S. Supporting Information

S1. Methods

S1.1. Examples of mapped structures

A1 - Storm drainage inlets on or next to roads or farm tracks

Storm drainage inlets on or next to roads or farm tracks were always considered as a potential shortcut in the connectivity model.

Figure S 1: Storm drainage inlet with a gridded metal lid on a road in the study area Nürensdorf

Figure S 2: Lateral concrete storm drainage inlet next to a road in the study area Molondin

Figure S 3: Storm drainage inlet with a gridded metal lid on a road in the study area Oberneunforn

A2 - Strom drainage inlets on fields

Storm drainage inlets on fields are always considered as a potential shortcut in the connectivity model.

Figure S 4: Storm drainage inlet with a metal grid lid in a field of the study area Meyrin

Figure S 5: Storm drainage inlet with a concrete grid lid in a field of the study area Nürensdorf

B1 – Maintenance manholes on or next to roads

Maintenance manholes on or next to roads are considered a potential shortcut if they are located in an internal sink (only for shortcut definition B).

Figure S 6: Maintenance manhole with a metal lid with a pick hole next to a road in the study area Buchs

Figure S 7: Maintenance manhole with a concrete lid with a pick hole on a road in the study area Courroux

B2 – Maintenance manholes on fields

Maintenance manholes on fields are considered a potential shortcut if they are located in an internal sink (only for shortcut definition B).

Figure S 8: Damaged tile drainage maintenance manhole in a field in the study area Vufflens-la-Ville

Figure S 9: Tile drainage maintenance manhole in a field in the study area Molondin

C1 – Channel drains

Figure S 10: Channel drain on a road in the study area Clarmont

Figure S 11: Channel drain and inlet with a metal grid lid on a road in the study area Lommiswil

C2 – Ditches

Figure S 12: Ditch between a field and a road in the study area Meyrin

S1.2. List of mapped structures

Table S 1: Types of mapped point features

ID	Description	Potential shortcut
1	Inlet	Yes
2	Maintenance manhole	If lying in an internal sink (shortcut definition B)
3	Other manhole	If lying in an internal sink (shortcut definition B)
4	Stormwater tank	If lying in an internal sink (shortcut definition B)
5	Spillway	If lying in an internal sink (shortcut definition B)

6	Pumping station	No
7	House connection	No
8	Other point object	No
9	Unknown manhole	If lying in an internal sink (shortcut definition B)
10	Outfall	No
11	Infiltration structure	If lying in an internal sink (shortcut definition B)
12	Unknown object	No

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989 **Table S 2: Types of lids**

ID	Description
1	Metal grid
2	Concrete lid with pick hole
3	Concrete lid without pick hole
4	Metal lid with pick hole
5	Metal lid without pick hole
6	Other lid type
7	Concrete grid
8	Concrete lid with lateral inlet
9	Metal lid with lateral inlet
0	Unknown lid type

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991 **Table S 3: Types of line features mapped**

ID	Description	Potential shortcut
1	Drainage pipe	No
2	Tile drainage pipe	No
3	Other pipe	No
4	Channel drain	Yes
5	Ditch	Yes
6	Sequence of channel drains & ditches	Yes
7	Stone wall	No
8	Earth wall	No
9	Hedge	No
10	River	No
11	Other line objects	No
12	Unknown line objects	No

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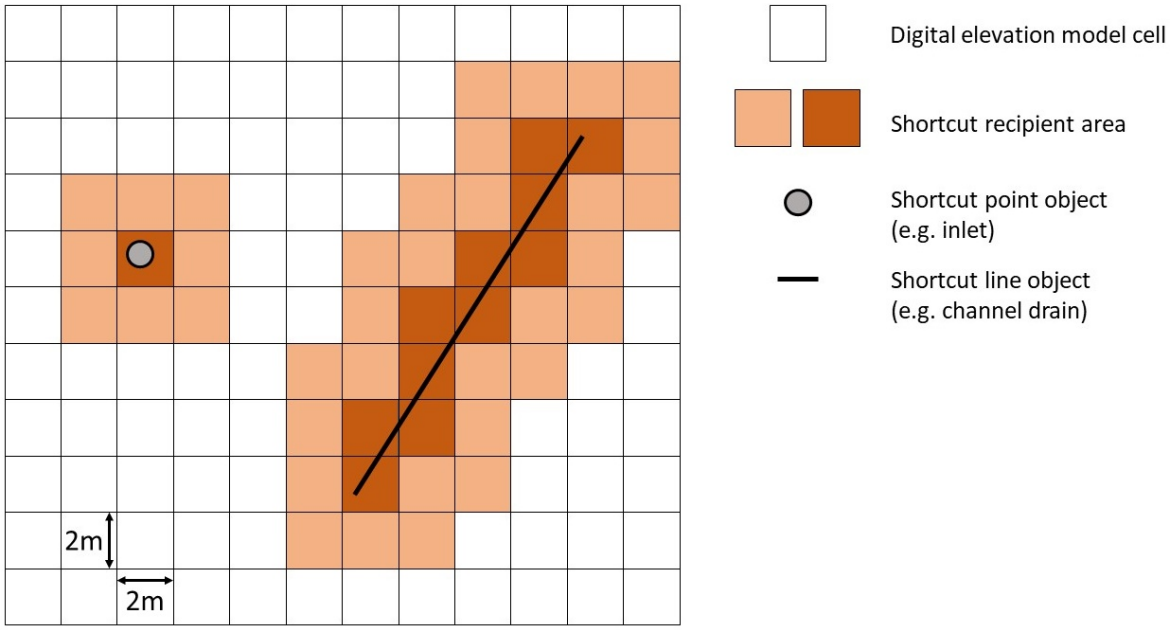


Figure S 13: Definition of shortcut recipient areas

S1.3. Dates of field mapping and drone flights

Table S 4: Dates of field mapping and drone flights for each study area. In some areas a second drone flight had to be performed to ensure sufficient image quality.

ID	Location	Date field mapping	Date drone flights
1	Böttstein	26.10.2017	26.10.2017
2	Ueken	25.10.2017	25.10.2017
3	Rüti b. R.	23.11.2017	23.11.2017
4	Romont	02.11.2017	03.11.2017
5	Meyrin	27.11.2017	Usage of cantonal aerial images only
6	Boncourt	24.11.2017	24.11.2017; 07.06.2018
7	Courroux	17.11.2017	17.11.2017
8	Hochdorf	29.09.2017	27.04.2018
9	Müswangen	21.09.2017	16.08.2018
10	Fleurier	24.05.2018	24.05.2018
11	Lommiswil	16.11.2017	16.11.2017
12	Illighausen	30.08.2017	07.12.2017
13	Oberneunforn	06.09.2017	01.11.2017; 19.04.2018
14	Clarmont	09.11.2017	10.11.2017; 04.12.2017
15	Molondin	02.11.2017	03.11.2017
16	Suchy	10.11.2017	08.11.2017
17	Vufflens	09.11.2017	08.11.2017; 24.08.2018
18	Buchs	23.08.2017	09.08.2017; 17.08.2017
19	Nürensdorf	18.09.2017	24.10.2017
20	Truttikon	20.09.2017	01.11.2017

S1.4. Catchment statistics

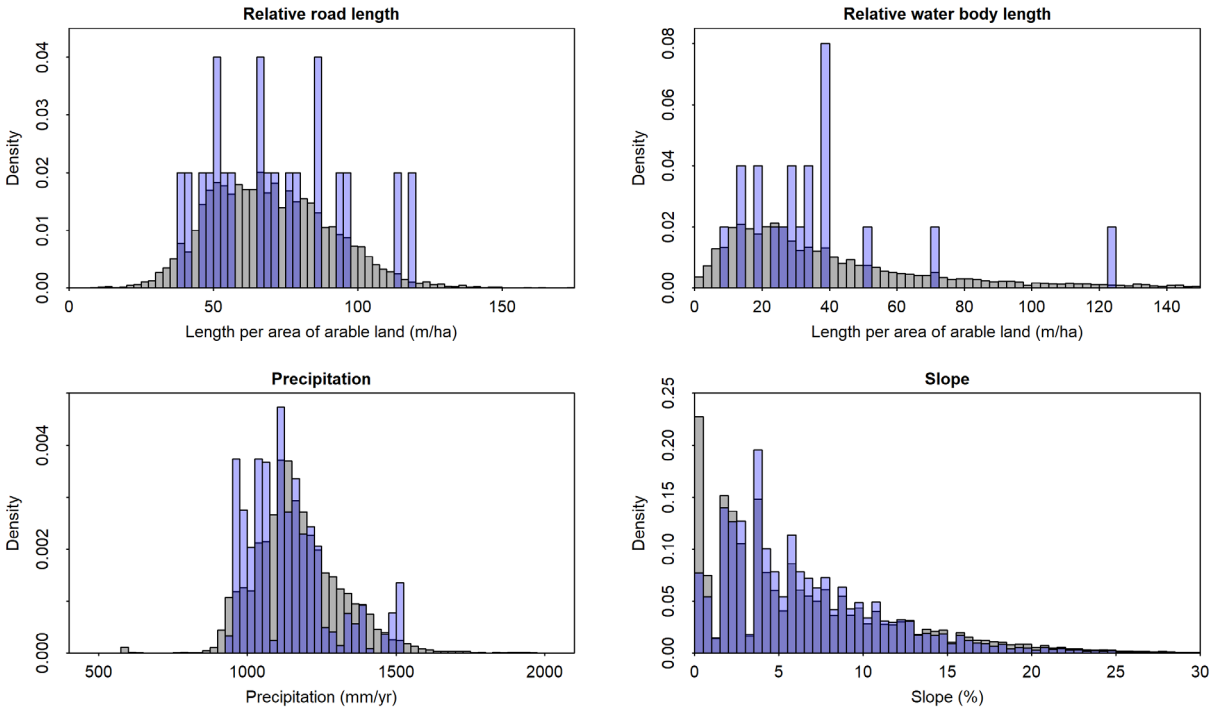


Figure S 14: Histogram of catchment statistics for study areas (blue) and all catchments in Switzerland containing arable land (grey). Catchment statistics were calculated only for catchment parts defined as arable land areas by the dataset BFS (2014). Relative road length (road length per arable land area) and relative water body length (water body length per arable land area) were derived from the dataset swissTLM3D (Swisstopo 2010). Precipitation was derived from Kirchhofer and Sevruk (1992), and slope from Swisstopo (2018).

Table S 5: Datasets used for calculating catchment statistics

Catchment statistic	Data source	Dataset used
Fraction of forests	swissTLM3D (Swisstopo 2010): TLM_BODENBEDECKUNG	OBJEKTART in [12,13]
Fraction of agricultural area	swissTLM3D (Swisstopo 2010): ○ TLM_BODENBEDECKUNG, ○ TLM_STRASSEN, ○ TLM_SIEDLUNGSNAME, ○ TLM_NUTZUNGSAREAL	(Total area) - (forests, water bodies, urban areas, traffic areas, and other non-agricultural areas)
Road density (total; paved; unpaved)	swissTLM3D (Swisstopo 2010): TLM_STRASSEN	BELAGSART in [100,200]; BELAGSART = 100; BELAGSART = 200
Water body density (total; rivers; lakeshores)	swissTLM3D (Swisstopo 2010): ○ TLM_FLIESSGEWAESSER ○ TLM_STEHENDES_GEWAESSER	Both datasets; TLM_FLIESSGEWAESSER only; TLM_STEHENDES_GEWAESSER only
Mean annual precipitation	Kirchhofer and Sevruk (1992)	Mean annual precipitation depths 1951-1980
Mean slope of agricultural areas	swissALTI3D (Swisstopo 2018)	Slopes as calculated by swisstopo, agricultural areas as defined above
Area fractions (direct; indirect; not connected)	Alder et al. (2015)	Fraction of total directly connected area; fraction of total indirectly connected area; fraction of total not connected area

S1.5. Extrapolation to the national scale

In the following, mathematical details on the extrapolation of the local surface runoff connectivity model (LSCM) to the national scale are given. A schematic overview is given in the main part of this publication. Our model is using the area fractions of the national erosion connectivity model (NECM) to extrapolate the LSCM to the national scale, resulting in area fractions of a national surface runoff connectivity model (NSCM).

We defined the area fractions of model *m* and catchment *c* as follows:

$$\boldsymbol{f_m} = \begin{pmatrix} \overrightarrow{f_{m,dir}}^T \\ \overrightarrow{f_{m,indir}}^T \\ \overrightarrow{f_{m,nc}}^T \end{pmatrix} = \begin{pmatrix} f_{m,dir,1} & \cdots & f_{m,dir,c} & \cdots & f_{m,dir,n} \\ f_{m,indir,1} & \cdots & f_{m,indir,c} & \cdots & f_{m,indir,n} \\ f_{m,nc,1} & \cdots & f_{m,nc,c} & \cdots & f_{m,nc,n} \end{pmatrix} = \begin{pmatrix} \frac{A_{m,dir,1}}{A_{tot,1}} & \cdots & \frac{A_{m,dir,c}}{A_{tot,c}} & \cdots & \frac{A_{m,dir,n}}{A_{tot,n}} \\ \frac{A_{m,indir,1}}{A_{tot,1}} & \cdots & \frac{A_{m,indir,c}}{A_{tot,c}} & \cdots & \frac{A_{m,indir,n}}{A_{tot,n}} \\ \frac{A_{m,nc,1}}{A_{tot,1}} & \cdots & \frac{A_{m,nc,c}}{A_{tot,c}} & \cdots & \frac{A_{m,nc,n}}{A_{tot,n}} \end{pmatrix} \quad (1)$$

with:

m: Model (either LSCM, NECM, or NSCM)

$A_{m,dir,c}$: Directly connected agricultural area of model m in catchment c (ha)

$A_{m,indir,c}$: Indirectly connected agricultural area of model m in catchment c (ha)

$A_{m,nc,c}$: Not connected agricultural area of model m in catchment c (ha)

$A_{tot,c}$: Total agricultural area in catchment c (ha)

$f_{m,dir,c}$: Fraction of directly connected agricultural areas of model m in catchment *c* (-)

$f_{m,indir,c}$: Fraction of indirectly connected agricultural areas of model m in catchment *c* (-)

$f_{m,nc,c}$: Fraction of not connected agricultural areas of model m in catchment *c* (-)

The area fraction matrices $\boldsymbol{f_m}$ underlie two boundary conditions (see main part). To ensure that extrapolation model meets these boundary conditions, we used a unit simplex transformation approach.

