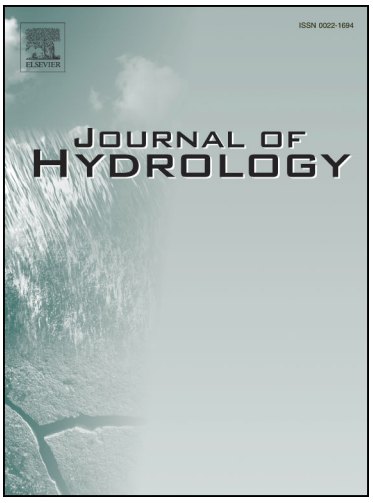
Journal Pre-proofs



Research papers

Infrastructural lock-ins in the temporal and spatial development of a long-distance water transfer in Germany

David Kuhn, Robert Luetkemeier, Fanny Frick-Trzebitzky, Linda Söller, Kristiane Fehrs

PII: S0022-1694(24)00465-7
DOI: https://doi.org/10.1016/j.jhydrol.2024.131070
Reference: HYDROL 131070

To appear in: *Journal of Hydrology*

Please cite this article as: Kuhn, D., Luetkemeier, R., Frick-Trzebitzky, F., Söller, L., Fehrs, K., Infrastructural lock-ins in the temporal and spatial development of a long-distance water transfer in Germany, *Journal of Hydrology* (2024), doi: https://doi.org/10.1016/j.jhydrol.2024.131070

Infrastructural lock-ins in the temporal and spatial development of a long-distance water transfer in Germany

David Kuhn[a,*,david.kuhn@isoe.de], Robert Luetkemeier[a,b,robert.luetkemeier@isoe.de], Fanny Frick-Trzebitzky[a,fanny.frick@isoe.de], Linda Söller[b,soeller@geo.uni-frankfurt.de], Kristiane Fehrs[c,kristiane.fehrs@tu-dresden.de]

[a]ISOE – Institute for Social-Ecological Research, Hamburger Allee 45, 60486 Frankfurt a.M., Germany

[b]Institute of Physical Geography, Goethe University Frankfurt, Altenhoeferallee 1, 60438 Frankfurt a.M, Germany

[c]Institute of Sociology, Dresden University of Technology, Chemnitzer Straße 46a, 01187 Dresden, Germany

[*]Corresponding author.

Highlights

- Germany plans more long-distances water transfers to secure drinking water supply
- Long-distance water transfers can unfold lock-ins that limit adaptive water governance
- Our interdisciplinary case study shows how lock-ins emerge over different spaces and times
- Commercialisation of water but also local protests contributed to various lock-ins
- We therefore call for context-specific assessments of potentials and risks of LDWT

Abstract:

Germany plans to expand water transfers over long distances in the light of numerous and pressing challenges for drinking water supply. Research on inter- and intrabasin water transfers warns, however, that major investments in large-scale infrastructure systems accompanied by institutional logics and political interests often lead to a so-called lock-in. As a consequence, long-distance water transfers can limit the potential for adaptive water governance in the involved supply areas over decades with negative impacts for people and the environment. By using a case study in Germany as an example, we researched when, where and how such lock-ins around long-distance water transfers emerge. In the infrastructural development of the Elbaue-Ostharz transfer system we found various lock-ins that overlap in space and time. Some are located at the centre others at the margins of the infrastructure and commercialization of the water sector as well as hydraulic and hygienic concerns interlock with local protests in a way that the expansion of the long-distance water transfer infrastructure is presented continuously as imperative. Our findings contribute to a relational understanding of lock-ins of long-distance water transfers as contingent and diverse processes. Given the widespread occurrence of lock-ins, we argue for a context-specific assessment of potentials and risks of long-distance water transfers in times of multiple crises.

Keywords: climate change adaptation, hydrosocial cycle, reservoir, groundwater, water transport

Funding: The Federal Ministry of Education and Research (BMBF) is funding the project “regulate – Regulation of Groundwater in Telecoupled Social-Ecological Systems” within the framework of the “Research for Sustainability” strategy (FONA) (https://www.fona.de/en/) as part of its Social-Ecological Research funding priority, grant number 01UU2003A. Responsibility for the content of this publication lies with the authors.

1 Introduction

In Germany, 99% of private households are connected to centralised public water supplies with 24/7 availability of high quality drinking water, low cost levels and rare failures. In recent years, however, supply security has become a widespread concern against the backdrop of droughts, contamination, changing water use patterns, capacity limits of hydraulic infrastructures being reached and potentially rising costs for drinking water treatment and distribution (ATT et al., 2020; DVGW, 2022; Hüesker et al., 2011; Libbe et al., 2017; Schramm and Winker, 2023). As a remedy to this situation, water suppliers and political decision-makers have regarded the use of long-distance water transfers (LDWTs) as a supply-side solution that aim to balance out the so-called water rich and scarce regions (BMUV, 2023; NDR, 2023; Stuttgarter Zeitung, 2023; Latz, 2022). However, research beyond Germany has shown, that LDWT can hamper flexible, local and learning water governance in the long-term and thereby, pose a risk, instead of a guarantee, for safe water supply for all (Bourguignon, 2023; Gupta and van der Zaag, 2008; Shumilova et al., 2018).

Evidence shows that drinking water resources, such as groundwater bodies, are subject to various anthropogenic stressors (Luetkemeier et al., 2022). Climate models for Germany project more frequent and longer drought periods alongside decreased water availability (Kahlenborn et al., 2021) connected to higher peak demands by households (Fiorillo et al., 2021). Water demand patterns also change due to demographic reasons and behavioural adaptations as seen, for example, in the COVID-19 pandemic (Lüdtke et al., 2021), while on several hot summer days in the recent years, water suppliers have actually reached capacity limits (Niehues, 2023). Furthermore, one third of German groundwater bodies are in a poor chemical state – despite recently adopted laws on the emission of fertilizers and pesticides to protect this drinking water resource (UBA, 2021). In addition, conflicts about the access to drinking water wells (Huth et al., 2022) or the potential increases in water costs (tagesschau.de, 2023) raise concerns about how certain the 24/7 supply for all remains sustainable.

Confronted with these multiple challenges to the drinking water supply in Germany, many suppliers, public authorities and politicians have suggested the expansion of LDWTs in Germany. Usually understood as the transport of water in pipelines by an independent preliminary supplier for two or more municipal end suppliers over a distance of at least 30 to 60 km (Mehlhorn and Weiß, 2009), the recently adopted first German National Water Strategy (BMUV, 2023) considers LDWTs as a potential for areas struggling with their water resources. This is reflected in planned investments. For example, a major preliminary supplier in the Harz Mountains is considering to enlarge an existing dam and build a new one for the supply of north-west Germany with drinking water (NDR, 2023), two long-

distance water suppliers in Baden-Württemberg are ready to invest large sums in their present infrastructure (Stuttgarter Zeitung, 2023) and the city of Berlin is considering the import of water from the River Oder (Latz, 2022).

LDWTs are already cornerstones of Germany's drinking water supply system. National water laws assign the supply of drinking water to the municipalities and demand the use of local (in German: *ortsnah*) resources first (BRD, 2009, 1949/2022). Nevertheless, in 2019, approximately 19% of the German population received water provided over long distances by a preliminary supplier (aquabench, 2022, 2018). Worldwide, the numbers, lengths and volumes of LDWTs are on the rise, including the prominent example of the South-North Water Transfer in China (Shumilova et al., 2018).

Research shows, however, that in the long term, LDWTs can limit the potential for adaptive water governance in the involved supply areas and lead to negative social and environmental consequences. Frequently, people are displaced by the dams or transportation infrastructure being built on their settlements and that disturb local water wells (Bourguignon, 2023; Gupta and van der Zaag, 2008; Purvis and Dinar, 2020). With LDWTs, the availability of water in so-called donating regions usually decreases, whilst in the receiving regions, rebound effects can be observed that further increase water demand (Gupta and van der Zaag, 2008). These consequences of LDWTs not only cause or drive conflicts between the donating and receiving regions but also between local actors and national governments (Gupta and van der Zaag, 2008; Bourguignon, 2023).

However, when affected local governments or activists demand the application of alternative solutions for the supply of water, the so-called *lock-ins* often show their strength and facilitate the presentation of LDWTs as being solutions without alternatives (Gupta and van der Zaag, 2008; Bourguignon, 2023). Widely used across institutional economics, marketing or governance research, the term lock-in with regard to LDWTs points to the specific constellation of long-lasting and buried materials, financial and engineering logics as well as institutional and political interests unfolding with such large-scale hydraulic infrastructures that eventually lead to a long-term inflexibility in water governance in affected spaces (Gupta and van der Zaag, 2008; Pahl-Wostl, 2002). Usually, with the high value investments, state and private investors argue for the need of long-time operations of LDWTs for amortisation purposes. Furthermore, they are complex technological systems often accompanied by experts whose knowledge dominates the debates about the potentials and risks. Moreover, LDWTs are inherently political as they are used instrumentally to manifest the political power and ideology of those in charge (Hommes et al., 2022). Here, Franco's dam and transfer building in Spain is a prominent example (Swyngedouw and Boelens, 2018). Hence, LDWTs tend to benefit some groups over the disregard of others (Bourguignon, 2023).

