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Environmental modelling for improved decision making

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Land use management impact on underground water systems of the Dinaric Karst region

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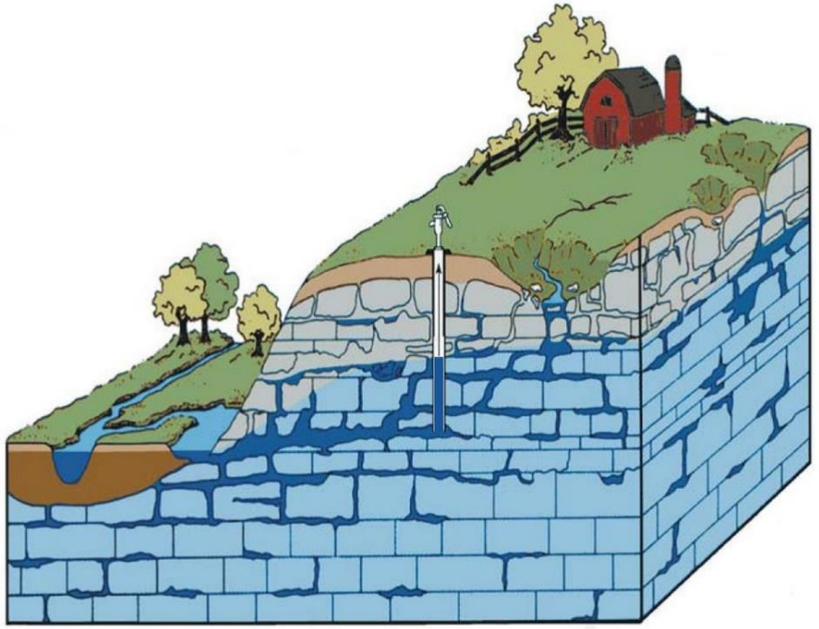
1. Introduction – RIVER BASIN

- The basic premise of the **RIVER BASIN** is that it is a single (complete) biological, physical, economic and social system.
- The river basin is a productive system that is affected by natural and human influences (rainfall, sun, land use, industry, technologies, institutions).
- This system therefore also has many effects, such as:
  - decline or improving the productive capacity of agricultural soils (erosion, leaching of nutrients),
  - decline or improvement of water quality,
  - changes in the water regime,
  - increase or reduction of flood risk,
  - decline or increasing economic power (e.g. agriculture, tourism)
  - changes in biodiversity as a result of all upstream activities having impact on the downstream system



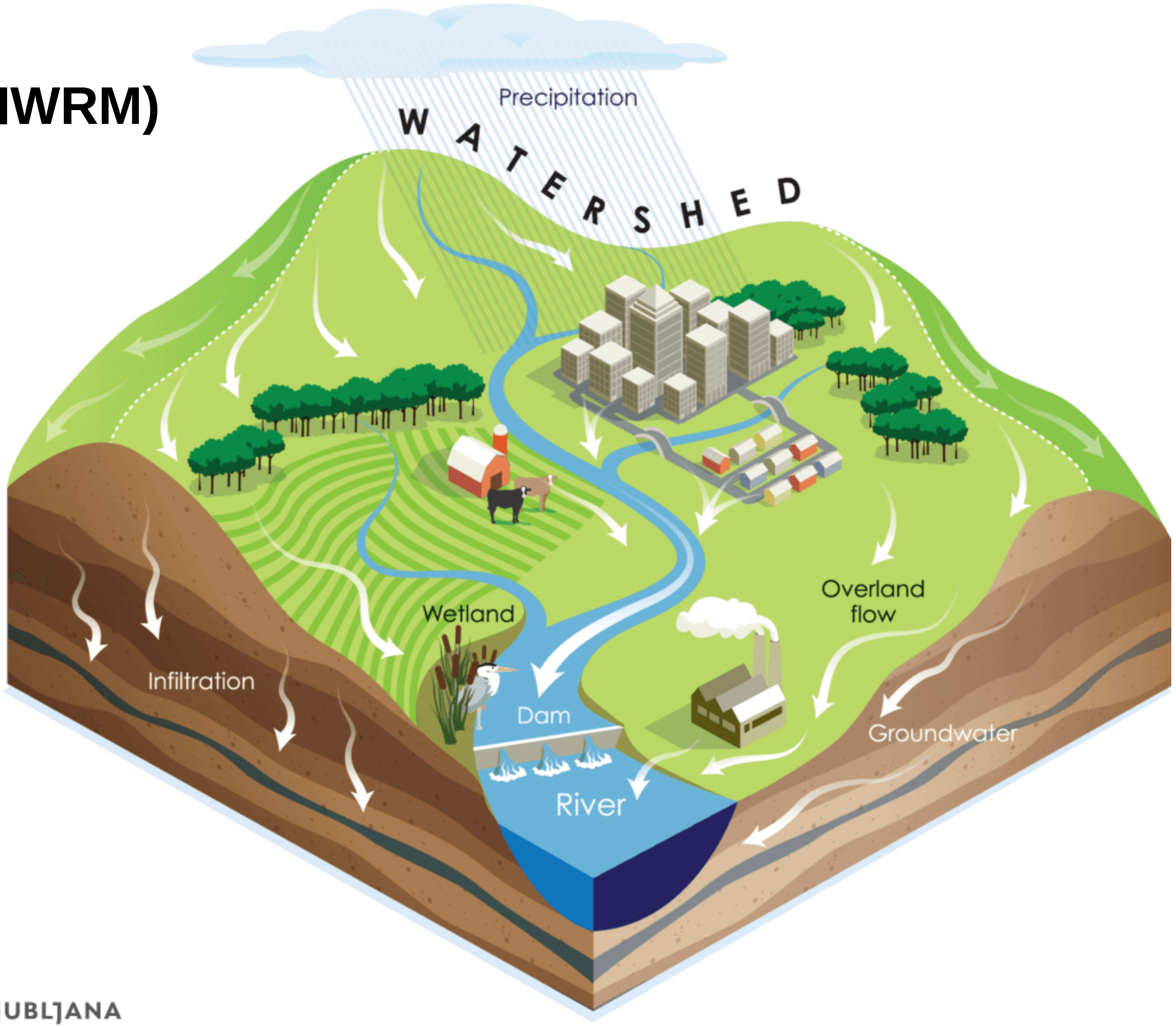
1. Introduction - IWRM

- Definition

Integrated water resources management (IWRM)
(Global Water Partnership)

"A process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems"

win : win : win ???



1. Introduction – Legislative framework

- Water Framework Directive (2000/60/EC)
- Nitrate Directive (91/676/EEC)
- Habitat Directive (92/43/EEC)
- Urban wastewater treatment Directive (91/271/EEC)
- Sustainable use of pesticides Directive (2009/128/EC)
- Common Agricultural Policy (EU CAP)

Diffuse source nitrogen, phosphorus, pesticides and sediments must be under careful supervision and control.

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2. Soil and Water Assessment Tool - SWAT

- The Soil & Water Assessment Tool is a small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change.
- SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds.

- Developed at the USDA Division of Agricultural Research in 1990's on 30 years of modelling experiences
- Texas A&M University (at present developer for USDA)

2. Soil and Water Assessment Tool - SWAT

- developed for use in ungauged catchments (for reliable results calibration is still required)
- to predict impacts of land management on water, sediment and agricultural chemical yields,
- it can predict impacts of climate changes,
- spatially semi-distributed hydrological model; spatially variable input parameters, such as land use change can easily be modelled,
- major model components are hydrology, weather, soil, temperature, plant growth, nutrients, pesticides and land management,
- capable of continuous simulation over long time periods,
- operates on a daily time step,
- allows the catchment to be subdivided into natural sub-catchments, and then into combinations of unique slope, soil, land use and management characteristics or **Hydrologic Response Units (HRU-s).**

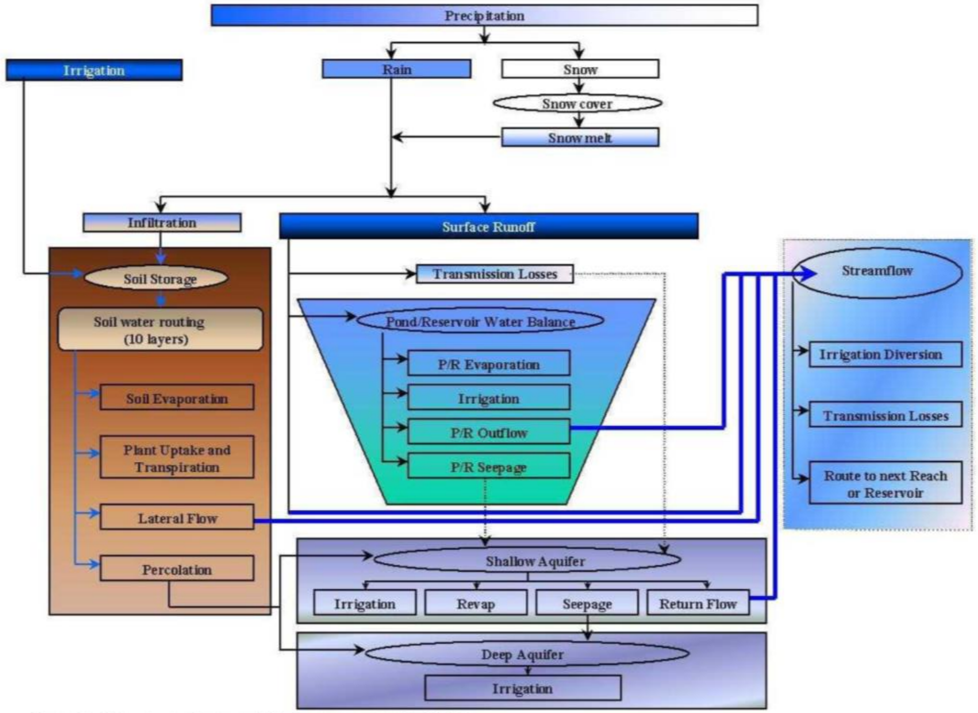

Figure 1.5: Schematic of pathways available for water movement in SWAT

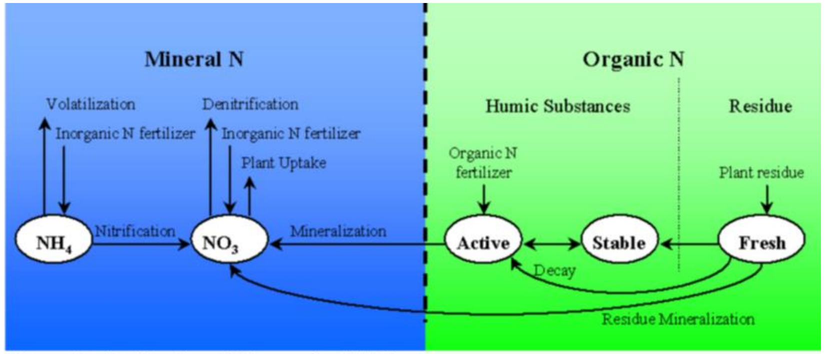

Figure 0.6: Partitioning of Nitrogen in SWAT

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3. Agricultural measures to protect black olm (*Proteus anguinus, Parkelj*) habitat from nitrate pollution

