

N₂O Emissions from Two Austrian Agricultural Catchments Simulated with an N₂O Submodule Developed for the SWAT Model

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1. The Nitrification and Denitrification Processes in the SWAT Model

The Nitrification Process

The SWAT model firstly simulates the total amount of nitrification and ammonia volatilization, and then partitions nitrification from volatilization [1]. Nitrification is a function of soil temperature and soil water content while ammonia volatilization is a function of soil temperature, depth and cation exchange capacity. The impact of environmental factors on nitrification and ammonia volatilization in a given layer is defined by the nitrification regulator and volatilization regulator.

The nitrification regulator is calculated:

$$\eta_{nit,ly} = \eta_{tmp,ly} * \eta_{sw,ly} \quad (S1)$$

and the volatilization regulator is calculated:

$$\eta_{vol,ly} = \eta_{tmp,ly} * \eta_{midz,ly} * \eta_{cec,ly} \quad (S2)$$

where $\eta_{nit,ly}$ is the nitrification regulator, $\eta_{vol,ly}$ is the volatilization regulator, $\eta_{tmp,ly}$ is the nitrification/volatilization temperature factor, $\eta_{sw,ly}$ is the nitrification soil water factor, and $\eta_{midz,ly}$ is the volatilization depth factor.

The nitrification/volatilization temperature factor is calculated:

$$\eta_{tmp,ly} = 0.41 * \frac{(T_{soil,ly}-5)}{10} \quad \text{if } T_{soil,ly} > 5 \quad (S3)$$

Where $T_{soil,ly}$ is the temperature of layer ly (°C). Nitrification/volatilization occurs only when the temperature of the soil layer exceeds 5 °C.

The nitrification soil water factor is calculated:

$$\eta_{sw,ly} = \frac{SW_{ly}-WP_{ly}}{0.25*(FC_{ly}-WP_{ly})} \quad \text{if } SW_{ly} < 0.25 * FC_{ly} - 0.75 * WP_{ly} \quad (S4)$$

$$\eta_{sw,ly} = 1.0 \quad \text{if } SW_{ly} \geq 0.25 * FC_{ly} - 0.75 * WP_{ly} \quad (S5)$$

Where $\eta_{sw,ly}$ is the nitrification soil water factor, SW_{ly} is the soil water content of layer ly on a given day (mm H₂O), WP_{ly} is the amount of water held in the soil layer at wilting point water content (mm H₂O), and FC_{ly} is the amount of water held in the soil layer at field capacity water content (mm H₂O).

The volatilization depth factor is calculated:

$$\eta_{midz,ly} = 1 - \frac{Z_{mid,ly}}{Z_{mid,ly} + \exp(4.706 - 0.0305 * Z_{mid,ly})} \quad (S6)$$

Where $\eta_{midz,ly}$ is the volatilization depth factor, and $Z_{mid,ly}$ is the depth from the soil surface to the middle of the layer (mm).

SWAT does not require the user to provide information about soil cation exchange capacity. The volatilization cation exchange factor is set to a constant value:

$$\eta_{cec,ly} = 0.15 \quad (S7)$$

The total amount of ammonium lost to nitrification and volatilization is calculated using a first-order kinetic rate equation:

$$N_{nit|vol,ly} = NH4_{ly} * (1 - \exp(-\eta_{nit,ly} - \eta_{vol,ly})) \quad (S8)$$

Where $N_{nit|vol,ly}$ is the amount of ammonium converted via nitrification and volatilization in layer ly (kg N/ha), $NH4_{ly}$ is the amount of ammonium in layer ly (kg N/ha), $\eta_{nit,ly}$ is the nitrification regulator, and $\eta_{vol,ly}$ is the volatilization regulator.

To partition $N_{nit|vol,ly}$ between nitrification and volatilization, the expression is solved using each regulator individually to obtain a fraction of ammonium removed by each process:

$$fr_{nit,ly} = 1 - \exp(-\eta_{nit,ly}) \quad (S9)$$

$$fr_{vol,ly} = 1 - \exp(-\eta_{vol,ly}) \quad (S10)$$

Where $fr_{nit,ly}$ is the estimated fraction of nitrogen lost by nitrification, $fr_{vol,ly}$ is the estimated fraction of nitrogen lost by volatilization, $\eta_{nit,ly}$ is the nitrification regulator, and $\eta_{vol,ly}$ is the volatilization regulator.

The amount of nitrogen removed from the ammonium pool by nitrification is then calculated:

$$N_{nit,ly} = \frac{fr_{nit,ly}}{(fr_{nit,ly} + fr_{vol,ly})} * N_{nit|vol,ly} \quad (S11)$$

The denitrification process

The effect of nutrient cycling temperature factor on denitrification [1]:

$$\gamma_{tmp,ly} = \text{Max} \left[\left(0.9 * \frac{SoilTemp}{SoilTemp + e^{(9.93 - 0.312 * SoilTemp)}} + 0.1 \right), 0.1 \right] \quad (S12)$$

The effect of nutrient cycling temperature factor on denitrification works only when the temperature of the soil layer is above 0°C. $SoilTemp$ is the temperature of layer ly (°C). The nutrient cycling temperature factor is never allowed to fall below 0.1.