Against the risk of such lock-ins, the likely investments in LDWTs in Germany appear counter-intuitive to uphold principles of today's water governance such as water security, adaptation and resilience, decentralisation, or inclusive and integrated water resources management (Gupta and van der Zaag, 2008). Nevertheless, for Germany, there has been no research conducted, as yet, that focusses on the development of LDWTs and the potential lock-ins created. International literature can help here only partially as the German water sector has its own particularities with, for example, its high number of almost 6,000 municipal water suppliers (ATT et al., 2020). Most importantly, the concept of lock-ins of LDWTs needs further empirical elaboration to increase its analytical significance. In his recently published article on how LDWTs bring about change for hydrosocial relations, Bourguignon (2023) calls for a stronger and interdisciplinary focus on the temporality of lock-ins, their interplays with local dynamics and the contestations that often accompany large hydraulic infrastructure projects. In general, many articles assign LDWTs a lock-in tendency that leads to negative social,

ecological and economic impacts by reviewing several or large-n cases. However, it often remains unclear how exactly lock-ins emerge, persist and play out.

Thus, while it is well researched that LDWTs pose the risk of lock-ins and what the negative consequences for the environment and people can be, there is the need for improving knowledge on the lock-in as a phenomenon itself. To contribute to the existing lock-in research around LDWTs as well as to the current debates around expanding LDWTs in Germany, we have, therefore raised the following question:

When, where and how do lock-ins of long-distance water transfers emerge?

For an in-depth investigation into this question, we chose the LDWT system of Fernwasserversorgung Elbaue-Ostharz (FEO) in Central Germany as a case study. By analysing its spatial and temporal development, we have identified various lock-ins and researched them in detail. We have carved out the specific economic, technological, institutional and political phenomena that had culminated in a certain time and space, in order to understand how their relationships became manifest. Such a perspective moves the focus away from the often contested construction processes of LDWTs and the negative effects unfolding with LDWTs to lock-ins as the primary object of study. However, we have not researched lock-ins in isolation from past, future or parallel dynamics. On the contrary, beyond a schematic perspective that understands large-scale infrastructures mainly as causes that lead to unjust social-ecological effects, we seek to understand lock-ins in their relationality, as situated, context-specific phenomena.

We start this paper by explaining how our methodological approach of conducting a case study in Germany from an interdisciplinary perspective can produce new insights into the when, where and how of lock-ins emerging with LDWTs (chapter 2). We then elaborate on three key periods in the infrastructural development of the FEO, a typical LDWT system in Germany (chapter 3.1). Based on this, we identify various lock-ins with their specific and overlapping qualities (chapter 3.2). By discussing our findings with existing literature, we emphasise the advantages of understanding lock-ins as being relational (chapter 4). We conclude by arguing for a context-specific assessment of the potentials and risks of LDWTs (chapter 5).

Background: Conceptualising LDWTs and lock-ins

In Germany, the term long-distance water supply (Deutsch: Fernwasserversorgung) only covers the role of the preliminary suppliers that do not supply the individual households directly but that are in charge of transporting water over large distances to the municipal water network; the supply is then handed over to the municipal supplier who is responsible for supplying water to every individual household. However, municipal suppliers in the metropolitan cities of Germany, such as Munich or Hamburg, directly import water from other administrative or hydrological areas. This further increases the actual number of people supplied over large distances. Such transports of water conducted by the municipal supplier are thus not included in the statistics and maps provided by Mehlhorn and Weiß (2009) or aquabench (2022, 2018). In contrast to this definition of long-distance water transfer as preliminary supply, referenced broadly in German literature, the internationally established term of interbasin water transfers (IBWTs) does not differentiate between preliminary long-distance and municipal suppliers. Instead, IBWTs follows the criterion of whether distinct river basins are connected. Research shows, however, that also water transfers within the same river basin can have manifold social and hydrological impacts (Purvis and Dinar, 2020). Therefore, in our research, we use the term long-distance water transfers (LDWTs) to cover all technologically enabled transports of water from presumed water-rich to water-poor areas crossing either hydrological (e.g. river basin, sub-basin or aquifer) or administrative (e.g. municipality, district or state) boundaries.

This includes the operations of the preliminary as well as municipal suppliers. Clearly, such a definition requires a context specific assessment of whether a water transport can be considered long-distance or not.

As a conceptual starting point for inquiring lock-ins, we have adopted the general dimensions suggested by Pahl-Wostl (2002) and further developed by Gupta and van der Zaag (2008) and extended them with the cross-cutting dimensions of temporality, spatiality and power following Bourguignon (2023) and Hommes et al. (2022). We understand a lock-in of an LDWT as a situation in which technological, institutional, political and economic processes, interests, or practices align in such a way that the transfer infrastructure manifests itself for decades as necessary and without alternatives. The process of interlocking between these different factors can occur in multiple temporal and spatial dimensions. We have therefore analysed when a lock-in happens, if temporal patterns can be observed and which spaces are created with lock-ins. Accordingly, spatiality refers to the territories and scales where a lock-in can be located or that are created with lock-ins. Lock-ins often introduce new scales by connecting two distinct river basins or administrative areas (Gupta and van der Zaag, 2008). Here, we wish to understand how these new scales interplay with the already existing scales such as the municipal scale (Bourguignon, 2023). Lastly, we have looked at power relations; this refers to the different forms of how lock-ins shape the possibility of agency for various groups in constructing societal relations to water (Hommes et al., 2022). With *lock-ins of LDWTs* we refer to lock-ins of large hydraulic infrastructures. The term infrastructure emphasises that LDWTs are not solely technological connections between two places but are always discursively enabled, powerfully contested and constantly remade by practices of operating or using the infrastructures (Hommes et al., 2022).

2 Research approach: Grounding socio-hydrology

We chose an interdisciplinary and grounded approach to identify lock-ins and to understand their temporal and spatial developments. We mobilized physical and human geography as well as anthropology through a conjoint socio-hydrology and hydrosocial perspective when collecting and analysing data.

Combining socio-hydrology and hydrosocial research has allowed us to analyse, which economic, technological, institutional or political factors are interlocked, and how. While both perspectives attempt to understand water-society-relations, socio-hydrology has its epistemological strength in emphasising the hydrological and technological dynamics that shape societal phenomena (Di Baldassarre et al., 2013), whereas hydrosocial research is conceptually and methodologically well-equipped to contest presumed natural hydrological processes and, thereby, underlines their societal, i.e contingent and powerful character. In line with the proposals from Ross and Chang (2020), Wesselink et al. (2017) or Bruns (2016) to focus more on the synergies of socio-hydrology and hydrosocial research instead of ontological and epistemological differences and the empirical illustration of this by, for example, Luetkemeier et al. (2021) for human-groundwater interactions over large distances or Savelli et al. (2021) for droughts, we mobilised both perspectives to complement their respective strengths.

When doing so, however, we chose a grounded approach rather than developing a strong explanatory framework encompassing the socio-hydrology as well as hydrosocial perspectives conceptually. Merging them into a uniform epistemology risks cutting off the strengths of both perspectives. Plausible yet highly generalized frameworks tend to prove or illustrate empirically what is broadly assumed conceptually and thereby tend to decrease the significance of the results. In turn, the detection of unexpected dynamics, factors or actors that lie beyond the surface of the research object becomes less likely.

We therefore decided to start with a shared empirical phenomenon instead. Grounding our various perspective in a single case study allowed us to find dynamics that evade clear conceptual distinctions between hydrosocial and socio-hydrological research. Thus, in place of a shared boundary *concept* like a framework, the case of Elbaue-Ostharz served as a real-world boundary *object* for bringing the social-hydrological and hydrosocial perspectives into engagement (Mollinga, 2010). While concepts primarily facilitate cross-cutting communication, boundary objects steer conjoint action in situations of incomplete, uncertain or even contradictory knowledge (Mollinga, 2010). Understood as a hydrological force, physical infrastructure but also discursive and political process, the LDWT Elbaue-Ostharz therefore allowed us to actively ground our perspectives in a shared research object and develop a contingent yet significant analysis of its lock-ins.

