The Water Industry as World Heritage

Thematic Study

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EXECUTIVE SUMMARY

The modern water industry grew in response to rising demand for water caused by industrialization and consequent concentrations of urban populations. By the early 19th century these were starting to overwhelm traditional sources of water and customs of waste removal, resulting in repeated epidemics of waterborne diseases like cholera, typhoid and yellow fever. To overcome this historical threat to human development, referred to by environmental historians as the Sanitary Crisis, new technological solutions, engineering practices, administrative arrangements and legal frameworks had to be worked out, underpinned by advances in scientific and medical understanding of the transmission of disease and the purification of water.

An infrastructure to collect, distribute and treat water for human consumption was assembled – and in many cases retro-fitted – first of all in the larger cities and subsequently to urban landscapes everywhere. Systems grew which integrated distant sources of fresh water from upland dams and reservoirs; pumped supplies raised from underground aquifers, rivers and lakes; distribution networks of aqueducts, pipelines, pumping stations and water towers; and filter and treatment centres where impurities could be removed. Early modern patchworks of local water supply gradually meshed, refashioned urban areas, extended to other technologies, and led to the development of the modern network city.

In helping to overcome the Sanitary Crisis, and enabling later urban growth to proceed without the suffering encountered during the 19th century, the water infrastructure made a major contribution to human development, and the most historically significant elements, taking authenticity and integrity into account, should be identified and recognized.

The present work, commissioned by TICCIH, is one in a series of comparative thematic studies which propose criteria by which the material evidence of different industrial sectors can be assessed. These are pertinent for the World Heritage List as well as for national and regional heritage inventories.

A historical summary identifies when and where the important advances in the water industry took place so as to help recognize both the outstanding as well as the most representative surviving sites – the unique but also the ubiquitous – and to locate potentially significant ones. A selection of case studies is included to aid the comparative analysis of historic properties.

Overall, in our view the water infrastructure from the pre-industrial period is comparatively well represented in the UNESCO list, although with a preponderance of aqueduct bridges, but the heritage of the modern water industry is almost entirely absent, despite its unarguable relevance to human development. A selection of outstanding networks or collections of integrated sites should be made to correct this imbalance.

1. Context

1.1 Thematic studies

This report forms part of a series of comparative thematic studies of the heritage of different industrial sectors organized by TICCIH in its role as the designated consultant to ICOMOS in matters related to the study and preservation of industrial heritage. ICOMOS counsels UNESCO on properties to be added to the World Heritage List, drawing on its advice from TICCIH.

Although the format varies, in general these comparative studies summarize the worldwide history of the sector, identifying the period, location and authors of the most significant developments in order to provide a contextual framework to help identify the outstanding as well as the most representative plant, buildings, sites or landscapes produced by the chosen sector. The theoretical and practical considerations of these properties as World Heritage sites is examined in the light of the criteria for Outstanding Universal Value in UNESCO's Operational Guidelines for the Implementation of the World Heritage Convention. A selection of case studies, written by different authors, contributes to the comparative evaluation of different sites around the world, although without making any recommendations. The immediate beneficiary of the report is UNESCO, to help it distinguish places eligible for inscription on the World Heritage List, but the criteria are applicable to other national or regional denominations.

1.2 Objectives

The report will

- summarize the global development of the infrastructure of the water industry and its impact on human settlements;
- plot the technical evolution of the main components to identify critical or gateway developments, as well as those of most widespread practical application;
- determine when the water industry made significant contributions to human development; and
- provide comparative data to help identify the sites or landscapes which best represent these contributions.

1.3 Methodology

The process of preparing this report consisted of a desk-based examination of the literature during 2017, consultation with relevant experts who were sought to give a representative geographical and professional spread, the incorporation of their suggestions and improvements, concluding with the presentation of the final document at an international meeting hosted by the Museu Agbar de les Aigües in Barcelona in April 2018 to confirm a consensus for the conclusions.

The study does not introduce new research, serving to draw together as much accessible information as possible on the heritage of this industry to facilitate the evaluation and comparison of different properties. This may be useful for assessing sites put forward for inscription on the World Heritage List by UNESCO. It does not recommend any specific places, intending rather to help characterize those features of this class of cultural heritage which ought to be taken into consideration in an assessment of Outstanding Universal Value. Among the places included in the discussion or presented as case studies are properties already inscribed on the World Heritage List as well as on national Tentative Lists. They serve to illustrate the theme and their inclusion is not intended as an indication of their potential as World Heritage sites.

2. Introduction

2.1 Scope

The parameters defining this study relate to the methodology outlined in Professor Michel Cotte's 2015 report for ICOMOS, *The cultural heritages of water.* This ambitious and wide-ranging work seeks to provide 'a methodology for the identification and then the preservation of such heritages, in a wider context, not only for properties which could be nominated for the World Heritage List, but also for places of regional or local importance' (Cotte 2015, 11).

Cotte recognizes the utility of a 'thematic category-based approach' similar to previous TICCIH comparative studies such as that of navigation canals (Hughes 1996), railways (Coulls 1999) or quarries (Gwyn, unpublished). This is the approach of the current study which is focused under the first general category in the typology that he proposes:

1. The acquisition, management and control of water to make it available for purposes of human use:
    - water collection, drainage, wells, boreholes, etc.,
    - the storage of water at various scales, dams, cisterns, etc.,
    - the transport of water as a tangible resource, [pumps],
    - water treatment upstream and downstream of use (settling, filtration, pollution removal, recycling, etc.).

The site typologies which will be examined therefore include:

- collection (wells, boreholes),
- storage (dams, reservoirs),
- distribution (aqueducts, pumping stations, reservoirs, cisterns, water towers, mains networks), and
- treatment of natural and wastewater (filtration, chemical and biological treatment).

Evidently many of these types of sites are not exclusively for managing water for human consumption, and may also serve for irrigation, as canals, to generate power, in flood control, for defence or recreation. Excluded from the scope of this study are the other five categories defined by Cotte:

2. Use of water for irrigation, transport and navigation, generating hydraulic energy, or direct water power.
3. Control of natural water (floods and droughts).
4. Water and health (leisure, spas, recreation).
5. Water knowledge (forecasting, mythology and religion).
6. Designed landscapes (parks and gardens).

2.2 Chronology

The TICCIH water industry study examines the infrastructure built for the management of drinking water during the industrial period, as TICCIH defines it in the 2003 Nizhny Tagil Charter. Simple pre-industrial urban supply networks such as are found in China, Arabia and the Classical world are included in so far as they provide some of the engineering origins to the infrastructure of the modern industry, primarily dams, aqueduct bridges and storage cisterns.

The simple urban water networks of early modern Europe are the pioneers of the modern water industry. Melosi refers to these as proto-systems, 'offering rudimentary distribution networks, pumping facilities and new sources of supply... precursors to more elaborate centralized city-wide systems adopted by many cities and towns by the late 19th century' (Melosi 2008, 39). The main historical focus of the study is therefore on the development of these networks from the onset of industrialization from the late 18th century, and the fundamental role of this infrastructure in the shaping of the modern city by the early 20th century.

2.3 Comparative studies

This is the first global comparative study assessing the significance of sites and landscapes of the water industry. The few partial investigations that have been found are limited either in the typologies they consider or to particular territories, and may be within the grey literature of unpublished agency reports. Partial comparative analyses are done for properties nominated for the World Heritage List, and these include Tarnowskie Góry Underground Water Management System in Poland, the Hydraulic Engineering and Hydropower, Drinking Water and Decorative Fountains of Augsburg (Kluger 2013) and the Upper Harz mining water-management system in Germany, and Banská Štiavnica and the Technical Monuments in Slovakia.

Douet (1995) is an assessment of the heritage of the water and sewage industry of England, and examines other water systems comparable to that of Augsburg. The International Canal Monument List (Hughes 1996) assesses dams, earthworks, aqueducts, and pumps for navigation canals, but includes examples built for water supply, notably in the Roman Empire. Billington et al. (2005) is a rigorous consideration of the application of the six American National Historic Landmarks criteria to high dams built by the Federal government in the 20th century but which are relevant to the rest of the world.

> *...while historians of technology have given little attention to sanitary technologies, urban historians and historians of public health have had much to say about the conditions that led to the need for new water supplies and sewers.* (Hamlin 1992, 682)

2.4 The water industry on the World Heritage List

At the time of publishing this report no modern systems or networks for supplying drinking water or for removing and treating wastewaters are inscribed on the World Heritage List, although some individual components are recognized by UNESCO (Willems & Schaik 2015).

The only property or landscape on the list including components for the industrialized supply of drinking water is the metal mining complex Tarnowskie Góry and its Underground Water Management System in Poland, inscribed in 2017. Part of the justification for its inscription is the claim that it includes 'the world's first large-scale public water supply systems based on the steam-powered pumping of groundwater', although ICOMOS' technical mission noted that there was little surviving tangible evidence of this. The criteria used to justify the inscription of this European metal mine are presented in Section 8.5.

Two sites directly associated with water supply are waiting to be assessed, the Hydraulic Engineering and Hydropower, Drinking Water and Decorative Fountains of Augsburg on the German Tentative List, and the Baroque Águas Livres Aqueduct, with its associated conduits and reservoir, on that of Portugal.

The properties on the List that are involved in transporting water for human use are inscribed for their architectural and engineering importance. These are the three Roman aqueducts in Segovia, Tarragona, Spain, and Pont du Gard, France, and the Padre Tembleque aqueduct in Mexico. Each is recognized for the technical skill of planning and construction to which they are testament. The 11th-century Rani-ki-Vav Stepwell in India is a characteristic typology with a monumental architectural design developed for accessing and storing ground water. The Gothic Maulbronn Monastery in Germany includes elements of a 13th-century monastic water system.

The only dams which are inscribed are along canal navigations. Two are part of the Canal du Midi in France, which were raised to retain feed water for the summit level. St Ferréol (1667–71) is an earth dam with low masonry revetment walls, while the masonry buttress dam at Lampy, added in 1777–81, was the second of that type to be built in Europe. The 1826–32 Jones Falls Dam forms part of the Rideau Canal in Canada.

Some urban water-supply networks are included as secondary features of canal navigations – the Old Town of Lijiang and the Ancient Villages in Southern Anhui – Xidi and Hongcun in China – , or early modern mining landscapes – the Upper Harz mining water-management system in Germany and Banská Štiavnica and the Technical Monuments in Slovakia.

2.5 Cooperation

This thematic review is the result of a wide interdisciplinary effort with a considerable team of experts. It was developed with the particular encouragement of Stephen Hughes and Patrick Martin of TICCIH, and Susan Ross and Dennis de Witt were generous in commenting on early versions. Eusebi Casanelles helped arrange the conference which concluded the project at the Museu Agbar de les Aigues whose director, Sònia Hernández, was instrumental in making it a success.

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3. Terminology

This section briefly defines the technical terms describing water infrastructure used throughout the report.

Public water supply (PWS): a system that provides water via piping or other constructed conveyances to the public for human consumption.

Public sewage collection and treatment (PSCC): a system that removes domestic sewage and treats it to remove contaminants and leave environmentally safe water.

Separate sewage system (SSS): separate sewers that do not carry storm water, which is removed in an independent pipe system.

Combined sewage system (CSS): combined sewage systems removing both sewage and urban rain run-off.

Sanitation: the systems for taking dirty water and other waste products away from building to protect people's health.

Waterworks: a general term covering the following
- a water or sewage treatment plant;
- a pumping station including the pump house, ancillary buildings, accommodation and landscaping; and
- a building containing pumps and the motor to drive them.

Collection and storage

cistern: a large covered holding reservoir.

dam: a barrier constructed to hold back water and raise its level, forming a reservoir used for water supply, as well as for other purposes such as irrigation or to generate electricity.
- embankment dams: made of compacted materials such as rock or earth and most have a core of impervious material.
- gravity dams: made from mass or reinforced concrete or stone masonry and designed to hold back water primarily by the weight of the materials. Most are straight but some have a curved axis.
- arch dams: curved upstream and direct the weight of the water against the foundations and abutments. Arch–gravity dams combine the properties of the two types.

qanat: an inclined gallery excavated into a hillside to strike an aquifer.

gatehouse, outlet works, valve house: houses sluice gates, valves or pumps.

reservoir: holds water collected from rainfall, and/or collected from rivers and underground aquifers, from which it can flow under gravity to the consumer.
- impounding reservoirs: formed when a valley is closed by a dam which holds back the water and allows the flow to be regulated.
- holding reservoirs: store pumped water.
- storage reservoirs: store water prior to treatment.
- service reservoirs: store water prior to distribution, under or above ground.

standpipe: tall, narrow tower to regulate mains pressure or act as a buffer for pumped water.

valve or discharge tower: regulates and controls the flow and level of reservoir water, and may be separate or incorporated in the dam.

water tower: raised water storage structure to hold water and pressurize mains.
well, borehole: a bored, drilled or driven shaft, or a dug hole whose purpose is to reach the aquifer and raise underground water supplies.

Distribution

aqueduct: a pipe, conduit or channel designed to transport water from a remote source, usually by gravity, but often applied to what is really an **aqueduct bridge**.

- mains: arterial pipelines carrying water from treatment plants to users.
- pipeline: closed, usually buried, tubes.
- conduit: open duct or channel.
- siphon: pipe or conduit through which water will flow against gravity.

cistern: small tank (usually covered) to store drinking water, often rainwater.
sewer: a system of underground pipes that collect and deliver wastewater to treatment facilities or rivers.
steam pumping engine: reciprocating prime mover linked to water pumps.

- beam engine: steam engine with a vertical cylinder, operating pumps through a horizontal beam supported either on the walls of the engine house or on iron columns. Both rotative models (with a crank and flywheel) and non-rotative models (the Cornish engine) are used.
- horizontal engine: steam engine with horizontal cylinder(s), operating pumps through cranks or rockers.
- vertical engine: steam engine with vertical cylinder(s), operating pumps directly or through a crank. 2- and 3-cylinder compounded examples were widely used.

outfall: the place where a sewer or drain discharges.
pumping station: a building housing pumps, which may be moved by animal power, steam engine, oil or electric motors, or other sources of motive power.
well-, fountain-, spring- or conduit head: point of public water distribution, usually free, often decorative and sometimes monumental in design.

Treatment

filter beds: layers of sand or gravel in a tank or reservoir drained at the bottom through which water passes to purify it.

- **slow and rapid gravity filter**: sand bed with a thin biological layer to treat drinking water. Rapid filters have a coarser filter medium and are cleansed by backwashing.
- **settlement**: open lagoon in which suspended pollutants sink to the bottom and the liquid overflows out of the enclosure.
- **contact beds**: container in which aerobic treatment of sewage is facilitated.
- **septic tank**: tank used to detain domestic wastes to allow the settling of solids.

filter house: building containing rapid filter tanks.
sedimentation tanks: wastewater tanks in which floating wastes are skimmed off and settled solids are removed for disposal.
sewage (or wastewater) treatment plant: a facility designed to receive the wastewater from domestic sources and to remove materials that damage water quality and threaten public health when discharged. Modern examples employ a combination of mechanical removal steps and bacterial decomposition to achieve the desired results.
sewage farm: a facility to dispose of human sewage by distributing it on agricultural land as a fertilizer; sometimes a euphemism for a sewage treatment plant.
water treatment plant: a facility designed to carry out primary, secondary and/or tertiary treatment of water for delivery to users.

4. Historical development of water infrastructure

The default or natural sources of water for human communities were rainfall collected in tanks or cisterns, raised or pumped up from the aquifer, or conveyed from the nearest stream, river or lake. Sewage and effluent was buried, spread on fields as manure, or allowed to disperse naturally from below-ground privies and cesspits. Surface drains carried waste away to the nearest water body with no attempt at treatment.

4.1. Ancient and Classical supply systems

Since the earliest attempts to obtain more reliable or abundant water, organized supply and waste removal systems have been structured around urban settlements (Angelakis & Zheng 2015).

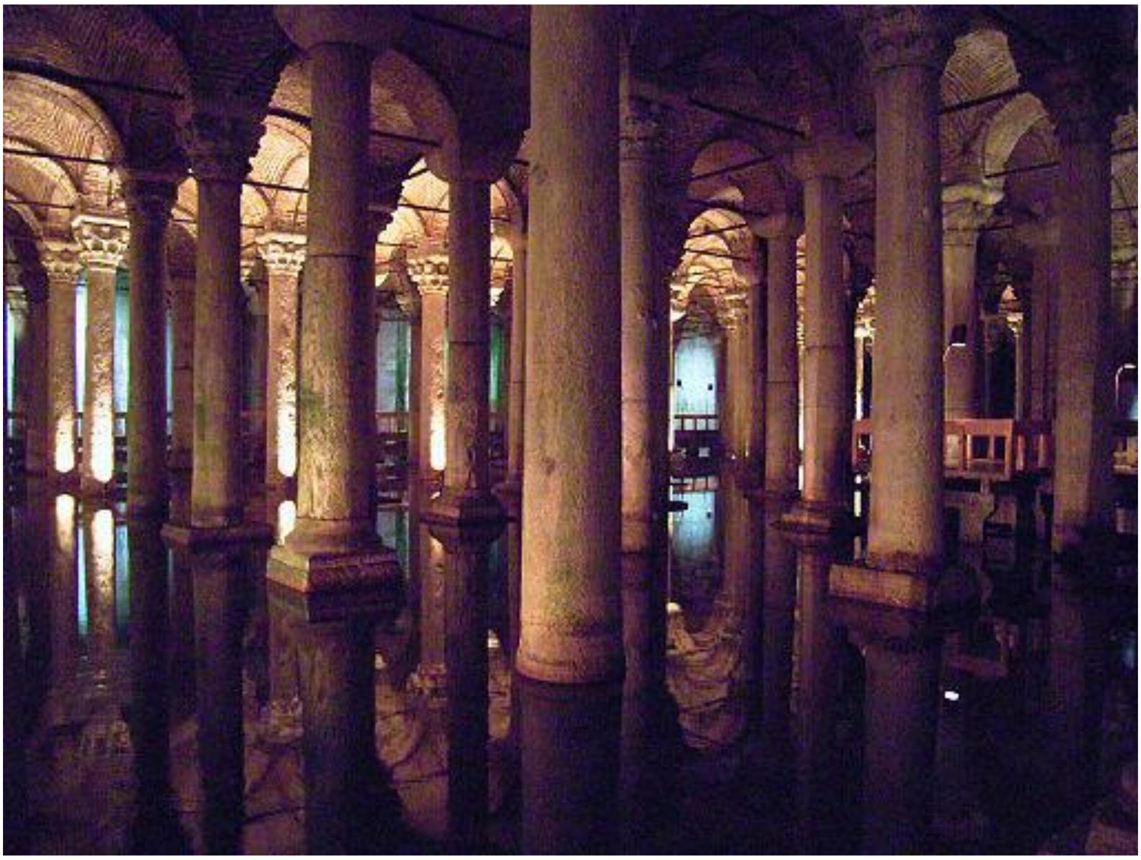
Many Roman towns were supplied by aqueducts with sophisticated raised bridge sections which were symptomatic of the Romans' commitment to large-scale water supply. Examples include the aqueduct bridges in Segovia, Spain (98 CE), or the Pont du Gard on the 50 km channel supplying Nimes, France (20 BCE). The Eifel aqueduct supplying Cologne (80 CE) had a total length of 130 km, mostly below ground, and was constructed with concrete. Lengthy pipelines included sections of pressurized siphon (Smith 1975).