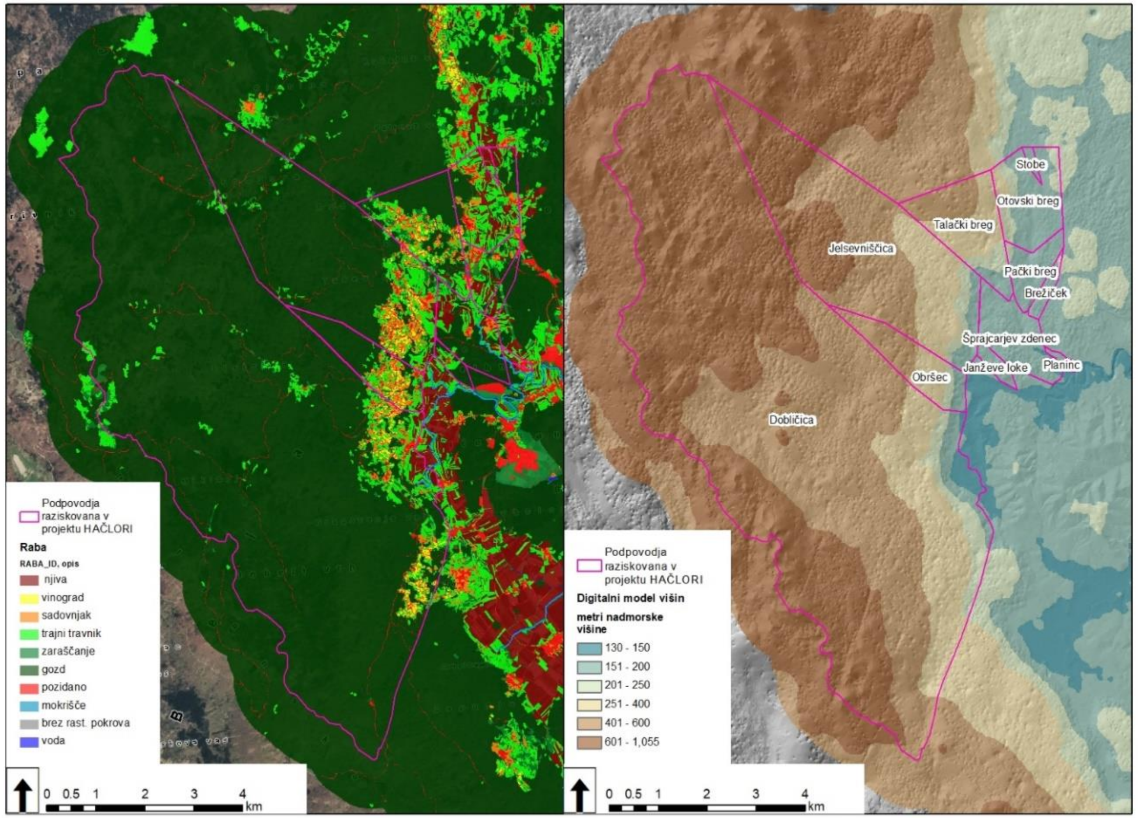
To identify **nitrate leaching hot-spots** in vulnerable aquifer of the Dobličica river in Slovenia and to assess *nitrate leaching* under different scenarios of **agricultural practices and land use**.

Holistic Approach

Is it good for the ENVIRONMENT?	**Is it good for the ECONOMY?**	**Is it good for the SOCIETY?**
Soil & Water Assessment Tool SWAT	APEX Agricultural Policy Environmental eXtender model	

3. Agricultural measures to protect black olm (*Proteus anguinus, Parkelj*) habitat from nitrate pollution

STUDY AREA



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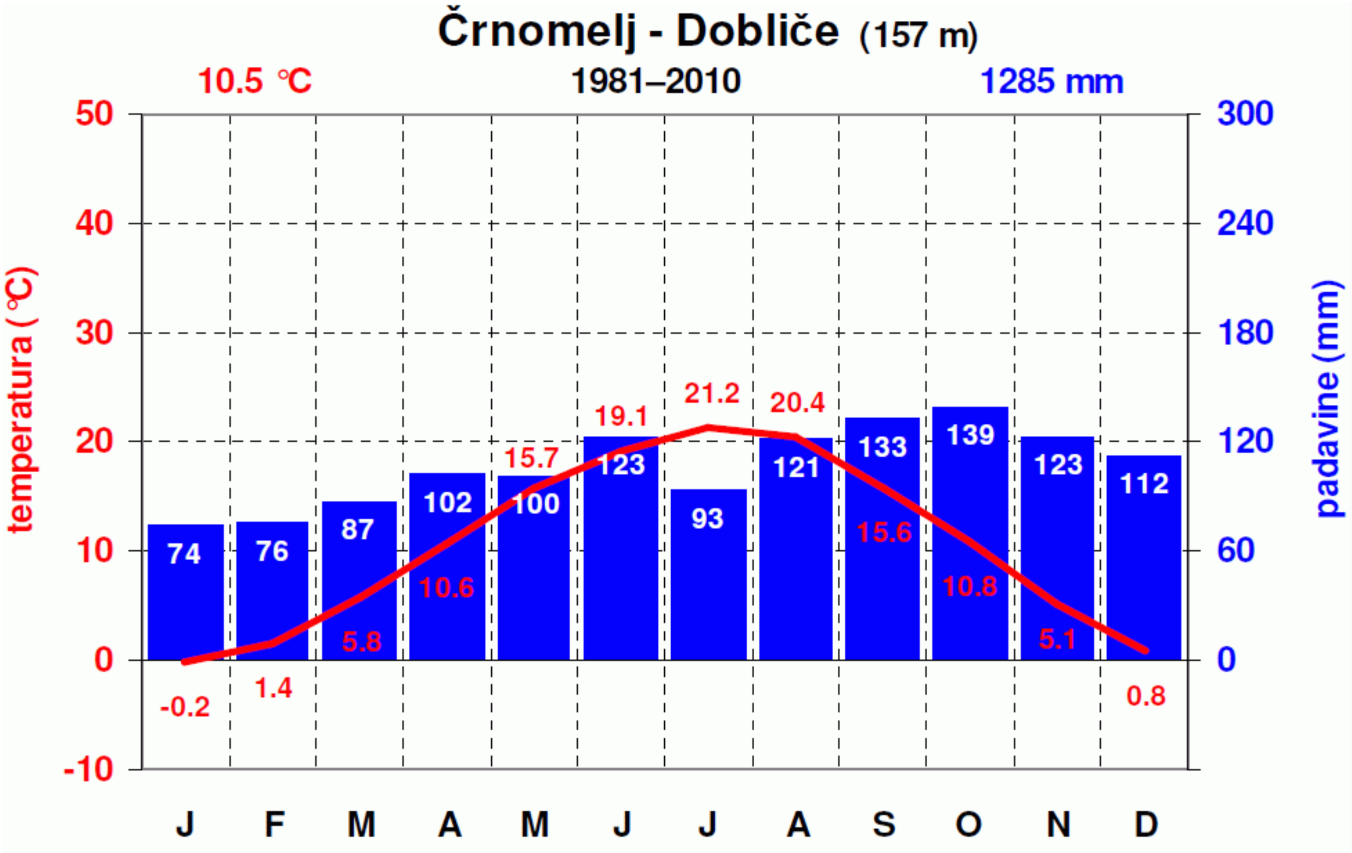
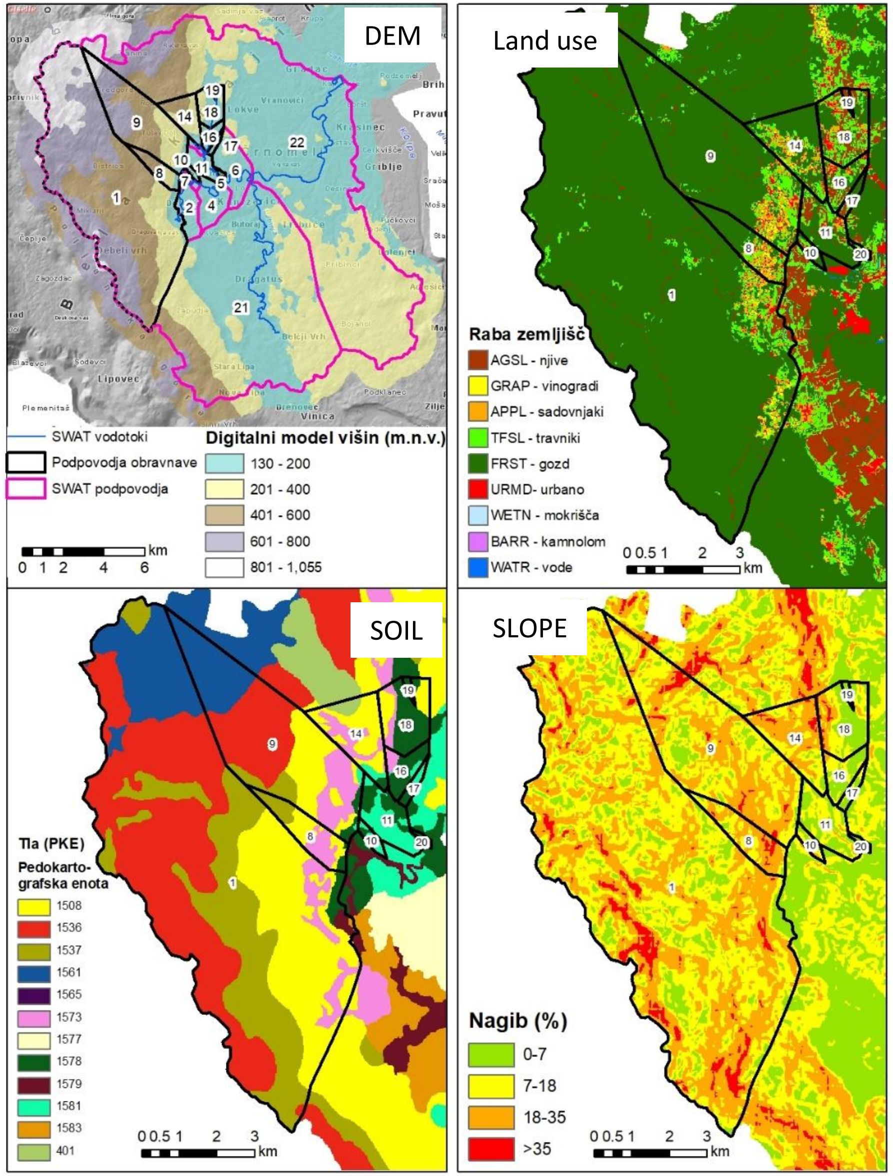
CLIMATE