The effect of nutrient cycling water factor on denitrification [1]:

$$\gamma_{sw,ly} = \frac{SW_{ly}}{FC_{ly}} \quad (S13)$$

Where SW_{ly} is soil water content (mm) and FC_{ly} is the amount of water held in the soil layer at field capacity water content (mm). The nutrient cycling water factor is never allowed to fall below 0.05.

2. The Existing SWAT N₂O Submodule Developed

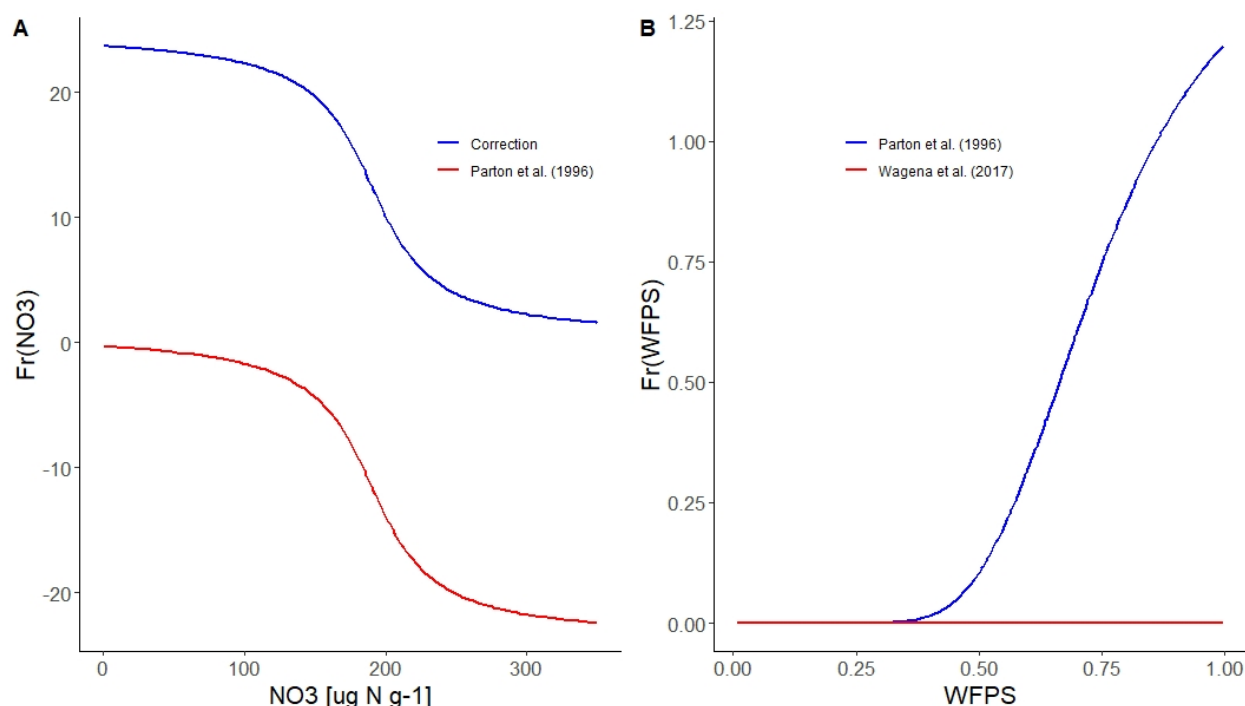


Figure S1. The representation of the equations for the impacts of soil NO₃⁻ (A) and soil water (B) on the ratio of N₂/N₂O in Parton et al. [2] and Wagena et al. [3]. Fr(NO₃) is the impact of soil NO₃⁻ on the N₂/N₂O ratio, and Fr(WFPS) is the impact of soil moisture on the N₂/N₂O ratio.

3. The Fraction of Nitrified N Lost as N₂O.

Table S1. Literature values of the fraction of nitrified N lost as N₂O, which is denoted by K₂.

