PLUMBING & SANITATION
FROM EARLIEST TIMES

History Part-1

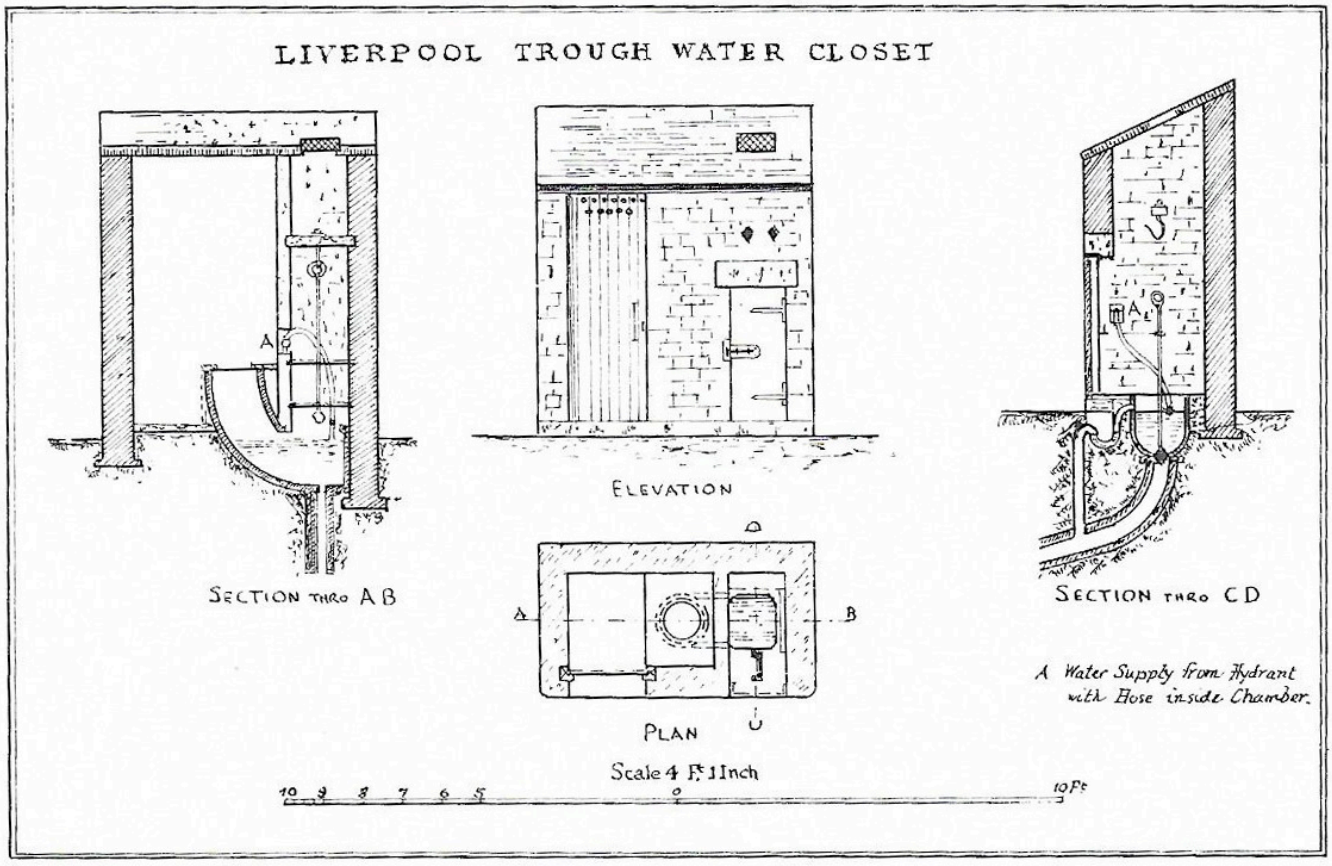

Fig. 7.8. Liverpool trough water closet.

From BUILDING SERVICES HERITAGE
A REVIEW OF ITS DEVELOPMENT
N S Billington & B M Roberts, 1982

Chapter 7
PLUMBING AND SANITATION

7.1 WATER SUPPLY

7.1.1 Early storage and distribution methods

The earliest water supplies were obtained from springs and rivers, surface water, shallow wells and dew-ponds. The first major developments were in the use of water for irrigation, and these are still the most important use in some areas. Organised irrigation is at least six thousand years old, dating from the New Stone Age. A change of climate, with less rainfall, in the Mediterranean and Near East forced the peoples to move into the river valleys, which had to be drained and cleared. Digging of drainage and irrigation channels could be achieved only by co-operative effort and team-work — a powerful force towards the formation of nations and a central power. This was an important advance in civilisation.

One of the oldest cities which has been excavated is Jericho, where digging in the 1950's uncovered enormous walls and ditches which modern dating techniques have placed as being constructed around 8000 B.C. Archaeologists examining these early constructions found large walls which had no opening except a top channel about 0.5 m deep, the channels being full of silt which implies running water. Running water at this height, since some of the walls were probably more than 4.5 m high, suggests aqueducts; possibly for purposes of irrigation, or possibly for sanitation.(5) If this assumption is correct Jericho had a planned water distribution system in daily use 5000 years before the building of Egypt's pyramids.

The earliest reservoir is probably that recorded at Babylon in about 4000 B.C. The Hanging Gardens (Fig. 7.1) were irrigated by means of a screw drawing water from the river.

