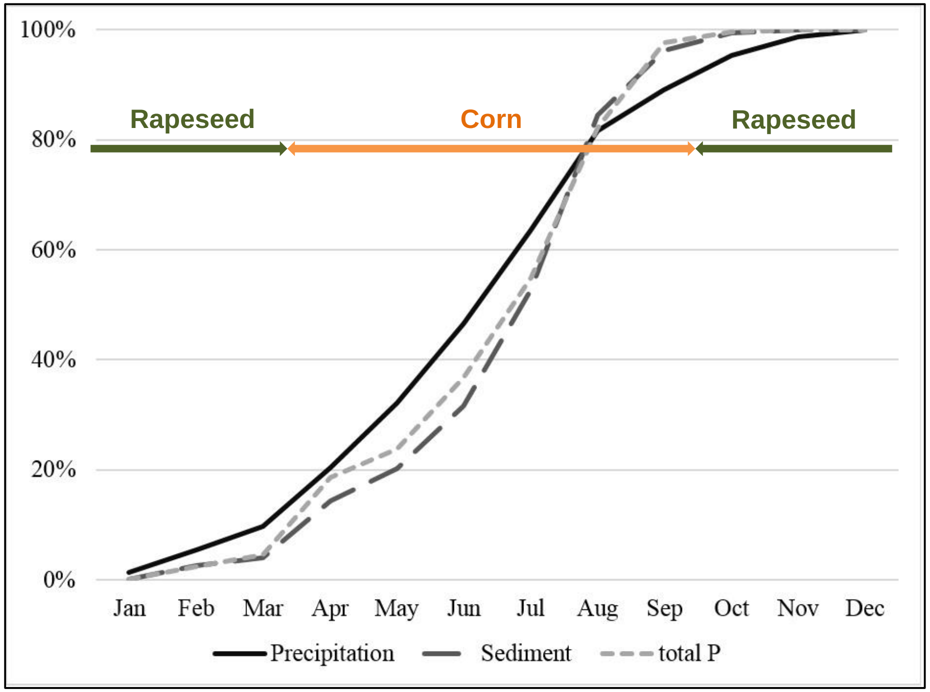


Adjustment of Terrace Conditions – Total P



Crop-wise evaluation

Crop (Rotation)	Area (km²)	Soil Erosion (t/ha/a)	total P release (kg/ha/a)
Corn – Rapeseed	211.1	9.6	2.64
Orange Orchard	114.2	0.4	0.04
Potato – Sweet Potato – Cabbage	44.9	7.8	0.40
Tea Plantation	17.0	0.4	0.01
Rice	14.6	2.2	0.30
Catchment	3208.8	2.6	0.25



Cumulative curves for the corn-rapeseed rotation

- High erosion rates on corn fields also confirmed in other studies (e.g., Barton et al., 2005; Wei et al., 2014)

Conclusions

What are suitable management strategies to reduce diffuse sediment and phosphorus pollution in the TGR?

- *Investments in terrace construction and maintenance are more effective measures than fertilizer reductions*
- *<u>Short-term:</u> Preference of 'Corn-Rapeseed' rotation to existing terraces with good conditions*
- *<u>Mid-term:</u> Investment in programmes to develop and maintain terraced agricultural land and to create incentives for farmers to abstain from corn cultivation*

- *Mitigation strategies for diffuse matter inputs have to be seen in the context of socio-economic developments of the TGR and in China*
- *Economic importance of corn cultivation in the region as key to a successful watershed management in the region*

Photo: A. Strehmel

Thank you for your attention!

