

## Supplementary Materials

**Table 1. Selected agricultural and Second Pillar priority 4 intervention indicators in German federal states. Data source: Own compilation based on indicated sources..**

	BB	BW	BY	HE	MV	NI	NW	RP	SH	SL	SN	ST	TH
<b>Agricultural indicators</b>													
<b>Agricultural area (2018)</b> 1000 ha <sup>1</sup>	1,450	1,612	3,280	882	1,442	2,787	1,623	816	1,087	110	1,003	1,237	868
% of total area <sup>2</sup>	47.5	45.1	46.5	41.8	61.9	57.9	47.6	41.1	68.8	42.9	54.4	60.5	53.6
<b>Nitrogen surplus (2010-14)</b> kg Nitrogen/ha/year <sup>3</sup>	54	69	83	62	56	93	92	53	88	58	62	57	61
<b>Livestock density (2010)</b> Livestock units/100 ha <sup>4</sup>	42	75	95	61	40	112	121	48	107	58	53	35	46
<b>Second Pillar priority 4 intervention indicators</b>													
<b>Priority 4 expenditures (2014-20)<sup>5</sup></b> m EUR <sup>6</sup>	603.1	1,118.4	2,002.0	273.9	424.5	646.6	599.1	315.4	281.5	29.5	455.9	503.0	442.7
% of total Second Pillar expenditures <sup>7</sup> EUR/ha agricultural area/year <sup>8</sup>	46.6	65.4	55.4	40.4	37.0	28.3	46.3	52.4	31.6	49.5	40.7	44.6	48.9
<b>Agricultural areas with administration agreements (2023)</b> % of agricultural area <sup>6</sup>	8.7	4.1	2.7	3.1	0.2	2.0	21.5	33.9	5.2	21.2	13.1	0.3	13.7

### Abbreviations:

BB – Brandenburg; BW - Baden-Wuerttemberg; BY – Bavaria; HE – Hesse; MV - Mecklenburg-Western Pomerania; NI - Lower Saxony; NW - North Rhine-Westphalia; RP - Rhineland-Palatinate; SH – Schleswig-Holstein; SL – Saarland; SN – Saxony; ST – Saxony-Anhalt; TH – Thuringia.

**Sources:** <sup>1</sup> Statistisches Bundesamt. *Flächennutzung - Bodenfläche nach Nutzungsarten und Bundesländern*. 2019. Available online: <https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Flaechennutzung/Tabellen/bodenflaeche-laender.html> (accessed on 15.10.19).

<sup>2</sup> Own calculation based on source 1.

<sup>3</sup> Own calculation (5-year-average) based on BMU and BMEL. *Nitratbericht 2016*. 2017, p. 56. Available online: [https://www.bmu.de/fileadmin/Daten\\_BMU/Download\\_PDF/Binnengewaesser/nitratbericht\\_2016\\_bf.pdf](https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Binnengewaesser/nitratbericht_2016_bf.pdf) (accessed on 015.10.19)

<sup>4</sup> Bäuerle, H.; Tamásy, C. *Regionale Konzentration der Nutztierhaltung in Deutschland*. Institut für Strukturforschung und Planung in agrarischen Intensivgebieten (ISPA), Universität Vechta, Mitteilungen (79), 2012. Kartendownload: Abb.3. Available online: [http://www.univechta.de/fileadmin/user\\_upload/ISPA/Publikationen/ISPA\\_Mitteilungen/MH\\_79\\_Karten\\_in\\_Farbe.pdf](http://www.univechta.de/fileadmin/user_upload/ISPA/Publikationen/ISPA_Mitteilungen/MH_79_Karten_in_Farbe.pdf) (accessed on 15.10.19)

<sup>5</sup> Second pillar priority 4 expenditures for restoring, preserving and enhancing ecosystems related to agriculture (without expenditures for forestry).