The ancient empires of the Near East (3200-600 B.C.), in Egypt, Mesopotamia and the Indus valley, were urban civilisations. The principal invention of this period was the aqueduct* — originally the Persian *qanat*.(28) The Shatt-el-Hai was built to convey the waters of the high-level Tigris over the plains to Ur. This system fell to ruin in the 13th century when the Mongols overran the region. The invention of the aqueduct meant that settlements no longer had to be situated by a river or other

*The aqueduct was then any channel, tunnel or bridge for carrying water, and not, as now, a bridge only.

source of water: the site could be chosen for other, perhaps more cogent, reasons. The Greeks, Romans and Palestinians all brought water to cities over long distances by these means. The Greek, Eupalinus of Megara, constructed an aqueduct on Samos in 600 B.C. and this included a tunnel 2.4 m in diameter and nearly 1.6 km long.[3] The Assyrian aqueduct to supply Nineveh, built by Sennacherib in 691 B.C., included a 300-m bridge over a valley and elaborate water conduits:

> "of a size never before equalled: eighteen canals carried water from 48 km away, and the entire system of graded reservoirs and aqueducts contained more than two million blocks of stone."[15]

An elaborate monolithic basalt water tank of this period still survives.

The supply to Pergamum was led from the mountains through a system of pipes over hills and valleys into the plains. The maximum pressure in the main was some 2 MPa. Knossos in Crete had a piped water supply, for which pottery pipes $\frac{3}{4}$ m long, and tapering from 150 to 100 mm were used (*ca.* 2000 B.C.). Pottery pipes in the Canaanite city of Hazor from about 1300 B.C. were 1 m long: they were elliptical in shape and could be fitted together. Branch pipes could be fitted into holes in the side of the main pipe. Socketed pipes were in use in Greece. By Roman times, parallel-sided pipes with well-formed sockets were common, examples having been found at Verulamium, Lincoln and Rome. They were joined with quicklime and oil.[25]

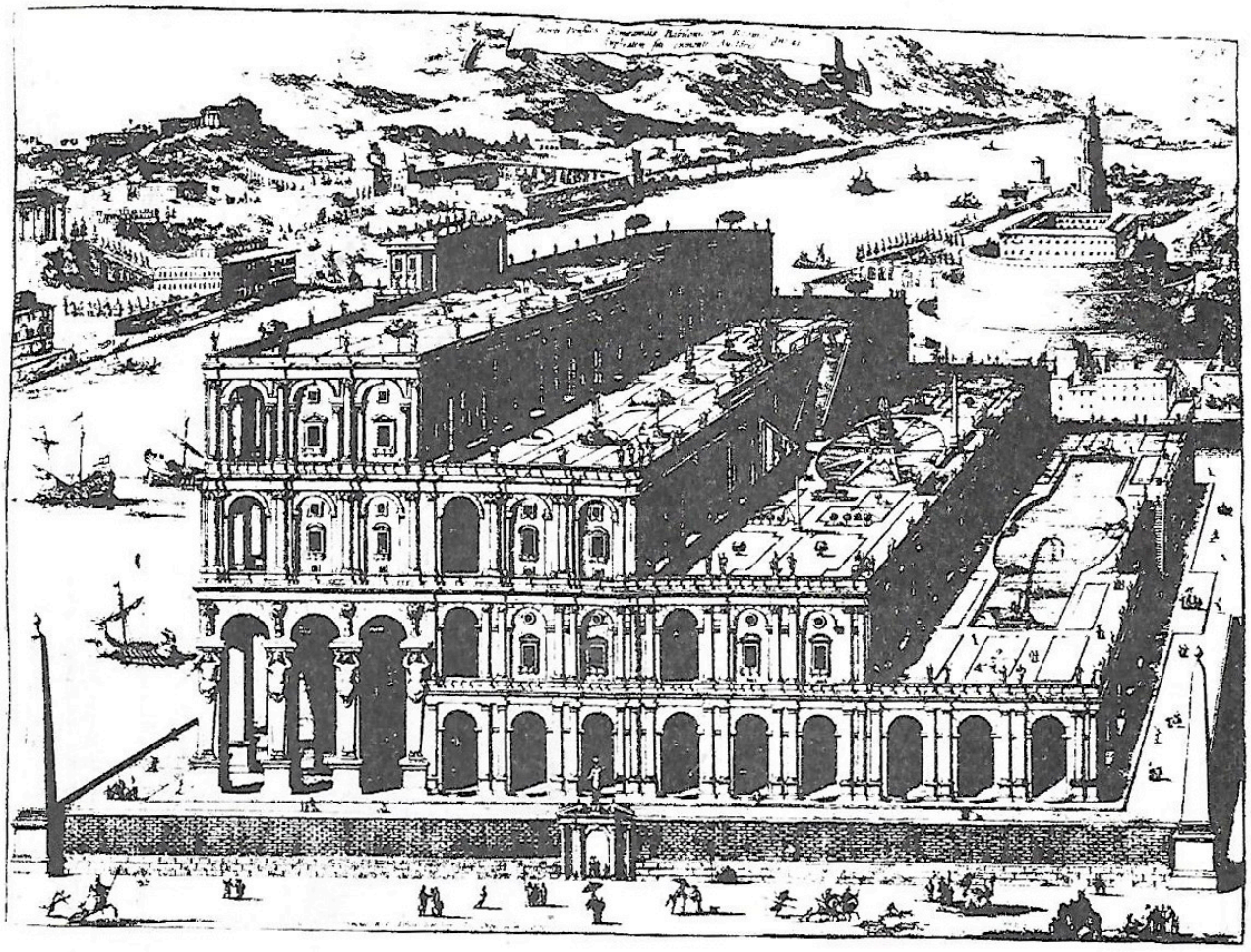

Fig. 7.1. The Hanging Gardens of Babylon (4000 B.C.).[15]

The earliest metal pipe, of copper, was found in the temple of King Sahura at Abusir in Egypt: it dates from *ca.* 2750 B.C. The piece is about 1.1 m long and 75 mm in diameter, and was formed from copper sheet lapped longitudinally. It may be seen in the National Museum in Berlin.

