Every Drop Counts—Pathways to Restore Germany's Water Balance

January 2026

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Founded in 1899, **NABU** (**Nature And Biodiversity Conservation Union**) is one of the oldest and largest environmental associations in Germany. The association encompasses about 960,000 members and sponsors. NABU's most important tasks are the preservation of habitat and biodiversity, the sustainability of agriculture, forestry and water management, and last but not least, climate protection. The communication of nature experiences and the promotion of natural history knowledge are among NABU's central concerns. About 70,000 volunteers play an active role in practical nature conservation work, with great success: this is something that is unique to NABU. These active NABU members look after more than 110,000 hectares of valuable protected reserves in Germany. NABU also has volunteer groups working on an international level to conserve nature and combat poverty in Africa, Eurasia, and the Caucasus. This work is supported by professionals at our regional offices and at our national headquarters in Berlin, who take care of public relations, project development and management, and political lobbying. NABU is part of BirdLife International.

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1. Foreword

Water is a vital foundation for societies, economies, and ecosystems. Yet across the world, water systems are coming under increasing pressure. Climate change, population growth, and land-use dynamics are altering natural water cycles and intensifying both scarcity and excess. Managing this finite resource sustainably has become one of the central environmental and economic challenges of our time.

Germany is not exempt from these developments. Although the country has long been considered water-abundant, recent years have shown growing regional disparities in water availability and a continual decline in water storage. Since the early 2000s, the country has seen an estimated cumulative decline of roughly 60 billion m^3. Periods of drought, declining groundwater levels, and water quality concerns highlight that even well-developed water systems face mounting stress. Forests, agriculture, industry, and urban areas are all affected in different ways, making integrated and forward-looking management more important than ever.

This report, a collaboration between the Nature and Biodiversity Conservation Union (NABU) and Boston Consulting Group (BCG), aims to provide a comprehensive view of Germany's current and future water challenges. It combines hydrological analysis, economic modeling, and ecological perspectives to explore pathways toward a resilient and sustainable water system.

If we want to build true water resilience, it is key to fundamentally rethink our view and management of water—taking a long-term perspective that focuses on regenerating and reactivating natural water cycles. Drawing from existing research and practical experience, the study outlines solution approaches that connect natural processes with technological innovation to not only optimize the use of existing water but also expand total water availability.

We hope that this report contributes to a broader understanding of the interconnections within Germany's water landscape and offers guidance for joint action. Achieving water resilience will require coordination between policymakers, the private sector, and civil society, as well as a shared commitment to long-term planning and investment.

By bringing together science, policy, and practice, we can strengthen the foundation for sustainable water management—in Germany and beyond.

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2. Executive Summary

Water sustains life, regulates climate, supports ecosystems, and underpins every aspect of society. Yet this apparent abundance is an illusion that has masked the fragility of our hydrological systems. Less than one percent of Earth's freshwater is directly available for human use. Decades of deforestation, soil sealing, and unsustainable land use have disrupted the small water cycles that keep landscapes cool, moist, and fertile. Water scarcity is therefore not only a climatic issue but a systemic land- and ecosystem challenge.

Globally, land use and land use changes, shifting rainfall, groundwater depletion, and contamination are intensifying scarcity. Germany, long considered "water-secure," is now experiencing these trends firsthand. Rainfall is less predictable, drought and floods occur more often. Wastewater discharge and conventional agricultural practices degrade water quality. At the same time aging and disparate infrastructure constrains access. An estimated water storage loss of roughly 60 billion m³ over the last two decades—about the volume of Lake Constance—reveals a clear imbalance and quantitative deficit between water supply and demand: Germany is losing more water than its systems can naturally restore.

The consequences are both visible and hidden. Annual damages from floods, droughts, and pollution could reach around €10 billion–15 billion. The slow depletion of groundwater, growing local imbalances between supply and demand, and rising competition for scarce resources could add at least €10 billion and up to roughly €25 billion, based on more extreme assumptions, in annual damages by 2050. The cost of inaction could therefore amount to at least €20 billion–25 billion per year, or at least €500 billion-625 billion by 2050—a significant burden on Germany's economy, environment, and resilience.

This study examines how Germany can restore its water balance through two complementary pathways: expanding the total water available and optimizing usage of existing water.

Expansion aims to increase the total amount of water retained and available in the landscape through both natural and technological means. Key levers include Regenerative Agriculture that rebuilds soil health and the soil carbon sponge—the soil's carbon-rich structure that enhances water retention, nutrient cycling, and resilience; Forest Management that facilitates the transformation of coniferous stands into more climate- resilient mixed-deciduous forest ecosystems; Dynamic Drainage that allows for adaptive landscape water management in the face of more frequent phases of water excess and scarcity; Other Landscape-Level Methods that retain water via wetlands and floodplains; Sponge Cities that unseal and re-green urban areas; and Technical Supply Expansion such as desalination or inter-basin transfer to diversify sources.

Optimization ensures that the available water is used smarter and more circularly through Gray Water Reuse and Water Use Optimization across agriculture, industry, and households. Together, these approaches balance natural restoration with technological innovation.

Our analysis shows that Regenerative Agriculture, Forest Management, and Dynamic Drainage have the largest combined impact, adding roughly 7 billion–7.5 billion m³ of additional water annually through improved infiltration, soil-moisture retention and groundwater recharge—enough to close Germany's current water-storage gap over time. Implemented at scale, they can transform depleted soils and forests into functioning water sponges that reduce runoff, stabilize microclimates, sustain ecosystems, and rebuild resilience from the ground up.

Achieving this transformation requires a shift in how water is governed, financed, and valued. Water's benefits are long-term and diffuse, while its costs are local and immediate, creating a funding gap. Those best positioned to restore water availability, such as farmers and forest owners, often lack incentives and capital, while those most dependent on water security, including industries and utilities, rarely co-invest in maintaining it.

Closing this gap calls for financial and policy mechanisms that treat water as a strategic resource. Redirecting infrastructure funds toward water resilience, harmonizing pricing and incentives, and creating water or nature credits that reward measurable improvements in retention, recharge, and quality will be key.

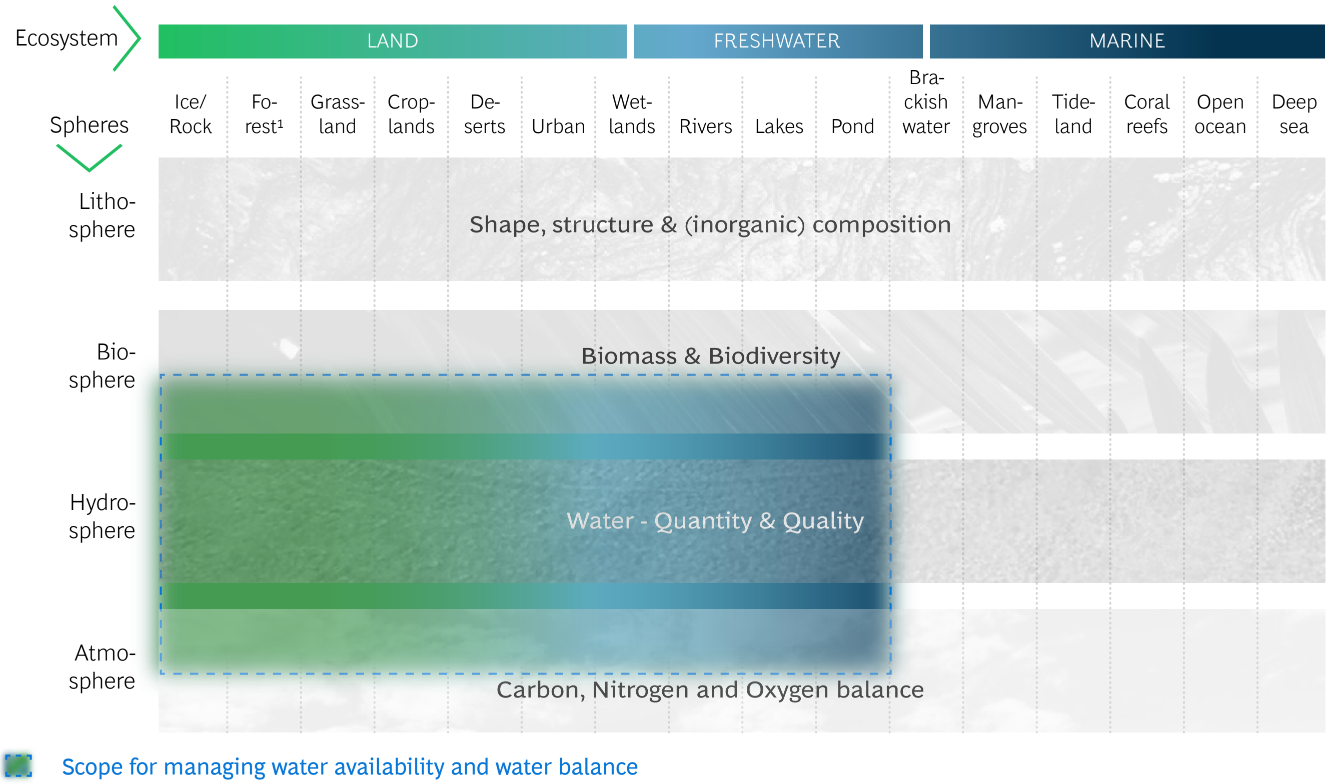
Building water resilience requires a coordinated effort across all sectors—public institutions, businesses, land managers, and financial actors working together to invest in long-term stability. Only through this shared responsibility can water security become the foundation of Germany's climate adaptation, ecological renewal, and economic resilience.

3. Understanding Water—A most precious resource

Water is Everywhere and Part of Everything. Water is fundamental to life across all ecosystems. Contrary to common belief, the hydrosphere is not only important for freshwater and marine ecosystems but equally vital for terrestrial ones, sustaining soils, vegetation, and the conditions that make life on land possible. (See Figure 1.) About two-thirds of our planet's surface is covered by it,[1] two-thirds of the food we produce depends on it,[2] and roughly two-thirds of the human body consists of it.[3] It connects every aspect of our lives from agriculture and energy to industry and health.

[1] USGS (2019): How Much Water is There on Earth? | U.S. Geological Survey
[2] EFSA (2010): Scientific Opinion on Dietary Reference Values for water
[3] USGS (2019): The Water in You: Water and the Human Body | U.S. Geological Survey

Figure 1: Water management is a key issue across the hydrosphere, biosphere, and atmosphere



1. Including Boreal, Temperate and Tropical forests

Sources: BCG analysis

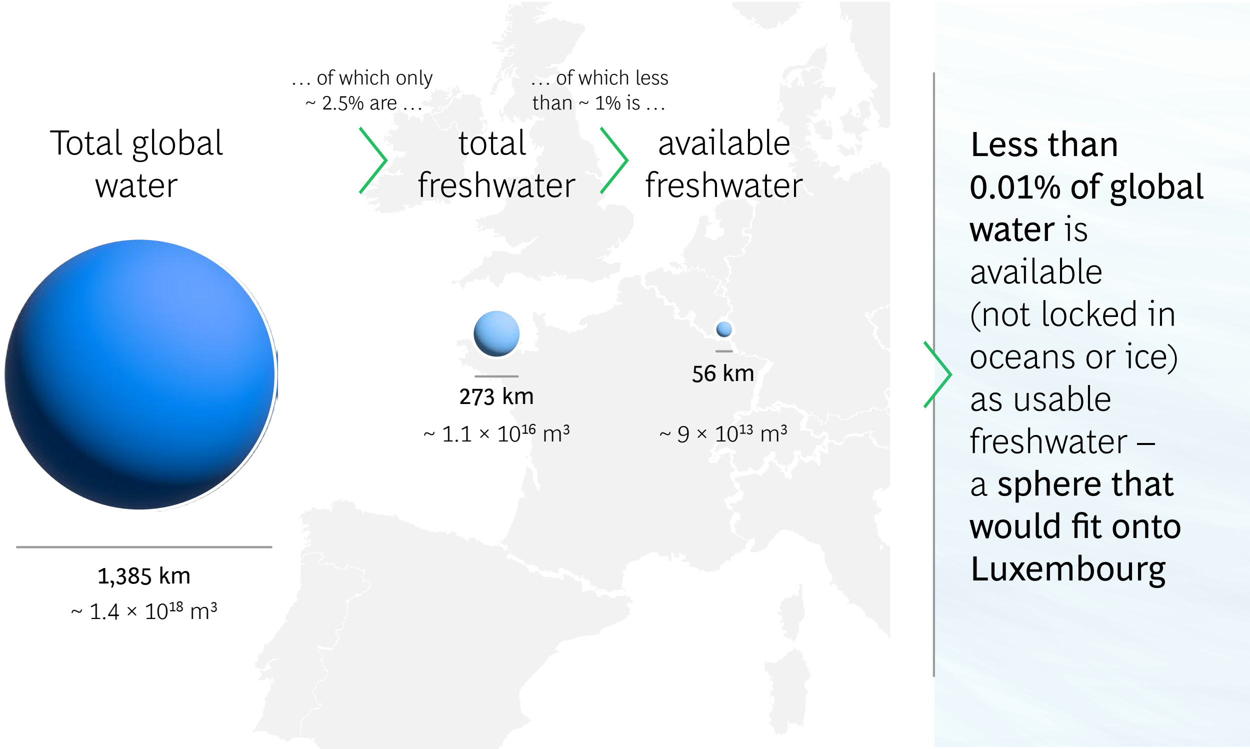
At first glance, this abundance seems reassuring. With so much water on Earth and within us, it is easy to assume there will always be enough. But that assumption does not hold up under closer examination.

The Illusion of Abundance. The Earth—our blue planet—holds around 1.4 quintillion m³ of water or a sphere roughly 1,385 km in diameter[4]: an almost unimaginable volume. Yet only about 2.5% of this is freshwater (a sphere about 273 km in diameter), and less than 1% of that freshwater (a sphere about 56 km in diameter) is directly available to humans.[4, 5] Put differently, the entire share of usable freshwater available to all people on Earth would form a sphere small enough to fit over Luxembourg. (See Figure 2.) In other words, while water appears to be everywhere, the portion available to sustain humanity is extremely limited. Most water is locked in oceans, ice, or deep underground. The share that flows through rivers, lakes, and shallow aquifers—the water we depend on daily—represents less than a drop in the planetary bucket. Water may seem abundant, but in practical terms it is a scarce resource.

[4] USGS (2019): How Much Water is There on Earth? | U.S. Geological Survey

[5] USGS (2019): Where is Earth's Water? | U.S. Geological Survey

Figure 2: The illusion of earth as a blue planet and the abundance of water



Sources: USGS, BCG & NABU analysis

Understanding How Water Flows—and in Which "Colors." The available water is never static; it is constantly cycling through the environment, sometimes stored where we can access it and sometimes locked away in forms or places we cannot use.

This movement happens through two interconnected systems. (See Figure 3.) The large water cycle operates on a global scale, transporting water between oceans, atmosphere, and continents. It redistributes moisture across the planet but is slow to respond to local shortages. The small water cycles, by contrast, comprise countless loops that work locally: Roughly two-thirds of continental rainfall evaporates from land and vegetation, condenses in the atmosphere, and falls again nearby.[6] Each local cycle is shaped by its landscape and climate conditions but interacts with adjacent ones, together forming a dynamic network that underpins regional hydrology. Their functioning depends strongly on land use and land cover, as well as on the soil's capacity to act as a carbon sponge—the porous, carbon-rich structure of healthy soils that stores rainfall, supports microbial life, and releases moisture back to the atmosphere through plants.[7,8,9] When intact, this living sponge enables infiltration, retention—1 gram of soil carbon can store 8 grams of water—and the slow release of water, allowing vegetation to return moisture to the atmosphere through evaporation and transpiration. This process is essential for sustaining continental rainfall.[10] Greener landscapes promote this feedback and strengthen local moisture recycling.[11] These processes increase energy capture through photosynthesis, improve carbon sequestration and nutrient cycling, and stabilize microclimates by enhancing the system's capacity to dissipate energy gradients rather than heating the surface, which are all key aspects of a functional thermodynamic balance.[11]

Land management practices that minimize runoff and maximize infiltration not only prevent erosion and nutrient loss but also sustain the upward flow of water that maintains regional precipitation: Moist soils enable vegetation to capture energy and CO_2 (roughly 120 GT C per year[7]) for photosynthesis and later evaporation as well as transpiration, thus acting as a land cooler and effective CO_2 sink,[6] while supporting the moisture recycling and feedback loop.

[6] Seneviratne et al.(2010): Investigating soil moisture–climate interactions in a changing climate: A review - ScienceDirect
[7] Jehne (2019): https://nzbiocharltd.co.nz/resources/Regenerate-Earth-Paper-Walter-Jehne%20%281%29.pdf
[8] Jehne (2014): https://irp-cdn.multiscreensite.com/d6b81fb6/files/uploaded/2017%20-%20Regenerating%20Earth%27s%20Soil%20Carbon%20Sponge.pdf
[9] Jehne: https://vernoux.org/agriculture_regenerative/Jehne-Restoring_water_cycles_to_naturally_cool_climates_and_reverse_global_warming.pdf
[10] Alpha Lo (2024): Map of the small water cycle - by Alpha Lo
[11] Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany

Degrading this soil carbon sponge collapses this mechanism:[12, 13, 14] When this balance is disturbed, runoff increases, evapotranspiration declines, and precipitation weakens. Dry soils force plants to close their stomata to conserve water, halting photosynthesis and evapotranspiration as well as reducing carbon uptake.[15] The land consequently loses its cooling and carbon-absorbing function, triggering a chain reaction of weather variability and extremes, such as heat accumulation, drought, and ultimately land degradation. This land-atmosphere coupling is especially pronounced in transitional zones between humid and arid climates such as Central Europe, where the loss of soil moisture sharply increases the likelihood and intensity of extreme temperatures.[15]

Intact small water cycles thus underpin the broader precipitation land-climate dynamic: Green, permeable landscapes recycle moisture, sustain rainfall, and buffer heat. Degraded or sealed surfaces, on the other hand, break the cycle, amplifying warming and undermining ecological resilience. They are not only important for the functioning of moisture feedback and ecological stability. As emphasized in the New Water Paradigm,[16] these local cycles are not isolated—they collectively sustain the large, planetary water cycle that connects land and ocean. The link between them is captured by the biotic pump principle: through evapotranspiration and condensation, vegetation generates pressure gradients that draw moist air inland, maintaining rainfall far from the coast. When countless small cycles function, they stabilize precipitation patterns, groundwater levels, and atmospheric moisture flows. Around 95% of the Earth's heat fluxes are controlled by water—through evaporation, condensation, and cloud formation—rather than by CO_2. Hydrological processes are thus the planet's dominant climate regulator.[12] When they collapse, the entire hydrological balance shifts, contributing to both continental drying and rising sea levels. Ensuring small local water cycles function is therefore not only local resilience action, but also global stabilization in practice.

[12] Jehne (2019): https://nzbiocharltd.co.nz/resources/Regenerate-Earth-Paper-Walter-Jehne%20%281%29.pdf
[13] Jehne (2014): https://irp-cdn.multiscreensite.com/d6b81fb6/files/uploaded/2017%20-%20Regenerating%20Earth%27s%20Soil%20Carbon%20Sponge.pdf
[14] Jehne: https://vernoux.org/agriculture_regenerative/Jehne-Restoring_water_cycles_to_naturally_cool_climates_and_reverse_global_warming.pdf
[15] Seneviratne et al.(2010): Investigating soil moisture–climate interactions in a changing climate: A review - ScienceDirect
[16] Kravčík et al. (2007): https://www.waterholistic.com/wp-content/uploads/2024/04/white-paper-nwp_water_for_climate_healing_white_paper_web_2023_final.pdf

Figure 3: Water flows across different cycles and in different colors

Large water cycle transports water between oceans, atmosphere & continents.

Small water cycles transport rain from land & vegetation via atmosphere to local ground.

Green water

Water that is stored in soil and plants – evaporated, transpired or used directly by forests, plants or livestock

Gray water

Water that has been used in households with some contamination (from showers, sinks and laundry, excl. toilets) but reusable after treatment

Blue water

Freshwater from surface or groundwater sources, such as rivers, lakes, reservoirs and aquifers used for irrigation, industry and in domestic & municipal contexts

Sources: Water Footprint Network, BCG & NABU analysis

While conventional wisdom assumes that water deserves attention mainly in summer, these cycles operate year-round with water availability depending on the balance between seasons: What falls and infiltrates in winter determines what remains available in summer. Neglecting one season disrupts the next, weakening the balance and resilience of the entire system.

Within these cycles, water exists in different functional manifestations or "colors,"[17] each representing a specific system and location: (See Figure 3.)

- **Green water** is the moisture stored in soil and plants—the foundation of rainfed agriculture and natural vegetation.[18]
- **Blue water** refers to visible freshwater in rivers, lakes, and aquifers—the part we can withdraw for irrigation, industrial processes, or domestic use.
- **Gray water** is water that has already been used and carries impurities but can be treated and reintroduced into the cycle.

Together, these cycles and colors describe how water transitions through the ecosystem—from clouds to soil, from surface to groundwater, and from clean to used. Managing water therefore means managing these transitions and respecting the interdependence between natural systems and human use.

[17] Water Footprint Network (2011): Glossary – Water Footprint Network, NABU & BCG analysis
[18] A study by Wang-Erlandsson et al. (2022) (https://www.nature.com/articles/s43017-022-00287-8) indicates that the green water planetary boundary is already transgressed.

Balancing Demand and Supply. Given natural systems and human use influence the flow of water, water systems are shaped by two sides of the equation: supply and demand.

On the supply side, the key factors are quantity, quality, and accessibility, each influenced by geography, climate, and infrastructure. Land use factors in as well. Here, not only the type of surface cover (e.g., forest, vegetated land, bare soil, or sealed surfaces) but also the quality of underlying soil and surface management (e.g., regenerative or conservation agriculture versus conventional practices) determines how water moves, is stored, and is filtered, hence reflecting on quantity, quality, and availability.

On the demand side, the main users are industry, households, and agriculture, all of which depend on water of different colors in specific ways and at different times.

Neither side alone determines whether a region experiences water abundance or stress. While conventional thinking often assumes that managing consumption and improving efficiency alone can solve water scarcity, these measures only address one part of the equation. Cutting abstraction can relieve pressure in the short term, but it does not tackle the structural imbalances between renewable water resources, storage capacity, and use. It is the interaction between demand and supply—how much water is available, how it is distributed, and how it is used—that shapes local and global realities. When this balance shifts, challenges can emerge: reduced groundwater recharge, declining water quality, seasonal shortages, or regional conflicts between competing users.

Figure 4: Clearing the waters around common myths

Myths	Reality
Water is **only important for freshwater & maritime ecosystems**	The hydrosphere influences the **functioning of freshwater, marine & terrestrial ecosystems alike**
Water on earth exists in **abundance**, there will always be enough	The entire share of **usable freshwater** available to all people fits the **size of Luxembourg**
If at all, we **only** need to **care about water in summer**	**All seasons contribute** to groundwater recharge, storage & balance
Managing use and **efficiency** solves water **scarcity**	Addressing structural challenges requires **solutions that look at the total water balance**
Water is **only a nature protection issue**	The **availability of water affects all sectors**, making it a core economic & societal concern
Germany **does not have any water-related issues**	**Local & seasonal shortage, quality issues,** and **flood risk** are becoming **more frequent & severe**

Sources: BCG & NABU analysis

4. Water Challenges—Too little, too much, too dirty

Introducing the BCG Water Risk Matrix. Water risks emerge when the balance between water supply and demand is disrupted. This imbalance is shaped by multiple, interlinked drivers[19] that also have a direct effect on water. Water use patterns, from intensive agriculture to industrial and household consumption, place growing pressure on available resources. Also, climate change alters rainfall patterns and accelerates evapotranspiration. Yet evidence increasingly shows that land use patterns more directly explain water extremes and challenges.[20] The type of surface cover and the way land is managed determine how water moves through the system. Vegetation, soil structure, and permeability regulate infiltration, storage, and evaporation: Where land is deforested, wetlands drained, soils sealed or compacted, or cropland left bare for long periods, the ability of the land and soil to act as a (carbon) sponge[21, 22, 23]—absorbing, storing, and recycling water—is reduced. These altered surface conditions have, among other things, influenced the observable global warming[21] as well as water cycle disruptions. This is because they weaken infiltration, evapotranspiration, and groundwater recharge, breaking the feedback loops that sustain rainfall and moderate temperature. In contrast, vegetated, permeable, and well-managed landscapes—through regenerative or conservation agriculture, reforestation, or wetland restoration—can act as sponges, maintaining soil moisture, recycling it to the atmosphere, and buffering heat, keeping the small water cycles intact. Pollution from agricultural runoff and industrial discharge diminishes water quality, while aging infrastructure limits the ability to distribute water reliably where and when it is needed. Together, these factors define whether regions experience abundance or scarcity, stability or stress.

To understand and address these risks systematically, BCG's Water Risk Matrix provides a structured lens to assess where and how challenges occur. (See Figure 5.) The framework evaluates water challenges across three key dimensions of water supply:

[19] IPBES (2019): Global Assessment Report on Biodiversity and Ecosystem Services | IPBES secretariat, NABU & BCG analysis
[20] Auerswald et al. (2024): EGUsphere - HESS Opinion: Floods and droughts – Land use, soil management, and landscape hydrology are more significant drivers than increasing temperatures
[21] Jehne (2019): https://nzbiocharltd.co.nz/resources/Regenerate-Earth-Paper-Walter-Jehne%20%281%29.pdf
[22] Jehne (2014): https://irp-cdn.multiscreensite.com/d6b81fb6/files/uploaded/2017%20-%20Regenerating%20Earth%27s%20Soil%20Carbon%20Sponge.pdf
[23] Jehne: https://vernoux.org/agriculture_regenerative/Jehne-Restoring_water_cycles_to_naturally_cool_climates_and_reverse_global_warming.pdf

- **Quantity** captures situations where there is too little or too much water, from prolonged droughts to floods.
- **Quality** refers to the condition of available water, whether it is clean enough for ecosystems, agriculture, or consumption.
- **Accessibility** considers whether water is available where and when it is needed, accounting for infrastructure, distribution, and governance.

Figure 5: BCG's Water Risk Matrix: Three types of challenges

Source: BCG analysis

While these dimensions are distinct, they are not entirely independent. Challenges in one area often coexist with or influence those in another. For example, too little water can limit accessibility, damaged infrastructure can cause contamination and thus the usable quantity of water, while reduced water volumes can concentrate pollutants.

The framework goes beyond categorizing challenges by type. It also examines their environmental, economic, and social impact. Contrary to common perception, water challenges are not merely an environmental concern. They touch every part of modern life, influencing agricultural productivity, industrial operations, energy systems, and public life and health.

By applying this matrix, water challenges can be categorized and compared consistently across contexts. It helps identify not only what kind of challenge exists but also how it impacts people, economies, and the environment, positioning water as a central pillar of both ecological and economic resilience.

4.1 Water Challenges in a Global Context

Water Challenges in a Global Context. Water-related challenges arise on all continents, in both advanced and developing economies.[24] (See Figure 6.) Their specific drivers vary depending on local water availability, climatic and temperature conditions, infrastructure quality, and the effectiveness of water governance. However, the resulting pressures on ecosystems, economies, and societies can be observed worldwide. Land-use change further amplifies these pressures: Since the emergence of human civilization, roughly half of the planet's plant biomass has been lost.[25] This large-scale depletion has not only released vast amounts of biogenic carbon but also reduced Earth's capability to regenerate. It has degraded the soil's ability to function as a living

[24] UBA (2024): Weltweite Temperaturen und Extremwetterereignisse seit 2010 | Umweltbundesamt
[25] Greenpeace (2018): How much of Earth's biomass is affected by humans? - Greenpeace International

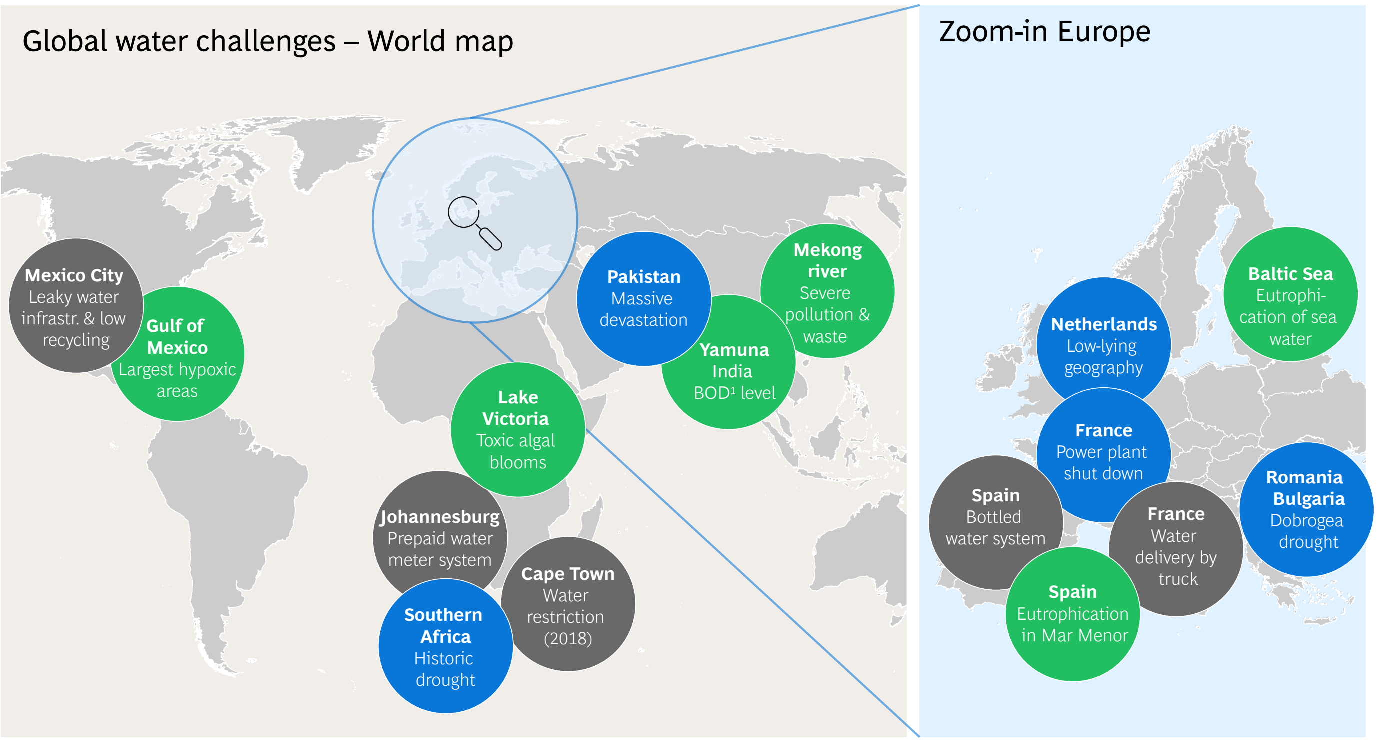
carbon sponge[26, 27, 28] reducing its ability to store water and sustain microbial life as well as halving the Earth's photosynthetic capacity[29]—the foundation of net primary production on which water and carbon cycles depend.

[26] Jehne (2019): https://nzbiocharltd.co.nz/resources/Regenerate-Earth-Paper-Walter-Jehne%20%281%29.pdf
[27] Jehne (2014): https://irp-cdn.multiscreensite.com/d6b81fb6/files/uploaded/2017%20-%20Regenerating%20Earth%27s%20Soil%20Carbon%20Sponge.pdf
[28] Jehne: https://vernoux.org/agriculture_regenerative/Jehne-Restoring_water_cycles_to_naturally_cool_climates_and_reverse_global_warming.pdf
[29] CLEAR Center (2020): The Biogenic Carbon Cycle and Cattle | CLEAR Center

Quantity-related challenges show that both scarcity and excess can disrupt water systems. In southeastern Europe, regions such as Romania and Bulgaria are experiencing prolonged droughts driven by arid climates and limited rainfall.[30] These conditions increasingly strain agriculture and ecosystems, a challenge further reinforced by conventional farming practices that deplete soil moisture and

[30] Water Europe (2025): Exposure of European ecosystems to drought | WISE Freshwater; Serban, Maftei (2025): Spatiotemporal Drought Analysis Using the Composite Drought Index (CDI) over Dobrogea, Romania

Figure 6: Examples of water challenges around the world



1. BOD = Biochemical Oxygen Demand

Source: BCG & NABU analysis

weaken the land's natural water retention capacity. In other areas, droughts have escalated into humanitarian crises: in Southern Africa, one of the most extreme droughts in 2024 affected millions of people through crop failures and hunger, with the region facing the risk of a full-scale humanitarian catastrophe.[31] Temporary water shortages can also emerge when rivers or reservoirs fall below operational levels, as seen in France in 2022, where drought forced nuclear power plants to scale back production.[32] At the other end of the spectrum, extreme rainfall can be equally damaging: Floods in Pakistan submerged vast areas and displaced millions,[33]

[31] Aljazeera (2024): Worst drought in century devastates Southern Africa, millions at risk | Climate News | Al Jazeera
[32] Reuters (2022): Europe's drought and heatwave threaten crops, energy production
[33] UNICEF (2023): One year on from catastrophic floods, millions of children in Pakistan still need urgent support

while low-lying countries like the Netherlands are continuously faced with managing high groundwater levels and flood risks through complex water management systems.[34] These examples underline that water quantity challenges are not confined to dry regions; they also affect areas with abundant rainfall or advanced infrastructure.

Quality-related challenges reveal how pollution and runoff can compromise even seemingly sufficient water resources. Across the Gulf of Mexico, excess nutrients from agricultural runoff have created one of the world's largest hypoxic zones, depleting oxygen and harming marine ecosystems.[35]

[34] Government of the Netherlands: Delta Programme: flood safety, freshwater and spatial adaptation | Delta Programme | Government.nl
[35] NOAA (2024): Gulf of Mexico 'dead zone' larger than average, scientists find | National Oceanic and Atmospheric Administration

Around Lake Victoria in Africa, agricultural effluents and sewage have led to recurring algal blooms, threatening biodiversity and local fisheries.[36] A similar crisis has unfolded in Spain's Mar Menor lagoon, where intensive vegetable cultivation in the surrounding Campo de Cartagena has caused massive nitrate inflows, turning the lagoon into a "green soup" of algae and triggering repeated fish die-offs and ecosystem collapse.[37] Likewise, in major Asian river basins such as the Mekong[38] and Yamuna[39], industrial discharge, plastic waste, untreated sewage, and agricultural runoff have severely degraded surface water quality. Comparable eutrophication pressures are also visible in the Baltic Sea, where a combination of natural factors such as shallowness and restricted water exchange, together with nutrient inputs from a densely populated drainage basin, has led to recurring algal blooms and oxygen-depleted "dead zones."[40] Despite significant reductions in nitrogen and phosphorus loads since the 1980s, internal nutrient recycling and climate-driven warming continue to sustain eutrophic conditions. Together, these cases show how insufficient wastewater treatment and diffuse pollution sources are eroding water quality globally, turning what appears to be plentiful water into a resource unfit for use.

Accessibility-related challenges demonstrate that water availability alone does not guarantee access. In Cape Town, limited infrastructure and mismanagement led to severe supply restrictions despite physical reserves in dams.[41] In Mexico City, aquifers remain a potential source of water, yet leaky infrastructure, low recycling rates, and uneven distribution leave large parts of the population underserved.[42] Across Southern Europe, water infrastructure constraints are also evident; for example, in Spain, bottled water extraction has strained local sources[43] and in Southern France, in 2022 villages such as Seillans had to rely on water being delivered by truck after natural springs ran dry amid extreme drought and record temperatures.[44] In Johannesburg, the use of prepaid water meters has restricted access for low-income residents, highlighting the social dimension of accessibility.[45] These examples make clear that ensuring access to water depends as much on governance and investment as on natural availability.

These cases illustrate that water challenges are not limited to a single geography or income level. They arise in both water-scarce and water-rich regions, with problems in quantity, quality, and accessibility often reinforcing one another. Whether it is too little, too much, too dirty, or too inaccessible, managing water sustainably requires understanding these challenges as part of a single, interconnected system.

4.2 Water Challenges in the German Context

From Perceived Security to Emerging Stress. For decades, the common belief has been that Germany does not face any serious water problems. The country has long been considered water-rich, with reliable rainfall, dense river networks, and advanced infrastructure.[46, 47] Yet, this conventional wisdom no longer holds true.[48]

According to a leading hydrologist, Germany is among the countries experiencing the largest groundwater losses worldwide,[48] while in recent years, patterns of water availability have changed noticeably. Rainfall has become less predictable, summers drier, and extreme weather events are more frequent.[49] Additionally, land use has emerged as one of the most direct drivers of these losses, with deforestation, soil sealing, drainage and compaction reducing infiltration, evaporation, and groundwater recharge. Localized shortages[50] and pollution incidents[51] are no longer isolated occurrences, and conflicts over water use are emerging in areas that historically had few concerns.

These developments show that Germany's water reality is changing. The long-held perception of abundant and reliable water no longer reflects the situation on the ground. What was once viewed as a stable resource is increasingly revealing signs of stress, both regionally and over time.

Drivers Across Quantity, Quality, and Accessibility. Applying the **BCG Water Risk Matrix** reveals that Germany faces drivers of stress across all three challenge dimensions: **quantity**, **quality**, and **accessibility**. (See Figure 7.)

Quantity Drivers

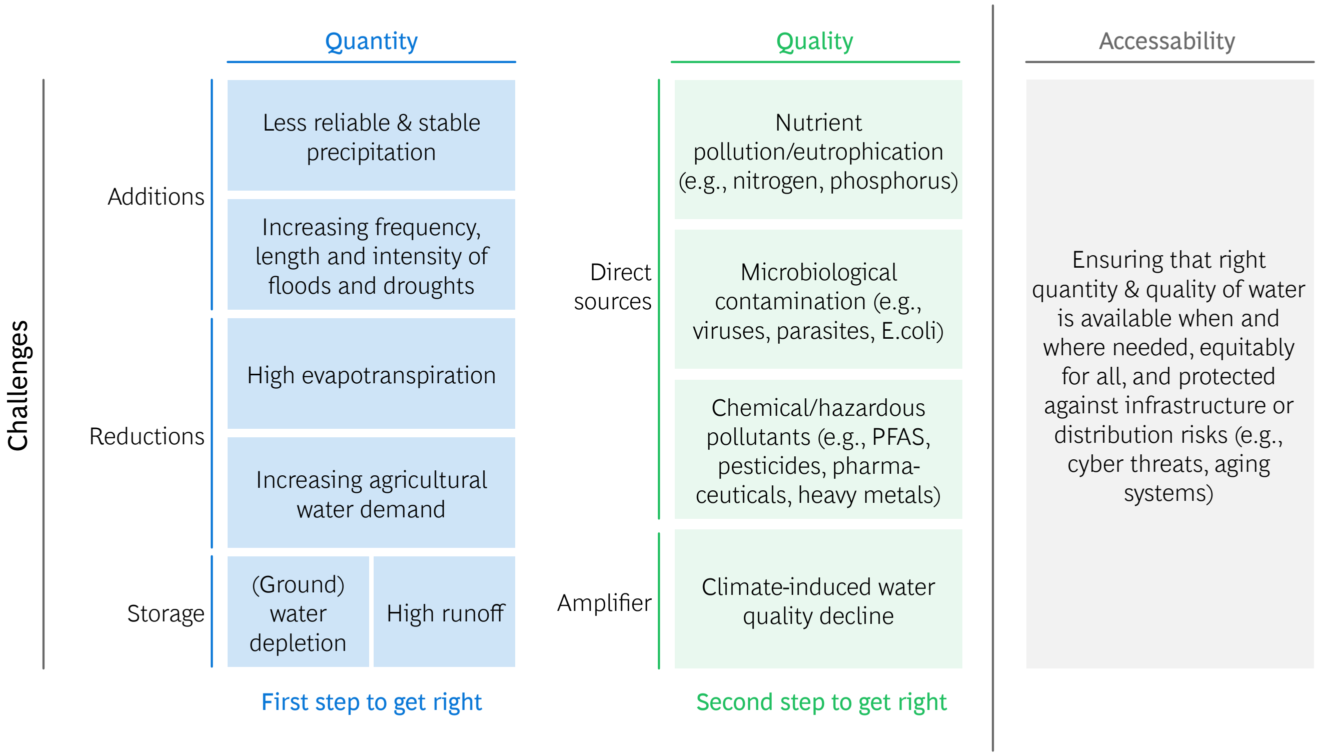
- ***Less reliable and stable precipitation.*** Germany's overall precipitation levels are projected to increase somewhat under climate change scenarios, but distribution will become far less stable.[52] Seasonal models show that while winters may become wetter, summer precipitation is expected to decline sharply by the end of the century, particularly under high-emission (RCP 8.5) pathways.[53, 52] This imbalance will heighten seasonal water stress: Soils will dry out faster in summer, while higher winter rainfall increases runoff and flood potential instead of replenishing groundwater.

- ***Increasing frequency, length, and intensity of floods and droughts.*** Droughts and floods are both becoming defining features of Germany's changing weather regime. In

[36] Nagi et al. (2022): A century of human-induced environmental changes and the combined roles of nutrients and land use in Lake Victoria catchment on eutrophication - ScienceDirect
[37] Deutsche Umwelthilfe (2023): Factsheet_Mar_Menor_final.pdf
[38] Mekong River Commission (2023): State of the Basin Report 2023 – Mekong River Commission
[39] India Express (2025): CPCB report: Yamuna stretch in Delhi continues to be among most polluted | Delhi News - The Indian Express
[40] Race for the Baltic (2025): State of the Baltic Sea
[41] City of Cape Town (2020): capetown.gov.za/Family and home/greener-living/water-wise-in-the-home/water-restrictions-explained
[42] CNN (2024): Mexico City may be just months away from running of out water | CNN
[43] The Guardian (2024): 'It's not drought - it's looting': the Spanish villages where people are forced to buy back their own drinking water | Water | The Guardian
[44] Reuters (2022): As southern France battles drought, water comes by truck to some villages | Reuters
[45] Law Library (2009): Mazibuko and Others v City of Johannesburg and Others [2009] ZACC 28 (8 October 2009) - LawLibrary

[46] ZDFheute (2025): Warum Wasser in Deutschland immer kostbarer wird | ZDFheute
[47] SZ (2025): Grundwasserstand sinkt in Deutschland - SZ.de
[48] Fokus (2025): Forscherin schlägt Alarm: „Deutschland war reich an Wasser, aber das ändert sich" - FOCUS online
[49] DVGW (2022): auswirkung-klimawandel-wasserdargebot-zukunft-wasser-factsheet.pdf
[50] UBA (2025): Trockenheit in Deutschland – Fragen und Antworten | Umweltbundesamt
[51] UBA (2024): Die Wasserrahmenrichtlinie - Gewässer in Deutschland 2021 | Umweltbundesamt
[52] DVGW (2022): auswirkung-klimawandel-wasserdargebot-zukunft-wasser-factsheet.pdf
[53] UBA (2017): Wasserwirtschaft in Deutschland – Grundlagen, Belastungen, Maßnahmen

Figure 7: Key drivers of Germany's water challenges



Source: BCG & NABU analysis

2018, precipitation between February and July dropped to just 61% of the usual levels, leaving up to 90% of German territory under drought conditions by August.[54] Projections indicate that the frequency and duration of droughts has[55] and will continue to rise throughout the century, with extremely dry months occurring by the end of almost every year.[56, 57, 58] Additionally, the drought intensity has increased substantially during the vegetation period in the past years[59] and is expected to further rise by the end of the century.[56] At the same time, flooding events are becoming more frequent and severe, while sealing and compaction decrease the soil's ability to let water infiltrate and thus substantially increase surface runoff,[60] with precipitation becoming increasingly concentrated in shorter, more intense periods.[61]
Insurers already report a clear surge in flood-related costs, reflecting the growing impact of these extremes.[62] According to Munich Re's latest analysis, Germany now ranks third worldwide—after the United States and China—among the countries most severely affected by weather-related disasters, with cumulative damages of around $210 billion in the period between 1980 and 2024.[63] Improved flood protection in China led to a decrease in relative damage costs. Conversely, Germany and the United States saw a sharp increase.[63, 64] Total annual precipitation is projected to increase slightly, and its redistribution across the year—with wetter winters and drier, more evaporative summers—will amplify flood risks, as more water falls within fewer events[65] and overwhelms existing landscapes and infrastructure that were designed for a more stable climate. Together, these trends illustrate a hydrological system under strain—one marked by both prolonged shortages and sudden excesses of water.

