Current status of water-related planning for climate change adaptation in the Spree River basin, Germany

Saskia Arndt[1], Stefan Heiland[1]

[1]Chair of Landscape Planning and Development, Technische Universität Berlin, Berlin, 10623, Germany

5 *Correspondence to*: saskia.arndt@tu-berlin.de

Abstract. Fuelled by climate change, low flows, heavy rain and flooding likely intensify in the future, adding to the pressures experienced by rivers in Western and Central Europe in recent decades. To meet these challenges, comprehensive water-related adaptation to climate change is indispensable. Based on the case study of the Spree River basin in Germany, this study analysed legally defined plans for water management, spatial and landscape planning for their current status of

10 integrated climate change adaptation. To pre-structure the document analysis, eight water management fields of action for adaptation to climate change were identified using official recommendations for action. 39 % of the 28 plans analysed specify objectives and measures for adapting to climate change. Of these, 55 % address the diverse impacts of climate change in a more comprehensive way, including prevention and mitigation of droughts and floods, and protection of water ecosystems and groundwater resources. Filling these planning gaps may include more frequent updating of plans, greater

15 focus on evidence from informal plans, multifunctional measures, and adaptation of best practice examples for systematic integration of climate change impacts and adaptation. Planning and implementing comprehensive climate change adaptation will strengthen the resilience of ecosystems and secure human livelihoods.

1 Introduction

According to the Intergovernmental Panel on Climate Change (IPCC, 2022), climate change is already affecting rivers in

20 Western and Central Europe with high confidence, and impacts are expected to accelerate. Precipitation in recent decades has significantly increased river flooding in Western and Central Europe and is estimated to further exacerbate in the future, as are the intensity and frequency of heavy rainfall events and related pluvial flooding (Ranasinghe et al., 2021). Furthermore, low flows are likely to become more frequent and severe, leading to streamflow droughts and water scarcity (ibid.). Over the last century, an increase in water temperature of about 1–3 °C has been observed in European rivers, with an

25 upward trend in the future, which may lead to significant changes in species composition and aquatic ecosystem functioning (EEA, 2017; Wanders et al., 2019).

In recent years, Germany has repeatedly experienced extreme weather events with deadly consequences, demonstrating the diverse threats associated with climate change. For example, heavy rainfall and flooding along the Ahr River in July 2021

caused deaths and damage to homes, businesses, and critical infrastructure (Tradowsky et al., 2023), summing up to an estimated €40.5 billion direct and indirect costs (Trenczek et al., 2022). Another widely regarded example is the Oder River: low water levels and higher water temperatures have made the river more sensitive to sewage disposal and pollutants, causing the collapse of the ecosystem in August 2022 with a fish kill of about 360 tonnes over a length of 500 km (Free et al., 2023).

Preventing and mitigating these and other effects of water-related hazards requires appropriate planning that fully addresses the impacts of climate change. Using the example of the Spree River basin, this study examines the current status of climate change adaptation in water-related planning.

2 Study area and scope

2.1 Spree River basin and its water management challenges

The Spree River basin (Fig. 1) is part of the German Elbe River basin (FGG Elbe, 2021b) and covers a river length of approximately 382 km (Uhlmann et al., 2023). It springs in south-eastern Saxony, flows northwards through Brandenburg and into the Havel in Berlin. It is therefore located in an area with one of the lowest precipitations in Germany, with average precipitation values of 500–700 mm in the Berlin-Brandenburg region for the years 1991–2020 (Umweltatlas Berlin, 2024). The middle section of the Spree, on the border between Saxony and Brandenburg, is part of the Lusatia region (Uhlmann et al., 2023). Here, large areas of the Spree River basin are characterised by around 150 years of active open-cast lignite mining and the resulting post-mining landscapes with many artificial lakes. To the north of the Lusatia region, the Spree flows through the Spree Forest, a lowland with extensive floodplains, moors, and swamps with a large water-related tourism industry (MLUR, 2000). The last part of the Spree River is heavily influenced by the capital region of Berlin with large sealed areas and a high population density (SenStadtUm, 2016).

The coal phase-out by 2038 for climate change mitigation is putting pressure on water management in the Spree River basin (Uhlmann et al., 2023). Due to lignite mining, the groundwater level is kept artificially low and swamp water is pumped into the Spree River. This, together with the construction of dams, has led to artificial discharge conditions and a water surplus in the Spree for over 60 years, benefitting the water balance in the subsequent Spree Forest and the Spree-dependent water supply for the capital region of Berlin. As part of the coal phase-out, the remaining open-cast mines in the Lusatia region must be redeveloped. Under the given environmental conditions, water resources of the Spree River basis without pumped water will not be sufficient to fill all dams and opencast mining holes located in the Spree region for efficient water storage, as was originally intended. The coal phase-out will consequently lead to a higher risk of water shortages in the Spree, negatively affecting the protected ecosystems and regionally significant tourism in the Spree Forest and the metropolitan water supply (ibid.). Regarding the latter, around 70 % of Berlin's water supply is currently obtained from bank filtration

along the rivers Spree and Havel (BWB, 2022), illustrating the high water supply pressure on the Spree water. Climate
60   change is expected to exacerbate the impending challenges to water management through rising temperatures, evaporation
and water demand (Uhlmann et al., 2023).

