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Adaptive Transformation of Historic Water Works in Hamburg, Germany: From Essential Infrastructure and Cornerstone of Public Health to Valuable Man-Made Ecosystems and Designed Public Spaces

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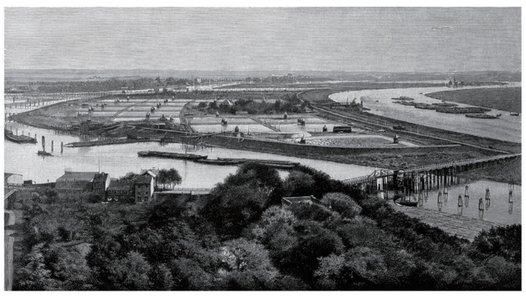
GRAPHICAL ABSTRACT

Implementation of water filtration system for drinking water on Kaltehofe Island

Wasserkunst Elbinsel Kaltehofe: industrial monument and nature park

1893 — 2011



Sand filtration plant right after construction
(source: Strumper and Co., Hamburg, taken in 1893)

Former sand filtration basins with restored slider buildings

HIGHLIGHTS

- Just 150 years ago, there was essentially no infrastructure in place to provide a clean and safe water supply, which is regarded as standard today
- Unique projects for the adaptive transformation of historical technical infrastructure over a period of more than 150 years address new needs and uses through design interventions towards blue and green infrastructure
- As legally mandated compensation mitigating environmental impacts caused by dredging the Elbe River, the redesigned former sedimentation ponds function as a new habitat for endemic species

KEYWORDS

Adaptive Transformation; Waterworks; Sand Filtration System; Cholera; Industrial Heritage; Recreation; Ecological Compensation; Ecosystem Restoration; Nature-based Solutions

ABSTRACT

A lack of safe drinking water supply is the cause of a number of waterborne diseases such as cholera. Even nowadays, an estimated 100,000 people die from cholera each year. Since the early/mid-19th century relatively simple but highly effective engineering solutions were developed that helped provide clean drinking water. In 1892 the City of Hamburg, Germany was hit by a cholera epidemic and more than 8,000 people died within a few weeks. As a consequence, sedimentation and filtration systems to provide clean drinking water were built. They were in operation for nearly a century and subsequently became disused in recent decades. Since then, a number of proposals including large mixed-use developments were put forward and over time adapted to the changing needs to offer educational and recreational services, as well as enhancing natural assets. While the historic buildings of high heritage value were conserved, the sedimentation and filtration systems in their landscape setting transformed through natural succession combined with design interventions into attractive and valuable habitats. In addition, some of the former sedimentation basins were found to be the most suitable locations to compensate for the environmental impact of the highly disputed dredging of the Elbe River and were redesigned to provide a new habitat for a rare and endemic plant species.

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1 Introduction: Evolution and Importance of Waterworks for the Provision of Drinking Water

Nowadays, in many countries around the world, people expect that perfectly safe, fresh drinking water is available by just turning the tap. On the other hand, even till now in many countries drinking water is a scarce resource. It is hard to believe that in the 19th century in industrialized countries such as Germany, or pretty much everywhere around the world there was no safe supply of drinking water. In Hamburg, one of the largest German cities at the time, people got their drinking water from the river Elbe, a major river originating at the Polish–Czech border and stretching over more than 1,000 km in length. As Hamburg is close to the sea, there is a considerable tidal influence[1], with an average difference of 3.66 m between high tide and low tide, exerting a major effect on water quality depending on ebb and flow[2]. At the same time, the river was used for drinking water and also as a natural sewer[3]. Not surprisingly, the drinking water was potentially dangerous.

As a consequence, William Lindley, a famous English engineer who worked all across Europe was hired to improve the situation[4]. Only from 1844 to 1848, an 11 km underground sewage system, as well as a waterworks a bit further upstream in the district of Rothenburgsort to supply the city of Hamburg with drinking water, was built[4]~[7] (Fig. 1). This was the first modern water and sewerage system in mainland Europe. Lindley also suggested a sand filtering system, but for economic reasons it was not implemented. Only four basins for basic sedimentation, without any filtering, were constructed nearby Billwerder[4].