<sup>6</sup> Own compilation based on Regional Rural Development Programmes for German Federal States. Latest version, chapter 5.4 (*Eine zusammenfassende Tabelle der Interventionslogik*). See:

**BB:** MLUL (2019): Entwicklungsprogramm für den ländlichen Raum Brandenburgs und Berlins 2014 – 2020 (4. Änderung, genehmigt von der EU KOM am 27.11.2018). P. 184, available online: <https://eler.brandenburg.de/eler/de/start/foerderung/foerderperiode-2014-%E2%80%93-2020/eplr/> (accessed on 16.10.19).

**BW:** Ministerium für Ländlichen Raum und Verbraucherschutz (2018): Germany - Rural Development Programme (Regional) – Baden-Württemberg. Version 4.1. P. 308, available online: [https://foerderung.landwirtschaft-bw.de/pb/\\_de/Startseite/Agrarpolitik/MEPL+III](https://foerderung.landwirtschaft-bw.de/pb/_de/Startseite/Agrarpolitik/MEPL+III) (accessed on 16.10.19).

**BY:** StMELF (2019): Germany - Rural Development Programme (Regional) – Bavaria. (zuletzt geändert am 15.05.2019). P.163, available online: <http://www.stmelf.bayern.de/agrarpolitik/foerderung/099468/index.php>, (accessed on 16.10.19).

**HE:** Hessisches Ministerium für Umwelt, Klimaschutz, Landwirtschaft und Verbraucherschutz. Germany - Rural Development Programme (Regional) – Hesse. Zuletzt geändert am 31.01.2019. P179, available online: <https://umwelt.hessen.de/landwirtschaft/laendlicher-raum/foerderung-der-entwicklung-des-laendlichen-raums/eplr-2014-2020> (accessed on 15.10.19)

**MV:** Gemeinsame Verwaltungsbehörde für den EFRE, ESF und den ELER des Landes Mecklenburg-Vorpommern (2019): Germany - Rural Development Programme (Regional) – Mecklenburg-Vorpommern. Zuletzt geändert 28.05.2019. P. 174, available online: [https://www.europa-mv.de/foerderinstrumente/fonds\\_mv/eler/](https://www.europa-mv.de/foerderinstrumente/fonds_mv/eler/) (accessed on 16.10.19)

**NI:** Niedersächsisches Ministerium für Ernährung, Landwirtschaft und Verbraucherschutz (2017): Germany - Rural Development Programme (Regional) – Lower Saxony + Bremen. Zuletzt geändert 01.03.17. P. 254, available online: [https://www.ml.niedersachsen.de/themen/entwicklung\\_laendlichen\\_raums/eufoerderprogramme\\_zur\\_entwicklung\\_im\\_laendlichen\\_raum/pfeil\\_20142020/pfeil-2014-2020-125826.html](https://www.ml.niedersachsen.de/themen/entwicklung_laendlichen_raums/eufoerderprogramme_zur_entwicklung_im_laendlichen_raum/pfeil_20142020/pfeil-2014-2020-125826.html) (accessed 16.10.19)

**NW:** Ministerium für Umwelt, Landwirtschaft, Natur und Verbraucherschutz (2019): Germany - Rural Development Programme (Regional) – North Rhine-Westphalia. Zuletzt geändert 17.09.19. P. 126, available online: <https://www.umwelt.nrw.de/landwirtschaft/foerderung/nrw-programm-laendlicher-raum-2014-2020-eler/> (accessed 16.10.19)

**RP:** Ministerium für Wirtschaft, Verkehr, Landwirtschaft und Weinbau (2018): Germany - Rural Development Programme (Regional) – Rhineland-Palatinate . Zuletzt geändert 07.12.18. P. 312, available online:

