The International Canal Monuments List

Preface

This list has been prepared under the auspices of TICCIH (The International Committee for the Conservation of the Industrial Heritage) as one of a series of industry-by-industry lists for use by ICOMOS (the International Council on Monuments and Sites) in providing the World Heritage Committee with a list of "waterways" sites recommended as being of international significance. This is not a sum of proposals from each individual country, nor does it make any formal proposals for inscription on the World Heritage List. It merely attempts to assist the Committee by trying to arrive at a consensus of "expert" opinion on what significant sites, monuments, landscapes, and transport lines and corridors exist. This is part of the Global Strategy designed to identify monuments and sites in categories that are under-represented on the World Heritage List.

This list is mainly concerned with waterways whose primary aim was navigation and with the monuments that formed each line of waterway.

Introduction

Internationally significant waterways might be considered for World Heritage listing by conforming with one of four monument types:

1. Individually significant structures or monuments along the line of a canal or waterway;

2. Integrated industrial areas, either manufacturing or extractive, which contain canals as an essential part of the industrial landscape;

3. Heritage transportation canal corridors, where significant lengths of individual waterways and their infrastructure are considered of importance as a particular type of cultural landscape.

4. Historic canal lines (largely confined to the line of the waterway itself) where the surrounding cultural landscape is not necessarily largely, or wholly, a creation of canal transport.

Definition

The *Information Document on Heritage Canals* produced for presentation to the World Heritage Committee by the experts meeting under the auspices of Parks Canada Heritage in 1994 (hereafter referred to as the *1994 Heritage Canals Document*) defined canals as follows:

> **A canal is a human-engineered waterway. It may be of outstanding universal value from the point of view of history or technology, either intrinsically or as an exceptional example representative of this category of cultural property. It may be a monumental work, the defining feature of a linear cultural landscape, or an integral component of a complex cultural landscape.**

This sectional study by TICCIH will, however, concentrate on canals that were, primarily, or secondarily, used for navigation.

Areas and values of significance in the canal heritage

The 1994 Heritage Canal Document noted that the significance of canals can be examined under technological, economic, social, and landscape factors as follows:

A TECHNOLOGY

Canals can serve a variety of purposes: irrigation, navigation, water-power, flood mitigation, land-drainage, defence, and water-supply. The following are the areas of technology which may be of significance:

1 The line and waterproofing of the water channel;

2 The engineering structures of the line with reference to comparative structural features in other areas of architecture and technology;

3 The development of the sophistication of constructional methods;

4 The transfer of technologies.

B ECONOMY

Canals contribute to the economy in a variety of ways, eg in terms of economic development and the conveyance of goods and people. Canals were the first effective man-made carriers of heavy bulk cargoes. Canals are of continuing economic and recreational use. The following factors are important:

1 Nation building;

2 Agricultural development;

3 Industrial development;

4 Generation of wealth;

5 Development of engineering skills applied to other areas and industries.

C SOCIAL FACTORS

The building of canals had social consequences:

1 The redistribution of wealth, with social and cultural results;

2 The movement of people and the interaction of cultural groups.

D LANDSCAPES

Such large-scale engineering works had an impact on the natural landscape. There was also the generation of new industrial settlement patterns from rural dispersed populations to the creation of urban nucleii.

NOTE: There are potentially some additional areas of significance associated with classifications of historic towns and natural criteria.

Technology transfer or indigenous development

The idea of a structure having an international, or indeed universal, influence is obviously central to it being viewed as of relevance to the heritage of a large part of mankind. However, before the end of the 18th century such a process of diffusion of knowledge is difficult to document. A particularly difficult problem is to assess how far early Chinese technology influenced the foundation of European canal building in Italy and the Netherlands, or how far these are processes of indigenous development for each continent.

There is some evidence for the international nature of the Dutch contribution. Among the examples of Dutch influence are the New Holland area of St Petersburg (Russia) and the canals in Nymburk (Czech Republic). Both are examples of canals used for fortification. There is also a Preussische-Holland canal in Poland, close to Elbing, which was built in 1297. There are several "Dutch" villages in the area. Dutch colonial government in Asia also developed inland waterways in Sri Lanka and Indonesia. In the early 19th century, the Dutchman, Wollant, was the Director-General of Transport in Russia, building many of the early canals there.[1]

Thomas Steers, the British engineer, learnt about water technology when he was a soldier fighting for William of Orange in the Netherlands. He was particularly important to the early import of hydraulic-engineering techniques to Britain in the early years of the world's first Industrial Revolution. He was the builder of Liverpool's first dock, the Mersey and Irwell, the Douglas and possibly the Weaver Navigations, and the Newry Canal in Northern Ireland. The last-named was the first summit level canal in the United Kingdom and the first canal in Ireland or Britain to use ground (French pattern) paddles. Steers showed to a British and Irish public that it was possible and economic to build inland waterways.

From Italy Leonardo da Vinci spread the idea of ambitious waterways to France. The Duke of Bridgewater observed the heavy engineering of the Canal du Midi and was able to use its example to supply cheap coal to Manchester and so to help to foster the Industrial Revolution. This in turn drew "industrial spies" from the continent of Europe and from North America in a process which is well documented and published.

In Russia the British sea captain, Perry, was brought over by Peter the Great between 1700 and 1712 to survey and make rivers navigable.[2]

The transfer of this new technology to the United States of America was particularly important to the success and speed of the early economic growth of what has become the world's most powerful and influential nation. The notion of cheap and replaceable structures in the rush to attain economic development is epitomized by the timber locks and aqueducts of the early American canals. The details of this particular intercontinental technology transfer are given in detail here both because of their importance and as an example of a known part of this process.

Work actually started on the first sizable (ie more than a navigable short-cut around rapids) American canal during the years of the British "canal mania" in the 1790s. In 1786 the South Carolina legislature enacted a law to connect the Santee and Cooper rivers above Charleston and work was entrusted to Colonel John Christian Senf. Senf was a Swede serving with the British forces when he was captured at Saratoga. He then served as an engineer with the South Carolina militia and became Chief Engineer for the State of South Carolina. He directed and did much of the detailed supervisory work on the project. It was 35km long and 10.7m wide with a 1.2m depth of water carrying boats of 22.4 tonnes burden, ie standard British narrow-boat size.[3]

In 1792, Pennsylvanians had written to a contact in Britain, asking him to find a civil-engineer who could take charge of canal- and road-building. He approached the leading civil-engineer in Britain, William Jessop, who recommended William Weston.[4] Weston had been employed on the Oxford Canal and had also built a large three-span turnpike bridge over the wide river Trent at Gainsborough in *c* 1786. He was probably a son or a nephew of Samuel Weston, an engineer who had worked on the Chester and Oxford Canals in Britain and who had surveyed for the Kennet and Avon and proposed Hampton Gay Canal. William arrived in Philadelphia with his bride, in January 1793 and immediately went to work designing locks for the Schuylkill & Susquehanna Canal. He brought with him a sophisticated optical surveying level: the Troughton "Wye Level" which had been unknown in the USA, but was soon in use on almost every canal project there.

In the same way Weston was the catalyst in starting a new generation of American engineers in developing their canal surveying and engineering skills. Loami Baldwin sought him out as the only experienced canal engineer in New England and persuaded him to spend a few weeks at Boston, running surveys for the second sizeable American canal, the 44.28km Middlesex Canal from Boston to Lowell (1794-1803). It had 20 locks, seven aqueducts, and 50 bridges; it became a field-study project for many of the engineers on the Erie Canal and facilitated the development of the great textile centre at Lowell. Loami Baldwin II followed his father's profession and became Chief Engineer of the Union Canal, connecting Middletown and Reading, Pennsylvania. Construction of the Schuylkill and Susquehanna Navigation ground to a halt and among other tasks he was called to assist in solving some of the problems besetting the builders of the Potomack Canal at Great Falls by the Company President, George Washington; Washington himself was involved in several canal schemes.

In 1792 two river navigation companies were incorporated in New York State, encouraged by Elkanah Watson and General Philip Schuyler of Albany. Watson had seen Dutch canals at first hand. The northern scheme did not then get past the surveys prepared for it by the young French engineer Marc Isambard Brunel. In 1794-95 Weston was employed on the western scheme to undertake surveys for various improvements on the Mohawk River in the Fort Stanwix area. He employed the young Benjamin Wright to assist him. In 1797-99 Weston then seems to have taken charge of the actual engineering works for two years, with Benjamin Wright again serving under him. On the Mohawk River two bypass canals and sets of locks were built, and a third to link the Mohawk to Wood Creek. By 1798 16-ton Durham boats could use the Mohawk River but could not reach either Lake Ontario or Albany: that had to await the resources available for building the later Erie Canal. After this and other varied work Weston returned to England in about 1800.[85]

In 1811 Weston was asked to review plans (by mail) for the Erie Canal, and in 1813 was offered the job of Chief Engineer of the Erie Canal at a high salary. The USA had been at war with Great Britain in 1812 and Weston refused. His former assistant, Benjamin Wright, was chosen instead. Work on canals in the USA had virtually ceased in the first fifteen years of the 19th century. Wright was joined by James Geddes on the Champlain Canal connection and the young Canvass White, who turned out to be the real engineering genius of the Erie Canal. In 1817 Canvass White was sent to Europe to inspect canal construction there and to obtain some up-to-date surveying equipment. White walked 3220km along the canals of Great Britain, studying all the features. He returned the following year with copious notes and drawings and new surveying instruments. On his return he quickly found a native deposit of hydraulic limestone. In 1825 the completion of the Erie Canal revolutionized transport between the eastern and western states of the union. Its success induced the 'canal fever' of the 1820s during which in Pennsylvania alone some 2254km of canal were in progress or planning by 1830.

The engineers trained on the Erie Canal or in New York were in demand everywhere and developed much of this new infrastructure: Nathan S Roberts (Pennsylvania Main Line), William Milnor Roberts (Lehigh Canal, Union Canal, Allegheny Portage Railroad, Monongahela Navigation), Canvass White (Union Canal, Delaware and Hudson Canal, Lehigh Canal), Samuel Honeyman Kneass (Susquehanna Division, Delaware Division, Delaware and Schuylkill Canal, and Wiconisco Canal), Horatio Allen (Delaware and Hudson Canal), John Bloomfield Jervis (Delaware and Hudson Canal), and Charles Ellet (Schuylkill Navigation).

Benjamin Wright, the "Father of American Civil Engineering" (1968 declaration: the American Society of Civil Engineers) and Chief Engineer of the Erie Canal, went on to be highly influential in canal and later railroad construction in the USA. He was a consultant on the Connecticut River Navigation (from Tidewater to Northampton, Massachusetts), a consultant on the Delaware and Hudson Canal, a consultant, and later Chief Engineer, on the James River and Kanawha Canal, a consultant on the Blackwater Canal in Rhode Island and Massachusetts, Chief Engineer on the Chesapeake and Ohio Canal, Chief Engineer on the Delaware & Hudson Canal, Chief Engineer on the St Lawrence Ship Canal, Chief Engineer on the Welland Canal, and a consultant on the Illinois-Michigan Canal.

The associated Champlain Canal was opened in 1823. The American engineer James Geddes had been assisted by Marc Isambard Brunel, who had carried out the original survey work between the Hudson River and Lake Champlain. This documentation seems to clearly show how European canal technology was directly transplanted to the United States of America.

Three other particularly well documented examples of international and intercontinental technology transfer are presented by the spread of boat lifts and large ship canals (see relevant sections).

The evaluation system used for this study

The first time a new technology is applied to civil engineering or architecture is of particular significance to the history of mankind, depending on how wide and useful that particular innovation is. Transport canals have historically been very important as the first economic means of transporting heavy and bulky goods, allowing the evolution of developed societies with a high degree of economic and commercial interchange. The application of existing, or new, technologies to the evolution in sophistication of the waterways infrastructure is particularly significant in that process. Equally important is the process of technology transfer between countries and continents, particularly in ways that this has significantly progressed the economic well-being of mankind and facilitated the development of sophisticated societies. Such arguments can be applied equally to individual canal structures, to whole waterways, to waterways with associated corridors of economic development, or to integrated industrial areas such as mining fields that are covered by successive integrated transport systems.

However, the present conditions of sites, structures, and waterways are obvious weighting factors in assessing the significance of such types of structures. It may well be that the present condition of the most significant sites as built do not warrant their designation as sites of world importance where sites elsewhere represent an important stage in the evolution of world canals to a greater extent.

Like many other types of industrial archaeological feature, canals and waterways are important because of their functional use. However, this functional use itself will mean that parts of a mechanism or infrastructure have to be maintained, modified, or renewed in order to maintain the primary function of the structure or route. That this concept of renewal will not result in an automatic rejection of a site as being of world importance has already been accepted by ICOMOS at its November 1994 meeting on authenticity in Nara (Japan). It was also recognized in the 1994 Canal Heritage Document that an element of the heritage of a canal is its evolution over the course of time.

Grading

This is being done by the number of asterisks (*) noted under each site entered under the following numbered categories. Each site is awarded one * for a suggested site of some international importance; two ** for a site suggested to be of great international importance; and three *** for a site suggested to be of outstanding international importance in relation to the following criteria (slightly adapted from criteria i-iv in para 24 of the *Operational Guidelines for the Implementation of the World Heritage Convention*, WHC/2/Revised January 1996: UNESCO):

1 To be a masterpiece of human creative genius;

2 To have exerted great influence on developments of technological importance;

3 To be an outstanding example of structure or feature which illustrates a significant stages in human history;

4 Directly associated with economic or social developments of outstanding universal significance.

For the purposes of this study **authenticity** is not accepted as being of outstanding significance in a type of functional structure or feature whose prime purpose was to meet an economic purpose facilitated by constant maintenance and partial renewal. The International Experts Meeting held in Canada in September 1994 concluded that the technological changes the canal has undergone may in themselves constitute an element in the heritage of the waterway.

The level of existing legal protection and management mechanisms is not considered of great importance in this advisory study since States Parties can introduce such mechanisms prior to any formal intended application for World Heritage status.

Units of measurement

In the final list most measurements will be in metric units, with some significant imperial measurements and distances given in parentheses.

1 foot (1ft) = 0.305 metres	1 mile = 1.61 kilometres
1 metre (1m) = 3.28 feet	1 kilometre (1km) = 0.62 miles.

General introduction to waterways history

The civil engineering need to construct an artificial navigable channel grew in sophistication in known stages throughout the history of civilization. The requirements for an inland navigation were rather different from those needed for channels accommodating sea-going craft and the former will be considered first. Simple river navigations would attempt to 'improve' the natural channel of rivers. The first recorded instance of this being done was in Egypt in *c* 2300-2180 BC. The Pharaoh Pepi I was sending expeditions up the Nile beyond the First Cataract near Aswan and therefore (as recorded by Uni, then governor of Upper Egypt on an inscription) "His Majesty sent me to dig five canals in the South and to make three cargo boats and four tow-boats of acacia wood. Then the dark-skinned chieftains … drew timber for them, and I did the whole in a single year."[6]

Gradually the artificial channels built bypassing bends and natural obstacles on inland rivers became longer, until they formed completely separate parallel courses or "lateral canals." The traversing of gradients involved the development of locks, inclined planes, and lifts to facilitate changes in level.

The first known canal to cross a marked watershed between river basins was the Ling Chu or "Magic Transport Canal," constructed in China in 219 BC (see "Contour canals"). The first river-to-sea canal is earlier: it is reputed to have been built by the Pharaoh Sesosteris I some 4000 years ago in Egypt.[7]

Canals needed to be able to rise out of one river valley and into the next (the Ling Chu left one river on the level and did not rise to a "summit level") in order to create networks able to facilitate the bulk carriage of cargoes across considerable distances. The Grand Canal in China was the first to do this. The secondary development of these waterways in Europe was particularly significant to the origin of the Industrial Revolution.

Deriving from Italy in the 15th and 16th centuries, sophisticated modern canal engineering was evolved in France in the 16th century, culminating in the Canal du Midi, arguably the world's greatest civil-engineering project since the constructions of the Roman period. This in turn inspired the Duke of Bridgewater to construct the first heavily engineered canal of the Industrial Revolution in Great Britain.

The explosion in waterway construction that followed in Britain resulted in the construction of some 1331 km of navigation that gave England the first integrated national system for the bulk transport of goods and materials in a modern industrialized economy. A second frenetic outburst of activity in Britain in 1789-98 (stimulated by the Industrial Revolution) produced a further 1931km of artificial waterway and was termed the "Canal Mania." The scale of civil engineering applied to canal construction grew ever more intense. Britain had built some 58km of canal tunnel - far more than existed in the rest of the world at that time. Large iron and masonry aqueducts also form part of the heritage of that first blooming of heroic-scale structures, including the great Pontcysyllte Aqueduct, at a height of 38.4m above the river Dee, still the loftiest navigable canal aqueduct ever built.[8]

In the mid-19th century the leadership in canal engineering passed to North America. There was some intercontinental technology transfer, one notable example being built by British military engineers in

Canada, the Rideau Canal. As well as adapting to canal construction in an almost virgin wilderness, this was one of the first canals built for the new technology of the steam-powered boat, which could carry passengers and goods with greater speed, regularity, and comfort than any sailing or towed vessel and which could enormously increase barge tonnages. Another example of such technology transfer was the Erie Canal in the USA, which arguably contributed substantially to the economic growth of what was then an undeveloped country and its transformation into the most powerful country in the world.

Later, towards the end of the 19th century, great strides in developing the sophistication of canal engineering on a larger scale were made successively in France and then in Germany. The evolution of waterways linking oceans and carrying sea-going craft is rather different and is dealt with separately in the "Ship canals" section.

Individual structures

A *Locks*

Fundamental to the ability of any navigation to rise or fall was the use of lock-gates to hold one stretch of water at a higher level than an adjoining section.

Single (or "flash") lock-gates were in use by the 1st century BC (Chien-Lu Dam and canals near Nanyang) but may have been used earlier (in the valley of the Euphrates, or the port of Sidon) for irrigation and sluicing purposes.

In Europe, the lock was developed initially to overcome two specific problems: a desire to allow boats to enter a drainage and navigable water system which was protected by dykes, and the need to increase the depth of water available for the navigation of rivers. For the former use they were originally of the single lifting gate portcullis type, while staunches or weirs with removable wooden boards sufficed for the latter, boats sailing up or down the river on the "flash" of water released when the boards were removed. The earliest single-gate locks were built in the Low Countries at Nieuwpoort and in Italy on the river Mincio at Governolo in the late 12th century, though there had probably been river staunches in Flanders earlier in the century.[9] At the end of the 14th century the opening of the Stecknitz Canal in Germany (1398) was the first summit canal in Europe, a progression made possible by the use of single locks.