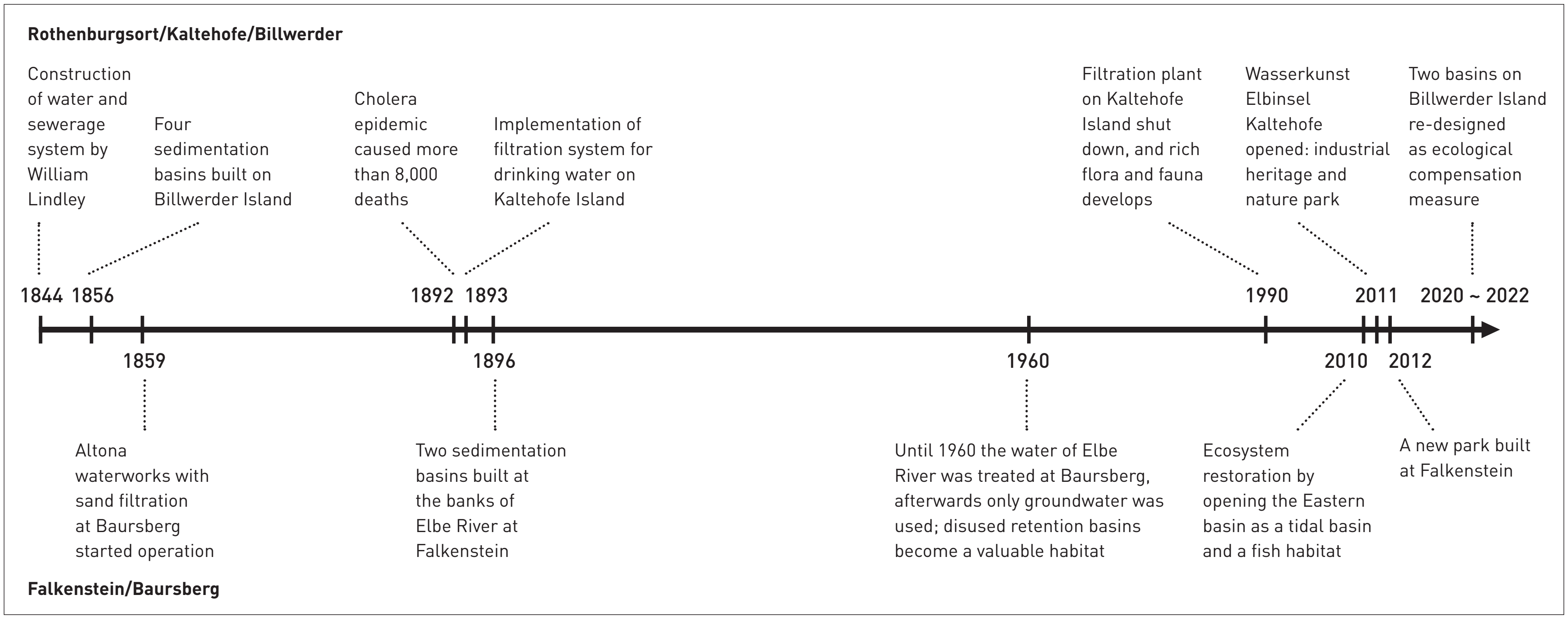
Although systems for the actual supply of drinking water have been used for thousands of years (e.g., in the Mesopotamian and Mediterranean Region), the actual engineered treatment of water started as late as 1804 when John Gibb designed a slow sand filter for his bleachery in Paisley, Scotland[8][9]. Other examples to treat sewage and wastewater include the trickle fields in Berlin, which were established in the late 19th century. The wastewater was dispersed over an area of around 100 km^2 and filtered by the sandy soil[10].