- [https://www.eleller.de/Internet/global/inetcntrmwvlw.nsf/dlr\\_web\\_full.xsp?src=1LOOK14PHL&p1=9B220Y05YB&p3=K0VCQN4G82&p4=U72MKGMG31](https://www.eleller.de/Internet/global/inetcntrmwvlw.nsf/dlr_web_full.xsp?src=1LOOK14PHL&p1=9B220Y05YB&p3=K0VCQN4G82&p4=U72MKGMG31) (accessed 16.10.19)
- SH:** Ministerium für Energiewende, Landwirtschaft, Umwelt, Natur und Digitalisierung des Landes Schleswig-Holstein (2019): Germany - Rural Development Programme (Regional) Schleswig-Holstein. Zuletzt geändert 06.08.19.P. 142, available online: <https://www.schleswig-holstein.de/DE/Fachinhalte/F/foerderprogramme/MELUR/LPLR/Landesprogramm.html> (accessed 16.10.19)
- SL:** Saarland - Ministerium für Umwelt und Verbraucherschutz (2018): Saarländischer Entwicklungsplan für den ländlichen Raum 2014-2020 (SEPL 2014-2020). Zuletzt geändert am 03.12.18. P.143, available online: <https://www.saarland.de/SID-A96F399A-0609F26C/98261.htm> (accessed 16.10.19)
- SN:** Sächsisches Staatsministerium für Umwelt und Landwirtschaft (2018): Germany - Rural Development Programme (Regional) – Saxony . Zuletzt geändert 11.12.18. P. 148, available online: <https://www.smul.sachsen.de/foerderung/3531.htm> (accessed 16.10.19)
- ST:** Verwaltungsbehörde ELER, Ministerium der Finanzen (2018): Germany - Rural Development Programme (Regional) – Saxony-Anhalt . Zuletzt geändert 20.11.18. P. 137, available online: <https://europa.sachsen-anhalt.de/esi-fonds-in-sachsen-anhalt/ueber-die-europaeischen-struktur-und-investitionsfonds/eлер/eplr/#c131929> (16.10.19)
- TH:** Thüringer Ministerium für Infrastruktur und Landwirtschaft (2018): Germany - Rural Development Programme (Regional) – Thuringia. Zuletzt geändert 19.10.18. P. 188, available online: <https://www.thueringen.de/th9/tmil/lawi/eler2014-2020/> (accessed 02.05.19)
- <sup>7</sup> Own calculation based on source 6.
- <sup>8</sup> Own calculation based on sources 1 and 6.

**Table S2: Types of measures to reduce nitrogen pollution of groundwater and surface waters.\***

Type of Measure	Relevant for Groundwater	Relevant for Surface Waters
Reducing agricultural nutrient inputs	Yes	Yes
Reducing erosion-related nutrient and fine-material inputs	No	Yes
Creation of buffer strips	No	Yes
Reduce nutrient inputs through leaching from agriculture	Yes	Yes
Reducing nutrient inputs by drainages	No	Yes
Reducing nutrient inputs in water protection areas	Yes	Yes
Reducing agricultural pesticide input	Yes	Yes
Reduce acidification (without nutrients) in groundwater due to agriculture	Yes	No

\* The Table contains 12 types of measures meant to reduce diffuse nutrient pollution from agriculture. These measures comprise both basic and supplementary measures according to Water Framework Directive. Basic measures are the minimum requirements for water protection and water development. They are laid down in existing directives or serve to fulfill basic water management requirements, like the Nitrates Directive. Supplementary measures are necessary if the basic measures are not sufficient to achieve the objectives of the WFD.

**Table S3: Interview results: Complexity of the problem 'Diffuse pollution of groundwater from agriculture'. Data source: Own representation and calculation based on Kirschke [24,25].**

Expert	Goals	Variables	Dynamics	Connections	Uncertainty
1	1	0	0	0	0
2	0	1	1	1	0,5
3	1	1	1	1	1
4	0	1	0,5	0,5	1
5	1	1	0,5	1	1
6	1	0	0,5	0,5	0,5
7	1	1	0,75	0,75	0,5
8	1	0,5	0,5	1	0,75
9	1	0,5	0,5	1	0,75
10	1	1	0,25	1	0,25
Average	0,80	0,70	0,55	0,78	0,63
Standard deviation	0,42	0,42	0,31	0,34	0,34