Therefore, the case study of the Spree River basin exemplifies the complexity of future water management, providing a study
area with diverse demands on water as a habitat and resource for the following analysis.
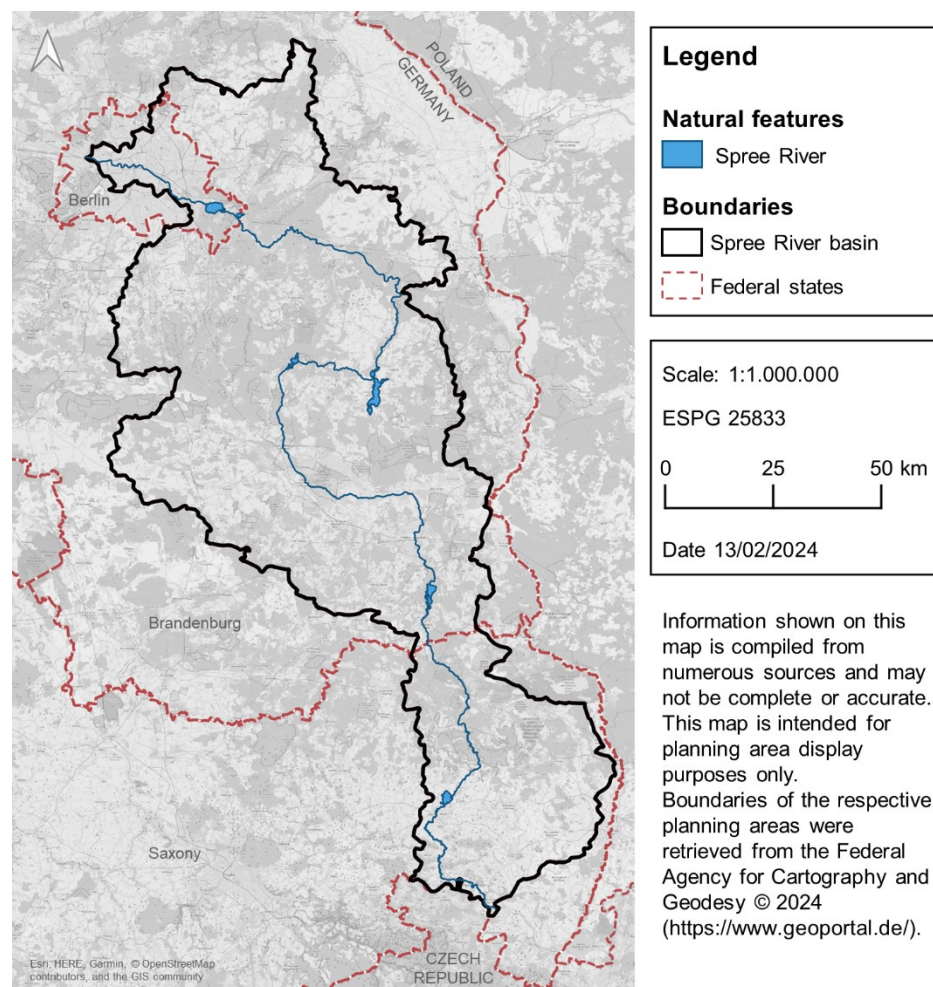
Figure 1. Spree River basin.

65   **2.2 Water-related planning**

In Germany, water issues are regulated by a variety of laws for water management (WHG[1]), spatial planning (ROG[2]), land
use planning (BauGB[3]) and landscape planning (BNatSchG[4]). Addressed are inter alia flood protection (§ 2 ROG, Section 6

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[1] *Wasserhaushaltsgesetz* (Federal Water Act of July 2009), incorporates the WFD in Germany

WHG), rainwater management (§ 55 WHG, § 9 BauGB), protection of groundwater resources (§ 1 BNatSchG, § 2 ROG) or protection of water(-dependent) ecosystems (§ 1 BNatSchG, § 6 WHG).

70 Water management in accordance with the Floods Directive (FD) and the Water Framework Directive (WFD) refers to plans of cross-administrative river basins. The Flood Risk Management Plan, the River Basin Management Plan and the Programme of Measures of the German Elbe River basin are legally binding for the federal state authorities (§ 2 BWG; MdJ, 2021; § 87 SächsWG). River basin management plans and programmes of measures can be concretised by river development plans on the sub-basin level (Article 13 WFD). Their preparation is not required by law, and the objectives described do not

75 impose binding obligations on public authorities. As such, they do not constitute formal planning. Nevertheless, they are useful, if not necessary, for the spatially specific implementation of the overarching river basin management plans and programmes of measures, and thus for achieving the WFD targets (Ormond et al., 2018). Given that Germany is significantly lagging behind in meeting the WFD targets (BMUV & UBA, 2022), their preparations are arguably even more important.

Spatial, land use and landscape plans usually exist at the administrative levels of the federal states, regions and

80 municipalities (§ 13 ROG, § 5 to 10 BauGB, § 10 to 11 BNatSchG). Spatial plans deal with the overall spatial development and are legally binding for public authorities (§ 3 ROG). Landscape plans concentrate on the sustainable development of natural assets (biodiversity, soil, water, air, climate, landscape) and open space recreation (§ 1 and 9 BNatSchG) and usually have to be integrated into spatial or land use plans to become legally binding (§ 10 and 11 BNatSchG). However, even without such integration, their content must be considered (not strictly followed) in all plans and projects that may affect

85 nature and landscape (§ 9 BNatSchG).

