UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO | DIPARTIMENTO DI SCIENZE AGRO-AMBIENTALI E TERRITORIALI

IRSA CNR Istituto di Ricerca sulle Acque CONSIGLIO NAZIONALE DELLE RICERCHE

Assessing the effect of BMPs in reducing nutrients and sediment loads in a Mediterranean basin

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Aims of the study

(i) Model point and diffuse sources of nutrient in an agricultural watershed characterized by scarcity of data;

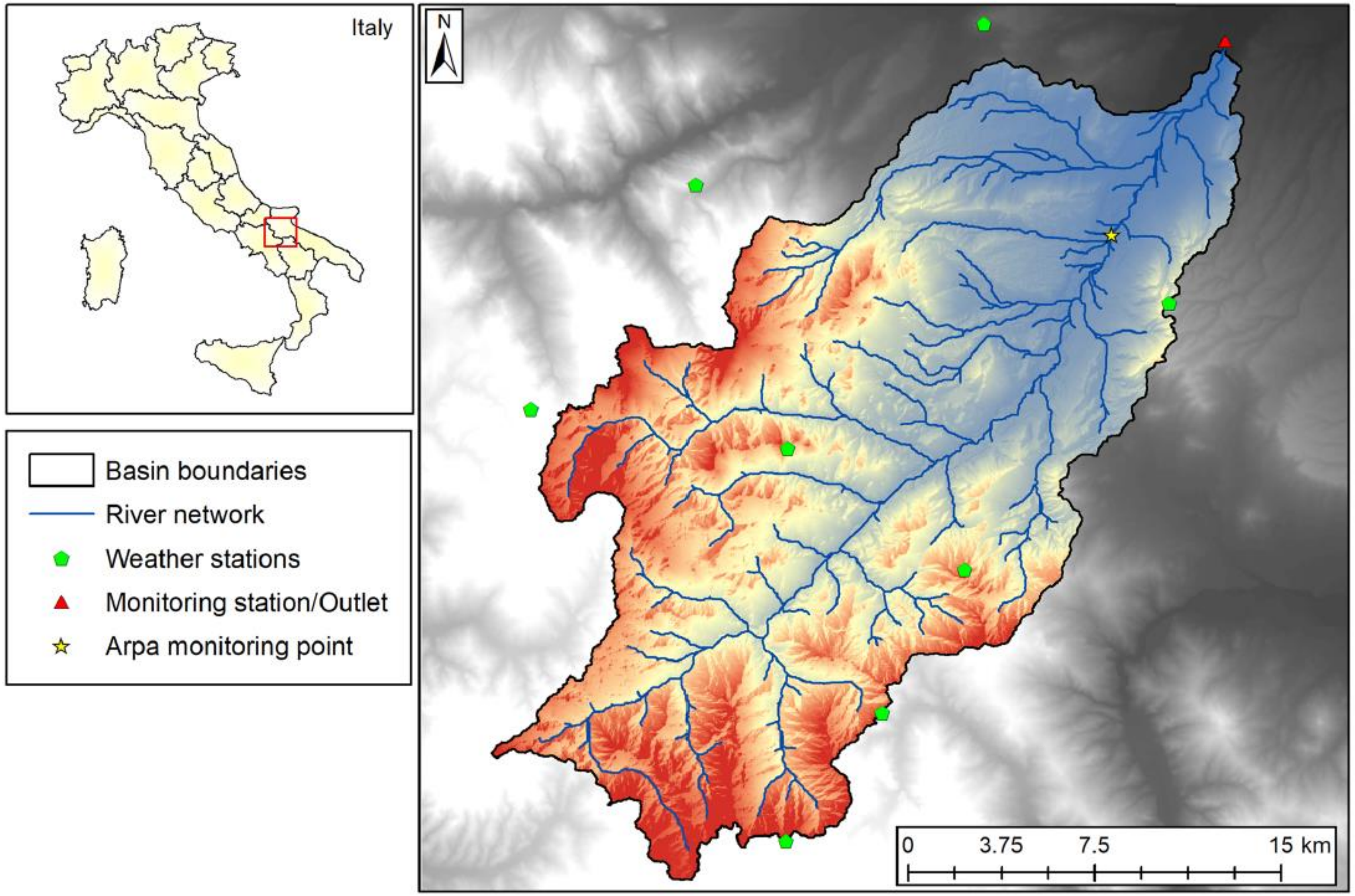
(ii) Test feasible BMP scenarios for sediment and nutrient load reduction based on the international environmental policies (i.e. Farm To Fork Strategy);

(iii) Assess the economic feasibility of BMPs at a farm and community scale (private and public sector).

Study Area

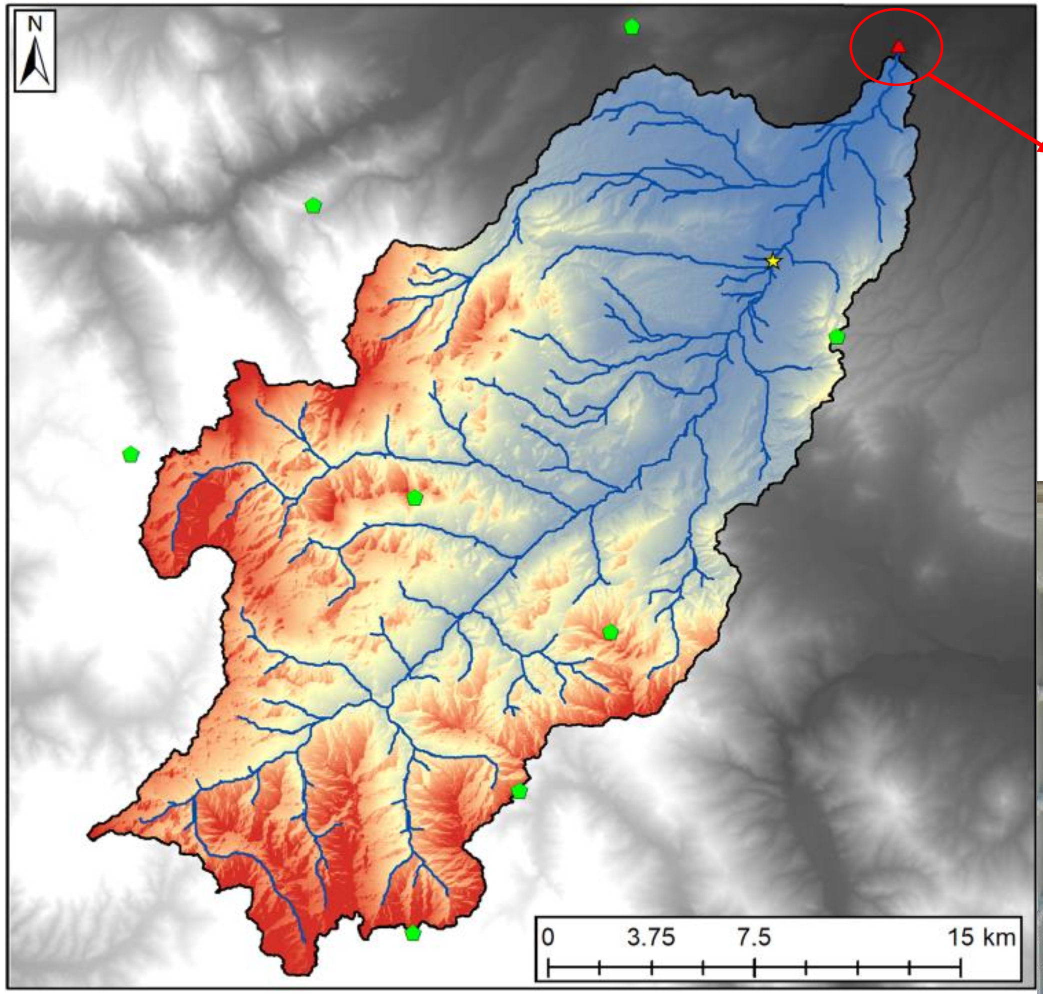
Carapelle	
Area	506 km^2
Max altitude	1089 m s.l.m.
Mean altitude	466 m s.l.m.
Min Altitude	120 m s.l.m.
Main stream length	52.16 km
Mean slope	8.20%

Station	Lat	Long	Altitude (m s.l.m.)
Ascoli	41°12'08.0"	15°33'54.8"	461
Bisaccia	41°00'28.9"	15°22'49.3"	916
Bovino	41°14'45.6"	15°20'18.0"	608
Castelluccio	41°18'13.2"	15°28'37.3"	282
Lacedonia	41°03'15.7"	15°25'35.9"	704
Monteleone	41°09'53.3"	15°15'34.4"	842
Rocchetta	41°06'21.7"	15°27'58.8"	694
S.Agata	41°09'00.9"	15°22'55.5"	694



Carapelle watershed (Puglia, southern Italy)