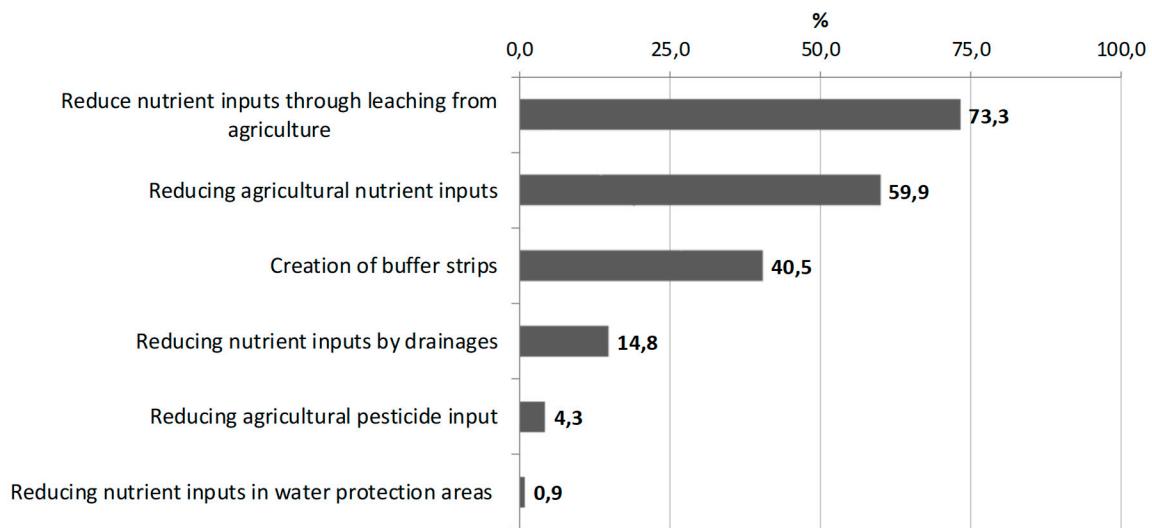
**Table S4: Qualitative arguments for the complexity of the problem ‘Diffuse nitrogen pollution from agriculture’. Data source: Own representations, partly based on Kirschke et al. 2017<sup>1</sup>**

Dimension of complexity	Name of arguments	Description of arguments
Variables	Natural locational factors	Soils (soil properties, especially its permeability and natural denitrification rates), climate and weather conditions (amount of precipitation), geological factors (slope angles), and the groundwater flow (e.g., flow velocity and direction)
	Non-natural locational factors	General demographic conditions (e.g., meat production, influencing the amount of slurry from livestock as well as agricultural modes of production), more specific management factors (e.g., amount and type of fertilizer, the way fertilizer is applied to soils, moment of application, type of cultivated plants, intensity and type of irrigation, technical equipment used)
	Solution options	Different types of technologies in the field of fertilization
Actors and their interest		
		Interests of producers (farmers), consumers (the general population), and specific interest groups (e.g., large-scale investors, environmentalists); the multiplicity of responsibilities amongst and within ministries
	Governance	Relevant policies (e.g., energy, agricultural and environmental, primarily water related policies at European level) and related instruments such as hard law (e.g., fertilizer ordinance), economic incentives (for cultivation of plants), and information (e.g., education of and advisory for farmers, availability of data) as well as overarching political and market conditions (e.g., energy prizes)
Dynamics	Natural locational factors	Change of weather and climate conditions (e.g., change in precipitation due to climate change), time-limited ecosystem services (e.g., denitrification potential of pyrite); static with respect to the soil conditions or slope inclination
	Non-natural locational factors	Demographic changes, changes of the type and amount of cultivated plants, changes in the amount of fertilizer in general and of slurry more particularly
	Solution options	Continuous technological development (e.g., non-plough tillage)
Governance conditions	Actors	Static conditions with respect to actor constellations (agricultural vs. environmental interests); changes of staff in politics and executive boards, of special interests (energy production from plants), or new types of actors (e.g., large scale investors), and of responsibilities (changing responsibilities after elections)
	Governance conditions	Slight dynamics, e.g. with regards to regulations (varying thresholds, funding opportunities), and prices (e.g., for mineral fertilizer and crops)
Uncertainty	Natural locational factors	Natural conditions, e.g. weather and climate conditions as well as groundwater-related data, specifically with regards to the subsurface distribution of nutrients
	Non-natural locational factors	Strong uncertainty exists with regards to the amount of nitrogen deployed to fields (on the sides of administrations), also resulting in significant control uncertainty
	Solution options	Slight uncertainty mainly regarding the effect and the right combinations of measures
Interconnections	Actors	Strong uncertainty with the regards to the behaviour of farmers. Administrations are thus not aware who is responsible for the input of nutrients, or they are only aware on a more aggregated level
	Governance conditions	Strong uncertainty concerning the development of market prices
	Natural and technical level	Connections between water bodies, between water quality and water quantity questions, between natural factors, management practices and problem solving
Social level		
	Social level	Impacts of politics of different policy fields and at different regional levels on regulations and therewith also on the application of fertilizer on a local level, but also supra-regional impacts of livestock farming via the transport of manure