The Romans were the first society to impound rivers for water supply, developing structural arch and buttress dams (Schnitter 1994). The oldest surviving example, the Vallon de Baume dam, stored water for the Roman town of Glanum in 1st century BCE. The two earth dams at Mérida, Spain, from the 2nd century CE created large holding reservoirs.

The Cornalvo gravity dam supplied water to the Roman city of Mérida in Spain. (© Charly Morlock, Wikipedia Commons)

Various low-lift pumping mechanisms were employed to raise water to higher levels to thereby move under gravity. These include wheels or *norias* moved by animal and water power; the *shaduf*, a swinging beam with a bucket and counterweight; and Archimedean screws, singly as well as in series (Hassan 2011).

Water transported to urban areas by aqueducts was typically stored in vaulted, masonry cisterns on the edge of towns. From here it might be raised to storage tanks and water towers, or distributed via conduits to public fountains and some private homes and workshops by both pipes and artisanal water carriers. It was also used to flush sewers. Rome, Carthage and Constantinople (Istanbul) had better developed water distribution systems than were achieved in modern cities until the 19th century. Capacious vaulted underground cisterns in Constantinople were partly filled by long aqueducts and had considerable capacity. The Yerebatan cistern (the Sunken Palace, or Cisterna Basilica) constructed between 532 and 542 was one of sixty to store up to 80,000 m^3 of water in the Byzantine capital (Mays et al. 2013).



Recycled columns support the vaults of the Yerebatan cistern in Istanbul. Water was brought 19 km through channels incorporating two Roman aqueducts. (© Robert Raderschatt, Creative Commons)

4.2. Early modern water provision 1500–1800

Centuries separate these sophisticated Roman and Byzantine networks from the much simpler schemes to supply water in medieval Europe. Water provision began to assume the character of an industrial sector from the 16th century. As urban populations grew, the traditional sources became stressed. Private cesspits and privies polluted the water raised from nearby wells and the amount supplied was increasingly stretched. Communities built themselves water-supply systems using aqueducts to bring natural water from more distant, uncontaminated, sources and contrived primitive pumps to raise river water to storage cisterns.

Distant gravity supply

Small-scale water-supply networks were built to serve monastic communities, such as the 12th-century system to bring spring water to Canterbury cathedral, and whose most visible surviving structures are cisterns and public fountains and conduit heads. The Cistercian monks at Maulbronn monastery built an extensive water system during the 13th century, and after the Protestant Reformation monastic systems were adapted into municipal networks. From public fountains, human water carriers distributed drinking water to consumers, while night-soil men collected excrement and disposed of it or sold it for manure.

A more extensive system was built in Istanbul between 1453 and 1755. The Ottoman Halkah urban supply network incorporated sixteen independent supply lines connecting dams and springs through aqueducts to some 435 fountains, public baths and mosques within the city. The Kirkçesme network supplied water free of charge to lower neighbourhoods from 1554–63 and had settling basins, covered masonry conduits, filters, distribution centres and water towers (Dinçkal 2008).

The Pius V *renovatio Romae* (restoration of Rome) programme adapted and modernized the ancient hydraulic infrastructure of the city after 1570: Acqua Vergine 1560–70, Acqua Felice 1585 and Acqua Paola 1607–12. By 1630, when the project was complete, there were eighty documented public fountains and hundreds of private ones, each connected to one of the aqueducts by hidden underground conduits (Rinnie 2011).

Public fountainheads like the Fontana dell'acqua Felice were part of the Counter Reformation renewal of the water-supply system in Rome. (Wikipedia Commons)

The Aqueduc Médicis was ordered by Henri IV to supply Paris and was completed in 1623. It also followed the line of a Roman aqueduct, water following the 13 km route mostly through an underground stone gallery accessed by small inspection houses, with sections of arched aqueduct.

Although Lisbon's 1744 Alcantará bridge on the Aguaducto das Aguas Livres and the Aqueduc Saint-Clément, erected in 1765 to carry water to Marseille, mark an apogee of the revived Roman tradition of gravity-fed bridge aqueducts with precisely engineered gradients, that tradition did not end for at least another century. The Alviela aqueduct in Portugal dates from 1880. However, as iron pipes became cheaper and more reliable in the 19th century they offered new possibilities. While the High Bridge that carries New York's 1837–42 Old Croton aqueduct across the North River to Manhattan looks like a spectacular example of a true aqueduct bridge, it rises to a significantly lower elevation than the masonry gravity conduits at its ends, and carries water between them through the iron pipes of an inverted siphon (Smith 1975). The Charles River crossing of Boston's 1846–8 Cochituate aqueduct is accomplished using a similar iron pipe inverted siphon.

The artificial New River in London opened in 1613 to carry fresh water from springs 45 km north of the city, with a channel including sections of wooden aqueduct. As well as marking the early participation of a private commercial company in urban water supply, the New River Company's network of wooden pipes connected to customers pioneered technological developments in water distribution which would lead to the modern urban model of the networked city. By the late 18th century the company had approximately 460 km of pipeline, divided between pressurized 'mains' and smaller service pipes linked to individual houses. London's consumer water network would remain unique until the 19th century, and was the constant reference point for growing European and American cities (Tomory 2015).

Je voudrais que toutes les maisons de Paris eussent de l'eau, comme celles de Londres. (I wish all the houses of Paris had water like those of London do.) (Letter from Voltaire to Antoine de Parcieux (1767), *Oeuvres complètes de Voltaire*, vol. 60, 241)

Pumped systems

While there was little pressure to advance water-supply technology in the early modern period, the sector benefited from water-management techniques developed for ore mining in central Europe. Pumping drinking water from rivers represented an important technological advance in the development of water supply, benefiting from the application of the piston pump to mine drainage. Central European towns began to be supplied with drinking water as a side benefit of sophisticated arrangements for draining mines, as in the case of the local silver mines of Banská Štiavnica in Slovakia.

In the 14th century complex lifting mechanisms were being constructed in towns in central Europe to take advantage of easily accessible river water. By the early 15th century citizens in Augsburg, Bremen and Danzig had mounted waterwheels below bridges to work piston pumps, raising river water up to storage cisterns. The oldest water system in central Europe is probably the Rotes Tor (Red Gate) in Augsburg, built in 1416. It housed reciprocating pumps driven by three waterwheels to lift river water to different holding towers and distribute it to public fountains. The system was well known and influential (Kluger 2013). Cities in Bavaria including Augsburg, Munich and Nuremberg also built gravity-fed water and wastewater networks in the 15th century using water from the Alps, drawing on Renaissance hydraulic techniques from Italy. The first aqueduct carrying water to Munich was built in 1422. After 1511 the city erected well houses where water was pumped up to the top of a tower and distributed via pipes to private households (Winiwarter et al. 2016).

Piston pumps worked by waterwheels raised river water up to the Rotes Tor in Augsburg, Germany: Upper Brunnenmeisterhaus (left), Kleiner Wasserturm (middle) and Großer Wasserturm (right). (Creative Commons)

A pumped system was constructed by a Dutch water engineer to raise water from the River Thames in London in 1582, two tidal waterwheels under London Bridge operating a series of bucket pumps, and two more were built for the Chelsea waterworks on the north bank in 1726, forcing river water to a higher reservoir from which it could flow to customers (Grudgings & Tymków 2014).

A large waterwheel pump was commissioned by Henri IV in Paris to raise water from the Seine to the Louvre palace and the Tuileries gardens and a small proportion went to some forty public fountains. The Pompe de la Samaritaine on the Pont Neuf bridge had two suction pumps which lifted 710 m^3 a day to a reservoir, and a second pumping system on the Notre-Dame bridge was built in 1673. They continued in service until they were dismantled in 1813 and 1853.

Water-management techniques were transferred from Europe to North America by immigrants. An early example is in Bethlehem, Pennsylvania, which was among the first of a number of Moravian communities in North America. The waterworks was begun in 1754 and is considered the oldest water pumping station in the United States. A waterwheel powered three single-acting cast-iron pumps which forced spring water through wooden pipes to a collecting tower, and from there water flowed by gravity to cisterns throughout the settlement.

When the location and the economic conditions were favourable, water-powered pumping was occasionally competitive even after steam-powered pumping engines became available. Benjamin Henry Latrobe used two rotary beam engines with wood-fired boilers to pump to a high-level service reservoir for the pioneer Centre Square scheme in Philadelphia, which started abstracting from the Schuylkill river in 1801. Disappointed with the service, Philadelphia's municipal Water Commission replaced them with four pairs of large breast waterwheels operating bucket pumps to raise water to the reservoir excavated on top of Fairmount hill. The Palladian architecture of the pump house made Fairmount waterworks famous, by the 1850s the most depicted architectural work in America (McMahon 1988; Marks 2010).

The Fairmount waterworks on the Schuylkill river in Philadelphia where waterwheels replaced beam engines to work the lift pumps. (© Ben Franske, Creative Commons)

Water-driven pumping was also preferred over steam in Montreal where two breast wheels were put into operation in 1856 to work lift pumps, and a Jonval turbine was added in 1864. A steam engine was incorporated in 1864 to overcome freezing in the winter. Four Worthington steam engines were added between 1886 and 1905, but the system remained a combination of water and steam power, with about 60 percent of the water still raised by the turbines. The first electric pumps were installed in 1903, until eventually hydroelectricity became the power source for the city's water supply (Ross 2013).

Steam pumping

The critical technological development for the progressive development of modern water and waste systems was the invention of the steam engine. This made river pumping and later borehole abstraction of groundwater into important additional sources of water, and would eventually provide the energy to remove large volumes of sewage and wastewater from even low-lying settlements.

Effective steam-powered pumping engines were first built in England in the early 18th century to drain coal mines, and development was driven by the imperative to reduce fuel consumption. The first 'fire engine' to be used for water supply was a Newcomen-type atmospheric engine which was operated in London between 1726 and 1732 by the York Buildings Company. Two more were built to supplement the Chelsea Water Works Company's Thames tide mills in 1743. Water was stored in service reservoirs and distributed intermittently through bored tree-trunk mains and lead pipes to both private homes and public fountains. Steam pumping technology was soon transferred to other large cities in Europe and in North America. Two engines were briefly used to pump water in New York in 1774. This first generation of steam engines overlapped with waterwheels, windmills and animal treadmills as a motive force pumping mechanisms.

From the 1780s onwards water supply projects could use the much more powerful, reliable and economical steam pumping engine with a separate condenser developed by James Watt and manufactured by his partnership with Mathew Boulton. The London companies relied exclusively on engines of the Watt type for new capacity (Tomory 2015). The private Compagnie des Eaux de Paris built two steam-powered pumping stations on the English model beside the Seine in 1782 and 1788 which trebled the quantity of water to the city, the Gros-Caillou pump house a fine example of early water architecture with two Watt-type engines. The scheme was not a commercial success and the company was bought by the city in 1788. Paris would in future rely on distant sources to river abstraction.

The 1820 Boulton & Watt beam engine, one of two originally installed at Chelsea pumping station beside the River Thames in London and moved upstream to the Kew Bridge pumping station in 1840. (© Chris Allen, Creative Commons)

4.3. Industrialization 1800–80

From the early decades of the 19th century, cities in Europe and North America faced a rising urban crisis of insanitary living conditions brought about by industrialization and the accompanying acceleration in population growth. Citizens and their representatives were faced with a bewildering set of technical, financial and legal problems of a form and magnitude they had not previously had to encounter (Hassan 1985).

Water consumed by industry contributed to the rise in consumption, processes such as dyeing and bleaching textiles demanding large quantities of soft water. Moreover, traditional industrial processes like tanning and brewing dumped wastewater far beyond the natural capacity of rivers to dilute. Later in the century, new chemical industries added toxic compounds. The deteriorating living conditions in urban areas could be tracked statistically in the rising mortality rate, while periodic epidemics of cholera and typhoid were powerful if intermittent stimuli to sanitary reform.

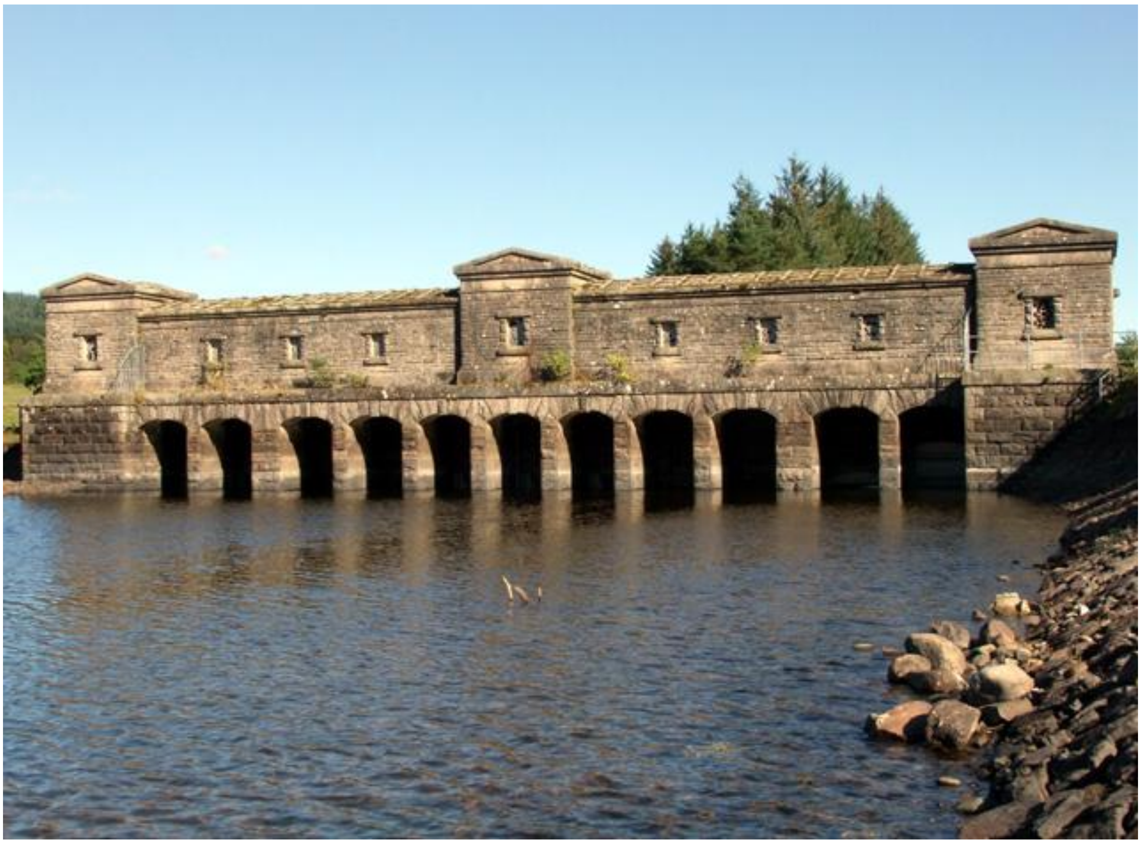
Distant gravity supply

The increase in urban populations encouraged initiatives to extend older water-supply systems and to build new ones, especially in the fast-growing manufacturing towns where obtaining soft water for industry was as often the motive as making clean and sufficient drinking water available to the citizens. With no way of treating dirty or polluted river water on a sufficiently large scale, engineers recommended bringing water from natural sources at ever greater distances. The planning, financing and execution of such large-scale projects was usually beyond the capabilities of existing private water companies, many of which were bought out and municipalized in towns throughout the industrializing world. The preference for naturally clean water opened a new period of long-distance supply from upland sources (Barraqué 2015).

Paris had drawn on remote supplies since Roman times, and continued to develop this system with ever-longer aqueducts throughout the 19th and early 20th centuries. The Canal de la Villette was started under Napoleon and completed in 1821. During Haussmann's reforms his engineer, Eugène Belgrand, added the Dhuis (1863–5) and Vanne (1866–74) aqueducts and three more were built – Avre (1890–3), Loing (1897–1900) and Voulzie – until the system was completed in 1925. Water was distributed to numerous public fountains, some dating back to the 15th century, both monumental, decorative (the emblematic Wallace fountains) and functional. They only lost their utility once homes began to be connected to the mains supply from the 1880s.

After a cholera outbreak in the 1830s, New Yorkers voted to construct the Croton water system, then the largest in the world, which dammed the Croton river and connected it with a 65 km aqueduct to pumping stations, service reservoirs and holding tanks within the city. This infrastructure was highly visible, and even though now much has disappeared it has left a 'ghost' landscape behind. The city continued to follow a distant supply strategy, adding the Catskill/Delaware watersheds from 1905 when the original Croton system proved insufficient for the ever-increasing consumption. By the time it was completed in 1911, the original Croton reservoirs and aqueduct had been overlaid by much larger ones (Bone 2006).

Glasgow's 1855 municipal scheme to bring water 55 km from Loch Katrine is exemplary. Faced with a rapidly expanding population and sequences of devastating cholera epidemics, the Glasgow Corporation took control of its water from private-sector suppliers and built a new gravitational scheme. The project was 'unquestionably the prime municipal showpiece for the city, combining the wonders of Victorian technology with the nurturing quality of pure Highland water' (Maver 2000).



Loch Venacher sluice house controls the water flow along the Loch Katrine scheme designed by civil engineer John Frederic Bateman for the Glasgow Waterworks in 1856-59. (© Sheila Winstone, Creative Commons)

Both structural arch dams and massive gravity or embankment dams were raised to create holding reservoirs. The Meer Alum dam in India was built in 1808, a multi-arch masonry buttress dam over 1 km in length that supplied water to Hyderabad, and was an outstanding example of dam construction from the era before modern analytical design methods (Chrimes 2009). In the mid-19th century, dam design advanced towards a more rational, scientific approach. The innovative masonry arch dam designed by François Zola as part of an integrated water-supply scheme for Aix-en-Provence was completed in 1854. Another early arch dam is at Lake Parramatta, Australia, completed in 1855 and used to supply drinking water, whose modest volume of masonry is indicative of a rational design method. By mid-century dam builders could draw on a growing body of theoretical research from the work of J. A. T de Sazilly (1853) in France and William Rankine (1858) in Britain. Many British industrial cities tapped long-distance supplies from upland reservoirs formed by impressive masonry gravity dams. The Vrynwy reservoir in Wales (1891) supplied Liverpool with water and was the largest in Europe, with an ornate dam and neo-Gothic outlet tower: 'the perfect monument to Victorian civic pride, conservative engineering and cheap labour. The fact that a whole village lies drowned in the depths… is almost completely forgotten' (Smith 1975, 123).

