Ecosystem Service	**Chemical condition of freshwaters**
CICES class name	Regulation of the chemical condition of freshwaters by living processes
CICES Section	Regulation & Maintenance (Biotic)
CICES Class code	2.2.5.1

Sample Indicators

Indicator values from			
Experiment or direct measurement		Survey	
Expert assessment		Statistical- or census data	
Model or GIS		Literature values	
Stakeholder participation		Not provided	

Table 1: Field Scale

Indicator	Unit	Indicator values from
[5] Seepage rate - amount of water that leaves the rooting zone toward the groundwater table	mm * yr^{-1}	
[6] Seepage rate - amount of water that leaves the rooting zone toward the groundwater table	mm * yr^{-1}	
[2] Concentration of nitrates in drained water	mg NO_3^- * l^{-1}	
[5] Nitrate concentration in seepage water	mg * l^{-1}	
[6] Nitrate concentration in seepage water	mg * l^{-1} * yr^{-1}	
[10] Soil mineral nitrogen content at the end of summer (0-90 cm, measured between October 1st and November 15th)	kg * ha^{-1}	 , 
[4] Nitrate leaching	kg NO_3^-N * ha^{-1} * yr^{-1}	
[9] Nitrate leaching prevention: nitrate concentration in drained water	mg NO_3^- * l^{-1}	
[8] NO_3^- loss through leaching and runoff, following cover crop or fallow period	kg * ha^{-1}	

[11] Groundwater: annual total nitrate (NO_3-N) leached at the bottom of the soil profile	kg * ha^{-1}	
[1] Nitrogen mineralization	kg N_{tot} * ha^{-1} * yr^{-1}	
[11] Surface water: annual total phosphorus yield in runoff	kg * ha^{-1}	
[8] Dissolved P loss through leaching and runoff, following cover crop or fallow period	kg * ha^{-1}	
[7] Total P leached from experimental pot 1 day after applying phosphorus solution	µg	
[5] Phosphorus loss (particulate phosphorus removed by water erosion)	kg * ha^{-1} * yr^{-1}	
[6] Phosphorus loss (particulate phosphorus removed by water erosion)	kg * ha^{-1} * yr^{-1}	
[6] Erosion by water	t * ha^{-1}	
[2] Concentration of pesticides in drained water	µg * l^{-1}	,
[6] Share of years within management period in which protection plant products were used	%	
[3] Natural attenuation/ clean groundwater: Indicator value calculated as: $$I=\frac{\sum \lvert \log(\frac{i}{i_{max}}) \rvert}{n}$$ With: I – indicator value, i – variable i measured, i_{max} – maximum ecologic potential of variable i in benchmark reference, n – number of variables. Where performance is considered better than in the benchmark and deviation, therefore, has a positive effect, $\lvert \log(\frac{i}{i_{max}}) \rvert$ is subtracted from the sum instead of added. For this ecosystem service, variables were: -Soil organic matter [% dw] -Bacterial biomass [mg C * g dw^{-1}] -pH in KCl -Physiological diversity bacteria [bBiolog. CLPP: Hill's slope] -Water-soluble P (Pw) and extractable P (PAL)		,

Table 2: Farm Scale

Indicator	Unit	Indicator values from
[14] Share of nitrogen retained during water passage between agricultural sub-catchment and sea	%	
[12] Share of waterways protected by buffers. The index is calculated by dividing the observed value with a target value. Target values may be average or maximum values found in region, or empirical values from literature. If the calculated index is higher than 1, it is set to one.	Index 0 - 1	
[13] Macroinvertebrates: index based on number of aquatic macroinvertebrates species	poor - fair - good - excellent	
[13] Turbidity: index based on the turbidity of water in the stream channel	poor - fair - good - excellent	
[14] Share of farmers that express clearly a value and care for the health of the land	%	

Table 3: Regional Scale

Indicator	Unit	Indicator values from
[20] Freshwater supply: Annual groundwater recharge	cm * yr^{-1}	 , 
[15] N export with seepage water	kg N * ha^{-1}	
[28] Nitrogen leaching	kg N * ha^{-1} * yr^{-1}	
[31] Nitrate leaching	kg * ha^{-1} * yr^{-1}	
[11] Groundwater: annual total nitrate (NO_3-N) leached at the bottom of the soil profile	kg * ha^{-1}	
[33] Potential nitrate leaching, estimated from agricultural productivity and associated inputs	kg NO_3^- * ha^{-1} * yr^{-1}	
[23] Risk of nitrate leaching: exchange frequency of the soil water in the root layer. Infiltration rate divided by field capacity	%	
[14] Share of nitrogen retained during water passage between agricultural sub-catchment and sea	%	
[35] Water purification: Nitrogen retention	g N * yr^{-1} * m^{-2}	