Reference	K ₂ (%)	Country	Clay	Silt	Sand
Yoshida [4]	0-95				
Bremner [5]	3.5		25-27	36-47	28-37
Freney et al. [6]	10	Australia	Average value		
Goreau et al. [7]	0.3-8	England			
Lipschultz et al. [8]	0.15-2.5	USA	Average value		
Goodroad & Keeney [9]	0.1-1.1	USA	19	50	31
Hynes & Knowles [10]	0.06-12.26	Canada			
Martikainen [11]	up to 20	Finland	forest soil		
Tortoso [12]	0.02	Sidney			
Remde [13]	0.1-3.9	Germany	Average value		
Martikainen [14]	up to 0.01	Netherland	Sandy		
Maag & Vinther [15]	0.17-0.93		coarse sandy soil/loamy sand/sandy loam		
Kester et al. [16]	0.04-0.78	Netherland			
Jiang & Bakken [17]	0.07-5	Norway			
Ingwersen et al. [18]	0.01-0.055	Germany			
Garrido et al. [19]	<-0.001-1	France	20-32.4		
Khalil et al. [20]	0.16-1.48	France	20	73	7
Cheng et al. [21]	0.01-0.22	China	Loam		
Bateman [22]	0.17-0.53	UK	15	68	17

Mathieu et al. [23]	0.13-2.32	eastern France	13.5	51.9	34.6
Morkved et al. [24]	<0.1-27	Norway	13	68	19
Morkved et al. [25]	0.02-7.6	Norway	21	40	39
Carter [26]	0.02-0.29	Denmark		Loamy sand	
Chen et al. [27]	0.03-0.12	Australia		Clay loam	
Gabally et al. [28]	0.01-0.05	Australia	14	23	53
Frame et al. [29]	0.4-2.2	USA		Average value	
Zhu et al. [30]	0.09-8.3	USA	13-44	15-49	22-42
Paul et al. [31]	0.025-0.85			Silt loam	

4. Crop Grouping in SWAT

Table S2. Crop classification into groups for the setup of the Melk catchment (M1).

SWAT code	Crops	SWAT code	Crops
WWHT	Silage rye	BARL	Summer barley
	Silage rye/ corn		Summer wheat
	Winter rye		Summer spelt
	Winter barley		Caraway
	Winter durum		Summer oats
	Winter beets		Oat and mixed grains
	Winter triticale		Poppy
	Winter wheat		Rape seed
	Einkorn/ Emmer		Triticale
	Winter spelt		Flax
	Winter rye and meslin		Buckwheat
	Winter caraway		Camellia
	Winter rapeseed		Quinoa
	Winter oats	PAST	Permanent pasture
			Bioenergy grasses
CORN	Corn / Beans in separated rows		20 years fallow
	Corn CORN-COB-MIX (CCM)		Alpine pasture
	Grain corn		Mountain pasture
	Millet		Blue lupine
	Sorghum		Pasture (once mowed)
	Sunflowers		Forage grasses
	Sweet corn		Fallow pastureland
			Herding pasture
SOYB	Soybeans		Pasture with two uses
	Broad beans- grain mix		Pasture with three or more uses
	Broad bean		Turf grass
	Peas – grain mix		Other forage crops
	Peas		Other pasture areas
	Common vetch		Pasture for bedding
	Hairy vetch		
	Lupine		
	Vetch – grain mix		
	Peavines		

Table S3. Crop classification into groups for the setup of the Melk catchment (M2).

SWAT code	Crops	SWAT code	Crops
FESI	Pasture with three and more uses	CORN	Grain corn
	Pasture with two uses		Corn CORN-COB-MIX (CCM)
	Other forage crops		Sorghum
	Forage grasses	SOYB	Soybeans
			Broad bean
WWHT	Winter wheat		Peas
	Winter barley		Broad beans – grain mix
	Winter triticale		Flax
	Winter rapeseed		Hemp
	Sugar beet	FESE	Permanent pasture
	Oil pumpkin		Pasture (once mowed)
	Nuts (walnuts, hazelnuts, ...)		Herding pasture
	Winter spelt		
	Winter rye		

The crops with small area not included in Table S6 were directly grouped into their neighbor main crops when we prepared the land use map.

Table S4. Crop classification into groups for the Zaya catchment.

SWAT code	Crops	SWAT code	Crops
WWHT	Winter wheat	BARL	Summer barley
	Winter rapeseed		Summer wheat
	Winter barley		Summer wheat
	Winter durum wheat		Summer oats
	Winter triticale		Buckwheat
	Winter spelt		Silage rye
	Winter rye		Summer einkorn/ emmer
	Winter vetch		Poppy
	Einkorn/ Emmer		Triticale
	Winter poppy		Summer rye
SGBT	Sugar beet	CORN	Grain corn
	Oil pumpkin		Silage
	Edible potatoes		Millet
	Starch potatoes		Sorghum
	Seed potatoes		Seed corn for propagation
	Food potatoes	FESC	Fallow
	Pumpkin		Pasture (once mowed)
FESI	Other forage crops		Herding pasture
	Pasture with two uses		Common vetch
	Permanent pasture		
	Forage grass		

The crops with small area not included in Table S7 were directly grouped into their neighbor main crops when we prepared the land use map.

5. Parameters Calibrated Based on the Sensitivity Analysis in SWAT

Table S5. The calibrated parameters with their initial ranges, and final validated values for the Melk and Zaya catchments.