Another ancient water engineering triumph is to be seen in Jerusalem. Threatened by Assyrian armies in 701 B.C., King Hezekiah of Judah built a pool and a conduit, and brought water into the city (II Kings 20:20). A tunnel leading to the Pool of Siloam still pours sparkling water from Gihon Spring in Kidron.(38)

7.1.2 The Maya, Aztecs and Incas(11)(23)(42)

As long ago as 1500 B.C. the Maya of Central America are known to have had a flourishing civilisation which extended from the Yucatán Peninsula to the base of the mountains of Guatemala. As in other civilisations, adequate water supplies were essential. In some parts of Yucatán seasonal water-holes (aguadas) are to be found, but since the earliest days settlements developed round the *cenote*. These are circular sink holes, often quite large, formed by the collapse of underground caves, which are filled throughout the year by water percolating through the limestone rock.

The grandest of the Mayan cities, in the middle of the Petén, was the huge centre of Tikal (*ca.* 300 B.C. to A.D. 900), which once boasted upwards of 10000 inhabitants.

> "There are ten reservoirs at Tikal from which the Maya obtained their drinking water, one of which was perforce refurbished by modern archaeologists in lieu of any other potable source."

To the west, near the border with Mexico, is the site of Piedras Negras where has been discovered:

> "eight sweat baths, complete with stone-built hearths lined with potsherds, masonry benches for the bathers, and drains to carry off water used in the bath."

In A.D. 300, close to what is now Mexico City, stood Teotihuacán, one of the most important of the religious and civic centres of Middle American culture:

> "Seven square miles in area, it boasted plazas lined with palaces and avenues, paved with polished stucco and drained by an elaborate system of underground conduits."(4)

In A.D. 1325 the Aztecs began to build the city of Tenochititlan on an outcrop in the saline lake where Mexico City now stands.(26)

> "They built a city that two centuries later caused the Spanish invaders to gasp in astonishment and admiration. Canals laced the island city. Great causeways connected it with the mainland. Aqueducts brought water from the springs of Chapultepec.
>
> For the Aztecs it was a superlative site. The climate was mild. The soil was fertile. The mountainsides were cloaked with trees whose roots helped to hold the surplus from the area's seasonal rains, giving the city a water supply from never-failing springs."(9)

The civilisations of the Andes date from about 1400 B.C., though hunting communities can be traced back much further (*ca.* 9000 B.C.). The Inca Empire was established around A.D. 1100. As imperial organisers, the Incas may be rated alongside the

Romans, and like the Romans they excelled at engineering, building roads over 5000 km long, complete with suspension bridges. They also piped irrigation water through mountain tunnels. To grow food, whole mountainsides were terraced, and watered by elaborate systems of ditches and sluices, while oases were formed in the desert regions by conveying water in vast aqueducts from the mountains as much as 600 km away.(4)(39)

The capital city of the Incas was Cuzco (where the Huatanay River's paved channel brought water and carried away sewage), but the most famous of their strongholds is the fortress city of Machu Picchu, which reached its zenith around A.D. 1450. Located astride a mountain ridge some 2450 m above sea level, Machu Picchu's water supply has been described as "an ingenious procession of fountains". These roughly bisected the city and brought water within easy reach of a thousand or so inhabitants:

> "Led by stone aqueducts from springs about a mile up the mountain, the water was piped to the fountains through an intricate network of holes bored through the thick granite walls. A stream poured in at the top of each fountain so that women could fill their earthenware jars, then fed to a basin carved in the rock beneath and passed through a duct to the next fountain in the long cascade."(40)

7.1.3 Islam

In Islam the supply, storage and distribution of water is an essential part of the design of the mosque for "water is the vehicle of purification and enjoys an almost sacramental status".(41) The mosque has a courtyard fountain, often with taps for lukewarm water, and with low stools so that the user can isolate himself from the ritually impure floor. The elderly or infirm may be provided with other ablution facilities inside the mosque, often in the form of a colossal marble jar with basin and taps. Early examples of the skilful use of water, in fountains and in water-channels, include the Qarawiyyn Mosque at Fez in Morocco (begun 859), the Great Mosque in Seville (1171-6) and the Al-Firidawsi Madrasa at Aleppo in Syria (1243-47).

The palatial royal caravanserai at Ribat-I Sharaf (1114) lies in north-eastern Iran on the road to Samarkand. The surrounding landscape is desolate, which no doubt accounts for the huge cistern set below ground in front of the main entrance to guarantee a supply of water throughout the year. The caravanserai of Aliabad, between Teheran and Qum, illustrates the elaborate planning and degree of sophistication achieved by the 19th century in this type of establishment, with its hot and cold water pools, and latrines with separate facilities for men and women.(41)

Over the years, customary law in particular places, or the edicts of the ruler, established various controls relating to the siting and construction of buildings, and these included control of the building services:

> "Water and drainage regulations were necessary to ensure that there was not a mixing of the sewage with fresh water supplies. Where channels or streams led fresh water into towns, sometimes to the houses themselves, they were to be designed and regulated so that they could not be used for ablution purposes until the channel had passed the point beyond which fresh water could not be drawn, and from there the water continued on its way carrying off the sewage led into it. Where houses depended on wells, it was usually left to the inhabitants to ensure that sewage pits were not built in such a way as to foul the wells."(41)