The Barrage Zola is an early masonry arch dam built to provide Aix-en-Provence with safe water following a cholera epidemic in the city. (Creative Commons)

Large dams to hold back river water to supply large cities continued to be built into the 20th century, especially in the United States, despite the improvements in filtering and treating water from rivers closer to hand. Opposition to cities sourcing their water from distant rural watersheds could already be observed in Manchester's Thirlmere project in the 1870s. It sparked a conflict that would serve as a prototype for a growing number of environmental confrontations between metropolitan centres and the inhabitants of their distant rural hinterlands, whose interests were threatened by ever-growing demand for clean water (Ritvo 2007).

Urban service reservoirs

Like the cisterns associated with Classical and pre-modern aqueducts, 19th century distant supply aqueducts frequently terminated in urban reservoirs, which might be open or covered, depending on their location and the space available. New York's Jerome Park reservoir is an open basin surrounded by an embankment, completed in 1906 at the confluence of the Old and New Croton aqueducts. Montreal built a sequence of eight reservoirs between 1856 and 1946, partly within the Frederick Law Olmsted designed Mount Royal Park, taking advantage of the topography of the mountain to serve as the city's virtual water tower (Ross 2011). Large masonry reservoirs were built in Haussmann's Paris to hold water brought in through its aqueduct system. Eugene Belgrand built Ménilmontant in 1865 with a capacity of 95,000 m^3 and Montsouris, with 202,000 m^3, in 1874, while Montmartre could store 11,000 m^3 divided between four floors with separate river and spring water (Beaumont-Maillet 1991).

Internally these massive storage cisterns had stone, cast-iron or concrete supports to the vaulted roofs, sometimes on multiple levels. Many such reservoirs are concealed, grassed over and double as local parks. Others have architectural camouflage: Montmartre was decorated with neo-Baroque details to complement the nearby Sacré Coeur church. A third typology were wholly mechanical structures, effectively very large tanks, of which the Palacio de los Aguas Corrientes in Buenos Aires is a notable example. Conceived as a kit of parts, it was manufactured by the Belgian Marcinelle et Couillet foundry and decorated with terracotta pieces made by Doulton & Co. England, and assembled in the Argentine capital between 1887 and 1894. Twelve water tanks on three floors stored 72,700 m^3 of water extracted from the River Plate.

Steam pumping

A reliable high-pressure steam engine was developed after 1812 in the English tin-mining district of Cornwall, from which it took its name. Cornish engines do not have rotating parts such as a flywheel, but rather are controlled by the piston movement and opening and closing the valves. Beam engines, many on the Cornish pattern, were the waterworks workhorse for much of the 19th century: three Cornish engines were erected in Lyon in 1853, of which one survives, abstracting water from the Rhone. The raw water was filtered through a covered gallery and then pumped up to high service reservoirs. The rotary compound engine designed by Arthur Woolf was used by French, British, German, Belgian and Dutch steam engineers in pumping stations all around the world, and operational examples can be found in Lisbon, Leicester and at the Goulburn waterworks in Australia.

A generally Italianate design of pumping station with semicircular arched windows became established by the 1850s as the 'waterworks style' of industrial architecture. Ryhope (1869) and Papplewick (1881) in England were designed by leading water engineer Thomas Hawksley (1807–93) and employed double-acting compounded beam engines to raise water from rural boreholes. With gleaming, oiled machinery in dark, richly tiled engine houses, set in landscaped parklands, they are the epitome of the 19th century beam engine waterworks.

The Italianate waterworks style as applied by engineer Thomas Coltrin Keefer in Hamilton waterworks, Canada, now a stream museum containing the original pair of Cornish engines. The pumping station was sufficiently important for the future British king to inaugurate it in 1859. (© John A. Speakman, Wikimedia Commons)

The higher pressures generated by steam pumping, combined with the rising cost of timber pipes, accelerated the introduction of cast-iron pipes in Europe in the early 19th century, although wooden pipes continued to be laid in North America and elsewhere.

Filtering

The first filtered river water to be supplied for local consumption was in 1804, the surplus from an experimental sand filter constructed for a bleach works at Greenock in Scotland. The technique was improved until the first public slow sand filters were installed in 1829 by water engineer James Simpson for water abstracted from the Thames in London, a pattern which became known as the English system. Though only a couple of metres deep, slow sand filters were very extensive undertakings usually constructed on urban margins such as at Ivry in Paris.

Filtry Lindleya (Lindley's filters) opened in 1886 to distribute filtered river water in Warsaw. Named after the prolific water engineer William Lindley, it includes a group of slow sand filters, covered reservoir, pumping station and water tower. (Creative Commons)

Filtering river water was made obligatory in England in 1855, but the use of slow sand filter beds spread only slowly in Europe and North America. Clear evidence that it was effective against disease was given by a typhoid outbreak in Hamburg in 1892 in which the unfiltered drinking water from the Elbe produced many more cases of the disease than the filtered water in nearby Altona.

Water towers

Water towers and standpipes were integral components of the new pressurized constant supply systems which became prevalent in towns from the middle of the 19th century. Standpipes were built to act as buffers between the pressure of water from steam-driven ram pumps and in the mains supply network. Standpipes were located close to pumping stations such as the spectacular examples in Hamburg (1842), Louisville (1860), Kew (1867) and Chicago (1869). Water towers combined the functions of high-level local storage and maintaining the pressure of supply to consumers. As the most visible representation of the spread of domestic water supply, towers in both the old and new worlds were frequently disguised to look like Classical columns or medieval citadels and turrets. Metal tanks, such as that patented by Otto Intze (1843–1904) in Germany in 1883, were very widely used and were notable landscape features in the United States. Modernism and concrete construction replaced historicist designs after the First World War with rationalist and expressionist water towers, sometimes designed by avant-garde architects.

The Greek Revival pumping station and its cast-iron standpipe tower in Louisville, USA. The waterworks was built in 1860 by public subscription following a damaging fire and a cholera epidemic. (Creative Commons)

Wastewater drainage systems

In towns benefiting from these new sources of clean water, the increase in the volume being brought in, coupled with the spreading uptake of the water closet, exacerbated rather than eased health and sanitary problems. Mid-19th century urbanites found themselves in a position of 'bewilderment... and confusion' (Hamlin 1988, 55). Although new urban districts like the 1850s Eixample in Barcelona might plan a rational drainage network before work began on building the houses, existing cities had to retro-fit waste removal infrastructure to an already complex urban environment. This makes the subsequent accomplishments associated with the sanitary revolution, whether measured in falling mortality rates or construction of infrastructure or personal amenities, all the more remarkable.

> *...a series of revolutionary technical initiatives, first associated with the water-borne removal of organic materials from burgeoning cities, then with the bacterial transmission of disease, and eventually involving chemical and mechanical means of purifying water supplies, now underpins vast networks of municipal infrastructure linking waste to water.* (Benidickson 2007, 4)

The water-supply networks that developed during the first half the 19th century increased pressure to remove wastewater from sodden and contaminated urban landscapes as the water closet began to replace the traditional privy pit and cesspool. Rivers were the traditional and most expedient way to remove the rising volume of waste, using their diluting and cleansing capacity as natural 'sinks' (Tarr 2011). Existing storm drains in many towns took on the additional function of sewers until overwhelmed, although the debate over separate or combined drainage systems continued (Gandy 1999).

The optimum practical means of large-scale urban distribution of water and removal of waste had still to be determined. The options included constant high-pressure domestic supply or intermittent pumping to cisterns; the conservancy/dry system of sewage disposal or waterborne flushing through sewers; human waste dispersed into rivers or spread on fields as fertilizer; the choice of the most adequate materials for pipelines and sewers (bored timber, cast-iron, brick, glazed pipe...); and even the most effective drain profile (round, oval, pear-shaped, etc.). This situation made waterworks engineers the key protagonists in the fight to improve urban living conditions.

Both private companies and public municipal authorities struggled to develop adequate water-supply and waste-treatment facilities. Municipalities generally had longer planning horizons, access to cheaper capital, stronger social motivation and freedom from profit and shareholder constraints. These are usually credited with the prevalence of municipal over private systems during the later 19th century: 'By the 1840s what may be described as the brief British experiment with *laissez-faire* in the water industry was beginning to be recognized as a failure' (Hassan 1985).

Before the work of Pasteur (1862), Schloesing and Munts (1877), and Koch (1880s) on bacterial purification, the rival theories of contagion and anti-contagion (the miasmic theory) further confused the task of choosing a suitable source of clean water and of building effective sanitary infrastructure. Influential proponents of practical hygiene, clean water and proper sewage disposal, such as the eminent epidemiologist Max von Pettenkofer (1818–1901), could also reject contagion as an explanation for disease, insisting on a focus on ventilation rather than drainage (Winiwarter et al. 2016).

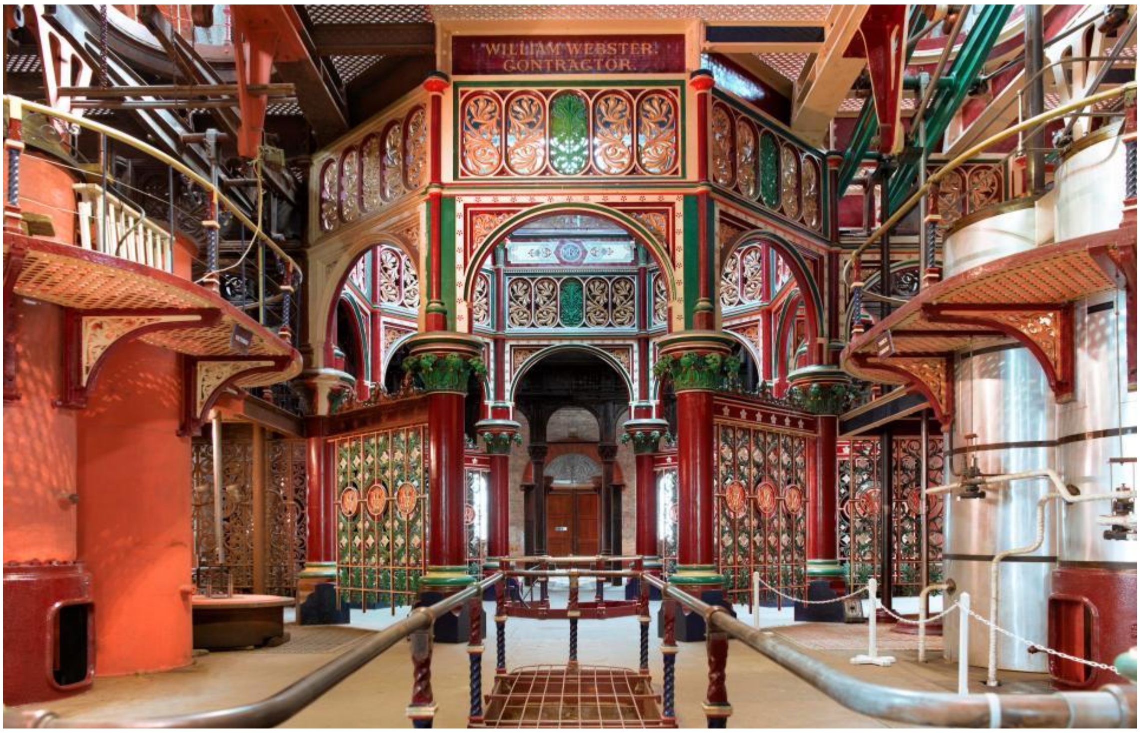
The Chadwick hydraulic system

The theoretical framework developed in England by Edwin Chadwick (1800–90) for building integrated water and sewage systems took shape between 1843 and 1845 (Melosi 2008). It was important not only in his own country and but was also influential in Europe and America: 'To the English sanitary reformer Edwin Chadwick, author of the famous Report of an Inquiry into the Sanitary of the Labouring Population of Great Britain (1842), goes credit for recognizing the central importance of public works – waterworks, sewers, better ventilated streets and houses – to public health' (Hamlin 1992, 680). The integrated engineering system that he advocated, imaginatively represented by the arterial/venous circulation of the blood, was centred on the hope that agricultural end-use of urban sewage would help pay for the construction of the previous drainage infrastructure.

A pioneering sewage system on the lines if not specifications advocated by Chadwick was already under construction in 1842 in Hamburg, to the design of the British engineer William Lindley (1808–1900), who consulted Chadwick. Hamburg's 48 km combined water and sewer network was built as part of the reconstruction of the city following its great fire in 1842. River water was abstracted above the city and the waste dumped in the River Elbe further downstream. Steam engines were used to pump the network, which included the well-known combined standpipe tower and chimney in Rothenburgsort. With a broad idea of the further social benefits which would flow from the system, Lindley built wash- and bathhouses following the example of Liverpool.

Rapidly growing Chicago was forced to abandon the Chicago river as the outfall for its drains when the pollution became unbearable for its citizens. Engineer Ellis Chesbrough (1813–86) designed a combined sewer system in 1855 which had to be laid on the surface of the flat, low-lying city, and existing buildings were literally jacked up over the brick sewers, raising the level of the city by 1–1.5 m. Mud from dredging the Chicago river helped filled the space under the raised buildings and between the brick sewer mains which led into the intercept sewer along the riverbank. Drinking water was abstracted from Lake Michigan, but the intake had to be moved further offshore in 1866, tunnelling 6.2 km deep under the lake to obtain water free from pollution (Cain 1972). The most highly visible components of the city's new system were the neo-Gothic pumping station and standpipe tower, which are outstanding examples of steam waterworks architecture and a public statement of the civic importance of the project.

Sanitary reform developed rapidly in Europe during the second half of the century as water and sewage systems came to be seen by urban elites as part of a 'new standard of civilized infrastructure' (Wolfgang Hofman, quoted in Brown 1988, 318).



The restored interior of the 1865 Crossness sewage pumping station, London, had four single cylinder James Watt beam engines, converted to triple expansion operation in 1901 and 1902. (© Christine Matthews, Creative Commons)

The size and importance of London prompted a comprehensive drainage scheme for the city to be implemented between 1859 and 1875. Following a horrendous sewage episode in 1858 in the Thames outside the British Parliament known as the Great Stink, a comprehensive plan by the sanitation engineer Joseph Bazalgette (1819–91) was accepted. It intercepted combined run-off and sewage before it entered the Thames and moved it downstream under gravity towards the sea, lifted periodically by steam pumping stations. The two intercept sewers were built into a substantial embankment parallel with the river incorporating an underground railway. The untreated wastewater was discharged onto the ebbing tide at two outfall steam pumping stations, Abbey Mills and Crossness, further impressive examples of public health architecture, with huge beam engines to operate the pumps.

The London model of intercept sewers, steam pumping, egg-shaped main sewers built of brick and Portland cement, and glazed pipes was adopted by other cities, including Amsterdam and

Brussels. Under Baron Haussmann (1809–91), Paris initially opted for a separate storm-water system and discouraged waterborne sewers, partly because of the long-established economic use made of sewage by farmers. Eventually a combined sewage system was constructed after a typhoid epidemic. Two intercept *collecteurs*, linked in 1868 by a huge iron siphon under the Seine, now discharged all wastewater into the river at just two points, Asnières and Saint-Denis.

Both Chadwick in London and Haussmann in Paris opposed waterborne waste removal because they wanted to reserve human faeces for their commercial value as fertilizer. The comprehensive sewer system integrated into Berlin applied this concept of using the waste to fertilize the surrounding farmland. It was designed in 1869 by the building engineer James Hobrecht (1825–1902) whose urban plan reformed the city. Hobrecht divided Berlin into twelve districts, setting a steam pumping station at the lowest part of each, from which the waste was pumped to the outskirts of the urban area. The first one, Radialsystem III, went into operation in 1878 and all twelve were completed by 1909, supplying sewage to fertilize 16,000 hectares of farmland. In cities without major rivers, land dispersal continued during the 20th century. Only rising levels of industrial pollution in the 1930s ended the system in the German capital, and it was replaced by modern filter treatment.


The Berlin sewage pumping station Radialsystem IX in Berlin. (Creative Commons)

Rotterdam followed the example of Hamburg and adapted its canal network in 1863 to a sewage system, but had to boost the movement of waste in the 1880s with steam pumping stations modelled on those in Berlin (Hård & Misa 2010).

British, French and German engineers transferred technology and infrastructure to later industrializing countries within Europe and later to Asia, South American and territories under colonial administration. For the integrated water and sewer system constructed in Buenos

Aires in 1872–83, water was drawn from the River Plate above the city. It was passed through sand filters, stored and pumped by James Watt & Co. steam engines to a monumental French Renaissance-style service reservoir, the 'Palacio de las aguas corrientes'. The public water supply was constructed in tandem with the sewer system, draining to the lowest part where the sewage was admitted via regular chambers into intercepting sewers. Most districts had combined sewage and storm water discharging continuously into the River Plate.

In American cities in the latter part of the 19th century, the economic cost and technical uncertainty of sewage treatment meant that the diluting capacity of local rivers continued to be the preferred option to solve their sewage problem rather than constructing infrastructure to treat the effluent.

> *By the end of the nineteenth century, the dual pressures of disease and growing water usage, along with the advent of inorganic fertilizers and growing public aversion to human waste, eventually overwhelmed the remnants of pre-modern conceptions of urban order and introduced a new set of relationships between water and urban society.* (Gandy 1999)

4.4. Water and sewage combined 1880–1920

By the 1880s, the basic technological patterns and administrative operation of urban water supply and sewage removal had been worked out. Under the continued pressure of waterborne disease epidemics combined with social pressure from citizens to improve living conditions, numerous cities began to commission and build water schemes, predominantly under municipal control. Louis Pasteur (1822–95) and Robert Koch (1843–1910) established the germ theory of disease and bacteria as the cause of cholera and typhoid. The emergence of bacteriology ended the miasma or anti-contagion theory as an explanation for how disease was transmitted in towns and finally provided sanitary engineers with a scientific understanding on which to plan sanitary systems. By the early 20th century urban mortality rates were falling and typhoid, a commonly used barometer of the state of public health, had almost vanished (Brown 1988).

Dams

Advances in the analysis of gravity dams, the introduction of Portland cement concrete, and modern construction equipment and techniques allowed dams of unprecedented size to be built from the early 20th century. The first high arch dams in the United States were constructed in 1907, the Pathfinder and Shoshone irrigation dams (Billington et al. 2005).

Water filtration

Rapid sand filters enhanced the speed of filtering drinking water using mechanical devices – water jets, backwashing, or revolving sand agitators or stirrers – to clean the filter beds. The first North American plant was built in Somerville, New Jersey, in 1885. Sanitary engineers introduced bleaching powder to drinking water in Austria in 1896. Construction of the first continuous-use chlorination plant in Middelkerke, Belgium, in 1902, was followed by Chicago five years later. Faster and more compact, this low-cost technique became widespread in the early 20th century to disinfect drinking water. Both slow sand and mechanical filters were built by municipalities to treat water supplies, and combined with chemical treatment they were able to prevent diseases like typhoid.

Steam-powered pumping

The most symbolic and representative architectural expression of the 19th-century sanitary revolution was the steam pumping station. Of the buildings of the period, only railway stations can compete with it for stylistic variety and exuberance, an expressiveness often carried through into the interior and the cherished steam engine.