The main problem with "flash" locks and single gates was that they used large volumes of water unless the levels on either side of the gate was equal. Two lock-gates placed close together made a huge saving in water and time in lock-use. This, the "pound" or "chamber" lock, originated in China by the 10th century AD and may have been in use in the Netherlands by the 14th century. A basin between the gates was capable of holding one or more boats. The chamber lock radically reduced water usage. The first recorded example (1373) in Europe was at Vreeswijk (Netherlands), where the canal from Utrecht entered the river Lek.[10] The use of the lock in more upland canal schemes was pioneered in 15th-century Italy with the building of a lock in Milan in 1420.

For very large steep sites the lower gate of one lock might form the upper gate of another. A Chinese text of 1072 mentions a staircase pair of locks.[11] In Europe they were first used in France, when the Canal du Briare (France) opened in 1642, 39 years after the first plans had been drawn up (*A History of Technology*, **3**, 460-3). In staircase locks, the upper gate of the lowest lock also forms the lower gate of the second lock, and so on up the flight. This method of construction reduced costs but caused hold-ups when boats working in opposite directions needed to use the locks. More importantly, from a canal engineering viewpoint, they were inefficient users of water, and canals on which they were built often had water-supply problems.

The two greatest of these early lock staircases are the eight lock rises at Fonserannes (Béziers) on the Canal du Midi (France) and at Banavie (Neptune's Staircase) on the Caledonian Canal (Scotland, UK). The Rideau Canal in Canada also made considerable use of staircase locks, with a great eight-lock rise at Ottawa. Technology transfer from the Caledonian Canal led to the seven-lock flight at Berg on the

Göta Canal (Sweden), where Thomas Telford was consultant, using his Caledonian Canal drawings as the basis for the Göta's Locks.[12] In his turn Telford had learnt from the engineering of the Canal du Midi, for in his library at the Institution of Civil Engineers in London are copies of the two older books (1778 and 1804) on the Canal du Midi with annotations in Telford's hand on them.[13]

A major improvement in the design of locks was the mitre gate. Because of the stresses involved, a single wooden gate restricted the width of lock which could be constructed. The mitre gate, where two gates meet at an angle on the centre line of the lock, increases the width of lock it is possible to build. The mitre gate was probably introduced in Italy by Bertola da Novate, though the earliest drawings are by Leonardo da Vinci and date from the late 15th century.

The early locks built in China and Italy were of stone, but elsewhere turf-sided locks were often used, where the section of lock between the gates consisted of sloping turf-covered sides. Vertical wooden guides were used to stop boats from sticking to these sloping sides. Such locks used larger amounts of water than conventional stone locks owing to leakage. They can still be found on the River Kennet Navigation in England and on the Grossefehn-Kanal near Emden (Germany). Wood was also used for the construction of locks, and a wooden lock survives from the old Maryinsk Canal (1810) in Vitegra (Russia).

A feature developed on French canals in the 17th century was the ground paddle, or sluice built into the stonework of the lock, which controlled the flow of water from the upper to the lower level. Previously locks had been emptied and filled by sluices in the gate. This restricted the depth of to which a lock could be built, as the water flowing through the gate paddle into a deep lock would flood the boat using the lock. By placing the sluices and their channels into the structure of the lock, water could be fed into the bottom of the lock without the possibility of flooding boats.

When the Canal du Midi was built, the side walls of the locks were built curved, making the centre of the lock wider than the gates. It was thought that this would counteract the forces tending to push out the side walls of the locks when the lock was empty. This disregarded the fact that when the lock was full the water provided a similar, but reversed, force, and consequently locks are better built with straight sides. However, several canals were built with curved lock sides, including the Canal de Castille in Spain (1790s) and the original Saimaa Canal in Finland (1845-56).

Water supply was the canal engineer's main problem, and there are hints in the documentation that the Grand Canal in China used side ponds to save water. Side ponds were built such that their level was half-way between the upper and lower levels of the lock. When emptying, the first half of the locking water could then be fed into the side pond, and this water could be used subsequently for filling the first half of the lock. Many European 18th- and 19th-century locks, such as the flight at Devizes on the Kennet and Avon Canal, were built with side ponds between locks.

In central and eastern Europe, double-width locks were sometimes constructed which allowed two boats to lock through together. Single-width gates were provided and these were offset, to the right at one end of the lock and to the left at the other. The first boat entered the lock and then moved over to allow a second boat to enter. The first use of such locks may have been on the Finow-Kanal (Germany) when it was rebuilt in the 1830s. They can also be found on other canals in Germany and on the Labe and Vltava in the Czech Republic.

Towards the end of the 19th century there was a growth of interest in canal engineering in Europe as more canals were planned and built. To reduce costs and to decrease the time taken to pass through them, locks were designed and built deeper than previously. This would have caused excessive stresses with mitre gates, so the shaft lock was successfully developed. In these, the lower end of the lock was enclosed by a wall, boats entering and leaving through a hole in the lower part of the wall. Both mitre gates and vertical lifting gates were used to seal this. Shaft locks, because of their depth, used large quantities of water. To reduce this usage chambers were built into the side walls of the locks which acted as side ponds. Up to five or six chambers could be used, one above the other on each side of the lock.

The earliest known (but unsuccessful) shaft lock was built on the line of the uncompleted trans-Sweden canal at Trollhättan in 1754. This was on the Karls Grav and had a fall of no less than 16m. Unfortunately the shaft-lock proved unusable in flood-time owing to insufficient height in the entrance tunnel, and in 1768 it was replaced by a staircase pair of locks.[14]

Improvements in lock design have continued throughout this century, with different types of gate design appearing. These have included gates which lift and rotate, increasing headroom under the raised gate, gates which slide to one side, gates which lower either sliding vertically or are hinged at the bottom, and sector and segment gates which are curved and thus distribute stresses more evenly. Gates are also now used for emptying and filling locks, doing away with the necessity for sluices and paddle gear.

S I T E S

a *Single-gate locks*

An important non-canal site in the evolution of the single-gate lock is the port of Sidon (2nd century BC or earlier); there are still extant Phoenician harbour works there, where rock-cut grooves (one still remaining) indicate the former existence of four sluice-gates, probably for flushing the harbour. These could well go back to the 8th-12th centuries BC.[15]

i **Nile to Red Sea Canal Lock (Egypt)**, rebuilding by Pharaoh Ptolemy II (Philadelphus), *c* 285 BC.
Grading: 1. ***; 2. ***; 4. ***. Total: 9

Diodorus Siculus wrote of this 97km canal that the Pharaoh: "… in the most suitable spot constructed an ingenious kind of lock. This he opened, whenever he wished to pass through, and quickly closed again, a contrivance which usage proved to be highly successful."[6]

ii **Magic Canal (China)** (see "Contour canals").
Grading: 1. **; 2. ***; 4. *. Total: 6

iii **Duckerschleuse, Stecknitz Canal (Germany)** Single-gate flash-type lock.
Grading; 1. *; 2. **; 3. **; 4. *. Total: 6

Eight kilometres north of Lauenburg, a town with a long tradition of inland water transport, on the Elbe, 30km east of Hamburg (Germany), the lock is close to the village of Witeeze. Alongside the lock is the lock-keeper's house. As boats only used the lock infrequently, the lock-keeper was also a farmer. The house is now used as a cafe and guest-house. The lock is currently under restoration. To gain access to the site, it is necessary to cross the Elbe-Trave Canal, which replaced the Stecknitz Canal in 1900, at Witeeze Lock. This, and the other locks on the canal, was built to the Hotropp design. Water is used to operate the gates by counterbalances and the sluices are activated by air, and also compressed by water flowing from the upper level to the lower.

Other associated sites include the Palm-Schleuse in Lauenburg, a circular chamber lock capable of accepting several of the small Stecknitz canal barges at one time. This lock was built in 1724 on the site of an earlier single-gate lock. It is named after Herr Palm, who was the local miller (the mill is next to the lock) and lock-keeper (see "Summit-level canals" for other details of this waterway).

b *Double-gate locks*

i **Grand Canal (China)**, 984 AD. Grading: 1. ***; 2. ***; 4. ***. Total: 9

The first recorded double-gate or pound lock in the world was built at the northern end of the Shan-yang Yun-Tao section between the Yangtze and Huai-yin in AD 984 by Chhiao Wei-Yo, Assistant Commissioner of Transport for Huainan.[17]

ii **The Conca di Viarenna, Via Arena, Milan (Italy)**, *c* 1400.
Grading: 1. ***; 2. ***; 4.*. Total: 7

In 1179-1209 a water-supply and irrigation canal was built over the 50 km from an intake on the river Ticino (running from Lake Maggiore) to the Po, southwards to Abbiategrasso and east to the south side of Milan. In 1269 this was enlarged and made navigable as the Naviglio Grande. In 1386 work began on the new cathedral that was being built with marble from quarries near Lake Maggiore. Boats were raised the 2m to the level of the city moat by stopping the flow of the Naviglio Grande at the most convenient times and raising its level to that of the moat with stop planks. The boats passed into the moat and on to a short canal to the cathedral site. When the boats had passed, stop planks were used to cut off the moat and reopen the Naviglio Grande. The procedure was reversed to allow boats to return. A staunch (single-lock gate) was then provided at the entrance to the linking canal at Viarenna, and later a second at the junction between the moat and the Naviglio Grande, to replace the stop planks. The engineers Filippo da Modena and Fioravante da Bologna created Italy's first pound lock (one of the first in Europe) by bringing the two lock gates nearer together to reduce water consumption. A second pound lock was built on the enlarged old moat by 1445 (now renamed the Naviglio Interno). The various sections of the Naviglio Interno have now either been culverted or filled in.

c *Lock staircases*

i **Rogny Staircase, Canal de Briare (France)**, 1605-10. **[Figure 1]**
Grading: 1. **; 2. **; 3. **; 4. **. Total: 8

The first staircase flight of locks in Europe is situated 130km south of Paris, 15km NE of Briare. From the point of view of technological innovation, this is a more important flight of locks than those on the Canal du Midi (see below). The canal was supplied with water from two lakes which fed its summit level. The flight of seven "staircase" locks at Rogny was at the northern end of this; they have straight sides and are fitted with ground paddles. When the latter were

Figure 1 The large early 17th century lock staircase at Rogny, Canal de Briare (France) introduced to the United Kingdom (on the Newry Canal in Northern Ireland) the locks were described as "after the French pattern." These original locks were bypassed at the end of the 19th century and they remain as substantial structures.

ii **Fonserannes (Béziers) Staircase, Canal du Midi (France)**, 1665-81.

Grading: 1. **; 2. **; 3. **; 4. ***. Total: 9

Original eight-rise staircase on the Canal du Midi (see section on "Technologically significant canals"), built 1665-81. The upper six locks are still in use and the lower two, below a later diversion of the canal, are used occasionally. Most traffic now uses the new "water-slope," completed in 1983.

iii **"Neptune's Staircase," Caledonian Canal (Scotland, UK)**, 1803-11.

Grading: 1. *; 2. *; 3. ***; 4. **. Total: 7

This 60-mile canal was designed to carry sailing ships, up to 170ft by 40ft, through the Great Glen of Scotland. Thomas Telford was principal, with William Jessop as consulting engineer. Telford had assembled a specialist construction team and the scale of the work set a precedent with the large use of construction railways and three steam engines for pumping. With the large lakes on the summit level of the canal there was no shortage of water. The locks were therefore placed in groups to save expense: at Bonavie was built the "Neptune's Staircase" of eight locks, at Fort Augustus five, at Muirtown another four, and double locks at Corpach and Laggan. The locks were designed for a navigable depth of 20ft, but the canal itself did not reach a depth of 17ft until 1847. The locks remain in substantially their original condition and are all still in active use on the Caledonian Canal (see Paget-Tomlinson 1978, 106).

d *Earth-sided locks*

These represent an early and primitive type of lock used on river navigations that have sometimes survived in use into the modern period.

i **Garston Lock, Burghfield, Kennet Navigation, England (UK)**, *c* 1854.

Grading: 3. ***. Total: 3

This is a conserved turf-sided lock, originally built in 1715-23 as part of the Kennet Navigation from Reading to Newbury. The survival of parts of a timber substructure indicate a rebuilding in *c* 1767 to a length of 37m and a width of 5.8m (with a lift of 2.5m) so that it could accommodate "Newbury" barges. It was absorbed as part of the arterial Kennet and Avon Canal and rebuilt as a smaller (27.6m long and 4.6-5.2m wide) turf-sided lock, revetted with slate, in *c* 1854. The lock was brought back into operation after conservation in 1993-94.[18]

e *Wooden-sided locks*

Another primitive type of lock that has remained in use intermittently.

i **Wooden-sided lock at Vitegra (Russia)**.

Grading: 3. ***. Total: 3

350km ENE of St Petersburg, on the southern shore of Lake Onega. This is the last remaining lock of the 39 built (size given as 74m by 10.3m) on the Maryinsk Canal, dating from 1810. The canal, which linked Lake Onega with Tcherepovetz, was repeatedly reconstructed and was awarded the Grand Gold Medal at the 1903 Paris International Exhibition as an outstanding example of Russian engineering. In the 1960s the canal was rebuilt to much larger standard and reopened in 1964.

f *Mitre-gated lock chambers*

Single tall and heavy gates both restricted the width of a lock chamber and were heavy to move. The introduction of double mitre-gates, which were kept closed by the pressure against them, became universal.

i **Spaarndam (The Netherlands)**, early mitre-gated chamber lock, 1572.

Grading: 2. *; 3. *. Total: 2

This is the site, 15km west of Amsterdam, of a chamber lock which possibly used mitre gates and was built in 1572. The lock allowed passage between the river Spaarne and the Haarlemmer (which was eventually drained by the Cruquis pumping engine). It is possibly on the site of an earlier lock dating from the mid-14th century. Also in the village are flood control sluices, a later stone-built lock, and a large modern lock. It is possibly worth considering because of the location's long history of hydraulic engineering. There were earlier structures here, and today there are two more recent locks close to the site.

g *Shaft locks*

i **Saint Denis Lock, central Paris (France)**, 1892. Grading: 2. **; 3. **. Total: 4

This was the first successful shaft lock. The Saint Denis Canal was rebuilt *c* 1892 to accommodate the deeper boats which were being built for the recently dredged Seine. The number of locks was reduced, and in one place a single lock, with a fall of 10m, replaced four older ones. This was the first shaft lock to be built, the lower end of the lock being traversed by a masonry bridge, which was also used to contain the water in the lock when the single gate fitted against it.[19]

ii **Horin Lock, near Melnik (Czech Republic)**, 1905.

Grading: 2. **; 3. *. Total: 3

This is an early shaft lock with offset gates, later to become a common feature. This lock, located close to the confluence of the Labe and Vltava rivers, is a shaft lock dating from 1905. It has twin lower gates which form a straight seal against the bridge section across the lower mouth of the lock. The lock gates are offset to allow two boats to use the lock simultaneously.

iii **Anderten Lock, Hannover (Germany)**.

Grading: 2. *; 3. ***. Total: 4

This shaft lock and associated complex, 5km east of Hannover, on the Mitteland-Kanal, built *c* 1930, raises the canal to its summit level. There are two locks, 225m by 12m, side-by-side. Five chambers, one above the other, are built into each lock side to conserve water. A water pumping station to feed the summit level is also built on the site. This lock, with its large size and water economy measures, represents the direction in which waterway engineering has proceeded up to the present.[20]

B *Inclined planes*

The idea for transporting boats over dry land must have grown out of the necessity in ancient times of having primitive rough portages around rapids on rivers, or to connect two arms of the sea across an isthmus. The Greeks called this a *diolkos*, and one of the earliest and largest, with a paved way, rails, and terminal slipways, was at Corinth (see below).

Differences of height on a canal line could also be overcome by pulling boats up ramps between varying levels of water, which overcame many of the water-supply problems generated by heavy lockage.

It was realized in China at an early date that if the ramp of a spillway was made to slope at a reasonably gentle gradient it would be possible to drag canal boats up and over it to the higher level. In this manner the double slipway was developed. This consisted of a pair of inclined stonework aprons over which boats were hauled, in China generally with the use of capstans, from a waterway at one level to a waterway at another. In 1696 Lecomte described the use of one as follows:

> At the end of the Canal they have built a double Glasis, or sloping Bank of Freestone, which uniting at the point, extends itself on both sides down to the Surface of the Water. When the barque is in the lower Channel they hoist it up by the help of several Capstans to the plane of the first Glacis, so far, till being raised to the Point, it falls back again by its own Weight along the second Glacis, into the Water of the upper Channel, where it skuds away during a pretty while, like an Arrow out of a Bow; and they make it descend after the same manner proportionably. I cannot imagine how these Barques, being commonly very long and heavy laden, escape being split in the middle, when they are poised in the Air on this Acute angle …

Passages of the slipway only took 2.5-3 minutes and European observers considered them much preferable to conventional pound locks, since it was also possible to construct them at a quarter of the expense.[21]

There was probably an indigenous development of the double slipway in Europe. This, the *overtoom*, was in use in the Netherlands by 1148, when there were two examples in use on the Nieuwe Rhijn Canal near Utrecht; there was probably another at Spaarndam in 1220 and elsewhere in Europe at Ypres in 1298.

The next stage in development was for rope-hauled short inclines to convey boats in wheeled cradles as had been used on the Corinth *diolkos*. In Italy a particularly well known one was that erected in 1437 at Lizzafusina or Zafosina on the river Brenta at Fusina near Venice (see below).[22]

It was gradually realized that larger inclined planes could be used in very hilly country to overcome large changes in level, initially with the use of very small boats. In such situations the alternative would have been the use of great flights of locks, expensive to build, slow to use, and requiring large amounts of water. The other, less common alternative, was a boat lift (see below).

A Sardinian-born engineer, Daviso de Arcort, was the first to design such long inclines on small "tub-boat" canals in hill country. He probably knew of existing short Italian inclines from first-hand knowledge of from books such as Leone Battista Alberti's *De re aedificatoria* (1485) or Cornelius Meijer's *L'Arte de restituire a Roma la tralasciata navigatione* (1685). In 1767 he began the construction of three inclined planes on a canal from Drumglass collieries, County Tyrone (Ireland), towards the river Blackwater. The eminent British engineers John Smeaton and his assistant William Jessop suggested that these inclines should be made double and counterbalanced. Davis Ducart (as de Arcort was known in Ireland) then substituted cradles on rails rather than the rollers on wooden ramps he had previously built. Even with these crucial innovations these inclines were abandoned largely unused.

The first successful modern inclined planes were those used in Shropshire (UK) from 1788 onwards. The international evolution of the canal inclined plane is a good example of international and intercontinental technology transfer. In 1795 a small inclined plane based on the Ketley type was built at Hadley, Massachusetts (USA), and in 1796 the American engineer Robert Fulton published his *Improvements in Canal Navigation*, partly based on his study of the Coalbrookdale planes. François de Recicourt, a French military and civil engineer, had a translation of Fulton's book produced in 1799. Fulton visited France from 1797 to 1801 and the French engineers Bossu and Solages built one incline and a lift at Le Creusot between 1801 and 1806.[12]

The underground incline at Worsley (Manchester), on the Bridgewater Canal in Britain, was built at the end of the 19th century and linked the main canal tunnel level with one of the other three levels which served the coal mine. It was particularly important for the way it was reported on, and because it caught the international imagination.