Parameters	Definition	Initial range (M1)	Initial range (M2/Zaya)	Validated value (M1)	Validated value (M2)	Validated value (Zaya)
v__AL-PHA_BF	Baseflow recession constant	(0, 1)	(0, 1)	0.05	0.110	0.49
v__AL-PHA_BNK	Bank flow recession constant or constant of proportionality	(0, 1)				
v__BIOMIX	Biological mixing efficiency		(0, 1)		0.749	0.087
r__CANMX	Maximum canopy storage	(-0.9, 3)				
v__CDN	Rate coefficient for denitrification	(0, 1.5)	(0, 3)	1.295	0.0005	0.01
r__CH_K1	Effective hydraulic conductivity	(-0.4, 0.4)				
r__CH_K2	Effective hydraulic conductivity of channel	(-0.4, 0.4)				
v__CMN	Rate coefficient for mineralization of the humus active organic nutrients		(0.0001, 0.003)		0.0027	0.0022
r__CN2	Curve number II	(-0.2, 0.1)		-0.199		
r__CNOP_HVST	SCS moisture condition II curve number for pervious areas specified in harvest/kill		(-0.25, 0.1)		-0.1	-0.101
r__CNOP_PLNT	SCS moisture condition II curve number for pervious areas specified in plant operation		(-0.25, 0.1)		-0.1	-0.067
r__CNOP_TILL	SCS moisture condition II curve number for pervious areas specified in tillage operation		(-0.25, 0.1)		-0.155	-0.197
v__EPCO	Plant uptake compensation factor	(0, 0.9)	(0, 1)		0.578	0.407
v__ERORGN	Organic nitrogen enrichment ratio		(0, 100)		1.383	14.337
v__ESCO	Soil evaporation compensation coefficient	(0, 0.9)	(0, 1)		0.758	0.41
v__GW_DELAY	Delay time for aquifer recharge	(0, 500)	(0, 250)		35.239	42.95
v__GW_REVAP	Revap coefficient		(0.02, 2)		0.293	0.56
v__GWQMN	Threshold water level in shallow aquifer for base flow	(0, 5000)	(0, 5000)	3494.76	117.093	245.61

v__HLIFE_NGW	Half-life of nitrate in the shallow aquifer	(0, 200)		197.869	54.601	
r__HRU_SL_P	Average slope steepness	(-0.25, 0.25)		-0.142	-0.184	
v__LAT_TTI_ME	Lateral flow travel time	(0, 180)				
v__N_UP-DIS	Nitrogen uptake distribution parameter	(0, 100)	(1, 31)	20.957	8.876	
v__NPERC_O	Nitrate percolation coefficient	(0.125, 1)	(0, 1)	0.959	0.791	0.938
a__OV_N	Manning's value for overland flow	(-0.09, 0.6)	(0.01, 0.6)	0.332	0.192	0.349
v__RCHRG_DP	Aquifer percolation coefficient	(0, 1)	(0, 1)		0.187	0.433
v__RCN	Concentration of nitrogen in the rain	(0, 10)		2.188		
v__REVAP_MN	Threshold water level in shallow aquifer for revap	(0, 500)	(0, 500)	105.999	103.12	
v__RSDCO	Rate coefficient for mineralization of the residue fresh organic nutrients		(0, 1)	0.3696	0.111	
v__SDNCO	Threshold value of nutrient cycling water factor for denitrification to occur	(0, 0.5)	(0, 1)	0.5801	0.983	
v__SFTMP	Mean air temperature at which precipitation is equally likely to be rain as snow/freezing rain		(-2, 2)	0.4	0.21	
v__SHALLS_T_N	Amount of nitrate in the shallow aquifer	(0, 1000)				
v__SLSOIL	Hillslope length	(0, 150)				
v__SLSUBBS_N	Slope length	(0, 150)	(-0.5, 0.5)	1.084	-0.104	0.283
v__SMFMN	Melt factor on December 21	(0, 10)	(1.4, 4)	3.5	3.07	
v__SMFMX	Melt factor on June 21	(0, 10)	(3, 6.9)	5	3.5	
v__SMTMP	Threshold temperature for snowmelt	(-2,2)	(-2, 2)	0.1	0.67	
v__SNO50C_OV	Fraction of SNOCOVMX that provide 50% cover	(0.1, 0.9)	(0, 1)	0.336	0.178	0.31
v__SNOCO_VMX	Threshold depth of snow, above which there is 100% cover	(0, 500)	(0, 500)	160.33	271.72	
r__SOL_AWC()	Available water capacity	(-0.9, 1.5)	(-0.5, 0.5)	0.073	0.095	
r__SOL_BD	Moist bulk density		(-0.5, 0.5)	0.170	0.159	
r__SOL_K()	Saturated hydraulic conductivity	(-1, 1)	(-0.5, 2)	0.415	0.124	
v__SURLAG	Surface runoff lag coefficient	(0, 1)	(0.05, 12)	0.267	0.05	
v__TIMP	Snow temperature lag factor	(0, 1)	(0.01, 1)	0.3	0.29	

v: the original parameter value in the SWAT model is to be replaced by validated value;
 a: the validated value will be added to the original parameter value; r: the original parameter value will be multiplied by $(1 + \text{validated value})$.