3. Agricultural measures to protect black olm (*Proteus anguinus, Parkelj*) habitat from nitrate pollution

DATABASE

- **weather** (temp. max and min, precip., humidity, sun, wind)
- **digital elevation model (DEM)**
- **soil**
- **land use**
- **agricultural management practices**
- **river flow**
- **water quality**



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Agricultural measures to protect black olm (*Proteus anguinus, Parkelj*) habitat from nitrate pollution

Agricultural area - arable rotation

- 40% maize
- 30% cereals
- 30% clover-grass mix

Year	Crop type	Date	Operation	Amount	N:P:K (kg)
1	Clover-grass mix	20. apr.	Košnja		
	Silage maize	22. apr.	Gnojenje	25 m^3	100:50:140
		23. apr.	Oranje		
		24. apr.	Predsetvena priprava		
		25. apr.	Gnojenje (ob setvi)	250 kg/ha	38:38:38
		25. apr.	Setev		
		10. jun.	Gnojenje	200 kg/ha	92
		15. sept.	Žetev		
	Winter wheat	15. okt.	Gnojenje	15 m^3	60:30:85
		16. okt.	Oranje		
		17. okt.	Predsetvena priprava		
		18. okt.	Gnojenje (ob setvi)	200 kg/ha	14:40:60
		18. okt.	Setev		
2		20. feb	Gnojenje	200 kg/ha	54
		25. mar.	Gnojenje	200 kg/ha	54
		16. jul	Žetev		
	Fallow (set-aside)	17. jul	začetek		
3		11. apr	konec		
	Silage maize	12. apr.	Gnojenje	25 m^3	100:50:140
		13. apr.	Oranje		
		14. apr.	Predsetvena priprava		
		15. apr.	Gnojenje (ob setvi)	250 kg/ha	38:38:38
		15. apr.	Setev		
		10. jun.	Gnojenje	200 kg/ha	92
		15. sept.	Žetev		
	Winter Barley	10. okt.	Gnojenje	15 m^3	60:30:85
		11. okt.	Oranje		
		12. okt.	Predsetvena priprava		
		13. okt.	Gnojenje (ob setvi)	200 kg/ha	14:40:60
		13. okt.	Setev		
4		15. mar.	Gnojenje	200 kg/ha	54
		25. jun.	Žetev		
	Clover-grass mix	1. jul.	Predsetvena priprava		
		2. jul.	Setev		
		30. sept.	Košnja		

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Calibration and validation

- The hydrological part of model was run with 30 years of daily time step data (1992 – 2022) (softening the effect of extreme meteorological events (storms) and for excluding the effect of dry and wet periods).

- The research period was divided into three periods:
  - warm-up (1993-1997) - stabilization of the model parameters,
  - calibration - 13 years (1998 – 2010),
  - validation - 12 years (2011 – 2022).
- Calibration was manual and automatic (SWAT-CUP Premium Program).

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SCENARIOS

No.	Scenarios	Properties	
		Arable	Grassland
0	BASE (OSN)	4 year rotation, no greening in second year after wheat (maize/wheat+no greening/maize/barley+clover grass mix(CGM))	3 cuts
ADJUSTMENT OF AGRICULTURAL ROTATIONS			
1	INTENZIVNI (INT)	2 year rotation (maize/barley+maize+CGM)	3 cuts
2	RAZŠIRJENI 1 (R1)	OSN + CGM in second year (maize/wheat+CGM/maize/barley+CGM)	3 cuts
3	RAZŠIRJENI 2 (R2)	R1 + -20% fertilisiation(maize/wheat+CGM/maize/barley+CGM)	3 cuts
4	RAZŠIRJENI 3 (R3)	6 year rotation, R2 + 2 years of CGM (maize/wheat+CGM/maize/barley+CGM/CGM/CGM)	3 cuts
5	RAZŠIRJENI 4 (R4)	6 year rotation, R3 + wheat replaced by winter feed peas (maize/winter pease+CGM/maize/barley+CGM/CGM/CGM	3 cuts
ADJUSTMENT OF AGRICULTURAL LAND USE			
6	EKSTENZIVNI 1 (E1)	OSN + some arable (AGSL) in to grassland (TFSL) (3 cuts); (nagib > 7%, PKE = 1508, 1536, 1537, 1561, 1573)	3 cuts
7	EKSTENZIVNI 2 (E2)	OSN + all arable(AGSL) in to grassland (TFSL) (3 cuts)	3 cuts
8	EKSTENZIVNI 3 (E3)	OSN + some arable into unfertilized grassland (1 cut); (slope > 7%, Soil type PKE = 1508, 1536, 1537, 1561, 1573)	1 cut
9	EKSTENZIVNI 4 (E4)	OSN + all arable in to unfertilized grassland (1 cut)	1 cut
10	EKSTENZIVNI 5 (E5)	OSN + E4 + all grassland in to forest	/
11	INTENZIFIKACIJA (E6)	R4 + some grassland (TFSL) in to arable (AGSL); (ravninski <7% nagiba, PKE 1578, 1579, 1583)	3 cuts
ADJUSTMENT OF PUBLIC WASTE WATER COLLECTION SYSTEM			
12	KOMUNALNA OPREMLJENOST (KOM)	OSN + waste water treatment plant (septic tanks eliminated)	3 cuts

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RESULTS

- MODEL CALIBRATION AND RELIABILITY

- PARAMETER SET

SWAT datoteke	SWAT Parametri		Range	Default	Final
Pretok					
.gw	GW_DELAY	Groundwater delay	0 – 500	31	3
	ALPHA_BF	Baseflow alpha factor	0 – 1	0,048	0,70
	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	0 – 5000	1000	500
	GW_REVAP	Groundwater "revap" coefficient	0.02 – 0.2	0,02	0,02
	RCHRG_DP	Deep aquifer percolation fraction.	0 – 1	0,05	0,01
	REVAPMN	Threshold depth of water in the shallow aquifer for “revap” to occur	0 – 1000	750	750
.mgt	CN2	SCS runoff curve number for moisture condition 2	0 – 100	različno	-14,4%
.hru	ESCO	Soil evaporation compensation factor	0 – 1	0,95	1,00
	SURLAG	Surface runoff lag time	0.01 – 24	4	4,00
.bsn	SFTMP	Snowfall temperature.	–5–5	1	2,3
	SMTMP	Snow melt base temperature.	–5–5	0,5	3,515
	SMFMX	Maximum melt rate for snow during year (occurs on summer solstice).	0–10	4,5	2,377
	SMFMN	Minimum melt rate for snow during the year (occurs on winter solstice).	0–10	4,5	3,457
	TIMP	Snowpack temperature lag factor.	0–1	1	0,203
	SNOCOVMX	Minimum snow water content that corresponds to 100% snow cover.	0–500	1	31,429
Dušik					
.bsn	CMN	Rate factor for humus mineralization of active organic nitrogen	0.001 – 0.003	0,0003	0,003
	RCN	Concentration of nitrogen in rainfall	0 – 15	0.9	1,150
	CDN	Denitrification exponential rate coefficient.	0–3	0.0003	1,4
.gw	HLIFE_NGW	Half-life of nitrate in the shallow aquifer [days]	1 – 365	0	32,5-365
.sep	ISEP_TYP	The type of septic system	1–100	1	1
	SEP_DEN	Number of septic systems per square kilometre	0.001–500	1,5	280
	ISP_OPT	Current condition of OWS (1=active septic,2=failing septic,0=non-septic)	0–2	0	1
	SEP_CAP	Number of permanent residents in the house	1	10000	2,5
Databases SepticWQ	SPTQ	Septic tank effluent (STE) flow rate (m3/capita/day)	0–1	0.227	0.227
	IDSPTTYPE	Type of a septic system	1–3	1	1