Long before the reign of Islam, Istanbul had a water supply, and parts of it are still in use. Instead of bridges, the Byzantines used "suterasi" to convey water across valleys. Towers were erected at intervals across the valley floor. Water from a channel on the hillside was taken in a pipe to the base of the first tower, and then by a rising pipe to the top, where it flowed into an open tank. A pipe led to the base of the tower, across the valley and up the next tower to another tank. The same procedure was repeated at each tower until the valley was crossed, and the water allowed to flow into the next section of channel.(2)

7.1.4 The Romans

The application of the principle that water finds its own level was described by Vitruvius, but the Romans went beyond using only a direct gradient to convey their drinking water across valleys, for they developed an elaborate system of siphons.(53) But the outstanding examples of Roman engineering works are those to be seen in the lofty single arches of the aqueduct between Zaghouan and Carthage in Tunisia (A.D. 117-138) which ran for 141 km with a capacity of 31.8 million litre/day; in the double-tiered aqueduct at Segovia (*ca.* A.D. 10); and in the even more famous three-tiered Pont du Gard (*ca.* A.D. 14) which once brought 450 l/day to each citizen of Nîmes.(10)(22)

The Roman water supply was initiated by Appius Claudius Crassus in 321 B.C. to meet a steadily increasing demand, and in 144 B.C. the first overhead system, the Aqua Marcia, was built (Fig. 7.2). By the 3rd century A.D., the eleven principal aqueducts brought to the city some 200 million litres per day -- about 200 l per person for all purposes including industry, fountains and baths.* By the 4th century A.D. Rome had 11 public baths, 144 public lavatories, 1352 public fountains and cisterns, and 856 private baths. At its peak Rome was supplied with something like 1350 litres of water per head of population per day.(54)

In constructing the water supply system, the Romans avoided the use of "high-pressure" pipe, using instead bridges to cross valleys. The incoming supply was taken to three reservoirs, one serving the baths, one the fountains, and the third private houses. Private supply was available as a concession on payment of a fee. Most Roman citizens had to rely on water carriers who drew water from the fountains. For distributing the water, pipes of earthenware, lead, wood and clay were used.

An insight into the Roman system is given by Frontinus, who was in charge from 97 to 104 A.D. Seven hundred personnel — surveyors, inspectors, masons, paviours, labourers, architects and plumbers, and administrative staff — were employed. A group of technicians calibrated the bronze nozzles used for metering, each nozzle being stamped with the rate of flow. (The method was soon discontinued, on account of the ease with which the device could be tampered with.) Frontinus measured the volume flow along the aqueducts and supply lines — 35% of the water was lost between the source and the consumer, due to leaks and faulty nozzles. The total supply at that time was 1200 million litres. Of this, 17% was used for industry, 39% for private purposes, and 44% on barracks, fountains, public buildings and baths. The Roman system was largely destroyed in A.D. 537 when the city was attacked, and it was only partially restored in the 8th century.

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*This figure is given by Robins.(49) According to an anonymous writer in *Sanitär, Heizung-technik*, the quantity was 700 l/person per day — a consumption which may be compared with 600 l/person per day in New York and the Ruhr in 1955 for all purposes, including industry.(2)

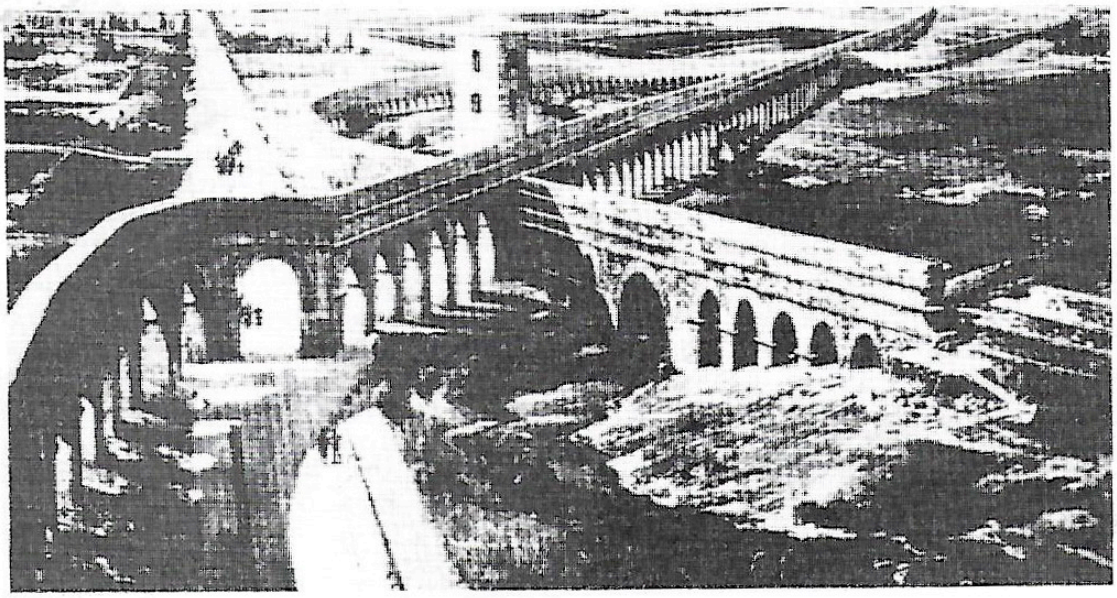

Fig. 7.2. Aqueducts outside Rome.
(Hodges, *Technology in the ancient world*)

The Romans installed the first piped supplies of water in Britain. Thus Lincoln was supplied by an aqueduct and carefully jointed pottery pipes. Wooden pipes have been found in other Roman towns (London, Silchester) and lead pipes in Bath.