6. Discharge and Nitrate Simulations in SWAT



Figure S2. Discharge hydrograph for the setup of the Melk catchment (M1).



Figure S3. Discharge hydrograph for the setup of the Melk catchment (M2).



Figure S4. Simulated NO₃ for the setup of the Melk catchment (M1).

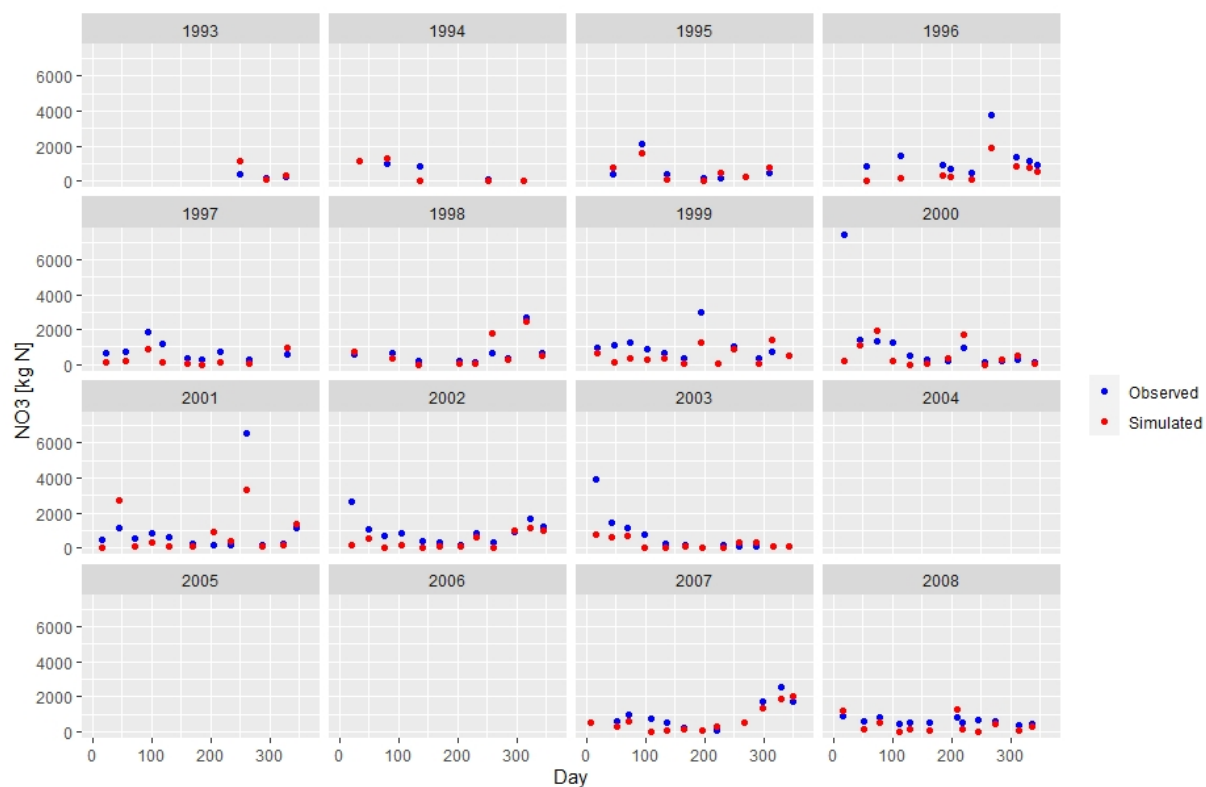


Figure S5. Simulated NO_3 for the setup of the Melk catchment (M2).