Later in the 19th century a wider variety of pumping technologies started to compete with beam engines for moving both water and sewage. The 1879 pumps at the Hochablass waterworks in Augsburg formed part of a comprehensive water-supply system worked by three Jonval turbines connected to horizontal double-acting pumps. A more common solution was horizontal compound steam engines, which were chosen for many waterworks as an inexpensive and reliable power source. Surviving examples include two pumping engines at Mill Meece in England, installed in 1914 and 1927 and still run with steam; four manufactured by the French Société Lyonnaise de Mécanique et d'Électricité at the Cornellà pumping station in Barcelona which generated electricity for submersible electric pumps, and two 1925 engines at the Zawada pumping station in Karchowice, Poland.

In 1886 the first inverted vertical triple expansion engines were introduced into a pumping station in the United States. In this configuration, steam is expanded successively through three cylinders arranged in line directly over the crankshaft, with the plunger pumps below, before passing to a condenser. By the end of the 19th century high-speed vertical compound engines predominated in the larger pumping stations. Spotswood sewage pumping station (1897) in Melbourne was equipped with four non-rotative 300 hp direct-acting triple expansion engines based on the American Worthington design, and there were eventually ten steam pumping engines. Five large triple expansion engines were installed at Kempton Park, London, in 1904, which became the biggest pumping station in Europe when two more were added in 1928. The four 1000 hp triple expansion engines erected in 1903 at the Cincinnati waterworks are the largest (by weight) in the world. This enormous plant drew water from the Ohio river, ended the city's periodic water shortages and greatly reduced its typhoid fever mortality rate.

Sewage treatment

Mechanical sewage treatment used strainers, filters and various settlement tanks to reduce the volume of waste and remove recyclable materials. William Lindley and his three sons were responsible for steam-powered water and waste systems for over thirty cities across central and east Europe during the second half of the 19th century.

Bacteriology lead to a conceptual revolution in sewage treatment in the 1890s, which now aimed to facilitate and accelerate the biological processes which decomposed sewage naturally. Bacteriological laboratories like the Lawrence Experiment Station of the Massachusetts Board of Health (1886) began to conduct chemical analysis of water and evaluate treatment techniques to make water safe. Sanitary engineering emerged as a corps capable of developing new sanitary infrastructure, and growing cities incorporated integral sanitary systems to ensure community health (Melosi 2008).

Biological decomposition was developed into a working principle by William Digbin working at the London Crossness outfall works, and he built the first contact bed at Sutton in south London in 1896. The Lawrence Experiment Station invented the trickling filter, and the modern airtight septic tank chamber containing anaerobic bacteria was patented in England in 1896 (Hamlin 1988). The activated sludge process was discovered in Manchester in 1912, resulting in a reduction in the size of the plant required to treat sewage.

4.5. Modern water systems since 1920

During the twentieth century, the symbiotic and material shrines of progress started to lose their mobilizing powers and began to disappear from the cityscape. Water towers, dams and [pumping] plants became mere engineering constructs,... while the water flows disappeared underground and in-house. They also disappeared from the urban imagination. (Kaika & Swyngedouw 2000, 121)

By the 1920s most existing towns and cities had inserted water-supply systems, and they had become an essential feature of modern urban infrastructure. The technical development of established systems, territorial expansion from urban to rural coverage, and improved treatment technologies, together with stricter legislative requirements, provided the parameters for the water industry's development in the new century.

With the changeover to electric pumps, a major part of the architectural expression of sanitation began to shrink and disappear. When Jules Verne wrote *Paris in the twentieth century*, projecting the 1860s city one hundred years into the future, he pictured the River Seine dominated by giant waterworks and pumping stations (Verne 1997). But by the 1920s steam engines were being replaced by much smaller and more compact electric motors linked to submersible pumps. Although many steam engines continued pumping steadily for decades, new pumping stations were small, non-descript buildings or were hidden underground.

Engineering design bravura became largely restricted to water towers and retention dams. Towers were built from reinforced concrete and, especially in the United States, metal tanks. Many places continued to use water towers as expressions of local identity; the Modernist Mechelen-Zuid (1978) in Belgium is claimed to be the world's tallest tower at 143 m. The *svampen* (or mushroom tower) designed in 1958 in Sweden has been widely reproduced, and is deployed in Kuwait and Saudi Arabia as a national symbol.

Whilst most large dams were built for flood control, irrigation or to generate hydroelectricity, dams for drinking-water reservoirs continued to have a major impact on urban development, such as those built to supply and extend the Los Angeles metropolitan area from 1936 (Billington et al. 2005).

Water- and waste-treatment plants were often complexes of low-level tanks and chambers of various dimensions running a sequence of mechanical filtration and biological treatment. Nevertheless, the combination of a particular technology with the local significance of clean water on occasions resulted in notable architectural projects. The scale, engineering innovation, landscape design and Art Deco architecture of the 1941 R. C. Harris water treatment plant in Toronto represented a threshold in Canadian public infrastructure. In Prague, the grandiose Podolské waterworks built in 1929 was constructed to filter water from the Vlatava river through aerated sand filters and a chlorination plant with a capacity of 35–40,000 m^3 per day.


Parabolic concrete arches over the 1929 filter house of the Podolské treatment plant in Prague. (© Prague Waterworks Museum)

Particular historical circumstances also sometimes also contributed to a higher standard of engineering and of its architectural manifestation. With the onset of the Great Depression in North America additional care was sometimes taken with the construction of water treatment plants in order to help provide work in the difficult economic circumstances. This can be clearly read in the designs of the 1930–3 Glenmore waterworks system in Calgary, Canada, with a storage reservoir and dam, pumping station and purification plant, as well as in Milwaukee’s imposing Art Deco Linnwood water-treatment plant. The construction of both was intended to help alleviate local unemployment.

5. Areas and values of significance

Technology: Specific areas of technology which are significant are

- Dam design
- Aqueduct planning
- Pumping technology
- The evolution of prime movers for pumping
- Water filtration
- Sewage treatment

Economy: The water industry has facilitated and promoted economic development associated with towns and industry

- Urban growth
- Industrial development
- Territorial expansion

Social factors: Some of the social consequences of the water industry are

- Enabling large-scale urban areas
- Elimination of waterborne disease
- Greater equality of living conditions
- Comfort and living standards of urbanites
- Superior personal hygiene

Landscape: Construction of networks and systems of water distribution have considerable rural and urban landscape implications:

- Transforming pre-19th-century urban landscapes
- Architectural design of water infrastructure, notably pumping stations, water treatment works and storage towers
- Alteration of natural fluvial and upland landscapes
- Habitation of arid territories
- Insertion of large-scale engineering infrastructure

6. The water industry as World Heritage

This section draws some conclusions from the historical study above, and suggests outstanding historical themes for the water industry and the attributes which might justify protecting and conserving the most significant properties and landscapes, including their consideration for inscription on the World Heritage List.

Authenticity and integrity

The authenticity of heritage sites means that their cultural value is 'truthfully and credibly expressed through a variety of attributes'. These are both tangible attributes, expressed in form, design, materials, use or function; and intangible ones, as in techniques and management systems, or traditions, customs and beliefs. For integrity UNESCO understands that the historic resource is sufficiently complete for its Outstanding Universal Value to be recognizable. In other words, its physical attributes must still survive and be evident so that they are able to communicate this value. Both authenticity and integrity have to be satisfied as part of the assessment of Outstanding Universal Value (UNESCO 2016).

One of the things which makes historic properties of the water industry remarkable, distinguishing them especially within the industrial heritage, is that a great number are still being used for their original purpose, including many covered by this study. Continual renewal, updating and maintenance are intrinsic to their character, an aspect already recognized in the Nara Declaration on Authenticity, as well as the World Heritage study on canals (Hughes 1996) and the *Operational guidelines for the implementation of the World Heritage Convention*, in the annex on historic transportation corridors (UNESCO 2016, 76). As indicated in *Railways as World Heritage sites*, 'continuity through change is part of what makes a railway landscape or location: railways are by their very nature evolving socio-technical systems' (Coulls 1999, 7).

Themes

The outstanding historical theme of universal human value is the response of the water industry to the urban Sanitary Crisis which accompanied industrialization.

From the late 18th century, the Industrial Revolution resulted in growing numbers of people moving to live in towns and cities and to work in the industries which were increasingly located there. The close concentration of people and factories which universally characterizes industrialization soon overwhelmed traditional small-scale systems for supplying water and removing waste, based around wells, privies, drains and nearby streams or rivers, and resulting in the poorest urbanites living in conditions of extreme squalor, and exposing even the wealthiest to deadly water-transmitted diseases such as cholera and typhoid.

A series of technical, scientific and administrative changes was introduced during the subsequent century and a half which reversed the rising mortality rate and prevented the breakdown of urban life. Water-supply and, later, sewage-management systems were retro-fitted to cities, despite debilitating inadequacies in understanding, technology, medical knowledge, financing and administrative capability. 'The sanitation revolution occupies a pivotal role in most accounts of late-nineteenth century urbanization in Europe and the United States' (Brown 1988, 307).

By the early 20th century the construction of vast infrastructure networks and the effective means to move large volumes of clean water and effluent, coupled with the invention of mechanical, biological and chemical techniques for purifying water, enabled life to continue without the filth and risk that had seemed to people through the preceding decades to jeopardize their future. Applying the technical solutions first tested in Paris, Philadelphia, London, New York, Berlin or Prague, the experience of the inhabitants of the early industrializing cities needed not to be repeated (even if they sometimes were) by later regions, as cities in the rest of the world followed the same route towards better living conditions.

Pride in these technical achievements and in the immense combined effort in response to the challenge of the industrial city meant that the design and execution of the visible, as well as invisible, components of these networks were of the highest quality. Contemporaries accepted that the architecture and engineering should go beyond functional to express the value they put on its contribution to civilised life.

The historic remains of urban water-supply and waste systems is the manifestation of an immense intellectual, financial and technological effort during the 19th and early 20th centuries. Allowing for maintenance and updating, much of it continues to provide the vital service for which it was built.

Priorities

In considering the heritage of the water industry, places and landscapes should be given particular attention when they contain tangible evidence to illustrate one or more of the following:

Ancient engineering solutions to water supply: Schemes involving impounding dams, lengths of channels or tunnels, and elevated aqueducts demonstrate impressive levels of technical knowledge and organizational capacity, not matched until the early modern period, and on which the designers of later schemes depended for practical understanding and inspiration.

Pre-industrial water-supply systems: City growth and technical advances in the Renaissance produced innovative networks for urban water distribution using both distant gravity supply and pumping technology to deliver potable water to public fountains and conduit heads, given further emphasis by Baroque urban planning concepts in the 17th century.

Dams and reservoirs: Distant supply schemes encouraged advances in dam technology and hydraulics which produced larger, cheaper and safer dams. They guaranteed greater and more regular volumes of water with important historical benefits for urban water-supply and waste-disposal systems, the growth of industry and the development of new settlements, but sometimes with negative effects on rural communities and the natural landscapes from which the water was obtained.

Pumping stations: Steam pumping engines were the critical technology for 19th-century water and waste systems. Their significance for the social and economic wellbeing of their communities was frequently made explicit in the quality of the mechanical engineering, through sophisticated architectural expressions and in the composed landscapes in which they were set. Some display multiple technologies, extending from hydraulic through steam to electric motive power for pumping.

Underground systems: The large underground networks of mains and intercept sewers retro-fitted to large cities were dramatic investments by urban governments, often made accessible for public visits, which contributed to the decline of mortality rates and the end of major epidemics.

Scientific advances: The scientific understanding of the transmission of waterborne diseases and of the treatment and purification of sewage produced the paradigm shift out of the 19th century 'miasmic' era of urban drainage to the modern one. Many of the discoveries were made at public laboratories and experimental treatment centres.

Further attributes which may contribute to the significance of water industry sites:

Connectivity is a fundamental attribute of water distribution systems and networks, so that by separating or isolating individual elements or sections their overall cultural value may be diminished. Pre-industrial distant supply infrastructure incorporated dams, reservoirs, wells, aqueducts, cisterns and towers as well as urban fountains or conduit heads. During the 19th century these developed towards the network model, both for collecting and distributing clean water and for removing and treating waste. This became customary in the 20th-century water and drainage systems, contributing to the development of the modern 'network city'.

Components of historic water systems may therefore be considered as parts of a whole, or as 'serial properties' as defined by UNESCO (2016, 29), which may combine multiple sites within a territory, as well as both cultural and natural properties, and in which the complete system has more value than its components considered separately.

Public utilities, particularly water, made possible the modern city. (Melosi 2012, 38)

7. UNESCO evaluation criteria relevant to the water industry

One aim of this report is to establish whether the most significant historic resources of the water industry can be considered as having 'universal human value', and, if so, on what grounds and how they should be evaluated.

Selection criteria

The criteria for choosing World Heritage are defined in the revised Operational Guidelines for the Implementation of the World Heritage Convention.

(i) to represent a masterpiece of human creative genius;
Although the collaborative character of major infrastructure projects is generally recognized above the 'heroic engineer' of a century ago, many major projects bear the strong imprint of an individual's knowledge and personality. Benjamin Henry Latrobe's pioneering scheme for Philadelphia reflects his combined architectural and engineering background. Bazalgette in London, Bertrand and Haussmann in Paris, Thomas Coltrin Keefer in Canada or the Lindley family in central Europe are all closely linked with major urban reforms which transformed the lives of citizens in particular cities and had wider repercussions as key exemplars of the new technology.

(ii) to exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design;
This criterion would apply to the diffusion of water management, technologies and architectural typologies, as well as intangible notions of modernity, cleanliness and scientific understanding. Renaissance water technology was carried into central Europe along trade routes. French engineering traditions were adopted in the United States after Independence. British military engineers transferred hydraulic techniques to India, Australia and elsewhere. During the early 19th century, European technology was transferred to North America, colonial possessions and later-industrializing nations in South America and Asia. Like Latrobe, many American water engineers travelled in Europe and were instrumental in transferring the emerging technology to North American cities, including Boston and Chicago. Towards the end of the century, this flow of technology transfer was reversed, notably in waste treatment and dam construction, as American sanitary engineers developed into environmental engineers and influenced infrastructure planning outside their country.

(iii) to bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared;

(iv) to be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history;
This is the most relevant of the selection criteria to the water industry. The complicated process of inventing and retro-fitting sanitary infrastructure into towns and cities in response to the 19th-century Sanitary Crisis is a fundamental aspect of urban history. Its technical origins extend back into the water-supply schemes of the early modern period. During the change from an agricultural to an industrial economy associated with the Industrial Revolution, both urban and upland rural landscapes were radically altered by the water infrastructure built to

cope with rising populations and water consumption. Higher standards of hygiene and health called for new purification facilities. Such landscapes, networks, more compact ensembles (waterworks, dams and aqueducts, treatment works) as well as individual buildings may illustrate this.

(v) to be an outstanding example of a traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change;

The relationship between settlements and their need for water has been one of the critical interfaces between humanity and nature, extending in some cases over many centuries or even millennia. The plans and buildings of numerous settlements are testimony to the need to manage the flow of clean and dirty water through the urban environment. Projects to obtain water from rivers through impounding and abstraction and from aquifers by pumping have altered natural environments, with both positive and negative consequences. The relationship between cities and the rural hinterlands from which they have sought water has been determined by the growth in consumption, both domestic and industrial. Finally, the defence and protection of natural landscapes has developed out of the popular resistance to the demands for more water for urbanites, evidenced from numerous schemes such as Manchester's Thirlmere reservoir, or San Francisco sourcing its water from the Hetch Hetchy valley in the Yosemite National Park.

(vi) to be directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance. (The Committee considers that this criterion should preferably be used in conjunction with other criteria);

This criterion supports the consideration of places associated with the scientific and technical understanding of how to resolve the urban Sanitary Crisis, as well as with the changes to urban administration and management required to put them into effect. For example, the huge contribution of Louis Pasteur or Robert Koch to understanding the role of bacteria in waterborne disease, or of William Chadwick in conceptualizing the technical solution to the mid-19th-century predicament.

8. Case studies: sites and networks for comparison

This section presents an array of historic infrastructure, buildings, ensembles and landscapes created by the water industry around the world, from different historical periods, technologies and degrees of completeness, prepared by or with the help of people familiar with their heritage values. The intention is to provide a selection of case studies by which heritage managers and others might make comparisons to gain a better idea of the relative significance of other sites and the importance of different attributes.

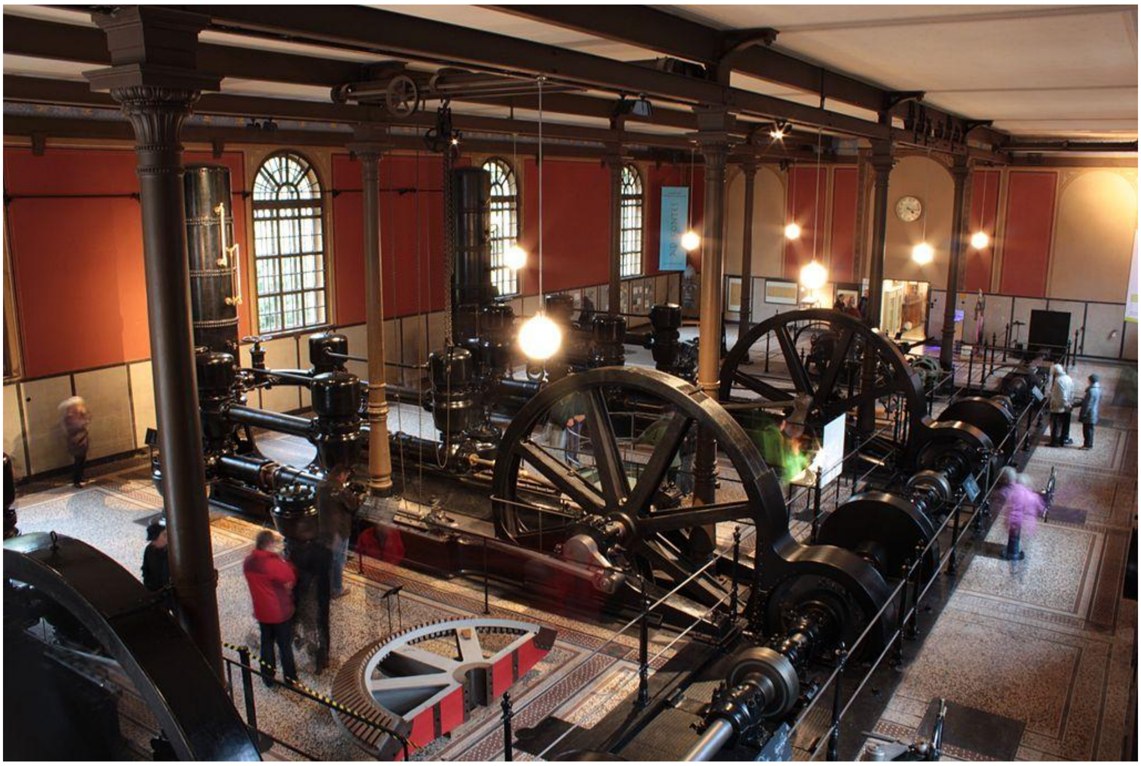
They are presented in a broad historical sequence, although some sites contain components separated by many hundreds of years. All of them include significant elements; their inclusion does not imply any recommendation, and the same applies to places not discussed here.

