The Water Industry as World Heritage

Thematic Study

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EXECUTUVE SUMMARY

The water industry developed from the mid-18th century in response to rising demand for water due to 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 water-borne 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 technical 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 constructed - and in many cases retro-fitted - first of all to the largest 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; distribution networks of aqueducts, pipelines, pumping stations and water towers; and filter and treatment centres where hazardous biological and chemical materials could be neutralised.

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

The present study, 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 national and regional heritage inventories. A number of case studies are included to aid the comparative analysis of historic water industry properties.

A historical summary identifies when and where the important advances in the water industry took place so as to help recognise both the outstanding as well as the most representative surviving sites - the unique but also the ubiquitous - and to locate potentially significant ones.

Overall, in our view the water infrastructure from the pre-industrial period is comparatively well represented in the UNESCO list, compared with that of the modern water industry, despite its unarguable importance to human development discussed above. A selection of outstanding networks or collections of integrated sites should be included 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 organised 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 advice from TICCIH.

Although the format varies, in general the comparative studies summarise 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 ten 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 objectives of this report are to

- summarise 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 watershed 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 represent these contributions.

1.3 Methodology

The process of preparing this report consisted of a desk-based research of the literature by the author during 2017, consultation with relevant experts chosen 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 held in Barcelona in 2018 to confirm a consensus for the conclusions.

The study does not introduce new research, serving only to draw together as much accessible published information as possible to facilitate the evaluation and comparison of different properties for inscription by UNESCO. Nor does it recommend any specific places, intending only to help characterise those features of this class of cultural heritage which ought to be taken into consideration in an assessment of Outstanding Universal Value. Places included in the discussion are used to illustrate the theme and their inclusion is not an indication of their significance or potential as World Heritage sites.

2. Introduction

2.1 Scope

The parameters defining this study relate to the methodology outlined in the 2015 report by Prof. Michel Cotte for ICOMOS, *Cultural Heritages of Water.* This ambitious and wide-ranging work hoped 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).

However, Cotte recognised the utility of a 'thematic category-based approach' similar to previous TICICH 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 focussed under the first general category in the typology he proposed:

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.).

Typologies: the site categories to be examined will therefore include

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

Evidently many of these sites are not exclusively for managing water for human consumption water supply, and may also serve for irrigation, as canals, in flood control, 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. Cultural landscapes (parks and gardens).

2.2 Chronology

The TICCIH water industry study examines the infrastructure built for the management of water during the industrial period, as TICCIH defines it in the 2003 Nizhny Tagil Charter. The components and scale of ancient urban supply and waste networks in China, Arabia and the Classical world are considered. The basic urban water networks of early modern Europe are examined as the precursors to the modern systems, but the main historical focus of the study is the development of the water industry through industrialization, and the fundamental role of its infrastructure in the growth of the modern city from the late 18th to the early 20th century.

2.3 Relevant comparative studies

This is the first attempt at a global comparative studies assessing the significance of sites and landscapes of the water industry. The few 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. Douet (1995) is an assessment of the heritage of the water and sewage industry of England, and Kugel (2013) examines other water systems comparable to that of Augsberg. The International Canal Monument List (Hughes 1996) assessed dams, earthworks, aqueducts, and pumps for navigation canals, but included examples built for water supply, notably in the Roman Empire. Billington (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.

Other comparative studies may be located during this study.

> '...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 sewer.' Hamlin 1992, 682

2.4. The water industry on the World Heritage list

At the time of writing this report no modern systems or networks for supplying drinking water or for removing and treating waste waters are inscribed on the World Heritage list, although some individual components are recognised by UNESCO (Willems & Shaik 2015).

The only property or landscape on the World Heritage 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 was as 'the world's first large-scale public water supply systems based on the steam-powered pumping of groundwater'. The criteria used to justify the inscription of this European metal mine are presented in full in the Case Study in Section 8.

Two sites directly associated with water supply were 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, was on that of Portugal.

The only properties involved in transporting water for human use are inscribed for their architectural and engineering importance. These are the three Roman aqueducts in Segovia, Tarragona and Pont du Gard, and the Padre Tembleque aqueduct in Mexico. Each is recognised for the technical skill of planning and construction to which they are testament. The 11th century Rani-ki-Vav Stepwell is a characteristic typology developed in India for accessing and storing ground water with a monumental architectural design.

The only dams which are inscribed are along canal navigations. Two are part of the Canal du Midi, built to hold feed water for the summit level. St Ferréol (1667-1671) 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 is on 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, Slovakia.

3. Terminology

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 do not carry storm water, which is removed in an independent pipe system.

Combined sewage system (CSS): Combined sewage systems remove both sewage and urban rain runoff.

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.
- a building containing pumps and the motor to drive them.

Collection and storage

Reservoirs: hold 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 reservoir: stores pumped water
  - storage reservoir: stores water prior to treatment
  - service reservoir: stores water prior to distribution, under or above ground.

Dams: **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 are made of compacted materials such as rock or earth and most have a core of impervious material.
  - gravity dams are 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 are curved upstream and direct the weight of the water against the foundations and abutments. Arch-gravity dams combine the properties of the two types.

