# Nuclearized River Basins: Conflict and Cooperation along the Rhine, Danube, and Elbe

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*Alicia Gutting & Per Högselius* *

**Abstract:** *»Nuklearisierte Flussgebiete: Konflikt und Kooperation an Rhein, Donau und Elbe«.* This article analyses the historical geography of nuclear energy through the spatial lens of river basins. Approximately half of the world's nuclear power plants were built along one or the other river. There, they gave rise to both conflict and cooperation. Drawing on the theoretical notion of water interaction, which takes into account relations of both conflictual and cooperative nature, we distinguish between such relations in three dimensions: space, environment, and infrastructure. The spatial dimension gravitates around social and political processes where proximity and distance are at the heart, often linked to the search for suitable sites for nuclear construction. The environmental dimension refers to conflict and cooperation around the radioactive and thermal pollution of waterways. The infrastructural dimension, finally, highlights how nuclear power plant builders, when they arrived from the 1950s onwards, had to relate to pre-existing infrastructural features of the rivers, which sometimes led to clashes with other actors and sometimes to more cooperative forms of interaction. In empirical terms, we focus on three European river basins that came to play particularly important roles in European nuclear history: those of the Rhine, Danube, and Elbe.

**Keywords**: River basins, nuclear energy, siting conflicts, borders, radioactivity, thermal pollution, hydraulic engineering, dams.

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## 1. Introduction

Nuclear energy is usually thought of as a uranium-manipulating technology. However, large-scale nuclear power plants (NPPs) also require massive volumes of another natural resource: water. This is because nuclear reactors need to be continuously cooled. The cooling needs are immense: a standard 1,000 MWe reactor needs a continuous water flow of around 50 cubic metres per second to operate efficiently and safely. Against this background, it is hardly surprising that all nuclear power plants worldwide were built near seas, lakes, and rivers. Approximately 45% of all nuclear plants in operation today are located by the seaside, whereas the remaining 55% make use of freshwater supplies, mainly from rivers (World Nuclear Association 2020).

This article examines the historical geography of nuclear energy from a river perspective. We ask questions such as: Which riverine sites were deemed most suitable for nuclear power plants and why? What opportunities and problems did nuclear builders face once they set out to construct riverine nuclear plants? How did they cope with the fact that the rivers were already used for a range of other purposes, and what forms of conflicts and cooperation did the arrival of the nuclear engineers generate? And, finally, how did nuclear builders and other actors cope with the fact that some rivers transcended national borders?

A look at the global map reveals that some rivers have historically been more attractive than others for nuclear construction. To date, the most "nuclearized" river basin in the world – defined as the one that came to host the largest number of operational reactors – is the Mississippi (with key tributaries such as the Missouri and Ohio rivers), where 40 large-scale nuclear reactors have been erected since the onset of the atomic age. Then follows the Danube with 32 reactors, the Rhine and the Dnieper with 27 each, the Loire and the Rhône with 19 each, the Don with 11, the Susquehanna with 8, the Meuse with 7, and the Elbe with 6.[1] This article zooms in on the Rhine, the Danube and the Elbe. Apart from belonging to the world's most nuclearized river basins, these are of special interest in the context of nuclear geographies due to their transboundary character.

To analyse the historical evolution of the three river basins, we make use of a theoretical framework that takes inspiration from, on the one hand, environmental and water history, and, on the other, social-science theorisations of conflict and cooperation in river basins. Having outlined this framework in section 2, we proceed, in sections 3-5, with an in-depth analysis of what we conceptualise as three forms of interaction in nuclearized river basins:

1 These figures, which are based on our own calculations, consider all reactors that are or have been operational according to the International Atomic Energy Agency (IAEA; 2023).

spatial, environmental, and infrastructural interaction. In section 6, finally, we elaborate on our key conclusions.

## 2. Conceptualising Conflict and Cooperation in Nuclearized River Basins

Rivers and their drainage basins play a key role in structuring the world, forming territories where the world's natural geography interacts with the making and unmaking of political, economic, and cultural spaces. For millennia, societies have sought to use and manipulate rivers for practical purposes. Rivers were used for the supply of drinking water, for irrigation, for fisheries, for the transport of people and goods, for waste management, for the generation of mechanical and electrical energy, and for recreation and leisure. At the same time, rivers constitute unique and fragile ecosystems. With their numerous tributaries, rivers both connect and separate different localities, creating opportunities for cooperation but also spurring competition and generating conflicts. This has been so ever since the rise of the ancient hydraulic societies in Mesopotamia, Egypt, China, and India (Mithen 2012). Analysing nuclear energy in riverine settings is to study how the arrival of the atom tied into these already existing physical and human river geographies.

Energy history, and especially the history of nuclear energy, has most commonly been analysed from a national viewpoint (Lindström et al. 2021). Our study challenges that tradition by deliberately abandoning the national focus and, instead, using river basins – rather than the nation state – as our main unit of analysis. Rather than following the evolution of national nuclear programmes (e.g., Radkau 1983; Hecht 2009; Hill 2013) or the formation of a national "technological style" (Hughes 1983), we follow the three rivers from source to sea, examining the nuclear histories that we encounter along the way.

We take inspiration from a few earlier studies of nuclear energy in riverine settings. The most important is Sara Pritchard's study of the remaking of the Rhône River in France during the 19th and 20th centuries. Pritchard shows that the construction of numerous nuclear facilities contributed decisively to the Rhône's reengineering, generating what she calls "envirotechnical systems." By extension, she demonstrates that nuclear energy can be integrated into longer histories of efforts to "improve" nature (Pritchard 2011). A related, though more succinct narrative is offered by Richard White, who integrates the history of the plutonium-producing reactors at Hanford, Washington, into an eco-biography of the Columbia River (White 1995). The vast nuclearization of the Rhine River basin has been sketched by Cioc (2002). Other examples of environmental explorations of nuclear energy in riverine settings include Dorothy Nelkin's, Robert Durant's, and Samuel Walker's early studies of thermal pollution from US nuclear power plants (Nelkin 1971; Durant 1984; Walker 1989).

We study not only the nuclear histories of the main rivers, that is, the Rhine, the Danube, and the Elbe as such, but also those of their tributaries. In other words, we take into account the entire river (or drainage) basins. This geographical approach takes inspiration from earlier, non-nuclear river studies that have pointed to the necessity of seeing the "big picture" (Zeitoun, Mirumachi, and Warner 2020).[2] Non-nuclear river studies have inspired us in other respects, too. In particular, they offer useful perspectives on what Zeitoun and Mirumachi (2008) call "water interaction." The notion of interaction relates to the common theme, in river studies and water history, of conflict and cooperation in river basins. However, it also suggests that it can be useful to analytically move beyond that simple dichotomy. Zeitoun and Mirumachi point to water interaction as "a series of dynamic and multidimensional processes" (Zeitoun, Mirumachi, and Warner 2020). They emphasize that conflict and cooperation can have different degrees of intensity. In a similar vein, conflict does not necessarily mean the end of cooperation, and cooperation does not necessarily stand for a friendly interaction between riparians. The formal resolution of a conflict does not necessarily mean that everyone is happy and that future interaction will be of a cooperative nature (Zeitoun and Mirumachi 2008; Zeitoun, Mirumachi, and Warner 2020). It is also important to note that the mere existence of formal or informal agreements between actors in a given riverine setting does not necessarily mean that cooperation is fair (Mirumachi 2015).

Environmental historian Joachim Radkau has noted that the word "rival" stems from the Latin notion of "rivalis," used to denote people who live by or use the same river (Radkau 2008). This etymology reminds us that rivers have for millennia been conflictual spaces. Yet as water researchers have pointed out that, given the existential importance of water for human survival, riparians are as a rule more likely to cooperate with each other around water than to engage in conflicts (Wolf 1998; Schmeier 2013). Such cooperation can take many different forms. In its simplest form, it may refer to the exchange of information and data. It is also common to see cooperation on an ad-hoc basis in the context of concrete problems that require the involvement of more than one actor. Beyond that, the actors involved can, more ambitiously, set

[2] Globally, there are 310 international river basins, which cover 47.1 % of the earth. In Europe alone there are 88 international river basins (McCracken and Wolf 2019). In our definition of a river basin, we acknowledge the concept of Wolf et al. (1999), who characterise a river basin as contributing hydrologically both by groundwater and surface water to a first-order river that flows into the ocean or a lake. To be an international river basin, at least one of the tributaries needs to cross the border of two or more states.

up joint programmes or create institutions (Farrajota 2009). A well-known example in the river basins at focus here is the International Commission for the Protection of the Rhine (ICPR).