In 1829, slow sand filtration was introduced on a large scale at the Chelsea Waterworks in London by the engineer James Simpson[8]. Sand filtration mimics natural processes by removing contaminants (e.g., organic pollutants) through physical (e.g., adsorption) and biological processes helped by non-pathogenic aerobic microorganisms[11].

2 Waterworks and Cholera: The Hamburg Cholera Epidemic of 1892

While the practice of sand filtration appeared to be very efficient in providing high quality drinking water, broader health science and knowledge about water sanitation was still in its infancy and the existence of pathogenic bacteria in water was unknown.

This was of particular importance as cholera was a widespread disease killing many thousands on a global scale. Quite similar to the early phase of the recent outbreak of the COVID-19 pandemic, at the time it was not clear how the cholera disease was spreading,



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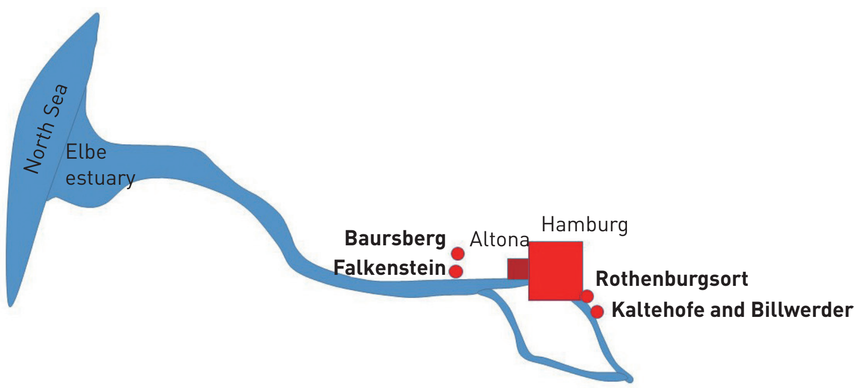
1. Timeline of events from the initial construction of the waterworks to the after-use as of today (sources: Refs. [4]~[7]).

for instance, water or air through poisonous vapors. In 1854, the physician John Snow investigated approximately 600 deaths in one week caused by cholera and discovered a causal connection between the type of water supply and the fatalities[12]. In autumn 1892 in Hamburg, there was a major outbreak of cholera killing more than 8,000 people in 10 weeks[3][13]. Taking into account the larger population nowadays, the death toll then was about three times higher than during the recent COVID-19 pandemic. Robert Koch, a pioneer in bacteriology, investigated the epidemic in Hamburg in detail[14]. He found that within the contiguous cities of Hamburg and Altona there were clear boundaries separating cholera-infected and non-infected areas[15].

All infected areas had their water supplied from the city of Hamburg, which drew the drinking water upstream from the Elbe River at Rothenburgsort (Fig. 2). The areas not infected were in the neighboring town of Altona which took its drinking water further downstream out of the Elbe River as well. The water quality in Altona was inferior, because the water of the Elbe was highly polluted by the sewage and faeces of about 800,000 people upstream[3]. However, unlike in Rothenburgsort, Altona had a sand filtration system which helped eliminate the cholera bacteria from the drinking water. Thus Koch was able to prove that cholera bacteria were transmitted via the water and that water filtration was key in providing healthy drinking water[8].

2. The city of Hamburg and the location of the waterworks.



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3 Waterworks in Rothenburgsort and Altona

3.1 Rothenburgsort Waterworks: The Filtration System on Kaltehofe Island and the Sedimentation Basins at Billwerder

Based on the proposals by Lindley, the city of Hamburg established the waterworks in the district of Rothenburgsort, upstream to the East of Hamburg, relying only on four simple sedimentation basins at Billwerder, completed by 1856 (Figs. 1, 3).

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3. Former sedimentation basins at Billwerder in 2015.
4. The structure of the sand and gravel filter layers with varied grain sizes as displayed at the Kaltehofe Museum. The depth is approximately 1.7 m.