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

spillway: a channel or bellmouth that carries water past the dam.

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

well, borehole: a bored, drilled, or driven shaft, or a dug hole whose purpose is to reach the aquifer and raise underground water supplies

water tower: raised water storage structure to hold water and pressurize mains.

standpipe: tall, narrow storage tower usually to pressurize mains or act as a buffer for pumped water.

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

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.

sewer: a system of underground pipes that collect and deliver wastewater to treatment facilities or rivers.

outfall: the place where a sewer or drain discharges.

well, fountain, springhead, conduit head: point of public water distribution, usually free, often decorative or monumental in design.

cistern: small tank (usually covered) to store drinking water; often rainwater.

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.

steam pumping engine: reciprocating prime mover linked to water pumps:

- beam engine (sometimes called house-built): steam engine with a vertical cylinder, operating pumps through a horizontal beam, usually supported on the walls of the engine house.
- 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.

Treatment

water treatment plant: a facility designed to carry out primary, secondary and/or tertiary treatment of water for delivery to users.

sedimentation tanks: wastewater tanks in which floating wastes are skimmed off and settled solids are removed for disposal.

filter house: building containing rapid filter tanks.

filter beds:

- **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

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.

4. Historical development of water infrastructure

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

4.1. Ancient and Classical public water supply systems

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

Many Roman towns were supplied by aqueducts with sophisticated raised sections which are symptomatic of the Roman's commitment to large-scale water supply, including 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 pressurised siphon (Smith 1976).

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

Various low-lift pumping mechanisms were operated using 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, for raising water to higher levels (Hassan 2011).

Inside urban areas, water was raised to storage cisterns and water towers, and 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 more developed water distribution systems than were achieved in modern cities until well into 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 60 to store up to 80,000 m^3 of water in the Byzantine capital.

4.2. Early-modern water provision 1500-1800

Centuries separate the sophisticated Roman and Byzantine networks from much simpler Medieval schemes to supply water. Water provision began to assume the character of an industrial sector in Europe from the 16th century. As urban populations grew, the traditional sources became stressed. Cesspits and privies polluted the water raised from nearby wells and the amount supplied was increasingly stretched. Settlements constructed water supply systems using aqueducts to bring more natural water from uncontaminated sources and pumps to raise river water to storage reservoirs. 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).

Distant gravity supply

Small-scale water supply schemes were built in Medieval Europe for monastic communities, such as the 12th century system to bring spring water to Canterbury cathedral (Barty-King 1992), and whose most visible surviving structures are conduit heads and cisterns.

The Ottoman Halkah urban supply network in Istanbul was built between 1453 and 1755. Sixteen independent supply lines connected dams and springs through aqueducts to some 435 fountains, public baths, and mosques. The Kirkçesme network supplied water free of charge to the lower part of the city from 1554 -63 and had settling basins, covered masonry conduits, filters, distribution centres and water towers (Dinçkal 2008).

Pius V's *renovatio Romae* (restoration of Rome) adapted and modernised 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).

The 48km Padre Tembleque Aqueduct in Mexico was completed in 1572, and had the effect of impelling the development of the Central Highland plateau of Mexico. The elevated section combined a European tradition of Roman hydraulics and traditional Mesoamerican construction techniques, and is part of an extensive hydraulic system.

The artificial New River in London opened in 1613 to carry clean water from springs 45 km to the north, and included sections of wooden aqueduct. From the fountains and conduit heads in which gravity supplies ended, human water carriers distributed water to consumers, while night-soil men collected excrement and disposed of it or sold it for manure.

Henri IV ordered the construction of a 13km aqueduct In Paris which was completed in 1623, the Aqueduc Médicis. It followed the line of a Roman supply, water mostly passing through an underground stone gallery accessed by small inspection houses, with sections of arched aqueduct. It is still in service.

As iron pipes became cheaper and more reliable during the 19th century, bridge aqueducts on the Roman model, with precisely calculated gradients, were no longer built. The last may have been the 18th century Águas Livres Aqueduct in Portugal.

Pumped systems

While there was little pressure to advance water supply technology in the pre-modern period, the sector benefited from water management techniques developed for mining, notably in central Europe. Pumping drinking water from rivers represented an important technological advance in the development of water supply which came out of the application of the piston pump to mine drainage. Cities like Banská Štiavnica in Slovakia were supplied with drinking water as a side benefit of the sophisticated drainage systems of the local silver mines.

By the early 15th century various German cities including Augsberg, Bremen and Danzig were using water wheels mounted under bridges to pump river water to raised storage tanks. 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 water wheels to raise water to different holding towers and distribute it to three monumental fountains. The system was well-known and influential (Kluger 2013). Cities in Bavaria including Augsburg, Munich and Nuremberg built both water and waste networks in the 15th century with water from the Alps using Renaissance techniques drawn 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 2016).

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 working a series of bucket pumps, and two more were built for the Chelsea Water Works on the north bank in 1726, forcing river water to a higher reservoir for distribution (Grudgings 2014).