Treaties offer another cooperation tool, especially in international contexts. In the Rhine River basin, treaties have existed since 1820; in the Danube River basin since 1862; and in the Elbe River basin since 1922 (United Nations Environment Programme 2002). These treaties serve as legal agreements between sovereign states and thus, in the cases of the Danube, the Elbe, and the Rhine, regulate the use of the respective rivers as well as the distribution of resources. Most of the treaties were set up to avert conflicts or to address existing problems (Lindemann 2006). These included, at the outset, first and foremost navigation and the removal of physical obstacles to trade (Högselius, Kaijser, and van der Vleuten 2016). More recently, the emphasis has shifted to environmental dilemmas, whereby representatives of polities that shared one or the other river sat down to negotiate about challenges such as the monitoring of water quality, drinking water provision, and waste water treatment (United Nations Environment Programme 2009; Disco 2013).

Zeitoun and Mirumachi (2008), in their conceptualisation, focus on transboundary water interaction. This theme is of relevance for our study of nuclear energy in the Rhine, Danube, and Elbe basins, which, as already noted, are all transboundary. However, we argue that the transboundary interaction focus needs to be complemented by the analysis of water interaction that takes place at local, regional, and national levels as well. Here we take inspiration from the field of transnational history, which sees the problematization of developments at different geographical levels as part and parcel of one and the same history (Iriye 2004; van der Vleuten 2008). Hence, even though our three river basins are all transboundary, we place much emphasis on interaction at "lower" geographical levels, too.

We propose to conceptualise conflict and cooperation in nuclearized river basins by distinguishing between three main dimensions of water interaction: space, environment, and infrastructure. The spatial dimension gravitates around social and political processes where proximity and distance are at the heart. For example, a common source of conflict in nuclearized river basins has been the fear of a major nuclear accident. This forced nuclear builders to engage in complex negotiations with other stakeholders about the establishment of safety zones (a theme explored in depth for the case of the Rhône by Louis Fagon [2024] in this special issue). There were also disagreements, and attempts to resolve these, about whether or not – and what types of – nuclear facilities could be built in certain sensitive parts of a river basin, such as in a port area, a seismically active region, or marshland. Overall, spatial interaction is thus closely linked to nuclear siting issues. The transboundary dimension comes to the fore in spatial interaction in situations where nuclear builders eyed promising riverine sites at stretches of a river that marked the border between countries, or where the selected site was located a short distance upstream from a border (Kaijser and Meyer 2018).

Environmental interaction mainly refers to conflict and cooperation around radioactive and thermal pollution of river basins. Wet pollution has, of course, been a major theme in environmental studies of rivers long before the onset of the atomic age. Not only water, but a variety of both visible and invisible objects travel with the current or are carried along (Disco 2013). Accordingly, actions in one place affect people, places, and things along other stretches of the same river. Historically, this has generated tension and conflict, but also cooperation.[3] Such environmental interaction may take different forms, some of which are more ambitious than others. On a basic level, riparians may agree to exchange data on radioactive pollution stemming from nuclear facilities. In the case of thermal pollution, different stakeholders' attempts to agree on the maximum limit of temperature increases for rivers have played an important role. As we will see, such agreements could have far-reaching impact since they often made it necessary to lower temperature increases through the construction of cooling towers.

Infrastructural interaction, finally, is closely related to Pritchard's elaboration of "envirotechnical systems." The rivers at focus in this article all have long histories of infrastructural manipulation, as they have been artificially rectified, dammed, dredged, diked, canalised, and equipped with navigational locks and hydroelectric facilities. Nuclear power plant builders, when they arrived from the 1950s onwards, had to relate to these pre-existing infrastructural features of the rivers, which sometimes led to clashes with other actors and sometimes to more cooperative forms of interaction.

We argue that all three dimensions of water interaction – spatial, environmental, and infrastructural – are needed if we are to grasp the dynamics and historical making of the world's nuclearized river basins. In the following we elaborate on our findings in each of these three dimensions.

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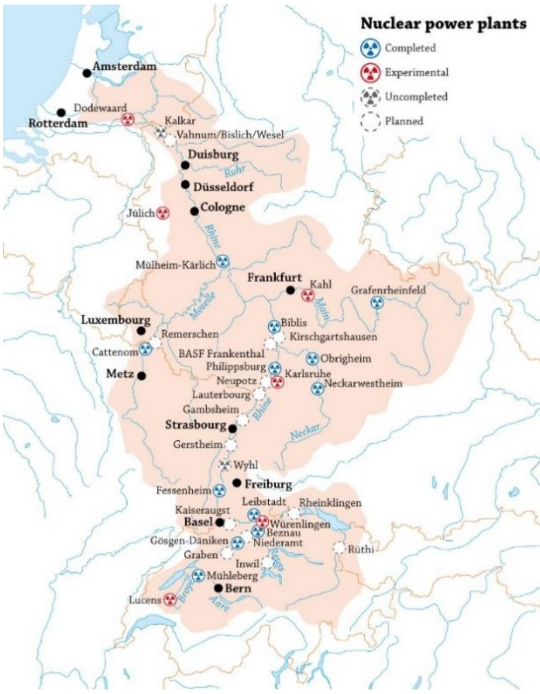
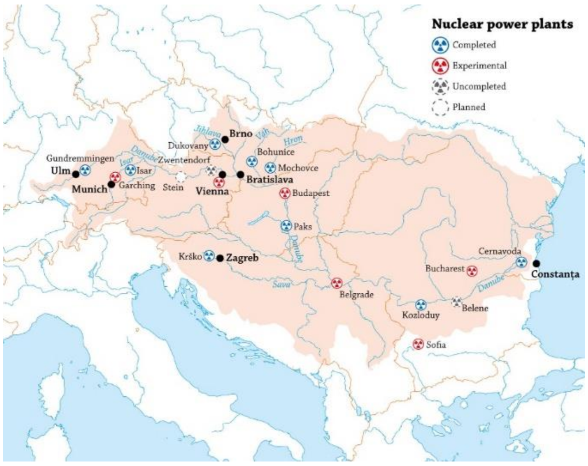
[3] The upstream-downstream conflict can work both ways. In the Rhine River basin, for example, the Netherlands was affected by industrialisation upstream and called for stronger measures concerning wastewater as early as back in 1932. Upstream riparians, on the other hand, have been affected by flood protection infrastructure in the Netherlands, as this obstructs fish migration (Kittikhoun and Schmeier 2021). Such problems have spurred attempts, some of which were successful and some not, to devise technical and political solutions that everyone could agree on (Molle 2009).

**Figure 1** Nuclear Power Plants in the Rhine River Basin



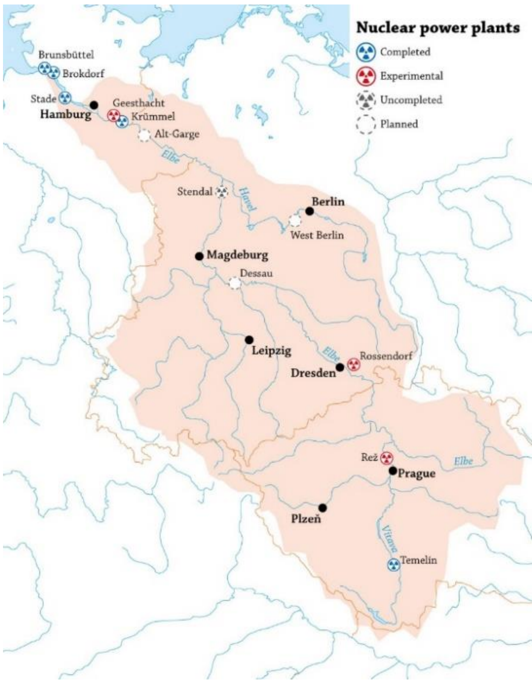

Source: Red Geographics.

**Figure 2** Nuclear Power Plants in the Danube River Basin




Source: Red Geographics.

**Figure 3** Nuclear Power Plants in the Elbe River Basin




Source: Red Geographics.

## 3. Space

In the early days of nuclear engineering, enthusiasts often pointed to the spatial-geographical advantages of this new energy source in terms of siting possibilities. The high costs of transporting coal called for erecting coal power plants as close as possible to the coal mining regions, and hydroelectric facilities could only be built where the river geography was suitable. In contrast, or so the argument went, nuclear power plants could be built virtually anywhere electricity was needed (Radkau 1983).