In 1824 the Pennsylvania Society sent the engineer William Strickland to Great Britain to study railway construction, and it was subsequently that the astonishing Allegheny Portage Tramroad was built as part of a composite railway and canal link, with no less than ten powered inclined planes. Later in the 19th century engineers from abroad studied the Morris Canal inclined planes in the USA and built canals with inclined planes in Poland and Japan.

S I T E S

i **Corinth *diolkos* (Greece)**, early 6th century BC.

Grading: 1. ***; 2. **; 3. **; 4. *. Total: 8

This was not strictly a canal line, but it did involve the movement of ships inland, pioneering the use of boat or ship cradles, and so it is included in this list. The *diolkos* was a stone-paved ship-railway with slipways at either end that traversed the 4 miles across the Isthmus of Corinth and remained in use until the 9th century AD. A roadway of stone blocks had very broad and shallow grooves of 5ft 6in gauge with an inner edge 4ft 11in apart. There was a passing place on a curve with double tracks. Ships were carried on wheeled cradles running in these stone-way grooves. Remains of part of the track have been excavated. Stone-track railways of later date are not uncommon; one of the more complete ran the 10 miles from granite quarries at Haytor on Dartmoor down to the navigable river Teign (Devon, England).[24]

ii **Double-slipways on the Chinese Canals**. Grading: 1. ***; 2. **; 4. **. Total: 8

Some were still in operation in 1934 (see section on the Grand Canal in "Technologically Significant Canals"). The specific site location of well preserved remains need to be established.

iii **Short incline at Lizzafusina, or Zafosina, on the River Brenta dam, near Venice (Italy)**.
Grading: 1. **; 2. ***. Total: 5

This dam stopped the river waters from silting-up the salt water of the Venetian lagoon. Boats were transported over the dam on a short incline, positioned on two strong cradles on wheels, drawn up by a rope passing over an axle which was worked by a horse gin. The surviving illustrations show a double-incline without any evident means of counterbalancing. The wheels of the cradle ran in grooves, as at Corinth, rather than the later use of upstanding rails.[25]

iv **The three inclines built by Daviso de Arcort near Coalisland, County Tyrone, Northern Ireland (UK)**, 1767-77.
Grading: 1. **; 2. ***; 3. *. Total: 6

The first was on the Drumglass colliery canal 862m from Coalisland basin with a rise of 16.7m; the second was 772m further on at Drumreagh House, with a rise of 20m. The third was just west of Farlough Lake, with a rise of 21m. The inclines were originally to be single water-wheel powered ramps, but there proved to be insufficient water and so counterbalanced railed inclines were substituted with horse gins to help the 2-tonne boats over the sills. Little traffic passed the inclines and they were abandoned in 1787. There may have been insufficient water for the working of the upper canal or the inclines may have been too steep for effective counterbalanced working. Substantial remains of these first long inclines, the first also fitted with upstanding rails, and the first to be worked by counterbalanced working, can still be seen. They were also important for sowing the idea of canal inclined planes in Britain and Ireland as the Industrial Revolution was starting.[26]

v **Hay Inclined Plane, Ironbridge Gorge Museum, Shropshire (UK)**. **[Figure 2]**
Grading: 1. *; 2. ***; 3. ***; 4. *. Total: 8

The first successful modern inclined-plane was that built by the Shropshire ironmaster William Reynolds in 1788 at Ketley near the modern town of Telford in 1788, with a vertical lift of 22.25m. It was counterbalanced, loaded boats descending on cradles running on rails. The first steam-powered inclines were then constructed by the same builder on the adjacent Shrewsbury Canal, which opened in 1791-92, the greatest having a rise of 63m.[27] This, the Hay inclined plane leading down the side of the Severn Gorge, has been re-railed and forms part of the Ironbridge Gorge Museum (a World Heritage site). Detailed drawings were made by French engineers and disseminated widely.

Figure 2 The 1790s Hay inclined plane at the Ironbridge Gorge World Heritage site, England (UK) vi **Underground incline, Worsley, Bridgewater Canal, Manchester (UK)**.

Grading: 1. **; 2. *; 3. *; 4. **. Total: 6

Deep coal-mining tunnels were built from the end of the Bridgewater Canal from its inception in 1759. By 1795 this level of underground waterways and one 32m above it extended for 24km. They may not have been the first underground mining canals in Britain but they attracted many visitors from home and abroad, who helped to spread the idea of canal mines widely and who also reported on this underground inclined plane.[28] The idea for the inclined plane was put forward by the originating mining engineer, John Gilbert, and construction took place between September 1795 and October 1797. It was sited on a 1 in 4 incline following a sloping bed of gritstone 4km from the surface entrance of the mining canals and was 138m long with the upper part consisting of a double railway 5.8m wide. At peak capacity it was capable of handling 30 boats each way in an 8-hour shift, a total weight of around 915 tonnes. The incline was abandoned in 1822 with the exhaustion of the upper shallow seams, but substantial remains survive underground.[29]

vii **Allegheny Portage Railroad, Pennsylvania (USA)**, 1831-34.

Grading: 1. ***; 2. *; 3. ***; 4. *. Total: 8

The 394 miles of the Pennsylvania Main Line was a unique composite canal and railway line linking Philadelphia and Pittsburgh, opened between 1826 and 1834. Built over mountainous terrain, and only made possible by the extensive use of steam-powered inclines, it was even more astonishing an innovation than the pioneering Erie Canal itself. Both passengers and goods could travel the whole distance without transshipment by the use of sectional boats that could be divided into three or four units. The 132km eastern section was operated as a horse and locomotive railway, but the 60km central section consisted of the Allegheny Portage Railroad with five steam-assisted counterbalance inclines reaching up and over Allegheny Mountain. Sylvester Welch built the railway over a 712m summit in three years. The Pennsylvania canals were a crucial step in establishing the industrial might of the most powerful nation on earth.[30]

viii **Elblag Canal (Poland)**, an outstanding example of a canal still in operation with multiple 19th-century inclined planes.

Grading: 1. *; 3. ***; 4. *. Total: 5

Between 1844-60 in what was then East Prussia, the Oberland or Elbing (now Elblag) Canal ran from the Frisches Haff (near Elblag) and the Geerich lake to Osterode. The canal originally had four counterbalanced inclined planes with waterwheel-powered assistance. In 1881 a fifth inclined plane with water-turbine power replaced five of the seven locks. 60-tonne barges have now been replaced by the regular use of passenger tour-boats. The original four inclines of 20-24.5m in rise were designed after study of America's Morris Canal.[31]

ix **Biwako Canal Inclines, Kyoto (Japan)**, 1885-90.

Grading: 1. *; 2. ***; 3. *. Total: 5

The Biwako Canal is an outstanding example of intercontinental technology transfer. The designer, Sakuro Tanabe, toured the USA (including the inclines of the Morris Canal) to study current practice in canal engineering and hydro-electric practice. It has one of the world's first hydro-electric power stations and in many ways is the climax to the building of 19th-century small canals.[32] The canal connected Lake Biwa (Biwako) to Kyoto via the counterbalanced Keage Incline. This has double-track inclines of 2.5m gauge. The incline descended 36m towards the City of Kyoto in a length of 555m on a gradient of 6.48%.[33] The twin steel-built boat cradles and the incline are preserved. There was also a second incline.

C *Boat lifts*

Some mid-18th century canals such as the Bridgewater in England used vertical haulage of loaded containers to overcome differences in level. The idea of lifting an actual boat from one canal level to another seems to have evolved separately in both England and Germany at the end of the 18th century.

The first recorded boat lift was constructed in 1788-89 on the short Churprinz Canal at Halsbrücke in Saxony (Germany). This was for small 2.5-tonne boats and involved the use of a five-fold manual tackle. The lift continued in use until 1868 (see "Sites" below).[34]

The more sophisticated experimental lifts built in the last decade of the 19th century in Britain were generally unsuccessful. These included deep shaft locks with caissons and boat cradles supported on pillars supported by floats immersed in under-lift tanks.[35]

Subsequent lifts have been largely successful. In the early 1830s the Grand Western Canal in the south-west of England was opened with no less than seven counterbalanced twin-chamber lifts and operated successfully until 1867 (see "Sites" below).[36]

Hydraulically operated lifts were the big success stories of the late 19th and early 20th centuries. Edwin Clark (1814-94) was the engineer behind their development, and it was his designs that have led to the widespread practical use of the lift. In 1846 Robert Stephenson appointed him to be superintending engineer to the Britannia and Conwy Tubular Bridges, the wrought-iron tubes of which were raised using hydraulic presses. In 1857 he became engineer to the Thames Graving Dock Limited, for which he designed a graving dock in which the ships to be repaired were lifted from the water by hydraulic presses. In 1866 he lectured on this, by which time the lift had been working for about seven years and had raised 1055 ships with an average tonnage of 686 tonnes.

A connection was made between the Weaver River Navigation and the Trent and Mersey (at Anderton, Cheshire, UK) using a 15.35m lift to Edwin Clark's design with two counterbalanced troughs. The hydraulic cylinders extended 21.35m below each tank. The lift was set in operation by removing some centimetres of water from the lower caisson. The speed of operation was controlled by transferring the hydraulic fluid through a 0.127m pipe from below one caisson to the other. The descending caisson became immersed in the canal water and for the last 1.22m had to be assisted by a steam-powered hydraulic accumulator. Boats of 102 tonnes could be raised in the 22.88m by 4.73m tanks. In 1904 the lift was converted to electrical operation because of chemical corrosion of the rams.[37]

Edwin Clark, his brother Latimer, and John Standfield went on to design a series of lifts on the European mainland in conjunction with the well known French engineering works, SA des anciens établissements Cail. Les Fontinettes lift was built to replace five locks in northern France in 1880-88 and could raise large 300-tonne barges in caissons 38.6m by 5m (see "Sites" below).[38]

During this important example of technology transfer to the European continent several developments were made on this larger lift that were to be important in later examples. Edwin Clark decided that the lift pits should be kept dry which did away with the necessity for the troughs to be moved for the final short distance by a hydraulic accumulator. A structural innovation was the introduction of masonry towers which supported the troughs at their centre-points and also supported the operator's cabin.

The hydraulic presses for operating the rams were made of cast-iron at Anderton and were designed to be of such at Les Fontinettes. However, on 26 April 1882, the side of one of the Anderton presses blew out during operation and so the Les Fontinettes presses were made of steel with a thin lining of copper. Water-turbines also provided the extra power needed to operate the lift and blow the seals on the gates.[39]

The last lifts to be built under the auspices of Messrs Clark, Standfield & Clark were the unequalled concentration of four added to the Canal du Centre; the first was built simultaneously with the Les Fontinettes Lift and opened on 4 June 1888. The building of the last three was delayed and they were opened in August 1917.[40]

Three other hydraulically operated lift schemes illustrate intercontinental technology transfer. The British engineer James Brunlees proposed a ship railway across the Central American isthmus in 1872. This was to take vessels of at least 1220 tonnes on six rails holding 60 four-wheel bogies. Propulsion would be by steam-powered rack-locomotives and ships would be got out of the water and returned to it by hydraulic lifts. This scheme was never built. H G C Ketchum, who had worked with Brunlees, then proposed a 27.4km ship-railway across the Chignecto peninsula that would save a 800km sea journey around Nova Scotia for shipping travelling from the eastern seaboard of the USA to the Gulf of St Lawrence. Ships of up to 2032 tonnes would be positioned over a gridiron and carrying cradle in a lifting dock at either end of the railway. The gridiron would then be raised by 20 hydraulic rams and presses and the ship on its cradle hauled on to the railway. The Chigneto Marine Transport Railway Company was formed in England by James Brunlees and Edwin Clark in 1883 and over half the work of construction was completed between 1888 and July 1891, when the company ran out of money. Remains of the formation survive.[41]

There followed the construction of two successful lifts on the Trent Canal in Ontario (Canada). These were constructed at Peterborough in 1896-1902 and in 1900-07 at Kirkfield. These followed on from earlier designs but are significant for being an example of intercontinental technology transfer. The still-operating Peterborough Lift, with a rise of 19.5m, was the highest hydraulic lift built.[42]

The next lifts moved away from the technology of having twin caissons counterbalanced by hydraulic pressure. Both of the next types - counterweighted and those using floats - were foreshadowed by early experiments: Woodhouse in the former case and Rowland and Pickering or Bossu and Solages in the latter case.

The Henrichenburg Lift in Germany was built between 1894 and 1899 to give access to Dortmund from the Dortmund-Ems Canal. This raised large 950-tonne craft through vertical rises of 14.5m. Five floats in a row beneath the caisson rose or fell in their respective pits as the water-level was changed. An experimental English lift had first used the system in 1796.[43]

An international competition for boat-lift design took place in 1902. A jury of international experts, including Sir Vernon Harcourt, considered over 200 designs for boat lifts to be used on the proposed Danube-Oder-Elbe Canal. Although the canal was not built (it is still being promoted), the designs became the inspiration for many of the boat lifts that were built subsequently.[44]

In Britain chemicals in the canal water caused problems with the hydraulic operation of the pioneering Anderton Lift, and in 1903-08 its system of operation was altered. The steam-power that had operated the accumulator was replaced by electricity. Over the next few years the hydraulic rams were taken out and each caisson was then operated separately by electric power assisted by counterweights.

S I T E S

i **Churprinz Canal Lift, Halsbrücke, Saxony (Germany)**, built 1788-89. **[Figure 3]**
Grading: 1. ***; 2. **; 3. **. Total: 7

The Churprinz Canal ran for 5.3km on the bank of the Freiberger Mulde river in order to carry ore to the Halsbrücke smelting works from the Churprinz-Friedrich-August mine adit. The whole operation was labour-intensive, with 2.5-tonne boats being towed by two men, a third man on the boat steering with a pole. The river was crossed on the level with the stone-built lifthouse entered through an arch on one bank. This was a rectangular chamber 5.5m wide and 17m long up which boats were lifted by a five-fold tackle into the upper level of the canal. Bad weather and high water in the river could disrupt the working of the lift but it continued in use until 1868. The substantial remains of the lift are still extant.[45]

ii **Grand Western Canal Lifts, Devon (UK)**, designed by James Green and built in 1832-35.
Grading: 1. **; 2. *; 3. **. Total: 6

The first successful twin-chamber counter-balanced canal lifts; in use until 1867. The biggest of the lifts rose 13m and there are substantial remains at Nynehead lift (7.32m). Two counterbalanced iron tanks were suspended by pulleys within a masonry framework.[46]

A lift important to the evolution of canal lifts (but not on a canal) was the ship lift at the Thames Graving Docks, Royal Victoria Dock, Woolwich, London, designed by Edwin Clark and built in *c* 1859. The lift was sited in a channel connecting the Royal Victoria Dock at Woolwich and the Pontoon Dock that lay on its south side and was the first of all the lifts using hydraulic power to lift vessels.

iii **Anderton Canal Lift, Weaver Navigation/Trent and Mersey Canal, Cheshire (UK)**, designed by Edwin Clark and built in 1872-75.
Grading: 1. ***; 2. ***; 3. **. Total: 8

This is important for being the first hydraulic canal lift and the first of a series of large late 19th and early 20th century lifts based upon it. Boats are carried through a lift of 15.35m in one of two tanks or caissons: 22.9m x 4.73m x 1.53m, encased within an iron framework. Each caisson, weighing 244 tonnes with its water, was originally supported in the centre by a 0.915m diameter iron ram extending downwards into a cast-iron hydraulic press with a 0.127m diameter pipe originally connecting it to the press beneath the second caisson. 0.1525m of water removed from the lower caisson were enough to start the lower caisson falling, its descent being controlled

Figure 3 The 18th century Churprinz canal lift at Halsbrücke (Germany) by the rate of flow of the water in the interconnecting 0.127m pipe. Since 1908 each caisson has been operated independently by electric power and two rows of counterbalance weights. The lift has been conserved as an ancient monument and is being restored to use.[47]

iv **Les Fontinettes Lift, Neufosse Canal linking the Pas de Calais ports to the Canal de St Quentin (France)**, 1883-88.

Grading: 2. **; 3. ***. Total: 5

The first large continental European lift, it bypassed no less than five old locks on a flight dating from 1760. The rise was rather less than Anderton but the capacity was much greater: 38.5m long, 305-tonne Freycinet standard barges drawing 1.8m of water. The design was that largely adopted on future lifts with central towers steadying great steel tanks that were cantilevered out from each side of the central rising column. The old locks were kept in case of breakdown but the lift was so successful that it carried 11,161 boats in 1905. A single large lock replaced the structure in daily use in 1967 and it remains as an industrial monument.[48]

v **Canal du Centre Lifts (Belgium)**, 1888-1917.

Grading: 1. **; 2.*; 3. ***. Total: 6

The difference in levels between the two ends of the canal was 89.45m and there were two distinct sections of the waterway, one of 13 km having five locks with a total rise of 23.26m and the other of 8km with a rise of 66.19m. To overcome part of the latter rise the 15.4m high La Louvière lift was opened in 1888, with the other three lifts of 16.93m rise opening in 1917. The first lift was designed by M P Nolet, an engineer at the Société Cockerill, Seraing, employed by Clark, Standfield & Clark. The framework of this lift was lattice girders rather than the masonry of Les Fontinettes. This unique concentration of lifts carried boats of 404 tonnes. All four of the Canal du Centre lifts have been replaced in use by the 73.15m Strepy Lift but are to be preserved.[49]

The lifts form part of an integrated industrial landscape, with the early continental European coal-mining at Bois-du-Luc, recommended as being of world significance by the TICCIH Board.

vi **Peterborough and Kirkfield Canal Lifts, Trent-Severn Waterway, Ontario (Canada)**, 1896-1902 & 1900-07. Grading: 1.*; 3. **. Total: 4

These followed on from earlier designs but are significant for being an example of intercontinental technology transfer. The still operating Peterborough Lift, with a rise of 19.5m, was the highest hydraulic lift built. It was also one of the world's largest concrete structures at the time of its completion: more than 19,890m^2 of concrete were poured. The commercial success of this link between the Great Lakes was impaired by there only being money available to build two small-scale inclined planes at two further changes of level. The second lift, at Kirkfield, illustrates the progression to a lighter steel structure. A large lock and bigger incline have now allowed more intensive use of the lifts, which are conserved with the canal by Parks Canada.[50]

vii **Henrichenburg Lift (Germany)**, 1899.