The results developed from such a grounded approach are, however, not bound to the specific case but can productively be brought into engagement with results from similar single or large-n case studies as well as conceptual works (Flyvbjerg, 2006). Here, our decision to choose a typical case increases the likelihood that similar and thus comparable cases exist. In addition, generalizing grounded research results is possible when e.g. choosing a case in which a certain phenomenon is expected to be most or least likely (Flyvbjerg, 2006). However, while grounding socio-hydrology does not impede comparison and generalization, we question whether this is necessarily the ultimate end of socio-hydrologic research. As argued above, generalized frameworks tend to prove points instead of facilitate learning. Furthermore, results grounded in a single case study might allow a better communication between science and policy and more pointed policy interventions given their proximity to empirical phenomena that are also experienced beyond science (Flyvbjerg, 2006). Applying the words of Flyvbjerg (2006) about case study research in general to our concern, we argue that socio-hydrology cannot and must not "[…] be all things to all people" (238). Instead, grounding socio-hydrology "allow[s] the study to be different things to different people" (238).

In summary, grounding socio-hydrology as a research approach refers to an open analytical process around a specific empirical phenomenon – here: lock-ins of LDWT – in a single case study. Instead of quantified models or strong concepts, a grounded investigation allows the generation of different results on different ontological and epistemological levels that yet draw together in one narrative (Zwarteveen et al., 2021; Flyvbjerg, 2006). Grounding can therefore contribute to a productive confrontation of hydrosocial and socio-hydrology approaches beyond a strict separation or total dissolvement. By these means, we tried to ensure a time-, space- and context-specific understanding of the dynamics, factors and events that permit lock-ins of LDWTs to emerge.

2.1 Case: Elbaue Ostharz Long-Distance Water Transfer (FEO)

The Elbaue-Ostharz LDWT (FEO) qualifies as a case study for our research as it is a typical LDWT in Germany. Constructed after the Second World War its primary aim was to supply metropolitan cities with drinking water (Mehlhorn and Weiß, 2009). Furthermore, with the FEO we can test our extended definition of LDWTs. While all transport pipelines of the FEO are located within the Elbe river basin, they physically connect various sub-basins and the federal states of Saxony and Saxony Anhalt (FEO, 2016). The several expansion stages even in times of decreasing water demand indicate the possibility of lock-ins at play. Lastly, the comparably extensive documentation of the FEO from the initial ideas until today allows identifying and researching in detail potential lock-ins.

The FEO is a large-scale infrastructure system for withdrawing, purifying, transporting and distributing drinking water and consists of a dam, wells, waterworks, pipelines and elevated tanks. With a length of about 800 km, it is the fifth largest LDWT pipeline system in Germany. It supplies about 2.5 million people with 80 million m^3 of water every year that is extracted from surface and groundwater resources (aquabench, 2018; FEO, 2016). While the western part of the network is

supplied with water extracted from the Rappbode Dam and treated by the Wienrode waterworks in the Harz Mountains, the eastern part is supplied with bank filtrate from the River Elbe allocated by the Torgau-Ost waterworks and with groundwater allocated by the Mockritz waterworks. The operator of the FEO is the Elbaue-Ostharz limited liability company (German: *GmbH*) that is owned by 66 municipalities which are, themselves, supplied by the FEO. The cities of Halle and Leipzig are the largest shareholders with almost 25% each (FEO, 2019). Operator of the Rappbode Dam is the public dam operator of Saxony-Anhalt (TSA, 2023).

The region's hydro-climatic conditions are characterized by sharp spatial discrepancies. While the Harz Mountains in the west receive more than 575 mm of precipitation annually, the central and eastern parts only show precipitation levels of 400 mm and less (LGG, 2022a). The western Harz Mountains gain orographic rainfall with an altitude of more than 1,100 m, whereas the eastern areas show rather dry conditions (Fabig, 2007). In addition, the climatic water balance of the region confirms this discrepancy with positive values of above 300 mm in the Harz Mountains and negative values of below 100 mm in the centre and in the east (LGG, 2022b). Thus, the Harz Mountains act as the regional water tower that feeds various perennial tributaries of the River Elbe. Overall, hydrogeology in the region is again complex with Karst formations in the Harz Mountains and porous aquifers in the floodplain areas of major rivers such as the Saale and Elbe (Hattermann et al., 2011). Figure 1 locates the FEO infrastructure in the region, indicating the hydrological and administrative boundaries crossed and schematically maps the different expansion stages of its pipelines.

Early industrialisation and the resulting higher demands of households and industries, together with a simultaneous decrease in water availability due to the pollution of local water bodies triggered the first plans for building LDWTs to supply Halle, Magdeburg and Bitterfeld in the late 19th century (Blackbourn, 2006; FEO, 2016; Malyska, 1995, 2001). With the birth of modern engineering and the foundation of a supra-regional institution for dam building in the Harz Mountains, further cornerstones were set (Blackbourn, 2006; FEO, 2016). After World War II, these small steps culminated in the actual construction phase. Within several years, the Rappbode Dam and hundreds of kilometres of pipelines both from the dam as well as from the River Elbe towards the industrial centres of the German Democratic Republic (GDR) were constructed (FEO, 2016). In the 1960s and 70s, the fusion of the operators of the pipelines from both directions and the growing demand for industrial development in metropolitan areas facilitated the stepwise enlargement of waterworks at the Elbe and the construction of new pipelines for municipalities previously not connected. After the German reunification in 1990, water demand decreased tremendously due to population emigration to Western Germany and the breakdown of former GDR industries. While downsizing some of its waterworks, the FEO extended tremendously its numbers of customers and pipelines in the 1990s. Furthermore, the past 10 to 20 years have been characterised by selective investments to acquire new customers and connect more municipalities in Saxony and Saxony-Anhalt (FEO, 2016). The latest connection occurred in 2018 with Sangerhausen, a city in the outskirts of the Harz mountains (Wasserverband Südharz, 2018).

2.2 Material and methods

We started our empirical research by collecting grey literature, scientific articles and conducting qualitative interviews about the development of the FEO (Figure 2: step A). Here, we made use of an

extensive description of the historical development of the FEO that was published by the supplier itself on the occasion of its 50th anniversary. We complemented this information with scientific articles on the history of the drinking water supply in Saxony-Anhalt, generally, and Halle, specifically, as well as with interviews. Semi-structured interviews were carried out with the FEO itself, the operator of the Rappbode Dam, the responsible ministry in Saxony-Anhalt and the waterworks of the city of Leipzig. In addition, we conducted seven interviews in the district of Mansfeld-Südharz in order to understand the local dynamics around the connection of the capital city of Sangerhausen and neighbouring municipalities to the FEO in 2018. The interview partners represented the regional water supplier, a non-governmental organisation (NGO) dedicated to sustainable alimentation, a citizen initiative, the water authority of the district, Sangerhausen's department for urban development, the regional section of an agricultural interest group and a concerned citizen active in the voluntary fire brigade[1].

We then coded our empirical material with an open approach framed by leading questions such as (1) which area was connected when (2) who was in favour, who against (3) what were the competing arguments and (4) what have been alternatives. After collecting numerous codes from the various sources, we grouped them together across the material and thereby identified key periods in the infrastructural development of the FEO (Figure 2: B). Within these key periods, we carved out various lock-ins by analysing in detail how specific technological, economic, institutional or political factors manifested and related to each other. As cross-cutting themes, the temporal and spatial interplays throughout the lock-ins and their constellations were investigated (Figure 2: C).

3 Results: Different lock-ins that overlap

In the following, we present three key periods of infrastructural development of the FEO infrastructure. Each periods is analysed in detail concerning technological, economic, institutional and political processes at play. Thus, we were able to carve out three lock-in situations. Figure 3 provides a visualization of the three infrastructural development periods identified. Besides major infrastructural investments and political events, the figure also shows how the total volume of water sold changed over the years.

[1] A list with all interviews used for this research is provided as an appendix after the reference list.

3.1 Major infrastructural developments in the history of the FEO

State-building in the 1950s

The first key infrastructural development of the FEO originated in the 1950s and has its spatial centre within Halle. At this time, in the recently founded GDR, technological means, high financial investments into economic growth, socialist ideology and centralised policy-making merged into the construction of the Rappbode Dam and the initial pipeline from there to Halle. Just prior to this, Halle was connected with existing waterworks on the River Elbe by another long-distance pipeline (FEO, 2016; Malyska, 1995). In the following, we expand on the various technological, economic, political and institutional aspects of this period and explain how they are related to each other.