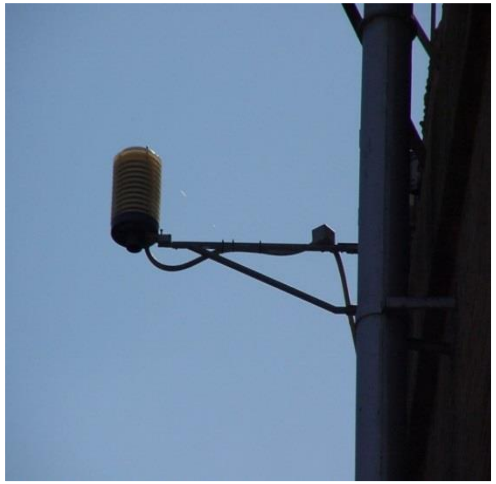
Study Area



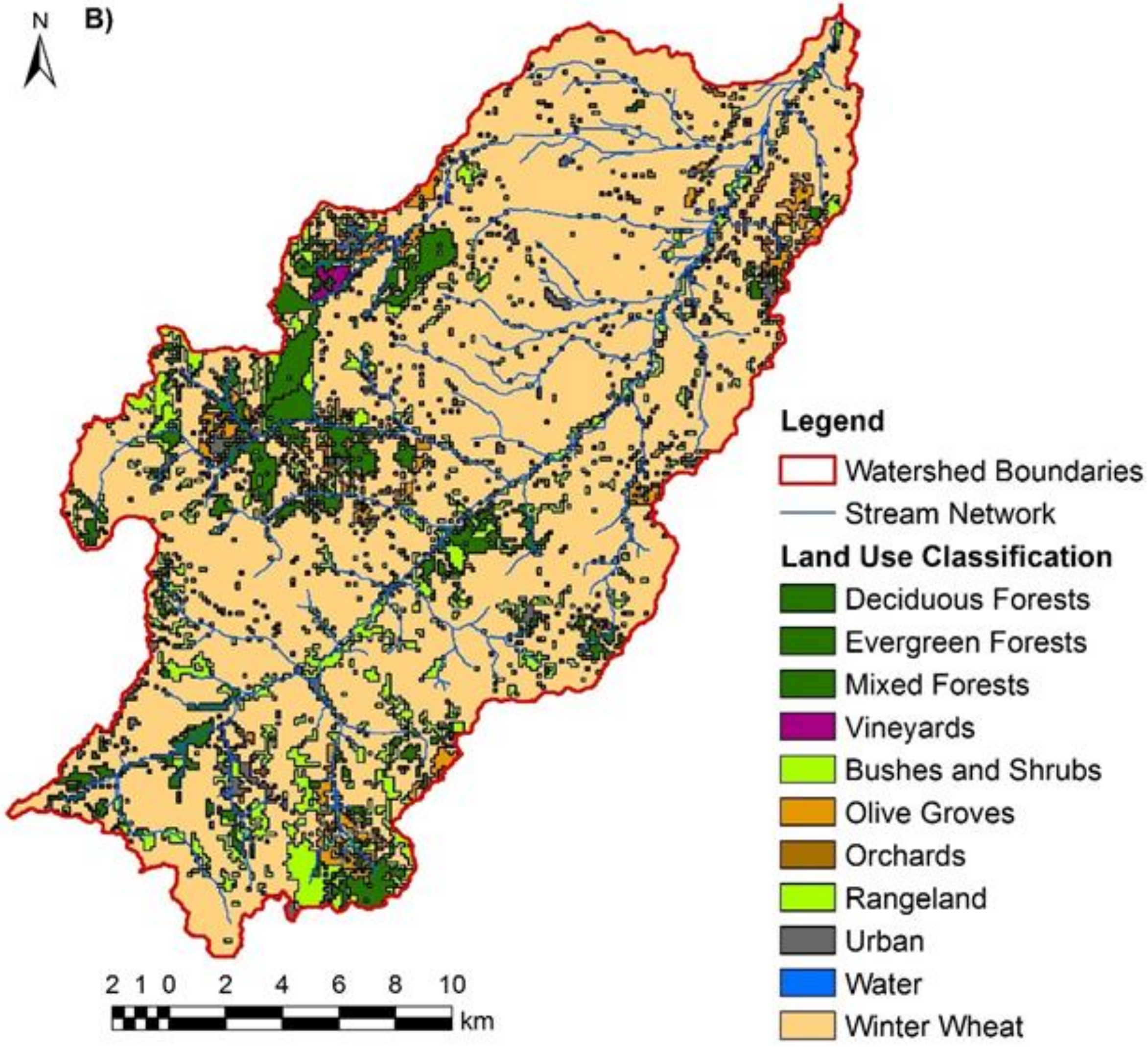
Watershed Outlet: Ponte Ordona-Castelluccio dei Sauri

Gaging Station:

- Datalogger
- Electromechanical and ultrasound stage metre for the streamflow
- Infrared optical probe for the suspended solid concentration (SSC)

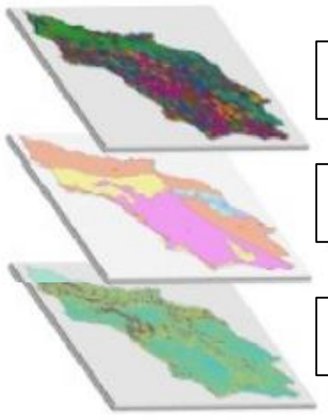


Study Area


N
B)
Legend
Watershed Boundaries
Stream Network
Land Use Classification
Deciduous Forests
Evergreen Forests
Mixed Forests
Vineyards
Bushes and Shrubs
Olive Groves
Orchards
Rangeland
Urban
Water
Winter Wheat
2 1 0 2 4 6 8 10
km

Materials and Methods

The SWAT model (Soil and Water Assessment Tool)



Land use

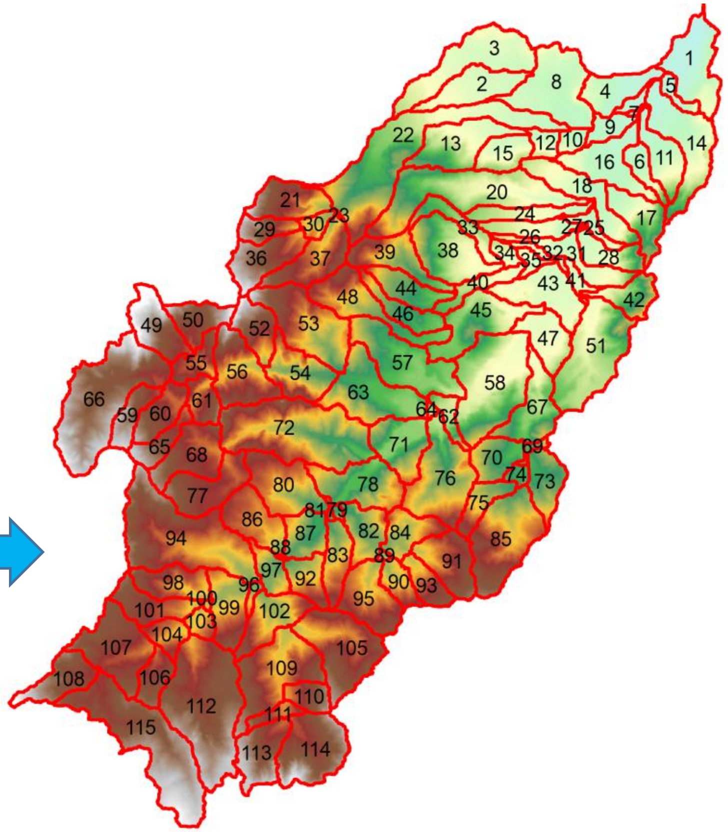
Soil type

Topography

Weather

Agricultural practices

SWAT input data



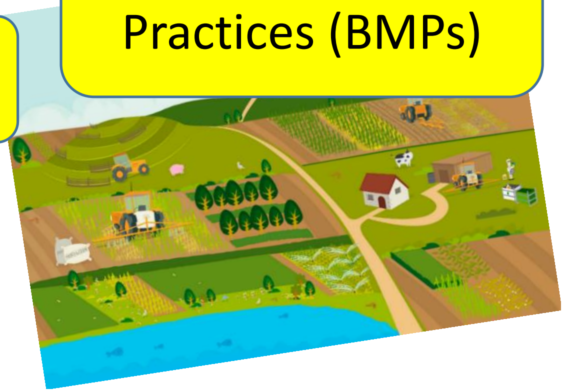
115 Sub-watershed
451 HRUs

SWAT watershed configuration

Daily calibration and validation of streamflow, sediment.
Daily discrete calibration of nutrients

Critical Sources Area

Best Management Practices (BMPs)