We performed a unit simplex inverse transformation to the area fraction matrices of the LSCM $\boldsymbol{f}_{LSCM}$ and the NECM $\boldsymbol{f}_{NECM}$ (3x20 matrices), resulting in the matrices $\boldsymbol{z}_{LSCM}$ and $\boldsymbol{z}_{NECM}$ (2x20 matrices).

$$\boldsymbol{z} = \begin{pmatrix} \overrightarrow{z_1}^T \\ \overrightarrow{z_2}^T \end{pmatrix} = \begin{cases} logit^{-1}\left(\overrightarrow{f_k}^T + log\left(\frac{1}{K-k}\right)\right) & | \, k = 1 \\ \left(1 - \sum_{k=1}^{k-1} \overrightarrow{z_k}^T\right) \cdot logit^{-1}\left(\overrightarrow{f_k}^T + log\left(\frac{1}{K-k}\right)\right) = \left(1 - \overrightarrow{z_1}^T\right) \cdot logit^{-1}\left(\overrightarrow{f_k}^T\right) & | \, k = 2 \\ with: K = 3 \end{cases} \quad (2)$$

In order to model the difference $\Delta \boldsymbol{z}$ (2x20 matrix) between the transformed LSCM and the transformed NECM ($\Delta \boldsymbol{z} = \boldsymbol{z}_{LSCM} - \boldsymbol{z}_{NECM}$), we tested the same list of nationally available catchment statistics that was already used before. For each of the two dimensions, we selected the variable that correlated best with $\Delta \boldsymbol{z}$. Those were the fraction of directly connected areas $f_{NECM,dir}$, and the fraction of indirectly connected areas $f_{NECM,indir}$. Using these variables, we performed the following linear regression to describe $\Delta \boldsymbol{z}$:

$$\Delta \boldsymbol{z} = \vec{a} + \vec{b} \cdot \begin{pmatrix} \overrightarrow{f_{NECM,dir}}^{T} \\ \overrightarrow{f_{NECM,indir}}^{T} \end{pmatrix} + \vec{\varepsilon} \tag{3}$$

For each of the catchments of the transformed national erosion connectivity model ($\boldsymbol{z}_{NECM}$, 2xn matrix, n = 11'503), this linear regression was used to calculate the transformed national surface runoff connectivity model ($\boldsymbol{z}_{NSCM}$, 2xn matrix):

$$\boldsymbol{z}_{NSCM} = \mathbf{z}_{NECM} + \Delta \boldsymbol{z} \tag{4}$$

Finally, using a unit simplex transformation, we transformed $\boldsymbol{z}_{NSCM}$ back, resulting in the area fraction matrix of the national surface runoff connectivity model $\boldsymbol{f}_{NSCM}$ (3xn matrix).

$$\boldsymbol{f}_{NSCM} = \begin{cases} \boldsymbol{f}_{NSCM,k} = logit\left(\boldsymbol{z}_{NSCM,k}\right) - log\left(\frac{1}{K-k}\right) & | \, \mathrm{k} = 1 \\ \boldsymbol{f}_{NSCM,k} = logit\left(\frac{\boldsymbol{z}_{NSCM,k}}{1-\sum_{k=1}^{k-1} \boldsymbol{z}_{NSCM,k}}\right) - log\left(\frac{1}{K-k}\right) & | \, \mathrm{k} > 1 \end{cases} \quad with\ K = 3 \tag{5}$$

This extrapolation model was run for each of the 100 area fractions matrices resulting from the Monte Carlo analysis that was performed on the local scale.

S2. Results

S2.1. Occurrence of hydraulic shortcuts

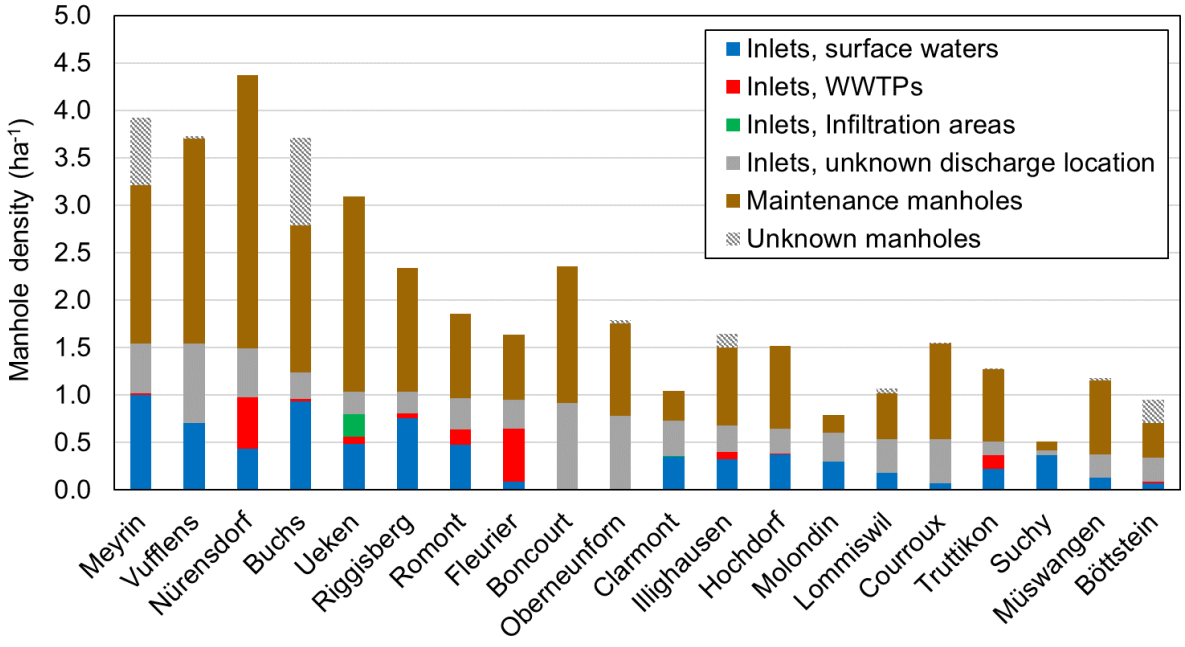


Figure S 15: Density of manholes (ha^{-1}) on agricultural areas of the study catchments

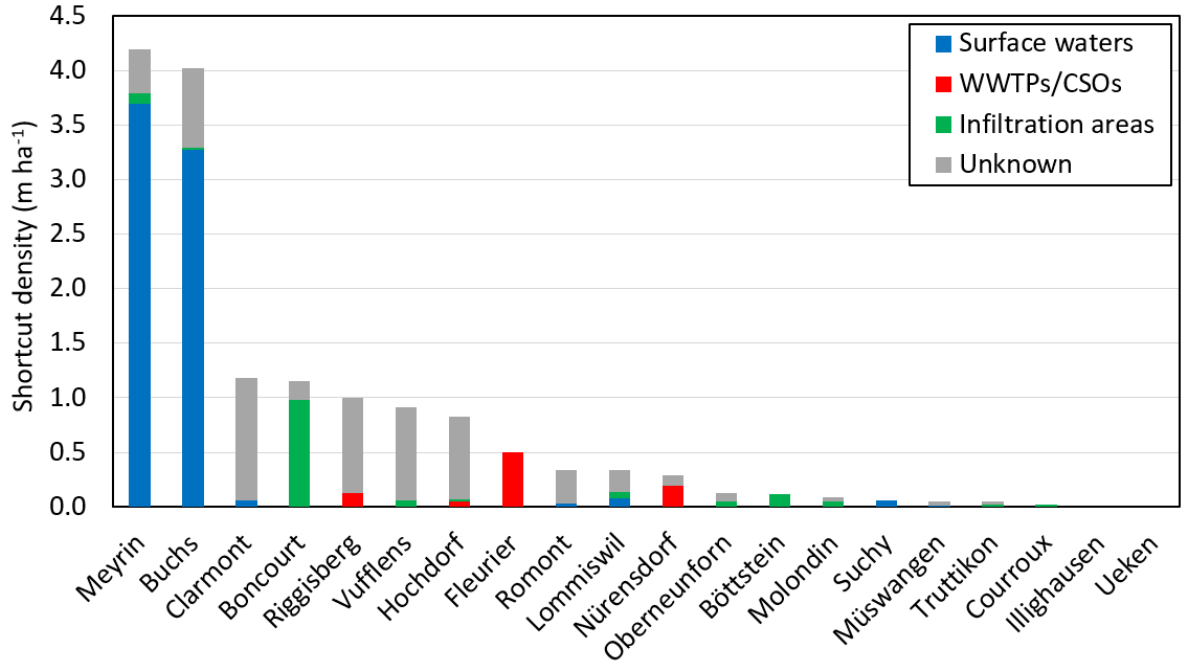


Figure S 16: Density of channel drains and ditches (m ha^{-1}) on agricultural areas of the study catchments

Table S 6: Linear regression of different catchment statistics with inlet densities (ha^{-1}) per study area. R^2 equals the coefficient of determination, m is the slope of the linear regression, and p is the p-value.

Catchment statistic	R^2	m	p
Paved road density (m^{-1})	3.3E-01	5.7E+01	8.4E-03**
Unpaved road density (m^{-1})	6.3E-02	-1.5E+01	2.8E-01
Mean annual precipitation (mm yr^{-1})	4.9E-04	-5.1E-05	9.3E-01
Mean slope on agricultural areas (deg)	8.3E-04	-4.7E-03	9.0E-01
Surface water body density (m^{-1})	4.4E-02	-4.3E-05	3.7E-01
Subsurface water body density (m^{-1})	6.2E-02	5.1E+02	2.9E-01

Table S 7: Linear regression of different catchment statistics with maintenance manhole densities (ha^{-1}) per study area. R^2 equals the coefficient of determination, m is the slope of the linear regression, and p is the p-value.

Catchment statistic	R^2	m	p
Paved road density (m^{-1})	3.7E-01	1.8E+02	4.6E-03**
Unpaved road density (m^{-1})	3.1E-02	-3.2E+01	4.6E-01
Mean annual precipitation (mm yr^{-1})	4.2E-03	-4.5E-04	7.9E-01
Mean slope on agricultural areas (deg)	1.6E-02	-6.2E-02	6.0E-01
Surface water body density (m^{-1})	3.5E-02	-1.2E-04	4.3E-01
Subsurface water body density (m^{-1})	1.2E-01	2.2E+03	1.3E-01

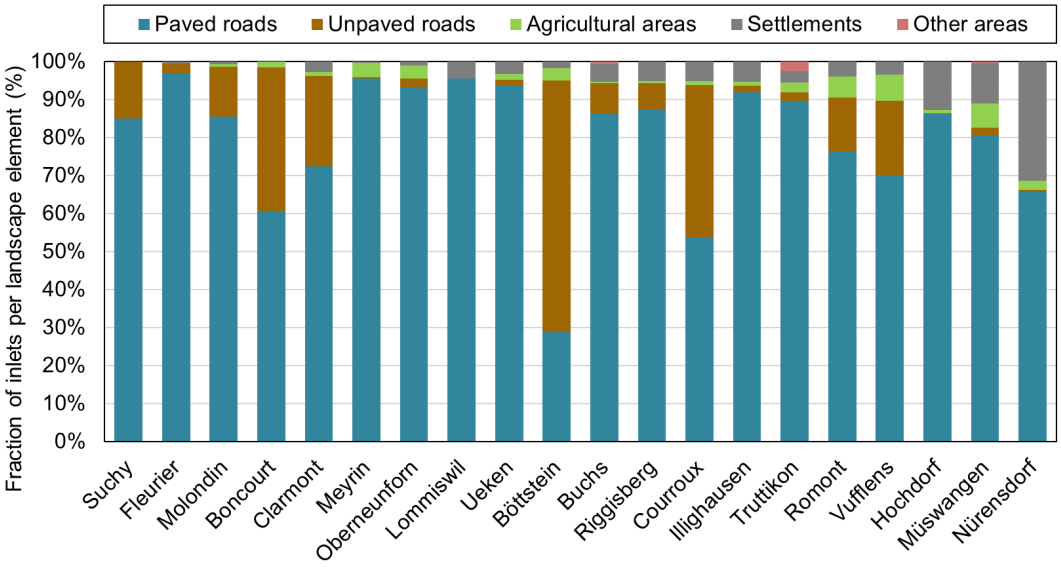


Figure S 17: Fraction of inlets per study area belonging to a certain landscape element