[21] Groundwater quality: Probability of groundwater nitrate concentration <3.0 mg per litre	0 - 1	
[26] Nitrogen retention at watershed level calculated with InVEST's Nutrient Retention Model. Calculation based on nitrogen loading and vegetation filtering value for different land-use classes.	t N * yr^{-1} * grid $cell^{-1}$	
[29] Total nitrogen export that reaches the nearest stream, calculated with InVEST model	t * ha^{-1}	
[11] Surface water: annual total phosphorus yield in runoff	kg * ha^{-1}	
[20, 21] Surface-water quality: Annual phosphorus loading, calculated using the InVest model	kg * ha^{-1}	
[29] Total phosphorus export that reaches the nearest stream, calculated with InVEST model	t * ha^{-1}	
[15] P export with seepage water	kg N * ha^{-1}	
[28] Phosphorus loss	kg P * ha^{-1} * yr^{-1}	
[18] Phosphorus retention, calculated with InVEST model	kg * ha^{-1}	
[16] Total N and P loading in lakes	t * yr^{-1}	
[16] Outflow N and P loading in lakes	t * yr^{-1}	
[16] N and P retention in lakes	t * yr^{-1}	
[16] N and P concentration in lakes	mg * l^{-1}	
[25] Water quality: concentrations of nitrogen, phosphorus, and sediments (including suspended solids and turbidity)	mg * l^{-1}	
[30] Leakage of nutrients	kg * ha^{-1} * yr^{-1}	
[30] Turnover rates of nutrients, e.g., N, P	kg * yr^{-1}	
[30] Total dissolved solids	mg * l^{-1}	
[30] Decomposition rate of organic matter	kg * ha^{-1}	
[34] Water quality of freshwater ecosystems	Not provided	

[30] Area occupied by riparian forests	ha	
[24] Share of natural forest cover in municipality's surface. Values were normalized [0-1] using benchmark values where available and observed values otherwise.	%	
[17] Area of buffer strips alongside rivers. Buffer strips are defined as areas connected to the river system and belonging to the land use classes: pasture, open space/heathland, woodland/single tree, tree hedgerow/hedgerow, arable field boundaries, grassland boundaries, deciduous tree dominated forest, coniferous tree dominated forest, or peatland	m^2	
[17] Arable land uphill from buffer strips alongside rivers	m^2	
[17] Arable land on slopes steeper than 3% uphill from buffer strips alongside rivers	m^2	
[17] Potential erosion from buffer strips and the area uphill from them (using RUSLE equation)	$t * yr^{-1}$	
[19] Mechanical filtration capacity: infiltration capacity, calculated as: $$IC = s_p * (1 - s)$$ With: IC – infiltration capacity, s_p – soil permeability [cm/day], s – share of anthropogenic surface sealing)	$cm * d^{-1}$	
[19] Physicochemical filtration capacity, calculated as: $$C = CEC_{eff} * (1 - s)$$ With: C – physicochemical filtration capacity, CEC_{eff} – effective cation exchange capacity, s – share of anthropogenic surface sealing	cmol(+) * kg dm^{-1}	
[22] Water purification: values for land cover classes. The matrix defined by Burkhard et al., 2012 (DOI:10.1016/j.ecolind.2011.06.019) was adapted and used in this study.	Index 0 - 5	
[27] Mediation of water pollution such as excess nitrogen removal: expert based index for ecosystem service supply by land cover class [1-5], multiplied by the area of the land cover class	km^2	
[27] Mediation of water pollution such as excess nitrogen removal value: expert based index for ecosystem service supply by land cover class [1-5], multiplied by the area of the land cover class and a literature-based monetary value of the ecosystem service	$\$ * ha^{-1} * yr^{-1}$	

[32] Water purification and provision, calculated as: $$W = NPP * (1 - VCNPP) * IC_s * S_{cf} * 1.75$$ With: W – water purification and provision, NPP – Net Primary Production calculated from NDVI-values and expressed on a relative scale set to [0 – 1000], VCNPP – coefficient of variation of NPP [0 – 1], IC_s – soil infiltration capacity [0 – 1], S_{cf} – slope average correction factor of the study area [0 – 1]	-	
[32] Waste purification, calculated as: $$W = NPP * (1 - VCNPP) * I_w * O_w * 1.75$$ With: W – waste purification, NPP – Net Primary Production [0 - 1000], VCNPP – coefficient of variation of NPP [0 – 1], I_w – water input to the system [0 – 1], O_w – water bodies occupancy percentage and flat floodplain area [0 – 1]	-	
[14] Share of farmers that express clearly a value and care for the health of the land. Values were scaled to [0-1]	%	