- ***High evapotranspiration.*** Rising temperatures and changes in land cover are jointly intensifying water losses from landscapes through two reinforcing dynamics. First, inadequate soil cover[66] and declining vegetation reduce evapotranspiration—the natural cooling process that dissipates solar energy as latent heat.[67] When soils are bare or sealed, this process stops and more energy is converted into sensible heat, leading to hotter surfaces.[67] Second, as temperatures rise, the atmosphere becomes thirstier, able to draw increasing amounts of moisture from soil, plants, and other water sources.[68] Vegetation transpires until water becomes scarce; then plants close their stomata to conserve moisture, halting

[54] KIT (2018): Dürre betrifft rund 90 Prozent der Fläche Deutschlands | KIT
[55] SZ (2025): Klimawandel sorgt für mehr Dürren - Wissen - SZ.de
[56] DVGW (2022): auswirkung-klimawandel-wasserdargebot-zukunft-wasser-factsheet.pdf
[57] UBA (2024): Auswirkung des Klimawandels auf die Wasserverfügbarkeit - Anpassung an Trockenheit und Dürre in Deutschland (WAD-Klim)
[58] UBA (2022): Dürre als Folge des Klimawandels | Umweltbundesamt
[59] Helmholtz Zentrum für Umweltforschung (2025): Dürren seit 1950 (jährlich und saisonal) - Helmholtz-Zentrum für Umweltforschung UFZ
[60] UfU e.V. (2025): UfU-Hintergrundpapier
[61] Spiegel (2021): Extremwetter: So hoch ist der Anteil des Klimawandels an der Flutkatastrophe - DER SPIEGEL
[62] GDV (2024): Dossier: Das Ausmaß der Schäden durch Naturgefahren nimmt zu
[63] Munich Re (2025): Unwetter nagen am Wohlstand – Wetterkatastrophen belasten viele Industrieländer zunehmend | Munich Re
[64] Tagesschau (2025): Naturkatastrophen kosten den Industrieländer immer mehr Wohlstand | tagesschau.de
[65] DWD (2021): Wetter und Klima - Deutscher Wetterdienst - Aktuelles - Faktenpapier zu Extremwetter in Deutschland aktualisiert
[66] Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
[67] Auerswald et al. (2025): EGUsphere - HESS Opinion: Floods and droughts – Land use, soil management, and landscape hydrology are more significant drivers than increasing temperatures
[68] SZ (2025): Klimawandel sorgt für mehr Dürren - Wissen - SZ.de

both transpiration and photosynthesis.[69] This feedback, known as atmosphere's rising thirst, accelerates water losses from soil vegetation, and surface water, as well as an eventual groundwater increase ultimately playing a decisive role in drought formation.[70] The interaction of these dynamics drives a self-reinforcing drying cycle: Reduced vegetation leads to less evapotranspiration and higher temperatures, while higher temperatures further increase evaporative demand. A regional example from Bavaria illustrates this relationship:[71] Even a moderate soil sealing rate of just 6% was found to reduce annual evapotranspiration by 230 m³ (23 mm) per hectare per year over the sealed area. To maintain an overall energy balance, non-sealed areas compensate for this loss through additional water use and higher evapotranspiration, effectively drawing more moisture from soil and vegetation. Projections indicate that compared with the 1961–1990 baseline, evapotranspiration will continue to increase across most of Germany throughout the century, reducing the share of precipitation available for groundwater recharge and runoff.[72] The effect is particularly pronounced in northern and eastern regions, where warmer conditions and sandy soils exacerbate losses, while southern and western areas such as Bavaria and Baden-Wuerttemberg are expected to remain comparatively better buffered. Rising temperatures and described drying cycles cause soil, rivers, and lakes to lose water - even if precipitation remains stable or increases. This undermines both ecological and hydrological balance.

- ***Increasing agricultural water demand.*** While industrial and domestic water use is expected to decline modestly over the century, agricultural water demand is projected to rise markedly, particularly for irrigation.[73] Scenario analyses indicate that irrigation needs could increase by more than 230% by the late 21st century (2061–2090) versus 1971–2000, driven by longer dry periods, higher evapotranspiration, and changing crop water requirements.[74] The increase will be most pronounced in northern and eastern Germany, notably Brandenburg, Saxony-Anhalt, and Lower Saxony, where rising irrigation needs coincide with decreasing groundwater recharge and limited storage capacity. This trend is already visible: Agricultural water withdrawals have more than doubled since 2020, reaching their highest level in decades.[75] Projections suggest that irrigated cropland could nearly triple by 2100, corresponding to a rise in annual water use from around 0.6 to 1.4 billion m³.[73] With agriculture expected to be the only sector with sustained long-term growth in water use,[73] it is set to become a key driver of water stress, intensifying competition between users during prolonged dry phases.

- ***(Ground)water depletion.*** Groundwater levels across Germany have been declining for years, reflecting a growing imbalance between natural recharge and water extraction[76, 77, 78]—with recent global analyses showing that Germany ranks among the countries experiencing the most severe groundwater losses worldwide.[79] The trend is particularly evident in the northern part of Germany, where the number of months with groundwater levels below the long-term average low point have increased significantly,[78] specifically in the northeast: According to research, groundwater levels in the Berlin-Brandenburg region have decreased in recent years, with a recharge rate of only 10 m³ (1 mm) per hectare per year in the drought year of 2018, while this value amounted to 3,760 m³ (376 mm) per hectare per year in a rainy year like 2010.[80] This has led to groundwater storage declining between 2007 and 2022 by an average of around 21 m³ (2.1 mm) per hectare annually.[80] This largely stems from high evapotranspiration under warmer conditions, compacted and drained soil, the type of vegetation cover, and Brandenburg's sandy soil structure that is unable to absorb water effectively, leading it to run off rapidly preventing sufficient infiltration and replenishment of deeper aquifers.[80, 81] A reduction in groundwater levels also influences surface water such as rivers or lakes, given surface waters in the region are largely fed by groundwater.[80] Across Germany, similar downward trends can be observed, with surface-water levels receding even in regions once considered water secure.[82, 83] Future projections indicate that this stress will intensify: The groundwater exploitation index is expected to exceed the threshold of 0.2 across large parts of northern and eastern Germany by 2100, signaling structural overuse.[84] Without measures to restore recharge capacity and manage withdrawals, local depletion risks solidifying into a long-term national water deficit.

- ***High runoff.*** Runoff in Germany is increasing as changing rainfall patterns and land-use practices cause the soils sponging capabilities to collapse[85, 86, 87] thereby reducing infiltration possibilities for water, which instead leaves the landscape more quickly as runoff. Warmer temperatures and a shift toward short, intense precipitation events lead to greater surface flow, while soil sealing, drainage, and compaction further reduce infiltration and delay or inhibit groundwater recharge.[88, 89] Despite Germany's political target to eliminate the net increase in sealed land by 2050, current sealing rates remain high, consistently failing to

[69] Seneviratne et al.(2010): Investigating soil moisture–climate interactions in a changing climate: A review - ScienceDirect
[70] SZ (2025): Klimawandel sorgt für mehr Dürren - Wissen - SZ.de
[71] Auerswald et al. (2025): EGUsphere - HESS Opinion: Floods and droughts – Land use, soil management, and landscape hydrology are more significant drivers than increasing temperatures
[72] BMBF (2013): https://www.fona.de/medien/pdf/Wasserfluesse_in_Deutschland_02.pdf
[73] DVGW (2024): szenarien-wassergewinnung-dvgw.pdf
[74] UBA (2024): Auswirkung des Klimawandels auf die Wasserverfügbarkeit - Anpassung an Tro-ckenheit und Dürre in Deutschland (WAD-Klim)
[75] UBA (2025): Wasserressourcen und ihre Nutzung | Umweltbundesamt
[76] ZDFheute (2025): Warum Wasser in Deutschland immer kostbarer wird | ZDFheute
[77] SZ (2025): Grundwasserstand sinkt in Deutschland - SZ.de
[78] UBA (2023): WW-I-2: Grundwasserstand und Quellschüttung | Umweltbundesamt
[79] Fokus (2025): Forscherin schlägt Alarm: „Deutschland war reich an Wasser, aber das ändert sich" - FOCUS online
[80] IGB (2025): The complex issue of drought | IGB
[81] IGB (2024): Water in the soil, but not in the groundwater | IGB)
[82] UBA (2023): https://www.umweltbundesamt.de/monitoring-zur-das/handlungsfelder/wasserhaushalt/ww-i-7/indikator
[83] UBA (2023): WW-I-3: Mittlerer Abfluss | Umweltbundesamt
[84] UBA (2024): Auswirkung des Klimawandels auf die Wasserverfügbarkeit - Anpassung an Tro-ckenheit und Dürre in Deutschland (WAD-Klim)
[85] Jehne (2019): https://nzbiocharltd.co.nz/resources/Regenerate-Earth-Paper-Walter-Jehne%20%281%29.pdf
[86] Jehne (2014): https://irp-cdn.multiscreensite.com/d6b81fb6/files/uploaded/2017%20-%20Regenerating%20Earth%27s%20Soil%20Carbon%20Sponge.pdf
[87] Jehne: https://vernoux.org/agriculture_regenerative/Jehne-Restoring_water_cycles_to_naturally_cool_climates_and_reverse_global_warming.pdf
[88] Auerswald et al. (2025): EGUsphere - HESS Opinion: Floods and droughts – Land use, soil management, and landscape hydrology are more significant drivers than increasing temperatures
[89] UfU e.V. (2025): UfU-Hintergrundpapier

meet the interim reduction paths required to mitigate these hydrological impacts.[90] As a result, larger volumes of water are flushed through rivers and streams instead of being stored in soils or aquifers. For Bavaria, research shows that assuming roughly 6% of total land area is sealed and an average annual precipitation of roughly 9,400 m^3 (940 mm) per hectare on average roughly 560 m^3 (56 mm) per hectare of rainwater directly run off.[91] Translating this to groundwater recharge, the following picture emerges: The overall mean groundwater recharge of around 2,060 m^3 (206 mm) per hectare per year is reduced by about 120 m^3 (12 mm). The reduction in groundwater recharge is even higher, assuming that surrounding vegetation fully compensates for the evaporative losses caused by sealed surfaces, namely approximately 440 m^3 (44 mm) per hectare per year—a roughly 21% loss in groundwater recharge.[91] Satellite observations corroborate this finding indicating that Germany now loses around 2.5 billion m^3 of water every year, approximately the volume of Lake Constance over the past two decades.[92] Hydrological analyses show that land-use structure and climatic factors jointly contribute to these increasing runoff rates, as altered surfaces and vegetation can no longer buffer water effectively.[91] A recent study demonstrates that the soil's limited ability to absorb and retain water—caused by compaction and unsustainable management practices—directly increases flood risk, as runoff accumulates instead of infiltrating.[93] An effect that can be mitigated through improved soil and surface management, such as Regenerative Agriculture or reforestation.[93] Besides intensified flood risks and erosion, the growing dominance of rapid runoff reduces soil moisture and groundwater replenishment, leaving less water available when it is most needed.

Outcome: Regional water stress. Germany's water exploitation index—the ratio of total water withdrawals to renewable resources—has declined in recent decades, largely driven by the overall decline in German water demand.[94] It currently lies at about 10%, so below the defined 20% threshold for national water stress.[94] However, this figure can be deceptive. The indicator is calculated as a multiyear national average, thus masking short-term fluctuations and strong regional differences. In reality, water availability varies widely across time and space. Even under an optimistic climate scenario, forecasts project that by 2050, large parts of northern and eastern Germany will face medium to high seasonal water stress, while some regions could experience severe scarcity during prolonged dry periods.[95] This means that, despite reassuring aggregate values, localized shortages and conflicts over use are likely to intensify.

Quality Drivers

Although the ecological condition of Germany's surface waters has improved slightly—with the share of rivers in at least "good" ecological condition or potential increasing by about 1% between 2015 and 2021—only around 8% currently meet this benchmark.[96] Many bodies of water exhibit moderate condition, as disturbed biological communities take time to recover.

- ***Nutrient pollution/eutrophication.*** Nutrients remain one of the main concerns for water quality, as large amounts can induce eutrophication and algal blossoms with negative effects for organisms living in affected waters.[97] While declining, more than half of all monitoring stations still record phosphate concentrations above acceptable thresholds.[97] Nitrate pollution has also improved slightly in recent years, yet roughly a quarter of stations continue to measure concentrations above 50 mg/l—a level that exceeds the limit set to protect groundwater and ecosystems.[98] Despite the EU closing its nitrate infringement case in 2023, an October 2025 Federal Administrative Court ruling now mandates a broader national action program, as current regulations still fail to meet reduction targets.[99]

- ***Microbiological contamination.*** Microbiological contamination represents another ongoing risk. It can occur when untreated wastewater, stormwater overflows, or agricultural runoff enter rivers and lakes, carrying fecal matter and pathogens into natural bodies of water.[100, 101] Through sewer systems and surface waters, such microbes can spread widely in the environment, while animals such as birds, rats, dogs, and even insects can further contribute to this transmission.[101] Fortunately, drinking water in Germany is one of the most carefully treated, tested, and regulated resources and thus one of the safest goods we consume. It is subject to strict quality standards and contains only minimal amounts of microorganisms, which are generally harmless or occur in concentrations that pose no health concern.[102]

- ***Chemical and hazardous pollutants.*** Chemical and hazardous pollutants, in particular PFAS (forever chemicals),[103] pesticides, and pharmaceuticals, are increasingly detected in both surface and groundwater.[104] Agricultural and industrial discharges, as well as urban wastewater, carry substances that accumulate in rivers and persist in ecosystems. PFAS are difficult to degrade, bioaccumulate in nature, and pose long-term risks to drinking water and human health.[104]

[90] UBA (2025): https://www.umweltbundesamt.de/daten/flaeche-boden-land-oekosysteme/flaeche/siedlungs-verkehrsflaeche
[91] Auerswald et al. (2025): EGUsphere - HESS Opinion: Floods and droughts – Land use, soil management, and landscape hydrology are more significant drivers than increasing temperatures
[92] UBA (2023): WW-I-1: Terrestrisch gespeichertes Wasser | Umweltbundesamt
[93] UfU e.V. (2025): UfU-Hintergrundpapier
[94] UBA (2025): Wasserressourcen und ihre Nutzung | Umweltbundesamt
[95] Aqueduct: Aqueduct Country Ranking

[96] UBA (2022): Indikator: Ökologischer Zustand der Flüsse | Umweltbundesamt
[97] UBA (2025): Indikator: Eutrophierung von Flüssen durch Phosphor | Umweltbundesamt
[98] UBA (2024): FAQs zu Nitrat im Grund- und Trinkwasser | Umweltbundesamt
[99] Water News Europe (2025): https://www.waternewseurope.com/german-court-rules-that-the-government-must-start-with-a-nitrate-action-programme/
[100] UBA (2019): Mikrobiologie | Umweltbundesamt
[101] GEO: Keime in Gewässern entdeckt: Wie gefährlich sind die multiresistenten Erreger? - [GEO]
[102] UBA (2019): Mikrobiologie | Umweltbundesamt
[103] Tagesschau (2025): Drohende Milliarden-Kosten wegen PFAS-Verschmutzung | tagesschau.de
[104] Heinrich-Böll Stiftung (2025): Vergiftete Flüsse: Lebensadern voller Chemie

- ***Climate-induced water quality decline.*** Climate change further exacerbates these challenges by raising water temperatures[105] and reducing dilution capacity during dry periods, amplifying pollutant concentrations. Together, these factors underline that maintaining water quality requires continuous monitoring, stricter controls on diffuse sources, and investment in treatment technologies capable of removing both traditional and emerging contaminants.

Accessibility Drivers

- Ensuring water accessibility in Germany is becoming more complex as physical and infrastructural pressures grow. While the country's supply networks are extensive, aging infrastructure,[106] uneven distribution, and localized system stress already lead to regional imbalances. In some areas, particularly around major cities, leaky or outdated systems cause substantial losses, while rural regions face growing abstraction restrictions.[107, 108] The increasing risk of infrastructure failures, such as pipeline bursts,[109] and digital threats, including cyberattacks on water utilities, adds another layer of vulnerability.[110] Maintaining equitable and reliable access will therefore require both modernization of physical networks and stronger resilience measures for digital and operational systems.

Measuring Water Accurately. While Germany's situation is far less severe than that of other countries, it would be a mistake to underestimate the trajectory and risk falling into familiar traps: over-reliance on past experience, focusing on non-comprehensive indicators and failing to recognize gradual but consequential shifts in the environment (often described as the "boiling frog" syndrome). History offers a warning: Mesopotamia,[111] one of the cradles of civilization, rose through agricultural and technological advancement but declined when water and land were mismanaged. Overextraction, erosion of soil used by agriculture, salinization, and floods turned fertile land into desert.[112] (See the sidebar "The Rise and Fall of Mesopotamia.") The lesson is not that Germany faces the same fate, but that even prosperous societies can overlook slow-developing water risks until the consequences become irreversible.

[105] UBA (2023): WW-I-8: Wassertemperatur von Seen | Umweltbundesamt
[106] VKU (2025): Studie_Investitionen_Wasserwirtschaft: VKU
[107] MLEUV Brandenburg (2025): Entnahmebeschränkungen | MLEUV
[108] Hessenmagazin (2022): Wasserentnahmeverbot in den Landkreisen - Update
[109] RBB (2025): Tausende Berliner Haushalte stundenlang ohne Wasser | rbb24
[110] DLF (2020): Cyberattacken - Hackerangriffe gefährden Wasserversorgung
[111] Laulima: End of Mesopotamia
[112] Montgomery (2007): Dirt : the erosion of civilizations : Montgomery, David R., 1961- : Free Download, Borrow, and Streaming : Internet Archive

The Rise and Fall of Mesopotamia

The ancient civilization of Mesopotamia flourished for nearly two millennia between the Tigris and Euphrates rivers. Its success rested on an intricate network of communal canals and irrigation systems that transformed arid plains into fertile cropland. Water was life—and law: Hammurabi's Code, one of the earliest written legal systems, even prescribed penalties for neglecting irrigation canals or causing floods.

But Mesopotamia's strength became its undoing. Intensive irrigation without proper drainage caused groundwater levels to rise, concentrating mineral salts in the soil. Over generations, once-productive fields turned saline and barren. Farmers shifted from wheat to more salt-tolerant barley yet yields continued to decline until agriculture could no longer sustain the empire. By the first millennium BC, the "land between the rivers" had lost its fertility, leading to economic decline and mass depopulation.

The lesson endures: managing water means balancing short-term gain with long-term sustainability. While Germany today does not face internal wars over water, it is part of the EU water network and depends on shared resources (e.g., the Rhine River). At the same time, Germany does not have large-scale irrigation as Mesopotamia did, however it relies on groundwater for more than 60% of its drinking water. Overuse and contamination threaten these reserves just as salinization did Mesopotamia's fields. Prosperity built on unsustainable water use can endure for centuries—but collapse comes swiftly once balance is lost.[113, 114, 115, 116]

[113] Kornfeld (2009): (PDF) Mesopotamia: A History of Water and Law
[114] Sabir (2025): https://www.athensjournals.gr/history/2025-11-1-4-Sabir.pdf
[115] Smithsonian Environmental Reserach Center: Ancient Mesopotamia
[116] Destatis (2025): Wasserwirtschaft - Statistisches Bundesamt

To manage what matters, the correct measurement is key. A variety of indices and formulas are used to assess water availability (See Figure 8.), such as the hydrological balance,[117] the Water Use Index (WNI),[118] or the Water Exploitation Index Plus (WEI+).[119] Each offers valuable insights, but most capture only parts of the full picture, building on varying methodologies, definitions of water balance elements and underlying data sources that are not harmonized.

Many commonly used metrics focus primarily on the state of renewable water resources. Some assess groundwater in isolation, while others partially incorporate human water use. Most, however, share a key limitation: they largely overlook runoff dynamics and changes in water storage (See Figure 8.). Indices like the WNI or WEI+ measure abstraction relative to renewable water resources but fail to reflect changes in storage or the resilience of supply systems. Others, like the "quantitative state of groundwater bodies,"[120] concentrate on groundwater alone, overlooking interactions with surface water and long-term recharge dynamics.

[117] Bundesamt für Umwelt (2025): Wasserhaushalt heute
[118] UBA (2025): Wasserressourcen und ihre Nutzung | Umweltbundesamt
[119] Eurostat: Water exploitation index, plus (WEI+) (sdg_06_60)
[120] UBA (2024): Mengenmäßiger Zustand des Grundwassers | Umweltbundesamt

At first glance, Germany's water situation appears stable when assessed through these indices. The WNI is below the 20% threshold,[118] indicating that total abstraction is relatively modest compared to available renewable resources. The WEI+ paints a similarly reassuring picture:[121] It has consistently stayed well below the 20% mark in recent years.[121] Likewise, roughly 95% of groundwater bodies[120] are shown to be in a good state, where abstraction is lower than recharge.[120] Taken together, these indicators suggest that Germany's water balance is secure, while in reality the groundwater level in Germany is decreasing significantly.

This apparent stability is partly the result of a historically shaped perspective. In contrast to e.g., Austria or Switzerland, where alpine topography has long required close monitoring of runoff[122, 123], Germany has traditionally paid little attention to runoff due to historically abundant water availability. The Netherlands, in turn, focuses primarily on runoff to the sea given its downstream and coastal posi-

[121] DVGW (2025): bund-studie-grundwasserstress-kritikpunkte-dvgw.pdf
[122] BMLUK: https://www.bmluk.gv.at/themen/wasser/wasser-oesterreich/hydrographie/Wasserbilanz.html#:~:text=Der%20Jahresniederschlag%20bezogen%20auf%20die,j%C3%A4hrliche%20Verdunstung%20betr%C3%A4gt%20514%20mm%20.
[123] BAFU (2024): https://www.bafu.admin.ch/de/wasserhaushalt-heute

Figure 8: Different metrics, different stories: Only the environmental-economic accounting view covers all elements

Selective water-related metrics	Water balance elements: Human use – Abstraction	Human use – Returns	Renewable water resource – Precipitation	Renewable water resource – Run-in	Renewable water resource – Evapotranspiration	Additional elements – Run-off[1]	Additional elements – Delta Storage	Resulting view on state of water in Germany
Water use index (WNI)	✓		✓	✓	✓			Declining index with level below 20% water stress mark since ~2004
Water exploitation index (WEI+)	✓	✓	✓	✓	✓			WEI+ consistently below 20% water stress mark over all past years
State of groundwater bodies	✓ (Groundwater abstraction)		✓ (Groundwater Recharge)	✓ (Groundwater Recharge)	✓ (Groundwater Recharge)		✓ (Delta Groundwater)	In ~95% of groundwater bodies abstraction is lower than recharge
Environmental-economic accounting	✓	✓	✓	✓	✓	✓	✓	⚠ Delta Storage has been declining steadily since 2001

✓ Water balance element is part of metric calculation

1. Includes runoff abroad and into the sea

Note: Methodologies, definitions of water balance elements, and underlying data sources vary across metrics and are not harmonized.

Source: UBA, EEA, Destatis, BCG & NABU analysis tion[124]. Yet Germany's hydrological reality is also strongly shaped by runoff: major river systems such as the Rhine, Elbe, and the Danube play a central role in national water flows[125] and storage. Under today's conditions of increasing variability and water stress, continuing to pay insufficient attention to runoff risk systematically drawing false conclusions.

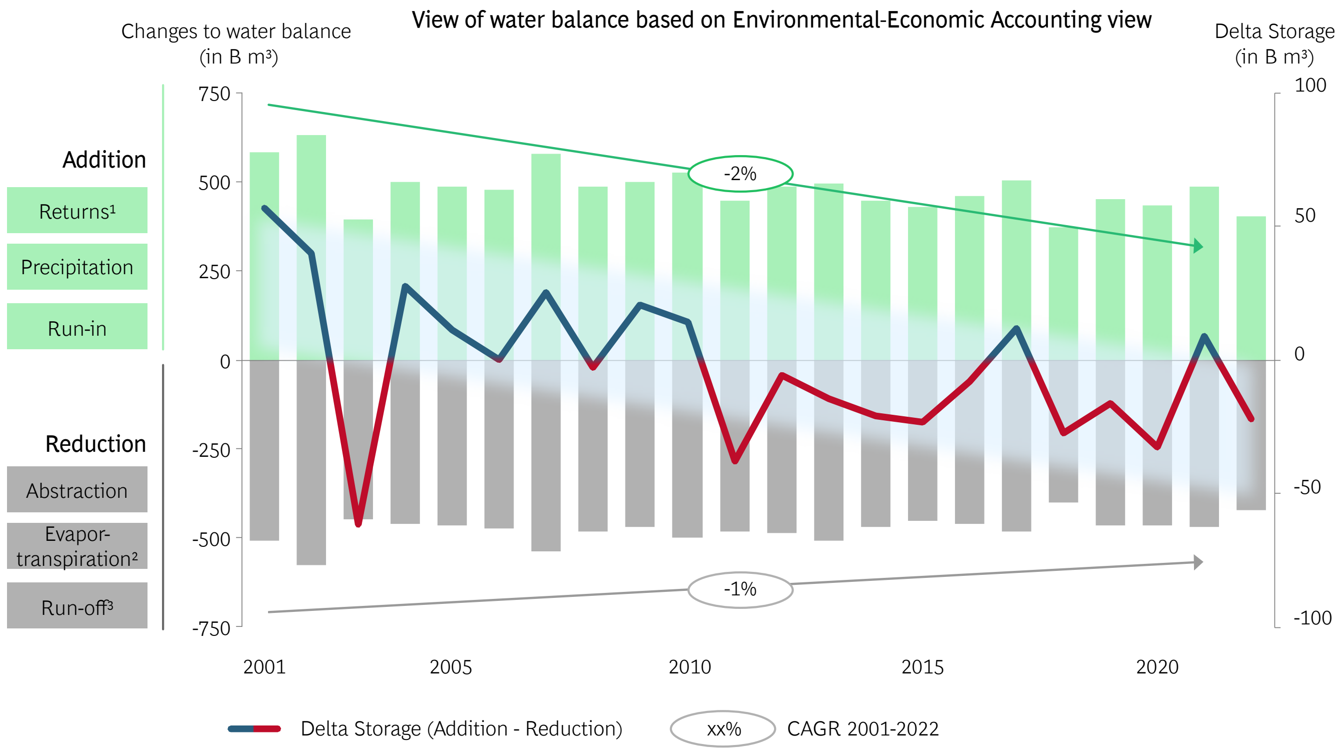
A more comprehensive perspective is provided by environmental-economic accounting (EEA), which captures the full interaction between water, the economy, and the environment. In Germany, the Umweltökonomische Gesamtrechnung Wasser[126] systematically records all water flows between nature, economic sectors, households, and even foreign trade, thus including natural and human components of the water system. It tracks how much water is abstracted from surface, ground, and soil sources—including rain and drainage water collected in sewer systems—and how water is used, consumed, or returned. On the return side, it accounts not only for wastewater discharges but also for evaporation, leakages, and water embedded in products. By integrating these inflows and outflows as well as changes in overall water stocks, the EEA provides a consistent national balance sheet for water, linking physical flows with economic activity and offering a far more realistic view of resource sustainability.

Germany's Water Balance: Signs of Depletion. Viewed through an environmental-economic accounts lens, Germany's natural water storage has been steadily declining since the early 2000s.[127] This finding is corroborated by GRACE satellite data, which tracks changes in the Earth's gravitational field to measure variations in groundwater and total terrestrial water storage.[128] Both perspectives indicate the same trend: Over the past two decades, more water has been leaving the system than entering it, suggesting that natural inflows such as precipitation and surface recharge are no longer fully compensating for abstraction and loss (e.g., run-off). (See the sidebar "Why Less Abstraction Does Not Mean More Water Security.") This long-term reduction in storage represents a clear quantity-related water challenge—one where increasingly less water remains within the system. In simple terms, Germany is losing more water than its systems naturally restore. (See Figure 9.)

[124] CBS (2023): https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiK0qzjyvuRAxWBg_0HHXI2ObsQFnoECFUQAQ&url=https%3A%2F%2Fwww.cbs.nl%2F-%2Fmedia%2F_pdf%2F2023%2F03%2Fwater-accounts-for-the-netherlands.pdf&usg=AOvVaw3GBI5HhE_bFhCt0mr5nQEN&opi=89978449
[125] BMBF (2013): https://www.fona.de/medien/pdf/Wasserfluesse_in_Deutschland_02.pdf
[126] Destatis (2025): Statistischer Bericht - Umweltökonomische Gesamtrechnungen - Wassergesamtrechnung - Berichtszeitraum 2001 - 2022 - Statistisches Bundesamt

[127] Destatis (2025): Statistischer Bericht - Umweltökonomische Gesamtrechnungen - Wassergesamtrechnung - Berichtszeitraum 2001 - 2022 - Statistisches Bundesamt
[128] UBA (2023): WW-I-1: Terrestrisch gespeichertes Wasser | Umweltbundesamt

Figure 9: Germany's biggest challenge is quantity: water storage is steadily depleting



1. Includes returns to domestic water resources (surface water, groundwater, soil water)

2. Excludes transpiration of soil water by agriculturally cultivated crops, as this is already accounted for under abstraction from the environment

3. Includes runoff abroad and into the sea

Source: Destatis, BCG & NABU analysis

Why Less Abstraction Does Not Mean More Water Security

Over the past three decades, Germany's use of freshwater has changed fundamentally. Since 1991, total abstraction from natural water sources has more than halved, falling from ~46 billion m³ per year to ~18 billion m³ in 2022. The primary driver behind this decline was the sharp fall in water withdrawals by the energy sector, which dropped from ~29 billion m³ in 1991 to ~7 billion m³ in 2022. This reflects the phase-out of conventional steam turbine power plants—most notably nuclear and coal-fired— with parallel shift toward renewables, which significantly reduces the demand for (cooling) water. Industrial abstraction has also decreased, though less dramatically, to ~5 billion m³, supported by the progressive closure of brown coal mines. Public water abstraction dropped steadily until 2013 before rebounding slightly to just over 5 billion m³ in 2022, as heatwaves and population growth raised demand. Agriculture, however, exhibits the opposite trend. While water extraction remains comparatively low, it has risen to ~0.5 billion m³ in 2022—roughly double the level of 2020.

Looking ahead, Germany's water abstraction is projected to continue its overall decline, though the sectoral composition will shift markedly. Analyses project that total withdrawals will fall from ~18 billion m³ in 2022 to ~15 billion m³ by 2100, driven largely by further reductions in energy and industrial sectors. As conventional power plants are fully phased out and replaced by more sustainable technologies with lower cooling requirements, the energy sector's abstraction is expected to decline steeply to ~3.7 billion m³ annually by mid-century. Industrial water use will likely continue its downward trajectory, though at a slower pace than in previous decades, stabilizing near 5 billion m³ annually by about 2050. This trend reflects the combined impact of the coal phaseout, efficiency gains, and expanded water recycling, partially offset by rising cooling demand from sectors such as data centers. In contrast, agricultural demand is projected to increase sharply, driven by the expansion of irrigated land. Together with livestock-related demand, agricultural abstraction could reach up to 1.4 billion m³ annually by around 2100. Meanwhile, public water supply is forecasted to rise moderately, reflecting warmer summers, population trends, and urban densification—expected to increase slightly by mid-century, reaching ~4.1 billion m³ per year by around 2100.

Altogether, these developments point to a redistribution of water consumption: less from industry and power generation, more from households and agriculture. However, despite declining absolute abstraction and decades of efficiency improvements, Germany's overall water balance is deteriorating and the water storage is decreasing.

This divergence indicates that Germany has largely exhausted the potential of abstraction-side efficiency gains as a sole lever for water security. Further reductions in withdrawals alone will not stabilize the system if water increasingly runs off via the landscape, failing to replenish soil moisture, groundwater bodies, and aquifers. Climate change and land-use dynamics are intensifying seasonal and regional mismatches, with longer dry periods and heavier severe rainfall events causing higher runoff, reduced infiltration and ultimately groundwater recharge. Water that runs off too quickly or arrives at the wrong time or place simply cannot contribute to replenishment of declining storages. Ensuring long-term water resilience will therefore require a shift beyond abstraction management toward integrated, regionally differentiated approaches that actively strengthen retention, recharge, so that water remains available when and where it is needed..[129, 130, 131, 132, 133]

[129] UBA (2025): Wasserressourcen und ihre Nutzung | Umweltbundesamt
[130] DVGW (2024): szenarien-wassergewinnung-dvgw.pdf
[131] DVGW (2022): auswirkung-klimawandel-wasserdargebot-zukunft-wasser-factsheet.pdf
[132] Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
[133] UBA (2024): https://www.umweltbundesamt.de/publikationen/auswirkung-des-klimawandels-auf-die

While the water balance equation provides a much more holistic picture than most conventional indices, it still relies on annual and nationwide averages. These aggregated figures conceal significant regional and seasonal differences that exist across Germany. Some areas are naturally better buffered, while others are increasingly exposed to water stress due to local conditions such as geography, geology, land use, and extraction intensity. The alpine area in Bavaria, for instance, generally benefits from higher precipitation and stronger natural recharge, whereas Brandenburg faces particularly high stress levels due to low rainfall, sandy soils, intensive agricultural land use patterns with low vegetation levels and concentrated industrial and agricultural demand.[134, 135, 136, 137, 138] Hence, these metrics need to be handled with caution, as they do not always convey regional or seasonal nuances.

[134] BMBF (2013): https://www.fona.de/medien/pdf/Wasserfluesse_in_Deutschland_02.pdf
[135] Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
[136] BZ (2023): Das sind Brandenburgs zehn größte Wasserverbraucher
[137] IGB (2021): The Berlin-Brandenburg region and the Tesla Gigafactory | IGB
[138] LfU Land Brandenburg: Boden | Startseite | LfU

5. The Cost of Inaction—Doing nothing is the more expensive option

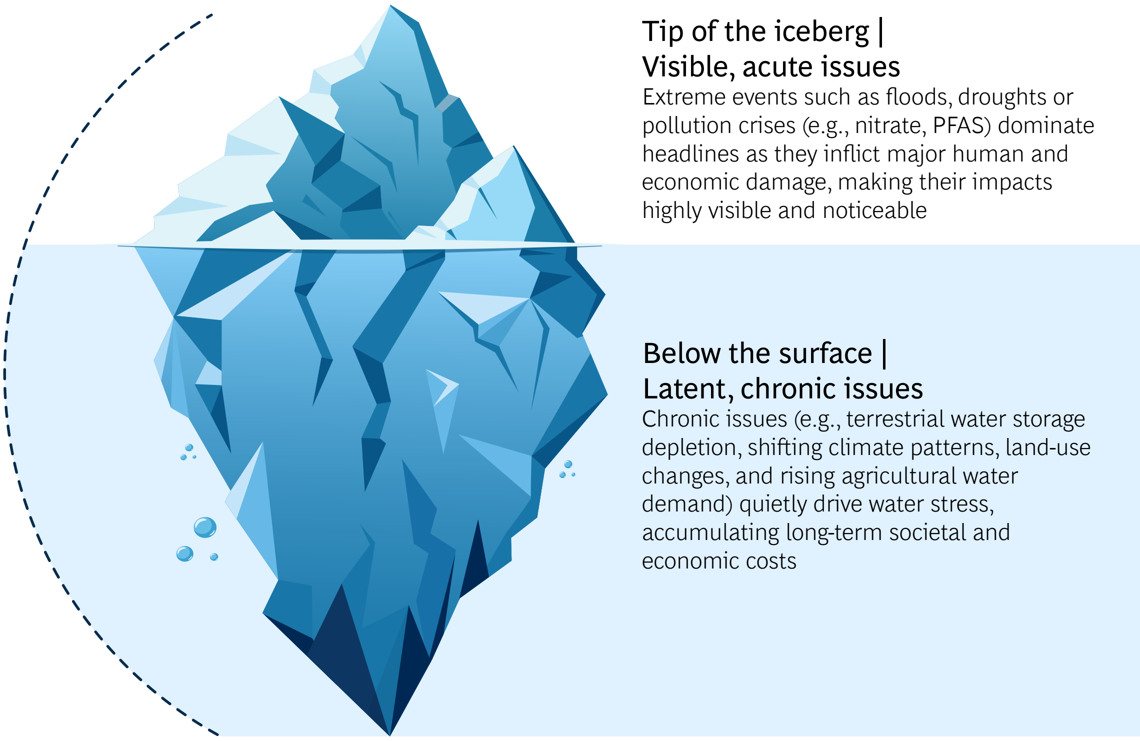
The Iceberg of Water Challenges. Germany's water balance makes one thing clear: The country's water storage is steadily depleting, and, with it, the pressures on available resources are increasing. If this trend continues and no decisive action is taken, costly consequences for the economy, society, and the environment will ensue—both visible and hidden. These costs can be imagined as an iceberg: Only a small portion is immediately visible above the surface, while a large share remains concealed below. (See Figure 10.)

At the tip of the iceberg are the acute, high-impact events that dominate public attention—floods, extreme droughts, or pollution crises—each causing measurable and recurring damage. Yet beneath the surface, chronic forms of water stress quietly accumulate: declining groundwater reserves, shifting climatic patterns, and growing competition for use. This ecological decline is also mirrored by the current state of Germany's ecosystems, with over 80% of habitat types in unfavorable condition and severe biodiversity losses across key species groups.[139]

In Germany, many of these chronic forms of water stress are beneath the surface, still appearing muted. The impacts of rising temperatures, changing rainfall and degraded small water cycles are not yet as starkly visible as elsewhere, and water scarcity tends to surface regionally; for example, in dry summers when competition over water demand occurs or when river levels drop and trade is inhibited. In Germany, these moments feel temporary and peripheral. Yet this perception contrasts sharply with reality in many other parts of Europe and the world, where chronic forms of water stress and shortages have started reaching the surface, becoming a permanent and demanding challenge.

[139] BFN (2025): https://www.bfn.de/ffh-bericht-2025#anchor-14967

Figure 10: While acute water problems draw public attention, less visible underlying issues tend to be overlooked



Source: BCG & NABU analysis

Together, these visible and hidden pressures represent the true cost of inaction—a burden that grows heavier the longer action is postponed.

A study published in 2022 attempts to capture the totality of costs—the whole iceberg—accumulating due to climate change. It takes extreme weather events like heat/droughts and floods as a proxy to account for direct material damage (e.g., building destruction, yield loss) and indirect economic effects (e.g., supply chain disruptions, production downtime); and induced impacts (e.g., changes in consumption or employment patterns). In conclusion, the study estimates the macroeconomic consequences of climate change–related extreme weather events and comes up with a cumulative GDP loss of €280 billion–910 billion between 2022 and 2050. The total cost depends on which of the three different climate change scenarios—weak, medium, or high—unfolds.[140] Expressed in annual terms, this corresponds to an average cost of inaction of €10 billion–30 billion per year. Since the calculation accounts only for costs induced by climate change and not for those linked to water quality degradation or pollution—and given that the lowest-impact scenario is now regarded as unrealistic—the actual costs of inaction are likely somewhat higher, making the upper estimates of up to €910 billion in cumulative losses and up to €30 billion annually more realistic.

[140] GWS (2022): GWS Research Report 2022#02 Volkswirtschaftliche Folgekosten durch Klimawandel

5.1 The Tip of the Iceberg

Visible Costs of Inaction. The visible effects of inaction provide a glimpse of what Germany may face if current trends persist. Historically, Munich Re's latest analysis shows that Germany ranks third worldwide—after the United States and China—among the countries most severely affected by weather-related losses (not water-specific), with total damages exceeding $210 billion between 1980 and 2024.[141] Based on a meta-analysis of historic events and forward projections, floods, extreme droughts, and water pollution together could cause around €13 billion annual damage in the coming years.[142] This estimate already partially reflects the expected rise in frequency and intensity of extreme water-related events driven by climate change and land use. However, it should be regarded as a lower-bound figure, as many climate- and land-use-related impacts (e.g., the true frequency or severity of extreme events) remain difficult to predict. Moreover, numerous effects—particularly those that are indirect in nature, that unfold over the long term, or that affect human health and livelihoods—remain hard to quantify accurately,[143] especially if they are non-monetary in nature.

[141] Munich RE (2025): Unwetter nagen am Wohlstand – Wetterkatastrophen belasten viele Industrieländer zunehmend | Munich Re
[142] NABU & BCG meta-analysis
[143] Prognos (2022): Schäden der Dürre- und Hitzeextreme 2018 und 2019

Despite its natural limitations, our study proceeds with the results of our meta-analysis—namely, annual water-related damage costs of approximately €13 billion—while recognizing that this figure likely underestimates the full economic, environmental, and social burden. The actual cost trajectory will depend on the pace and effectiveness of adaptation measures as well as the extent of future climate change impacts and land coverage choices.

Floods

- Existing literature on floods offers a wide range of estimates for both total damage costs and future increases in flood frequency. One study projects that flood events comparable to those of July 2021 could become 1.2 to 9 times more frequent, with such floods currently expected to occur roughly once every 400 years under today's climate conditions.[144, 145] In terms of damage, one analysis estimates annual gross value losses due to floods of approximately €730 million in 2025 and €2.3 billion in 2029.[146] Average annual insurance claims expenditures between 2002 and 2024 amounted to around €2 billion.[147, 148] Assuming a five-year moving average CAGR of roughly 3%, this figure could increase to about €4.3 billion annually in the coming years. If total flood damage is approximately three times higher than insured losses,[149] total damage costs could rise to between €6 billion and €13 billion per year. Another study calculated total flood damage between 2000 and 2021 resulting in average annual losses of around €3.7 billion.[150]

- Considering that data derived from long-term historical time series—such as insurance claims and comprehensive extreme-weather event analyses including direct and indirect costs—tends to be more reliable, we use these sources to estimate an average expected annual flood damage of roughly €6 billion across Germany, primarily affecting infrastructure, housing, and transport corridors and trade.

[144] GWS (2022): Schäden der Sturzfluten und Überschwemmungen im Juli 2021 in Deutschland
[145] Kreienkamp et al. (2023): Attribution of the heavy rainfall events leading to severe flooding in Western Europe during July 2021 | Climatic Change
[146] Usman et al. (2025): Dry-roasted NUTS: early estimates of the regional impact of 2025 extreme weather by Sehrish Usman, Miles Parker, Mathilde Vallat :: SSRN
[147] GDV (2025): Langzeitbilanz: Schäden durch Naturgefahren in Deutschland using the following conversion data: Conversion of annual insurance claims expenditures into '24 price levels using factor 1 (VPI 2024/2023) Verbraucherpreisindex: Deutschland, Jahre
[148] GDV (2024): naturgefahrenreport-2024-datenservice-download-data.pdf
[149] NABU & BCG analysis based on: https://www.gdv.de/resource/blob/183710/ce0eff-6cd00569d1f67d1289b16a7325/naturgefahrenreport-2024-datenservice-download-data.pdf, Übersicht vergangener Extremwetterschäden in Deutschland, Langzeitbilanz: Schäden durch Naturgefahren in Deutschland, using the following conversion data: Conversion of damage values into '24 price levels using factor 1.16 (VPI 2024/2021) for total damage costs and 1 (VPI 2024/2023) for insurance data Verbraucherpreisindex: Deutschland, Jahre
[150] GWS (2022): Übersicht vergangener Extremwetterschäden in Deutschland using the following conversion data: Conversion of damage costs into '24 price levels using factor 1.16 (VPI 2024/2021) Verbraucherpreisindex: Deutschland, Jahre

Droughts

- Research on the damage caused by droughts similarly reveals a wide range of estimates for both frequency and economic impact. (See the sidebar "Why Recorded Drought Damages Underestimate the True Magnitude of Burden.") One study projects that two-year droughts will become up to seven times more frequent under the RCP 8.5 climate scenario (between 1850 and 2005, such droughts occurred roughly twice).[151] Another study estimates that droughts comparable to that of the summer of 2022 will occur five times more often under present climate than in preindustrial times, when events of this magnitude took place approximately once every 100 years.[152] Droughts of lesser intensity are expected to increase in frequency two- to fourfold, depending on temperature increases[153] and the degree of vegetation cover.[154]

- Damage estimates also vary: One analysis projects €80 million in annual losses by 2025 and €200 million by 2029,[146] while another study assessing total damage from heat and droughts between 2000 and 2021 finds average annual losses of around €2 billion.[150] Combining event frequency and cost estimates yields similar results. Assuming that a two-year drought, such as the 2018/19 event, causes around €40.5 billion in losses[155] and may occur roughly four times more often: If a sevenfold increase in frequency (about every 78 years) applies to the period of 2051–2100, and we assume a linear trend, the increase should be around fourfold (about every 19 years) 2006–2050. This implies average annual damages of approximately €2 billion. Other assessments using smaller-scale drought events estimate €1 billion–2 billion in annual losses, based on an average per-event cost of about €5 billion across all droughts from 2000 to 2021 and different temperature scenarios.[150, 153]

- Given that both the 2018/19 drought and the drought occurrences over 2000–2021 have been extensively analyzed, these figures provide a robust empirical basis for estimating long-term impacts. They indicate an average annual drought-related loss of around €2 billion, primarily from agricultural, industrial, and (trade) infrastructural damages. However, health-related costs are typically excluded from these estimates: Studies report €200 million–500 million annually[156, 155] for hospitalization and treatment alone—excluding mortality, long-term health effects, and reduced quality of life—suggesting that an expected total average annual drought damage of at least €3 billion is a conservative and reasonable estimate for Germany.