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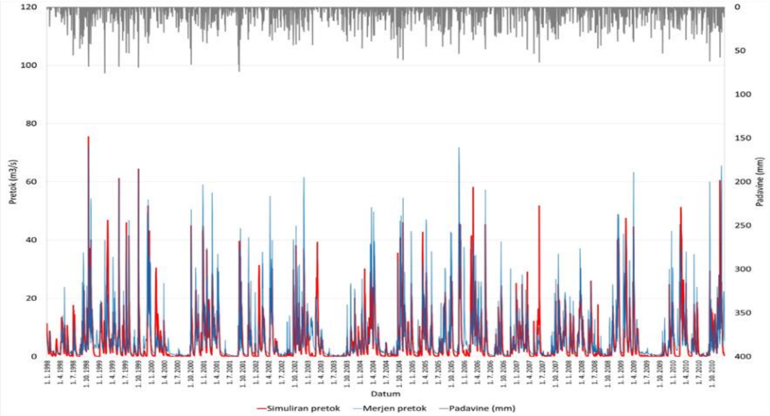

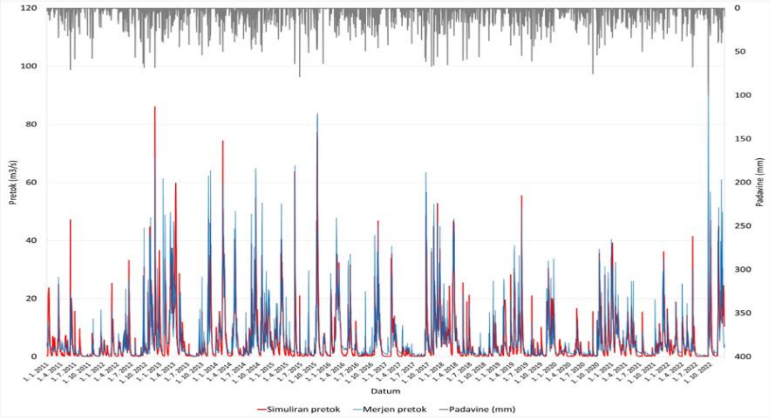

	Statistical objective functions		
	E_{NS}	R^2	PBIAS
River Flow Lahinja – daily observed data at gauging station Gradac			
Calibration (1998 – 2010)	0,59	0,61	0,09
Validation (2011 – 2022)	0,69	0,71	-2,28
Flow – Karst sources – calibration – average annual flow from water balance 2020-2022 (m^3/s)			
Dobličica			7,56
Obršec			-5,60
Jelševniščica			3,14
Janževe loke			0,69
Šprajcarjev zdenec			27,86
Talački breg	**+ less** **- more**		1,02
Pački breg			-14,25
Otovski breg			-11,01
Brežiček			-38,88
Stobe			-80,54
Planinc			-57,69

Nitrate nitrogen ($N\text{-}NO_3^-$) – average observed value and simulation 2021 – 2022 (kg/day)

Karst source	Observed	Simulation
Dobličica	83,92	83,92
Obršec	8,59	8,59
Jelševniščica	21,51	21,52
Janževe loke	0,57	0,58
Šprajcarjev zdenec	13,48	12,48
Talački breg	13,01	13,01
Pački breg	18,05	18,07
Otovski breg	13,83	13,84
Brežiček	0,99	0,99
Stobe	0,34	0,34
Planinc	0,41	0,41

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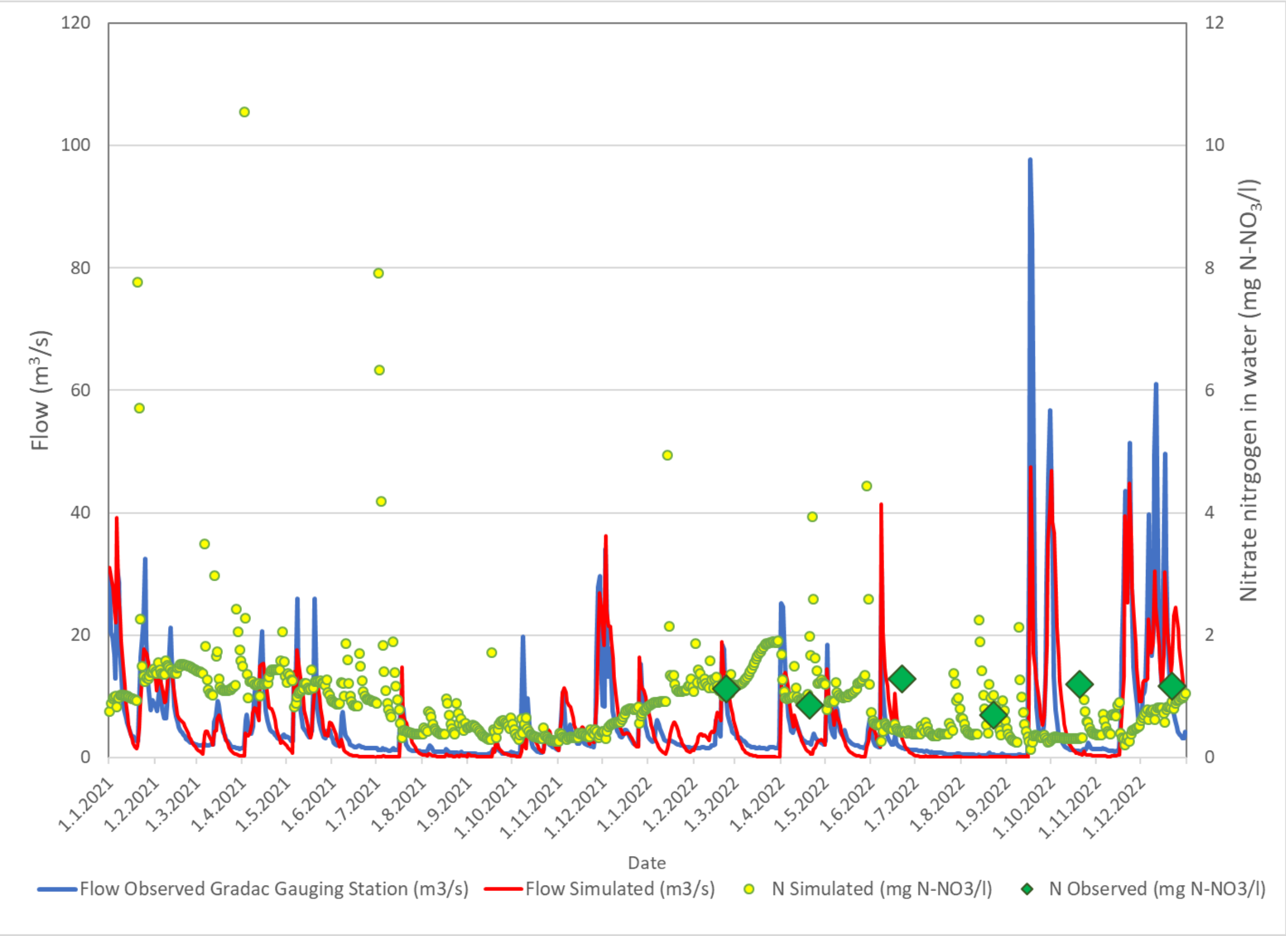