Table 4: National Scale

Indicator	**Unit**	**Indicator values from**
[37] Denitrification capacity	kg N * ha^{-1} * yr^{-1}	
[37] Phosphorus sorption capacity	kg P * ha^{-1} * yr^{-1}	
[38] Chemical status	Not provided	
[38] Ecological status	Not provided	
[34] Water quality of freshwater ecosystems	-	
[36] Water quality: Expert assessment for each land use class, based on the indicators: nutrient efficiency; pesticides (units not given)	very negative (−3) to very positive (+3)	
[38] Groundwater: Indicators of groundwater quality	Not specified	
[38] Wetlands: Potential of water purification of wetlands	Not specified	

Table 5: Multinational Scale

Indicator	Unit	Indicator values from
[34] Water quality of freshwater ecosystems	-	
[35] Water purification: Nitrogen retention	$g\ N * yr^{-1} * m^{-2}$	
[39] Water purification: values for Corine land cover classes, based on values published by Burkhard et al. (2009; DOI: 10.3097/LO.200915) and modified for the context of riparian zones.	Index 0 - 5	

Table 6: Global Scale

Indicator	Unit	Indicator values from
[34] Water quality of freshwater ecosystems	-	

References

No.	Citation
1	Kragt ME, Robertson MJ (2014) Quantifying ecosystem services trade-offs from agricultural practices. Ecological Economics 102: 147-157. DOI: 10.1016/j.ecolecon.2014.04.001
2	Demestihas C, Plénet D, Génard M, Raynal C, Lescourret F (2017) Ecosystem services in orchards. A review. Agronomy for Sustainable Development 37(2): 12. DOI: 10.1007/s13593-017-0422-1
3	Rutgers M, van Wijnen HJ, Schouten AJ, Mulder C, Kuiten AMP, Brussaard L, Breure AM (2012) A method to assess ecosystem services developed from soil attributes with stakeholders and data of four arable farms. Science of the Total Environment 415: 39-48. DOI: 10.1016/j.scitotenv.2011.04.041
4	Syswerda SP, Robertson GP (2014) Ecosystem services along a management gradient in Michigan (USA) cropping systems. Agriculture Ecosystems & Environment 189: 28-35. DOI: 10.1016/j.agee.2014.03.006
5*	Tsonkova P, Bohm C, Quinkenstein A, Freese D (2015) Application of partial order ranking to identify enhancement potentials for the provision of selected ecosystem services by different land use strategies. Agricultural Systems 135: 112-121. DOI: 10.1016/j.agsy.2015.01.002
6	Tsonkova P, Quinkenstein A, Bohm C, Freese D, Schaller E (2014) Ecosystem services assessment tool for agroforestry (ESAT-A): An approach to assess selected ecosystem services provided by alley cropping systems. Ecological Indicators 45: 285-299. DOI: 10.1016/j.ecolind.2014.04.024
7	Verbruggen E, Kiers ET, Bakelaar PNC, Roling WFM, van der Heijden MGA (2012) Provision of contrasting ecosystem services by soil communities from different agricultural fields. Plant and Soil 350(1-2): 43-55. DOI: 10.1007/s11104-011-0828-5
8	Daryanto S, Fu BJ, Wang LX, Jacinthe PA, Zhao WW (2018) Quantitative synthesis on the ecosystem services of cover crops. Earth-Science Reviews 185: 357-373. DOI: 10.1016/j.earscirev.2018.06.013
9	Demestihas C, Plénet D, Génard M, Garcia de Cortazar-Atauri I, Launay M, Ripoche D, Beaudoin N, Simon S, Charreyron M, Raynal C, Lescourret F (2018) Analyzing ecosystem services in apple orchards using the STICS model. European Journal of Agronomy 94: 108-119. DOI: 10.1016/j.eja.2018.01.009
10	Van Vooren L, Reubens B, Broekx S, Reheul D, Verheyen K (2018) Assessing the impact of grassland management extensification in temperate areas on multiple ecosystem services and biodiversity. Agriculture, Ecosystems and Environment 267: 201-212. DOI: 10.1016/j.agee.2018.08.016
11	Qiu JX, Carpenter SR, Booth EG, Motew M, Zipper SC, Kucharik CJ, Loheide SP, Turner AG (2018) Understanding relationships among ecosystem services across spatial scales and over time. Environmental Research Letters 13(5): 054020. DOI: 10.1088/1748-9326/aabb87
12*	Quinn JE, Brandle JR, Johnson RJ (2013) A farm-scale biodiversity and ecosystem services assessment tool: the healthy farm index. International Journal of Agricultural Sustainability 11(2): 176-192. DOI: 10.1080/14735903.2012.726854
13	Fleming WM, Rivera JA, Miller A, Piccarello M (2014) Ecosystem services of traditional irrigation systems in northern New Mexico, USA. International Journal of Biodiversity Science, Ecosystem Services and Management 10(4): 343-350. DOI: 10.1080/21513732.2014.977953
14	Andersson E, Nykvist B, Malinga R, Jaramillo F, Lindborg R (2015) A social–ecological analysis of ecosystem services in two different farming systems. Ambio 44(1): 102-112. DOI: 10.1007/s13280-014-0603-y