7.1.5 Mediaeval times

With the decline of the Roman Empire, its expertise was largely lost in Europe, and for some centuries, less sophisticated methods of supply were employed, using mainly local sources of water. Outside the Roman empire, in Byzantium and Islam, the methods of water supply and sanitation were continued and developed, and

> "the recovery of material civilisation on the west depended on the Byzantine and other technologically more advanced societies farther east".(27)

Not until Norman times (1100 onwards) is there any record of piped supply to buildings in Britain, and then only to the very important ones. Robins writes:

> "In medieval Europe, such communal and social activities as were embarked upon were almost invariably under the aegis of the Church and especially the monastic orders.
>
> Water was rarely used for drinking save by the poorer classes. Washing was a more conspicuous habit in the religious houses than in secular establishments."(49)

The larger monastic houses (in England) collected water from springs or in reservoirs, and distributed it through pipes of wood, earthenware or lead. There were also usually underground sewers flushed by a flowing stream of water.(37)

> "A very early account exists of Ethelwold, Abbot of Abingdon, who is recorded as having made a water course (ductum acquae) in 960 which ran under the dormitory to the 'Hokke' stream. This was obviously an efficient diversion of a stream or a conveniently placed spring source, and is the first post-Roman account of sanitation in England".

More elaborate developments followed, and many a medieval monastery became the possessor of a "laver" or lavatory, which was a trough with running water, usually close to the refectory, where the monks washed their hands before meals or on leaving. Good examples of lavers of the 11th and 12th centuries are to be found at Durham, Dacre (in Cumbria), Goodrich (Herefordshire), at Gloucester, in Norwich and at Much Wenlock Priory (Shropshire).(7)(8)(35)(54)

In Canterbury Cathedral, the water works were carried out by Prior Wibert in 1160. Water was taken from springs outside the city, some 1¼ km from the monastery, to a circular conduit house, from whence it was conveyed through a perforated screen and several settling tanks by pipe to the city. Within the monastery, the water was taken underground to various offices and lavatories. Waste water went to a fish-pond and on to the "Prior's water-tub" where it was "joined by the waste from the bathhouse and the rainwater from the roofs, to provide a hearty cleansing flow through the main drain running under the 'reredorter' latrines". The original plans of the system still exist.

Some of these monastic systems remain in use. One conduit still serves the swimming baths of Sherbourne School; and the lead pipes at Lacock were in use in 1941. At Southampton, part of the friary water supply was for the use of the townspeople (*ca.* 1310). In 1420, the mayor and community of Southampton acquired the whole system, undertaking to supply both the town and friary. This remained the town supply until the beginning of the 17th century. An extensive system of tunnels under Exeter, dating from 13th century, acted as conduits for water supply to the city and the cathedral. In the 15th century, the Exeter authorities laid lead pipes from another source. Robins(49) gives a detailed account of the mediaeval supplies to many English cities. He notes, too, that there was a public, and publicly-owned, supply in Bruges in the 14th century.

From the 13th and 14th centuries, water supply systems were constructed in several important cities. Nuremberg was given a supply in 1361, via a network of wooden pipes, and only in the 19th century was the last of these replaced by cast iron.

While mediaeval Cambridge relied for its water supply on the local river, shallow surface wells and collected rainwater, there was one piped supply, that to the Grey Friars' House, said to have been carried in leaden pipes laid in 1327. Under Henry VIII the house of the Franciscans was suppressed, and in 1547 this pipeline was granted to Trinity College (where it still supplies the fountain in the Great Court). After the plague of 1574, another supply was obtained from Nine Wells, carried in a conduit planned by Edward Wright (1610).*(30)

London obtained its first water supply in 1237: the water was taken from a spring at Tyburn and distributed through pipes to a conduit at Cheapside, where the people could draw the water they needed. The Great Conduit of Chepe (Cheapside) was fed from Highgate, from where the Tyburn flowed down to a waterhead (now Stratford Place, Oxford Street). From here it was channelled through some 5.3 km of leather pipes to a stone basin (the Great Conduit) at the east end of Cheap for public supply. Another conduit built by William Lamb (remembered by Lamb's Conduit Street)

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*In later years the conduit came to be known as Hobson's Brook, after Thomas Hobson the carrier and wealthy Cambridge townsman.

supplied Holborn. Later, in 1441 the Tyburn was also brought to "The Little Conduit in West-Cheap by Paul's Gate", attached to the Church of St. Michael-le-Quern, which was later destroyed in the Great Fire.

7.1.6 Water-carriers

In London, many early supplies were found from springs, wells (hence Holywell and Clerkenwell) and rivers, and were the result of private benefactions. The better class families often hired professional water-carriers to bring the water to their homes. In 1496, the carriers formed themselves into a Company of Water Tankard Bearers, which soon had a membership of 4000 (Fig. 7.3). They went so far as to impose a toll on those who wished to carry their own supplies.

Fig. 7.3. A London water carrier (1572).[14]

Water carriers have existed in many countries, from very early times even up to the present day. (Braudel[16] believes them to have been indispensable in every town in the world.) A print of 1829 shows them drawing water from a conduit in High Street, Edinburgh. Water carts appeared in England in the 16th century; they were still in use there, and in Sweden, Russia, and Peking in the 19th century, and they are still used in some countries. Snow water was sold in Istanbul in the summer, and in Valladolid in the early 1600's – though perhaps only for cooling drinks.

In the 18th century, New York relied on water, often foul, drawn from wells. However, one public well known as the "Tea Water Pump" (situated on today's Park Row) was famous for its fine clear water, and

"water from there was distributed in horse-drawn tank wagons to households, where it was almost a luxury item."(52)

7.1.7 Municipal supplies

In 1582, the eastern part of the City of London was supplied from the Thames by a pump near London Bridge.(49) The Corporation granted the use of the first arch of the Bridge for 500 years to a Dutchman, Peter Morice, who installed a waterwheel to drive a pump to raise Thames water into a reservoir, whence it was taken by lead pipes to some houses in the City (Fig. 7.4). The Guild of Water Bearers opposed the scheme, but they were eventually persuaded to agree by the Lord Mayor. This machine ran until 1822.