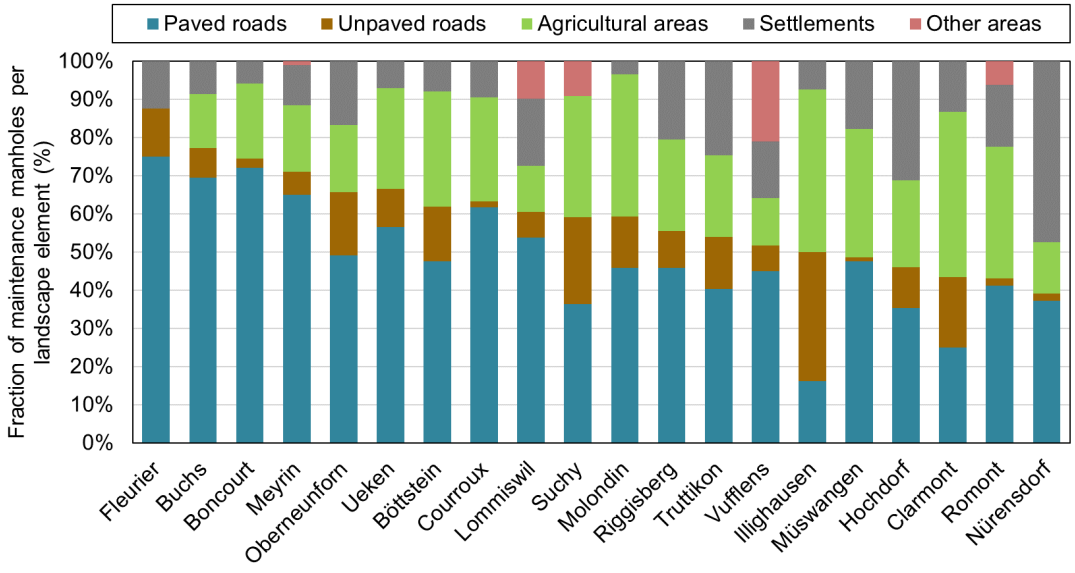
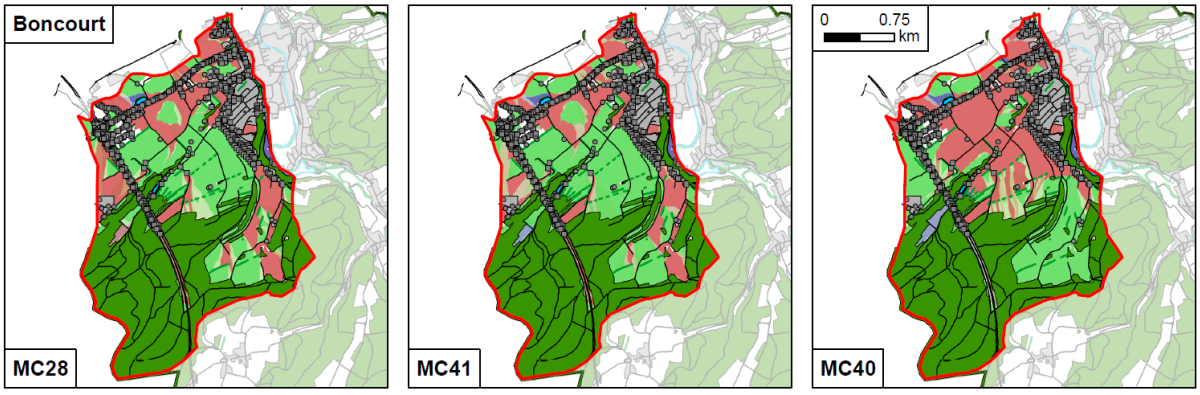


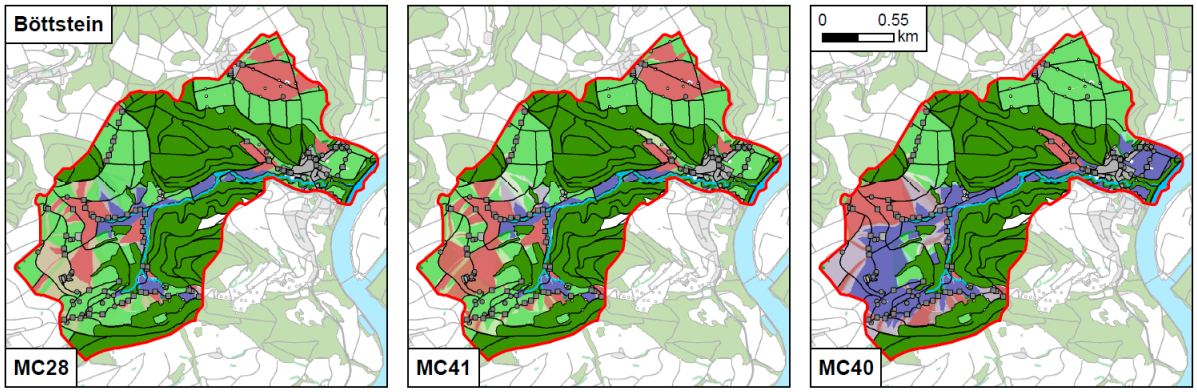
Figure S 18: Fraction of maintenance manholes per study area belonging to a certain landscape element

S2.2. Surface runoff connectivity: Study areas

S2.2.1. Example results for each study area

In the following, three example Monte Carlo analysis results (MC28, MC41, and MC40) are given for each of the study areas. The figures below correspond to Figure 5 in the main part.





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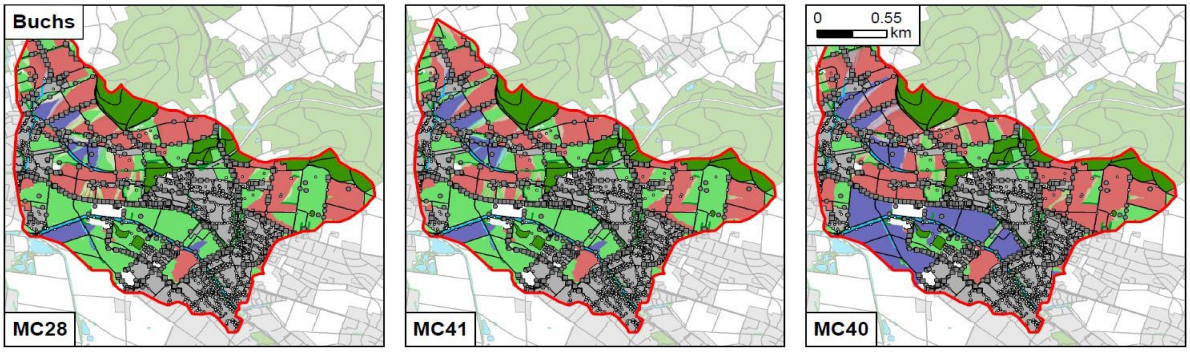

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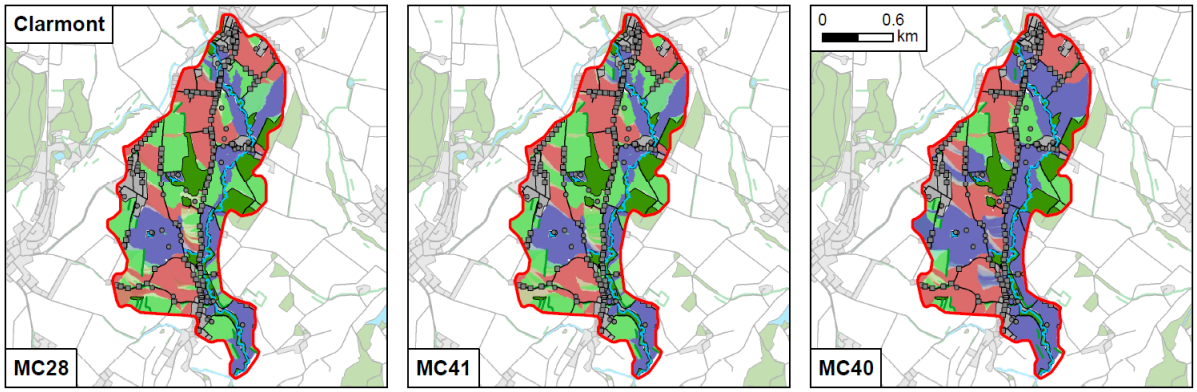

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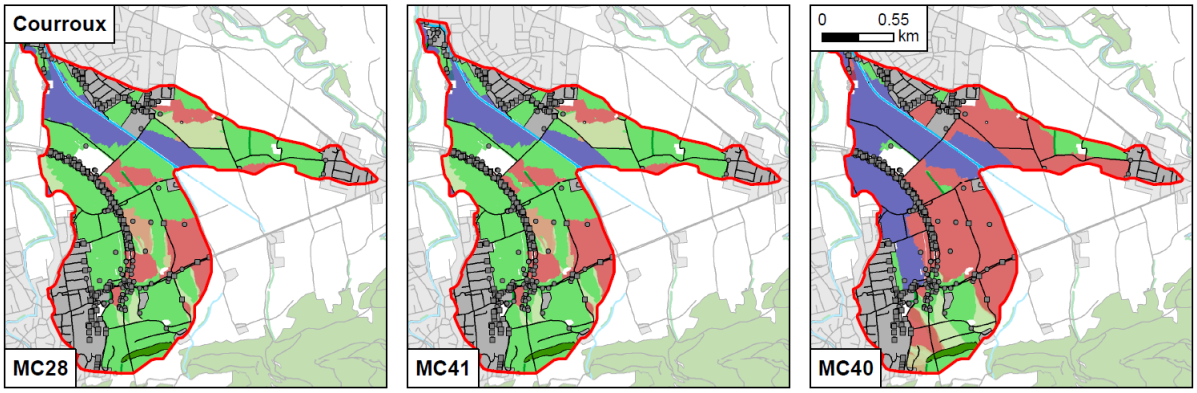

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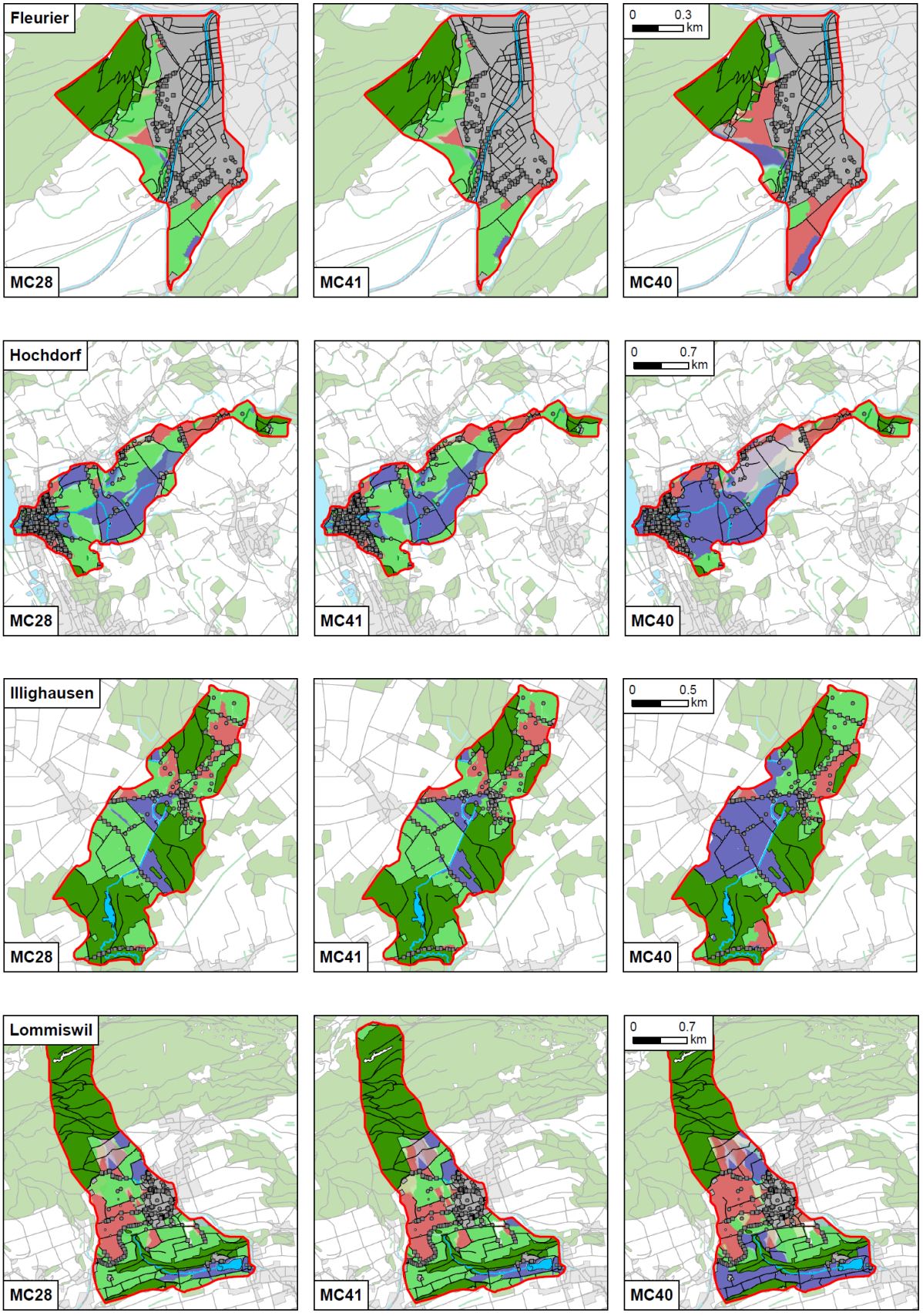