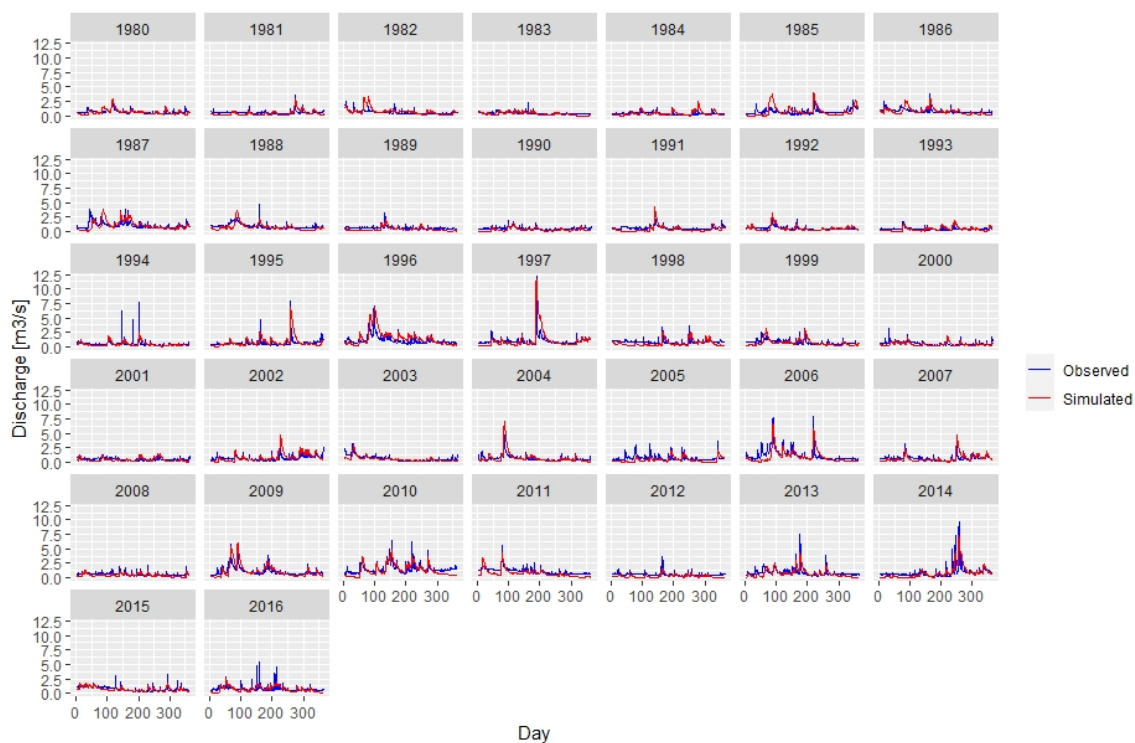


Figure S6. Discharge hydrograph for the setup of the Zaya catchment.

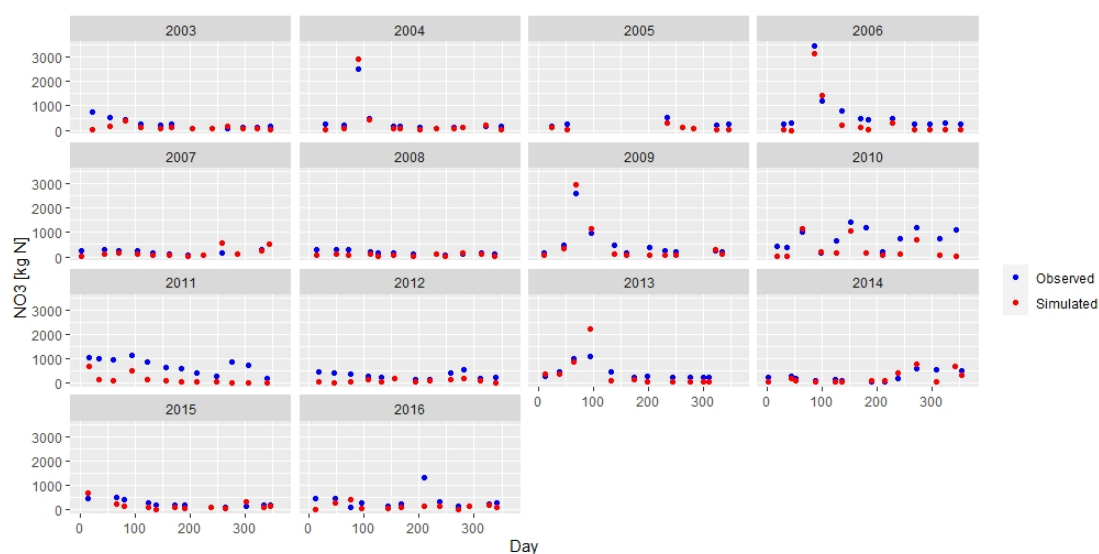


Figure S7. Simulated NO₃ for the setup of the Zaya catchment.

7. Annual Water Balance Calculations

Table S6. SWAT simulated water balance for the M1 setup in the Melk catchment.