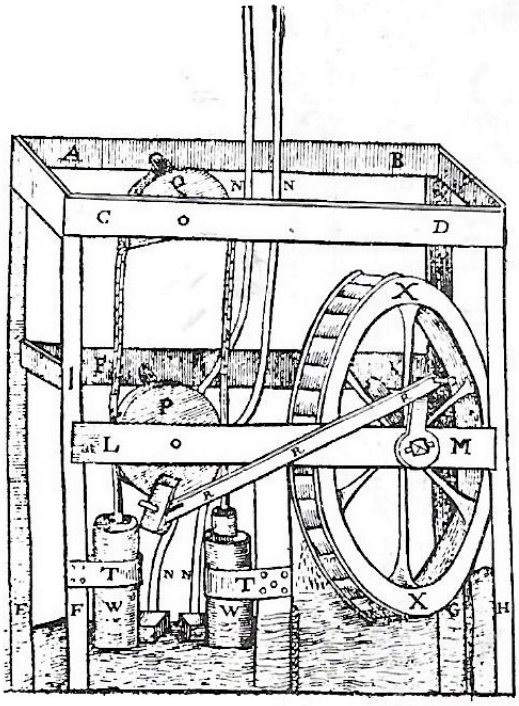

Fig. 7.4. London Bridge waterworks, 1635.

"A water tower at Queenhithe and another supplied by a water wheel at London Bridge helped to bring piped river water to houses for domestic use and for anyone enterprising enough to install a flushing water closet, the recently invented device of Queen Elizabeth's godson, Sir John Harington."(14)

The water tower at Queenhithe Dock was one of London's earliest (1594), and had water pumped into it from the river, its height providing sufficient pressure to convey the water through lead pipes to houses in West Cheap and Fleet Street.

The City Corporation obtained powers to bring water from Middlesex and Hertfordshire by means of a leat, a scheme put forward by Hugh Myddleton, a friend of Raleigh. Its construction was authorised by an Act of 1606; and King James I undertook, in 1612, to pay half the cost. The "New River" was begun in 1609, and opened in 1613.

> "Pure Hertfordshire spring water flowing down a gradient of two inches in the mile, was carried into London across dips and valleys by more than a hundred wooden bridges. The longest of these aqueducts was just over a quarter of a mile, and another seventeen feet high. The flow, controlled by forty sluices, was augmented by thirteen wells from which water was pumped. The end of its winding course was a circular reservoir in Islington named New River Head."(14)

The channel, 3 m wide and 1.2 m deep, ran some 50 km from Chadwell Spring to a circular pond at Islington, then to existing conduits and street pumps. The New River Company continued in being until taken over by the Metropolitan Water Board in 1904; and the New River remains a part of the present Thames Water Authority system. The distribution mains were of wood, and eventually reached a total of 640 km. In the early days of the Company, water was laid on to storage cisterns in basements and then pumped to other cisterns to give the necessary head for wc's (which became general in the 18th century). Since ball-valves were not mentioned until about 1748, the early supplies must have been controlled by taps.

Wells and deep boreholes were also used, though they became ineffectual as London grew and the water table sank. A well sunk in Trafalgar Square in 1845 found water at a depth of 34 m; by 1911, the level had dropped to 72 m, and the well was abandoned.(27) At Grenelle (Paris) a bore struck water at 550 m and yielded $3\frac{1}{2}$ million l a day (mid 19th century).

In the West of England, water from moorland springs was led to towns in open leats. The 13th century leat at Tiverton is still visible in Castle Street. The Plymouth system — the oldest municipal supply in Britain — was authorised by 'an Act for the preservation of the houses of Plymouth" in 1585. A weir was built across the River Meavy on Dartmoor, to divert water to an open channel and convey it to Plymouth. Sir Francis Drake was Mayor of Plymouth in 1581, and was largely responsible for the initiation of the project, which became known as Drake's leat. Some of the water was distributed through wooden or lead pipes to public conduits, where the supply was free; some was piped to private houses, for which a charge of 4 shillings a year was made.

A spring-water aqueduct was built to supply Lisbon in the 18th century.

In Paris, monastic endeavours brought in water by aqueducts from Belleville and Près St. Gervais, and this, with some private wells, stood alone until the 17th century. The supply amounted to only one litre per person per day, and was only twice this at the end of the century, when the Seine and the aqueduct of Arcueil were the principal supplies. Lintelaer constructed a water supply to Paris in the reign of Henri IV, by putting a pump, driven by a waterwheel, at the Pont Neuf, and feeding the water into a system of lead and wooden pipes. Additional pumps were installed at other bridges after 1585. The first large main led water from a spring north of Paris after 1656. "This chaotic system of tapping water from the river and from aqueducts lasted well into the 19th century, and it is typical of other European water systems as well."(28) Louis XIV caused the Marly waterworks to be built to supply the fountains at Versailles in 1682. The Seine was dammed, and its level raised by 3 m. A pumping station containing 14 waterwheels to drive 259 pumps, with a head of 155 m, was built to force water for 40 km along a pipe 150-200 mm diameter to Versailles. The water supply (and sewerage) of Paris was greatly improved by Haussman in the mid-19th century.(55)

Ramelli's "Le diverse et artificiore machine" of 1588, illustrates Juanelo Turriano's "Artificio" (Fig. 7.5), which provided Toledo with water from the River Tajo:(52)