* The ecosystem service discussed on this factsheet is not a focus of the cited paper

No.	Citation
15*	Fürst C, Frank S, Witt A, Koschke L, Makeschin F (2013) Assessment of the effects of forest land use strategies on the provision of ecosystem services at regional scale. Journal of Environmental Management 127: 96-116. DOI: 10.1016/j.jenvman.2012.09.020
16	Holmberg M, Akujarvi A, Anttila S, Arvola L, Bergstrom I, Bottcher K, Feng XM, Forsius M, Huttunen I, Huttunen M, Laine Y, Lehtonen H, Liski J, Mononen L, Rankinen K, Repo A, Piirainen V, Vanhala P, Vihervaara P (2015) ESLab application to a boreal watershed in southern Finland: preparing for a virtual research environment of ecosystem services. Landscape Ecology 30(3): 561-577. DOI: 10.1007/s10980-014-0122-z
17	Lautenbach S, Kugel C, Lausch A, Seppelt R (2011) Analysis of historic changes in regional ecosystem service provisioning using land use data. Ecological Indicators 11(2): 676-687. DOI: 10.1016/j.ecolind.2010.09.007
18	Meyer MA, Chand T, Priess JA (2015) Comparing Bioenergy Production Sites in the Southeastern US Regarding Ecosystem Service Supply and Demand. Plos One 10(3): e0116336. DOI: 10.1371/journal.pone.0116336
19	Nordborg M, Sasu-Boakye Y, Cederberg C, Berndes G (2017) Challenges in developing regionalized characterization factors in land use impact assessment: impacts on ecosystem services in case studies of animal protein production in Sweden. International Journal of Life Cycle Assessment 22(3): 328-345. DOI: 10.1007/s11367-016-1158-x
20	Qiu J, Wardropper CB, Rissman AR, Turner MG (2017) Spatial fit between water quality policies and hydrologic ecosystem services in an urbanizing agricultural landscape. Landscape Ecology 32(1): 59-75. DOI: 10.1007/s10980-016-0428-0
21	Qiu JX, Turner MG (2015) Importance of landscape heterogeneity in sustaining hydrologic ecosystem services in an agricultural watershed. Ecosphere 6(11): 229. DOI: 10.1890/es15-00312.1
22*	Zhang ZM, Gao JF, Fan XY, Lan Y, Zhao MS (2017) Response of ecosystem services to socioeconomic development in the Yangtze River Basin, China. Ecological Indicators 72: 481-493. DOI: 10.1016/j.ecolind.2016.08.035
23	Bastian O, Lupp G, Syrbe RU, Steinháußer R (2013) Ecosystem services and energy crops - Spatial differentiation of risks. Ekologia Bratislava 32(1): 13-29. DOI: 10.2478/eko-2013-0002
24	Rodríguez-Loinaz G, Alday JG, Onaindia M (2015) Multiple ecosystem services landscape index: A tool for multifunctional landscapes conservation. Journal of Environmental Management 147: 152-163. DOI: 10.1016/j.jenvman.2014.09.001
25	Duarte GT, Santos PM, Cornelissen TG, Ribeiro MC, Paglia AP (2018) The effects of landscape patterns on ecosystem services: meta-analyses of landscape services. Landscape Ecology 33(8): 1247-1257. DOI: 10.1007/s10980-018-0673-5
26	Hashimoto S, DasGupta R, Kabaya K, Matsui T, Haga C, Saito O, Takeuchi K (2018) Scenario analysis of land-use and ecosystem services of social-ecological landscapes: implications of alternative development pathways under declining population in the Noto Peninsula, Japan. Sustainability Science 14: 53-75. DOI: 10.1007/s11625-018-0626-6
27	Huq N, Bruns A, Ribbe L (2019) Interactions between freshwater ecosystem services and land cover changes in southern Bangladesh: A perspective from short-term (seasonal) and long-term (1973-2014) scale. Science of the Total Environment 650: 132-143. DOI: 10.1016/j.scitotenv.2018.08.430
28	Kay S, Crous-Duran J, García de Jalón S, Graves A, Palma JHN, Roces-Díaz JV, Szerencsits E, Weibel R, Herzog F (2018) Landscape-scale modelling of agroforestry ecosystems services in Swiss orchards: a methodological approach. Landscape Ecology 33(9): 1633-1644. DOI: 10.1007/s10980-018-0691-3

