Blue Papers 2025 (Vol. 4 No. 2)
10.58981/bluepapers.2025.2.09
Received 29.01.2025; Received in revised form 18.06.2025; Accepted 26.07.2025

Modern Water Management and the Challenges of Climate Change at the World Heritage Property Upper Harz Water Management System

Manuela Armenat, Christian Bellak & Andreas Lange

Abstract

The Upper Harz Water Management System is an outstanding example of effective water management over the centuries. Through historical development and adaptive change over centuries, a multifunctional system has evolved that remains in active use today. Since the site's UNESCO designation as a World Heritage property in 2010, continuous monitoring and maintenance have been integral to its management. In recent years, challenges arising from climate change and safety-related hydraulic engineering issues, as well as financial constraints, have put the monument under increasing pressure. With the common goal of ensuring that the historic elements and their operation continue to contribute to a wide range of Sustainable Development Goals (SDGs) and provide essential public services in the future, changes are necessary. World Heritage management that incorporates the importance of water management is therefore essential, just as, conversely, the World Heritage and the monument play a supporting role and basis for the management of water in the Upper Harz Water Management System.

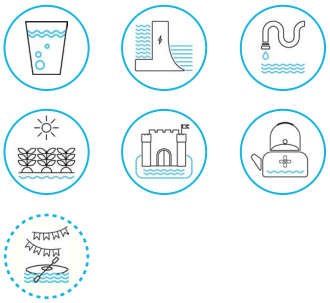
Policy Recommendations

- Maintain constant communication and coordinated, integrated management to balance hydraulic engineering, economic, World Heritage, and sustainability requirements, fostering a willingness to compromise and find future-oriented solutions.
- Recognize that a Living World Heritage property is subject to change, and as for this, it is important to clearly define the non-negotiable features to ensure the preservation of its Outstanding Universal Value (OUV).

KEYWORDS

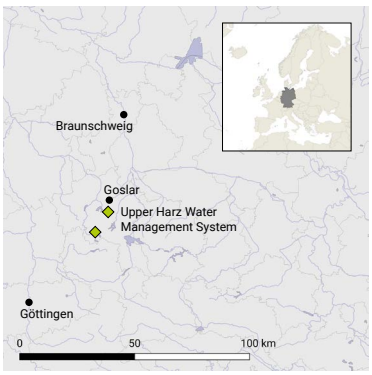
UNESCO World Heritage
energy
recreation and tourism
mining history
integrated management

WATER ICONS



CLIMATE

Cfb: Oceanic climate



< Fig. 1 Hirschler-Pfauenteiche pond cascade (Source: Stiftung Welterbe im Harz 2018, photographer: Stefan Sobotta).

Introduction

The Harz low mountain range is located in the center of Germany. Due to its geological development, it is particularly rich in ore deposits. Mining was carried out in the region for many centuries, particularly for the non-ferrous metals lead, silver, copper and zinc. Upper Harz ore mining reached depths of 300 meters as early as the seventeenth century. An energy supply was essential for pumping the sump water and transporting ore, materials and personnel. Water played an important role as a source of energy. Over the course of 800 years, a highly complex surface and underground water power system developed in the high altitudes of the western Harz. Even today, the water and the historic facilities are still used in various ways. The status of the Rammelsberg mine, the old town of Goslar and the Upper Harz Water Management System as an ensemble of monuments and, since 2010, as a joint World Heritage property, entails a particular responsibility for the protection and preservation of these facilities under changing conditions, including climate change.

The Upper Harz Water Management System: Elements and Function

The aim of the world's largest pre-industrial energy supply system was to provide the Upper Harz mining industry with water on a permanent basis and, if possible, all year round. Its function and components are briefly described below (see fig. 1, also Harzwasserwerke 2011, Malek-Custodis 2022, 81–9).

The water was channeled parallel to the slope from the distant areas and raised bogs via collecting ditches, starting from streams. In order to shorten a ditch or overcome the unfavorable topography of the terrain, so-called water tunnels were driven into the mountains. This not only shortened the route, but also prevented the water from freezing in winter. The water was directed into the storage ponds. These artificial ponds were mainly constructed with dams made of earth and turf sods. The only exception to this construction method is the Oderteich, near Sankt Andreasberg. This dam was built from granite stones, with granite grit used as sealing material. The excess water was drained via the outlets. The water flowed from the ponds to the wheel pits via surcharge ditches. There it drove sweep wheels or waterwheels, which were used for transportation or for pumping and driving stamp mills (for crushing ore). Finally, after being used several times, the water ran out of the mountain through so-called water drainage galleries to receiving watercourses. To supply as many users as possible with the same water, "keeping the water high" became a central principle.