Furthermore, Lindley suggested to construct a large sand filtration system on Kaltehofe Island, just nearby. For financial reasons, it was put on hold until 1890 to start with the construction of the filtration plant[16]. Already by May 1893, but rather tragically, just after the cholera epidemic, 18 sand filtration basins were completed on Kaltehofe Island with another four by 1896 (Fig. 4), constituting the largest plant for water purification of any city at that time[17]. Initial cleaning was performed by the basins at Billwerder. This ensured provision of safe and clean drinking water from Rothenburgsort to Hamburg until 1990 when the filtration plant on Kaltehofe Island was shut down[4]. Kaltehofe Island is a unique example of industrial heritage from the 19th century, as it is the only place worldwide where these sand filtration basins still exist and are now transformed and adapted to new functions.

3.2 Altona Waterworks: The Water Pumping System and Sedimentation Basins at Falkenstein

Already in 1859 Altona waterworks started their operation. The key feature was pumping the water directly from the Elbe River at Falkenstein up to the nearby Baursberg Hill, which at 91.6 m elevation is by far the highest point along the Elbe River, a distinctly visible moraine remnant of the glaciation several thousand years ago. The pumping typically happened during or just before high tide, when the best water quality in the Elbe River was reached, i.e. at that point the polluted water from Hamburg which lies upstream was pushed back by the tide[4]. In addition, in 1896 two sedimentation basins along the banks of Elbe River at Falkenstein were constructed to ensure a pre-cleaning process before the water was pumped uphill (Fig. 5). This system involving sedimentation and pumping the water uphill to Baursberg was in operation until 1960. Because of the increasing levels of pollution of the river, the waterworks switched to pumping groundwater.

4 Transition Towards Nature Protection, Recreation, and Industrial Heritage at Rothenburgsort/Kaltehofe

After the sedimentation basins on Kaltehofe Island were shut down in 1990 and fenced off, natural succession with pioneer vegetation took over, including shrubs and trees, wild perennials, and aquatic plants, forming an undisturbed habitat for birds (44 breeding species), bats, small mammals, and amphibians[18].

An initial proposal was developed to turn the disused site into a mixed-use urban development for approximately 10,000 people living and working on the site, comprising apartment blocks with 4 ~ 6 stories, as well as 7-story office buildings and associated infrastructure such as hotels, restaurants, and 4,500 spaces for parking. This failed because it was too costly and there were high levels of contamination in the soil due to the nearby copper industry[19]. At the same time local nature protection organizations wanted to conserve and protect the habitats. This conflict of opposing interests could not be solved and in order to coordinate the various stakeholders and their ideas, a local Agenda 21 process was initiated in 2004[16]. This process builds on the 1992 Rio conference[20] aiming

5. Former sedimentation basins at Falkenstein (bottom) with pump house and new park, and Baursberg waterworks and former sand filtration system (top).

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to develop locally tailored plans for sustainable development by addressing local needs and concerns through the integration of local stakeholders in the decision-making process[21].

Through meetings, workshops, and conferences, a range of proposals was jointly developed resulting in a masterplan for Kaltehofe Island, which featured a wide variety of possible recreational activities such as swimming, boating, and a 50-meter tall viewing tower as a key attraction[22]. Again, this proposal was not financially viable.

Based on a downscaled masterplan, Wasserkunst Elbinsel Kaltehofe opened in 2011[23], consisting of a 143,000 m^2 sized park in the central part of the island. The majority of the area is inaccessible or even designated as nature reserve and protected area according to the EU birds directive (Fig. 6). The term "Wasserkunst" refers to water engineering, which had originated centuries ago in Germany; also, in the context of establishing water features such as fountains in parks of the nobility, the term linguistically relates at the same time to the terms "art," "artificial," and "skill."

