# Early Canals, The Evolution of the Technology

## Introduction

Canals have been excavated for drainage and irrigation for thousands of years. Once built, the larger of the canals were undoubtedly used for trade (boats were far more efficient for transporting goods), and later a few were built specifically for commerce. However, for several thousand years canals were restricted to areas where the land was relatively flat. Some gradient was needed to allow water to flow for both drainage and irrigation purposes, but this was limited to a gradient less than 0.5% (½ meter per kilometre [1:200], or 0.25°). An increase in gradient caused by even small hills and ridges caused the water to flow too fast for boats to use and scoured out the banks of the channel.

This article looks at the development of the technologies that allowed canals to traverse hills and valleys.

## Ancient Canals

Naturally occurring waterways, rivers, lakes, and the seas have been used for movement and the transport of goods for tens of thousands of years. Water transport was easier, quicker, and safer than travelling over land. Over time improvements were made to the waterways to facilitate this use including the construction of harbours, wharfs, and improvements in the depth and alignment of suitable rivers (river navigations[1]). Canals are different, they are artificial waterways flowing in engineered channels, that were excavated for a purpose such as flood control, irrigation (drainage management), defence, and/or trade. In many situations, the waterway served several purposes as the commercial opportunities created by drainage canals were quickly exploited and the waterway improved to facilitate navigation by suitably designed boats.

The oldest-known canals of this type were built for irrigation in Mesopotamia circa 4000 BCE and by the Indus Valley Civilization in Pakistan and North India from circa 2600 BCE. Similar canals were dug in China a few centuries later[2].

The distinguishing feature for location of these early developments was the relatively flat topography and the presence of rivers and lakes that were exploited by the canal builders. Relatively flat land meant controlling the level and flow rate of water in the canals was either unnecessary, or only required simple sluices and blocking boards; techniques still used today in many irrigation systems. Dealing with significant changes in level introduces a whole new set of issues.

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[1] For more on some early river navigations in England see ***Early Canal Projects in the UK***: https://mosaicprojects.com.au/PDF_Papers/P207_The_first_canal_projects.pdf

[2] These early canals are discussed in more detail in ***The First Canals***: https://mosaicprojects.com.au/Mag_Articles/AA036_The_First_Canals.pdf

## Dealing with Hills

The maximum gradient for most navigable rivers is significantly less than 0.5% (½ meter per kilometre [1:200], or 0.25°), any steeper and the flow rate causes problems. The same issue affects canals with the added problem that fast water-flows will also erode the channel banks.

The standard way of overcoming this issue as well as ensuring an adequate depth of water is to build a series of dams or weirs across the river, or canal channel, with some form of spillway or gate to regulate the water level and create reservoirs of low-speed current flow upstream of the weir. These sections of the river, or canal, where the water level and flow rate are controlled are often referred to as *levels*.

This basic approach to managing the flow of water is still used through to the current day. The challenge is allowing fish and boats to cross the weir efficiently. Modern weirs often have 'fish ladders' built in; allowing the movement of boats presents a more difficult challenge.

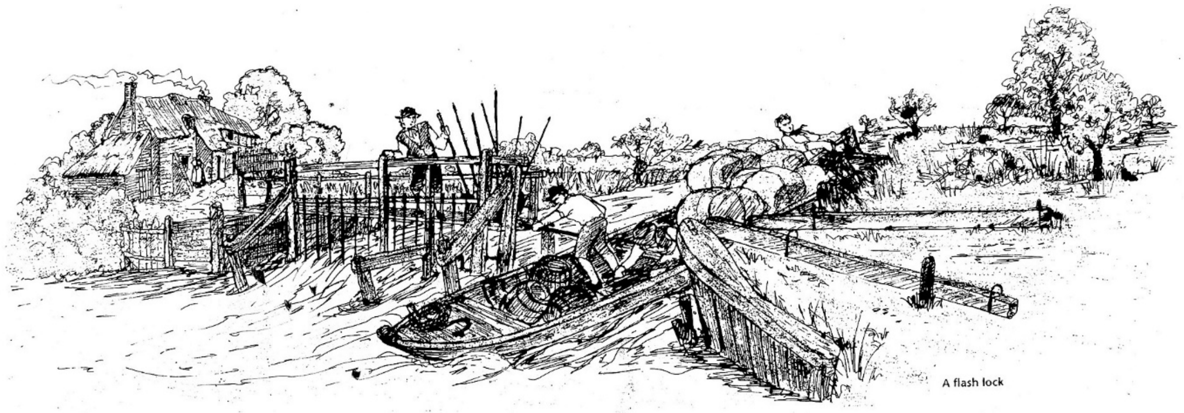
## Crossing the Weirs

As outlined above, the original way of establishing a set of *levels* was to build a series of relatively low dams across the canal or river, but this requires the creation of a place where boats could cross the dam or weir[3].