A large water wheel pump was commissioned by Henri IV in Paris to raise water from the Seine to the Louvre palace, the Tuileries gardens and a small proportion to some 40 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 with 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 special, water-powered pumping was occasionally competitive with steam. The first waterworks abstracting from the pioneering Fairmount waterworks on the Schuylkill river in Philadelphia in 1814 used two beam engines with wood-fired boilers to pump to a high-level service reservoir. 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 Fair Mount 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).

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, and eventually hydroelectricity took over the city's water supply (Ross 2003).

Steam pumping

The key technological development for the evolution of modern water and waste systems was the invention of the steam engine, which made river pumping and later borehole abstraction of groundwater into important additional sources of water.

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' used for water supply was a Newcomen-type atmospheric engine 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 elm mains and lead pipes to both private homes and public fountains. Steam engines overlapped with water wheels, windmills and animal treadmills for moving pumping mechanisms, but from the 1780s onwards, the London companies relied exclusively on steam engines of the James Watt type for new capacity (Tomory, 2017).

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. 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 business was not a success and the company was bought out by the city in 1788. Paris in future preferred distant sources to river abstraction.

4.3. Industrialisation 1800 - 1880

From the early 19th century, cities in Europe and America faced a rising urban sanitary crisis caused by industrialisation and accelerating 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, notably for processes such as dyeing and bleaching textiles which demanded large quantities of soft water. Moreover, traditional industrial processes like tanning and brewing dumped waste 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.

Water supply: distant water sources

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 soft water for industry was as often the motive as clean and sufficient drinking water. With no way of treating dirty or polluted river water on a sufficiently large scale, engineers recommended transferring 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 municipalised in cities throughout the industrialising 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 (1863-1865) and Vanne (1866-1874) aqueducts and three more were built (the Avre (1890-1893), le 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, damming the Croton river and connecting 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 2003).

Glasgow's 1855 municipal scheme to bring water 55 km from Lock Katrine is exemplary. 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, pp?).

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 1km 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 continued to advance toward a more rational approach. The Zola dam supplied Aix-en-Provence from 1837 and is an early masonry arch dam. The Parramatta dam in Australia was completed in 1855 and used to supply drinking water. By mid-century dam builders could draw in a growing theoretical body of research from the work of J A T de Sazilly (1853) in France and William Rankine (1858) in Britain. Many British industrial cities built long-distance supplies from upland reservoirs formed by impressive masonry gravity dams. The reservoir formed by Vrynwy in Wales (1891) for Liverpool's water supply 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' (Stone 1975, 123).

Distance systems continued to be built into the 20th century, especially in the United States, despite the gradual improvement 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 served as a prototype for numerous environmental confrontations to proposals by urban centres to enlarge the water they obtain from distant projects (Ritvo 2007).

Steam pumping 1820 - 1880

The atmospheric Newcomen engine of the 1720s was superseded in the 1780s by the Boulton and Watt-type beam engine with a separate condenser, while a reliable high-pressure engine was developed after 1812 in the English tin-mining district of Cornwall, from which it took its name.

Beam engines on the Cornish pattern became the pumping work horse during much of the 19th century. Benjamin Latrobe Bateman used two rotary beam engines for the pioneer Centre Square scheme in Philadelphia which started in 1801 and continued in use until 1911. Three Cornish engines were erected in Lyon in 1853 (one survives) and abstracted water from the river Rhone. The raw water was filtered through a covered gallery, and pumped up to high service reservoirs (Frangin).

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 wood pipes continued to be laid in North America and elsewhere.

Filtering
Cleaning water for public consumption by filtering it through beds of sand began early in the 19th century. Municipal filters were built in Greenock, Scotland, in 1804. The technique was refined until the first public slow sand filters were constructed in 1829 by water engineer James Simpson for water abstracted from the Thames, a pattern which became known as the English system. Though only a couple of meters deep, slow sand filters were extensive undertakings usually constructed on urban margins such as Ivry in Paris.

Mechanical filtering was made obligatory in England in 1855 but spread only slowly in Europe and north America. Clear evidence that it was effective against disease was given from 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. They were built as buffers between the flow of water from steam-driven lift pumps and the mains supply network. Standpipes were located close to pumping stations such as in Hamburg (1842) Louisville (1860), Kew (1867) or 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 decorated in historicist, frequently Gothic, architectural idioms. Metal tanks such as that patented by Otto Intze (1843-1904) in Germany in 1883 were very widely built. Modernism and concrete construction replaced historicist designs after the First World War, with rationalist and expressionist towers sometimes designed by avant-garde architects.

Holding reservoirs
Buenas Aires, numerous other cities

Wastewater drainage systems
In towns benefiting from new sources of water, the increase in the volume being brought in, coupled with the spreading use of the water closet, exacerbated rather than eased the 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 could 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, 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 developed during the first half the 19th century increased pressure to remove wastewater from sodden and contaminated urban landscapes, particularly as the water closet replaced the 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). Both Edwin Chadwick and Baron Haussmann opposed water-borne waste removal because they wanted to reserve human faeces for their commercial value as fertiliser. 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 water-borne flushing through sewers; the choice of most adequate materials for pipelines and sewers (bored timber, cast-iron, brick, glazed pipe...); and the best drain profile (round, oval, pear-shaped). This situation made waterworks engineers the 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) 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 like 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 (1800-1890) for building integrated water and sewage systems took shape between 1843 and 1845 (Melosi 2008). It was important in his own country and 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, 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 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 innovative 48 km combined water and sewer system 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 system, including 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 those in Liverpool.