The reality of siting nuclear facilities, however, was less rosy. It did not take long before planners discovered that several spatial-geographical factors severely restricted siting freedom. As we have seen, nuclear facilities were critically dependent on large-scale cooling water supplies, which in a continental context translated into a need for locating plants near rivers (or lakes). But where, along a given river, could a nuclear research centre or a large-scale nuclear power plant be built? Could they, for example, be built in areas where the river marked a political border? Could they be constructed near major cities, and if so, what was a reasonable safety distance? To what extent was it acceptable to build nuclear plants in seismically active regions, and in wine districts? Could they be spatially – and safely – integrated with major ports? And was it feasible to erect large-scale nuclear plants in swampy areas, in flood plains, in estuaries, and in delta regions? As we will see in this section, such siting considerations came to decisively shape both cooperation and conflict along the Rhine, Danube, and Elbe.

We start out by discussing the transboundary dimension. Several sections of the three rivers coincided with border regions. In such regions the river became a (geo)politically charged space, and nuclear planners needed to adapt to it. Empirically, we can see that nuclear power plants were eventually erected in some border regions but not in others. In the following, we discuss regions of both types, seeking to understand the underlying factors that made it possible or impossible to nuclearize the transboundary sections of a river.

In the spirit of European integration efforts and, in particular, the establishment of Euratom, the German and French governments initiated talks early on about a possible joint reactor project on the Upper Rhine. The fact that the Rhine marked the border between West Germany and France was not seen as an obstacle to the river's nuclearization, but rather as an opportunity to strengthen ties between the two riparians. Électricité de France (EdF) and Rheinisch-Westfälische Elektrizitätswerke (RWE) signed a cooperative agreement in 1964. However, these plans failed due to German criticism of the technology. EdF then decided to pursue the endeavour alone, and what had been envisaged as a symbolically important transnational effort morphed into a project with nationalist overtones. In 1969, France started to erect two 900 MW pressurized water reactors at Fessenheim, halfway between Basel and Strasbourg. The Fessenheim nuclear power plant went operational in 1977 (Cioc 2002).

For some time, West Germany, after the failure to forge cooperation with France, hoped to build its own nuclear power plants on the Upper Rhine. There were several proposals, of which the most promising was an envisaged plant near the town of Breisach, a mere 20 km downstream from Fessenheim. This was clearly not ideal since the discharge of warmed cooling water from Fessenheim might impair the operation of the intended Breisach plant. To the local population it seemed as if France and West Germany were making nuclear power plant plans without really communicating with each other. In 1973, Badenwerk, the German utility in charge of the project, moved the proposed construction site downstream to Wyhl (Engels 2003), but this did not reduce public criticism. On the contrary, Wyhl was to become synonymous with the first, iconic success of the German anti-nuclear movement, which managed to prevent Badenwerk's nuclear plant from being built. However, the fact that the Wyhl site was on the Franco-German border does not appear to have been a significant factor in bringing the project to a halt. There was nothing in Franco-German political relations that would have hindered Wyhl from materializing.

The High Rhine, for its part, marked the border between West Germany and Switzerland. Actors from both countries were interested in exploiting this section of the Rhine for nuclear purposes. The two countries had a long history of transboundary cooperation in electricity, and that spirit was carried over into the atomic age. Actors on both sides of the river agreed that the existence of a political border should not hinder nuclear power plants from being built. Switzerland went ahead constructing its Leibstadt NPP on its bank of the river (Herzig 2015). Interestingly, the Leibstadt NPP's cooling water supply depended on a dam and hydroelectric facility, built in the early 1930s, that extended across the Swiss-German border. West Germany, however, in the end refrained from contributing to the High Rhine's nuclearization. Although Germany's political relations with Switzerland were historically less troubled than its relations with France, regional utilities prioritised nuclear construction on the Upper Rhine rather than the High Rhine. It hence appears that technical and economic aspects, such as the possibilities for integration into larger electricity networks, were more decisive in the siting of Germany's nuclear facilities than any geopolitical factors.

In the Elbe River basin, nuclear planners in Czechoslovakia, East Germany, and West Germany all eyed both the main river and its tributaries as well-suited for nuclear construction. Some sites were found attractive as far as cooling water supply was concerned but potentially problematic from a geopolitical point of view. This concerned, for example, West Germany's early elaboration on a possible nuclear power plant for West Berlin. In May 1962, in a confidential report to its supervisory board, the city's electric utility, Bewag, proposed to erect a nuclear plant on the Wannsee island. This would enable the plant to use the Havel, a key Elbe tributary, for nuclear cooling. Wannsee was in the southwestern corner of the American zone of occupation, just on the border to Potsdam in the Soviet zone. Surprisingly, this circumstance was not problematized at all in the documents that Bewag's leadership presented to its board, just a few months after the erection of the Berlin Wall (Berliner Kraft- und Licht-Aktiengesellschaft 1962). The project never materialised, mainly because the idea of building nuclear power plants directly in or just next to major cities gradually came to be understood as unacceptable from the mid-1960s onwards. We may only speculate whether the geopolitically sensitive location would also have been enough to stop the project.

By the 1970s, East and West Germany were busy planning numerous nuclear facilities on the Elbe itself. When the two German states became aware of each other's nuclear plans, they felt that it would be appropriate to communicate with each other about their plans. The question became acute when, in 1976, a group of West German utilities applied for permission to build a new NPP at Alt-Garge upstream from Hamburg, in the immediate vicinity of the intra-German border. The West German government saw the situation as analogous to the Upper and High Rhine, where, as we have seen, Germany, France, and Switzerland planned NPPs on stretches of the river that coincided with a political border. But in view of the East-West conflict, the situation became much more sensitive than on the Rhine. Bonn complained about "politically conditioned difficulties with the direct communication between responsible authorities in the Federal Republic of Germany and the German Democratic Republic (GDR) (Bundesministerium des Innern 1976a, 1976b). In the end, West Germany appears to have concluded that the Elbe River, where it formed the intra-German border and hence the Iron Curtain, was a geopolitically impossible or at least highly unsuitable site for nuclear construction. There is no evidence in the available sources that Bonn and East Berlin ever reached the point of even discussing such an idea.

In the Danube case, too, several sections of the river marked political borders. The longest was on the Lower Danube, where the river separated Bulgaria from Romania. Bulgaria was the more eager of the two countries to explore the opportunities linked to nuclear energy. Already in 1966 it concluded an agreement-in-principle with the Soviet Union, which would deliver the reactors and key equipment for a large-scale nuclear power plant on Bulgarian soil. Energoproekt, Bulgaria's chief technical design institute with expertise in hydraulic engineering, studied 21 potential sites for the project. Eventually the immense water needs of the planned facility dictated that it would have to be built on the Danube, and since there was no stretch of the river that was on Bulgarian territory only, the facility had to be erected directly on the border. At a party plenum held in November 1969, it was decided to build the plant near the town of Kozloduy in northwestern Bulgaria, on the right-hand bank of the Danube. Ivaylo Hristov, who has studied this case in depth, makes no mention of Romanian participation in the siting process. However, as we will see in the next section, the fact that Kozloduy was built on the border stimulated extensive environmental interaction between the two countries. Bulgaria subsequently started to build a second nuclear power plant further downstream on the Danube, this time near the town of Belene. In contrast to Kozloduy, it was never completed (Hristov 2014).

There was one stretch of the Danube that proved impossible to exploit for nuclear construction: the section where the river marked the Czechoslovak-Hungarian border. For Czechoslovakia, in particular, this part of the Danube would have been excellent from a cooling water supply perspective. Like Bulgaria, Czechoslovakia had direct access to the Danube only where the river marked the political border, except for a short stretch near Bratislava, where both banks were on Czechoslovak territory. But Czechoslovakia and Hungary had a troubled geopolitical relationship; in the aftermath of World War I they had even fought a war against each other (Aleksov and Piahanau 2020).

Although they both ended up in the Soviet sphere of influence in the post-World War II period, the impression is that the idea of constructing a nuclear power plant directly on the border remained geopolitically too sensitive. This forced Czechoslovakia's nuclear-hydraulic engineers to retreat to the valleys of the Danube's left-bank tributaries. These were fully on Czechoslovakian territory. The alternative would have been to erect a nuclear plant in the immediate vicinity of Bratislava. The problem was that the VVER-440 reactors that the Soviet Union offered lacked containment.[4] This made it unacceptable to site them in the immediate vicinity of densely populated areas.[5] In summary, a combination of technological characteristics of the Soviet nuclear reactors and geopolitical considerations shaped Czechoslo-vakia's nuclear geography.