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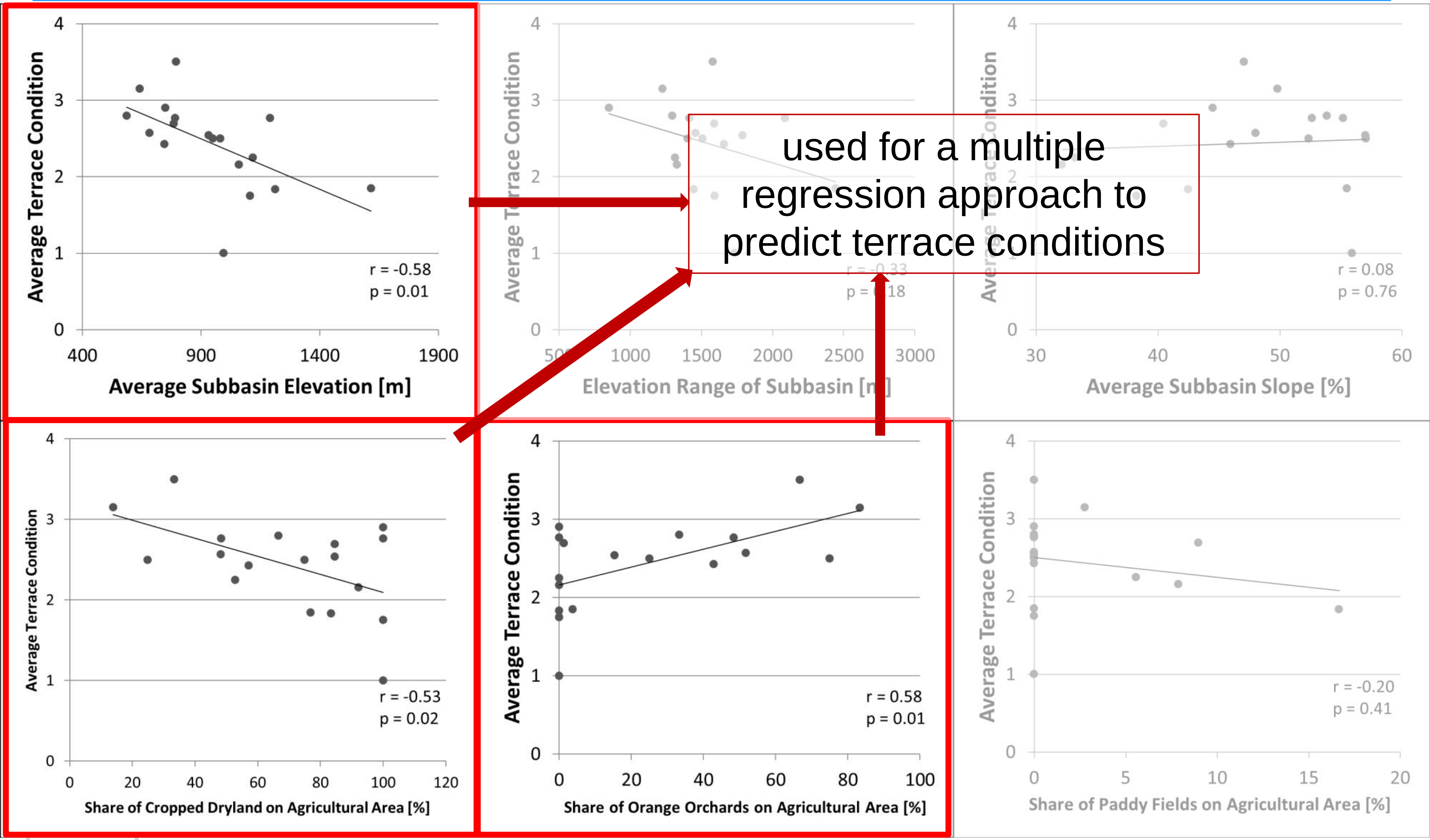
Backup