In the post-war 1950s, the industrial and domestic water demand in urban agglomerations, such as Halle, increased. This was driven by the political plans of the GDR to establish chemical industries in the region, expanding mining activities and subsequent urban population growth. Located in the so-called rain shadow of the Harz Mountains, this put enormous pressure on the existing water bodies. The growing coal, potash and chemical industries, together with intensified agricultural land use as well as higher volumes of municipal wastewater led to elevated concentrations of heavy metals, ammonium, salt, nitrate, nitrite and oxygen consuming micro-organisms in local surface and groundwaters. The river Saale suffered from water quality deterioration and significantly increased water treatment costs (FEO, 2016; Malyska, 1995). Under these conditions, more efficient water use or lower thresholds for pollutants in the water bodies would have protected the quantity and quality of the local waters. Instead, Halle was connected to the recently built Rappbode Dam as well as to already existing waterworks at the River Elbe. Already several decades before, the president of the province of Saxony called the supply of Halle with LDWT “imperative” (1936, cited from FEO, 2016, p. 22, translated by David Kuhn). But, how could the idea of transferring drinking water over tens and hundreds of kilometres for Halle and other industrial cities such as Bitterfeld and Leipzig, appear as necessary solution without any alternative?

Since the late 19th century, plans to dam the River Rappbode in the eastern part of the Harz Mountains were discussed across Central Germany. Engineers, politicians and public officials at the state level, and also those from growing cities like Leipzig, Bitterfeld or Halle, highlighted the potential for energy production and long-distance supply of drinking water. Parts of the local population in the Harz region also hoped for enhanced flood prevention by building a dam. However, for decades, the construction plans were not materialised due to financial concerns and protests by the people who would have been resettled (FEO, 2016). After the Second World War and with building of the GDR state those ideas became a physical reality rather quickly and the Rappbode Dam was built from 1952-1959. Centralised policy making in the GDR facilitated the realisation of such large-scale infrastructures. Shortly after the foundation of the GDR in 1949, the Rappbode Dam as well as the Elbe transfer project were prioritised politically by including them in the so-called 5-year-plan for economic development in the GDR (FEO, 2016). In addition, the GDR government presented the Rappbode Dam as a symbol for the superiority of the socialist political system. The historian David Blackbourn writes:

"There is no better example than the symbolic significance accorded to dam-building. The showpiece here was the series of great dams constructed in the river basins of the Bode and Wipper, beginning with the Sosa *Peace Dam* [highlighted by Blackbourn] opened in 1952. Size was important to their advocates - the fact, for example, that the retaining wall of the Rappbode Dam was the highest and largest in either Germany. The dams were an advertisement for *peaceful construction* [ibid.] and the virtues of socialist planning, the realization of 'good and progressive ideas' that had been thwarted by the economic conflicts of the capitalist system" (Blackbourn, 2006, p. 336).

The legitimisation of long-distance water transfers for growing cities in Central Germany was further pushed by the so-called "Chemical Programme" (German: *Chemieprogramm*) announced by the GDR-president Ulbricht. Prioritising the upscaling of the production capacity of the chemical industry marginalised existing concerns about the quality and quantity of local water bodies and politically constructed a *water scarce* region. The large political visions not only materialised into physical dams and pipelines, but also institutionally. In 1966, the separately existing Elbaue and East-Harz suppliers were amalgamated with the aim of increasing organisational efficiency. With this, a supra-regional institution was formed that supplied huge parts of the populations and industries in the GDR (FEO, 2016). Examples of the long-term impact of this new institution include the complementary laboratory practices that are still in existence today. To save costs, the laboratory of the Wienrode waterworks (Harz) and that of the Elbe waterworks are each specialized in analysing certain water quality parameters and therefore send samples to each other – alongside the pipelines connecting Harz and Elbe (interview 1, FEO). Furthermore, in the two decades following the amalgamation, the pipeline network was gradually extended towards smaller municipalities located along the main tubes and volumes of water sold increased exponentially until 1989 (FEO, 2016).

Consolidation in the 1990s

We situated a second temporally and spatially intense development period of the FEO in the 1990s. The rather unforeseen breakdown of the German Democratic Republic (GDR) in 1989, led to the collapse of the water intensive industries and a population exodus to Western Germany (FEO, 2016; Malyska, 1995). Within five years, the volumes of water sold by the FEO almost halved. The FEO perceived this development as a serious hydraulic, hygienic, economic and institutional threat. If the transport capacity of long-distance water transfers is used below a certain minimum flow, then the piped network does not perform as designed (Haakh and Horlacher, 2018). This, in turn, can create supply problems in the connected municipal networks due to low volumes of water arriving with low hydraulic energy. In addition, if less water is consumed, the water travel times increase, which can increase the risk of hygienic problems (Haakh and Horlacher, 2018). Lastly, the decreasing volume sold led to decreasing revenue and put economic pressure on the FEO that was after 1990 converted from a public into a private limited liability company (German: *GmbH*) with the supplied municipalities as shareholders (FEO, 2016).

In few of the tremendous drop in water demand, it would have been an option to downsize or even fully shut down the transfer infrastructure of the FEO. Consequently, the connected municipalities would have had to switch back to local resources, reuse grey water or find alternative water sources. Indeed, several waterworks alongside the Elbe were closed. However, at the same time, huge investments were made. Some waterworks at the Elbe wetlands were renewed, but, most strikingly, the pipeline infrastructure was expanded in length and the number of customers increased. New pipelines were built to connect Zorbau, Gleina, Bischofrode and other municipalities during the 1990s. The FEO actively intensified the acquisition of new customers with the aim of compensating the reductions in water volumes sold and subsequent revenues (FEO, 2016) (interview 1, FEO; 2, dam operator). Here, the institutional conversion of the FEO played out institutionally and economically. Up to this day, Leipzig and Halle each own almost 25% of the shares (FEO, 2019). Losing the FEO as a

major supplier was not in their interest as it would have meant significant investments in order to secure their municipal supply without water being imported over long distances. Furthermore, as a water supplier working under the water laws of the Federal Republic of Germany, the paradigm of cost recovery in the water supply and treatment sector had also applied to the FEO from 1990 onwards. Thus, the price per litre for drinking water a supplier obtains from private households must cover all the costs for water withdrawal and distribution. Subsequently, selling less volumes of water while maintaining the existing infrastructure would have led to enormous increases in prices per litre.

In this situation, the FEO itself and its shareholders including the federal states of Saxony and Saxony-Anhalt decided to ensure the further existence of the FEO as an institution and the LDWT infrastructure by expanding, instead of downsizing its pipelines.

Branching in the 2010s

A third key development is showcased by the connection of the city of Sangerhausen, located in the south-western outskirts of the Harz Mountains, to the FEO infrastructure in 2018. Prior to this, several groundwater wells supplied the municipality with drinking water. However, in 2009, traces of uranium were found in one well that considerably exceeded the threshold of 10 mg/l; likely due to geogenic reasons (Koch, 2018). Consequently, the regional water supplier installed filters to upgrade treatment facilities and separate the uranium. However, the disposal of the hazardous uranium was challenging and treatment costs further increased (interview 9, regional water supplier). In addition, high concentrations of nitrate and sulphate from agricultural practices were perceived as another threat to the local water supply. After almost a decade of intense public debates between the regional water supplier, local and regional politicians, a citizen initiative and an NGO, the city of Sangerhausen today receives water transported over long distances from the Rappbode Dam (Wasserverband Südharz, 2018).

This most recent, yet selective, expansion of the FEO infrastructure can however, not be understood when only analysing the large-scale infrastructural development of the FEO. The connection of Sangerhausen was strongly demanded by local forces. The public opinion in favour of long-distance water transfer was heavily shaped by a citizen initiative supported by a national NGO who expressed negative perceptions of the local, decentralised and groundwater-based supply (interviews 6, NGO; 7, citizen initiative). The key argument was built on the uranium, nitrate and sulphate concentrations being presented as serious threats to the health of the population by relating them to the suspected high cancer rates in the region (Koch, 2016b). Public attention was created by the initiative through an open letter sent to the German Minister for Health (Koch, 2016a) and with a petition that reached 30,000 signatures (LandesNachrichtenPortal, 2017). In addition, mistrust was expressed about the reliability of the official threshold levels for uranium and whether the monitoring systems of the water suppliers and public authorities worked correctly (interviews 5 farmers association; 6, NGO; 7, citizen initiative). In sharp contrast, the water transported from the Rappbode Dam was presented as the “good” water (interviews 6, NGO; 7, citizen initiative). The regional water supplier, however, ensured that the supplied water was harmless as the values of potentially hazardous substances remained under the officially suggested thresholds (interview 9, regional water supplier).

These local developments have become intertwined with supra-regional dynamics, such as the ministerial financial support by the federal state of Saxony-Anhalt (Env. Ministry S-A, 2016). While a representative of the responsible state department emphasised the competence of the municipality when it comes to its water supply, the federal state can exercise indirect influence by providing financial support for certain development pathways (interview 3, env. ministry). In addition, arguing for the technical feasibility of a connection to Sangerhausen was facilitated by an earlier expansion

phase of the FEO in the 1990s when a pipeline to a nearby elevated tank (Bischofrode) was constructed but not put into use – until 2018 (Koch, 2018).