The main features of the design include buildings of the former waterworks as industrial heritage, now used as a museum for educational purposes including a café and a venue for meetings. Other interpretative features and historical artifacts include information panels along the water basins, restored slider buildings controlling the waterflow, and a small train reminding visitors that the sand of the filtration basins had to be transported to a special sand washing facility[23] (Fig. 7).

Introduction of new uses include a barefoot trail, a nature discovery trail, wild flower meadows, bee hives, and a bird observation platform to provide opportunities for educational and recreational activities, and support ecological diversity of the site.

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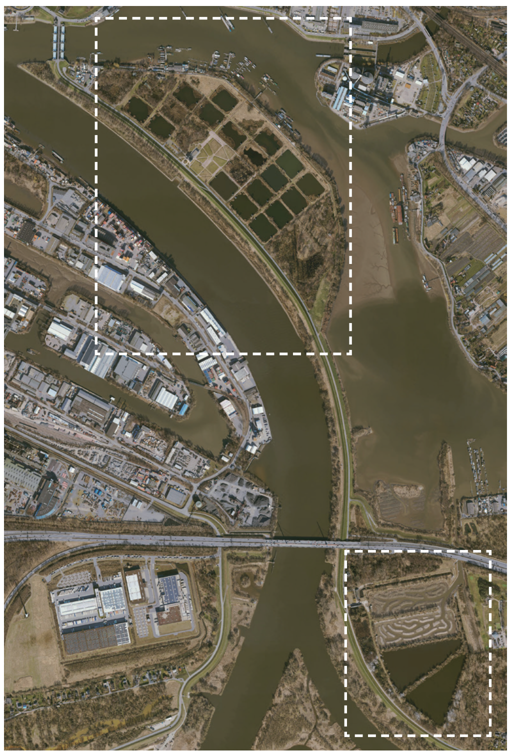

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6. Kaltehofe Island (top) and the sedimentation basins at Billwerder indicated by their geometric outline (bottom).
7. The former sand filtration basins with restored slider buildings on Kaltehofe Island. The small train was used for transporting the sand and gravel mixture to a washing facility.

5 Transition Towards Nature Protection, Recreation, and Industrial Heritage at Falkenstein and Baursberg

Similar to Kaltehofe Island, there is an accessible as well as an inaccessible part of the site at Falkenstein and Baursberg. As the historic ensemble of the waterworks including the former pump house next to the Elbe River were not in use anymore, in 2015 they were sold to a private investor. To preserve the cultural heritage of the waterworks, the buildings were renovated by keeping the style and combining detailing from the 19th century with modern comfort. The buildings are now being used as private luxury homes as well as a rather unique event space for concerts and exhibitions. The sale of the property was granted subject to the grounds between the waterworks and the shore of Elbe River being accessible to the public[6].

Since the time when the waterworks at Falkenstein and Baursberg switched to pumping groundwater instead of using the water from the Elbe River from the early 1960s onwards, the two sedimentation basins at Falkenstein became disused and over time turned into a valuable habitat for fish and amphibians[24]. Right next to the Elbe River, the largest container vessels pass by on their way to and from the North Sea to the port of Hamburg, which ranks 18th

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globally in terms of tonnage[25].

In 2010 an ecosystem restoration project in one of the basins took place[5]. The eastern basin was opened to the Elbe River (Fig. 8) and designed as an oxygen-rich shallow water site exposed to the tidal flow in order to serve as breeding and nursery area for a number of fish species including Twait Shad (*Alosa fallax*) and Asp (*Aspius aspius*)[26].

The western basin remains as a key habitat for amphibians (Fig. 9). Because of this, four special amphibian tunnels were built underneath the minor road separating the sedimentation basin and the nearby forest[24].

Next to the basins a new park of 4,000 m^2 was built in 2011 and further extended in 2017[27]. It is characterized by an orchard-type style with apple and pear trees, as well as by hedges and seating along the riverbank. Similar to Kaltehofe Island, interpretative panels inform people about the history of the waterworks making connections with features and relicts of the history of the site and the waterworks. Besides, the site on top of Baursberg Hill is still used as waterworks and is not accessible by the public. The buildings there are listed as cultural heritage.