* The ecosystem service discussed on this factsheet is not a focus of the cited paper

No.	Citation
29	Li T, Lü Y, Fu B, Hu W, Comber AJ (2019) Bundling ecosystem services for detecting their interactions driven by large-scale vegetation restoration: enhanced services while depressed synergies. Ecological Indicators 99: 332-342. DOI: 10.1016/j.ecolind.2018.12.041
30	Pham HV, Torresan S, Critto A, Marcomini A (2019) Alteration of freshwater ecosystem services under global change - A review focusing on the Po River basin (Italy) and the Red River basin (Vietnam). Science of the Total Environment 652: 1347-1365. DOI: 10.1016/j.scitotenv.2018.10.303
31	Kay S, Crous-Duran J, Ferreiro-Domínguez N, García de Jalón S, Graves A, Moreno G, Mosquera-Losada MR, Palma JHN, Roces-Díaz JV, Santiago-Freijanes JJ, Szerencsits E, Weibel R, Herzog F (2018) Spatial similarities between European agroforestry systems and ecosystem services at the landscape scale. Agroforestry Systems 92(4): 1075-1089. DOI: 10.1007/s10457-017-0132-3
32	Barral MP, Oscar MN (2012) Land-use planning based on ecosystem service assessment: A case study in the Southeast Pampas of Argentina. Agriculture, Ecosystems and Environment 154: 34-43. DOI: 10.1016/j.agee.2011.07.010
33	Posthumus H, Rouquette JR, Morris J, Cowing DJG, Hess TM (2010) A framework for the assessment of ecosystem goods and services; a case study on lowland floodplains in England. Ecological Economics 69(7): 1510-1523. DOI: 10.1016/j.ecolecon.2010.02.011
34*	Feld CK, Sousa JP, da Silva PM, Dawson TP (2010) Indicators for biodiversity and ecosystem services: towards an improved framework for ecosystems assessment. Biodiversity and Conservation 19(10): 2895-2919. DOI: 10.1007/s10531-010-9875-0
35	Maes J, Hauck J, Paracchini ML, Ratamaki O, Hutchins M, Termansen M, Furman E, Perez-Soba M, Braat L, Bidoglio G (2013) Mainstreaming ecosystem services into EU policy. Current Opinion in Environmental Sustainability 5(1): 128-134. DOI: 10.1016/j.cosust.2013.01.002
36	Helfenstein J, Kienast F (2014) Ecosystem service state and trends at the regional to national level: A rapid assessment. Ecological Indicators 36: 11-18. DOI: 10.1016/j.ecolind.2013.06.031
37	Schulte RPO, Creamer RE, Donnellan T, Farrelly N, Fealy R, O'Donoghue C, O'HUallachain D (2014) Functional land management: A framework for managing soil-based ecosystem services for the sustainable intensification of agriculture. Environmental Science & Policy 38: 45-58. DOI: 10.1016/j.envsci.2013.10.002
38	Maes J, Liquete C, Teller A, Erhard M, Paracchini ML, Barredo JI, Grizzetti B, Cardoso A, Somma F, Petersen JE, Meiner A, Gelabert ER, Zal N, Kristensen P, Bastrup-Birk A, Biala K, Piroddi C, Egoh B, Degeorges P, Fiorina C, Santos-Martín F, Naruševičius V, Verboven J, Pereira HM, Bengtsson J, Gocheva K, Marta-Pedroso C, Snäll T, Estreguil C, San-Miguel-Ayanz J, Pérez-Soba M, Grêt-Regamey A, Lillebø AI, Malak DA, Condé S, Moen J, Czúcz B, Drakou EG, Zulian G, Lavalle C (2016) An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020. Ecosystem Services 17: 14-23. DOI: 10.1016/j.ecoser.2015.10.023
39	Clerici N, Paracchini ML, Maes J (2014) Land-cover change dynamics and insights into ecosystem services in European stream riparian zones. Ecohydrology and Hydrobiology 14(2): 107-120. DOI: 10.1016/j.ecohyd.2014.01.002

* The ecosystem service discussed on this factsheet is not a focus of the cited paper