After the connection, many perceived the drinking water as tasty and less harmful to kitchen machines due to lower concentrations of calcium carbonate (interviews 7, citizen initiative; 8, water authority; 10, city of Sangerhausen). Furthermore, the regional water supplier saw advantages when monitoring water originating from one single source in a huge protected environment, which is, thus, less susceptible to pollution (interview 9, regional water supplier). Overall, some interview partners considered the district's water supply security to be enhanced as the Rappbode Dam may be well adapted to climate change, while the contract with FEO ensures long-term supply security. On the other hand, representatives from the regional water supplier or the city of Sangerhausen remain concerned due to the high dependency on one preliminary supplier, the FEO, and only one source, the Rappbode Dam. In addition, since local groundwater wells are no longer used for the drinking water supply, water protection areas have expired and more intensive land use is again possible. This will likely decrease the possibility of using the local groundwater bodies at a certain point again as drinking water resource. Furthermore, municipalities around Sangerhausen concerned with local drinking water resources are now also considering the connection to the FEO via Sangerhausen (interview 11; citizen.

3.2 Situating lock-ins in FEO's infrastructural development

We have situated various lock-ins within and across the three key periods of FEO's infrastructural developments. In the following, we show how specific lock-in formations emerge in specific temporal and spatial contexts. We then argue how the different lock-ins cannot be understood separately but are powerfully intertwined over time and space.

The 1950s period shows similarities to more recent prominent examples of how a lock-in around large hydraulic infrastructure emerges. The technological potentials of modern engineering and the corresponding idea of *taming* water (Blackbourn, 2006) have merged with state-building efforts of the German Democratic Republic. Centralised policy-making for fast economic development towards industrialisation released high investments into the construction of the prestigious Rappbode Dam and the first pipelines to Halle. Within a decade, a new hydrological and institutional scale was created between the Harz in the west and the Elbe wetlands in the east that remains up to this day (interview 4, waterworks Leipzig). Throughout the following decades, the volumes transported by the FEO were growing together with the number of municipalities supplied. Once the main pipelines for Halle, Bitterfeld and Leipzig were built, increasing numbers of junctions were installed to connect rural supply areas along the way.

With the political and economic breakdown of the GDR in 1989 and 1990, the technological and economic pressures, in particular, formed a situation that could be titled "consolidation lock-in". By downsizing some parts, and renovating and expanding other parts of the infrastructure, the FEO was re-materialised physically as a long-distance transfer infrastructure but also institutionally as the most important preliminary water supplier in volume, pipeline length and number of connected municipalities and households in all of Central Germany. As shown above, the decision against alternatives to the FEO was also shaped by the conversion of the formerly nationally-owned company (German: *Volkseigener Betrieb*) to a private-law company owned by the supplied municipalities and working under the condition of cost recovery.

This constellation cannot, however, be understood as being detached from the first lock-in. For example, even though the FEO was now operating in the political system of the Federal Republic of Germany with strong competences for the federal states and the municipalities, the FEO remained a

supra-regional institution across the two federal states of Saxony and Saxony-Anhalt. These federal states were clearly against a privatisation and when the national government still decided to do so, they bought the shares themselves – together with municipal water suppliers and cities like Halle and Leipzig. Thus, once established as a supra-regional institution in 1966, the FEO even survived a fundamental system change. In addition, the high investments seen as necessary to operate further under the principle of cost recovery in the 1990 not only resulted from decreasing water demand and new legal conditions but also from the oversized infrastructural investments in the 1970s and 1980s. The already exponentially growing water transport was expected to reach even higher levels in the 1990s and 2000s. In anticipation, the GDR decided to enlarge waterworks and pipelines and therefore manifested an infrastructural future for socio-economic conditions that up until today have not become a reality but rather turned out to be the opposite of what has been expected.

Regarding the occurrence of the lock-in situations in the 1950s and 1990s, constellations on the national, supra-regional and state levels have been the dominant drivers. In addition, they can both be characterised by the high investments into large-scale infrastructure in a short time. Therefore, they can be seen as situations in which a lock-in formed rather abruptly. To describe the period since the 2000s with the connection of Sangerhausen, the term *gradual* appears to be more apt. Selective investments in specific items of the LDWT infrastructure over years that are also strongly shaped by local actors can be considered key characteristics for a rather slow formation of a lock-in. However, the gradual expansion, for example, Sangerhausen that was driven by local forces was only possible due to the abrupt expansion in the 1990s, when the construction of the branch towards Sangerhausen was started without being finished and was not used until its later completion 2018 (Koch, 2018). Thus, the lock-in situated between the LDWT development and Sangerhausen's groundwater conflict was also shaped by previous lock-in formations.

4 Discussion: Lock-ins as relational phenomena

The analysis of the infrastructural development of the Elbaue-Ostharz LDWT has revealed various constellations that qualify as lock-ins: high investments over short periods of time in large-scale, long-living infrastructures charged with political and economic visions that limit for decades the potential for adaptive (drinking) water governance in the involved supply areas and systems. This is in line with existing lock-in literature which suggests that the construction of LDWTs unfolds large-scale technological, institutional, economic and political dynamics that eventually lead to a long-lasting and robust but inflexible water infrastructure (Gupta and van der Zaag, 2008; Pahl-Wostl, 2002). Nevertheless, with our interdisciplinary and grounded research approach we could show that lock-ins are not uniform, static or natural attributes to LDWTs but are contested processes that emerge, decline and are re-manifest in different times and spaces.

Firstly, our findings reveal how in different situations, technological, institutional, economic or political factors play out in different shapes and intensities. We located the initial first lock-in of the FEO temporally in the 1950s and spatially in the industrial centres like Halle of the recently founded German Democratic Republic. Here, mainly large-scale political and economic visions merged with the large-scale engineering plans into the creation of a supra-regional infrastructure system and its operating institution. In the 1990s, however, it was hydraulic, hygienic and amortisation factors that were prominent. Moreover, in the 2010s, when detecting a "small" lock-in, political protest and the public mistrust of the regional water supplier were key drivers.

Among these factors, the high pressure for amortisation that nurtured the decision to expand, rather than dismantle, large parts of the FEO in the 1990s deserves special attention. Most municipal and preliminary drinking water suppliers in Germany are public companies or are owned by public institutions. However, while not being fully privatized like in other European countries, also the

German water sector has been shaped by neoliberal ideas since the late 1990s. Thus, the FEO decision to acquire more customers in order to ensure cost recovery can be embedded in what Wissen and Naumann (2006) called the “commercialization” (p. 20) of water supply. This term exceeds the conceptual division between public versus private, and demonstrates how publicly owned companies are also not free from market logics.

Furthermore, our results offer a nuanced perspective on the spatiality of lock-ins. While previous research often explains the construction of LDWTs as state-led top-down development projects (Gupta and van der Zaag, 2008; Hommes et al., 2022), we could show how the local scale matters. In many case studies, the local populations in the sending or transmitting regions oppose the construction of LDWTs, suspecting or already experiencing negative environmental, social and economic effects (Bourguignon, 2023). In our case, however, the expansion of the LDWT towards Sangerhausen was clearly demanded by many local citizens due to concerns about the local groundwater quality and was intertwined with political and infrastructural developments on a larger scale. Thus, it needs to be assessed for every case if and how exactly the large-scale infrastructure manifests the power of whom. Local concerns not only matter as contestations to the infrastructure, but can in some cases also be key drivers of an expansion. Especially in countries like Germany where municipalities have strong competencies in regard to drinking water supply, local perceptions about supply security can vary from village to village.

In addition, our findings show that the industrial centres of the GDR, such as Halle, are at the heart of the pipeline network, but over time, small and rural municipalities have also been connected to the FEO. Thus, while literature on LDWTs beyond Germany argue that usually, LDWTs serve urban supply or irrigation purposes (Bourguignon, 2023), our case shows that while urban supply was the primary goal, the FEO now also supplies sparsely populated and economically marginal municipalities. Furthermore, we argue based on our findings that lock-ins not only create infrastructure persistence and thereby shape territorial boundaries but can also lead to the spatial expansion of the pipeline system beyond originally receiving areas. In such cases, it is likely that it is not only the net length of pipelines that expands. For Sangerhausen, findings have shown how the regional administrative, hydrological and infrastructural systems of the municipal water supply are also altered in the course of the connection to the FEO (Frick-Trzebitzky et al., 2023)

It is not just spatially but also temporally, that the lock-ins of the FEO appear to be not linear; rather, they are contingent processes. While the 1950s and 1990s stand out due to the intense infrastructural expansion in such a short period of time, the 2010s show a different velocity in infrastructural development. Nevertheless, we see such gradual developments as another side of the lock-in coin. Our findings suggest that the gradual infrastructural expansions seen in the 2010s, but also in the 1970s and 1980s, have been facilitated by large-scale investments that eventually trickle down into the peripheries of the pipeline system. Vice versa, gradual developments completed over much time can culminate towards reaching infrastructural capacity limits and, therefore, this scenario can be used as an argument for another abrupt expansion phase.