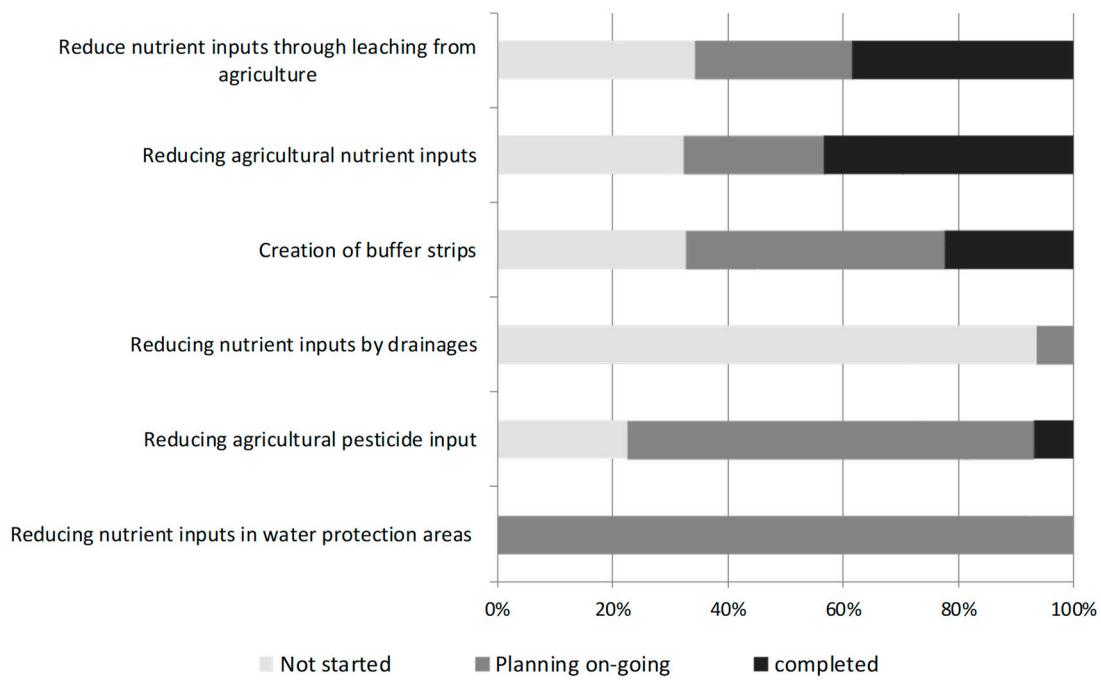
	Combined natural, technical and social interactions	Combined effects as described above
Goals	Value conflict	Generally, no value conflict, meaning that stakeholders are in general interested in reducing the input of nutrients into groundwater
Implementation of measures		Strong goal conflicts between the goals of environmental protection (water protection through the reduction of discharges, associated nature conservation and biodiversity goals) and agricultural production goals (for food and energy security, including related goals of maximizing benefits); Conflicts within the water sector with regard to thresholds and the distribution of loads