Because of the constraints under which this thematic study was undertaken it has not been possible to obtain the global geographical representation of the historic sites of the water industry which was sought at the outset. Here the historical and technological gaps are less problematic than the cultural ones: outstanding examples are provided from throughout the period of industrialization, covered by this study, and of all the site typologies which were introduced in Section 2.1. But as we have maintained through this report, the water industry heritage is also a powerful mirror of the human values of the communities for which it was built, and it is this which would be better illuminated by more examples from settlements in Asia and Latin America.

The case studies have been edited so that they conform as closely as possible to a regular format to help make comparisons.

8.1. Augsburg hydraulic engineering, hydropower and drinking water, Germany

Rolf Höhmann, Bureau for Industrial Archaeology, Germany



The double-acting piston pumps and air pressure vessels in the 1879 Hochablass water pumping station. (© Felix Hartmann, Wikimedia Commons)

Presentation and analysis

Location: City of Augsburg and Landkreis of Augsburg, Germany

General description: The Bavarian city of Augsburg contains a remarkable landscape of water infrastructure developed as an integrated urban water-management system from the 13th century, and updated and expanded in the late 19th century in response to modern demands for water from citizens and for industry.

Brief inventory: The city's water infrastructure includes aqueducts, water towers, canals and weir, water-driven pumping stations and monumental cistern heads of the Baroque period, a 19th-century water-power pumping station, and 19th- and early 20th-century water-power generating stations.

Brief history: Augsburg was one of the self-governed German Free Cities, and the earliest canals collecting clean water from the Stadtwald forest are documented from 1216. The Augsburg water system developed in two phases: the water management of early modern times, between the 13th and 17th centuries, separated clean drinking water from process water. The Hochablass weir appeared in public records in 1346 and guides water from the River Lech into a broad network of canals. It was reconstructed several times between 1552 and 1912. Watercourses ran on the surface, sometimes side by side, and so were endangered by contamination.

Water from the canals was raised using piston pumps driven off reversible waterwheels via a set of levers (*Wasserkünste*). The bored timber pipes that distributed the water were sensitive to pressure changes so open compensation reservoirs were installed, and these in turn necessitated the construction of towers – the precursors to later water towers. The key building of this phase was the Rotes Tor (Red Gate) which housed the technical installations to pump and distribute the different water qualities into the city centre, where three bronze drinking fountains (Augustus, Mercury and Hercules) were installed around 1600, designed by celebrated sculptors.

During the 19th-century industrialization process, cholera epidemics and the resulting research into hygiene led to a new evaluation of the Augsburg water supply. The surface drinking water channels from the Stadtwald forests were replaced by water pumped from deep wells. The towers were decommissioned and the neo-Renaissance Neubach waterworks was built in 1879. It has horizontal pumps and four air pressure chambers built by Maschinenfabrik Augsburg, predecessor of today's MAN, to pump the water. The existing water courses outside the historic city walls were widened to supply the growing industrial demand for water, and industry developed along the course of the Lech and Wertach rivers. Water power was at first used for direct mechanical drives using waterwheels and turbines, but these were later followed by hydraulic electrical power generation.

Cultural and symbolic dimension: The remarkable collection of historic sites in Augsburg provide evidence for the development of urban water management over 800 years. The Große Wasserturm (Large Water Tower) and the Kleine Wasserturm (Small Water Tower) at the Rotes Tor (Red Gate) as well as the Untere Brunnenturm (Lower Waterworks) are essentially the oldest water towers in Germany and probably in central Europe. The development of water pumping techniques reflecting Renaissance technical developments derived from ore mining in central Europe. These find architectural expression in buildings and monumental fountains equivalent to the 17th-century Baroque water management of Rome.

Responding to its industrialization, the city updated the system to raise underground supplies with innovative pumping technology, some manufactured by local manufacturers including the international MAN company. The water power provided by the canals supported the early industrialization of Augsburg, encouraging textile, machine and paper factories.

Comparative analysis: Few towns in the world can provide such complete evidence for the response by urban governors to the needs of their citizens for adequate provision of drinking water, showing the continuous development of an urban water-supply system from the early modern period up to the challenge of industrialization and the Sanitary Crisis. This includes pre-modern water canals, buildings and water infrastructure from the Renaissance and Baroque periods, late 19th-century waterworks using innovative pumping technology and wider exploitation of the water supply for generating power.

Present site management
Present use: In use

Protection regime: Bavarian state conservation law. The Hydraulic Engineering and Hydropower, Drinking Water and Decorative Fountains in Augsburg is on the German World Heritage Tentative List. The nomination document *The Water Management System of Augsburg* was delivered to UNESCO in 2018.

Management: Most of the sites are owned by the city of Augsburg.

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8.2. Sete Fontes aqueduct, Portugal

José Manuel Lopes Cordeiro, Social Sciences Institute, University of Minho, Portugal

Mina do Dr. Alvim (1744) with the nearby Mina Preta. (© Benkeboy, Wikimedia Commons)

Presentation and analysis

Location: Braga, Portugal

General description: The Sete Fontes (Seven Fountains) water-supply system is a unique example of Portuguese hydraulic architecture ordered in the 18th century by the Archbishop of Braga D. José de Bragança (1741–56) and was the main source of water supply to Braga until 1913.

Brief inventory: The original Sete Fontes water-supply system is still largely in existence and continues in operation. It is composed of fourteen underground galleries (water mines), made of worked stone and having ventilation wells, and six Baroque junction tanks ('chapels', or mothers of water), of Baroque style, with a cylindrical structure and vaulted dome arranged 500 m apart. At present Sete Fontes extends about 3500 m.

The different catchments direct the water to a main conduit – which bears the arms of its patron, engraved in granite – and continues, capturing the water of the remaining mines and 'chapels', to the last.

The water was conducted in 1.2 m long granite pipes with square section prisms drilled through the longitudinal axis. Throughout the time, there were several 'general boxes' that received the water driven by the Sete Fontes hydraulics system, the most important inaugurated in 1719.

Brief history: The system was constructed between 1744 and 1752, possibly over an already existing one, one of a number built perhaps from the beginning of the Roman period. Its construction culminated in a period of intense activity from the first decades of the 18^{th} century to solve the problem of water supply to the city, following rapid population growth and urban development.

Cultural and symbolic dimension: Due to the fact that it constitutes a unique case, the Sete Fontes hydraulic system has an enormous cultural value.

Comparative analysis: There is no possibility of making any kind of comparison.

Present site management
Present use: Disabled, but still in working condition

Protection regime: Considered to be a 'set of exceptional value, whose characteristics must be fully preserved', was classified as a National Monument and a Special Protection Zone.

State of conservation: With the exception of one 'chapel', which has been destroyed, the system is well preserved.

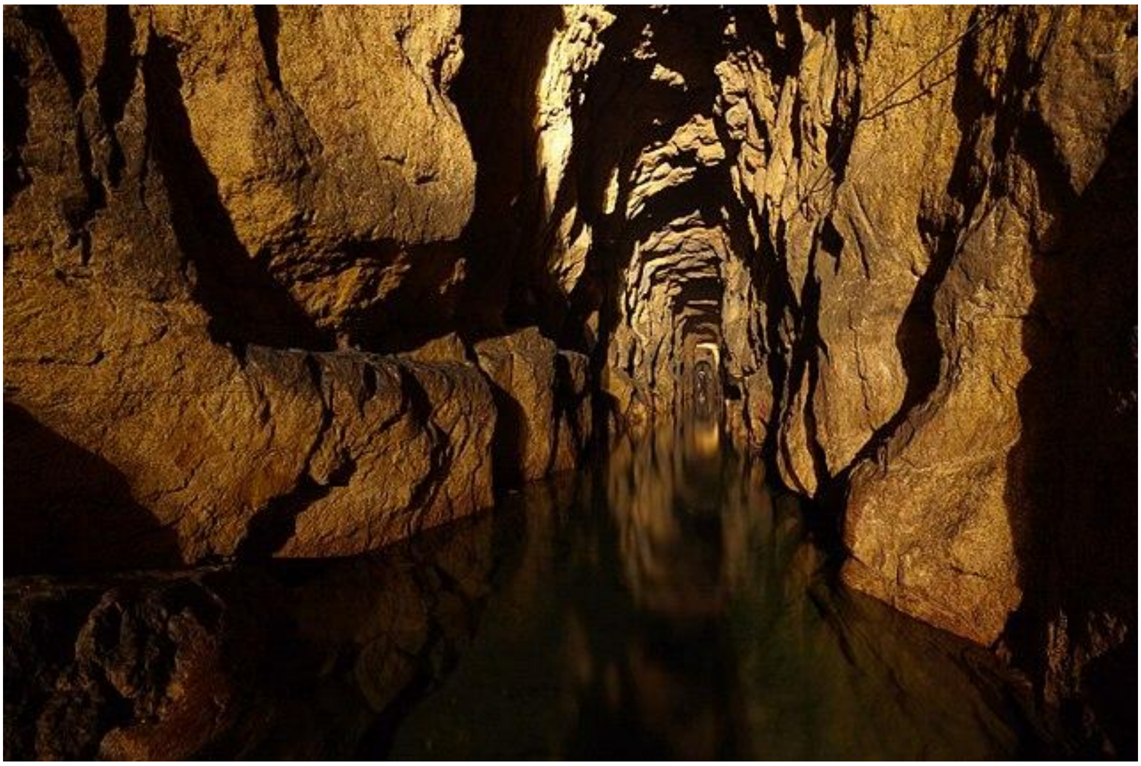
Context and environment: The system is located in an area of the city which has recently been urbanized, which may constitute a threat to its future conservation. To avoid this situation, the municipality of Braga intends to create a park encompassing the entire system.

Management: The management of the system is the responsibility of the AGERE Municipal Public Company.

Additional bibliography
Cordeiro, José Manuel Lopes. *História do abastecimento de água a Braga (1913–2013).* Braga: AGERE (forthcoming).

8.3. Tarnowskie Góry mine and water-management system, Poland

Tarnowskie Góry was inscribed on the World Heritage List in 2017 and this description has been adapted from the site nomination document. It is the first cultural property in which the surviving evidence of a modern water-supply system – in this case one set up to exploit the flow of water from dewatering deep ore mines – formed part of the justification for inscription. This section is taken from the state party's Draft Statement of Outstanding Universal Value, and is included here to assist comparative assessments of other historic water industry sites.



A flooded section of the mine. (© Stowarzyszenie Miłośników Ziemi Tarnogórskiej, Wikimedia Commons)

Presentation and analysis

Brief synthesis: Tarnowskie Góry is the largest historic underground lead-silver-zinc mine with a monumental drainage network. This features a unique integrated public water supply that was both pioneering and the largest of its kind in the world. Constructed in technically challenging terrain, the underground mining and water system comprises over 50 km of main drainage tunnels and 150 km of secondary drainage and access tunnels, numerous ore-extraction chambers and shafts. This network is complemented by substantial remains of the principal water-supply infrastructure (above and below ground) together with directly connected surface elements that comprise essential mining landscape features (such as adit portals and ditches, shafts and tips), and the most important examples of post-mining community commemorative and recreational sites that are a characteristic of the early preservation of Tarnowskie Góry's distinctive mining topography.

Interrelated outstanding values include: The ingenious technical ensemble of mine drainage and water supply illustrates the vigorous pan-European development and exchange of mining technology and demonstrates how mine water was managed.

The underground water-management system reflects a masterpiece of hydraulic engineering, a 300-year development that adapted with changes in scale and technology to combat an unusually high water inflow of up to three times that commonly encountered in central European mines. Dewatering developed in symbiosis with water supply from as early as 1797 when the mine adopted the first Boulton & Watt steam pumping engine exported for metal mining purposes on the European continent. This was followed by their purposeful imitation (and of earlier imported British Newcomen engines), a consequence of which was the foundation, in Silesia, of the German steam engine manufacturing industry that impacted substantially on global industrialization. It was mining, too, that provided the technical wherewithal for the development of the world's first large-scale public water supply systems based on the steam-powered pumping of groundwater, mining engineers inadvertently contributing to the foundations of the modern water industry. The site is a palimpsest that resulted in a complementary and sustainable relationship of mine drainage with water abstraction for local and regional supply and, later, of both potable and industrial water to sustain exponential population growth and development of the emergent Prussian (German) industrial revolution and the foundation of the Upper Silesian Industrial Agglomeration that was in its vanguard.

Justification for criteria

(i) to represent a masterpiece of human creative genius: The extensive underground adit network, and its functional connecting elements of shafts and surface channels, together with the pioneering waterworks that was integrated with underground mine water management, are a masterpiece of mid-sixteenth to late-nineteenth century hydraulic engineering. They represent the peak of European skills in such dewatering technology at a time when mining engineering provided the technical wherewithal for the development of the world's first large-scale public water-supply systems based on the steam-powered pumping of groundwater;

(ii) to exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town planning or landscape design: The colossal and accessible underground network, including the mine dewatering system, ore extraction network and its topographical expressions at surface, together with the pioneering and integrated public water-supply facility, are testimony to larger socio-technical world systems from the very beginning. They exhibit the interchange of technology, ideas and expertise in mining engineering, metallurgical systems and public water supply between leading mining and industrial centres in Saxony, Bohemia, Hungary, Britain and Poland;

(iii) to bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared: The historic underground mining environment together with directly connected surface features, including commemorative public parks and nature reserves that reutilize yet preserve distinctive mining topography, are protected by a vibrant living culture with a long-standing commitment to conservation and public access. The property is vivid testimony to a mining tradition with a 500-yearold pedigree, and commitment to it, from local to national levels, reflects a further contribution to Poland's conservation of some of the world's most significant underground mining heritage;

(iv) to be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history: Substantial remains of the principal integrated public water-supply infrastructure, together with an unusually accessible and monumental underground network of over 50 km of main drainage tunnels and 150 km of secondary drainage and access tunnels, shafts and extensive mined chambers, with the addition of directly connected surface and landscape features, are a unique and enduring

technical ensemble of metal mining and water management. The ensemble is distinguished by a significant output of lead and zinc that sustained international metallurgical and architectural demands of the time, and a water system that ultimately drained the mine by gravity and met the needs of the most industrialized and urbanized region in Poland, and amongst the largest in Europe, providing a unique and early model of sustainable water management in the active mining environment.

Statement of integrity: The overall size of the property provides a complete representation of all the significant attributes of the mine and its water-management system, supporting historical and geographical–spatial integrity, as well as the structural and functional integrity. A substantial part of the property is underground, and all surface features are linked directly to it in the three dimensions, and have been delineated at surface as discrete character areas.

Statement of authenticity: The cultural value of the nominated site is reliably and credibly expressed through the form and design of mining features both below and above ground, their materials and workmanship manifested by original and intact physical and structural remains, their use and function evidenced by archives and detailed archaeological investigation, and its location and setting still pervaded by highly authentic and characteristic mining features in the landscape.

8.4. Águas Livres aqueduct and water-supply system, Portugal

The Alcântara aqueduct bridge crossing central Lisbon. (Wikipedia Commons)

Presentation and analysis
Location: Lisbon, Portugal

General description: A gravity-fed water-supply system built during the 18th century to supply Lisbon and extended as the city grew in the late 19th century. Water was drawn from springs to the north-west. Once the aqueduct reaches the city it passes across the spectacular Alcântara aqueduct bridge and finishes at the Mãe d'Água das Amoreiras cistern. Additional storage was provided by the Patriarcal reservoir, and further supplies were added later through the Alviela aqueduct and Barbadinhos reservoir, from which four French beam engines pumped water to the higher areas of the city.

Brief inventory: A main 14 km section of the aqueduct ends at the Mãe de Água das Amoreiras reservoir in Lisbon. Several tributary sections and head race tunnels contributed water from around sixty sources. The water moved under gravity over a fall of roughly 3 mm each metre, in some sections underground and at other times following surface contours. At its origin are two catchment reservoirs, the Mãe de Água Velha (old reservoir) in Sintra and the Mãe de Água Nova (new reservoir) in Amadora.

The aqueduct is constructed from blocks of limestone which support the water conduits which are protected by stone walls with roof. Vents or skylights illuminate the channels and provide access. The final Alcântara bridge aqueduct is more elaborate and has thirty-five arches. Both the Arco das Amoreiras and the Arco de São Bento are characterized by their neoclassical composition adorned with Baroque details.

Mãe d'Água das Amoreiras reservoir is a monumental stone building with a capacity of 5500 m^3 of water, closer to a water tower than a cistern. A vaulted cupola supports the terrace overlooking the city. The water inside spouts from the mouth of a dolphin onto a cascade, then flows into a 7.5 m deep tank. The western front holds the Register House, from where the water was discharged to five 18th-century galleries which supplied around thirty fountains, factories, convents and noble houses.

The octagonal Patriarcal Reservoir beneath the Príncipe Real garden is divided into two compartments with a capacity of 884 m^3. It regulated the pressure between the Arco reservoir and the pipe distribution network.

The Alviela aqueduct conveyed water to the last water deposit built for the system, the Barbadinhos reservoir. Alongside is the Barbadinhos steam pumping station which includes an engine house, boiler room and coal deposit; the chimney was demolished in the 1950s. Four rotary Woolf compound beam engines by the French manufacturer E. Windsor & Fils were installed in 1876.

Brief history: The growth of Lisbon in the 16th century prompted the Portuguese king to order the construction of the Águas Livres (Free Waters) aqueduct. It was built between 1731 and 1799, the route coinciding with that of an old Roman aqueduct. Undamaged by the Lisbon earthquake of 1755, work continued well into the 19th century with the building of its secondary branches – subsidiary aqueducts, water conduits and head race tunnels – and its conduit fountains, and finally the Mãe de Água reservoir in Amoreiras.

The Patriarcal reservoir was built between 1860 and 1864 as part of the project to augment the system designed by the French engineer Louis-Charles Mary, and initially supplied by the Aguas Livres aqueduct. It was intended to supply the Lisbon downtown area.

The Alviela aqueduct was constructed between 1871 and 1880 to help meet continuing rising demand for water, which it collected from 114 km north of Lisbon. The Barbadinhos pumping station went into operation in 1880; steam pumping ceased in 1928. The waters of the aqueduct have not been used for human consumption since the 1960s.

Cultural and symbolic dimension: The Aguas Livres aqueduct represents the technical development of water provision spanning the final application of Roman engineering principles through a gravity fed masonry aqueduct, Baroque water management using galleries, urban cisterns and public fountains, and industrial technology characteristic of the 19th century with steam-powered pumping, iron pipes and water treatment.

All the major elements manifest a high quality of engineering in their conception and execution, consistent with an urbane vision of public water supply. An example is the way that the cisterns have a secondary role as elegant public spaces. The aqueduct bridge is constructed from the highest pointed arches ever used for such a piece of engineering, the tallest of the thirty-five arches reaching to 65 m.