Rapidly growing Chicago was forced to abandon the polluted Chicago River as the outfall for its drains. The combined sewer system designed in 1855 by Ellis Chesbrough (1813-1886) was laid on the surface of the flat, low-lying city and existing buildings were literally jacked up over them, raising the level of the city by 1-1.5m. Mud from dredging the Chicago River filled the space under the raised buildings and between the brick sewer mains which led into the intercept sewer along the river bank. Drinking water was abstracted from Lake Michigan, but the intake had to be moved further offshore in 1866, tunnelling 6.2km deep under the lake to obtain water free from pollution (Cain 1972). The associated neo-gothic pumping station and standpipe tower are outstanding examples of steam waterworks architecture.

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 the river Thames outside the British Parliament known as the Great Stink in 1858, a comprehensive plan by the sanitation engineer Joseph Bazalgette (1819-91) was accepted. It intercepted combined run-off and sewage before it entered the river Thames and moved it downstream under gravity towards the sea, lifted periodically by steam pumping stations. The two intercept sewers were built into a new embankment parallel with the river incorporating an underground railway, and executed as befitted the then-imperial capital. The untreated wastewater was discharged onto the ebbing tide at two outfall steam pumping stations, Abbey Mills, on the north side, and Crossness on the south. Both were impressive examples of eclectic Victorian design as were the huge beam engines which operated the pumps.

The London model of intercept sewers, steam pumping, egg-shaped main sewers built of brick and Portland cement, and glazed pipes was followed by other cities including Amsterdam and Brussels. Under Baron Haussmann, Paris initially opted for separate storm water system and discouraged water borne 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 waste water into the river at just two points, Asnières and Saint-Denis.

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 civilised infrastructure' (Wolfgang Hofman, quoted in Brown 1988, 318). The comprehensive sewer system integrated into Berlin followed Chadwick's concept of using the waste to fertilize the surrounding farmland. It was designed in 1869 by the building engineer James Hobrecht (1825 - 1902) whose plan is still in use today. 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 city. The first one, Radialsystem III, went into operation in 1878 and all twelve were completed in 1909, supplying sewage to 16,000 hectares of farmland. Only rising levels of industrial pollution from 1931 ended the system, which was replaced with modern filter treatment.

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 (Hard & Misa 2008).

French, German and British engineers often transferred European technology and infrastructure to later industrialising countries. 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 and 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 the intercepting sewers. Most districts had combined sewage and storm water discharging continuously into the Plate (Chrimes ?).

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 construction of 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. 1880-1920

By the 1880s, the basic pattern and function of urban water supply and sewage removal had been determined. Urban mortality rates were falling and typhoid, a commonly used barometer of the state of public health, had almost vanished by the early 20th century (Brown 1988). Louis Pasteur (1822-1895) 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 urban disease was transmitted and finally provided sanitary engineers with a scientific understanding on which to plan sanitary systems.

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 America were constructed in 1907, the Pathfinder and Shoshone irrigation dams (Billington 2005).

Water treatment

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 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. Only railway stations can compete with it for stylistic variety and exuberance, an expressiveness often carried through the interior and on to the cherished steam engine. A generally Italianate design with semicircular arched windows became recognisable as the 'waterworks style' of architecture, a distinguished example being the Spotswood sewage pumping station in Melbourne.

Later in the 19th century a wider variety of steam pumping technologies started to compete with beam engines for both water and sewage. Ryhope (1869) and Papplewick (1881) in England employed double-acting compounded beam engines to raise water from rural boreholes. They were designed by the leading water engineer Thomas Hawksley (1807-1893). 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. Horizontal compound engines were installed at a number of sites, but from the end of the 19th century high-speed vertical compound engines, especially triple expansion engines, pre-dominated in the larger pumping stations. In 1997, Spotswood sewage pumping station in Melbourne, Australia, was equipped with four non-rotative 300hp 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 1000hp triple expansion engines erected in 1903 at the Cincinnati Water Works 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

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 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 and Swyngedouw 2000, 121).

By the 1920s most existing towns and cities had inserted water supply systems, which had become an essential feature of new urban infrastructure. With electrical pumping, the architectural expression of sanitation partly disappeared. When Jules Verne wrote 'Paris in the 20th 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 in service for decades more, new pumping stations were small non-descript buildings or were hidden underground.

Engineering design bravura became restricted to water towers and retention dams. Towers were of reinforced concrete and, especially in the United States, metal tanks. Many places continued to use them as expressions of identity with Modernist designs, such as Mechelen-Zuid (1978) in Belgium, claimed to be the world's tallest tower at 143m. 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 the Los Angeles metropolitan area from 1936 (Billington 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 technology of treatment at times combined with the local significance of water treatment, resulting in impressive architectural projects. The grandiose Podolské waterworks built in Prague in 1929 was constructed to filter water from the Vlatava river through aerated sand filters and chlorination plant with a capacity of 35-40,000m^3 per day. The scale, engineering innovation, and Art Deco architecture of the 1941 R.C. Harris Water Treatment Plant in Toronto represented a threshold in public infrastructure.