<sup>1</sup>Kirschke, S.; Borchardt, D.; Newig, J. Mapping Complexity in Environmental Governance: A comparative analysis of 37 priority issues in German water management. Environmental Policy and Governance 2017, 27(6), 534-559. Doi: 10.1002/eet.1778

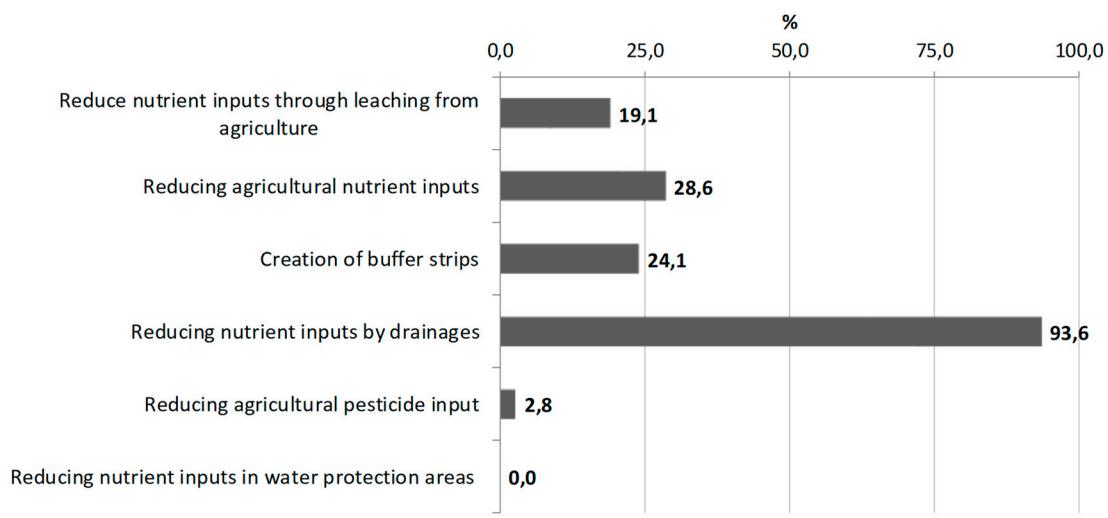
**Figure S1: Amount of reported measures in surface water bodies with measures to reduce diffuse nutrient pollution (n=2500). Data source: Berichtsportal WasserBLicK/BfG; last updated 31 October 2012.**