Today, a large number of these water management facilities (see fig. 2, table 1) are still in operation and are used for various purposes. The operational water-bearing infrastructure has been managed and maintained by Harzwasserwerke GmbH, the regional water utility, since its transfer was completed in 1996 (a process initiated in 1992).

Living World Heritage and Climate Change

The Upper Harz Water Management System has been in continuous use for centuries. Since the 1980s, it has undergone a significant change in importance: from being a focal point of the energy supply system to a recreational and tourism attraction. However, many of the old functions are still in use today (see fig. 3, also Harzwasserwerke 2011, 18–19). Climate

^ Fig. 2 Functional diagram of the Upper Harz Water Management (Source: H. J. Boyke in the 1990s, colored by J. Bintakies in 2013).

change is currently playing an increasingly important role in management and operation (Armenat 2022). Various measures for the Upper Harz Water Management System are therefore being discussed, for reasons that include safety. Solutions are being sought that reconcile monument protection, World Heritage conservation and water management concerns. The various uses, challenges and possible measures are presented below.

Recreation and tourism

Of the sixty-three ponds in operation today, ten ponds have been designated as bathing ponds by the Harzwasserwerke GmbH and four have camping facilities. Fishing is permitted as a recreational sport at more than half of the ponds.

The water management elements characterize the landscape of the Upper Harz and are a flagship for the region, combining culture and nature. The Upper Harz is a popular hiking destination. The facilities contribute directly to SDG 3 (good health and well-being). In addition, the mining museums in the region and guided tours for locals and visitors fulfill the educational and public outreach mission of the World Heritage property and SDG 4 (quality education).

Ecological niche

Over the centuries, special flora and fauna have developed in the ponds due to the changing water levels caused by the operation. Red-listed species (at risk of extinction) such as the European crayfish can be found in the nutrient-poor

^ Fig. 3 Overview of water management in the northwestern Upper Harz (Source: A. Dumreicher, 1866).

Element	In total	In operation	Archaeological monument
Pond	95	63 (10 Mio. m³)	32
Ditch	309.3 km	69.7 km	239.6 km
Water tunnel	30.7 km	21.3 km	9.4 km
Water drainage gallery	92.2 km	4.5 km	87.7 km

^ Table 1. Elements of the Upper Harz Water Management System (UNESCO 2010).

and cool still waters. These species can survive here thanks to the favorable habitat and isolated location. Some of the ponds around Clausthal-Zellerfeld are also Flora Fauna Habitat (FFH) areas (LAVES 2011, 4). However, climate change and rising water temperatures are also causing problems for plant and animal communities. The nature conservation authorities have agreed on plans with the the site's operators, Harzwasserwerke GmbH, to ensure the survival of plants such as the whorled knotted chickweed, the stag's head, the beach lily and the small sedge reeds in the affected water bodies. Plans include regulating the water levels in the ponds. In this way, the ponds also contribute to SDG 14 (life below water - bodiversity in water bodies).

Power generation

Until the early 1980s, numerous Upper Harz ponds continued to be used to generate electricity despite the cessation of mining. Today, five hydroelectric power stations are in operation in the World Heritage property. The largest and historically significant plants are located underground as cavern power plants in the Samson mine in Sankt Andreasberg and are operated by Harz Energie GmbH. Frequently, private individuals consider constructing additional small plants in the Upper Harz water management area. This development is positively supported by Harzwasserwerke and the monument conservation authorities, provided the monument is not impaired. In this way, the World Heritage

facilities contribute directly to SDG 7 (affordable and clean energy).

Drinking water supply

Another current use of the facilities in operation is the provision of drinking water. In six of the sixty-three ponds, drinking water is used directly by communities in the Upper Harz region, which are facing growing challenges due to climate change. The water supply is becoming increasingly scarce and for longer periods of time and it is often necessary to treat surface water at great expense in order for it to be used as drinking water and thus contribute to SDG 6 (clean water and sanitation). The necessary interventions in the monument are carried out in consultation with the conservation authorities and in such a way that they are as reversible as possible. For example, floating deep-water aeration systems were installed at the drinking water pond Hirschler Teich to stabilize the ecological balance (Schrader et al. 2023, 14–19). In addition, the increased input of sediments due to the current climate-induced forest conversion and the increase in extreme weather events is leading to further measures being taken to treat drinking water (Schrader et al. 2023, 14–15).