To analyse and assess the current status of water-related climate change adaptation in the Spree River basin, the study scope covers relevant plans of water management, spatial and landscape planning. The study focuses on formal plans that have a legal basis and need to be prepared and updated, with the exception of the river development plans, which have a legal basis in the WFD but are not required to be prepared or updated. Selection criteria for the plans included a spatial reference to the

90 Spree River basin, a preparation by or on behalf of a public authority, and digital availability. In the case of the Flood Risk Management Plan, the River Basin Management Plan and the Programme of Measures of the German Elbe River basin, the study scope includes measures limited to a smaller part of the Elbe River basin, the coordination area "Havel". For plans requiring mandatory updating, the most recently published version or the current draft (if already publicly available and participation procedures completed) was analysed. Land use and landscape plans on the municipal level were not

95 investigated, due to their large number, which exceeded the working capacities. Berlin is an exception, as it is a city-state with only two formal administrative levels (city-state and districts).

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[2] *Raumordnungsgesetz* (Federal Spatial Planning Act of December 2008)

[3] *Baugesetzbuch* (Federal Building Code in the version of the announcement of November 2017)

[4] *Bundesnaturschutzgesetz* (Federal Nature Conservation Act of July 2009)

3 Methodology

A document analysis (Bowen, 2009) allowed the evaluation of the current status of water-related climate change adaptation in the study's relevant plans. Firstly, a general analysis examined the consideration of climate change aspects in the plans,

100 using three predefined categories (Table 1).

Table 1. Analysis categories.

Category	Description
CC	Climate change or a closely related term (e.g., global warming) is mentioned in the plan.
CCI	(Potential) climate change impacts concerning the planning area are described in the plan.
CCA	Climate change adaptation is considered in the context of water management in the plan.

Secondly, a more detailed analysis investigated the comprehensiveness of climate change adaptation within the plans. Here, the pre-structuring of the data largely corresponds to the updated Climate Change Report of 2020 by the German Working Group on water issues of the Federal States and the Federal Government (*Bund/Länder-Arbeitsgemeinschaft Wasser*)

105 (LAWA, 2020). The report contains 15 nationwide water management fields of action with an extensive list of (superordinated) measures and (subordinated) actions to adapt to climate change for each field of action. For the Spree River basin and with consideration of the selected water management, spatial and landscape plans, eight fields of action are relevant for the analysis:

(a) Low water management

110 (b) Groundwater protection and use

(c) Public water supply

(d) Agricultural irrigation

(e) Water ecosystem protection

(f) Flood protection during heavy rain

115 (g) Inland flood protection

(h) Urban drainage and wastewater treatment

The exclusion of some measures from the list of climate change adaptation measures proposed by the LAWA increased its suitability for the study area and the examined plans. The final selection of the water management fields of action and associated climate change adaptation measures with potential actions provides an overview of possibilities to implement

120 climate change adaptation in the Spree River basin (see S1–S8 in the Supplement) and serves as the basis for the analysis of the climate change adaptation planning status.

Planning statements concerning objectives, measures or actions were included in the analysis as direct quotes if they met the following requirements:

■ The statement is described in the context of climate change adaptation or climate change and its (potential) impacts.

- ▪ The statement is linked to at least one of the water management fields of action suggested by the LAWA.
- ▪ The statement corresponds with a proposed climate change adaptation measure and/or action by the LAWA.

The analysis excluded planning statements relevant to but without textual reference to climate change adaptation. This ensured the focus on the current consideration of climate change adaptation in water management, rather than the potential for climate change adaptation (see discussion, Sect. 5.6).

4 Results

The document analysis includes a total of 28 plans, consisting of 19 water management plans, 5 spatial plans and 4 landscape plans (Table 2). Not all regional and landscape master plans falling within the Spree River basin could be analysed, as they only exist in analogue form or only parts of the plans are available. The River Basin Management Plan and the Programme of Measures of the German Elbe River basin are considered together and therefore counted as one plan in the analysis. 17 river development plans constitute the largest share. The plans' publication dates range from 2021 back to 2000.

Table 2. Overview of the plans examined and their allocation to the analysis categories (n = 28, 1 = applies). Plan abbreviations are composed of plan acronym, area allocation and publication date. Plan acronyms are FRMP (flood risk management plan), RBMP (river basin management plan), PoM (programme of measures), RDP (river development plan), SDPro (state development programme), SDP (state development plan), RP (regional plan), LUP (land use plan), LaPro (landscape programme) and LaMaP (landscape master plan). Area allocations for water management plans are the German Elbe River basin (Elbe) or Spree River sub-basins (divers) with federal state affiliation (BB for Brandenburg, BE for Berlin, SN for Saxony). Area allocations for spatial and landscape plans refer to their respective administrative levels, either labelled with the federal state or the region/county with federal state affiliation.