Particular historical circumstances sometimes contributed to a higher standard or engineering. The Glenmore Water Works System in Canada was built in 1930-33 and comprised a storage reservoir and dam, a pumping station, a purification plant and a pipe line system. With the onset of the Great Depression additional care was taken with the construction of the Water Treatment Plant to help provide work in the difficult economic circumstances.

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 water-borne 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 study and suggests the outstanding historical theme for the water industry, and the attributes which might justify the inscription of properties and landscapes on the WH list.

Authenticity and integrity

Authenticity means that 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 traditions, customs or beliefs, and techniques and management systems. Integrity means that the nominated property is sufficiently complete for its Outstanding Universal Value to be recognisable. In other words, its physical attributes must be such 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).

A great many of the sites or properties covered by this study are still used for their original purpose. Continual renewal, updating and maintenance are intrinsic to their character, an aspect already recognised in the Nara Declaration on Authenticity, as well as the World Heritage study on canals and the Operational Guidelines for the World Heritage 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 industrialisation.

From the late 18th century, the Industrial Revolution resulted in growing numbers of people moving to live in cities and to work in the industries which were increasingly located there. The close concentration of people and factories which universally characterises industrialisation soon overwhelmed traditional small-scale systems for supplying water and removing waste, based around wells, privies, drains and nearby streams or rivers, 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 revolutionary technical initiatives was introduced during the subsequent century 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 city networks of mostly underground infrastructure and the invention of mechanical, biological and chemical means of purifying water enabled life to continue without the filth and risk that had seemed to contemporaries to jeopardise their future. Applying the technical solutions developed in Paris, Philadelphia, London, New York, Berlin, or Prague, the experience of the inhabitants of the early industrial cities needed not to be repeated (though often were) by later industrialising regions as cities in the rest of the world followed the same route toward 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 much of the visible, as well as invisible, components of these networks were of high quality in their design, execution and social meaning. Allowing for maintenance and updating, they continue in numerous places to provide the vital service for which they were built.

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.

Priorities

In considering the heritage of the water industry, places and landscapes should be given particular consideration which 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.
>
> 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 composed landscape settings. Some display multiple technologies 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 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 water-borne 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 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 cultural value may be diminished. Pre-industrial distant supply infrastructure incorporated dams, reservoirs, wells, aqueducts and towers as well as urban fountains or conduit heads. During the 19th century these developed toward the network model, including both collecting and distributing clean water and removing and treating waste. This became customary in the 20th century water and drainage systems, contributing to the development of the 'network city'.
>
> Components of a historic water systems should therefore be considered as parts of a whole, or as 'serial properties' as defined by UNESCO (UNESCO 2015, 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.

7. UNESCO evaluation criteria relevant to the water industry

This aim of this report is to establish whether the most significant components 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 a single person. Benjamin Latrobe Bateman's pioneering scheme for Philadelphia reflects his combined architectural and engineering background, Bazalgette in London, Bertrand and Haussmann in Paris, and the Lindley family in central Europe are all closely linked with major urban reforms which transformed the life 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 industrialising nations in South America and Asia. Like Bateman, many American water engineers travelled to Europe and were instrumental in transferring the emerging technology back 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 is a fundamental aspect of urban history. Its origins extend back into 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 changed by the water infrastructure built to cope with rising populations. Rising 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. Size and technical precedence are relevant but not in themselves significant.

(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 cities and their need for water has been one of the critical interfaces between humanity and nature. 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 have altered natural environments. with both positive and negative consequences. The relationship between cities and the rural hinterlands from which they have sought water have 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 instance, the huge contribution of Louis Pasteur or Robert Koch to understanding the role of bacteria in water-borne disease, or of William Chadwick in conceptualizing the technical solution to the mid-19th century predicament.

8. Case studies: sites and landscapes

This section presents a variety of historic infrastructure, buildings, ensembles and landscapes created by the water industry in different regions, periods, technologies and degrees of completeness, prepared by authors 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 the other sites.

All the places presented here include significant elements; their inclusion does not imply any recommendation, and the same applies to places not discussed here.

Template

Case Study: Name

Presentation and analysis of the site
- *Location:*
- *General description:*
- *Brief inventory:*
- *History of the sites:*
- *Cultural and symbolic dimension of the site:*
- *Comparative analysis:*

Present site management
- *Present use:*
- *Protection:*
- *State of conservation:*
- *Context and environment:*
- *Management:*

Additional bibliography

Early-modern water provision 1500-1800

Case Study 1: Sete Fontes water supply system, Portugal

José Manuel Lopes Cordeiro

Presentation and analysis of the site

Location: Braga

General description:
The Sete Fontes water supply system, a unique example of Portuguese hydraulic architecture, was ordered to build in the 18th century by the Archbishop of Braga D. José de Bragança (1741-1756) and was the main source of water supply to the city of Braga until the start of operation of the catchment system of the river Cávado, in October 1913, based on a modern Water Pumping Station.