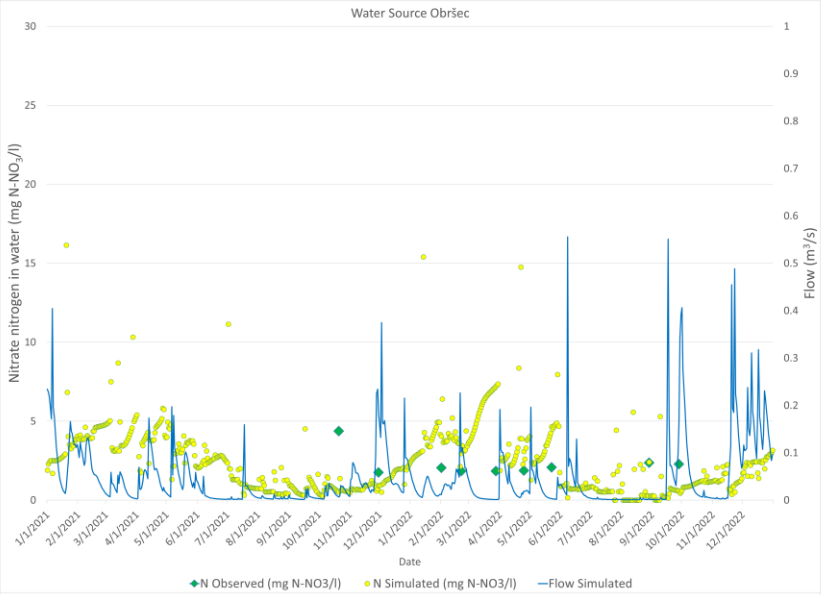

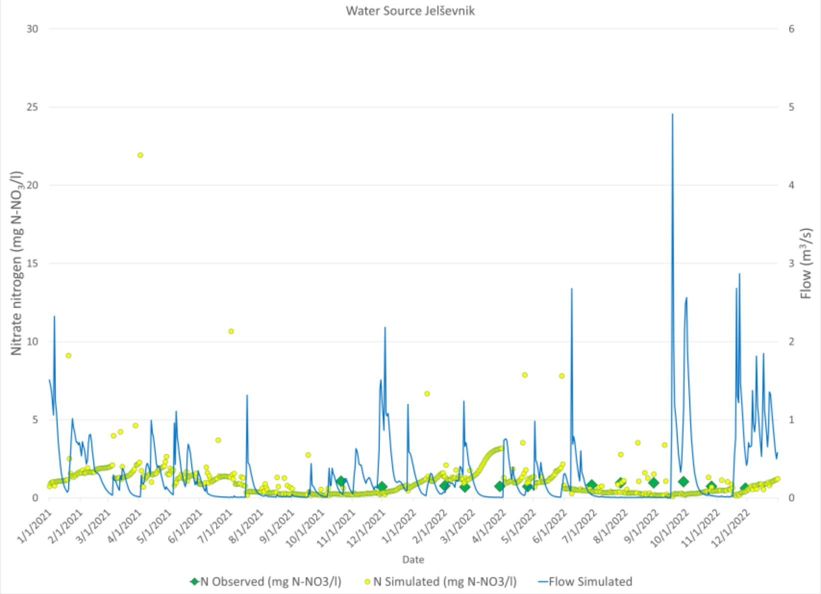

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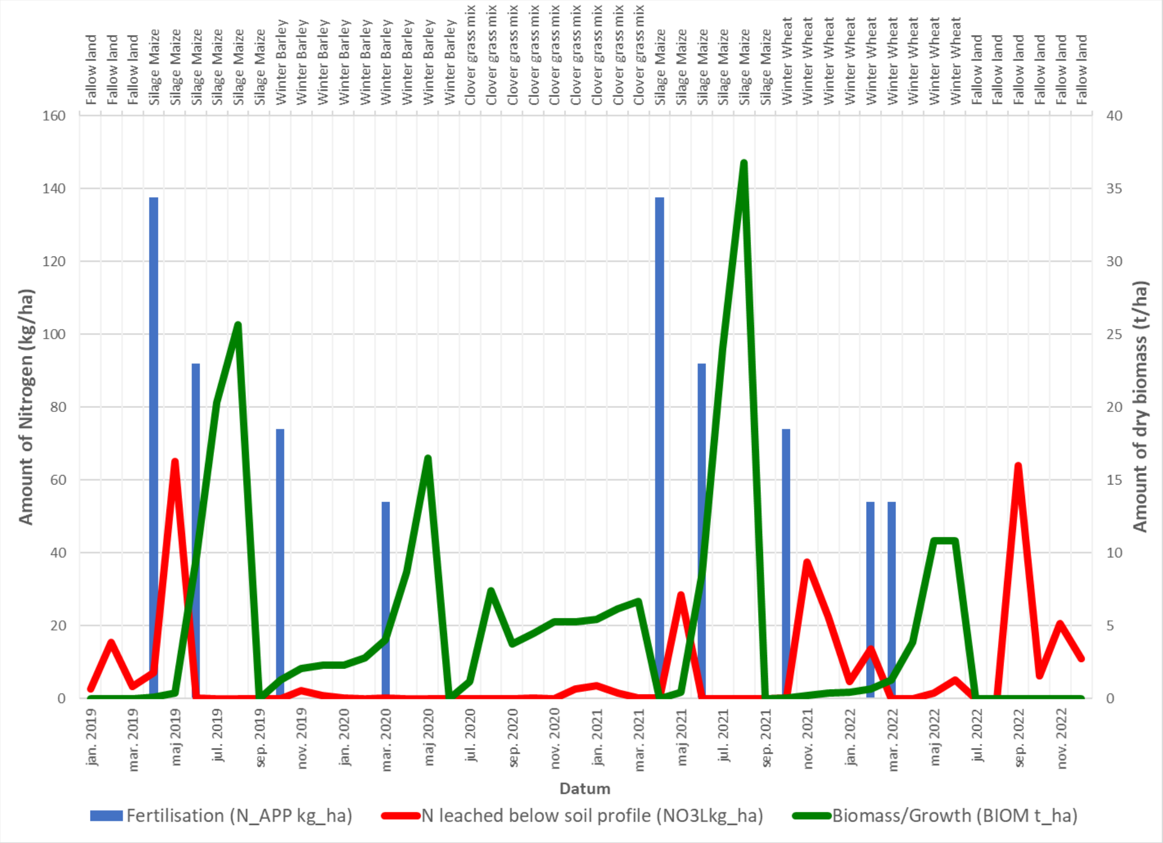

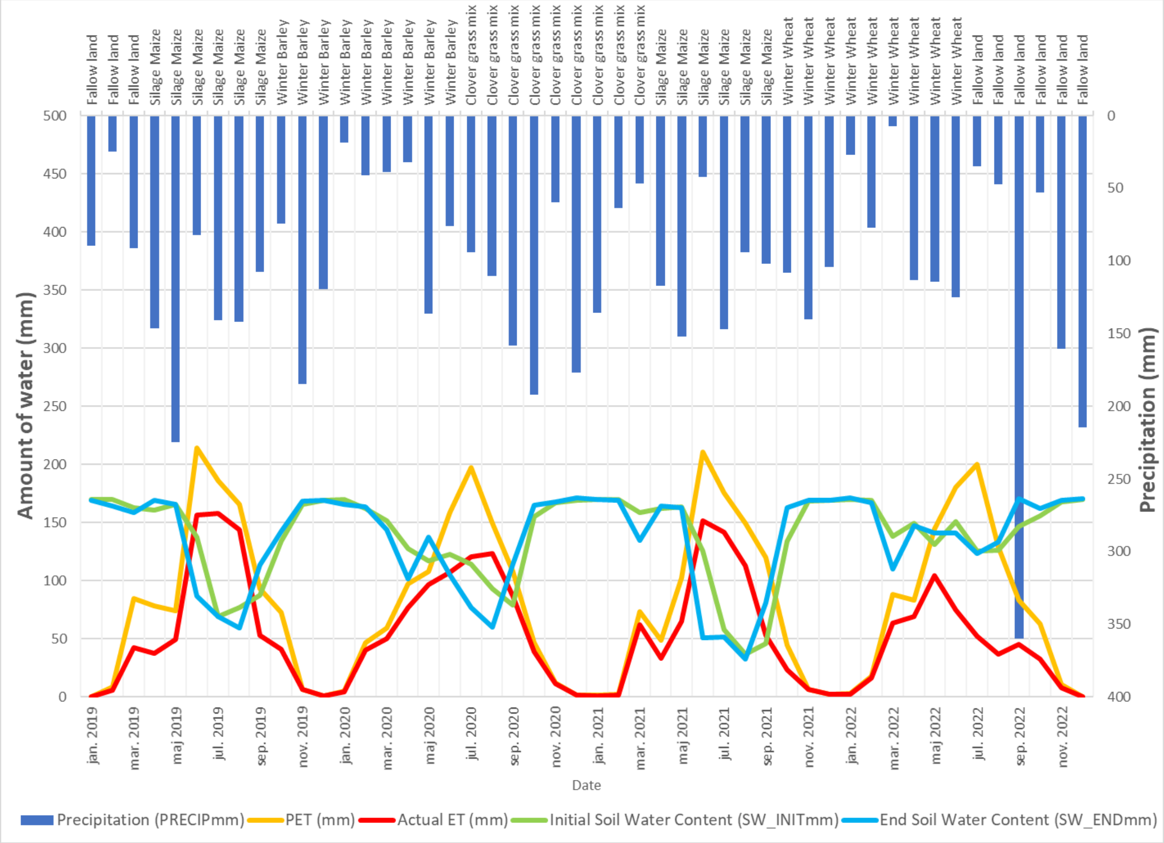

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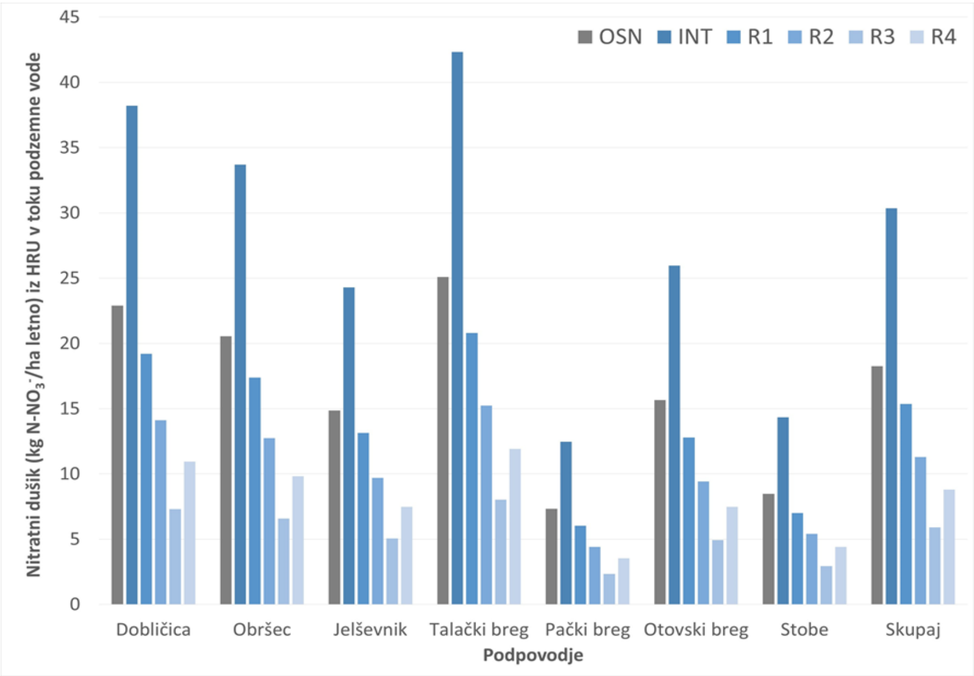
NO3GW (kg/ha)		Average change (%) in nitrate nitrogen load ($N\text{-}NO_3^-$) leached from HRU						
- Arable land		Dobličica	Obršec	Jelševnik	Talački breg	Pački breg	Otovski breg	Stobe
Average 1998-2022		1	8	9	14	16	18	19
Base - NO3GW (kg/ha)		23	21	15	25	7	16	8
- StDv NO3GW (kg/ha)		17	16	12	18	7	13	7
SCENARIOS								
1	INT	67	64	63	69	70	66	69
2	R1	-16	-15	-12	-17	-17	-18	-17
3	R2	-38	-38	-35	-39	-40	-40	-36
4	R3	-68	-68	-66	-68	-68	-68	-65
5	R4	-49	-49	-50	-49	-53	-50	-51