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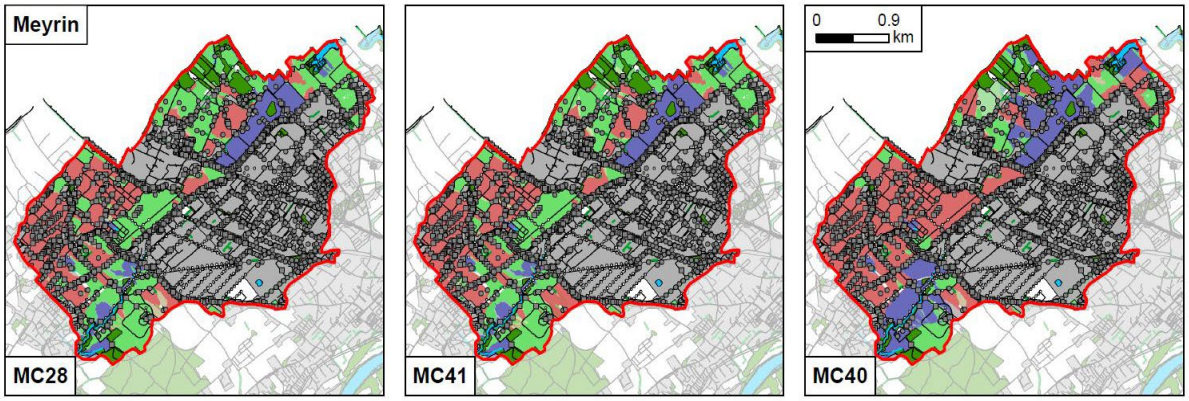

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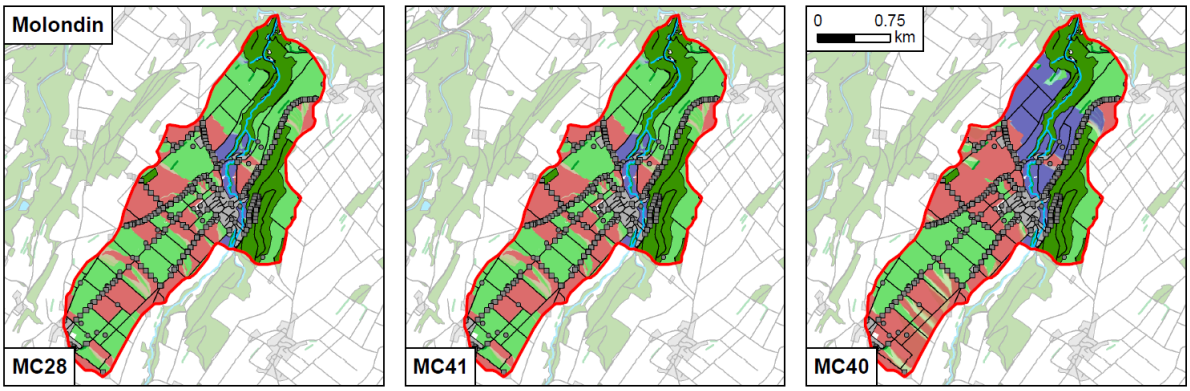

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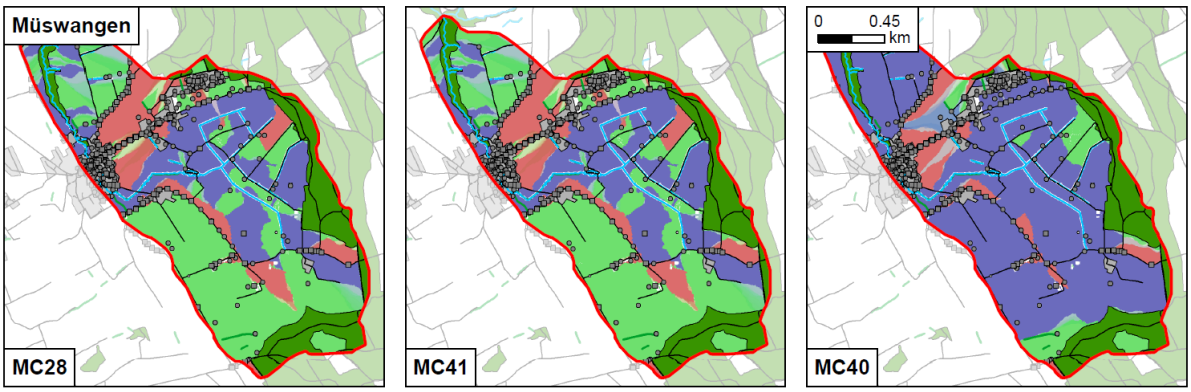

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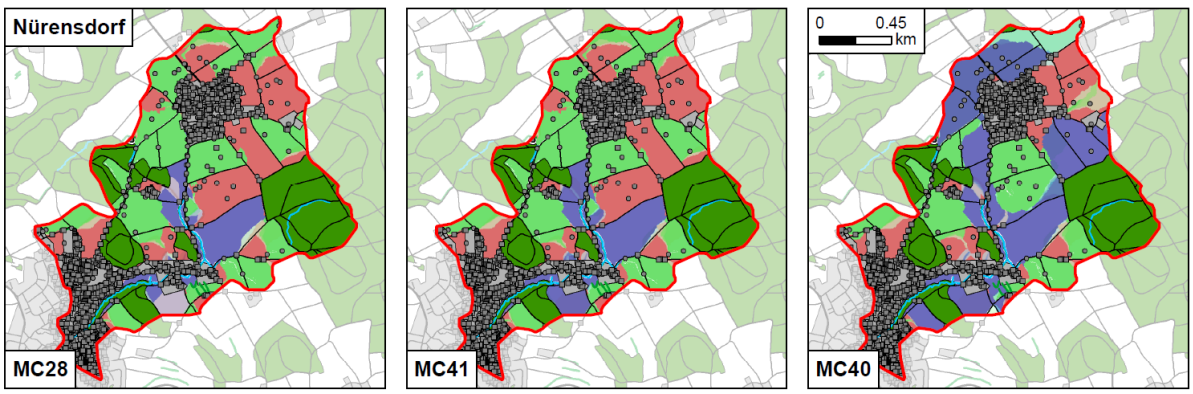

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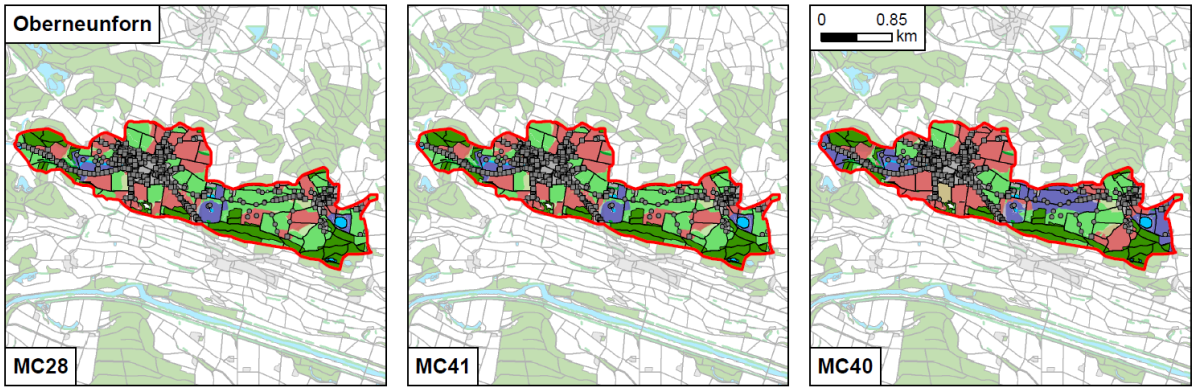

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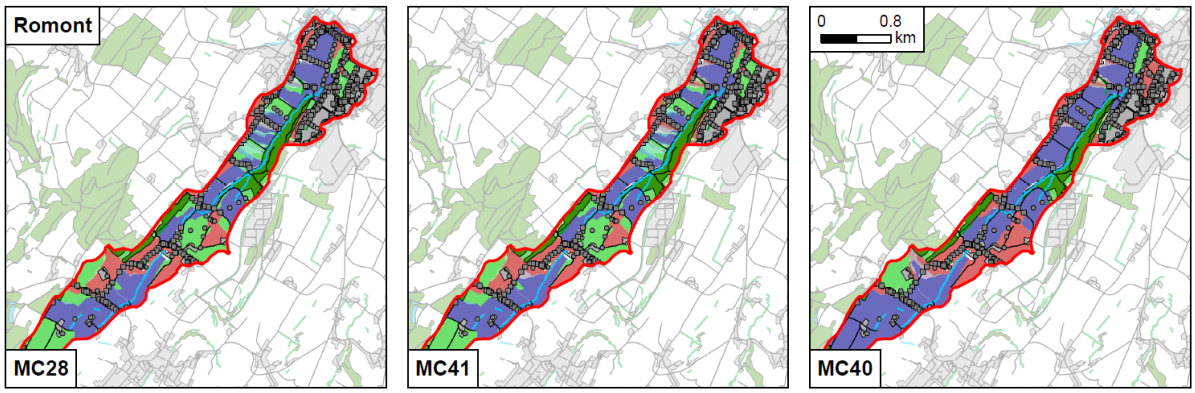

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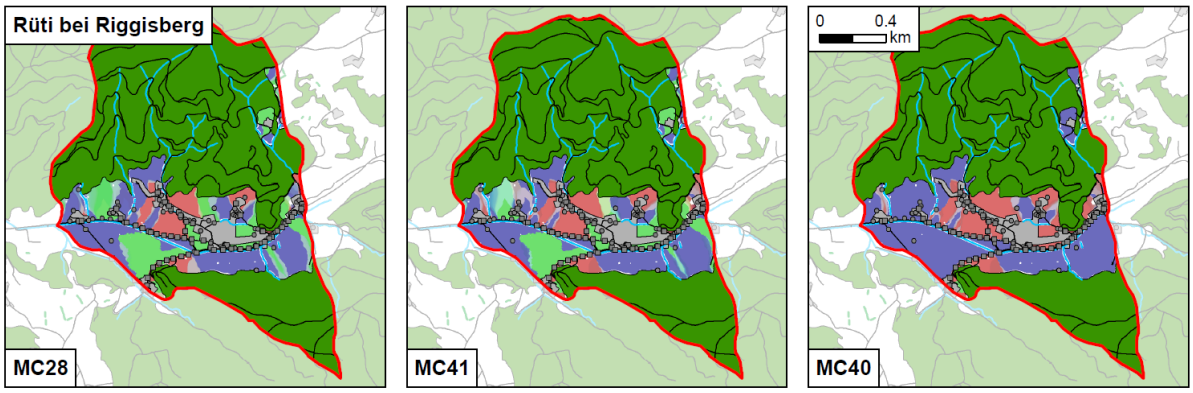

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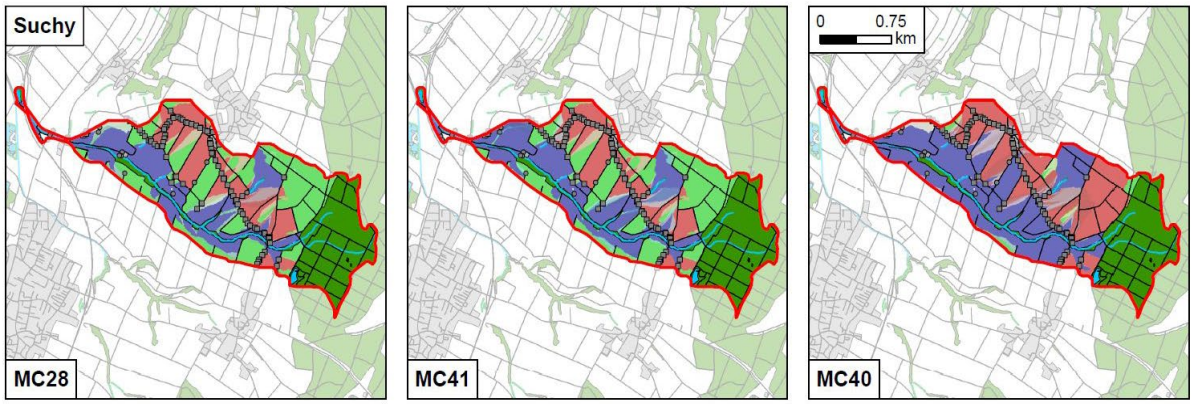