Grading: 1.*; 3. ***. Total: 4

Situated on the Dortmund-Ems Canal, the site dates from 1899, when the first boatlift was built. The tank of this lift is supported on five flotation cylinders fitted underneath. It soon proved inadequate to cope with the volume of traffic and a shaft lock with side chambers was built close by in 1914. By the 1960s, boats had increased in size, so a new lift was built, this time with just two flotation cylinders. This in turn has been supplemented in 1989 by a new shaft lock, capable of accommodating a 2000-tonne push-tow unit. This complex of structures illustrates the rapid development in scale of 19th and 20th century waterways and could be considered for any designation as a group.[51]

D *Earthworks*

The civil engineering of the artificial waterways had to develop in order to allow the line of water channel to be conveyed over undulating countryside.

Because of the problems in moving the large volumes of earth required and the difficulty in understanding soil stability, large embankments did not feature on the earliest canals. It also accounts to some extent for the use by the Romans of aqueducts, rather than earthworks, for their water supply systems.

By the late 18th century, engineers began to overcome these problems. One of the greatest of the early embankments was at Burnley, on the Leeds and Liverpool Canal (UK), where the canal is carried 1km over the valleys of the rivers Brun and Calder at a height of over 12m. The section of the Leeds and Liverpool Canal between Burnley and Wigan, built between 1796 and 1816, features eight large embankments and shows the confidence then being discovered by canal engineers.

The British engineer Thomas Telford was involved in three notable early uses of large-scale earthworks. These are, first, the approach embankments to the Pontcysyllte Aqueduct on the Ellesmere Canal, Wales (UK), dating from 1795-1805 (see "Aqueducts" and "Technologically significant canals") and, secondly, the great embankment at Shelmore and the nearby Tyrley (Woodseaves) Cutting, Shropshire (UK). The third of his works noted here is the Smethwick Cutting, a 3660m cutting up to 20m deep on Telford's low-level line for the Birmingham Canal, one of the greatest excavations to that date in Britain.[52]

The construction of the great ship canals - Manchester, Kiel, and Panama - saw the mechanization of earth movement and the ability to construct the vast cuttings on those canals. The largest embankment to be built on a conventional canal was the Raguser Dam, Brandenburg (Germany) on the Havel-Oder Canal. Opened in 1914, it carries the canal some 28m above the valley of the river Raguser. The embankment has a cross-section of 2800m^2 and contains around 1 million m^3 of earth.[53]

E *Reservoirs*

A most important aspect of canal engineering is the adequate supply of water. The height of a canal's summit level is dictated by the method of supplying water. Early canals, such as the 1398 Stecknitz Canal (Germany), had low summit levels, which were supplied with water directly from lakes, rivers, and streams. The Canal de Briare (France) of 1642 was also supplied from existing water supplies, but the water supply to the Canal du Midi (1681) came from dams and water feeders built specifically for that purpose (see "Dams").

Large European ecclesiastical and monastic estates of the Middle Ages had sufficient resources and need for a moderate development of waterway transport, and the first recorded navigation dam survives from this period.

S I T E S

i **Alresford Dam and 200-acre (80ha) reservoir, Itchen River Navigation, (UK)**.

Grading: 1. ***; 2. **; 3. **. Total: 7

The earthen dam is overgrown but still holds 24.3ha of water. This was the first known navigation dam in the world.[54]

Seven hundred years ago the area around Winchester, the early medieval capital of England, was prosperous because of its wool and cloth industries. In 1189 Godfrey de Lucy, Bishop of Winchester, decided to improve the commercial potential of the area by making the river Itchen navigable along its entire length between Alresford and Southampton Water. This work required the construction of a series of flash locks whose subsequent operation depended on a supply of water in excess of the river's natural flow. Bishop de Lucy therefore constructed a reservoir just to the north of Alresford which stores the water of two small streams (see "Dams").

ii **Reservoir on the Grand Canal (China)**, *c* 1411.

Grading: 1. **; 2. **; 3. ***. Total: 7

A reservoir with a 1 mile long dam on the Kuang River, north of Ningyang. This is the second known recorded navigation dam in the world, built around 1411.[55] (see "Dams" and "Technologically significant canals").

iii **Canal du Midi reservoirs and feeder system (France)**. **[Figure 4]**

Grading: 1. **; 2. ***; 3. ***; 4. **. Total: 10

The Canal du Midi was a summit-level canal with a heavy lockage requiring a large quantity of water. To the north of the canal's summit, suitable sources of water were found in the rivers of the Montagne Noire. Pierre-Paul Riquet planned a 42km long feeder system in 1661. The only drawback was that more water than was needed was available in the winter, and less in the summer. He therefore took the logical step of building a reservoir to store the surplus winter run-off for use during the following summer.

The dam of St Ferréol was built across the river Laudot about 2 miles south-east of Revel. Later, a second dam was required, the stone Lampy Dam, built by the canal engineer Garripuy in 1777-81 (see "Dams").

Figure 4 Low-level outlet tunnel in the base of the large earthwork reservoir dam of Saint Ferréol, Canal du Midi (France), 1667-71

F *Water pumps*

Water usage on canals with heavy lockage could be enormous and might easily outstrip the water supply available from gravity feeders. The use of pumps goes back to at least the end of the 11th century AD, when there are Chinese references dated 1098 and 1120 to batteries of hand-pumps built to supply water to summit levels and probable references to pumps mounted on pontoons that were used to pump water back at pound locks.[56] The Archimedean screw was extensively used on canals, not so much for water supply as for ensuring dry conditions when construction or maintenance work was being undertaken.

On the first canals of the Industrial Revolution at the end of the 18th and the beginning of the 19th century power pumps began to become fairly common: they were powered by water-wheels and steam engines. Two of the more significant early examples are listed below. Two more steam-engine houses have significant remains at Smethwick on the Birmingham Canal mainline (see "Technologically significant canals").

During the later part of the 19th century, manual and animal-powered pumps used for maintenance purposes were replaced by steam-driven reciprocating and centrifugal ones. Generally, Archimedean screws were used for water supply where there was only a low head to overcome, such as on river navigations. At Locquinol on the river Sambre (northern France), an electrically powered screw pump is still in operation. It was formerly driven by a steam-powered beam engine which is preserved on site.

On the Mitteland Canal, in Germany, there are impressive late water-pumping systems at Minden (*c* 1914), and at Anderton, Hannover (*c* 1930).[57]

S I T E S

i **Crofton pumping station, Kennet and Avon Canal (UK)**, begun in 1800.
Grading: 1. *; 2. *; 3. ***. Total: 5

This pumping station was intended to supply the summit level of the Kennet and Avon barge canal that runs across southern England. The brick-built engine house with its separate iron-bound chimney stands above the canal near the village of Great Bedwyn and not far from Hungerford. It houses the only Boulton & Watt engine still doing the work for which it was originally installed. Built in 1812, it is the oldest working steam engine in the world.

There was also an earlier Boulton & Watt engine which began work here in 1809. Both were low-pressure engines, fitted with Watt's parallel-motion linkage and his patent separate condenser. The 1812 engine was converted to high-pressure working in 1844, and a Sims engine was installed to replace that of 1809. The latter was rebuilt in 1905 when new Lancashire boilers were added. The Sims engine worked until 1952 and the 1812 one until 1958, when the top 6m had to be removed from the chimney and the steam-engine pumping was replaced by electric pumps. Restoration of the steam-pumps began in 1968 and both steam engines have been regularly operated since 1971, the 1812 engine raising 1 tonne of water at a stroke.

ii **Claverton water-powered pumping station, Kennet and Avon Canal (UK)**, 1813.
Grading: 1. *; 3. ***. Total: 4

This installation lifts water 16m from the river Avon to the Kennet and Avon Canal. A tall Bath-stone building houses the original beam-worked bucket pumps with the smaller wheelhouse alongside. There was originally a breast waterwheel 7.6m (25ft) wide and 5.58m (18ft 4in) dia In 1858 this was replaced by two 4.73m (15ft 6in) dia waterwheels on a single shaft, each 3.36m (11ft) wide. A small diesel pump replaced them in 1952, but restoration began in 1969 and the waterwheel pumps are now run on a regular basis.[59]

There was a third pumping station on the Kennet and Avon Canal and the remains of this are now within the World Heritage site of the Georgian City of Bath. The ornamental stone chimney of this former pumping station is situated halfway down the six-lock (formerly seven) flight leading to the river Avon. The old steam-engine house is at the bottom of the flight.

The World Heritage site at Bath also includes two iron arch bridges (7m and 9.15m in span) over the canal cast at Ironbridge in 1800 and sited in the 18th-century Sydney Gardens and adjacent to the elegant classical canal offices which straddle the canal on a bridge.

G *Aqueducts*

A canal used a natural resource, water, as the medium of its transport way. Deep natural obstacles needed to be bridged by large structures, including a waterproofing medium. Until the 19th century the technology of building masonry walls and arches was better understood than the science of soil mechanics, which was required to design stable earthworks. Before the advent of steam-powered machinery aqueducts were more practical to build than large earthworks. Such structures bridging natural watercourses also ensured the separation of the artificial water-economy of the canal from the natural land drainage and considerably eased the water management of the artificial navigation.

Non-navigable aqueduct bridges, often of considerable size and length, were common in antiquity. One of the first recorded was built by King Sennacherib of Assyria (*c* 705-681 BC) on the 50-mile long water-supply canal to his capital at Nineveh from springs at Bavian. This Jerwan aqueduct was 305m long and 11.9m wide and an inscription was excavated in the present century that read "I caused a canal to be dug to the meadows of Nineveh. I spanned a bridge of white stone blocks. These waters I caused to pass over it."[37]

The Romans built huge lengths of high arches carrying channels waterproofed with hydraulic mortar. Some 1600 million litres of water daily poured into Rome through eleven great aqueducts. Across low-lying land, particularly outside towns, an aqueduct had to be raised high enough to give a sufficient "head" to the supply, and the use of arches both removed a potential barrier to communication and lessened the amount of stone required for construction. The water-channels above the arches varied from 0.46m to 1.2m wide and from 0.6m to 2.4m high.

The Aqua Marcia (144 BC) actually forms part of a three-deck aqueduct at the Porta San Lorenzo gate into Rome; the arches of the gate also carry the Aqua Tepula (127 BC) and the Aqua Julia (33 BC) aqueducts. Probably the finest Roman aqueduct is the 72km of the Aqua Claudia, built by the Emperors Caligula and Claudius to bring water from Subiaco to Rome. Part of its length is on solid masonry and for 15.3km it is borne on lofty arches, some over 30m high, great lengths of which remain in the Campagna. It is joined 3 miles from Rome by the Anio Novus (AD 38), 99km in length.

Technology transfer over the large extent of the Roman Empire was especially noteworthy. The Pont du Gard (*c* AD 14) at Nîmes (France), which is on the World Heritage List, was part of a 40km long aqueduct to bring water from the neighbourhood of Uzès. The aqueduct bridge itself has a triple arcade carried 47km above the river Gard and is 270m long, of largely unmortared masonry. The double arcade of the aqueduct at Segovia (Spain), dating from *c* AD 10 and also on the World Heritage List, is another of the more remarkable water-supply bridges spread throughout the Roman Empire.[61]

Such water-supply, irrigation, water-power, and dual-purpose aqueducts continued to be built into the modern period and have had a significant influence on those built primarily for navigation.

It is arguable that the birthplace of highly engineered canals in the modern period was in 15th-century Italy. A navigable canal aqueduct was built on the Martesana Canal from the river Adda to Milan between 1462 and 1470. The Canal du Midi was the largest civil-engineering enterprise of its time and by 1661 a large 9.15m (30ft) span aqueduct had been built on its line at Répudre. The Duke of Bridgewater, inspired by a visit to this canal, planned the first major canal of the world's first Industrial Revolution. This included a three-arched aqueduct carrying the canal 11.6m above the navigable river Irwell, the central arch being 19.2m (38ft) in span.[62]

Waterproofing varied, with the earlier continental European examples often using hydraulic mortar whereas most British examples used vast amounts of puddled clay - an unstable waterlogged mass.

The scale and monumental character of the masonry aqueduct developed considerably in the first new national integrated transport network that served England's first Industrial Revolution and produced such superb masonry structures as the Lune, Dundas, and Marple Aqueducts.

Iron as a constructional material for girder bridges was used by the ancient Chinese by AD 1000, and in the modern period first for large arches of wrought iron, as at Kirklees, Yorkshire (UK), and then cast iron over the river Severn at Ironbridge, Shropshire (UK) in 1779 (part of the World Heritage site). It was only a matter of time before the material was applied in aqueducts.

The world centre of the iron trade at the beginning of the 19th century was Merthyr Tydfil, Wales (UK), which successively had the two largest ironworks of the 19th century. It was here in 1793 that a two-deck water-power aqueduct was constructed with the lower deck and trough made of iron: the Pont y Cafnau. A sketch of this appeared in the sketchbook of the Shropshire ironmaster William Reynolds in 1794, when he was working on the first large-scale navigable aqueduct made out of iron at Longdon-on-Tern in Shropshire in conjunction with Thomas Telford. This project led on to Jessop and Telford's Pontcysyllte Aqueduct with its 307m long and 38.4m high iron trough, the loftiest navigable canal aqueduct ever built. On the way were several aqueducts that combined cast-iron and hydraulic lime in their waterproofing, such as Chirk and the Edinburgh and Union Canal aqueducts.

The USA had aqueducts that served its developing New World economy, cheaply built in timber with a limited life-span but which enabled the local economy to develop and thrive via accessible cheap transport. Some of these were of great length, and the immense weight of the water carried ensured that these were not simple wooden troughs but had strong lateral reinforcement. One of the Delaware and Hudson Canal aqueducts designed by John Roebling and completed in 1847 survived after conversion to a road bridge. It is the earliest wire-cable suspension "bridge" in the world to retain its principal original elements.[63]

In the 20th century reinforced concrete became the standard material used for large-scale canal aqueducts. Notable are the reinforced-concrete aqueduct at Minden (Germany) of 1914, which crosses the valley of the Weser (375m long and Europe's longest canal aqueduct)[64] and the remains of the unfinished concrete aqueduct (1939) which was to cross the Elbe at Magdeburg, and which it is currently proposed to complete. This may mean that the existing remains will be removed.

S I T E S

i **River Molgora Aqueduct, Martesana Canal, near Milan (Italy)**.

Grading: 1. ***; 2. ***; 3. ***; 4. *. Total: 10

In 1462-70 Bertola da Novate, engineer to the Duke of Milan, built his second large navigable canal (29km long) eastwards from Milan to near the river Adda at Groppello, then north for 8km to its intake at Trezzo. It had a small three-arched aqueduct over the river Molgora; the river Lambro was also culverted under this canal, which also had two staunch or flash locks. There are remains of this waterway.[65]

ii **Répudre Aqueduct, Canal du Midi (France)**, 1665-81.

Grading: 1. *; 2. ***; 3. ***; 4. **. Total: 9

The whole line and the scale and sophistication of all its engineering works were an inspiration to succeeding canal engineers in the Industrial Revolution. Other aqueducts over the Orbiel and Cesse rivers were designed by the French military engineer Sébastien Vauban and built by Antoine Niquet on the Canal du Midi in 1686.[66]

iii **Pontcysyllte Aqueduct, Ellesmere Canal, Wales (UK)**, 1795-1805. **[Figure 5]**

Grading: 1. ***; 2. ***; 3. ***; 4. *. Total: 10

One of the heroic monuments that symbolizes the world's first Industrial Revolution and its transformation of technology. Thomas Telford, the Ellesmere Canal "general surveyor and agent," was working under William Jessop, the most prolific engineer of the British canal mania. The relative roles of these two engineers in the design is not totally clear.[67] The construction of this landmark, the highest navigable canal aqueduct built, led to the formation and consolidation of a team important to the subsequent development of civil engineering on such large projects as the Caledonian Canal.

The decision to build such a high deck, and in the new civil-engineering medium of cast-iron, was a bold one. The canal surface is carried 38m over the river Dee on an iron-arched deck, 313m long, comprised of nineteen spans of 13.6m (44ft 6in). The 3.6m (11.8ft) wide trough is carried on successive spans of four arched ribs spanning between slender masonry piers, which are partly hollow and taper to 3.96m (13ft) by 2.29m (71ft) at their summit. The southern approach embankment was one of the largest earthworks built up to this time.[68]

Other aqueducts linked to the genesis of this structure might also be associated in any designation. Pont y Cafnau was a cast-iron aqueduct whose construction was authorized in 1793 in order to

Figure 5 The huge cast-iron aqueduct of Pontcysyllte, Wales, 1795-1805 carry both a water-supply channel and a horse-worked railway into what was the largest ironworks in the world by the early 19th century at Cyfarthfa, Merthyr Tydfil, Wales (UK). A sketch of this done in 1794 survives in William Reynolds's sketchbook. Also in this collection of papers is a sketch made by Telford of a design for a high iron aqueduct made in 1794. Reynolds was the ironmaster who was experimenting, together with Thomas Telford, in 1795 on the first iron canal aqueduct to be designed. This Longdon-upon-Tern aqueduct is a protected monument 57m long, with four spans of 14.5m (47ft 8in), and a trough 2.7m (9ft) wide and 0.9m (3ft) deep. One month before it was completed in 1796 a much smaller single-span iron canal aqueduct was built by the engineer Benjamin Outram (William Jessop's business partner) on the Derby Canal (demolished 1971).[69]

On the Ellesmere Canal, near Pontcysyllte, the earlier Chirk Aqueduct had a cast-iron base to the water-channel, and Telford went on to advise a further group of three very large aqueducts with cast-iron channels on the Glasgow and Edinburgh Union Canal in Scotland (see the section on "Technologically significant canals").

iv **Delaware River Aqueduct, Lackawaxen, Pike County, Pennsylvania (USA)**.

Grading: 1. **; 2. *; 3. **; 4. *. Total: 7

The ambitious Pennsylvania Main Line (see "Inclined planes") of 1826-34 entered Pittsburgh at its western end by passing over a 348m long wooden-trough aqueduct over the Allegheny River. The pioneering engineer John Roebling replaced it in 1845 with a new one of seven 49.4m (162ft) spans reinforced by wire suspension cables.[70] In 1847 two rivers formerly crossed by the Delaware and Hudson Canal on the level were given two of the four new aqueducts commissioned from Roebling by the canal company.[71] The Delaware River aqueduct survived after conversion to a private road bridge and was carefully restored in the 1980s and conserved as a National Historic Site.

This is the earliest wire-cable suspension bridge in the world to retain its principal original elements.[72] The bridge runs from Pennsylvania into Minisink Ford, Sullivan County, New York. There are four spans of 43m (141ft 5in) from the centre of one 2.9m (9ft 6in) wide suspension tower to the next. The stone piers and abutments carried the 2.6m (8ft 6in) deep trough 9.5m above the level of the river. The wooden floor of the trough was held by wrought-iron hangers from the suspension cables that were largely hidden in the side-bracing for the wooden canal trough, with the two towing paths being almost at the level of the top of the low suspension pylons.[73] Barges of 132 tonnes used the canal from 1852.