### Flash locks

One of the earliest options for crossing small dams and weirs was a *flash lock* or *staunch lock*. The earliest European references to this type of lock are from Roman times. This type of lock was typically included in small dams or weirs that had been built across a river either to create a head of water for use powering a water mill, or to manage the water flow to create navigable *levels*; keeping the *level* above the weir at sufficient depth to allow navigation and/or power the mill.

Flash locks was traditionally designed with a single removable gate consisting of a set of boards, called *paddles*, supported against the current by upright timbers called *rymers.* When in place, these restricted the flow of water creating the *level*. Boats moving downstream would wait above the lock until the *paddles* and *rymers* were removed, which would allow a 'flash' of water to pass through, carrying the boats with it. Boats travelling upstream would be winched or towed through the lock once the gate was opened.

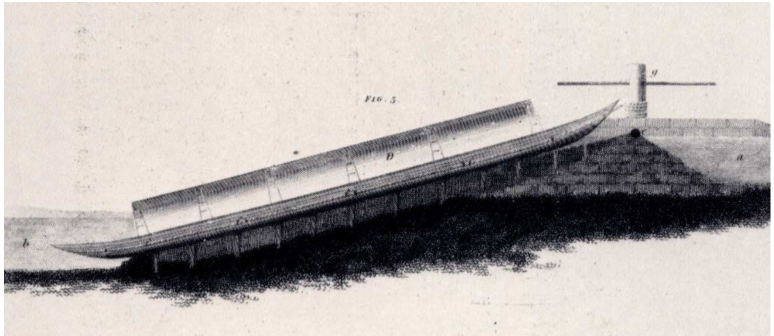



Considerable skill was involved both in removing and replacing the paddles in a timely manner, and in navigating the boat through the lock. Flash locks are still used today, but usually have mechanical gates to shut off the water flow when boats are not using the lock.

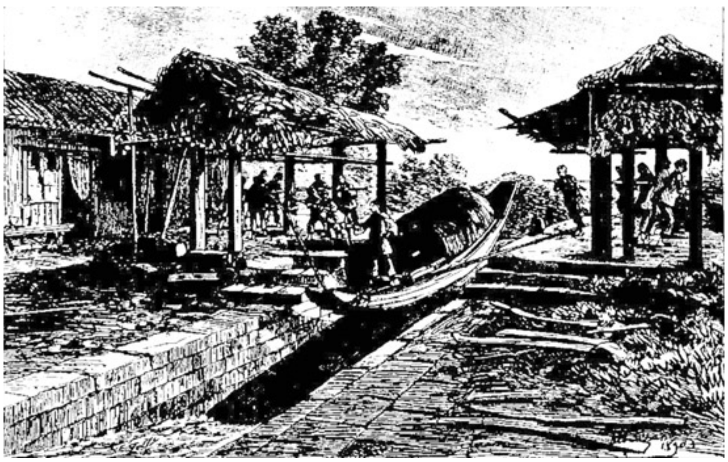
[3] **Note**: The difference between a dam and a weir is usually based on how the water flow is managed. Weirs tend to be designed to allow water to flow over the top (crest). Dams use gates or spillways to regulate the flow.