Comparative analysis: The aqueduct and its urban distribution elements follows the model developed for Counter-Reformation Rome in the 17th century, and compares with royal water-supply projects such as the 1623 Aqueduc Médicis in Paris. The aqueduct bridge can be compared with the contemporary Aqueduc Saint-Clément in Marseille (1765), marking the end of the Roman tradition of gravity flow bridge aqueducts. The highest such bridge is the 1846 Roquefavour bridge on the Canal de Marseille, at almost 100 m, and the High Bridge on the old Croton aqueduct, built between 1837 and 1842, both of which transport water in iron pipes.

The urban reservoirs in Lisbon can be compared with Byzantine cisterns, although smaller than those in Istanbul, or with the much larger covered reservoirs built in many 19th-century cities in Europe and North America.

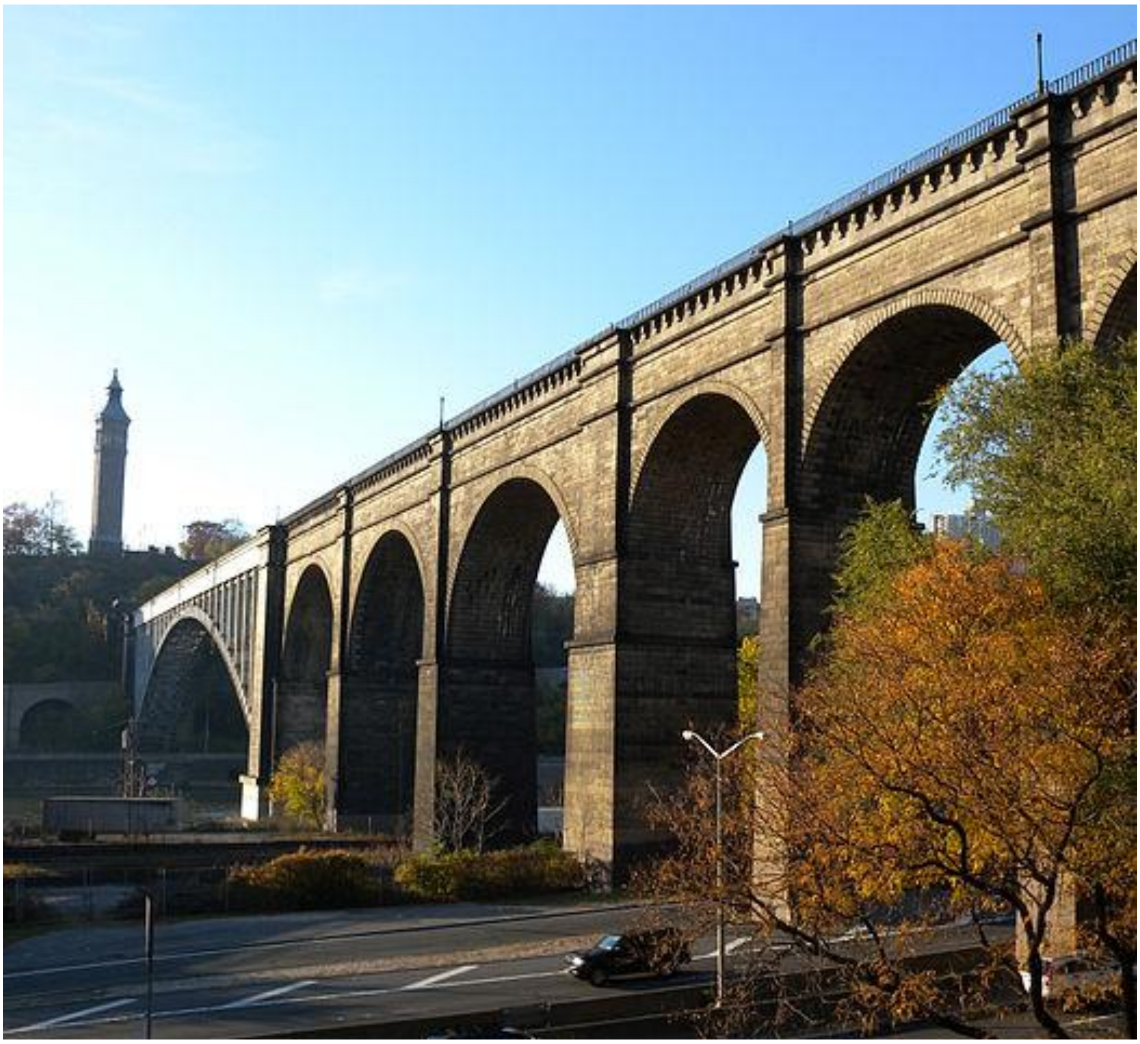
The Barbadinhos waterworks is a late example of beam engine pumping, though such technology continued to be installed into the early 20th century. It is notable for the quality of the engineering and architecture, despite the loss of the boiler chimney. Comparable examples of Woolf compound pumping engines include the 1883 Goulburn waterworks in Australia or the 1891 Abbey sewage pumping station in Leicester, UK.

Present site management
Present use: The aqueduct is a monument and the Mãe de Água reservoir, Patriarcal reservoir and Barbadinhos pumping station form part of the Museo da Água.

Protection regime: The aqueduct has been a National Monument since 1910. This guarantees the aqueduct a Special Protection Area of 50 m throughout its length. The pumping station building was classified as a Set of Public Interest (Ordinance no. 117/2010).

8.5. Old Croton aqueduct, USA

Meisha Hunter, Senior Preservationist, Li/Saltzman Architects, USA


The 1837–48 High Bridge entering Manhattan. Most of the masonry arches were replaced by the 1927 steel arch. (© Jim Henderson, Wikimedia Commons)

Presentation and analysis
Location: Putnam, Westchester, Bronx and New York counties, NY, USA

General description: The first Croton aqueduct campaign, begun in 1837 and completed in 1842, was one of the most significant civil engineering achievements in 19th-century America and one of the most ambitious municipal public works projects ever undertaken in the United States. The 41-mile aqueduct was designed and constructed to provide a reliable source of abundant, potable water to New York City and critical to its long-term prosperity, as well as the safety and health of its residents.

The Croton aqueduct featured spectacular superstructures at topographically challenging locations or at junctures of water collection and distribution: the monumental masonry-arched Valley Crossing at Sing Sing Kill; the 1450 ft-long, 100 ft-high masonry-arcaded High Bridge over the Harlem river; the 1900 ft-long Clendening Valley Crossing; the York Hill reservoir in Central Park; and the neo-Egyptian style Murray Hill distributing reservoir. South of the Harlem river, Croton water flowed in brick-lined channels and iron mains. Gatehouses whose function was to control and regulate the water supply were constructed at 142nd, 135th and 119th Streets in the middle of 10th Avenue.

Brief history: Built in response to the fires and epidemics that repeatedly devastated New York City owing in part to its inadequate water supply and contaminated wells, the aqueduct's completion was a milestone in the history of the city. Major David B. Douglass (1790–1849), the project's first chief engineer, planned the route and structures and established the project's hydraulic principles. In 1836, John B. Jervis (1795–1885) completed the final design and led the complex construction effort. Jervis studied Roman aqueducts, aqueduct bridges and hydraulic mortar applications in addition to contemporary civil engineering works such as the first sub-aqueous tunnel under the River Thames, built in 1841.

Croton dam (later submerged inside of the New Croton dam) consisted of bolder-filled, timber-cribbed aprons, keyed masonry and granite facing all using hydraulic mortar, and earth embankments. Jervis's unique design for the S-shaped profile of the Old Croton dam minimized the 'destructive force of overflowing water' and became an industry standard for American dam design. Water descended in a gravity-fed, horseshoe-shaped, brick-lined channel. Regularly spaced ventilating shafts were located every mile along the aqueduct's route.

Cultural and symbolic dimension: As a costly municipal enterprise, the Croton was imbued with civic pride and the expectation that it would serve many generations. There was widespread recognition of the Croton as a monumental achievement, as evidenced by visits from the national and international engineering community. The Croton became the subject of books, paintings and other media which communicated the significance of this civil engineering achievement.

Among its immediate and palpable benefits are its influences on domestic convenience and comfort, the promotion of sobriety and personal cleanliness, the purification of our streets, the consequent increase of public health, the facilities it will extend to mechanical and manufacturing industry, the vast increase of steam power among us to be employed in the arts, the supply to our mariners of a necessary element which will remain comparatively unaffected by change of climate, and pre-eminently the security it will afford against the dangers of conflagration. (1842 address by Charles King, president of Columbia College)

Comparative analysis: The successful design and construction of the Croton aqueduct not only helped the city's rise to prominence but served as a model for other municipal water-supply systems.

The New York City water supply system... was in its time the model for large-scale municipal water supply systems throughout the United States... the system that resulted stood as an international example of engineering skills in an era of rapid growth and formed a cornerstone in the creation of the modern city. (Professor Daniel L. Schodeck, Harvard University Graduate School of Design)

Present site management

Present use: The Old Croton Aqueduct State Historic Park is a linear park that runs from Van Cortlandt Park at the Bronx County/City of Yonkers border to the Croton dam in Cortlandt.

Protection regime: The Croton aqueduct is listed on the National Register of Historic Places. The American Society of Civil Engineers designated the Croton water supply system as a Historic Civil Engineering Landmark. In 1992, 26 miles of the northernmost segment of the aqueduct’s above-grade linear corridor were designated a National Historic Landmark, from the Croton dam in Westchester County until the Manhattan touchdown of the High Bridge in Manhattan, including the submerged portion of the aqueduct between the Old and New Croton dams, as well as the Bronx portion of the aqueduct running from Westchester to the Manhattan touchdown of High Bridge.

Several individual structures of the Croton aqueduct are listed individually on the New York State Register of Historic Places, including the High Bridge, aqueduct, and water tower; Old Croton dam site; 135th Street gatehouse; High Pumping Station; and Jerome Park reservoir. Several individual structures of the Croton aqueduct are also designated individual landmarks under the protection of the New York City Landmarks Preservation Commission, including the High Bridge, aqueduct and pedestrian walk; the High Bridge water tower; the 135th Street gatehouse; the High Pumping Station; and the 119th Street gatehouse.

Heritage management protections are offered at the municipal, state and federal levels: New York City Landmarks Law (1965), the New York State Environmental Review Quality Act; the National Environmental Policy Act (NEPA); National Historic Preservation Act of 1966 (as amended); and the Department of Transportation Act (1966).

Context: New York’s water supply is sourced from the Croton, Delaware and Catskill watersheds, covering a surface area of 2000 square miles. The system contains nineteen reservoirs and three controlled lakes with a storage capacity of 580 billion gallons that cumulatively serve over 9 million New Yorkers.

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8.6. Kew Bridge and Kempton Park pumping stations, UK


Kempton Park engine house is the grandest expression of the waterworks style of industrial architecture. (Wikipedia Commons)

Presentation and analysis

Location: The London Museum of Steam and Water**,** Green Dragon Lane, Brentford, and Kempton Steam Museum, Kempton Park Water Treatment Works, Snakey Lane, Hanworth, Greater London

General description: Two exceptionally complete and historically important conserved steam pumping stations which supplied London with water.

Brief inventory: The Kew Bridge pumping station (now the London Museum of Steam and Water) includes the Main Engine house built in 1836–8 and the Great Engine house of 1845–6 and 1869–70, both containing contemporary beam pumping engines filling the building. The neighbouring standpipe tower was rebuilt in 1867 and was a buffer against damage to the pumping engine should pressure be abruptly lost by a break in the mains.

The outstanding pumping engines are:

- Boulton & Watt engine built in 1820 for the earlier Chelsea Water Works and moved to Kew in 1839–40, and restored to operating condition.
- Maudslay engine built in 1838 and converted to the Cornish cycle in 1848.
- Grand Junction 90-inch engine built by Sandys Carne & Vivian in 1846, one of only four remaining Cornish engines with a cylinder diameter greater than 80 inches and the only one still operating.
- Bull engine built by Harvey & Co., Hayle, in 1856, the only example of this type of direct-acting pumping engine on its original site.
- 100-inch engine built by Harvey & Co., Hayle, in 1869, the ultimate development of the Cornish engine.

The museum also displays compound vertical rotative, horizontal compound and other steam pumping engines that have been moved there as well as diesel and electric pumps on display.

Nearby Kempton Park pumping station (now the Kempton Steam Museum) includes the 1897 Lilleshall engine house and the Triple House containing two large Worthington Simpson inverted vertical triple expansion engines, one in working order, with the crane, original tools and controls used to monitor each engine's output. Each engine stands 19 m high from the basement to the tops of the valve casings, and is 13.7 m long. Including the ram pumps, each weighs 1000 tons (1016 tonnes) and was capable of producing 1008 water hp.

Brief history: The first waterworks in this part of London was built for the Grand Junction Waterworks Company in 1811. It took water from the Grand Junction Canal, but when the water proved to be unsuitable the company built a new waterworks at Chelsea in 1820. Here, too, the water became polluted so the two engines from Chelsea were moved to Kew Bridge and began pumping in 1838.

Slow sand filter beds were built in 1845, one of which still survives. After filtration, the clean water was pumped up to a covered service reservoir at Campden Hill before gravitating to individual streets and houses. River extraction was again moved upstream in 1855, this time above the tidal reach to Hampton. In 1903 a laboratory was built at Kew for water analysis, a very early example indicating the more scientific approach to water provision in the 20th century.

All London's private water companies were taken into municipal control within the Metropolitan Water Board in 1904. The MWB added diesel pumps at Kew in 1934, and electric pumps in 1944. When the MWB phased out its older steam engines in 1944, five classic engines at Kew Bridge were selected for preservation. The pumping station operated until 1985 and is now the London Museum of Steam and Water.

Kempton Park pumping station was built in 1897 by the New River Company. Five Lilleshall triple expansion steam engines were installed to lift water from the Thames to two holding reservoirs supplying twelve slow sand filter beds. Work on a second set of pumps, in the Triple House, was completed in 1928 when the two Worthington-Simpson triple expansion engines were commissioned. A pair of steam turbines were added in 1933.

Cultural and symbolic dimension of the sites: Kew Bridge pumping station is the oldest waterworks in the world containing its original steam pumping engines, and is the most complete early pumping station in Britain. It is the most important historic site of the water industry in Britain, and arguably the world, for its early date (it started pumping in 1838) and the completeness of the station, including the engines, standpipe tower, laboratory, offices and gatehouse.

The museum is a rare experience wherein five original beam engines present the progressive development of the Cornish-cycle steam engine for waterworks service from 1820 to 1869. During the period represented at the museum, cylinder diameter increased from 65 to 100 inches.

The two 1000-ton triple-expansion steam pumping engines at Kempton Park have been preserved and one is restored to steam, the largest working example of this technology in the world.

Taken together, the two sites conserve outstanding in situ examples of the technological evolution of steam-powered water supply over more than a century, as well as three notable examples of the development of waterworks architecture. The history of the sites covers the transfer of responsibility for domestic water supply from private, commercial companies to municipal administration. Finally, they are testament to the progressive rise in the quality, as well as the quantity, of water supplied to a major metropolitan centre, in the relocation of the sites of abstraction further upstream on the Thames, the incorporation of slow later rapid filtering, and of chemical and biological analysis.

Comparative analysis: The combined sites are the most important sites of historic water pumping infrastructure in the world, for their early date and period, technological range, authenticity and integrity, and their social significance for Londoners, to which the high quality of the mechanical engineering and architecture bear witness.

Preserved water-supply pumping engines with which comparison might be made include the beam engines at Papplewick and Ryhope (UK), Goulburn, NSW (Australia) and Lisbon (Portugal); while the triple expansion engines in Cincinnati, OH, Buffalo, NY (five engines) and Boston, MA in the United States can be compared with Kempton Park although none are currently steamed.

Present site management
Present use: Museums

Protection regime: The Kew Bridge site comprises a mix of listed Grade I and II* buildings; the principal ones have been restored including the 1867 standpipe tower. The site is in the Kew Bridge Conservation Area and Nature Conservation Area; and partially in the buffer zone of the Royal Botanical Gardens World Heritage Site. Kempton Park is listed Grade I.

Management: The London Museum of Steam and Water is an independent Accredited Museum, governed by the Kew Bridge Engines Trust. The Kew Bridge Engines Trust and Water Supply Museum Limited, a registered charity, was formed in 1973. The Kempton Great Engines Trust is a registered National Monument.

8.7. Berlin Radialsystem sewage treatment network, Germany

Radialsystem V, now part of a popular arts space. (Wikipedia Commons)

Presentation and analysis

Location: Berlin (various sites)

General description: The Radialsystem waste removal and treatment plan developed for Berlin consisted of twelve steam pumping stations which collected waste and rain water, partially filtered it, and raised it to be piped to peripheral sewage farms where it fertilized fields. This distinctive system continued well into the 20th century. Today the pumping stations have been converted to various new cultural and commercial uses.

Brief inventory: The Radialsystem has twelve former steam pumping stations and the associated fields on the edge of the 19th-century urban area which were used for dispersing the waste which they collected.

Brief history: The first Berlin waterworks was opened by a company founded in London in 1856. In 1866 a cholera epidemic forced the city council to seek a practical and cost-effective sewage removal system and civil engineer James Hobrecht (1825–1902) was commissioned to design an urban development plan for the whole city. Incorporated within the Hobrecht plan was a comprehensive waste-treatment network.

Hobrecht divided Berlin into twelve topographical districts, or Radialsystems, setting a steam pumping station at the lowest part of each. Hobrecht's plan allowed the Spree river to continue to be used as a supply of fresh drinking water. Domestic, commercial and industrial wastewater as well as rain was collected under gravity through a series of underground sewers below the pumping stations, and pumped in pressurized iron pipes to 16,000 hectares of sewage farms on the outskirts of the city. The sewage was filtered and used as fertilizer for crops grown on the drainage fields. The Berlin sewer system officially opened in1878.

All twelve pumping stations and the underground network connecting them were completed by 1909, a feat of engineering that succeeded in serving the needs of most of Berlin's 1.5

million residents. The stations consisted of a collection tank into which the wastewater of the district was collected; the machine hall and boiler room, designed respectively to house the pumps and steam engines in operation; living quarters for the workers on duty; and a workshop and storage area.

The first pumping station, Radialsystem III, went into operation in 1878. Radialsystem V was built on Holzmarktstrasse in 1881; it became the largest pumping station of Berlin in 1905 after architectural modifications. The building is typical of the industrial architectural style in this region at the time, architect Richard Tettenborn using decorative elements of the Märkische Backsteingothik (brick Gothic) style with large windows to light the machine hall interior. It followed James Hobrecht's ideals of cleanliness and elegance in industrial architecture and technology. Six 220 hp horizontal steam engines working twelve pumps pumped the mechanically pre-cleaned waste over a sand trap by means of vertically standing rolls grating wastewater to the sewage. Six additional 320 hp steam engines were added later.

Radialsystem VII, built in 1881–3, had three steam pumps until electrification in the 1930s. Pumping station VIII was built in 1889–90 at the confluence of Gotzkowskystraße, and Radialsystem XI in 1907–8 on Erich-Weinert-Straße.