Brief inventory: The Sete Fontes water supply system, which is still in existence for the most part and in operation, is composed of 14 underground galleries (water mines), made of worked stone and having ventilation wells, and 6 junction tanks ("Chapels" or mothers of water), of baroque style, with a cylindrical structure, in dressed stone and vaulted dome, that are arranged in a distance of approximately 500 meters. At present the system of the Sete Fontes (Seven Fountains) has an extension of about 3,500 meters.

The different catchments direct the water to a main conduit, which is born in the first deposit (mother of water) - which bears the stone of arms of its patron, engraved in granite - and continues, capturing the water of the remaining mines and mothers of water, to the last mother of water. This, as well as part of the respective channel, were destroyed a few years ago by a construction company to give way to an urbanization, when the system was still without legal protection, which does not happen nowadays.

The water was conducted in granite pipes (with square section prisms, 1.20 m long, drilled through the longitudinal axis, with a 0.20 m diameter hole). Throughout the time, there were several "general boxes", that received the water driven by the Sete Fontes hydraulics system, having the most important – because it was in her that the water was distributed–, inaugurated on March 5, 1719.

History of the observatory: The period of construction of that system will have occurred essentially between 1744 and 1752, possibly over an already existing one, successively built over the preceding historical epochs, perhaps from the beginning of the Roman period. Its construction culminated a period of intense activity that had been registering since the first decades of the century XVIII to solve the problem of water supply to the city, following the population growth and urban development then recorded, as evidenced by several sources, among which numerous municipal documentation.

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

Comparative analysis: Due to the fact that it is a unique case, there is no possibility of making any kind of comparison.

Present site management

Present use: Disabled, but still in working condition.

Protection: Considered a "*set of exceptional value, whose characteristics must be fully preserved*," was classified as a National Monument by Decree No. 16/2011, published in the *Diário da República*, Lisbon, Series I, no. 101, dated May 25, 2011, and its Special Protection Zone was promulgated by Ordinance No. 576/2011, published in the *Diário da República*, Lisbon, Series II, No. 110, dated June 7, 2011.

State of conservation: With the exception of one mother of water, 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 in this area 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).

Steam-powered urban waste treatment systems

Case Study 1: Melbourne Sewage System, including Spotswood Pumping Station, Australia

Presentation and analysis of the site

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 10 lagoons used as oxidation ponds to treat the sewage, with remnants of the former grass filtration beds are 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 of the site or landscape: The construction of the main sewers was 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 of the site: 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 of 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 in the city.

The construction of the system was one of the most significant single infrastructure projects ever undertaken in the history of 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 sewerage 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.

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.

State of conservation: A significant portion of the system survives intact to demonstrate the original function and layout of the works, including the underground sewers, Spotswood Pumping Station, Main Outfall Sewer and the Werribee Sewage Farm. The pumping station and steam engines are in good condition, one engine is operated by compressed air.

Management: Melbourne Water Corporation; Scienceworks, Museum of Victoria

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).

Case studies under preparation

- Kew Bridge water supply. London, UK
- Augsburg water supply system, Germany
- Cornellà borehole pumping station, Spain
- Radial System waste pumping network, Berlin, Germany
- Thames intercept sewer and pumping stations, London, England
- R.C. Harris Water treatment plant, Toronto, Canada
- Staré čistírny Bubenči water treatment plant, Prague, Czech Republic
- Cropston water supply, New York, US
- Harris Water Treatment Plant, Toronto, Canada

Tarnowskie Góry Lead-Silver-Zinc Mine and its Underground Water Management System

Tarnowskie Góry was inscribed on the World Heritage List, in 2017. 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.

Brief synthesis

Tarnowskie Góry is located in the Silesian plateau of southern Poland, in one of Europe's classic metallogenic provinces. It is the largest and most significant historic underground lead-silver-zinc mine in Poland, and possesses a monumental drainage network that features a uniquely 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. Preserved with sustained access by a community association for over sixty years, 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. The challenge was exacerbated by a gentle undulating topography with only two small rivers, at just slightly lower elevations and with corresponding shallow river gradients, to serve as mine water receivers. 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 industrialisation. Whilst it was mining that engendered the development of the steam engine, 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 nominated 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.

9. Conclusions

10. Acknowledgments

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12. Bibliography

TICCIH Thematic studies:

Bergeron, L. (1995). Les villages ouvriers comme éléments du patrimoine de l’industrie
Delony, E. (1996). Context for World Heritage Bridges
Coulls, A. (1999). Railways as World Heritage Sites
Hughes, S (1996). The International Canal Monuments List
Hughes, S. (2001). The International Collieries Study
Ulrich, C & Gwyn, D. (2016). Stone Quarrying Landscapes as World Heritage Si**tes**

Angelakis, A., & Zheng, X. (2015). Evolution of Water Supply, Sanitation, Wastewater, and Stormwater Technologies Globally. *Water*, *7*(2), 455-463. doi:10.3390/w7020455

Baker, M. N., & Taras, M. J. (1981). *The quest for pure water: The history of water purification from the earliest records to the twentieth century*. Denver: American Water Works Association.