Our findings demonstrate how the various, detected lock-ins are entangled over time and space. For example, the branching in the 1990s towards Sangerhausen was a key component of the argument for supplying Sangerhausen with imported water instead of the local groundwater. Thus, locating lock-ins within the infrastructural development over time and space provides more detail when explaining how such situations emerge and offers an understanding of lock-ins as relational and contingent processes. This agrees with the proposed relational understanding of hydraulic infrastructure in general by, for example, Hommes et al. (2022), when researching the making of hydrosocial territories. They emphasise how hydraulic infrastructures are not static expressions of the power relations that are built into it. Rather, through changing meanings, materialities and

practices with and around such infrastructures, hydrosocial territories are made and remade over time and space and thereby infrastructures can also change power relations (Hommes et al., 2022).

When reflecting on our research approach, we do indeed see various advantages of mobilising socio-hydrology and hydrosocial research around one case study serving as a boundary object. Broad frameworks that attempt to integrate the different epistemologies may blunt the sword of interdisciplinarity. Hence, we perceived the open approach to our empirical material as productive polishing between the perspectives that revealed the multifaceted and relational character of lock-ins. Here, the broadened definition of LDWTs as crossing either hydrological or administrative boundaries was supportive as it broadened our focus towards the local scale and how it is plays out with larger hydrological but also administrative or political scales.

Despite this positive side of an open approach to LDWTs and lock-ins, we expect that with a stronger hydrosocial framework like governmentality (Hommes et al., 2022) or socionatures (Bourguignon, 2023) we may have been able to elaborate better on the powerful discourses and practices unfolding with the hydraulic infrastructures.

5 Conclusion

Ensuring secure public drinking water supply is challenging in times of climate change, with the additional burden of altering demand patterns and land use practices that deteriorate the local groundwater bodies. In Germany, long-distance water transfers (LDWTs) are regarded as a key supply-side answer to these multiple challenges. As large-scale hydraulic infrastructures can limit the potential for adaptive water governance in the involved supply areas over decades, we analysed where, when and how such *lock-ins* emerge. Taking the example of the Elbaue-Ostharz water transfer system (FEO) in Central Germany, we identified three lock-ins throughout its temporal and spatial development and researched them in detail. Our findings reveal, how the various lock-ins show different constellations of technological, economic, political and institutional factors. In particular, the conversion of the legal form of the FEO and the cost recovery principle in the German water sector as well as the hydraulic and hygienic concerns are key for explaining the lock-in that emerged in the 1990s. In addition, some lock-ins were located in the metropolitan areas, within the original territorial boundaries of the infrastructure, while other lock-ins occurred beyond the major cities, in small and rural municipalities. We have shown how large-scale developments can interlock with local protests in a way that the expansion of the long-distance water transfer infrastructure is presented as necessary. In summary, our findings contribute to a relational understanding of the lock-ins of long-distance water transfers and suggest a context-specific assessment of the potentials and risks of long-distance water transfers in times of multiple crises.

Here, we wish to emphasise that water supply security is not an uncontested concept. While there is a technical norm for Germany that defines a certain quality, quantity and redundancy of drinking water supply to be considered secure (DVGW, 2022), our case shows how a plurality of perceptions can exist over what constitutes drinking water of good quality is and whether local groundwater resources or the transport over large distances from a dam is more secure. Therefore, we suggest to regard the current debate in Germany at the national level as well as at the local levels as a powerful discursive struggle over how to structure the *problem* of climate change and drinking water supply that, in its effect will favour certain *solutions* over others. A securitization perspective could be beneficial here. Arguing for LDWTs to ensure water security fearing water shortages may alternative solutions such as local water reuse, for example: “By working with and justifying concepts of water surplus and scarcity […] these concepts become naturalized and unquestioned within scientific and public discourse” (Bourguignon, 2023: 243).

With this critical perspective, we do not wish to argue against LDWTs. Rather, we want to emphasise that building and expanding LDWTs for drinking water security belong to "supply-oriented engineering measures to large societal challenges" (Gupta and van der Zaag, 2008: 28). This means that climate change and drinking water supply, as large societal challenges, are discursively and materially confined to technological but also powerful measures when highlighting LDWTs as the preferable solution. It will therefore be decisive whether LDWTs are used as a quick technological-fix or form part of a conjunctive use of different socio-hydrologic strategies like water demand management, wastewater reuse, water conservation with sponge cities and just water practices.

Acknowledgements

The authors wish to express their gratitude to Ulrike Mausolf for providing relevant interview material that she had collected as part of her master's thesis. We also would like to emphasise the valuable support we received from Sarah Wohlmann and Vinzent Rüttger (student assistants of the regulate project) in analysing and visualising data. Furthermore, we thank all our interviewees for providing in-depth insights into the case. The authors also owe a huge debt of gratitude to the two anonymous peer reviewers. The original manuscript benefitted tremendously from the critical yet profound and constructive revisions suggested by them. Finally, we would like to thank the guest editors of this Special Issue for giving us the opportunity to contribute to this highly relevant research field.

Appendix 1.

Appendix: List of interviews

All interviews were conducted individually or together by members of the research project *regulate* and made accessible for all team members after seeking consent from the interviewees. David Kuhn and Linda Söller conducted the interviews as part of their PhD projects, and Kristiane Fehrs and Ulrike Mausolf as part of their master's theses. Each interviewer therefore had specific and partly diverging research questions that, in turn, shaped the interview questions raised.

No.	**Name of institution**	**Explanation**	**Legal form**	**Interview conducted by**
1	Fernwasserversorgung Elbaue-Ostharz GmbH (FEO)	Operator of the Elbaue-Ostharz LDWT	Limited liability company with the supplied municipalities as shareholders	Linda Söller, Kristiane Fehrs, Ulrike Mausolf
2	Talsperrenbetrieb Sachsen-Anhalt AöR	Operator of the Rappbode Dam	Public agency of the state of Saxony-Anhalt	Kristiane Fehrs

3	Ministry for Science, Energy, Climate Protection and Environment of the Federal State of Saxony-Anhalt	Responsible for water resources in the federal state of Saxony-Anhalt	Public agency	David Kuhn
4	Kommunale Wasserwerke Leipzig GmbH	Operator of the centralised public water supply system in the city of Leipzig	Limited liability company owned by the municipality of Leipzig	David Kuhn
5	Bauernverband Mansfeld-Südharz	District level group of the largest interest organisation of farmers in Germany	Registered association	Linda Söller, Ulrike Mausolf
6	foodwatch	NGO active on the German national level dedicated to sustainable alimentation	Registered association	David Kuhn
7	Bürgeraktion gegen uranbelastetes Trinkwasser	Citizen initiative protesting against high uranium levels in drinking water in Sangerhausen	Not formalised	Kristiane Fehrs, Ulrike Mausolf
8	Untere Wasserbehörde, Landkreis Mansfeld-Südharz	Water authority of the district of Mansfeld-Südharz	Public authority	Linda Söller, Kristiane Fehrs, Ulrike Mausolf
9	Wasserverband Südharz	Water supplier for western municipalities in the district of Mansfeld-Südharz	Public administration union	Linda Söller, Kristiane Fehrs, Ulrike Mausolf
10	Fachbereich Stadtentwicklung und Bauen, Stadt Sangerhausen	Department of urban development, city of Sangerhausen	Public authority	Linda Söller, Ulrike Mausolf

11	Citizen of a spatially independent neigbourhood of Sangerhausen	Concerned citizen who is also active in the voluntary fire brigade	Individual	David Kuhn

6 References

aquabench, 2018. 10 Jahre Benchmarking Fernwasserversorgung in Deutschland, Köln. https://www.aquabench.de/fileadmin/user_upload/10_Jahre_Benchmarking_Fernwasserversorgung.pdf. Accessed December 01, 2023.

aquabench, 2022. Dataset on population supplied by long-distance water transfers in Germany between 2003 to 2021 based on Benchmarking assessments, Köln.

ATT, BDEW, DBVW, DVGW, DWA, VKU, 2020. Profile of the German Water Sector 2020, Bonn. https://de.dwa.de/files/_media/content/07%20Englische%20Homepage/DWA/FINAL_brachenbild_ENGL_wasserwirtschaft_2020_DIN_A4_15032021.pdf. Accessed December 01, 2023.