Implementation of Terraces



Implementation of Terraces

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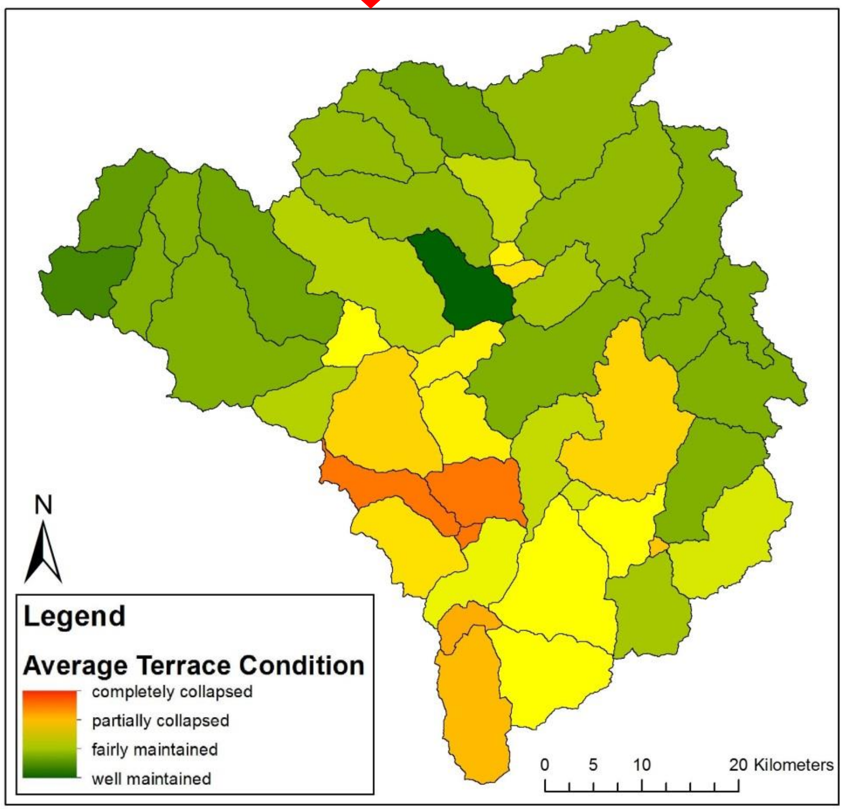


Validation:

Subbasin	Predicted Terrace Condition	Difference to Measured Condition
11	2.17	-1.17
18	2.79	-0.29
20	1.72	0.12
22	3.15	0.00
23	2.06	-0.31
24	2.75	0.02
27	2.86	-0.29
28	2.15	0.01
29	1.99	0.78
30	2.80	0.00
32	2.37	0.13
34	2.05	-0.22
35	2.87	0.63
36	2.39	0.51
38	2.45	0.25
39	2.30	-0.05
41	2.73	-0.30
42	2.34	0.19
	Mean absolute error:	**0.29**
	RMSE:	**0.42**

Parameters for SWAT Calibration

Streamflow Parameter	File	Type of value change	Fitted value	
ESCO	.bsn	Replace value	0.61	Evapotranspiration
CN2	.mgt	Percent change	-14.5%	Surface Runoff
SURLAG	.bsn	Replace value	0.11	
SLSUBBSN	.hru	Percent change	-40.7%	Lateral Flow
SOL_K(1)	.sol	Percent change	-13.8%	
SOL_AWC(1)	.sol	Percent change	-8.0%	Soil Water
SOL_Z(1)	.sol	Percent change	+27.9%	
ALPHA_BF	.gw	Replace value	0.08	Groundwater
GW_DELAY	.gw	Replace value	29.7	
GW_REVAP	.gw	Replace value	0.20	
GWQMN	.gw	Replace value	1291.25	
ALPHA_BNK	.rte	Replace value	0.18	Channel
CH_K2	.rte	Replace value	29.00	
CH_N2	.rte	Replace value	0.07	

Sediment Parameter	File	Type of value change	Fitted value	
USLE_P	.mgt	Percent change	-13.4%	Landscape
USLE_K(1)	.sol	Percent change	+19.5%	
LAT_SED	.hru	Replace value	154.5	Lateral Flow
SPCON	.bsn	Replace value	0.0016	Channel
SPEXP	.bsn	Replace value	1.05	

Parameters for SWAT Calibration

Phosphorus Parameter	File	Type of value change	Fitted value
PSP	.bsn	Replace value	0.017
P_UPDIS	.bsn	Replace value	16.6
PPERCO	.bsn	Replace value	10.3
GWSOLP	.gw	Replace value	0.016
SOL_SOLP(1)	.chm	Replace value	0.059
SOL_ORGP(1)	.chm	Replace value	0.901
FRT_KG	.mgt	Percent change	-70.1%
AUTO_NAPP	.mgt	Percent change	0.183

Streamflow Calibration & Validation

Setup of four SWAT models:

Calibration towards setup with land management and terraces

Calibration/Validation Streamflow (daily)	base model	model with land management	model with terraces	model with management & terraces
NSE	0.69/0.70	0.69/0.70	0.69/0.70	0.69/0.70
KGE	0.81/0.75	0.81/0.75	0.81/0.75	0.81/0.75
PBIAS	-0.01/-1.25	0.07/-1.16	-0.43/-1.59	-0.36/-1.48

Sediment Calibration & Validation

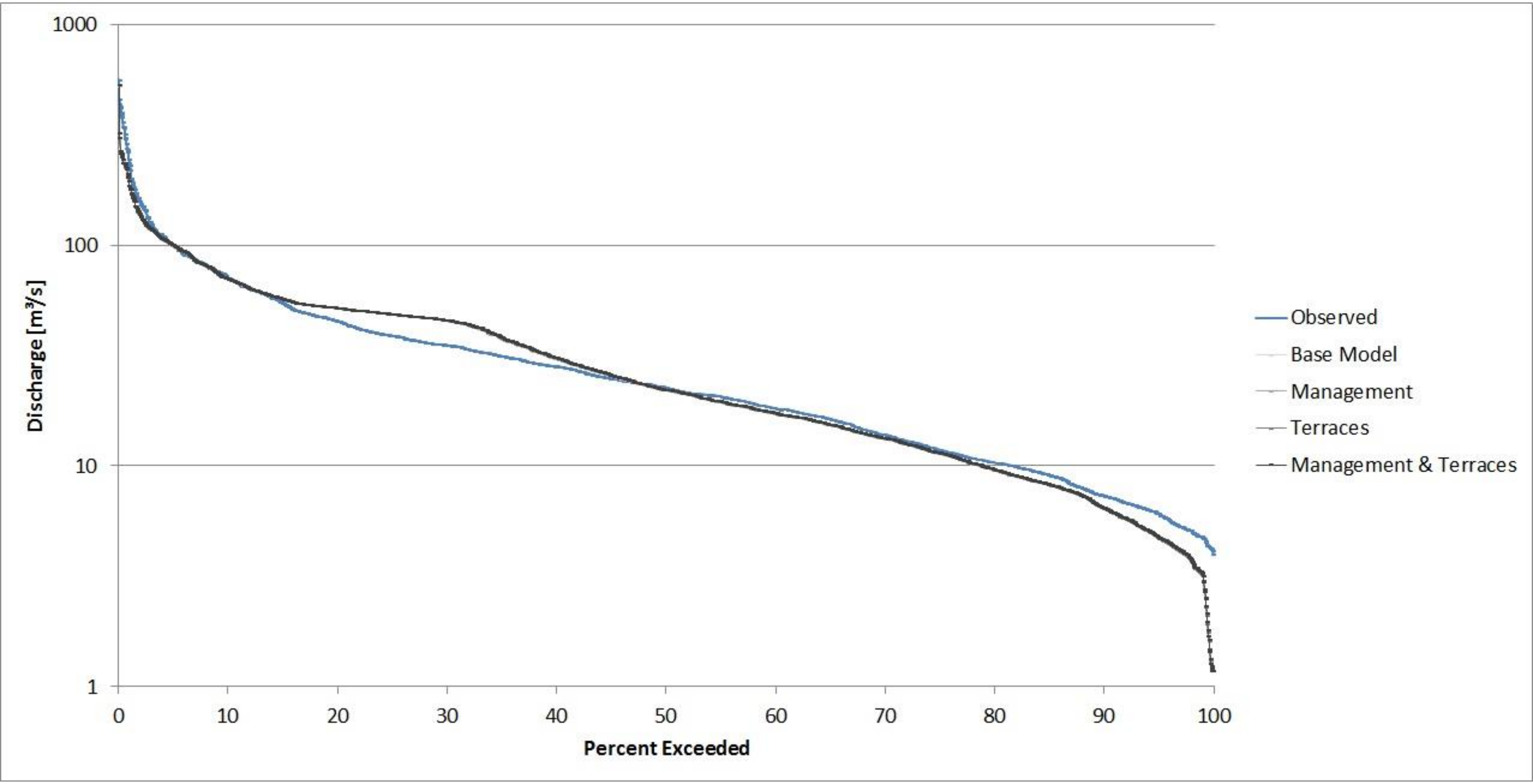
Calibration towards setup with land management and terraces →