Calibration, validation and scenario simulations

Materials and Methods

Calibration and Validation
Streamflow and sediment

Parameters	Description	Calibrated value
	Runoff	
CN2.mgt	Curve Number	60-88
GWQMN.gw	Threshold depth of water in shallow aquifer	1281.62
GW_DELAY.gw	Groundwater delay time	92.76
ALPHA_BF.gw	Baseflow alpha factor	0.59
GW_REVAP.gw	Groundwater “revap” coefficient	0.028
REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur	172.61
RCHRG_DP.gw	Deep aquifer percolation fraction	0.38
SURLAG.bsn	Surface runoff lag time [days]	4.00
SOL_AWC.sol	Available water capacity of the soil layer	0.08-0.26
SOL_K.sol	Saturated hydraulic conductivity	1.95-13.15
CH_N1.sub	Manning's "n" value for the tributary channels	0.08
CH_K1.sub	Effective hydraulic conductivity in tributary channel	1.00
CH_K2.rte	Effective hyd. Cond. In the main channel	56.68
OV_N.hru	Manning's "n" value for overland flow	2.99
	Sediment	
CH_N2.rte	Manning’s “n” value for main channel	0.05-0.14
ADJ_PKR.bsn	Peak rate adjustment factor for sediment routing in the subbasin (tributary channels)	3.00
PRF_BSN.bsn	Peak rate adjustment factor for sediment routing in the main channel	2.9
SPEXP.bsn	Exponent parameter for calculating sediment reentrained in channel sediment routing	2.00
SPCON.bsn	Maximum amount of sediment reentrained during channel sediment routing	0.001

SWAT most sensitive parameter and calibrated values used to obtain the best simulation at daily time scale

Materials and Methods

Calibration and Validation Nutrient

TN - total nitrogen
$N\text{-}NO_3$ - nitrate-nitrogen
TP - total phosphorous
$P\text{-}PO_4$ -orthophosphate

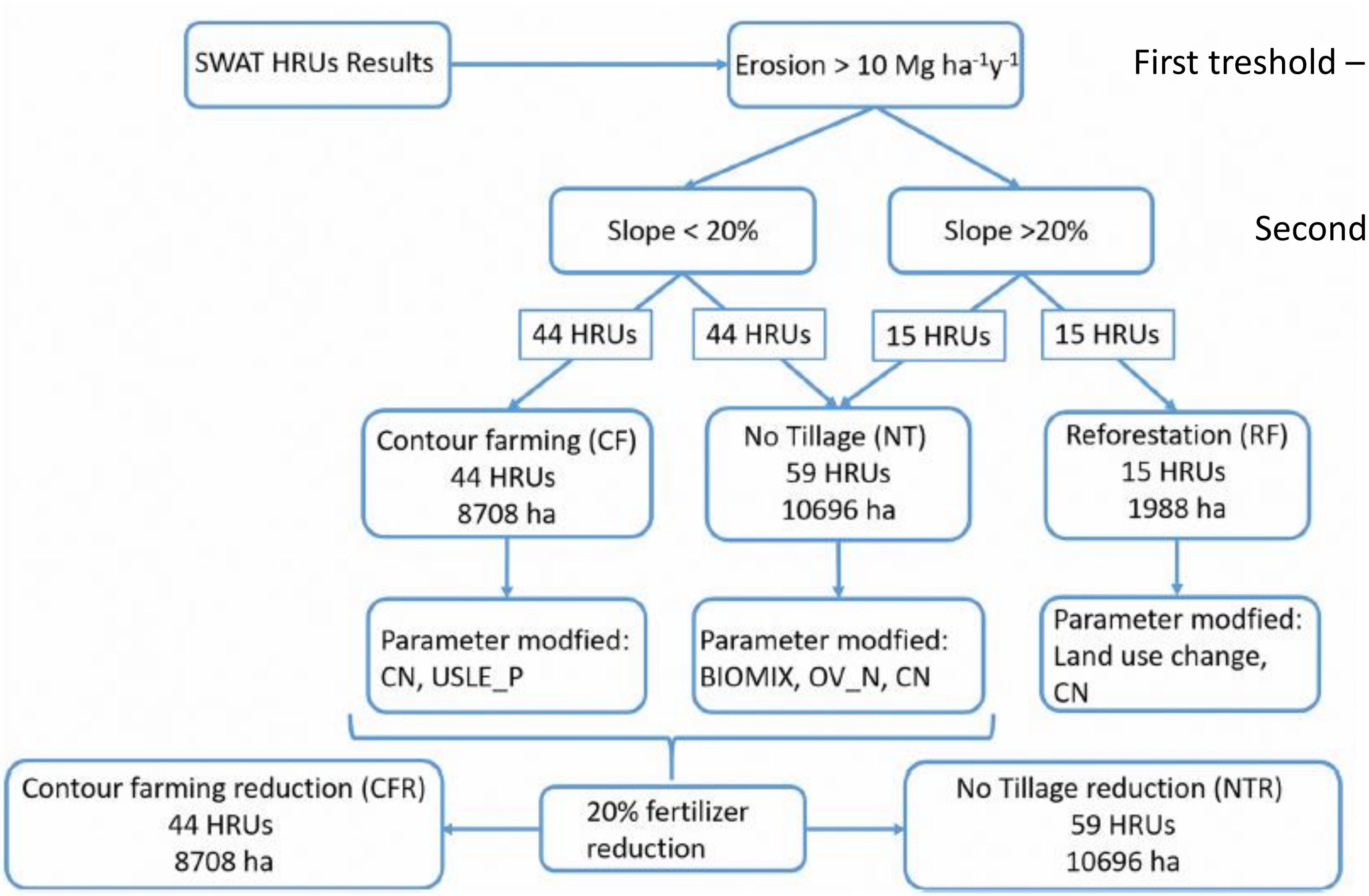
Parameter	Description	Calibrated Value
CDN.bsn	Denitrification exponential rate coefficient	0.243
NPERCO.bsn	Nitrogen percolation coefficient	0.081
ANION_EXCL_BSN.bsn	Fraction of porosity from which anions are excluded	0.027
SDNCO.bsn	Denitrification threshold water content	0.997
RSDCO.bsn	Residue decomposition coefficient	0.096
PPERCO.bsn	Phosphorus percolation coefficient	8.058
N_UPDIS.bsn	Nitrogen uptake distribution parameter	94.886
P_UPDIS.bsn	Phosphorus uptake distribution parameter	15.2999
PSP.bsn	Phosphorus sorption coefficient	0.296
RS4.swq	Rate coefficient for organic N settling in the reach at 20°C	0.076
AI1.wwq	Fraction of algal biomass that is nitrogen	0.087
AI2.wwq	Fraction of algal biomass that is phosphorus	0.015*
FRT_SURFACE.mgt	Fraction of fertilizer applied to top 10mm	0.374

*The calibrated value relative to parameter AI2 differs only for the fourth decimal (0.0155).
**The initial ranges of FRT_SURFACE were comprised between 0.35 and 0.50.

SWAT most sensitive parameter and calibrated values used to obtain the best simulation

Materials and Methods

Best Management Practices (BMPs)



First treshold – erosion rate

Second treshold - slope

BMPs scenarios selecting criteria and parametrization in the SWAT model

Materials and Methods

Economic Assessment

Main income and costs considered for the economic assessment at private scale and data sources

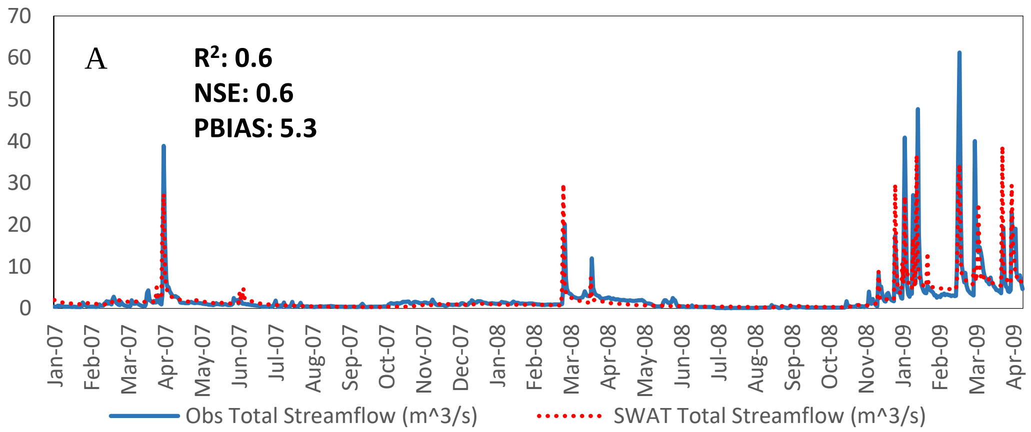
Items	Sub-items	Unit	Value	Data source
Farmer Income				
Selling unit price for winter wheat		Euro t^{-1}	222	https://www.obiettivocereali.com
Selling unit price for wood		Euro t^{-1}	25.7	PSR, 2014 (measure 8.1)
Subsidy for conventional agriculture and contour farming		Euro $ha^{-1} y^{-1}$	100	https://terraevita.edagricole.it
Subsidy for No Tillage		Euro $ha^{-1} y^{-1}$	322	PSR, 2014 (measure 10.1.3)
Subsidy for Reforestation	implant (for the first year)	Euro ha^{-1}	6000	PSR, 2014 (measure 8.1)
	management operation (for 12 years)	Euro $ha^{-1} y^{-1}$	2500	PSR, 2014 (measure 8.1)
	lost icome	Euro $ha^{-1} y^{-1}$	100	PSR, 2014 (measure 8.1)
Production Costs				
Winter wheat production	Operation costs	Euro $ha^{-1} y^{-1}$	544	https://terraevita.edagricole.it
	Fertilizer costs	Euro $ha^{-1} y^{-1}$	140	https://terraevita.edagricole.it
No Tillage implementation	Transaction (10% of the tillage cost)	Euro ha^{-1}	63	PSR, 2014 (measure 10.1.3)
	Upgrading machinery	Euro	6000	Farmers survey
Reforestation implementation	implant (for the first year)	Euro ha^{-1}	6051	PSR, 2014 (measure 8.1)
	management operation (for 12 years)	Euro $ha^{-1} y^{-1}$	2518	PSR, 2014 (measure 8.1)
Community costs				
Soil loss replacement cost		Euro t^{-1}	19.46	Panagos et al., 2015b
Nitrogen value		Euro kg^{-1}	0.8	http://www.al.camcom.gov.it