[151] Hari et al. (2020): Increased future occurrences of the exceptional 2018–2019 Central European drought under global warming | Scientific Reports
[152] Schumacher et al. (2024): ESD - Detecting the human fingerprint in the summer 2022 western–central European soil drought
[153] UBA (2022): Dürre als Folge des Klimawandels | Umweltbundesamt
[154] Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
[155] GWS (2022): Schäden der Dürre- und Hitzeextreme 2018 und 2019 using the following conversion data: Conversion of damage costs into '24 price levels using factor 1.16 (VPI 2024/2021) Verbraucherpreisindex: Deutschland, Jahre
[156] GWS (2022): GWS Research Report 2022#02 Volkswirtschaftliche Folgekosten durch Klimawandel

Why Recorded Drought Damages Underestimate the True Magnitude of Burden

According to EEA statistics, Germany recorded the highest total economic losses from natural disasters in Europe between 1980 and 2023—about €180 billion in total. More than 85% of these losses occurred after 2001, and when scaled per square kilometer, Western and Central European countries exhibit the highest loss densities. Across the EU-27, hydrological events such as floods dominate total and uninsured losses in absolute terms, whereas meteorological and climatological events like heatwaves or droughts typically account for smaller reported shares.

This raises the question: Are droughts truly "cheaper" than floods? The answer is no. Several factors contribute to the systemic underestimation of drought losses, reflecting aspects like reporting and valuation methods as much as real differences in impact.

- **Timing:** Floods cause sudden, concentrated destruction: Houses, roads, and factories are visibly damaged, and losses are immediate. Droughts, by contrast, unfold gradually over months or years, making their effects diffuse and far harder to capture statistically. These aspects of chronic water stress linked to dry conditions also interlink with other acute damages: Droughts cause long-term ecosystem degradation—such as the hardening of soils and drying of peatlands—which in turn reduces the land's ability to absorb water, directly intensifying the severity of floods from heavy rain events like thunderstorms which oftentimes follow after dry periods.

- **Nature of damage:** Besides direct costs like harvest failures, a large portion of drought damage involves indirect and structural costs. This includes production losses due to supply-chain disruptions, lower groundwater recharge, and an increased risk of vegetation fires threatening settlements and infrastructure. Furthermore, the persistent financial pressure and extreme singular events accelerate the decline of farms (Höfesterben), leading to a permanent erosion of income, hence decreasing satisfaction and resilience of the rural community.

- **Insurance protection:** Insurance coverage against drought impacts remains limited—particularly in agriculture—meaning that a large share of the damage never appears in official records and is likely underestimated in its true magnitude. The situation worsens due to increasing insurance tariffs and de-facto uninsurability of particular landscapes or damage events, as recently observed in California, where escalating wildfire risks have already led to massive withdrawal of insurers from the market.

- **Fatalities:** Most recorded natural disasters in Germany are linked to floods or storms, which leave immediate and clearly identifiable victims. Fatalities from these hazards are systematically collected across Europe. In contrast, while droughts themselves are rarely directly fatal in Central Europe, the lethal impact of associated heatwaves often results in much higher mortality rates, although these deaths are more difficult to identify and are usually based on statistical estimations.

The result is a statistical illusion: Floods appear costlier because their damage is immediate and visible, while droughts—though acting as a silent catalyst for economic decline and ecological vulnerability—leave deeper, structural scars that remain largely invisible and thus difficult to capture in their entirety.[157, 158, 159, 160]

[157] EEA (2025): Economic losses and fatalities from weather- and climate-related extremes | Publications | European Environment Agency (EEA)
[158] Drought.gov: drought.gov/sites/default/files/2023-11/NIDIS_DroughtAssmt2023_Focus11.pdf
[159] World Meteorological Organization (2021): Weather-related disasters increase over past 50 years, causing more damage but fewer deaths
[160] MWK (2023): Was uns die Folgen des Klimawandels kosten – Merkblatt #03: Schäden von Wetterextremen

Water Pollution

- Costs associated with water pollution span multiple dimensions—from impacts on water ecosystems to infrastructure expenditures and regulatory penalties—and vary widely across these categories. In terms of ecosystem-related costs, one study estimates that the removal of nitrate from drinking water amounts to €580 million–767 million per year, depending on desired nitrate levels.[161] For PFAS contamination, the removal of existing substances from the environment is projected to cost roughly €800 million annually, while continued emissions of new PFAS could increase total annual removal costs to over €17 billion.[162] Annual costs for water restoration in Germany could amount to around €900 million, assuming annual costs of approximately €5 million for an area of about 2,000 km².[163] In terms of infrastructure, introducing a fourth filtration stage in wastewater treatment plants is expected to require significant investments (total of €8.7 billion until 2045). It will also entail annual operating and maintenance costs of around €750 million. This assumes a maintained OPEX level of around €550 million like in 2046 and additional yearly reinvestment costs of about €200 million (average CAPEX 2026–2045).[164] The implementation of the EU Water Framework Directive (WRRL) is estimated to cost €61.5 billion between 2010 and 2027.[165] Assuming annual operating and maintenance costs of approximately 4% of total investment costs[166] leads to an estimated €2.5 billion annually attributable to WRRL-related operations and maintenance. Annual investments in Germany's water infrastructure—including drinking water supply systems, wastewater and stormwater infrastructure, and treatment facilities—amount to an average of €14.7 billion.[167] From a regulatory perspective, potential EU penalty payments for exceeding nitrate thresholds could reach around €370 million per year,[168] with the possibility of higher costs if other pollutants are included.
- Penalty data remains limited and primarily nitrate-specific, making it less reliable for projecting broader future liabilities. While ecosystem restoration and infrastructure investments provide relatively robust indicators of water pollution costs, PFAS-related estimates encompass environmental elements beyond water systems, meaning that only a share of those costs is water-specific. Taking the average across ecosystem and infrastructure estimates, expected annual costs associated with water pollution in Germany amount to approximately €4 billion.

Together, these projections illustrate the visible price of inaction—the apparent part of the iceberg that inflicts major and noticeable human and economic damage. Yet, another additional part of the burden lies below the surface, where chronic and cumulative forms of water stress quietly build over time.

5.2 Below the Surface

Chronic Water Stress. While the visible costs of floods, droughts, and pollution already signal the price of inaction, the more persistent burden lies beneath the surface. Chronic water stress develops gradually, often unnoticed, yet it shapes the long-term resilience of regions, economies, and ecosystems. (See the sidebar "Below the Surface" Uncovered: A New Normal for Tourism and Cities.) It is here that the additional costs of inaction accumulate, in the slow depletion of groundwater, growing local imbalances between supply and demand, and rising competition for scarce resources.

[161] UBA (2017): Factsheet Nitratkosten
[162] Tagesschau (2025): Drohende Milliarden-Kosten wegen PFAS-Verschmutzung | tagesschau.de
[163] MAZ (2019): Kreistag für Machbarkeitsstudie zur Sanierung der Seen und Flüsse in Teltow-Fläming - Entschlammung des Rangsdorfer See möglich
[164] VKU (2024): Erweiterte Herstellerverantwortung und Kosten der Viertbehandlung
[165] LAWA Expertenkreis (2021): lawa.de/documents/abschlussbericht-kosten-umsetzung-eg-wrrl-barrierefrei_1689845137.pdf
[166] CCWP (2018): Appendix F - CCCWP GI Cost Estimation Method
[167] VKU (2025): Studie_Investitionen_Wasserwirtschaft: VKU
[168] SZ (2023): Nitrat-Streit beendet: Deutschland entgeht Millionenstrafe der EU - Wirtschaft - SZ.de

"Below the Surface" Uncovered: A New Normal for Tourism and Cities

Chronic water stress and water scarcity is no longer a distant or abstract issue—it's increasingly visible in the lives of tourists and locals alike. Around the world, the impacts of chronic water stress are reshaping industries and lifestyles that once took abundant water for granted.

Cape Town's "Day Zero" wake-up call

In 2018, after three consecutive years with historically low rainfall, Cape Town, South Africa, came dangerously close to becoming the first major city to run out of water. The threat of "Day Zero" triggered strict restrictions: residents limited showers, and hotels closed pools. Tourism suffered a sharp blow—new arrivals dropped by about 20%, causing losses in visitor revenue and threatening thousands of hospitality jobs.

Europe's car bans and dry fountains

In France, an unusually dry winter in 2023 led authorities to impose nationwide bans on car washing, on top of restrictions on garden watering and filling of swimming pools to preserve water for the summer that were already in place in some regions. A year earlier, Barcelona implemented similar measures: prohibiting car washing and cancelling its famous Magic Fountain spectacle, a major tourist attraction, due to severe drought conditions.

Drought on the rivers and slopes

In Germany and Switzerland, low water levels on the Rhine River disrupted one of Europe's key tourism and transport arteries. During the worst periods, river cruise passengers were forced to complete sections of their journeys by bus, because vessels could no longer navigate shallow stretches. Meanwhile, Europe's ski resorts are feeling the impact of milder, drier winters. In France's Jura region, tourist numbers in February 2023 were 69% below the five-year average, as low levels of winter precipitation made skiing nearly impossible.

Mediterranean islands under pressure

Chronic water shortages have also hit the Greek islands, where demand peaks precisely when rainfall is lowest. On Mykonos, an island that has been suffering from significant water scarcity problems in recent years, low water levels forced authorities to start investing in and relying on desalination systems to sustain supply during high seasons. Meanwhile in Naxos, authorities restricted the filling of private swimming pools and limited nonessential use.

Energy under pressure: France's nuclear plants forced offline

Water scarcity doesn't just impact leisure, it also hits the energy sector. In recent years, France's nuclear power plants, which rely heavily on river water for cooling, have faced repeated output reductions during heat waves as water levels in adjacent rivers dropped and water temperatures rose to threatening heights. For example, in the summer of 2022, several reactors had to cut production or temporarily shut down, reducing available supply and driving up electricity prices across Europe.

These stories reveal a broader pattern: Water stress is changing the rhythm of daily life. From closed fountains to dry ski slopes, cancelled cruises, and empty hotel pools, the effects are becoming tangible, visible, and economically costly. For many regions, adapting to chronic water scarcity is no longer optional—it is a matter of survival for both communities and the industries that depend on them.[169, 170, 171, 172, 173, 174, 175, 176, 177, 178]

[169] McCarroll et al. (2024): Tourism resilience to drought and climate shocks: The role of tourist water literacy in hotel management - ScienceDirect
[170] Times live (2022): Cape Town seeking to change Day Zero narrative to bring tourists back
[171] Carwashpro (2023): Autowaschen in Frankreich verboten | CarwashPro
[172] TAZ (2022): Dürre in Spanien: Autowaschen in Barcelona verboten | taz.de
[173] DW (2023): How Europe's droughts are affecting tourism – DW – 04/03/2023
[174] Reuters (2024): Greek islands face water crisis as tourist season peaks | Reuters
[175] Atay & Saladié (2022): Water Scarcity and Climate Change in Mykonos (Greece): The Perceptions of the Hospitality Stakeholders
[176] GRS (2024): Built close to water – do increasing droughts and hot spells affect nuclear power plants? | GRS gGmbH
[177] GRS (2023): Situation of the nuclear power plants in France - how has the situation evolved in our neighbouring country since the summer? | GRS gGmbH
[178] The Energy Mix (2022): Failing French Nuclear Plants Drive Up Electricity Costs as Heat Waves Cut Production

Brandenburg, a Hotspot of Regional Water Stress. Brandenburg serves as a particularly telling example of how these underlying pressures unfold over time, due to four interlinked factors. (See Figure 11.) First, its hydrological and geological conditions make it one of Germany's driest federal states[179] and inherently prone to drought.[180] That stems from its sandy soils[181] with low water-retention capacity,[180] thin humus layers, groundwater pollution,[182] and limited groundwater recharge.[183] Even moderate shifts in rainfall or temperature can therefore trigger pronounced hydrological deficits. Second, Brandenburg and the Berlin metropolitan area are hydrologically and geographically interconnected, sharing groundwater systems and river basins. For example, Berlin sources its drinking water supply from groundwater but also heavily relies on bank filtrate, which is highly dependent on rivers like the Havel and Spree.[184] As water demand grows across the Berlin-Brandenburg area, Berlin is ever more affected by and dependent on water resources and management decisions in Brandenburg, creating a tightly linked regional water system where pressures in one area directly influence the other. Third, the region's water balance has been fundamentally altered by the hydrological effects of mining. Historically, massive groundwater extraction lowered groundwater levels while simultaneously increasing the flow of the Spree River. With the phase-out of lignite (brown coal), this extraction is ending. The loss of these inflows to the Spree, along with the extensive flooding of former mines and other large-scale hydrological interventions in the Lausitz region, has already reshaped—and will continue to reshape—groundwater flows, with substantial impacts on water levels across the Spree catchment.[185, 186] These transformations continue to require complex water management, with competing interests and demands from ecology, industry, and especially agriculture, which makes up around 45% of Brandenburg's total area.[187] Another 36% of the area is coverd by forests of which more than 50% are pines, mostly monocultures and only roughly 13% are meeting near-natural forest management criteria.[188, 189] Finally, Brandenburg has drawn significant public and media attention due to the water consumption of major industrial developments—an automotive gigafactory, power generation plants and ChemParks e.g., Schwarze Pumpe[190]—topped off with plans of tech companies that planned on setting up data centers in Brandenburg.[191, 192] Over the past years, groundwater, lake, and river levels have steadily fallen[193, 194, 195] while agriculture, industry, and municipalities increasingly compete for the same limited water resources.

[179] IGB (2021): The Berlin-Brandenburg region and the Tesla Gigafactory | IGB
[180] LfU Land Brandenburg: Water |
[181] LfU Land Brandenburg: Boden | Startseite | LfU
[182] LfU Land Brandenburg: Grundwassergefährdung und -schutz | Startseite | LfU
[183] IGB (2024): Water in the soil, but not in the groundwater | IGB
[184] Berliner Zeitung (2021): In Berlin-Brandenburg wird das Wasser knapper
[185] UBA (2023): Wasserwirtschaftliche Folgen des Braunkohleausstiegs in der Lausitz - Abschlussbericht
[186] LEAG (2019): Spree fließt mit bis zu 60 Prozent Grubenwasser | LEAG
[187] Statistik Berlin Brandenburg (2022): Mehr als 1,3 Millionen Hektar landwirtschaftlich genutzte Fläche in Brandenburg
[188] LfU Land Brandenburg (2024): https://mleuv.brandenburg.de/sixcms/media.php/9/Waldzustandsbericht-BB-2024.pdf
[189] PEFC (2025): https://www.pefc.de/media/filer_public/65/ea/65ea3279-1636-43ab-ad34-95475dbb503a/reg_wber_brandenburg_20251010.pdf
[190] BZ (2023): Das sind Brandenburgs zehn größte Wasserverbraucher
[191] RBB (2025): Mittenwalde: Google stoppt Pläne für Rechenzentrum in Südbrandenburg | rbb24
[192] Deutschland Funk (2022): Gigafactory in Grünheide - Wasserknappheit wegen Tesla?
[193] UBA (2023): WW-I-7: Wasserstand von Seen | Umweltbundesamt
[194] UBA (2023): WW-I-6: Niedrigwasser | Umweltbundesamt
[195] UBA (2023): WW-I-2: Grundwasserstand und Quellschüttung | Umweltbundesamt

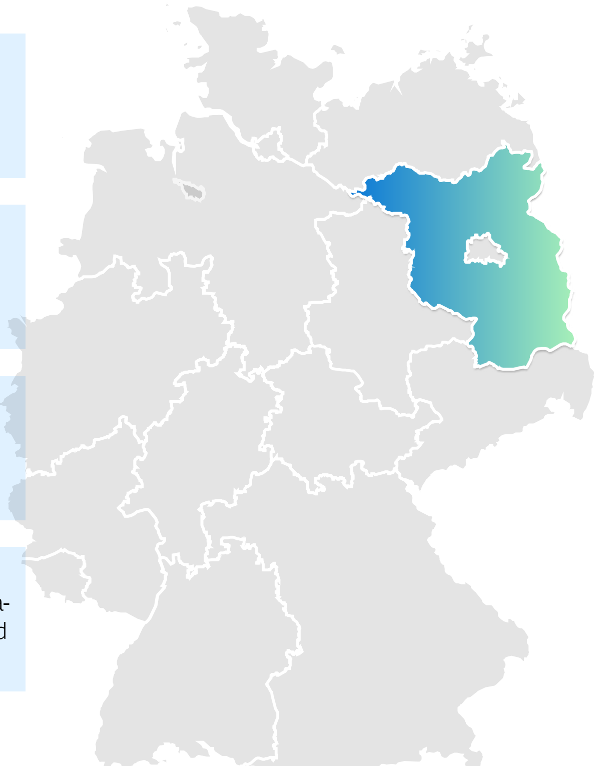
Figure 11: Why Brandenburg is a prime example of regional water stress

Hydro- & Geological conditions
Sandy soils, low-water retention capacity, thin humus layers, groundwater pollution, and limited groundwater recharge make Brandenburg one of the dries areas in Germany

Berlin – Brandenburg interconnection
Berlin's growing water demand and reliance on Brandenburg's shared groundwater and river systems intensifies pressure on Brandenburg's water resources

Post-mining water use
Lausitz mining phase-out is reducing groundwater inflows to Spree, while filling of post-mining lakes increases water demand, reshaping water balance and intensifying competition across sectors

Media attention on industrial users
Rising water demand from major industrial sites, e.g., an automotive gigafactory, power generation plants, and other large facilities, has heightened public concerns about competition over limited regional water resources



Source: BCG & NABU analysis

Together, these factors make Brandenburg both a hotspot and a microcosm of Germany's broader water challenges and stress: a region where climatic vulnerability, industrial expansion, and ecological transformation converge—and where the hidden costs of inaction become most visible over time.

Measuring Water Stress. To quantify regional water scarcity, our study applies the Water Stress Index (WSI), following the World Resources Institute's (WRI) Aqueduct 4.0 Baseline water stress method.[196] Water stress is defined as the ratio of total water demand to available water supply, with higher ratios indicating stronger competition among users. A value above 40% signals high stress, meaning that more than two-fifths of available water resources are already withdrawn each year. Germany's national average WSI of roughly 2.0 places it in the medium-to-high stress range, though strong regional disparities exist. In comparison, countries like Spain and Italy display far higher WSIs of 2.9 and 3.3 respectively, while Norway ranks low on the water stress index scale with a value of 0.2. Assessing water stress, both today and in the future, in this way allows us to visualize competition for water, estimate its evolution under climate change, and evaluate the effectiveness of targeted mitigation and adaptation measures across regions.

Assessing Water Stress in Brandenburg. Building on this definition, water stress in Brandenburg is assessed by modelling the balance between water demand and available supply across the region's main user groups: industry, domestic and municipal use, and agriculture.

For industry, the analysis captures water used in manufacturing, energy production, and industrial processes, with surface water from rivers, lakes, and reservoirs serving as the primary source. For domestic and municipal use, demand reflects household consumption (e.g., drinking, cleaning) and service-sector needs (e.g., schools, hospitals, and public facilities) for a population of approximately 2.5 million residents—excluding roughly 3.7 million of Berlin's inhabitants.[197] Water in this category is abstracted from both groundwater and surface water. For agriculture, the model considers water used to produce key regional crops such as wheat, barley, and sugar beet. Supply for this demand comes mostly from rain, as less than 3% of the cropland in Brandenburg is irrigated.[198]

To estimate expected water stress, we combine multiple datasets to model how both demand and supply evolve under changing climatic conditions. These datasets include climate projections (NASA NEX-GDDP-CMIP6 and HDX),[199, 200] regional agricultural statistics (MAPSPAM),[201] and hydrological data on surface and groundwater availability (ISIMIP),[202] as well as water resource management (FAO AQUASTAT).[203] Water demand in the agricultural sphere is modelled by considering, among other things, regional crop mix, the crop calendar, and crop water needs, while domestic, municipal, and industrial usage is projected by adjusting for economic growth, temperature rise, and technological efficiency gains. The water supply accounts for rainfall water, groundwater storage, and surface water. The resulting WSI captures the ratio of total water demand to available supply for each sector, allowing us to visualize local competition for water and identify potential deficits. It also enables the estimation of the cost of inaction by linking unmet water demand to potential productivity losses[204]—highlighting how water scarcity translates directly into economic and environmental risks for Brandenburg.

This sector-based assessment allows us to quantify local competition for water, showing how both supply and demand dynamics contribute to regional stress, with climate change and related effects of land management expected to affect both demand and supply, intensifying these pressures on both sides of the equation.

Industrial Water Stress[205]

- Industrial activity in Brandenburg—including manufacturing, energy production, and large-scale industrial processes such as those around the Tesla Gigafactory—depends heavily on surface water from rivers, lakes, and reservoirs. Today, areas like Potsdam and Oberhavel have water stress levels of 2.4 and 0.9 respectively. Regional water availability will fall sharply with industrial unmet water needs increasing from 10% in 2025 to 23% in 2050 and with the closure of the Lausitz lignite (brown coal) mines drastically reducing inflows from mine drainage that currently account for more than half of the Spree River's discharge during dry periods. As this artificial groundwater pumping ceases, the Spree's baseflow will decline and seasonal shortages will intensify.[206]

  This, in combination with other effects of technological and industry advancements, will lead industrial water stress to almost triple by 2050 compared to today.[207] In Potsdam, water stress is expected to rise to 4.4 in 2050, an 80% increase, while Oberhavel will reach a water stress level of 1.6 in 2050, a plus of 75%.
  This escalation translates into an economic cost of inaction of 1–2% of Brandenburg's GDP, or roughly €1.8 billion–3.6 billion annually[208, 209] by mid-century. In in-

[196] WRI Aqueduct 4.0 (2023): Aqueduct 4.0: Updated Decision-Relevant Global Water Risk Indicators | World Resources Institute
[197] Statistik Berlin Brandenburg (2024): Bevölkerungsstand in Berlin und Brandenburg – Jahresergebnisse
[198] Mirschel et al. (2016): (PDF) Simulated additional crop yields due to irrigation of agricultural fields throughout Brandenburg, Germany, for 1975-2075.
[199] NASA: Downscaled Climate Projections (NEX-GDDP-CMIP6) - NASA
[200] HDX: Germany: Administrative Division with Aggregated Population | Humanitarian Dataset | HDX
[201] MAPSPAM: Home of the Spatial Production Allocation Model (MAPSPAM) | IFPRI INFO: Conversation – collaboration – community site

[202] ISIMIP: ISIMIP - The Inter-Sectoral Impact Model Intercomparison Project
[203] FAO Aquastat: AQUASTAT - FAO's Global Information System on Water and Agriculture
[204] Sector-specific cost of inactions were estimated using effective service and industrial Water Use Efficiencies. Values were adjusted to account for the share of water contributing to the GDP, and marginal corrections for every unit of water not being as valuable as the average – using the FAO AQUASTAT Domestic Water Use Intensity index
[205] NABU & BCG analysis based on Amt für Statistik Berlin-Brandenburg; https://data.ece.iiasa.ac.at/ssp/; Japan's CGER (Center for Global Environmental Research); Murakami, Daisuke, and Yoshiki Yamagata. "Estimation of gridded population and GDP scenarios with spatially explicit statistical downscaling." Sustainability 11.7 (2019): 2106
[206] UBA (2023): Wasserwirtschaftliche Folgen des Braunkohleausstiegs in der Lausitz - Abschlussbericht
[207] Difference between averaged water stress over 2040-2050 period, and the value for 2025
[208] Using conversion factor of 1 Dollar = 0.89 Euro (Average 31/12/2024-17/10/2025): US dollar (USD)
[209] Based on 2050 GDP projections excluding inflation (real GDP, expressed in constant 2005 PPP USD)

dustrial centers such as Potsdam and Oberhavel, stress levels are expected to nearly double by 2050. Beyond direct financial losses, these shortages could disrupt production cycles, limit future investments, and constrain regional competitiveness.

Domestic and Municipal Water Stress[210]

- Domestic and municipal water demand in Brandenburg is projected to rise steadily, driven by population growth in suburban areas and higher consumption per capita during warmer summers.[211] At the same time, groundwater availability is expected to decline by around 12% by 2050, with the northern area of Brandenburg most exposed, while the average domestic water stress index in areas such as Potsdam could increase by 50%, from 3.0 today to 4.6 in 2050.[212]

- Without intervention, these trends could lead to significant economic and social costs. The annual cost of inaction from unmet domestic and municipal water demand could reach 3–5% of Brandenburg's GDP, equivalent to €5.3 billion–9 billion per year[213, 214] by 2050. Reduced groundwater supply, more frequent abstraction restrictions, and higher treatment costs will affect not only households but also essential services such as hospitals, schools, and local utilities.

Agricultural Water Stress

- Agricultural area, capturing around 45% of Brandenburg's total land area,[215] contributes greatly to the livelihood of the rural economy but is also a highly water-dependent sector. The region's production of grains and vegetables relies almost entirely on rainfall, with less than 3% of cropland irrigated.[216] Agricultural water stress in Brandenburg is already high, with areas such as Prignitz or Elbe-Elster exhibiting water stress indices of 2.0 and 2.1 respectively. Under a "do nothing" scenario (climate scenario SSP5-8.5), agricultural water stress is projected to remain high and intensify by 2050,[217, 218] leading to an increase in water stress by 0.1 in Prignitz and 0.19 in Elbe Elster[212] with up to 50% of crop water needs going unmet. Across Brandenburg, the crops where production is the most threatened are wheat, maize, and other vegetables. The resulting annual production losses are estimated at €270 million–380 million by 2050,[213] threatening regional food supply and farmer livelihoods.

- The stress on crops is projected to become increasingly volatile and crop-specific under future climate conditions. For winter wheat, which accounts for roughly one quarter of Brandenburg's agricultural output,[219] water-stress events are expected to become shorter but more intense (~25% contraction in stress duration), with the peak intensity rising by about 30% and occurring around six weeks later in the growth cycle, during the reproductive phase when grains are most sensitive. This shift leaves farmers with less time to respond and increases the likelihood of yield losses if adaptation measures are not timely. Corn, representing about 4% of Brandenburg's production,[219] is expected to experience longer stress periods, extending by up to two months, combined with an approximate 10% increase in stress intensity. These changing stress profiles for both crops illustrate how climatic shifts can simultaneously shorten response windows and extend exposure to water deficits, thereby amplifying yield volatility, production risk, and economic instability across Brandenburg's agricultural sector.

The results for Brandenburg make one point clear: The economic cost of inaction for chronic water stress is substantial across all sectors. The effects for agriculture, domestic and municipal use, and industry were modelled separately to isolate sector-specific dynamics and sensitivities. Hence, these sector (GDP) results cannot simply be aggregated. Doing so would overlook interdependencies and crossover effects between sectors; for instance, when scarce industrial water supplies also disrupt agricultural supply chains or municipal demand. The figures should therefore be viewed as indicative within-sector effects rather than cumulative totals.

The Chronic Cost of Water Stress in Germany. Extrapolating results from a regional subset to the national level should always be treated with caution and should be determined via detailed, country-wide modelling. Given this was outside the scope of this study, but to nevertheless provide an indicative assessment of the below-the-surface impact in the context of this study, a set of assumptions was applied. First, to avoid overestimation through intersectoral spillovers, a correction factor was applied to aggregated sectoral losses derived from the Brandenburg analysis. Second, given water stress in Brandenburg is roughly four times higher than the national average,[220] the extrapolation to Germany was adjusted accordingly to reflect less severe but still significant impacts elsewhere. Third, the extrapolation combined per-capita and areal factors, accounting for both population density and land area differences between Brandenburg and the rest of the country. Finally, as chronic water stress and extreme drought events are difficult to separate empirically, some overlap with the tip-of-the-iceberg cost estimates may remain.

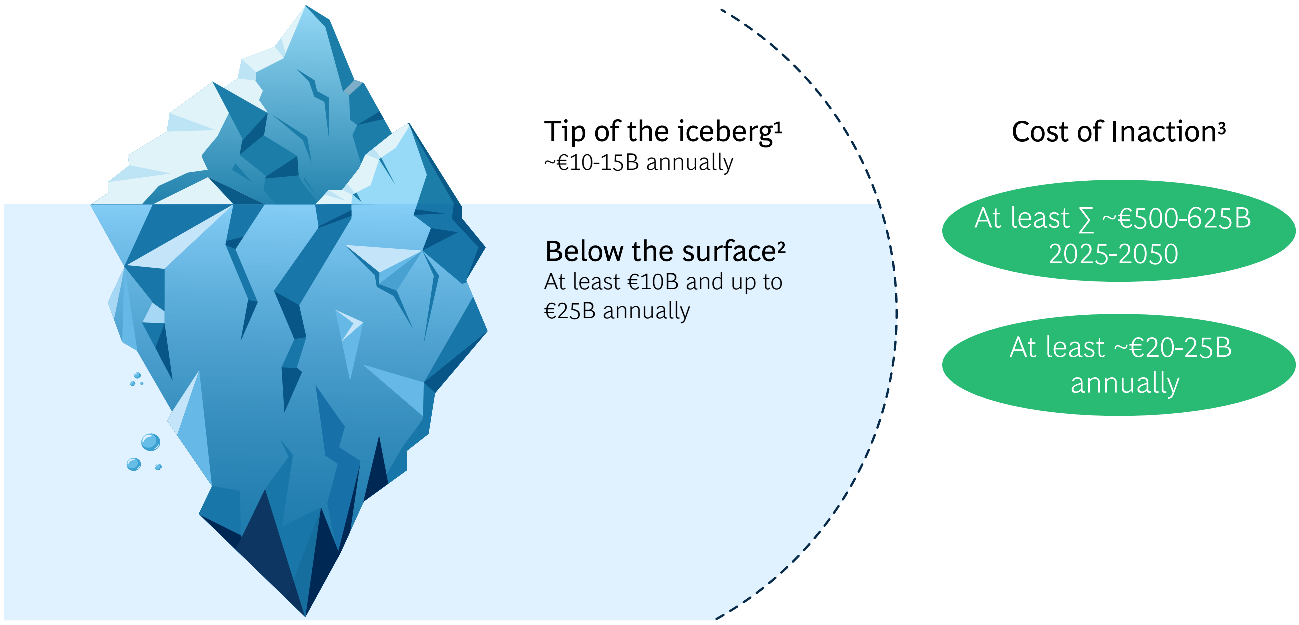
[210] NABU & BCG analysis based on Amt für Statistik Berlin-Brandenburg; https://data.ece.iiasa.ac.at/ssp/; Japan's CGER (Center for Global Environmental Research); Murakami, Daisuke, and Yoshiki Yamagata. "Estimation of gridded population and GDP scenarios with spatially explicit statistical downscaling." Sustainability 11.7 (2019): 2106
[211] Additionally, we also account for water demand from Berlin by assuming external supply for Berlin is coming exclusively from Brandenburg.
[212] Difference between averaged water stress over 2040-2050 period, and the value for 2025
[213] Using conversion factor of 1 Dollar = 0.89 Euro (Average 31/12/2024-17/10/2025): US dollar (USD)
[214] Based on 2050 GDP projections excluding inflation (real GDP, expressed in constant 2005 PPP USD)
[215] Statistik Berlin Brandenburg (2022): Mehr als 1,3 Millionen Hektar landwirtschaftlich genutzte Fläche in Brandenburg
[216] Mirschel et al. (2016): (PDF) Simulated additional crop yields due to irrigation of agricultural fields throughout Brandenburg, Germany, for 1975-2075.
[217] Cropland area and crop mix are considered constant over time to isolate the effect of climate change.
[218] Based on average of historic crop prices over historic dataset
[219] NABU & BCG analysis estimating each crop's share of total production using the 2020 Spatial Production Allocation Model (SPAM), calibrated to 2024 production volumes based on Destatis data
[220] Aqueduct: Aqueduct Country Ranking

Applying these assumptions yields an estimated average annual below-the-surface cost of at least €10 billion, reflecting a more optimistic, lower-bound scenario based on conservative assumptions that does not include overlaps with tip-of-the-iceberg cost estimates. Under more extreme (climatic) assumptions, estimated costs can rise up to €25 billion per year by 2050. This range should be interpreted as indicative.

5.3 The Full Cost of the Iceberg

The Cumulative Cost of Inaction. The cost of inaction on Germany's growing water stress can be derived by consolidating the complementary estimates introduced in the previous sections. (See Figure 12.) The tip of the iceberg, representing direct and visible damages from droughts, floods, and water pollution, accounts for roughly €13 billion per year, converted to a range, amounting to €10 billion–15 billion. The below-the-surface losses, capturing indirect and systemic impacts on ecosystems, groundwater, and long-term productivity, are estimated to be at least €10 billion, building on more optimistic assumptions, and up to €25 billion annually by 2050, applying more extreme assumptions, extrapolated from Brandenburg to the national scale. Combining these two estimates yields an annual loss estimate for the whole iceberg of at least €20 billion–25 billion. Extrapolated over the period 2025–2050, this translates into a cumulative economic burden of at least €500 billion–625 billion, underscoring the scale of the financial risk posed by continued water depletion and delayed adaptation.

Figure 12: Water-related events could cause annual losses of at least ~ €20-25B or cumulatively ~ €500-625B by 2050, if no action is taken



1. Based on BCG & NABU meta-analysis

2. Extrapolation of Brandenburg estimates to all of Germany in a more optimistic and more extreme scenario, based on the following assumptions: a) Inter-sectoral spillover factor applied to Brandenburg's aggregated Cost of Inaction to avoid overestimation, b) Brandenburg's 2050 water stress (optimistic scenario) is ~ 4× higher than the German average, hence only 25% of Brandenburg's Cost of Inaction considered, c) Adjustment of Brandenburg's Cost of Inaction for per capita and areal factors, and d) Accounting for overlaps with the "tip of the iceberg" cost estimates

3. Combined estimate adding "tip of the iceberg" estimate with an optimistic "below the surface" estimate, while recognizing that the latter could increase when applying more extreme assumptions and when including overlaps with "tip of the iceberg" cost estimates

Note: Values shown on this slide are rounded and provided as ranges

Source: BCG & NABU analysis

6. Acting in New Water Realities—Solutions to improve water availability

6.1 Controlling the Controllables

From Ecosystem Layers to Water Balance. While many aspects of the water cycles are governed by natural forces, not all ecosystem layers are beyond human control. (See Figure 13.) The atmosphere cannot be influenced locally—only through globally coordinated action. Processes such as cloud formation, precipitation, and deep groundwater flow are complex and difficult to steer, though they can be (somewhat indirectly) influenced locally; for instance, through targeted land-use practices or weather modification efforts such as cloud seeding. (See the sidebar "Cloud Seeding: Engineering Rain.") However, interventions like cloud seeding are resource-intensive, scientifically uncertain and raise ethical and political questions, particularly concerning the ownership and redistribution of water. By contrast, the surface and topsoil layers—where water interacts directly with vegetation, soil structure, and land use—can be managed far more effectively. These layers determine how much water infiltrates, evaporates, or runs off, making them the first, most immediate and reliable leverage points in shaping Germany's overall water balance.

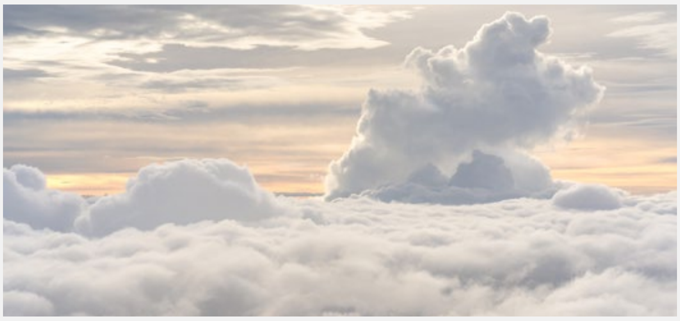
Figure 13: While deep waterflows and precipitation are hard to change, surface and topsoil offer management opportunities

Ecosystem layer	Degree of controllability[1]
Atmosphere	We **cannot control the atmosphere locally**; we can **influence** its **composition & behavior** via our collective global actions
Clouds	**Cloud formation can be influenced indirectly** via landcover or experimentally via cloud seeding (high costs, ethical & political concerns)
Water body	**Marginally controllable** via the amount of water extracted for use across different sectors (e.g., households, industry)
Surface	**We can control the surface** via our coverage choices and thus influence all ecosystem layers
Topsoil	**Our land use and management choices influence the topsoil structure** and thus how much water can infiltrate
Parent material/bedrock	We **cannot control** or change the composition or structure of parent material/bedrock easily
Aquifer	We **cannot control** groundwater deposits easily - we are able to extract & pollute them, but replenishment is difficult

Degree of controllability: Low – High

1. Refers to the degree of local controllability — for example, the atmosphere can only be influenced globally, whereas cloud formation can be influenced locally

Source: BCG & NABU analysis



Cloud Seeding: Engineering Rain

Cloud seeding, the deliberate modification of clouds to induce rainfall, is increasingly used as a tool to combat drought and water scarcity. The method involves dispersing tiny particles, often silver iodide, dry ice, or salts, into clouds using aircraft, drones, or ground-based generators. These particles act as nuclei around which water vapor condenses, forming droplets or ice crystals that grow until they fall as rain or snow.

While the technique has been tested for decades, its effectiveness remains contested. Recent projects, such as those in China's Xinjiang region, claim rainfall increases of around four percent across several thousand square kilometers after the deployment of drones releasing about one kilogram of silver iodide. Yet, experts caution that such results are difficult to separate from normal meteorological variability, and reliable, large-scale evidence remains limited.

Beyond scientific uncertainty, cloud seeding raises ethical, environmental, and geopolitical questions. Redirecting precipitation in one area can unintentionally reduce it in another, creating tension over "weather ownership" and resource distribution. Although current research suggests that the small quantities of silver iodide used pose minimal health or environmental risks, long-term impacts are not yet fully understood. Furthermore, there is no international legal framework governing weather modification, leaving the practice largely unregulated.

Cloud seeding illustrates both the promise and peril of climate engineering—a potentially valuable response to drought. However, it underscores how human attempts to control nature remain bound by uncertainty and trade-offs, therefore not making it a viable option for addressing water challenges at scale.[221, 222, 223, 224]

[221] Vision Factory (2019): Cloud Seeding Technology: Can We Really Control the Weather?
[222] U.S. Government Accountability Office (2024): Cloud Seeding Technology: Assessing Effectiveness and Other Challenges | U.S. GAO
[223] DRI: What is Cloud Seeding? - DRI
[224] Interesting Engineering (2025): China tests drones to make it rain over drought-prone Xinjiang

Three recent strands of research underscore how important these controllable layers are for both water and climate resilience. A hydrological study[225] shows that the condition of soil and land surfaces, particularly sealing, compaction, and drainage, can explain more of the variation in water availability and the frequency of floods and droughts than climate-induced temperature change alone. When compacted or sealed, they lose the capacity to store water, generating rapid runoff and reducing groundwater recharge; when porous and vegetated, they act as distributed retention systems that moderate extremes and sustain baseflow. This is also in line with the soil carbon sponge concept. That is the ability of soils to act as a living carbon sponge—a porous, biologically active structure that absorbs, stores, and slowly releases water—and it depends directly on how they are managed. Practices that disturb or oxidize soil carbon, such as intensive tillage or deforestation, weaken this function, while regenerative approaches that maintain cover, enhance soil biology, and reduce compaction strengthen it.[226, 227, 228] New research[229] further supports this and highlights that soil compaction represents a controllable factor in this balance: Reducing compaction increases the soil's natural sponge-like properties. This drives infiltration and the soil's temporary storage capacity, enabling soils to act as a sponge that can delay or mitigate flooding. Managing soil structure, therefore, not only improves agricultural productivity but also strengthens flood protection and hydrological stability. Thus, by altering infiltration, storage capacity, and lateral flow, human management of these layers can directly determine whether rainfall becomes runoff or infiltrates into the ground and supports groundwater recharge, making them some of the most controllable levers of the water balance. Complementary atmospheric research[230] demonstrates that vegetated and well-hydrated landscapes exert measurable control over local climate dynamics: Greener surfaces remain cooler, recycle moisture through evapotranspiration, and enhance convective cloud formation that can stimulate rainfall. On the other hand, degraded or dry surfaces heat rapidly, suppress rainfall, and intensify drought-heat feedback. The New Water Paradigm[231] enforces this view by showing that the health of water cycles depends directly on how we manage the land surface, emphasizing that land use and land cover are not just passive backdrops but active drivers of hydrological and climatic stability. By restoring vegetation, soil moisture, and infiltration capacity, the paradigm argues, humans can rehydrate landscapes, regenerate the small water cycles that regulate local rainfall and temperature, and thereby strengthen the large, planetary water cycle. In this sense it demonstrates that water security begins with how we treat the land itself. Together, these findings show that the land surface is not only a reflection of climate forces but also a functional part of the water cycle itself, capable of buffering, redirecting, and even amplifying water and energy flows across ecosystem layers, depending on how the land is managed.

Runoff: The Water Balance Expression of Surface Control. In the water balance equation, runoff is the measurable expression of what happens within the surface and topsoil layers. While precipitation and inflows from abroad depend primarily on large-scale climatic and geographic forces, their local distribution, retention, and impact are influenced by surface conditions, such as vegetation cover, soil permeability, and land use. Similar dynamics hold for losses like evapotranspiration that are partially manageable via surface cover choices, but are also driven by local characteristics. Runoff, though, directly reflects human choices about how the land is structured and managed.

In 2022, water leaving Germany through runoff—into the oceans or across borders—accounted for the largest controllable share of total storage depletion.[232] Reducing this outflow therefore represents the most direct way to keep water within the system longer, strengthen local availability, and improve ecosystem resilience. Runoff is where the water balance equation and ecosystem management meet—the point where human-scale interventions can alter national-scale outcomes.