In Yugoslavia, Tito's regime identified a future shortage of electricity in the northern part of the federation as a problem that needed to be dealt with, leading to the idea of constructing a nuclear power plant. As always, there was a need to find a good source of cooling water, and the obvious choice was the Sava River, the Danube's largest tributary. In the mid-1960s, the Krško plain in southern Slovenia was identified as "the potential location for a nuclear power plant." From a transboundary point of view this was an intriguing site, located just upstream from the internal Yugoslavian border between Slovenia and Croatia. The central government in Belgrade appears to have supported the location, with the explicit idea that a nuclear power plant there could stimulate the political and economic cohesion of Yugoslavia as a federation. This spirit is reflected by the close cooperation between Slovenian and Croatian construction companies in erecting the Krško NPP. The foundation stone was laid in 1974. It took until 1984, however, before it was actually completed (Savšek-Safić et al. 2008).[6]

The transboundary dimension aside, a key spatial concern had to do with the proximity issue hinted at in the Bratislava case. Keeping a safe distance to major population centres was identified as a basic risk management strategy, especially at a time when nuclear energy was anything but a mature technology. This was the main reason, for example, why Switzerland's early experimental reactor, Diorit, was built at Würenlingen on the Aare (Wildi 2005; Fischer 2019). Switzerland's other experimental plant, the Lucens facility,

4 This was because the components of the primary circuit were placed in a "pressure room system" whose volume did not suffice to absorb the entire water-steam mix that would leak into the facility from the primary circuit. To prevent a collapse of the reactor building, it was equipped with pressure-release valves, which in the case of such a big accident would enable the release of the excess pressure into the atmosphere.

5 This is very nicely described in East German government sources, see "Information für den Staatssekretär Genossen Mitzinger: Festlegung des Standortes für das Kernkraftwerk III," 2 October 1972. This document also mentions that the Soviet Union considered the possibility of adding a containment structure to the VVER-440, but in September 1972 this option was eventually abandoned.

6 The companies involved included Gradis, Hidroelektra, Hidromontaza, and Ðuro Ðakoviæ.

was likewise built as far away as possible from major population centres. Overall, however, Swiss government officials were troubled by the difficulty of finding suitable locations for the country's nuclear projects. As one cantonal official put it, "It should be borne in mind that, given the dense population of our country, it would be difficult to find sites for nuclear power plants where there are no large agglomerations" (Regierungsrat des Kantons Aargau 1969).

West Germany was also densely populated, a fact that gave nuclear planners much headache. An illustrative case is the chemical company BASF's plans, launched in 1967, to build a large-scale nuclear facility on its premises in Ludwigshafen on the Upper Rhine. In 1970, the city council of Ludwigshafen agreed to the project, but the restrictions and safety regulations were subsequently tightened several times. There was a severe discrepancy between the risk perception of the public and the political representatives. Overall, Ludwigshafen's political leaders as well as the West German chancellor Willy Brandt were in favour of the project, but the general public feared the massive undertaking. Germany was not the only country where the possibility of building nuclear power plants close to cities was subject to discussion, but BASF's plans to build a nuclear power plant in the middle of Ludwigshafen were found to be extreme from a geographical point of view (Radkau 1983). In 1976, BASF decided to move the NPP site from the city to the nearby municipality of Frankenthal. This had to do with stricter safety regulations, including a minimum distance of 500 metres to the Rhine. Soon afterwards, however, BASF decided to scrap the whole plan altogether (Radkau 1983; Laufs 2018).

East Germany's planning agencies, meanwhile, considered the possibility of erecting a large-scale nuclear plant just a few kilometres downstream from Magdeburg, a major city. The location was considered ideal from a logistical as well as a cooling water point of view. A major advantage was seen to lie in the availability of workers from the city. The East German nuclear regulatory agency considered the urban location acceptable in principle, but only for a plant that comprised reactors with full containment. East Berlin sought to negotiate access to such reactors from the Soviet Union, but the Soviet nuclear industry was for the time being only able to offer inferior, less safe reactors of the already mentioned VVER-440 type. This forced the East German planning agencies to look for an alternative site. They eventually picked a spot on the river's left bank 80 km downstream from Magdeburg, near the town of Stendal. It was a safer location, but as regional (Bezirk) officials pointed out, also a much more problematic site from a logistical point of view (Högselius and Klüppelberg 2024).

The Stendal project illustrates how the safety distance principle sometimes forced nuclear builders to relocate to riverine sites that were far from ideal from technical, hydrological, and logistical points of view. The same dilemma came to the fore in cases where large-scale nuclear plants were built in floodplains, peatbogs, and wetlands. Such areas were clearly not optimal, neither from an engineering point of view nor from an environmental perspective. In the Elbe estuary, which was in essence a huge marshland, construction of the Stade, Brunsbüttel, and Brokdorf NPPs could only begin after tedious and expensive drainage and piling works. Drainage canals had to be built and thousands of 25-metre-long piles had to be inserted into the ground to prevent the nuclear power plant from sinking into the estuary. In the Brokdorf case, this led to a 6-month delay in construction and to escalating costs (Schubert and Barg 1986). The situation was similar at Bulgaria's Kozloduy NPP. This site offered excellent cooling water supply and the advantage of being far away from population centres, but from a geological point of view it was problematic. Once the first excavation works started in 1969, the nuclear builders found that "the loess soil in which they were digging became visibly unstable; it was inadequate for such heavy weights." Energoproekt forged cooperation with experts from the Bulgarian Academy of Science in its search for a solution (Hristov 2014).

## 4. Environment

In this section we look at conflict and cooperation linked to the environment. The impairment of water quality and quantity and the general impact of nuclear power on riverine environments have been of utmost concern in all three river basins covered here. This section zooms in on radioactive and thermal pollution and how these were perceived in relation to drinking water resources, agriculture, fisheries, and leisure activities. The period from the late 1950s to the mid-1970s became a particularly intense period of environmental interaction along the Rhine, Danube, and Elbe. Actors set out to both cooperate and compete in their attempts to enable nuclear plants to be built along rivers, to prevent them from being built, to enforce technological fixes such as cooling towers, and to establish guidelines on the levels of radioactive and thermal pollution that everyone could agree on. The impact of cooling towers on riverine landscapes was also much discussed.

Fears of contaminated drinking water supplies loomed large early on. When West Germany laid the foundation stone for the Rhine's nuclearization with the Karlsruhe Nuclear Research Centre in 1956, the local population was very critical. Originally the centre was to be built next to the Rhine, but the planners moved the site a few kilometres away from the river due to flooding risks, deep terrain, and high groundwater. The local population perceived the relocation of the centre as problematic because they feared the impact of the nuclear site on their drinking water resources. The protests could not prevent the facility from being built, but the drinking water concerns were to haunt the Karlsruhe centre for decades, culminating in a harsh conflict in the 1990s linked to the municipality's attempt to take over the nuclear centre's water supply system (Gutting 2023). Key components of the centre included a multipurpose research reactor, which was operative from 1966 to 1984 and a pilot-scale fast breeder that operated from 1979 to 1991 (IAEA 2023).

Drinking water concerns were also of critical importance when nuclear visionaries started to eye the Danube and its tributaries as suitable sources of cooling water. It was on the Upper Danube that West Germany entered the atomic age in earnest, through the construction of a first large-scale nuclear power plant. RWE and Bayernwerk, the utilities involved, initially proposed to build this plant at Bertoldsheim near Neustadt a.d. Donau. In 1961, however, when planning gained momentum, Bavarian water authorities noted that the proposed site coincided with a high-quality groundwater area, which the rapidly growing urban region around Nuremburg hoped to turn into a source of drinking water. The Bavarian agencies also argued that the planned NPP would disturb the unique landscape in the area, which featured a number of small islands in the river; the nuclear plant would constitute an "alien body" intruding into the landscape and the ecosystem (Bayerisches Staatsministerium für Wirtschaft und Verkehr 1962). After a fierce power struggle, the utilities were forced to give in and pick another site further upstream, near the village of Gundremmingen. That site was regarded as inferior from a safety and logistical point of view, but in view of the water protests in Bertoldsheim it nevertheless came to be interpreted as the most reasonable option (Dr. Dietrich, Bundesministerium für Atomenergie und Wasserwirtschaft 1961; Dr. Finke, Bundesministerium für Atomenergie und Wasserwirtschaft 1961). The Gundremmingen case thus highlights how environmental concerns and conflicts over non-nuclear water uses shaped the geography of nuclear energy. The first reactor at the Gundremmingen plant was eventually taken into operation in 1965. It was subsequently expanded with two larger reactors.