NO3L (kg/ha)		Average change (%) nitrate nitrogen load ($N\text{-}NO_3^-$) leached below soil profile						
- Arable land		Dobličica	Obršec	Jelševnik	Talački breg	Pački breg	Otovski breg	Stobe
Average 1998-2022		1	8	9	14	16	18	19
Base - NO3L (kg/ha)		61	65	73	60	66	61	72
- StDv NO3L (kg/ha)		46	48	58	44	47	45	46
SCENARIOS								
1	INT	70	68	64	72	70	71	66
2	R1	-13	-12	-8	-15	-14	-14	-12
3	R2	-35	-35	-31	-37	-36	-36	-32
4	R3	-66	-65	-62	-66	-66	-65	-62
5	R4	-56	-56	-55	-57	-57	-56	-54

BIOM (t/ha)		Average change (%) of biomass dry matter						
- Arable land		Dobličica	Obršec	Jelševnik	Talački breg	Pački breg	Otovski breg	Stobe
Average 1998-2022		1	8	9	14	16	18	19
OSN - BIOM (t/ha)		25	25	24	26	26	26	26
StDv BIOM (t/ha)		13	13	13	13	13	13	13
SCENARIOS								
1	INT	16	16	16	17	17	16	16
2	R1	18	18	18	18	18	18	18
3	R2	14	14	15	15	15	14	14
4	R3	-5	-4	-3	-4	-4	-5	-5
5	R4	-7	-7	-6	-8	-7	-13	-8



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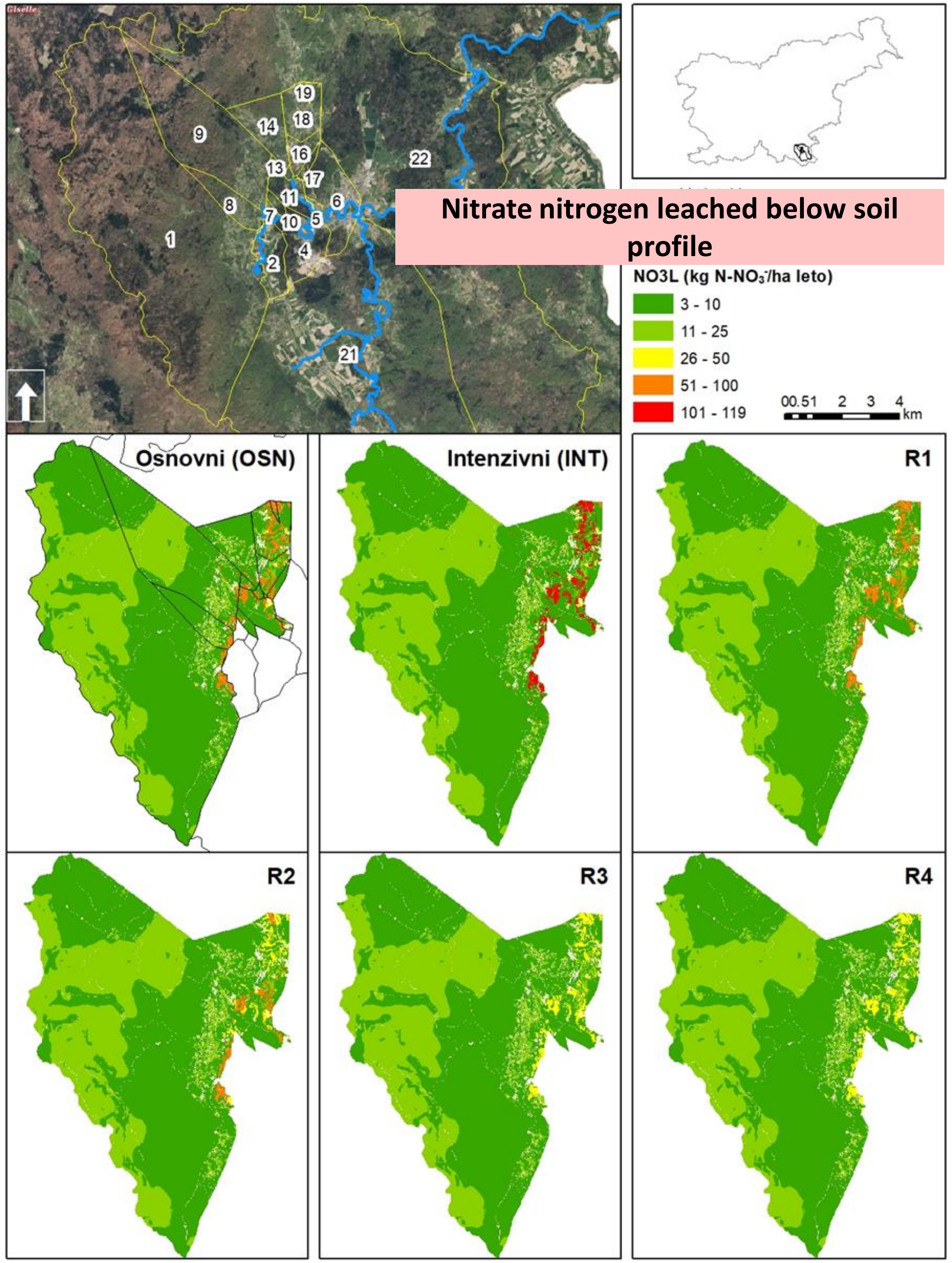

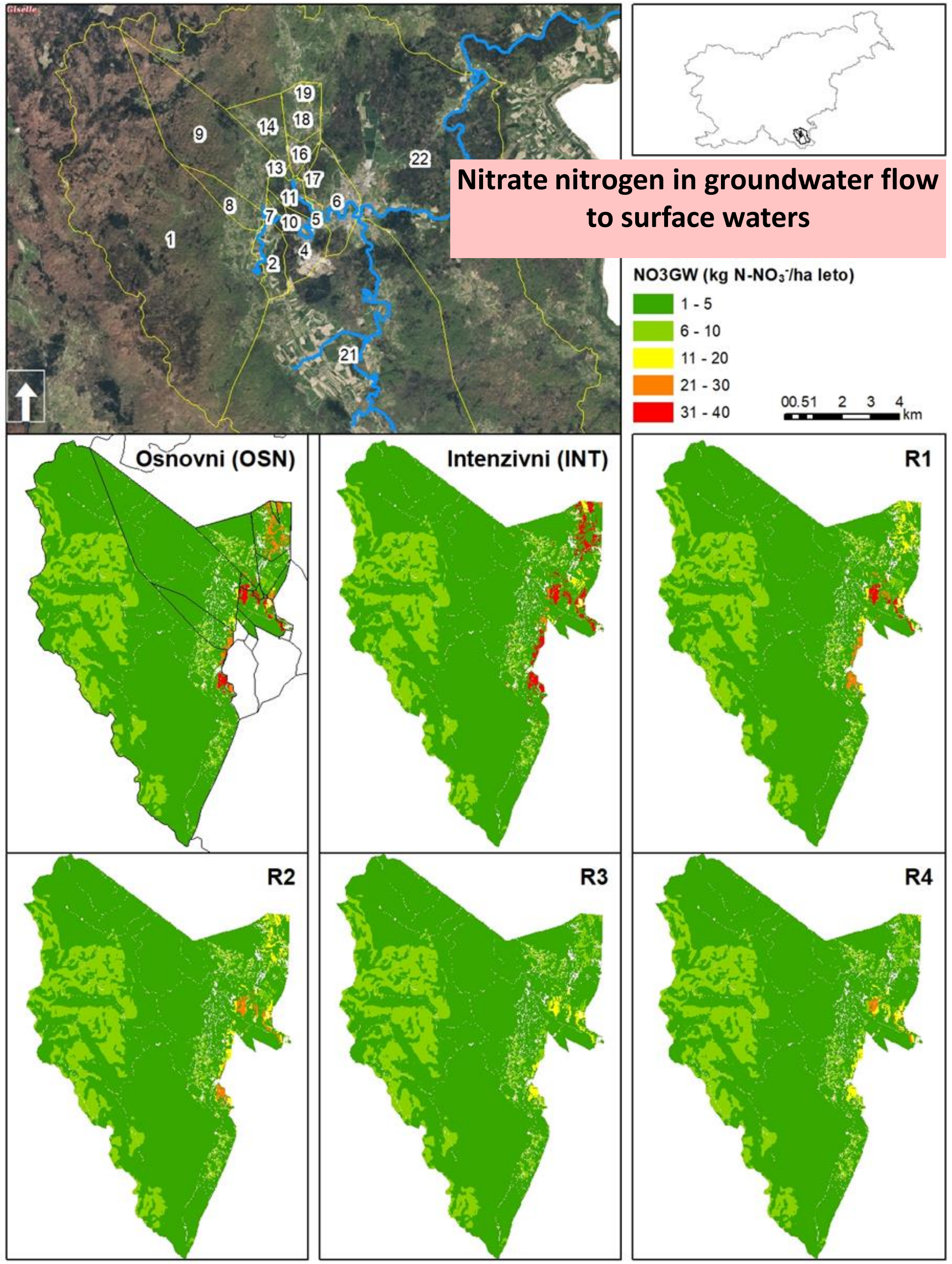

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Soil type	Physical soil properties						Avearge annual nitrate nitrogen leached below soil profile (kg/ha year)			Average annual yiled of plant biomass (t d.m./ha year)	
			Texture (%)				NO3L			BIOM	
PKE No.	Soil depth (mm)	Hydrological group	By soil horizonts	caly	silt	sand	arable	grassland	SUM	arable	grassland
1508	1100	B	MI-MI-MGI-MG-MG	21	66	13	56	6	27	26	9
1536	700	B	MI-MI-MGI-G	17	66	17	-	11	11	-	8
1537	950	C	MI-MGI-MGI	24	69	7	57	6	21	25	8
1561	250	D	MGI-MGI-G	37	57	6	118	16	37	17	7
1565	1000	C	I-I-I-G	14	48	38	68	8	38	25	9
1573	1200	D	MGI-MGI-G	27	64	9	59	7	29	26	9
1577	800	C	MI-MG-MGI	20	73	7	70	8	36	24	8
1578	920	B	MI-MI-MI-MGI	15	74	10	71	8	38	26	9
1579	900	C	PI-PI-PI-PI	6	38	55	72	9	40	23	9
1581	1200	B	MI-MI-MGI-MGI	18	62	20	59	6	29	27	9
1583	1200	C	MI-MI-MI-MGI	16	72	12	54	6	30	27	9
401	1300	B	MI-MI-MI-MGI-MGI-MG	14	79	7	56	6	27	28	9
						Average of SUM	64	8	32	25	9