The extensive sewage farms around the periphery of the city included fruit trees, ponds, dairy farms and other secondary operations.

Cultural and symbolic dimension: The Holbrecht plan is among the influential urban plans which reordered numerous cities in the 19th century to help them cope with rapid population growth and industrial expansion, and is fundamental to the history and form of the German capital. The importance of the Radialsystem in helping the city overcome previous epidemics was critical to Berlin's development. It effectively applied steam pumping technology and pipe networks to collect and remove the city's domestic and industrial waste, keeping it out of the River Spree, and successfully putting into large-scale practice the goal of 19th-century sanitary reformers of using sewage for fertilizer.

Comparative analysis: Holbrecht's Radialsystem was a unique solution to waste removal, conditioned by the circumstances of the city's new plan, its geographical relationship with the river and with its hinterland, and the current technological options. Comparison can be made with London's intercept system, which used steam pumping stations the dump the city's waste in its river, rather than put it to advantage, but which has also a distinguished heritage of waterworks and steam engines.

Berlin is one of very few 19th-century waste systems built to resolve the Sanitary Crisis of a large city for which there remains a substantially intact heritage as evidence for the immense value which they had for citizens at that time.

Present site management
Present use: Several of the former pumping stations have been converted to museums, offices, cultural centres or restaurants. Radialsystem V is a well-known music venue.

Protection regime: Most of the pumping stations are designated on the Denkmaldatenbank of Landesdenkmalamt Berlin. The drainage fields of Radialsystem V located in Bürcknersfelde and Falkenberg are now a nature reserve; part of the original layout of the Falkenberg drainage field is still recognizable today.

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8.8. Boston Metropolitan Waterworks Museum, USA

Dennis J. De Witt, Metropolitan Waterworks Museum, Boston, MA, USA

The Metropolitan Waterworks Museum occupies the former Chestnut Hill high service pumping station, Boston. (© D. J. De Witt)

Presentation and analysis

Location: 2450 Beacon St., and other sites, Boston, MA, USA

General description: The Metropolitan Waterworks Museum (MWM) is housed in the former Chestnut Hill high service pumping station (CHHSPS), constructed in 1884–8 and extended in 1898–9, which pumped water from the adjacent Chestnut Hill reservoir to the nearby Fisher Hill reservoir. The MWM and the Chestnut Hill reservoir stand at a nexus of Boston's water-supply system of historic, standby and active aqueducts established between the mid-19th and early 20th centuries and of a system of deep tunnels that now allow delivery of 90 percent of the system's water to its customers without pumping.

Brief inventory: The pumping station, originally designed by Boston's official city architect, Arthur H. Vinal, is a sophisticated example of the influential Romanesque style of Boston architect H. H. Richardson, with each of its major components – coal store, boiler room, engine room – functionally articulated. The 1898–9 addition was designed to house a vertical triple expansion engine rather than the original building's intended horizontal engines. The cathedral-scaled interior, has a marquetry panelled ceiling, and the glass-walled exhibits gallery overlooks the Leavitt-Reidler engine.

The engine room houses three major steam pumping engines:

1. 1894 Leavitt-Riedler triple expansion engine, the only surviving example of his innovative work.
2. 1899 Allis triple expansion engine, the first of its much-emulated design.
3. 1921 Worthington-Snow compound engine.

The two triples, each as tested new, successively had the most efficient ‘duty ratings’ of any engine to date.

Adjacent to the MWM are:

- The 1848 Cochituate aqueduct and two of its subsequent gatehouses associated with the Chestnut Hill reservoir and the high service pumping station. The Cochituate aqueduct’s nearby principal gatehouse has the oldest iron roof and iron stairs intended for public use in the USA. The Brookline reservoir, the receiving reservoir of the 1848 Cochituate aqueduct, is a National Historic Landmark.
- The 1870 Chestnut Hill reservoir, together with its first and second effluent gatehouses.
- The terminus gatehouse of the 1870 Sudbury aqueduct.
- The 1888 gatehouse of the Fisher Hill reservoir that was supplied by the pumping station, was designed in the pumping station’s Richardson style.
- The 1899 neoclassical Chestnut Hill low service pumping station.

Brief history: The Cochituate aqueduct was Boston’s first public water supply. It was laid out by J. B. Jervis, who built New York’s Croton aqueduct, and was designed under the supervision of E. S. Chesbrough, famous for his later work in Chicago. The Cochituate and Sudbury aqueducts supplied the Chestnut Hill reservoir, and thence most of Boston by gravity. Due to the quality and quantity of the city’s water supply, a series of annexations beginning in the 1860s required a separate high service system for the higher annexed areas.

The CHHSPS originally had two Holly Gaskell compound engines with room for a third between them. The Leavitt-Riedler was squeezed between them in 1894. A seamlessly matching 1898–9 addition, designed by Edmund March Wheelwright, houses the Allis engine. The adjacent, competition winning, neoclassical low service pumping station was added in 1898–9.

One of the original Holly Gaskell engines was replaced in 1921 by the Worthington-Snow engine. The other was replaced in the 1930s by two steam turbines, as the station converted to oil and the adjacent low service station ceased operation. Today Boston’s Metropolitan Water Resources Authority (MWRA) delivers 90 percent of its water without pumping.

In 1906, the Wachusett dam and reservoir, then the largest drinking water reservoir in the world, was completed. Eventually, as deep tunnels distributed water under pressure from it, almost all pumping was eliminated.

From the mid-1970s the building and site were the focus of a stakeholder process that eventually spelled out the redevelopment and preservation of the exteriors of all three historic buildings on the site as well as of the MWM space and engines. The principal change in the MWM was the insertion of a glass-walled structure containing entrance and exhibit galleries. A stakeholder group, Friends of the Waterworks, took title to the space as Metropolitan Waterworks Museum, Inc. in 2009.

Cultural and symbolic dimension: The components of the metropolitan Boston system of dams, reservoirs, aqueducts, pumping stations and ancillary structures is notable for the consistent high quality of the workmanship and design. The prominently located Chestnut Hill waterworks site, including its three historic buildings, is listed on the National Register of Historic Places, as is the adjacent Chestnut Hill reservoir, the abutting Cochituate and Sudbury aqueducts and the entire historic metropolitan Boston water-supply system.

Comparative analysis: The Boston water system exemplifies the 19th-century policy of large American cities that exploited distant rural sources of pure water, stored behind massive dams and delivered to metropolitan areas by gravity, as opposed to pumping and filtering from nearby rivers as was more commonly practised in European cities such as Hamburg or London.

The MWM and its site is the only publicly accessible, institutionally secure location in the USA with 19th-century triple expansion steam pumping engines. Federal security restrictions limit access to the River Station, Cincinnati, with three 1000 hp vertical triple expansion engines, and Buffalo's Col. Francis G. Ward pumping station with five 1914 vertical triple expansion engines. The architectural character and proximate location of the high and low service pumping stations embody the aspirations of America's City Beautiful Movement and Boston's post-Civil War Golden Age.

The MWM is a focus for the investigation of Boston's remarkable historic water-supply system which, along only with New York's, is unique in delivering unfiltered, non-chlorinated water of the highest quality. The MWRA, in cooperation with the Metropolitan Area Planning Council (MAPC) is developing the system's six surface aqueducts, with their multiple dams and, well maintained, numerous architect-designed gatehouses, as a network of walking trails, a terminus of which is the Chestnut Hill reservoir.

Present site management

Present use: The MWM site has three historic buildings – the low service pumping station and stables, both converted to residential condominia, and the museum building. The museum building's coal store and boiler room now house condominium units.

Protection regime: A binding, state promulgated Land Disposition Agreement (LDA) underlies the buildings' condominium regimes and provides state oversight of any changes possibly disadvantageous to the MWM. The historic buildings are also City of Boston Landmarks, subject to design review, and they and the engines are subject to a Massachusetts Historical Commission preservation easement.

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8.9. Vyrnwy and Elan Valley distant supply schemes, UK

Stephen Hughes, TICCIH Secretary and vice-president ICOMOS-UK, UK

Claerwen Dam was added to the Elan Valley scheme in 1957. Tough built of concrete it wasfaced in masonry to be inkeeing with the older structures nearby. (Wikipedia Commons)

Presentation and analysis

Location: Lake Vyrnwy and Elan Valley, Mid Wales, Liverpool and Birmingham, UK

General description: The rapid growth of Liverpool and Birmingham in the late 19th century, driven by industrialization and each stricken by successive public health crises, prompted an unprecedented demand for new, large, clean sources of drinking water. Both cities looked west to the mountains of Mid Wales.

In 1880, the Corporation of Liverpool built the first high masonry gravity dam in Britain on the River Vyrnwy, feeding a 105 km gravity aqueduct pipeline to the city. The Birmingham scheme began 13 years later (first phase 1893-1904) and was a more sophisticated complex of four reservoirs and two connecting tunnels leading to the head of a 117 km aqueduct which terminated at the Frankley treatment works outside the city.

Brief inventory: The large Vyrnwy Dam and its valve tower, designed in the form of a Rhenish Castle, the aqueduct and 30 m monumental receiving water tower at Norton in Liverpool. The aqueduct had siphons and tunnels including an innovatory cast-iron tunnel under the river Mersey accommodating the aqueduct pipes. Birmingham's Elan Valley system had four dams and reservoirs linked by two intermediate tunnels, the uppermost being Craig Goch Dam, then Penygarreg, Garreg Ddu and Caban Coch. The foundations of an intended fifth dam clearly exhibit how such Victorian structures were designed. Monumental bridge aqueducts, tunnels and siphons mark the passage of the long pipeline.

Brief history: Vyrnwy was investigated in 1866, designed and authorised in 1880, and built between 1881-91. The Elan Valley scheme was investigated in 1871 and 1891 and built in one campaign between 1893 and 1904.

Cultural and symbolic dimension: The Elan and Vyrnwy schemes represent the solution for the critical public health problems in two of the largest urban populations resulting from the Industrial Revolution. Both complexes were consciously creating a picturesque mountain and water landscape with ornamental valve towers and Arts and Crafts-style villages, churches and chapels rebuilt to replace those submerged by the reservoirs. The Vyrnwy and Elan reservoirs drowned about 70 houses in Welsh-speaking settlements. They were the beginning of a larger trend of flooding the heartlands of a minority culture for urban water supply that led to a growth in political activism and the devolution of political power.

Comparative analysis: Vyrnwy was the first high (44.2 m) masonry gravity dam to act as a weir, dispensing with the need for a separate spillway. The dam was also the first to incorporate a drainage system to combat uplift pressure. It created the largest reservoir in Europe. The Vyrnwy Aqueduct was the longest in the world when constructed. The principal Vyrnwy engineer, Thomas Hawkesley, was one of the most prolific and influential international water-supply and sewerage scheme engineers of the 19th century. He designed over 150 waterworks including examples in Stockholm, Altona (Denmark) and Vienna as well as Great Britain.

The Elan Valley Reservoirs were the largest complex of dams, reservoirs and connecting tunnels planned in one campaign in the 19th century. They were considered the masterpiece of the internationally influential water engineer James Mansegh (1834-1905), who acting for 360 urban water-supply and sewage schemes, producing more than 250 reports. Among them is the Werribee Sewage Works and Farm in Melbourne, Australia (see the Case Study), and he also worked on schemes in Philadelphia and Antigua.

Present site management

Present Use: Still active water-supply schemes with tourist use especially along the course of the complex construction railways (50 km) in the Elan Valley.

Protection regime: The Vyrnwy Dam is listed Grade I and the Norton Water Tower is part of the Liverpool World Heritage Site. The Elan Dams and valve towers are Grade II*. The Elan Maintenance Workers village is listed Grade II. The Elan Valley is registered by ICOMOS-UK/Cadw as a Landscape of Historic Interest in Wales.

Management: The Vyrnwy Dam is owned by Severn Trent Water. The Elan Dams are owned by Welsh Water and the Aqueduct by Severn Trent Water.

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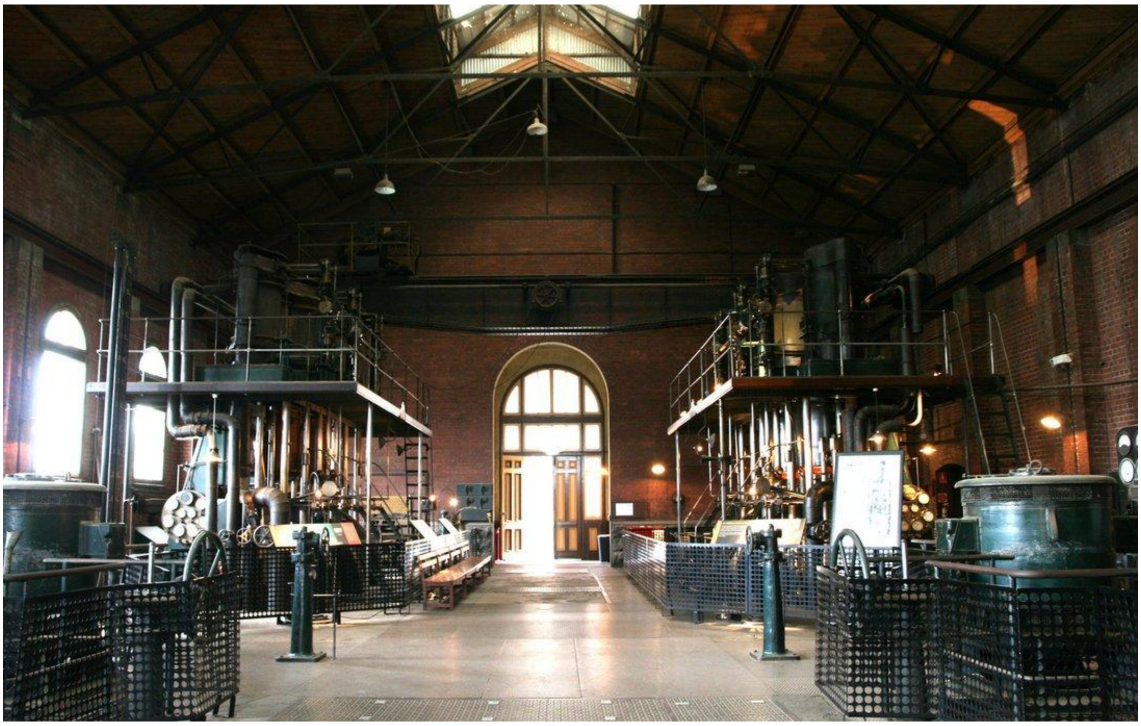
8.10. Melbourne sewage system and Spotswood pumping station, Australia



Vertical triple expansion engines within the typically clean and ordered interior of a waterworks engine house. (Wikipedia Commons)

Presentation and analysis

Location: 2 Booker Street, Spotswood, Victoria 3015

General description: Spotswood pumping station was designed to pump the gravitated sewage collected from Melbourne City and suburbs through a rising main to Brooklyn where it discharged into the main outfall sewer which then conveyed the sewage to the Werribee sewage farm, where it was purified by land treatment.

Brief inventory: Spotswood pumping station consists of two mirror-image pumping houses containing steam pumping machinery included ten triple expansion condensing steam engines driving vertical direct acting plunger pumps, and associated boiler houses and coal bunker buildings.

The first four engines were non-rotative and manufactured by Thompsons of Castlemaine, two in each pump house. Two rotative engines were added, one based on an American design built locally by the Austral Otis Engineering Company, the second by the British pump builder Hathorn Davey & Company in 1901. The final group of four engines were close copies of the Hathorn Davey engine made by Austral Otis. A unique collection of steam engine driven pumps, electric motor driven pumps and control equipment as well as tools, furniture and other objects, remain at the station.

Werribee sewage farm has ten lagoons used as oxidation ponds to treat the sewage, with remnants of the former grass filtration beds still evident, along with the concrete and earth channel distribution network. The main outfall sewer is largely converted to bike trails. The sewage reticulation and main trunk network is a vast engineering structure, hundreds of kilometres of brick lined tunnels large enough to stand upright in, or row a boat through.

Brief history: The construction of the main sewers commenced in 1893; Spotswood pumping station was built between 1894 and 1897; and in 1914 all ten steam engines were in operation. The first electric powered pumps were installed in 1921, and by 1925 most of the daily flows were pumped by electricity.

Spotswood ceased operation in 1965, but sewage still flows under the site on its way to Brooklyn and the Western treatment plant at Werribee. In 1989, the Museum of Victoria took over the pumping station site to develop Scienceworks, an interactive science and technology centre, which opened in 1992.

Cultural and symbolic dimension: The sewage system is one of the few large turn-of-the-century filtration sewage systems in the world which is still operating, and one of the earliest built in Australia. It is significant for its critical historical role in the development of Melbourne, leading to dramatic improvements in hygiene, health, urban character and quality of life in the city at the end of the 19th and throughout the 20th centuries. As such it led directly to a substantial reduction in death and illness from typhoid and other infectious diseases.

The construction of the system was one of the most significant single infrastructure projects ever undertaken in Australia and was a major achievement in terms of surveying, engineering and construction work. The steam pumping engines in Spotswood are one of the most complete collections of triple expansion pumping engines in the world.

Comparative analysis: The Melbourne sewage system is the first fully integrated sewerage system in Australia, notable for the engineering excellence incorporated in the scheme. It is representative of the comprehensive drainage and treatment schemes using triple expansion pumping engines built in the late 19th century and comparable with similar works in Berlin, Boston or Cincinnati.

Present site management
Present use: Museum exhibitions

Protection regime: Spotswood pumping station and the main outfall sewer are on the Victorian Heritage Register, and Spotswood is on the register of the National Trust of Australia.

Management: Melbourne Water Corporation; Scienceworks, Museum of Victoria

Additional bibliography
This short summary is based on the much more comprehensive *Nomination for the Engineering Heritage Australia Heritage Recognition Program*, prepared by Engineering Heritage Victoria (2014).

8.11. Palacio de las Aguas Corrientes service reservoirs, Argentina

Dr Jorge Tartarini, Director del Museo del Agua y de la Historia Sanitaria, Argentina

The glazed ceramic exterior of the Palacio de las Aguas Corrientes. (Wikipedia Commons)

Presentation and analysis

Location: Ciudad Autónoma de Buenos Aires

General description: Three raised water tanks are examples of the storage and distribution techniques for drinking water and of the significance given to public hygiene in the culture of the time, with the construction in 1894 of the Palacio de las Aguas Corrientes, and continuing with the erection of the two Depósitos de Gravitación in 1915 and 1917.

Brief inventory: Palacio de las Aguas Corrientes or Gran Depósito Distribuidor, also known officially as Gran Depósito Ingeniero Guillermo Villanueva, was conceived as a huge kit of parts to be assembled on site. The project took definitive shape in 1886 and construction developed between 1887 and 1894. In an eclectic style, related to that of the French Second Empire, the spectacular exterior façade is covered with more than 300,000 ceramic pieces made by the English terracotta manufacturer Royal Doulton, while the great interior iron structure composed of 180 columns on three floors with twelve water tanks, capable of storing 72,300 m^3 of water, was manufactured by the Marcinelle et Couillet group of Belgian iron foundries. With a plan of 90 m on each side, surrounded by gardens, the reservoir operated between 1894 and 1978.