Local conflicts over drinking water aside, the spectre of radioactive contamination spurred environmental interaction at regional, national, and transnational levels, too. In the Rhine basin, multiple agencies and organizations wanted to have a say in this context, including the Arbeitsgemeinschaft der Länder zur Reinhaltung des Rheins (Working Group of the Länder for the Protection of the Rhine against Pollution, ARGE Rhein, founded by the West German states of Baden-Württemberg, Bavaria, Hesse, Rhineland-Palatinate, and Saarland), the International Commission for the Protection of the Rhine (ICPR), and Euratom. Attempts to bring about cooperation within and between these bodies were not always successful. For example, although the radioactivity laboratory of Baden-Württemberg's Chemical State Research Institute started to carry out regular measurements on the Upper Rhine, there were no coordinated measurements and no exchange of data with other states (Landesstelle für Gewässerkunde und Wasserwirtschaftliche Planung Baden-Württemberg 1964; Flussgebietsge-meinschaft Rhein 2023). Meanwhile, ICPR complained about difficulties in cooperating with Euratom. Euratom was running a programme to measure radioactivity in the Rhine catchment area and signalled an interest in exchanging data with ICPR, but the ICPR representatives regarded this with suspicion. The Dutch delegation suspected that Euratom was not actually interested in real cooperation, but merely wanted to obtain ICPR's extensive datasets (International Commission for the Protection of the Rhine against Pollution 1962). Overall, although there were many activities going on related to the measurement of radioactivity and the general environmental effects of the Rhine's nuclearization, cooperation was fragmented at best. The various organizations worked on their own without much coordination.

There were transboundary efforts to monitor and regulate radioactive contamination in the Danube basin as well. A particularly interesting case is the environmental interaction spurred by Bulgaria's early efforts to build the Kozloduy NPP. As we have seen, this nuclear plant was built on a stretch of the Danube that formed the political border with Romania. Romania early on voiced fears of a potential nuclear accident and its consequences. These concerns were linked to a wider debate in the entire Danube region about the radioactive pollution of Danubian waters. In 1975, the IAEA decided to form "a special working group to study the cooperation among the countries bordering on the River Danube." At the group's second meeting, held in Bucharest in 1977, representatives from all Danube countries, including Austria and West Germany, "discussed statements and reports on the radiation pollution of the Danube" and "the protection of the Danube basin and its population from radiation fallout and exposure to radiation" (Hristov 2014).

The Romanian government also approached the Bulgarian foreign ministry directly, seeking to initiate bilateral cooperation in the form of information exchange. The Bulgarian nuclear agencies, however, while offering specialists in Romania to investigate the Danube region for radiation, were "not willing to inform Romanian authorities about accidents" in their nuclear power plants. Romania then turned to the recently established Permanent Commission for the Peaceful Uses of Atomic Energy of the Council for Mutual Economic Assistance (CMEA), suggesting stepping up nuclear safety cooperation among all Danube countries. This multilateral approach proved more successful. Ivaylo Hristov writes that Romania, in the CMEA discussions,

> proposed uniform methods for measuring and observing radiation pollution in the environment of nuclear power plants, in border areas, and near water bodies. They also requested procedures for timely informing neighboring countries in case of a nuclear accident. This proposal was accepted by the CMEA's Permanent Commission. (Hristov 2014)

Fears of radioactive contamination aside, thermal pollution became a major bone of contention from the late 1960s onwards. Interaction around this dilemma was most pronounced in regions where utilities planned to build multiple nuclear power plants close to each other, which was the case especially in the Rhine River basin. Switzerland, for example, planned to erect four large plants – Mühleberg, Graben, Gösgen-Däniken, and Beznau – along the Aare alone, and three more – Rheinklingen, Leibstadt, and Kaiseraugst – along the High Rhine (Figure 1). As of the mid-1960s, when the first two large-scale plants – Mühleberg and Beznau – started to be planned in earnest, the responsible Swiss utilities thought it self-evident that they could rely on "once-through" cooling systems, which meant that water was taken directly from the Aare and discharged back into the same river immediately after it had passed through the plant's condensers. The water was then approximately 10°C warmer, a circumstance that critics conceptualized as "thermal pollution" of the river. The threat of thermal pollution became a key topic of debate in the years around 1970, along the Aare and elsewhere in the Rhine River basin. It was considered harmful not only for the riverine environment, but also for the prospects to build numerous nuclear power plants along one and the same stretch of river. In the end, the decision in favour of once-through cooling arrangements in Beznau and Mühleberg meant that nuclear power plants built later on along the Aare as well as on the Rhine had to be equipped with expensive cooling towers; scientists insisted that the heat load of the rivers would otherwise become too great. Along the High Rhine, this concerned not only Swiss nuclear plants, but tentative German ones as well. This led to tensions with the German federal government and the state of Baden-Württemberg (Gutting, forthcoming). In the domestic Swiss context, meanwhile, tensions loomed large between the federal government in Bern and pro-nuclear regional interests of the Aargau canton, on the one hand, and the downstream cantons of Basel-Stadt and Basel-Landschaft on the other. The latter found themselves in the role of recipients of the heated and potentially radioactively contaminated water. The Aare's and High Rhine's nuclearization thus shows how the Swiss state's vision of a radiant future collided with the interests of individual cantons as well as with German interests. From a transboundary river perspective, this can be regarded as a typical conflict between upstream and downstream interests.

It is interesting to observe how cooling towers, from around 1970, were identified as suitable technical fixes in the context of thermal pollution. The ICPR pointed to them as the only viable solution at a time when dozens of nuclear power plants were under construction or planned in the Rhine basin (German Delegation of the ICPR 1971). Cooling towers meant that much less cooling water was discharged back into a river from a nuclear plant, thus considerably reducing the river's artificial warming. But the cooling towers generated their own set of environmental problems, as demonstrated by large-scale nuclear projects such as Switzerland's Kaiseraugst NPP. This plant was to be built on the High Rhine just upstream from Basel. Bern demanded that the plant be built with a recirculating cooling system, which would necessitate two expensive cooling towers. The cooling towers themselves quickly became controversial, however, due to their immense size and the plumes of water vapour that they would discharge. For this reason, the municipality where the plant was to be built opposed the plan. Local opposition then spilled over to Basel as well. The protest reached its peak in 1975 with an occupation of the company grounds, which lasted several weeks. In the following years, legal disputes stalled the planning of the Kaiseraugst NPP. In 1988, the project was abandoned (Boos 1999; Kupper 2003). By contrast, two other Swiss NPPs, the Leibstadt and Gösgen-Däniken stations, were completed, both equipped with immense cooling towers that came to totally dominate the riverine landscape around the two sites.

In some regions the local population was more fearful of how cooling towers would alter the landscape than of how cooling water would affect the riverine environment and the water quality. This was the case with Switzerland's planned Rüthi nuclear power plant on the Alpine Rhine, whose abandonment in 1980 was closely linked with the controversies over the planned cooling towers (Holzknecht 2018). The most iconic case of protest against nuclear energy in the context of thermal pollution and cooling towers, however, was West Germany's already mentioned Wyhl NPP on the Upper Rhine. Worried about the thermal load of the Rhine (Tauer 2012), vintners, researchers, and academics protested vehemently against this project. The Wyhl protests served as inspiration for other protest groups, such as at Kaiseraugst (Boos 1999).

In terms of the Rhine's tributaries, electricity companies further eyed the Moselle as a suitable cooling water source. France, Germany, and Luxembourg all hoped to build nuclear power plants on this river. This gave rise to conflicts. In 1973, RWE and the Luxembourg government jointly founded the Société Luxembourgeoise d'Energie Nucléaire (SENU) to build a nuclear plant in Remerschen, Luxembourg, on the Moselle's left bank. This was a rural setting with low population density. The region was located in the border triangle between Germany, France, and Luxembourg and, like Wyhl, was perceived as idyllic and characterized by viticulture. Germany maintained close relations with Luxembourg and saw the construction of a nuclear power plant on Luxembourg soil as an extension of its own electricity grid. France, on the other hand, informed the other two countries at the same time about its plans for a much larger, four-reactor nuclear power plant to be built at Cattenom, only ten kilometres upstream from the town of Schengen on the Franco-German-Luxembourg border. In this case, too, fears quickly became public, especially among the local population, which feared environmental impacts for which the French government, as the locals put it, showed no understanding

(Tauer 2012). Germany and Luxembourg believed the cooling capacity of the Moselle did not suffice for two nuclear power plants. In addition, the French safety standards were seen by others as inadequate and inferior to the German and Luxembourg standards.