Calibration/Validation Sediment (monthly)	base model	model with land management	model with terraces	model with management & terraces
NSE	0.53/-0.60	0.58/-0.32	0.82/0.45	0.81/0.51
KGE	-0.13/-0.44	-0.07/-0.31	0.78/0.55	0.77/0.59
PBIAS	-59.55/-129.14	-57.41/-118.88	5.33/-26.87	5.54/-22.25

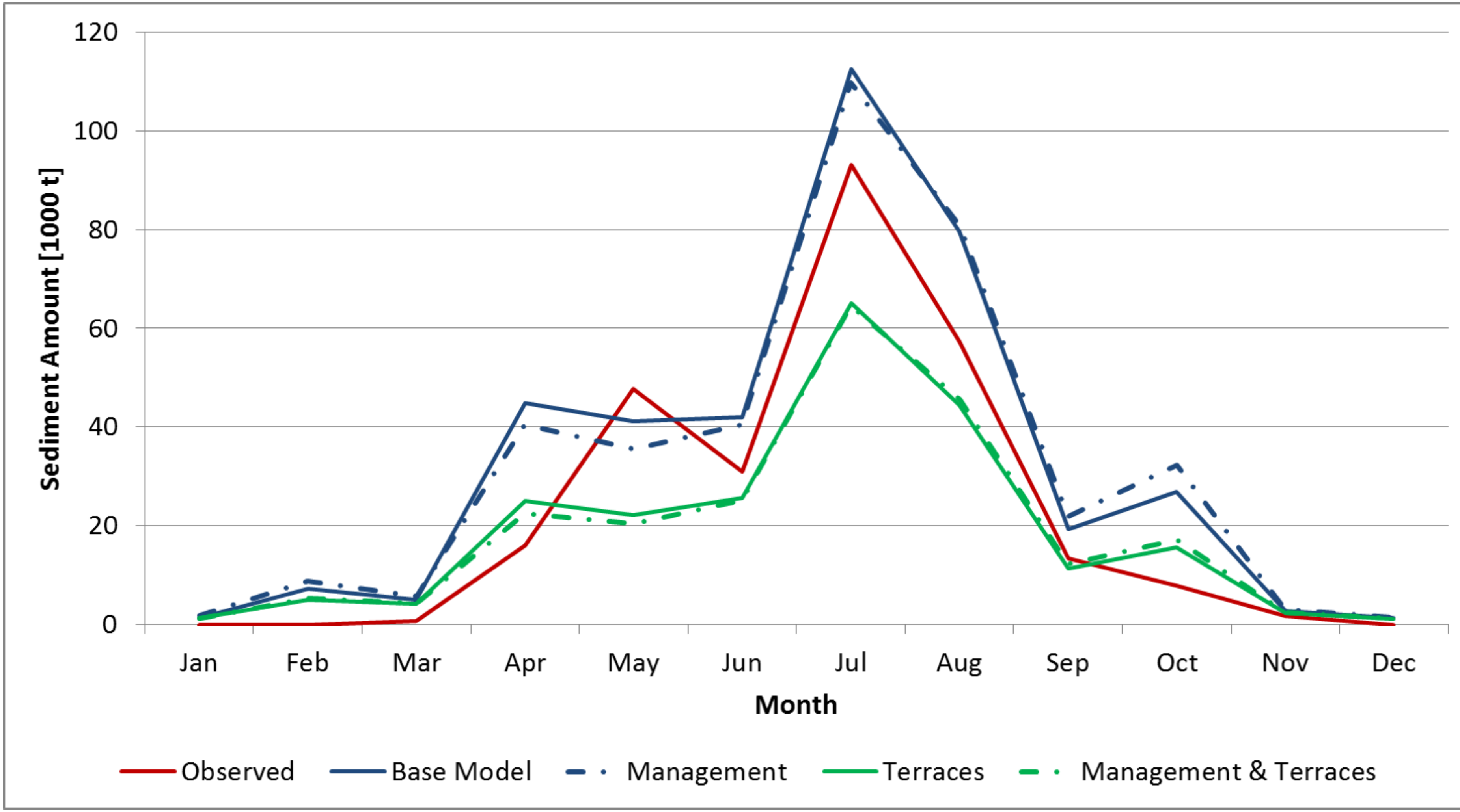
But:
There are different calibration parameter sets showing only slightly lower model efficiencies than the terrace models

→ Equifinality problem
→ Process representation?