Land Management as the Lever for Change. Because surface and topsoil as well as groundwater are tightly interconnected,[225] how we manage land determines how water moves through the system—and how local climates evolve. High surface runoff leads to rapid water loss, erosion, and heat accumulation, while effective infiltration supports groundwater recharge, sustains vegetation, and stabilizes soil moisture and local humidity levels.[233]

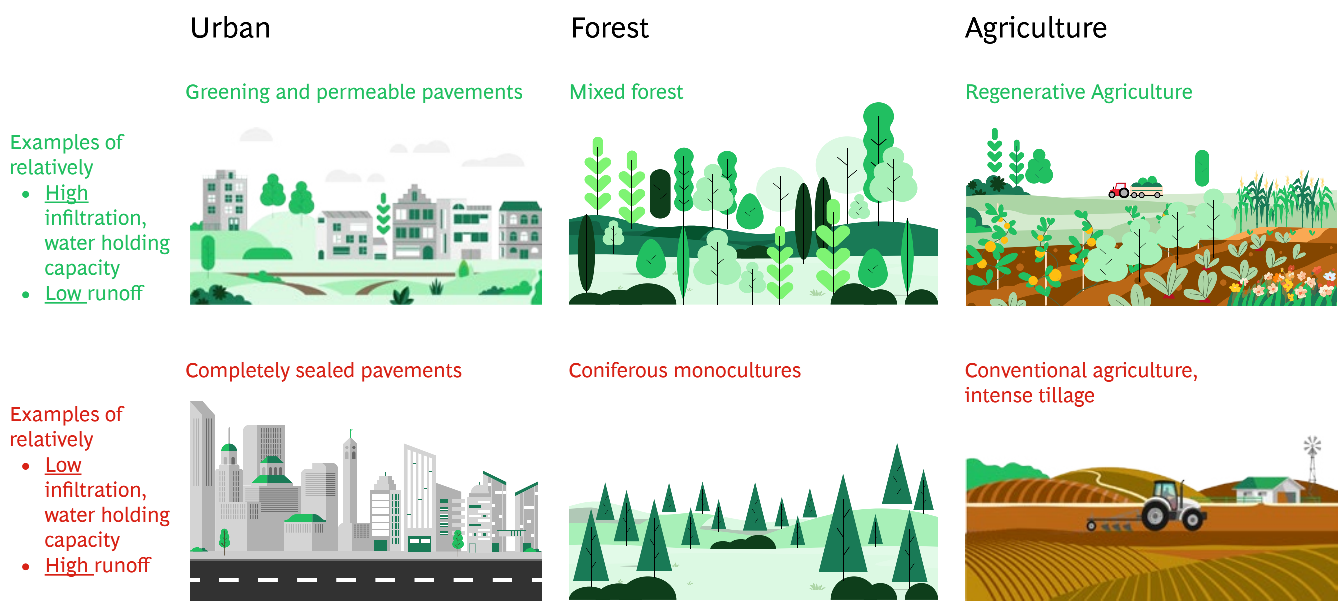
Across Germany, current land-use patterns often work against these functions: (See Figure 14.)

- In **urban areas**, extensive sealing limits infiltration and amplifies runoff.
- In **forests**, simplified monocultures have reduced the soil's ability to hold and filter water.
- In **agriculture**, bare-soil periods and intensive tillage reduce infiltration and increase evaporation.

[225] Auerswald et al. (2024): EGUsphere - HESS Opinion: Floods and droughts – Land use, soil management, and landscape hydrology are more significant drivers than increasing temperatures
[226] Jehne (2019): https://nzbiocharltd.co.nz/resources/Regenerate-Earth-Paper-Walter-Jehne%20%281%29.pdf
[227] Jehne (2014): https://irp-cdn.multiscreensite.com/d6b81fb6/files/uploaded/2017%20-%20Regenerating%20Earth%27s%20Soil%20Carbon%20Sponge.pdf
[228] Jehne: https://vernoux.org/agriculture_regenerative/Jehne-Restoring_water_cycles_to_naturally_cool_climates_and_reverse_global_warming.pdf
[229] UfU e.V. (2025): UfU-Hintergrundpapier
[230] Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
[231] Kravčík et al., (2007): https://www.waterholistic.com/wp-content/uploads/2024/04/white-paper-nwp_water_for_climate_healing_white_paper_web_2023_final.pdf
[232] Destatis (2025): Statistischer Bericht - Umweltökonomische Gesamtrechnungen - Wassergesamtrechnung - Berichtszeitraum 2001 - 2022 - Statistisches Bundesamt
[233] Alpha Lo (2024): The missing link: groundwater creates rain - by Alpha Lo

Reversing these dynamics requires rethinking how surfaces are structured and managed, from cities to croplands to forests. Increasing infiltration and reducing runoff through greening, permeable pavements, mixed forests, and regenerative agricultural practices can reconnect the upper ecosystem layers with groundwater systems.

Figure 14: Water flows are influenced by surface coverage: high-capacity permeable surfaces can decrease runoff



Surface coverage influences both the infiltration rate and the soil's water-holding capacity—key factors that determine whether water is retained in the landscape or lost as runoff. As a result, it plays a key role in the landscape's resilience to extreme weather events

Source: BCG & NABU analysis

At the same time, vegetation and soil restoration regenerates small water cycles by enhancing local moisture recycling and contributing to more rainfall, complemented by changing precipitation patterns that are becoming more erratic, extreme, and frequent.[234] This additional water will only strengthen resilience if landscapes are equipped to absorb, store, and process larger and more intense precipitation events. Without adequate infiltration capacity and retention infrastructure, more rain may simply translate into more runoff and flooding. Hence, building the right physical and ecological structures to manage this water surge is therefore of as much importance as restoring the processes that generate it.

In a world where precipitation is becoming more erratic and extreme events are more frequent, managing the surface and topsoil is the most direct and powerful way to influence the local water cycle. (See the sidebar "Reforestation and Rainfall: How Greening Deserts Reshapes Local Water Cycles.") By restoring infiltration, vegetation cover, and soil function, landscapes not only reduce runoff but can moderate temperature and stabilize local hydrological and climatic conditions, strengthening resilience from the ground up.

[234] DVGW (2022): auswirkung-klimawandel-wasserdargebot-zukunft-wasser-factsheet.pdf

Reforestation and Rainfall: How Greening Deserts Reshapes Local Water Cycles

From China's vast Three-North Shelterbelt Project to Africa's Great Green Wall, large-scale reforestation has become one of the world's most ambitious responses to desertification: the spread of sand driven by wind that gradually consumes vast areas of land. Launched in 1978 and scheduled for completion by 2050, China's program has so far planted more than 300,000 km² of forest across the Gobi Desert and northern plains to halt advancing sands and reduce dust storms. In Sahel, the African Union's Great Green Wall—stretching from Senegal to Djibouti—was initiated in 2007 to restore degraded land, secure food supplies, and stabilize rural livelihoods.

Results to date are mixed. In both regions, vegetation cover and density as captured by the Normalized Difference Vegetation Index (NDVI) has increased. In northern China, studies link rising NDVI to a measurable decline in dust-storm intensity, and the Chinese state forestry administration reports a decrease in sandstorm occurrence, consistent with other findings of improved wind erosion control and a slower rate of desert expansion. Africa's Great Green Wall aims to reduce the frequency and intensity of dust storms as well, although research in the field remains limited so far. Beyond these effects, studies in Senegal have shown associated gains in rainfall—with precipitation rising by up to 8% versus the 2000–2020 average, while soil moisture increased by as much as 50% along the reforestation corridor. Restoration techniques such as zai pits—small indentations that collect water—and half-moon-shaped swales that trap and retain rainfall help reactivate the local water cycle. Yet, in northern China, vegetation recovery has not always coincided with higher precipitation. Changes in NDVI and rainfall have often diverged, suggesting that greening alone cannot fully determine regional climate outcomes.

This divergence reflects a fundamental hydrological trade-off: forests act as both "pumps" and "sponges." While they increase evapotranspiration and soil water use, they also improve soil structure and water retention. In humid regions, the sponge effect often dominates, stabilizing dry-season flows. In semi-arid and Mediterranean climates, however, dense plantations—especially fast-growing evergreen species such as Eucalyptus—can overwhelm the sponge effect, depleting groundwater and disconnecting soils from streams.

Near-natural deciduous forests offer a more hydrologically sustainable restoration pathway. By shedding leaves during dry periods, they reduce water demand while preserving soil moisture benefits, mirroring temperate deciduous forests that suppress transpiration during dormant seasons. Successful forest-based hydrological restoration therefore depends on species and management choices, as hydrological recovery is slow: degradation can occur within a season, while rebuilding stable soil water systems typically takes decades.

Still, mounting research reveals an important pattern: Green cover plays a decisive role in regulating both water and energy cycles. Studies show that vegetation density shapes temperature, evaporation, and moisture recycling—the "green–moist–cool" triad that sustains local small water cycles. Through evapotranspiration, tree release moisture into the atmosphere, cooling surfaces and fostering cloud formation and rainfall. In this sense, forests quite literally "plant" water. Acting like the Earth's sweat glands, vegetation dissipates heat by evaporating large amounts of water while shading the ground and preventing desiccation. At the same time, this atmospheric moisture contributes to larger cycles. Agricultural areas in 155 countries rely on transboundary forests for up to 40% of their annual precipitation. As forests mature, they slow runoff, enhance infiltration, and restore the land's natural water metabolism. Reforestation is thus not only a means of halting desertification but also of reactivating the hydrological engine that keeps landscapes cool, green, and habitable—provided the balance between the "pump" and the "sponge" is carefully maintained.[235, 236, 237, 238, 239, 240, 241, 242, 243, 244,245, 246, 247, 248, 249, 250, 251,252]

[235] Word Forest (2022): Assessing China's 'Green Wall': Lessons To The World On Afforestation - Word Forest
[236] INAS: Using the Great Green Wall of China to halt desertification - Gobi Desert | Inspired by Nature-based Action and Solutions (INAS) -Showcase NbS
[237] UN Convention to Combat Desertification: Great Green Wall Initiative | UNCCD
[238] Reuters (2024): China completes 3,000-km green belt around its biggest desert, state media says | Reuters
[239] Gore et al. (2023): Recent Vegetation Cover Dynamics and Climatic Parameters Evolution Study in the Great Green Wall of Senegal
[240] Tan & Li (2015): Does the Green Great Wall effectively decrease dust storm intensity in China? A study based on NOAA NDVI and weather station data - ScienceDirect
[241] Alpha Lo (2025): How much land do we have to restore to bring back the rain?
[242] Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
[243] Seneviratne et al.(2010): Investigating soil moisture–climate interactions in a changing climate: A review - ScienceDirect
[244] Asselin et al. (2024): Blue in green: forestation turns blue water green, mitigating heat at the expense of water availability - IOPscience
[245] Duveiller et al. (2021): Revealing the widespread potential of forests to increase low level cloud cover | Nature Communications
[246] Li et al. (2018): Divergent hydrological response to large-scale afforestation and vegetation greening in China | Science Advances
[247] Hoek van Dijke et al. (2022): Shifts in regional water availability due to global tree restoration | Nature Geoscience
[248] Cui et al. (2022): Global water availability boosted by vegetation-driven changes in atmospheric moisture transport | Nature Geoscience
[249] Liu et al. (2025): Recent Forest Loss in the Brazilian Amazon Causes Substantial Reductions in Dry Season Precipitation - Liu - 2025 - AGU Advances - Wiley Online Library
[250] Martinez et al. (2025): Forests support global crop supply through atmospheric moisture transport | Nature Water
[251] Bruijnzeel et al. (2025): https://www.sciencedirect.com/science/article/pii/S2197562025000855
[252] Douville et al. (2024): https://www.sciencedirect.com/science/article/abs/pii/S0048969724054494?via%3Dihub

6.2 The Solution Landscape

Closing a Gap in the Water-related Literature Landscape. A growing body of research and publications in Germany and beyond has examined the diverse dimensions of water challenges. Many of these studies focus on specific subtopics, such as groundwater depletion,[253, 254] infrastructure resilience,[255] or agricultural practices,[256] and provide valuable education on hydrological dynamics, emerging trends, and water-related risks.[257, 258, 259] However, they often remain fragmented, offering in-depth information on and analysis of challenges without presenting a structured or comprehensive range of solutions. Others do concentrate on developing recommendations but provide limited educational or explanatory context to support a holistic view. Across most existing work, quantification efforts primarily relate to the scale of problems rather than the impact or effectiveness of solutions—and where quantification is provided, it is typically done in the broader macroeconomic context of climate change rather than from a water-centric perspective.[260]

One publication that seeks to focus on the provision of a holistic solution space to tackle the water challenges we are facing in Germany is the National Water Strategy, written by the Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety.[261] It adopts a comprehensive perspective across all key domains—public institutions, agriculture, forestry, urban and industrial water management, and ecosystem protection—and formulates a shared vision for sustainable water use by 2050 with implementation by 2030. However, while the strategy's breadth is considerable, its depth lies primarily in the structural and institutional dimension. It focuses on creating an enabling environment for action: legal harmonization, intergovernmental coordination, data infrastructure, monitoring systems, participatory planning processes, and raising awareness. The proposed measures thus emphasize framework conditions, governance mechanisms, and strategic guidance rather than focusing on specific green solutions or technological or operational interventions.

Concrete, on-the-ground actions, such as soil regeneration, climate-resilient forestry, floodplain reconnection, peatland rewetting, drainage repurposing, circular economy, or wastewater use, are referenced only in broad terms or delegated to future programs at the state or municipal level.[261] As a result, the strategy establishes a solid systemic and regulatory foundation for sustainable water management but leaves considerable space for concrete, operational, and technological implementation roadmaps. While it identifies many relevant fields of action, some of the most directly controllable levers—as mentioned before, such as runoff and surface-water management, which strongly influence our water balance and contribute to both drought and flood resilience—are treated as part of a broader framework rather than a central operational focus.

Complementary to the National Water Strategy, two additional federal frameworks—the Deutsche Anpassungsstrategie an den Klimawandel (DAS)[262] and the Aktionsprogramm Natürlicher Klimaschutz (ANK)[263]—have expanded the national adaptation and nature-based restoration agenda. The DAS recognizes water as a cross-cutting foundation of climate adaptation, emphasizing that many climate impacts in Germany manifest through the water cycle—droughts, floods, and groundwater variability—and calls for integrated water management, retention, and drought preparedness across all sectors. The ANK translates this vision into concrete, nature-based measures such as peatland rewetting, floodplain restoration, and green-blue infrastructure. Both frameworks provide important conceptual and strategic impulses, reinforcing the role of ecosystem restoration and water retention as key levers of resilience. However, their orientation remains largely high-level and programmatic: they focus on governance, coordination, and educational guidance, aiming to raise awareness and create enabling conditions for action rather than providing detailed, quantifiable implementation pathways. Neither the DAS nor the ANK systematically measure or compare the hydrological or economic effects of their proposed measures.

One example that ties directly into these adaptation frameworks is the GWS Research Report,[260] which presents a selective set of adaptation measures and instruments centered on responding to the impacts of climate change. They are grounded in the analytical framework of DAS, using its monitoring and analysis system as an empirical foundation. By translating the qualitative climate-impact fields defined in the DAS, such as drought risk, agricultural yield losses, and flood damage, into a macroeconomic model, the study estimates the potential costs of climate impacts and the benefits of adaptation across selected sectors. It combines regulatory and policy instruments with practical, application-oriented measures, thereby providing valuable economic evidence for the relevance of adaptation. While many of the modeled impacts unfold through water-related vectors, the study does not focus on water-specific mechanisms or the measurable hydrological effectiveness of individual interventions. It therefore does not place water itself—or the physical levers that directly shape the water balance, such as runoff, infiltration, or surface and topsoil composition—at the center of its analysis but instead concentrates on aggregate economic outcomes.

[253] BUND (2025): grundwasserstress-deutschland-studie-wasser-analyse-strukturell-entnahme-landkreise-bund-isoe-2025.pdf
[254] ZDF (2025): Warum Wasser in Deutschland immer kostbarer wird | ZDFheute
[255] VKU (2025): Studie_Investitionen_Wasserwirtschaft: VKU
[256] AXA (2025): AXA Climate_How to Manage the Economic Risks of the Agricultural Transition?
[257] DVGW (2024): szenarien-wassergewinnung-dvgw.pdf
[258] DVGW (2022): auswirkung-klimawandel-wasserdargebot-zukunft-wasser-factsheet.pdf
[259] Heinrich-Böll Stifung & BUND (2025): Wasseratlas 2025: Online, als PDF oder per Post
[260] GWS (2022): GWS Research Report 2022#02 Volkswirtschaftliche Folgekosten durch Klimawandel
[261] BMUKN (2023): BMUKN: National Water Strategy | Publication
[262] BMUV (2024): Deutsche Anpassungsstrategie an den Klimawandel 2024
[263] BMUKN (2023): BMUKN: Aktionsprogramm Natürlicher Klimaschutz | Publikation

In contrast, the publication Water for the Recovery of the Climate: A New Water Paradigm[264] places the management of rainwater and landscape runoff—the retention, infiltration, and reuse of water within the land system—at the center of its approach. It builds its reasoning around the restoration of small water cycles, the local circulation of water between soil, vegetation, and atmosphere, as a key mechanism for stabilizing both hydrological and climatic systems. The authors argue that the accelerated drainage of rainwater from agricultural and urban areas has disrupted this cycle, leading to soil degradation, the loss of vegetation, and increasing temperature and precipitation extremes. To counter these effects, the publication advocates a reversal of the conventional "drainage mindset" toward one of retention and rehydration, calling for the conservation of rainwater where it falls and for its reintegration into natural and human systems through infiltration and evaporation. In doing so, it offers a rich conceptual framework supported by a range of practical approaches and examples—such as decentralized rainwater harvesting, small-scale retention structures, reforestation, terracing, infiltration ditches, contour plowing, and permeable urban surfaces—that together define a new culture of water management focused on keeping water in the landscape. This perspective aligns closely with ecological regeneration approaches, such as those by Walter Jehne, that emphasize restoring the soil's ability to act as a living sponge[265, 266, 267] —enabling infiltration, moisture retention, and gradual release through vegetation. Such measures, which include Regenerative Agriculture, wetland and forest restoration, and the rehydration of degraded soils, represent complementary pathways to operationalize the paradigm's principles.

Yet, while the New Water Paradigm presents these ideas vividly and persuasively, it does so in an argumentative and explanatory manner, illustrating possible approaches for retention and rehydration. Its focus lies in reshaping understanding rather than prescribing a comprehensive, implementation-ready framework. It explains what needs to happen and why but not in full detail how it can be implemented across sectors and at scale. This practical dimension is developed further by Walter Jehne, who translates many of the paradigm's principles into a concrete set of measures aimed at drawing down atmospheric carbon to cool the planet and counterbalance emissions. In his approach, surface management and water cycles are placed at the center of climate action; however, they serve primarily as mechanisms to offset net emissions rather than as tools for managing the water balance itself. Water resilience, in Jehne's framing, emerges as a by-product of restoring the soil carbon sponge and reactivating biological processes—crucial for the water cycle but not positioned as the central driver of addressing water quantity and availability challenges.

[264] Kravčík et al., (2007): vodna paradigma / water paradigm 2007-09-16
[265] Jehne (2019): https://nzbiocharltd.co.nz/resources/Regenerate-Earth-Paper-Walter-Jehne%20%281%29.pdf
[266] Jehne (2014): https://irp-cdn.multiscreensite.com/d6b81fb6/files/uploaded/2017%20-%20Regenerating%20Earth%27s%20Soil%20Carbon%20Sponge.pdf
[267] Jehne: https://vernoux.org/agriculture_regenerative/Jehne-Restoring_water_cycles_to_naturally_cool_climates_and_reverse_global_warming.pdf

The EU Water Resilience Strategy: A Framework for a Water-Secure Future

In June 2025, the European Commission launched the EU Water Resilience Strategy as a forward-looking framework to address Europe's mounting water stress, from drought and floods to pollution and aging infrastructure. The strategy's ambition is to make Europe water-smart and water-secure by 2050.

Three core objectives

1. **Restoring and protecting the water cycle:** The strategy places priority on repairing the land-to-sea water continuum—rivers, lakes, wetlands, groundwater—recognizing that safeguarding the physical cycle is foundational for resilient supply.

2. **Building a water-smart economy:** It emphasizes demand reduction, infrastructure modernization, digitalization, and reuse. The goal includes targeted efficiency improvements (for example, a 10% reduction in water use by 2030) and positioning Europe's water sector as globally competitive.

3. **Securing clean and affordable water for all:** A social equity dimension is included: ensuring access to safe drinking water and sanitation, promoting responsible pricing, and empowering citizens.

Five enabling areas (priority "levers" for action)

To deliver on those three objectives, the strategy identifies five cross-cutting enabling areas:

- **Governance and implementation:** Strengthening policy, improving coordination across sectors (water, agriculture, energy, climate), and aligning EU and Member State actions

- **Finance, investments, and infrastructure:** Mobilizing public and private funds, modernizing infrastructure, and improving leak reduction and reuse systems

- **Digitalization and artificial intelligence:** Harnessing data, monitoring, early-warning systems, and modelling to drive smarter water use and risk management

- **Research, innovation, water industry, and skills:** Driving new technologies, nature-based solutions, upskilling the sector, and enhancing the EU water industry's global footprint

- **Security and preparedness:** Enhancing collective resilience to water-related disasters (droughts and floods), supporting cross-border cooperation, and elevating water risk in security thinking

As a European policy framework, rather than an operational blueprint, the Water Resilience Strategy defines how the EU intends to manage water as a strategic and cross-cutting resource.[268, 269]

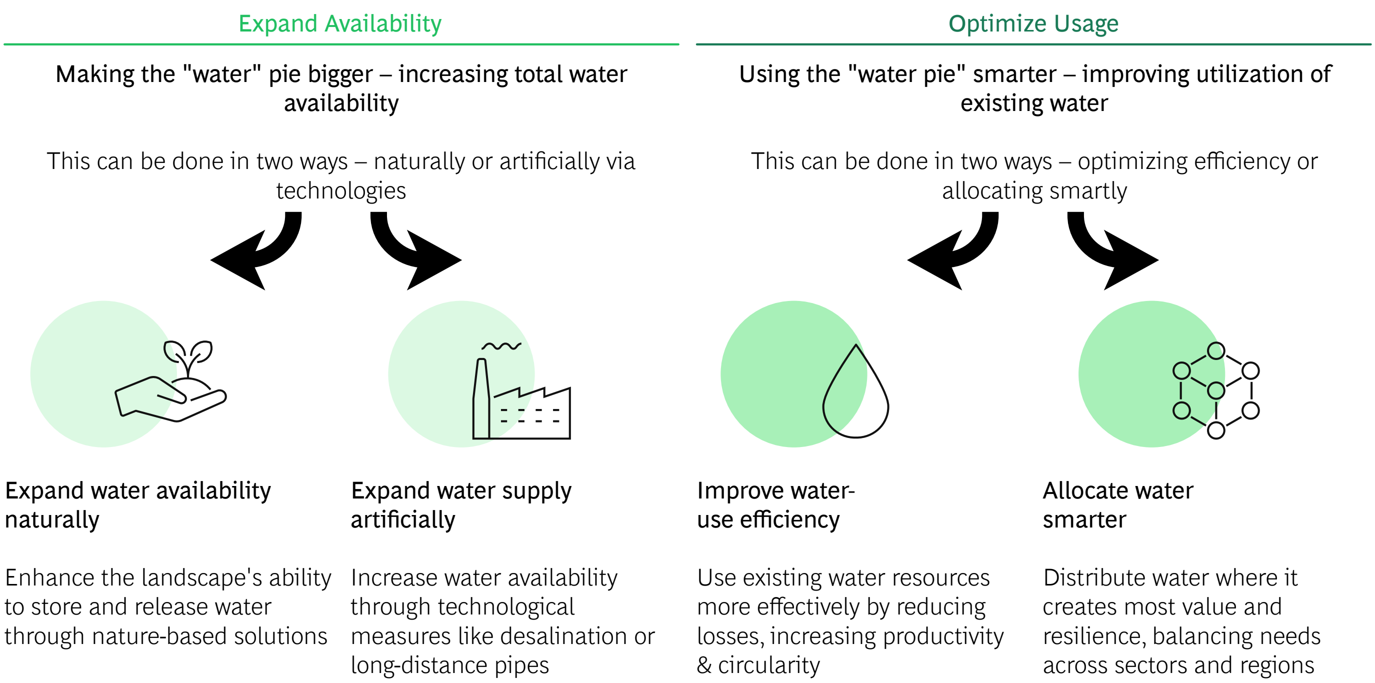
[268] EU (2025): EUR-Lex - 52025DC0280 - EN - EUR-Lex
[269] European Commission (2025): European Water Resilience Strategy

This is precisely the gap that our study addresses: By translating these overarching ambitions into actionable, measurable, and cross-sector interventions that can be implemented on the ground, our approach complements the strategic direction of the National Water Strategy, DAS, ANK as well as the New Water Paradigm while advancing it into the realm of concrete practice to address water quantity and availability challenges.

Two Ways of Managing Water Availability: Expand Availability and Optimize Usage. (See Figure 15.) The way water interacts with the surface and topsoil determines whether it infiltrates and replenishes the system or runs off and is lost downstream. Managing this interface—the controllable layer of our ecosystems—is therefore the basis to shaping overall water availability. By enhancing the landscape's natural capacity to capture, store, and recycle water, we can expand nature's ability to retain water and thereby increase the total amount available within the system. Such expansion can occur through natural or mixed (nature and technological) means; for example, by increasing the permeability of surfaces, restoring soils, managing vegetation or Dynamic Drainage solutions that enable water storage in the landscape, and through purely technological pathways such as desalination, which convert otherwise inaccessible sources into usable freshwater and effectively enlarge the share of available water.

In addition to these approaches that increase total water availability, there are complementary strategies that focus on optimizing the use of water once it has been captured or supplied. These aim to make the existing share of available water work smarter—reducing losses, improving efficiency and circularity, and ensuring that water is allocated where it creates the highest value and resilience. Optimization therefore combines technological efficiency improvements with smarter allocation decisions, balancing needs across sectors and regions to ensure that every unit of water delivers maximum social, economic, and environmental benefit.

Figure 15: There are two ways to manage water: expand availability and optimize usage



Source: BCG & NABU analysis

In Germany, water utilities carry much of the responsibility on the optimize side. They play a key role in ensuring reliability and safety through water treatment, distribution, reuse, and loss reduction—shouldering a tremendous portion of the effort required to secure water availability. Yet, opportunities extend beyond the utility domain. The other side of the equation—expanding water availability—lies largely within the landscape itself: in soils, vegetation, and surface structures that determine how much water is retained, infiltrated, and circulated back into the local system.

Our study builds on this broader perspective. It identifies optimization efforts that go beyond those already existing in the utility sector and compliments them with additional nature-based, technological, and mixed measures that contribute to expansion. This strengthens the natural and artificial storage capacities that underpin long-term water resilience. The resulting solution landscape (See Figure 16.) thus encompasses both pillars of water management:

1. ***Expand total water availability—Solutions 1–6:*** Measures that increase the total water available through natural, hybrid, and technological means. Most focus on runoff and surface coverage management as key leverage points—enhancing how much water reaches the ground, how efficiently it infiltrates into the ground and how much of it is retained and stored in the ground and, consecutively, fills aquifers.

   They also include Technical Supply Expansion options that turn previously unusable sources into freshwater.

2. ***Optimize usage of existing water – Solutions 7–8:*** measures that use existing water more efficiently through technological and behavioral approaches. They aim to reduce losses by enhancing the reuse and circularity of lightly contaminated water across sectors, while also optimizing water consumption in areas such as industry and agriculture.

Figure 16: Our solution landscape spans measures that expand total water availability and optimize usage of existing water

Group		Solution	Applicable area	Description
Expand Availability	1	Regenerative Agriculture/ Agroforestry	Arable land	Regenerates soil by minimum disturbance through practices like minimum till and cover crops
Expand Availability	2	Forest Management	Forest	Maintain healthy and diverse forests, through practices like forest restructuring or selective logging
Expand Availability	3	Sponge Cities	Urban areas	Urban design that replicates natural water cycles, using permeable pavements, trees, and green roofs
Expand Availability	4	Techn. Supply Expansion	Urban areas	Technologies that increase local freshwater supply through desali-nation or long-distance pipelines
Expand Availability	5	Dynamic Drainage	Arable land, Forest, Urban areas	Precipitation-responsive drainage that removes excess water in wet and stores it for reuse in dry periods
Expand Availability	6	Other Landscape-Level Methods	Arable land, Forest, Urban areas	Multifunctional terrain features that capture and store water e.g. cisterns, terraced basins, wetlands
Optimize Usage	7	Gray Water Reuse	Arable land, Urban areas	Recycling of lightly contaminated household water from e.g. shower & sink (excl. toilets)
Optimize Usage	8	Water Use Optimization	Arable land, Urban areas	Technologies that optimize water consumption e.g. industry usage, residual appliances, smart irrigation

Solution type
- Nature-Based Solution
- Mixed Solution
- Technology Solution
- Behavioral Solution

Applicable area
- Arable land[1]
- Forest
- Urban areas

1. Including cropland and grassland

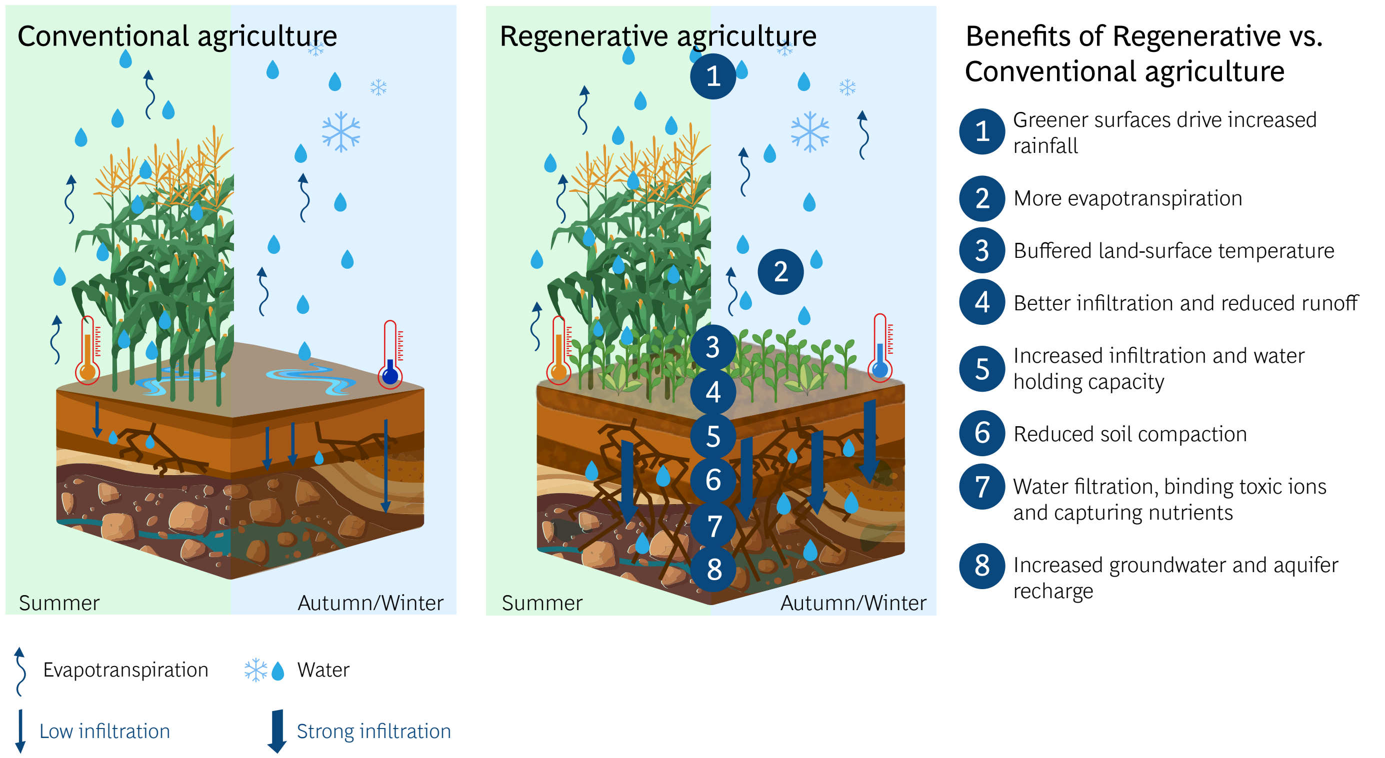
Source: BCG & NABU analysis

Together, these dimensions define a portfolio of ***eight key solutions:***

1. ***Regenerative Agriculture.*** Regenerative Agriculture restores soil health and ecosystem functions by minimizing disturbance, enhancing biodiversity, and improving soil structure. Core practices such as cover cropping, reduced or no-tillage, organic amendments, legume rotations, and agroforestry promote infiltration, rebuild the soil's natural (carbon) sponge capabilities[270, 271 272] and water-holding capacity, foster water filtration and deep groundwater recharge, reduce erosion, compaction, and nutrient runoff.[273] These effects arise largely from the accumulation of soil organic matter. As studies show[273, 274] when humus accumulates, it builds soil porosity and aggregate stability, allowing water to infiltrate more easily from the surface. The carbon compounds within organic matter also help create micropores that retain moisture, forming small reservoirs within the soil matrix. Over time, these micro-reservoirs act collectively as a natural soil carbon sponge, storing water that can later be accessed by plants and microorganisms. At the same time, healthy soil functions as a natural filtering system, reducing the number of pollutants in the water infiltrating into the ground.[275] As soil becomes moister and more resilient, irrigation needs decline, and water stress in agricultural systems reduces.[273, 275] By fostering healthy soil structure composition and water holding capacity, Regenerative Agriculture strengthens the resilience and buffering capacity of entire landscapes. Through continuous vegetative cover and year-round evapotranspiration, it cools the land surface and enhances atmospheric moisture recycling, supporting the formation of local precipitation. At the same time, these improved soils can both absorb excess rainfall and store water for dry periods, enabling landscapes to cope with too much or too little water alike.[273, 276] (See Figure 17.)

[270] Jehne (2019): https://nzbiocharltd.co.nz/resources/Regenerate-Earth-Paper-Walter-Jehne%20%281%29.pdf
[271] Jehne (2014): https://irp-cdn.multiscreensite.com/d6b81fb6/files/uploaded/2017%20-%20Regenerating%20Earth%27s%20Soil%20Carbon%20Sponge.pdf
[272] Jehne: https://vernoux.org/agriculture_regenerative/Jehne-Restoring_water_cycles_to_naturally_cool_climates_and_reverse_global_warming.pdf
[273] NABU & BCG (2023): the-case-for-regenerative-agriculture-mar2023.pdf
[274] White (2020): Why-regenerative-agriculture.pdf
[275] NABU & BCG (2025): healthy-soil-grows-healthy-food-mar-2025-wo-spine.pdf
[276] UfU e.V. (2025): UfU-Hintergrundpapier

Figure 17: Regenerative methods improve soil moisture and help recharge groundwater more effectively than conventional agriculture



Source: Jehne (2019), BCG & NABU (2023, 2025), White (2020), UfU e.V. (2025), Adhikrai, Ibisch et al. (2025), Alpha Lo (2024), DBU (2025), Kravčík et al. (2007), Auerswald et al. (2024), BCG & NABU analysis

In Germany, pioneering initiatives are already demonstrating the potential of these methods. The Thünen Institute's EILT experimental fields (Experimental Interdisciplinary Landscape Laboratory at the Thünen Institute)[277] establish a unique research platform to assess the long-term impacts of regenerative practices at the intersection between agriculture, forestry, fisheries, and engineering, including climate-adapted trees, hedgerows, "meadow-field-animal-woodland," grassland without ruminants, green mineral fertilizer, or ponds and water. These experiments test how alternative forms of land use affect biodiversity, climate, soil carbon buildup, infiltration capacity, and water storage—developing scientific evidence for scaling such measures nationwide. Similarly, the EU-funded Agromix project[278] brings regenerative principles into practice by developing and testing agroforestry and mixed-farming systems that integrate crops, livestock, and trees. Pilot farms across Europe, including in Germany, demonstrate how diverse land-use structures enhance soil fertility, biodiversity, and carbon capture while maintaining economic viability for farmers.[279]

2. ***Forest Management.*** Forest Management strengthens forests' role as natural water regulators through a combination of ecological and silvicultural measures. These include reduced heavy machinery use and minimal proportion of skid trails to minimize soil compaction, optimized minimal drainage management, optimized deadwood management to support soil life and moisture retention, and restructuring stands to align composition and density with site-specific natural conditions.[280] Together, these actions transform forests from passive vegetation into active components of the water cycle: reducing runoff and erosion, improving soil infiltration, and mitigating local and microclimates by balancing rainfall distribution and moderating temperature extremes.[280, 281, 282] Through these mechanisms, they act as natural buffers against droughts, heat stress, and floods, building long-term landscape resilience via enhanced water retention, evaporation, and groundwater recharge.[280, 281]

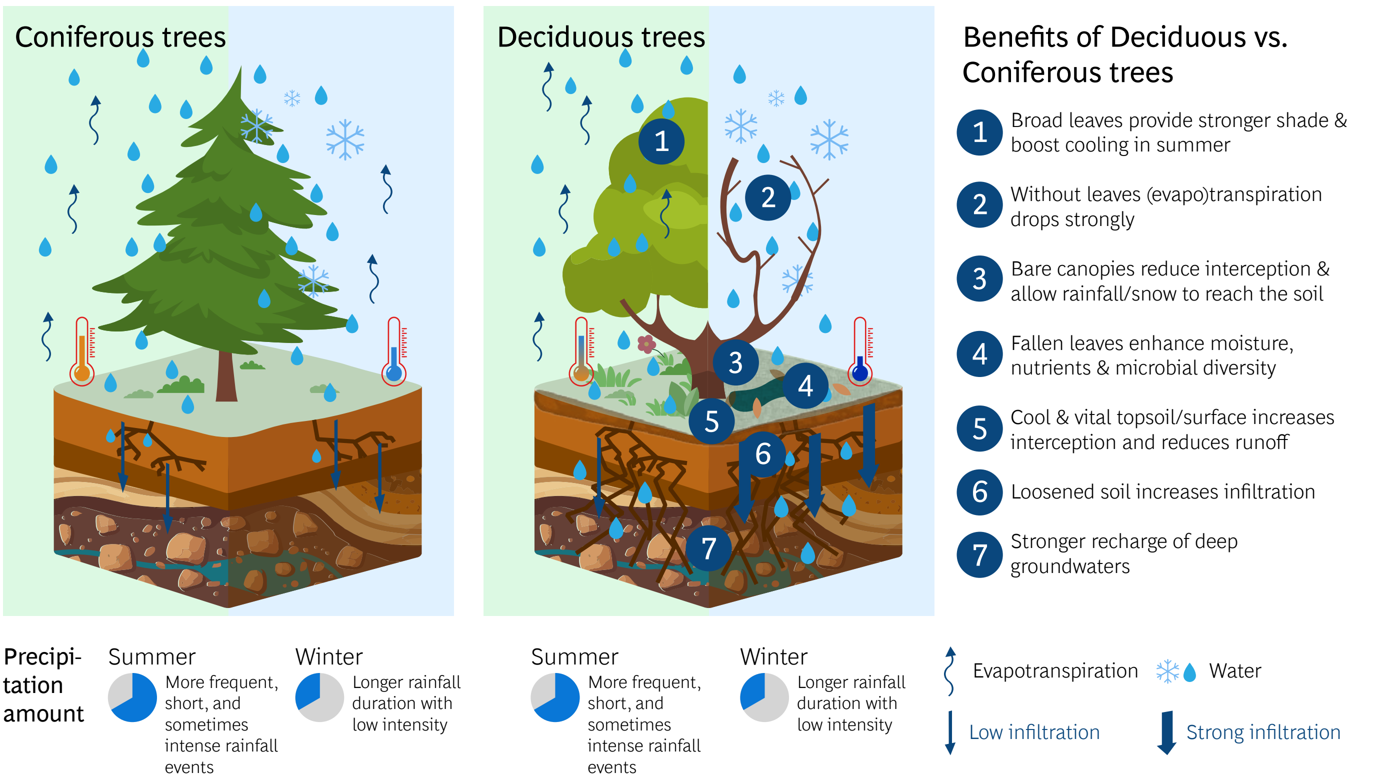
[277] Thünen Institute (2025): https://eilt.thuenen.de/
[278] RPTU (2024): AGROMIX - Fachbereich Natur- und Umweltwissenschaften an der RPTU
[279] Agromix: AGROMIX | Project

[280] Öko-Institut e.V. (2020): https://www.nabu.de/imperia/md/content/nabude/wald/200915-nabu-wasserhaushalt_wald.pdf
[281] BMLEH (2024): Der Wald in Deutschland - Ausgewählte Ergebnisse der vierten Bundeswaldinventur
[282] Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany

Converting monocultures of coniferous trees—especially pine and spruce—into mixed or deciduous stands is an especially powerful measure, as it improves seasonal groundwater recharge, heat mitigation, and forest resilience, while also strengthening biodiversity and municipal climate adaptation.[283, 284] This is largely driven by the fact that close-to-nature, mixed and multilayered stands provide diverse habitats and genetic variety, enabling forests to better withstand pests, diseases, and climatic stress, while their more complex canopy and root structures enhance soil stability and infiltration and thus groundwater recharge.[283, 284, 285, 286] Deciduous trees contribute to fostering water balance by seasonal logic: Their leafless winter phase minimizes transpiration from vegetation for several months and allows precipitation to reach the surface.[283] Fallen leaves cover the ground, reducing soil drying, while leaf litter improves soil health and microbial diversity.[287] Additionally, the smooth bark and funnel-shaped crowns of beeches increase stemflow.[283] The combined effect of rainfall and snow reaching the ground, as well as moist and healthy soils allowing for a reduction in runoff and higher and deeper infiltration, contribute to deep groundwater recharge.[283] In contrast, conifer monocultures maintain higher year-round transpiration and intercept large portions of winter rainfall with a large surface of needle leaves and bulky litter on the ground, leaving less precipitation to reach and infiltrate into the ground.[283] (See Figure 18.)

[283] Öko-Institut e.V. (2020): https://www.nabu.de/imperia/md/content/nabude/wald/200915-nabu-wasserhaushalt_wald.pdf
[284] BMLEH (2024): Der Wald in Deutschland - Ausgewählte Ergebnisse der vierten Bundeswaldinventur
[285] Beugnon et al. (2025): Improving forest ecosystem functions by optimizing tree species spatial arrangement | Nature Communications
[286] Murray et al. (2025): (PDF) Structural diversity is an important predictor of forest productivity responses to drought
[287] Floriancic et al. (2022): Potential for significant precipitation cycling by forest floor litter and deadwood - Floriancic - 2023 - Ecohydrology - Wiley Online Library

Figure 18: Close to nature forestry has a positive impact on reduced interception, improved micro-climate and soil health



Source: Öko-Institut e.V. (2029), BMLEH (2024), Adhikari, Ibisch et al. (2025), Beugnon et al. (2025), Murray et al. (2025), Floriancic et al. (2022), BCG & NABU (2025), BCG & NABU analysis

Besides apparent ecological benefits, close-to-nature forest management also drives economic and societal benefits by linking ecological stability with long-term value creation.[288] Economically, it secures renewable resources such as timber and biomass, supports rural employment, and protects infrastructure and farmland by stabilizing soils and regulating water flows. Well-managed forests also enhance carbon storage and water quality, reducing public costs for climate and water protection. Societally, they provide recreation, health, and cultural value while strengthening community resilience in rural areas.

These combined effects are illustrated by Waldvision Brandenburg,[289] a large-scale effort to transform pine-dominated forests into climate-resilient mixed stands. The program focuses on assisting with gradual development toward close-to-nature, managed forests, using natural processes and regeneration and supplementary planting to enhance biodiversity, improve infiltration, and manage temperatures.

3. ***Sponge Cities.*** The Sponge City concept applies nature's logic to urban design. It mimics natural water cycles by turning impermeable surfaces into water-absorbing, -storing, and -cleaning systems.[290] Through a combination of green roofs, permeable pavements, rain gardens, bioswales, urban wetlands, and rainwater harvesting systems, Sponge Cities capture, store, and locally manage rainwater where it falls. This approach not only mitigates flood and drought risks but also can enhance local infiltration and, depending on design and site conditions, contribute to groundwater recharge, while also improving water quality through natural infiltration processes. Beyond their hydrological functions, Sponge Cities deliver wider environmental and social benefits. They reduce urban heat island effects, enhance air quality, and create greener, more livable urban spaces. Well-designed sponge systems moderate runoff peaks during heavy rain, retain moisture during dry periods, and foster local biodiversity.