Barraqué, B. (2003). The three ages of engineering for the water industry. Retrieved from http://stanford.edu/dept/france-stanford/Conferences/Risk/Barraque.pdf

Barty-King, H. (1992). *Water: the book: An illustrated history of water supply and wastewater in the United Kingdom*. London: Quiller Press.

Barty-King, H. (1992). *Water: the book: an illustrated history of water supply and wastewater in the United Kingdom*.

Beaumont-Maillet, L. (1991). *L'eau à Paris*. Paris: Hazan.

Benidickson, J. (2014). *The Culture of Flushing: A Social and Legal History of Sewage*. Vancouver: UBC Press.

Bernhardt, C. (2004). *Environmental problems in European cities in the 19th and 20th century*. Munster: Waxmann.

Berthier, K., Housieaux, P., & Kruszyk, L. (2013). *L'aqueduc Médicis: Des sources de Rungis aux fontaines de Paris*. Paris: Somogy.

Billington, D. P., Jackson, D. C., & Melosi, M. V. (2005). *The history of large federal dams: Planning, design, and construction in the era of big dams*. Denver, CO: U.S. Dept. of the Interior, Bureau of Reclamation.

Binnie, G. M. (1981). *Early Victorian water engineers*. London: Telford.

Binnie, G. M. (1987). *Early dam builders in Britain*. London: Thomas Telford.

Blake, N. M. (1995). *Water for the cities: A history of the urban water supply problem in the United States*. Ann Arbor, Mi: University Microfilm international.

Bone, K., Pollara, G., & Appleton, A. F. (2006). *Water-works: The architecture and engineering of the New York City water supply*. New York: Monacelli Press.

Brock, W. H., & Hamlin, C. (1992). A Science of Impurity: Water Analysis in Nineteenth Century Britain. *Technology and Culture*, *33*(1), 164. doi:10.2307/3105826

Broich, J. (2013). *London: Water and the making of the modern city*. Pittsburgh, Pennsylvania: University of Pittsburgh Press.

Brown, J. C. (1988). Coping with Crisis? The Diffusion of Waterworks in Late Nineteenth-Century German Towns. *The Journal of Economic History*, *48*(02), 307-318. doi:10.1017/s0022050700004927

Brown, J., & Smith, D. (1999). *Studies in the history of civil engineering: Vol. 5*. Aldershot [u.a.: Ashgate.

Cain, L. P. (1972). Raising and Watering a City: Ellis Sylvester Chesbrough and Chicago's First Sanitation System. *Technology and Culture*, *13*(3), 353. doi:10.2307/3102489

Cech, T. V. (2016). *Principles of water resources: History, development, management, and policy*. Chichester: John Wiley.

Chrimes, M. (2009). A Forgotten Chapter in Dam History: Masonry Dams in British India in the Nineteenth Century. *Proceedings of the Third International Congre ss on*

Construction History. Retrieved from http://www.bma.arch.unige.it/pdf/CONSTRUCTION_HISTORY_2009/VOL1/Chrimes-Mike_layouted.pdf

Condit, C. W., & Cain, L. P. (1979). Sanitation Strategy for a Lakefront Metropolis: The Case of Chicago. *Technology and Culture*, *20*(4), 813. doi:10.2307/3103652

Cotte, M. (2015). *The cultural heritages of water*. Paris: ICOMOS.

Dinçkal, N. (2008). Reluctant Modernization: The Cultural Dynamics of Water Supply in Istanbul, 1885–1950. *Technology and Culture*, *49*(3), 675-700. doi:10.1353/tech.0.0079

Gandy, M. (1999). The Paris Sewers and the Rationalization of Urban Space. *Transactions of the Institute of British Geographers*, *24*(1), 23-44. doi:10.1111/j.0020-2754.1999.00023.x

Gandy, M. (2014). *The fabric of space: Water, modernity, and the urban imagination*. Cambridge, MA: The MIT Press.

Gierlinger, S., Haidvogl, G., Gingrich, S., & Krausmann, F. (2013). Feeding and cleaning the city: the role of the urban waterscape in provision and disposal in Vienna during the industrial transformation. *Water History*, *5*(2), 219-239. doi:10.1007/s12685-013-0075-1

Grudgings, S., & Tymków, P. (2014). Water-Raising Technologies of the Chelsea Water Works Company Prior to the Introduction of their First Boulton and Watt Steam Engine. *The International Journal for the History of Engineering & Technology*, *84*(1), 88-104. doi:10.1179/1758120613z.00000000038

Guillerme, A. (2013). *The age of water: [the urban environment in the north of France, A.D. 300 - 1800]*. College Station, TX: Texas A et M Univ. Press.

Hamlin, C. (1988). William Dibdin and the Idea of Biological Sewage Treatment. *Technology and Culture*, *29*(2), 189. doi:10.2307/3105523

Hamlin, C. (1992). Edwin Chadwick and the Engineers, 1842-1854: Systems and Antisystems in the Pipe-and-Brick Sewers War. *Technology and Culture*, *33*(4), 680. doi:10.2307/3106586

Hamlin, C. (2009). *Cholera: The biography*. Oxford [u.a.: Oxford Univ. Press.

Hassan, F. A. (2011). *Water, history for our times*. Paris, Paris: UNESCO.