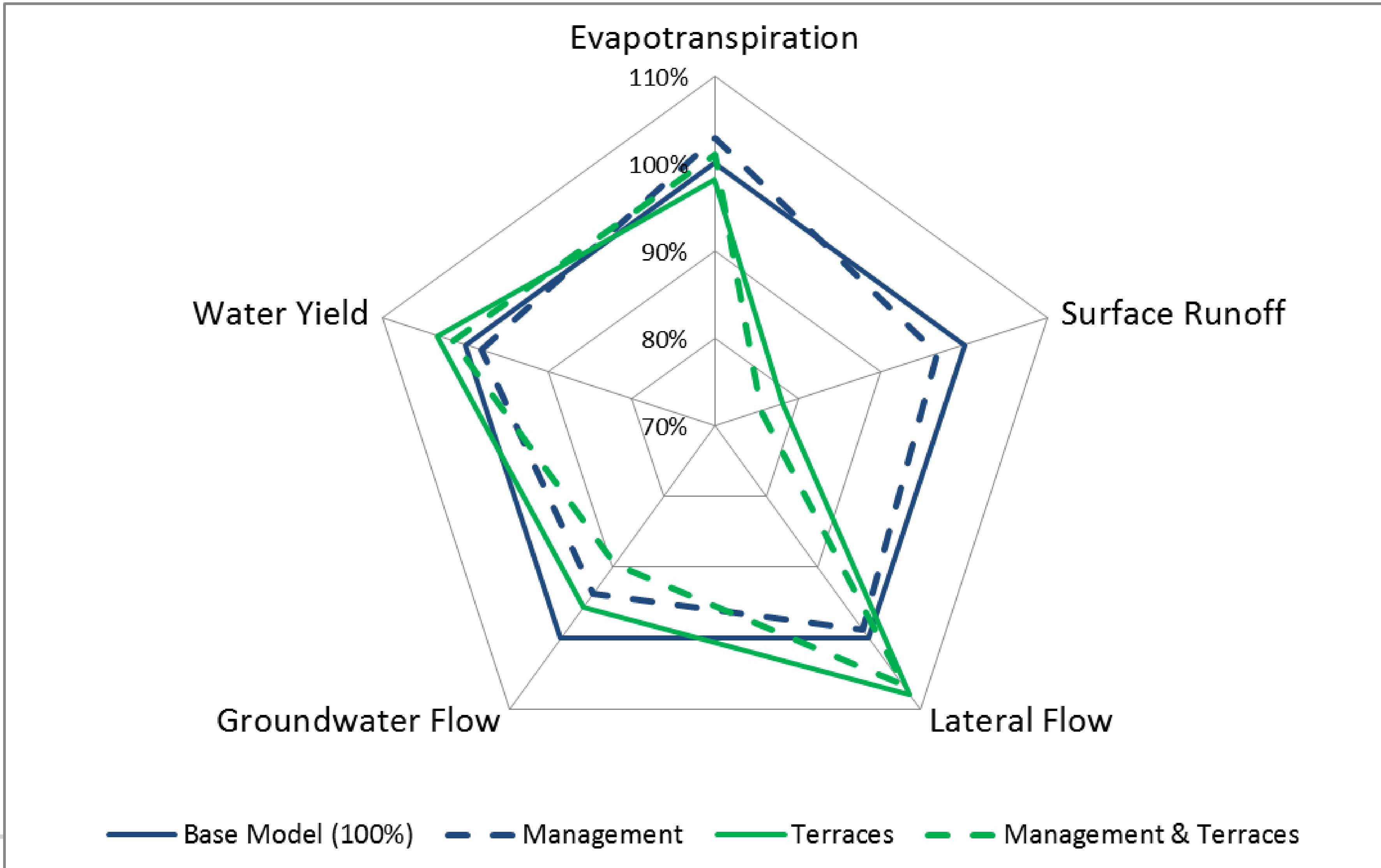
Flow Duration Curve (Calibration Phase)