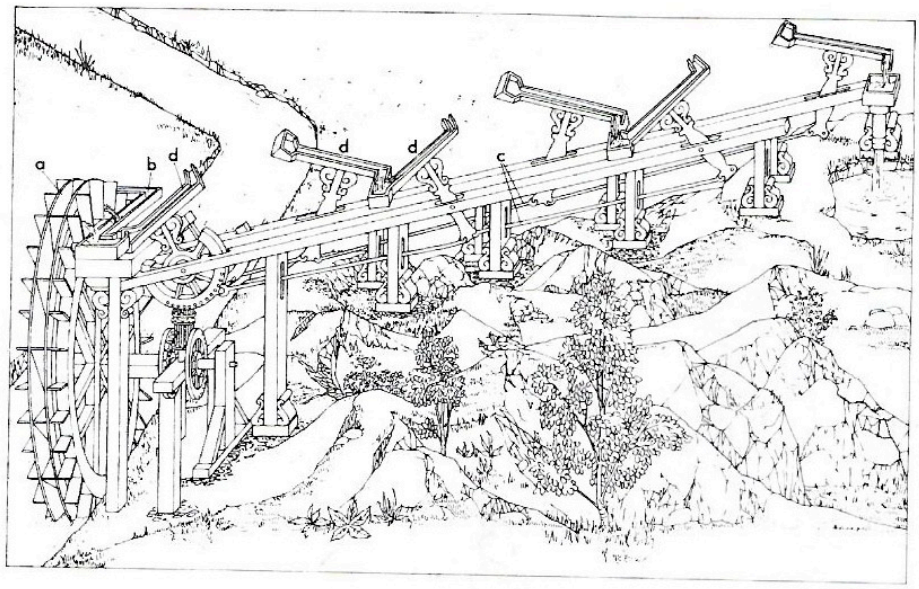

Fig. 7.5. Juanelo Turriano's Artificio at Toledo.

"The water-wheel continually filled a container with water and, at the same time, drove two rows of oscillating rods and levers so that ladles kept rocking to and fro. The water was thus poured from ladle to ladle all the time."

Sea-water distilled in alembics was used to supply Spanish settlements in North Africa in the 16th century; otherwise, water would have been imported from Spain or Italy. In Venice the water supply was obtained from tanks half-filled with sand, through which rain water filtered into a well running down the centre. The supply was, however, inadequate, and had to be supplemented by boat-loads of water brought daily from the mainland.(16) A similar situation existed in some Dutch towns.

7.1.8 Pumped supplies

After the Roman era, pumps were not used until the 16th century, and even then mainly for drainage. The displacement pump, driven by a waterwheel, seems to have originated in Germany, and its first use was for water supply. Scorrold of Derby, at the end of the 17th and the beginning of the 18th centuries, used a similar system to raise water to towers in provincial towns, and the pressure facilitated the laying of water pipes direct to the houses of those prepared to pay. The first installation was at Derby in 1692, but even in the mid-1800's there were still only 6½ km of main. Waterwheel pumps remained in use until this time. Some were installed in the USA, notably at the public waterworks at Bethleham, Pa, in 1762. The first public water supply in the USA was at Boston in 1652, the water being distributed by gravity through wooden pipes.(3) Montreal pioneered water supplies in Canada, where a private company was established in about 1800. The American Corps of Engineers was authorised to develop a city water supply for Washington DC from the Potomac River in 1850.

Steam pumping began in England, and did not spread to the USA until about 1800. Dr Desaguliers invented a pump to be driven by a Newcomen steam engine in 1720, and this was employed at a waterworks in the Strand, to take Thames water to a tower and thence to the Marylebone reservoir.* Another 18th century invention for raising water was the "shock siphon".

Steam pumping engines had been used by Smeaton at York in 1784, and by Watt at Hull (1793) and Chelsea (1810). This allowed the pressure to be increased sufficiently to supply the top floors of houses, and a constant supply could be maintained. Thomas Hawkesley (a pioneer of water engineering) at the age of 23 designed what Rowntree describes as one of the first successful continuous water supplies in a pressure pipe system at Nottingham in 1830. The city of Cambridge was provided with a pumped supply from Cherry Hinton in 1855, which:

> "consisted of two single-cylinder beam engines each of 15 ihp driving bucket type pumps lifting 11 gallons per stroke against a head of 135 ft, and working at a speed of 24 strokes per min".(30)

The Perrier brothers installed two steam pumps at Chaillot in 1782, as a result of English experience.

Organised water distribution in New York began in 1799 with the founding of the private Manhattan Company, which installed a piping system of hollowed-out logs. Within 10 years some 2000 households were supplied with water, which was pumped into the reservoirs by two 18-hp steam engines. In 1829 the city authorities began the construction of a network of 300-mm cast iron mains, again with a pumped supply.(52)

7.1.9 Mains construction

Wooden mains continued in use up to the beginning of the 19th century, with lead pipes to the houses. There was considerable leakage from the mains, and the companies would not undertake to supply water above ground level as the pressure was insufficient. A common water butt in a back yard was often shared by several householders: only the wealthy had cisterns of their own. Turncocks were appointed to look after several "districts" in London. The turncock would go round each district in turn, and by opening the mainvalves, would allow water to fill cisterns and tanks. Although each district was supposed to receive a supply on three, or at least two, days a week, consumers complained that they were often without water for a week or more. The most effective way of ensuring a reasonable supply was to bribe the turncock. In 1800, Plymouth Dock Waterworks Company guaranteed water for two hours every other day. It charged £1.8s per annum for a household. In York, in 1846, the hours of supply were similar.