   The concept has been successfully demonstrated at scale. In Seoul, South Korea, the Cheonggyecheon Restoration Project renaturalized a formerly polluted, concrete-covered waterway by pumping water back into the riverbed, restoring the riparian ecosystem of the stream and creating wide pedestrian sidewalks for leisure and recreation.[291] Beyond its positive effect on the city's landscape, the stream also functions as a flood-control and climate-adaptation corridor.[292] The restored stream lowered surrounding temperatures by up to 3°C, reduced particulate matter, and became a central urban ecosystem that absorbs stormwater naturally while enhancing quality of life. Similarly, Schumacher Quartier in Berlin—part of the redevelopment of the former Tegel Airport—serves as Germany's first fully water-sensitive district.[293] The area is designed for complete local rainwater retention, using green roofs, infiltration zones, and constructed wetlands to manage precipitation on-site. Its integrated system keeps rainwater within the urban cycle, preventing overload of the public sewer network and can support the replenishment of local groundwater.

4. ***Technical Supply Expansion.*** Technical Supply Expansion encompasses large-scale infrastructure and technologies that create or redirect new freshwater sources to enhance regional water security. These include seawater desalination,[294] long-distance pipelines and aqueducts, river rerouting,[295] and flow augmentation systems. Together, such measures provide a reliable and controllable water supply, reduce pressure on overused aquifers, and help stabilize river and ecosystem flows, while increasing independence from seasonal volatilities.[296] They are particularly relevant in regions where natural water resources are insufficient or highly variable, offering an important safeguard for urban, industrial, and agricultural resilience. While beneficial in terms of the large amount of water they can supply and only limited by the capacity of the plant or the river flowthroughs, these measures come with high capital cost, intensive energy use, and complex environmental implications.[296]

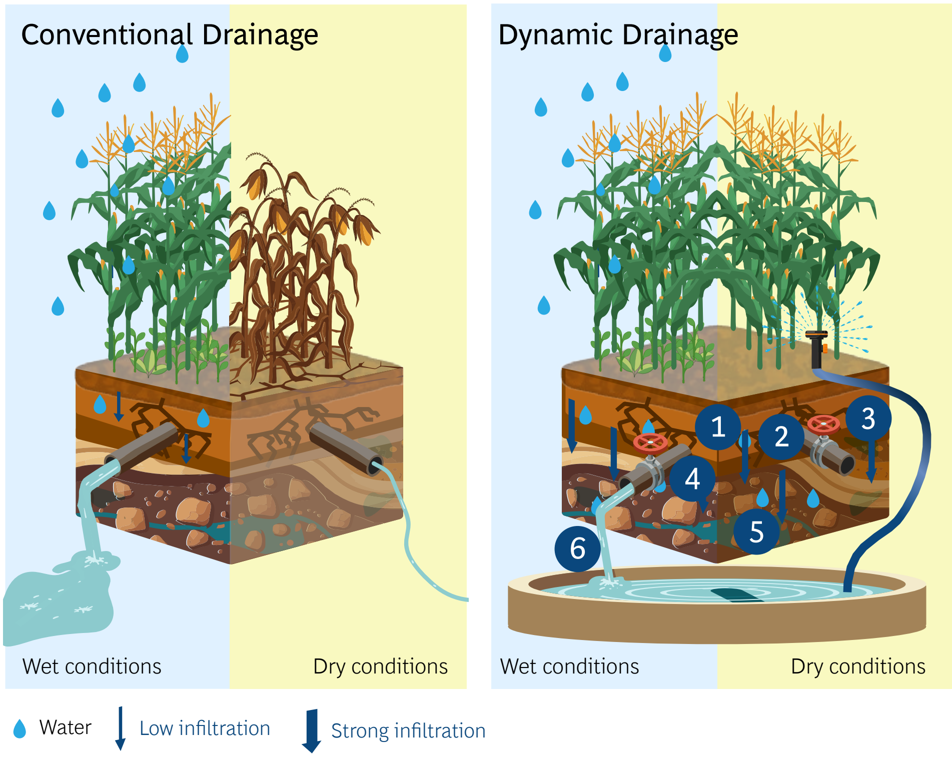
   The Claude "Bud" Lewis Carlsbad Desalination Plant in California illustrates the potential of these technologies. As one of the largest seawater desalination facilities in the Western Hemisphere, it was built for roughly €900 million and produces around 190,000 m³ of drinking water per day, covering roughly 10% of San Diego County's demand and providing a drought-resilient, locally controlled supply of water.[294] On a larger scale, China's South-to-North Water Diversion Project demonstrates how inter-basin transfer infrastructure can rebalance water distribution across vast regions. The project, comprising eastern, central, and western routes extending over roughly 4,300 km, is designed to reroute more than 40 billion m³ of water annually from the Yangtze basin to water-scarce northern provinces, supporting municipal, industrial, and agricultural needs.[297, 298]

[288] Murray et al. (2025): (PDF) Structural diversity is an important predictor of forest productivity responses to drought
[289] MLEUV Land Brandenburg: Waldvision 2050 | MLEUV
[290] Heinrich-Böll-Stiftung (2025): Wasseratlas 2025 | Heinrich-Böll-Stiftung
[291] Arch Daily (2024): Re-Naturalization of Urban Waterways: The Case Study of Cheonggye Stream in Seoul, South Korea | ArchDaily
[292] Landscape Performance Series (2011): Cheonggyecheon Stream Restoration Project | Landscape Performance Series
[293] Schumacher Quartier: Schumacher Quartier - Berlin TXL
[294] San Diego Country Water Authority (2025): https://www.sdcwa.org/wp-content/uploads/2020/11/desal-carlsbad-fs.pdf
[295] UBA (2023): Wasserwirtschaftliche Folgen des Braunkohleausstiegs in der Lausitz - Abschlussbericht
[296] NEWater: What are the Pros and Cons of Desalination Plants?-NEWater
[297] Zhang (2009): https://www.researchgate.net/publication/227808725_The_South-to-North_Water_Transfer_Project_of_China_Environmental_Implications_and_Monitoring_Strategy1
[298] Xin et al. (2023): content

5. ***Dynamic Drainage.*** Conventional drainage systems use underground pipes to continuously discharge excess water from agricultural land and other surface areas, like forests or streets—a practice that historically helped convert wet areas into usable, arable fields and manage heavy rainfall.[299] Under today's changing climate conditions, however, characterized by both more intense precipitation events and prolonged dry periods, such systems have become counterproductive.[300] By constantly draining water, they accelerate soil drying, erosion, and the loss of valuable nutrients.[301] Dynamic Drainage, in contrast, modernizes agricultural water management by making existing systems adaptive to real-time soil and weather conditions.[300, 301] Using adjustable gates, valves, water retention basins or smart sensors connected to digital control technologies, these systems enable predictive water regulation based on soil moisture and precipitation forecasts.[299, 302, 301] Water is retained during wet periods and gradually released only when soil begins to dry.[303, 300] This adaptive management reduces peak runoff and flood risk, while optimizing soil moisture, enhancing infiltration, and minimizing nutrient leaching, ultimately strengthening both drought resilience and groundwater recharge.[299, 300, 301, 302] (See Figure 19.)

[299] Geiger (2025): EKODRENA | GEIGER agri solutions
[300] LTZ: Smarte Drainagen - Infodienst - LTZ Augustenberg
[301] Stowa: Controlled drainage | STOWA
[302] SpreeWasser:N: Oberflächennahe Wasserspeicher – SpreeWasser:N
[303] LBEG (2014): https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjN7fzw6ZaQAxW7nP0HHQEvGR8QFnoECBkQAQ&url=https%3A%2F%2Fwww.lbeg.niedersachsen.de%2Fdownload%2F133097&usg=AOvVaw0oSTiMm1XRX97FDh7-LNW5&opi=89978449

Figure 19: Dynamic drainage manages two-way water flows, balancing soil moisture and ensuring optimal soil conditions in changing weather



Benefits of Dynamic Drainage vs. Conventional Drainage

1. Balanced soil moisture for better crop and soil performance
2. Controllable drainage, allowing for flexible management of water in the landscape
3. Limited nutrient loss by reducing runoff and leaching pathways
4. Enhanced percolation below drainage level, keeping more water in the landscape
5. Improved soil structure, boosting natural groundwater recharge
6. Reduced peak drainage, lowering erosion and flood risk

Source: Geiger (2025), LTZ, Stowa, SpreeWasser:N, BCG & NABU analysis

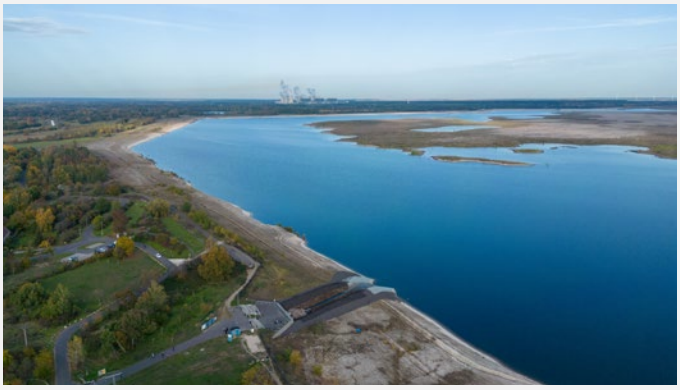
Pilot projects such as SpreeWasser:N[302] in Brandenburg illustrate the potential of this approach: It aims to develop practical solutions for how water can be better distributed, used, and protected across Berlin and Brandenburg. The project focuses on creating tools, strategies, and exemplary practices for sustainable water management by connecting disciplines and involving regional stakeholders from agriculture, industry, and policy. Within this broader framework, Dynamic Drainage plays a central role. By using controllable valves, adjustable weirs, and smart monitoring systems, the project demonstrates how water can be retained locally in the landscape instead of being drained away. This stabilizes groundwater levels and strengthens regional resilience against both droughts and floods. In Baden-Württemberg, the feasibility project Machbarkeit von Smarten Drainagen in Baden

Wuerttemberg[304] examines how existing agricultural drainage infrastructure can be retrofitted with smart controls: By closing drainage systems in winter to retain precipitation in situ, soil moisture can be maintained during dry spells, supporting both groundwater recharge and yield stability.

6. ***Other Landscape-Level Methods.*** On the landscape scale, terrain-based interventions—such as wetlands, terraces, swales, and artificial lakes—capture, store, and gradually release water to restore the natural hydrological balance, acting as a natural water sponge. By reducing runoff, enhancing infiltration, and replenishing groundwater, these measures mitigate both flood and drought risk while improving soil fertility and ecosystem stability.[305] They act as natural buffers that moderate extreme events, enhance local microclimates, and strengthen long-term water retention across regions.[305] Such systems can operate across multiple spatial levels: microscale (e.g., ponds, cisterns, or infiltration ditches) for local storage and recharge; mesoscale (e.g., stormwater basins, terraces, or retention areas) for managing surface flows; and macroscale (e.g., floodplains, rewetted peatlands, or artificial lakes) for regional hydrological restoration.

   The Cottbuser Ostsee (See the sidebar "Cottbuser Ostsee.") or Gesamtkonzept Elbe project[306] exemplifies a large-scale, multifunctional approach to landscape water management in Germany. As a joint initiative by the federal government and the riparian states, it aims to restore the natural dynamics of the Elbe River and its floodplains as natural retention areas, thus improving both the flood protection[306] and ecological integrity along one of Central Europe's largest river systems. By reconnecting floodplains, reactivating retention areas, and rehabilitating wetlands, the program enhances natural water storage, groundwater recharge, and biodiversity across the catchment. Beyond its hydrological benefits, the approach supports climate adaptation, landscape resilience, and regional recreation, demonstrating how integrated river-basin management can align ecological restoration with long-term water security. In southern Spain, the AlVelAl initiative[307] demonstrates how integrated land restoration can improve water balance in semiarid regions. Through the construction of small ponds, stone barrages, and natural water-harvesting systems, combined with reforestation, Regenerative Agriculture, and soil management practices, AlVelAl's efforts slow runoff, enhance infiltration, and boost soil moisture retention. These interventions have reduced erosion, increased vegetation cover, and improved the water cycle across degraded hillsides and farmlands.

[304] LTZ: Smarte Drainagen - Infodienst - LTZ Augustenberg
[305] Heinrich-Böll-Stiftung (2025): Wasseratlas 2025 | Heinrich-Böll-Stiftung
[306] Gesamtkonzept Elbe: Projektseite Gesamtkonzept Elbe - Startseite
[307] Alvelal: What we do - AlVelAl Association



Cottbuser Ostsee

The Cottbuser Ostsee is one of Germany's most ambitious landscape transformation projects: a former open-cast lignite mine converted into a future water reservoir. Located in Lausitz, Brandenburg's historic mining region, the lake is being created in the former Cottbus-Nord mine, which closed in 2015 after decades of coal extraction that profoundly altered regional hydrology. Mining activities left deep depressions and disrupted natural groundwater flows, while continuous pumping artificially stabilized water levels throughout the Spree river system. For years, up to 60% of the Spree's runoff consisted of pumped mine water. With the coal phaseout, these artificial inflows have ceased, creating a significant hydrological deficit and placing downstream sections of the Spree—key sources of Berlin's drinking water supply—under growing stress.

Since 2019, the energy company LEAG has been flooding the pit using controlled inflows from the Spree. Once filled, the Cottbuser Ostsee is expected to cover approximately 1,900 hectares, making it Germany's largest artificial lake. Beyond ecological restoration and recreation, the project is promoted as a strategic measure to rebuild regional water storage capacity, helping to close the Spree's water balance gap, buffer floods and droughts, and support local climate stabilization, including for Berlin's water supply.

However, the transformation entails substantial risks. The large volumes of water required for flooding further strain the already fragile Spree system, and without sustained freshwater inflows and active management, the lake could become an ecological liability. Its large surface area and shallow depth may result in high evaporation rates, potentially turning the reservoir into a net water consumer during droughts rather than a buffer. In addition, significant water quality risks remain: the leaching of iron and sulfate from former mine soils threatens to acidify the lake and increase sulfate loads in the Spree, complicating downstream drinking water treatment for Berlin.[308, 309]

[308] UBA (2023): Wasserwirtschaftliche Folgen des Braunkohleausstiegs in der Lausitz - Abschlussbericht
[309] LEAG (2019): Spree fließt mit bis zu 60 Prozent Grubenwasser | LEAG

7. ***Gray Water Reuse.*** Gray Water Reuse involves the collection, treatment, and recycling of lightly contaminated household water—for example from showers, sinks, and laundry—for non-potable applications such as toilet flushing, landscape irrigation, or groundwater recharge.[310] By integrating on-site[311] or district-scale treatment and storage systems, this approach reduces overall freshwater demand and wastewater discharge while enhancing urban water resilience and local availability. Depending on the scale, systems range from building-level installations using filters or membrane bioreactors to district networks that collect and treat gray water across multiple properties.

   The NEWater program in Singapore,[312] led by the national water agency PUB, demonstrates how reclaimed water can become a core part of a city's supply system, serving as a model for circular urban water management. The program treats wastewater to ultrapure standards through microfiltration, reverse osmosis, and UV disinfection. The water is used for both non-potable use cases, such as industrial or air-conditioning cooling processes, and for potable uses by being added to reservoirs and mixed with raw water, so that consumers can receive it as tap water. With the water sector in the German Baltic Sea region challenged by extreme weather events such as droughts and floods, water scarcity is projected to intensify in the future.[313] In this context, the WaterMan project[313] explores how decentralized Gray Water Reuse can be integrated into local systems by testing treatment modules and typical use cases an a neighborhood scale, such as irrigating green spaces and parks or cleaning streets in urban areas.

8. ***Water Use Optimization.*** Water Use Optimization encompasses technologies and practices that improve water consumption and efficiency while reducing losses across all major water-consuming sectors—agriculture, industry, and households. It focuses on getting more value out of every cubic meter of water used through measures such as smart irrigation systems, leak detection and monitoring, water-efficient appliances, and industrial water recycling and reuse. Beyond reducing withdrawals and thus supporting water replenishment, these measures can also lower energy demand and emissions, contributing to both water and climate resilience.

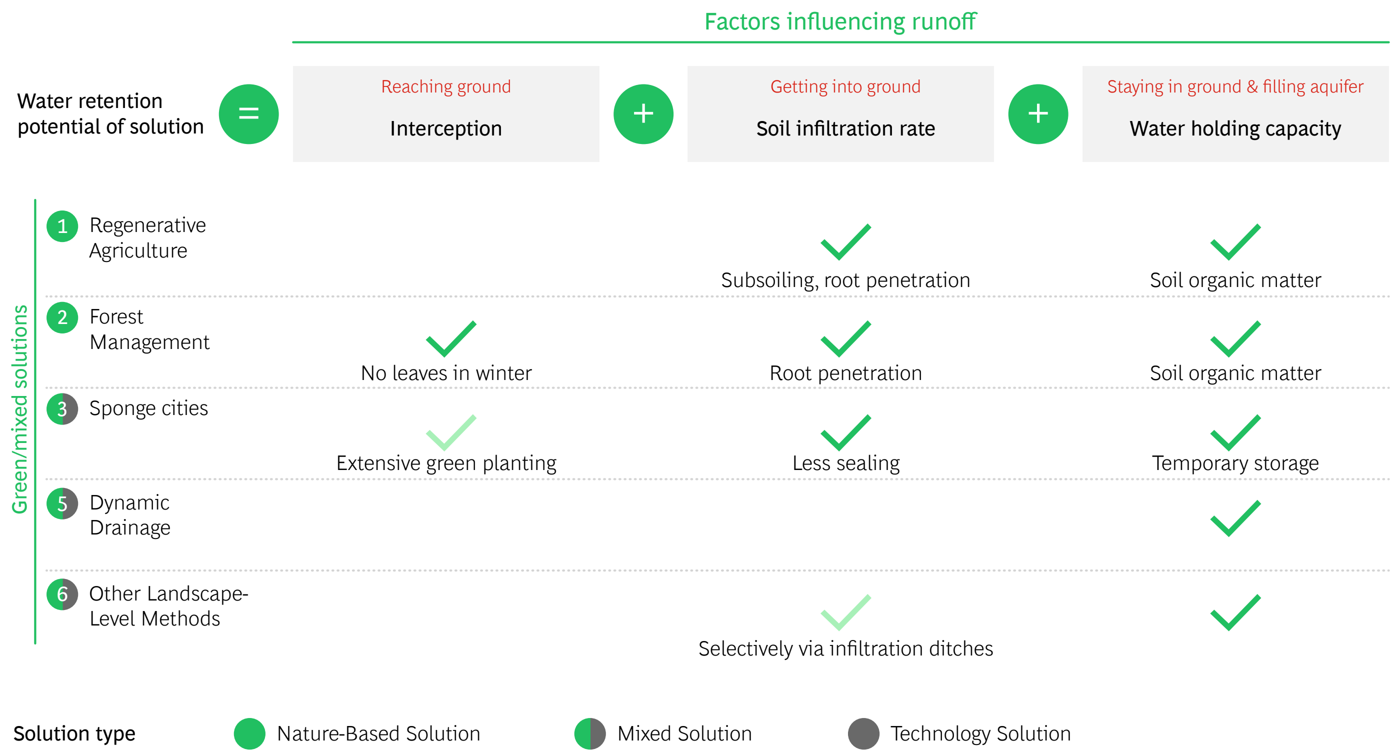
   In Germany, the BayWater project[314] develops innovative management solutions to minimize industrial water demand. It combines digital process monitoring, water recycling loops, and efficiency audits to minimize freshwater intake while not disturbing production processes and maintaining high product quality. The initiative also explores new management models that link industrial water savings with regional water availability, demonstrating how technology-driven efficiency can strengthen supply security in production-intensive regions.[315] In Mendoza, Argentina, Water Use Optimization is applied in agriculture through precision irrigation and treated wastewater reuse, It allows farmers to fine-tune irrigation volumes according to crop demand, reducing groundwater abstraction and improving productivity under semiarid conditions.[316]

In essence, the presented solutions span two complementary dimensions. The first distinguishes between the ways water availability can be managed: by expanding overall availability or by optimizing existing use. Expansion measures such as Regenerative Agriculture, Forest Management, Other Landscape-Level Methods, and Dynamic Drainage strengthen the land's ability to retain and circulate water, while Technical Supply Expansion adds new sources through engineered systems like desalination and long-distance transfer. Optimization measures, including Gray Water Reuse and Water Use Optimization, enhance efficiency and circularity across sectors, reducing losses and improving allocation.

[310] Ghaitidak, Yadav (2013): Characteristics and treatment of greywater–a review - PubMed
[311] Yu et al. (2019): innovation.luskin.ucla.edu/wp-content/uploads/2019/03/Cost-Benefit_Analysis_of_Onsite_Residential_Graywater_Recycling.pdf
[312] PUB: NEWater | PUB, Singapore's National Water Agency
[313] KWB: WaterMan | Kompetenzzentrum Wasser Berlin
[314] BayFor (2024): News Detail - BayFOR
[315] BayWater: Baywater - baywater-info.de
[316] Duek (2016): Water in the Mendoza, Argentina, food processing industry: water requirements and reuse potential of industrial effluents in agriculture | Ambiente e Agua - An Interdisciplinary Journal of Applied Science

The second dimension reflects the solution type. While some solutions work with nature, such as Regenerative Agriculture or Forest Management, strengthening ecosystems and landscapes to retain water and regulate flows more effectively (See Figure 20.), others, like Technical Supply Expansion and Gray Water Reuse, apply technological means, such as innovative systems, engineering, and digitalization to improve control and efficiency or create additional usable water when natural systems reach their limits. Together, these perspectives define a comprehensive solution space where solutions across nature and technology complement those across expansion and optimization.

Figure 20: Geen & mixed solutions enhance landscape water retention capacities by addressing various factors that help prevent runoff



Source: BCG & NABU analysis

6.3 Assessing Solution Effectiveness

Different Types of Solution Effectiveness. The solutions presented differ not only in their approach but also in the type and scope of their effects. Their impacts can be viewed across two orders of effectiveness. (See Figure 21.) First-order effects relate directly to water outcomes, namely a solution's ability to expand water availability as well as supply and to improve natural water quality through filtration, infiltration, or purification processes. Second-order effects extend beyond hydrology and capture the broader ecosystem and societal benefits that emerge as a consequence. These include contributions to climate resilience, biodiversity and biosphere health, and overall quality of life.

Figure 21: Green solutions have water & ecosystem benefits, while sponge cities mainly support ecosystems and gray solutions boost supply

	1st order effect: water		2nd order effect: Ecosystem benefits¹		
	Water availability expansion	Natural water quality improvement	Climate resilience	Biosphere/ Nature	Quality of life
1 Regenerative Agriculture	High	Very high	High	Very high	Medium
2 Forest Management	Medium-High	Very high	Very high	Very high	High
3 Sponge cities	Medium	Medium	High	Medium	Very high
4 Techn. Supply Expansion	Very high	Low	Low	Low	Low
5 Dynamic Drainage	High–Very high	High	Medium	Medium	Low
6 Other Landscape-Level Methods	Medium-High	High	Medium	High	Medium

Expand Availability

Solution type: Nature-Based Solution; Mixed Solution; Technology Solution

Source: BCG & NABU analysis

Nature-based measures such as Regenerative Agriculture and forest management perform strongly across both first- and second-order dimensions, combining substantial improvements in water retention and natural purification with broad ecosystem and climate co-benefits. In addition to their hydrological impact, these solutions enhance climate resilience by stabilizing local temperatures and mitigating the effects of drought and extreme rainfall, strengthen biodiversity and ecosystem health through richer vegetation cover and improved soil and habitat quality, and contribute to quality of life by creating more resilient, productive, and visually diverse landscapes, making them the most impactful solutions within the solution landscape we are introducing in this study. Among the mixed solutions, Other Landscape-Level Methods and Dynamic Drainage achieve solid results on the water-related dimension, particularly in expanding availability and regulating runoff. Yet, they deliver somewhat fewer ecosystem benefits compared to purely nature-based approaches. Sponge Cities present the inverse pattern: Although they cover only a small share of Germany's surface area, their location in densely populated regions means they directly benefit a large portion of the population. While their overall hydrological impact is therefore spatially limited, they offer exceptional ecosystem and societal benefits. Through increased vegetation, permeable surfaces, and local water retention systems, Sponge Cities enhance urban livability, reduce heat stress, and promote biodiversity. In contrast, technological solutions such as Technical Supply Expansion, Gray Water Reuse, and Water Use Optimization perform comparatively lower on ecosystem-related effects, contributing little to climate resilience, biodiversity, or quality of life. Regarding their first-order water impacts, only Technical Supply Expansion significantly increases water availability, though without enhancing natural water quality. Gray Water Reuse and Water Use Optimization, meanwhile, deliver limited direct hydrological or ecological benefits, primarily serving to improve efficiency within existing systems rather than expanding or restoring the natural water cycle.

6.3.1 Solution Effectiveness in Brandenburg

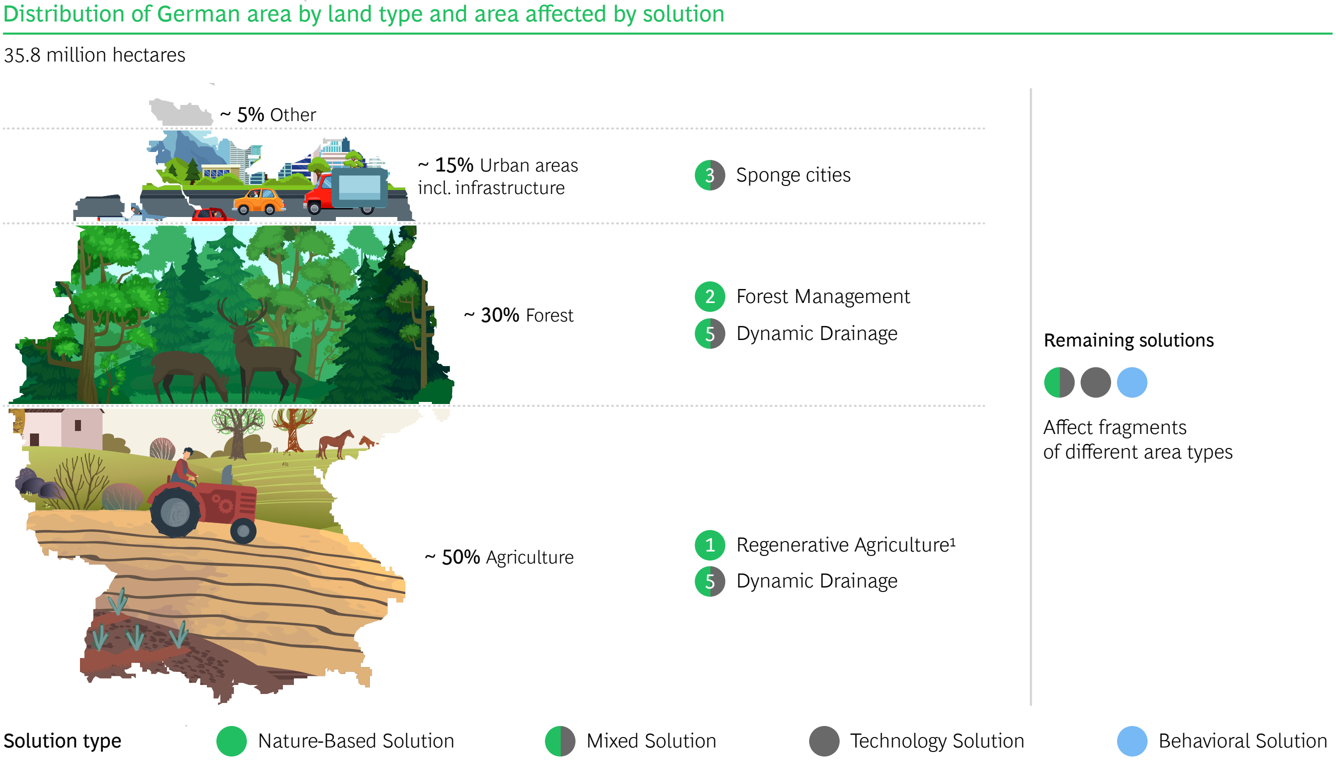
Nature-based Solutions in Focus. Brandenburg, one of Germany's regions most exposed to water scarcity, offers a compelling test case for assessing how targeted nature-based measures can mitigate both acute and long-term hydrological pressures. As highlighted earlier in this study, the state already faces water stress, which is projected to intensify even under conservative climate scenarios.[317] The application of effective water-management solutions is therefore not only beneficial but necessary to stabilize the regional water balance and secure future resilience.

[317] Aqueduct: Aqueduct Country Ranking

In this analysis, the focus is placed on Regenerative Agriculture and Forest Management, the two solutions with the broadest spatial leverage across Germany's land types. Agricultural land covers roughly 50% and forest land another 30% of the national territory[318]—together representing about 80% of Germany's total surface area. (See Figure 22.) Both measures therefore act at a structural scale, directly targeting the ecosystems that dominate the country's landscape and offer the greatest potential for systemic water impact.

[318] BMEL (2023): BMEL-Statistik: Bodennutzung in Deutschland

Figure 22: ~80% of Germany's area can be addressed via Regenerative Agriculture and Forest Management, having the biggest impact



1. Effect of Regenerative Agriculture on grassland slightly lower

Source: BMLEH, BCG & NABU analysis

Beyond their reach, these solutions are also among the most holistically effective. As shown earlier, both perform strongly across first-order effects, expanding water availability and improving natural water quality, and second-order effects, strengthening climate resilience, ecosystem health and biodiversity as well as quality of life. Implementing Regenerative Agriculture and Forest Management across Brandenburg's agricultural and forested areas would directly address the surface and topsoil layer, where runoff, infiltration, and groundwater recharge are most controllable. Together, they represent a nature-based foundation for restoring the regional water balance, mitigating economic losses expected under a "do nothing" scenario and building long-term ecological stability.

Methodology: Estimating Solution Impacts for Brandenburg. To quantify the potential impact of Regenerative Agriculture and Forest Management in Brandenburg, a structured modelling approach was applied, linking each solution's practices to key components of the regional water balance, specifically evaporation, runoff, and groundwater recharge.

The analysis establishes a "do nothing" baseline, using previously derived projections of future water stress in Brandenburg as reference scenarios. In parallel, evidence from peer-reviewed studies, meta-analyses, and hydrological research was compiled to capture the known effects of surface cover, crop rotation, mulching,[319] and tree species diversification[320] on water balance parameters, such as runoff, evaporation, infiltration, and water use.

[319] Based on FAO-56 crop water & soil evaporation, JRC/ESDAC studies on cover crops and Meta-analyses on mulching, runoff and infiltration

[320] Parameters set to mid-range literature values and adjusted with local data where available

Against this baseline, the two solutions were broken down into core practices for modelling purposes, recognizing that this simplified framework does not capture every effect but provides a direction on their overall potential. For Regenerative Agriculture, the focus was placed on cover crops (non-harvested plants that protect the soil, reduce evaporation, and improve moisture retention) and crop rotation (alternating harvest cycles to reduce water demand). For Forest Management, the practices modelled included tree-species diversification (mixing species to improve resilience and optimize water use) and forest density and coverage adjustments (modifying canopy structure to enhance infiltration and reduce surface runoff).

Each practice was modelled to assess how it would influence the key supply and demand components of the hydrological cycle:

- ***Evaporation reduction***, achieved through improved soil cover, shading, and moisture retention
- ***Runoff reduction***, by increasing vegetation and soil residue that slow surface flow
- ***Groundwater recharge enhancement***, through improved infiltration and reduced water loss

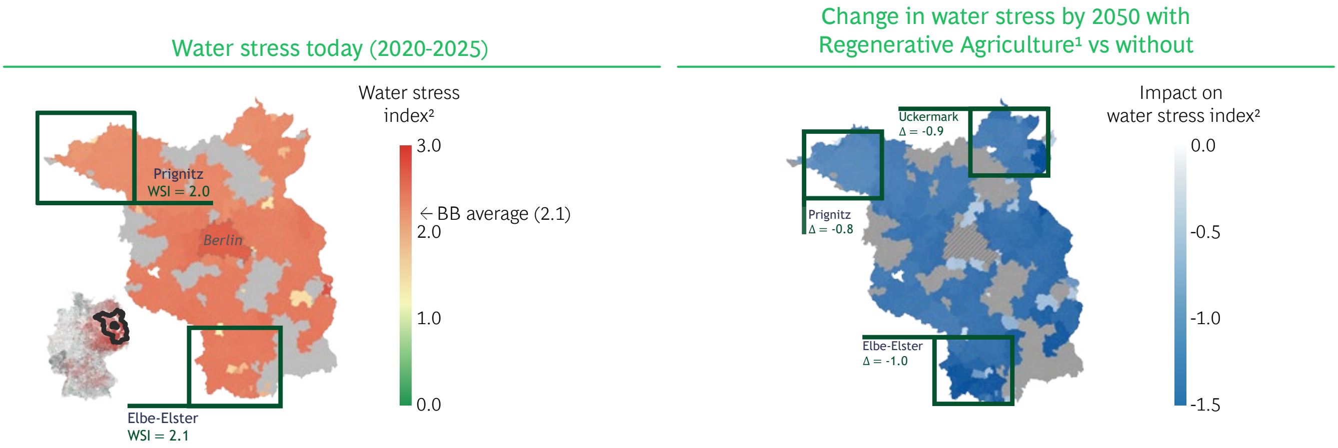
The modelling concentrated on the most relevant hydrological effects for each solution. For Regenerative Agriculture, the analysis focused on evaporation and runoff reduction, reflecting the fact that Brandenburg's agriculture is largely rainfed and operates primarily within the topsoil layer, making soil moisture conservation and retention particularly important, while groundwater management plays a less immediate role in day-to-day agricultural practice. For Forest Management, the emphasis was placed on runoff reduction and groundwater recharge, as forests are key regulators of flow regimes—benefiting both agricultural water availability and aquifer replenishment for municipal supply. This focus does not imply that groundwater recharge is irrelevant for Regenerative Agriculture or that evaporation reduction is insignificant for forest management. Rather, these are secondary effects relative to the main levers of water supply and demand for each solution. Beyond the three quantified parameters, both interventions also influence other elements of the small water cycles, including temperature moderation, precipitation dynamics, and water holding capacity, which were considered qualitatively but not explicitly modelled in this analysis.

Finally, the model compared projected water stress levels with and without the implementation of each solution and assessed their relative effectiveness in mitigating regional water scarcity and offsetting the economic cost of inaction.

Regenerative Agriculture.[321] Implementing Regenerative Agriculture across Brandenburg's agricultural land[322] could cut agricultural water stress by around 50%, lowering the Water Stress Index from 2.1 to roughly 1.1 by 2050.[323] This reduction translates into an up to 85% decrease in annual economic losses[324] from climate-driven water shortages—from an estimated €270 million–380 million to €36 million–45 million per year.[325] (See Figure 23.)

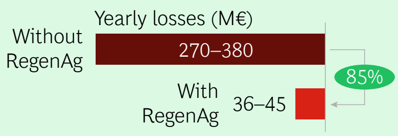
[321] NABU & BCG analysis based on Eurostat AEI – Soil cover (EU winter 2016); FAO-56, Chapter 7 (dual-Kc / soil-evaporation shares); FAO-56, Effects of soil mulches; Soil Use & Management (2024), Western Europe meta-analysis (runoff capture).
[322] Regenerative Agriculture practices considered in the model are: cover crops and crop rotations
[323] Regenerative Agriculture measures are modelled across all crops in Brandenburg, leading to a "final picture" upper-bound of estimated impact
[324] Losses are calculated based on production shortfalls due to unmet water demand, using the average crop market price
[325] Using conversion factor of 1 Dollar = 0.89 Euro (Average 31/12/2024-17/10/2025): US dollar (USD)

Figure 23: Regenerative Agriculture is projected to reduce agricultural water stress by half and losses due to chronic water stress by up to 85 %



Projected impact of regenerative agriculture

With implementation of regenerative agriculture **50%** estimated reduction in water stress



Reduction of annual losses due to change up to **85%** (agricultural use³)

1. Regenerative agriculture practices considered in the model are: cover crops and crop rotations

2. Losses are calculated based on production shortfalls due to unmet water demand, using the average crop market price

3. Regenerative agriculture measures are modelled across all crops in Brandenburg, leading to a "final picture" upper-bound of estimated impact

Sources: Eurostat AEI – Soil cover (EU winter 2016); FAO-56, Chapter 7 (dual-Kc / soil-evaporation shares); FAO-56, Effects of soil mulches; Soil Use & Management (2024), Western Europe meta-analysis (runoff capture).

This improvement stems directly from the solution's two primary hydrological mechanisms:

1. ***Reduced evaporation***—continuous soil cover through cover cropping lowers bare-soil exposure, preserving soil moisture and reducing agricultural water demand.

2. ***Reduced runoff***—the use of cover crops and crop rotations improves surface protection and infiltration, increasing the effective water supply available to plants.

Other regenerative practices, such as no-till, direct seeding, or interseeding, were not explicitly modelled, but their main hydrological effects are indirectly captured through the same drivers represented in the model: By maintaining surface residue and permanent greening while improving soil structures, these practices tend to influence water dynamics in similar ways to cover crops and crop rotations. Soil structure and compaction play a pivotal role in this process: Less compacted soils allow more rainfall to infiltrate rather than run off, directly reinforcing the runoff-reduction mechanisms captured in the model.

To illustrate the magnitude of this effect, a recent study[326] quantified the gains in soil-water storage associated with lower compaction under regenerative management. Applying the study's results to Brandenburg's arable land as a reference (~0.99 million ha[327]) leads to an estimated additional 218 million m³ of soil-water storage capacity, equivalent to roughly 22 mm of water spread across the region's arable land. This example highlights in physical terms what improved soil structure and reduced compaction mean for water retention.

Beyond these quantified effects, Regenerative Agriculture also delivers broader ecosystem and climatic co-benefits. Increased vegetation cover cools local microclimates and can enhance precipitation through evapotranspiration feedback. Recent research[328] shows that greener landscapes with higher vegetation indices (NDVI) generate substantially more local rainfall. Applied to Brandeburg's roughly 0.99 million ha of arable land, regenerative practices that increase vegetation cover could add up to 1,000 m³ (100 mm) of rainfall per hectare annually, roughly one-eighth of Germany's average annual precipitation (~8,000 m³/800 mm)[329] and equivalent to about one billion m³ or 100 mm of additional precipitation across the arable land area each year.

[326] NABU & BCG analysis based on UfU e.V. (2025): UfU-Hintergrundpapier and Die Brandenburger Landwirtschaft in Zahlen

[327] Statistik Berlin Brandenburg (2025): Die Brandenburger Landwirtschaft in Zahlen

[328] Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany

[329] UBA (2017): Wasserwirtschaftin Deutschland – Grundlagen, Belastungen, Maßnahmen

This effect may be amplified by the vegetation's indirect cooling influence on land-surface temperature. Each 1°C temperature reduction can increase rainfall by approximately 40 m³ per hectare per year.[330] Applied to Brandenburg's arable land, this corresponds to about 30 m³ per hectare, or 28 million m³ in total, equivalent to roughly 3 mm of extra rainfall per year across the arable land area. Together, these processes reinforce moisture recycling and local cooling, underscoring Regenerative Agriculture's role as a climate-positive solution that enhances both water availability and resilience at the landscape scale.

Forest Management.[331] Forest Management strengthens the landscape's natural buffering capacity; for example, by mixing tree species, like converting monoculture pine forests into diverse, climate-resilient stands or adjusting tree structures and composition in terms of density and coverage to optimize water flows.[332] In Brandenburg, this transformation could reduce regional water stress by around 12%, stabilizing both municipal and agricultural water use when applied across an area equivalent of roughly 15% of today's forest cover.[333] Implementation of Forest Management across this area lowers water-stress indices in areas such as Brieselang (~-1.4), Falkensee (~-0.9), or Cottbus (~-0.7) and is projected to reduce climate-induced annual losses by at least 12% in the domestic and municipal context from €5.3 billion–9 billion to €4.5 billion–8 billion and roughly 15% in the agricultural context from €270 million–380 million to €220 million–320 million.[334, 335]

These improvements are primarily driven by the solution's two key hydrological mechanisms:

1. ***Reduced runoff and interception losses***, resulting from mixed tree species and more balanced canopy density that slow surface flow and increase soil infiltration

2. ***Enhanced groundwater recharge***, as deeper root systems and improved soil structure allow more water to percolate into aquifers

A recent study quantifies the latter effect based on observations in Brandenburg:[336] Transitioning from coniferous to mixed deciduous stands can increase groundwater recharge by approximately 500 m³ (50 mm) per hectare each year. Deciduous species shed their leaves during winter, allowing more precipitation to reach the ground and infiltrate the soil more effectively during the dormant season.[337] This additional percolation capacity illustrates, in physical terms, how forest diversification strengthens the same infiltration and recharge processes captured in the model, underscoring the hydrological benefits of a more diverse forest structure.

Beyond these hydrological effects, Forest Management also generates broader climatic feedback. Increased vegetation density enhances both local precipitation and reduced land-surface temperatures. Research[330] shows that even small increases in forest greenness (NDVI) can measurably raise rainfall and reduce surface heat, reinforcing the feedback between vegetation, evapotranspiration, and moisture recycling. Because the proportion of Brandenburg's forest area that will ultimately be eligible or prioritized for transformation remains uncertain, these effects are presented as per-hectare estimates rather than extrapolated to the full forest area. For the transition considered here—from coniferous to mixed stands—these correspond to roughly 150 m³ (15 mm) of precipitation per hectare annually, on top of Germany's average 8,000 m³ (800 mm) per hectare and year,[338] complemented by a modest cooling effect that further amplifies precipitation by around 5 m³ (0.5 mm). Together, these mechanisms reinforce forests' role as natural regulators of regional climate and hydrology.

Drainage and Its Hidden Impact. The modelling framework applied in this study assumes that rainfall divides into runoff and infiltration, with a larger share percolating into the ground. What the model does not explicitly capture is the impact of subsurface drainage systems, which remove substantial volumes of water from the landscape before they can infiltrate and contribute to groundwater recharge. The omission was deliberate: Reliable, spatially consistent data on drainage coverage and discharge volumes across Germany is lacking, and available information differs considerably between federal states.[339] For consistency and transparency, drainage was therefore excluded from the model calculations, meaning that the reported water stress baseline might only represent a lower bound. In reality, water stress levels could be even higher, as a considerable fraction of water continues to drain away.

To illustrate the magnitude of this hidden outflow, we conducted an indicative calculation for Brandenburg, a region where drainage intensity is known to be high and likely above the national average. Observed drainage losses in the state range from approximately 1,200 m³ (120 mm) per hectare annually[340] on lightly drained land to 2,500 m³ (250 mm) on moderately drained areas,[340] and up to 5,200 m³ (520 mm) on heavily drained sites:[340] (See Figure 24.) equivalent to roughly 15% to more than half of Germany's average annual precipitation. Due to the lack of comprehensive, state-level data, the share of drained cropland in Brandenburg is uncertain. Based on available research and regional observations, it can be broadly estimated at 30–

[330] Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
[331] NABU & BCG analysis based on Ding, Bingbing, et al. "Effects of forest cover type and ratio changes on runoff and its components." International Soil and Water Conservation Research 10.3 (2022): 445-456
[332] Forest management practices considered in the model are: forest species diversification & forest coverage and density management. The solution impacts both surface runoff and groundwater recharge
[333] Forest management practices include varying tree cover density, increasing forest coverage where most beneficial and diversifying tree species
[334] Using conversion factor of 1 Dollar = 0.89 Euro (Average 31/12/2024-17/10/2025): US dollar (USD)
[335] Impact on sectors are estimated independently, with no secondary cross-sectoral effect. Forest management measures are considered across Brandenburg; modelling conservatively assumed maximum local tree cover does not surpass current average values for highly forested areas (40%). This leads to a lower-bound for estimated impact.
[336] HAWK (2025): Studie belegt: Waldumbau als Schlüssel zur Entlastung der Grundwasserbilanz in Grünheide | HAWK Hochschule für angewandte Wissenschaft und Kunst
[337] Öko-Institut e.V. (2020): https://www.nabu.de/imperia/md/content/nabude/wald/200915-nabu-wasserhaushalt_wald.pdf
[338] UBA (2017): Wasserwirtschaftin Deutschland – Grundlagen, Belastungen, Maßnahmen
[339] Agrarheute (2025): Zwischen Dürre und Flut: Darum nerven heute alte DDR-Drainagen | agrarheute.com
[340] LfU Brandenburg (2025)

40% of the total arable land (about 0.99 million hectares in total[341]) corresponding to roughly 300,000–400,000 ha. Depending on drainage intensity, this translates into potential water losses between roughly 0.4 billion and 2.0 billion m^3 per year.