## Double slipways

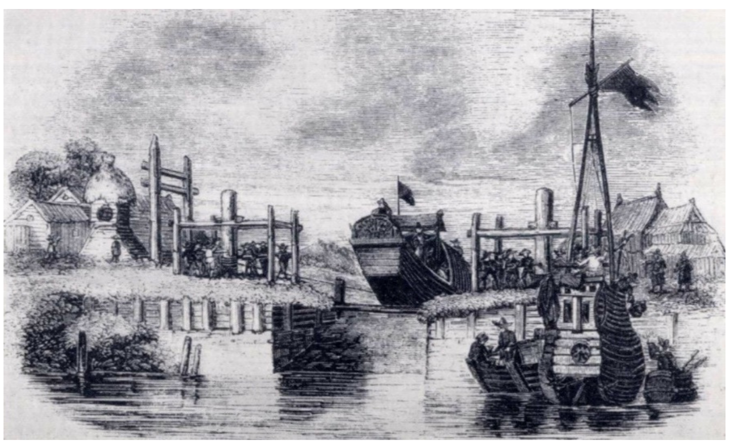
The concept of a double slipway appears to have been developed in China at some time before 984 CE to replace flash locks, reducing water usage and allow the passage of larger boats. Chinese boats, did not have any keels and were almost flat-bottomed, allowing them to move between lower and higher water levels in canals over double slipways.



The slipway acts as a spillway to regulate water levels, but with ramps on both sides extending into the water. A ship would approach and be fastened to ropes attached to capstans (man powered or ox powered). Within two or three minutes the ship would be hauled up the ramp and for a moment would balance insecurely in the air. Then it would shoot forward, scudding down into the canal at a level several feet higher or lower than it had started. The disadvantage of this technique was that boats and their cargoes often sustained severe damage.



The image below is on the Grand Canal China, where this type of lock was in use from the 3rd century through to the 20th century. Note the flat bottom of the boats.



## Removing the Weirs - Locks

The next improvement in design was the pound lock. This type of lock acts as a dam, and incorporates a chamber with gates at both ends that control the level of water in the pound. Pound locks were first used in China during the Song Dynasty (960–1279 CE), having been pioneered by the Song politician and naval engineer Qiao Weiyue in 984 as a replacement for the problematic double slipways. This is the standard type of lock used on canals today.

These early locks used vertical gates, counterweighted, and lifted by winch or other gearing mounted on an overhead gantry. This type of gate can operate against water pressure; as the gate leaves the sill, water enters the chamber, supplementing or replacing the culvert supply. But the turbulence is more difficult to control, and the overhead gantries impose restrictions on masts and other superstructures of a vessel.