6 Linking the Two Sites and Linking the Past and the Present Towards a Safe Future for an Endemic Rare Species

Because of the economic importance of the port of Hamburg, there was a strong interest not only in maintaining but also in widening and deepening the Elbe navigation channel[1]. As a result of this highly disputed dredging project in the Elbe River fairway between Falkenstein and the island of Neßsand, now ships with a draught of 13.1 m (regardless of tide) or even up to 15.4 m (the largest current container ships) can pass each other on their way to Hamburg Port[28].

This area is not only a special zone of conservation (a Natura 2000 site) of European dimension as a valuable fish habitat, but also home to an endangered and endemic plant species, the Elbe Water Dropwort (*Oenanthe conioides*)[26]. It grows in freshwater tidal

8. Former sedimentation basins at Falkenstein, opened towards the Elbe River, with waterworks including the pump house (center right). The hillside of Baursberg features some of the most expensive homes in entire Hamburg.
9. Former sedimentation basin, looking towards the Elbe River, with a very large container ship just passing by.
10. Former sedimentation basins at Billwerder in 2020, after re-design and implementation of compensation measures for the Elbe Water Dropwort.

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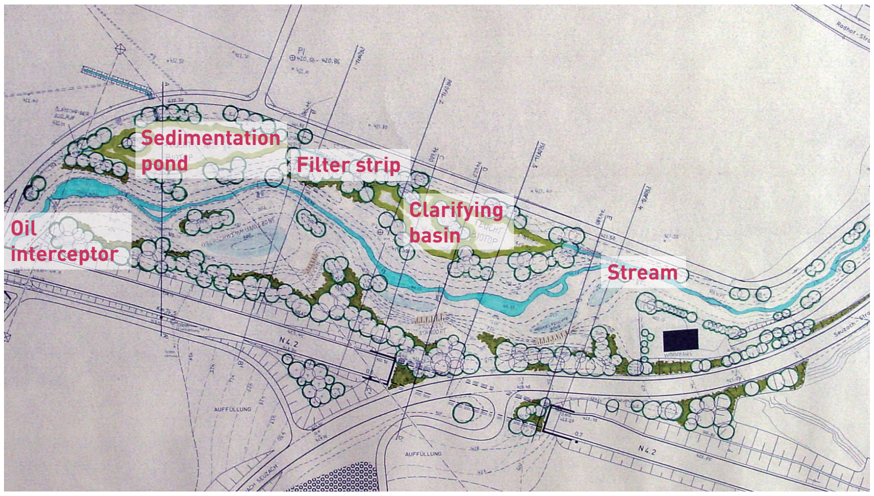

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11. Artificial wetland with natural filtration for cleaning the runoff from the A4 highway in Switzerland near Zürich (designed by Eckart Lange, in 1990).

12. The site of the artificial wetland with natural filtration for cleaning the runoff from the A4 highway, photographed in 2007.

zones[29] nearby the island of Neßsand and at a number of locations in the Elbe estuary, nowhere else on this planet. After 12 years of legal dispute the Federal Administrative Court of Germany in 2017[30] ruled to permit the dredging of the river bed on the basis of establishing compensation measures to ensure survival of the plant. Following the mitigation hierarchy principle[31], it was decided to offset the impact and to create a similar habitat at another location. Two of the four sedimentation basins on the island of Billwerder, originating from the waterworks project from 1844 and now also part of a nature reserve, were selected as the most suitable location to compensate the impact of dredging the Elbe River[32].

As part of the project, an artificial habitat was created (Fig. 10), resembling a maze of tidal creeks, mudflats, and small islands with shrubs and an alluvial forest along the river bank. Complicating matters even more, the site is at the same time the largest colony of cormorants in Hamburg[33]. Because of their breeding season, the construction period had to be limited from September to February.