Indirectly, additional ponds can also be used to supply drinking water in times of extreme drought. This primarily concerns the supply of localities outside the Harz via the supply line to the large reservoirs of the Harzwasserwerke GmbH located on the edge of the Harz. The ponds only have a very limited significance and use for the Harzwasserwerke in terms of drinking water production in regular operation, but are an important component when it comes to adapting to changing climate conditions, including with flood protection, in keeping with SDG 13 (climate action – adaptation to climate change).

Flood protection

The ponds have always been part of flood protection. Today, numerous ponds (16, as of 2011) are used directly for flood protection, while all others contribute indirectly to flood attenuation via their retention areas (Harzwasserwerke 2011, 18). Changes in use, climatic changes and the increase in extreme events are increasing the pressure on the monument. As the ponds are legally classified as dams under water law, the Harzwasserwerke, which own and maintain the components in operation, are also confronted with new and in some cases increased demands on the dam structures and their stability.

Due to climate change and changing hydrological conditions, it is necessary from a hydraulic engineering perspective to make appropriate structural adjustments to the facilities in order to minimize the risk of failure – i.e., dam failure – in extreme cases. For example, the Harzwasserwerke has proposed redesigning some spillways in order to increase their capacity as a way to meet water law requirements. The relevant laws pertaining to water make no distinction between historical and modern dams. The World Heritage nomination document (UNESCO 2010) and the management plan already assume that the constantly evolving system must continue to change and adapt. A viable solution for future challenges must be found in a joint process of mediation between national monument protection law, UNESCO World Heritage standards, and water law.

In addition to the above-ground facilities, flood protection planning is now also incorporating the underground facilities of the Upper Harz Water Management System that can be incorporated in plans for flood protection. Care must also be taken to ensure that the substance of the

monuments is not damaged in the long term. Extreme flooding and the constant ingress of surface water promote the instability of underground mine sections that have not been flooded for long periods of time. This structural instability can lead to increased subsidence and collapse due to washout. The situation requires regular monitoring and, if necessary, permanent rock stabilization to prevent further damage to the structure. Extreme amounts of water can severely damage the tunnels and carry away existing cultural assets such as historical fixtures. A possible countermeasure here could be to salvage the assets after emergency documentation of the condition on site.

Monitoring and management

An important aspect of the operation, preservation and safety of the Upper Harz Water Management System is monitoring the facilities. The system of the Upper Harz ponds is very complex and is now only monitored and controlled by a small number of employees. To meet today's safety requirements for such systems, it is necessary to use as many automated measuring points as possible. The location and number of measuring points are always agreed on in advance with the monument preservation authorities. Hence, the installation of these measuring points ideally involves only very limited interference with the substance of the protected facilities. The water level measurements are already largely automated and allow targeted deployment planning in the event of flooding. Work is also underway to make key measurement data available automatically and online for pond monitoring. This further development in operation, which is necessary from a water management perspective, is currently focused on stability. The aim is to carry out as little intervention as possible and only as much as necessary in the monument and World Heritage property. Innovative applications and new monitoring options are also required. These can be part of preventive risk management that includes aspects relevant to World Heritage as well as hydraulic engineering.

Conclusion

The Upper Harz Water Management System has evolved over 800 years and is still changing today, not only due to changes in use, but also in operation and its requirements. As a result of the climatic changes that have already occurred and those that are expected as well as the increasing importance of the water supply, adjustments to the facilities will also be necessary in the future, just as they were in the past, and not least because many of the system's functions also contribute to achieving sustainability goals. It is crucial to define the framework conditions, both legal and financial, to coordinate new approaches and solutions with the monument protection authorities, the World Heritage management and also the supervisory authorities for dam operation. A more comprehensive view of water management in the World Heritage property is therefore an essential building block.

Acknowledgment

This contribution was peer-reviewed. It was edited by members of the editorial team of the UNESCO Chair Water, Ports and Historic Cities: Tino Mager, Zuzanna Sliwinska and Carola Hein.