[341] Statistik Berlin Brandenburg (2025): Die Brandenburger Landwirtschaft in Zahlen

Figure 24: Brandenburg loses large amounts of water each year through drainage, limiting the effectiveness of any solution, if not addressed

		Water runoff due to drainage, in m^3/ha/year		
		Brandenburg – light drainage	Brandenburg – moderate drainage	Brandenburg – strong drainage
		~ 1,200	~ 2,500	~ 5,200
Million ha	Applicable area options	Total water runoff due to drainage, in B m^3/year		
0.3	~30% of Brandenburg's agricultural land is drained	~ 0.4	~ 0.7	~ 1.5
0.4	~40% of Brandenburg's agricultural land is drained	~ 0.5	~ 1.0	~ 2.0

Source: LfU Brandenburg, BCG & NABU analysis

These figures underline both the data gaps and the scale of the challenge: Even as measures such as Regenerative Agriculture or Forestry Management help expand water availability, their positive impact will remain limited if water continues to be drained from the system at comparable rates. The situation can be compared to filling a bathtub without a plug—no matter how much additional water is poured in, it will simply run out through the drain. Addressing drainage, therefore, is not just a complementary action but a precondition for long-term water resilience in Brandenburg and beyond.

From Regional Insights to National Perspective. The Brandenburg analysis demonstrated the tangible impact that nature-based measures can have in reducing regional water stress. Yet the challenges observed there are not unique: They mirror patterns emerging across Germany. To understand the broader implications and identify where the greatest leverage lies, the next step scales the lens from regional to national application.

6.3.2 Solution Effectiveness Across Germany

Quantifying First-Order Effects and Cost-Effectiveness. While recognizing that the effectiveness of a solution is multifaceted, encompassing both water-related and broader ecosystem impacts, our quantitative analysis in this study for all of Germany focuses primarily on first-order effects—those that directly influence the dimension of water and its availability. This focus allows for a consistent comparison of the effectiveness and cost-efficiency of each measure in terms of water created or retained per unit of investment.

Since Germany's primary water challenge concerns overall water availability, it is crucial to assess the effectiveness of measures aimed at increasing total water supply, as this represents a far greater lever for impact than efficiency optimization, even though the latter remains highly valuable. Accordingly, the assessment does not include those solutions that optimize the utilization of existing water (*Solutions 7 and 8*) but rather concentrates on those solutions that expand the total water availability (*Solutions 1–6*). However, there is one exception: Other Landscape-Level Methods. While Other Landscape-Level Methods influence water dynamics across entire catchments by capturing, storing, and gradually releasing water through natural or seminatural features, these interventions can take many forms—from microscale elements, such as ponds, swales, or small retention basins, to macroscale systems, like wetlands, terraced slopes, or restored floodplains. Because their design, size, and hydrological context vary widely, both the water benefits and cost profiles of such measures differ substantially from site to site. As a result, their impact cannot be meaningfully represented through a single quantitative range. Acknowledging their pivotal role in restoring local water cycles, buffering floods and droughts, and enhancing ecosystem resilience, they are thus only discussed qualitatively alongside the quantitative findings of the other solutions.

Introducing the MaCoWA. Many are familiar with the Marginal Abatement Cost Curve also known as a MACC curve, a common tool in climate economics that illustrates how different measures reduce CO_2 emissions relative to cost. A similar concept has been missing in the field of water management—despite the growing need to understand which interventions most efficiently increase water availability. To fill this gap, this study introduces the Marginal Cost of Water Availability (MaCoWA) curve. The MaCoWA visualizes the amount of water created or retained by each solution in relation to its investment cost per hectare, allowing for a clear comparison of cost-effectiveness across the solution spectrum—from nature-based measures such as Regenerative Agriculture or Forest Management to technological approaches like desalination, long-distance pipes, or river rerouting. By quantifying and juxtaposing these effects, the MaCoWA provides a transparent, decision-oriented framework for identifying the most impactful and efficient levers to strengthen Germany's water resilience.

Given the diversity of scales, local conditions, and implementation contexts, the quantitative potential and cost-effectiveness of each measure naturally vary. The ranges presented in this analysis are derived from existing literature and research, representing the best available evidence while acknowledging uncertainty. These values are not meant as fixed predictions but as directional indicators that convey the relative magnitude and efficiency of different interventions. The MaCoWA curve thus offers a starting point for transparent discussion and prioritization, helping policymakers and stakeholders identify where investments can deliver the highest water returns. As data, technologies, and experience continue to evolve, this framework should be seen as a living evidence base—one that will be refined over time to deepen the understanding of how best to allocate resources to manage and secure water.

- ***Regenerative Agriculture.*** Regenerative Agriculture enhances landscape water availability by rebuilding soil structure, increasing organic matter, and improving infiltration and water retention.[342, 343, 344] By restoring soil health, these practices enable land to retain a greater share of the water it receives, while also influencing local climatic conditions by actively driving the water cycle.

  Practices such as cover cropping, interseeding, and continuous vegetative cover can enhance the local water cycle, leading to an uplift in precipitation through increased evapotranspiration, surface greening and cooling effects. Recent research[345] shows that an increase in the Normalized Difference Vegetation Index (NDVI), a proxy for vegetation greenness, correlates strongly with higher precipitation levels. Specifically, a one-unit rise in NDVI corresponds to an additional 2,970 m³ (297 mm) of rainfall per hectare per year. Given that bare cropland typically has an NDVI of around 0.2 and vegetated land around 0.55, regenerative practices that increase NDVI by roughly 0.35 could thus induce an additional 1,000 m³ (100 mm) of precipitation per hectare annually.

  Not all rainfall contributes directly to aquifer replenishment; only a portion infiltrates deeply enough for groundwater recharge, which varies significantly by soil type and region. In Germany, recharge rates are generally higher in the south and lower in the northeast,[346] with a representative range between 10% and 25%,[346] and a mid-point of about 18% based on the assumption of an annual average precipitation of ~8,000 m³ (800 mm) per hectare per year.[347] Under these assumptions, Regenerative Agriculture can add roughly 100–250 m³ (10–25 mm) of groundwater recharge per hectare per year. Applied across the approximately 13.3 million ha of land suitable for regenerative practices in Germany—about 10 million ha of cropland and 3.3 million ha of grassland[342]—this equates to an additional 1.3 billion–3.3 billion m³ of groundwater recharge annually, with the study using the midpoint estimate of around 2.4 billion m³. (See Figure 25.) That is enough to fill roughly 960,000 Olympic swimming pools, corresponding to an average of around 18 mm per hectare per year (based on 13.3 million ha of agricultural land), or expressed more simply, roughly 24 mm of rainfall over 10 million ha.

[342] NABU & BCG (2023): https://web-assets.bcg.com/20/43/809680664811998e-155baeee1e30/the-case-for-regenerative-agriculture-mar2023.pdf
[343] NABU & BCG (2025): healthy-soil-grows-healthy-food-mar-2025-wo-spine.pdf
[344] White (2020): Why-regenerative-agriculture.pdf
[345] Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
[346] UBA (2024): Auswirkung des Klimawandels auf die Wasserverfügbarkeit - Anpassung an Tro-ckenheit und Dürre in Deutschland (WAD-Klim)
[347] UBA (2017): Wasserwirtschaftin Deutschland – Grundlagen, Belastungen, Maßnahmen

Figure 25: Sensitivity analysis of water benefits from **Regenerative Agriculture** depending on groundwater recharge rate

		Precipitation uplift based on Adhikari, Ibisch et al., in m³/ha/year		
		~ 1,000		
		Groundwater recharge rate, in % per year		
		Based on Wadklim[1]	Based on Wadklim[2]	Based on Wadklim[3]
		~ 10%	~ 18%	~ 25%
Million ha	Applicable area options	Increase in groundwater recharge, in B m³/year		
13.3	~10 M ha cropland and ~3.3 M ha grassland	~ 1.3	~ 2.4	~ 3.3

Chosen scenario

Source: LfU Brandenburg, BCG & NABU analysis

None of this groundwater recharge would be possible without improvements in soil structure delivered by regenerative practices. Techniques such as no tillage reduce the use of heavy machinery, and when combined with deep-rooting plants, legumes, and cover crops, they improve soil structure and reduce compaction. Healthier, more porous soils allow water to infiltrate more effectively, unlocking their natural sponge-like properties. A recently published study[348] confirms this: Even a modest reduction in soil compaction (assuming ~8% compaction reduction [0.1 g/cm³] increases soil porosity by 3.7% and water storage capacity by 11 l/m² at 0.3 m soil depth) can significantly increase the soil's temporary storage capacity, while also reducing later runoff in the compacted soil layer. Using the Saale catchment as a model, the study estimated that slightly less compacted soils across roughly 224,300 ha agricultural land could store an additional 177 million m³ of water—equivalent to roughly 20 days of the river's average discharge. This added retention capacity can act as a natural buffer and sponge, reducing peak runoff during extreme rainfall and potentially lowering flood heights by several centimeters. For agricultural land, that's two days of peak flood discharge—meaning this improved infiltration could make the difference between a flood and a catastrophe.

[348] UfU e.V. (2025): UfU-Hintergrundpapier

Beyond its hydrological benefits, Regenerative Agriculture is also economically positive. Practices such as no-till farming, cover cropping, and legume rotations not only increase soil moisture and long-term water-holding capacity but also improve farm profitability through avoided yield losses, reduced fertilizer demand, and higher soil productivity. Assuming basic and intermediate implementation, Regenerative Agriculture can deliver average profits of roughly €225 per hectare per year (€152/ha in stage 1, €73/ha in stage 2). Put differently, it can increase farm profits by up to 60% compared to conventional systems.[349] In addition, downstream food producers, distributors, and retailers can reduce supply-chain risks by up to 50% in years marked by droughts or excessive rain,[350] demonstrating that Regenerative Agriculture is one of the few solutions that simultaneously strengthens water resilience, restores ecosystems, and generates lasting economic value.

[349] NABU & BCG (2023): https://web-assets.bcg.com/20/43/809680664811998e-155baeee1e30/the-case-for-regenerative-agriculture-mar2023.pdf
[350] NABU & BCG (2023): https://web-assets.bcg.com/20/43/809680664811998e-155baeee1e30/the-case-for-regenerative-agriculture-mar2023.pdf

- ***Forest Management.*** Forest Management contributes to water resilience by restructuring existing forest stands to improve infiltration, reduce runoff, and enhance groundwater recharge. Estimates of the forest area in scope for such restructuring vary depending on the definition applied. A narrow assessment would focus solely on pine monocultures (~0.9 million ha)[351], while broader estimates also would include other coniferous monocultures such as spruce (~2.5 million ha).[352] From a purely water-optimization perspective, even mixed forests dominated by coniferous species—covering up to around 3.2 million ha[353]—could theoretically be transformed to increase groundwater recharge. However, given the ecological advantages of mixed forests,[351] only a share of these will likely be converted in practice.

  Hydrologically, deciduous forests enable higher groundwater recharge than coniferous stands.[353] Because coniferous trees retain their needles year-round, they intercept rainfall and reduce infiltration, while deciduous trees shed their leaves in winter, allowing greater percolation and recharge during the dormant season. Research estimates the resulting increase in groundwater recharge from conversion to be between 500[354] and 950 m³ (50–95 mm) per hectare per year,[355] with a midpoint of 700 m³ (70 mm),[353] depending on regional soil and climatic conditions. In Brandenburg, recharge rates are expected near the lower to mid-range, while wetter regions such as Lower Saxony are likely to reach the upper end.[356] Applying these rates to the applicable area range yields an annual groundwater recharge potential of roughly 0.5 billion–3.0 billion m³, with the study proceeding on the midpoint assumption—around 1.8 billion m³ of additional recharge per year (See Figure 26.)—as much as about 720,000 Olympic swimming pools or corresponding to an average of around 70 mm per hectare per year (based on 2.5 million ha). Expressed more simply, this equates to roughly 18 mm of rainfall per year if distributed evenly across 10 million ha.

[351] BMLEH (2024): Der Wald in Deutschland - Ausgewählte Ergebnisse der vierten Bundeswaldinventur
[352] BMLEH, Thünen (2024): BUNDESWALDINVENTUR ERGEBNISDATENBANK
[353] Öko-Institut e.V. (2020): https://www.nabu.de/imperia/md/content/nabude/wald/200915-nabu-wasserhaushalt_wald.pdf
[354] HAWK (2025): Studie belegt: Waldumbau als Schlüssel zur Entlastung der Grundwasserbilanz in Grünheide | HAWK Hochschule für angewandte Wissenschaft und Kunst
[355] Schultze & Scherzer (2015): https://www.lwk-niedersachsen.de/services/download.cfm?pmofile=396
[356] UBA (2024): Auswirkung des Klimawandels auf die Wasserverfügbarkeit - Anpassung an Tro-ckenheit und Dürre in Deutschland (WAD-Klim)

Figure 26: Sensitivity analysis of water benefits from **Forest Management** based on groundwater recharge and forest area

		Additional groundwater recharge from pine-deciduous shift, in m³/ha/year		
		Based on HAWK (Brandenburg)	Based on Öko-Institut e.V. (Brandenburg)	Based on Schultze & Scherzer (Lower Saxony)
		~ 500	~ 700	~ 950
Million ha	**Applicable area options**	**Increase in groundwater recharge, in B m³/year**		
0.9	Pine monoculture	~ 0.5	~ 0.6	~ 0.9
2.5	Coniferous monoculture	~ 1.3	~ 1.8	~ 2.4
3.2	Coniferous dominated mixed forests	~ 1.6	~ 2.2	~ 3.0

Chosen scenario: ~ 1.8 (Coniferous monoculture, Based on Öko-Institut e.V.)

Source: HAWK, Öko-Institut e.V., Schultze & Scherzer, BMLEH, BCG & NABU analysis

These groundwater gains are supported by two complementary mechanisms: First, the implementation of minimal soil compaction measures as well as the introduction of diverse and deeper-rooting species improves soil structure, increases organic matter, and enhances the forest floor's water-holding capacity. This allows more rainfall to infiltrate and be retained in the soil rather than lost as surface runoff. This is also shown by the study conducted in the Salle catchment, that estimates slightly less compacted soils across roughly 110,700 ha forest could store an additional 67 million m³ of water—equivalent to roughly one week of the river's average discharge. During extreme rainfall, this added retention capacity can reduce forest's peak runoff by about one day of peak flood discharge. Second, beyond infiltration benefits, forest restructuring also influences precipitation patterns. Increased vegetation density, reflected in higher NDVI values, enhances local rainfall through evapotranspiration feedback. Based on research[357] showing that a one-unit increase in NDVI generates approximately 2,970 m³ (297 mm) of additional rainfall per hectare per year, shifting from coniferous forests (NDVI ~0.72) to mixed or deciduous stands (~0.78) corresponds to an uplift of around 150 m³ (15 mm) per hectare annually—on top of Germany's average precipitation of about 8,000 m³ (800 mm) per hectare.[358]

Implementation costs for forest conversion vary widely and depend strongly on conditions on-site, management objectives, and the chosen approach. In some areas, natural regeneration can occur almost without cost when existing vegetation and seed banks allow forests to recover autonomously. In other cases, costs can be considerably higher, particularly where fencing, planting, selective thinning, or long-term maintenance are required to protect young stands and guide structural transformation. Earlier studies have estimated typical implementation costs in the range of €5,000–6,500 per ha[359] for replanting and full reforestation, though actual values can deviate substantially in both directions. Forgone timber revenues are expected to remain limited or may even be offset over time. Deciduous species produce lower volumes but higher-quality wood compared to fast-growing conifers such as spruce and pine—species increasingly affected by pests like the bark beetle, which have caused severe economic losses across German forests in recent years.[360, 361]

- ***Sponge Cities.*** While the primary purpose of Sponge Cities is to increase the livability in cities by engineering a better micro-climate and improve air quality, they also contribute to restore elements of natural water cycles by increasing local water retention, infiltration, and delayed runoff through a combination of nature-based and engineered solutions[362] that absorb, store, clean and reuse rainwater in urban areas. Typical measures include the greening of roofs and façades, the installation of rain gardens and bioswales, and unsealing paved surfaces, e.g., in residential, industrial, and commercial areas.[363, 364, 365] The potential area suitable for Sponge City implementation depends strongly on the type of measure and urban context. In the context of increasing available water volumes, two measures are of particular importance: i) unsealing of paved areas to enable infiltration of rainwater and ii) allowing rainwater from roof areas to infiltrate into the ground using e.g., sinking shafts instead of discharging it through the sewer system. Based on these measures the total area realistically applicable is estimated at approximately 0.1 million[366]–0.6 million hectares, with a midpoint of around 0.3 million hectares.[367, 368] (See Figure 27.) This footprint is small compared to landscape-scale measures such as Regenerative Agriculture or Forest Management.[363, 365]

  Also, the extent to which infiltrated water contributes to net groundwater recharge depends strongly on surface type, soil properties, vegetation cover, and groundwater depth[369]. In particular, vegetated systems, especially those with deep-rooted trees, can exhibit substantially higher evapotranspiration, which may partially or fully offset gains in infiltration[369]. Empirical studies from urban environments show that while unsealed or sparsely vegetated urban soils can achieve high percolation rates, park-like or tree-dominated areas often exhibit lower groundwater recharge, and in settings with shallow groundwater may even act as net water consumers[369].

  Against this background, Sponge City interventions are assumed to increase the effective share of rainfall available for potential groundwater recharge rather than uniformly increasing recharge across all surface types[362, 369]. Drawing on research from Kompetenzzentrum Wasser Berlin[370], groundwater recharge rates can rise from approximately 18% under predominantly sealed conditions to up to around 25% under favorable infiltration-oriented designs[362], corresponding to an up-

[357] Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
[358] UBA (2017): Wasserwirtschaftin Deutschland – Grundlagen, Belastungen, Maßnahmen
[359] UBA (2023): FW-R-1_Indikator_Foerderung_Waldumbau
[360] BMLEH (2024): Der Wald in Deutschland - Ausgewählte Ergebnisse der vierten Bundeswaldinventur
[361] Deutscher Bundestag (2024): https://dserver.bundestag.de/btd/20/140/2014052.pdf

[362] Del Punta et al. (2024): https://www.bmbf-wax.de/wp-content/uploads/17_del-punta_et_al_icud2024-abimo_abstract_poster.pdf
[363] Heinrich-Böll-Stiftung, BUND (2025): Wasseratlas 2025 – Daten und Fakten über die Grundlage allen Lebens
[364] Destatis (2024): Floor area total according to types of use in Germany - German Federal Statistical Office
[365] Del Punta et al. (2025): V09-DEL_PUNTA-Beitrag.pdf
[366] Der Dichte Bau: Flachdächer - Der dichte Bau
[367] BMLEH: BMEL-Statistik: Bodennutzung in Deutschland
[368] UBA (2025): Bodenversiegelung | Umweltbundesamt
[369] Guericke et al (2023): communication novatech
[370] Kompetenzzentrum Wasser Berlin Presentation (2025)

per-bound increase of roughly 7 percentage points. This upper bound is most representative of measures such as the unsealing of paved surfaces, permeable pavements, infiltration zones, and lightly vegetated systems[371]. To account for the substantial variability introduced by vegetation cover, soil texture, and groundwater conditions—ranging from sparsely vegetated infiltration-oriented surfaces with high percolation potential to tree-dominated or groundwater-near systems with strongly reduced or even negative net recharge[372]—two additional scenarios are considered: a moderate increase of 3.5 percentage points and a conservative increase of 1 percentage point. (see Figure 27.)

Assuming Germany's average annual precipitation of approximately 8,000 m³ (800 mm) per hectare[373], these scenarios imply an additional potential groundwater recharge of roughly 80–560 m³ per hectare and year. Applied to our applicable area estimates, Sponge City measures could generate an additional 10 million–340 million m³ of groundwater recharge per year, with the study using a midpoint estimate of approximately 0.08 billion m³. (see Figure 27.) This is roughly equivalent to 32,000 Olympic swimming pools or corresponding to an average increase of around 27 mm per hectare per year (based on 0.3 million ha). This is only about 1% of the total positive impact of the landscape level measure in agriculture and forest landscapes, hence rather unimportant for the total water balance—again noting that the primary purpose of Sponge Cities is not the contribution to water balance but increasing livability for the urban population. These values should be interpreted as indicative order-of-magnitude estimates, with realized groundwater recharge depending on local design choices and site conditions.[374, 371]

Because Sponge City measures require substantial modifications to existing urban infrastructure, implementation costs are relatively high when deployed at scale. Providers estimate average costs of around €50 per m² for standard green-roof systems[375] (approximately ~€500,000 per hectare), with higher costs for roofs designed to maximize water retention e.g., engineering sinking shafts at scale. The unsealing of paved surfaces and their conversion into green or permeable areas typically costs on the order of €2 million per hectare, depending on surface type and the extent of additional greening measures.[376] However, these costs reflect full upfront implementation. In practice, Sponge City elements can be integrated gradually through regular building renovations, roof replacements, and street redevelopments. In new housing constructions the cost of these measures are only marginally higher than those of conventional buildings. Phasing implementation over existing infrastructure renewal cycles can significantly reduce marginal costs, spread investments over time, and improve economic feasibility, albeit at the expense of slower system-wide impacts.

[371] Del Punta et al. (2025): V09-DEL_PUNTA-Beitrag.pdf
[372] Guericke et al (2023): communication novatech
[373] UBA (2017): Wasserwirtschaftin Deutschland – Grundlagen, Belastungen, Maßnahmen
[374] Del Punta et al. (2024): https://www.bmbf-wax.de/wp-content/uploads/17_del-punta_et_al_icud2024-abimo_abstract_poster.pdf
[375] Sedum Dachbegrünung: SedumDachbegrünung | Dach begrünen leicht gemacht
[376] Regenwasseragentur: Entsiegelung von Flächen in Berlin: Jetzt informieren und loslegen

Figure 27: Sensitivity analysis of water benefits from **Sponge Cities** depending on groundwater recharge rate and applicable area

Average precipitation in Germany, in m³/ha/year: ~ 8,000

Additional groundwater recharge, in %-points per year

Million ha	Applicable area options	Conservative estimate – extrapolated from KWB (~ 1%)	Moderate estimate – extrapolated from KWB (~ 3.5%)	Optimistic estimate – based on KWB research (~ 7%)
		Increase in groundwater recharge, in B m³/year		
0.1	Total flat roof area	~ 0.01	~ 0.03	~ 0.06
0.3	Unsealing of ~50% of all sealed area excl. settlement	~ 0.02	~ 0.08	~ 0.17
0.6	Unsealing of all sealed area excl. settlement	~ 0.05	~ 0.17	~ 0.34

Chosen scenario: ~ 0.08 (0.3 million ha, moderate estimate)

Source: KWB, Der Dichte Bau, UBA, Destatis, BCG & NABU analysis

- ***Technical Supply Expansion.*** Large-scale engineered supply measures—including desalination, river rerouting, and long-distance water transfer pipelines—can substantially increase available freshwater volumes by sourcing water beyond local catchments. Among these, desalination plays a particularly important role: by converting seawater into potable water, it offers an almost inexhaustible and climate-independent supply option.[377] However, this reliability comes at the cost of high capital expenditure, energy intensity, and environmental impact.[377]

  Global reviews indicate that the cost of seawater desalination typically ranges between €0.40 and €1.80 per cubic meter,[378] depending on feedwater type, technology, and location. Brackish water desalination tends to be cheaper but geographically limited, while seawater desalination is more energy-intensive but universally available.[379] Costs decrease where facilities benefit from economies of scale, employ advanced reverse-osmosis membranes, and rely on low-carbon or low-cost energy sources.[379] Conversely, smaller or older plants powered by fossil fuels remain considerably more expensive to operate. Despite such advances, desalination still entails significant environmental externalities, including brine effluent disposal, which alone can account for roughly 3% of total production costs, and a large carbon footprint.[379] According to the World Bank Group, energy constitutes the largest recurring cost, with modern reverse-osmosis systems consuming 3–7 kWh of electricity per cubic meter of water produced.[379]

  A notable example is the Claude "Bud" Lewis Carlsbad Desalination Plant in California, built at a cost of approximately €0.9 billion.[380] The plant produces around 190,000 m³ of freshwater per day, supplying about 10% of San Diego County's demand.[380] Constructed on an area of about 2.4 hectares (6 acres),[380] this equates to a capital cost of roughly €350 million per hectare—a conversion made here only for comparative purposes. Under its long-term water purchase agreement, the delivered water price is set at around €2.50 per m³ for fiscal year 2024,[381] meaning that desalinating 1 billion m³ of water at this rate would cost about €2.5 billion annually.

  Comparable inter-basin transfer and river diversion projects—such as China's South-to-North Water Diversion Project[382] or the diversion of rivers like the Elbe or Neisse to ensure the Spree receives sufficient water after the lignite phaseout[383]—can also deliver significant additional volumes, yet require extensive civil works, continuous pumping energy, and ongoing management of hydrological and ecological impacts in donor basins. Overall, Technical Supply Expansion offers reliability and scalability but remains among the most capital- and energy-intensive pathways to increasing water availability, thus making it far less efficient compared to nature-based solutions.

- ***Dynamic Drainage.*** Drainage systems are widespread across Germany—in agricultural areas, forests, and urban landscapes[384]—and were originally designed to remove excess water from soils to make land usable for farming or construction.[385] While this was beneficial in the past, under today's changing climate conditions these systems have become increasingly counterproductive.[385] Continuous drainage accelerates runoff, limits infiltration, and removes water from the landscape precisely when it is most needed to buffer prolonged dry periods.[386] Dynamic Drainage modernizes these conventional systems by enabling adaptive water regulation: instead of discharging continuously, adjustable gates, valves, and smart control systems retain water during wet periods and release it only when needed.[386, 387, 388] This approach reduces peak runoff and flood risk, while improving soil moisture and groundwater recharge.

  Instead of focusing on the amount of water running off, our calculation focuses on the volume that can be retained in the ground through the implementation of Dynamic Drainage solutions. Estimates of the retention potential vary depending on soil type, hydrological conditions, and local topography. Accounts from a farmer in Brandenburg reveal that he was able to retain roughly 40% of the water previously lost through conventional drainage by optimizing it for his purposes.[389] This corresponds to an additional roughly 1,000 m³ (100 mm) of water per hectare per year. Other research in Lower Saxony shows that smart drainages were able to retain up to around 1,400 m³ (140 mm),[390] with a midpoint of about 1,200 m³ (120 mm) between both estimates. In areas with naturally high drainage flows—such as southern Bavaria, where runoff can exceed 5,000 m³ (500 mm) per hectare annually[384]—the retention potential may be even higher.

  For the quantitative assessment, this study focuses on agricultural drainage systems, as they represent the most extensive and best-documented application area in Germany. Agricultural land covers roughly half of the country's total area,[391] and about 23% of it[384]—equivalent to 4.1 million ha—is estimated to be artificially drained. Considering lower sensitivity bounds of 8–16%, the applicable area lies at roughly 1.4 million

[377] NEWater: What are the Pros and Cons of Desalination Plants?-NEWater
[378] Wittholz et al. (2008): Estimating the cost of desalination plants using a cost database - ScienceDirect
[379] World Bank Group (2019): https://documents1.worldbank.org/curated/en/476041552622967264/pdf/135312-WP-PUBLIC-14-3-2019-12-3-35-W.pdf
[380] San Diego County Water Authority (2025): https://www.sdcwa.org/wp-content/uploads/2020/11/desal-carlsbad-fs.pdf
[381] San Diego County Water Authority (2025): https://www.sdcwa.org/wp-content/uploads/2020/11/desal-carlsbad-fs.pdf
[382] Xin et al. (2023): content
[383] UBA (2023): Wasserwirtschaftliche Folgen des Braunkohleausstiegs in der Lausitz - Abschlussbericht

[384] Auerswald et al. (2024): EGUsphere - HESS Opinion: Floods and droughts – Land use, soil management, and landscape hydrology are more significant drivers than increasing temperatures
[385] Agrar heute (2025): Zwischen Dürre und Flut: Darum nerven heute alte DDR-Drainagen | agrarheute.com
[386] LTZ: Smarte Drainagen - Infodienst - LTZ Augustenberg
[387] Stowa: Controlled drainage | STOWA
[388] Spreewasser:N: Oberflächennahe Wasserspeicher – SpreeWasser:N
[389] LfU Brandenburg (2025)
[390] NDR (2025): Mit smarten Drainagen gegen Trockenheit und Starkregen | ndr.de
[391] BMEL (2023): BMEL-Statistik: Bodennutzung in Deutschland

or 2.9 million hectares, respectively. Applying the estimated retention rates results in 1.4 billion–5.7 billion m³ of additional water retained in the ground per year, with the study proceeding on the midpoint estimate of around 3.5 billion m³ per year (See Exhibit 28.)—roughly as large as 1.4 million filled Olympic swimming pools or corresponding to an average of around 120 mm per hectare per year (based on 2.9 million ha). Expressed more simply, that equals roughly 35 mm of rainfall per year if distributed evenly across 10 million ha. This figure should be seen as indicative, as the extent, condition, and design of Germany's drainage infrastructure are not comprehensively documented and local site conditions strongly influence outcomes.

Figure 28: Sensitivity analysis of water benefits from **Dynamic Drainage** based on water retention and applicable area

Million ha	Applicable area options	Additional water retained in the ground, in m³/ha/year: Based on Farm observation (Brandenburg)	Mid-point between data-points	Based on NDR article (Lower Saxony)
		~ 1,000	~ 1,200	~ 1,400
		Increase in groundwater recharge, in B m³/year		
1.4	8% of total agricultural land is drained – 1/3 of Auerswald et al. estimate	~ 1.4	~ 1.7	~ 2.0
2.9	16% of total agricultural land is drained – 2/3 of Auerswald et al. estimate	~ 2.9	~ 3.5 (chosen scenario)	~ 4.1
4.1	~23% of total agricultural land is drained – based on Auerswald et al.	~ 4.1	~ 4.9	~ 5.7

Chosen scenario

Source: LfU Brandenburg, NDR, Auerswald et al., BCG & NABU analysis

Implementation costs for Dynamic Drainage vary by system sophistication and scale. Material costs for manual or climate-adapted systems amount to roughly €1,300–2,500 per hectare,[392, 393, 394] while advanced, sensor-controlled systems with automation can at least triple costs[395] reaching roughly €3,900–7,500 per hectare. Material costs per hectare decrease with system size, as larger collectors serve more area, but installation and construction expenses can add significantly to material costs.[396] Costs for maintenance, interest, and depreciation are estimated to amount to roughly €700 per hectare per year.[397]

[392] LBEG (2014): https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjN7fzw6ZaQAxW7nP0HHQEvGR8QFnoECBkQAQ&url=https%3A%2F%2Fwww.lbeg.niedersachsen.de%2Fdownload%2F133097&usg=AOvVaw0oSTiMm1XRX97FDh7-LNW5&opi=89978449
[393] Stowa: Controlled drainage | STOWA
[394] Ingeniuergesellschaft Prof. Dr. Sieker mbH E-Mail correspondence (2025)
[395] Geiger agri solutions ekoDrena Price list 2025 E-Mail correspondence (2025)
[396] Geiger agri solutions E-Mail correspondence (2025)
[397] Wageningen University & Research (2020) – E-Mail correspondence (2025)

- ***Other Landscape-Level Methods.*** Other Landscape-Level Methods—such as floodplain restoration, wetland reactivation, terracing, and catchment-scale retention systems—influence water dynamics across entire hydrological basins. By reestablishing natural retention areas, reconnecting rivers with their floodplains, and restoring the infiltration capacity of degraded soils and slopes, these interventions can significantly increase water storage and slow surface runoff, thereby stabilizing baseflows and replenishing groundwater over wide areas.[398]

  While their effects depend strongly on local topography, soil characteristics, and hydrological connectivity, Other Landscape-Level Methods can be implemented across multiple scales. At the local level, farmers and landowners can create small retention basins, ponds, or field swales to collect runoff and store water for irrigation or

[398] Heinrich-Böll-Stiftung, BUND (2025): Wasseratlas 2025 – Daten und Fakten über die Grundlage allen Lebens

infiltration, directly improving local water availability and drought resilience.[399] At the regional or catchment scale, initiatives such as the Gesamtkonzept Elbe[400] and other European floodplain restoration programs (See the sidebar "Room for the River (Netherlands) demonstrate how reconnecting rivers to their floodplain landscapes and reactivating natural retention areas can generate substantial water gains, enhance groundwater recharge, and buffer both floods and droughts. Together, these interventions show that Other Landscape-Level Methods form a flexible spectrum of solutions—ranging from small-scale water retention to large-scale hydrological restoration—capable of improving water balance and ecosystem resilience across diverse spatial contexts. Their cost, however, typically falls on the higher end of nature-based solutions—driven by planning complexity, land-use trade-offs, and the need for coordinated, multistakeholder implementation.

Directionally, landscape-level interventions can be considered moderate to high in water impact—depending on their scale—and moderate to high in cost, with significant co-benefits for ecosystem resilience, flood protection, and biodiversity. In qualitative terms, they represent a powerful but investment-intensive lever for restoring the natural water balance and increasing long-term landscape resilience in Germany.

[399] Manheim Township: Detention vs Retention Basin | Manheim Township, PA - Official Website
[400] Gesamtkonzept Elbe: Projektseite Gesamtkonzept Elbe - Startseite

Room for the River (Netherlands)

After severe floods in the early 1990s exposed the limits of endlessly raising dikes, the Netherlands adopted a new strategy: give rivers more space. In response, the Dutch government launched the Room for the River program, a national initiative designed to give rivers more space to safely accommodate high water. The program, implemented between 2006 and 2018, marked a paradigm shift in Dutch water management—from defending against water to living with it.

At more than 30 project sites along the Rhine-Meuse delta, measures such as floodplain lowering and depoldering, dike relocation, side channels and bypasses, and removal of hydraulic obstacles restored rivers' capacity to store and convey water safely. In Nijmegen, for example, relocating the Lent dike and creating the Spiegelwaal side channel lowered extreme water levels by almost 30 cm and produced a new river park that combines safety, recreation, and ecology.

With a total investment of around €2.2 billion, the program was completed on time and within budget. It increased the Rhine's discharge capacity by about 10% and reduced flood risk while delivering broad co-benefits: restored wetlands and biodiversity, improved landscape quality, and new recreational areas. Evaluations found the investment economically justified through avoided flood damage and social and ecological gains.

These benefits are deeply connected to the dynamics of small water cycles. By giving rivers room to breathe, restoring wetlands, and creating diverse landscape mosaics around them, the program reactivated natural processes that link water, vegetation, and climate. Greener landscapes enhance evapotranspiration, which supports local rainfall. Expanded riverbeds and healthy soils then capture and store that water, slowing runoff and reducing flood peaks. This interplay between water retention, vegetation, and climate regulation shows that when the water balance is managed as an integrated system, nature and infrastructure can reinforce one another to deliver powerful, self-sustaining resilience.

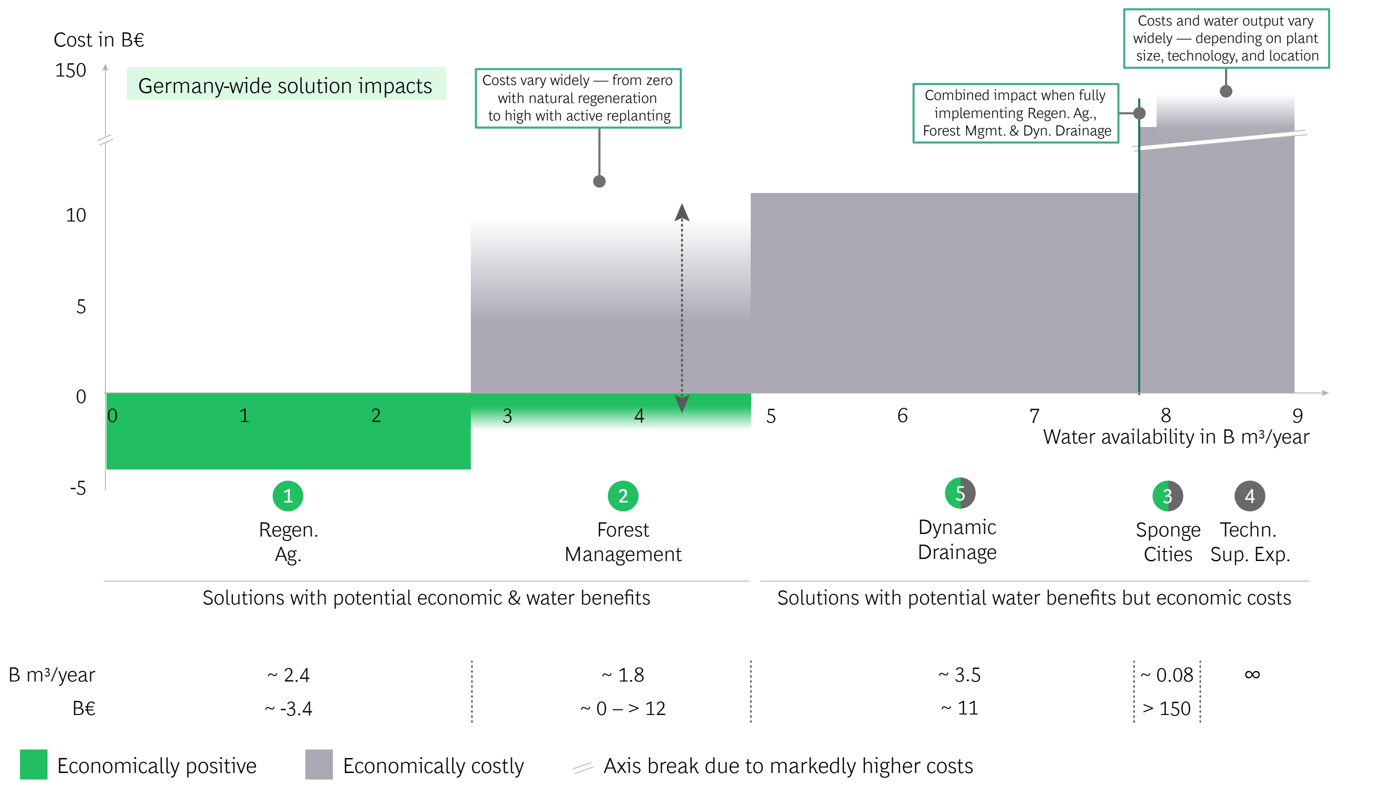
Building on this success, the Dutch government launched Room for the River 2.0 in 2025, extending the concept to address low-water periods, sedimentation, and freshwater shortages under a changing climate. The initiative reinforces the Netherlands' global reputation for landscape-scale, nature-based water management, showing that flood protection and ecological restoration can advance together toward long-term climate resilience.[401, 402, 403, 404, 405, 406, 407, 408]

[401] Rijkswaterstaat: Room for the River
[402] Stowa: Room for the river | STOWA
[403] European Environment Agency (2018): Interview — The Dutch make room for the river — European Environment Agency
[404] H+N+S: Room for the River Nijmegen - HNS
[405] Climate Adapt (2020): Room for the River Waal – protecting the city of Nijmegen | Case studies | Discover the key services, thematic features and tools of Climate-ADAPT Climate-ADAPT
[406] Deltares (2025): Working on a future-proof river area | Deltares
[407] Dutch Water Sector (2025): Room for the river 2.0: preparing the Netherlands for future high and low water | Dutch Water Sector
[408] Haskoning: Room for the river | Haskoning

Putting our Solutions into Perspective. When comparing the different measures that expand water availability, clear patterns emerge in both water impact magnitude and cost-efficiency. Additionally, as mentioned above, some solutions also exhibit greater "leverage" due to their wide applicability across Germany's land types. Regenerative Agriculture can be applied to roughly half of Germany's land area, covering both cropland and grassland. Forest Management can have relevance across about 30% of the country, primarily in forested regions. Dynamic Drainage can be introduced across multiple land types—from agricultural fields to urban and forested areas—but is particularly effective and scalable within agricultural landscapes. By contrast, Sponge Cities and other infrastructure-based measures can address only smaller, more fragmented surface areas, mainly in urban environments.

On a per-hectare basis, Regenerative Agriculture, Dynamic Drainage, and Forest Management demonstrate the highest potential to increase water retention and groundwater recharge. Applied across all of Germany, these three nature-based solutions could add up to approximately 7.7 billion m³ of additional water annually (See Exhibit 29.)—a volume corresponding to roughly 77 mm of rainfall per year if distributed evenly across 10 million hectares. Put differently, it exceeds Germany's total public water extraction in 2022. Among them, Dynamic Drainage provides the single largest contribution, retaining around 3.5 billion m³ per year, followed by Regenerative Agriculture with around 2.4 billion m³, and Forestry Management with about 1.8 billion m³.

Figure 29: Germany could gain ~ 7.7B m³ water—exceeding 2022 public water extraction—via Regen. Ag., Dynamic Drainage and Forest Mgmt.



Note: Other Landscape-Level Methods are excluded from the visual, given their impact cannot be meaningfully represented via a single quantitative range. Water Use Optimization and Gray Water Reuse are not shown either, since the visual includes only measures that expand overall water availability — the two solutions improve efficiency, but do not add new water

Source: BCG & NABU analysis

These measures stand out not only for their collective scale but also for their favorable cost profile. Regenerative Agriculture can even generate net economic gains through improved soil productivity and reduced input costs. Forest Management, depending on site conditions, management objectives, and approach, can range from virtually cost-free—where natural regeneration occurs—to more capital-intensive, where fencing, planting, and long-term maintenance are required.

Beyond their immediate cost advantages, such green solutions have self-renewing effects: They continuously enhance soil fertility, water retention, and carbon storage, meaning that the value of the initial investment grows over time rather than depreciating. Dynamic Drainage delivers substantial water gains at moderate investment levels, offering one of the most cost-efficient technological upgrades in agricultural water management, though not with the same self-regenerative capacity of ecosystem-based approaches. While it retains substantial amounts of water locally, its benefits depend on active management. Nevertheless, it not only complements but is also a necessary precondition for green solutions to be able to unlock their potential: Their positive impact will remain limited if water continues to be drained from the system. It is therefore a key lever for making landscape hydrology more balanced and resilient.

Sponge Cities, by contrast, demonstrate strong local effectiveness but limited national impact. With an estimated 50 million m³ of additional groundwater recharge per year, their contribution remains small in aggregate due to their limited applicable area. Yet, their co-benefits for urban cooling, air quality, and livability make them a valuable complementary measure in densely populated regions.

At the other end of the spectrum, technological solutions such as desalination and large-scale inter-basin transfers can, in principle, provide unlimited volumes of freshwater, but at significantly higher cost. For example, desalinating 1 billion m³ of water costs roughly €2.5 billion per year at current electricity prices—orders of magnitude higher than most nature-based approaches.

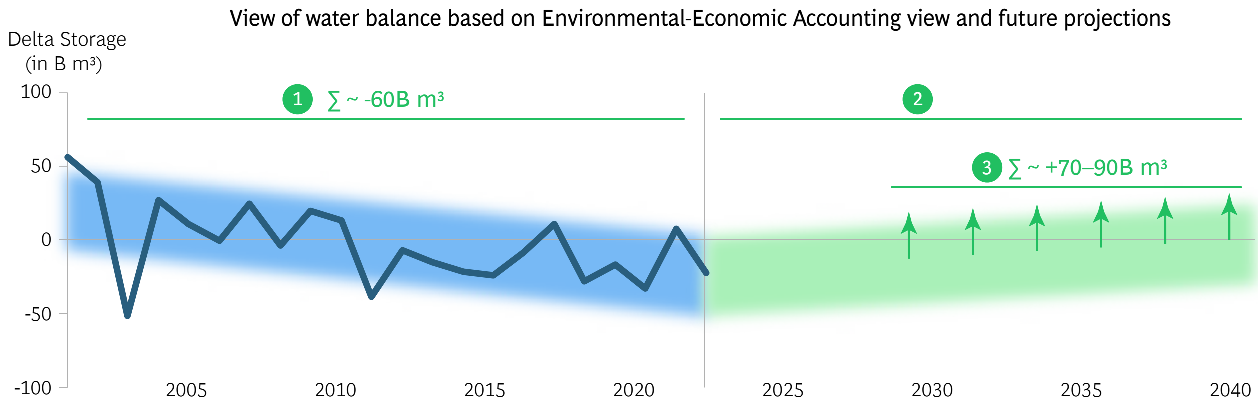
Taken together, the analysis highlights that nature-based and landscape-oriented solutions—particularly Regenerative Agriculture, Dynamic Drainage, and Forest Management—offer the greatest water returns for the lowest relative cost. They strengthen both water security and ecosystem resilience, while technological options, though virtually limitless in output, come with substantial economic and environmental trade-offs.