In the end, Remerschen slowly lost political support from Luxembourg and was postponed indefinitely in 1978 (Tauer 2012). The French were more successful. Construction of the first reactor at Cattenom began that same year. By 1991, no fewer than four large reactors had gone into operation at the site (IAEA 2023). However, the downstream countries – Germany and Luxembourg – were successful in forcing France to invest in an unusually sophisticated (and expensive) recirculating cooling system. It comprised not only four large cooling towers, but also an artificial lake – a cooling pond – that helped to further reduce the extent of thermal pollution of the Moselle (Figure 4). The Cattenom case thus illustrates how downstream riparians were not powerless in their struggle against upstream actors.

**Figure 4** The Cattenom NPP

The four cooling towers and the artificial lake, visible here, all serve to reduce thermal pollution of the Moselle, from which the cooling water is sourced.
Photo: Per Högselius, April 2022.

Conflicts over thermal pollution were not as pronounced along the Elbe and Danube as in the Rhine River basin. Yet the problem was far from absent from the agenda. On the Lower Elbe, for example, Nordwestdeutsche Kraftwerke (NWK) was criticized for downplaying the potentially negative effects of cooling water discharged from its Stade NPP. The State Fishing Agency (Staatliches Fischereiamt) ridiculed NWK’s claim that the Elbe would be warmed by only 0.05°C – a “much too optimistic” figure that, according to the agency, was based on the unrealistic assumption that the discharged cooling waters would mix perfectly and instantly with the mighty flow of the river. It concluded that the actual thermal pollution would be much more severe, which, as the fisheries experts warned, would have "biological consequences." They also criticized the design of the cooling water intake, which they judged would suck a large number of fish into the cooling water system, and worried that the pH value of the discharged cooling water would be too low (Staatliches Fischereiamt 1968).

Further upstream the Elbe, beyond the Iron Curtain, East Germany was preparing the construction site for the already mentioned Stendal NPP, which was the first East German facility to make direct use of the Elbe as a cooling source. Here, the initial plan was to erect four reactors in two stages. For the first stage, the involved actors agreed in 1973 on a once-through cooling water supply arrangement (i.e., no cooling towers). However, the nuclear builders were troubled by regulations issued by East Germany's water agencies, which stipulated that the discharged cooling water must not be warmer than 38°C. They predicted that this would force the Stendal plant to reduce electricity production during parts of the summer. Moreover, they anticipated that the water agencies might tighten the discharge rules; for this reason, they already reserved space at the construction site to enable the erection of cooling towers later on (VEB Kombinat Kraftwerksanlagenbau 1974). The Stendal NPP was still under construction at the time of communism's collapse and Germany's reunification. Then construction stopped and the project was abandoned.

On the Danube, an interesting case is Hungary's Paks NPP, which after completion of four Russian-designed VVER-440 reactors became "the greatest industrial water consumer in Hungary." The facility was built without cooling towers. In the late 1980s, when the environmental debate rose to prominence, the adverse effects of thermal pollution started to be seriously discussed. It was found that since the plant relied on once-through cooling, the Danube's temperature increased by 7 to 9°C in summer, a figure that grew to 10°C at times of reduced flow in the river. There were environmental regulations in place that were more or less similar to Western European regulations, specifying that the discharged cooling water must not exceed a temperature of 30°C at a checking point 500 metres from the discharge into the river. Water experts found that thermal pollution from the Paks NPP had a clear impact on the river temperature all the way down to the Hungarian-Yugoslavian border, where a temperature difference of 1°C could still be detected, while 20 to 40 km downstream from the plant the temperature difference was as high as 2 to 3°C. Thermal pollution was hence not merely a local problem of relevance for the immediate vicinity of the NPP. The impacts on the Danubian eco-system were by no means negligible, as the Hungarian water experts noted (Szolnoky and Raum 1991).

## 5. Infrastructure

Rivers were, as we have seen, attractive for nuclear builders because they offered ample and inexpensive access to cooling water. However, not all rivers were found suitable for nuclear construction. In general, given the immense cooling water needs, a large river was better than a small one. But what also mattered were the reliability and evenness of the river's flow. Nuclear reactors needed to be cooled at all times, throughout the year. The flow must never be disrupted, not even for a minute; if that happened, the reactor risked heating up in a dangerous way, and in the worst case a core meltdown might occur. Due to unstoppable decay heat, the cooling water flow needed to be guaranteed even after a reactor had been shut down. For this reason, wild, pristine rivers were not suitable for nuclear construction; they were too unreliable. Nuclear builders needed regulated rivers whose water flows could be artificially controlled to the greatest possible extent (Högselius 2022).

This challenge could be turned into an opportunity. In many cases, electric utilities and construction companies involved in nuclear projects found that they could piggyback on the achievements of earlier hydraulic engineering efforts, making use of the many dams, weirs, and dikes that had been erected in the Rhine, Danube, and Elbe basins for non-nuclear purposes since the 19th century. In other cases, they were able to link up in fruitful ways with hydraulic engineering projects that were still ongoing or in a planning phase. This generated what we refer to as infrastructural interaction in nuclearized river basins.

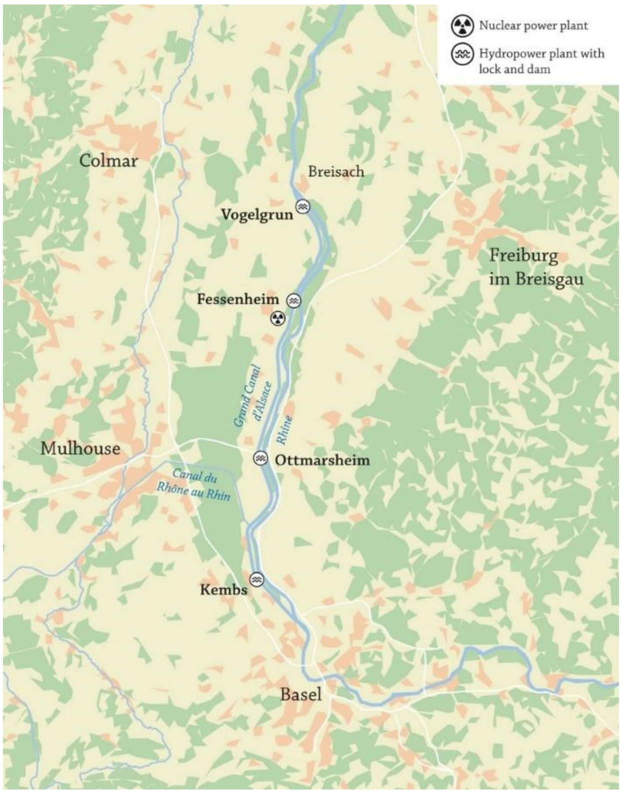
The case of the Beznau NPP in Switzerland exemplifies how nuclear builders were able to exploit the achievements of earlier hydraulic projects. Nordostschweizerische Kraftwerke AG (NOK), a Swiss electric utility, announced in 1964 that it wanted to build a nuclear power plant on the island of Beznau in the Aare. This site was attractive because the nuclear builders realised that they could profit from an old hydroelectric facility that had commenced operation in the river 60 years earlier; for this purpose, a canal and a dam had been built back then, resulting in a more regular and reliable flow, thus facilitating the supply of nuclear cooling water. Since the nuclear plant was erected below the water level in the dammed part of the river, water from the canal could even flow into the plant's condensers by gravity, thus reducing the facility's vulnerability to pump failures. The old hydroelectric plant also served as a back-up source of electricity supply for the cooling water pumps and other machinery. Construction of Beznau I started in 1965; in July 1969, the reactor delivered electricity for the first time. A second reactor was subsequently added (Die Nordostschweizerischen Kraftwerke AG 1976).

**Figure 5** The Beznau NPP in Winter

The two reactor buildings and the pumping houses are erected below the water surface on the regulated canal, which is formed by damming the Aare. The old Beznau hydropower plant, built in the early twentieth century, is visible in the background.
Photo: Per Högselius, December 2022.