References

Armenat, Manuela. 2022. "UNESCO-Welterbe im Harz in Zeiten des Klimawandels." *Berichte zur Denkmalpflege in Niedersachsen* 42 (2). Edited by Niedersächsisches Landesamt für Denkmalpflege.

Deutscher Wetterdienst. 2022. *Zeitreihen und Trends 1881-2024*. Accessed January 22, 2025. .www.dwd.de/DE/leistungen/zeitreihen/zeitreihen.html.

Dumreicher, Alfred. 1866. *Profilriß der Oberharzer Wasserwirtschaft*. HSTAH BaCl Rissarchiv No. 996-2. Niedersächsisches Hauptstaatsarchiv Hannover, Hanover, Germany.

Harzwasserwerke GmbH. 2011. *UNESCO-Welterbe Oberharzer Wasserwirtschaft. Das Oberharzer Wasserregal. Das bedeutendste vorindustrielle Energiegewinnungs- und Energieversorgungssystem der Welt*. Broschüre 24 Seiten. Accessed January 22, 2025. https://www.harzwasserwerke.de/wp-content/uploads/2023/10/unesco-welterbe-oberharzer-wasserwirtschaft-1.pdf.

Harzwasserwerke GmbH. 2019. *Wasserwirtschaft im Westharz. Hydrologische Untersuchungen mit Blick auf ein sich veränderndes Klima*. Accessed January 22, 2025. https://www.harzwasserwerke.de/wp-content/uploads/2023/10/Wasserwirtschaft_im_Westharz_1941-2018.pdf.

Malek-Custodis, Katharina. 2022. "Wasser Marsch! Mehr Kraft für mehr Tiefe." *Bergbau durch die Jahrtausende. Montanarchäologie in Deutschland* (January 2022).

LAVES (Lower Saxony State Office for Consumer Protection and Food Safety). 2011. "Vollzugshinweise zum Schutz von Wirbellosenarten in Niedersachsen. – Wirbellosenarten des Anhangs V der FFH-Richtlinie mit Priorität für Erhaltungs- und Entwicklungsmaßnahmen – Edelkrebs (Astacus astacus)" – *Niedersächsische Strategie zum Arten- und Biotopschutz*.

UNESCO. 2010. Mines of Rammelsberg, Historic Town of Goslar and Upper Harz Water Management System (Nomination File 623ter). Paris: UNESCO World Heritage Centre. Accessed January 22, 2025. https://whc.unesco.org/uploads/nominations/623ter.pdf.

Schrader, Dirk, Thomas Herberger and Christian Kiechle. 2023. "Oberflächenwasseraufbereitung im Harz – Fallstudie Clausthal-Zellerfeld." *energie | wasser-praxis* (Sepember 2023).

Manuela Armenat studied geology and paleontology and obtained a doctorate at the Institute of Historical Geography at the University of Göttingen. Her doctoral research within the DFG-funded Graduate Research Training Group (GRK) 1024 'Interdisciplinary Environmental History' focused on cultural landscape change, flood history, and hydraulic engineering planning history. She served as coordinator of the DFG-GRK 1086, during which time she conducted research on dealing with cultural monuments on and in watercourses within the framework of the European Union Water Framework Directive. Since 2013 she is an employee at the World Heritage Foundation in the Harz Mountains. Since 2019 she is also a deputy managing director of the foundation.

Contact: armenat@welterbeimharz.de

Christian Bellak studied at the University of Applied Sciences North-East Lower Saxony as a civil engineer specializing in hydraulic engineering, and graduated as Dipl.-Bauingenieur (FH). From 1997–2000, Christian worked in a specialized civil engineering company for international projects, and since 2000 has been employed at Harzwasserwerke GmbH in dam operation. Christian has served as head of the reservoir operation department since 2020.

Contact: christian.bellak@harzwasserwerke.de

Andreas Lange studied civil engineering and obtained a doctorate at the Institute of Hydrology and Water Ressources Management at the University of Hannover. From 1995 to 2000, Andreas served as a project engineer in an engineering office, completing expert reports on hydrogeology and hydrology. Since 2000, Andreas has been head of Water Resources and, since 2014, an authorized officer of Harzwasserwerke GmbH, Hildesheim.

Contact: andreas.lange@harzwasserwerke.de