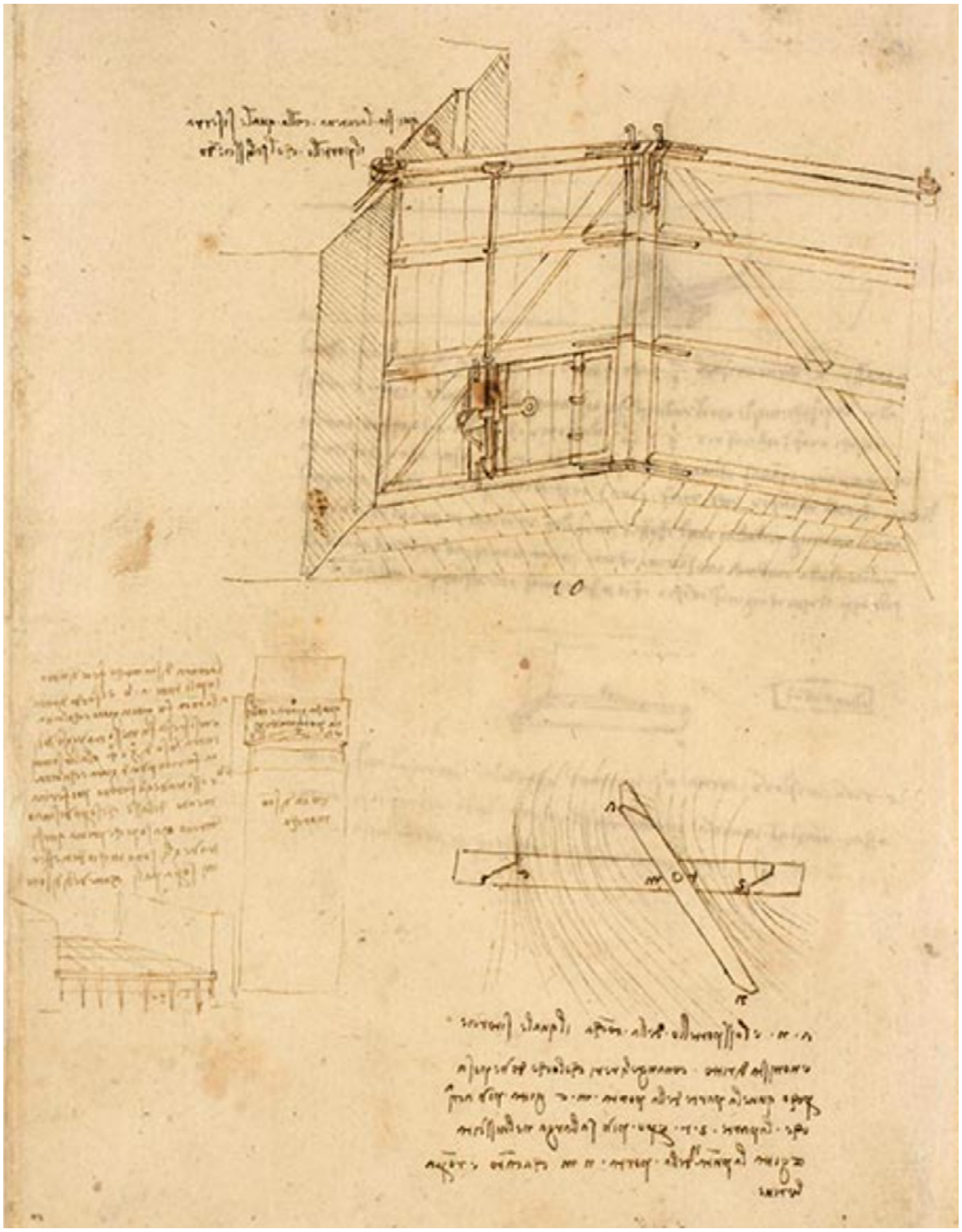

In Europe, a primitive form of lock had been in operation from 1180 at Damme, on the canal from Brugge to the sea. However, the first example of a pound lock, was probably built at Vreeswijk, Netherlands, in 1373. Situated at the junction of the canal from Utrecht with the Lek River, outer and inner gates contained a basin, the water level of which was controlled by alternatively winding up and lowering the gates. In the 15th century the lock-gate system was much improved with the addition of paddles to control the flow of water in and out of the lock chamber through sluices in the gates or sides of the lock. This pound lock serviced many ships at once in a large basin and appears to have been used to manage the difference in water level between the basin and the tidal river.

The first true pound lock was built in 1396 at Damme near Bruges, Belgium. A bit later, the Italian Bertola da Novate (c. 1410–1475) constructed 18 pound locks on the Naviglio di Bereguardo (part of the Milan canal system sponsored by Francesco Sforza) between 1452 and 1458. All of these early locks used the vertical gate[4].

[4] For more on these early canals see ***The First Canals***: https://mosaicprojects.com.au/Mag_Articles/AA036_The_First_Canals.pdf

The mitred canal gate was the next major development, replacing the earlier vertical lift gate. The gates are set at an angle facing into the flow of the stream using the angle of the two gates to resist the load of the water.

This type of gate may have been invented by Leonardo da Vinci in 1487 for the San Marco canal in Milan where the lock was used to overcome the difference in water levels and connect the Martesana Canal and the Naviglio Grande. The Naviglio Martesana still has the decaying wooden lock gates which are identical to those in a drawing from Leonardo's Atlantic Codex (Codex Atlanticus)[5].



[5] Source: http://codex-atlanticus.ambrosiana.it/#/Detail?detail=656 page 656 (year 1493)

One great advantage of mitre gates is that they were self-sealing by the pressure of the water (since they point upstream). As can be seen from the drawing, Leonardo also developed an improvement on the lock-gate mechanism with the addition of a lower opening operated by a specially designed off-centre hinge. This allowed for gradual opening in response to the increasing flow of water and easier regulation of the pressure exerted on the lock gates.