Scope	Plan abbreviations (plan acronym, area allocation, publication date)	Citation	Analysis categories		
			CC	CCI	CCA
Water management (according to the WFD and FD)	FRMP_Elbe_2021*	FGG Elbe, 2021a	1	1	1
	RBMP+PoM _Elbe_2021*	FGG Elbe, 2021b, 2021c	1	1	1
	RDP_Berste_BB_2013	LUGV, 2013a	1		
	RDP_Cottbuser_Spree_BB_2011	LUGV, 2011a			
	RDP_Erpe_BB_2011	LUGV, 2011b			
	RDP_Erpe_BE_2013	SenStadtUm, 2013			
	RDP_Greifenhainer_Fließ_BB_2011	LUGV, 2011c	1	1	1
	RDP_Großes_Fließ_BB_2011	LUGV, 2011d	1	1	
	RDP_Kleine_Spree_SN_2011	LfULG, 2011	1	1	
	RDP_Krumme_Spree_BB_2013	MLUV, 2013	1	1	1
	RDP_Löcknitz_BB_2013	LUGV, 2013b			
	RDP_Mügelspree-see_BE_2015	SenStadtUm, 2015			
	RDP_Panke_BB_2009	MLUV, 2009			
	RDP_Panke_BE_2009	SenGUV, 2011			
	RDP_Pretschener_Spree_BB_2013	LUGV, 2013c			
	RDP_Schwielochsee-Dammühlenfließ_BB_2016	LUGV, 2016			
	RDP_Spree-2_SN_2020	LfULG, 2020	1	1	1
	RDP_Unterer_Spreewald_BB_2012	LUGV, 2012	1	1	
	RDP_Wuhle_BE_2014	SenStadtUm, 2014			

Spatial planning	SDPro_BE-BB_2007*	GL, 2007	1		
	SDP_BE-BB_2019*	GL, 2019	1	1	1
	SDP+LaPro_SN_2013*	SMI, 2013a, 2013b	1	1	1
	RP+LaMaP_Oberlausitz-Niederschlesien_SN_2019*	RPV Oberlausitz-Niederschlesien, 2019	1	1	1
	LUP_BE_2020*	SenSW, 2020	1	1	1
Landscape planning	LaPro_BB_2000*	MLUR, 2000			
	LaPro_BE_2016*	SenStadtUm, 2016	1	1	1
	LaMaP_Oder-Spree_BB_2021*	Landkreis Oder-Spree, 2021a, 2021b	1	1	1
	LaMaP_Spree-Neiße_BB_2009*	Landkreis Spree-Neiße, 2009			
			16	**14**	**11**

* Formal plans (preparation and updating are legally required)

4.1 Consideration of climate change

Regarding the analysis category "CC" (Table 1), 16 plans examined (57 %) mention climate change. 9 out of 21 plans published before 2019 address climate change, and from 2019 onwards all plans do (see Figure S1 in the Supplement). Of the 11 formal plans (marked with * in Table 2), 9 plans (82 %) consider climate change, their publication dates range from 2007 to 2021. Among the 17 river development plans published between 2009 and 2020 (preparation and updating is not legally required), 7 plans (41 %) mention climate change.

4.2 Consideration of climate change impacts

Concerning the analysis category "CCI" (Table 1), 14 plans (50 %) recognise climate change as an issue for the water balance in the planning area and describe (potential) impacts of climate change. The thematic focus lies on increasing low water situations and decreasing water supply due to climate change (described in 12 plans) (see Figure S2 in the Supplement). Seven plans refer to increasing heavy rainfall events and flooding as (potential) climate change impacts. Five plans address the deterioration of the water status in the context of climate change. Overall, 4 out of the 14 plans with climate change impacts (29 %) cover the full range of potential impacts (increasing low water, heavy rainfall and flooding events as well as deterioration of the water status) in their respective planning area.

4.3 Consideration of climate change adaptation

With regard to the analysis category "CCA" (Table 1), 11 plans (39 %) contain planning statements on adaptation to climate change, all of them also considering climate change impacts. Of nine formal plans that consider climate change, all plans except the oldest one (from 2007) address climate change adaptation. Of the seven river development plans recognising climate change, three address climate change adaptation.

Figure 2 panel "(total)" gives a spatial overview of the 11 plans considering climate change adaptation. Panels (a) to (h) show the consideration and spatial distribution of the plans in relation to each water management field of action. Whereas all 11 plans consider the water management field of action "Water ecosystem protection", only five take into account "Flood