The two gravity service reservoirs in the Caballito and Villa Devoto neighbourhoods formed part of a public health plan developed by Obras Sanitarias de la Nación (OSN) in response to the great population growth of Buenos Aires at the beginning of the 20th century, and inaugurated in 1915 and 1917. Using a comparable architectural composition to the Palacio de Aguas Corrientes, but covered with *piedra Paris* (an artificial stone), the two reservoirs' interior iron structures were manufactured in Great Britain.

Brief history: The city suffered epidemics of cholera, typhoid and yellow fever. The Palacio de las Aguas Corrientes forms part of the supply system of the city, essential in a city with little variation in height, since it collected and distributed the water extracted from the Río de la Plata, previously purified in establishments near the riverbank, and pumped up with steam pumps. It was designed in 1872 by the engineer John Fredrick Bateman. When Bateman's plan was practically completed in 1905, the growth of the city made it obsolete, forcing the national water company to expand with the construction of a new purification plant and the large gravity deposits of Caballito and Villa Devoto, among other constructions and infrastructures. These complemented the work of the Palacio de Aguas Corrientes, especially in the centre of the city, where the tallest buildings were concentrated.

Cultural and symbolic dimension: The Palacio de las Aguas Corrientes today constitutes an exceptional testimony to the moment when advances in medical science and technology (steam power) allowed governments to fight against the scourge of epidemics, developing large-scale health infrastructure previously unknown in these latitudes. In its execution, the expansion of the production of industrialized countries had a fundamental role through the transfer of materials, technology, projects, professionals and self-assembled iron structures. The three water deposits are expressions of the degree of development achieved by the iron industry applied to the manufacture of large water reservoirs. In addition, the Palacio de Aguas Corrientes is, by itself, a unique work of its kind, both for its monumental iron interior structure and for the ornamental display achieved by the terracotta external coverings of its architectural envelope.

The two service reservoirs in Caballito and Villa Devoto districts denote the technical and professional development achieved by local sanitation agencies, with a high degree of accuracy and integrity, and favour the reading and understanding of their purpose within the system of storage and distribution of water.

Comparative analysis: There seem to be no examples constructed for the storage and distribution of water comparable to those presented here. The closest comparisons are with the Reservorio del Mocó in Manaus, Brazil, which is a much smaller cast-iron tank with a masonry exterior, inaugurated in 1899. The Tallah tank in Calcutta, India, is made of riveted mild steel sheets; built between 1907 and 1911 it is claimed to be the largest overhead storage tank in the world, for some 40,000 m^3 of drinking water.

Present site management

Protection regime: Monumento Histórico Nacional, Bien catalogado con Protección integral por el Gobierno de la Ciudad Autónoma de Buenos Aires.

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8.12. Old Wastewater Treatment Plant Prague-Bubeneč, Czech Republic

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The complex of sewage pumping station and treatment plant at Prague-Bubeneč. (Wikipedia Commons)

Presentation and analysis

Location: Papirenska 6, Prague 6-Bubeneč, 16000, Czech Republic

General description: The former mechanical gravity wastewater treatment plant illustrates the history of architecture, technology and water management, specifically the treatment of wastewater in connection with the drainage of an urban area in the early 20th century. Between 1906 and 1967 wastewater collected by a gravity sewage system under Prague passed through this site to remove dangerous materials before flowing out in to the Vltava river. It enabled the development of the city of Prague and its industry by overcoming the threat of waterborne diseases.

Brief inventory: The plant consists of underground and aboveground constructions built in 1906: the main operation building and a group of buildings related to water cleaning: an underground sewage network, a sludge pump chamber with entry building, underground settling tanks, sludge wells, remains of rails, a bridge of narrow-gauge railway, sand washing machinery. There are also technology process buildings from 1930: a chlorination plant and a new screens room. Wastewater treatment technology and machinery remain preserved inside all of these buildings, including boilers and two Breitfeld & Danek horizontal compound steam engines.

Brief history: The Prague sewer system project was designed by the international water and sewage systems engineer William Heerlein Lindley.

An essential part of this project was the mechanical treatment of wastewater. This meant establishing a wastewater collection and transfer system and constructing a suitably located wastewater-treatment facility on the outskirts of Prague that would be large enough to treat the quantity of wastewater from the city, before discharging it into the Vltava. Construction started in 1899 and the wastewater-treatment plant in Prague-Bubenec was built and put into operation in 1906. The plant ceased operation in 1967.

Though the old wastewater-treatment plant (OWTP) has been well maintained we can recognize modernization including electrification, mechanical electric driven type of screens and facilities for employees.

Cultural and symbolic dimension: The OWTP is an example of the early implementation of effective steps to ensure healthy, hygienic living conditions in a developing metropolis and a solution to the impact of drainage, pollution and eliminating waste from the urban environment. This allowed Prague to develop into a modern metropolis.

This is the only completely preserved facility by the influential civil engineer William Lindley (1808–1900). The preserved wastewater-treatment machinery and equipment are the only examples of their kind. The facility is an example of the precise craft of masons and carpenters, using special bricks for the construction of the plant and sewage system. Exceptionally high-quality construction materials were used, produced specifically for this project in areas affected by the water.

The steam engines and powered machinery, the only example of the most widespread version of the steam power in the Czech Republic, illustrate engineering design in the early 20th century, a historically valuable collection documenting the state of the art of mechanical piston and paddle machines and electric motors.

Comparative analysis: The site is the first modern wastewater-treatment plant in the Czech Republic and the only one of its kind in Europe which has been preserved in its original form (a worldwide comparative study is under preparation.) Comparison can be drawn with the sewage pumping stations in London and Berlin although each had a different approach to waste treatment.

Present site management

Present use: The OWTP is a preserved site developed as an educational and cultural centre with its administration and varied programme presenting the original use of the site and the history of Prague´s sewage system.

Protection regime: A national cultural monument of the Czech Republic (the highest valuation of the culture heritage in the Czech Republic). In 2016, the OWTP became an anchor point of the ERIH tourist-information network (European Route of Industrial Heritage) as the only representative of wastewater-treatment plants showing the history of water purification in Europe.

Context and environment: When the OWTP closed in 1967, mains sewers were redirected to the new mechanical–biological processes in the Central WTP built in the same locality (Prague-Bubenec). The city is currently completing a new sewage wastewater-treatment plant in the same locality; it will start service in 2018.

Management: Since 2010 the complex, which is the property of the city, has been leased and operated by the non-profit organization Tovarna o.p.s, sprava industrialnich nemovitosti, based on its concept and renewal plans (validated by the National Heritage Institute).

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8.13. Prague-Podolí water treatment plant, Czech Republic

Dr Šárka Jiroušková, with Pražské vodovody a kanalizace a.s. (Prague Water Supply and Sewerage, plc)

The magnificent neoclassical design of the Prague-Podolí treatment plant emphasizes the importance to the city of its water-supply system. (Wikipedia Commons)

Presentation and analysis

Location: Podolská 17, Praha 4-Podolí, 140 00, Czech Republic

General description: The Prague-Podolí plant filters raw water from the River Vltava to provide Prague with drinking water and is a monument to public architecture, engineering technology and water management. Operation of the plant started in 1929; it was extended in a matching style between 1954 and 1965. The whole complex has been in continuous operation, serving as a backup source of drinking water for Prague.

Brief inventory: The water-treatment plant consists of a filtration building, pumping station and office building, and a complex of facilities from the 1965 extension and modernization phase: a raw water abstraction facility on Veslařský Island and a monumental building for new equipment (raw and treated water pumping stations, an underground water reservoir, Binar-Bělský clarifiers, chemical treatment facilities and ancillary equipment). The buildings are linked through a 1965 pipe bridge supplying clarified water to the filtration facility.

The three-storey building accommodated rough screen filters, pre-filters, fine filters and a clean water tank. A total of 35,000 m^3 of drinking water was produced daily. From the structural point of view, an interesting feature is the filtration hall's 16 m parabolic arches spanning 29 m. The project also included a machine room and an office building. The original technological process was based on the Puech-Chabal multi-stage filtration system. During treatment, water was aerated, pre-filtered three times, and the treatment process completed in slow biological filters. The plant capacity was 400 l/second.

The current treatment process is complex due to the poor quality of the river water. It is based on multi-stage filtration with chemical treatment. The river water abstraction facility (located on Veslařský Island near the filtration facility) supplies water by a gravity-fed water system of twin reinforced concrete pipes into the basement of the raw water pumping station. The treated water is pumped out of the treatment plant to water storage facilities in the Prague water-supply network.

Brief history: The history of the facility is connected with the effort to find a high-quality drinking water source for Prague after the city's 1922 expansion to incorporate surrounding suburbs and villages; its population had more than tripled in the first quarter of the 20th century.

The new waterworks was built on the bank of the River Vltava to abstract raw water from the river and turn it into drinking water. The plant was built between 1924 and 1929 on the site of one of the original stations pumping water from the Vltava. The technology was designed in Paris by H. Chabal et Cie. The architectural design was by Antonín Engel, a prominent Czech architect.

The modernization of the operation and the need for more drinking water for the growing metropolis resulted in renovation and extension in 1954–65. The design was drawn up by the Prague water-supply company's design studio, but the same architect, Antonín Engel, drew a design unifying the technical buildings of the two different eras to form a harmonized unit. New representative symmetrical buildings housing operating halls were constructed around the courtyard and accommodated the new technology involving raw water pre-treatment in clarifiers with the addition of chemical reagents. Chemical treatment premises are located in the significantly higher southern wing, whose main front façade is decorated with eleven statues representing the River Vltava and its tributaries.

Between 1929 and 1972, the Vltava's treated water was the main source of drinking water for Prague. Since 1972, drinking water has been supplied from another source, the Želivka water treatment plant. The waterworks in Podolí has been a backup drinking water source since 2003.

Cultural and symbolic dimension: The water-treatment plant in Prague-Podolí is an illustrious example of the 20th-century development of natural river water treatment for supplying the growing metropolis with drinking water, and a magnificent architectural conception of the waterworks which is unique in the Czech Republic. The extraordinary architecture reflects the importance of the service to the city and is an exceptional example of a distinctive design of community infrastructure facilities. In 1929 the filtration building was the largest reinforced concrete construction in what was then Czechoslovakia, quite exceptional from the structural perspective.

Comparative analysis: The waterworks is among the major projects of Europe's modern industrial architecture. In purpose, significance and architecture, the only comparable project might be the R. C. Harris filtration plant in Canada. No detailed comparative analysis has yet been made.

Present site management

Present use: The site still serves its original purpose. A permanent exhibition, the Prague Waterworks Museum, is in a part of the 1929 filtration building. Sightseeing tours of the water treatment plant can also be arranged.

Protection regime: Cultural monument of the Czech Republic

State of conservation: The waterworks has retained its original appearance and, due to its continuous operation, has been maintained in an excellent condition.

Context and environment: Once built on the right bank of the River Vltava, in what then was a suburb of the city, the waterworks was gradually surrounded by residential housing as the city developed. Currently the waterworks is a symbol of industrial development incorporated in an urban area bordering on the centre of the city. Tourists often consider the waterworks to be the Houses of Parliament.

Management: The waterworks is owned by the city of Prague and operated by Prague Water Supply and Sewerage.

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8.14. R. C. Harris filtration plant, Canada

Professor Susan Ross, Carleton University, Ottawa, Canada

The Art Deco buildings and crafted landscapes are refined examples of when public works were treated as expressions of civic vision and invested with fine materials and monumental public and service spaces. (© Taylor Hazell Architects)

Presentation and analysis

Location: 2701 Queen Street East, Toronto, Ontario

General description: The R. C. Harris filtration plant is the main water-treatment plant for Toronto, Canada's largest city. It has been in continuous use since 1941, taking raw water from Lake Ontario through a gravity-based gravel-sand filtration process, followed by chemical treatment, to produce potable water that is then pumped through the city's wider system, with major additions in the 1950s designed compatibly with the 1930s structures.

It occupies an 8 hectare site directly overlooking Lake Ontario consisting of an architect/engineer planned landscape of above-ground pumping, treatment and administration structures, with subterranean tunnels, filtration and settlement basins. Built as a major extension to the existing plant, it both doubled the city's filtration capacity and allowed for full redundancy of the system's supply and distribution capacity in case of failure of any element.

Brief inventory: The process of water treatment includes intake of water from the lake, pre-chlorination and screening, then pumping up to the filtration level, where alum is added, and mixed in a series of chambers. After slow settlement in basins, the water passes through graduated gravel, sand and anthracite or carbon filtration to post-treatment chlorination and fluoridation.

The waterworks ensemble is built on the former Victoria Park and oriented to the lake. Visible structures from the lake up include the pump house (1935–7), followed by the service building with the alum tower at one end, and then a viewing terrace and fountain (1935). The principal structure, the filter and administration building, was built in two stages, a west wing (1935) and matching east wing (1956), with a central connecting rotunda and viewing galleries. Underground structures from the lake up include two concrete-lined steel intakes that extend out 1300 m into the lake; a 1000 m tunnel from seawall to pump house; and six settlement basins beyond the filter building below the large lawn.

Buildings are in yellow brick and Queenston limestone, with copper flashings and roofs, black-painted metalwork and considerable ornamental bronze work. Decorative relief carvings provide an iconography of water processes, such as the 'turbine frieze' of the pump house (Mannell, 1999). The interiors include marble finishes and a grand staircase from the lakeside up.

Brief history: Characterized as the 'Palace of Purification', the plant is named after the Commissioner of Works and City Engineer for the City of Toronto who began planning for it in 1913. Scottish architect Thomas C. Pomphrey, a member of the staff of the project engineers Gore, Nasmith & Storrie, designed the buildings. This integrated team also planned water-treatment plants in Ottawa, Hamilton, Niagara Falls and Calgary, but the Toronto plant was their major project. Engineers William Gore and William Storrie were renowned for their work in water supply and sewage treatment; bacteriologist George Nasmith had been decorated for designing mobile water purification units for the CEF and the British Army (Reeves, 2010). When the plant opened in 1941 it was one of the largest water filtration plants in North America, applying leading-edge technology. It was presented at the American Water Works Association and was the subject of significant attention in the trade press (Mannell, 1999).

Cultural and symbolic dimension: The relationship of the site to the surrounding community is unusual, both for its public use as a park, and the involvement of the community in its management. The vast scale, the engineering innovation, and the buildings' architectural design 'represented a new threshold in Toronto's history of public infrastructure and design'. The plant has been used in dozens of films and television series as a prison, clinic or headquarters. Its construction is a central part of Michael Ondaatje's 1987 novel *In the skin of the lion*.

Comparative analysis: During the early decades of the 20th century, engineering criteria combined with social priorities made water-treatment plants important public works projects, and this is reflected in their architecture. The R. C. Harris filtration plant, Calgary's Glenmore and Milwaukee's Linnwood water-treatment plant were all built as Depression-era 'make-work' programmes.

Outstanding elements of the R. C. Harris filtration plant include its remarkable ensemble of Art Deco structures set in a unique landscape setting on Lake Ontario, and its ongoing use to supply purified water by its original alum-based settlement and sand and gravel filtration system. The plant is a rare example of a building from the period still being used as intended, due to expansions and repairs which have been carefully managed to preserve and enhance overall character.

The theme of water treatment is central to 20th-century development of waterworks, and this is one of the most outstanding examples of integrated engineering, architectural and landscape design from this era.

Present site management

Present use: The plant remains the principal source of filtered pressurized water supply for the Toronto region. The plant grounds are open year-round, while the interiors are usually accessible during Doors Open Toronto.

Protection regime: In 1992 the Canadian Society for Civil Engineering declared the R. C. Harris water-treatment plant a Canadian National Historic Engineering Site within a unique landscape setting. In 1998 the property was designated by the City of Toronto under the Ontario Heritage Act (Part IV) to be of historical and architectural value and interest (City of Toronto, 1998).

State of conservation: The buildings, equipment and landscape are generally in an excellent state of conservation. Leading firms in architectural conservation working with the successor firm have planned conservation and rehabilitation works on structures above and below ground. A new residue management facility was completed in 2008. A project to rehabilitate the settlement basins while improving access and security is underway.

Context and environment: The plant is set in a public park landscape just beyond the Eastern city limit and the residential neighbourhoods called 'the Beaches' along the shore of Lake Ontario. The waterworks site comprises a series of longitudinal structures set in steps down a terraced slope to Lake Ontario

Management: The City of Toronto is responsible for management of the site. The master plan, conservation and new construction are subject to careful review by the City of Toronto and Public Advisory Committee (PAC) that includes local residents. PAC members meet periodically with City staff and consultants to advise the City about residents' perspectives on issues such as heritage conservation, security upgrades, future plant improvements and residue management.

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9. Conclusions

This study has attempted to lay out a historical framework for the infrastructure of the water industry so that the relative significance of its physical heritage might be established with some objectivity. To achieve this it has proposed the major historical theme of the developing urban Sanitary Crisis as a way of considering the contribution of the sector to 'outstanding universal value', the measure used by UNESCO for considering World Heritage sites.

Evidently the other criteria by which historic industrial sites and landscapes are habitually judged – technological primacy, aesthetic quality, virtuosity of construction, social and economic consequence, association with people and events, etc. – will also apply. But this large theme provides a historical context in which a global evaluation can be made.

There are apparently no comparative international studies for the structures, sites and landscapes examined here. This is a significant drawback for the worthwhile consideration of any class of historic resources, and makes it harder to suggest precise proposals for identifying the most significant examples. It is doubly so for the heritage of an industry in which the routes of international technology transfer form a significant part of its interest. Further research will no doubt produce greater certainty in identifying those places whose protection and conservation are most valuable.

For example, assessing the historical importance of dams is especially challenging: not only due to their enormous number, technical variety and multiple purposes, but because their impact may be viewed as beneficial or detrimental according to the standpoint from which they are considered: upstream or down.

In 1975, the United States Army Corps of Engineers identified more than 65,000 American dams over twenty-five feet tall (7.6 m) or with a reservoir storage capacity of at least fifty acre-feet (30,000 m^3). By virtue of the centrality of water to human settlement, population growth, and agricultural and industrial endeavour, each of these 65,000 dams had a significant impact on local development. Many impacted a larger geographic region. A few changed the course of American and international technological history, reverberated through the national economy, and marked significant transitions in American politics and culture. (Billington et al. 2005, 421)

Steam pumping stations are a valuable heritage resource whose attractive design, in terms of engineering, architecture and landscaping, is testimony to the importance that the water industry had for citizens. The extent of the international survival of this typology should be examined in greater detail.

Contrary to the situation of many old industrial sites, historic properties of water supply and treatment may continue in the same use for centuries, maintenance and upgrading changing the fabric but not necessarily their form or their purpose.

Finally, the linked or networked nature of infrastructure built by the water industry is a special attribute which should be taken into consideration when assessing the historic cultural value of a site.

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