Closing Germany's Water Storage Gap. Earlier sections of this study showed that Germany's water balance has been in long-term decline. Despite annual fluctuations between wetter and drier years, the cumulative storage trend between 2001 and 2022 has been consistently negative, amounting to a total loss of around 60 billion m³ in stored water. This deficit reflects the combined effects of reduced infiltration, accelerated runoff, and increasing evaporation under a changing climate. The key question is whether targeted measures can reverse this depletion and rebuild storage capacity over time.

The results of this analysis indicate that they can. Assuming slightly changing environmental conditions; for example, marginal increases in precipitation based on a higher average atmosphere temperature and water holding capacity of the air,[409] the combined implementation of Regenerative Agriculture, Forest Management, and Dynamic Drainage could offset the cumulative storage deficit by 2040. If implementation begins within the next 3–5 years, the following 10–12 years would be sufficient to realize the full hydrological benefits. Together, these three measures could add 7 billion–7.5 billion m³ of water annually, wequating to roughly 70 billion–90 billion m³ by 2040—equivalent to at least 1.5 times Lake Constance's volume and enough to fully close the historic storage gap that accumulated between 2001 and 2022 in Germany and contribute to stabilizing its long-term water balance. (See Exhibit 30.)

[409] DVGW (2022): auswirkung-klimawandel-wasserdargebot-zukunft-wasser-factsheet.pdf

Figure 30: Germany could gain ~ 7.7B m³ water—exceeding 2022 public water extraction—via Regen. Ag., Dynamic Drainage and Forestry Mgmt.



1. Despite pronounced year-to-year fluctuations the 2001-2022 **water balance shows a declining trend**: a cumulative s**torage deficit of ~60bn m³**

2. Assuming **environmental** conditions change slightly (e.g., increased precipitation based on higher average atmosphere temperature and water holding capacity of the air¹), the **overall storage deficit is not expected to grow significantly**

3. Full implementation of Regen. Ag., Forest Management, and Dynamic Drainage in 3–5 years, could **yield ~7–7.5 bn m³/year (~70–90 bn m³ total)** in the remaining 10–12 years to 2040, **offsetting the ~60 bn m³ storage deficit**

1. According to DVGW meta-analysis, precipitation is assumed to increase

Source: DVGW, Destatis, BCG & NABU analysis

In practical terms, this would mean that by the early 2040s, Germany could transition from a trajectory of depletion to one of recovery. Accelerating the rollout of these large-scale, nature-based solutions over the coming decade is therefore crucial.

Alleviating the Cost of Inaction. Restoring Germany's water storage capacity through Regenerative Agriculture, Forest Management, and Dynamic Drainage not only addresses physical scarcity but also helps to reduce the economic burden of water stress. As outlined in the chapter "The Cost of Inaction - Doing nothing is the more expensive option", total climate-related water losses were estimated to be at least €500 billion–625 billion between 2025 and 2050, equivalent to at least €20 billion–25 billion in annual economic costs across sectors such as agriculture, industry, households, and municipal services. Importantly, the measures assessed here are not expected to eliminate water-related costs entirely, but to substantially reduce them—particularly the underlying damages and associated costs that sit "Below the surface" of the iceberg—by addressing key drivers of chronic water stress. In doing so, they can in turn also help mitigate the more visible, acute impacts from floods, droughts, and water pollution that appear at the "Tip of the iceberg."

To assess the potential economic relief from targeted action, a set of assumption-based scenarios was modelled based on the following assumptions:

- An investment of roughly **€15 billion–20 billion** is needed for the combined implementation of the three green, nature-based/mixed solutions.

- Between **5% and 20% of the total cost of inaction** can be avoided by 2050.

This corresponds to €25 billion–125 billion in avoided damages, yielding a return on investment of roughly one to eight times the initial outlay.

These estimates are indicative and designed to show the order of magnitude rather than precise prediction. Actual benefits will depend on implementation speed, scope, climatic trends, regional conditions as well as the exact solutions selected. Other large-scale Landscape-Level Methods are not included in the core solution set assessed here; however, they can deliver additional benefits, particularly reducing "Tip of the iceberg" costs e.g., through improved flood protection, moisture-driven drought resilience and the natural filtering function of soils. However, the contrast with technical supply measures such as desalination or large-scale water transfers is stark: While they can, in principle, add unlimited volumes of water, they come at high capital and energy costs, limited ecological value, and no improvement in natural buffering capacity. In contrast, nature-based and mixed solutions strengthen the very systems that regulate water—soils, vegetation, and groundwater—thereby reducing vulnerability, restoring ecosystems, and mitigating the compounding economic impacts of droughts and floods.

In this sense, investing in regenerative, landscape-based water management serves not only as an environmental restoration strategy but also as a financial hedge against climate inaction. By harvesting "low hanging fruits" and positioning the management of water availability as a true priority, these measures can deliver water resilience and economic return, while laying the groundwork for long-term investments into water security.

7. The Implementation Ecosystem—What we need to get right to get it done

7.1 The Reasons for Investing in Water Resilience

A Mixed Outlook. At present, water pricing in Germany remains highly fragmented, varying not only between federal states but also across user groups and sectors.[410] Industrial users often face markedly different fees compared to drinking water providers, while certain sectors even benefit from partial exemptions. In some federal states, water extraction is free of charge for agricultural users and some industries. Such differences in water pricing are common also in other countries and cause agriculture users in particular to benefit from not paying the true cost of water (see also BCG study "Watering Growth").

This patchwork system means that the current Wasserentnahmeentgelt, commonly referred to as Wassercent (See the sidebar "The "Wassercent": Putting a Price on a Vital Resource."), where applied, fails to reflect either the true value or scarcity of water.[411] As a result, it creates little incentive for efficiency, innovation, or reinvestment in water-saving and replenishment measures.

[410] BUND (2025): BUND Bericht: Wasserentnahmeentgelte der Länder (Stand: 06/25)

[411] ZEIT (2025): Wasser: Betriebe zahlen auch in Dürrezeiten kein Grundwasser-Entgelt | DIE ZEIT

The “Wassercent”: Putting a Price on a Vital Resource

The Wasserentnahmeentgelt, commonly referred to as the Wassercent, is the fee levied by most German federal states for extracting groundwater or surface water. It was introduced to implement the polluter-pays principle of the EU Water Framework Directive and to fund measures for water protection, ecosystem restoration, and infrastructure maintenance. Yet, despite its shared legal foundation, the Wassercent remains a patchwork system, marked by significant regional variation and widespread exemptions.

As of 2025, 13 of 16 federal states currently apply a Wassercent, while Bavaria, Hesse, and Thuringia have not yet introduced one or, as in the case in Bavaria, are considering a rollout. The rates for groundwater extraction for drinking water supply generally range between €0.05 and €0.30/m³, depending on the region. Berlin charges the highest with around €0.31/m³, followed by Hamburg, Lower Saxony, and Schleswig-Holstein with roughly €0.15–0.18/m³. In most other states—such as North Rhine-Westphalia, Saxony, or Rhineland-Palatinate—fees for groundwater extraction are between €0.05 and €0.10/m³, and for surface water use typically far lower, often below €0.05/m³. Despite the strained groundwater conditions in Brandenburg, the federal state is among those charging the lowest for groundwater extraction, namely a fee of €0.10-0.11/m³. In some states, charges for cooling water are reduced, while in some states it is equally expensive compared to water for other use cases.

The complexity of these differences is further compounded by broad sectoral exemptions. In nearly all states, agriculture, mining, hydropower, and large parts of industry are either fully or partially exempt from the fee. Only Rhineland-Palatinate has recently begun phasing out blanket exemptions for irrigation and forestry. As a result, such disparities create competitive distortions between neighboring states—for instance, Berlin charges some of the highest extraction costs, while adjacent Saxony and Mecklenburg-Vorpommern levy minimal or no charges at all.

Nationwide, the Wassercent generates around €430 million per year, but the use of these revenues also varies considerably. In some federal states, proceeds flow directly into water management, infrastructure, or conservation programs, while in others, they are absorbed into the general state budget without earmarking.

Environmental organizations argue that the Wassercent’s current design and rate levels are insufficient to drive efficiency or incentivize conservation—especially given the widespread exemptions for heavy users. They call for a harmonized national pricing system that aligns industrial and agricultural use with sustainability goals and channels revenues consistently into ecosystem restoration and water protection. Utility associations such as the VKU also advocate reform but from a different perspective: They emphasize the need to use Wassercent revenues more consistently and transparently to finance investments in water and wastewater infrastructure, securing the resources needed to adapt networks to climate change. Economic stakeholders such as the chambers of industry and commerce (IHK), in turn, criticize the fragmented system for creating competitive distortions between states and uneven cost burdens across sectors, which undermine fair market conditions. Together, these perspectives highlight that a coherent reform of the Wassercent is needed—one that balances ecological incentives, infrastructure investment, and economic fairness within a unified national framework.[412, 413, 414, 415, 416, 417]

Such underpricing may appear advantageous for heavy

[412] IHK (2016): bundeslaendervergleich-wasserentnahmeentgelte-data.pdf
[413] BUND (2025): BUND Bericht: Wasserentnahmeentgelte der Länder (Stand: 06/25)
[414] UBA (2022): Microsoft Word - Tabelle_Wasserentnahmeentgelte_der_Laender_Stand_2022_Endfassung (003).docx
[415] Kommunal (2025): Wassercent in Bayern: Neue Steuer trifft auch Kommunen | KOMMUNAL
[416] VKU (2025): Studie_Investitionen_Wasserwirtschaft: VKU
[417] IHK (2016): bundeslaendervergleich-wasserentnahmeentgelte-data.pdf

water users in the short term, but in the long run it erodes sustainability and economic resilience. When water scarcity intensifies, the costs inevitably ripple through the entire economy. Competition for limited resources drives up allocation and production costs; while households and essential services also feel the effects of higher costs, they take priority for allocation, while industry and business absorb the shortfall. The consequence is higher input costs, lower productivity, and a decline in Germany's attractiveness as an industrial and investment location.[418, 419] In effect, a pricing system designed to keep water cheap today risks making it unaffordable tomorrow—both economically and environmentally.

Turning the Tide. To avoid such a trajectory, reframing water as the strategic resource it truly is, can drive the change in perspective that is needed.[418] The evidence is overwhelming: Investing in Germany's water balance and resilience is important both from an economic as well as an ecological perspective. The implementation of Regenerative Agriculture, Forest Management, and Dynamic Drainage alone could add an amount of water higher than Germany's total public abstraction in 2022 back to the national balance each year.[420]

Beyond their hydrological impact, these measures can deliver significant ecological and economic dividends—improving soil health, biodiversity, and local climate regulation while also strengthening Germany's position as a stable and competitive business location. A secure and predictable water supply underpins industrial productivity, agricultural viability, and societal well-being. Without it, long-term economic growth and quality of life are uncertain.

Encouraging investment in sustainable, nature-based solutions, complemented by targeted technological measures, will therefore be key to expanding the total amount of water available, while simultaneously optimizing existing use. This dual approach not only safeguards ecosystems but also fortifies the foundations of the German economy, ensuring that people, nature, and industry can continue to thrive together.

This priority aligns closely with the EU Water Resilience Strategy,[421] which stresses that strategic investment in water resilience is needed to maintain Europe's long-term competitiveness and security. The strategy highlights that targeted funding in both nature-based and technological solutions—from ecosystem restoration and soil management to efficient water systems and innovation—offers the highest returns for strengthening resilience. It underscores that investing in water is investing in the economy, as healthy water systems underpin productivity, supply security, and sustainable growth.

[418] BDI (2024): Artikel
[419] IHK (2016): bundeslaendervergleich-wasserentnahmeentgelte-data.pdf
[420] UBA (2025): Wasserressourcen und ihre Nutzung | Umweltbundesamt
[421] European Commission (2025): eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52025DC0280

7.2 The Power of Shared Responsibility and Collaboration

A Multi-Stakeholder Approach. Achieving water resilience cannot be the responsibility of a single actor. No sector can carry the weight alone. Germany's water security depends on the collective engagement of public institutions, private companies, land managers, and citizens alike. While water utilities form the operational backbone of the system, they cannot by themselves shoulder the growing pressures of drought, pollution, and infrastructural renewal. Ensuring long-term water resilience builds on a joint effort that integrates all stakeholders—from agriculture and forestry to industry, municipalities, and research.

Both the EU Water Resilience Strategy[421] and Germany's National Water Strategy[422] strongly emphasize this collaborative approach. The EU framework calls for a "whole of society" response, mobilizing actors across policy areas and sectors, and encouraging partnerships between governments, business, and civil society to drive investment and the implementation of water resilience measures. Similarly, Germany's National Water Strategy underscores the need for joint action by federal, state, and municipal authorities, coordinated with agriculture, industry, and citizens, to lay the foundation for sustainable water use and secure supply nationwide.

In practice, this means that all actors play an important part:

- **Public authorities** provide the legal frameworks, incentives, and infrastructure investment.
- **Businesses and industry** integrate water efficiency and reuse into their operations.
- **Farmers and landowners** contribute through regenerative practices that restore small water cycles.
- **Citizens** participate through responsible consumption and awareness.

Water is both an economic input and a shared public good. Its resilience depends on shared responsibility. Only by aligning public and private action can Germany build the collective capacity needed to safeguard its ecosystems, economy, and society against future water crises.

[422] BMUV (2023): BMUKN: Nationale Wasserstrategie | Publikation

7.3 Building Financing and Enabling Mechanisms

Financing the Transition. The evidence is clear: Investing in water resilience is no longer optional. Yet while the need is evident, the key question remains how to finance this transition. Building a water-secure Germany calls for substantial and sustained investment—far beyond what utilities or local authorities can shoulder alone. To make this shift, existing financial instruments merit re-evaluation, supported by the introduction of new incentives, and the mobilization of both public and private capital. What matters now is creating the right mix of funding, incentives, and partnerships to translate ambition into implementation.

7.3.1 Building on Existing Financial Resources

Mobilizing Existing Resources. The implementation of Germany's National Water Strategy is intended to rely on a mix of financial instruments, primarily by leveraging existing funding vehicles and programs to support the rollout of the measures defined in the strategy.[423] One potential funding source is the federal budget. The federal budget for 2026, allocates resources to water-related areas such as waterways, water infrastructure, flood protection, and to climate-adaptation measures that also influence water management and water availability and are financed across several ministries, for example the Federal Ministry for Agriculture, Food and Regional Identity (BMLEH) or the Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMUKN).[424, 425] Yet, in the overall context and volume of the total federal budget, these expenditures represent only a small fraction of total ministerial investments, underlining that water resilience is not yet a central budgetary focus.[426] Another major funding vehicle is the federal Infrastruktur-Sondervermögen, with a total volume of €500 billion.[427] Of this, €300 billion are allocated to the federal government, €100 billion to the states and municipalities, and the remaining €100 billion to the Klima- und Transformationsfonds (KTF). The funds assigned to the federal government and the states/municipalities are largely dedicated to investments in transport infrastructure, buildings, energy efficiency, digitalization, and healthcare infrastructure, while the KTF focuses on the energy transition, climate neutrality, and transformation measures. In the 2026 budget, the climate-protection tasks that were newly transferred to the BMUKN and BMLEH are now financed mainly through the KTF.[428, 429] While some of these investments include water-related and ecosystem-based solutions, the majority of KTF funding remains concentrated on energy efficiency and mobility. Although these priorities play an important role for Germany's modernization and decarbonization efforts, water infrastructure, ecosystem restoration, and climate adaptation measures have yet to be established as more central funding priorities within this framework.

However, calls to reconsider this allocation are growing louder, particularly from within the water utility sector itself. The Verband Kommunaler Unternehmen (VKU),[430] representing municipal utilities, has warned that Germany's drinking water and wastewater infrastructure requires billions in additional investment to remain resilient under increasing climatic and demographic pressure. The VKU estimates a funding need of around €40 billion annually instead of the current annual investments of roughly €10 billion for infrastructure modernization, renewal, and adaptation to droughts and extreme rainfall events, amounting to a total investment need of €800 billion in the next 20 years. Of the total investment need, roughly 10–15% are assumed to be required for climate-change adaptation, amounting to roughly €80 billion–120 billion over the next two decades. Not only the VKU, but other associations[431] such as the Allianz der öffentlichen Wasserwirtschaft e.V. (AöW)[432] or Bauindustrie[433] have therefore urged that a portion of the Infrastruktur-Sondervermögen be earmarked specifically for upgrading and climate-proofing water networks and waterways.

Yet, while water infrastructure investment is undeniably important, building water resilience reaches beyond pipelines and treatment plants. As demonstrated by the solutions developed in this study—for example Regenerative Agriculture, Forest Management, and Dynamic Drainage—the stability of Germany's water balance also depends on actions in agriculture, forestry, and urban planning. Increasing the share of the Sondervermögen that is allocated to such measures could bridge existing financing gaps and catalyze a systemic shift toward integrated water management, combining technological infrastructure with landscape restoration and ecosystem services.

This approach is fully in line with the EU Water Resilience Strategy, which highlights that current annual water investments across the EU fall short and calls on Member States to reorient existing budgets to close the gap.[434] The European Commission explicitly encourages Member States to prioritize water resilience within their investment frameworks, linking it to competitiveness, security of supply, and environmental protection.

Reallocating part of Germany's existing infrastructure funding toward water-related projects would not create a new financial burden—it would future-proof the investments already planned. By embedding water resilience

[423] BMUV: BMUKN: Nationale Wasserstrategie | Publikation
[424] Bundeshaushalt (2025): Haushaltsplan 2026 - Einzelplan
[425] Bundeshaushalt (2025): https://www.bundeshaushalt.de/static/daten/2026/soll/draft/epl16.pdf
[426] Bundesrechnungshof (2025): Information über die Entwicklung des Einzelplans 16 (Bundesministerium für Umwelt, Klimaschutz, Naturschutz und nukleare Sicherheit) für die Beratungen zum Bundeshaushalt 2026
[427] BMF (2025): Bundesfinanzministerium - Sondervermögen für Infrastruktur und Klimaneutralität
[428] Bundesrechnungshof (2025): Information über die Entwicklung des Einzelplans 16 (Bundesministerium für Umwelt, Klimaschutz, Naturschutz und nukleare Sicherheit) für die Beratungen zum Bundeshaushalt 2026
[429] Bundesrechnungshof (2025): Beratungen zum Entwurf des Wirtschaftsplans 2026 des Klima- und Transformationsfonds, Kapitel 6092
[430] VKU (2025): https://www.vku.de/studie-investitionen-wasserwirtschaft/
[431] Handelsblatt (2025): Klimawandel: Wasserwirtschaft fordert Geld aus dem Sondervermögen
[432] AöW e.V. (2025): AoeW_Position_Sondervermoegen-Infrastruktur_06-03-2025-final.pdf
[433] Bauindustrie (2025): Wasserstraße: Auch sicherheitskritischen Bauprojekten droht Stopp durch Unterfinanzierung - Bauindustrie
[434] European Commission (2025): eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52025DC0280

into the country's broader infrastructure and transformation agenda more fundamentally, Germany can ensure that its roads, grids, and industries remain functional and competitive even under growing climatic stress. At the same time, it would elevate landscape restoration and ecosystem services from peripheral considerations to central pillars of national investment—transforming an environmental necessity into a foundation for long-term economic stability.

7.3.2 Creating New Incentives

Beyond Existing Funding Mechanisms. While reallocating existing public funds is an important first step, it alone will not be sufficient to finance Germany's transition to water resilience. Complementary financing and investment models as well as incentive structures are needed to mobilize additional capital, including from the private sector. Public resources can lay the foundation, but long-term transformation depends on mechanisms that make water stewardship economically meaningful and reward those who invest in it. Encouraging such innovation merits the use of financial instruments and market-based incentives that assign tangible value to water as a shared resource. Developing these approaches can broaden the financial base for action, foster collaboration across sectors, and support that investment in water security becomes a sustained, collective effort rather than a one-off public initiative.

The Investment Dilemma. Despite its central role in economic stability and social well-being, water is not an obvious investment case. Traditional infrastructure projects such as desalination plants, pipelines, or wastewater treatment systems tend to attract investors because they generate direct, measurable returns through tariffs or service fees. In contrast, nature-based solutions, like Regenerative Agriculture, forest management, or soil restoration, produce primarily diffuse, long-term public benefits that are harder to monetize. They strengthen the water cycle, reduce climate risks, and secure future supply, but their payoffs are distributed across ecosystems, sectors, and time.

This imbalance is reinforced by the low cost of water extraction in Germany. When the marginal cost of using or abstracting water is lower than the cost of restoring or retaining it, there is little financial incentive to invest in replenishment or retention measures. As a result, capital tends to flow toward optimization and efficiency improvements—such as leakage reduction, reuse, or metering—rather than toward solutions that expand total water availability. While optimization is vital, it does not address the core quantity challenge: ensuring that more water enters and stays in the system.

In this context, green water investments struggle to compete with gray infrastructure, even though they can deliver greater systemic resilience per euro spent. Their benefits rarely appear on balance sheets or yield immediate revenue. Consequently, the measures that are important for long-term water security often remain underfinanced, not because they lack value but because that value is diffuse, indirect, and poorly reflected in current economic metrics. This imbalance needs to change. A growing body of scientific evidence—featured in our study and reinforced by the findings of our own analysis—shows that nature-based and regenerative approaches provide measurable, long-term returns in resilience, climate stability, and resource security that far exceed their initial cost. Recognizing and integrating these benefits into investment and policy frameworks is key to ensuring true water security.

The Disconnect Between Creators and Users. Financing water resilience is further complicated by a mismatch between those who create water security and those who benefit from it. In Germany, farmers, forest owners, and land managers are the primary implementers of green solutions that enhance infiltration, retention, and groundwater recharge. Through regenerative practices, reforestation, or floodplain restoration, they strengthen the water cycle and provide benefits that extend well beyond their own land—helping municipalities, industries, and households downstream.

However, these "creators of water resilience" rarely receive adequate recognition or compensation for the public value they generate. Their efforts produce collective and delayed benefits that are difficult to capture in conventional economic systems. Meanwhile, the main users and beneficiaries—industries, utilities, and households—primarily operate on the abstraction and consumption side of the water cycle. For them, the connection between upstream ecosystem management and supply reliability often remains indirect or time-lagged: By the time scarcity becomes tangible, the opportunity for preventive investment has often been missed.

This asymmetry results in uneven financial responsibility: Those who can most efficiently restore water availability lack incentives to do so, while those who depend on these ecosystem services are not required—or encouraged—to cofinance them. The result is a disconnect between creators and users, both spatially and temporally. To close this gap, the priority will be to shift this perspective. Recognizing the shared value chain of water is the foundation to build fair, coordinated investment mechanisms and ensure that all actors contribute to maintaining the balance of the water cycle.

The Mindset Shift. Closing the gap between creators and users of water resilience will require more than new financing instruments: a system wide shift in mindset. Reframing water as a shared system of interdependence—rather than an isolated input or private commodity—opens new pathways for action. Every actor—whether a farmer retaining rainwater in the soil, a company cooling its machinery, or a municipality maintaining drainage infrastructure—contributes to and depends on the same hydrological cycle. Investments made in one part of that system can create value for many others. Recognizing this mutual dependency is the first step toward a more balanced and cooperative approach to financing water security.

Seeing water investments through a broader lens is important. An agricultural measure that improves infiltration may not yield a direct return for the farmer, but it reduces flood risks for communities downstream and stabilizes water availability for industries and households. Similarly, corporate or municipal investments in reforestation or retention landscapes may not translate into immediate profit, but they alleviate the pressure on central infrastructure and safeguard long-term access to water—a result of increasing importance in a changing climate. When water is not just viewed as a cost factor but as a strategic asset, the investment logic starts to align with the true value of water.

To enable this mindset shift, financial and policy nudges can make the shared value of water more visible. Instruments such as stormwater fees (Niederschlagswassergebühr[435]), tax incentives, or preferential financing rates and subsidies for water-positive (co)investments[436] can reward those who contribute to system-wide resilience. Likewise, corporate accounting frameworks that recognize water risk and water stewardship as material factors can help shift investment behavior. Ultimately, the goal is to foster a cross-sector financing culture—one where public and private actors jointly invest in the natural and technological systems that sustain Germany's water balance.

Credit Systems: Monetizing Environmental Stewardship. Over the past two decades, credit systems have become influential market-based tools to align economic activity with environmental goals. By assigning measurable value to ecological improvements or avoided damage, they internalize the costs of degradation and reward restoration. The best-known example is the carbon credit system, which caps total emissions and allows companies to trade allowances, embedding the cost of pollution into business models and mobilizing investment toward decarbonization.[437] The same logic now extends to biodiversity and nature credits, which quantify ecological gains such as habitat restoration or improved species diversity. Verified credits can be traded in either compliance or voluntary markets, as demonstrated by pilots like the UK's biodiversity net-gain schemes[438] or Germany's Ökokonto[439] models.

The Credit System for Water. Applying this principle to water is the next logical step. Water credits—or, as described in the EU Water Resilience Strategy,[440] "nature credits"—aim to quantify and monetize measurable improvements in water availability, quality, or efficiency. They create financial value for actions that save, recharge, or purify water, turning sustainable management into an investable outcome. Farmers, municipalities, and industries could generate credits through certified projects that retain or restore water, while others could purchase them to offset consumption or meet regulatory obligations.

The EU Water Resilience Strategy explicitly outlines the Roadmap for Nature Credits to scale such mechanisms and mobilize private investment in water resilience and ecosystem restoration. Although still in its infancy, practical models already demonstrate how this concept could work. In the United States, the EPA's Water Quality Trading Program[441] allows facilities to meet discharge limits by purchasing credits from others who reduce nutrient pollution more cost-effectively. Arizona's Groundwater Banking[442, 443] system enables users to store surplus water in aquifers and later withdraw or trade it during dry periods. In Africa, the Green Water Credits Initiative[444] compensates farmers for soil and land management practices that increase infiltration and reduce erosion, rewarding actions that sustain local water cycles and downstream availability. A similar model is now emerging in Europe: In the United Kingdom, the Wildfarmed Water Premium[445] brings together public and private actors to share the costs of water protection. By co-funding regenerative farmers who reduce runoff and pesticide use in drinking-water catchments, water companies lower the need for expensive downstream treatment, while farmers receive stable income streams for ecosystem services that benefit society at large. This cost-sharing approach reflects a broader shift—away from paying solely for water extraction and treatment, toward jointly investing in the living systems that keep water clean in the first place. Together, these examples show how financial incentives can translate stewardship into measurable outcomes and highlight the potential of water credits as a bridge between ecological and economic value creation.

The Local Nature of Water Credits: Valuing a Resource That Defies Uniform Markets. Unlike carbon, which mixes evenly in the atmosphere and has a global effect regardless of where emissions come from, water is inherently local. Its value, scarcity, and impact depend on geography, seasonality, and hydrological context. A cubic meter of water saved in one region cannot alleviate scarcity in another, nor can clean water restored upstream automatically offset pollution downstream. This spatial and temporal variability makes water credits uniquely complex to design and trade.

Effective systems therefore operate at the catchment or subbasin level, not within a uniform global market. The timing of availability is as important as its volume: An additional cubic meter captured during winter floods does not have the same value as one retained during a summer drought. Likewise, the economic and ecological value of water differs sharply between regions: Where abundant rainfall offers limited marginal benefit, scarcity dramatically increases the impact of each unit saved. Seasonal and annual variability add further complexity, as the same intervention can yield different outcomes depending on rainfall, temperature, and demand.

[435] Berliner Wasserbetriebe: Gebühren - Berliner Wasserbetriebe
[436] IBB: GründachPLUS – Berlins Förderung für mehr Dachbegrünung - IBB Business Team GmbH
[437] European Commission: About the EU ETS - Climate Action - European Commission
[438] Gov UK (2025): Understanding biodiversity net gain - GOV.UK
[439] Hochschule für Wirtschaft und Umwelt: FAQ – Ökokonto
[440] European Commission (2025): eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52025DC0280
[441] EPA (2025): Water Quality Trading | US EPA
[442] Arizona Water Banking Authority: Home | Arizona Water Banking Authority
[443] CAP: Water Bank Recovery - Central Arizona Project
[444] ISRIC: Green Water Credits (GWC)
[445] Agronomists & Arable Farmers (2024): Water company premiums for Wildfarmed wheat | News from AA Farmer

Opportunities and Limitations. Properly designed, water credits could create financial incentives for sustainable water use and unlock private investment in retention, recharge, and pollution reduction measures. They could complement public funds, improve data transparency, and offer new income opportunities for farmers, landowners, and other actors implementing water-benefit projects. By monetizing measurable improvements in water availability and quality, water credits can help turn stewardship from a public obligation into an economic opportunity.

Yet, water's local and variable nature makes such systems complex to design and verify. Regional differences in hydrology and scarcity, challenges in quantifying benefits, and risks of excessive bureaucracy all pose significant hurdles. Equity concerns may also arise, as larger players typically have greater capacity to participate than smaller ones. Finally, a moral hazard exists if companies simply buy credits instead of reducing their own water use, undermining behavioral change.

Despite these challenges, water credits could serve as a complementary tool if existing instruments fail to mobilize action at scale, ultimately necessary to trigger the investment and cooperation required for long-term resilience.

Applying a Water Credit System in Germany. A German water credit system could become a practical mechanism to channel investment into actions that strengthen the country's hydrological balance. Its initial focus would likely be on water availability—rewarding measures that enhance retention, infiltration, and groundwater recharge—while leaving room for later expansion into credits linked to water quality and efficiency improvements. By assigning tangible value to these activities, the system could mobilize funding for green and hybrid solutions that complement traditional infrastructure and help close existing investment gaps.

Given Germany's federal structure and established water governance, such a system would most effectively start as a voluntary instrument. Participation could extend across sectors—agriculture, forestry, industry, utilities, and municipalities—allowing stakeholders to invest directly in water-positive projects or cofinance measures where benefits are shared. Rather than replacing existing regulation, the mechanism would create additional incentives for stewardship, enabling both public and private actors to contribute visibly to national water resilience.

To ensure feasibility, a practice-based approach would be the most pragmatic starting point. Linking credits directly to verified practices—such as cover cropping, agroforestry & reforestation, soil decompaction, or wetland restoration—would minimize administrative effort while ensuring that certified activities deliver measurable hydrological benefits. Although an outcome-based model would be preferable in the long term, it would require extensive monitoring and data collection. Selected indicators, such as vegetation cover or evapotranspiration, could eventually be tracked through satellite-based methods (such as NDVI), but most effects would remain difficult to quantify consistently across regions.

Ensuring comparability and credibility across catchments will be central to the system's integrity. Credit valuation should be grounded in regional hydrological modelling that reflects local water stress, soil and groundwater conditions, and seasonal variation. A standardized weighting factor could then normalize credits beyond individual catchments, incorporating both the hydrological importance and scarcity value of each intervention. In this way, a cubic meter of water retained in drought-prone Brandenburg would be appropriately weighted against one in wetter Schleswig-Holstein—creating a transparent and equitable market framework across Germany.

7.4 Toward a Water-Resilient Germany

Taken together, the measures outlined in this study—spanning Regenerative Agriculture, Forest Management, Dynamic Drainage, and complementary technological innovations—form a roadmap for restoring Germany's water balance. The evidence is clear: Investing in water resilience is not only attractive from an environmental but also from an economic perspective, safeguarding competitiveness, livelihoods, and long-term stability. Achieving this transformation, however, calls for coordinated effort across all levels of government, industry, and society.

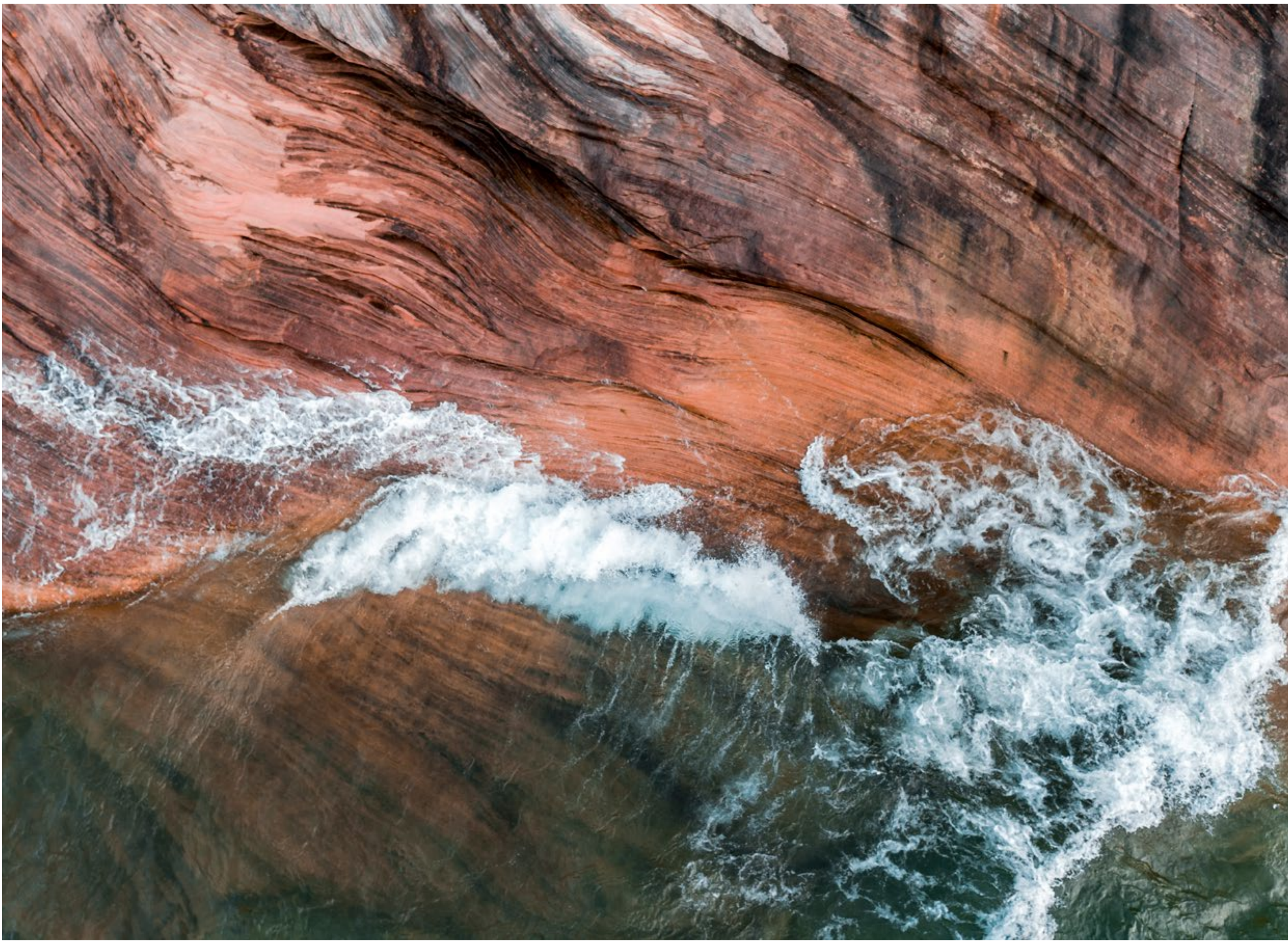
Building on the foundations of Germany's National Water Strategy, this effort is meant to bring together the country's key water actors: the government, municipal utilities, industry associations, farmers and forest owners, research institutions, and the financial sector—with the shared vision to align policy, funding, and innovation to make water security via availability a pillar of economic strategy and climate adaptation.

If implemented soon and in collaboration, these measures can transform Germany's water challenges into an opportunity—to secure the country's hydrological future, strengthen its natural capital, and thus build a resilient economic foundation.

8. Glossary

Term	Definition
Aquifer	A subsurface layer of permeable rock or sediment that stores and transmits groundwater. It serves as a natural reservoir that sustains rivers, wetlands, and drinking-water supply
Biotic Pump	Describes how forests and vegetation generate pressure gradients through evapotranspira-tion, drawing moist air inland and thus sustaining continental rainfall
Blue Water	Liquid freshwater from surface or groundwater sources, such as rivers, lakes, reservoirs and aquifers that can be directly abstracted for irrigation, domestic, or industrial use
Carbon Sponge (Soil Carbon Sponge)	The porous, rich structure of healthy soil that stores water and car-bon, linking both cycles by enhancing infiltration, evapotranspiration, cloud formation, and climate cooling while supporting plant growth
Catchment (River Basin)	An area where all precipitation drains to and is collected in a shared outlet such as a river or sea—the fundamental spatial unit for integrated water management
Compaction	The compression of soil particles that reduces pore space, infiltration, and water retention, weakening the soil's sponge function, increasing runoff, and limiting plant growth, as well as groundwater recharge
Cost of Inaction	The cumulative social, economic, and ecological losses from not addressing water stress, including both visible and hidden, chronic impacts as well as direct and indirect costs
Environmental–Econom-ic Accounting (EEA)	A framework linking water, economy, and environment by integrating natural and human water system components, tracking abstraction, use, return, and storage for a comprehen-sive national water balance
Evapotranspiration (ET)	The combined transfer of water from land to atmosphere through evaporation and plant transpiration, driving local cooling and rainfall formation
Green Water	Water and moisture from precipitation that is stored in soil and vegetation that is evaporated, transpired, or used directly by forests, plants, or livestock

Term	Definition
Gray Water	Water that has been used in households and carries impurities (from showers, sinks, and laundry, excl. toilets) but can be treated and reused
Groundwater Exploitation Index	Measures the ratio of groundwater abstraction to its long-term recharge—values above 0.2 indicate structural overuse and risk of aquifer depletion
Groundwater Recharge	The infiltration of water from the surface through soil and rock into aquifers, replenishing underground storage and ensuring long-term supply stability
Hydrological Balance (Water Balance)	Accounting of natural water inflows, outflows, and storage changes (excl. human influence); covering precipitation, evapotranspiration, and runoff; showing if a system is gaining or losing water over time
Infiltration	The downward movement of water through soil into deeper soil layers, with high infiltration rates preventing runoff, enhancing groundwater recharge, and reducing erosion
Land–Atmosphere Coupling	Interaction between soil moisture, vegetation, and climate, where changes in land cover influence temperature, humidity, and precipitation
Local (Small) Water Cycles	A self-contained loop of evaporation, condensation, and rainfall that transports water from land via the atmosphere back to land surfaces, with healthy small cycles sustaining local rainfall and buffering drought
Marginal Cost of Water Availability (MaCoWA) Curve	An analytical tool showing the relationship between water management solutions' ability to create/retain additional water and required investment cost, helping to compare their cost-effectiveness
Runoff	The portion of precipitation flowing over land surfaces instead of infiltrating soil, often intensified by sealing or compaction and contributing to floods and erosion
Soil Sealing	Covering soil with impermeable materials such as asphalt or concrete, which blocks infiltration, increases runoff, and disrupts water and carbon cycles
Sponge Landscape	A land system—natural or engineered—that absorbs, stores, and slowly releases water, reducing flood peaks and replenishing groundwater
Surface Water	All water visible above ground, including oceans, rivers, lakes, and wetlands, forming the most accessible component of blue-water resources
Water Exploitation Index (WEI+)	An indicator measuring total water consumption (difference between abstraction and returns) as a share of renewable water resources, with values above 20% signaling water scarcity and unsustainable use
Water Risk Matrix	A BCG framework assessing water challenges across three dimensions—quantity, quality, and accessibility—and their environmental, economic, and social impacts
Water Stress Index (WSI)	Represents the ratio of total water demand to available water supply, with levels above 40% indicating high competition among users and scarcity risk
Water Use Index (WNI)	Compares total annual water withdrawals to renewable water resources at the national level, providing an aggregate measure of use intensity, with levels above 20% indicating water stress
Wassercent (Water Extraction Fee)	A levy applied by most German federal states on surface and groundwater abstraction to reflect environmental costs and fund water protection



9. Appendix

Appendix Table 1 – Tip of the Iceberg

Assumptions/Estimates	Source
Floods	
Frequency Data Points	
Floods of the type "July 2021" will become 1.2–9.0× more frequent:	GWS (2022): Schäden der Sturzfluten und Überschwem-mungen im Juli 2021 in Deutschland
• Today such floods occur every 400 years • With climate change, floods will occur every ~330 years (1.2×) to ~45 years (9×)	Kreienkamp et al. (2023): Attribution of the heavy rainfall events leading to severe flooding in Western Europe during July 2021 | Climatic Change

Assumptions/Estimates	Source
Damage Data Points	
~€1.5B average annual gross value added (GVA) loss from floods: • GVA loss estimates from floods in 2025 is ~€730M and in 2029 is ~€2.3B • Future average annual loss will remain constant at average GVA loss from 2025 and 2029	Usman et al. (2025): Dry-roasted NUTS: early estimates of the regional impact of 2025 extreme weather by Sehrish Usman, Miles Parker, Mathilde Vallat :: SSRN
~€2B average annual insurance claims expenditure for floods: • 2002–2024 average annual insurance claims for property insurance: natural hazards amount to ~€2B (excl. car insurance, as it is assumed that most of the damage in this category comes from storms and hail and not from floods) (converted from the 2023 to 2024 level) • Future average annual insurance claims expenditure will remain constant at 2002–2024 average	GDV (2025): Langzeitbilanz: Schäden durch Naturgefahren in Deutschland GDV (2024): naturgefahrenreport-2024-datenservice-download-data.pdf Use of Verbraucherpreisindex: Deutschland, Jahre to convert total insurance claim data into '24 price levels using 1 (VPI 2024/2023)
~€4.3B average annual insurance claims expenditure for floods: • Analysis of 2002–2024 claims for property insurance reveals a five-year moving average CAGR of ~3% • Applying this CAGR to the 2002–2024 average annual claims for property insurance of ~€2B leads to ~€4.3B in 2050 • Future average annual claims will stay constant at ~€4.3B	GDV (2025): Langzeitbilanz: Schäden durch Naturgefahren in Deutschland GDV (2024): naturgefahrenreport-2024-datenservice-download-data.pdf
~€6B average annual damage from floods: • In 2002–2024, the average annual insurance claims for property insurance were ~€2B • Total damage is ~3.0× higher than insurance claims expenditure • Future average annual claims will remain constant at ~€6B	GDV (2025): Langzeitbilanz: Schäden durch Naturgefahren in Deutschland GDV (2024): naturgefahrenreport-2024-datenservice-download-data.pdf GWS (2022): Übersicht vergangener Extremwetterschäden in Deutschland

Assumptions/Estimates	Source
~€13B average annual damage from floods: • Future average annual expenditure claims will be equal to ~€4.3B • Total damage is ~3.0× higher than the insurance claims expenditure • Future average annual claims will remain constant at ~€13B	GDV (2025): Langzeitbilanz: Schäden durch Naturgefahren in Deutschland GDV (2024): naturgefahrenreport-2024-datenservice-download-data.pdf GWS (2022): Übersicht vergangener Extremwetterschäden in Deutschland
~€3.7B average annual damage from floods: • In 2000–2021, total damage from floods and torrential rains amounted to €82.5B (converted from 2021 to 2024 level) • Total damage is distributed equally across 22 years and will remain constant	GWS (2022): Übersicht vergangener Extremwetterschäden in Deutschland Use of Verbraucherpreisindex: Deutschland, Jahre to convert total damage costs into '24 price levels using factor 1.16 (VPI 2024/2021)
Average Expected Annual Flood Damage	
~€6B average expected annual flood damage across Germany: • Data derived from long-term historical time series—such as insurance claims (~€2B, ~€4.3B, ~€6B, and ~€13B) and comprehensive extreme-weather event analyses (~€3.7B) including direct and indirect costs—are considered to have higher reliability and are thus used to arrive at the average expected annual flood damage	BCG & NABU analysis (2025)
Drought & Heat	
Frequency Data Points	
Two-year droughts will become 7× more frequent, assuming the RCP 8.5 climate scenario: • Two-year droughts occurred every ~78 years between 1850 and 2005 • Two-year droughts will occur every ~11 years between 2051 and 2100	Hari et al. (2020): Increased future occurrences of the exceptional 2018–2019 Central European drought under global warming | Scientific Reports
Droughts of the type "Summer 2022" will become 5× more frequent: • They occurred every 100 years in preindustrial times • They will occur every 20 years in the current climate	Schumacher et al. (2024): ESD - Detecting the human fingerprint in the summer 2022 western–central European soil drought