The problem of ensuring an adequate continuous supply was not solved until the introduction of iron pipes and steam pumping. The first cast-iron pipes were made in Germany, originally for gun barrels. The oldest cast iron water main dates from 1455. Cast iron was also used for the Versailles works in 1682.

The first cast iron pipes in London had been laid in 1745 by the London Bridge Company. This seems to have been unusual. The Metropolis Paving Act of 1817 prohibited the use of wooden pipes, and from then on cast-iron pipes were general. Progress in manufacturing techniques was slow, but by 1817, a high-pressure cast iron pipe had been used to supply Berchtesgaden. Steel pipe came into use after Mannesmann had developed the production of seamless tube.

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*Derry and Williams state that a Savery pump was used here in 1699.

Pipes caulked with lead and covered with a coal-tar composition coating against corrosion (invented by Angus Smith) were first used in Liverpool in 1860. In 1850, experiments were being made in France with glass pipes coated with bitumen, and in 1890, Messrs Seume of Prague used glass pipe with a 1-mm coating of asphalt for both mains water and sewage. Concrete pipes were not used in England until 1906; asbestos cement pipes were first made in Italy in 1928.

In Britain, extensive trunk mains and complex networks were, until about 1930, confined to urban areas. Villages depended on small local supply reservoirs or, at worst, on the village pump to supplement rain water collected from the roofs of houses. Indeed, Raynes[47] shows that in 1909 rainwater was often collected, both for general household use and for supplying sanitary fittings. The Roberts' rain-water separator was designed to reject the initial run-off which contained the impurities which accumulated on the collecting area (Fig. 7.6). He quotes the *per capita* use of mains water as 90 to 270 l/day in towns and 40 to 90 l/day in rural areas.

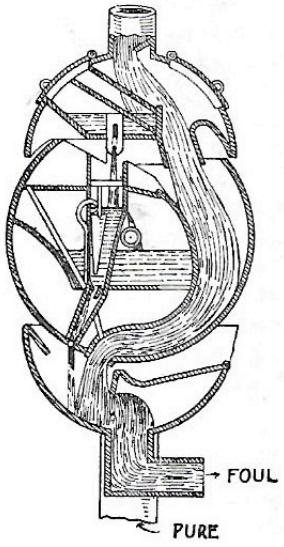

Fig. 7.6. Roberts' rain-water separator.

The change from cast iron pipe to the much cheaper spun iron pipe facilitated the move to provide rural supplies by extensive pipe-line networks. At about the same time, the bitumen-lined steel main was replacing the large diameter heavy cast iron pipes which had served for 100 years and more to convey water in bulk.[50]

7.1.10 The 19th century

In spite of the progress which had been made, a Royal Commission in 1844 found that relatively few houses in Britain yet had a piped supply: in Nottingham 8000 out of 78000; in Bristol 5000 out of 130000, and in Birmingham 8000 out of 40000.* Yet

*The Birmingham Waterworks Company, founded in 1826, was quite well run; but Chamberlain used the situation to further his political career. He declared that poor people in Birmingham were so short of water that they were driven to steal it from others. Chamberlain eventually succeeded in getting the company transferred to municipal ownership in 1876.[17]

the Glasgow and Gorbals companies were, in 1852, supplying 64 million l/day to 360000 people.

Chadwick gives an insight into the state of water supply in the early 1840's:[21]

> "No previous investigation had led me to conceive the great extent to which the labouring classes are subject to privations, not only of water for the purpose of ablutions, house-cleaning and sewerage, but of wholesome water for drinking and culinary purposes.
>
> "In Manchester ... the custom is for owners of small cottage property to erect a pump for the use of a given number of houses; this pump is frequently rented by one of the tenants, who keeps it locked, and each of the other tenants are taxed a certain sum per month for the use of it. One poor woman told me she paid 1s. per month. The water company gives a plentiful supply to small houses at 6s a year. The Stockport Local Act empowers the Commissioners of that town to *compel* the cottage owners to provide a supply of water to their tenants."

Attempts to provide towns and cities with a satisfactory water supply were often resisted by the borough councils on grounds of economy. Briggs records several instances of this.[17] Apathy and ignorance also played their part.

Chadwick advocated that the provision of a good water supply to houses should be included in Building Regulations.

At that time, one London water company did maintain the supply at all times, to save the expense of water tanks in private houses. The usual charge in London was a maximum of 6d a ton, whereas in Paris the water-carriers (who supplied the majority of the private houses of the city) charged 9s a ton for filtered water. (Du Châtelet believed that the cost of emptying cesspools was a factor in delaying the demand for, and supply of, water in Paris. The vested interests of the water-carriers and the chiffoniers opposed both water supply and improved sewage collection.)[21]

The Waterworks Clauses Act of 1847 empowered the utilities to cut off water supplies to premises (e.g. for non-payment). This led to conflict, since under a different Act dwellings were considered "uninhabitable" if water was cut off. The Act, and its successor in 1863, introduced the principle of compulsory supply,* and fixed annual value of the property as the basis for charging. These Acts remained in force until 1945. They established the pattern for the development of water supplies and their management in the public interest. Rowntree holds the view that the legislation since 1945 has been generally less satisfactory. The Municipal Corporations Act of 1835 reversed the trend towards private water undertakings, and began to encourage municipal enterprise. By the middle of the 19th century, almost every house in London had a cistern filled at stated times; in Paris, on the other hand, reliance was still placed on water carriers.

7.1.11 Water supply in Germany and Australia

Public water supply was further advanced in England than in continental countries or America. We may cite Abel[12] describing conditions in Germany in the 1870's:

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*The first recording water meters were introduced in 1873 to check waste, but the British public soon learned to turn off taps when they no longer risked missing an intermittent supply.

Continued in Part-2