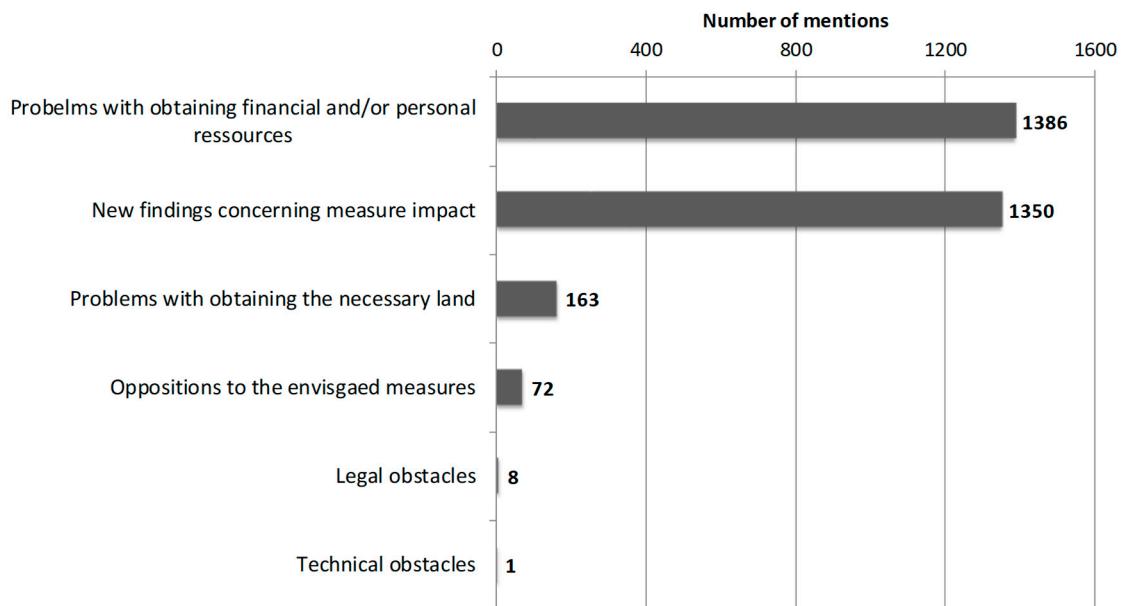
**Figure S2: Implementation status of measures to reduce diffuse nutrient pollution in surface waters. Data source: Berichtsportal WasserBLicK/BfG; last updated 31 October 2012.**



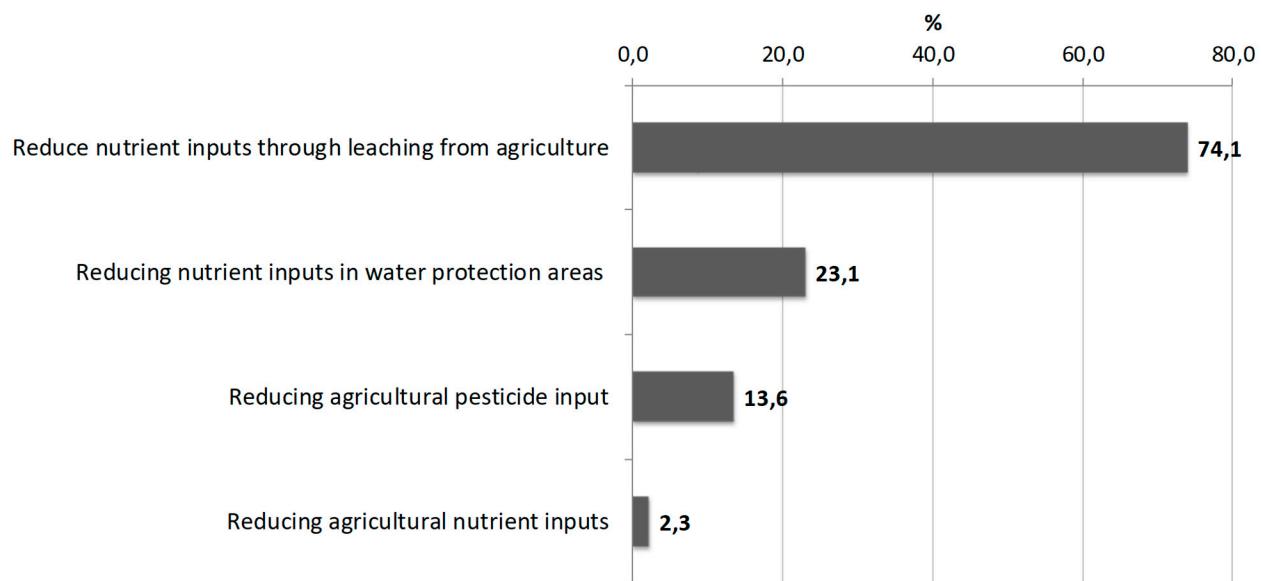
**Figure S3: Substantial delays of measures to reduce diffuse nutrient pollution in surface waters. Data source: Berichtsportal WasserBLicK/BfG; last updated 31 October 2012.**