Another interesting case is France's Fessenheim NPP, which we touched briefly upon in section 3. It was built in the Rhine's former floodplain. In its original, pre-industrial state, the floodplain would not have been suitable for nuclear construction because of irregularity of water flows. In the early 19th century, however, Johann Gottfried Tulla famously initiated a major reengineering of the Upper Rhine. Over several decades, hydraulic engineers struggled to deepen and straighten the river, with the ultimate aim to make the river navigable while protecting the population from disastrous flooding events. The project was not entirely successful. Among other things, a faster water flow resulted in serious erosion of the riverbed. In the years around 1900, the Alsatian hydraulic engineer René Koechlin proposed to deal with this problem by damming the Upper Rhine at several locations. After World War I, this vision materialised in such a way that a lateral canal, or as the French called it, the Grand Canal d'Alsace, was excavated on what was now the French side of the Rhine. Construction of the canal and the dams and locks along it commenced in 1928 and proceeded for several decades (Cioc 2002). From 1953 to 1956, a dam and hydroelectric facility were erected at Fessenheim, halfway between Basel and Strasbourg. When France's nuclear builders arrived at this site a few years later, they found a waterway that in its artificial form seemed perfectly suited for meeting nuclear cooling water needs (Figure 6). The Fessenheim case thus illustrates how nuclear builders, in this case EdF, stood on the shoulders of earlier hydraulic engineers like Tulla and Koechlin, without whose river reengineering efforts the nuclear plant would not have been feasible.

**Figure 6** The Fessenheim NPP in Its Wet Geographical Setting




Source: Red Geographics.

In the Elbe basin, an intriguing case of infrastructural interaction is the Krümmel NPP, which Hamburgische Electricitäts-Werke (HEW) and PreussenElektra started to build 40 km upstream from Hamburg in 1974. This site had a proud pre-history, having been used a hundred years earlier by the Swedish inventor and entrepreneur Alfred Nobel's pioneering dynamite factory. In the 1950s it had come to host a nuclear research centre specialised in nuclear propulsion; for this purpose, a research reactor was erected. In 1958, HEW had taken into operation a pumped-storage hydropower plant at Geesthacht, just next to the later nuclear construction site. In parallel, the Federal Ministry of Transport had overseen the construction of a weir and lock on the Elbe just five kilometres downstream from Krümmel.[7] These earlier hydraulic interventions suited the nuclear builders exceptionally well. The damming of the river ensured that cooling water would always be available, while the

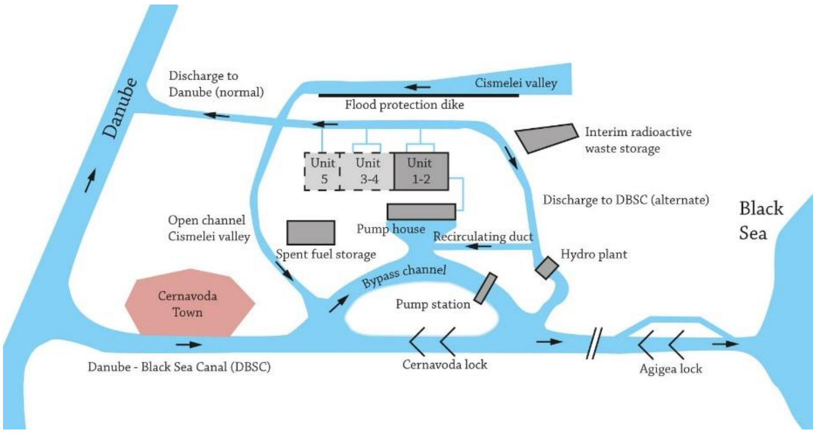
7 The history of the Geesthacht weir and lock is documented in, e.g., BArch B 108/15639.

pumped storage hydropower plant could store excess nuclear electricity. Moreover, the hydropower plant was ready to help out the nuclear plant in case of a regional electricity blackout; this made it unnecessary to install emergency diesel generators (Garske 2011).

When the Austrians, after much hesitation, decided to go nuclear in the 1970s, they intuitively eyed the Danube as the most suitable source of cooling water. In March 1971, the federal government decided to pick a site 50 km upstream from Vienna for its first nuclear power plant, the Zwentendorf NPP. In terms of infrastructural integration, the attempts to bring about an Austrian nuclear age became closely connected to ongoing Danubian reengineering schemes that entailed damming the Danube for the combined purpose of hydropower production and navigation. The navigation part had to do with the construction of the Rhine-Main-Danube Canal and the adaptation of the Danube that was deemed necessary in this context to accommodate the barges that would pass through that canal. For this purpose, the Danube was dammed at Altenwörth, just three kilometres upstream from Zwentendorf, in a project carried out between 1973 and 1976 in parallel with the nuclear construction. The Altenwörth weir enabled regulation of the Danube's water level, thus ensuring a steady cooling water supply for the nuclear power plant. Once the Zwentendorf NPP was completed in 1978, however, Austria voted in a referendum held in December that year to abandon nuclear energy, and the plant was never taken into operation (Bianchi and Weber 2006).

Romania's Cernavoda NPP, which was built on the Lower Danube, further illustrates the logic of infrastructural interaction. Here, a diverse constellation of actors from different countries had pursued ambitious hydraulic engineering projects since the mid-19th century, the chief aim being to improve transport between the Black Sea and the agriculturally productive regions in the Lower Danube area. In the 20th century, the key challenge was seen to lie in the creation of a shortcut to the Black Sea. Romanian water agencies opted to do so by building a canal from the town of Cernavoda to the Black Sea port of Constanța. This canal eventually materialized only during communist times under the Ceaușescu regime from 1976 to 1984. The construction of the new waterway coincided with a wave of interest in nuclear energy in Romania. While the construction of the canal was ongoing, nuclear scientists and engineers elaborated on how the canal could be combined with Romania's emerging atomic visions (Dorondel et al. 2022). The engineers opted to draw maximum utility from the emerging hydraulic structures of the canal for nuclear energy production. They picked a site just 1.5 km from the first lock on the Danube-Black Sea Canal. They then set out to build a bypass canal around that lock to provide the nuclear reactors with ample cooling water, along with a specially designed intake canal and a distribution basin. The heated cooling water was discharged through a system of additional canals into the Danube proper and partly also into the Danube-Black Sea Canal beneath the lock (Ciurea 2013; Sundri and Gomoiu 2014) (Figure 7).

**Figure 7** Water Flow Scheme for the Cernavoda NPP




The plant was built on the Danube and the Danube-Black Sea Canal.
Source: Red Geographics.

The interaction between nuclear builders and navigational interests could also become problematic, however. In 1970, Hamburgische Electricitäts-Werke (HEW) and PreussenElektra began construction of their Brunsbrüttel NPP on the right bank of the Lower Elbe. It was erected in the immediate vicinity of the Kiel Canal's southern outlet – not unlike the way Romania's Cernavoda NPP was built by the Danube-Black Sea Canal. This meant that large ships would be passing very near the plant, heading both for the Baltic Sea (by way of the canal) and up the Elbe to Hamburg. This co-location of a nuclear power plant with major shipping lanes became a topic of much concern and discussion both locally and nationally in West Germany during the planning and building period. The discussions intensified in connection with the most controversial of all West German nuclear projects: the Brokdorf NPP, which Nordwestdeutsche Kraftwerke (NWK) started to build in 1975 just a few kilometres upstream from Brunsbüttel. Whereas nuclear construction co-evolved with navigational projects in a cooperative fashion at sites such as Zwentendorf and Cernavoda, the relationship became more conflictual along the Lower Elbe. At focus was the potential explosion of an oil or gas tanker that passed by Brunsbüttel or Brokdorf. Nuclear builders proposed technical fixes; the Elbe NPPs were eventually designed to cope with such an event by making the walls of the reactor buildings extra thick, 80 cm (Schubert and Barg 1986).

**Figure 8** The Brokdorf NPP

This plant was built on the Lower Elbe, which was one of Europe's most heavily used maritime transport routes. The passing of large cargo ships, oil and gas tankers was interpreted as a danger to nuclear safety, necessitating additional investments in the containment structure.
Photo: Per Högselius, November 2021.