The economic value of the soil loss was calculated multiplying the sediment load (t yr-1) by the commercial price of soil estimated in 20$ (Panagos et al., 2015)

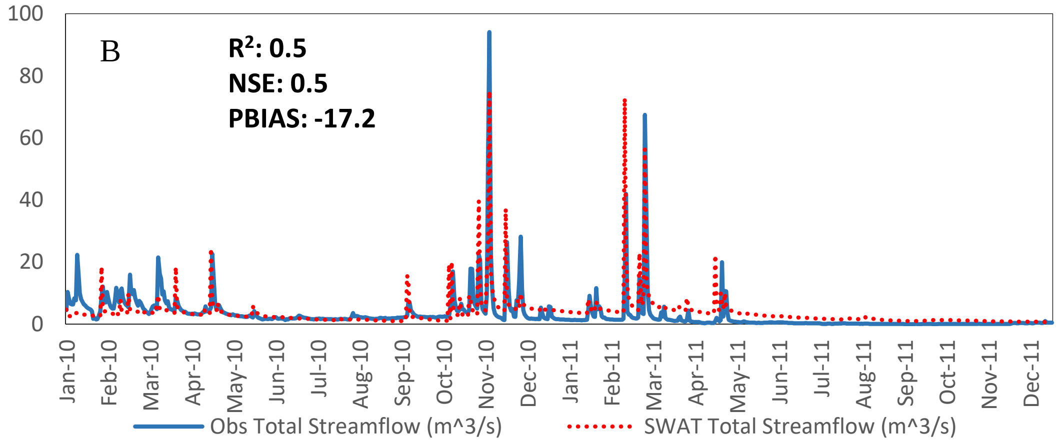
A replacement cost criteria was used to determine the economic Value of TN Losses.
The price of Urea (N content 46%), was utilized to calculate the N Unit Price (NUP, Euro kg^{-1})

Results

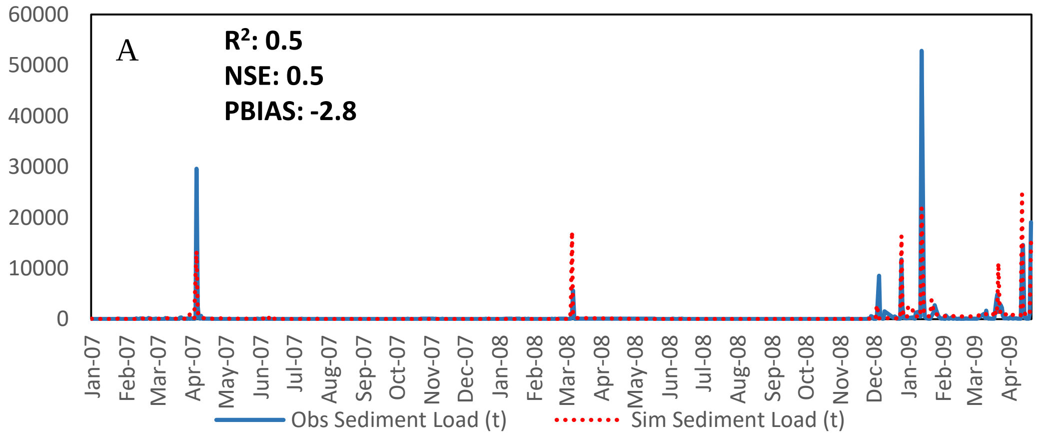
Calibration and Validation Streamflow and sediment