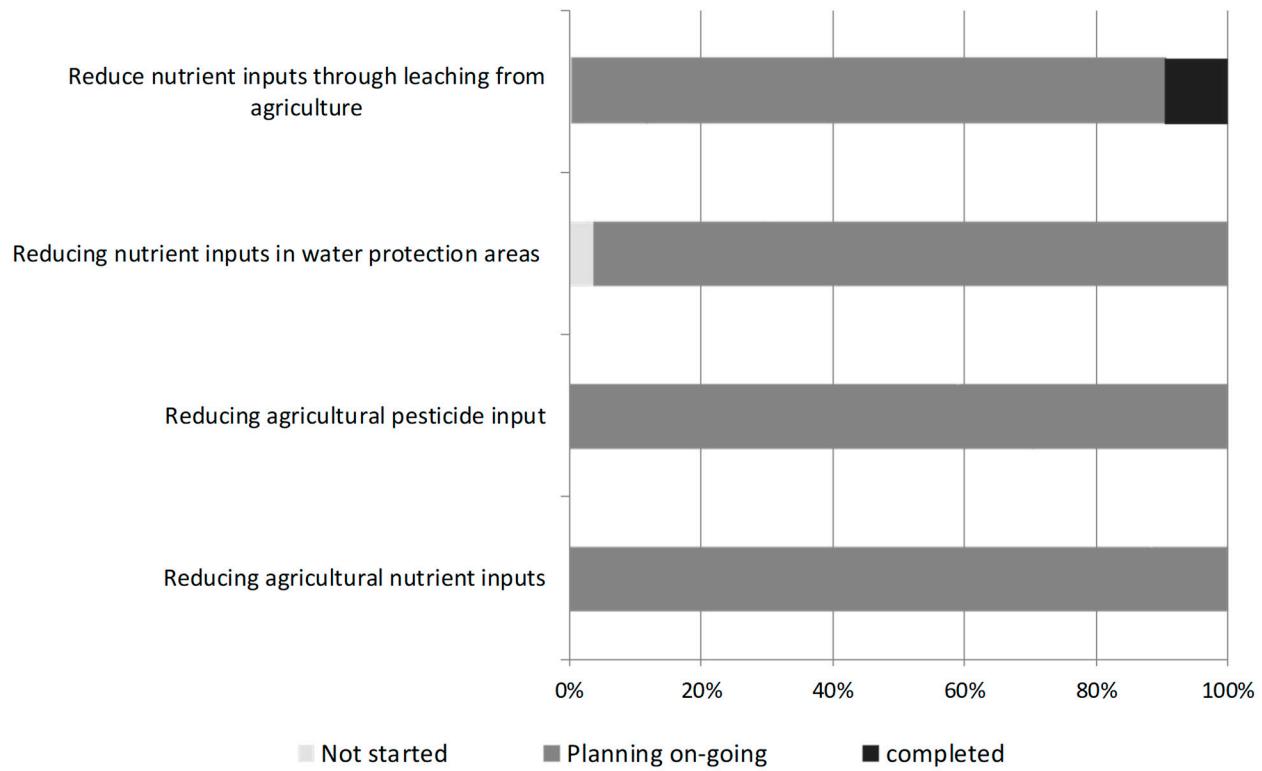
**Figure S4: Reasons for substantial delays of measures to reduce diffuse nutrient pollution in surface waters. Data source: Berichtsportal WasserBLicK/BfG; last updated 31 October 2012**



**Figure S5: Amount of reported measures in groundwater bodies with measures to reduce diffuse nutrient pollution (n=610). Data source: Berichtsportal WasserBLicK/BfG; last updated 31 October 2012.**



**Figure S6: Implementation status of measures to reduce diffuse nutrient pollution in groundwater. Data source: Berichtsportal WasserBLicK/BfG; last updated 31 October 2012.**



**Figure S7: Amount of measures to reduce agricultural nutrient pollution in surface water bodies (n=5266) and groundwater (n=718) according to RBMP 2015.**