Year	PREC (mm)	ET (mm)	SW (mm)	PERC (mm)	SURQ (mm)	GWQ (mm)	WYIELD (mm)	LATQ (mm)	ΔSW (mm)	Balance (mm)	Percentage error (%)
1985	882	435	269	306	91	0	144	42	4	-8	-0.9
1986	710	404	287	191	71	0	114	31	-14	16	2.2
1987	953	407	265	407	106	0	180	56	8	-49	-5.1
1988	921	404	272	408	33	38	146	56	1	0	-0.1
1989	880	417	266	375	50	179	308	58	7	-47	-5.4
1990	693	360	279	258	21	135	209	40	-6	7	1.0
1991	766	397	274	259	76	168	294	38	-1	-15	-1.9
1992	754	381	266	308	28	191	279	47	7	-31	-4.1
1993	772	399	272	291	31	235	323	42	1	-8	-1.0
1994	686	361	266	266	22	213	292	41	7	-27	-4.0
1995	826	381	267	355	36	283	385	51	6	-18	-2.2
1996	979	405	266	426	91	380	554	63	7	-33	-3.4
1997	852	423	265	339	44	276	388	50	8	-29	-3.4
1998	851	425	290	308	45	304	414	49	-17	26	3.0
1999	864	416	280	333	77	282	423	47	-7	-18	-2.1
2000	748	392	281	263	37	252	345	42	-8	8	1.0
2001	831	398	293	314	66	266	393	46	-20	11	1.4
2002	1026	407	286	435	138	366	582	61	-13	-20	-2.0
2003	623	383	275	188	30	216	293	31	-1	-22	-3.6
2004	753	350	267	307	66	275	398	44	7	-34	-4.5
2005	963	379	273	399	119	367	560	56	0	-9	-1.0
2006	877	350	269	378	102	350	524	53	4	-29	-3.3
2007	1030	403	276	459	95	350	526	63	-2	-7	-0.6
2008	875	400	264	382	51	395	524	56	9	-45	-5.1

2009	1105	384	274	487	156	475	726	69	-1	-16	-1.4
2010	880	375	293	365	68	345	487	53	-20	18	2.1
2011	697	393	270	237	54	195	297	36	4	-39	-5.6
2012	740	385	268	277	39	232	323	40	6	-19	-2.5
2013	1034	366	265	494	108	459	659	70	8	-35	-3.4
2014	848	356	267	362	70	338	479	53	7	-18	-2.1
2015	661	374	263	237	22	217	291	38	10	-34	-5.2

Abbreviations: PREC: precipitation; ET: evapotranspiration; SW: soil water content; PERC: water entering the vadose zone from the soil profile; SURQ: surface runoff; GWQ: groundwater contribution to streamflow; WYIELD: water yield; LATQ: lateral flow; Δ SW: the change of soil water content.

Table S7. SWAT simulated water balance for the M2 setup in the Melk catchment. .

Year	PREC (mm)	ET (mm)	SW (mm)	PERC (mm)	SURQ (mm)	GWQ (mm)	WYIELD (mm)	LATQ (mm)	Δ S (mm)	Balance (mm)	Percentage error (%)
1985	913	527	273	91	85	4	303	203	-0.1	-4	-0.4
1986	726	459	287	42	98	15	237	116	-13.9	17	2.3
1987	952	526	273	92	148	10	383	205	0.3	-40	-4.2
1988	982	508	274	130	78	22	381	262	-1.1	-13	-1.3
1989	979	578	274	107	50	24	346	249	-0.6	-27	-2.7
1990	781	508	291	62	21	8	209	168	-17.9	27	3.5
1991	897	509	284	89	102	8	327	201	-11.3	-9	-1.0
1992	782	486	271	85	21	15	262	210	2.3	-38	-4.9
1993	842	516	273	75	55	14	265	182	0.3	0	0.0
1994	806	508	266	85	28	16	257	196	6.5	-35	-4.4
1995	932	529	273	107	41	16	317	242	-0.4	-5	-0.5
1996	997	517	275	124	102	26	408	258	-2.5	-23	-2.4
1997	926	544	273	107	40	16	319	241	-0.3	-29	-3.1
1998	926	540	292	90	54	21	313	221	-19.1	22	2.4
1999	948	533	291	88	125	13	354	199	-18.1	4	0.4
2000	745	485	257	66	46	13	237	160	16.1	-45	-6.1
2001	879	512	295	79	76	9	288	197	-22.0	32	3.6
2002	1040	520	293	134	118	33	444	271	-19.7	-6	-0.6
2003	608	461	258	37	43	14	180	105	15.2	-72	-11.8
2004	779	500	261	55	75	4	234	144	11.7	-19	-2.4
2005	981	531	274	104	96	6	345	227	-1.0	9	0.9
2006	926	524	270	85	134	5	353	197	2.7	-34	-3.7
2007	1008	515	275	143	51	36	392	287	-2.5	-4	-0.4
2008	829	541	273	81	20	18	254	195	-0.2	-28	-3.4
2009	1131	545	281	155	115	27	480	309	-8.3	-13	-1.2
2010	864	528	280	75	66	4	266	178	-7.1	6	0.7
2011	676	513	259	37	43	2	172	120	13.6	-58	-8.5
2012	762	522	263	54	32	10	200	150	9.9	-15	-2.0
2013	991	524	268	128	68	23	382	270	4.6	-24	-2.4
2014	862	534	270	78	50	8	268	194	3.2	-12	-1.4
2015	627	480	247	40	16	8	153	118	25.9	-65	-10.3

Abbreviations: PREC: precipitation; ET: evapotranspiration; SW: soil water content; PERC: water entering the vadose zone from the soil profile; SURQ: surface runoff; GWQ:

groundwater contribution to streamflow; WYIELD: water yield; LATQ: lateral flow; Δ SW: the change of soil water content.