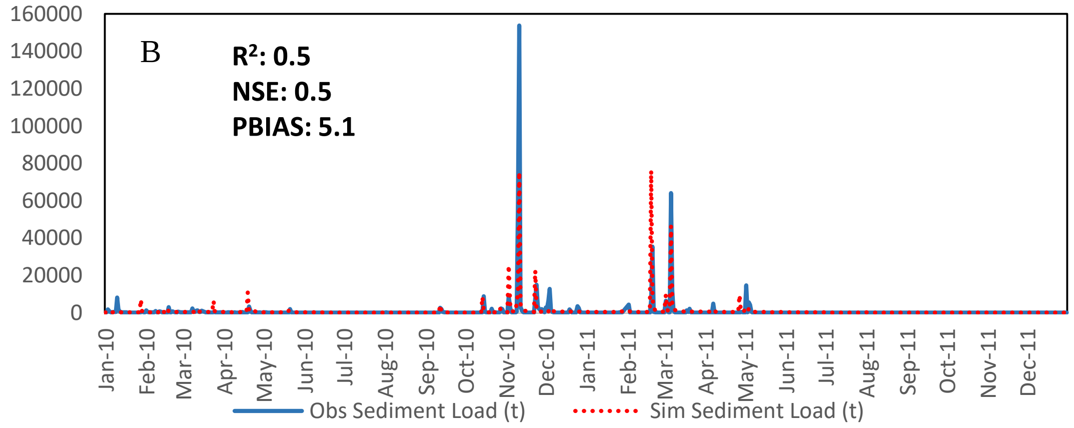
Daily streamflow calibration



Daily streamflow validation



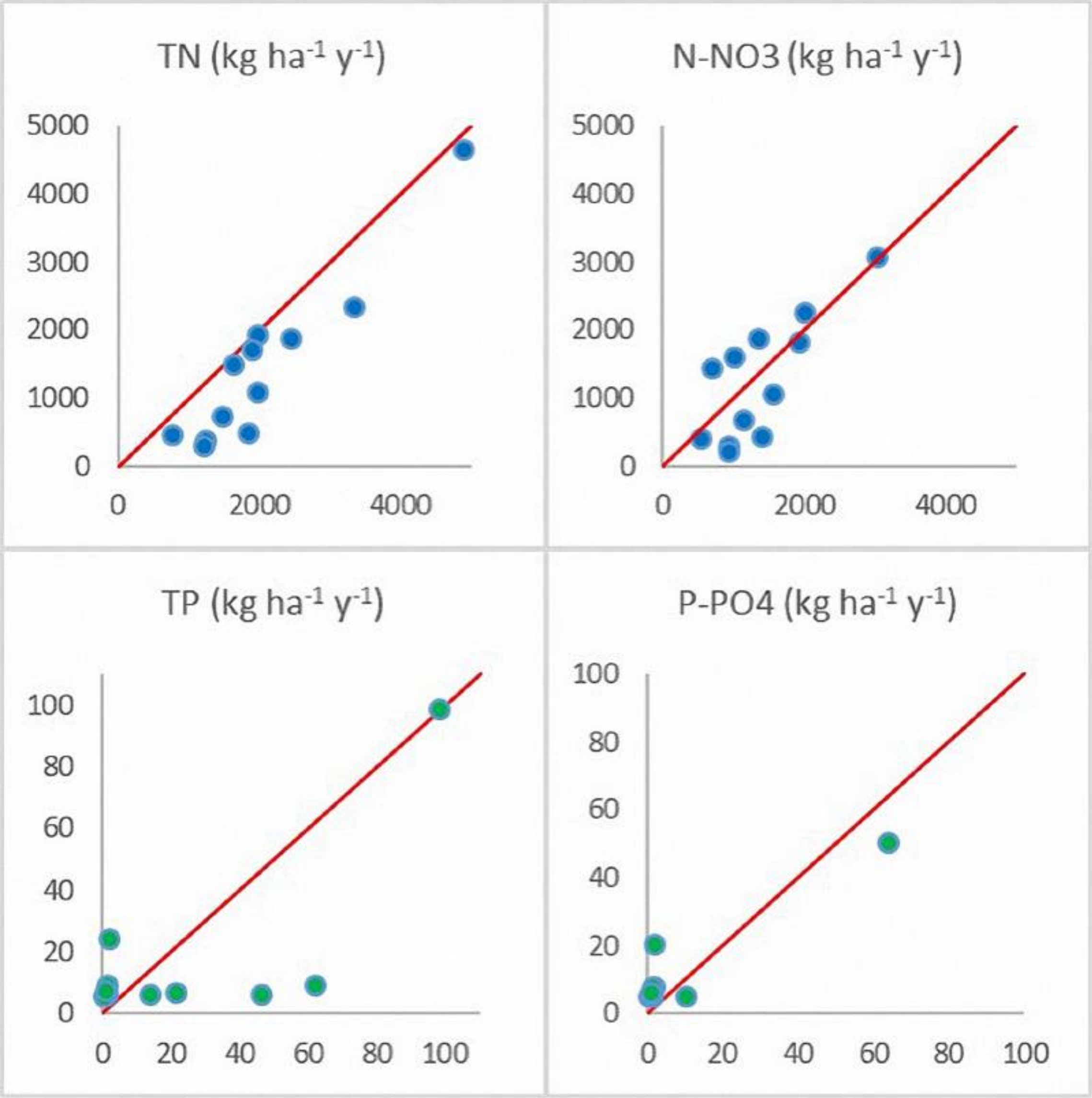
Daily sediment load calibration



Daily sediment load validation

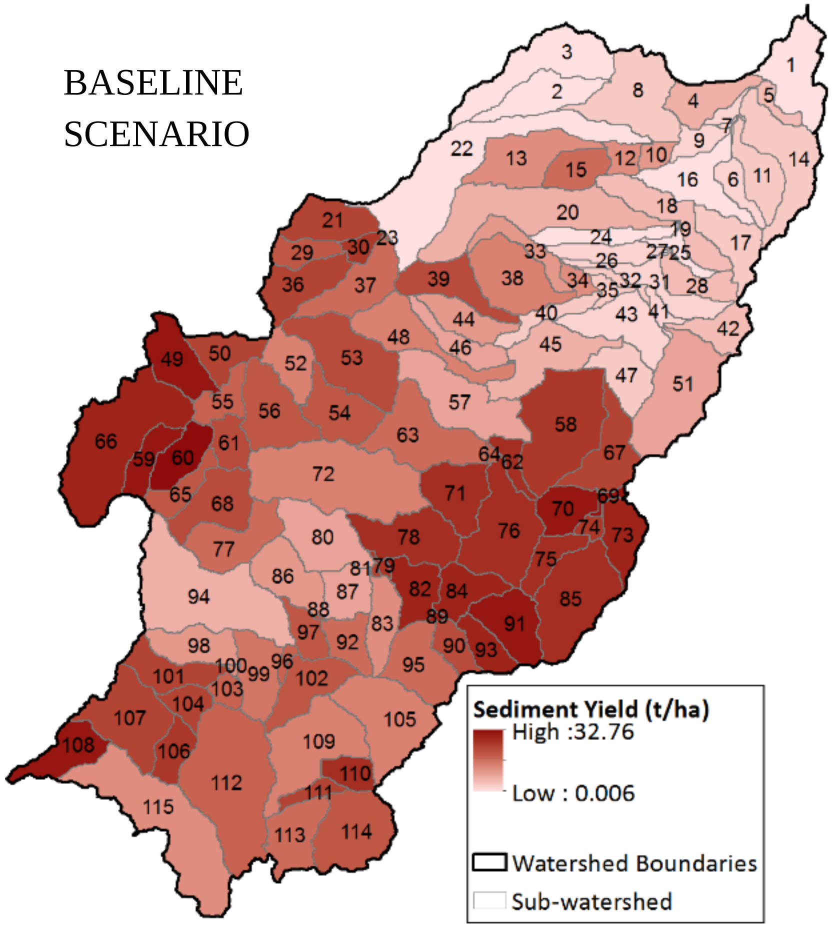
Results

Calibration and Validation Nutrient



	Calibration		
	R^2	NSE	PBIAS
TN	0.9	0.5	29.4%
$N\text{-}NO_3$	0.6	0.3	8.5%
TP	0.5	0.5	25.7%
$P\text{-}PO_4$	0.9	0.8	-42.7%

Modeling results – Sediment



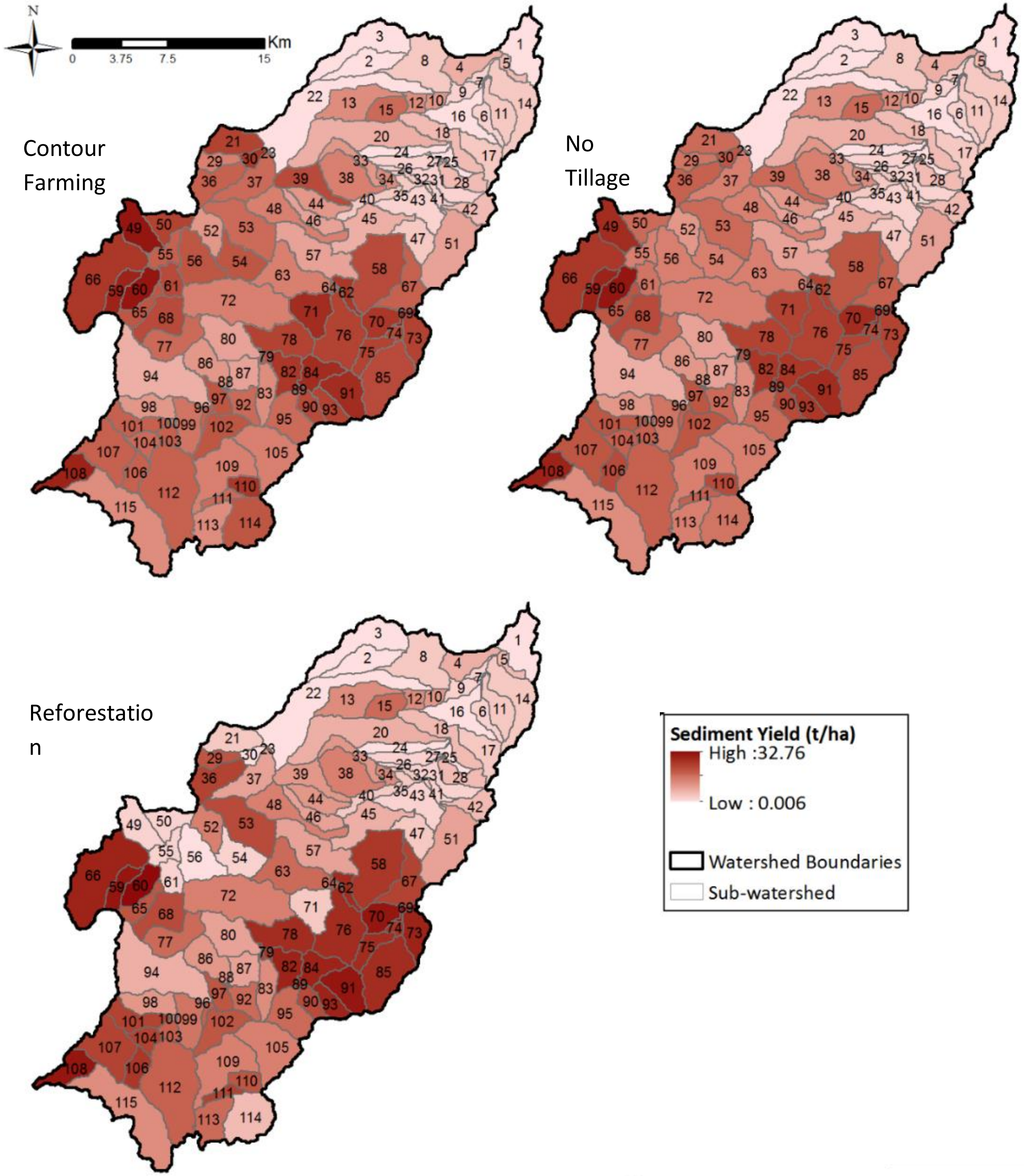
SWAT model simulated sediment yield (t ha^{-1}) and critical source area localization

Sediment load (t ha^{-1})				
Months	Actual	CF	NT	RF
1	1.64	1.26	1.06	1.37
2	0.92	0.72	0.68	0.81
3	1.22	0.97	0.96	1.05
4	0.23	0.18	0.19	0.20
5	0.02	0.01	0.01	0.01
6	0.04	0.03	0.03	0.03
7	0.06	0.05	0.05	0.04
8	0.01	0.00	0.00	0.01
9	0.09	0.06	0.07	0.08
10	0.24	0.17	0.17	0.21
11	0.76	0.61	0.60	0.64
12	0.72	0.54	0.41	0.59
Total	6.0	4.6	4.2	5.0

