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.

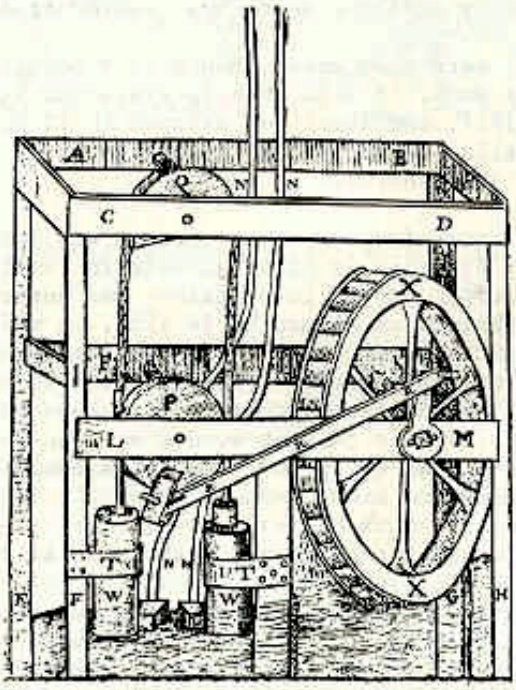

Fig. 7.4. London Bridge waterworks, 1635.

"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 3½ 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)

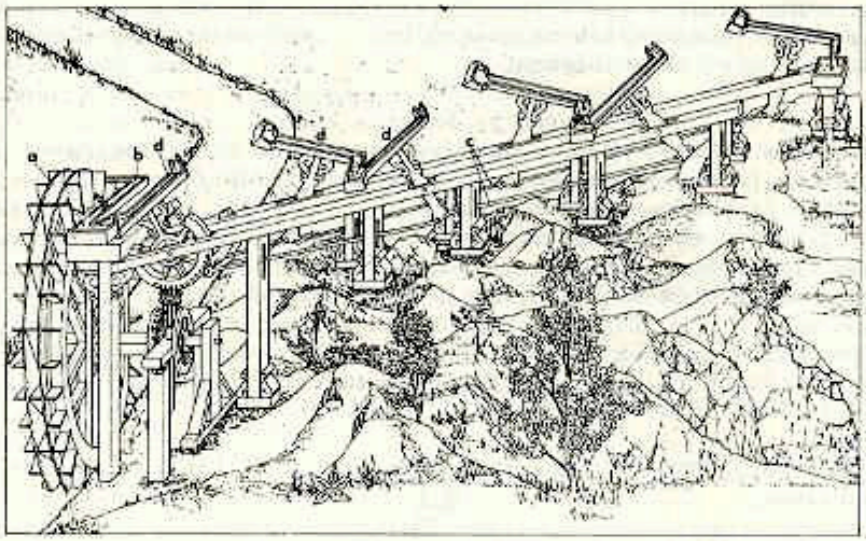

Fig. 7.5. Juanelo Turriano's Artificio at Toledo.

"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.

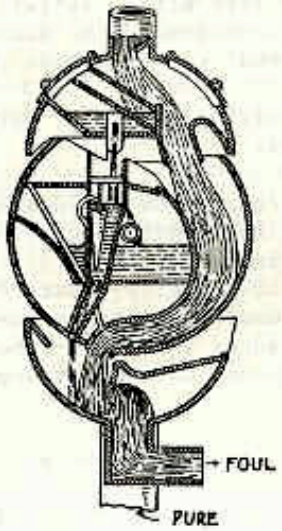

Fig. 7.6. Roberts' rain-water separator.

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.

"Water distribution from the Oberspree, with sand filtration, had been installed by an English company in 1856, and it was taken over by the municipality in 1873. But this served only part of the city (Berlin). In 1878, besides many private wells, there were 1133 public fountains which gathered their supplies from the grossly polluted ground in the city. In 1877, a borehole was sunk in Tegel, which supplied water containing iron; it had to be closed in 1882... . The streams were polluted, and it was said that the Spree entered Berlin like a swan and left it like a pig."

Ninety-five new mains distribution systems were installed in Prussia in 1871-80 rising to 1633 new systems between 1901 and 1908. By 1903, in 303 towns in Germany with more than 15000 inhabitants, only 4% were still served by wells and cisterns; the remainder had mains supplies — 25% using surface water, 70% spring water or ground water, and ½% from artificial reservoirs. An ozonising process (used abroad more than in Germany) was introduced in 1895, and in 1910 chlorination was introduced.

The city of Melbourne (Australia) was founded in 1835, and according to Briggs, a supply of fresh water above the Yarra Falls was a great attraction to early settlers. But as Melbourne grew, the supply proved inadequate in quantity and unsatisfactory in quality. Attempts to set up a public water company in the early 1840's failed. One might have expected the lessons of the old world to have been learned, but it seems that this was not the case. Water distribution was in the hands of men who might be seen plying their vocation all day long through the streets of Melbourne. Exactly the same points were being made about Melbourne's water supply in the 1850's as in any European city. In 1853 the Commissioners of Water Supply and Sewage were appointed. When the Yan Yean water system was completed in 1857, and for the first time Melbourne had water laid on, the event was celebrated with a great procession of plumbers, firemen and members of the town's temperance societies.(17)

The first mains water system in Japan was put in the city of Yokohama in 1885-7, to a British design.(34)

7.1.12 Internal connections

The great majority of water undertakings in the UK have for many years prohibited direct-on-mains systems, that is, systems which permit water to be drawn off without the use of break- or storage-tanks (the only exception is one cold tap in the kitchen). The object has been to prevent any possibility of mains contamination, though the method has the advantage of providing some local reserve against failure of the mains supply. Most other countries permit domestic systems to be connected direct to the mains, and without any apparent hazard to health. In both, an adequate air-gap must be provided at each terminal fitting (tap or wc) between the supply pipe and the appliance, to avoid the possibility of back siphonage.