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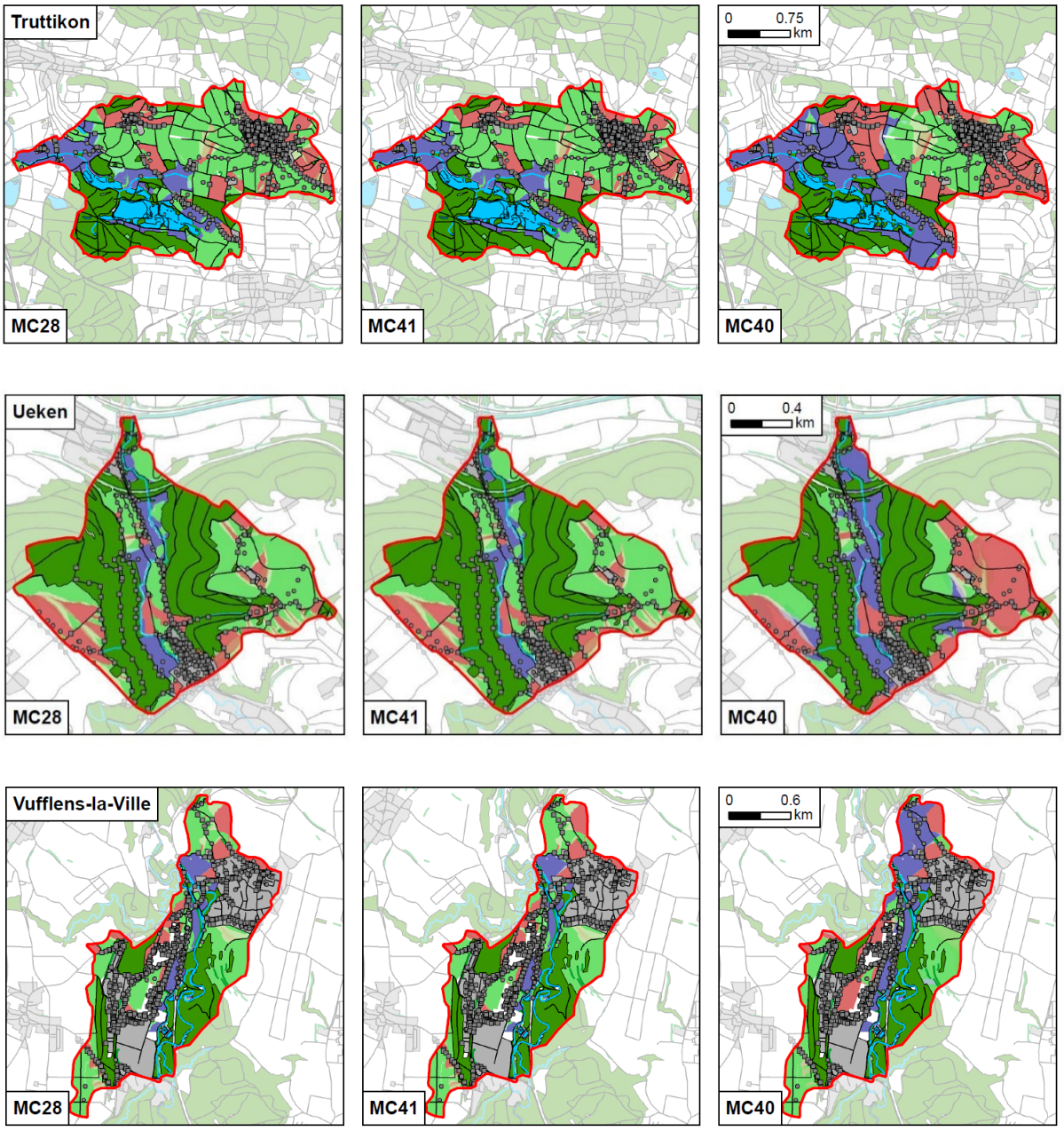

Truttikon
MC28
MC41
0 0.75 km
MC40
Ueken
MC28
MC41
0 0.4 km
MC40
Vufflens-la-Ville
MC28
MC41
0 0.6 km
MC40

S2.2.2. Monte Carlo Results: Directly, indirectly, and not connected areas

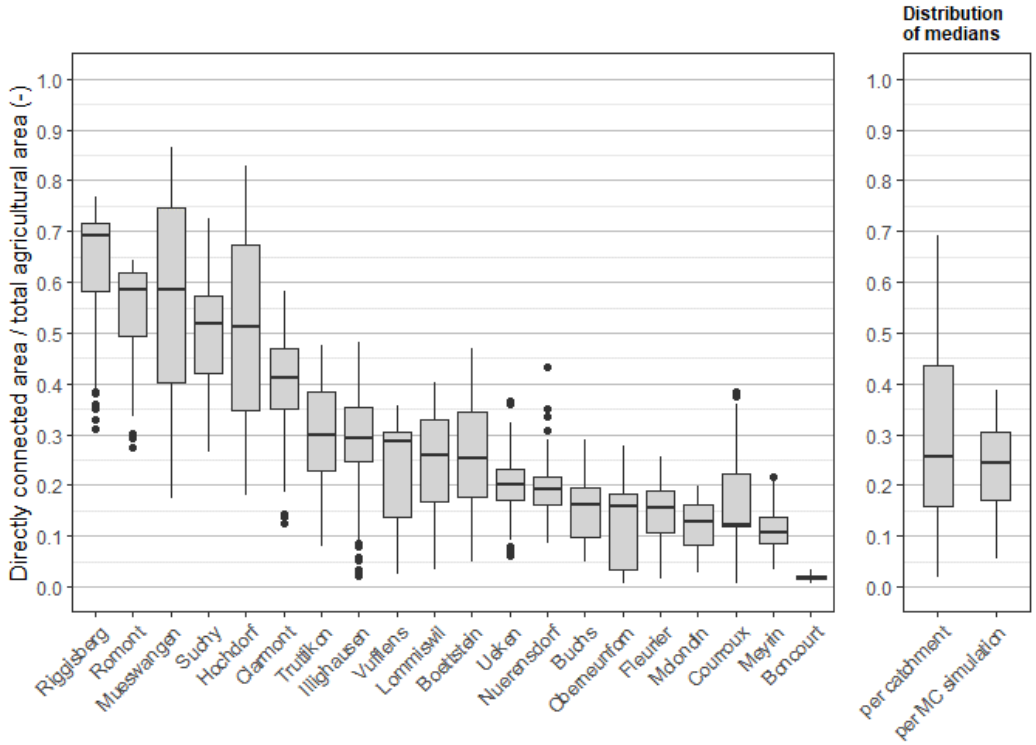


Figure S 19: Left: Directly connected area per total agricultural area (-) as calculated by the Monte Carlo analysis for each study area. Right: Distribution of medians of directly connected area per total agricultural area (-) per study area and per Monte Carlo simulation.

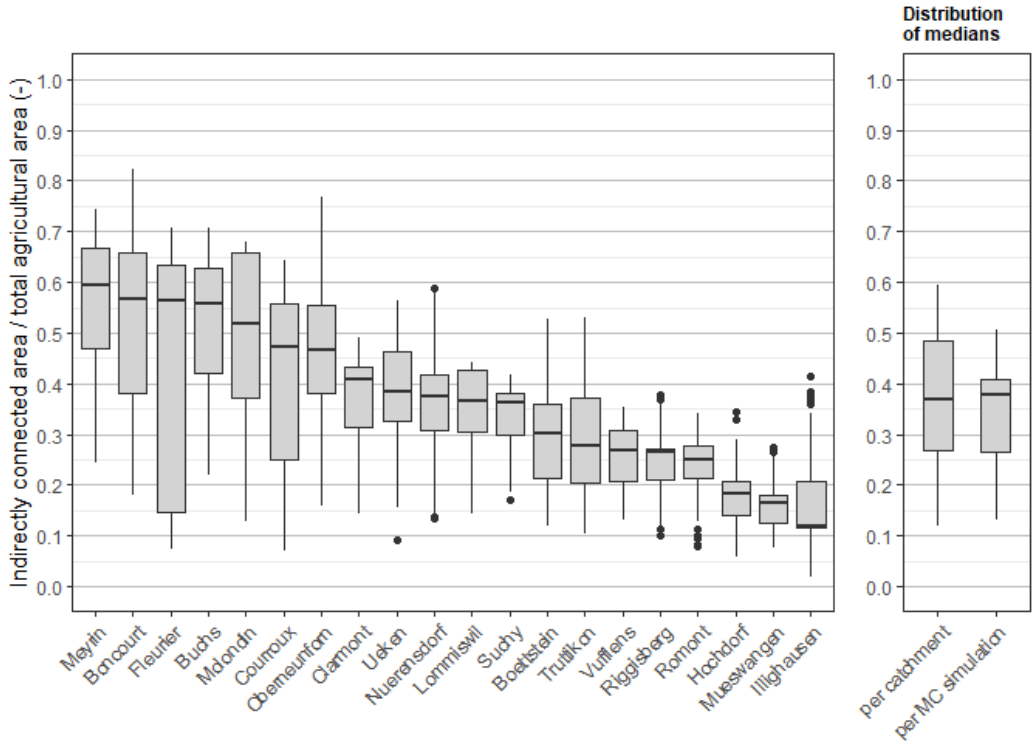


Figure S 20: Indirectly connected area per total agricultural area (-) as calculated by the Monte Carlo analysis for each study area. Right: Distribution of medians of indirectly connected area per total agricultural area (-) per study area and per Monte Carlo simulation.

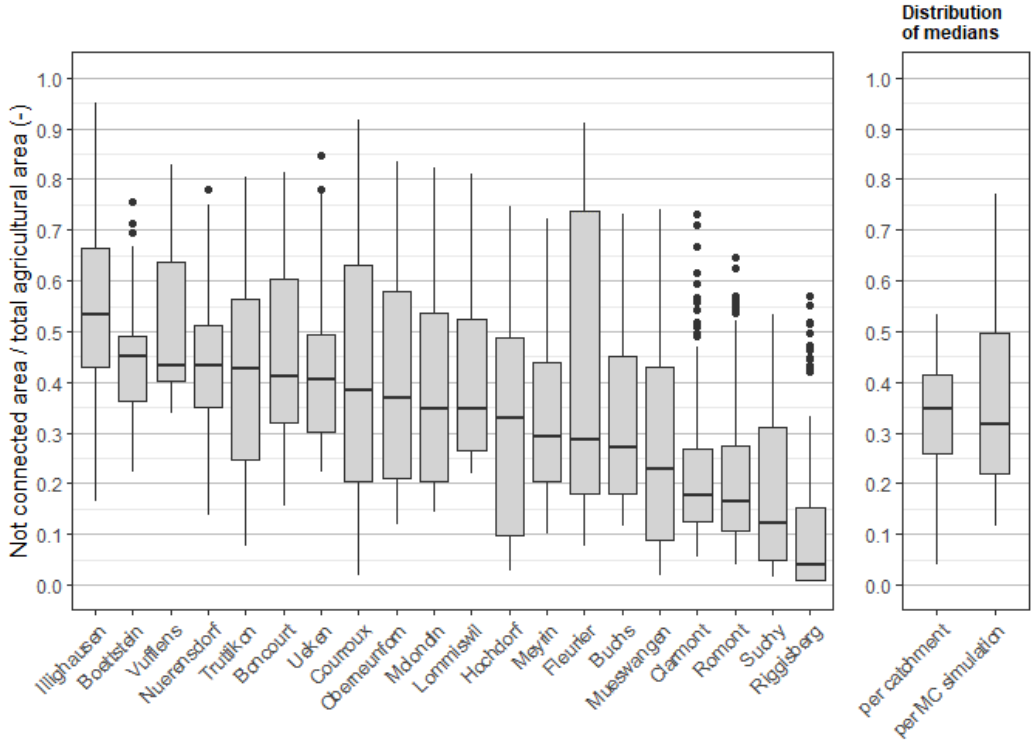


Figure S 21: Not connected area per total agricultural area (-) as calculated by the Monte Carlo analysis for each study area. Right: Distribution of medians of not connected area per total agricultural area (-) per study area and per Monte Carlo simulation.

S2.2.3. Correlation of connectivity fractions with catchment statistics

Table S 8: Correlation of catchment statistics with fractions of connected area connectivity. For each of the four columns, a different area fraction of the national connectivity model (first row) was used. Those were directly connected agricultural area area per total agricultural area $f_{NECM,dir}$, indirectly connected agricultural area per total connected agricultural area $f_{NECM,indir}$, not connected agricultural area per total agricultural area $f_{NECM,nc}$, and indirectly connected agricultural area per total connected agricultural area $f_{NECM,fracindir}$.