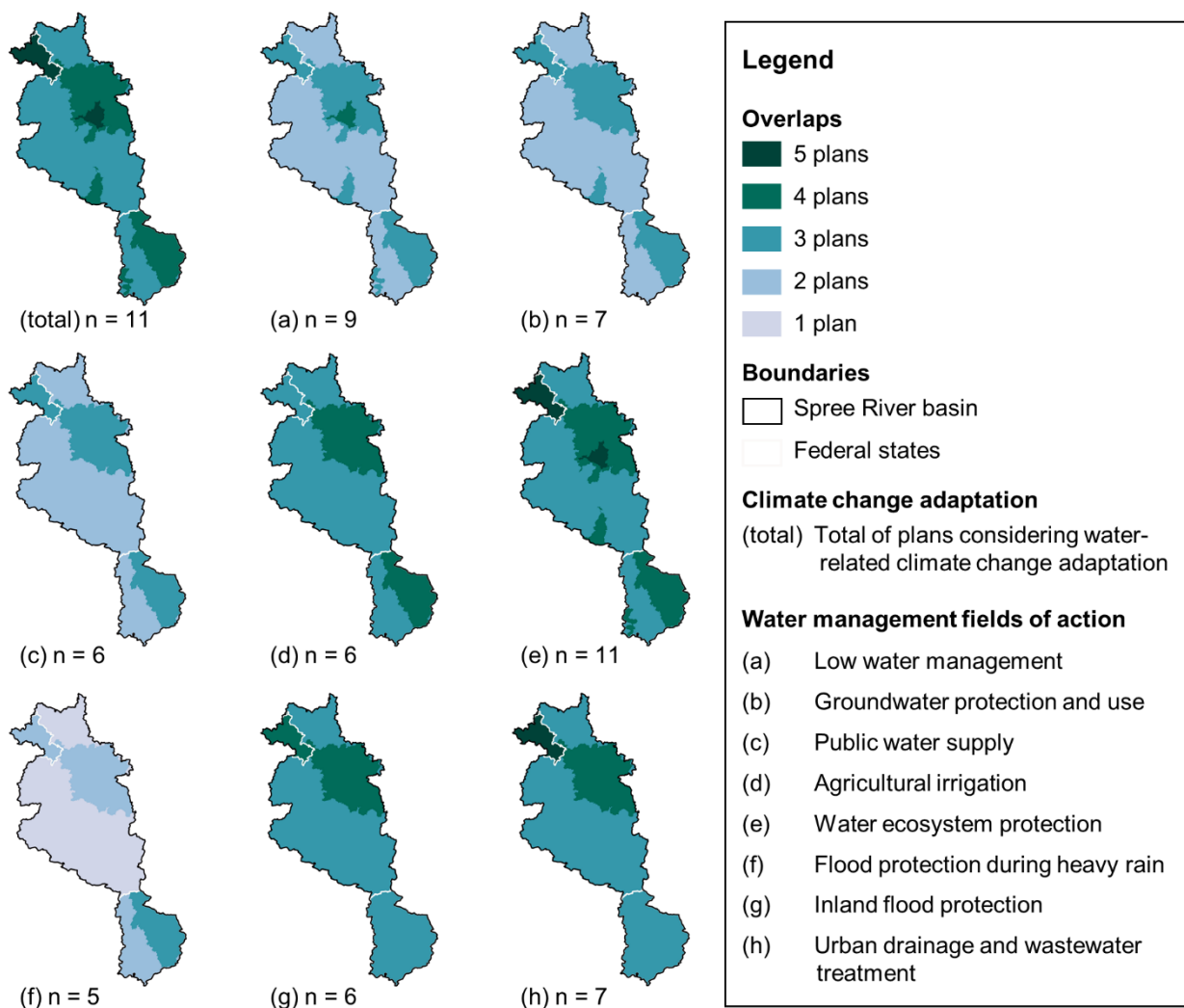
protection during heavy rain". Regarding the latter, relevant measures such as "Water retention in urban areas" or "Exploiting infiltration potentials" are assigned to the action field "Urban drainage and wastewater treatment", and must therefore also be considered (see also Table 3). All other fields of action are dealt with by 6 to 9 plans

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Figure 2. Spatial distribution of plans with proposed climate change adaptation measures corresponding with water management fields of action of the Spree River basin. Boundaries of the respective planning areas were retrieved from the Federal Agency for Cartography and Geodesy © 2024 (https://www.geoportal.de/).

Regarding the consideration of the action fields per plan, four plans refer to all eight or seven action fields, another three plans consider six or five action fields and the remaining four plans address two or three action fields (see Table S9). The latter group includes the three river development plans.

Considering the scope of measures mentioned in the plans for each water management field of action, "Groundwater protection and use", "Agricultural irrigation" and "Inland flood protection" are the most comprehensive. Here, more than half of the plans considering the respective field of action refer to more than two measures (see Table S11, S13 and S16 in the Supplement). For the remaining five action fields more than half of the plans refer to one or two measures (see Table S10, S12, S14, S15 and S17 in the Supplement).

Table 3 gives an overview of the climate change adaptation measures proposed by the LAWA for each action field and the number of plans with corresponding planning statements. For a better understanding of the individual measures, please note the proposed actions for each measure by the LAWA listed in Table S1–S8 in the Supplement or the original Appendix II of the Climate Change Report by the LAWA (2020).

Table 3. Water management fields of action with climate change adaptation measures adopted from the Climate Change Report by the LAWA (2020) and number of plans with corresponding planning statements in the context of climate change adaptation.