H *Dams*

Canal dams are of more significance when considered as part of an overall canal scheme than as isolated structures significant in the history of technology. Outside the world of artificial navigations the first known dam was built near Helwan, some 20 miles south of Cairo at a date between 2950 and 2750 BC.[74] This was built to create a reservoir for irrigation purposes in the Wadi el-Garawi with a crest length of 106m and a base length of 81m, and a maximum height of 11.3m. Twin dry-stone masonry walls, each 24m in thickness, had a core of gravel 36m in thickness. Substantial remains of this structure have a gap in them 46m across with a lack of silt, suggesting a wash-out of the unmortared structure soon after construction.

Until the 19th century dams were of massive construction, using the weight of the structure to counteract the force exerted by the water contained. It was in France that the theory of the lightweight arched dam evolved, making the construction of dams easier and quicker, although by this time most dams were provided for non-navigational purposes. The Rideau Canal in early 19th-century Canada consisted partly of lakes created behind arched dams (notably at Jones Falls).

French engineers built an arch dam on the Rio Grande, 11.6m high and 2.35m thick, in 1888 as part of their work on the Panama Canal. The arch design was not to influence European dam construction until later, but this type of dam was soon widely built in North America and Australia.[75]

S I T E S

i **Alresford Dam, Itchen Navigation (UK)**, built 1189-1200 (see "Reservoirs").

The water from two small streams is contained by an earth embankment 76m long, 18m thick at its base and 9m at its crest, with a maximum height of 6m. The dam is now overgrown and, owing to the formation of swallow holes, the reservoir now holds back 24ha of water rather than the original 80ha.

ii **Grand Canal Dam (China)**, second water-feeder dam built (see "Reservoirs").

iii **St Ferréol Dam, Canal du Midi (France)**, built 1667-1671.

Grading: 1. *; 2. ***; 3. ***; 4. *. Total: 8

Built on the first heavily engineered, and hugely influential, canal of the modern period (see "Canal du Midi" in Section 3). To the north of the canal's summit, suitable sources of water were found in the rivers of the Montagne Noire, the only drawback being that more water than was needed was available in the winter, and less in the summer. Pierre-Paul Riquet therefore took the logical step of building a reservoir to store the surplus winter run-off for use during the following summer.

The dam of St Ferréol was built across the river Laudot about 2 miles south-east of Revel. A wide and shallow valley and the availability of suitable materials allowed Riquet to build an earth dam of impressive size, holding 5400 acre-feet capacity. The dam of St Ferréol is 780m long at its crest, has a maximum height of 32m above the river-bed, and at the centre has a base thickness of more than 137m. Two low masonry revetment walls flank an earthen core, capped in clay, which encases a full-height central wall. All three walls penetrate into bedrock for a depth of 3-4m.[76]

The 18th-century (1777-81) masonry buttress dam on the Canal du Midi feeder system at Lampy is also of some significance and was the second of its type to be built in Europe. In fact the whole water supply system, which extended about 15km from the dam to the canal, is of considerable significance.

Figure 6 Jones Falls Dam, one of a series erected to create large sheets of navigable water along the line of the pioneering Rideau Canal, Ontario (Canada), 1826-32

iv **Jones Falls Dam, Rideau Canal, Ontario (Canada)**, 1826-32. **[Figure 6]**
Grading: 1. **; 2. **; 3. ***. Total: 7

The Rideau Canal was a canalized waterway consisting largely of channels linking a series of lakes artificially created and heightened by the construction of some 52 dams and embankments in the Canadian wilderness. The highest is at Jones Falls, located 43km north of Kingston, at the junction of Sand and Whitefish lakes, where a 2.5km long set of rapids fell 18m, the largest drop between Ottawa and Kingston. The dam rises 19m from a narrow rocky ravine and was double the height of any other dam existing in North America at that time. The dam measures 107m along its crest, which curves to a radius of 53.4m and is arched in plan and concave in profile, thus giving the appearance of a true arched dam. The ratio of base width to height of 0.44 falls short of the minimum accepted ratio for a gravity dam and may explain why the Royal Engineers strengthened its upstream side with a considerable earth bank extending beyond the clay-puddled core. The dam survives in very good condition and is maintained by Parks Canada.[77]

I *Weirs*

The submerged type of low dam with water continually flowing over the top, known as a weir, was also quite important. Weirs were a major feature of river navigations. Needle weirs, developed from flash-lock technology, can still be found on navigable rivers in central and southern France and on the Naviglio Grande in Italy; they have disappeared from northern Europe because they are difficult to operate in icy winter conditions. Weirs have often been rebuilt as water-flow conditions and demands have changed. However, some old weirs still remain. At Gathurst, near Wigan (UK), one of the weirs of the Douglas Navigation still survives. A stepped stone weir, built in 1741, the navigation ceased operation in the 1780s, though this weir was needed for access to colliery wharves by boats passing through a lock between the canal and the river. It was probably isolated and taken out of use in the 19th century. For weirs on the Vltava (Czech Republic), see "Rafting."

J *Overflow weirs*

Canals, despite their main use as navigable channels, are also an important feature of land drainage. During wet weather their water-levels rise, which could result in breaching of the canal banks. Overflow weirs are a vital stabilizing device which keeps water-levels in artificial channels at the height required.

The first recorded use of these was in ancient China. Early examples were set in the Kuanhsien Irrigation System and the Ling Chhu Transport Canal. In Sung Period texts the terms *shih-to* and *shui-to* were mentioned many times, often in connection with the *Pien* or Grand Canal, which in some sections had rows of ten or thirteen spillways, one after the other, along it. Side sluice stop-log gates (*cha*) were in common use for the rapid evacuation of flood water.[78]

Perhaps the most famous overflow weir was that which was originally installed at Castlefield, Manchester (UK). It was of clover-leaf formation, an optimum design as the volume of water which an overflow weir can handle depends upon its length. Using a clover-leaf shape maximized the length of the overflow, but kept the area it occupied to a minimum. The water passing over the weir drained into the river Medlock through a shaft and tunnel built in the centre of the clover-leaf. Unfortunately it has been rebuilt to a more standard design.

K *Outlet sluices*

Any artificial waterway had to have a mechanism by which it could be quickly emptied in the case of a breach, flood, the sinking of a vessel, or for purposes of cleaning.

The early terminology of ancient Chinese canals is complex, but some names used such as *shih-tha-yen* (stone gate dam) suggest heavy sluice drainage gates: this particular dam impounded the Khun-ming Chhih Lake south-west of Chhang-an, a stretch of water created in 120 BC for naval combat exercises. The same term is used later, as at Haichow in AD 1020 when Wang Kuan-Chih wanted to take water from such a spillway dam for the Grand Canal. Smaller-scale culvert spillways (*tung*), of stone, 3-4ft square, were often placed at suitable heights in the embankments enclosing a canal.

An emergency release sluice was also an early development in China. A *pa* (flying dyke) was a very long shallow U-shaped spillway with a stone revetment and masonry cheeks, running along the bund of a canal or lake. Usually this was full of reed bundles, fascines, earth, etc, forming part of the embankment. In times of emergency a small breach could intentionally be made in the centre of the fill, whereupon the force of the water would quickly wash it all away, flood and debris discharging together through previously prepared channels. Eleven flying dykes of this kind, built between 1680 and 1757, in the defences of the Hung-Tse Hu (lake) and the Grand Canal, measured an average length of 122m and an average height of 2.75m.[79] Good examples of these need to be identified on the Grand Canal if possible.

Many later canals were provided with drainage sluices, built into the bed of the canal, which drained into culverts passing under the canal. On 18th and early 19th century canals, the plugs which sealed these drains were made from wood and were hinged. An iron chain was attached which allowed them to be raised, thus draining the section of canal. Groves were provided at bridges and other points into which wooden stop-planks could be inserted. This ensured that only short sections of canal needed to be drained, and helped to conserve water. A good example can be found on the Manchester, Bolton and Bury Canal (UK), next to the Clifton Aqueduct.

Stop planks were also provided at either end of embankments or at places where the canal was in danger of breaching, such as in coal-mining areas throughout Europe. In some cases, automatic gates were built in their place, such that when there was a breach, the flow of water would close the gates and thus save water and damage. Examples can be seen on the Leeds and Liverpool Canal, Burnley (UK), although they are not now in use.

Culverts into which the canal drained were often used for allowing streams to pass under the canal. They were also built specifically for this purpose. If they were not built, the construction of the canal would interfere with land drainage, the land on the higher side of the canal becoming inundated. This could cause failure of the canal banks.

L *Accommodation bridges*

These are a very common type of feature, to accommodate existing tracks, roads, and rights-of-way and to connect lands divided by the new waterway. The outstandingly important Grand Canal in China has some particularly elegant large stone-arched examples. The historic Canal du Midi by contrast had 139 road bridges over its course, which are of surprisingly modest dimensions and with a towing-path underneath that is not large enough for a horse.

Most of these 17th-century stone-arched bridges have a height from water-level to the underside of the crown of the arch of 3.25m (10 ft 91 in), not much larger than the later typical broad-canal bridges used in the Industrial Revolution in Britain. However, the over-bridges on any canal could be a mixture of stone- or brick-arched bridges and draw (lift) and swing bridges. Many British canals in the Industrial Revolution were originally built with lifting or swing bridges. Arch bridges replaced them as road traffic increased during the late 18th and 19th centuries.

One important development of the canal age in Britain and Ireland was the skew bridge, first introduced by Chapman in 1808 on the Naas branch of the Grand Canal in Ireland. In a conventional bridge the arch is at right-angles to the canal and springs from a flat bed. In a true skew bridge, the arch is not at right-angles, so the beds of the arch are not directly opposite each other, but are slightly staggered along the line of the canal. The bed of the arch is also angled from the horizontal so that the forces act through the centre of the bridge. Brick bridges built on this principle are now widespread, and one can be found on the main line of the Grand Canal (Ireland), near Sallins, where the canal to Naas branched off. Unfortunately, the original ones have been rebuilt. Angled bridges were also built using a conventional right-angled arch, but with additional angled stone or brickwork at each side of the bridge. A typical example can be seen at Eanam Wharf, Blackburn (UK), built in 1810, on the Leeds and Liverpool Canal, though there are other examples throughout the British canal system. Such angled bridges are not as strong as a true skew arch because the forces do not act through the centre of the bridge.

Later came iron-girder and iron-arch bridges. There was a "Bridge of the Iron Window Lintels" built over a water-course in China about AD 1000, and the first known cast-iron bridge in the modern world, the Iron Bridge in Shropshire (UK), now part of a World Heritage site, spanned the navigable river Severn. The first iron bridge over a navigable canal was appropriately one of those built in the then iron-smelting centre of the world in Merthyr Tydfil, Wales (UK), for the opening of the Glamorganshire Canal in 1794. The Coalbrookdale Company cast two overbridges for the opening of the Kennet and Avon Canal in 1800; these are sited in the 18th-century Sydney Gardens in the World Heritage Site city of Bath. Telford also built two composite bridges with iron ribs supporting shallow stone-arches at the Trefor Basin to the north of the Pontcysyllte Aqueduct in 1805.

S I T E S

i **Notable overbridges on the Grand Canal (China)**.

Grading: 1. * 3. ***; 4. **. Total: 6

There are a large number of high-arched masonry bridges surviving along the line of the Grand Canal.

ii **Original overbridges on the Canal du Midi (France)**.

Grading: 1. *; 2. *; 3. ***. Total: 5

The features of this canal inspired succeeding developments on waterways of the modern period.

iii **Rhyd-y-car Iron Bridge, Glamorganshire Canal, Merthyr Tydfil, Wales (UK)**, 1790-94.

Grading: 1. ***; 2. ***; 3. **; 4. *. Total: 9

Erected by the local engineering genius Watkin George in 1790-94 in what was then the world centre of the iron industry. This was the first iron-girder bridge in the modern world. The sides of the bridge are single rectangular castings with two intermediate uprights and an enclosed arch with radial struts. Lobes underneath formed mortises for the tenons of the deck girders (now renewed) in a continuance of the use of woodworking-type joints by the earlier builders in cast iron. The bridge has been resited with other conserved canal remains at Chapel Row, Georgetown, Merthyr Tydfil. This bridge with Pont y Cafnau (see "Aqueducts") forms part of the integrated industrial landscape of Merthyr Tydfil that has already been considered by TICCIH as one of the 28 industrial sites of outstanding international importance.

iv **Sydney Gardens overbridges, Kennet & Avon Canal, Bath (UK)**, 1800.

Grading: 3. ***; 4. *. Total: 4

Cast in 1800 by the Coalbrookdale Company to span the canal in this elegant 18th-century pleasure garden, now part of the World Heritage city of Bath. One of the bridges is a footbridge of about 7m span and 3.05m width, with cast-iron deck and railings supported by four arched ribs, cast in two sections with compressive rings in the spandrels. The bridge was restored in 1978. The second bridge crosses the canal at an oblique angle in spans of over 9.15m (30ft) and carries a 5.8m (19ft) wide roadway. The face ribs are solid panelled in two sections and there are five interior ribs of T- or +-section carrying 3.05m (10ft) wide deck plates set parallel to the canal. The cast-iron parapets have diamonds superimposed on crosses.[80]

v **Trefor Basin overbridges, Ellesmere (Llangollen) Canal, Trefor, Ruabon, Wales (UK)**, 1805. Grading: 2. *; 3. ***; 4. *. Total: 5

Thomas Telford took advantage of the new adjacent Plas Kynaston Foundry where William Hazeldine was casting the deck of the Pontcysyllte Aqueduct in 1805 to produce cast-iron arched ribs to support the elegant segmental arches of masonry of the two canal overbridges at the north end of the aqueduct. Both bridges still carry public roads.

vi **Galton Bridge, Birmingham Canal (UK)**, 1827-30. **[Figure 7]**

Grading: 2. *; 3. ***; 4. *. Total: 5

The deep cutting proposed by Telford for the new low summit-level of the Birmingham Canal Navigation necessitated the use of the early type of large-span cast-iron arched-bridge developed by Telford in association with the ironfounder William Hazeldine. This was in order to carry a road across the canal. This remained in use for traffic until 1974 and the bridge has been retained as a footway. The bridge is flanked by huge, finely detailed, stone and brick abutments standing on the upper slopes of the deep cutting (see the new Birmingham Canal mainline in "Technologically significant canals").[81]

Figure 7 The substantial 46m cast-iron span of the Galton Bridge carries an 8m wide earlier public road over the 22m deep new canal to Wolverhampton: Birmingham, England (UK), 1827-30

M *Tunnels*

The civil-engineering technology applied to canal tunnels was not an innovation: Roman water-supply and lake-drainage tunnels of quite large section were not uncommon. That built in AD 41-52 to drain Lake Fucino was 5.5km long and 6m high and had some 40 construction shafts on its line. The surviving *Cloaca Maxima* draining the Forum area of Rome (a World Heritage site) was large enough to take boats used in periodic cleaning of the silt. There were even Roman road transport tunnels. One such carried traffic through the Posillipo Hill between Naples and Pozzuoli. It was driven through tufa bedrock and was 915m long and 7.6m wide. To try and admit light to the interior, the roof and floor converged towards the middle from the portals, which are no less than 23m high. It is thought to date from the time of Augustus (31 BC-AD 14).[82] Tunnels used by boats led into the city of Damascus from the river.

The Canal du Midi was the first heavily engineered summit canal of the modern age and enormously influential in the construction of waterways during the world's first Industrial Revolution. The Duke of Bridgewater saw the large Malpas tunnel on the Canal du Midi and was inspired to build the first heavily engineered modern canal in Britain, which terminated in canal systems at both ends.

The British canal network was notable for the extent of tunnelling needed to adequately serve the upland districts at the heart of the Industrial Revolution. The origin of this use may have been in flooded mining tunnels or "levels" where boats were used as a convenience on the large amounts of mine drainage water. One such at the then world copper-smelting centre of Swansea, Wales (UK), was constructed to supply coal to a new copper smelter constructed in 1748 and was reported on by the Swedish industrial spy Svedenstierna in 1803-04. At the Worsley Collieries end of the Bridgewater Canal (1759-60) the waterway was tunnelled into a hill for a at least a mile to drive directly into colliery workings. By 1878 it extended for a total of 40 miles underground on three levels connected by winding shafts and an inclined plane, and this well publicized system was widely copied in Britain and on the mainland of Europe.

At the Bridgewater Canal's other terminus in Manchester it terminated in a tunnel under Castle Hill, from whence coal was wound up for sale via a vertical shaft. A second longer tunnel of this type was added later.

While working on the Bridgewater Canal, its engineer, James Brindley, agreed to carry out a much larger canal, the Grand Trunk, traversing the centre of England to connect the large Trent and Mersey rivers. Near the middle, just north of the potteries at Stoke-on-Trent, was the Harecastle Ridge. This was the first intermediate tunnel on a British canal (1766-77) and the first large-length tunnel on any waterway in the world, and Brindley's opponents saw it as evidence of his insanity. More details of this work are given below. It is now impassable, as are the earlier Worsley mine tunnels, but still accessible are the slightly later (1775-92) Dudley limestone mining canals and associated Dudley Canal Tunnel, near Birmingham (see description below).

Some large waterway areas are characterized by a low use of canal tunnelling activity, notably India and North America, with only one substantial canal tunnel built in each. However, the unfinished Marshall canal tunnel on the Kanawha Canal in the USA provides a valuable time-capsule of 19th-century tunnelling methods.

S I T E S

i **Malpas Tunnel, Canal du Midi (France)**, 1681-83. **[Figure 8]**

Grading: 1. ***; 2. ***; 3. ***; 4.*. Total: 10

Built as part of the first heavily engineered summit canals of the modern age, this was the first navigable canal tunnel built and the first tunnel to be excavated by gunpowder, the use of which represented a most significant advance in rock tunnelling. Situated at Malpas, about 6 miles from Béziers, the tunnel is 157m long, 6.7m (22ft) wide, and 8.2m (27ft) high. After two years' work it was finished in 1681 and arched some ten years later.[83] Some 15.5m beneath is an earlier tunnel into which a shaft drains. This was built to drain the Étang de Montardy in 1247 and is an underground water-drainage culvert 1.5m (5ft), 2m wide, and 1360m long which is still in use.[84]

ii **Worsley Colliery Canal Levels, Bridgewater Canal, Lancashire (UK)**, 1759-.

Grading: 1. **; 2. ***; 3. ***; 4. **. Total: 10

This is the largest and earliest internationally known example of the extensive use of canal tunnels in a mine and it is important for being part of the most influential canal built as part of the Industrial Revolution (see "Technologically significant canals"). The entrance basin, surrounding quarry faces, bridges, and tunnel entrances are conserved and protected monuments.

iii **Harecastle Tunnels, Trent & Mersey Canal, Stoke-on-Trent (UK)**, 1766-77 & 1825-27.