## Maintaining Water Levels

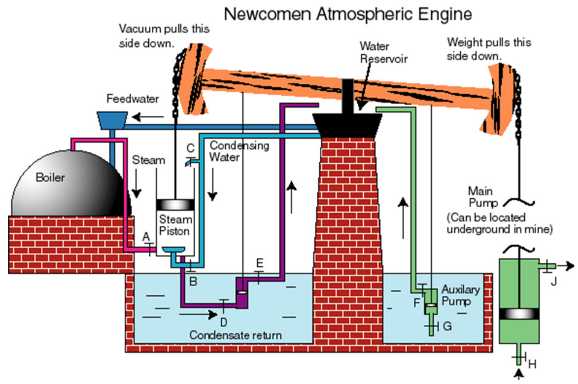
The introduction of the water efficient pound lock allowed canals to climb over hills and cross valleys, but water only runs downhill. So, while the pound lock was far more water efficient than the earlier flash locks, measures were required to keep the top levels filled all year, and other measures to prevent the water level becoming too high during rainy periods.

### Canal overflows

Many lock gates are designed to act as a weir:

Alternatively, overflow channels are designed into the canal, bypassing the lock, directly transferring water to the lower level. The sill of the overflow is set at the desired maximum water level:

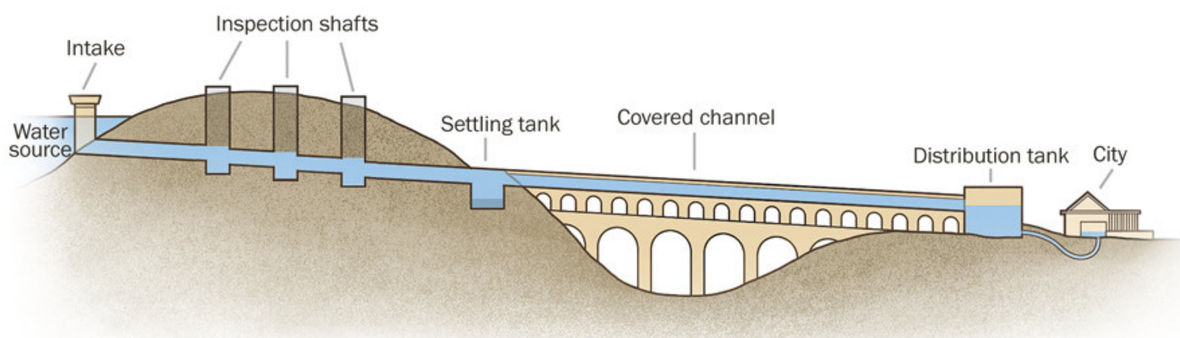
## Keeping the canal full




The challenge of keeping the top *levels* of a canal full depended on circumstances and finding a water source was a major constraint on design. Most canals used a combination of stream diversions, tapping into springs and ducting water to the canal, constructing large reservoirs and pumping. Large steam pumps for dewatering mines had been relatively common since the invention of the Newcomen Atmospheric Engine in the early 18th century and could easily be adapted to pumping water from a reservoir up to the top *level* of a canal. As pumps improved, this option became more viable but was still expensive compared to using natural water resources.

## Tunnels and aqueducts

The idea of using tunnels and aqueducts to smooth the flow of water dates back to before Roman times. The first aqueduct in Rome was the Aqua Appia, built in 312 B.C.E. by Appius Claudius, it was 16 km in length (mostly in underground tunnels).




Adapting these ideas to the construction of 17th century canals was straightforward. The oldest canal tunnel in the world is the Malpas Tunnel in France, built in 1679 to carry the Canal du Midi under the d'Ensérune hill in Hérault, France.