Water management fields of action (Total of plans)		Climate change adaptation measures according to the Climate Change Report by the LAWA (2020)	Number of plans with corresponding planning statements
(a)	Low water management (n = 9)	Low water and temperature forecasting	0
		Water use restrictions	5
		Ensuring water quality	5
		Oxygen management through aeration	0
		Artificial raising of low water levels	3
		Creating artificial water reservoirs	1
		Promoting natural water retention	7
(b)	Groundwater protection and use (n = 7)	Climate-specific evaluation and adaptation of groundwater monitoring	0
		Promoting groundwater-friendly agriculture (quality and quantity)	4
		Land use changes	5
		Protecting groundwater-dependent terrestrial ecosystems (peatlands)	7
		Promoting groundwater recharge	7
		Increasing groundwater supply	1
		Sustainable groundwater management	3
(c)	Public water supply (n = 6)	Redundant water harvesting systems	1
		Adapting water supply infrastructure	3
		Rainwater harvesting	1
		Reducing water demand	3
		Improving water quality in the pipeline network	0
		Advanced drinking water treatment	0
		Comprehensive water supply management	3
(d)	Agricultural irrigation (n = 6)	Soil and erosion protection	6
		Conservation tillage	4
		Humus accumulation	4
		Adaptations in cultivation	1
		Efficient irrigation	1
		Groundwater substitution	0

(e)	Water ecosystem protection (n = 11)	Improving continuity of flowing waters	1
		Variation of hydromorphological structures	8
		Protecting and developing riparian strips	3
		Installing sedimentation barriers	4
		Nature-conserving watercourse maintenance	2
		Conservation and expansion of protected areas and biotope networks	6
		Reducing diffuse pollutant entry and nutrient inputs	4
		Adapting abstraction and discharge threshold values	4
		Water quality warning service	0
		Climate-specific adaptation and evaluation of water monitoring	1
(f)	Flood protection during heavy rain (n = 5)	Retention through changes in forest management	3
		Establishing and securing emergency waterways	0
		Object protection in case of flood risk	1
		Organised measures in case of extreme rainfall and flash flooding events	1
		Behavioural precautions and training in the event of extreme rainfall and flash flooding	3
		Regular maintenance and inspection of the drainage systems	1
		Flood risk assessment (e.g., heavy rain hazard and risk maps)	1
(g)	Inland flood protection (n = 6)	Technical flood protection	5
		Recovery of flood plains and renaturation of floodplains	5
		Activating additional and optimising existing retention areas	5
		Land use regulations in flood plains/areas at risk of flooding	4
		Designation of *Vorranggebiet*[5] and *Vorbehaltsgebieten*[6]	1
		Flood hazard and risk maps	4
		Identifying and mapping areas at risk of waterlogging (groundwater)	0
		Property protection in the event of damaging high groundwater levels	2
		Flood partnerships	2
		Organised measures in case of an extreme inland flooding event	2
		Behavioural precautions and training in the event of extreme inland flooding	4
(h)	Urban drainage and wastewater treatment (n = 7)	Optimising the construction and operation of existing sewer systems	3
		Adapting wastewater treatment operations	1
		Installations for precipitation water treatment	1
		Water retention in urban areas	4
		Exploiting infiltration potentials	7
		Incentives for rainwater management	0
		Protecting wastewater facilities from floods	1

5 Discussion

The analysis reveals some considerable gaps in the comprehensiveness of climate change adaptation in water-related
190   planning. Merely half of the plans we examined refer to (potential) climate change impacts within their designated planning
areas, and less than half also make planning statements about adapting to these changes. Only about one third of the plans
mentioning climate change adaptation refers to all eight or seven water management fields of action. Gaps become

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[5] *Vorranggebiet* is an area in which certain spatially significant functions or uses (here: preventive flood protection) have
priority over conflicting uses and must be designated by spatial planning (Scholich, 2018).

[6] *Vorbehaltsgebiet* is an area in which certain spatially significant functions or uses (here: preventive flood protection) must
be given special weight when considering competing spatially significant uses and must be designated by spatial planning
(Scholich, 2018).

particularly evident in the limited extent of measures (only one or two) on "Low water management", "Public water supply", "Water ecosystem protection", "Flood protection during heavy rain" and "Urban drainage and wastewater treatment" that
195 most plans refer to. Therefore, the subsequent sections elaborate on opportunities to improve the integration of climate change adaptation into planning instruments that treat water management issues.

5.1 Updating plans more frequently

The analysis shows that the publication date has a significant impact on the extent to which climate change is addressed in the plans. The year 2019 draws the line from which all plans address climate change, its impacts and adaptation measures (7
200 out of 7). The plans published before 2019 show lower consideration rates. Here, only one third of the plans describes climate change impacts (7 out of 21 plans), and only 19 % climate change adaptation measures (4 out of 21) (Figure S1 in the Supplement).

Schliep et al. (2017) examined landscape programmes and landscape master plans in Germany concerning their consideration of climate change and associated objectives and measures in the context of biodiversity conservation. The
205 study shows similar results: the more recent the plan, the higher the rate of climate change consideration. According to § 10 of the BNatSchG, landscape master plans have to be updated at least every ten years. Taiber (2023) indicates a high need for action regarding the updating and digital provision of landscape master plans in Germany, with the majority exceeding a ten-year planning horizon.