Hassan, J. (1998). *A history of water in modern England and Wales*. Manchester [etc.: Manchester University Press.

Hassan, J. A. (1985). The Growth and Impact of the British Water Industry in the Nineteenth Century. *The Economic History Review*, *38*(4), 531. doi:10.2307/2597187

Hohensinner, S., Sonnlechner, C., Schmid, M., & Winiwarter, V. (2013). Two steps back, one step forward: reconstructing the dynamic Danube riverscape under human influence in Vienna. *Water History*, *5*(2), 121-143. doi:10.1007/s12685-013-0076-0

Hård, M., & Misa, T. J. (2010). *Urban machinery: Inside modern european cities*. Cambridge: MIT press.

Jackson, D. C. (1998). *Dams*. Brookfield, VT: Ashgate.

Kaika, M., & Swyngedouw, E. (2000). Fetishizing the modern city: the phantasmagoria of urban technological networks. *International Journal of Urban and Regional Research*, *24*(1), 120-138. doi:10.1111/1468-2427.00239

Kluger, M. (2013). *Historische Wasserwirtschaft und Wasserkunst in Augsburg: Kanallandschaft, Wassertürme, Brunnenkunst und Wasserkraft*. Augsburg: Context-Verl.

Konvitz, J. W., Rose, M. H., & Tarr, J. A. (1990). Technology and the City. *Technology and Culture*, *31*(2), 284. doi:10.2307/3105664

Marks, A. S. (2010). Palladianism on the Schuylkill: the work of Frederick Graff at Fairmount. *Proceedings of the American Philosophical Society*, *154*(2), 201-257.

Maver, I. (2000). *Glasgow*. Edinburgh: Edinburgh University Press.

McMahon, M. (1988). Makeshift Technology: Water and Politics in 19th-Century Philadelphia. *Environmental History Review*, *12*(4), 21-37. doi:10.2307/3984076

Melosi, M. V. (2008). *The sanitary city: Urban infrastructure in America from colonial times to the present*. Baltimore: Johns Hopkins University Press.

Melosi, M. V. (2012). *Precious Commodity: Providing Water for America's Cities*. Pittsburgh, PA: University of Pittsburgh Press.

Rinnie, K. (2011). *The waters of Rome: aqueducts, fountains, and the birth of the baroque city* . CO: Yale University Press.

Ritvo, H. (2007). Manchester v. Thirlmere and the Construction of the Victorian Environment. *Victorian Studies*, *49*(3), 457-482. doi:10.2979/vic.2007.49.3.457

Ross, S. (2013). Steam or water power? Thomas C. Keefer and the engineers discuss the Montreal Waterworks in 1852. *Industrial Archaeology*, *29*(1), 49-64.

Ruggles, C. L., & Cotte, M. (2011). *Heritage sites of astronomy and archaeoastronomy in the context of the UNESCO World Heritage Convention: A thematic study*. Paris, France: International Council of Monuments and Sites.

Schnitter, N. J. (1994). *A history of dams: The useful pyramids*. Rotterdam: Balkema.

Smith, C. S. (2014). *City water, city life: Water and the infrastructure of ideas in urbanizing Philadelphia, Boston, and Chicago*. Chicago: University of Chicago Press.

Smith, D. (1999). *Water-supply and public health engineering*. Aldershot: Variorum.

Smith, N. (1976). *Man and water: A history of hydro-technology*. London: P. Davies.

Smith, N. A. (1972). *A history of dams*. Secaucus, NJ: Citadel Press.

Soll, D. (2013). *Empire of water: An environmental and political history of the New York City water supply*. Ithaca: Cornell University Press.

Solomon, S. (2010). *Water: The epic struggle for wealth, power, and civilization*. New York: Harper.

Tarr, J. A., & Dupuy, G. (Eds.). (1988). *Technology and the rise of the networked city in Europe and America*. Philadelphia: Temple University Press.

Tarr, J. A. (1979). *The city and technology*. Beverly Hills, CA: Sage.

Tarr, J. A. (2011). *The Search for the Ultimate Sink*. The University of Akron Press.

Tomory, L. (2017). *The history of the London water industry, 1580-1820*.

Tvedt, T. (Ed.). (2011). *A history of water: Volume 3*. (A history of water.) London: I.B. Tauris.

Unesco. (2015). *Operational Guidelines for the Implementation of the World Heritage Convention*. Paris: Author.

Verne, J. (1997). *Paris in the twentieth century*. New York: Del Rey/Ballantine Books.

Willems, W. J., & Schaik, H. P. (2015). *Water & heritage: Material, conceptual and spiritual connections*. Leiden, Netherlands: Sidestone Press.

Winiwarter, V., Haidvogl, G., & Bürkner, M. (2016). The rise and fall of Munich's early modern water network: a tale of prowess and power. *Water History*, *8*(3), 277-299. doi:10.1007/s12685-016-0173-y

Wohl, A. S. (1983). *Endangered lives: Public health in Victorian Britain*. London: J.M. Dent.

Zheng, X. Y. (2016). Ancient Urban Water System Construction of China. *Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures*, 320-325. doi:10.1007/978-94-007-7747-7_10221