	Fraction directly connected $f_{LSCM,dir}$ (-)			Fraction indirectly connected $f_{LSCM,indir}$ (-)			Fraction not connected $f_{LSCM,nc}$ (-)			Fraction indirectly connected to total connected $f_{LSCM,fracindir}$ (-)		
Variable	**R^2**	**Slope**	**P**	**R^2**	**Slope**	**P**	**R^2**	**Slope**	**P**	**R^2**	**Slope**	**p**
Area fractions of national erosion connectivity model ($f_{NECM,dir}$, $f_{NECM,indir}$, $f_{NECM,nc}$, $f_{NECM,fracindir}$) (-)	0.71	1.0E+00	**< 0.001** ***	0.52	6.0E-01	**< 0.001** ***	0.26	4.0E-01	**0.022** *	0.60	7.4E-01	**< 0.001** ***
Surface water body density (m^{-1})	0.51	2.2E+02	**< 0.001** ***	0.35	-1.4E+02	**0.006** **	0.14	-7.6E+01	**0.10** *	0.51	-2.5E+02	**< 0.001** ***
Paved road density (m^{-1})	0.20	-2.2E+01	**0.049** *	0.19	1.7E+01	0.053 -	0.04	6.5E+00	0.41 -	0.21	2.7E+01	**0.040** *
Inlet density (ha^{-1})	0.07	-1.3E-01	0.28 -	0.10	1.2E-01	0.17 -	0.00	1.0E-02	0.90 -	0.11	1.9E-01	0.15 -
Manhole density (ha^{-1})	0.15	4.0E+02	0.09 -	0.07	-2.0E+02	0.27 -	0.07	-1.8E+02	0.27 -	0.08	-3.4E+02	0.23 -
Yearly rainfall (mm/year)	0.10	-5.2E-02	0.17 -	0.06	3.2E-02	0.28 -	0.04	2.0E-02	0.43 -	0.11	6.4E-02	0.15 -
Total road density (m^{-1})	0.05	2.6E-01	0.35 -	0.05	-2.0E-01	0.33 -	0.00	-4.5E-02	0.80 -	0.07	-3.5E-01	0.26 -
Subsurface waterbody density (m^{-1})	0.11	-7.5E+00	0.14 -	0.04	3.3E+00	0.40 -	0.10	4.5E+00	0.18 -	0.08	7.3E+00	0.22 -
Fraction of agricultural area (-)	0.00	2.6E+01	0.94 -	0.03	-1.7E+02	0.48 -	0.03	1.7E+02	0.43 -	0.00	-1.0E+02	0.78 -
Unpaved road density (m^{-1})	0.15	4.4E-04	0.09 -	0.02	-1.2E-04	0.55 -	0.18	-3.2E-04	0.063 -	0.10	-4.3E-04	0.17 -
Lake shore density (m^{-1})	0.03	1.3E-02	0.49 -	0.02	7.7E-03	0.60 -	0.13	-1.9E-02	0.13 -	0.00	5.5E-04	0.98 -
Slope on agricultural areas (°)	0.04	-5.8E+00	0.41 -	0.00	2.2E-01	0.97 -	0.09	6.0E+00	0.19 -	0.01	4.1E+00	0.61 -

S2.2.4. Sensitivity analysis

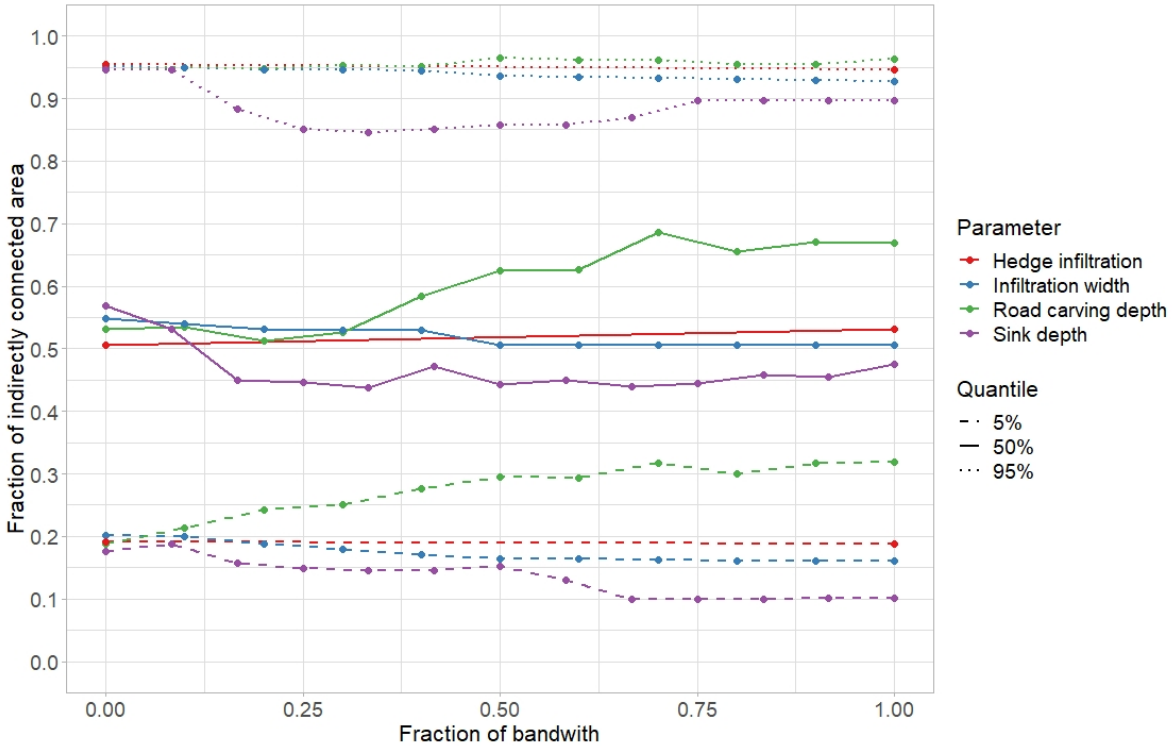


Figure S 22: Sensitivity analysis for shortcut definition A. The y-axis shows the fraction of indirectly connected area per total connected area. The parameters were varied within the following bandwidths. Hedge infiltration [no; yes], infiltration width [6 m; 100 m], road carving depth [0 cm; 100 cm], sink depth [0 cm; 100 cm]

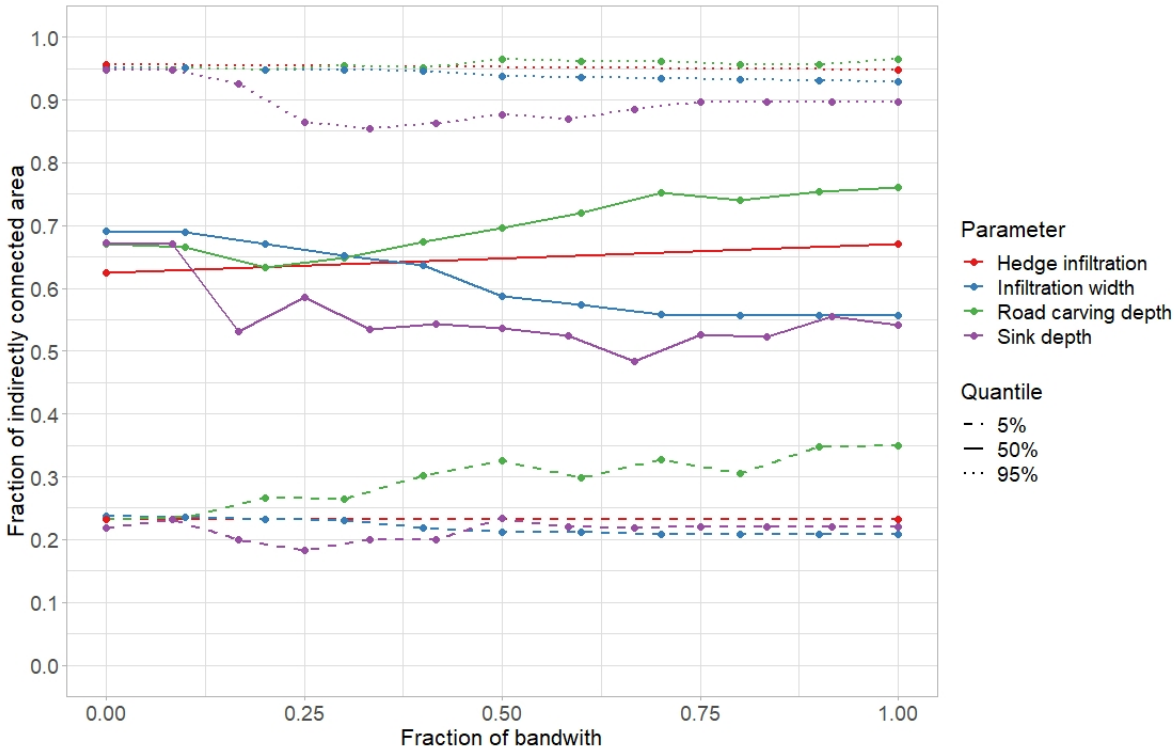
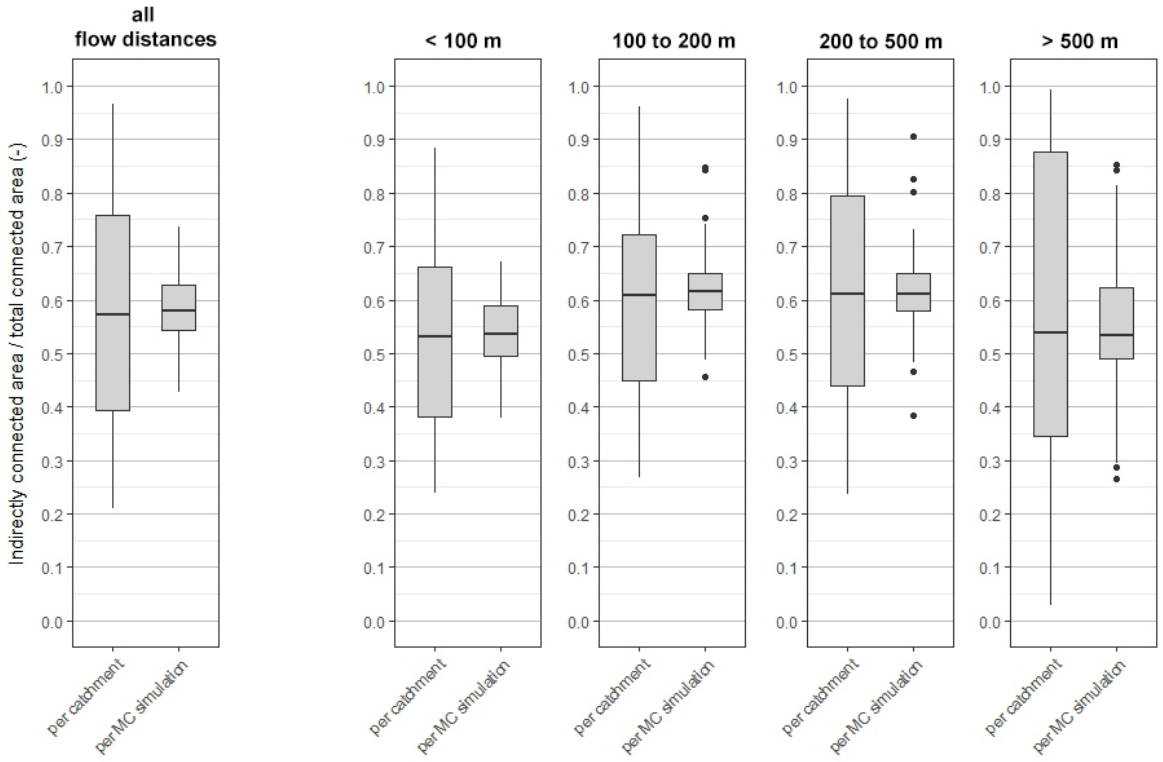


Figure S 23: Sensitivity analysis for shortcut definition B. The y-axis shows the fraction of indirectly connected area per total connected area. The parameters were varied within the following bandwidths. Hedge infiltration [no; yes], infiltration width [6 m; 100 m], road carving depth [0 cm; 100 cm], sink depth [0 cm; 100 cm]



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1133 **Figure S 24: Influence of flow distance on Monte Carlo results. Distribution of medians of indirectly connected area**
1134 **per total connected area (-) per study area and per Monte Carlo simulation for different flow distances. Left:**
1135 **Consideration of all flow distances. Right: Consideration of flow distances of smaller than 100 m, 100 to 200 m, 200 to**
1136 **500 m, and larger than 500 m, respectively.**