5.2 Including insights from informal planning

210 Regular updating of plans allows for the inclusion of ongoing environmental changes and new policy priorities. For example, the Berlin Senate faced (potential) impacts of climate change, the coal phase-out and a growing population in the informal Master Plan Water from 2022 (SenUMVK, 2022). The plan includes a variety of measures in the areas of low water management, rainwater management, wastewater infrastructure and public water supply, where the analysed formal plans for Berlin show gaps. In Brandenburg, the informal Federal Low Water Concept has been introduced in 2021 (MLUK, 2021).
215 Among other things, it addresses the introduction of a water quality warning service focused on low water, which was not envisaged in the water management field of action "Water ecosystem protection" by any of the preceding plans. Such informal plans are not legally formalised, standardised and directly legally binding but are characterised by a high degree of flexibility and adaptability, allowing pressing issues to be addressed in a timely manner (Danielzyk and Sondermann, 2018). Incorporating their respective findings and suggestions into formal plans offers opportunities for a more comprehensive
220 integration of climate change adaptation, achievable if formal plans are regularly updated.

5.3 Promoting multifunctional measures to address various climate change impacts

Four out of 14 plans describing potential climate change impacts address the variety of potential impacts of climate change (increasing low water, heavy rain and flood events and deterioration of water status) for their respective planning area (see Figure S2 in the Supplement). Only 2 out of 11 plans addressing climate change adaptation measures for all eight water

225   management fields of action, another two plans do so for seven action fields, another two for six, one for five and the remaining four plans mention measures for two or three action fields (see Table S9). Here, the river development plans in particular show a very narrow planning approach, as they do not formulate climate adaptation measures for the water management fields of action "Public water supply", "Agricultural irrigation", "Flood protection during heavy rain", "Inland flood protection" or "Urban drainage and wastewater treatment". However, according to Article 1 of the WFD, inland

230   surface waters should also be developed and protected in the most natural way possible for sustainable and equitable water use and to minimise flooding. Furthermore, the majority of plans that mention climate change adaptation for the water management fields of action "Low water management", "Water ecosystem protection", "Flood protection during heavy rain" and "Urban drainage and wastewater treatment" refer to only one or two measures.

Such planning gaps could be filled by focusing more on the multifunctionality of measures. Planning approaches like the

235   sponge landscape concept (BBSR, 2023a), sponge city concept (BBSR, 2023b) or nature-based solutions (EU, 2015) already include integrative planning for both periods of water abundance and water scarcity.

Many potential climate change adaptation measures are multifunctional and serve multiple water management fields of action. They contribute to improving the functioning of ecosystems and the quality of human life, also in the absence of climate change impacts, and can therefore be defined as no-regret measures (cf. FGG Elbe, 2021b). Measures promoting

240   natural water retention and groundwater recharge, improving water quality and protecting biodiversity include peatland protection, floodplain restoration, establishing riparian strips and riverbank planting, soil-conserving agriculture, forest protection and afforestation, forest restructuring from pure pine to mixed broadleaved forests and unsealing. For comprehensive and efficient climate change adaptation in water-related planning, planned measures should be multifunctional and address multiple potential climate change impacts.

245   **5.4 Adopting best practice examples for systematic integration of climate change impacts and adaptation**

The analysis shows considerable variation in the way climate change impacts and adaptation are addressed. Out of 14 plans that refer to (potential) climate change impacts, only five do so by a separate section or extensive references. The remaining nine plans include only sporadic references to (potential) climate change impacts.

Given that climate change is already having an impact on the natural environment and is expected to further do so, plans

250   should systematically include (potential) climate change impacts. Climate scenarios and models can be used to assess climate change-related hazards for the planning area. The DWD (2021) provides guidance on the possible interpretations of

climate models. Linke (2023) specifically helps with the interpretation of regional climate model data, which may be helpful for German planners.

Of the 11 plans that refer to climate change adaptation, eight do so systematically or through extensive references. The
255   remaining three plans only sporadically mention climate change adaptation. The systematic and extensive consideration of climate change adaptation in eight plans contrasts with the five plans that comprehensively address climate change impacts, meaning that at least three plans consider adaptation measures without having thoroughly addressed climate change impacts. This discrepancy might be attributed to (one of) the following reasons: high level of uncertainty in predicting and interpreting climate change impacts at regional/local level, insufficient databases and resources in terms of time, money,
260   staff and expertise. However, this discrepancy shows that adaptation to climate change and precautionary measures (e.g., no-regret measures) can be taken into account in planning even under conditions of uncertainty.

A best practice example for the systematic integration of climate change adaptation is the review of a plan's catalogue of measures for its potential for adaptation to climate change, as demonstrated in the Flood Risk Management Plan, the River Basin Management Plan and the Programme of Measures of the German Elbe River basin (FGG Elbe, 2021a, 2021b, 2021c).
265   In these plans, all planned measures are assessed from two perspectives: firstly, their suitability for adaptation to climate change, and secondly, their vulnerability to progressive climate change. Table 4 illustrates an example from the Programme of Measures of the German Elbe River basin.

Table 4. Best practice example of a systematic integration of climate change adaptation of the catalogue of measures, adopted from the Programme of Measures of the German Elbe River basin (FGG Elbe, 2021c, Anhang M1; translation by the authors).