Assumptions/Estimates	Source
Depending on temperature rise, drought frequency will increase by 2.0–4.1× • In the pre-1990s, droughts occurred every 10 years • If temperatures increase by 1.5°C, droughts will occur every ~5 years • If temperatures increase by 4°C, droughts will occur every ~2.5 years	UBA (2022): Dürre als Folge des Klimawandels | Umweltbundesamt
Damage Data Points	
~€150M average annual gross value added (GVA) loss from drought: • GVA loss estimate from drought in 2025 is ~€80M and in 2029 is ~€220M • Future average annual loss will remain constant at an average GVA loss from 2025 and 2029	Usman et al. (2025): Dry-roasted NUTS: early estimates of the regional impact of 2025 extreme weather by Sehrish Usman, Miles Parker, Mathilde Vallat :: SSRN
~€2B average annual damage from heat and drought: • In 2000–2021, the total damage from heat and droughts amounted to €48.3B (converted from the 2021 to 2024 level) • Total damage is distributed equally across 22 years and will remain constant	GWS (2022): Übersicht vergangener Extremwetterschäden in Deutschland Use of Verbraucherpreisindex: Deutschland, Jahre to convert total damage costs into '24 price levels using factor 1.16 (VPI 2024/2021)
Frequency x Damage Data Points	
~€2B average annual loss from drought: • If 2-year droughts occurred every ~78 years in 1850–2005 and will occur every ~11 years in 2051–2100; then, under a linear trend, they should occur ~4× more often, so every ~19 years in 2006–2050 • The cost of the 2018/19 drought amounted to ~€40.5B (converted from the 2021 to 2024 level) and is considered representative of damage magnitude of a 2-year drought	Hari et al. (2020): Increased future occurrences of the exceptional 2018–2019 Central European drought under global warming | Scientific Reports GWS (2022): Schäden der Dürre- und Hitzeextreme 2018 und 2019 Use of Verbraucherpreisindex: Deutschland, Jahre to convert convert total damage costs into '24 price levels using factor 1.16 (VPI 2024/2021)
~€1B/€2B average annual loss from drought depending on climate scenario: • Droughts will occur every ~5 years for +1.5°C and every ~2.5 years for +2°C scenarios • A 10-year drought will cause ~€5B (converted from the 2021 to 2024 level) in damage—equal to the average damage cost of a drought in 2000–2021	UBA (2022): Dürre als Folge des Klimawandels | Umweltbundesamt GWS (2022): Übersicht vergangener Extremwetterschäden in Deutschland Use of Verbraucherpreisindex: Deutschland, Jahre to convert total damage costs into '24 price levels using factor 1.16 (VPI 2024/2021)

Assumptions/Estimates	Source
Average Expected Annual Drought Damage	
At least ~€3B average expected annual drought damage across Germany: • The 2018/2019 drought (~€2B) and the drought occurrences in 2000–2021 (~€2B) have been extensively analyzed. Therefore, these figures provide a robust empirical basis for estimating long-term impacts and are thus used to arrive at the average expected annual drought damage • Given health-related costs are typically excluded from these estimates, it is assumed that at least an additional ~€1B needs to be added for hospitalization, treatment, and long-term effects such as mortality and reduced quality of life	GWS (2022): GWS Research Report 2022#02 Volkswirtschaftliche Folgekosten durch Klimawandel GWS (2022): Schäden der Dürre- und Hitzeextreme 2018 und 2019 GWS (2022): Übersicht vergangener Extremwetterschäden in Deutschland BCG & NABU analysis (2025)
Water Pollution	
Water ecosystem	
€580M–767M annual cost for removal of nitrate from drinking water: Reaching a nitrate level of 37.5 mg/l costs €580M–684M per year Reaching a nitrate level of 25 mg/l costs €615M–725M per year Reaching a nitrate level of 10 mg/l costs €651M–767M per year	UBA (2017): Factsheet Nitratkosten
>€800M annual cost for removal of existing PFAS from environment: • Includes only PFAS that are already in the environment, not exclusively referring to PFAS in water	Tagesschau (2025): Drohende Milliarden-Kosten wegen PFAS-Verschmutzung | tagesschau.de
>€17B annual cost for removal of existing and new PFAS from environment: • Includes PFAS that are already in and will enter the environment, not exclusively referring to PFAS in water	Tagesschau (2025): Drohende Milliarden-Kosten wegen PFAS-Verschmutzung | tagesschau.de
~€900M annual cost for water restoration in Germany: • Teltow-Fläming water restoration costs ~€150M over 30 years, (~€5M per year for an area of ~2,000 km^2) • Assuming Teltow-Fläming has water conditions and composition representative of all of Germany: ~€5M extrapolated to German area (357,000 km^2) is ~€900M annually	MAZ (2019): Kreistag für Machbarkeitsstudie zur Sanierung der Seen und Flüsse in Teltow-Fläming - Entschlammung des Rangsdorfer See möglich Landkreis Teltow-Fläming: Geschichte - Landkreis Teltow-Fläming BMLEH (2023): BMEL-Statistik: Bodennutzung in Deutschland

Assumptions/Estimates	Source
Infrastructure	
~€750 annual operating and maintenance costs for 4th water filtration level OPEX after full rollout of 4th water filtration level in 2046 are ~€550M Maintenance after 2046 will cost as much as the average CAPEX in 2026–2045, amounting to ~€200M per year	VKU (2024): Erweiterte Herstellerverantwortung und Kosten der Viertbehandlung
~€2.5B average annual investment for operating and maintenance of WRRL • Between 2010 and 2027 ~€61.5B will be invested in the implementation of the WRRL (Wasserrahmenrichtlinie): • Operating and maintenance costs are ~4% of total investment costs	LAWA Expertenkreis (2021): lawa.de/documents/abschlussbericht-kosten-umsetzung-eg-wrrl-barrierefrei_1689845137.pdf CCWP (2018): Appendix F - CCCWP GI Cost Estimation Method
~€14.7B average annual investment in water infrastructure: • Investment of €284B in drinking water supply infrastructure, lifetime ~60 years, leading to ~€4.7B per year • Investment of €256B in wastewater infrastructure, lifetime ~80 years, leading to ~€3.2B per year • Investment of €102B in wastewater treatment, lifetime ~35 years, leading to ~€2.9B per year • Investment of €154B in stormwater overflow system, lifetime ~40 years, leading to ~€3.9B per year	VKU (2025): Studie_Investitionen_Wasserwirtschaft: VKU
Penalties	
~€370M annual EU penalties in case of nitrate level violations: • In case of EU sentencing, Germany would have had to pay penalties of ~€17M once plus an additional ~€1M daily	SZ (2023): Nitrat-Streit beendet: Deutschland entgeht Millionenstrafe der EU - Wirtschaft - SZ.de

Assumptions/Estimates	Source
Average Expected Annual Water Pollution Damage	
~€4B average expected annual water pollution damage across Germany: • Penalty data remains limited and primarily nitrate-specific, making them less reliable for projecting broader future liabilities • Ecosystem restoration (€580M–767M and ~€900M) and infrastructure investments (~€750M, ~€2.5B, and ~€14.7B) provide relatively robust indicators of water pollution costs • PFAS-related estimates encompass environmental elements beyond water systems, meaning that only a share of those costs are water-specific (~50%)	BCG & NABU analysis (2025)

Modelling Step	Substep	Why	How	Source
Water stress assessment for agriculture	*Boundary data*	Provide polygons/IDs to disaggregate SPAM and join climate at admin-3 levels	Collect official admin-3 boundaries data	HDX, Administrative Division for Germany
	Crop calendar	Align crop growth stages with monthly timing to accurately reflect seasonal water demand	Build monthly crop calendars for all crops in Brandenburg, by assigning each crop's phenological stage (establishment, vegetative, reproductive, and maturity) to specific months	USDA, adapted with sources on Brandenburg
	Crop KC coefficients	Convert ET_0 to crop-specific ETC per stage, which translates into demand	For each crop and stage, set a corresponding Kc coefficient from FAO-56	FAO, "Chapter 6 - ETc - Single crop coefficient (KC)"
	ET data	Determine the climate-based baseline for how much water crops would need under future conditions	Collected monthly high-resolution 0.25° evapotranspiration data as the driver for calculating water demand	NASA NCC, Nex-GDDP CMIP6 data
	Crop data	Scale modeled water demand (ETC) from per-hectare values to total demand based on cultivated area per crop and region	Use harvested area data by crop and administrative unit to weight and aggregate ETC values, producing total water demand per crop and geography	SPAM, Spatial Production Allocation Model
	Crop mix demand	Estimate monthly water demand by crop and admin unit (feeds water stress)	Merge crop mix with monthly ET_0 by unit → join calendar stage + Kc → compute total water demand	N/A
	Precipitation data	Quantify natural water input available (rainfall) for crops each month across regions	NEX-GDDP CMIP6 daily precipitation → filter by SSP, spatially join to admin polygons, aggregate	NASA NCC, Nex-GDDP CMIP6 data

Modelling Step	Substep	Why	How	Source
Water stress assessment for agriculture	*Runoff data*	Estimate the portion of rainfall that flows off the land instead of infiltrating, to derive the water available to crops	Fit a precipitation–runoff regression using CMIP6 daily data, then apply it to NEX-GDDP daily series to generate monthly runoff estimates per admin-3 unit	CMIP6, Coupled Model Intercomparison Project Phase 6, and NASA NCC, Nex-GDDP data
	Rainfed supply	Determine how much rainfall effectively contributes to meeting crop water needs each month	Calculate rainfed supply as total rainfall minus runoff over each crop area	N/A
	Water stress index (WSI)	Summarize the balance between water demand and available supply into one comparable metric per region	Calculate the WSI as the ratio of total demand to total supply for each crop, year, and admin-3 unit	N/A
	Cost of inaction	Quantify the economic loss from water stress in a do-nothing scenario by linking reduced yields to market value	Estimate yield loss using the crop's yield–water response curve and multiply the lost production by crop market price to obtain the cost of inaction in monetary terms	Aquacrop, The FAO Crop Water Productivity Model

Modelling Step	Substep	Why	How	Source
Demand assessment for industry	*Industrial water demand baseline*	Provide a current, credible anchor for projecting industrial water demand	Collect the latest industrial water withdrawal baseline and use it as the reference level for extrapolation	Aquastat, Germany's industrial withdrawal for 2021
	Industrial water use efficiency	Represent expected efficiency gains that reduce industrial water demand through technological progress	Collect historic industrial water use efficiency (WUE) data for Germany and use it to project improvements in water intensity over time	Aquastat, all of Germany's historical industrial WUE values

Modelling Step	Substep	Why	How	Source
Demand assessment for industry	*GDP per SSP*	Capture the effect of economic growth on future industrial water demand across climate scenarios	Use GDP projections from the IIASA SSP database to scale industrial water demand according to each scenario's economic trajectory	IIASA, SSP public database
	Population data	Disaggregate national or regional water demand to local (admin-3) level based on population distribution	Use high-resolution gridded population data to allocate water demand across admin-3 units	Eurostat, gridded population data from 2021 census

Modelling Step	Substep	Why	How	Source
Demand assessment for domestic and municipal use	*Domestic and municipal water demand baseline*	Provide a current, credible anchor for projecting domestic and municipal water demand	Collect the latest service sector water withdrawal baseline and use it as the reference level for extrapolation	Aquastat, Germany's service sector withdrawal for 2021
	Service sector water use efficiency	Represent expected efficiency gains that reduce service sector water demand through technological progress	Collect historic service sector water use efficiency (WUE) data for Germany and use it to project improvements in water intensity over time	Aquastat, all of Germany's historical industrial WUE values
	GDP per capita per SSP	Capture the effect of economic growth on future service sector water demand across climate scenarios	Use GDP projections to scale domestic and municipal water demand according to each scenario's economic trajectory	IIASA, SSP public database and gridded data
	National statistics of admin-1 GDP in Germany	Align national GDP projections with regional (admin-1) economic structures for spatial consistency	Apply the RAS balancing method to redistribute national GDP values across admin-1 regions while preserving total GDP consistency	Statistische Ämter des Bundes und der Länder, Statistikportal – Kreisebene BIP/BWS (2024)
	Light and population data	Distribute regional industrial demand to local units based on proxies of economic and population activity	Combine high-resolution gridded population data and nighttime light intensity to proportionally downscale industrial demand from admin-1 to admin-3	Eurostat, gridded population data from 2021 census; light data

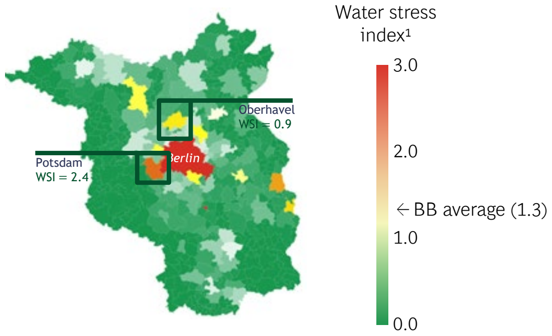
Modelling Step	Substep	Why	How	Source
Demand assessment for domestic and municipal use	*Water recycling factor*	Account for the share of water that is reused, reducing total freshwater withdrawal needs	Collect data on recycled water rates and the proportion of used water that is treated and reused to adjust net water demand	
Supply assessment for domestic and municipal use	*Groundwater input (recession, recharge) alignment*	Use consistent inputs for groundwater behavior and recharge	Reproject both datasets to a common grid, patch small gaps, and clip recession rates to plausible bounds	**PCR-GLOBWB groundwater properties (4TU/ THREDDS server)** PCR-GLOBWB2 Version 2019_11 Beta: Groundwater Properties (5 Arc-Min). 4TU. ResearchData/ THREDDS Data Server, Nov. 14, 2019 **ISIMIP (h08 MPI-ESM1-2 HR, SSP5-8.5, W5E5 bias correction)** ISIMIP: h08 MPI-ESM1-2 HR W5E5 SSP5-8.5 2015soc Default qr Dataset. Potsdam Institute for Climate Impact Research (PIK)
	Recharge to monthly/ annual totals	Express recharge as yearly and monthly volumes to enable consistent year-over-year comparison and aggregation by area	Convert monthly recharge to depth per cell, aggregate over area, and sum by year to obtain annual groundwater recharge per area	
	Initial storage (previous-year average)	Initialize each simulation year with a realistic groundwater level based on prior recharge behavior	Set the starting storage for each year using the previous year's average daily recharge scaled by the local groundwater recession rate	
	Monthly reservoir and outputs	Model how groundwater recharge translates into monthly outflows and yearly storage changes across regions	Update storage and outflow each month, sum results by year, and aggregate across grid cells to obtain regional groundwater totals in cubic kilometers (Bm^3)	

Modelling Step	Substep	Why	How	Source
Supply assessment for industry	*Supply and demand alignment*	Identify spatial correspondence between water supply points and industrial demand areas under modeled constraints	Load river discharge, administrative boundary, and industrial demand datasets, then configure environmental flow share, abstraction caps, and connectivity parameters for allocation	Discharge: HypflowSci6 v1.0 (PCR-GLOBWB CMIP6 IPSL-CM6A-LR SSP5-8.5 outputs). Geo Public Data (Utrecht University) **Boundaries:** HDX, Administrative Division for Germany
	Outlets and budgets	Identify where supply can be taken and how much	Select inland river cells as potential outlets; set an annual abstraction budget per outlet after reserving environmental flow	
	Admin snapping and connectivity	Connect industrial demand points to nearby river outlets in a hydrologically consistent way	Snap each district to its nearest river cell, connect to a limited set of nearby or same-basin outlets, and distribute outlet budgets with greater weight to closer sources	
	Potential and allocation	Allocate available water among districts while respecting outlet limits and assessing unmet demand	Distribute supply across districts without exceeding outlet budgets or total demand, then compute allocated volumes, unmet demand, and water stress per district	
Water stress assessment for both industry and domestic and municipal use	Water stress index calculation	Summarize water availability pressure by comparing total demand to available supply for each region and crop	Calculated the WSI as demand over supply for each (admin-3, crop, year)	N/A
	Cost of inaction estimate	Quantify the economic impact of unmet water demand using projected efficiency levels	Calculated the cost of inaction (COI) as the unmet water demand multiplied by the projected water use efficiency (WUE)	Aquastat, Germany's service sector and industrial sector WUE historic values

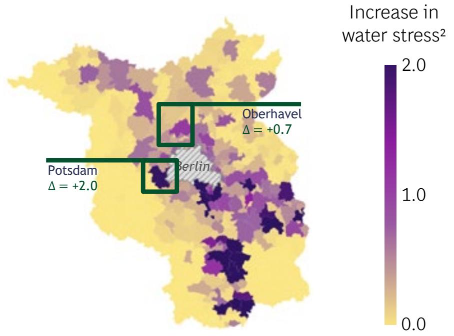
Figure 31: Industrial water stress is driven by an increase in unmet water demand, leading to a yearly cost of inaction of up to 2% of GDP

The average water stress across Brandenburg is expected to more than triple by 2050 …

Water stress today (2020-2025)



Increase in water stress¹ by 2040-2050



… with a cost of inaction largely driven by unmet industrial water demand

+13% increase — In unmet water demand by 2050, primarily driven by an increase in industrial water needs Projected to increase from 10% in 2025 to 23% in 2050

+80% increase — In Potsdam's water stress by 2050, rising from 2.4 in 2025 to 4.4 in 2050; Oberhavel sees its water stress increase by +75% (0.9 to 1.6 by 2050)

1–2% of Brand. GDP (~€1.8-3.6B) — in annual estimated economic losses³ due to unmet water demand in 2050; projected to rise from ~€0.9B losses in 2025

1. Water stress = Water demand/Water supply. The 2050 analysis included the modelling of closure of the Lausitz brown coal mines and their effects on the Spree river

2. Difference between averaged water stress over 2040-2050 period, and the value for 2025

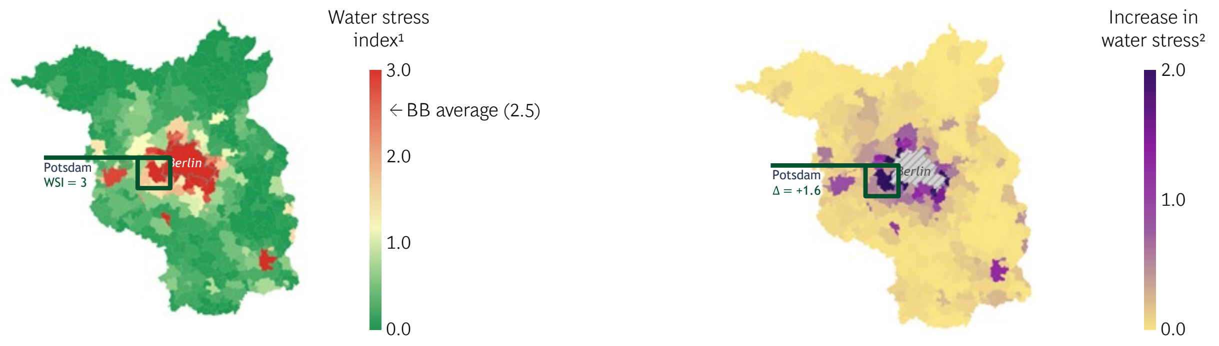
3. According to the FAO AQUASTAT Industrial Water Use Intensity index

Sources: Amt für Statistik Berlin-Brandenburg; https://data.ece.iiasa.ac.at/ssp/; Japan's CGER (Center for Global Environmental Research); Murakami, Daisuke, and Yoshiki Yamagata. "Estimation of gridded population and GDP scenarios with spatially explicit statistical downscaling." Sustainability 11.7 (2019): 2106.

Figure 32: Water stress is driven by a decrease in groundwater availability, leading to a yearly cost of inaction of up to 5% of Brandenburg GDP

Domestic & Municipal water stress is expected to intensify by 2050, with Potsdam area most at risk…

Water stress today (2020-2025) | Increase in water stress[1] by 2040-2050



… with a cost of inaction driven by a decrease in groundwater supply

+12% decrease — In groundwater supply available by 2050, with the Northern area of Brandenburg most exposed

+50% increase — In Potsdam's water stress by 2050, rising from 3 in 2025 to 4.6 in 2050

3–5% of Brand. GDP (~€5.3-9B) — in annual estimated economic losses[3] due to unmet water demand in 2050; projected to rise from ~€4B losses in 2025

1. Water stress = Water demand/Water supply. Water demand from Berlin is accounted for by assuming external supply is coming from Brandenburg

2. Difference between averaged water stress over 2040-2050 period, and the value for 2025

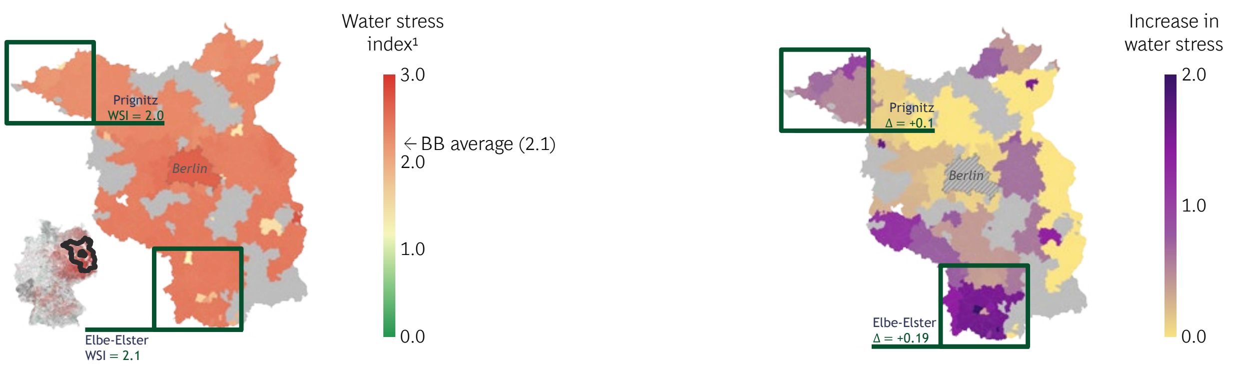
3. According to the FAO AQUASTAT Domestic Water Use Intensity index

Sources: Amt für Statistik Berlin-Brandenburg; https://data.ece.iiasa.ac.at/ssp/; Japan's CGER (Center for Global Environmental Research); Murakami, Daisuke, and Yoshiki Yamagata. "Estimation of gridded population and GDP scenarios with spatially explicit statistical downscaling." Sustainability 11.7 (2019): 2106.

Figure 33: Brandenburg is expected to face continuous agricultural water stress, with yearly losses of €270M-€380M by 2050

Brandenburg is expected to continue to face similar and significant agricultural water stress …

Water stress today (2020-2025) | Increase in water stress[1] expected by 2040-2050



… threatening the production of main regional cereals & vegetables

Up to **50%** unmet water demands — By 2050 in highly agricultural areas such as Prignitz, with a stress index of 2.0. Across Brandenburg, the crops where production is the most threatened are Wheat, Maize, and Other Vegetables

€270–380M yearly economic loss — By 2050 due to yearly production losses driven by unmet crop water needs

1. Cropland area and crop mix are considered constant over time to isolate the effect of climate change

Sources: Natural Earth States and Provinces boundaries without large lakes; MAPSPAM

Modelling Step	Substep	Why	How	Source
Regenerative Agriculture: Crop rotation	*ET0 data by admin-3*	Provide monthly reference evapotranspiration at district level to drive stage-specific crop water demand calculations	Aggregate NEX-GDDP daily ET_0 to monthly values, merge historical (<2015) and SSP585 (≥2015) periods, then area-weight grid cells to admin-3 polygons using an equal-area projection	NASA NCC, Nex-GDDP CMIP6 data
	Water-intensity ranking (targets)	Identify lower water-use crops to prioritize when reallocating cultivation areas	Calculate annual water intensity per crop as the sum of monthly $ET_0 \times KC$ values (m^3/ha/year) and rank crops in ascending order to select eligible low-intensity targets	FAO-56 (dual-KC), internal crop calendars; NEX-GDDP ET_0
	Rotation caps by crop	Prevent dominance of high-water or monoculture crops and promote diversified, water-efficient rotations	Apply crop-specific area caps per admin-3 unit, redistribute excess area to other permitted crops based on remaining capacity, and maintain total cultivated area constant	N/A
	Minimum shares (floors)	Maintain essential crop presence to meet agronomic and market requirements	Apply minimum crop share thresholds per unit, reallocate excess area from other crops above their floors, and renormalize total area to 100%	N/A
	Yearly rotation mix table	Extend the optimized crop rotation mix consistently across all modeled years to track long-term effects	Replicate crop share distributions by year, generate annual area/harvest/production (A/H/P) records, and retain baseline yields to compute yearly production	Areas and yields from SPAM (Spatial production allocation model)

Modelling Step	Substep	Why	How	Source
Regenerative Agriculture: Crop rotation	*Rotation demand recomputation (crop mix demand redone)*	Measure how revised crop rotations change total water demand compared to the baseline scenario	Recalculate per-hectare water need (ET_0 × KC × 10), multiply by updated crop areas, and aggregate results monthly and annually to quantify total and saved demand	N/A
	Past rainfed supply data	To recalculate water stress	Use saved past rainfed supply data	N/A
	Adjusted water stress	Have a single index to summarize water stress situation for each admin-3	Calculate the WSI as demand over supply for each (admin-3, crop, year)	N/A
	Reduction in cost of inaction	Estimate the monetary benefit of implementing interventions compared to maintaining current water stress conditions	Compute production loss using each crop's yield–water response curve and multiply by market value to derive the avoided Cost of Inaction in dollars	FAO's Aquacrop (Crop Water Productivity Model)

Regenerative Agriculture: Cover crops	*Monthly cover fraction*	Represent seasonal variation in soil cover to capture when mulch or vegetation influences water balance	Define monthly cover fractions (0–1) for each month based on Brandenburg patterns, with higher winter cover (~0.6) and lower summer cover (0.1–0.3), adjusted using local remote sensing and LPIS data	Eurostat AEI – Soil cover, EU winter 2016 breakdown
	Evaporation share of evapotranspiration by crop stage	Distinguish the portion of evapotranspiration that comes from soil evaporation and can be reduced by surface cover	Assign evaporation shares by crop stage (e.g., 0.80 establishment, 0.40 vegetative, 0.10 reproductive, 0.25 maturity, 0.00 empty) and link them to monthly crop stages using crop calendars	FAO-56 (Chapter 7)
	Mulch/cover strength scale	Translate surface cover into percentage of ET reduction.	effective_fraction = fao_mulch_scale × cover_frac[month] × evap_share[stage] × growth (year) clip between 0 and max reduction	FAO-56, dual-KC and effects of soil mulches

Modelling Step	Substep	Why	How	Source
Regenerative Agriculture: Cover crops	*Runoff capture factor for supply*	Cover increases infiltration/retention → less runoff loss	Reduce the runoff by the capture factor (%)	Soil Use & Management (2024), Western Europe meta-analysis
	Adjusted demand	Demand after crop-cover effect	Subtract the reduction on demand via evaporation reduction	N/A
	Adjusted supply	Supply after cover-driven runoff capture	Readd the runoff reduced as volume to the baseline supply	N/A
	Adjusted water stress	Have one index that summarizes water stress situation for an admin-3	Calculated the WSI as demand over supply for each (admin-3, crop, year)	N/A
	Reduction in cost of inaction	Have a dollar amount for the do-nothing scenario of current water stress situation	Calculated the COI as the production lost due to the crop's yield curve then multiplied by crop market value to get a dollar value	Aquacrop, The FAO Crop Water Productivity Model

Forest Management (forest optimization impact on groundwater and surface water)	*Boundary data*	Provide polygons/IDs to disaggregate SPAM and join climate at admin-3	Load official admin-3; harmonize IDs; validate topology; use as spatial join key for rasters/tables	HDX – Administrative Division for Germany
	Elevation (DEM)	Slope affects runoff/infiltration; ML feature	Load DEM → slope (°/%); area-weight to admin-3; standardize feature	/elevation.pkl
	GW recharge baseline	Baseline supply to adjust with forest levers	Read admin-3 GW; later: Recharge_adj = Recharge_baseline × (1 + m_recharge)	Project datasets
	Forest cover (`/DEU.xlsx`, admin-2)	Driver of hydrologic response; basis for levers	Load forest shares/types; map to admin-3; define scenarios (baseline, broadleaf, mixed)	Internal compilation
	QR recharge (NetCDF 2015–2100)	Monthly recharge trajectory under SSPs	Open NetCDF; subset region/SSP; aggregate to admin-3 monthly means	Pcr glowb

Modelling Step	Substep	Why	How	Source
Forest Management (forest optimization impact on ground-water and surface water)	*Rainfed agri supply (/ rainfed_supply_22%_ runoff_adjusted.csv)*	Links land-cover changes to agri supply used in stress Predict landscape effects on runoff/recharge | Train	Load monthly rainfed supply; adjust with runoff deltas from forest scenarios	Project CSV
	Hydrological ML (XG-Boost)	Runoff/Recharge = f(ForestCover, Precipi-tation, Slope)`; vali-date; infer per scenar-io	Project model/data	
	Forest lever implemen-tation (type/area multi-pliers)	Simulate conifer→broadleaf/ mixed effects	Apply multipliers: `Runoff_adj = Runoff baseline × (1 + m_run-off)`; `Recharge_adj = Recharge baseline × (1 + m_recharge)`	Peer-reviewed litera-ture synthesis
	Stress integration (to agri & GW)	Translate forest im-pacts into availability	Adjust agri supply via runoff deltas; GW via recharge multipliers; output: `/merged_for-est_rain_Broadleaf. parquet`, `/gw_for-ests.parquet`	N/A
Domestic stress analysis with levers	*Forest scenario inputs*	Bring forest-improved recharge/supply into domestic stress	Join GW deltas to admin-3 supply timeseries	Forest_cover optimiza-tion outputs
	Domestic demand projections	Future household demand driver	Load admin-3 month-ly/annual demand; align to decades; QC	`/domestic_water_de-mand_admin3.par-quet`, SSP585
	Berlin baseline and transfers	Model Berlin–Bran-denburg coupling (10% import)	Export_to_Berlin = 0.10 × Demand_Ber-lin`; allocate to con-nected admin-3	/gw_annual_supply_ admn3.parquet`
	Knapsack optimization (≤100,000 ha)	Prioritize highest monetary benefit per ha	Maximize `∑ Saved_ COI_i` s.t. `∑ Area_i ≤ 100,000 ha` (0/1 selection by admin-3)	Domestic optimiza-tion module
Industrial stress with mine closure	Stress baselines 2025/2050	Reference stress to compare/amplify	Load admin-3 stress; clip extremes; prep for scenario overlay	Project datasets
	Mine closure impacts (district declines)	Reflect decline in mining regions	Apply rates: Od-er-Spree 50%, Ober-spreewald-Lausitz 70%, Dahme-Spreewald 70%, Cottbus 50%.	Peer-reviewed litera-ture

Effects of Regenerative Agriculture on Soil-Water Storage

Assumptions/Estimates	Source
Amount of arable land in Brandenburg: 0.99M ha	Statistik Berlin Brandenburg (2025): Die Brandenburger Landwirtschaft in Zahlen
• Change in dry bulk density (Δρβ): −0.1 g cm^{-3} • Change in porosity: +3.7% (= 0.037, dimensionless) • Particle density: 2.65 g cm^{-3} • Soil depth: 0.30 m • Result: additional storage of 11 L m^{-2}/ 110 m^3 ha^{-1}	Reck, UfU e.V. (2025): UfU-Hintergrundpapier
Since storage capacity increases linearly with depth, at 0.60 m depth the storage is doubled: • 11 L m^{-2} × (0.60 / 0.30) = 22 L m^{-2} = 220 m^3 ha^{-1}	Reck, UfU e.V. (2025): UfU-Hintergrundpapier

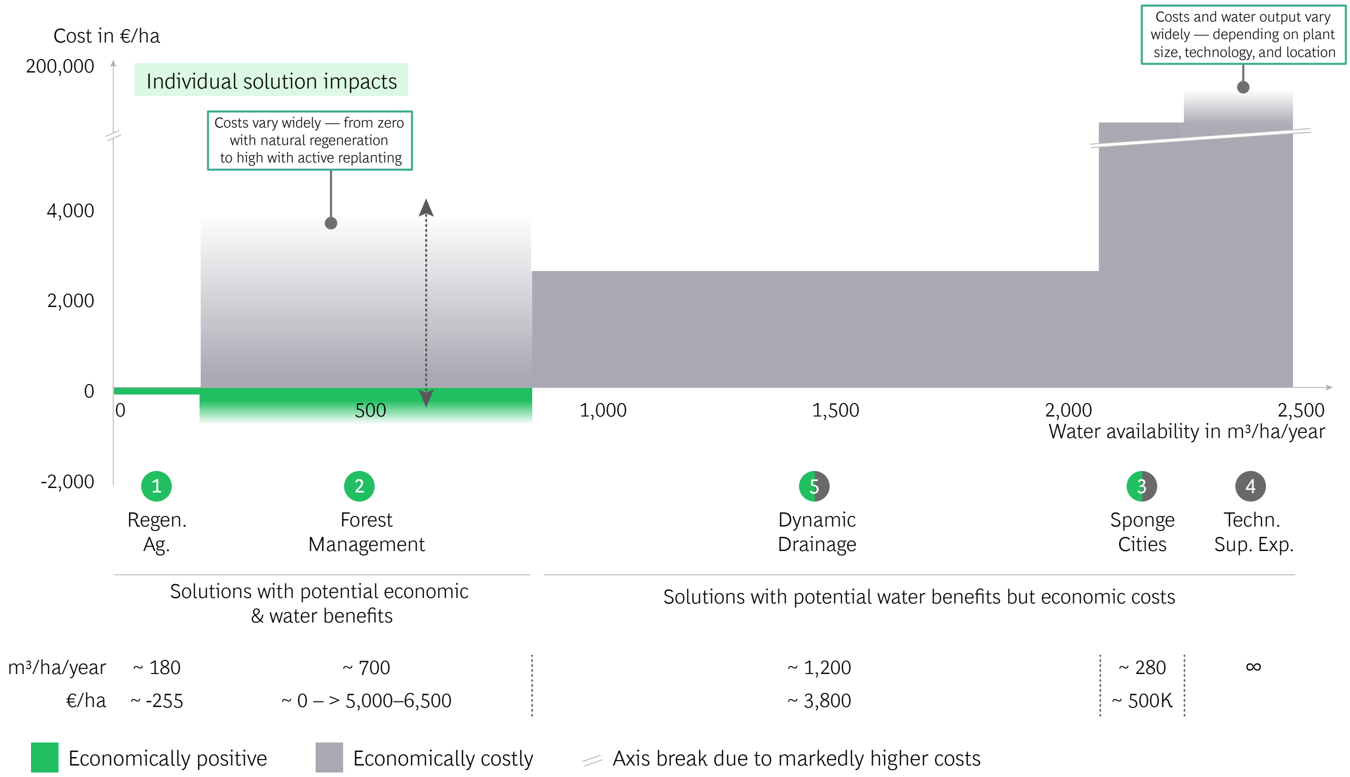
Green-Moist-Cool Effect

Assumptions/Estimates	Source
• A one-unit increase in NDVI leads to −1.97 °C • A one-unit increase in NDVI leads to +297 mm in precipitation • +1 °C leads to a precipitation reduction of -4.05 mm	Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany

Appendix Table 4 – Drainage and Its Hidden Impact

Assumptions/Estimates	Source
Lightly drained area: 35.66 l/min on 15.6 ha = 120 mm/year or 1,200 m3/ha/year	NABU & BCG analysis based on data from LfU Brandenburg (2025)
Moderately drained area: 18.77 l/min on 3.9 ha = 250 mm/a or 2500 m3/ha/year	LfU Brandeburg (2025)
Heavily drained area: 72.84 l/min on 7.34 ha = 520 mm/a or 5200 m3/ha/year	NABU & BCG analysis based on data from LfU Brandenburg (2025)
Amount of arable land in Brandenburg: 0.99M ha	Statistik Berlin Brandenburg (2025): Die Brandenburger Landwirtschaft in Zahlen
30–40% of Brandenburg's arable land are drained, roughly 300K–400K ha	NABU & BCG analysis (2025)

Figure 34: Technological solutions provide unlimited water but are costly, while nature-based options boost water availability at lower or positive cost



Note: Other Landscape-Level Solutions are excluded from the visual, given their impact cannot be meaningfully represented via a single quantitative range. Water Use Optimization and Gray Water Reuse are not shown either, since the visual includes only measures that expand overall water availability — the two solutions improve efficiency, but do not add new water

Source: BCG & NABU analysis

Assumptions/Estimates	**Source**
Regenerative Agriculture	
Precipitation uplift per NDVI unit: 2,970 m3/ha/year	Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
NDVI for bare acre: ~0.2	Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
NDVI for acre with cover crops/grassland: ~0.55	Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
Average annual precipitation: ~8,000 m3/ha/year	UBA (2017): Wasserwirtschaftin Deutschland – Grundlagen, Belastungen, Maßnahmen

Assumptions/Estimates	Source
Average groundwater recharge Germany—low: ~750 m3/ha/year	UBA (2024): Auswirkung des Klimawandels auf die Wasserverfügbarkeit - Anpassung an Tro-ckenheit und Dürre in Deutschland (WAD-Klim)
Average groundwater recharge Germany—medium: ~1,500 m3/ha/year	UBA (2024): Auswirkung des Klimawandels auf die Wasserverfügbarkeit - Anpassung an Tro-ckenheit und Dürre in Deutschland (WAD-Klim)
Average groundwater recharge Germany—high: ~2,000 m3/ha/year	UBA (2024): Auswirkung des Klimawandels auf die Wasserverfügbarkeit - Anpassung an Tro-ckenheit und Dürre in Deutschland (WAD-Klim)
Applicable agricultural land: 13.3M ha • 10.0M ha cropland • 3.3M ha grassland	NABU & BCG (2023): the-case-for-regenerative-agriculture-mar2023.pdf
Profitability: €225/ha/year (€152/ha in Stage 1, €73/ha in Stage 2)	NABU & BCG (2023): the-case-for-regenerative-agriculture-mar2023.pdf
Forest Management	
Additional groundwater recharge from conversion of pine monocultures to mixed stands in Brandenburg: 400 m3/ha/year	HAWK (2025): Studie belegt: Waldumbau als Schlüssel zur Entlastung der Grundwasserbilanz in Grünheide | HAWK Hochschule für angewandte Wissenschaft und Kunst
Groundwater recharge in Brandenburg: • Pine: 80,000 m3/ha over 120 years • Beech: more than double the amount Groundwater recharge in Lower Saxony: • Pine: 1,100 m3/ha/year • Oak/beech: 1,830 m3/ha/year	Öko-Institut e.V. (2020): https://www.nabu.de/imperia/md/content/nabude/wald/200915-nabu-wasserhaushalt_wald.pdf Schultze & Scherzer (2015): https://www.lwk-niedersachsen.de/services/download.cfm?pmofile=396
Groundwater recharge in Lower Saxony: • Pine: 1,100 m3/ha/year • Oak: 2,060 m3/ha/year	Schultze & Scherzer (2015): https://www.lwk-niedersachsen.de/services/download.cfm?pmofile=396
Pine monoculture area: ~0.9M ha	BMLEH (2024): Der Wald in Deutschland - Ausgewählte Ergebnisse der vierten Bundeswaldinventur
Coniferous monoculture area: ~2.5M ha	BMLEH, Thünen (2024): BUNDESWALDINVENTUR ERGEBNISDATENBANK
Coniferous dominated mixed forests: ~3.2M ha	BMLEH, Thünen (2024): BUNDESWALDINVENTUR ERGEBNISDATENBANK

Assumptions/Estimates	Source
Precipitation uplift per NDVI unit: 2,970 m3/ha/year	Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
NDVI for coniferous forests: ~0.72	Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
NDVI for mixed or deciduous stands: ~0.78	Adhikari, Ibisch et al. (2025): Working landscapes under climate change need to be green, moist and cool - a case study of Germany
Implementation costs for replanting and full reforestation: €5,000–6,500 per hectare	UBA (2023): FW-R-1_Indikator_Foerderung_Waldumbau
Sponge Cities	
Average annual precipitation: ~8,000 m3/ha/year	UBA (2017): Wasserwirtschaftin Deutschland – Grundlagen, Belastungen, Maßnahmen
Groundwater recharge rate under permeable surface conditions: 25%	Kompetenzzentrum Wasser Berlin Presentation (2025)
Groundwater recharge rate under nonpermeable surface conditions: 18%	Kompetenzzentrum Wasser Berlin Presentation (2025)
Area with flat roofs in Germany: ~0.12M ha	Der Dichte Bau: Flachdächer - Der dichte Bau
German settlement and transport area: ~15%, equivalent to 5.4M ha of total German area (35.8M ha)	BMEL: BMEL-Statistik: Bodennutzung in Deutschland
Settlement and transport area sealed: ~45%, equivalent to 2.4M ha	UBA (2025): Bodenversiegelung | Umweltbundesamt
German living space and industrial and commercial space: ~5%, equivalent to 1.8M ha of total German area	Destatis (2024): Floor area total according to types of use in Germany - German Federal Statistical Office
Average costs for installation of basic green roof: €50 per m², or roughly €500,000 per hectare	Sedum Dachbegrünung: SedumDachbegrünung | Dach begrünen leicht gemacht
Average costs for conversion of sealed surfaces into green, permeable areas: €2M per hectare	Regenwasseragentur: Entsiegelung von Flächen in Berlin: Jetzt informieren und loslegen
Dynamic Drainage	
Water loss through drainage in Brandenburg: ~2,500 m3/ha/year	LfU Brandenburg (2025)
Water retention after drainage optimization: 40%	LfU Brandenburg (2025)
Water retained in ground via smart drainage in Lower Saxony: ~1,400 m3/ha/year	NDR (2025): Mit smarten Drainagen gegen Trockenheit und Starkregen | ndr.de

Assumptions/Estimates	Source
Amount of German agricultural land drained: ~23%	Auerswald et al. (2024): EGUsphere - HESS Opinion: Floods and droughts – Land use, soil management, and landscape hydrology are more significant drivers than increasing temperatures
Material costs for manual or climate-adapted systems: €1,300–2,500 per hectare	Stowa: Controlled drainage | STOWA Ingeniuergesellschaft Prof. Dr. Sieker mbH E-Mail correspondence (2025) LBEG (2014): Link
Advanced, sensor-controlled systems with automation: can at least triple costs; using material costs from above, reaching €3,900–7,500 per hectare	Geiger agri solutions ekoDrena Price list 2025 E-Mail correspondence (2025)
Costs for maintenance, interest and depreciation: €700 ha/year	Wageningen University & Research (2020) – E-Mail correspondence (2025)

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Acknowledegements

The authors would like to thank the following for their contributions to this study:

NABU

Christine Toelle-Nolting, Bjoern Ellner, Simon Kraemer, Maximilian Wolff as well as the other dedicated team members across NABU's regional branches

BCG

Paul Ploetner, Hamid Maher, Flavien Hardy, Omar Kami, Romy Uhlig, Marleen Mammen, Dean Muruven, Vuk Trifkovic

They would also like to thank their discussion partners from DVGW and KWB for their input and insights: Marika Holtorff, Marie-Ann Koch, Pascale Rouault and Andreas Matzinger