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1138

S2.2.5. Distribution of slope and wetness index

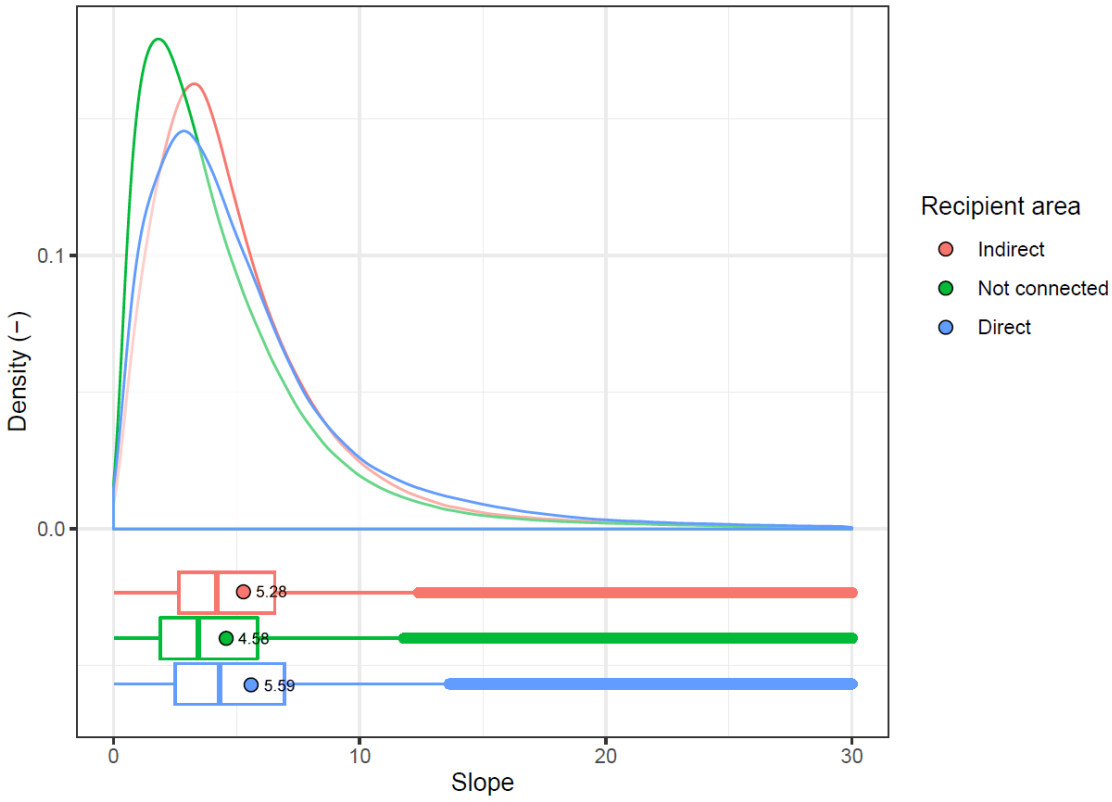


Figure S 25: Slope distribution (degrees) on different source area types

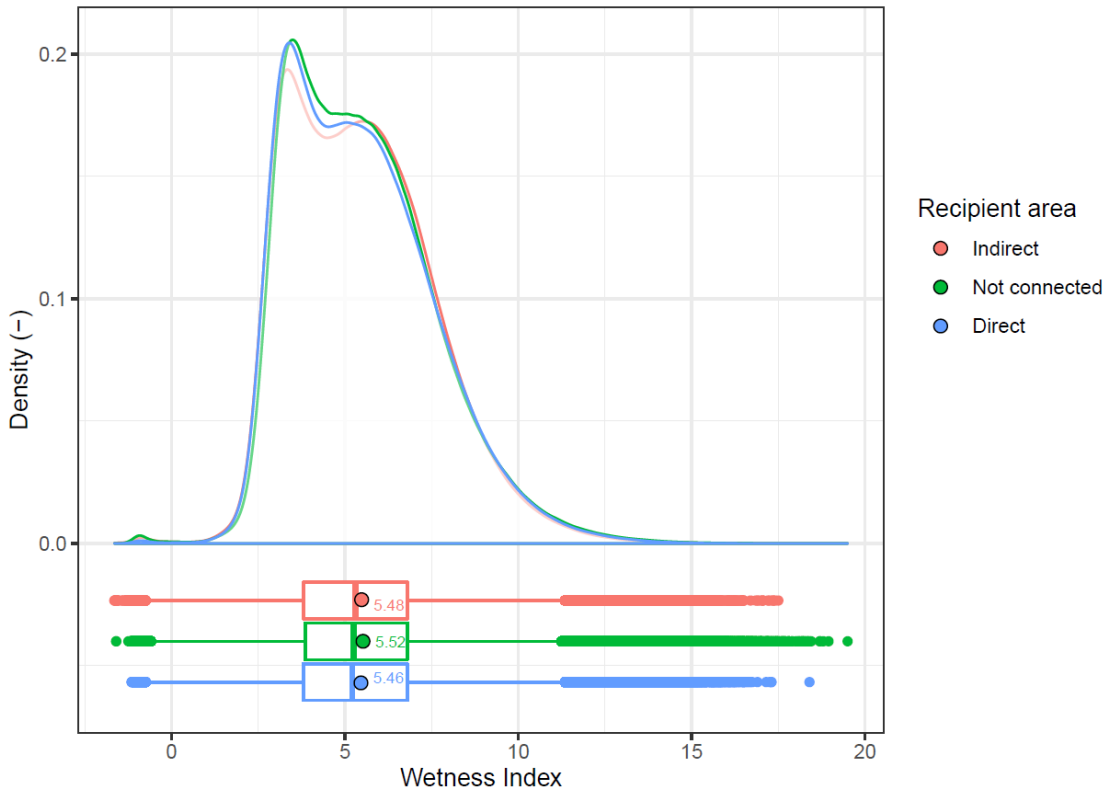


Figure S 26: Topographic wetness index distribution (-) on different source area types

S2.3. Surface runoff connectivity: Extrapolation to national level

S2.3.1. National area fractions

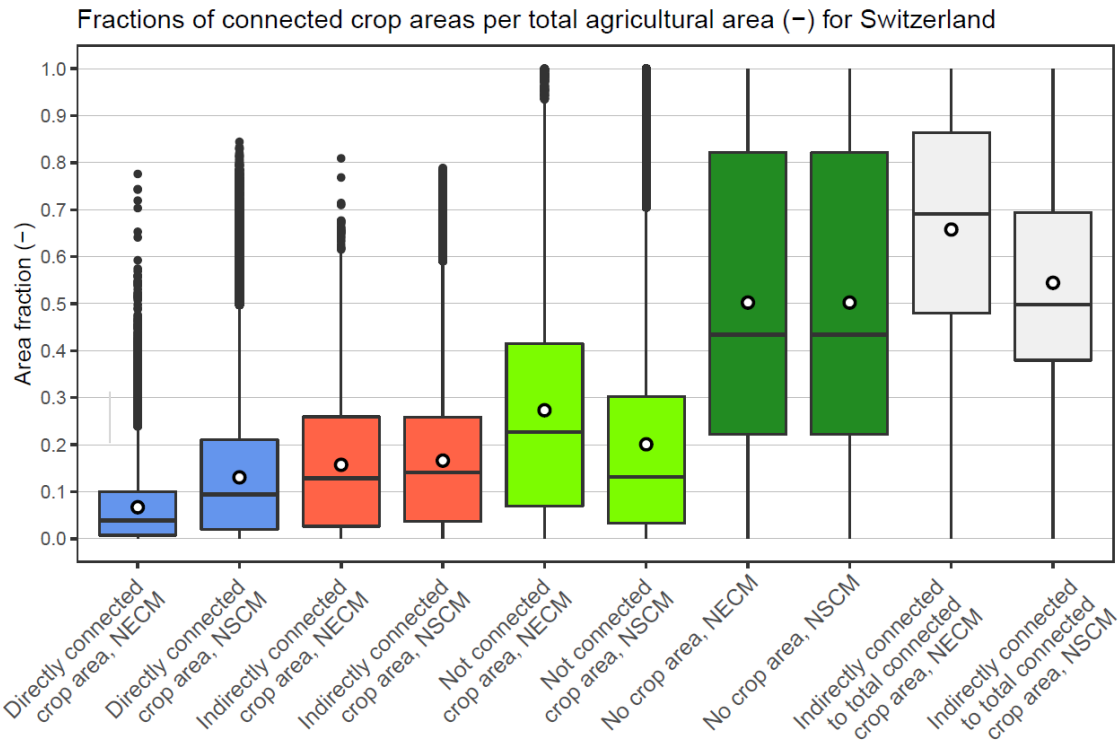
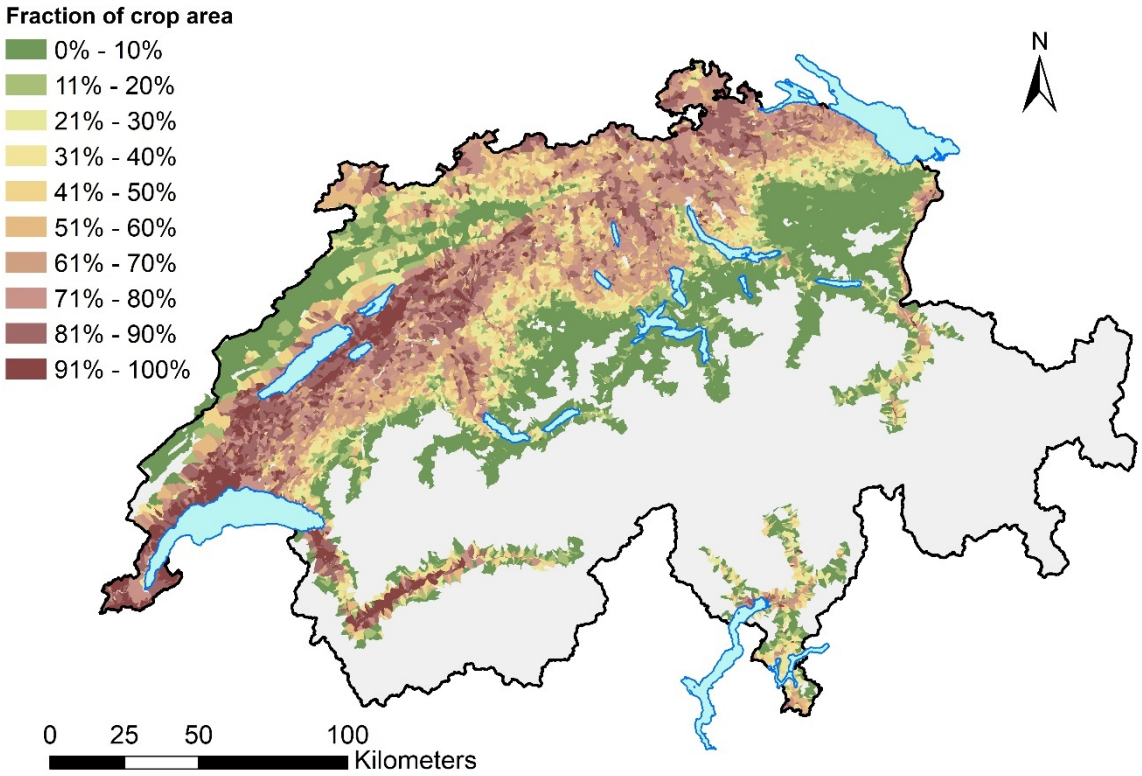


Figure S 27: Modelled fractions of connected crop areas per total agricultural area by the NECM and the NSCM: Directly, indirectly, and not connected crop areas per total agricultural area, non-cropping area per total agricultural area, and indirectly connected crop area per total connected crop area for all catchments in Switzerland.



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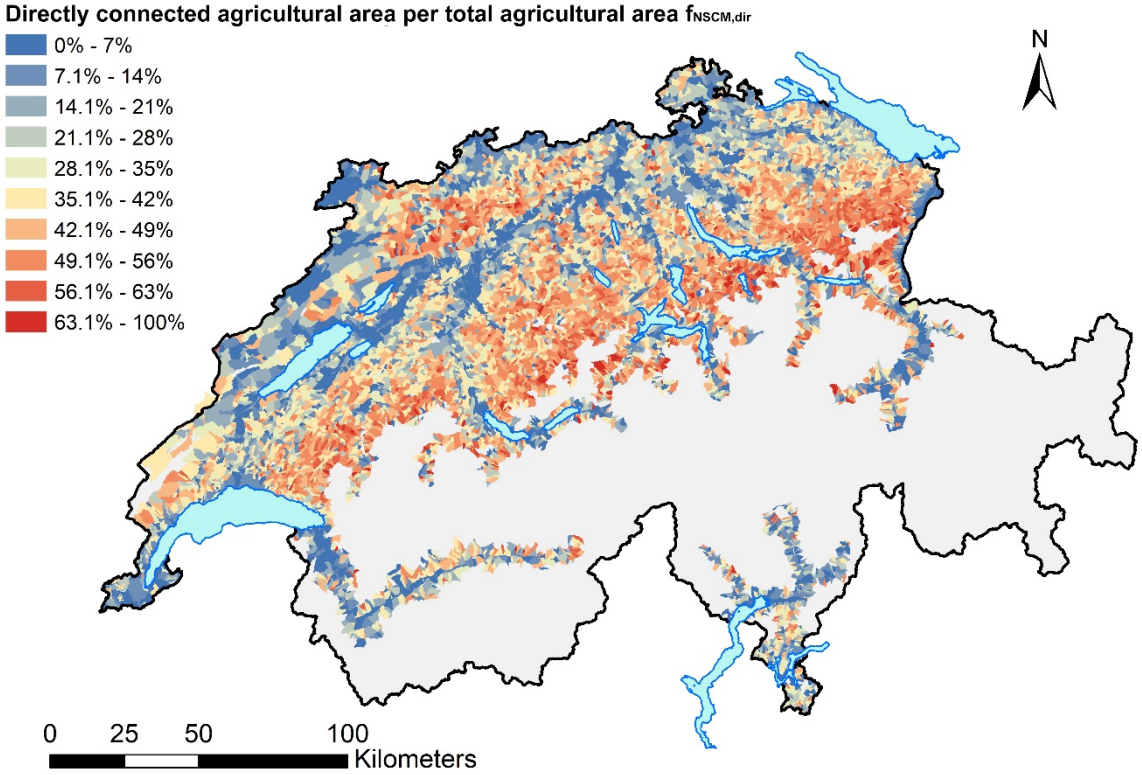
1152 **Figure S 28: Fraction of crop area (arable land, vineyards, orchards, horticulture) per total agricultural area per**
1153 **catchment. Source of background map: Swisstopo (2010)**

1154



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1156 **Figure S 29: Fraction of directly connected agricultural area per total agricultural area per catchment $f_{NSCM,dir}$.**
1157 **Source of background map: Swisstopo (2010)**