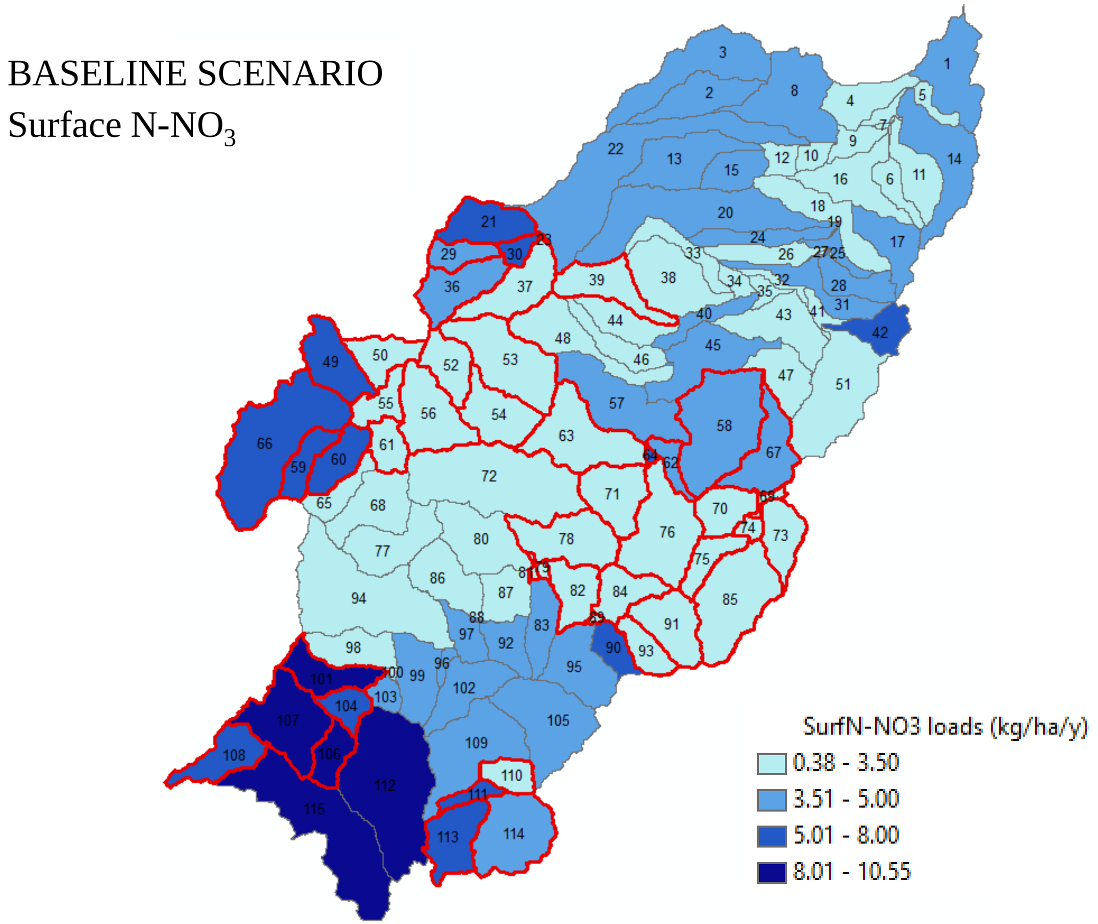
All the modeled scenarios gave a reduction in terms of sediment load at the watershed outlet, in particular in the winter month.

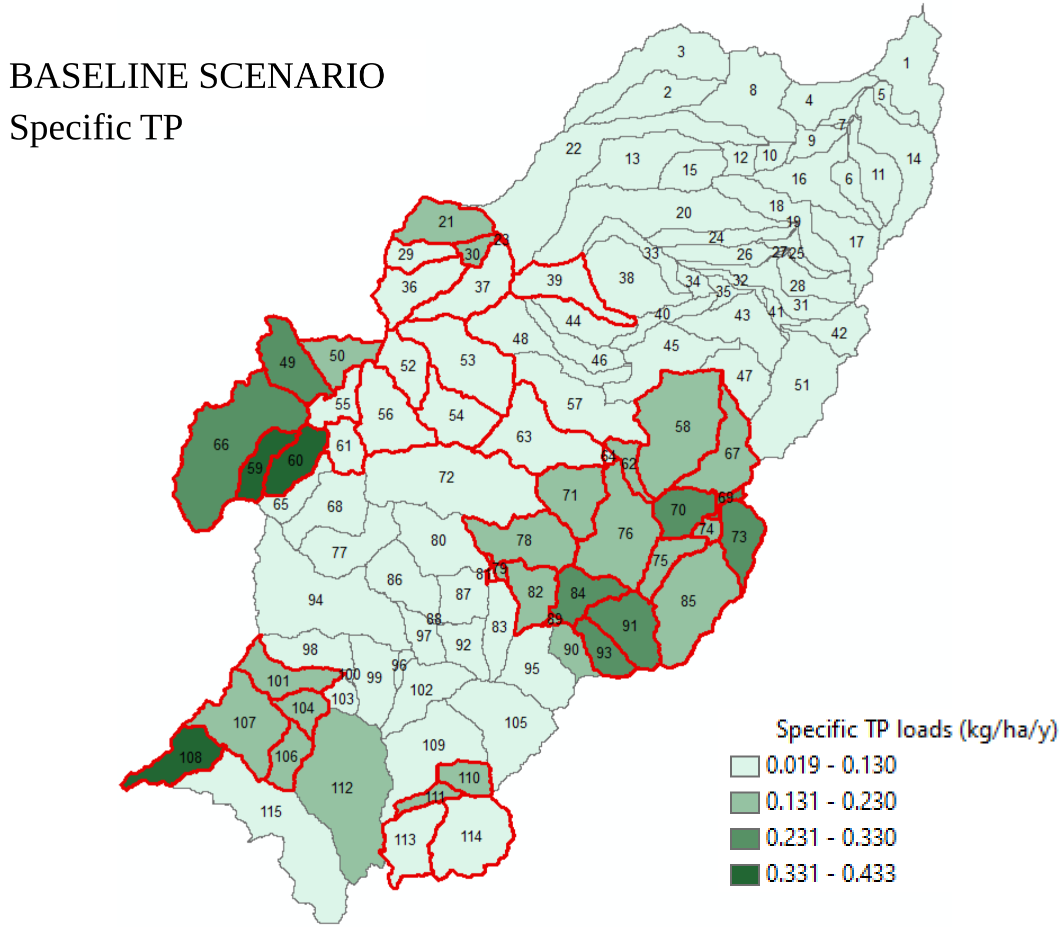
Modeling results – Sediment

- CF has reduced the sediment yield by 36%
- NT has reduced the sediment yield by 37%
- RF showed a higher reduction of sediment yield in particular sub-watersheds (e.g. n°21, from 8.74 t ha $^{-1}$ to 0,168 t ha $^{-1}$)