With a total budget of 11.1 million Euro more than 2,000 Elbe Water Dropwort were planted. As this plant is rather sensitive in terms of habitat needs, several nature protection organizations including WWF raised doubts whether the endangered plant will survive in the newly created habitat in the long term[34].

7 Conclusions

Similar to other delta regions in the world, such as the Pearl River Delta[35][36], the Elbe River is of key economic importance for the city of Hamburg, while at the same time it is home to valuable habitats for animals and plants, offering a range of ecosystem services. This leads to a number of potentially serious conflicts. Adapting the disused waterworks to new needs and uses, instead of destroying them, provides a multitude of opportunities and benefits. Industrial heritage can be experienced in its original setting and at the same time recreational activities as well as nature protection is supported. These unique projects are characterized by their inventive after-use and subtle interventions as valuable elements of the natural and cultural landscape.

Learning and benefitting from the principles of sand filtration and the positive effects on water purification[37] only for decades, artificial wetlands (Figs. 11, 12), reedbeds or even wetland parks have been built and are nowadays established design interventions[38][39]. While in the past such projects were solely approached from a water engineering perspective, they are now a well-established design feature in the project portfolio of landscape architects[40][41].

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Competing interests | The authors declare that they have no competing interests.

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德国汉堡历史水利设施的适应性转型：从保障公共卫生的关键基础设施到宝贵的人工生态系统和公共空间

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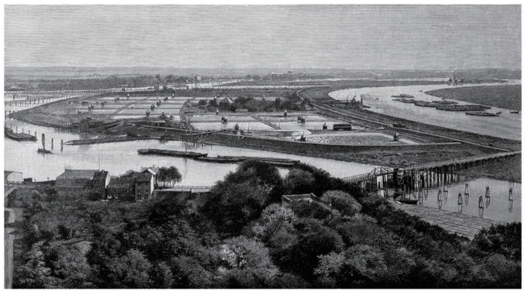
图文摘要

卡尔特霍费岛饮用水过滤系统的实施

1893

卡尔特霍费水景艺术公园：工业纪念博物馆和自然公园

2011



砂滤厂刚刚建成时的照片

（照片来源：汉堡斯塔穆珀公司，拍摄于 1893 年）

废弃砂滤池和修复的滑块建筑

摘要

缺乏安全的饮用水供应是引起霍乱等水源性传播疾病的一大原因。即使在现代，每年仍有约10万人死于霍乱。20世纪初至中叶以来出现的一些相对简单但高效的工程解决方案为人们提供了清洁的饮用水。1892年，德国汉堡市爆发霍乱疫情，短短几周内就有超过8 000人丧生。为了应对这一危机，汉堡市建立了沉淀和过滤系统以提供清洁饮用水，自此该系统运行了将近一个世纪。近几十年来，这些设施逐渐废弃，人们提出了大型综合用地开发等多项提案，而后又根据不断变化的需求进行调整，以提供教育和休闲服务，同时提升自然资产价值。那些保存下来的历史建筑具有较高的文化遗产价值，在自然演替和设计干预的共同作用下，它们与景观环境相融合，转变为了具有美学价值的宝贵栖息地。此外，易北河疏浚曾饱受争议，为补偿其造成的环境影响，一些旧沉淀池因适宜的地理位置被重新设计为栖息地，为当地特有的罕见植物提供了家园。

文章亮点

- 直至150年前，尚未出现如今习以为常、可以提供清洁安全水源的基础设施
- 一些拥有150多年历史的技术基础设施通过适应性设计干预，转型为蓝绿基础设施，可以满足新的使用需求
- 为对疏浚易北河所造成的环境影响实施法定补偿措施，旧沉淀池被重新设计为新栖息地，为当地物种提供了家园

关键词

适应性转型；自来水厂；砂滤系统；霍乱；工业遗产；游憩；生态补偿；生态系统修复；基于自然的解决方案

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