PKE – pedokartographic soil unit of Soil Map of Slovenia

3. Agricultural measures to protect black olm (*Proteus anguinus, Parkelj*) habitat from nitrate pollution

RESULTS

NO3_OUT (kg/leto)		Average change (%) in nitrate nitrogen load (N-NO_3^- / kg year) at the subbasin outlet						
Nitrate nitrogen in surface water		Dobličica	Obršec	Jelševnik	Talački breg	Pački breg	Otovski breg	Stobe
Povprečje 1998-2022		1	8	9	14	16	18	19
OSN - Pretok (m^3/s)		1,201	0,046	0,297	0,064	0,078	0,055	0,003
- NO3_OUT (kg/leto)		27.911	3.041	7.321	4.617	6.416	4.928	124
- StDv NO3_OUT (kg/leto)		9.620	1.081	2.715	1.663	2.302	1.788	45
SCENARIOS								
1	INT	2	6	2	2	14	16	35
2	R1	0	-1	-1	-1	-3	-4	-8
3	R2	-1	-3	-1	-1	-8	-9	-17
4	R3	-2	-6	-2	-2	-14	-16	-32
5	R4	-1	-4	-2	-2	-10	-12	-23
6	E1	0	0	-1	-1	-1	-1	0
7	E2	-3	-8	-3	-3	-19	-22	-44
8	E3	1	2	1	2	3	3	3
9	E4	-1	-5	-1	1	-14	-16	-36
10	E5	-2	-7	-3	-2	-16	-18	-38
11	E6	-1	-3	-1	-1	0	0	-10
12	KOM*	-22	-64	-49	-66	-63	-60	-40

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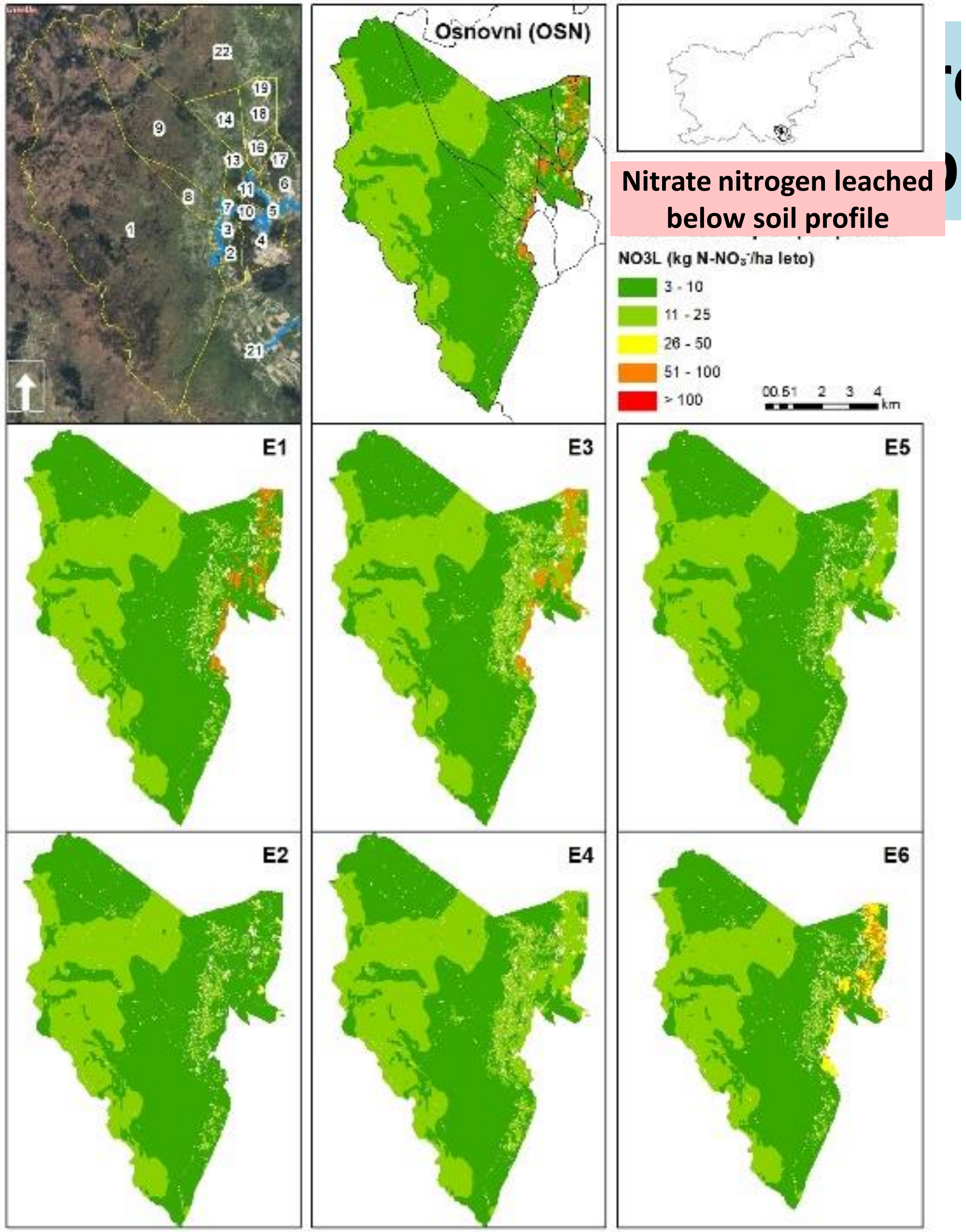
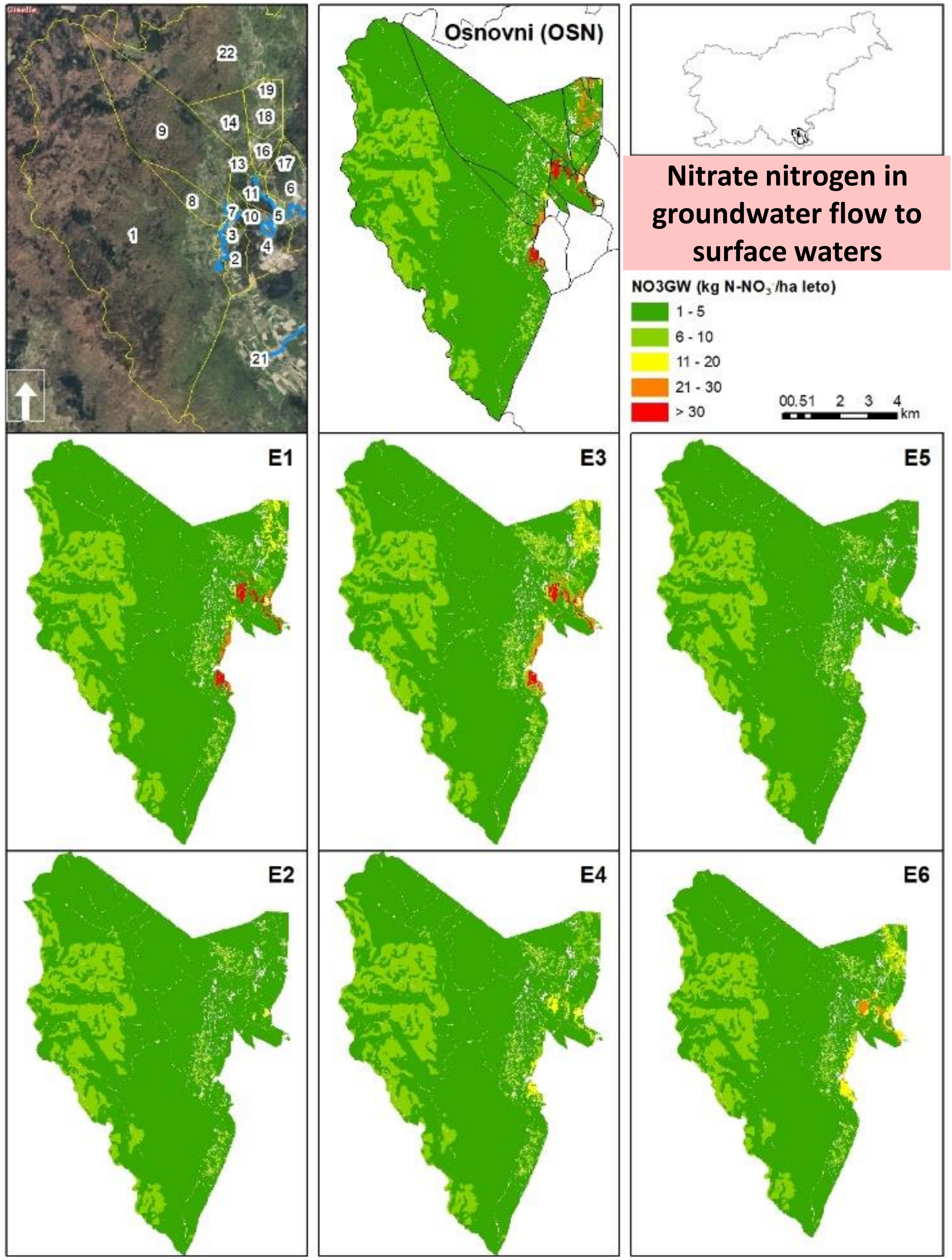
RESULTS