Modeling results – Nutrient



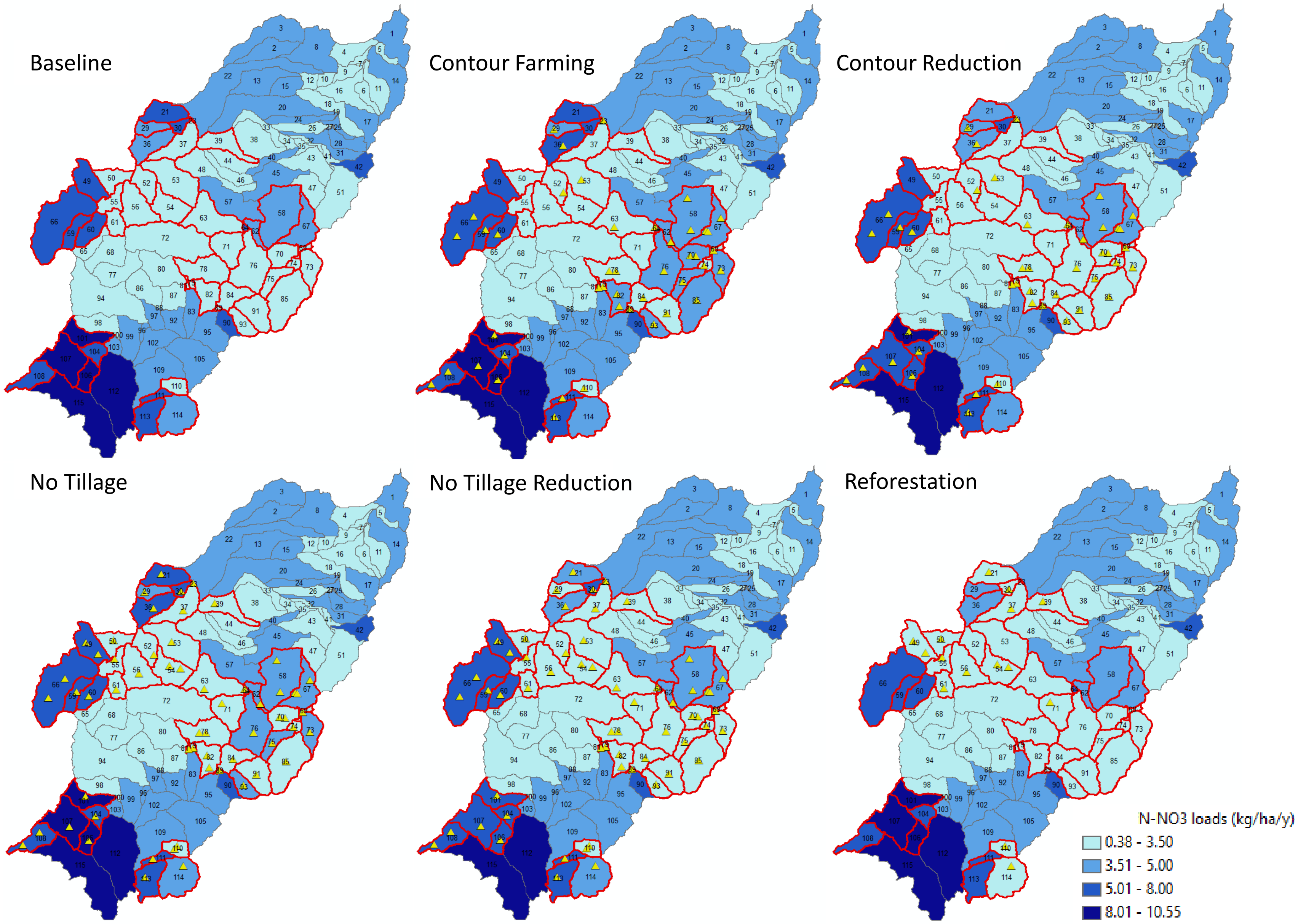


SWAT model $N\text{-}NO_3$ ($kg\ ha^{-1}\ y^{-1}$) and TP ($kg\ ha^{-1}\ y^{-1}$) critical areas localization

$N\text{-}NO_3$ ($kg\ ha^{-1}\ y^{-1}$) and TP ($kg\ ha^{-1}\ y^{-1}$) are the primary sources of water pollution (FAO, 2018)

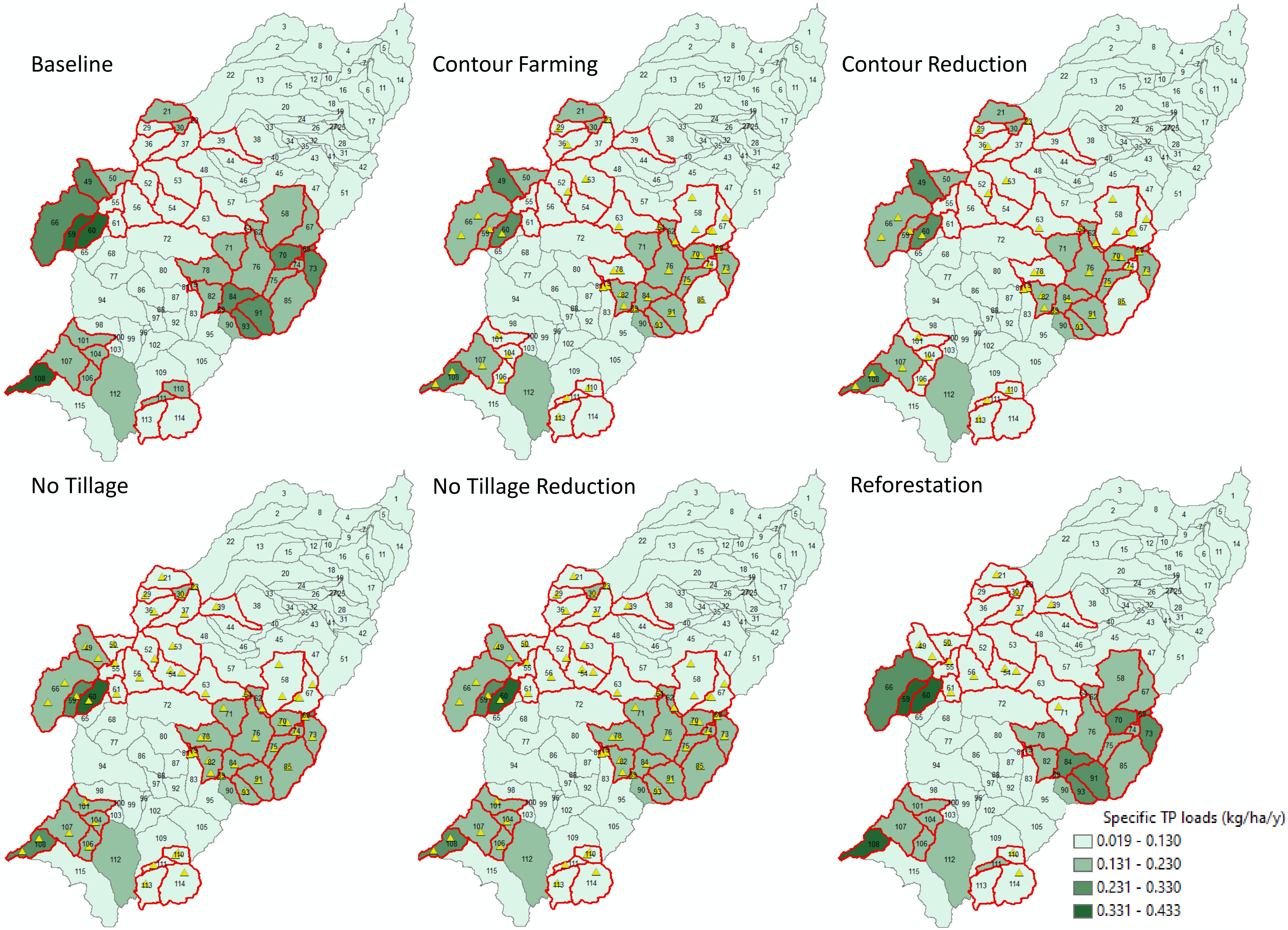
Modeling results – Nutrient

- CF and NT increment specific N-NO_3 load in south-est sub-basins (i.e. Sub-basins 70, 73, 76, 85)
- RF, CFR, and NTR showed an overall reduction across the basin
- RF has reduced the N-NO_3 loads by 19%