Grading: 1. *; 2. ***; 3. ***. Total: 7

Built 1766-77 by James Brindley, the first intermediate tunnel on a British canal and the first intermediate long-length canal tunnel (2635m long) in the world. Excavation was effected in both directions from a number of shafts sunk to the tunnel's course, the spoil being loaded into buckets that were drawn up the shafts by horse-powered windlasses (horse gins).

A new technology of civil-engineering pumping was being deployed. First, wind- and water-driven pumps were installed to deal with the small quantities of water that were encountered. As the shafts penetrated deeper into the hill, water was met with in quantities sufficient to drown the bottom of the shafts, and also methane gas, which made working difficult. Only 374m of canal were driven in two years. Consequently windmill-driven ventilation was introduced and a Newcomen atmospheric (early low-pressure) steam engine was erected to pump the shafts dry. However, Brindley had known of the high water-table and relied on it to feed the summit-level of the new canal. Contemporaries called it "the eighth wonder of the world," and after Brindley's death in 1772 it was completed by his brother-in-law Hugh Henshall. It was 2.7m (9ft) high and 2.7m wide. Coal was found during the driving of the tunnel and side tunnels were driven along the coal seams at right-angles, so that 10-tonne boats could bring the coal out.

In 1827 Thomas Telford opened a larger parallel tunnel which had a horse towpath and one-way traffic was introduced on both tunnels. Subsidence is now affecting Brindley's tunnel and only Telford's is still in use.[85] Both tunnels are important in illustrating the early and progressive development of canal tunnelling technology.

Figure 8 The first known canal tunnel at Malpas, Béziers, Canal du Midi (France), 1681-83

iv **Dudley Limestone Mining Canals and Dudley Tunnel, near Birmingham (UK)**, 1775-92.
Grading :2. *; 3. ***. Total: 4

Parts of the mining system are maintained and are accessible by special trip-boats, and the main canal tunnel has been consolidated as part of the main canal system. Lord Ward's Canal was built from Brindley's adjacent Birmingham Canal in 1775-78 and penetrated through a 206m tunnel to terminate in underground limestone workings. The main canal tunnel that absorbed this was commenced through the 2.8km to the Dudley Canal in 1785-92. The 4.3m (14ft) high, 2.7m (9ft) wide tunnel was constructed with Abraham Lees as resident engineer and Thomas Dadford Senior (who had worked with James Brindley) as consultant. By 1790 two areas of limestone workings had opened up parts of the tunnel and a branch canal had been built along one of the limestone beds. This eventually extended for three-quarters of a mile with junctions, tramways, passing bays, and even a roving bridge. This is the system still accessible via a new section of tunnel. Among other canal branches is the 1084m tunnel driven westward to limestone mines under Wrens Nest Hill.[86]

v **Saint Quentin (Le Grand Souterrain de Riqueval), Canal de St Quentin (France)**.
Grading: 1. *; 2. *; 3. ***. Total: 5

The tunnel at St Quentin is 5670m long and was opened in 1810 by Napoleon I. Until 1864, boats were moved through the tunnel by gangs of seven or eight men. In 1864 chain towage was introduced, the chain tug using a horse gin built on board to pull the tug and vessels in tow. From 1874, steam-powered chain tugs were used, and these were replaced in 1910 by electrically powered chain tugs, which are still operating. During World War I the tunnel was used as a hospital, with additional side tunnels being built to accommodate the wards.

vi **Marshall Canal Tunnel, Kanawha Canal, Virginia (USA)**.
Grading: 3. ***; 4. *. Total: 4

The Kanawha Canal's Unfinished Division from Eagle Rock to Buchanan in Virginia was begun in 1851 and abandoned in 1856, leaving locks, culverts, aqueducts, and tunnels in an incomplete state. The unfinished 571m long Marshall Tunnel, like the rest of the canal, is a valuable time-capsule on canal construction strategy. There were three intermediate shafts to provide ventilation and from which construction could proceed. That on the east was in part at least a natural sinkhole (this is now filled with clay). The central shaft was some 30m deep and construction in the two headings at the bottom proceeded for about 41m (the shaft is now infilled). The western shaft is shallower and only about 30m from the mouth of the western heading, from which some 64m of tunnel was driven. From the east heading 138m of tunnel was driven as far as the natural eastern shaft. The processes of tunnelling with hand drills and black powder are clearly illustrated by this untouched time-capsule. Most of the canal remains were designated the Upper James Scenic River by the Virginia General Assembly in 1985.[87]

N *Cargo handling*

The ease of loading and unloading cargoes from inland vessels is one of the most important factors in the decision to send goods by water. Treadmill cranes were often used on early waterways, the example at Gda_sk (Poland) also being used for removing and fitting the masts of sailing ships. Several examples of smaller treadmill cranes can be found alongside German waterways, in Lüneburg, Stade, Würzburg, and Rüdesheim. Trier (Germany) retains two large cranes on the banks of the Moselle (see below). Small cast-iron-framed cranes can be found in many places, particularly on the British canal system (one at Worsley on the Bridgewater Canal). Steam-powered cranes are also widespread across Europe. More unusual, and particularly noteworthy, is the compartment boat hoist at Goole (UK). The last remaining of five such hydraulically powered lifts, it unloaded specially built coal carrying compartment boats. The system was in use from 1863 to 1986. When the Dortmund-Ems Canal (Germany) was being designed in the 1880s, the system was studied, though not used. A similar, but more developed, system of compartment boats was used on waterways linked to the Mitteland Canal (Germany) between 1941 and the 1980s.

S I T E S

i **Trier Cranes, Rhineland-Palatinate (Germany)**, 1413 & 1774.

Grading: 3. ***. Total: 3

Trier was a capital of the western Roman Empire, situated on the navigable river Moselle. The river was always important to the wine trade and two old cranes, dating from 1413 and 1774, survive on the river bank at Trier that were largely used for loading casks of wine. Both are sited in squat circular masonry towers with high conical roofs constructed in two sections. The upper, turning, sections each have two angled 13m long jibs protruding. These could be used both to serve boats on the river and the road on the bank simultaneously. Each crane was powered by two treadwheels, 4.2m in diameter and 1.2m wide.[88]

O *Warehouses*

Warehouses of one sort or another to hold high-value and perishable goods must be a building type as old as inland, coastal, and maritime shipping itself. One particularly notable range of warehouses was arranged round the Roman Emperor's great new octagonal port basin at Portus, west of Rome. All canals built in the modern industrial period have warehousing provision.

In Europe, there are fine early (16th-18th century) examples of salt warehouses in Lübeck and Regensburg (Germany). Early merchandise warehouses can be found in the old ports, such as Hoorn and Harlingen, around the former Zuider Zee (now the _sselmeer) in The Netherlands. Although designed for Dutch East India Company trade, they were often alongside canals and were probably used in conjunction with the *trekvaart* system.

The development of warehouses following the Industrial Revolution in Britain is best illustrated by structural evolution in that country. Early examples of British warehouses have unsupported wooden beams. Later, to increase the width, wooden and then cast-iron columns were introduced. At first, no external awnings were provided so that cargoes were unloaded in the open.

A development of the late 18th century on British canals was the use of "boat holes" - large arched openings on the ground floors of warehouses that gave access to an internal boat-loading dock with a hoist to the upper floors. This type originated on the pioneering Bridgewater Canal at Manchester, where in 1765 the canal was extended underground by tunnel to give access to a haulage shaft up street level that was driven by a waterwheel operated by surplus water flowing out of the canal. In the 1770s a dry-goods warehouse was built by the canal engineer James Brindley over the mouth of the access tunnel; this winding shaft and the waterwheel were then adapted to drive the hoists in the new warehouse. Some canalside warehouses were the earliest such structures having railways going into them. They are described in the "Early railways" section below. External awnings began to be provided on canal warehouses generally following the stimulus to competition provided by railways in the later 19th century.

Steel and brick had replaced iron and stone as structural materials by the start of the 20th century, with concrete being used later. The warehouses of the Leeds and Liverpool Canal (UK), built between the opening of the canal in 1773 and the 1920s, exhibit all these features. Good examples of early 20th century warehousing can be seen in the Westhaven, Berlin (Germany) of 1914-1923, with its associated port administration buildings, and in the haven of Prague (Czech Republic). Both these sites had railway connections, as is usual in Europe for inland ports built after the late 19th century.

S I T E S

i **Bridgewater Canal Warehouses, Manchester (UK)**, 1770s; 1827-28.
Grading: 1. **; 2. ***; 3. **; 4. *. Total: 8

The Manchester canal warehouses exhibit innovation in the introduction of internal boat unloading and the facility for goods movement from the waterways at the front through to cart loading at the rear.[89]

i.a **Dry Goods or "Grocers" Warehouse, Castlefields, Manchester**, 1770s. **[Figure 9]** Designed by James Brindley at the Manchester end of the Bridgewater Canal and extended in a large range eastwards by 1829. In 1960 much of the original building was demolished, except for the back and side walls, unloading basins and the shipping holes where boats drew in to be unloaded and originally continued to the vertical shaft where coal was hoisted to an upper coal wharf; the wheel-pit and underground channels for powering the warehouse and shaft hoist also survived. In 1986 this served as the basis for a partial reconstruction of the warehouse, waterwheel, and hoist.[90] This site could be combined with any designation of the Bridgewater Canal (see "Technologically significant canals").

i.b-d **Merchants' Warehouse, Bridgewater Canal, and other waterways warehouses at Manchester**. The last intact early 19th-century warehouse to survive at the Manchester end of the Bridgewater Canal, it was built in 1827-28, mainly in brick. Two central high-arched shipping holes allow canal boats into the centre of the four-storey warehouse where an internal hoist could unload them. Four full-height loading bays on the front facade also facilitated external loading. Internally brick cross-walls both supported the floors and reduced the likely spread of any fire. The building has recently been renovated and entered re-use.

The later, but still early 19th-century Middle Warehouse at Manchester has been renovated and converted to apartments. It retains a huge arch spanning the two former boat holes in the centre of the building. All these warehouses could also be combined with any designation of the Bridgewater Canal which they served (see "Technologically significant canals").[91] The Old Quay Company's New Botany Warehouse of 1824, on the banks of the Irwell Navigation nearby, exhibits a mature use of cast-iron internal

Figure 9 "Merchants" and Middle Warehouses, Castlefields Basin, Bridgewater Canal, Manchester, England (UK): part of a series of innovative late 18th and early 19th century warehouses with internal boat-unloading docks (prior to restoration) columns and could be grouped with these other Manchester waterways warehouses.[92] This warehouse has also been recently renovated and entered reuse.

P *Canal railways and railway/waterway warehouses*

Most considerations of the railway heritage are preoccupied solely with the development of the modern locomotive railway, which is generally agreed to have started with the building of the Liverpool and Manchester Railway in 1830. However, railways were common underground in the Middle Ages in mines in the German-speaking areas of Europe. In 1603 the first substantial above-ground railway was constructed at Wollaton (UK) and from then until 1800 such lines were generally short transport ways connecting mines to the nearest navigable water. They were traffic feeders to the existing waterways, with which they formed an integrated transport system. Always horse-drawn, they developed considerably in sophistication in Britain during the period 1800-30, with experimentation in types of mechanical propulsion and iron track. Again they were generally part of a larger system based on navigable waterways. After the construction of the Liverpool and Manchester Railway in 1830 they spread world-wide as a more rapid arterial transport system that in many areas rivalled and even superseded water-borne transport in the later 19th century.

The interchange warehouses on early 19th century railways were important structures, not least because they form the first warehouses on railway systems. Even as railways became independent arterial systems of transport in their own right, interchange points still remained of great importance, especially with the larger canals bringing goods from abroad.

S I T E S

i **Railway Warehouses on and around the Brecknock and Abergavenny Canal, Wales (UK)**. Grading: 1. **; 2

The Brecknock and Abergavenny Canal has a series of warehouses at interchange points with horse-drawn railways feeding traffic from nearby ironworks. These warehouses, all standing on canal wharves, are some of the earliest railway warehouses built. They are all part of one of the 28 industrial landscapes and sites already recommended by TICCIH as being of prime importance. A fourth early railway warehouse 9 miles to the west of the Canal at Brecon was linked to the Swansea Canal over the mountain.

i.a **Bailey's and Brewer's iron warehouses (now known as Auckland House), Gilwern**, 1819 & 1820.

The warehouses on the canal bank were connected to the Clydach Rail Road (Railway) which was completed in 1794. The Baileys, ironmasters at nearby Nant-y-glo, were given permission to erect a warehouse on the new wharf at Llanelly at a maximum cost of £120 in August 1819.

A second warehouse was built at Gilwern when another ironmaster, George Brewer, of nearby Coalbrook Vale Ironworks also requested warehouse accommodation on Llanelly Wharf on 17 January 1820. New railways built from the rival Monmouthshire Canal to Coalbrook Vale in 1828 made the second warehouse redundant.

Both these two-storey stone-built warehouses have survived in use as domestic accommodation. Multiple arches, now blocked, once allowed railways into their interior. An impressive bank of early 19th-century canalside railway-fed limekilns survives alongside.

i.b **Baileys' iron-warehouse, Govilon**.

Another pig-iron and iron-castings warehouse was built at the end of a new railway built from the Baileys' Nant-y-glo blast-furnaces to the Brecknock & Abergavenny Canal at Govilon, opened on 6 December 1821. This railway ended against the eastern wall of the canalside warehouse and a second railway of a different gauge, leading to towns and cities to the east, ended against the western wall. The three-storeyed rubble-sandstone warehouse has important cast-iron fittings: a loading-crane anchorage and loading platform. The building has been sympathetically converted to British Waterways canal offices. Another impressive bank of early 19th-century limekilns survives nearby.

i.c **Hill's iron-warehouse, Llanfoist**. **[Figure 10]**

This warehouse was completed in 1820-21 at the end of the ironmaster Anthony Hill's railway to the Brecknock & Abergavenny Canal wharf at Llanfoist. The ground-floor was open and supported on pillars: grooves were cut into the rock over which the warehouse was built, conforming to the 2ft (0.61m) gauge of the railway. The two-storey stone-built structure is built into a hillside and another railway branch probably ran along the terrace at the rear of the upper storey of the structure. There is a central boat loading-door on the upper storey which is supported by large timber beams spanning the stone pillars of the ground-floor. The upper floor of the warehouse has been converted into a house.

i.d **Castell-du warehouse, Sennybridge**.

This warehouse of 1834 is sited 9 miles west of the Brecon end of the Brecknock & Abergavenny Canal, at the northern roadside terminus of a railway from the Swansea Canal to the south. A now blocked stone arch gave this horse-drawn line access into the warehouse interior for the storage of valuable goods coming from the canal to the south. This two-storeyed stone-built structure is used as a farmhouse with early railway stables, offices, and limekilns attached to one side.[93]

ii **Gare Maritime and Tours et Taxis Warehouse, Brussels (Belgium)**.

Grading: 2. *; 3. ***; 4. *. Total: 5

This warehouse complex impressively illustrates the later important relationship between ship canals and inland locomotive-railway transport. The canal from Willebroek and the sea was opened in the 16th century, and extended beyond Brussels to Charleroi in 1827-32, with a widening carried out in the early 20th century. Between the Avenue du Port and the Rue Picard is the Gare Maritime built between 1902 and 1910 by the architects C Bosmans and H Van de Veld, and the Tours et Taxis freight company public warehouse built between 1904 and 1907 by E Van Humbeek. This latter includes three huge freight-handling sheds with cast-iron roofs. The complex has continued in use as a railway goods depot.94 There is now a proposal to re-use part

Figure 10 Hills iron-warehouse, Powys, Wales (UK), 1820-21: one of a series along the Brecknock and Abergavenny Canal that were served by associated horse-drawn railways of the buildings as a concert-hall. This is one of the 28 industrial archaeological sites recommended by TICCIH as being of outstanding importance.

Q *Limekilns*

Many canals carried coal and limestone for the use of the surrounding agricultural community. Lime was an important cargo for mid-18th century canals in Britain. It was the agricultural revolution which had brought about a large demand for lime as a fertilizer. More lime was also needed for use as a mortar to construct the new workers' housing in the Industrial Revolution. Inside, lime was also used as limewash to make the rooms light enough in the north of England for weaving. Limekilns stood alongside the canals, and some horse-drawn railways also brought limestone and coal down to the canal bank so that the lime produced could be distributed via the canal. It would be difficult to identify one set of limekilns as being of particular technological significance. Rather, they are important for being part of the cultural landscape of the canal.

R *Passenger carrying*

Canals have always been used for transporting passengers. Indeed, many of the earliest canals in China were designed for carrying troops. This military use continued into the 19th century, with Sweden and Britain, at least, having inland "Royal Retreats" with associated barrack complexes accessible via their inland waterway systems.

Civilian passenger traffic generally developed on a more *ad hoc* basis, with organized services probably starting on the Willebroek Canal, 30km north of Brussels, in 1618. By 1628 there were services between Groningen and Zuidbroek and from Utrecht to Amsterdam, the latter service operating on a new, and specially built, canal. These services, known as the *trekvaart*, were to spread all over the Low Countries, with timetables introduced which allowed people to travel widely, regularly, and speedily. The system was one of the most important reasons for the economic development of the 17th-century Netherlands in much the same way as British canals were to serve during the Industrial Revolution in 18th and early 19th century Britain.

In Britain and Ireland similar services grew with the canal system. Many canals had important services, but those on the Grand Canal in Ireland and on the Lancaster Canal in north-western England were particularly influential in the early industrial period. In Ireland, along the Grand Canal, the large hotels built for passengers are still standing, while the Packet Houses in Lancaster and Leeds have recently been restored. In the USA the many waterway passenger routes included the spectacular Pennsylvania Main Line (see "Inclined planes"). Passenger services over the vast distances of China, Russia, the USA, and Canada were particularly important in the process of nation-building. The importance of this type of passenger service declined rapidly with the advent of rail travel but remained of significance on the large waterways of the USA, eastern Europe, and India.

Even today there are many regular services, and although most are for pleasure, there are still some commuter passenger services. In Moscow the Northern River Terminal, built in the 1930s, still serves as a terminus for both pleasure and commuter services. There is also an impressive passenger station at Galati (Romania) on the Danube.

S I T E S

i **Grand Canal Passenger Hotels (Ireland)**, 1800-10.

Grading: 3. ***; 4. **. Total: 5

The 127km of the Grand Canal mainline were built between 1755 and 1804. Six passenger "passage boats" were operating by 1790, and lighters with both common and state cabins were introduced in 1834. Five hotels in fine classical style with central pediments and features were built in the first decade of the 19th century and three of these remain at Portobello in Dublin, Robertstown and Shannon Harbour.[95]

ii **Northern River Terminal, Moscow (Russia)**, 1930s.