Other navigational concerns included water losses stemming from recirculating cooling systems (that is, systems that relied on cooling towers) and the increase in fog formation (Wyss 1970). In the case of Switzerland, the country's Meteorological Institute was tasked with investigating the impact of nuclear power plants on fog formation. However, it found the problem to be negligible, citing theoretical calculations and real-world experiences from Switzerland and abroad; these showed that there would only be a slight increase in the frequency of fog (Eidgenössisches Verkehrs- und Energiewirtschaftsdepartement 1969).

Czechoslovakia's nuclear power plants, which were built in the Danube and Elbe basins, took the logic of infrastructural interaction to a more complex level. Construction of Czechoslovakia's NPPs was linked to major reengineering of entire river stretches, leading to a radical transformation of riverine landscapes. Czechoslovakia completed three major NPPs with a total of ten Soviet-designed VVER-440 reactors on the Váh, the Jihlava, and the Hron – tributaries to the Danube – and two additional reactors on the Vltava in the Elbe basin. Building on a longer tradition of hydraulic engineering and river improvement projects that can be traced back to Habsburg times (Janáč

2012), Czechoslovakia eagerly set out to dam the Danubian tributaries and create giant artificial reservoirs that could be used as a safe and reliable source of nuclear cooling water. In a way that resembled the United States' famous Tennessee Valley Authority (TVA) scheme, they combined nuclear-hydraulic engineering with efforts to make further productive use of the rivers for irrigation, hydropower, drinking water supply, navigation, recreation, and fishing.

The Dukovany NPP illustrates the Czechoslovakian strategy. It was built in the south-eastern foothills of the Bohemian-Moravian Highlands, whose topography and hydrology were found suitable for the building of an enormous nuclear-hydraulic complex. Apart from the nuclear power plant as such, the complex comprised two large artificial water reservoirs, supported by two huge dams, along with a once-through hydropower facility and, most importantly, a pumped-storage hydropower plant. At the heart of the complex was the Jihlava, a small river in the basin of the Morava, a Danube tributary. The nuclear plant was built one kilometre from the river. Downstream from the two reservoirs, the Jihlava flowed "through a recreation and fishing area" and subsequently into the Dyjsko-Svratecký valley, where the river was "intensively used for irrigation," while its "recreational and fishing use" was "also significant." In addition, the Jihlava was used as a source of drinking water. Dukovany hence became tightly interlinked with a range of other uses of the available river. By 1987, four reactors had been taken into operation (Rabusic 1990). The facility was equipped with eight large cooling towers, each approximately 120 metres tall (Skokan 1986).

The Mochovce NPP was equally intriguing. In this case, the Czechoslovakian planners identified the Hron River as a suitable source of cooling water. However, they found that the natural water flow in the river was too limited and above all too unreliable. Hence, they set out to reengineer the Hron by straightening and damming it. They also used the opportunity to erect hydroelectric turbines at the dam. Construction of the dam started in spring 1984 and was completed in summer 1988. Damming the river lifted its water surface by 7.5 metres, leading to inundation of large tracts of land and generating a large cooling water reservoir for the NPP, supported by dikes. Despite the land loss, the regional government was highly supportive of the project, because apart from serving nuclear cooling needs, the system allowed "for the irrigation of more than 13,000 ha of land." It also strengthened the reliability of the region's urban and industrial water supply. "Another use of the reservoir," local agencies claimed, was "landscaping." The reservoir was regarded as "an important element of the ecosystem" and served "recreational purposes," while "fishermen also enjoy themselves" (Municipal Office of Veľké Kozmálovce 2022). In other words, an impressive range of ways to make productive use of the river's water were framed as a harmonious win-win situation, dominated by cooperation in several dimensions, while there was no mention of any potential conflicts. Construction of the nuclear plant itself was severely delayed, first by the 1986 Chernobyl disaster and then by the collapse of communism and the partition of Czechoslovakia. But the nuclear builders did not give up. In 1998, the first reactor was finally connected to the grid. A second was completed a year later, and the last two have just gone into operation at the time of writing.

## 6. Conclusion

This article has examined how three major European river basins came to host a range of nuclear facilities from the 1950s onwards and how this generated conflict and cooperation – or as we have termed it, water interaction – in three major dimensions: space, environment, and infrastructure. The Rhine, Danube, and Elbe rivers and their tributaries were attractive for nuclear builders because they offered ample cooling water, of utmost importance for the operation of large-scale nuclear power plants. All three river basins were heavily exploited by nuclear builders. If we count the nuclear reactors that were eventually connected to the electricity grid, the Danube eventually became the most nuclearized basin, containing no less than 32 reactors. The Rhine was not far behind with 27 reactors. However, if we consider the fact that the Rhine basin is much smaller than the Danube basin, it becomes clear that the Rhine underwent a spatially denser nuclearization than the Danube. This is also reflected in the striking variety and intensity of interaction around nuclear projects in the Rhine basin. The Rhine River basin is also the basin that comprises the largest number of planned projects that ultimately failed to materialize. The Elbe in the end became host to no more than six large-scale reactors. The number would have been higher if East Germany's massive plans for nuclear expansion had been realised. A striking find is, furthermore, that not only the main rivers came to host large-scale nuclear plants; many surprisingly small tributaries likewise underwent nuclearization.

Our study has identified different types of interaction relating to space, environment, and infrastructure in nuclearized river basins. This interaction has sometimes been of a more conflictual, sometimes of a more cooperative nature. In terms of conflicts we see, on the one hand, how many protests against nuclear construction were related precisely to the riverine setting of nuclear power plants, and how anti-nuclear groups in West Germany, Switzerland, and Austria were able to strengthen their cause by pointing to the plants' expected impact on the rivers and the riverine environment. Nuclear energy can here be seen to add a new layer to a longer history of rivers as conflictual spaces. The most typical situation was one in which nuclear energy was seen as incompatible with or as a threat to other human activities along the same river, or as a threat to the wet environment. In all three river basins we thus observed, for example, conflicts between the expansion of nuclear power and the provision of drinking water. In some cases, this existential threat forced the nuclear builders to give up a site and move elsewhere, or even abandon their project altogether. In this way, spatial and environmental interaction became interlinked. Another class of conflictual relations originated from the threat of thermal pollution. This dilemma was most hotly debated in the Rhine River basin, but it was also, to a lesser extent, problematized along the Danube and the Elbe. The threat of thermal pollution strongly shaped nuclearized landscapes in the three river basins, especially in cases where cooling towers emerged as a technical fix; eventually these became icons of riverine nuclear plants. Over time, the cooling towers themselves became the source of conflicts and concerns, but from a thermal pollution point of view they served as useful tools to resolve both regional and transboundary conflicts.

The threat of geopolitical conflicts in some cases prevented the construction of nuclear power plants in areas where the rivers also formed the borders between two countries. This was the case, in particular, along the border between Czechoslovakia and Hungary and between West and East Germany. To circumvent these conflicts, nuclear planners moved their projects elsewhere, as can be seen especially in the case of Czechoslovakia. Counterexamples, where potential geopolitical tensions did not prevent nuclear plants from being built on certain stretches of the rivers, are the construction of nuclear power plants along the border between Germany and both France and Switzerland as well as Bulgaria and Romania. Germany and Switzerland notably saw intensive debates and were in principle sympathetic to each other. The eventually failed attempt by Germany and France to cooperate in constructing nuclear power plants along the Upper Rhine, and Yugoslavia's decision to build the Krško NPP in Slovenia next to the Croatian border, testifies to a perceived potential to use nuclear energy as a "positive" geopolitical tool to strengthen cross-border relations.

An intriguing aspect of nuclearized river basins, when it comes to cooperation, is how nuclear builders sought to build fruitful relations with other actors along one or the other river, and how they sought to make productive use of earlier hydraulic engineering feats. Nuclear actors made use of earlier damming, dredging, and rectification projects, or even built their plants on artificial canals. This signified a view of nuclear construction as an activity that could – and should – be integrated with and even contribute to non-nuclear river activities such as navigation, irrigation, hydropower, and sometimes even fisheries, all of which were presented as potential beneficiaries of nuclear energy.

Overall, our study suggests that interaction in nuclearized river basins comprised not only conflicts and tensions, but also a great deal of cooperation. In this sense, our analysis may serve as a much-needed counterweight to the scholarly tradition, in studies of nuclear energy, to emphasise conflictual aspects. Seen in relation to earlier social and historical research on rivers, our finds are less surprising. There, as pointed out in the introduction, it is widely recognized that, given water's critical importance for human survival, riparians usually have stronger incentives to cooperate with each other around water than to engage in conflicts. By extension, this article points to the fruitfulness of merging river research with studies of nuclear energy.

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