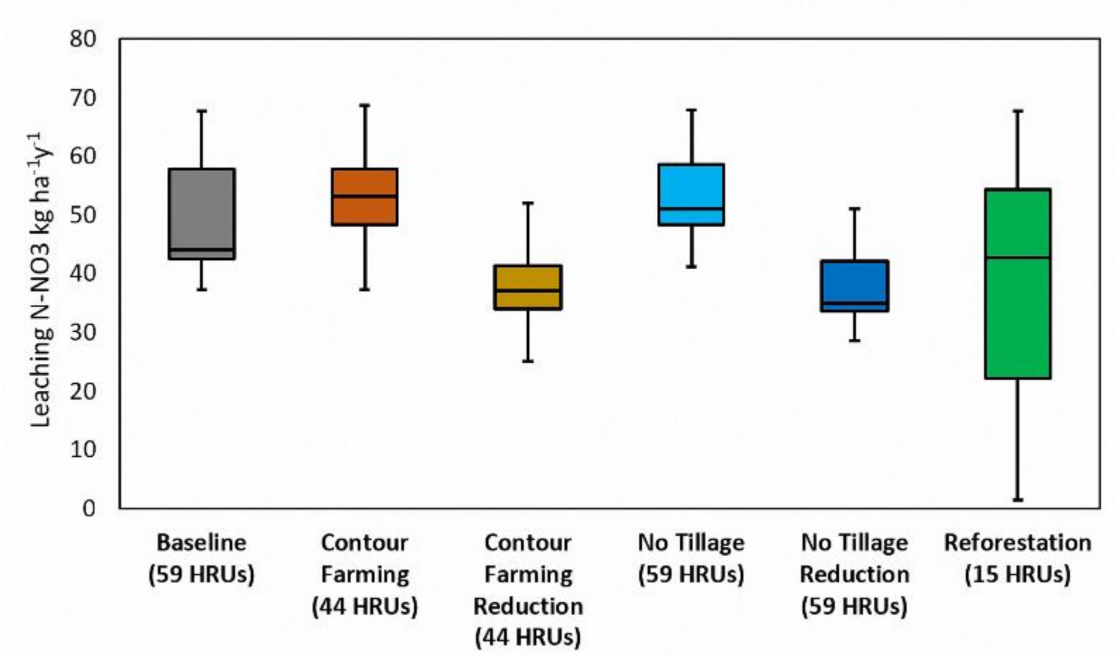
Modeling results – Nutrient

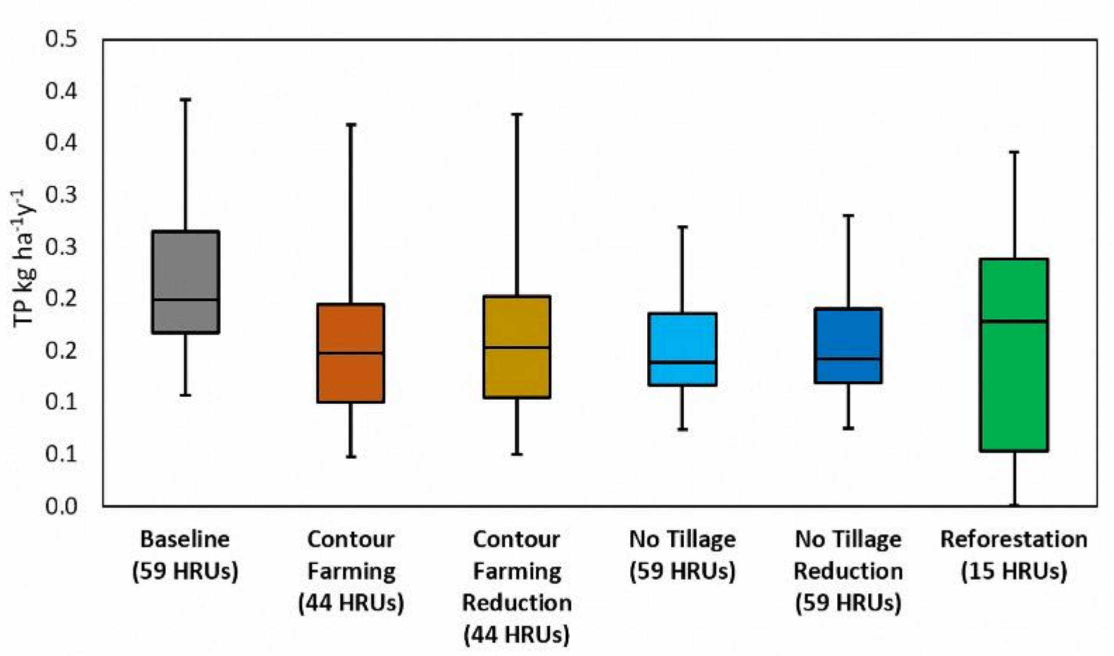
- All BMP scenarios showed an abatement of TP loads
- CF and CFR proved most effective in reducing TP loads (27.36% and 26.03%, respectively)
- RF resulted in a reduction of 25.13%
- NTR and NT showed a lower reduction of TP (21.22%, and 21.05%, respectively)



Modeling results – Sediment

Specific Loads (kg ha^{-1}y^{-1})						
	Actual (AC)	Contour Farming (CF)	Contour Reduction (CFR)	No Tillage (NT)	No Tillage Reduction (NTR)	Reforestation (RF)
Nitrogen-Nitrate in streamflow	3.841	4.052	3.209	4.005	3.168	3.705
Nitrogen-Nitrate Leached	43.366	44.491	32.015	44.263	31.853	41.574
Organic Nitrogen	2.001	1.700	1.681	1.619	1.590	1.758
Total Phosphorous	0.044	0.040	0.039	0.045	0.043	0.042





At the farm (HRU) level, agricultural fields are known to have a great influence on N-NO_3 leaching (FAO, 2018)

- CFR and NTR were found to be the two most efficient scenarios in reducing N-NO_3 leaching
- NT and NTR emerged as the most efficient BMPs in reducing TP

Economic assessment for private sector

Practice	Num. of HRUs	Area	Specific Yield (SY)	Unit Price (UP)	Subside (S)	Subside first year (SFY)	Farm returns (FR[a])	Operation Costs (OC)	Fertilizers Costs (FC)	Production Costs (PC)	Investments Cost (IC)	(FR+SFY)-C[a]	FR/PC
		ha	Mg ha^{-1}y^{-1}	Euro Mg^{-1}	Euro ha^{-1}y^{-1}	Euro ha^{-1}y^{-1}	Euro ha^{-1}y^{-1}	Euro ha^{-1}y^{-1}	Euro ha^{-1}y^{-1}	Euro ha^{-1}y^{-1}	Euro ha^{-1}	Euro ha^{-1}	
					Slope <20%								
BA	44	8708	3.00	222	100		766	544	140	684		82	1.12
CF	44	8708	3.15	222	100		799	578	140	718		81	1.11
CFR	44	8708	2.93	222	100		751	578	112	690		61	1.09
NT	44	8708	3.30	222	322		1055	492	140	632	63[c]	361-A[d]	1.67
NTR	44	8708	3.07	222	322		1004	492	112	664	60[c]	340-A[d]	1.66
RF	-												
					Slope >20%								
BA	15	1988	2.70	222	100		699	612	140	752		-53	0.93
CF	-												
CFR	-												
NT	15	1988	2.97	222	322		981	555	140	695	69[c]	217-A[d]	1.41
NTR	15	1988	2.76	222	322		935	555	112	667	67[c]	202-A[d]	1.40
RF	15	1988	87.50	25.70	2500[b]+100[b]	6000	4849			2518[b]+732[e]	6051	1548	1.49

[a] FR= (SY × UP) + S, C= PC + IC; [b] for the first 12 years; [c] transaction costs for the implementation of the no tillage; A[d] cost of depreciation (6000 Euro) must me added for every farm; [e] cost for cutting the forest after 12 years

- NT and NTR were the most economically advantageous for slope > 20%;
- RF was the most profitable option in > 20% slope areas;
- CF and CFR can be defined as a “zero investments cost” solution in area with slope < 20%;
- Baseline was not economically advantageous in areas with slope > 20%.

Economic assessment for public sector combining sediment and nutrient reduction

Practice	LPL	CPL	CPL*UP	Soil Loss	Soil loss Replacement cost	Soil loss value	Nitrogen Loss	Nitrogen Value	Nitrogen Loss value	Total Practice cost first year[a]	Total Practice cost second year[a]	Total Practice cost after 12 year[a]
			Euro	(Mg ha^{-1})	Euro Mg^{-1}	Euro	(kg ha^{-1})	Euro kg^{-1}	Euro	Euro	Euro	Euro
BA	0.021	2510	557115	6	19.46	4692233	49.208	0.8	1582017	4018699	4018699	4018699
CF	0.012	1508	334698	4.6	19.46	3597378	50.224	0.8	1614681	4018699	4018699	4018699
CFR	0.012	1508	334698	4.6	19.46	3597378	38.843	0.8	1248787	4018699	4018699	4018699
NT	0.01	1273	282619	4.2	19.46	3284563	49.968	0.8	1606451	6393211	6393211	6393211
NTR	0.01	1273	282619	4.2	19.46	3284563	36.611	0.8	1177029	6393211	6393211	6393211
RF	0.017	2043	453554	5	19.46	3910194	47.037	0.8	1512220	20916699	8988699	3819899

* LPL is for Land Production Loss=(areas under severe erosion (> 10 Mg ha^{-1}) / Total agricultural areas) x 0.08 , CPL is for Crop Production Loss=crop area ha x SY Mg ha^{-1}y^{-1} x LPL % x UP), UP is for Unit Price. [a] TPC is for Total Practice Cost=(BMP subsidy × BMP ha) + (subsidy conventional tillage × conventional tillage ha). Soil loss replacement cost: 19.46 Euro Mg^{-1}.

- Baseline showed the highest values in terms of CPL
- CFR and NT were economically convenient since there was a moderate reduction both in soil and TN losses.
- NT and NTR were the most expensive for the public sector, considering the subsidies
- RF showed the highest practice costs in first years, however become economic after 12 years (no more subsidies)

Conclusions

- At the watershed outlet, CFR and NTR proved to be the best practices for the study area in terms of both nutrient and soil losses reduction.
- Despite a decrease in crop production (7%), he economic assessment revealed that FR/PC for CFR and NTR was almost the same as that of CF and NT (reduced amount of nutrients)
- Although BMPs, especially CFR and NTR, were able to reduce nutrient loads, the $N\text{-}NO_3$ concentration level remained higher than the threshold limits (1.2 mg l^{-1}; Level II) required to support the functioning ecosystem in all the analyzed scenarios.
- Defining the BMPs to be implemented in an area is a complex process which must take into account the peculiarities of the basin (i.e. morphology, slope, rainfall regime), the efficiency in reducing sediment and nutrient loads of each BMPs and economic aspects (i.e. available subsidies)

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CONSIGLIO NAZIONALE DELLE RICERCHE

Thank you!!

More information:

- Ricci GF, D' Ambrosio E, D e Girolamo A M, Gentile F. 2022. Efficiency and feasibility of Best Management Practices to reduce nutrient loads in an agricultural river basin. Agricultural Water Management. 259, 2022, 107241. https://doi.org/10.1016/j.agwat.2021.107241
- Ricci, G. F., Jeong, J., De Girolamo, A. M., & Gentile, F. (2020). Effectiveness and feasibility of different management practices to reduce soil erosion in an agricultural watershed. Land Use Policy, 90, 104306. https://doi.org/10.1016/j.landusepol.2019.104306

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