Grading: 3. **; 4. **. Total: 4

In Moscow, the Northern River Terminal, built in the 1930s, still serves as a terminus for both pleasure and commuter services. The Moscow-Volga Canal, completed from the enlargement of earlier canals and navigations, was 128km long and 5.5m deep and is remarkable for both the elaboration and the size of its structures. It was planned to carry 5 million passengers a year and 3.6 million tonnes of goods traffic and to generate electricity at its eleven locks that could take passenger vessels up to 290m long and 30m wide. It is illustrative of the large scale of waterways traffic on the bigger navigations of the world.[96]

S *Rafting Timber*

Many waterways were used for rafting and storing timber. On river navigations, weirs were often designed with sections which could be used by rafts. The weirs on the Vltava, in Prague (Czech Republic), are good examples of those which still have slopes built into them. The large rafts could pass down these without being split into smaller sections.

Many early versions of North American river navigations were specifically built for this trade using rafts or primitive vessels that were broken up for their timber on arrival at their downstream terminus.

Two European canals were built specifically for this trade. The Gaujau Daugava Canal, Riga (Latvia), built between 1899 and 1903, includes what is probably the world's longest lock, over 1km in length. Small rafts brought down the Gauja could be collected together and floated through the canal system, which linked several small lakes, for eventual use in factories in Riga or for export from the port (information from Andris Biedrins, Riga). The canal could be used by conventional boats, unlike the Schwarzenberger Schwemmkanal, crossing the Austrian-Czech border near Aigen (Austria), which was purely for rafting timber. The logs were floated down the canal individually, with "locks" controlling the flow of water; there is even a tunnel. The first section opened in 1793 and the canal was last used in 1961.[97]

T *Canal-trade complexes*

Canal ports evolved at strategic points on every canal and waterway as trade developed. There were docks for boat building, stabling, workers' housing, and a range of other functions.

i **Worsley canal complex, Bridgewater Canal, Manchester (UK)**.

Grading: 1. *; 3. **; 4. **. Total: 5

Adjacent to the conserved twin entrances to the Worsley canal mines are two original masonry overbridges. Between these is the packet house and restored steps from which the early passenger service on the canal was run. Nearby are a crane, an early dry-dock, and a large granary and warehouse; the latter two have been converted into apartments. There are the remains of a limekiln and two large ranges of housing for the workers who toiled at the joint canal and colliery yard alongside the canal. The Earl of Ellesmere's castellated boathouse still stands, from which his passenger barge emerged to convey Queen Victoria along the canal. The surroundings of this complex were later formed into a garden village. The complex is important for being at one of the centres of the Industrial Revolution.

ii **Lauenburg (Germany)**.

Grading: 1. *; 3. **; 4. *. Total: 4

In Germany there are still many canal communities as, unlike those in Holland and Belgium, it is traditional for boatmen to have their own house. Many of these communities had boatmen's associations or societies, some dating back to the 13th century. Lauenburg, on the Elbe and at one end of the pioneering Stecknitz Canal (see "Locks" and "Summit level canals"), is one of the oldest such communities. The old town, close to the river, has many houses dating back to the 17th century. The town still has a boating community and there is also a large shipbuilding yard.[98]

Integrated Industrial Areas

i **The metals mining landscape of the Harz Mountains, Lower Saxony, including the mines of Rammelsberg and the historic town of Goslar (Germany).**

Grading: 1. **; 2. ***; 3. ***; 4. *. Total: 9

The medieval and later mining landscape of the Harz Mountains, which includes the Rammelsberg mining area and Goslar, is already recognized by inscription on the World Heritage List. It includes many underground mining canals.

ii **Ironbridge Gorge, Shropshire (UK).**

Grading: 1. **; 2. ***; 3. ***; 4. *. Total: 9

This is an ironmaking and collieries landscape centred on the navigable river Severn and its connecting horse-drawn railways and small-boat canals. The latter includes the Hay inclined plane and the Tar Tunnel, which was intended to be an underground mining canal. The Ironbridge Gorge is already a World Heritage site.

iii **Blaenavon, Gwent, Wales (UK)**.

Grading: 1. *; 2. **; 3. ***; 4. *: Total: 7

The area of the Heads of the Valleys in South Wales had the largest ironworks in the world in the early 19th century, and Blaenavon retains the substantial remains of works complexes and surrounding settlements, as well as a publicly accessible conserved coalmine. Around this is an ironmaking and collieries landscape which includes the formation of many horse-drawn railways and what was in the early 19th century the longest railway tunnel in the world. The oldest existing railway/canal interchange warehouses (1810-20) survive on the Brecknock and Abergavenny Canal that forms the eastern boundary of the area. This area has been recommended by TICCIH as one of the 28 most important international industrial sites not on the World Heritage List.

iv **Ancoats, Manchester (UK)**.

Grading: 1. *; 2. ***; 3. ***; 4. **. Total: 9

The first steam-powered textile mills were in Ancoats.[99] When the Rochdale Canal opened, arms of the canal were built to serve these mills, which are on the banks of the canal, only a road separating them. Although the first mill opened before the canal, subsequent developments were encouraged by the canal. The whole area shows how important good transport was to the development of industrial England. Cotton textiles were the most important factor in the economic success of Britain in the 19th century, and this site can be said to symbolize the importance of all these factors.

More of the original canalside factory development has disappeared in Birmingham: both Manchester and Birmingham were manufacturing areas at the centre of the Industrial Revolution, where the accessibility of cheap canal transport was crucial to the development of some of the earliest large factory complexes in the world.

Historic urban areas

In addition to these industrial areas, the designation of any historic city will almost inevitably include the canals or waterways that served these urban centres and their attendant industries. Significant examples of this are Venice (Italy) and the 18th-century City of Bath (UK), both on the World Heritage List. The 19th-century infrastructure and architecture of the City of Glasgow (Scotland, UK) also survives as a substantially intact mercantile and manufacturing centre of the former British Empire, with one of the most impressive intact 19th-century wharfages on the early Forth & Clyde ship canal at Port Dundas.

Historic canal lines and heritage transportation canal corridors

In many cases involving canal monuments it is most sensible to consider a related group of waterway structures or the whole, or part of, a canal line. Often such a designation made for conservation purposes will include a buffer zone flanking the waterway to safeguard the visible cultural landscape beyond the actual boundaries of the waterway. These designations of a waterway will include a grouping of the types of features whose significance has been considered above. In the following section the various types of waterway line are considered.

This "corridor" designation is especially popular in North America as one aspect of the concept of cultural landscapes. A valuable *Information Document on Heritage Canals* was drawn up in consultation with canal experts by the Department of Canadian Heritage in 1994 and has been forwarded to the World Heritage Committee for consideration. Whether a particular waterway is designated as a line of canal and associated engineering works, or whether its significance merits the designation of a wider corridor, ought perhaps to relate to how much the canal has influenced the development of the economic development of the corridor through which it runs. A problem in this concept is in densely developed "integrated industrial landscapes" (see above), where successive arterial transport routes intersect one another and relate to a landscape area as a whole and not a definable corridor.

A *River navigations*

Improvements to bypass natural obstacles along the line of both major and minor rivers have probably been constructed since very early times. It has already been noted how the ancient Egyptians built a canal around the First Cataract on the Nile; they also built a slipway around the Second Cataract at Aswan.

The *Fossa Mariana* was built in southern Gaul by Caius Marius in about 101 BC and bypassed the difficult Rhône delta via a cut from Arles to the Mediterranean, the course of which was later followed by the now disused Canal d'Arles at Fos. Before the time of the Emperor Trajan the Romans had taken steps to improve the navigation of the Danube. In part of the Carpathian gorges they had made a towing path, in one stretch cut out from the cliff and elsewhere supported on wooden beams in holes drilled into the rock. When Trajan was preparing his conquest of Dacia across the river he strengthened this path and cut one or more canals near Sip at the Iron Gates, up which boats could be towed by teams of oxen. This enabled the two Roman Danube fleets, the *Classis Moesica* based near the river mouth and the *Classis Pannonica*, to make contact. The raising of levels at the Iron Gates locks has drowned these remains.

B *Lateral canals*

These are "simple" navigations running parallel to existing rivers. They usually raise no complex problems of water supply or civil engineering and therefore lack the general significance of other types of waterway.

Figure 11 Transformation of the Milan (Italy) water-supply and irrigation canal of 1179-1209 into the lateral Naviglio Grande in 1269 lies at the beginning of the development of the modern canal

S I T E S

i **Naviglio Grande, Milan (Italy)**, 1179-1209 & 1269. **[Figure 11]**
Grading: 1. **; 2. ***; 3. ***; 4. **. Total: 10

This is a particularly significant and important example dating from the beginning of the development of the modern canal. The origin of this canal lies in an irrigation channel and water supply for Milan which runs from the river Ticino near its outlet from Lake Maggiore south to Abbiategrasso and then east to the southern suburbs of Milan. It was built between 1179 and 1209 from an intake near Casa della Camera for 50km with a fall of 33.5m. In 1269 it was enlarged into a navigation and named the *Naviglio Grande*.[100]

C *Contour canals*

A simple navigation between two valleys could be established by a canal leaving one river and circumventing the adjoining spur on the level, so avoiding the need for an elevated summit level with its water-supply problems.

S I T E S

i **Magic Transport Canal (China)**, *c* 219 BC.
Grading: 1. ***; 2. ***; 3. ***; 4. **. Total: 11

The *Ling Chhii* (Magic Canal) was constructed for reasons of military transport and supply through the high watershed connecting rivers flowing north and south between the Hsiang and Li rivers. It is the first known contour transport canal. The part of the Ling Chhii which justifies this designation was called the Nan Chhii and branched off from the Hsiang River to run along a suitable level or slightly falling contour for some 3 miles until it met the upper waters of the Li. Additionally to the summit cut, the small Li was canalized using lateral canals for 28km and the larger Hsiang for 2.5km (first mentioned during a rebuilding in AD 825). The locks were transformed from flash to pound locks, possibly in 1059, during general repairs to the canal. There is a large intake dam to the waterway on the Hsiang river; locks were sited at either end of the waterway. The canal formed part of a 1250 mile waterway by 200 BC. It continues in heavy use.[101]

ii **Karlsgraben (*Fossa Carolina*), Treuchtlingen, Bavaria (Germany)**, AD 793.
Grading: 1. ***; 2. *; 3. *; 4. *. Total: 6

This was the first attempt to cross the greatest of the European watersheds, and was begun by the Emperor Charlemagne in 793. The canal was to link the rivers Altmühl and Schwäbische Rezat, thus joining the Danube to the Rhine. Around 7000 workmen were engaged on the project, but it is uncertain if the canal was ever used. Today it is still possible to see the excavations, part of which are in water.[102]

iii **Bridgewater Canal, Manchester (UK)**.

For Grading see below.

A particularly influential waterway built at the beginning of the Industrial Revolution (see "Technologically significant canals").

D *Summit-level canals*

Canals could only become an effective means of long-distance communication when the abilities of contemporary engineering were such that they could pass from one valley to the next. These most closely involved two or three technologies. The waterway would have to rise to the top or summit level over a watershed from each side. The huge amounts of water needed to supply the extensive lockage on each side of the summit would need to be supplied via a system of water-feeder channels and reservoirs.

i **Grand Canal (China)**.

For Grading see below.

See "Technologically significant canals" and "Reservoirs" for details.

ii **Stecknitz Canal (Germany)**. **[Figure 12]**

Grading: 1. ***; 2. ***; 3. **; 4. *. Total: 9

This was built to transport salt from Lüneburg to the river Trave and Lübeck, whence the salt was exported to Russia and Scandinavia, mainly for salting herring. The Duke of Saxony and Lübeck agreed to make the Delvenau and Stecknitz rivers navigable via the Mölln lake and thus provide a navigation between the Elbe and Trave rivers in 1390. Fifteen staunches were constructed and a 13km summit level. The summit level had little water and millers only opened the flash locks on alternate days. The journey of 100km could take several weeks. The first boat traversed the system in July 1398 and the 12.5-tonne capacity boats were 19m x 3.25m. The first two pound locks were built on the canal in 1480 and the system was improved and carried on in use until replaced by the Elbe-Trave Canal in 1900.[103]

See "Locks" for details of the substantial remains at the Dückerschleuse, Stecknitz, and the Palm Schleuse in Lauenburg. Several churches along the route of the canal have items given by the Stecknitz boatmen, some dating back to the 16th century. In Lübeck there are two salt warehouses, dating from 1579 and 1745 respectively, which were used to store the salt brought from Lüneburg by the canal boats. There are also warehouses in Lüneburg with a treadmill crane to serve boats.

iii **Canal de Briare (France)**, 1605-42.

Grading: 1. **; 2. ***; 3. ***; 4. *. Total: 9

This very influential 55km waterway joins the Loire and Loing rivers. It is the first modern summit level canal in Europe and arguably the ancestor of all the large summit-level waterways of the modern age. Leonardo da Vinci discussed the possibility of two summit-level canals with the French king Francis I: waterways between the Saône and the Loire and between the Garonne

Figure 12 The Palmschleuse (1724) and part of the line of the Stecknitz Canal (Germany), the first summit-level canal in Europe (1398) and the Aude (the Canal du Midi project). A start was made on a simpler project - a canal between the Loire and the Seine which could supply food to Paris.

Hugues Cosnier was appointed engineer-contractor in 1604. The summit level had a 5.25km feeder leading into the Étang de la Gazonne, which acted as a reservoir for the canal, as did the deepening of 2.8km of the 6km of the summit level with one lock that could be taken out of service as the level fell. There were to be 41 masonry locks. There was a 7-rise lock at the northern end of the summit level and 2, 3, and 4 rises elsewhere. The construction was completed in 1638-42 with a second feeder from the Loing to the summit level. A modernized version of the canal is still operating.[104]

iv **Canal du Midi (France)**, 1667-71.

For Grading see below.

See the entry for this canal in "Technologically significant canals."

E *Technologically significant canals*

Listed here are canals that were significant in their overall concept and construction. These are the most influential waterways in this document. All are landmarks in the world history of canals.

i **Grand Canal (China)**, 4th century BC and AD 581-617 onwards.

Grading: 1. ***; 2. ***; 3. ***; 4. **. Total: 11

In spite of its great age this remains in use and is still the longest canal in the world. The earliest use of canals in China was for the transport and provisioning of troops and for the transport of grain taxes. The main purpose of the Grand Canal was the collection of the latter. It grew out of the Pien (Bian) Canal in Henan, built in about the 4th century BC. This left a grain-growing area around the Yellow River near Xinyang and ran almost level to the Huaihe and Hongze Lake.

The first of many extensions and rebuildings to form the Grand Canal began in the Sui Dynasty (AD 581-617). It left Hangzhou, ran north across the Yangtse and Yellow Rivers, and eventually ended near Beijing. Parts were lateral canals and part was the first summit-level canal known (see "Reservoirs"). The first recorded pound lock was built on the canal in the 10th century (see "Locks"). A text of 1072 mentions the first recorded staircase lock.

However, the development of technology in China switched to sea transport in the 13th century and the grain taxes were moved by large sailing ships. Consequently the lesser canal traffic could use double slipways (see "Inclined planes") and simple single-gate locks.[105]

ii **Canal du Midi (France)**, 1665-81.

Grading: 1. ***; 2. ***; 3. ***; 4. **. Total: 11

This was the first heavily engineered summit canal of the modern period and was enormously influential in the conception of canal schemes. It was the greatest civil-engineering project of 17th-century Europe and possibly the world. The idea sprang from an engineering project envisaged by Leonardo da Vinci during the last three years of his life (1516-19), but not executed until 1665-81. It was supported by Louis XIV's chief minister, Colbert, and carried through by Pierre-Paul Riquet, an engineer of great talent and dedication.

The canal, which is still fully operational, is 240km long, rises 62.8m from the Garonne at Toulouse to the summit, and then falls 190m to the Étang de Thau. There are a hundred locks, three large aqueduct bridges, a tunnel and numerous weirs, road-bridges, control works and a large and complex water-supply system.[106]

iii **Bridgewater Canal, Manchester (UK)**, 1759-61.

Grading: 1. *; 2. ***; 3. **; 4. ***. Total: 9

This canal in many ways was the harbinger of the Industrial Revolution that started in Britain but spread across the world. The application of advanced civil engineering to solve the problems of economic bulk transport was inspired by the completion of the Canal du Midi in 1681, which the Duke of Bridgewater visited on his continental European travels.

The engineers John Gilbert and James Brindley built a 11.7km long canal from tunnels inside the coal mine at Worsley (eventually 42 miles of canal underground on four different levels); on an aqueduct 11.9m above the navigable River Irwell on a 183m long aqueduct to unloading tunnels with shafts to wharves in the town of Manchester above.[107]

The building of the Bridgewater Canal in England in the 1760s inspired nine decades of canal building in Britain where 6500km (4000 miles) of canals had been built in England and Wales by 1850. It also in turn inspired the construction of many canals in continental Europe and in North America.[108]

The canal is still open, although a swing aqueduct over the Manchester Ship Canal has replaced Brindley's original aqueduct. The twin entrances to the Worsley underground mining canals are a protected ancient monument and the remaining features and warehouses (see "Warehouses") at the Manchester end are being conserved.

iv **Ellesmere Canal, Clwyd and Shropshire, Wales & England (UK)**, original mainline, 1793-1805.

Grading: 1. **; 2. ***; 3. ***. Total: 8

On the Ellesmere Canal the chief engineer of one generation of British canal engineering, William Jessop, oversaw the development of the outstanding canal engineer of the next generation, Thomas Telford, and the genesis of the team that were to develop new structures and canals. The spur that produced these advances was the fusion of lowland English canal technology with the challenges of an upland Welsh landscape.

Two deep valleys had to be crossed by the projected mainline of the canal and Jessop also planned tunnels on a grand scale: 4215m at Ruabon, 1131m at Chirk, and 436m at Weston. In the end only 28.6km of this mainline was completed, but its engineering was publicized in *Telford's Atlas* and by engravings and became very well known and influential internationally.

Pont-y-Cafnau, Telford's Longdon-upon-Tern, and Jessop's partner's Derby Holmes iron aqueducts provided the context for Jessop to propose cast-iron aqueducts for Chirk and

Pontcysyllte in 1795. Telford acted as resident engineer and Chirk Aqueduct was opened in 1801 as a constructional hybrid. Instead of the unstable mass of puddled clay that characterized the waterproofing of most British aqueducts, the sides of the water channel were sealed in the hydraulic lime used in both earlier continental canal and Roman water-supply aqueducts.