Table S8. SWAT simulated water balance for the Zaya catchment.

Year	PREC (mm)	ET (mm)	SW (mm)	PERC (mm)	SURQ (mm)	GWQ (mm)	WYIELD (mm)	LATQ (mm)	Δ S (mm)	Balance (mm)	Percentage error (%)
1985	664	543	237	26	9	0	44	29	-50.6	102.1	15.4
1986	504	514	177	24	7	0	45	23	8.8	-88.4	-17.6
1987	693	569	228	40	10	0	59	33	-41.6	67.1	9.7
1988	484	461	189	33	4	0	42	23	-2.4	-49.4	-10.2
1989	463	501	133	3	2	0	22	16	53.2	-115.8	-25.0
1990	448	395	153	1	2	0	17	14	32.8	1.8	0.4
1991	469	431	169	3	6	0	23	17	17.5	-6.4	-1.4
1992	444	418	165	10	3	0	29	22	21.6	-34.6	-7.8
1993	538	492	173	4	3	0	23	19	12.9	6.2	1.2
1994	495	506	141	7	3	0	26	20	45.4	-90.9	-18.4
1995	696	529	224	16	10	0	46	32	-38.2	143.8	20.7
1996	669	563	221	65	18	0	86	40	-34.3	-9.9	-1.5
1997	631	544	246	34	15	0	62	34	-59.5	50.1	8.0
1998	558	527	235	10	3	0	35	25	-48.8	35.3	6.3
1999	548	533	196	24	6	0	40	23	-9.9	-38.9	-7.1
2000	495	484	175	8	4	0	26	18	11.4	-34.4	-7.0
2001	540	508	170	4	4	0	25	19	16.3	-13.6	-2.5
2002	705	564	245	25	5	0	49	39	-58.6	125.6	17.8
2003	386	442	166	17	6	0	32	14	19.9	-124.3	-32.2
2004	530	484	163	21	7	0	41	24	23.2	-38.7	-7.3
2005	571	523	155	2	9	0	25	16	30.8	-9.3	-1.6
2006	617	568	156	33	9	0	56	33	30.2	-70.5	-11.4
2007	585	467	224	14	4	0	38	30	-37.9	103.9	17.8
2008	485	533	153	6	3	0	27	18	33.0	-114.0	-23.5
2009	670	528	203	41	8	0	63	39	-17.0	54.2	8.1
2010	780	617	235	56	11	0	76	44	-48.6	81.0	10.4
2011	469	532	141	27	8	0	45	21	45.7	-181.3	-38.7
2012	464	445	130	0	2	0	16	13	56.0	-51.9	-11.2
2013	629	550	169	17	7	0	44	30	17.1	-0.1	0.0
2014	683	528	252	26	6	0	49	38	-65.6	146.1	21.4
2015	430	465	176	18	4	0	39	20	9.9	-102.3	-23.8

Abbreviations: PREC: precipitation; ET: evapotranspiration; SW: soil water content; PERC: water entering the vadose zone from the soil profile; SURQ: surface runoff; GWQ: groundwater contribution to streamflow; WYIELD: water yield; LATQ: lateral flow; Δ SW: the change of soil water content.

8. ANOVA Analysis

Table S9. ANOVA analysis for identifying the impact of daily precipitation on daily N₂O emissions from spring barley.

Year	Df	Sum Sq	Mean Sq	F value	Pr(>F)
2006	1	0.08	0.08007	4.467	0.0352*
2007	1	0.000042	4.24E-02	3.511	0.0618
2008	1	2.8E-06	2.84E-03	0.394	0.53
2009	1	0.000057	5.71E-02	3.883	0.0495*
2010	1	0.000116	1.16E-01	5.087	0.0247*
2011	1	0.000204	2.04E-01	3.256	0.072
2012	1	0.000011	1.06E-02	0.289	0.591
2013	1	0.000117	1.17E-01	8.893	0.00306 **
2014	1	0	5.00E-05	0.001	0.976
2015	1	0.00006	6.38E-02	0.6	0.439

Df: the degrees of freedom for the independent variable, and the degrees of freedom for the residuals. Sum Sq: the sum of squares. Mean Sq: the mean of the sum of squares. F value: the test statistic from the F test. Pr(>F): the p-value of the F-statistic. Significant codes: 0 '****', 0.001 '***', 0.01 '**', 0.05 '.'. The absolute percentage errors of simulated water balance for the years 2006, 2009, 2010 and 2013 were <11%.

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