Blackbourn, D., 2006. The Conquest of Nature. Water, Landscape and the Making of Modern Germany. W.W. Norton & Company, New York, London.

BMUV, 2023. National Water Strategy. Cabinet decision of 15 March 2023, Berlin. https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Binnengewaesser/nationale_wasserstrategie_2023_en_bf.pdf. Accessed December 01, 2023.

Bourguignon, N., 2023. Connected and disrupted hydrosocial territories: the making of modern socionatures through inter-basin water transfers. Journal of Political Ecology 30 (1), 240–273. https://journals.librarypublishing.arizona.edu/jpe/article/id/2848/.

BRD, 1949/2022. Grundgesetz (GG). https://www.bundestag.de/gg. Accessed December 01, 2023.

BRD, 2009. Gesetz zur Ordnung des Wasserhaushalts (Wasserhaushaltsgesetz - WHG). https://www.gesetze-im-internet.de/whg_2009/BJNR258510009.html. Accessed December 01, 2023.

Bruns, A., 2016. Socio-Hydrology: The combined analysis of social and ecological challenges in the water sphere – A Syllabus. Trier University, Trier. https://ubt.opus.hbz-nrw.de/frontdoor/index/index/year/2019/docId/1325. Accessed December 01, 2023.

Di Baldassarre, G., Kooy, M., Kemerink, J.S., Brandimarte, L., 2013. Towards understanding the dynamic behaviour of floodplains as human-water systems. Hydrol. Earth Syst. Sci. 17 (8), 3235–3244. https://hess.copernicus.org/articles/17/3235/2013/. Accessed December 01, 2023.

DVGW, 2022. Resilienz und Versorgungssicherheit in der öffentlichen Wasserversorgung. Technische Regel - Arbeitsblatt DVGW W 1003 (A). https://www.dvgw-regelwerk.de/plus#technische-regel/dvgw-arbeitsblatt-w-1003/a00473. Accessed December 01, 2023.

Env. Ministry S-A, 2016. 1,6 Mio. Euro Fördermittel für den Wasserverband Südharz. Land unterstützt Bau der Anschlussleitung an die Fernwasserversorgung. https://www.sachsen-anhalt.de/bs/pressemitteilungen/pressemitteilung-details/?no_cache=1&tx_tsarssinclude_pi1%5Buid%5D=74854&tx_tsarssinclude_pi1%5Baction%5D=single&tx_tsarssinclude_pi1%5Bcontroller%5D=Static&cHash=4f5849bc8294283eb49774b01e6d63c2. Accessed December 01, 2023.

Fabig, I., 2007. Wandel der Niederschlagsverhältnisse im Lee des Harzes: Indikatoren eines regionalen Klimawandels? Hercynia N.F. 40, 33-39. https://opendata.uni-halle.de/bitstream/1981185920/95307/1/hercynia_volume_40_2887.pdf. Accessed December 01, 2023.

FEO, 2016. 50 Jahre Fernwasserversorgung Elbaue-Ostharz. Chronik, Torgau.

FEO, 2019. Anteilseigner der Fernwasserversorgung Elbaue-Ostharz GmbH. https://www.feo.de/files/inhalte/unternehmen/Aktuelles/GesellschafterListeGr%C3%B6%C3%9FeAnteile.pdf. Accessed December 01, 2023.

Fiorillo, D., Kapelan, Z., Xenochristou, M., Paola, F. de, Giugni, M., 2021. Assessing the Impact of Climate Change on Future Water Demand using Weather Data. Water Resources Management 35 (5), 1449–1462. https://link.springer.com/article/10.1007/s11269-021-02789-4. Accessed December 01, 2023.

Flyvbjerg, B., 2006. Five Misunderstandings About Case-Study Research. Qualitative Inquiry 12 (2), 219–245. https://journals.sagepub.com/doi/10.1177/1077800405284363. Accessed December 01, 2023.

Frick-Trzebitzky, F., Alba, R., Fehrs, K., 2023. Adaptive governance as bricolage. Geographica Helvectica (78), 397–409. https://gh.copernicus.org/articles/78/397/2023/. Accessed December 01, 2023.

Gupta, J., van der Zaag, P., 2008. Interbasin water transfers and integrated water resources management: Where engineering, science and politics interlock. Physics and Chemistry of the Earth, Parts A/B/C 33 (1-2), 28–40. https://www.sciencedirect.com/science/article/abs/pii/S1474706507000666. Accessed December 01, 2023.

Haakh, F., Horlacher, H.-B., 2018. Planung, Bau und Betrieb von Fernwasserleitungen. In: H.-B. Horlacher, U. Helbig (Editors), Rohrleitungen 2. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 153–184. https://link.springer.com/chapter/10.1007/978-3-662-60804-3_23. Accessed December 01, 2023.

Hattermann, F.F., Weiland, M., Huang, S., Krysanova, V., Kundzewicz, Z.W., 2011. Model-Supported Impact Assessment for the Water Sector in Central Germany Under Climate Change—A Case Study. Water Resour Manage 25 (13), 3113–3134. https://link.springer.com/article/10.1007/s11269-011-9848-4. Accessed December 01, 2023.

Hommes, L., Hoogesteger, J., Boelens, R., 2022. (Re)making hydrosocial territories: Materializing and contesting imaginaries and subjectivities through hydraulic infrastructure. Political Geography 97, 1–10. https://www.sciencedirect.com/science/article/pii/S0962629822001123. Accessed December 01, 2023.

Hüesker, F., Moss, T., Naumann, M., 2011. Managing Water Infrastructures in the Berlin-Brandenburg Region between Climate Change, Economic Restructuring and Commercialisation. DIE ERDE – Journal of the Geographical Society of Berlin 142 (1-2), 187–208. https://www.die-erde.org/index.php/die-erde/article/view/48. Accessed December 01, 2023.

Huth, K., Joeres, A., Steeger, G., Donheiser, M., Jacobsen, M., 2022. Knappes Wasser in Deutschland: Immer mehr Konflikte vor Gericht. correctiv.org. https://correctiv.org/aktuelles/klimawandel/2022/06/14/klimawandel-konflikt-um-wasser-in-deutschland/. Accessed December 01, 2023.

Kahlenborn, W., Porst, L., Voss, M., Fritsch, U., Renner, K., Zebisch, M., Wolf, M., Schönthaler, K., Schauser, I., 2021. Climate Impact and Risk Assessment 2021 for Germany. Summary, Dessau-Roßlau. https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/cc_27-2021_climate_impact_and_risk_assessment_2021_for_germany_english_summary_bf.pdf. Accessed December 01, 2023.

Koch, H., 2016a. Gesundes Trinkwasser in Sangerhausen: Minister Hermann Gröhe bleibt Antwort schuldig. mz.de. https://www.mz.de/lokal/sangerhausen/gesundes-trinkwasser-in-sangerhausen-minister-hermann-grohe-bleibt-antwort-schuldig-1177678. Accessed December 01, 2023.

Koch, H., 2016b. Uran im Trinkwasser: Uran im Trinkwasser: Eklat bei Fernwasser-Debatte in Sangerhausen. mz.de. https://www.mz.de/lokal/sangerhausen/uran-im-trinkwasser-eklat-bei-fernwasser-debatte-in-sangerhausen-1203910. Accessed December 01, 2023.

Koch, H., 2018. Uranfreies Trinkwasser: Fernwasser fließt in Sangerhausen ab Donnerstag. https://www.mz.de/lokal/sangerhausen/uranfreies-trinkwasser-fernwasser-fliesst-in-sangerhausen-ab-donnerstag-1478721. Accessed December 01, 2023.

LandesNachrichtenPortal, 2017. Uranbelastetes Wasser in Sangerhausen | LandesNachrichtenPortal. https://www.landesnachrichtenportal.de/uranbelastetes-wasser-in-sangerhausen/. Accessed December 01, 2023.

Latz, C., 2022. Masterplan für Berlins Wasserversorgung: Senat denkt über Trinkwasser-Rationierung bei Trockenheit nach. https://www.tagesspiegel.de/berlin/senat-denkt-uber-trinkwasser-rationierung-bei-trockenheit-nach-6853459.html. Accessed December 01, 2023.

LGG, 2022a. Annual precipitation in Saxony-Anhalt as long-term mean from 1991-2020 (November-August). Landesanstalt für Landwirtschaft und Gartenbau Sachsen-Anhalt, Magdeburg.

LGG, 2022b. Climatic Water Balance in Saxony-Anhalt as mean from 1991-2020 (November-August). Landesanstalt für Landwirtschaft und Gartenbau Sachsen-Anhalt, Magdeburg.

Libbe, J., Trapp, J.H., Winker, M., 2017. Derzeitige Ausgangslage. In: M. Winker, J.H. Trapp (Editors), Wasserinfrastruktur: Den Wandel gestalten. Technische Varianten, räumliche Potenziale, institutionelle Spielräume. Difu, Berlin, pp. 29–33.