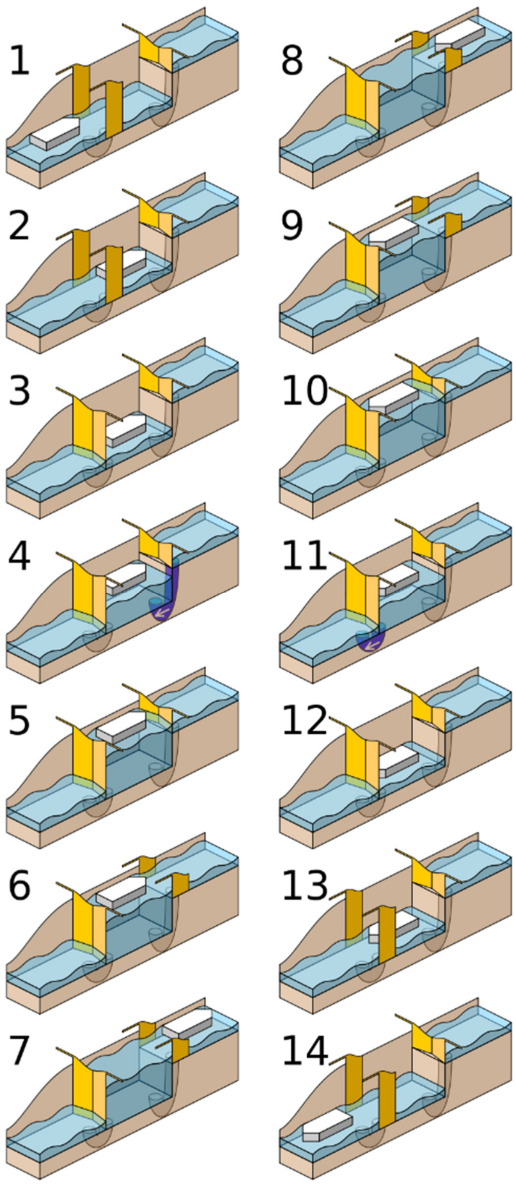
In some canal tunnels the towpath continues through the tunnel. In other cases, especially on English narrow canals, there is no towpath. The horse would be led over the hill and the boat would be propelled by legging (two boatmen laying on their backs moving the boat along with their legs pushing on either the wall or the roof of the tunnel.

Canal aqueducts were used to cross valleys and rivers. Early aqueducts such as the three on the Canal du Midi that were built in 1690 had stone or brick arches, the longest span being 18.3 metres (60 ft) on the Cesse Aqueduct.

Later aqueducts often used cast iron for improvements in weight and water retention

## Working the locks

Despite the improvements in technology, the sequence of operation of a canal pound lock has not changed over the centuries:




1. Boat sailing upstream
2. Boat enters lock
3. Downstream gates close
4 and 5. Chamber filled
6. Upstream gates open
7. Boat leaves lock
8. Boat sailing downstream
9. Boat enters lock
10. Upstream gates close
11 and 12. Chamber emptied
13. Downstream gates open
14. Boat leaves lock

What has changed is the gates. In some configurations the upstream gate is a single flat leaf, it does no have to hold a particularly great depth of water. In larger canals, the gates are made of steel and the way the gates operate has shifted from manual to mechanical.

Despite these changes, the functioning of a pound lock has remained essentially the same since the 15th century, paving the way for the canal booms in Europe[6] and England[7].

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6 For more on the early European canals see ***The First Canals***: https://mosaicprojects.com.au/Mag_Articles/AA036_The_First_Canals.pdf

7 For more on early British canals see ***Early Canal Projects in the UK*** https://mosaicprojects.com.au/PDF_Papers/P207_The_first_canal_projects.pdf and ***Cost Overruns on Early Canal & Railway Projects***: https://mosaicprojects.com.au/PDF_Papers/P207_Canal+Wagonway_Cost_Overruns.pdf

## Other technologies

In addition to individual locks, other techniques for dealing with changes in levels included lock 'staircases', inclined planes, and lifts.

At Bingley on the Leeds and Liverpool Canal, a five-lock staircase was built in 1774, rising 60 meters. A 'staircase' is formed where the top gate of one lock is the bottom gate of the next. This is different to a 'flight' of locks which consists of a series of individual locks situated fairly close together but with some canal between each.

An inclined plane is a type of cable railway used on some canals for raising boats between different water levels. Boats may be conveyed afloat in caissons, or may be carried in cradles or slings. In 1788 an inclined plane was built on England's Ketley Canal in Shropshire to haul boats from one level to another.

The most spectacular inclined plane was built in the United States on the Morris Canal, which linked the Hudson and Delaware rivers. An inclined plane, descending on a gradient of 1 in 10 to 1 in 12, ran down to the pound below. Barges

24 metres (79 feet) long with loads up to 30 tons were hauled up by trolleys running on rails, on which they settled as the top or bottom lock emptied; the barges descended under gravity into the lower pound to float on an even keel when the water levelled off. In the reverse direction, they were hauled up by a drum-and-cable mechanism.

Vertical lifts counterweighted by water were also used; a set of seven was built on the Grand Western Canal in the 1830s, while at Anderton in Cheshire a lift was built in 1875. It was later converted to electrical power and wis still operating.

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