Measure	Potential actions	Does the measure support adaptation to climate change?	Does climate change affect the effectiveness of the measure?
Improving habitats in the riparian zone	Creation of riparian strips with native trees and shrubs, replacement of technical structures with bioengineering constructions	Yes, because near-natural water bodies are more resilient to climate-related changes in the hydrological regime.	No, because it supports adaptation to climate change.
Establishing linear continuity at dams and retention basins	Construction of passable structures such as bypass channels or fish ladders	Possible, because improved river continuity allows aquatic organisms to avoid adverse climate-related changes in the water body.	Possible, because climate change may change the assessment bases for low and high water levels in water bodies and facilities.
Reducing the impact of leisure and recreational activities	Regulation of recreational use and visitor guidance, prohibition of travelling on waters, camping and/or making fire	Possible, if the adverse effects in the water body are due to activities caused by climate-related changes (e.g., heatwaves).	Yes negatively, longer periods of drought and heat increase the demand for activities in and around water.

270   The adoption of best practice examples can help to facilitate and systematise the integration of climate change adaptation into planning, and can also be beneficial when prioritising measures for implementation.

5.5 Mentioning climate change explicitly in the WFD

All 18 water management plans according to the WFD included in the analysis address measures to improve water status. This is based on the objective in Article 4 of the WFD to achieve "good surface water status" by ensuring at least good

275 ecological and chemical status in surface waters. Eight water management plans mention climate change, of which seven
     also refer to climate change impacts. However, only two of the latter make a specific link between climate change and the
     deterioration of water status, thus addressing a potentially more challenging achievement of good ecological and chemical
     status (see Figure S2 in the Supplement).

     The WFD does not explicitly mention climate change. This has already been addressed and criticised in the literature
280 (Hendry, 2017; Lamon et al., 2009; Reese et al., 2016). However, the 2019 evaluation of the WFD concludes that the
     directive is generally fit for purpose, but that implementation needs to be accelerated (DG ENV, 2019). Nevertheless,
     specifically mentioning climate change as an aggravating factor in achieving the WFD targets and emphasizing its
     consideration in planning of measures may strengthen the integration of climate change adaptation into water-related
     planning.

285 **5.6 Limitations of the methodological approach**

     There are mainly three methodological limitations to our study. Firstly, not all planning areas of the analysed plans lie
     entirely within the Spree River basins, but also extend beyond it. Therefore, we excluded all measures and statements
     referring to areas outside the Spree River basin as far as possible. In some cases, this was not possible with certainty, which
     is why it cannot be ruled out that planning statements have been included in the analysis that do not relate to the Spree River
290 basin. Secondly, climate change adaptation measures solely referring to other river basins were not included in the analysis.
     Therefore, it cannot be excluded that, regarding the single plans, we do not fully have done justice to them with regard to
     how they consider climate change adaptation.

     Thirdly, measures relevant to climate change adaptation are also mentioned in the plans without addressing the measure's
     particular importance in the context of climate change. These measures were excluded from the document analysis, as the
295 primary interest was to determine the extent to which existing plans consciously and explicitly consider the climate-water
     nexus, resulting in the applied methodological approach and the predefined analysis categories. This leads to a partly
     distorted picture of the actual potential for climate change adaptation in planning. However, establishing links between
     existing measures and climate change adaptation is necessary: primarily to highlight conflict awareness in plans and to
     consciously take precautions against climate change impacts. Secondarily to facilitate the prioritisation of actions in the
300 context of ongoing climate change and to demonstrate the diversity of climate change adaptation.

     6 Conclusions

     This study analysed the current consideration of climate change, its impacts and adaptation in water-related planning as a
     governance instrument in the case study of the Spree River basin. We analysed 28 water management, spatial and landscape
     plans. 16 (57 %) refer to climate change and 14 (50 %) also address (potential) impacts of climate change on the respective

305 planning area. Furthermore, a total of 11 plans (39 %) also mention climate change adaptation measures. Here, the majority of the plans address water ecosystem protection, low water management, groundwater protection, urban drainage and wastewater treatment, public water supply, agricultural irrigation and inland flooding. Flood protection during heavy rainfall is considered by less than half of the plans with integrated climate change adaptation. The findings indicate gaps in a comprehensive planning approach to the different impacts of climate change, particularly evident in the limited extent of

310 measures mentioned in the water management fields of action "Low water management", "Public water supply", "Water ecosystem protection", "Flood protection during heavy rain" and "Urban drainage and wastewater treatment". Shortcomings in planning might be caused by insufficient update of the plans and therefore a lack of appropriate mentioning of climate change. In particular, the river development plans, which are an essential contribution to the implementation of the WFD at the sub-basin level, lack references to climate change.

315 The results show a great need for updating plans, especially for many river development plans and to some extent for landscape plans in Brandenburg. Also, recognizing climate change as a threat to the achievement of environmental objectives in the legal basis may strengthen the integration of climate change adaptation into planning. Additionally, more attention should be paid to the findings from current informal plans, to the multifunctionality of existing measures, and to a consistent structured integration of climate change impacts and adaptation into plans to enable comprehensive and effective

320 water management in times of climate change. This work aims to encourage authorities, planning agencies and water management practitioners to use the potential of water-related planning for climate change adaptation to enhance the resilience of the Spree River ecosystem and to ensure a liveable future in the Spree River basin.

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325 developed the research methodology. Saskia Arndt carried out the document analysis and wrote the initial draft. Both authors repeatedly reviewed and edited the following draft versions.

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