Where it was revolutionary was in the use of cast iron for part of the trough of such a large structure, the bottom of the water channel being formed of cast-iron plates. Adjacent to the north was the Chirk Tunnel (1377 ft). With its opening coal could be taken south to branch canals at Frankton leading to Llanymynech limestone quarries and used in limekilns en route. The huge 307m long and 38.4m high Pontcysyllte Aqueduct with its cast-iron deck cast in the specially built Plas Kynaston Foundry nearby was the highest canal aqueduct ever built. The huge approach embankment on its western side would itself stand as a remarkable civil-engineering structure even if the aqueduct did not exist.

The abandonment of the proposed canal mainline up to the intended summit level north of the aqueduct meant that an alternative water supply had to be sought. A (navigable) feeder to the river Dee was completed in 1808 with an elegant weir called the Horseshoe Falls. Upstream the large Bala Lake in the Welsh mountains was heightened by a dam (now replaced) in order to serve as a reservoir.

The Trevor canal basin to the north of the Pontcysyllte Aqueduct has two original (1805) overbridges which are composite structures of iron and ashlar masonry, having shallow segmental masonry arches supported on curved cast-iron ribs. The basin also served as a transshipment point for the twin-track horse-drawn railway that brought coal down to the canal from the collieries further north. This replaced the proposed flight of locks, which was presumably where the important experimental canal lift, using floats, of Edward Rowland and Exuperius Pickering was built in 1796.[109]

The ironfounder William Hazeldine, a key member of Telford's contracting team, then used his Plas Kynaston Foundry to cast other bridges and aqueducts on projects engineered by Telford, such as the Caledonian Canal in Scotland and his new Birmingham mainline.

There are three great aqueducts that are direct successors of those at Chirk and Pontcysyllte and were built on the 31.5 mile long Edinburgh & Glasgow Union Canal in 1817-22 to take boats 12.5 ft wide, twice the width of those crossing the earlier aqueducts. Telford advised the engineer Hugh Baird on their design but, although they superficially resemble Chirk, they have all-iron troughs and Avon is the second biggest aqueduct in Britain. The aqueducts are 7.24m wide: Slateford is 23m high and 153m long over eight arches, Almond is 23m high and 128m long over five arches, and the Avon is 26m high and 247m long with each of its twelve arches spanning 15.25m (50ft). Telford described one of these as "superior perhaps to any aqueduct in the Kingdom."[110]

v **Birmingham Canal Mainline/Liverpool and Birmingham Canal (UK).**

Grading: 1. *; 2. *; 3. ***; 4. *. Total: 6

Building on the heavy engineering techniques pioneered on the Ellesmere Canal, these improvement works necessitated by traffic congestion pioneered the use of huge earthworks and

Figure 13 In 1826-38 Thomas Telford pioneered the use of huge earthworks and straight formations on waterways such as the Birmingham Canal Mainline at Smethwick, England (UK). This 22m deep cutting replaced two earlier and higher canals, one of which is seen to the right straight formations in 1826-38 on a scale not seen before. Telford drew up the original report in 1824.

In 1827-29, Brindley's (1768-69) and Smeaton's (1790) summit levels on the Birmingham Canal were bypassed by a new 22m deep cutting at Smethwick with double towing-path and Telford's magnificent cast-iron Galton Bridge, an overbridge spanning the 45.75m (150ft) wide cutting in a graceful arch. An earlier branch canal was taken over the new mainline by the elegant cast-iron Engine Branch Aqueduct. Brindley's main line had been shortened from 37km to 26km as work progressed in 1837-38. A new 330m Coseley Tunnel was authorized in 1835 with a double towing-path.

The new Birmingham and Liverpool Junction Canal carried this scale of engineering northwards for another 64km in 1826-35. The Tyrley and Grub Street cuttings and the Nantwich, Shebdon, and Shelmore embankments were on a huge scale: Tyrley is 1.6km long and 27m deep, with a soaring masonry bridge on its length; Grub Street is 80 ft deep and 3.2km long, with another high bridge with intermediate strut across the waterway; Shelmore Embankment is 1.6km long and 18m high. Telford lay dying as it slipped and settled continuously: the alternating friable rock and clay at Tyrley also caused continual rock falls during construction.

William Cubitt, Telford's assistant on the Birmingham and Liverpool Junction, later went on to do similar work during the straightening of the Oxford Canal.[111]

vi **The Erie Canal (USA)**, 1817-25.

Grading: 1. **; 2. ***; 3. **; 4. **. Total: 9

This canal was significant for being the product of the intercontinental transfer of technology (see "Technology transfer"). Over and above this it pioneered the use of an indigenous culture of low-cost renewable engineering that was vital to the rise of the USA as the world's most powerful nation. The Rideau Canal in Canada, surveyed at the same time, also demonstrates the intercontinental transfer of technology and the adaptation of advanced, highly financed engineering to the circumstances of a developing country. Indeed, the differing states of preservation of the waterways may well mean that the Rideau, rather than the original Erie Canal, is selected as an illustration of this process of intercontinental transfer and development.

However, at the time it was the Erie that was far more economically significant. Its engineering works were considerable. One aqueduct over the Mohawk was 228m long, the other was 362m long, and a third over the Genesee at Rochester was 245m long. There were twin five-lock staircases cut into rock at Lockport, near Buffalo, and a deep cutting to the west. There was a great embankment over the Cayuga Marsh, 3.2km long and up to 21m high.

Such was the huge success of the waterway that it led to a great "canal mania" opening up much of the USA. The first rebuilding of the Erie Canal took place in 1835, but substantial sections of the canal escaped the successive rebuildings.

vii **Rideau Canal, Ontario (Canada)**.

Grading: 1. **; 2. **; 3. ***; 4. **. Total: 9

This was one of the first canals designed specifically for steam-powered ships. It was built in 1826-32 as a military supply route by the British Corps of Royal Engineers and so it is an important example of intercontinental technology transfer. It runs over 202km from Kingston to Ottawa. There are 47 large masonry locks and 52 dams and embankments. A series of stone-arch dams, including the large one at Jones Falls (the first large stone-arch dam in North America), created the series of lakes used to form the waterway. Now a National Park and a popular recreational waterway, it is particularly important in international terms because it is the only canal dating from the great North American canal-building era of the early 19th century that remains operational along its original line with most of its original structures intact.[112]

F *Ship Canals*

Under this heading are considered waterways of significance that linked oceans or were large enough to accommodate contemporary sea-going craft.

The first of this type was that built some 4000 years ago by the Pharaoh Sesosteris I, who is recorded as having linked the Nile (which empties into the Mediterranean) with the Red Sea. This important waterway had a very long and significant history (see "Sites" below) interrupted by blockages from lack of maintenance, sandstorms, and silting from the Nile and its floods. The Red Sea was also difficult to navigate with its multiple reefs and shallows and prevailing northerly winds.[113]

The earliest recorded direct sea-to-sea canal was that built by Xerxes, King of Persia, in 480 BC through the 4km neck of the Mount Athos peninsula as his invasion force closed on Greece.[114] The concept of large ship canals was obviously current in the western world even if the technological resources were not generally equal to the task. Periander (600 BC), Demetrius Poliorcetes (4th century BC), Julius Caesar (1st century BC), Caligula, Nero (1st century AD), and Herodes Atticus (2nd century AD) all considered making a canal across the comparatively narrow isthmus of Corinth. Nero actually attempted to build the deep 4-mile canal across the isthmus in AD 67 and, had he survived, it might have been completed. Nero's workers moved half a million cubic metres, out of the necessary 13.5 million, in the three or four months that they were at work. Their engineering works, up to 30m deep and 50m wide for 2km at the western end and 1.5km at the eastern, were visible until the modern canal was completed on the same alignment.[115]

Over a period of time the size of what were considered to be standard ocean-going vessels changed dramatically. In the modern period many of the European maritime states saw the possibility of extending their surrounding sea-borne trade by large canals extending inland or cut-through appropriate through appropriate necks of land. This process was very widespread and it is difficult to identify any one waterway as being outstandingly significant in this process of evolution.

The Forth and Clyde Canal may have been the first very large totally artificial water channel in the modern period that was completed to carry sea-going ships from sea to sea. Early experiments in steam navigation were held on the canal. The opening of the Kiel Canal as an international waterway in 1785 was also an event of significance.

The Crinan Canal was 9 miles long through the Mull of Kintyre peninsula in Scotland (UK) and was opened in 1809 to aid the development of the western Highlands and Islands. Steamer services used it from 1819 when Henry Bell's pioneering steamship *Comet* began running between Glasgow and Fort William by way of the canal.[116] The Rideau Canal has some significance as the first canal specifically designed for steamships (see "Sites" below).

S I T E S

i **Nile (and Mediterranean) to Red Sea (Egypt)**.

Grading: 1. ***; 2. *; 3. ***; 4. **. Total: 9

This canal was 97 km long from near the later site of Cairo to the northern part of the Bitter Lakes and thence to the Red Sea. First built 4000 years ago by the Pharaoh Sesosteris I, it was used five centuries later when Queen Hatshepsut employed it to transport myrrh trees from the land of Punt (Eritrea) to decorate the terrace of a temple she had built to Amon-Ra; the story of the trade is related on the walls of this temple at Der el-Bahari in Thebes (1520 BC).[117] The canal features again in a wall painting of the time of Seti I (*c* 1380 BC), but it was gradually overwhelmed by sandstorms and fell into disuse through lack of adequate maintenance.[118] Rameses II is said to have rebuilt it in the 12th century BC.[119] Around 600 BC the Pharaoh Necho had it partially re-excavated, but killed 100,000 workers in the process, according to Herodotus. However, he did not complete the work as he was "admonished by an oracle that all his labour would turn to the advantage of a barbarian."[120] Archaeologists present at the cutting of the modern Suez Ship Canal in 1866 confirmed that King Darius of Persia, who occupied Egypt in 521 BC, completed Necho's canal. The fragments were found of a red granite tablet in the Persian, Median, Assyrian, and Egyptian languages describing the opening of the canal.[121] Diodorus Siculus wrote of a later restoration by Ptolemy II that "…Ptolemy Philadelphus … in the most suitable spot constructed an ingenious kind of lock. This he opened, whenever he wished to pass through, and quickly closed again, a contrivance who usage proved to be highly successful."

In fact the canal was often rebuilt - a total of four times between *c* 600 BC and the 2nd century AD. It was rebuilt again by the Arab 'Amr ibn-al-'As in 641-42. The usability of the canal, at least in that period, seems to have depended on the varying flood or high-water in the Nile itself. In 710 the Arab governor of Egypt wrote a letter to the administrator of Aphrodito up the Nile asking him to send supplies across to Suez: "If you fail to send any of the said materials and provisions and the water has subsided, you will have to carry them by road as far as Suez, paying the expense of porterage out of your private substance. "

The surviving remains of the canal suggest that it was about 97km long, 46m wide, and 5m deep.[122]

ii **Mount Athos Canal (Greece)**, 480 BC.

Grading: 1. ***; 2. **; 3. **; 4. **. Total: 9

Xerxes, King of Persia, was taking his army to attack Greece. The first major engineering work en route was a bridge of boats over the Hellespont and the second was a canal so that his ships could avoid the 48km passage round the Mount Athos peninsula. This 4km waterway was given breakwaters at each end to prevent silting. Herodotus described how the Phoenicians showed the

Figure 14 The Rideau Canal, Ontario (Canada), was one of the first canals specifically designed with locks large enough for steam-powered ships other labourers how to excavate a canal cutting by constructing sloping rather than vertical walls. Remains of the canal are still visible.[123]

iii **Rideau Canal, Ontario (Canada)**. **[Figure 14]**

See "Technologically significant canals."

iv **Suez Canal (Egypt)**, 1854-69.

Grading: 1. ***; 2. ***; 3. *; 4. **. Total: 9

The influence of the scale and constructional methods of this waterway profoundly affected all canals built afterwards, and not just ship canals. There was a time in the mid-19th century when it might have been thought that the new railway age would supersede all the relatively small canals built before this period. The 1350-tonne standard barge was a long time in the future. Robert Stephenson, whose Alexandria to Suez Railway was opened in 1856-59, pronounced the Suez Canal impracticable. The French ex-diplomat Ferdinand de Lesseps was a superb organizer and created the first great isthmian canal between two oceans with modern steam-powered dredgers and 20,000 workmen. The 164km lockless canal had a depth of 8m and a bottom width of 22m.

Ship canals proliferated all over the world, inspired by the example of Suez. In the Netherlands waterways to the sea from Amsterdam and Rotterdam were constructed in 1862-76 and 1863-72 respectively. A canal was constructed between St Petersburg and Kronstat (Russia) in 1875-84. De Lesseps began work on the Panama Canal in 1884 and a French-promoted company on the Corinth Canal in 1882. In England the Manchester Ship Canal was built to the same depth as the Suez Canal in 1887-94. The Kiel Canal linked the Baltic and North Seas across the Jutland Peninsula in 1887-95.[124]

This canal is of profound significance but has been repeatedly rebuilt and enlarged.

G *Multi-purpose canal systems*

As has already been discussed, waterways are unique in being a bulk-cargo transport way utilizing as its transport medium a natural resource. They constitute a resource that can itself be used for a variety of purposes. The extent of this multi-purpose use in some areas can be gauged from the following data: in India out of 11,000km of navigable waterways, 25% were constructed primarily as irrigation canals, 60% were navigable rivers, and 15% were primarily made as navigation canals and are mostly tidal.[125]

The huge and complex irrigation system of the island of Sri Lanka was built in the 5th century BC and in its complexity it has no parallel, even in contemporary India.[126] Much of this system has had an extensive secondary use as a navigation. Details of it are given in the "Sites" section below. In the African state of Mali, canals that were extensively used for irrigation were also used for transport and extended to the old Royal Capital of Tombouctou (Timbuktu).

Many of the early European waterways primarily built for navigation also had a secondary use (often neglected by historians) for powering mills and industrial works.[127] Navigable water was also widely used for such purposes in Canada and the rest of North America.

The canals built by the British in mid-19th century India were similarly multi-purpose in type and incorporated some huge aqueduct structures. The primary function of these canals was as irrigation watercourses, but their gradient profile and hence water flow was decided by a determination to allow navigation by the building of frequent locks.

Intercontinental technology transfer of a different type was illustrated by the building of the multipurpose Biwako Canal. The Japanese engineering student Sakuro Tanabe visited the USA to study contemporary canal-building and hydro-electric practice, and on his return built the Biwako Canal in the years 1885-90: this included one of the first hydro-electric power-stations ever built.

S I T E S

i **Irrigation/transportation canals system (Sri Lanka)**, 5th century BC.

Grading: 1. ***; 2. **; 3. ***; 4. **. Total: 10

A colossal and complex system of inter-related dams, canals, and lakes (tanks and reservoirs) linking to the rivers radiating from the island's central highlands. Aryan settlers of the 5th century BC who practised an agrarian system of agriculture almost immediately started the construction of tanks and irrigation canals in the dry zones of the north, east, and south of the island. Rivers were dammed to feed tanks that had an ingenious technique of locking and letting-out water through a system of valves within cisterns. Channel gradients were very low. The Jaya Ganga (Victorious River) Canal ran down from the Kalaveva reservoir to the Tissavapi reservoir in the ancient capital Anuradhapura, 54 miles (87km) away at a gradient of 6in to the mile. Water from these large reservoirs flooded the paddy-fields and also supported a large secondary trade in rice and timber.[128]

ii **The Ganges Canal, Roorkee, Uttar Pradesh (India)**, 1842-54.

Grading: 1. **; 2. *; 3. ***; 4. **. Total: 7

Over 300 miles long, this is India's most notable canal, built during India's "Golden Age" of irrigation when, between 1817 and 1901, 5483km of main channel and 29,282km of distributaries were built in upper India alone, with many of the main channels also being made navigable.[129] The Ganges Canal is still considered to be one of the great irrigation works of the world.

The then Governor-General of India, Lord Ellenborough, only agreed to the work being begun provided that it should be first a navigation and only fulfil a irrigation purpose as a secondary role. The Ganges Canal was both the longest navigation and the longest irrigation canal in the world,with 827km of dual-purpose waterway from the Ganges to Nanoon, including its two branches, one to Kanpur, the other to Farrukhabad, and a further 740km of irrigation-only branches. The most spectacular section is the 27km downstream from the Haridwar intake to Roorkee, situated in the foothills of the Himalaya, 160km north-east of Delhi. The canal drops through four 2.7m (9ft) falls, each with a former navigation lock. Two large aqueducts carry the Ranipur and Pathri rivers over the canal whilst the Ratmau River is crossed on the level with an attendant spillway which is opened out during the monsoon. The Solani river is crossed on a magnificent 15-arch aqueduct ornamented with lions and with approach embankments over 2 miles long.[130]

The canal's engineer, Sir Proby Cautley, founded the University of Roorkee as a training ground for canal engineers. This is now India's famed engineering school, and internationally its origins parallel the central engineering workshops of the Göta Canal at Motala Verkstad, Sweden (1822), which produced many of that country's brilliant early engineers.

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Several of the illustrations of European waterways in this study have kindly been supplied by Michael Clarke of Milepost Research.

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50 paces [250ft], and the whole space was covered over with a great roof like a shed. The gates were "hanging" or portcullis gates (*hsuan men*); [when they were closed] the water accumulated like a tide until the required level was reached, and then when the time came it was allowed to flow out."

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Yellow River at a point south of Tung-a in western Shantung and reached as far as An-Shan near Tung-phing, where it met the northern end of the summit level completed six years before. On the way it incorporated the short canal, the *Chhing Chi Tu*, which had been built by Hsun Hsien in AD 352. The important summit section of the completed 1035 mile new line of the Grand Canal was itself the work of a Mongol military engineer, Oqruqui, in 1283 and the following years. It had been built in accordance with plans drawn up by Kuo Shou-Ching and the canal was conveyed through a cutting 30ft deep. The canal was known as the *Chi Chou Ho* and at its northern end connected with the *Chhing Chi Tu* of AD 352 and at its southern end, at Chi-ning, with the *Huan Kung Kou*, built in AD 369 for the campaigns of Marshal Huan Wen. The summit level of the 1280s was 138ft above sea level and always caused problems for the overall use of the canal, so that the parallel sea-trade prospered. As a consequence the central and most difficult parts of the Grand Canal were remodelled to a high level of efficiency in 1411. This was carried out by Sung Li, an engineer who had trained at the Imperial University and been the Minister of Works, at the proposal of the Assistant Administrator of Chi-ning, Phan Cheng-Shu. He was advised by "an old countryman" (probably an irrigation-worker) of Wen-shang, Pai Ying, who showed how the waters of the Wen and Kuang Rivers could be used more effectively. Pai Ying suggested that a new 1 mile long bund or dam be constructed on the latter north of Ning-yang to form a reservoir which would always keep the canal full, with the aid of a forking lateral canal from the former, and these major works were successfully completed in 200 days by a force of 165,000 men. Sung Li also installed four small reservoirs near the canal itself, known as "water boxes" (*shui kuei*). These may have been the first side pounds. They were repaired and enlarged in 1540 and 1616.

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