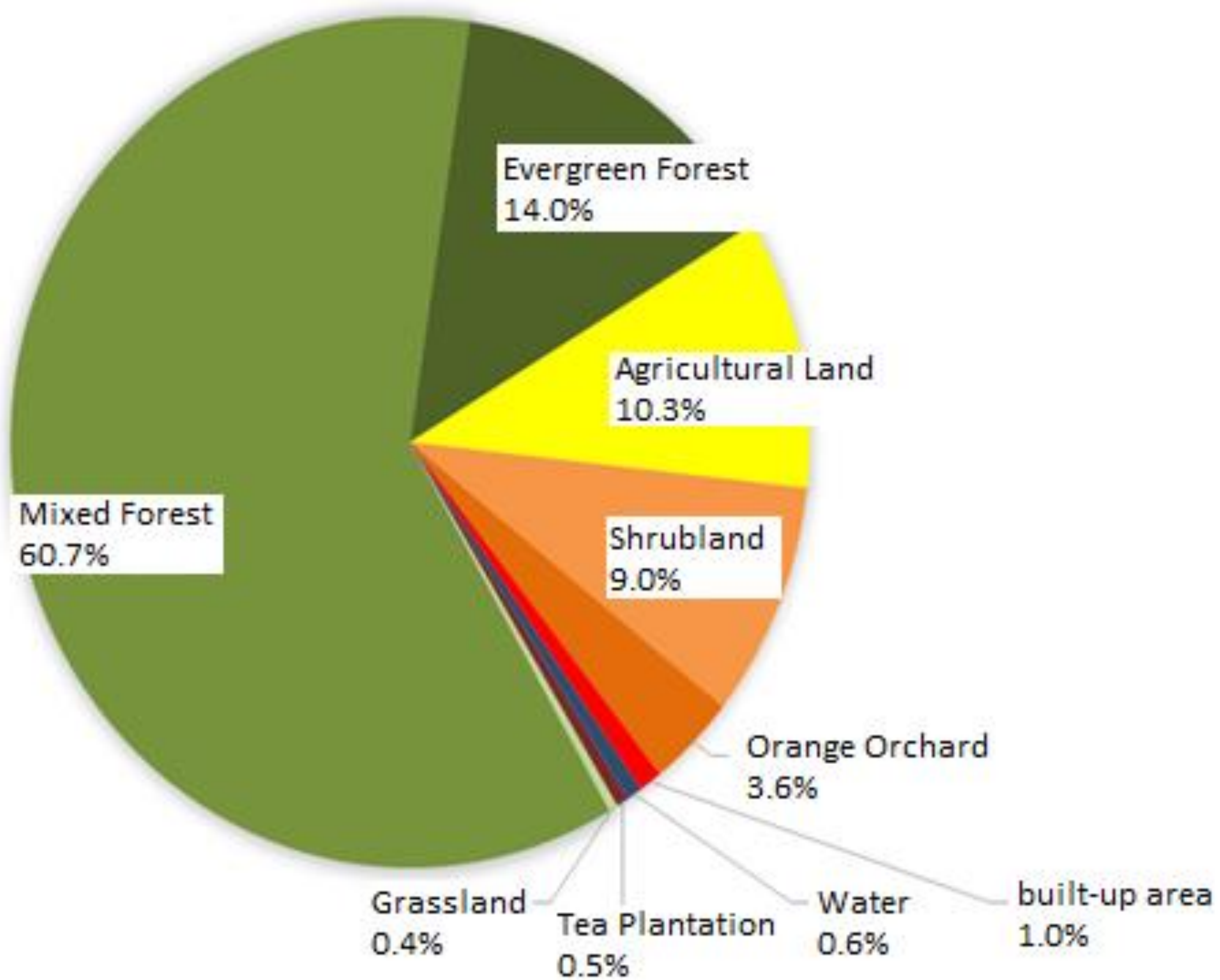
Long-Term Average Annual Sediment Graph



Water Balance on Agricultural Areas



Land Use Distribution in the Xiangxi Catchment



Hydrograph (Calibration Period)