Lüdtke, D.U., Luetkemeier, R., Schneemann, M., Liehr, S., 2021. Increase in Daily Household Water Demand during the First Wave of the Covid-19 Pandemic in Germany. Water 13 (3), 260. https://www.mdpi.com/2073-4441/13/3/260. Accessed December 01, 2023.

Luetkemeier, R., Frick-Trzebitzky, F., Hodžić, D., Jäger, A., Kuhn, D., Söller, L., 2021. Telecoupled Groundwaters: New Ways to Investigate Increasingly De-Localized Resources. Water 13 (20), 2906. https://www.mdpi.com/2073-4441/13/20/2906. Accessed December 01, 2023.

Luetkemeier, R., Söller, L., Frick-Trzebitzky, F., 2022. Anthropogenic Pressures on Groundwater, Encyclopedia of Inland Waters. Elsevier, pp. 548–559. https://www.sciencedirect.com/science/article/abs/pii/B9780128191668001833?via%253Dihub. Accessed December 01, 2023.

Malyska, G., 1995. Die Trinkwasserversorgung der Stadt Halle von ihren Anfängen bis zur Gegenwart. Hercynia N. F. 29, 147–171.

Malyska, G., 2001. Die Entwicklung der Trinkwasserversorgung im südlichen Sachsen-Anhalt. Hercynia N. F. 34, 33–51.

Mehlhorn, H., Weiß, M., 2009. Fernwasserversorgung und Verbundsysteme in der Wasserversorgung. gwf-Wasser | Abwasser 150 (Spezial 1), 74–94. https://gwf-wasser.de/produkt/fernwasserversorgung-und-verbundsysteme-in-der-wasserversorgung/. Accessed December 01, 2023.

Mollinga, P.P., 2010. Boundary Work and the Complexity of Natural Resources Management. Crop Science 50 (S1). https://acsess.onlinelibrary.wiley.com/doi/full/10.2135/cropsci2009.10.0570. Accessed December 01, 2023.

NDR, 2023. Harzwasserwerke prüfen Bau einer neuen Talsperre im Harz. https://www.ndr.de/nachrichten/niedersachsen/braunschweig_harz_goettingen/Harzwasserwerke-pruefen-Bau-einer-neuen-Talsperre-im-Harz,talsperren214.html. Accessed December 01, 2023.

Niehues, B., 2023. Resilienz und Versorgungssicherheit der öffentlichen Wasserversorgung 2022 – Ergebnisse der dritten Online-Umfrage des DVGW. energie | wasser-praxis 67, 36–45. https://www.dvgw.de/medien/dvgw/wasser/klimawandel/dvgw-versorgungssicherheit-resilienz-wasserversorgung-umfrage2022.pdf. Accessed December 01, 2023.

Pahl-Wostl, C., 2002. Towards sustainability in the water sector – The importance of human actors and processes of social learning. Aquatic Sciences 46, 394–411. https://link.springer.com/article/10.1007/PL00012594. Accessed December 01, 2023.

Purvis, L., Dinar, A., 2020. Are intra- and inter-basin water transfers a sustainable policy intervention for addressing water scarcity? Water Security 9 (3), 1–27. https://www.sciencedirect.com/science/article/abs/pii/S246831241830004X. Accessed December 01, 2023.

Ross, A., Chang, H., 2020. Socio-hydrology with hydrosocial theory: two sides of the same coin? Hydrological Sciences Journal 65 (9), 1443–1457. https://www.tandfonline.com/doi/full/10.1080/02626667.2020.1761023. Accessed December 01, 2023.

Savelli, E., Rusca, M., Cloke, H., Di Baldassarre, G., 2021. Don't blame the rain: Social power and the 2015–2017 drought in Cape Town. Journal of Hydrology 594, 125953. https://www.sciencedirect.com/science/article/pii/S0022169420314141. Accessed December 01, 2023.

Schramm, E., Winker, M., 2023. Transformation der Wasserinfrastruktur im Siedlungsbestand als Herausforderung. Pfade, Instrumente und Entwicklungsbedarf. ISOE-Materialien Soziale Ökologie, 68. Frankfurt a.M. https://www.isoe-publikationen.de/publikationen/publikation-detail/?tx_refman_pi1%5Brefman%5D=2404&tx_refman_pi1%5Bcontroller%5D=Refman&tx_refman_pi1%5Baction%5D=detail&cHash=5075779801d38eedc29501b844b20abc. Accessed December 01, 2023.

Shumilova, O., Tockner, K., Thieme, M., Koska, A., Zarfl, C., 2018. Global Water Transfer Megaprojects: A Potential Solution for the Water-Food-Energy Nexus? Frontiers in Environmental Science 6, 1-11.

Stuttgarter Zeitung, 2023. Bodensee-Wasserversorgung - Investitionen bedeuten Preiserhöhungen. https://www.stuttgarter-zeitung.de/inhalt.bodensee-wasserversorgung-millioneninvestitionen-bedeuten-preiserhoehungen.db6acd1f-762e-4848-a780-d1addb3747ef.html. Accessed December 01, 2023.

Swyngedouw, E., Boelens, R., 2018. "… And Not a Single Injustice Remains": Hydro-Territorial Colonization and Techno-Political Transformations in Spain. In: R. Boelens, T. Perreault, J. Vos (Editors), Water justice. Cambridge University Press, Cambridge, Cambridge, UK, pp. 115–133. https://www.cambridge.org/core/books/water-justice/and-not-a-single-injustice-remains-hydroterritorial-colonization-and-technopolitical-transformations-in-spain/E8F373EBDC91150B4A0850CE02D238C0. Accessed December 01, 2023.

tagesschau.de, 2023. Kommunale Versorger warnen vor steigenden Wasserpreisen. tagesschau.de. https://www.tagesschau.de/wirtschaft/verbraucher/trinkwasser-preise-wasserqualitaet-100.html. Accessed December 01, 2023.

TSA, 2023. Gebietsstaubereich Nord | Talsperrenbetrieb Sachsen-Anhalt. https://www.talsperren-lsa.de/tsb/talsperren/gebietsstaubereich-nord.php. Accessed July 31, 2023. Accessed December 01, 2023.

UBA, 2021. 20 Jahre Wasserrahmenrichtlinie: Empfehlungen des Umweltbundesamtes, Dessau-Roßlau. https://www.umweltbundesamt.de/publikationen/20-jahre-wasserrahmenrichtlinie-empfehlungen. Accessed December 01, 2023.

Wasserverband Südharz, 2018. Informationen zu der Umstellung auf Fernwasser. https://www.wasser-suedharz.de/news/1/461977/nachrichten/informationen-zu-der-umstellung-auf-fernwasser.html. Accessed December 01, 2023.

Wesselink, A., Kooy, M., Warner, J., 2017. Socio-hydrology and hydrosocial analysis: toward dialogues across disciplines. Wiley Interdisciplinary Reviews: Water 4 (2). https://wires.onlinelibrary.wiley.com/doi/full/10.1002/wat2.1196. Accessed December 01, 2023.

Wissen, M., Naumann, M., 2006. A New Logic of Infrastructure Supply: The Commercialization of Water and the Transformation of Urban Governance in Germany. Social Justice 33 (3), 20–37. http://www.jstor.org/stable/29768383. Accessed December 01, 2023.

Zwarteveen, M., Kuper, M., Olmos-Herrera, C., Dajani, M., Kemerink-Seyoum, J., Frances, C., Beckett, L., Lu, F., Kulkarni, S., Kulkarni, H., Aslekar, U., Börjeson, L., Verzijl, A., Dominguez Guzmán, C., Oré, M.T., Leonardelli, I., Bossenbroek, L., Ftouhi, H., Chitata, T., Hartani, T., Saidani, A., Johnson, M., Peterson, A., Bhat, S., Bhopal, S., Kadiri, Z., Deshmukh, R., Joshi, D., Komakech, H., Joseph, K., Mlimbila, E., Bont, C. de, 2021. Transformations to groundwater sustainability: from individuals

and pumps to communities and aquifers. Current Opinion in Environmental Sustainability 49, 88–97. https://www.sciencedirect.com/science/article/pii/S1877343521000439. Accessed December 01, 2023.

Figure 1. The FEO pipeline network crossing hydrological and administrative boundaries and its several development stages.

Figure 2. Sequence of our research steps indicating the type of material collected and methods applied. Own figure.

Figure 3. Major infrastructural developments and political events against the trajectory of drinking water volumes sold by the FEO over time. Due to the lack of data, the values of sold water for 1954 – 1974 are estimated and represented by a dashed line. Own figure based on FEO (2016).