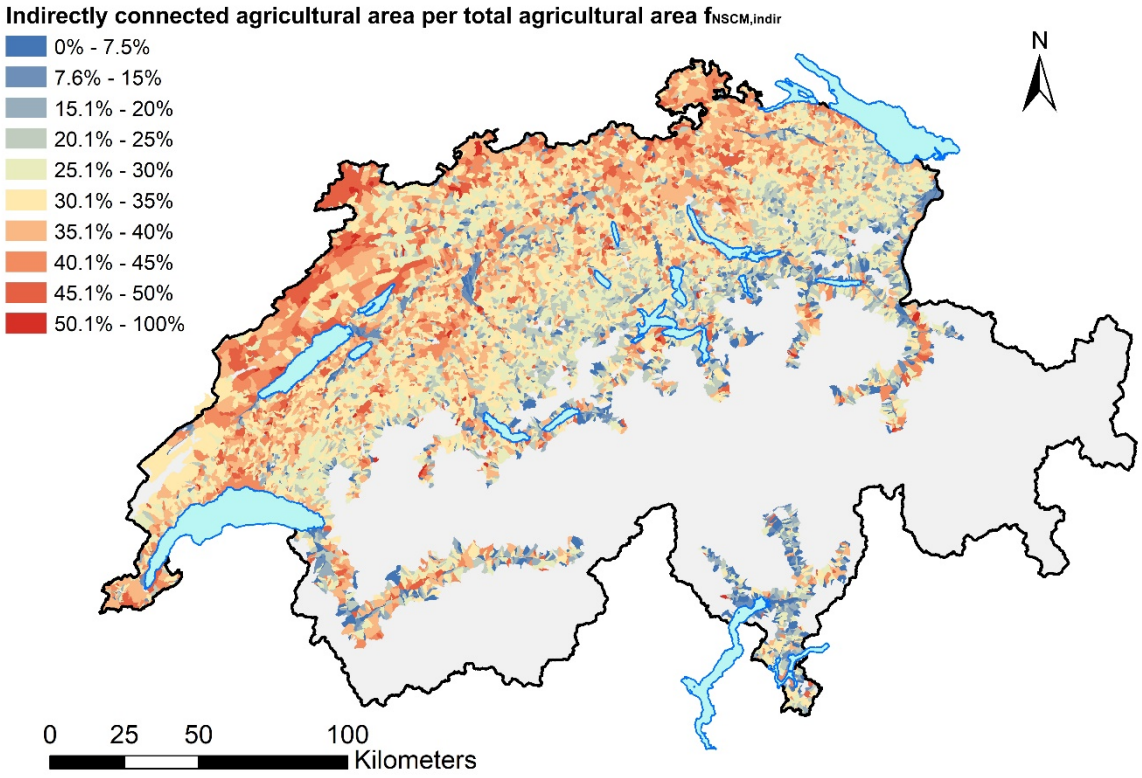


Figure S 30: Fraction of indirectly connected agricultural area per total agricultural area per catchment $f_{NSCM,indir}$. Source of background map: Swisstopo (2010)

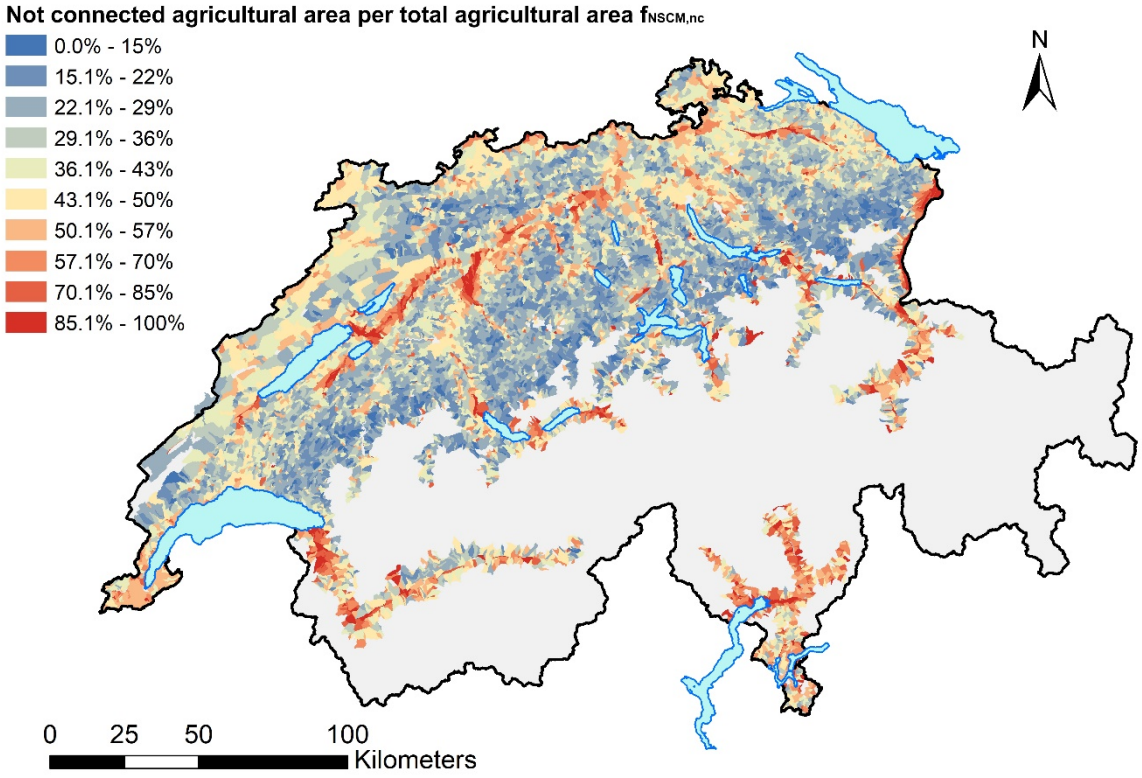
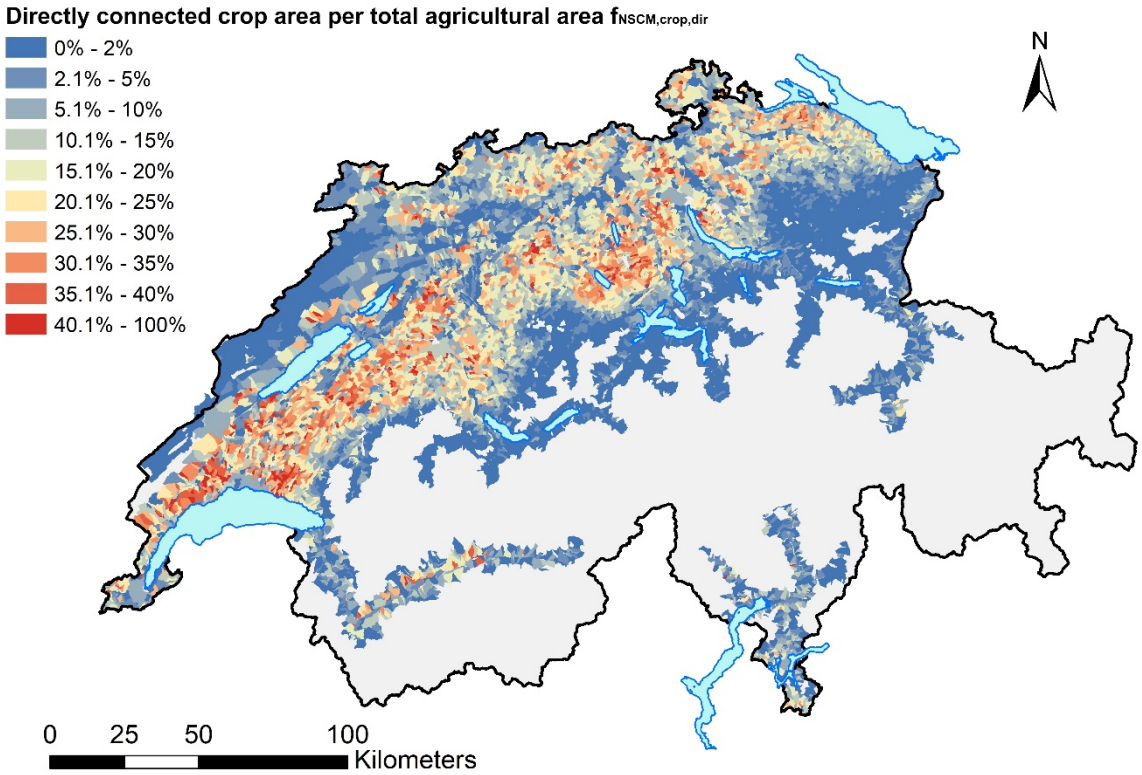


Figure S 31: Fraction of not connected agricultural area per total agricultural area per catchment $f_{NSCM,nc}$. Source of background map: Swisstopo (2010)



1165

1166 **Figure S 32: Fraction of directly connected crop area per total agricultural are per catchment $f_{NSCM,drop,dir}$. Source of**
1167 **background map: Swisstopo (2010)**

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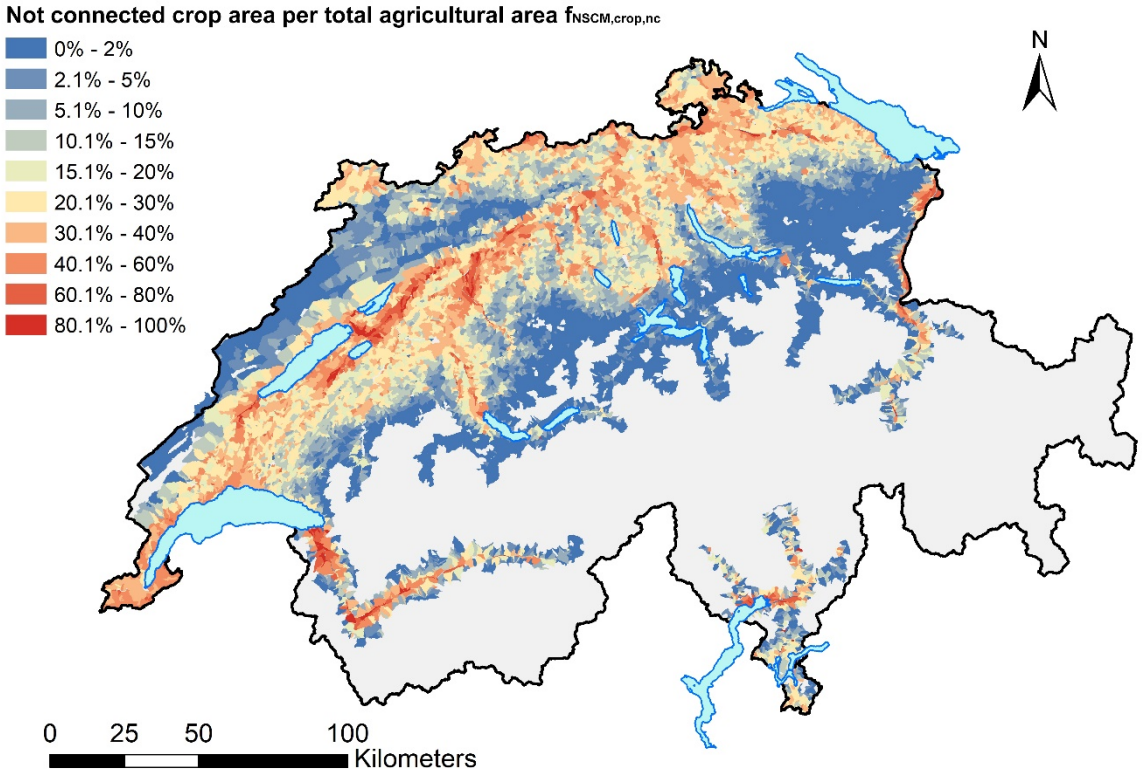

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1170 **Figure S 33: Fraction of not connected crop area per total agricultural area per catchment $f_{NSCM,drop,nc}$. Source of**
1171 **background map: Swisstopo (2010)**

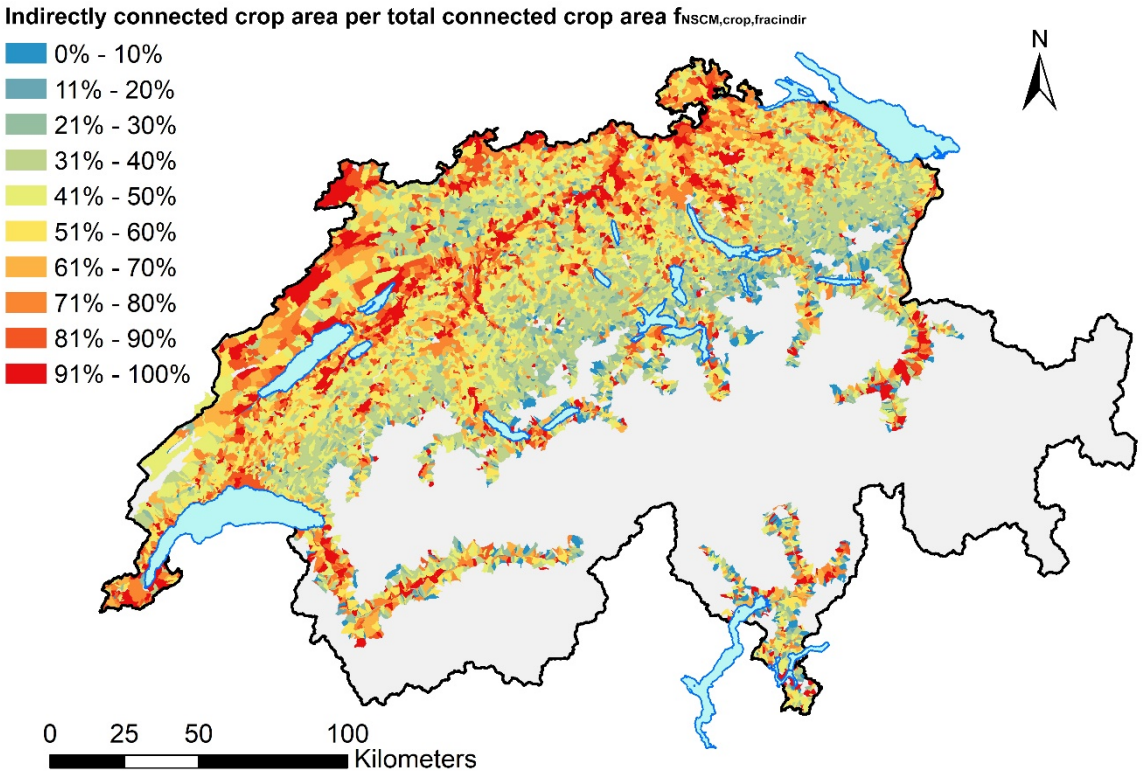

Figure S 34: Fraction of indirectly connected crop area per total connected crop area $f_{NSCM,drop,fracindir}$. Source of background map: Swisstopo (2010)