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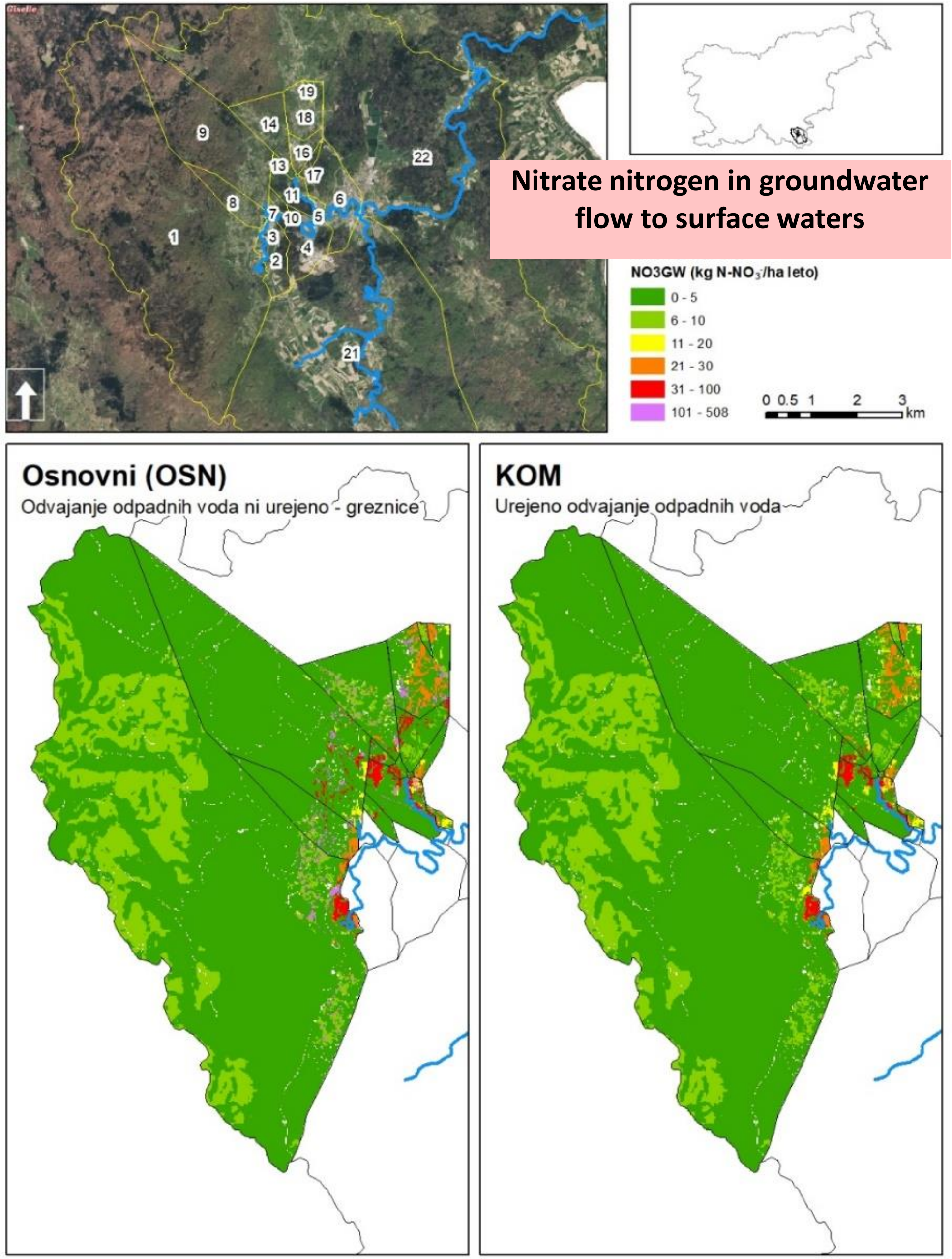
o protect black olm from nitrate pollution

RESULTS



4. Conclusions (1/4)

Key proposals for agriculture sector

a) The introduction of the principles of conservation farming, i.e. the implementation of a wide rotation (4 years and more) and the soil always covered with greening, preferably for the winter (DTM, TDM).

b) The soil should not be bare between two main crops (summer or winter). Bare soils without plant cover are subject to nutrient leaching. Tillage and sowing should be done only a few days apart.

c) Legumes (clover-grass mix, clover) should be included in the existing crop rotation to reduce the use of fertilizers. Research in the field of improving drinking water sources (URAVIVO) has also shown that in some cases nitrogen fertilizer doses can be reduced by 20% without negatively affecting the crop yield. We took this into account when creating the proposal for an extended rotation (R2), where we considered the possibility of reducing nitrogen fertilization.

d) We recommend more efforts by professional services and incentives from the legislator in the introduction of agricultural crops that need lower nitrogen inputs, as well as in raising awareness of the need to fertilize crops with more dozes of smaller quantities. Legumes, for which technology requires the addition of fertilizers, should not be encouraged in the research area (e.g. fodder peas, soybeans).

e) Cultivation technologies with a higher input of N into the soil have negative consequences on the N balance, which is shown by a higher leaching. One type technology is not suitable for all types of soil. The same cultivation technology, which contributes minimally to the N balance on relatively deep soils or soils with a clay-silt soil texture, can cause significantly greater leaching of N on shallow soils. The results show that in order to prevent a potential negative N balance, it would be necessary to manage the areas also depending on the type of soil (depth, texture, rock, hydraulic conductivity, water-holding capacity).

f) We suggest that, in the future, the land management measures should be designed according to the soil properties. In order for this to be possible, it will be necessary to prepare a new soil map with a higher accuracy (1:10,000 or 1:5,000). It should be prepared on the basis of field soil sampling.

4. Conclusions (2/4)

Key proposals for agriculture sector

g) At certain cases, fertilizers are applied with doses than are inappropriate from soil type and geology. It is necessary to invest more in farmers education (agricultural technologies, crop rotations, soil knowledge, economics of nutrient balance) and in meeting compliance with CAP Strategic Plan Conditionally requirements in relation to fertilization plans.

h) We suggest that one or more representative test plots (different soils) be created in the area. They could be used to determine the impact of agro-environmental measures in the area on plant growth, yield, leaching of nitrogen and pesticides. These plots could also be used to educate farmers, in a practical way by presenting the environmental and economic effectiveness of measures. The number of individual consultations on agricultural technologies adapted to the characteristics of farms should be increased.

i) From the point of view of N leaching, organic farming is comparable to the current practice as long as we want to achieve the same yields per hectare. The mineralization of N from organic fertilizers is highly dependent on weather conditions and cannot be controlled. **When promoting organic agriculture, it is necessary to ensure that there will be no surpluses in N balance from livestock and other organic fertilizers (compost, green manure).**

j) Through all the alternative scenarios, grassland use proved to have an extremely favorable N balance in the soil. The properties of the soil have a significant influence on the N balance, this is of particular importance in cases where fertilization with manure or slurry or grazing is carried out on shallow soils, which are usually typical of meadow lands on karst geology. It is important that in the research area there is already a low intensity of animal production (0.48 LU/ha), which enables a better spatial dispersion of organic fertilizers and thus a better efficiency of nutrient utilization by plants.

k) The area is due to large proportion of meadow areas suitable for raising grass-eating animals. Breeding of suckler cows, sheep and goats with smaller livestock units per hectare should receive special incentives. Grassland is a good alternative to arable land, but with the help of professional services, it is necessary to clearly define the type and the number of animals per hectare and define the amount and type of fertilizer and dozes of N according to the type and properties of the soil.

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4. Conclusions (3/4)

Key proposals for agriculture sector

l) Significant proportion of the land is occupied by orchards and vineyards, which in terms of cultivation (cultivated grassland in the inter-row space) are partly similar to meadow use. Fruit growing appears to be a good alternative that should be encouraged as fertilisation methods in fruit growing and viticulture have progressed over the past decades with new insights into the impact of excessive fertilization on the quality and storability of crops.

m) **However, viticulture and fruit growing bring new challenges. It is important to provide a water source for irrigation in the orchards. An even more difficult challenge is the sustainable use of phytopharmaceuticals in cultivation technology (fungicides, insecticides, herbicides). Therefore, it is important to manage cultivation with the help of professional services when growing and using pesticides.**

n) Despite the positive results, some limitations and uncertainties of the research should be noted. One of the main drawbacks is the limited availability of more spatially accurate data on the physical properties of the soil, which affect the accuracy of the simulations. Modeling is also based on certain assumptions that may not reflect all the variability of natural processes in karst systems. In the future, it would be useful to include an even greater number of measurements (flow, nitrogen content in water), which would further improve the accuracy of the forecast.

o) Uncertainties also arise from various factors such as cultivation technologies, crop rotations, harvest timings, machine operation timings and fertilizer applications. All the given data are therefore only average estimates, as each farmer adjusts his term plan and production technology according to specific agricultural crops, type of animals, production intensity and changing weather conditions.

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Conclusions (4/4)

The proposals should be considered as potential responses of the system to changes in land use and agricultural technologies and as a possible impact of agro-environmental measures on the nitrogen balance in the soil.

Modeling results and their interpretation by researchers should serve as a starting point for a CONSTRUCTIVE DISCUSSION aimed at achieving and maintaining good water quality and state of the habitat in the research area, which is also the goal of the water directive and related legislation related to the protection of water resources and habitats.

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